

DE LA RECHERCHE À L'INDUSTRIE



Mardi 12/07 11h (Orme)
Lundi 18/07 12h (Centre)
Visite Labo (Centre)
Lundi 18/07 17h15 (Centre)



Mesurer l'infiniment petit et observer l'infiniment grand



Stages : <http://irfu.cea.fr/Phocea/stages/index.php>

Maxence Vandenbroucke
07/2022

Université
PARIS-SACLAY

Cours 1 : Généralités

- Introduction générale sur l'importance de la mesure
- Qu'est-ce qu'une expérience de physique subatomique ?
- Que veut-on observer à propos d'une particule?
- Architecture générale d'une expérience en physique subatomique

Cours 2 : Les détecteurs dans le détails

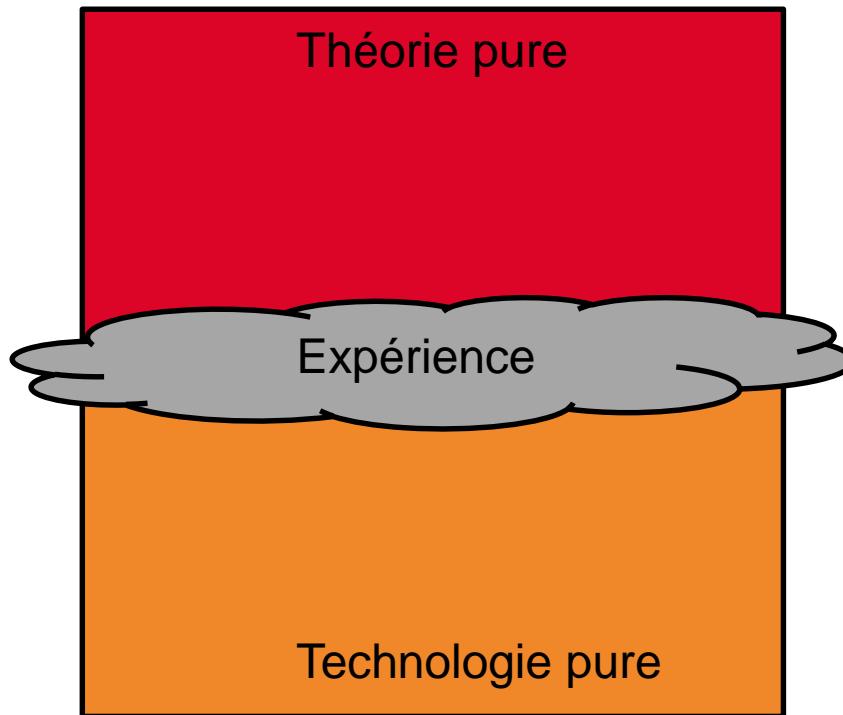
- Interaction particule-matière
- Les Détecteurs à ionisations
- L'exemple des détecteurs gazeux
- Experiences de Physique des Particules

Cours 3 : Exemples d'expériences

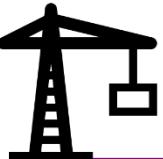
Cours 1 : Généralités

- Introduction générale sur l'importance de la mesure
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- Que veut-on observer à propos d'une particule?
- Architecture générale d'une expérience en physique subatomique





- Théorie
 - Construction des Modèles
 - Prédiction avec des Modèles
 - Simulation de l'expérience
-
- Design d'expérience
 - Choix du dispositif expérimental
 - Electronique/acquisition
 - Reconstruction des évènements
 - Comparaison avec la simulation/calcul
 - Papier, Communication

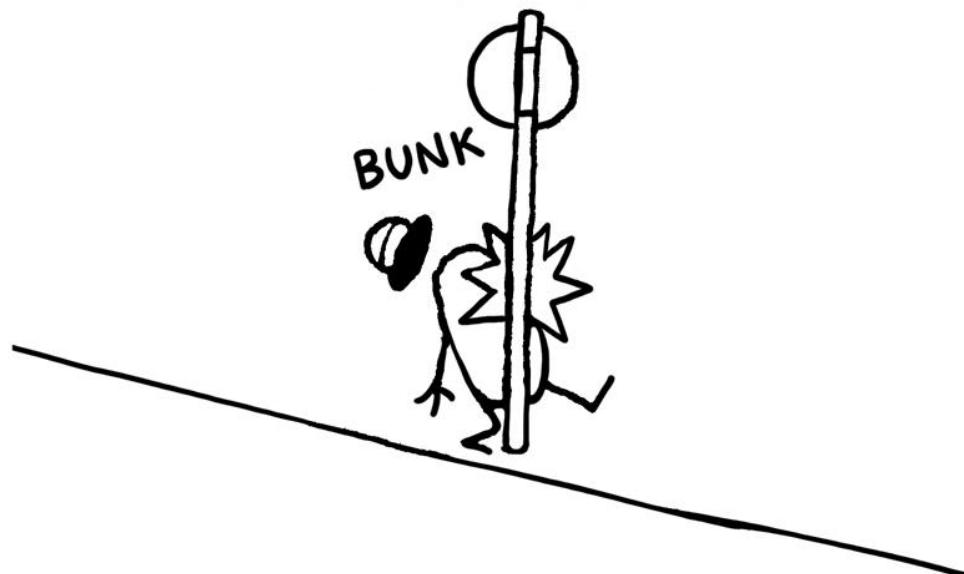
Le physicien complet est à la fois proche des interrogations fondamentales, mais aussi des avancés technologiques pour trouver un espace de découverte potentielle

(vision un peu naïve)

UNE EXPERIENCE C'EST QUOI ?

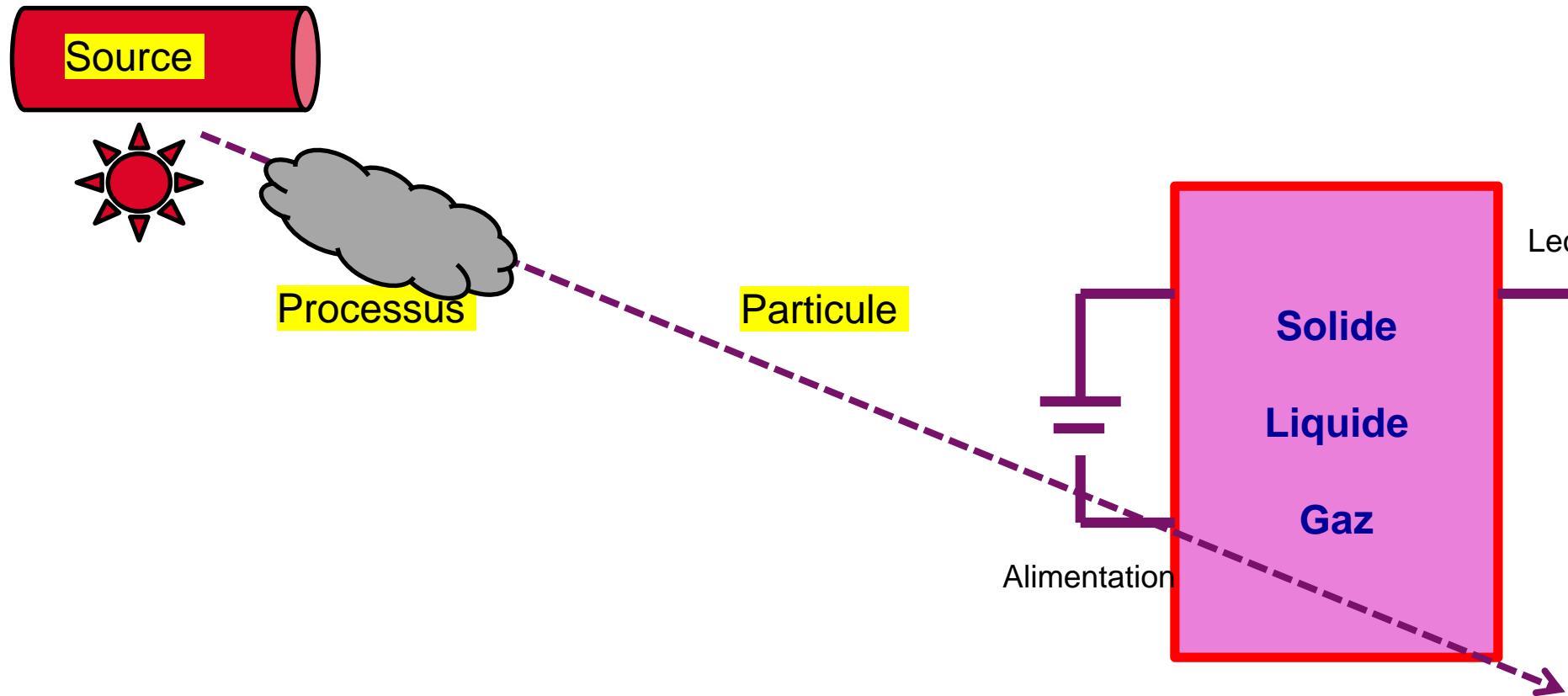
Dernier "*BUNK*"

- *Higgs (2012)*
- *No SUSY*
- *GW (2015)*
- ...

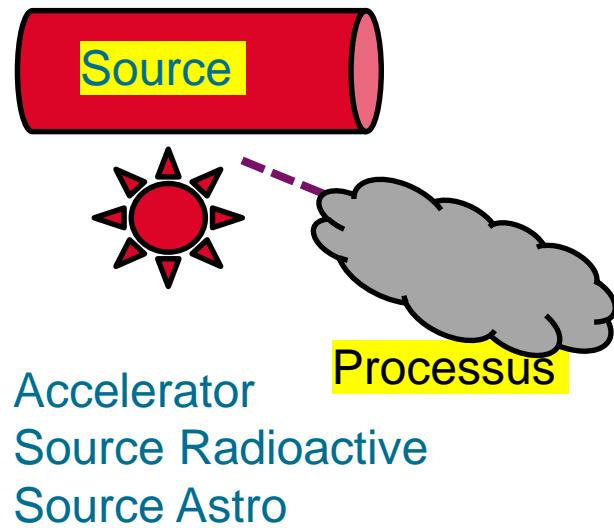


LE RÉEL, C'EST QUAND ON SE COGNE.

Schématiquement (*****)



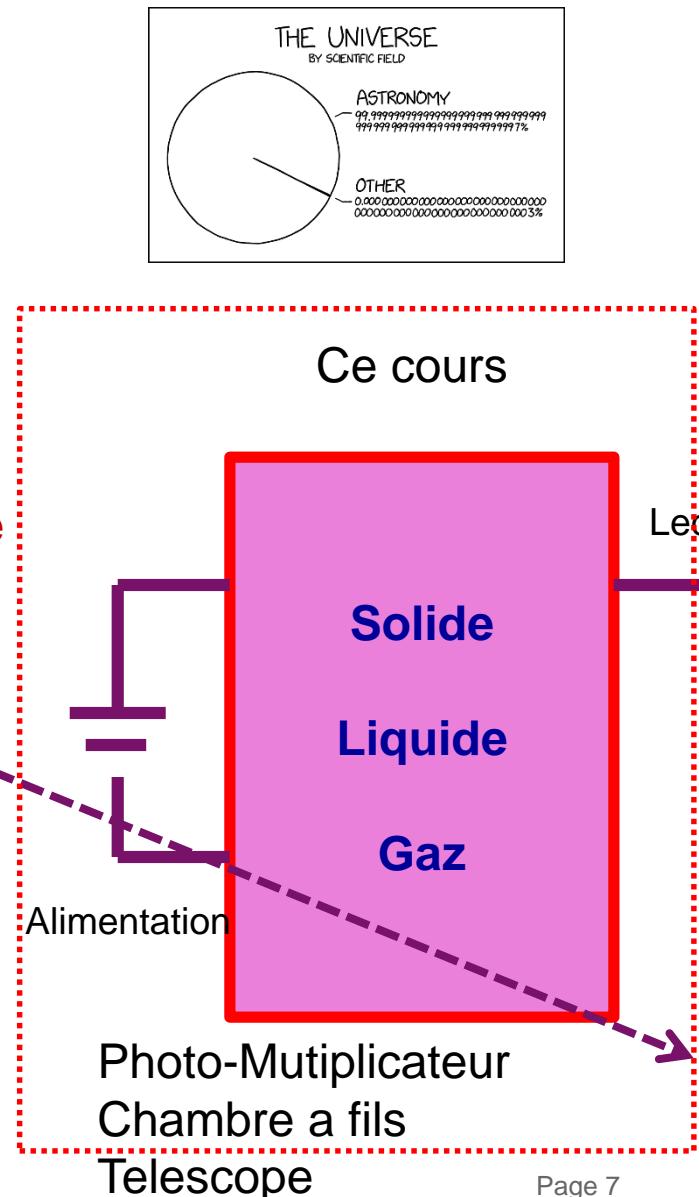
Schématiquement (*****)



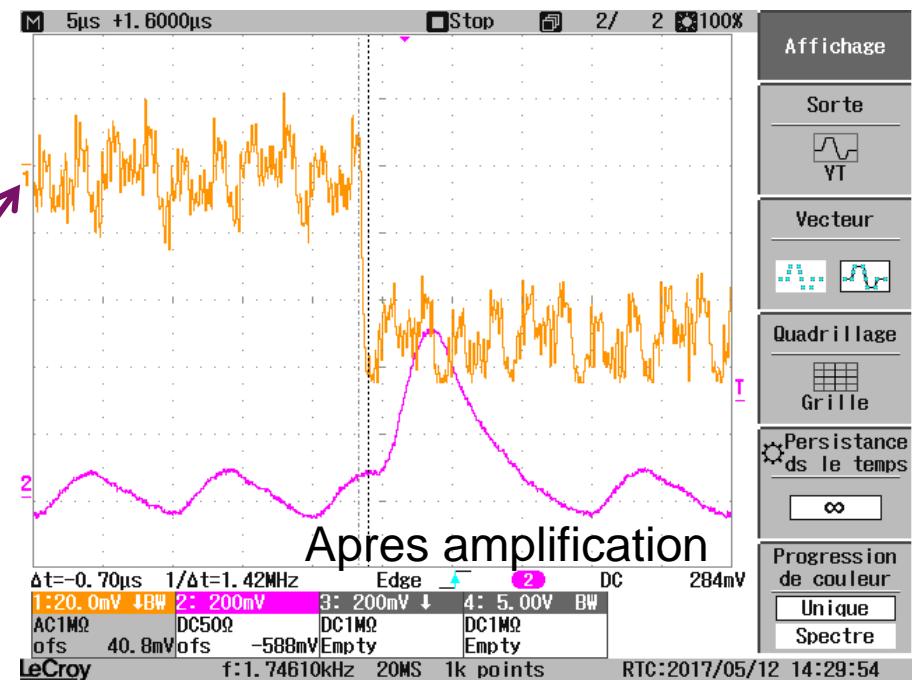
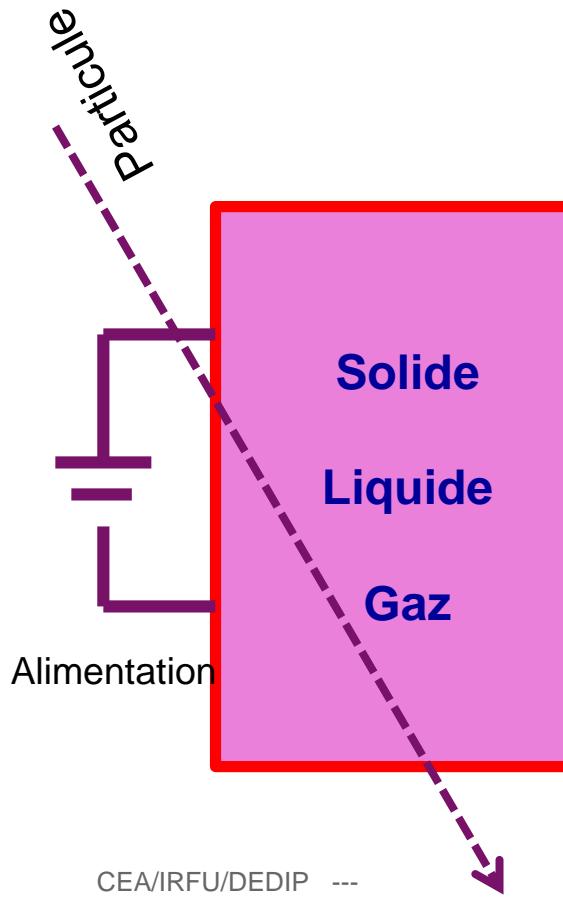
Diffusion
Interaction
Reaction
=> Processus physique

Photon
Electron
Hadrons
Noyaux
=> Particule stable

Particule

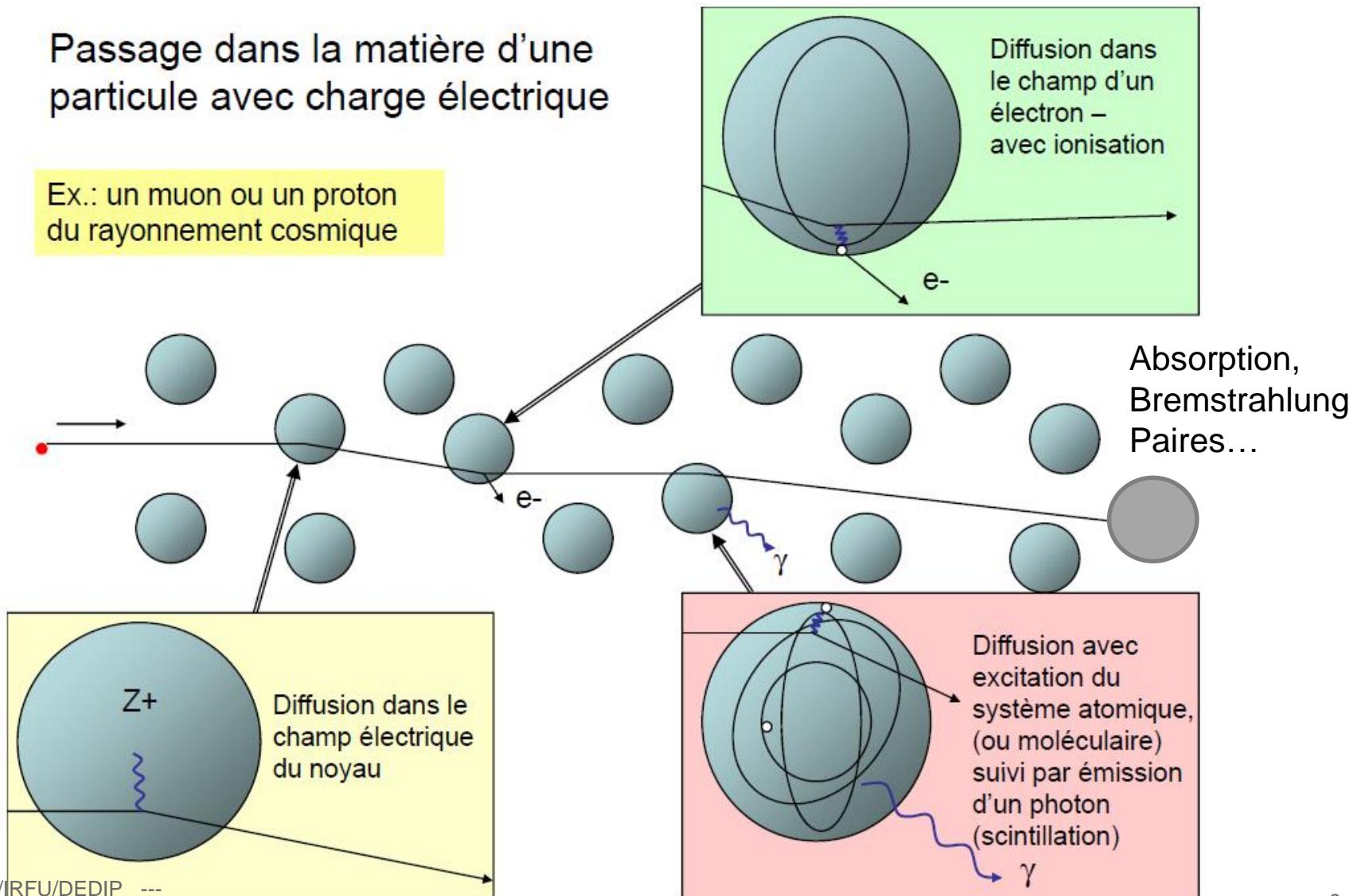


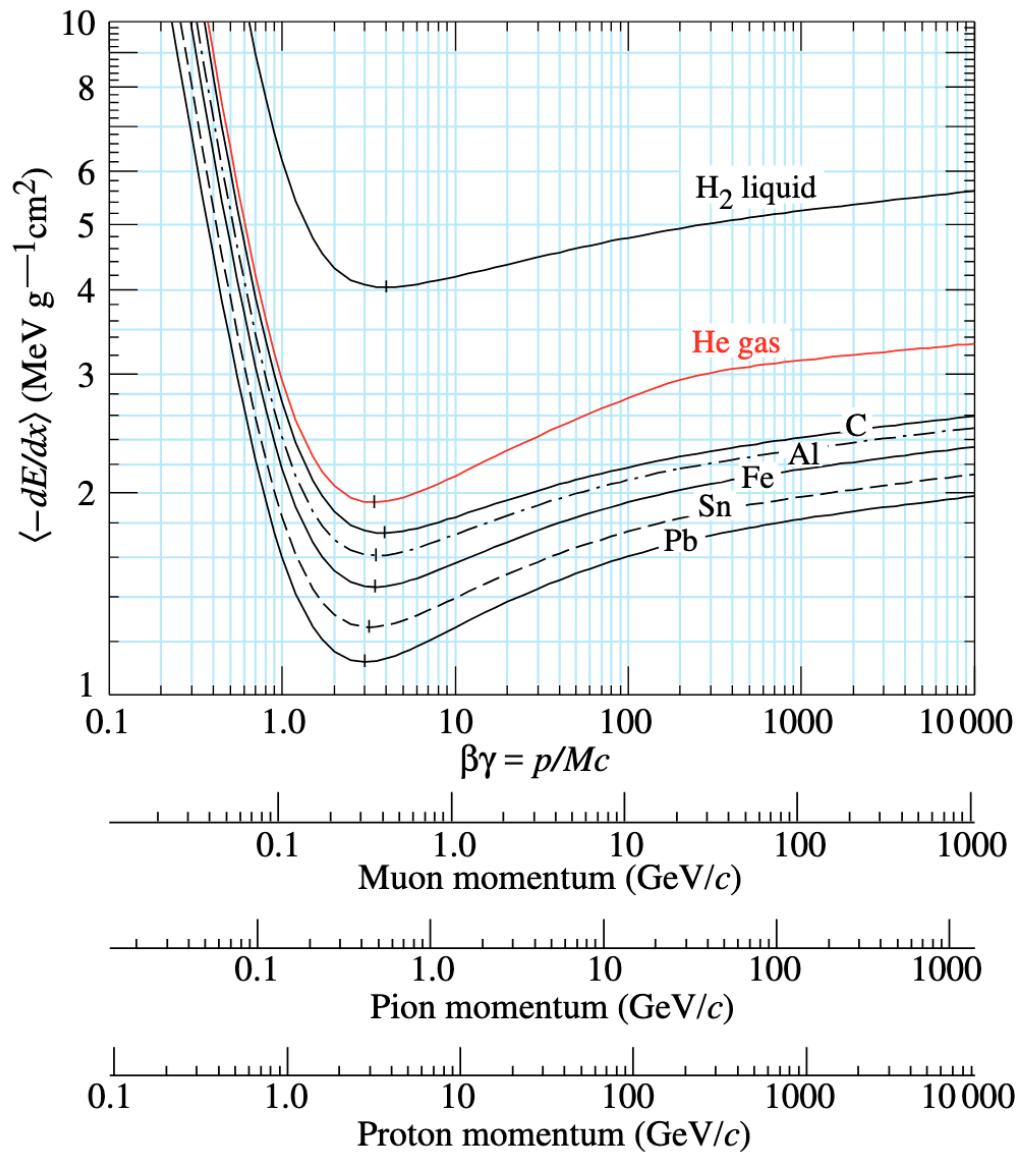
MESURER C'EST QUOI ?



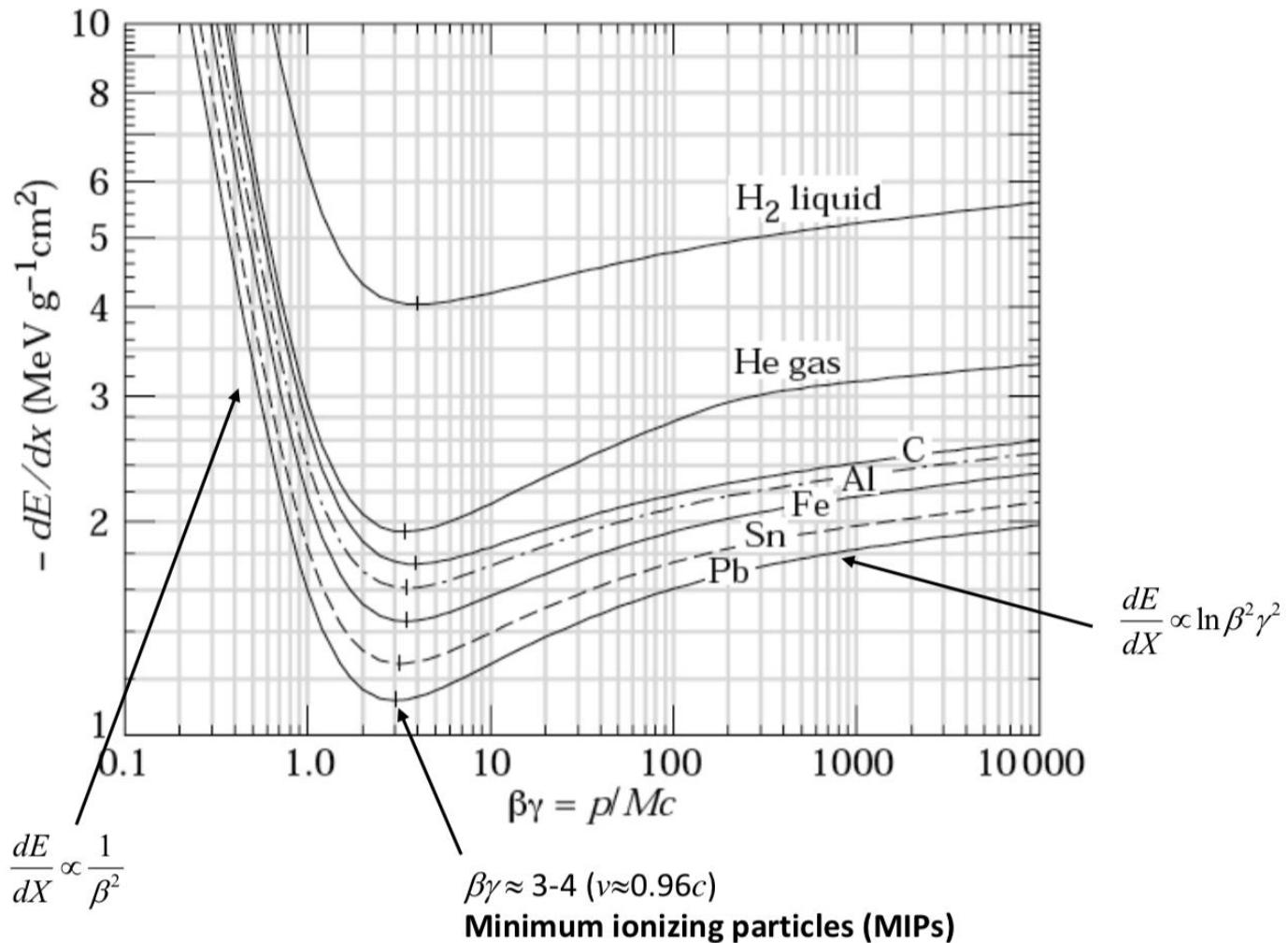
Passage dans la matière d'une particule avec charge électrique

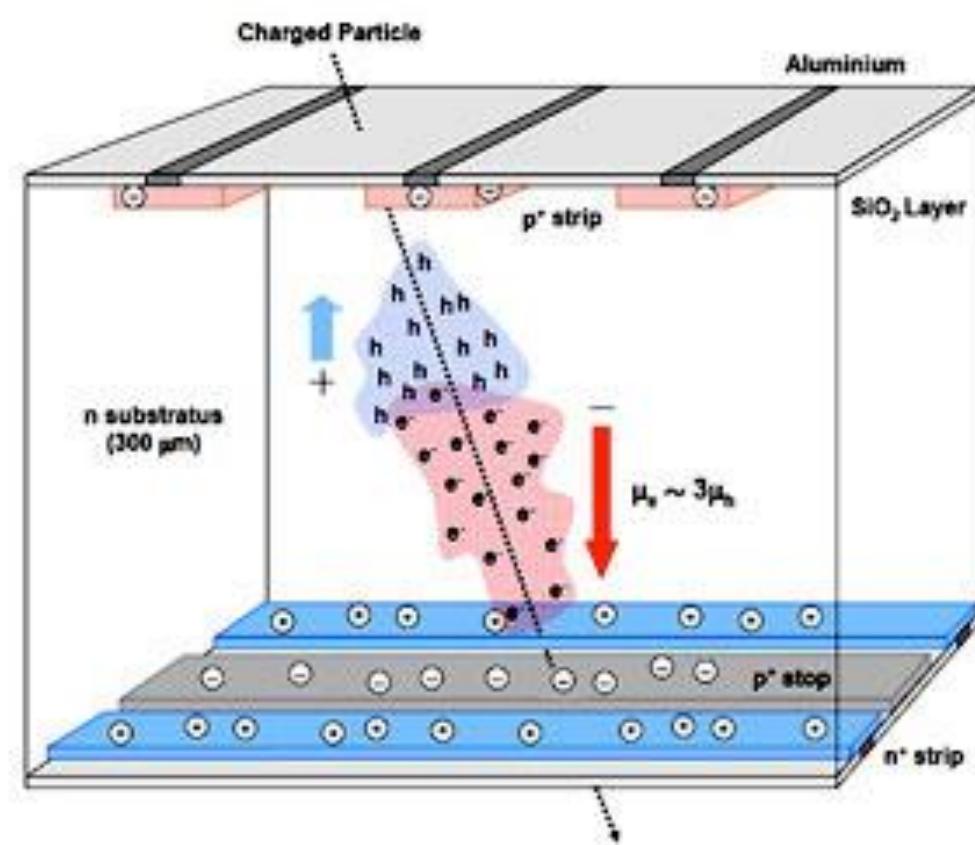
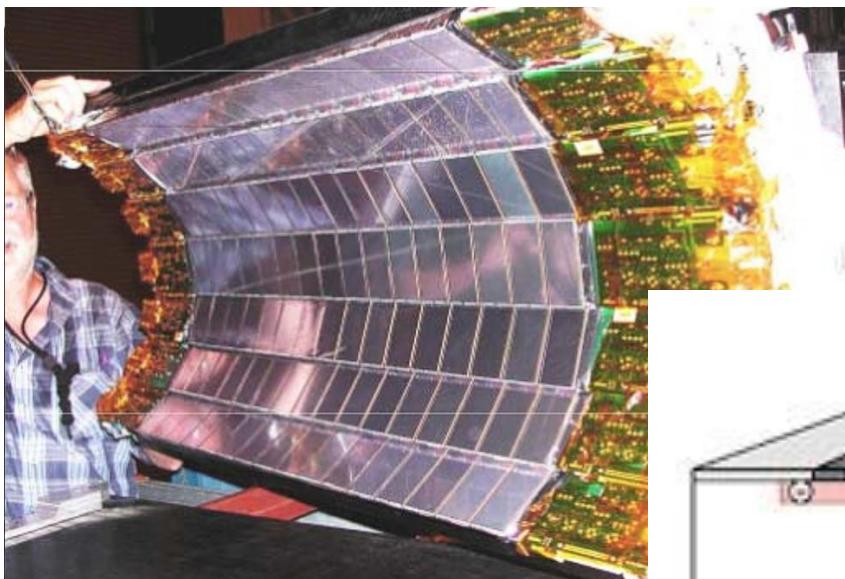
Ex.: un muon ou un proton du rayonnement cosmique





$$-\frac{dE}{dX} = 4\pi N_A r_e^2 m_e c^2 z^2 \frac{Z}{A} \rho \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2m_e c^2 \gamma^2 \beta^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta}{2} - \frac{C}{Z} \right]$$

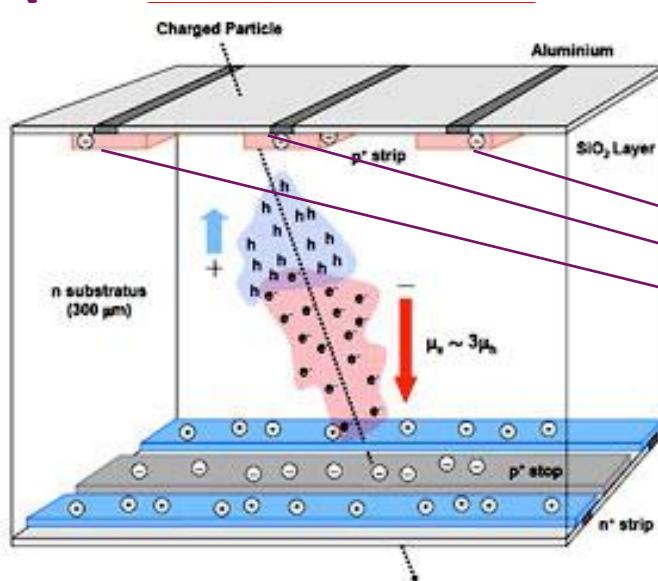




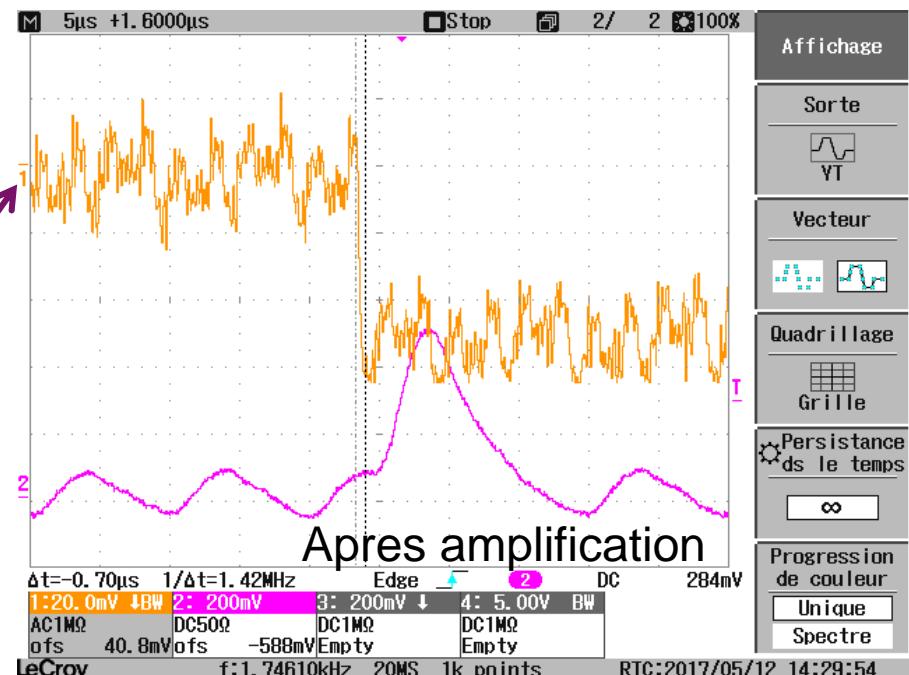
Les autres type de detecteurs =>
Cours 2

MESURER C'EST QUOI ?

Particule

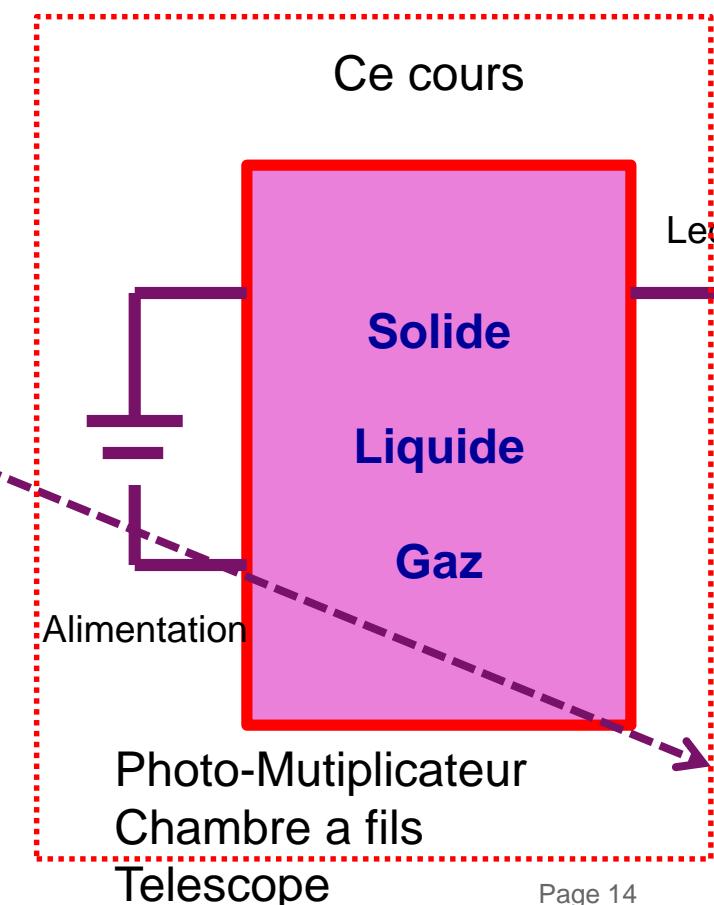
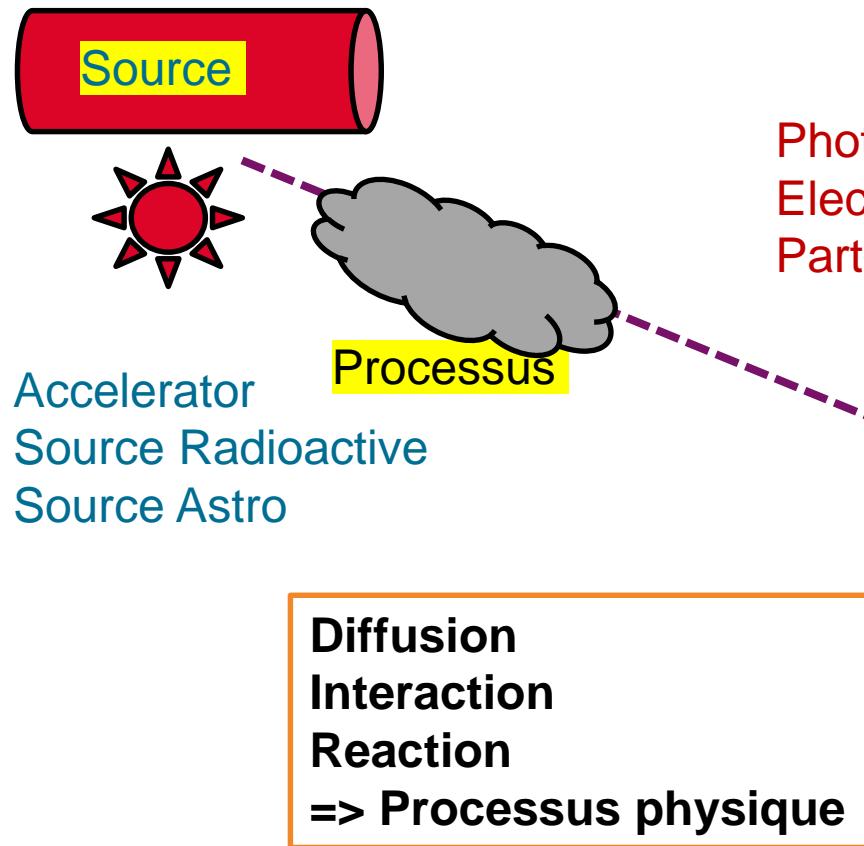


Sortie signal

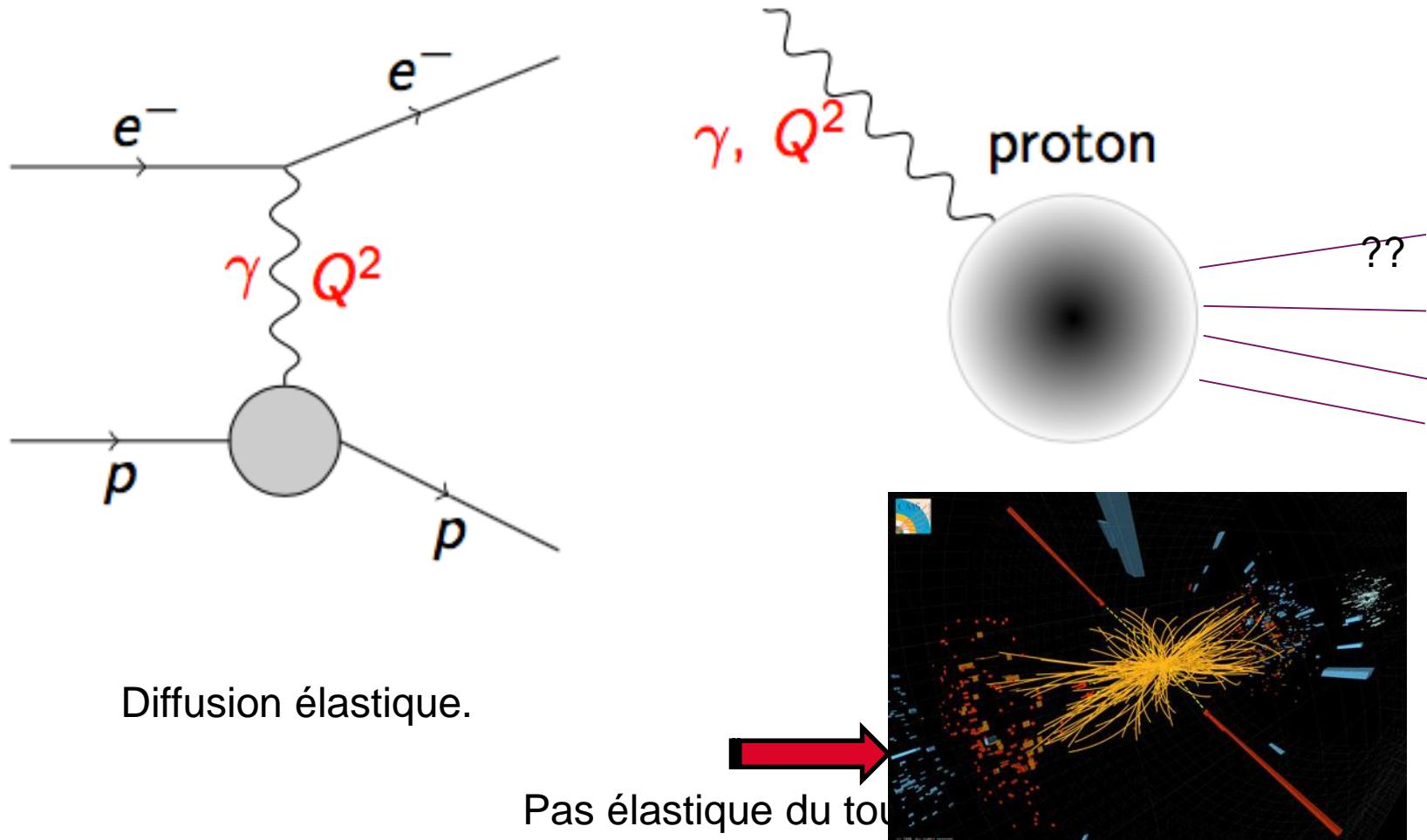


Un Canaux = Un signal
Plein de canaux => Analyse

Schématiquement (*****)



MESURER QUOI ?

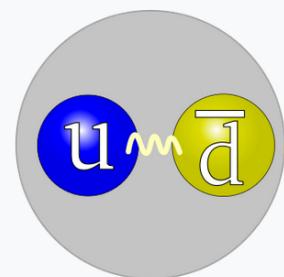


MESURER QUOI ?



Déterminer la carte d'identité d'une particule :

Pion



The quark structure of the pion.

Composition	π^+ : $u\bar{d}$ π^0 : $u\bar{u}$ or $d\bar{d}$ π^- : $d\bar{u}$
Statistics	Bosonic
Interactions	Strong, Weak, Electromagnetic and Gravity
Symbol	π^+ , π^0 , and π^-
Theorized	Hideki Yukawa (1935)
Discovered	César Lattes, Giuseppe Occhialini (1947) and Cecil Powell
Types	3
Mass	π^+ : 139.570 18(35) MeV/ c^2 π^0 : 134.9766(6) MeV/ c^2
Electric charge	π^+ : +1 e π^0 : 0 e π^- : -1 e
Spin	0
Parity	-1

Mesure de l'impulsion (masse et/ou vitesse)

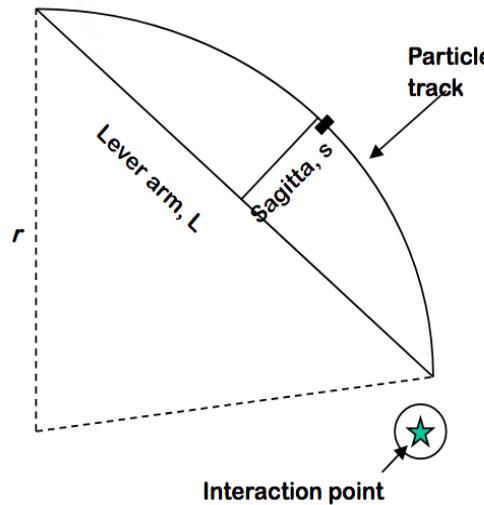
$$p=mv$$

Mesure de l'impulsion

- Technique de spectrométrie magnétique (ou du B-rho)

$$qvB = mv^2/\rho \rightarrow p_{\perp} = p \cos \theta = qB\rho$$

- Tracking measures particle 3-momenta**



$$p = qBr \approx \frac{qBL^2}{8s}$$

$$\frac{\sigma_p}{p} = \frac{\sigma_s}{s} = \frac{8p}{qBL^2} \sigma_s$$

Precision of sagitta measurement: $\sigma_s \approx \sqrt{\frac{3}{N}} \sigma_{hit}$ (**N** position measurements)

Mesure de l'impulsion

- Technique de spectrométrie magnétique (ou du B-rho)

$$qvB = mv^2/\rho \quad \rightarrow \quad p_{\perp} = p \cos \theta = qB\rho$$

- Technique de temps de vol (TOF pour Time Of Flight)

$$L = v\tau = \beta c\tau = \beta c\gamma\tau_0 = p\tau_0/m$$

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- Effet Vavilov-Tcherenkov

$$\cos \theta_c = \frac{c}{n\beta c} = \frac{1}{n\beta} .$$

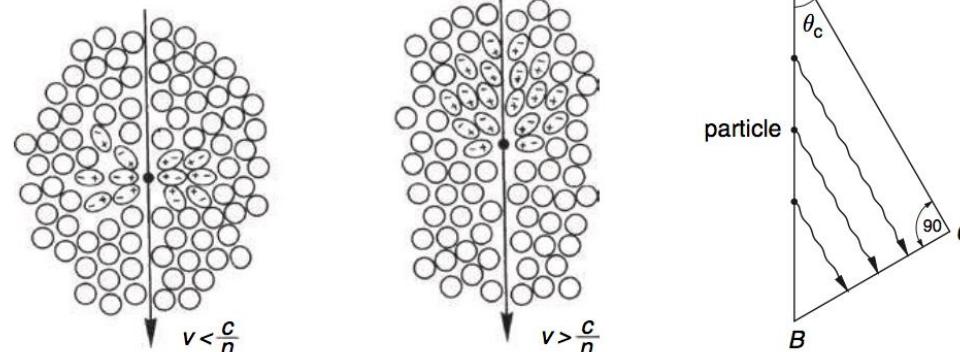


Fig. 5.39. Illustration of the Cherenkov effect [140, 141] and geometric determination of the Cherenkov angle.

Mesure de l'impulsion

- Technique de spectrométrie magnétique (ou du B-rho)
- Technique de temps de vol (TOF pour Time Of Flight)
- Effet Vavilov-Tcherenkov

Mesure de l'énergie

- Calorimétrie
- Perte d'énergie dE/dx

Mesure de l'impulsion

- Technique de spectrométrie magnétique (ou du B-rho)
- Technique de temps de vol (TOF pour Time Of Flight)
- Effet Vavilov-Tcherenkov

Mesure de l'énergie

- Calorimétrie
- Perte d'énergie dE/dx
- Fréquence

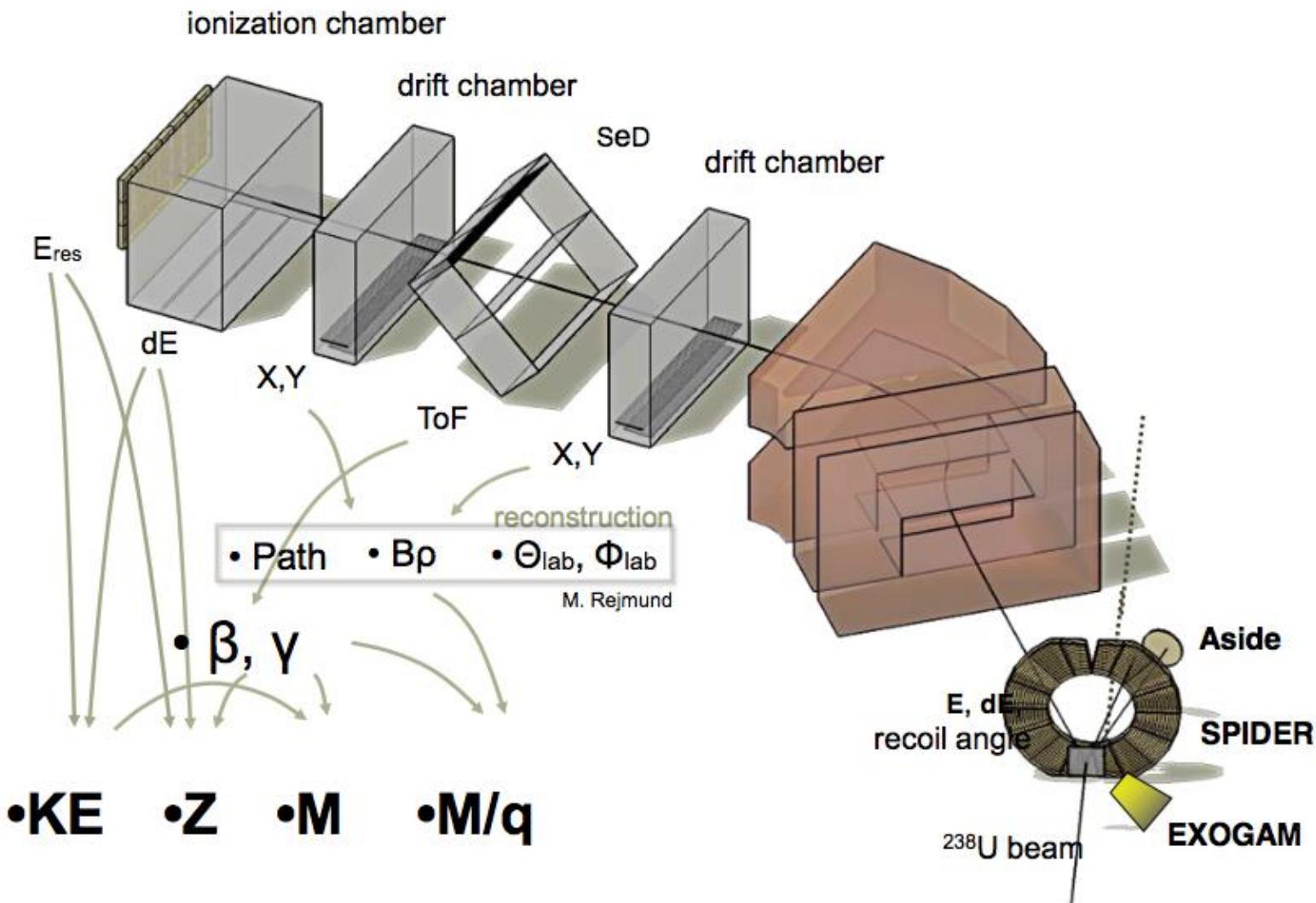
Mesure de spin et de la parité

- (Pas traitée ici)
- Avec un polarimètre indirectement
- Par sélection

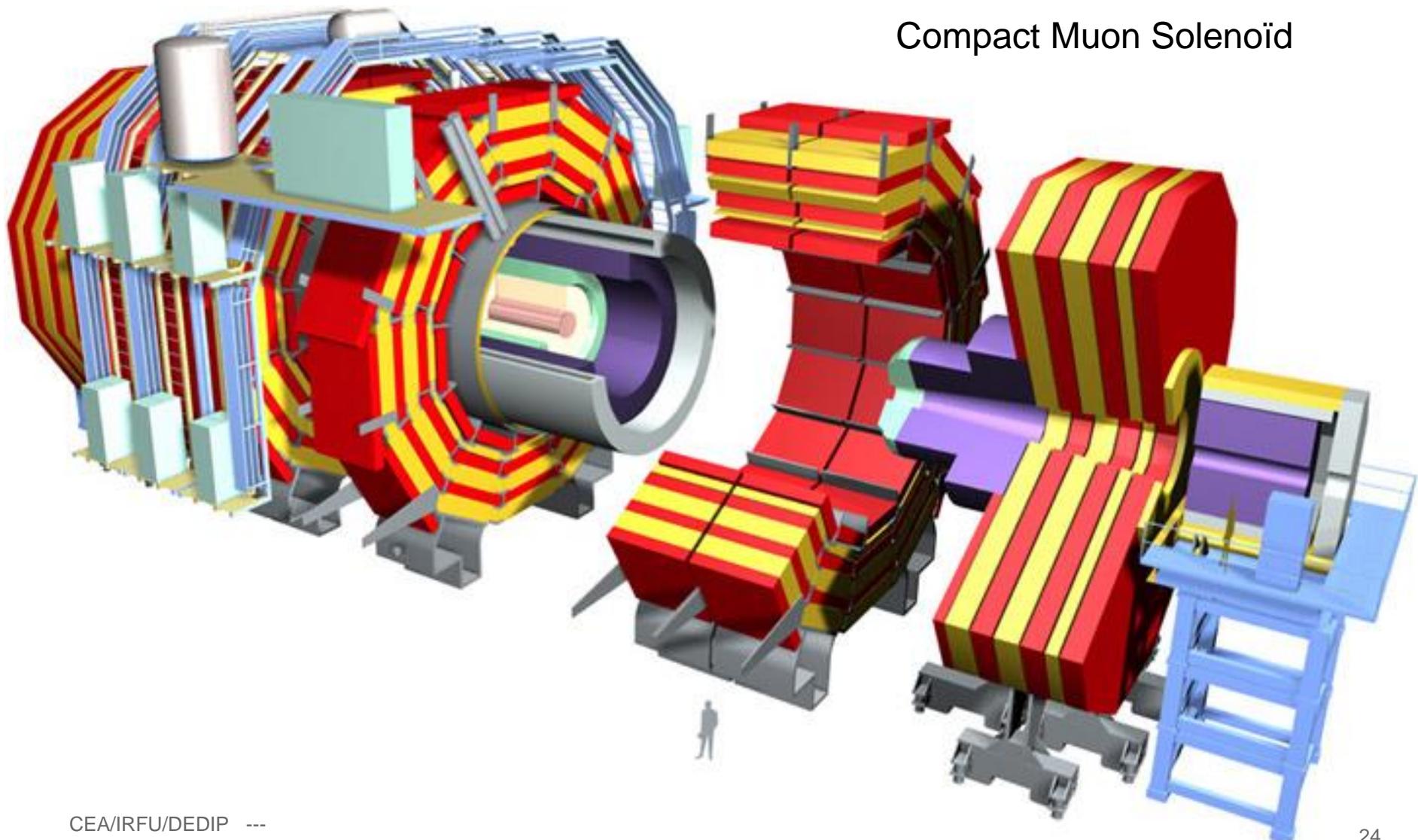
Mesure de la masse et de la charge (PID)

- Combinaison B-rho et TOF
- Combinaison B-rho et dE/dx
- Masse manquante ...
- Direction de la courbure dans un spectromètre magnétique
- Mesure de la perte d'énergie dE/dx qui dépend de la charge
- L'electromètre

UN EXEMPLE



UN PLUS GROS



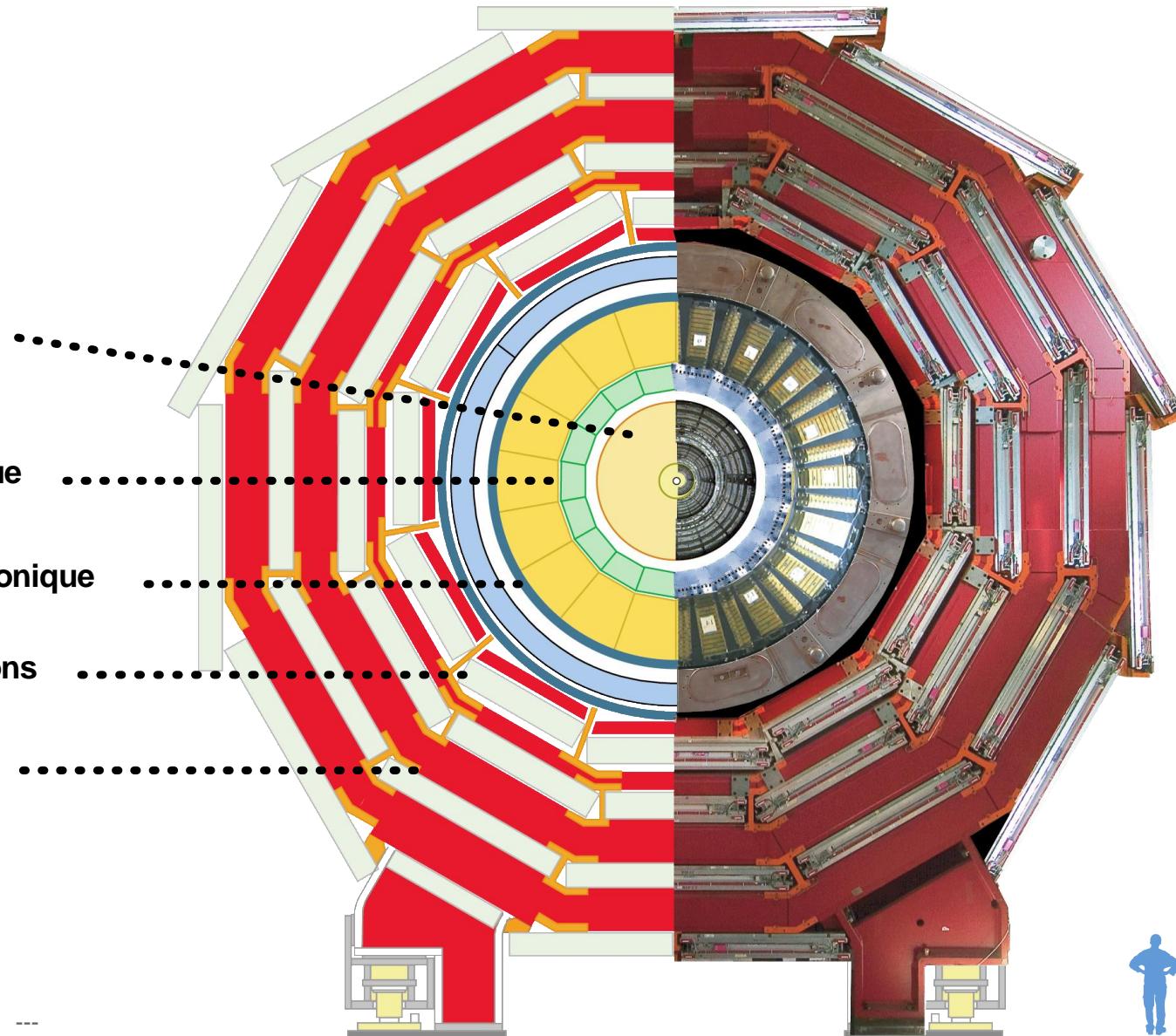
Trajectographe

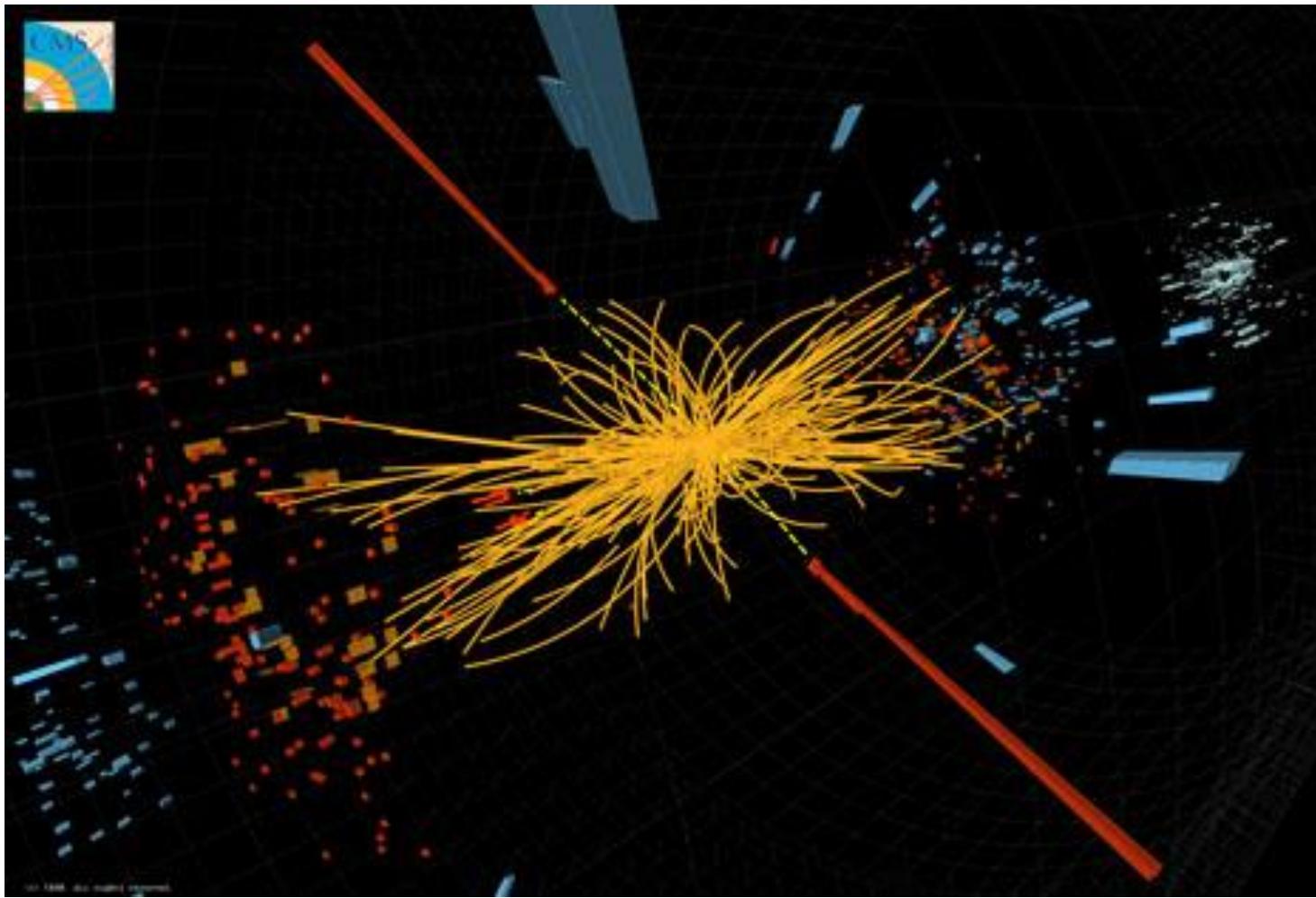
Calorimètre
électromagnétique

Calorimètre hadronique

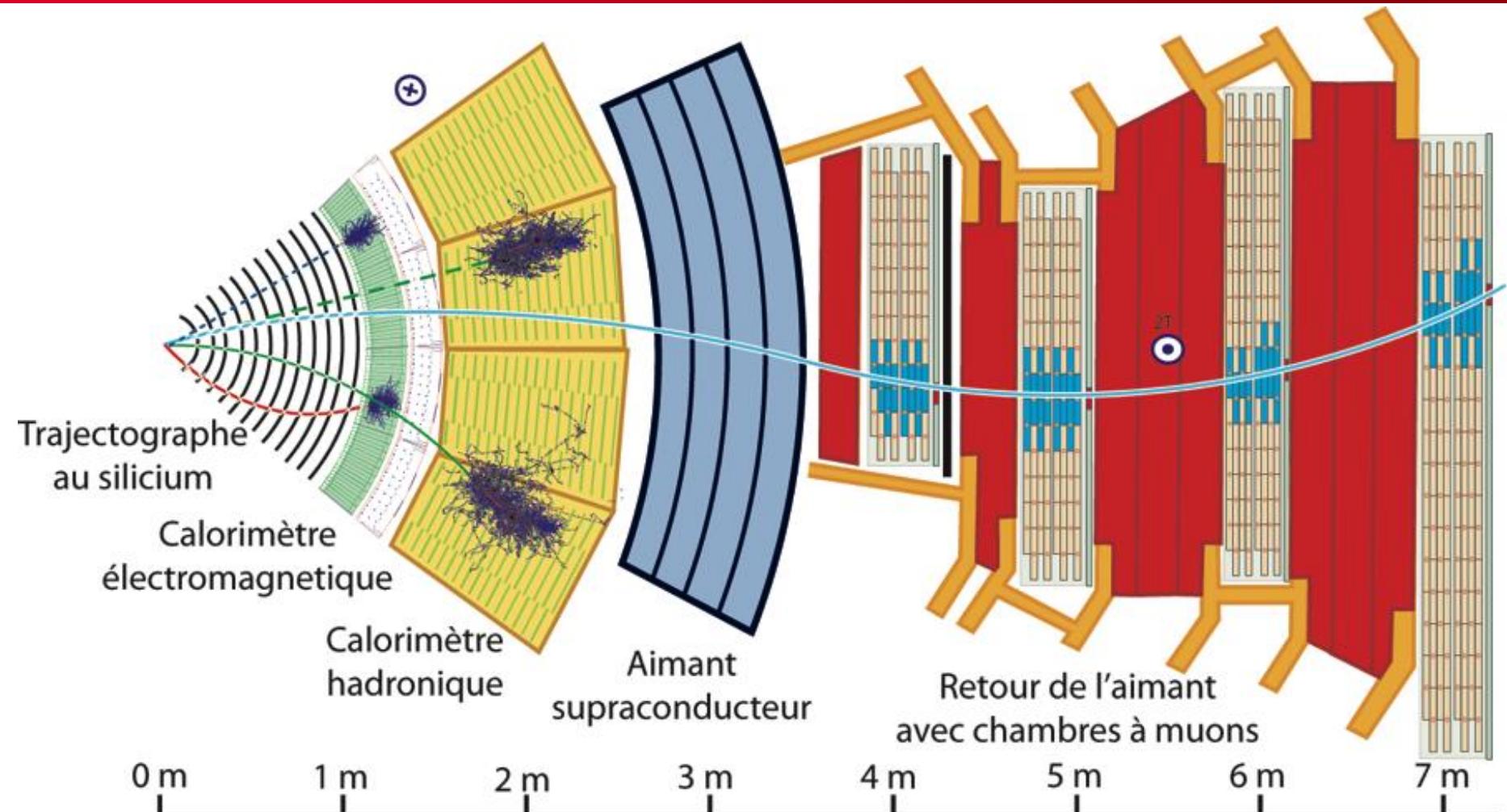
Détecteurs à muons

Aimant





Courbes = trajectoire mesurée par les trajectographes
Barres = Mesure d'énergies dans les calorimètre



légende :

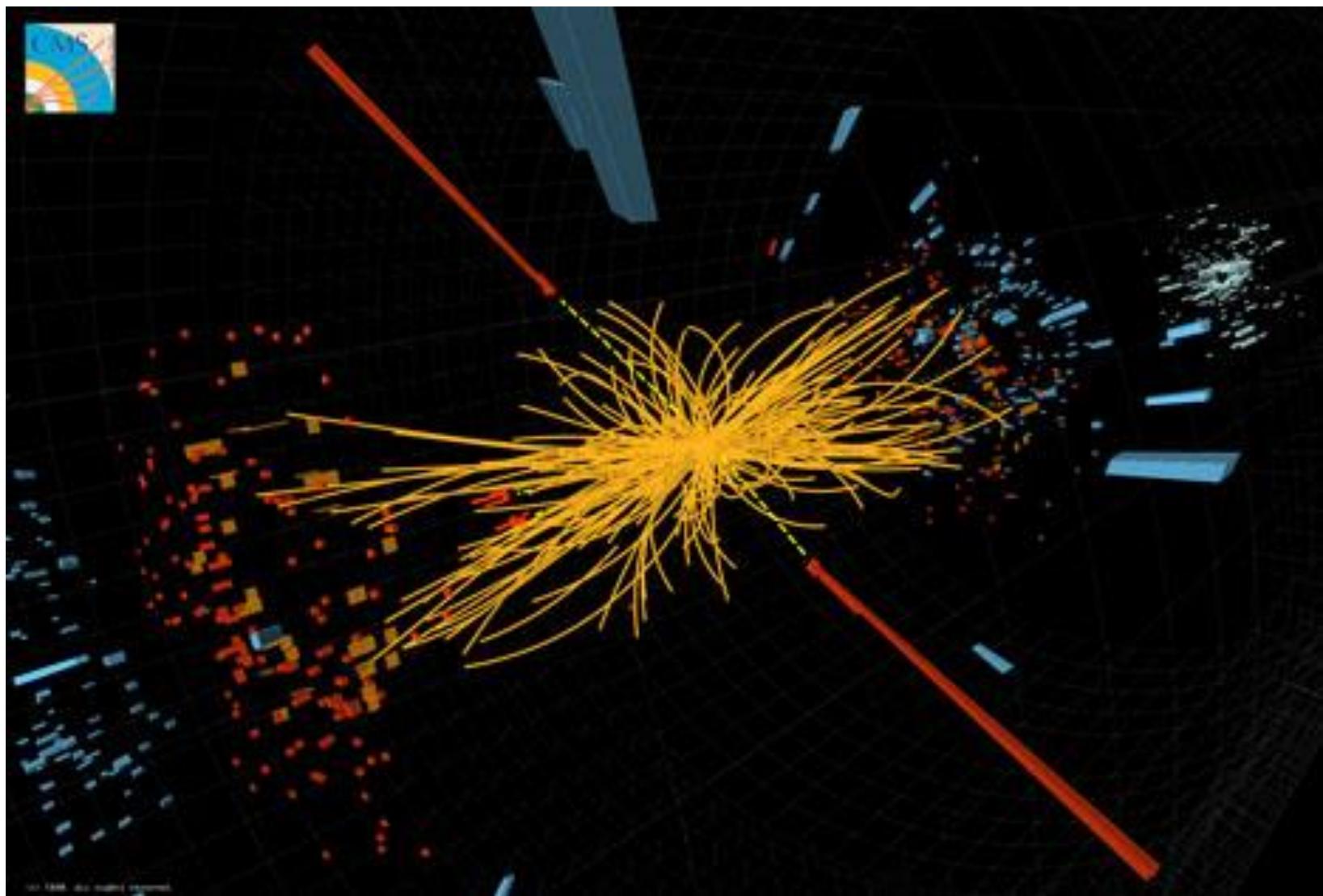
Muon

Électron

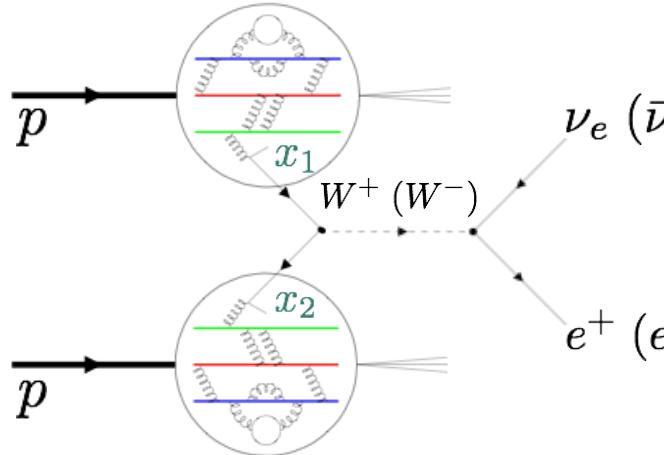
Hadron chargé

Hadron neutre

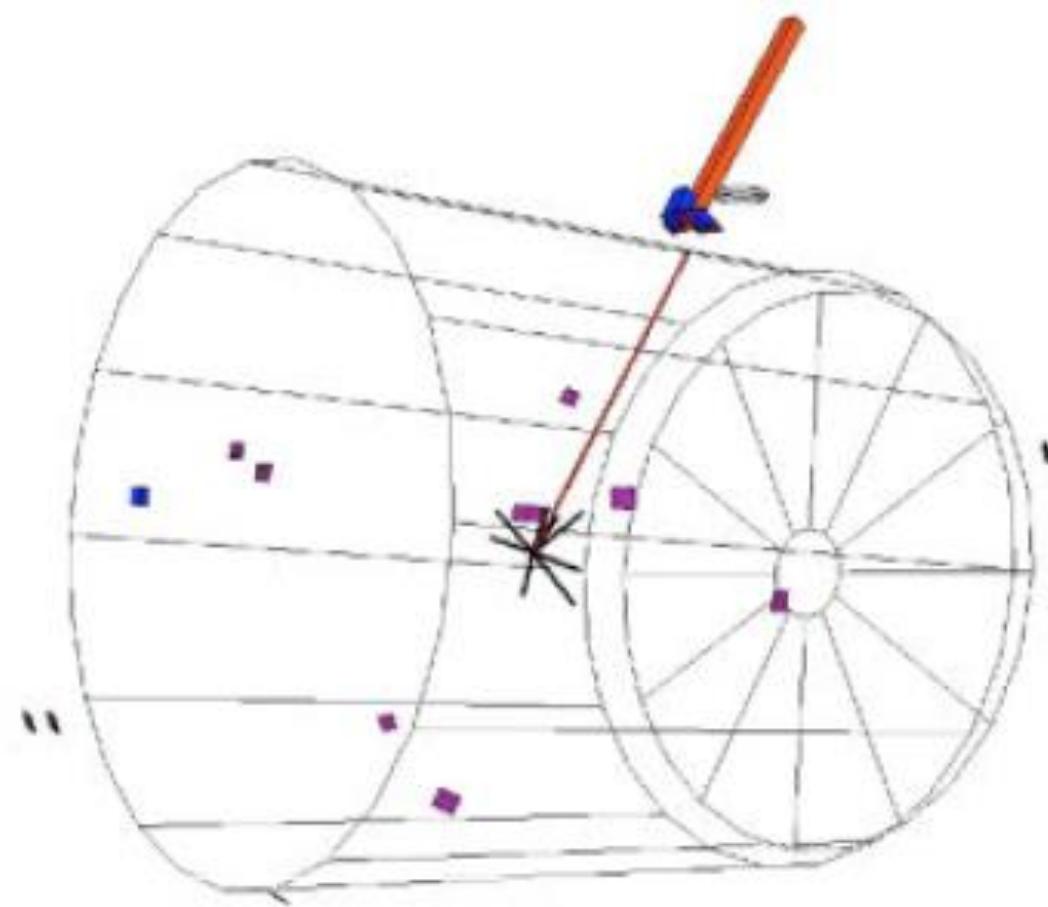
Photon

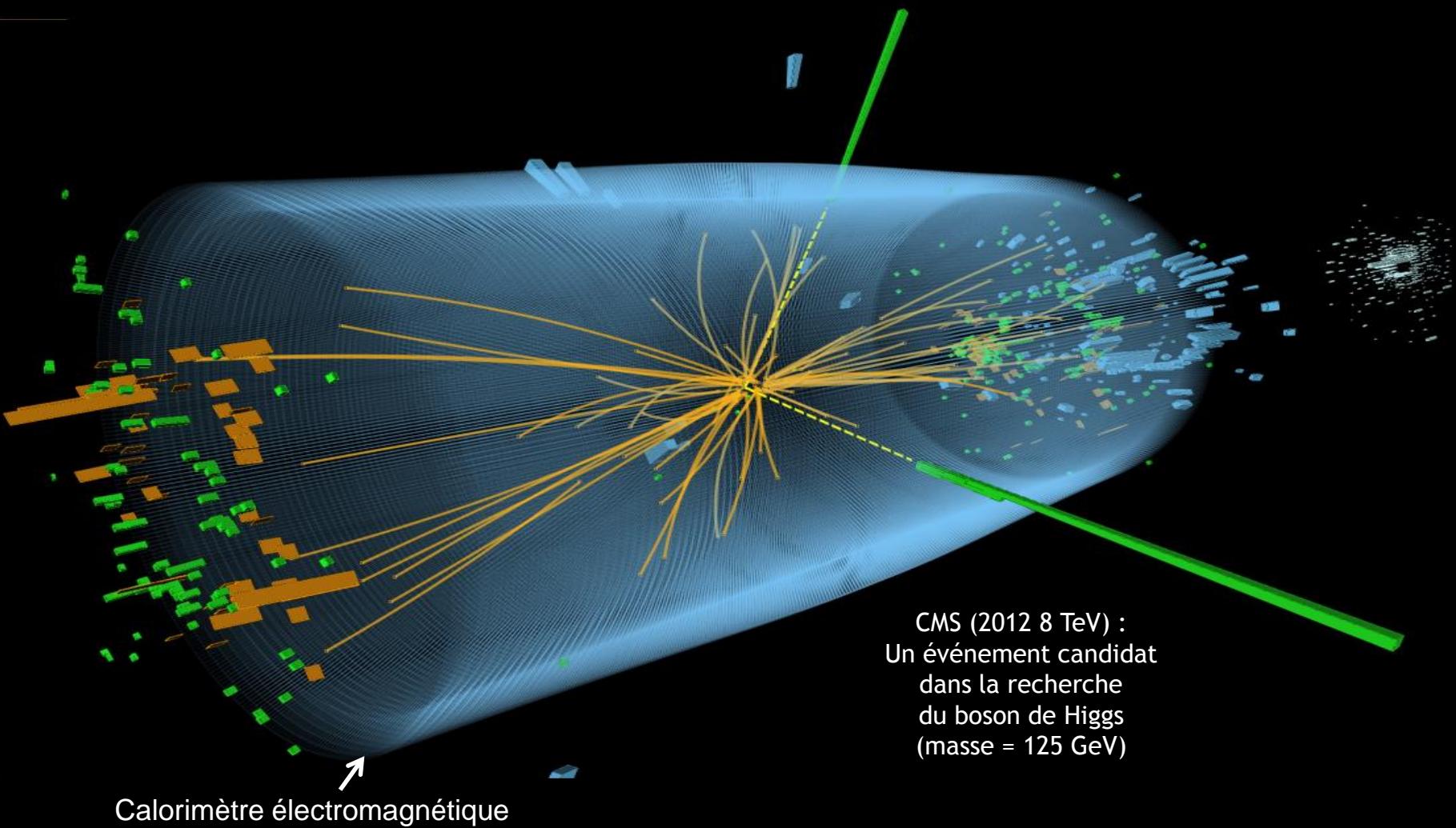


W EVENT -> ISOLATED LEPTON



"Did you see it?"
"No nothing."
"Then it was a neutrino!"

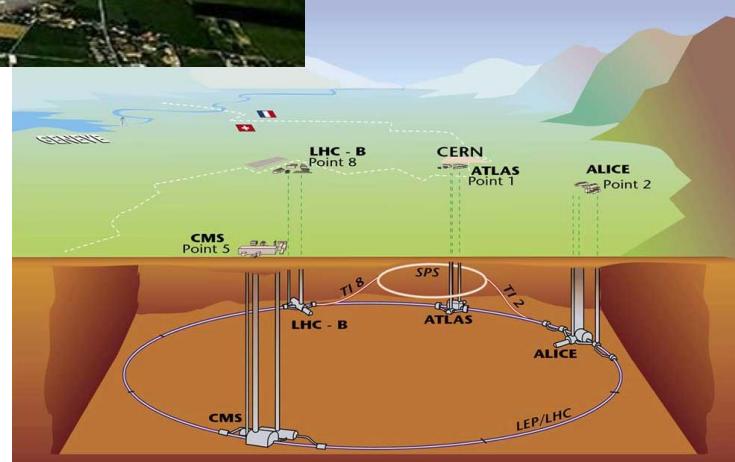




Le Large Hadron Collider



27 km
8.3 T
 $1.9 \text{ K} (-271.3^\circ\text{C})$
 10^{-13} atm
362 MJ



The LHC accelerator

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Cours 2 : Les détecteurs de particules

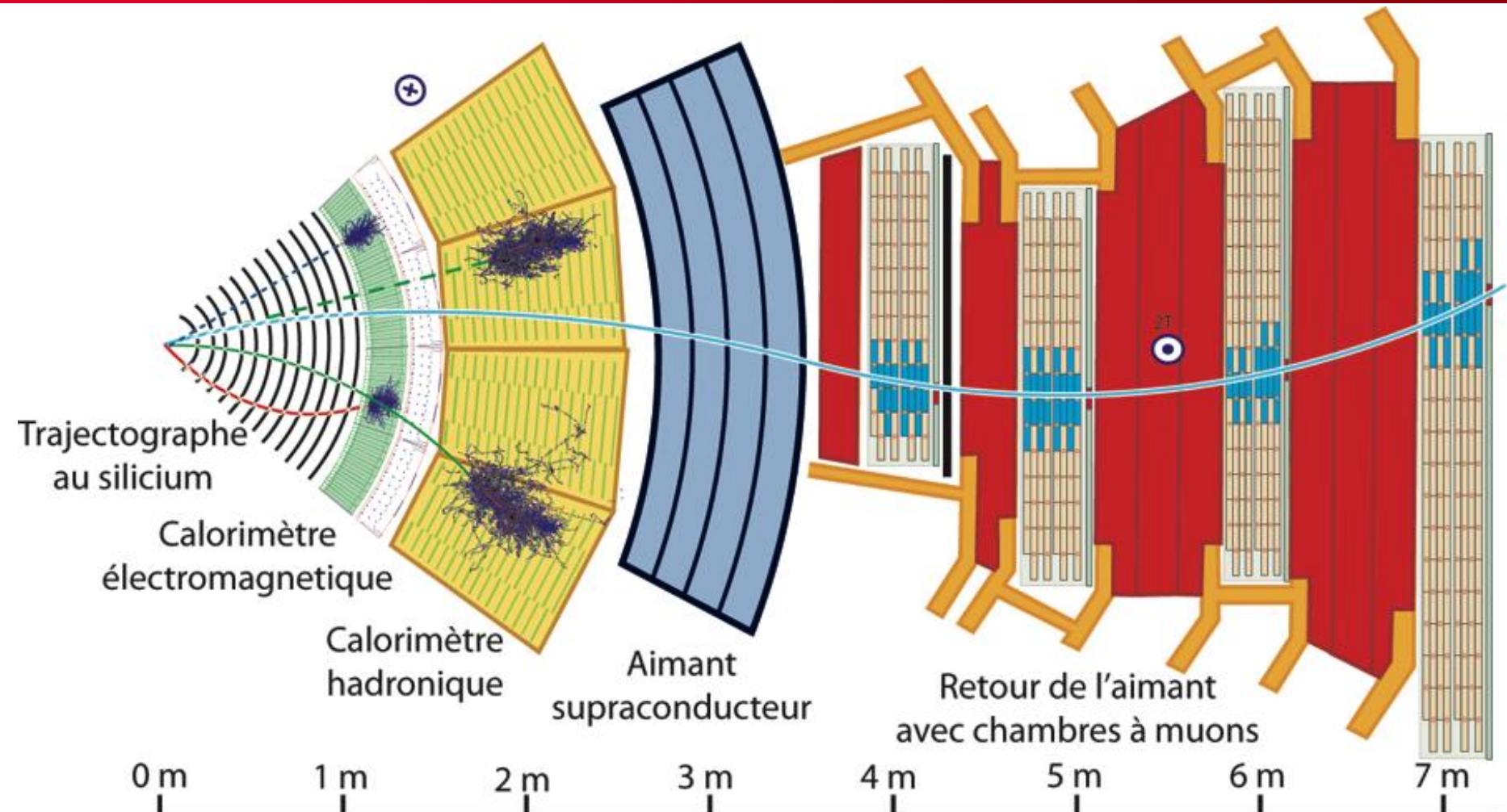
- DéTECTEURS au Silicium
- Calorimétrie
- Scintillation
- DéTECTEURS Gazeux

Basé sur les cours de Stefano Panebianco (CEA/IRFU), et le cours de Werner Riegler (CERN), Particle Detectors , Second Edition, C. Grupen & B. Shwartz



"Did you see it?"
"No nothing."
"Then it was a neutrino!"





légende :

— Muon

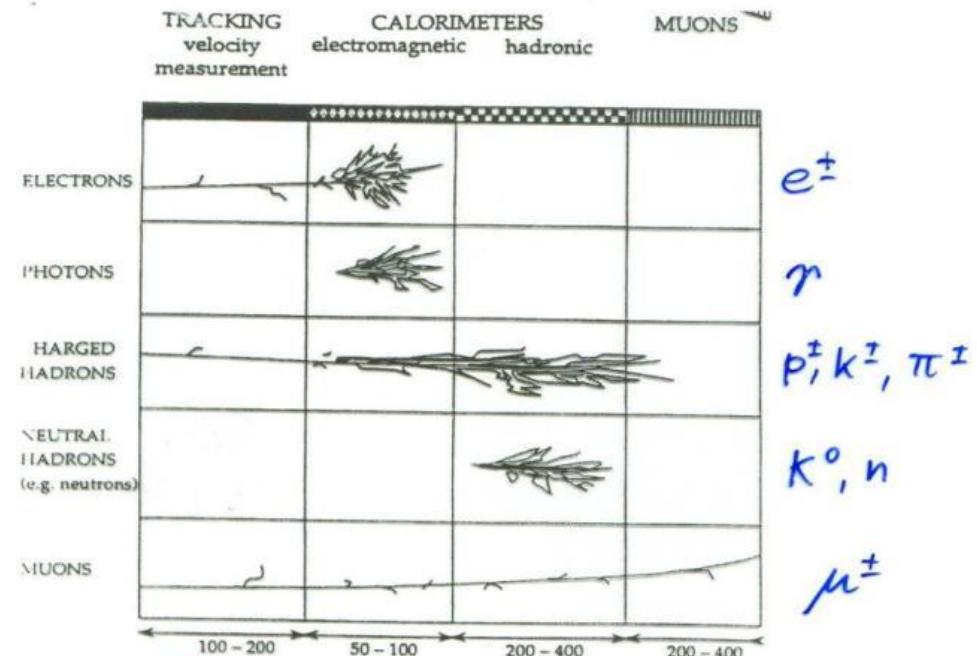
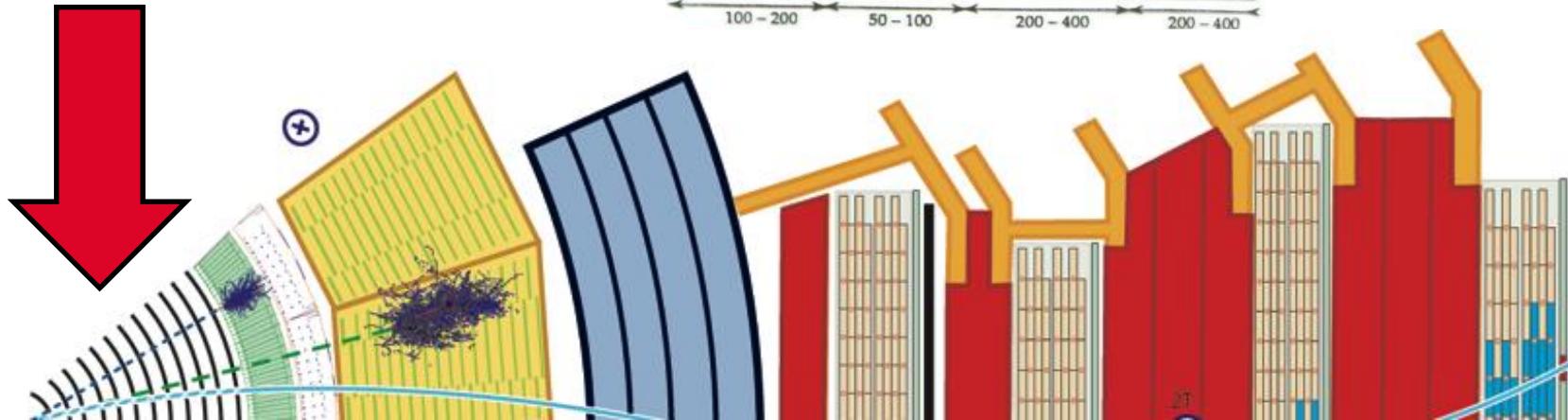
— Électron

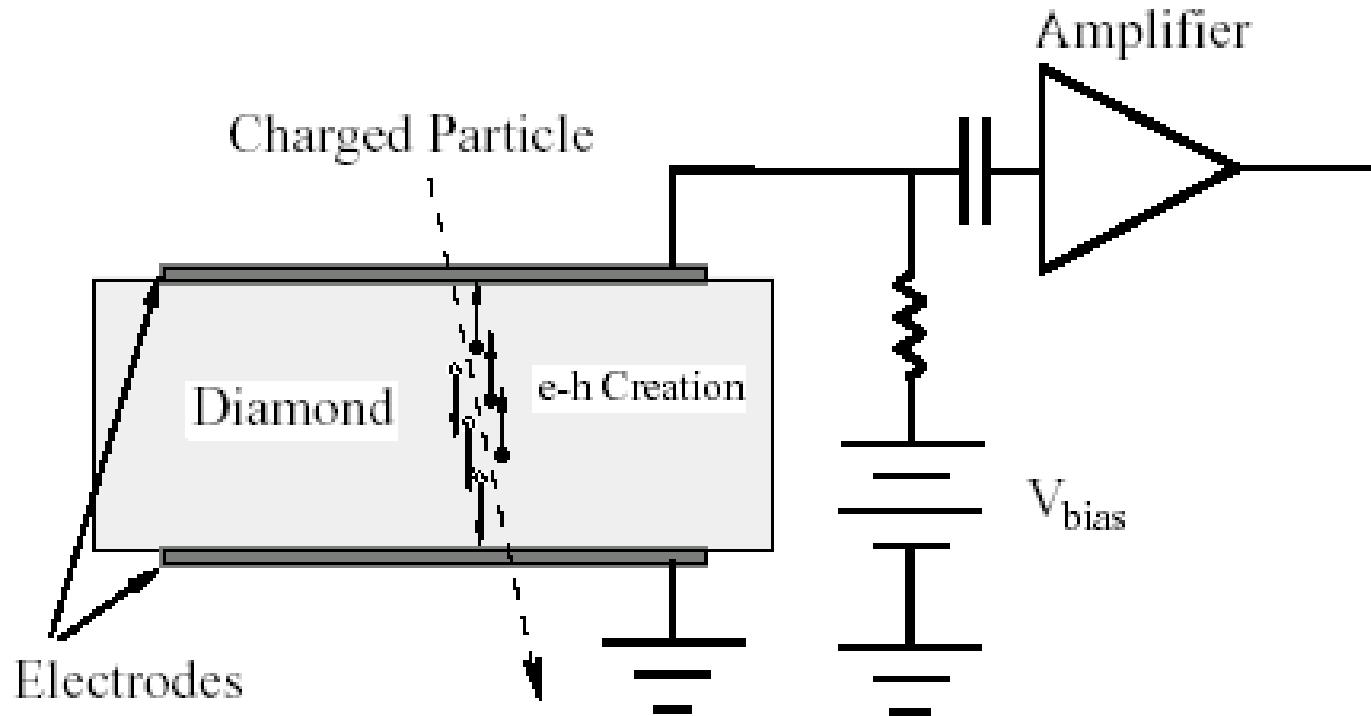
— Hadron chargé

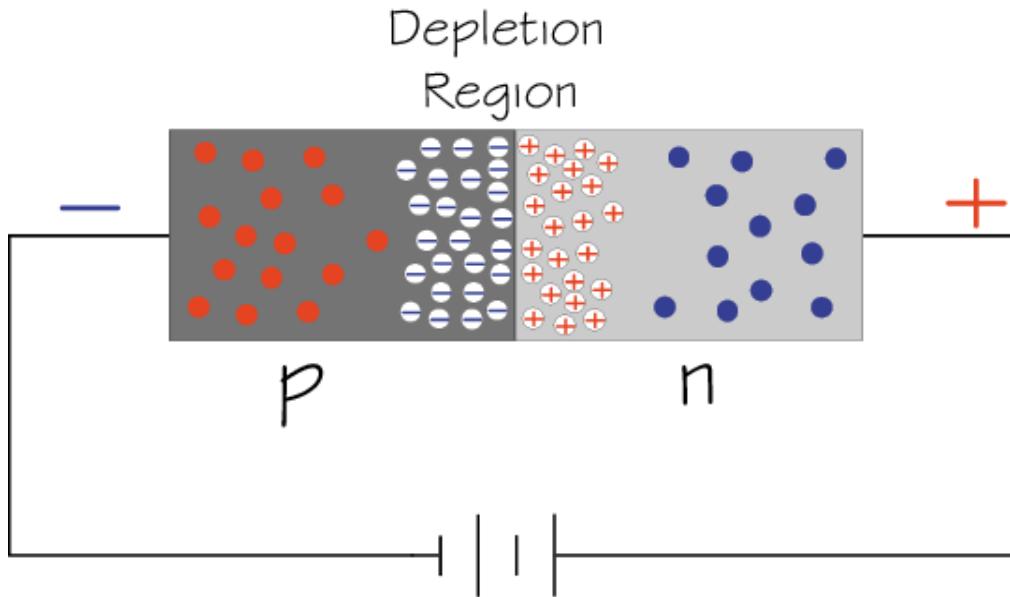
- - - Hadron neutre

----- Photon

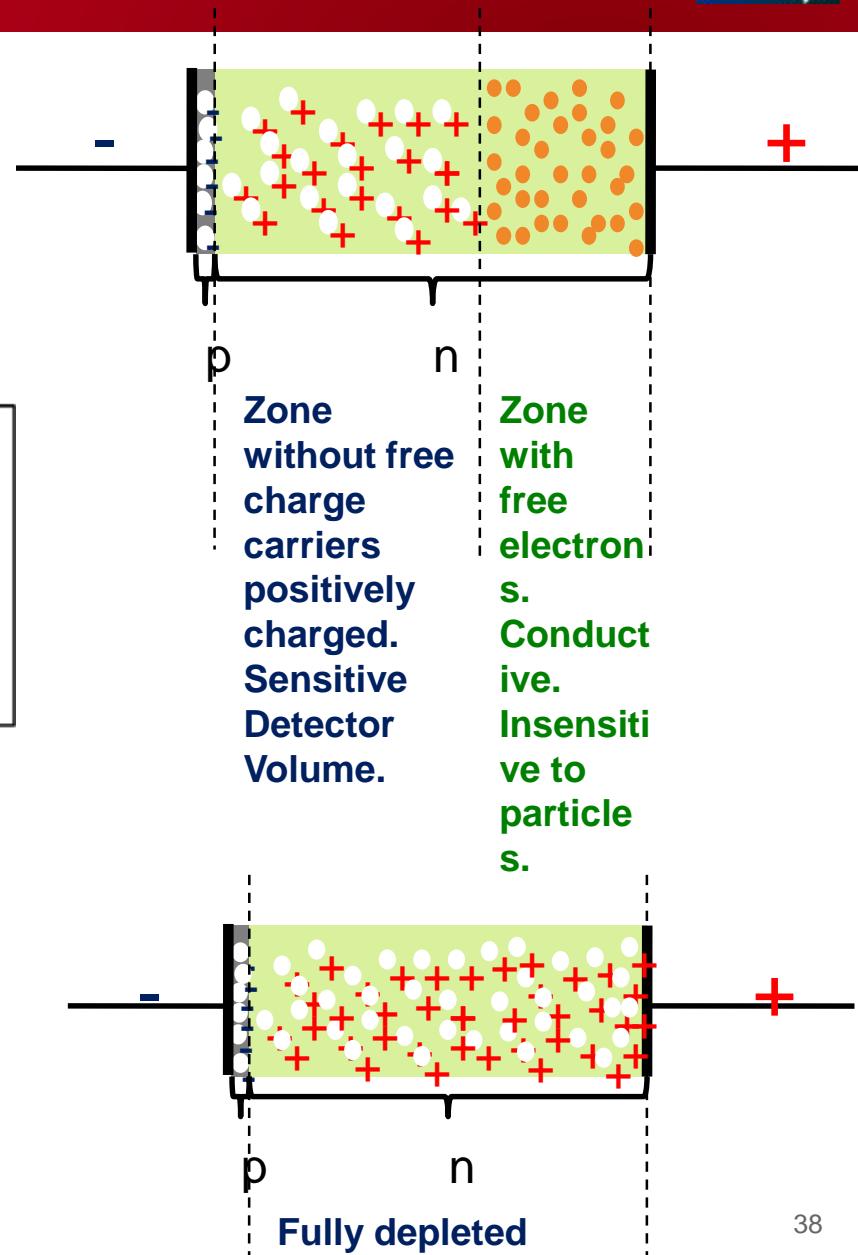
Trajectographes Semi-Conducteur



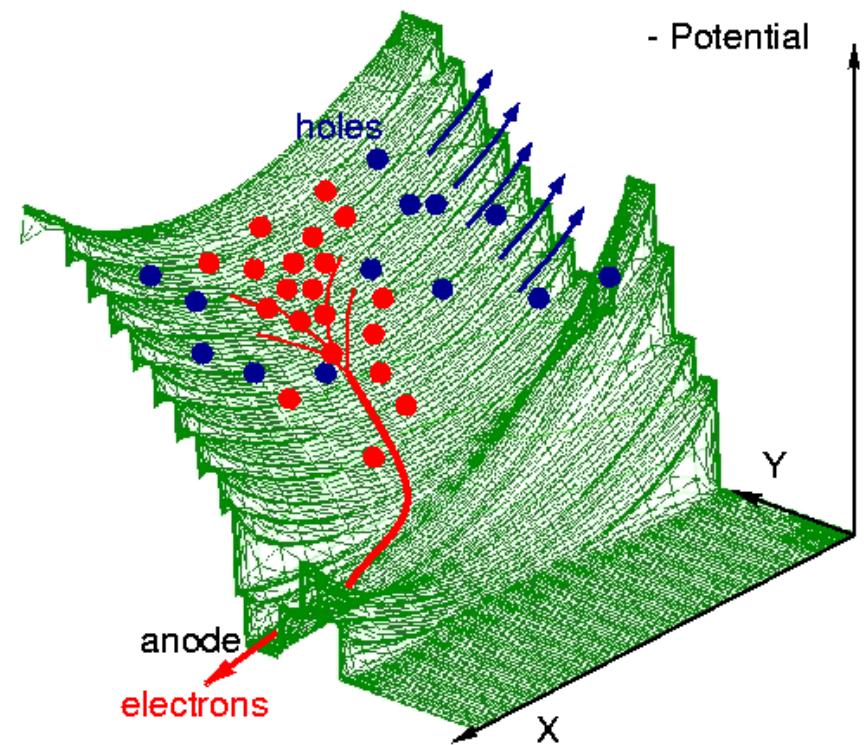
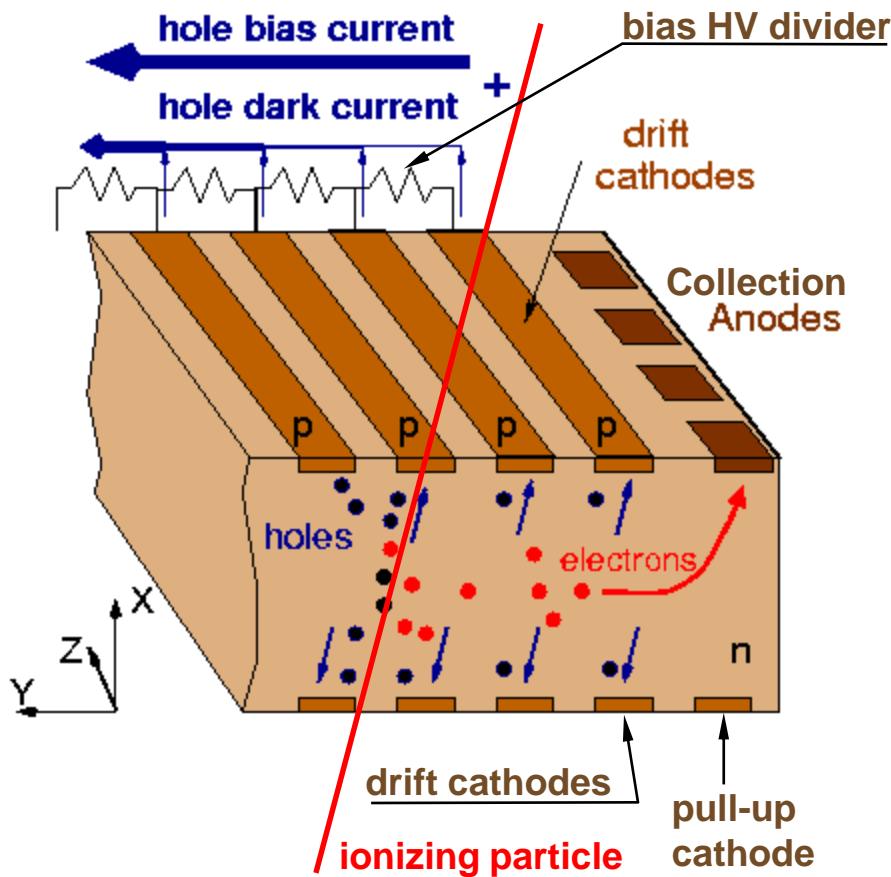




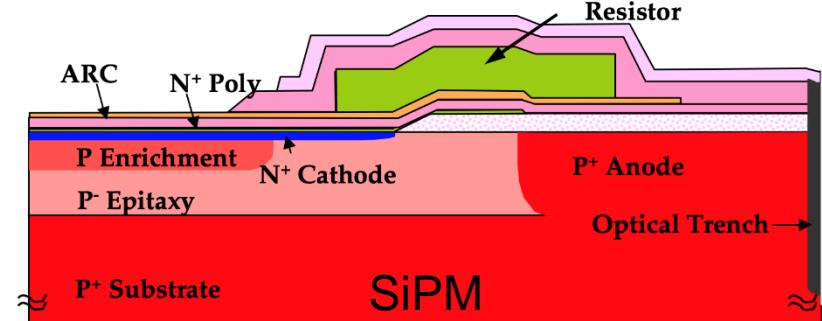
- Electron
- ⊕ Positive ion from removal of electron in n-type impurity
- ⊖ Negative ion from filling in p-type vacancy
- Hole



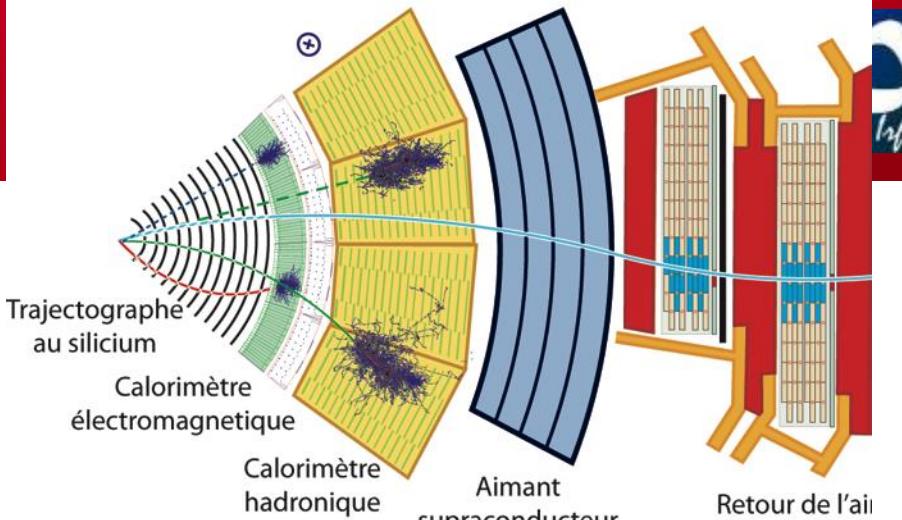
Silicon Drift Detector



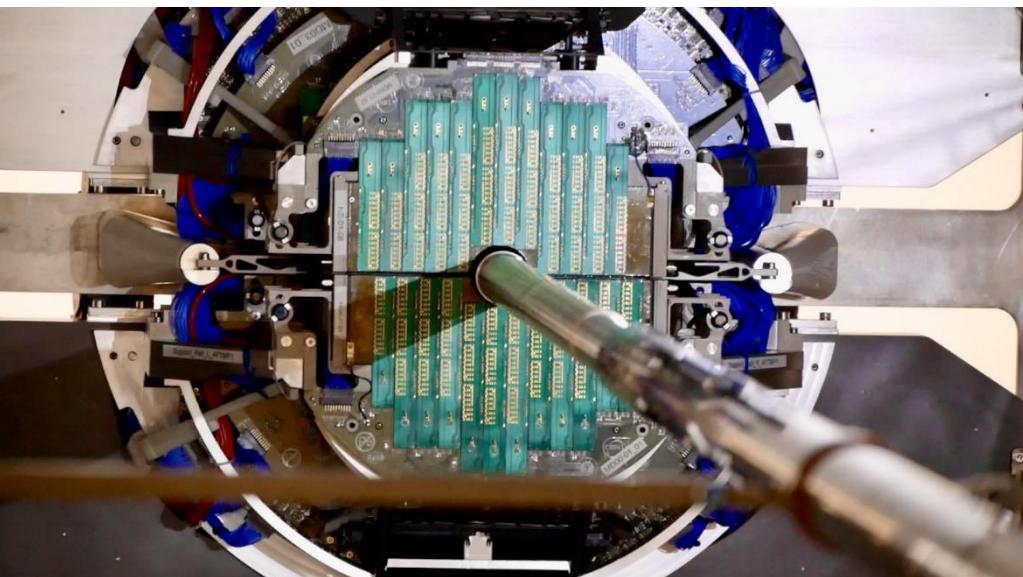
Schematic cross section Poly-silicon Quenching Resistor



Si Tracker

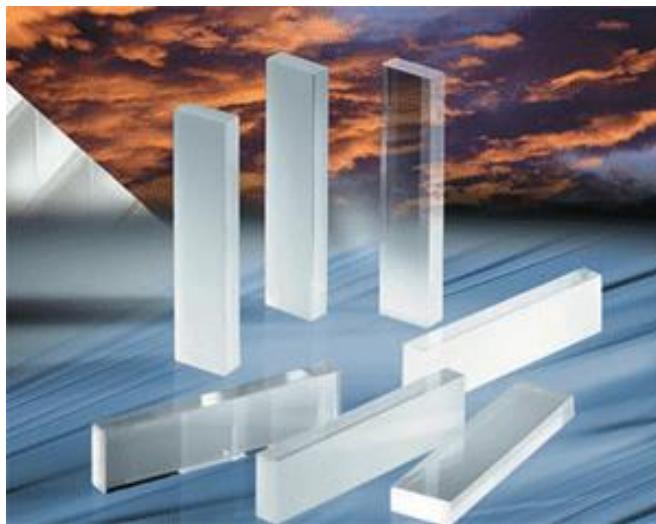


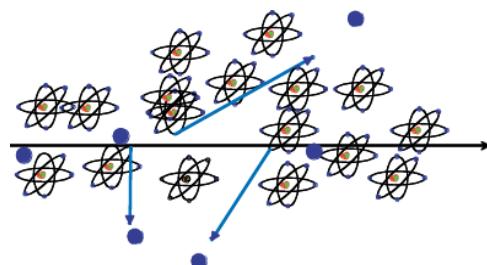
ALICE – MFT (Muon Forward Tracker)





Les DéTECTEUR à base de scintillation

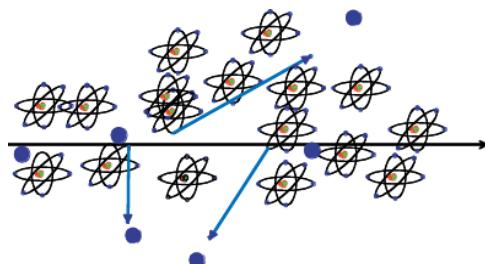




Detectors based on Registration of excited Atoms → Scintillators

Emission of photons by excited Atoms, typically UV to visible light.





Detectors based on Registration of excited Atoms → Scintillators

Emission of photons by excited Atoms, typically UV to visible light.



a) Observed in Noble Gases (even liquid !)

b) Inorganic Crystals

→ Substances with largest light yield. Used for precision measurement of energetic Photons. Used in Nuclear Medicine.

c) Polycyclic Hydrocarbons (Naphtalen, Anthrazen, organic Scintillators)

→ *Most important category. Large scale industrial production, mechanically and chemically quite robust. Characteristic are one or two decay times of the light emission.*

Organic ('Plastic') Scintillators

Low Light Yield

Fast: 1-3ns

Type	Light ^a output	$\lambda_{\text{max}}^{\text{b}}$ (nm)	Attenuation ^c length (cm)	Risetime (ns)	Decay ^d time (ns)	Pulse FWHM (ns)
NE 102A	58–70	423	250	0.9	2.2–2.5	2.7–3.2
NE 104	68	406	120	0.6–0.7	1.7–2.0	2.2–2.5
NE 104B	59	406	120	1	3.0	3
NE 110	60	434	400	1.0	2.9–3.3	4.2
NE 111	40–55	375	8	0.13–0.4	1.3–1.7	1.2–1.6
NE 114	42–50	434	350–400	~1.0	4.0	5.3
Pilot B	60–68	408	125	0.7	1.6–1.9	2.4–2.7
Pilot F	64	425	300	0.9	2.1	3.0–3.3
Pilot U	58–67	391	100–140	0.5	1.4–1.5	1.2–1.9
BC 404	68	408	—	0.7	1.8	2.2
BC 408	64	425	—	0.9	2.1	~2.5
BC 420	64	391	—	0.5	1.5	1.3
ND 100	60	434	400	—	3.3	3.3
ND 120	65	423	250	—	2.4	2.7
ND 160	68	408	125	—	1.8	2.7

Inorganic (Crystal) Scintillators

Large Light Yield

Slow: few 100ns

	Relative light output	$\lambda_{\text{max}}^{\text{e}}$ emission (nm)	Delay time (ns)	Density (g/cm ³)
<i>Inorganic crystals</i>				
Nal(Tl)	230	415	230	3.67
CsI(Tl)	250	560	900	4.51
Ba ₄ Ge ₁₂ O ₃₂ (BGO)	23–86	480	300	7.13
<i>Organic crystals</i>				
Anthracene	100	448	22	1.25
Trans-stilbene	75	384	4.5	1.16
Naphthalene	32	330–348	76–96	1.03
p,p'-Quaterphenyl	94	437	7.5	1.20
<i>Primary activators</i>				
2,5-Diphenyl-oxazole (PPO)	75	360–416	5*	
2-Phenyl-5-(4-biphenylyl)-1,3,4-oxadiazole (PBD)	96	360–5		
4,4"-Bis(2-butyloctyloxy)-p-quaterphenyl (BIBUQ)	60	365,393	1.30 ^b	

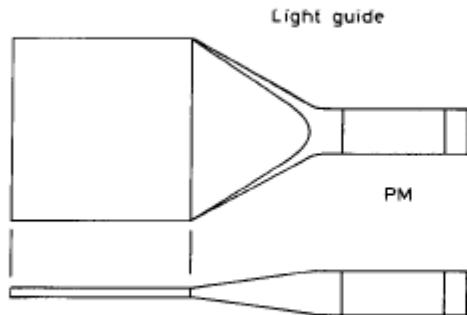
LHC bunchcrossing 25ns

LEP bunchcrossing 25μs

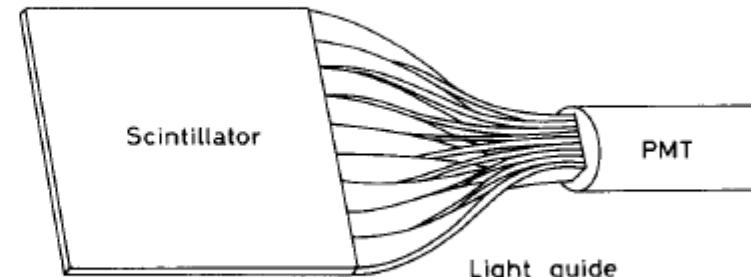
Typical Geometries:

- Light guides: transfer by total internal reflection

(+outer reflector)

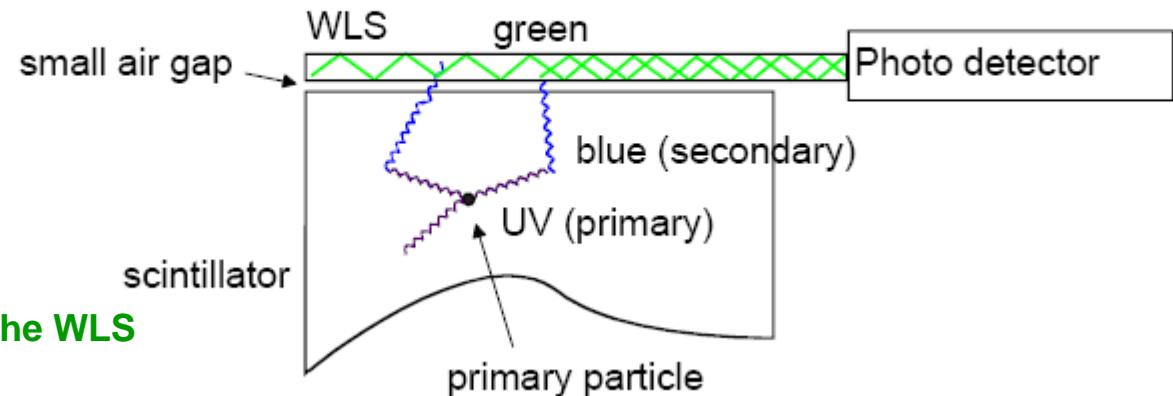


"fish tail"



adiabatic

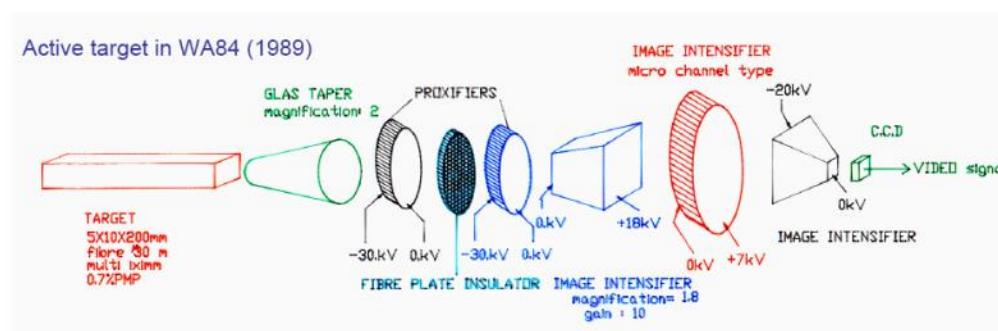
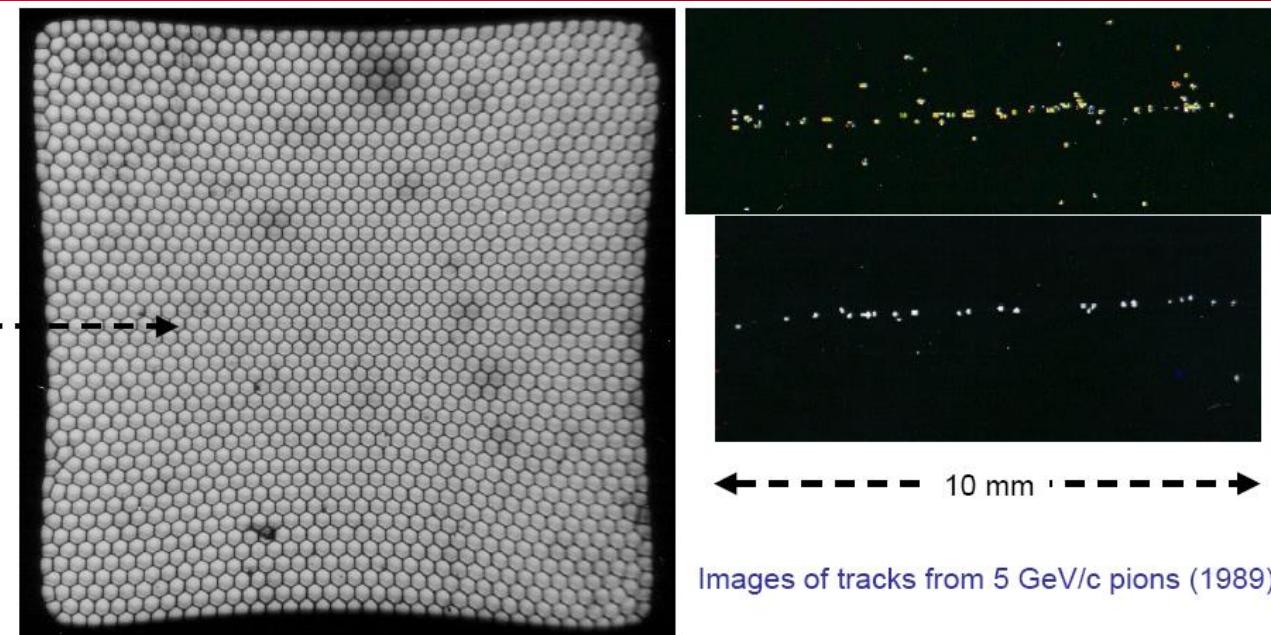
- wavelength shifter (WLS) bars



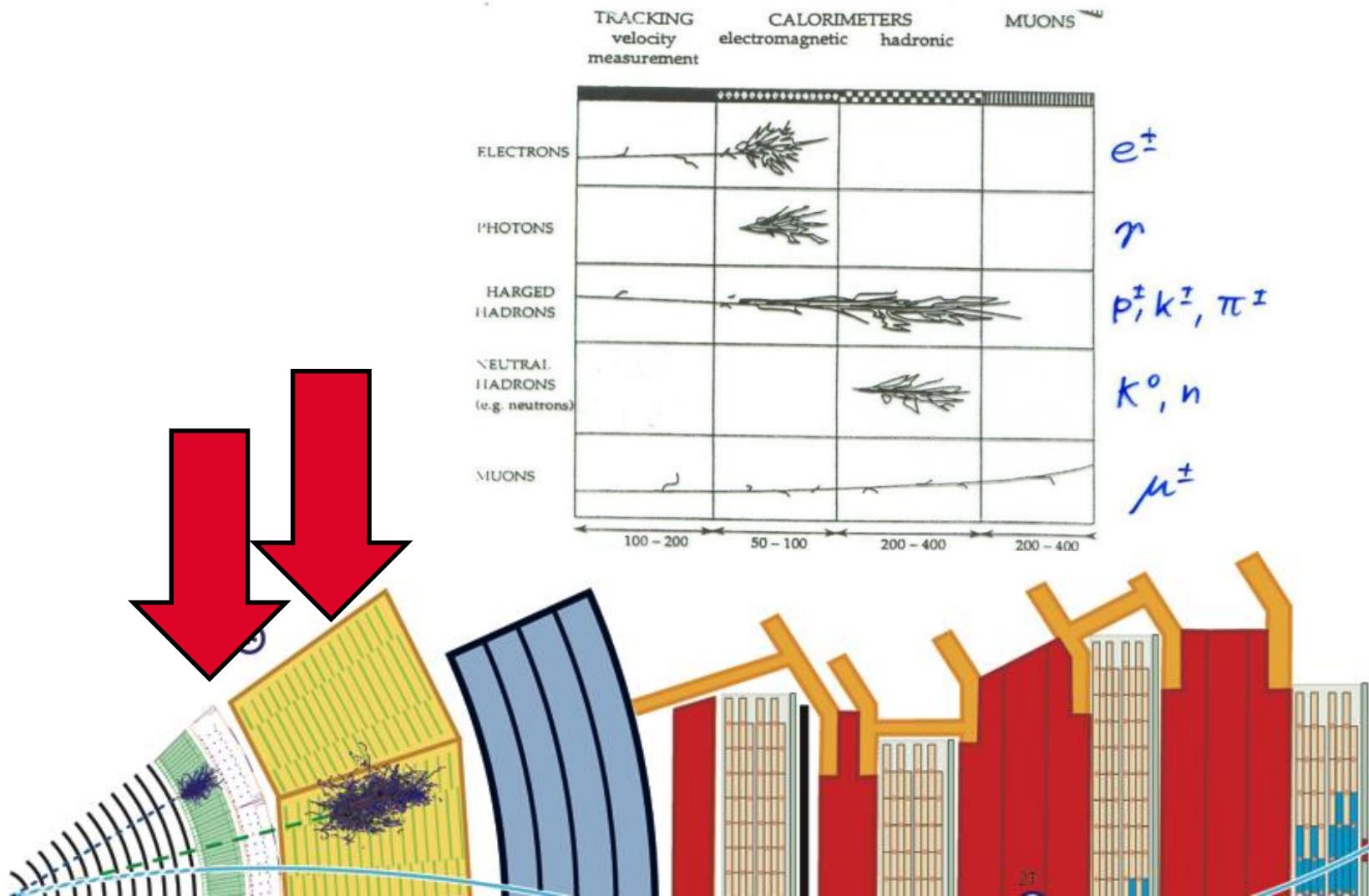
UV light enters the WLS material
Light is transformed into longer
wavelength

→ Total internal reflection inside the WLS
material
→ 'transport' of the light to the photo
detector

Fiber Tracking



Readout of photons in a cost effective way is rather challenging.



Calorimeters can be classified into:

Electromagnetic Calorimeters,
to measure electrons and photons through their EM interactions.

Hadron Calorimeters,
Used to measure hadrons through their strong and EM interactions.

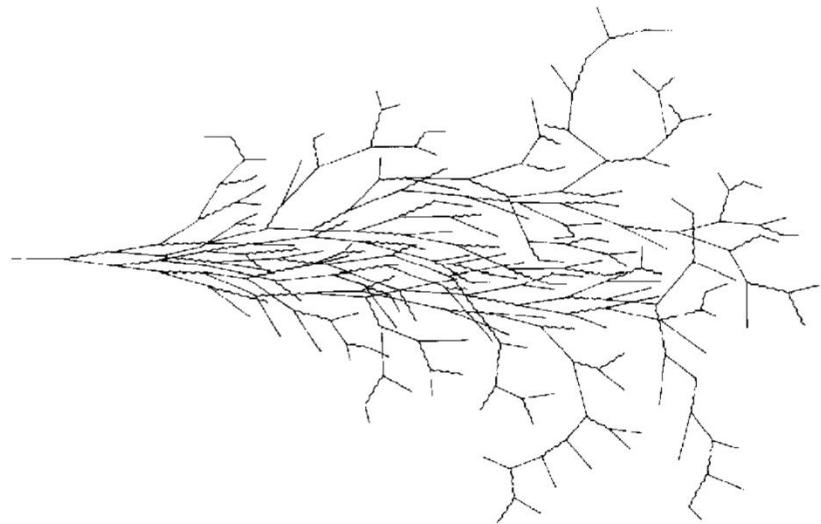
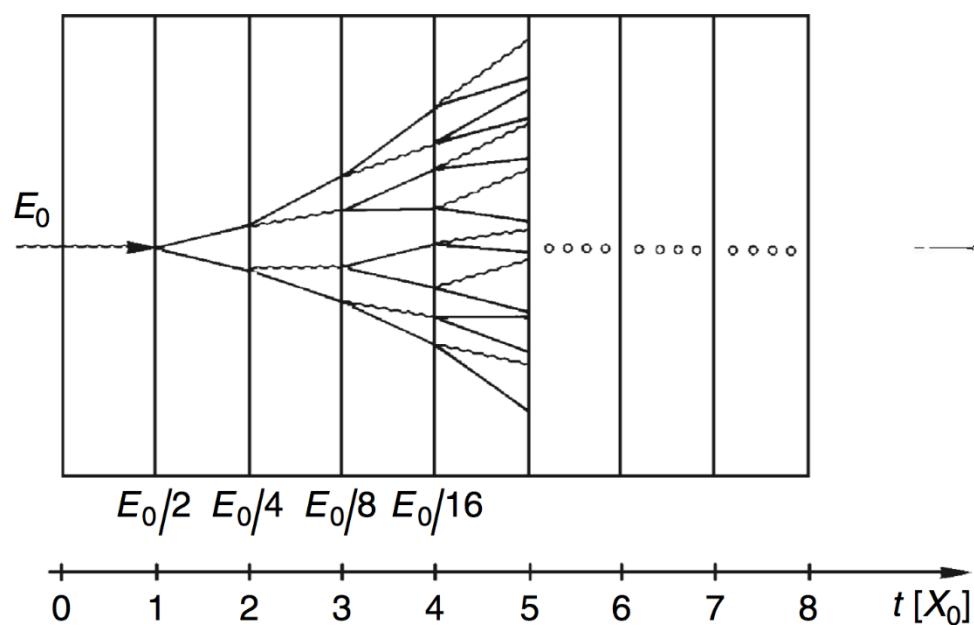
The construction can be classified into:

Homogeneous Calorimeters,
that are built of only one type of material that performs both tasks, energy degradation and signal generation.

Sampling Calorimeters,
that consist of alternating layers of an absorber, a dense material used to degrade the energy of the incident particle, and an active medium that provides the detectable signal.

C.W. Fabjan and F. Gianotti, Rev. Mod. Phys., Vol. 75, N°. 4, October 2003

At high energies (higher than 100 MeV) electrons lose their energy almost exclusively by bremsstrahlung while photons lose their energy by electron–positron pair production



Crystals for Homogeneous EM Calorimetry

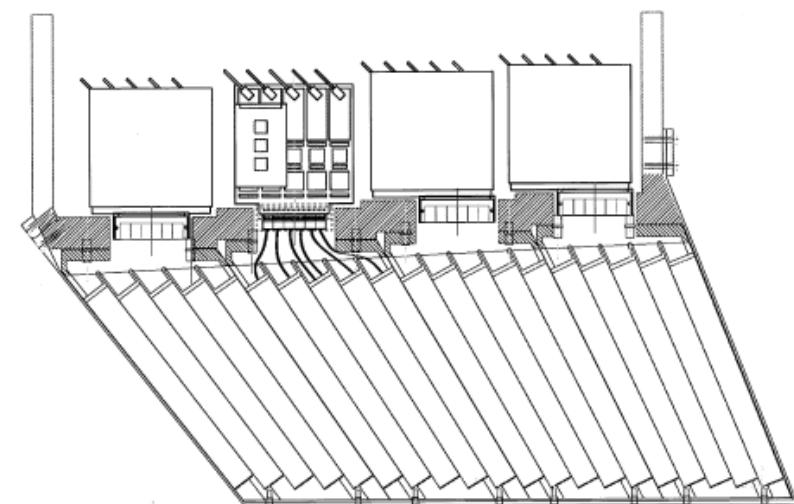
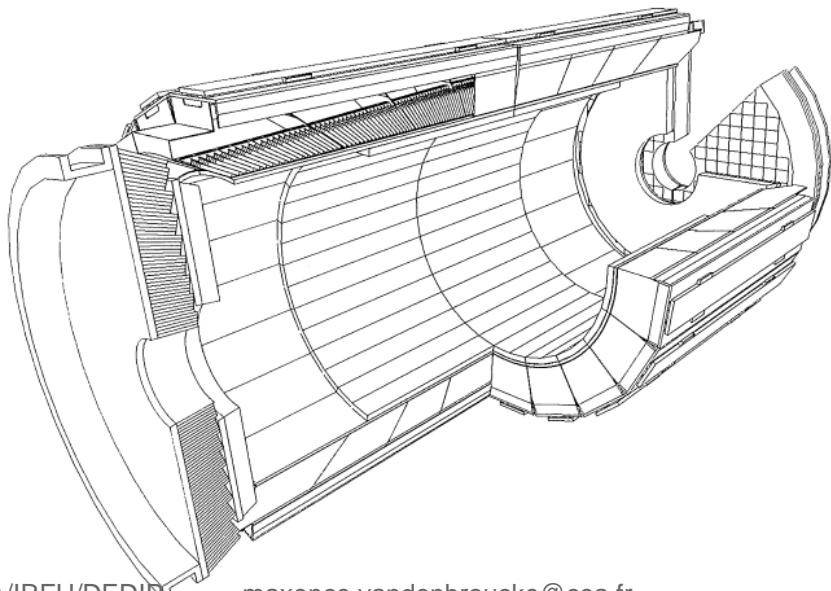
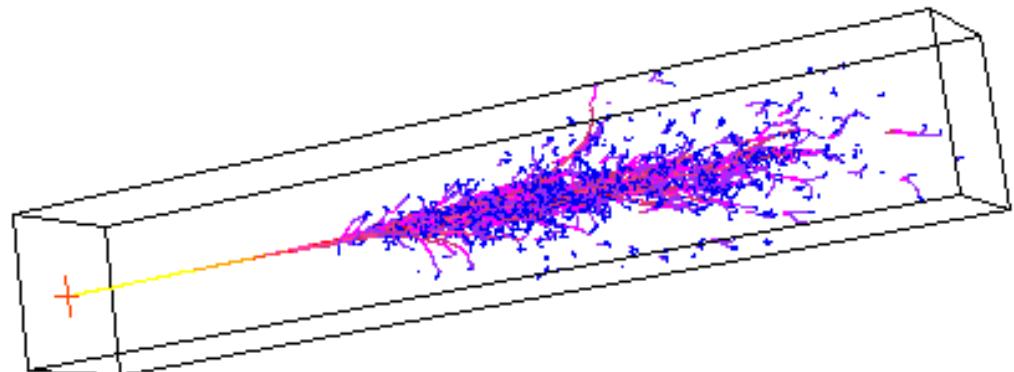
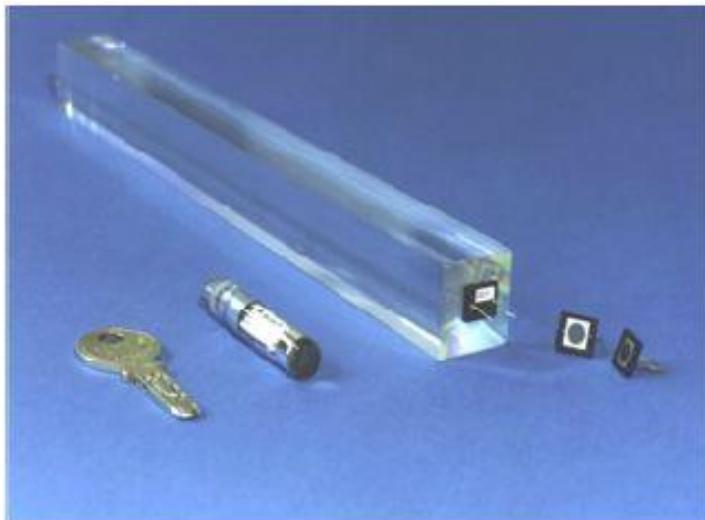


Fig. 2. Longitudinal drawing of module 2, showing the structure and the front-end electronics layout.

Hadron Calorimeters are Large because $\bar{\ell}$ is large

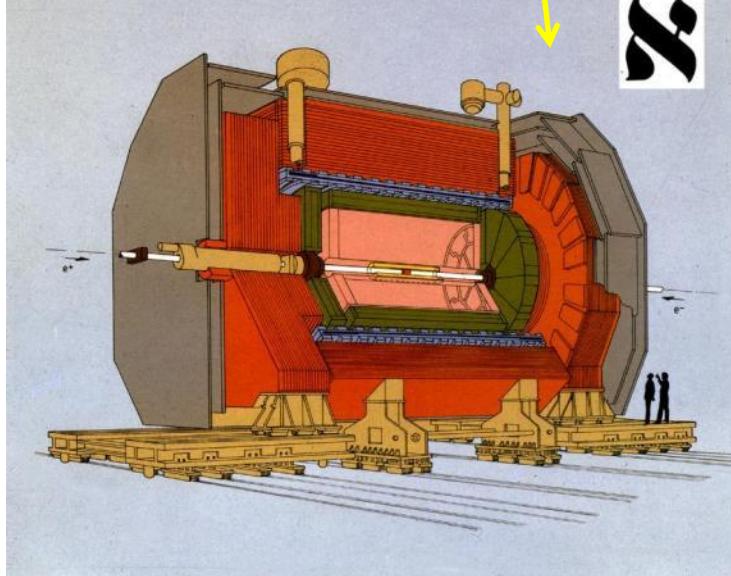
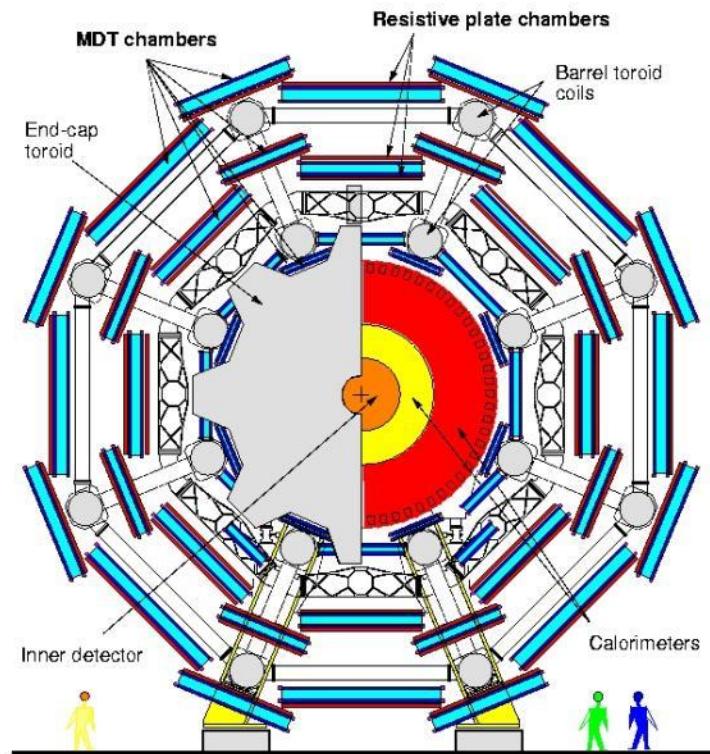


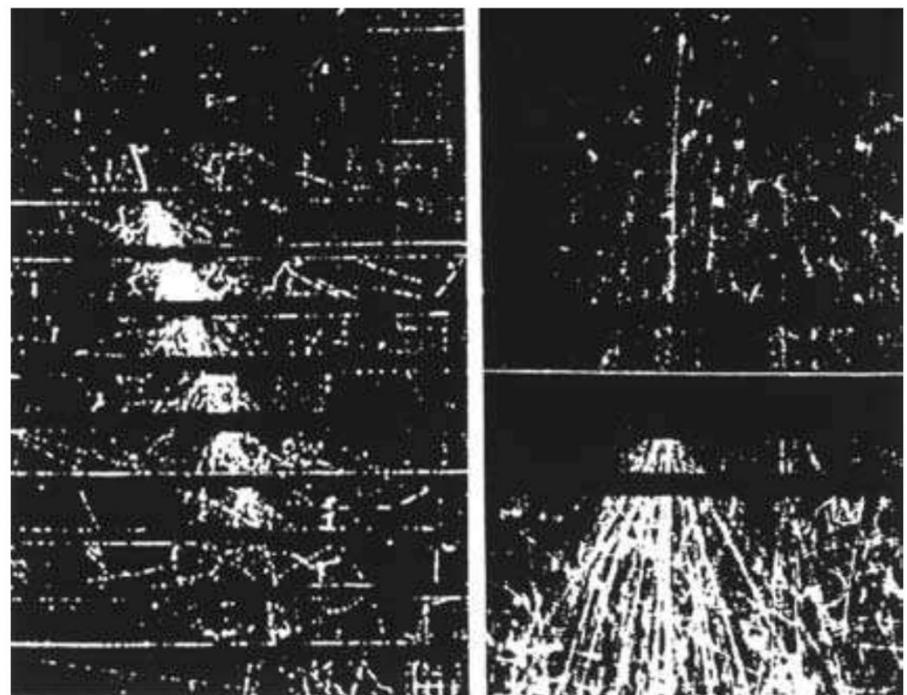
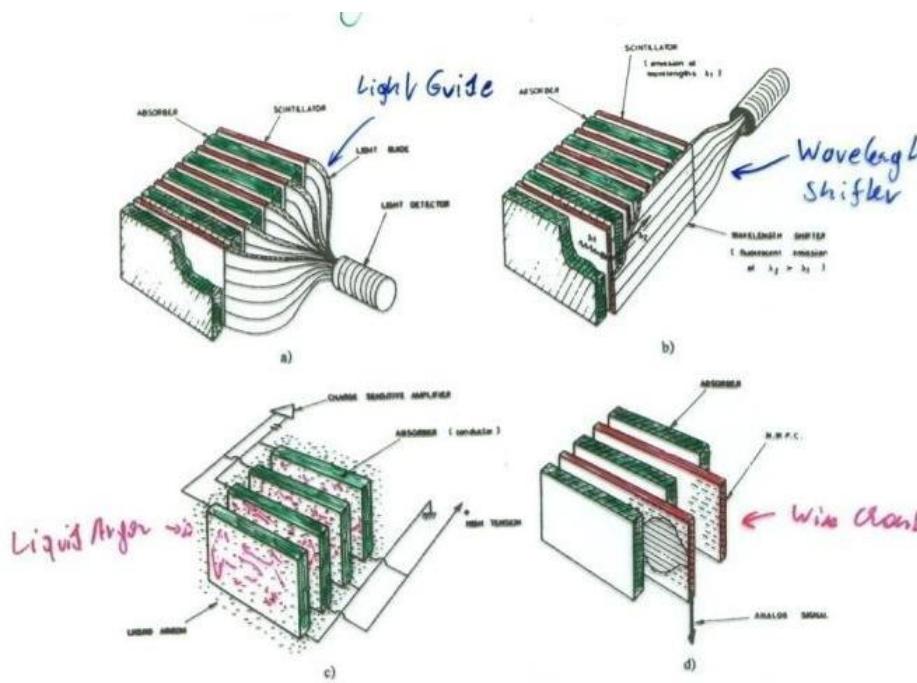
Fig. 1 - The ALEPH Detector

- Vertex Detector
- Inner Track Chamber
- Time Projection Chamber
- Electromagnetic Calorimeter
- Superconducting Magnet Coil
- Hadron Calorimeter
- Muon Detection Chambers
- Luminosity Monitors

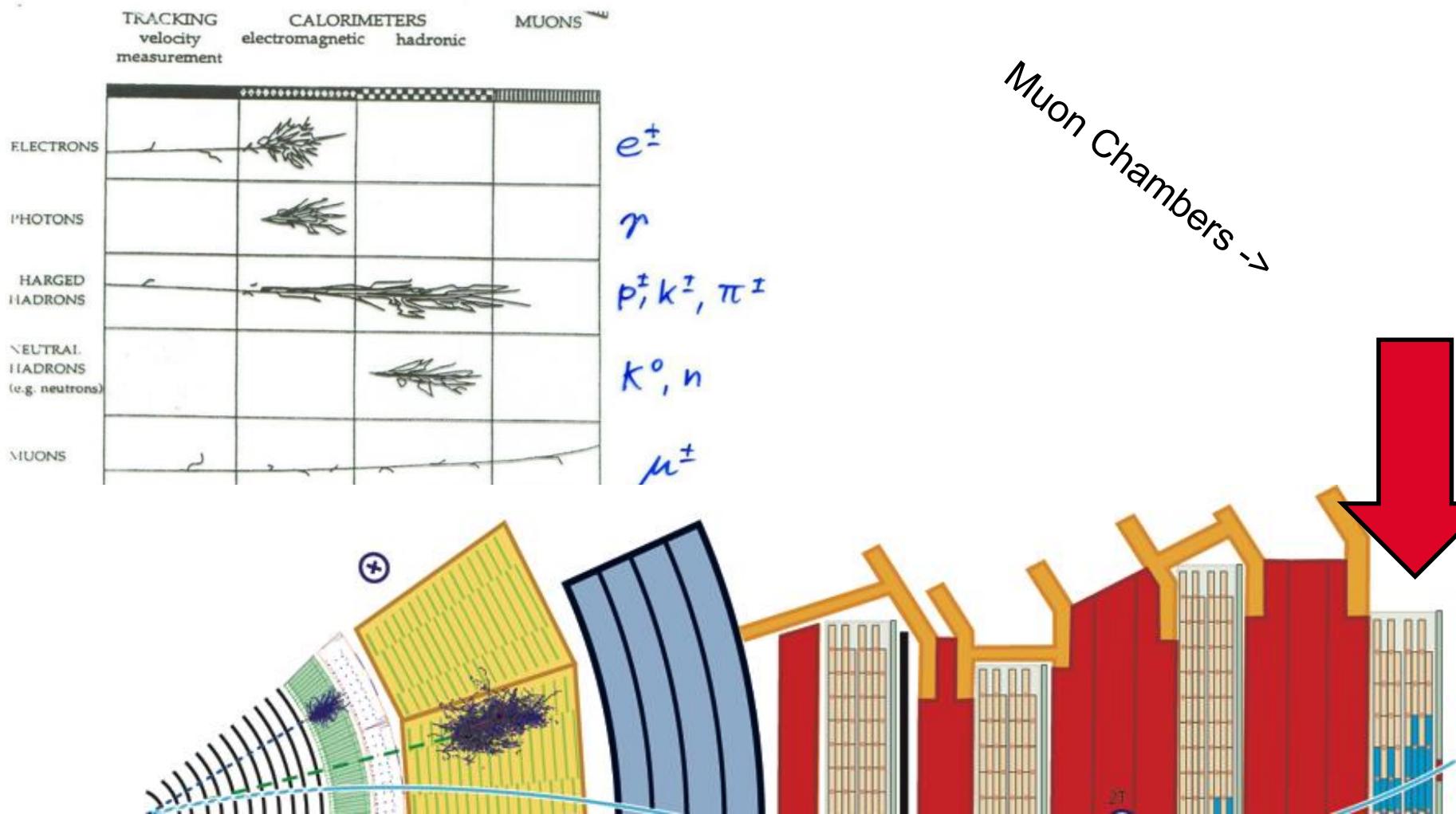
Hadron Calorimeters are large and heavy because the hadronic interaction length $\bar{\ell}$, the ‘strong interaction equivalent’ to the EM radiation length X_0 , is large (5-10 times larger than X_0)



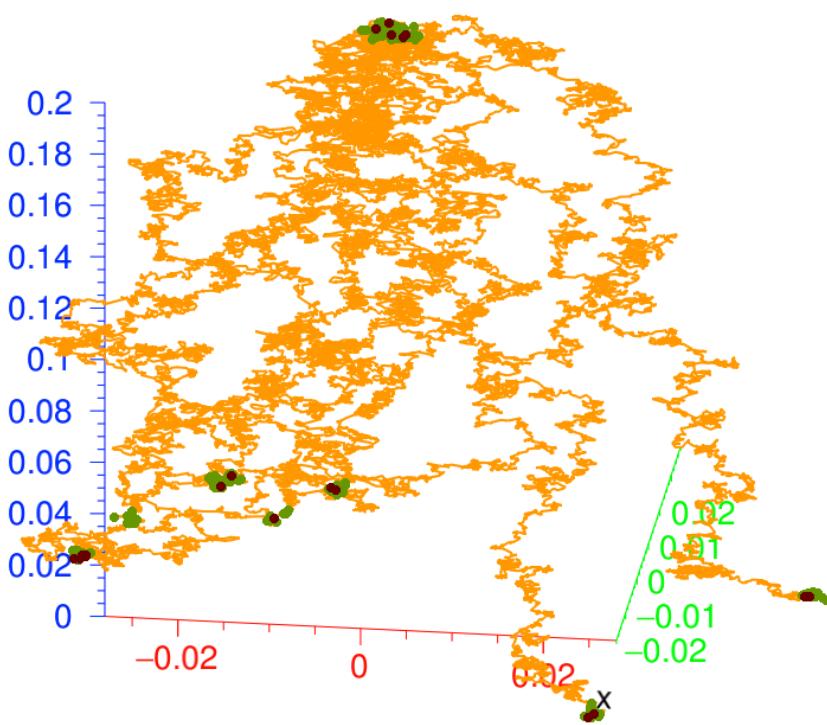
Sampling Calorimeters



Détecteurs Gazeux



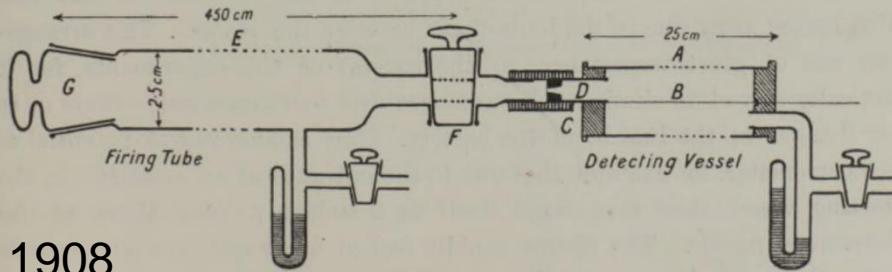
La détection des particules: exemple des détecteurs gazeux



EXEMPLE SIMPLE DE DÉTECTEUR

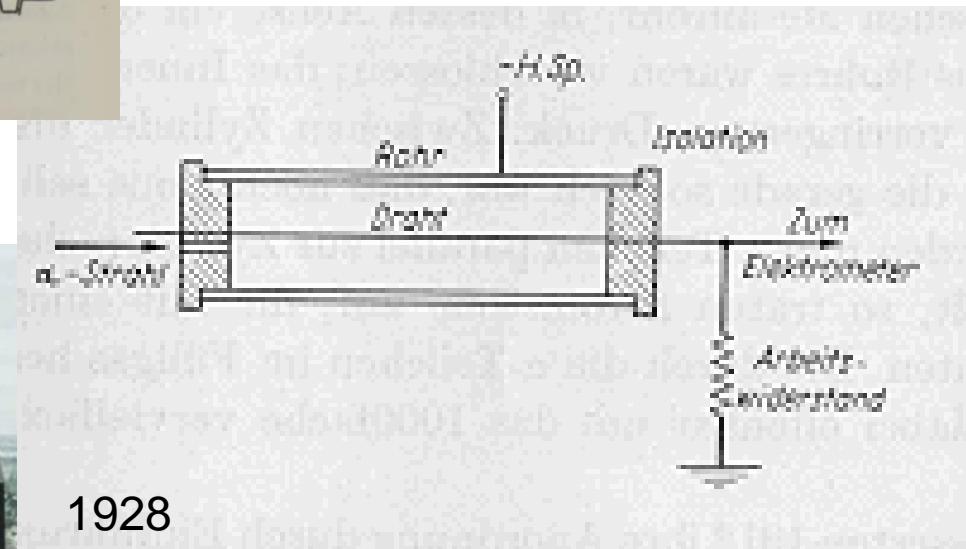
electrometer.

Experimental Arrangement.—Before considering the various difficulties that arose in the course of the investigations, a brief description will be given of the method finally adopted. The experimental arrangement is shown in fig. 1. The detecting vessel consisted of a brass cylinder A, from 15 to



1908

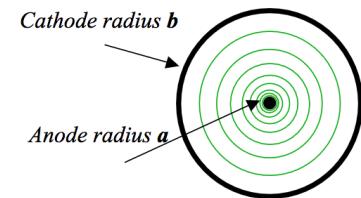
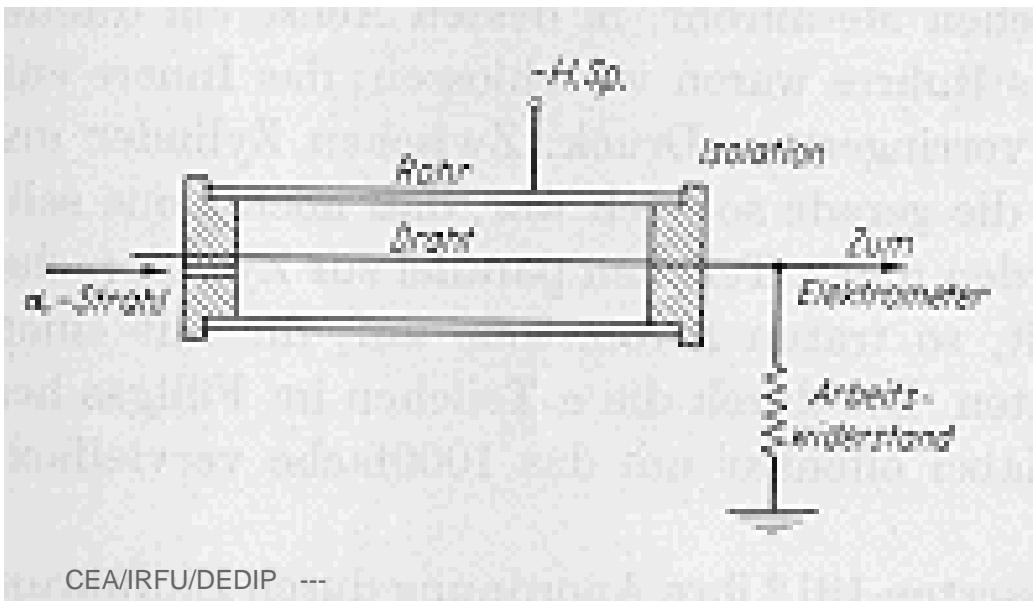
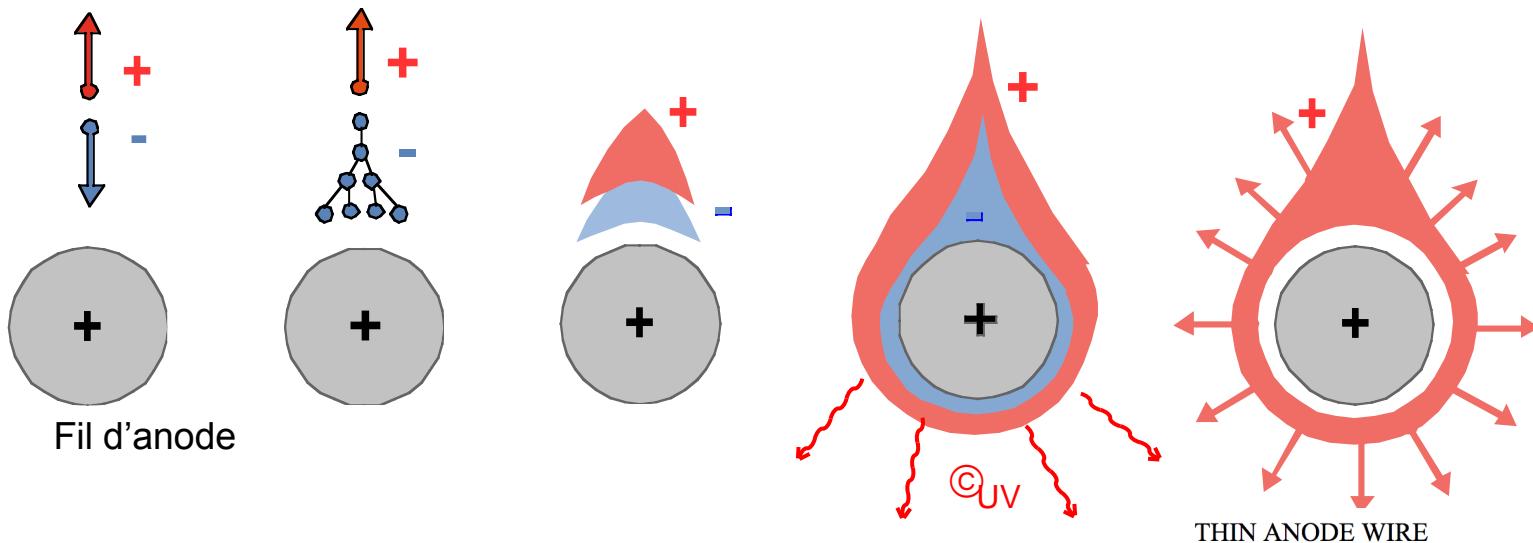
FIG. 1.



1928

Dans les films

PHÉNOMÈNE D'avalanche AUTOUR D'UN FIL



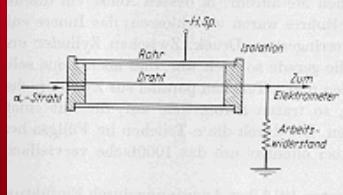
ELECTRIC FIELD AND POTENTIAL:

$$E(r) = \frac{CV_0}{2\pi\epsilon_0 r} \frac{1}{r}$$

$$V(r) = \frac{CV_0}{2\pi\epsilon_0} \ln \frac{r}{a}$$

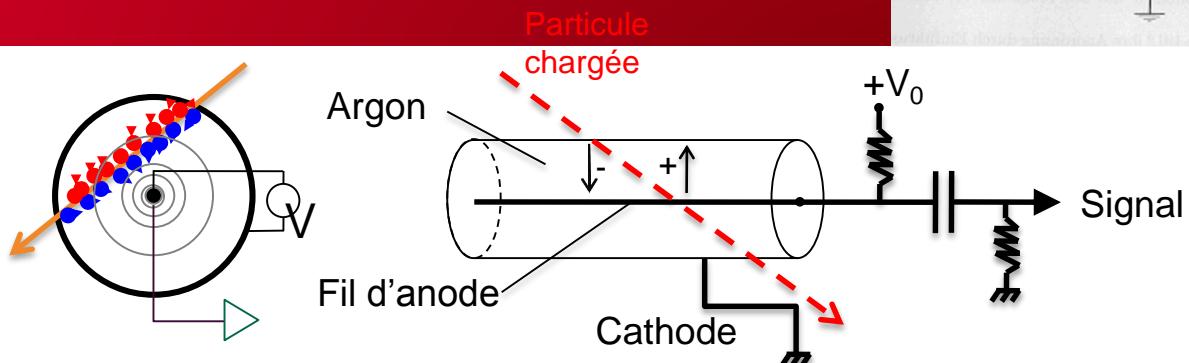
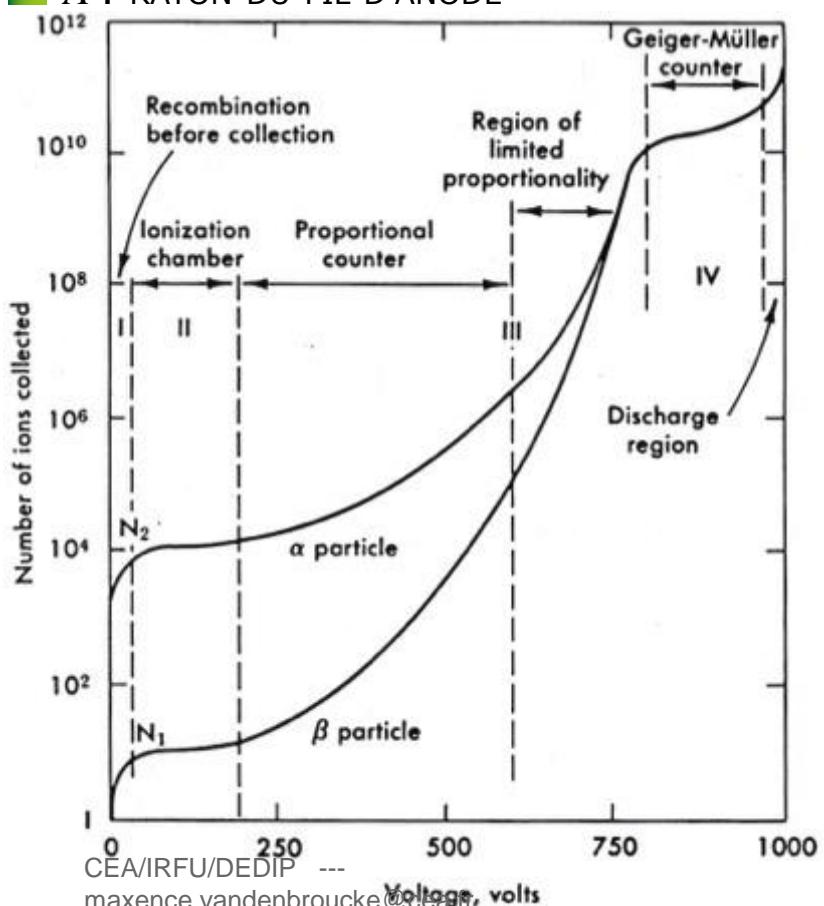
$$C = \frac{2\pi\epsilon_0}{\ln(b/a)} \quad \text{capacitance per unit length}$$

EXEMPLE SIMPLE DE DÉTECTEUR

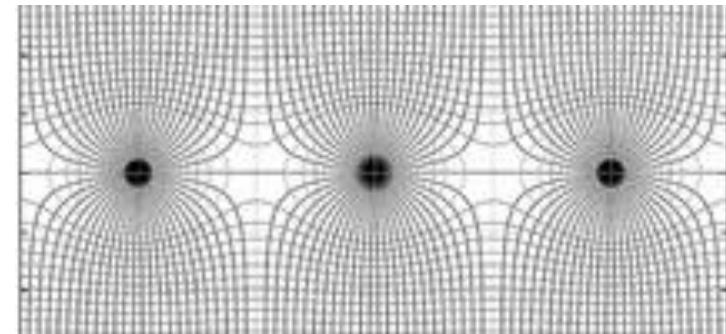
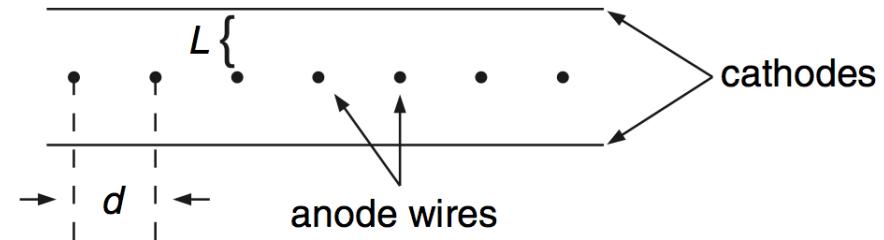
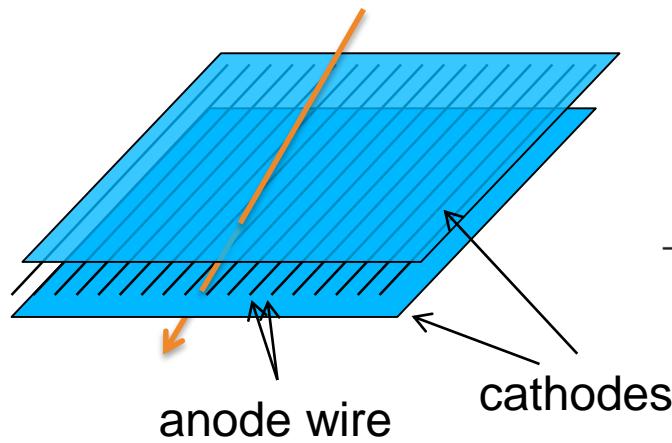


(RADIAL) AVEC: $E = \frac{1}{r} \frac{V_0}{\ln(b/a)}$

- R : DISTANCE RADIALE À L'AXE
- B : RAYON INTERNE DU CYLINDRE
- A : RAYON DU FIL D'ANODE



- I: tension trop faible → recombinaison
- II: Chambre d'ionisation. Collection des charges sans amplification.
- IIIa: Mode **proportionnel**. Le signal est amplifié et proportionnel à l'énergie déposée.
- IIIb: Mode **Streamer**. Phénomènes secondaires induits par les photons de la première avalanche → Gaz quencher
- IV: Mode **Geiger-Müller**. Avalanche dans tout le détecteur. Le courant de sortie est saturé.



GRANDE CHAMBRE À FILS (1972)

EN COMPARAISON DES CHAMBRES À ÉTINCELLES ET DES CHAMBRES À BULLES, LES CHAMBRES À FILS SONT PLUS RAPIDES, PRÉSENTENT DE MEILLEURES RÉSOLUTIONS SPATIALE ET TEMPORELLE, SANS TEMPS MORT SIGNIFICATIF ET RÉSISTANTES AUX RADIATIONS.



PRIX NOBEL DE PHYSIQUE 1992



The Royal Swedish Academy of Sciences awards the 1992 Nobel Prize in Physics to **Georges Charpak** for his invention and development of particle detectors, in particular the multiwire proportional chamber.

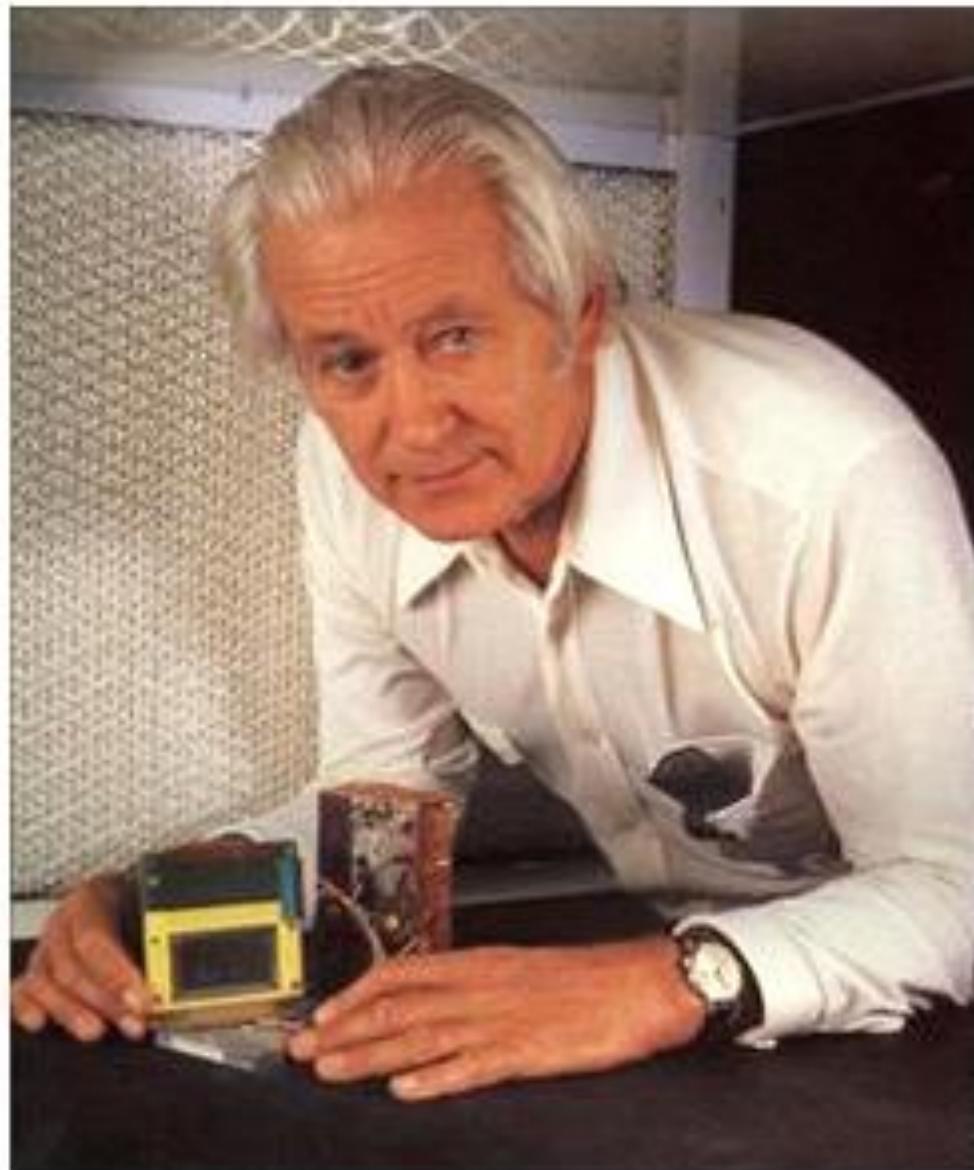


Photo: D. Parker, Science Photo Lab, UK

Georges Charpak

CERN, Geneva, Switzerland

CEA/IRFU/DEDIP ---

maxence.vandenbroucke@cea.fr

1927: C.T.R. Wilson, Cloud Chamber

1939: E. O. Lawrence, Cyclotron & Discoveries

1948: P.M.S. Blacket, Cloud Chamber & Discoveries

1950: C. Powell, Photographic Method & Discoveries

1954: Walter Bothe, Coincidence method & Discoveries

1960: Donald Glaser, Bubble Chamber

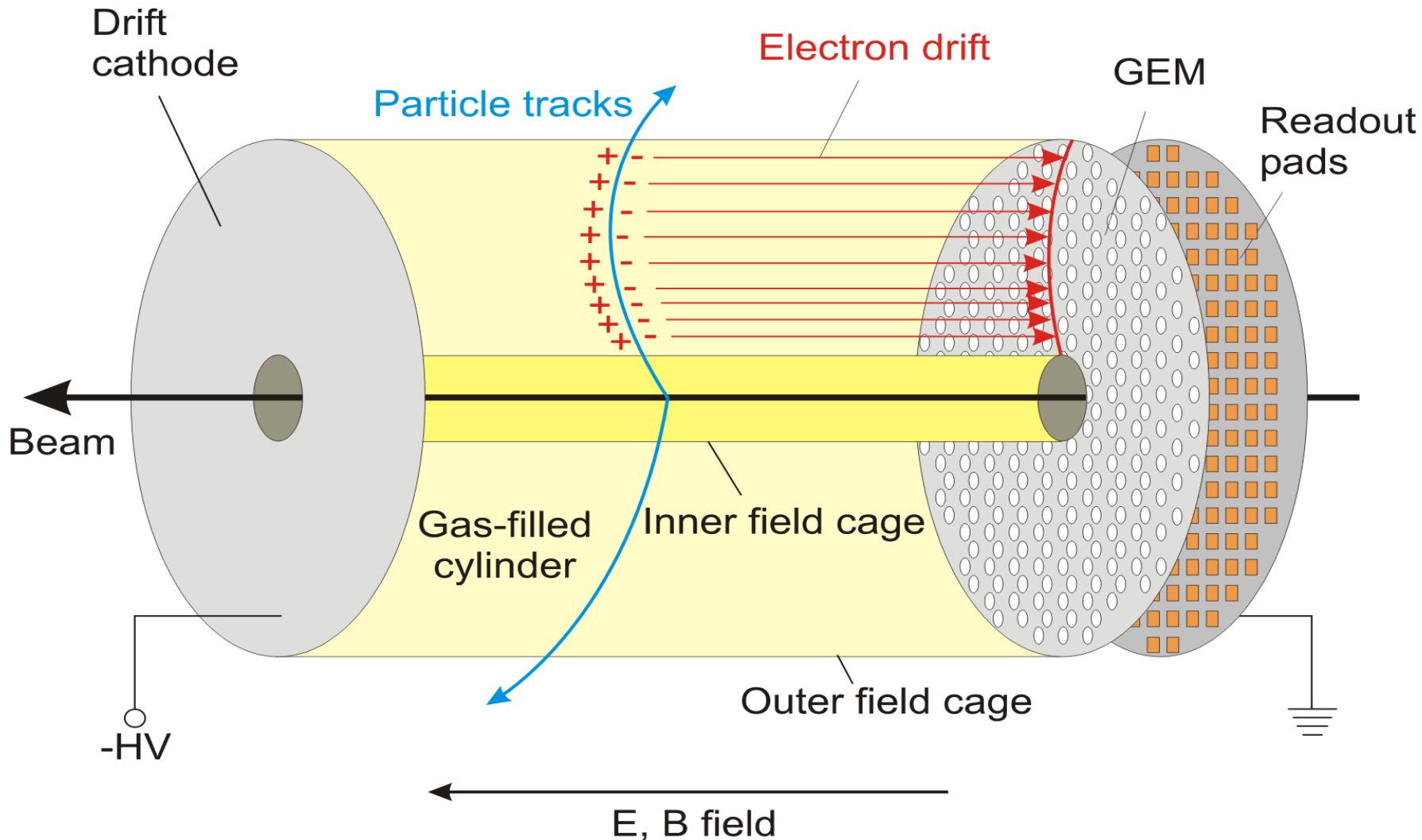
1968: L. Alvarez, Hydrogen Bubble Chamber & Discoveries

1992: Georges Charpak, Multi Wire Proportional Chamber

2009: Boyle and Smith for the CCD sensor

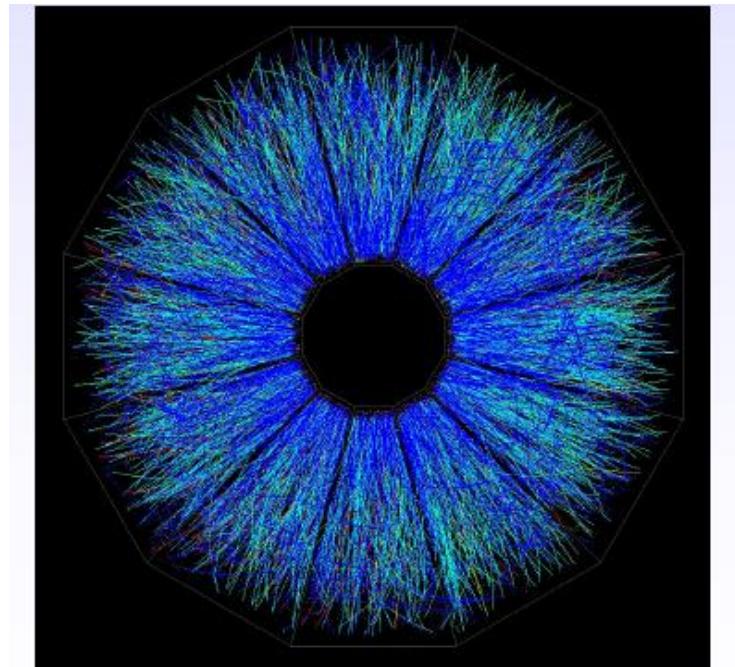
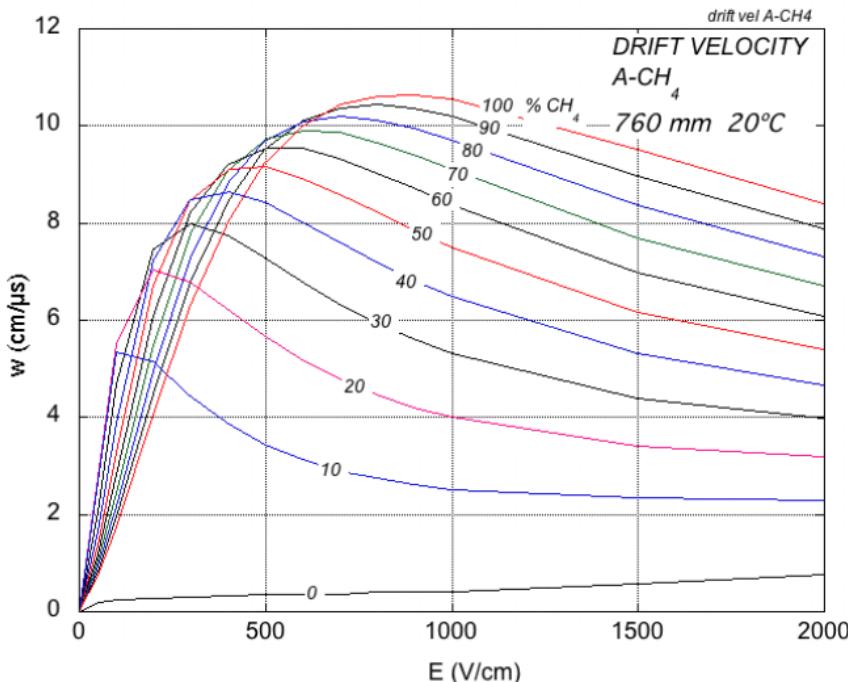
2017 : Weiss, Thorne, Barish LIGO observatory

Time Projection Chamber (TPC):

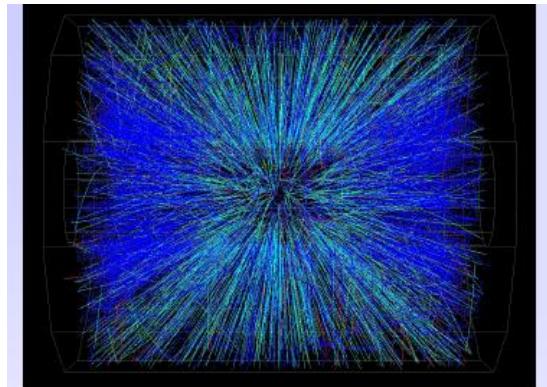


Event display of a Au Au collision at CM energy of 130 GeV/n.

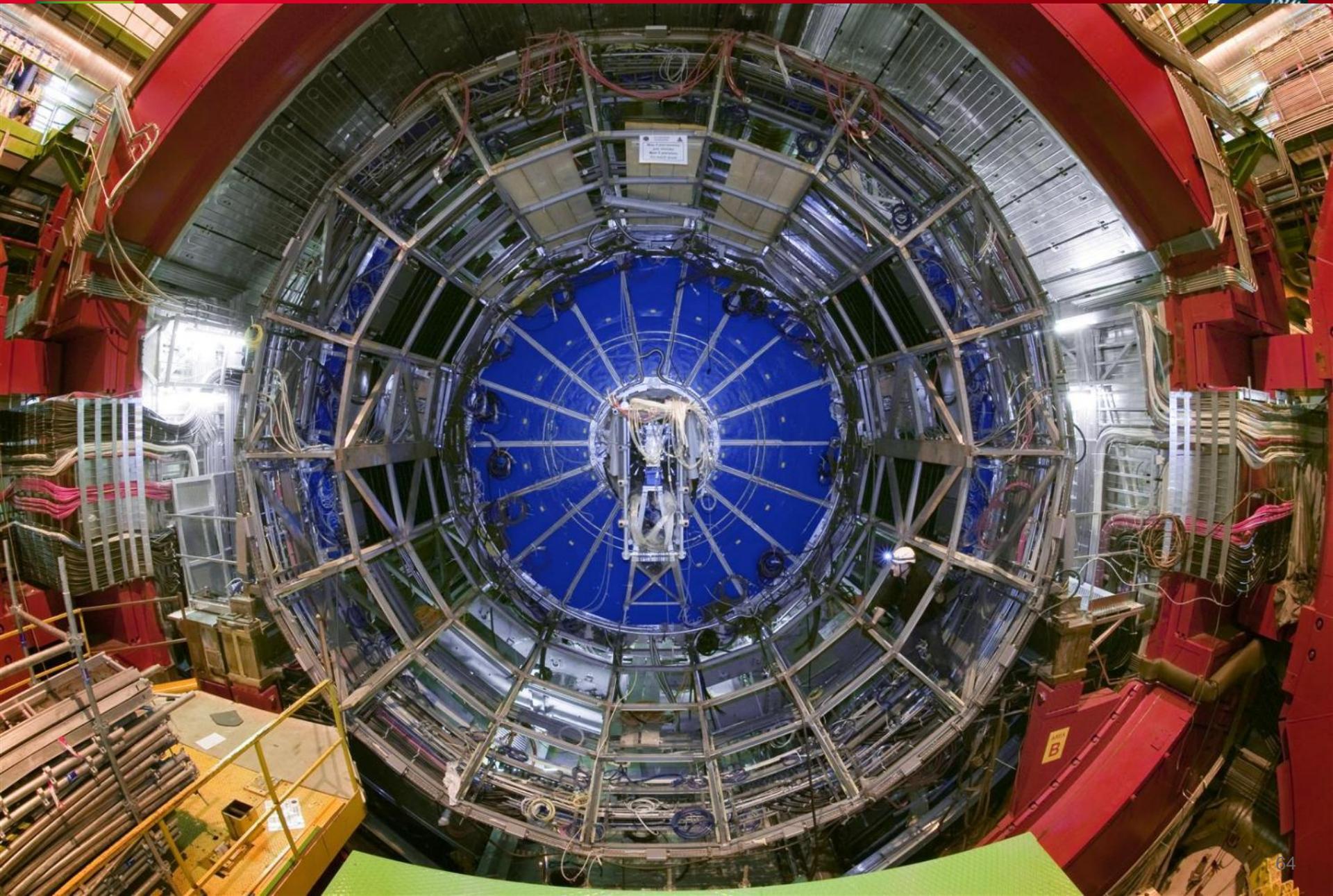
Typically around 200 tracks per event.



EXAMPLE: Ar-CH₄ 90-10 , E=1kVcm⁻¹ w- = 2.5 cm μ s⁻¹



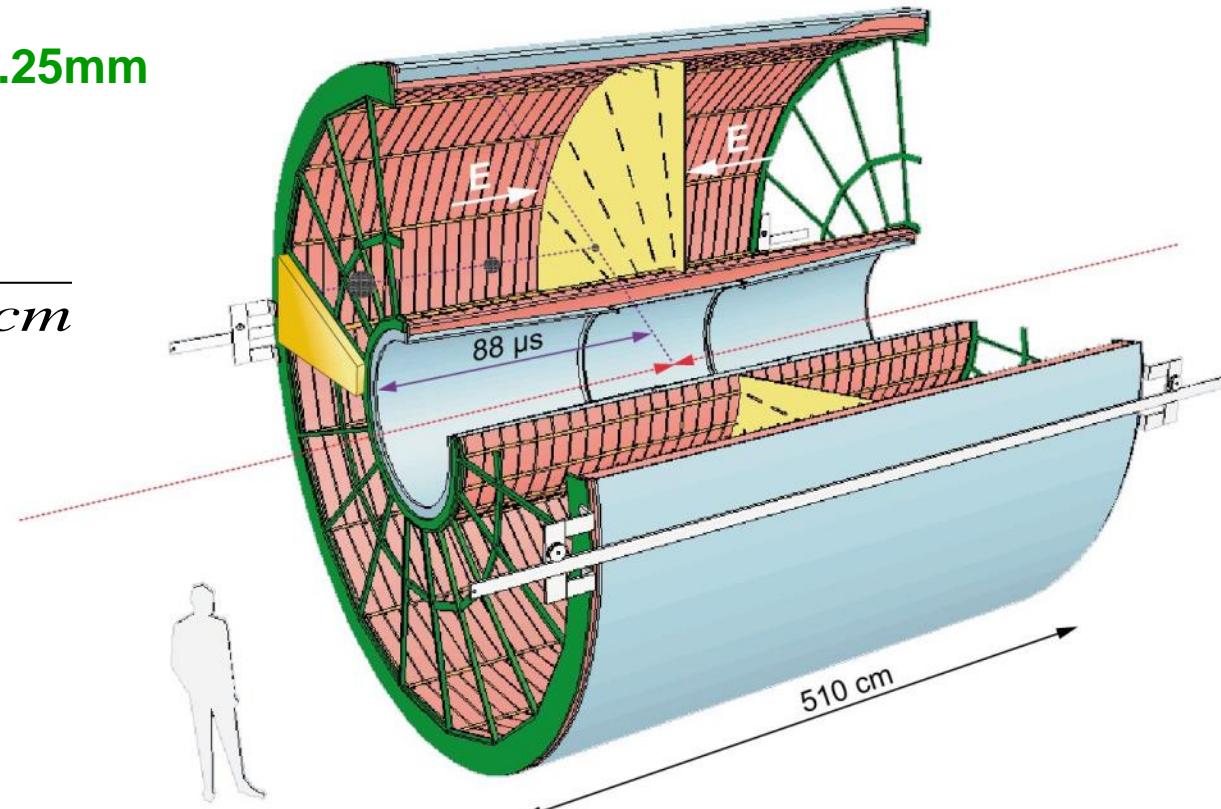
TPC installed in the ALICE Experiment



ALICE TPC: Detector Parameters

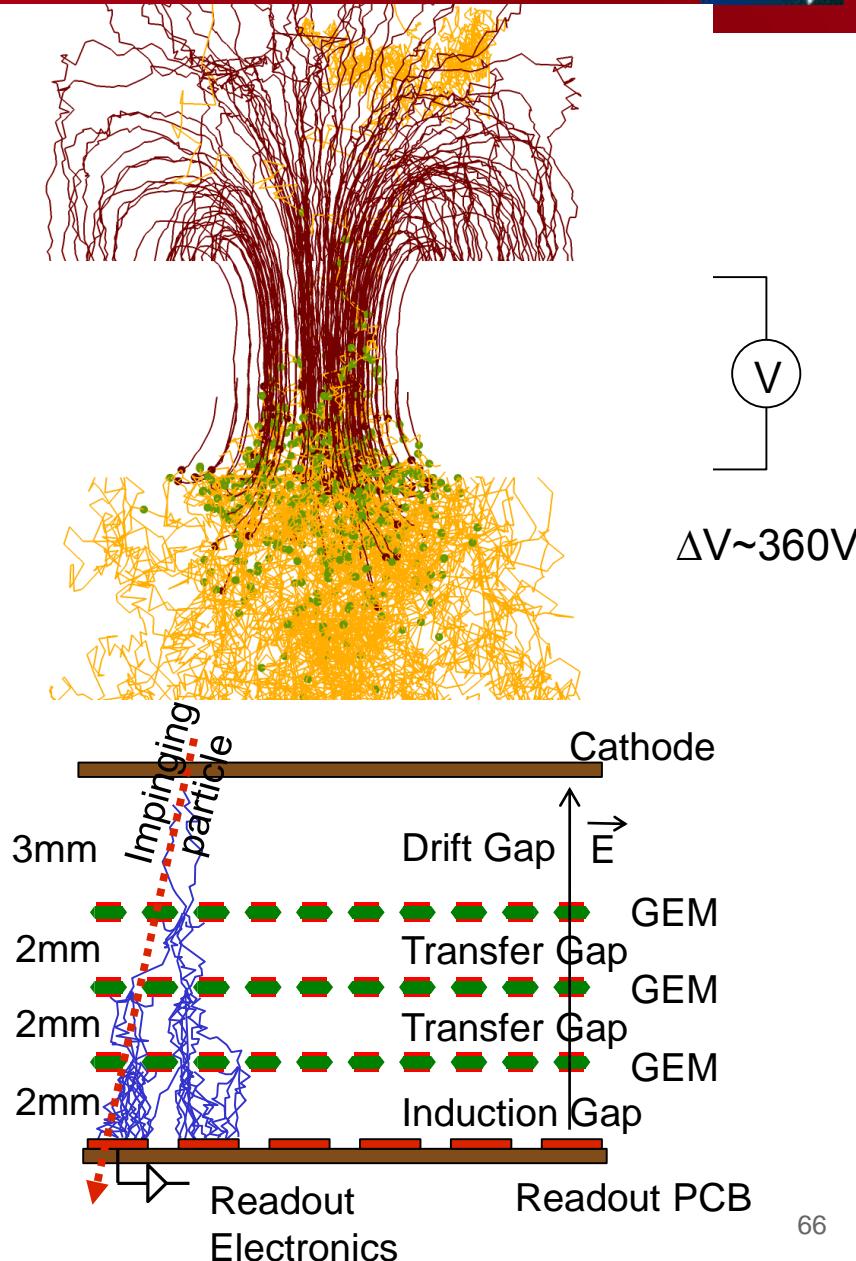
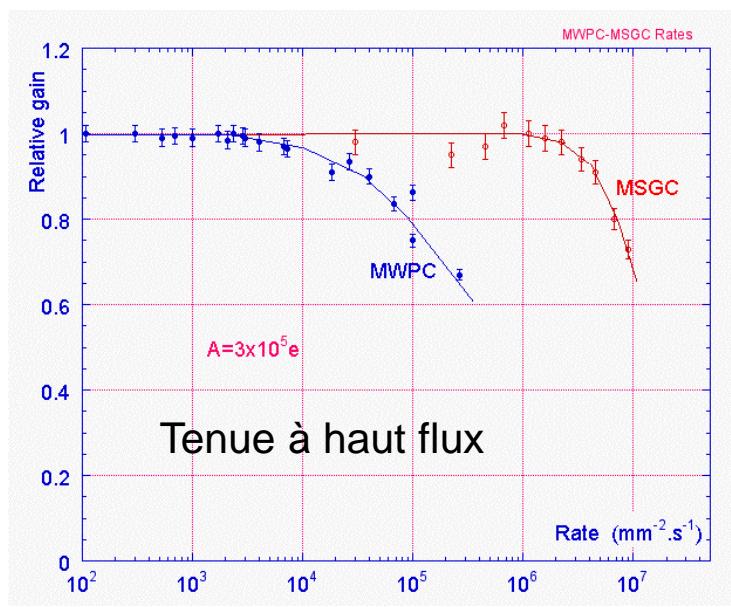
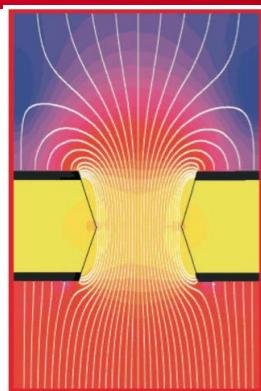
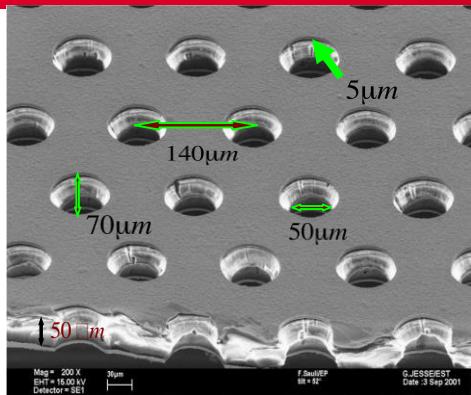
- Gas Ne/ CO₂ 90/10%
- Field 400V/cm
- Gas gain >10⁴
- Position resolution $\sigma = 0.25\text{mm}$
- Diffusion: $\sigma_t = 250\mu\text{m}$
- Pads inside: 4x7.5mm
- Pads outside: 6x15mm
- B-field: 0.5T
- Largest TPC:
 - Length 5m
 - Diameter 5m
 - Volume 88m³
 - Detector area 32m²
 - Channels ~570 000
- High Voltage:
 - Cathode -100kV

$\sqrt{\text{cm}}$

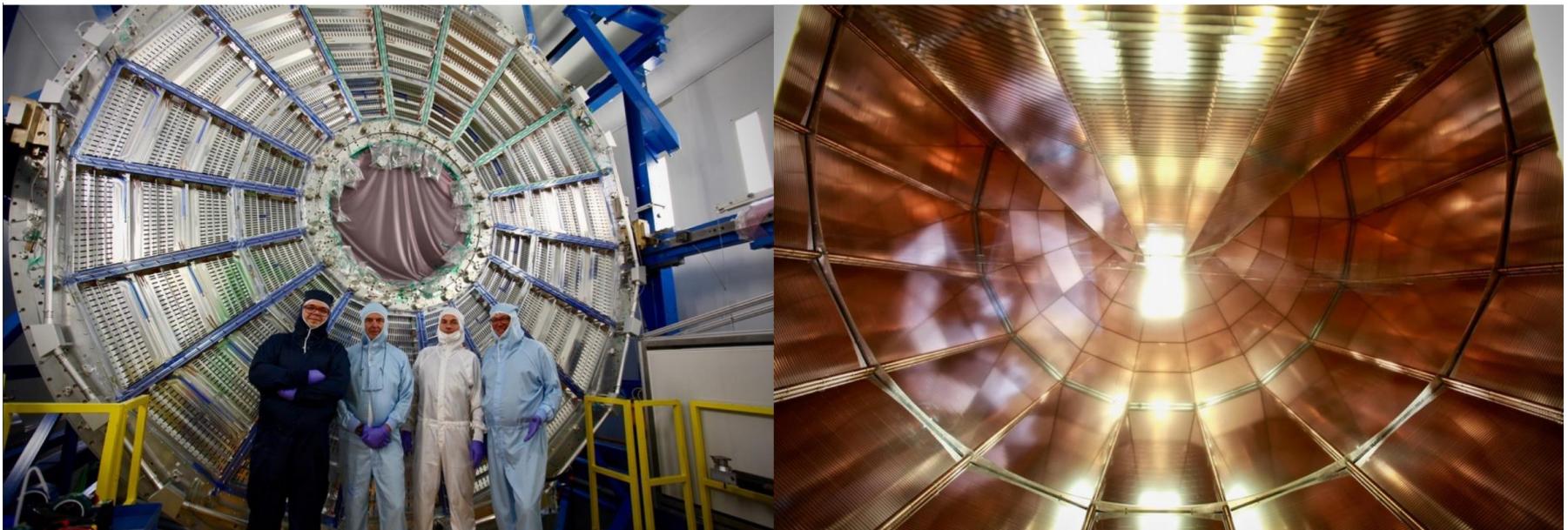


=> Gated grid ~15kHz max

GEM : GASEOUS ELECTRON MULTIPLIER



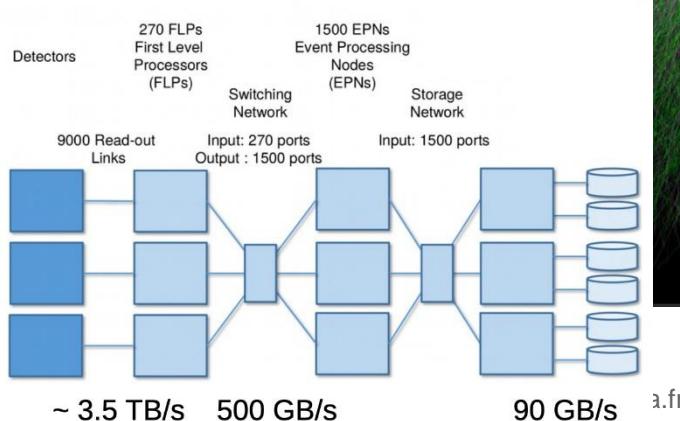
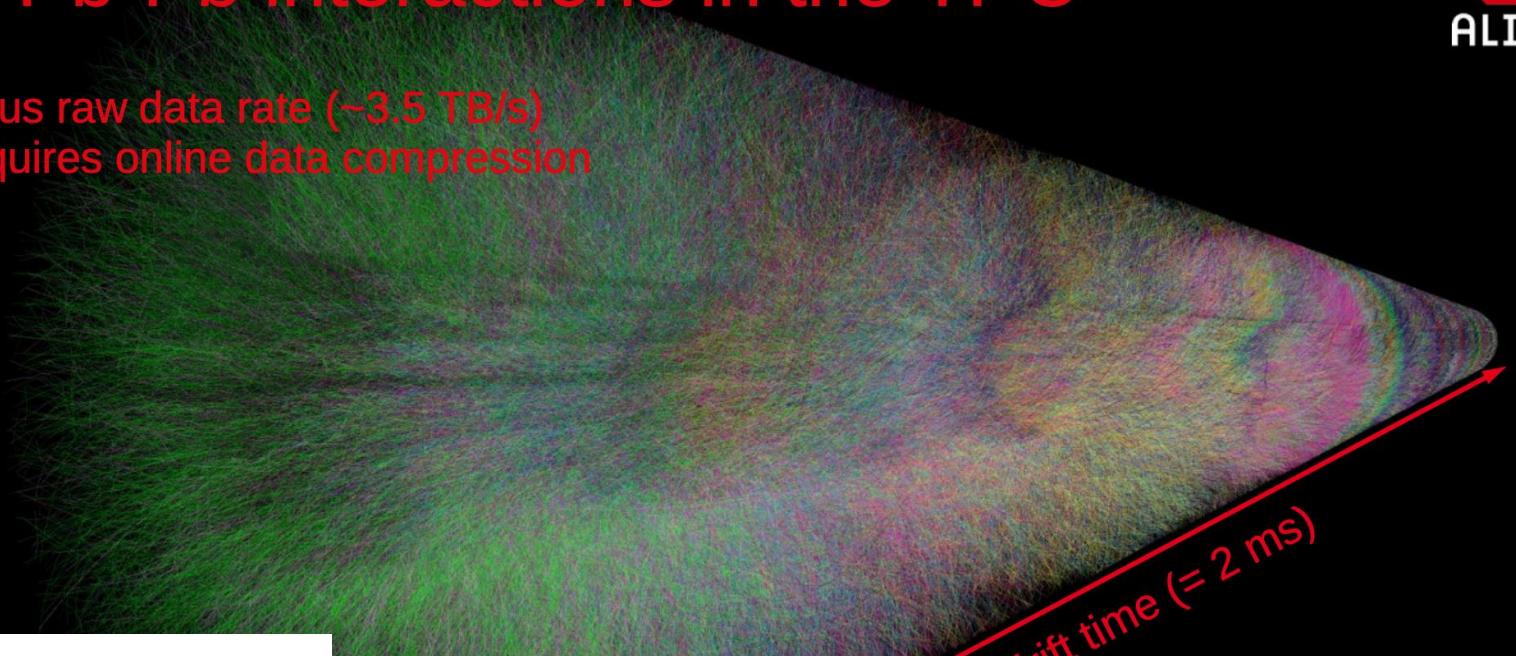
ALICE UPGRADE



50 kHz Pb-Pb interactions in the TPC

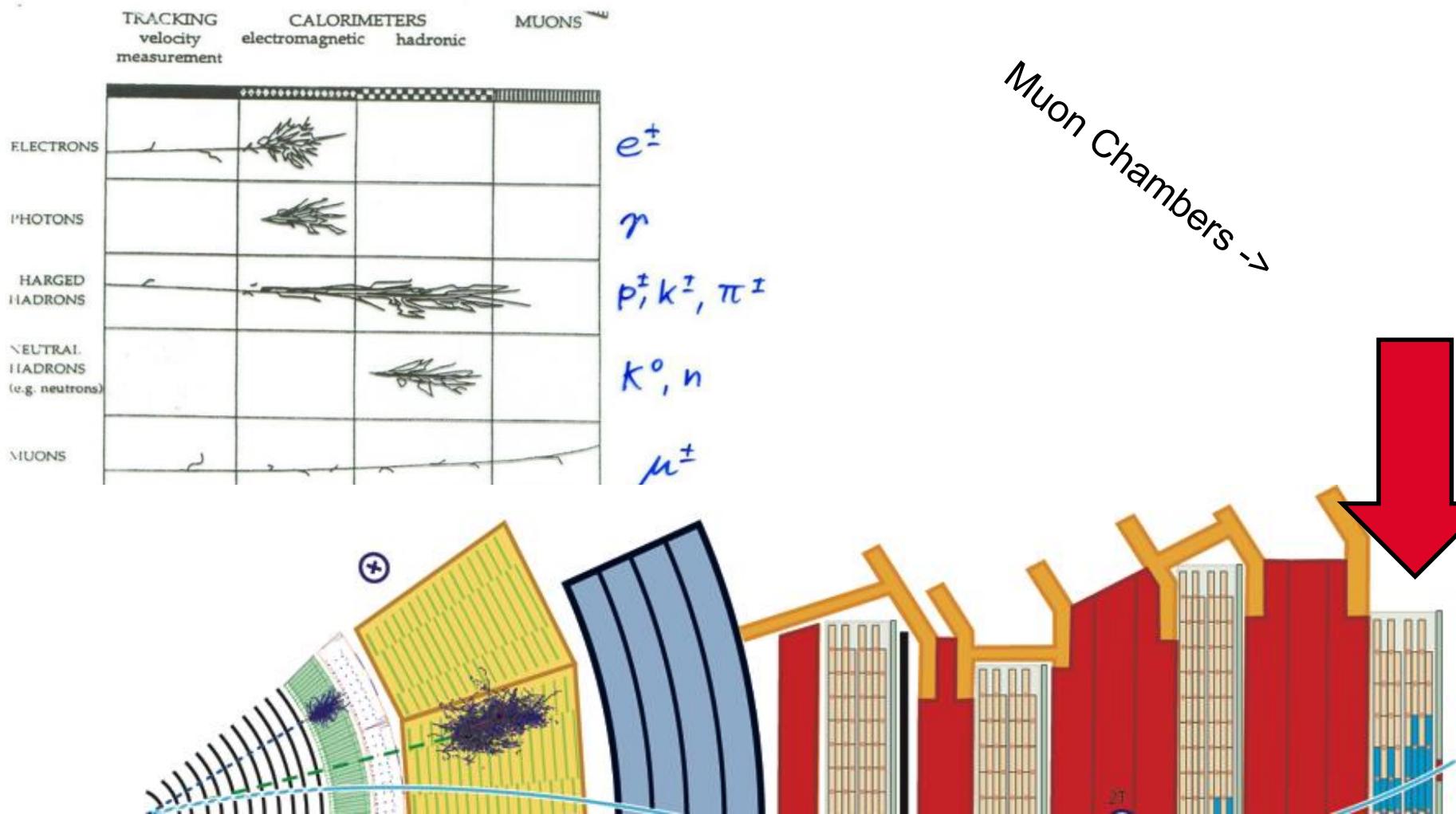


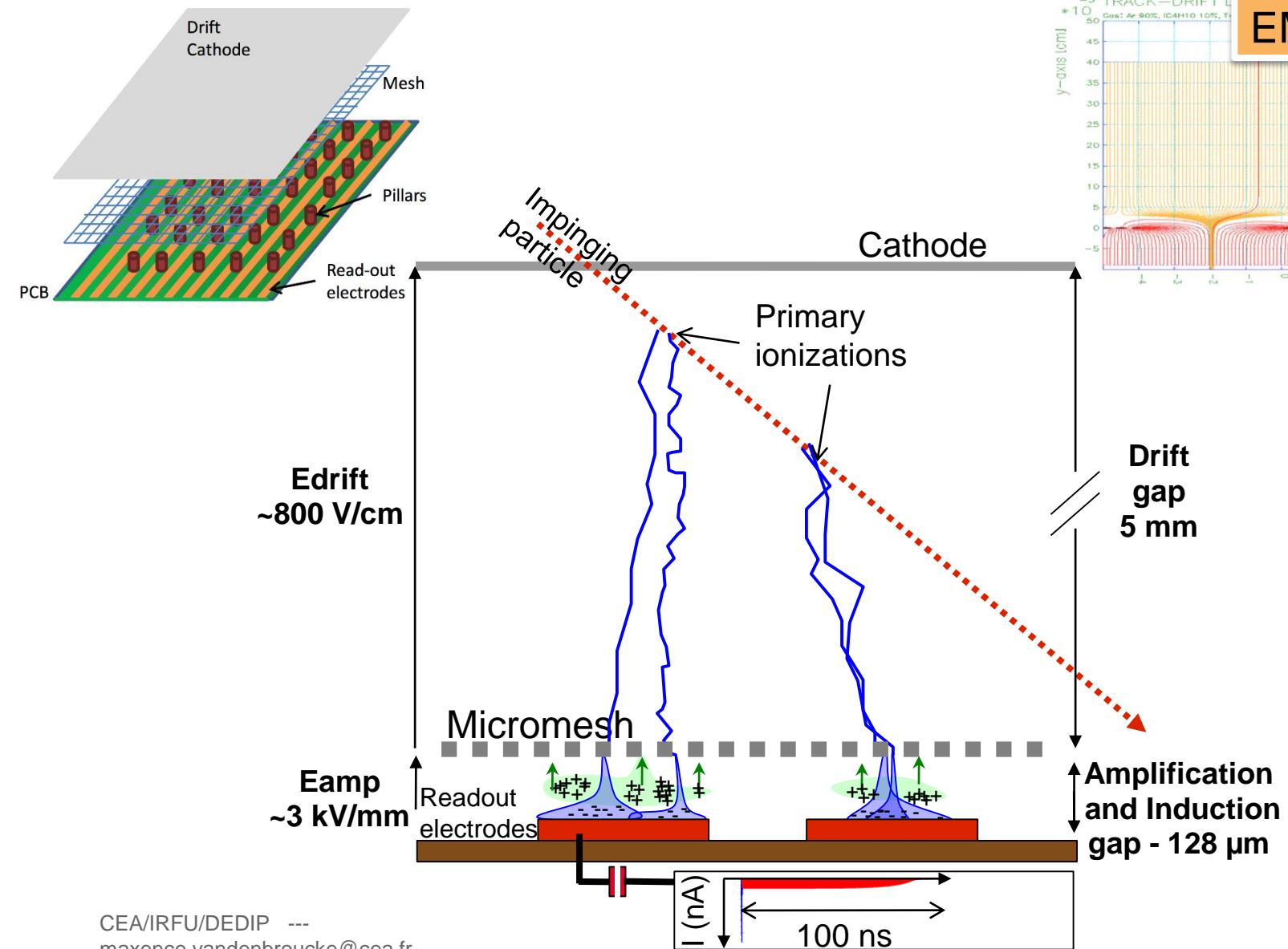
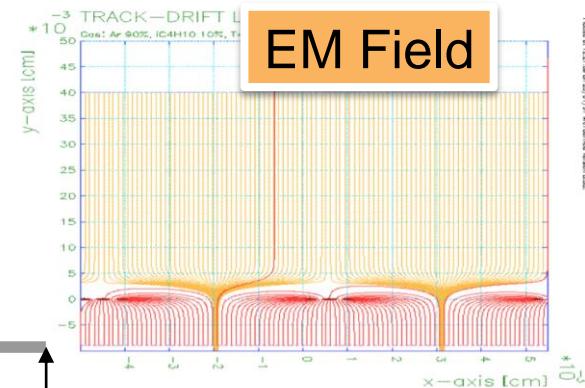
- Enormous raw data rate (~3.5 TB/s)
 - Requires online data compression



(YouTube it's 500Gb/s in upload)

Détecteurs Gazeux

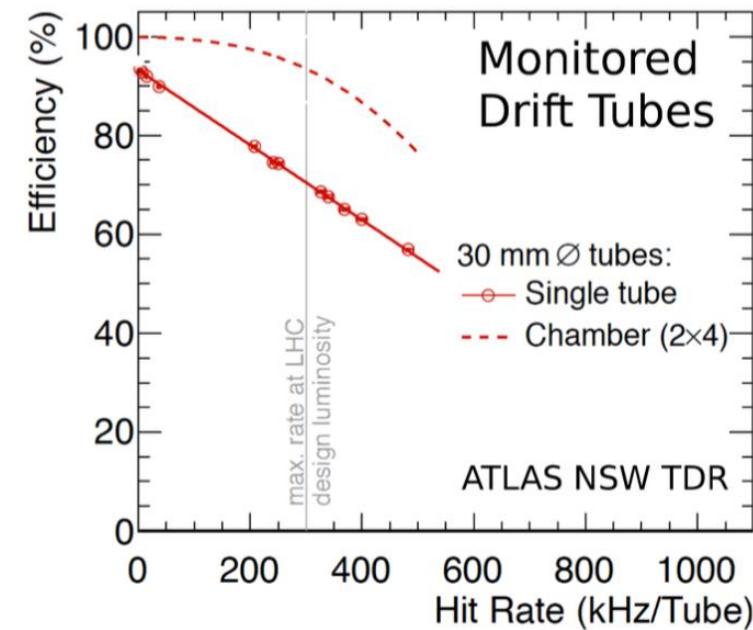
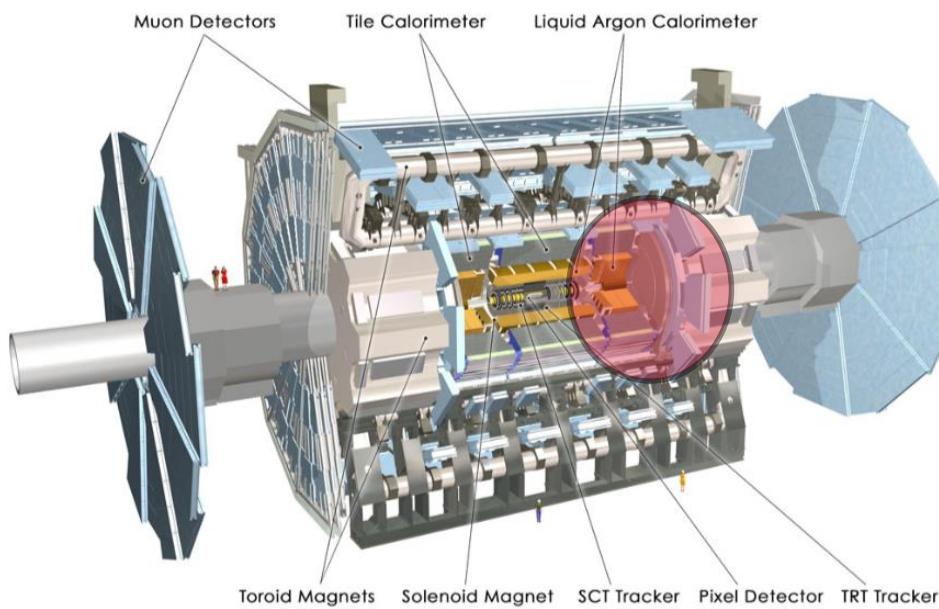
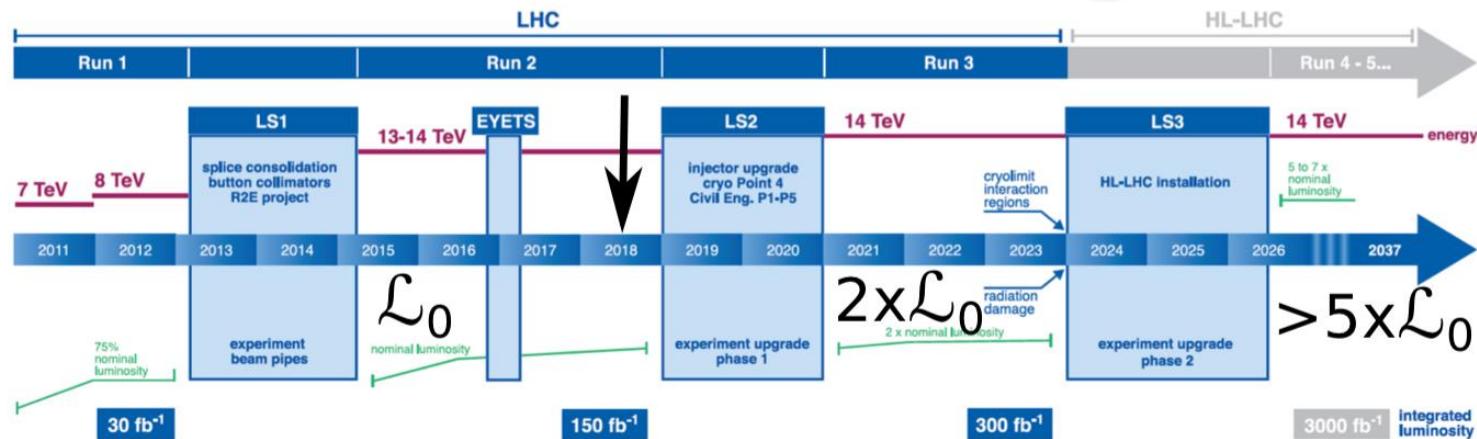


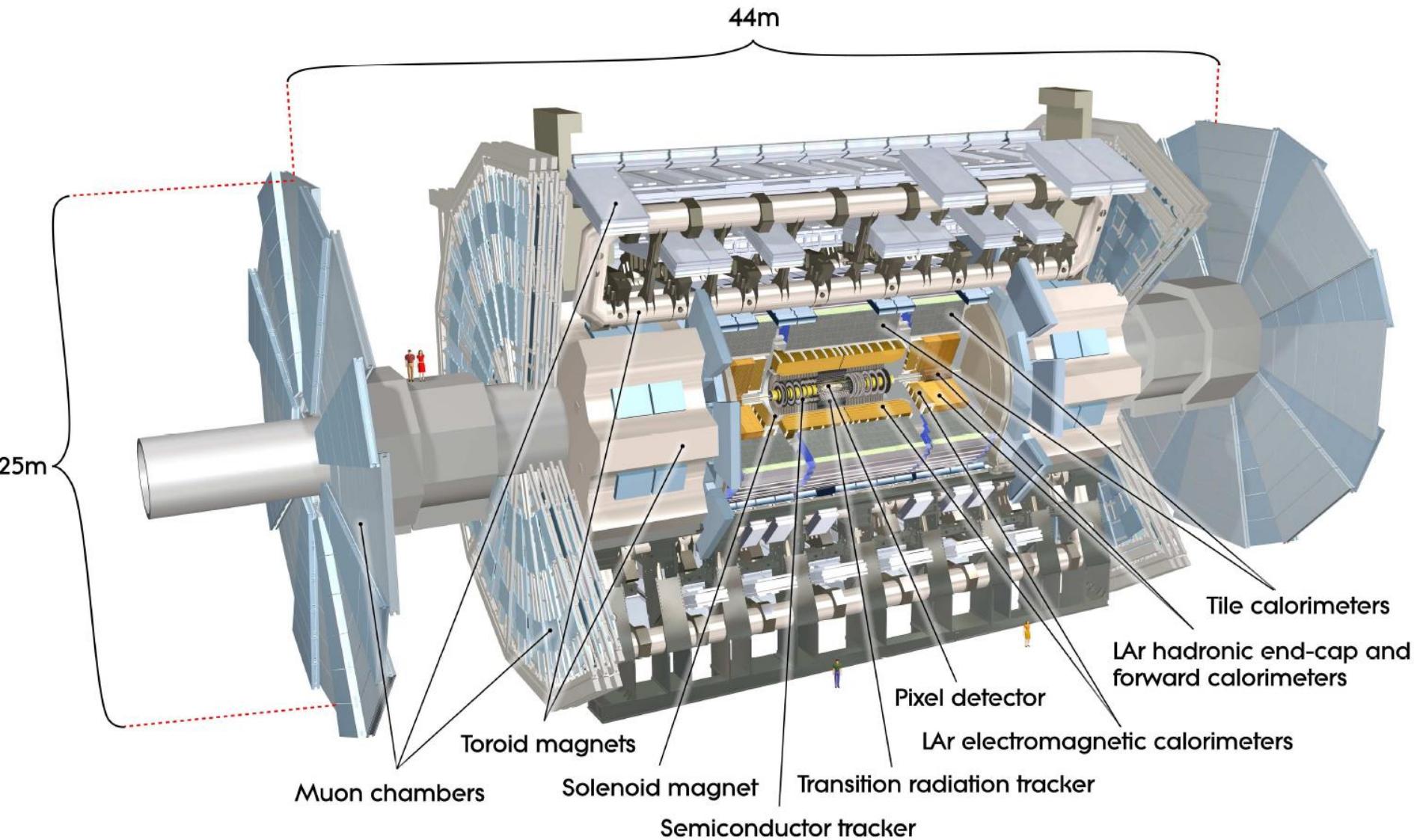


ATLAS - UPGRADE



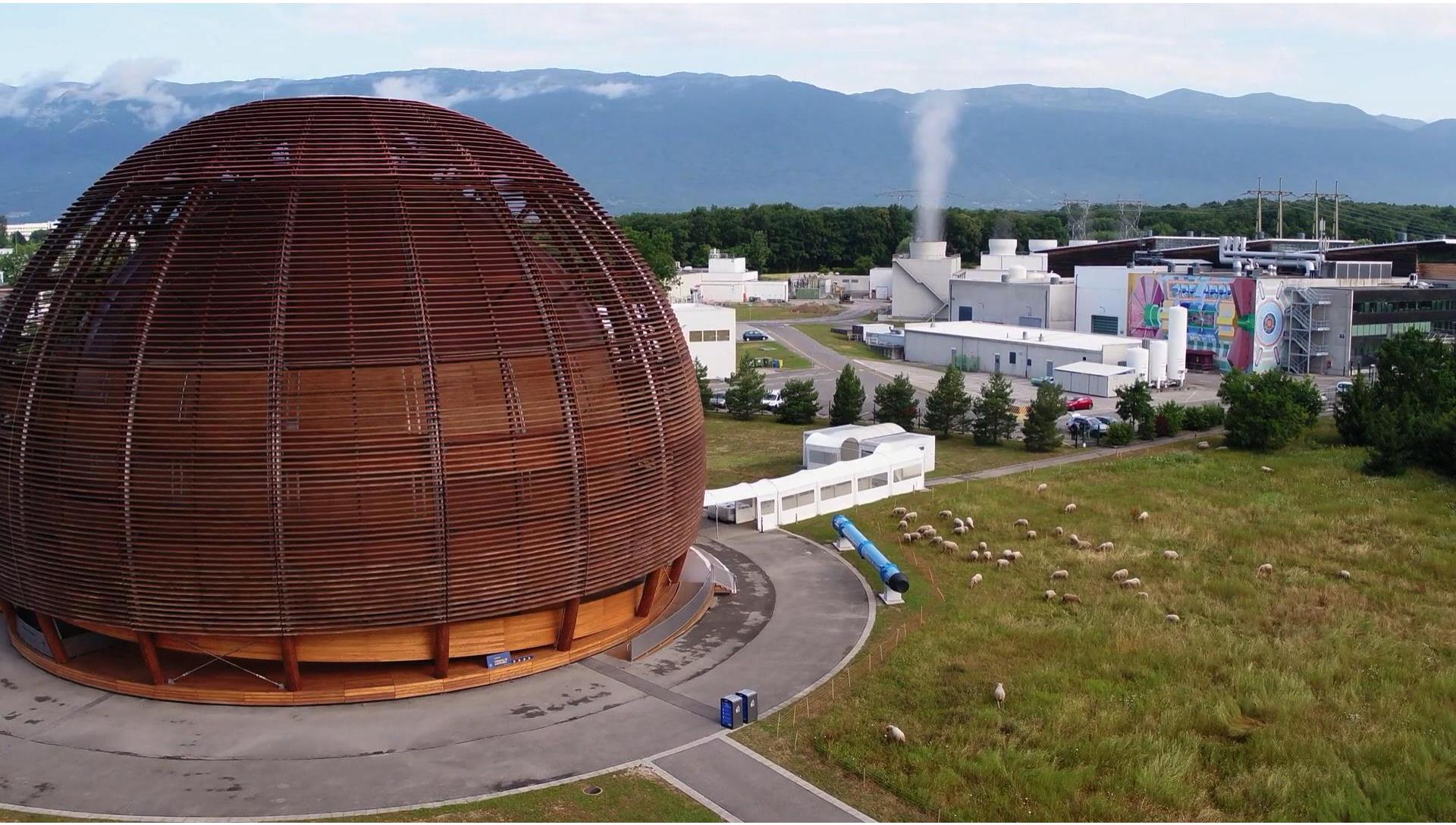
LHC / HL-LHC Plan





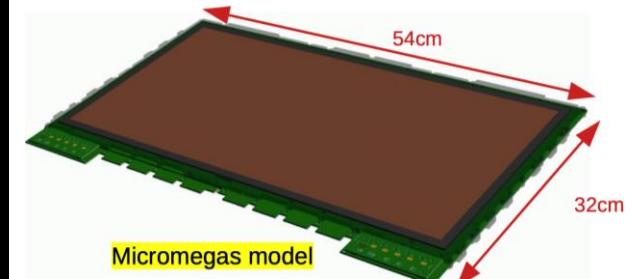
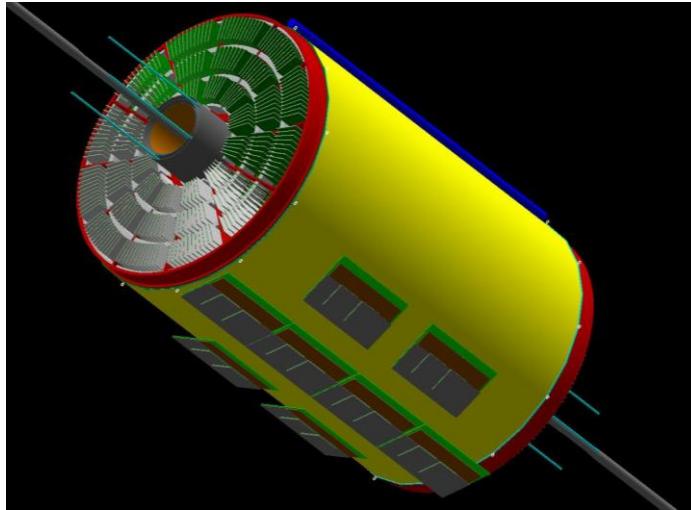


NSW INSTALLATION

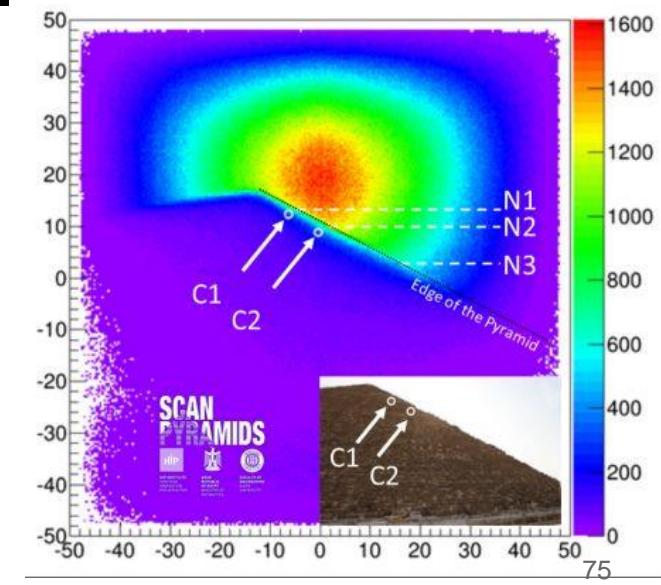
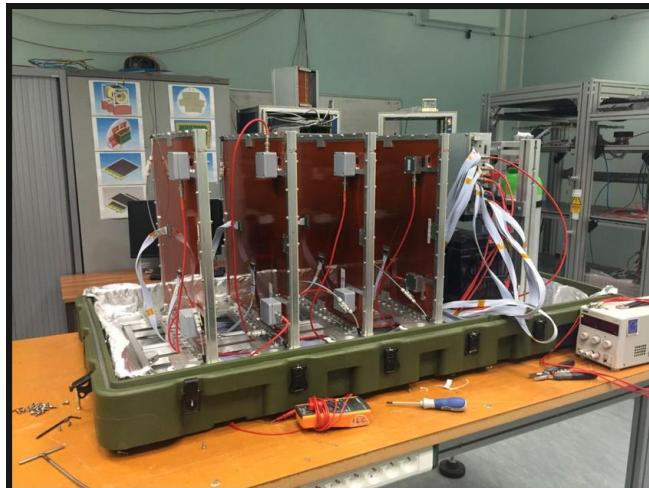


NSW : Dernière chambre vers ITK (Tanguy)

TPOT :



Tomographie :



MUON TOMOGRAPHY

MUON TOMOGRAPHY



- Cosmic muons produced by cascade of reactions induced by cosmic rays in the upper atmosphere

- Flux: $\sim 150/\text{m}^2/\text{s} \sim \cos^2\theta$ (maximum in zenith direction)
- Mean energy: 4 GeV
- Life-time: 2 μs
- Natural, free and harmless radiation
- Straight propagation (in mean)

- Muon interaction with matter

- Bethe-Bloch ionization stopping power

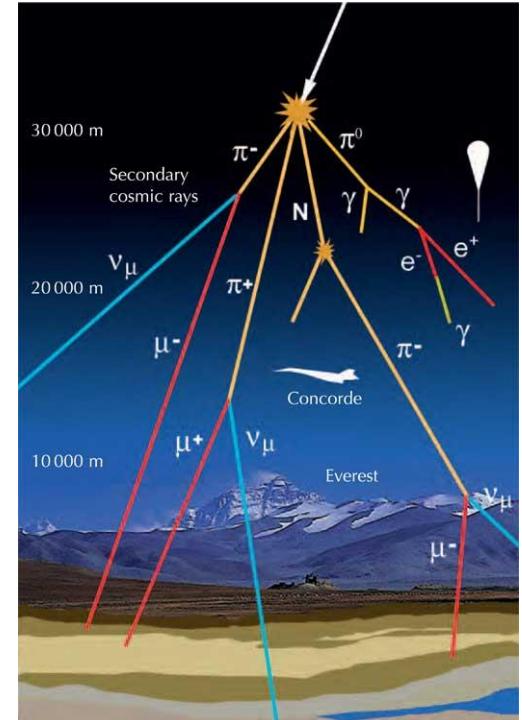
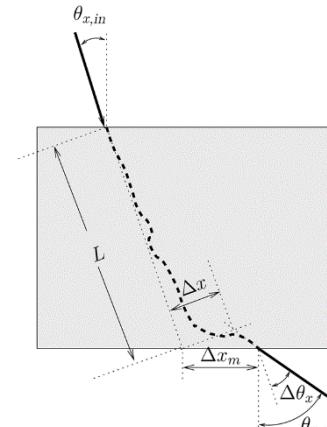
$$-\frac{dE}{ds} = \rho q^2 \frac{N_A e^4}{4\pi\epsilon_0^2 m_e c^2} \frac{Z}{A} \frac{1}{\beta^2} \left(\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 W_{max}}{I^2} - \beta^2 - \frac{\delta}{2} \right)$$

- Standard deviation of the scattering angle

$$\sigma_\theta = \frac{19.2 \text{ MeV}}{\beta pc} \sqrt{\frac{\rho s}{X_0}} \left(1 + 0.038 \ln \frac{\rho s}{X_0} \right)$$

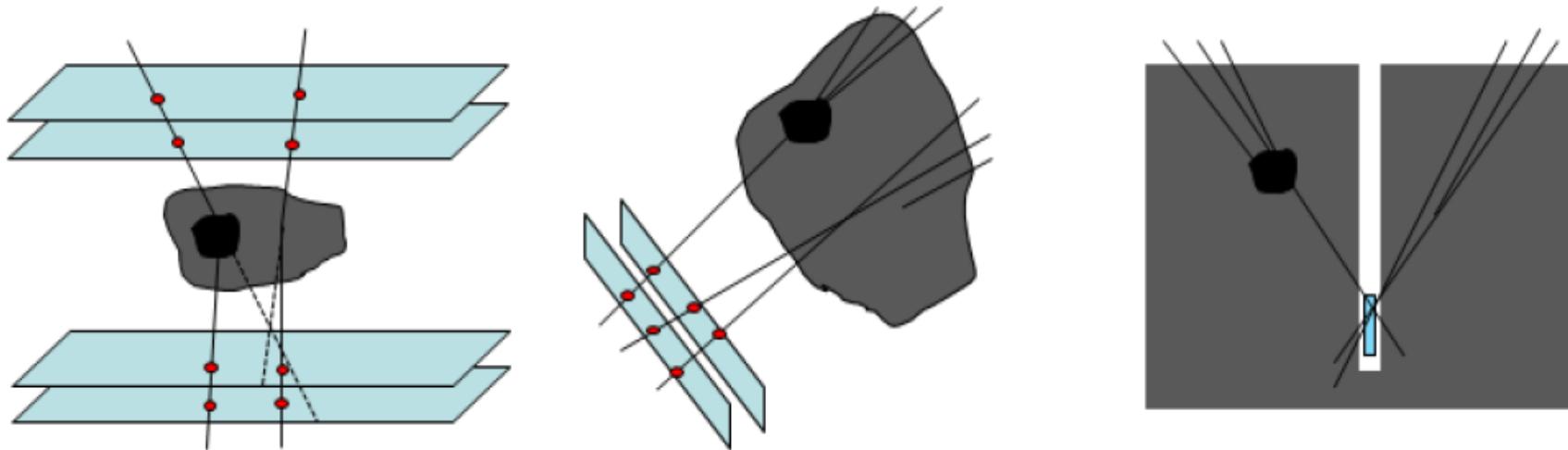
- Radiation length

$$X_0 = 716.4 \text{ g cm}^{-2} \frac{A}{Z(Z+1) \ln \frac{287}{\sqrt{Z}}}$$



Material	Thickness	$\theta (\circ)$	$P_{\text{absorption}}$
Air	100 m	0.094	0.78%
Lead	10 cm	1.01	2.9%
Water	1 m	0.35	4.2%
Ground	100 m		99%

- Muons can be stopped (decay) or their trajectory can be changed
- Two modes of muon tomography can be extracted from muon flux
 - Absorption muography
 - Deviation muography

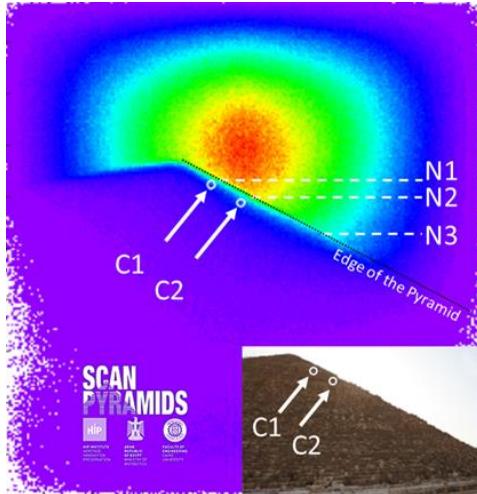


- High potential of societal applications in many fields:
 - volcanology, archaeology
 - mineral exploration, civil engineering, ...

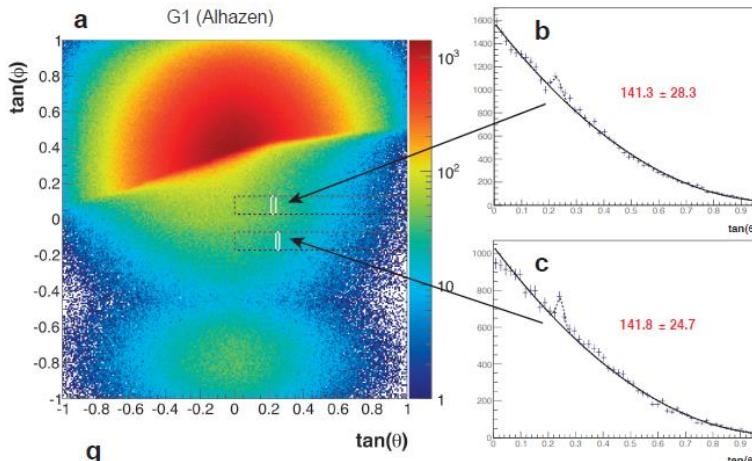
RESULTS

- Discoveries of new cavities large void above the Grand Gallery

2016

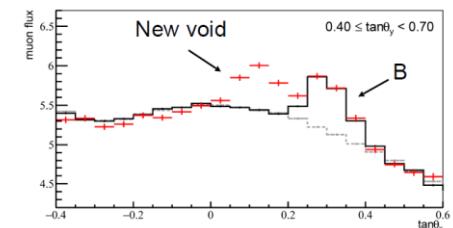
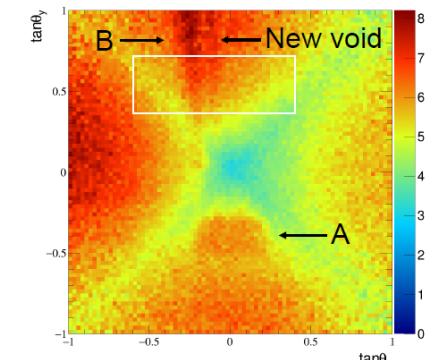


CEA

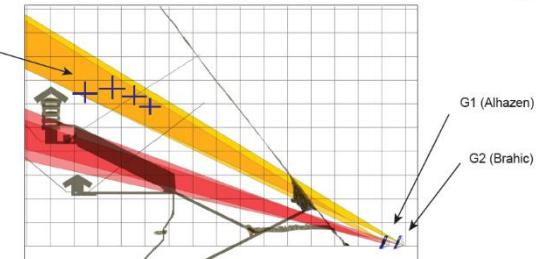


2017

Nagoya



Triangulation positions from Nagoya University



DE LA RECHERCHE À L'INDUSTRIE



Mardi 12/07 11h (Orme)
Lundi 18/07 12h (Centre)
Visite Labo (Centre)
Lundi 18/07 17h15 (Centre)



Mesurer l'infiniment petit et observer l'infiniment grand



Stages : <http://irfu.cea.fr/Phocea/stages/index.php>

Maxence Vandenbroucke
07/2022

Université
PARIS-SACLAY

Cours 1 : Généralités

- Introduction générale sur l'importance de la mesure
- Qu'est-ce qu'une expérience de physique subatomique ?
- Que veut-on observer à propos d'une particule?
- Architecture générale d'une expérience en physique subatomique

Cours 2 : Les détecteurs de particules

- Trajectographie :
 - Détecteurs Gazeux
 - Détecteurs au Silicium
- Calorimétrie
- Scintillation

Cours 3 : Exemple d'expériences

- Autour du Neutrino
- Nucléaire et Hadronique
- Rayons Cosmiques
- Antimatière

Cours 3 : Exemple d'expériences

- Autour du Neutrino
- Nucléaire et Hadronique
- Rayons Cosmiques
- Antimatière
- Matière sombre



11-22 JUILLET 2022

Orsay
Palaiseau
Paris
Saclay

Rencontres
Promotion Richard Feynman

de L'INFINIMENT
GRAND
à L'INFINIMENT
petit

VISITES
DE LABOS,
CONFÉRENCES,
DÉBATS

Niveau L3

Comprendre l'infiniment petit
Les noyaux et leurs interactions
Des particules aux étoiles
jusqu'au cosmos
Mesurer l'infiniment petit,
observer l'infiniment grand
Applications médicales
Maîtriser l'énergie
Enregistrer, analyser, découvrir

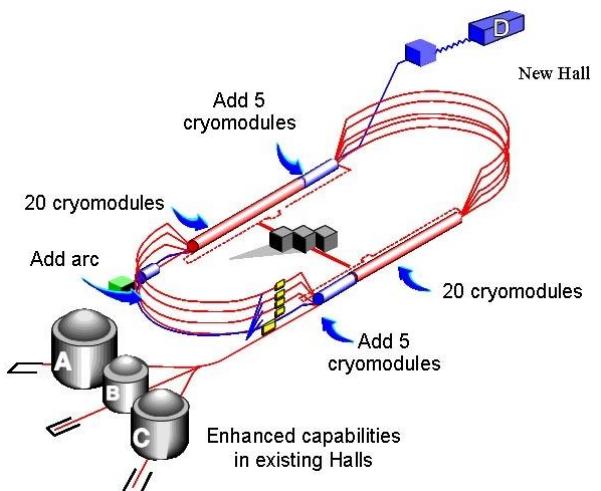
INFORMATIONS ET INSCRIPTIONS
indico.in2p3.fr/event/rencontres-physique-infinis

2022 - Institut de Physique Nucléaire de Paris

Physique Hadronique

COMPASS et CLAS12

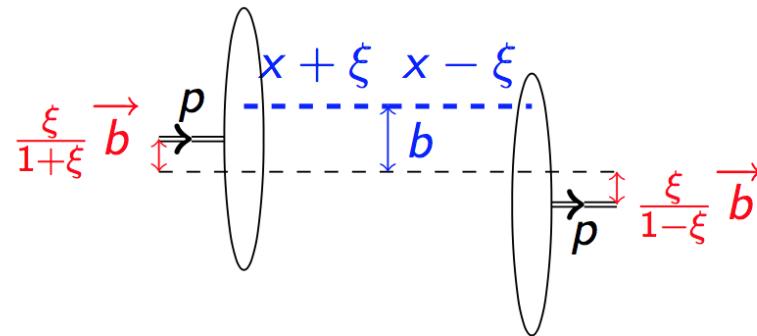
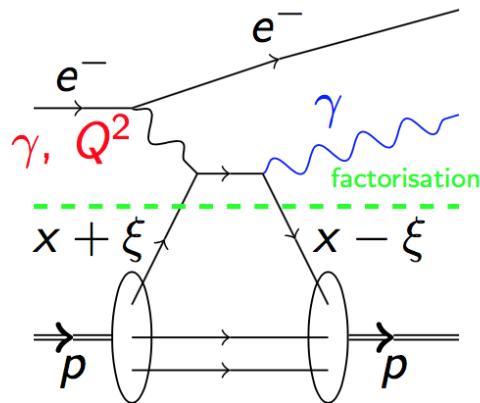
CLAS12 at Jefferson Lab



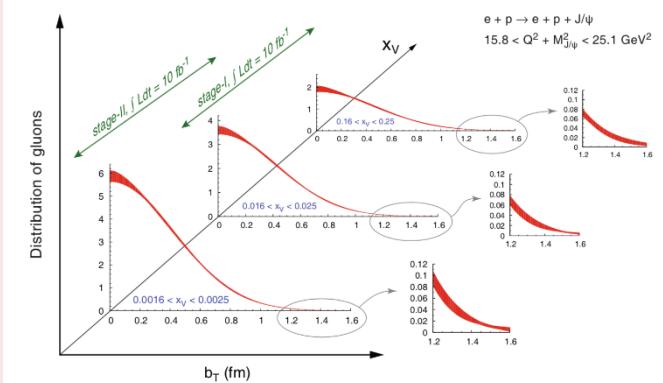
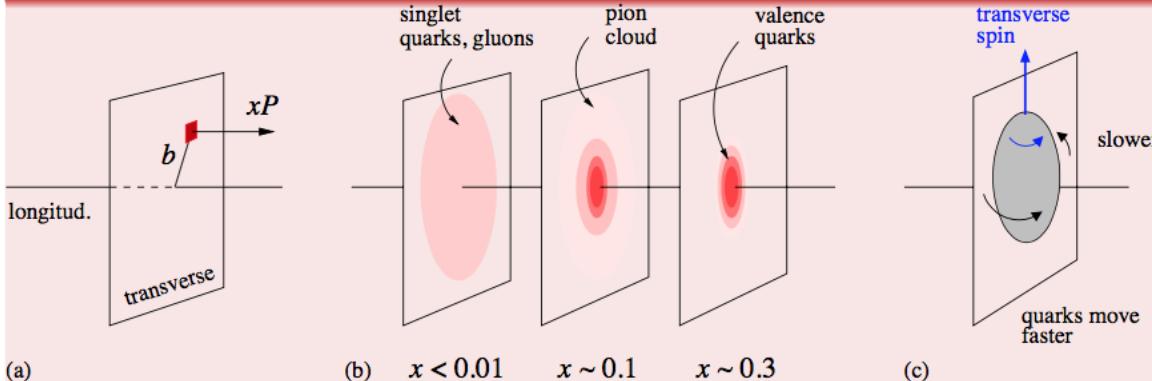
CLAS12 at Jefferson Lab

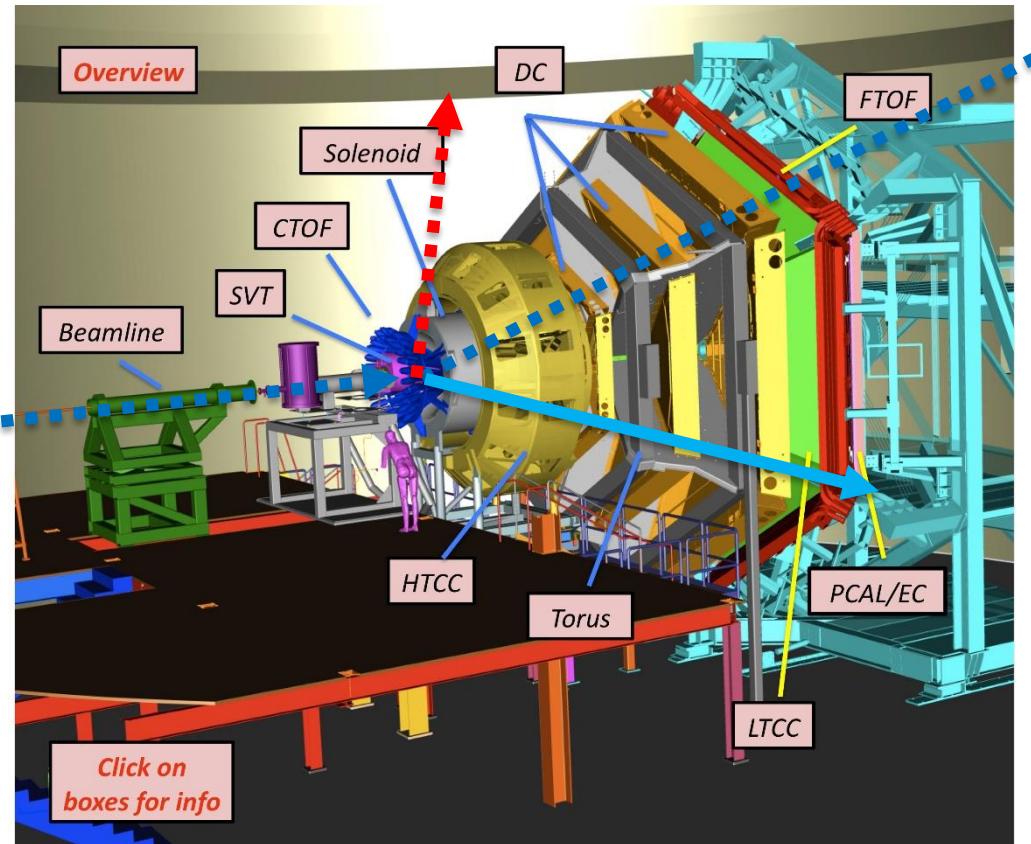
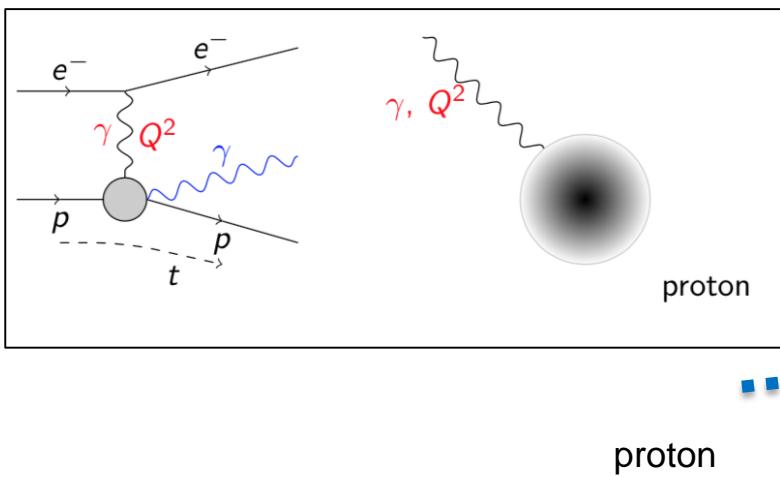


Diffusion Compton profondément virtuelle (DVCS)

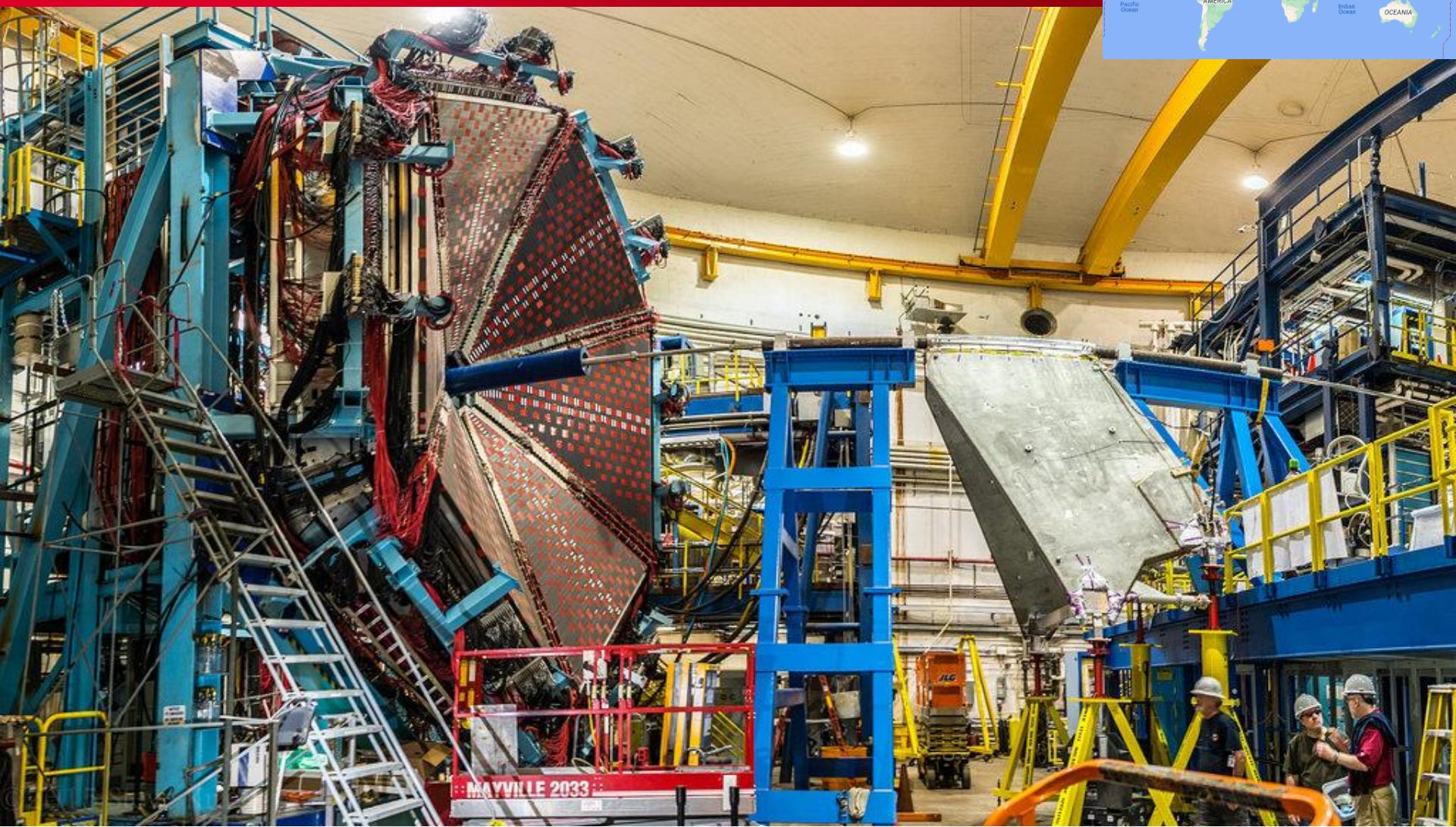


Vers une visualisation en 3d du nucléon !

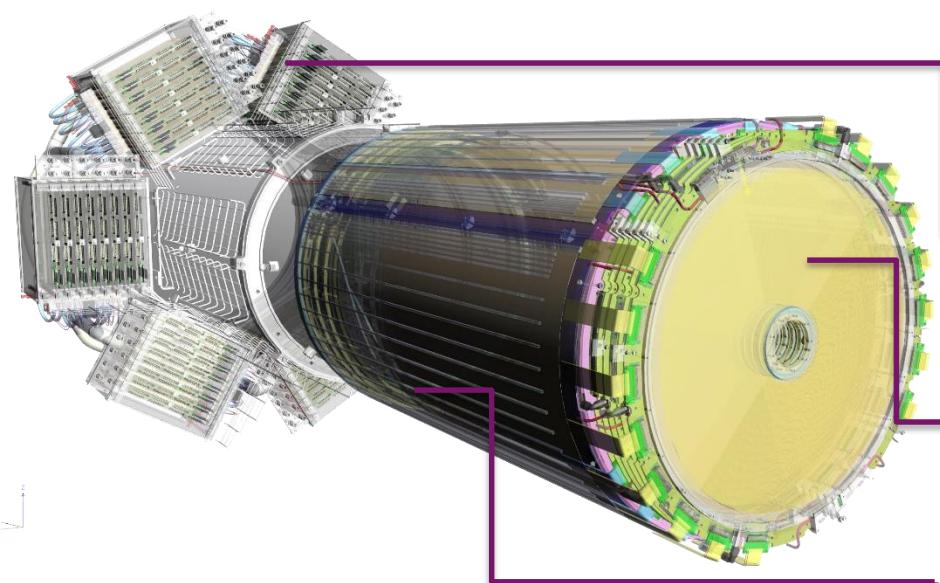




CLAS12 at Jefferson Lab



CLAS12 - THE MICROMEGAS VERTEX TRA



- ▶ 4 m² of Micromegas detectors to be installed in 2017
- ▶ DREAM based Front-End Electronics
- ▶ Remote off-detector frontend electronics connected with 2m micro-coaxial cables
- ▶ **Forward Detectors**

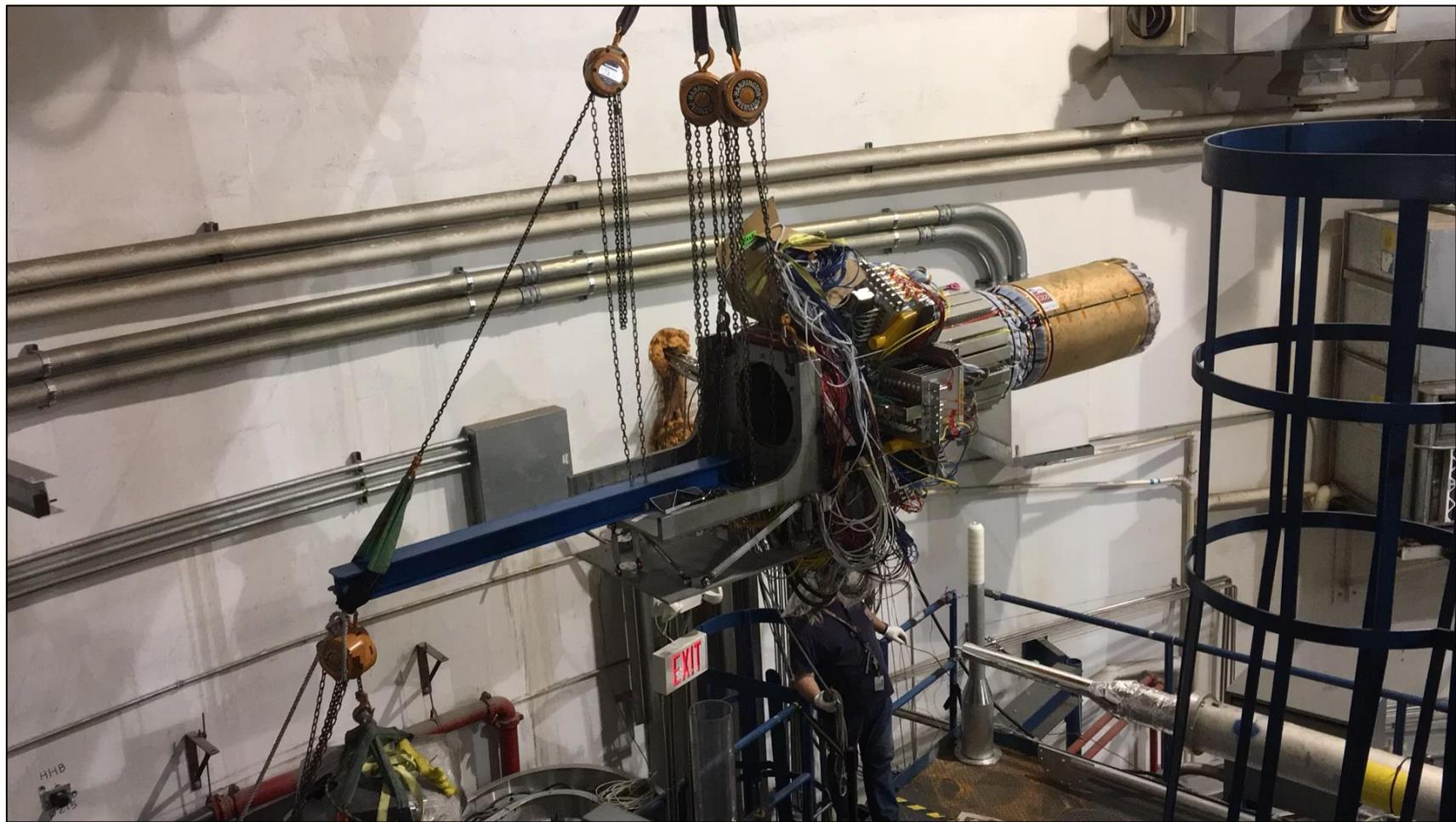
- ▶ **High particle rate (30MHz)** => Fast detectors
- ▶ Resistive strips divided in 2 zones inner/outer
- ▶ Dimensions: 6x 430 mm diameter disk with a 50 mm diameter hole at the center

Cylindrical Barrel

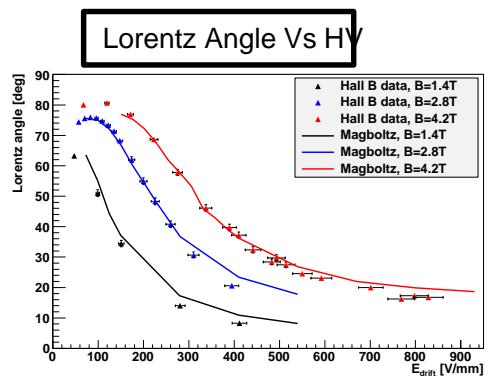
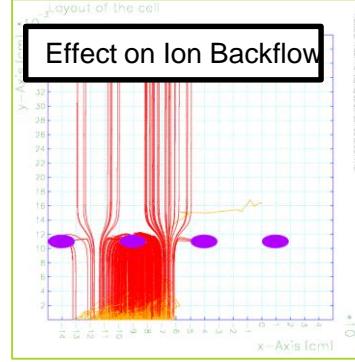
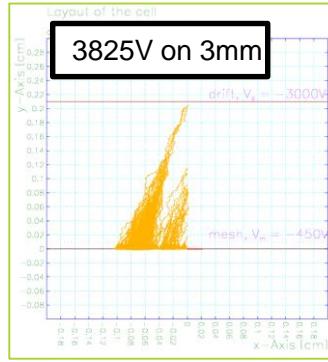
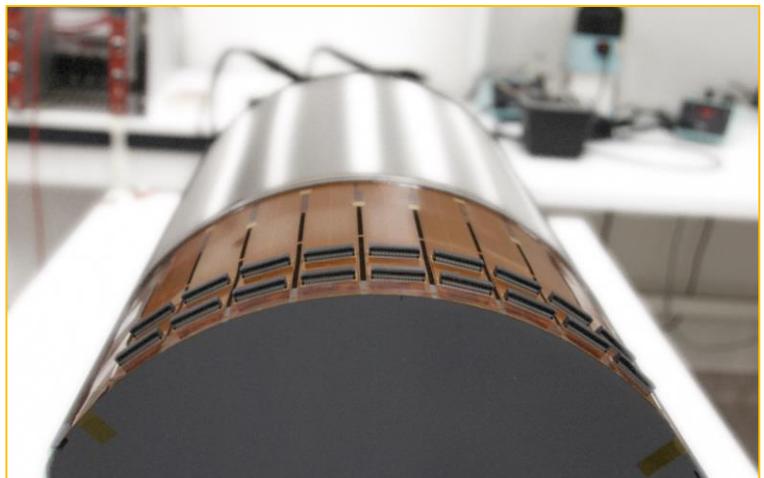
- ▶ **Low momentum particles** => Light Detectors
- ▶ Limited space of ~10 cm for 6 layers
- ▶ **High magnetic field (5T)**
- ▶ Phase 1 (2016) : 2 Layers (6 Det. of 120°)
- ▶ **Phase 2 (2017) : 6 Layers (18 Det.)**



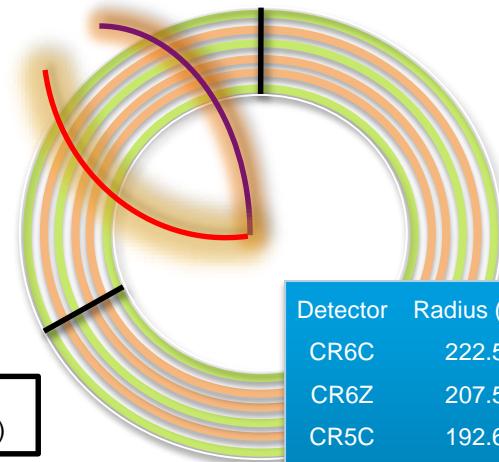
CLAS12 at Jefferson Lab



CLAS12 - THE MICROMEGAS VERTEX TRA

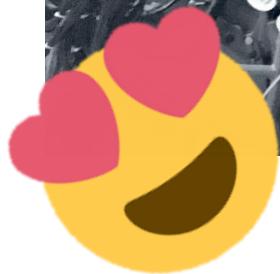
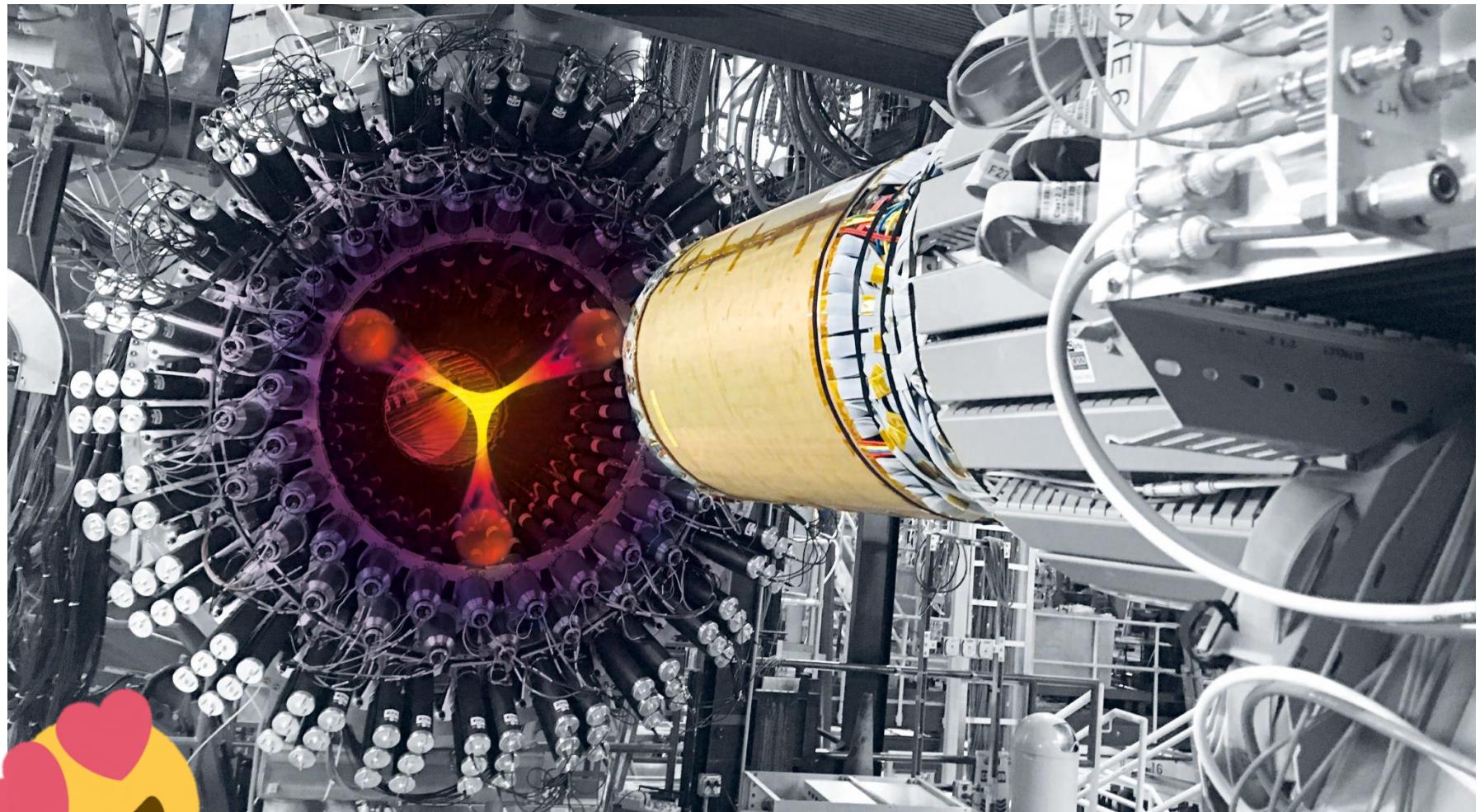


=> Clas-note 2007-004: Simulations of Micromegas detectors for the CLAS12 experiment (S. Procureur)



Detector	Radius (mm)
CR6C	222.53
CR6Z	207.54
CR5C	192.65
CR5Z	177.57
CR4Z	162.56
CR4C	147.57

CLAS12 – Central Tracker



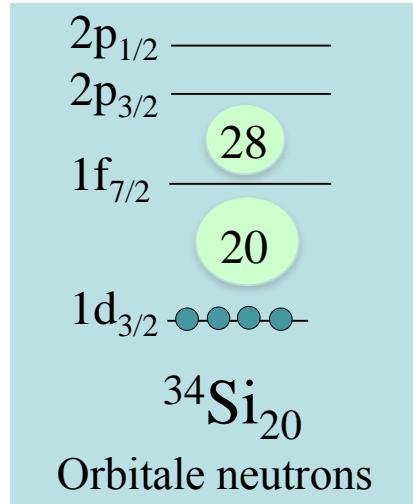
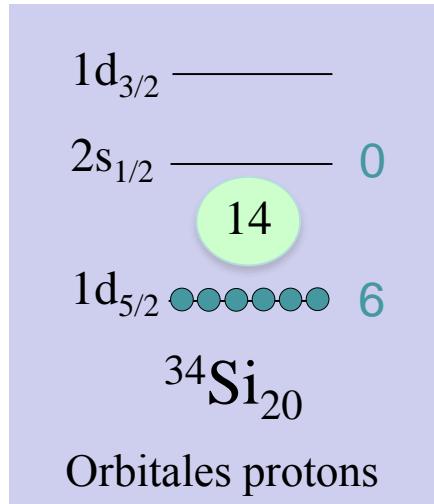
Physique Nucléaire

Noyaux Bulles et Spectroscopie Gamma

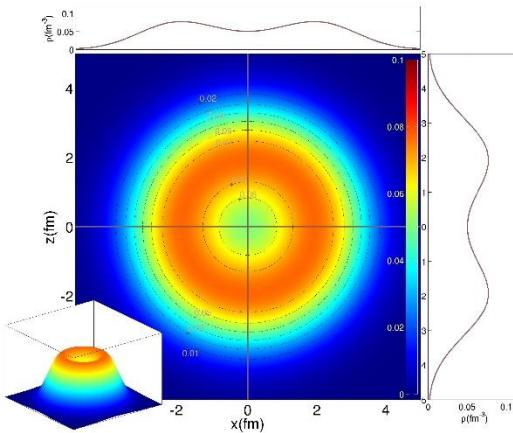
Cas physique : Etude des noyaux bulles



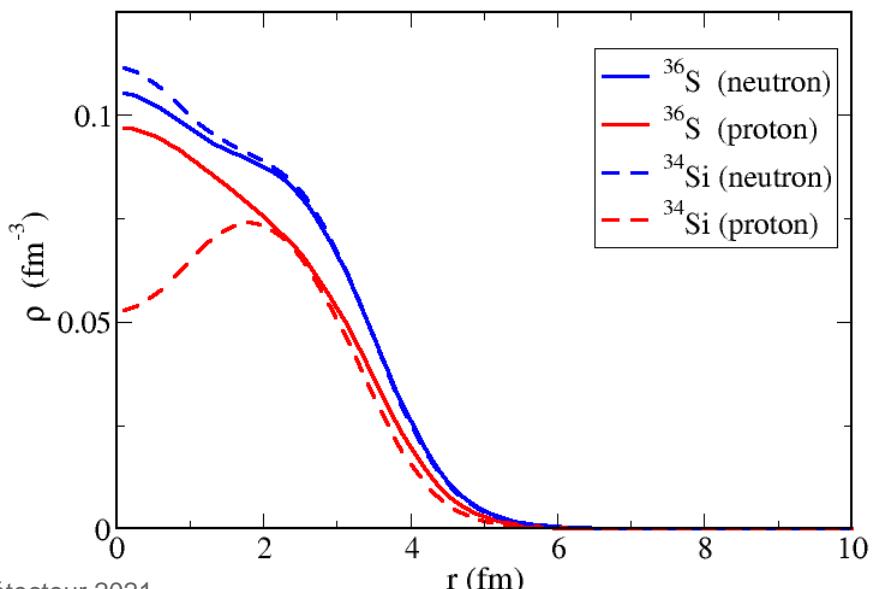
- Origine d'une déplétion centrale dans le noyau ^{34}Si



→ A cause de son orbitale $2s1/2$ vide, le ^{34}Si ($Z=14$, $N=20$) présenterait une déplétion centrale comparativement au ^{36}S ($Z=16$, $N=20$)

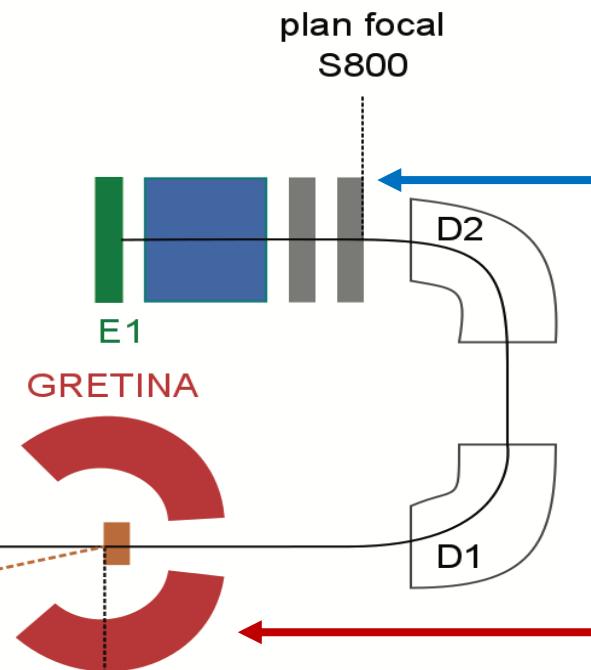
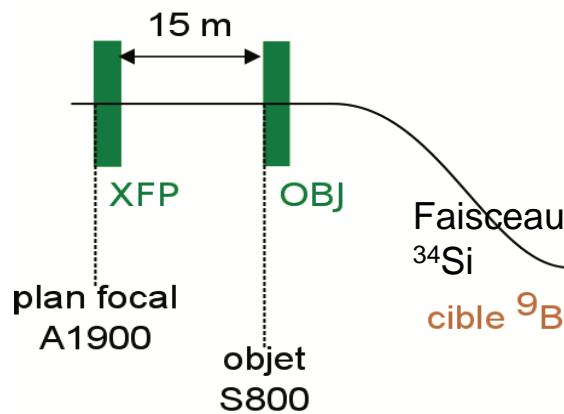
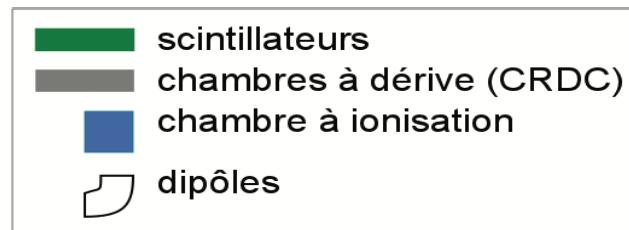


Ground State Density
Skyrme Harte- Fock Calculations





- Expérience @NSCL, MSU USA. Objectif : étudier l'occupation de l'orbitale $2s1/2$ dans le ^{34}Si et ^{36}S . Réaction d'arrachage d'un proton (1 proton knockout) $^{34}\text{Si}(-1\text{p})^{33}\text{Al}$ and $^{36}\text{S}(-1\text{p})^{35}\text{P}$ et on essaye d'identifier d'où a été arraché le proton



ACCELERAT EUR

SYSTEME DE PRODUCTION IONS RADIOACTIFS

SEPARATEU R A1900

DETECTEURS γ + SPECTRO

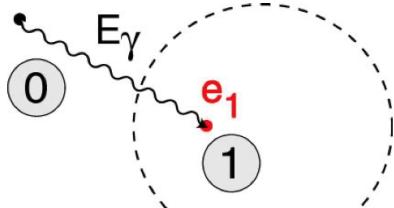
Spectroscopie Gamma



- Comment interagit un γ avec la matière ?

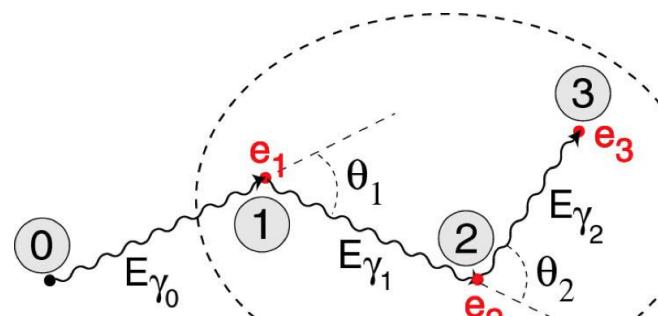
 $\sim 100 \text{ keV}$ $\sim 1 \text{ MeV}$ $\sim 10 \text{ MeV}$ γ ray energy

Photoelectric



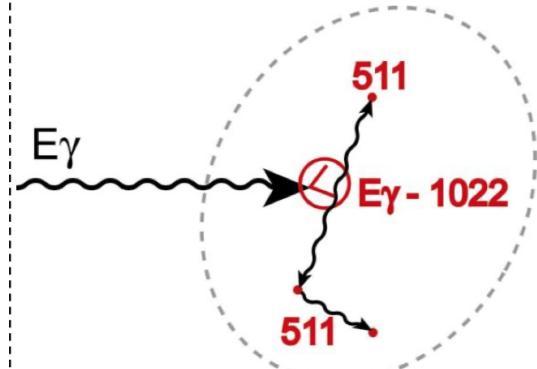
$$E_{e1} = E_{\gamma} - E_b$$

Compton Scattering



$$E_{\gamma'} = \frac{E_{\gamma}}{1 + \frac{E_{\gamma}}{m_0 c^2} (1 - \cos \theta)}$$

Pair Production



$$(E_{\gamma} > 2m_e c^2)$$

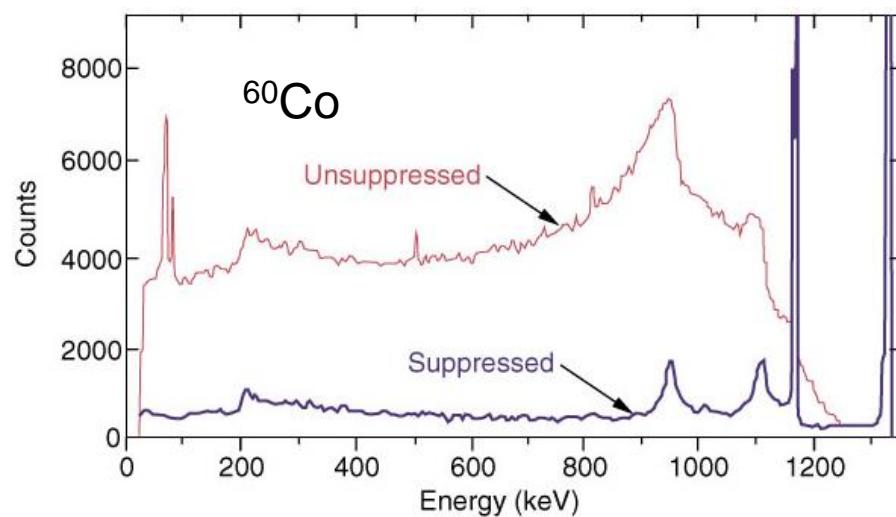
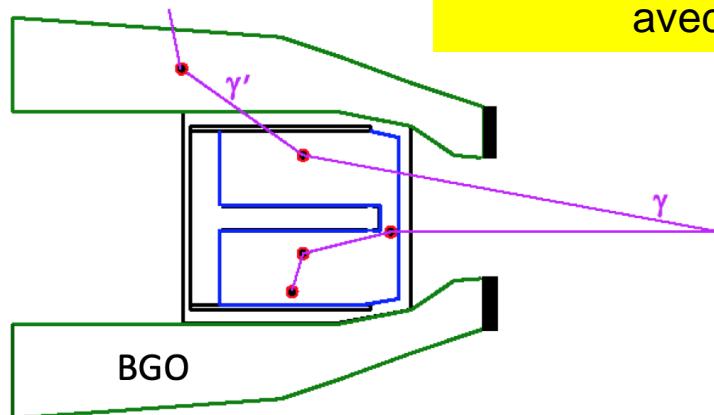
Spectroscopie Gamma



DETECTEUR
γ Germanium

- Les détecteurs γ , la lutte contre la diffusion Compton

Astuce 1 : se débarrasser du Compton
avec un bouclier BGO

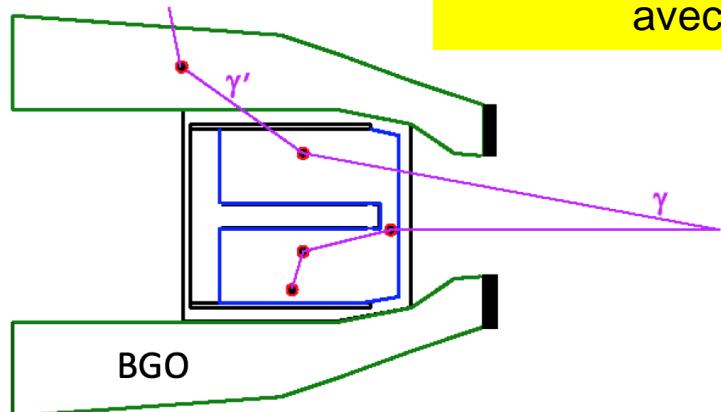


Spectroscopie Gamma

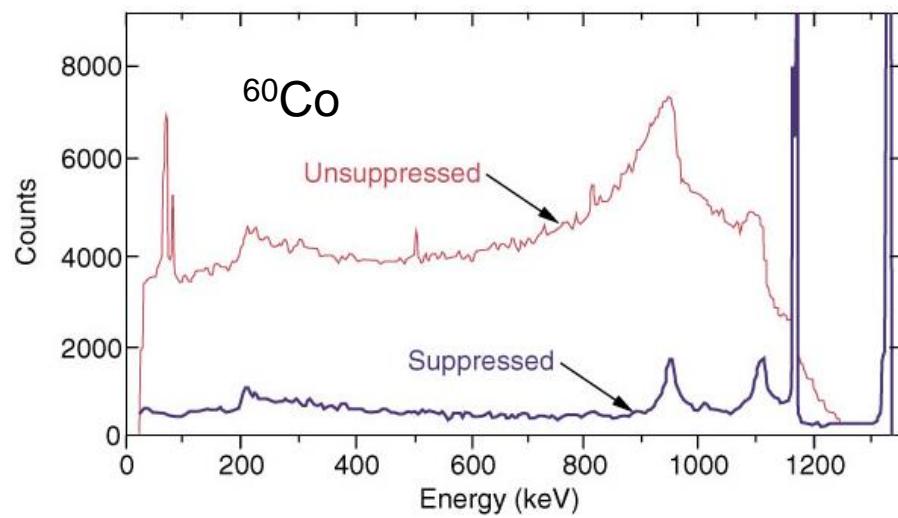


- Les détecteurs γ , la lutte contre la diffusion Compton

DETECTEUR
 γ Germanium



Astuce 1 : se débarrasser du Compton
avec un bouclier BGO



GAMMASPHERE @ANL

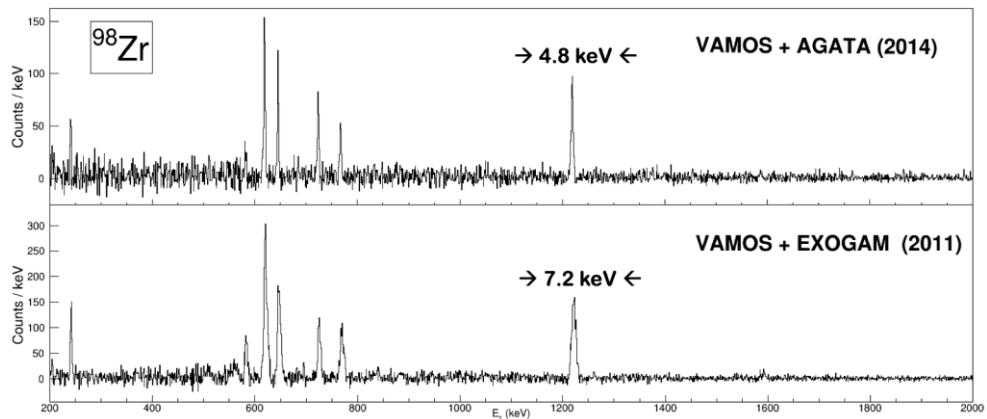
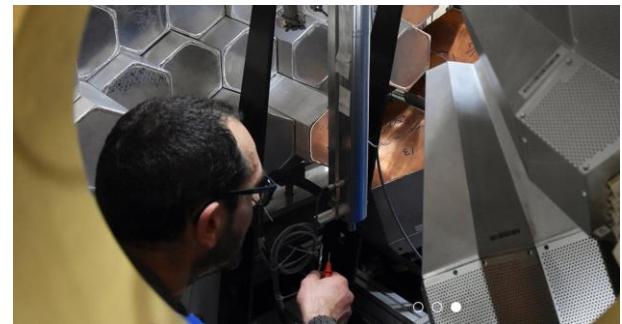
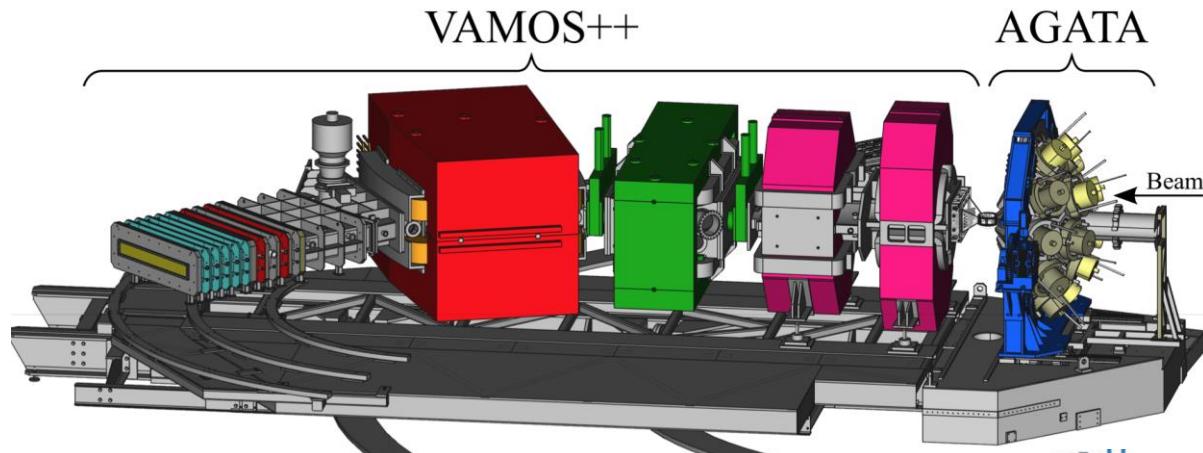


EXOGAM @GANIL

Spectroscopie Gamma



- La campagne VAMOS-AGATA @GANIL 2014-2021



29 expériences



558 To de données



6568 heures de faisceau sur cible



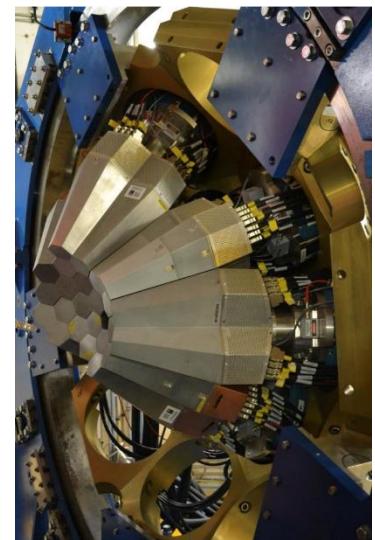
14 034 entrés dans le elog



2386 jours de surveillance cryogénique



11,5 tonnes de matériel scientifique



Cas physique : Etude des noyaux bulles



- Alors bulle ou pas bulle ?

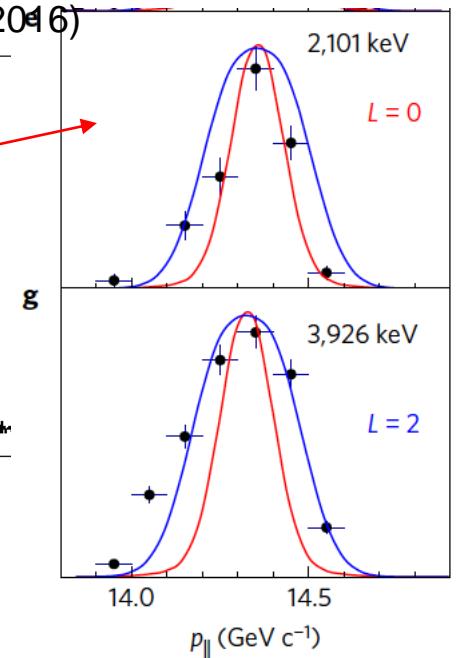
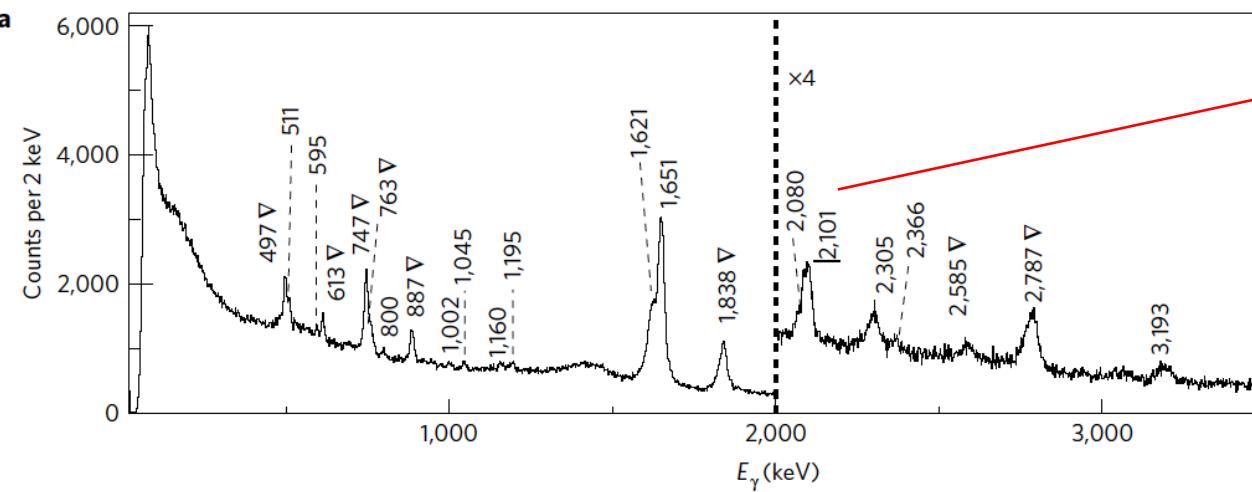
Cas physique : Etude des noyaux bulles



- Alors bulle ou pas bulle ?

1) $^{34}\text{Si}(-1\text{p})^{33}\text{Al}$, détection des γ issus de la désexcitation du ^{33}Al dans GRETINA en coïncidence avec le noyau ^{33}Al au plan focal du spectromètre S800

A. Mutschler et al. Nature Physics 3916 (2016)

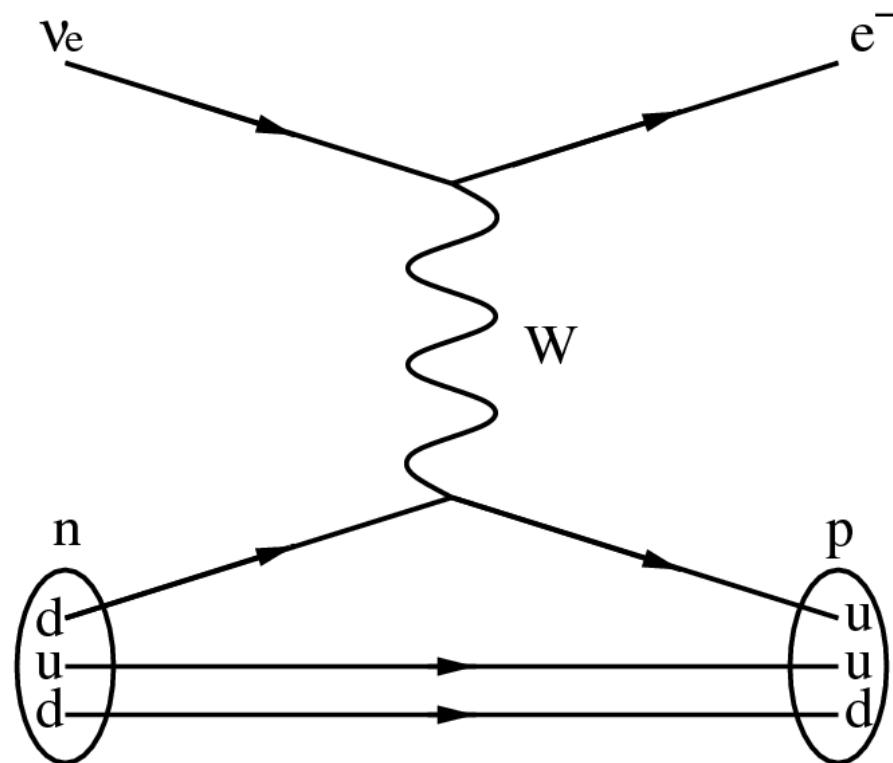


2) Le moment orbital angulaire l de l'orbitale d'où est arraché le p est déterminé en mesurant la distribution en moment longitudinal du ^{33}Al pour l'état peuplé

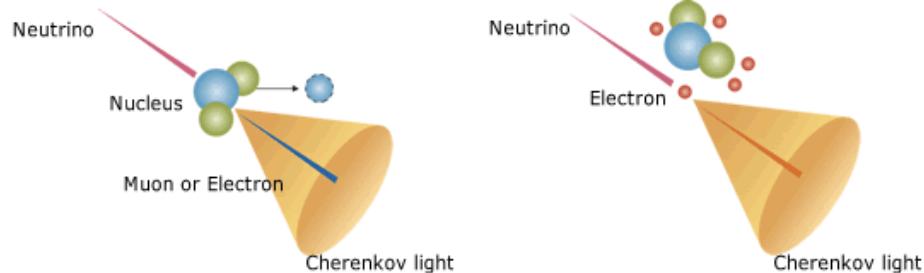
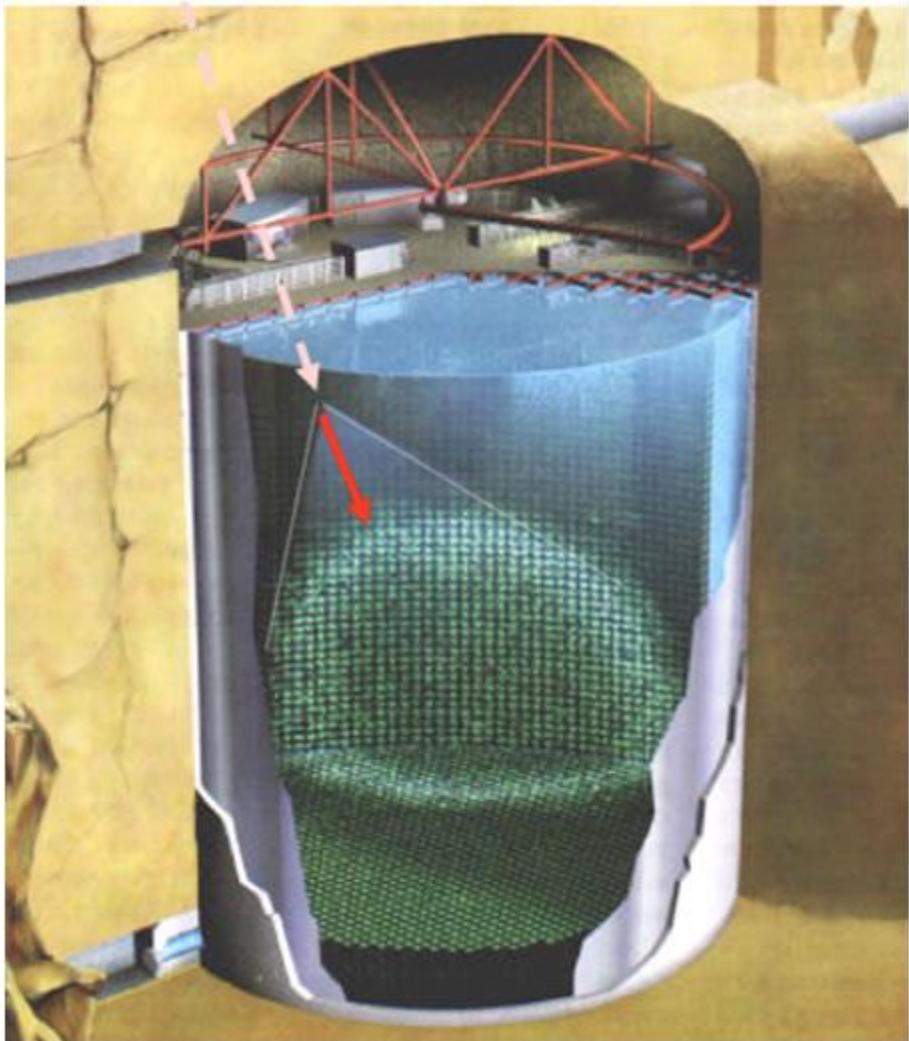
3) L'occupation de l'état $2s1/2$ est déduite en de la section efficace expérimentale pour arracher un p depuis cette orbitale (rappel : orbitale $2s1/2$ peut accueillir 2 nucléons)

Dans le ^{34}Si 0.17(3)
Dans le ^{36}S 1.7(4)

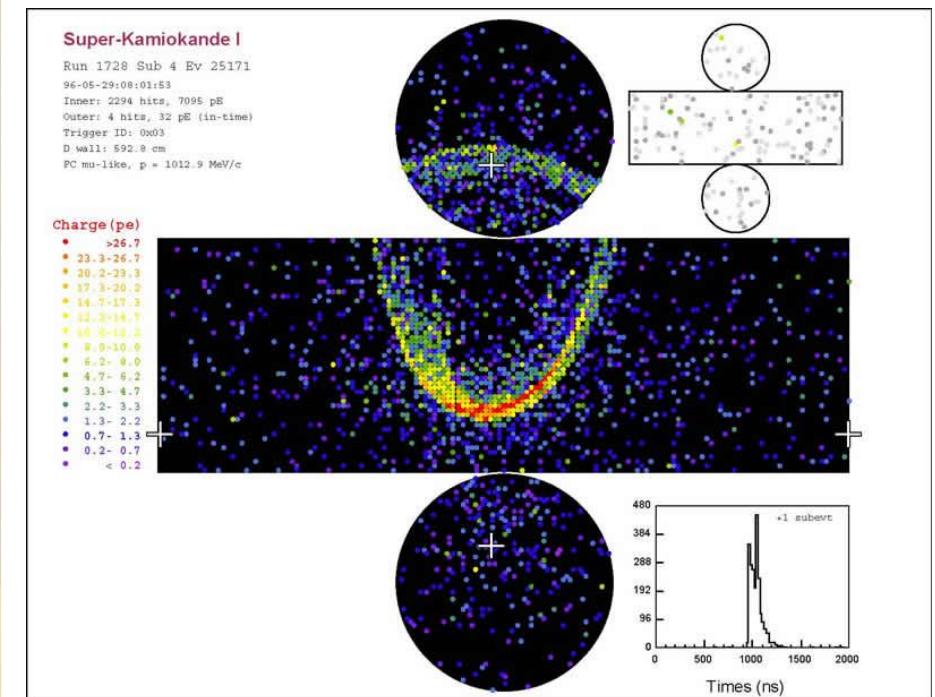




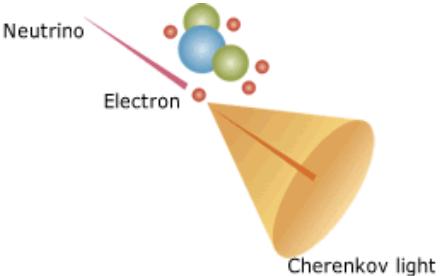
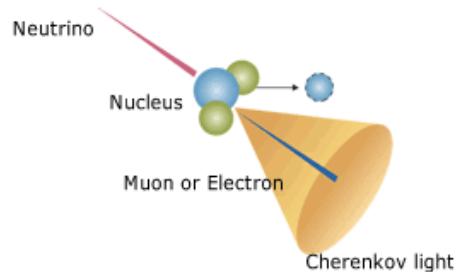
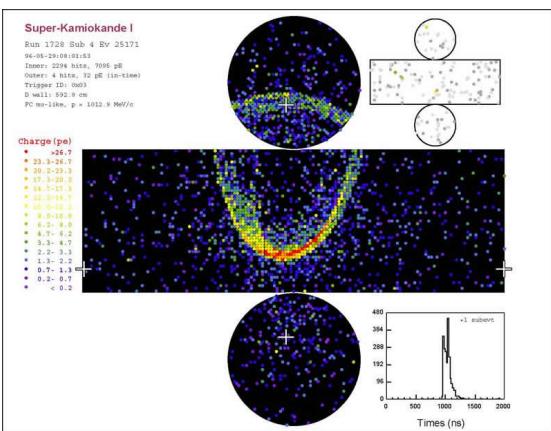
Super Kamiokande



The generated charged particle emits the Cherenkov light.

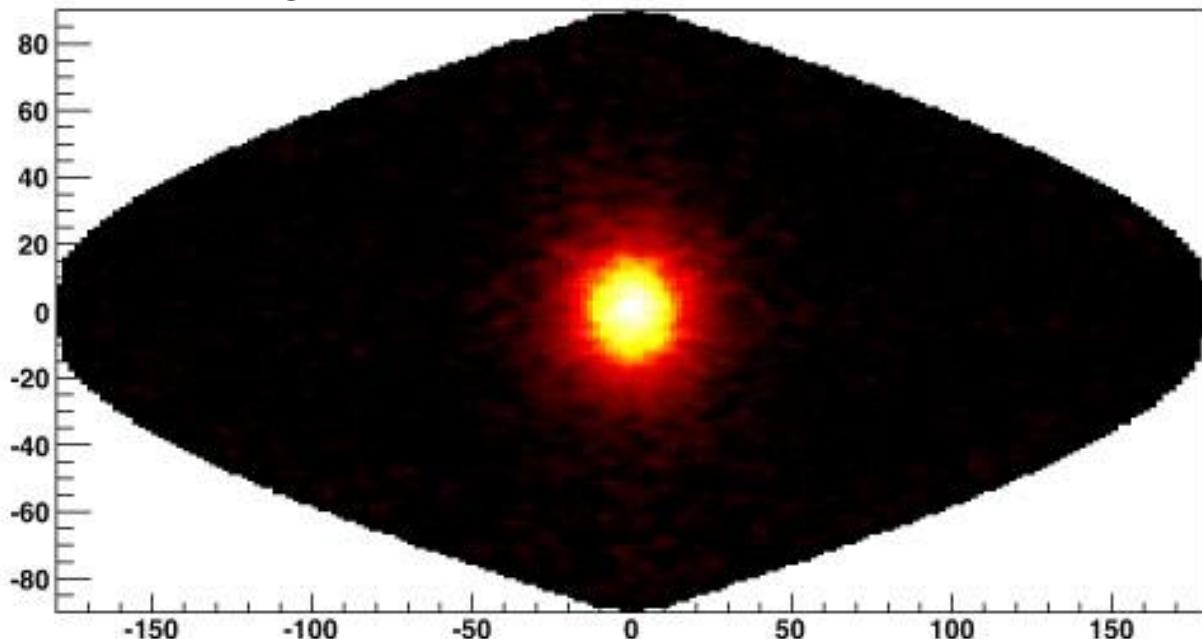


Super Kamiokande



The generated charged particle emits the Cherenkov light.

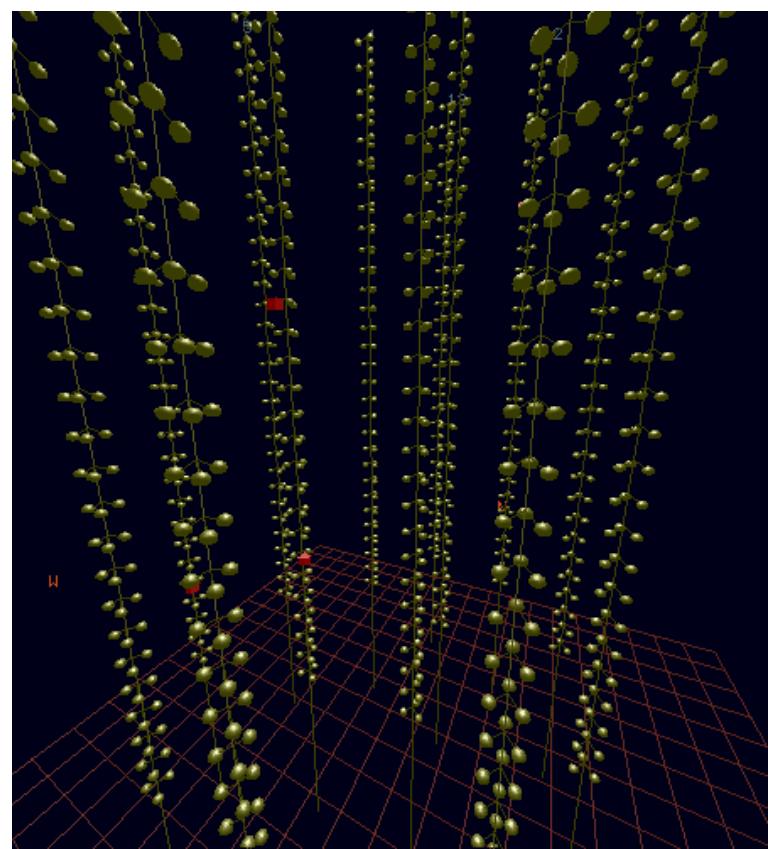
Image du soleil en Neutrino Electronique



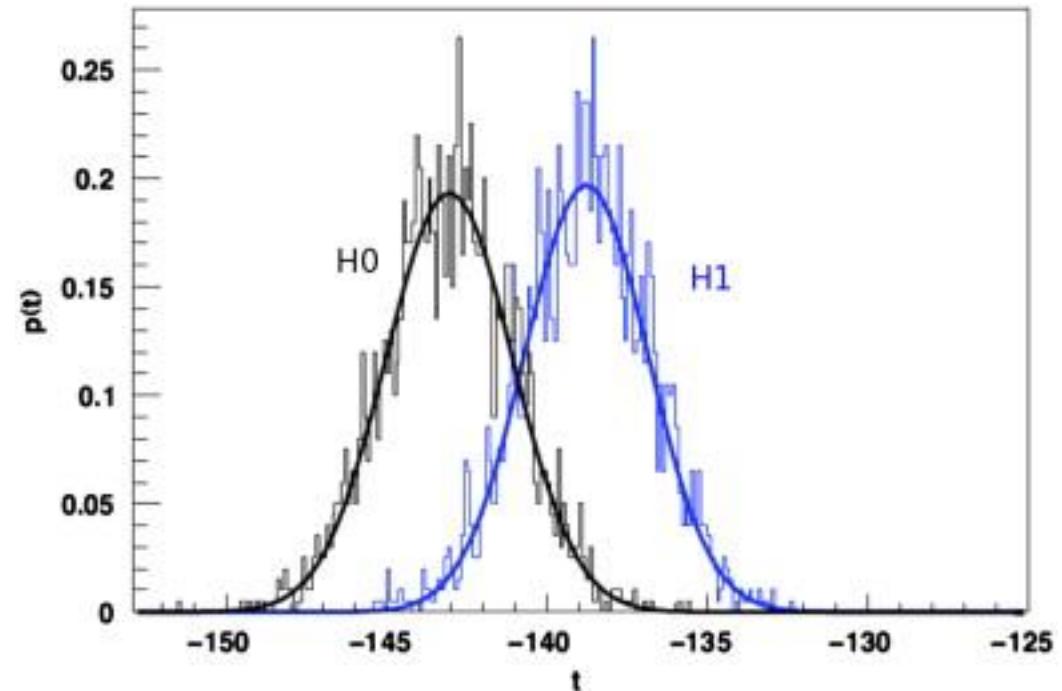
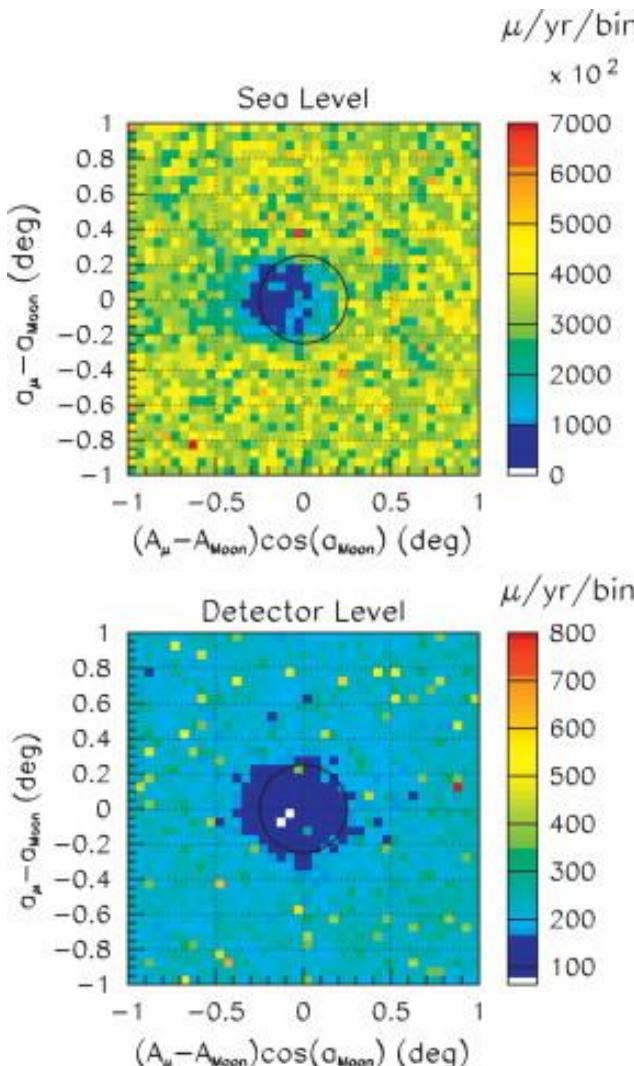
Antares



FIG. (ii) 1.7: Photographie d'un individu bioluminescent prise par l'une des caméras installées sur la ligne d'instrumentation IL07 (lire le paragraphe (II) 3.1). L'échelle n'est pas précisément connue (elle dépend de la distance à la caméra).



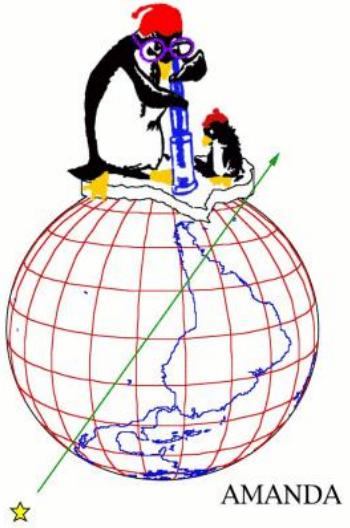
Antares



Moon hypothesis confirms at 2.9σ

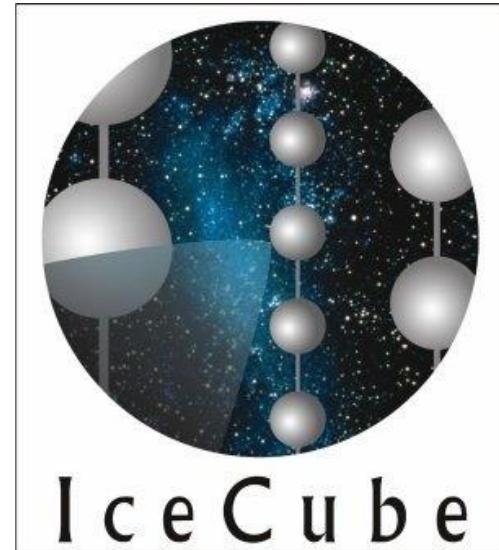
Sun is at 3.7σ

Moon Shadow in cosmic rays



AMANDA

Antarctic Muon And Neutrino Detector Array



AMANDA



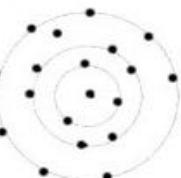
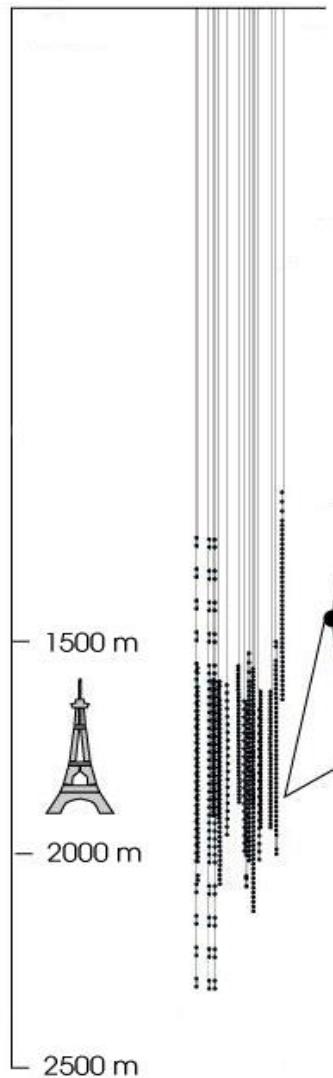
South Pole



AMANDA

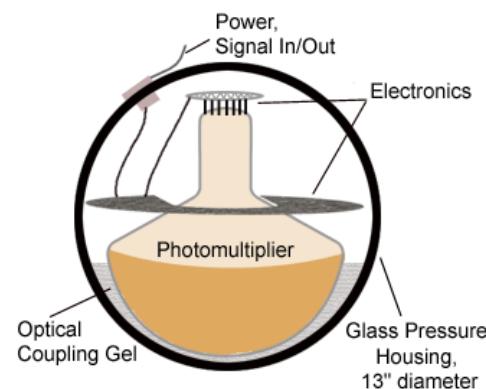
AMANDA-II

Depth



top view

200 m



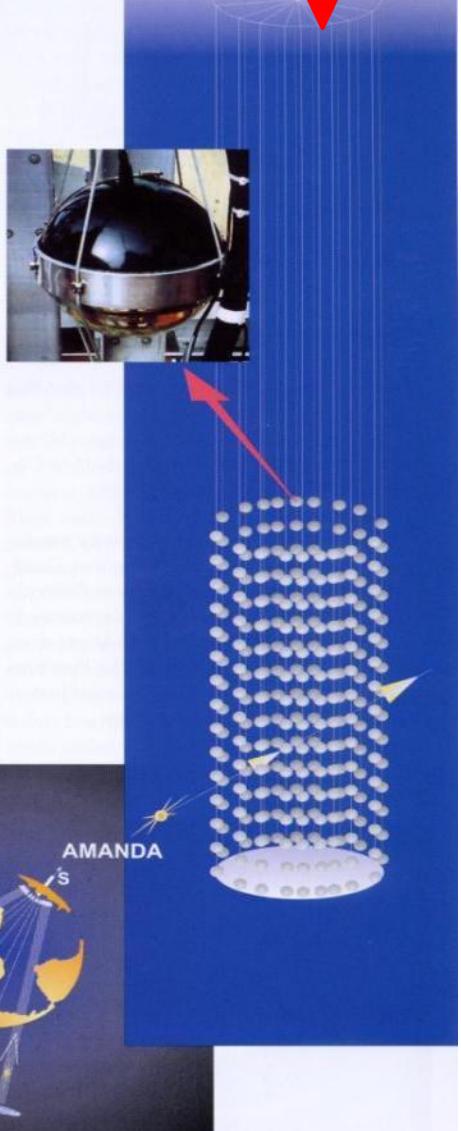
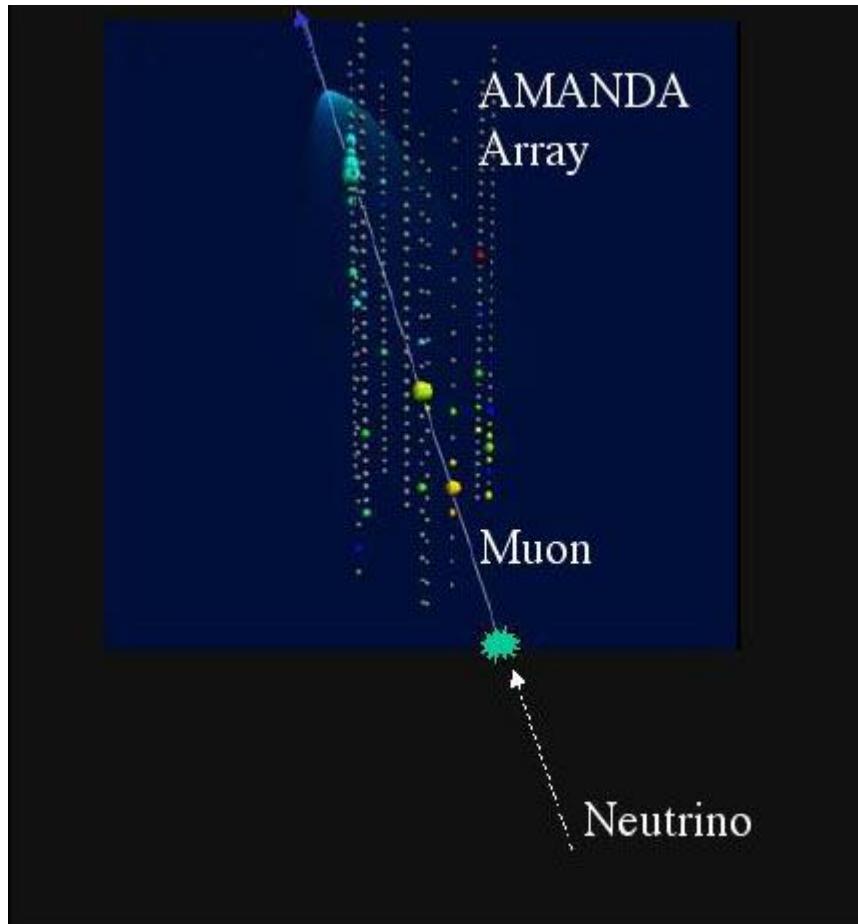
**Photomultipliers in the Ice,
looking downwards.
Ice is the detecting medium.**



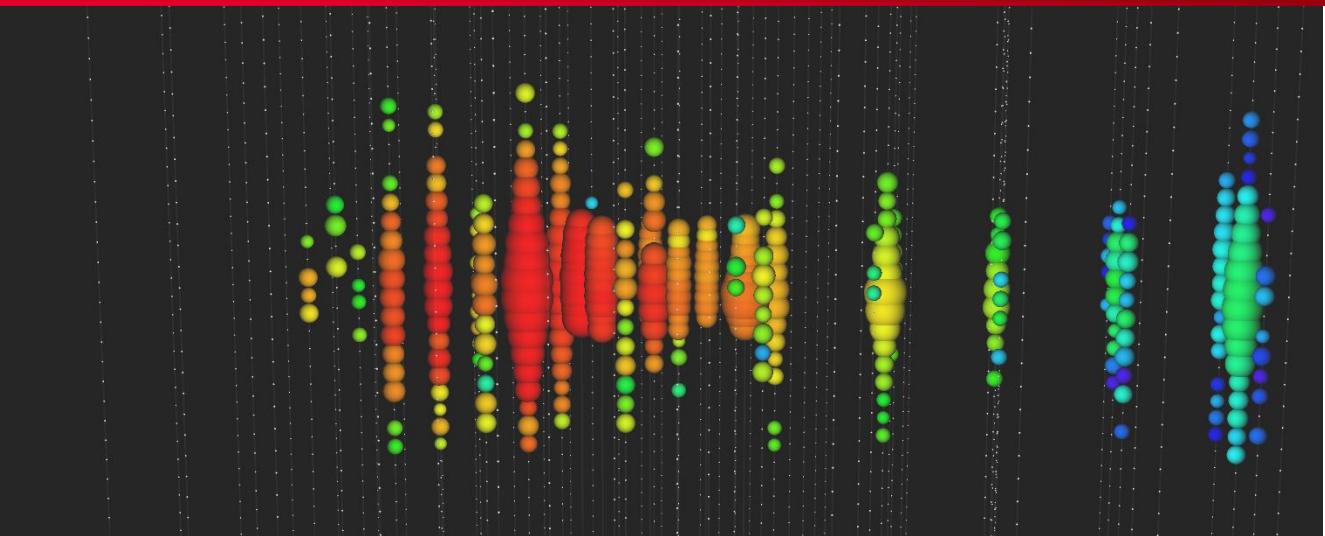
AMANDA

**Look for upwards going Muons from Neutrino Interactions.
Cherenkov light propagating through the ice.**

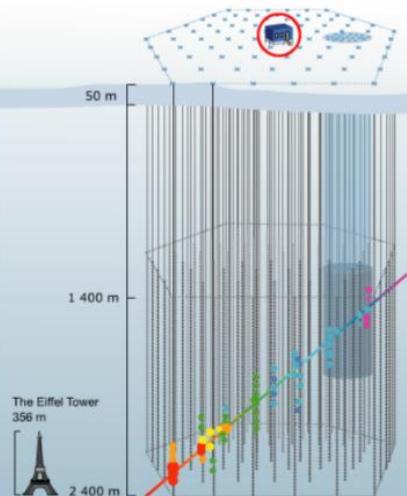
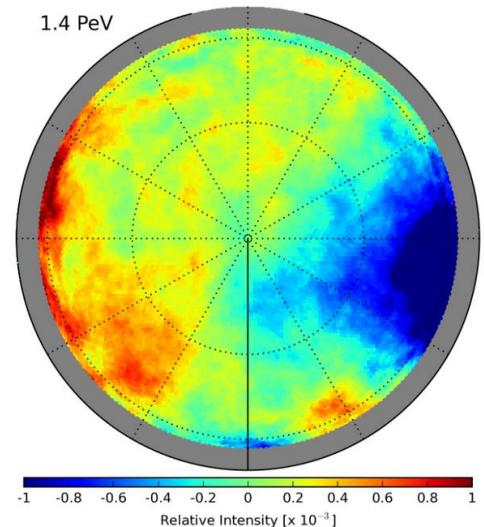
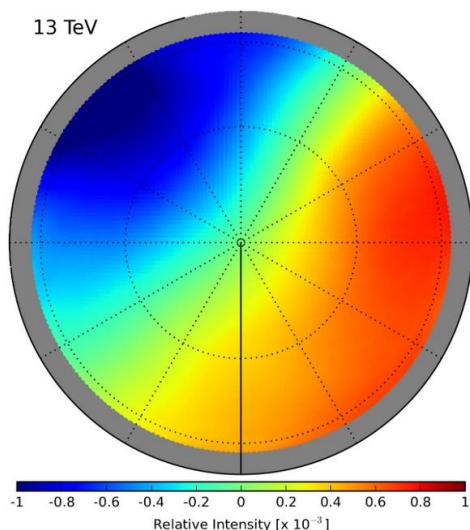
→ Find neutrino point sources in the universe !



AMANDA – ICE CUBE



A very high energy neutrino detected in IceCube on November 12, 2010, with an energy of 71 TeV.
Image: IceCube Collaboration



Animation by Jenny Alvin & Anna Byström
In co-operation with Svenska Diagnoseteknik

START AGAIN

Detector Design

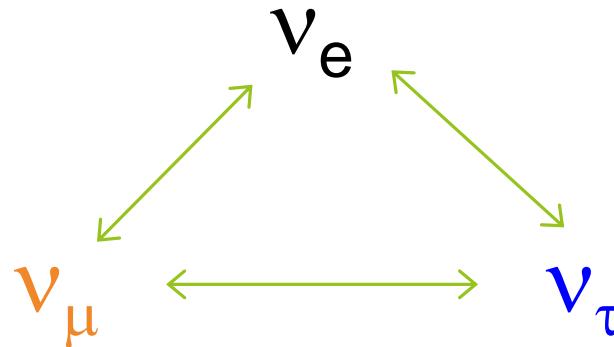
- 1 gigaton of instrumented ice
- 5,160 light sensors, or digital optical modules (DOMs), digitize and time-stamp signals
- 1 square kilometer surface array, IceTop, with 324 DOMs
- 2 nanosecond time resolution
- IceCube Lab (ICL) houses data processing and storage and sends 100 GB of data north by satellite daily

CERN Neutrino Gran Sasso

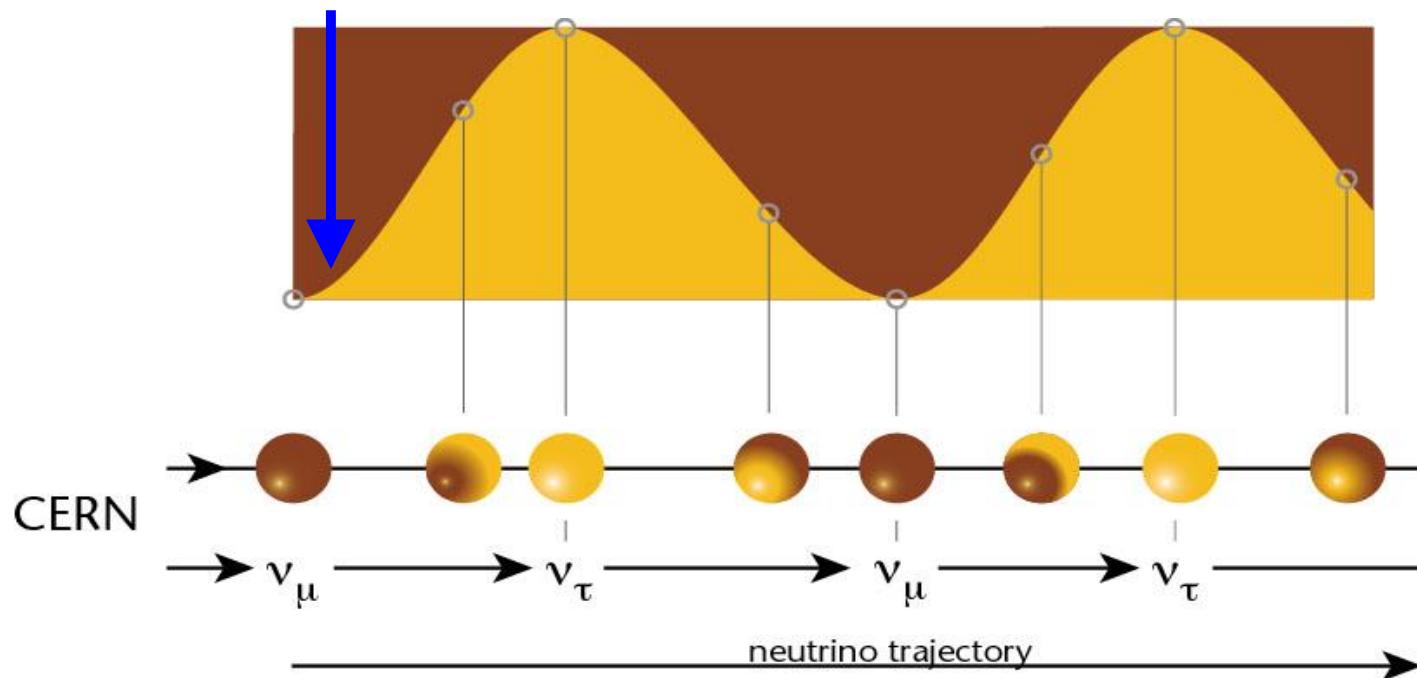
(CNGS)



If neutrinos have mass:



Muon neutrinos produced at CERN.
See if tau neutrinos arrive in Italy.



CNGS PROJECT



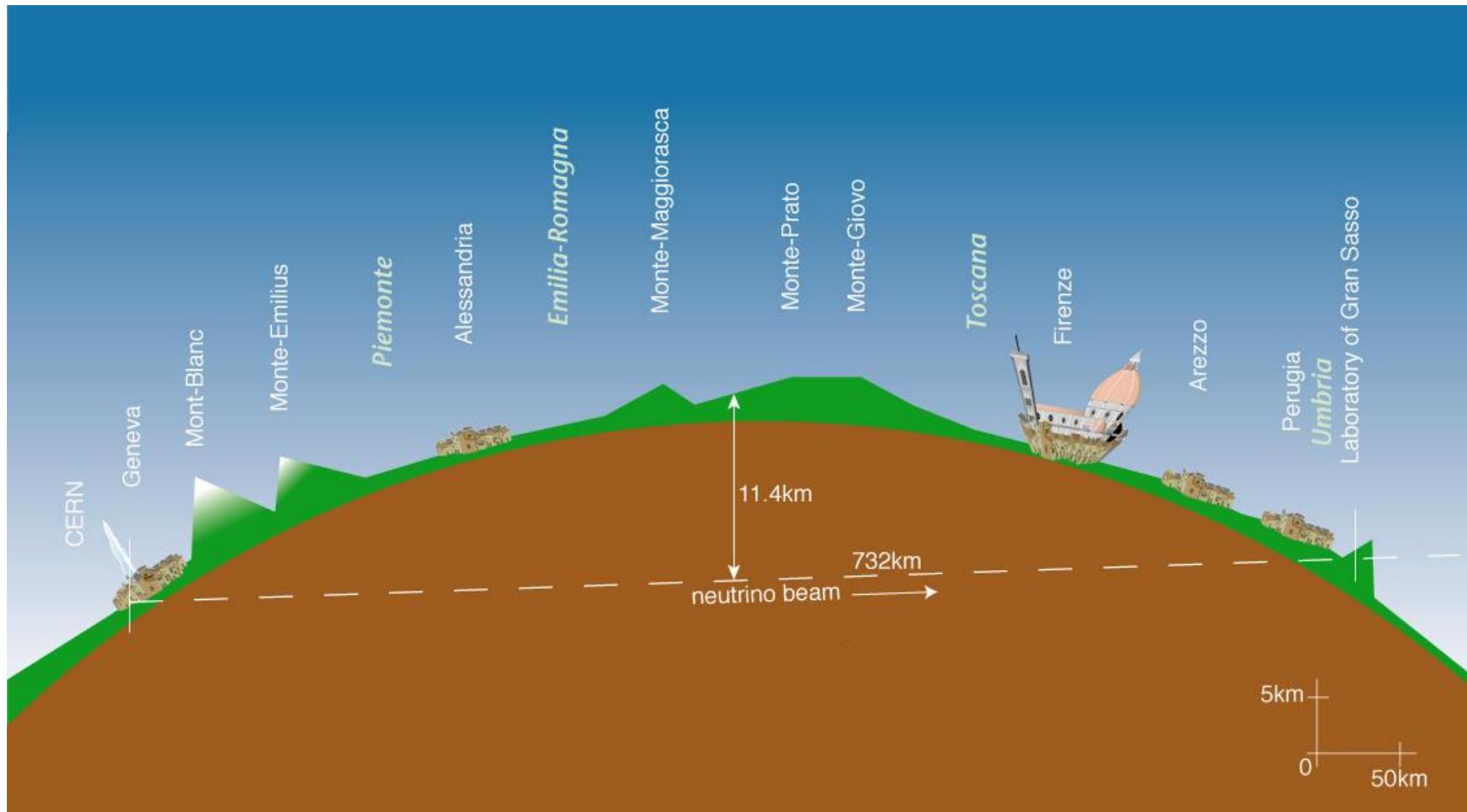
CNGS (CERN NEUTRINO GRAN SASSO)

- A LONG BASE-LINE NEUTRINO BEAM FACILITY (732KM)
- SEND N_M BEAM PRODUCED AT CERN
- DETECT N_T APPEARANCE IN OPERA EXPERIMENT AT GRAN SASSO

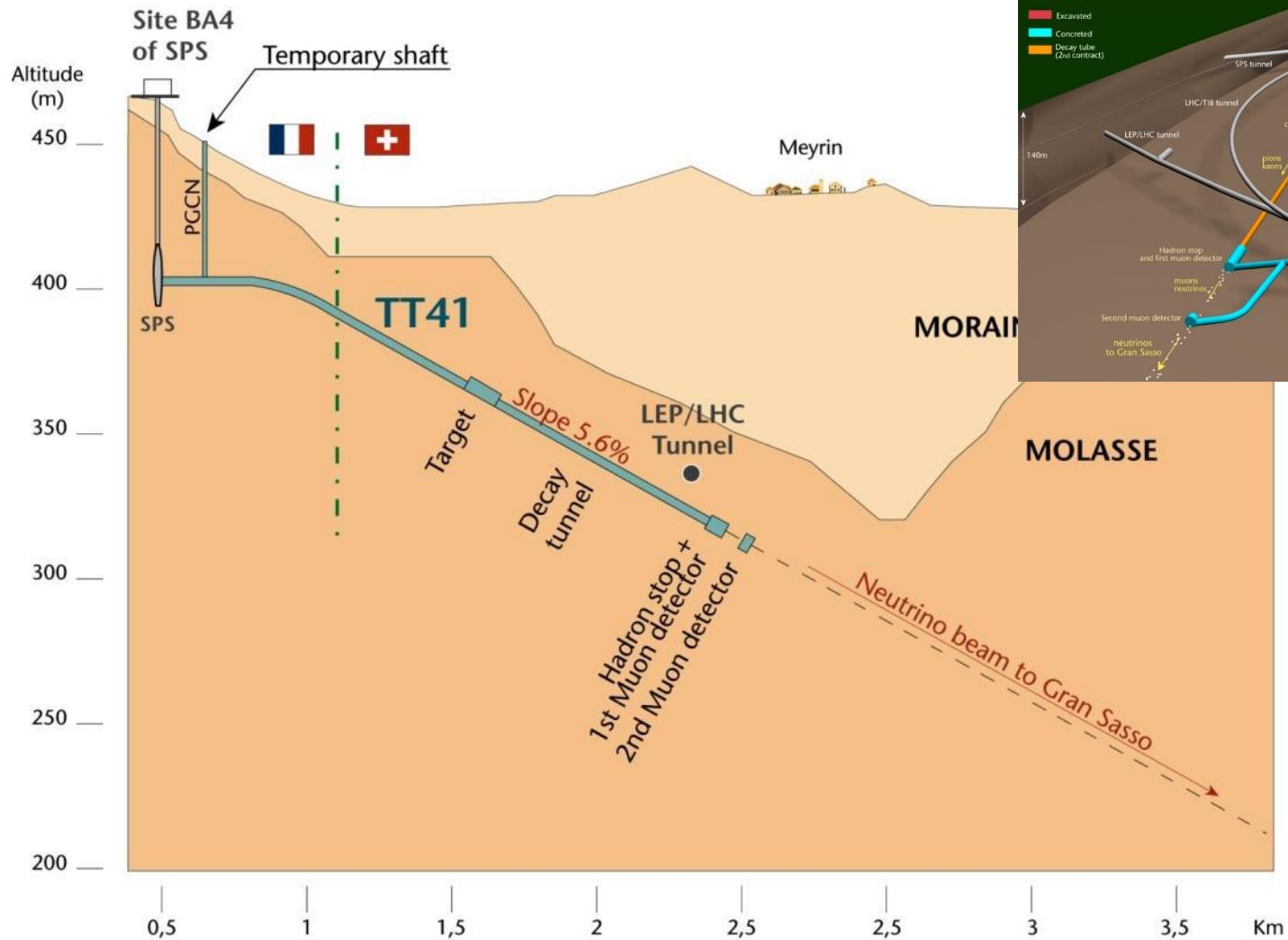


→ direct proof of $\nu_\mu - \nu_\tau$ oscillation (appearance experiment)

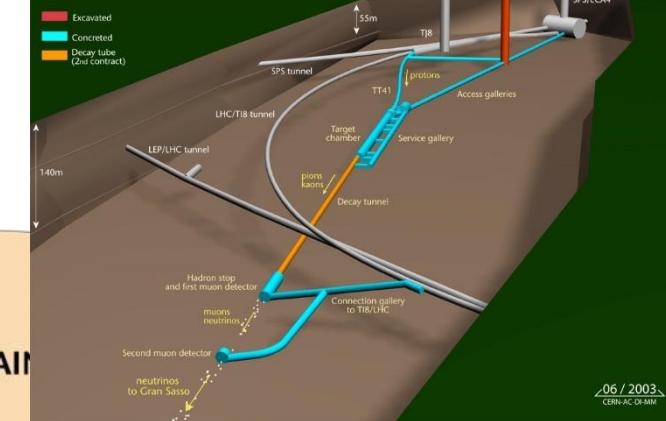
CNGS



CNGS



CERN NEUTRINOS TO GRAN SASSO
Underground structure





For 1 day of CNGS operation, we expect:

protons on target 2×10^{17}

pions / kaons at entrance to decay tunnel 3×10^{17}

ν_μ in direction of Gran Sasso 10^{17}

ν_μ in 100 m^2 at Gran Sasso 3×10^{12}

ν_μ events per day in OPERA ≈ 25 per day

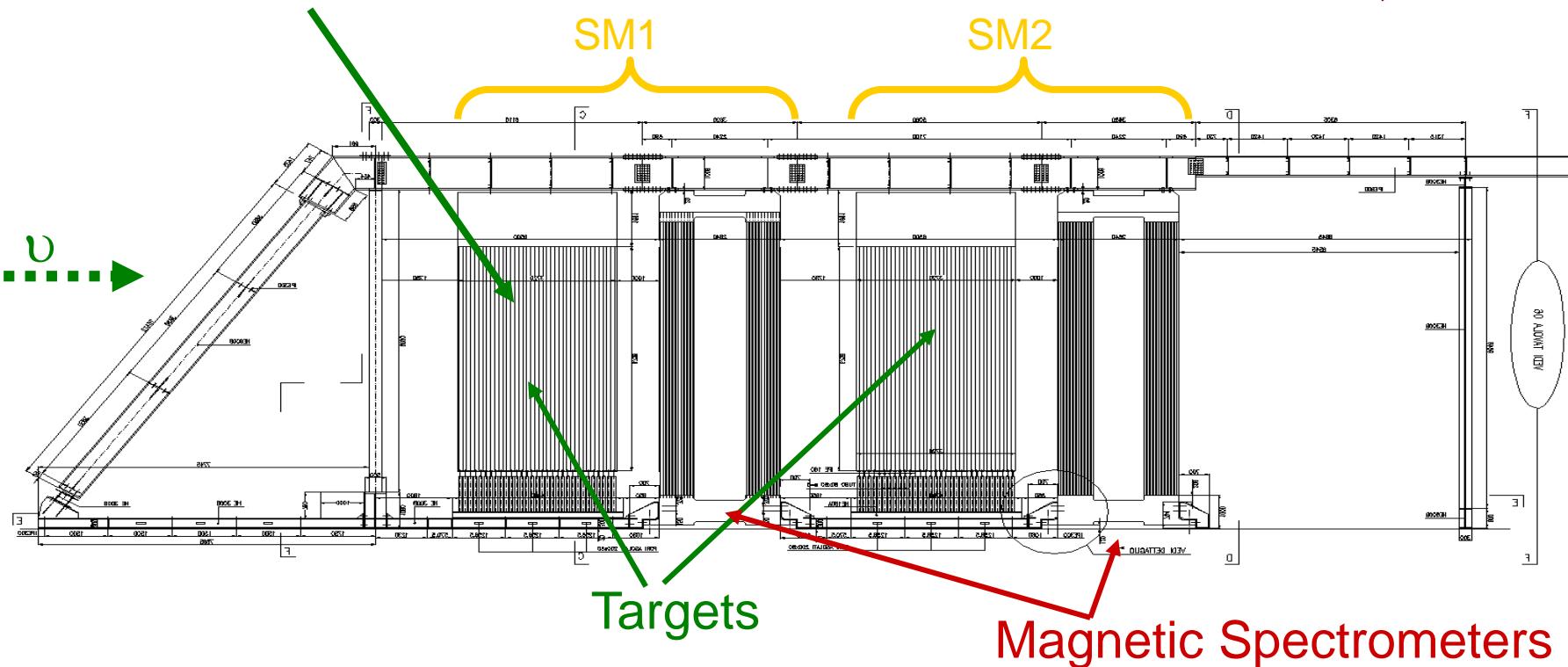
ν_τ events (from oscillation) ≈ 2 per year

Opera Experiment at Gran Sasso



31 target planes / supermodule

In total: 206336 bricks, 1766 tons



First observation of CNGS beam neutrinos : August 18th, 2006

Opera Experiment at Gran Sasso

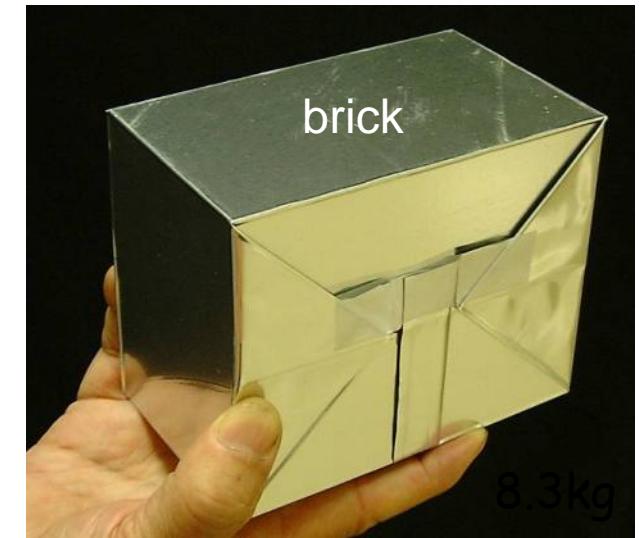
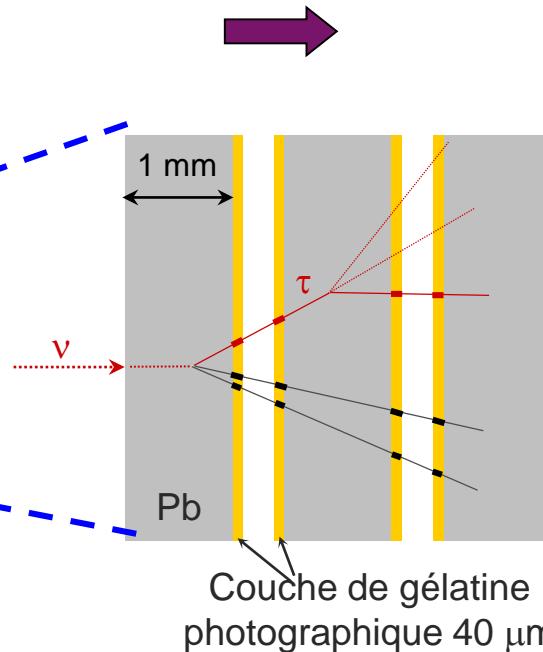
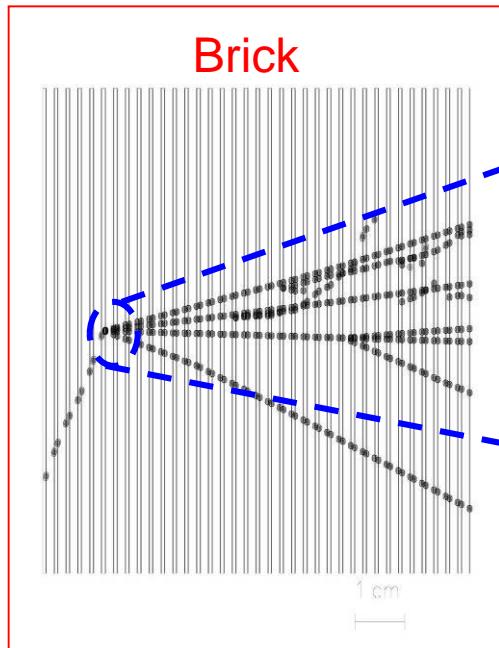


Basic unit: brick

56 Pb sheets + 56 photographic films (emulsion sheets)

Lead plates: massive target

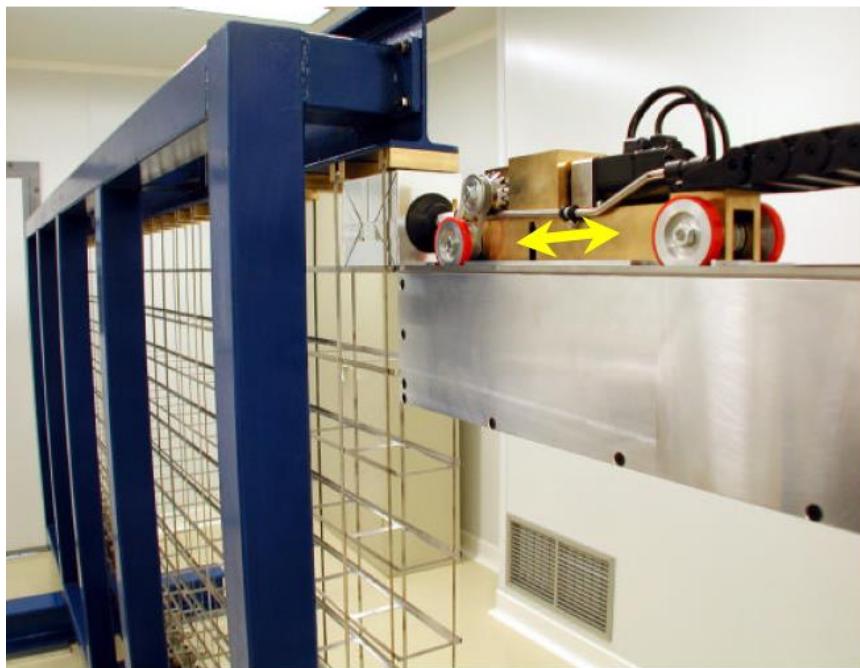
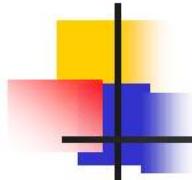
Emulsions: micrometric precision



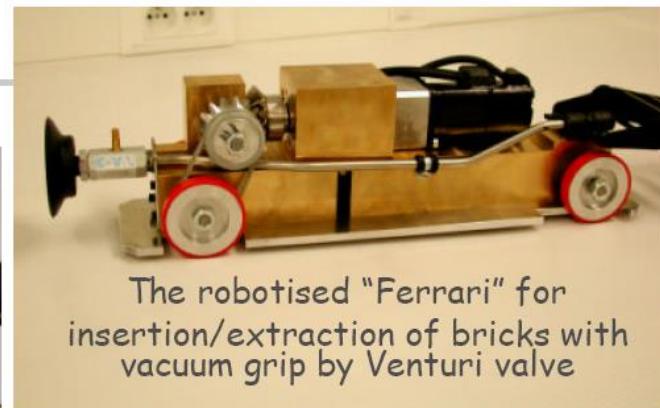
Opera Experiment at Gran Sasso



The Brick Manipulator System (BMS) prototype:
a lot of fun for children and adults !



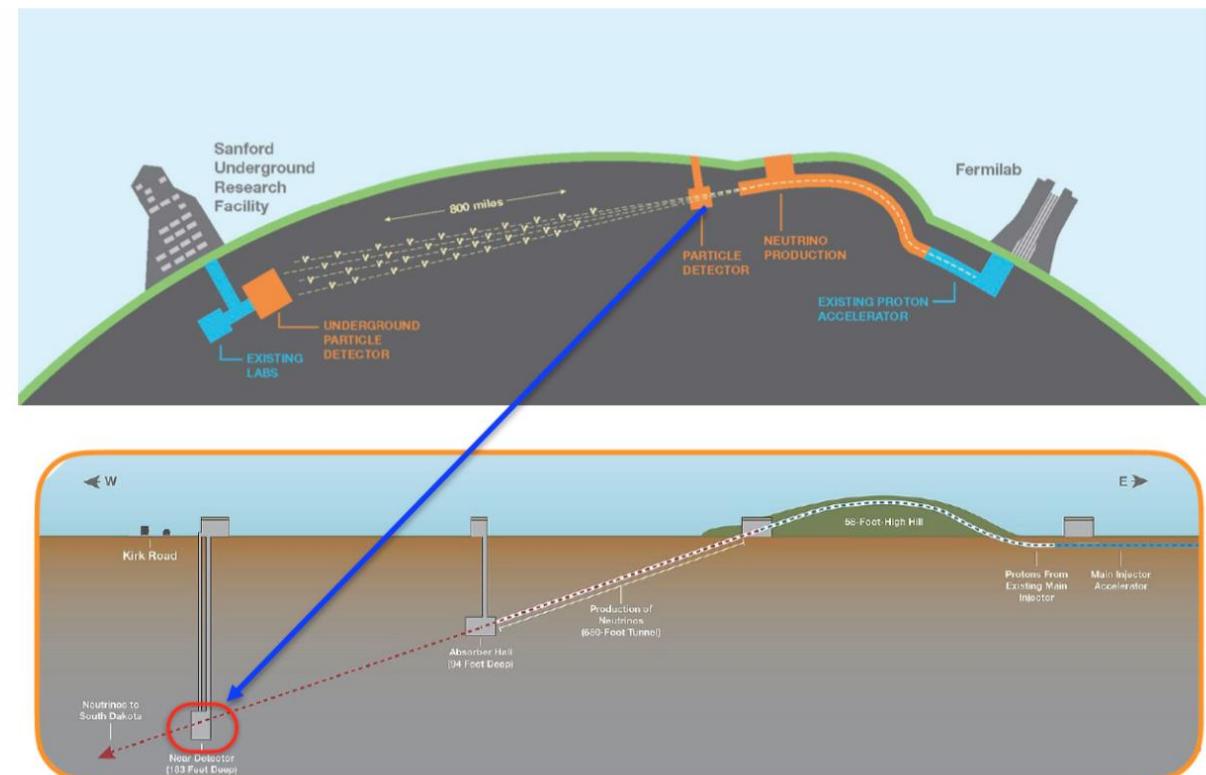
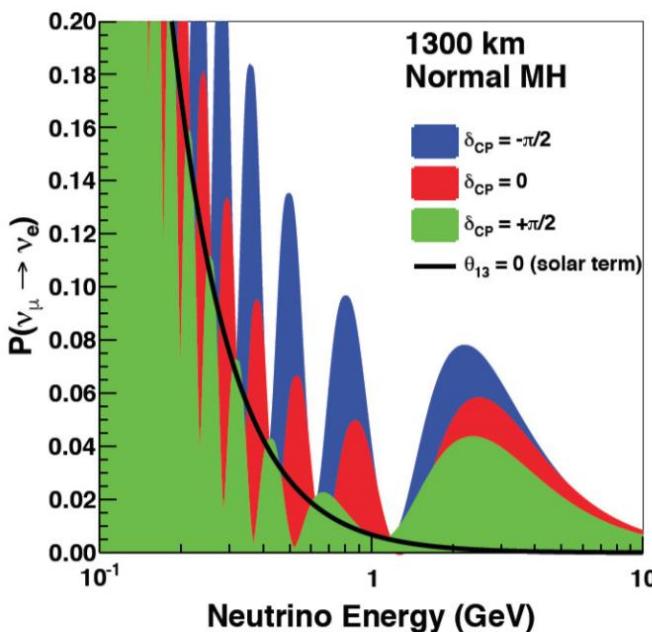
Tests with the prototype wall



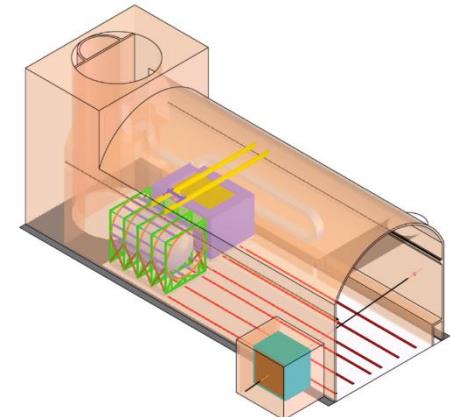
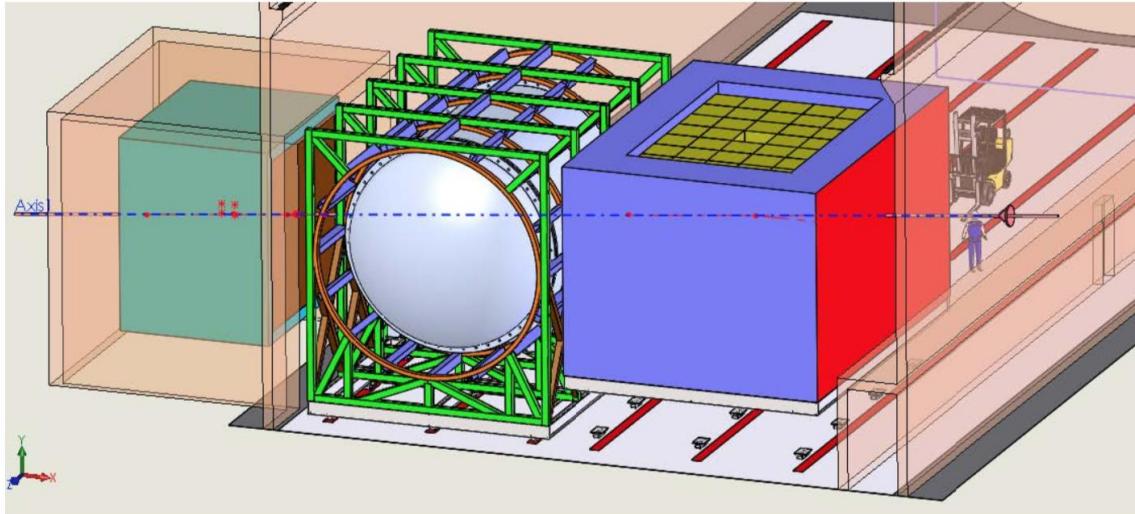
DUNE



- Observe ν_e appearance and ν_μ disappearance at long baseline in a wideband beam to precisely measure the neutrino oscillation parameters δ_{CP} , θ_{23} , θ_{13} , and Δm^2_{32} in a single experiment.



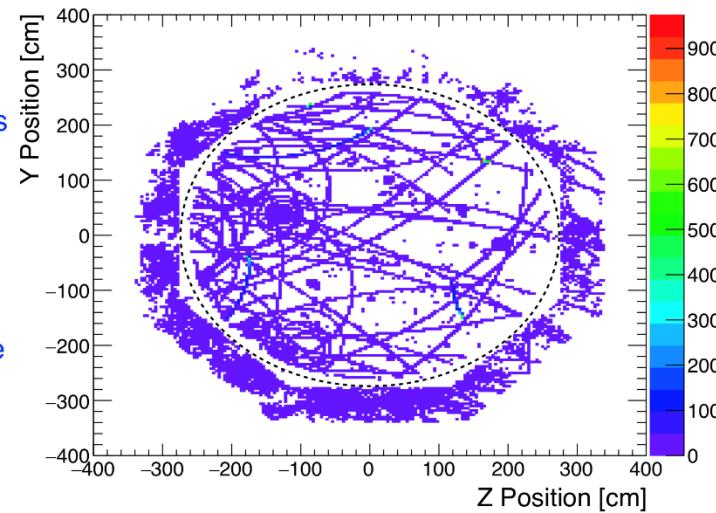
Reference Design



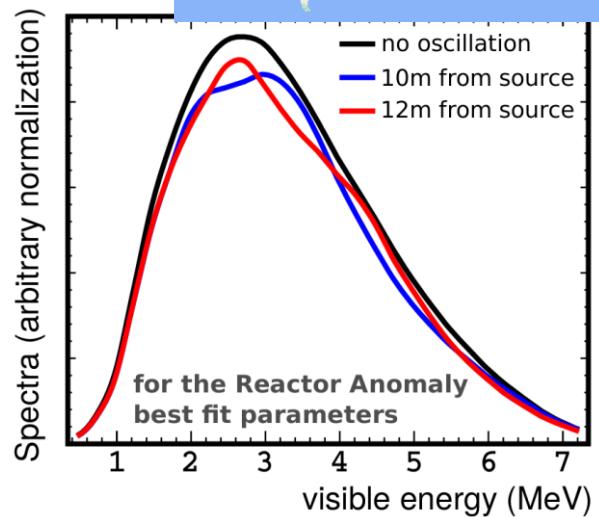
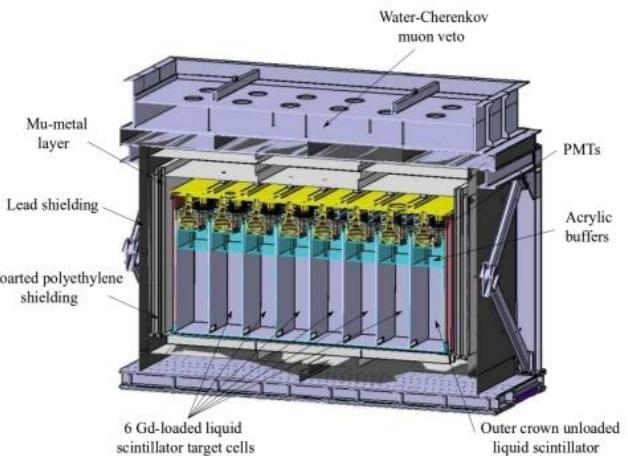
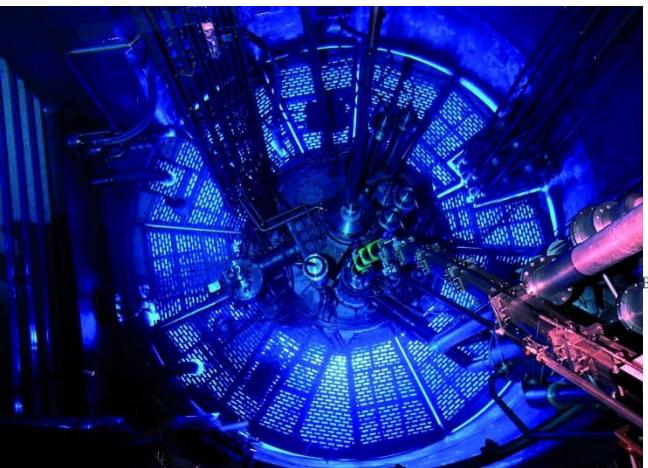
- 3 components (Right-to-left)
 - LAr TPC with pixelated readout (50t)
 - Multi-Purpose Detector - MPD
 - HPgTPC(1t) + ECAL + magnet
 - 3DST-S: Three-Dimensional Scintillator Track

Z-Y projection full spill & event

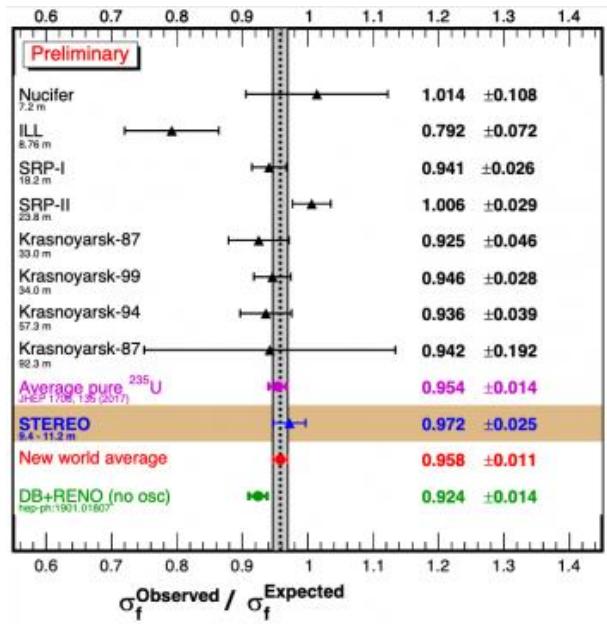
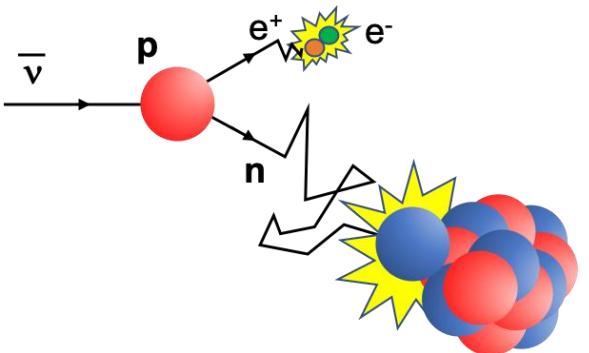
- Corresponds to full spill exposure
- Overlay of test event plus 60 events in the ECAL



STEREO a ILL



The reactor antineutrino anomaly (RAA) is the observation that the neutrino flux measured in many experiments close to nuclear reactors is significantly (more than 6%) lower than one would expect by theory.



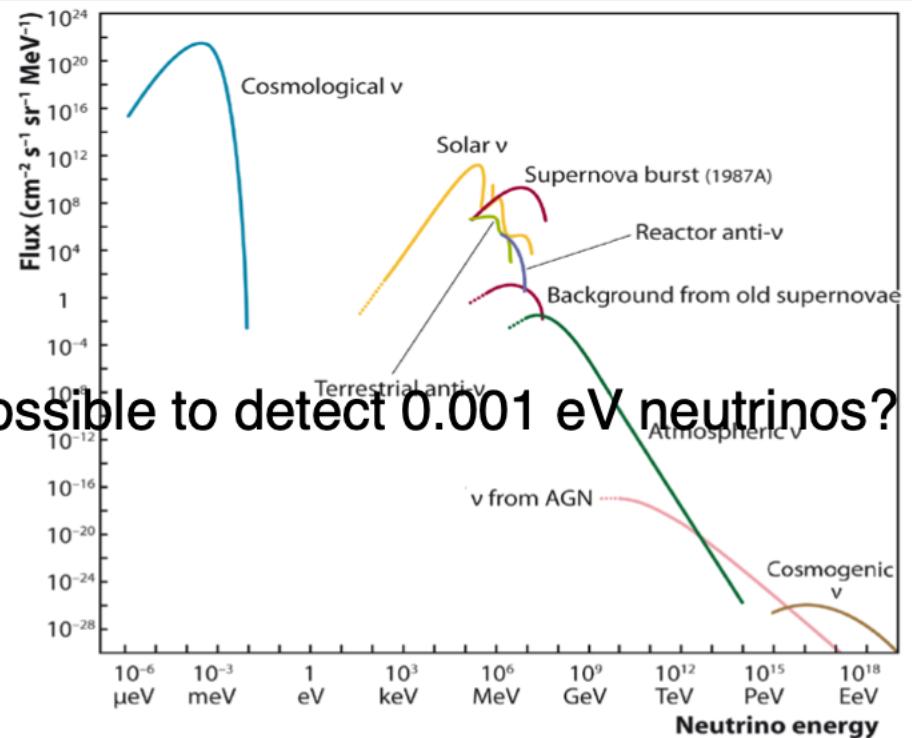


Neutrino flow

$$T \approx 1.9 \text{ K} \Rightarrow p_\nu \approx 0.001 \text{ eV}$$

$$n \approx 56 \text{ cm}^{-3} \times 6$$

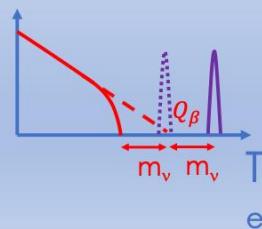
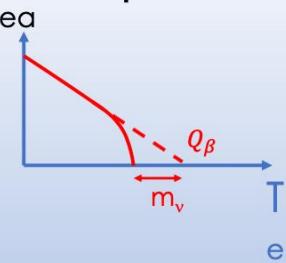
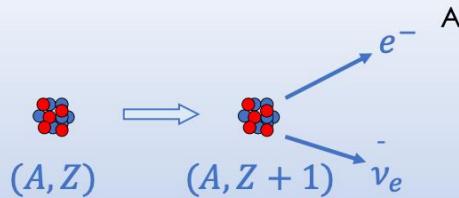
Is it possible to detect 0.001 eV neutrinos?



PTOLEMY

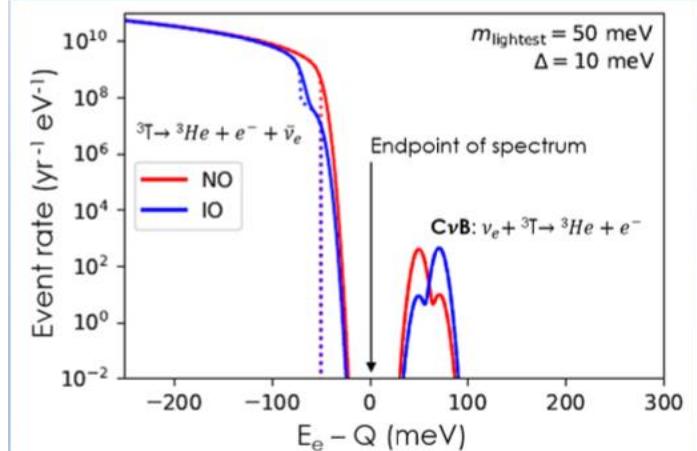


Detection principle

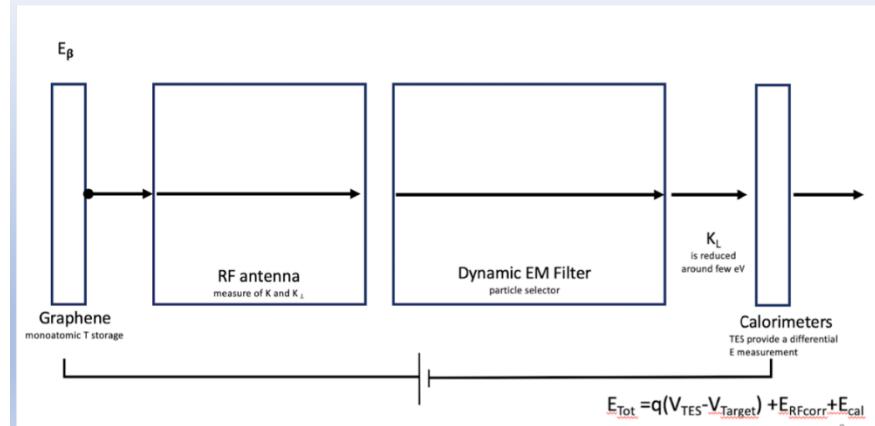


A.G.Cocco, G.Mangano and M.Messina JCAP 06(2007) 015

5

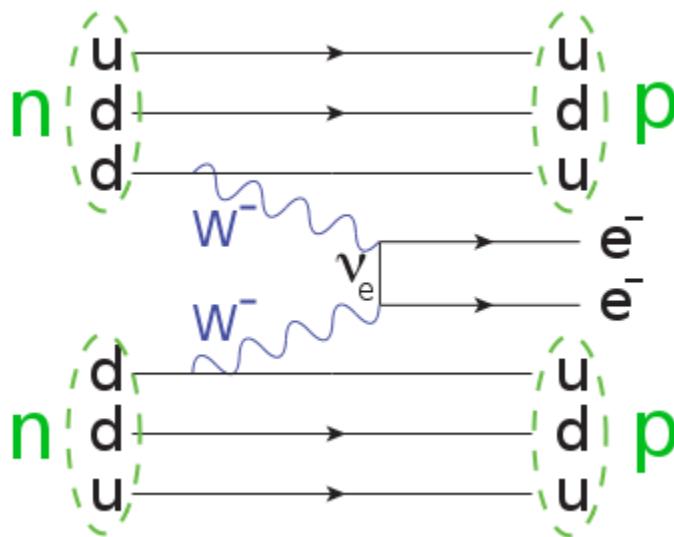


PTOLEMY: experiment layout



124

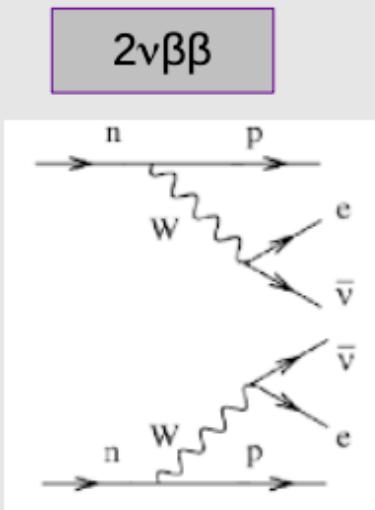
DOUBLE BETA DECAY



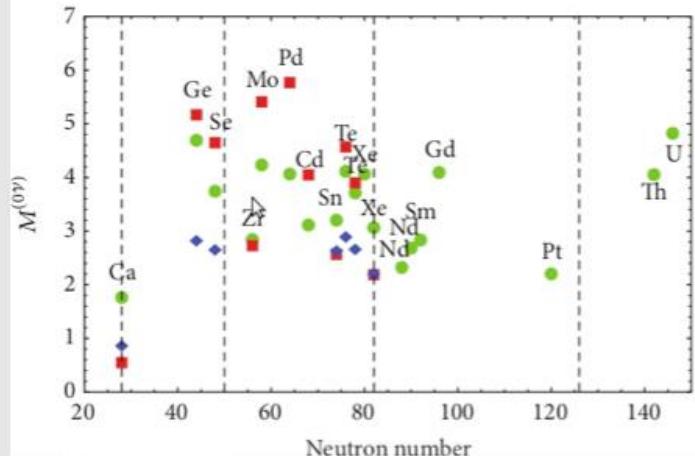
$0\nu\beta\beta$ of ^{136}Xe : $^{136}Xe \rightarrow ^{136}Ba + 2e^-$



Double beta decay



Nuclear matrix elements (NME) via theory.



Experiment	Isotope	Technique	Main Strength
CUORE (LNGS)	130Te	Bolometers	Resolution, Efficiency
GERDA II (LNGS)	76Ge	Ge Diodes	Resolution, Efficiency
KamLANDZen (Kamioka)	136Xe	Xe Liquid scintillation	Background, efficiency
MAJORANA (SURF)	76Ge	Ge Diodes	Resolution, Efficiency
NEXT (LSC)	136Xe	Tracking + Calorimetry	Background Rejection, Efficiency
SNO+ (SNOLAB)	130Te	Te Liquid Scintillation	Background, Mass
SUPERNEMO (LSM)	82Se, 150Nd	Tracking + Calorimetry	Background Rejection, Isotope Selection
1TGe (GERDA+MJ)	76Ge	Best technology from GERDA, MAJORANA	Resolution, Efficiency
CUPID	130Te	Hybrid bolometers	Background, Resolution
nEXO (WIPP)	136Xe	TPC Ionization + Scintillation	Mass, Efficiency, Final State Signal
AMORE (Y2L)	100Mo	CaMoO ₄ bolometers	Resolution
CANDLES (Kamioka)	48Ca	CaF ₂ Scintillation	Background, Efficiency
COBRA (LNGS)	130Te, 116Cd	ZnCdTe Semiconductors	Resolution, Efficiency
LUCIFER (LNGS)	82Se	ZnSe bolometers	Resolution, Background
MOON (UW)	100Mo	Tracking + Scintillation	Compactness, Background

On-going or commissioning few kg

R&D -tonne

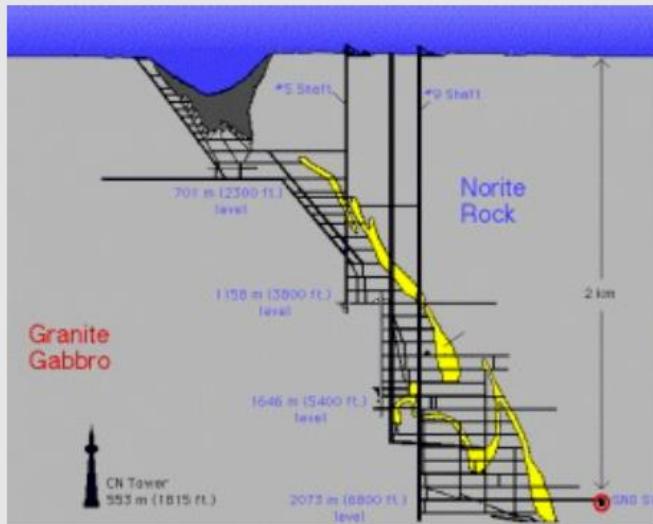
R&D further

SNO



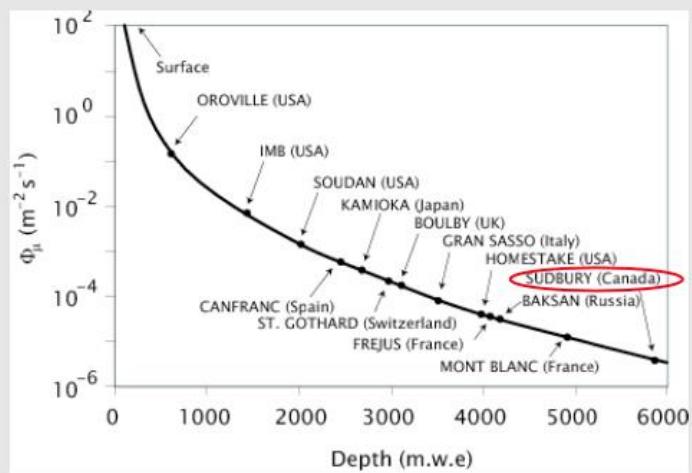
The SNO+ Experiment

3.- Ti



- Located at SNOLAB inside the Creighton mine near Sudbury, Canada.
- SNO+ is the successor to Sudbury Neutrino Observatory (SNO).

- Depth = 2070 m (6000 m.w.e.)
- ~60 muons /day in SNO+
- 10,000 sq ft Class-2000 clean room

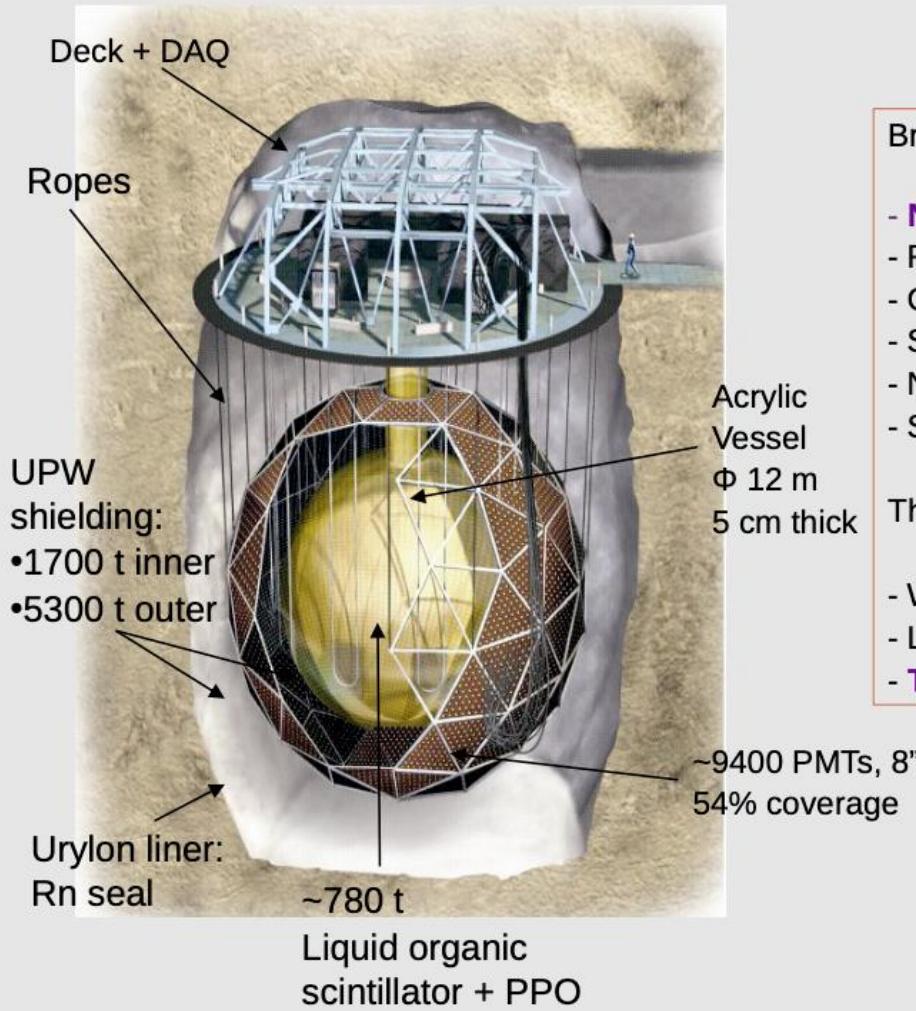


SNO



3.

The SNO+ Detector

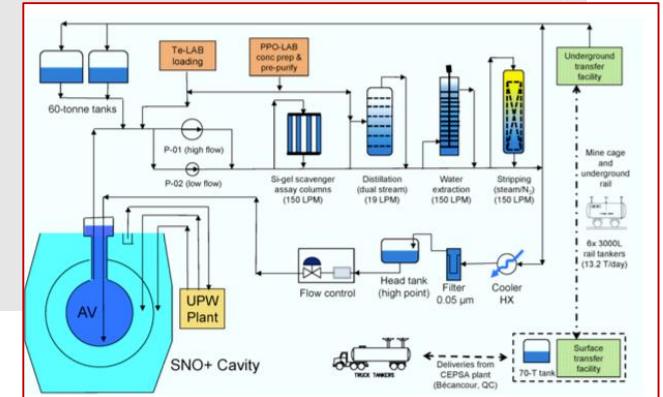


Broad neutrino physics program

- Neutrinoless double beta decay of ^{130}Te
- Reactor anti-neutrinos
- Geo anti-neutrinos
- Supernovae neutrinos
- Nucleon decay and exotic physics
- Solar neutrinos (pep, CNO, low E ^8B)

Three Experimental Phases

- Water-Phase
- Liquid scintillator phase
- Te-loaded liquid scintillator



PandaX

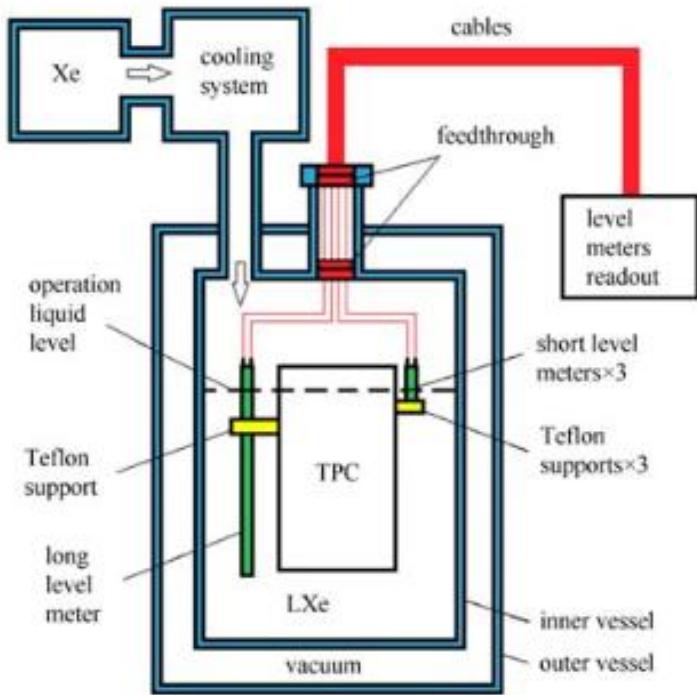
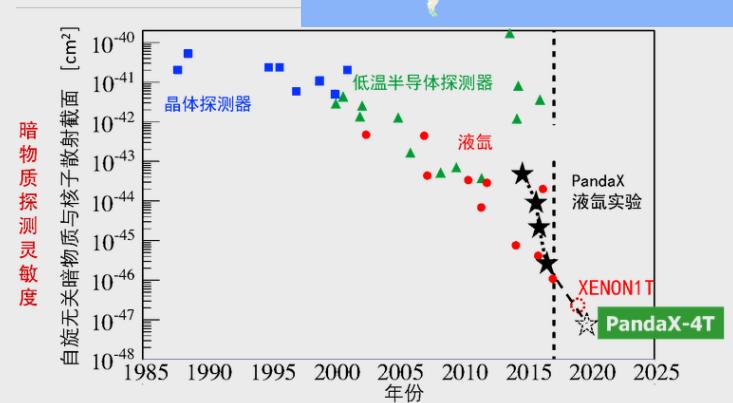
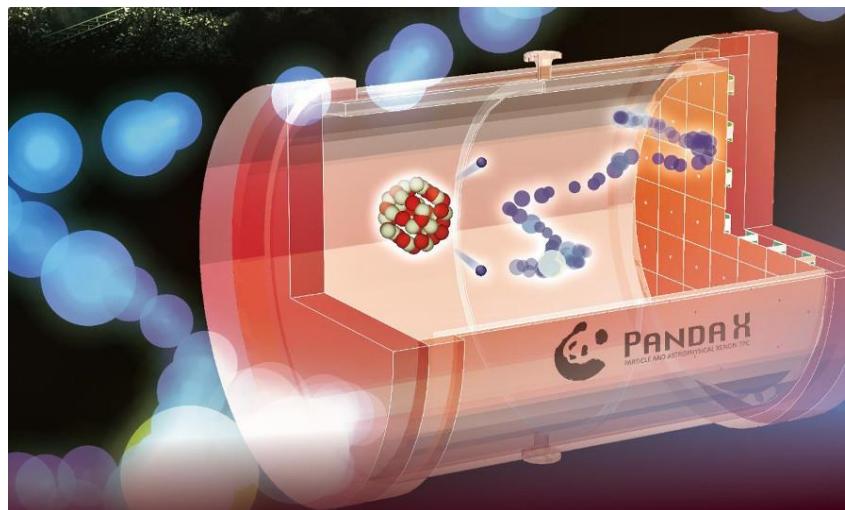


Fig. 1. Schematics of the two-phase xenon detector as used in PandaX. LXe is contained in an inner vessel insulated by vacuum from the outside. One long liquid level meter monitors the overall liquid xenon height and three short level meters monitor the height of the liquid-gas interface around the TPC.



2016年PandaX二期实验（500公斤级液氙）取得了世界领先的暗物质探测灵敏度。在这个基础上，我们进行下一代四吨级液氙探测实验的研发，将暗物质探测灵敏度继续向前推进1-2个数量级。除了暗物质，四吨级液氙实验将能够测量到低能量太阳中微子信号并研究其磁矩等性质。另外，四吨液氙中含有有的放射性同位素¹³⁶Xe有可能进行一种新型的贝塔衰变-无中微子双贝塔衰变模型。该衰变模式的探测将能确定中微子是否为马约拉纳中微子等基本物理问题。



ANTI-MATIERE

The Positive Electron



MARCH 15, 1933

PHYSICAL REVIEW

VOLUME 43

The Positive Electron

CARL D. ANDERSON, *California Institute of Technology, Pasadena, California*

(Received February 28, 1933)

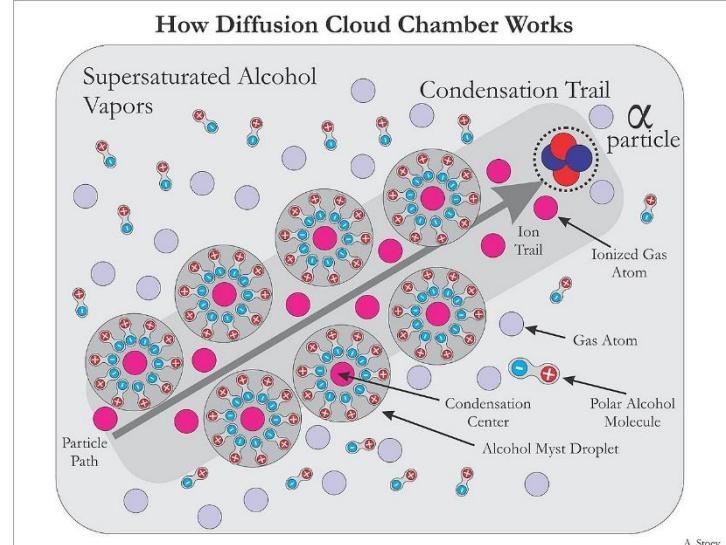
Out of a group of 1300 photographs of cosmic-ray tracks in a vertical Wilson chamber 15 tracks were of positive particles which could not have a mass as great as that of the proton. From an examination of the energy-loss and ionization produced it is concluded that the charge is less than twice, and is probably exactly equal to, that of the proton. If these particles carry unit positive charge the

curvatures and ionizations produced require the mass to be less than twenty times the electron mass. These particles will be called positrons. Because they occur in groups associated with other tracks it is concluded that they must be secondary particles ejected from atomic nuclei.

Editor

1930 : Data taking
1932 : Analysis
1933 : Paper

1.5T Wilson Chamber
Rec. Cosmic Rays
1300 events
15 tracks with e^+



The Positive Electron



492

CARL D. ANDERSON

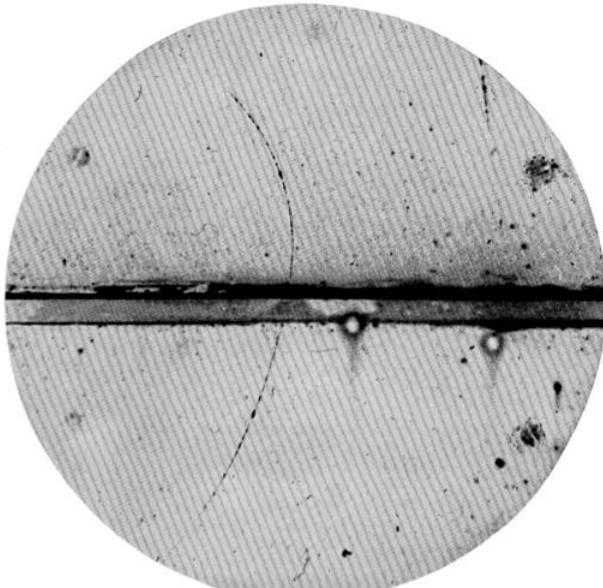


FIG. 1. A 63 million volt positron ($H_D = 2.1 \times 10^5$ gauss-cm) passing through a 6 mm lead plate and emerging as a 23 million volt positron ($H_D = 7.5 \times 10^4$ gauss-cm). The length of this latter path is at least ten times greater than the possible length of a proton path of this curvature.

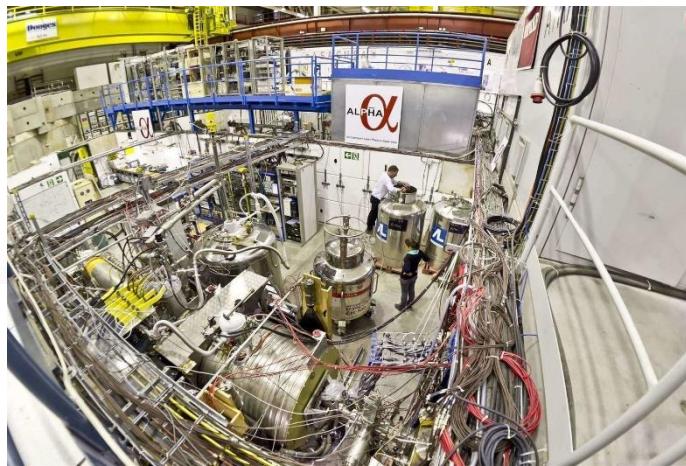
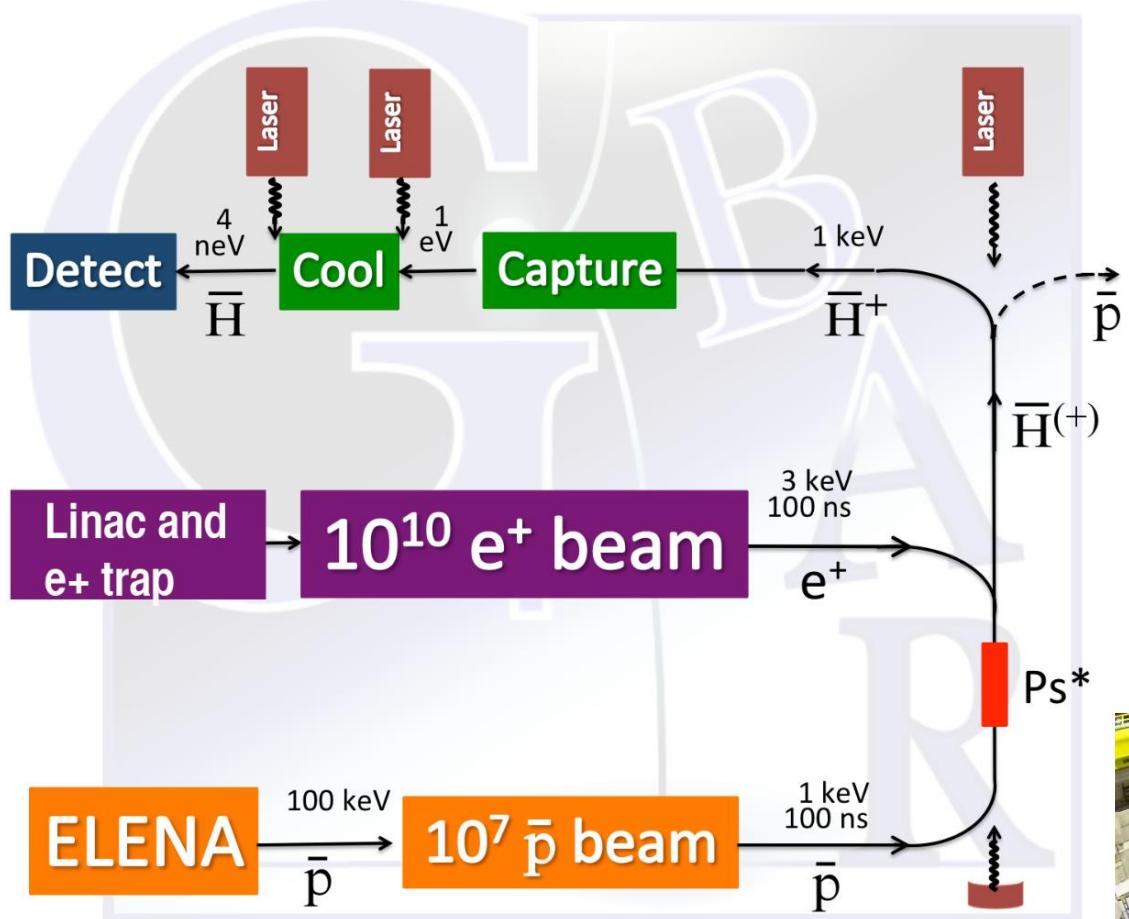
1930 : Data taking
1932 : Analysis
1933 : Paper

1.5T Wilson Chamber
Rec. Cosmic Rays
1300 events
15 tracks with e^+

GBAR at CERN



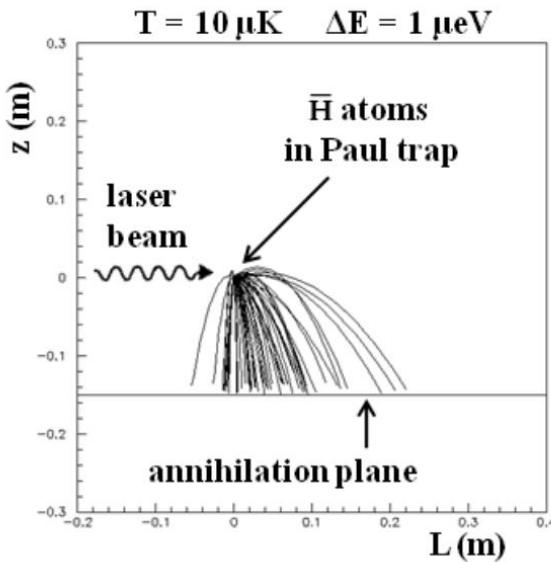
Schematic



GBAR at CERN



Detection



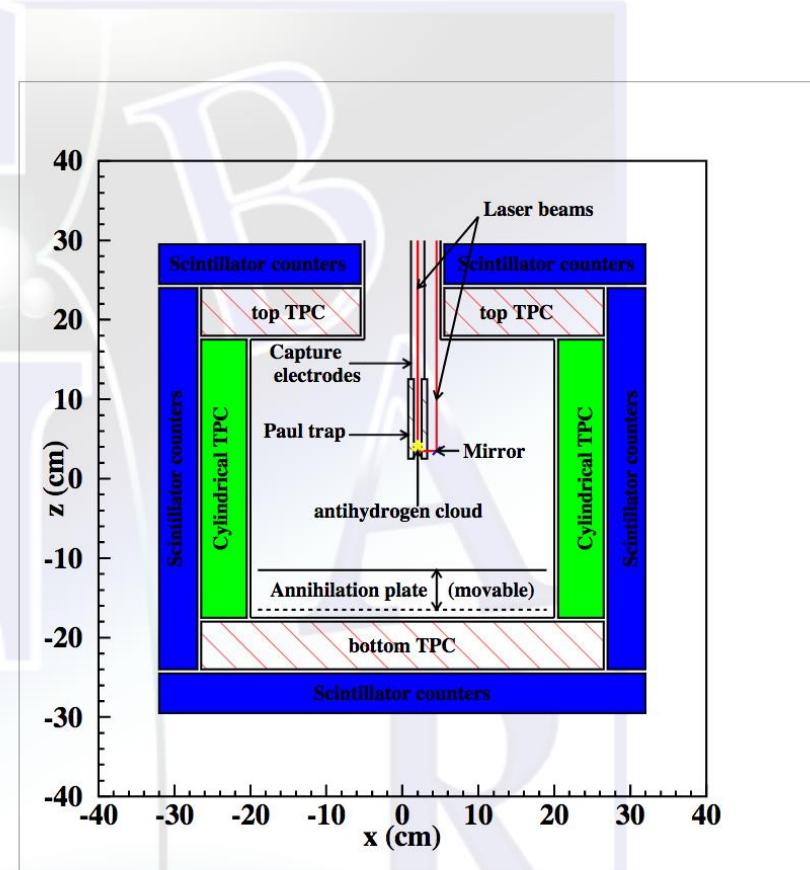
Detection requirement:

TOF precision : $150 \mu\text{s}$

Annihilation vertex precision : 1 mm

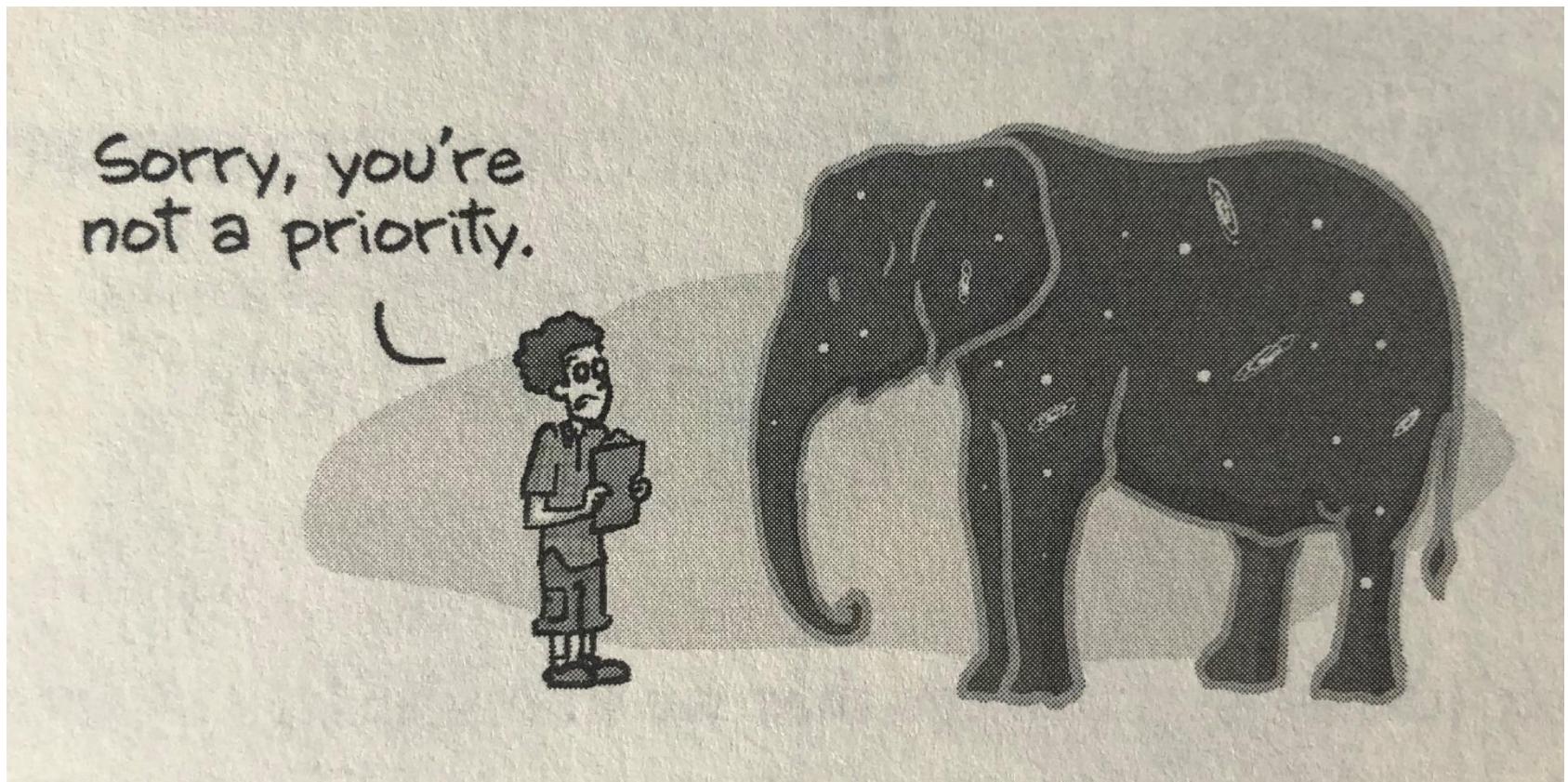
Background rejection through event topology

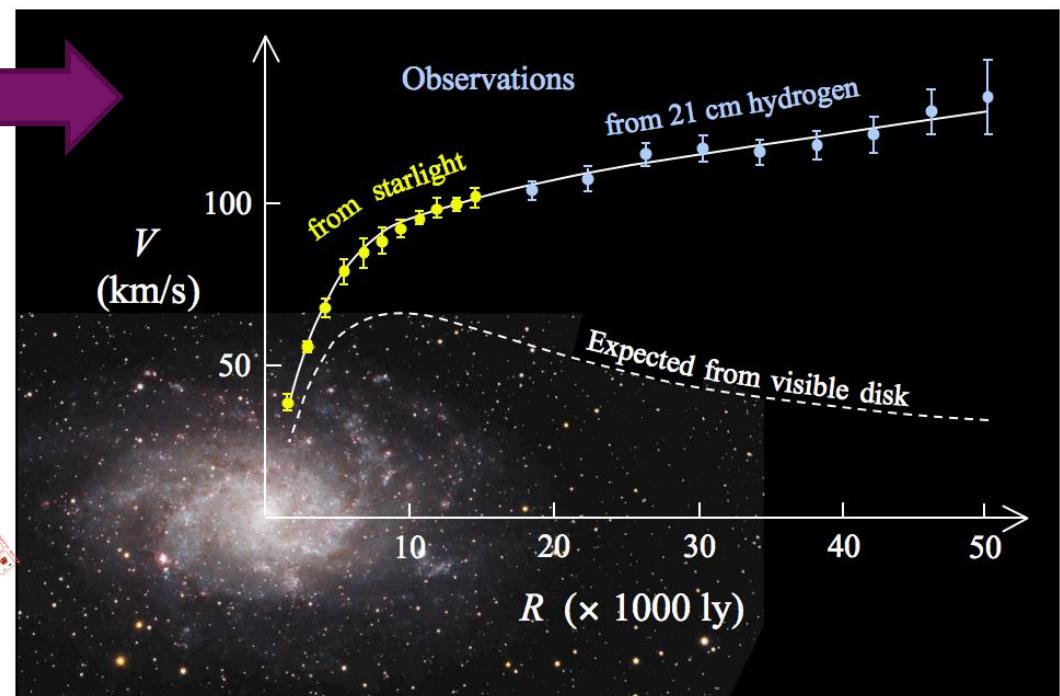
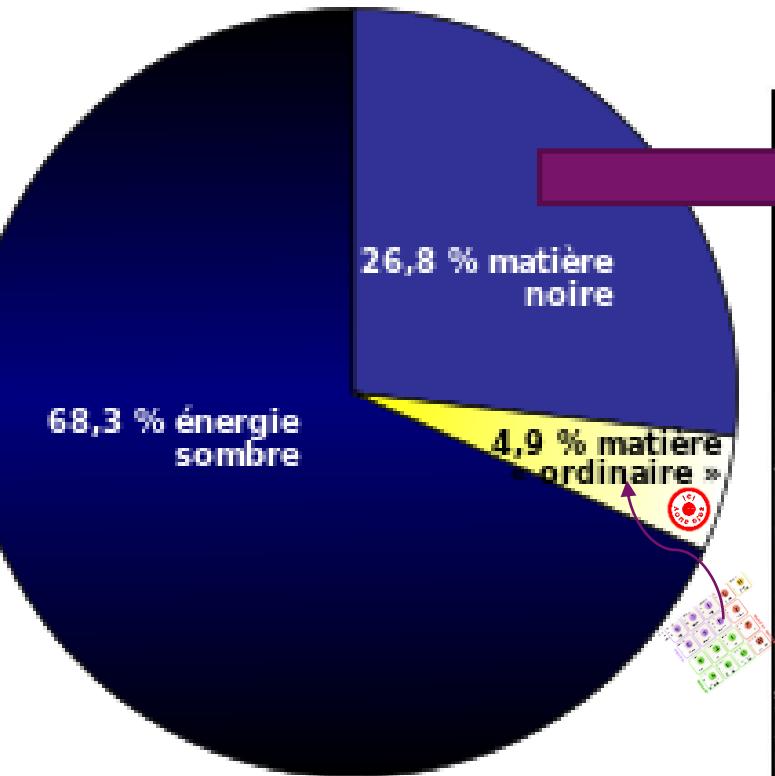
Scheme under design: TPC with micromegas chamber (as in T2K near detector)



$$\frac{\Delta \bar{g}}{\bar{g}} \approx 10^{-2}$$

MATIERE SOMBRE

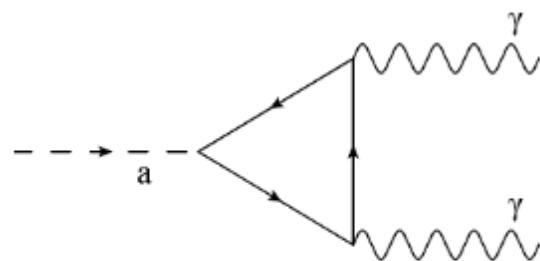
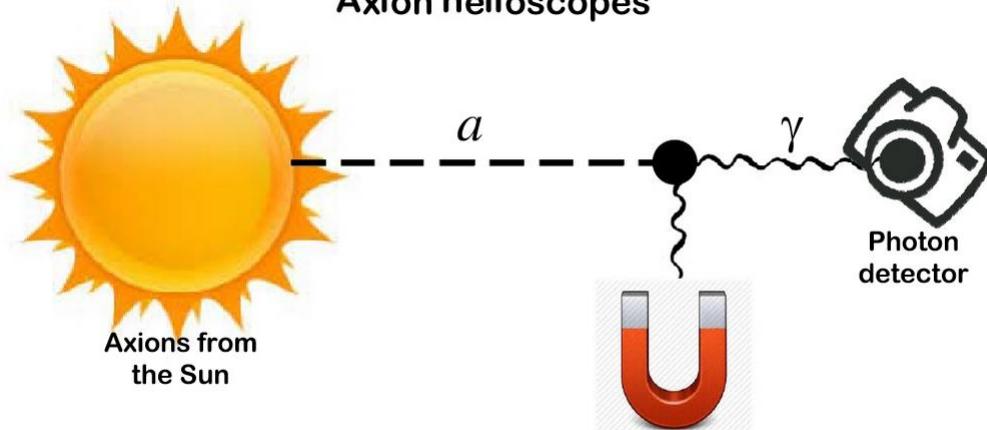




AXIONS



Axion helioscopes



© Igor G. Irastorza

Figure 2: Feynman diagram, associated with the coupling between an axion and two photons.

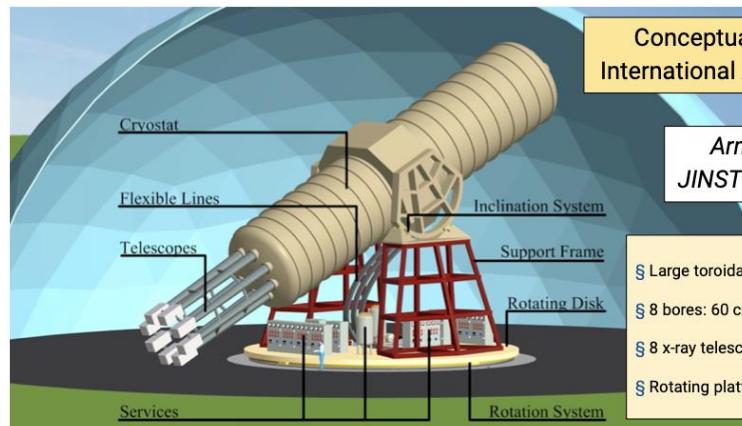
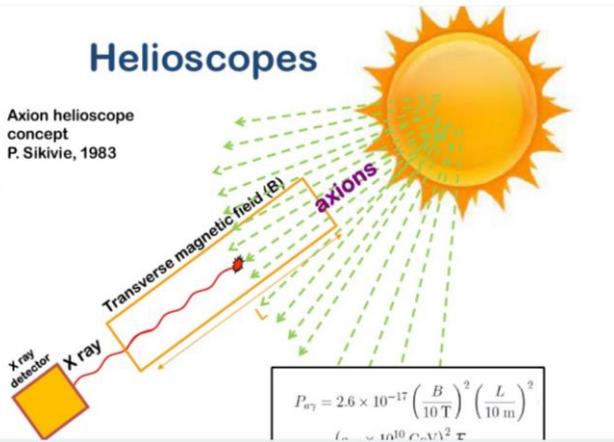
CAST - IAXO



Helioscopes



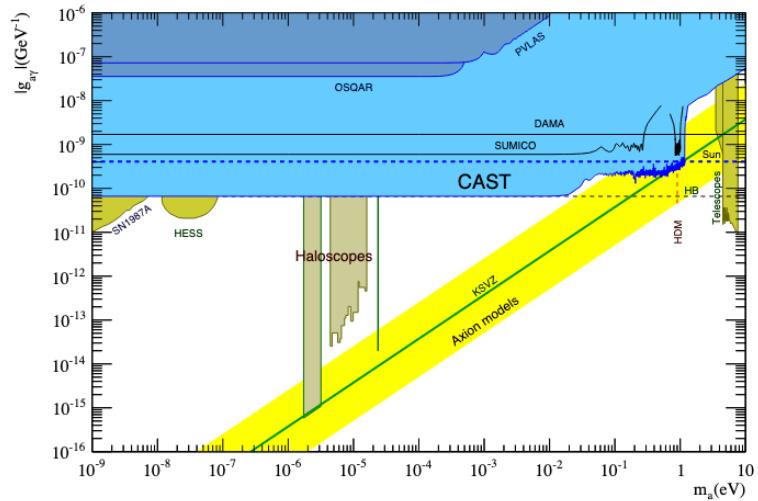
Axion helioscope
concept
P. Sikivie, 1983



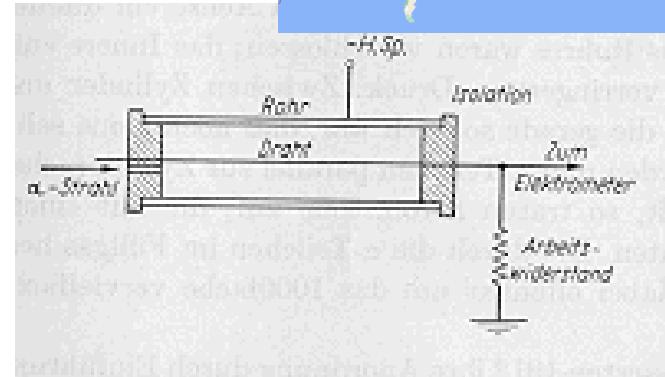
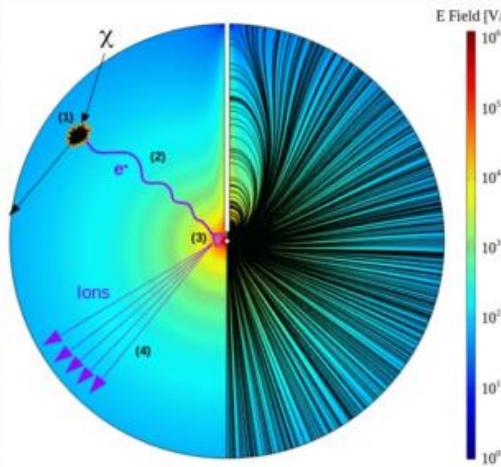
Conceptual Design of the
International Axion Observatory

Armengaud et al.
JINST 9 T05002 (2014)

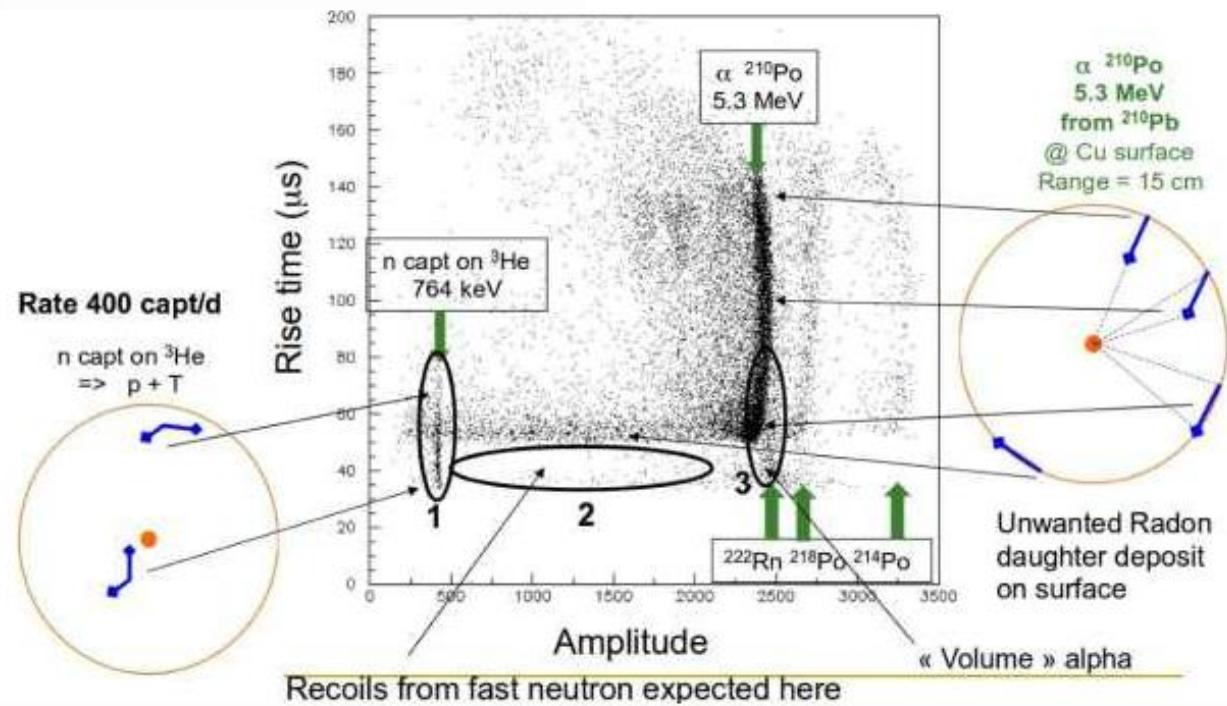
- § Large toroidal 8-coil magnet L = 20 m
- § 8 bores: 60 cm diameter each
- § 8 x-ray telescopes + 8 detection systems
- § Rotating platform with services



NEWS



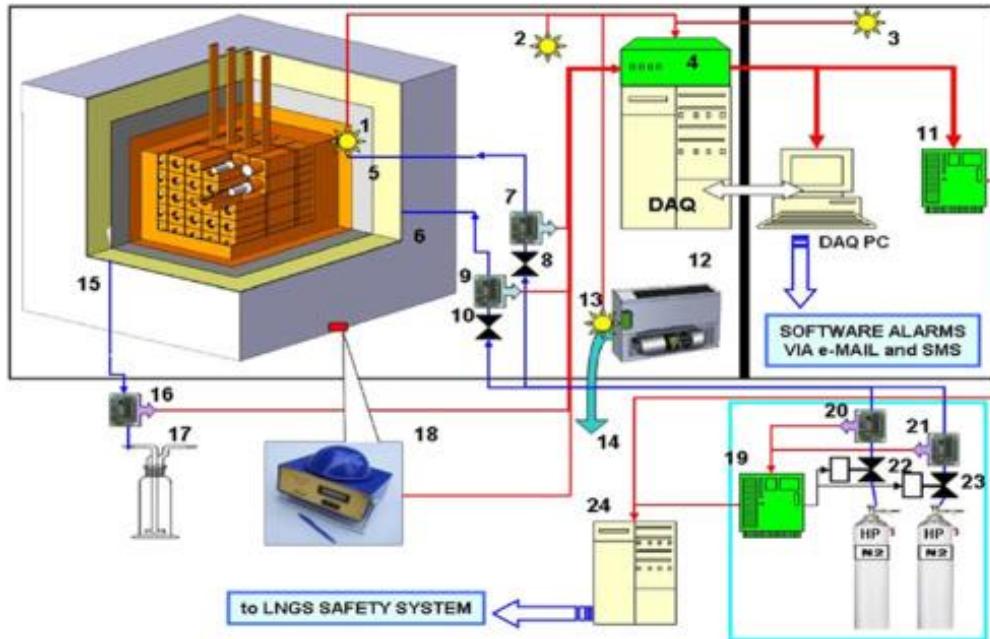
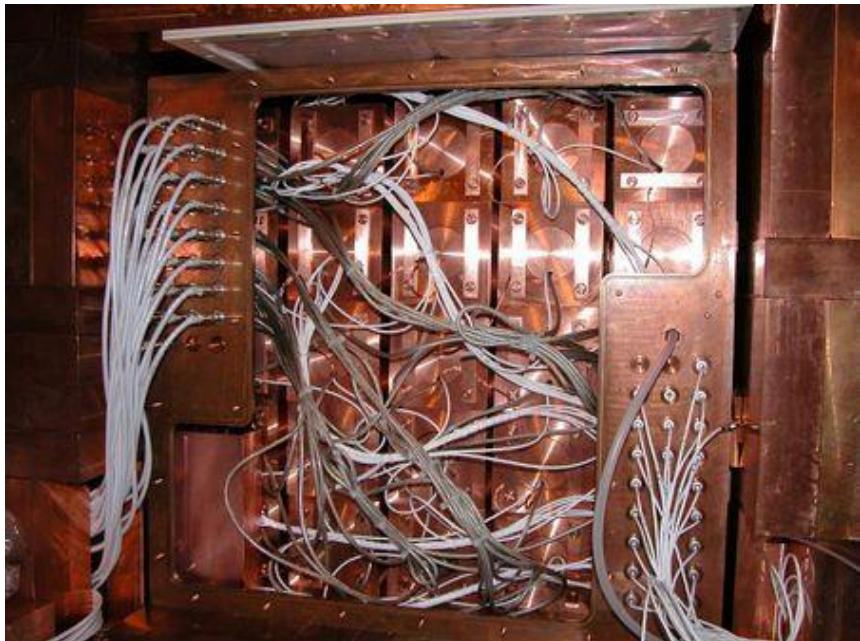
Recul noyau dû aux WIMPs avec threshold la plus basse possible



DAMA / LIBRA



LABORATORI NAZIONALI DEL GRAN SASSO



Thallium-doped sodium detector

DAMA / LIBRA

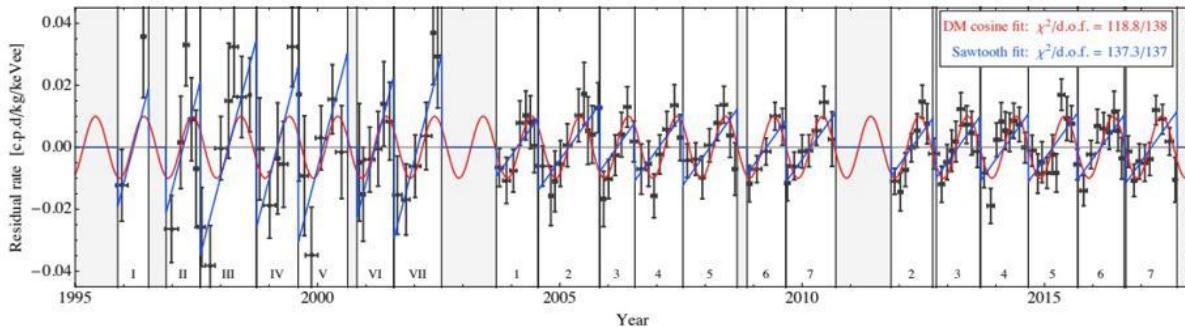
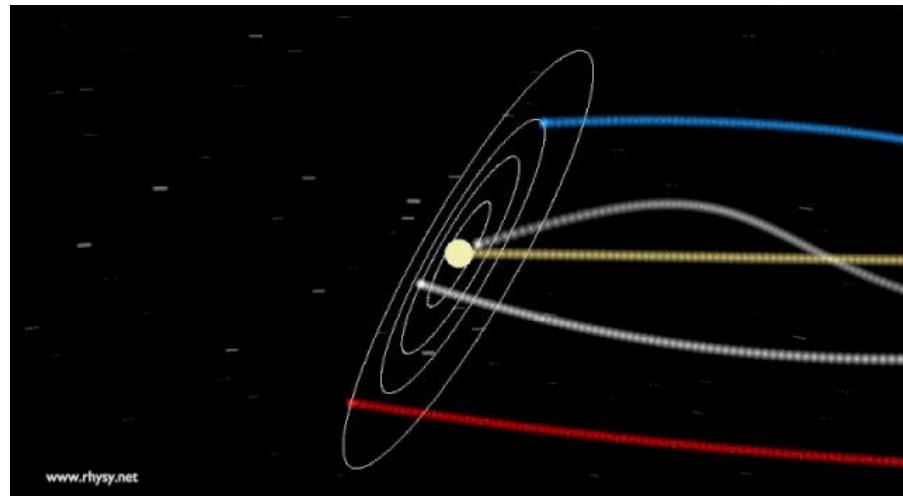
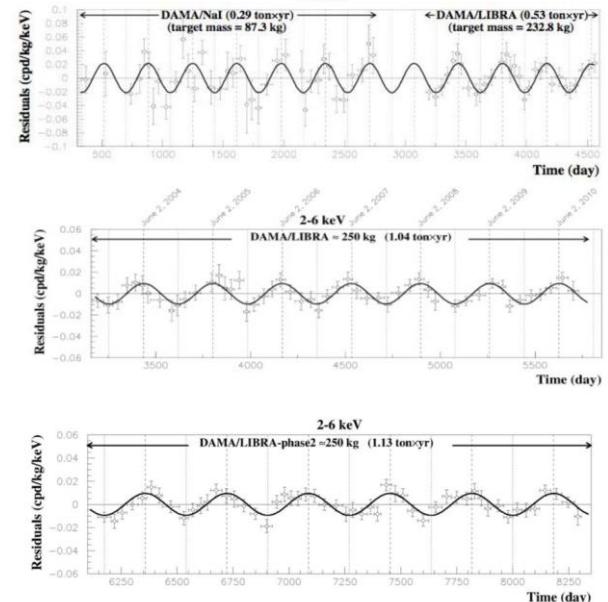


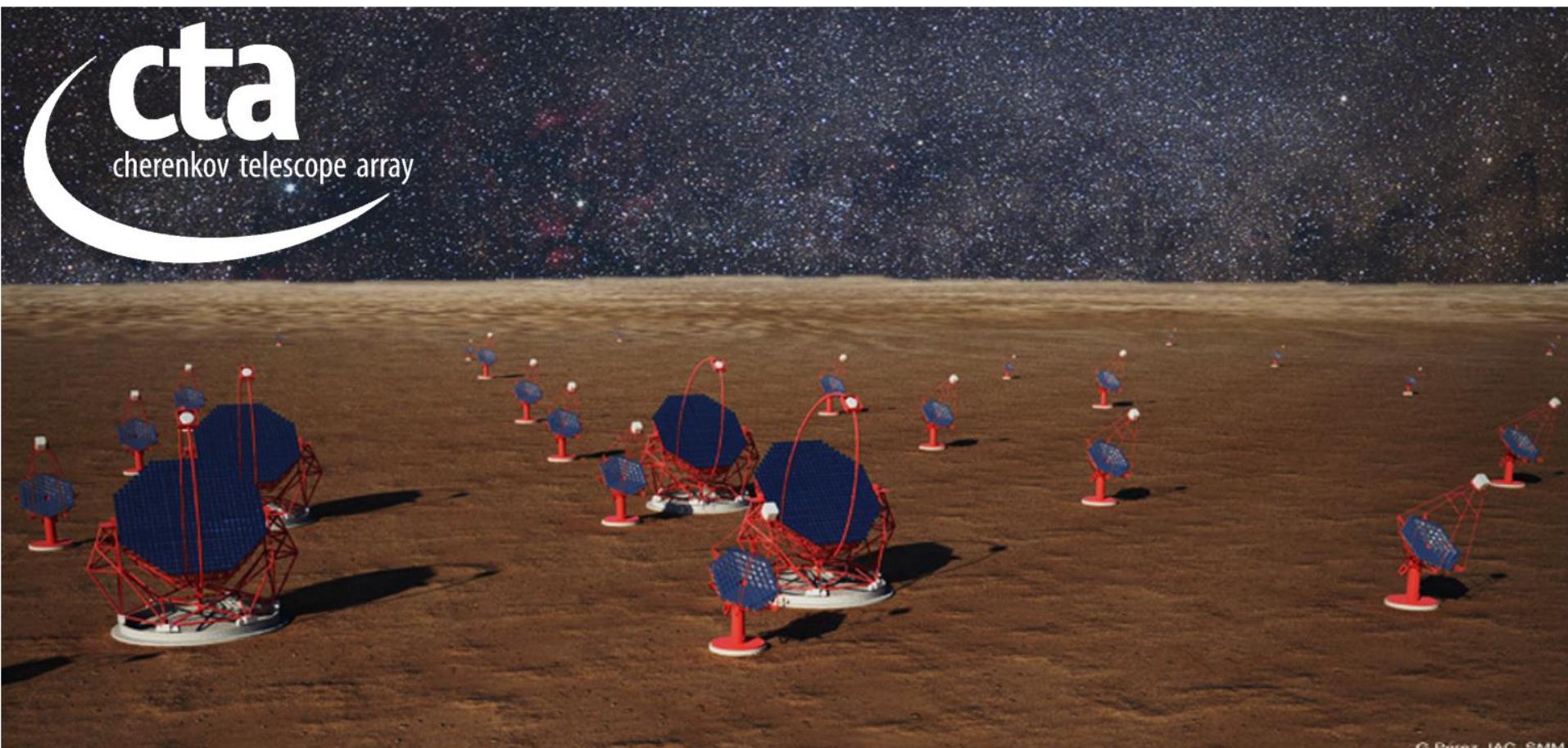
Figure 5. The black data points are the DAMA residuals in the (2–6) keVee energy window, taken from [1, 5]. The curves are fits to a cosine annual modulation peaked on June, 2nd (red curve), as expected for a DM signal, and to the irregular sawtooth obtained from a continuously growing background (blue curve). The roughly annual data-taking cycles of DAMA/NaI, DAMA/LIBRA Phase 1, and DAMA/LIBRA Phase 2 are shown as vertical lines.



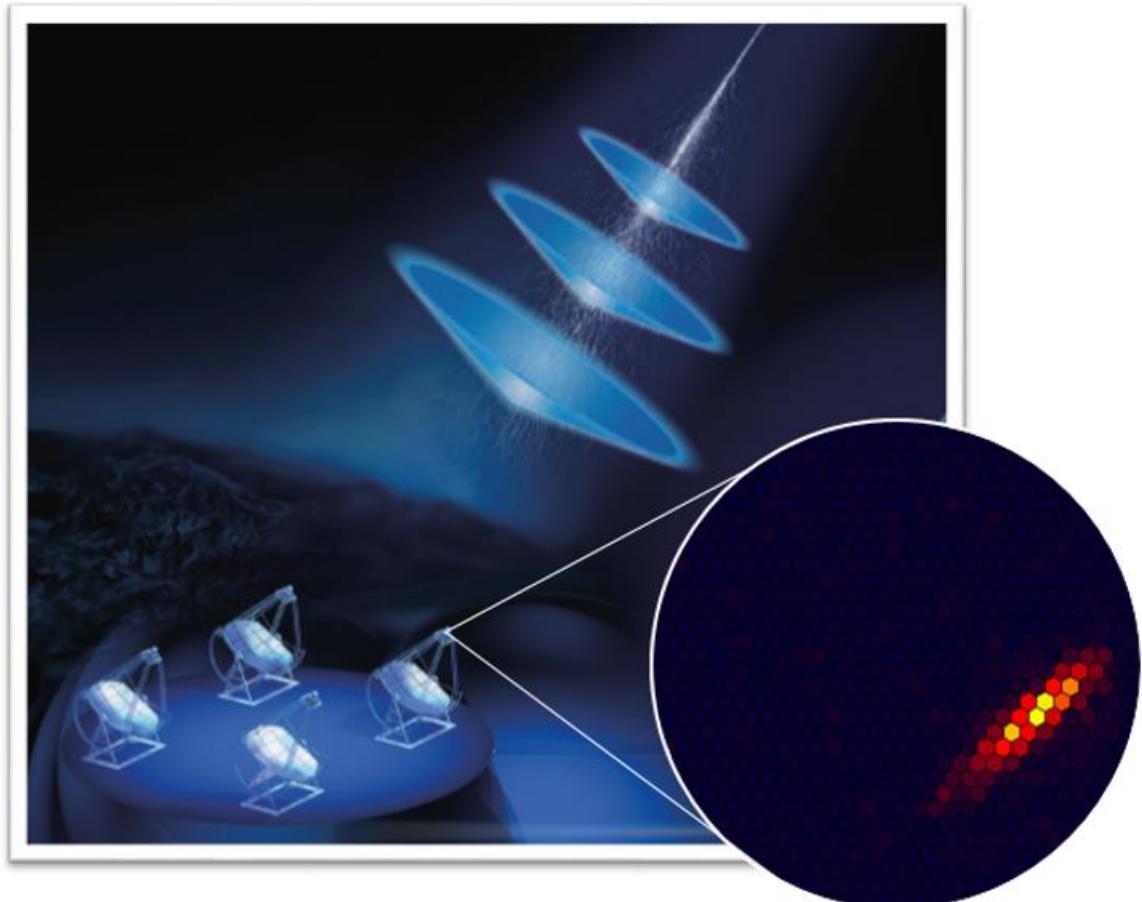
But Replication failed 😞
ANALIS (Spain)
COSINE (Germany)

ASTRO- PHYSIQUE

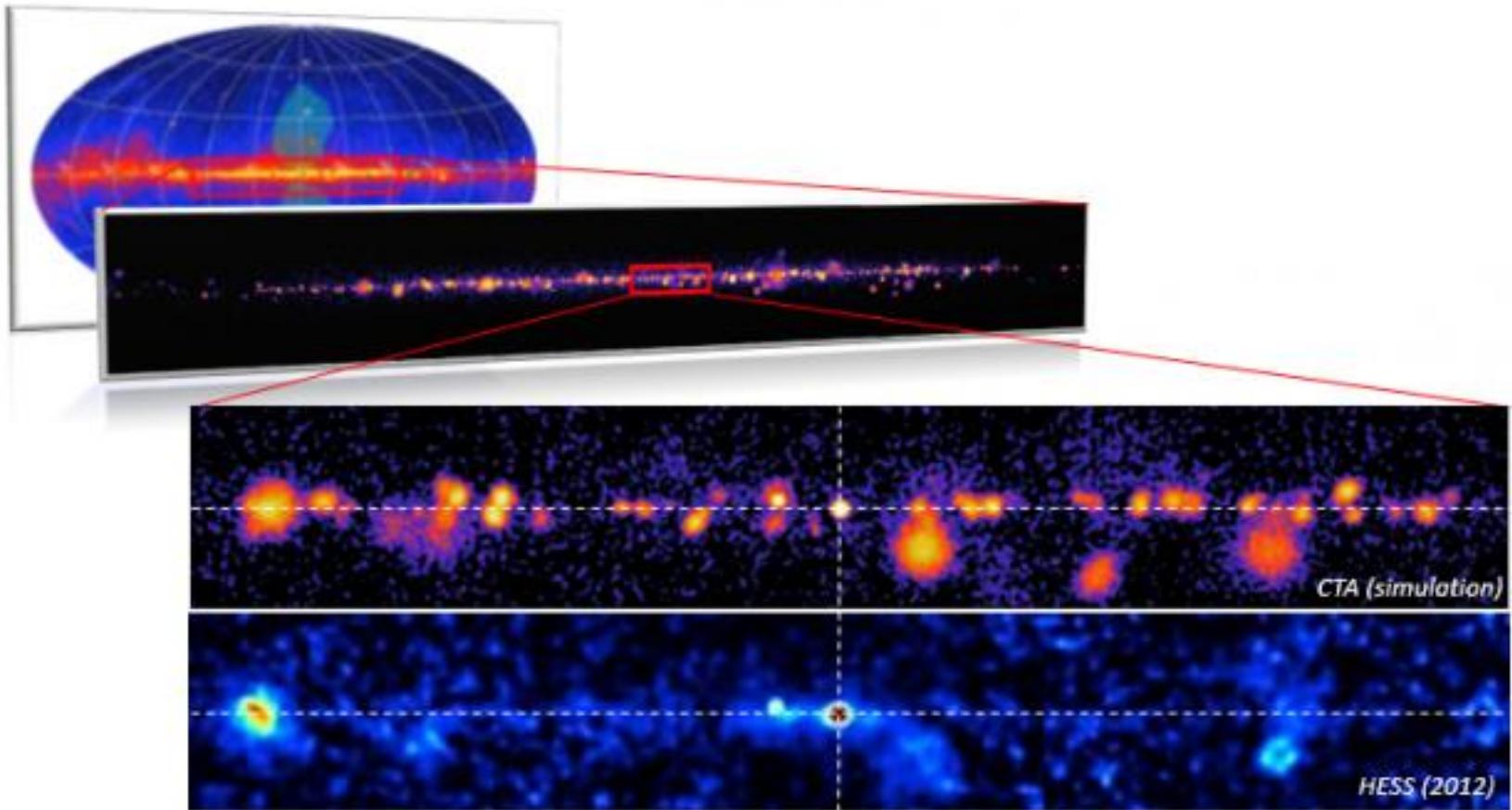
CTA



CTA



CTA

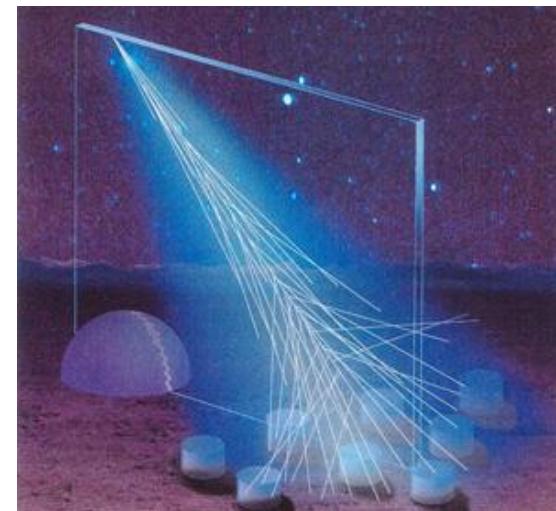




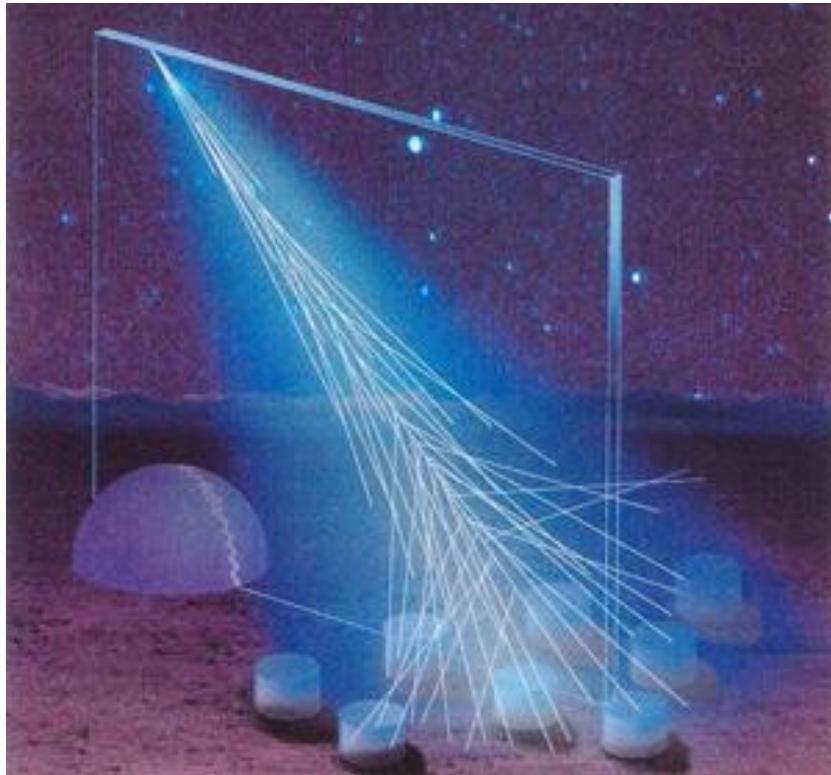
Pierre Auger Observatory
studying the universe's highest energy particles



Pierre Auger Cosmic Ray Observatory



Pierre Auger Cosmic Ray Observatory

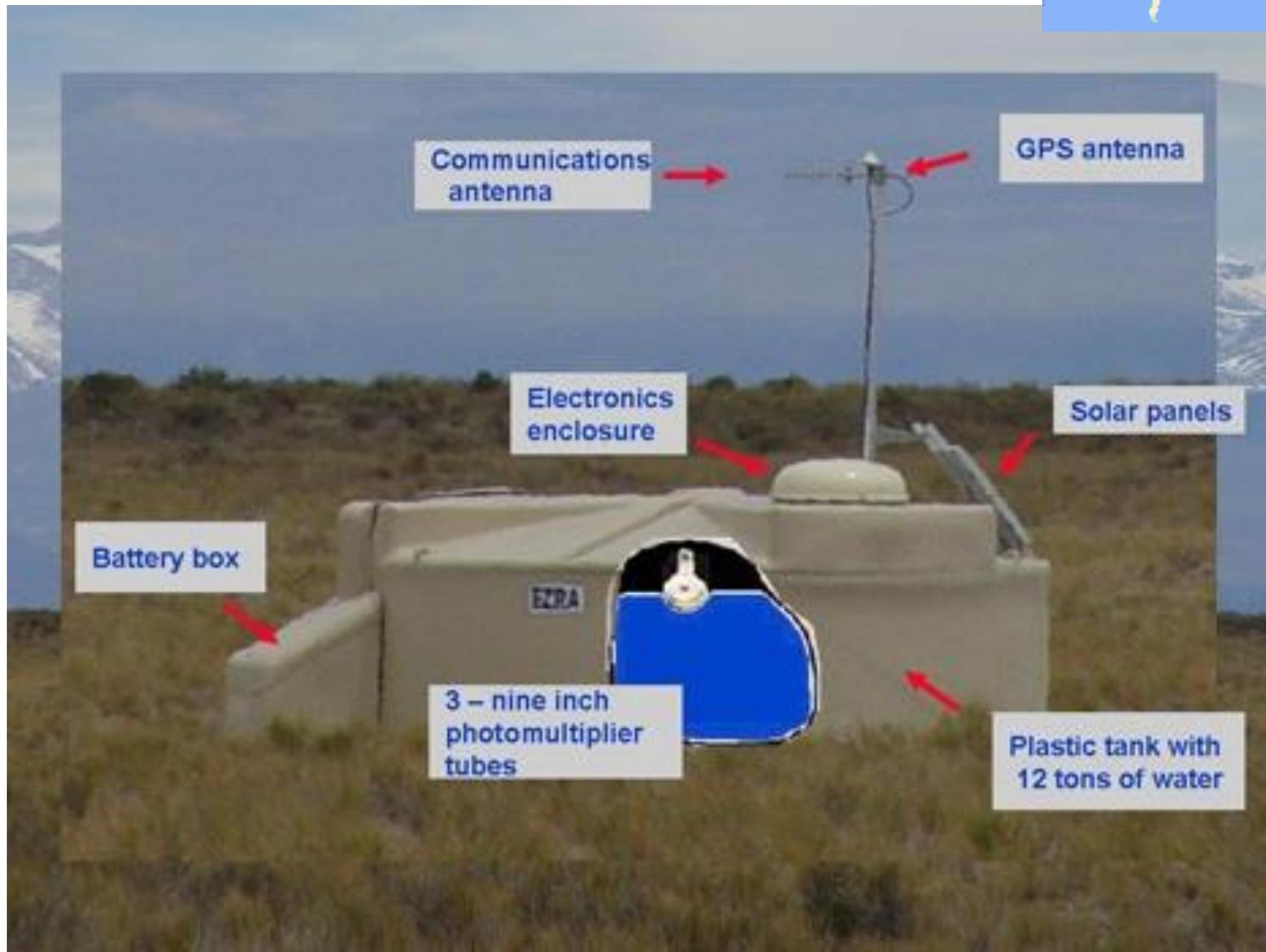


Use earth's atmosphere as a calorimeter. 1600 water Cherenkov detectors with 1.5km distance.

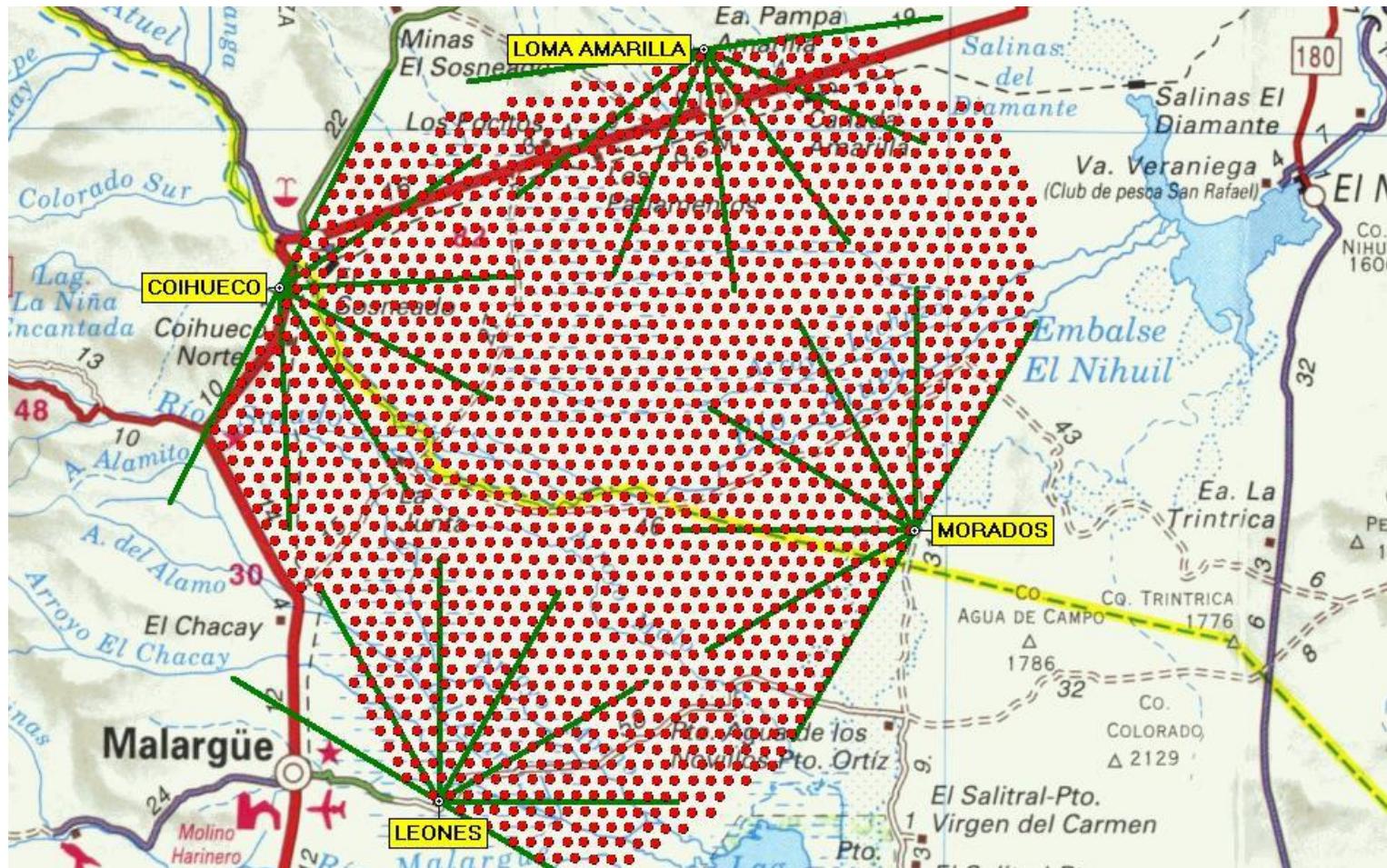
Placed in the Pampa Amarilla in western Argentina.

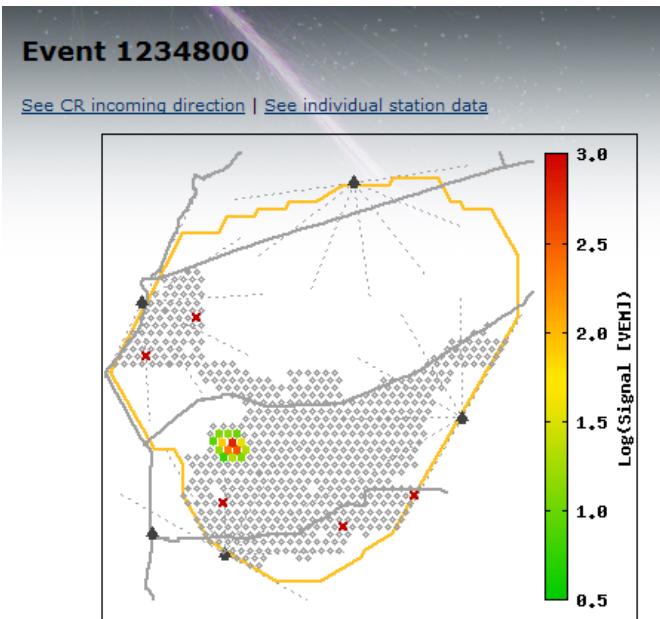


Pierre Auger Cosmic Ray Observatory



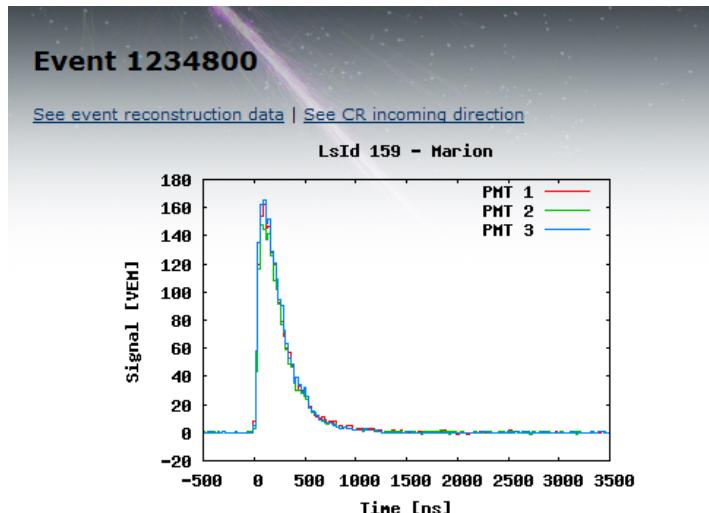
Pierre Auger Cosmic Ray Observatory



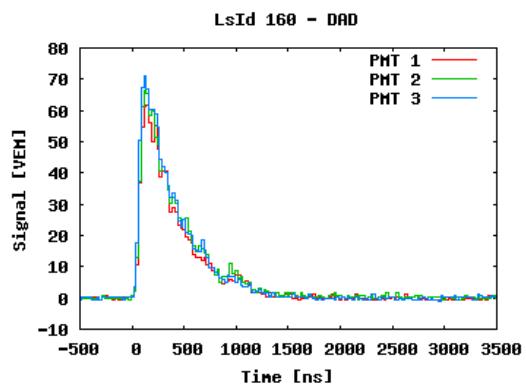


37 EeV = Exa Electron Volt = 37×10^{18} eV

Generic Information	
<u>Id</u>	1234800
<u>Date</u>	Sat Mar 5 15:54:48 2005
<u>Nb Station</u>	14
<u>Energy</u>	37.4 ± 1.2 EeV
<u>Theta</u>	43.4 ± 0.1 deg
<u>Phi</u>	-27.3 ± 0.2 deg
<u>Curvature</u>	15.8 ± 0.8 km
<u>Core Easting</u>	460206 ± 20 m
<u>Core Northing</u>	6089924 ± 11 m
<u>Reduced Chi²</u>	2.30



Signal in VEM for the 3 PMTs of station 159 (Marion) as a function of time



Signal in VEM for the 3 PMTs of station 160 (DAD) as a function of time

Application to use smartphones camera as cosmic rays detectors



3

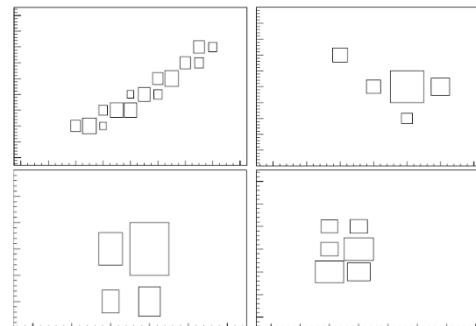


FIG. 4: Activated pixels above threshold in a Samsung Galaxy SIII phone, during exposure to ^{60}Co . Box size is proportional to pixel response values

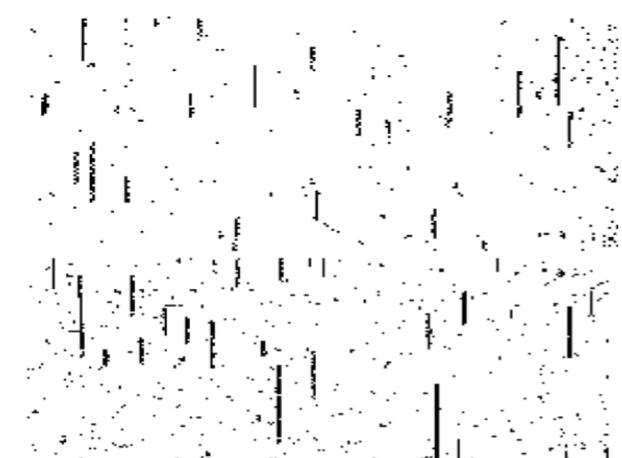
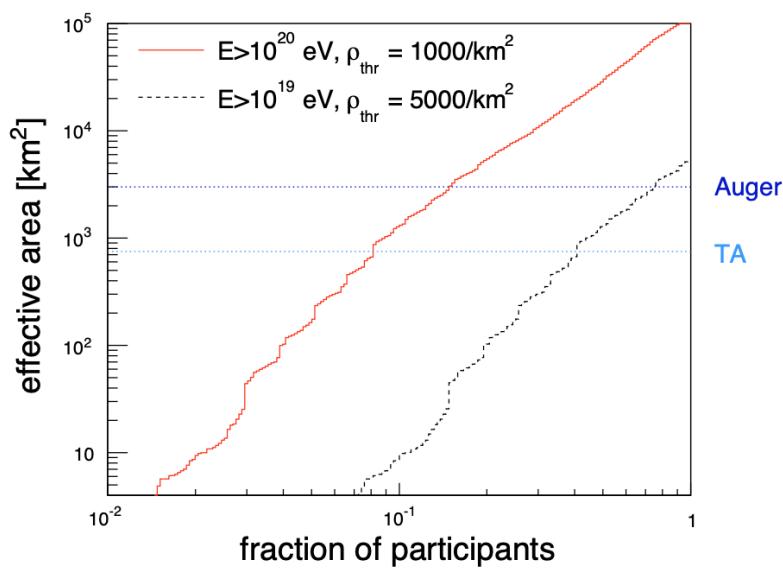


FIG. 5: Composite image of activated pixels in data collected from phones exposed to a muon beam. The phones were arranged such that the muon beam was incident on the side of the sensor, giving visible tracks where muons pass through several pixels.



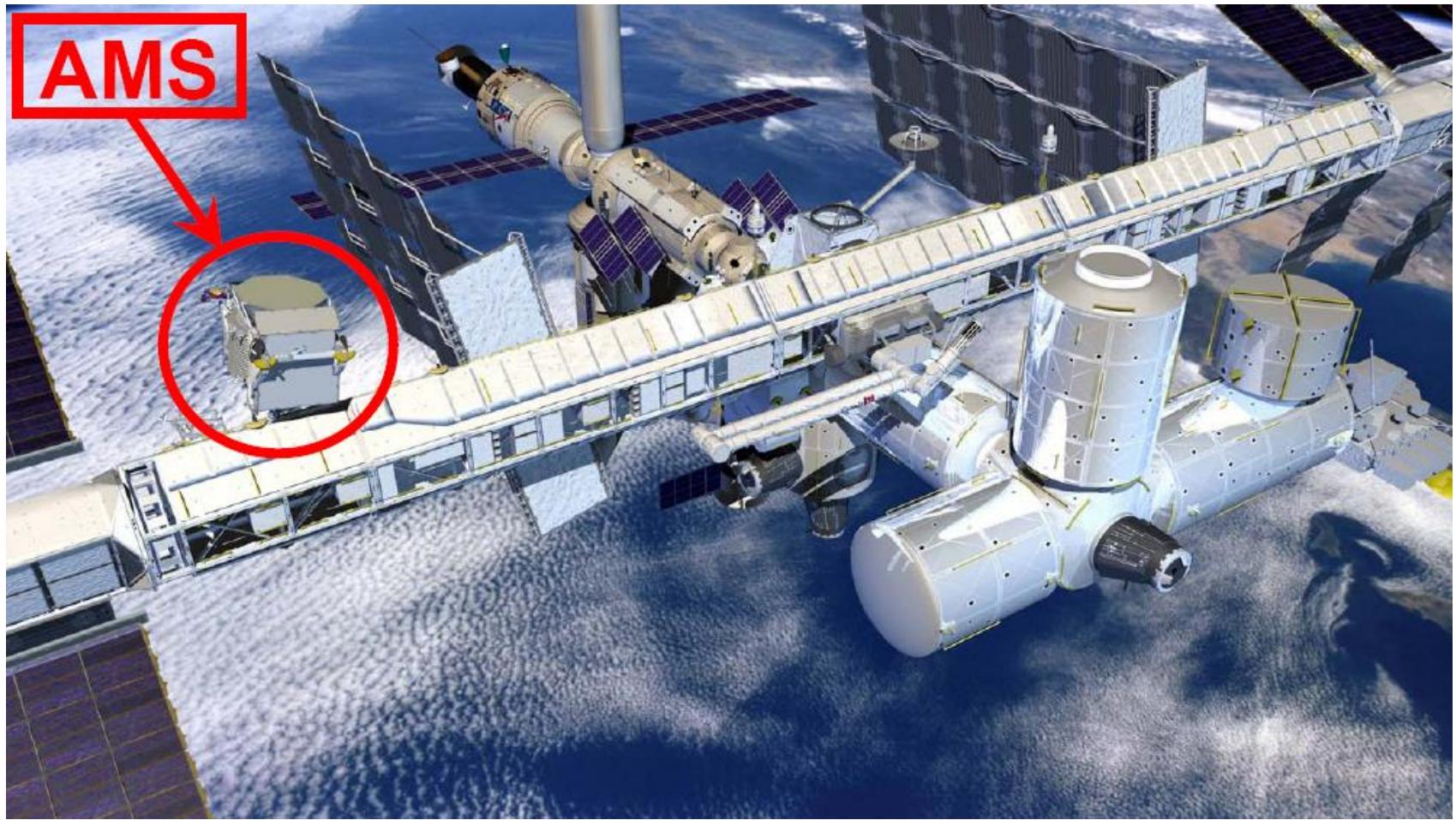
AMS

ALPHA MAGNETIC SPECTROMETER

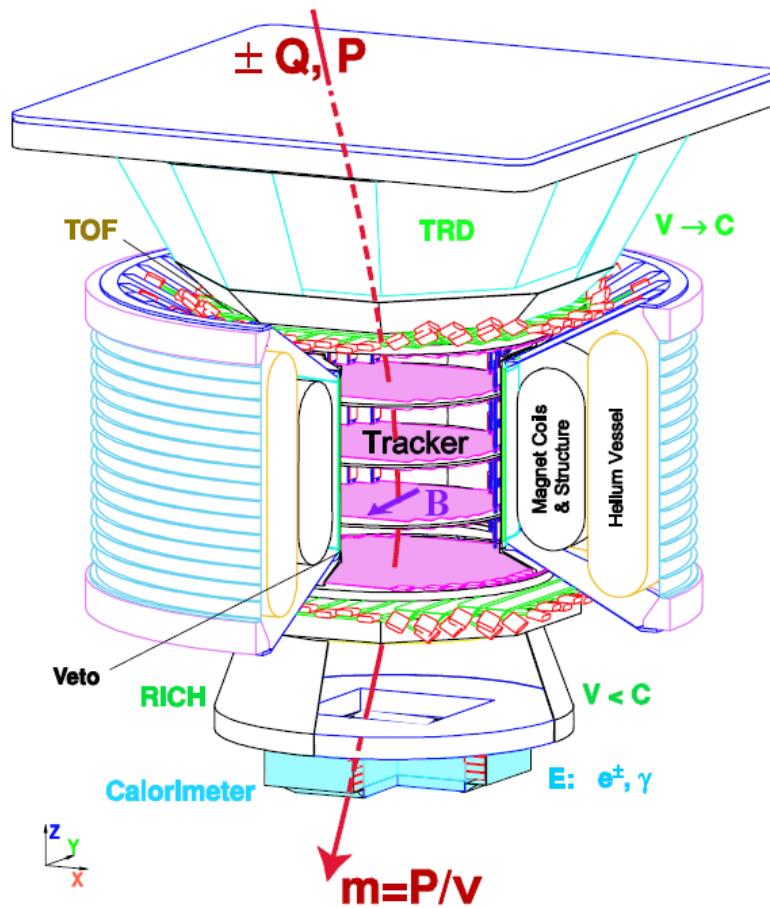
Try to find Antimatter in the primary cosmic rays.
Study cosmic ray composition etc. etc.

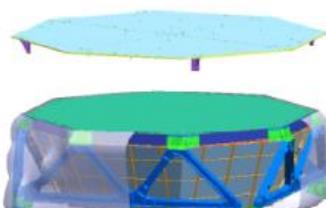


Will be installed on the space station.



AMS





Zenith Radiator



USS:

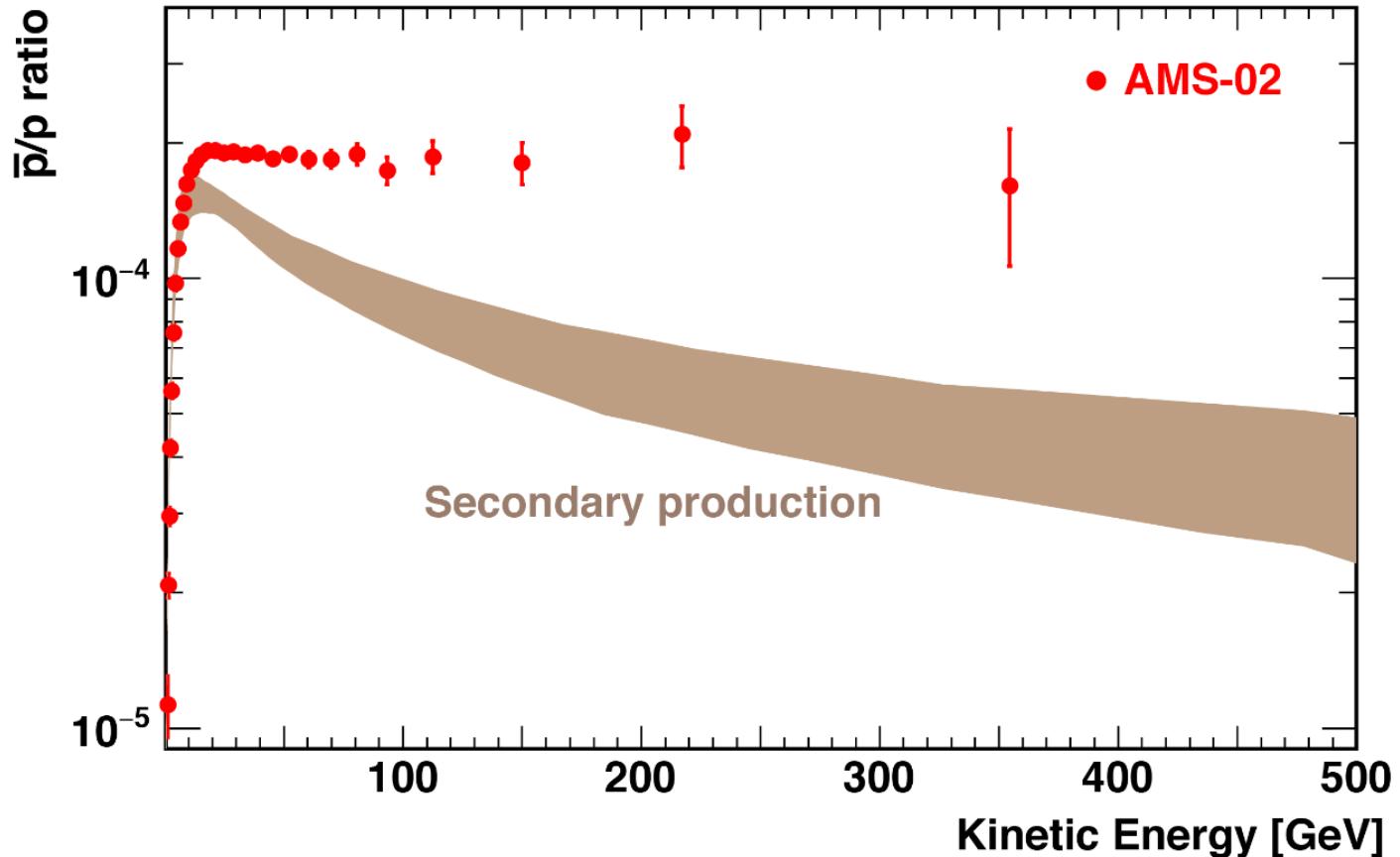
TRD:
Transition Radiation Detector

Figure 1. Antiproton to proton ratio measured by AMS. As seen, the measured ratio cannot be explained by existing models of secondary production.



PAS:
Payload Attach System

Cours 1 : Généralités

- Introduction générale sur l'importance de la mesure
- Qu'est-ce qu'une expérience de physique subatomique ?
- Que veut-on observer à propos d'une particule?
- Architecture générale d'une expérience en physique subatomique

Cours 2 : Les détecteurs de particules

- Trajectographie :
 - Détecteurs Gazeux
 - Détecteurs au Silicium
- Calorimétrie
- Scintillation

Cours 3 : Exemple d'expériences

- Autour du Neutrino
- Nucléaire et Hadronique
- Rayons Cosmiques
- Antimatière

SOURCES



Basé sur les cours de Stefano Panebianco (CEA/IRFU) rencontre d'ete 2016

Le cours de Werner Riegler (CERN Summer Student Lecture Program 2009)

Particle Detectors , Second Edition, C. Grupen & B. Shwartz