

DE LA RECHERCHE À L'INDUSTRIE



Jeudi 2/07 12h (LLR)
Jeudi 2/07 14h45 (LLR)



Mesurer l'infiniment petit et observer l'infiniment grand

XIII^e édition des **Rencontres d'été de physique**
de **L'INFINIMENT GRAND** à l'infiniment petit

29 juin au 3 juillet 2026

• Orsay
• Palaiseau
• Paris
• Saclay

Rencontres
Promotion **Claudine HERMANN**

de **L'INFINIMENT GRAND**
à **L'INFINIMENT petit**

Niveau L3 ou équivalent

Visites de labos,
conférences, débats,
observation du ciel

- 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
- Les détecteurs spatiaux et auprès d'accélérateurs
- L'Intelligence Artificielle

Région Île-de-France DIMORIGINES

irfu cnrs Université Paris 12 Université Paris-Saclay ASTRO P21 LM UCub IAS

indico.in2p3.fr/event/rencontres-physique-infinis

INFORMATIONS ET CANDIDATURES

Maxence Vandenbroucke
07/2026

université
PARIS-SACLAY

Cours 1 : Généralités

- Introduction de la théorie à la pratique
- Qu'est-ce qu'une expérience de physique?
- 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

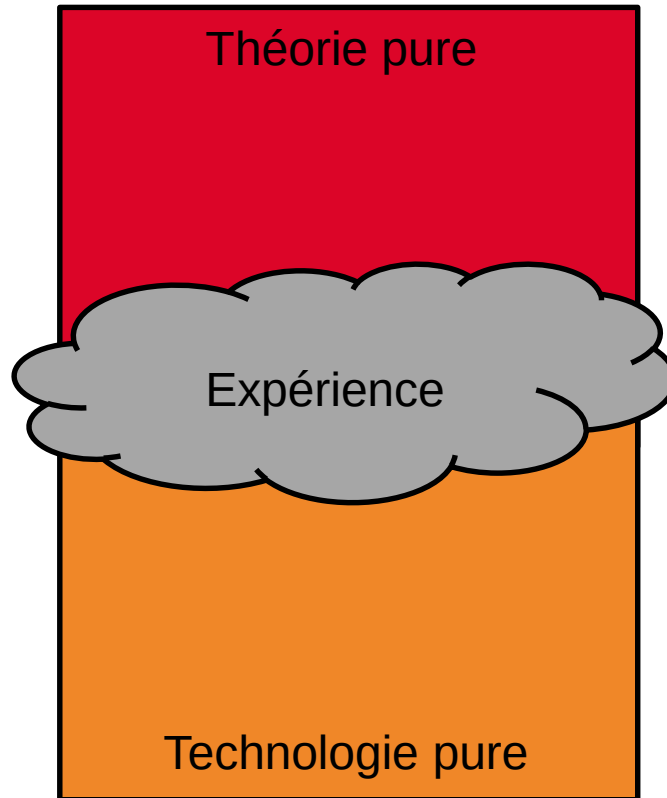
Cours 3 : Exemples d'expériences

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

Cours 1 : Généralités

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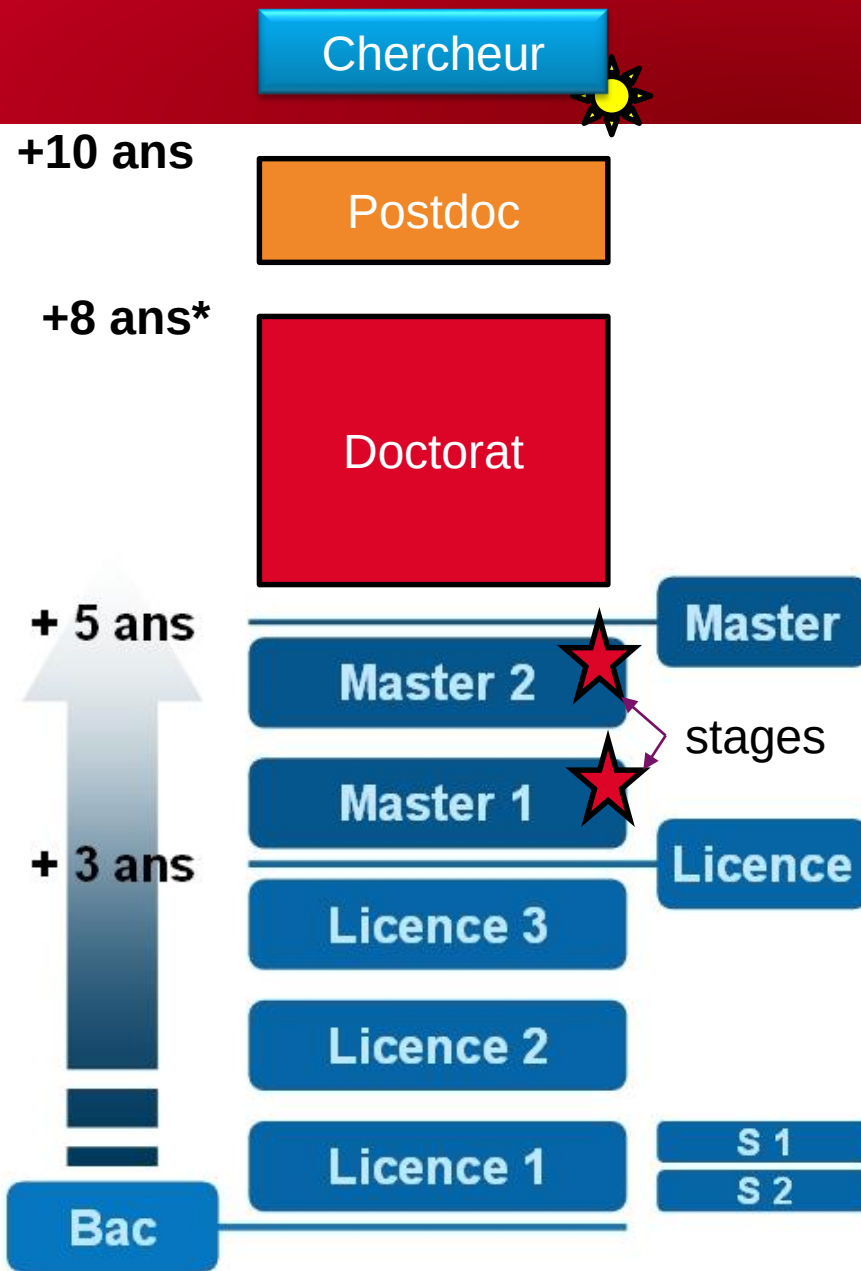
- Théorie
- Construction des Modèles
- Prédiction avec des Modèles
- Simulation de l'expérience
- Design d'expérience
- Choix du dispositif expérimental
- Electronique/acquisition
- Reconstruction des évènements
- Comparaison avec la simulation/calcul
- Papier, Communication

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



	Astr o	Nucl eaire	Parti cule s	Cos mo	Medical	...
Inge						
Prof						
Analyse						
Detection			X			
Chef						
Theoricien						
Communication						
... ..						

Un choix matriciel !



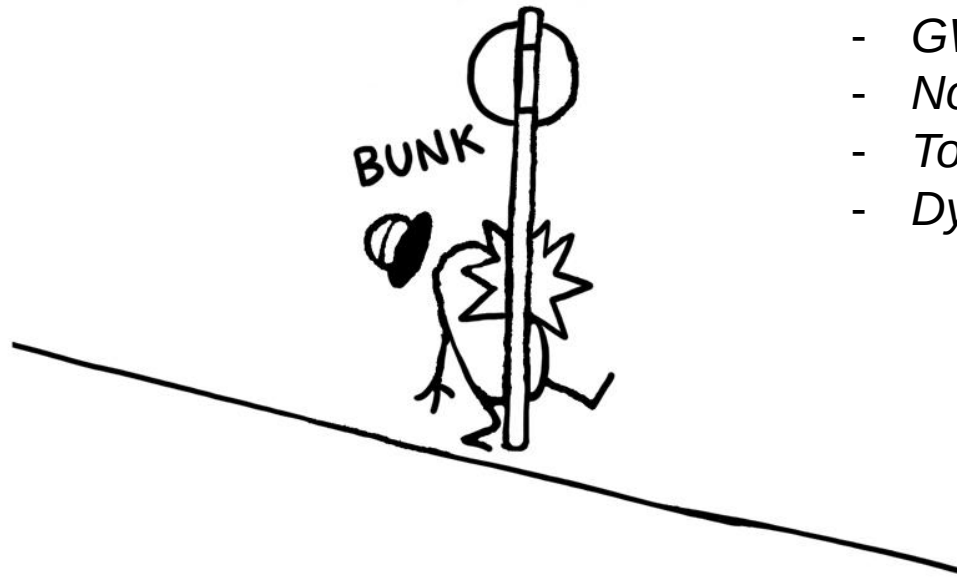
*en France, 3-7ans sinon

UNE EXPÉRIENCE C'EST QUOI ?



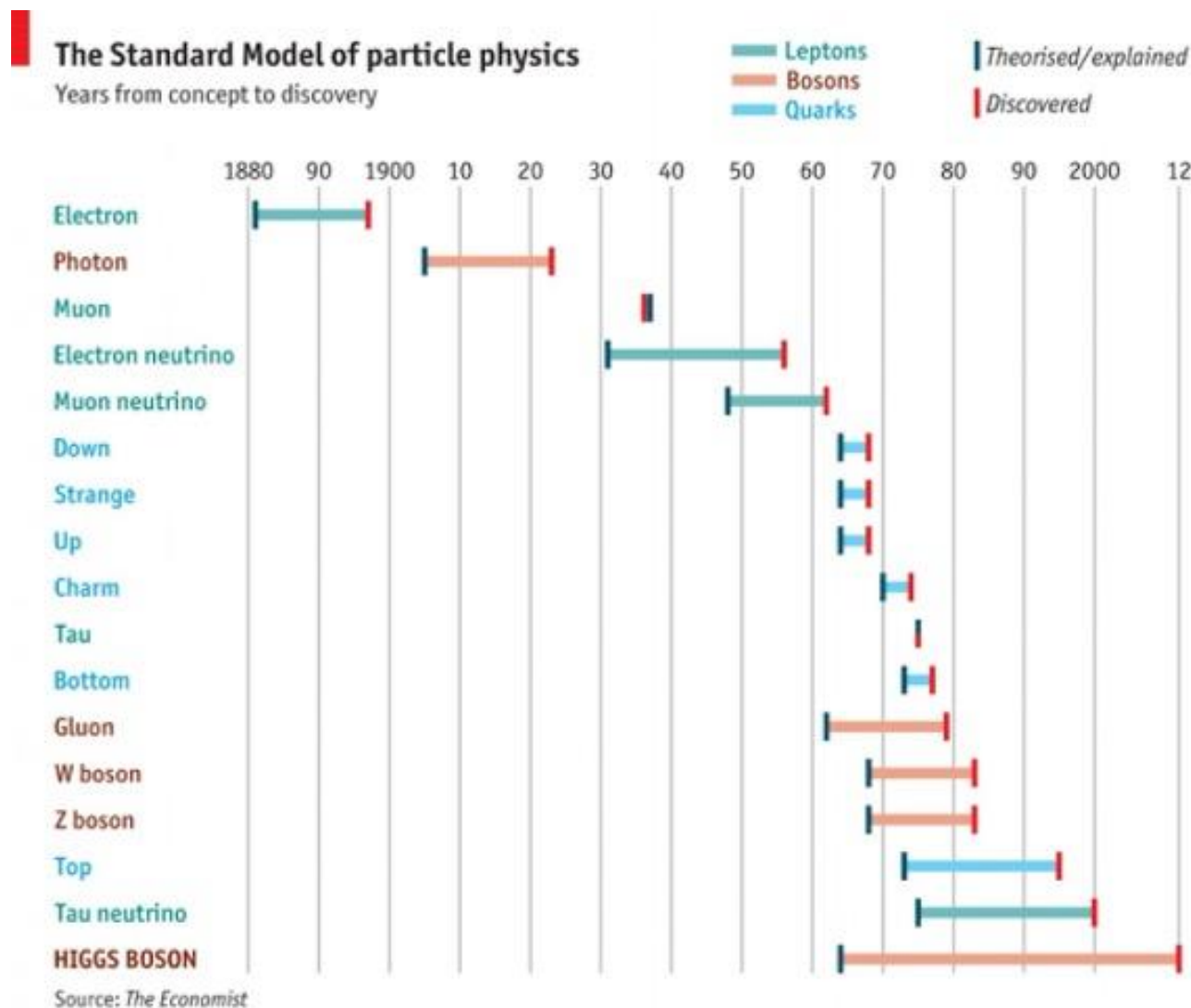
Dernier "**BUNK**"

- Oscillation ν (2002)
- Higgs (2012)
- No SUSY
- GW (2015)
- No Wimps ? (2023)
- Toponium (2025)
- Dynamic DM ? (2026)

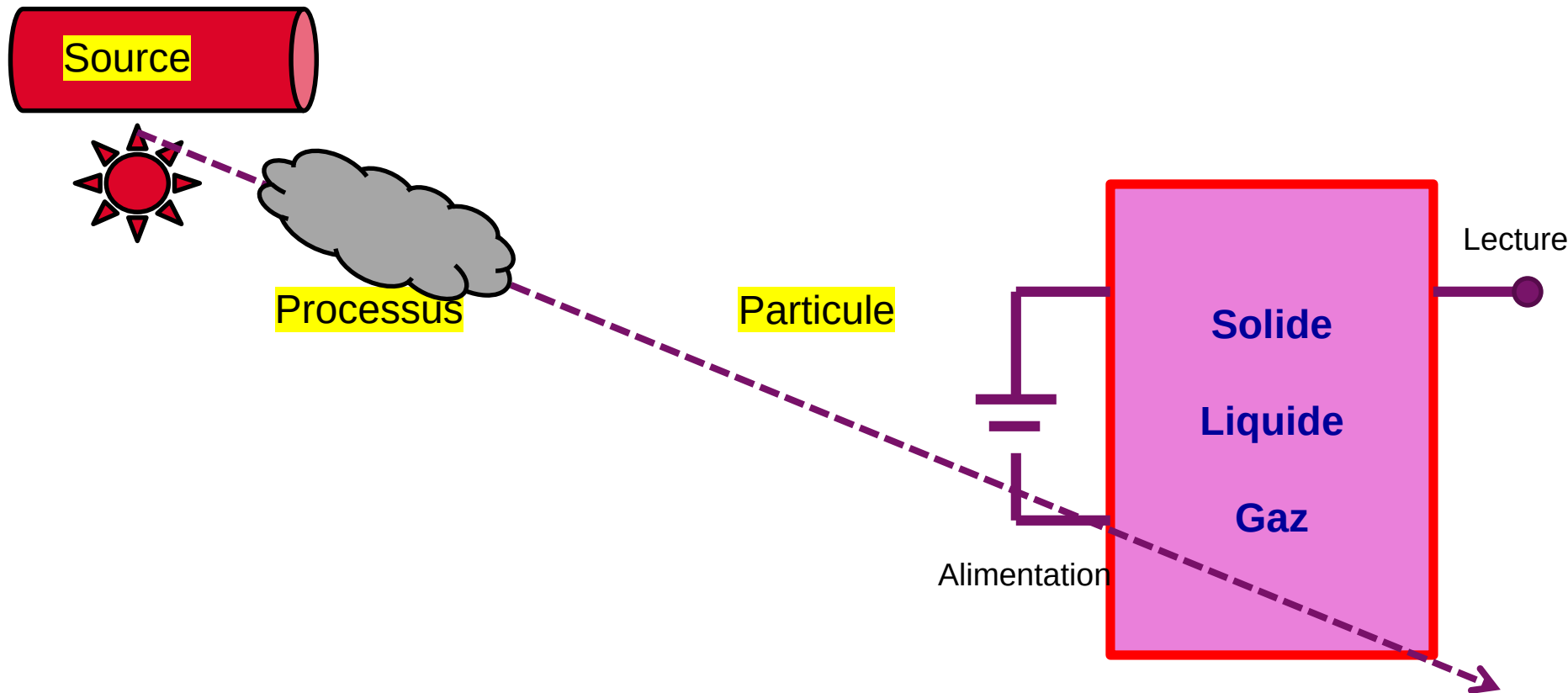


LE RÉEL, C'EST QUAND ON SE COGNE.

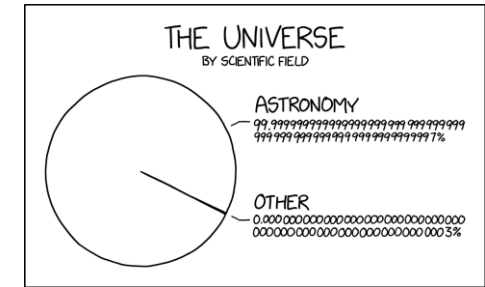
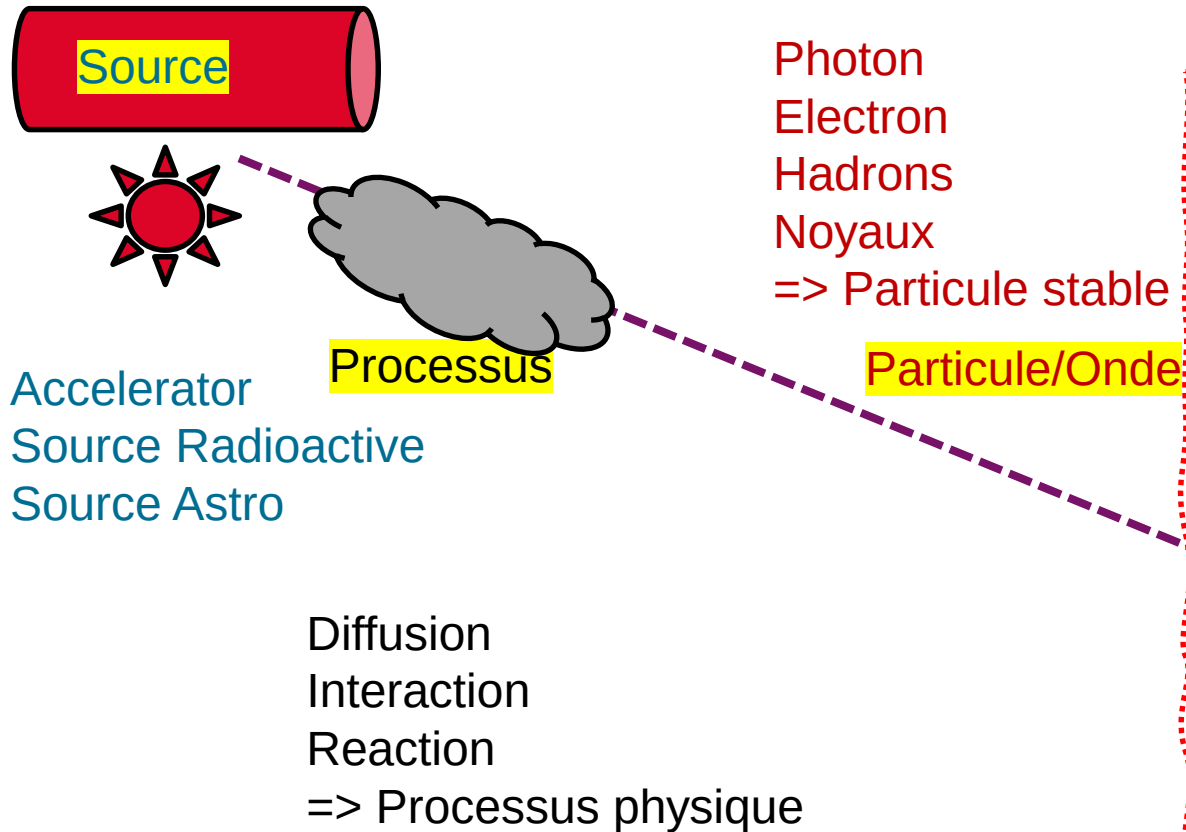
UNE EXPÉRIENCE C'EST QUOI ?



Schématiquement (*****)



Schématiquement (****)



Ce cours

Solide

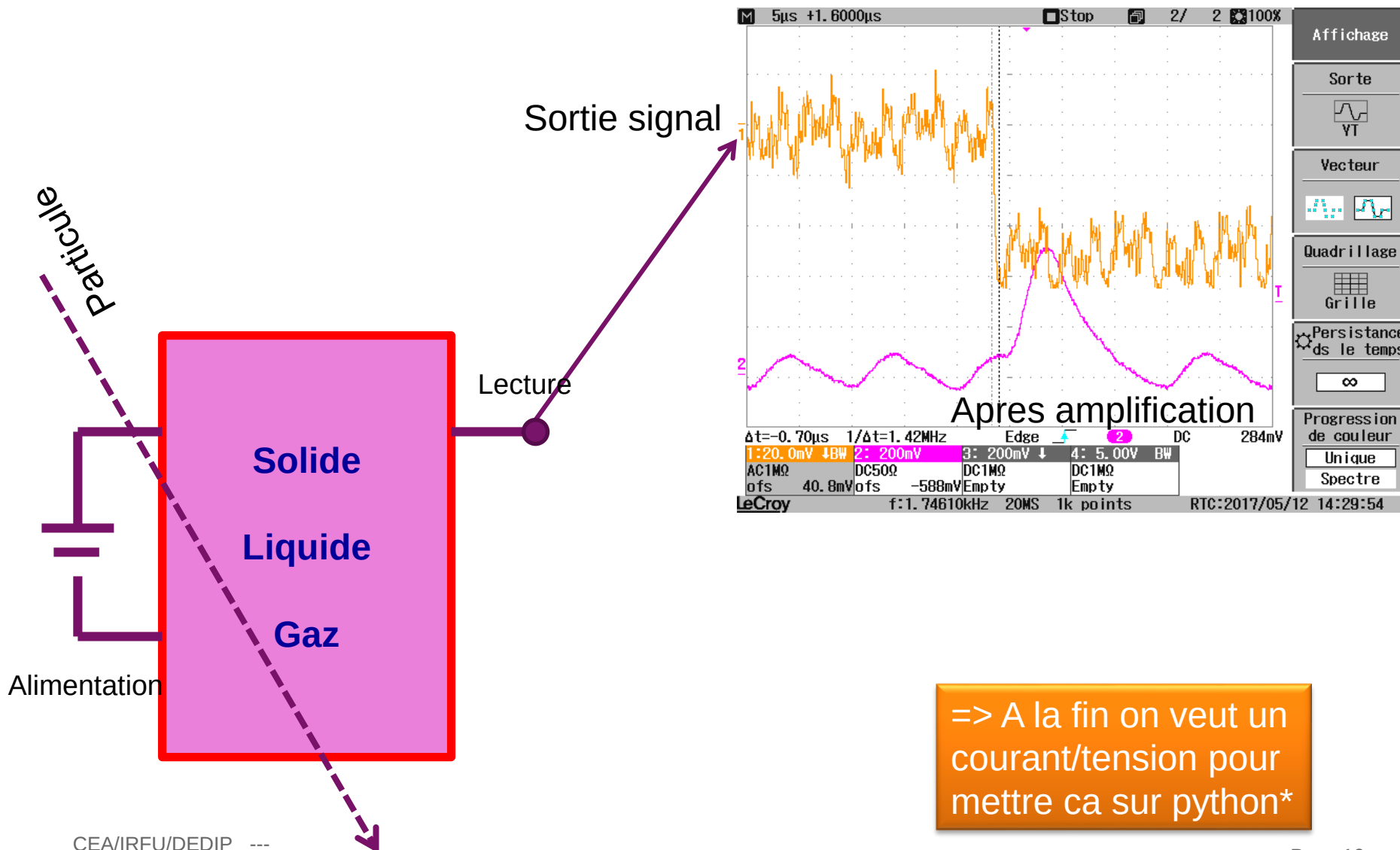
Liquide

Gaz

Alimentation

Photo-Mutiplicateur
Chambre a fils
Telescope

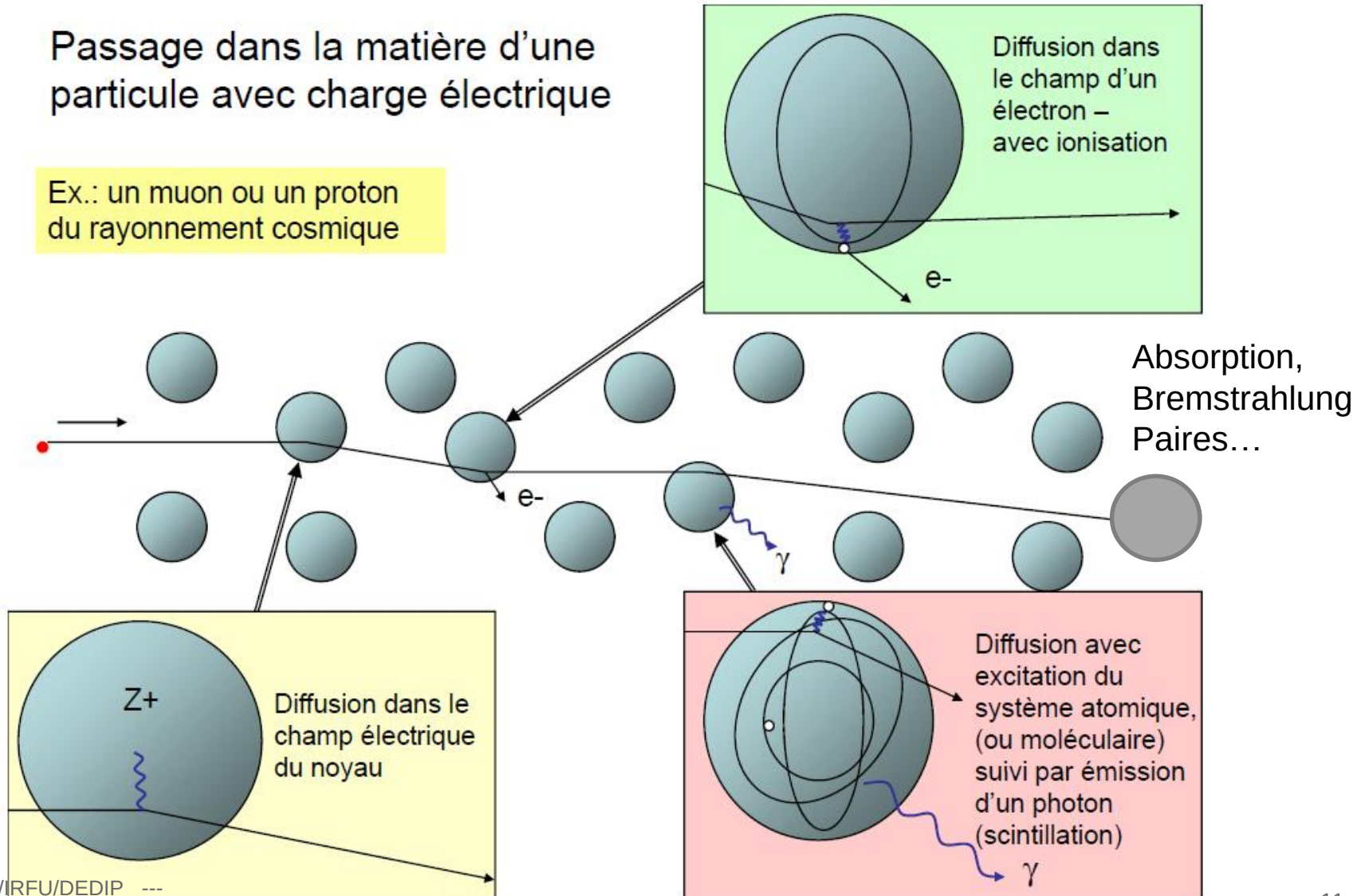
MESURER C'EST QUOI ?



=> A la fin on veut un courant/tension pour mettre ca sur python*

Passage dans la matière d'une particule avec charge électrique

Ex.: un muon ou un proton du rayonnement cosmique



- Comment interagit un **Photon** avec la matière ?

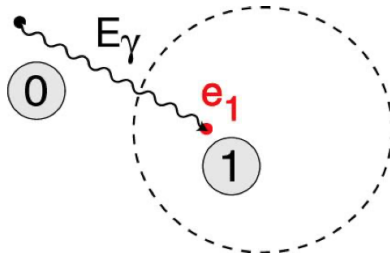
~ 100 keV

~1 MeV

~ 10 MeV

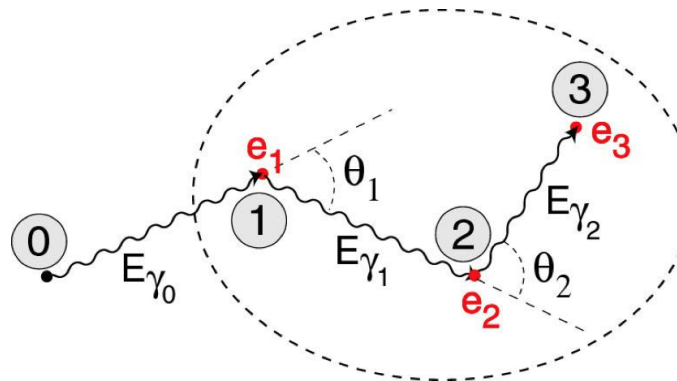
γ ray energy

Photoelectric



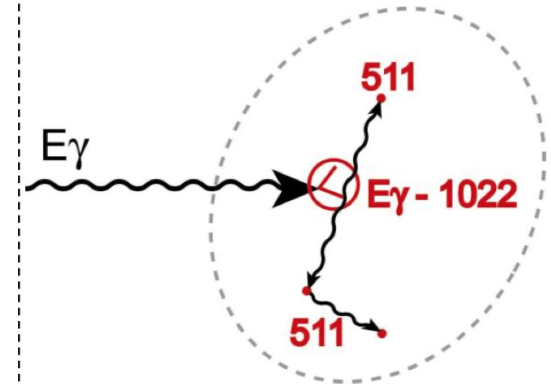
$$E_{e1} = E_{\gamma} - E_b$$

Compton Scattering



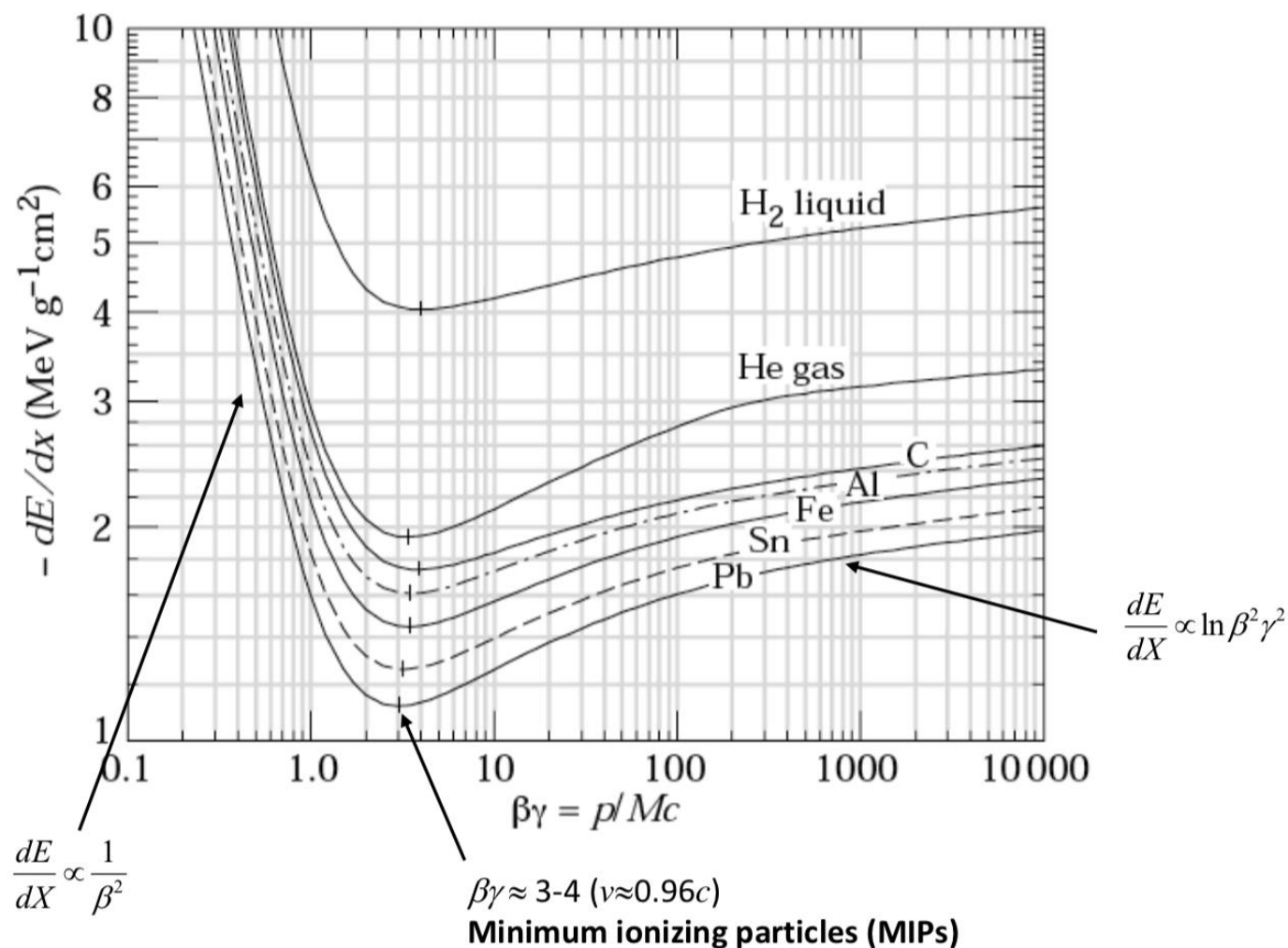
$$E_{\gamma'} = \frac{E_{\gamma}}{1 + \frac{E_{\gamma}}{m_0 c^2} (1 - \cos \theta)}$$

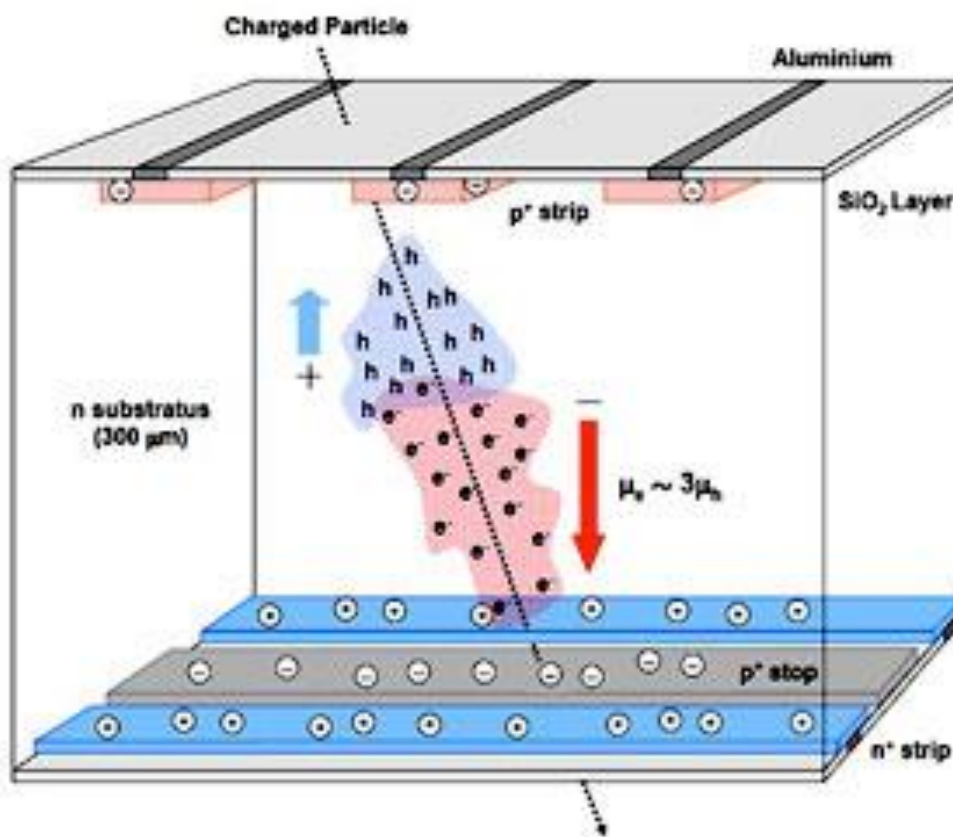
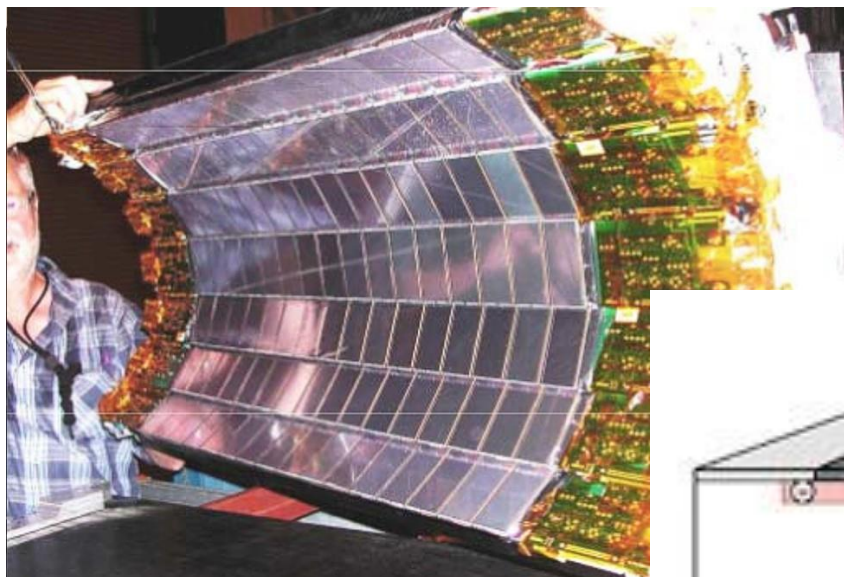
Pair Production



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

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

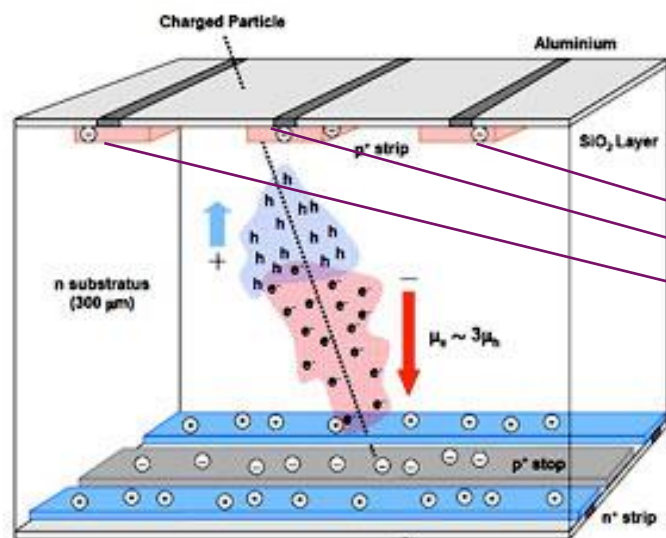




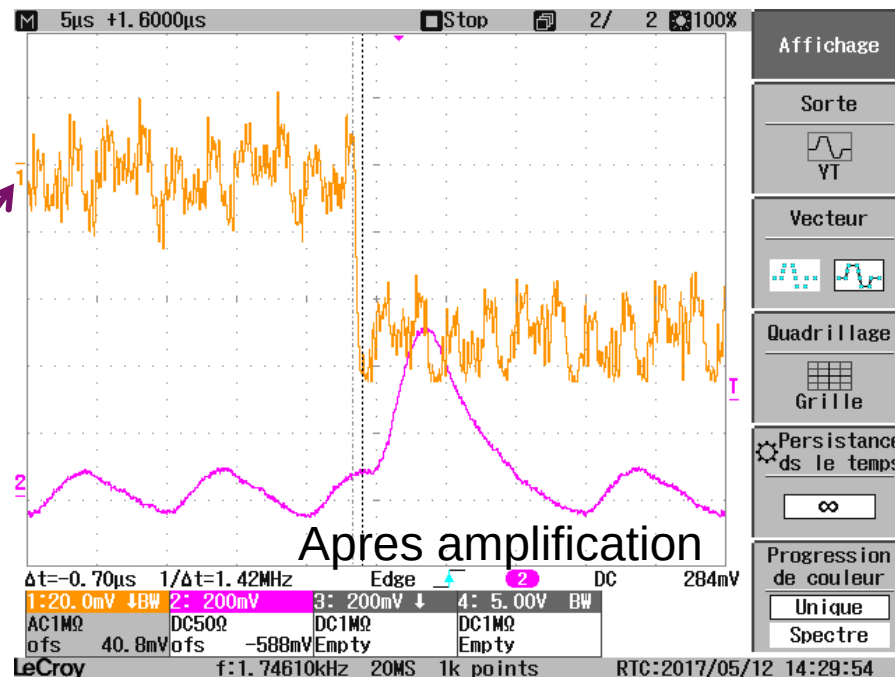
Les autres type de detecteurs =>
Cours 2

MESURER C'EST QUOI ?

Particule

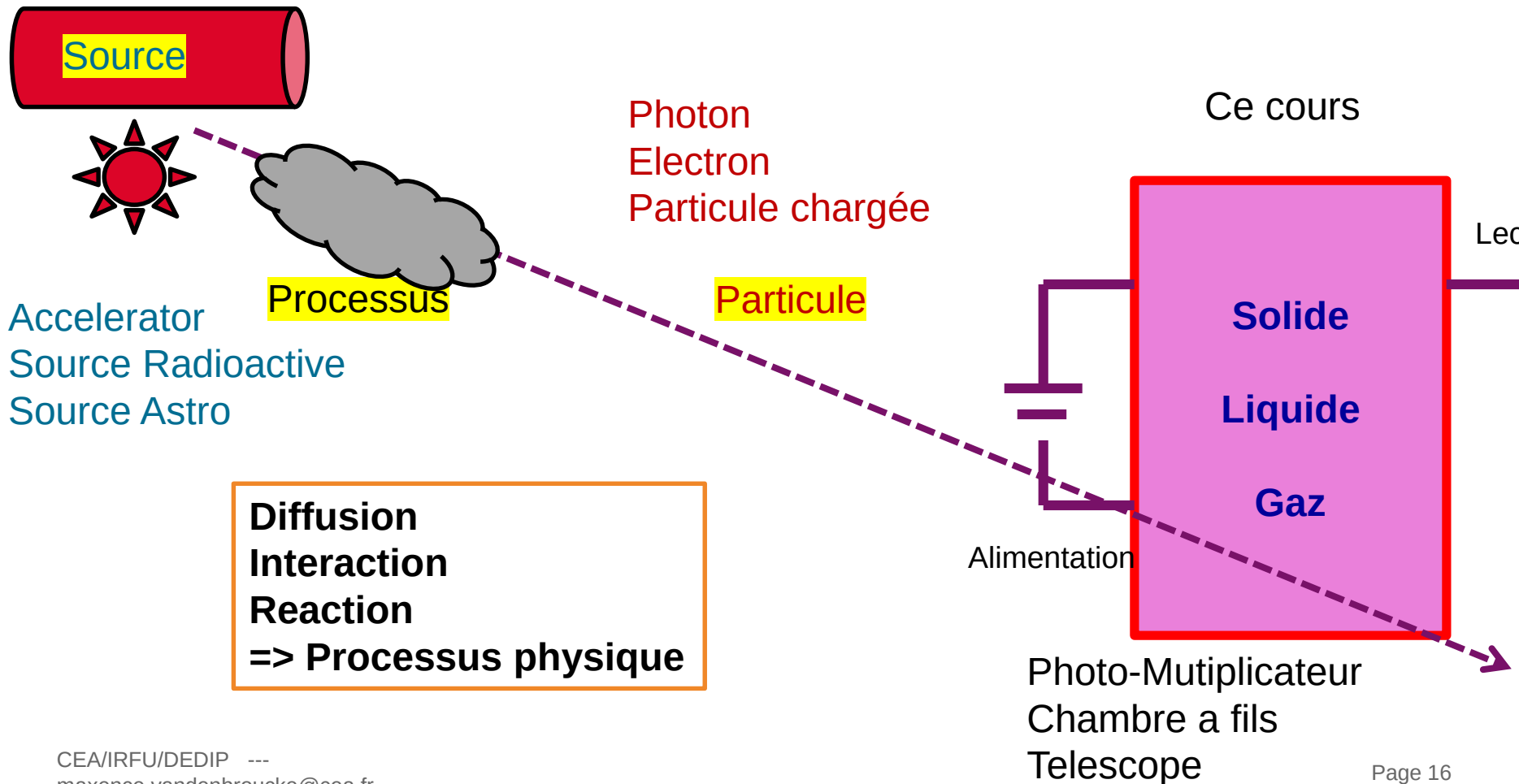


Sortie signal



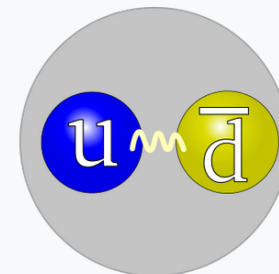
Un Canaux = Un signal
Plein de canals => Analyse

Schématiquement (*****)



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	$\pi^\pm$: 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

- 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

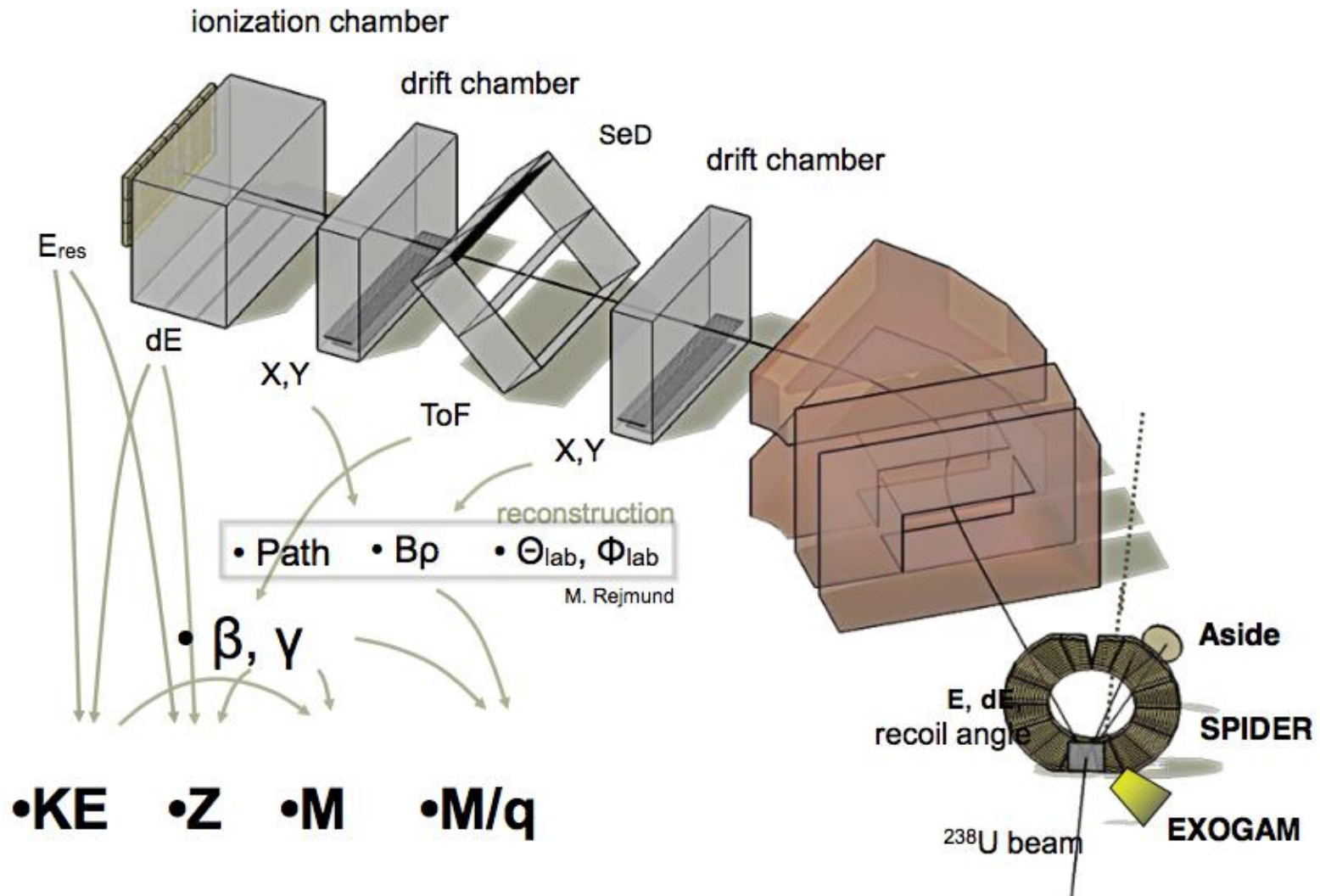
- Calorimétrie
- Perte d'énergie dE/dx
- Fréquence

Mesure de spin et de la parité

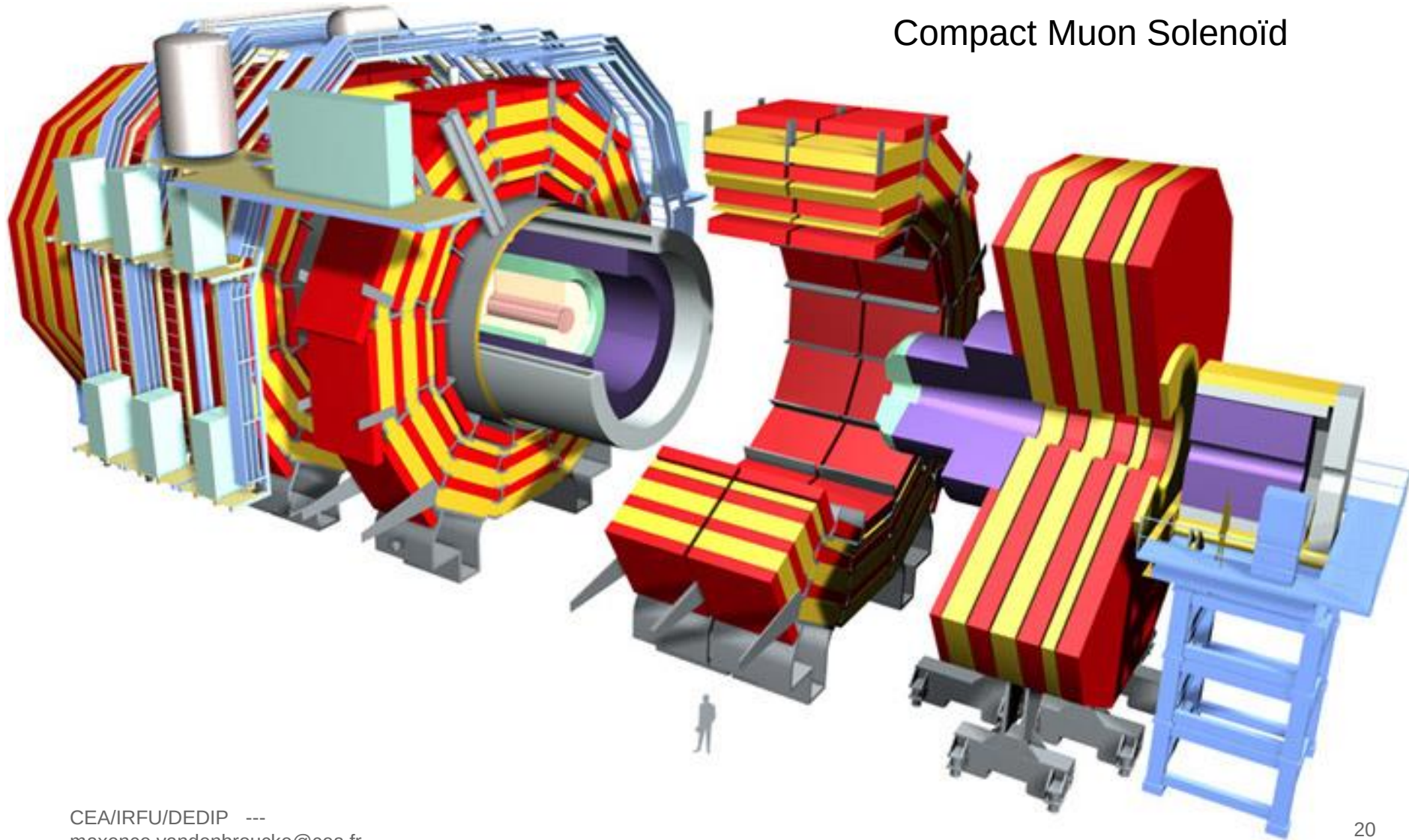
- (Pas traitée ici)
- Avec un polarimètre indirectement
- Par sélection

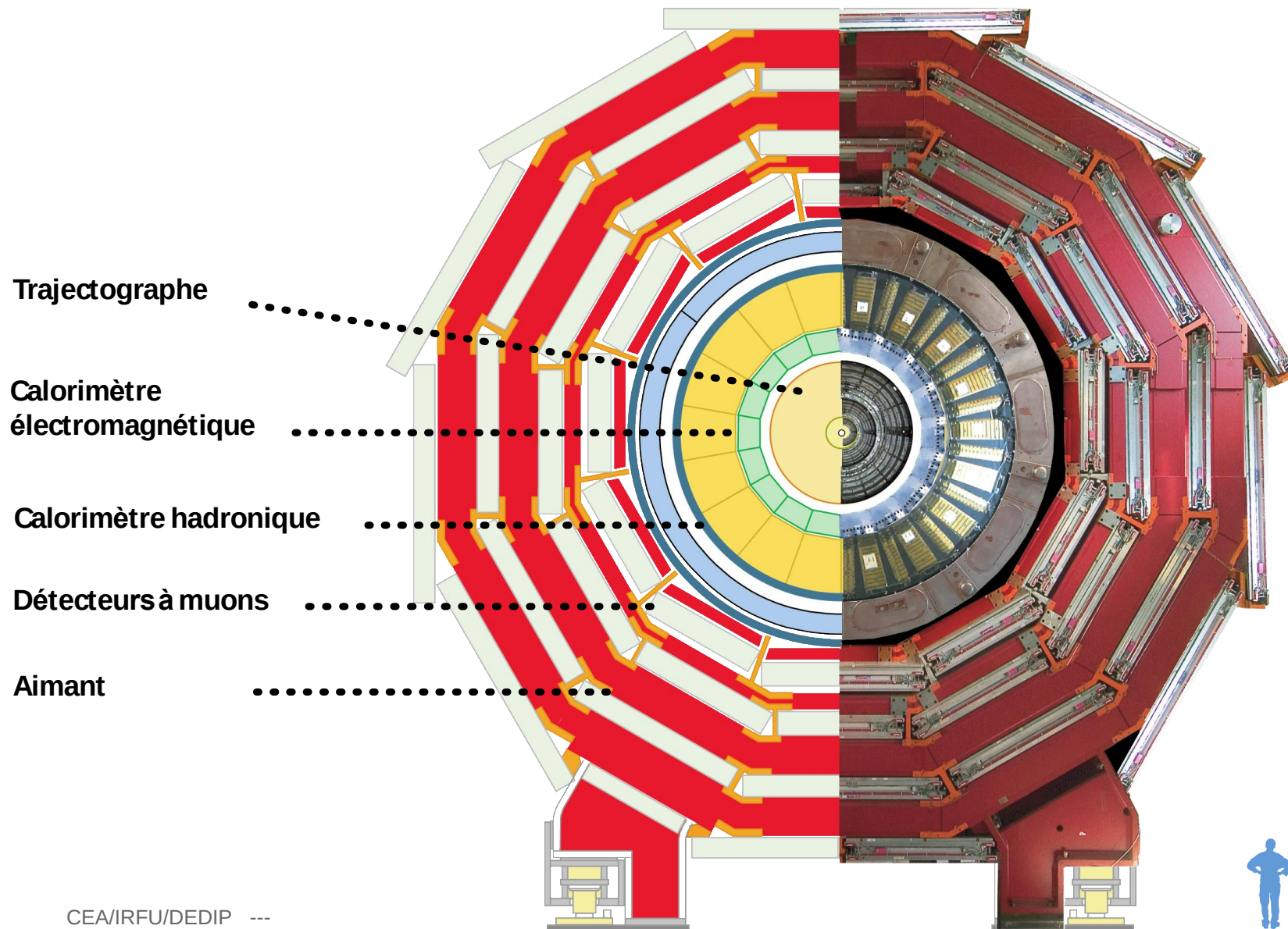
Mesure de la masse et de la charge (PID)

- 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'électromètre

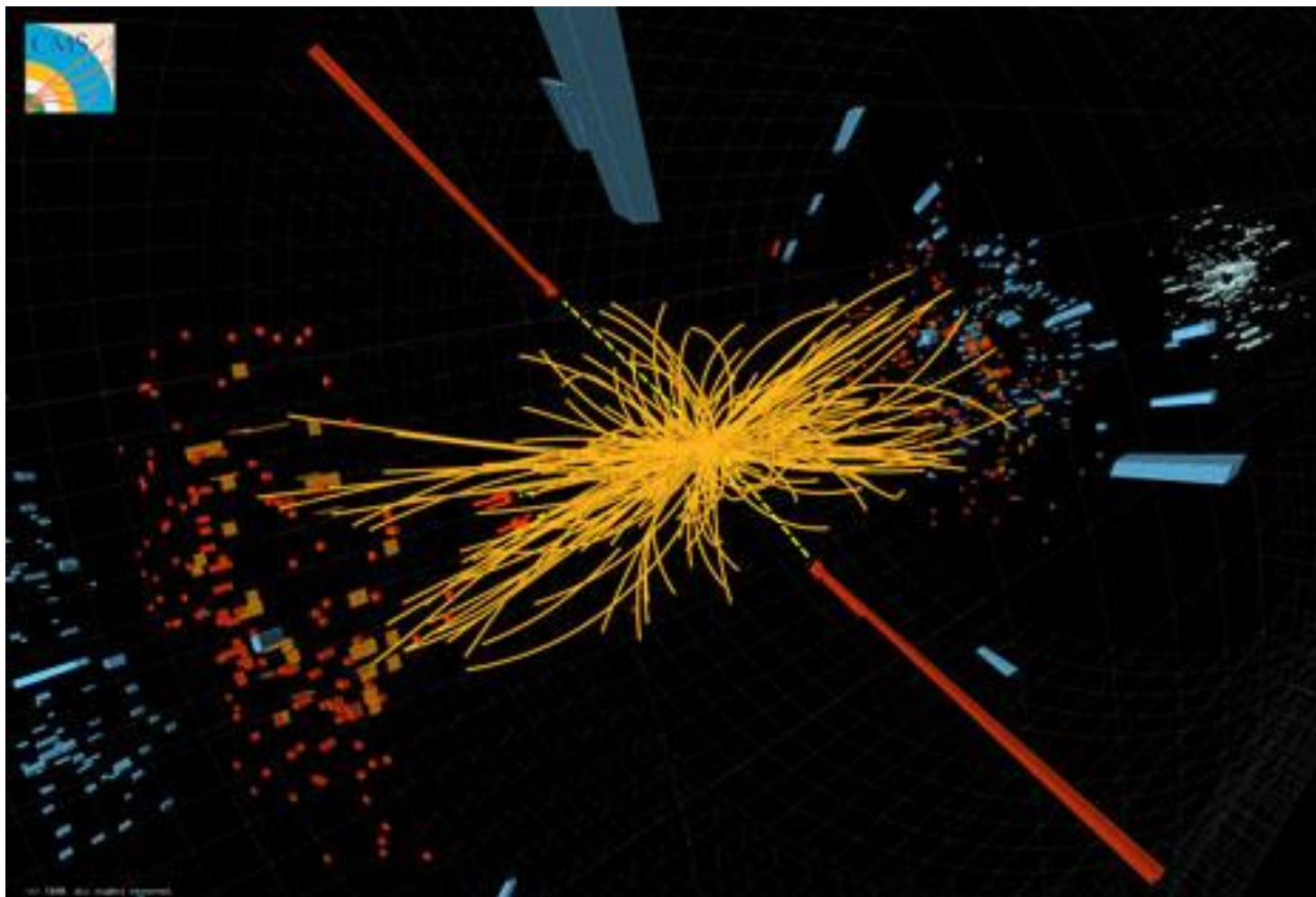


Compact Muon Solenoid

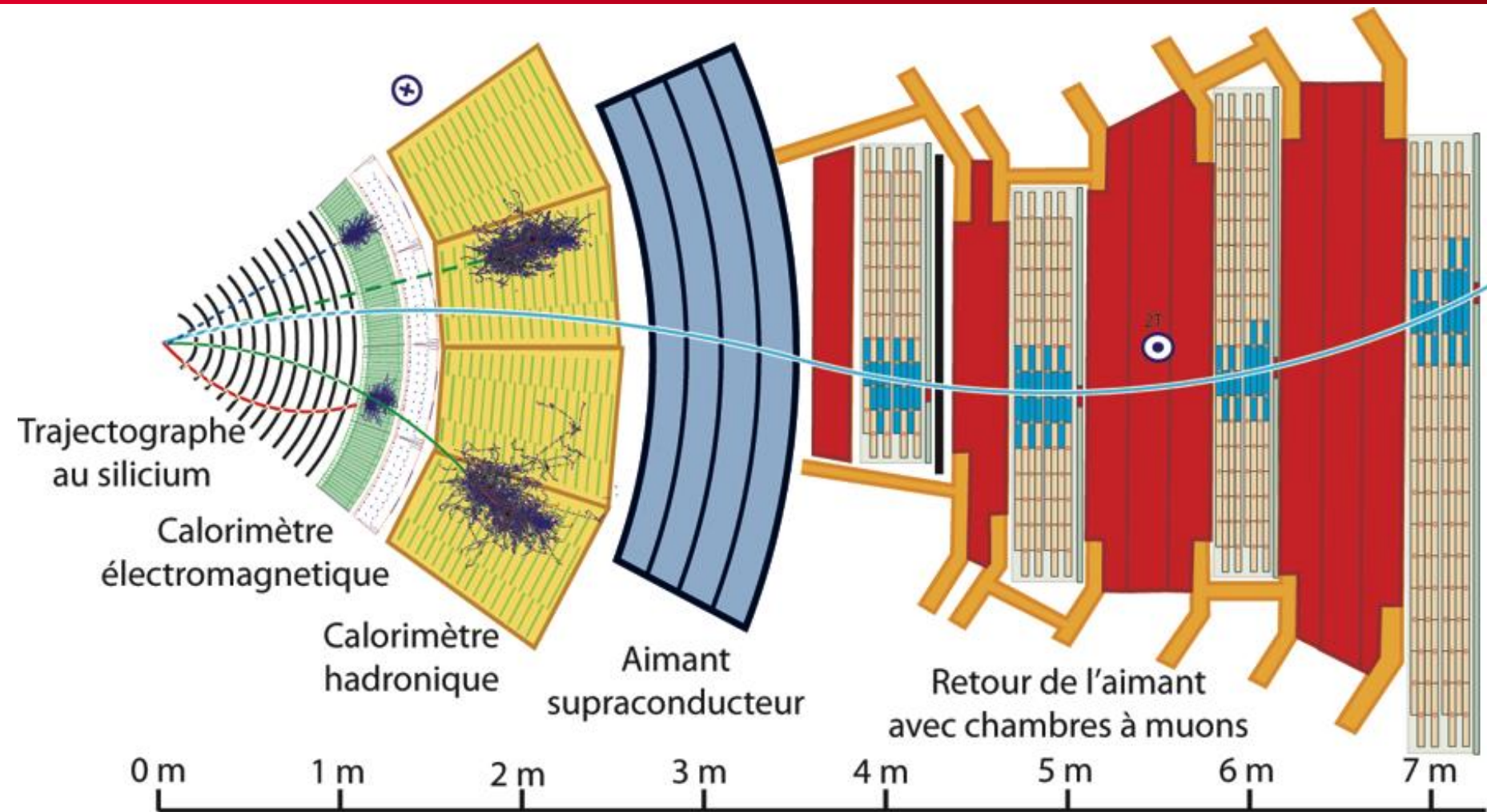




The LHC accelerator



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



légende :

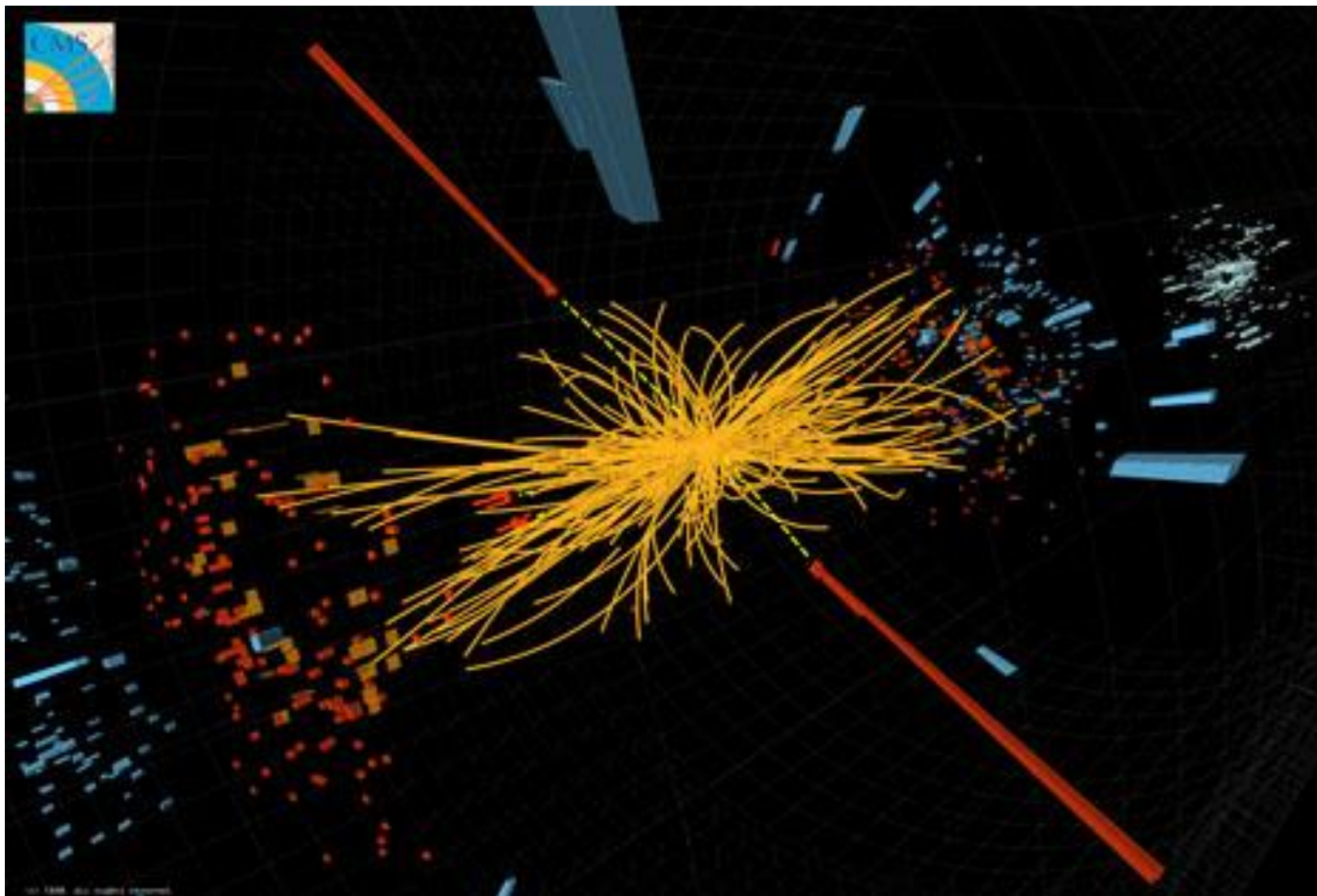
Muon

Électron

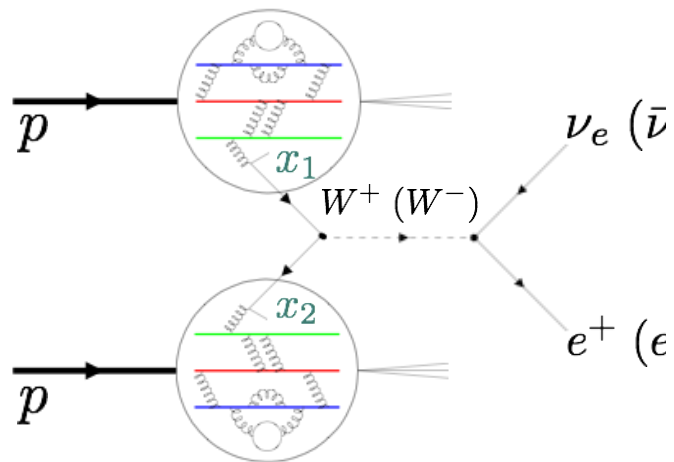
Hadron chargé

Hadron neutre

Photon



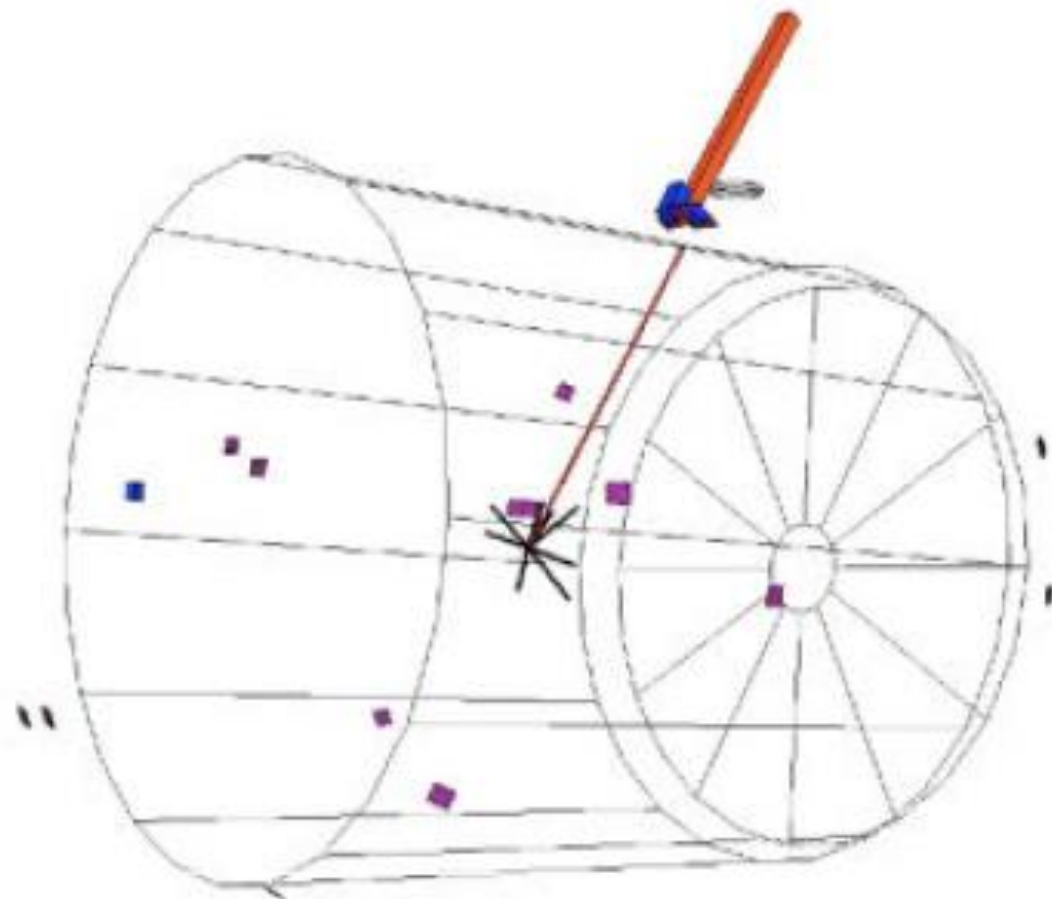
W EVENT -> ISOLATED LEPTON



“Did you see it?”

“No nothing.”

“Then it was a neutrino!”



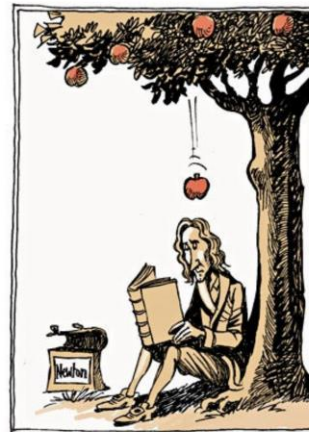
STAR experiment at BNL

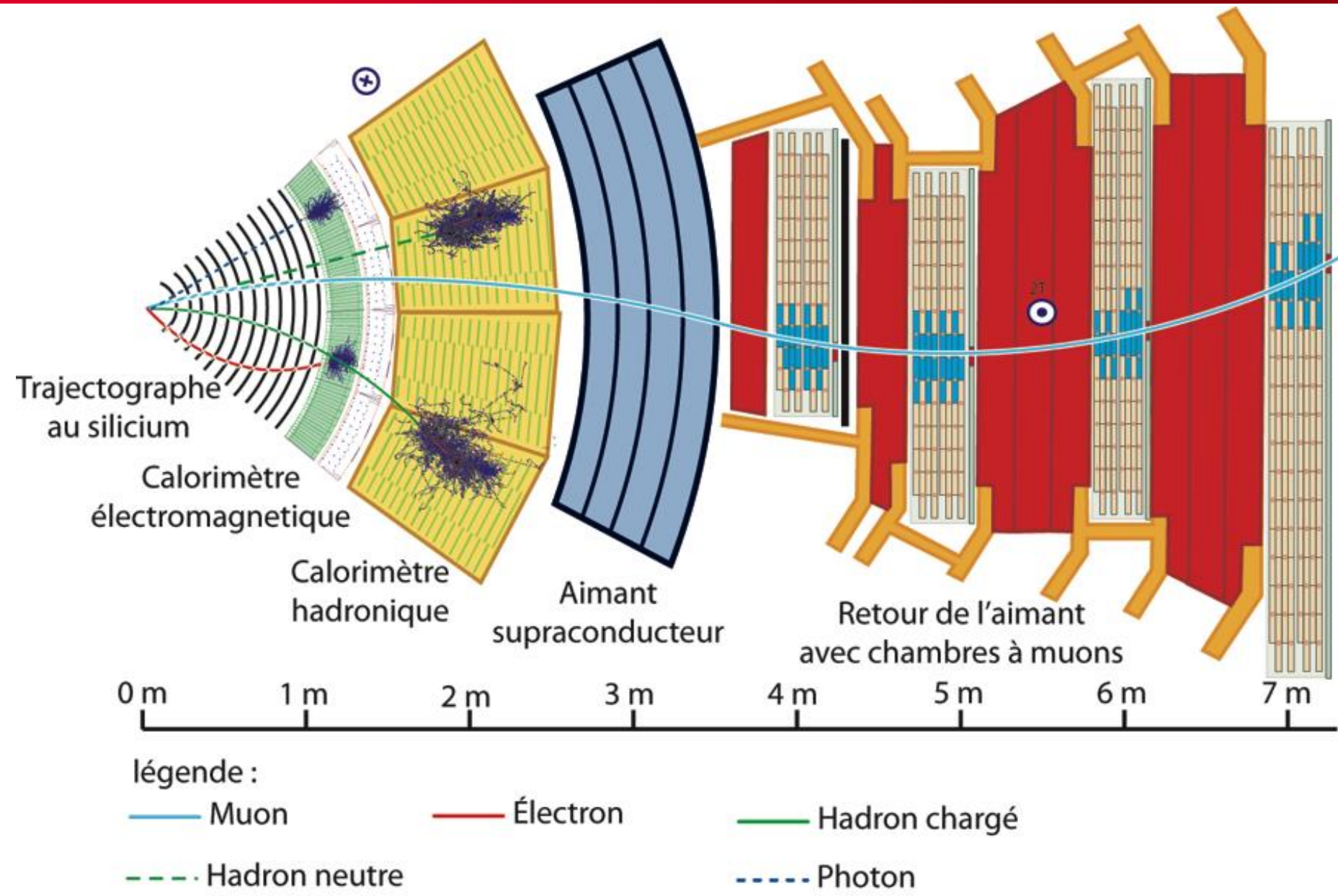
Cours 2 : Les détecteurs de particules

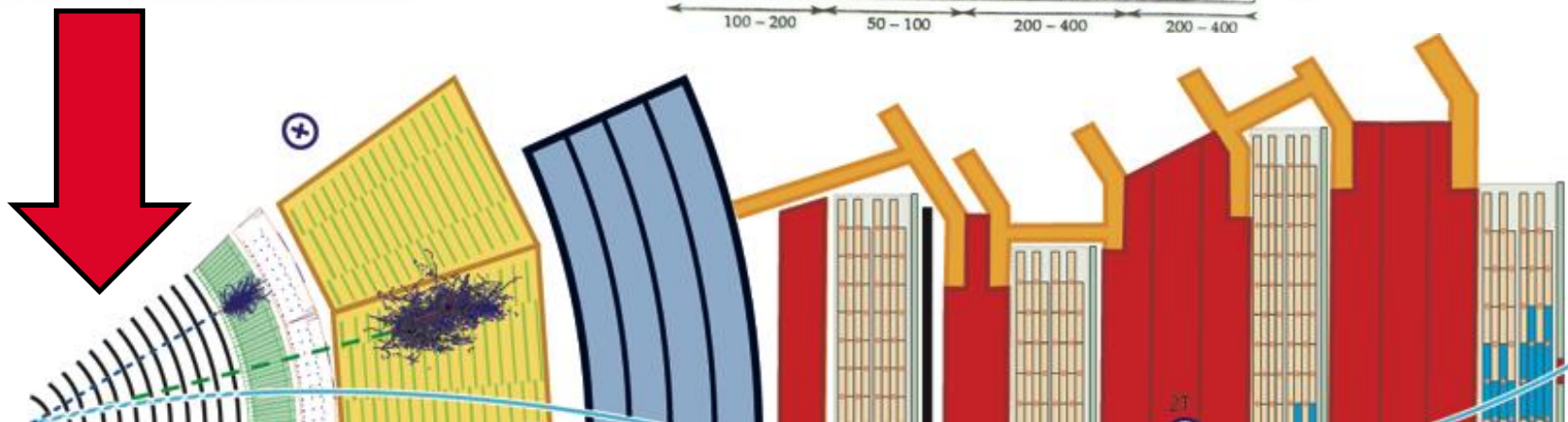
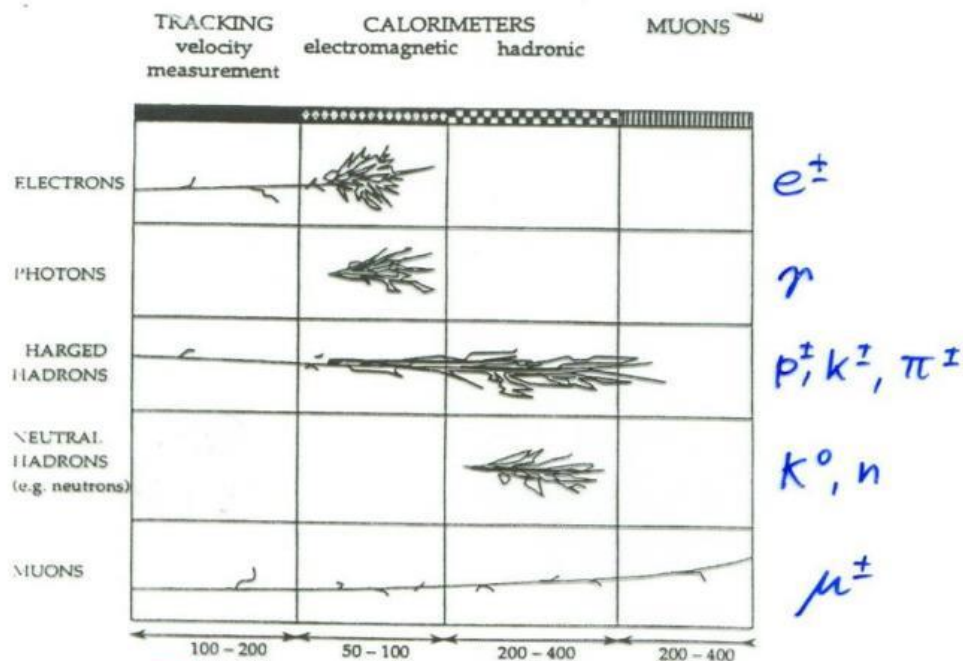
- Détecteurs au Silicium
- Calorimétrie
- Scintillation
- Détecteurs Gazeux

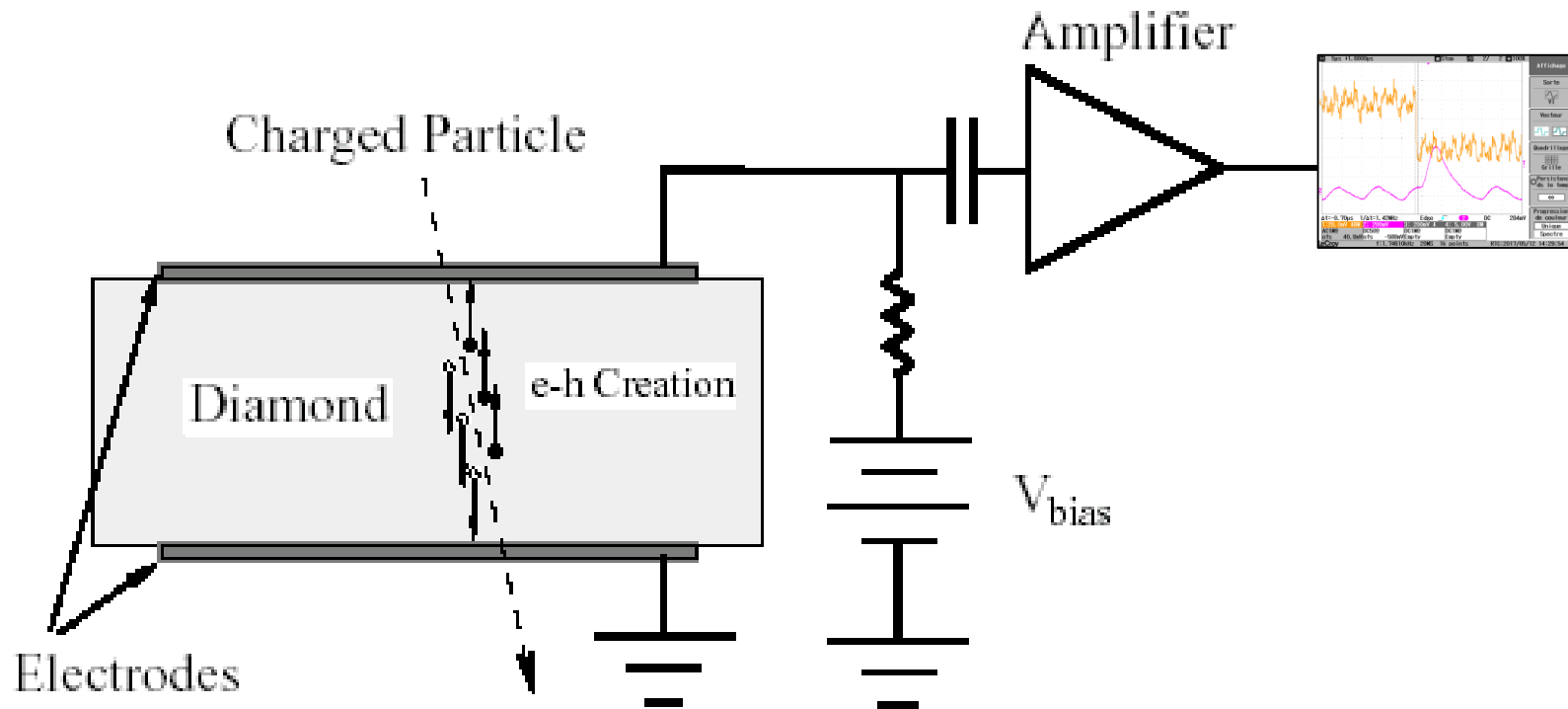
Basé sur les cours de Stefano Panebianco (CEA/IRFU),
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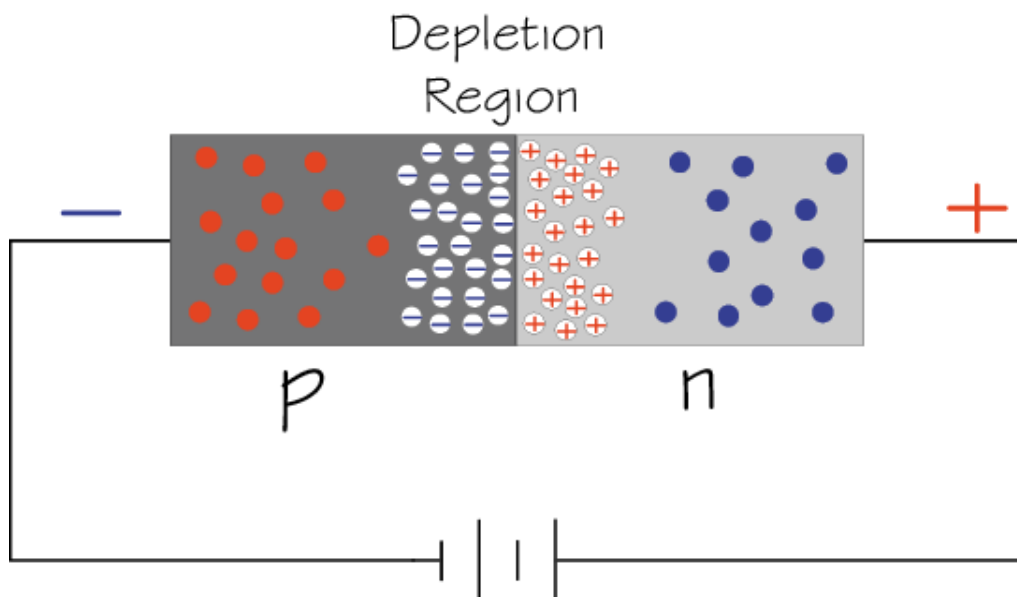
Collisions That Changed The World



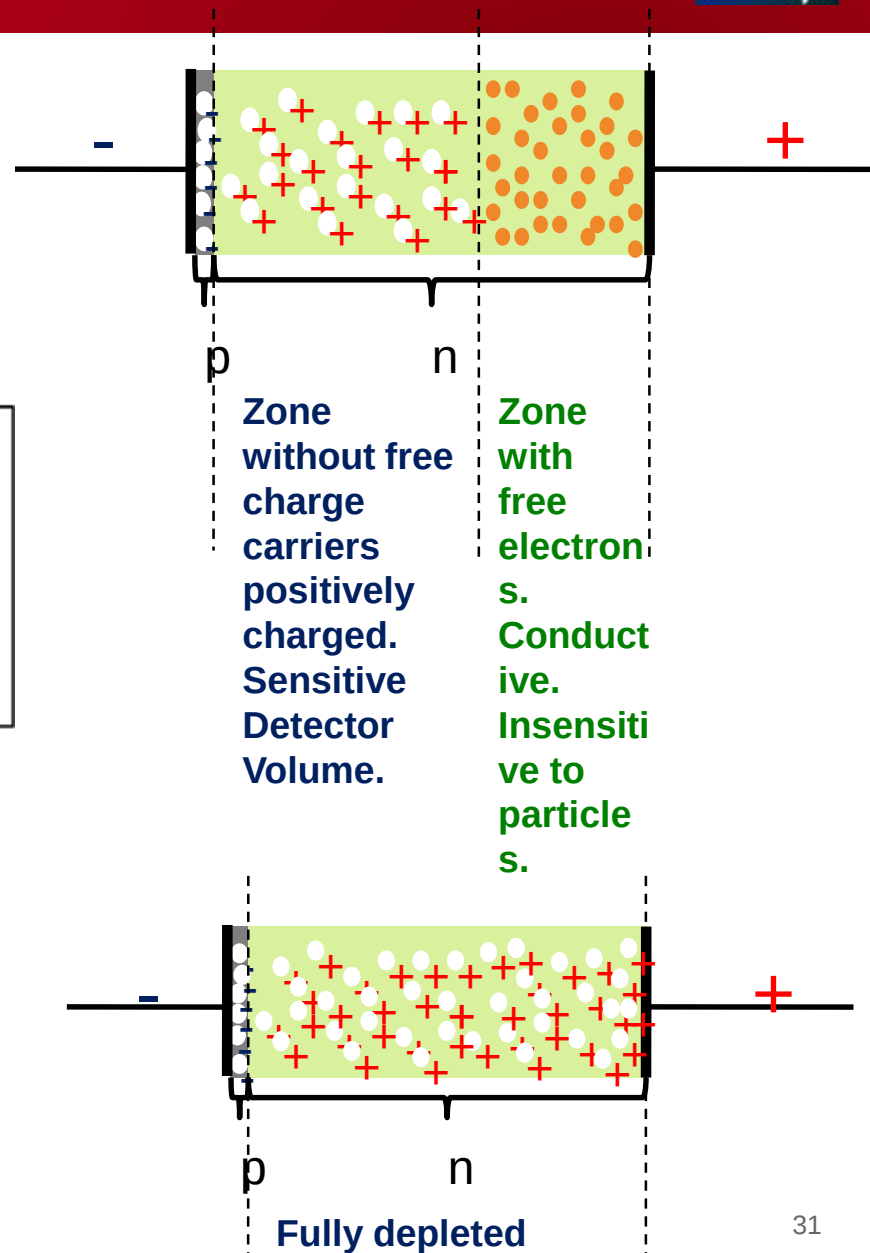






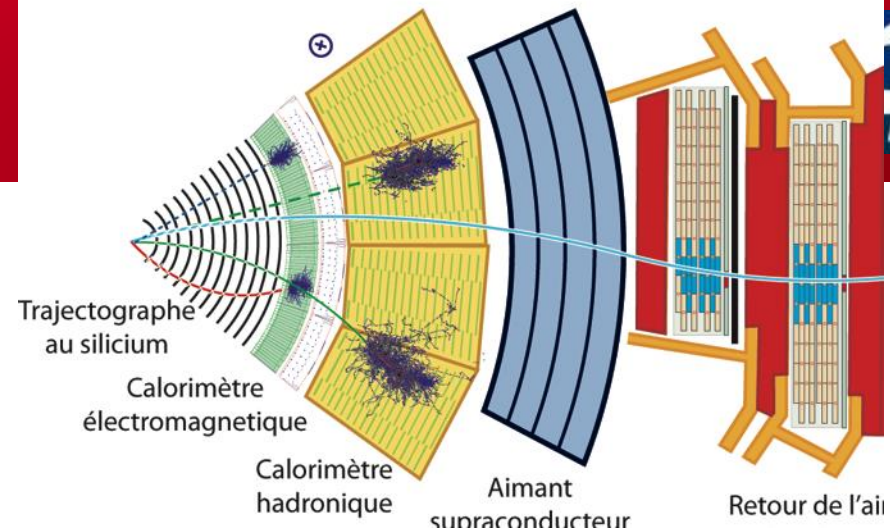


- Electron
- ⊕ Positive ion from removal of electron in n-type impurity
- ⊖ Negative ion from filling in p-type vacancy
- Hole

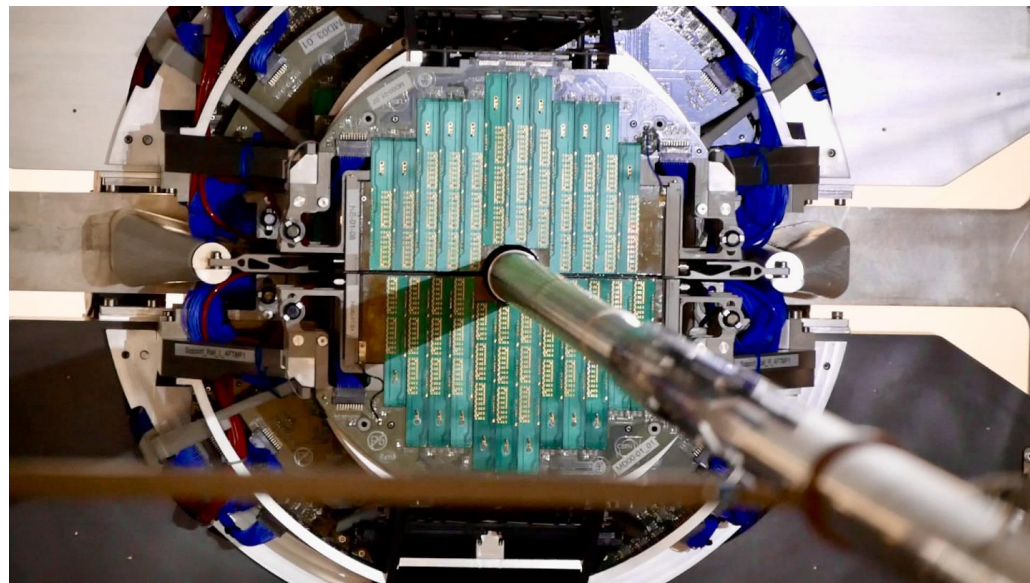




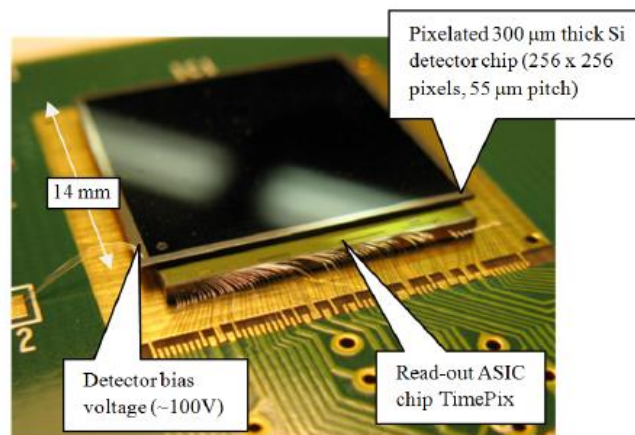
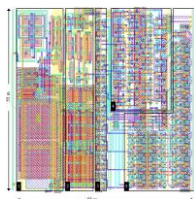
Si Tracker



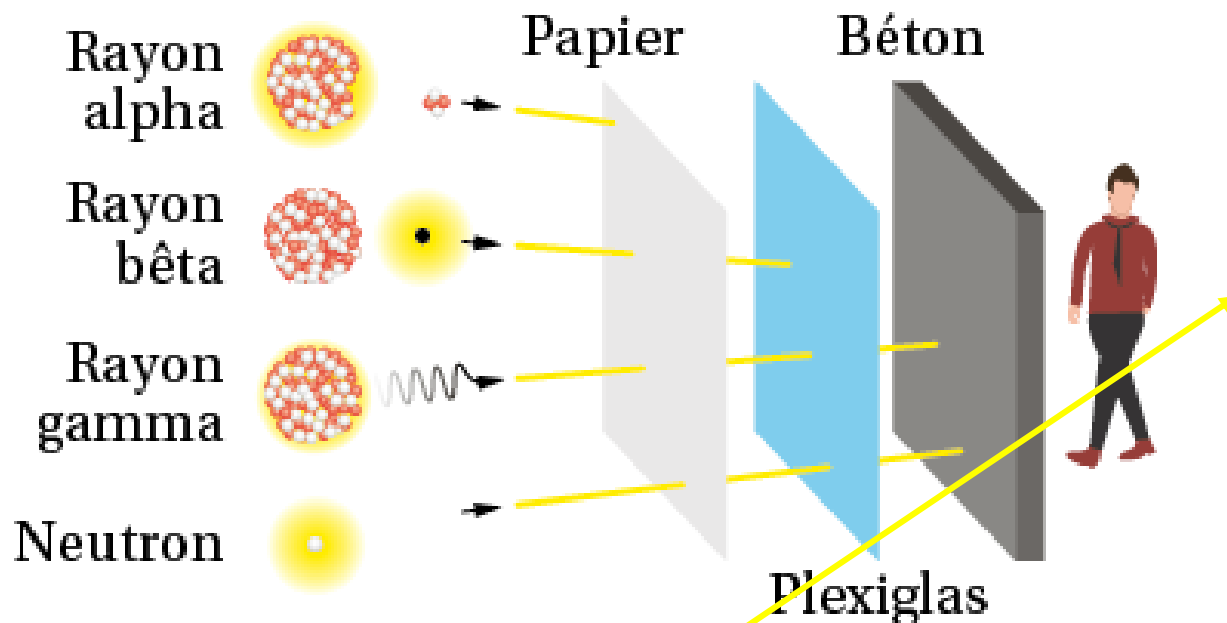
ALICE – MFT (Muon Forward Tracker)



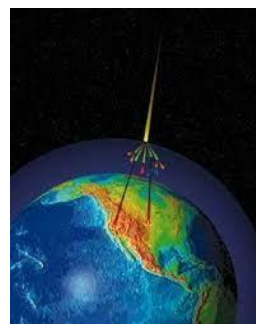
Et si on en observait ?



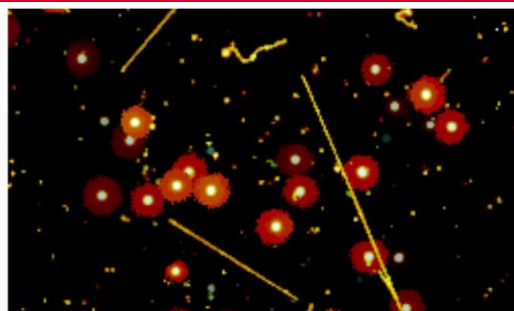
Sensor Material:	Si
Sensor Thickness:	300 μm and 500 μm
Sensitive Area:	14 mm x 14 mm
Number of Pixels:	256 x 256
Pixel Pitch:	55 μm
Resolution:	9 lp/mm
Readout Speed:	55 frames/s
Threshold Step Resolution:	0.1 keV
Energy Resolution:	0.8 keV (THL) and 2 keV (ToT)
Min Detectable Energy:	5 keV for X-rays
Photon Counting Speed:	up to 3×10^6 photons/s/pixel
Readout Chip:	Timepix
Pixel Mode of Operation:	Counting, Time-over-Threshold, Time-of-Arrival
Connectivity:	USB 2.0
Dimensions:	89 mm x 21 mm x 10 mm (L x W x H)
Weight:	30 g
Software:	Pixet PRO or ask for RadView radiation visualization software



Muon



QUARKS	mass $\approx 2.3 \text{ MeV}/c^2$ charge $+\frac{2}{3}$ spin $\frac{1}{2}$	mass $\approx 1.275 \text{ GeV}/c^2$ charge $+\frac{2}{3}$ spin $\frac{1}{2}$	mass $\approx 173.07 \text{ GeV}/c^2$ charge $+\frac{2}{3}$ spin $\frac{1}{2}$	0 0 1	mass $\approx 126 \text{ GeV}/c^2$
	u up	c charm	t top	g gluon	H Higgs boson
	mass $\approx 4.8 \text{ MeV}/c^2$ charge $-\frac{1}{3}$ spin $\frac{1}{2}$	mass $\approx 95 \text{ MeV}/c^2$ charge $-\frac{1}{3}$ spin $\frac{1}{2}$	mass $\approx 4.18 \text{ GeV}/c^2$ charge $-\frac{1}{3}$ spin $\frac{1}{2}$	0 0 1	
	d down	s strange	b bottom	γ photon	
LEPTONS	mass $0.511 \text{ MeV}/c^2$ charge -1 spin $\frac{1}{2}$	mass $105.7 \text{ MeV}/c^2$ charge -1 spin $\frac{1}{2}$	mass $1.777 \text{ GeV}/c^2$ charge -1 spin $\frac{1}{2}$	91.2 GeV/c ² 0 1	
	e electron	μ muon	τ tau	Z Z boson	
	mass $< 2.2 \text{ eV}/c^2$ 0 $\frac{1}{2}$	mass $< 0.17 \text{ MeV}/c^2$ 0 $\frac{1}{2}$	mass $< 15.5 \text{ MeV}/c^2$ 0 $\frac{1}{2}$	80.4 GeV/c ² ± 1 1	W W boson
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino		



You will see that different types of radiation make different mysterious patterns on your screen:

Large roundish blobs by alpha particles, long strikes by cosmic muons, curving worms of electrons or small dots by gamma or X-rays.



From time to time even more rare can be observed: Delta electrons, recoiled nuclei, cascade of two or more nuclear transitions, proton tracks...

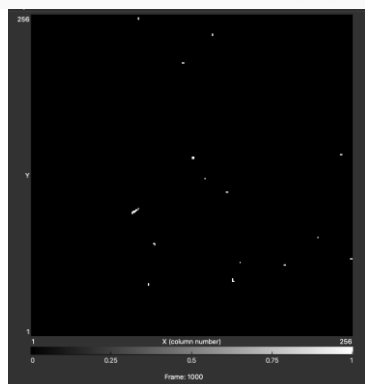
Rayon
alpha



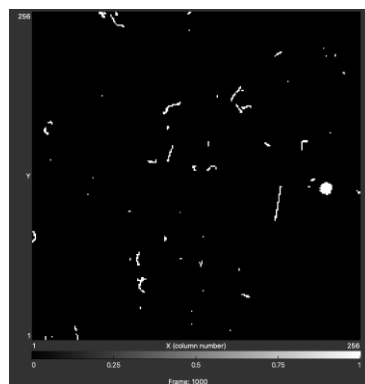
Rayon
bêta



Muon
Cosmique



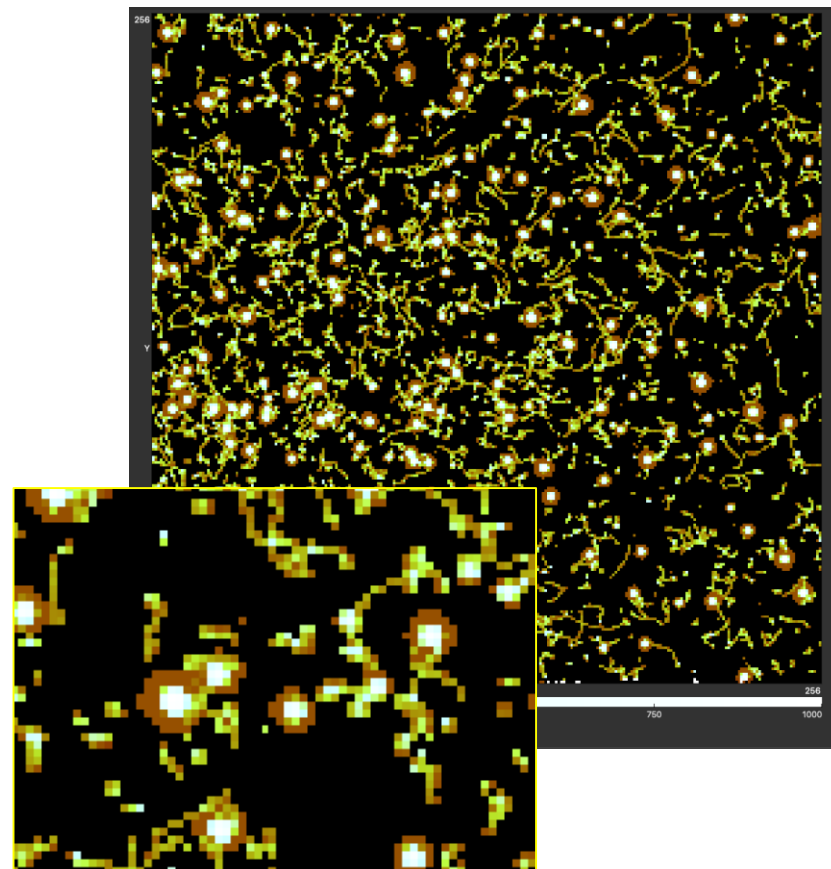
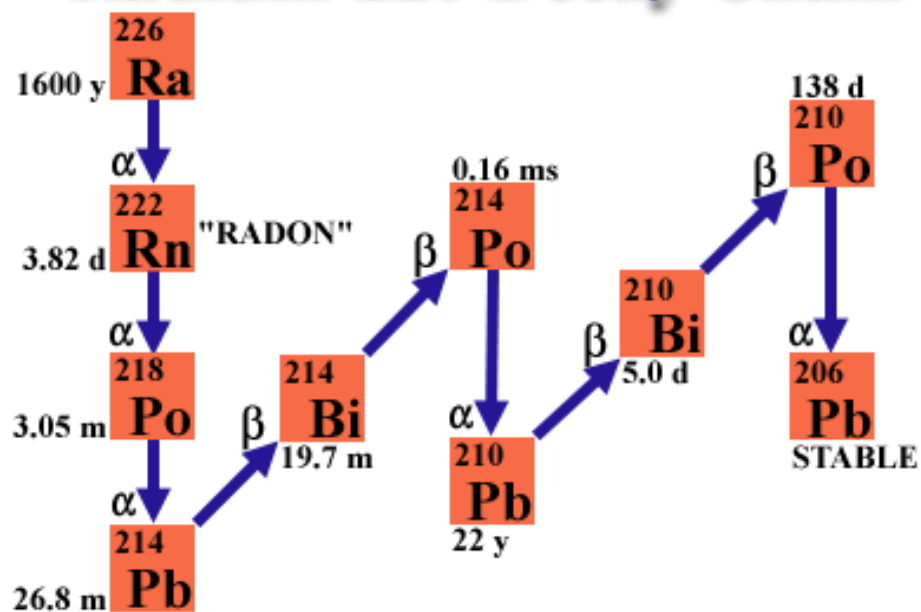
Surface



Granite

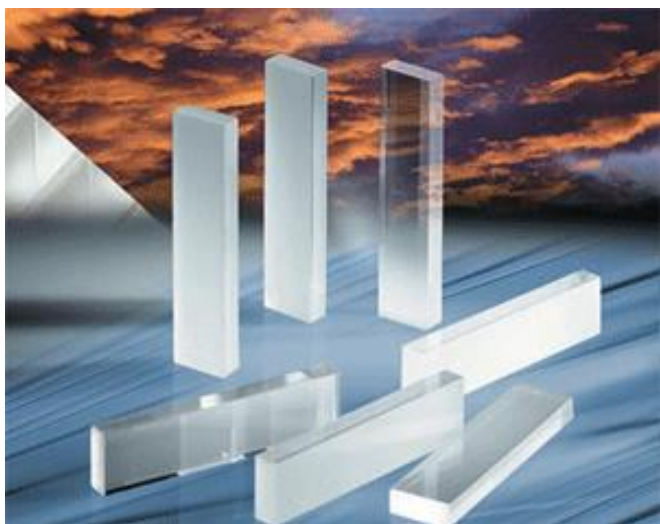
Et si on en observait ?

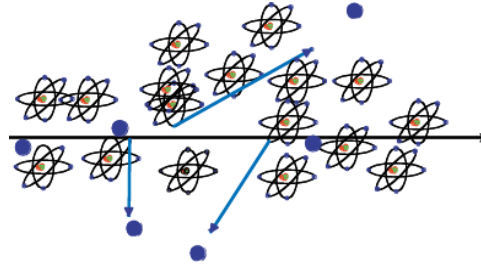
Radium-226 Decay Chain





Les Détecteur à base de scintillation



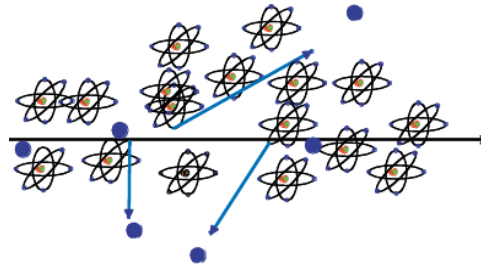


Detectors based on Registration of excited Atoms → Scintillators

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

What scintillates ?





Detectors based on Registration of excited Atoms → Scintillators

Emission of photons of 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	λ_{max}^b (nm)	Attenuation ^c length (cm)	Risetime (ns)	Decay ^d time (ns)	Pulse FWHM (ns)
NE 101A	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

LHC bunchcrossing 25ns

Inorganic (Crystal) Scintillators

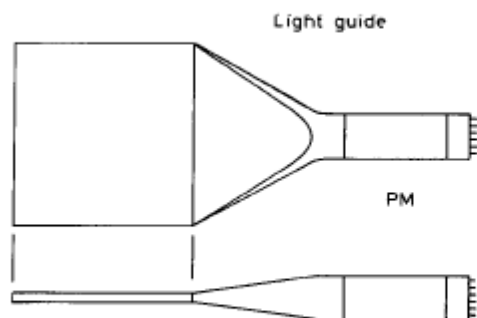
Large Light Yield

Slow: few 100ns

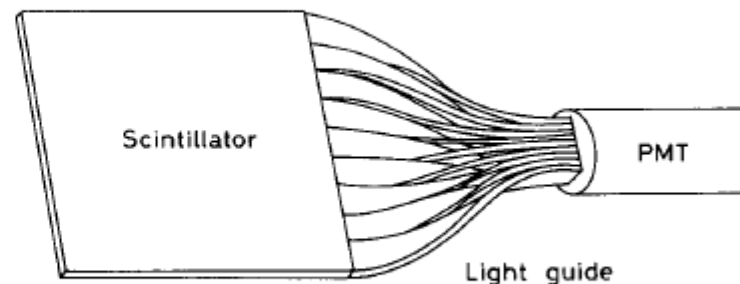
	Relative light output	λ_{max} emission (nm)	Decay time (ns)	Density (g/cm ³)
<i>Inorganic crystals</i>				
Nal(Tl)	230	415	230	3.67
CsI(Tl)	250	560	900	4.51
Bi ₄ Ge ₃ O ₁₂ (BGO)	23-86	480	300	7.13
<i>Organic crystals</i>				
Anthracene	100	448	22	1.25
Trans-stilbene	75	384	4.5	1.16
Naphthalene	32	330-348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

LEP bunchcrossing 25μs

- Light guides: transfer by total internal reflection (+outer reflector)



“fish tail”



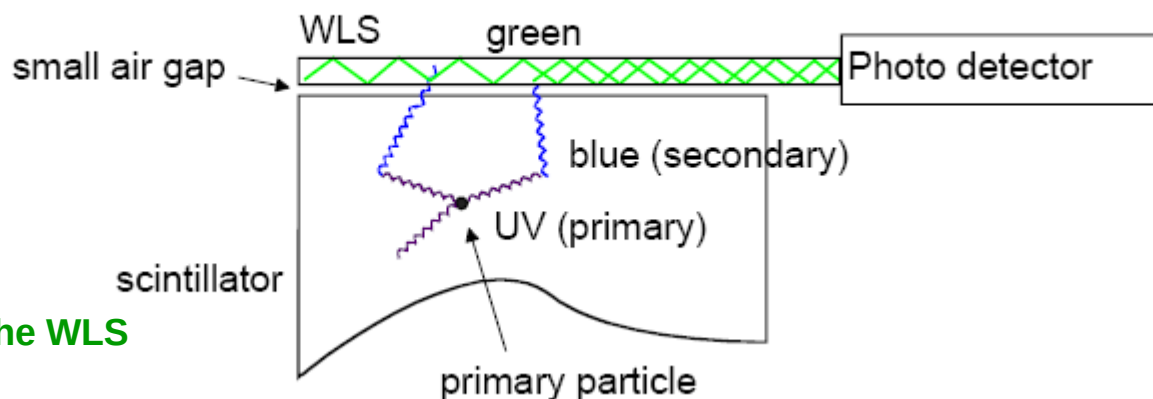
adiabatic

- wavelength shifter (WLS) bars

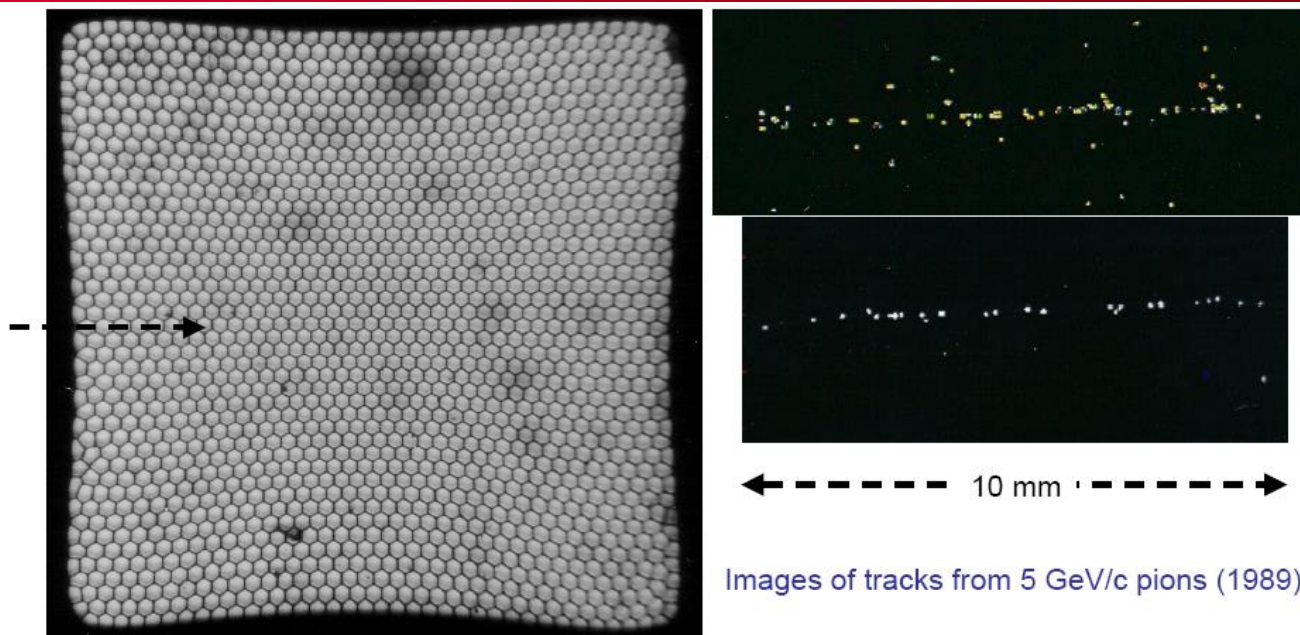
UV light enters the WLS material
Light is transformed into longer wavelength

→ Total internal reflection inside the WLS material

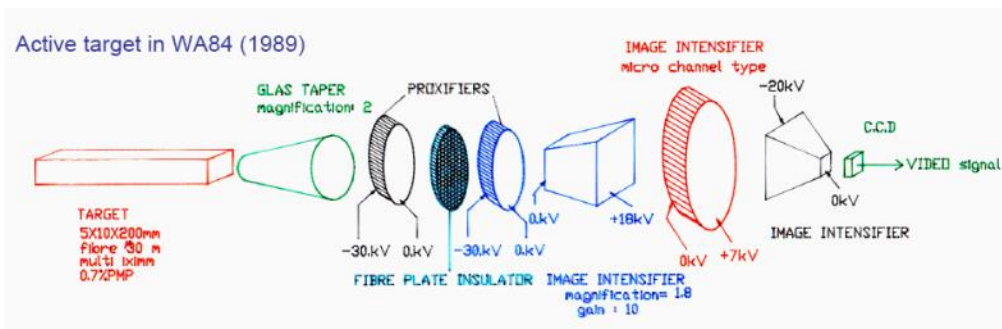
→ ‘transport’ of the light to the photo detector



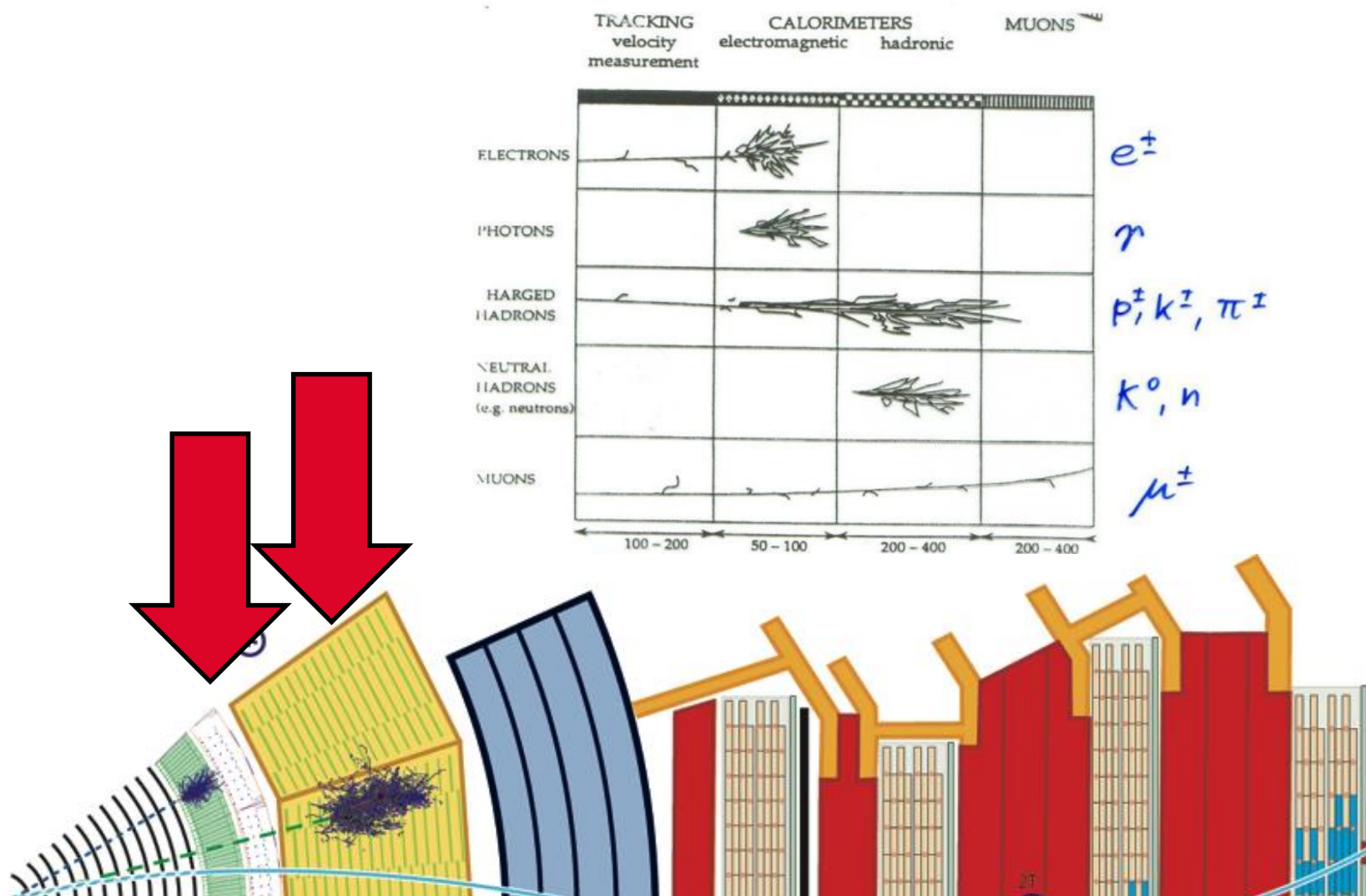
Fiber Tracking



Images of tracks from 5 GeV/c pions (1989)



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, N0. 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

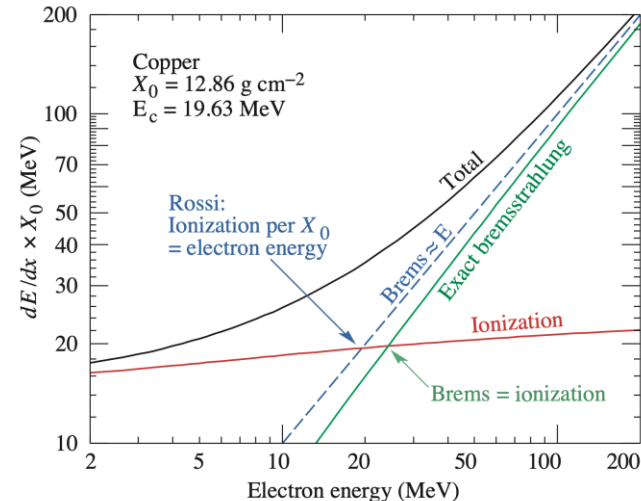
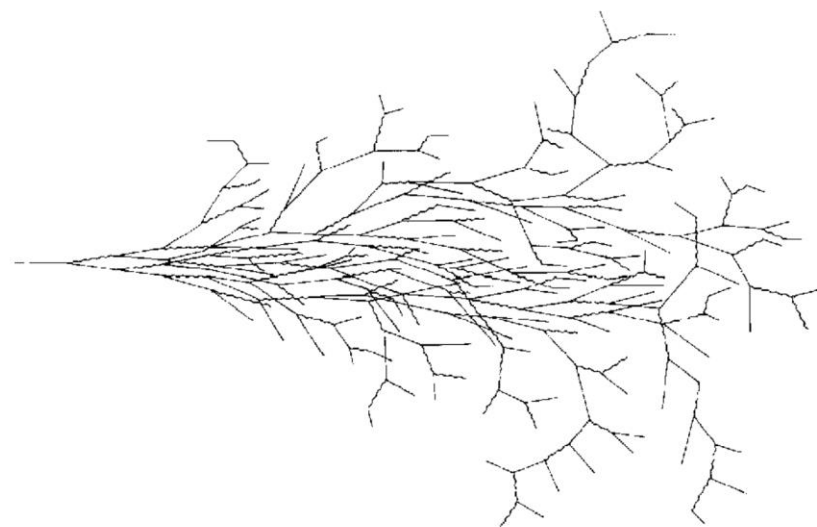
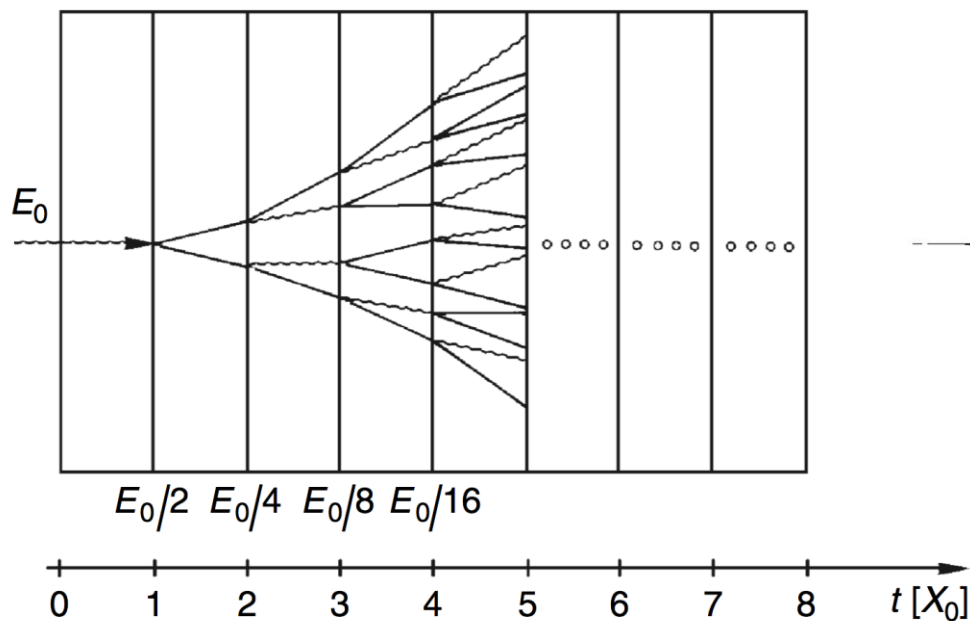


Figure 34.13: Two definitions of the critical energy E_c .



$$\frac{1}{X_0} = 4 \left(\frac{\hbar}{m_e c} \right)^2 Z(Z+1) \alpha^3 n_a \log \left(\frac{183}{Z^{1/3}} \right),$$

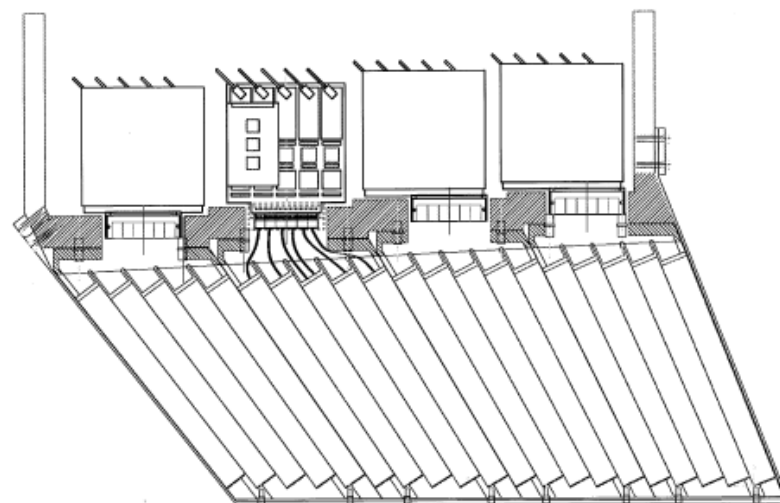
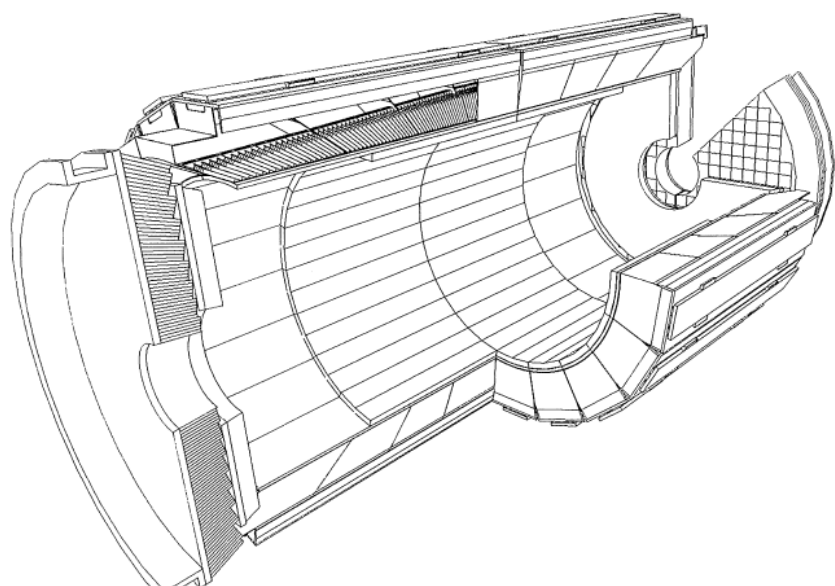
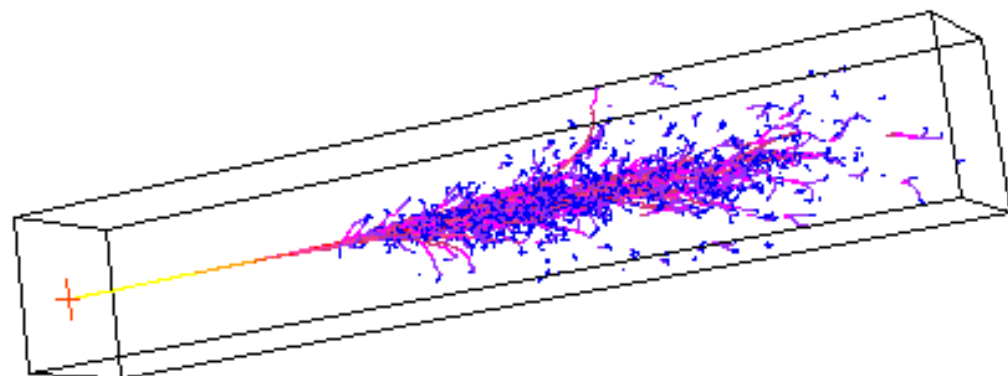
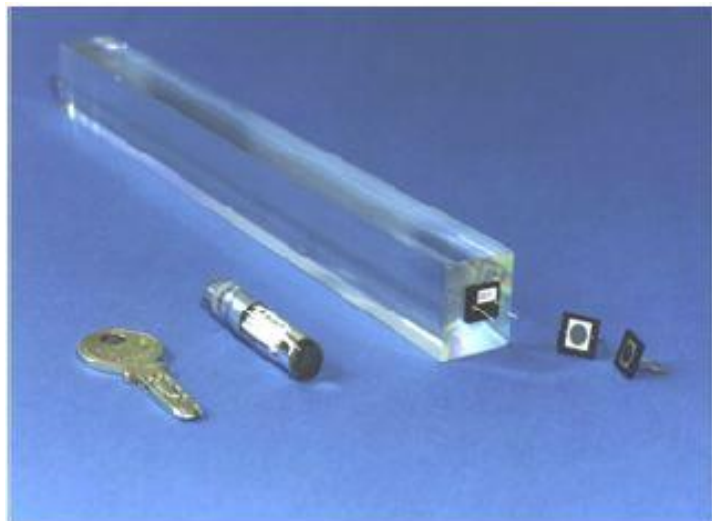


Fig. 2. Longitudinal drawing of module 2, showing the structure and the front-end electronics layout.

Hadron Calorimeters are Large because hadrons are hard to stop

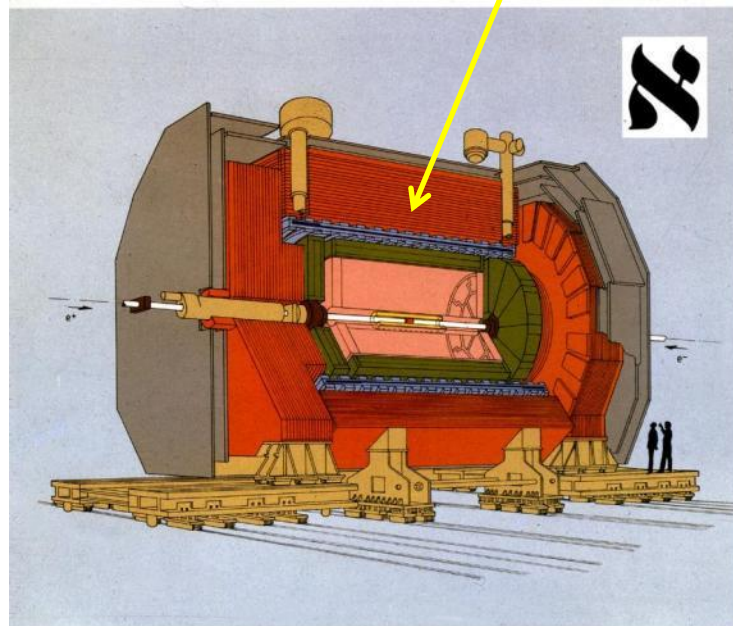
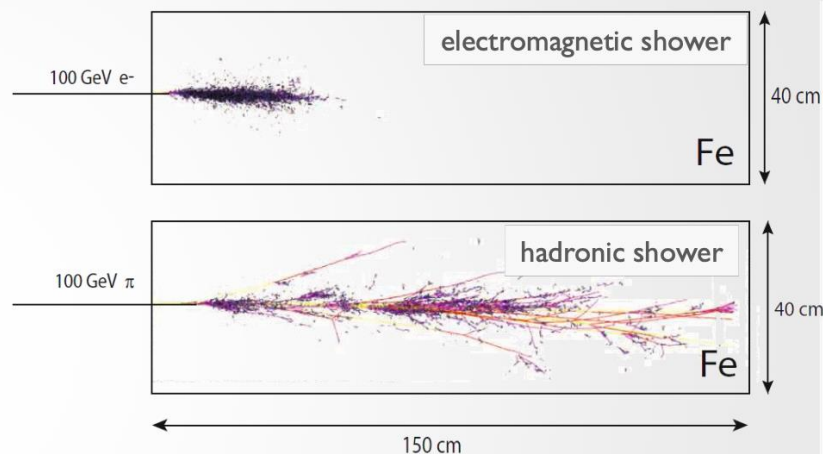


Fig. 1 - The ALEPH Detector

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

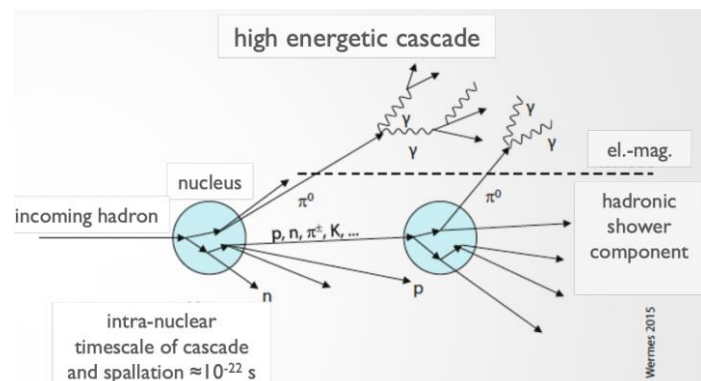
Hadron Calorimeters are large and heavy because the hadronic interaction length α , the 'strong interaction equivalent' to the EM radiation length X_0 , is large (5-10 times larger than X_0)

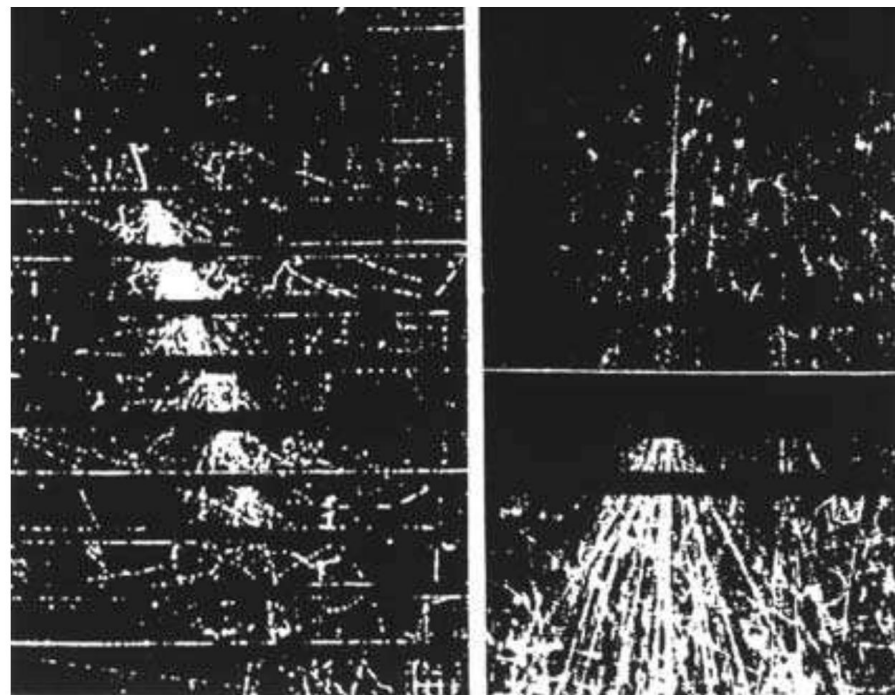
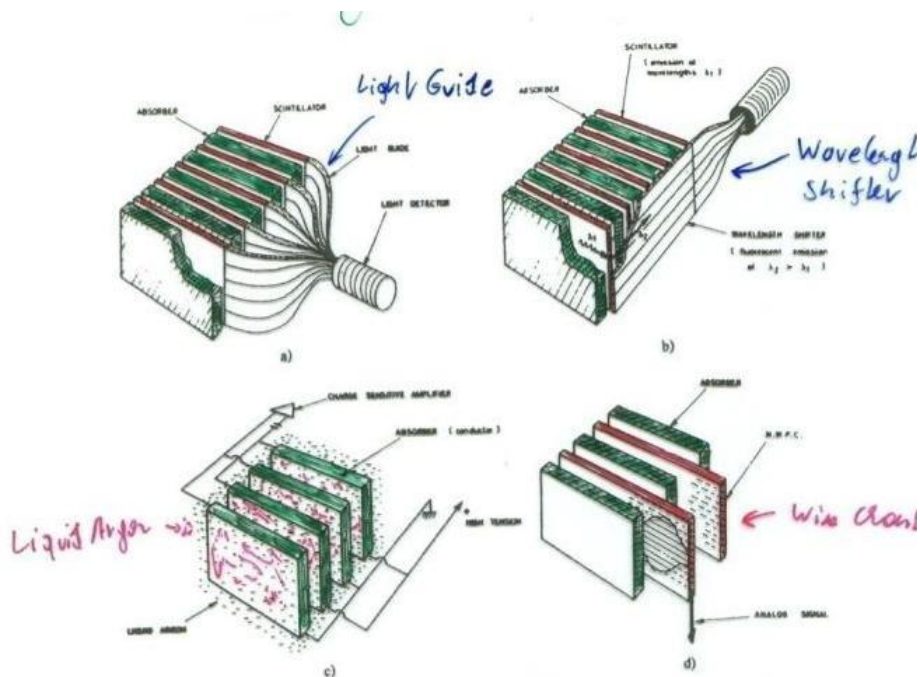


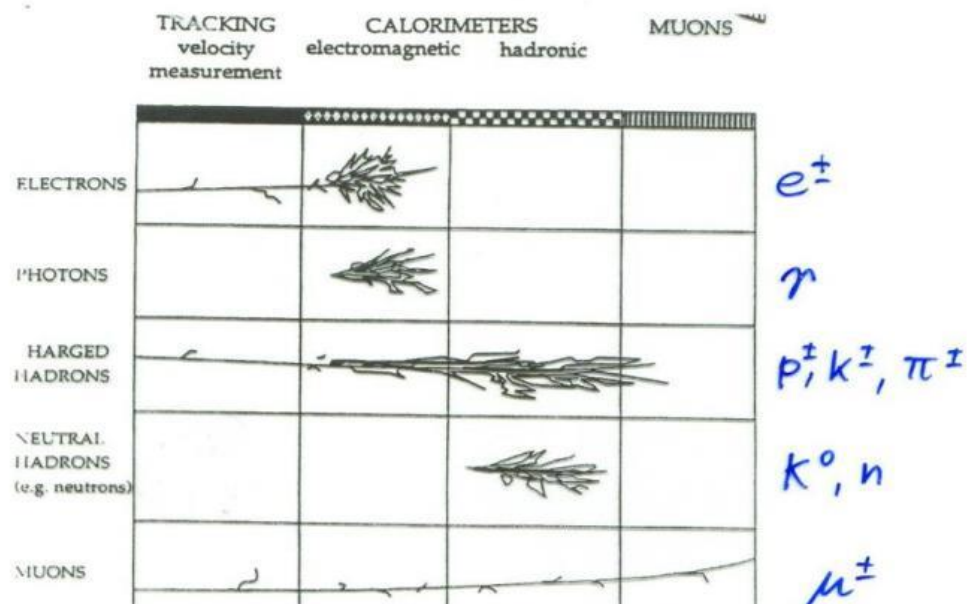
Material	Z	Density [g/cm ³]	E_c [MeV]	X_0 [cm]
C	6	2.2	81.7	19.3
Al	13	2.7	42.7	8.90
Fe	26	7.8	21.7	1.76
Cu	29	8.96	19.4	1.44
W	74	19.3	8.0	0.35
Pb	82	11.4	7.4	0.56

Material	Z	Density [g/cm ³]	λ [cm]
C	6	2.2	37.3
Al	13	2.7	35.4
Fe	26	7.8	15.1
Cu	29	8.96	13.9
W	74	19.3	8.9
Pb	82	11.4	15.7

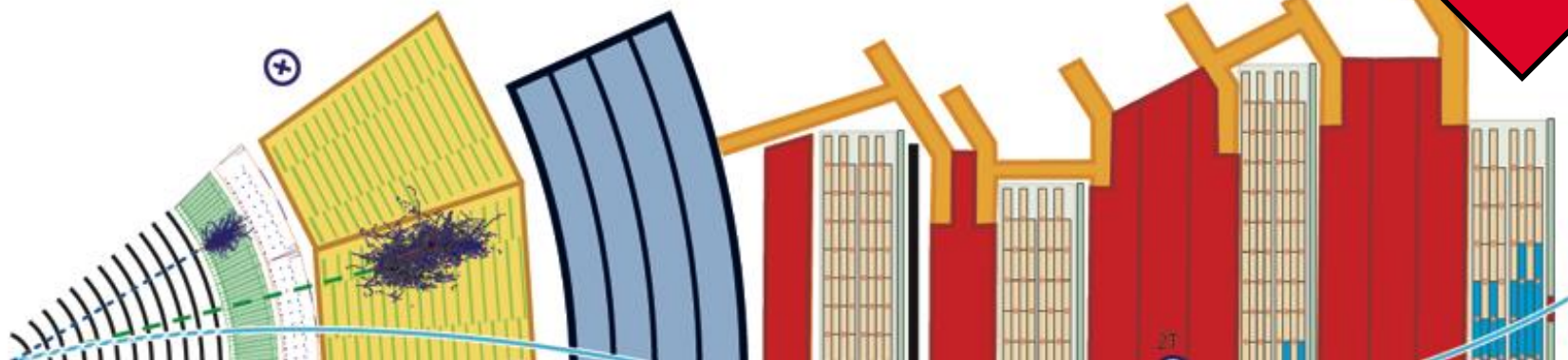
For 7TeV protons







Muon Chambers ->



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

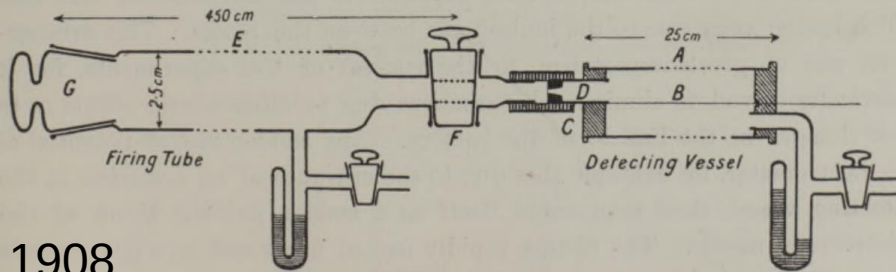
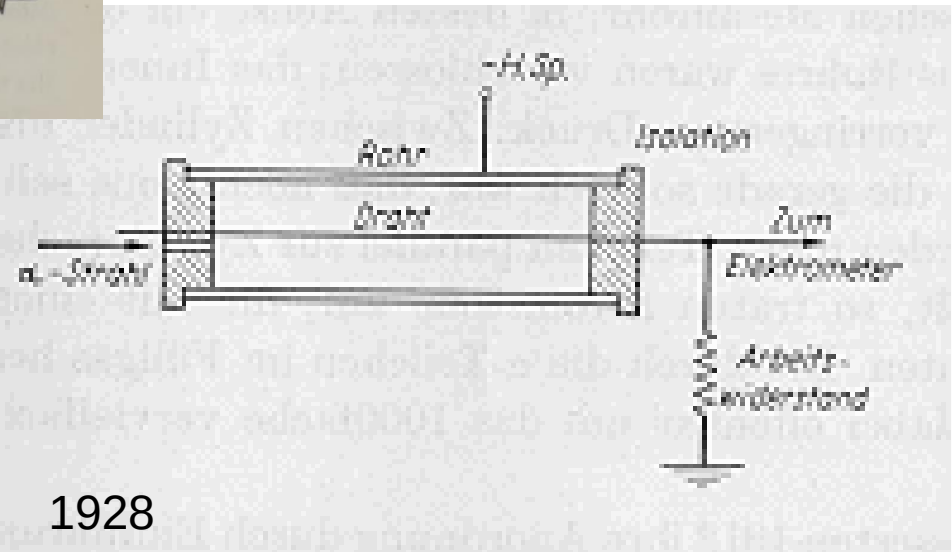


FIG. 1.

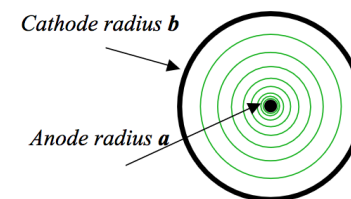
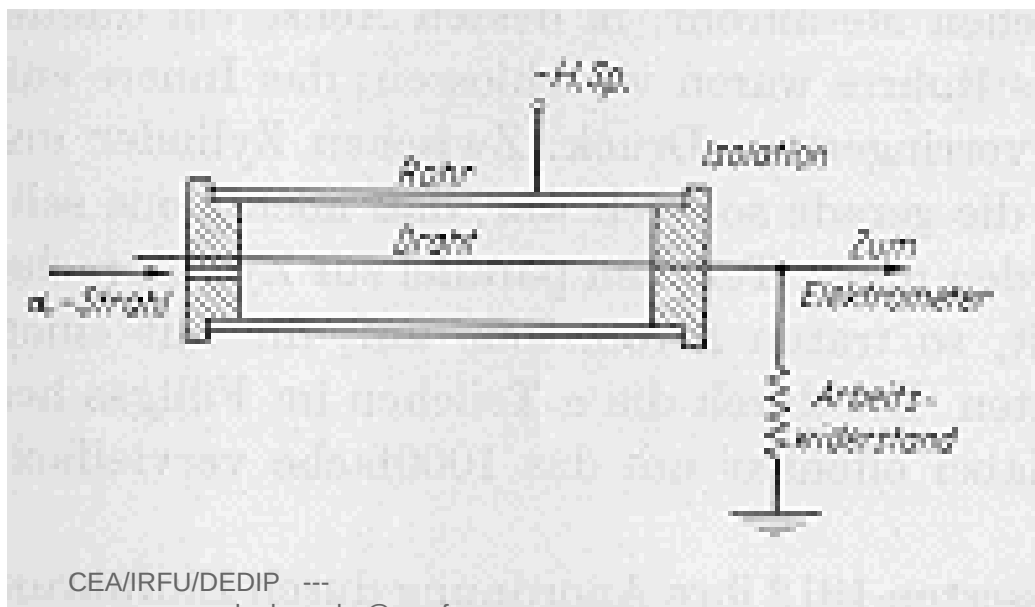
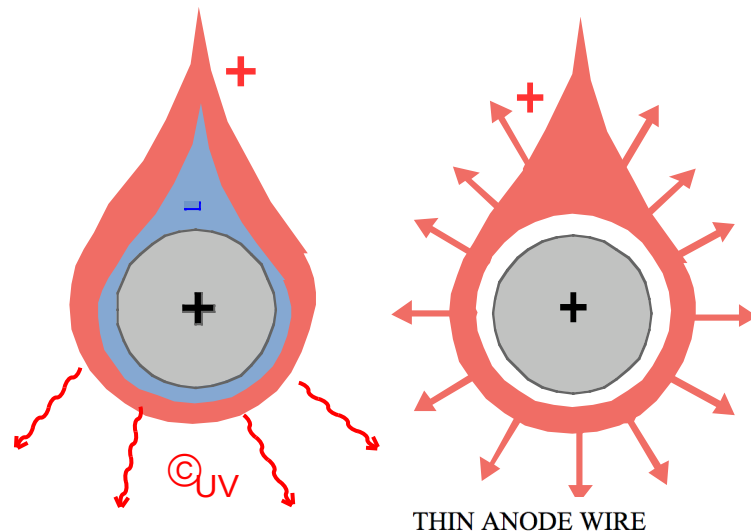
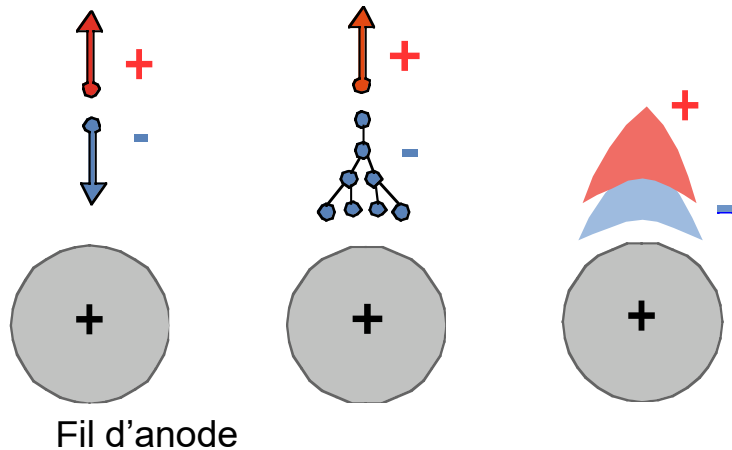
1908



1928

Dans les films





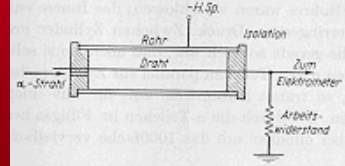
ELECTRIC FIELD AND POTENTIAL:

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

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

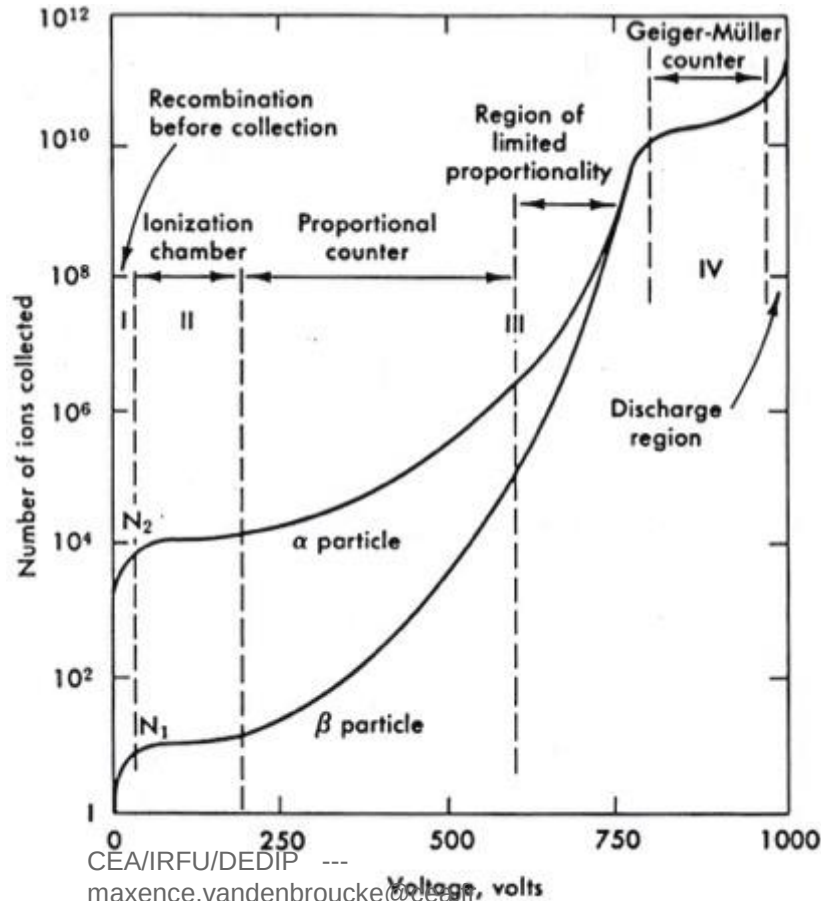
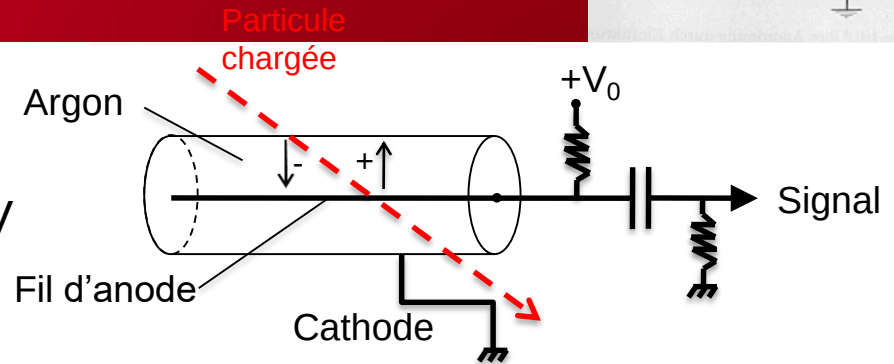
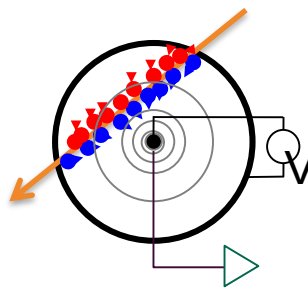
$$C = \frac{2\pi\epsilon_0}{\ln(b/a)} \quad \text{capacitance per unit length}$$

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



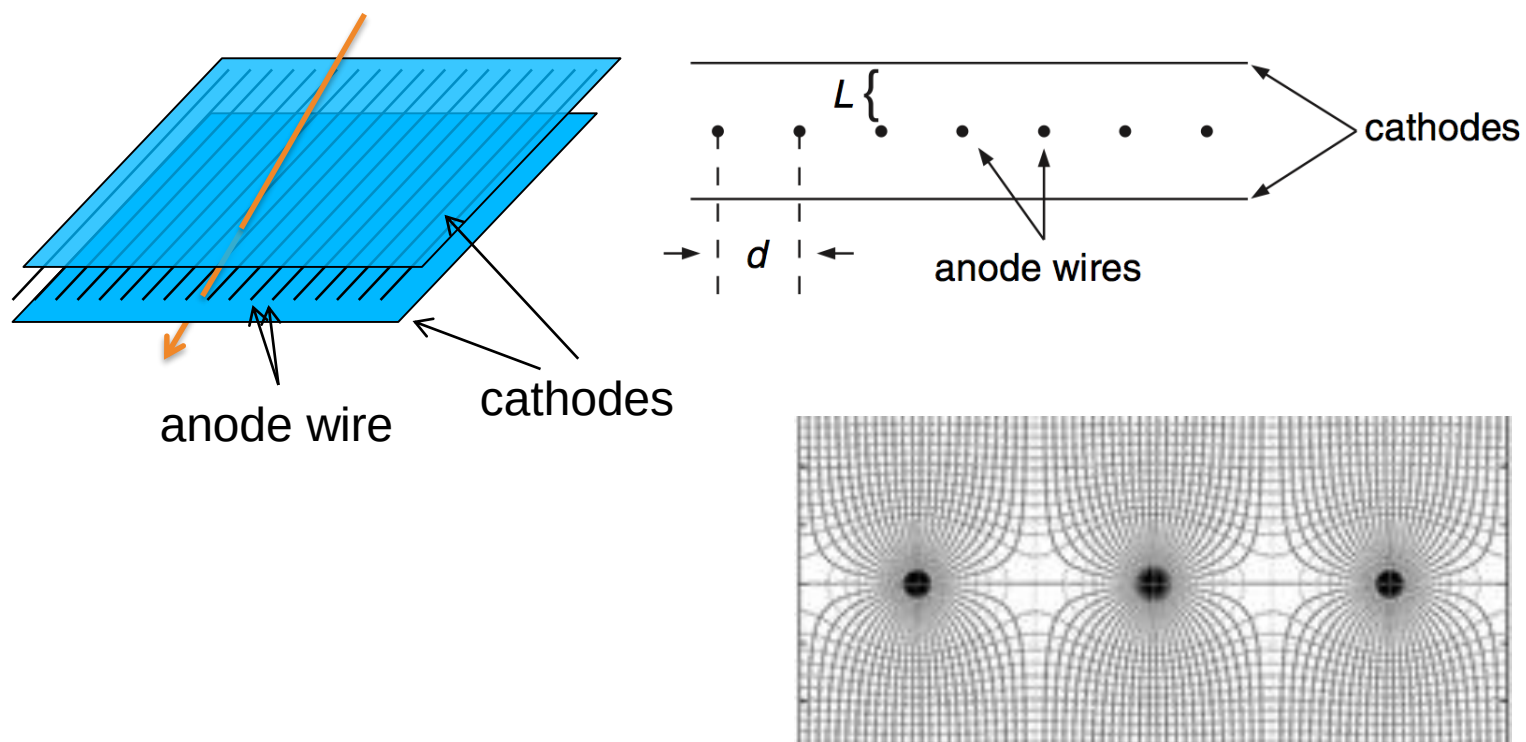
I: tension trop faible → recombinaison

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.



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



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.

Georges Charpak
CERN, Geneva, Switzerland

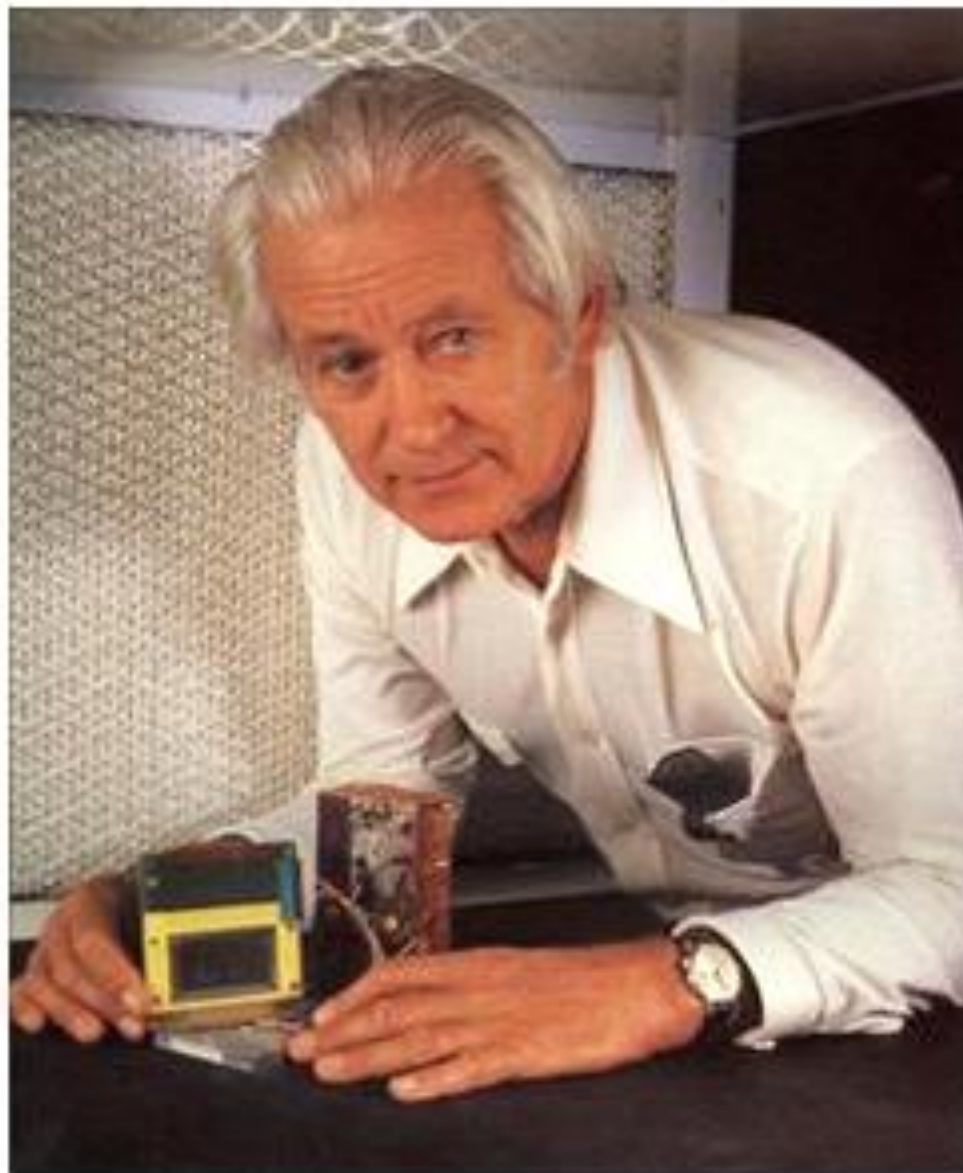
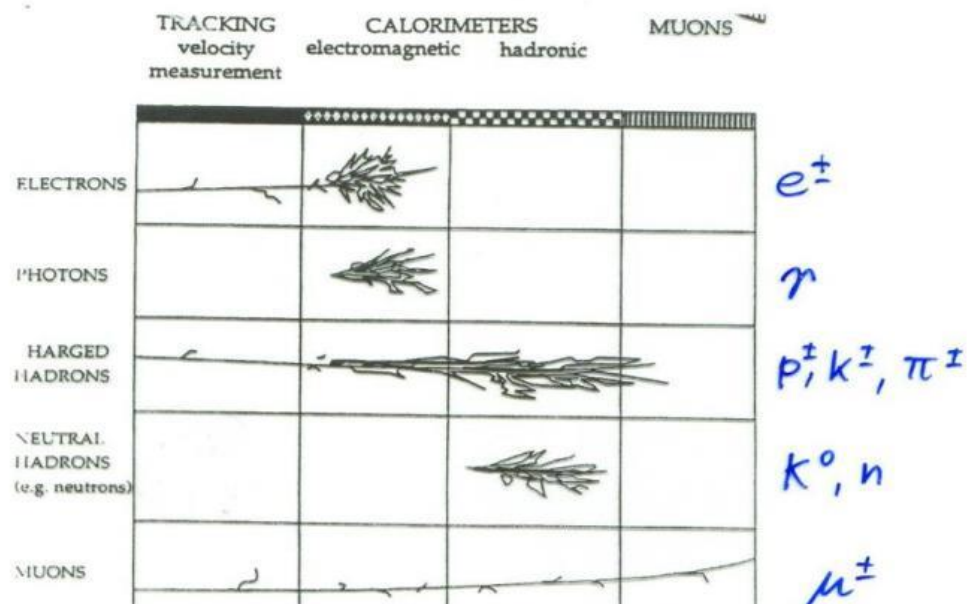


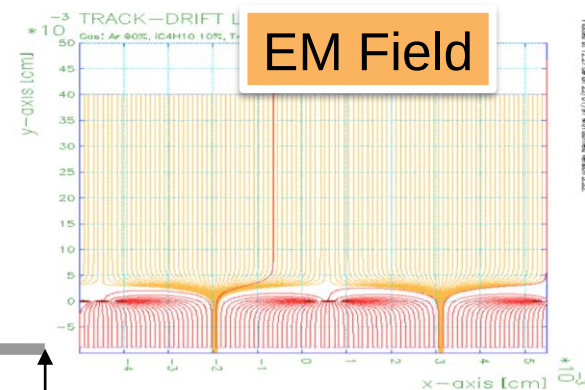
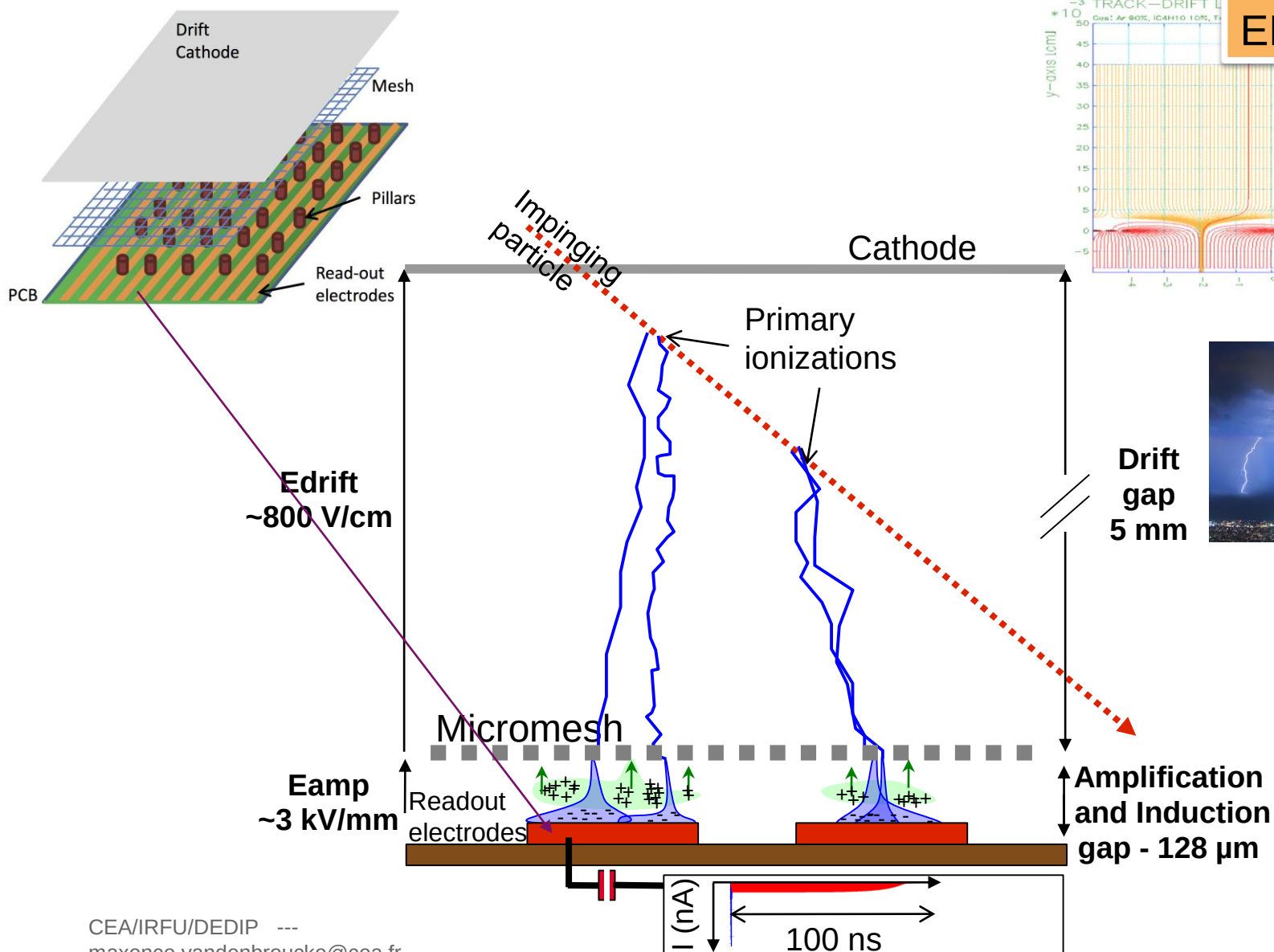
Photo: D. Parker, Science Photo Lab, UK

- 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

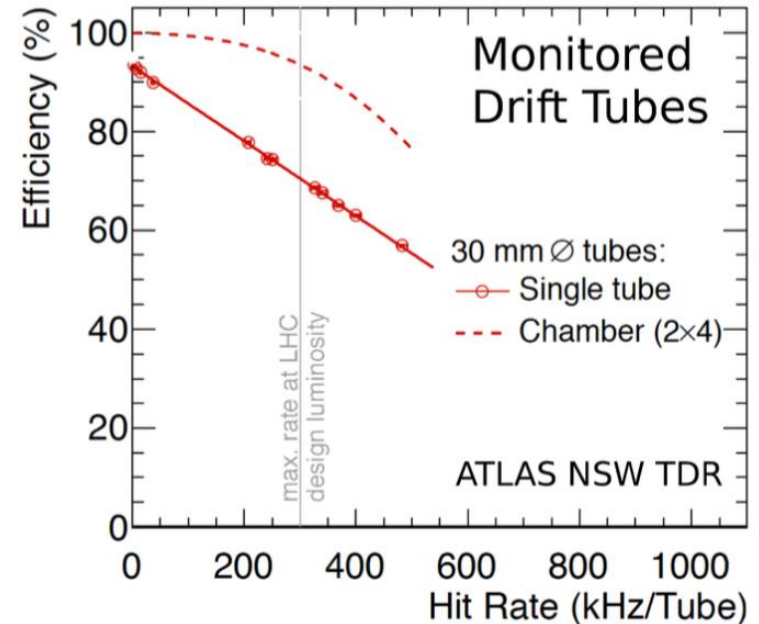
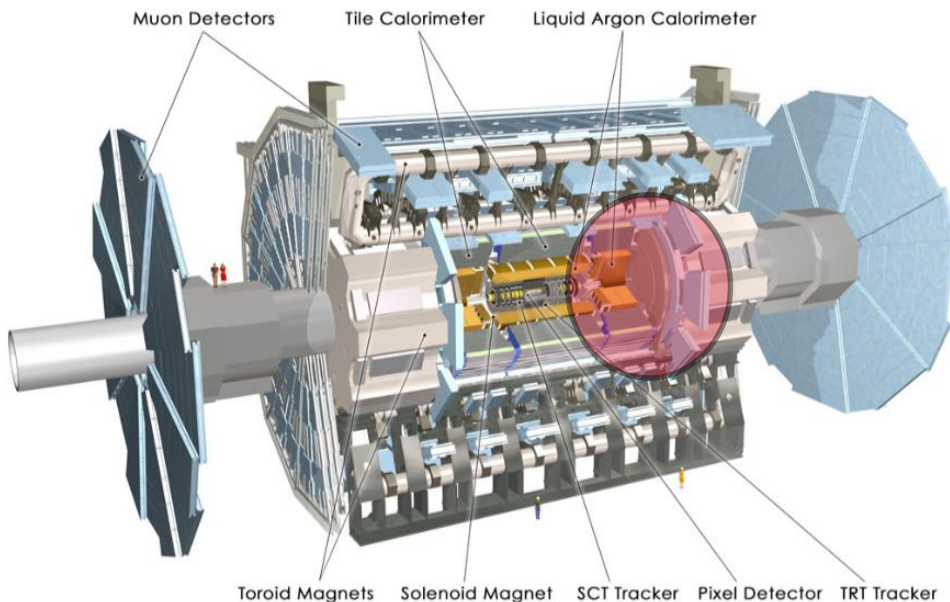
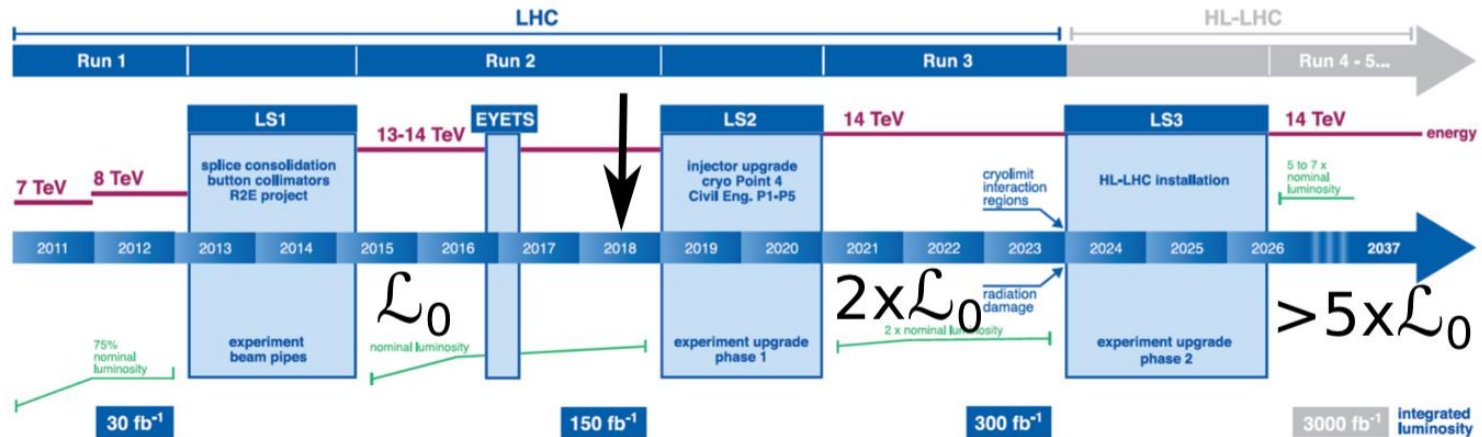


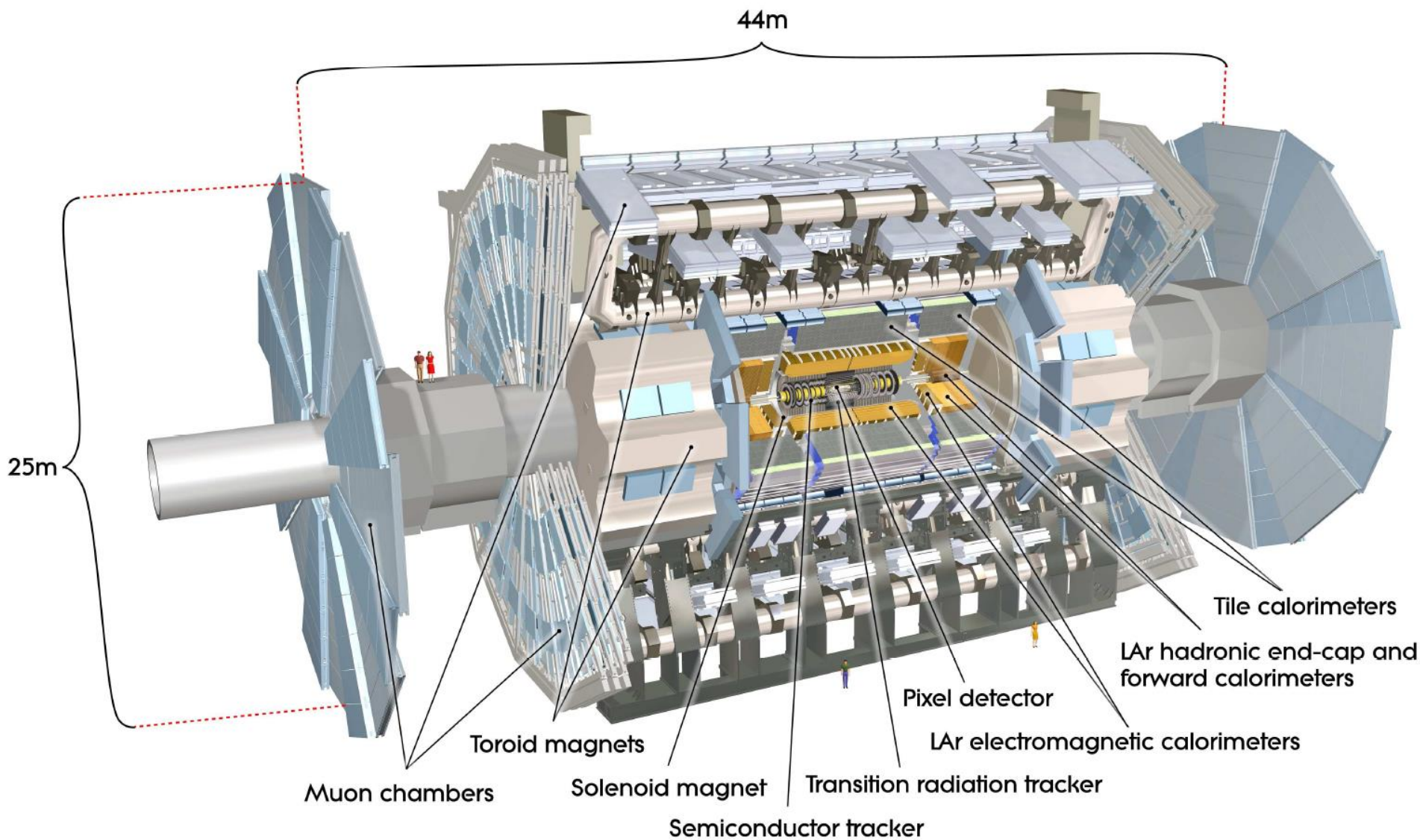
Muon Chambers ->

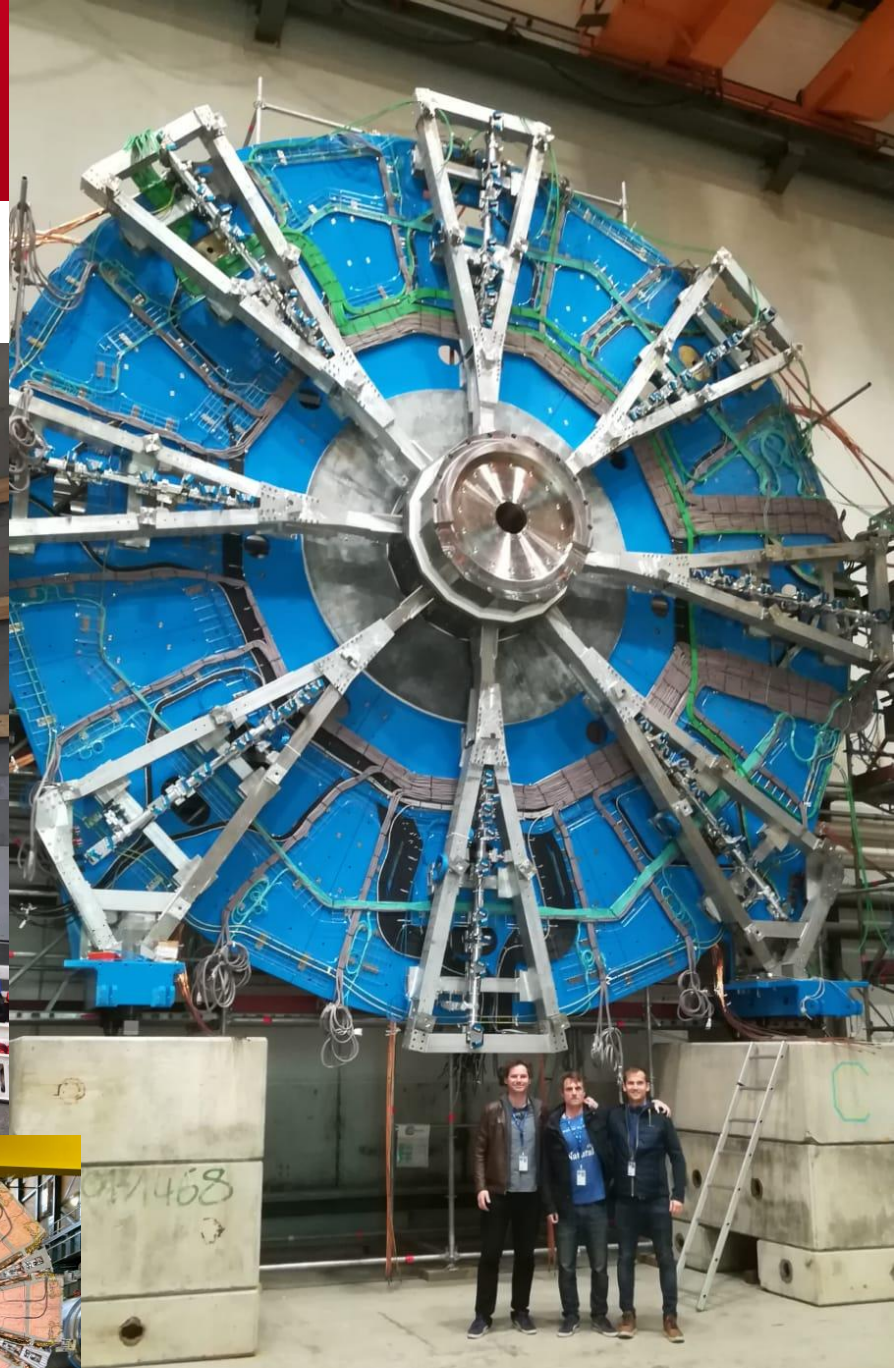




LHC / HL-LHC Plan









Cours 1 : Généralités

- Introduction de la théorie à la pratique
- Qu'est-ce qu'une expérience de physique?
- 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

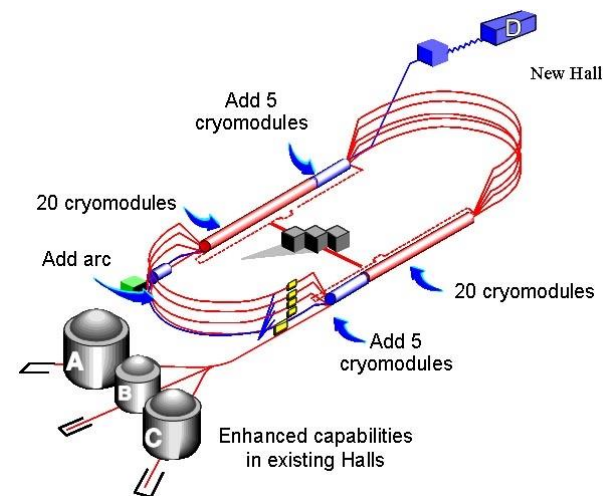
Cours 3 : Exemples d'expériences

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

Physique Hadronique

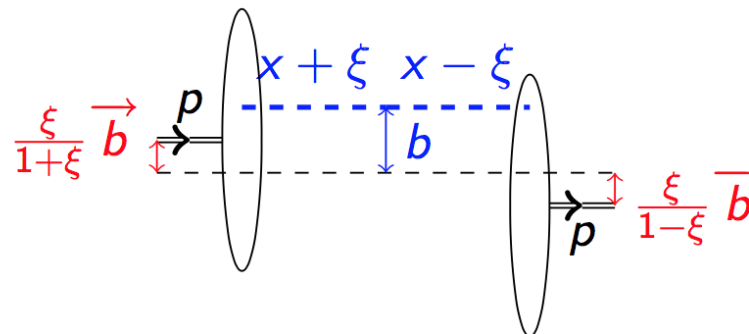
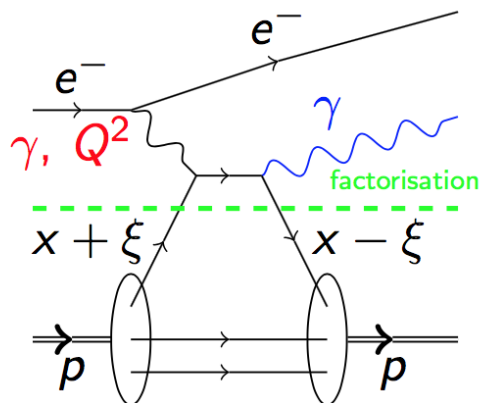
CLAS12

CLAS12 at Jefferson Lab

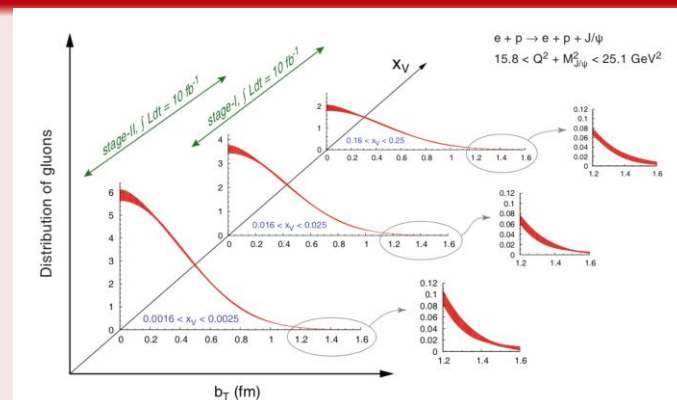
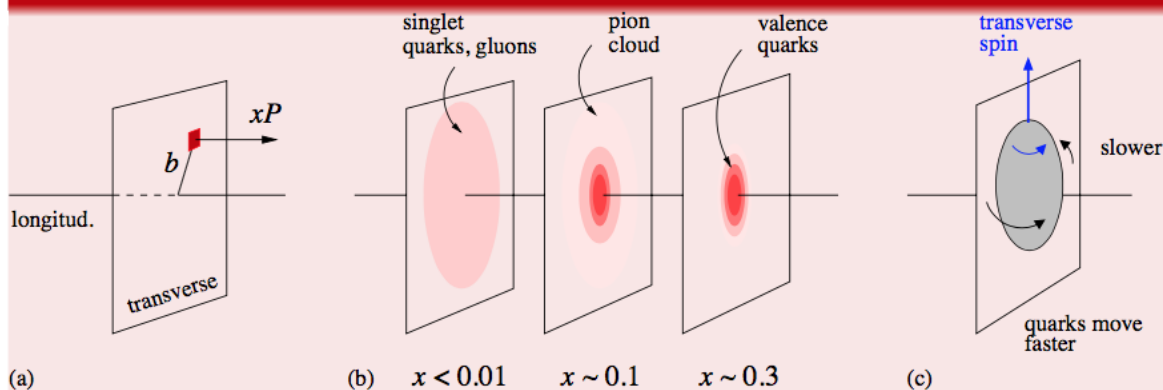


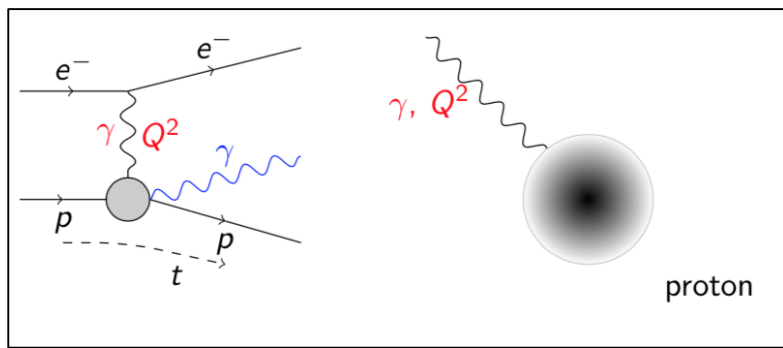


Diffusion Compton profondément virtuelle (DVCS)

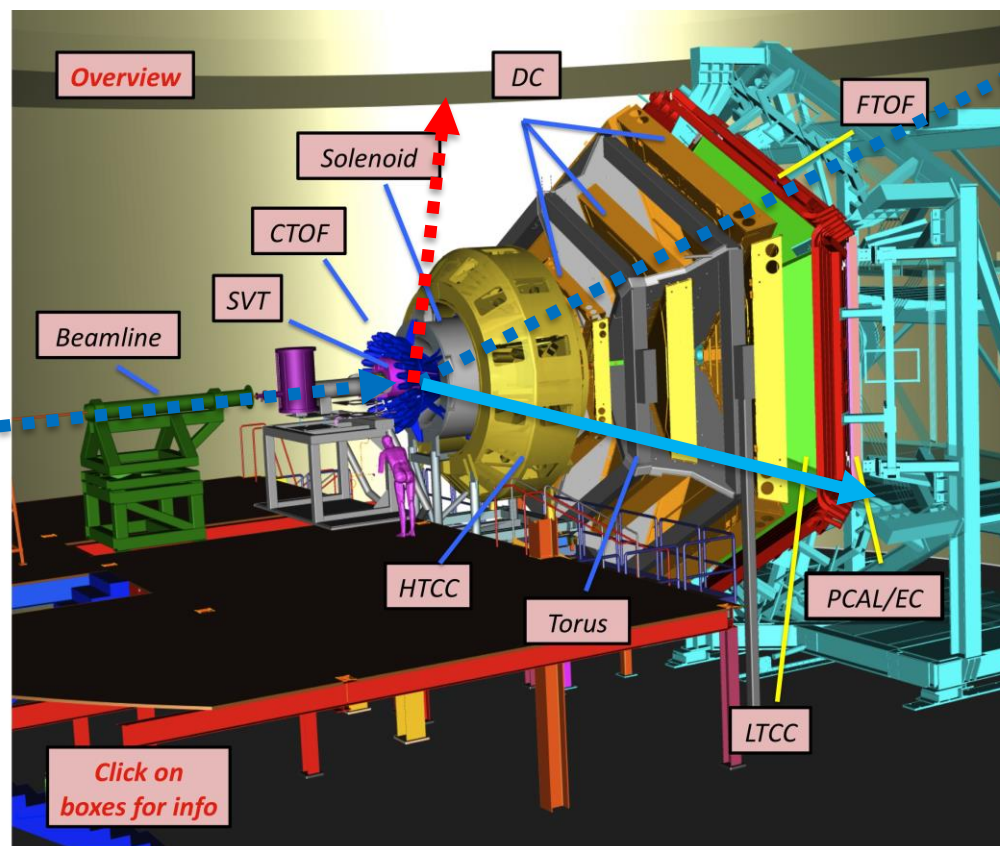


Vers une visualisation en 3d du nucléon !

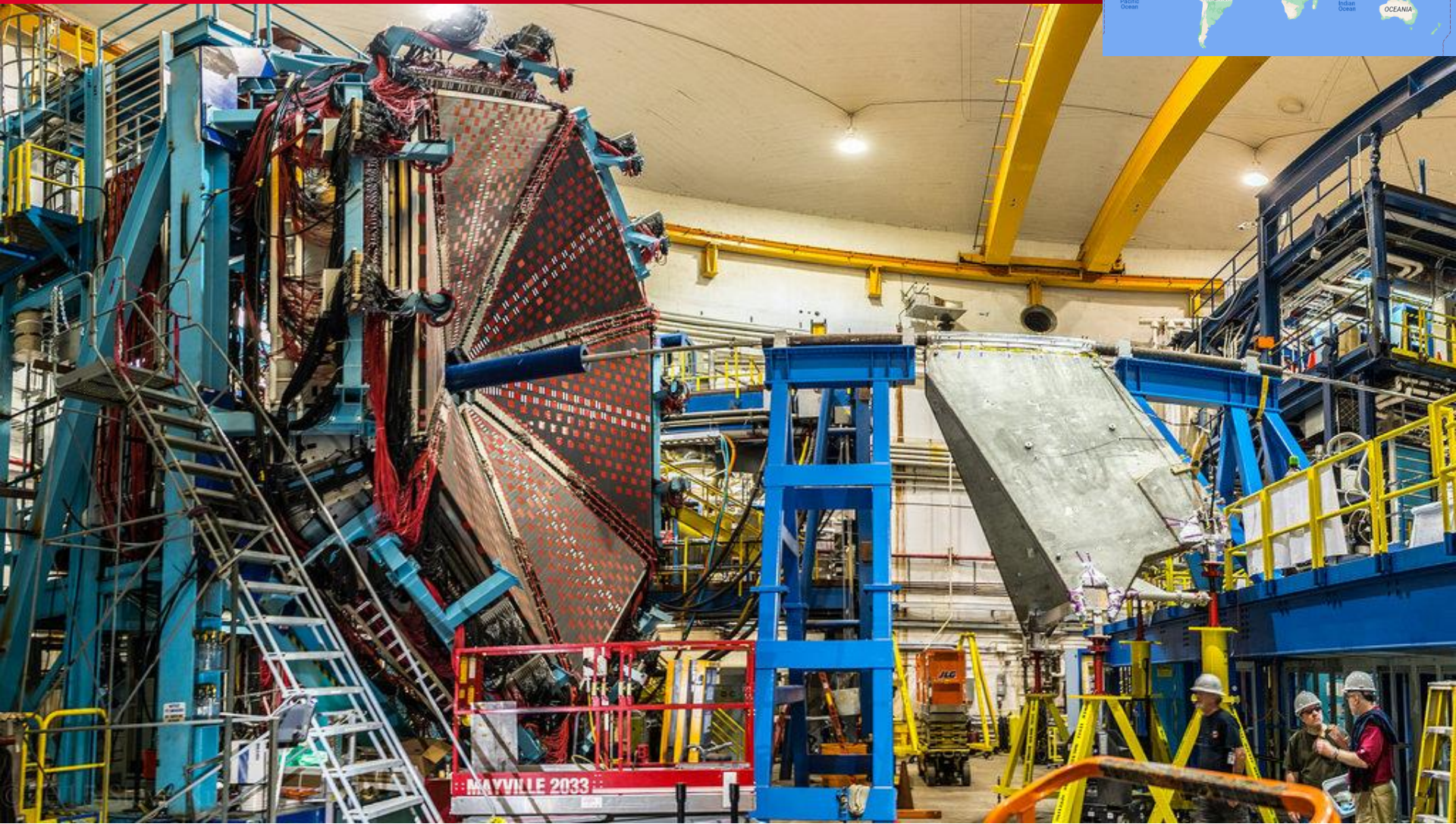
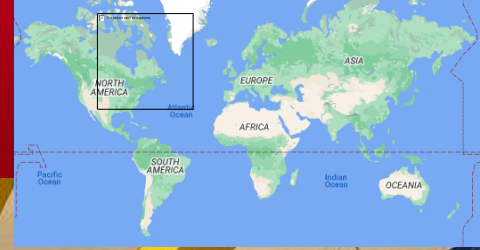


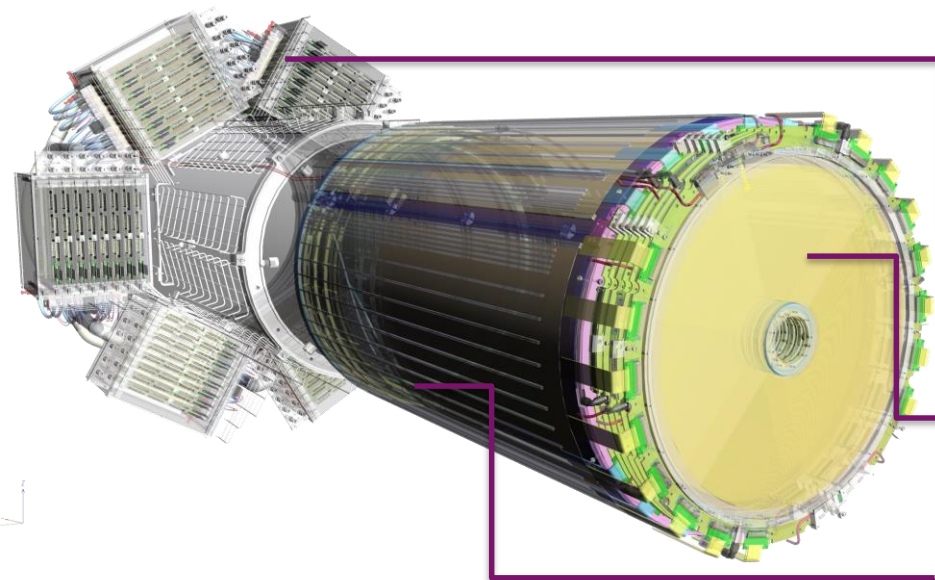


proton



CLAS12 at Jefferson Lab





- ▶ 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

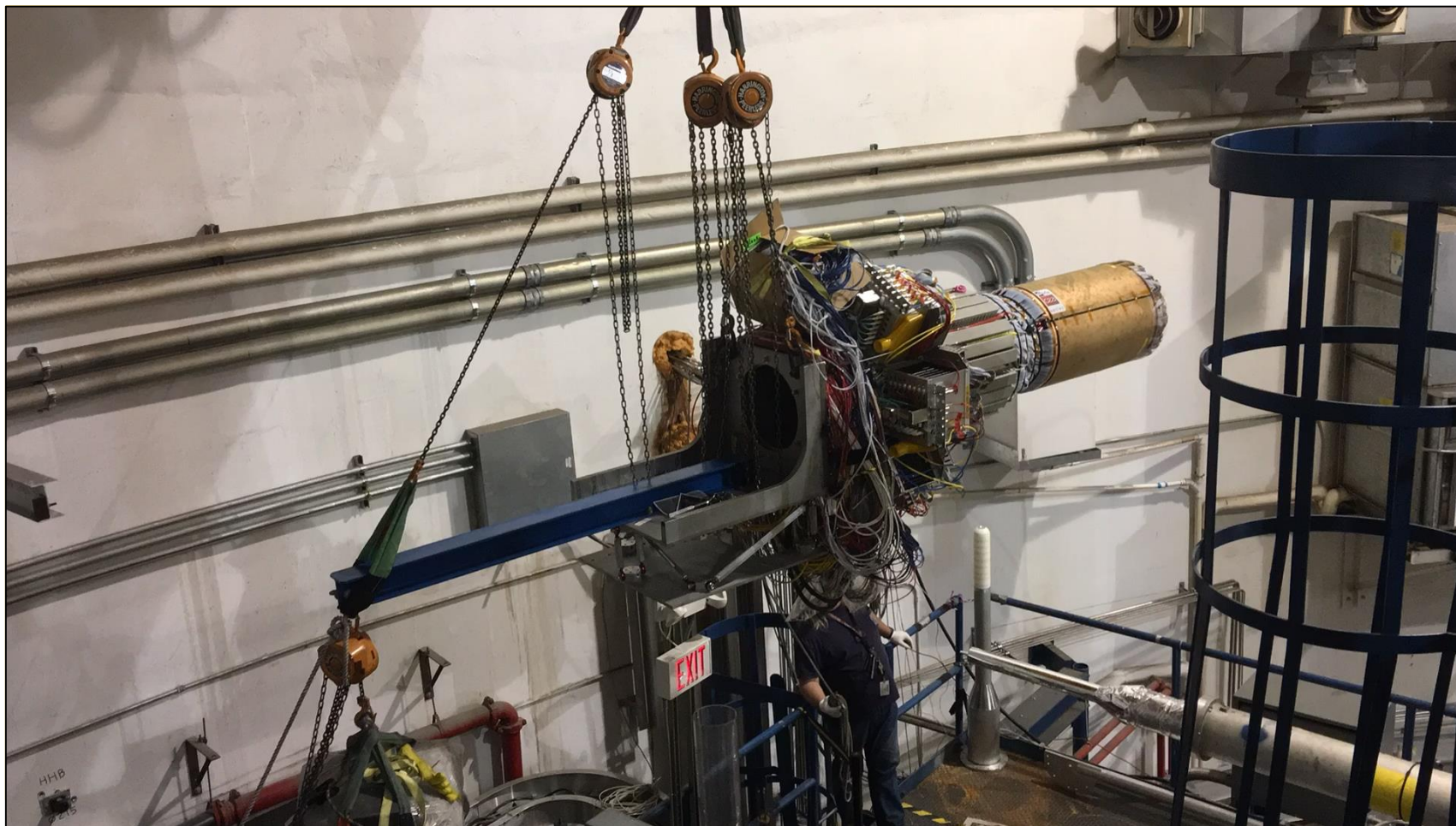
- ▶ High particle rate (30MHz) => Fast detectors
- ▶ Resistive strips divided in 2 zones inner/outer
- ▶ Dimensions: 6x 430 mm diameter disk with a 50 mm diameter hole at the center



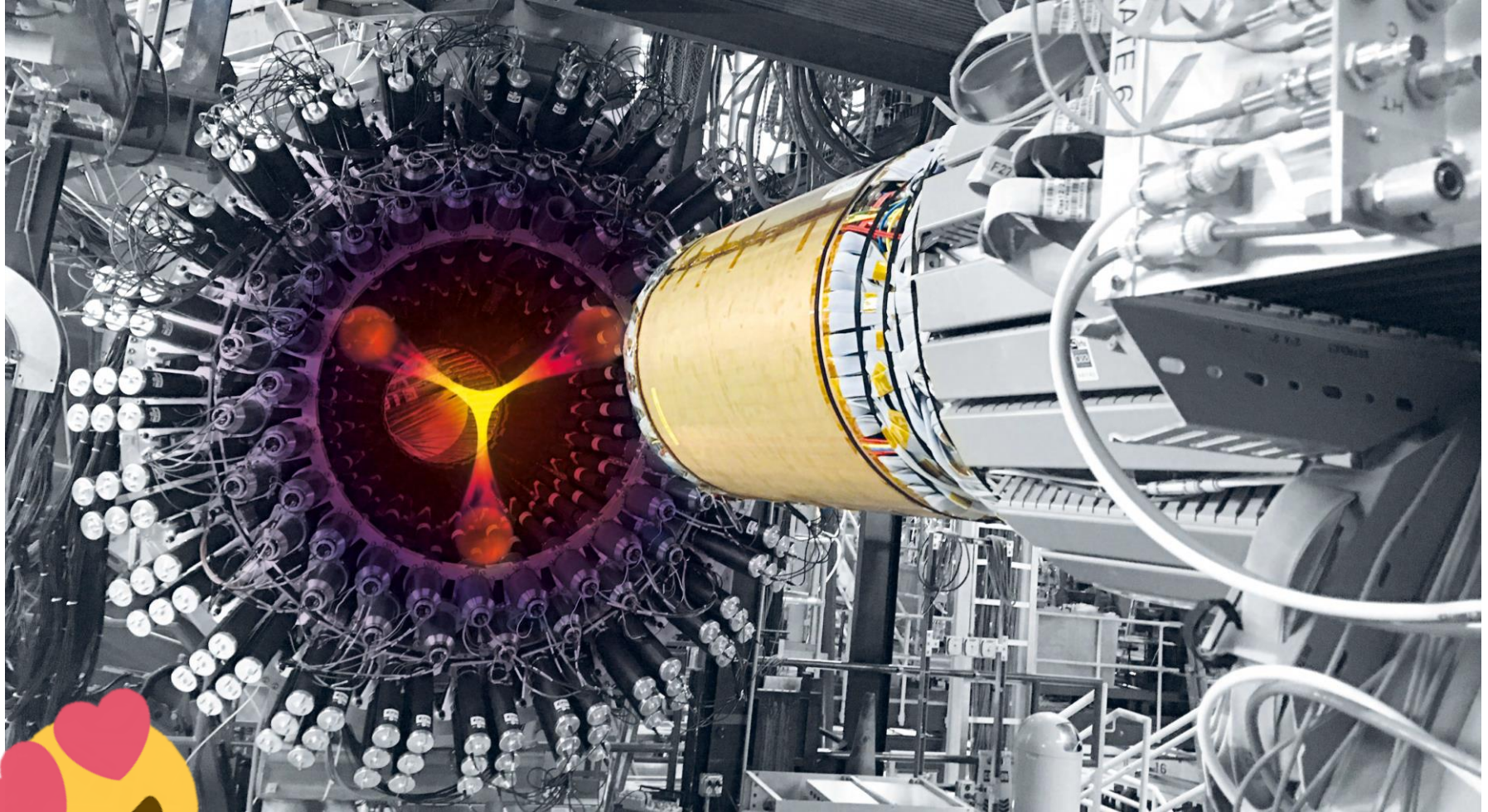
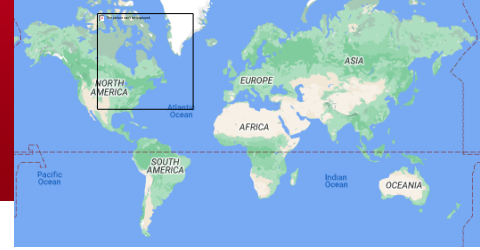
Cylindrical Barrel

- ▶ 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 – Central Tracker

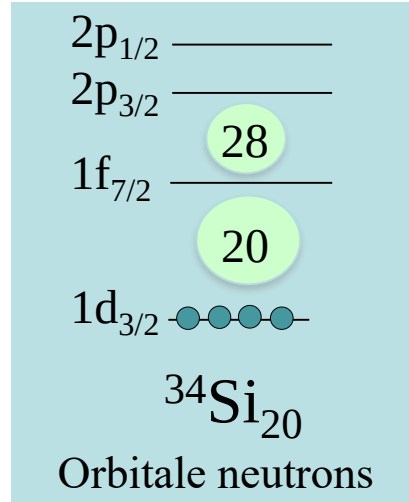
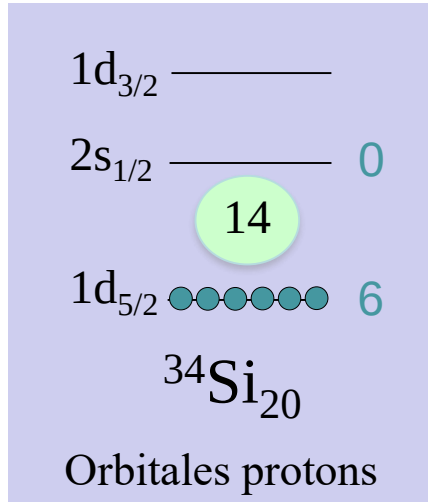


Physique Nucléaire

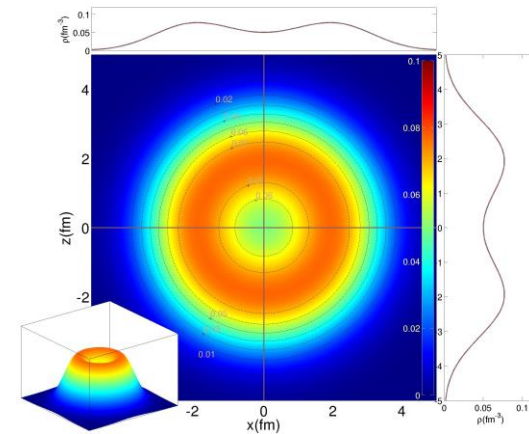
Noyaux Bulles et Spectroscopie Gamma



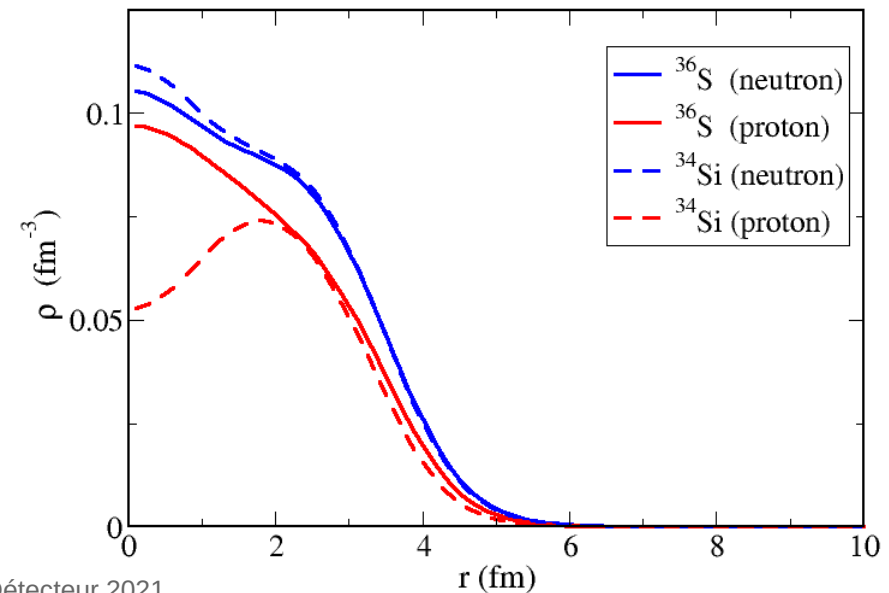
- Origine d'une déplétion centrale dans le noyau ^{34}Si



➡ A cause de son orbitale $2s_{1/2}$ vide, le ^{34}Si ($Z=14$, $N=20$) présenterait une déplétion centrale comparativement au ^{36}S ($Z=16$, $N=20$)



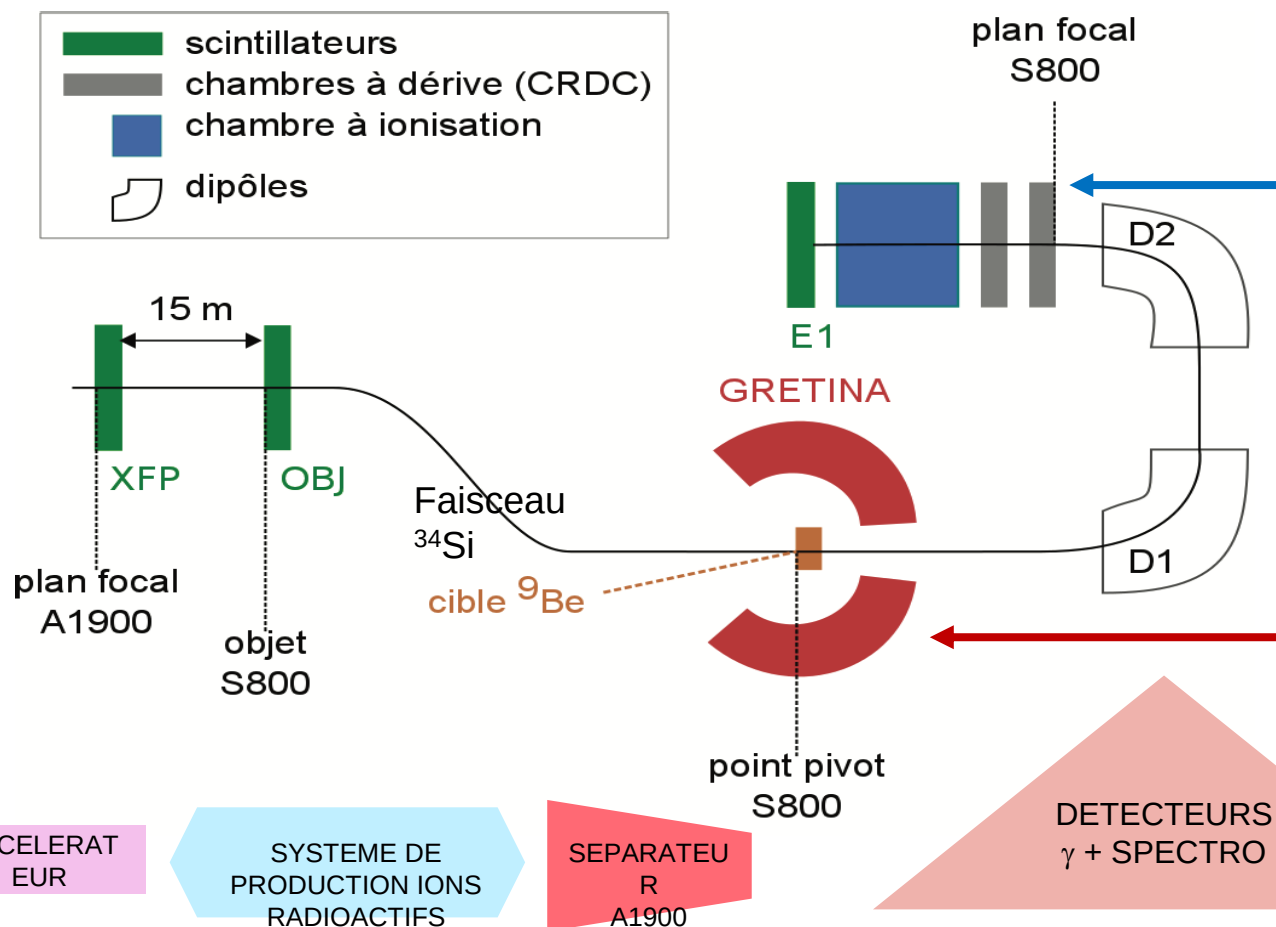
Ground State Density
Skyrme Hartree-Fock Calculations



Cas physique : Etude des noyaux bulles



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

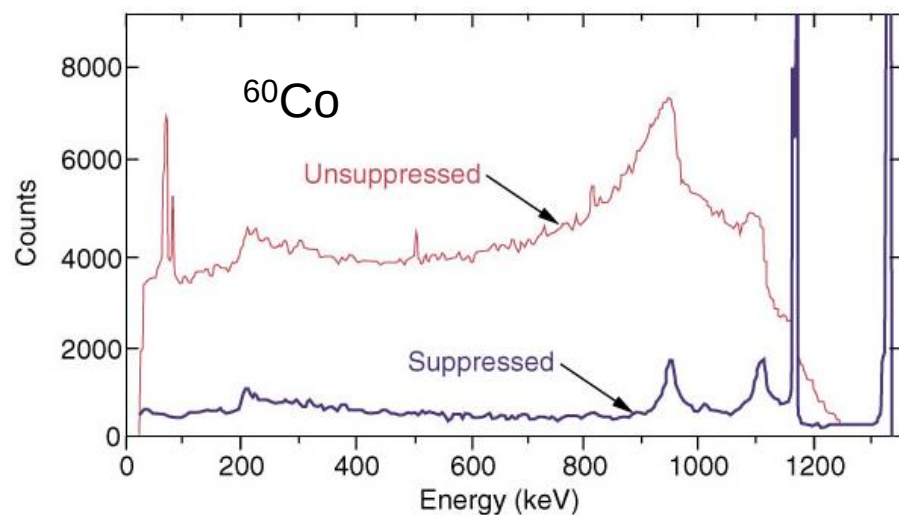
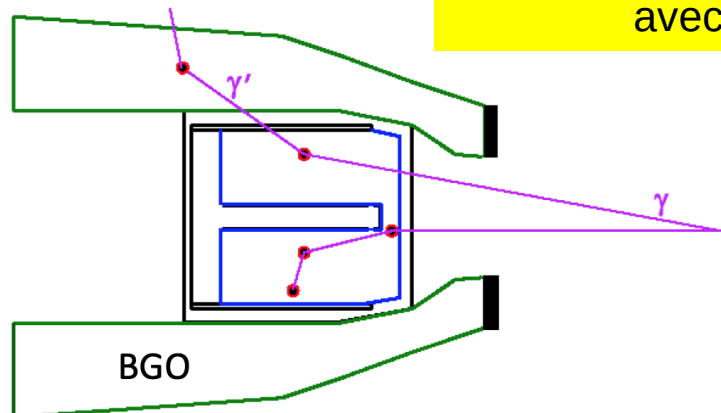




DETECTEUR
 γ Germanium

- Les détecteurs γ , la lutte contre la diffusion Compton

Astuce 1 : se débarrasser du Compton avec un bouclier BGO

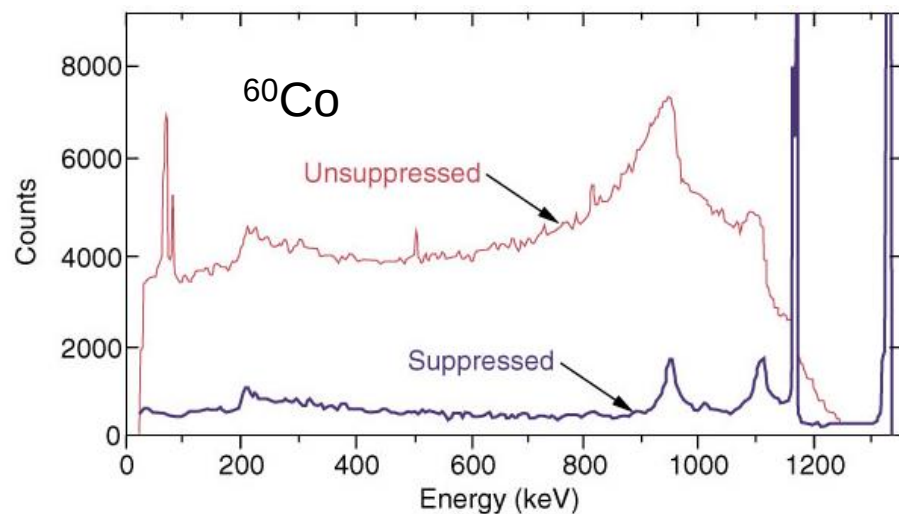
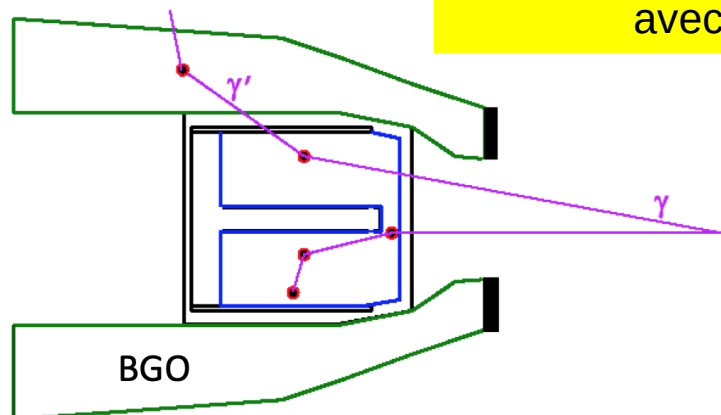




DETECTEUR
 γ Germanium

- Les détecteurs γ , la lutte contre la diffusion Compton

Astuce 1 : se débarrasser du Compton avec un bouclier BGO



GAMMASPHERE @ANL



EXOGAM @GANIL

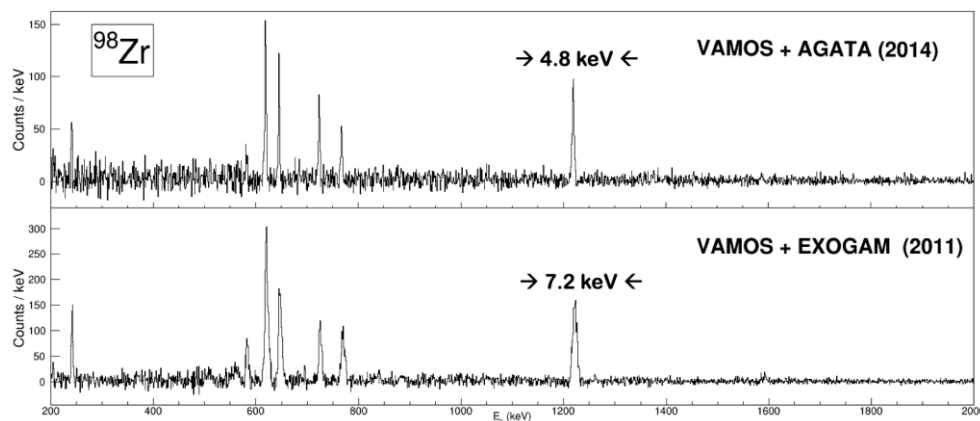
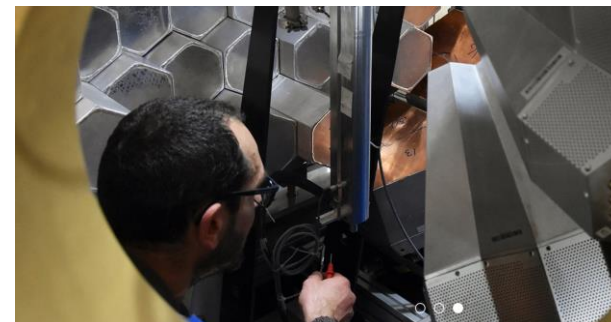
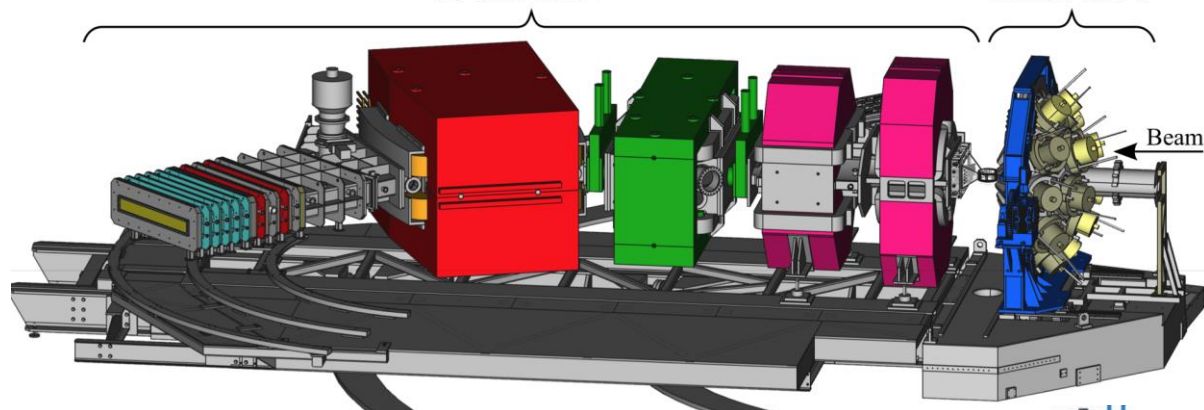


DETECTEUR
 γ Germanium

- La campagne VAMOS-AGATA @GANIL 2014-2021

VAMOS++

AGATA



29 expériences



558 To de données



6568 heures de faisceau sur cible



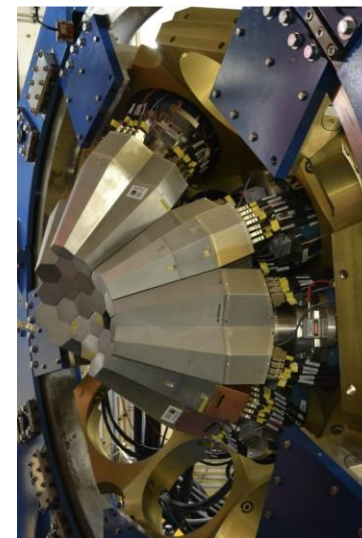
14 034 entrées dans le elog



2386 jours de surveillance
cryogénique



11,5 tonnes de matériel scientifique





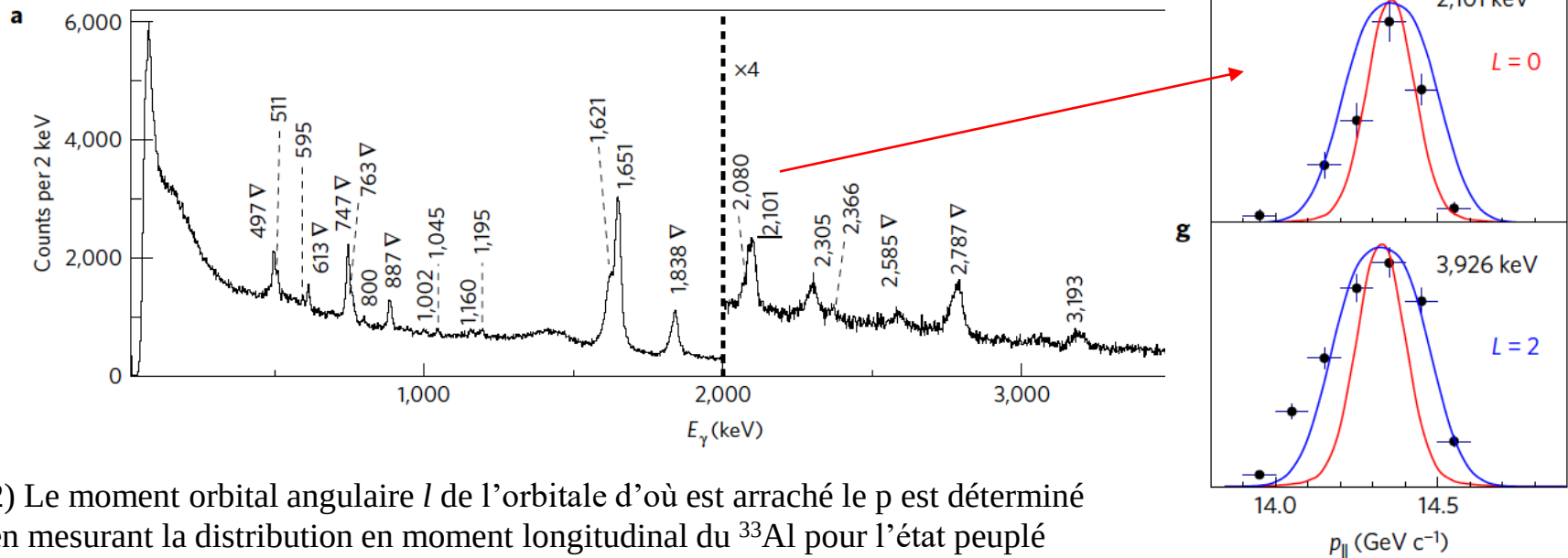
- Alors bulle ou pas bulle ?



- Alors bulle ou pas bulle ?

1) $^{34}\text{Si}(-1p)^{33}\text{Al}$, 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)

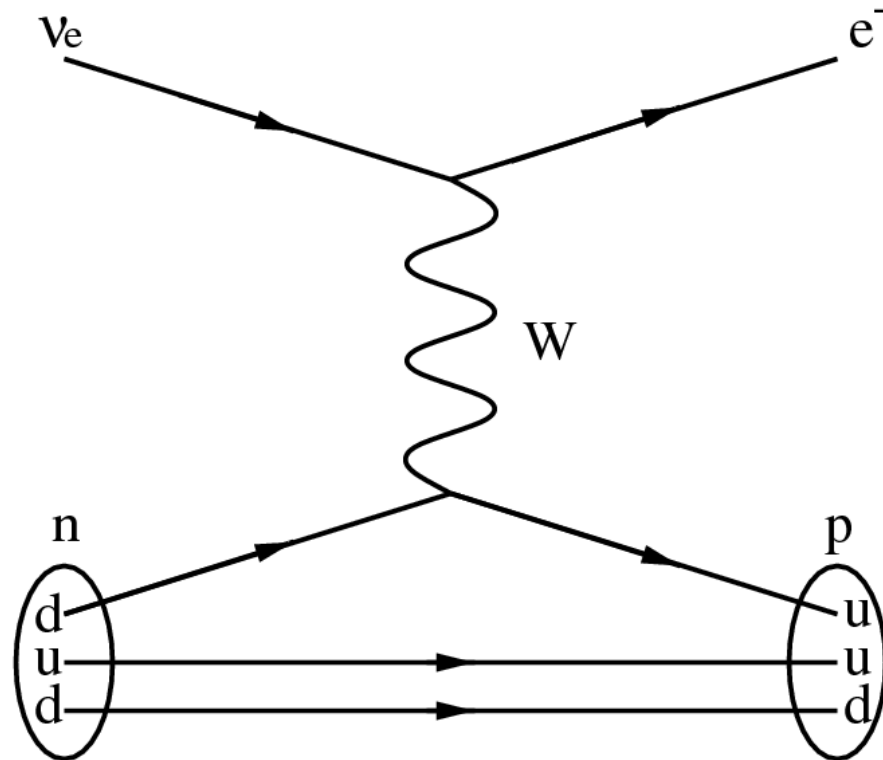


2) Le moment orbital angulaire l de l'orbitale d'où est arraché le p est déterminé en mesurant la distribution en moment longitudinal du ^{33}Al pour l'état peuplé

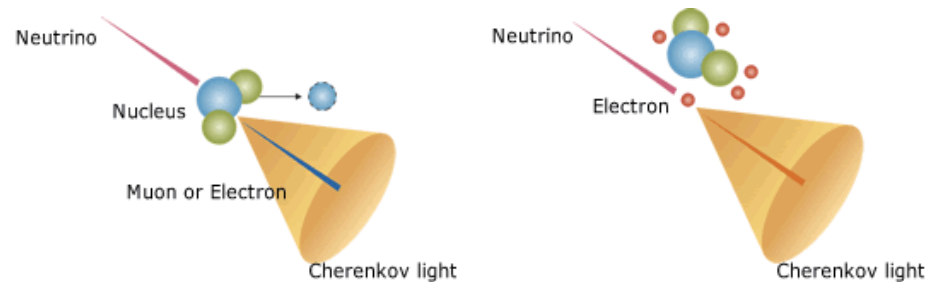
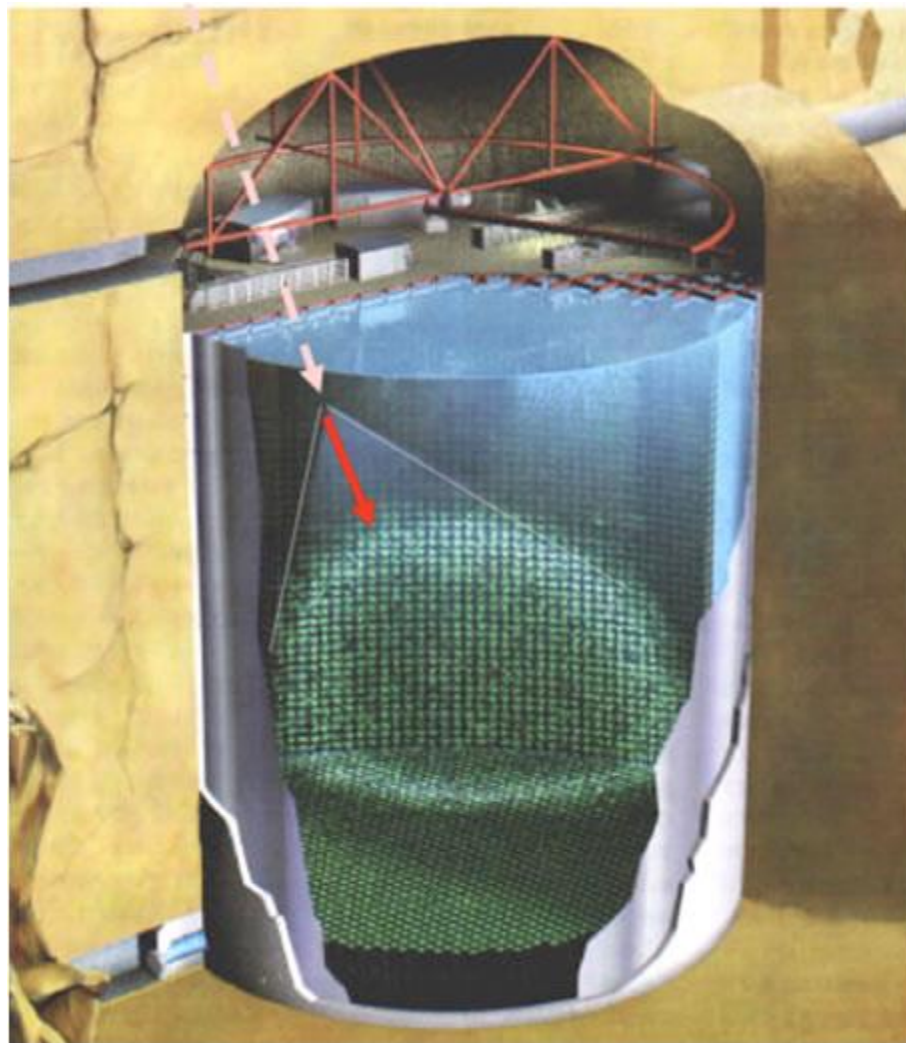
3) L'occupation de l'état $2s_{1/2}$ est déduite en de la section efficace expérimentale pour arracher un p depuis cette orbitale (rappel : orbitale $2s_{1/2}$ peut accueillir 2 nucléons)

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





Super Kamiokande



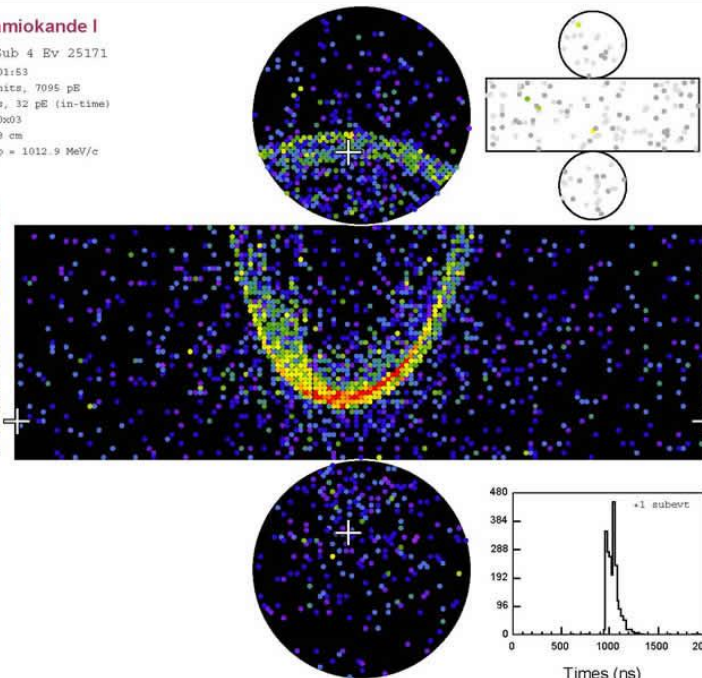
The generated charged particle emits the Cherenkov light.

Super-Kamiokande I

Run 1728 Sub 4 Ev 25171
96-05-29:08:01:53
Inner: 2294 hits, 7095 pE
Outer: 4 hits, 32 pE (in-time)
Trigger ID: 0x03
D wall: 592.8 cm
FC mu-like, $p = 1012.9 \text{ MeV/c}$

Charge (pe)

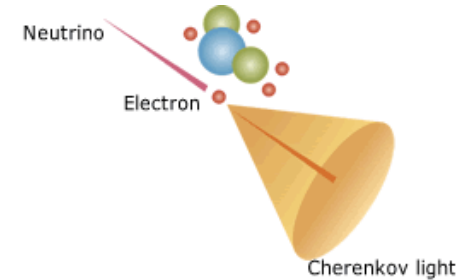
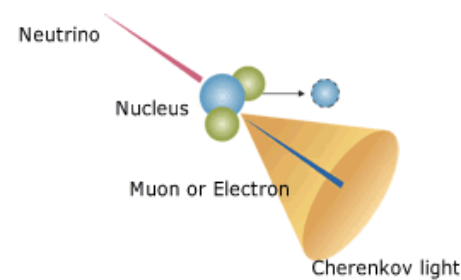
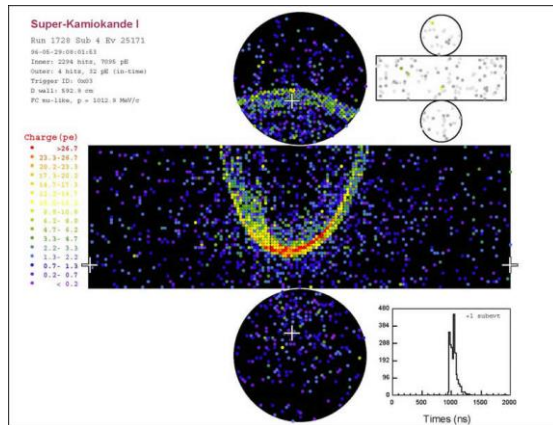
- >26.7
- 23.3-26.7
- 20.2-23.3
- 17.3-20.2
- 14.7-17.3
- 12.3-14.7
- 10.0-12.3
- 8.0-10.0
- 6.2-8.0
- 4.7-6.2
- 3.3-4.7
- 2.2-3.3
- 1.3-2.2
- 0.7-1.3
- 0.2-0.7
- <0.2



Super Kamiokande

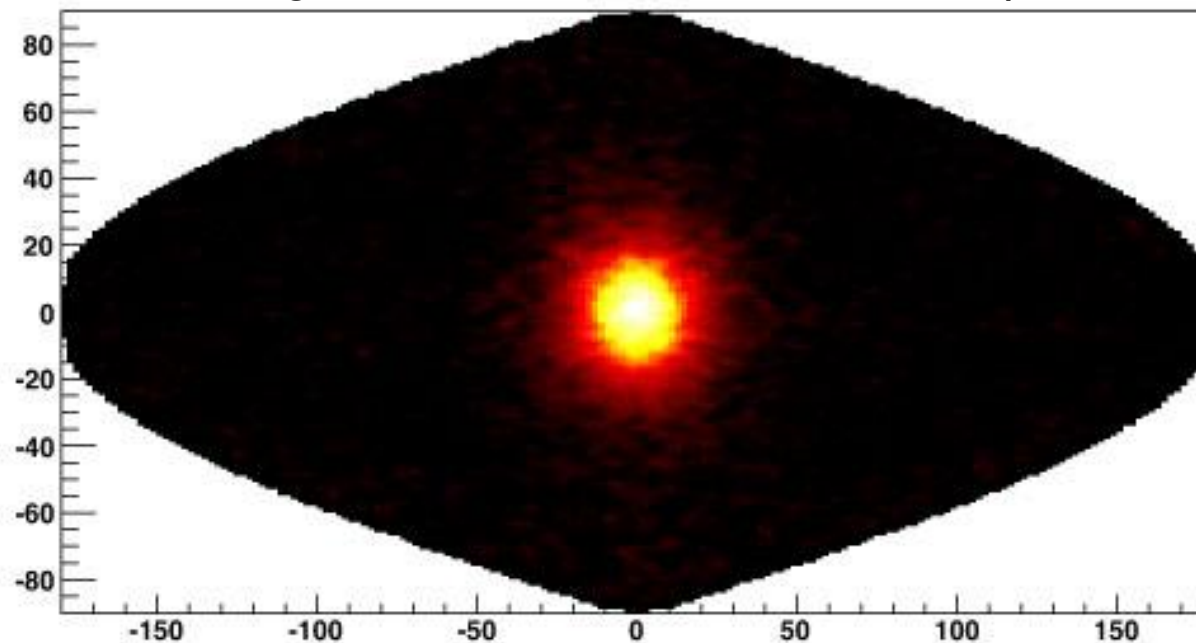


Super Kamiokande

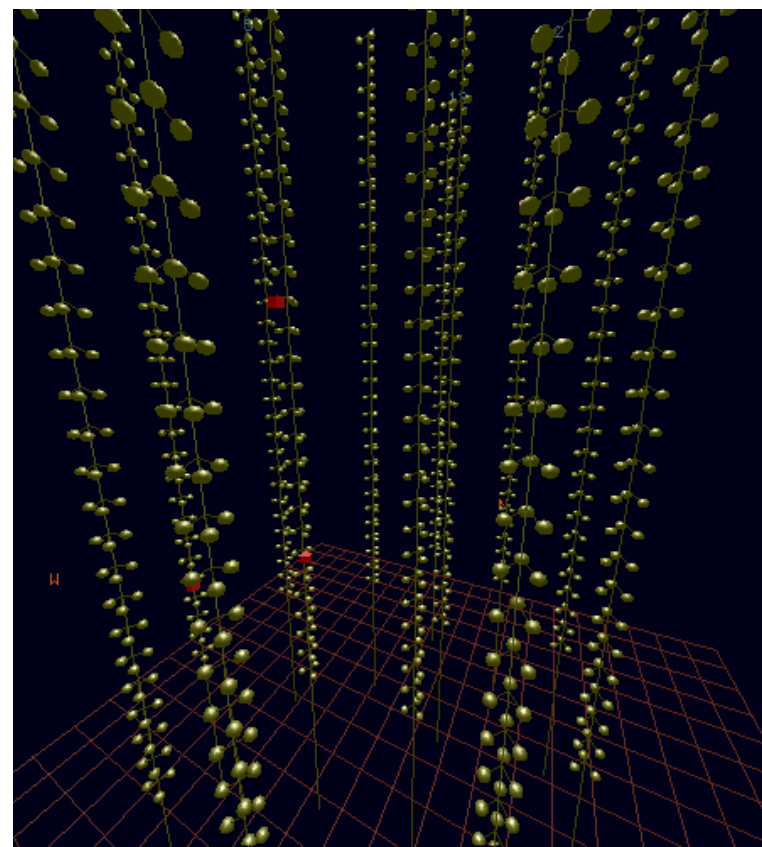


The generated charged particle emits the Cherenkov light.

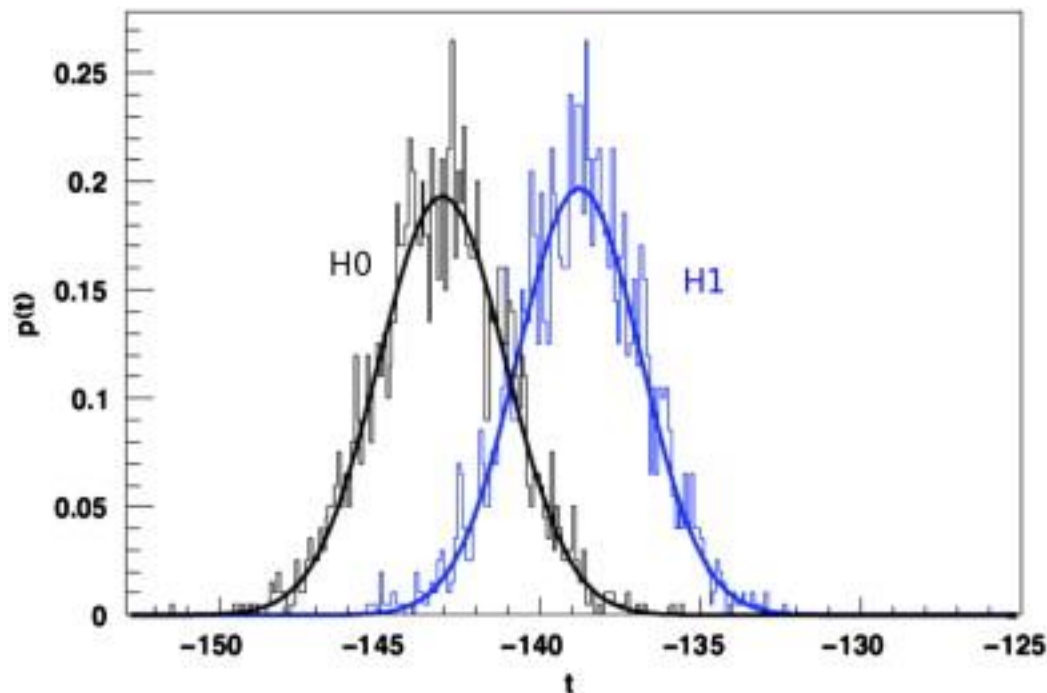
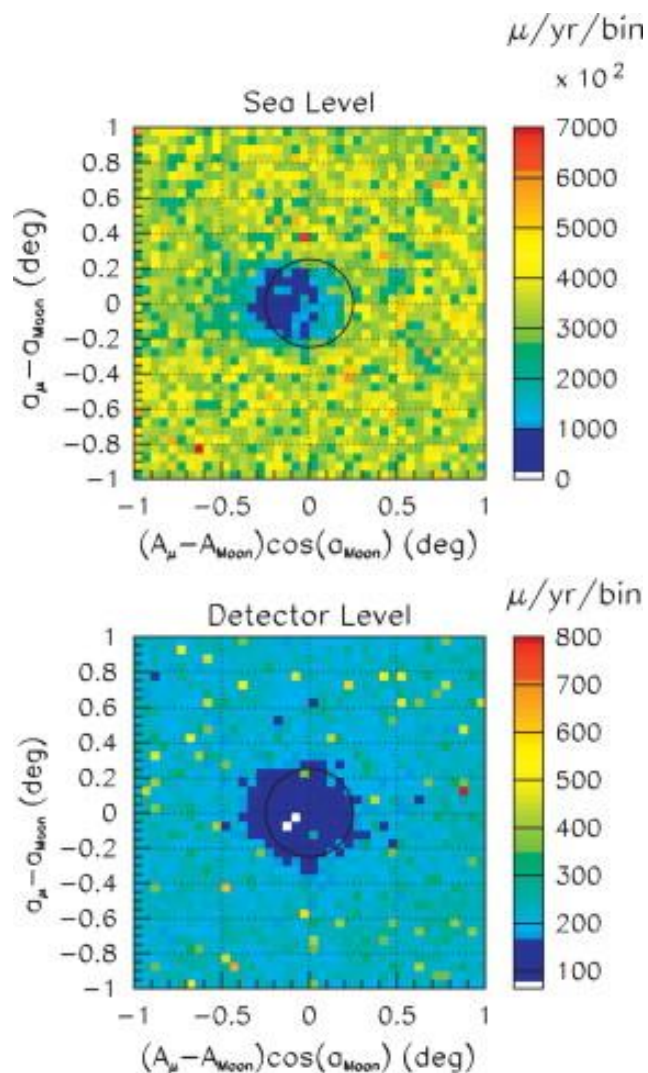
Image du soleil en Neutrino Electronique



Antares



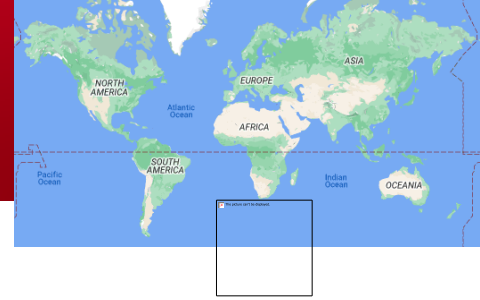
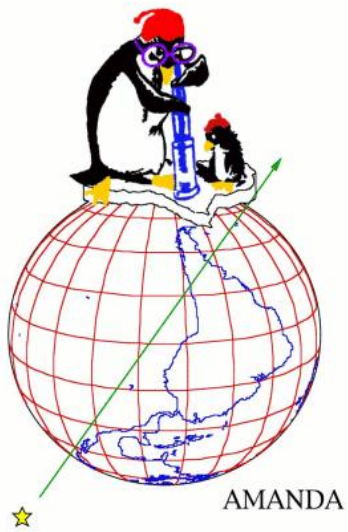
Antares



Moon hypothesis confirms at 2.9σ

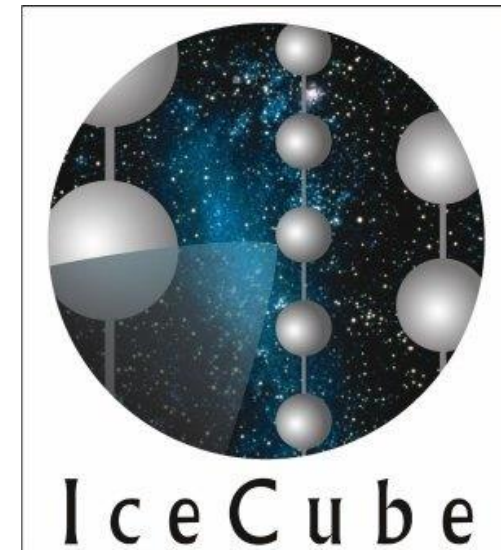
Sun is at 3.7σ

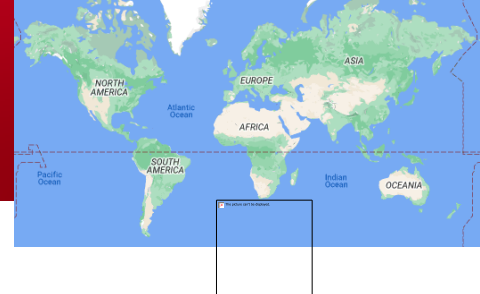
Moon Shadow in cosmic rays



AMANDA

Antarctic Muon And Neutrino Detector Array





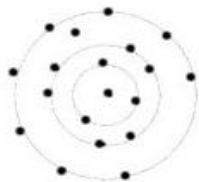
South Pole



AMANDA

AMANDA-II

Depth



top view

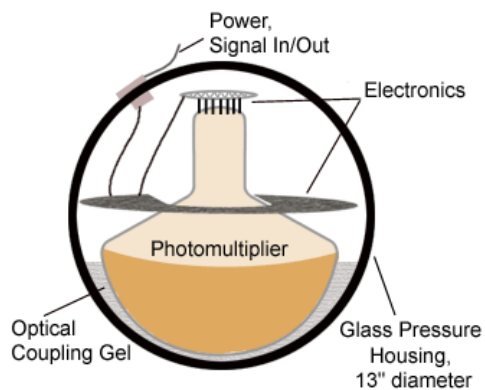
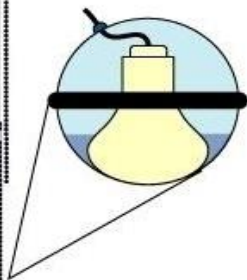
200 m

1500 m



2000 m

2500 m

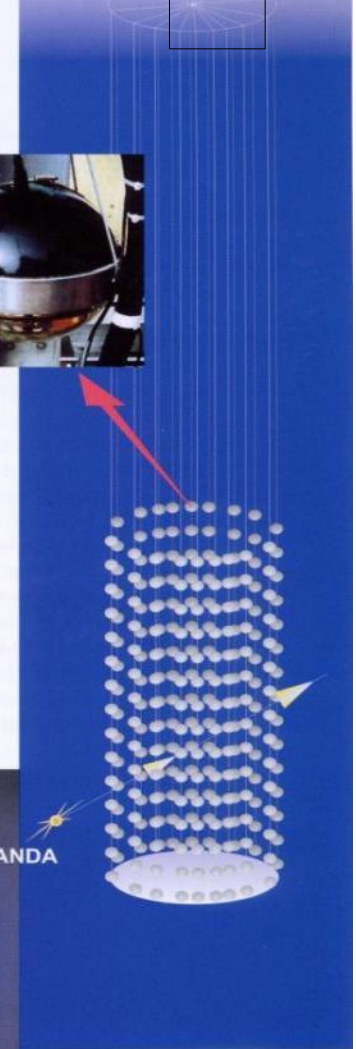
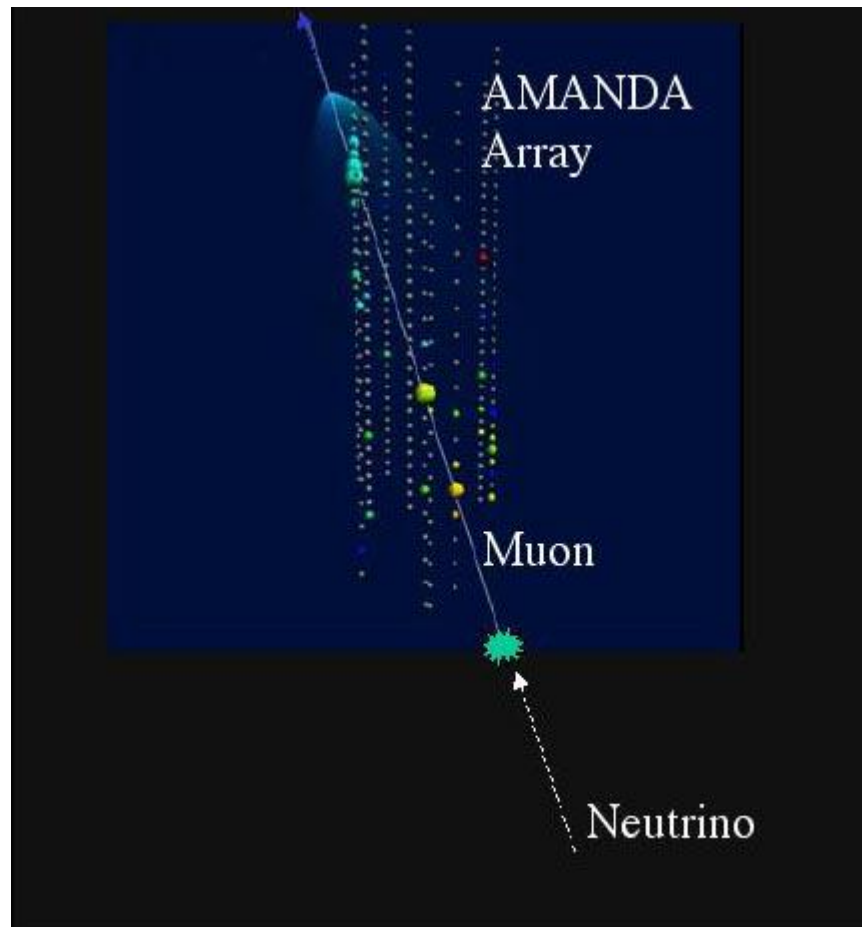


Photomultipliers in the Ice,
looking downwards.
Ice is the detecting medium.

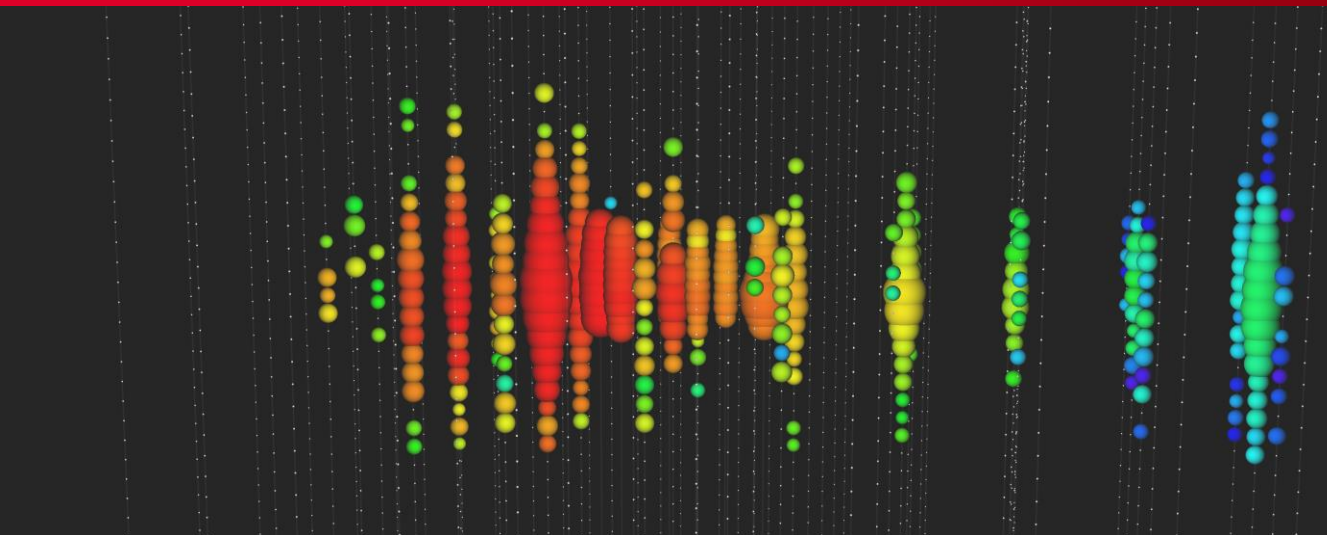
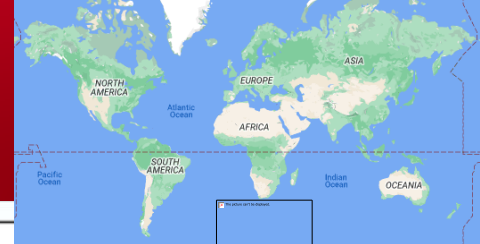


Look for upwards going Muons from Neutrino Interactions.
Cherekov light propagating through the ice.

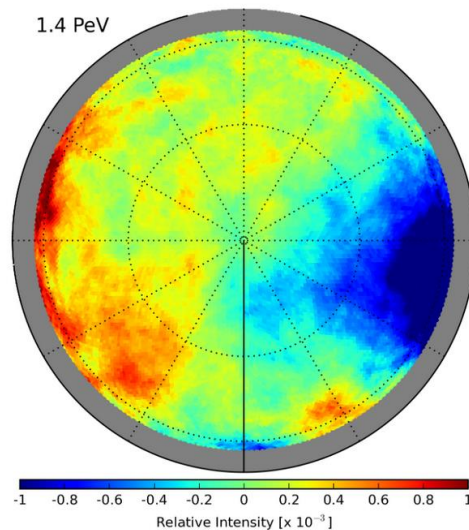
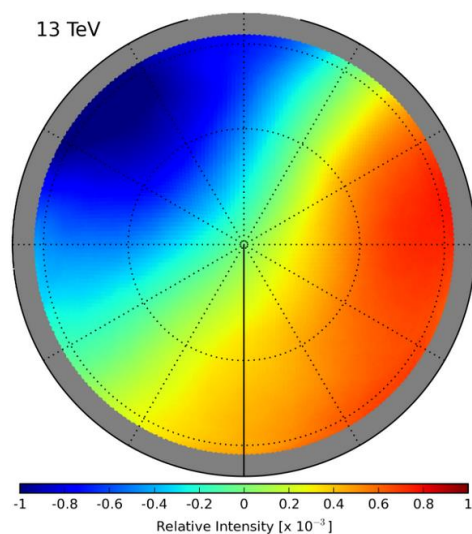
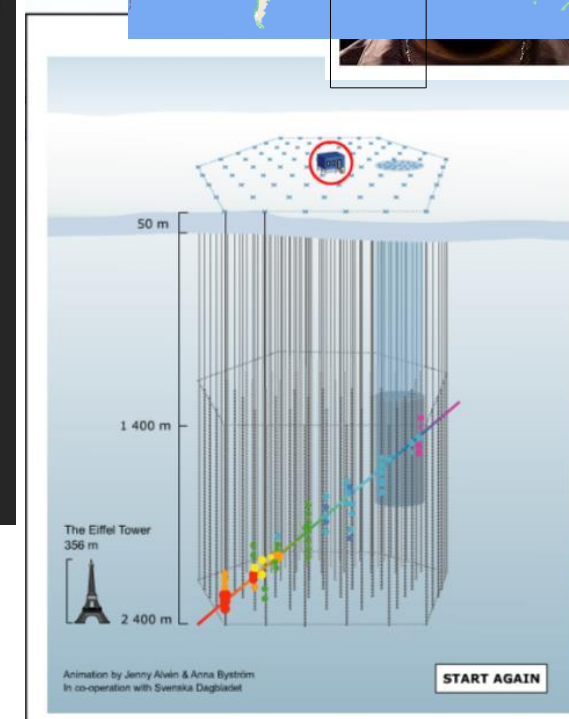
→ Find neutrino point sources in the universe !



AMANDA – ICE CUBE



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



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

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

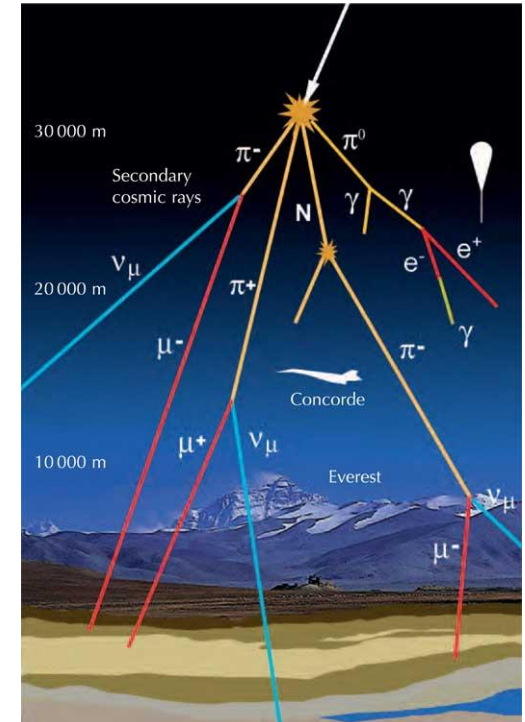
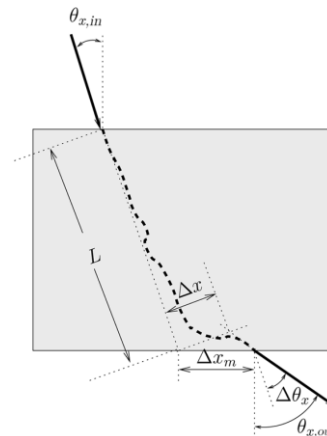
$$-\frac{dE}{ds} = \rho q^2 \frac{N_A e^4}{4\pi\epsilon_0^2 m_e c^2} \frac{Z}{A} \frac{1}{\beta^2} \left(\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 W_{max}}{I^2} - \beta^2 - \frac{\delta}{2} \right)$$

- Standard deviation of the scattering angle

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

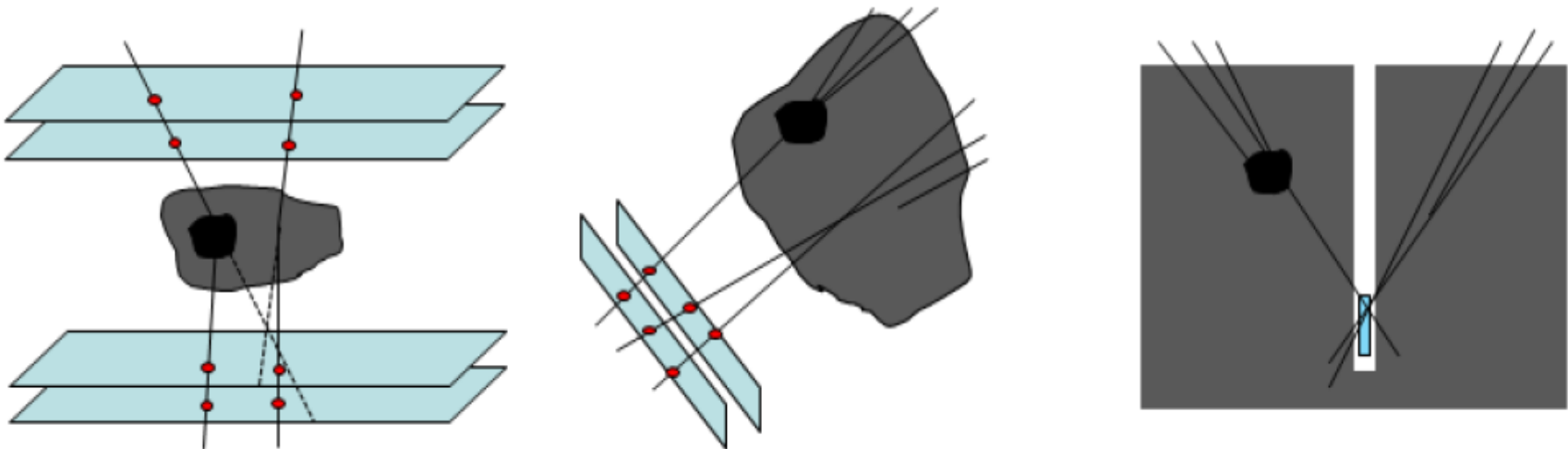
- Radiation length

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

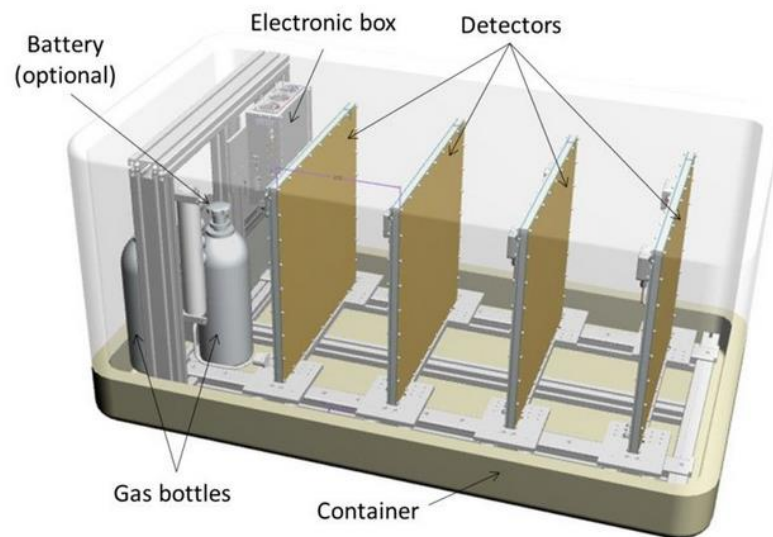
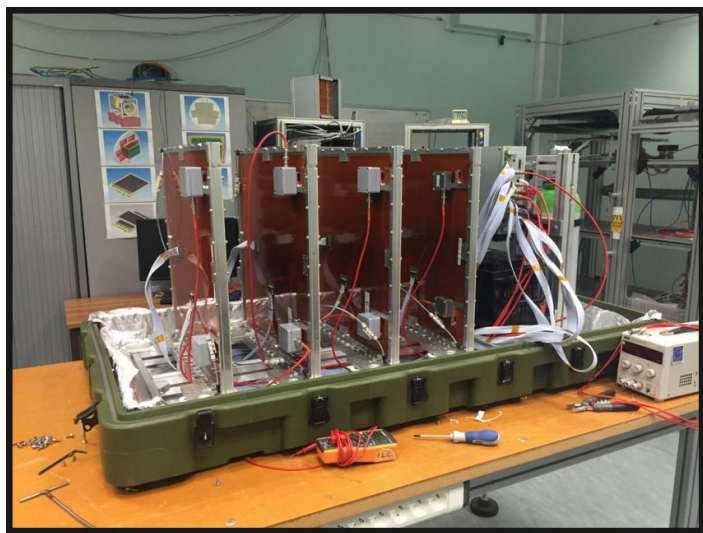
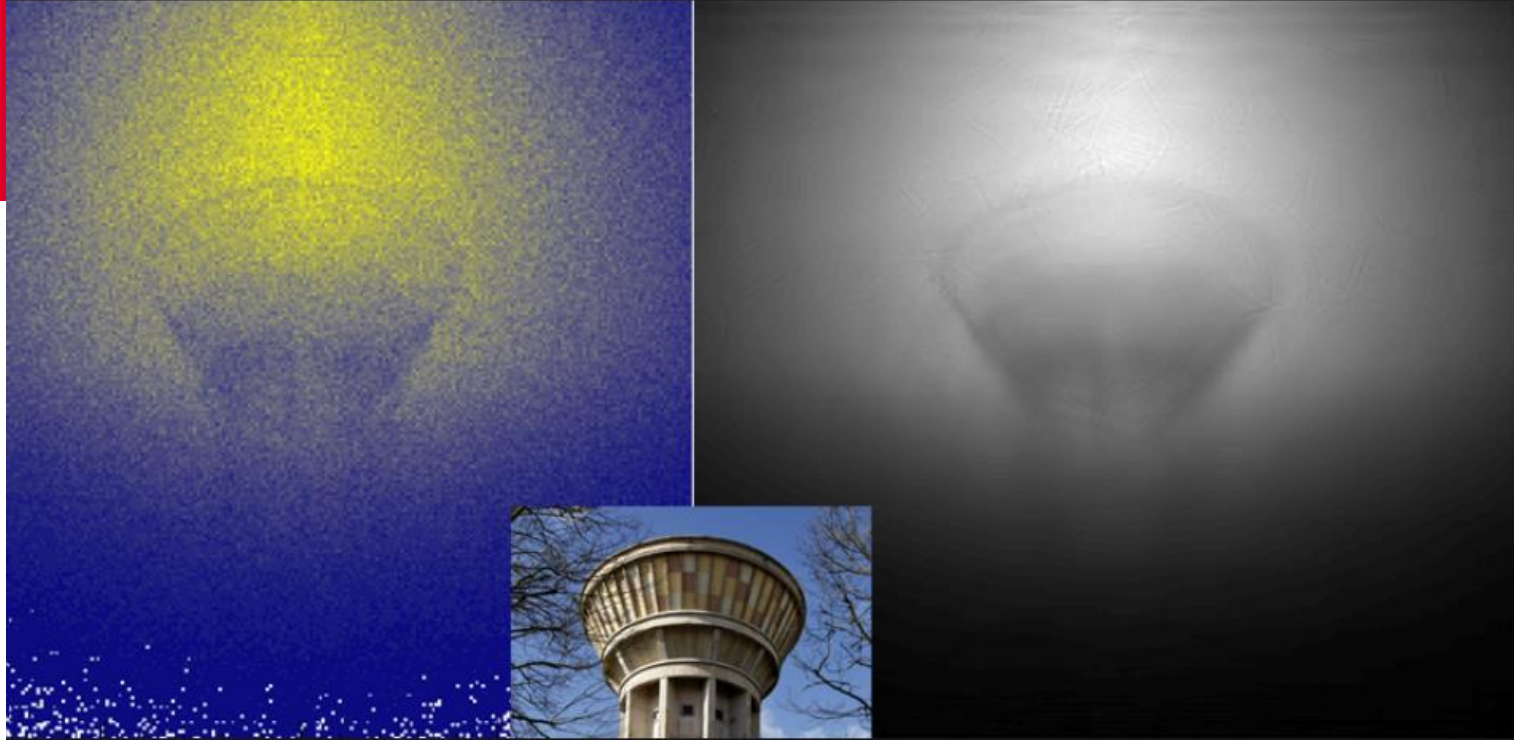


Material	Thickness	θ (°)	$P_{\text{absorption}}$
Air	100 m	0.094	0.78%
Lead	10 cm	1.01	2.9%
Water	1 m	0.35	4.2%
Ground	100 m		99%

- 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, ...



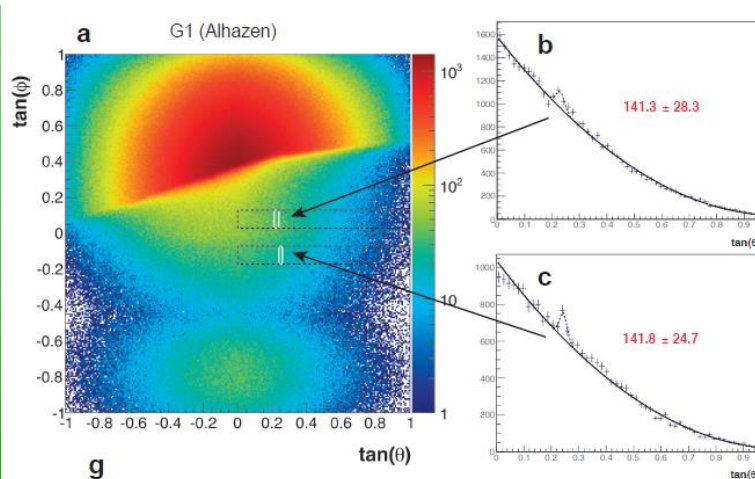
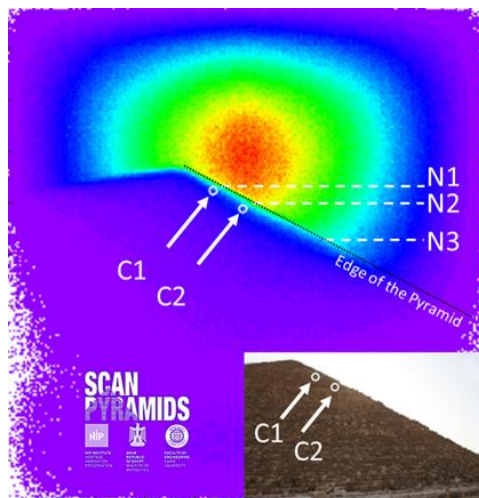
- Discoveries of new cavities large void above the Grand Gallery

2016

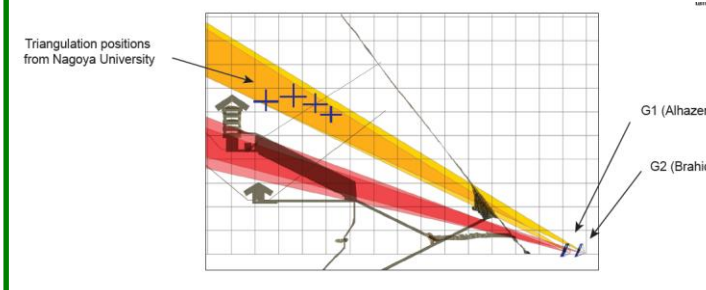
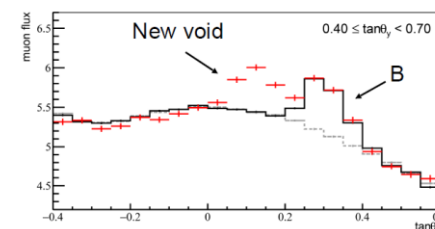
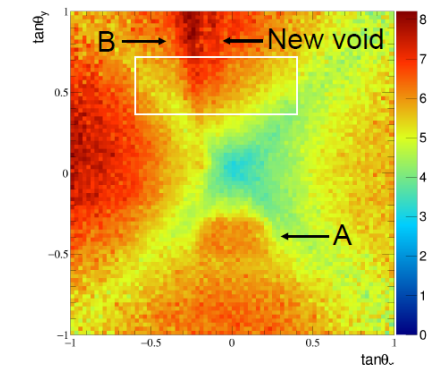
CEA

2017

Nagoya



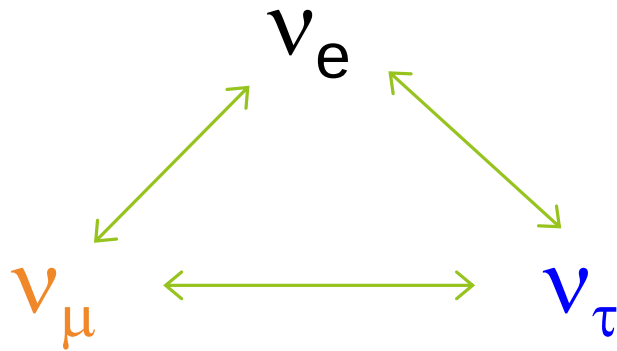
- Only 2 such voids detected
- 1st detection ever from outside of a deep structure



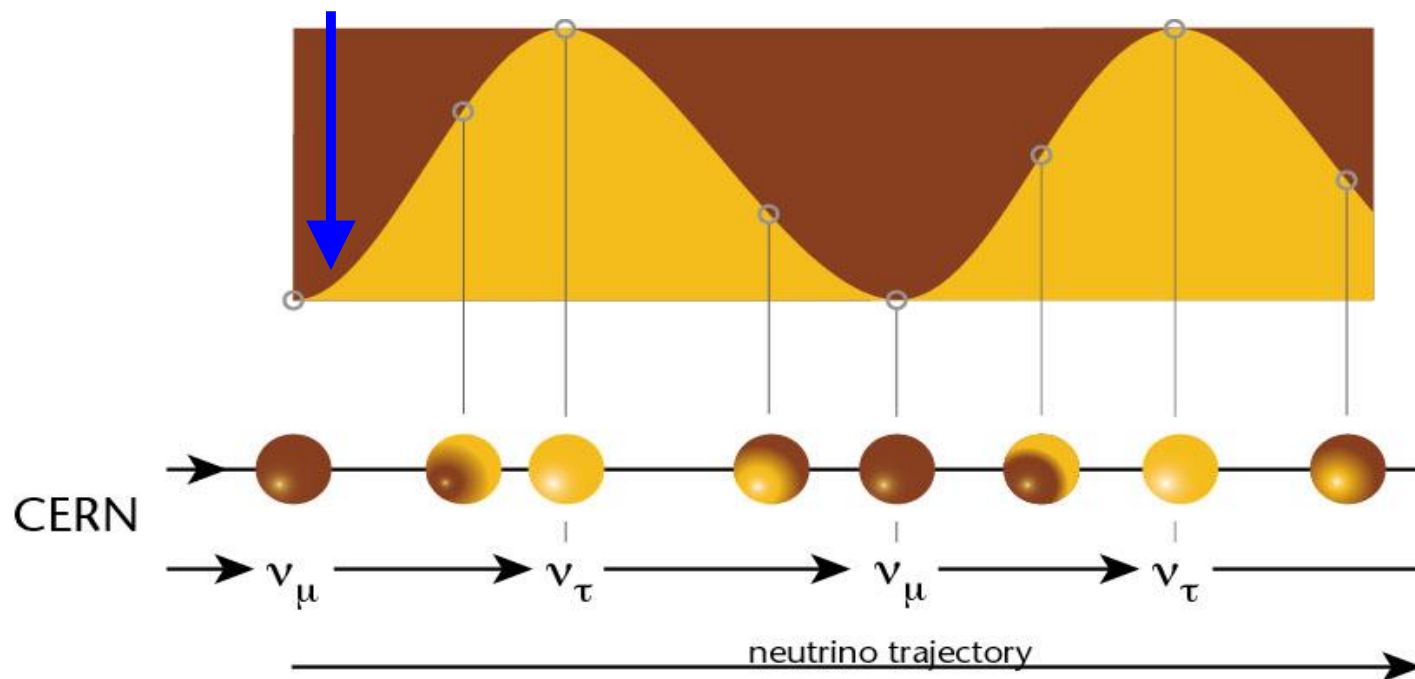
CERN Neutrino Gran Sasso (CNGS)



If neutrinos have mass:



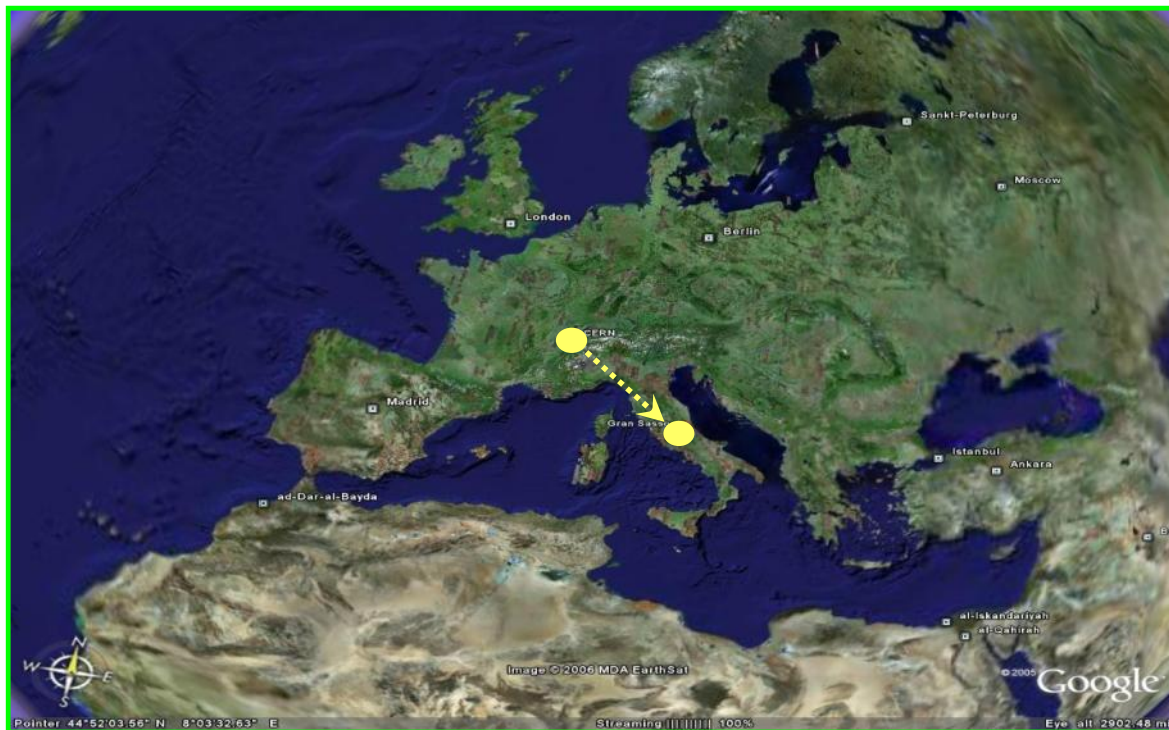
**Muon neutrinos produced at CERN.
See if tau neutrinos arrive in Italy.**





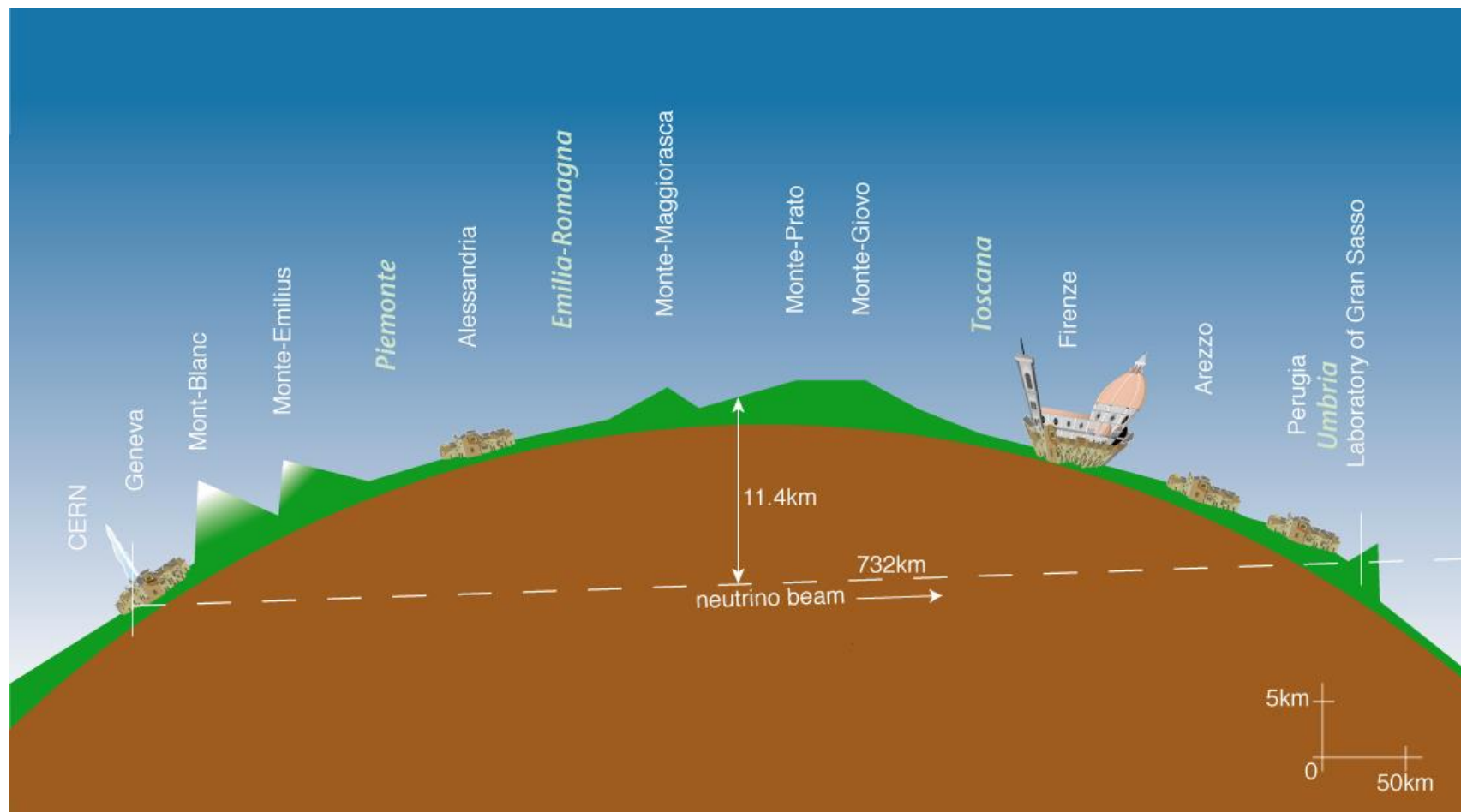
CNGS (CERN NEUTRINO GRAN SASSO)

- 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

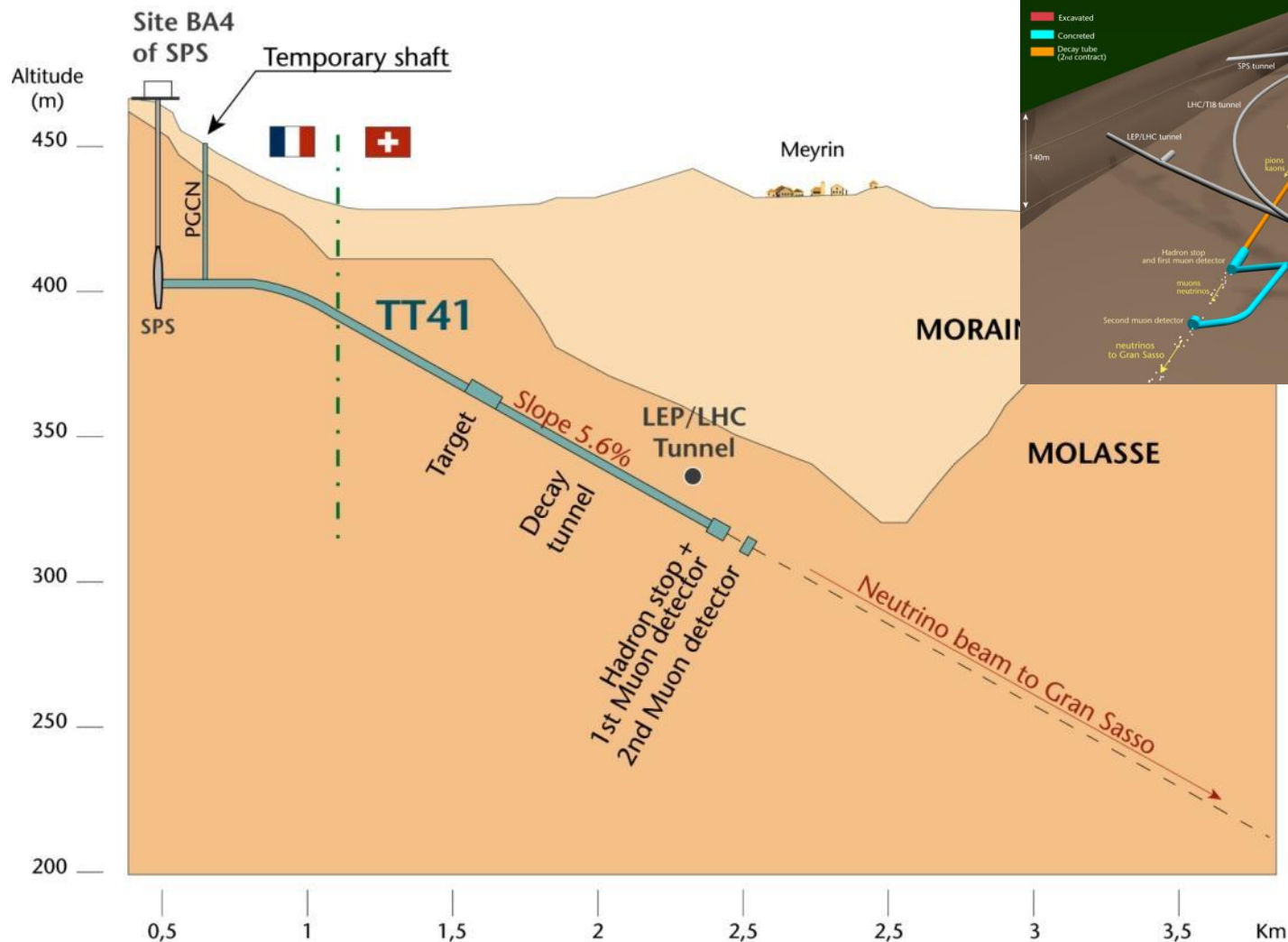


➔ direct proof of $\nu_\mu - \nu_\tau$ oscillation (appearance experiment)

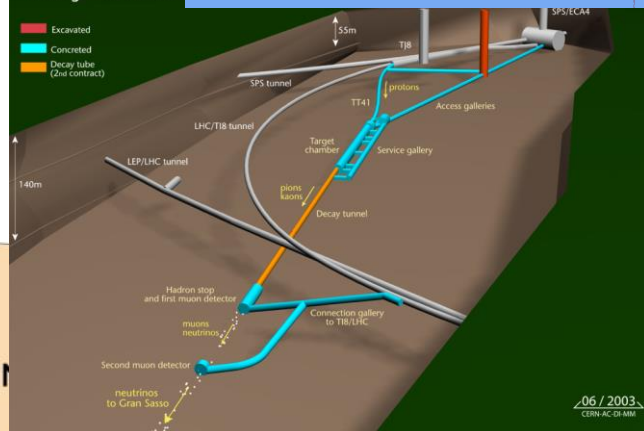
CNGS



CNGS



CERN NEUTRINOS TO GRAN SASSO
Underground structure





For 1 day of CNGS operation, we expect:

protons on target

$$2 \times 10^{17}$$

pions / kaons at entrance to decay tunnel

$$3 \times 10^{17}$$

ν_μ in direction of Gran Sasso

$$10^{17}$$

ν_μ in 100 m² at Gran Sasso

$$3 \times 10^{12}$$

ν_μ events per day in OPERA

≈ 25 per day

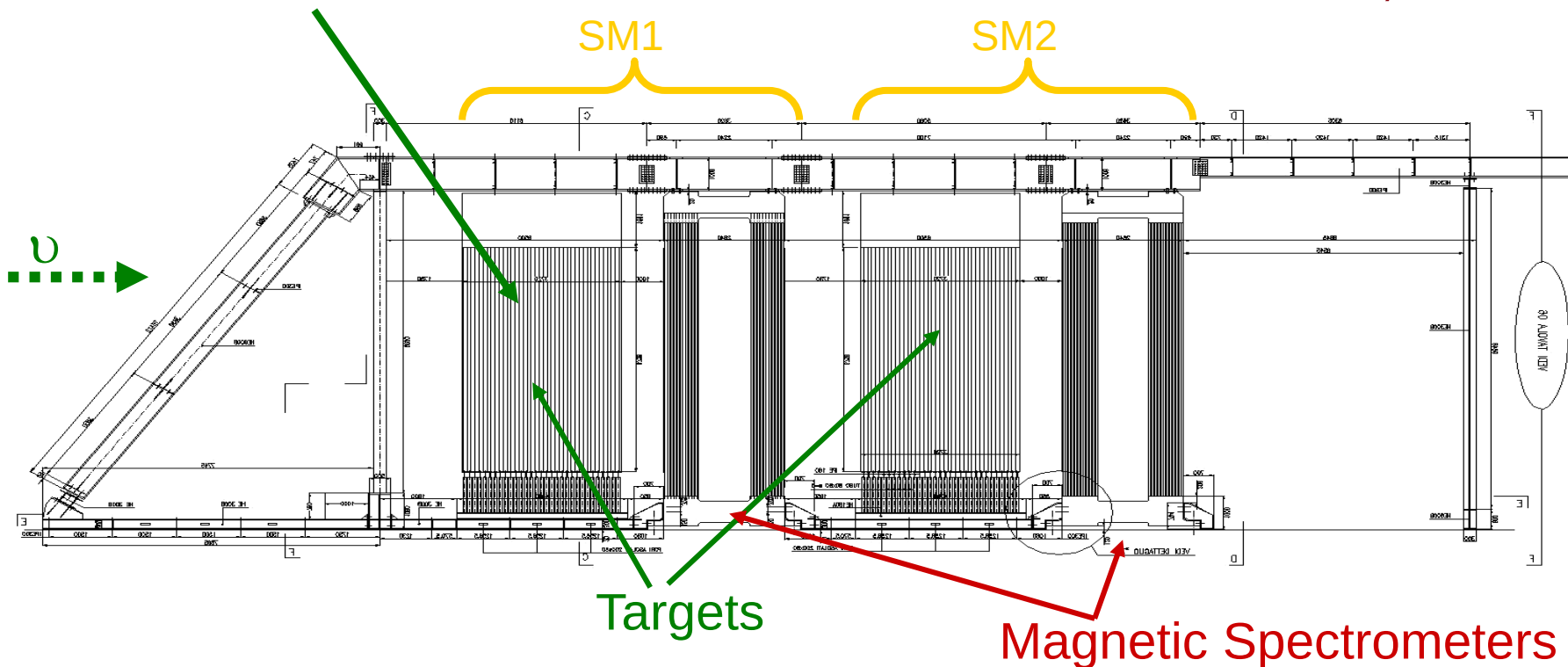
ν_τ events (from oscillation)

≈ 2 per year



31 target planes / supermodule

In total: 206336 bricks, 1766 tons



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

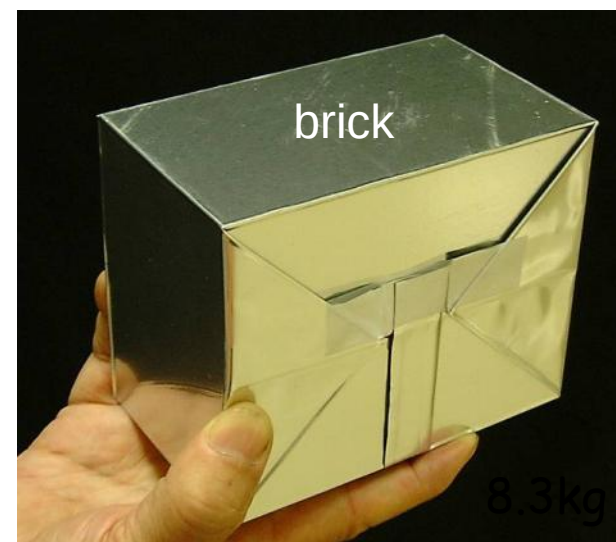
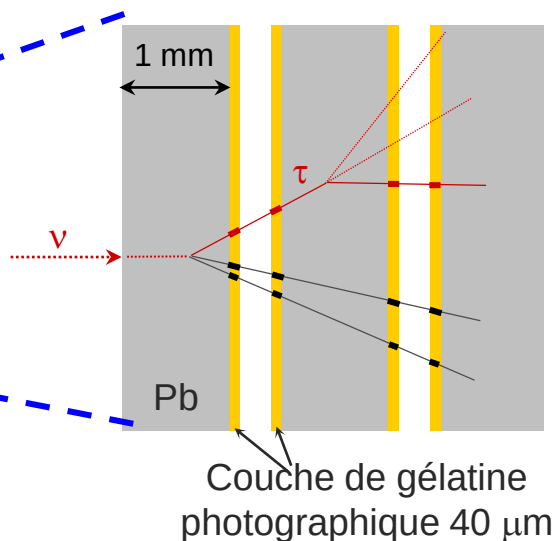
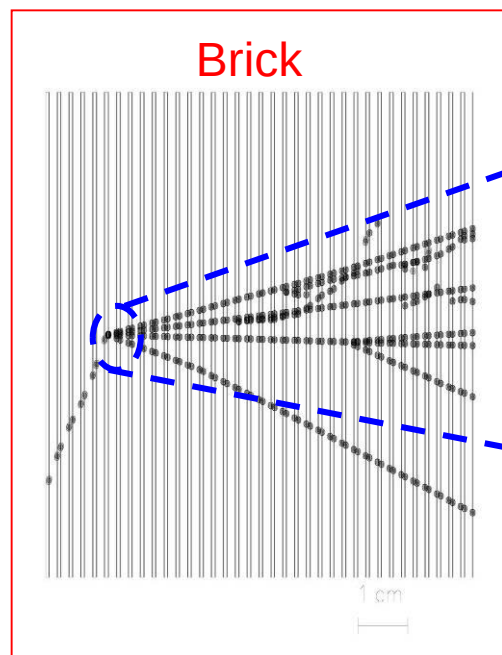


Basic unit: brick

56 Pb sheets + 56 photographic films (emulsion sheets)

Lead plates: massive target

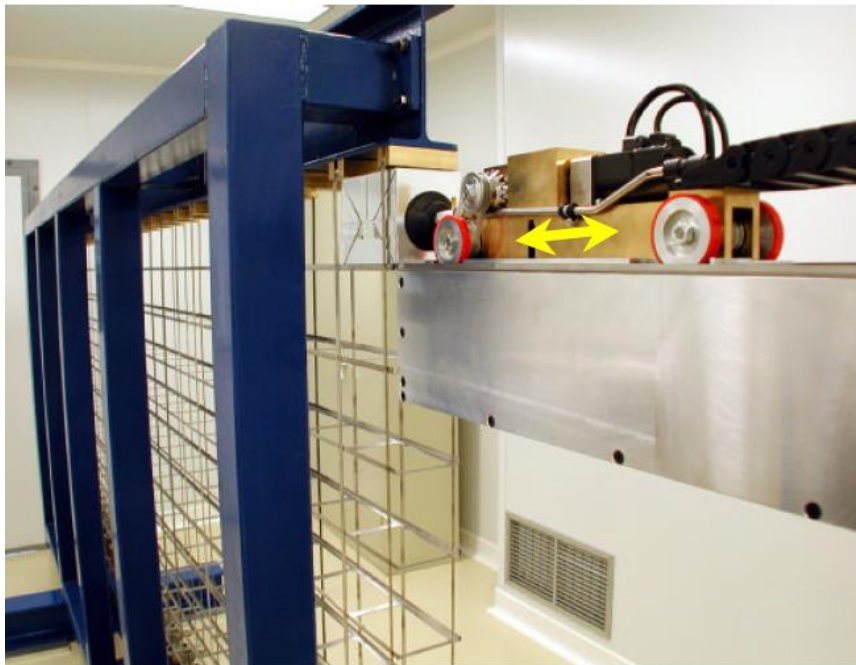
Emulsions: micrometric precision



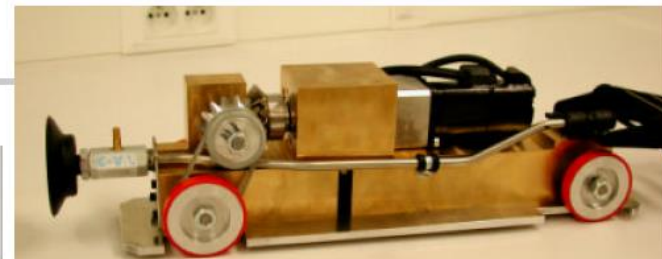
10.2 x 12.7 x 7.5 cm³



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



Tests with the prototype wall



The robotised "Ferrari" for
insertion/extraction of bricks with
vacuum grip by Venturi valve



"Carousel" brick dispensing
and storage system

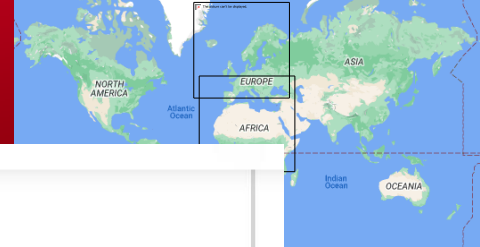
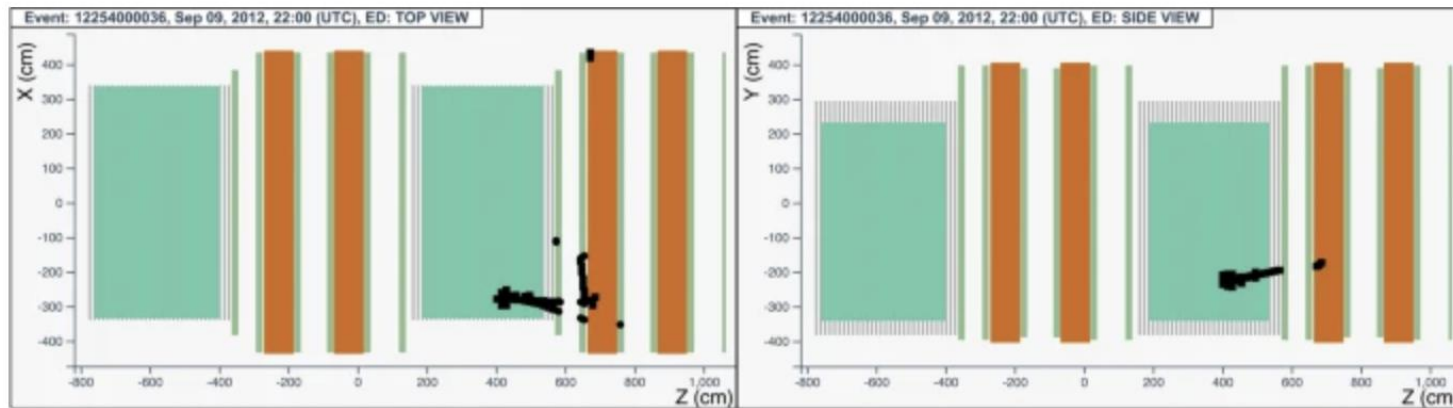
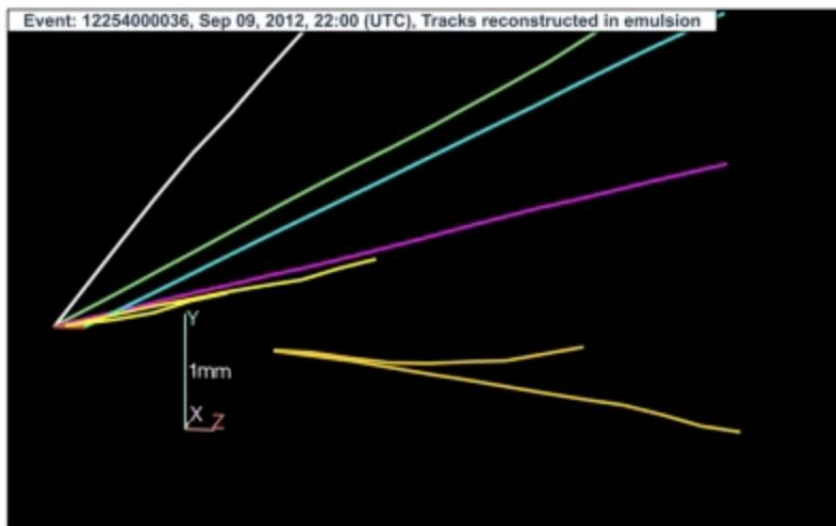


Fig. 15



(a)



Track types

- tau lepton
- hadron (daughter)
- proton
- hadron
- hadron
- e+/e- (gamma)
- e+/e- (gamma)

(b)

Tau event (2021)

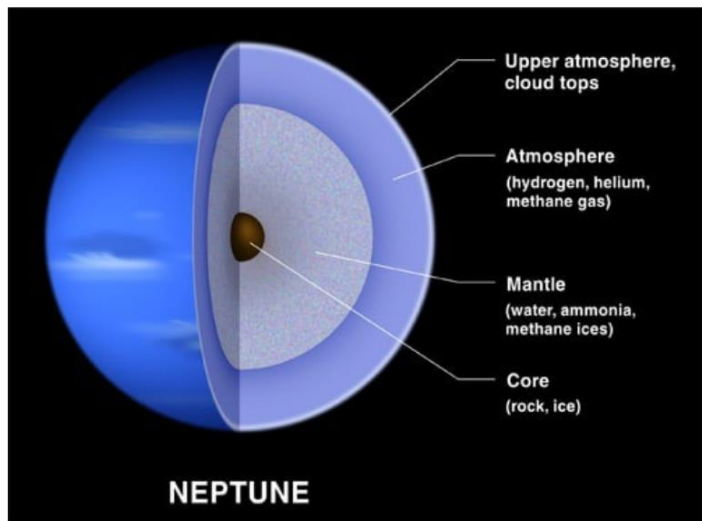


Fig. 15 Sketch of the Internal Structure of Neptune produced by NASA

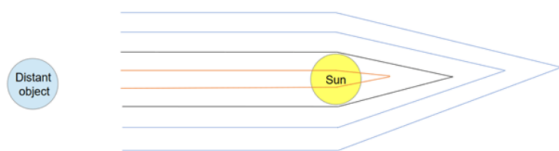


Fig. 4. Depiction of Neutrino Gravitational Lensing of the Sun.

To see Galactic core and BH

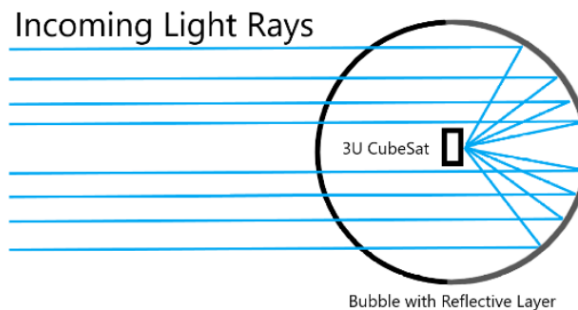


Fig. 14 Diagram of reflective bubble environment redirecting the incoming light rays back to the CubeSat.

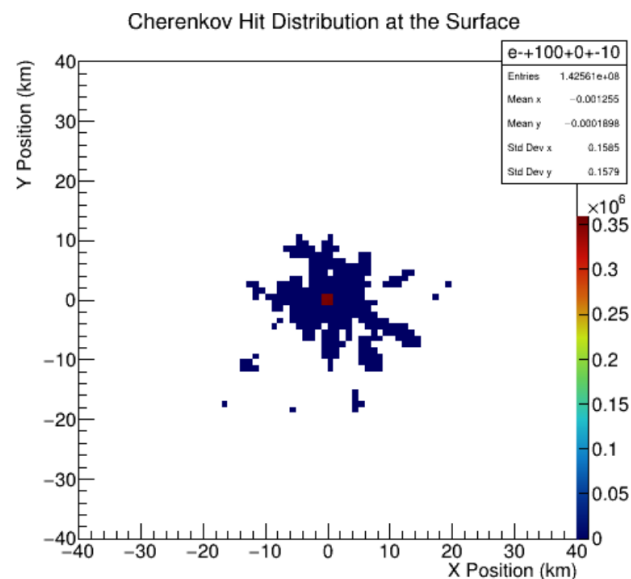
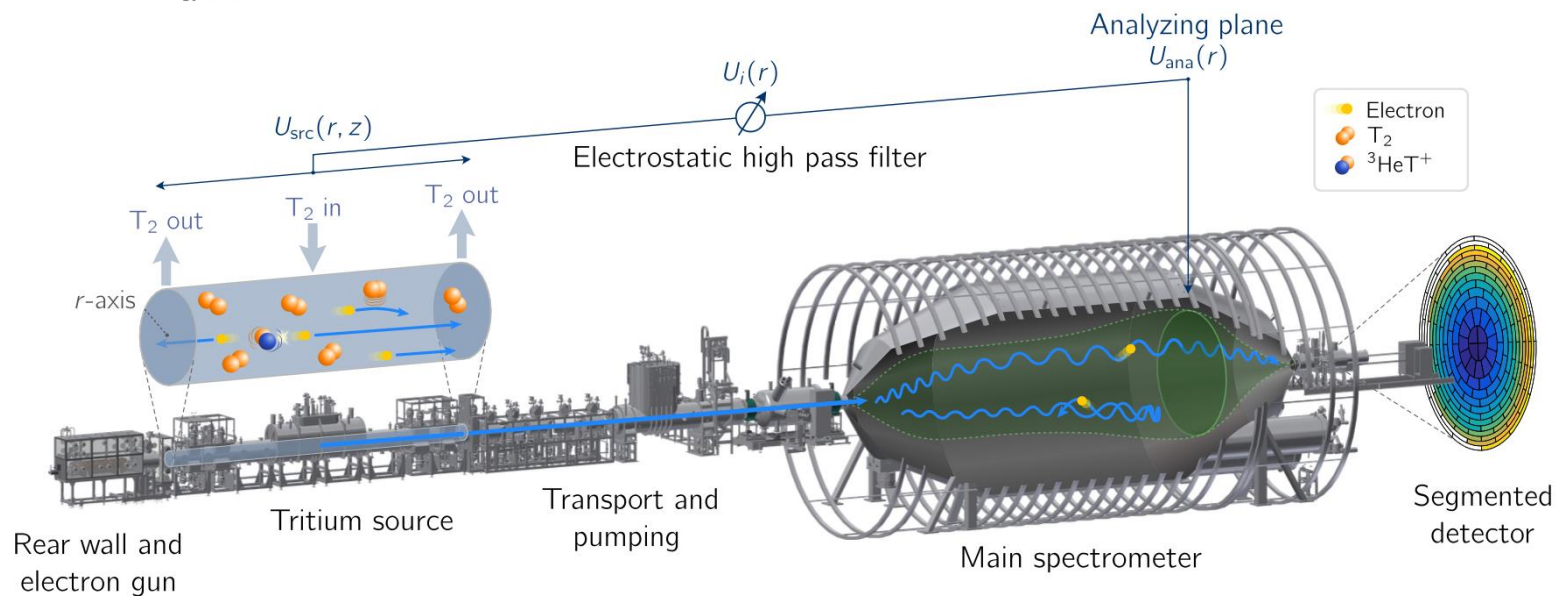
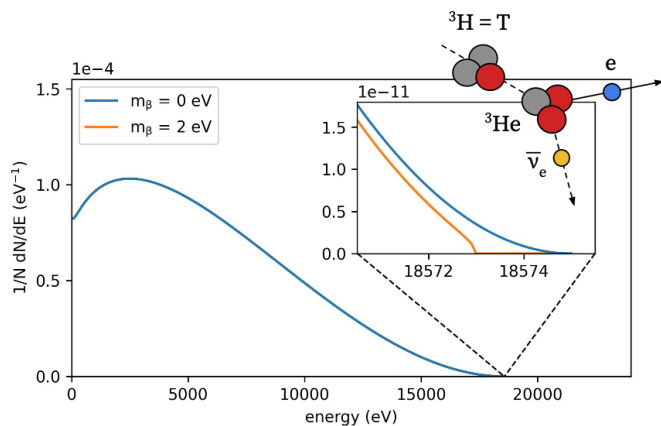
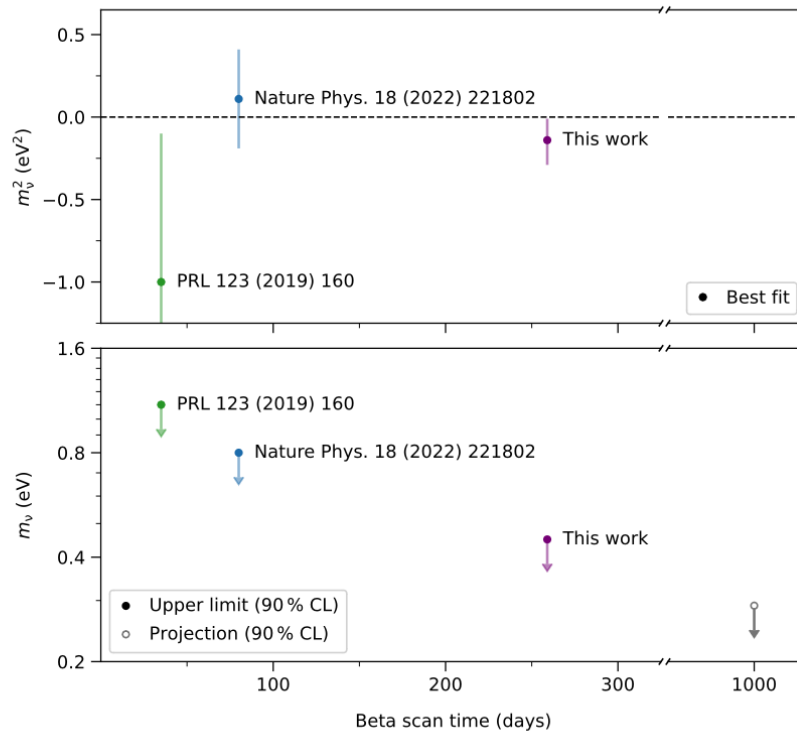


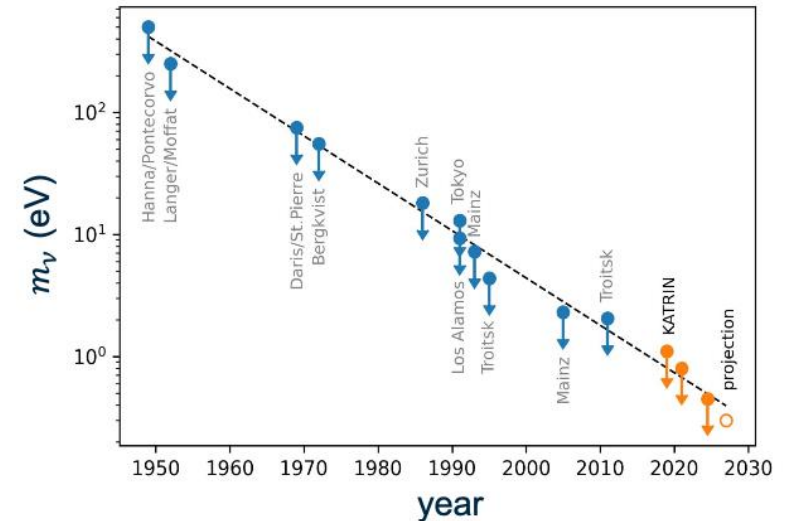
Fig. 7 Cherenkov hit distribution generated by a 100 GeV Electron at the surface of the atmosphere.







Karlsruhe Tritium Neutrino (KATRIN) experiment



Submitted on 19 Jun 2024
Direct neutrino-mass measurement
based on 259 days of KATRIN data

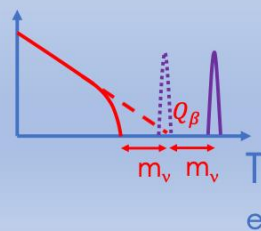
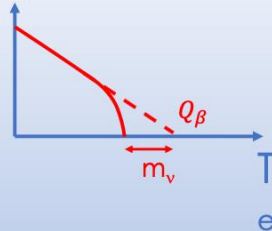
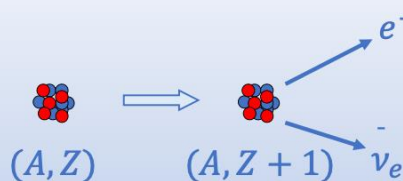
2026





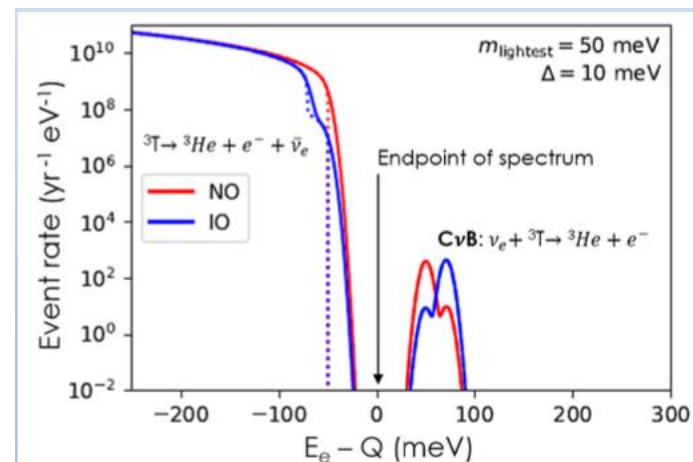
Detection principle

A new idea

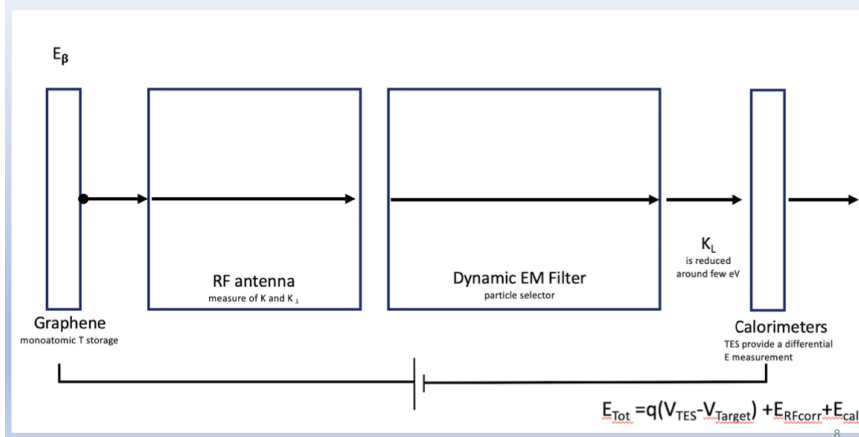


A.G.Cocco, G.Mangano and M.Messina JCAP 06(2007) 015

5



PTOLEMY: experiment layout



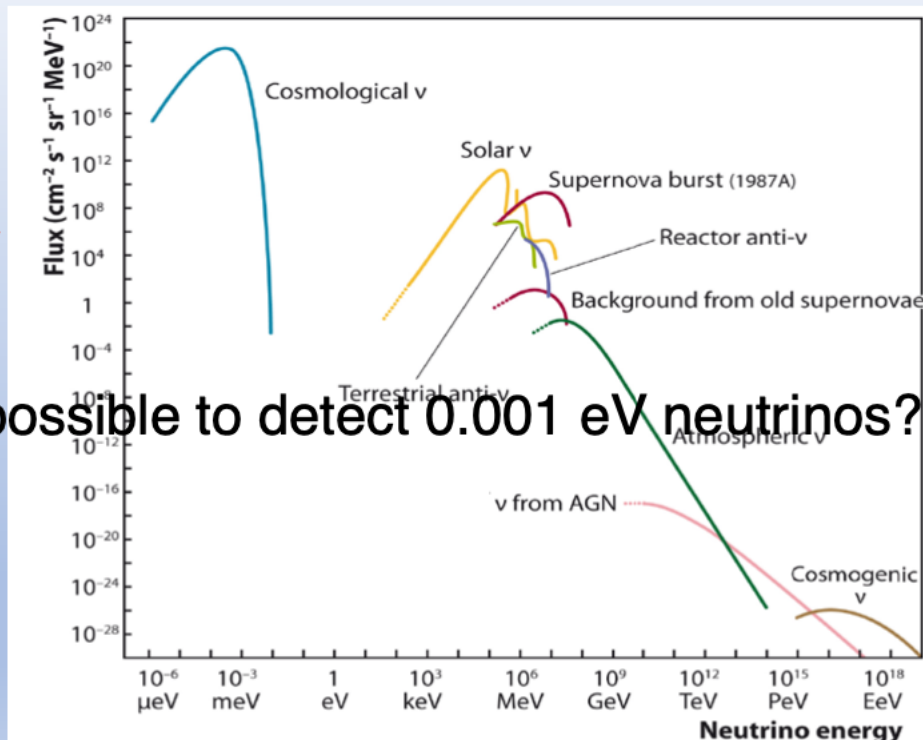


Neutrino flow

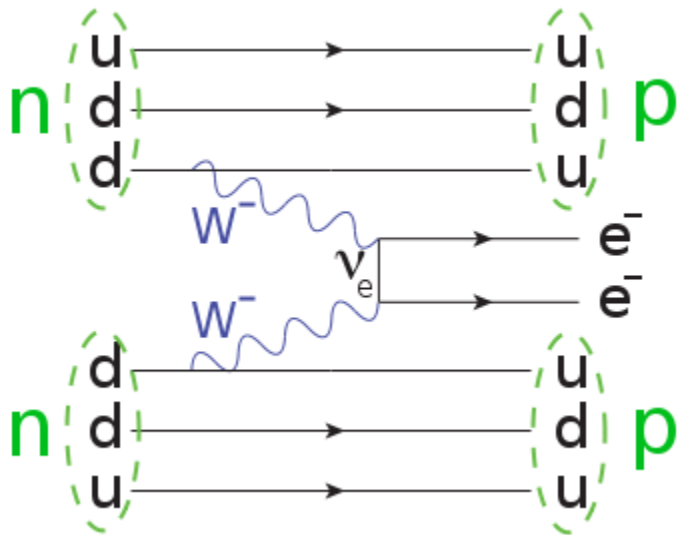
$$T \approx 1.9 \text{ K} \Rightarrow p_\nu \approx 0.001 \text{ eV}$$

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

Is it possible to detect 0.001 eV neutrinos?



DOUBLE BETA DECAY

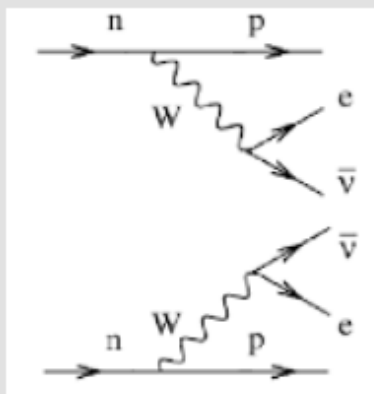


$0\nu\beta\beta$ of ^{136}Xe : $^{136}\text{Xe} \rightarrow ^{136}\text{Ba} + 2e^-$

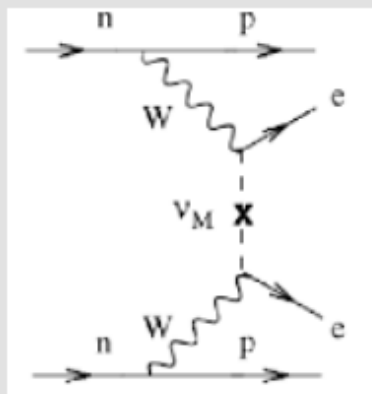


Double beta decay

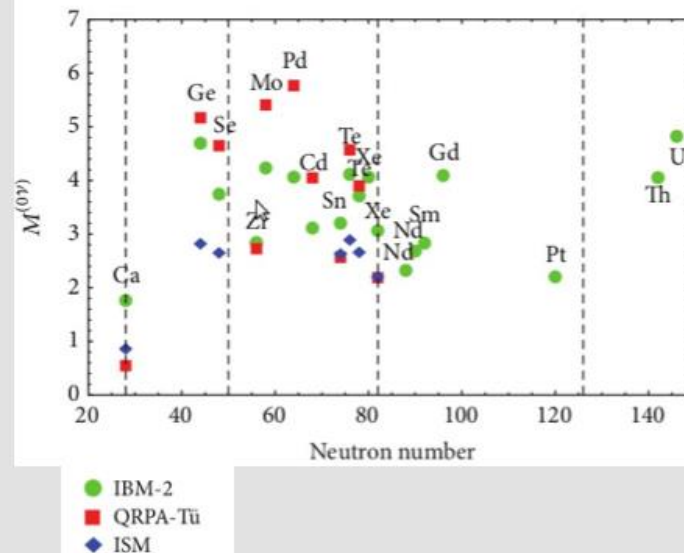
$2\nu\beta\beta$



$0\nu\beta\beta$



Nuclear matrix elements (NME) via theory.

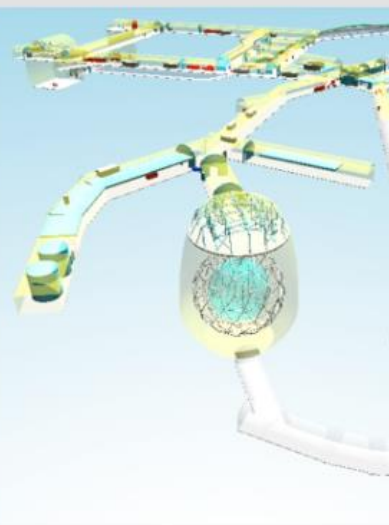
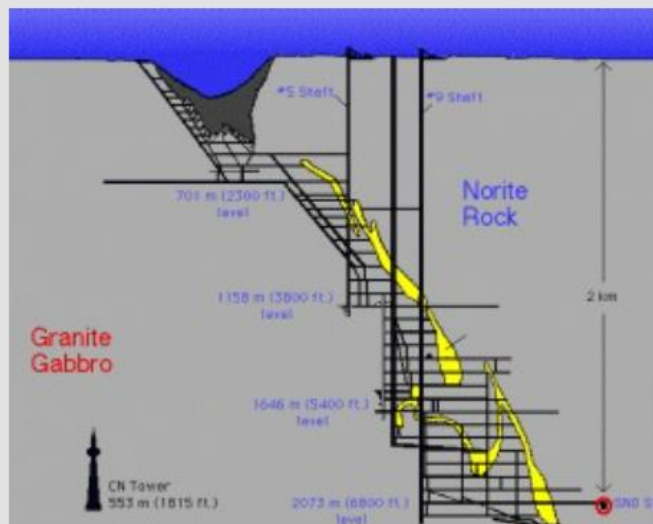


Experiment	Isotope	Technique	Main Strength	
CUORE (LNGS)	¹³⁰ Te	Bolometers	Resolution, Efficiency	On-going or commissioning few kg
GERDA II (LNGS)	⁷⁶ Ge	Ge Diodes	Resolution, Efficiency	
KamLANDZen (Kamioka)	¹³⁶ Xe	Xe Liquid scintillation	Background, efficiency	
MAJORANA (SURF)	⁷⁶ Ge	Ge Diodes	Resolution,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



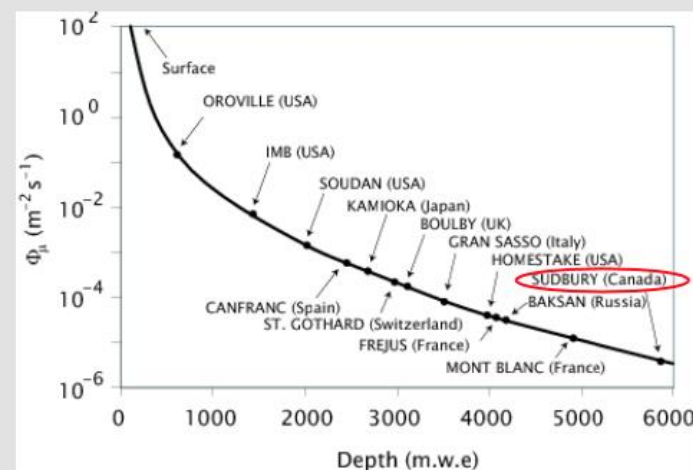
The SNO+ Experiment

3.- T



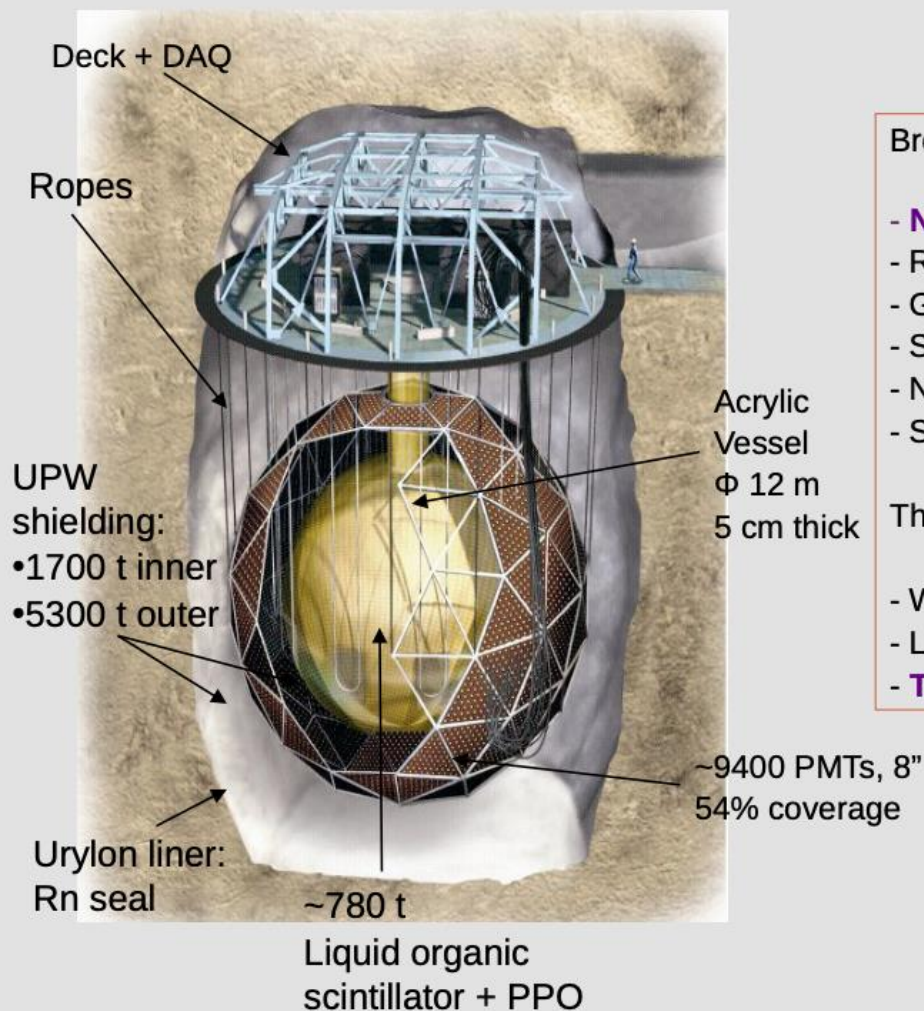
- Located at SNOLAB inside the Creighton mine near Sudbury, Canada.
- SNO+ is the successor to Sudbury Neutrino Observatory (SNO).

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





The SNO+ Detector

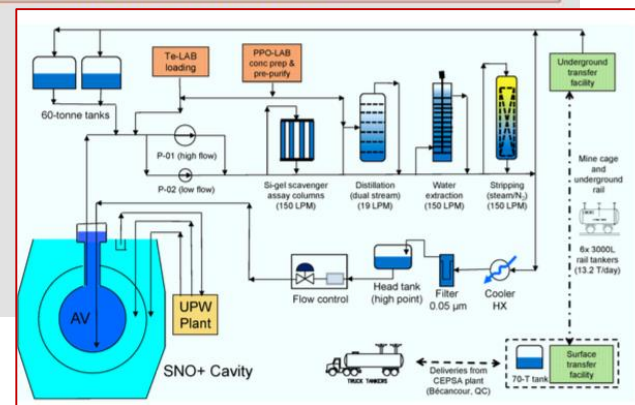


Broad neutrino physics program

- **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**



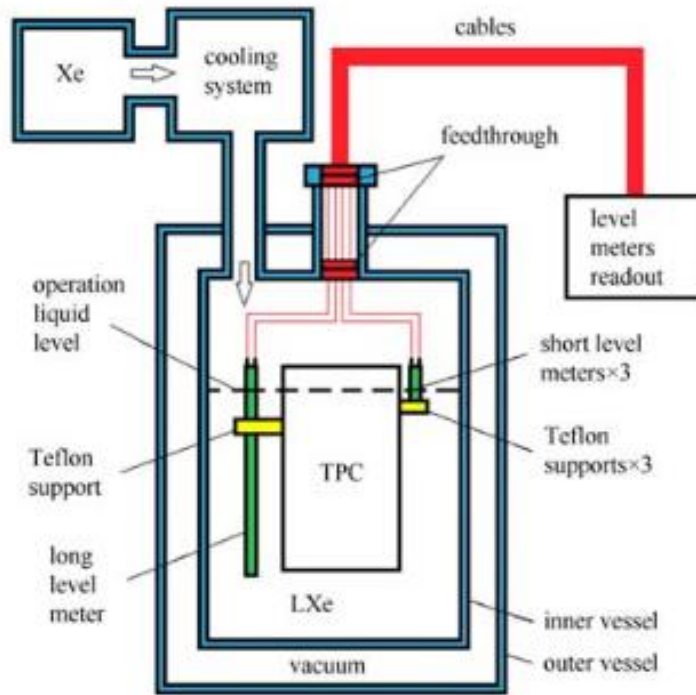
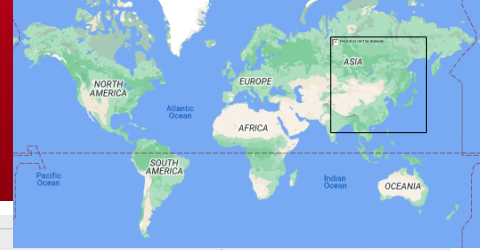
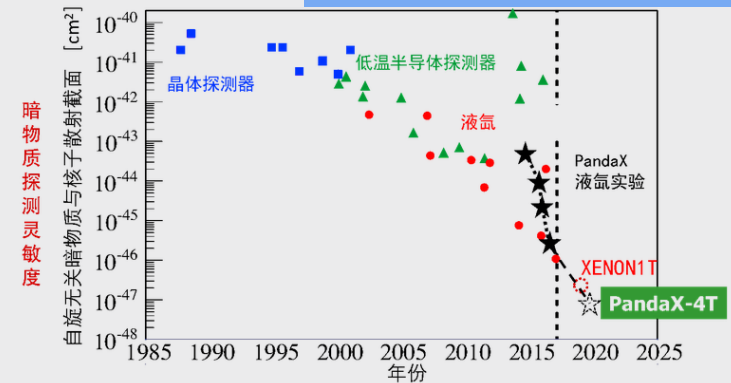
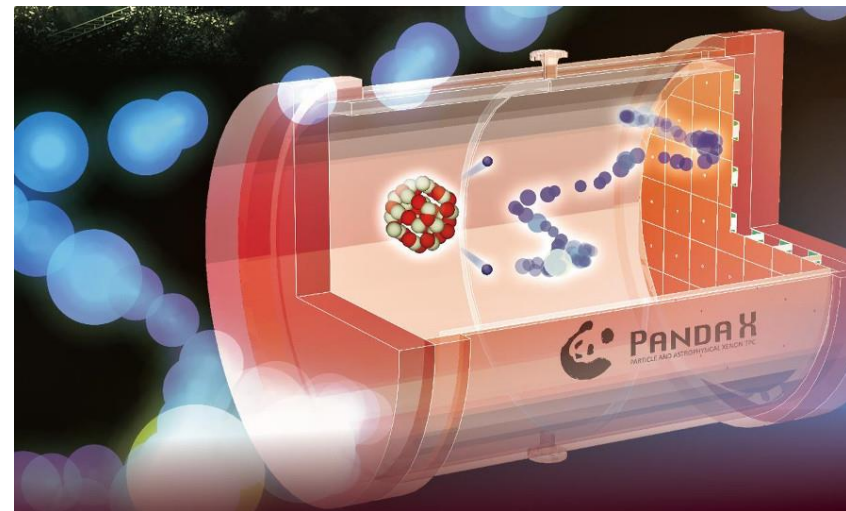


Fig. 1. Schematics of the two-phase xenon detector as used in PandaX. LXe is contained in an inner vessel insulated by vacuum from the outside. One long liquid level meter monitors the overall liquid xenon height and three short level meters monitor the height of the liquid-gas interface around the TPC.



2016年PandaX二期实验(500公斤级液氩)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氩探测实验的研发,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,四吨级液氩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,四吨液氩中含有的放射性同位素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)

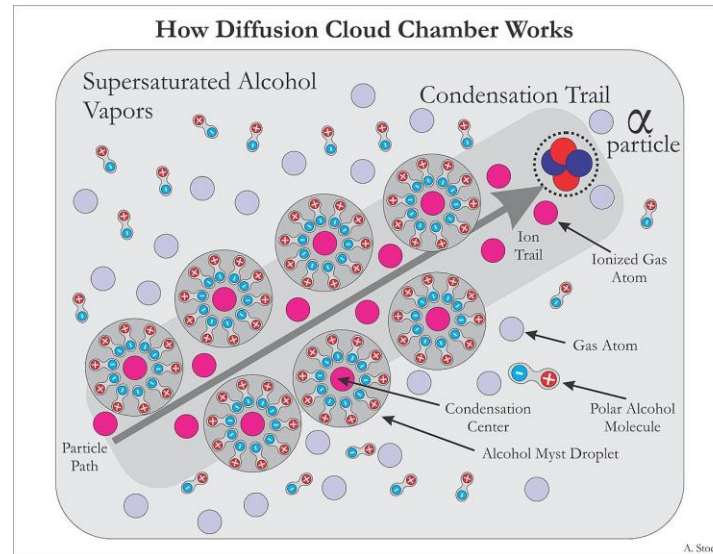
Out of a group of 1300 photographs of cosmic-ray tracks in a vertical Wilson chamber 15 tracks were of positive particles which could not have a mass as great as that of the proton. From an examination of the energy-loss and ionization produced it is concluded that the charge is less than twice, and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



1930 : Data taking
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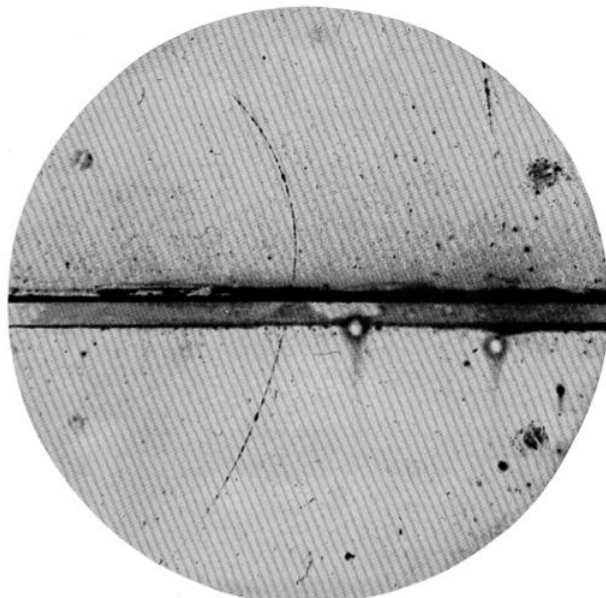


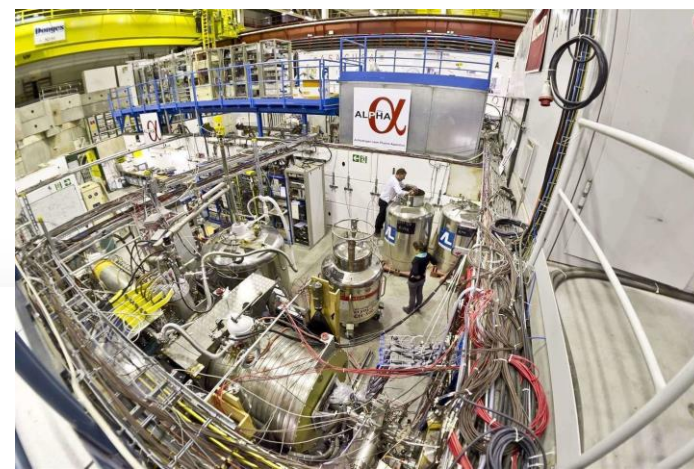
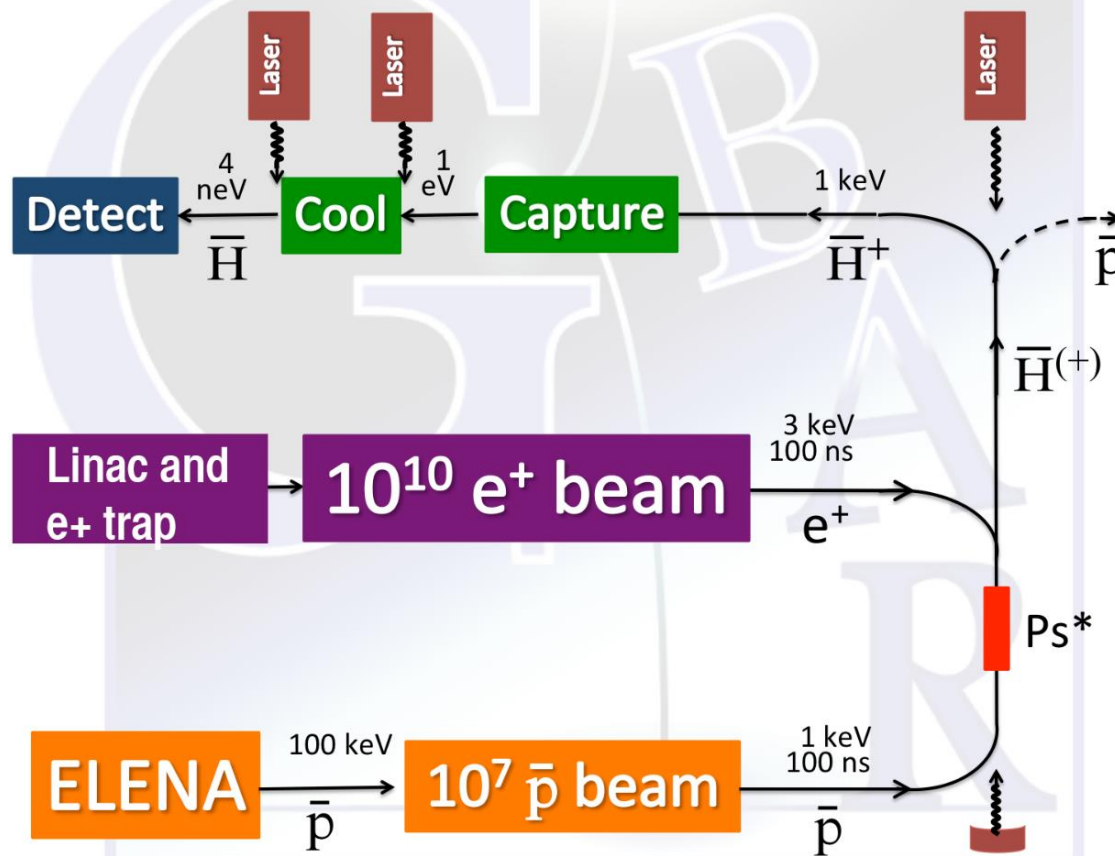
FIG. 1. A 63 million volt positron ($H_p = 2.1 \times 10^6$ gauss-cm) passing through a 6 mm lead plate and emerging as a 23 million volt positron ($H_p = 7.5 \times 10^6$ gauss-cm). The length of this latter path is at least ten times greater than the possible length of a proton path of this curvature.



GBAR at CERN

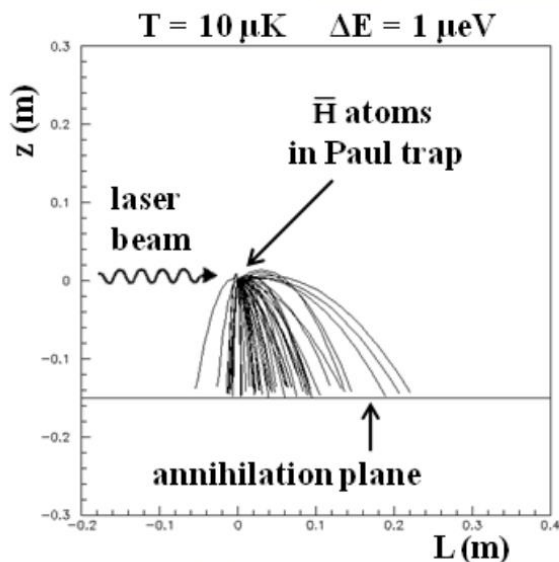


Schematic





Detection



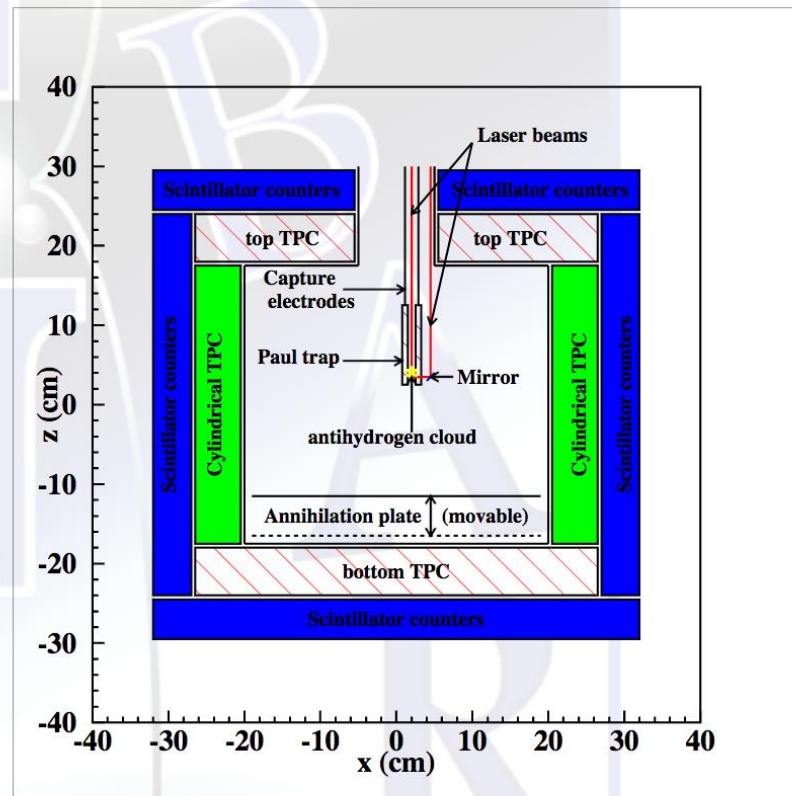
Detection requirement:

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)



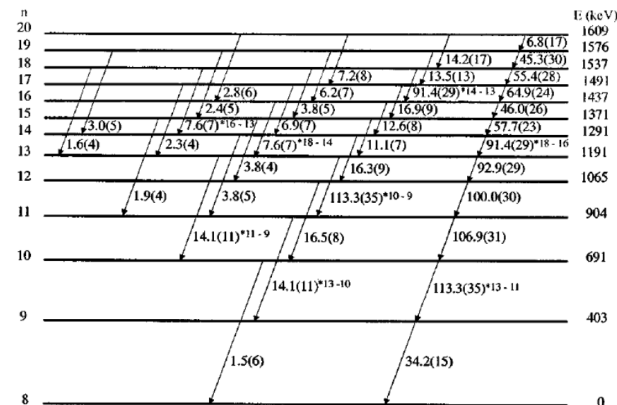
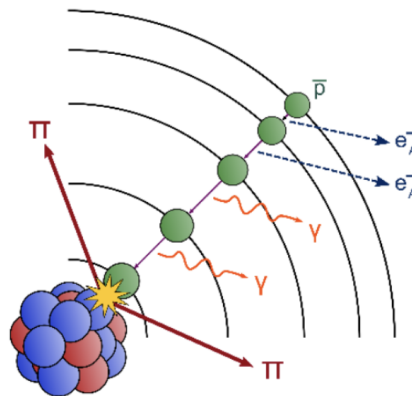
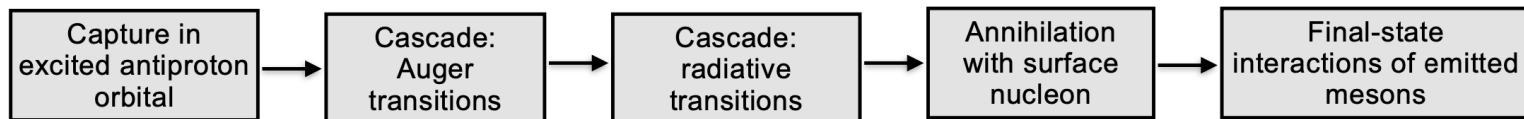
$$\frac{\Delta \bar{g}}{\bar{g}} \approx 10^{-2}$$



antiProton Unstable Matter Annihilation (PUMA)



Proposed technique: Low-energy antiprotons as a probe



R. Schmidt, PRC (1998)

Clara Klink | CERN | TU Darmstadt – Institute for Nuclear Physics
FuPhy 2024 | 08. - 10. Apr 2024, SMI, Wien





Transporting Antiprotons from AD to ISOLDE



- There is no connecting beam line between the 2 facilities
- Requirements:
 - a transportable ion trap with sufficient storage capabilities
 - XHV vacuum conditions for the storage of antiprotons (20 cm^{-3})
 - a detection system for monitoring annihilation rates during the transport

Good news:

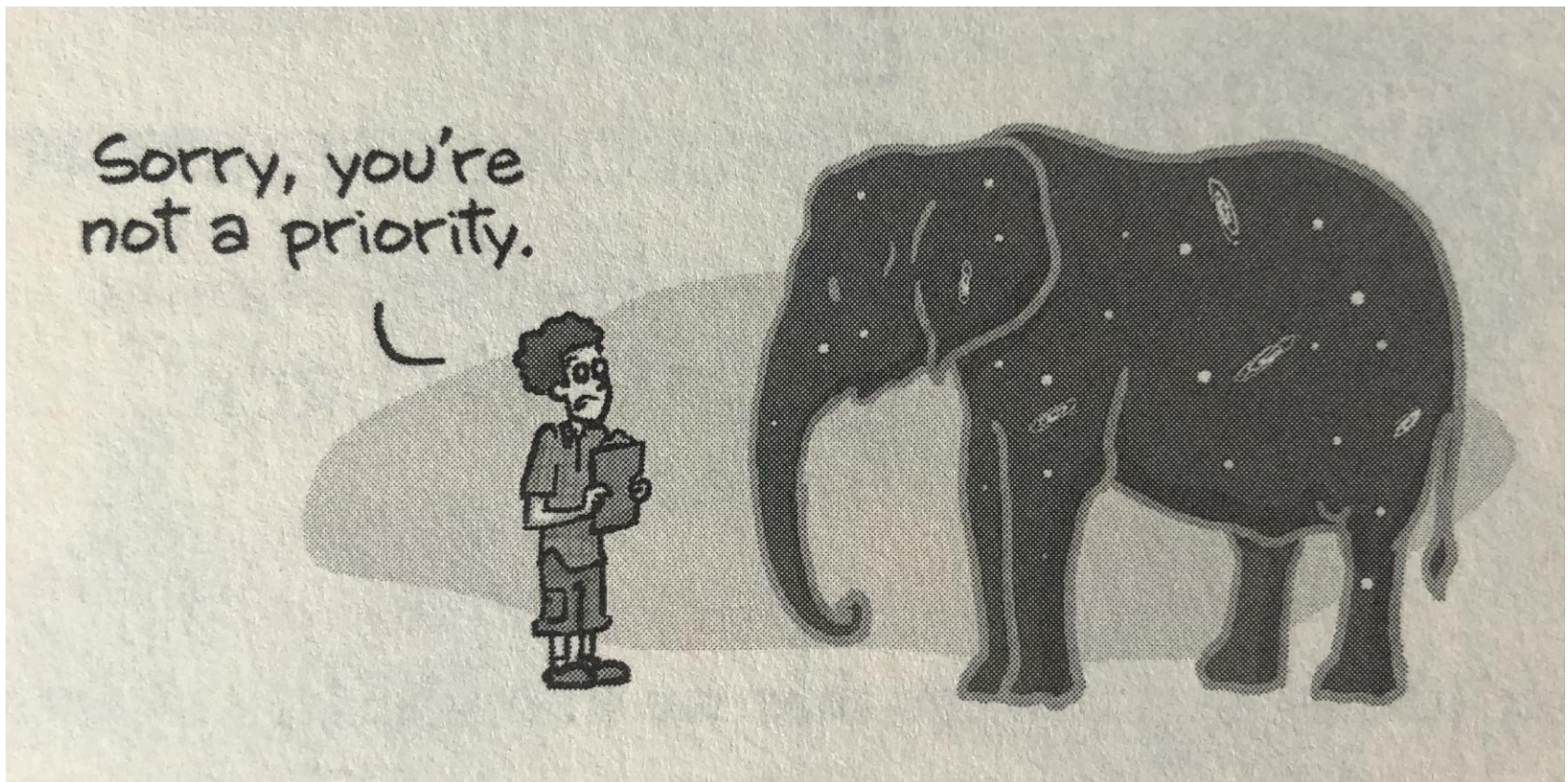
- Long antiproton trapping time already achieved.
Ex. BASE: > 50 years
- Transportation of antiprotons is also a core component of BASE-STEP (PI: C. Smorra, Mainz)

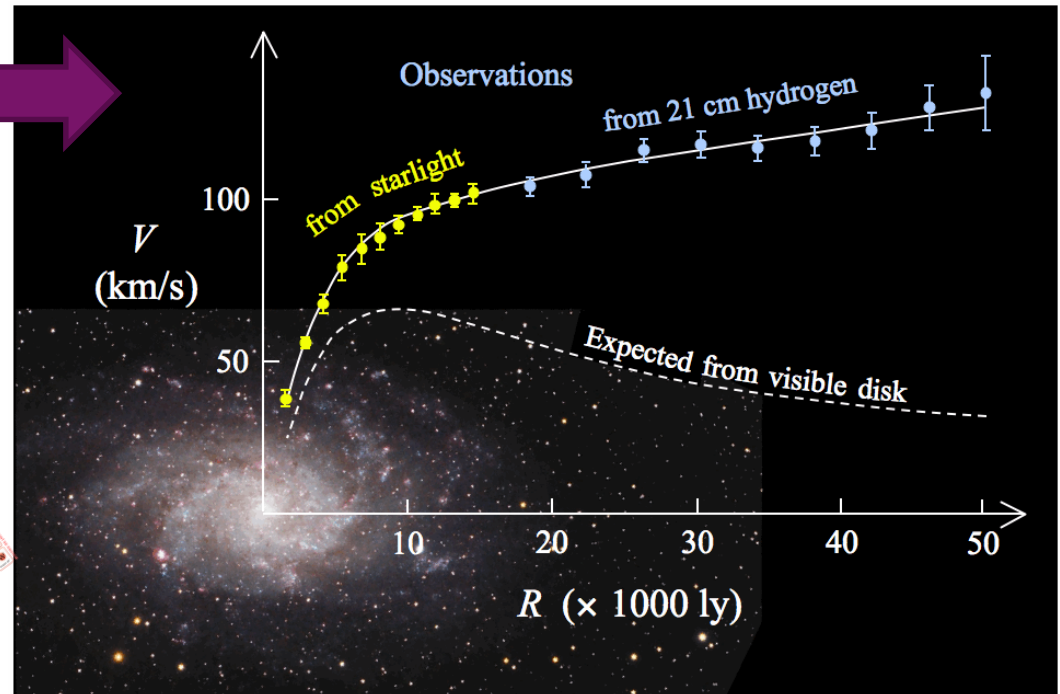
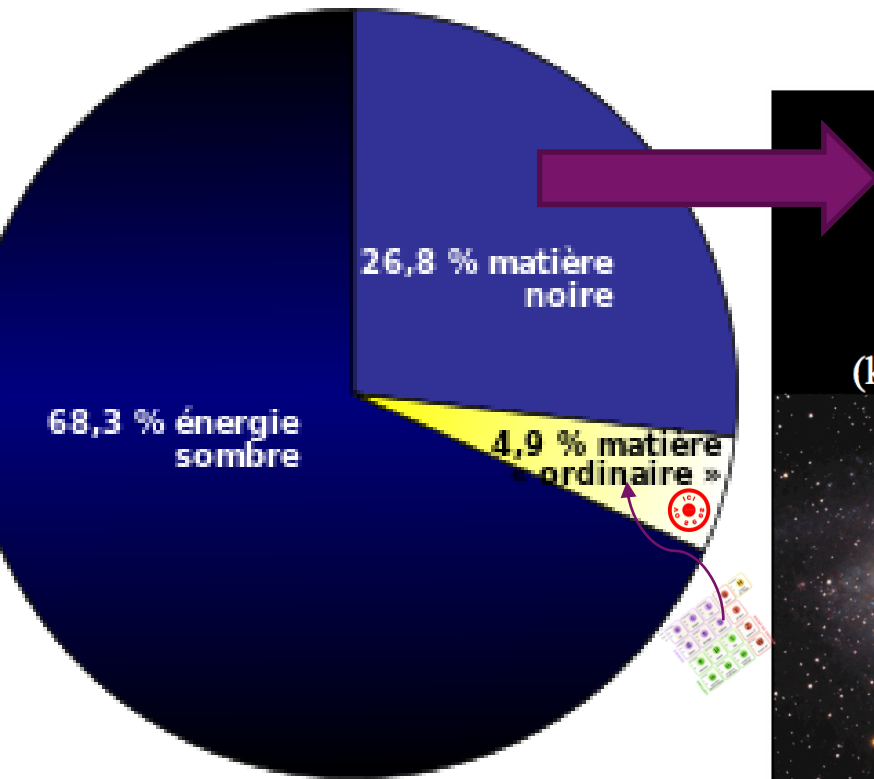
Clara Klink | CERN | TU Darmstadt – Institute for Nuclear Physics
FuPhy 2024 | 08. - 10. Apr 2024, SMI, Wien



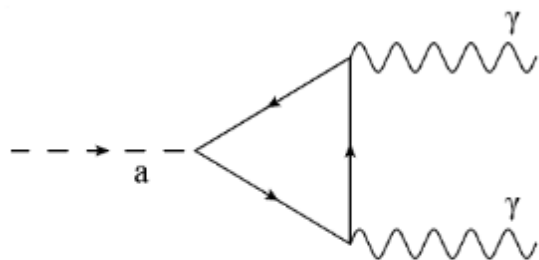
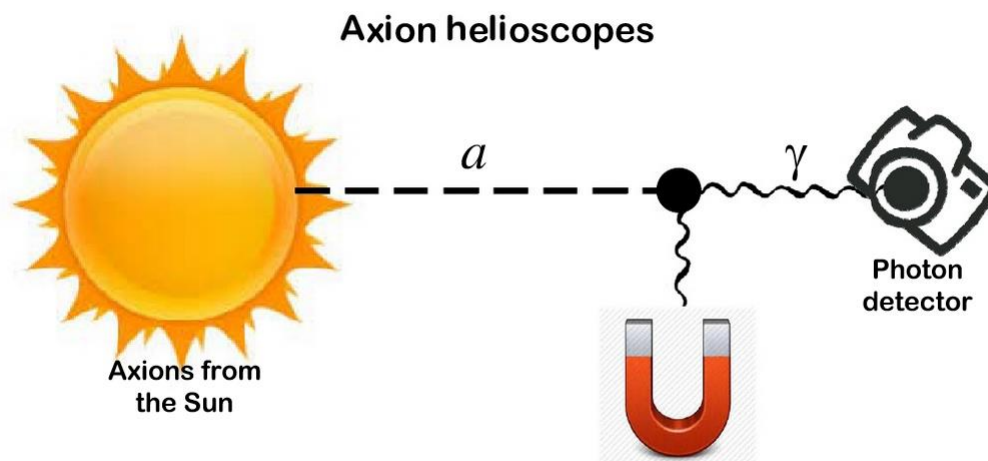
9

MATIERE SOMBRE





AXIONS



© Igor G. Irastorza

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

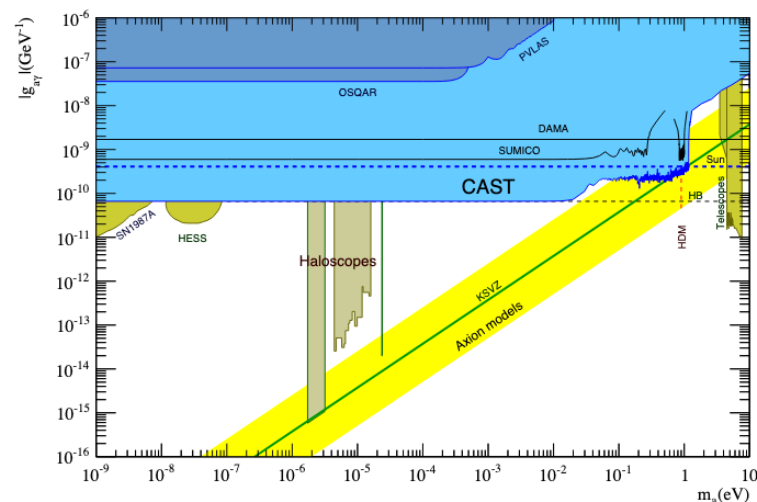
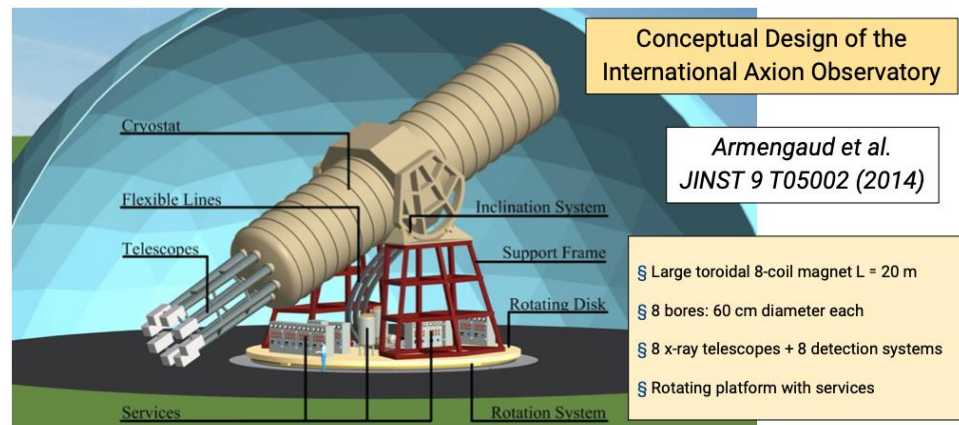
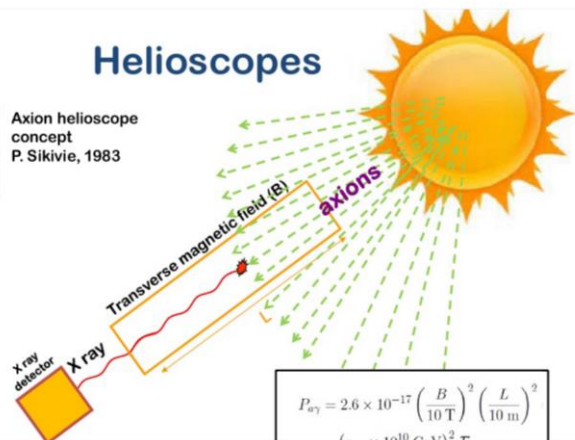
CAST - IAXO

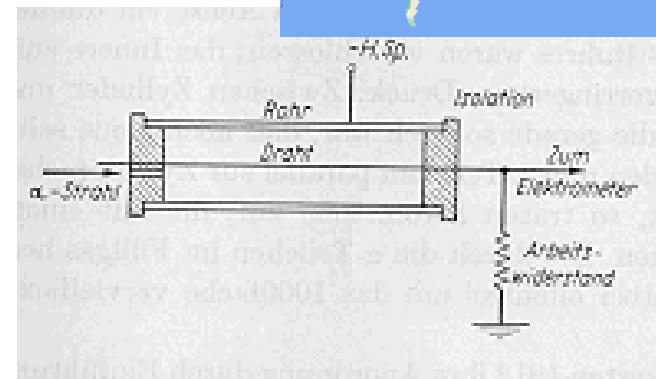
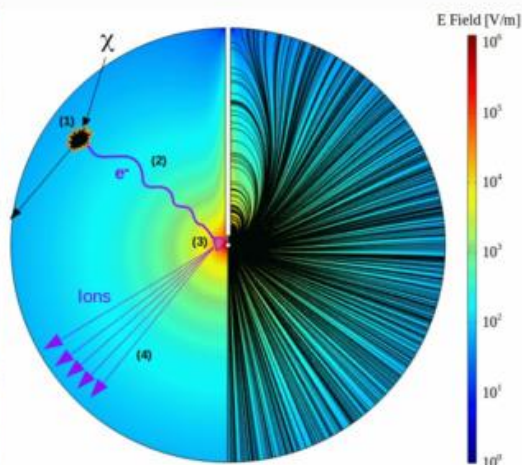


Helioscopes

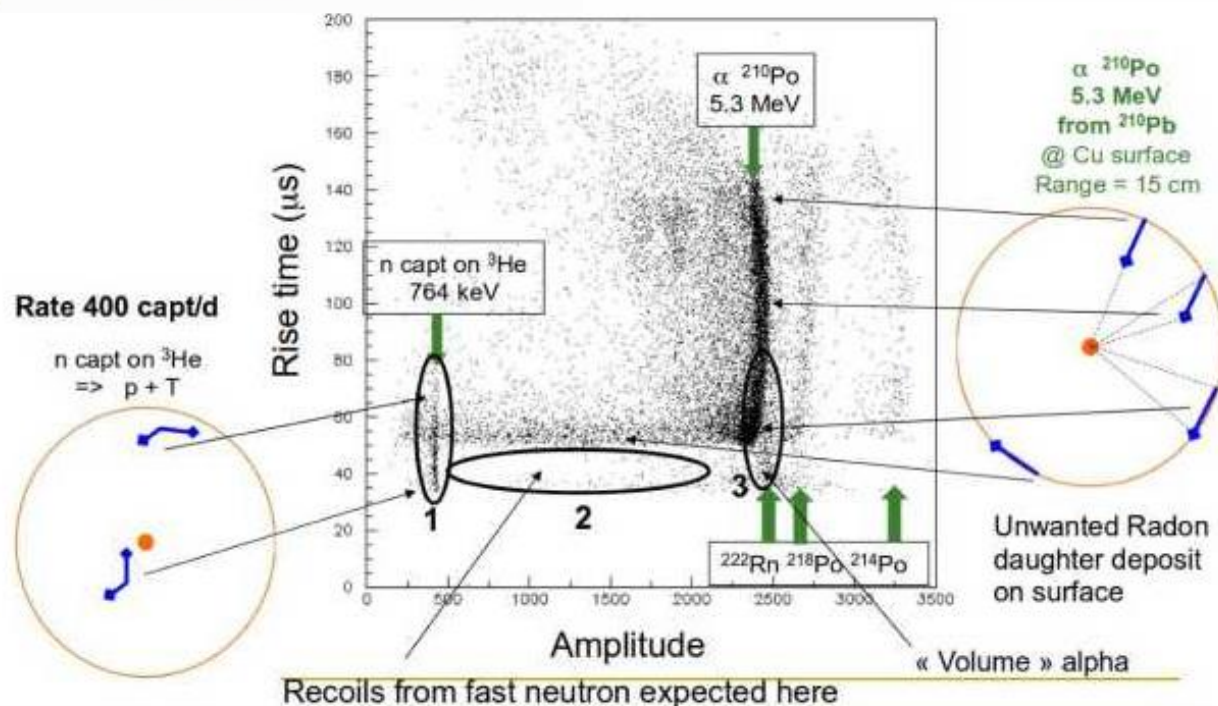


Axion helioscope concept
P. Sikivie, 1983



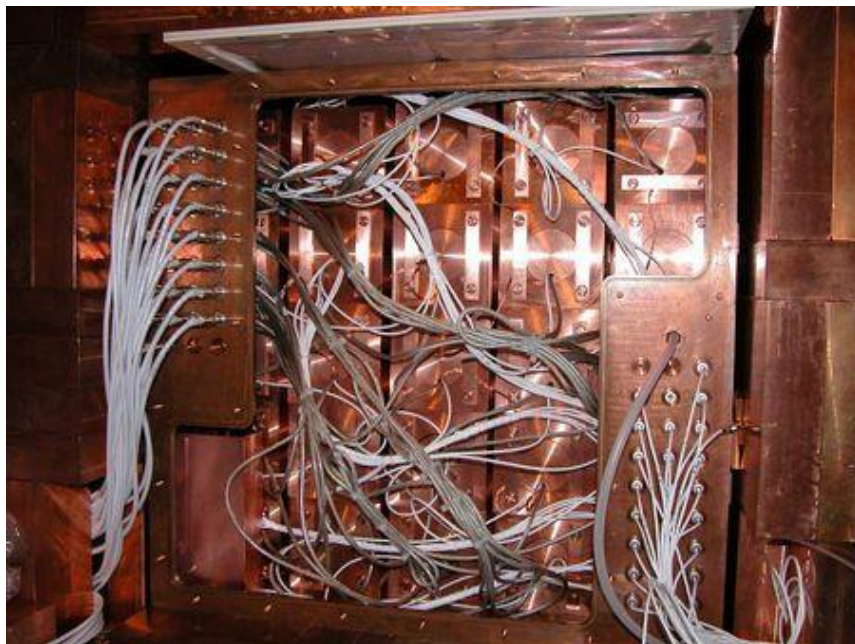


Recul noyau dû aux
WIMPs avec
threshold la plus
basse possible

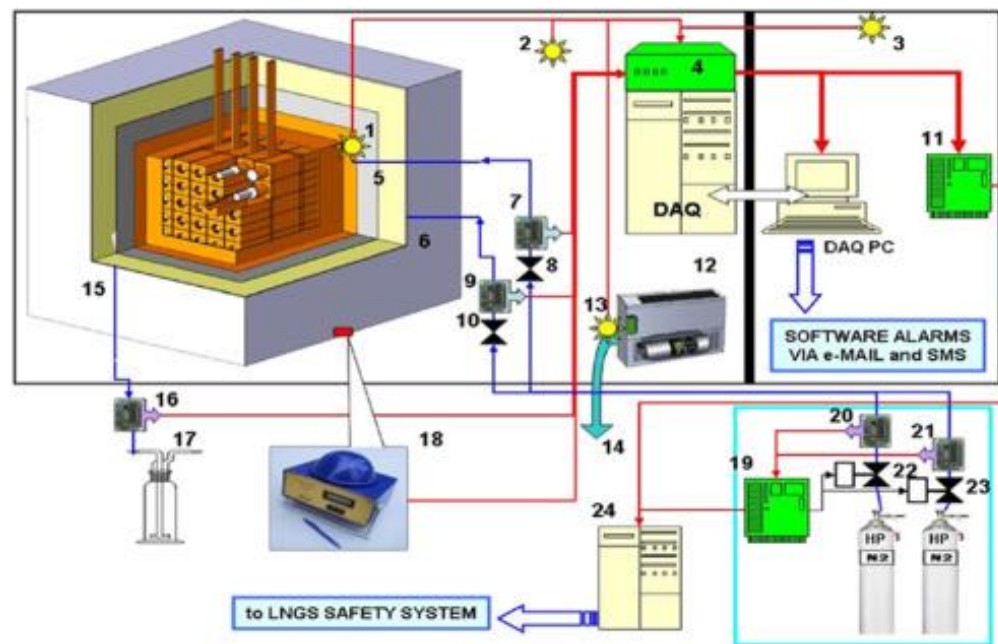




LABORATORI NAZIONALI DEL GRAN SASSO



Thallium-doped sodium detector



DAMA / LIBRA

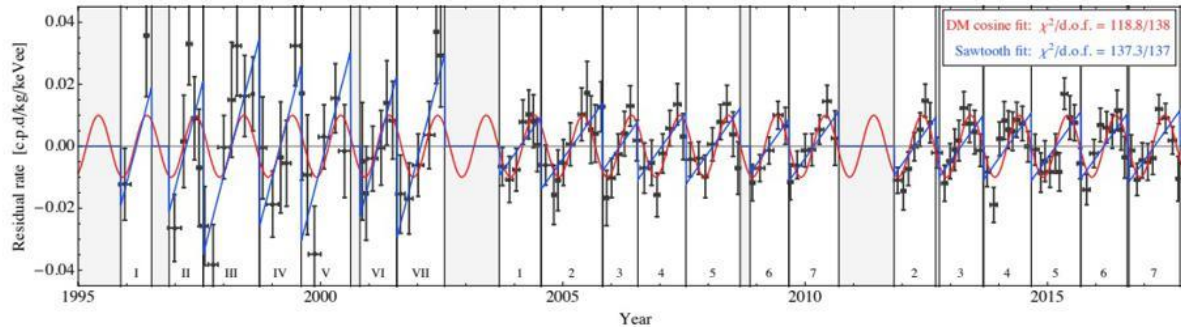
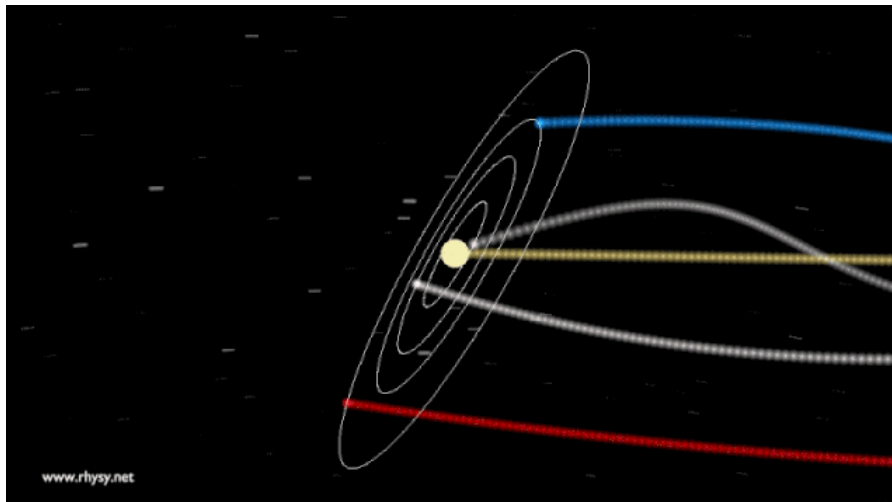
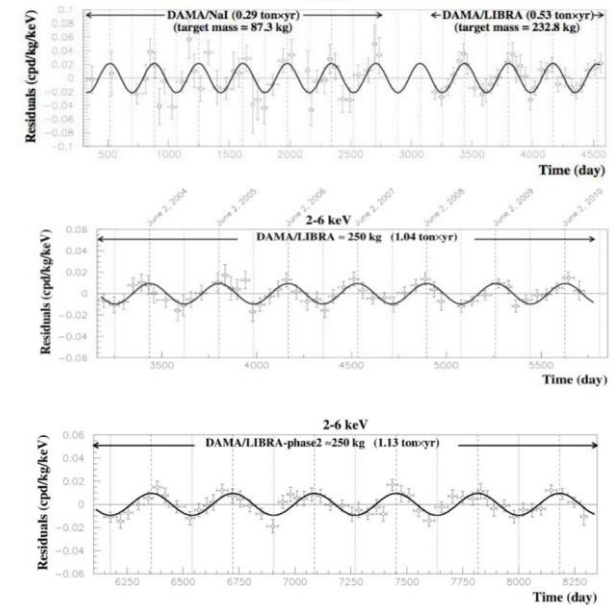


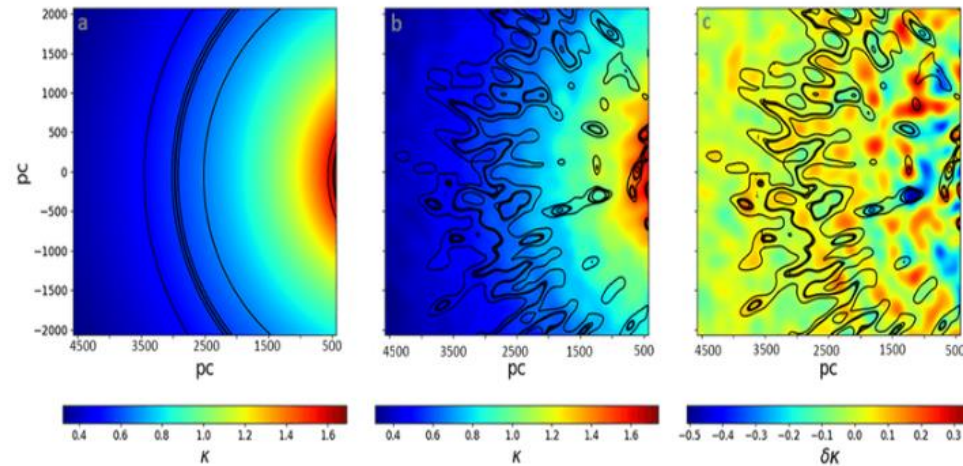
Figure 5. The black data points are the DAMA residuals in the (2–6) keVee energy window, taken from [1, 5]. The curves are fits to a cosine annual modulation peaked on June, 2nd (red curve), as expected for a DM signal, and to the irregular sawtooth obtained from a continuously growing background (blue 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 ☹️
ANAIS (Spain)
COSINE (Germany)
SABRE (Australia/Italia)



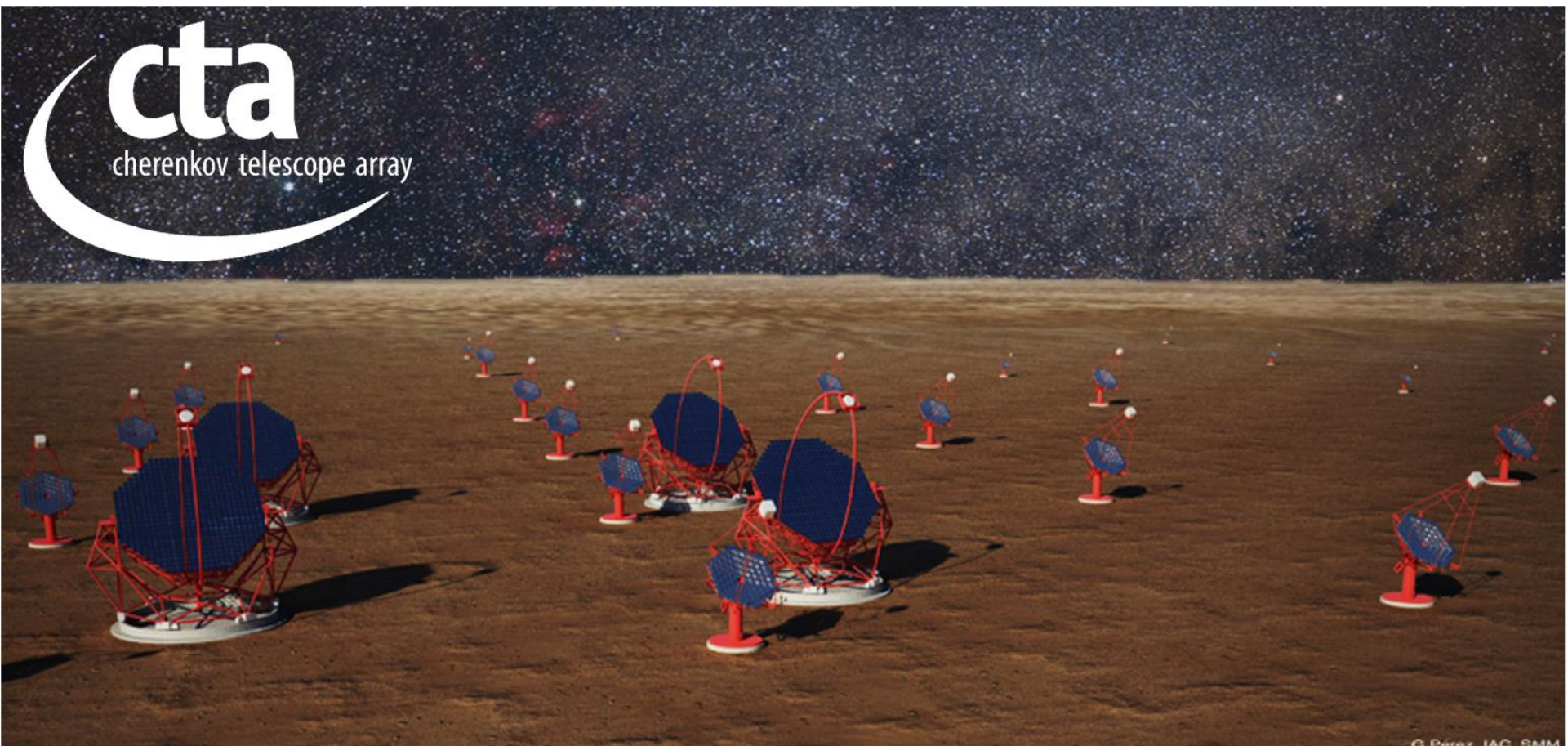
Anomalies in Gravitational-Lensed Images Revealing Einstein Rings Modulated by Wavelike Dark Matter

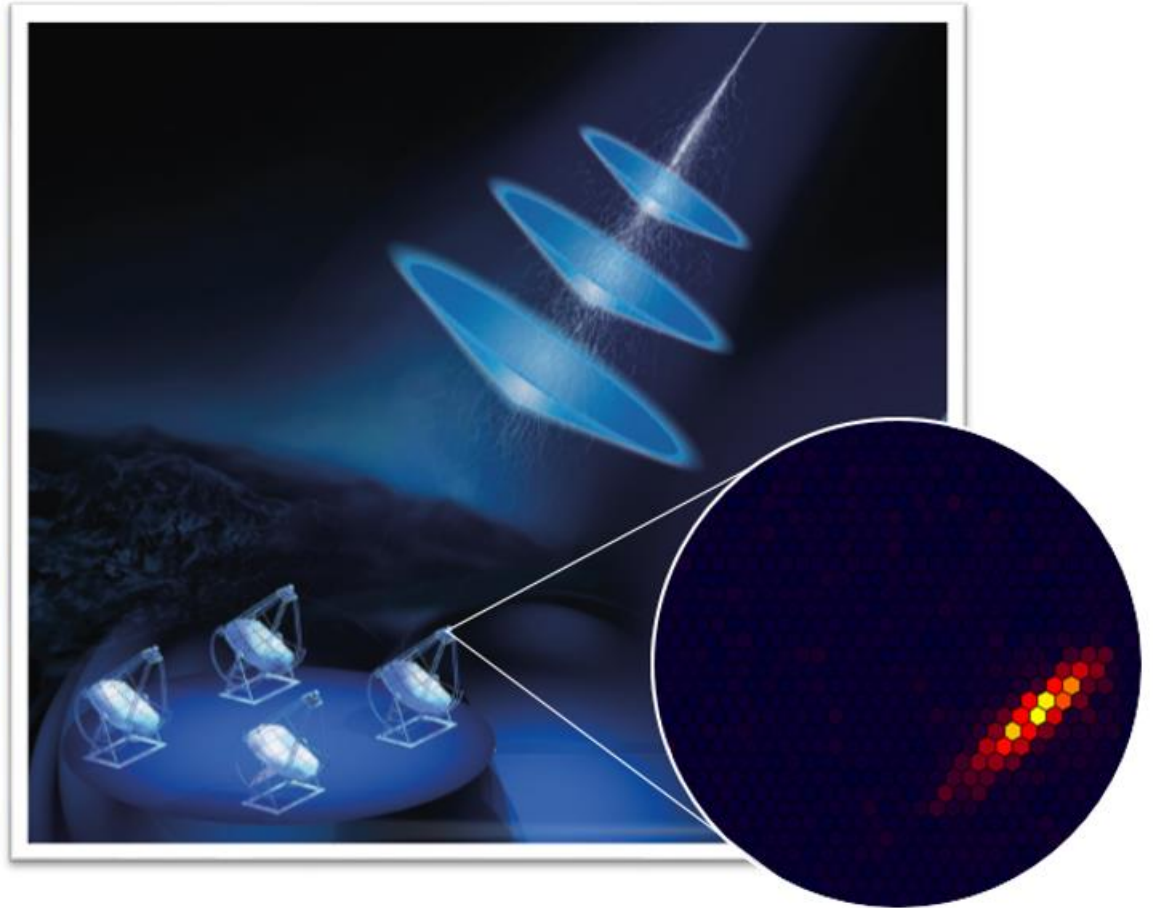
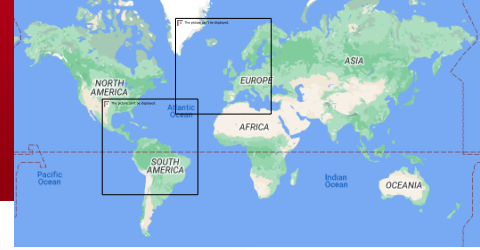


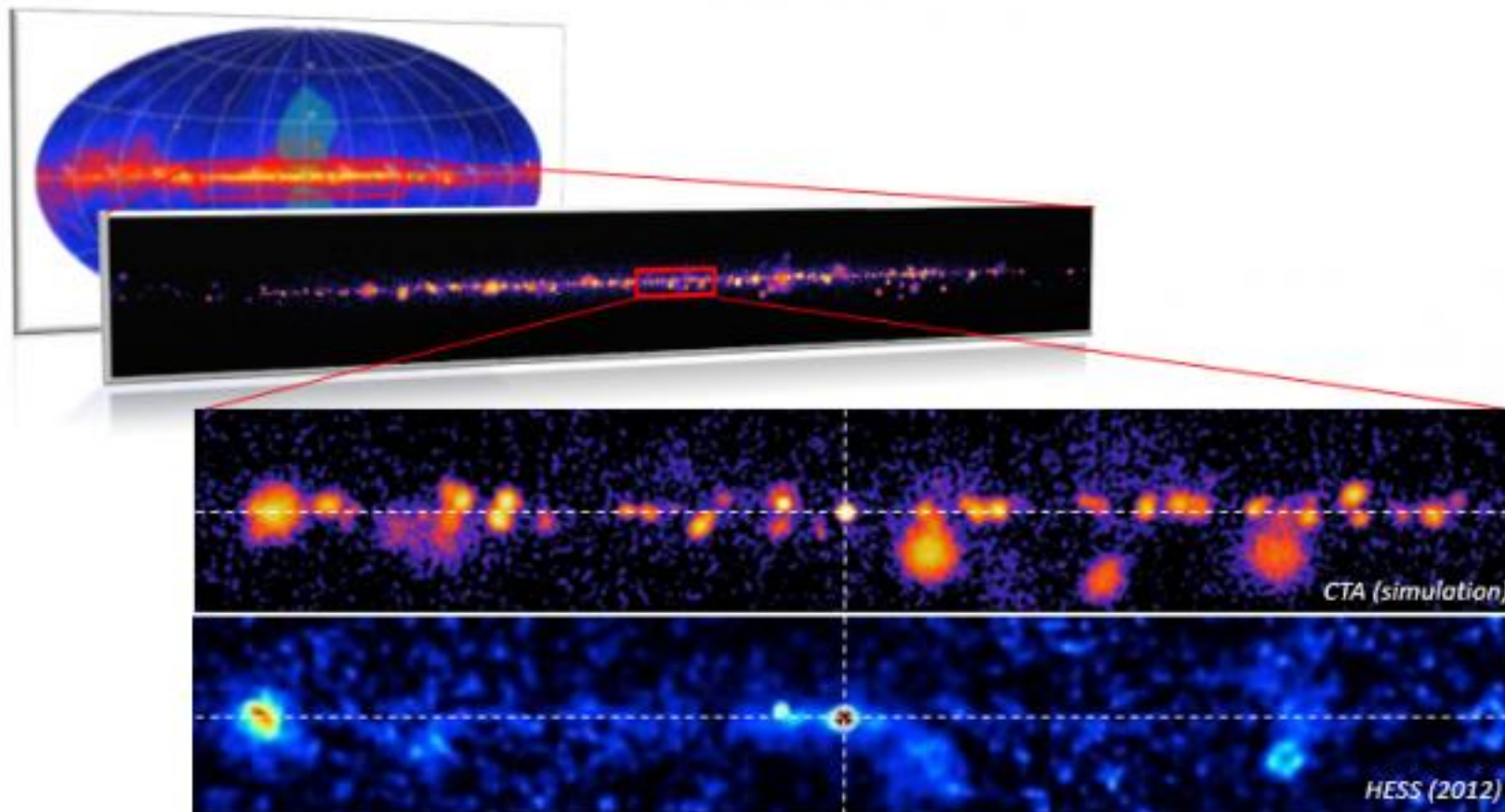
HS 0810+2554 was discovered in 2002 by the Hubble Space Telescope

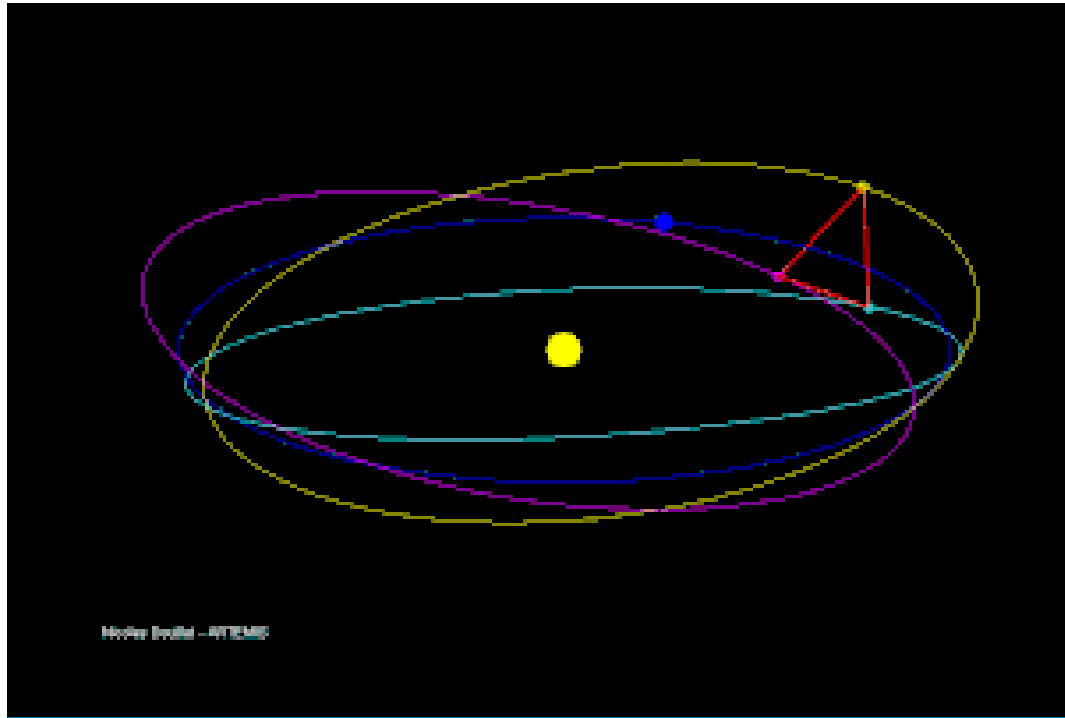
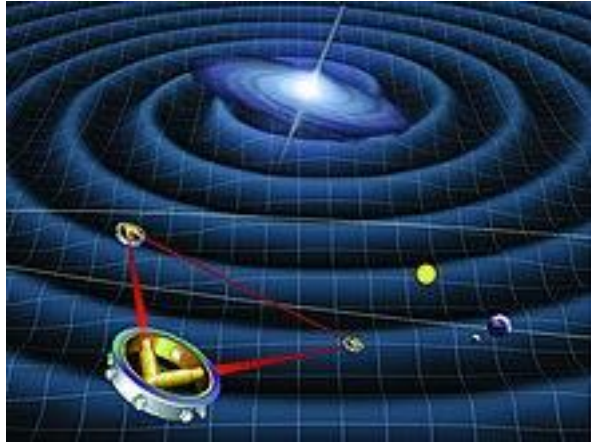
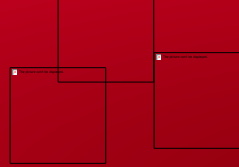
=> The growing success of ψ DM in reproducing astrophysical observations tilt the balance toward new physics invoking axions.

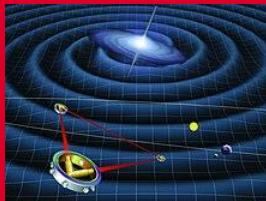
ASTRO- PHYSIQUE











LISAMax: Improving the Gravitational-Wave Sensitivity by Two Orders of Magnitude

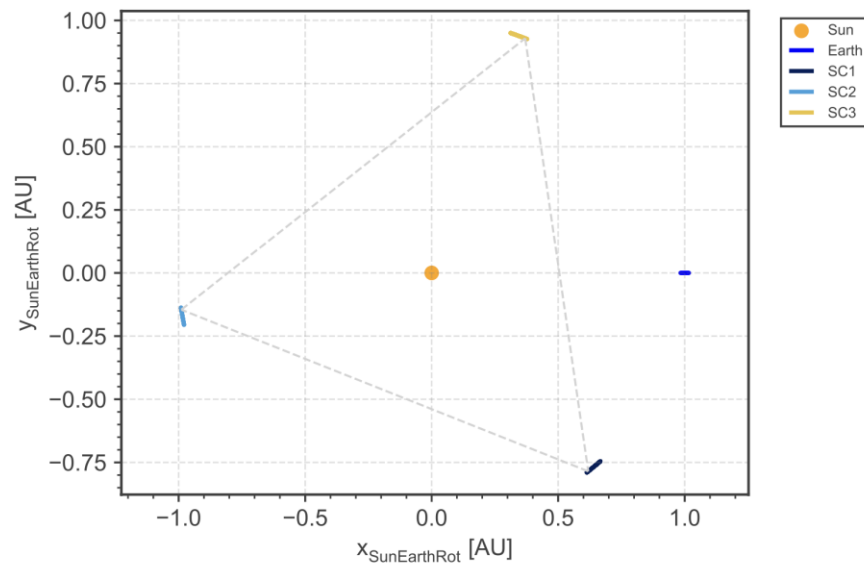
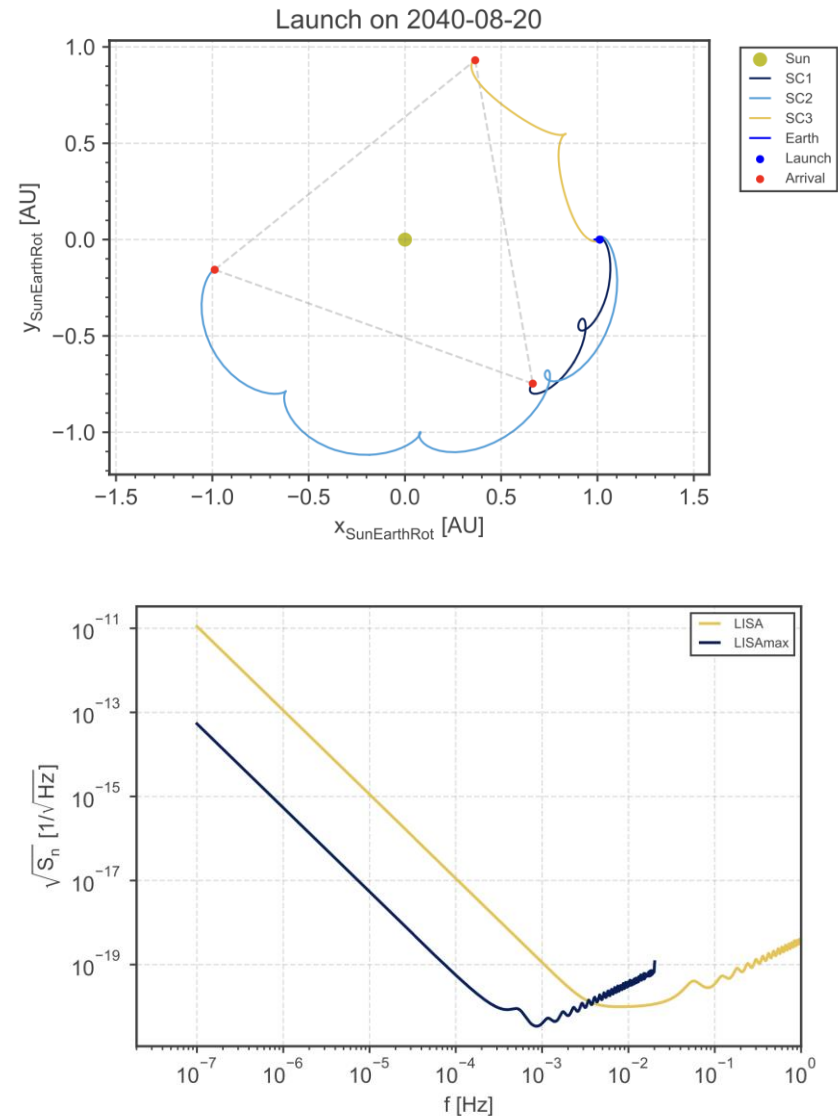


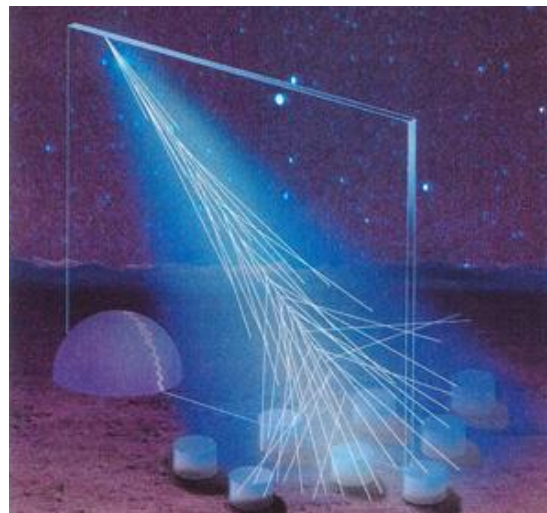
Figure 1: The optimized science orbit of LISAMax over a 10-year duration in the Sun-Earth rotating frame.

LISAMax: Improving the Gravitational-Wave Sensitivity by Two Orders of Magnitude

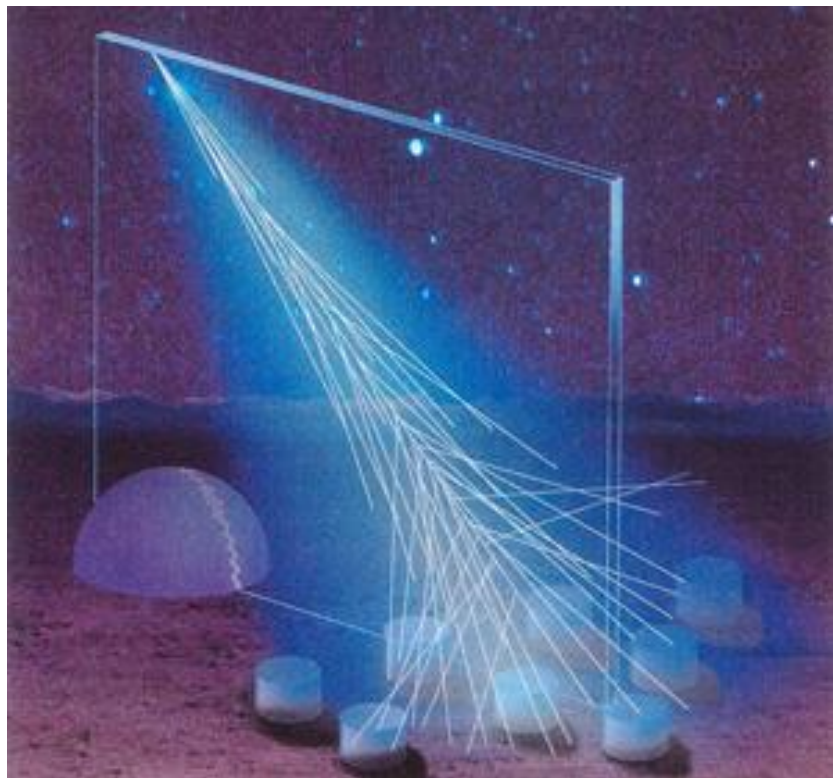




Pierre Auger Cosmic Ray Observatory



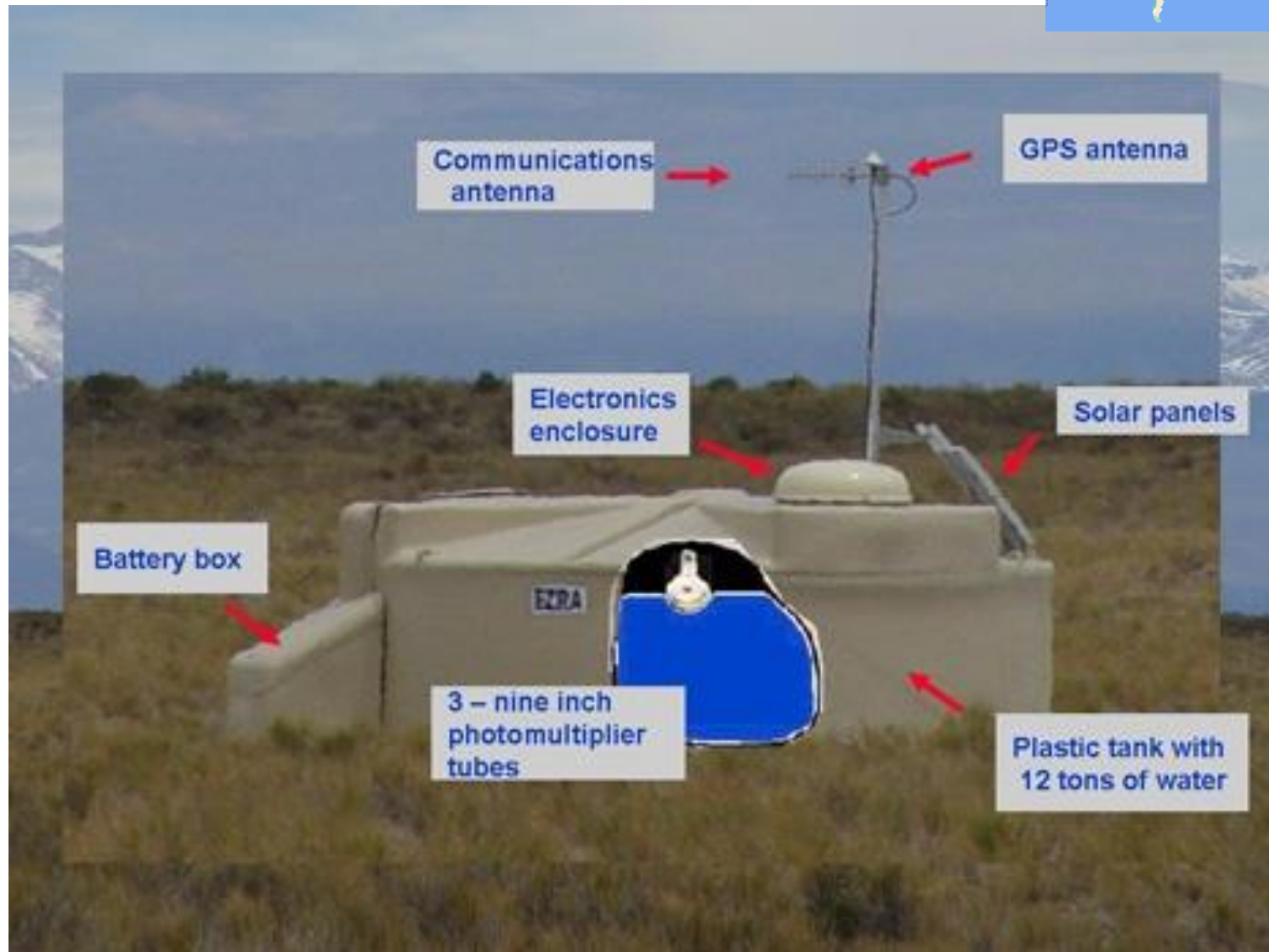
Pierre Auger Cosmic Ray Observatory



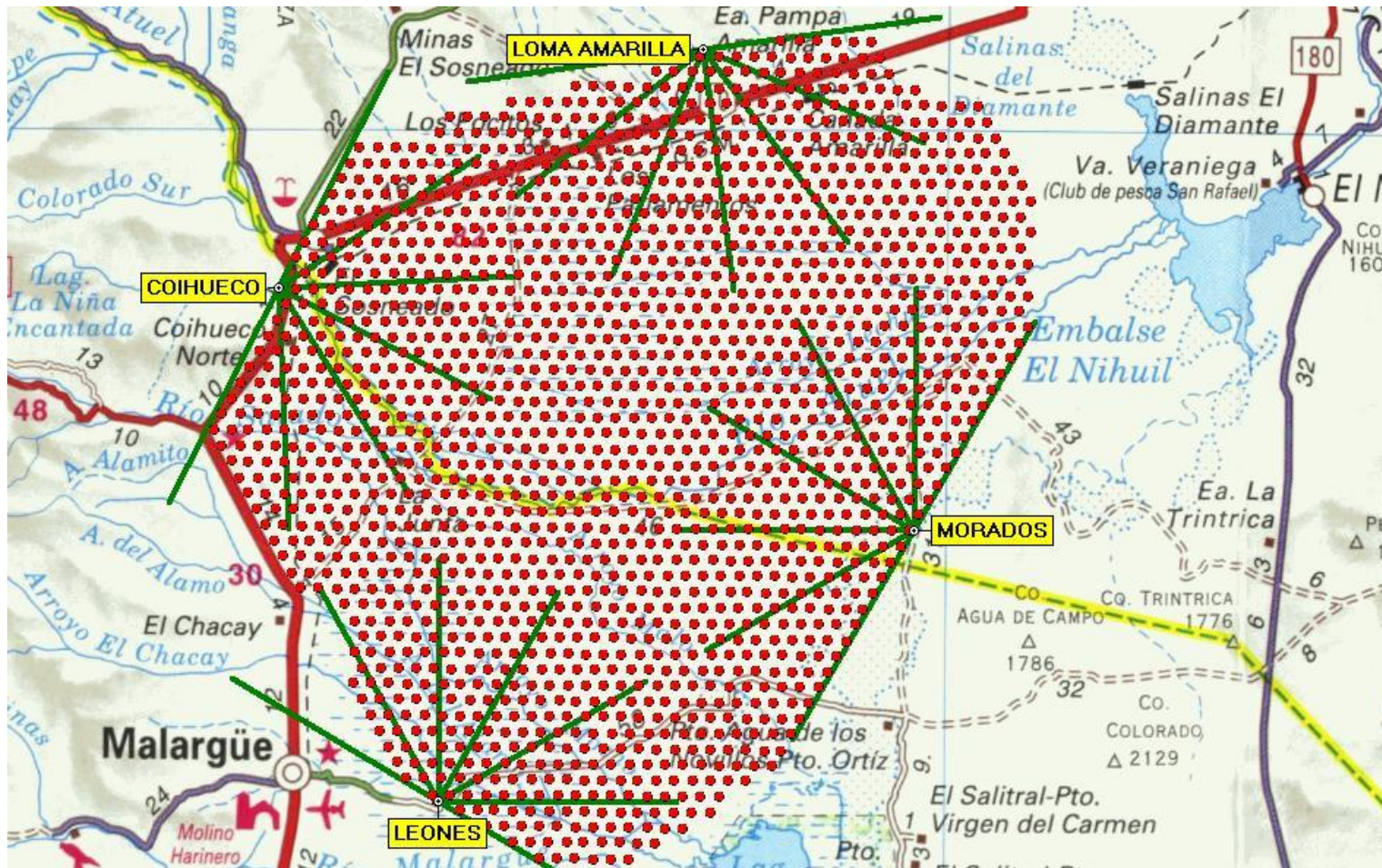
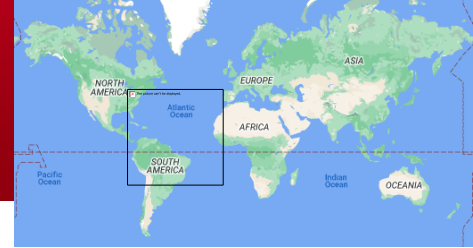
Use earth's atmosphere as a calorimeter. 1600 water Cherenkov detectors with 1.5km distance.

Placed in the Pampa Amarilla in western Argentina.

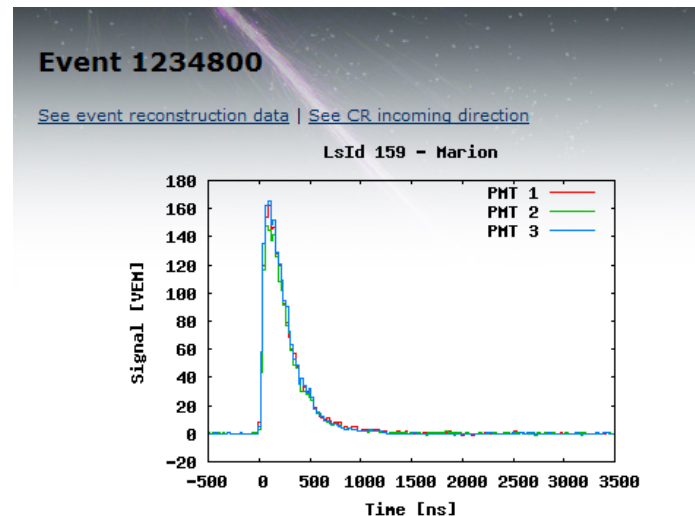
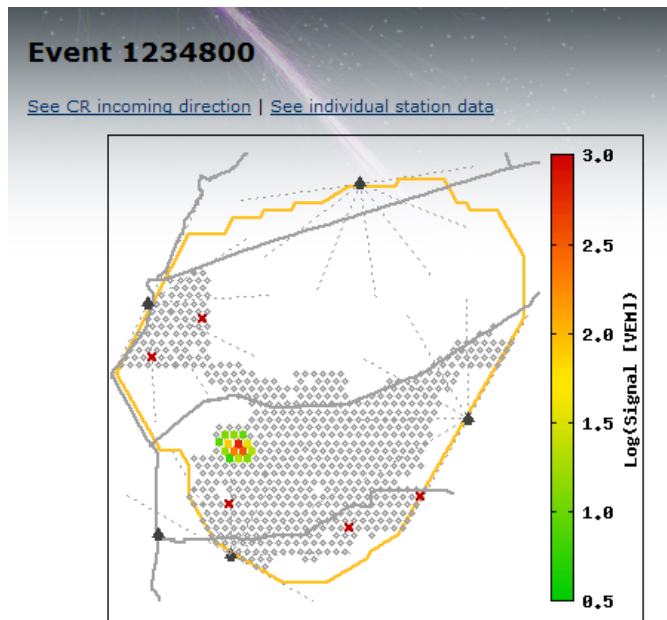




Pierre Auger Cosmic Ray Observatory



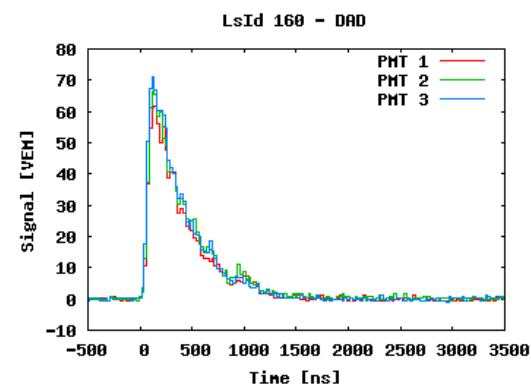
Pierre Auger Cosmic Ray Observatory



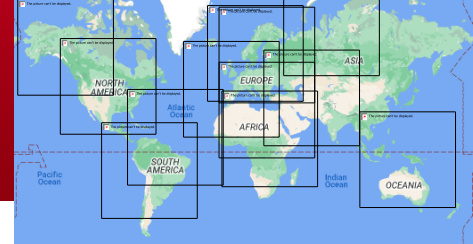
Signal in VEM for the 3 PMTs of station 159 (Marion) as a function of time

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 160 (DAD) as a function of time



Application to use
smartphones camera as
cosmic rays detectors

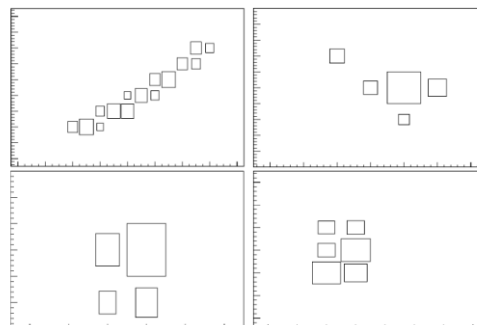


FIG. 4: Activated pixels above threshold in a Samsung Galaxy SIII phone, during exposure to ^{60}Co . Box size is proportional to pixel response values

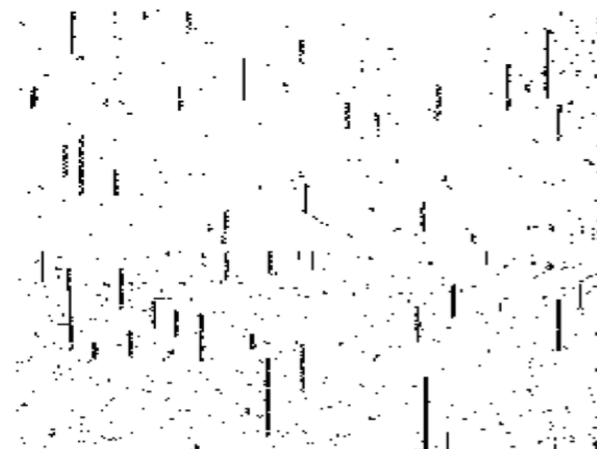
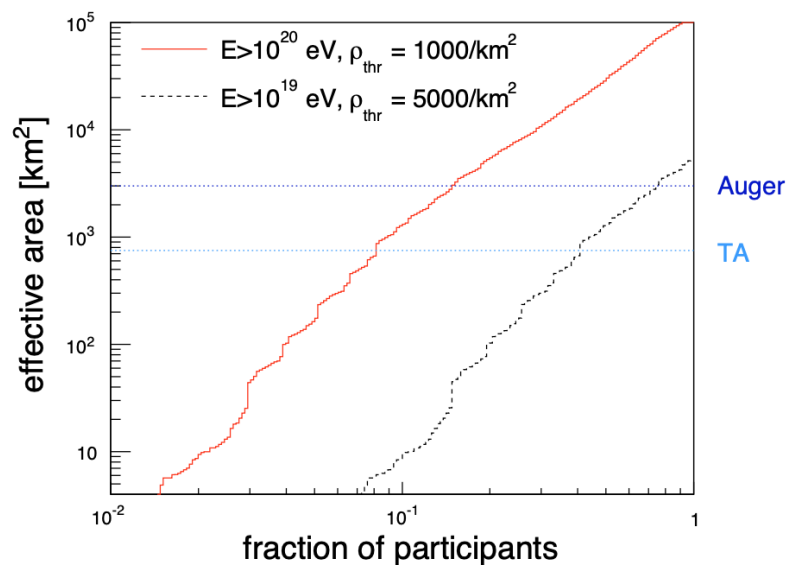


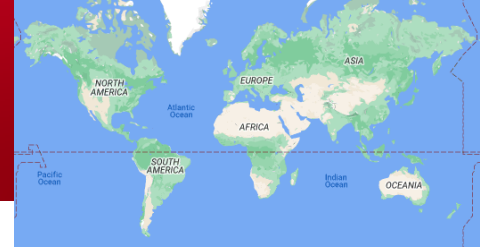
FIG. 5: Composite image of activated pixels in data collected from phones exposed to a muon beam. The phones were arranged such that the muon beam was incident on the side of the sensor, giving visible tracks where muons pass through several pixels.



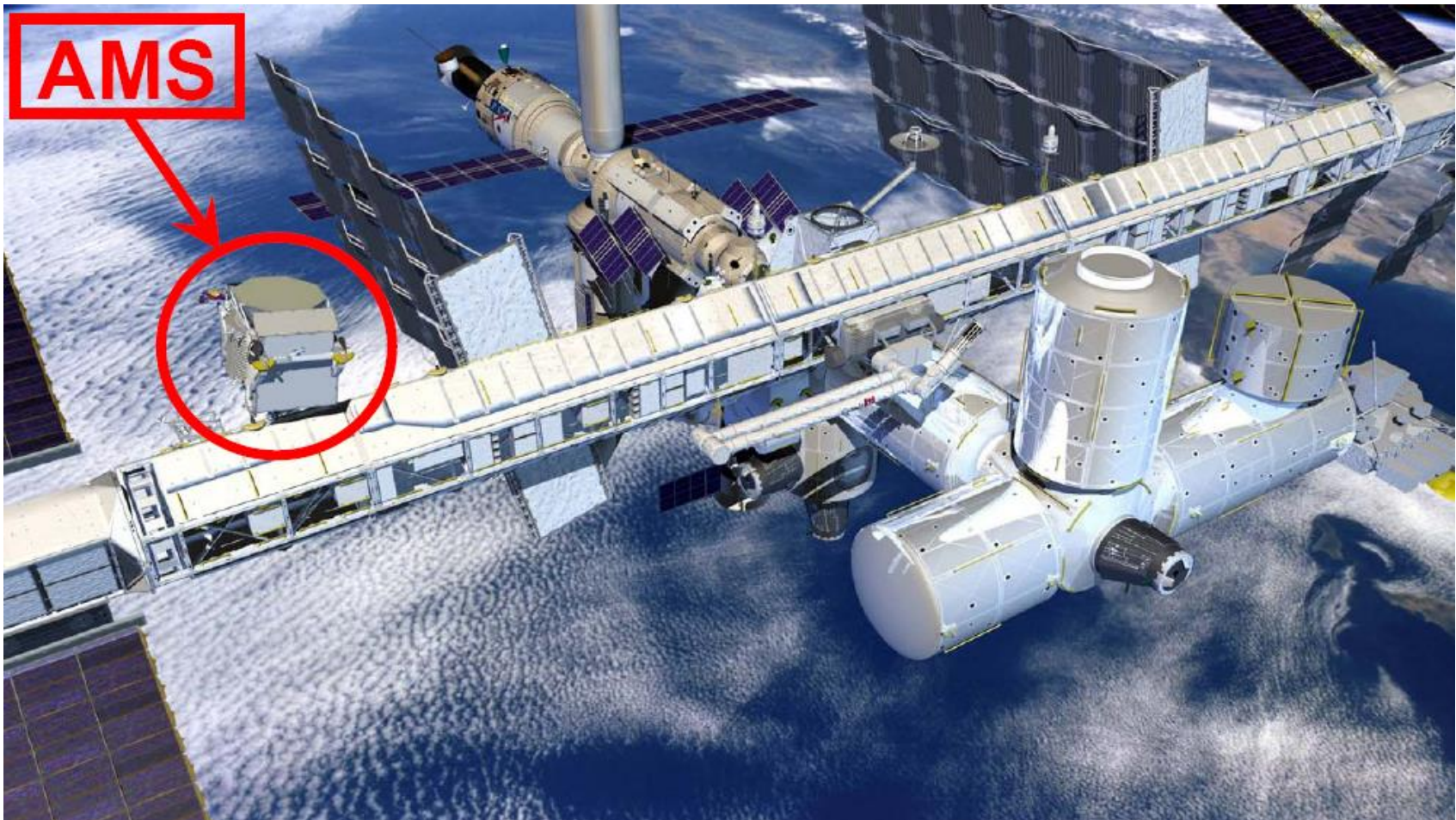
AMS

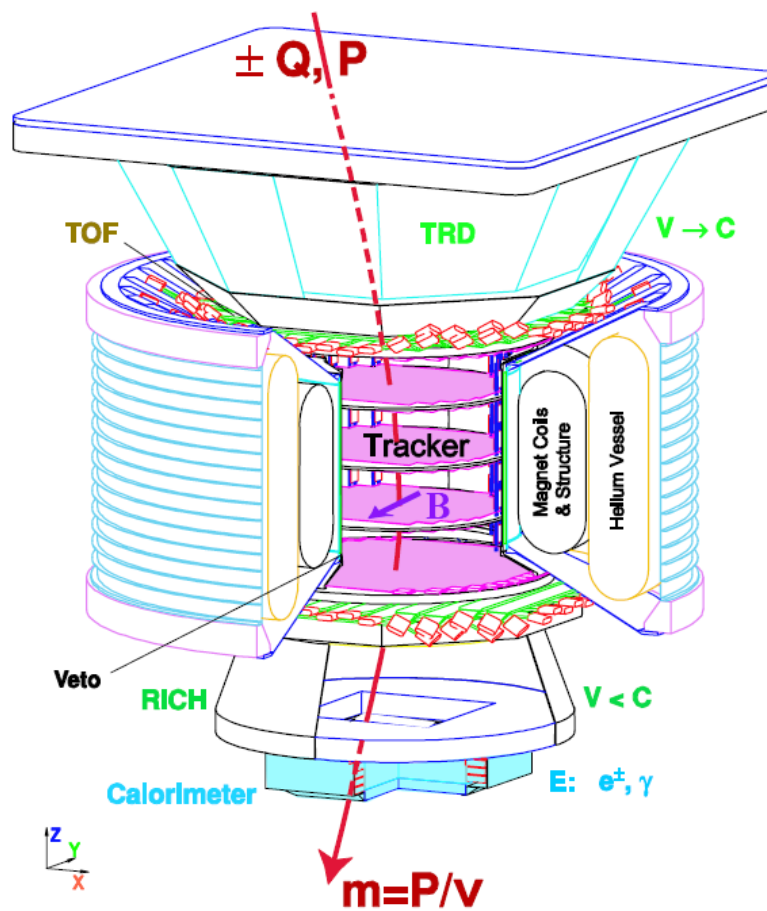
ALPHA MAGNETIC SPECTROMETER

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



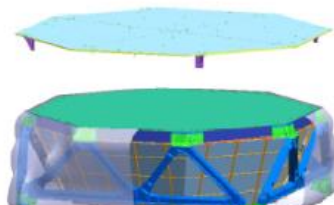
Will be installed on the space station.





USS:

Ultra-Sensitive



Zenith Radiator

TRD:

Transition Radiation Detector

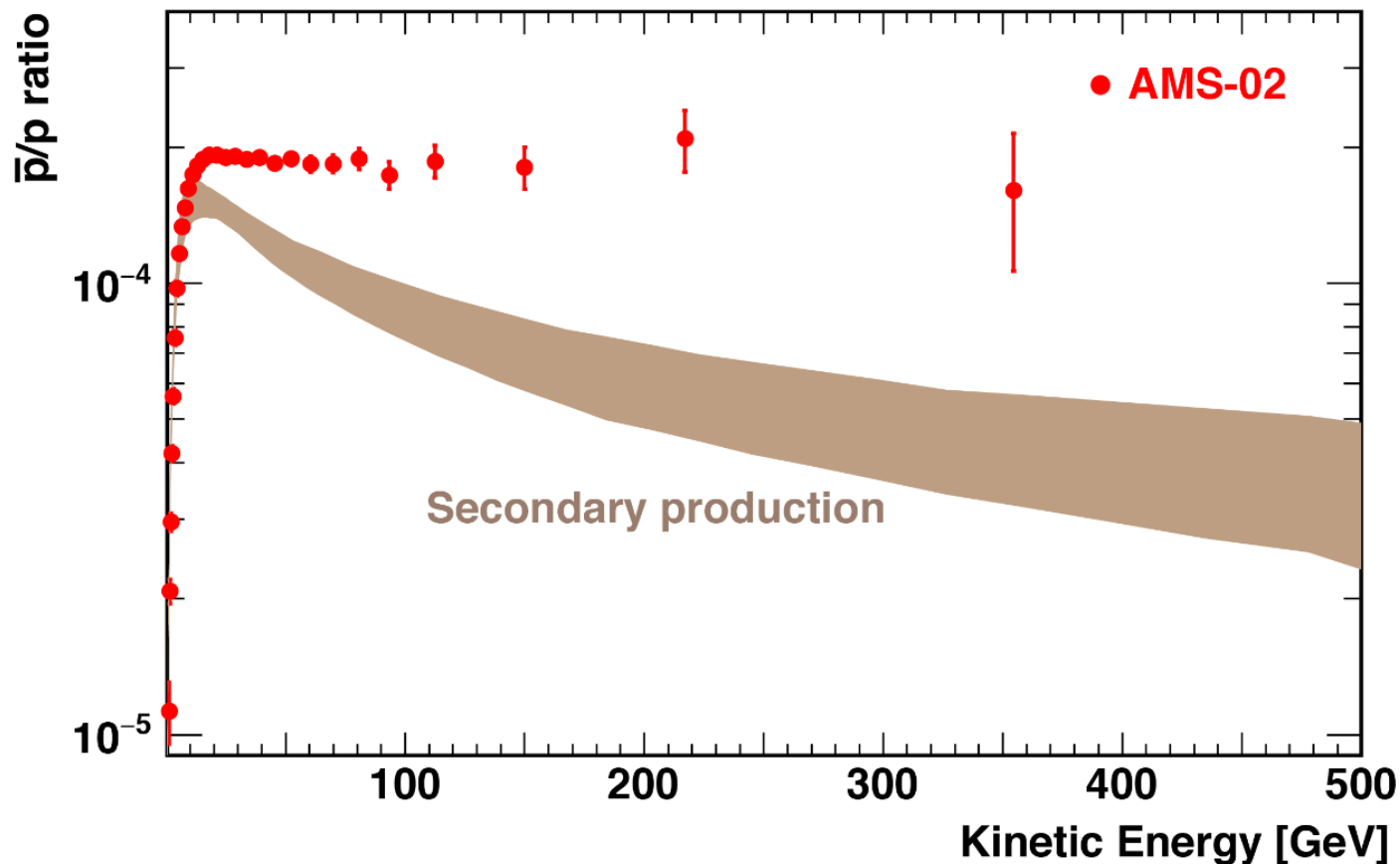
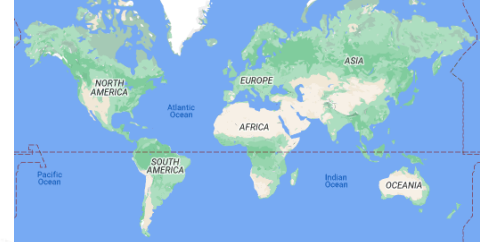


Figure 1. Antiproton to proton ratio measured by AMS. As seen, the measured ratio cannot be explained by existing models of secondary production.



PAS:

Payload Attach System

Vendredi 5/07 11h (IJCLAB)
Lundi 8/07 12h (CEA IRFU)
Visite Labo 14h (CEA IRFU)
Mercredi 10/07 11h (IAS)

DE LA RECHERCHE À L'INDUSTRIE



STAGE / QUESTIONS

[maxence.vandenbroucke](mailto:maxence.vandenbroucke@cea.fr)

[@cea.fr](mailto:maxence@cern.ch)

maxence@cern.ch



Mesurer l'infiniment petit et observer l'infiniment grand

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

Maxence Vandenbroucke

07/2024

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

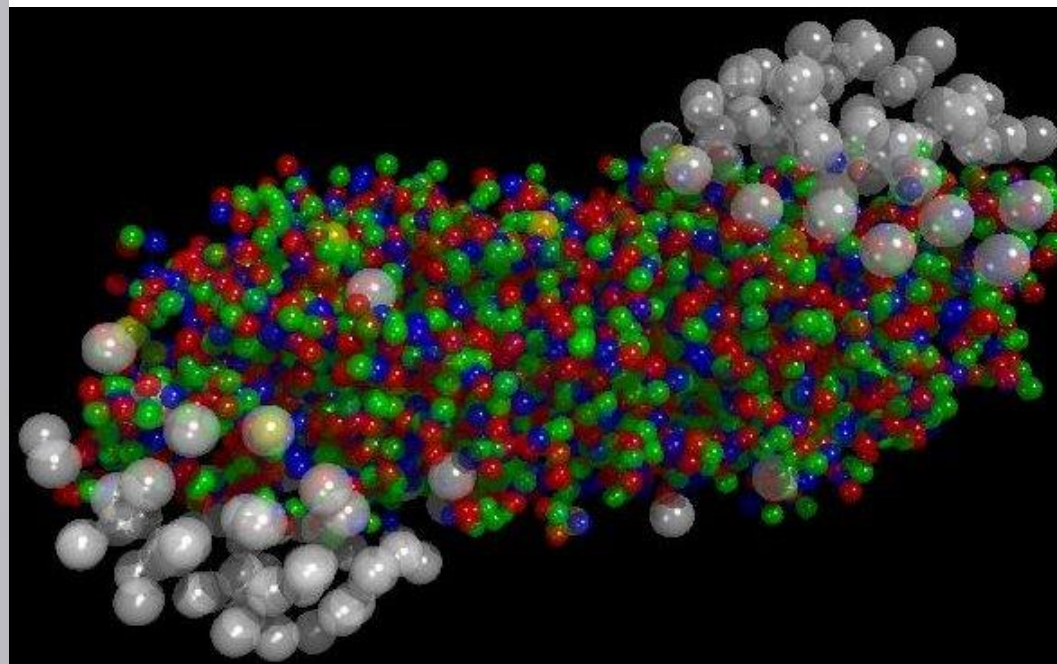
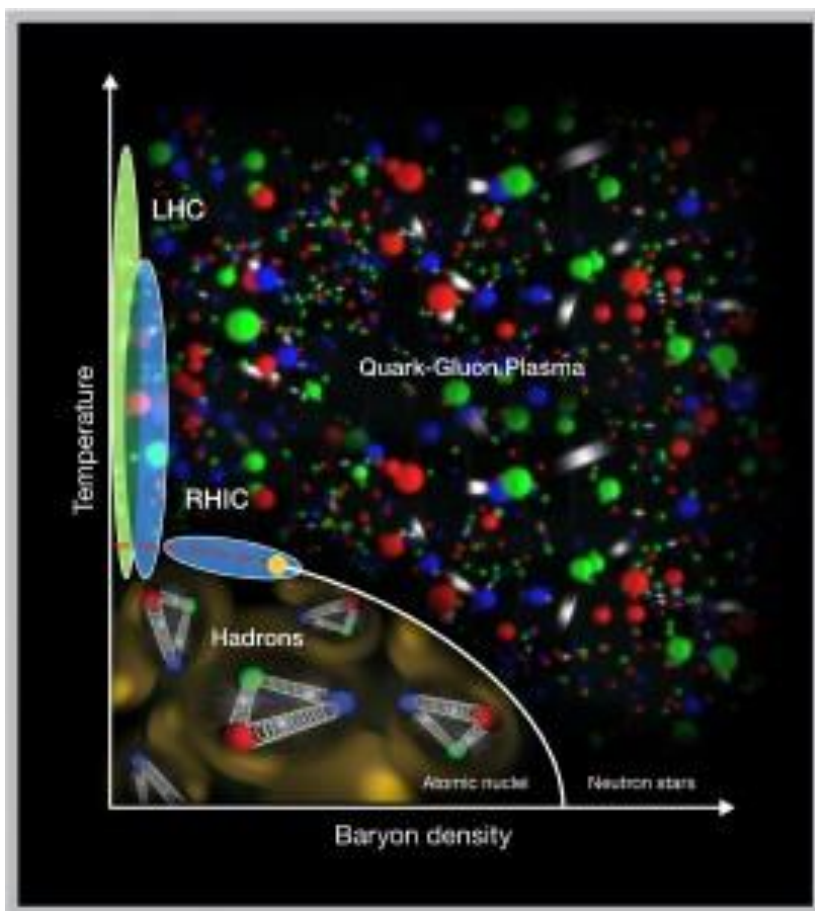
Basé sur les cours de Stefano Panebianco (CEA/IRFU) rencontre d'été 2016

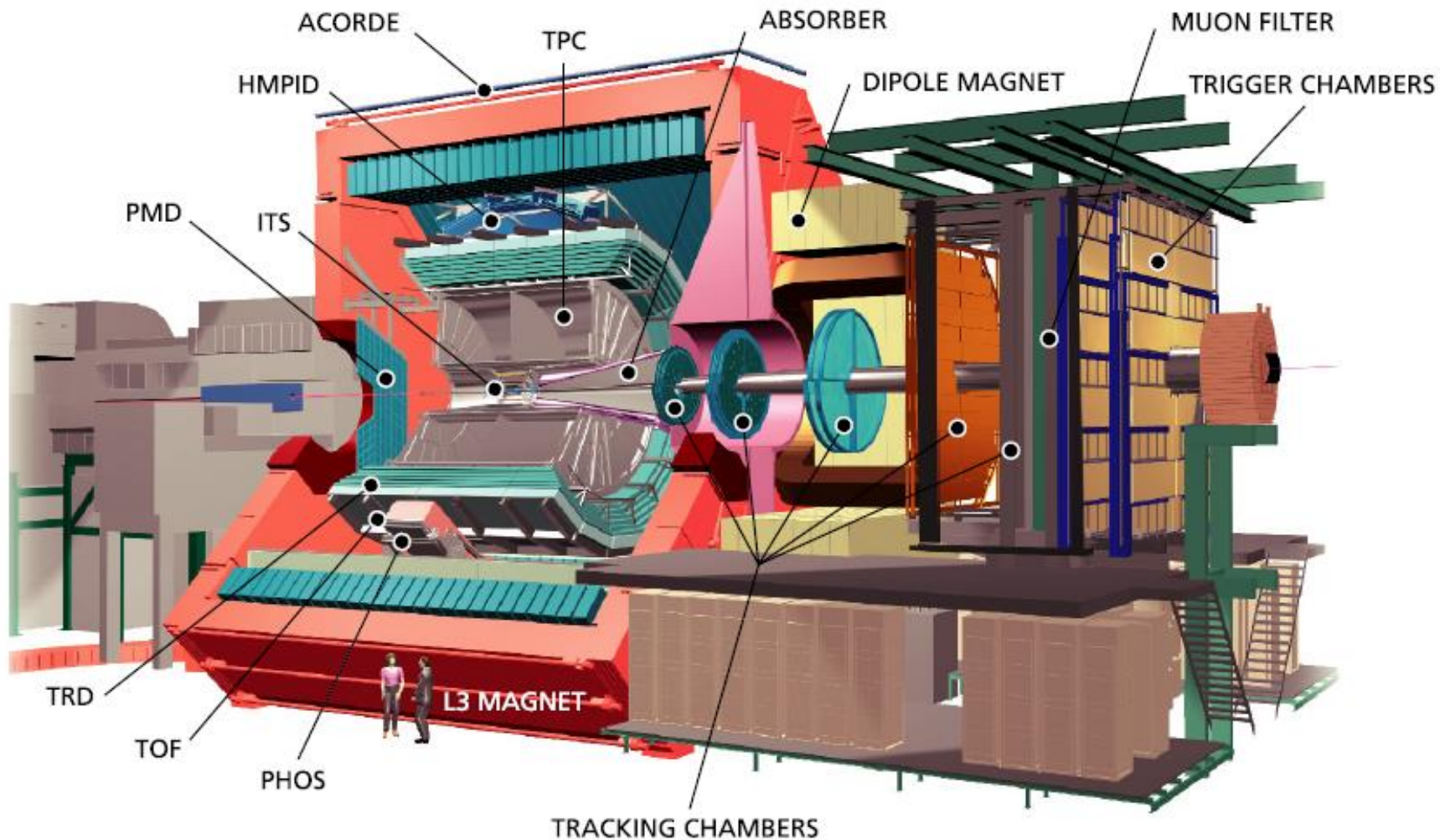
Le cours de Werner Riegler (CERN Summer Student Lecture Program 2009)

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

ALICE

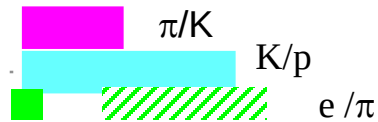
A heavy Ion Experiment at the LHC





**Alice uses ~ all
known techniques!**

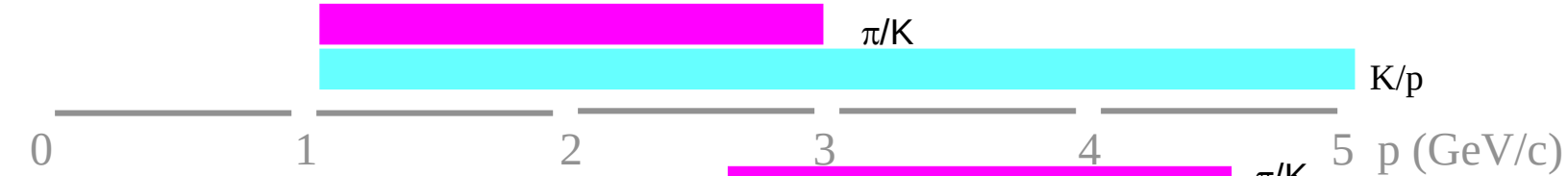
TPC + ITS
(dE/dx)



TOF



HMPID
(RICH)



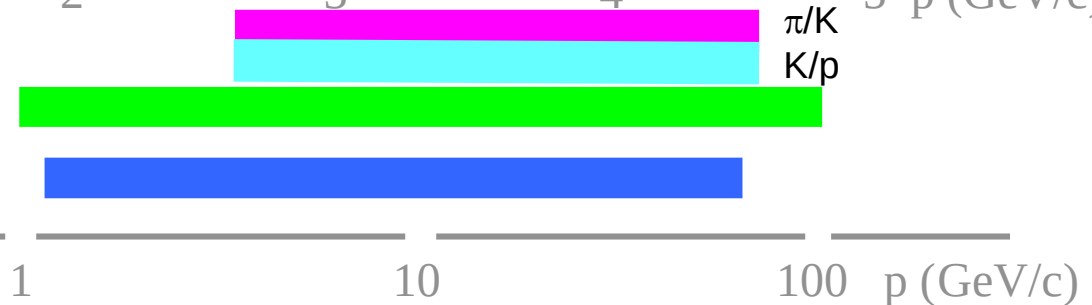
TPC (rel. rise) $\pi/K/p$

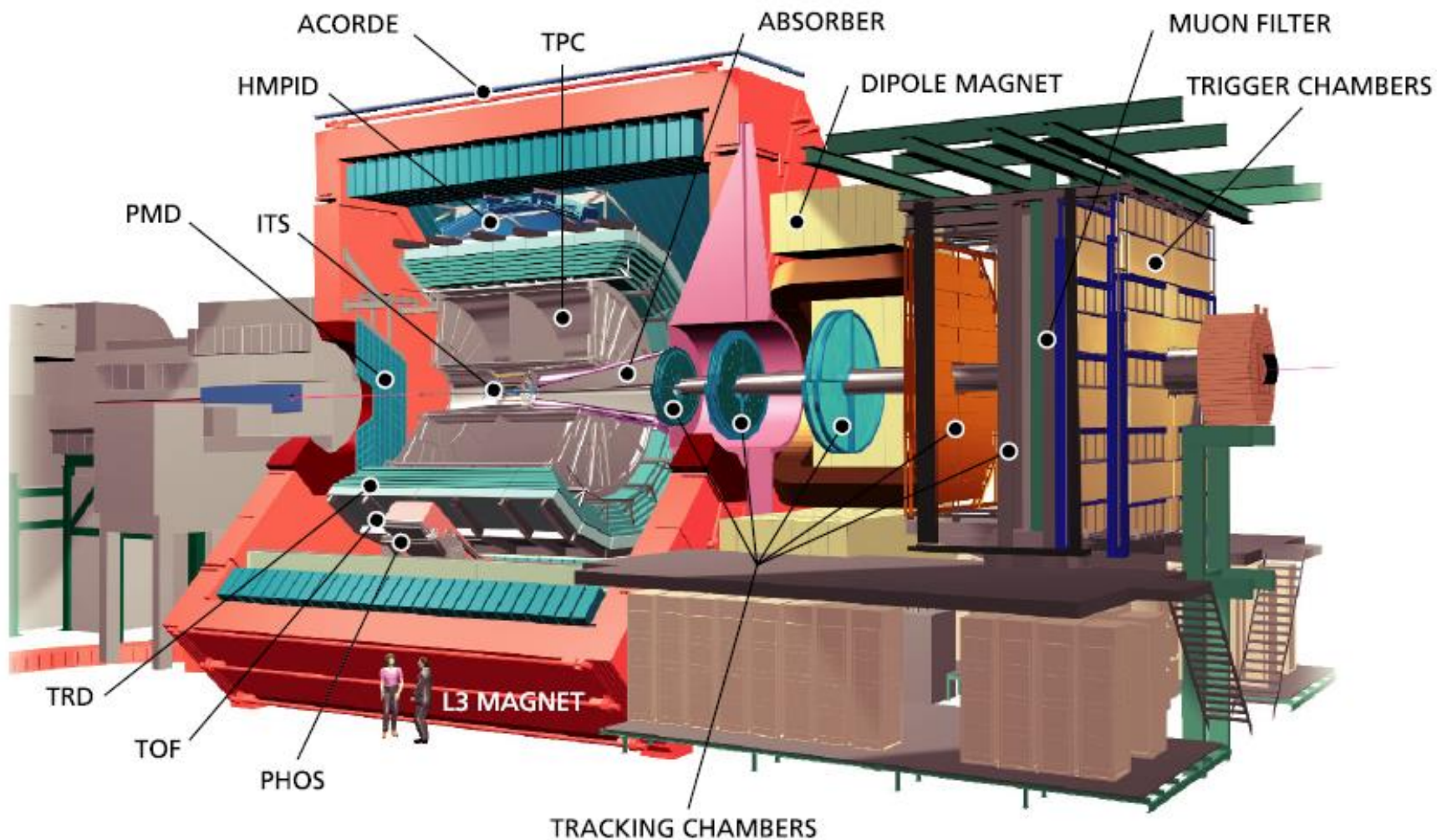
TRD

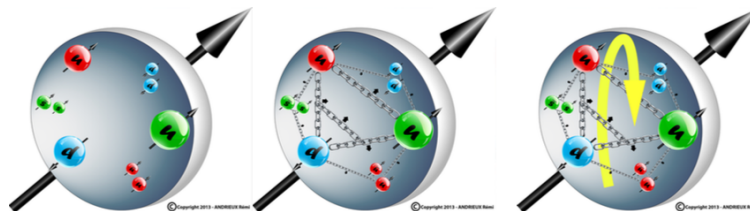
PHOS

e/π

γ/π^0







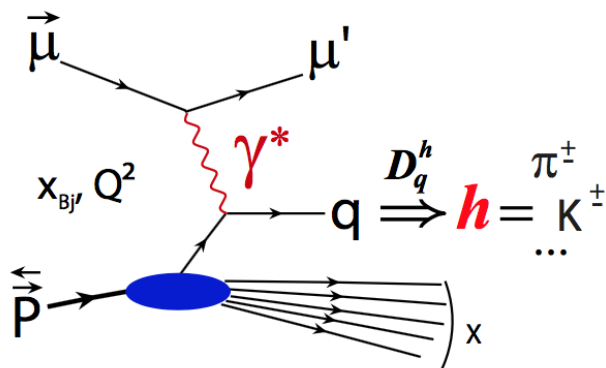
Différentes contributions

$$\frac{1}{2} = \frac{1}{2} (\Delta u + \Delta d + \Delta s) + \Delta G + L_g + L_q$$

Spin des quarks
 $\Delta\Sigma \sim 0.3$

Spin des gluons
 $|\Delta G| < 0.5$

Moments orbitaux
 $L_{q+g} = ??$

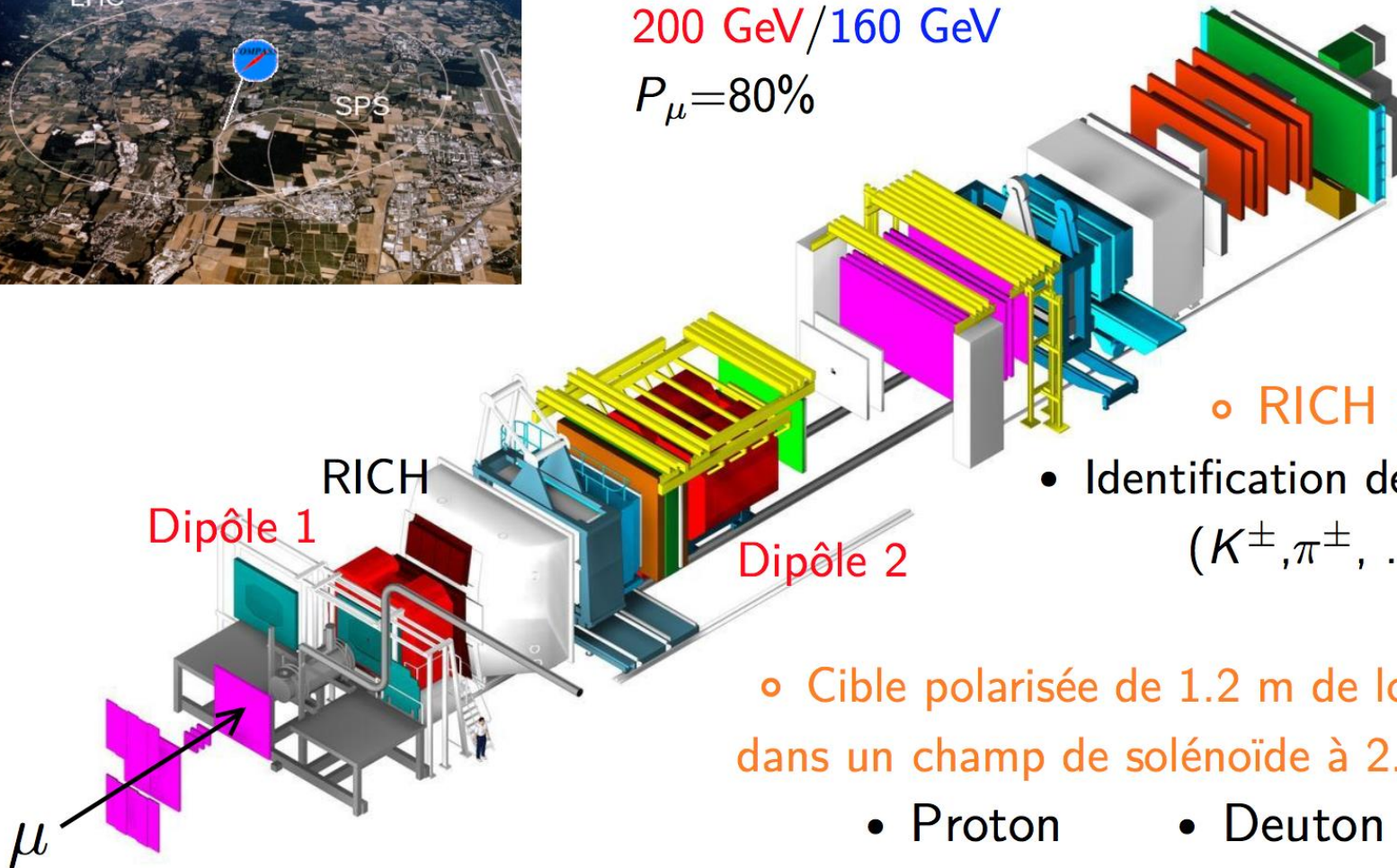


Section efficace DIS

$$\frac{d^2 \sigma}{dx dQ^2} = \underbrace{c_1 F_1(x, Q^2) + c_2 F_2(x, Q^2)}_{\text{fonctions de structure non-polarisées}} + \underbrace{c_3^{s,S} g_1(x, Q^2) + c_4^{s,S} g_2(x, Q^2)}_{\text{fonctions de structure polarisées}}$$



- Faisceau polarisé de μ^+ du SPS
 $1 \cdot 10^8 / 2 \cdot 10^8 \mu$ par déversement de ~ 10 s
 $200 \text{ GeV} / 160 \text{ GeV}$
 $P_\mu = 80\%$



◦ RICH :

- Identification des hadrons ($K^\pm, \pi^\pm, \dots$)

- Cible polarisée de 1.2 m de long dans un champ de solénoïde à 2.5 T

- Proton
- Deuteron



$$\nu_{\tau} N \rightarrow \tau^{-} X$$

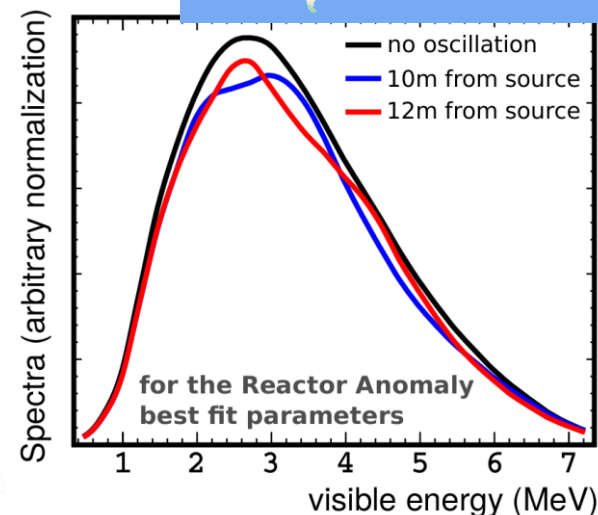
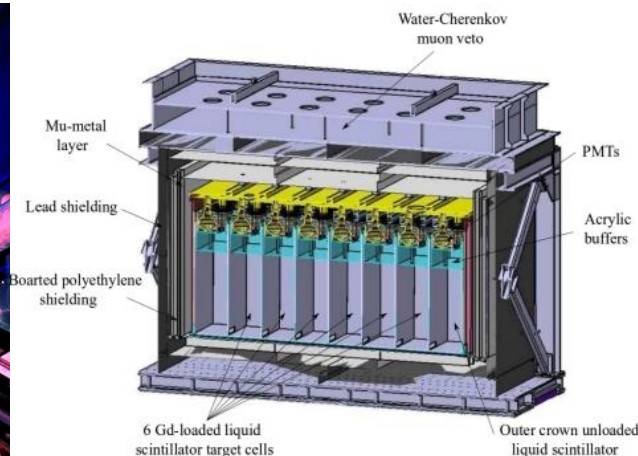
$$\tau^{-} \rightarrow \mu^{-} \nu_{\mu} \bar{\nu}_{\tau} \quad \text{with} \quad BR = 17.36 \pm 0.05\% \quad (1)$$

$$\tau^{-} \rightarrow e^{-} \nu_e \bar{\nu}_{\tau} \quad \text{with} \quad BR = 17.85 \pm 0.05\% \quad (2)$$

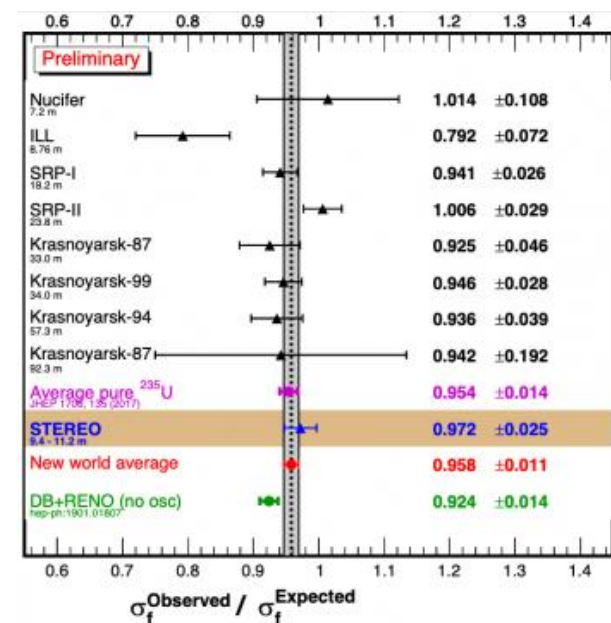
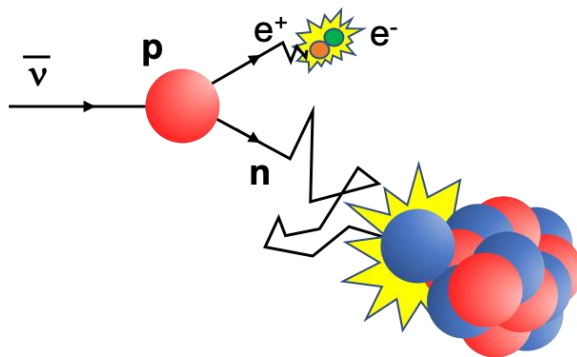
$$\tau^{-} \rightarrow h^{-} (n\pi^0) \bar{\nu}_{\tau} \quad \text{with} \quad BR = 49.52 \pm 0.07\% \quad (3)$$

$$\tau^{-} \rightarrow 2h^{-} h^{+} (n\pi^0) \bar{\nu}_{\tau} \quad \text{with} \quad BR = 15.19 \pm 0.08\%. \quad (4)$$

<https://arxiv.org/pdf/1305.2513.pdf>



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.



Production de paires électron-ion :

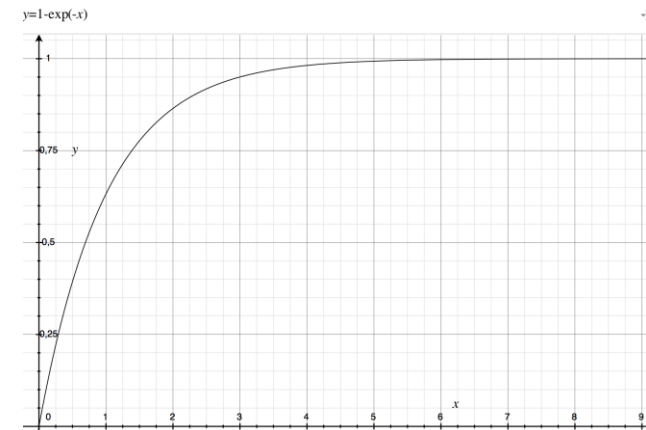
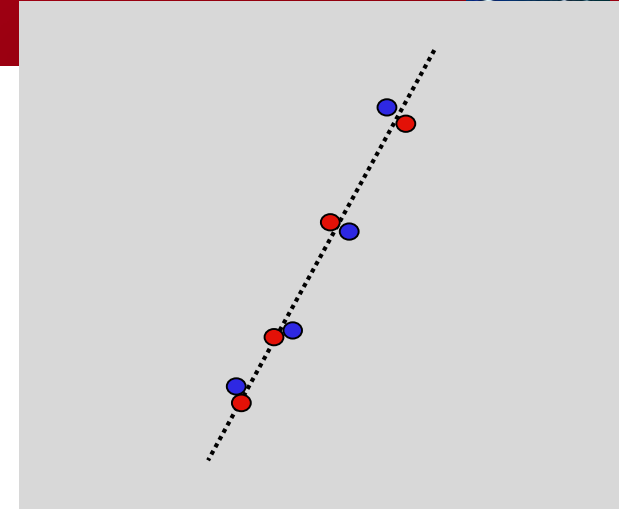
- Les interactions Coulombiennes entre le champ électrique de la particule et les atomes du milieu produisent des paires électron-ion.
- Les ionisations multiples suivent une statistique de Poisson:

$$P_k^n = \frac{n^k}{k!} e^{-n} \quad \begin{array}{l} n : \text{moyen} \\ k : \text{mesuré} \end{array}$$

- Efficacité de détection: $e = 1 - P_0^n = 1 - e^{-n}$

– Mécanismes
d'ionisation :

- Excitation: $X + p \rightarrow X^* + p$ puis $X^* \rightarrow X^+ + e^-$
- Ionisation: $X + p \rightarrow X^+ + p + e^-$
- *Effet Penning*: $Ne^* + Ar \rightarrow Ne + Ar^+ + e^-$



- Les électrons primaires ionisent à nouveau le milieu et produisent localement de nouveaux groupes de paires électron-ion. Si l'électron secondaire a suffisamment d'énergie il peut produire une longue trace (électron δ).
- Nombre total de paires:

$$n_T = \frac{\Delta E}{w_i}$$

ΔE : perte d'énergie de la particule
 w_i : énergie moyenne par paire

M.I.P. dans l'argon:

- $\Delta E = 2,65 \text{ keV/cm}$ $w_i = 25 \text{ eV}$
- $n_T \approx 106 \text{ paires électron-ion/cm}$

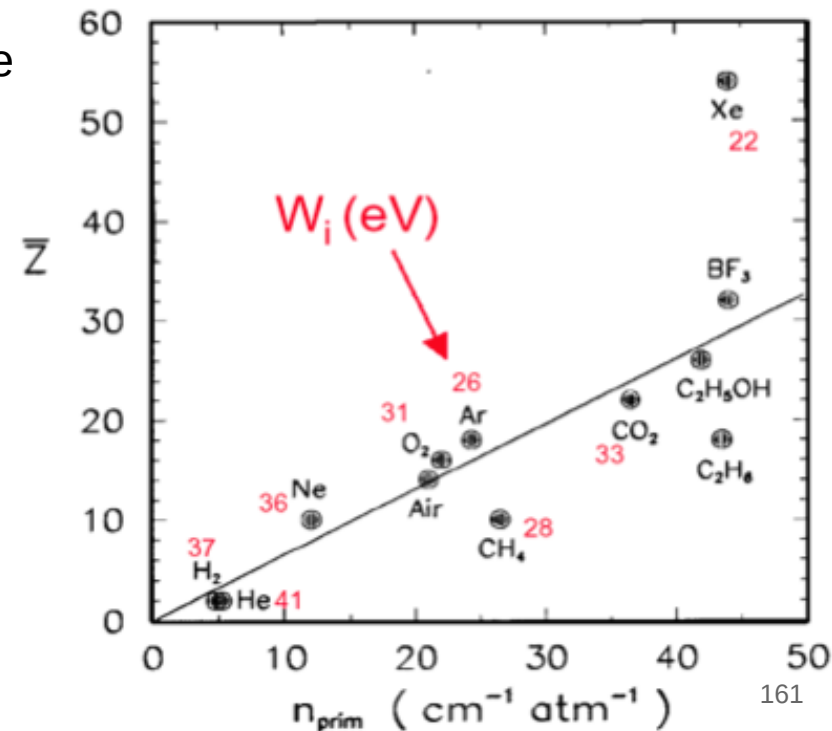
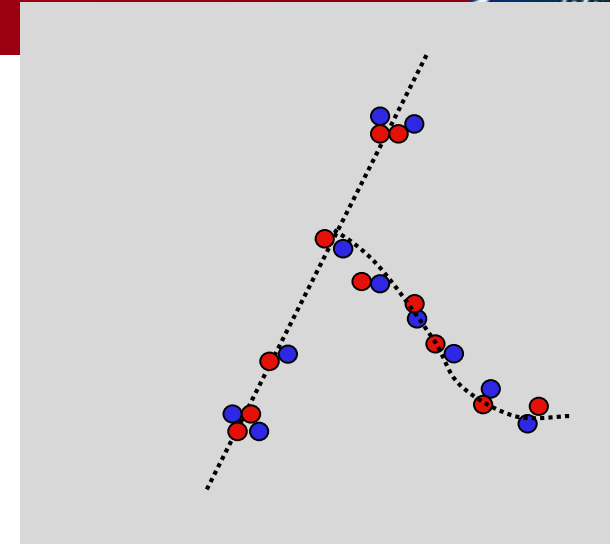
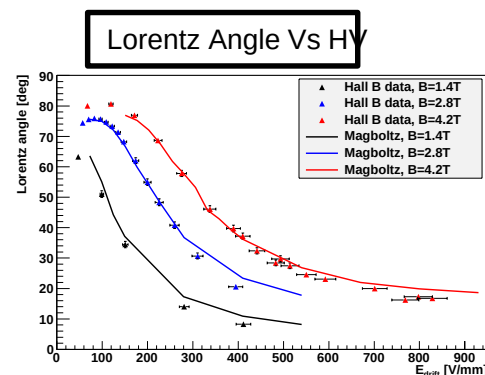
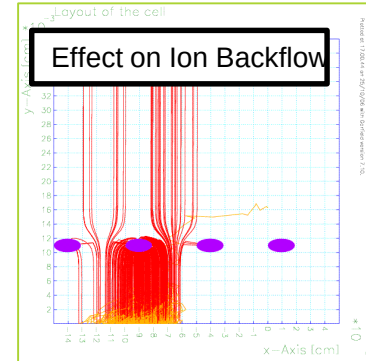
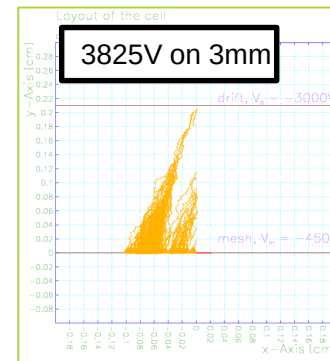
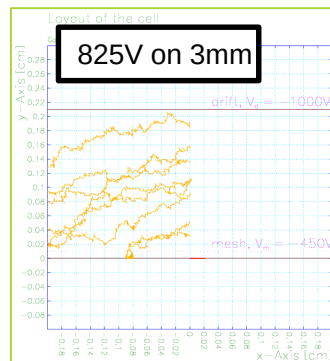
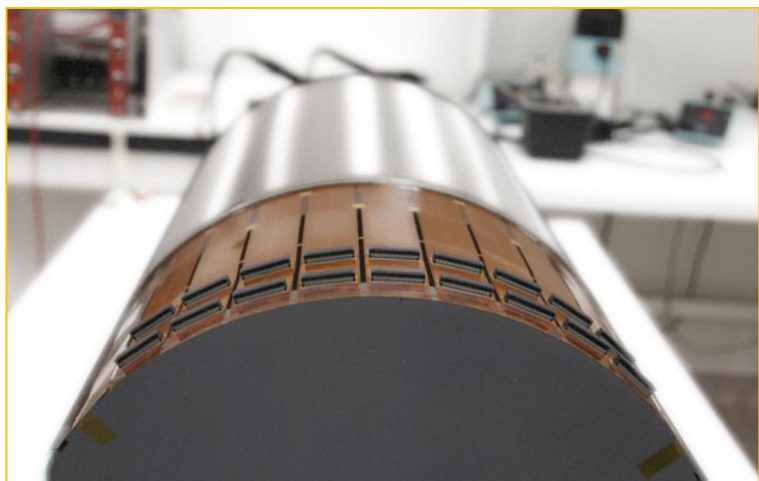
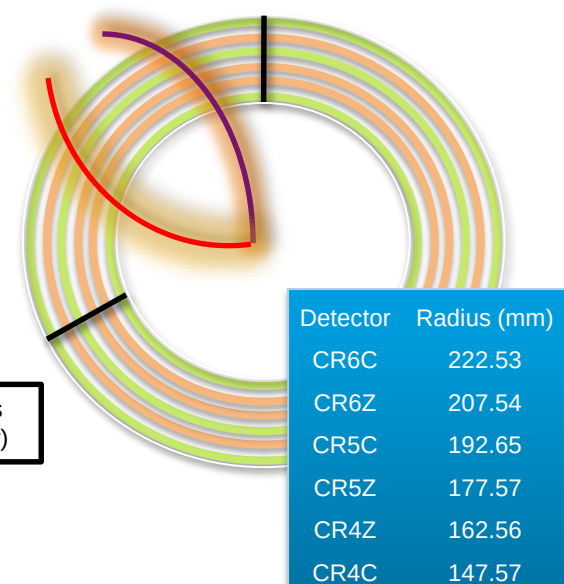




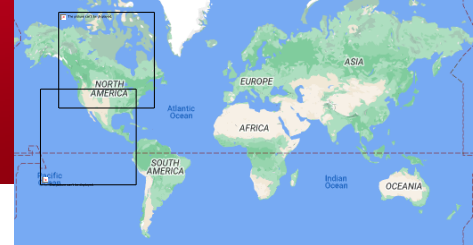
FIG. (II) 1.7: Photographie d'un individu bioluminescent prise par l'une des caméras installées sur la ligne d'instrumentation IL07 (lire le paragraphe (II) 3.1). L'échelle n'est pas précisément connue (elle dépend de la distance à la caméra).



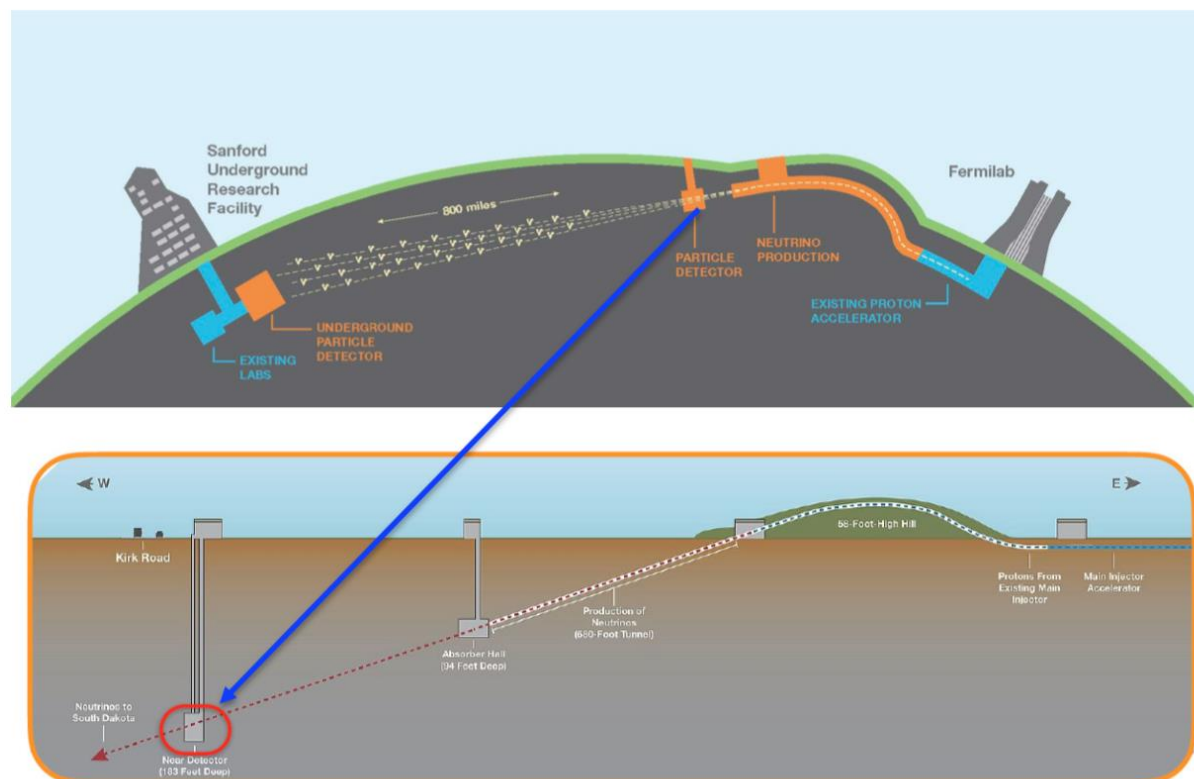
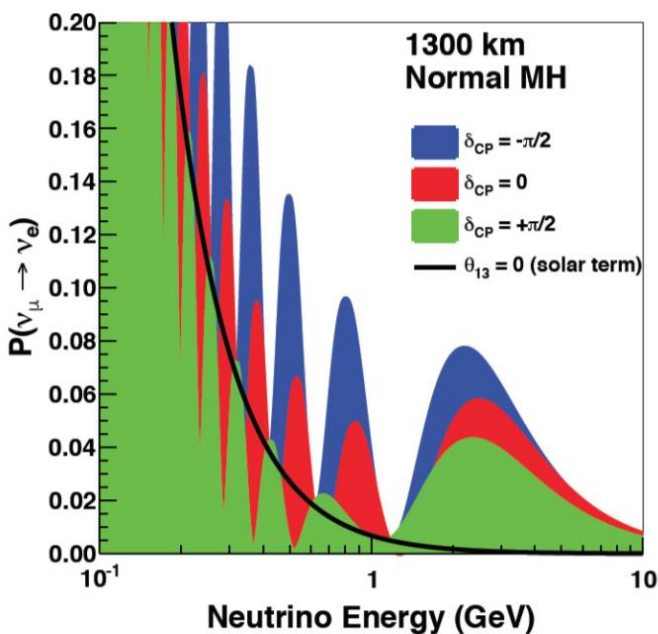
=> Clas-note 2007-004: Simulations of Micromegas detectors for the CLAS12 experiment (S. Procureur)



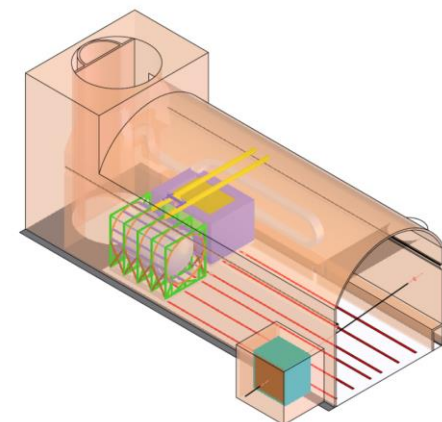
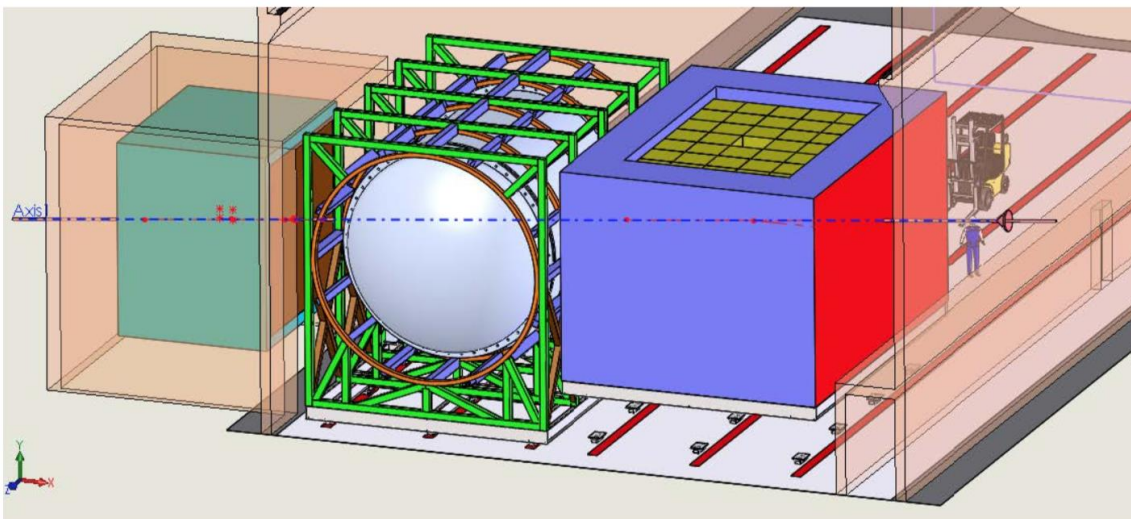
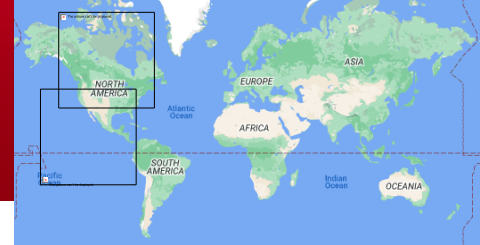
DUNE



- 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

