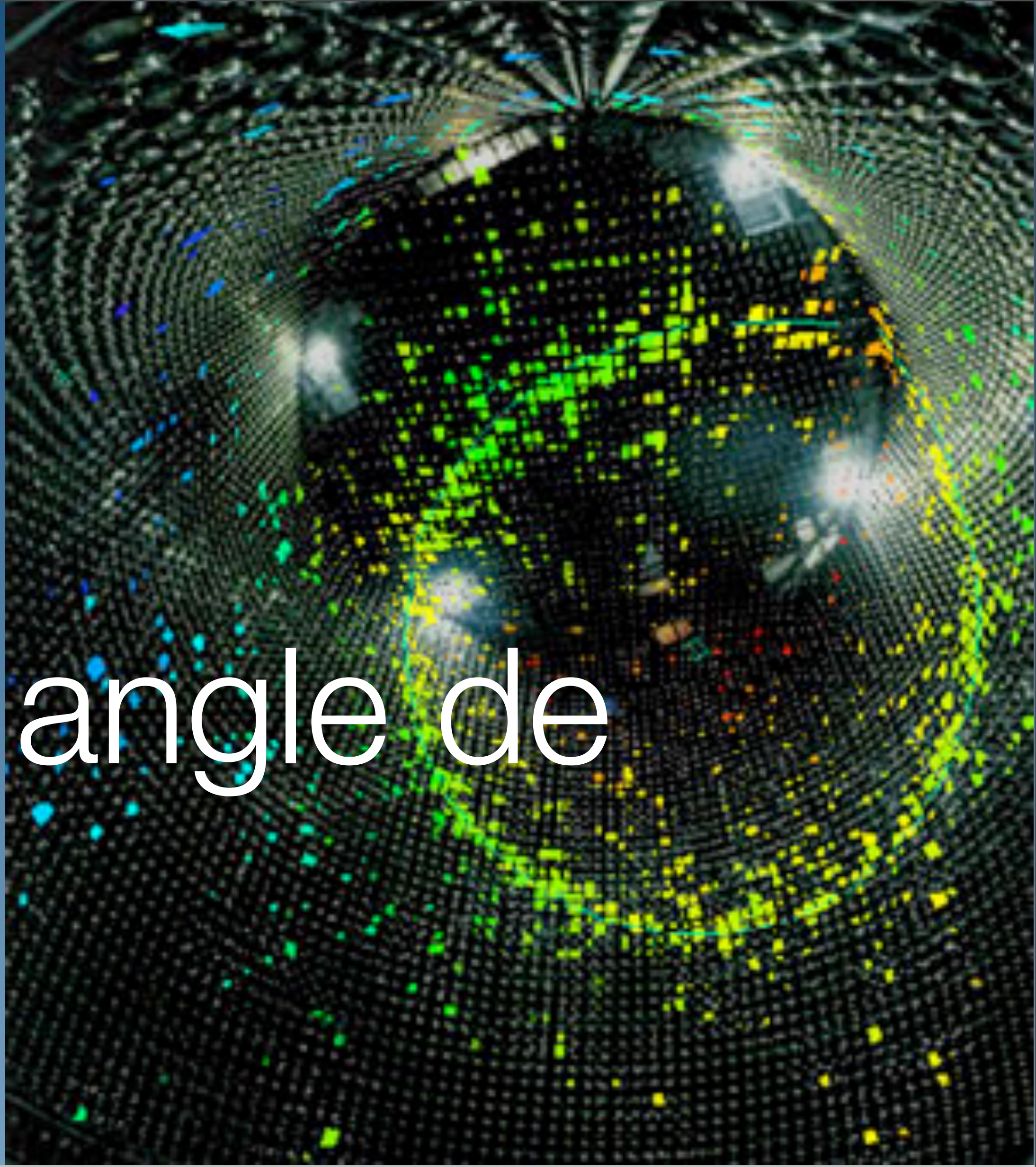
Imperial College London

Tokai 2 Kamioka : à la recherche du 3^{e} angle de mélange



Antonin Vacheret

Contexte expérimental

Oscillation est possible si masse > 0 : $\Delta m^2 \gtrsim \frac{E}{L}$

30 ans de mesures (et un peu de chance !) pour localiser et mesurer les paramètres d'oscillation :

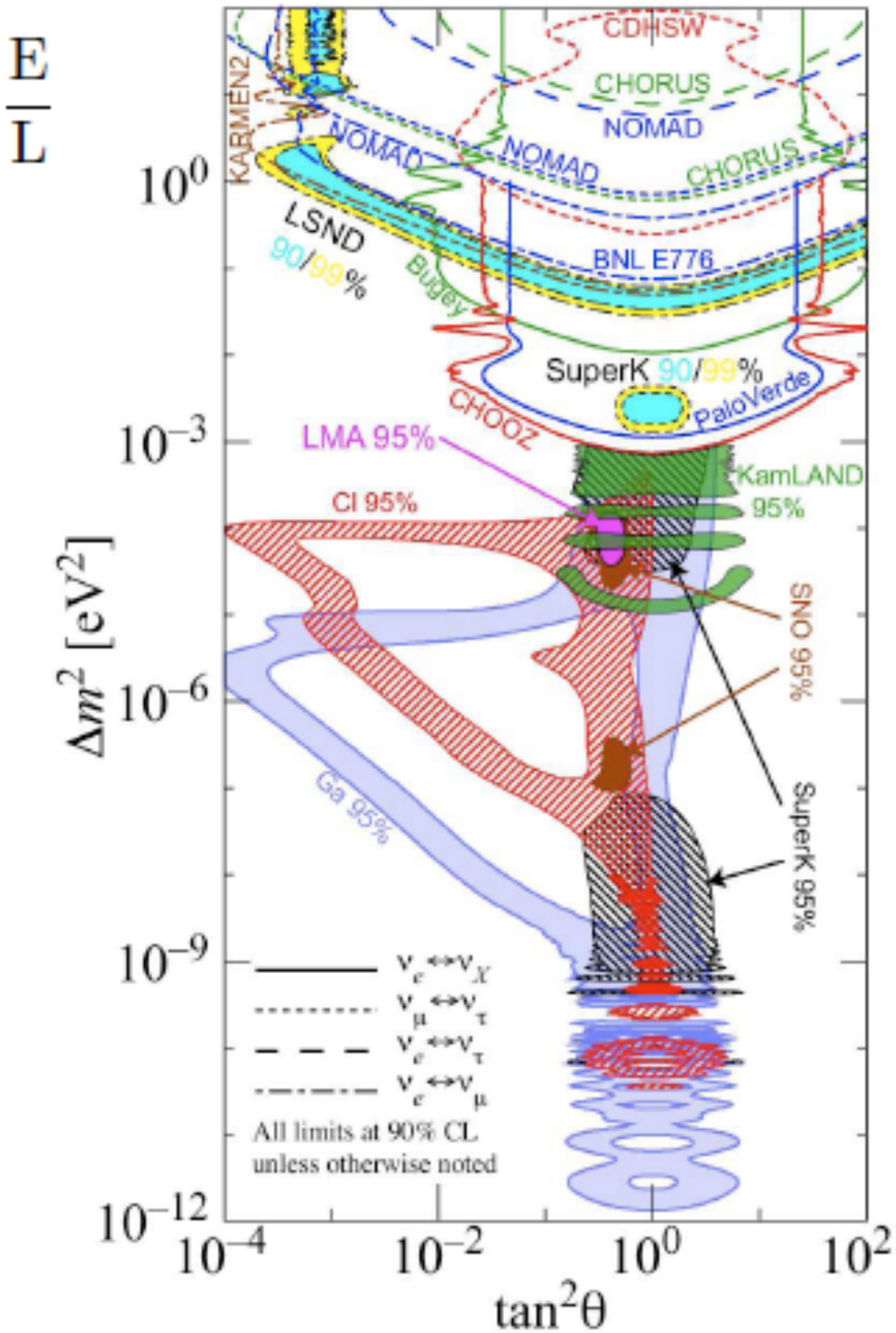
- Domaine de fréquence immense
- Effets mesurés dans deux régions :

neutrino solaires (Homestake, SAGE, GALLEX, SuperK, SNO, KAMLAND)

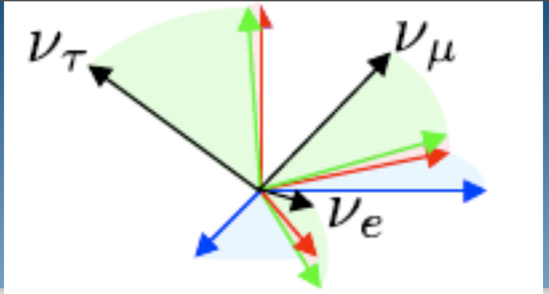
$$\Delta m^2_{\odot} \lesssim 10^{-4}\ \mathrm{eV}^2$$

neutrino provenant de l'atmosphère (SuperK) et sur accélérateurs (K2K)

$$\Delta m^2_{\mathrm{atm}} \gtrsim 10^{-3}\ \mathrm{eV}^2$$



Matrice de mélange



Flavor   Mass

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \begin{pmatrix}1 & 0 & 0\\ 0 & \cos\theta_{23} & \sin\theta_{23}\\ 0 & -\sin\theta_{23} & \cos\theta_{23}\end{pmatrix}\begin{pmatrix}\cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta}\\ 0 & 1 & 0\\ -\sin\theta_{13}e^{i\delta} & 0 & \cos\theta_{13}\end{pmatrix}\begin{pmatrix}\cos\theta_{12} & \sin\theta_{12} & 0\\ -\sin\theta_{12} & \cos\theta_{12} & 0\\ 0 & 0 & 1\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

SK, K2K, MINOS — CHOOZ — Solar, KamLand

$\Delta m^2_{23} \approx 2.4 \pm 0.15\ ({}^{+0.47}{}_{-0.46}) \times 10^{-3}\ eV^2$

$\Delta m^2_{12} \approx 7.7^{+0.22}{}_{-0.21} ({}^{+0.67}{}_{-0.61}) \times 10^{-5}\ eV^2$

δ is unknown

$\theta_{23} \approx 42.3^{+5.1}{}_{-3.3} ({}^{+11.3}{}_{-7.7})^o$

$\theta_{12} \approx 34.5 \pm 1.4\ ({}^{+4.8}{}_{-4.0})^o$

$\theta_{13} < 0.0^{+7.9}{}_{-0.0} ({}^{+12.9}{}_{-0.0})^o$

Mixing	Quarks	Leptons
1-2 θ_{12}	13°	34°
2-3 θ_{23}	2.3°	42°
1-3 θ_{13}	~ 0.5°	<13°

Mesures de probabilités d'oscillation

Mesure d'antineutrino auprès des réacteurs nucléaires : Double CHOOZ, Daya Bay

- probabilité P(anti$\nu_e \rightarrow$antiν_e) : disparition

pas d'effet de matière, pas de dégénérence et peu affecté par autres paramètres

Mesure avec faisceau intense et de longue portée : T2K, NOvA

- $P(\nu_\mu \rightarrow \nu_e)$: mesure d'apparition
- $P(\nu_\mu \rightarrow \nu_\mu)$: mesure de disparition
- Si $P(\nu_\mu \rightarrow \nu_e)$ visible alors possibilité d'accéder a la phase de violation de CP :

$$A_{CP} = \frac{P(\nu_\mu \rightarrow \nu_e) - P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)}{P(\nu_\mu \rightarrow \nu_e) + P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)} \approx \frac{\Delta m^2_{12} \sin 2\theta_{12}}{4\, E_\nu \sin \theta_{13}} \sin \delta$$

Mesures accessibles par T2K

T2K 1ère phase (5 ans)

- Quelle valeur pour Θ_{23} ? $\pi/4$?

Y a-t-il une symétrie entre 2e et 3e génération ?

- A-t-on une probabilité non nulle d'oscillation $\nu_\mu \rightarrow \nu_e$? Θ_{13} est-t-il suffisamment grand pour être mesuré ?

Y a-t-il mélange entre 1ère et 2e génération ?

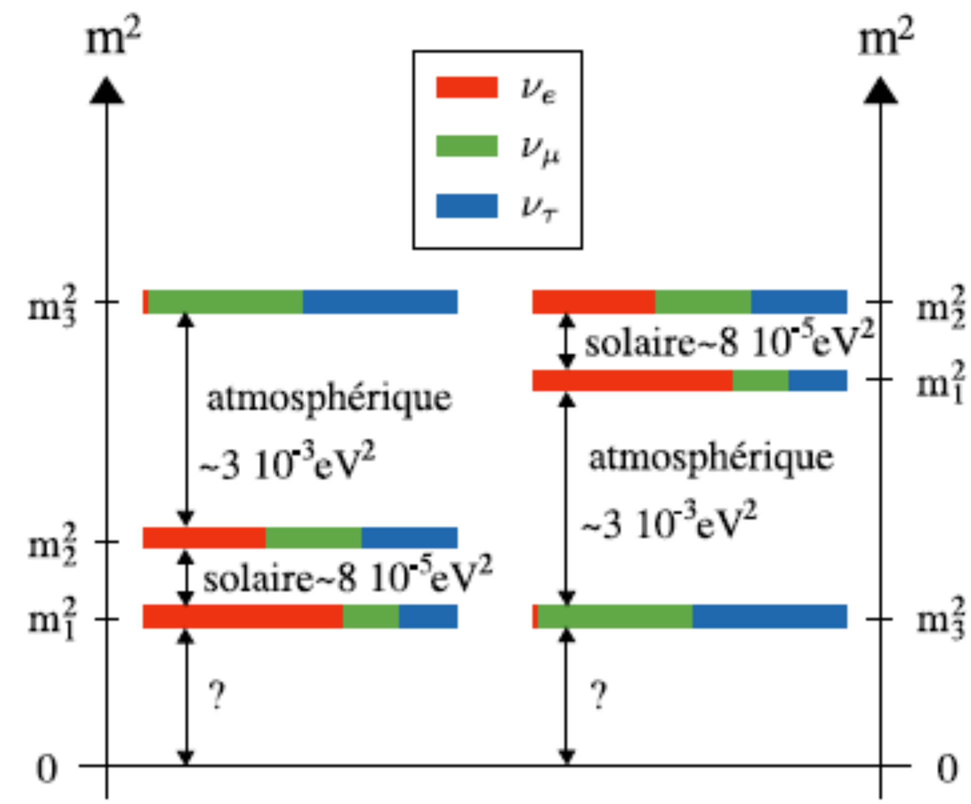
Phase 2 possible : violation CP dans le secteur leptonique

- δ_{CP} large ?

Y a-t-il une violation de CP dans le secteur leptonique ?

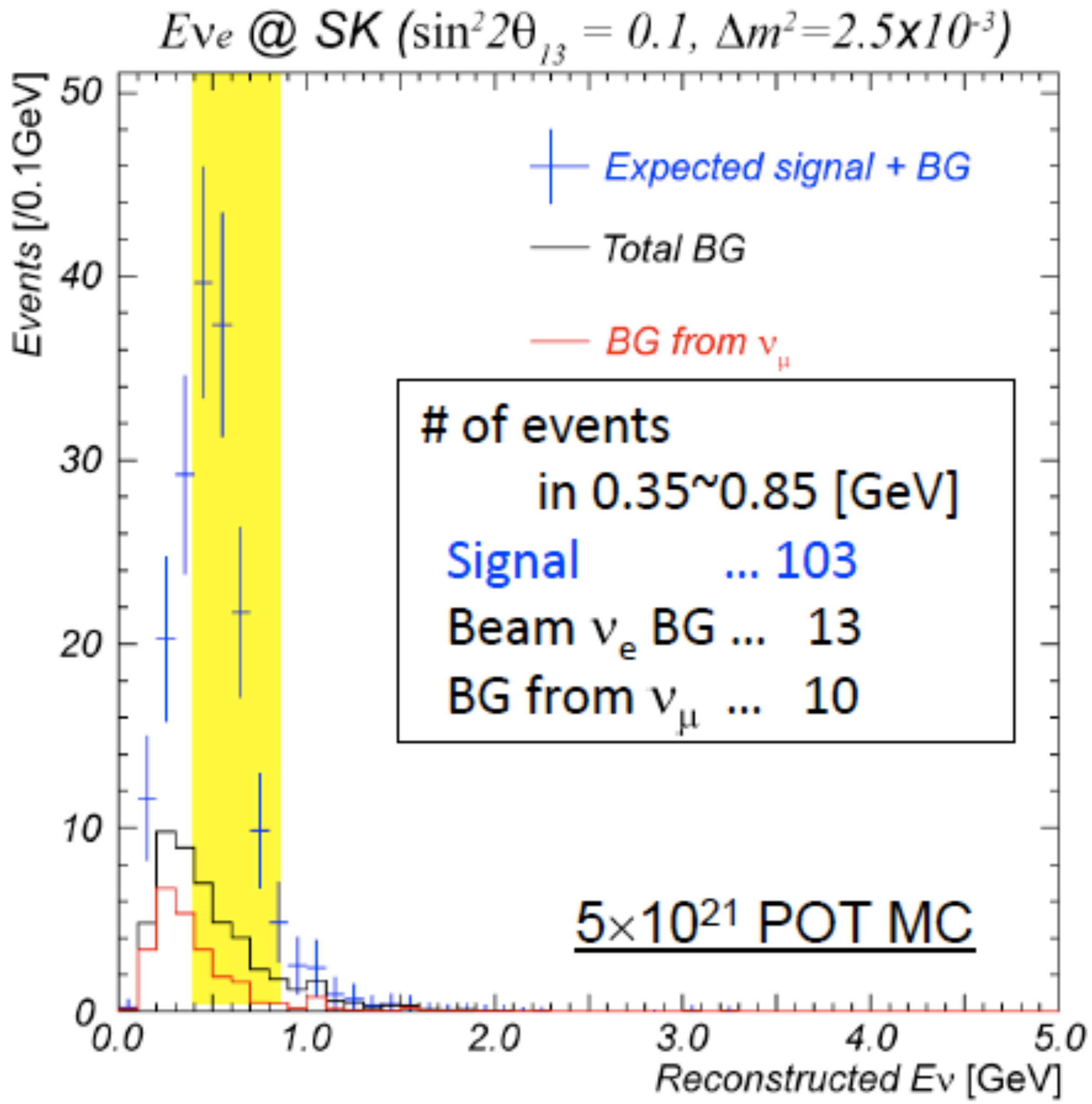
- Quelle hiérarchie des masses pour les neutrinos ?

Quelle amplitude pour les effets de matière ?



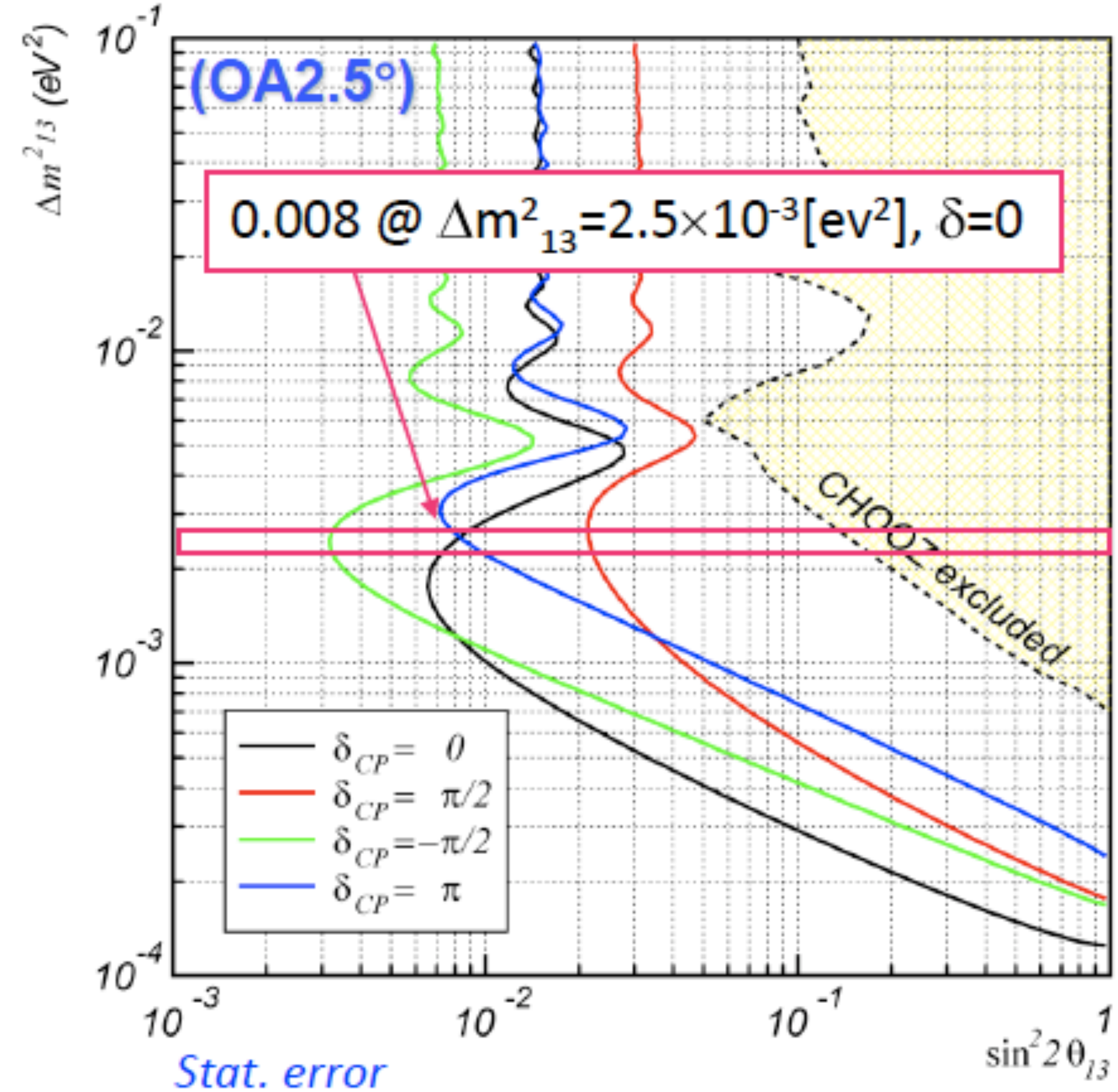
Sensibilité expérimentale

- ν_e appearance



T2K 90%CL sensitivity

5×10^{21} POT ~ 5 years@full intensity

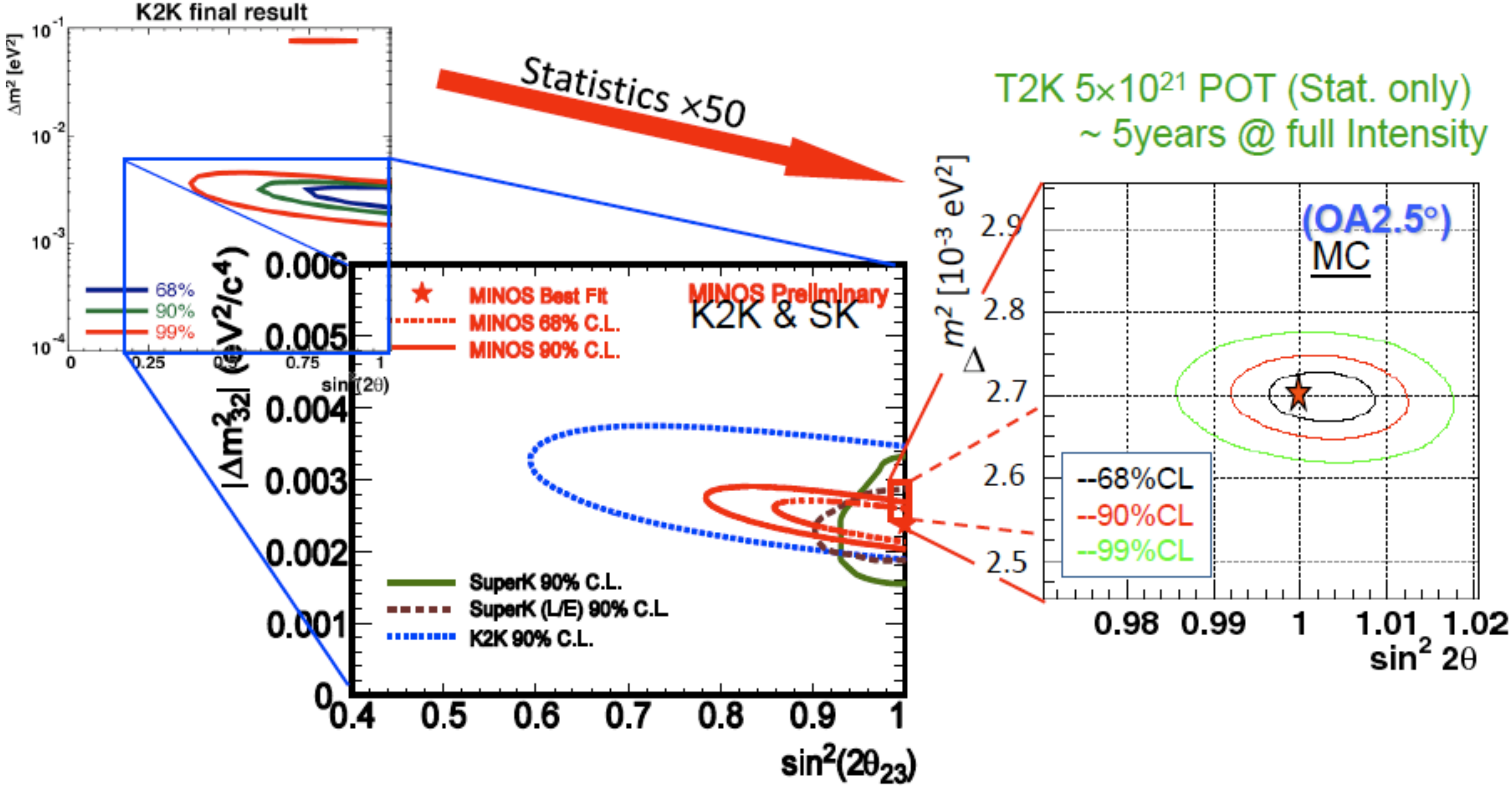


Stat. error
+ Syst. error for BG subtraction (10%)

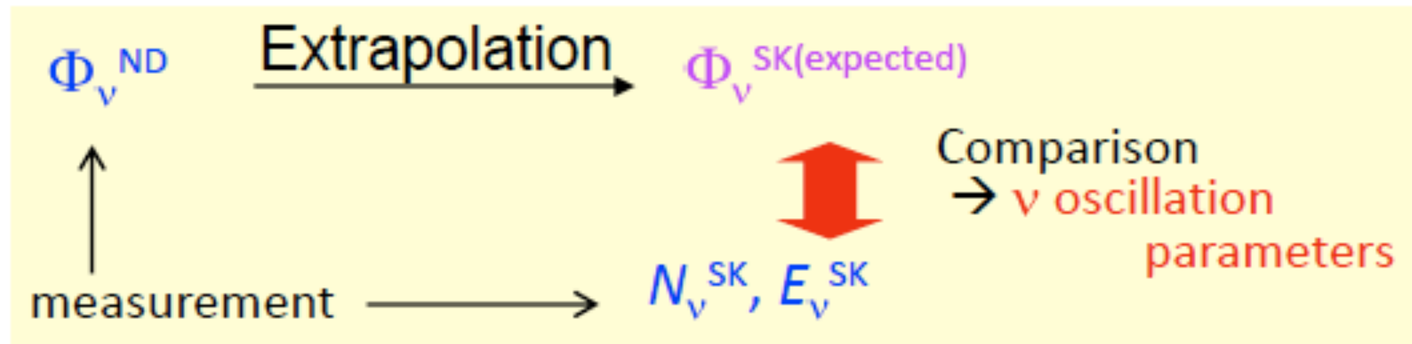
21

Sensibilité expérimentale II

- ν_μ disappearance : $P(\nu_\mu \rightarrow \nu_\mu)=1-\sin^2\theta_{23}\sin^2(1.27\,\Delta m^2_{23}L/E)$
  - Goal : $\delta(\sin^2 2\theta_{23})\sim 0.01$, $\delta(\Delta m^2_{23}) < 1\times 10^{-4}$ [eV²]

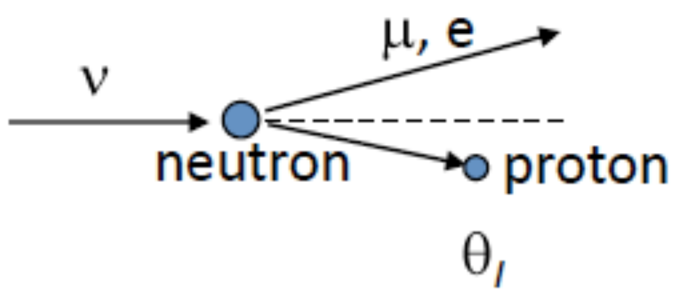


Principe d'analyse d'oscillation



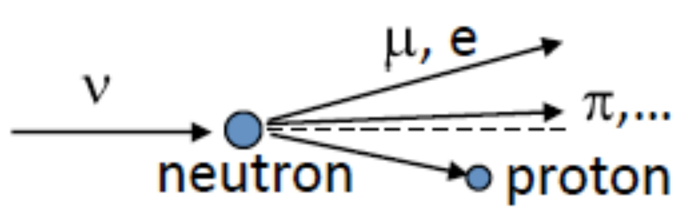
Use Sub-GeV ν_μ beam

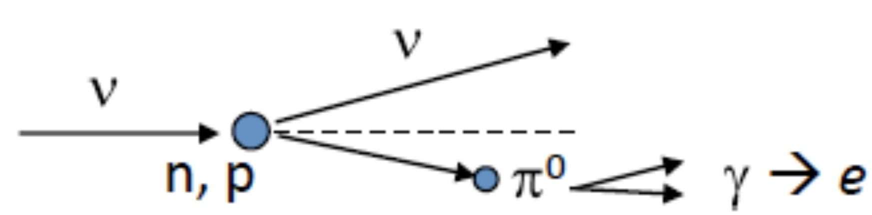
- CC-QE is dominant process in ν-N interactions.
- Neutrino Energy reconstruction by CC-QE kinematics.
  ... δE ~ 60MeV, δE/E ~ 10%



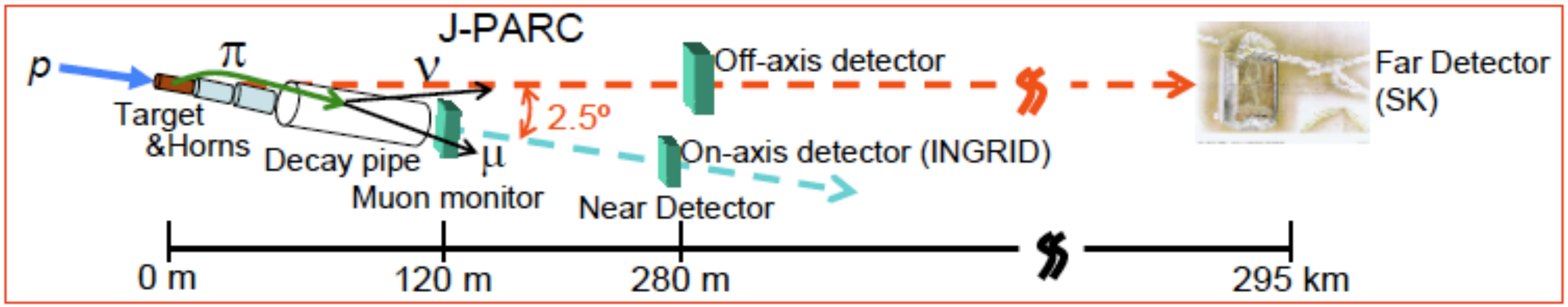
$$E_\nu = \frac{m_N E_l - m_l^2/2}{m_N - E_l + p_l \cos\theta_l}$$

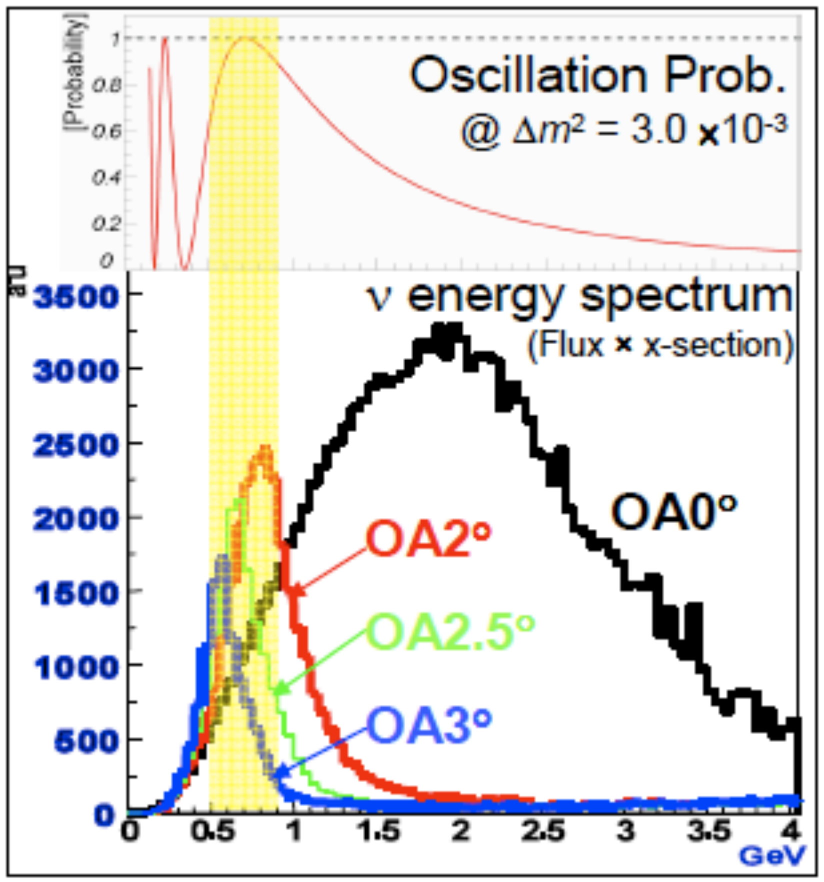
- **Backgrounds :**
  - CC-non QE events are background for Eν reconstruction.
  - π^0 from NC events are dominant background for ν_e signal.





Les éléments de la “ligne faisceau”





- Off-axis beam technique
  - Intense narrow band beam
- 2.5° off-axis
  - Energy peak tuned at oscillation max. ~ 0.7 GeV

- Statistics at Super-K
  - ~1600 ν_μ CC int./22.5kt/year (with 0.75kW beam, no oscillation case)
- Pure ν_μ beam
  - Beam ν_e contamination ~0.4% at ν_μ peak energy

La collaboration T2K

Canada
TRIUMF
U. Alberta
U. British Columbia
U. Regina
U. Toronto
U. Victoria
York U.

France
CEA Saclay
IPN Lyon
LLR E. Poly
LPNHE Paris

Germany
U. Aachen

Italy
INFN, U. Roma
INFN, U. Napoli
INFN, U. Padova
INFN, U. Bari

Japan
Hiroshima U.
ICRR
ICRR Kashiwa
ICRR RCCN
KEK
Kobe U.
Kyoto U.
Miyagi U.
Osaka City U.
U. Tokyo

Poland
A.Soltan, Warsaw
H.Niewodniczanski, Cracow
T.U. Warsaw
U. Silesia, Katowice
U. Warsaw
U. Wroklaw

Russia
INR

South Korea
N.U. Chonnam
U. Dongshin
N.U. Gyeongsang
N.U. Kyungpook
U. Sejong
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Switzerland
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ETH Zurich

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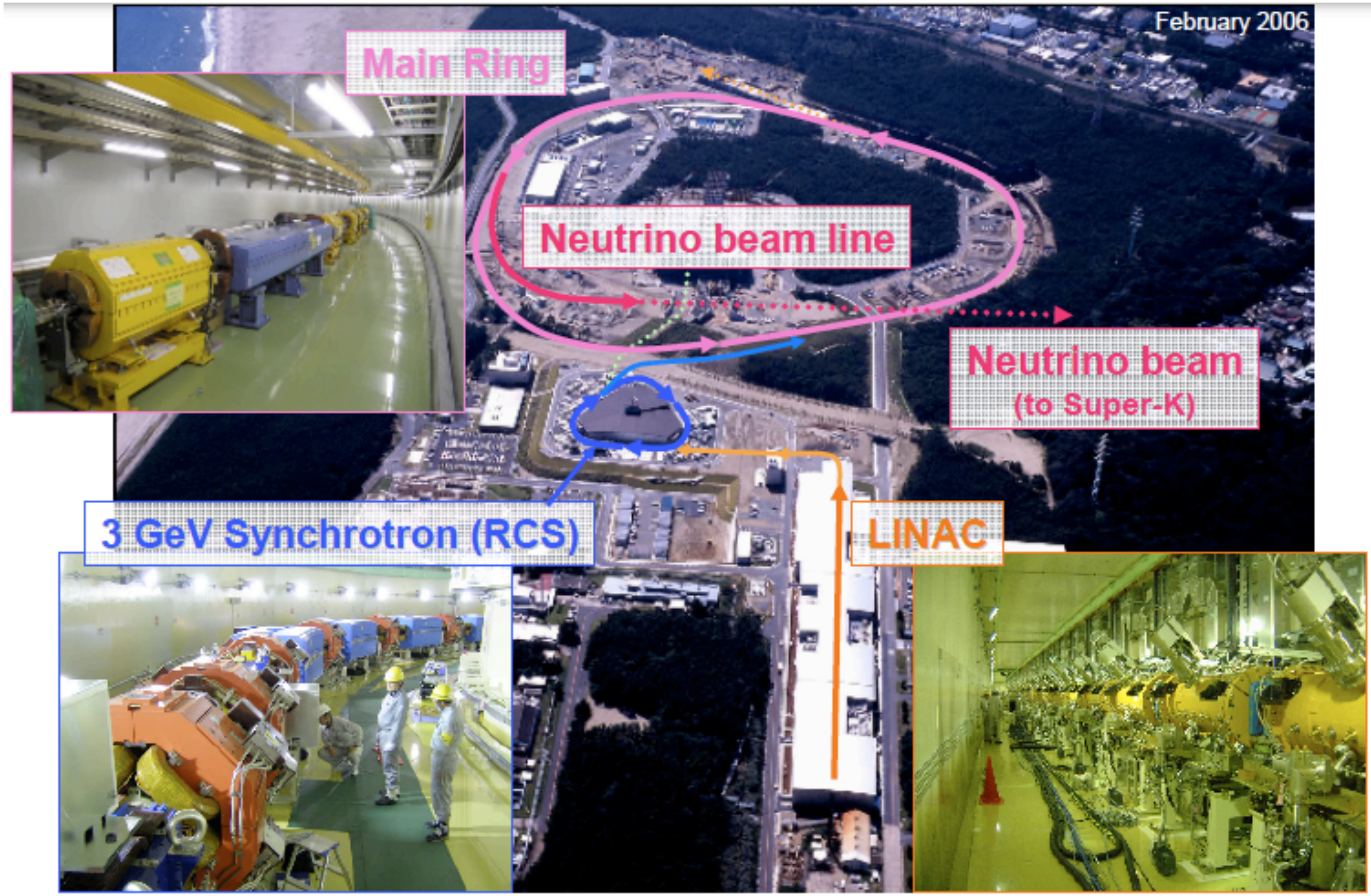
Lancaster U.
Liverpool U.
Oxford U.
Sheffield U.
Warwick U.
STFC/RAL
STFC/Daresbury

USA
Boston U.
BNL
Colorado S.U.
Duke U.
Louisiana S.U.
Stony Brook U.
U.C.Irvine
U. Colorado
U. Pittsburgh
U. Rochester
U. Washington

L'accélérateur de proton J-PARC



Préparation de du faisceau de J-PARC

LINAC : commission terminée

- 181 MeV obtenue en **janvier 2007**. Bonne stabilité faisceau

Synchrotron 3 GeV (RCS) :

- Accélération de 3 GeV reussie en **octobre 2007**
- 4.4×10^{12} particules accélérées a 25 Hz : correspond à 100 kW de puissance.

Anneau principal (MR) :

- Premiers tests en **mai 2008** : faisceau injecté du RCS, capturé par RF et envoyé vers le “beam dump”
- accélération à 30 GeV réussie en **décembre 2008**

ligne neutrino assemblée en **janvier 2009**, premier test de refroidissement aimaints supraconducteurs reussie (la semaine dernière).

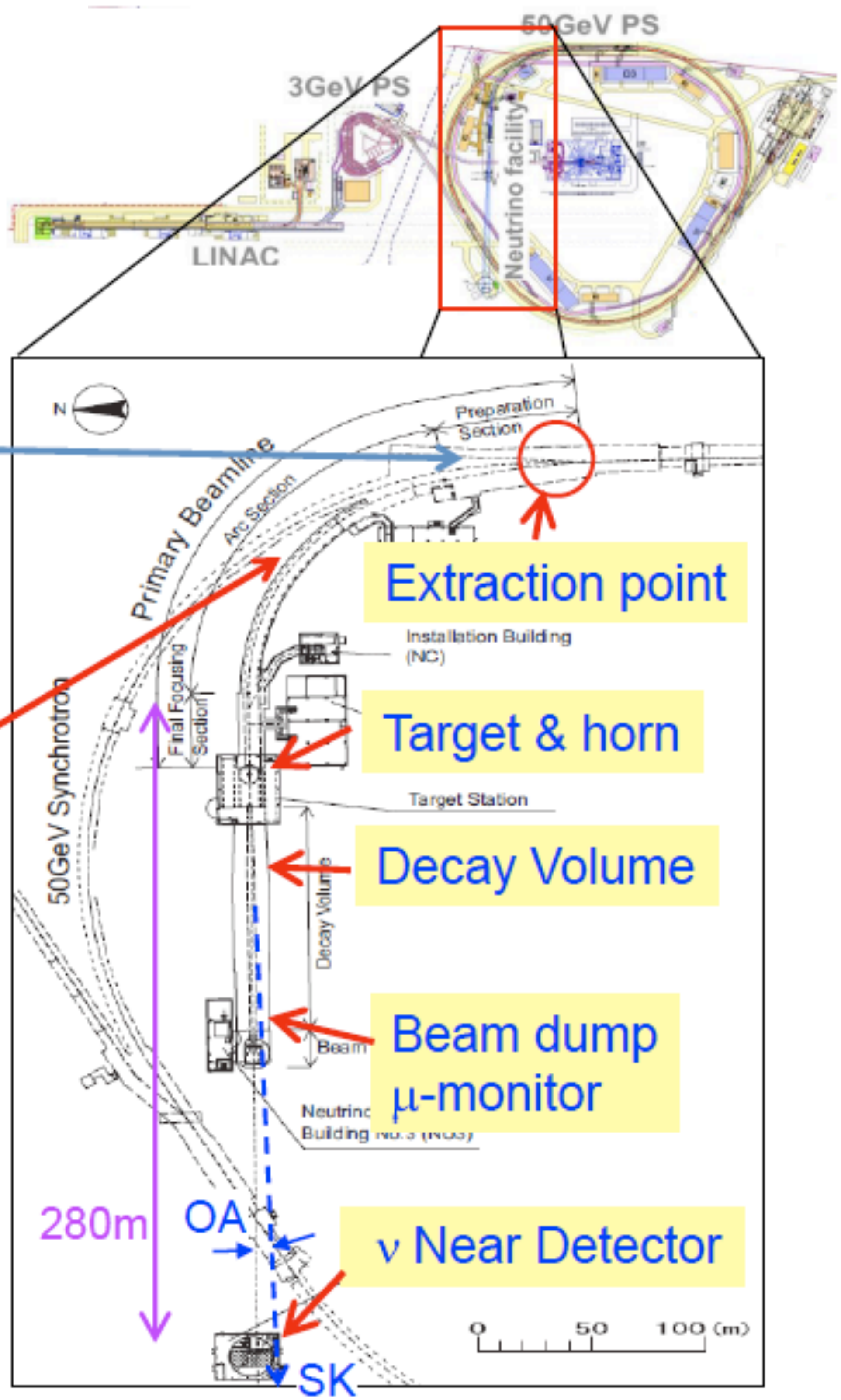
La ligne de faisceau neutrino

Primary beamline:

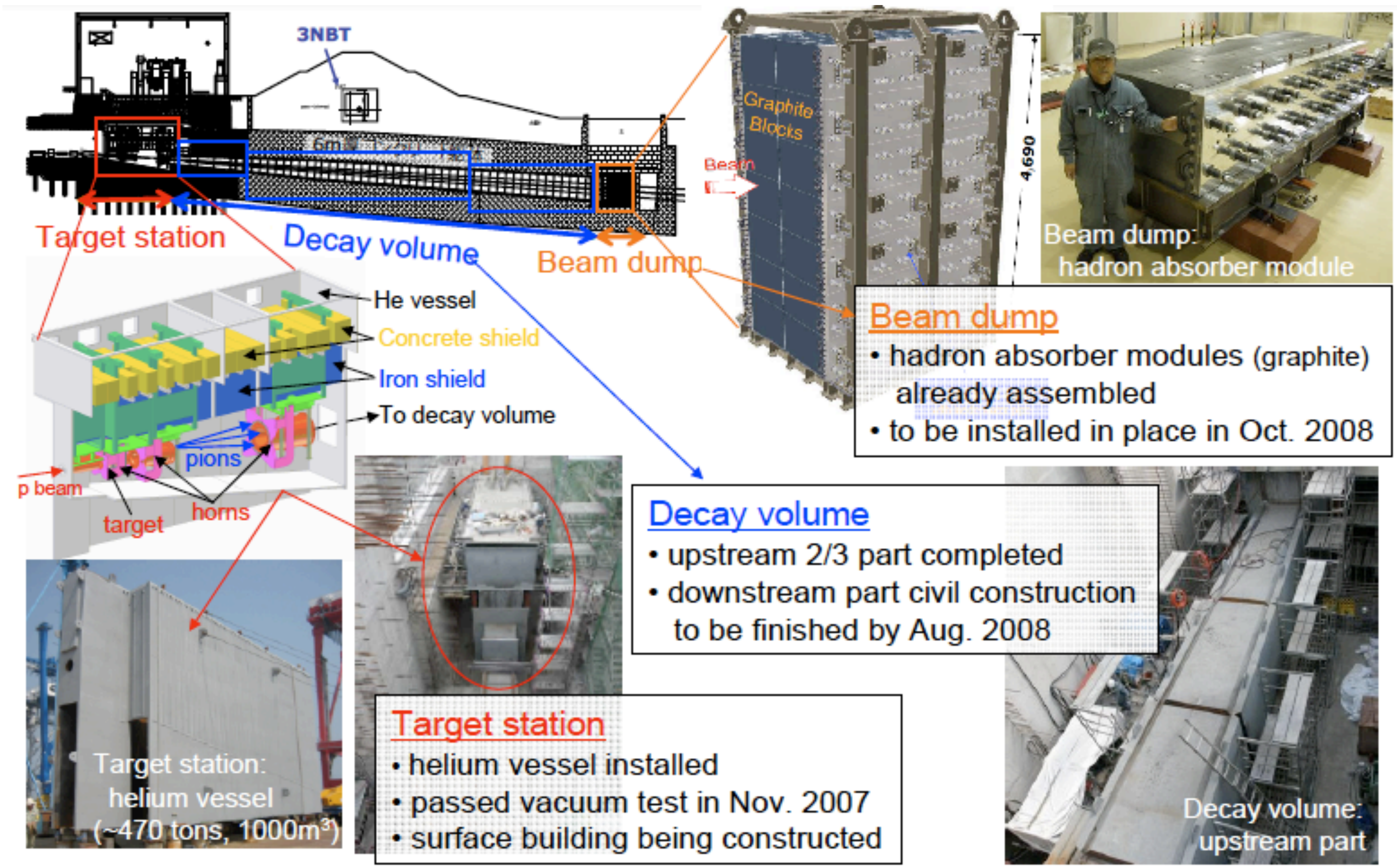
- Preparation section: normal magnets installed and aligned
- Arc section: 10 out of 14 super conducting combined function magnets installed and aligned

Preparation section

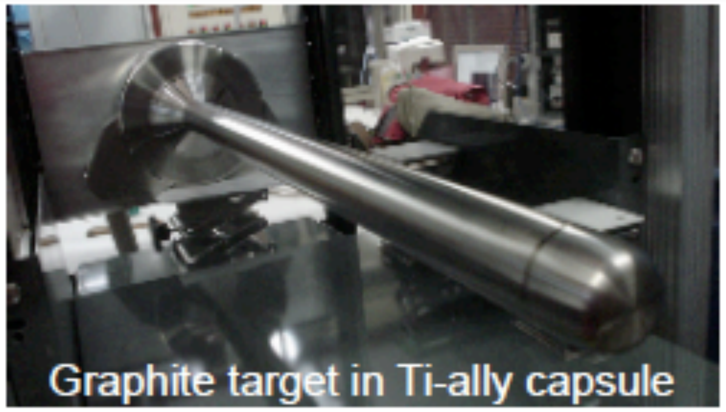
Superconducting magnets (doublets) in tunnel



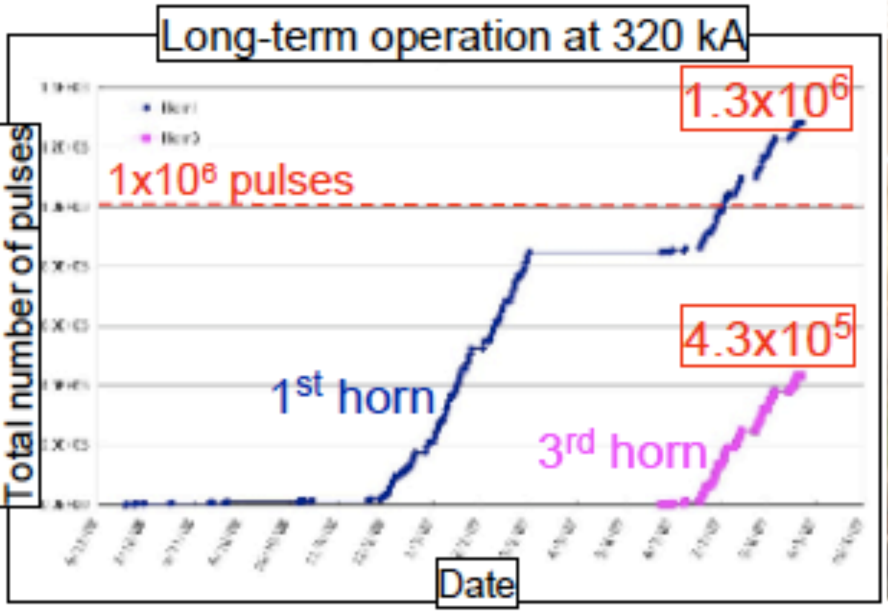
La cible et la ligne secondaire



Cible et cornes de focalisation

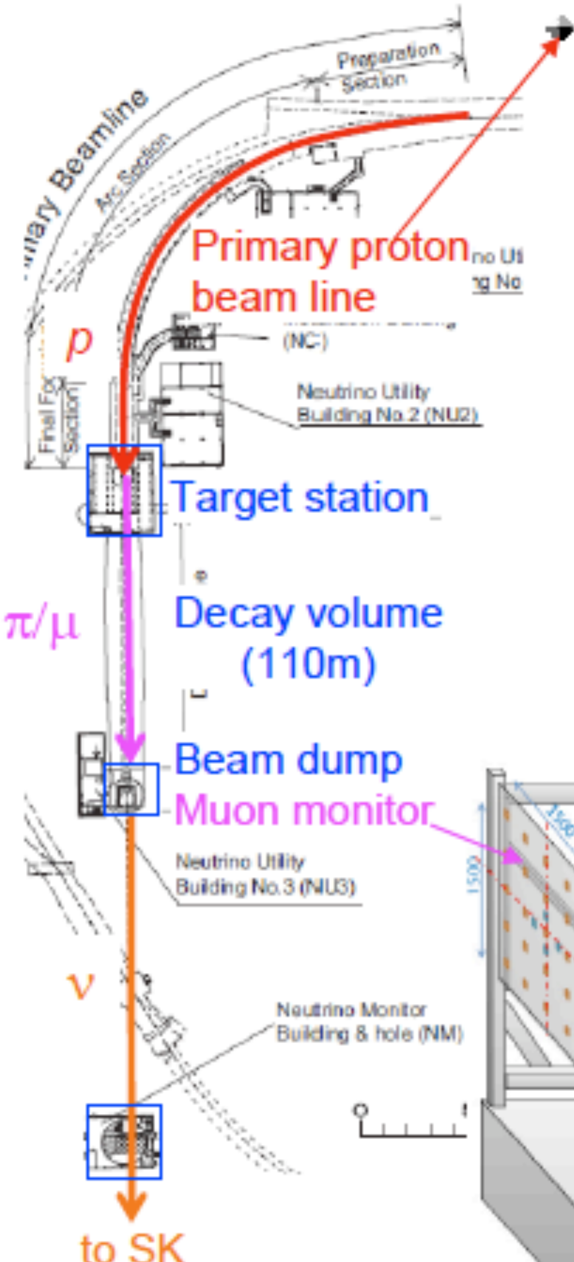


Target
- graphite core: 26 mm (D) x 900 m (L)
- forced flow helium gas cooling in Ti-alloy capsule
- day-1 target delivered
- full-spec helium flow rate for cooling achieved

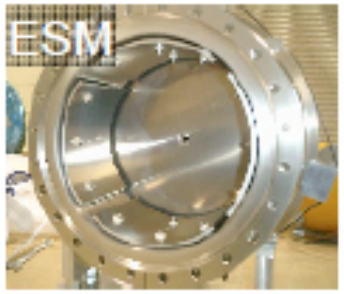


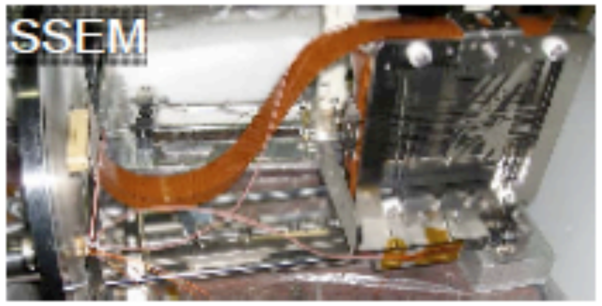
Electromagnetic horns
- long term test with 320 kA for 1st and 3rd horns successfully performed
- 1st and 3rd horns for Day-1 delivered
- 2nd horn to be delivered from the US in Jun/Jul
- full system setup at KEK
  - remote maintenance demonstrated
  - 320 kA operation succeeded
- assembly/installation will start in Aug. 2008

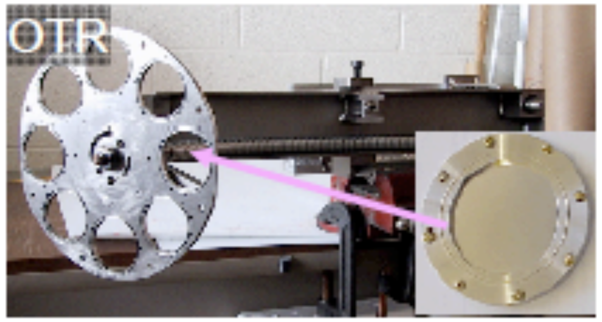
Tunnel de désintégration et moniteurs faisceau

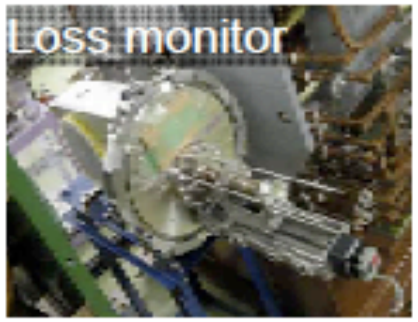


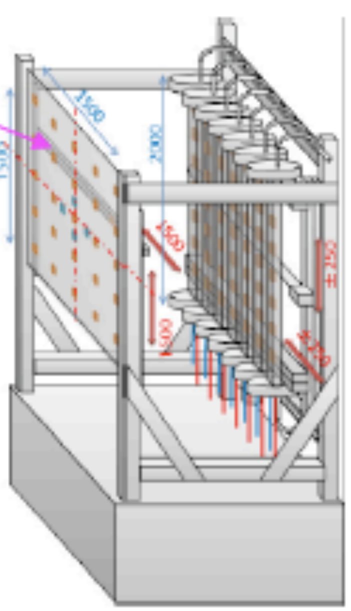
- **Primary proton beam monitors**
  - Intensity: current transformer (CT)
  - Position: electro-static monitor (ESM)
  - Profile: segmented secondary emission monitor (SSEM)
  - Beam loss: Ionization chamber
  - Beam profile in front of target: optical transition radiation (OTR)
  - All monitors to be installed by Oct.2008





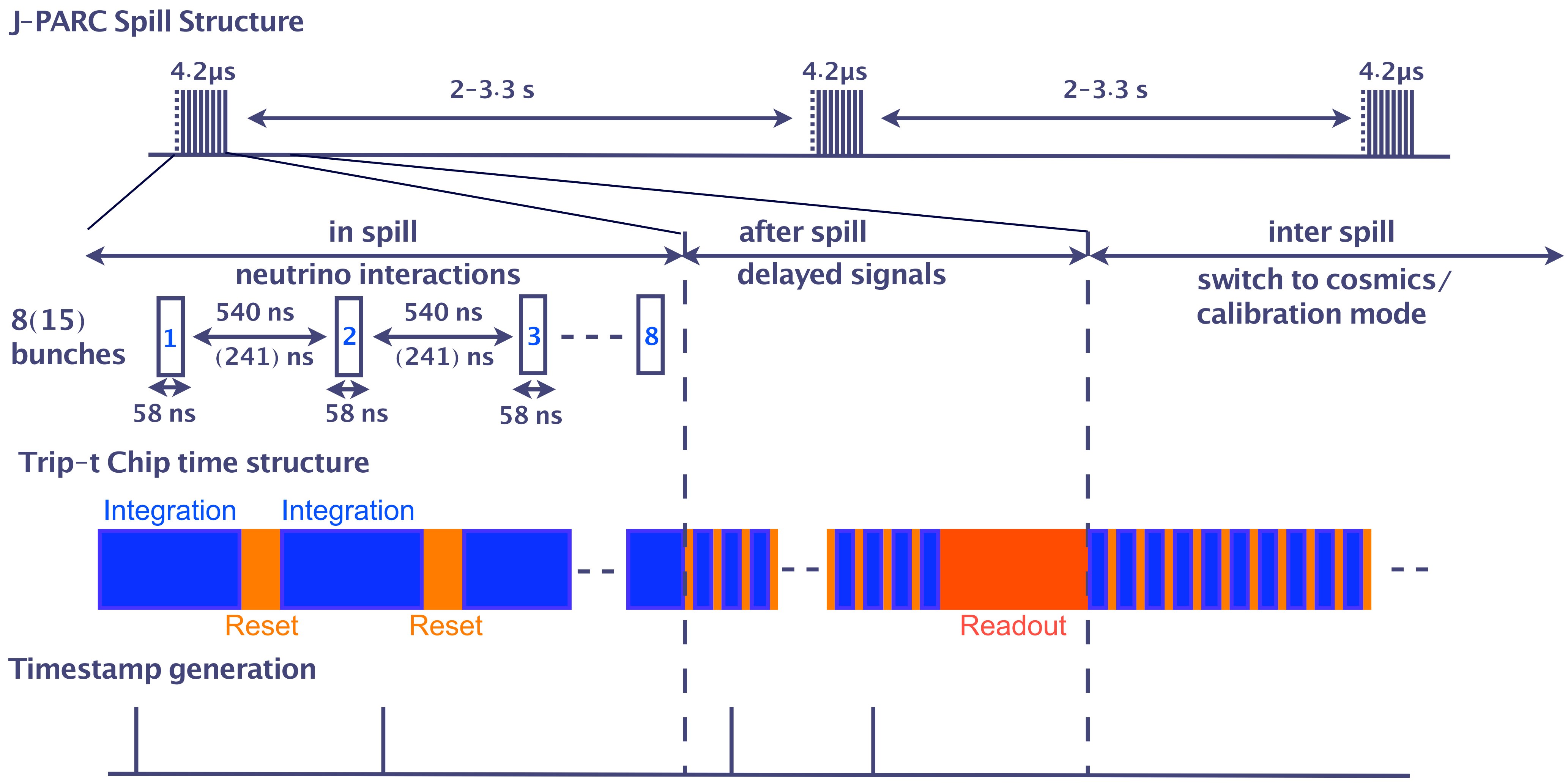






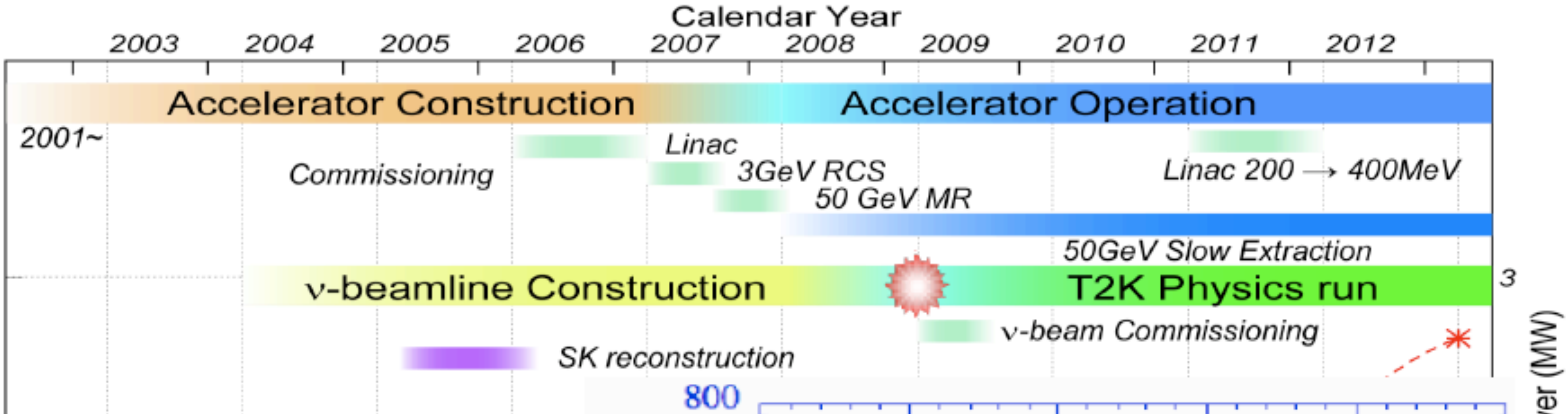
- **Secondary beam monitors**
  - Muon profile center after beam dump
    muon monitor: Ionization chamber
    Si PIN/Diamond
  - To be installed in fall-winter 2008

Structure du faisceau de protons



- ➡ 8(15) bunches per spill
- ➡ 4(2) muon lifetime after spill active period (90(80)% active)
  - translates to 50-70% in Michel electron tagging efficiency

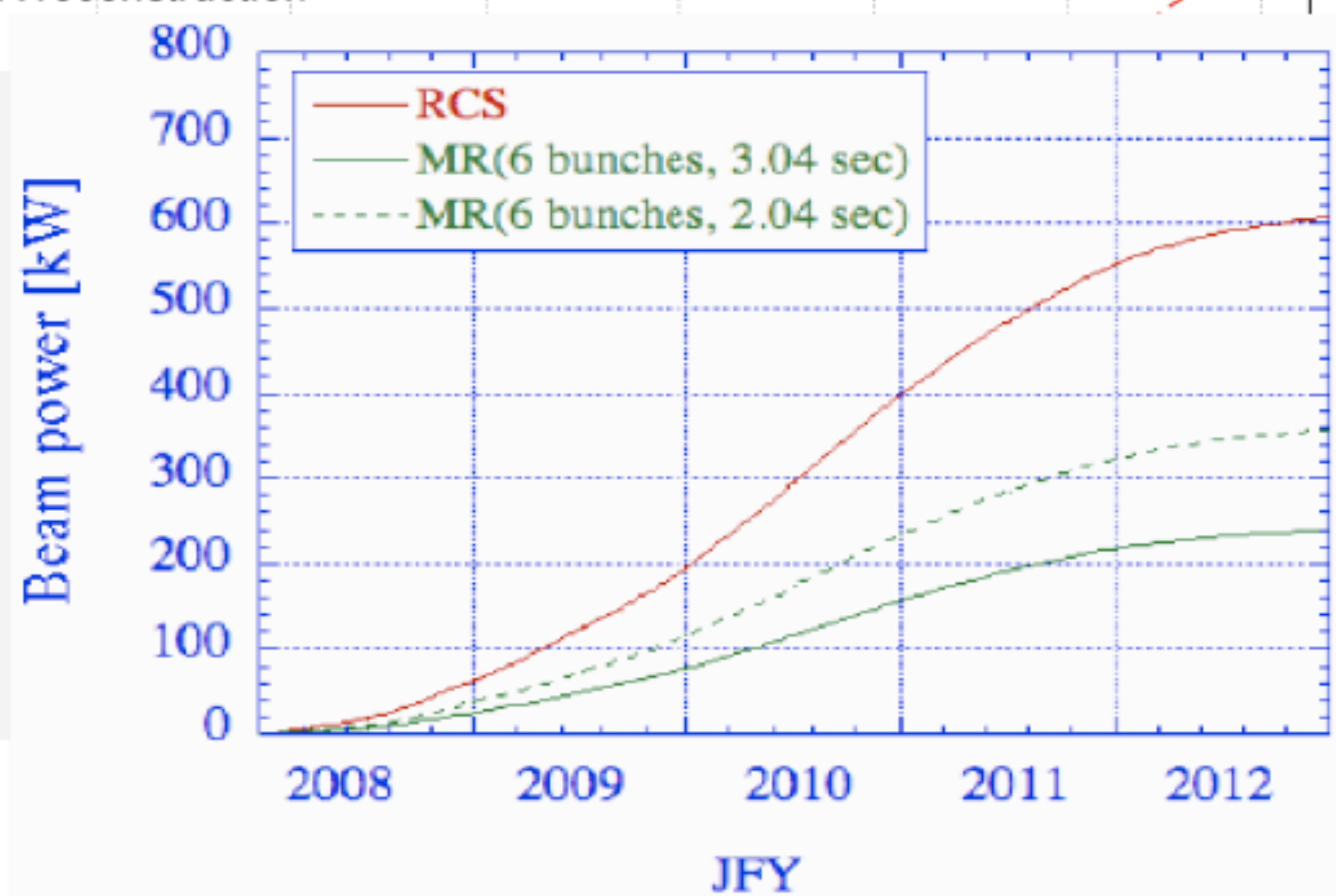
Puissance faisceau



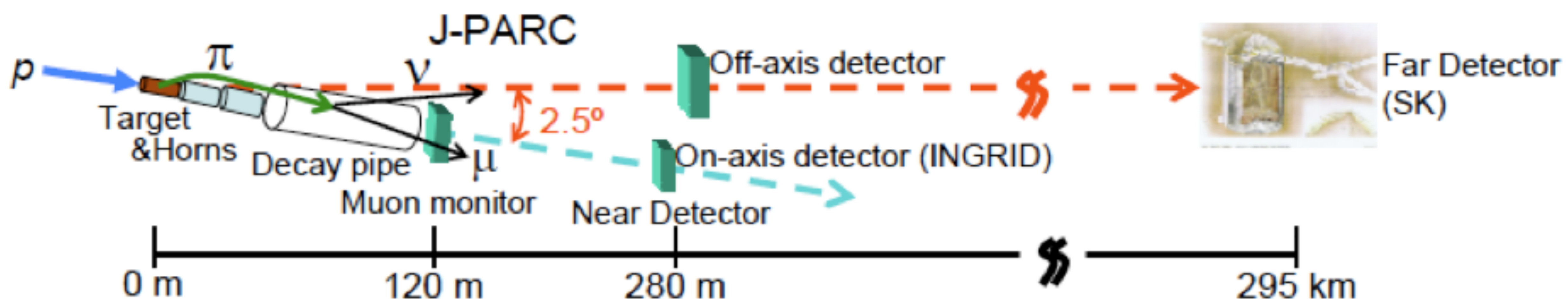
Request: 100kW operation of MR for more than 10^7s (several months)

Critical to obtain significant result

Nominal beam power: 30GeV; 9μA to be achieved by JFY2012



Les détecteurs neutrinos



Recherche d'oscillation $\nu_e \rightarrow \nu_\mu$

Recherche d'événements un anneau de type électron à SK

Expected number of events at SK (0.75kW beam x 5yr)

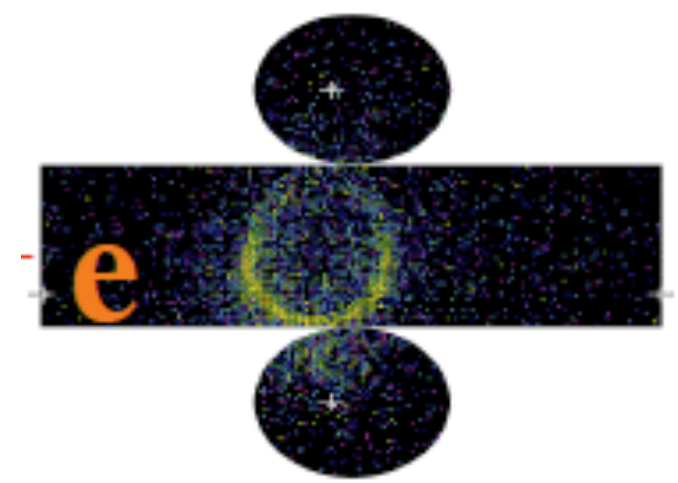
$\sin^2 2\theta_{13}$	Backgrounds			Signal
	ν_μ induced	Beam ν_e	Total	
0.1	10	13	23	103
0.01				10

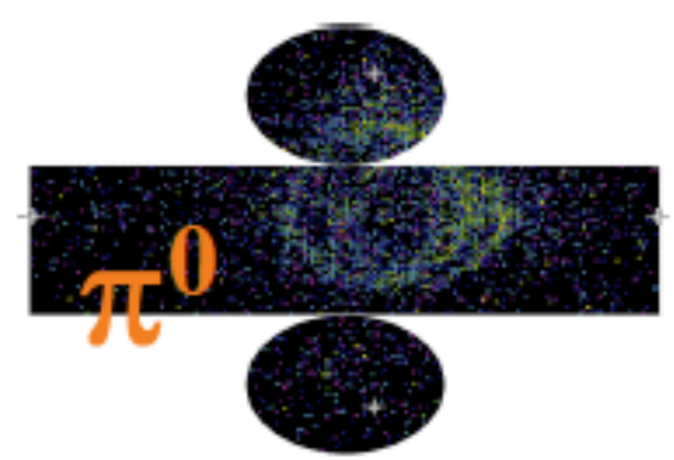
source de bruit de fonds :

- contamination intrinsèque en νe du faisceau : irréductible
- événements courant neutre avec

cas ou l'un des deux photons est non reconstruit. Réductible mais demande l'estimation du nombre d'interaction

- **recours au détecteurs proches pour mesurer précisements ces intéractions**



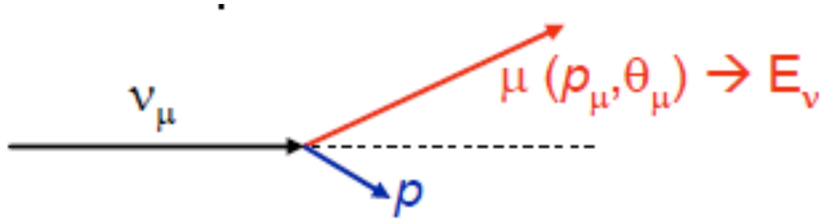


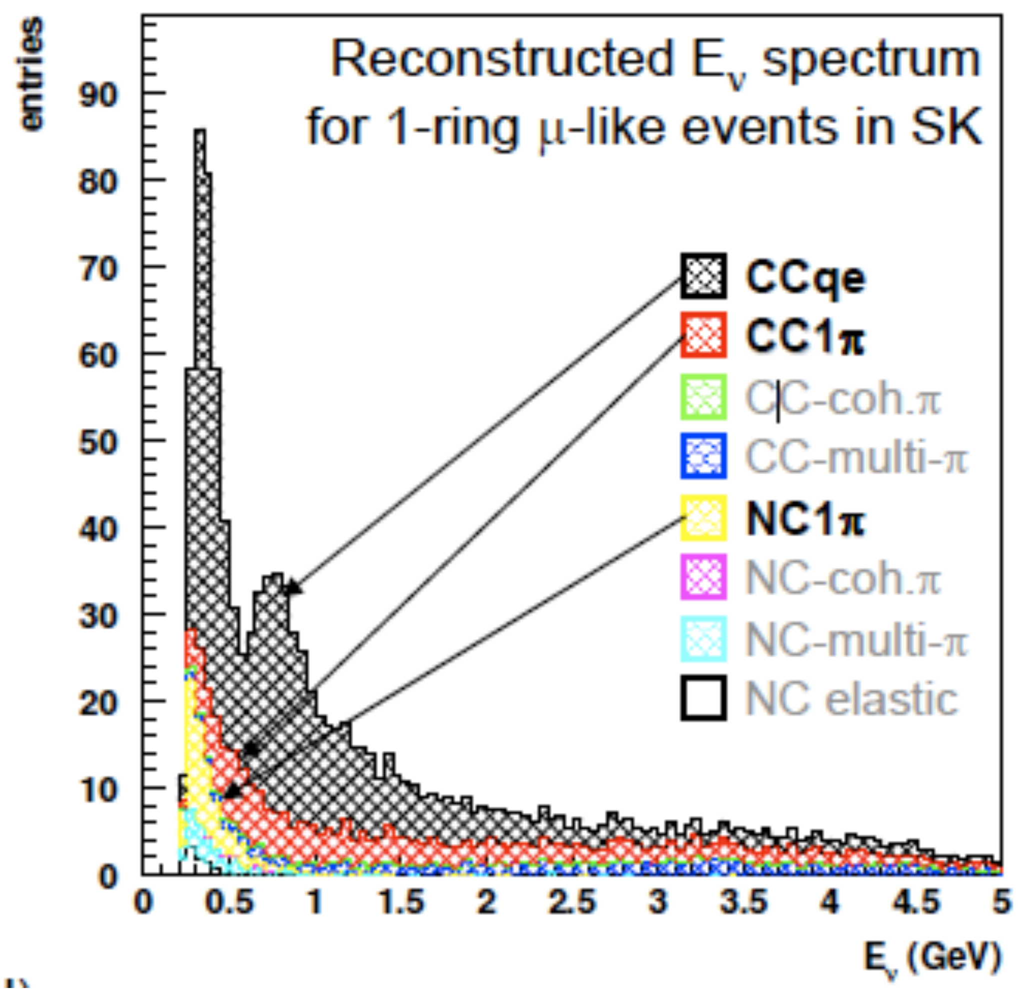
Mesure de disparation de ν_μ

Mesure la déformation du spectre engendrée par l'oscillation :

- comparaison avec prediction : **connaissance du spectre en énergie est crucial !**

Reconstruction de l'énergie du neutrino avec la réaction CCQE. Signature a SK : anneau seul de type "muon"



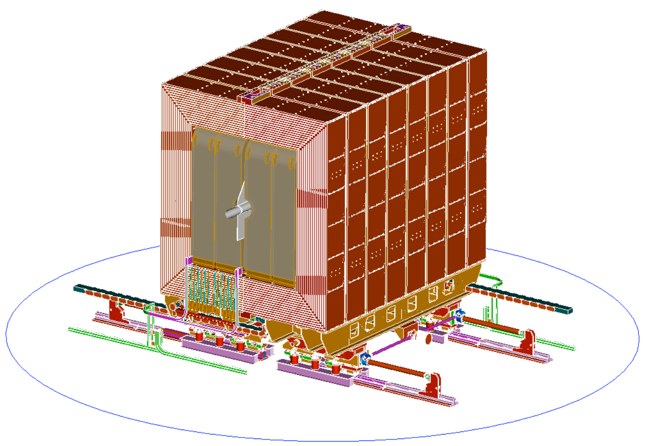


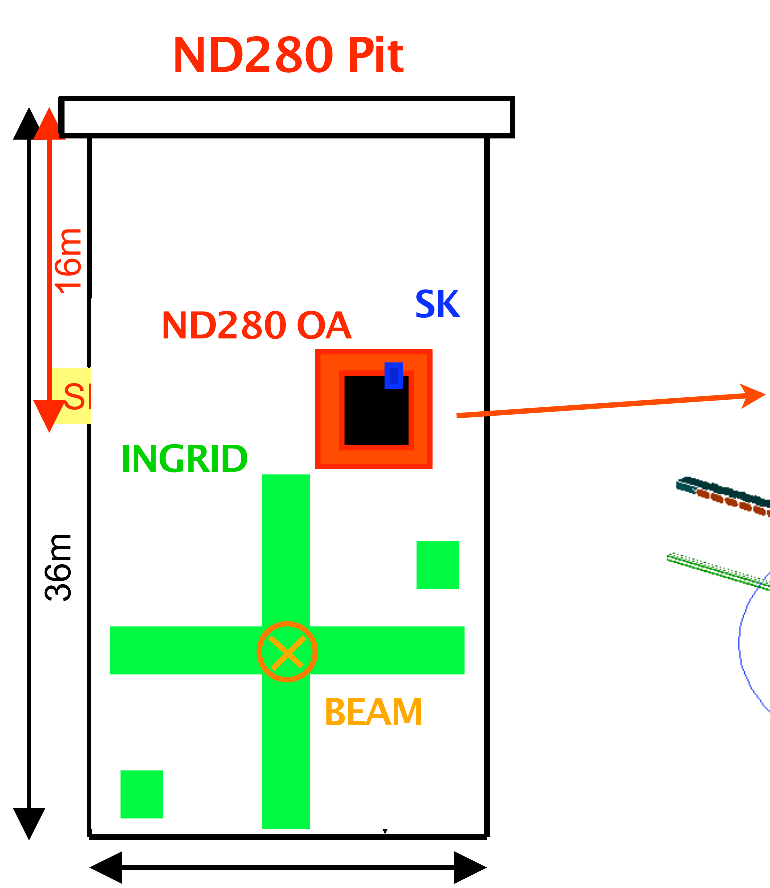
Bruit de fonds non CCQE : CC-1$\pi\pm$ et CN-1$\pi\pm$ dominent. Pions < seuil Cherenkov

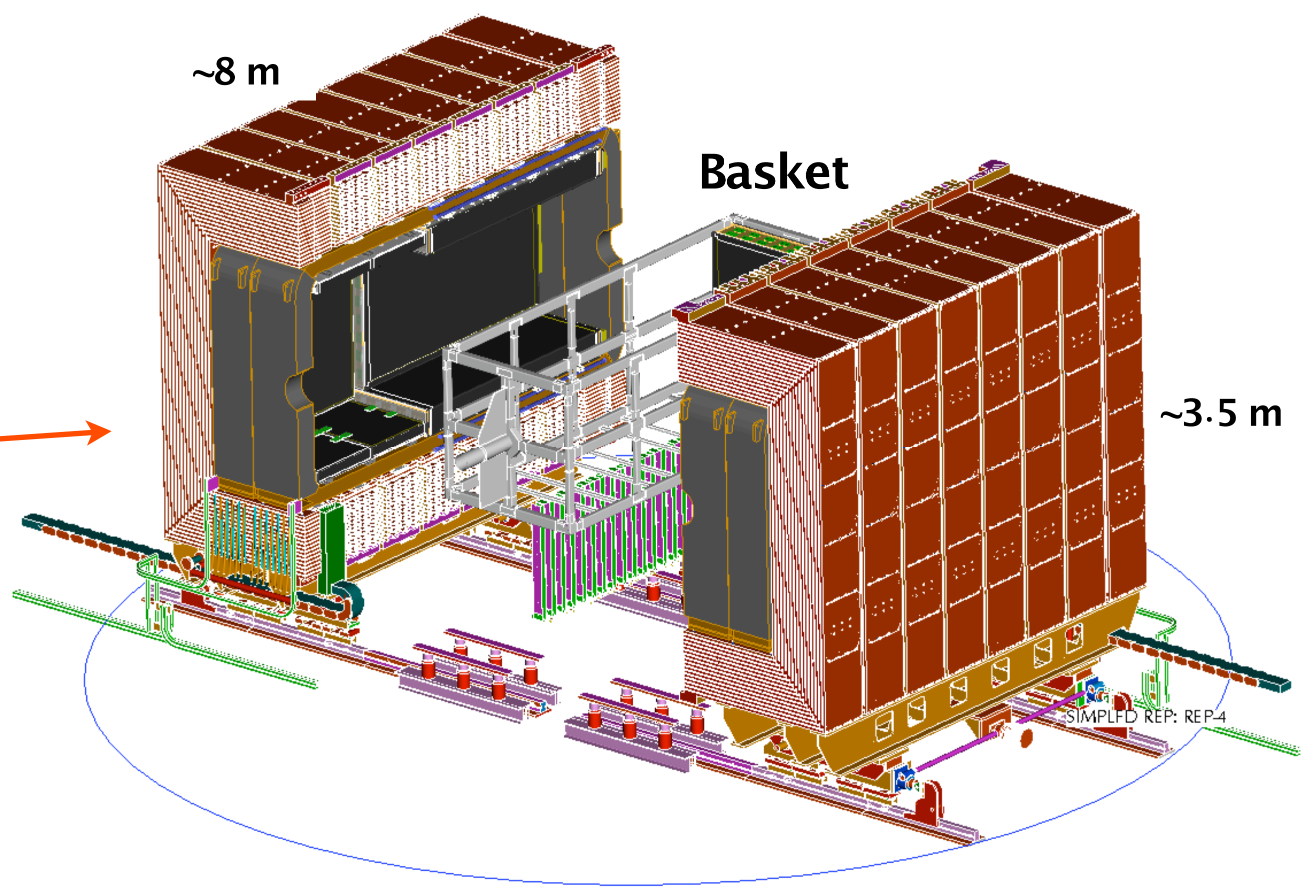
Estimation précise (haute statistique) avec détecteur proche

Les détecteurs proches (280 m)

- INGRID : mesure de flux et angle hors-axe (2-2.5 deg)
- ND280 : utilise l'aimant dipolaire de UA1. B = 0.2 T

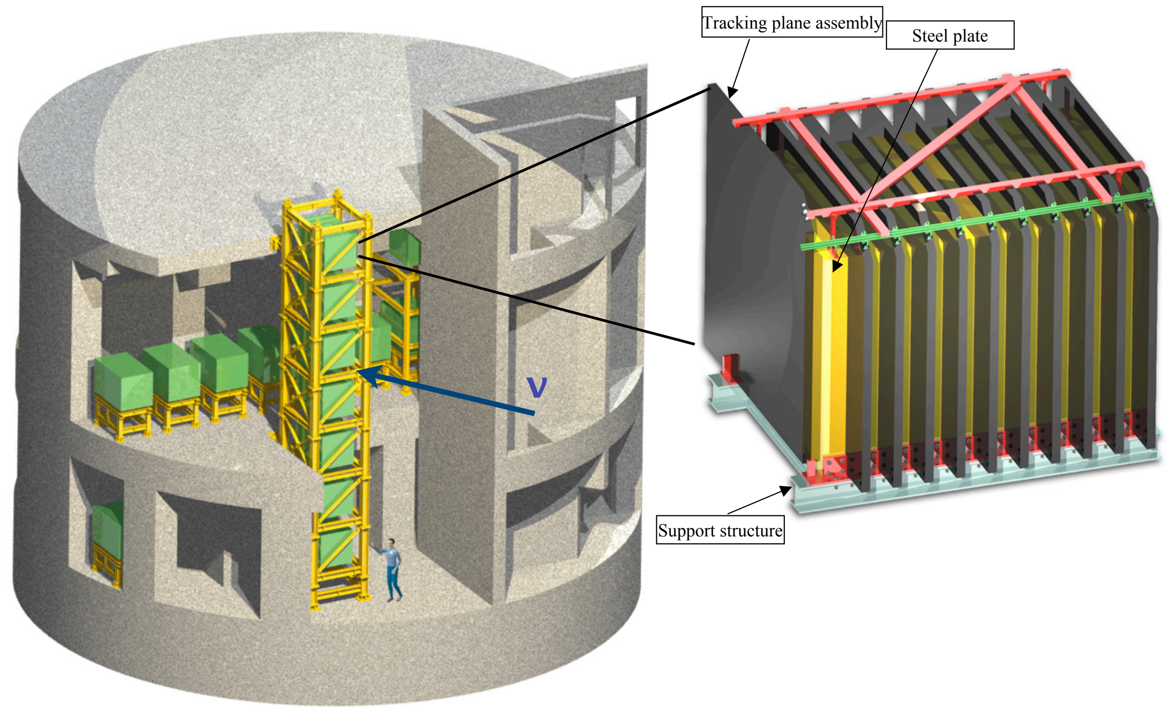


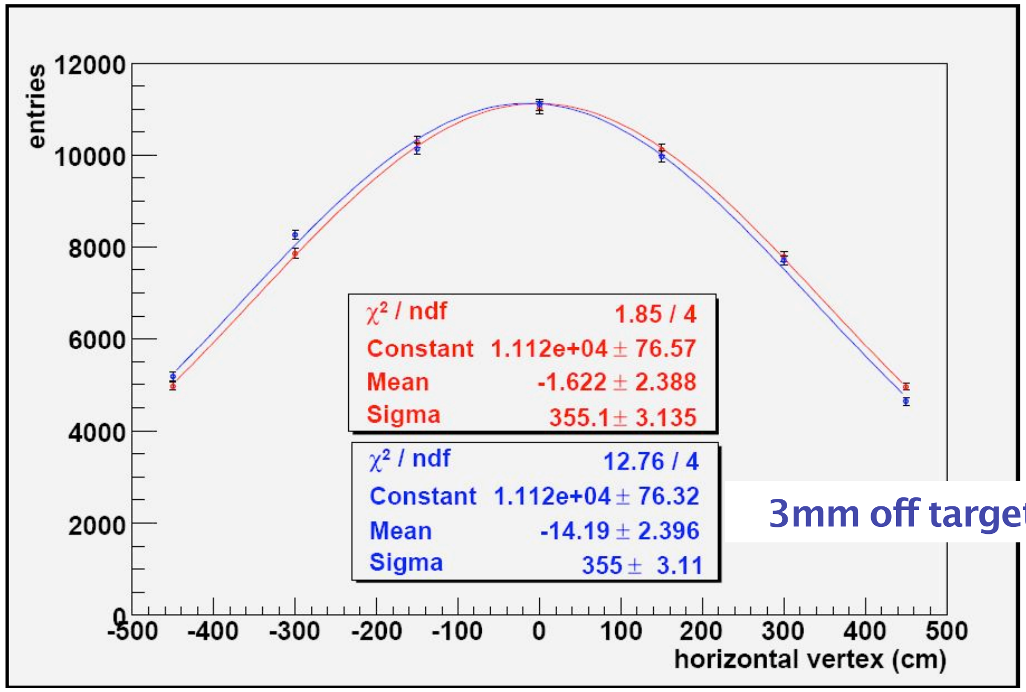




Détecteur sur axe : INGRID

- Monitor beam direction, intensity and mean energy
- Beam coverage 10x10 m^2
- 16 Modules
  - Fe/Scint (5x1x100cm bar)
- Off-axis angle measurement accuracy : 1mrad (<15MeV)
  - **10k events per day**
- Shift resolution 3cm -> 1mm at target



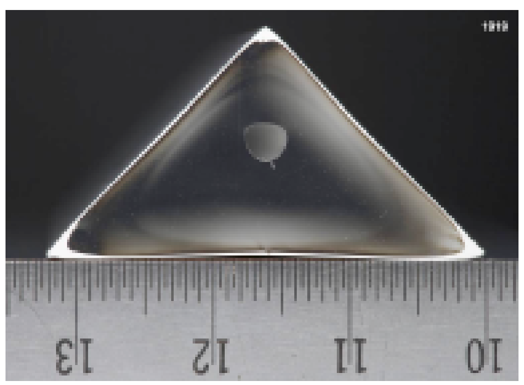


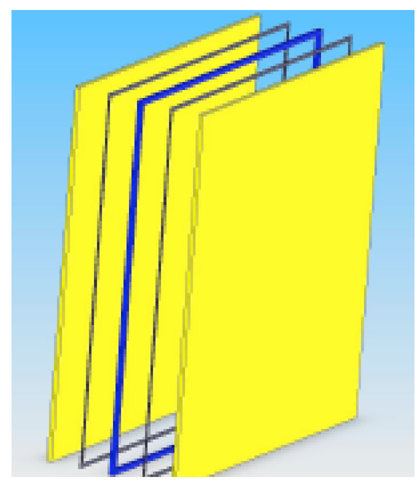
Détecteur π^0: le P0D

Pi0 detector(P0D) Target

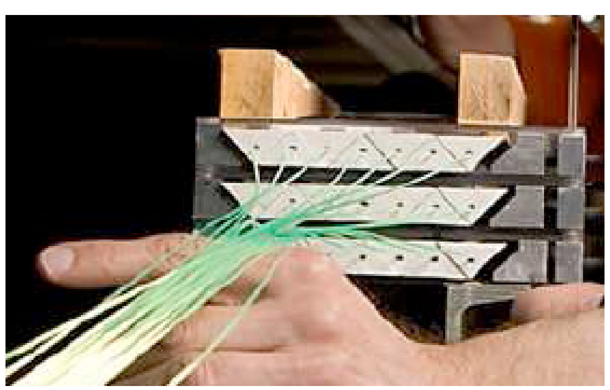
40 X-Y Pb/plastic planes
40% H_2O Passive
6t fiducial mass
10560 total channels

Minerva bar

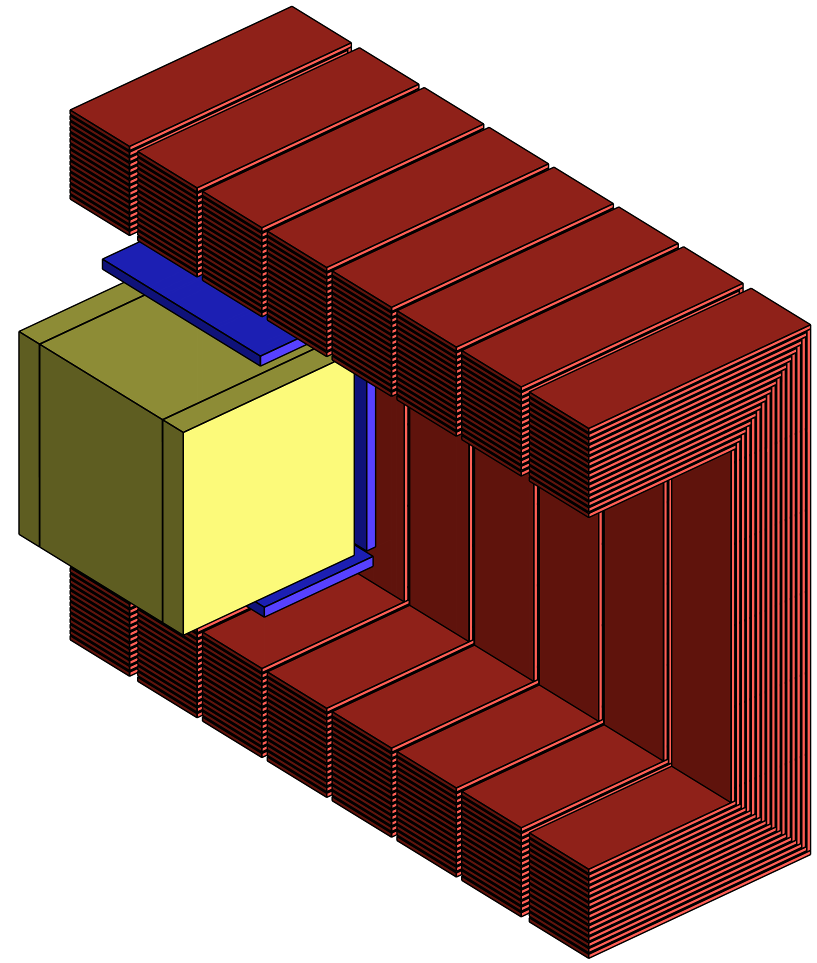




Water bag in gasketed container



Scintillator Planes layout



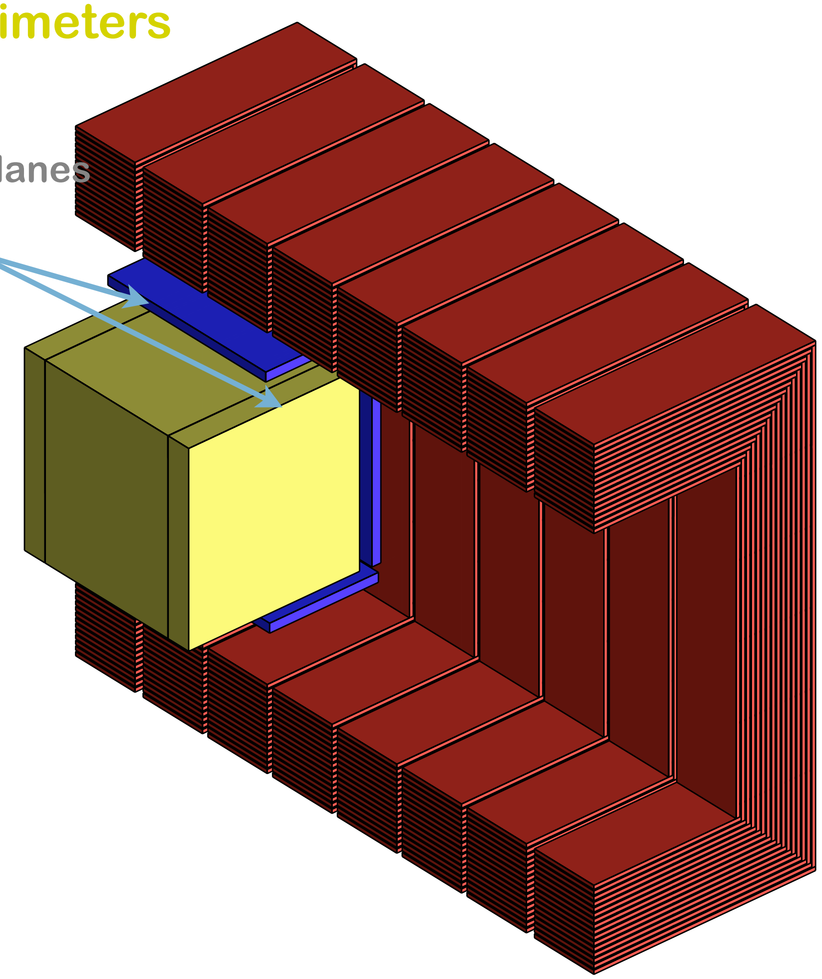
Détecteur π^0: le P0D

Pi0 detector(P0D) Target

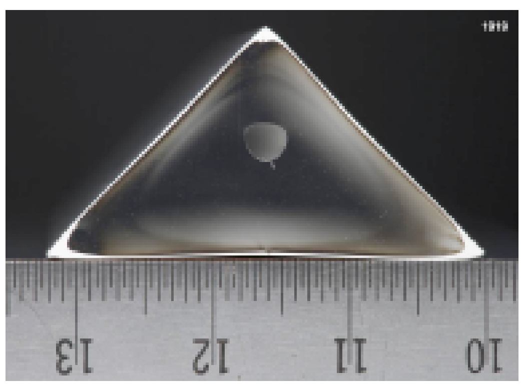
40 X-Y Pb/plastic planes
40% H_2O Passive
6t fiducial mass
10560 total channels

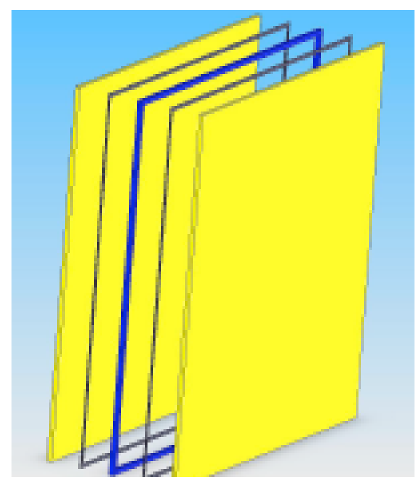
P0D Up/Central Calorimeters Modules

30 cm thick 5.7X0
X-Y Pb/plastic thicker planes
gamma catcher
active veto

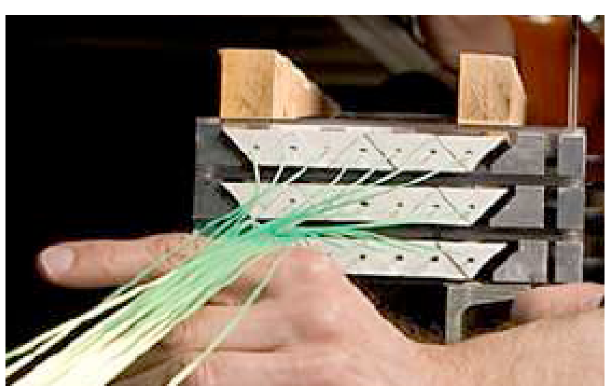


Minerva bar





Water bag in gasketed container



Scintillator Planes layout

Détecteur π^0: le P0D

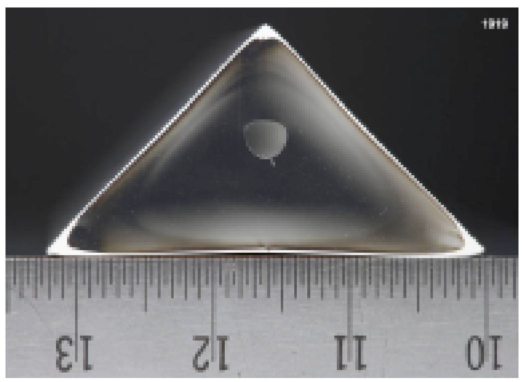
Pi0 detector(P0D) Target

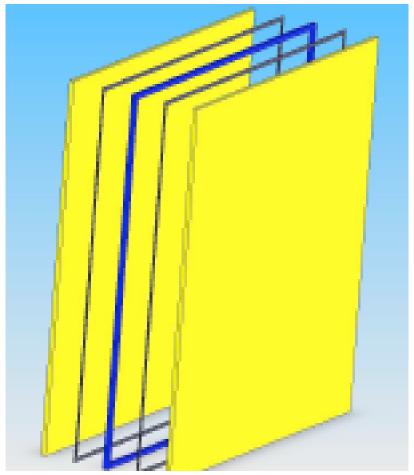
40 X-Y Pb/plastic planes
40% H_2O Passive
6t fiducial mass
10560 total channels

P0D Up/Central Calorimeters Modules

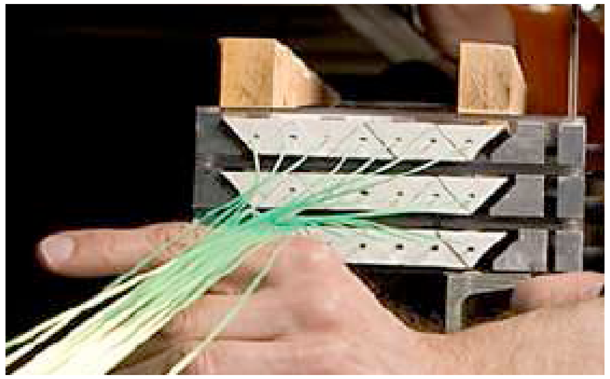
30 cm thick 5.7X0
X-Y Pb/plastic thicker planes
gamma catcher
active veto

Minerva bar

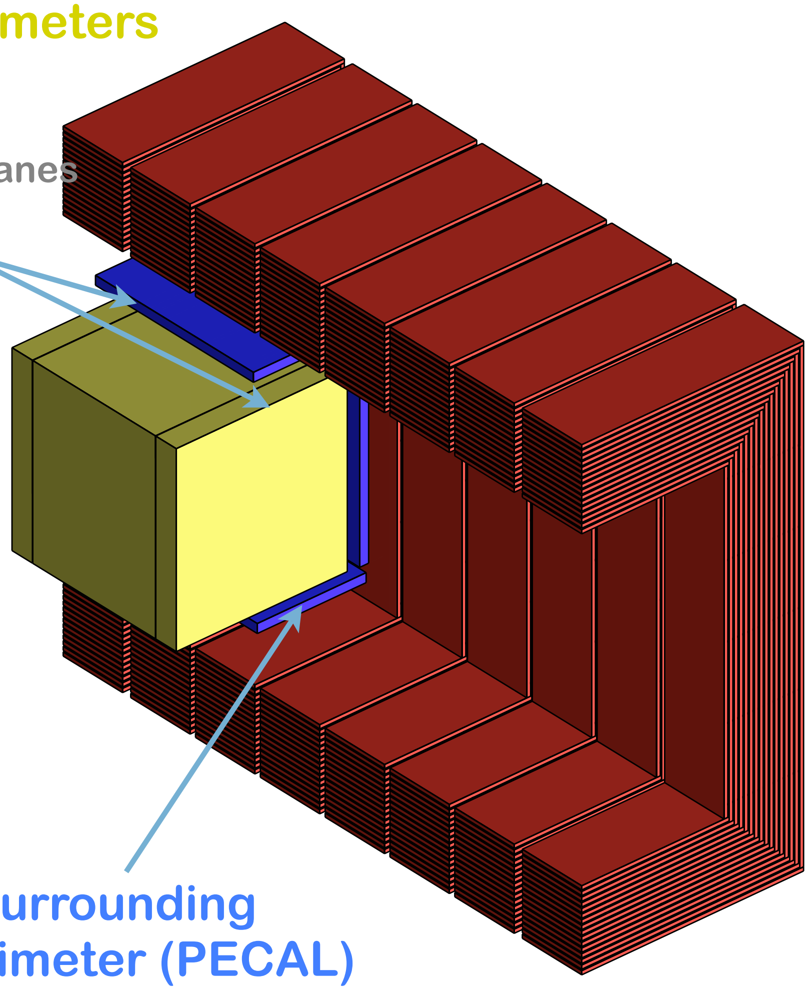




Water bag in gasketed container



Scintillator Planes layout

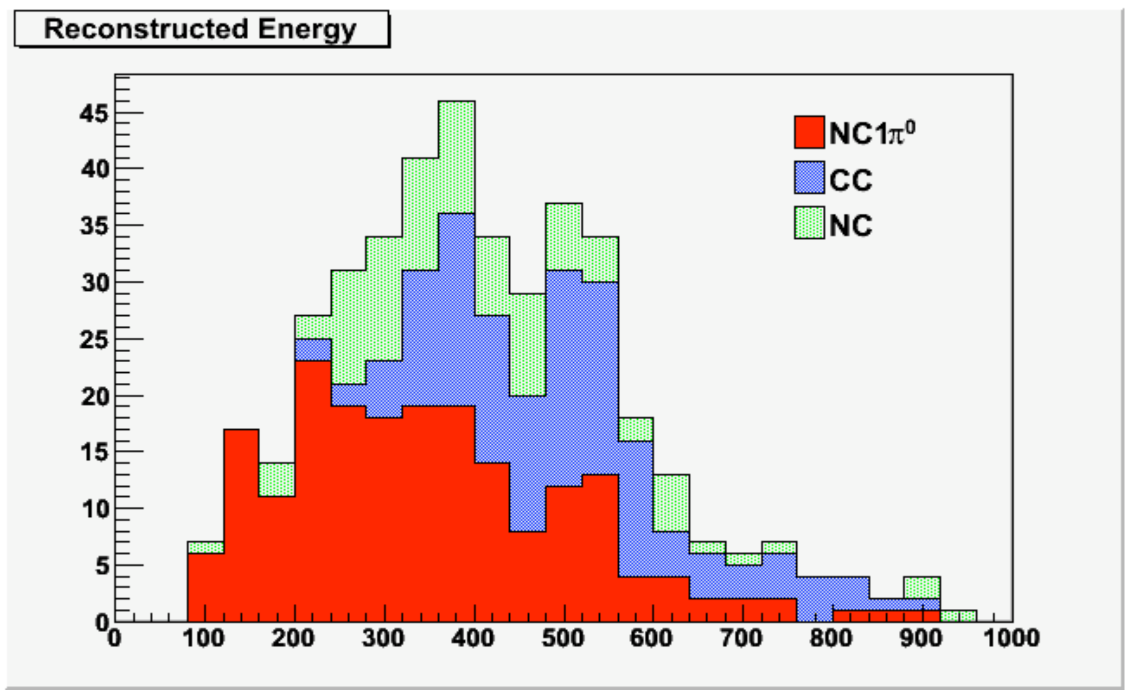


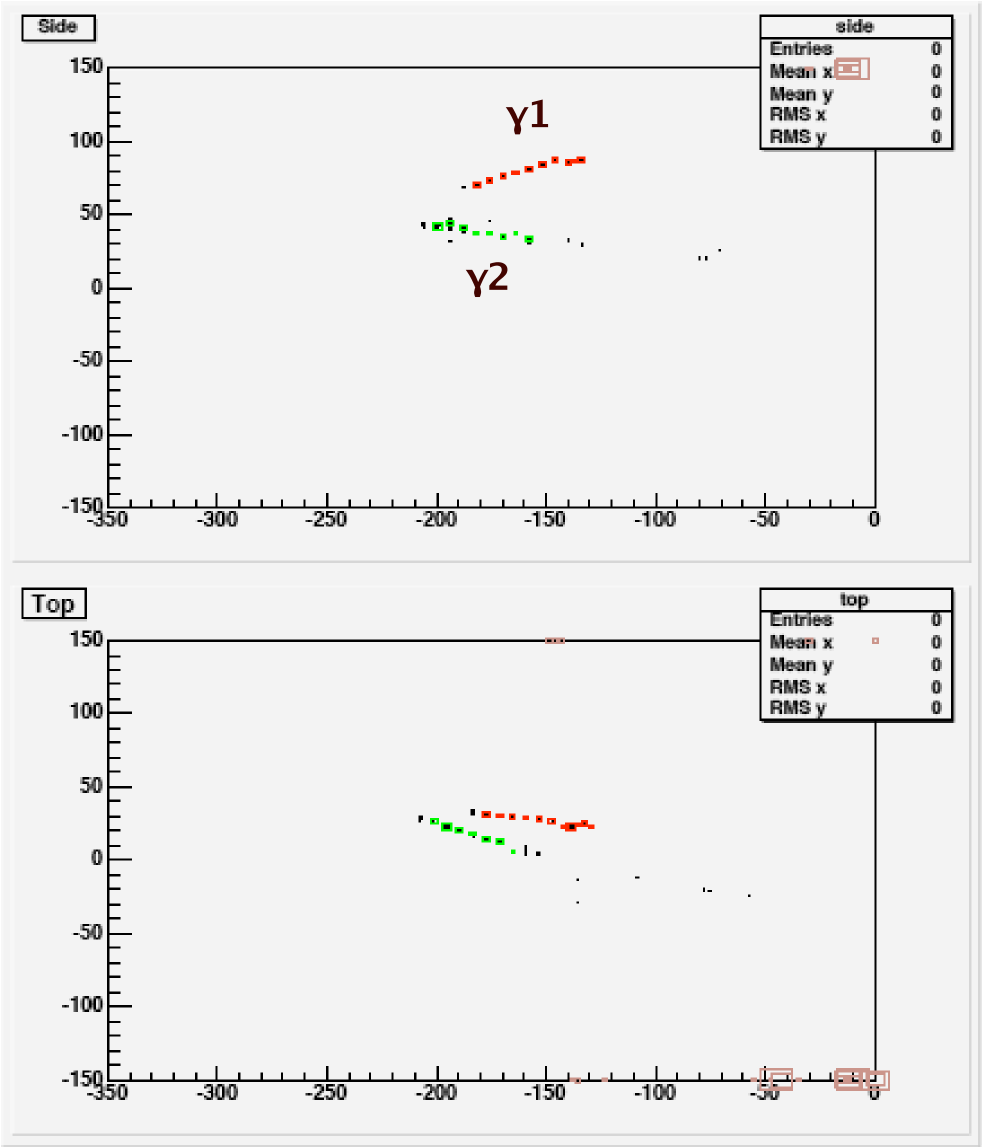
Surrounding Calorimeter (PECAL)

Coarse Pb/Plastic (4x1cm bar)
10cm thick ~5.0X0
γ catcher
MIP tagging
~2k Channels

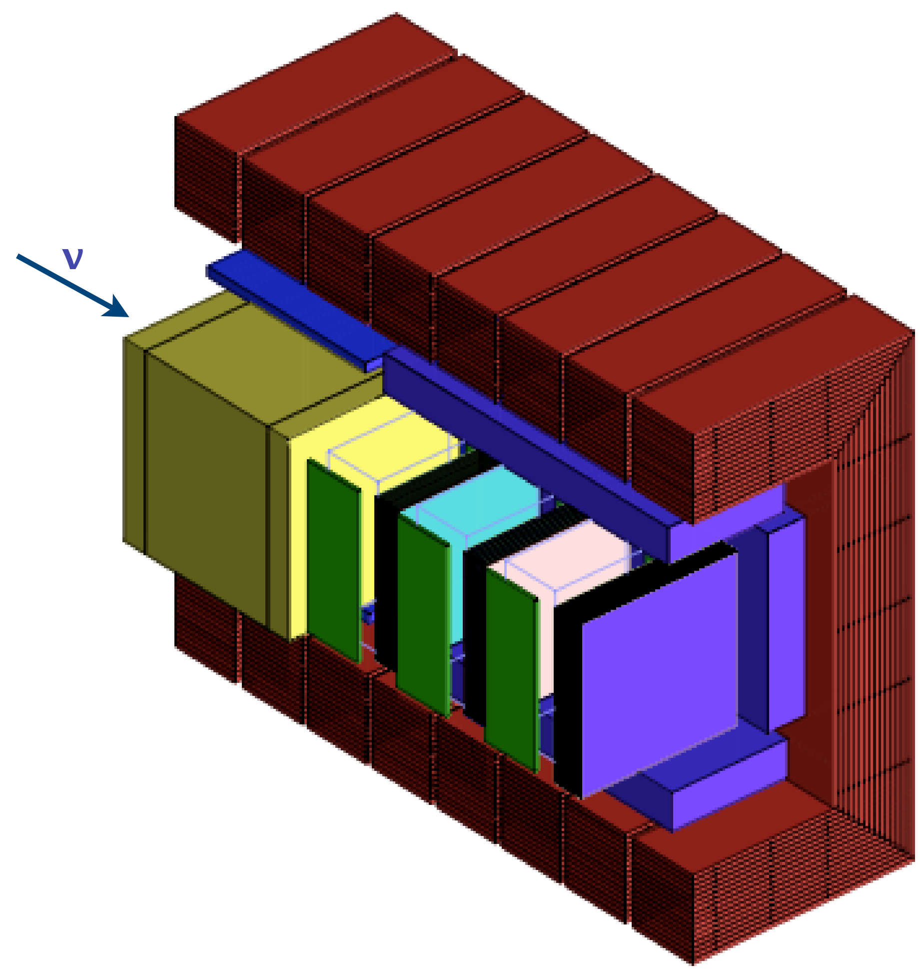
P0D : mesure de courant neutres

- Dedicated to appearance backgrounds
  - **$1.7x10^4$ NC-Res1π^0** events in H_20 target per year
  - **~6000 π^0 reconstructed**
  - **Water in/out** periods : C/H_20 differences
  - Inclusive NC/CC production
  - Beam ν_e





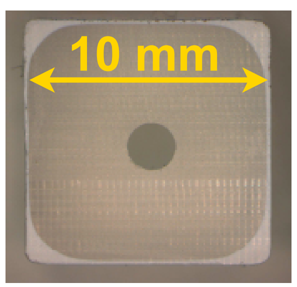
Détecteur région “tracker”

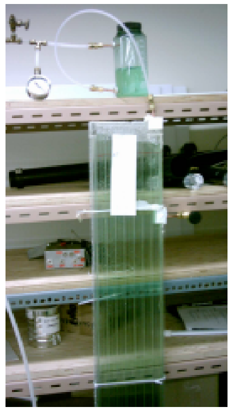


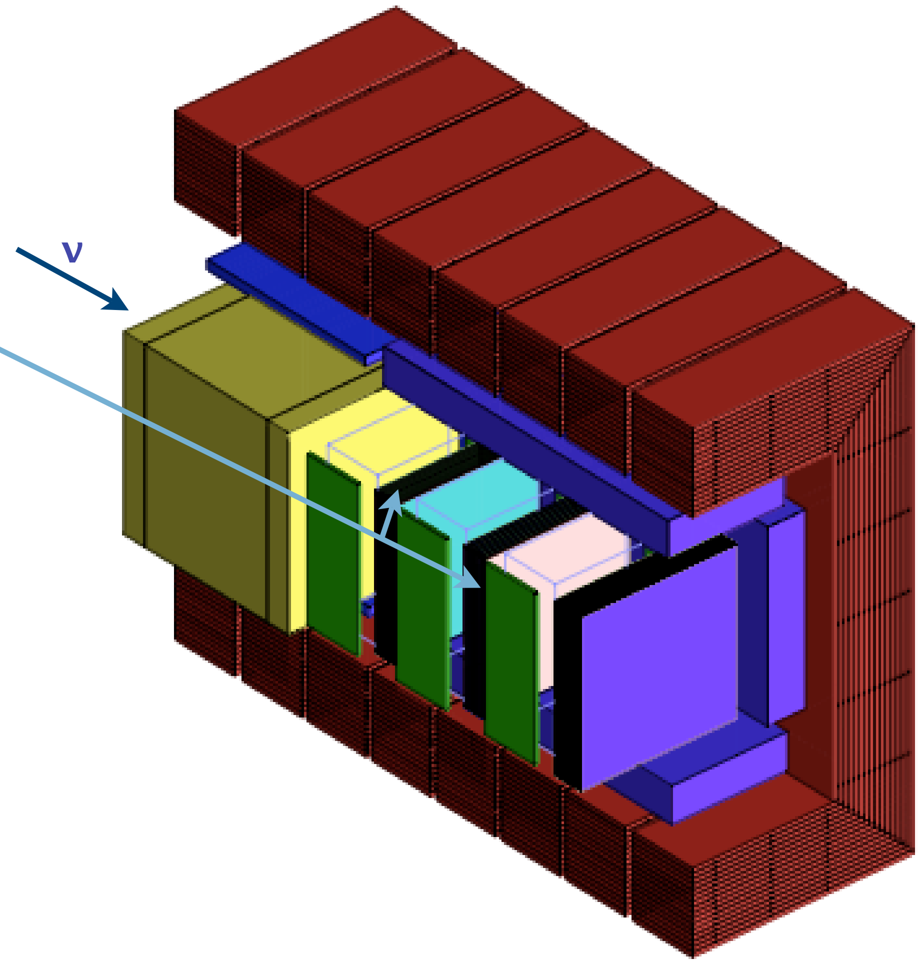
Détecteur région “tracker”

2 Fine Grained 2x1.3t target detectors (FGD)

FGD1(C): X-Y plastic
FGD2(H_2O): X-Y plastic
+passive water target
8k channels







Détecteur région "tracker"

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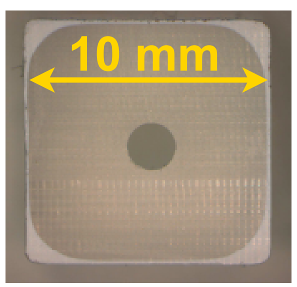
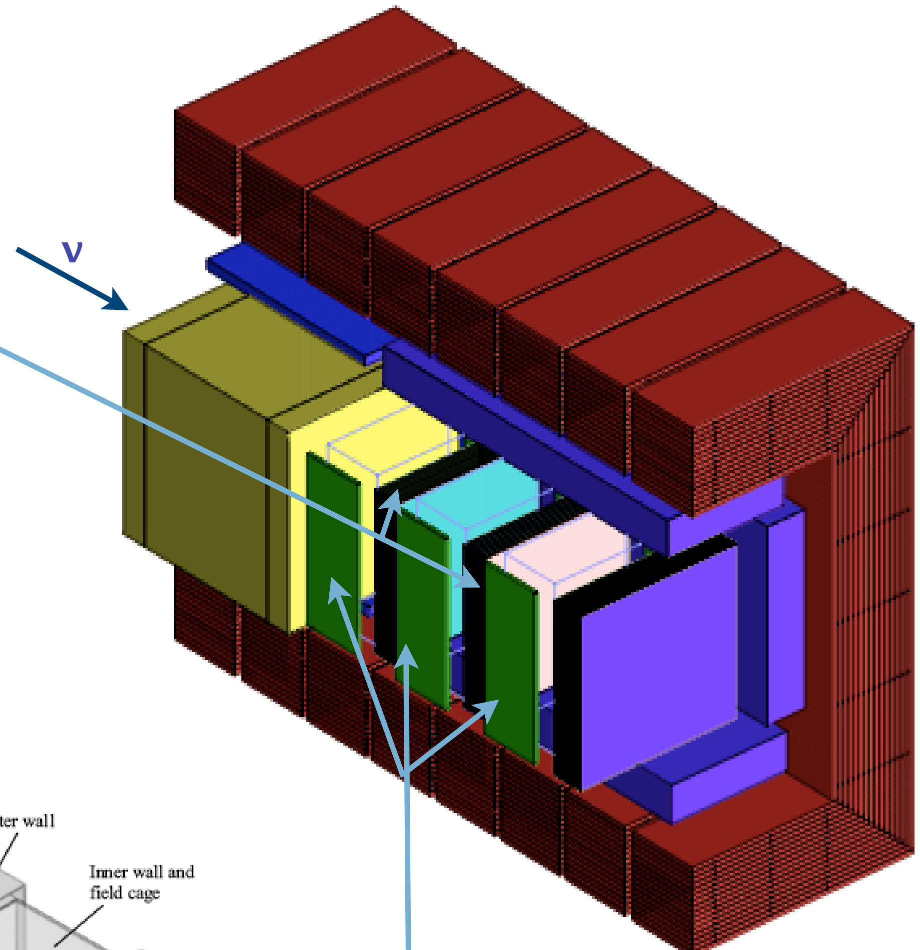
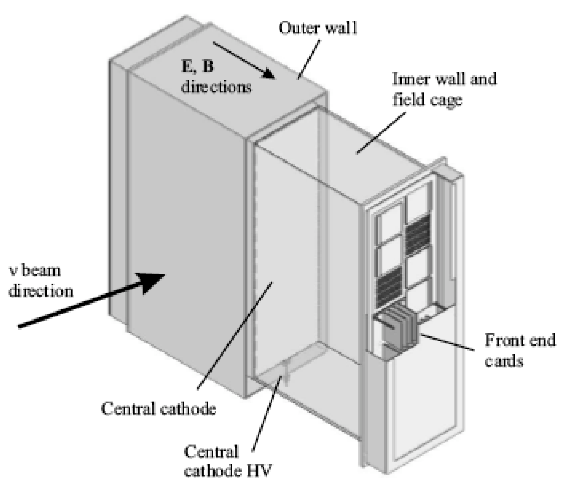




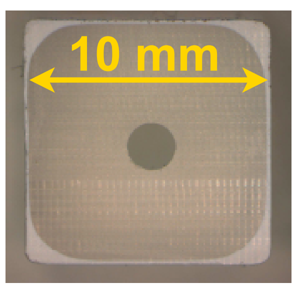


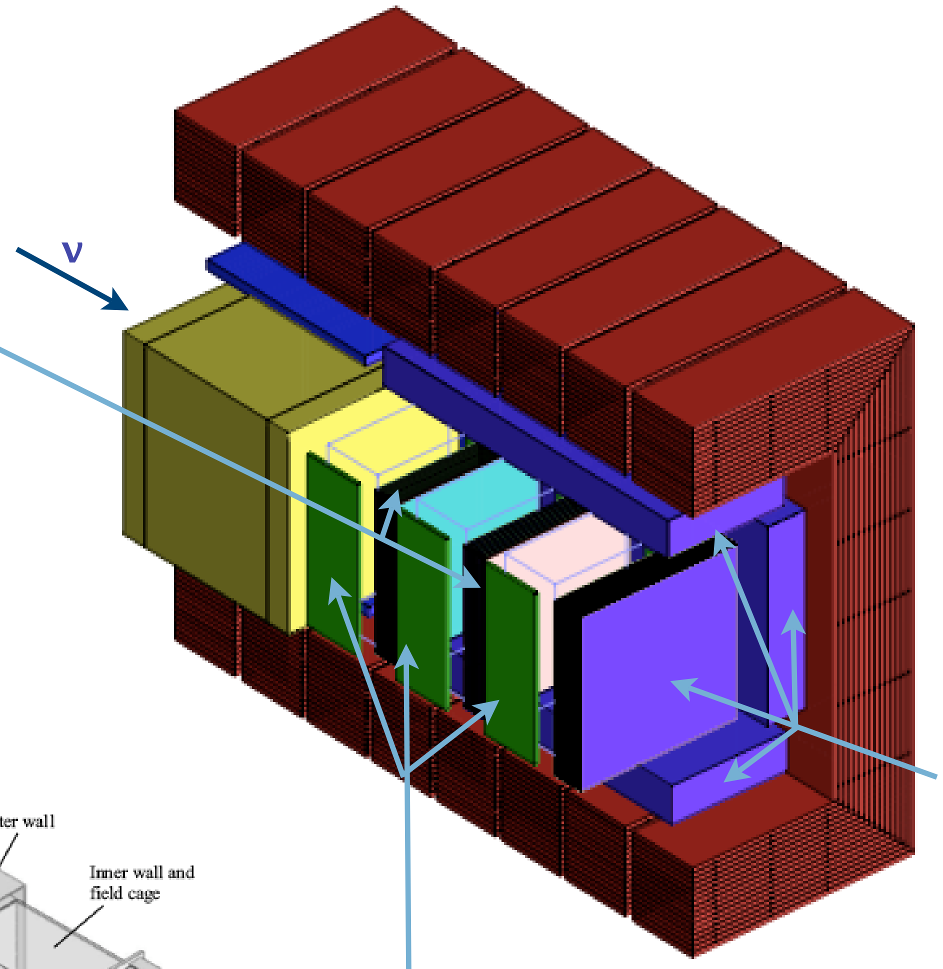
3 TPC modules

Micromegas modules
Position resolution < 0.8 mm
Mom resolution to 1GeV <7-8%

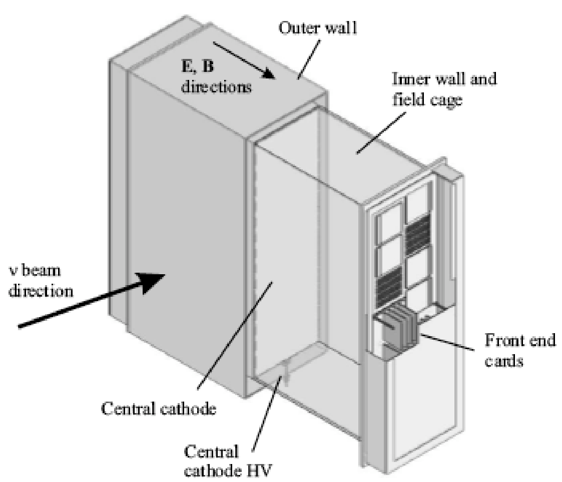
Détecteur région “tracker”

2 Fine Grained 2x1.3t target detectors (FGD)
FGD1(C): X-Y plastic
FGD2($H_2$0): X-Y plastic
+passive water target
8k channels





Tracker Calorimeter
X-Y fine grained Pb/Plastic
(4x1cm bar)
Eres ~7.5%/√E
20K channels



3 TPC modules
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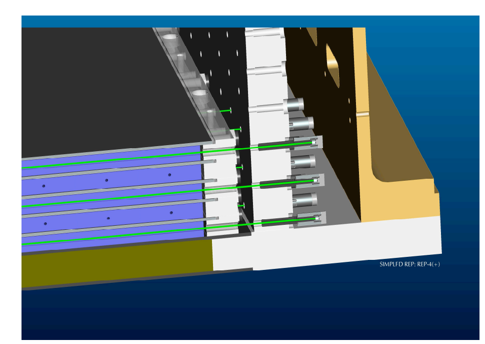
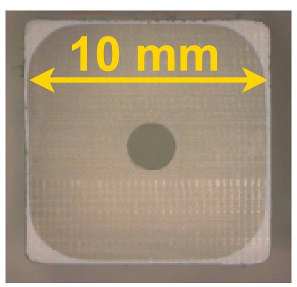
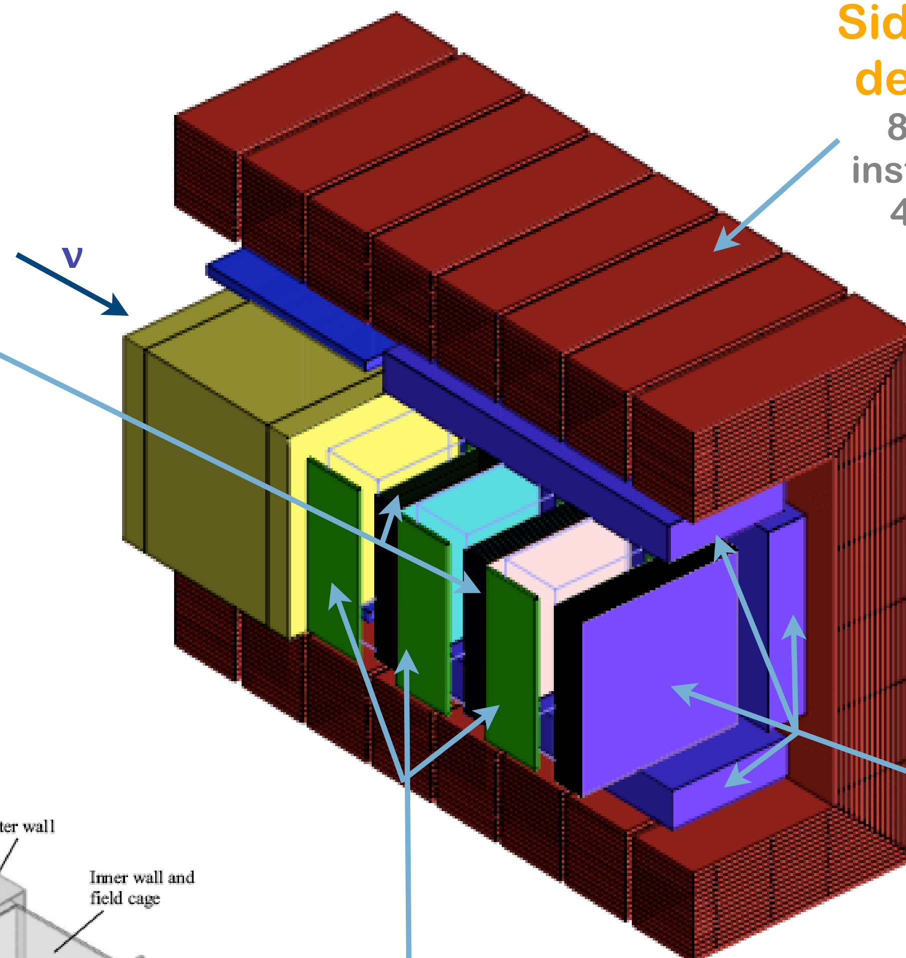


Détecteur région “tracker”

2 Fine Grained 2x1.3t target detectors (FGD)

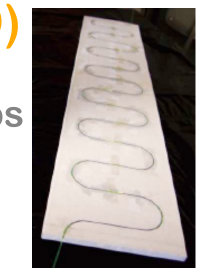
FGD1(C): X-Y plastic
FGD2(H_2O): X-Y plastic
+passive water target
8k channels

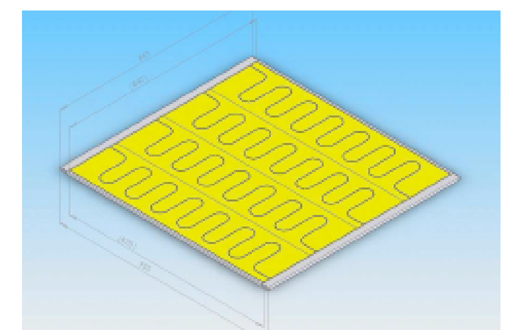




Side muon ranging detector (SMRD)

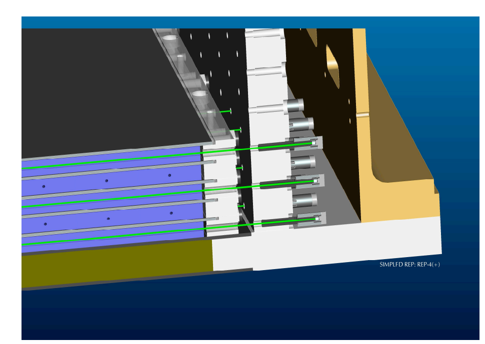
87x17x1cm planes
instrumenting air gaps
4 slabs per planes
μ ranging
active veto
cosmic trigger

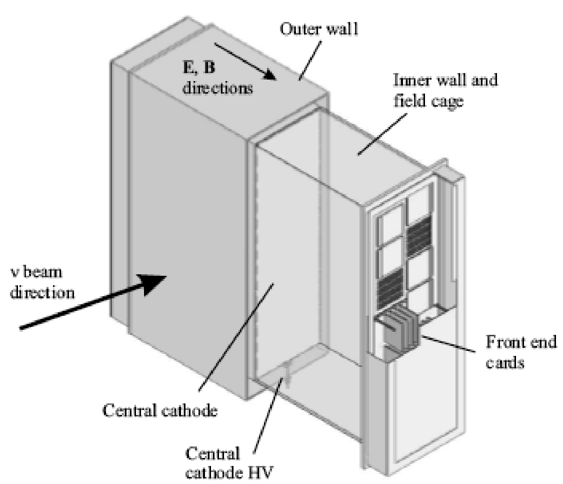




Tracker Calorimeter

X-Y fine grained Pb/Plastic
(4x1cm bar)
Eres ~7.5%/√E
20K channels





3 TPC modules

Micromegas modules
Position resolution < 0.8 mm
Mom resolution to 1GeV <7-8%

MPPC : nouveau détecteurs photons

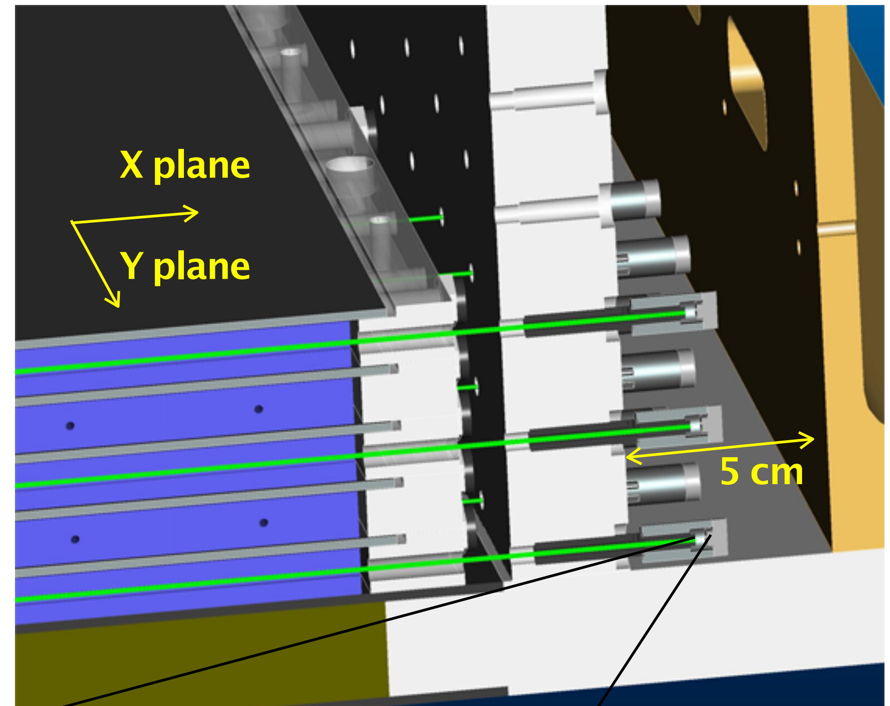
ND280 scintillator readout constraints :

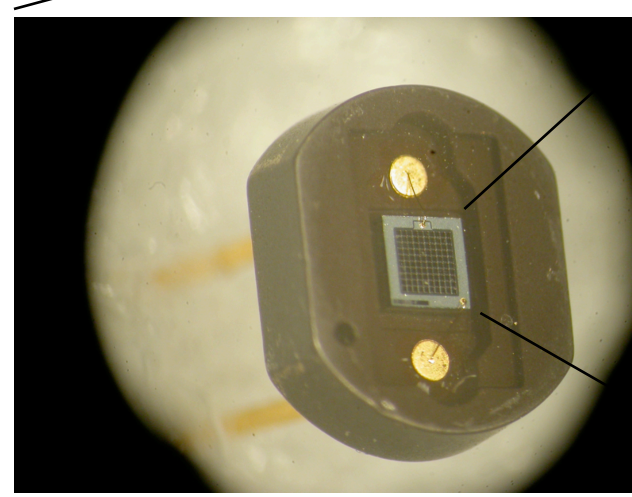
- Magnetic Field B= 0.2T (UA1 magnet)
- Very tight space constraints
- Low light yield at end of WLS fibre
- High number of channels (56k total)
- Detector operation 5 years

MPPC :

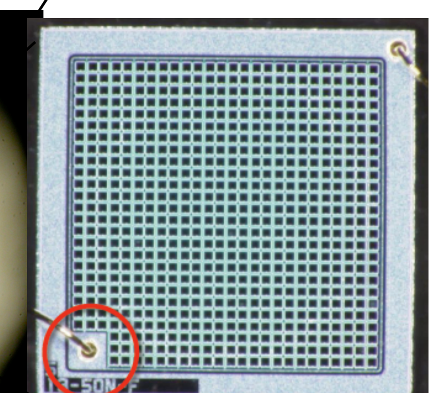
- Insensitive to magnetic field (tested to 4T)
- Combines photon counting with good dynamic range
- Photon detection efficiency ~20% at 500nm
- Small ceramic package
- Bias voltage 70V
- Gain G~ 5-7x10^5
- Low power consumption
- Dark count rate low ~0.5-0.7MHz/mm^2 at 25°C
- Longevity OK

Scintillator bar readout cut view (ECAL)



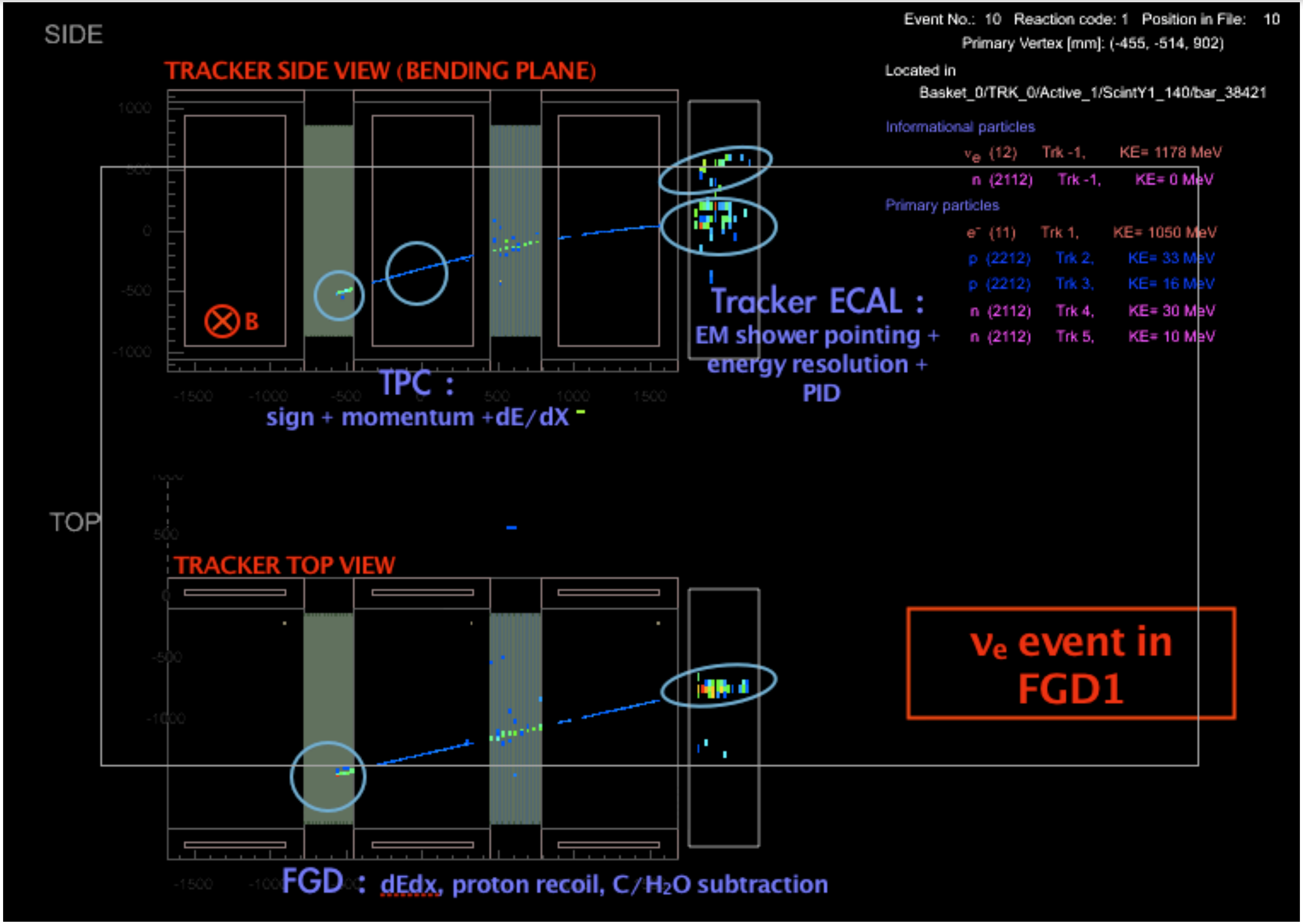


MPPC ceramic package



1.3 mm
50 µm pitch
667 pixels
(special T2K)

Reconstruction dans le ND280

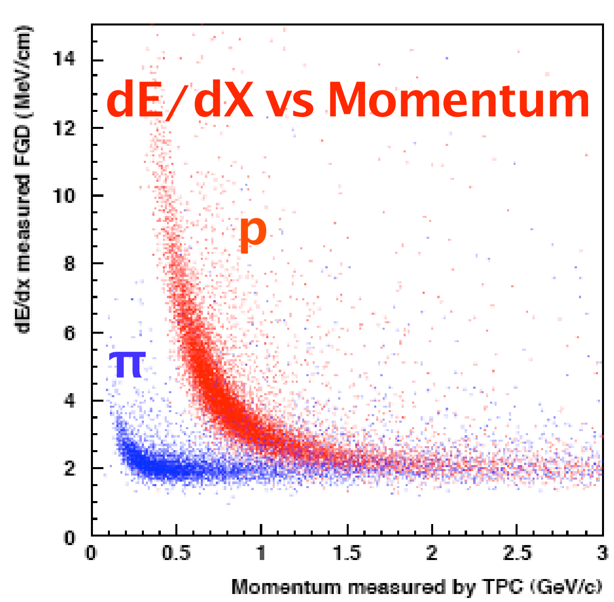


Performance tracker : FGD-TPC-ECAL

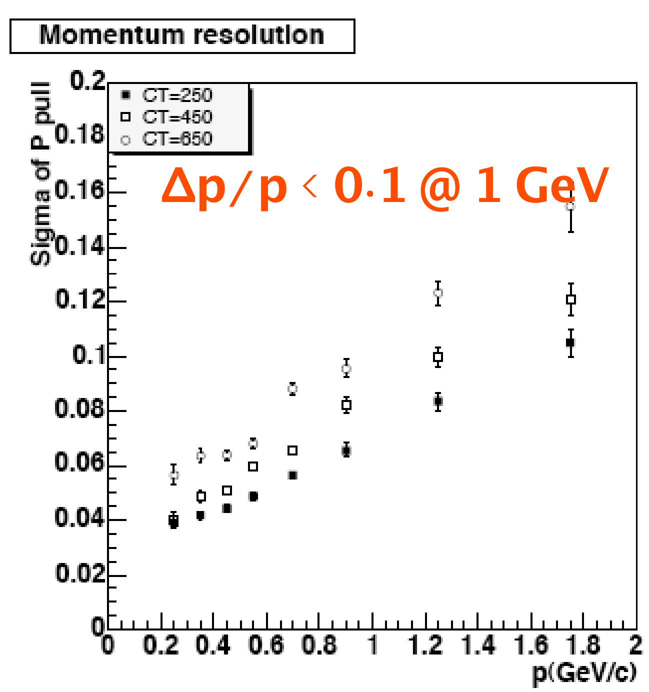
- ➡ Off-axis beam flux and energy spectrum measurement
  - Select pure QE events
- ➡ Background measurements (CC-$1\pi^+$, NC-$1\pi^0$)
  - Select/ reject CC-1π events
- ➡ Cross-section studies

	total	CCQE	CCQE eff.	CCQE purity
generated	5000	1767	1	0.3534
negative track in TPC	1971	1086	0.614	0.551
π^+ veto in TPC	1700	1084	0.613	0.638
π^+ veto in FGD	1577	1080	0.611	0.685
photon veto in Ecal	1303	1054	0.596	0.809
μ^- ID in Ecal	1270	1049	0.594	0.826

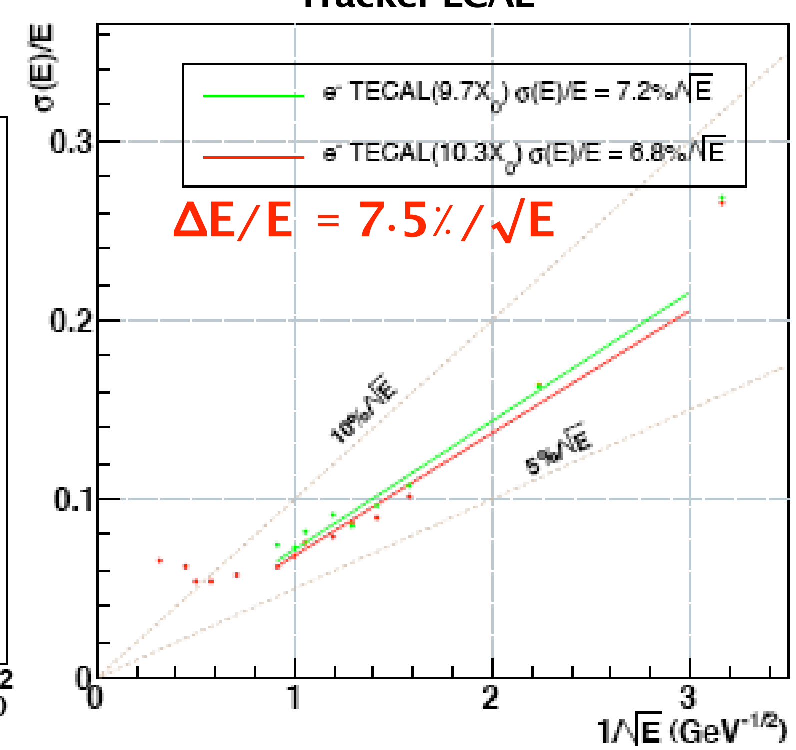
FGD



TPC

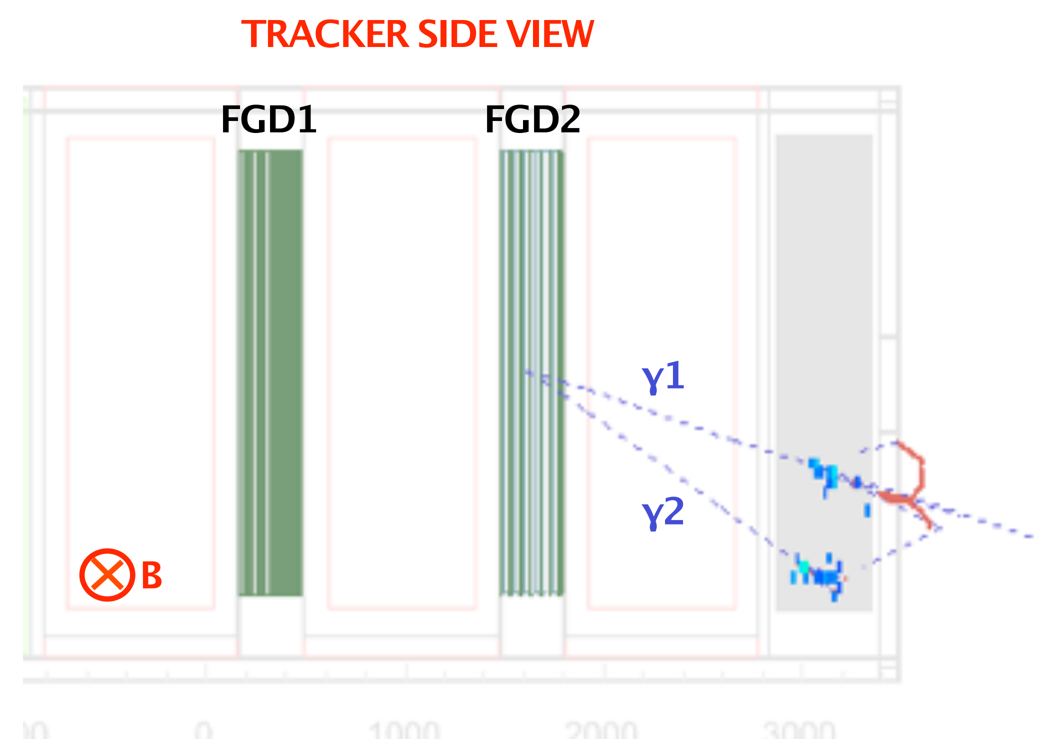


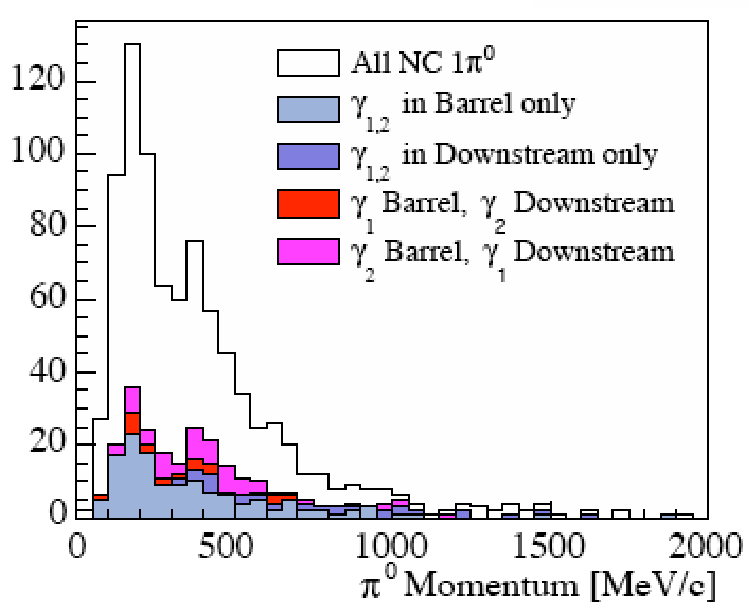
Tracker ECAL

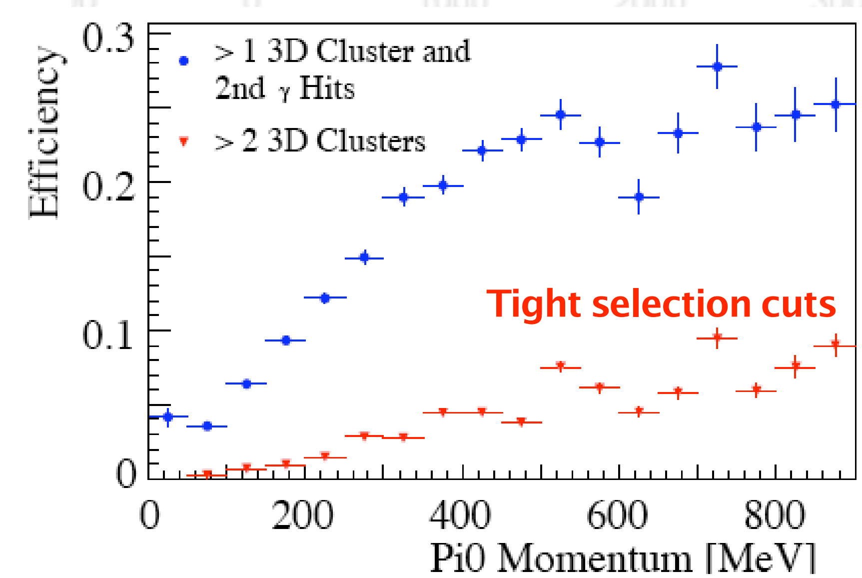


Mesures de courant neutres

- Exclusive NC-1π^0
- Statistically limited
  - ~ 800 NC-π^0 evts/year(10^{21} POT)
- use Tracker ECAL fine shower sampling and pointing capability to reconstruct π^0 decay







ND280 Construction

ND280 detector pit excavated

UA1 magnet yokes at J-PARC

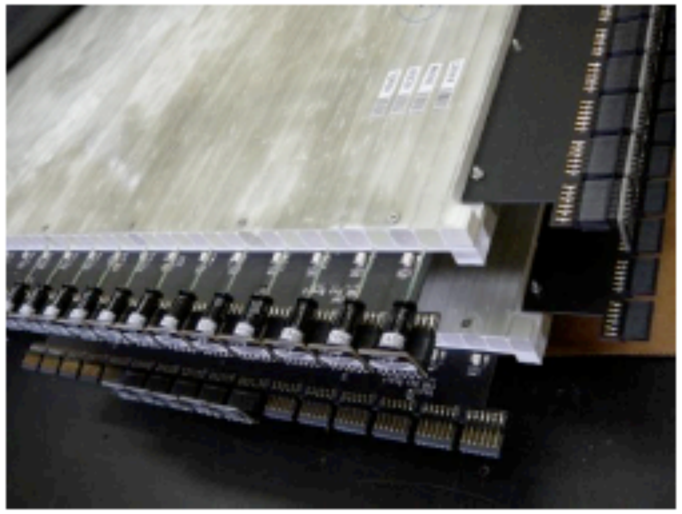
Magnet carriage installation

Carriages in the ND280 pit

- ND280 detecter pit excavated
- UA1 magnet from CERN arrived at J-PARC in March

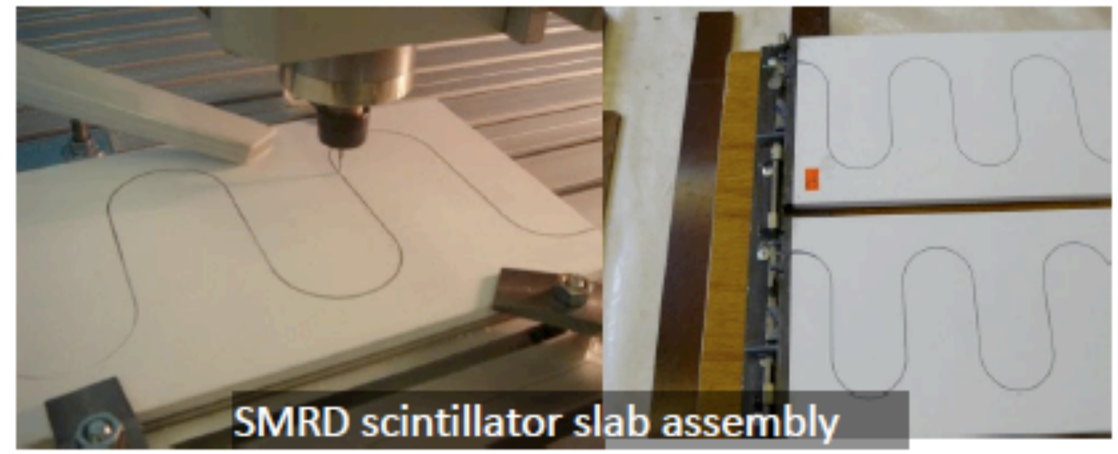
- Magnet carriage installed in the pit in April
- Yoke reassembly complete
- Magnet assembly and installation in progress, to be completed by June

Construction détecteurs

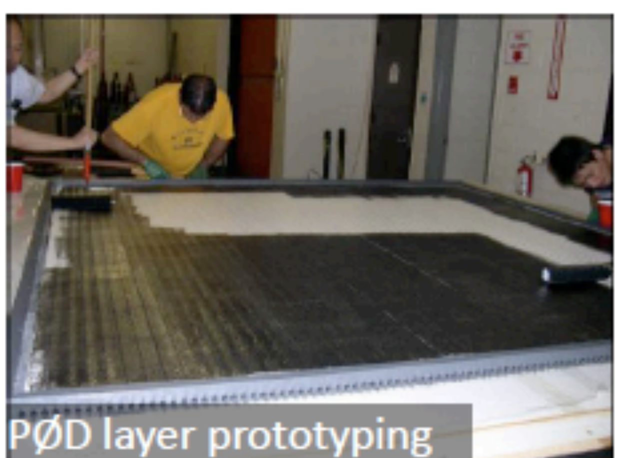


FGD:
Assembly in progress
1st module expected to be complete by July 2008

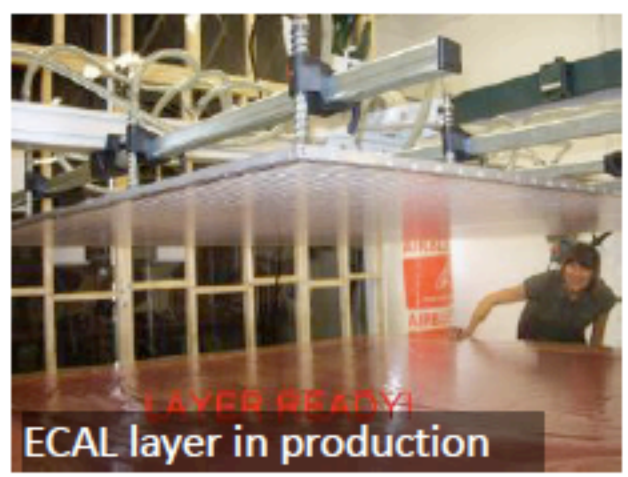
TPC: box construction



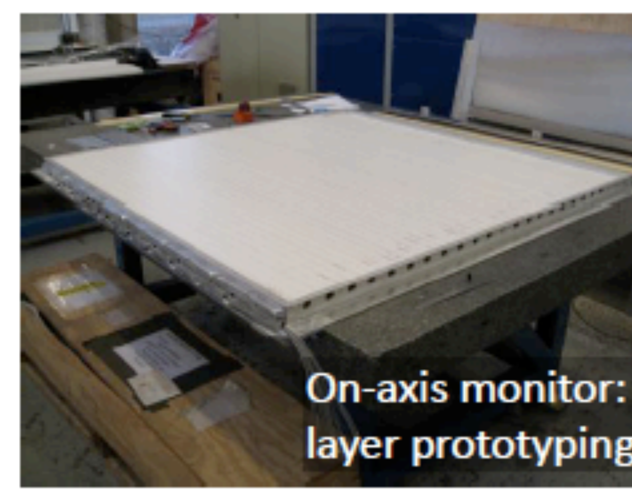
SMRD:
Scintillator slabs being assembled
50% by Oct.2008, the rest by Mar.2009



PØD:
preparing for production
Expect to complete by Jan. 2009

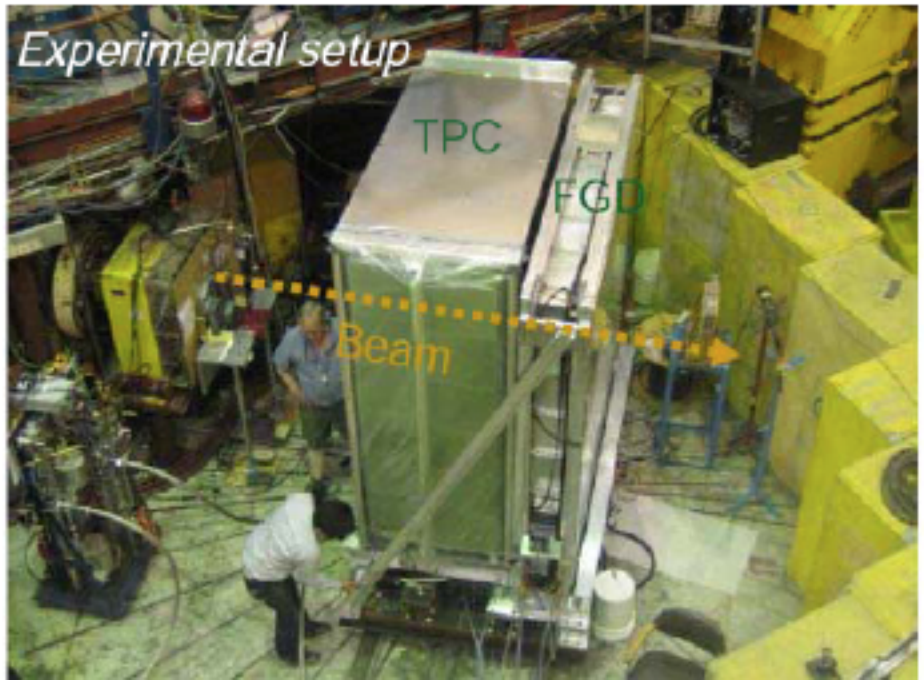


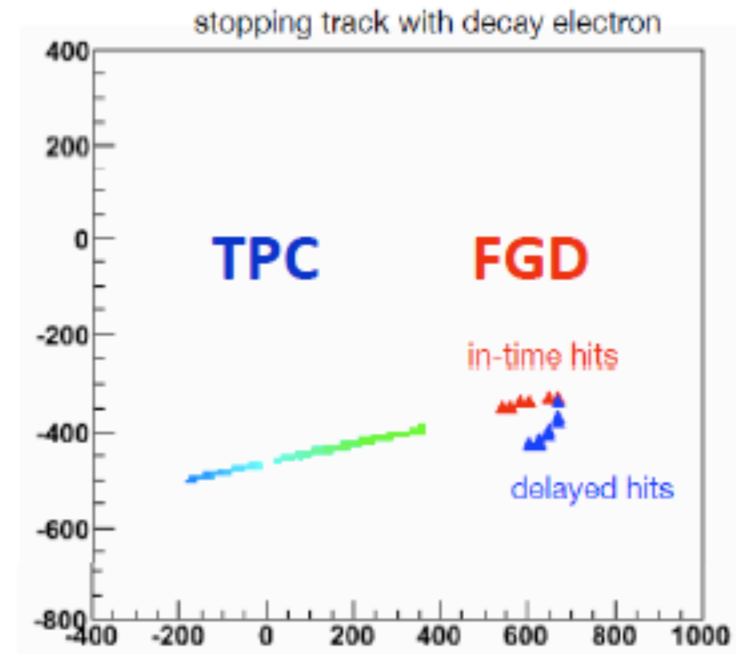
Downstream ECAL:
to be completed by Nov. 2008



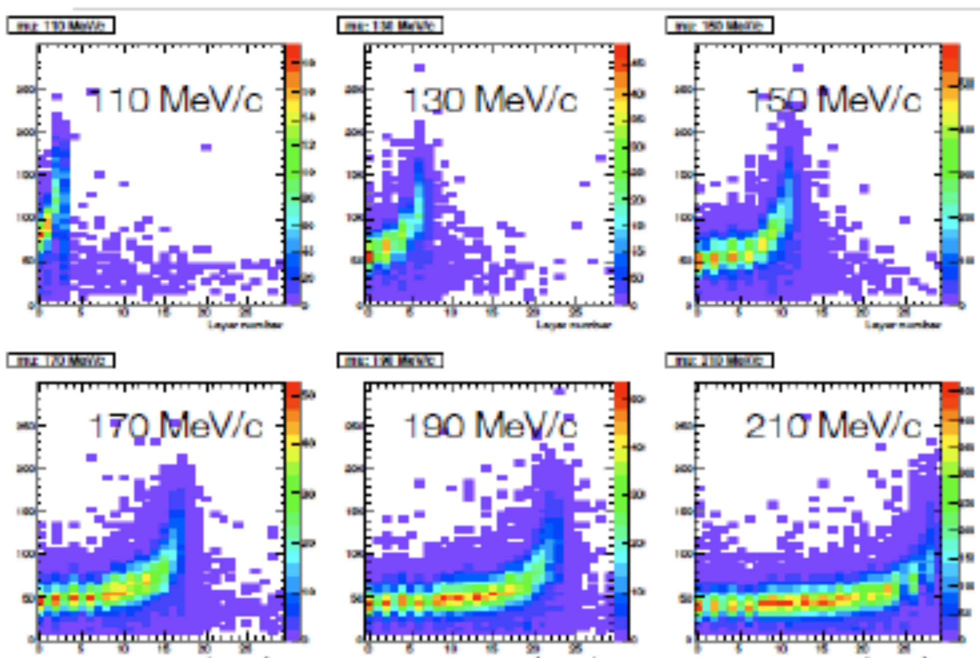
On-axis ν monitor:
Start assembly in this summer

Premiers tests FGD-TPC à TRIUMF

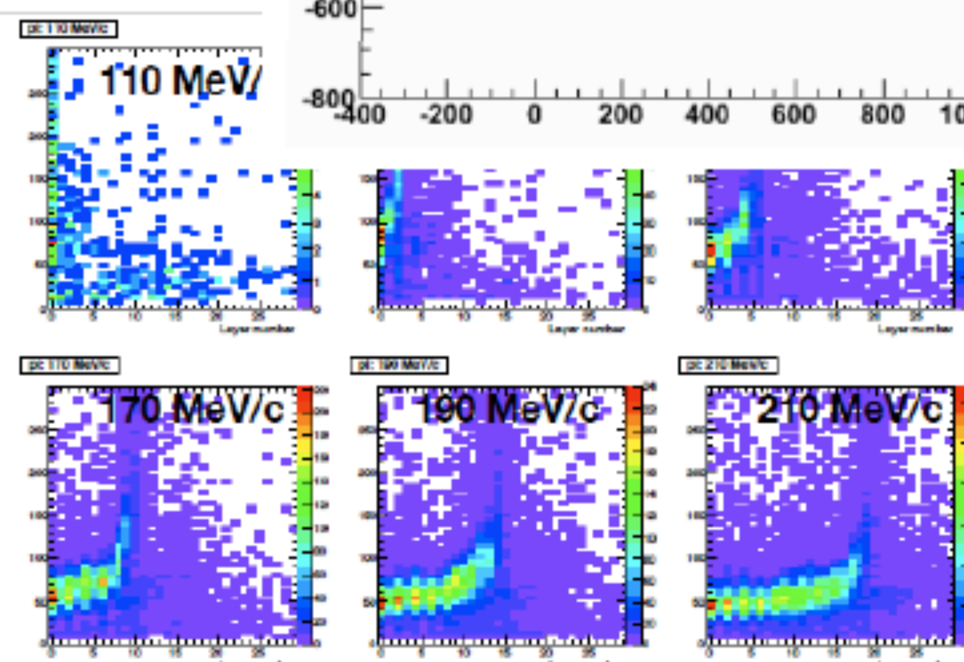




Muon and Pion energy deposit vs



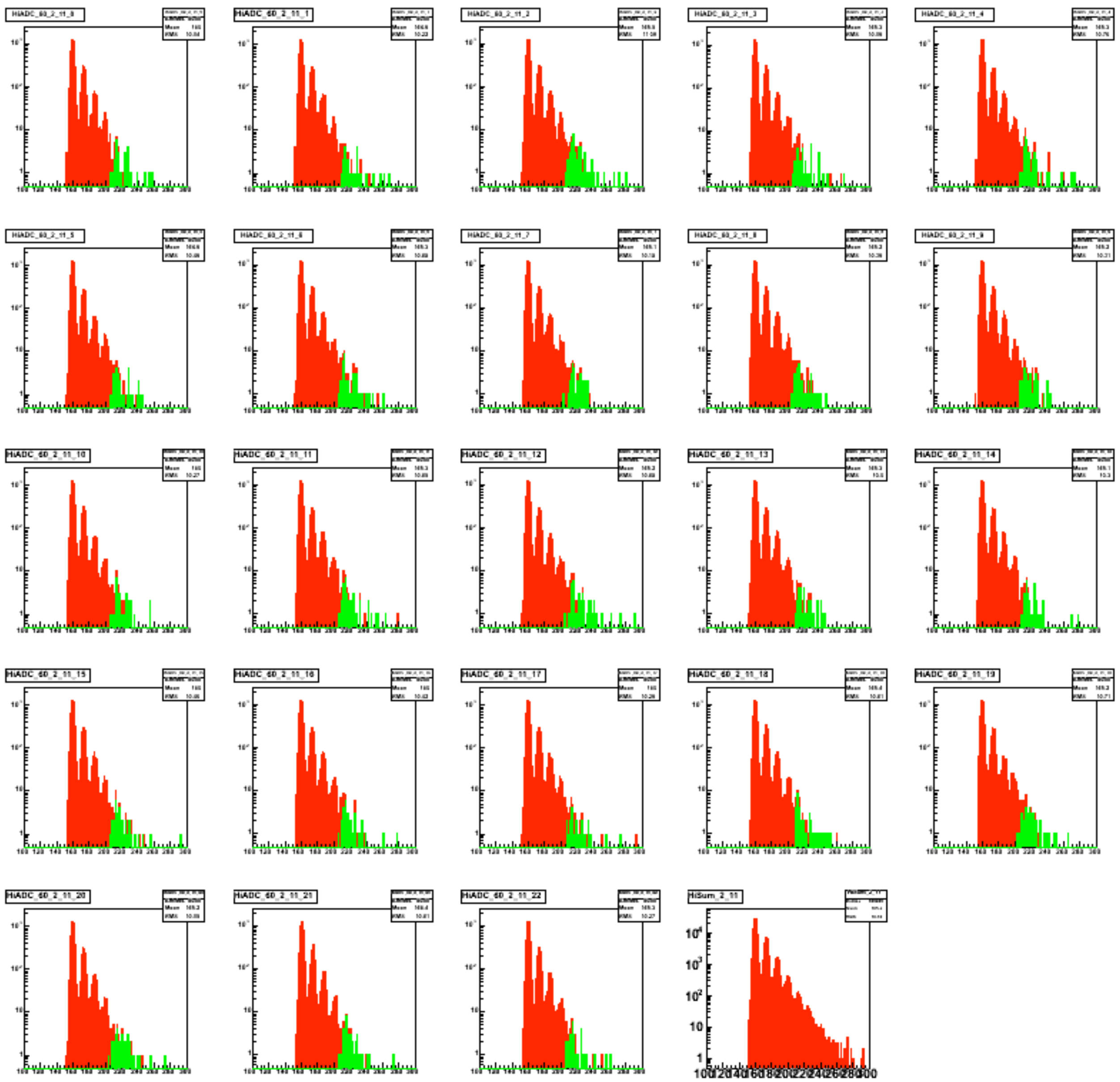
Muon

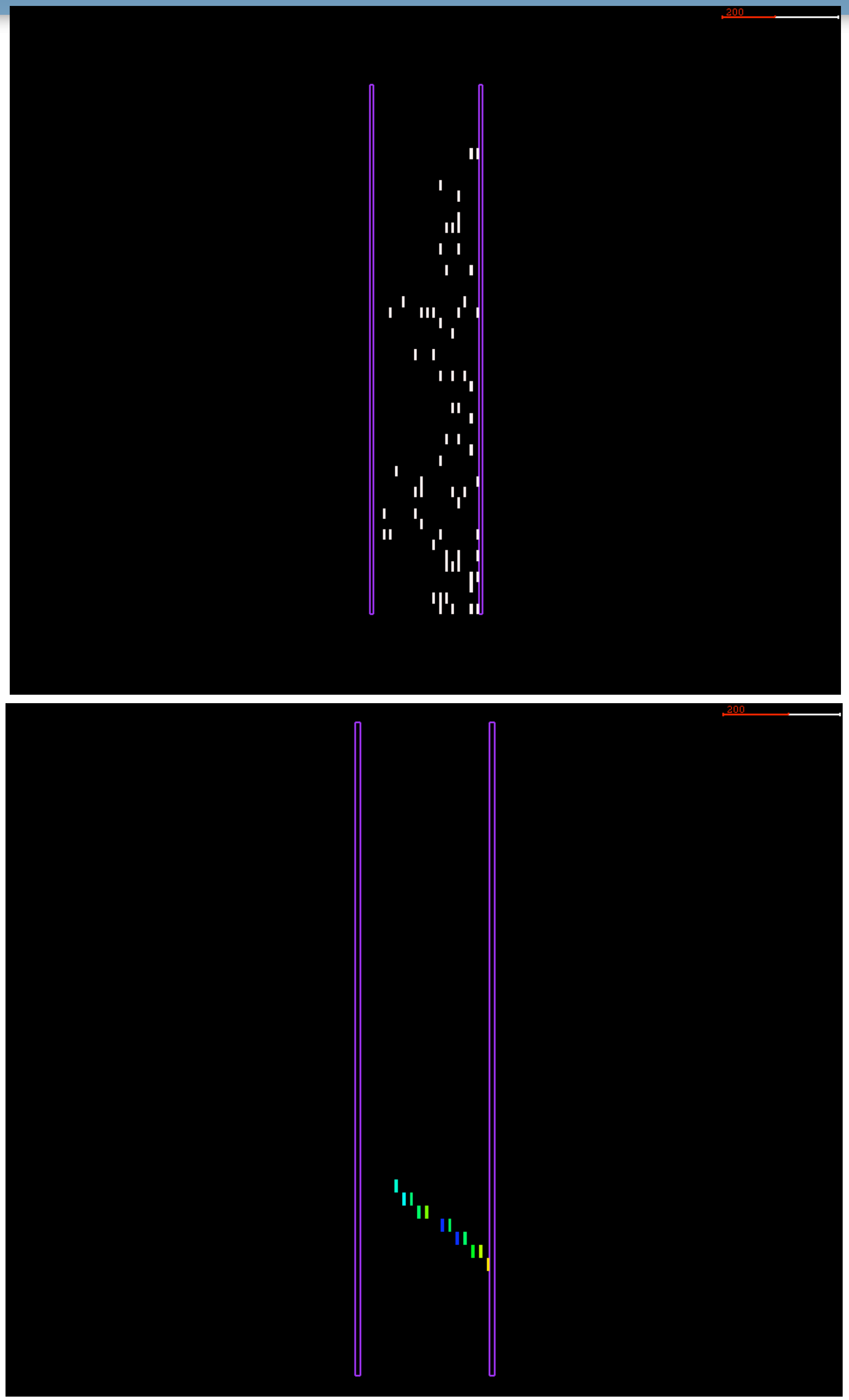


Pion

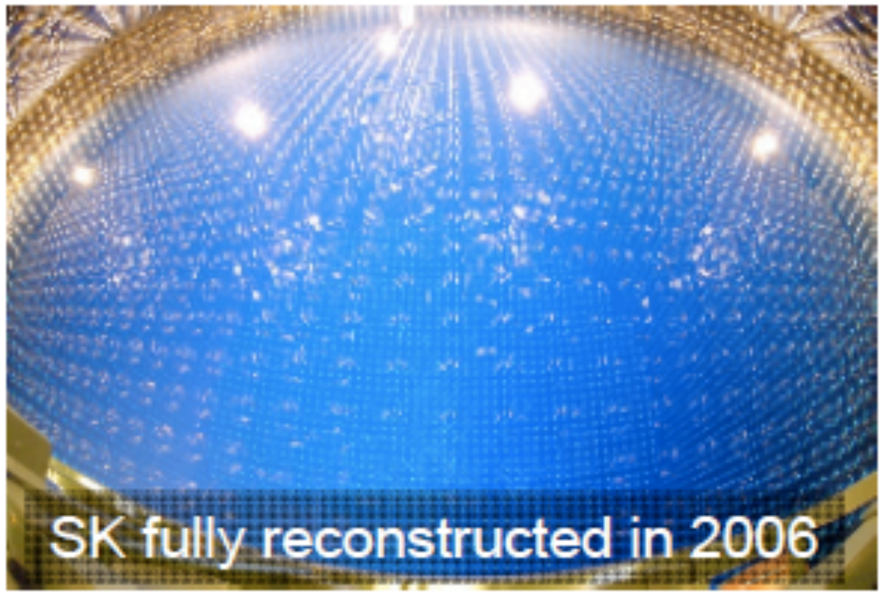
ECAL Premier événement muon !

19 février 2009



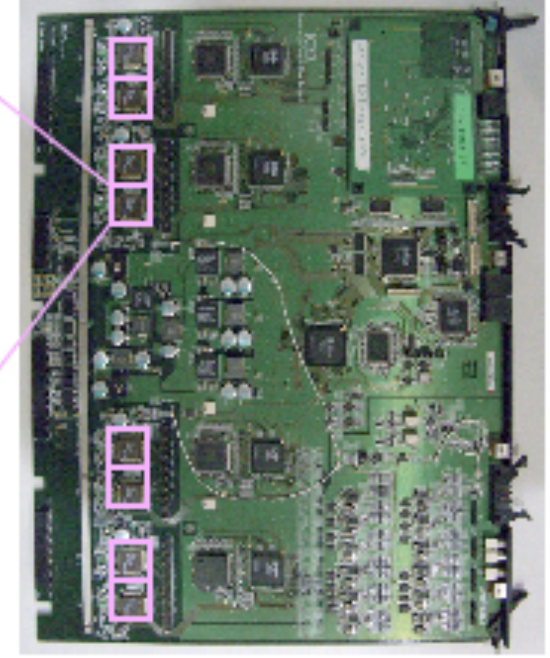


Super Kamiokande IV



Custom ASIC QTC
3ch x 3 gains

QBEE board:
QTC-based electronics w/ ethernet



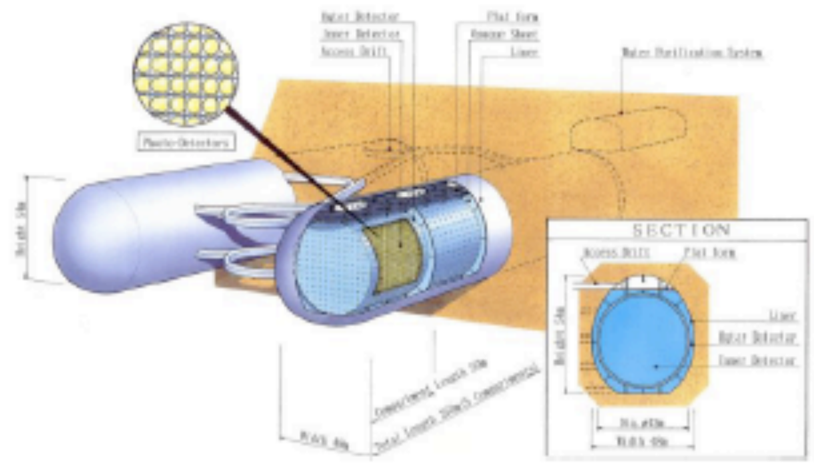
- SK fully reconstructed in 2006, 'SK-III' taking data
- Electronics & online DAQ full-upgrade in preparation
  - for high-speed & dead-time-less DAQ, for wider dynamic range
  - electronics (QTC and QBEE) development and production done, being delivered
  - installation in Aug./Sep. 2008
  - will start 'SK-IV' data taking in fall 2008

T2K deuxième phase

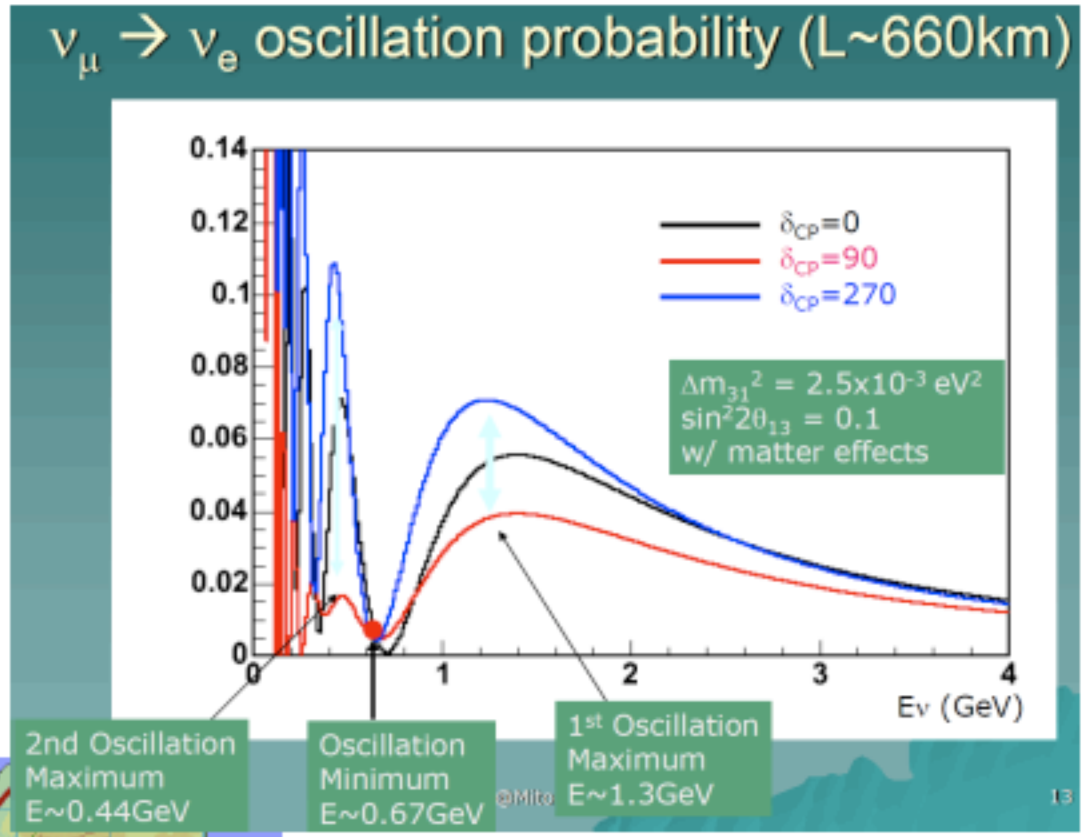
If $\sin^2 2\theta_{13}$ measured at T2K-I ≥ 0.01,

→ ν CP violation measurement possibilities:

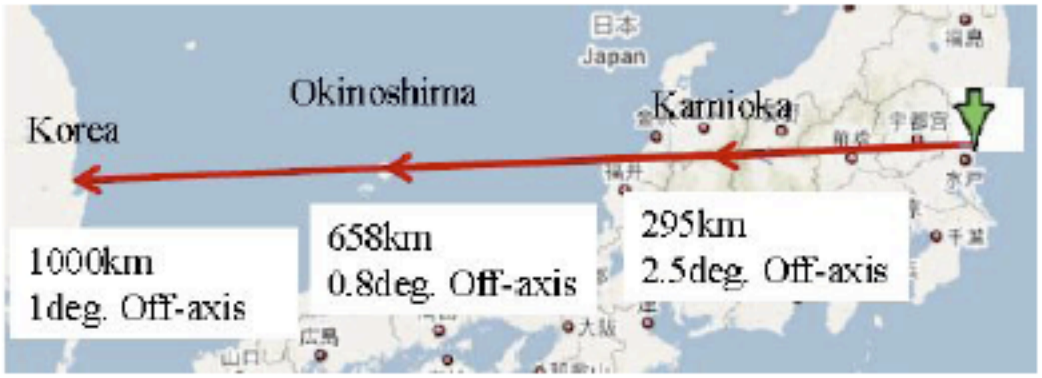
J-PARC upgrade: → *~1.7 MW*

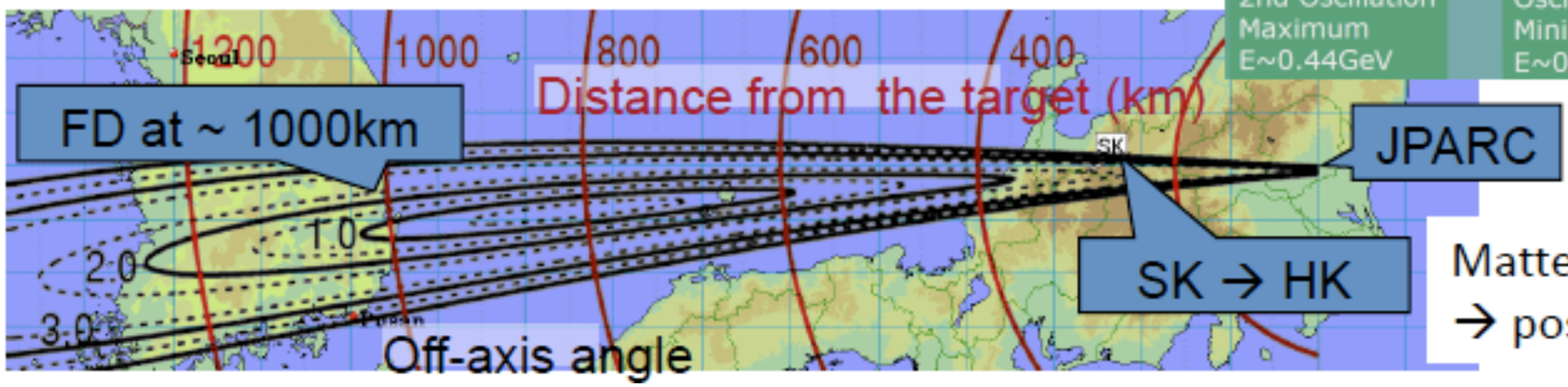


1. SK (*50kt*) → Hyper Kamiokande (HK): *~1Mt; L= 295 km*
2. ***100kton*** liquid Ar detector at ***L= 660 km***
3. ~***1 Mt*** detector at ***L= ~1000 km***



Comparison between ν_μ and anti-ν_μ beam and/or very good ΔE/E and high ν flux to measure 1st and 2nd oscillation maxima

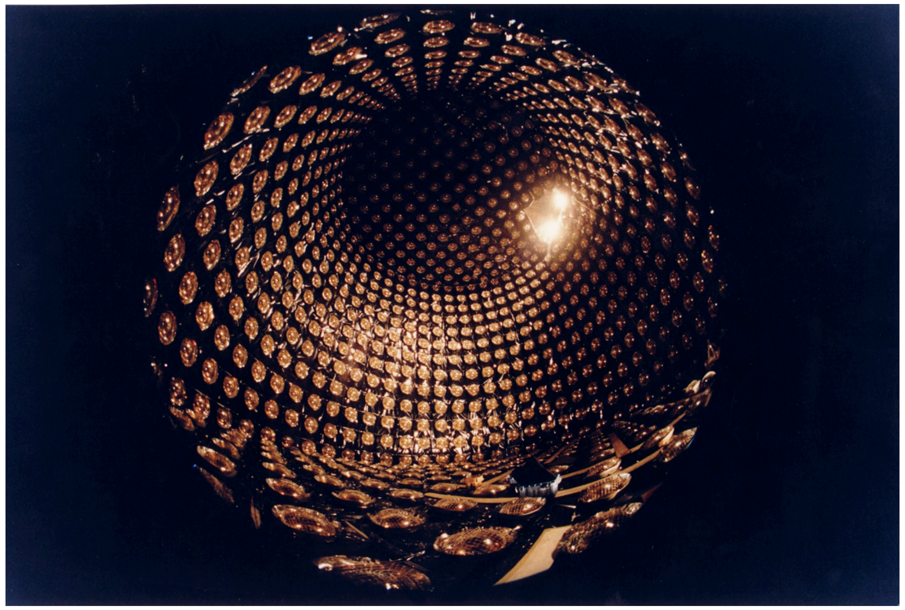




Matter effect becomes significant

→ possibility to resolve mass hierarchy

Conclusion



- The T2K experiment will
  - intensively search for ν_e appearance
    - $\sin^2 2\theta_{13}$ down to ~0.008 (90%C.L.)
  - precisely measure ν_μ disappearance
    - $\delta(\sin^2 2\theta_{23}) \sim 0.01$, $\delta(\Delta m^2_{23}) < 10^{-4}$ eV^2

    after 0.75kW x 5yr accumulation
- J-PARC accelerator is now being commissioned
  - LINAC and 3 GeV RCS successfully commissioned
  - Main Ring commissioning started, succeeded to turn beam in MR
  - On schedule
- Construction / preparation / installation works for neutrino beam line are in progress
- ND280 detector aims to address
  - energy spectrum, backgrounds, neutrino interactions
- Detector construction are also in progress

Aujourd'hui ! premier résultats officiels de MINOS sur la recherche d'oscillation sous-dominante

- FERMILAB : video stream