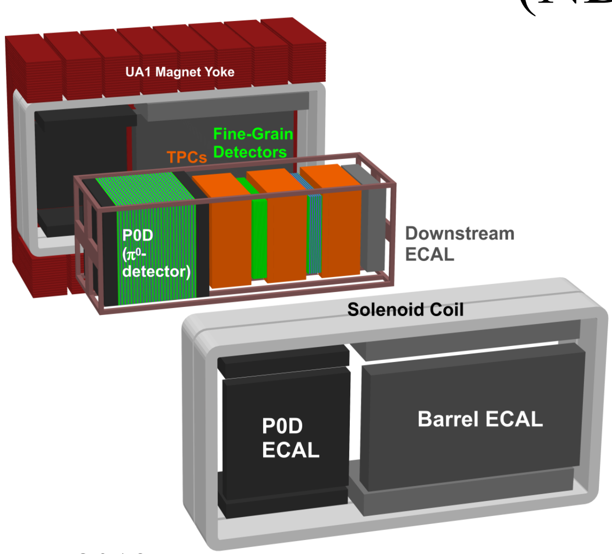
Stony Brook University

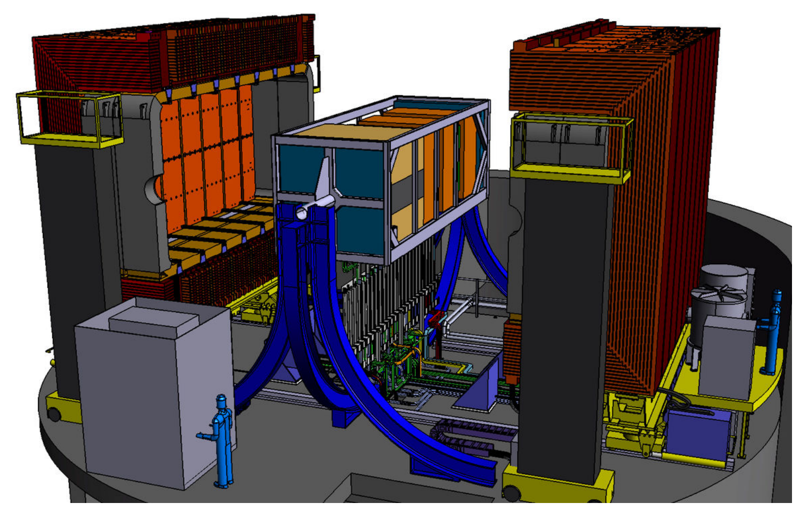
Lepton Photon 2019

The T2K ND280 Upgrade

Clark McGrew
Stony Brook Univ.
for the
T2K Collaboration
(ND280 Upgrade Working Group)



Upgrade



The T2K Collaboration

~ 500 members, 68 Institutes, 12 countries

Canada
TRIUMF
U. Regina
U. Toronto
U. Victoria
U. Winnipeg
York U.

CERN

France
CEA Saclay
LLR E. Poly.
LPNHE Paris

Germany
RWTH Aachen

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

Japan
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Osaka City U.
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United Kingdom
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Louisiana State U.
Michigan S.U.
SLAC
Stony Brook U.
U. C. Irvine
U. Colorado
U. Pennsylvania
U. Pittsburgh
U. Rochester
U. Washington

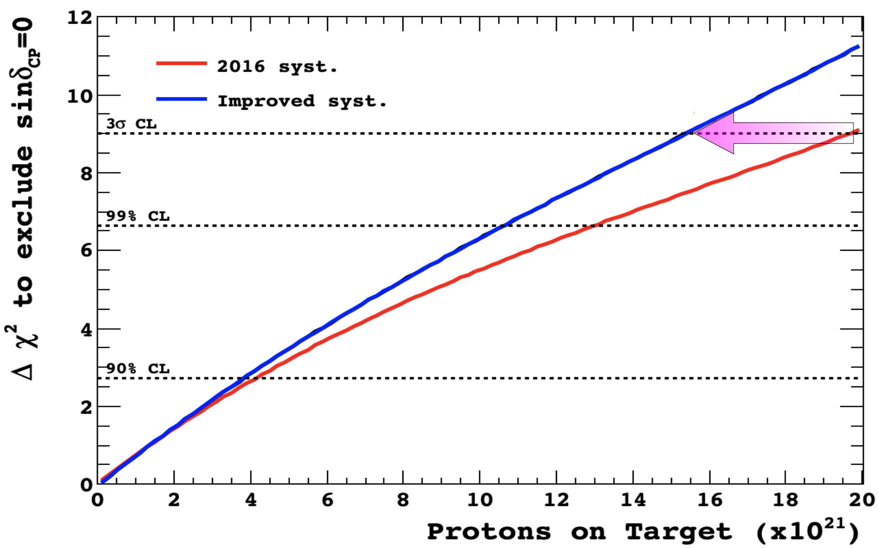
Vietnam
IFIRSE

(2019)

Search for CP Violation w/ T2K-II

- T2K-II extends T2K exposure from 7.8×10^{21} POT to 20×10^{21} POT.
- Requires systematic uncertainty be significantly reduced
  - Goal: 3σ sensitivity for CP violation

Expected exposure to exclude $\sin\delta_{CP} = 0$

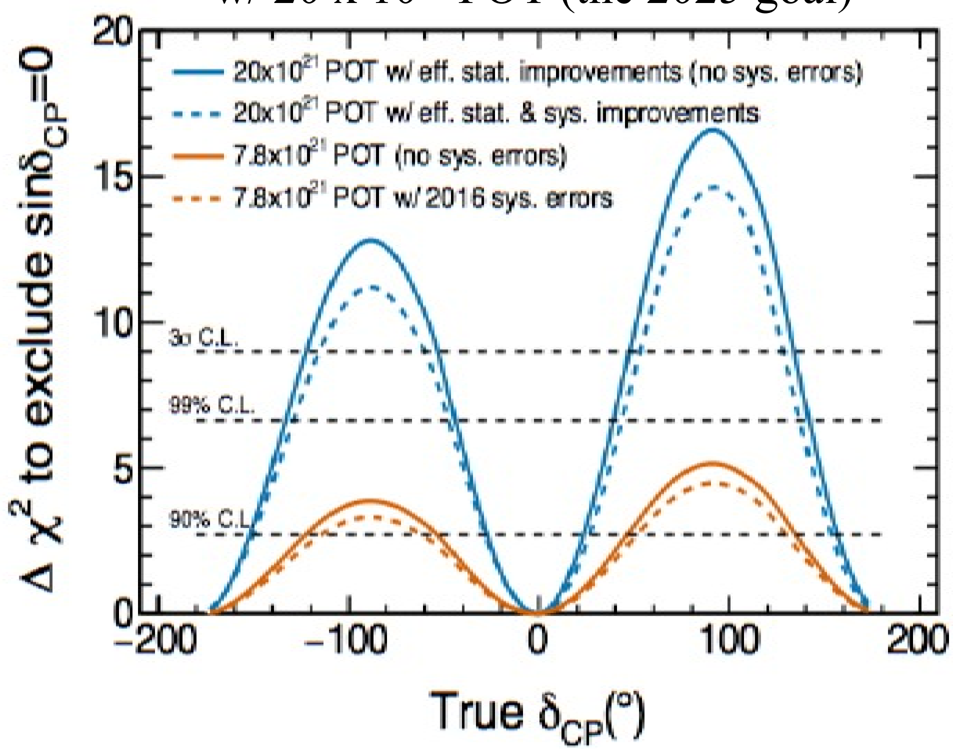


Reduction in flux & cross section systematics

Parameter	Current ND280 (%)	Upgrade ND280 (%)
SK flux normalisation	3.1	2.4
$(0.6 < E_\nu < 0.7$ GeV)		
MA_{QE} (GeV/c^2)	2.6	1.8
ν_μ 2p2h normalisation	9.5	5.9
2p2h shape on Carbon	15.6	9.4
MA_{RES} (GeV/c^2)	1.8	1.2
Final State Interaction (π absorption)	6.5	3.4

> 30 % reduction

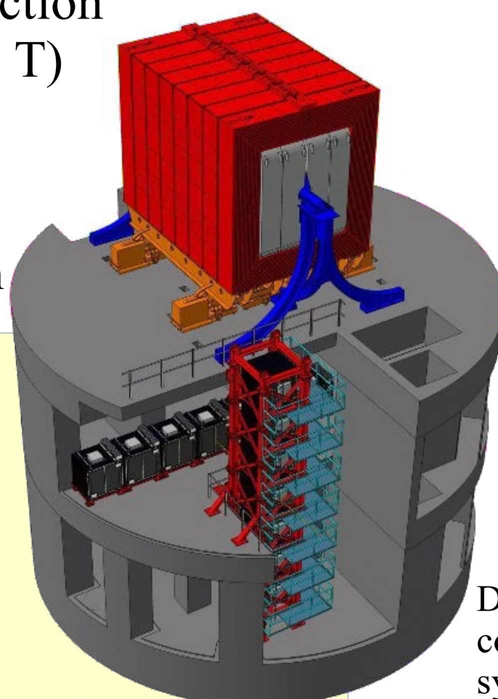
T2K-II CP conservation exclusion goal w/ 20×10^{21} POT (the 2025 goal)

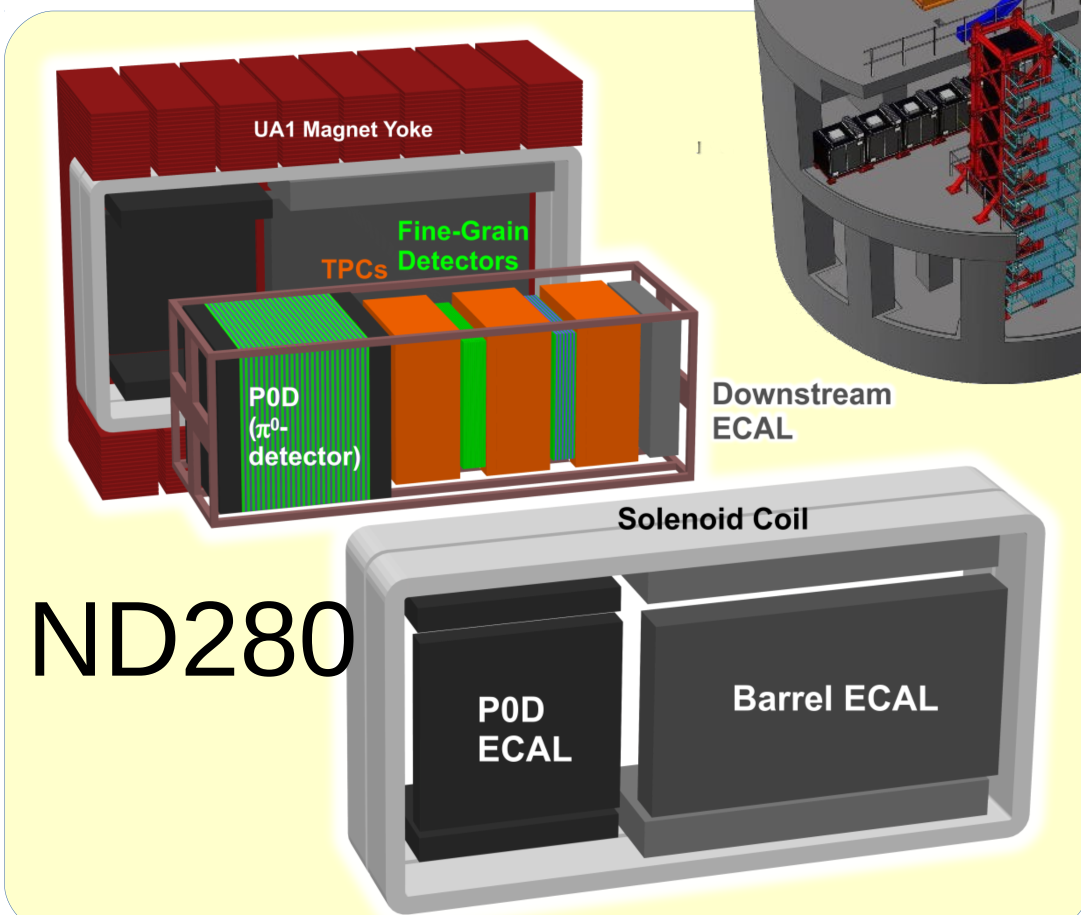


The Existing ND280 Detectors

- Off-Axis: ND280 @ 2.5 deg
  - Water Target for stat. subtraction
  - Uses “UA1” magnet (@ 0.2 T)
    - Target+Particle Tracking
    - π^o detection
    - EM calorimetry
    - Side muon range detection

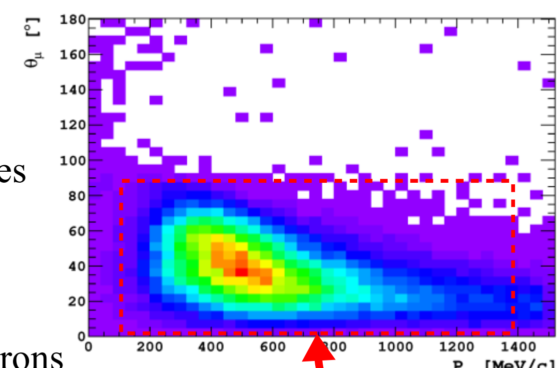
- Proton momentum threshold:
  - 450 MeV/c (i.e. ~100 MeV KE)
- Acceptance in forward direction
  - SK has 4π acceptance
- Uncertainty in track direction and charge
  - Limit timing and TPC acceptance



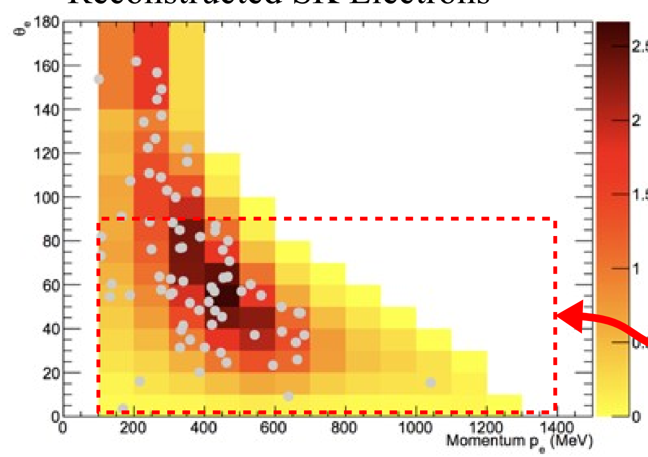


Different acceptances contribute to systematic uncertainty

Reconstructed ND280 Muons



Reconstructed SK Electrons

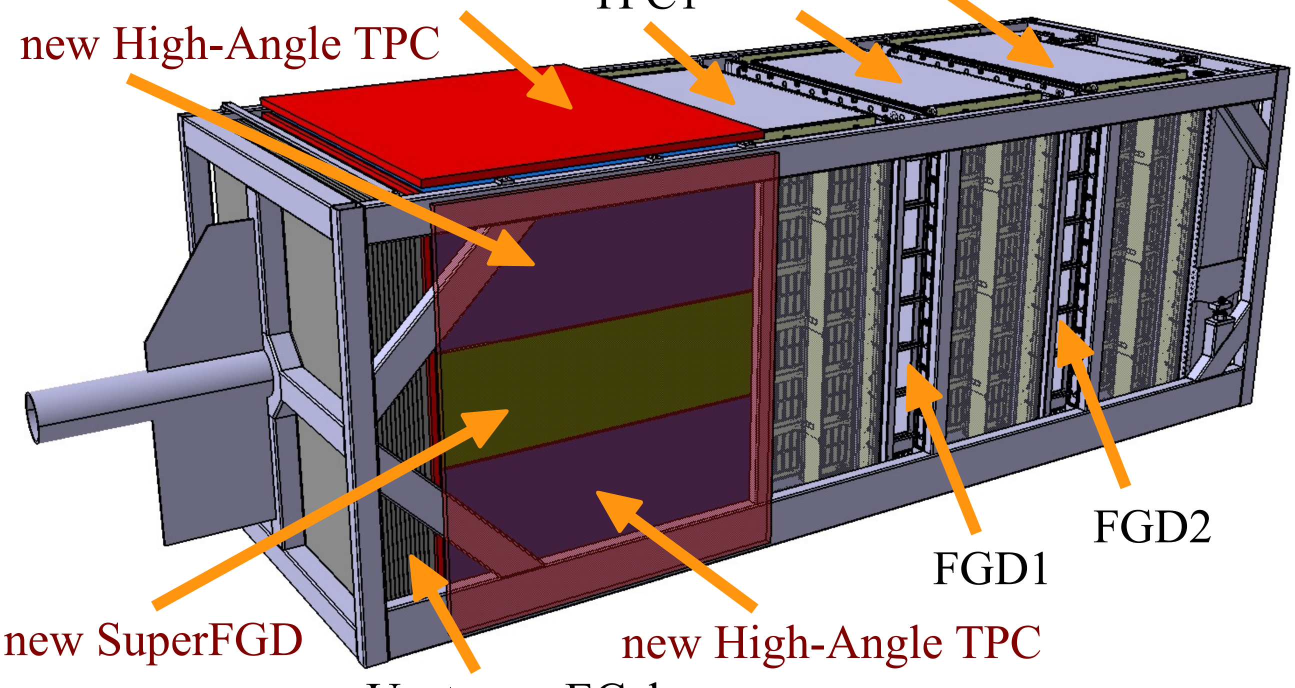


Phase-space where muon is well measured at the ND280

The ND280 Upgrade Detector

- Goal: Reduce ND systematics
  - Fully active target
  - "4π" acceptance for charged particles
  - Improved $e^{\pm}/\gamma$ separation
  - Neutron detection
    - Measure kinetic energy

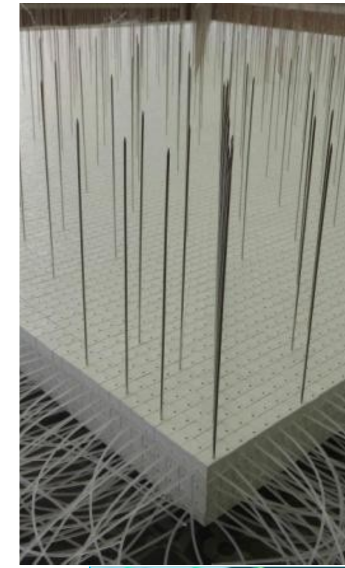
- SuperFGD
  - Active Target Mass: ~2 tonne
  - Scintillator: 1 cm^3 cubes
- New TPCs
  - High Angle TPCs
    - Good acceptance for muons transverse to ν beam
- New TOF
  - Clear tag for entering charged particles
- Existing Components
  - Surrounding ECals
    - Minimum of ~5 Rad. Lengths
  - Downstream TPCs
  - Magnet: 0.2 T

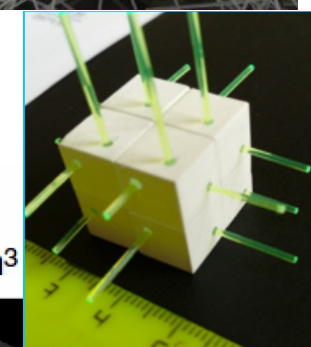


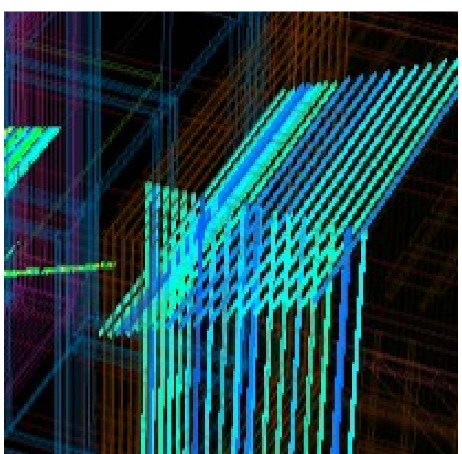
arxiv:1901.03750

The SuperFGD Concept

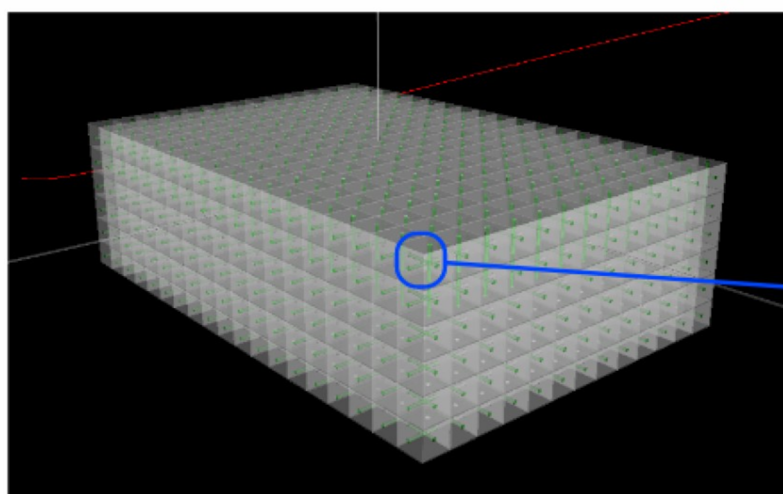
- Neutrino interactions have particles going in all directions
- A plastic scintillator active target is usually constructed with bars
  - Defines a preferred axis → Acceptance varies relative to bar orientation
- Need a "4π" scintillator detector
  - Use cubes not bars (light contained in each cube)
  - Read-out in 3 projections using wavelength shifting fiber
    - A single energy deposit gives an "XYZ" coordinate (not just "XZ", or "YZ")
- Segmentation scales like volume → Readout scales like area
  - 2M cubes need ~60K channels (a ~ 200cm × 200cm × 60cm target)
- Uniform target material (Scintillator and WLS fibers)
- Excellent performance in Beam Tests

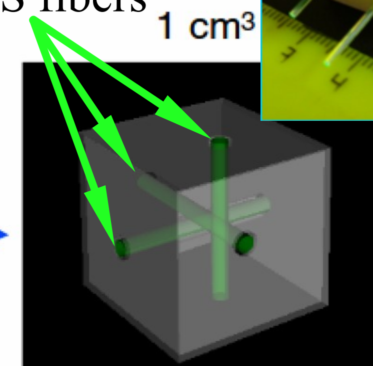






A T2K ND280 CR Muon
Need 2 layers for 3D





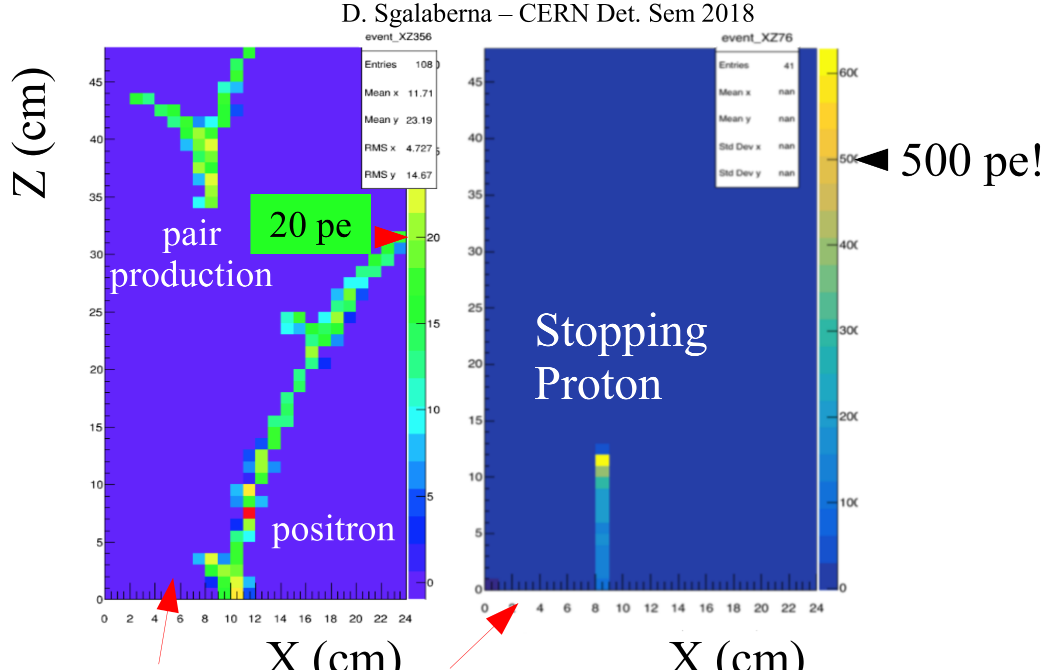
Yuri Kudenko – Scintillating perspective, 2017

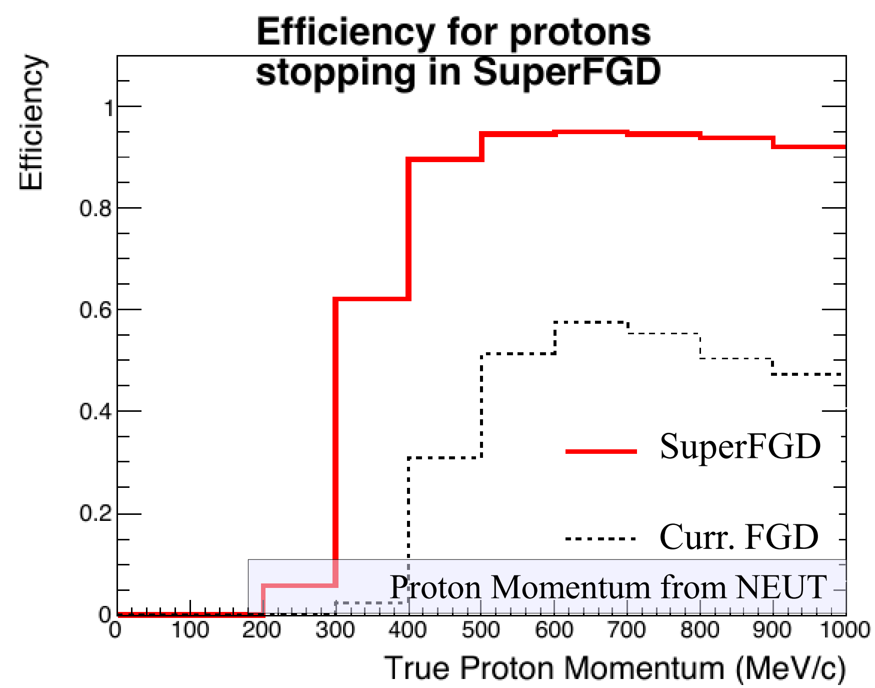
SuperFGD Performance

- High Granularity
  - Reduces proton threshold
  - Detailed track reconstruction
- Precise timing
  - Identify track direction and reduce external backgrounds
- High light yield
  - Unambiguous proton identification
  - Low hit threshold
- Improved Sensitivities
  - Light and timing → neutrons
  - Reduced proton threshold

Beam test events from SuperFGD

D. Sgalaberna – CERN Det. Sem 2018





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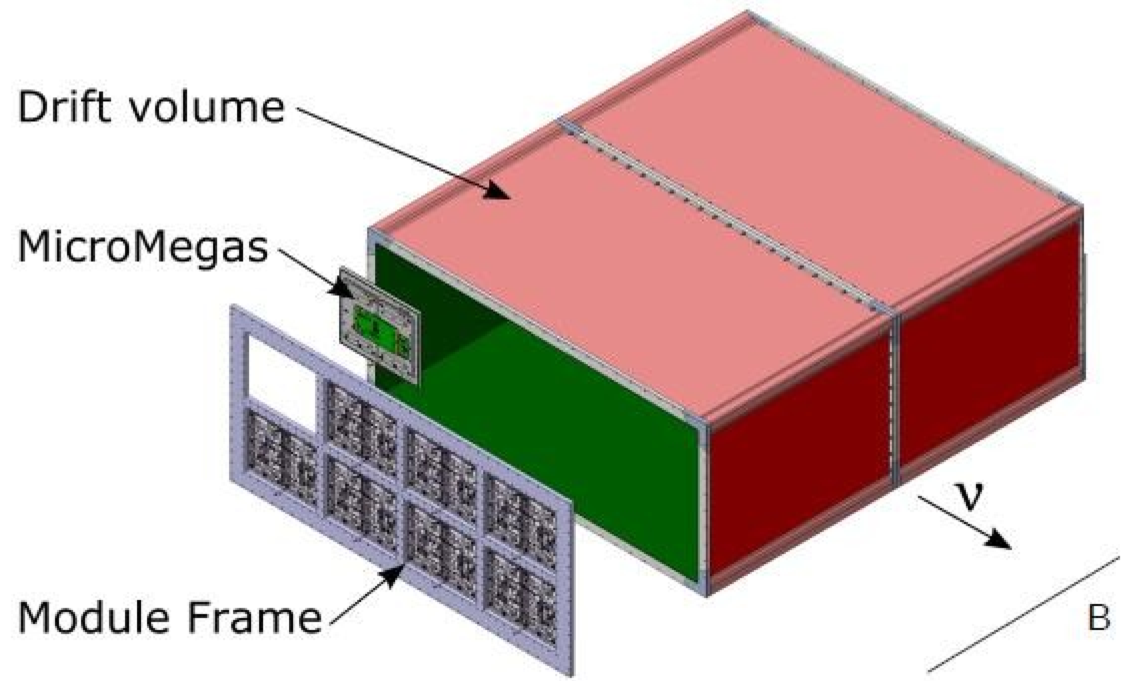
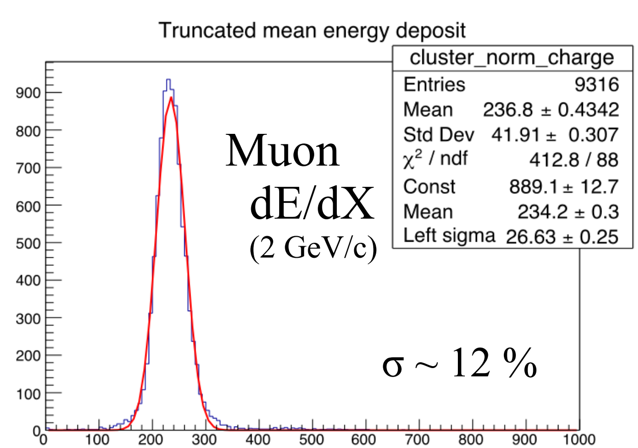
High Angle TPC

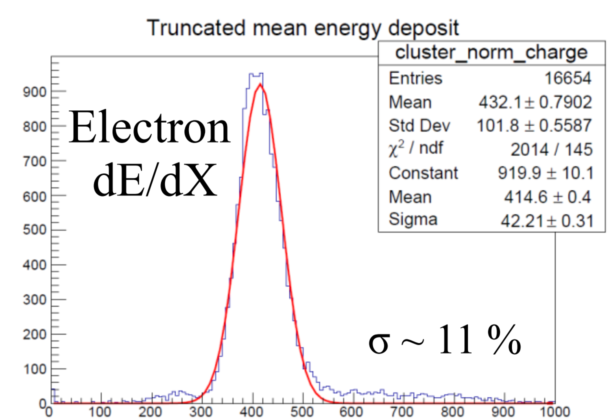
(Instrumented with Resistive Micromegas)

- Instrumented with Resistive Micromegas
  - Minimizes sparking
  - Improves resolution (per pad)
- Field Cage
  - Thin solid insulator wall to minimize dead space volume



Parameter	Value
Overall x × y × z (m)	2.0 × 0.8 × 1.8
Drift distance (cm)	90
Magnetic Field (T)	0.2
Electric field (V/cm)	275
Gas Ar-CF_4-iC_4H_{10} (%)	95 - 3 - 2
Drift Velocity $cm/\mu s$	7.8
Transverse diffusion ($\mu m/\sqrt{cm}$)	265
Micromegas gain	1000
Micromegas dim. z×y (mm)	340 × 410
Pad z × y (mm)	10 × 11
N pads	36864
el. noise (ENC)	800
S/N	100
Sampling frequency (MHz)	25
N time samples	511





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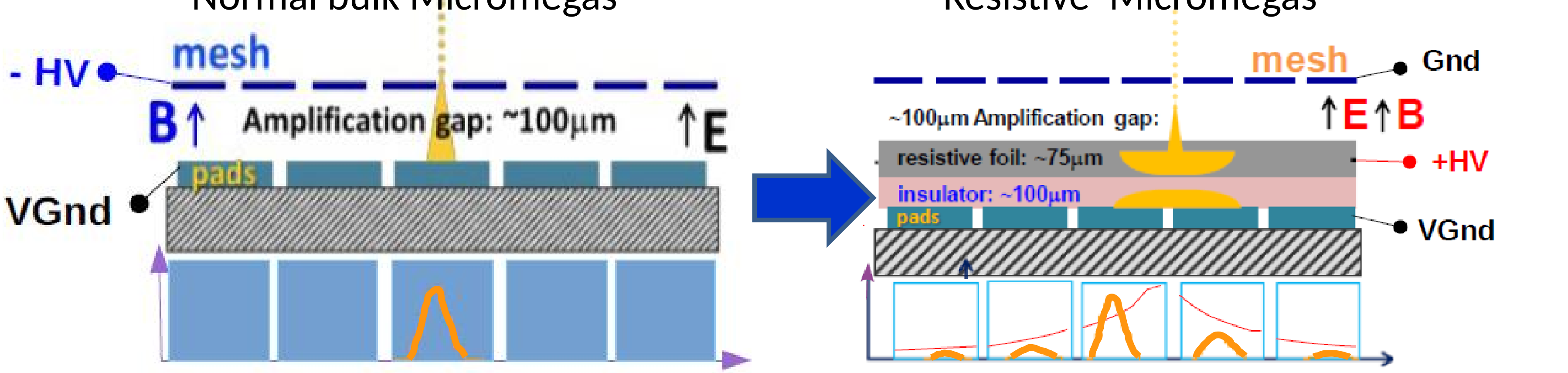
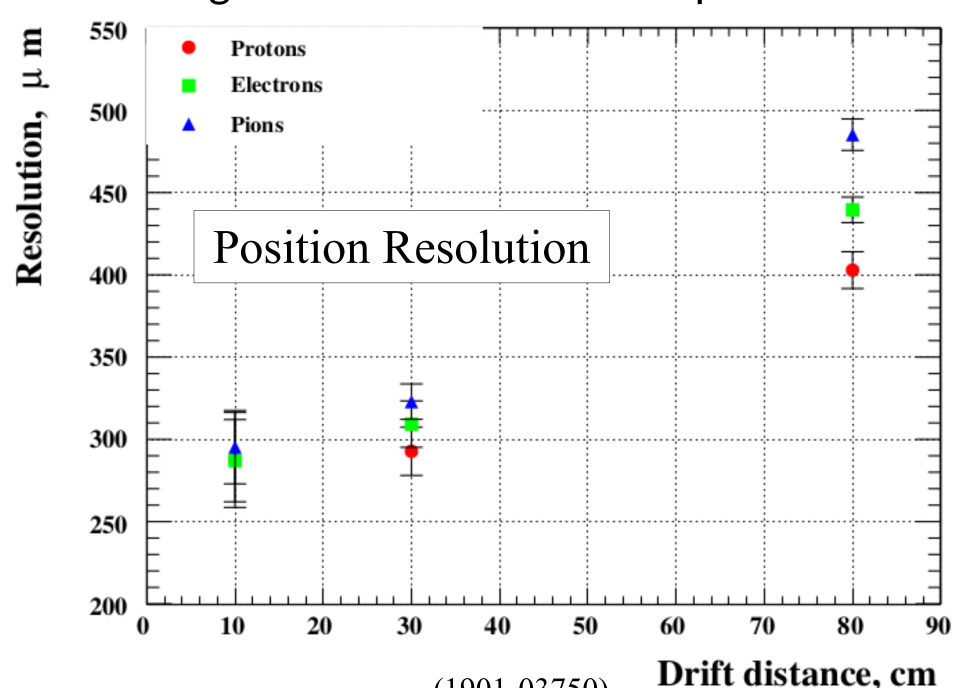
Resistive Micromegas

(Encapsulated resistive anode with grounded mesh)



Charge detected over several pads

- Beam Test at CERN 2018 using HARP field cage
  - T2K MM Pad geometry with resistive foil
    - T2K resolution: ~ 0.7 mm
    - With resistive foil: < 0.5 mm
  - Get similar resolution with fewer pads
- Recent test at DESY
  - Used candidate resistive MM module



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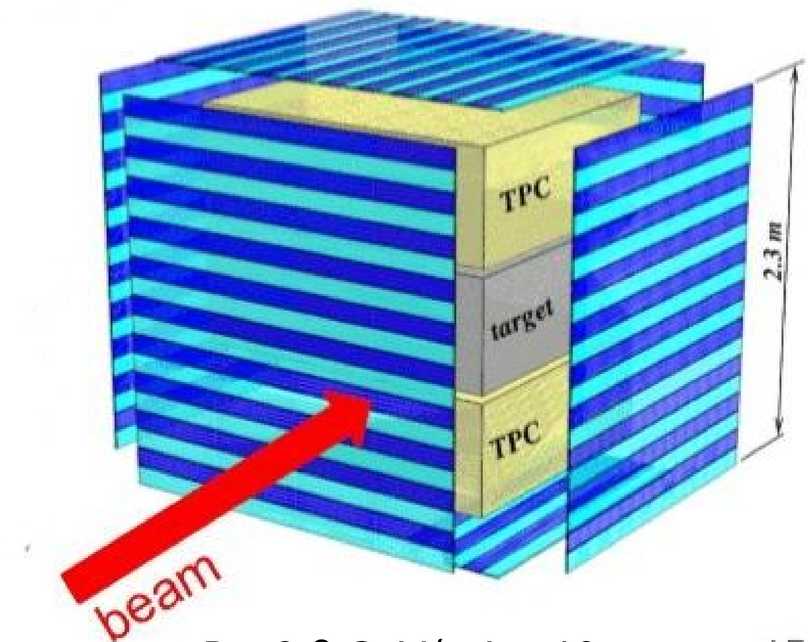
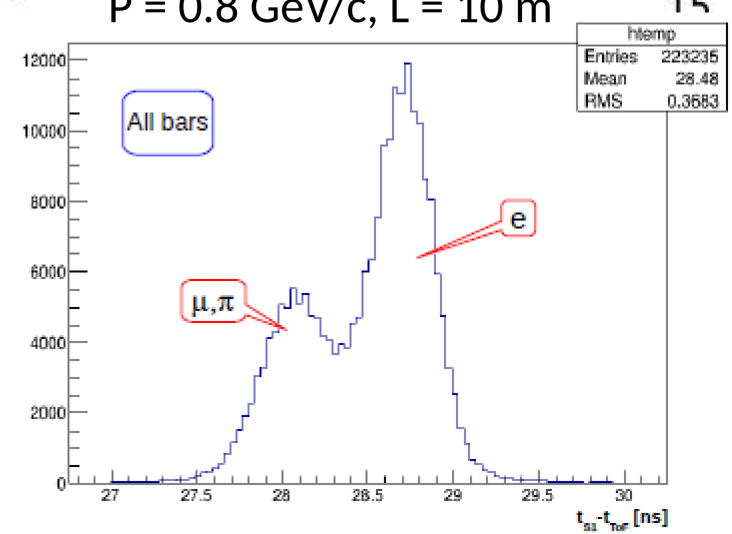
Time Of Flight Detector

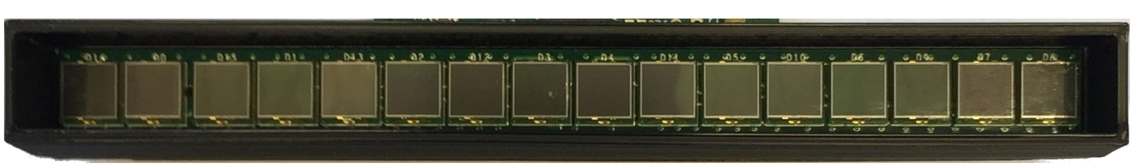
- New detectors are enclosed in a Time-of-Flight detector
  - Nearly hermetic coverage for the new TPCs and the SuperFGD.
- Improves rejection for incoming backgrounds
  - Achieved timing resolution is ~ 70 ps
  - Charged track direction unambiguously determined (in combination with the SuperFGD)





Achieved time resolution σ~70 ps

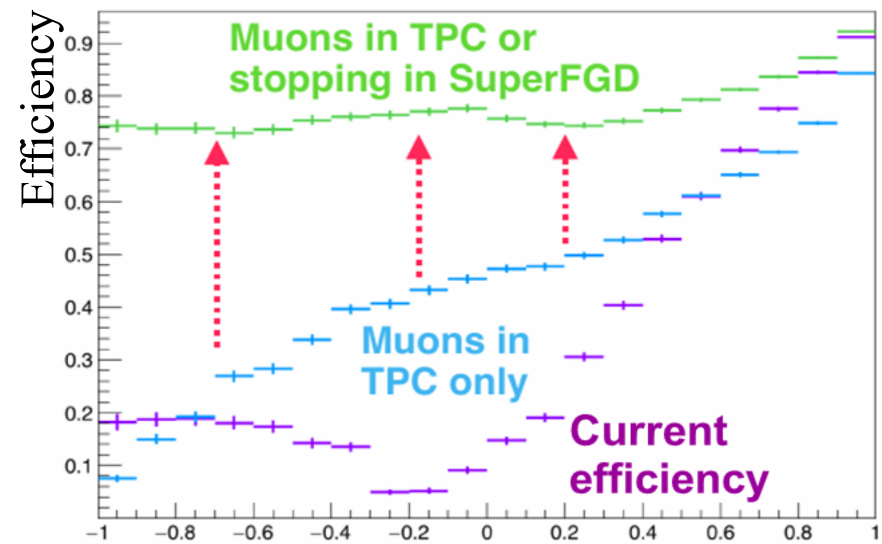
Sixteen 6x6 mm^2 MPPC attached in parallel used to achieve timing resolution.



Effects of the Upgrade: Increased Acceptance for Muons

- Expanded coverage for TPCs
  - Charge identification
  - dE/dX
- High efficiency for stopping muons
  - Measure kinematics
- Muon acceptance almost independent of angle
- Forward/Backward separation from timing
- Significant coverage for the full phase space

Efficiency to measure muon vs direction



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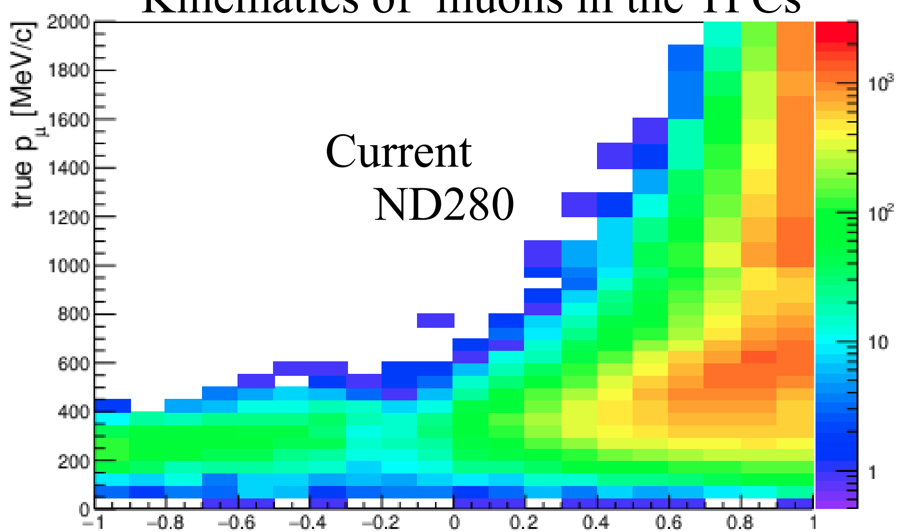
Kinematics of muons in the TPCs



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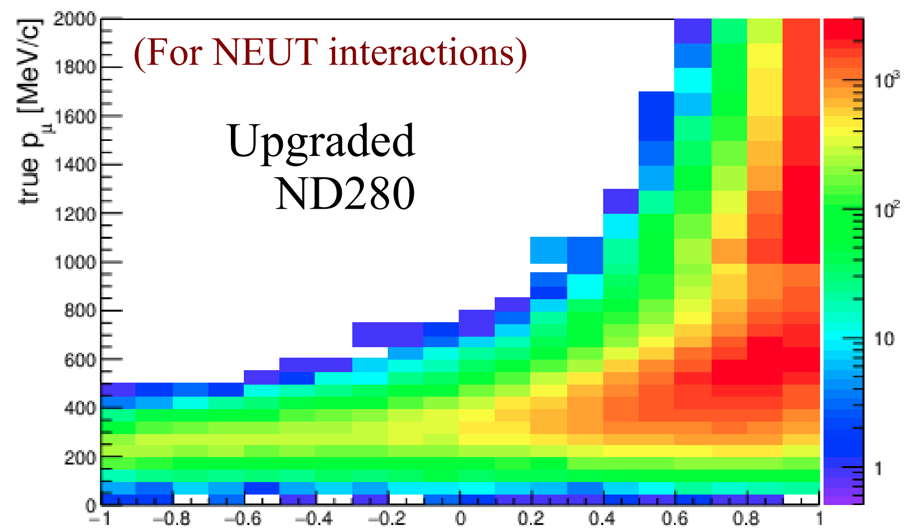

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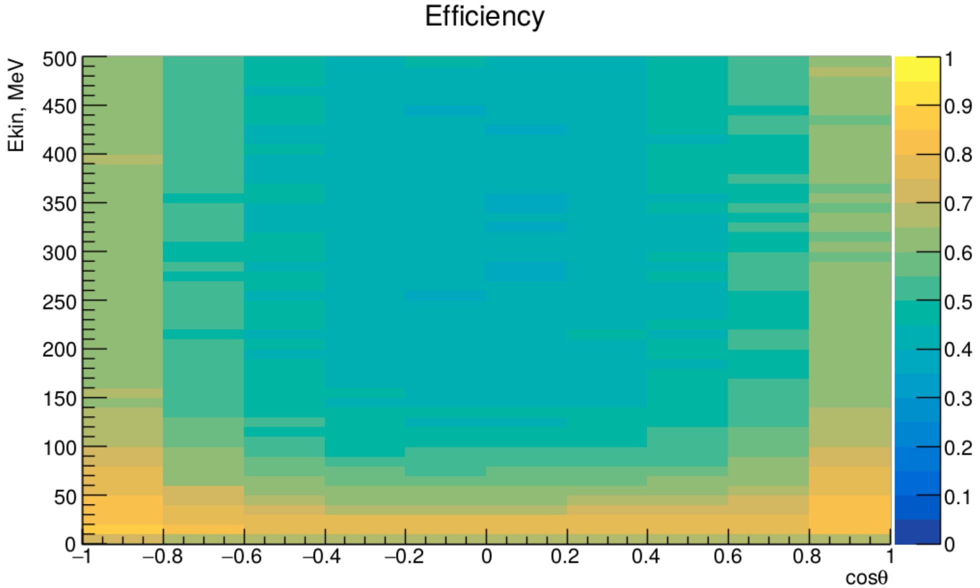
Effects of the Upgrade: Neutrons in the sFGD

- Detector
  - High granularity gives significant efficiency for neutrons
  - Energy resolution for longer path lengths
- Neutron selection looks for hits separated from the vertex
  - Must also be outside of a 3cm x 3cm cube around the reconstructed vertex.
  - Time defined by the first neutron hit
  - Roughly 60% efficiency to detect neutrons from a neutrino interaction
- Neutron energy reconstructed from time-of-flight
  - Shown resolution assumes a 0.9 ns single fiber time resolution



Neutrons start at center of the sFGD

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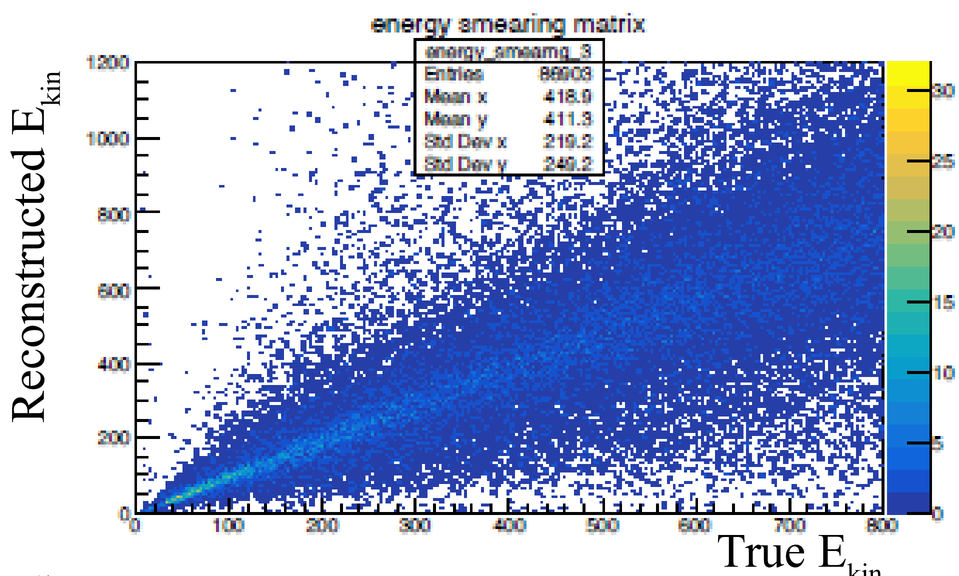
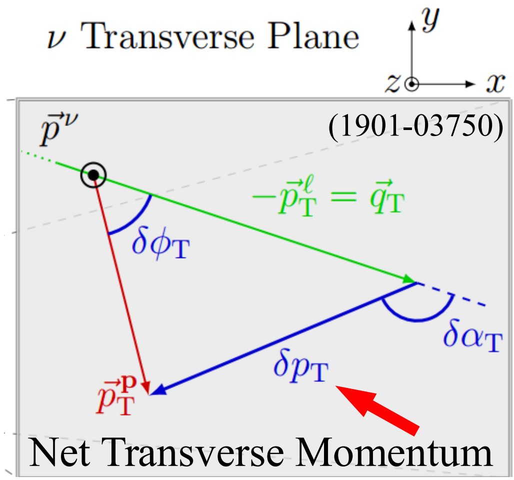


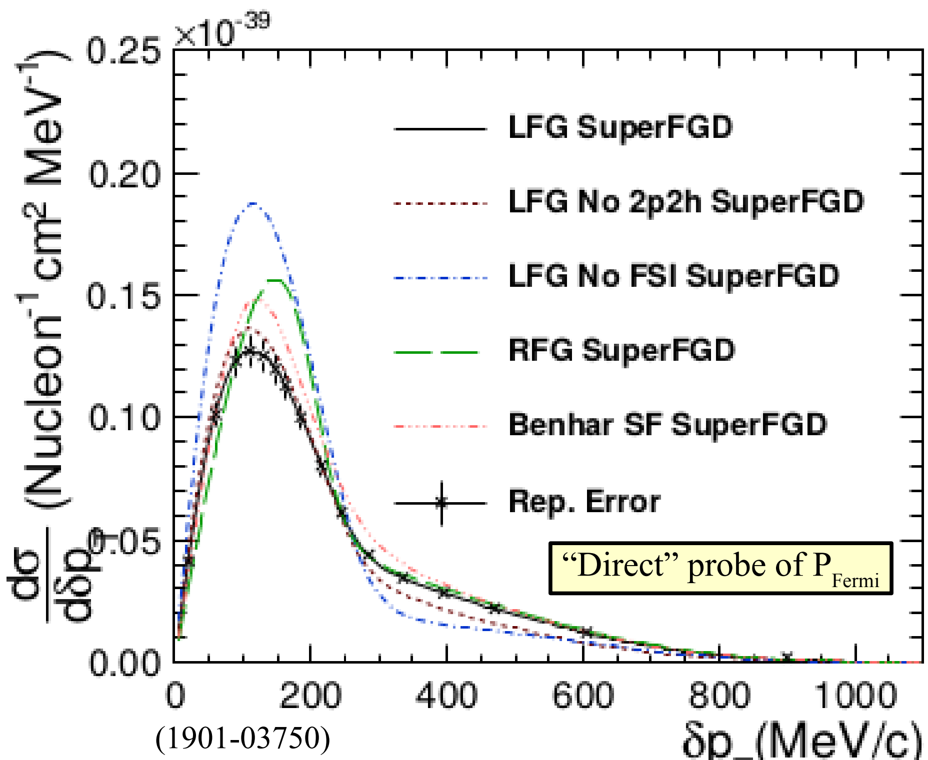
Resolution for travel distance > 50 cm

Transverse Momentum for ν_μ and $\bar{\nu}_\mu$



- Improved acceptance gives better "direct" probes of nuclear effects[1]
  - Low sFGD proton threshold
  - sFGD sensitivity to neutrons

  } ν_μ and $\bar{\nu}_\mu$
- Example: Lepton+Nucleon (CCQE-like) events
  - Magnitude of net transverse momentum → P_f
  - Orientation of net transverse momentum → FSI



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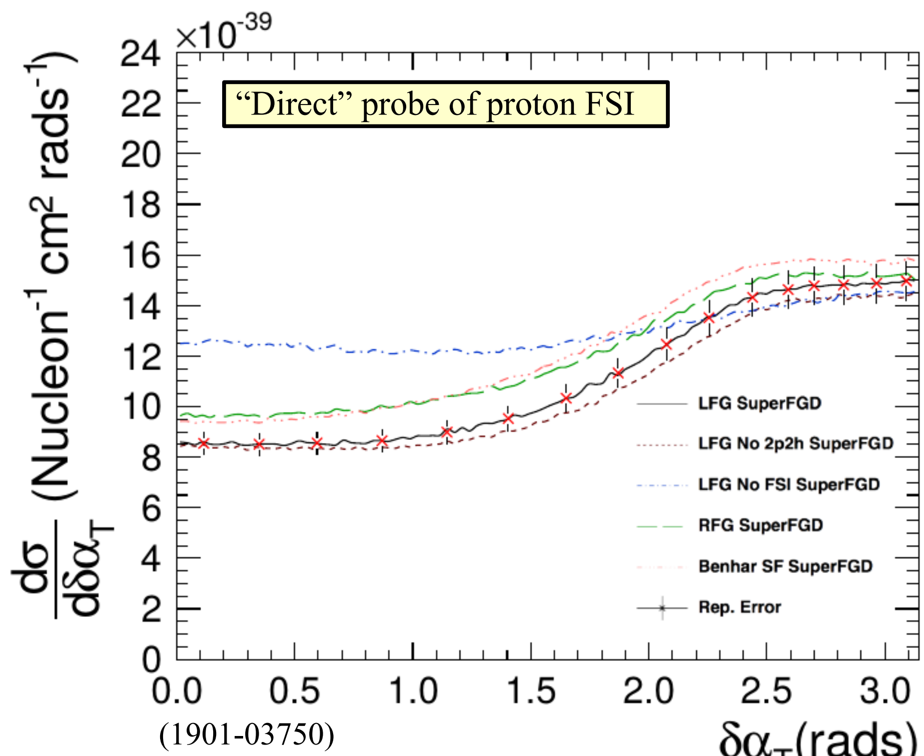

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[1] PRC 94 (2016) 015503

Summary and Conclusions

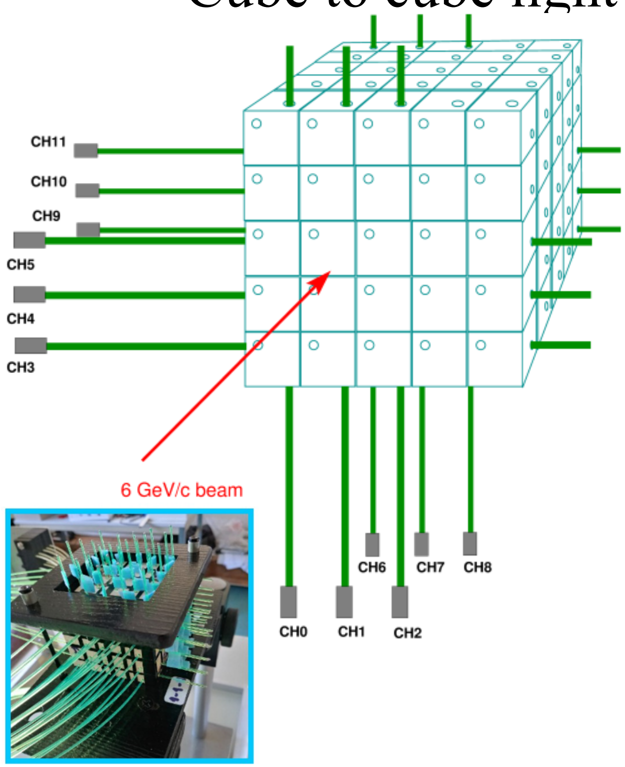
- To fully exploit T2K we need a better understanding of neutrino interactions
  - Leads to a better understanding of oscillation systematic uncertainties
- The T2K ND280 detector is being upgraded to meet this challenge
  - Measure neutrino events over an expanded phase space
  - Nearly "4π" acceptance to measure muons in a TPC
  - First significant acceptance for neutrons in the T2K ND280
- Active target using an innovative scintillator target (SuperFGD)
  - Fully active, and 4π acceptance for charged particles
- TPCs instrumented with Resistive Micromegas
  - Improved resolution (or reduced number of electronics channels)
- Beam tests have demonstrated the performance of the new systems
  - Tests of SuperFGD, TPCs with resistive micromegas, and TOF
- Schedule:
  - Production during 2019 and 2020
  - Installation during 2021
  - Propose a 20×10^{21} POT exposure

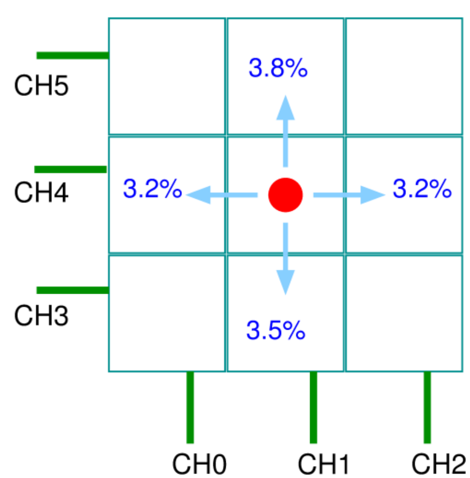
Backup Slides

Basic Active Target Performance

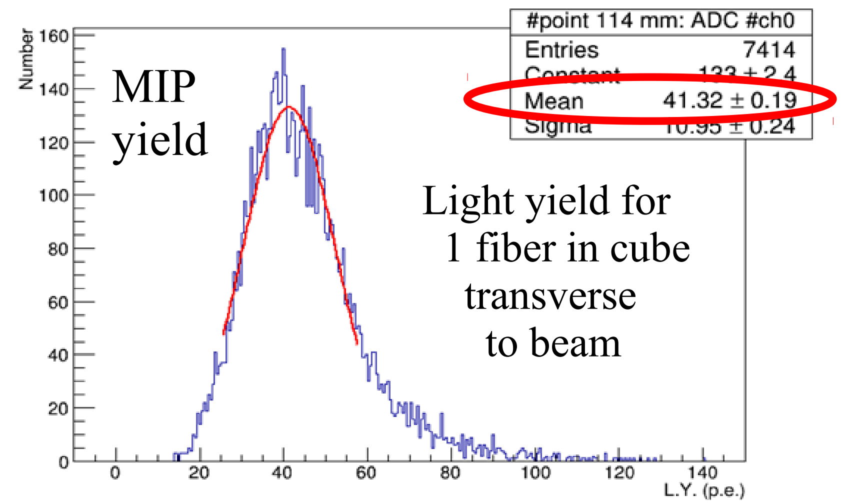
CERN 2017 Beam Test – NIM A923 (2019) 134

- Measurements of
  - Light yield ~ 40 pe/fiber
    - MPPC readout
    - 1 mm Y11 fibers w/ 1.3 m length
  - Timing resolution
    - σ_t ~ 0.9 ns/fiber → 0.7 ns for two fibers
  - Cube to cube light propagation (<4%)





1 Fiber/1 Cube



1 Fiber/1 Cube