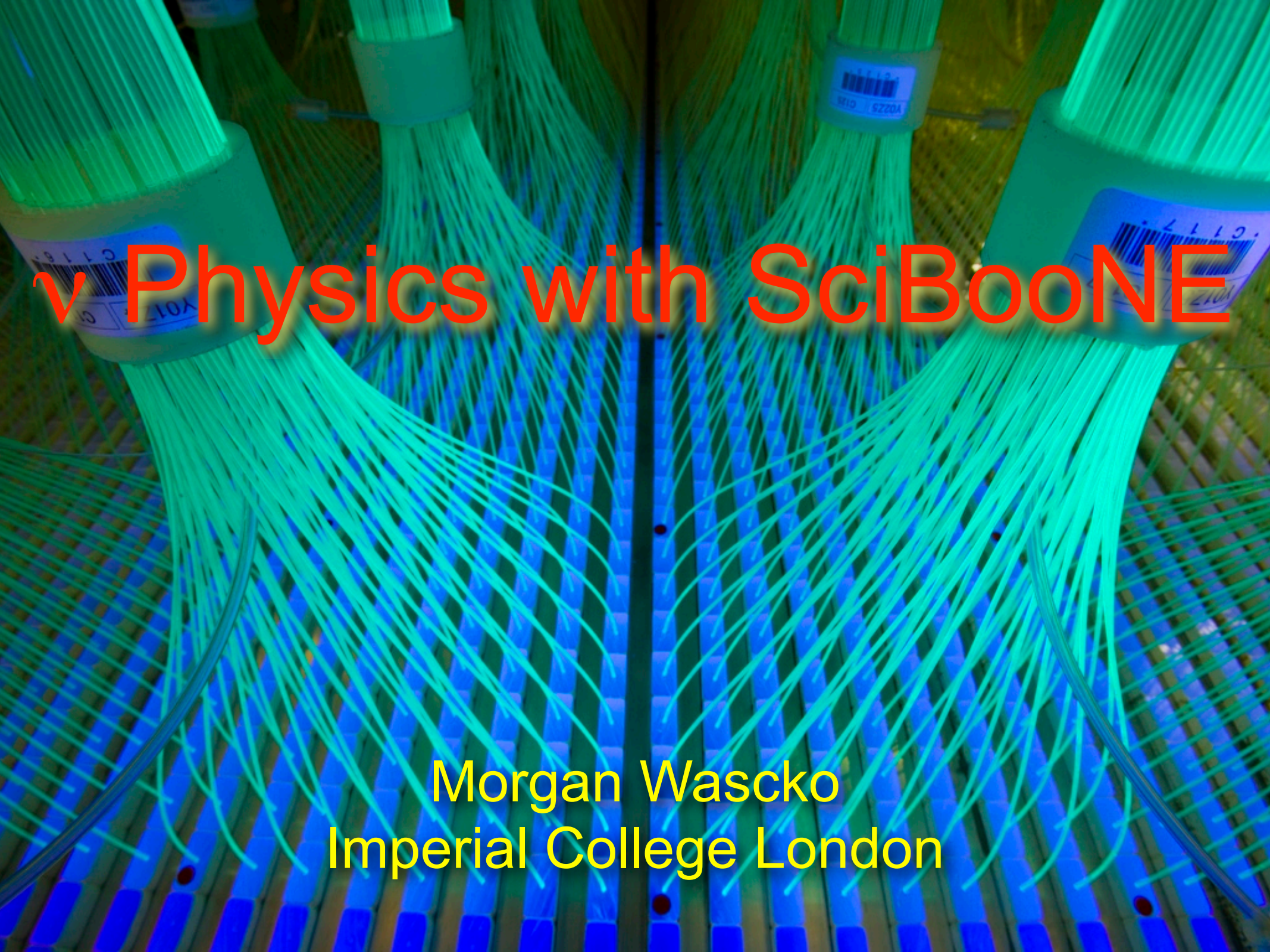

ν Physics with SciBooNE

Morgan Wascko
Imperial College London

Physics of SciBooNE

We stand on the threshold of the ν precision era

- Precise cross section measurements, ~1 GeV
- ν_μ and $\bar{\nu}_\mu$!
  - $\bar{\nu}_\mu$ needed for CP violation search
  - Especially useful for T2K θ_{23} , θ_{13} search

(MiniBooNE near detector)

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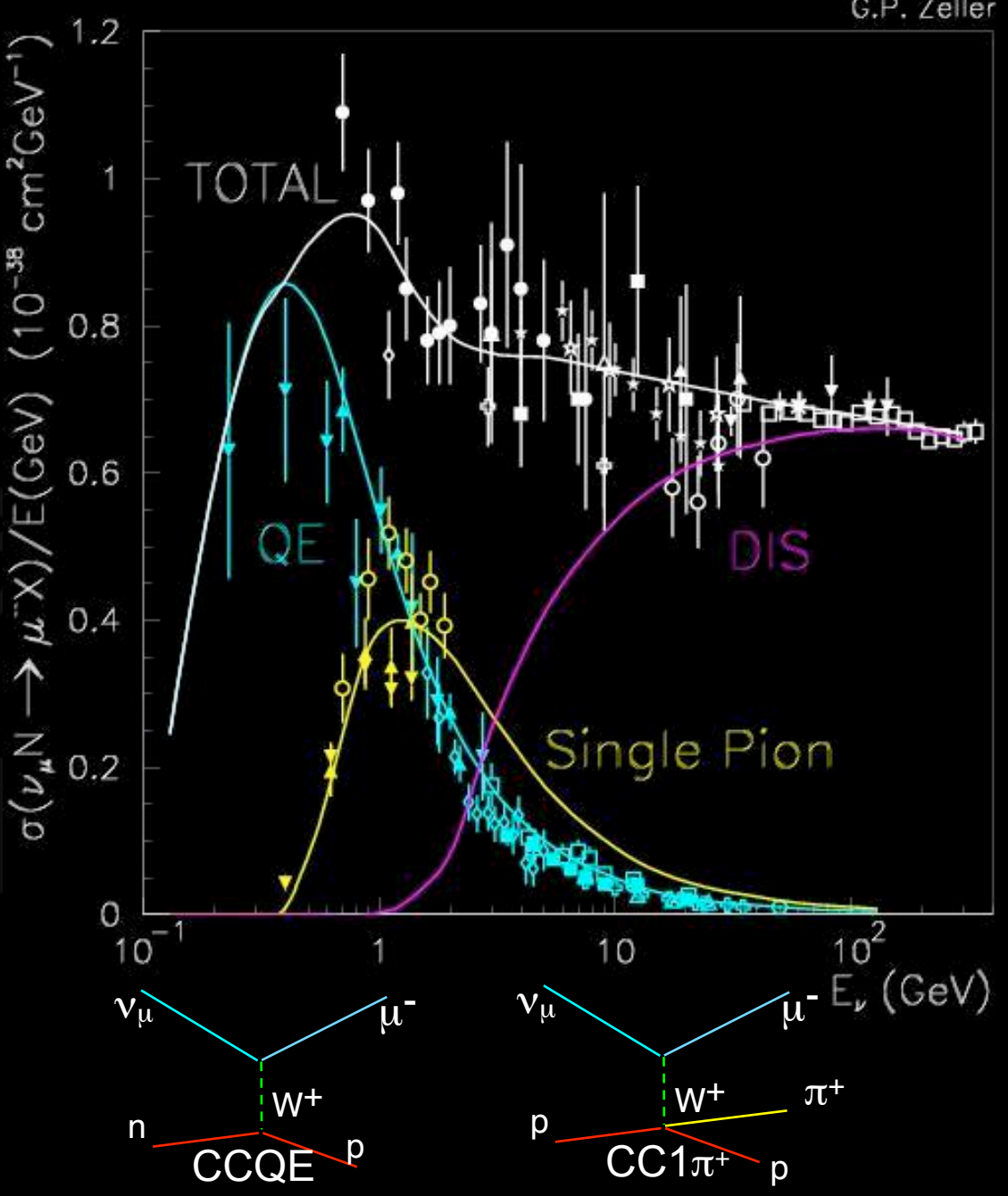

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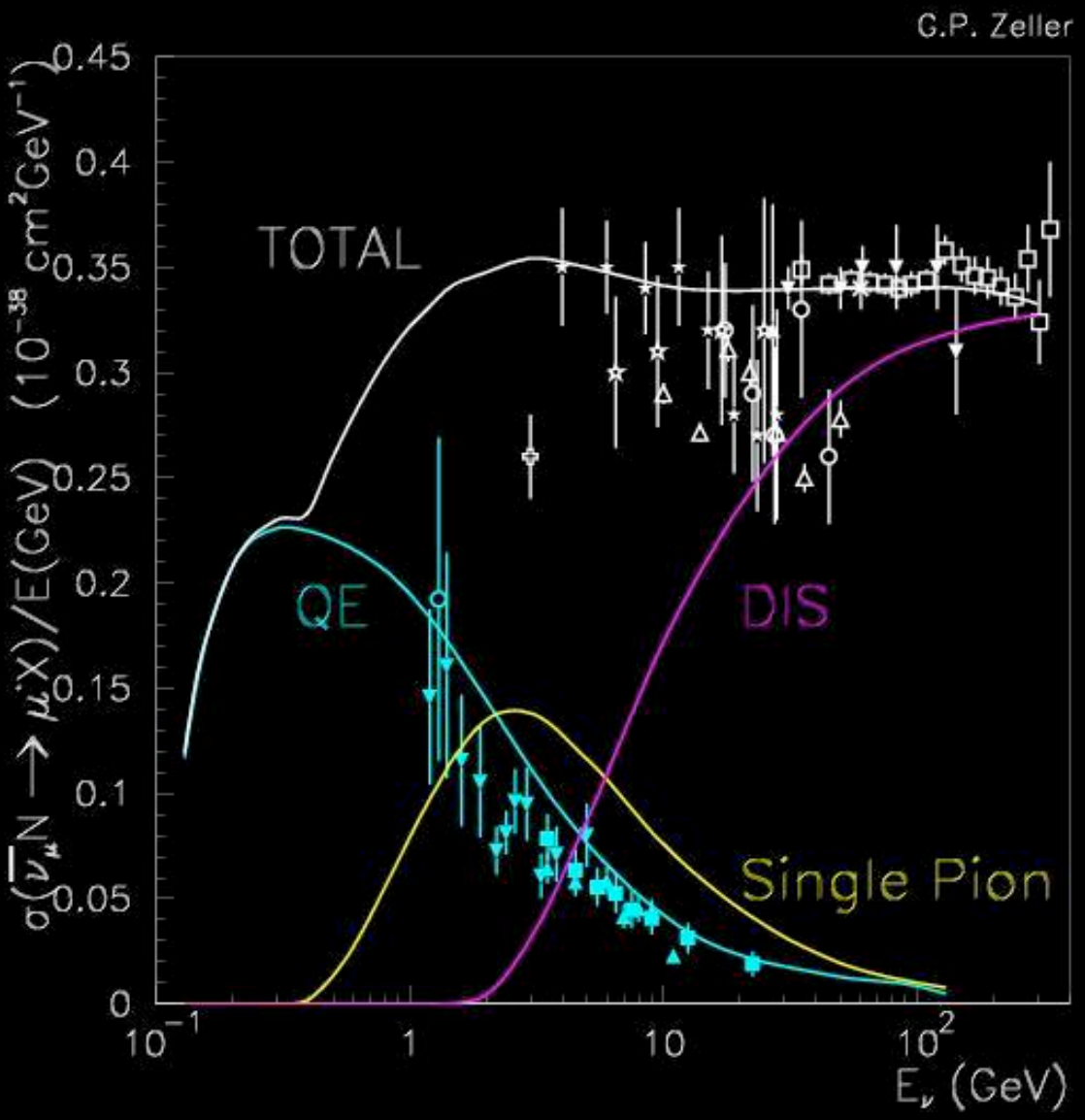

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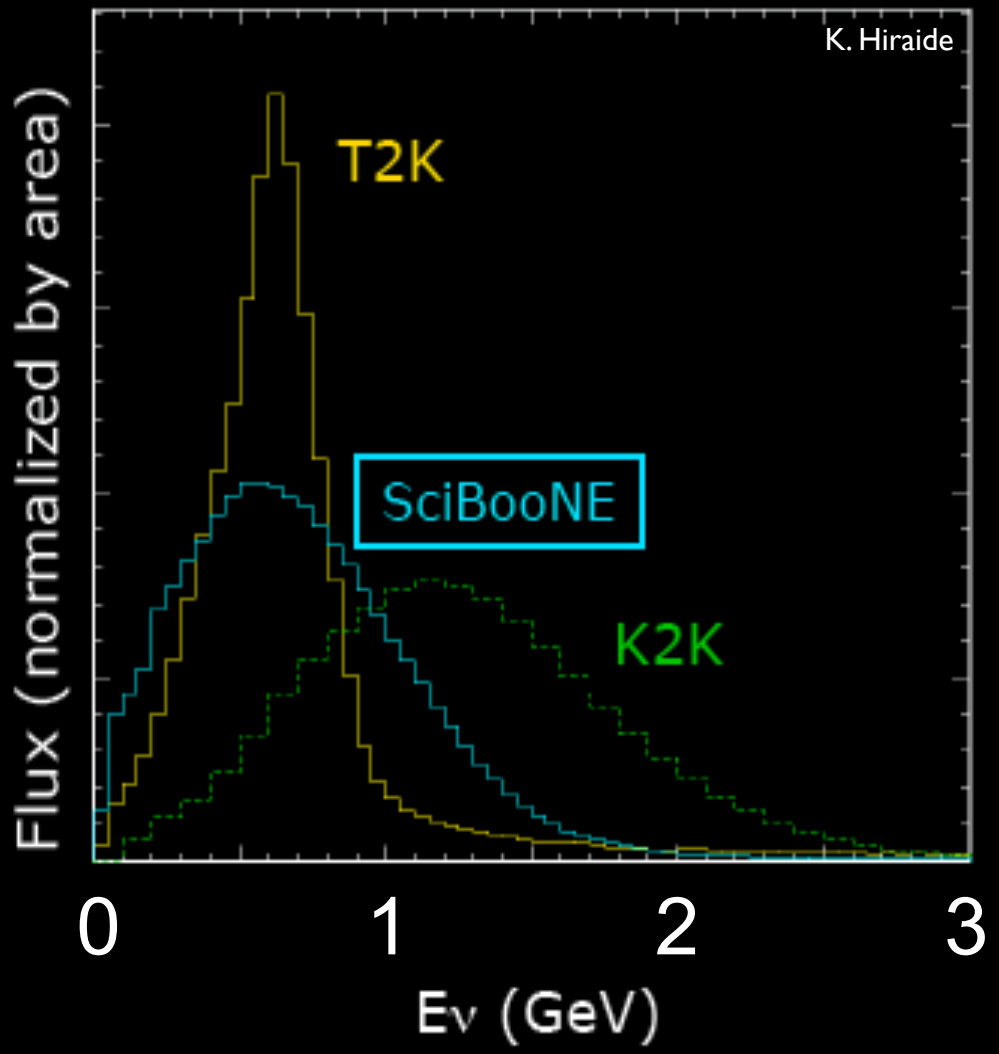


Outline

- Introduction
  - Motivation & context
  - Experiment performance and progress
- SciBooNE cross section analyses

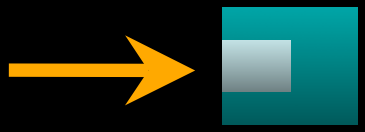
  Signals and backgrounds
  - Charged current (CC)
  - Neutral current (NC)
- Outlook

SciBooNE

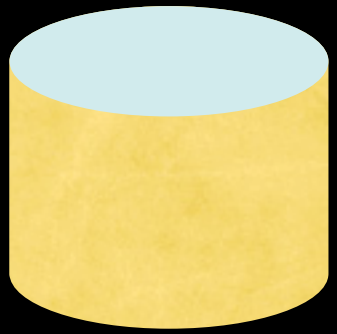
Accelerator ν experiment strategy

Intense beam

protons



Gigantic detector



Imperial College London

SciBooNE

Accelerator ν experiment strategy

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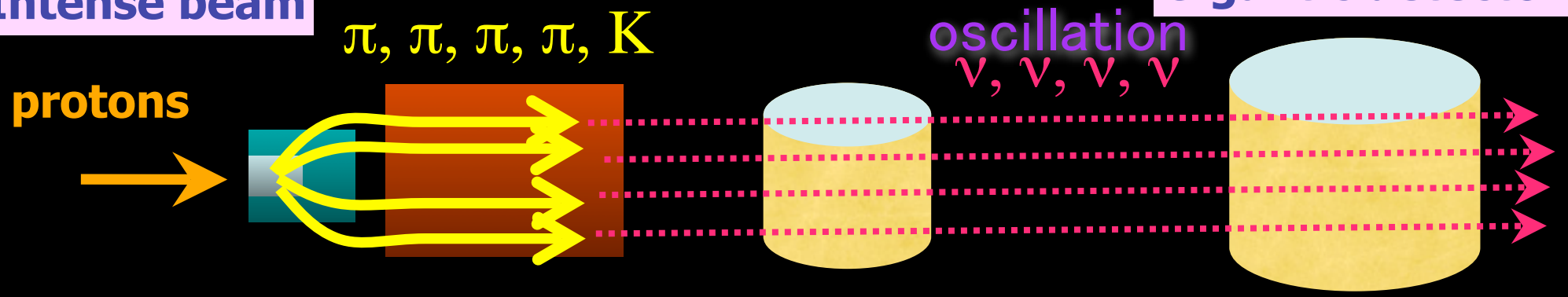


Imperial College London

Accelerator ν experiment strategy

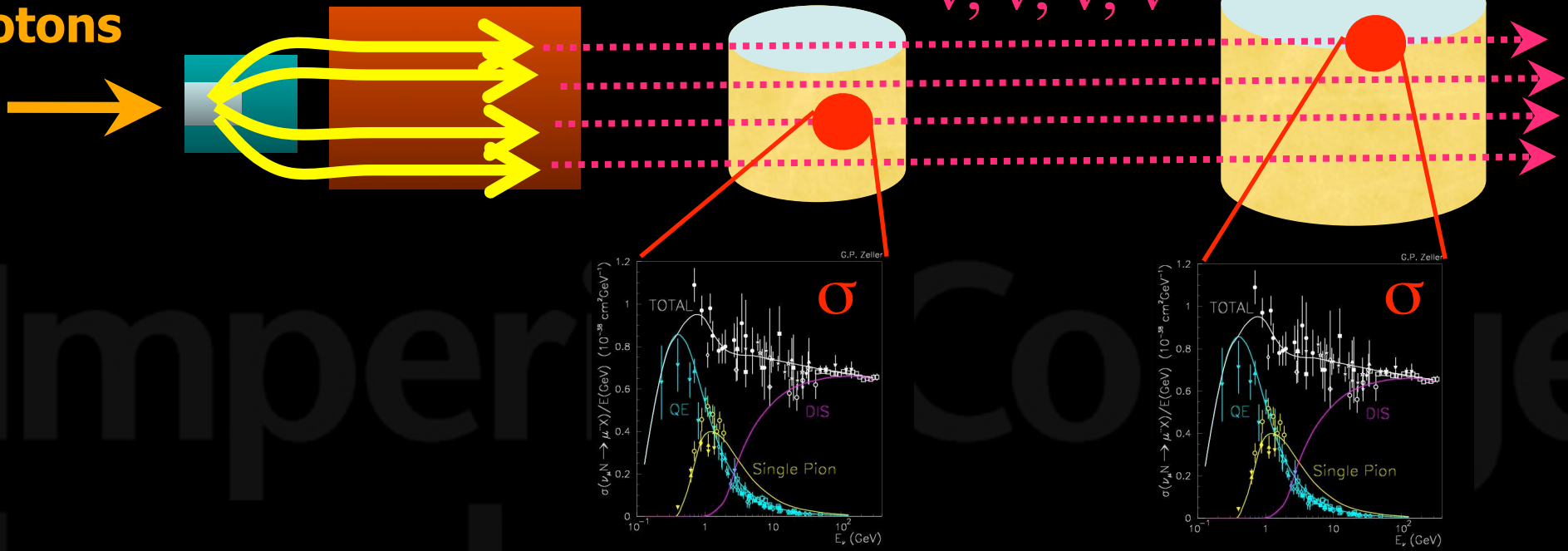
Intense beam

Gigantic detector

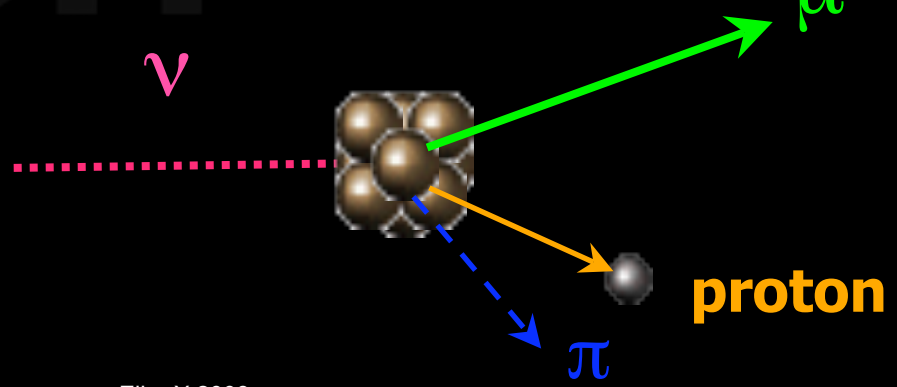
π, π, π, π, K

oscillation
ν, ν, ν, ν

protons



$$\sigma(E)\cdot\Phi_{\nu}^{near}(E) \Leftrightarrow \sigma(E)\cdot\Phi_{\nu}^{far}(E)$$



Accelerator ν experiment strategy

Intense beam

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π, π, π, π, K

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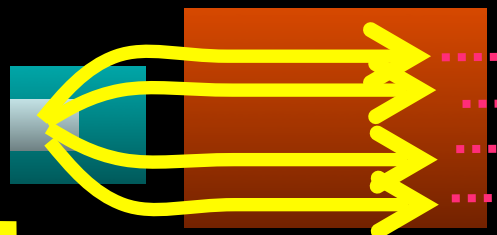
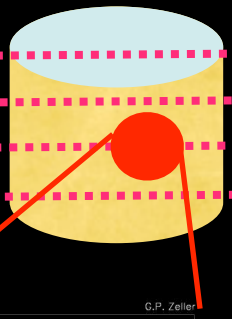
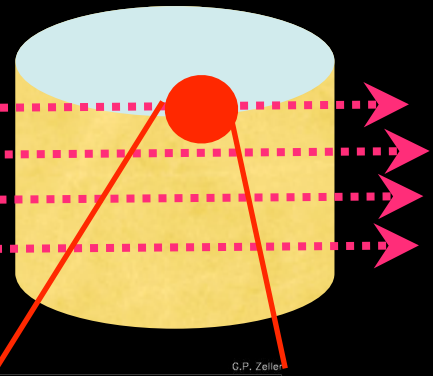
ν, ν, ν, ν

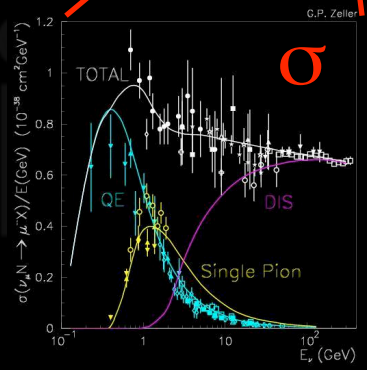


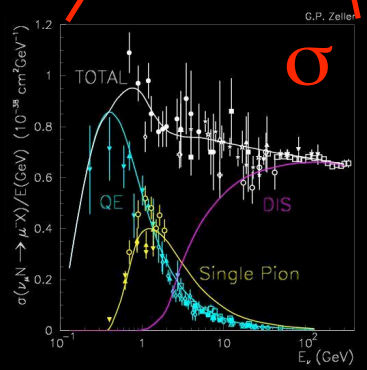




HARP **NA-61**

MIPP $\Phi_\nu(E)$





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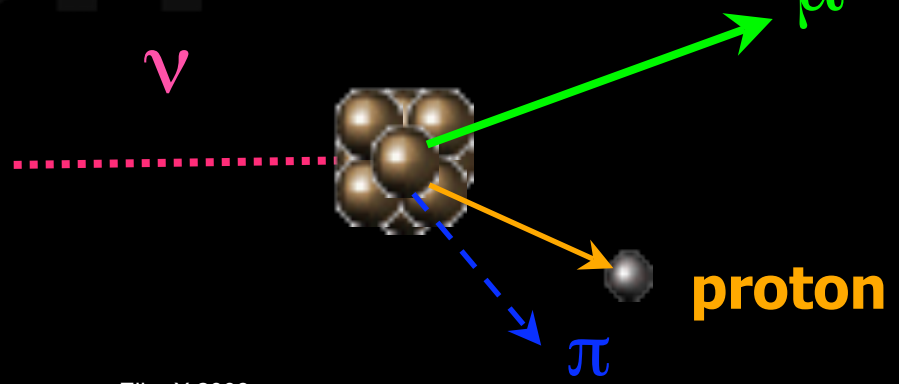


Accelerator ν experiment strategy

Intense beam

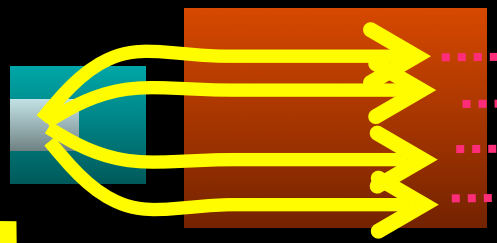
Gigantic detector

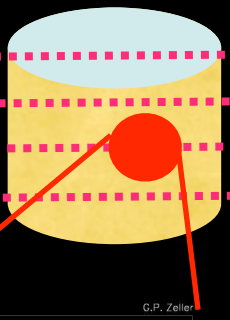
π, π, π, π, K

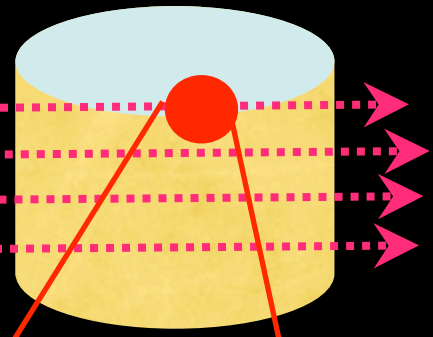
oscillation

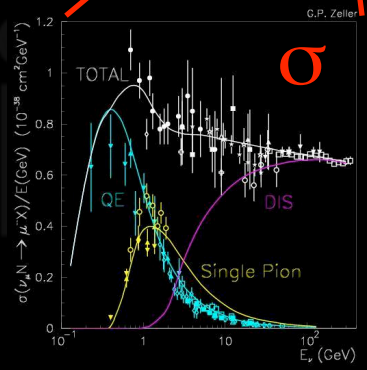
ν, ν, ν, ν

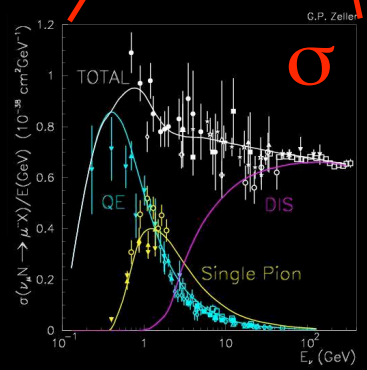
protons











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MIPP $\Phi_\nu(E)$

$$\sigma(E)\cdot\Phi_\nu^{near}(E) \Leftrightarrow \sigma(E)\cdot\Phi_\nu^{far}(E)$$

MiniBooNE **K2K-ND**

SciBooNE **MINERνA**

ν

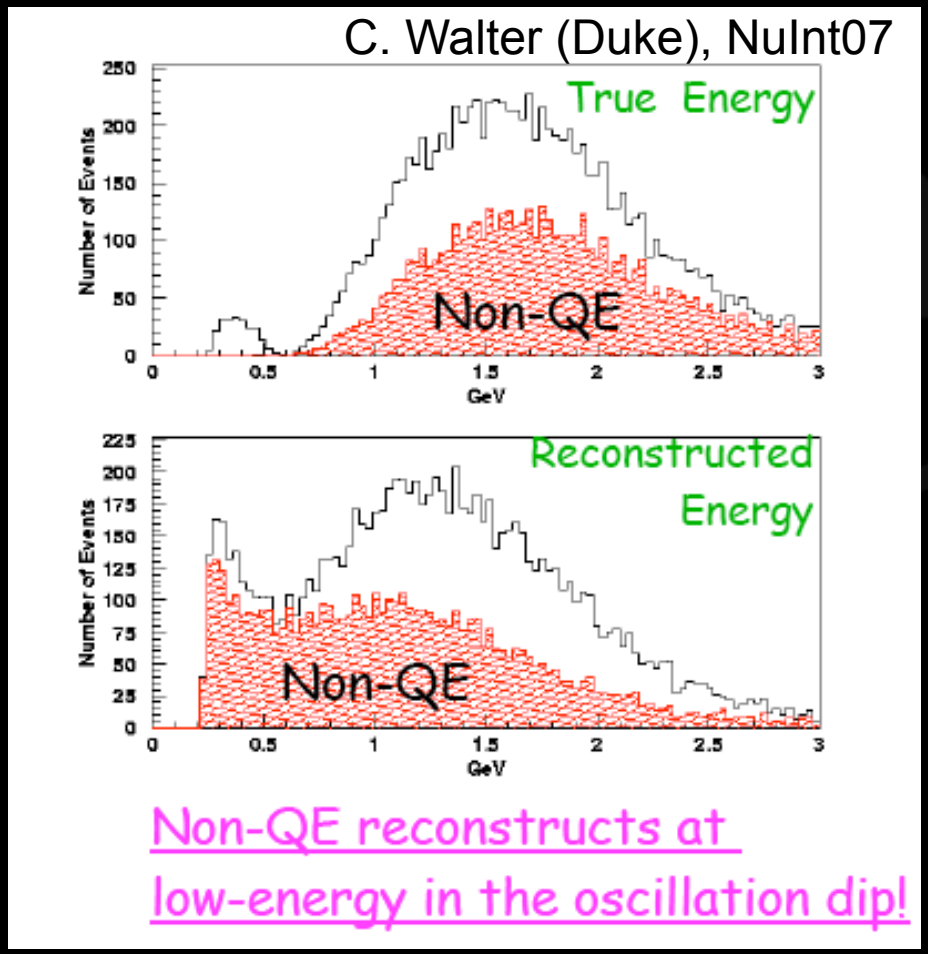
μ

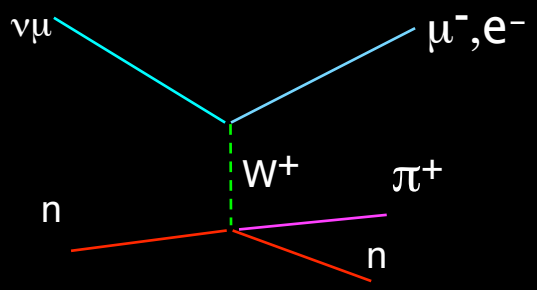
proton

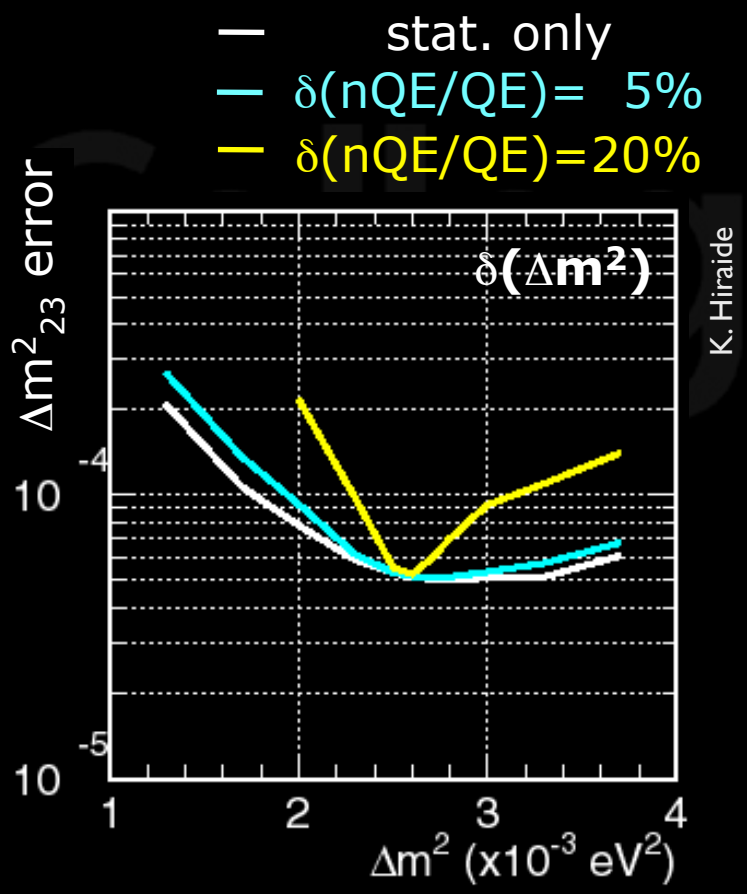
π

Need for CC σ_ν

In oscillation disappearance analysis,
CCQE = signal
CC1π = background

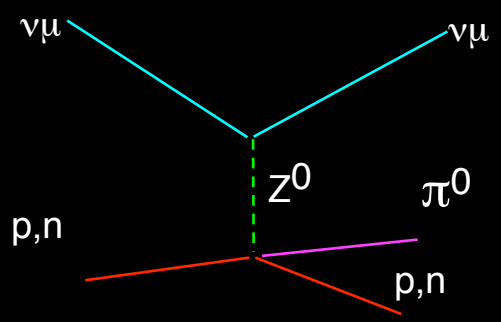


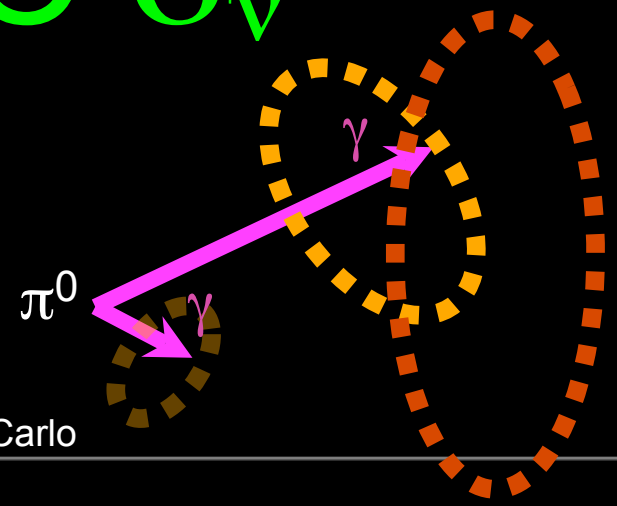




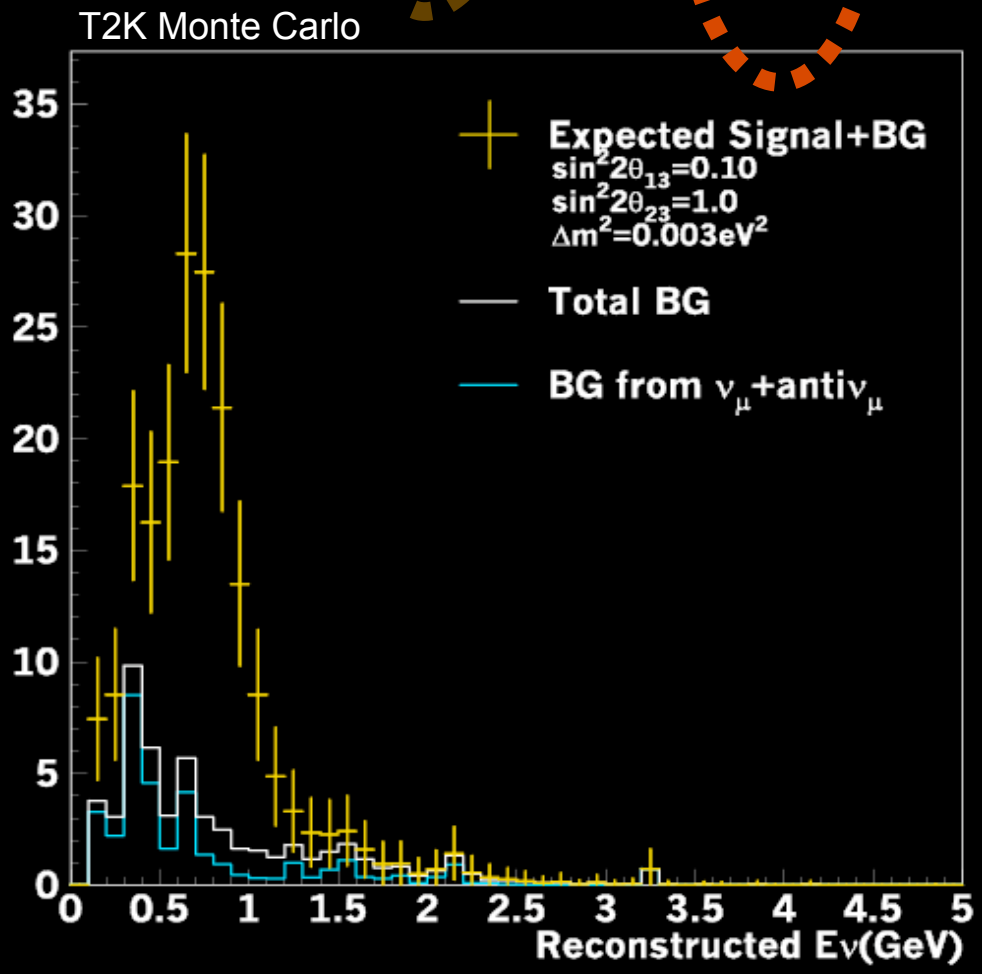
Goal: 5% uncertainty ($\sigma_{CC1\pi}/\sigma_{CCQE}$)

Need for NC σ_ν





- $\nu_\mu \rightarrow \nu_e$ backgrounds from intrinsic ν_es and misidentified ν_μ events
- Major background for T2K (and MiniBooNE)
- Goal: 10% NC1π^0 uncertainty
  - 2x increase in θ_{13} sensitivity
  - 4 years vs. 2.5 years

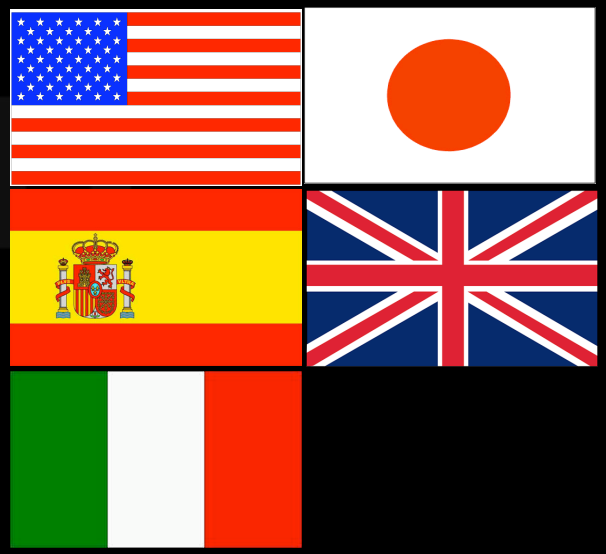


Experiment Overview

SciBooNE collaboration

- Universitat Autonoma de Barcelona
- University of Cincinnati
- University of Colorado
- Columbia University
- Fermi National Accelerator Laboratory
- High Energy Accelerator Research Organization (KEK)
- Imperial College London*
- Indiana University
- Institute for Cosmic Ray Research
- Kyoto University*
- Los Alamos National Laboratory
- Louisiana State University
- Purdue University Calumet
- Università degli Studi di Roma and INFN-Roma
- Saint Mary's University of Minnesota
- Tokyo Institute of Technology
- Universidad de Valencia

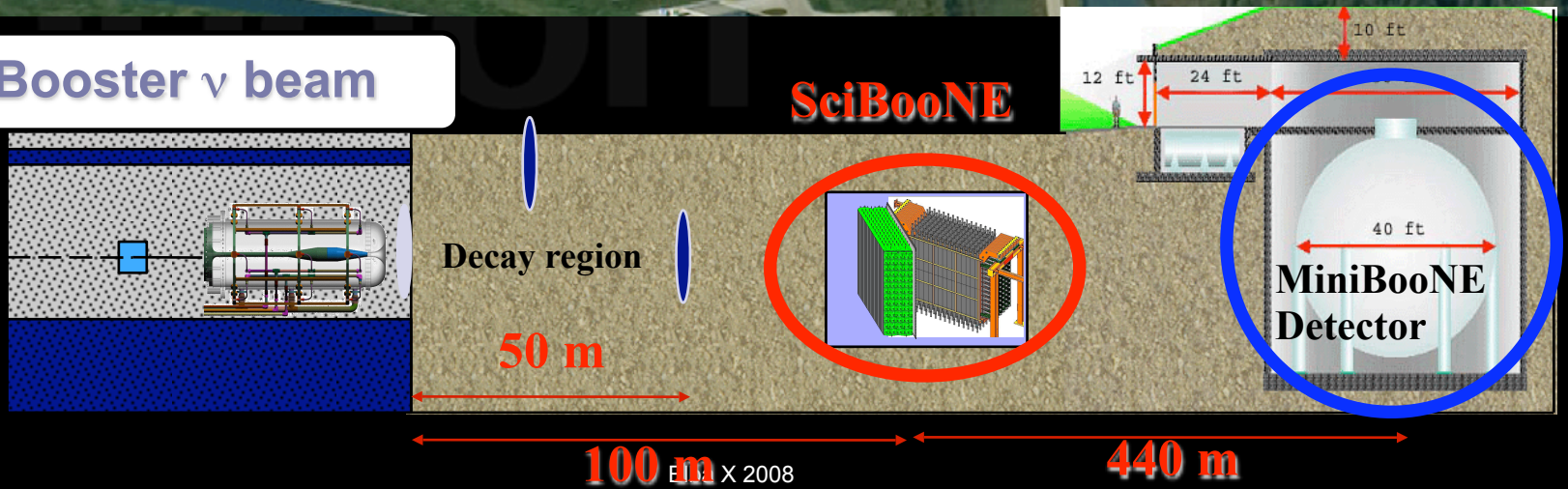
SciBooNE, 2006



Spokespeople:
T. Nakaya, Kyoto University
M.O. Wascko, Imperial College

Overview

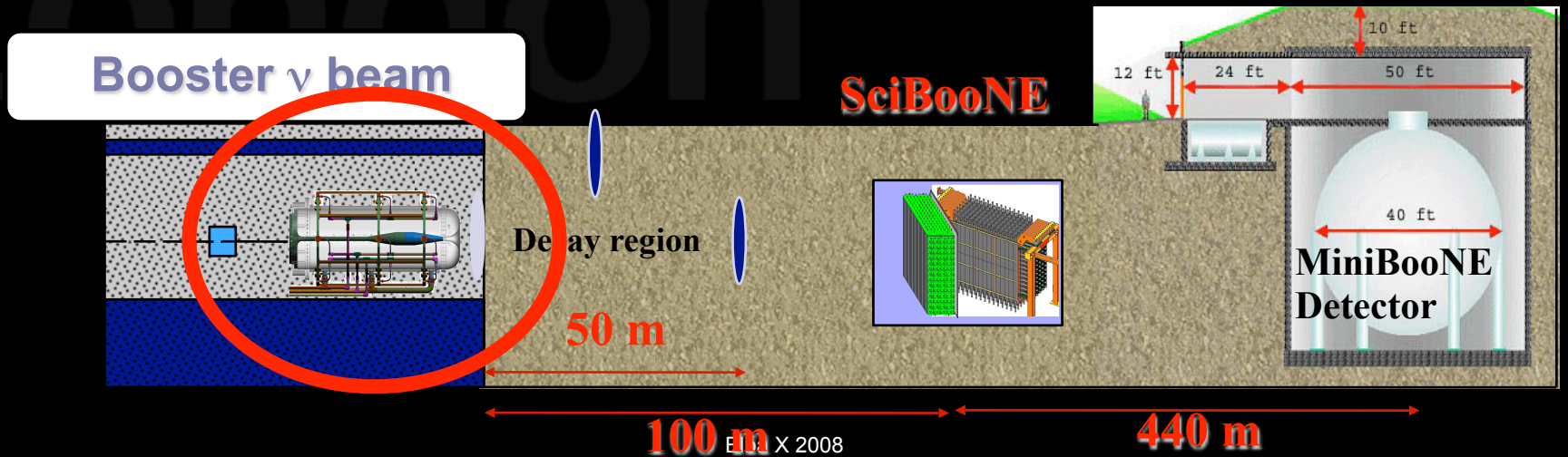
Booster ν beam



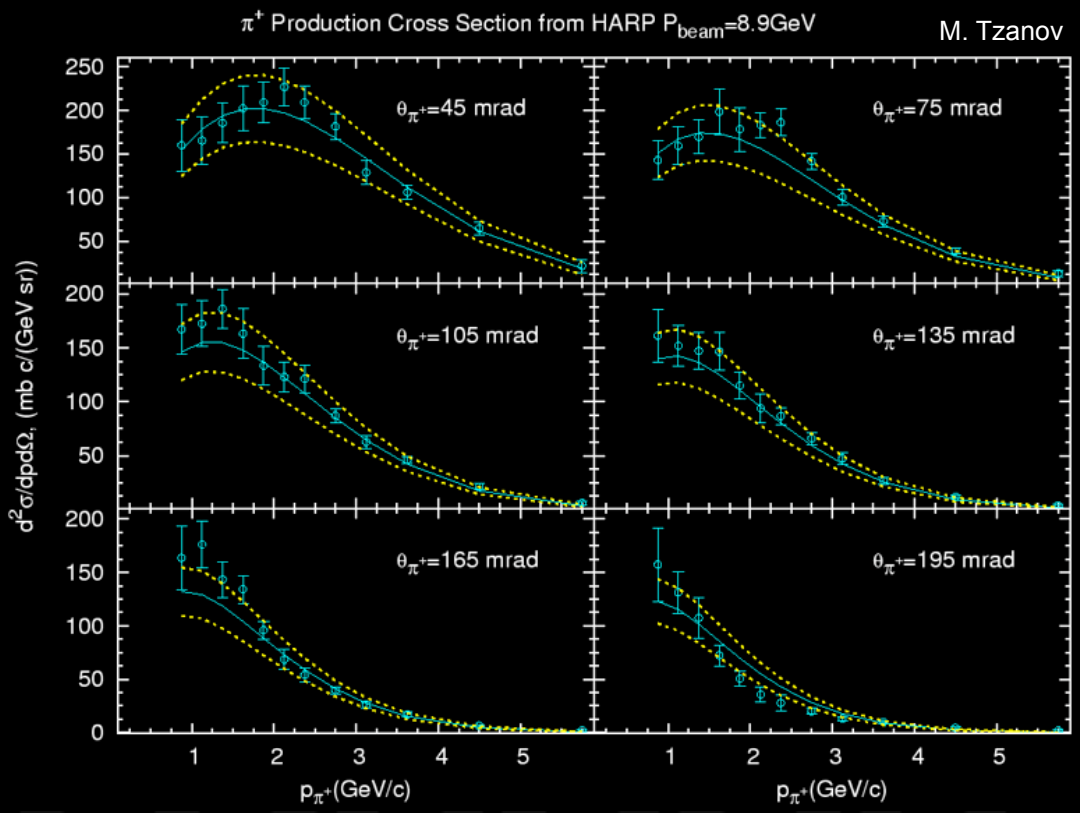
Target & Horn

Main components of Booster Neutrino Beam (BNB)

(96M and 179M+ pulses)

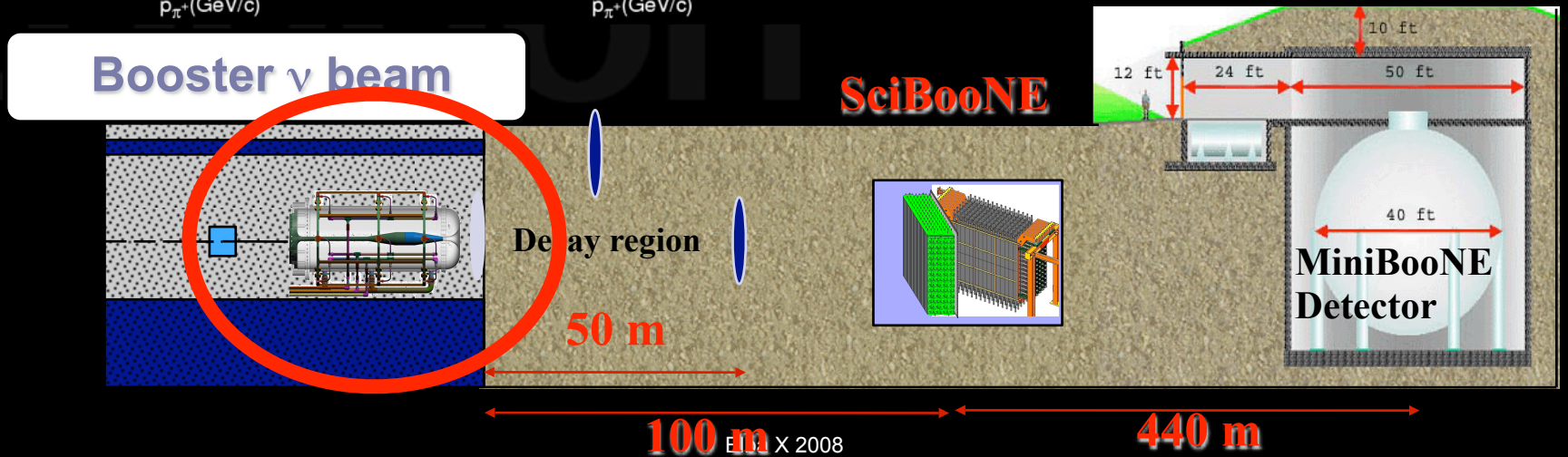


ν Flux Prediction



- External meson production data
  - E910 (BNL), HARP (CERN)
  - Need thick target data for absolute cross sections
- Parametrisation of cross sections
  - Sanford-Wang for pions
  - Feynman scaling for kaons

NIM paper available (MiniBooNE)
arXiv:0806.1449 [hep-ex]



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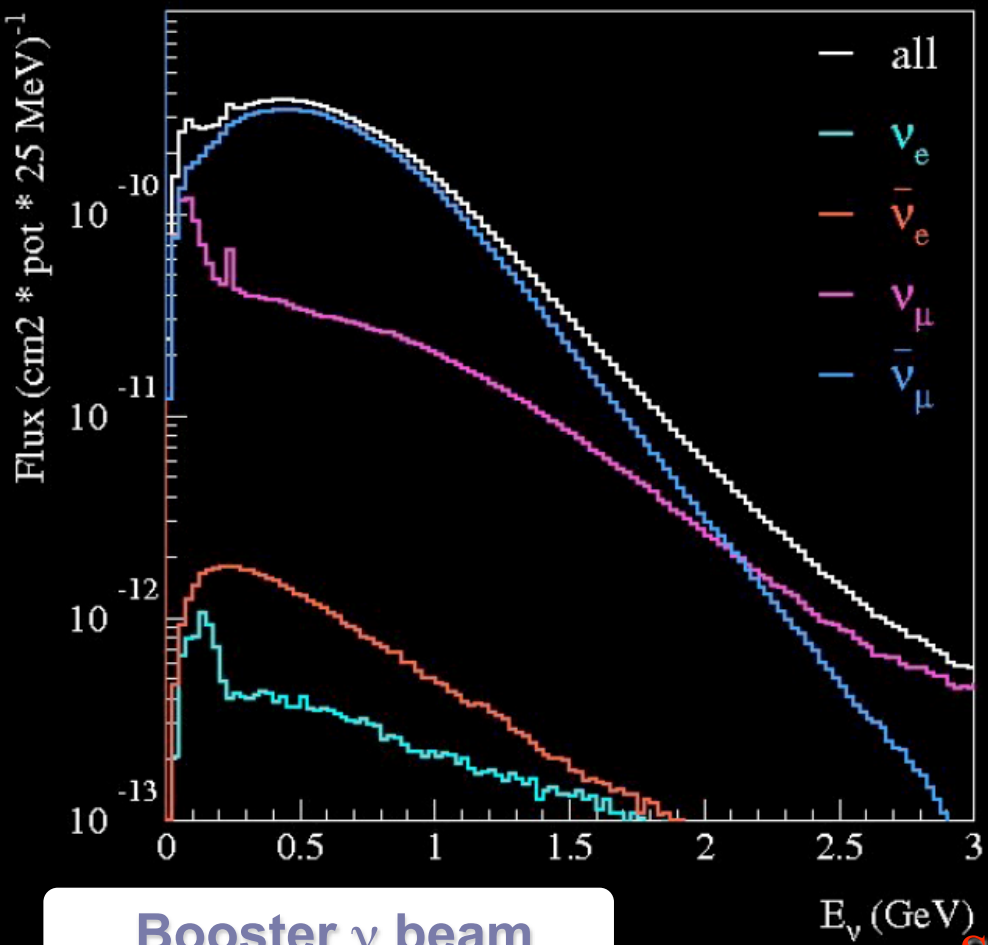

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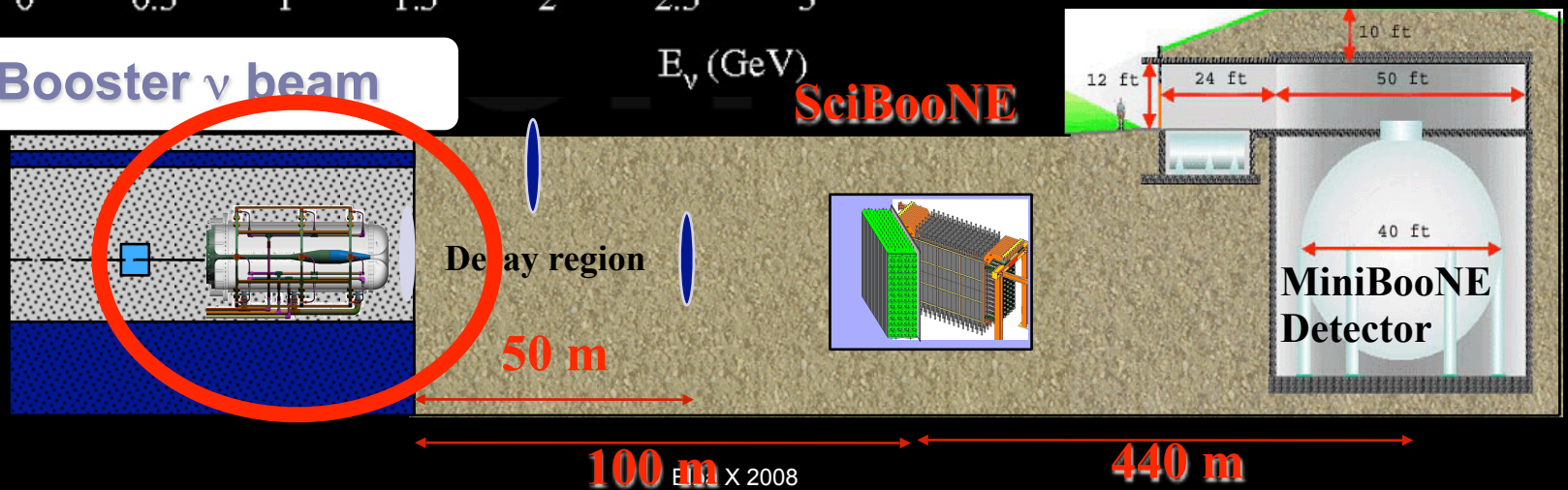
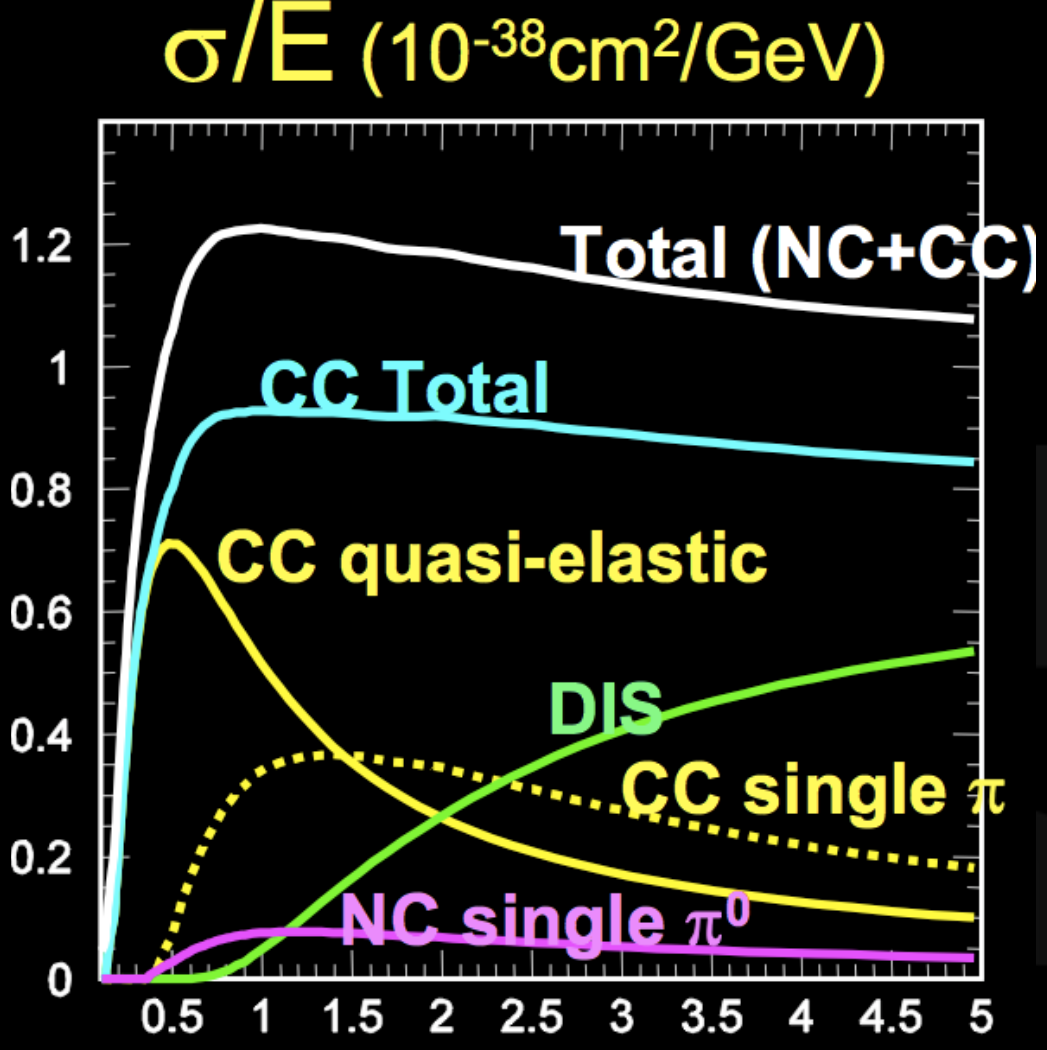


σ_ν predictions



Target: CH

NEUT Monte Carlo

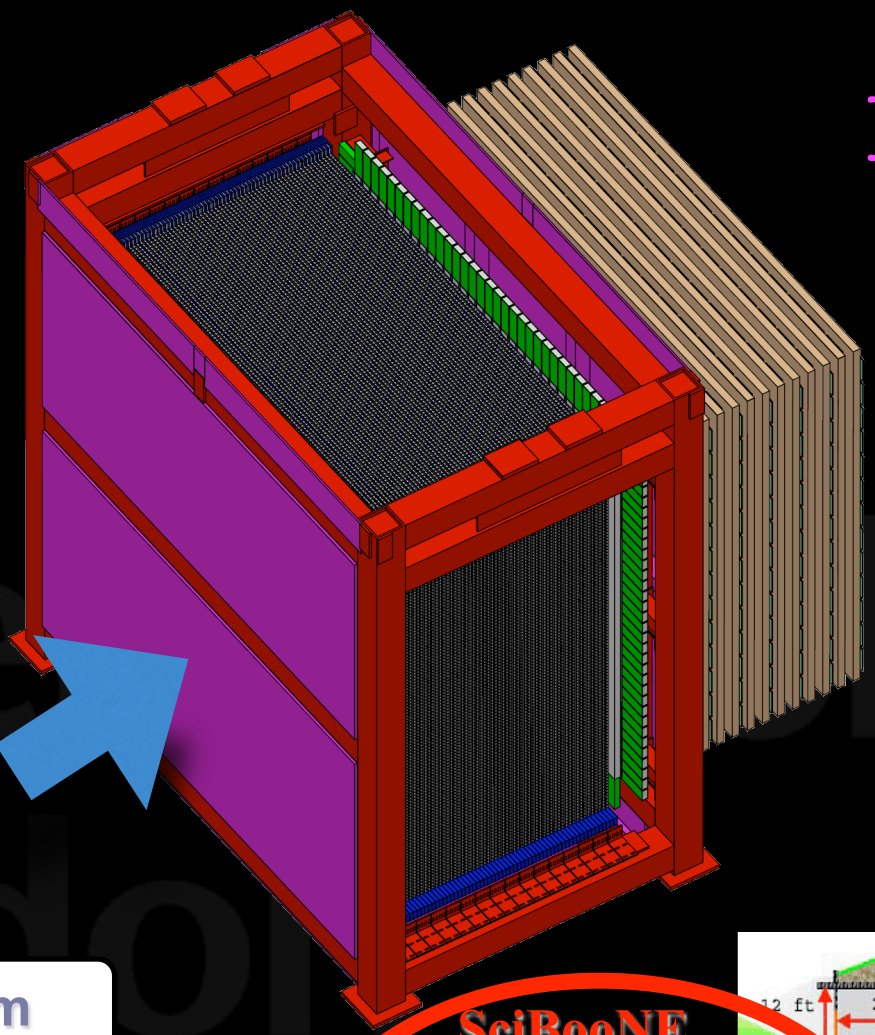
- QE
  - Llewellyn-Smith
    - M_A = 1.1 GeV/c2
    - Non-dipole Vector FF (BBBA)
  - Rel. Fermi Gas (Smith & Moniz)
    - p_F=217 MeV/c, E_B=27 MeV
- Resonant π
  - Rein & Sehgal
    - M_A = 1.1 GeV/c2
- Coherent π
  - Rein & Sehgal w/ lepton mass corrections
- DIS
  - GRV98 w/Bodek & Yang correction
- Nuclear effects:
  - Formation zone & nucleon final state interactions

Experiment Description

SciBooNE

SciBar (Scintillator Bar)

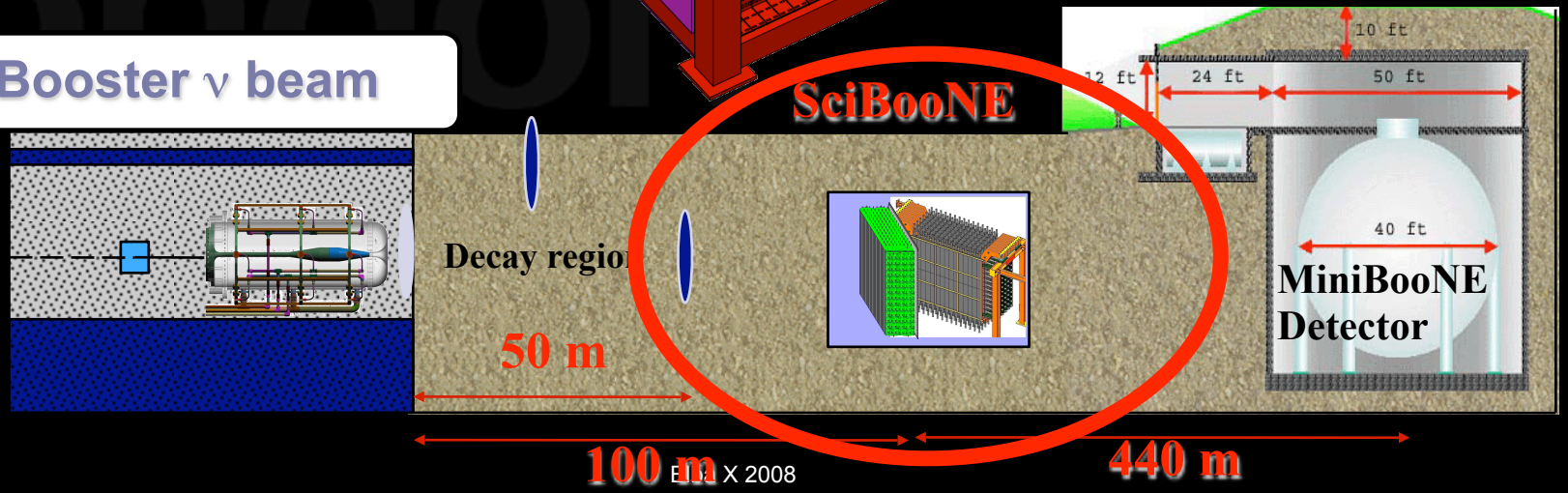
Muon Range Detector (MRD)



ν beam

Electron Catcher (EC)

Booster ν beam

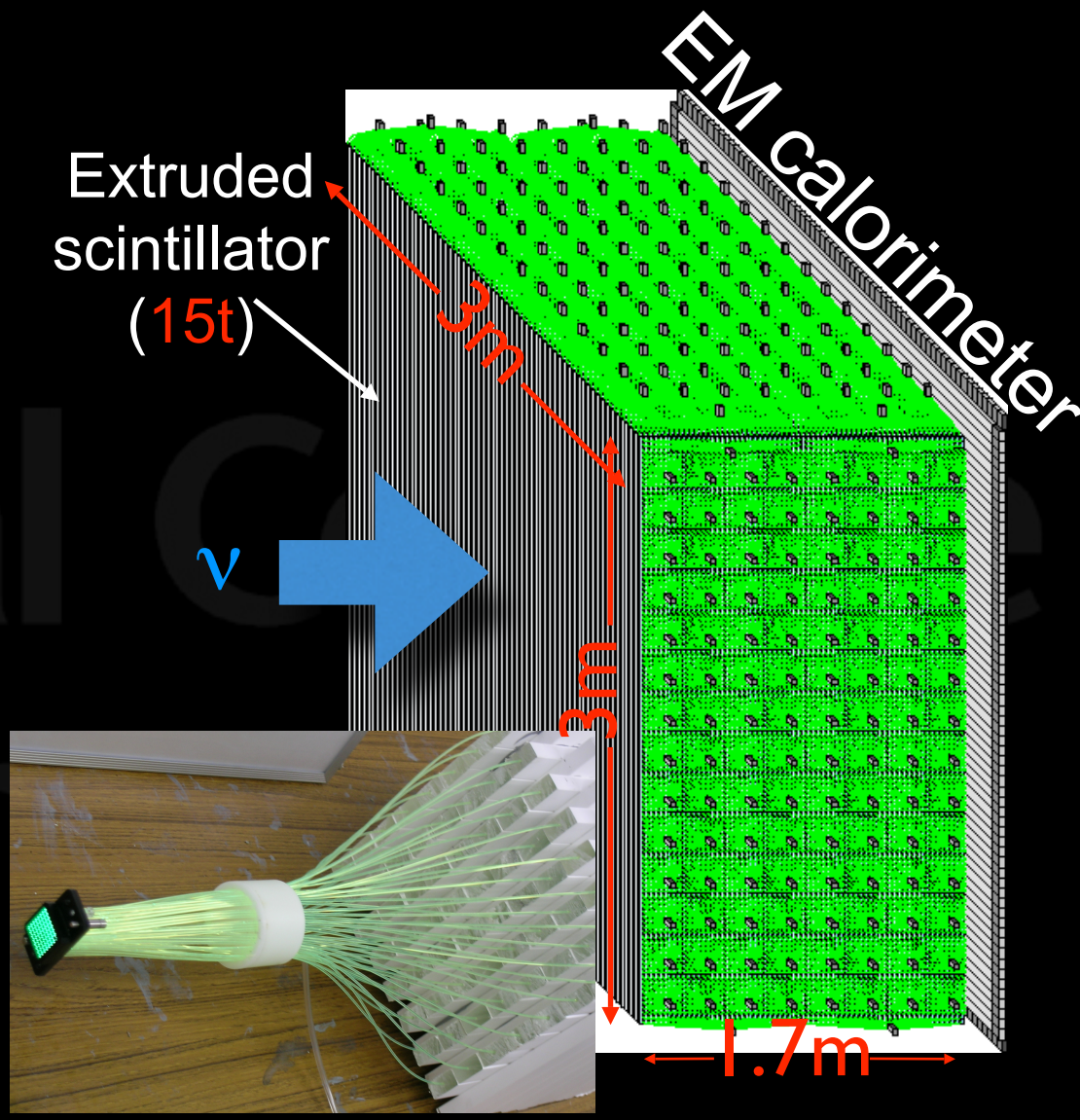


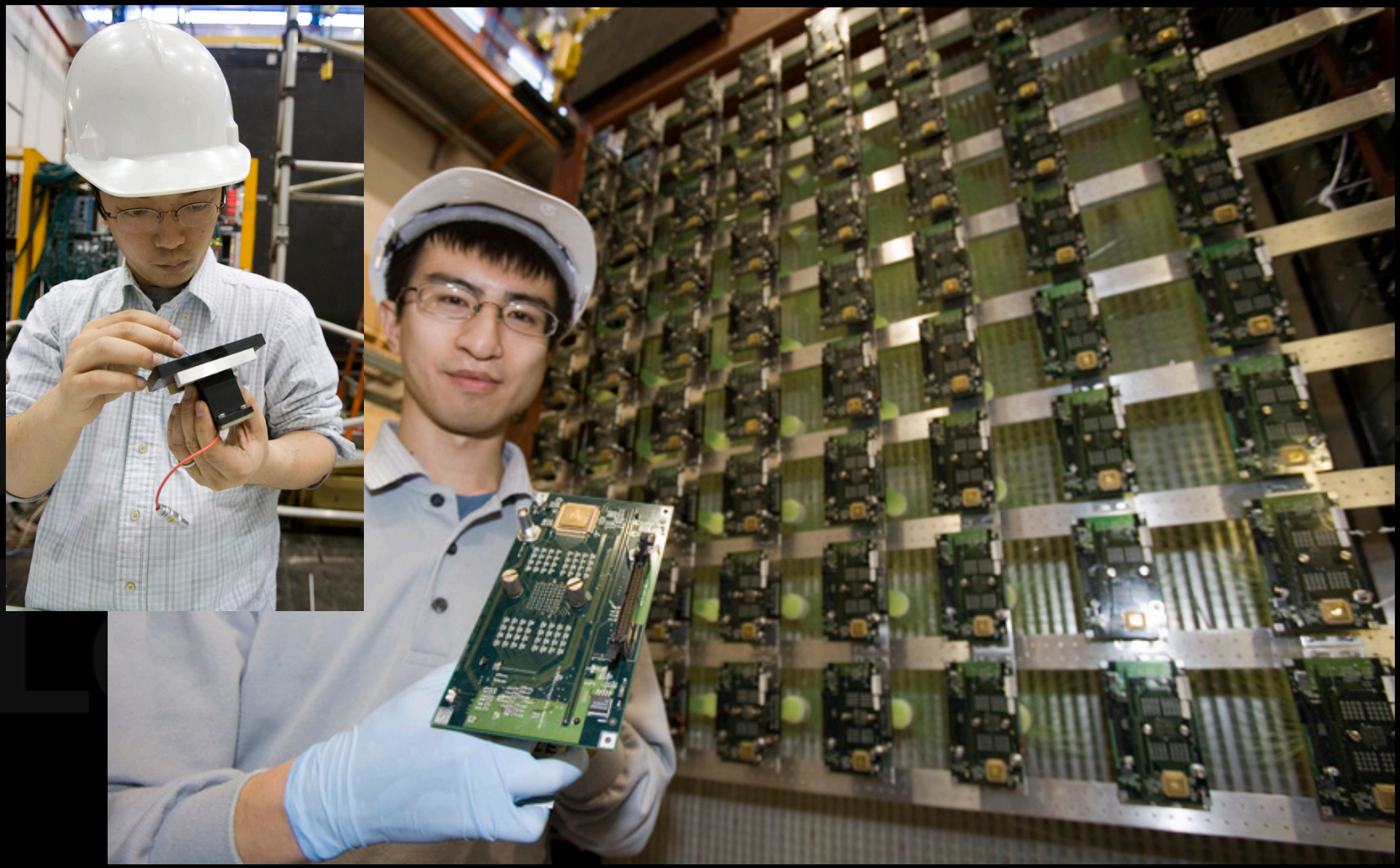
Vertex Detector: SciBar

- Fine-grained neutrino vertex detector
- Extruded plastic scintillator with WLS fibres
  - 64 channel MAPMTs
  - ~15k channels
    - All channels operational
- 15 tonne total mass

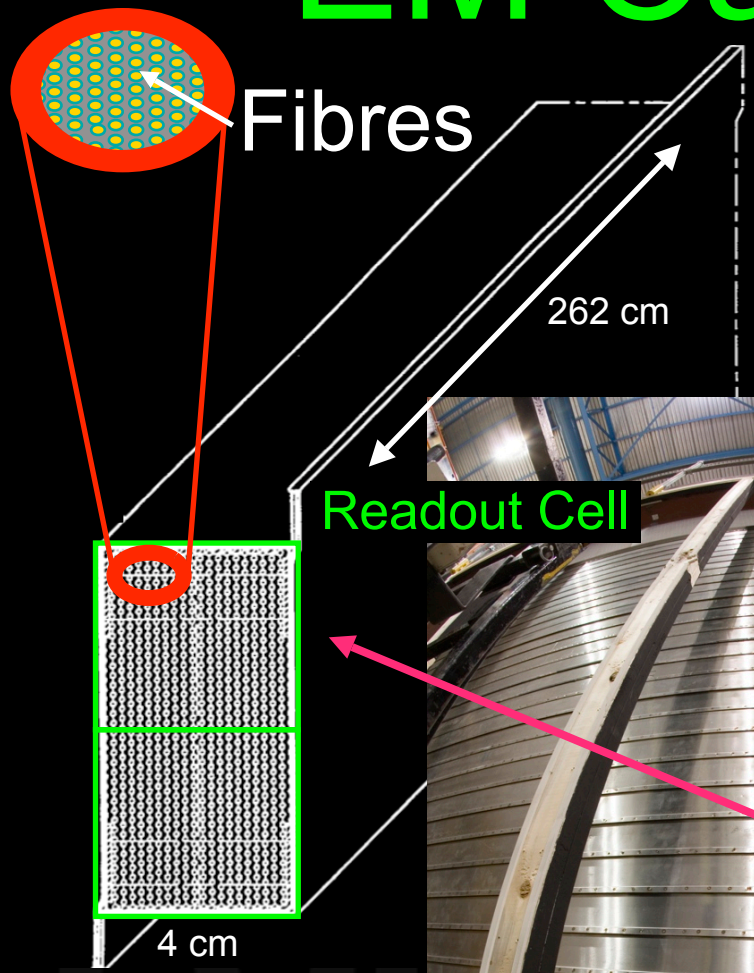
Originally used in K2K experiment in Japan

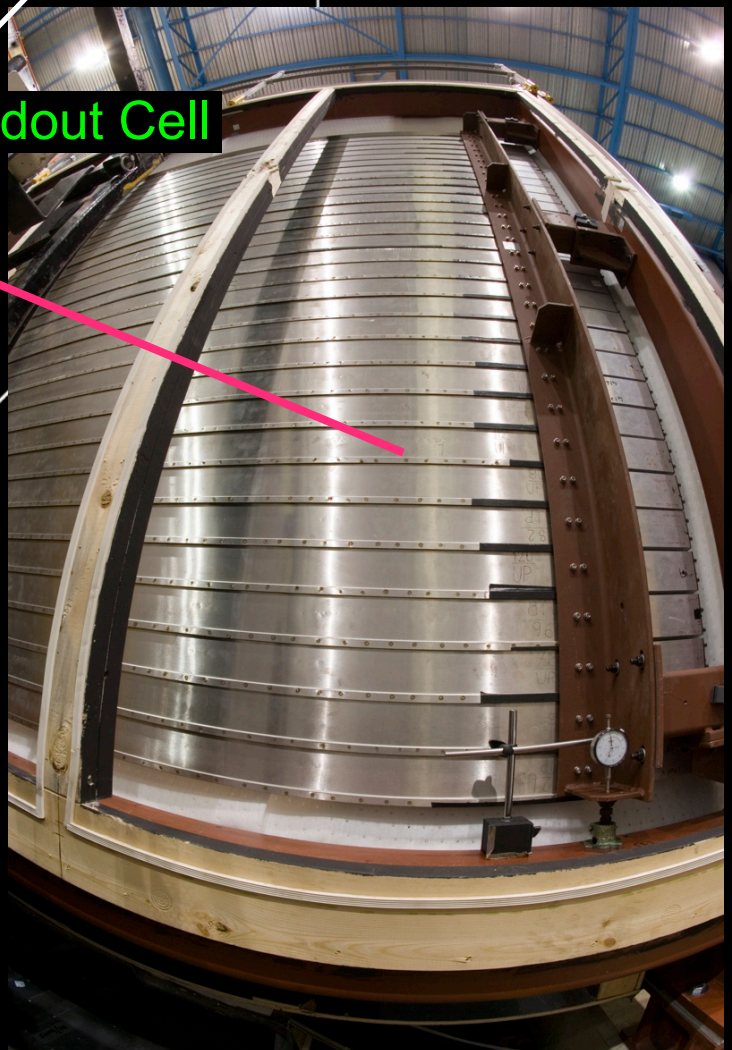
(See Sakuda-san's talk next)





EM Calorimeter: EC

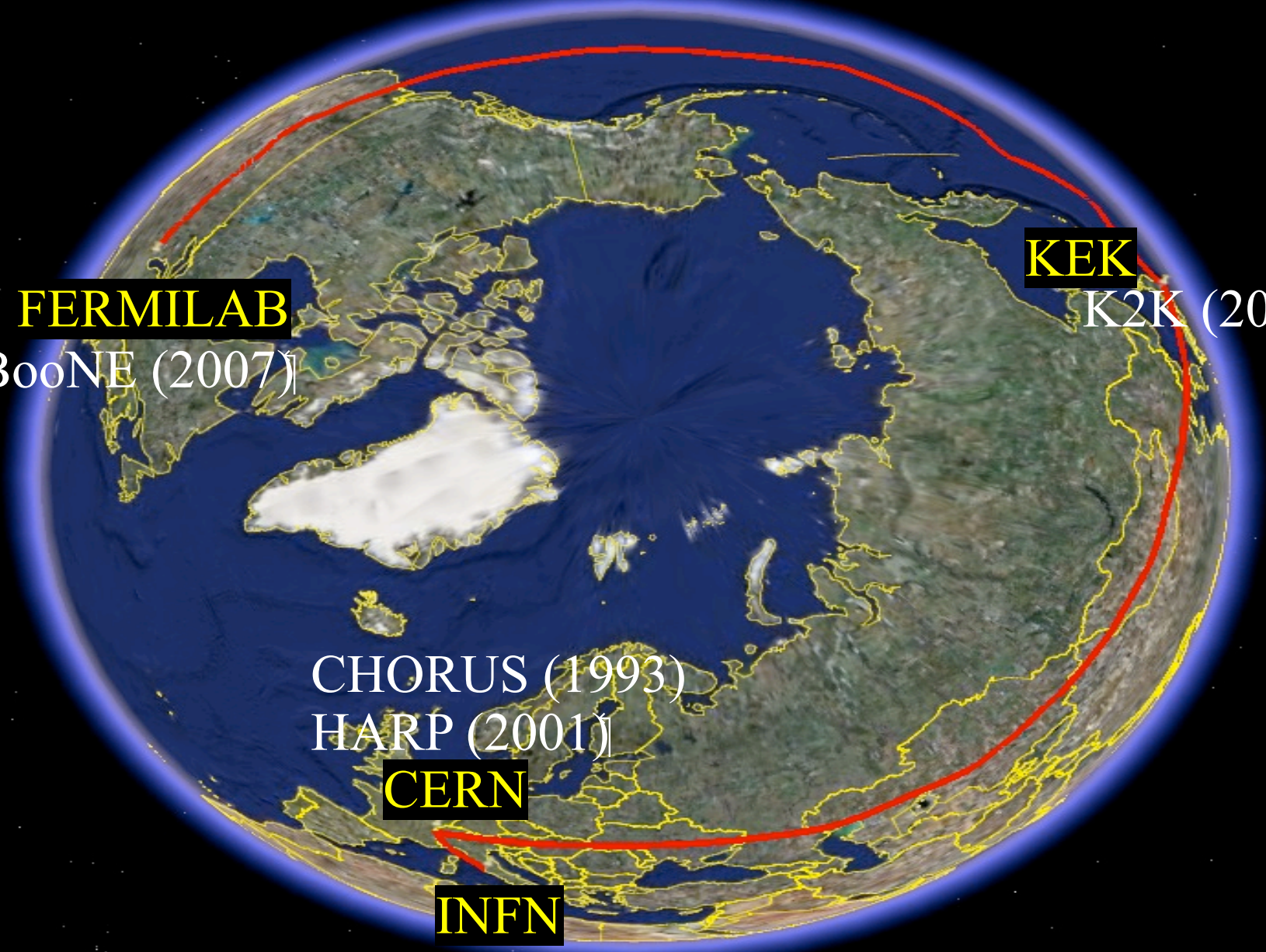




- "Spaghetti" calorimeter
  - Scintillating fibres sandwiched in lead foils
  - PMT readout at both ends
- good energy resolution and linearity
  - 14%/√E resolution
  - MC tuned with cosmic data
- 11 X_0 thick

Originally built for CHORUS; used in K2K

EC modules's travels



© 2008 Tele Atlas
© 2008 Europa Technologies
Image © 2008 TerraMetrics
Image NASA
©2007 Google™
Pointer 85°11'38.65" N 22°57'42.76" E
Streaming 100%
Eye alt 10313.54 km

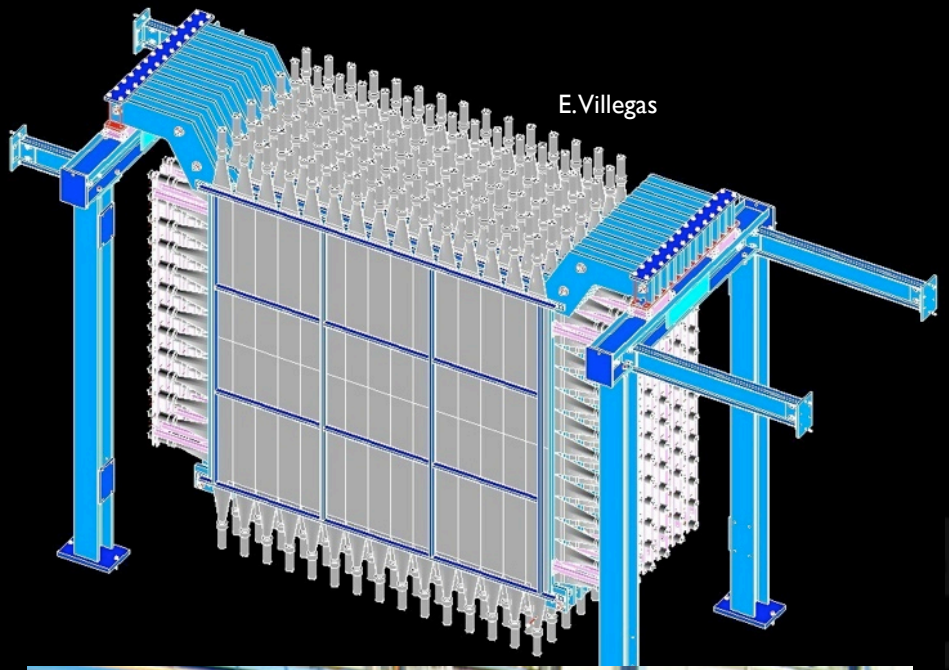
Roma 1 students built the EC

Claudio Giganti
(now at Saclay)

Camillo Mariani
(now at Columbia)

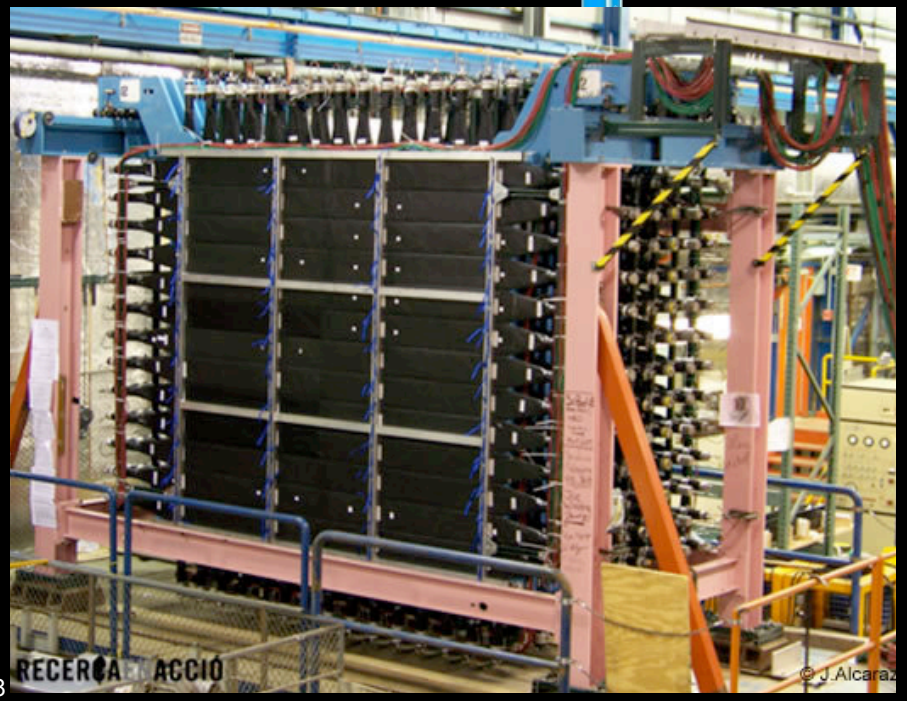
Muon Range Detector

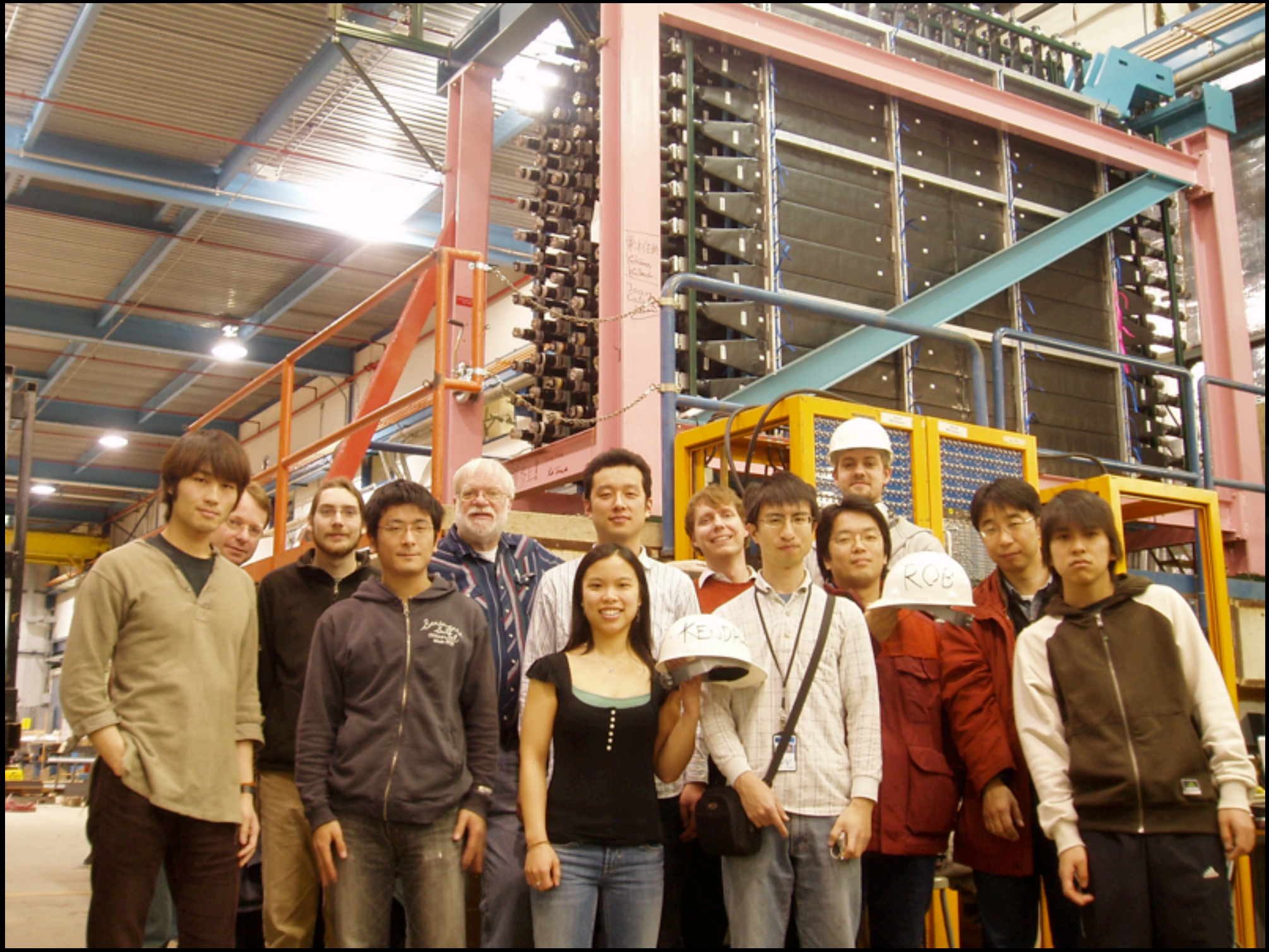
- Iron plates (5cm) with scintillation counters
  - Measure up to ~1.2 GeV muons
  - ~5% momentum resolution



Recycled from past FNAL experiments

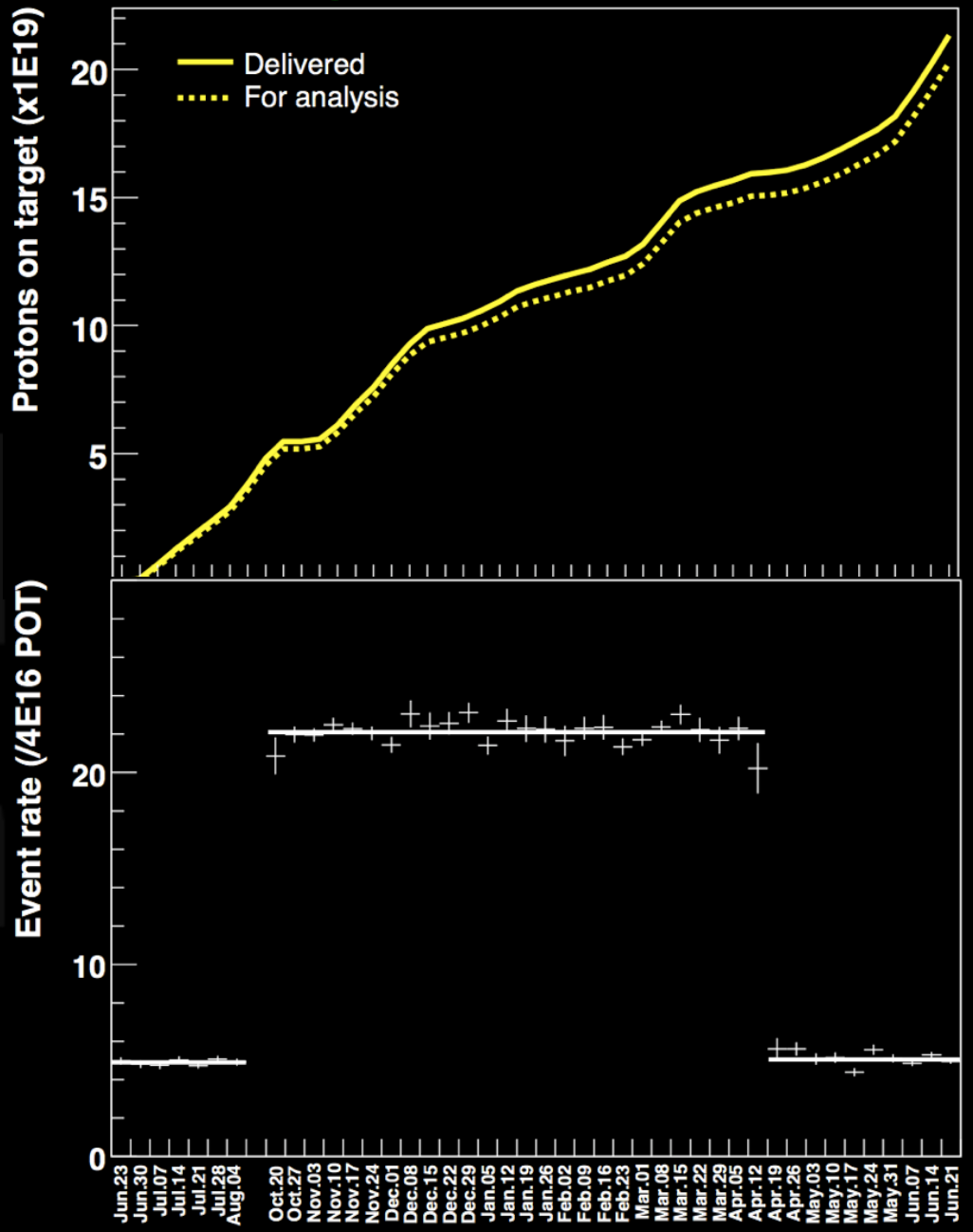
Won DOE "Closing the Circle" and P2 awards



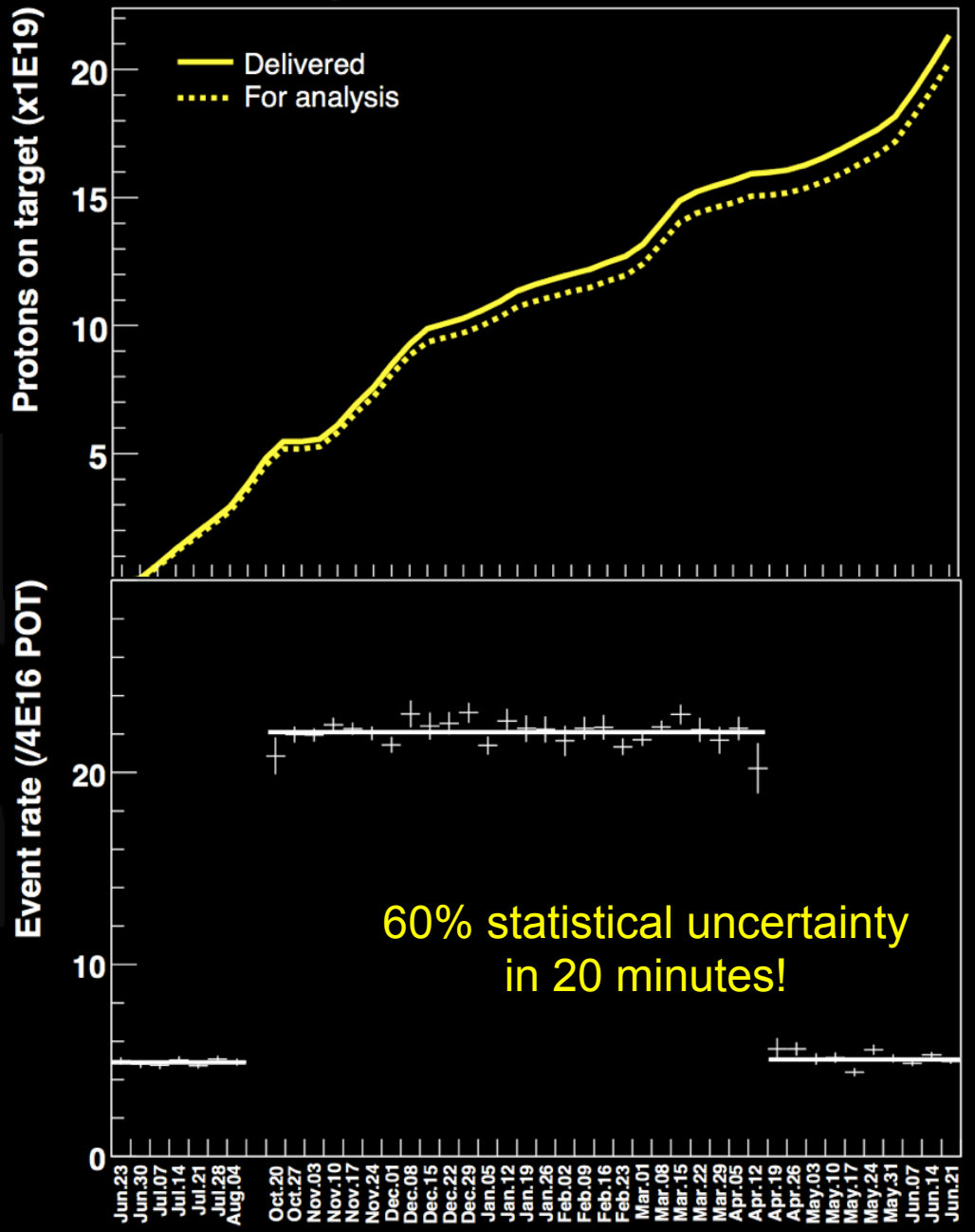

ROB

SciBooNE Progress

SciBooNE installed and commissioned in spring 2007



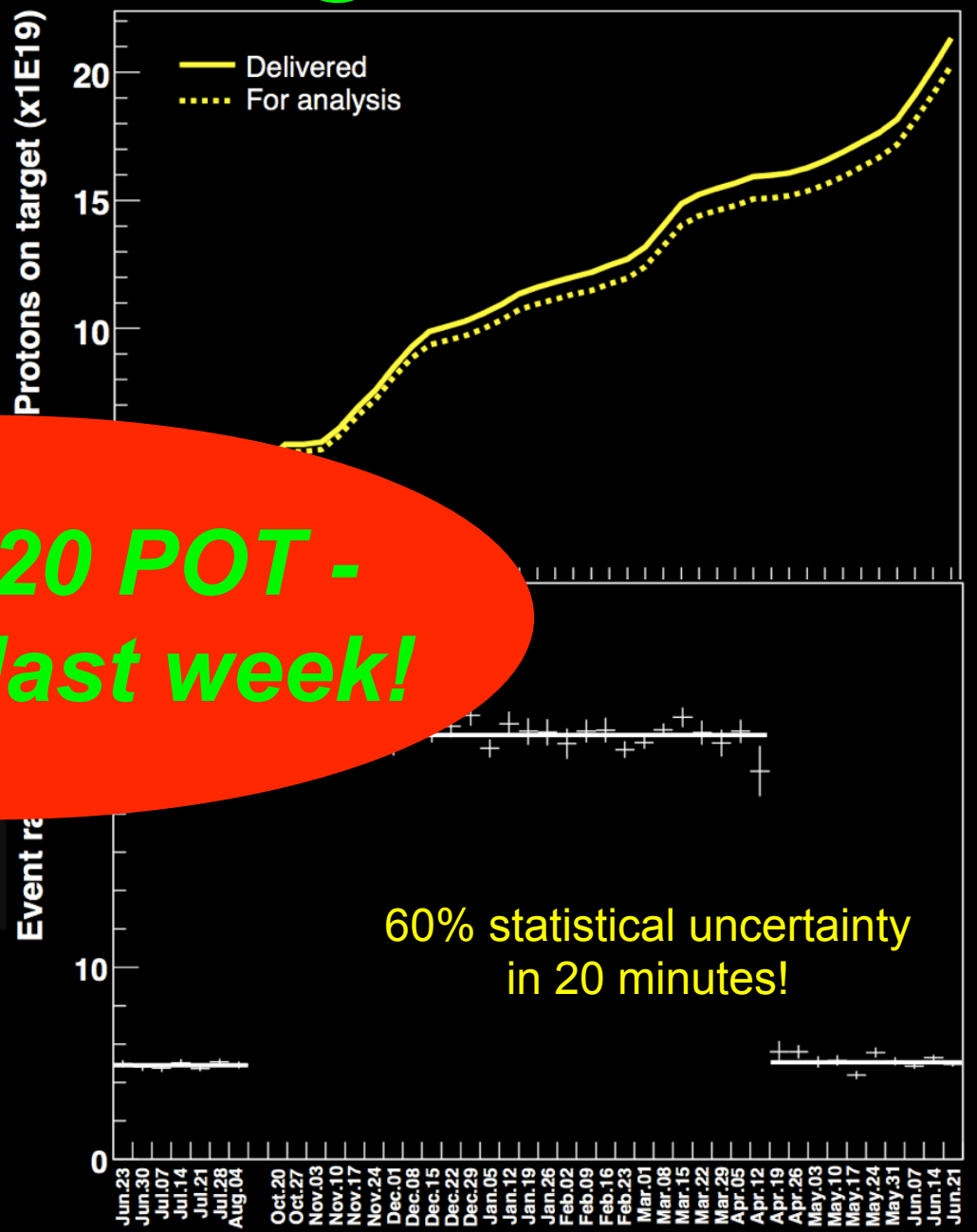
SciBooNE Progress



SciBooNE Progress

SciBooNE installed and commissioned in spring 2007

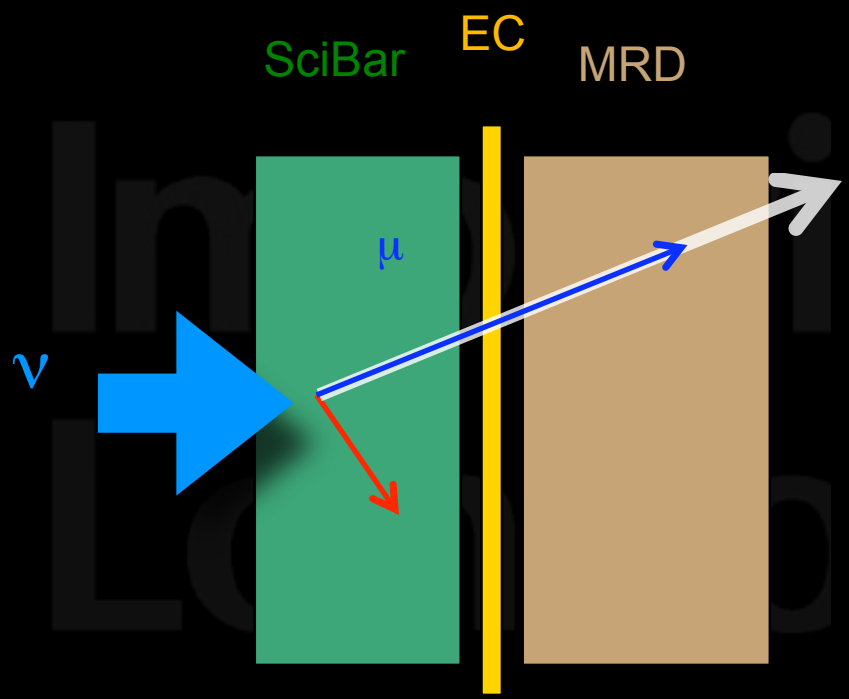
Goal: 2E20 POT - achieved last week!



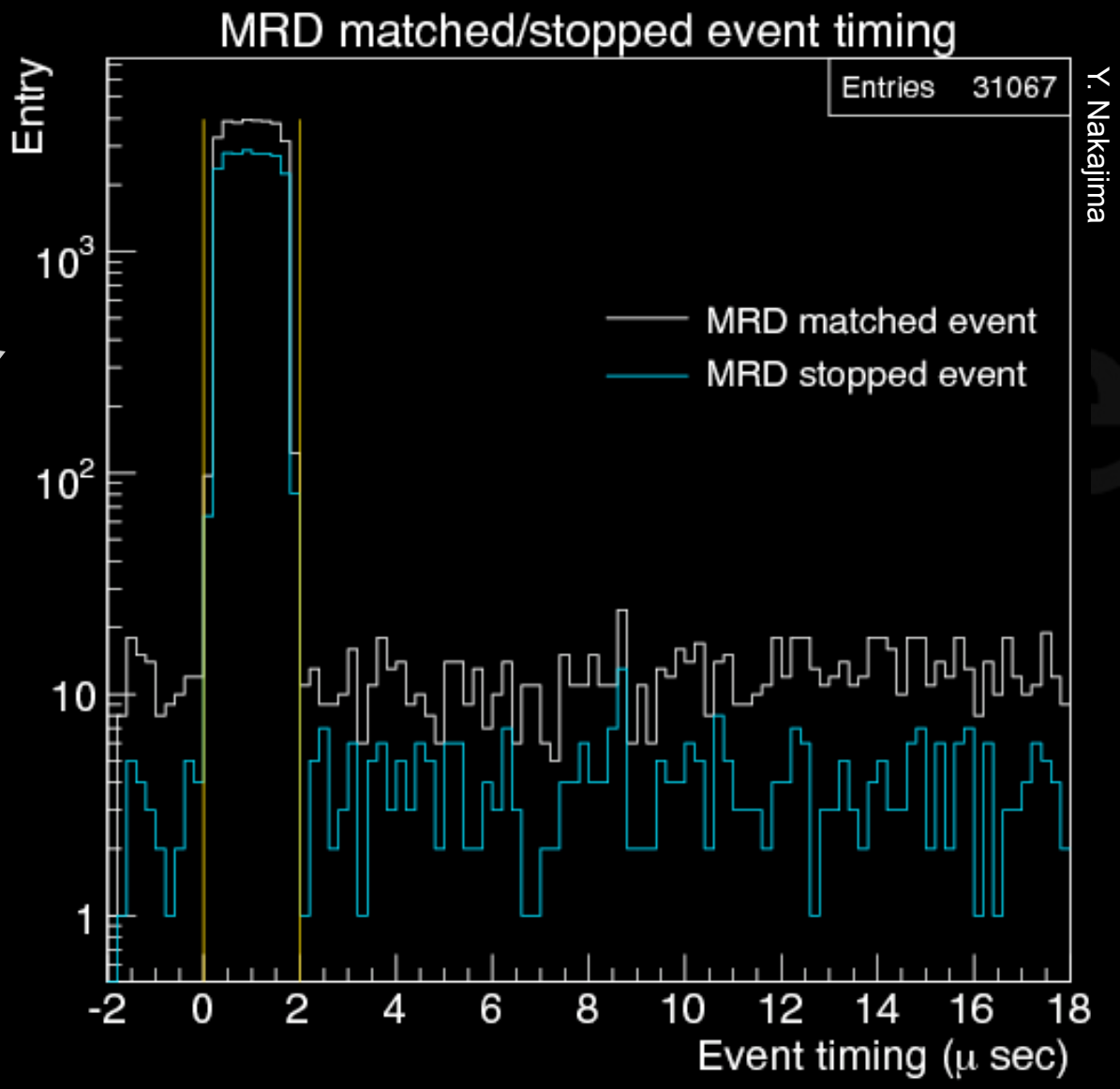
Analysis Progress

CC Inclusive

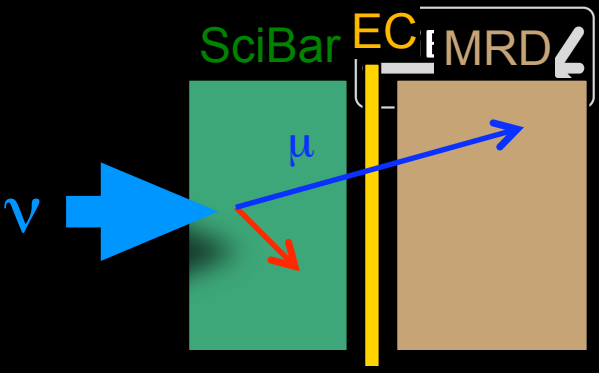
μ's easily identified if penetrate MRD
96% pure CC
21,431 stopped ν events



Normalisation set by MRD-matched events



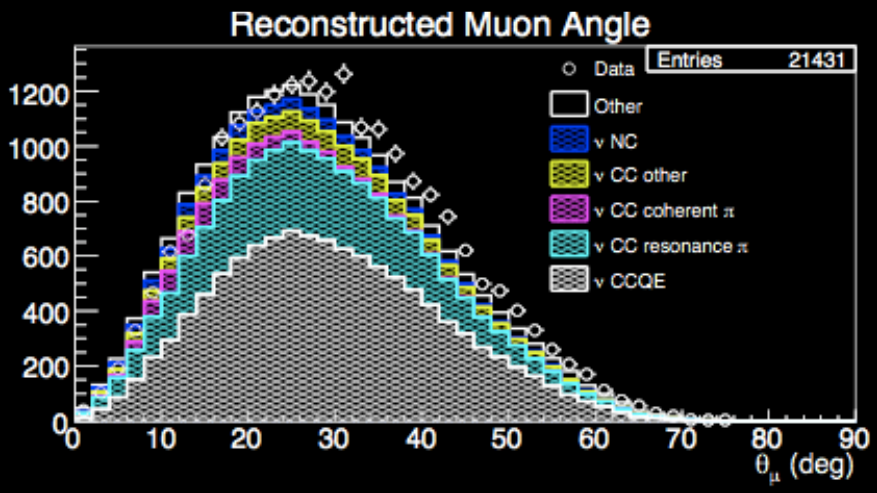
CC Inclusive

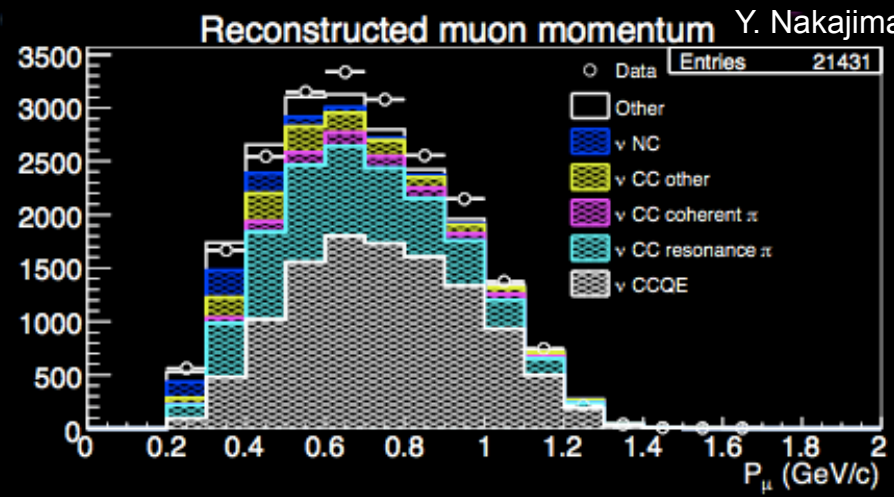


MRD stopped events

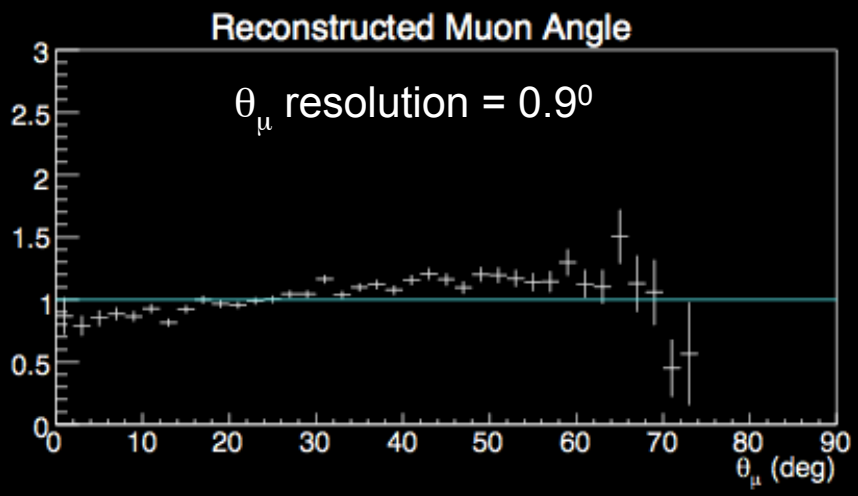
Y. Nakajima

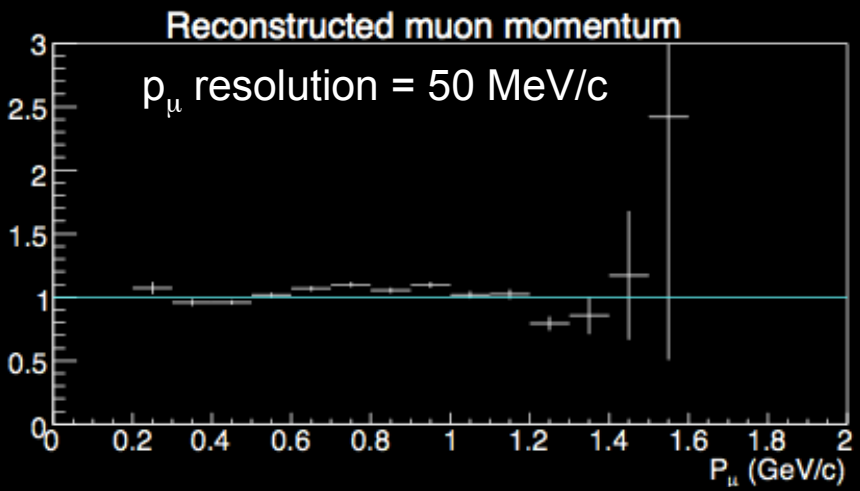
Normalised to MRD matched events





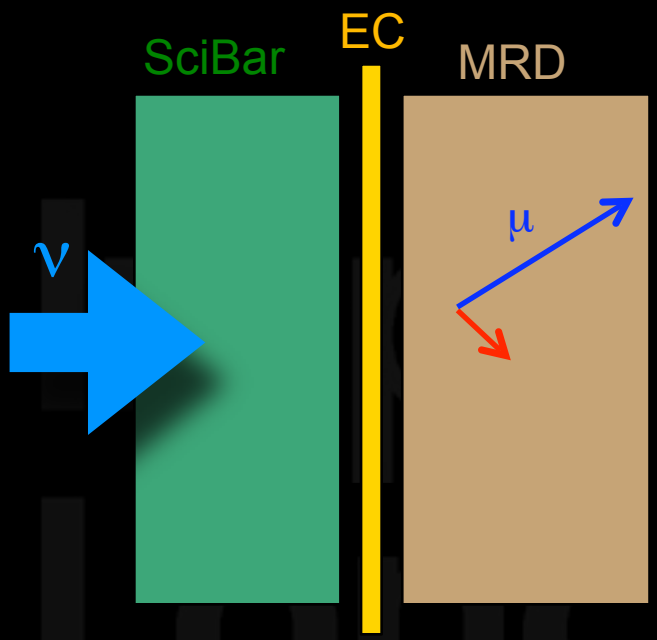
Angular discrepancy is not detector effect →physics?

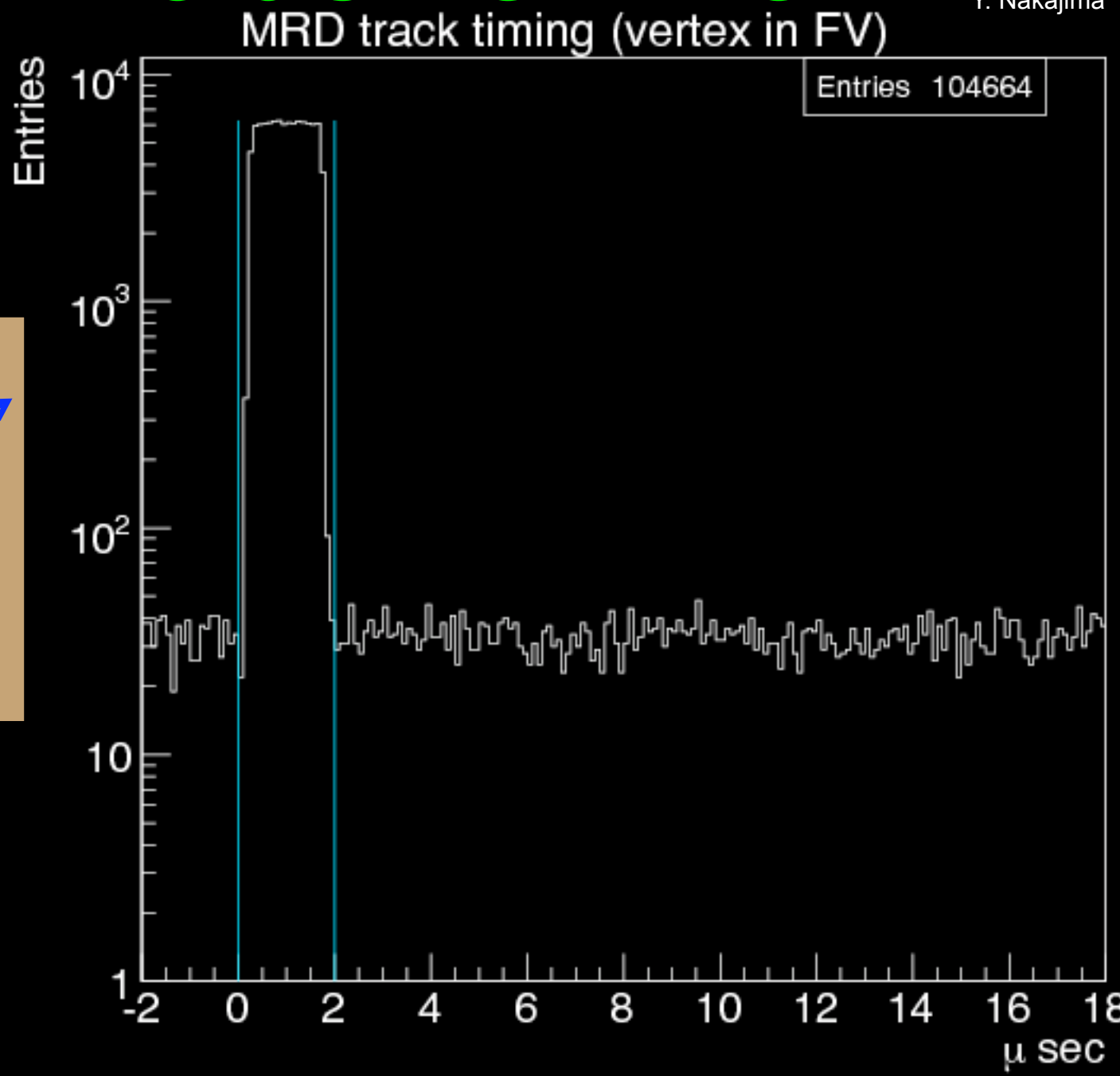




CC Inclusive - Fe

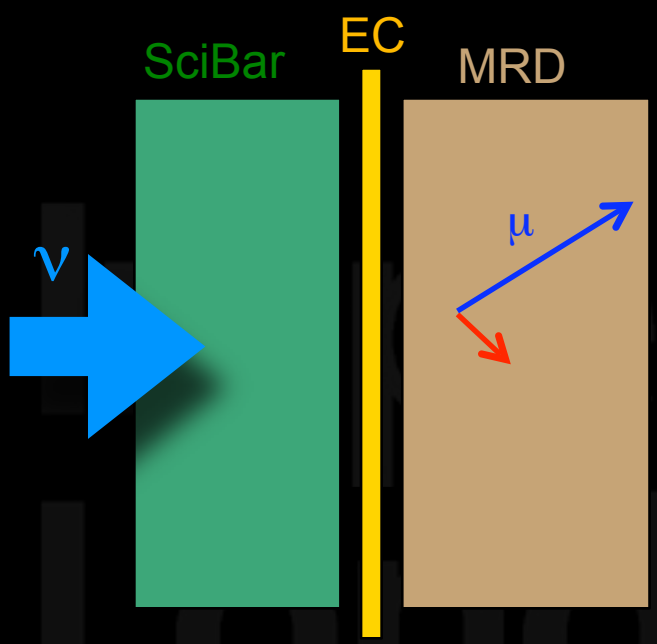
Y. Nakajima

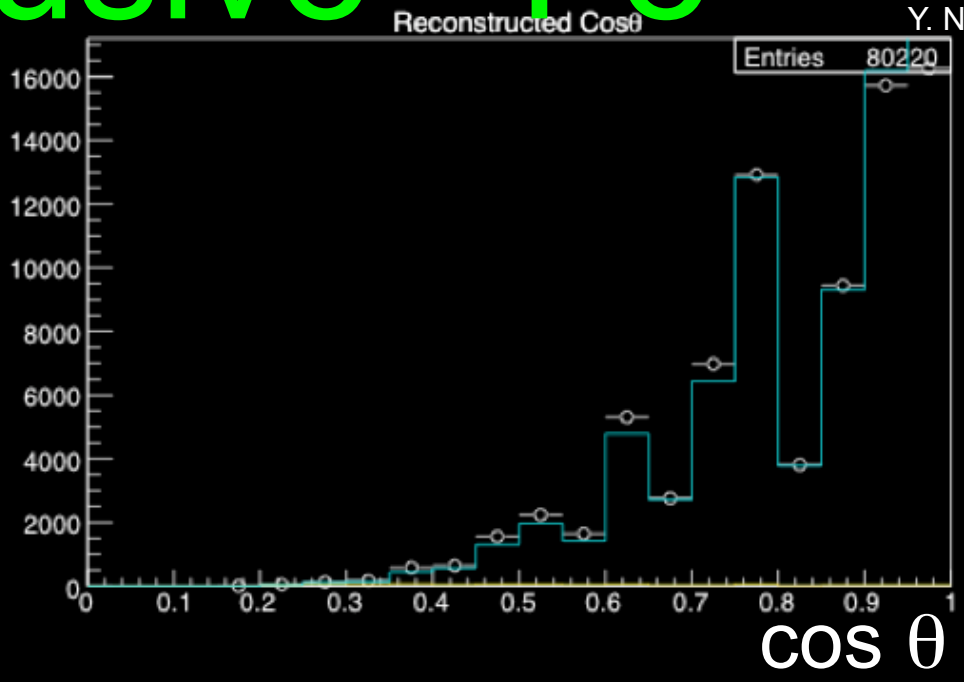


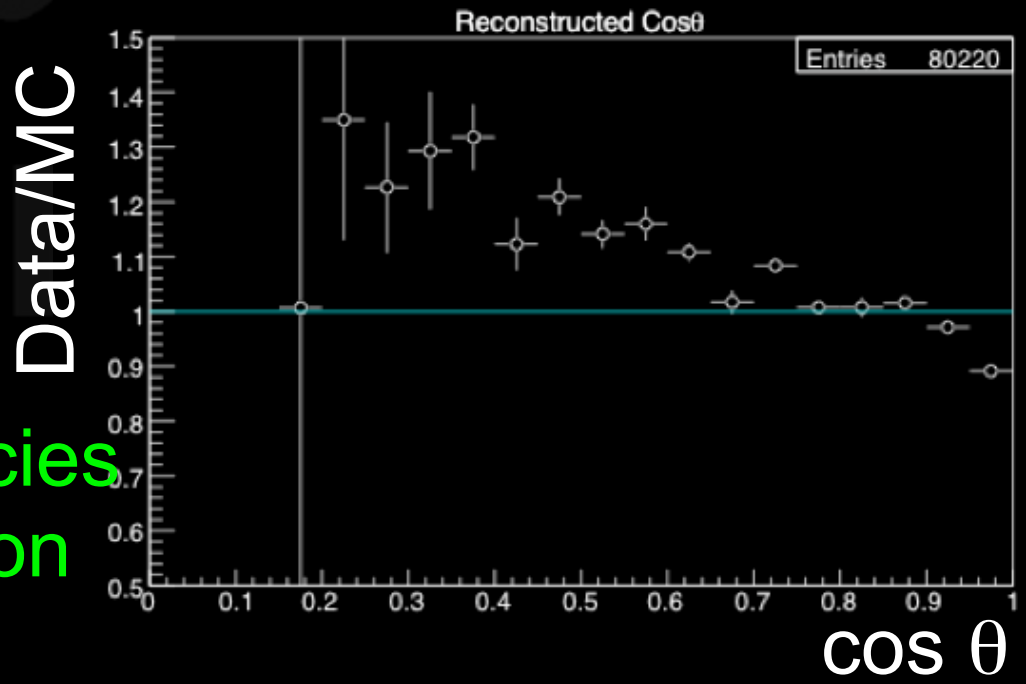


CC Inclusive - Fe

Y. Nakajima

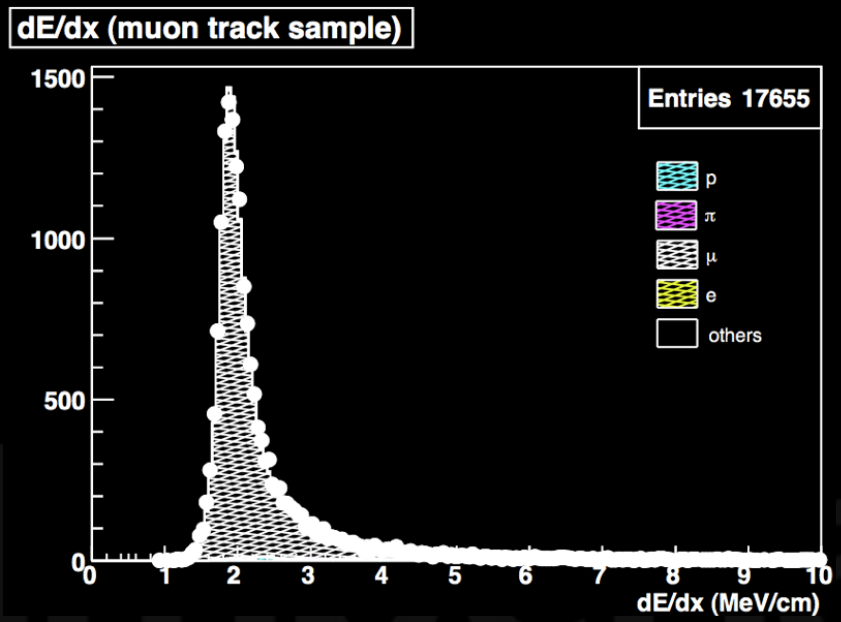


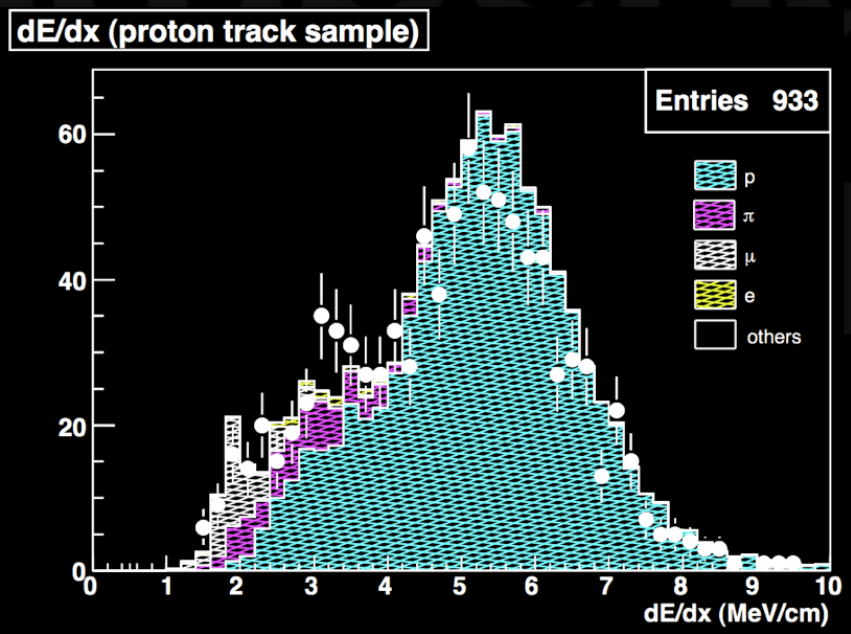




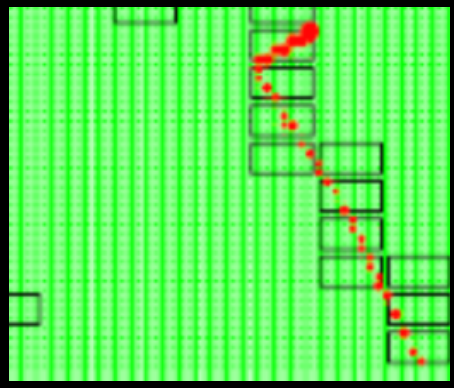
Muon angular discrepancies under active investigation

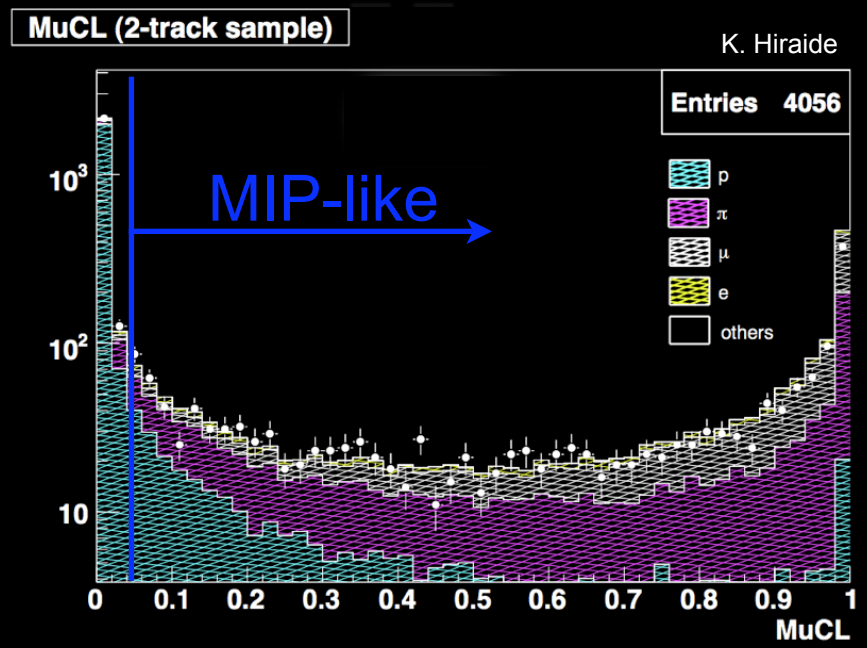
SciBar PID





Energy deposit used as PID

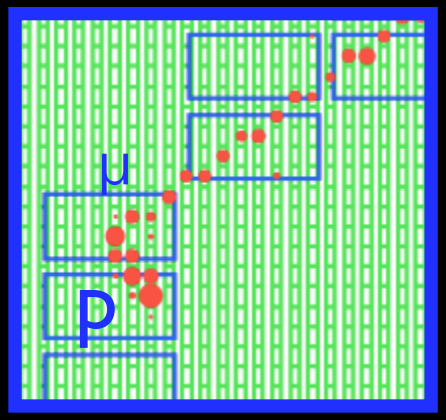


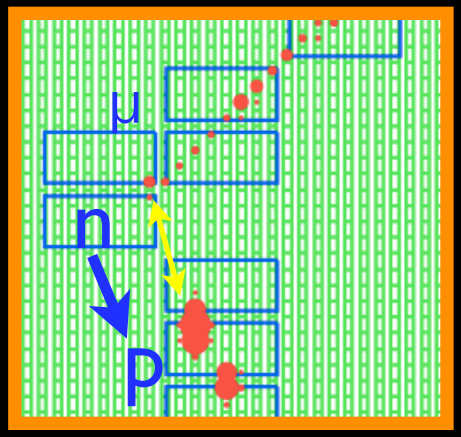


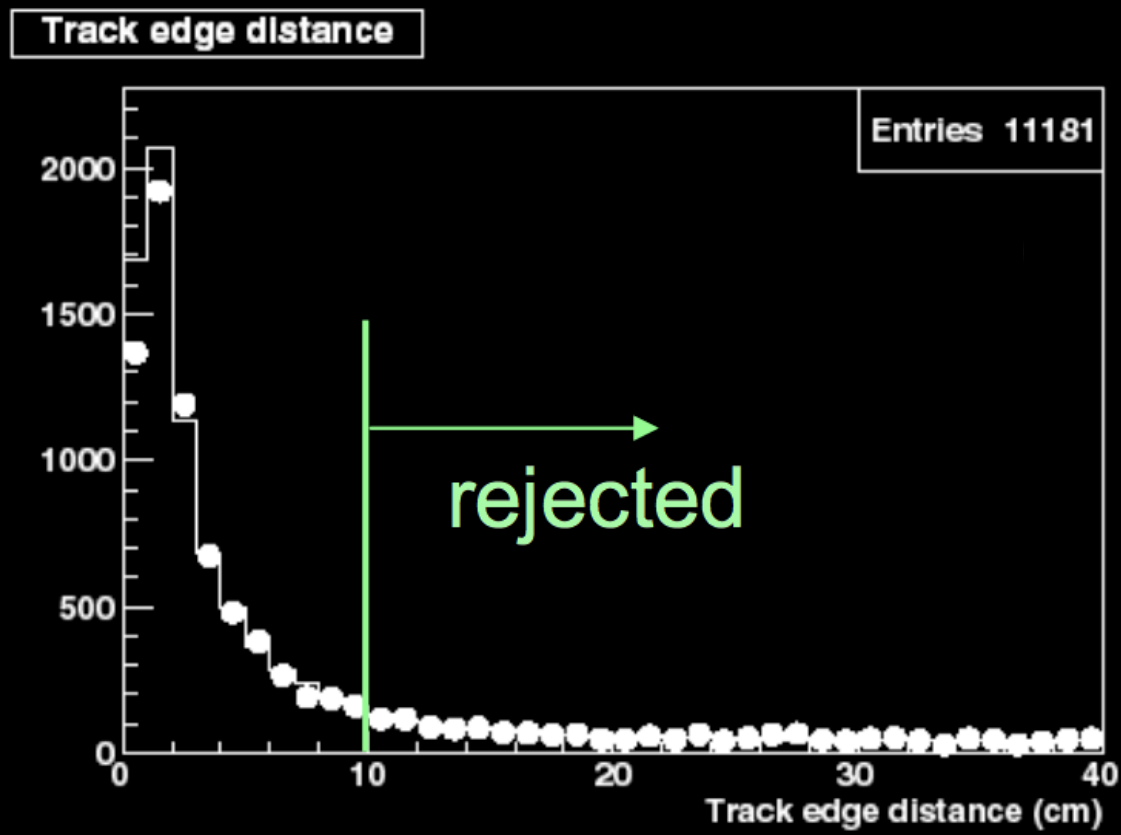
Cut at MuCL>0.05 for 2nd tracks:
84% π+ efficiency
~90% p rejection

SciBar Cuts

- Additional track parameters used to distinguish interaction signatures
  - Vertex separation
  - 2nd track angle
    - $\Delta\theta_p$

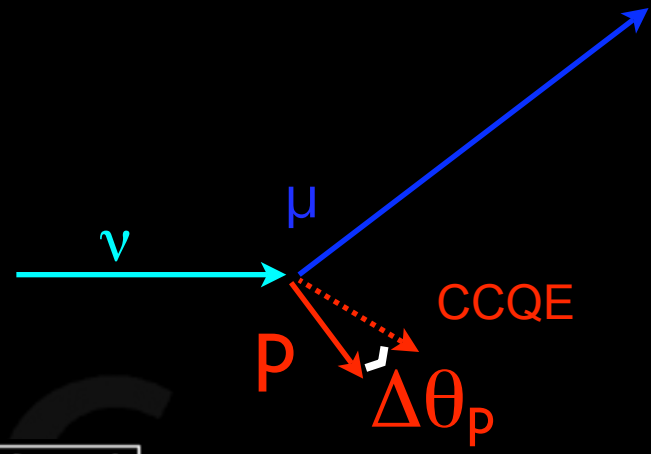


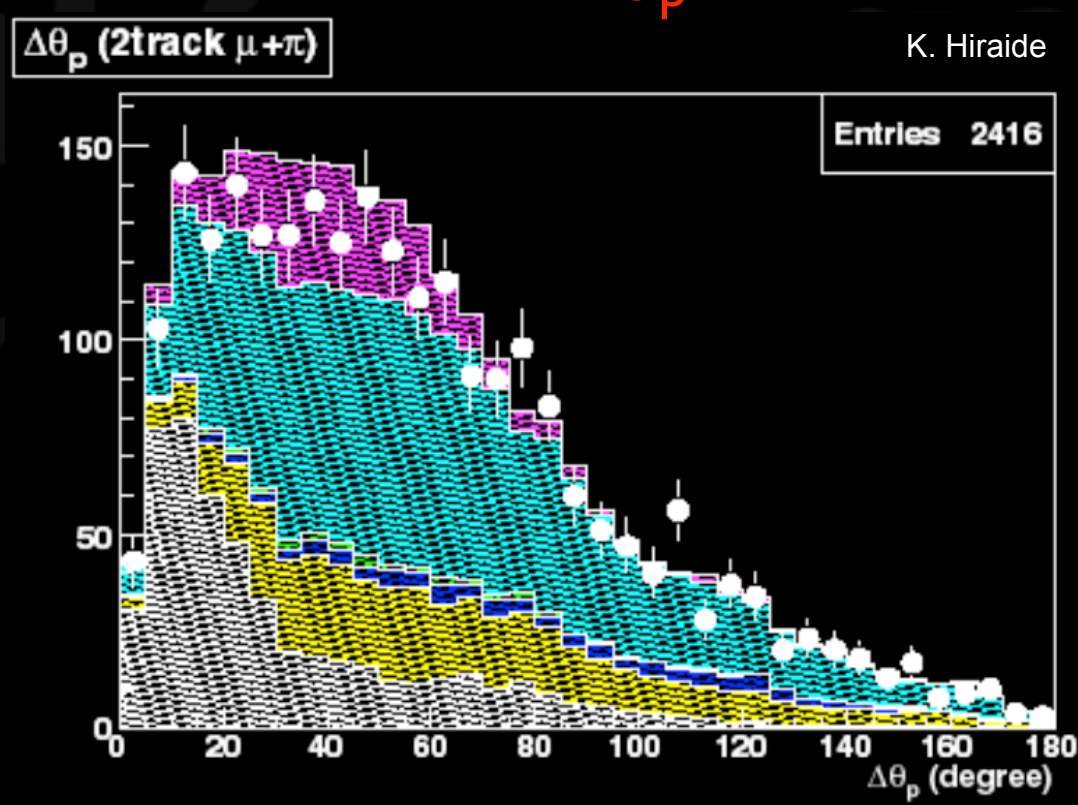




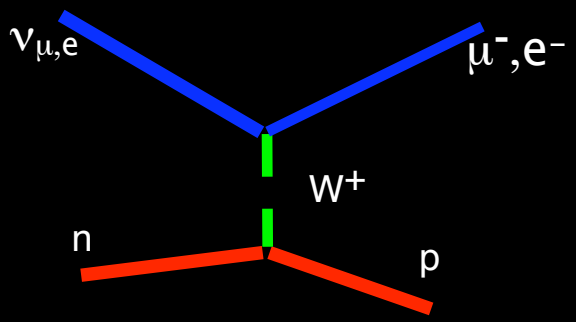
SciBar Cuts

- Additional track parameters used to distinguish interaction signatures
  - Vertex separation
  - 2nd track angle
    - $\Delta\theta_p$

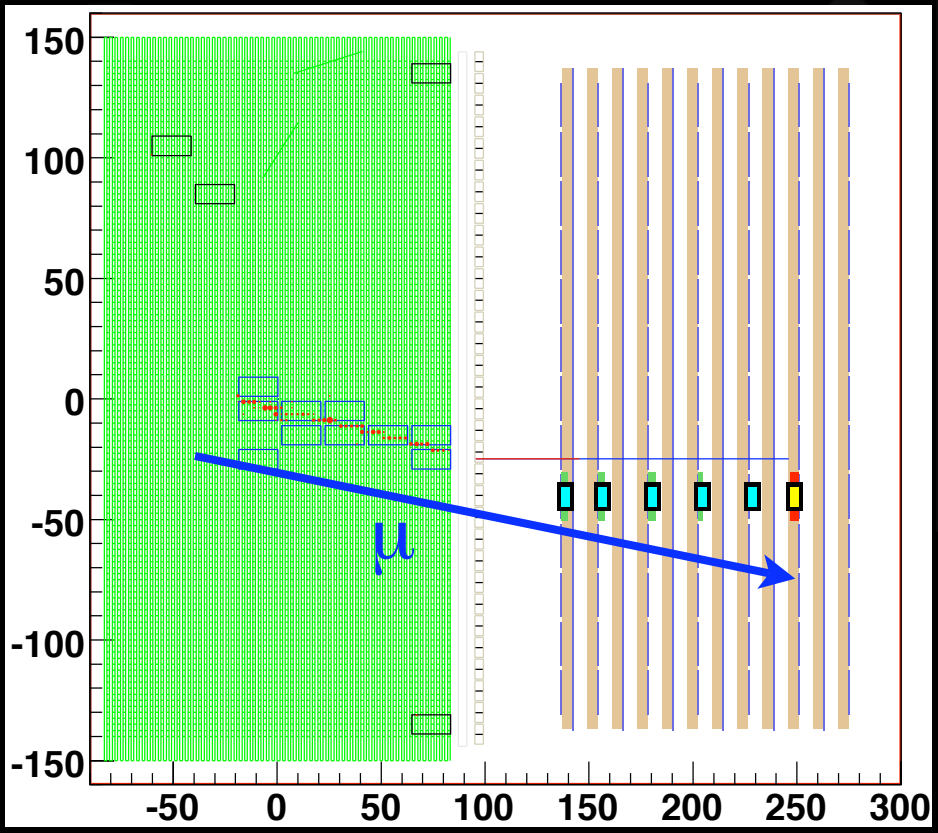




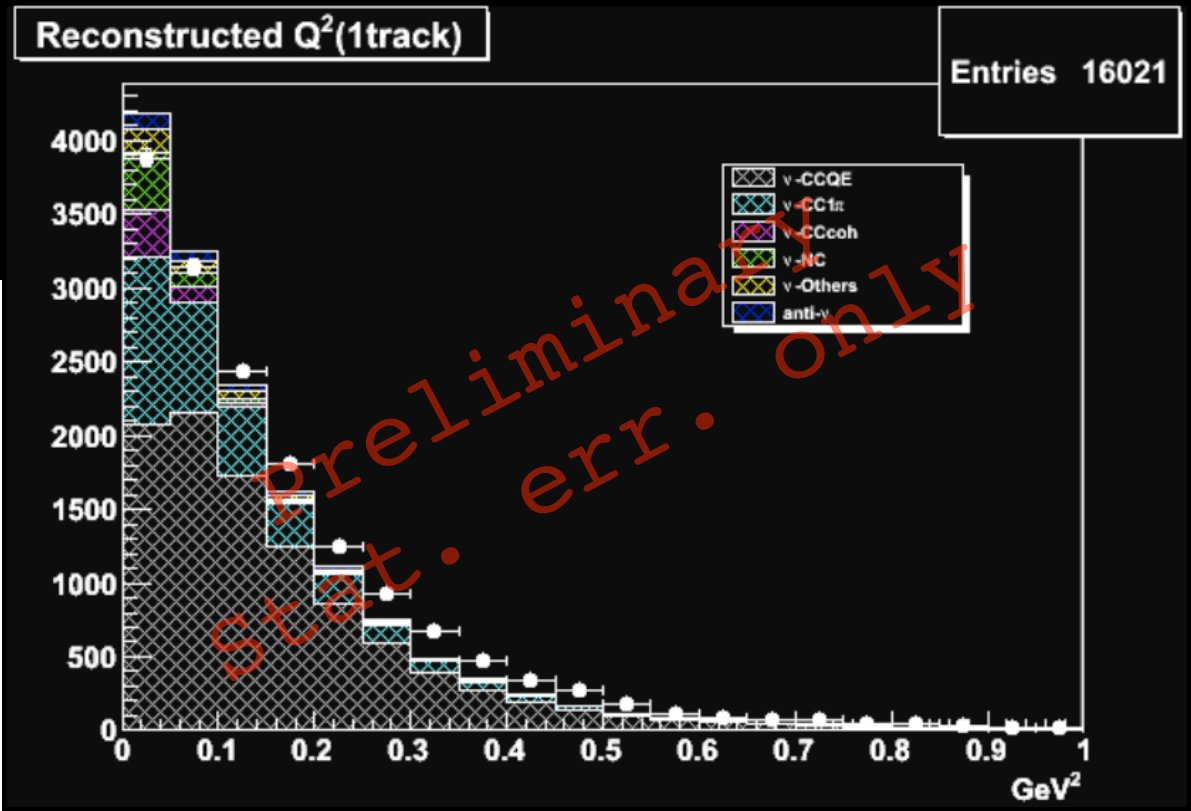
CCQE



SciBooNE data



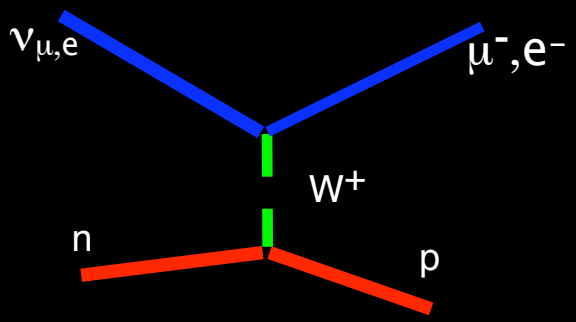
J. Alcaraz-Aunion



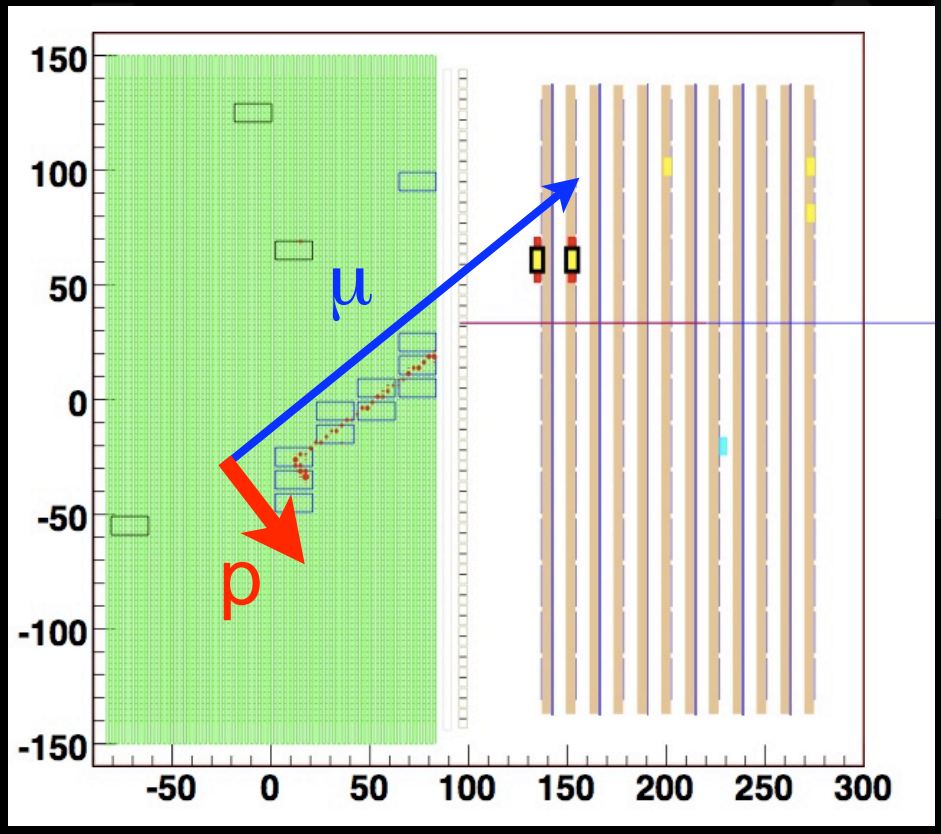
1 track events 67% pure CCQE

using NEUT (M_A=1.1 GeV)

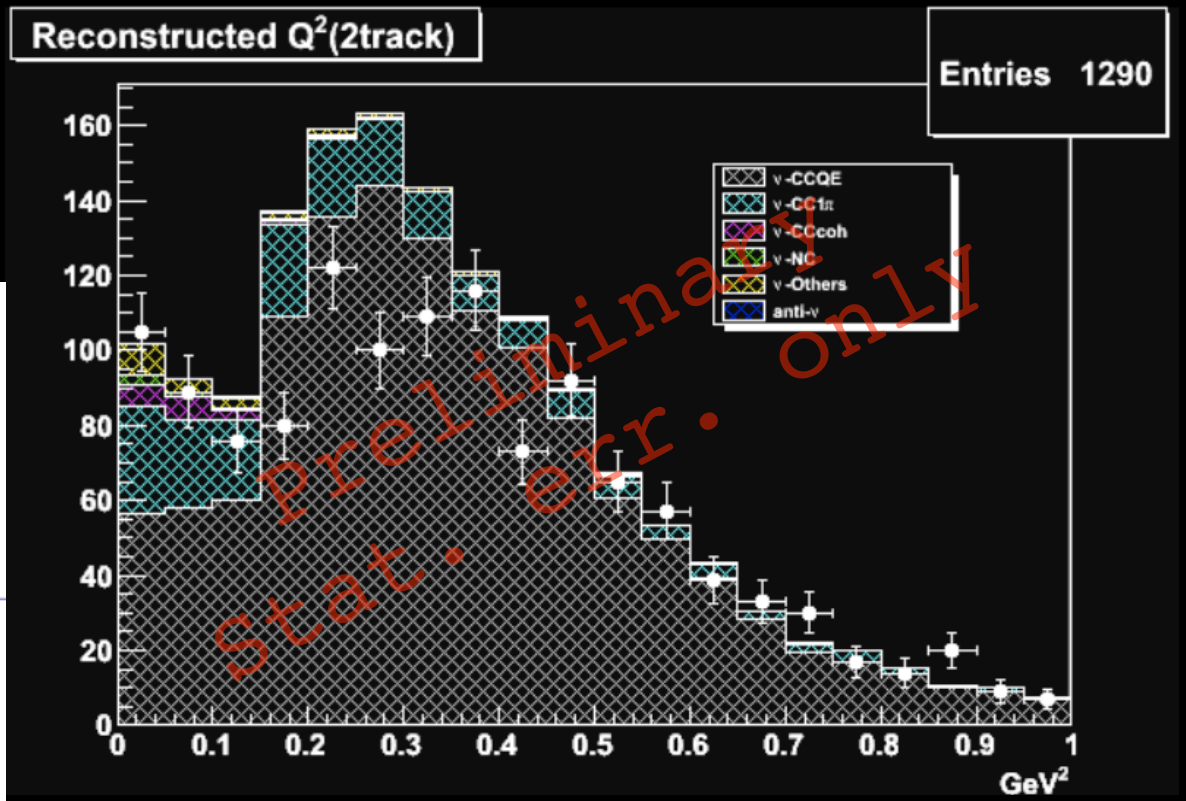
CCQE



SciBooNE data



J. Alcaraz-Aunion

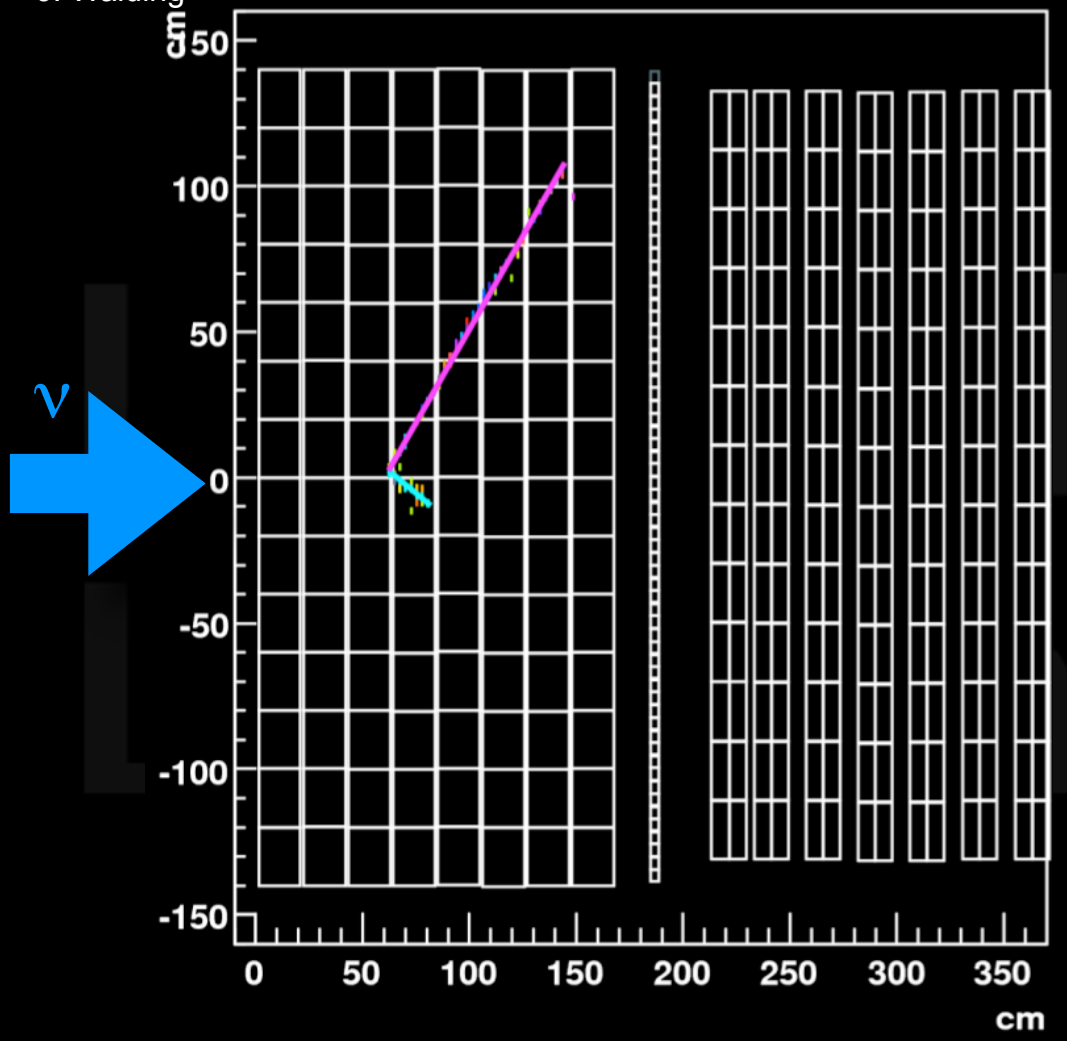


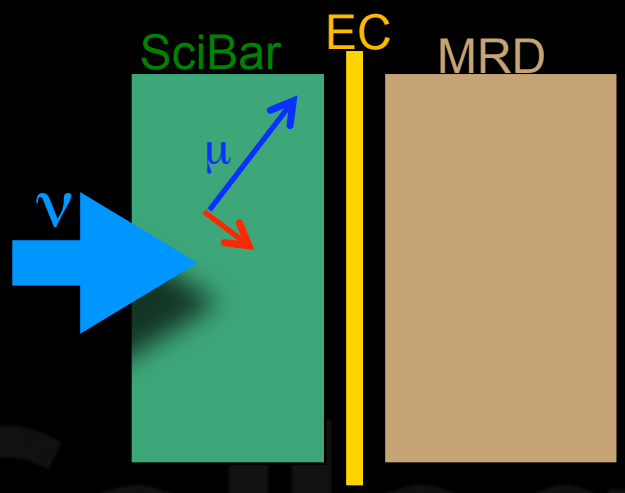
2 track events 81% pure CCQE

using NEUT (M_A=1.1 GeV)

Results in 2009

CCQE - SciBar only



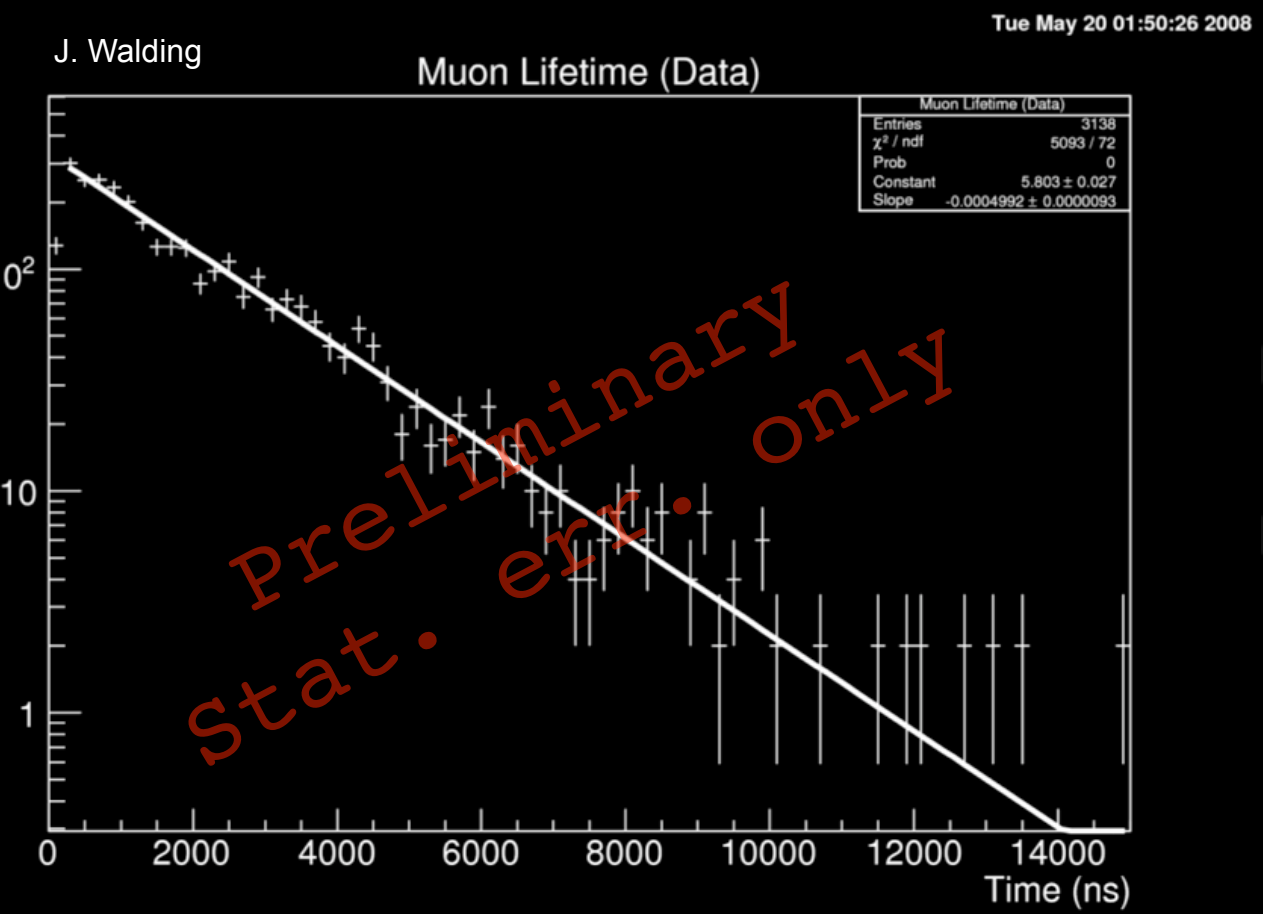


- Events can remain in SciBar only
  - Look for muon decay to tag the muon tracks

Different kinematic regions

Different systematics on p_μ measurement

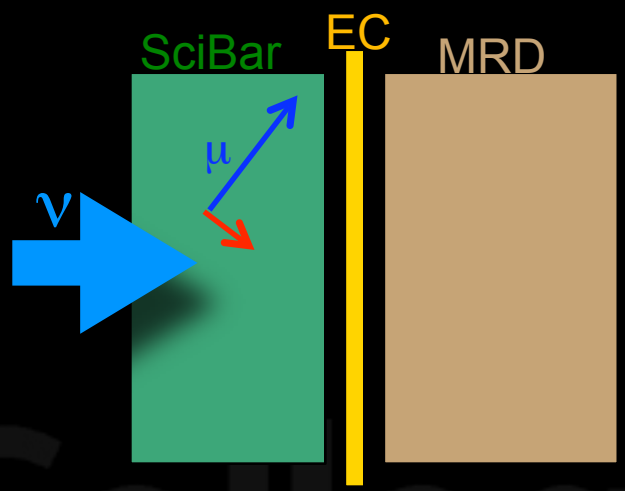
CCQE - SciBar only



τ_μ = 2.003 ± 0.047 (stat) μs

expected = 2.026 ± 0.001 μs

Suzuki, et al., PR**C35**, 2122 1987



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Different kinematic regions

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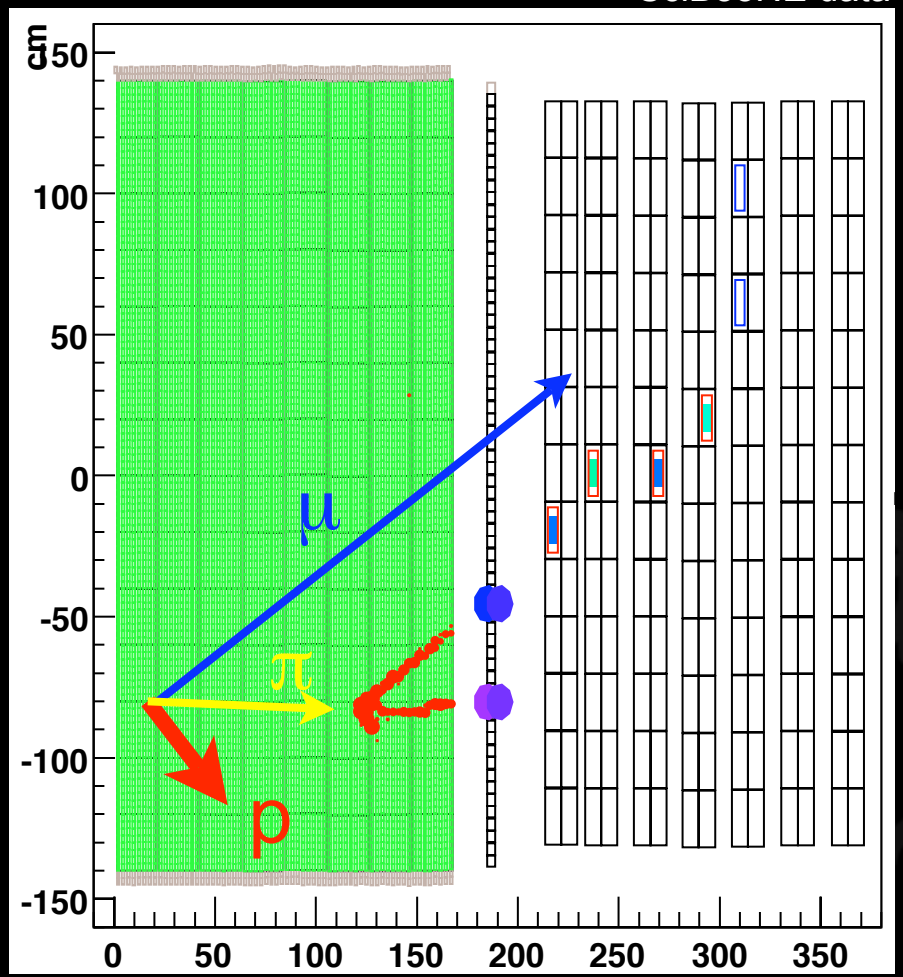
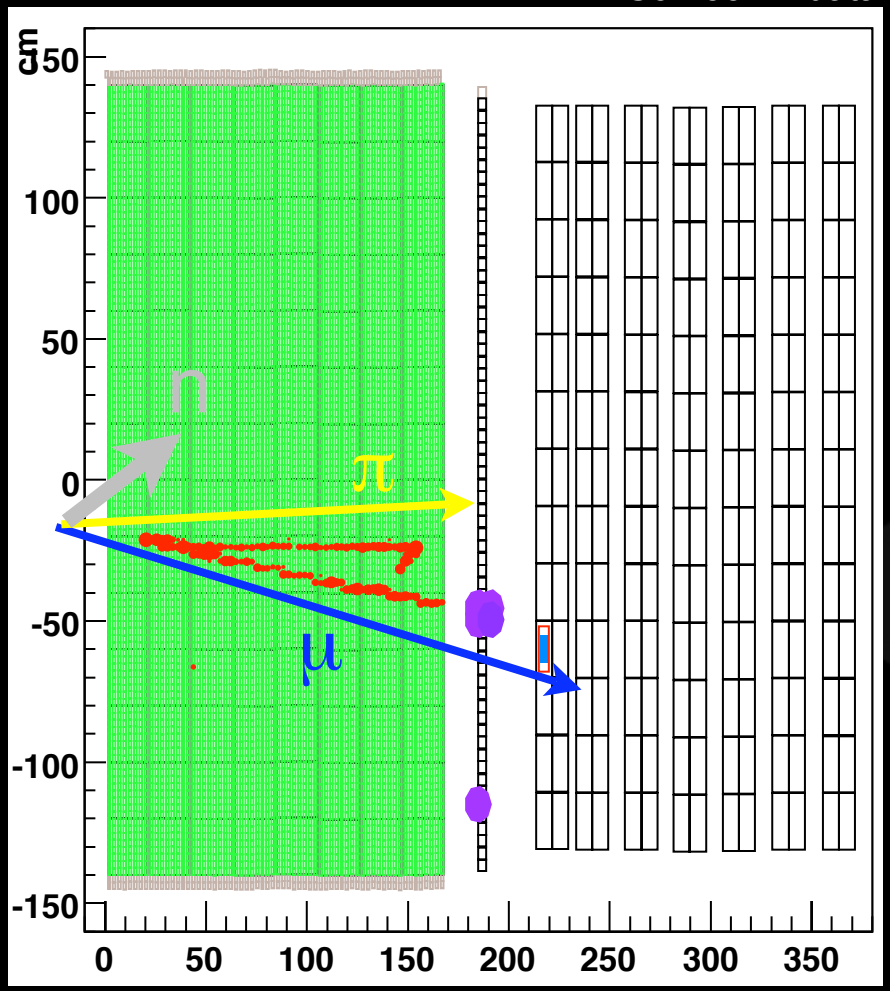
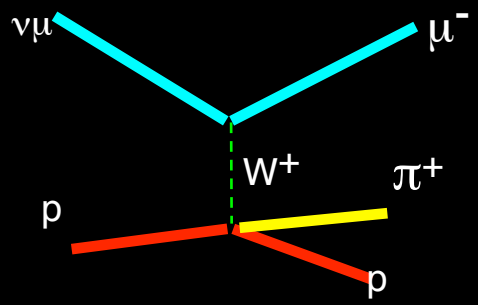
CC1π^+ events

SciBooNE data

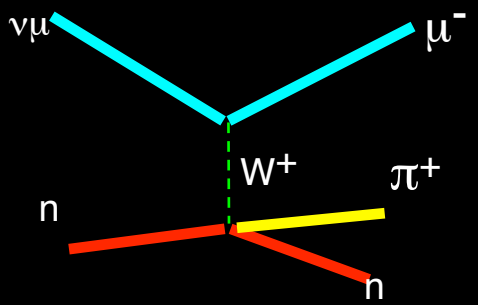


SciBooNE data





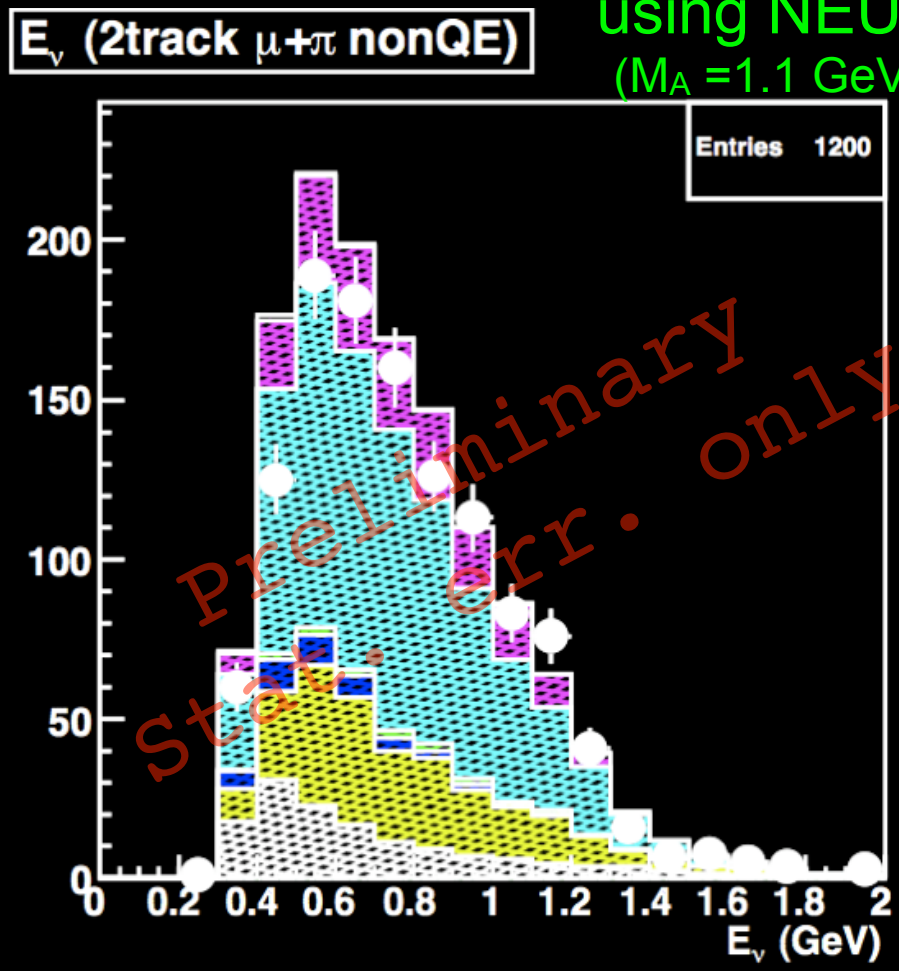
$\nu_\mu p \rightarrow \mu^- \Delta^{++} \rightarrow p\pi^+$

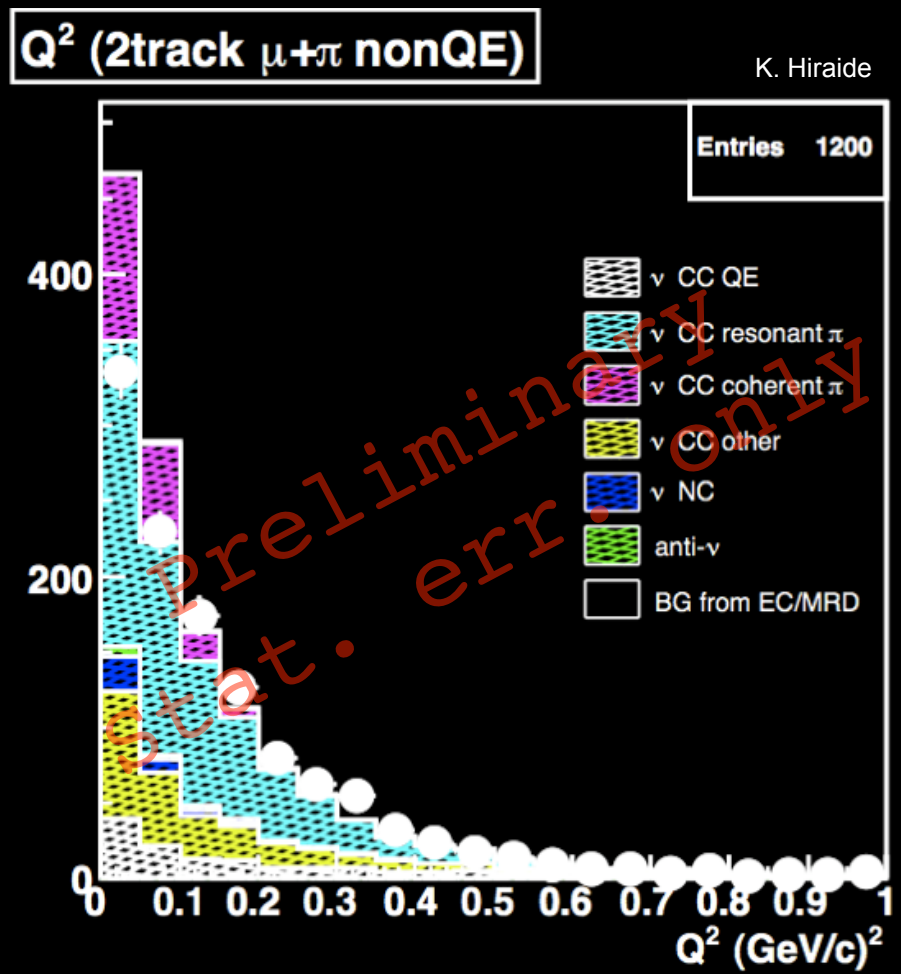


$\nu_\mu n \rightarrow \mu^- \Delta^+ \rightarrow n\pi^+$

CC1π^+

using NEUT
(M_A =1.1 GeV)

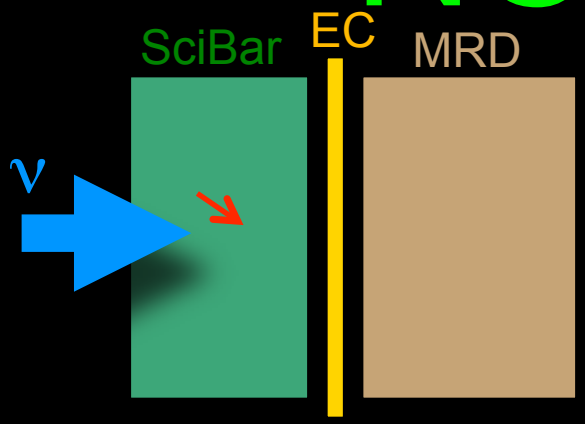




Important measurements of major background for ν_μ disappearance (both T2K and MiniBooNE)

Results for ICHEP08

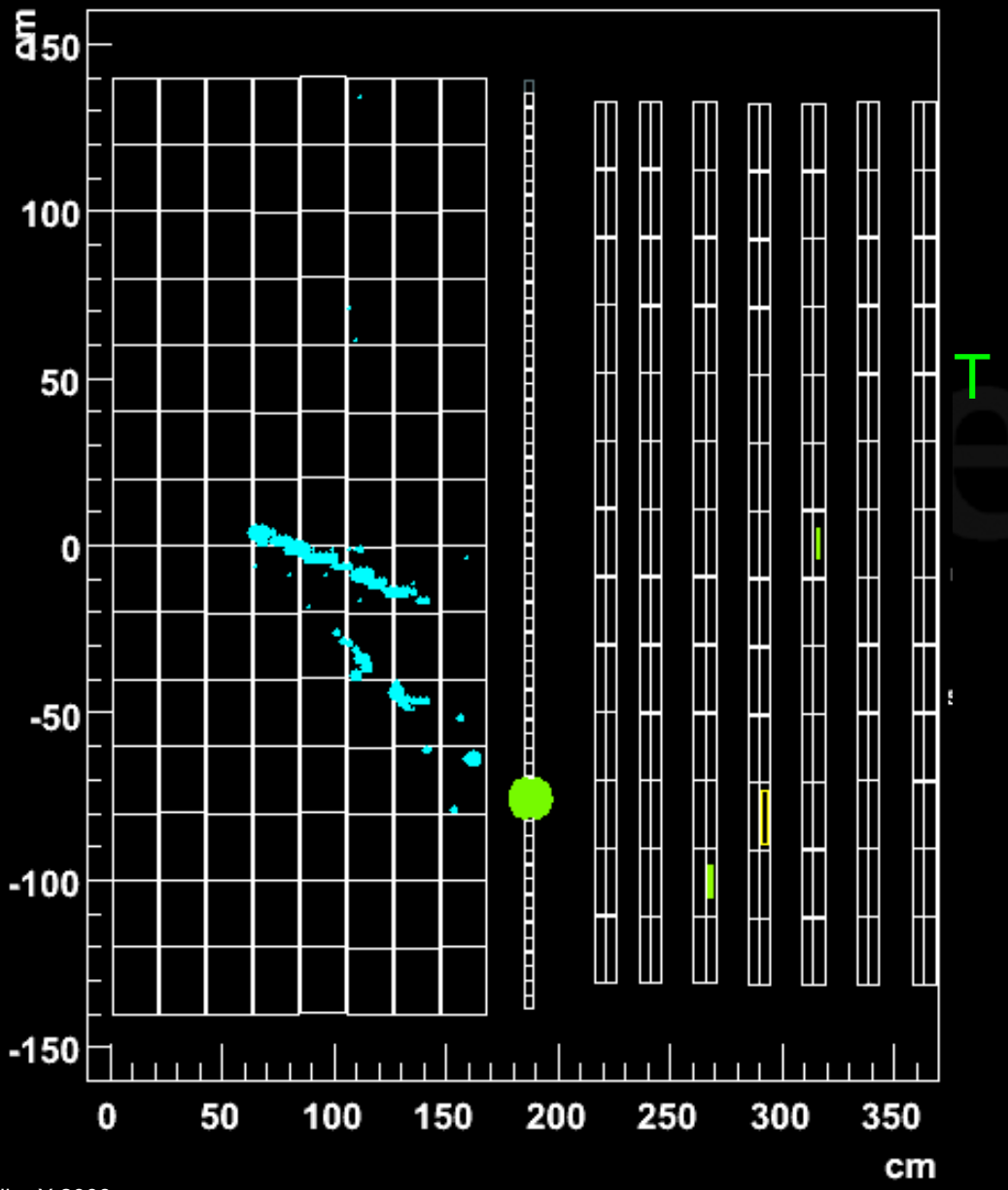
NCπ^0 scattering



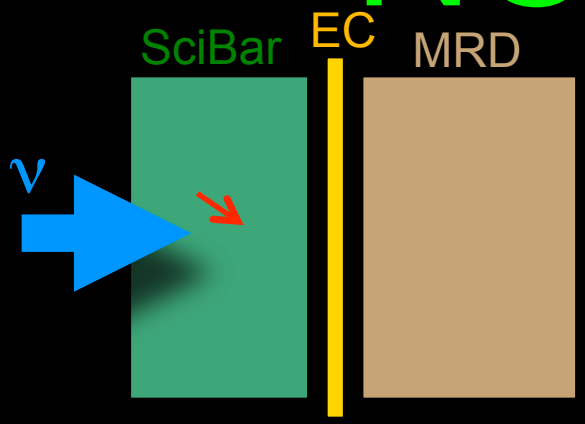
- NC signature: no muons
- SciBar's tracking and PID clearly identify γs from π^0 decay
- EC increases acceptance for high momentum π^0s
- Cut on vertex separation - but now reject joined tracks!

Results in 2009

Y. Kurimoto
SciBooNE data



NCπ^0 scattering



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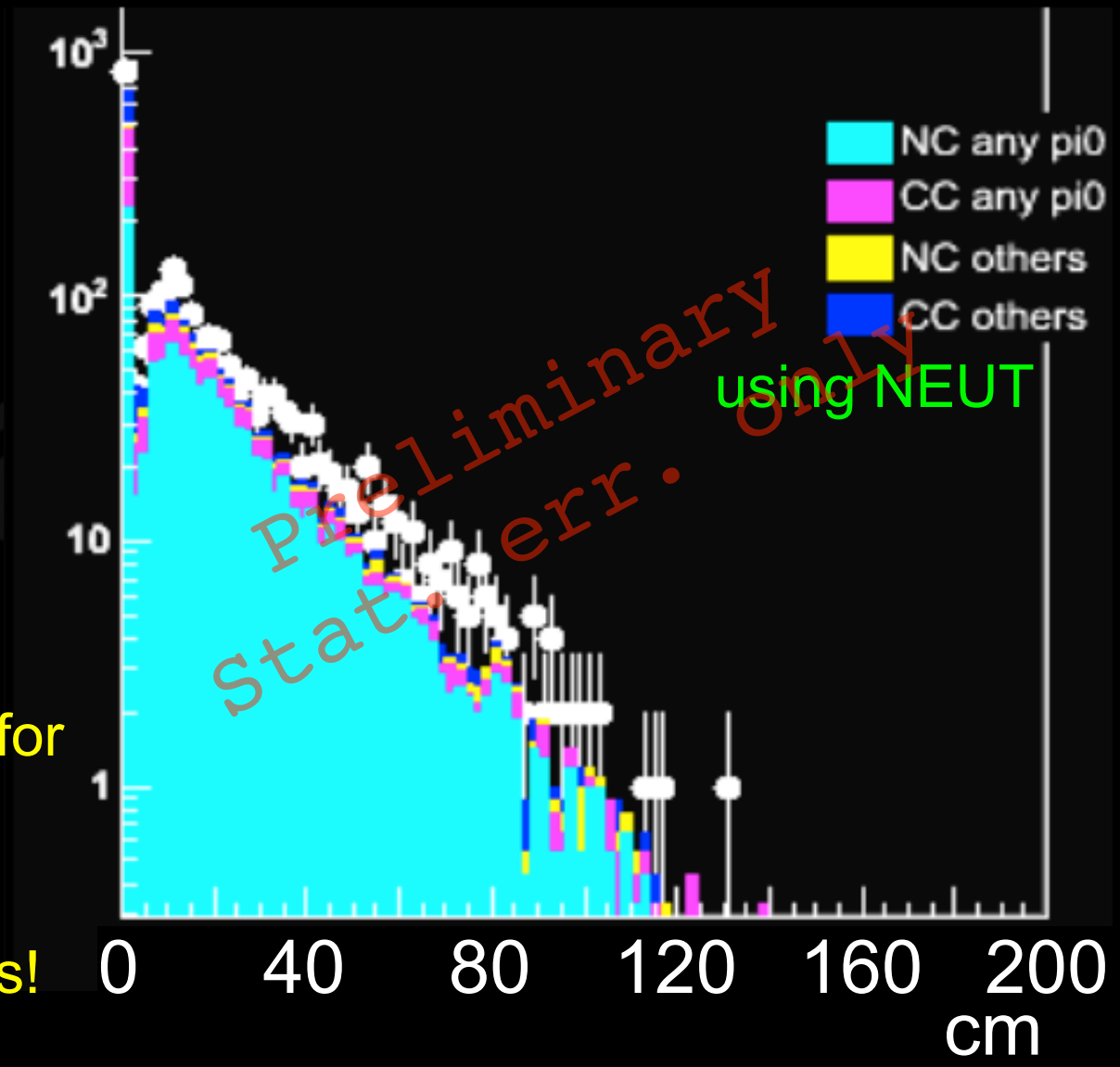
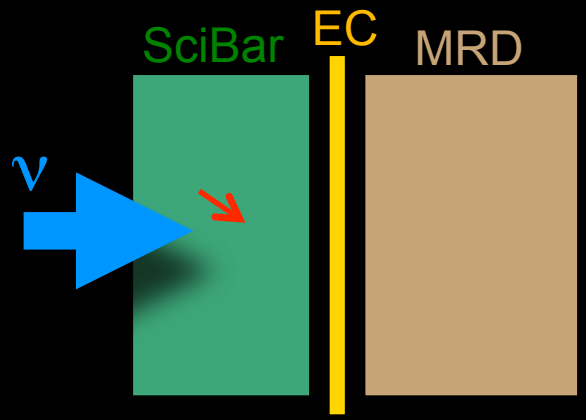
Y. Kurimoto



Results in 2009

NC elastic scattering

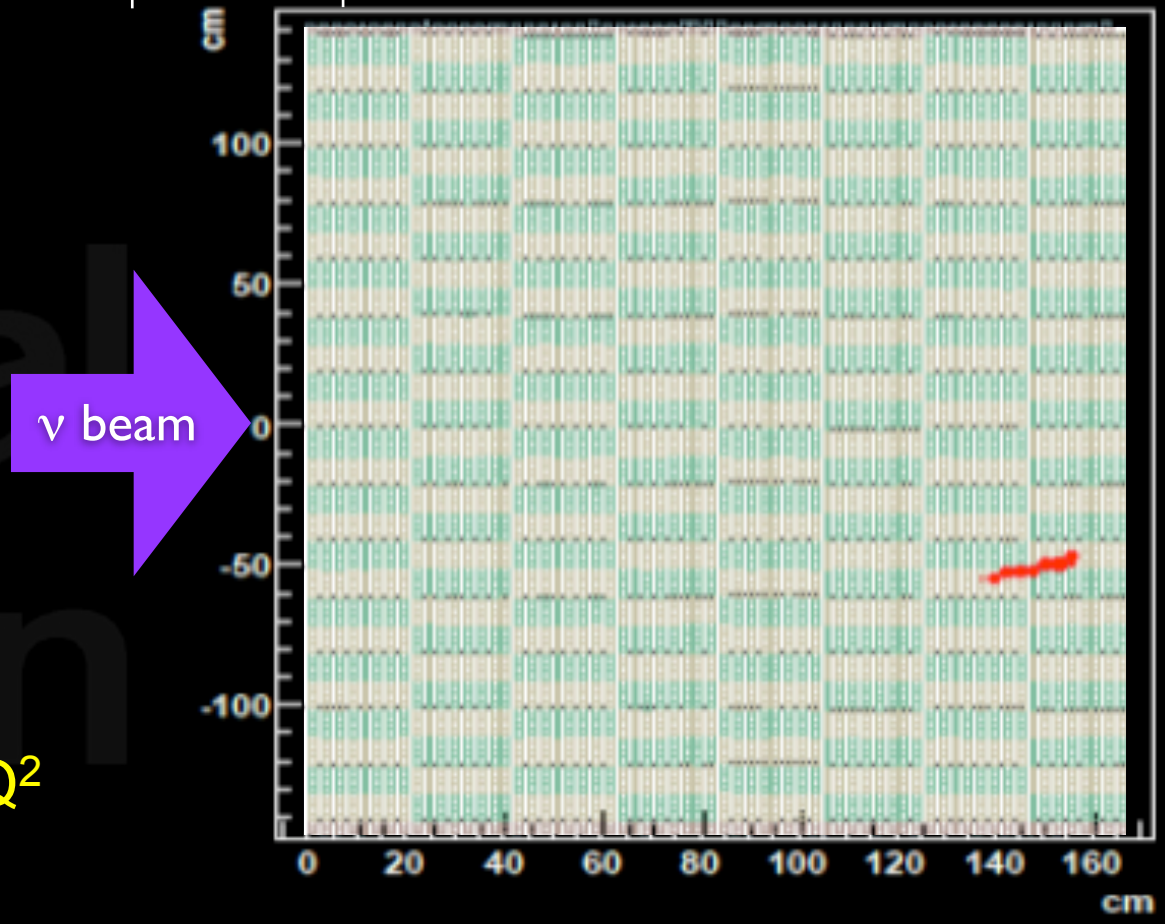


- No interference from photon propagator
- Simple signature: recoiling nucleon
- Tuning PID cuts
- Few measurements at low Q^2

Gives access to strange spin content of nucleon

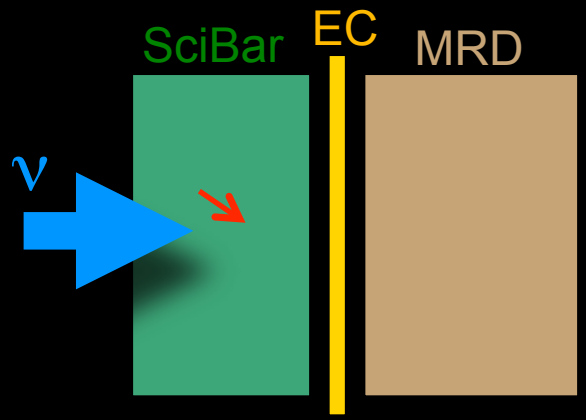
Top view

H. Takei



Results in 2009

NC elastic scattering



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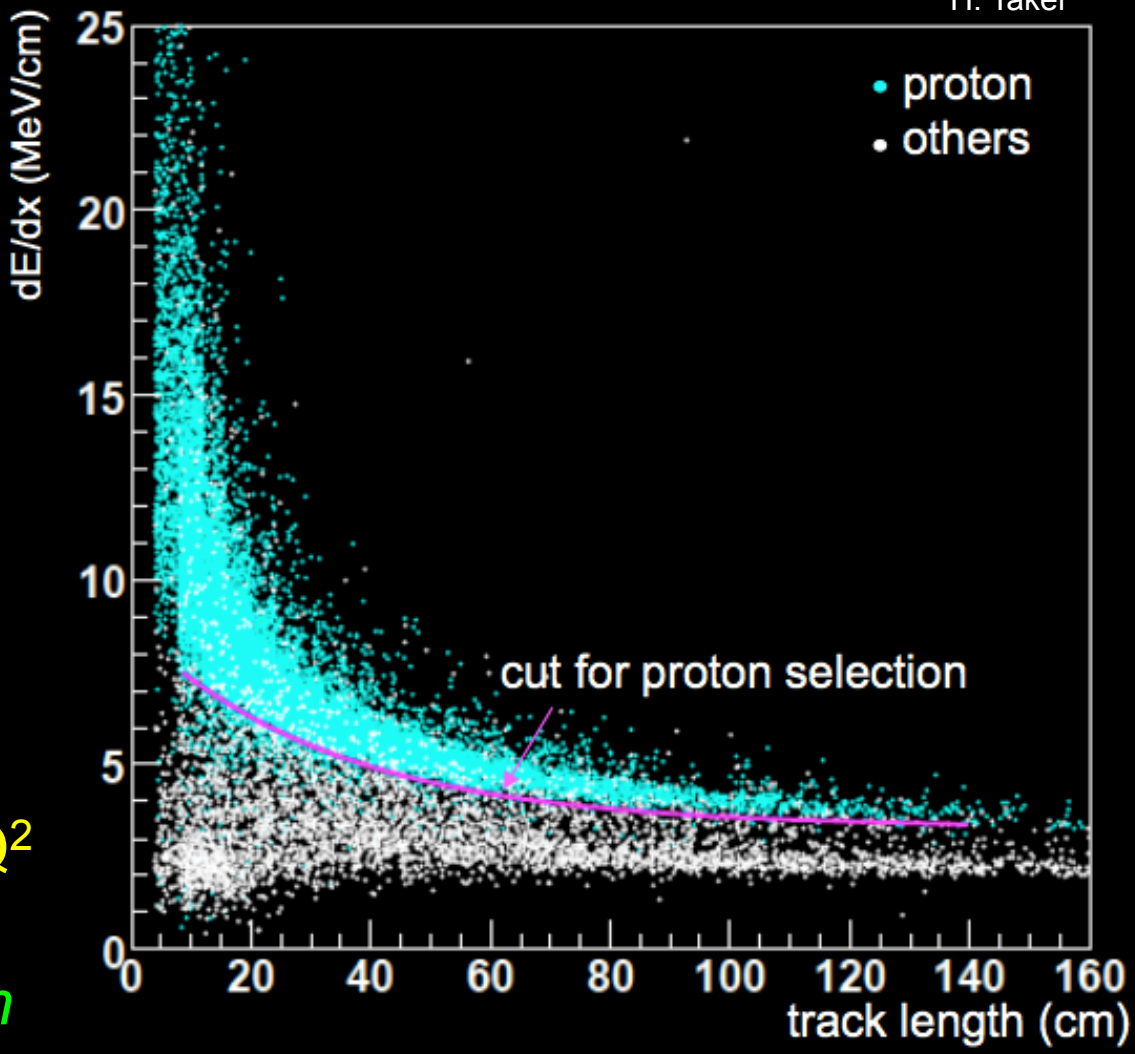
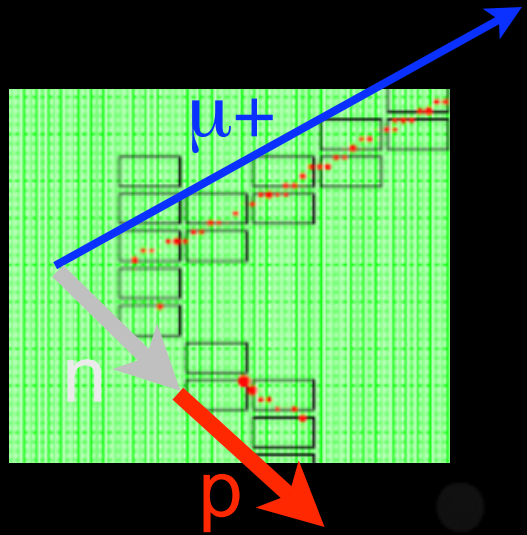


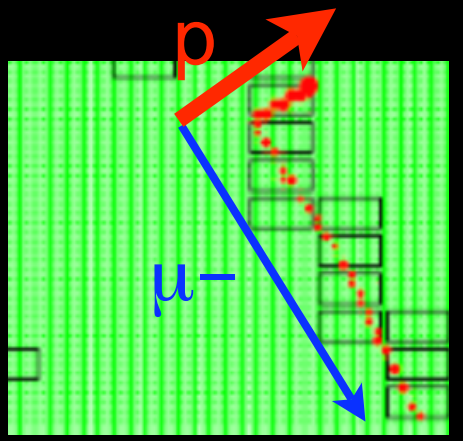
Results in 2009

SB $\bar{\nu}$ cross sections

Right Sign



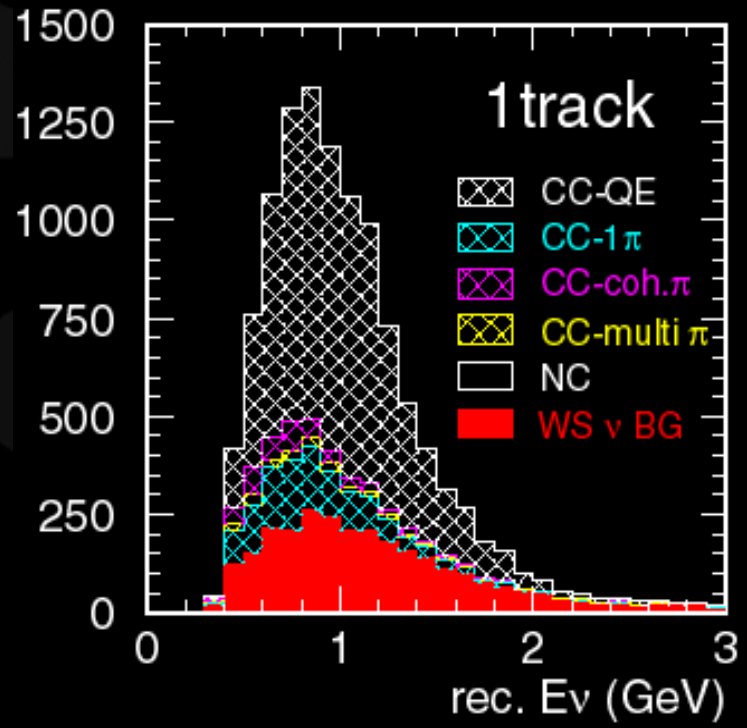
SciBooNE data

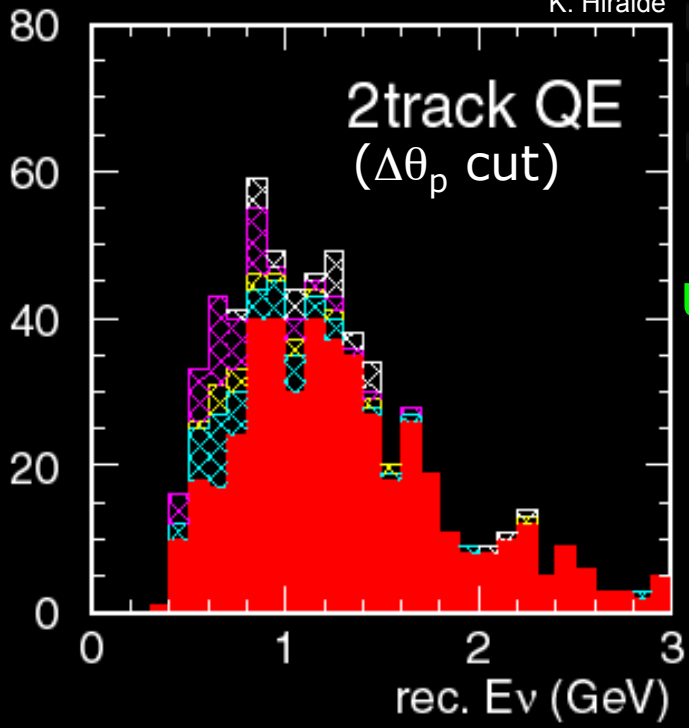


Wrong Sign

WS = 30% of events!

K. Hiraide





MC only

using NEUT

Results in 2009

Looking ahead

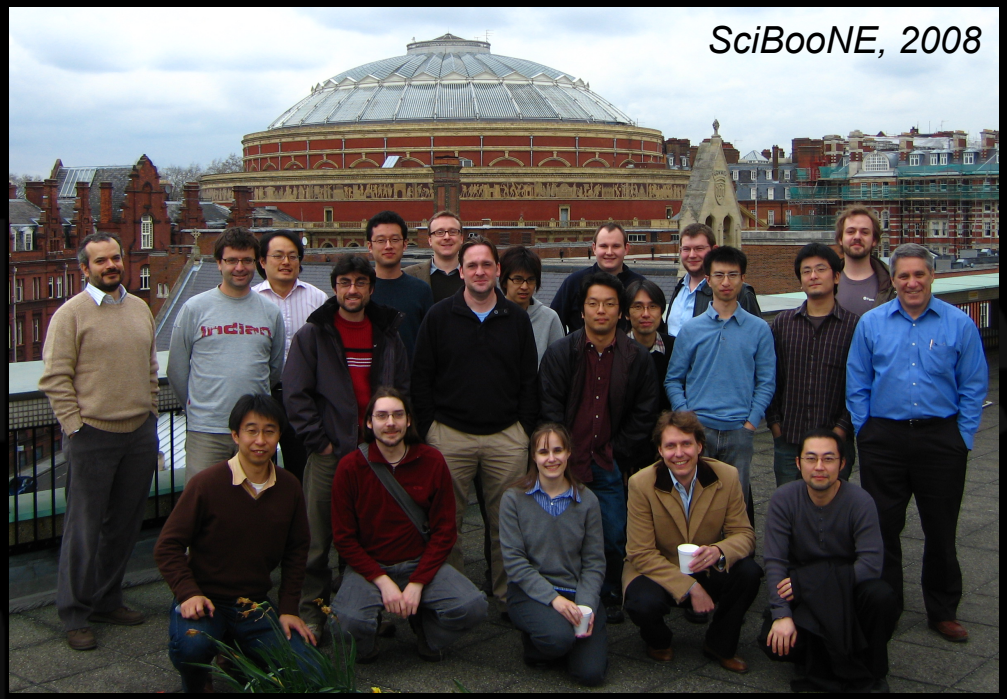
Many more analyses!

- CC1π^0 cross section
- Δs
- Radiative Δ decay branching ratio
- **Antineutrino analyses!**
- Short range nuclear correlations
- Modern nuclear models and nuclear effects

Lots to learn form e- scattering community!

Conclusion

- ν-nucleus scattering is entering the precision era
- SciBooNE is running well
  - already achieved POT goal
- SciBooNE analyses are progressing quickly
  - Measurements important for next generation of oscillation experiments
- (SciBooNE will also provide important new constraints for improved MiniBooNE analyses)



Many new results coming this year!

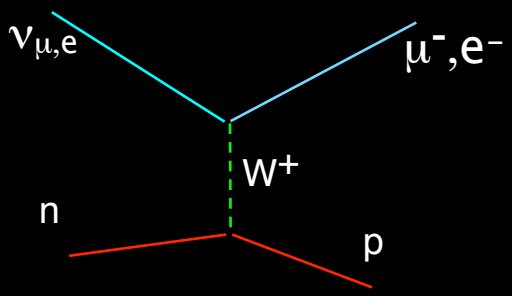
Thank you!

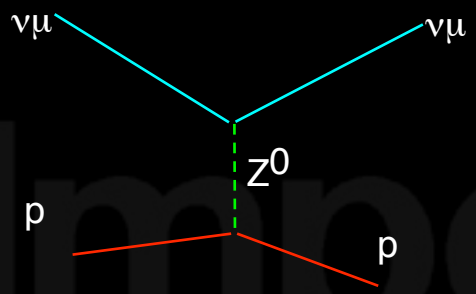
backup slides

Imperial College London

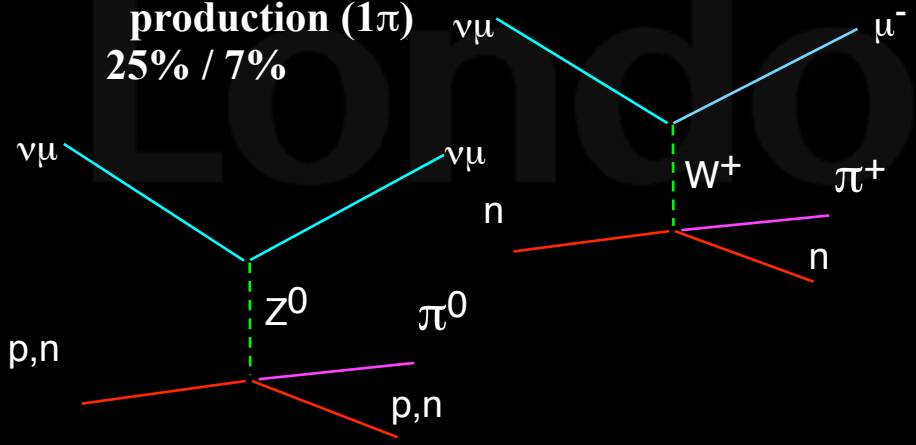
Cross Sections

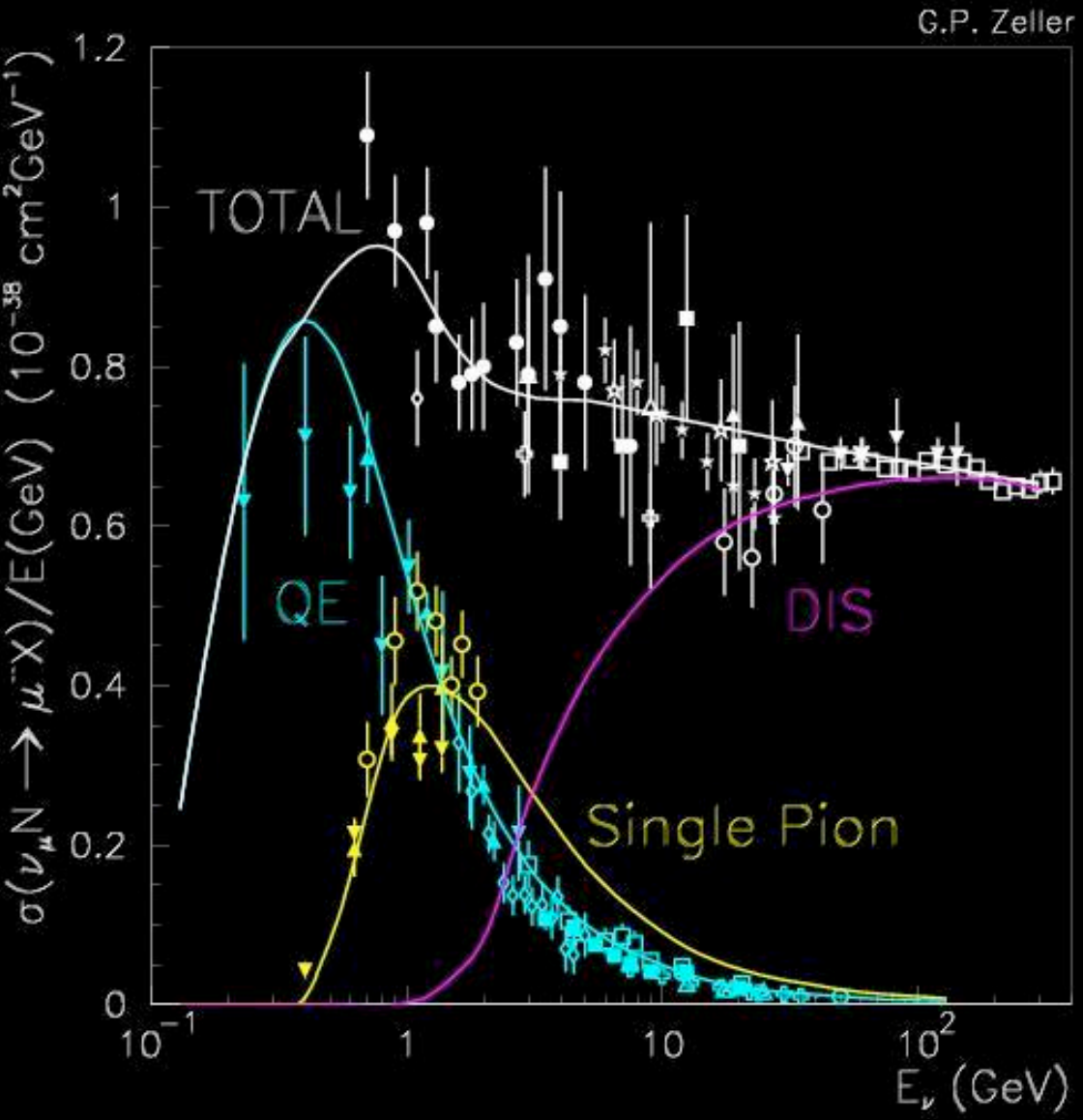
CC / NC quasi-elastic scattering (QE) 42% / 16%





CC / NC resonance production (1π) 25% / 7%

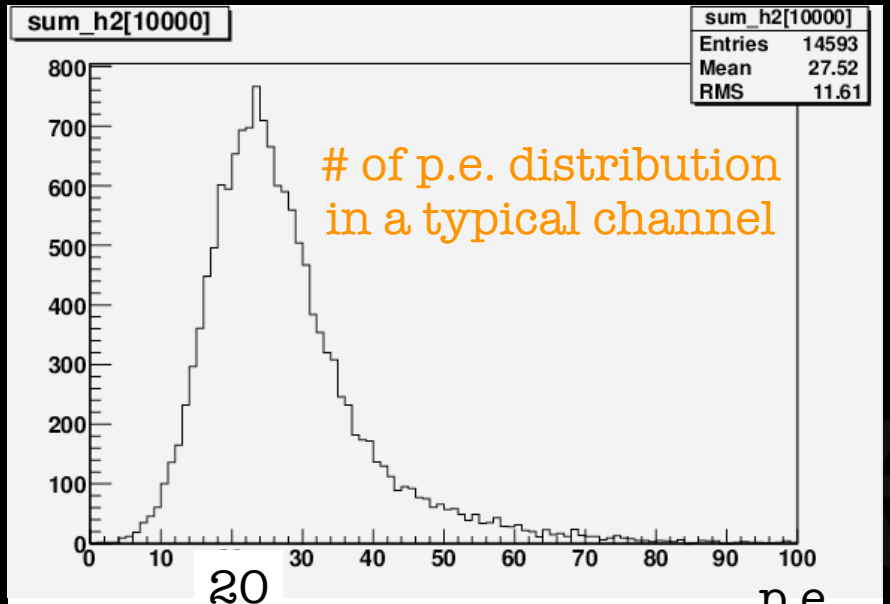


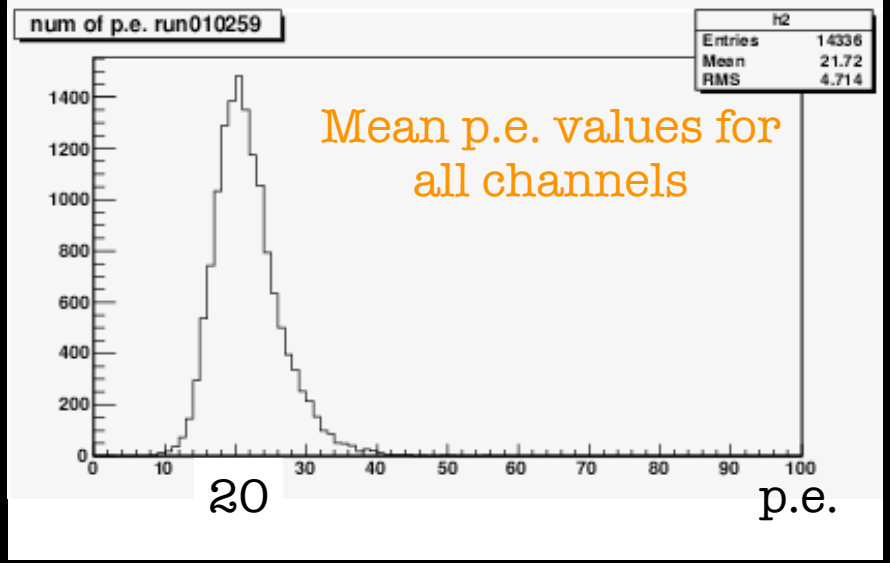


SciBar Performance

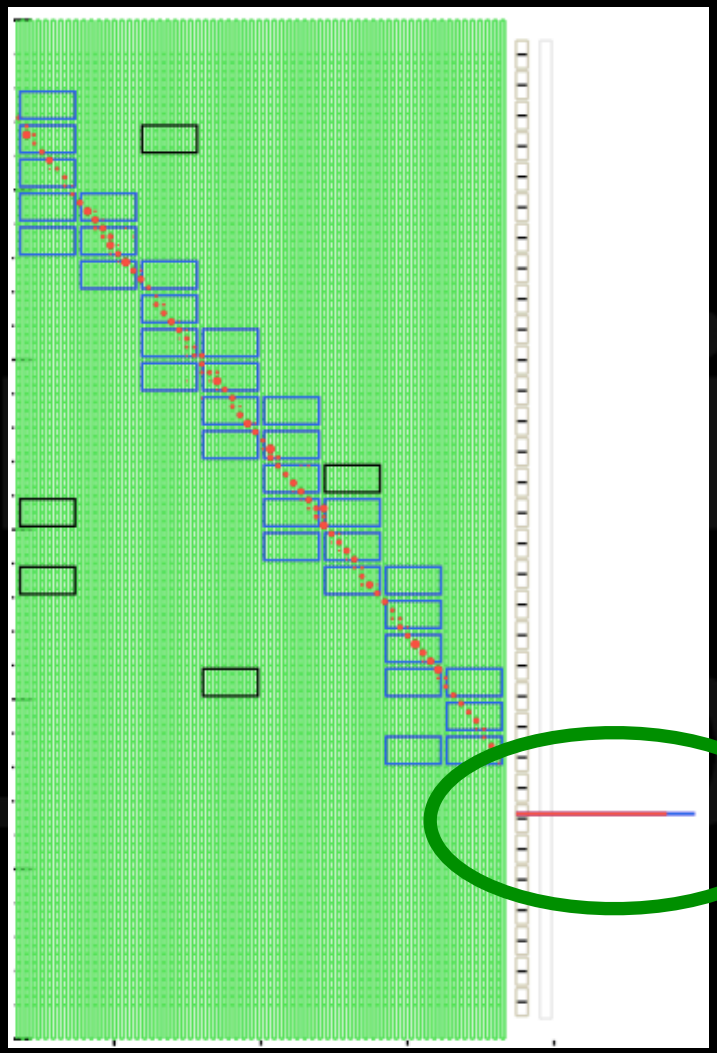
- Light yield for MIP
  - ~20 p.e./ 1.3cm (average over all channels)
- Hit finding efficiency (cosmic)
  - Horizontal plane: 99.9%
  - Vertical plane : 99.8%

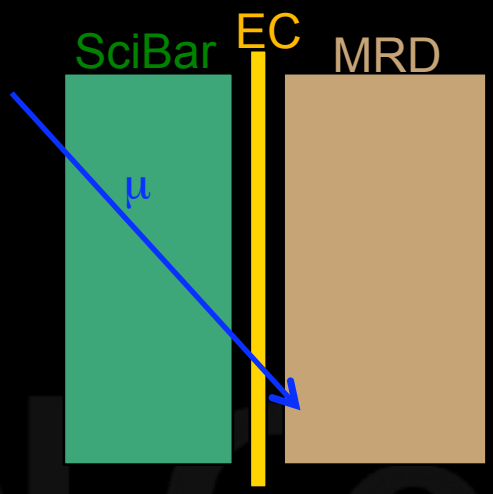
Y. Kurimoto



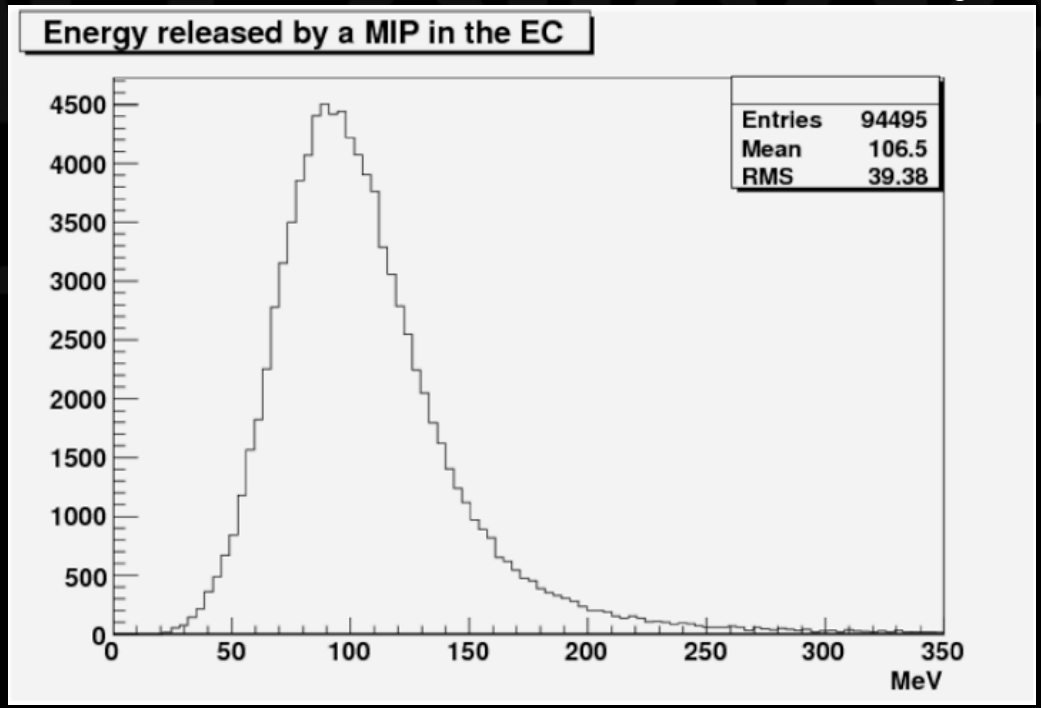


EC's Performance



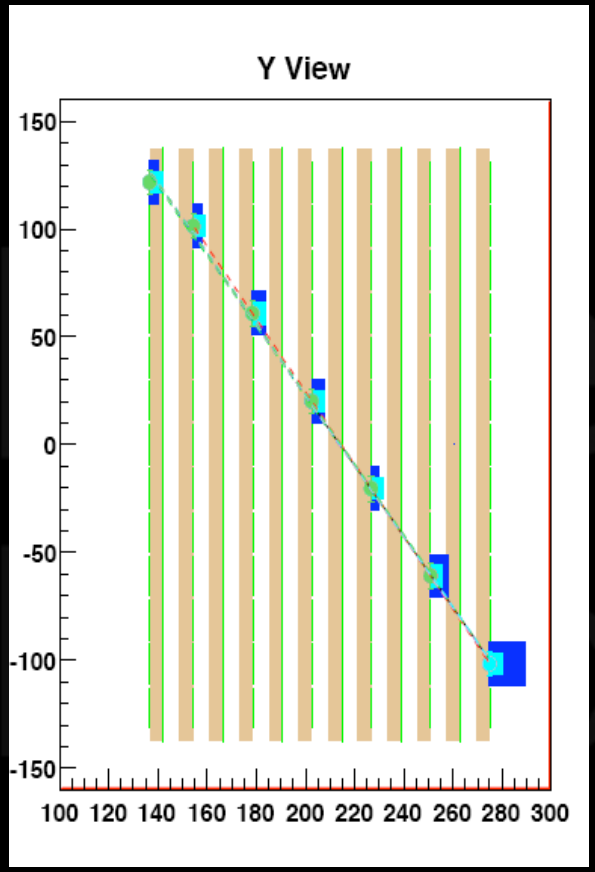


C. Giganti

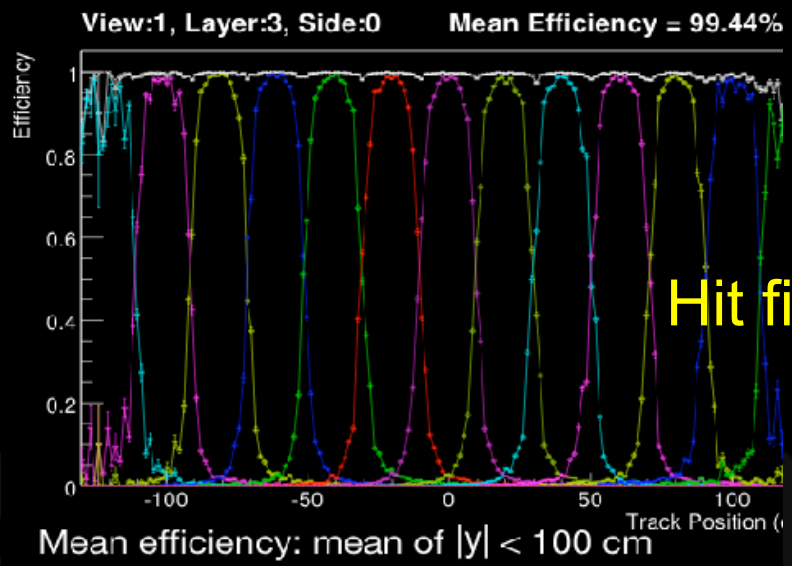


MRD Performance

SciBooNE cosmic data



Y. Nakajima

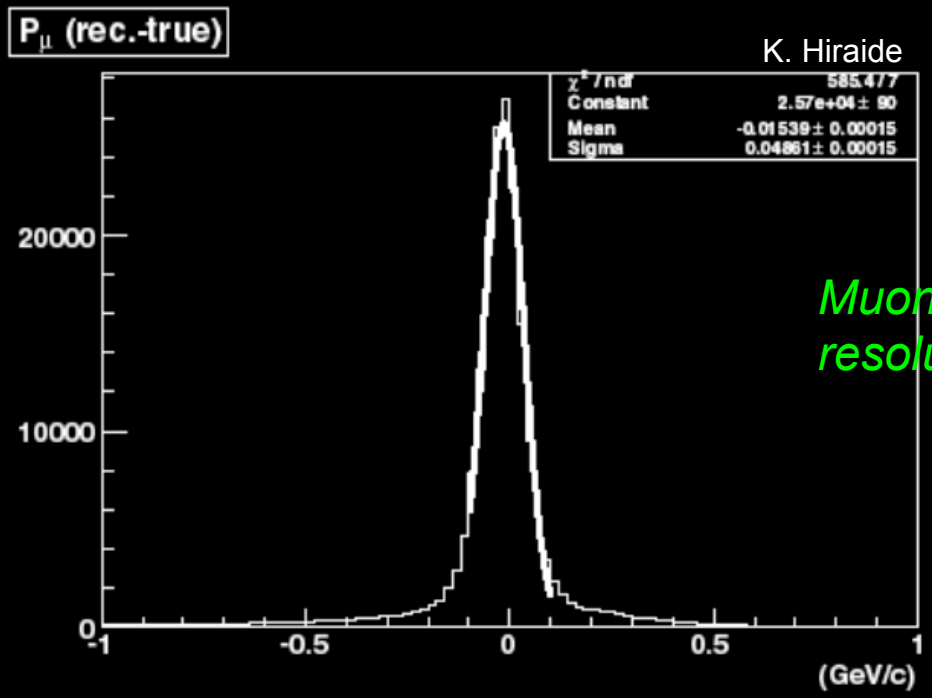


Mean efficiency: mean of |y| < 100 cm

Hit finding efficiency - typical horizontal plane

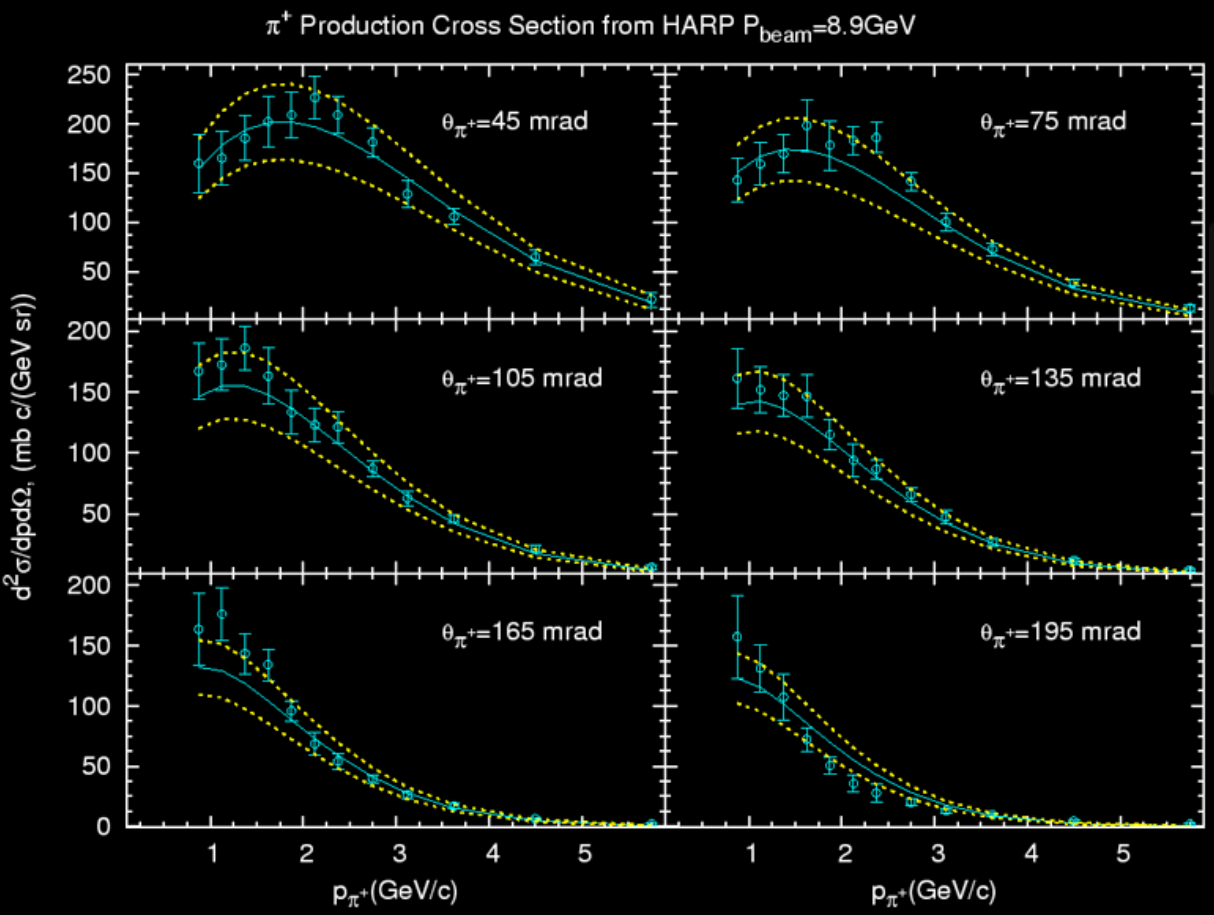
Hit finding efficiency~99%

K. Hiraide



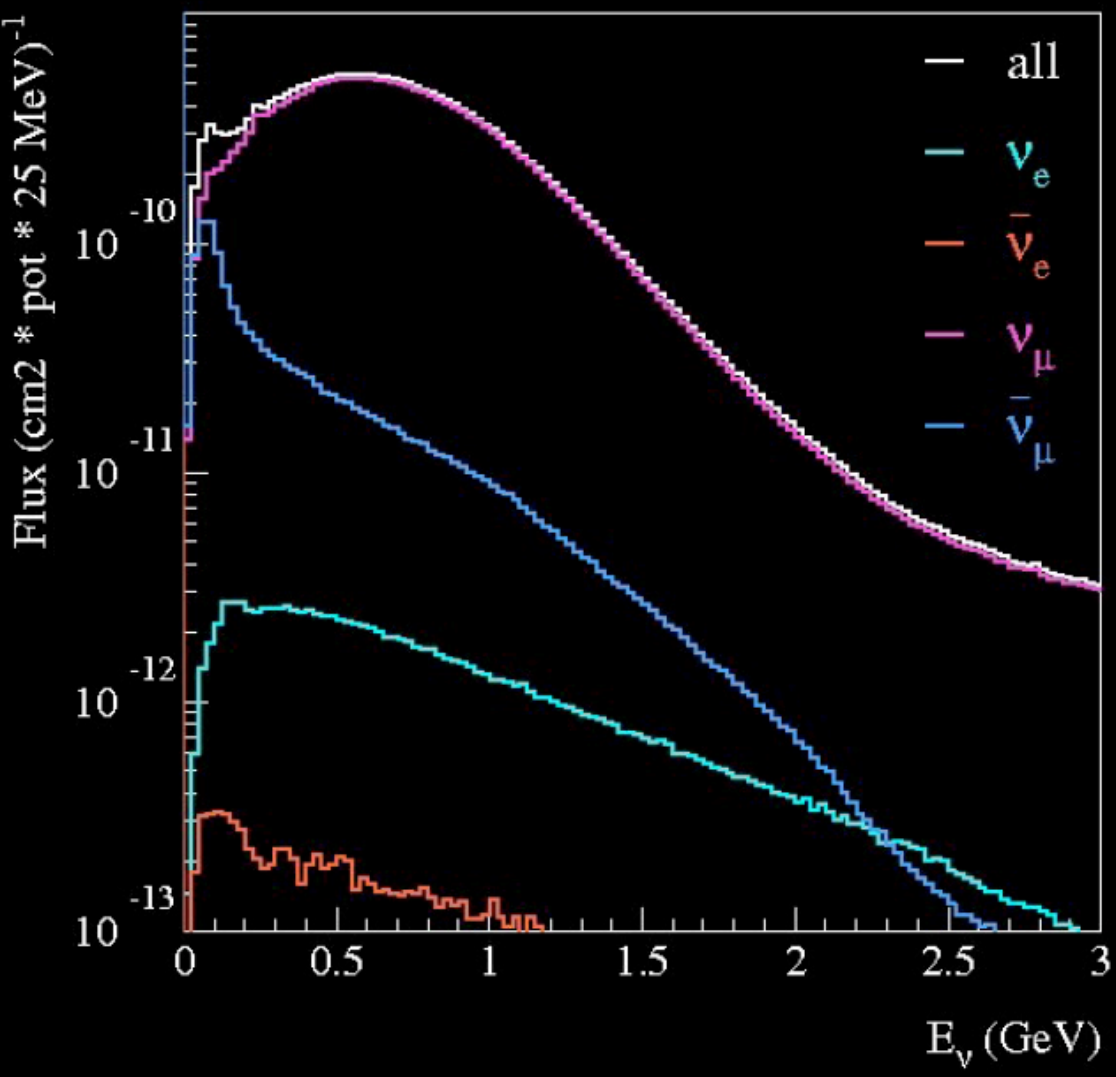
Muon momentum resolution ~50 MeV RMS

Neutrino Flux



- Use external data for meson flux predictions
  - HARP data for pions
  - Feynman scaling model for kaons
- GEANT4 simulation of neutrino decay volume
  - ν and $\bar{\nu}$ fluxes
  - currently ~18% uncertainty
  - expect ~8% uncertainty
- Same as MiniBooNE beam simulation

Neutrino Flux



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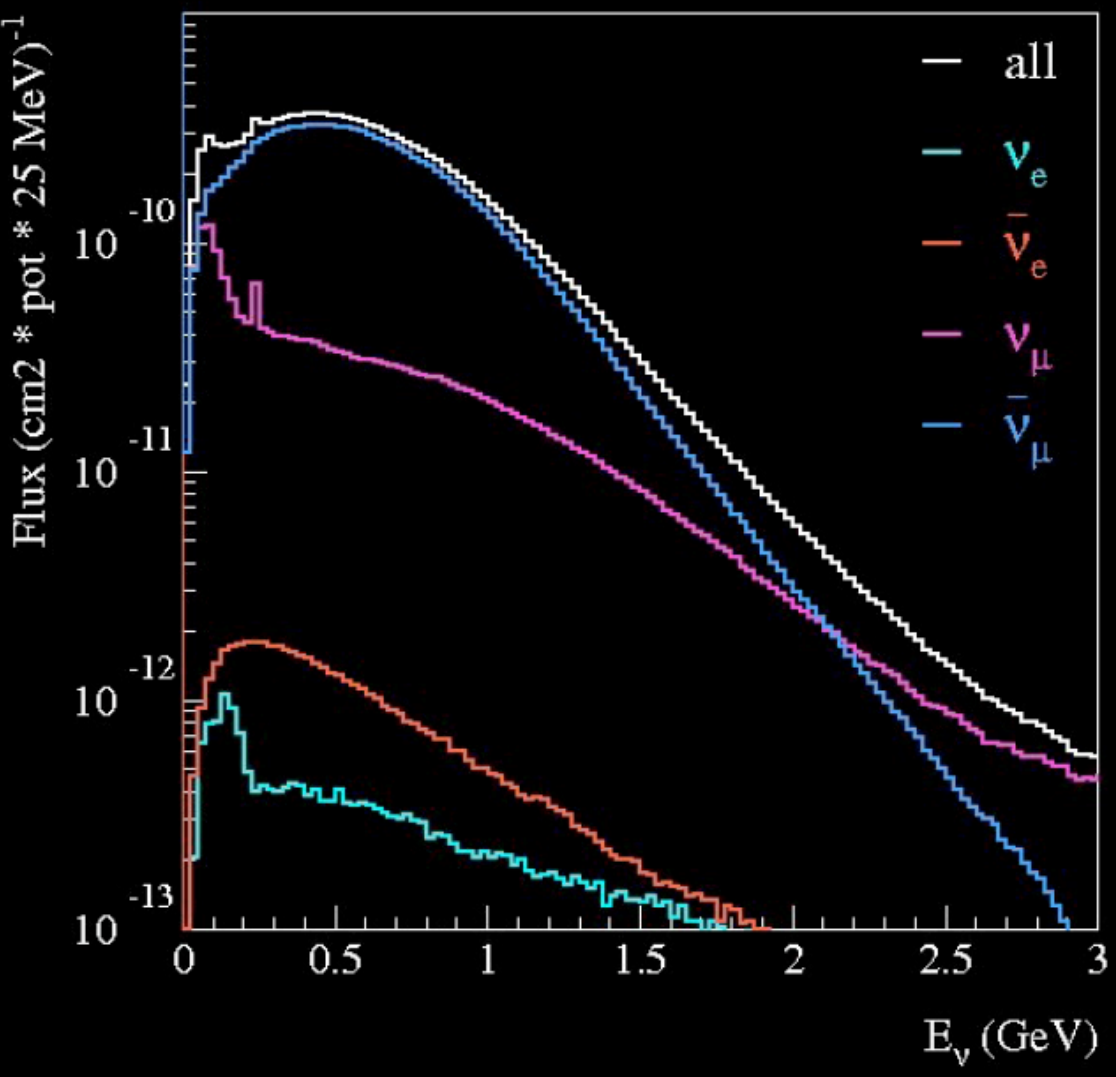

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Event rates

Channel	Number ν_μ
CCQE	39k
NCE	17k
CC1π^+	24k
CCnπ	5k
NC1π^0	9k
Misc	2.1k
NCcohπ	0.8k
CCcohπ	1.2k?
TOTAL	98k

Imperial College London

Event rates

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- (In fiducial mass)

Event rates

Channel	Number $\bar{\nu}_\mu$
CCQE	7.5k
NCE	3k
CC1π^-	2k
CCnπ	0.5k
NC1π^0	1.3k
Misc	1k
NCcohπ	0.3k
CCcohπ	0.5k?
TOTAL	16k

- (In fiducial mass)
- Neutrino mode
  - 1e20 POT
  - Also expect ~800 ν_e events

Imperial College London

Event rates

Channel	Number $\bar{\nu}_\mu$
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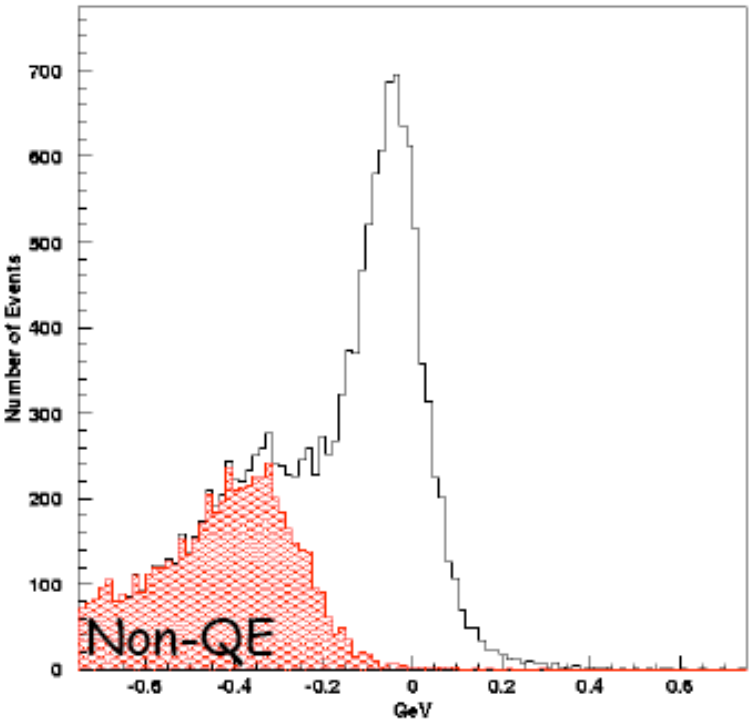
CCcohπ	0.5k?
TOTAL	16k

- (In fiducial mass)
- Neutrino mode
  - 1e20 POT
  - Also expect ~800 ν_e events
- Antineutrino mode
  - 1e20 POT
  - Also expect 8k ν_μ events

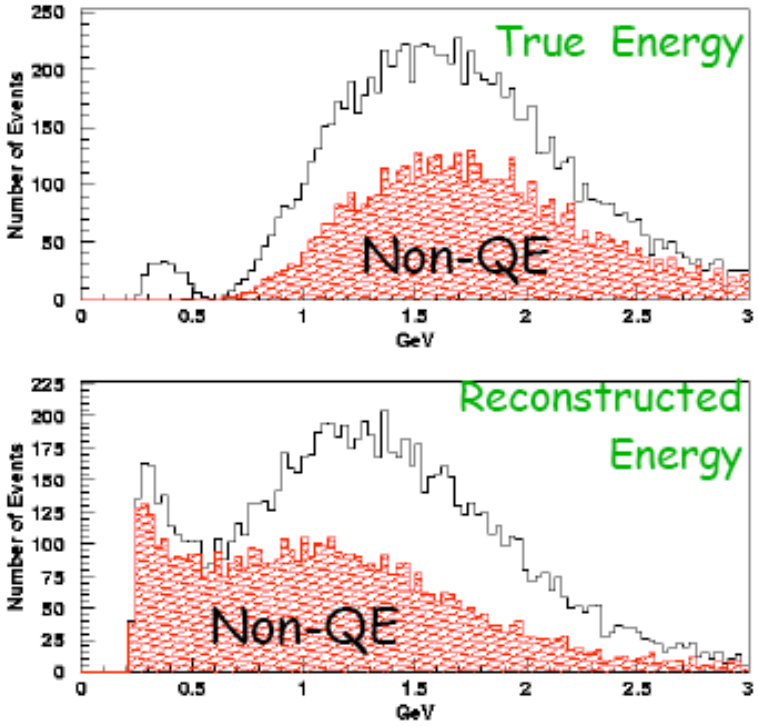
Single π backgrounds

Non-QE interactions and E_ν Reconstruction

Example: K2K Flux MC



True - Reconstructed Energy



Non-QE reconstructs at low-energy in the oscillation dip!

C. Walter (Duke), NuInt07

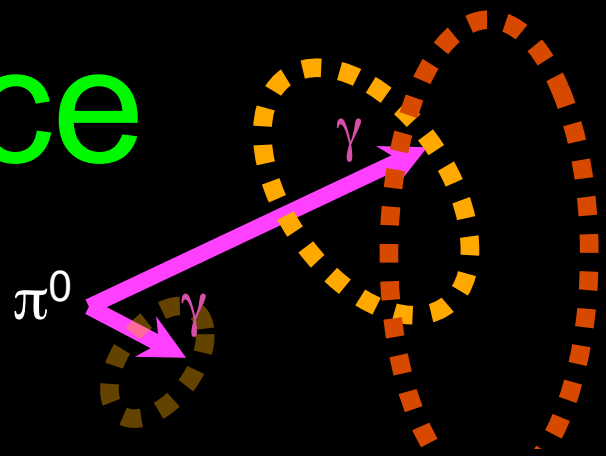
Search for θ_{13}: ν_e appearance

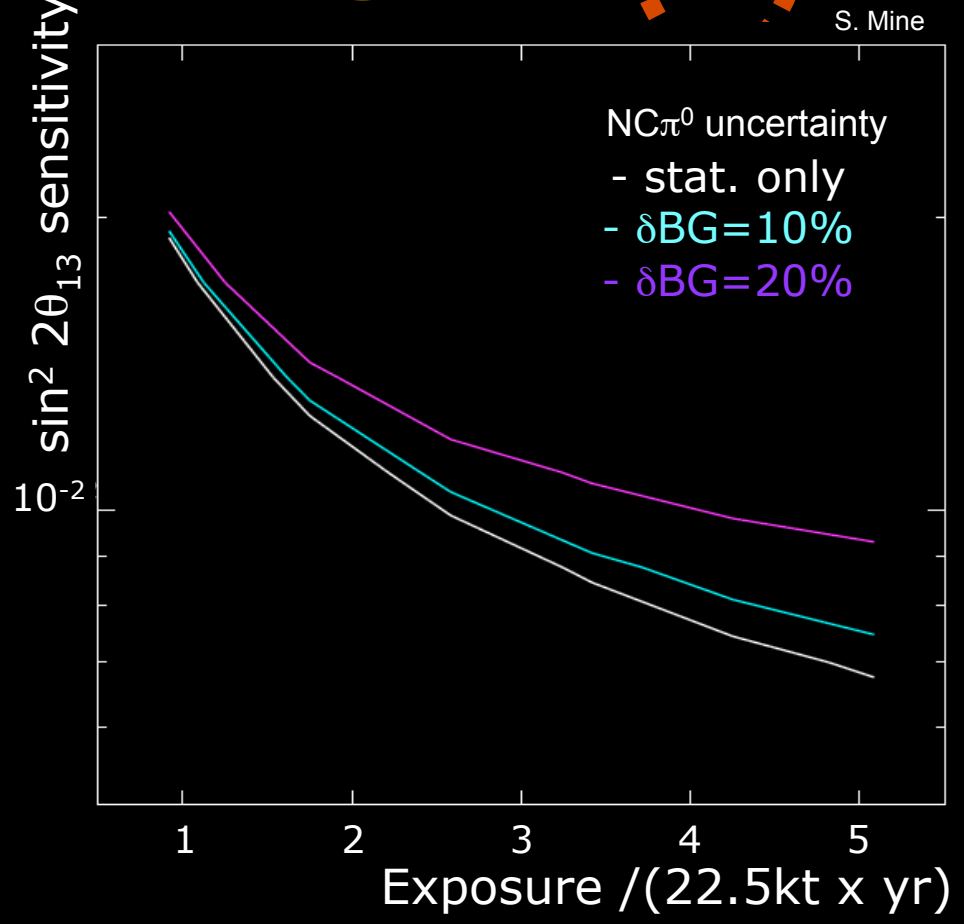
- Subdominant oscillation

  $\sin^2 2\theta_{\mu e} \sim \sin^2\theta_{23} \cdot \sin^2 2\theta_{13}$

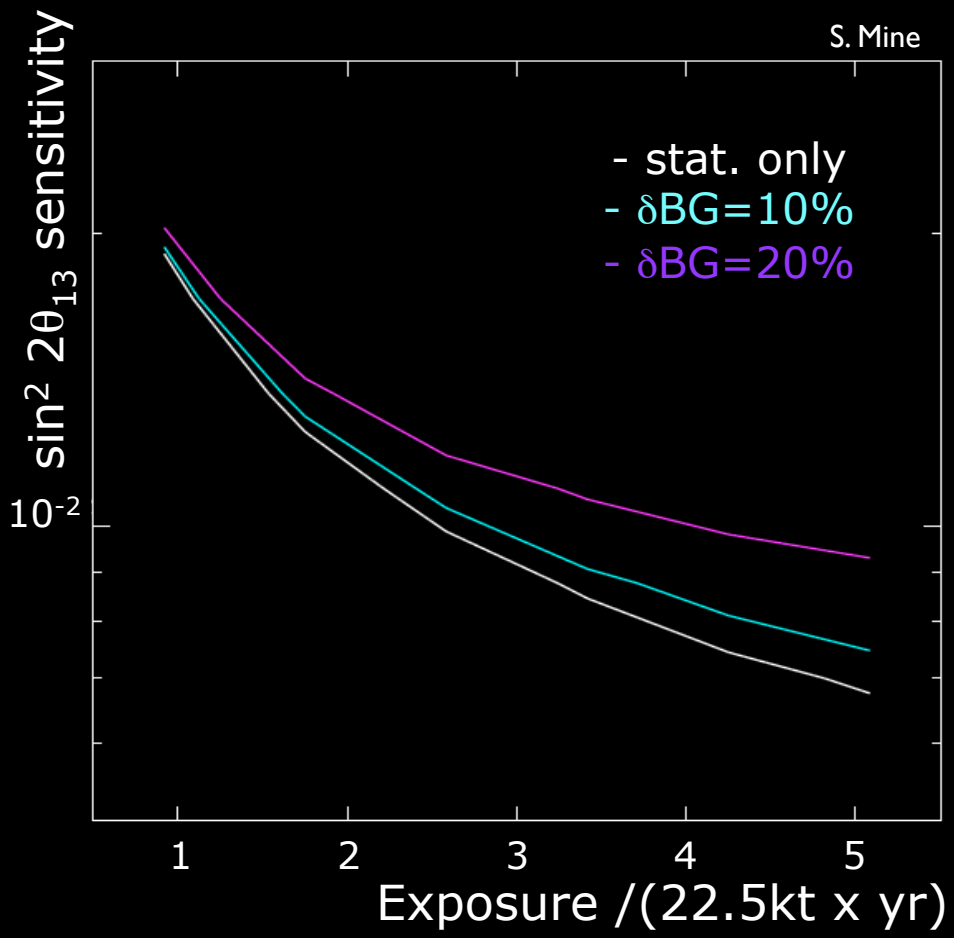
  Need good measurement of θ_{23}

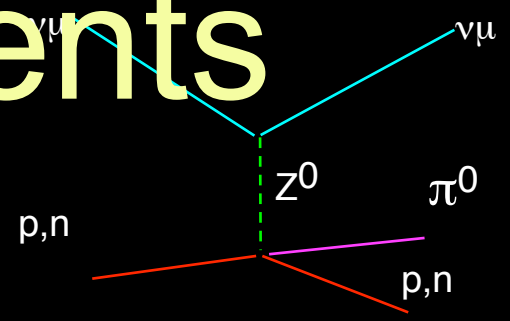
- Major background from NCπ^0 events
  - γ rings mimic e rings in Super-K
- Must reduce uncertainty on NCπ^0 cross section





Need for σ_ν Measurements





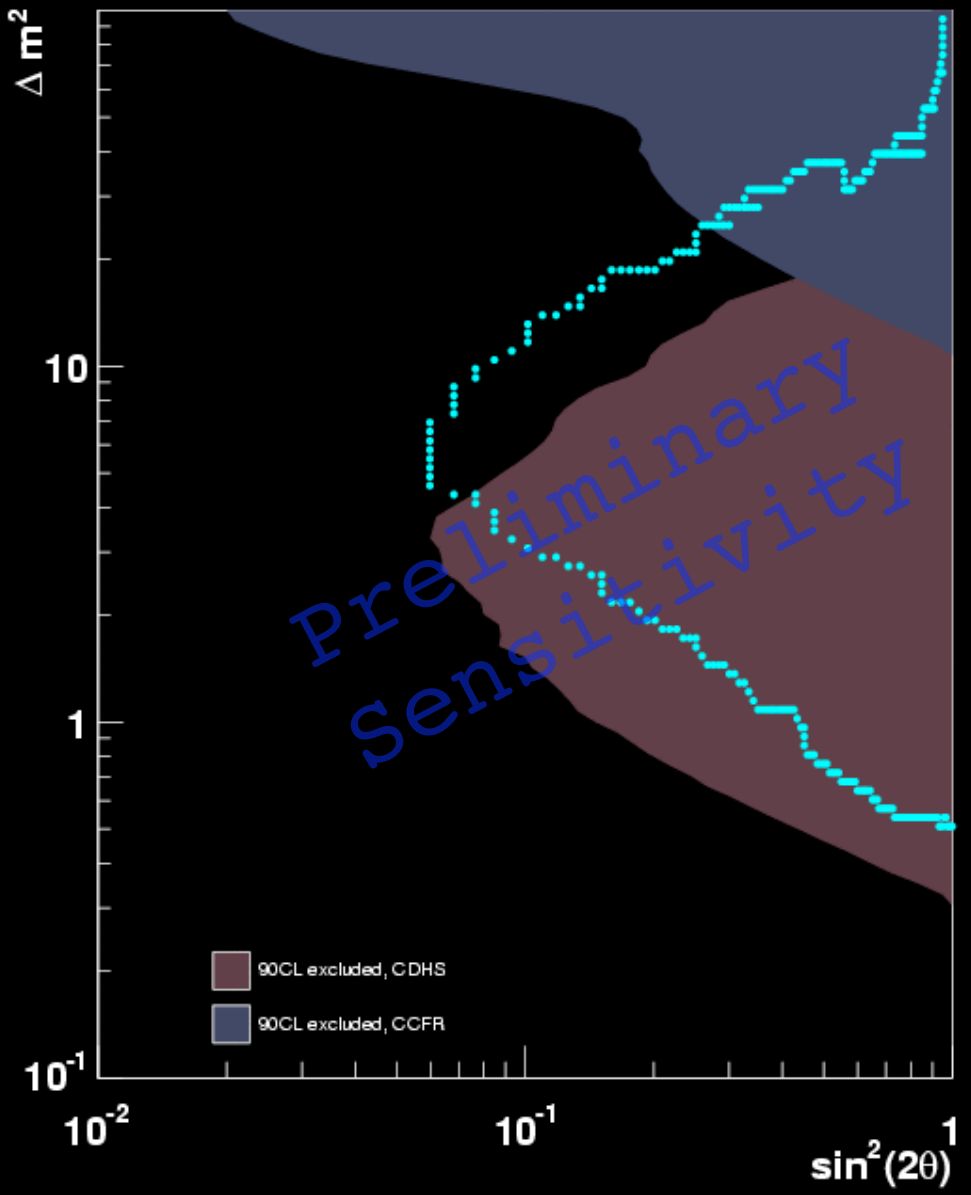
- Want to reduce uncertainty in σ(NCπ^0) from 20% to 10%
  - improvement of factor of 2 in ultimate T2K sensitivity to θ_{13}
  - or 2.5 years vs. 4 years to 10^{-2}

ν_μ disappearance

- With one detector, compare Eν data to MC and look for shape distortions
- MiniBooNE alone has significant reach in sensitivity

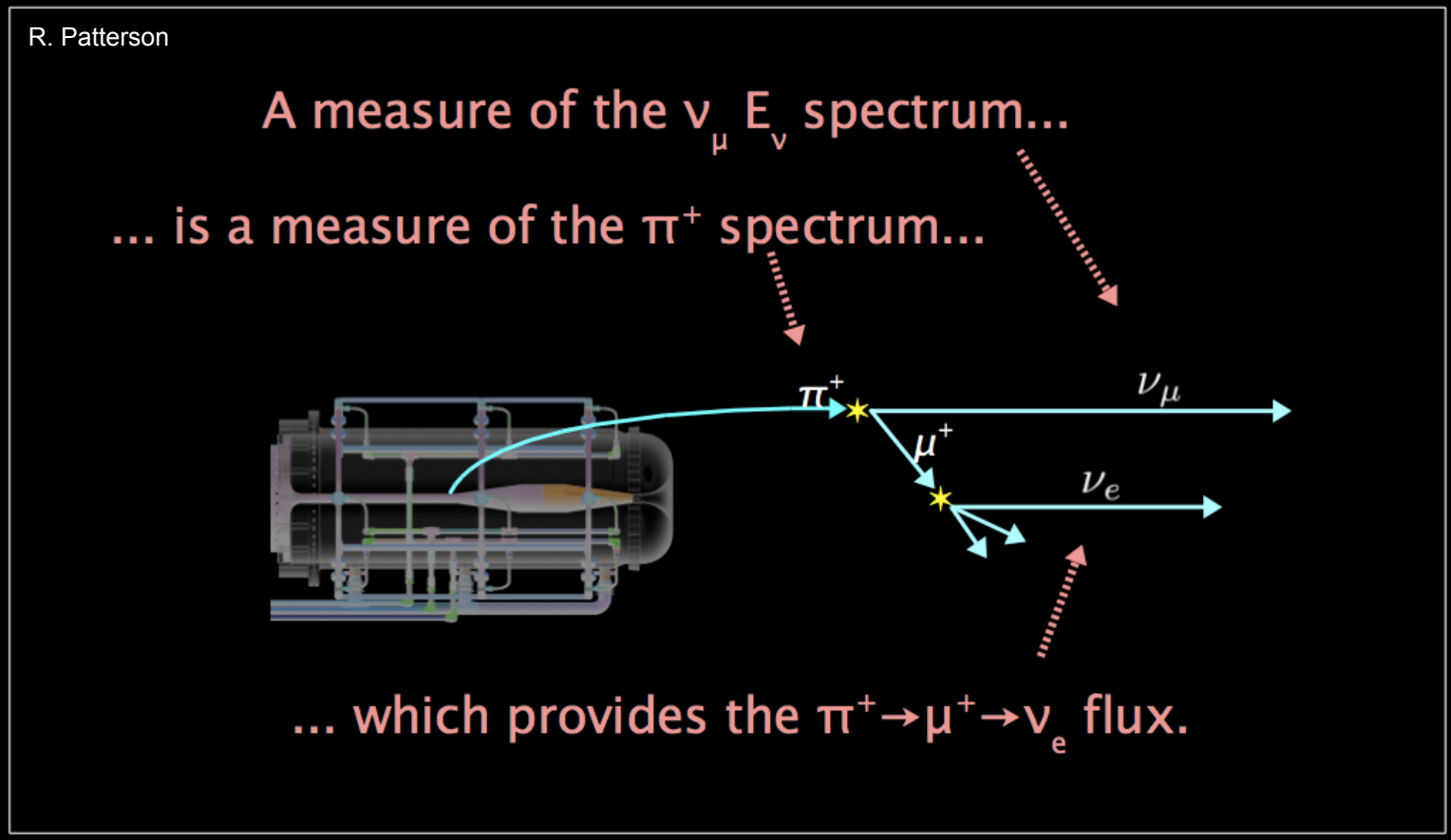
Results coming soon!

K. Mahn



Imperia
Londor

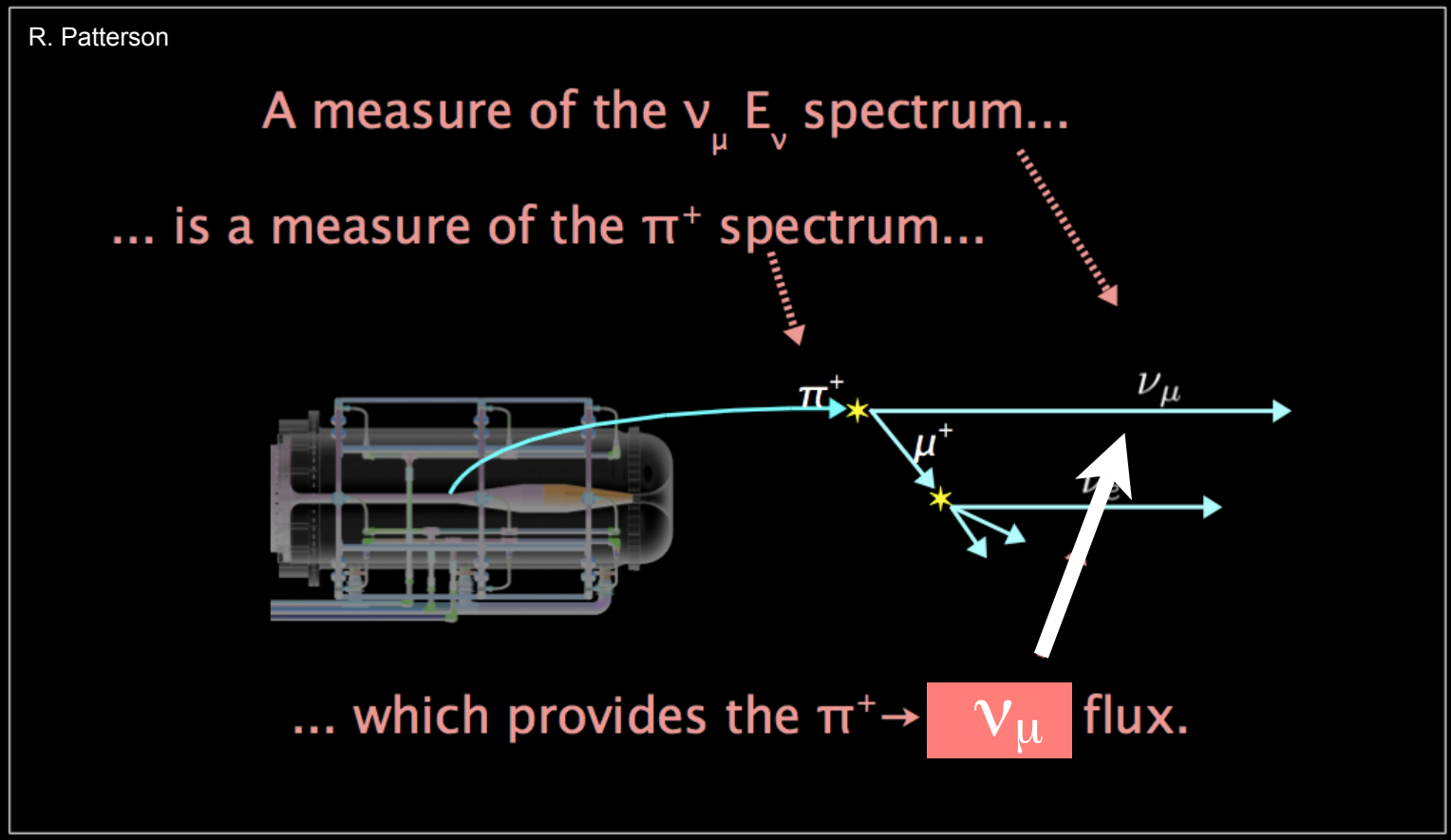
Joint ν_μ disappearance



SciBooNE provides constraint on π^+ parents of ν_μ events in MiniBooNE *with same nuclear target*

results later this year

Joint ν_μ disappearance

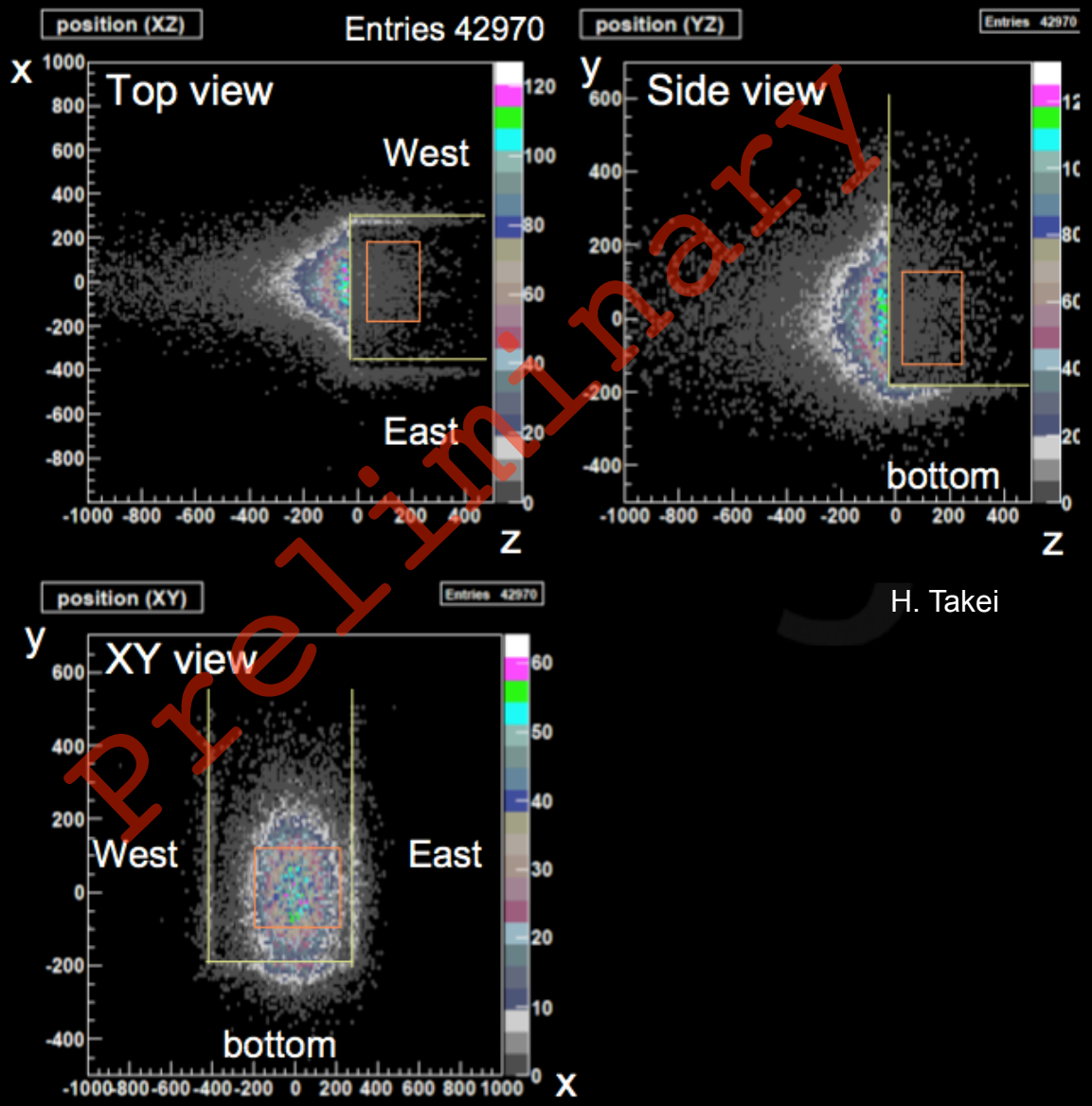


SciBooNE provides constraint on π^+ parents of ν_μ events in MiniBooNE *with same nuclear target*

results later this year

Dirt backgrounds

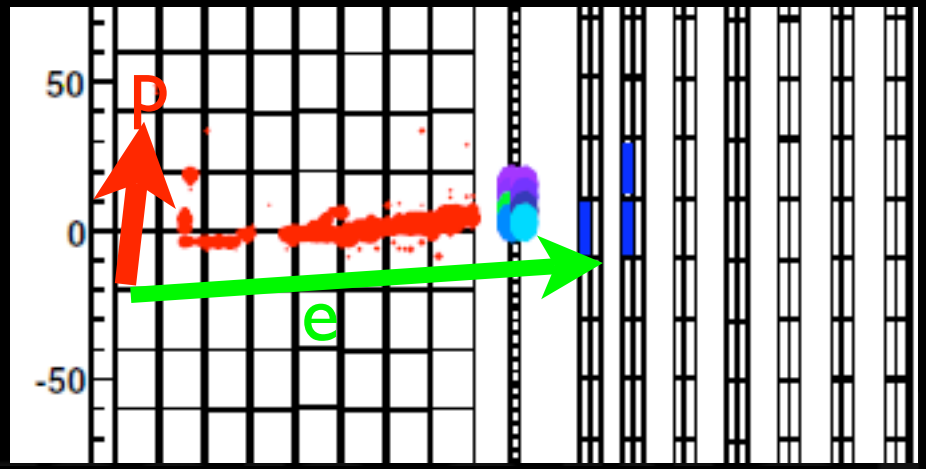
- Neutrinos interact in surrounding materials
- Hits in both views
- >1 hit with >10 PE
- Area of active investigation

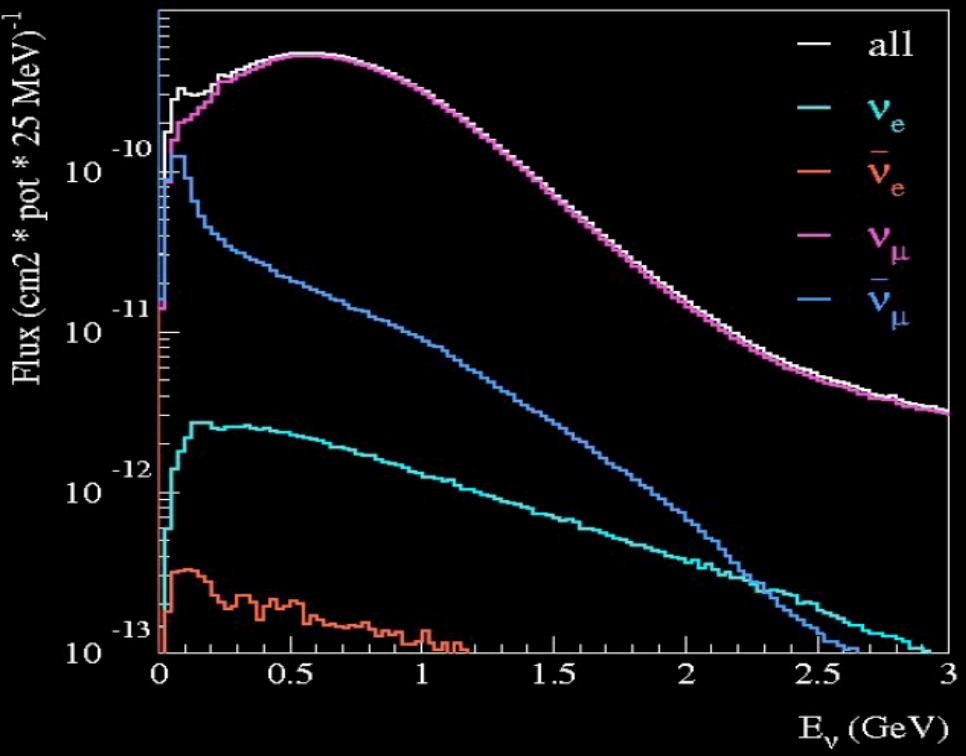


H. Takei

ν_e from K^+ decays

SciBooNE data





- SciBar/EC events have good acceptance for high energy νe events
  - mainly from K+ decay
- Expect to measure rate with ~17% uncertainty in SciBooNE
- Improve MiniBooNE constraint (32%)

Results later this year