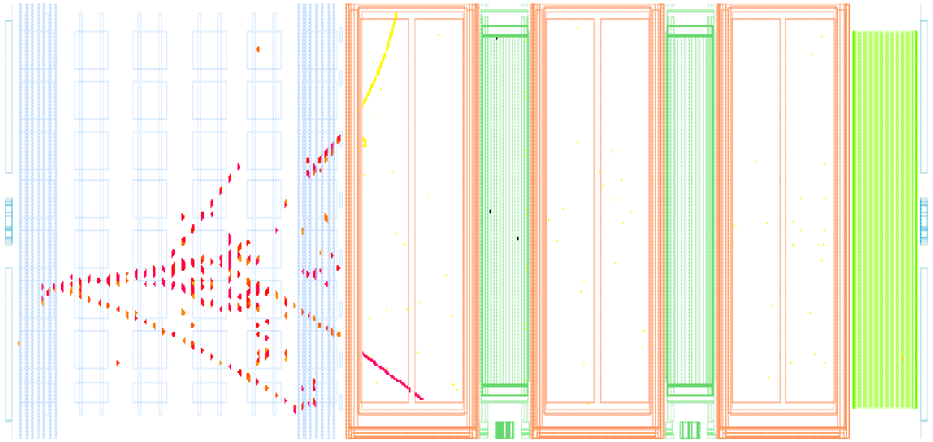
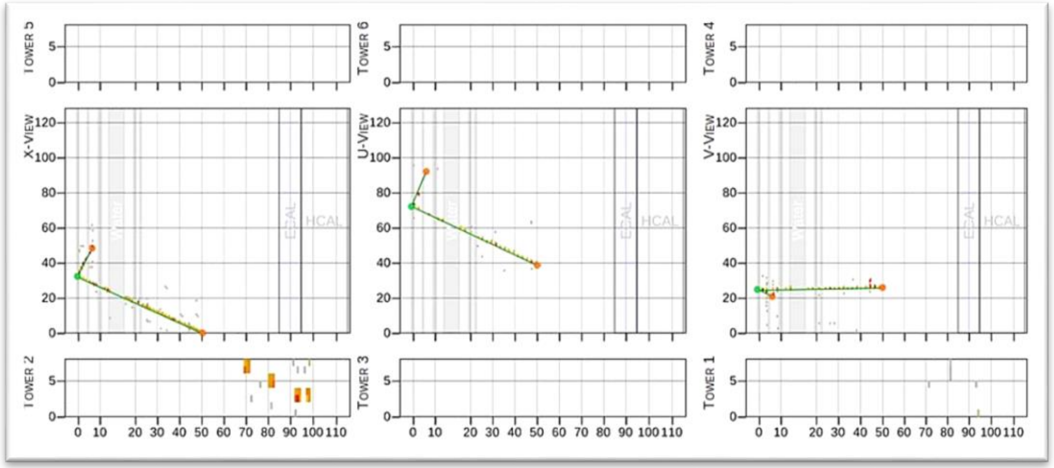
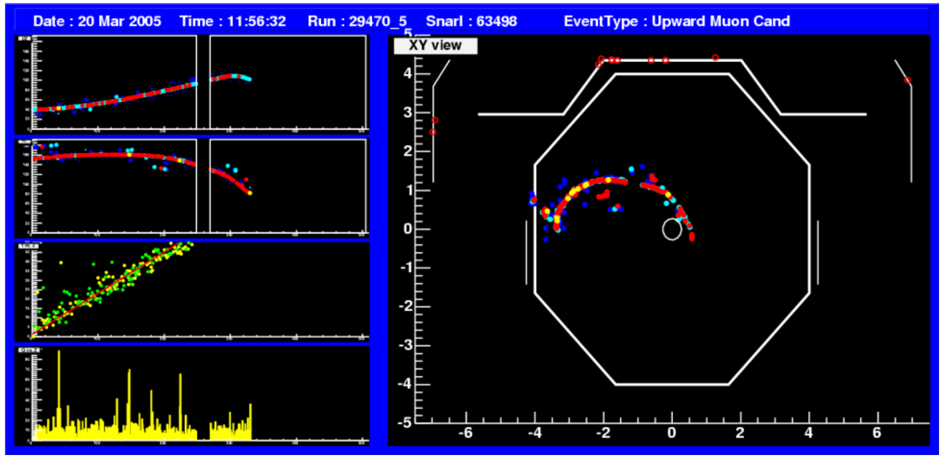
Thoughts on a plastic scintillator tracker option

DUNE Near Detector Workshop
FNAL
March 27-29, 2017

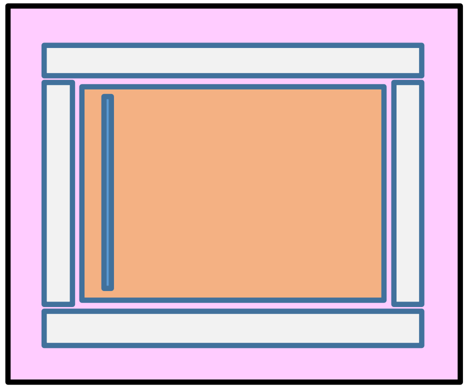
S. Manly
University of Rochester



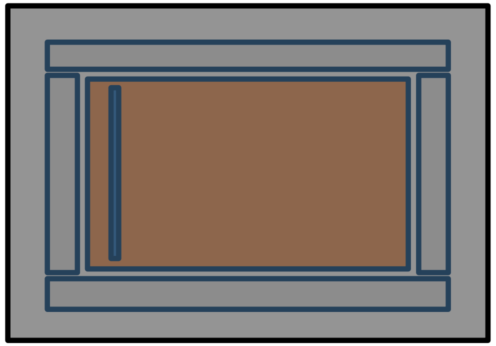




Some possibilities to consider

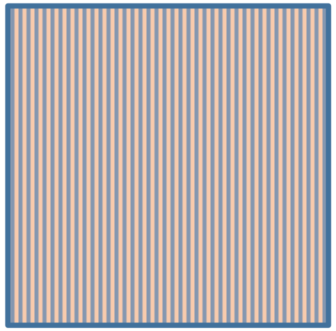


Scintillator tracker surrounded by ecal with plane of high pressure Ar gas tubes and a B-field

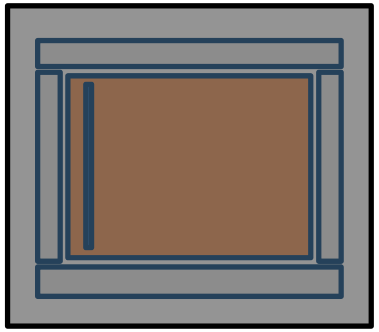


Unmagnetized black box tracker/ecal

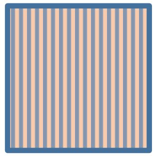
+

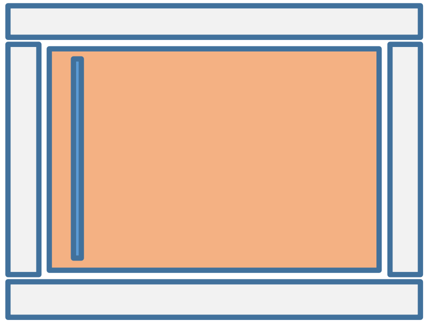


Magnetized muon spectrometer with active planes of scintillator readout

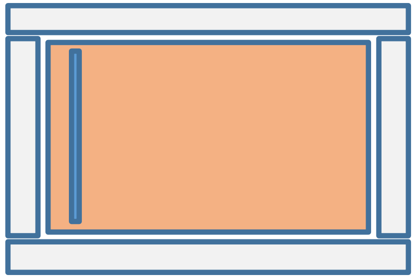


Black box ND with Unmagnetized scintillator “outrigger(s)” off-axis to constrain beam direction and focusing errors





Unmagnetized scintillator tracker/ecal



Unmagnetized scintillator tracker/ecal

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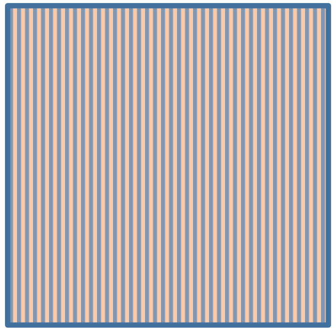
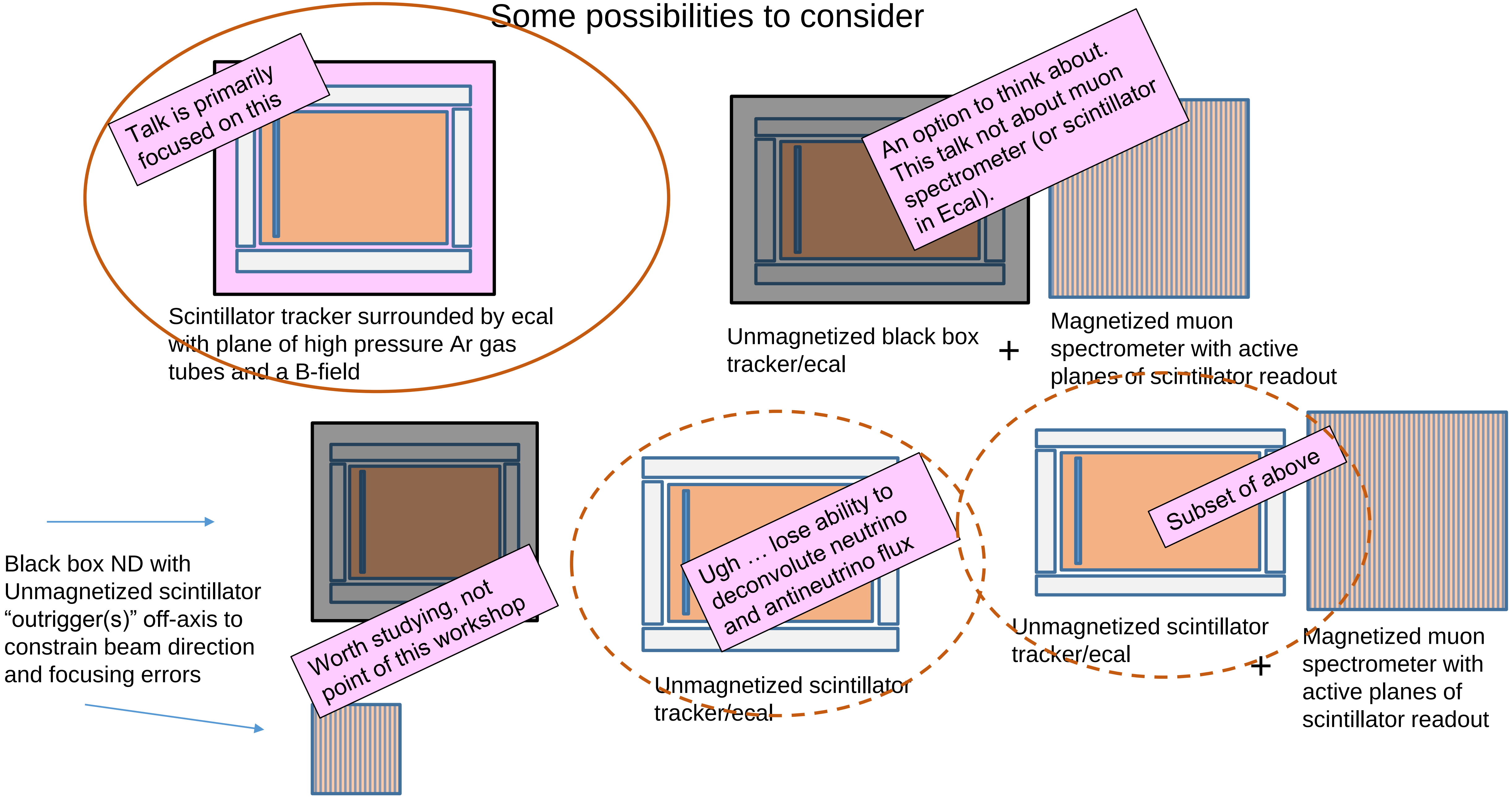


Magnetized muon spectrometer with active planes of scintillator readout

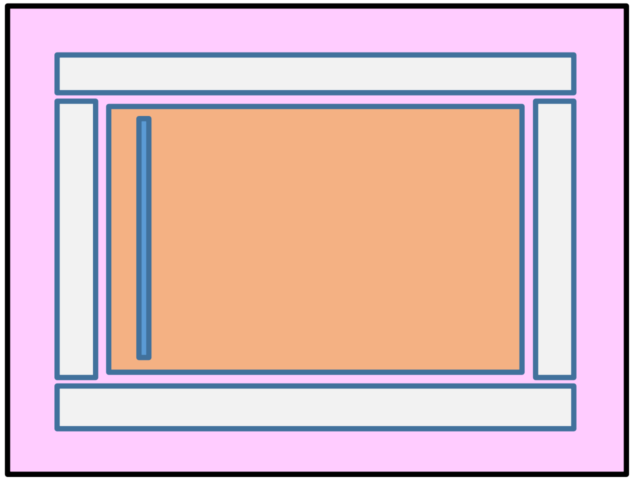
Some possibilities to consider



What we need from ND

Flux measurement:
CCnumu (+other three types), nu-e scat, low-nu, inverse muon decay, maybe others.

Detector reconstruction systematics (best if ND has Ar target and is similar to FD)



Program to improve xsec errors and constraints
(want a versatile and powerful detector with good vtx/tracking/energy resolution and ability to select topologies. Want full angular coverage.)

Beam monitoring
(high stats, post-target, post-horn)

DUNE is an precision exploration experiment and needs to be ready for surprises

Systematics from nuclear effects
(Ar and perhaps a program of studying diff. nuclear targets)

Need ND that CAN be built technically with the financial and people resources we can pull together

Naïve grade expectations for scintillator tracker option

A-

Flux measurement:
CCnumu (+other three types)
nu-e scat, low-nu, inverse
muon decay, maybe others

Done by MINERvA and T2K

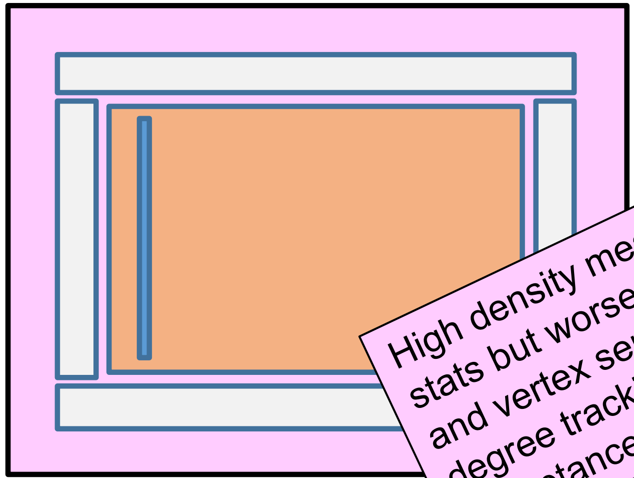
Detector reconstruction systematics (best if ND has Ar target and is similar to FD)

D

Can use layers of Ar targets (similar to FGT) but detector not at all like LArTPC

Program to improve xsec errors and constraints
(Want a versatile and powerful detector with good vtx/tracking/energy resolution and ability to select topologies. Want full angular coverage.)

B



High density means good stats but worse resolution and vertex sensitivity. 90 degree tracking acceptance hole.

A

Done by MINERvA and T2K

Beam monitoring
(high stats, post-target, post-horn)

DUNE is an precision exploration experiment and needs to be ready for surprises

B

Systematics from nuclear effects
(Ar and perhaps a program of studying diff. nuclear targets)

B

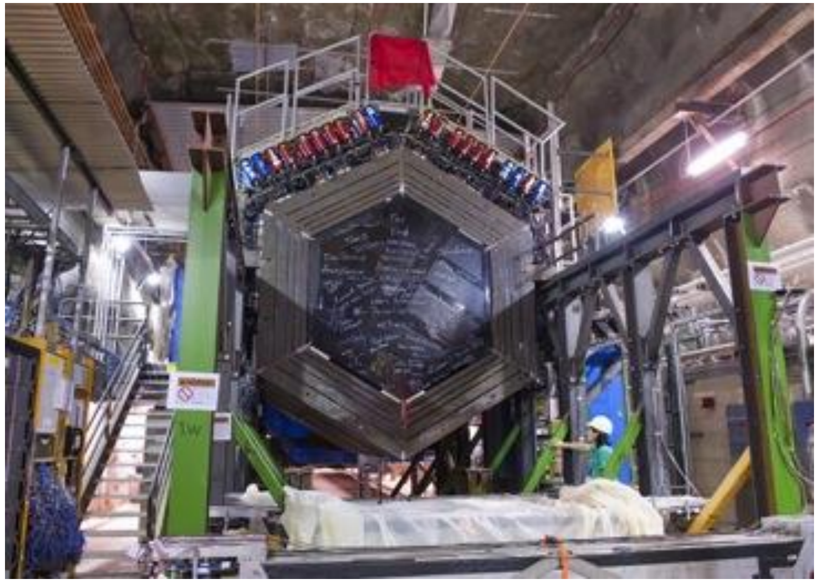
Can use layers of Ar and other targets as done by MINERvA (similar to FGT)

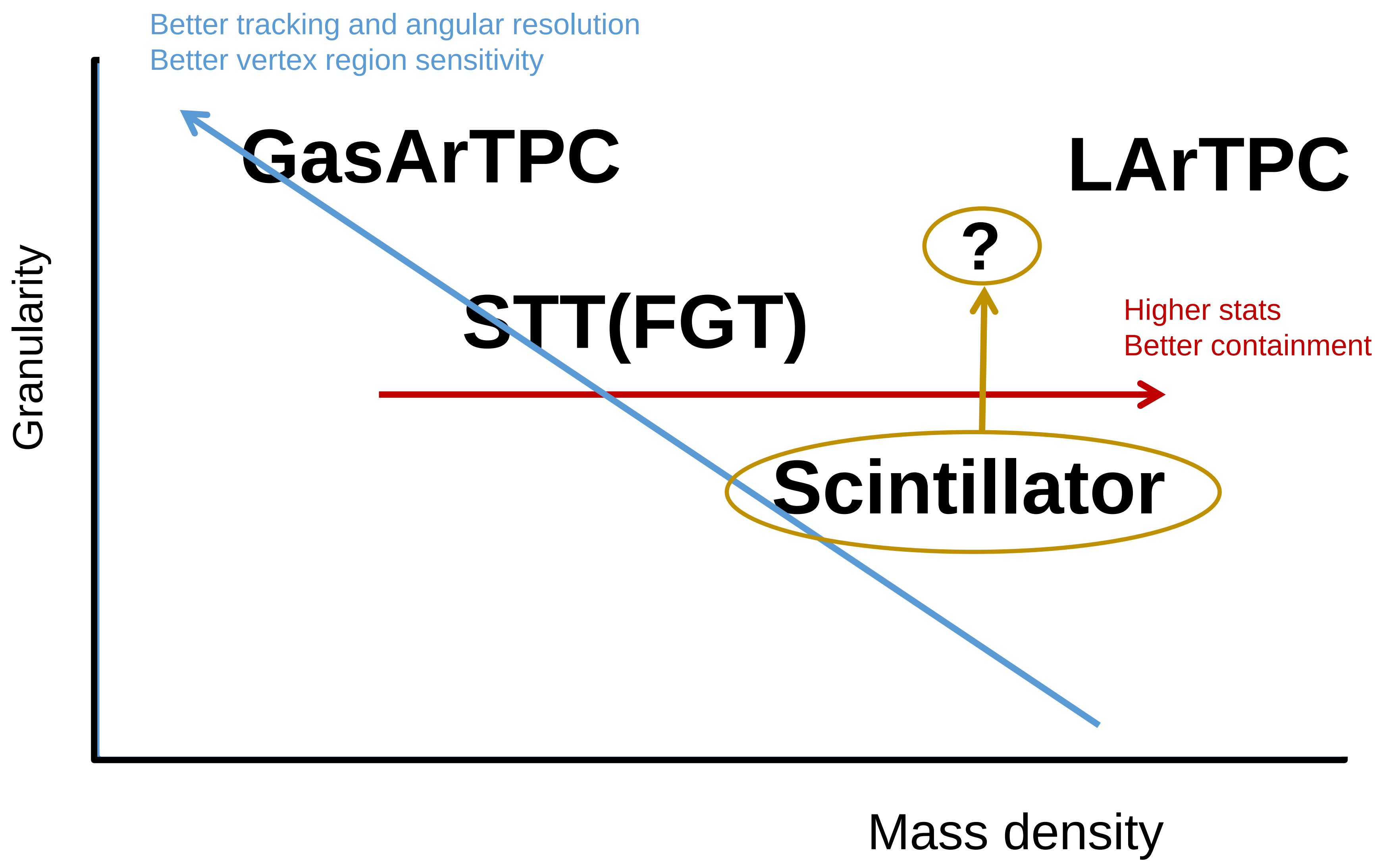
Need ND that CAN be built technically with the financial and people resources we can pull together

A

Similar scale detectors built before, tracker part probably on "cheap" end of options?

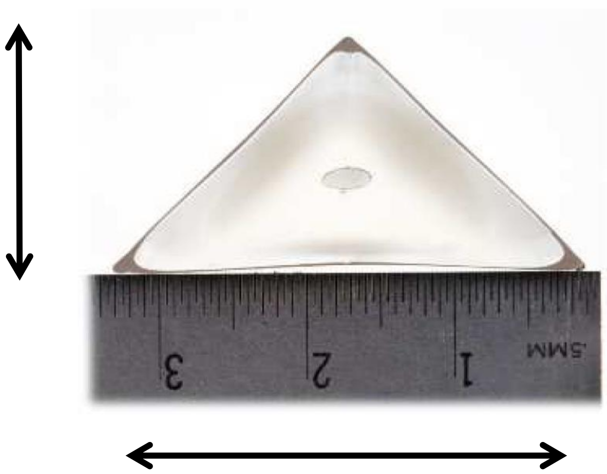
Recent scintillator tracker existence proofs.
What have we learned?
What can we do better (and where not)?



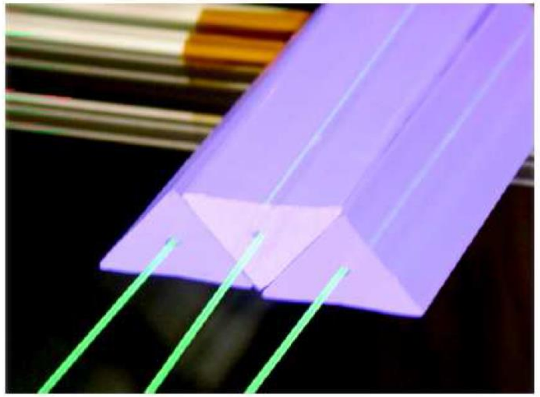

Better tracking and angular resolution
Better vertex region sensitivity
GasArTPC
LArTPC
?
STT(FGT)
Higher stats
Better containment
Scintillator
Granularity
Mass density

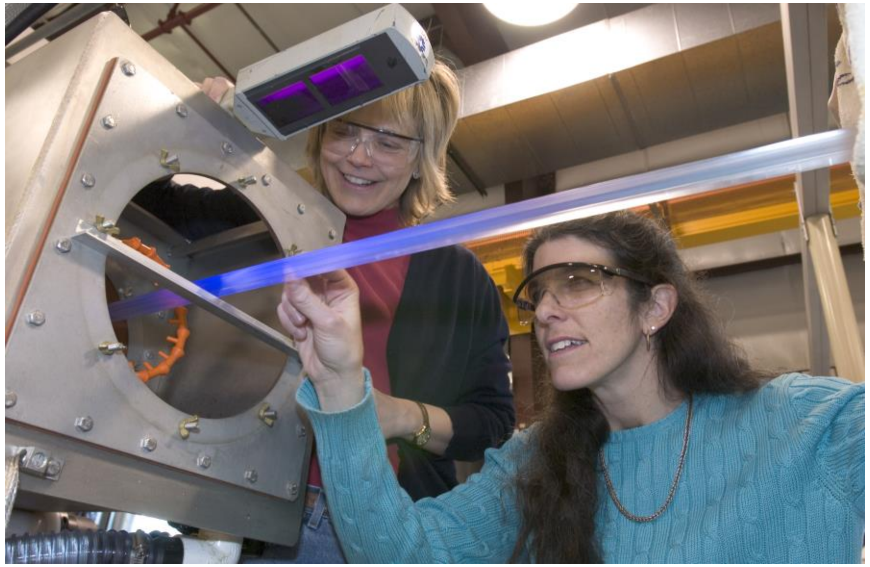
MINERvA (and T2K P0D) scintillator

1.7 cm



3.3 cm





Extrusion Line Facility at Fermilab

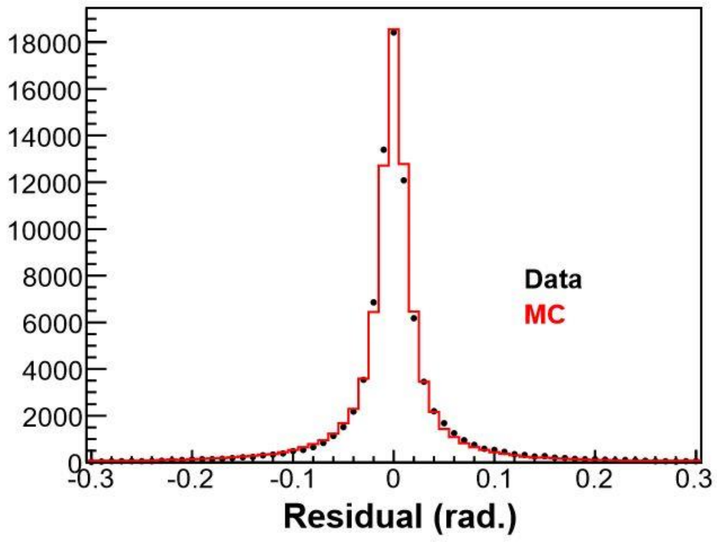
Anna Pla-dalmu: Probably can make extrusions down to 1 cm.
Have done 1 cm^2 xsec with 2.5-3 mm hole before.

For a few plots in this talk, assume triangles with
1.5 cm base and 0.77 cm height

Charged track angular resolution performance

$$\vartheta_{rms}\Big|_{multscatt} = \frac{0.015}{p}\sqrt{\frac{t}{X_o}}$$

Option	~thickness	Xo	ϴrms @ 1 GeV/c
Minerva-like	7 cm (4 hits)	40 cm	6.3 mrad
Scint. With smaller strips	3.1 cm (4 hits)	40 cm	4.2 mrad
LArTPC	1 cm?	14 cm	4 mrad
STT	16 cm (4x and 4y hits) 8 cm (~2x and ~2y hit)	5.5 m	2.5 mrad 1.3 mrad
GasArTPC	1 cm?	12.6 m	0.04 mrad



MINERvA angular resolution from rock muon study (from detector NIM)

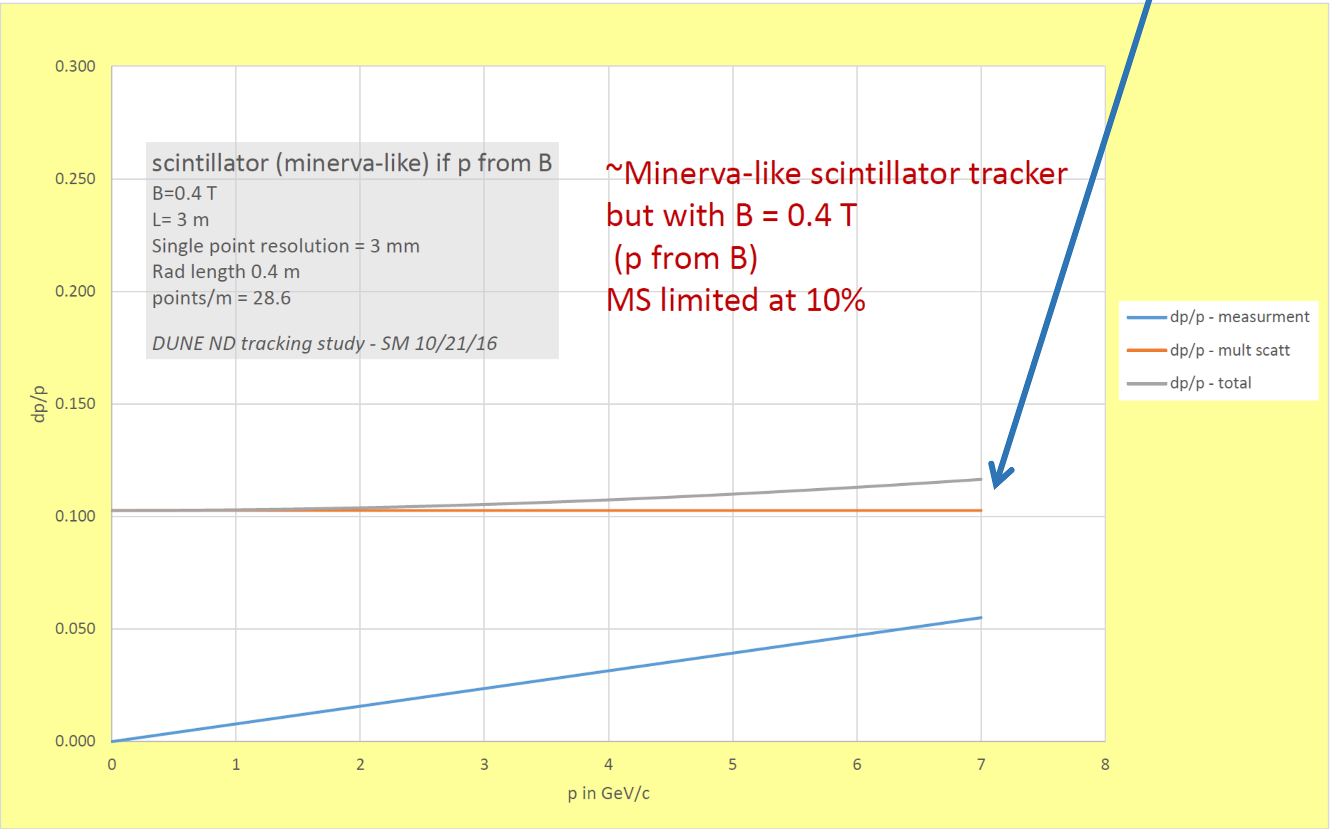
Charged track dp/p performance

$$\left(\frac{\delta p}{p}\right)^2 = \left(\frac{\sigma_s p}{0.3BL^2}\sqrt{\frac{720}{N+4}}\right)^2 + \left(0.045\frac{1}{B\sqrt{LX_o}}\right)^2$$

Multiple scattering dominated. Expect to see relatively little improvement with smaller transverse xsec strips.

All options are multiple scattering limited

	$\frac{\delta p}{p}$
FGT (straw tube tracker 0.4 T B)	~3%
HPLArTPC (0.4 T B)	~2%
LArTPC (1 T B)	~7%
MINERvA-ish with 0.4 T B	~10%



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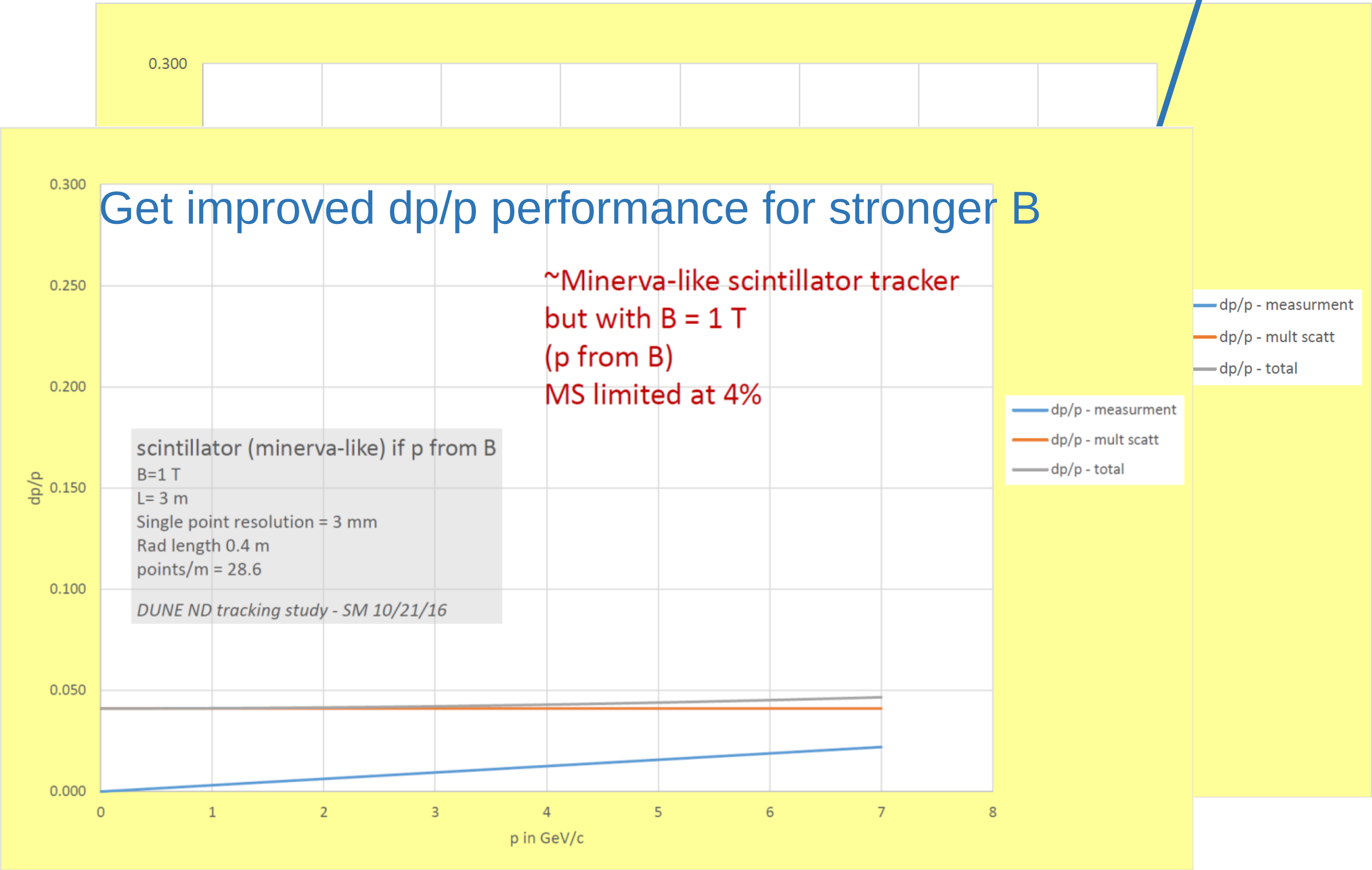
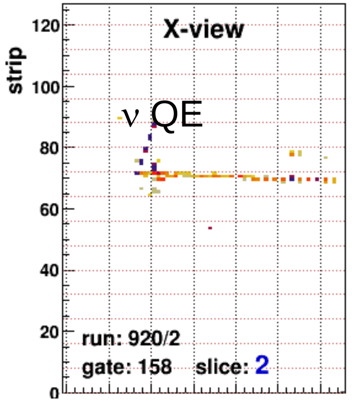
LArTPC (1 T B)	~7%
MINERvA-ish with 0.4 T B	~10%
Scint. Tracker with 1 T B	~4%

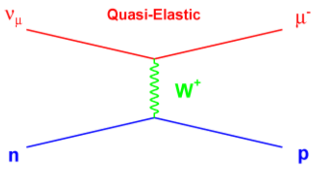


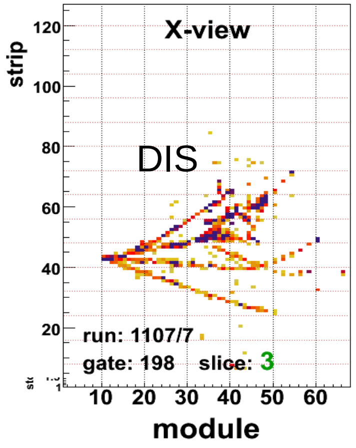
MINERνA Events
(X view)

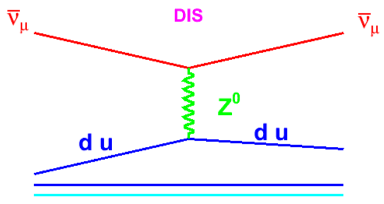
Can see that scintillator tracker is able to select topologies.

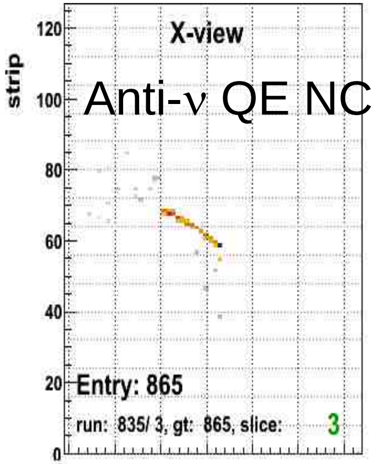
Expect this/vertex sensitivity/two-track separation to improve with smaller strips

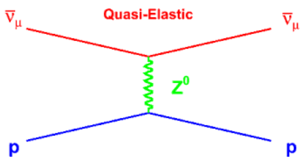


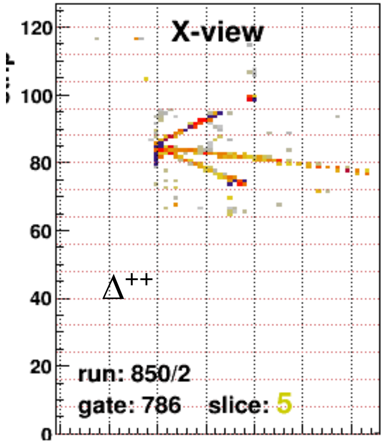


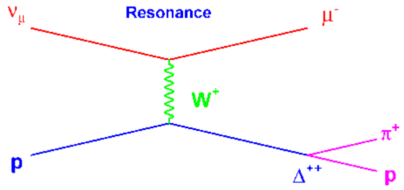




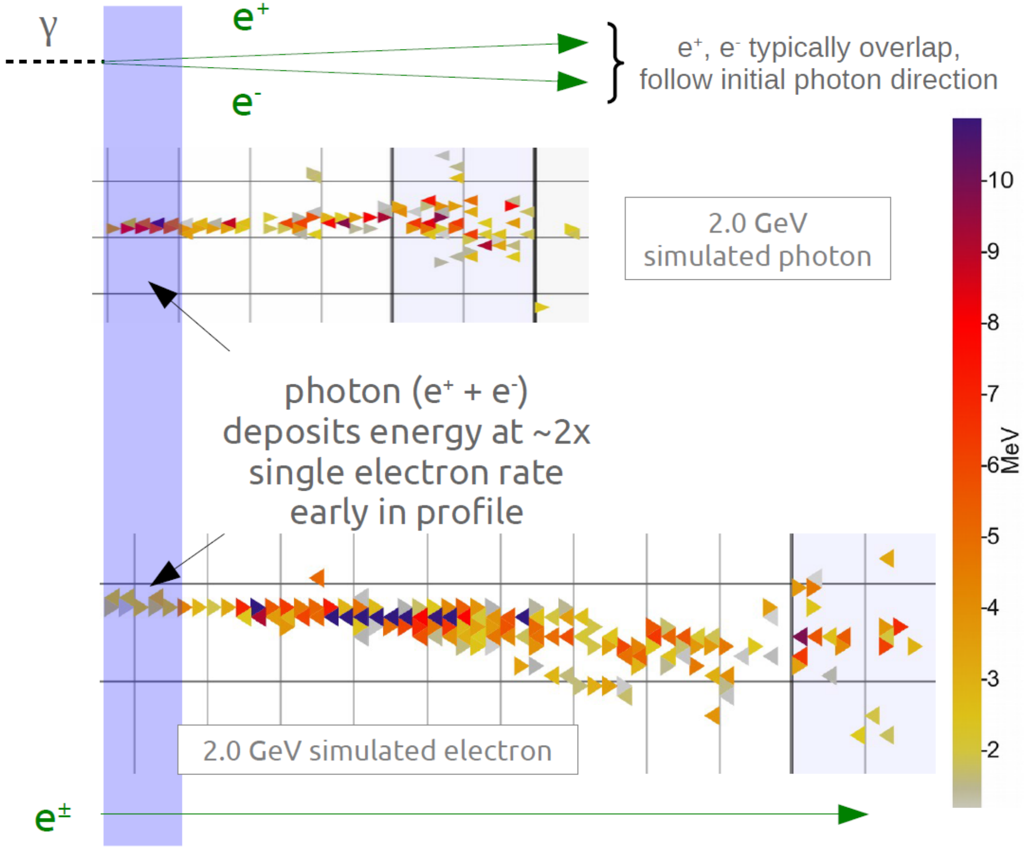


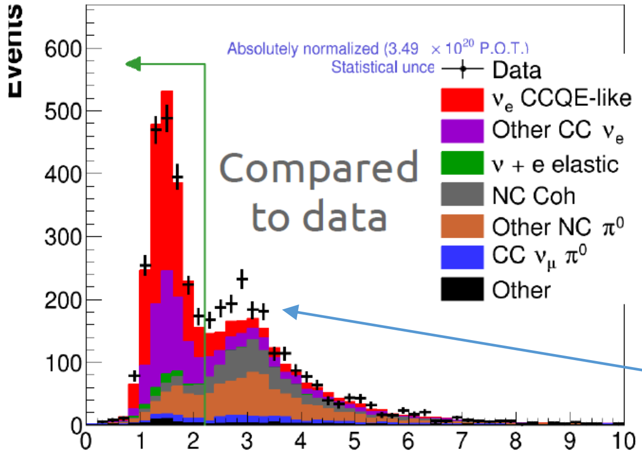


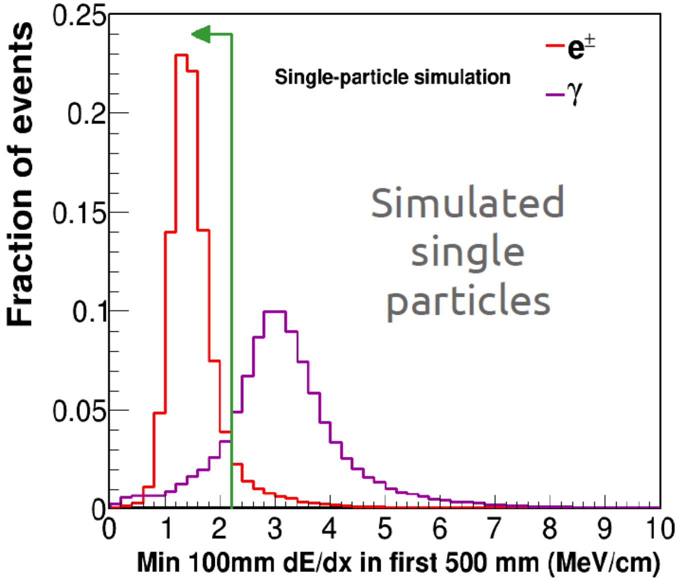




MINERνA γ-e separation







NC diffractive pizero production (off H) not in version of MC used at time

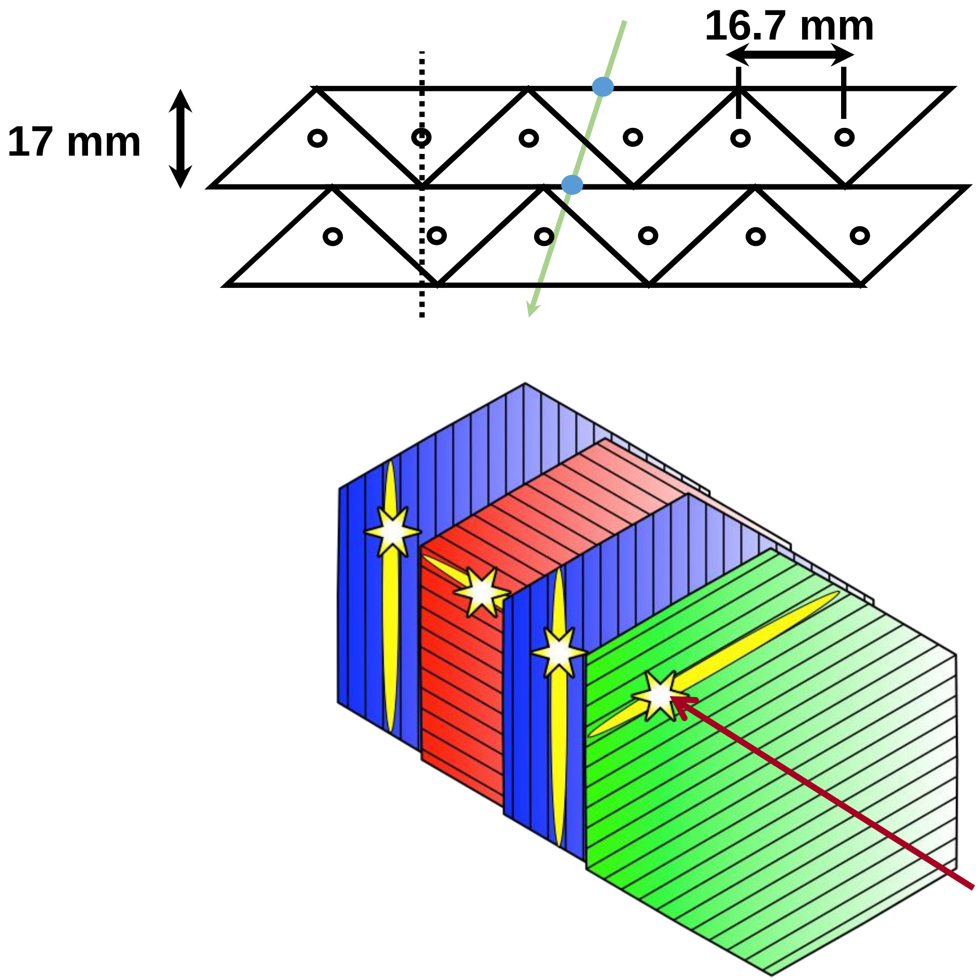
MC nicely validated with Michels and photons from pizeros

J. Wolcott

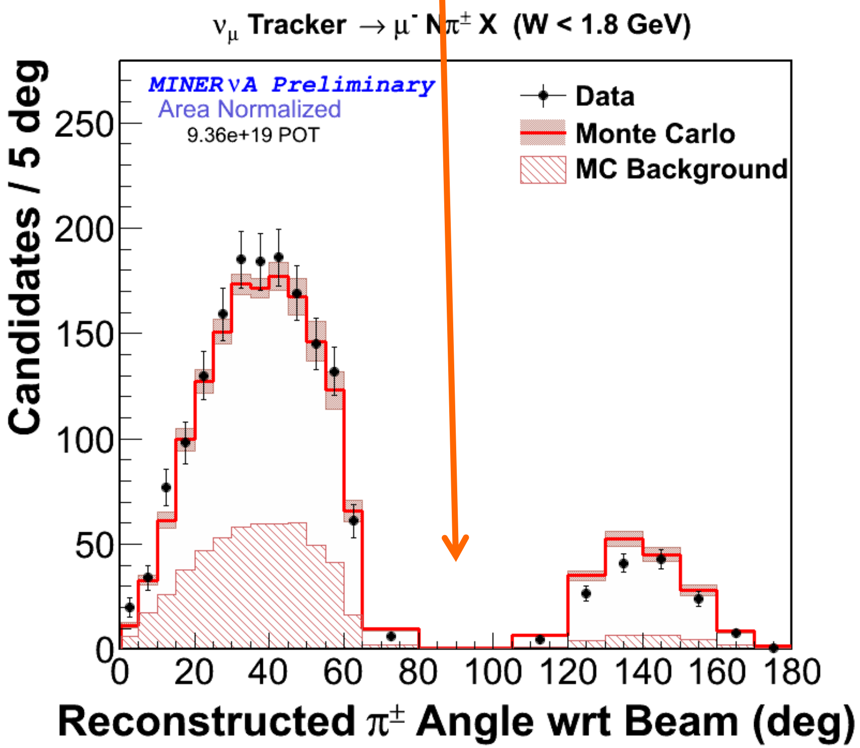
Might improve somewhat with more granularity

Hurts acceptance and identification by topology.
Less vertex region phase space covered.

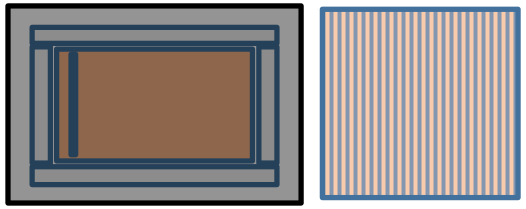
MINERνA planes



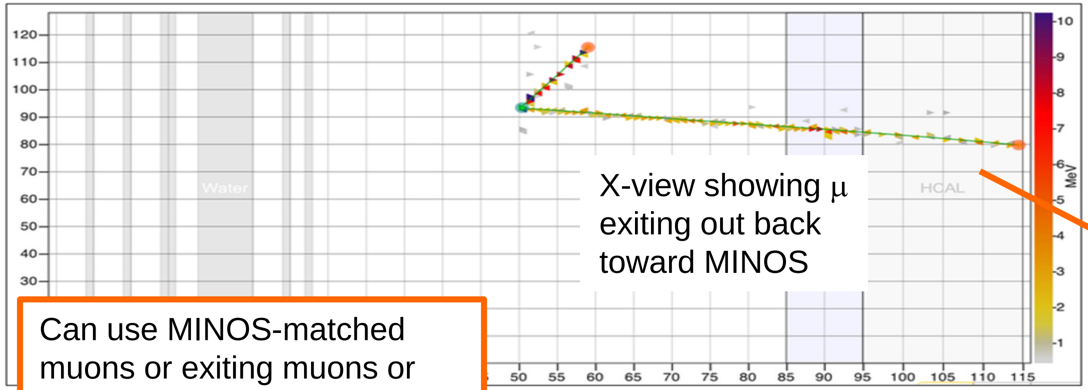
Construction of tracker gives a hole in reconstruction at 90°



For scintillator tracker (or other tracker) if used in non-magnetized target plus muon spectrometer configuration

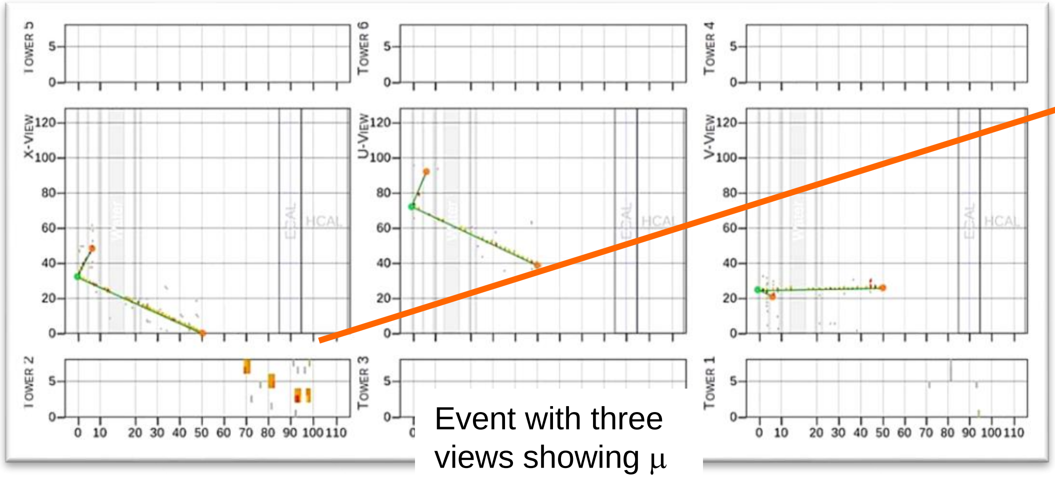


2-track CCQE analysis

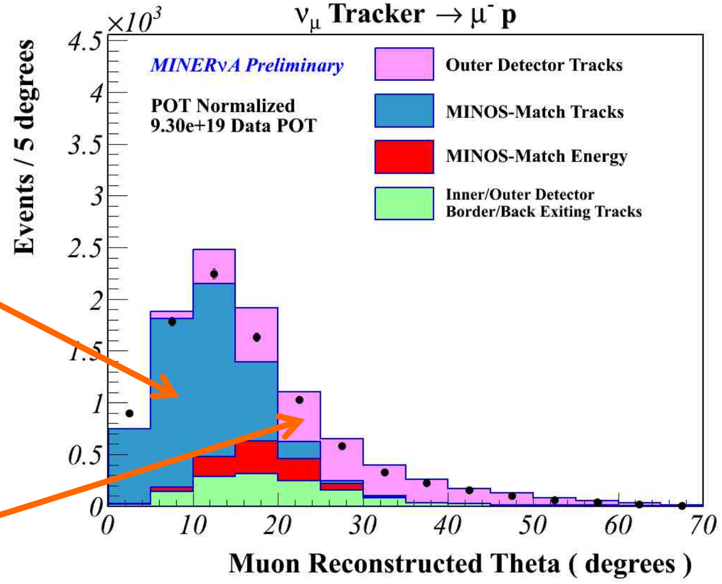


X-view showing μ exiting out back toward MINOS

Can use MINOS-matched muons or exiting muons or even stubs in MINOS

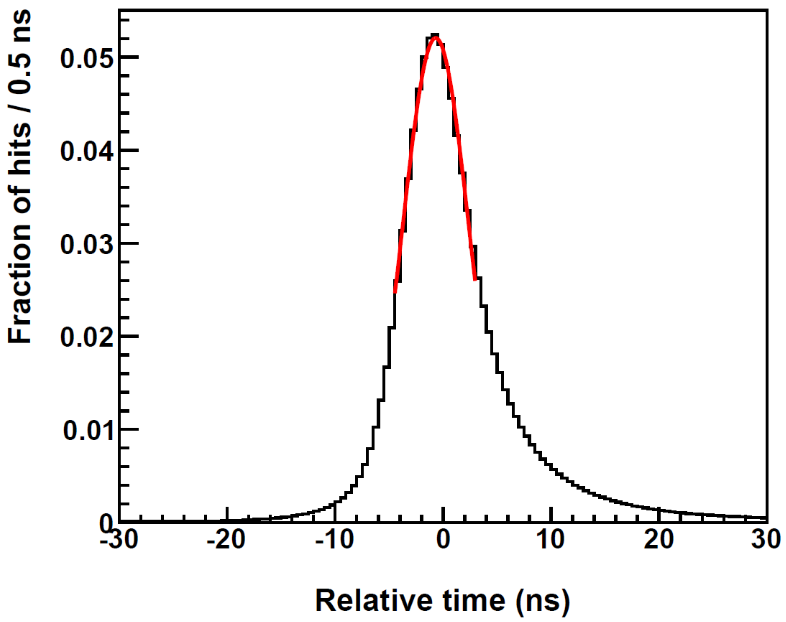


Event with three views showing μ exiting out side



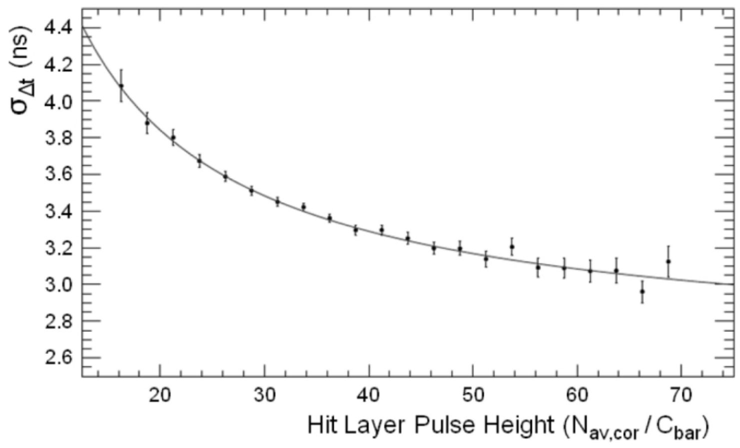
Limited angular acceptance for momentum-analyzed muons causes sculpting in angular and Q^2 acceptance.

Scintillator detectors have fast timing – few ns

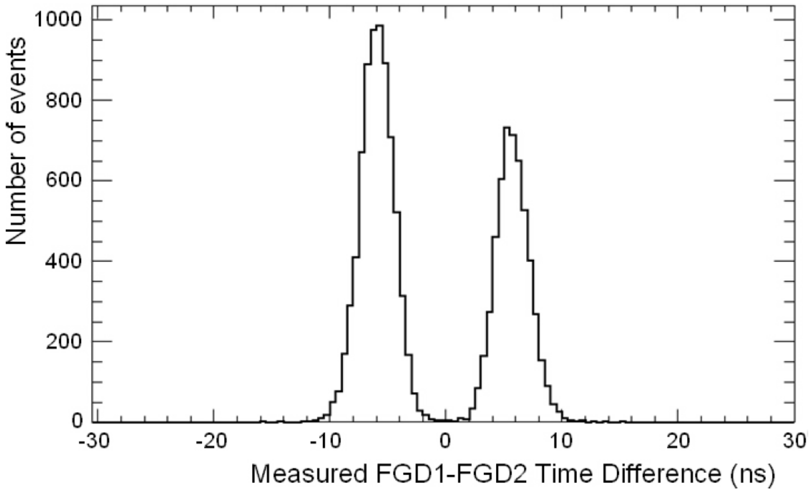


MINERvA calibrated hit time along rock muon tracks relative to the truncated mean calibrated hit time

From MINERvA NIM



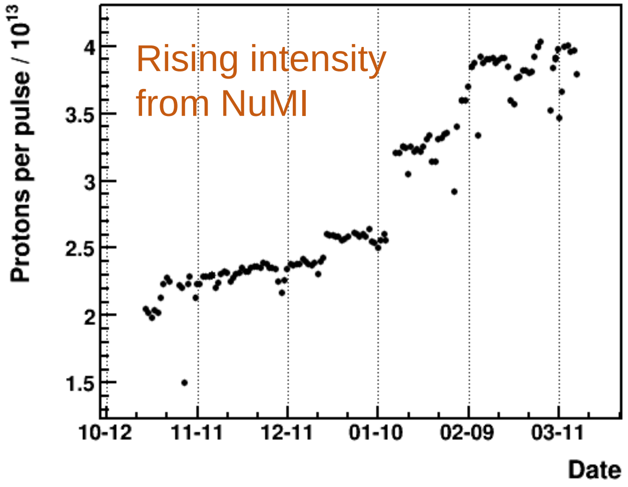
T2K FGD spread of timing residuals between a hit layer and a reference layer as function of hit layer charge

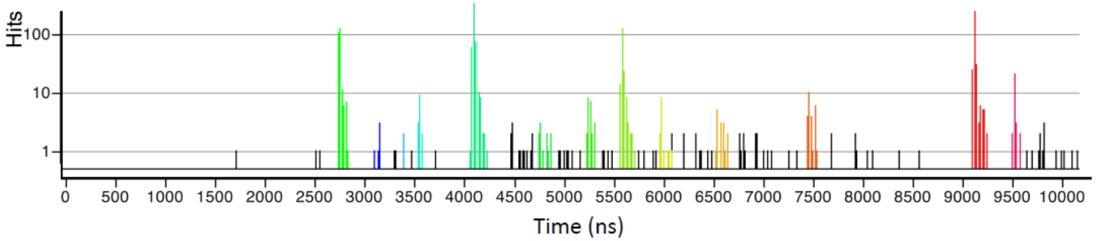


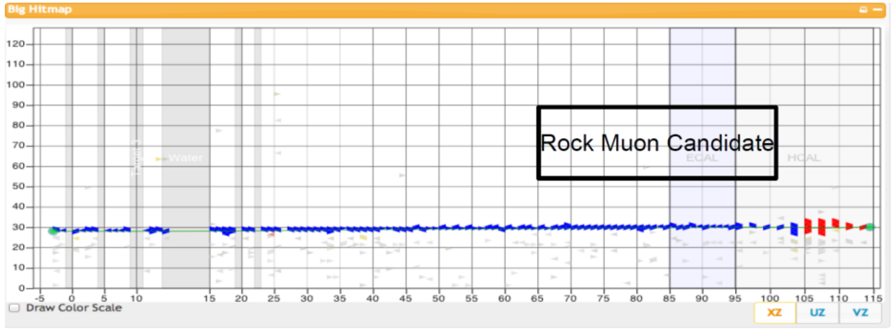
From T2K ND280 NIM

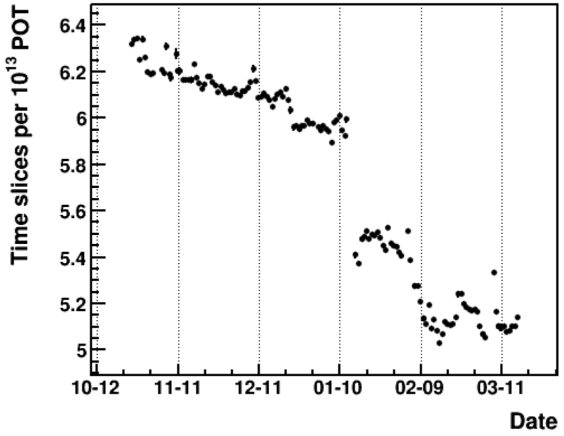
FGD1-FGD2 time difference for cosmics passing through both FGD detectors

MINERvA sees intensity effects

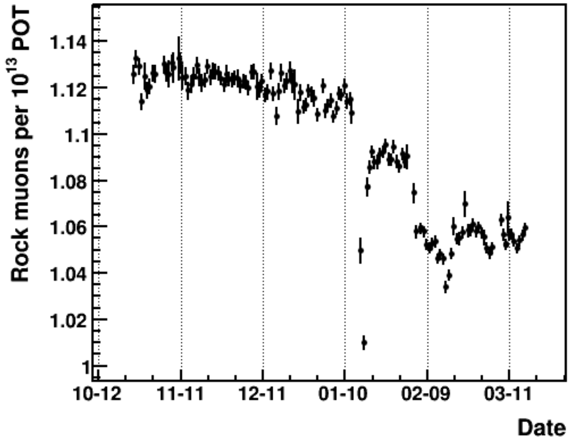






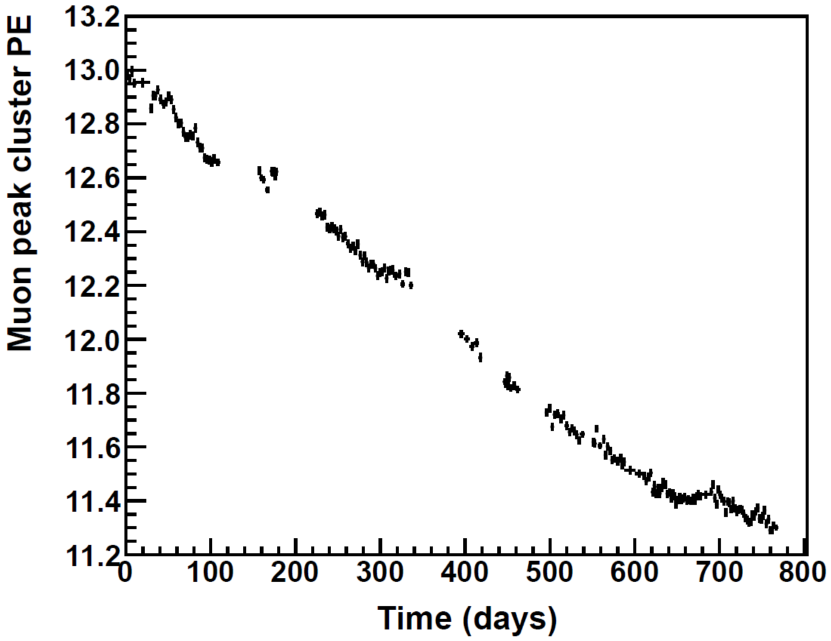


Number of temporally separated bits of activity in the detector drops – more activity means overlap increases within the time resolution of our algorithm



Number of reconstructed rock muons traversing the detector drops – extra activity and overlaps causes drop in track reconstruction efficiency

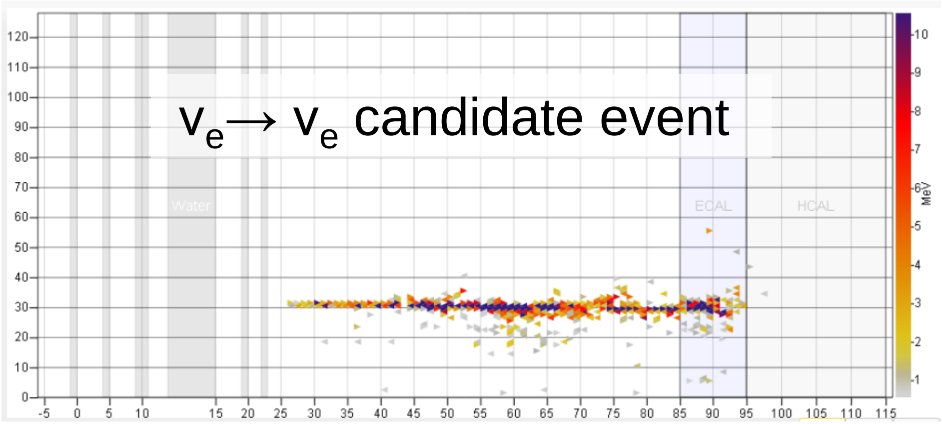
Scintillator ageing leads to slow light loss with time

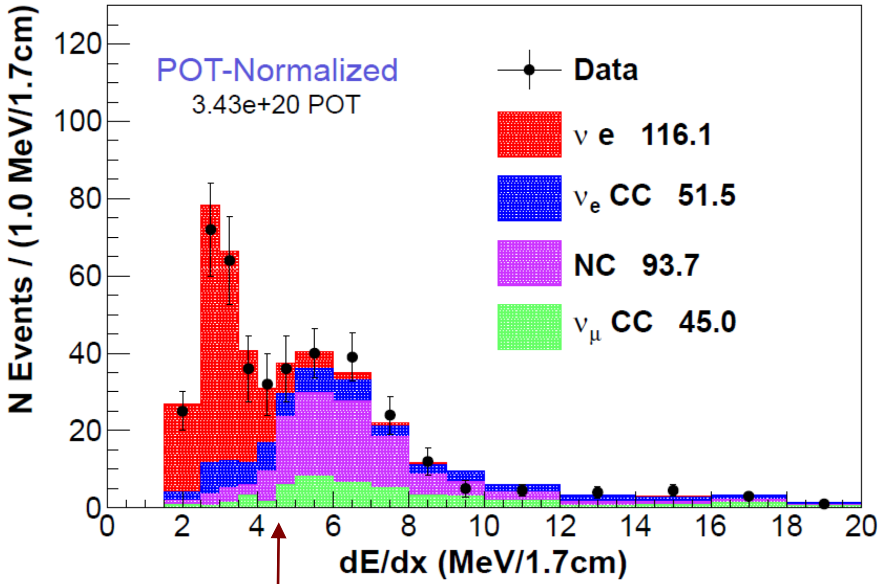


From MINERvA NIM

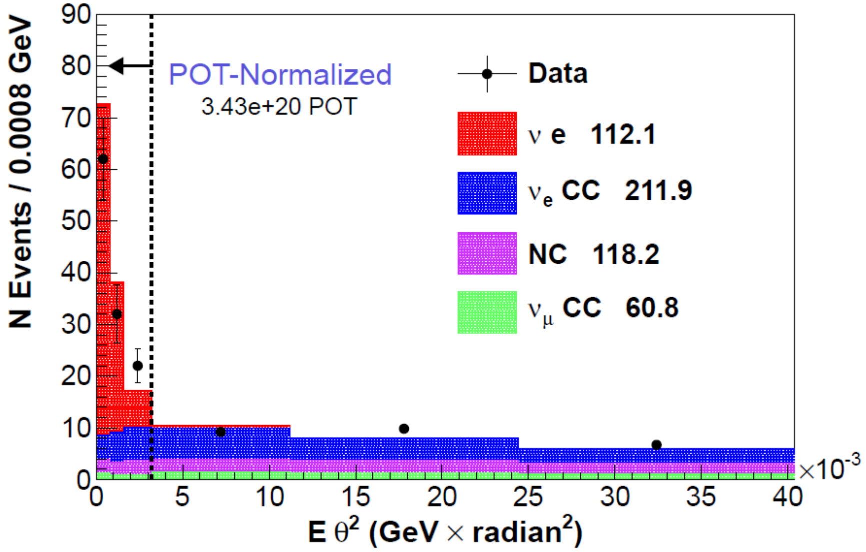
First MINERvA detector module was completed in 2006, detector completed in 2009-2010. T2K P0D and FGD detectors installed in 2009.

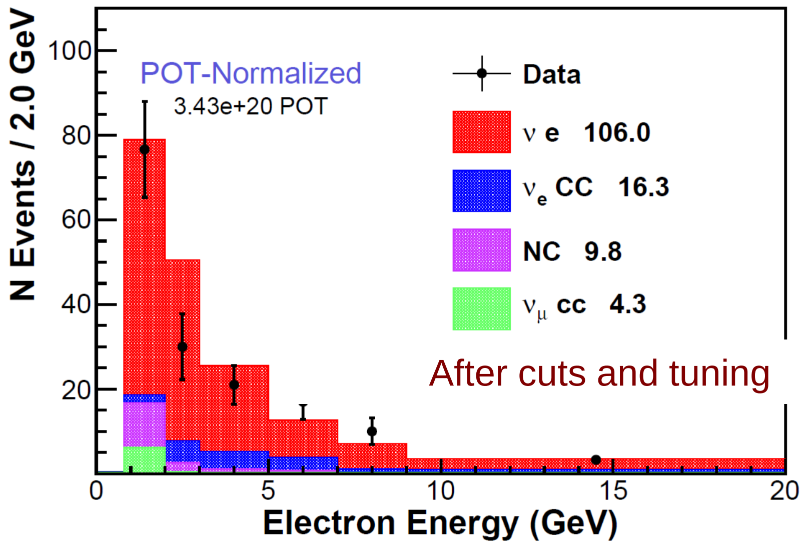
MINERvA and T2K experience can give insight on the limiting errors

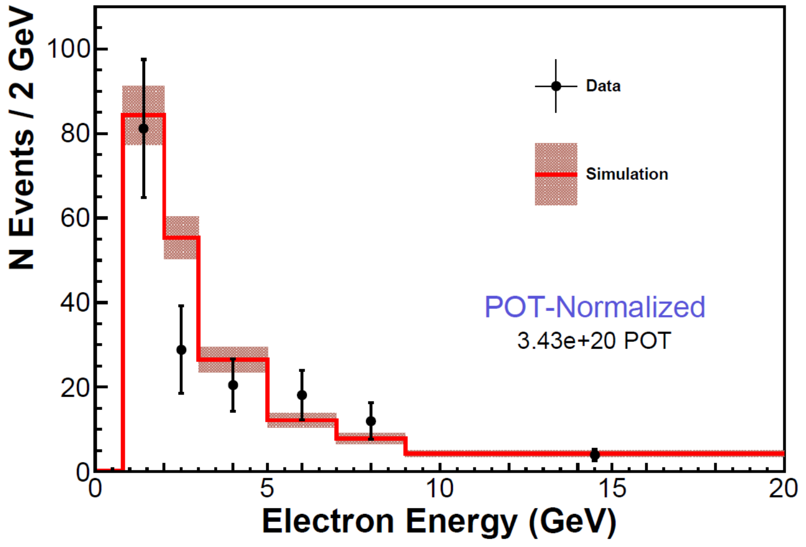




Demand dE/dx near start of track be <4.5 MeV/1.7 cm
Removes most of NC photon background

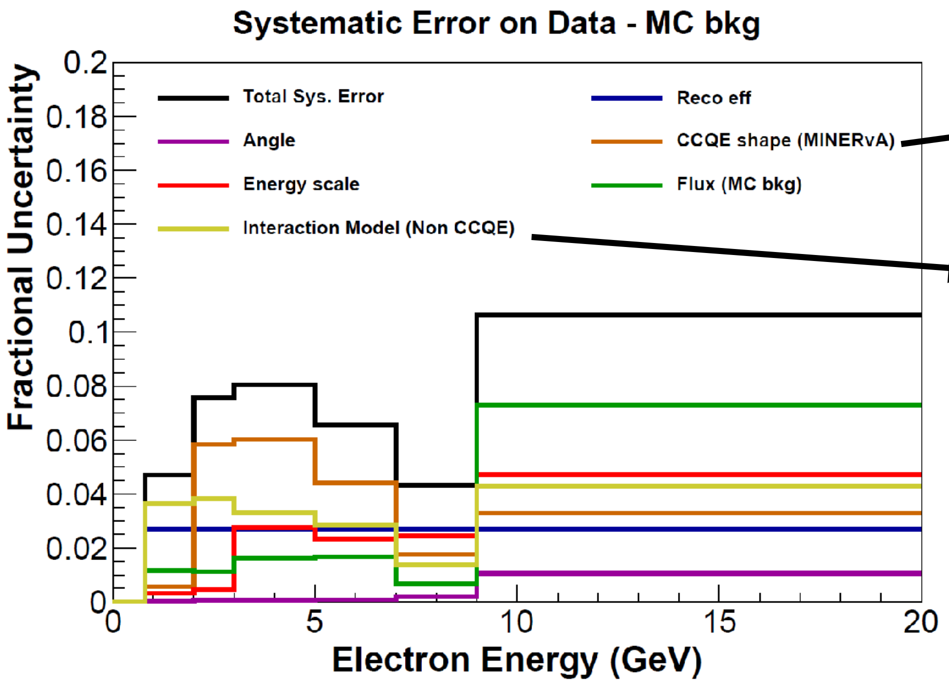






After the tuned background subtraction and efficiency correction (systematic errors shown in the MC, data errors statistical only)

Used to constrain the flux and reduce the error envelope on the flux



Not relevant for DUNE

Some improvement for DUNE perhaps

EM energy scale – data and Michel comparison

Reconstruction efficiency – extracted from muon tracking efficiency looking at muons in MINOS and MINERvA (these electrons are seeded in the same way)

Plastic scintillator tracker option

Pros

- High mass density – high statistics
- Good containment
- Can put in layers of Ar targets (and other targets)
- Fast – can take high rate
- Decent segmentation – can isolate different topologies
- Can separate e from gamma
- Tracking and angular resolution fairly good

Cons

- Not at all like FD
- Ar target layers possible, but those will not be useful for 1-track topologies
- Angular hole in acceptance at 90 degrees

Probably a cheap-ish option

No real attempt at costing.

A very rough guess based on a few T2K P0D & MINERvA numbers and number of channels is O($10M) for tracker (not including ECAL or magnet or Ar target planes)

Backup slides

$$\left(\frac{\delta p}{p}\right)^2 = \left(\frac{\sigma_s p}{0.3BL^2}\sqrt{\frac{720}{N+4}}\right)^2 + \left(0.045\frac{1}{B\sqrt{LX_o}}\right)^2$$

Single point measurement resolution (m)

Track length in m

Track momentum in GeV/c

B field strength in T

Number of measurement points

Radiation length of medium (m)

Measurement term

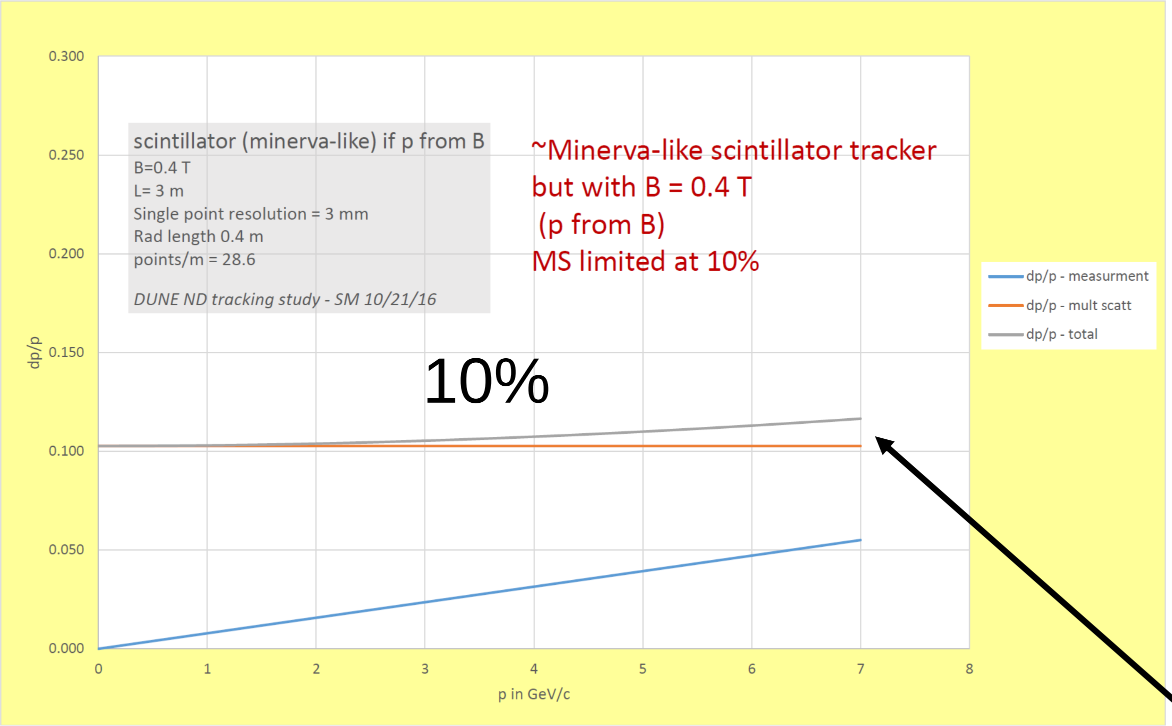
Multiple scattering term

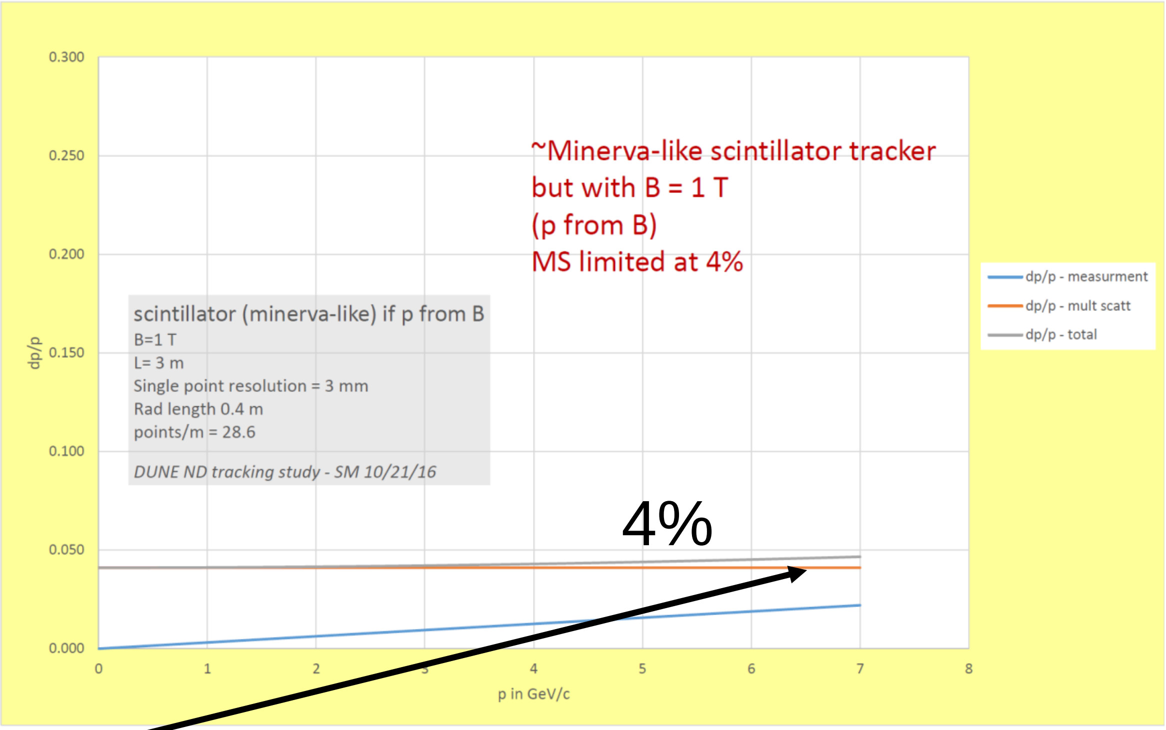
From:
Gluckstern NIM 24 (1963) 381
Michael Moll, presentation at CERN on tracking on 15 May 2011

dp/p Performance

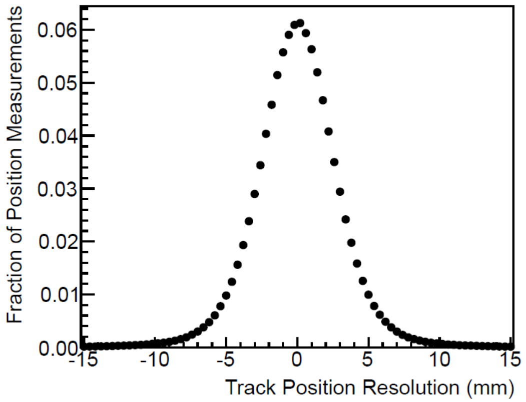
B = 0.4 T

B = 1.0 T



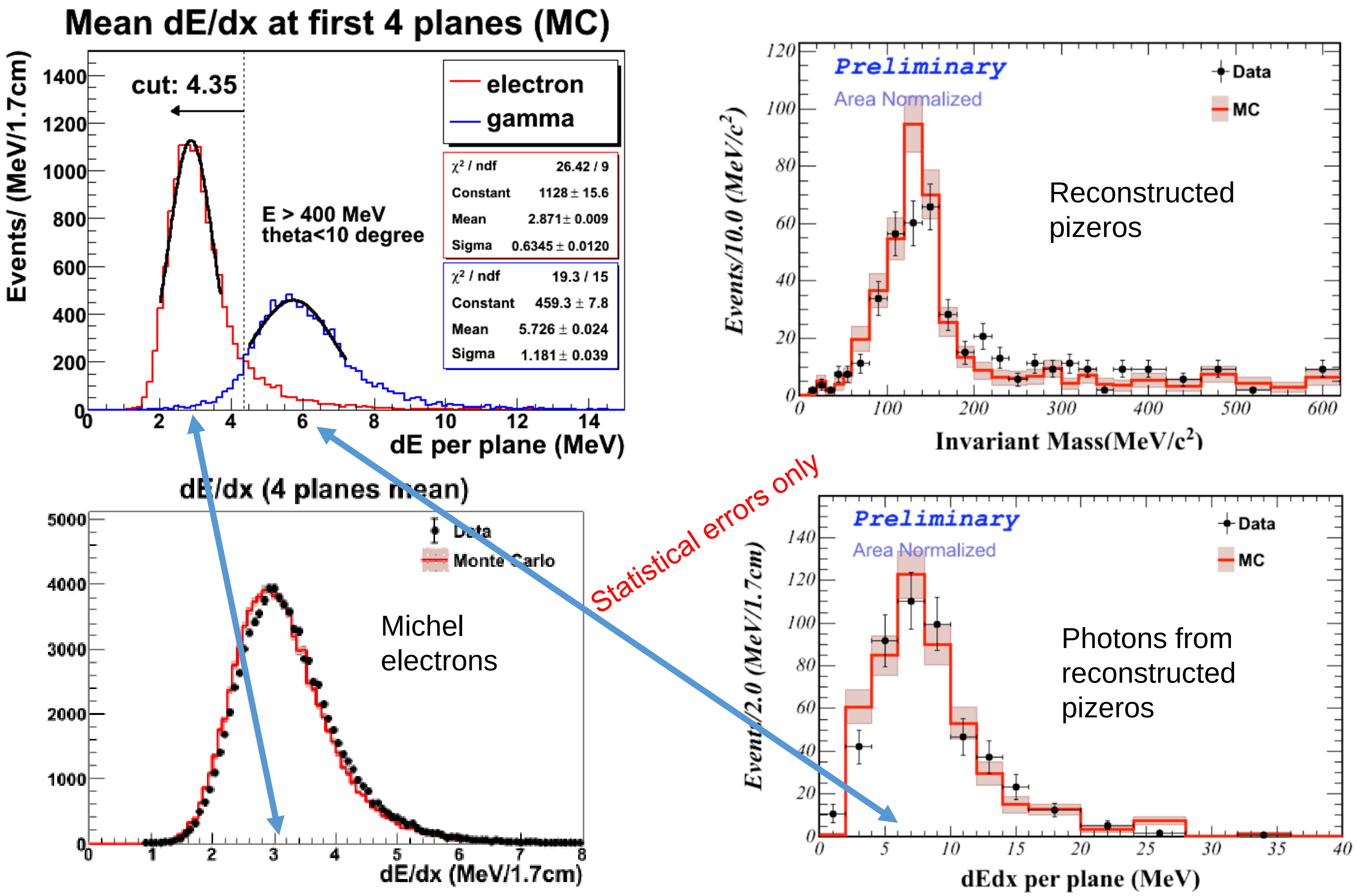


Multiple scattering dominated. Expect to see relatively little improvement with smaller transverse xsec strips.



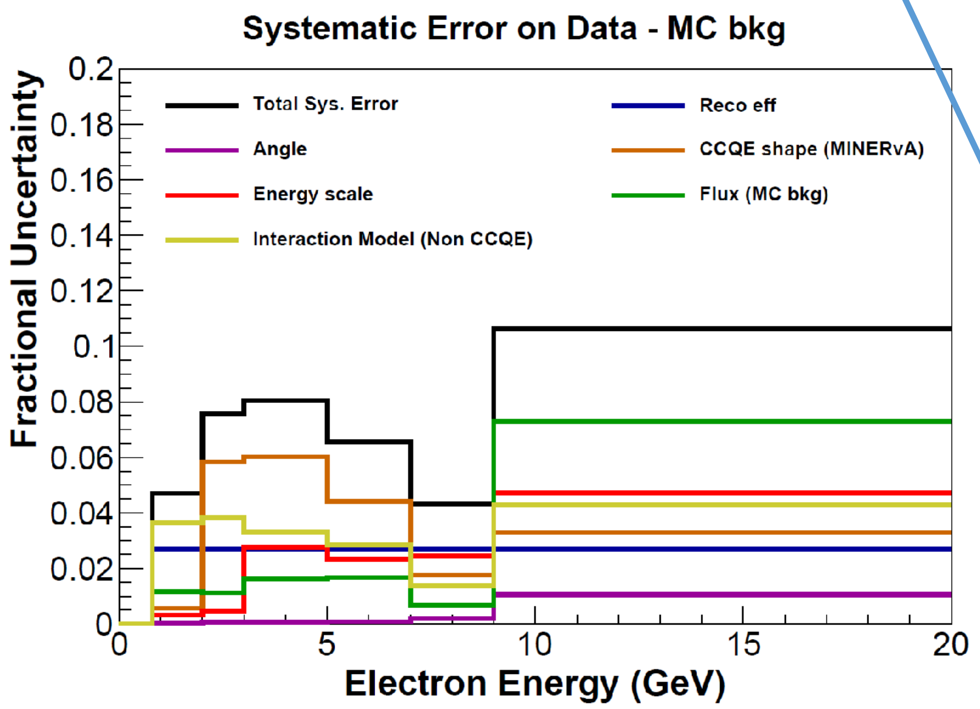
Resolution of fitted positions along a traci relative to the measured cluster postion for a sample of data rock muons, RMS is 3.1 mm

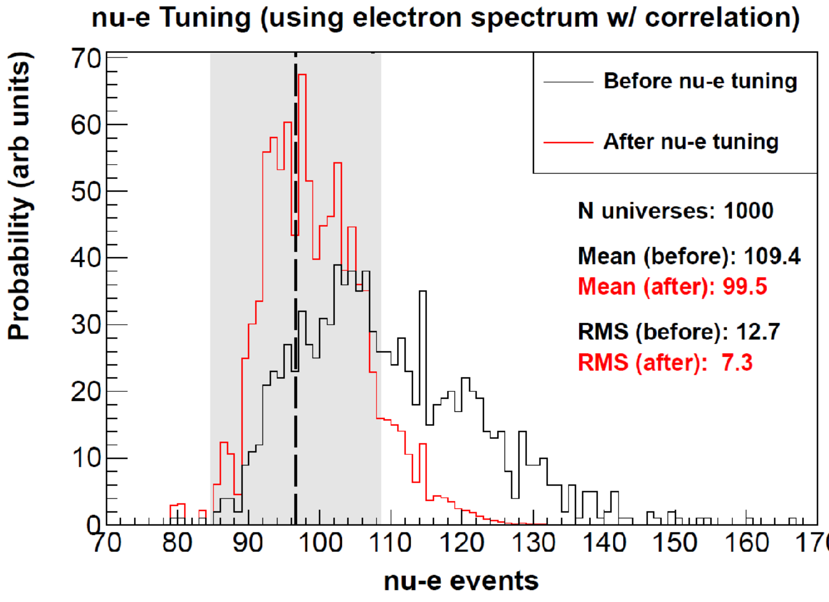
Michels, pizeros and e/γ separation

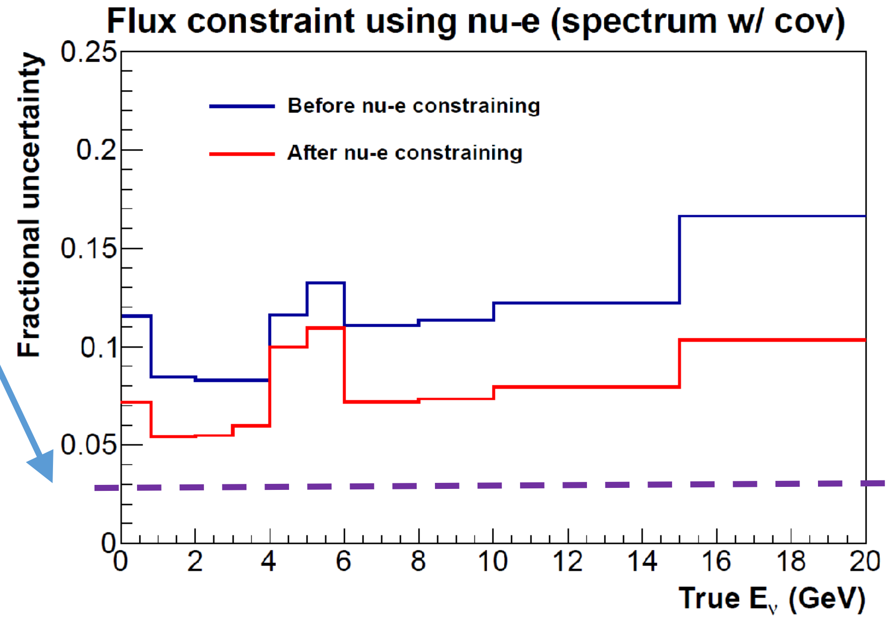


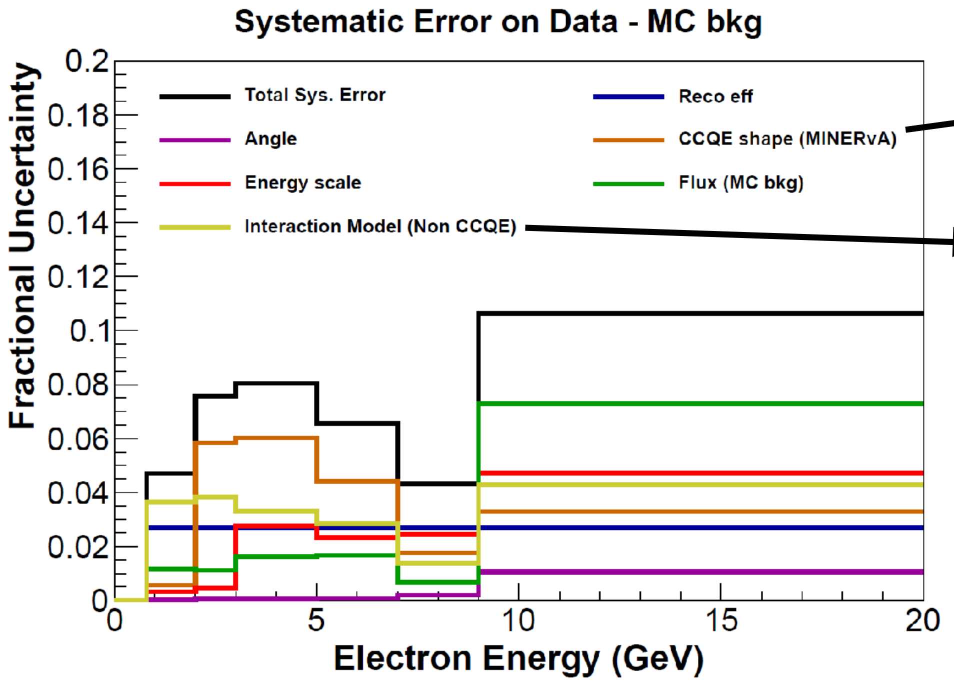
CDR (physics 6-93) states absolute neutrino flux known to <3% in 0.5-10 GeV neutrino energy range

Neutrino-electron scattering state-of-art MINERvA PRD









Not relevant for DUNE

Some improvement
for DUNE perhaps

- DUNE – higher stats (can use non-Ar part of FGT)
- Premium on EM energy recon and electron angular resolution (for background rejection)
- EM energy scale error important (want test beam probably)
- Full analysis should be done to see how a 3% error in number of events as function of electron energy translates into error in absolute flux as function of neutrino energy

- Aggressive but perhaps not crazy

Low ν method

Claim gives absolute shape of numu and numubar flux to 1-2% precision for 1<Ev<50 GeV.
Gives FD/ND(Ev) to 1-2% precision.

MINERvA reports flux shape from Low nu with lower limit Ev=2 GeV due to worries about sensitivities to mis-modeling for v<300 MeV.

MINERvA normalizes to NOMAD data in the 9-12 GeV region with a 3.6% uncertainty. Statistical error in the normalization bin (9-12 GeV) blows up the normalization error. FD/ND should be much smaller.

For antineutrinos lack of good normalization data has MINERvA normalizing to GENIE tuned to world average neutrino xsec

Needs study. (1-2% seems optimistic. 3-4% likely doable)
DUNE ND might have better stat error. But not clear to me there is a better normalization at higher energy to use. Not sure how plays out in the ratio.