Measurement of Charged Pion Absorption and Charge Exchange Cross Sections: DUET Experiment

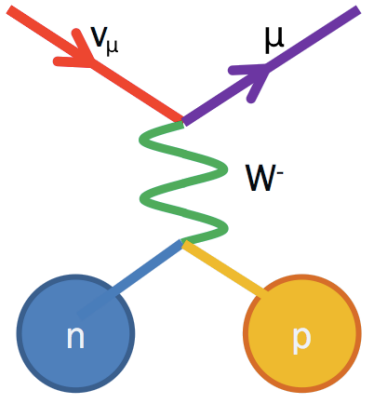
Elder Pinzon

for DUET Collaboration

Kyoto University, TRIUMF,
UBC, University of Tokyo,
University of Toronto,
York University

Pions in ν Interactions

- Neutrino flavour and energy determined from flavour and momentum of outgoing lepton

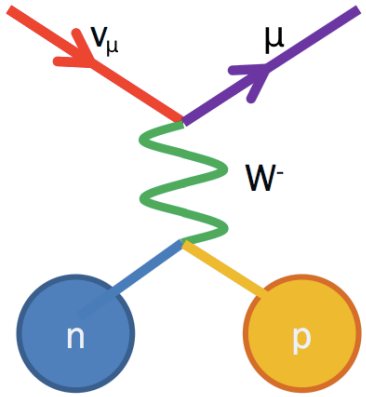


CCQE Interaction.
Signal event

Use two-body decay kinematics to reconstruct neutrino energy

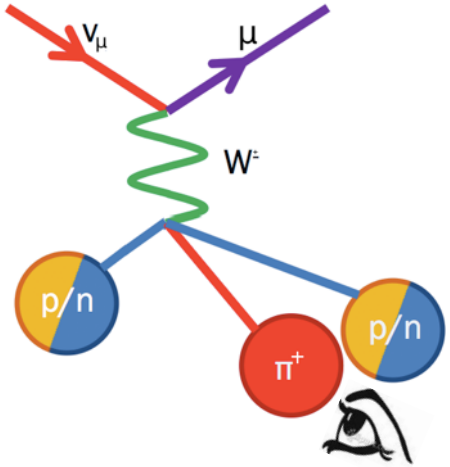
Pions in ν Interactions

- Neutrino flavour and energy determined from flavour and momentum of outgoing lepton



CCQE Interaction.
Signal event

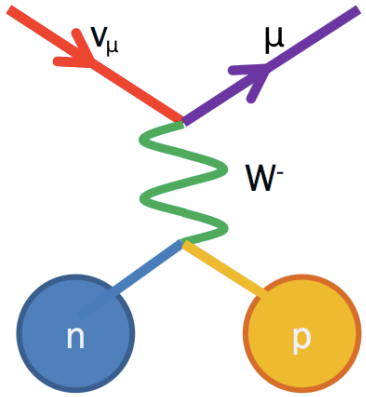
Use two-body decay kinematics to reconstruct neutrino energy



CC1π Interaction.
Background

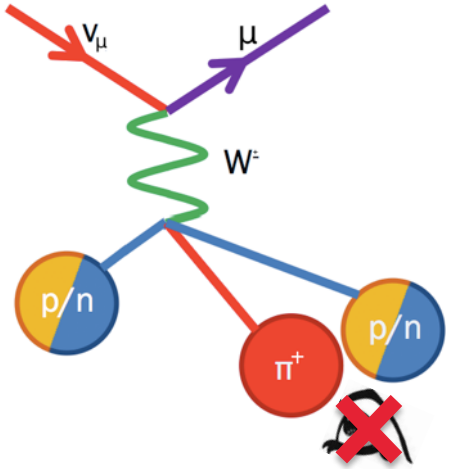
Pions in ν Interactions

- Neutrino flavour and energy determined from flavour and momentum of outgoing lepton



CCQE Interaction.
Signal event

Use two-body decay kinematics to reconstruct neutrino energy

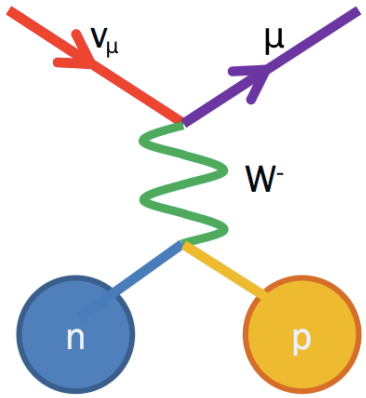


CC1π Interaction.
Background

Unidentified pion leads to wrong reconstructed energy

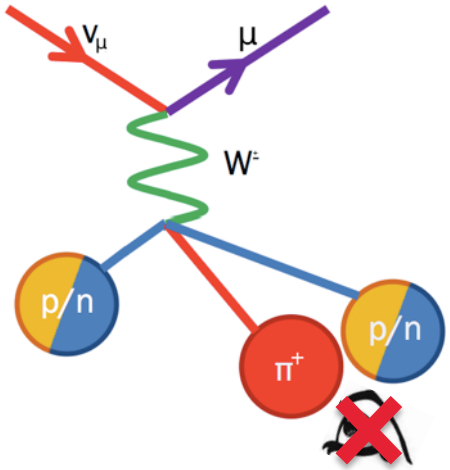
Pions in ν Interactions

- Neutrino flavour and energy determined from flavour and momentum of outgoing lepton



CCQE Interaction.
Signal event

Use two-body decay kinematics to reconstruct neutrino energy



CC1π Interaction.
Background

Unidentified pion leads to wrong reconstructed energy

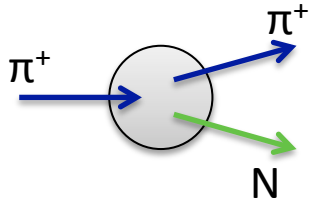
Pion Interactions are very important for ν experiments

↓

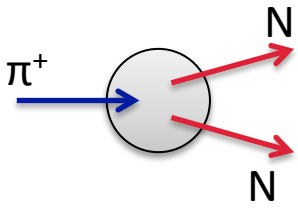
Measure cross sections!

Pion Interaction modes

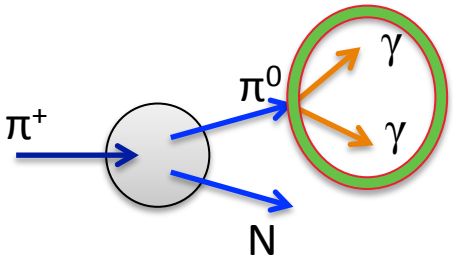
1. Scattering



2. Absorption (Abs)



3. Charge Exchange (CX)

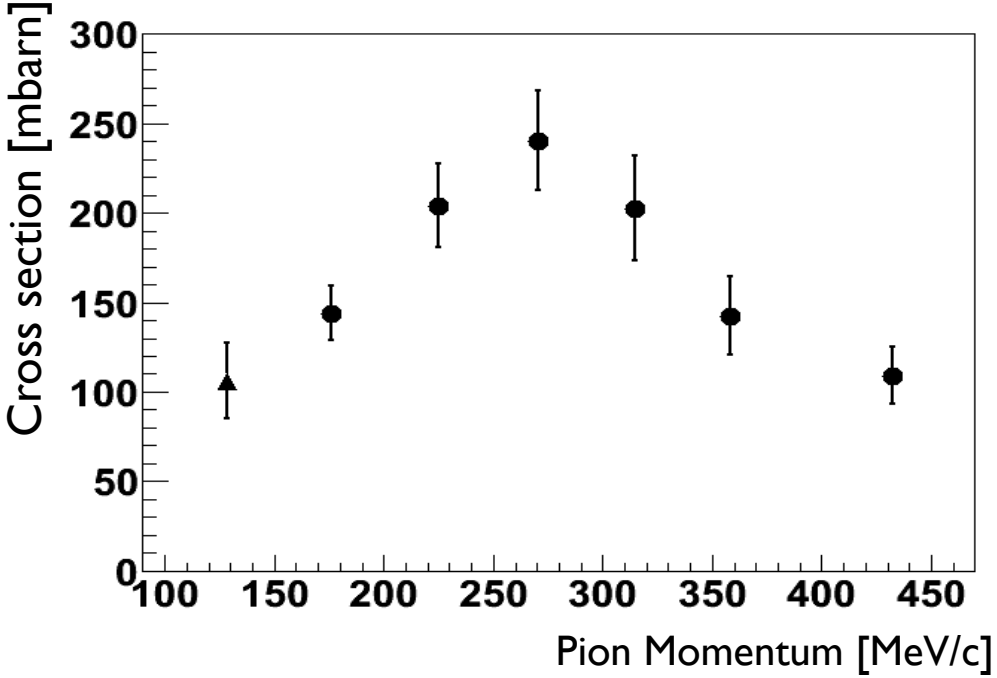


No pion in final state

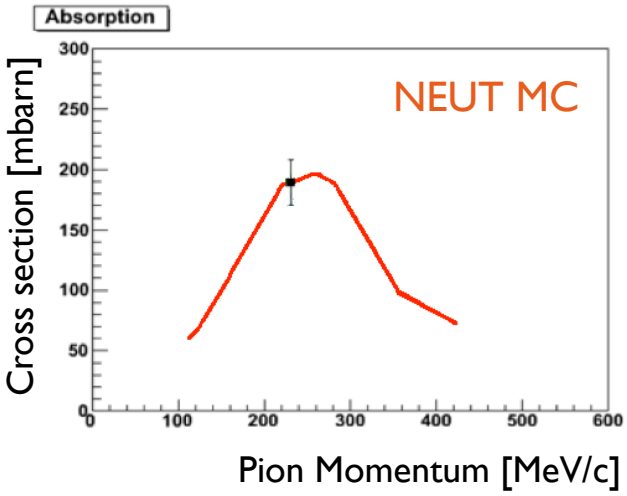
Previous experiments

Ashery et al., Phys. Rev. C23, 2173 (1981)
Bellotti et al., Nuovo Cimento 14A, 567 (1973)
Jones et al., Phys. Rev. C48 2800 (1993)
Navon et al., Phys. Rev. C28, 2548 (1983)

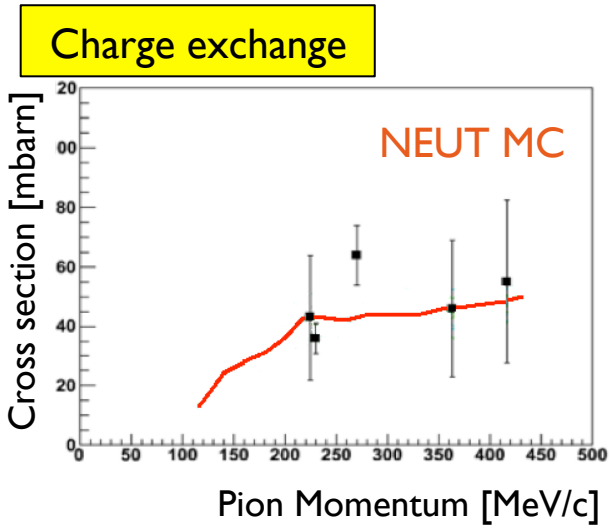
Absorption + Change exchange



Absorption

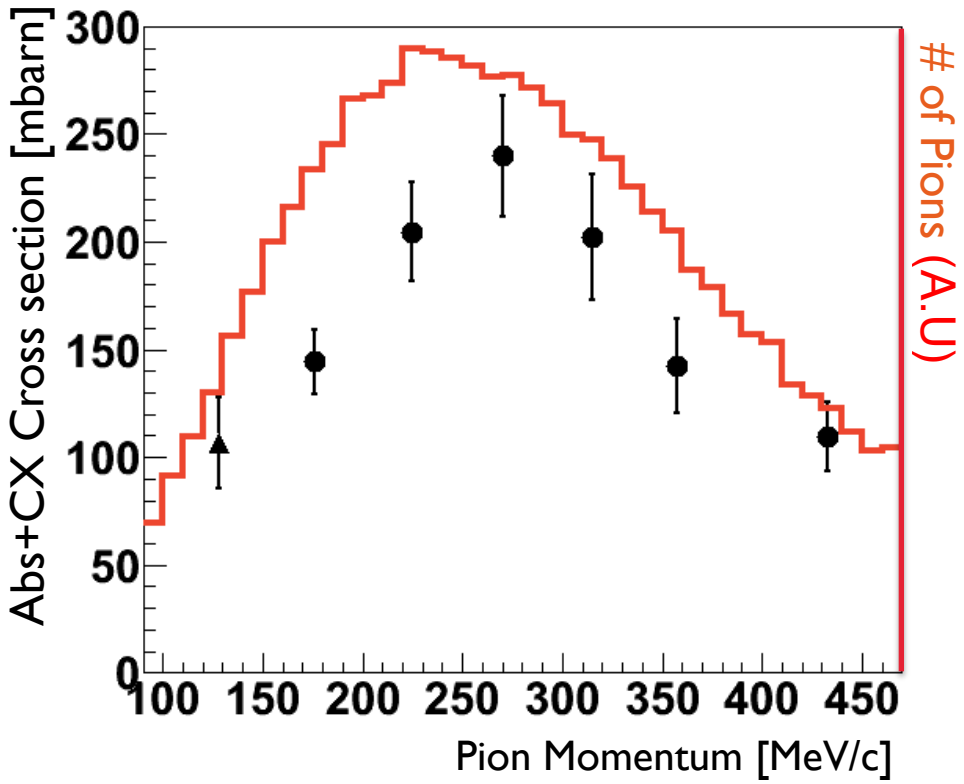


Charge exchange



DUET Experiment

Pion momentum spectrum for T2K ν interactions



Very relevant processes for pions in ν experiments

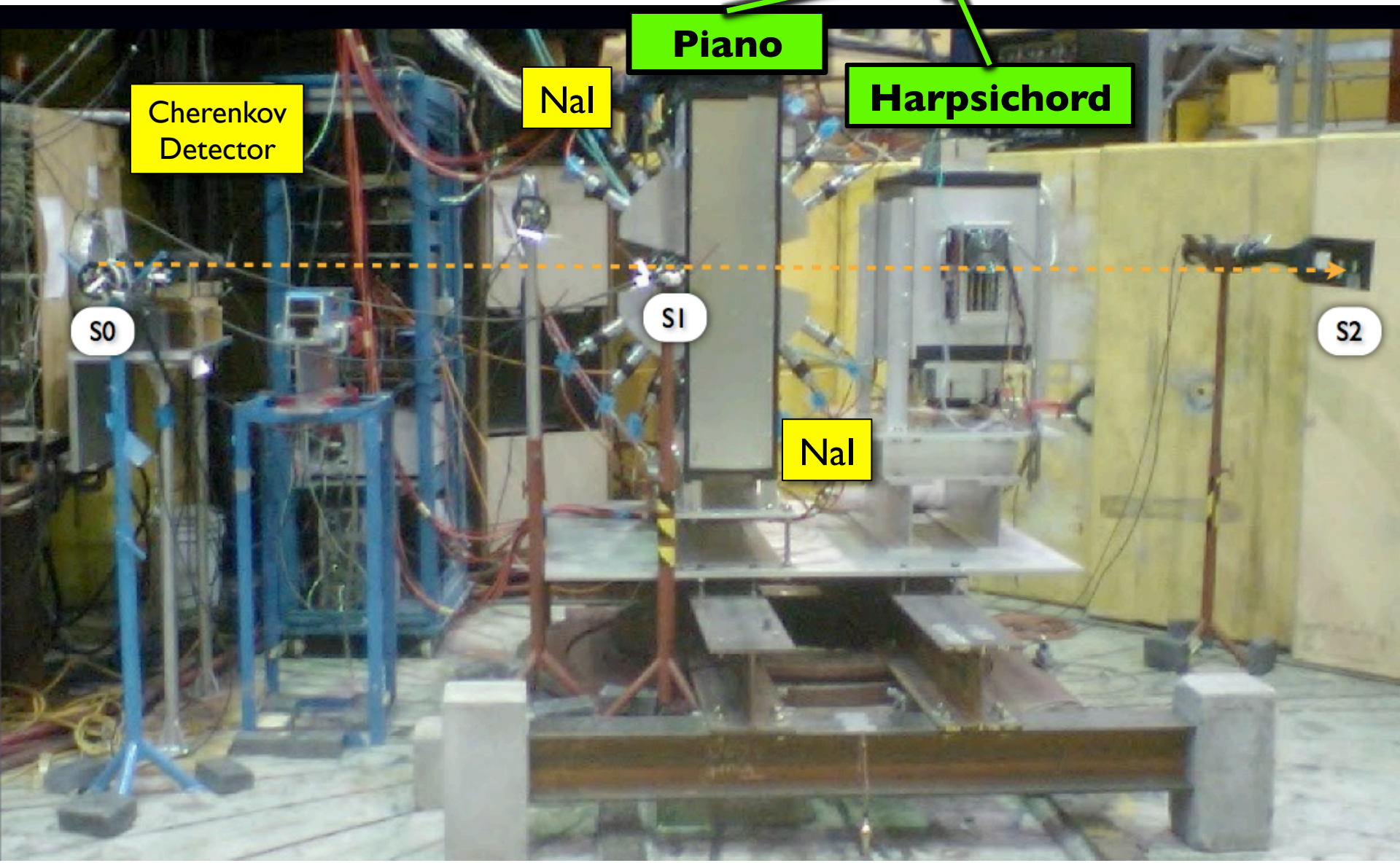
GOAL:

Measure pion absorption with ~10% accuracy and charge exchange with ~20% accuracy

Use TRIUMF secondary beam line

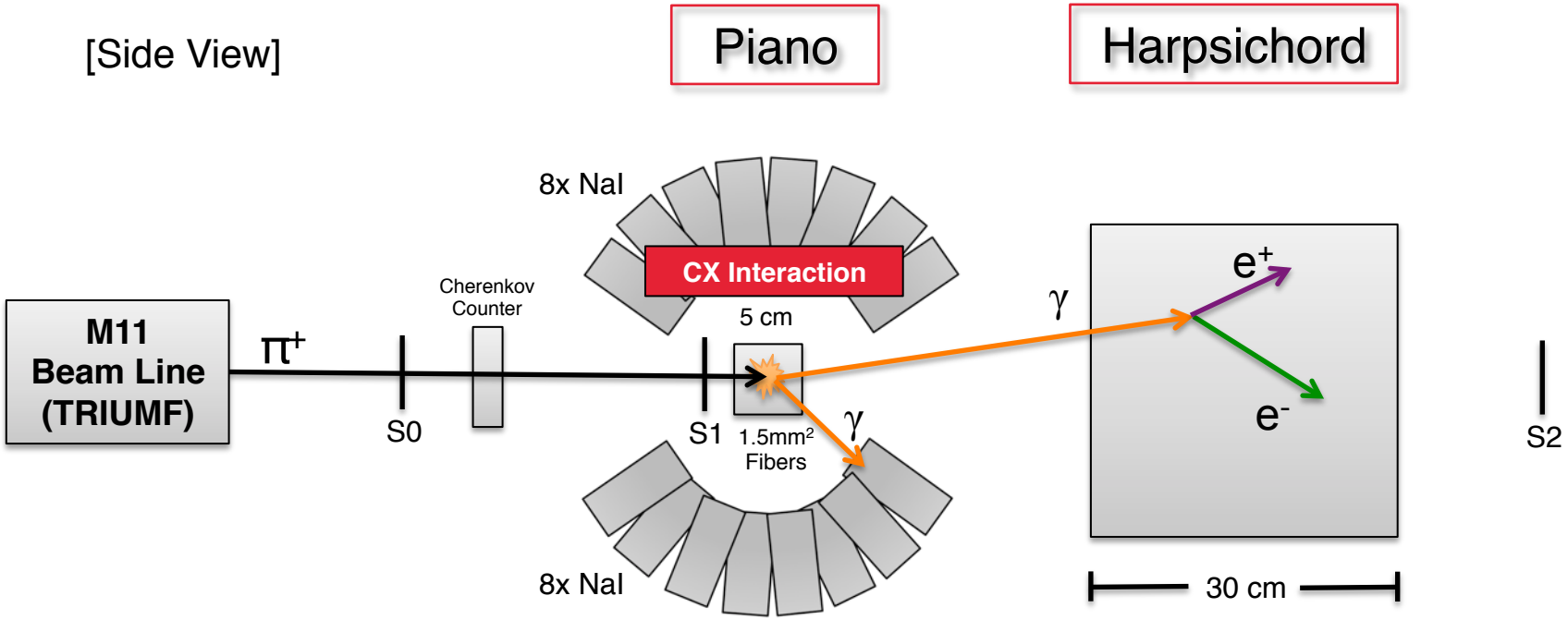
YORK UNIVERSITÉ UNIVERSITY

Detector setup: DUET



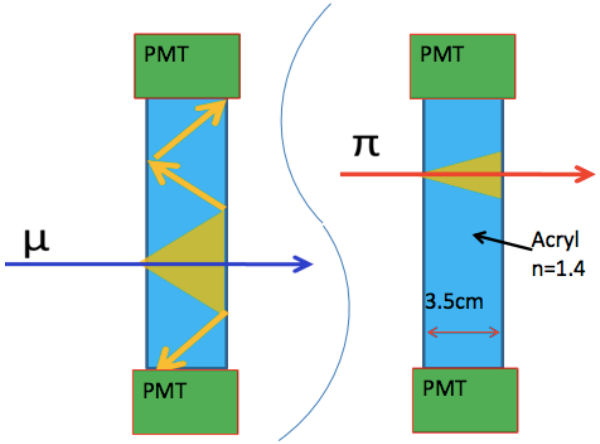
Detector setup: DUET

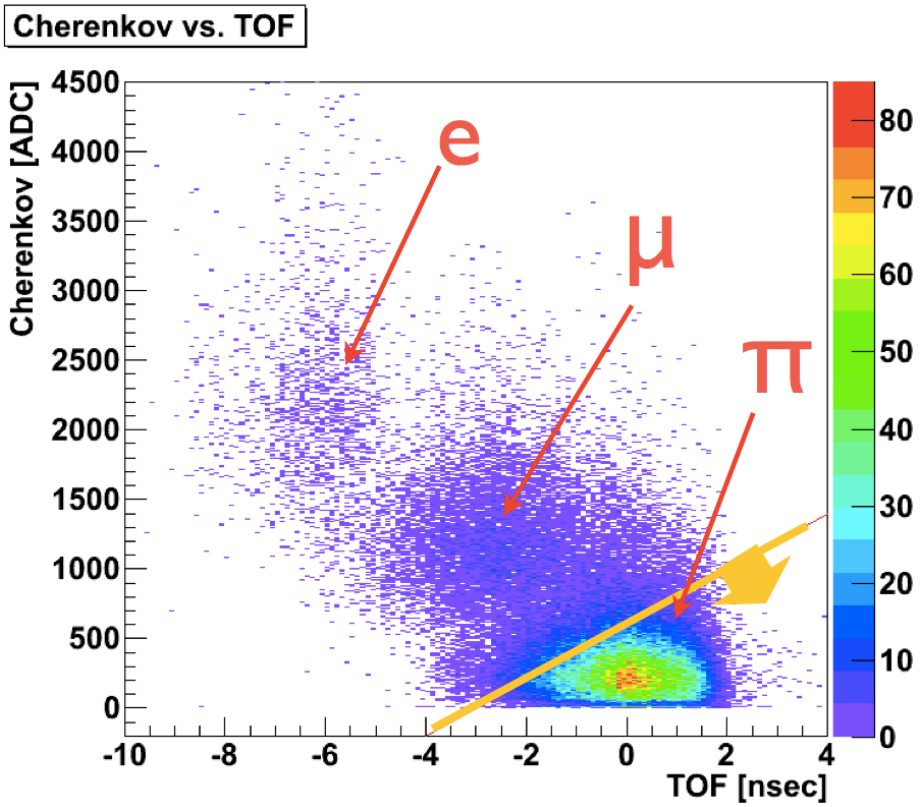
- Main Components:
  - **Piano**: Scintillating fibers and NaI detectors
  - **Harpsichord**: **Miniature Fine Grained Detector for T2K**
    (Scintillating bars + Lead layers)



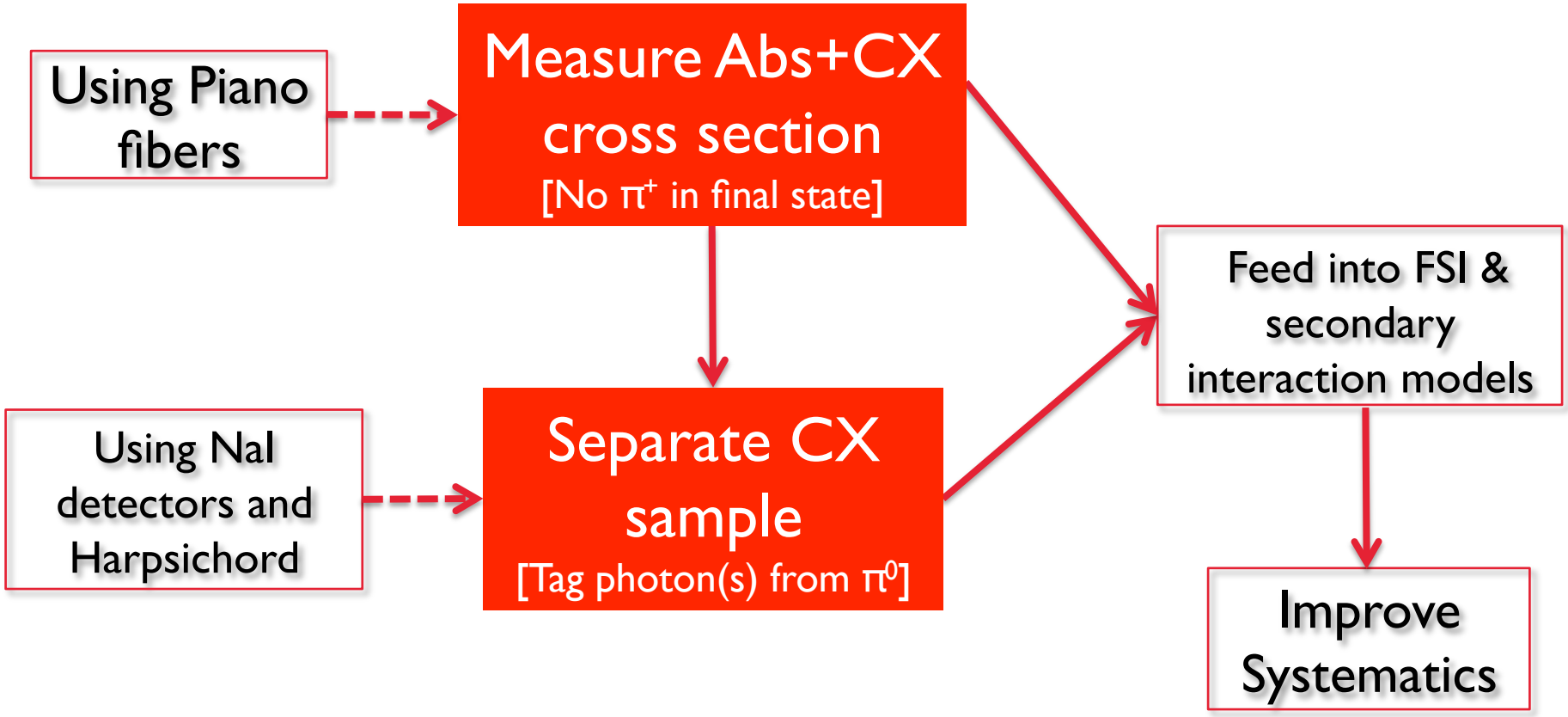
TRIUMF Beam line

- Secondary beam line with momentum tunable in the range from 150 MeV/c to 375MeV/c delivering e, μ and π.
- Beam PID from Time Of Flight (TOF) counters.
- Above 250 MeV/c use Cherenkov detector to select pions.



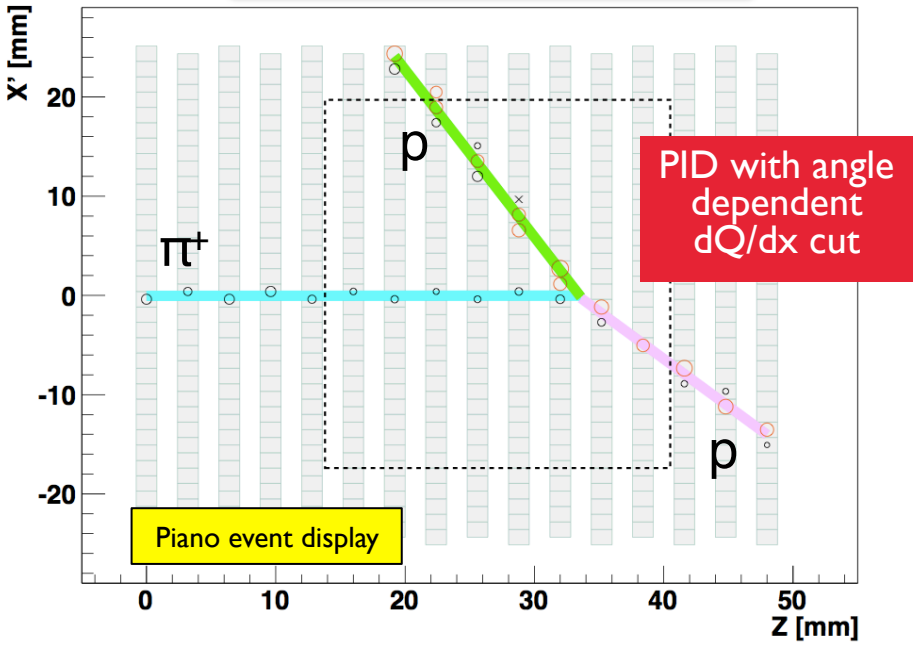


Analysis Outline



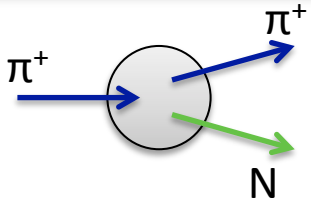
Event Selection: No π^+ in final state

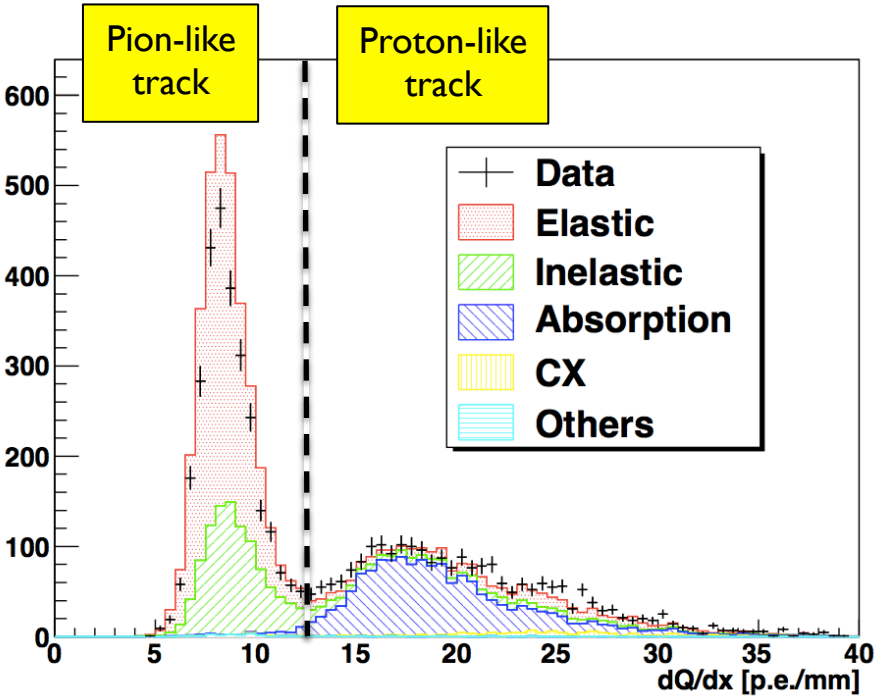
Vertex inside Piano's Fiducial Volume



Pion absorption interaction in **Piano**

Reject:

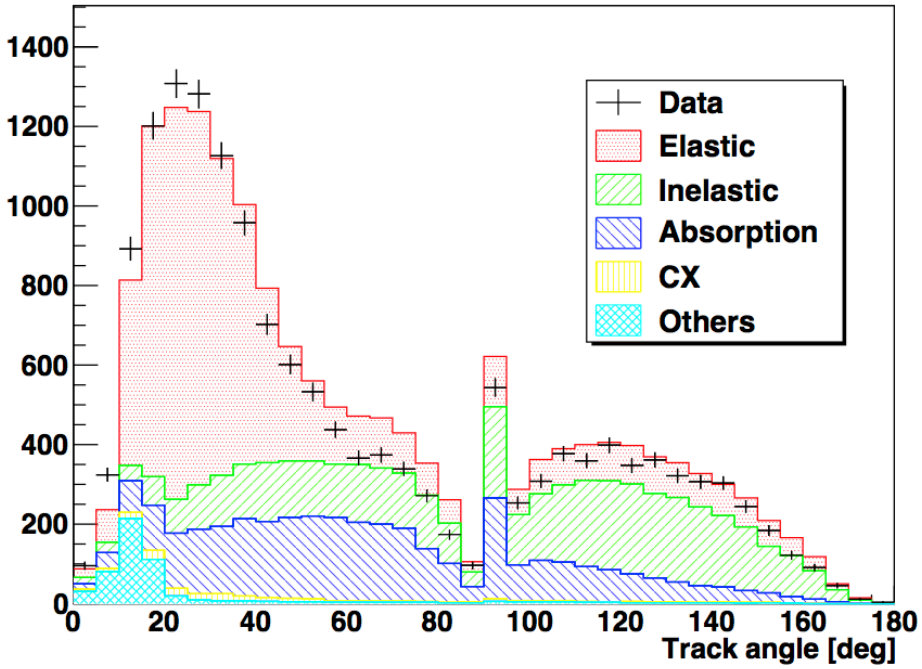




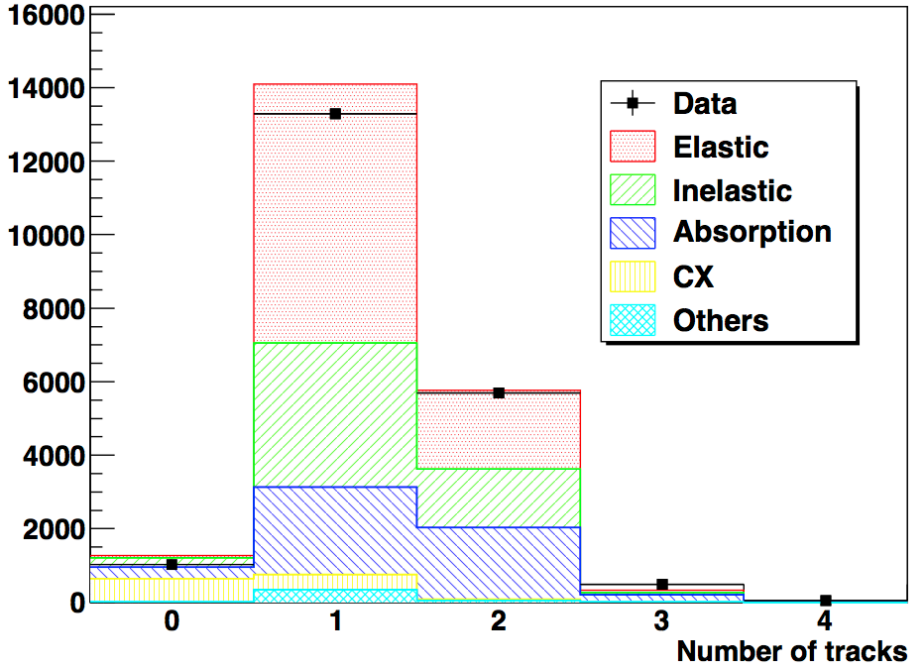
Example of dQ/dx distribution

Event Selection: Data/MC comparisons

- Distributions before applying the "no π^+ in final state" cut:
- Good agreement between Data and MC.



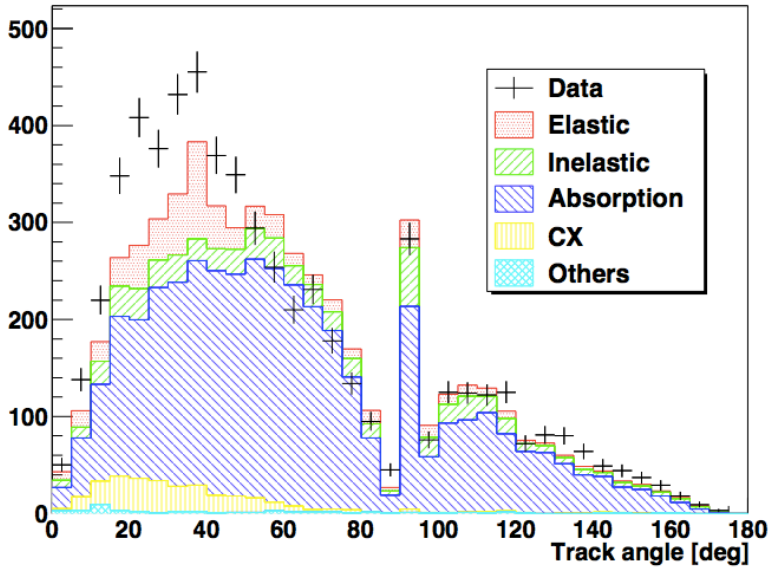
Angular distribution of reconstructed tracks



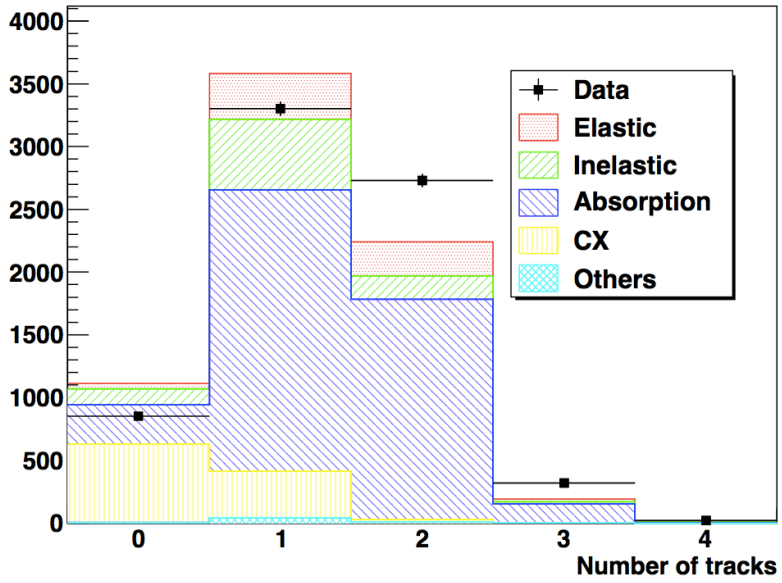
Distribution of number of reconstructed tracks in the final state

Event Selection: Data/MC comparisons

- For 238MeV/c π^+ data set, the efficiency is 79.8% and the purity is 76.8%.
- ~7000 events selected on each momentum data set after all cuts are applied.
- Agreement becomes worse.



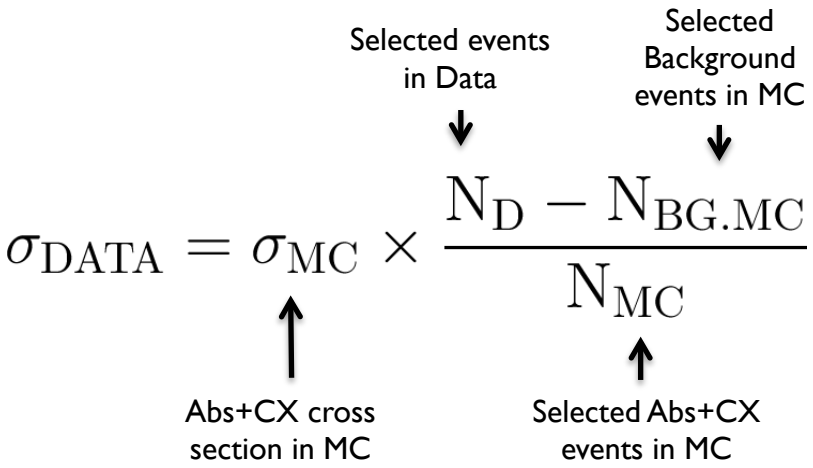
Angular distribution of the proton-like track



Distribution of number of reconstructed tracks in the final state

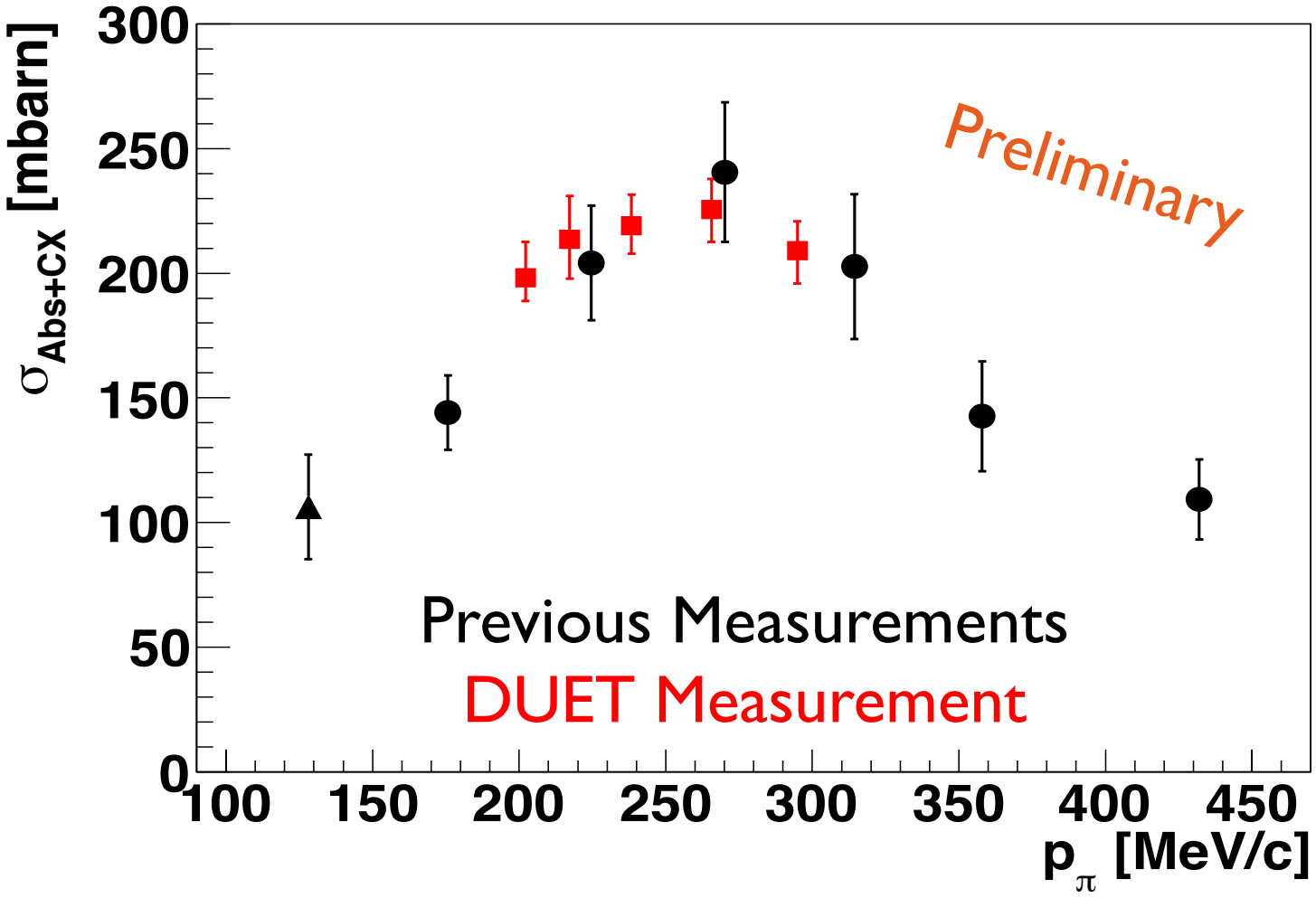
Abs+CX Cross section

- We calculate the Abs+CX cross section using this formula:



- All systematic errors have been evaluated.
- Corrections for interactions in other nuclei (O, Ti) are also applied.

Abs+CX Cross Section Result



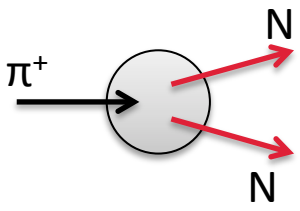
Good agreement and much smaller errors

YORK UNIVERSITÉ UNIVERSITY

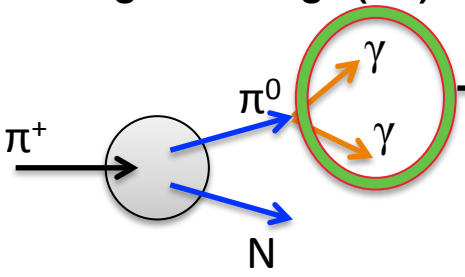
Extracting the Charge Exchange cross section using Harpsichord

REJECT NUCLEONS

2. Absorption (Abs)

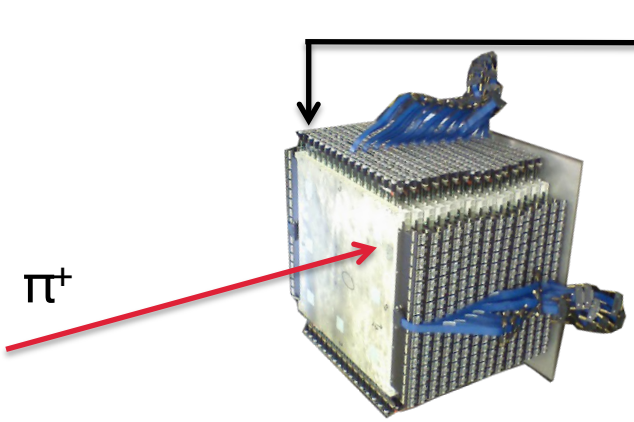


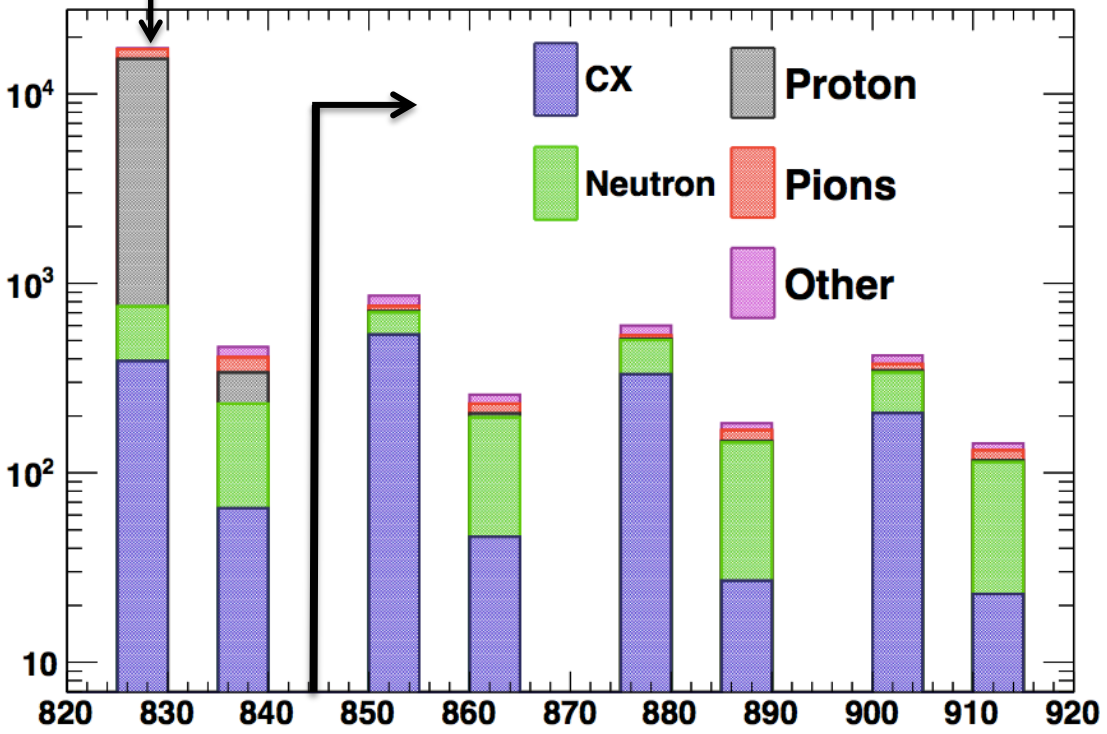
3. Charge Exchange (CX)



TAG PHOTON!

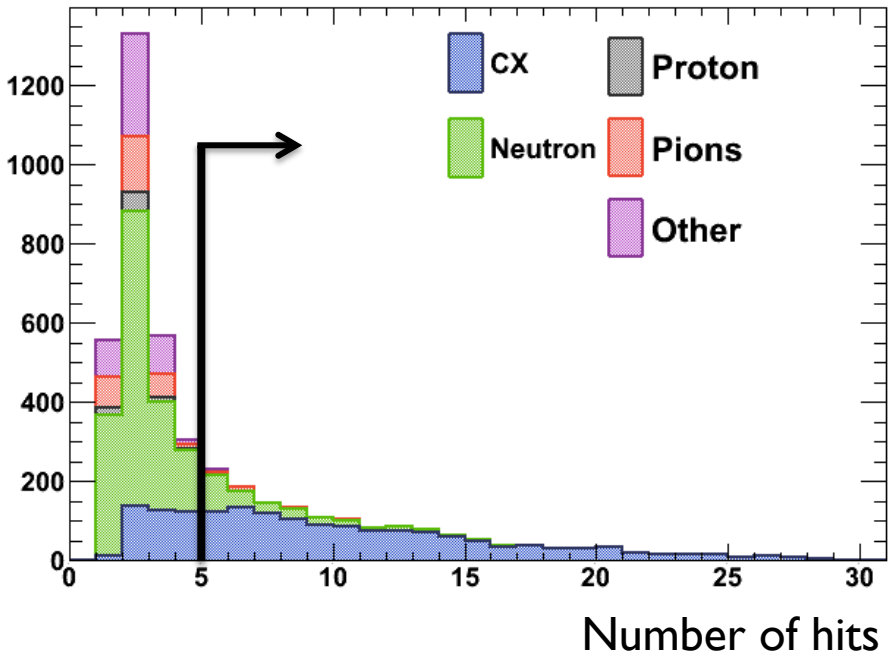
CX Event Selection

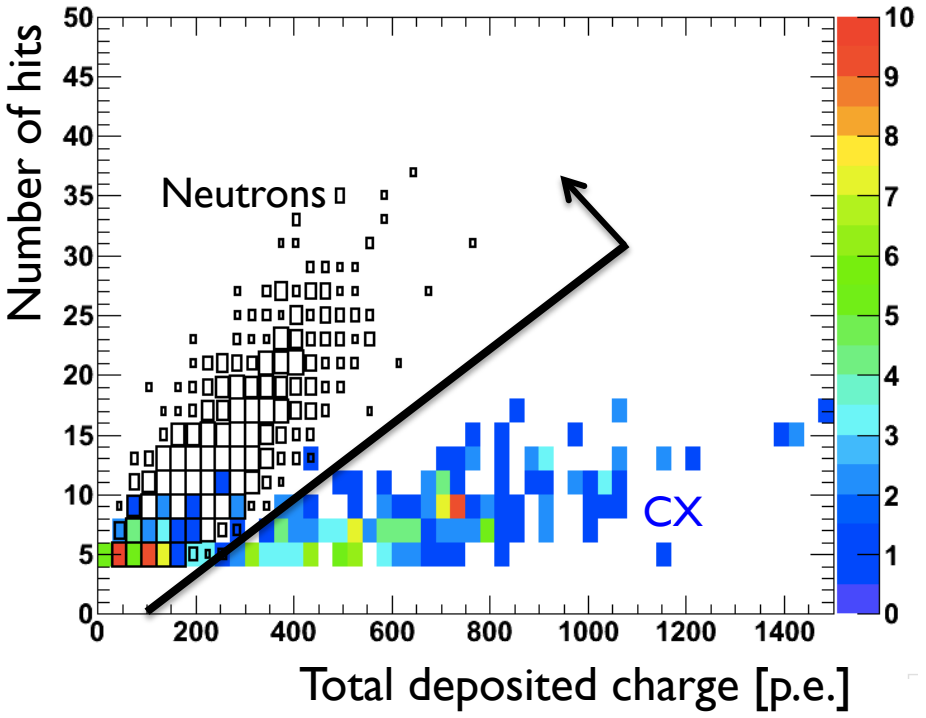




- Charged pions and **protons** immediately leave a signal in the scintillating detector
- Photons are neutral, so they must interact before they can be detected
- The **first two layers** are used as a **veto cut** in order to remove pions and protons.

CX Event Selection: Neutron Rejection





- **Neutrons** will also mostly make hits after the first two layers
- Use number of hits and total charge deposited to remove most of background

$$\text{Efficiency} = \frac{\text{Selected CX events}}{\text{True CX events}} = 25\%$$

$$\text{Purity} = \frac{\text{Selected CX events}}{\text{Total number selected events}} = 95\%$$

Summary and Outlook

- DUET measures pion-nucleus interaction cross-sections using the pion beam at TRIUMF
- Results for a combined Absorption + Charge Exchange cross section are consistent with previous results and have smaller errors
  - Paper will be submitted for publication in the next few weeks
- Work for a separate charge exchange measurement is in progress
- This will feed into a better model of pion Final State and Secondary Interactions
  - Reduce systematics for neutrino experiments

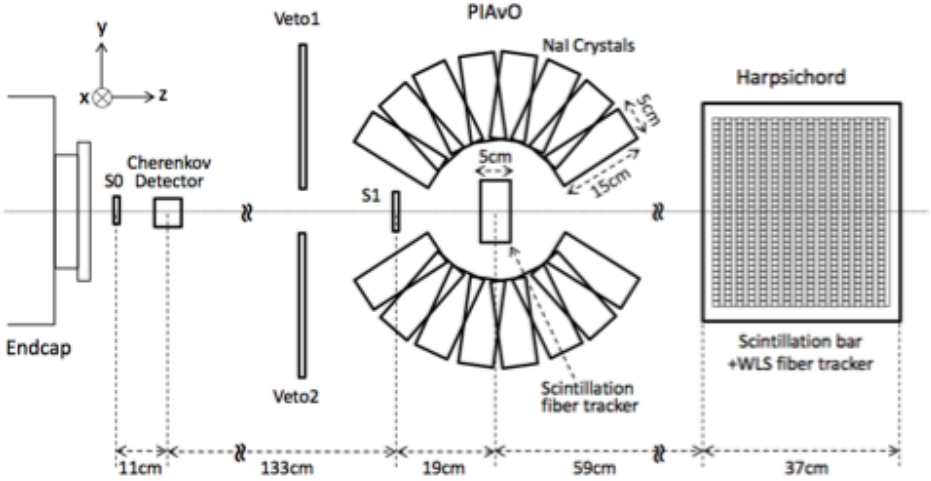
YORK UNIVERSITÉ UNIVERSITY

Thank you

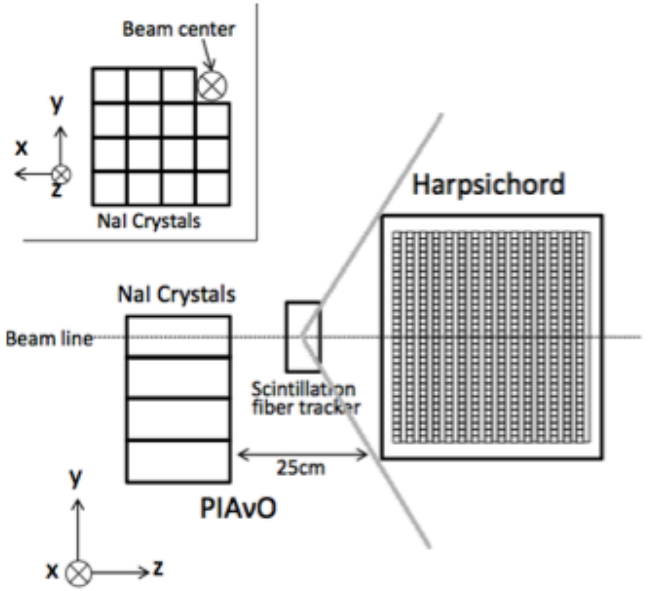
Piano & Harpsichord!

[Backup]

DUET Experiment

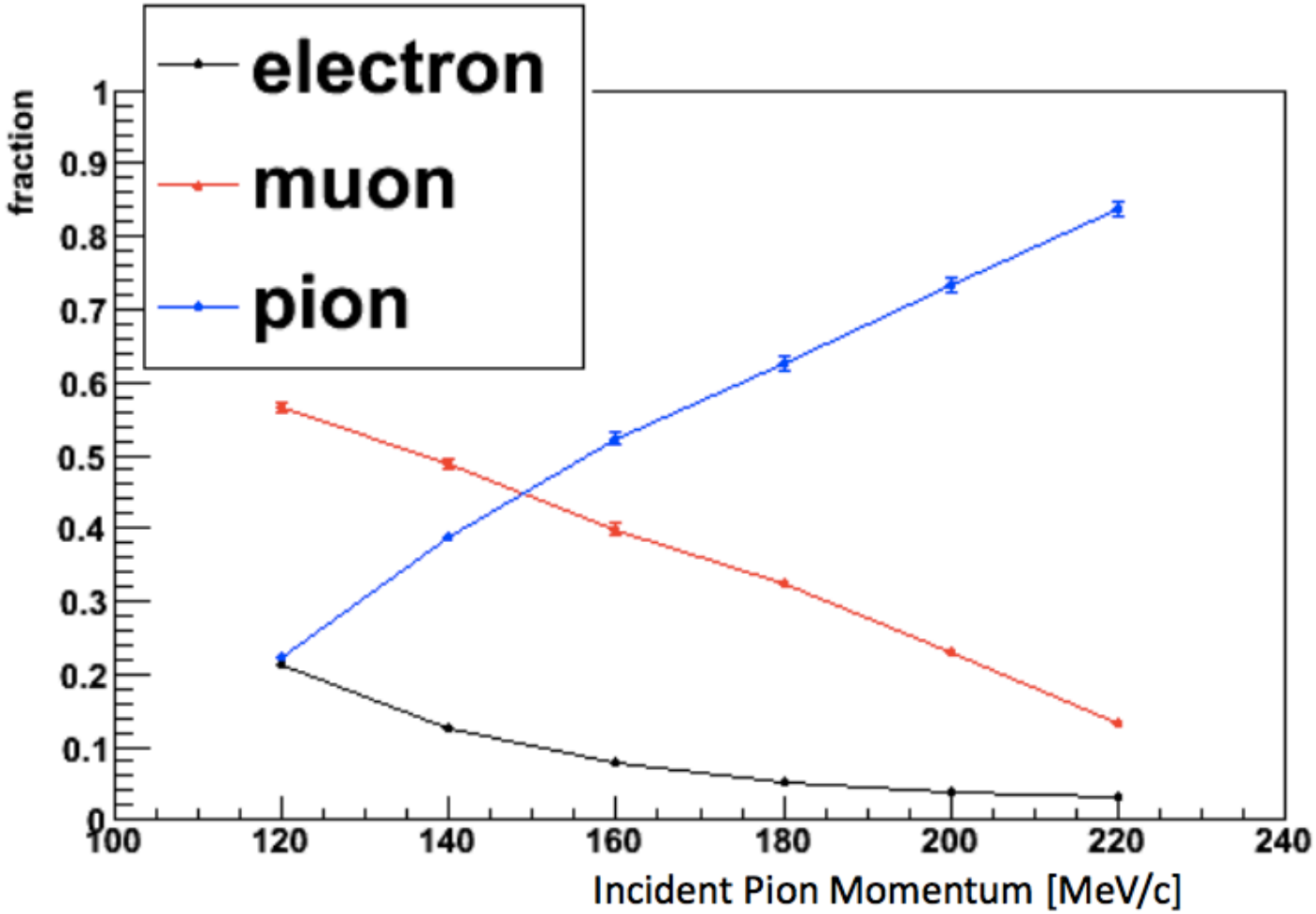


(a) Piaνo and Harpsichord in configuration 1. The angular distribution of photons can be measured using the NaI detectors.

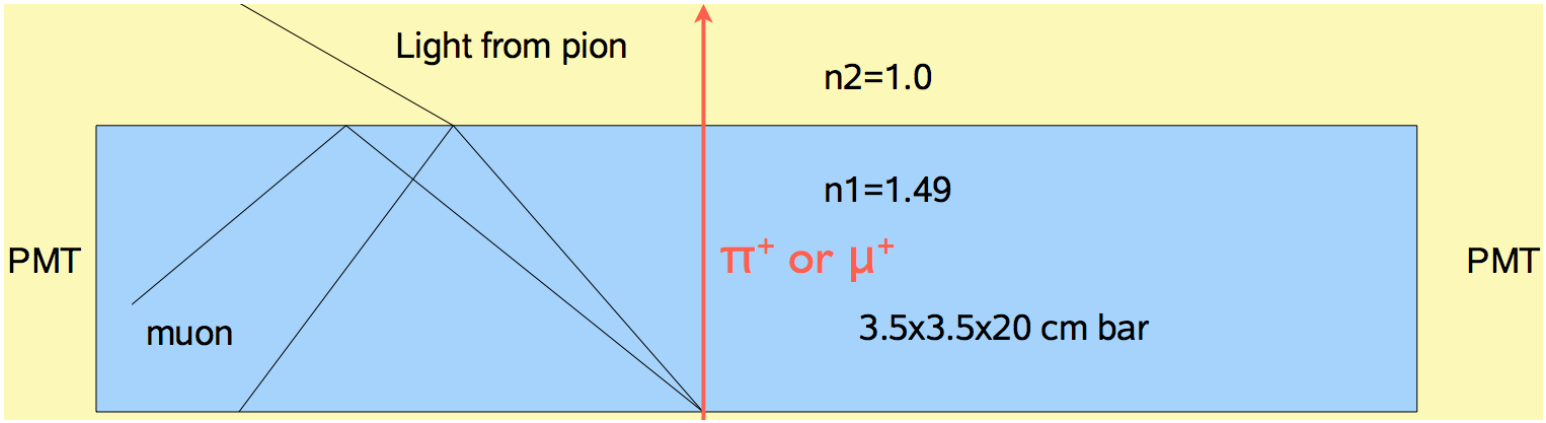


(b) Piaνo and Harpsichord in configuration 2. Lead layers are added to Harpsichord to increase photon conversion.

Beam particle fraction



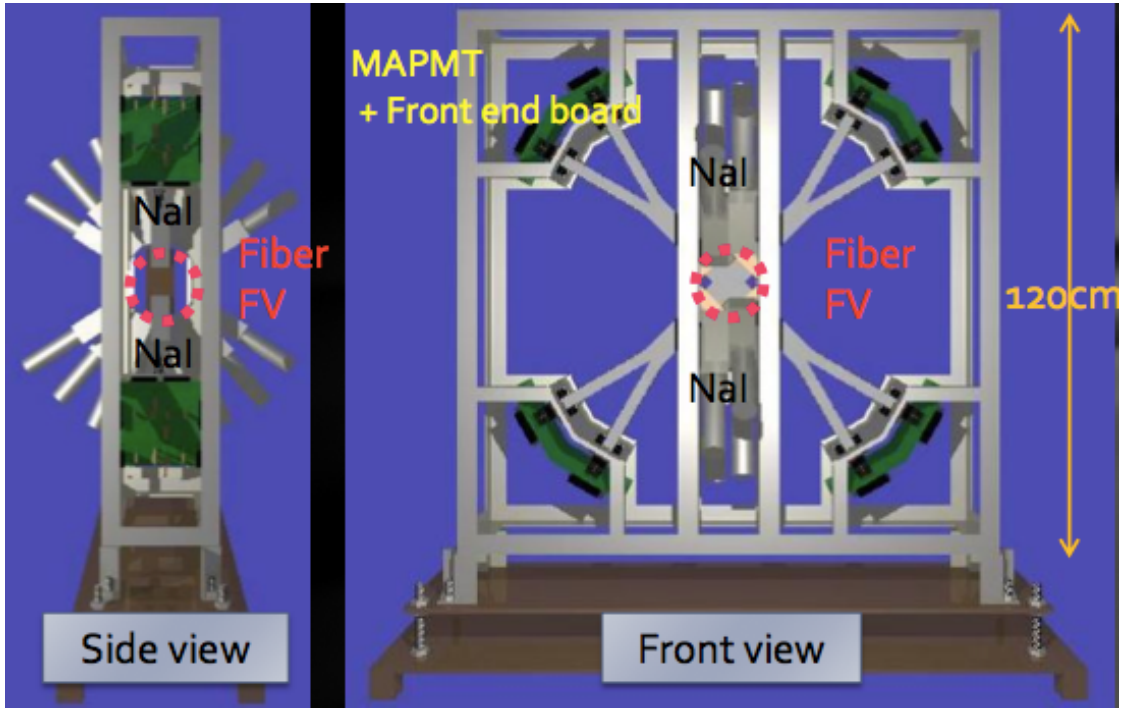
Cherenkov Counter



- TOF is not enough to separate pions and muons above 200MeV/c

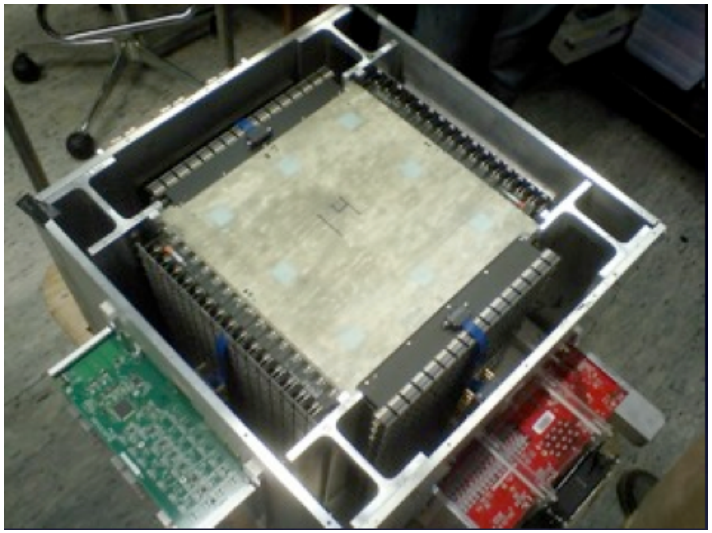
- Different β for e, μ, π → Detected light will be different due to different light yield and angle

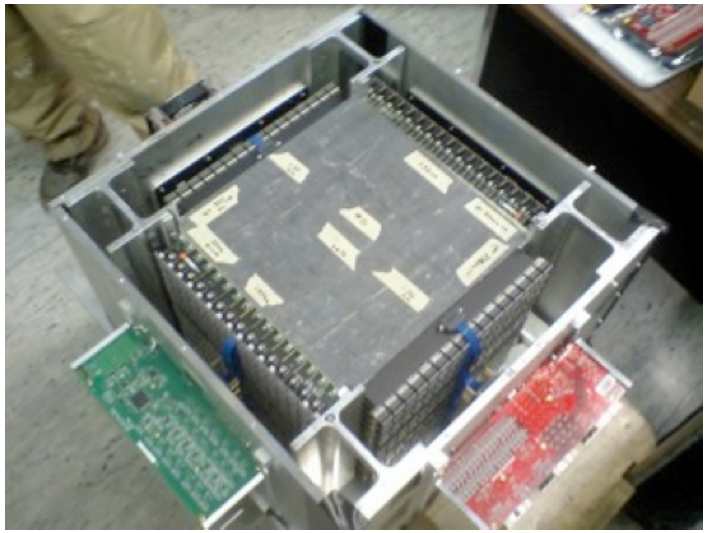
Piano



- Scintillating light are read out by MAPMT×16
- Fiber×1024 ch, NaI×16ch
- Fiber main volume: 48mm×48mm×48mm

Harpsichord

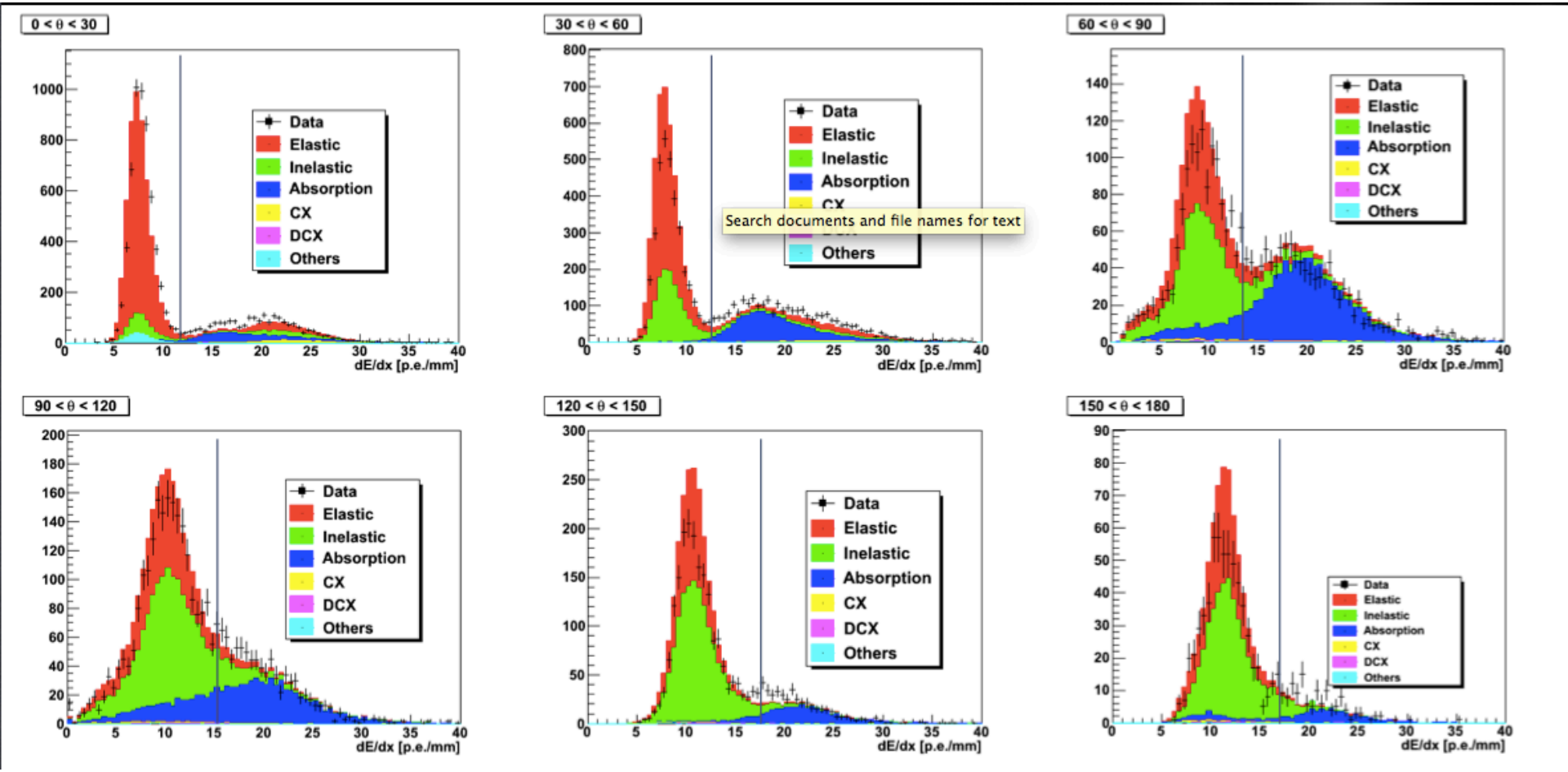




- Harpsichord
  - 1/6 X 1/6 scale FGD
  - Same numbers of layers, electronics as FGD
- Cembalos
  - Added lead layers between XY scintillator modules
  - Increased photon conversion

dE/dx Distributions

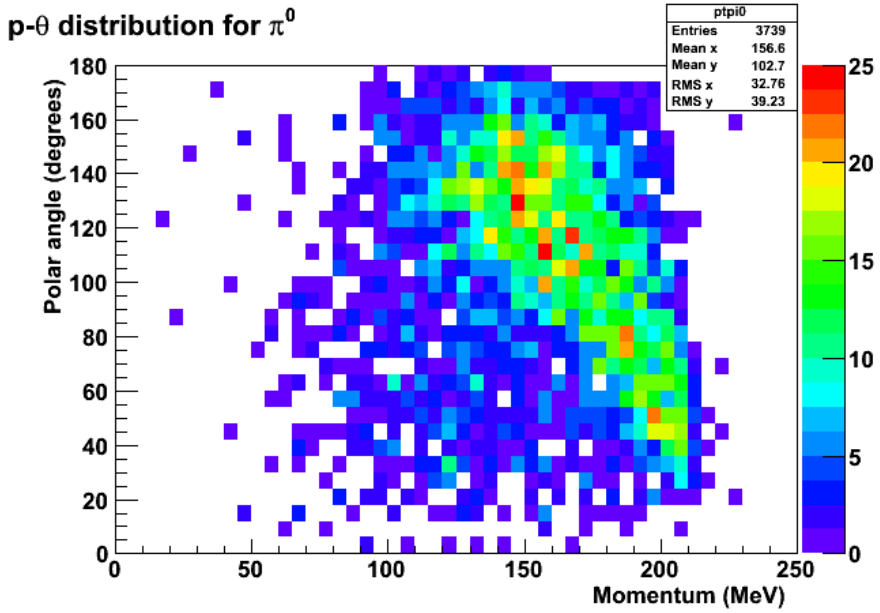
- Used for PID

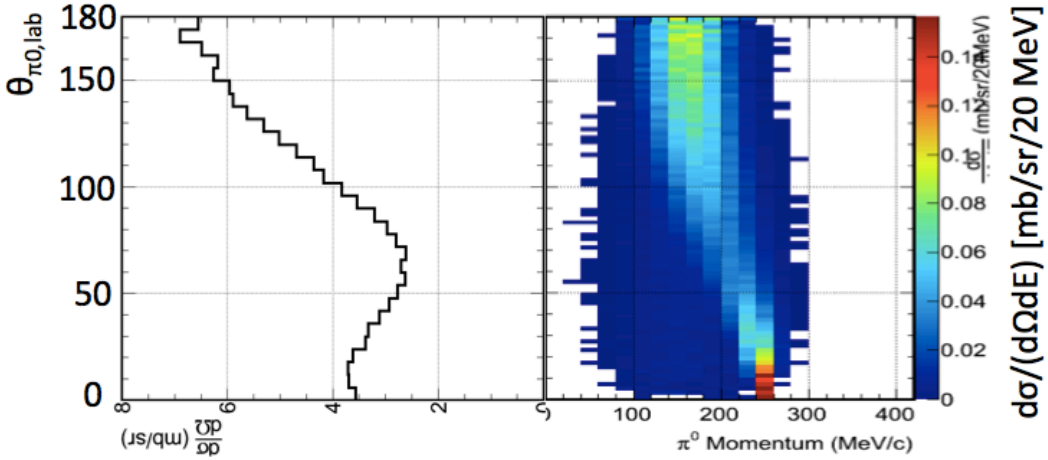


Systematic errors Abs+CX

		200MeV/c	225	250	275	300
Profile		1.54%	2.18%	1.55%	1.91%	1.77%
Momentum		1.19%	1.92%	1.34%	0.96%	0.42%
FV		0.97%	1.68%	1.87%	0.57%	1.58%
Charge		1.38%	2.21%	0.46%	0.42%	2.37%
Crosstalk		1.50%	1.34%	0.53%	0.59%	1.75%
Alignment		0.29%	2.43%	0.82%	−0.42%	0.54%
Hit efficiency		−0.27%	0.78%	0.76%	0.26%	0.67%
μ contami		0.45%	0.78%	0.89%	0.86%	0.88%
Target		0.84%	0.85%	0.86%	0.83%	0.95%
Efficiency		1.39%	4.03%	2.33%	4.15%	1.94%
Background	+	2.78%	1.82%	2.41%	2.28%	3.98%
	-	−6.07%	−3.72%	−3.57%	−1.50%	−2.58%
Total	+	4.43%	6.73%	4.71%	5.44%	6.04%
	-	−6.98%	−7.47%	−5.40%	−5.16%	−5.23%

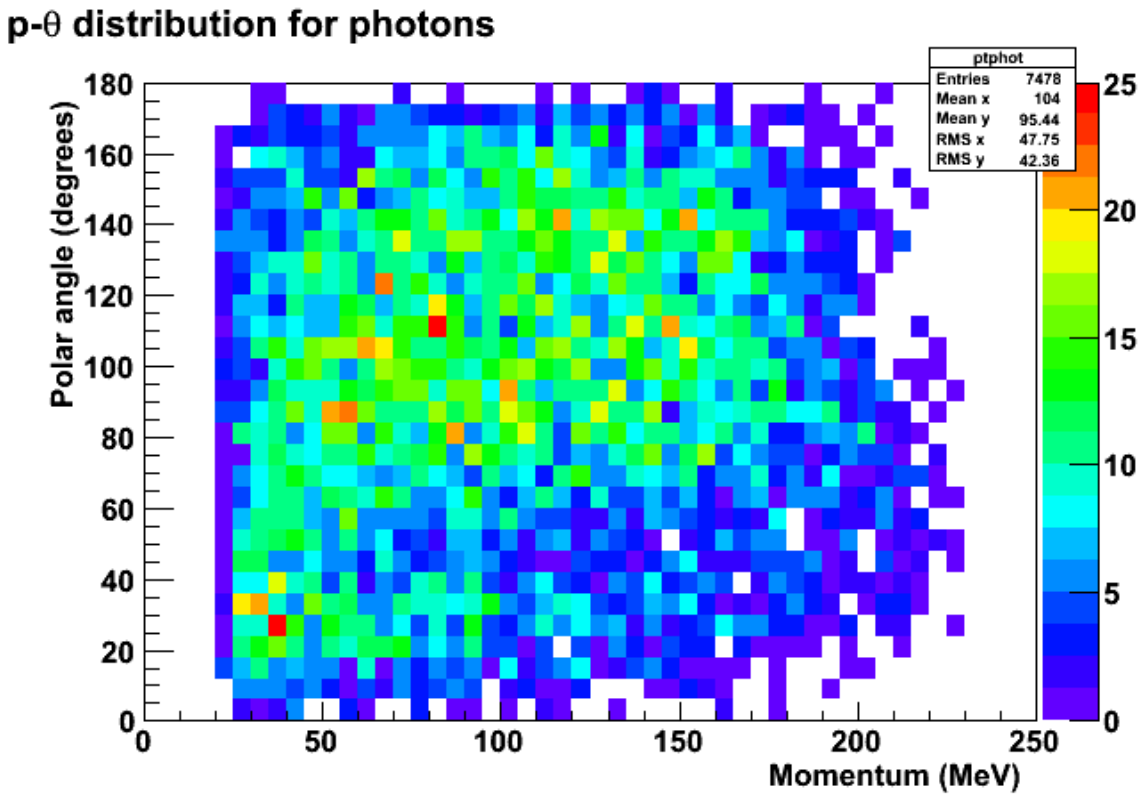
p-θ for π 0's



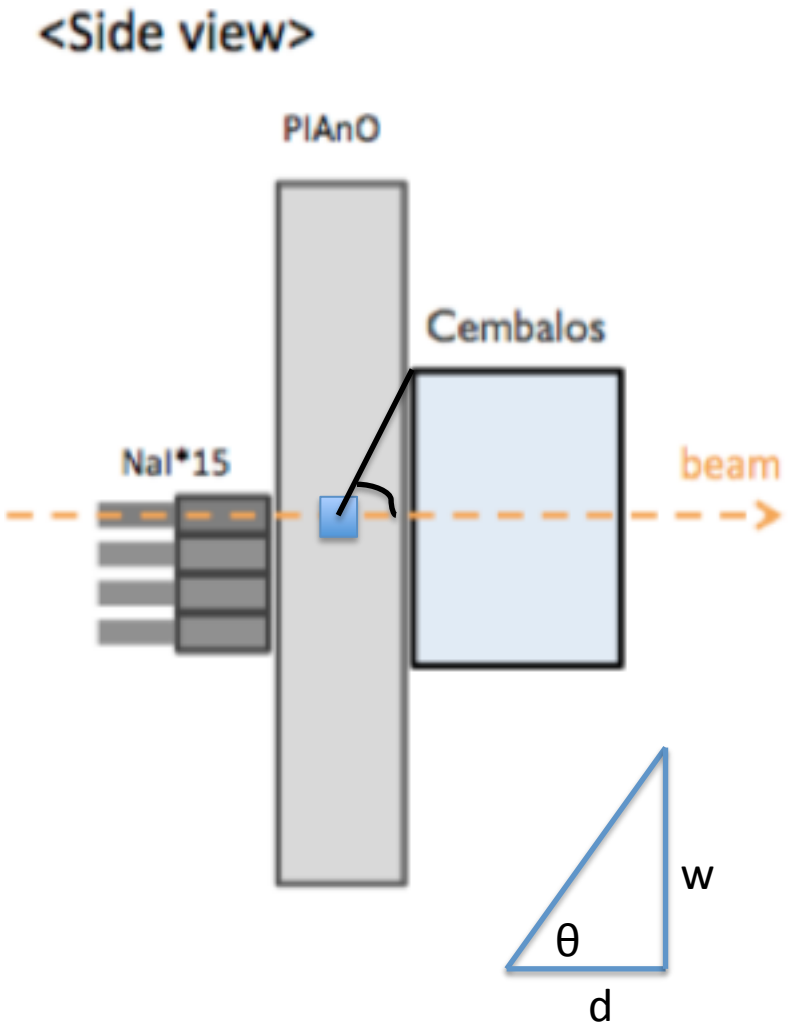


Photon distribution

- For all the photons



Solid angle subtended



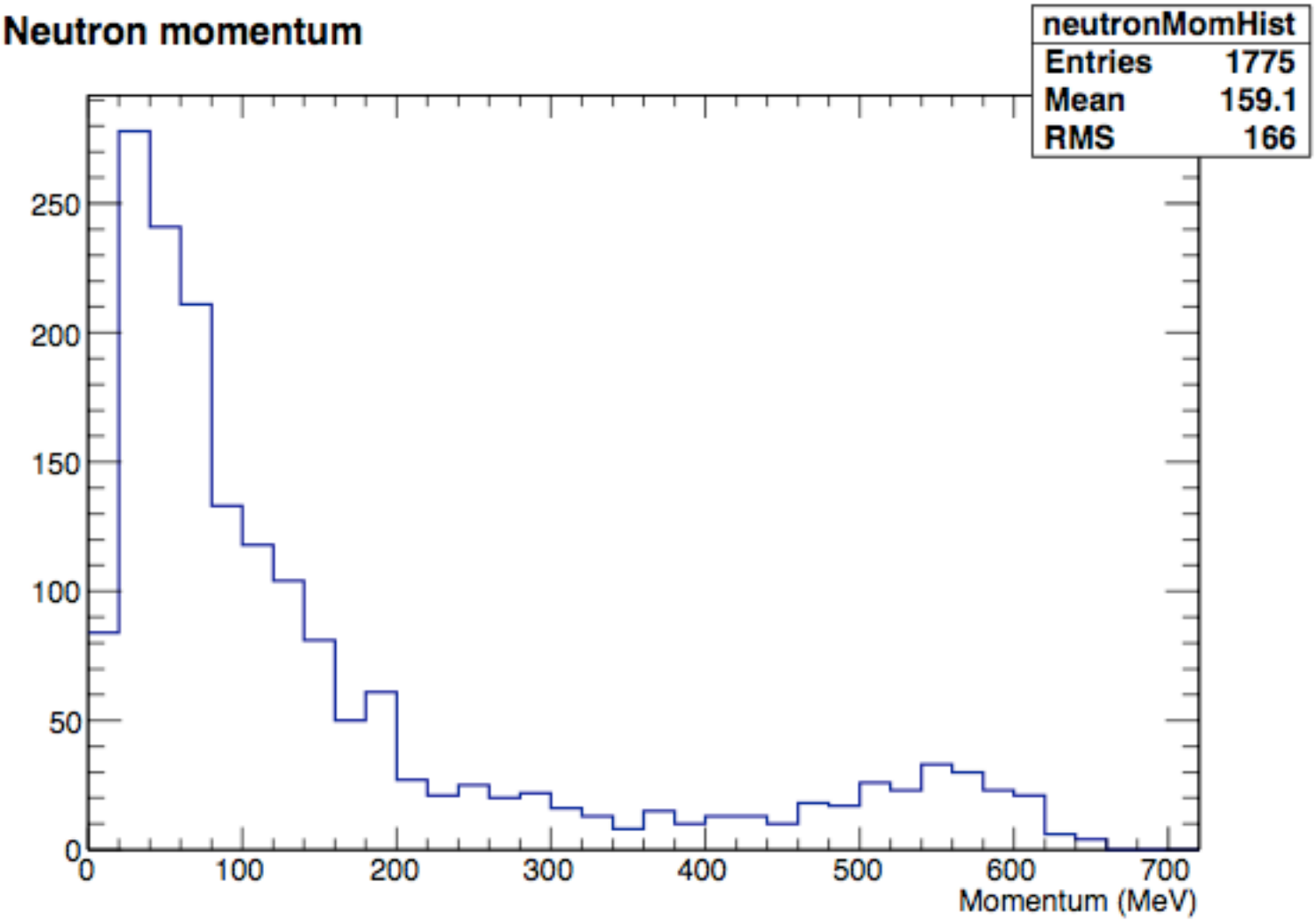
- Rough calculation
  - Take Piano as a point
  - Ignore rectangular shape of Harpsichord
- A cone with opening angle:

  θ =arctan(w/d) = arctan(175/190)

  = 42.6°
- The solid angle is:

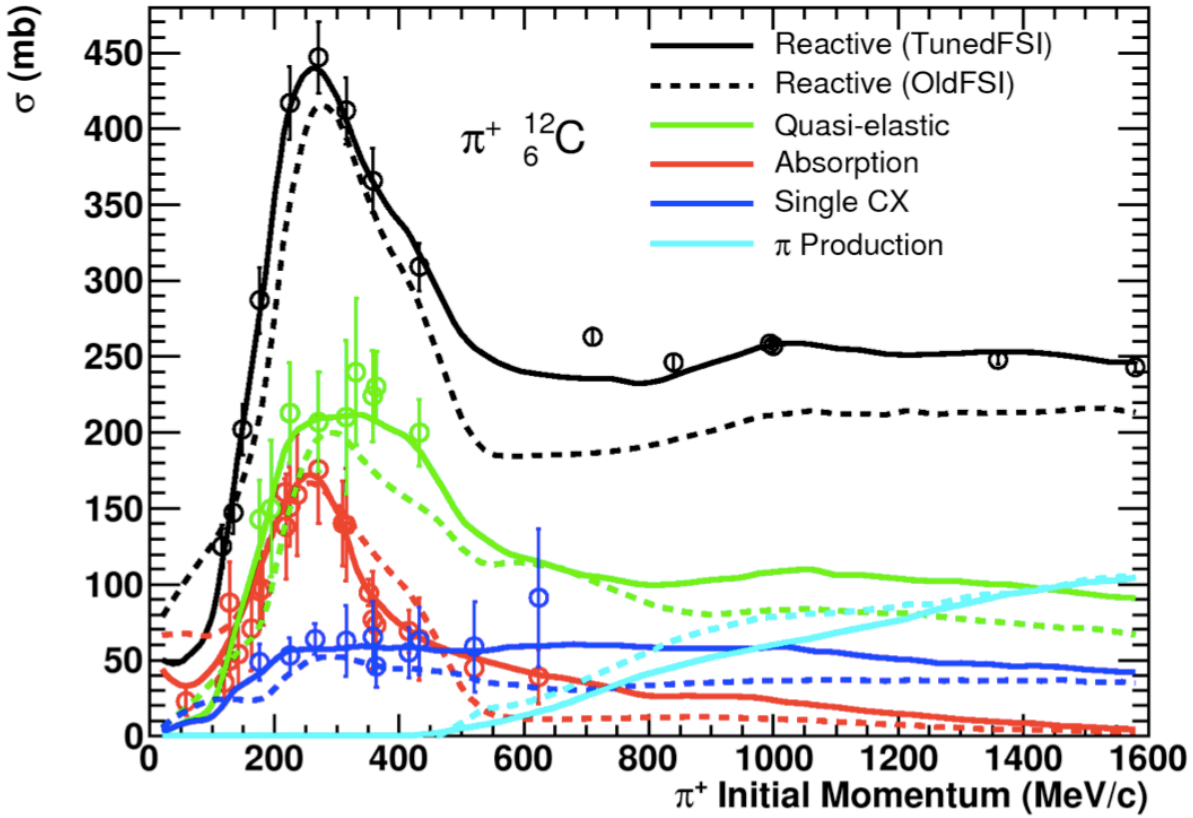
  $\Omega = 2\pi(1-\cos\theta) = 0.53\pi$
- Or, around 13% of the whole sphere

Neutron momentum



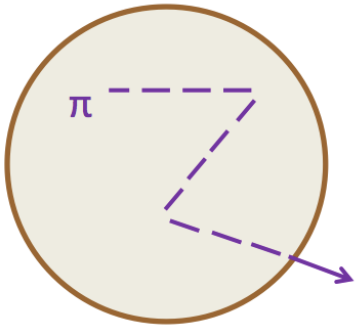
Tune FSI Model

- Current:



NEUT FSI

- NEUT FSI model simulates pion interaction by stepping through the nuclear medium (cascade).
- The interaction probability in each step is defined by the microscopic Scattering/Abs/CX cross sections.



- The microscopic cross sections are tuned so that the resulting Scat/Abs/CX cross section agree with external data.

- Add DUET data for tuning