T2K Near Detector Upgrades and Plans for T2HK

Thorsten Lux

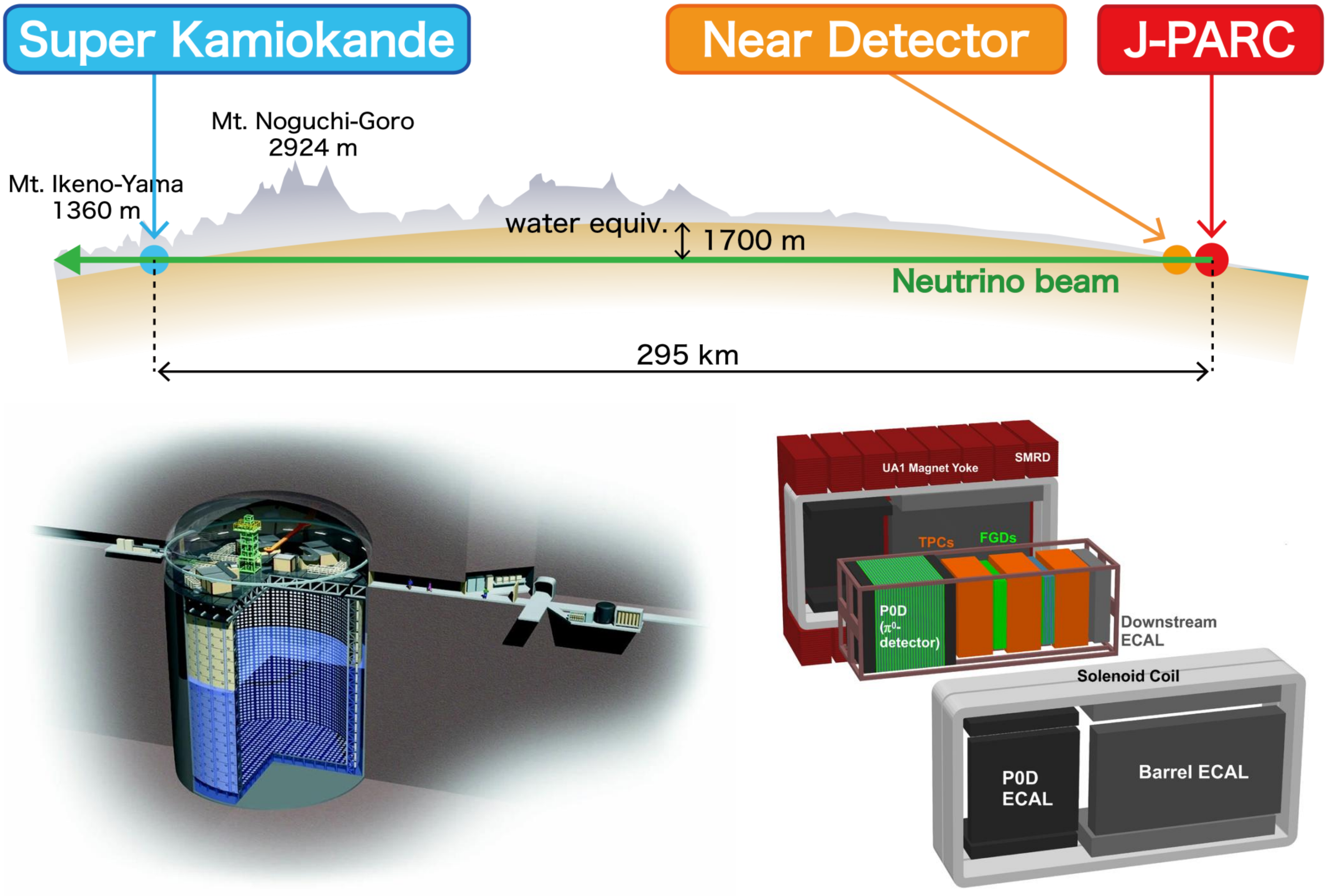
On behalf of the

ND280 Upgrade Working Group

Institute for High Energy Physics

EXCELENCIA SEVERO OCHOA

Barcelona Institute of Science and Technology

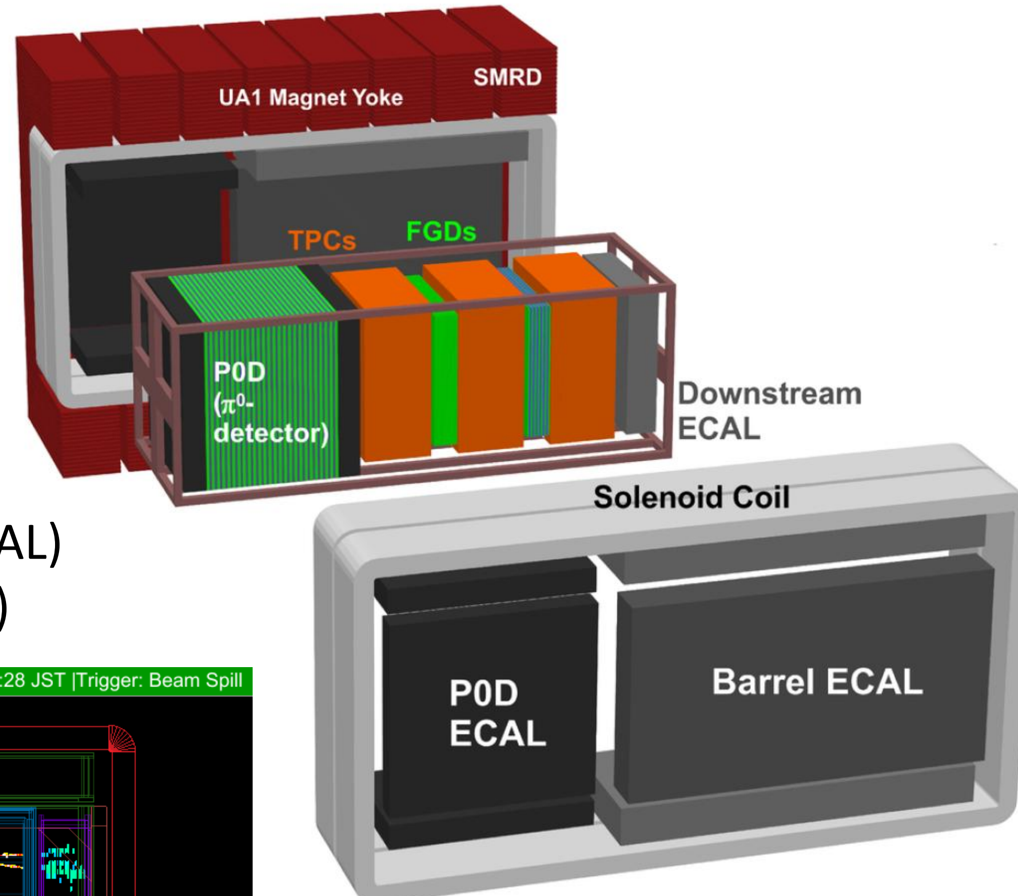


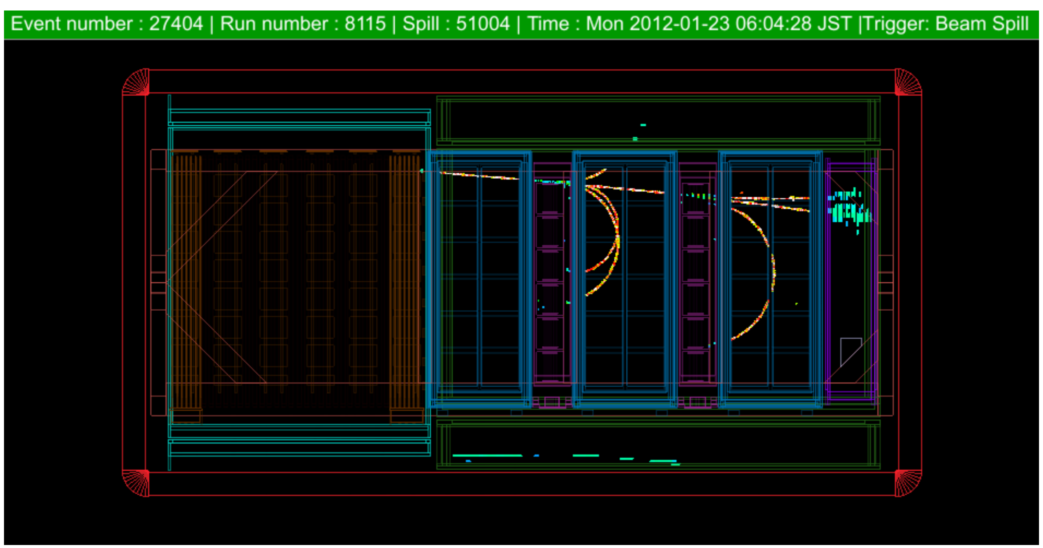
Super Kamiokande
Near Detector
J-PARC
Mt. Noguchi-Goro
2924 m
Mt. Ikeno-Yama
1360 m
water equiv.
1700 m
Neutrino beam
295 km
UA1 Magnet Yoke
SMRD
TPCs
FGDs
P0D
(π^0-
detector)
Downstream
ECAL
Solenoid Coil
P0D
ECAL
Barrel ECAL

ND Purpose: Measurement of neutrinos before oscillation

ND components:

- UA1 magnet: 0.2 T
- π0 detector (POD)
- 2 Fine Grain Detectors (FGD):
    - target, FGD2 with H2O
    - XY scintillator bars
    - 1 ton each
- 3 Time Projection Chambers (TPC)
- Electromagnetical Calorimeter (ECAL)
- Side Muon Range Detector (SMRD)





T2K-II

arxiv:1609.04111

- aim: systematics from 5-6% to 4%
- beam power upgrade:

485 kW → 1.3 MW

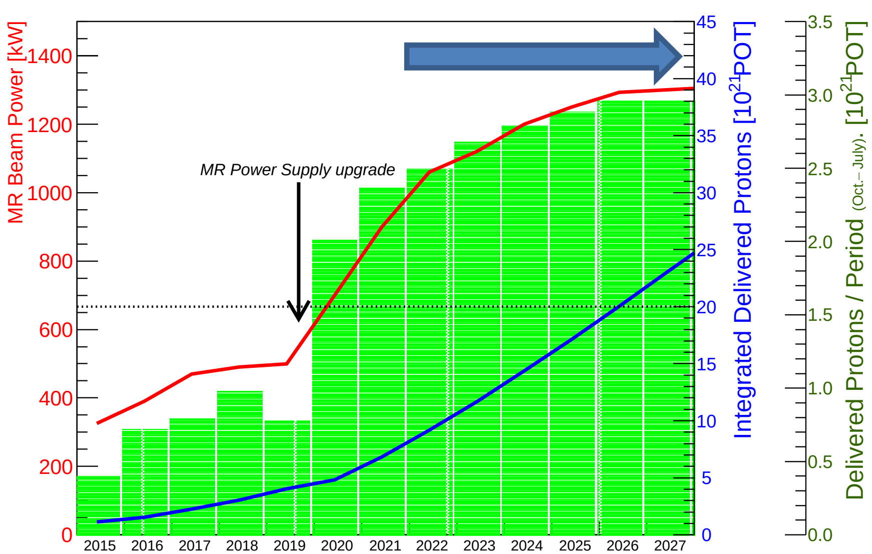
- statistics:

3E21 POT (2018) → 20E21 POT (2026)

- Aim for CPV observation in optimal

scenario at 3σ

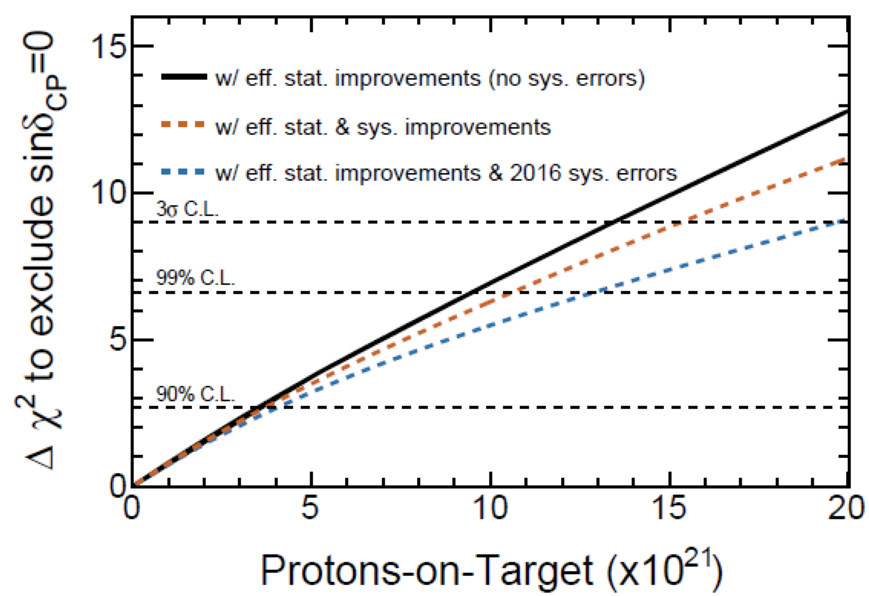
T2K-II Protons-On-Target Request



arXiv:1609.04111

Phys. Rev. D, 96:092006, 2017

Source of uncertainty	ν_e CCQE-like $\delta N/N$	ν_μ $\delta N/N$	ν_e CC1π^+ $\delta N/N$
Flux (w/ ND280 constraint)	3.7%	3.6%	3.6%
Cross section (w/ ND280 constraint)	5.1%	4.0%	4.9%
Flux+cross-section			
(w/o ND280 constraint)	11.3%	10.8%	16.4%
(w/ ND280 constraint)	4.2%	2.9%	5.0%
FSI+SI+PN at SK	2.5%	1.5%	10.5%
SK detector	2.4%	3.9%	9.3%
All			
(w/o ND280 constraint)	12.7%	12.0%	21.9%
(w/ ND280 constraint)	5.5%	5.1%	14.8%



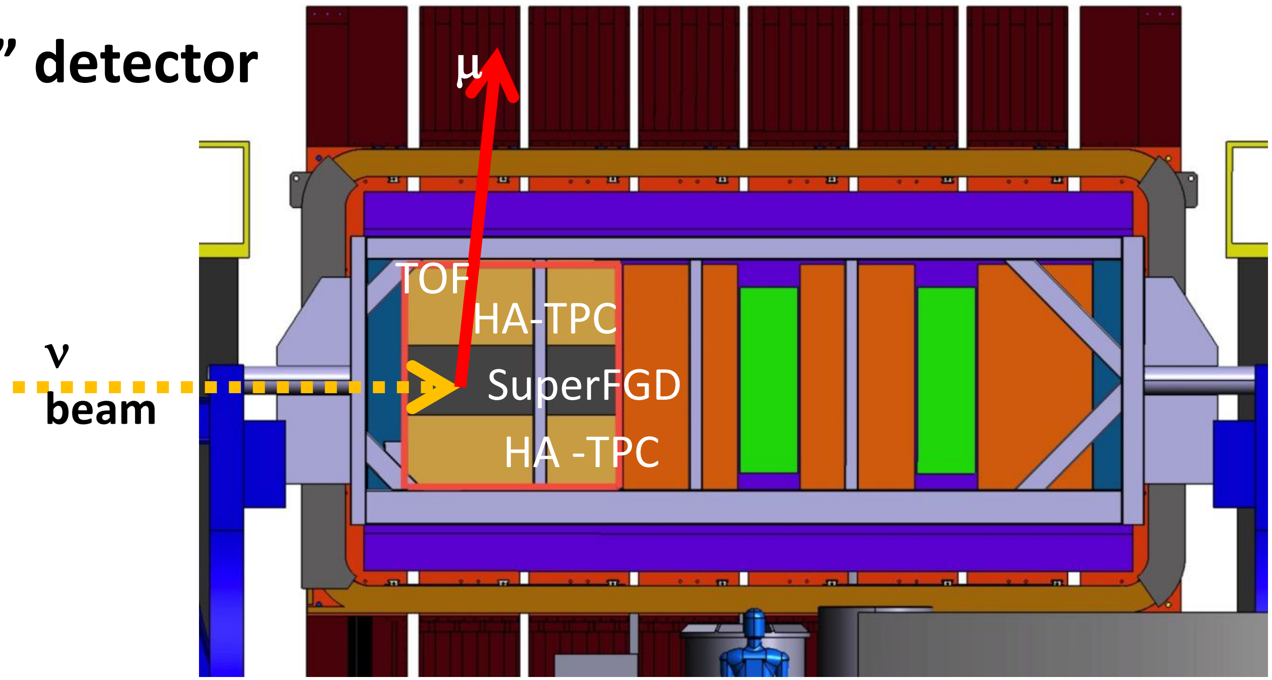
N280 Upgrade replace POD by:

- 1 fine graned scintillator target (SuperFGD)
- 2 high angle TPCs (HA-TPC)
- 6 time of flight panels (TOF)

	Current (FGDs)	Upgrade (FGDs + SuperFGD)
Target mass (tons)	2.2	~4.2

CERN-SPSC-P357

“4π” detector

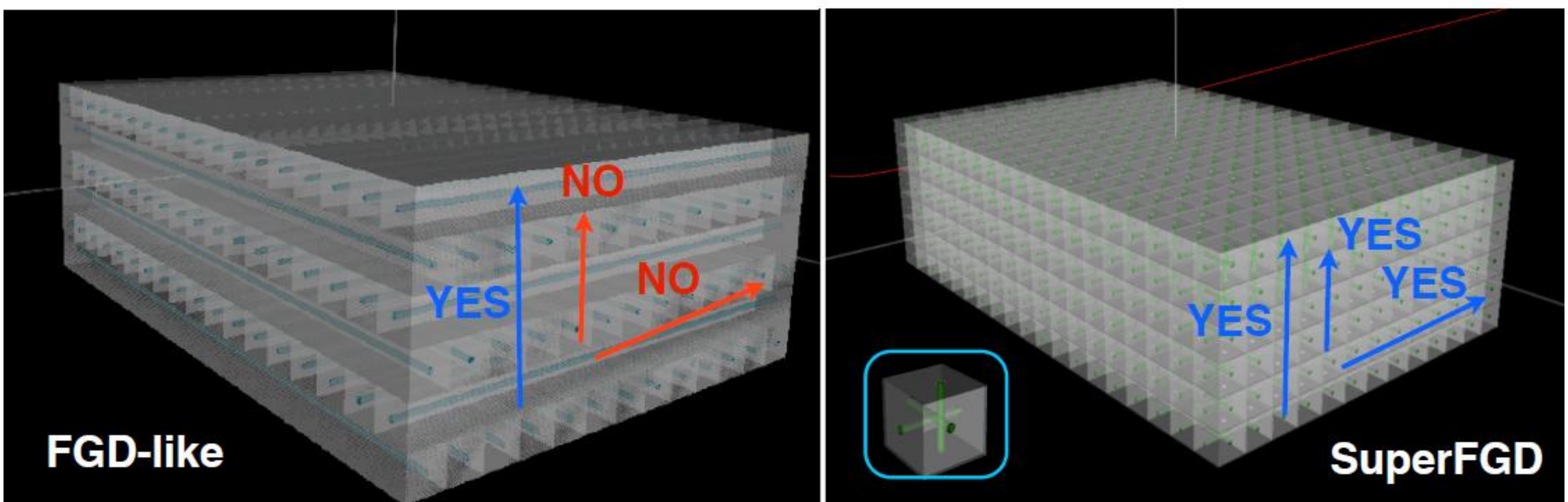


SuperFGD

JINST 13 (2018) no.02, P02006

- scintillator, WLS fibers + MPPCs
- classical 2D approach reconstruction limitations
- new 3D approach: 1x1x1 cm^3 cubes with 3 WLS fibers
- size: ~1.8x0.6x2 m^3

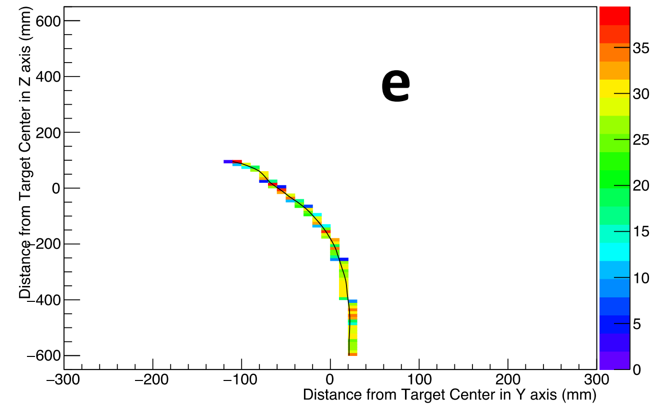
Parameter	Cube edge: 1 cm
# of cubes	2,160,000
# of channels	58,800
Total fiber length	65 km

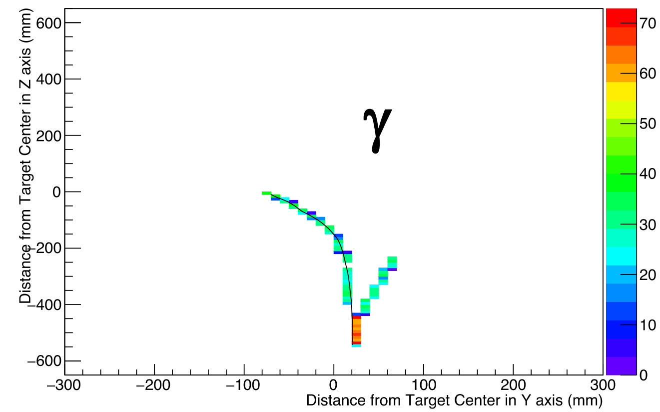


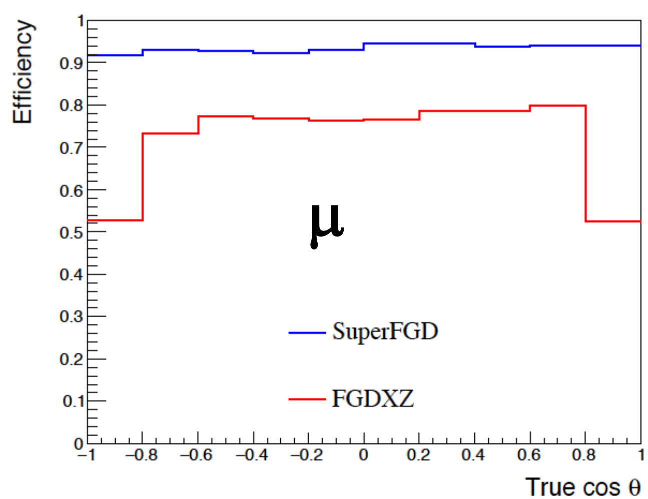
SuperFGD

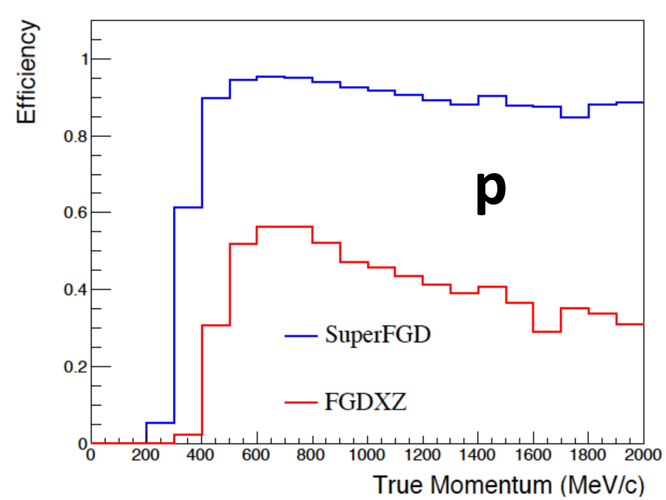
Simulation studies:

- high granularity allows excellent pattern recognition
- light yield from the 3 fibers helps to distinguish 1 from 2 particles => e/γ separation
- significant improvement on **p** reconstruction efficiency



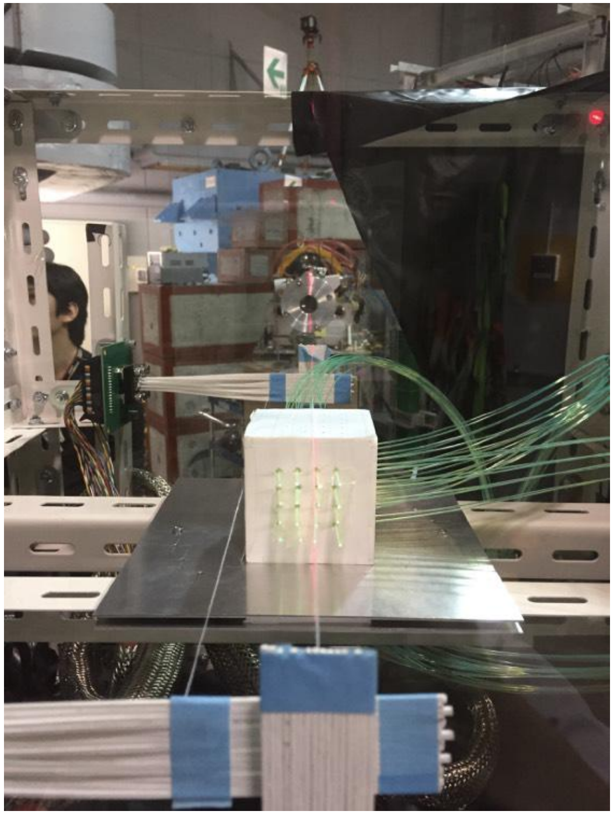


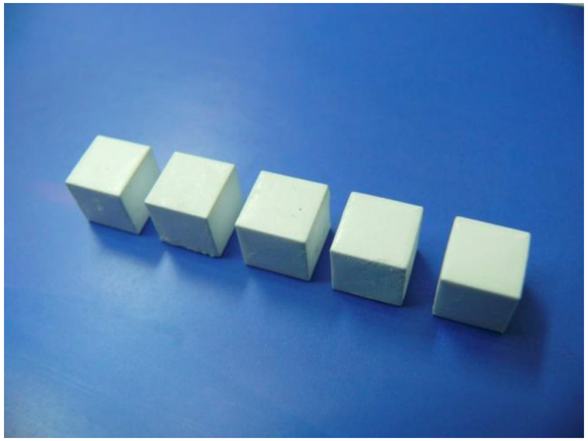


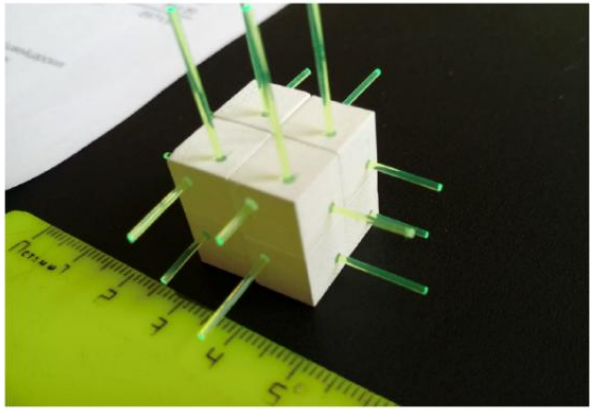


SuperFGD

- Cube production by injection mold method at INR RAS (uncertainty ~35 μm)
- Reflector coating (~50 μm) by chemical etching Uniplast (Russia)
- 2017: prototype of 5x5x5 tested at CERN testbeam:
    - light yield
    - cross talk
    - timing resolution

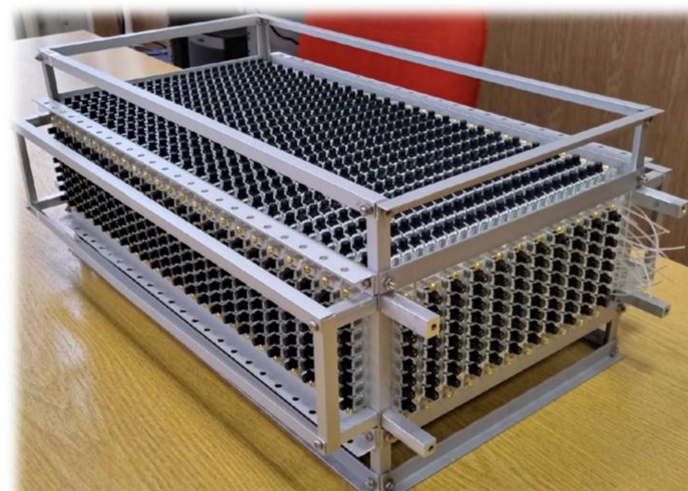






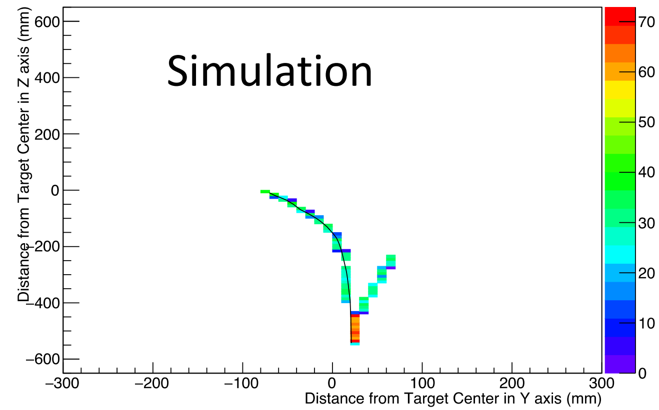
SuperFGD: Is it scaleable?

- prototype of 9216 cubes
- size: 8x24x48 cm^3
- 1728 fibers/MPPCs
- 3 type of MPPCs
- adapted Baby MIND electronics (based on CITIROC chip) for readout
- Testbeam at CERN beginning of July
- e, μ, π, protons and γ (!)

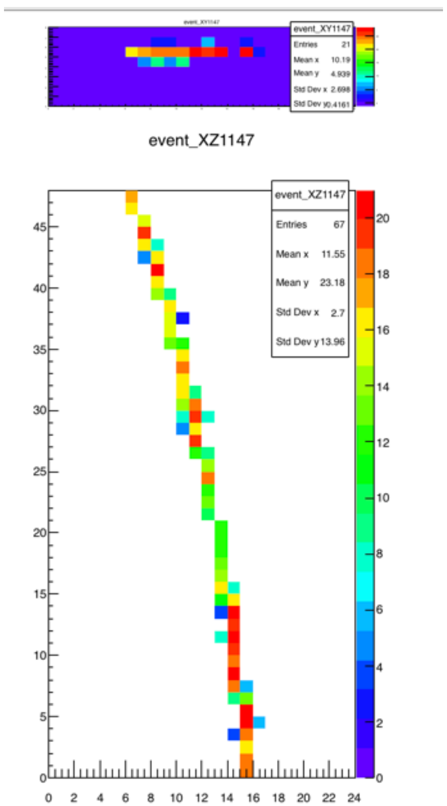


SuperFGD:

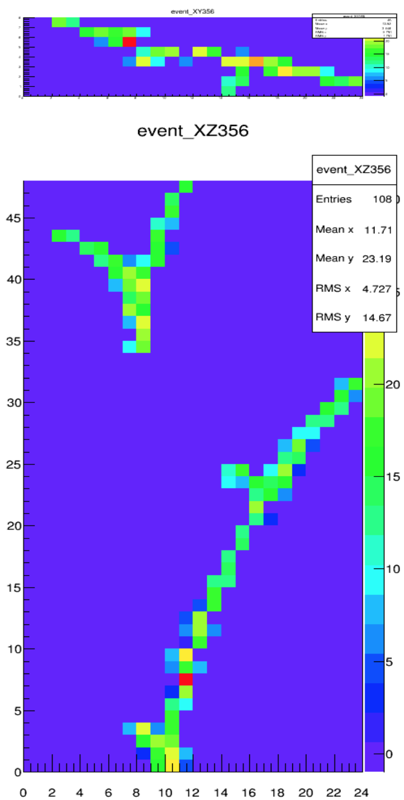
- very successful data taking
- important step towards full size detector
- detailed data analysis ongoing



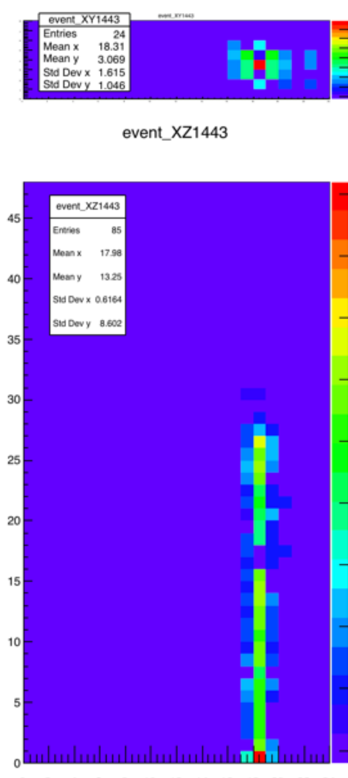
Single track



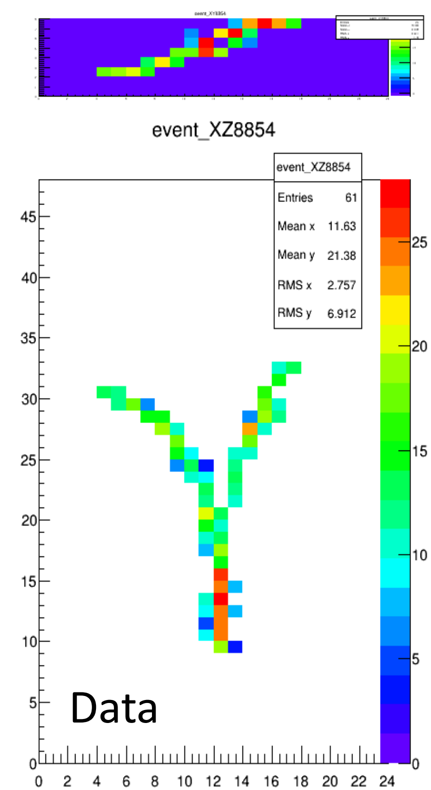
Pion beam



Stopping proton

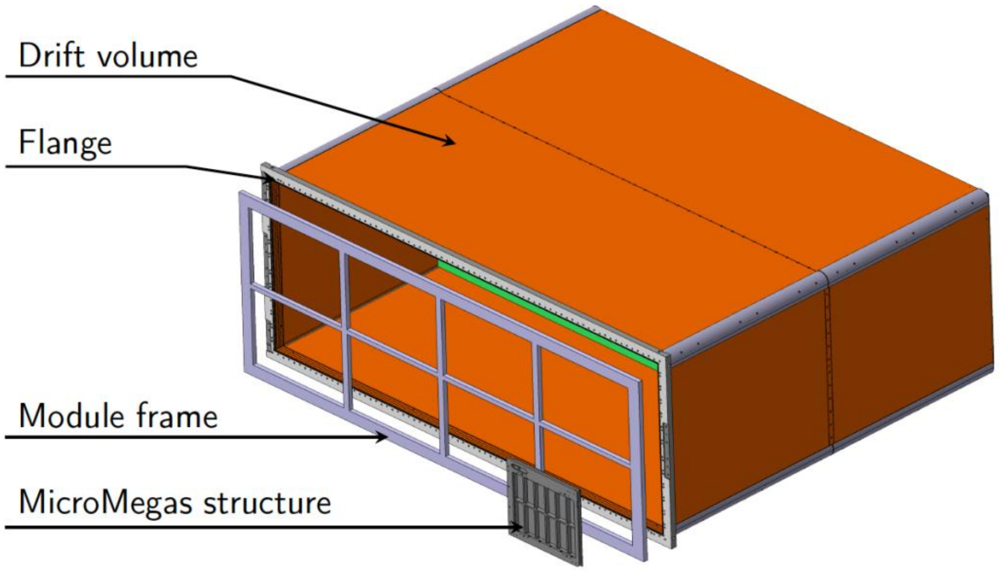


Photon beam



HA-TPC:

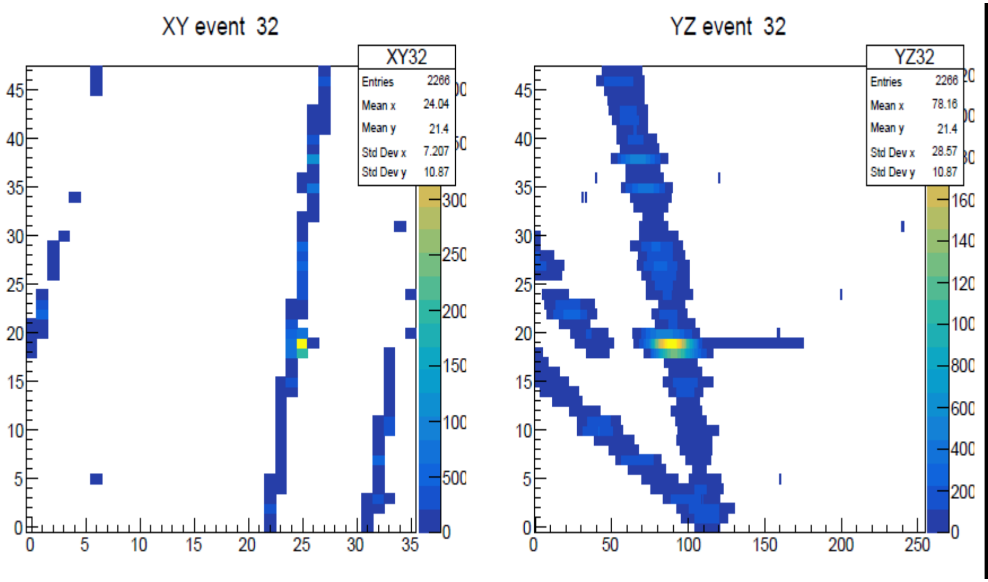
- 2 rectangular TPCs
- inner dimensions:
  - 1.8 m wide
  - 0.7 m height
  - 2 x 1.06 m drift
- single gas volume
- composite material FC
- radiation length: 2-3% X_0
- 8 resistive MicroMegas
- T2K gas: 93% Ar, 3% CF_4, 2% iC_4H_{10}
- Cathode voltage: ~25 kV
- readout electronics based on AFTER chip
- 10% $\Delta p/p$ at 1 GeV/c

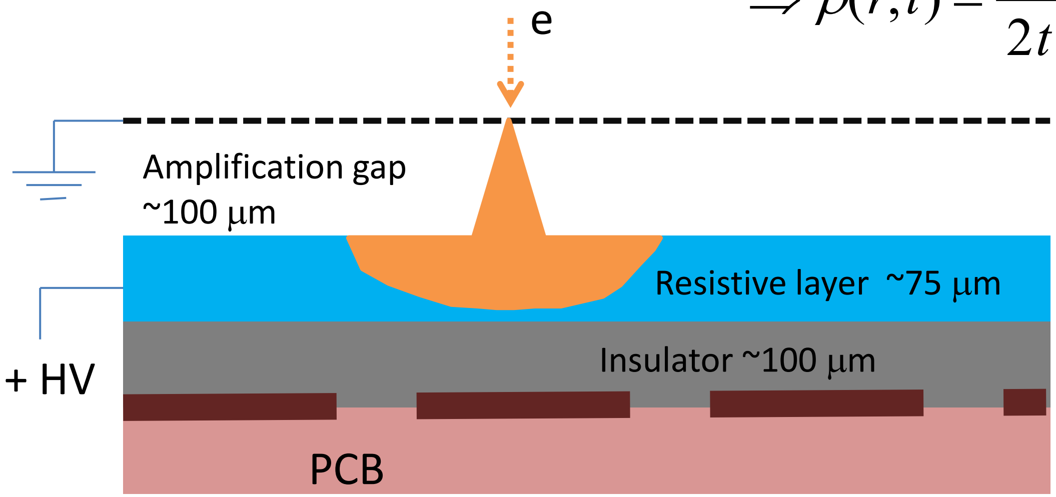


Material	**Thickss (mm)**
Copper coated polymide film	***~ 0.15***
Aramid Fiber Fabric (Kevlar)	***2.00***
Aramide HoneyComb panel	***30.00***
Aramid Fiber Fabric (Kevlar)	***2.00***
Polymide film (insulation)	***~ 0.10***
Strips (double later) on Kapton foil	***~ 0.15***
TOTAL	***~34.40***

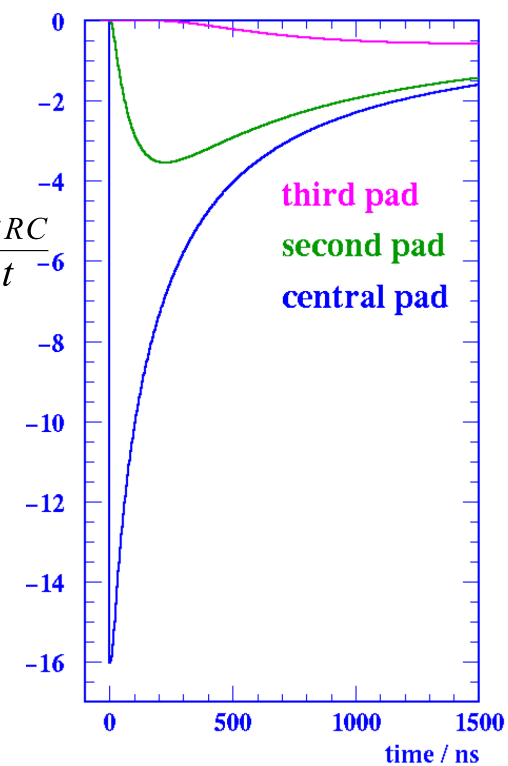
HA-TPC:

- avalanche size in MM few microns => no charge sharing between pads
- adding resistive layer to spread charge *(NIM* A518 *(2004) 721)* => reduction of electronics channels
- first prototype tested with cosmics and 15 cm drift at Saclay
- testbeam with 150 cm drift end of August





$$\Rightarrow \rho(r,t) = \frac{RC}{2t} e^{\frac{-r^2 RC}{4t}}$$

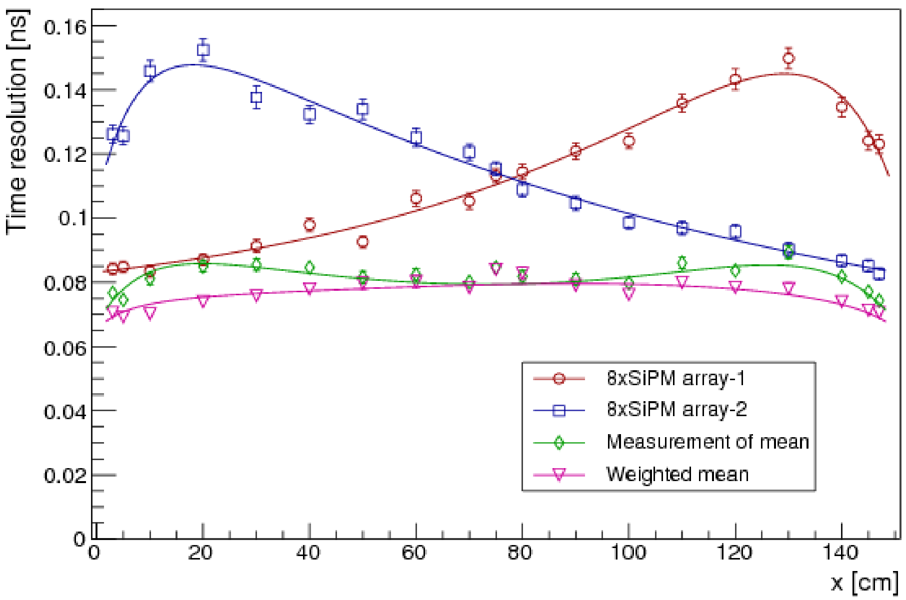


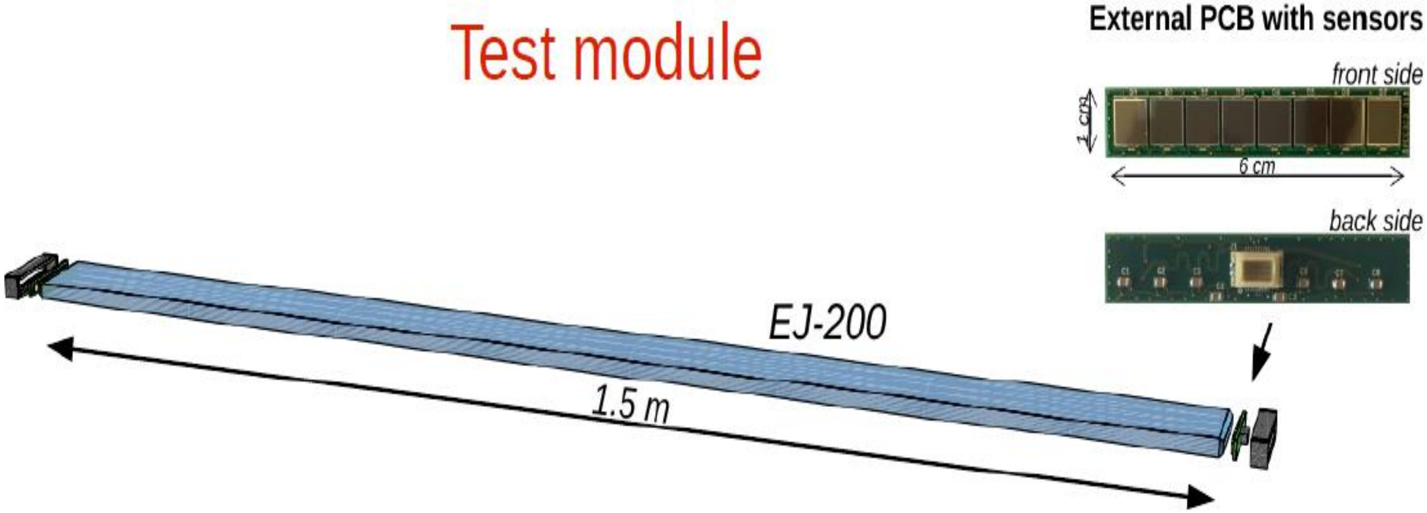
TOF:

JINST 12 (2017) no.11, P11023 (arXiv:1709.08972)

Baseline choice:

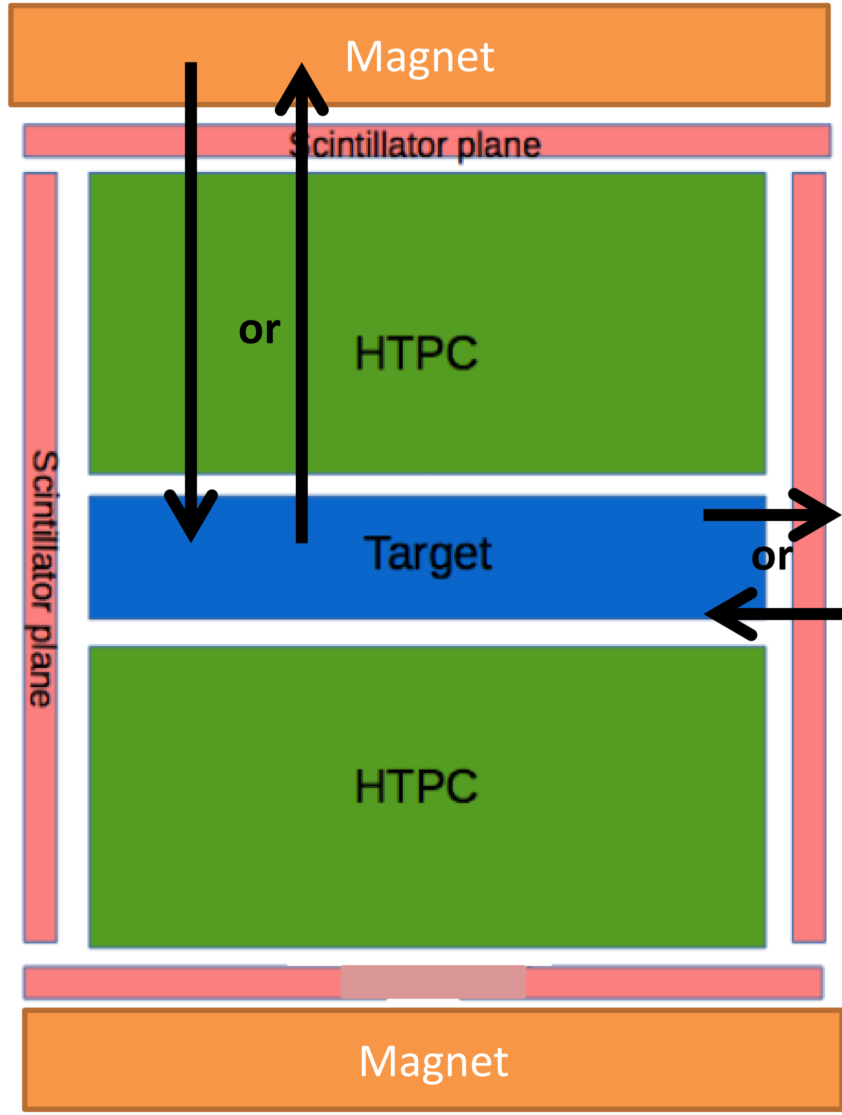
- Cast plastic scintillator: EJ-200
- 8 SiPM (6x6 mm2) directly coupled to scintillator
- readout from both sides
- tested in CERN testbeam 2017
- ~70 ps time resolution for 1.5 m bars achieved





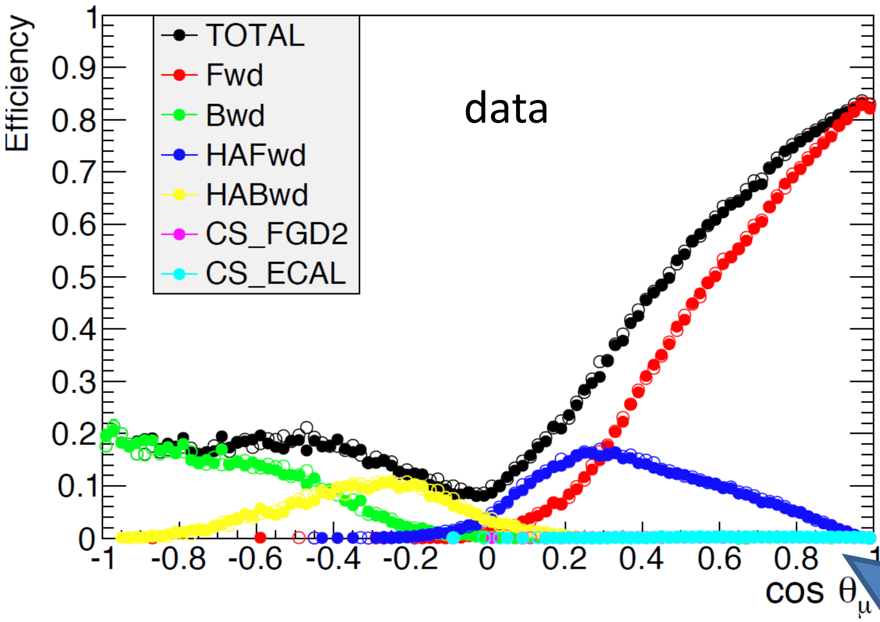
TOF:

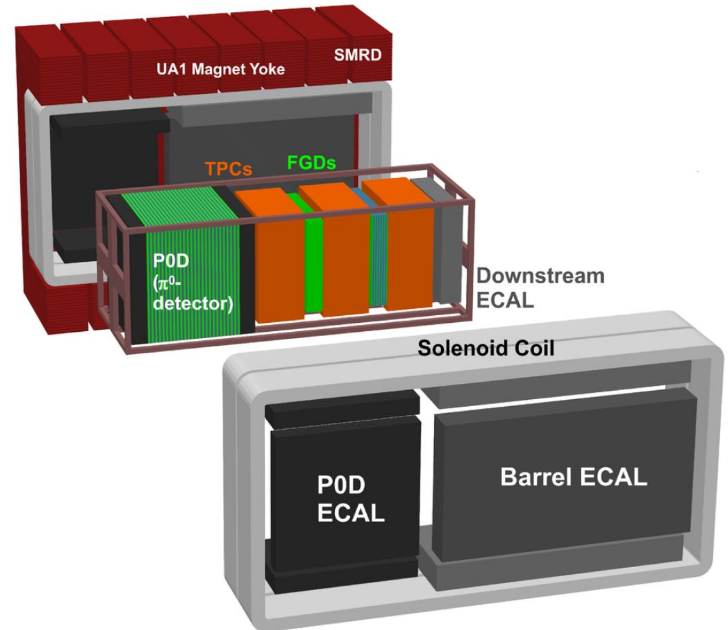
- ND280 panels: 12x230x1 cm^3
- readout electronics based on MUSIC ASIC (UB) and SAMPIC digitizer (LAL)
- purpose: identify if particles from target to magnet and improve backward efficienty for current tracker

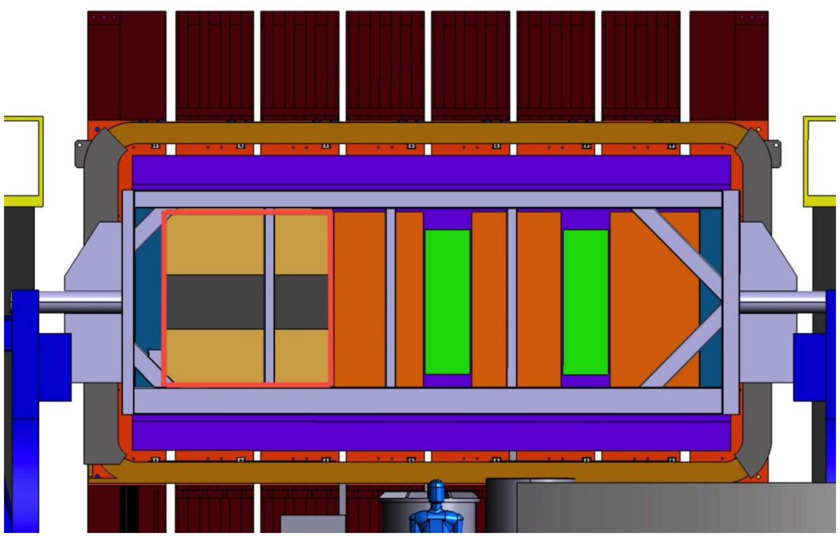


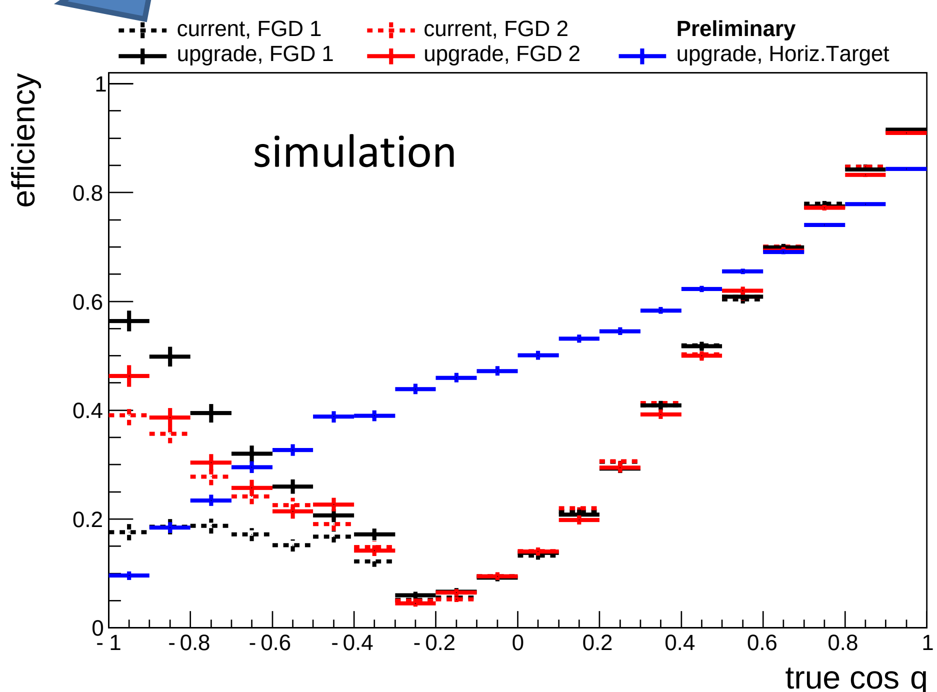
Front view

Side view

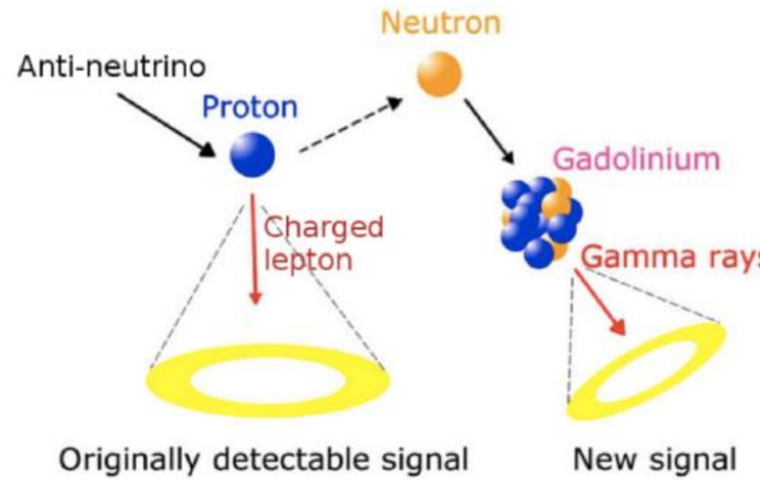

Efficiency
TOTAL
Fwd
Bwd
HAFwd
HABwd
CS_FGD2
CS_ECAL
data
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
cos θ_μ


UA1 Magnet Yoke
SMRD
TPCs
FGDs
P0D
(π⁰-
detector)
Downstream
ECAL
Solenoid Coil
P0D
ECAL
Barrel ECAL



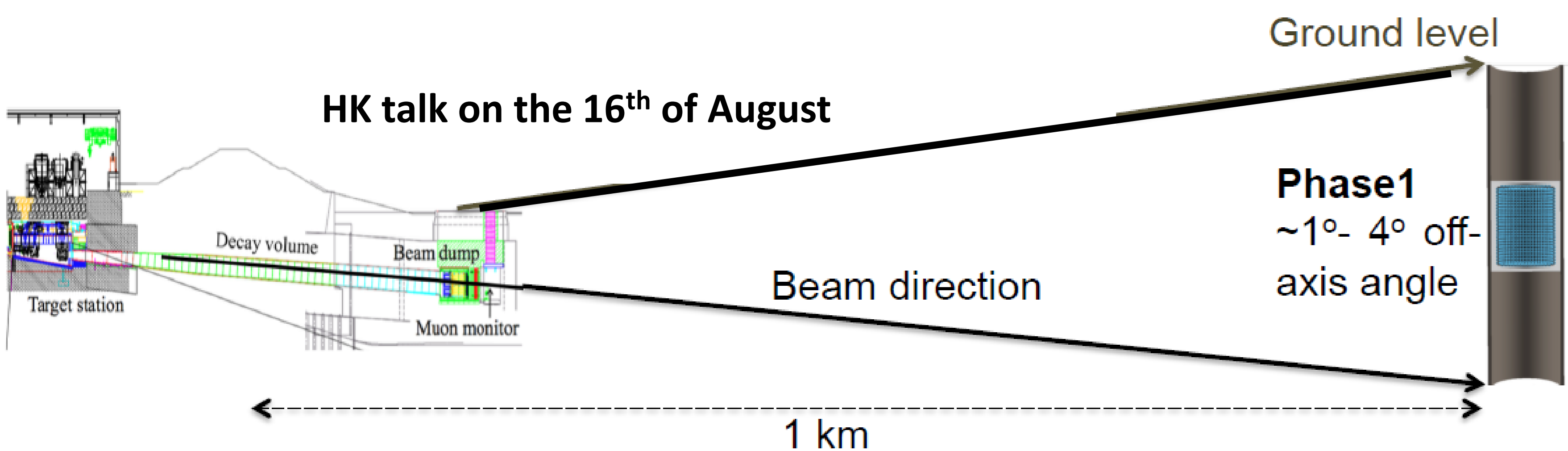

current, FGD 1
current, FGD 2
Preliminary
upgrade, FGD 1
upgrade, FGD 2
upgrade, Horiz.Target
efficiency
simulation
0 0.2 0.4 0.6 0.8 1
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1
true cos q

Beyond T2K II:



- T2K-II will improve systematics to 4%
- aim for HK is 3%
- idea is to add intermediate detector
- Water Cherenkov detector doped with Gd
- intense R&D program
- 2 phases:
  - Phase 0: 50 ton test experiment at Fermilab or CERN (2021/22)
  - Phase 1: full detector, movable (2025 and beyond)

HK talk on the 16th of August



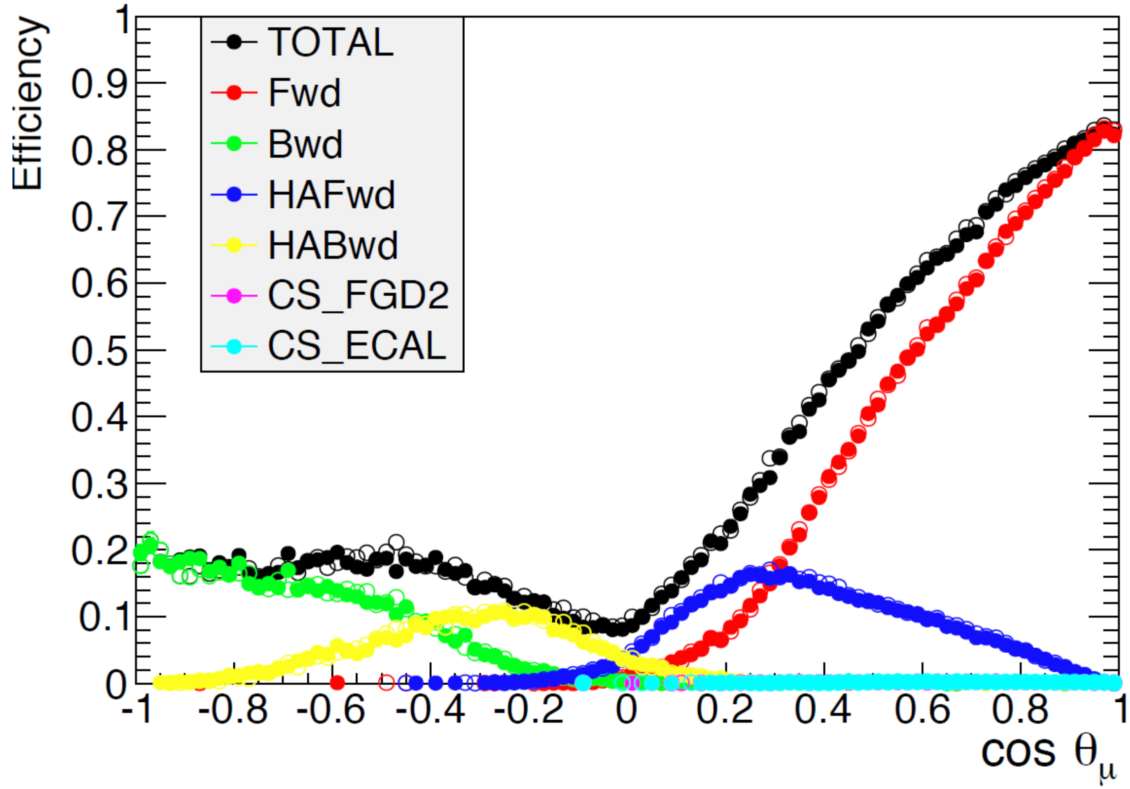
Conclusions

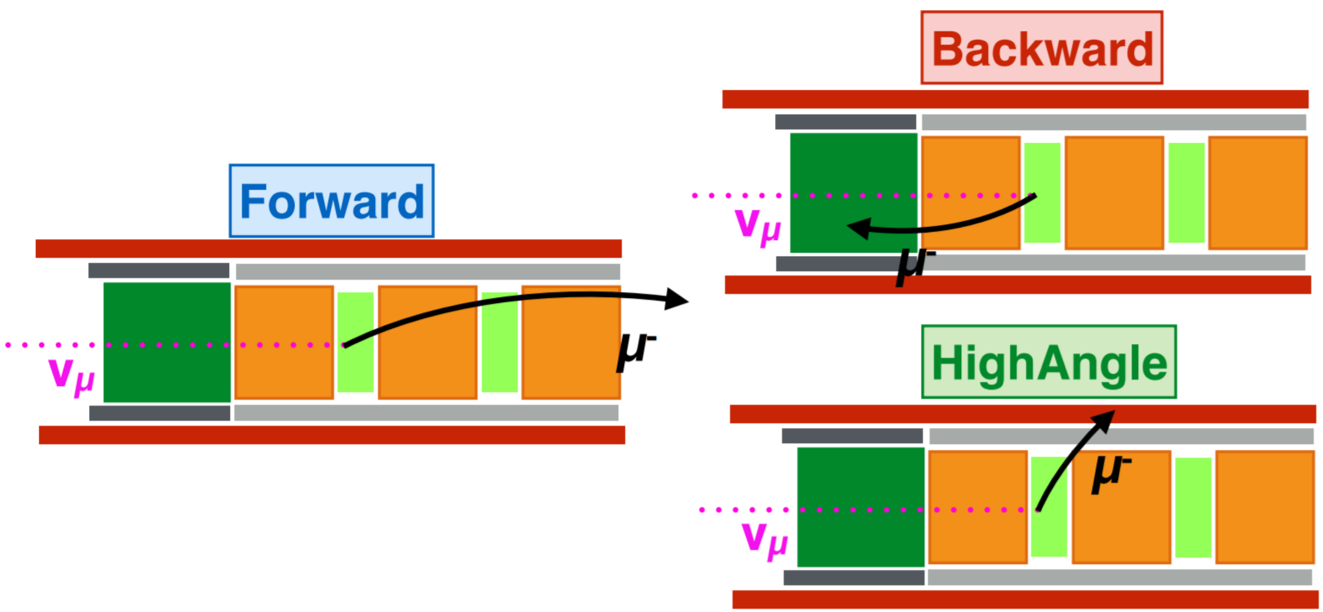
- **ND280 and Beam Upgrade for T2K-II**
  - High angle acceptance and low momentum measurement by SuperFGD, HA-TPCs and ToF counters
  - R&D and simulation studies in progress
  - Proposal submitted Jan 2018 (SPSC@CERN & PAC@J-PARC)
  - Beam power increased to 1.3 MW

- **Schedule for the ND280 Upgrade:**
  - June - August 2018: SuperFGD and HA-TPC beam test @ CERN
  - **Acknowledgement: Many thanks to CENF for support!**
  - End of 2018: Technical Design Report
  - **2021: Installation and commissioning in Japan**
  - **Reduction of systematics to about 4%**

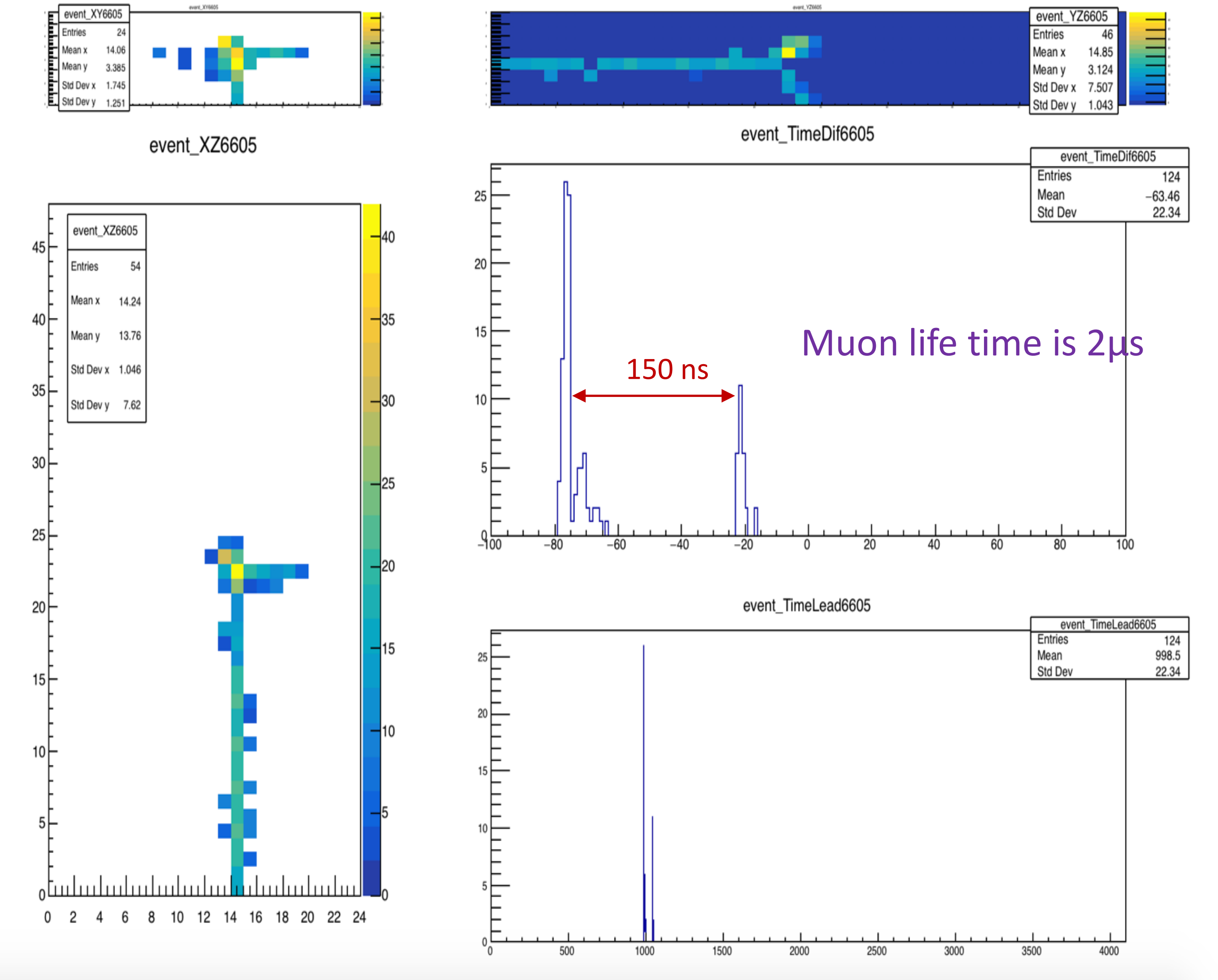
- **Plans for time beyond T2K-II well progressing:**
  - Intermediate water Cherenkov detector, movable
  - Aim: reduce systematics to 3%

BACKUP SLIDES


Efficiency
TOTAL
Fwd
Bwd
HAFwd
HABwd
CS_FGD2
CS_ECAL
cos θμ

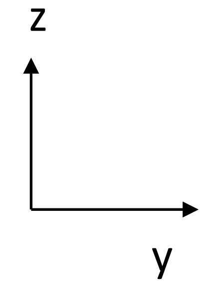

Forward
Backward
HighAngle
νμ
μ-

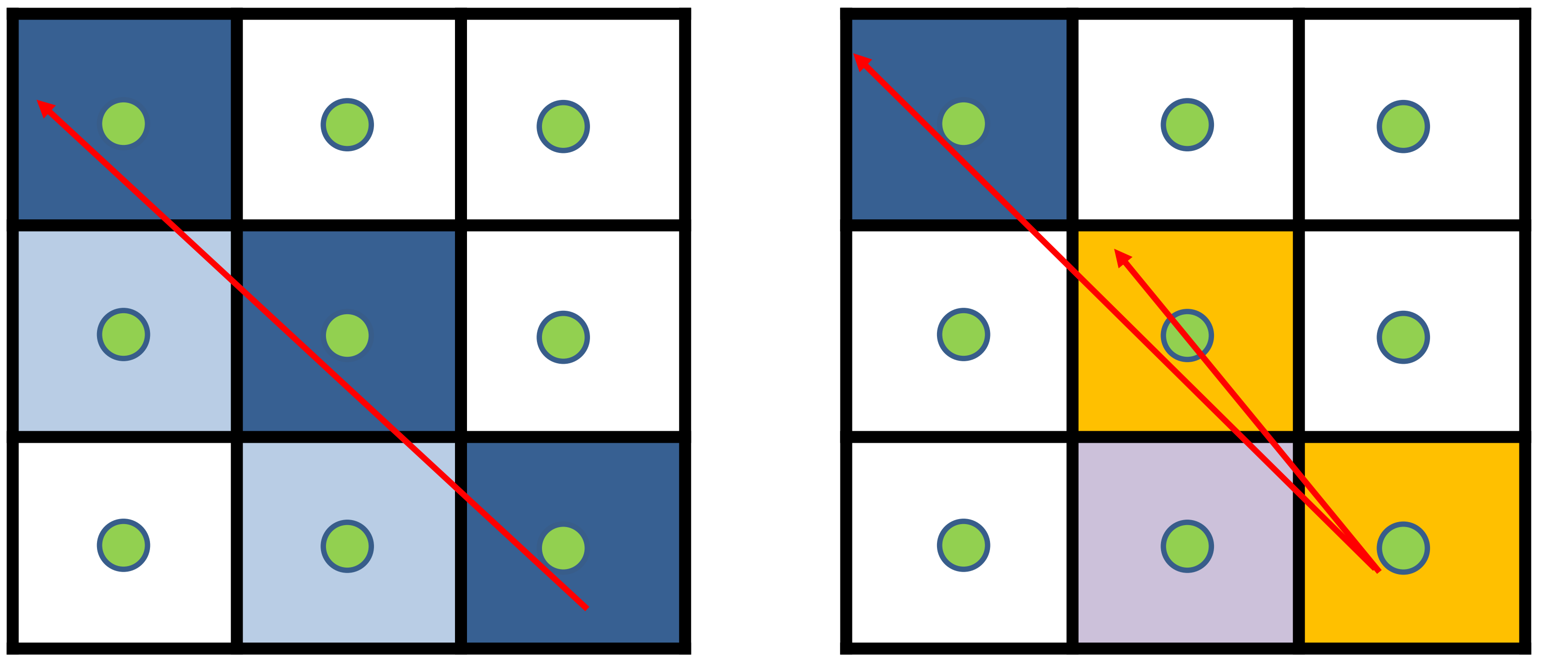
Event displays (decay candidate)



e/γ Separation in ND280 Upgrade Target

- Goal to distinguish e/γ events that are single-track, electron-like, low momentum (200 < p < 600 MeV/c)
- Distinction between 1 (e^-) and 2($\gamma \rightarrow e^-e^+$) MIP events using the MPPC light yield from the tracks
  - Considering the light yield before and after the e^-e^+ tracks split into different scintillator segments

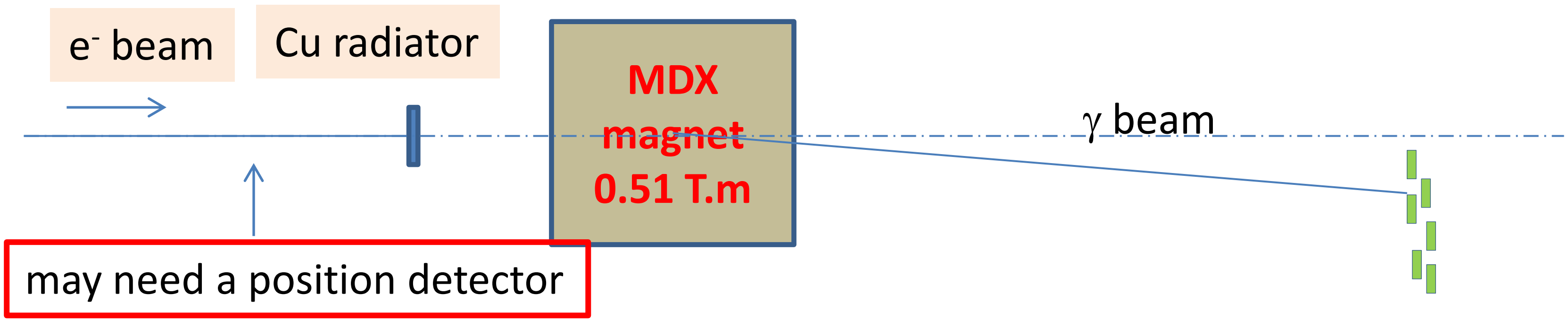




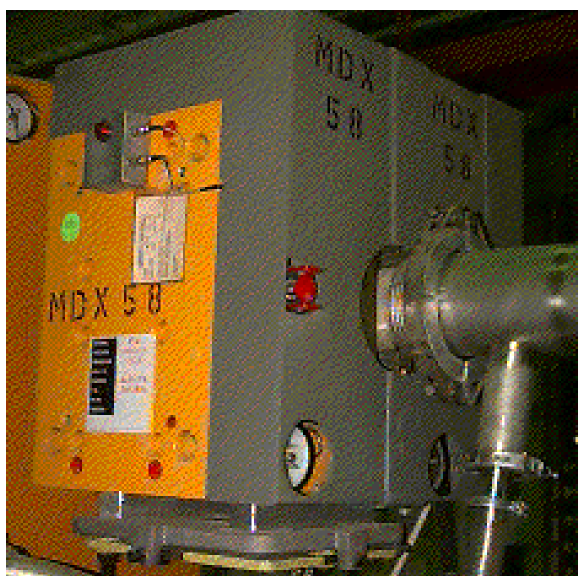
A Photon beam in T9 area

A. Blondel, L. Gatignon

Principle



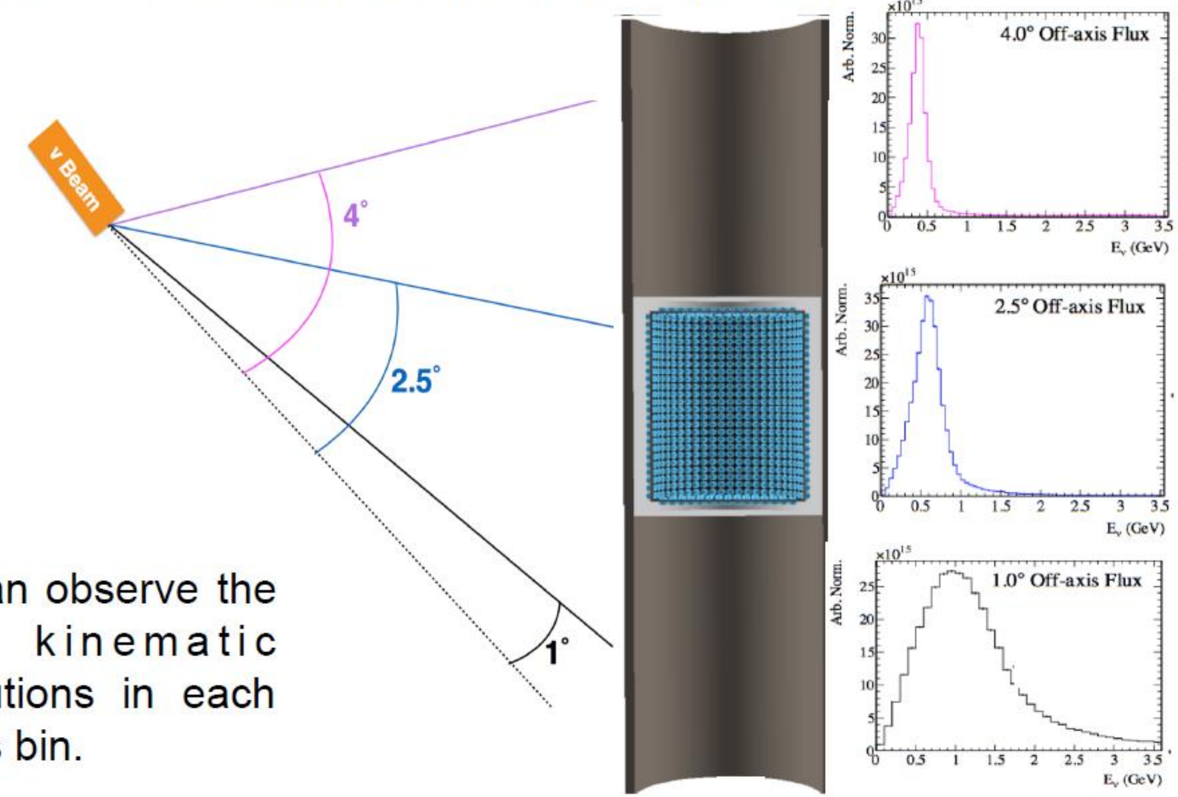
best is probably around 2 GeV/c e- for 200-800 MeV photons
(should be simulated)



hodoscope
(measures electron momentum ➔ photon energy)

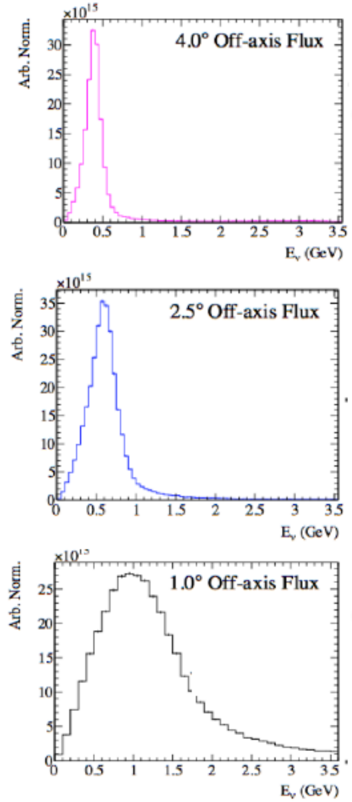
Off-axis spanning

- A detector that spans 1-4 degrees off the neutrino beam axis will measure the final states for varying neutrino spectra.

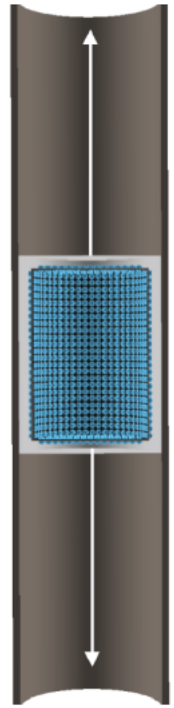


- E61 can observe the muon kinematic distributions in each off-axis bin.

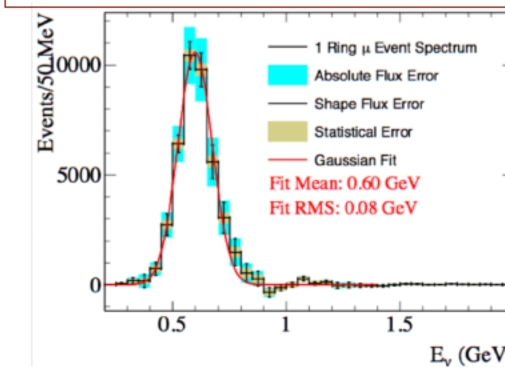
Off-axis spanning

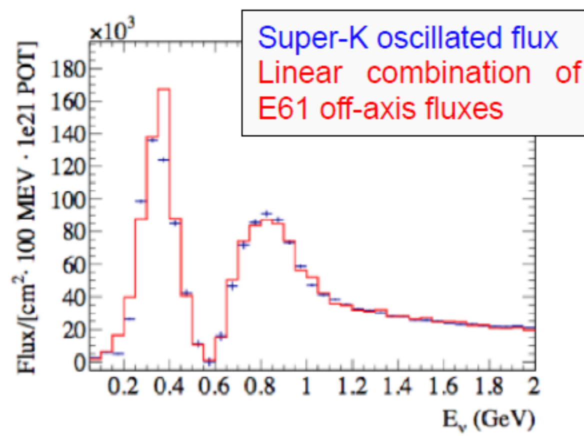


Spectra at each off-axis bin



Linear combinations: 600 MeV mono-energetic beam using slices in off-axis angles





Linear combinations and hypotheses for oscillation parameters reproduce the **oscillated flux**.