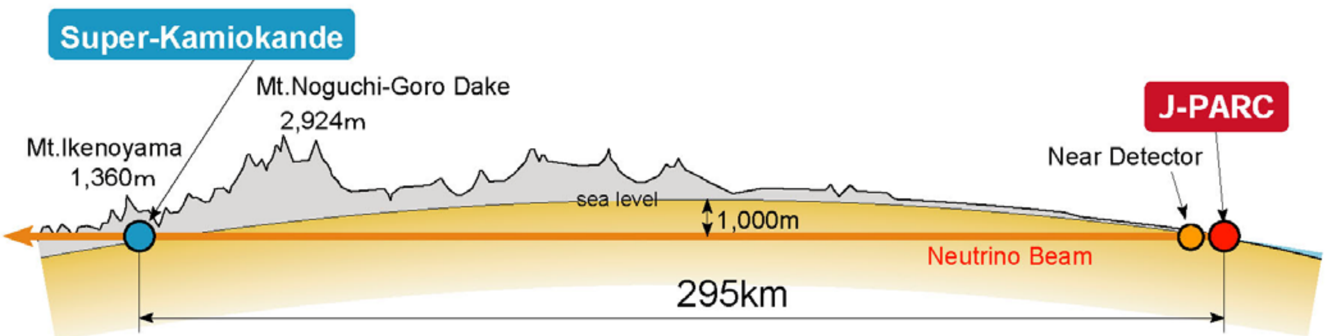
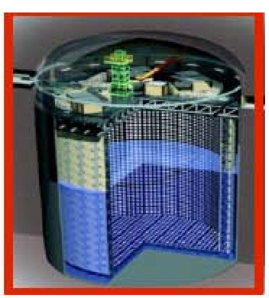
T2K Near Detector Upgrade

Thorsten Lux

T2K

- Long baseline neutrino oscillation experiment
- 2 detectors:
  - Near Detector: measure before oscillation
  - Far Detector: measure after oscillation

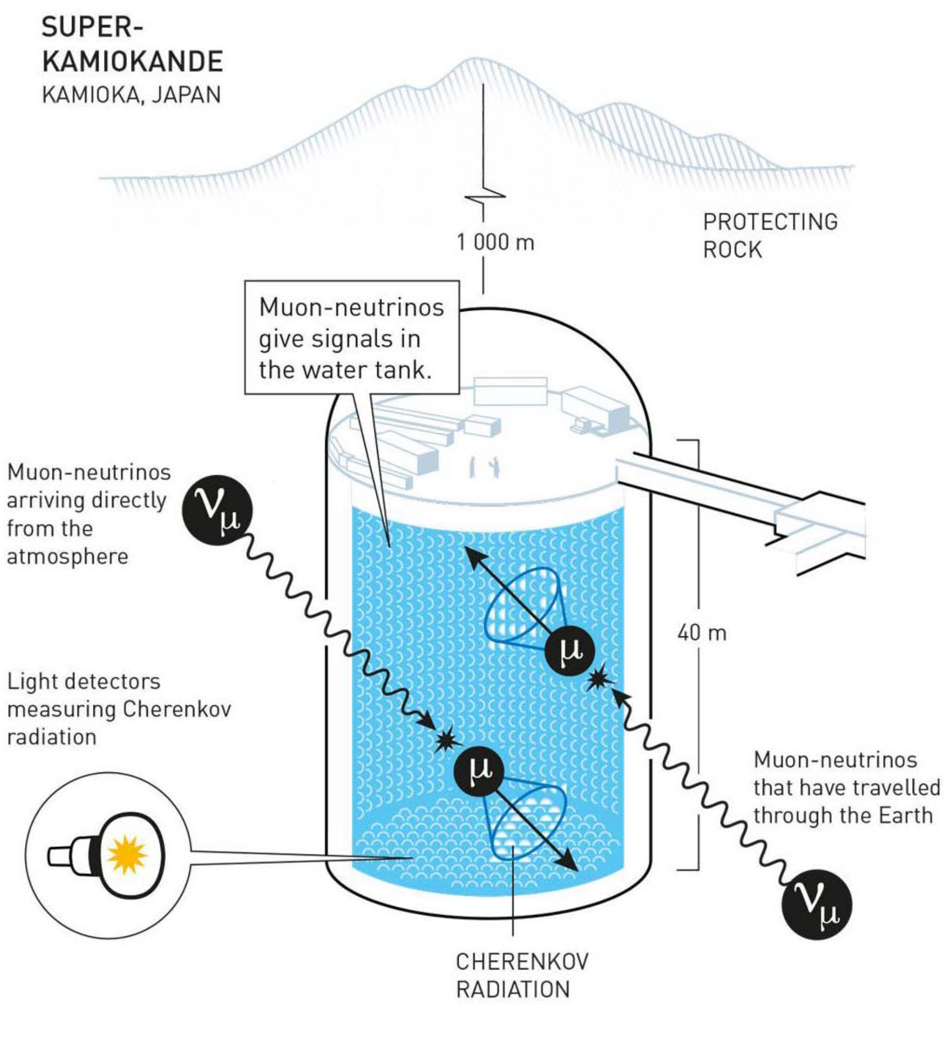



Far detector

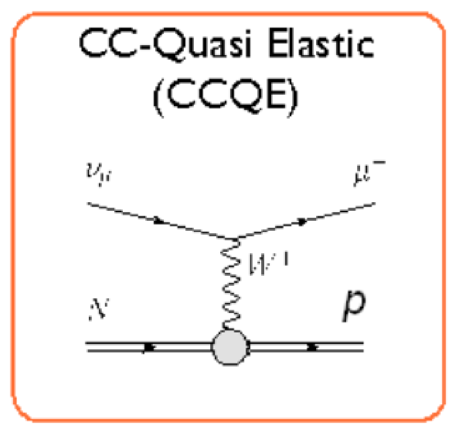

Near detector

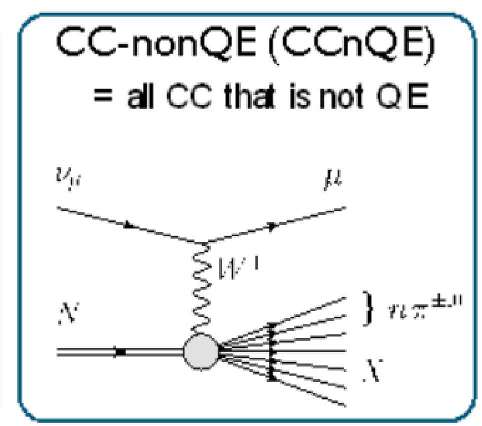

J-PARC proton accelerator

Far Detector: SuperKamiokande

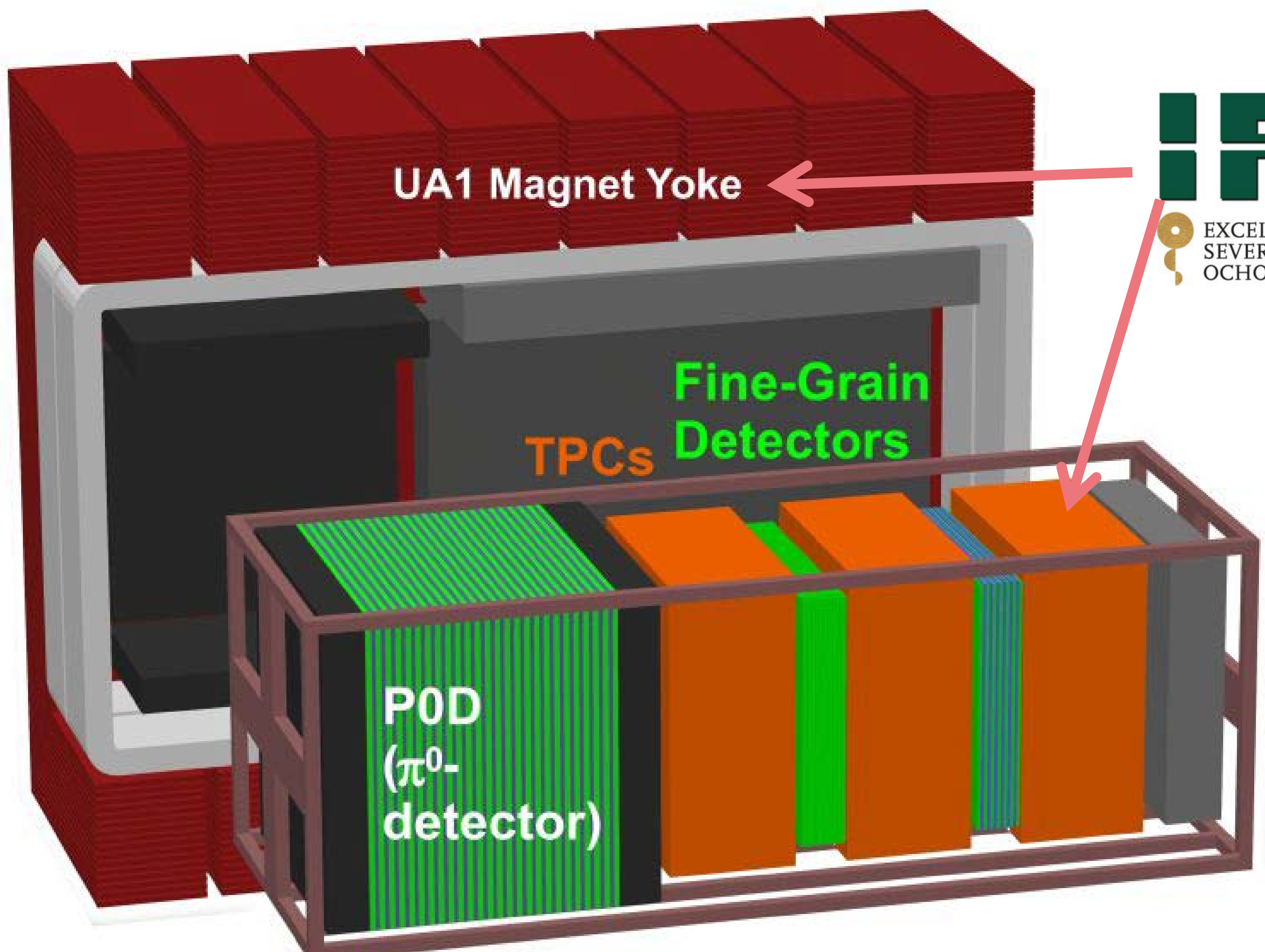


- Water Cherenkov detector
- 4π sensitivity
- CC events
- Relatively high threshold for particle detection => mainly detection of charged lepton





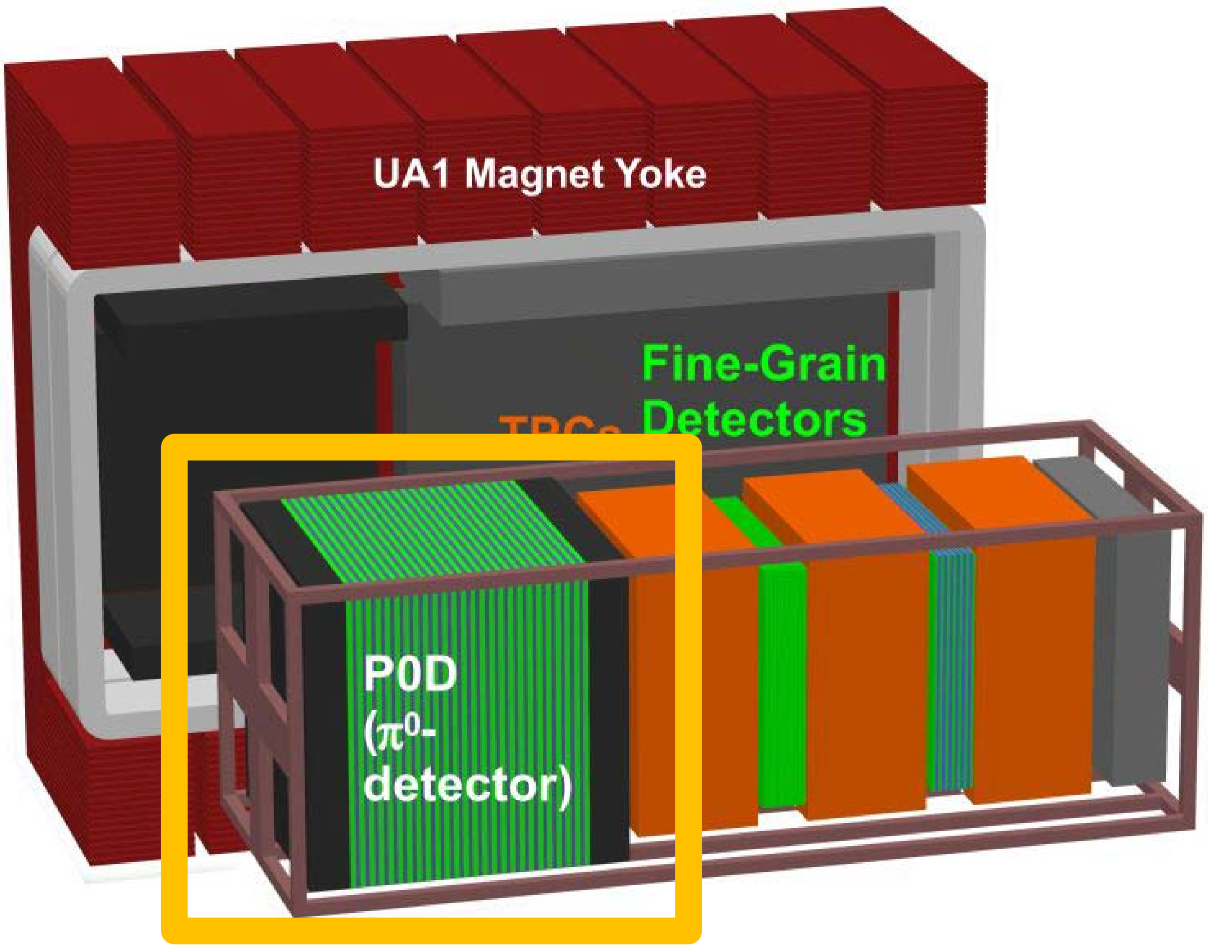
Current Near Detector: ND280



EXCELENCIA
SEVERO
OCHOA

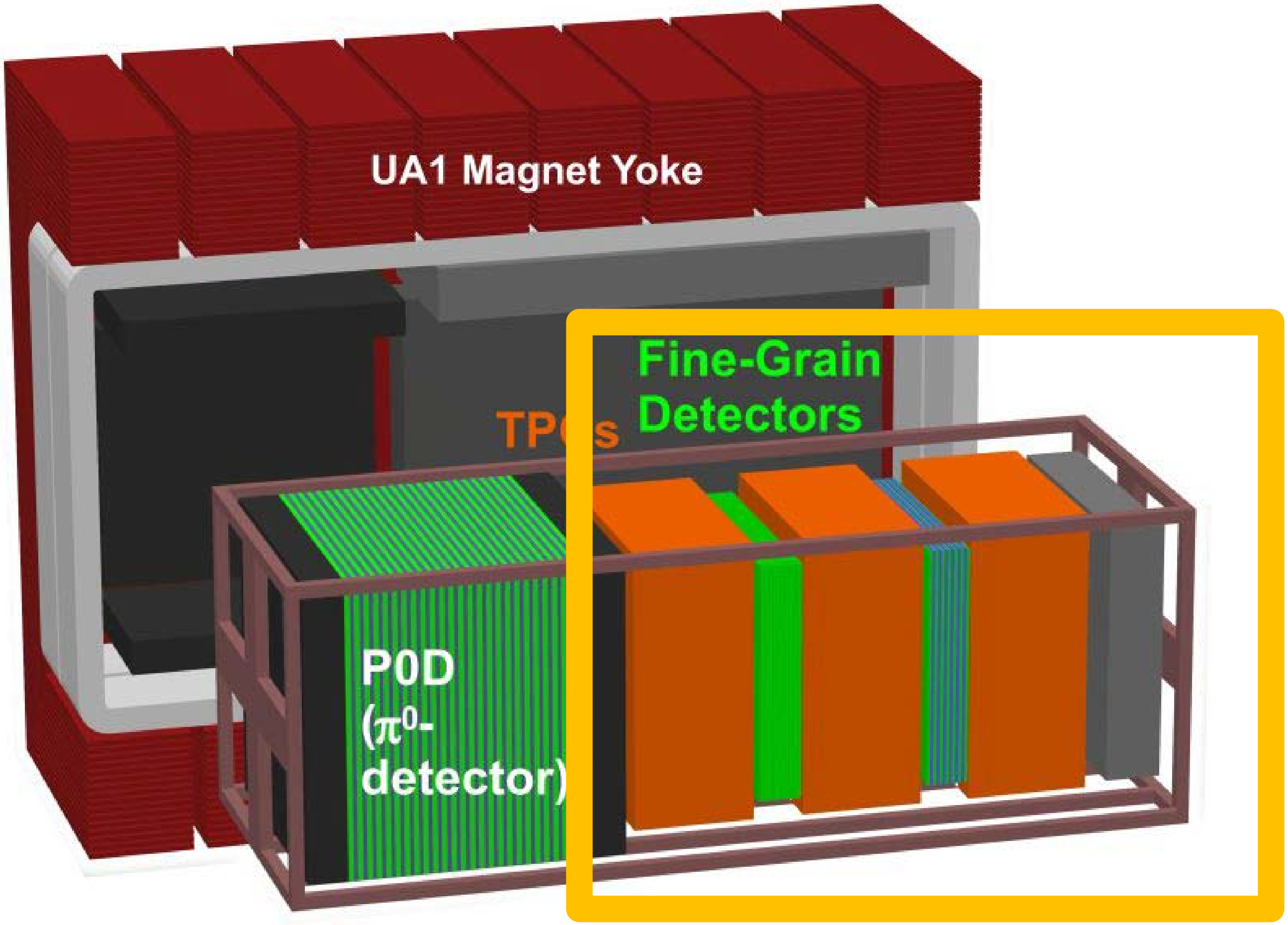
Barcelona Institute of
Science and Technology

Current Near Detector: ND280



- target and detector
- NC events
- background in SK

Current Near Detector: ND280

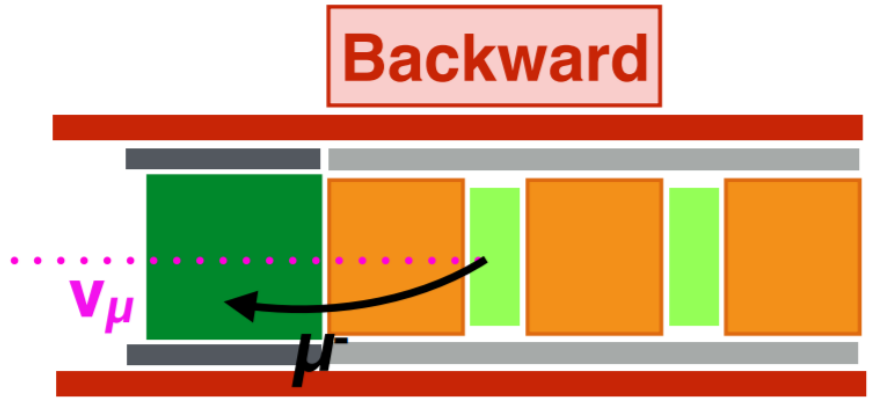


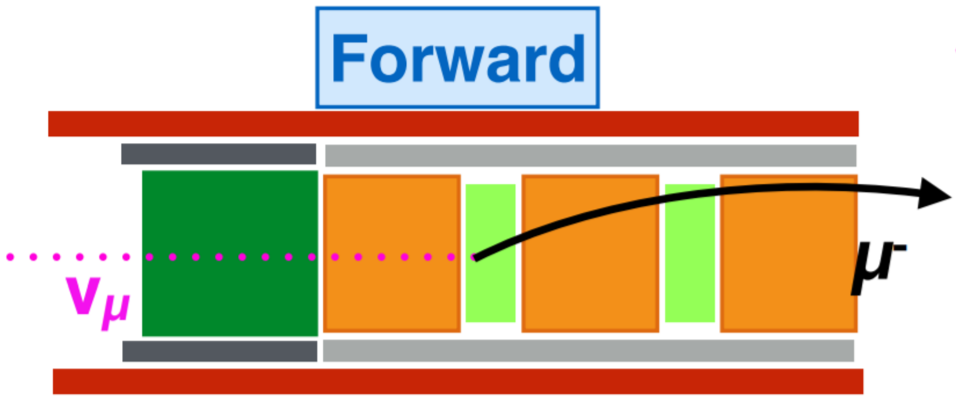
- FGD: target, TPC: tracker
- CC events
- signal in SK

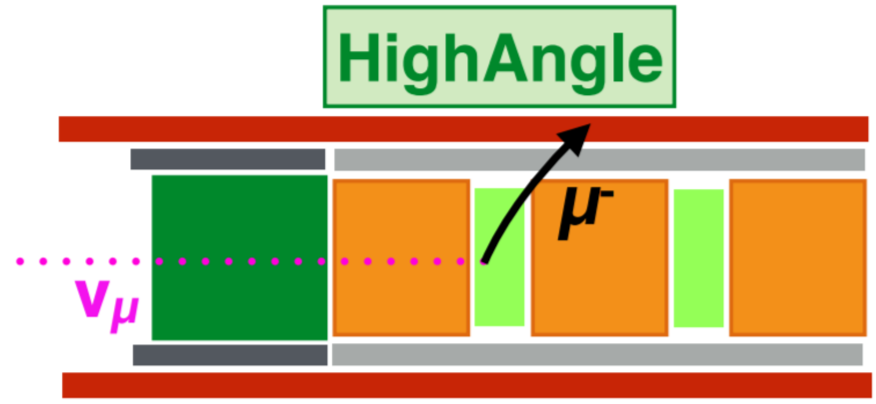
Current Near Detector: ND280

- not 4π detector
- optimized for forward direction
- high angle has problems:
  - FGD dense material
  - short track in TPC => bad for p and dE/dx measurement => bad for PID

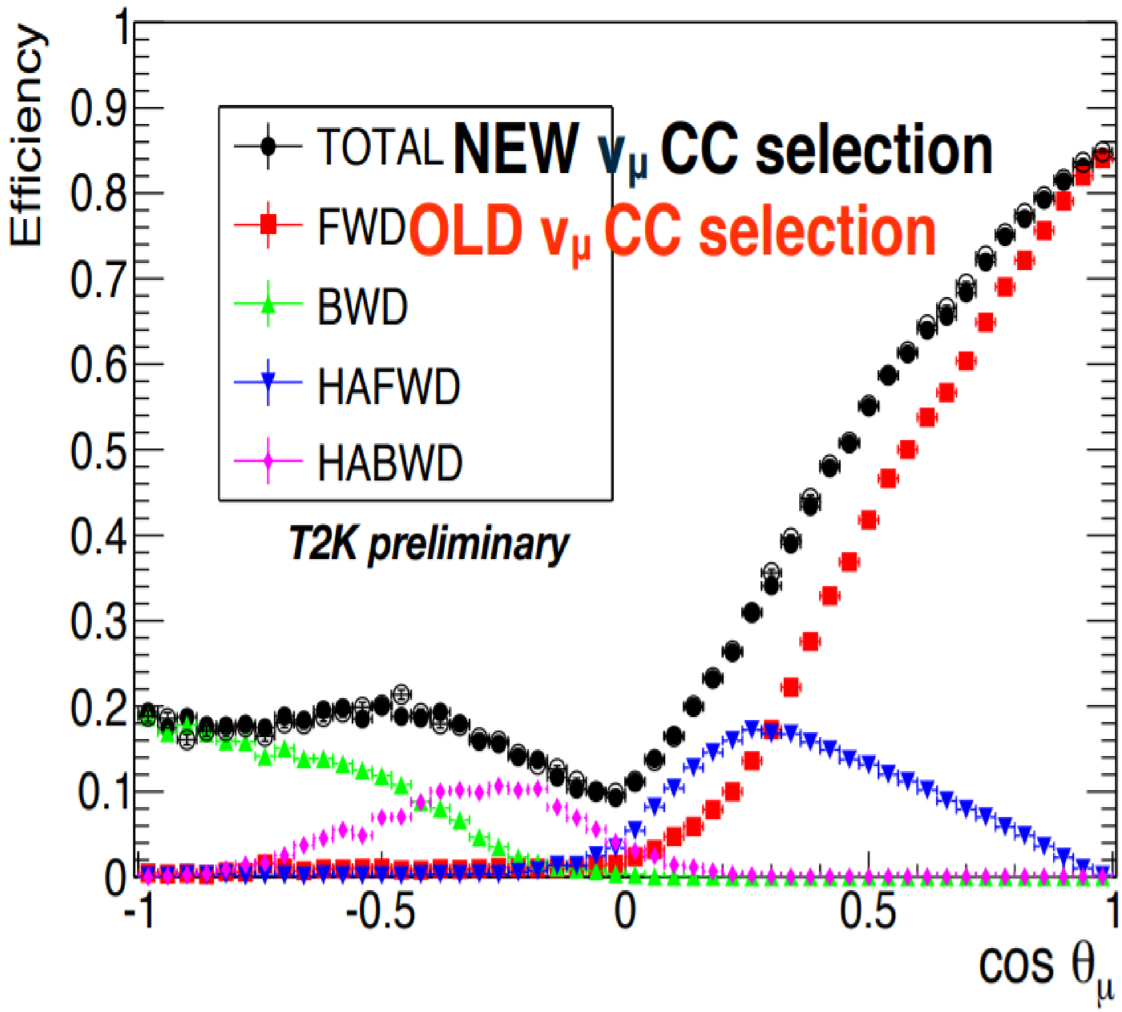
- backward: without time information difficult to identify correctly backward going lepton







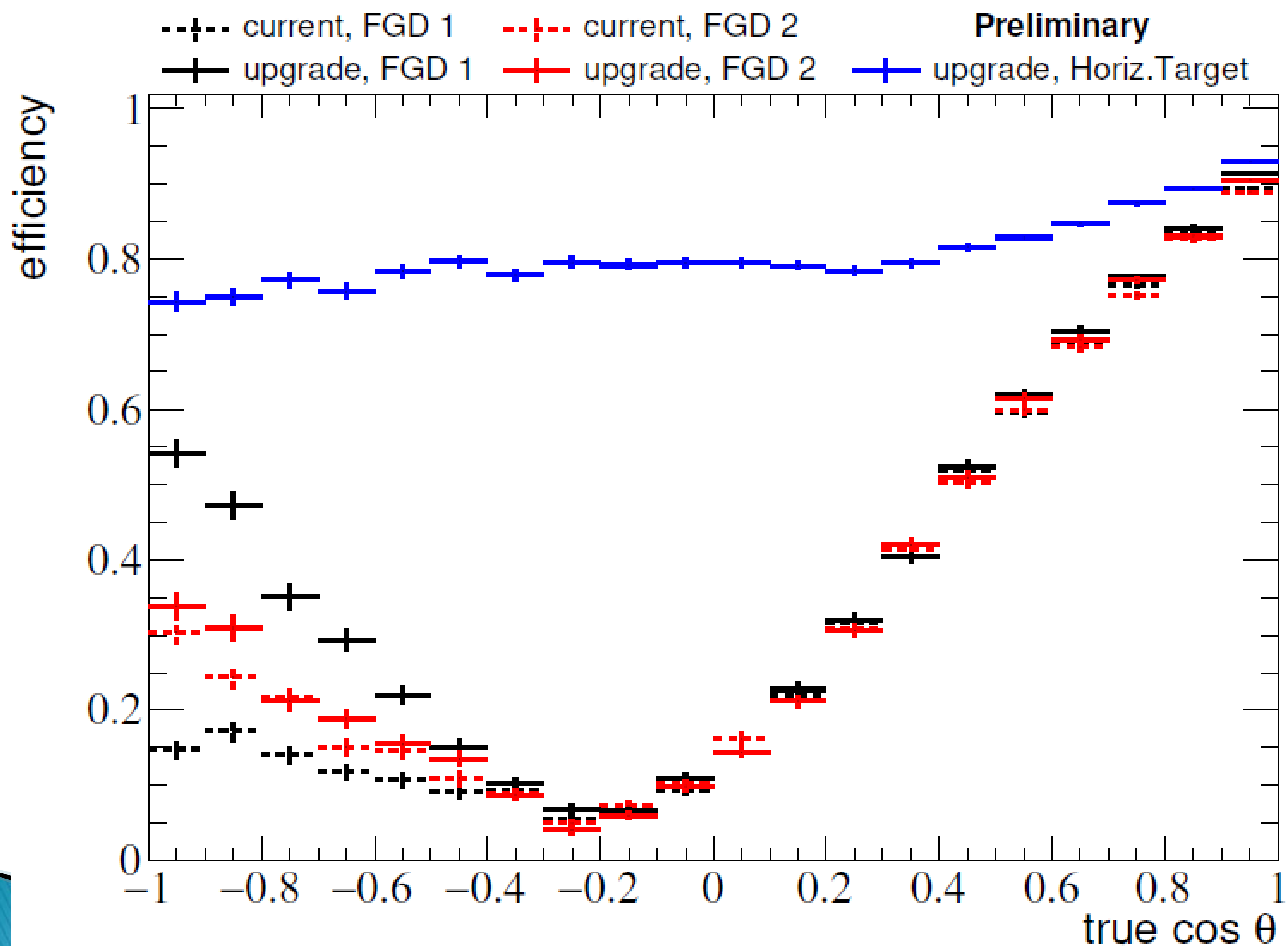
Current Near Detector: ND280



- selection efficiency high in forward direction
- originally only forward direction
- for current detector already achieved some efficiency for high angle and backward
- Alfonso Garcia (IFAE) thesis
- still very low efficiency for high angle and backward direction

=> Significant systematic error for SK results

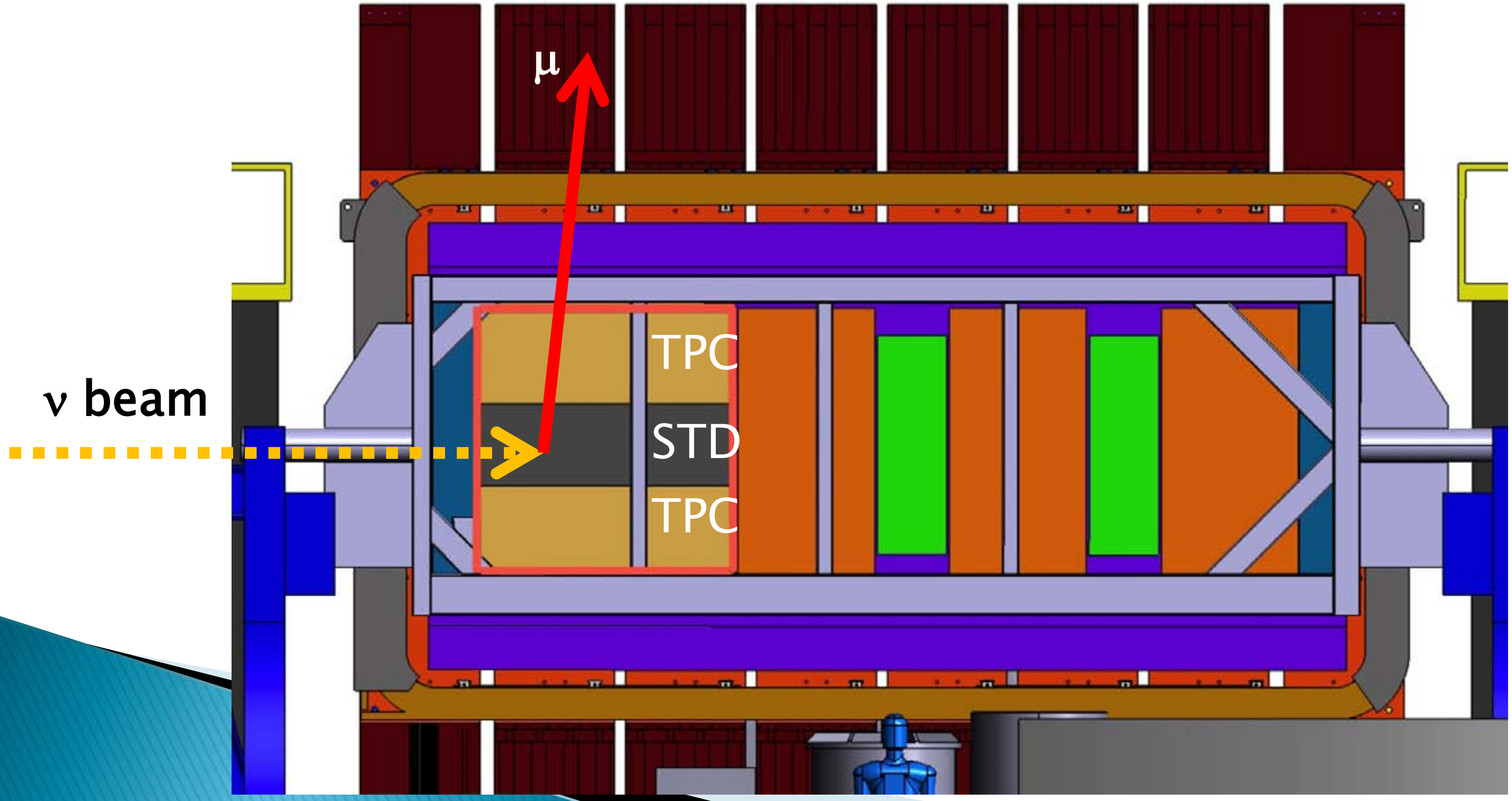
What we want



current, FGD 1
current, FGD 2
Preliminary
upgrade, FGD 1
upgrade, FGD 2
upgrade, Horiz.Target
efficiency
1
0.8
0.6
0.4
0.2
0
−1
−0.8
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
0.8
1
true cos θ

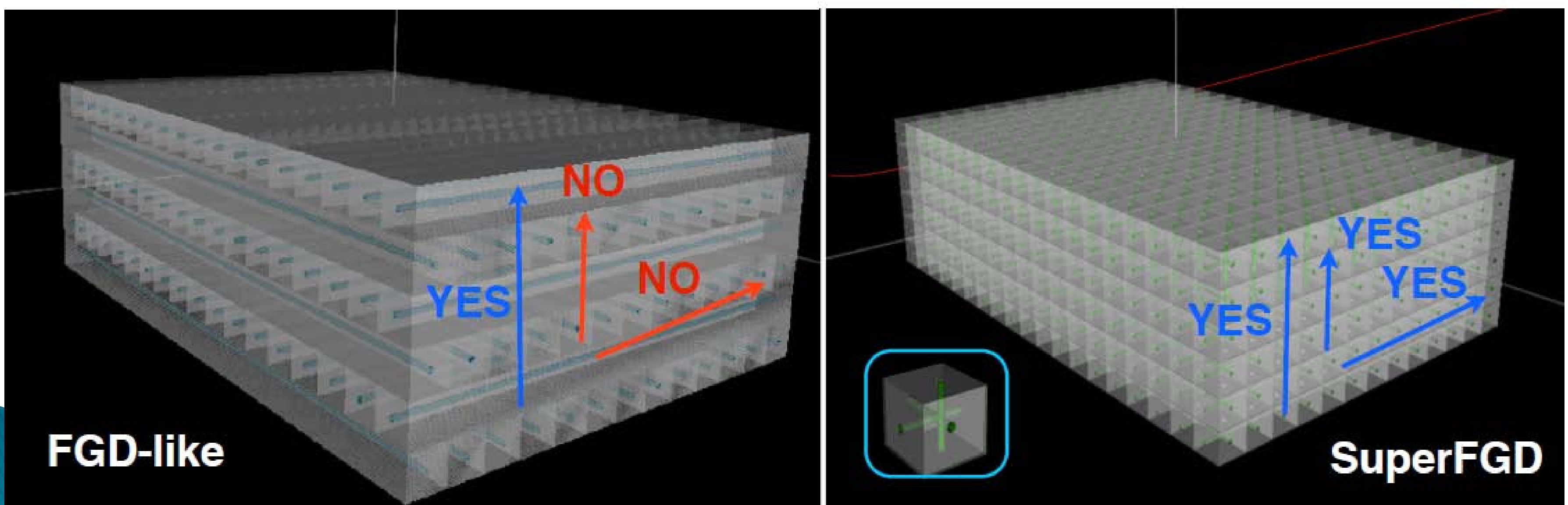
How to achieve this?

- Get rid of P0D and replace it by something more useful!
  - Scintillator tracker as target
  - 2 vertical TPCs as tracker
  - TOF panels surrounding all other detectors



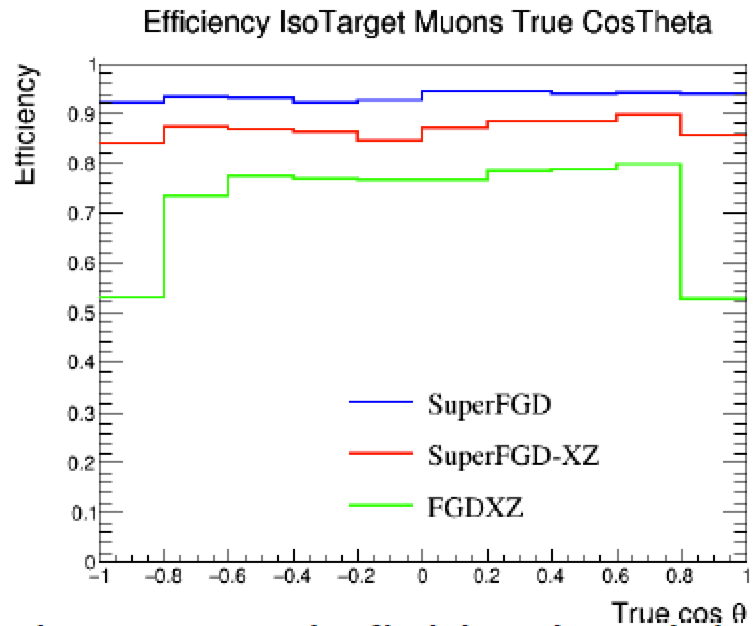
Scintillator Tracker

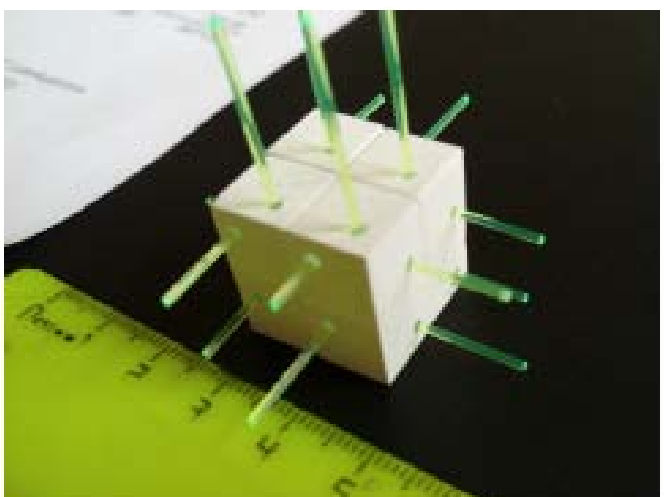
- Scintillator with WLS fiber read out by MPPC/SiPM
- 2 variations under consideration: 2D and 3D (SuperFGD)
- 2D FGD well known technology
- 3D would provide 4π sensitivity
- 3D needs factor 2-3 more readout channels
- Target mass: ~2 ton



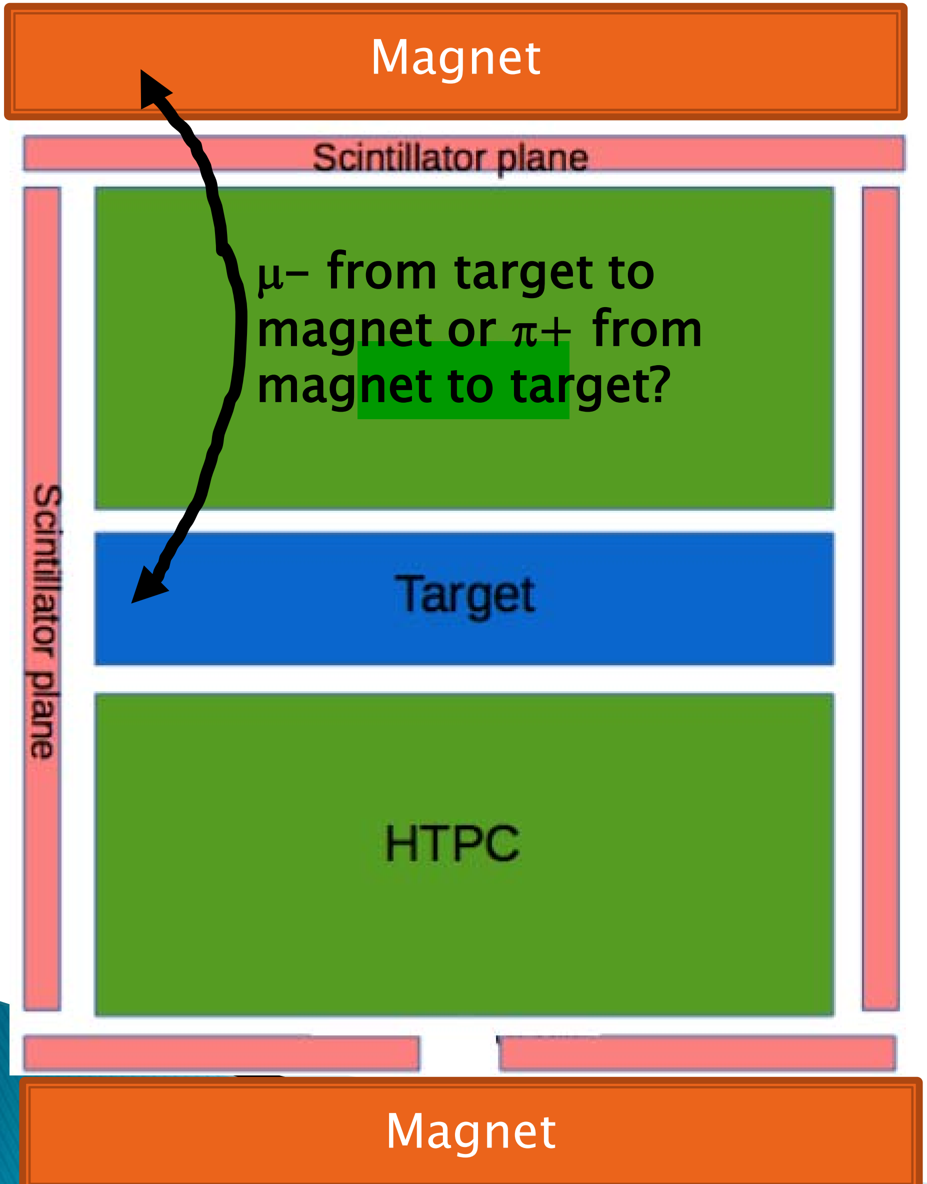
Scintillator Tracker

- Current baseline choice: SuperFGD
  - 1 cm^3 cubes, optically isolated, each with 3 WLS fibers
  - Fibers read out by ~60.000 MPPCs
  - Total detector: 2.000.000 cubes
- Simulations indicate that SuperFGD in 2D performs better than classical 2D FGD





Time of Flight

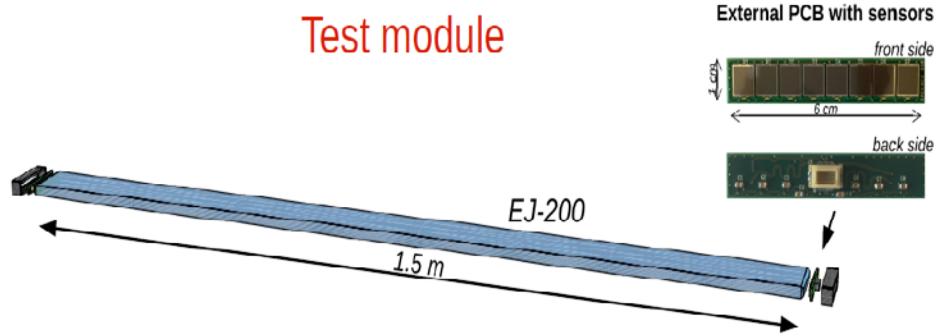


- TOF will provide:
  - PID with p from track curvature

$$m_{ToF} = p \times \sqrt{\frac{c^2(\Delta t_{reco})^2}{L^2} - 1}$$

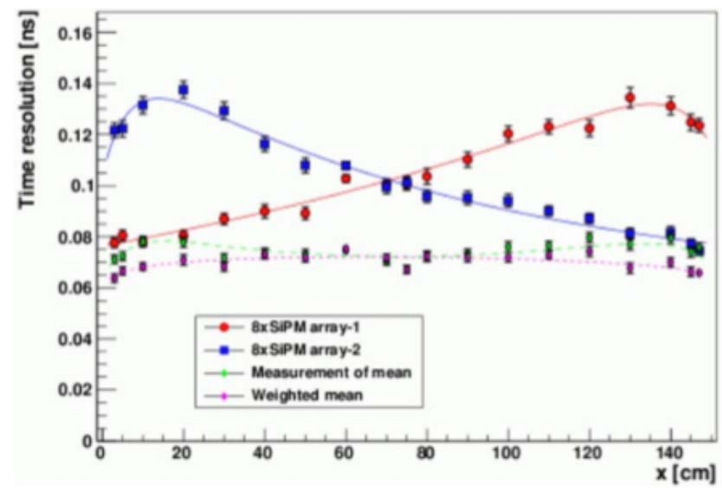
  - Identify direction of particle
- Crucial time resolution: scintillator, electronics, ...

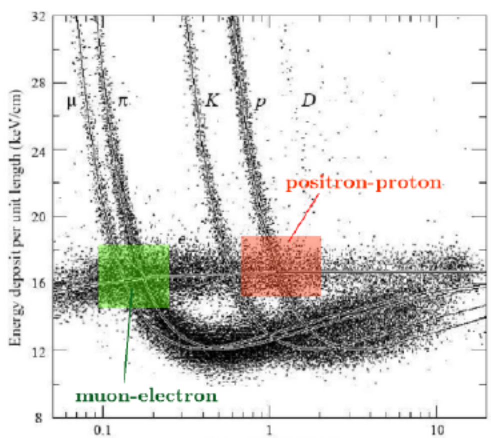
Time of Flight



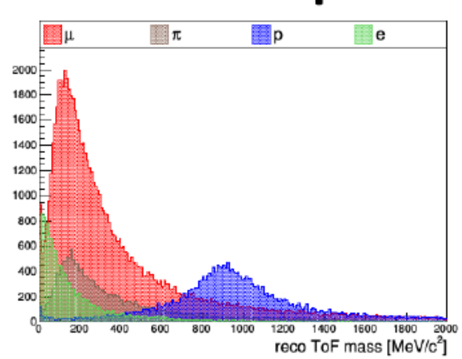
Baseline choice:

- Cast plastic scintillator: EJ-200
- 6 or 12 SiPM (6x6 mm2) directly coupled to scintillator
- readout from both sides
- tested already in CERN testbeam
- ~70 ps time resolution for 1.5 m bars achieved
- electronics could increase this to 150 to 600 ps

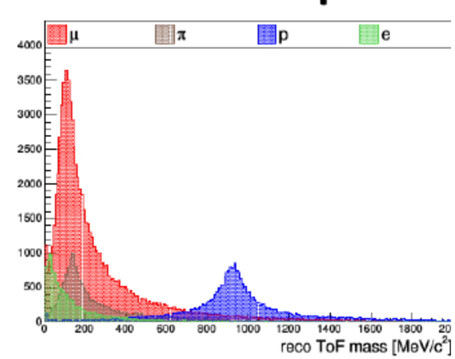




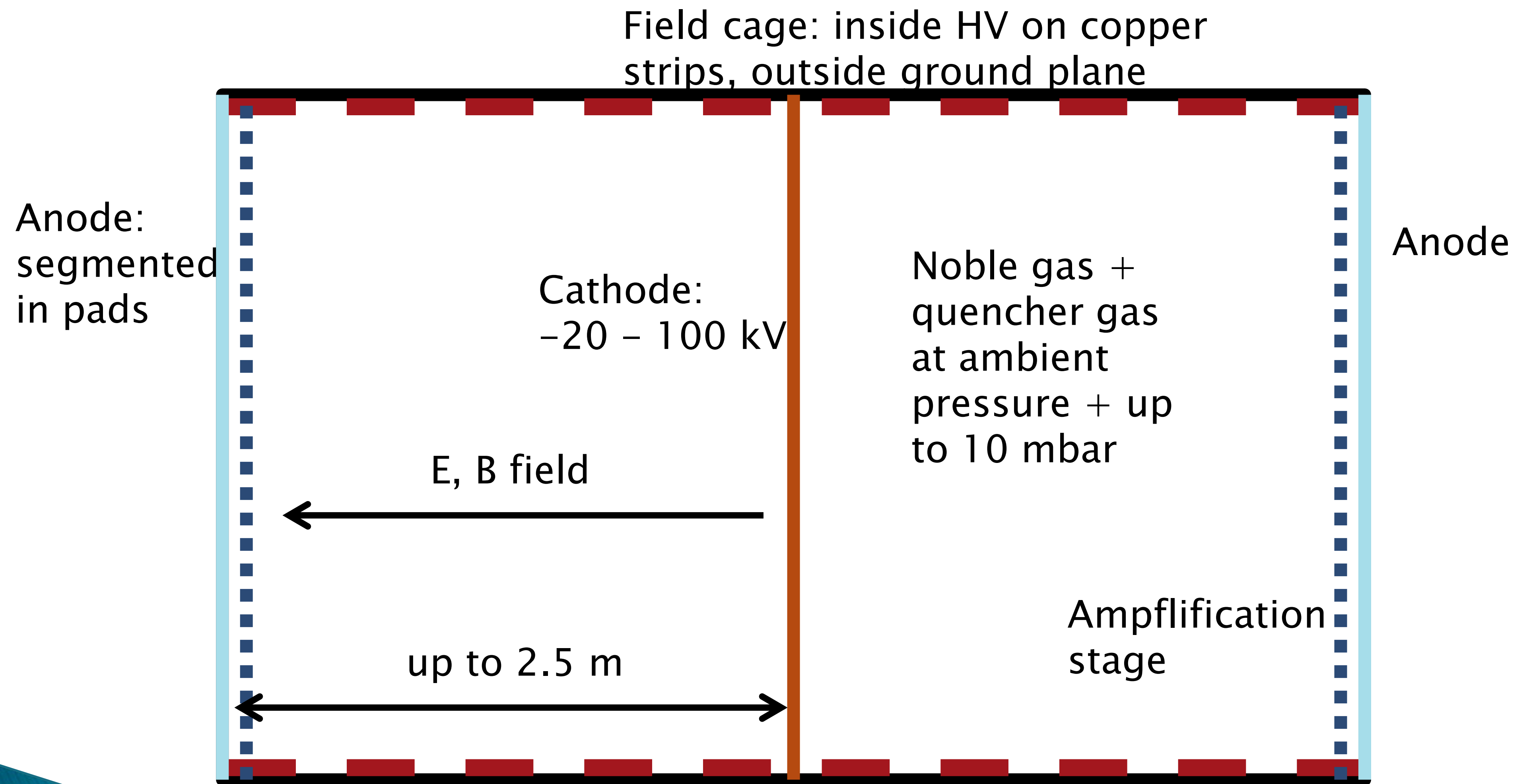
$\sigma = 600$ **ps**



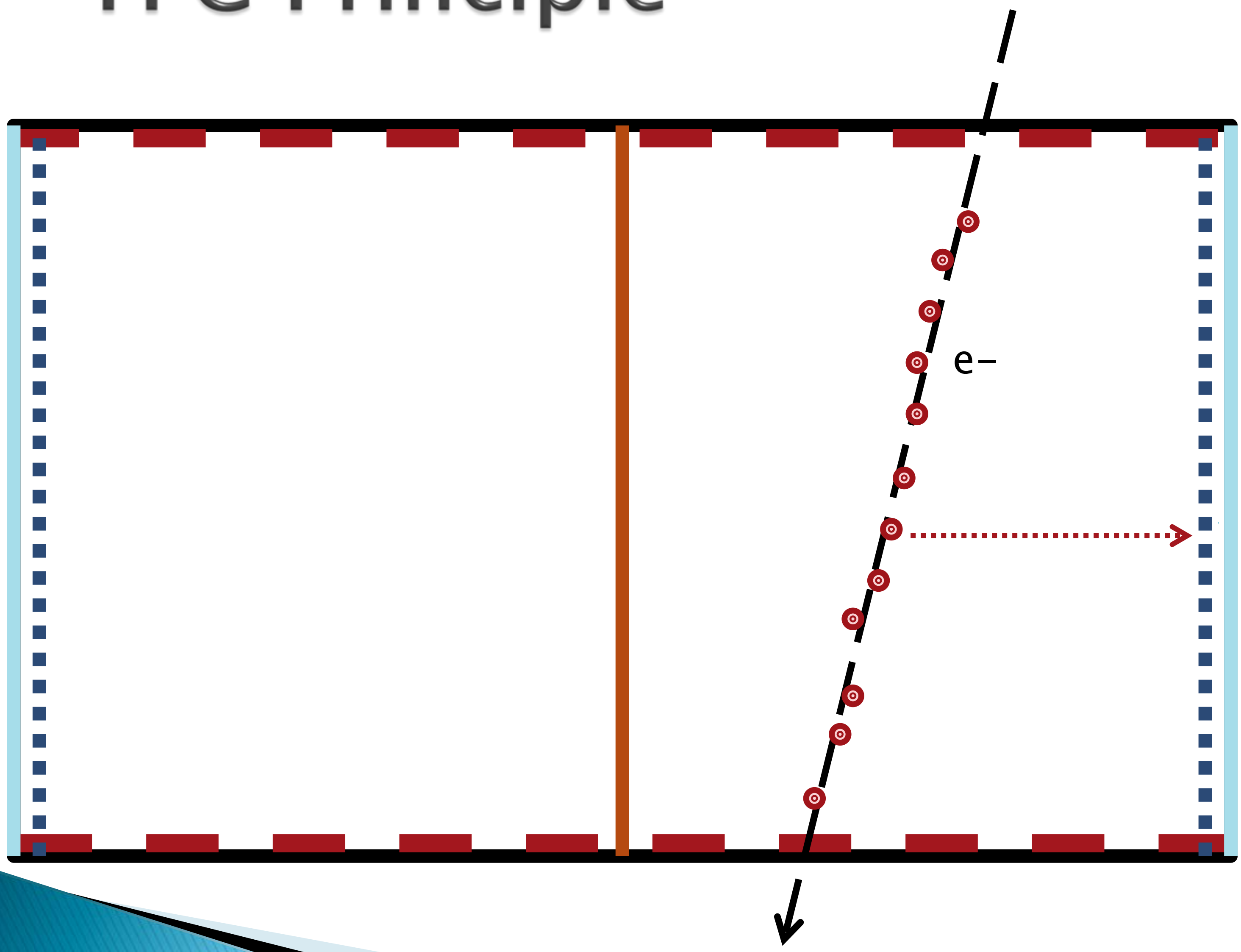
$\sigma = 150$ **ps**

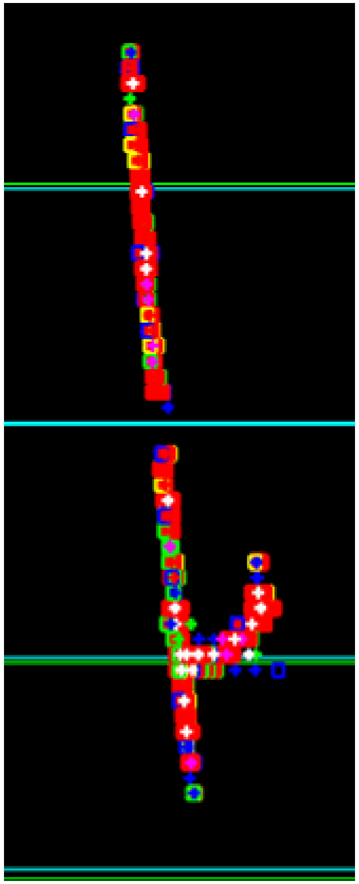


TPC Principle



TPC Principle



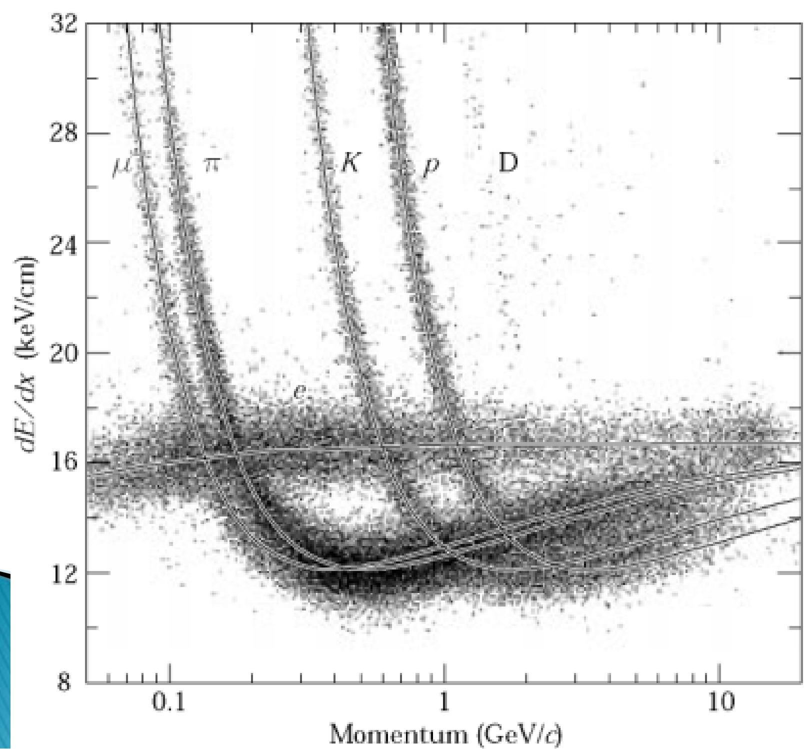


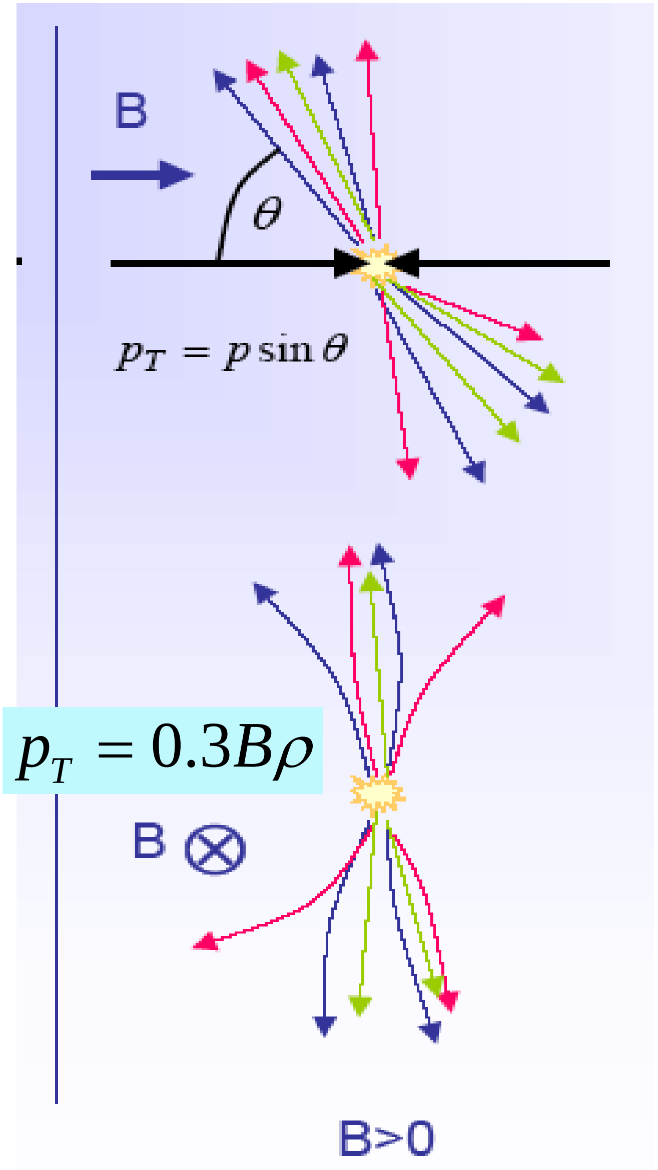
TPC Principle

$$p = p_{\perp} / \sin\theta = p_{\perp}\sqrt{1+\cot^2\theta}$$

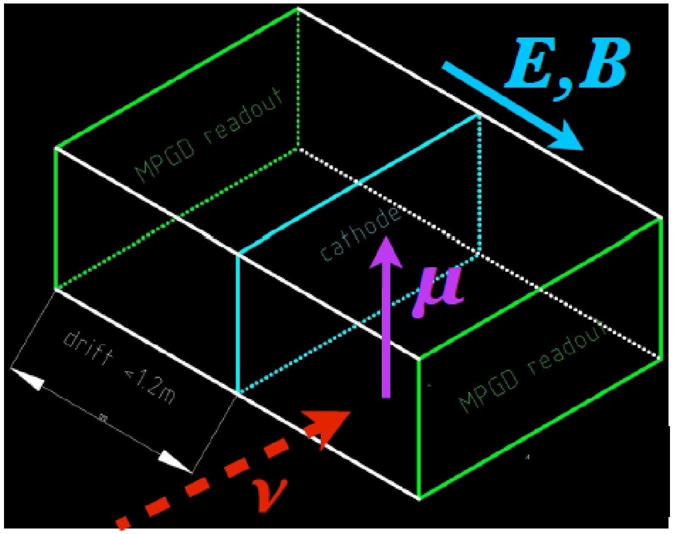
- momentum from track reconstruction
- dE/dx from deposited charge along track

=> Particle identification (PID)





New vertical TPCs



Parameter	Value for 1 TPC
Dimension	1.8(x) x 0.8(y) x 2.0(z) m^3
Volume	2.9 m^3
Drift Length	90 cm
Pad area	~1 cm^2 (~2 cm^2 resistive MM)
Sensitive area	3.2 m^4
# MM	16 (50x50 cm^2 each MM)
# channels	3.2×10^4

Walls have to ensure:

- Gas tightness
- Passing of low momentum particles => light materials
- Electric insulation of tens of kV for years
- Minimal deformations due to overpressure and gravity

Already done for ALEPH/DELPHI/... but these were cylindrical TPCs while we have rectangular TPCs!

New vertical TPCs

Challenging requirements/tolerances:

- Flatness of the cathode 100 μm
- Flatness of anode 200 μm
- Anode and cathode parallel within 200 μm
- Electric field homogeneity $<= 10^{-4}$ **(199.98 < E <200.02 V/cm)**
- Sensitive volume starts 1.5 cm from wall surface
- Withstand at least 30 kV
- Oxygen levels <= 10 ppm (21% ⇒ 0.001%)
- ...

And all this with a tight time schedule of course!

=> Many design choices to be taken soon!

Field Cage Wall Material

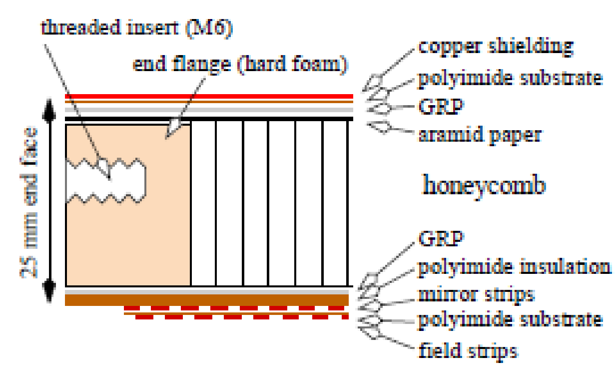
Flat surface suffering gravity and overpressure

⇒ What is the right choice for the wall material?

⇒ Composite materials but which?

First iteration based on choice of other experiments (for cylindrical TPCs):

WALL LAYERS	Thickness [mm]	Ex [N/mm^2]	Ey [N/mm^2]	vx -	Gxy [N/mm^2]	d [Ton/mm^3]
Copper shielding	0,010	110000		0,34	41045	7,76E-09
Polyimide substrate	0,050	2500		0,34	933	1,42E-09
outer GRP	0,300	28000		0,15	12174	1,80E-09
Honeycomb	23,500	1	1	0,3	56	4,00E-11
inner GRP	0,300	28000		0,15	12174	1,80E-09
Polyimide insulation	0,125	2500		0,34	933	1,42E-09
Mirror strips	0,280	110000		0,34	41045	7,76E-09
Polyimide substrate	0,050	2500		0,34	933	1,42E-09
Field copper strips	0,280	110000		0,34	41045	7,76E-09

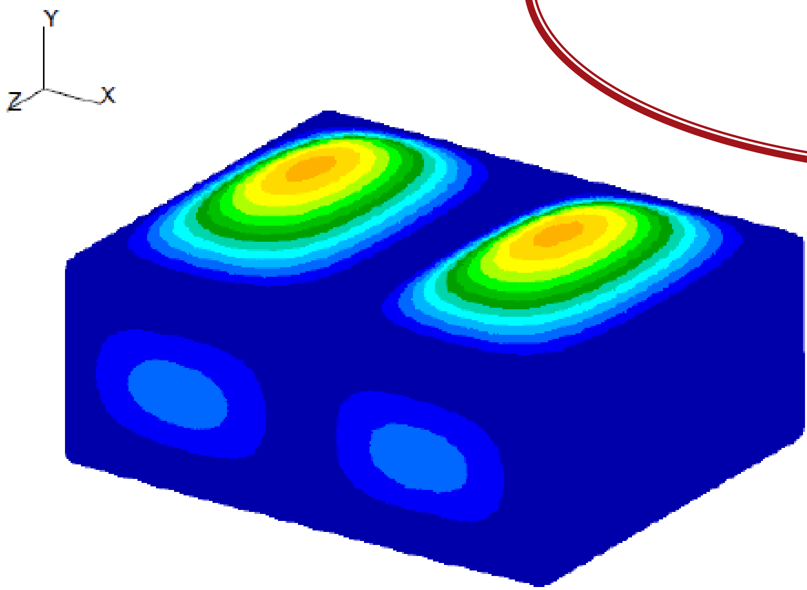


Field Cage Wall Material

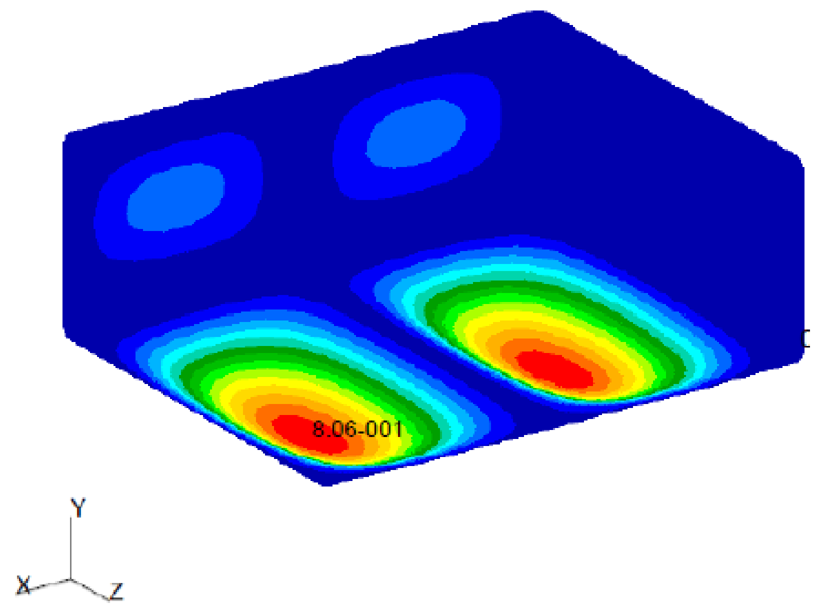
RESULTS

10 mbar - ILC TPC WALL - **MAX DEFORMATION = 0,806 mm**

Rad. Length: 1.6%



That is a lot!

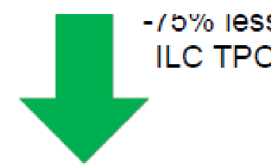


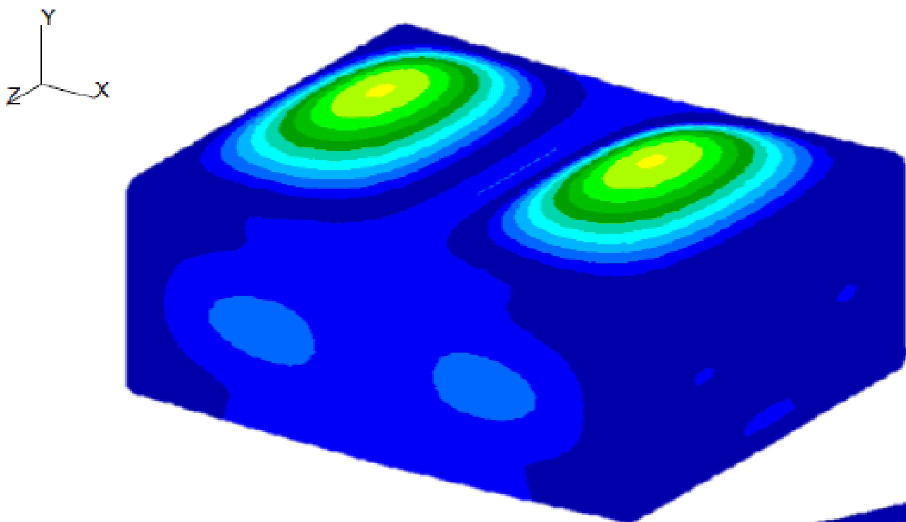
Structural simulations done by Juli

Field Cage Wall Material

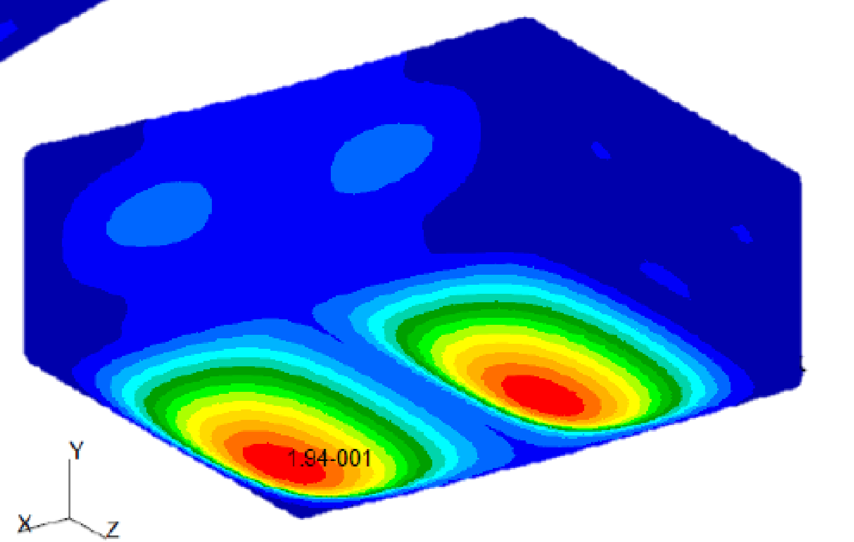
Rad. Length: 2.4%

10 mbar - ILC TPC + CF 2mm - **MAX DEFORMATION = 0,194 mm**





Adding 2 mm of carbon fiber helps a lot!



More options under study and iterations required. Also thermal expansion will be studied.

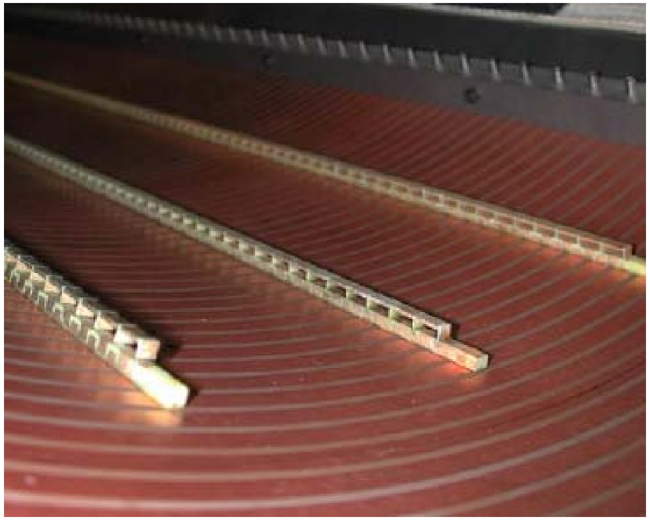
Field Forming Structure

Aim: continuous degradation of potential between anode and cathode
Practice: Do it in small steps! Parallel copper strips on the walls connected by resistors.

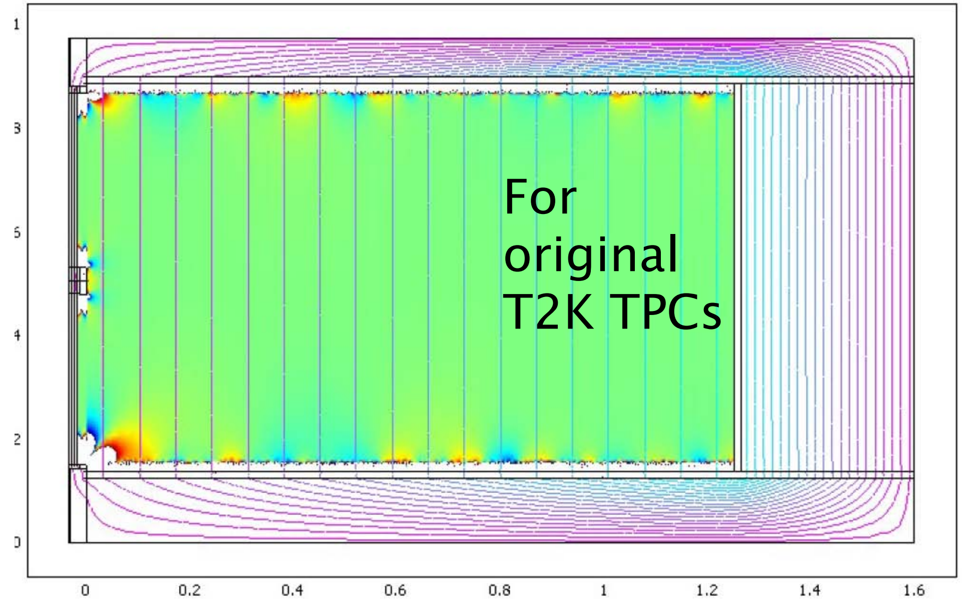
Sounds simple but many options how to realize it:

Double sided copper strips on Kapton: more expensive

Mirror strips inside the gas: cheaper but more space lost

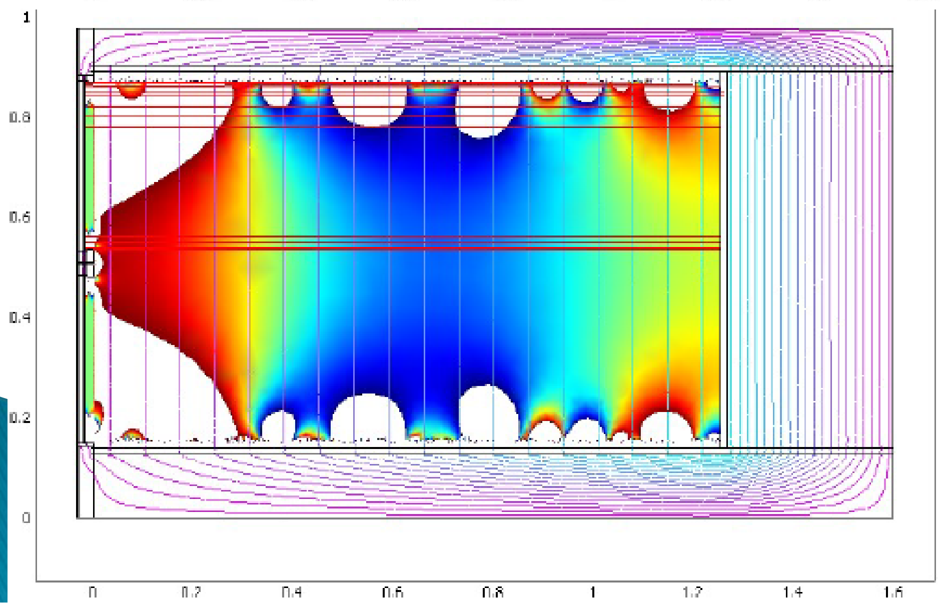


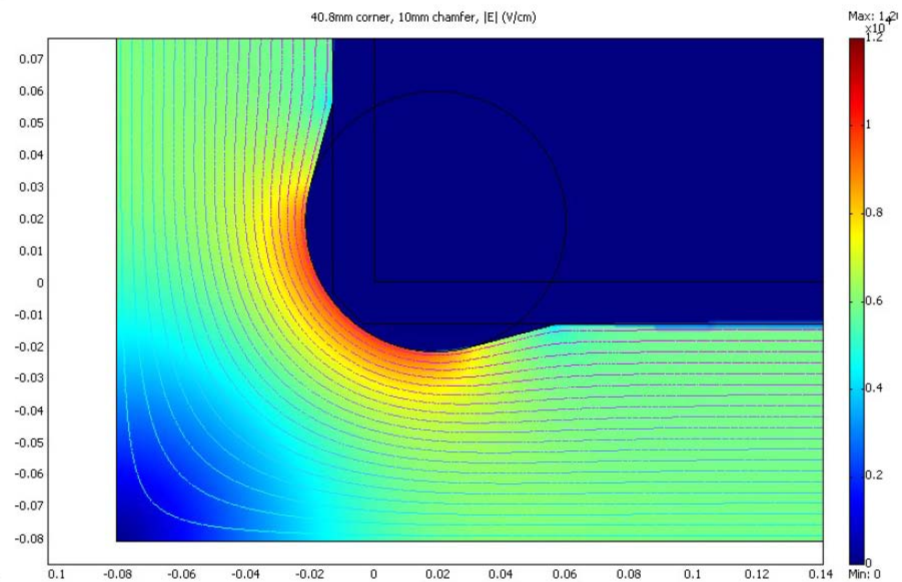
Electric Field Simulations



Many electric field simulations needed for detector optimization:

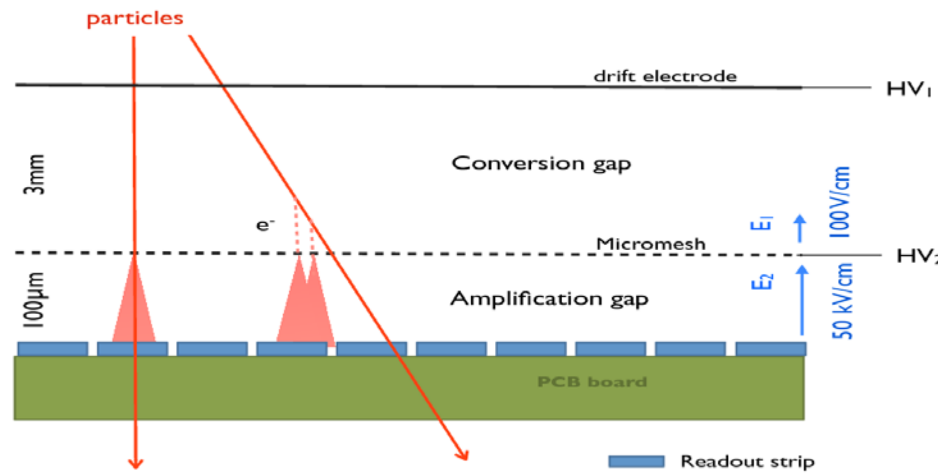
- realistic resitors have tolerances e.g. 0.1%
- Corners of the TPC
- Readout plane integration
- Cathode integration
- ...

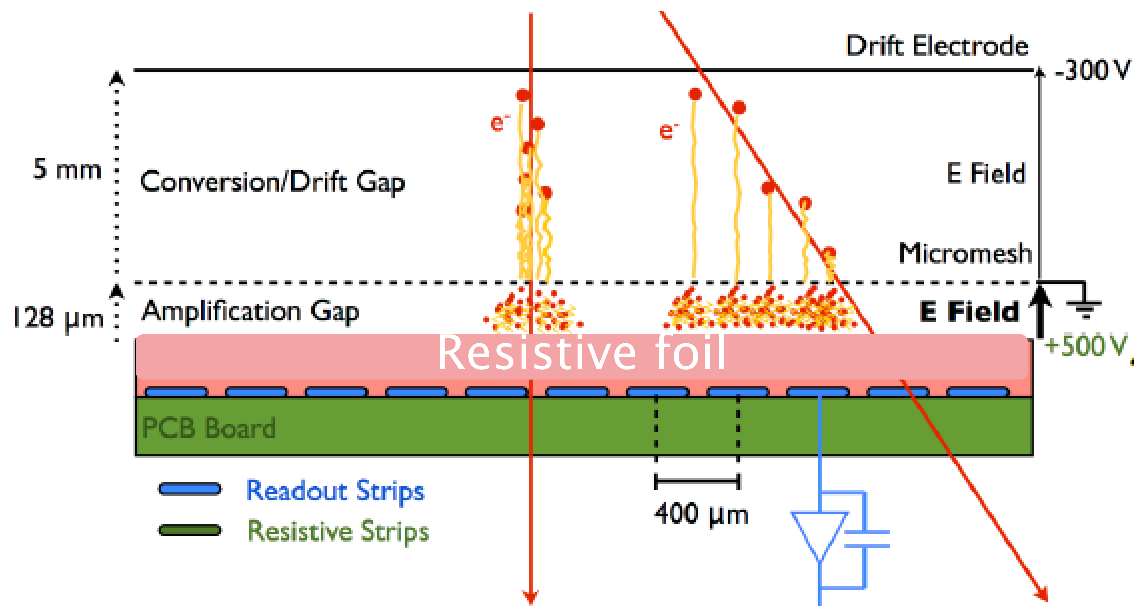




Micromegas Readout

- T2K was first full size TPCs with MPGD readout
- Good performance for T2K but further development ongoing
- Aim: use resistive foil in readout to spread charge over several pads
- T2K will have first TPCs with resistive MM readout



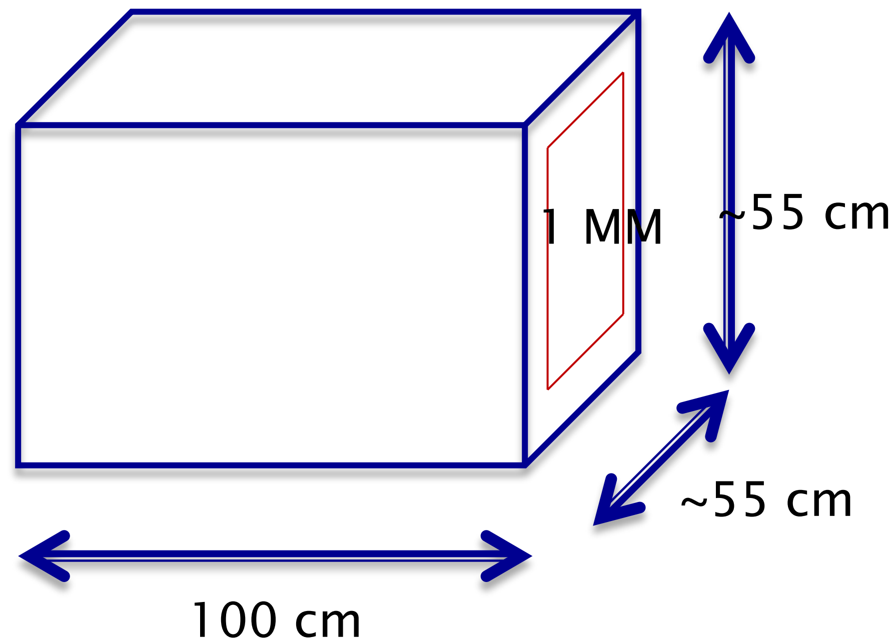


Time Schedule

2 phases:

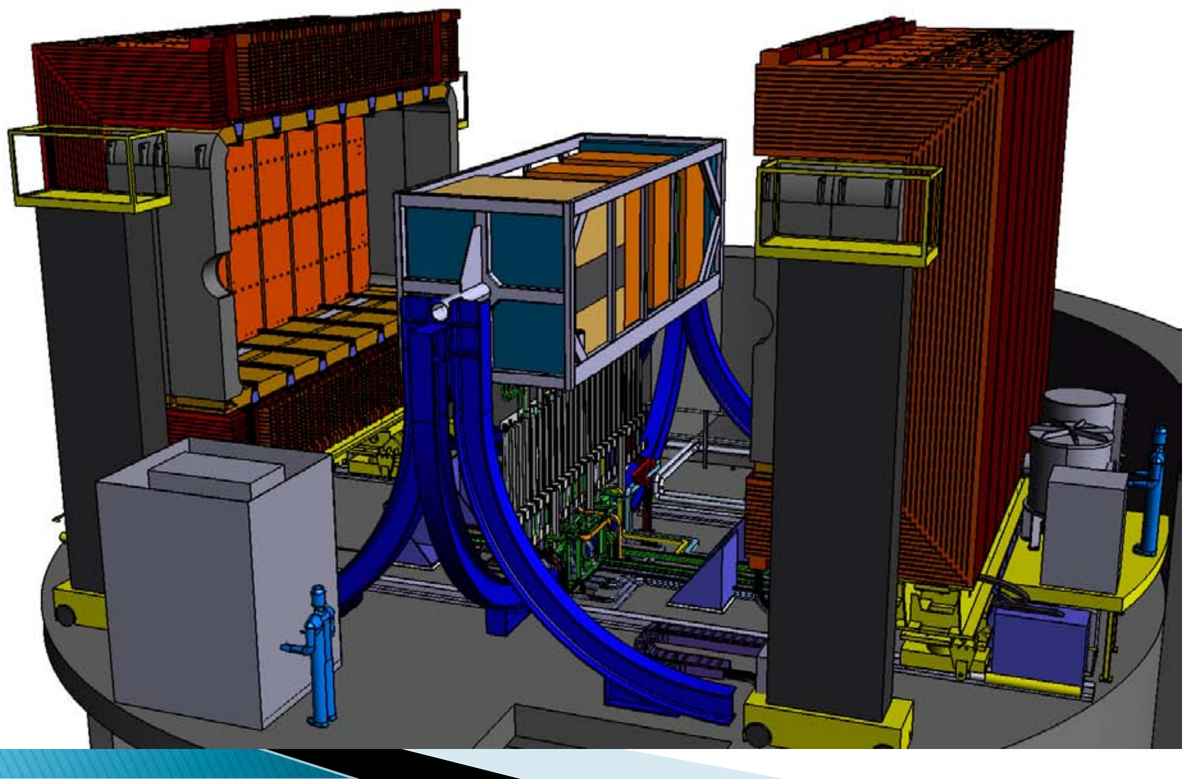
- TPC Prototype (funds available):
  - Currently design phase
  - Production of pieces in spring/early summer
  - Assemblying of field cage: June/July 2018 at INFN Padua
  - Full integration: July/August 2018 at CERN
  - Testbeam: September 2018

  ⇒ Test resistive foil MMs and production process of TPC construction



Time Schedule

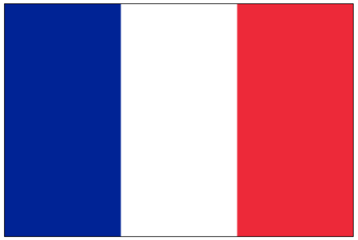
- Final TPCs:
  - Optimize design
  - Production 2019/20
  - Commissioning with cosmics
  - 2021 installation at JPARC



T2K TPC Collaboration

Bari and Padova

Krakow



IFAE Contribution to Upgrade

F. Sanchez:

- Testbeam working group convener

T. Lux:

- Overall integration working group convener
- TPC field cage design

J. Mundet:

- TPC field cage design

J. Boix:

- Optimization of electronics readout

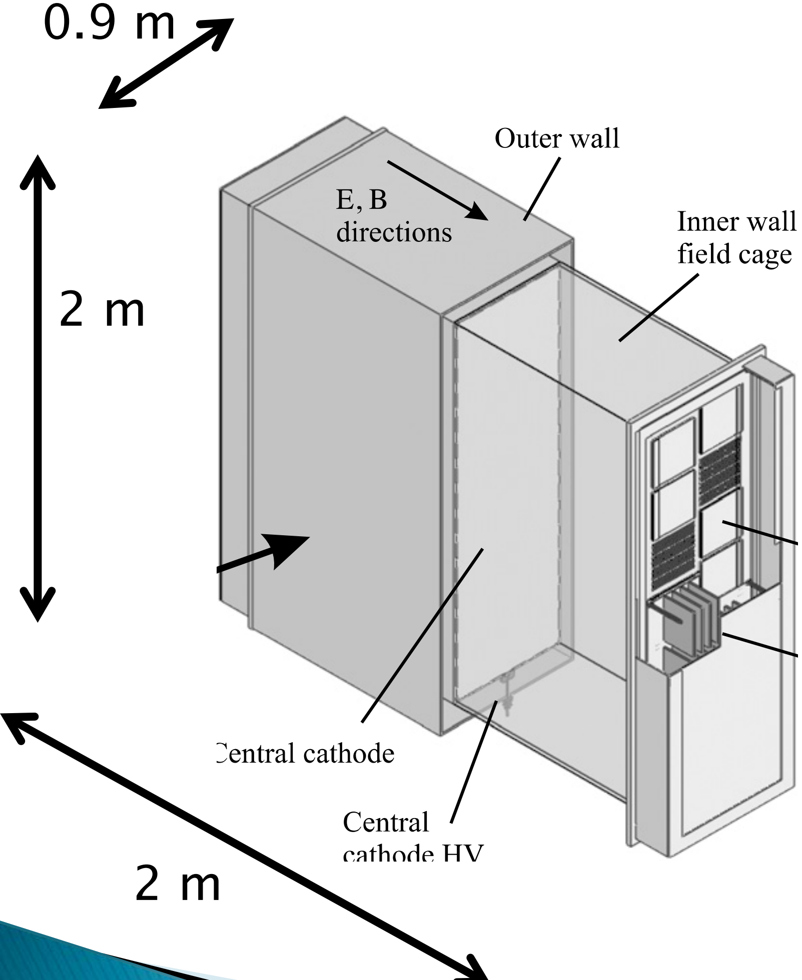
PhD student (candidate there but funding to be ensured):

- Geant 4 simulations related to TPC
- TPC prototype construction, commissioning, testbeam and data analysis

Conclusions

- IFAE Neutrino group: Back to the roots!
- Participating in the upgrade of T2K ND
- Focussing on TPC where our expertise lays
- Number of important positions in management organization
- Challenging year with design, production and testing of TPC prototype lays ahead
- Final TPCs have to be delivered in 2021 to Japan

Current horizontal TPCs



- dual gas volume design
- outer volume filled with CO_2
- inner/sensitive volume with Ar:iC4H10:CF4 gas

- Pros:
  - electric insulation by CO_2 gas => undestrutable
  - practivally no pressure difference between inner and outer volume => no deformation of inner walls
  - additional layer of gas purity protection
- Cons:
  - 2 volumes to be produced
  - **large dead volume between subdetectors: ~10 cm**

New TPC Geometry

two of the dimensions are very large in
kness).