Detectors for future neutrino facilities

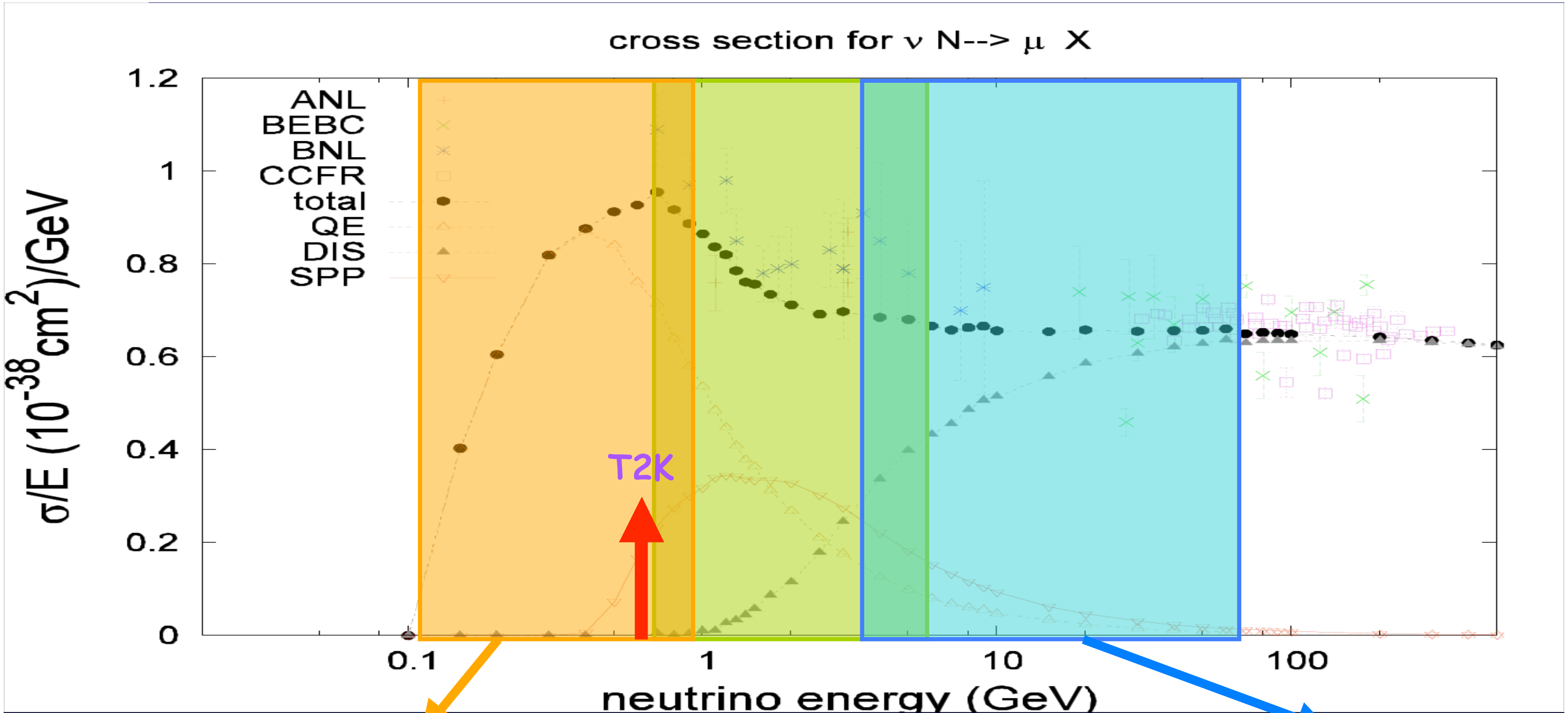
Missions of ISS study:

"--Evaluate the options for the neutrino detection systems
"Provide a research-and-development program

Funding request for four years of detector R&D "2008-2011" (In Europe: DEvDET)

- IDS--> Neutrino factory detectors (Magnetized)
- NNN--> non magnetic detectors (Larg, Water Cherenkov)

The nice thing with neutrino beams is that one can have more than one detector on the same beam line!



Low energy region:
QE dominates νN-> e/mu N'

Low energy super beam
(T2K, T2HK, T2KK, Frejus)
Low energy beta-beam
(CERN baseline scenario)

WATER CHERENKOV (Mton)

Mid-energy region:
QE+ 1π + nπ

Super beam
(Numi off, T2KK, CNGS+)
high Energy beta-beam
(CERN highQ or SPS+)

WATER CHERENKOV (Mton)
TASD (NOvA), LArg TPC

High-energy region:
DIS

Neutrino Factory

Magnetized Iron
Emulsion

large magnet around:
emulsion, TASD, Larg

DETECTORS

Superbeam & beta-beam:
Non-MAGNETIC

Beta beam ^{18}Ne: $\nu_e \rightarrow \nu_\mu$	T violation	Superbeam π^+: $\nu_\mu \rightarrow \nu_e$
CP violation	CPT	CP violation
Beta beam ^{6}He: $\bar{\nu}_e \rightarrow \bar{\nu}_\mu$	T violation	Superbeam π^+: $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$

Nu-Fact: MAGNETIC

$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$	$\mu^- \rightarrow e^- \nu_\mu \bar{\nu}_e$	reaction	
$\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$	$\nu_\mu \rightarrow \nu_\mu$	CC	Disappearance
$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	$\nu_\mu \rightarrow \nu_e$	CC	Appearance ('platinum' channel)
$\bar{\nu}_\mu \rightarrow \bar{\nu}_\tau$	$\nu_\mu \rightarrow \nu_\tau$	CC	Appearance (atmospheric oscillation)
$\nu_e \rightarrow \nu_e$	$\bar{\nu}_e \rightarrow \bar{\nu}_e$	CC	Disappearance
$\nu_e \rightarrow \nu_\mu$	$\bar{\nu}_e \rightarrow \bar{\nu}_\mu$	CC	Appearance: 'golden' channel
$\nu_e \rightarrow \nu_\tau$	$\bar{\nu}_e \rightarrow \bar{\nu}_\tau$	CC	Appearance: 'silver' channel
$\nu \rightarrow \nu_s$	$\bar{\nu} \rightarrow \nu_s$	NC	Global disappearance, sterile neutrinos

Water Cerenkov

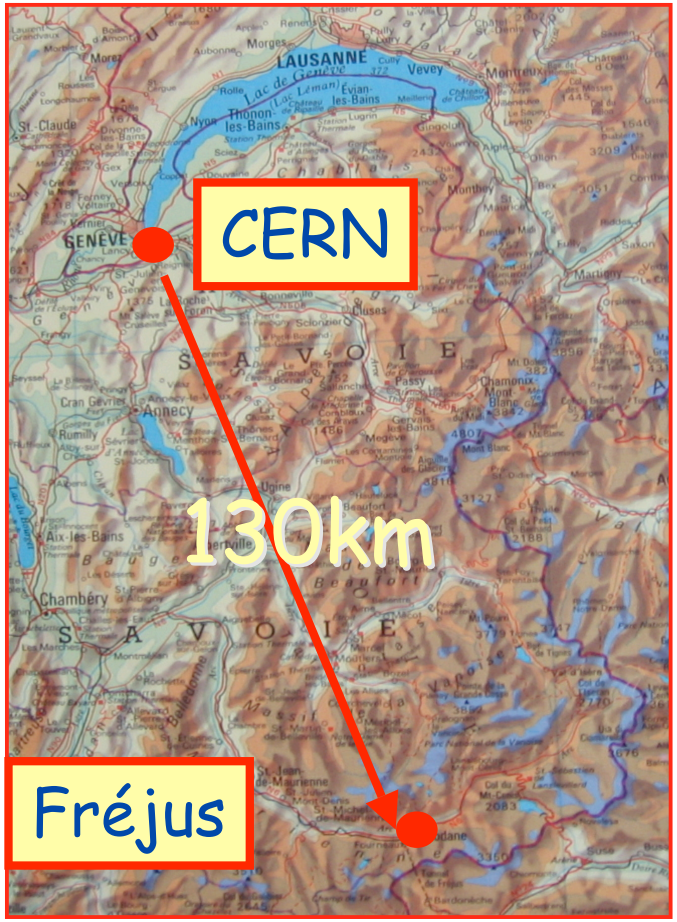
-- can be made in very large volumes (already SK =50kton)
-- very well known technology
-- other applications: proton decay, low energy natural neutrinos, atmospheric, solar and SN neutrinos, Gadzooks, etc…

-- cannot be magnetized easily
-- pattern recognition ~limited to 1 ring events (--> sub GeV neutrinos)
-- baseline detector for sub-GeV neutrinos.

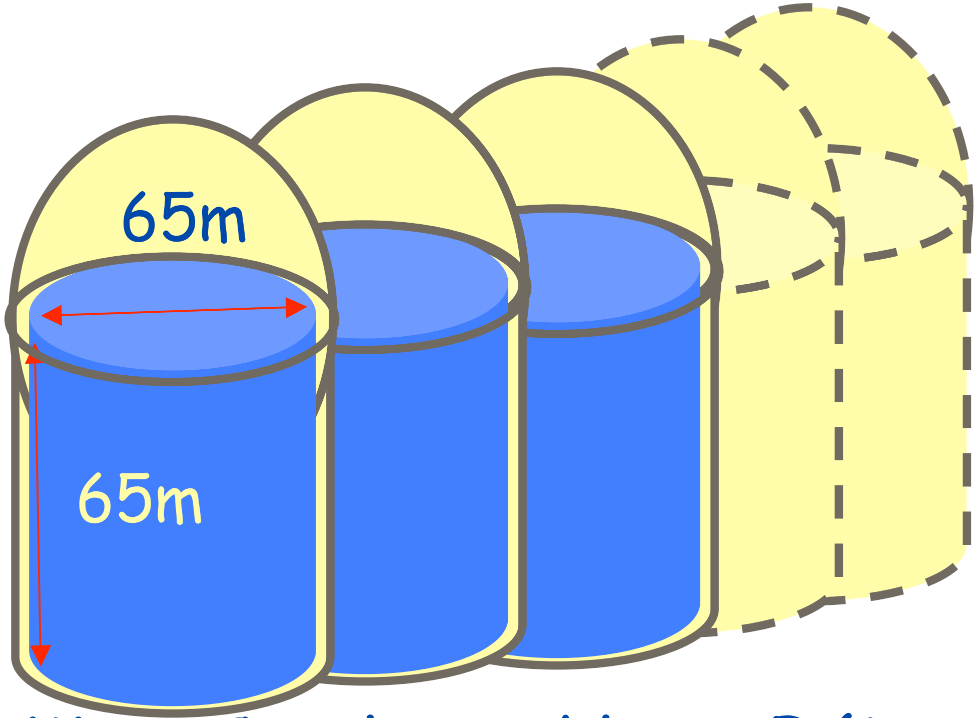
-- three projects around the world: HK, UNO, MEMPHYS
-- community organized and coordinated in its own

cost estimates range from 0.5 G$ (HK) to 1G€ (MEMPHYS) for 1 MTon

The MEMPHYS Project



4800mwe



Water Cerenkov modules at Fréjus

CERN to Fréjus
Neutrino Super-beam and Beta-beam

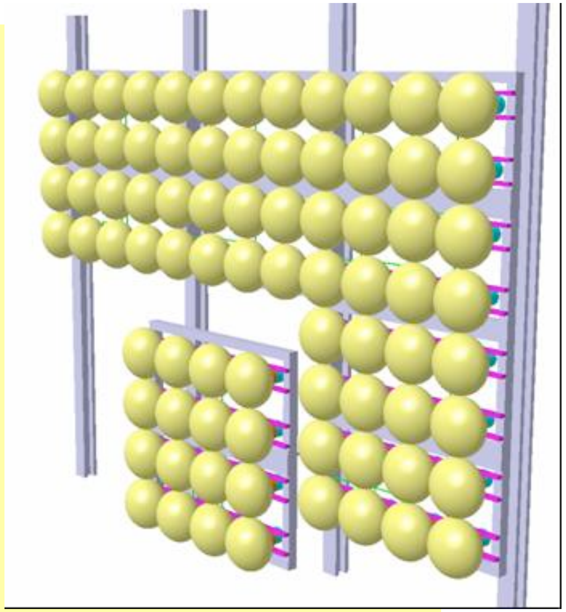
Excavation engineering pre-study has been done for 5 shafts

R&D on electronics (ASICs)

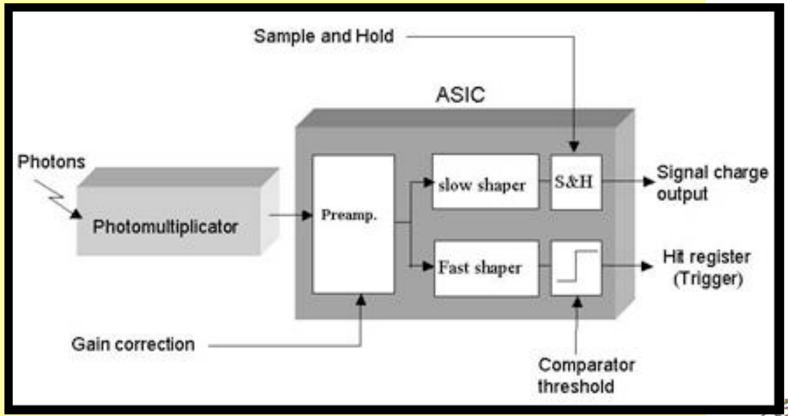
Integrated readout : "digital PM (bits out)"
- Charge measurement (12bits)
- Time measurement (1ns)
- Single photoelectron sensitivity

High counting rate capability (target 100 MHz)

Large area pixellised PM : "PMm^2"
- 16 low cost PMs
- Centralized ASIC for DAQ
- Variable gain to have only one HV



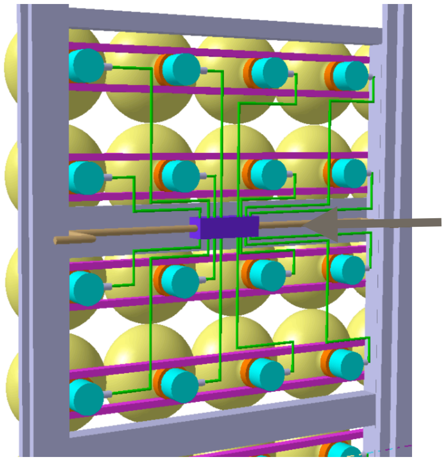
Multichannel readout
- Gain adjustment to compensate non uniformity
- Subsequent versions of OPERA_ROC ASICs



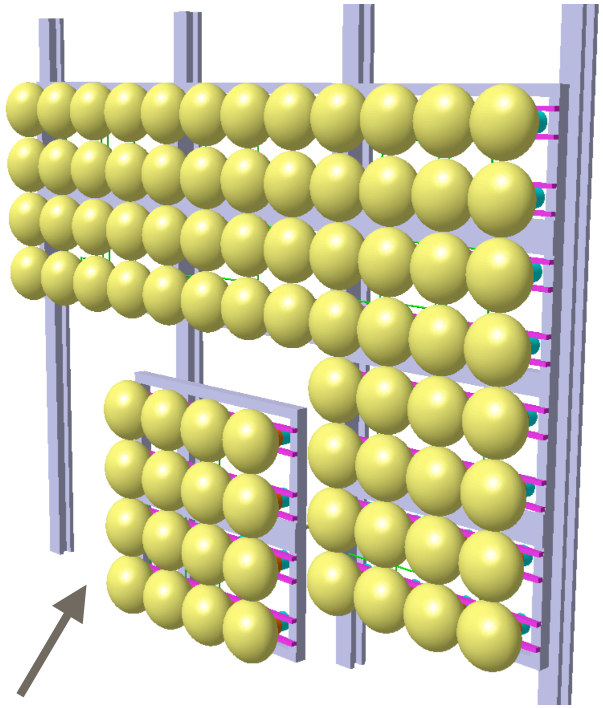
aim at 200 euros/channel

Mechanics & PMT tests

Taken in charge by IPNO: well experienced in photodetectors (last operation: Auger). With PHOTONIS tests of **PMT** 8", 9" → **12"** and Hybrid-PMT and HPD



Electronic box water tight



Basic unit that we want to build and test under water

IPNO

A possible schedule for MEMPHYS at Frejus

Year	2005	2010	2015	2020
Safety tunnel	Excavation			
Lab cavity	P.S / Study	Excavation		
detector	PM R&D	PMT production		
Det.preparation		Outside lab.	Installation	
Non-acc.physics				**P-decay, SN**
Superbeam		Construction		**Superbeam**
betabeam		Construction		**Beta beam**

decision for cavity digging
decision for SPL construction
decision for EURISOL site

Superbeam + beta beam together

2 beams

1 detector

SUPERBEAM

4 ν flavours + K

2yrs $\nu_\mu \rightarrow \nu_e$

π^+/π^-

8yrs $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$

BETABEAM

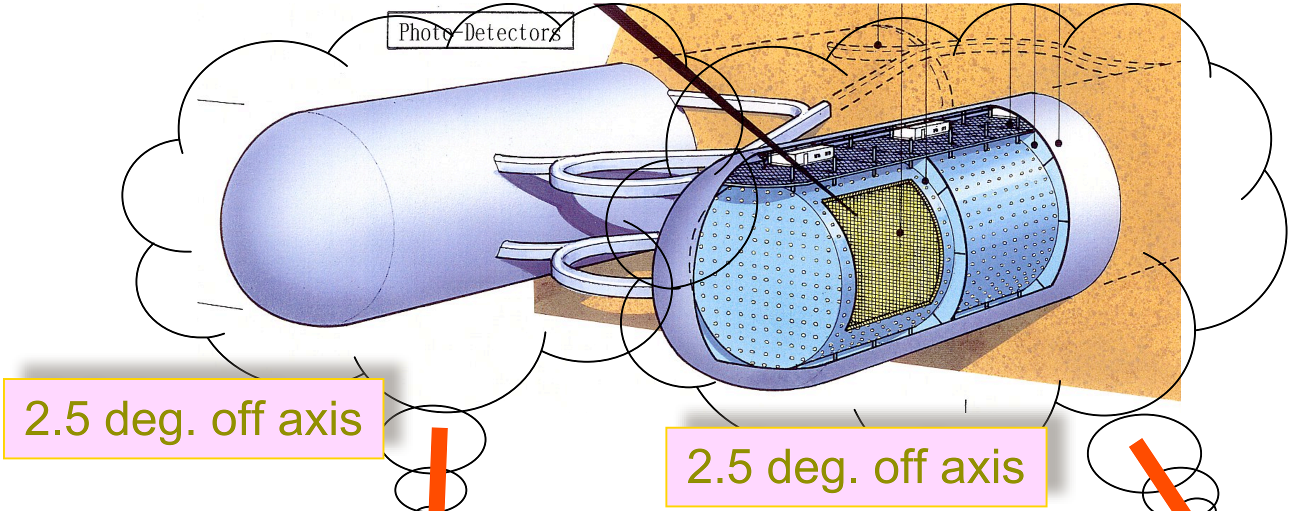
pure

$\nu_e \rightarrow \nu_\mu$ 5yrs

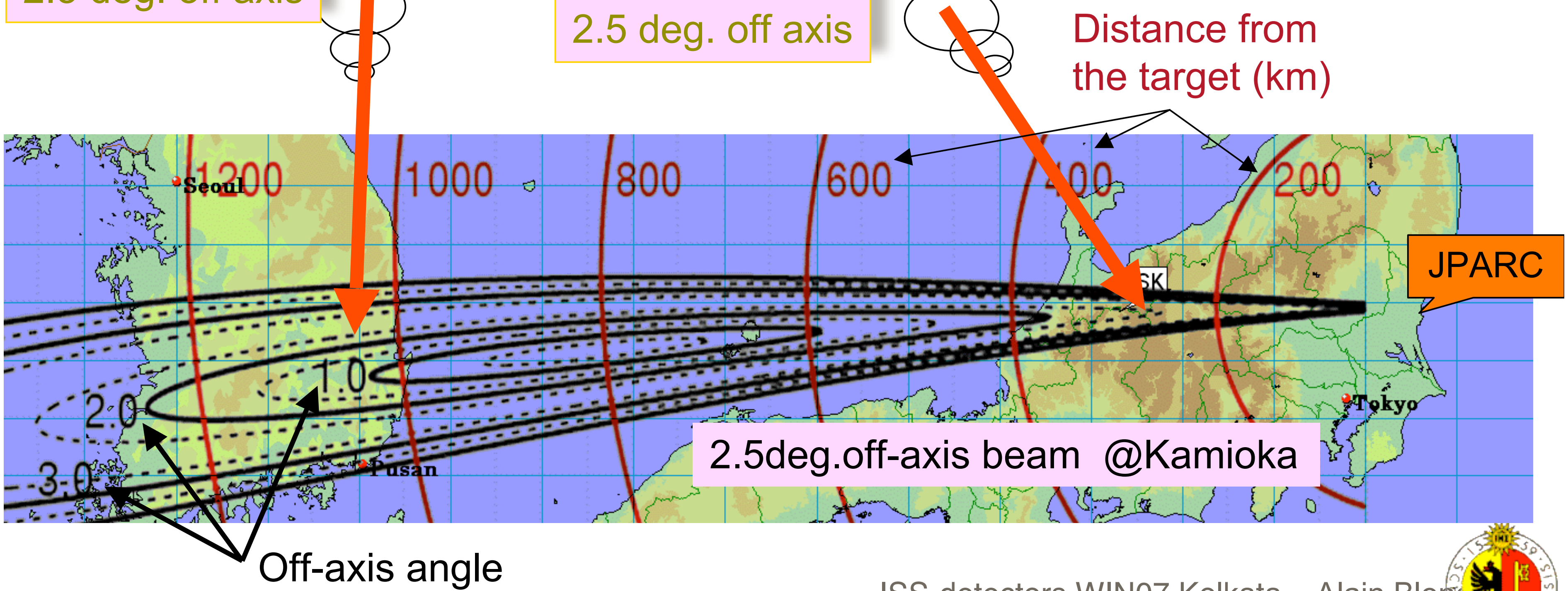
$\bar{\nu}_e \rightarrow \bar{\nu}_\mu$ 5yrs

2 ways of testing CP, T and CPT : redundancy and check of systematics

Possible experimental set-up

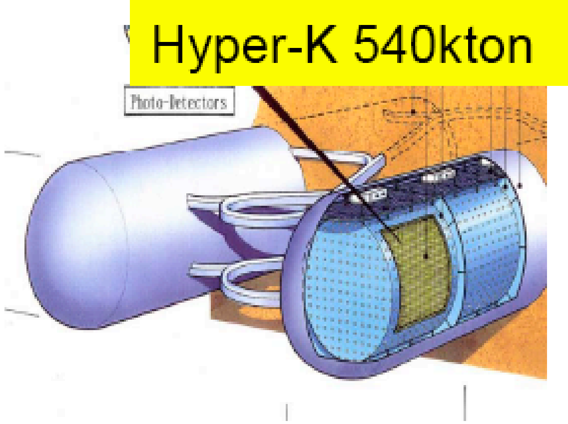


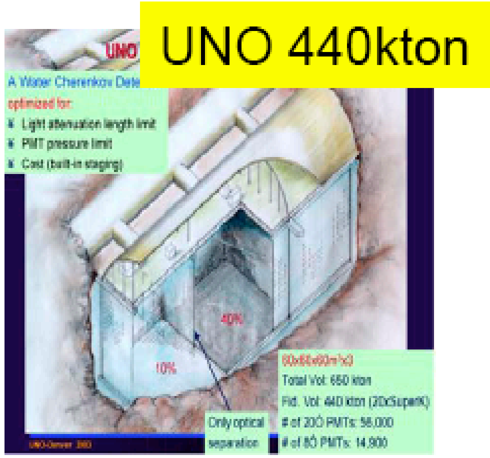
Total cost must be similar to the baseline design.

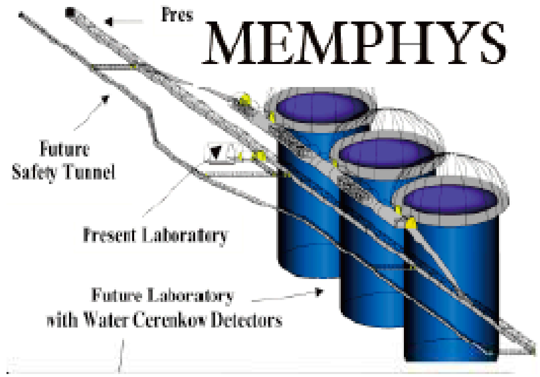


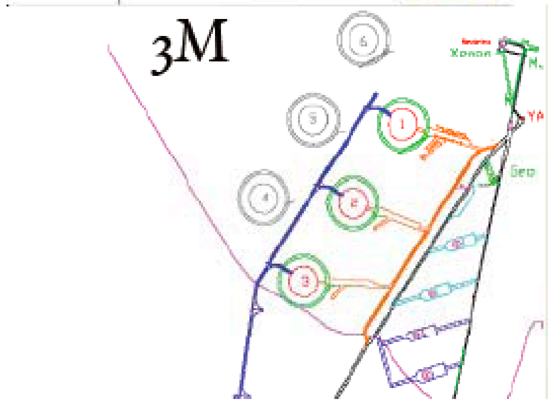
‘Standard’ Next Neutrino Oscillation Experiments

- Aim to study CPV, Mass hierarchy
- Megaton Scale Detector + Upgraded Accelerator
- Typical → Detector 0.5 Mton (fiducial Volume)



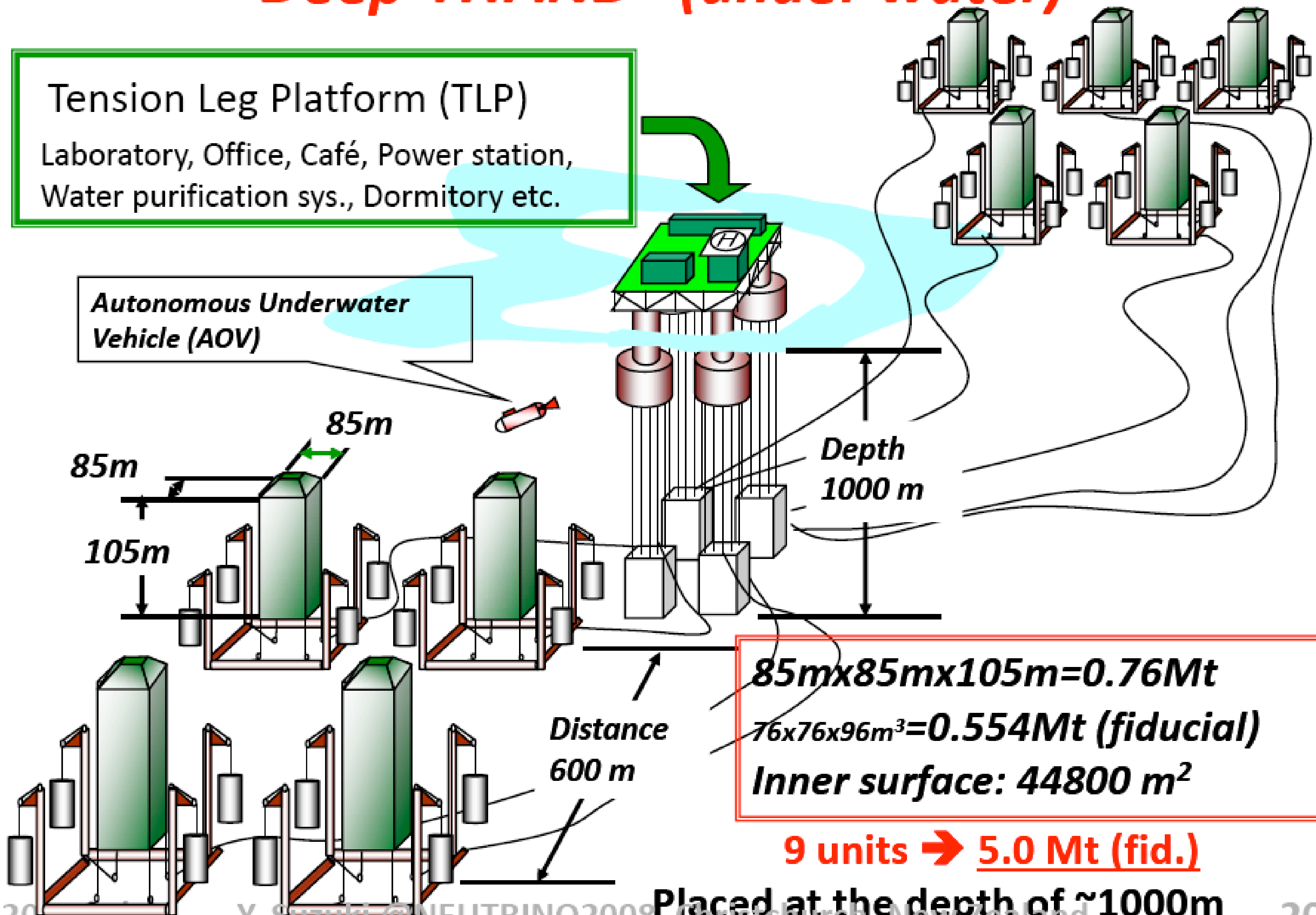






- Other Subjects
  - Proton Decay (10^{35} years for $e\pi^0$)
  - SN neutrinos

Deep-TITAND (under water)



85mx85mx105m=0.76Mt
76x76x96m³=0.554Mt (fiducial)
Inner surface: 44800 m²

9 units ➔ 5.0 Mt (fid.)

Placed at the depth of ~1000m

5 Mt Neutrino Oscillation Detector

- *Proton decay search ~10^{36}yr*
- *SN neutrino detection: ~1 every year*
  - *Reaches 5Mpc w/ ~ 5 events*

➔ *PD and SN really add the value to the experiment*

- *Precise atmospheric neutrino measurements*
- *Flexible location of the detector for a long baseline neutrino oscillation experiment*
- *Effective investment: accelerator or detector*
  - *More on detector*

➔ ***possibility to find unexpected***

- *Many technical challenges*

➔ ***Need to start R&D now for a detector of more than 20 year from now***

-- Liquid Argon TPC:

DOE (detector of everything)
it can do everything, can it do it BETTER
than a dedicated standard technique? Case by case…

impressive progress from ICARUS T600

recent highlights

-- observation of operation in magnetic field
-- programme on-going to demonstrate long drift, or long wires

100 kton fid… ? When, how, how much?

Trade off between mass and detector quality

Main advantage (in superbeam like T2K) pi0/electron separation
Less advantageous for betabeam (low energy mu/pi separation)

NEUTRINO FACTORY DETECTORS

An ideal detector exploiting a Neutrino Factory should:

Identify and measure the charge of the muon ("golden channel") with high accuracy

Identify and measure the charge of the electron with high accuracy ("Platinum channel")

Identify the τ decays ("silver channel")

Measure the complete kinematics of an event in order to increase the signal/back ratio

-- Magnetized Iron Neutrinofactory Detector*)

this is a typical NUFACT detector for E_ν>1.5 GeV $\nu_e \rightarrow \nu_\mu$

GOLDEN CHANNEL

experience from MINOS & NOvA
designs prepared for Monolith and INO

iron-scintillator sandwich with sci-fi + APD read-out

proposed straightforward design 90kton for ~175M$ (Nelson)

*) MIND

Magnetized Iron calorimeter

(baseline detector, Cervera, Nelson)

$B = 1$ T $\Phi = 15$ m, $L = 25$ m

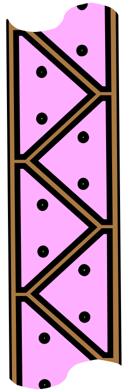
t(iron) =4cm, t(sc)=1cm

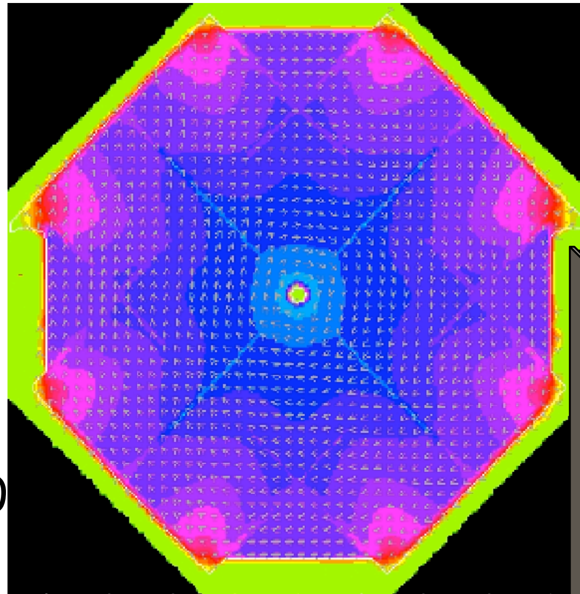
Fiducial mass = 100 kT

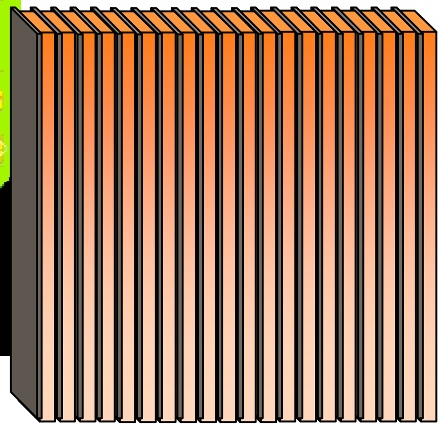
Charge discrimination down to 1 GeV

very similar to MINOS/NOvA/ND280

ex. detector: sci. fi. detector with multipixel APD readout



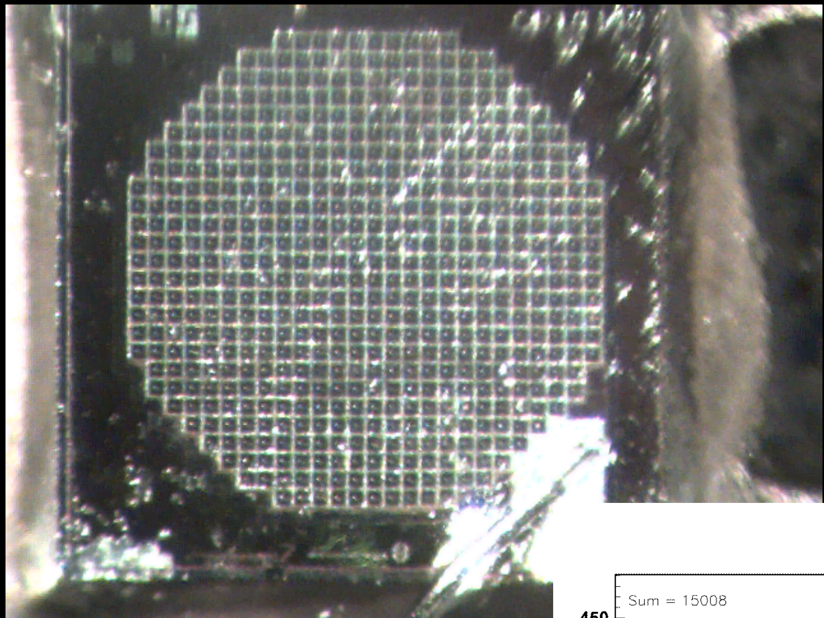


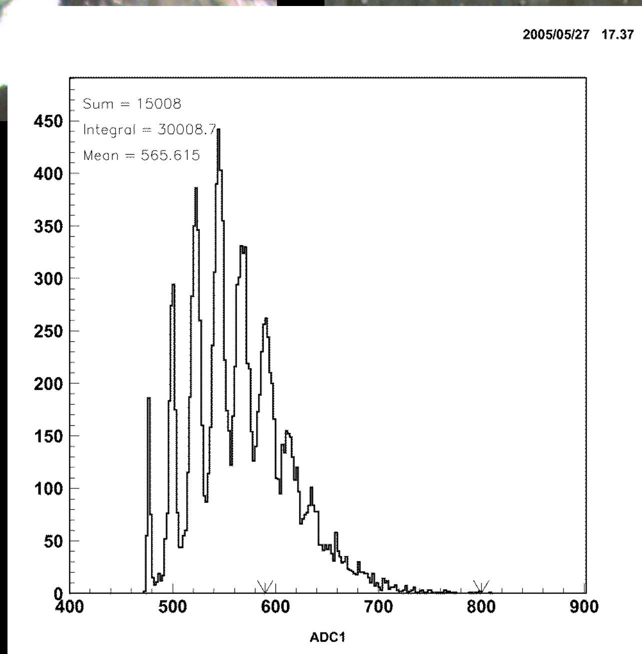


Event rates for 10^{21} muon decays for 50 GeV beam

Baseline	$\bar{\nu}_\mu$ CC	ν_e CC	ν_μ signal ($\sin^2\theta_{13}$=0.01)	
732 Km	10^9	2×10^9	3.4×10^5	(J-PARC I→ SK = 40)
3500 Km	4×10^7	7.5×10^7	3×10^5	

Multi-Pixel-Photon-Counter Operation





baseline detectors for T2K ND280 detectors!

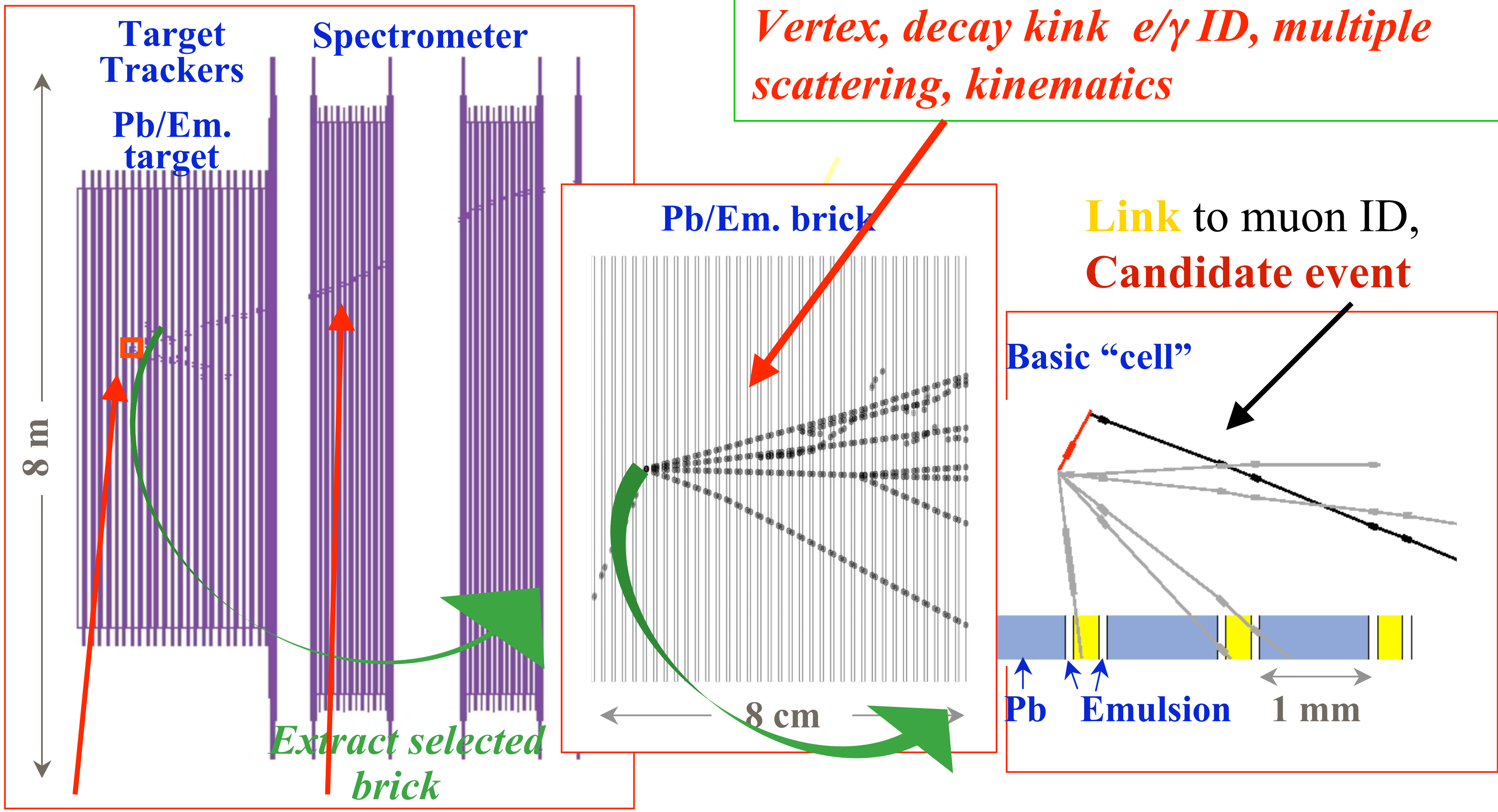
Kudenko

BASELINE SILVER DETECTOR

Electronic detectors:

ECC emulsion analysis:

Vertex, decay kink e/γ ID, multiple scattering, kinematics



Brick finding, muon ID, charge and p

$\Delta p/p < 20\%$

LARGE MAGNETIC VOLUME

MIND + emulsions provide
golden
+ silver with low efficiency (muon decays)

these are feasible and of established performance.

Observing the **platinum** channel $\nu_\mu \rightarrow \nu_e$

or the **silver** channel $\nu_e \rightarrow \nu_\tau$ for more decay channels

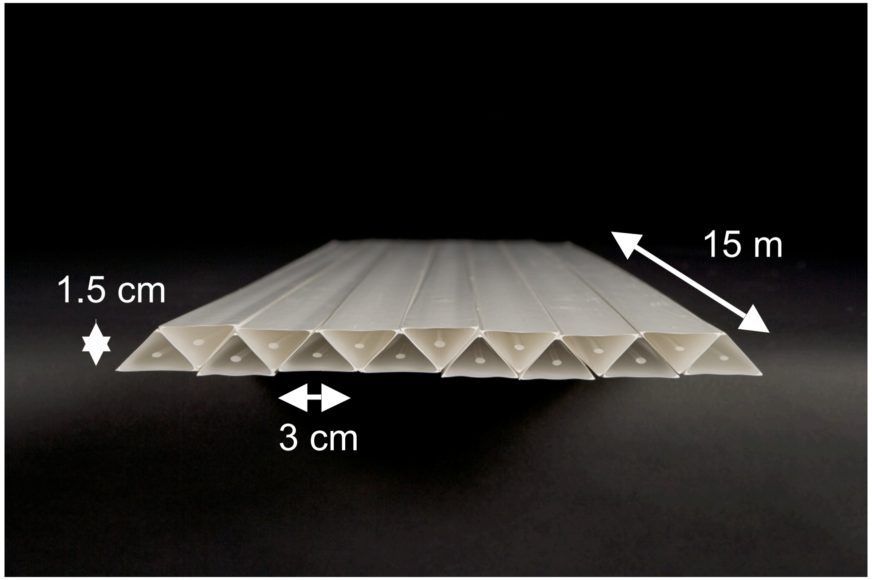
requires a dedicated

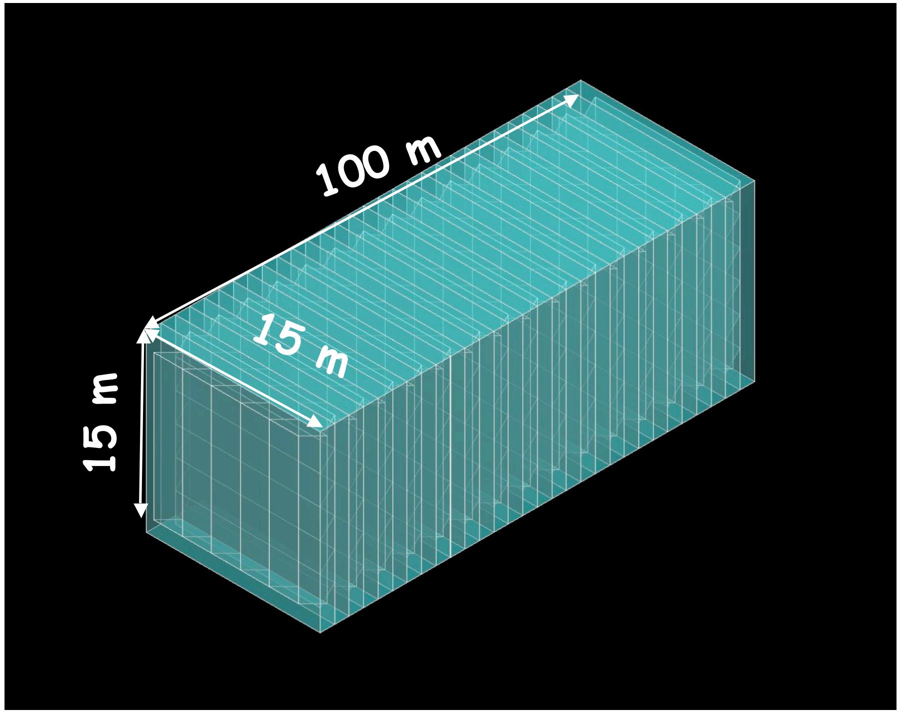
Low Z and very fine grained detector
immersed in a large magnetic volume (CF NOMAD)

Totally Active Scintillating Detectors (TASD)

Possible improvement: Totally Active Scintillating Detector (TASD) using Nova and Minerva concepts

3333 Modules (X and Y plane)
Each plane contains 1000 slabs
Total: 6.7M channels





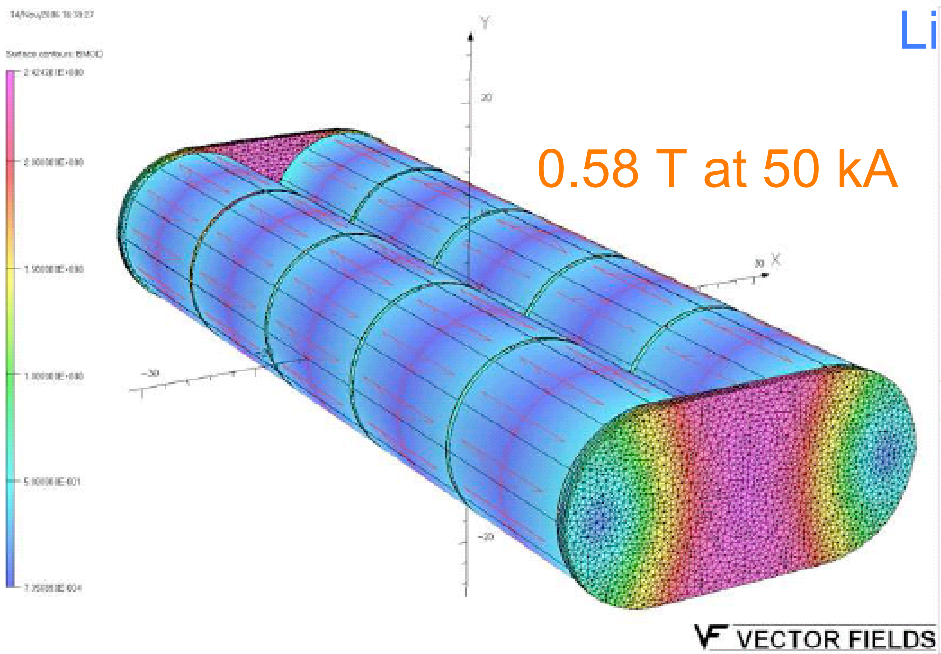
Momenta between 100 MeV/c to 15 GeV/c
Magnetic field considered: 0.5 T
Reconstructed position resolution ~ 4.5 mm

Reduction threshold: access second oscillation maximum and electron identification

Totally Active Scintillating Detectors (TASD)

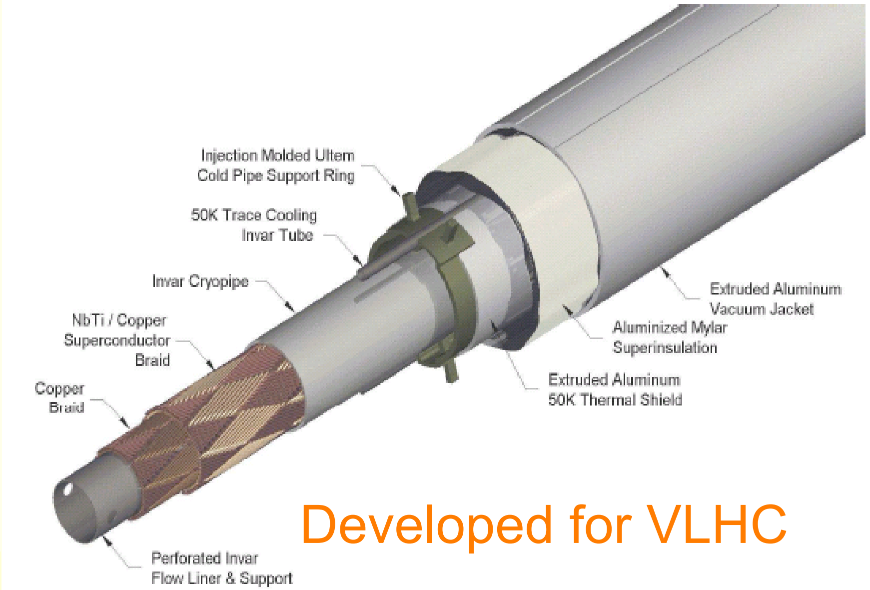
However, possible magnetisation can be achieved using magnetic cavern concept (10 modules with 15m x 15 m diameter)

Bross



0.58 T at 50 kA

Use Superconducting Transmission Line (STL): cable has its own cryostat



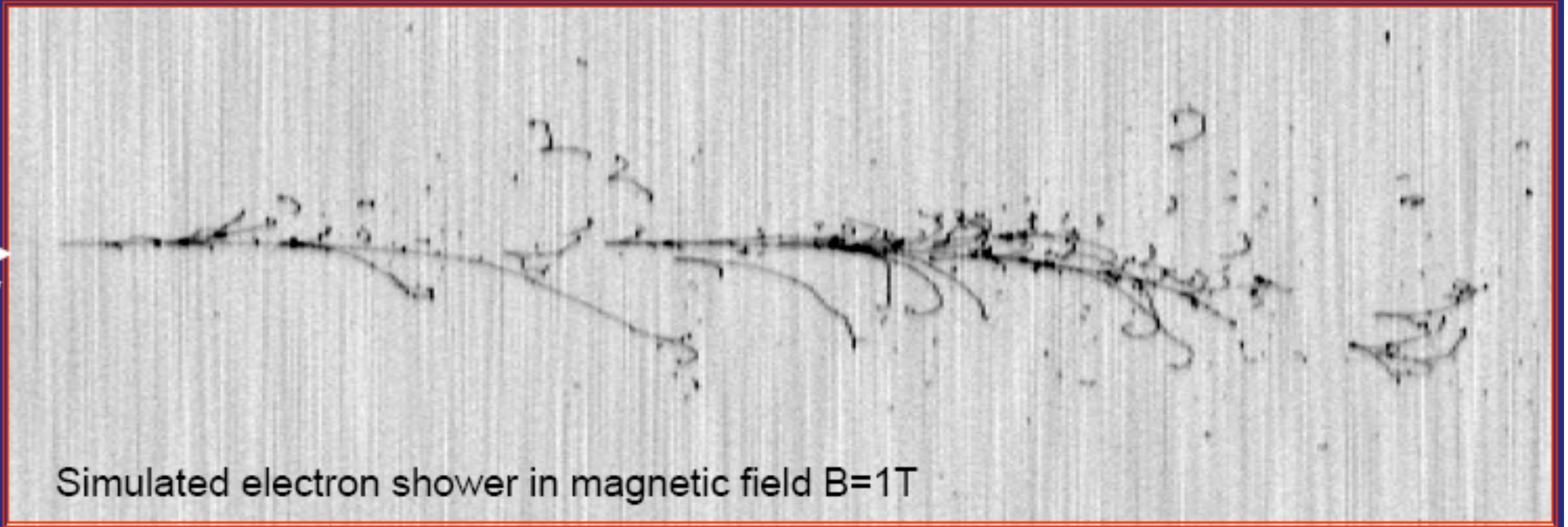
Developed for VLHC

R&D + engineering needed to develop concept!!

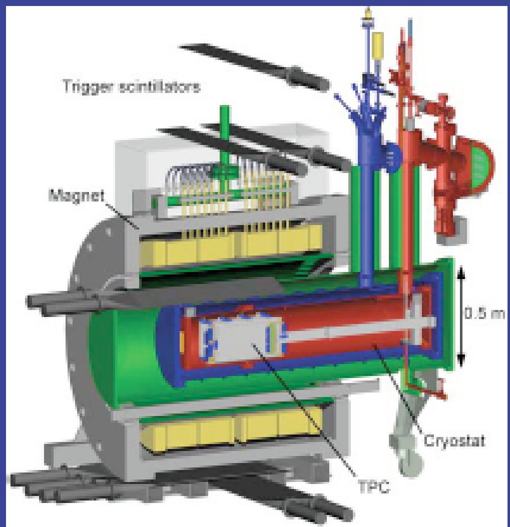
A superconducting magnetized LAr TPC detector

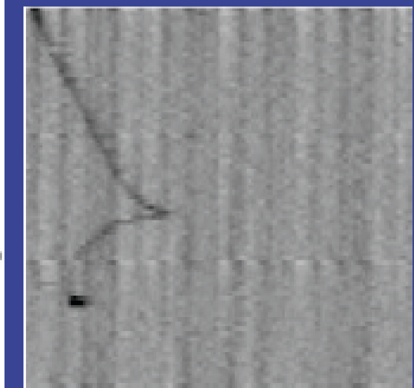
e⁻

2.5 GeV



First real events in B-field (B=0.55T):





Required field for 3σ charge discrimination:

x=track length

λ=pitch angle

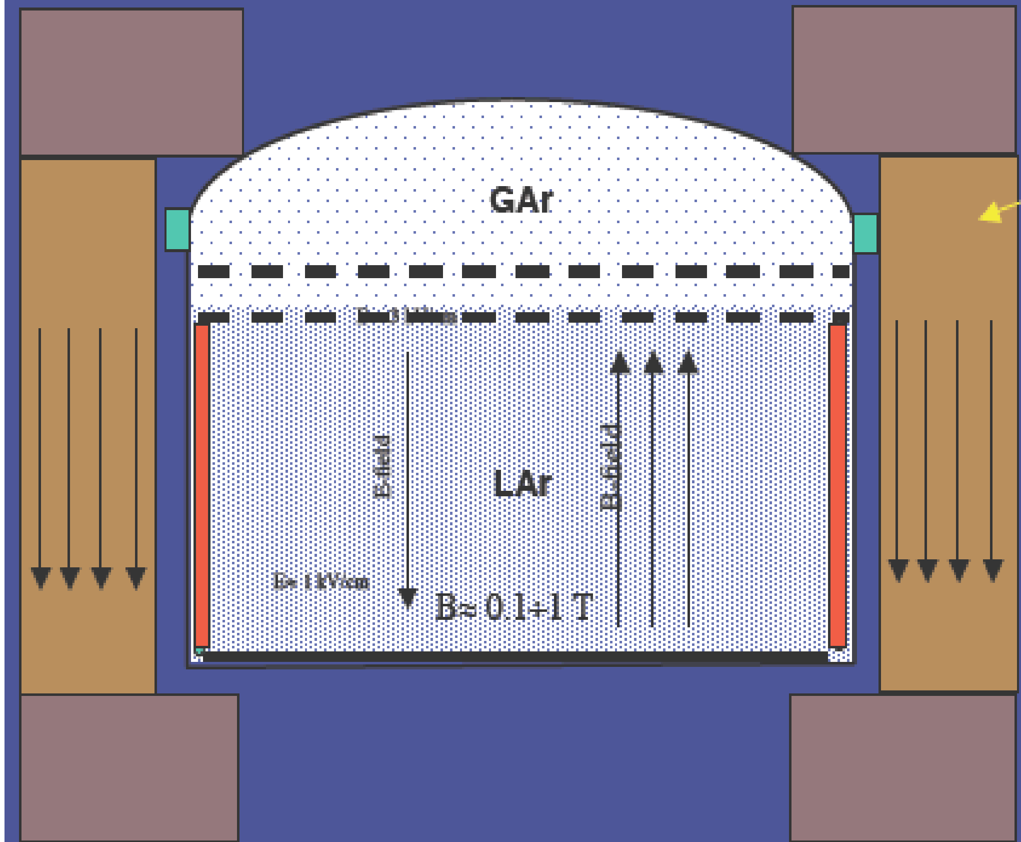
$$B \geq \frac{0.2\,(Tesla)}{\sqrt{x(m)\,\cos^3\lambda}}$$

x ~ a few X0=14cm….

B > 0.5 T

Tentative Yoke parameters

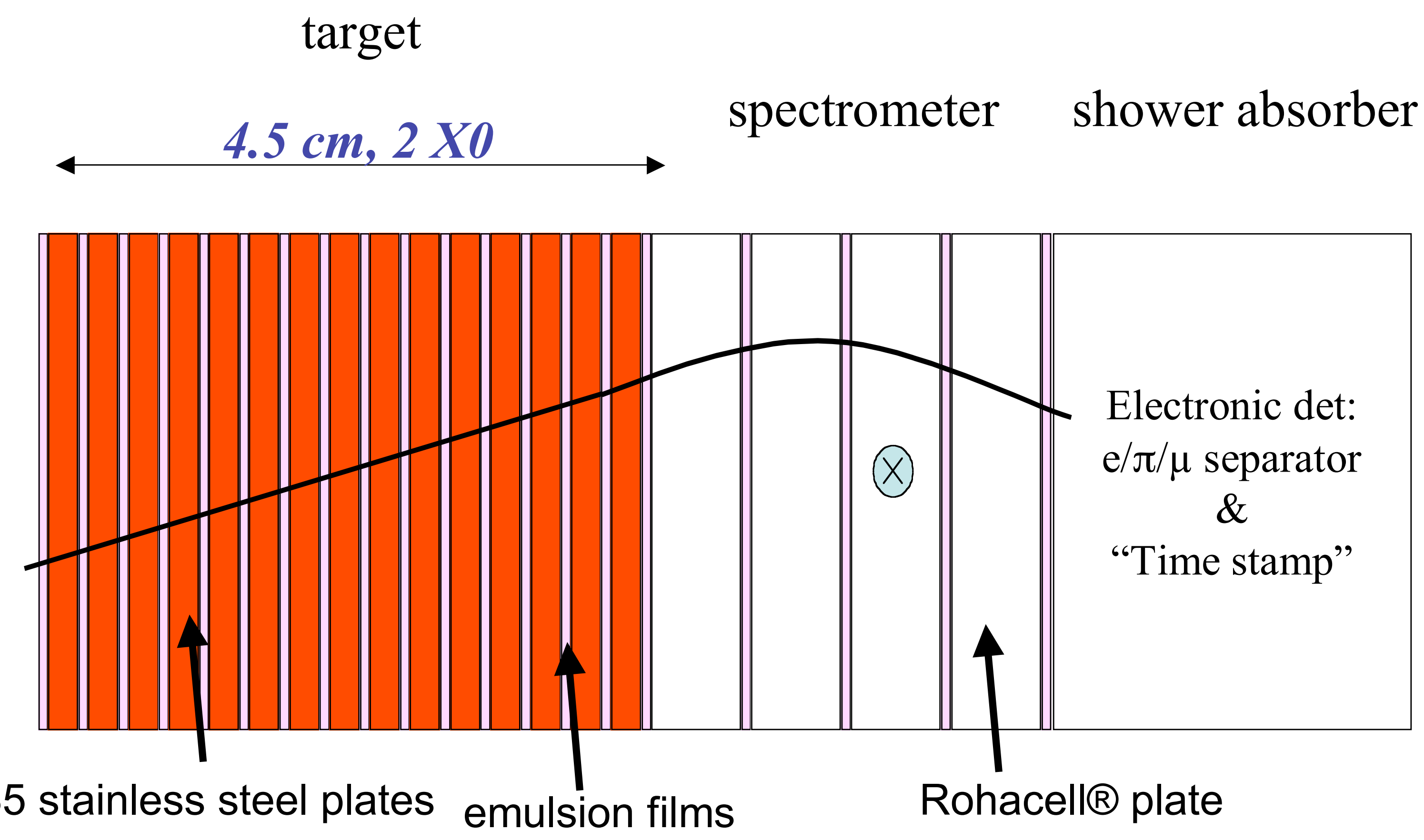
Cylindrical Fe yoke	10 kton LAr			100 kton LAr		
Magnetic induction (T)	0.1	0.4	1.0	0.1	0.4	1.0
Magnetic flux (Weber)	70	280	710	385	1540	3850
Assumed saturation field in Fe (T)	1.8			1.8		
Thickness (m)	0.4	1.6	3.7	1	3.7	8.7
Height (m)	10			20		
Mass (kton)	6.3	25	63	34	137	342



Cylindrical Fe yoke.
(Instrumented?)

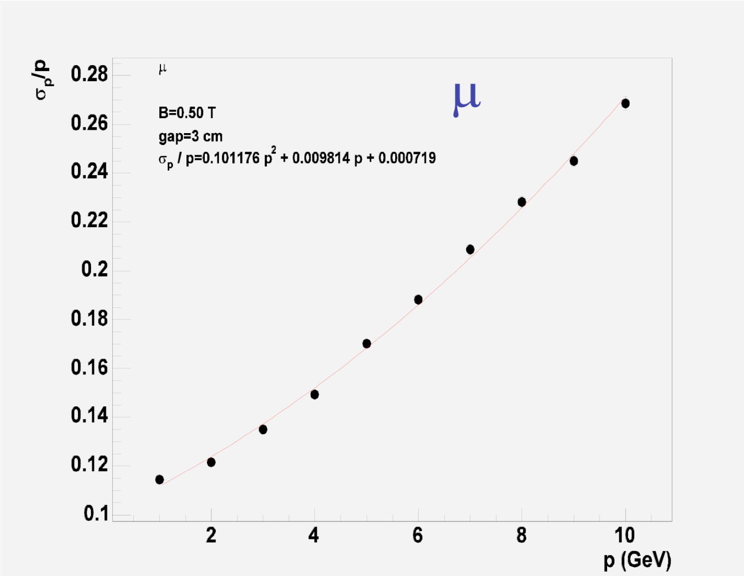
NB: Superconducting Magnetic Energy Storage (SMES) systems were considered for underground storage of MJ energy without return yoke buried in tunnels in bedrock (see e.g. Eyssa and Hilal, J. Phys. D: Appl. Phys 13 (1980) 69). Avoid using a yoke?

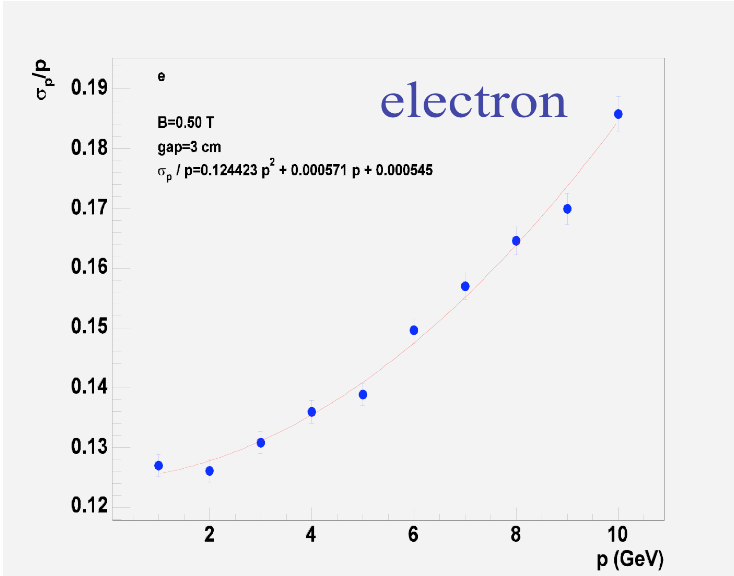
Magnetized ECC structure



We have focused on the “target + spectrometer” optimization

μ end electron momentum resolution: 3 gaps (3cm thick) and 0.5 T





For the electron only hits associated to the primary electrons used in the parabolic fit (Kalman not used)
Given the non negligible energy loss in the target, the electron energy is taken downstream for the comparison of true against reconstructed

FIRST INDICATION THAT THE PLATINUM CHANNEL COULD BE USED!

Near detectors and flux instrumentation

near detector constraints for CP violation

ex. beta-beam or nufact (interchange role of ν_e and ν_μ for superbeam)

$$\frac{P(\nu_e \rightarrow \nu_\mu) - P(\bar{\nu}_e \rightarrow \bar{\nu}_\mu)}{P(\nu_e \rightarrow \nu_\mu) + P(\bar{\nu}_e \rightarrow \bar{\nu}_\mu)} = A_{CP} \; \alpha \; \frac{\sin\delta \sin(\Delta m^2_{12} L/4E) \sin\theta_{12} \sin\theta_{13}}{\sin^2\theta_{13} + \text{solar term}\ldots}$$

Near detector gives ν_e diff. cross-section*detection-eff *flux and ibid for bkg

BUT: need to know ν_μ and $\bar{\nu}_\mu$ diff. cross-section* detection-eff

with small (relative) systematic errors.

→knowledge of cross-sections (relative to each-other) required

→knowledge of flux!

European Effort

EuroNu: four year EU Design Study for "A High Intensity Neutrino Oscillation Facility in Europe" (Super-beam, Neutrino Factory, Beta-beam, neutrino detectors and physics performance).

- Neutrino detectors: study Magnetised Neutrino Iron Detector (MIND) performance for golden measurement at a neutrino factory, water Cherenkov detector for beta and super beams and near detectors for all facilities EUROv APPROVED for 4M€, begins now

- DevDet is a new Integrating Activity proposal across Europe to coordinate "Detector Development Infrastructures for Particle Physics Experiments"
  - It is a 37.8 M€ proposal to the European Union (EU) with a requested EU contribution of 11.0 M€. It has 87 participants from 21 different countries
  - It includes the luminosity-upgraded LHC (SLHC), future Linear Colliders (ILC/CLIC), future accelerator-driven neutrino facilities and B-physics facilities
  - Funding for R&D and test beams (including neutrino test beam)

Neutrino detector questions

SIZE matters

-- Liquid Argon drift

-- scintillator/fibers light transmission

-- price per channel

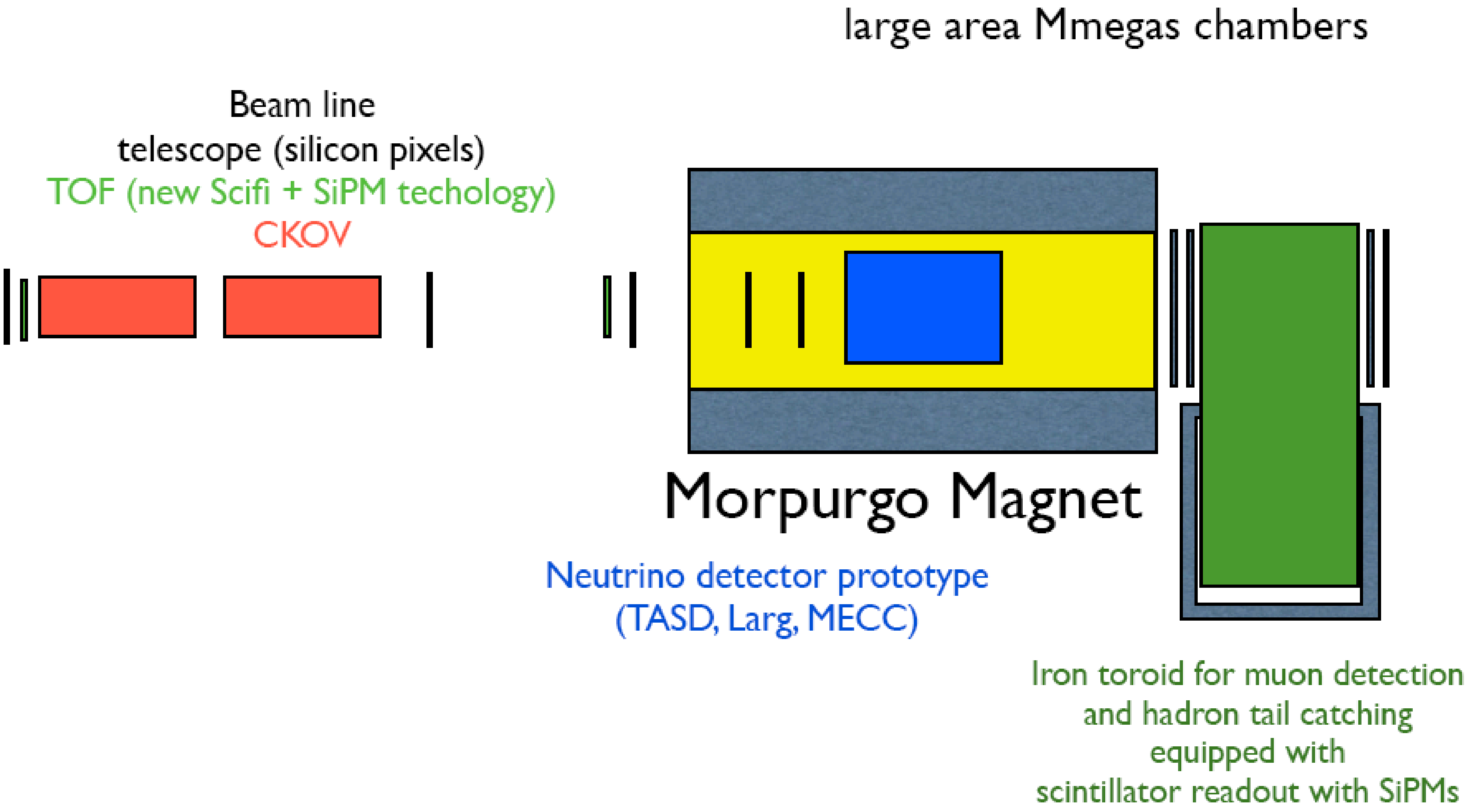
PID e/mu, pi0/e, (SB)

pi+-/muon (BB)

two track resolution

Muon and electron Charge assignement (NUFACT)

==> redundant combined low energy test beam



Neutrino test beam proposal (DEνDET)

Bern, ETHZ, UniZ: Larg

GVA: muon spectrometer