The Main Injector Particle Production (MIPP) Experiment

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on behalf of the
MIPP Collaboration

{*Poster by Ms.Sonam Mahajan from the Indo-US ν-Collaboration*}

ॐ *Measure High-Statistics, Unbiased, Particle Production Cross-sections in Hadron-Nucleus Collision*

Beam Projectile: (anti)Proton, π^+, π^-, K^+, K^-

Beam Energy: $O(1) \leq P_{Beam} \leq 90$; 120 GeV Proton

Target: $1 \leq \boldsymbol{A} \leq 238$ (H/Be/C/Al/Bi/Pb/..); NuMI/LBNE-Target (C); Thin & Thick

Particle-ID: TPC(dE/dx); ToF; Cerenkov; RICH; Calorimeter

Physics of MIPP

Neutrino Flux

- π^+, π^-, K^+, K^-, K^0_L yields (x_F, p_T) in Proton(π^{+-} , K^{+-})-Nucleus Collision

⇒Accelerator Neutrinos {primary target & beam-elements}

⇒Atmospheric Neutrinos {N, O ? }

Service Measurements

- Hadron Shower Simulation (MARS, Geant4, Fluka, ..) ⇒ Calorimetry
- Proton Radiography

Particle Physics

- Non-perturbative QCD; Baryon Resonances; Meson Sepectroscopy
- Fragmentation-rules in (semi)Inclusive Processes
- Precision measurement of K+ (NIM A631)

Nuclear Physics

- Strangeness
- Flavor Propagation
- Scaling

The MIPP experiment

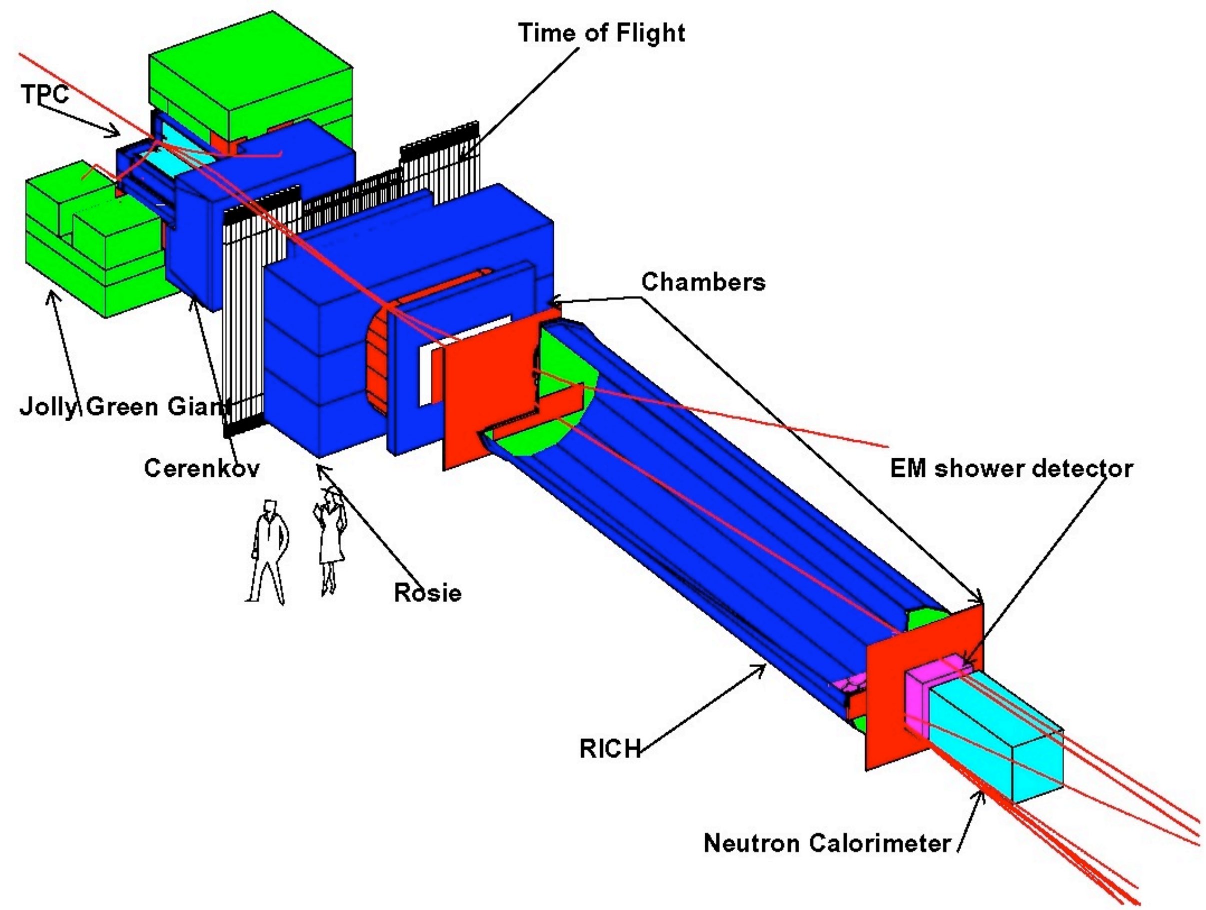
MIPP

- Approved in November 2001, installed in Meson Center MC7,
  14 months physics run ended in February 2006 – 18 million events
- Use 120 GeV/c Main Injector protons to produce
  - secondary beams of $\pi^{\pm}$, $K^{\pm}$, and p, $\overline{p}$ from 5 GeV/c to 90 GeV/c
  - 120 GeV/c proton beam for NuMI and nuclear targets (A=1 to A=238)
- **Measure particle production cross sections** on fixed targets
  - various nuclei including hydrogen and the NuMI target
- Momenta of ~all charged particles measured with TPC and tracking chambers.
- Particle identification with dE/dx, ToF, multicell Cherenkov, and RICH detectors and calorimeter for neutrons.
- Open Geometry – Lower systematics than single arm spectrometers
- A proposal FNAL-P960 to **upgrade** MIPP was **deferred until publications**

DAQ rate
Increase
x100

The MIPP detector

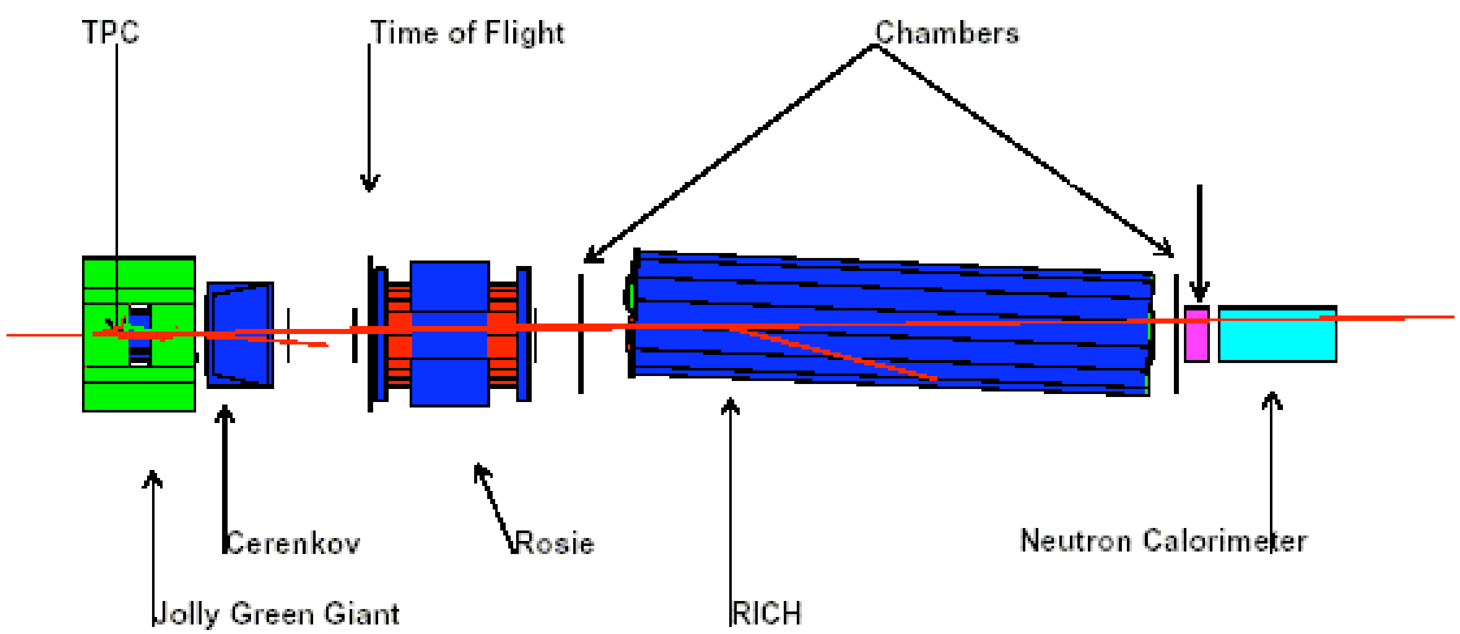
TPC and 6 Chambers for tracking



MIPP

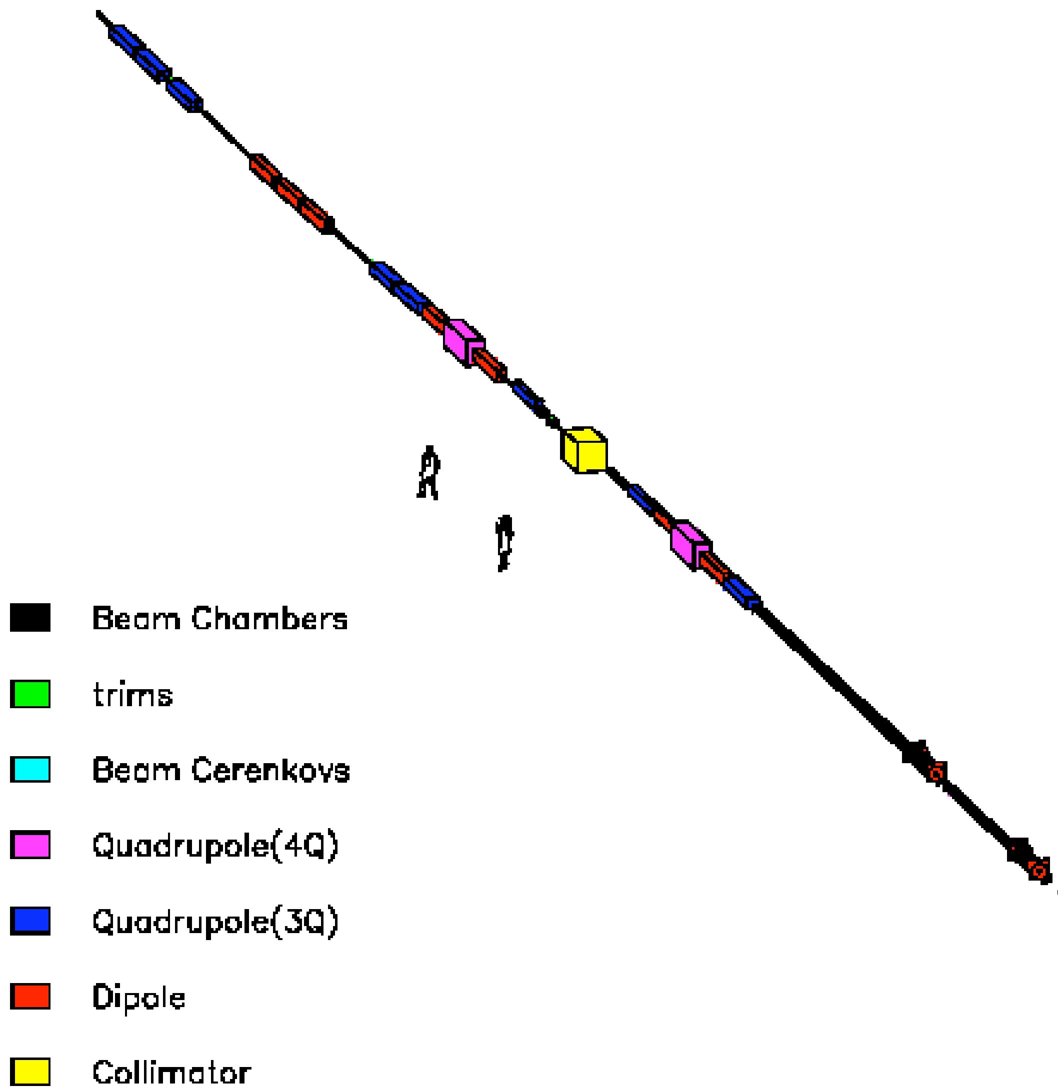
Main Injector Particle Production Experiment

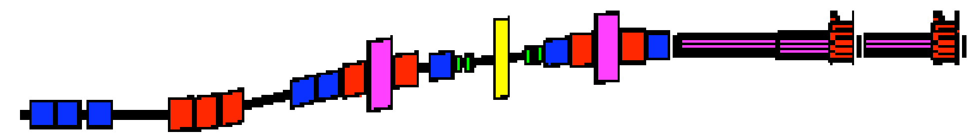
Vertical cut plane



TPC dE/dx	0 to 1 GeV/c
ToF	to 2 GeV/c
Ckov	to 17 GeV/c
RICH	to 120 GeV/c

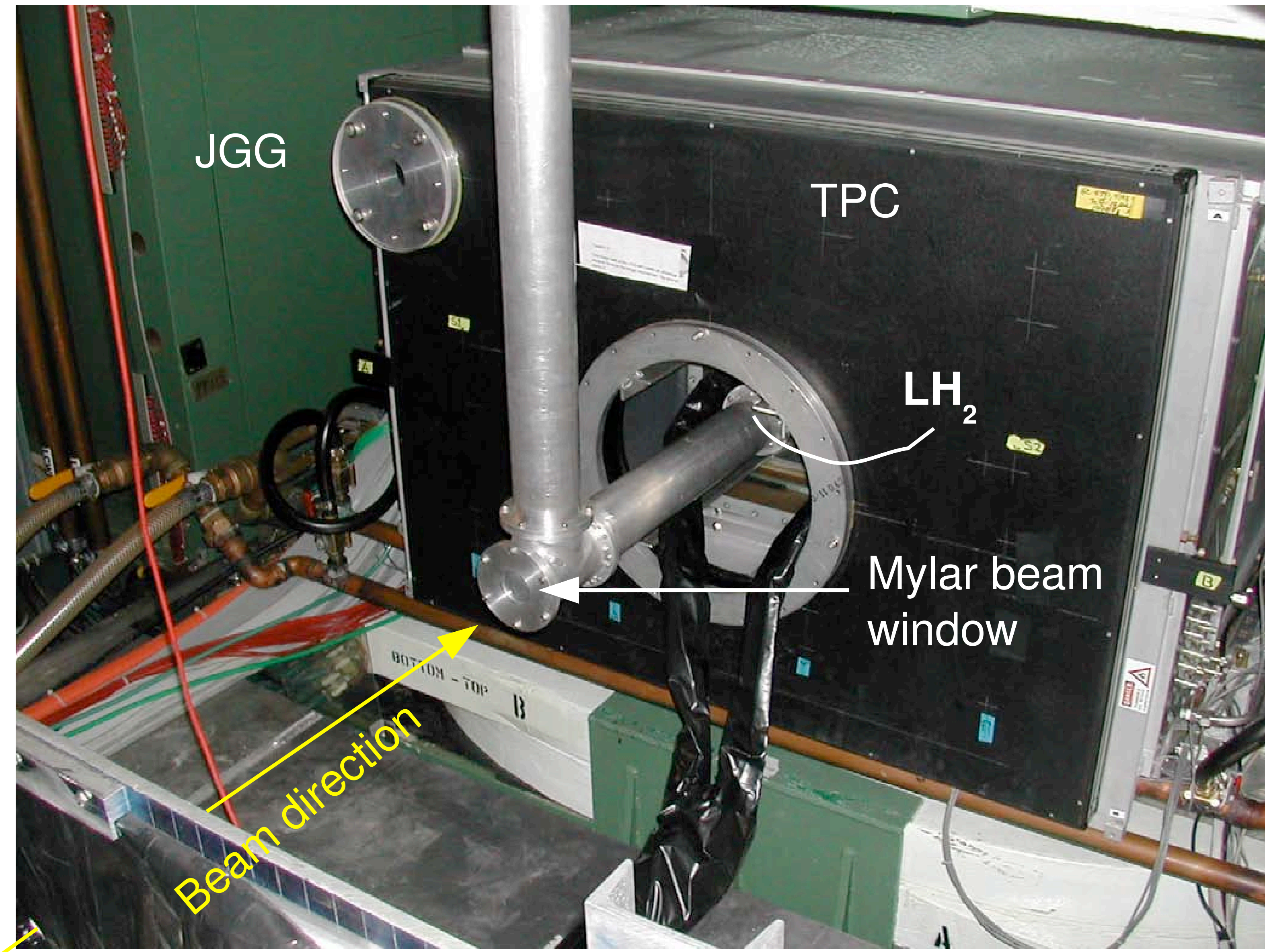
The MIPP beam



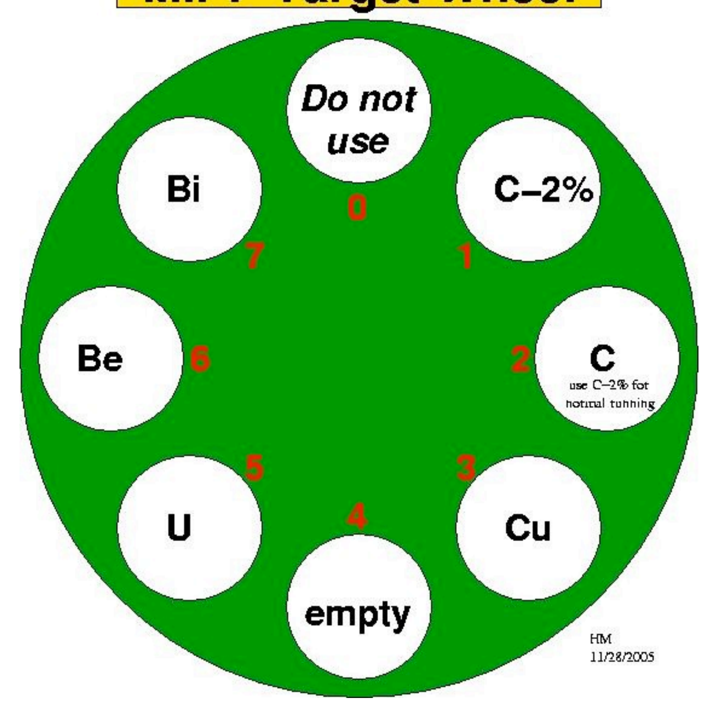


- MIPP design, very short from primary to secondary target (95 m)
- Excellent performance, kaons down to 3 GeV/c (in upgrade), enough kaons survive.
- Ran it successfully in MIPP from 5-85 GeV/c secondaries and 120 GeV/c primary protons.
- Excellent particle ID capabilities using 2 Beam Cherenkovs. For low momenta (<~10 GeV/c) Beam-ToF is also used for pid.
- Design principles and lessons learned used in M-test at Fermilab.

Cryogenic target mounted in TPC, NuMI target and target wheel



MIPP Target Wheel

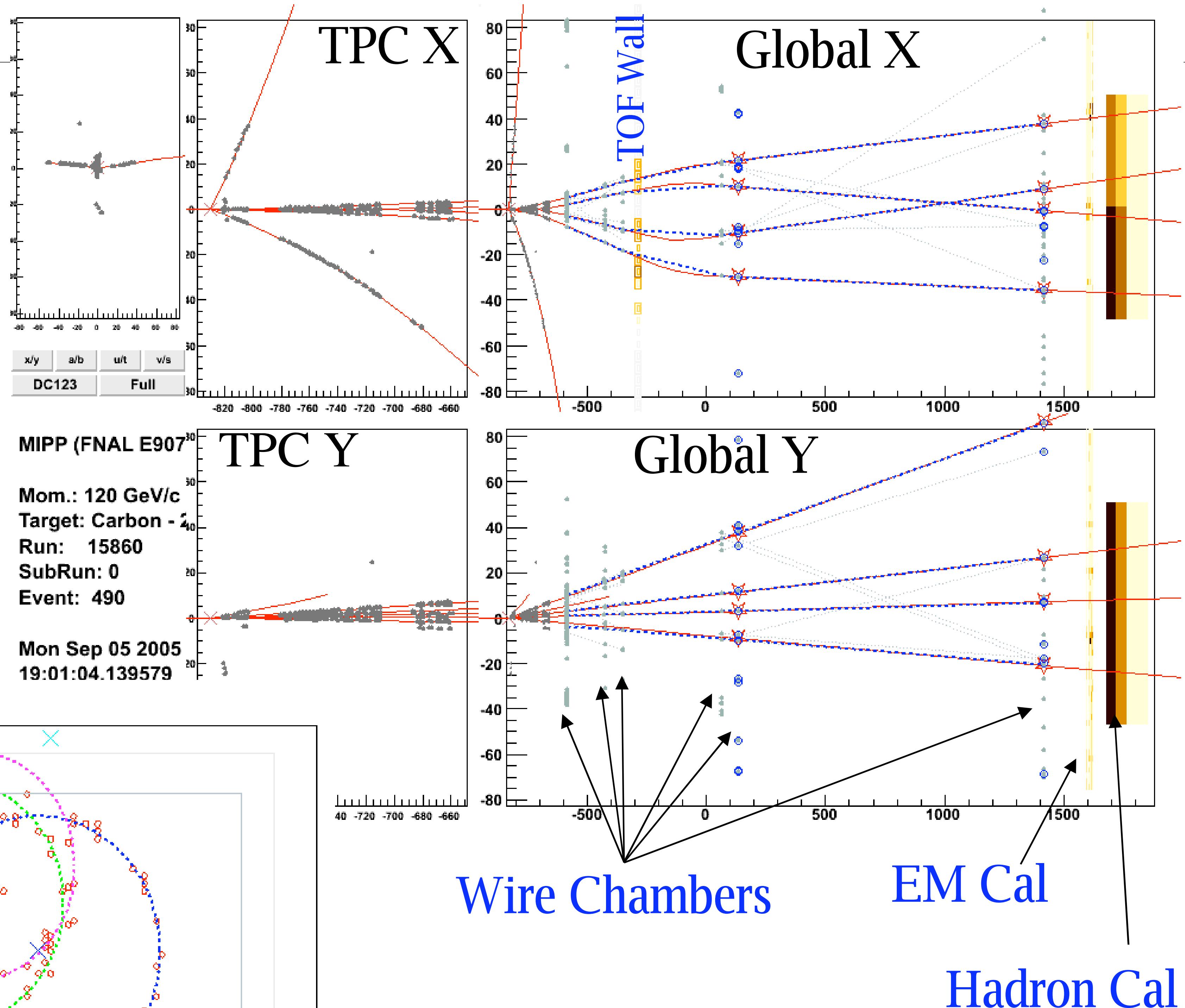


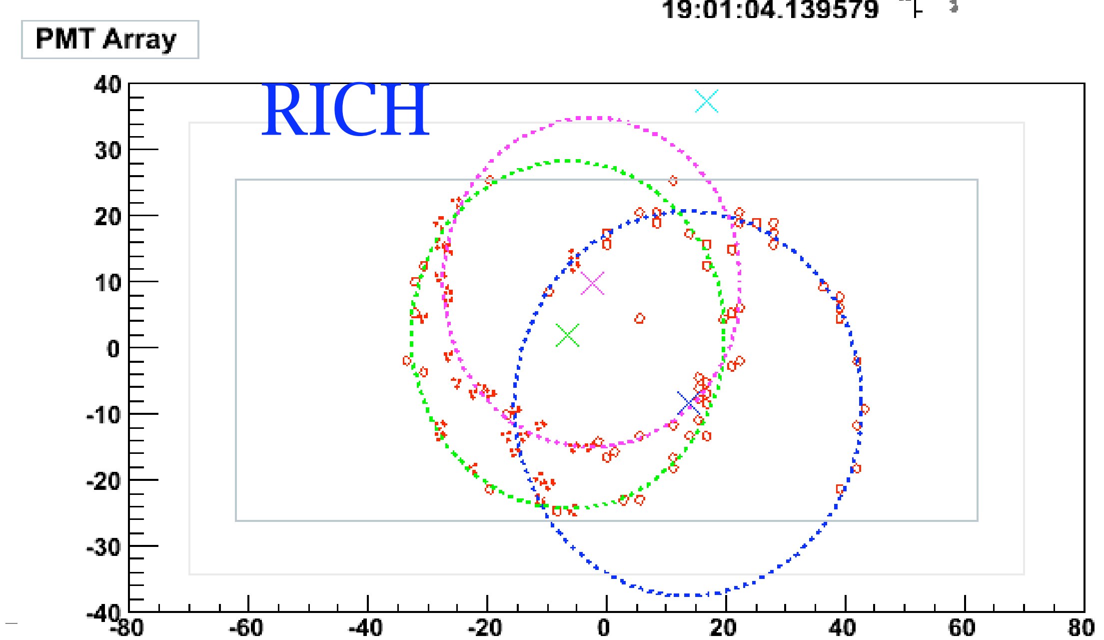
Reconstructed p-C 120GeV/c event

Tracking and RICH displays

TPC (Bevalac/E910):

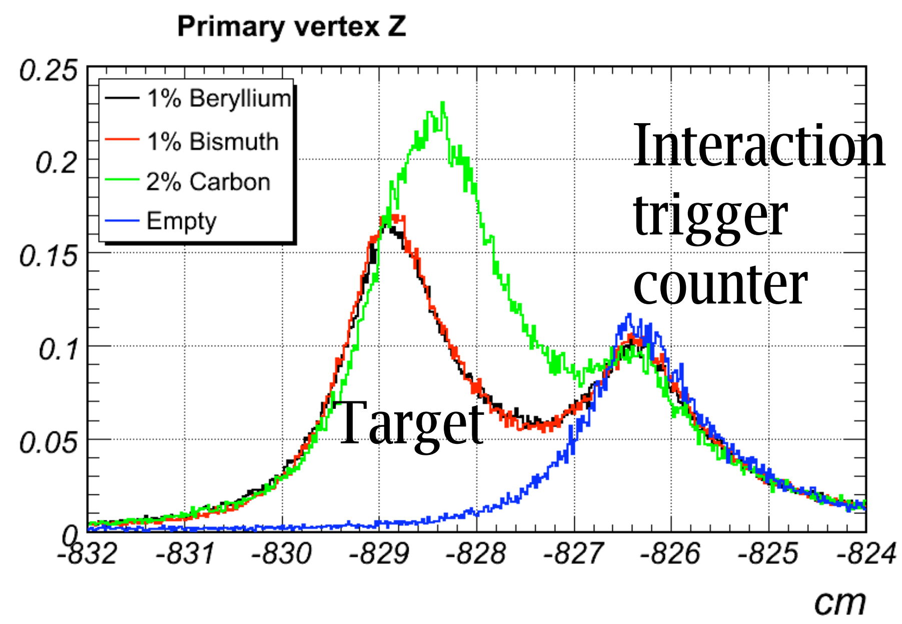
- *Gas: P10*
- *Readout:*
  *X-Z via 120x128 pads(≃1cm**2);*
  drift ⇛ Y (10kV)
- *Magnet: 0.7T JGG*
- *Can handle much larger multiplicity than MIPP*

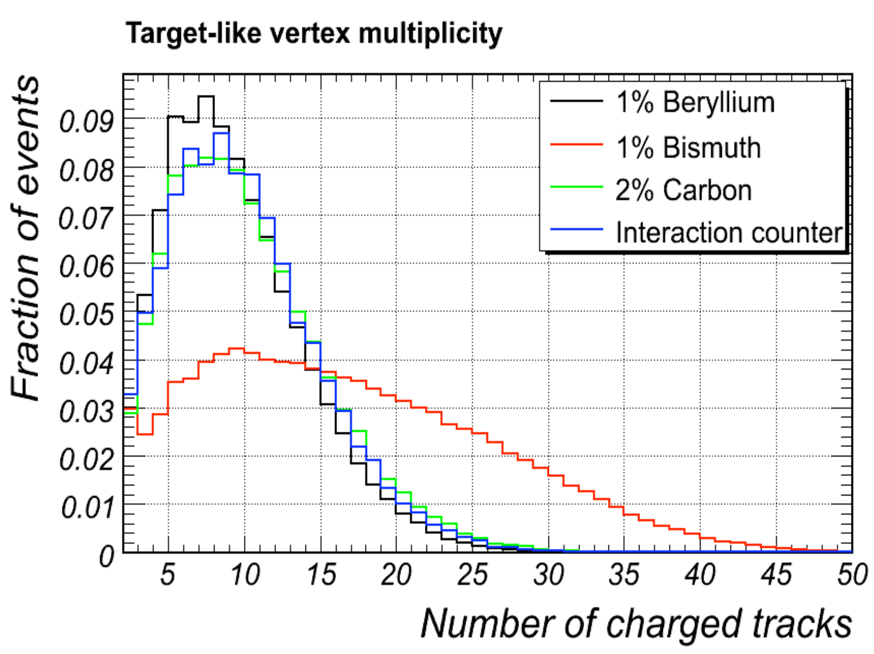




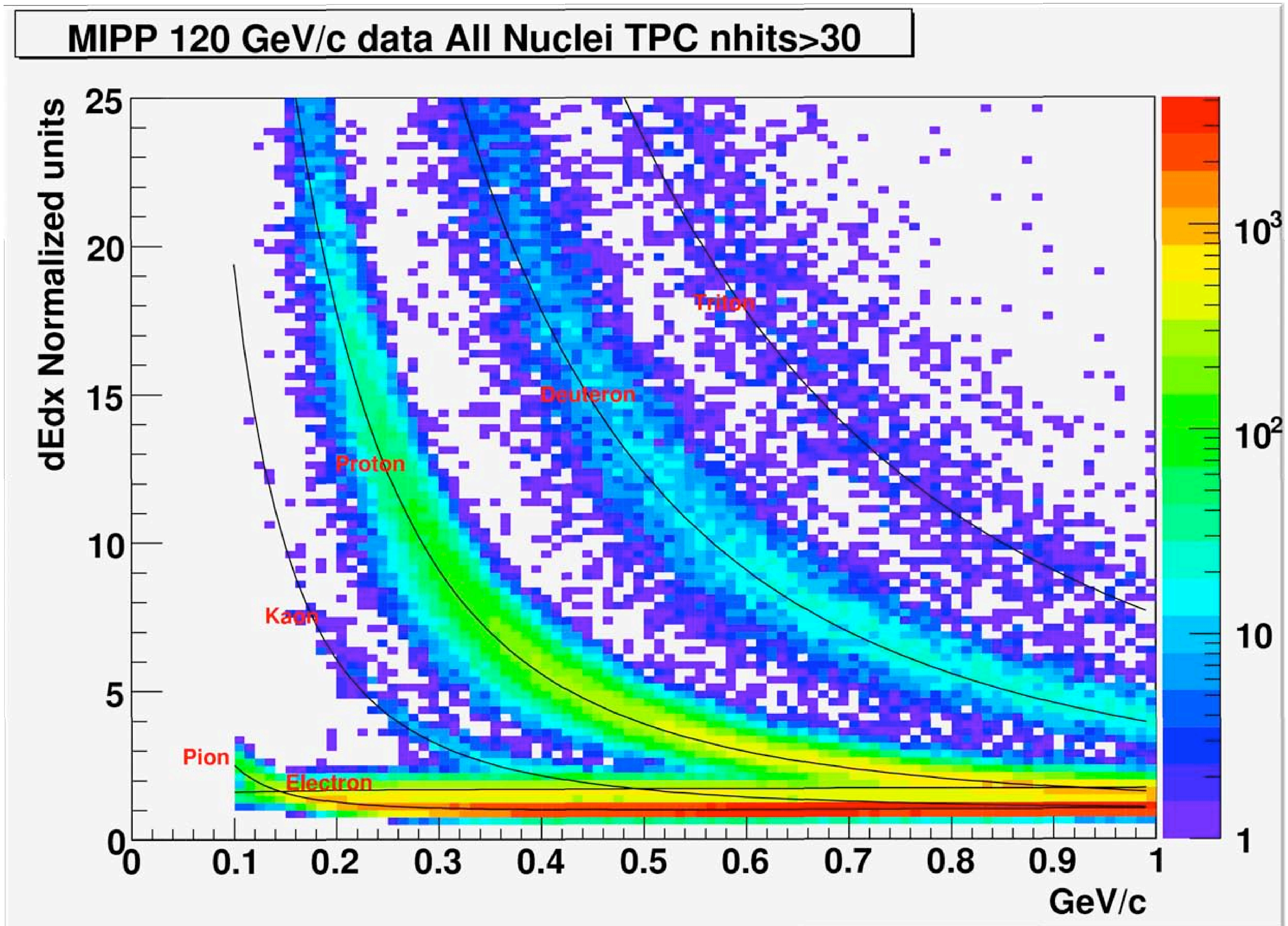
Vertex reconstruction

- Two steps to vertexing:
  - Vertex finding is done with iterative algorithm.
  - All tracks of each vertex are refit with the constraint of originating at the vertex. Uses track templates.
- Vertex resolution:
  - 6mm vertex Z resolution
  - X,Y resolution < 1mm
- Good separation of target interactions from background



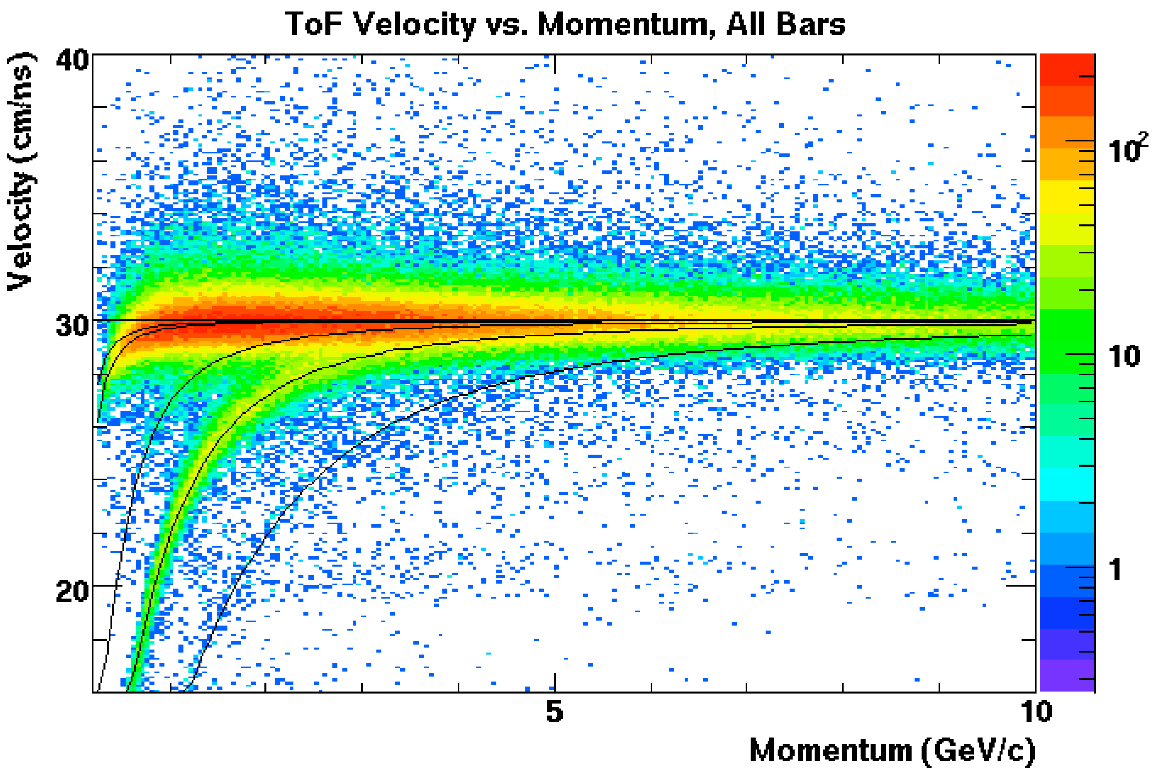


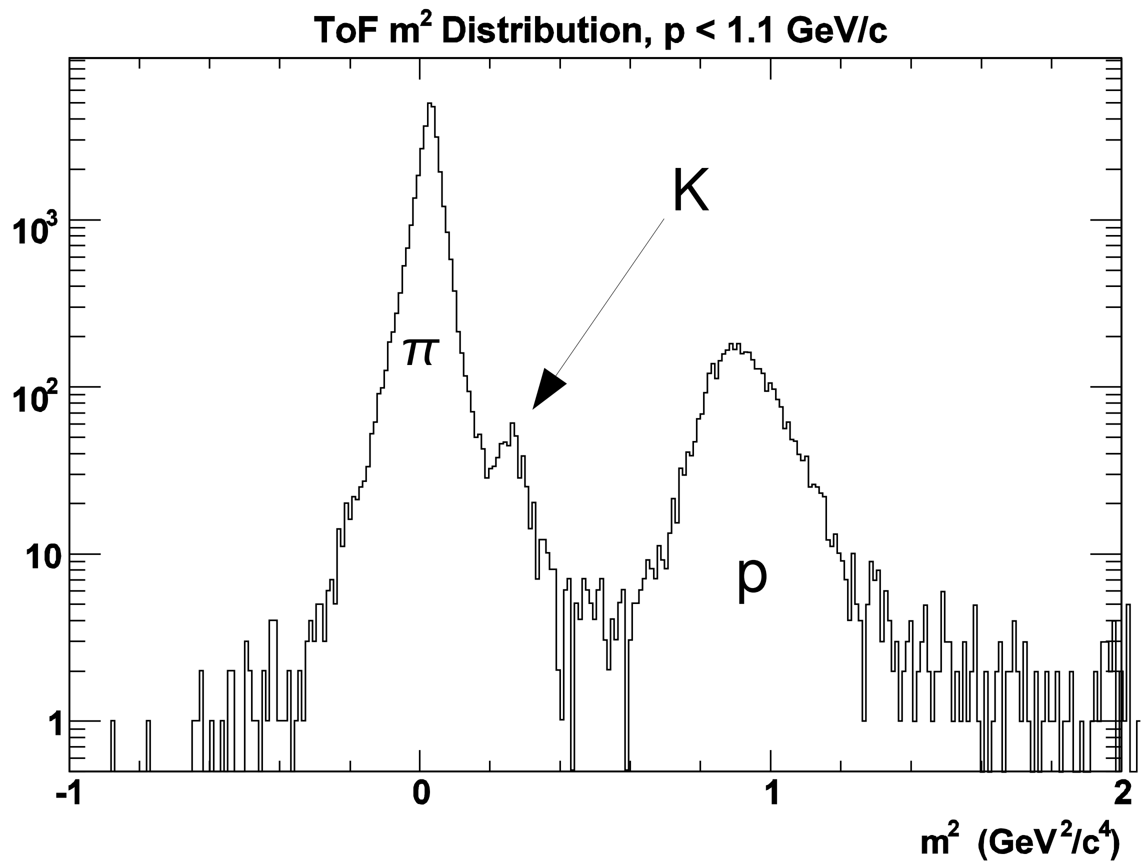
dE/dx in the TPC - data



TOF particle ID

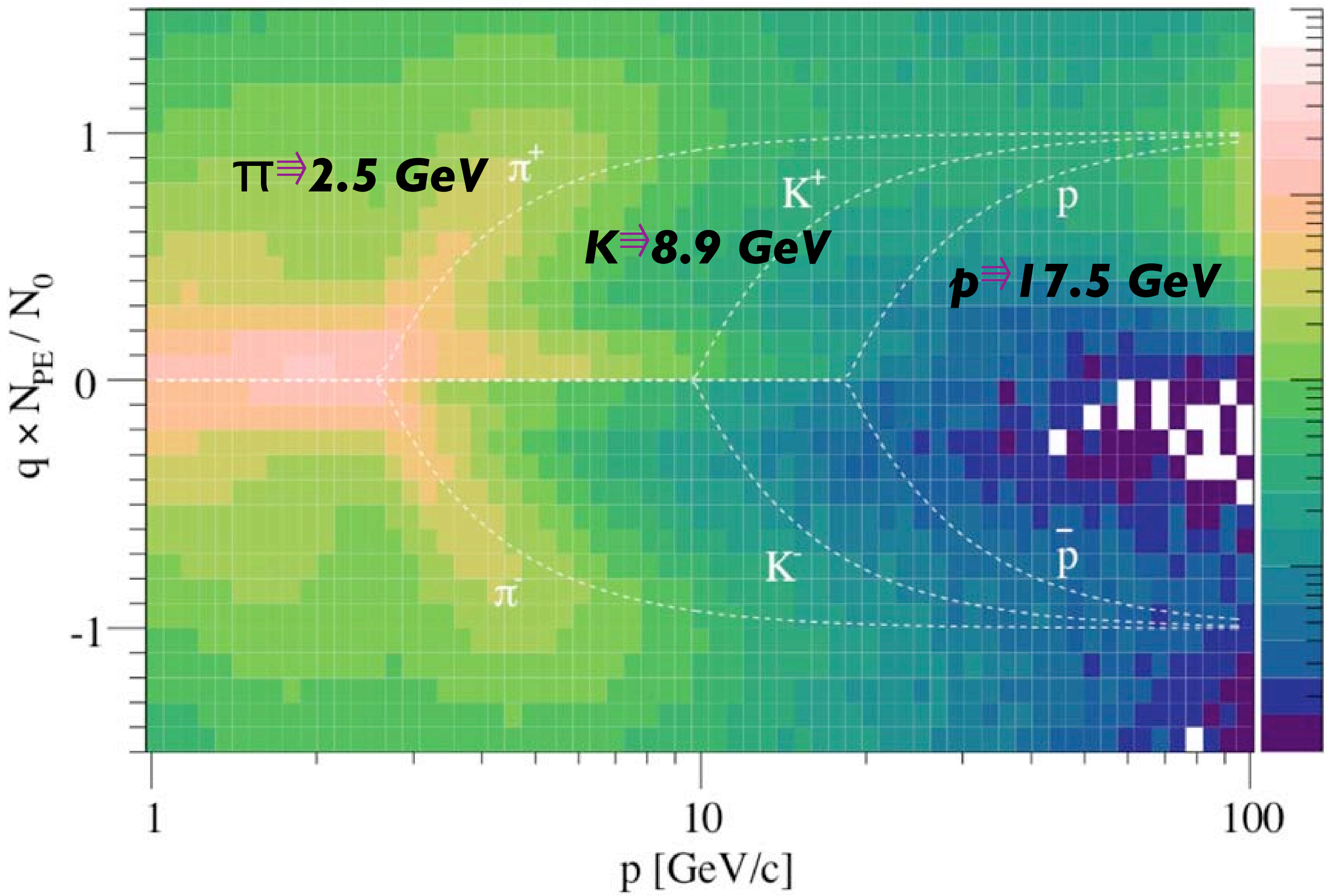
- TOF did not work as well as designed, but gives good PID over most of the momentum region it was supposed to cover after all corrections are applied carefully.

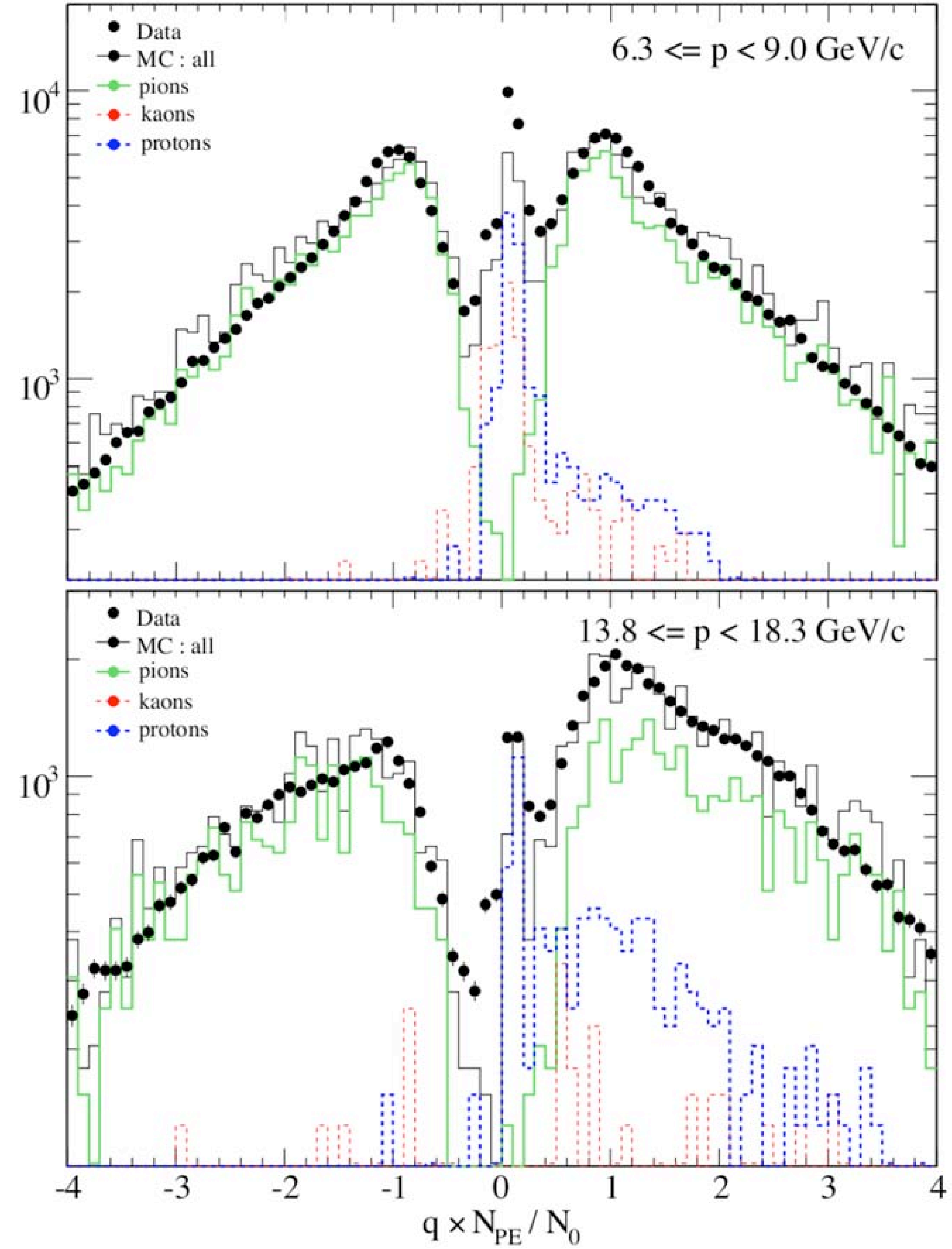




Cherenkov particle ID

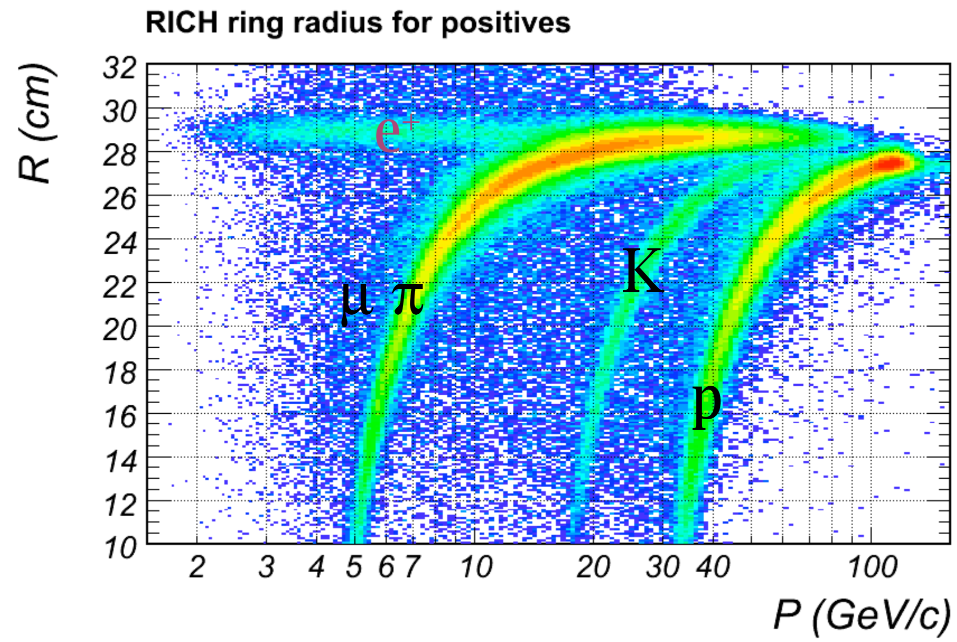
- Every mirror calibrated with data assuming pions and Poisson statistics.
  - Light yield lower than expected.
  - Normalized to β=1 to put all mirrors in same plot
  - NuMI target data and MC shown here

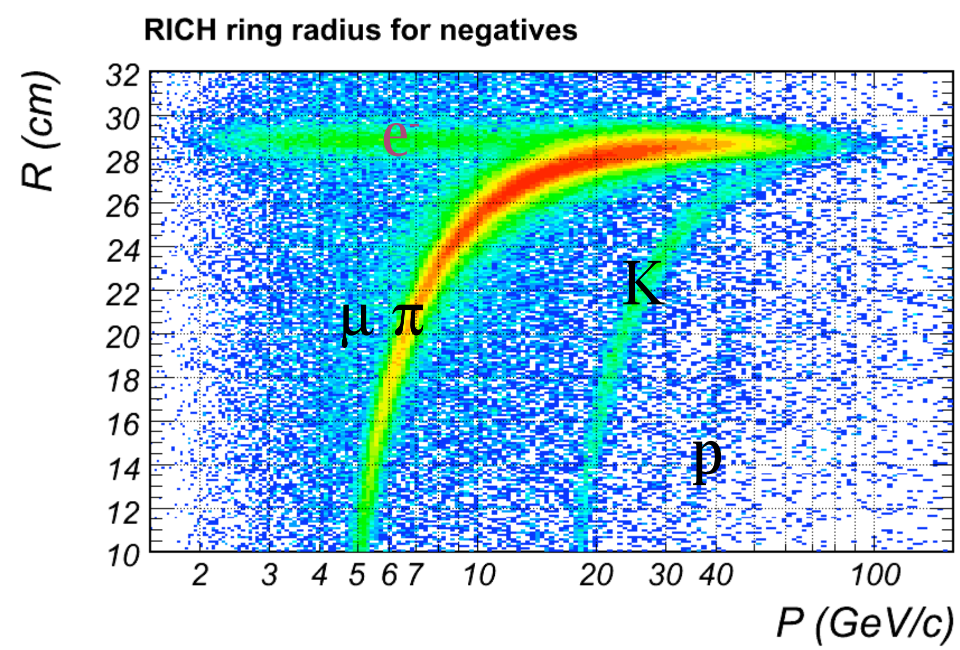




RICH particle id

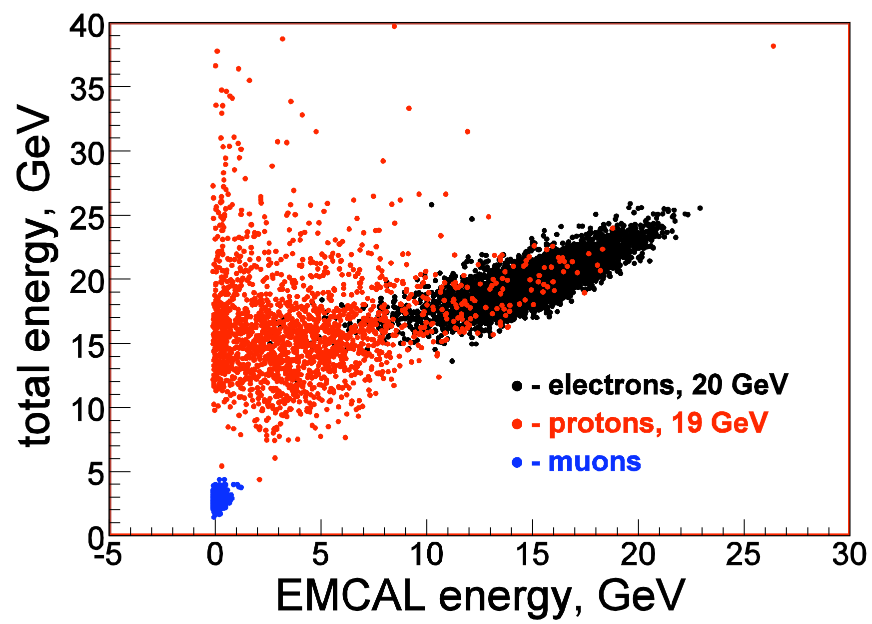
- From Selex, entirely new readout electronics and some PMTs replaced
- Radiator: CO_2 gas at STP
- Gives lots of hits for MIPP momentum range.
  - easy to fit good circles
- RICH ring radius gives very good particle ID
  - e/μ/π up to 12 GeV/c
  - π/K/p to 120 GeV/c

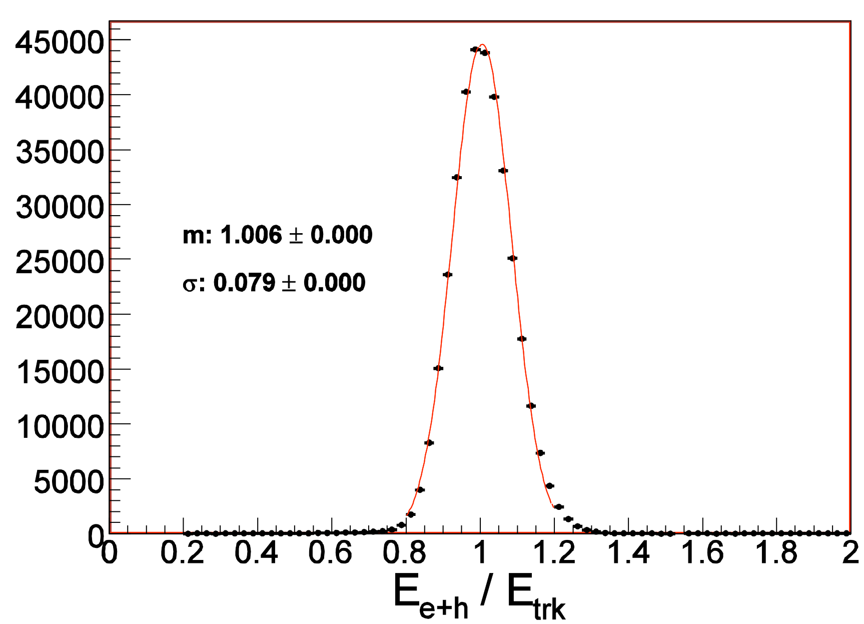




Calorimeters

- EM calorimeter followed by hadronic calorimeter
- NIM A598 (2009) 394-399

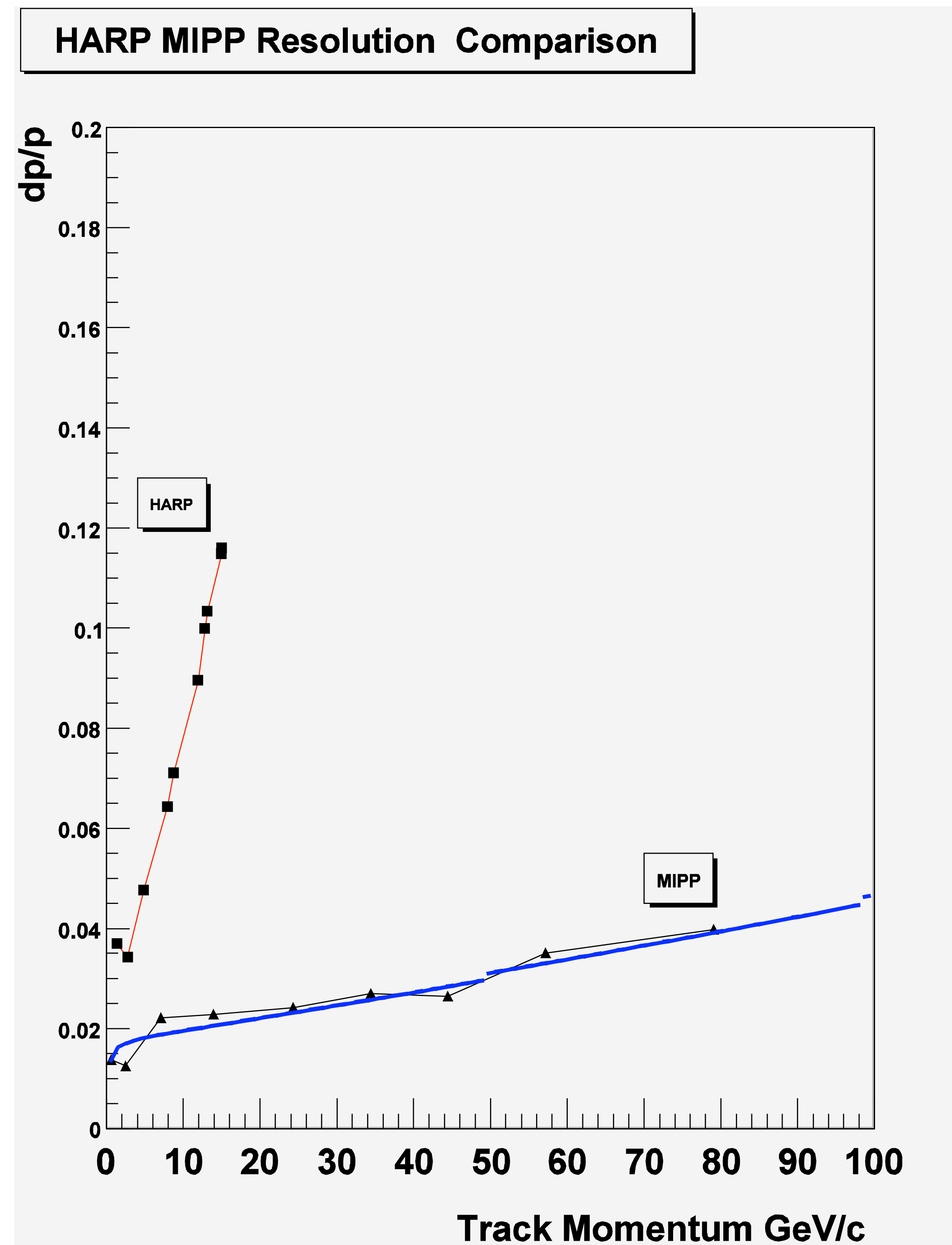




$$\frac{\sigma}{E}=\frac{0.554}{\sqrt{E}}\oplus 0.026$$

Momentum resolution compared to HARP at CERN

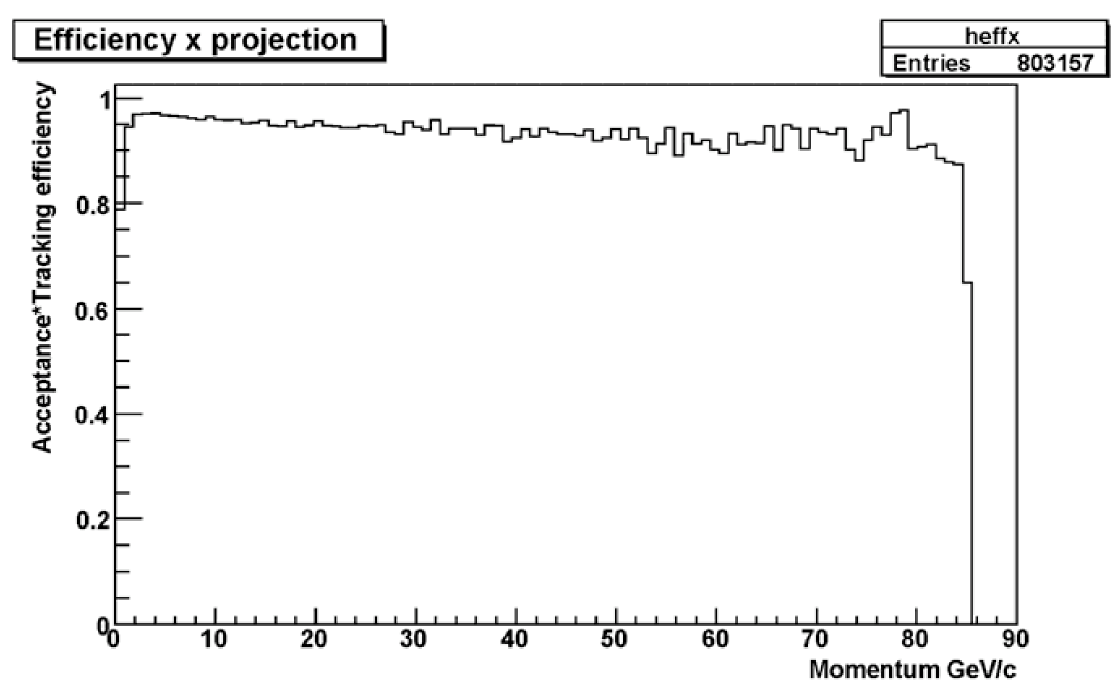
- MIPP momentum resolution is excellent
  - TPC with JGG field at low momenta
  - Rosie magnet and Drift Chambers at higher momenta
  - Redundancy
    - 128 TPC hits
    - 24 wire chamber planes



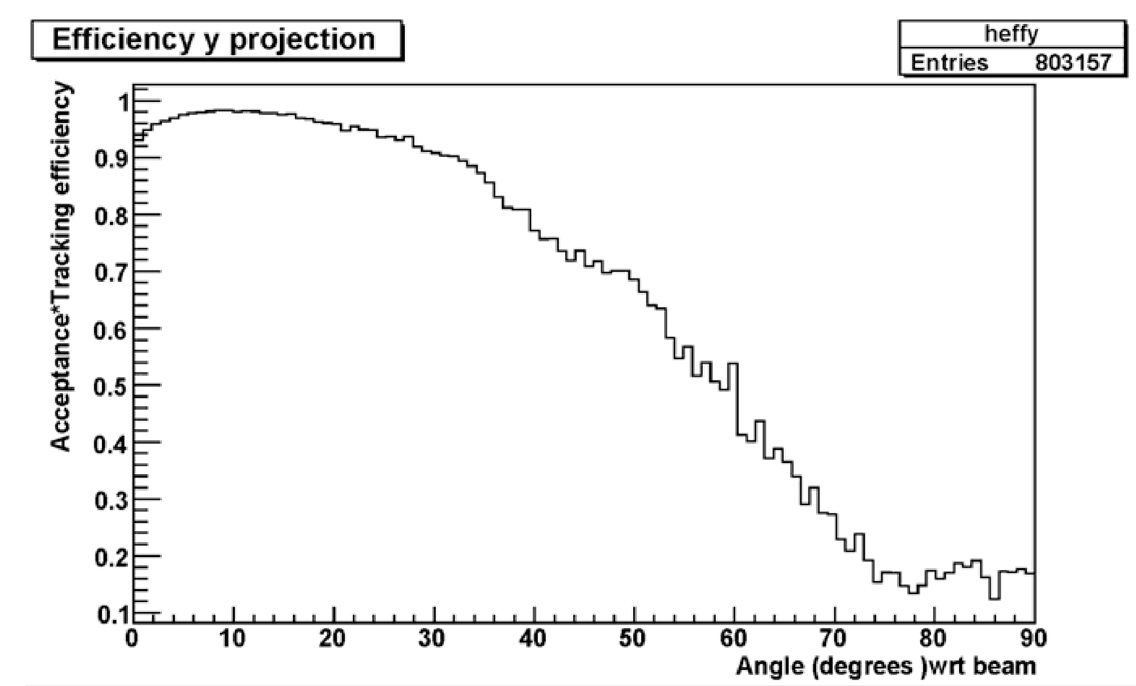
Detector acceptance

MIPP-I Acceptances
MIPP-II will have backward acceptances.

Efficiency vs. momentum

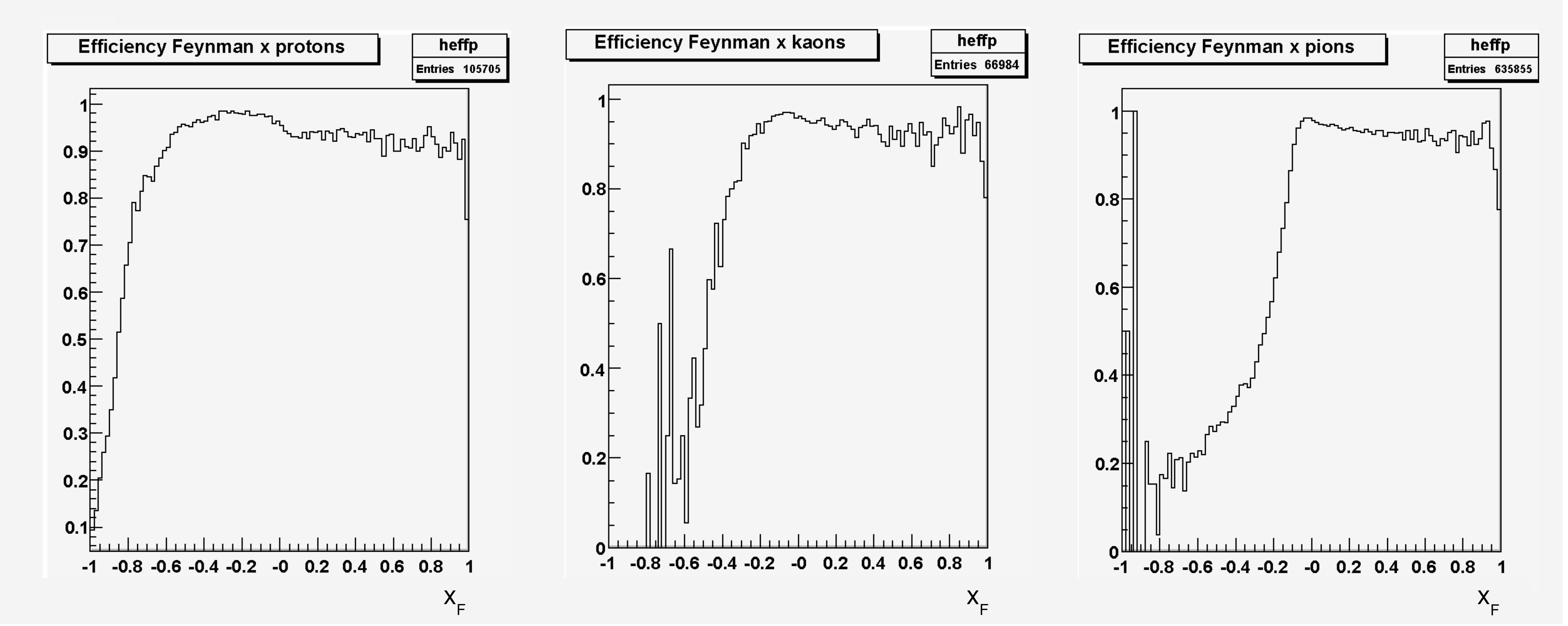


Efficiency vs. θ_{lab}



Detector acceptance

- Pions at low x_F move backward in the lab



- Plastic Ball detector in the upgrade will increase acceptance.

MIPP Data set

Final Data Summary, Number of events x 10^6												
Target			Beam momentum (GeV/c)									
Z	Element	Trigger Mix	5	20	35	40	55	60	65	85	120	Total
0	Empty thin	Normal		0.10	0.14			0.52			0.25	1.01
	Empty cryo	Normal		0.30				0.61		0.31		1.22
	K mass	No Int.				5.48	0.50	7.39	0.96			14.33
1	LH	Normal	0.21	1.94				1.98		1.73		5.86
4	Be	p only									1.08	1.74
		Normal			0.10			0.56				
6	C	Mixed						0.21				1.33
	C-2%	Mixed		0.39				0.26			0.47	
	NuMI	p only									1.78	1.78
13	Al	Normal			0.10							0.10
83	Bi	p only									1.05	2.83
		Normal			0.52			1.26				
92	U	Normal						1.18				1.18
Total			0.21	2.73	0.86	5.48	0.50	6.58 +7.39	0.96	2.04	4.63	17.05 +14.33

MIPP Results

- Published Articles
  - K+ Mass: NIM A631, Mar/10
  - Calorimetry: NIM A598, Jan/09

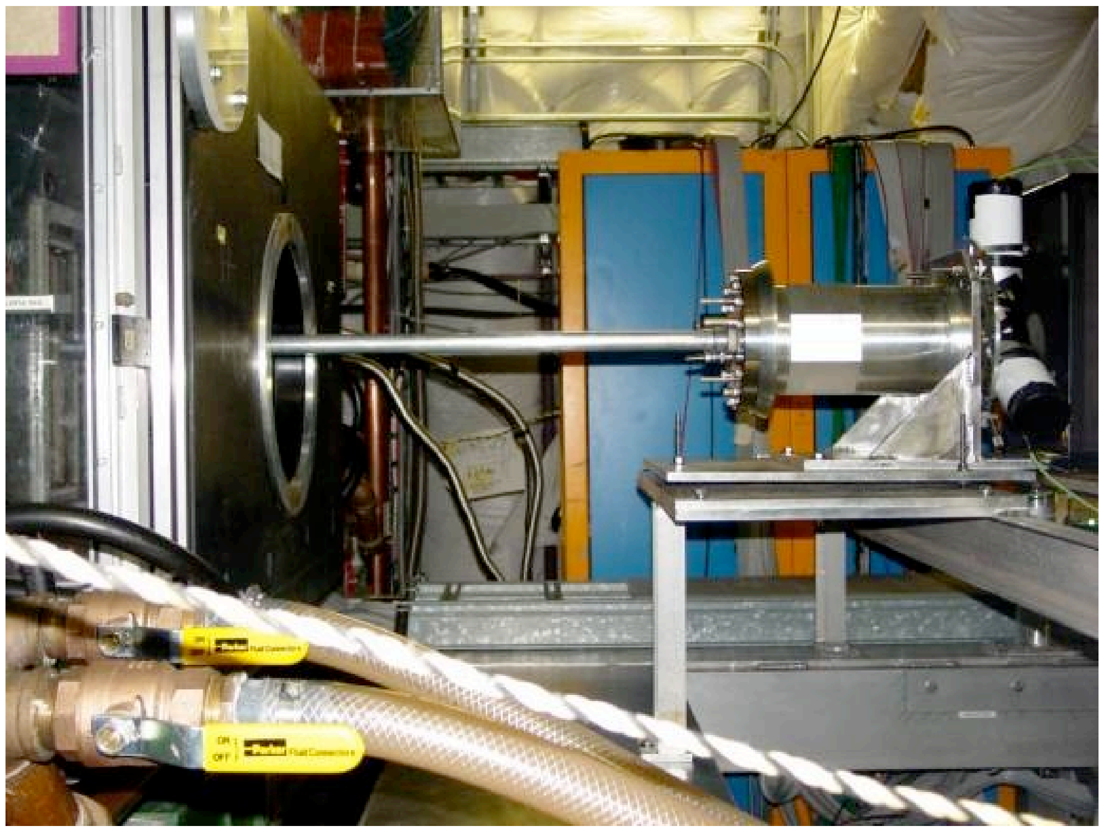
- Advanced Analyses
  - *NuMI Target Particle Yields*
  - *Forward Neutron Production Cross-Section*

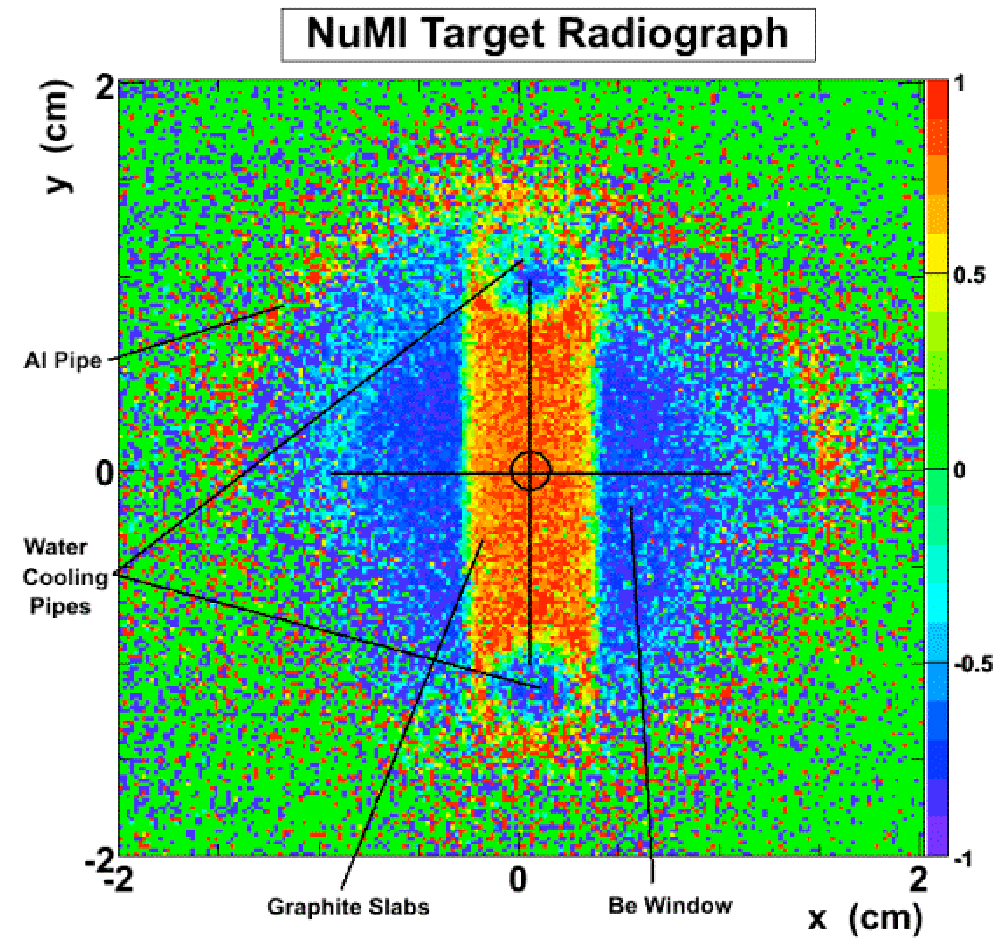
- In works
  - Lot more cross-sections, Nuclear Physics
  - Physicists and Students in Indo-US collaboration

- Ph.D. Theses
  - Five Ph.D's awarded
  - 3-4 in progress

The NuMI target measurement

2 interaction length

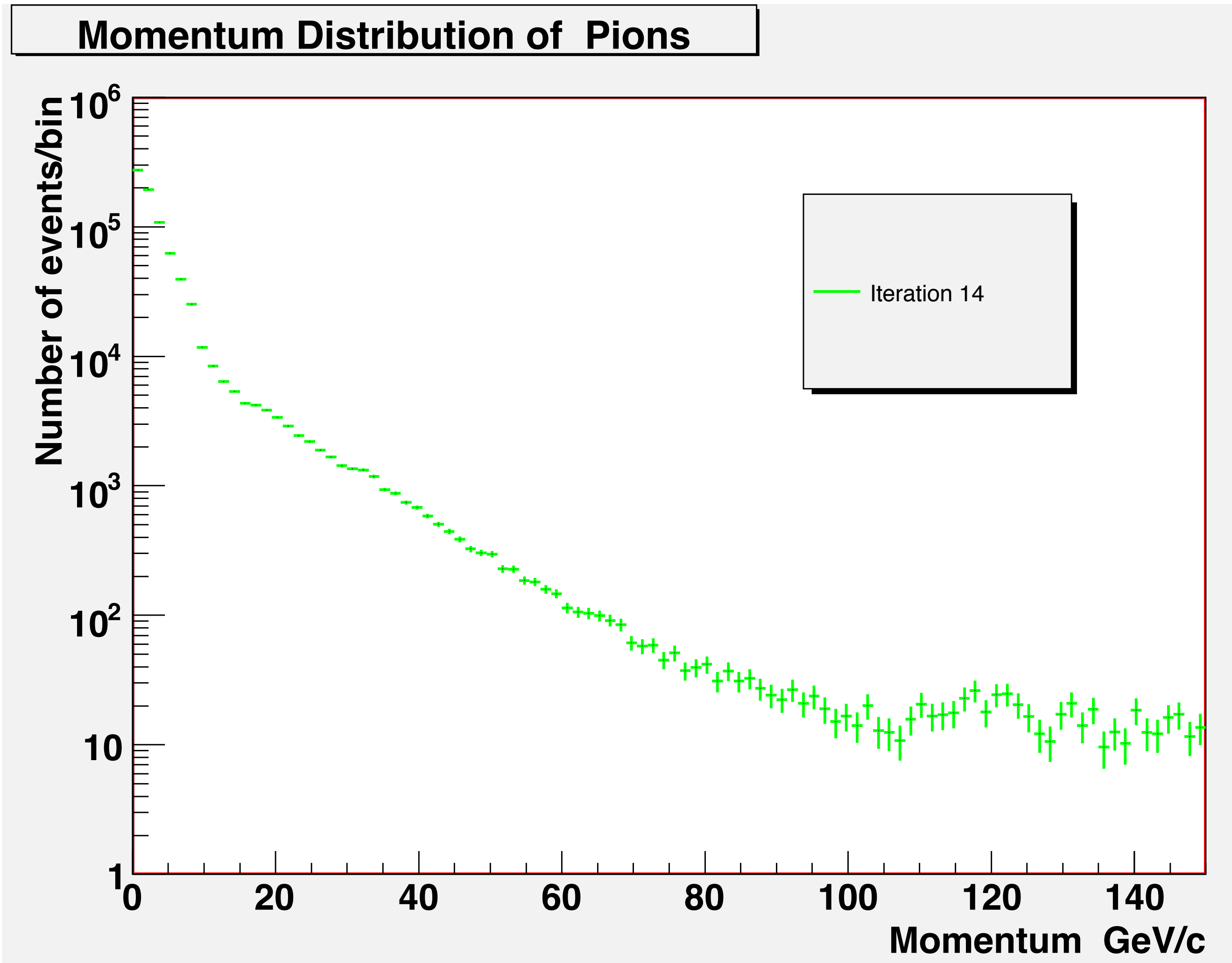


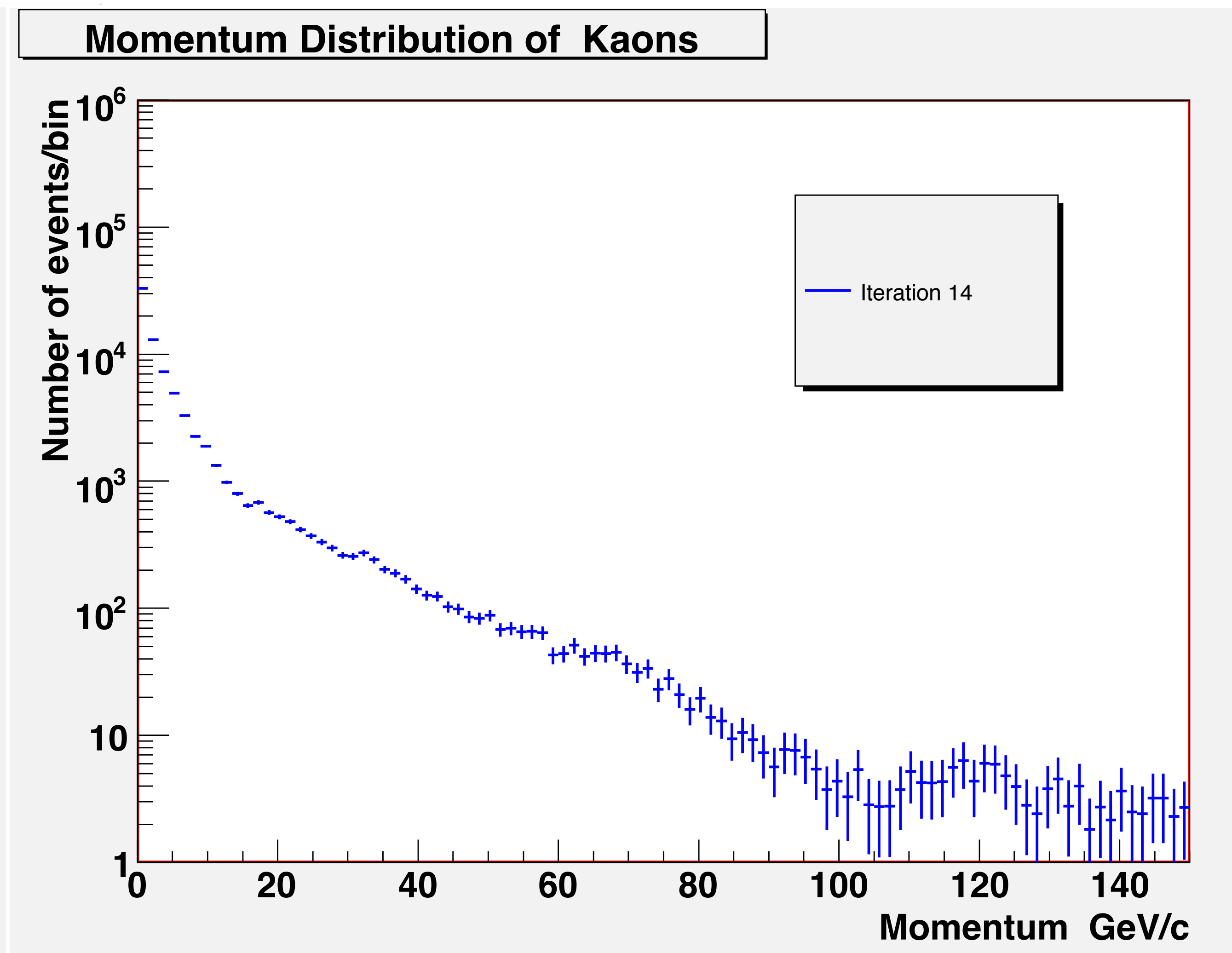


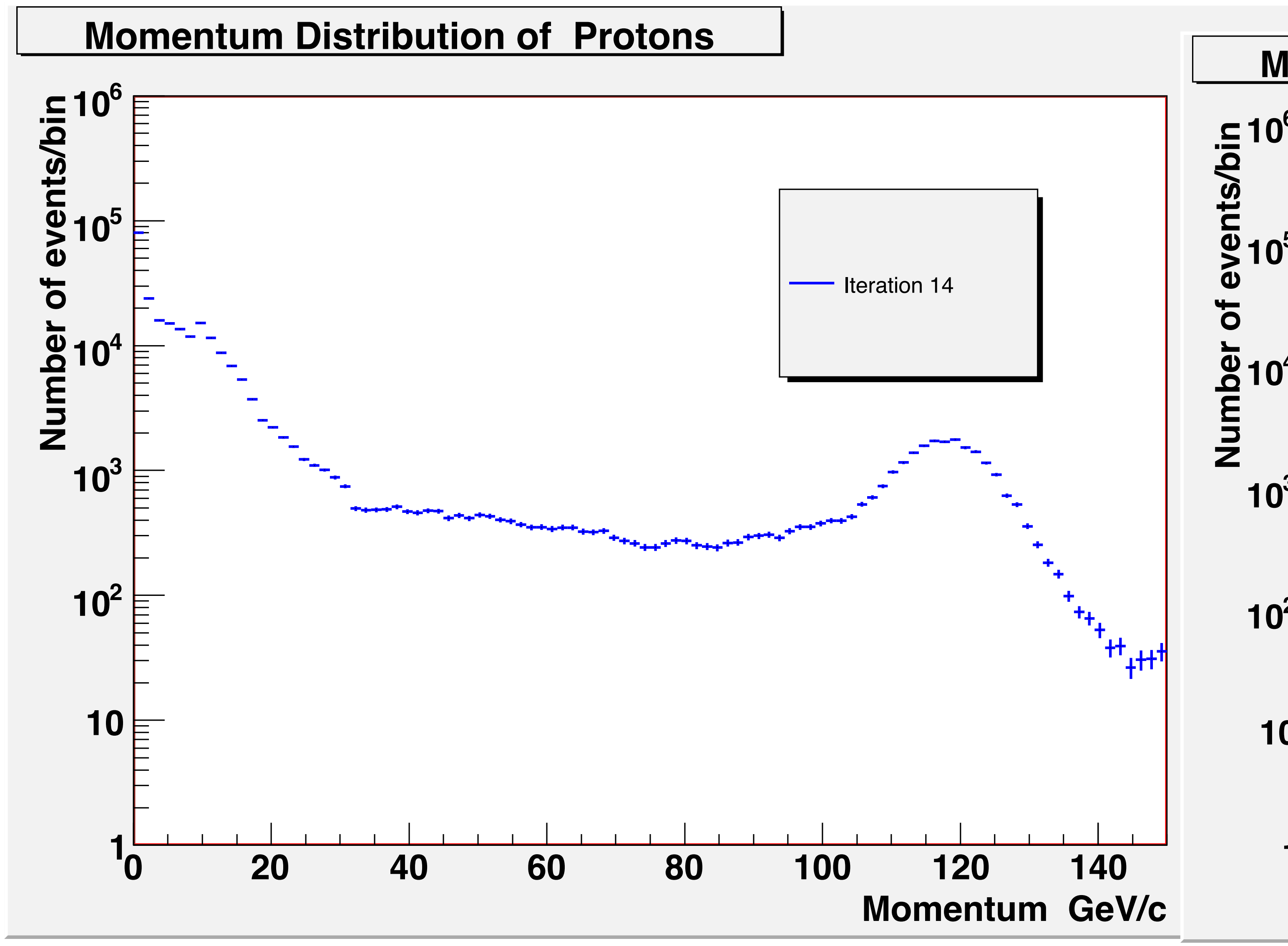
- NuMI analysis goal:
  - provide particle spectra from direct measurement to reduce systematic uncertainty in ND/FD ratio of neutrino spectra.

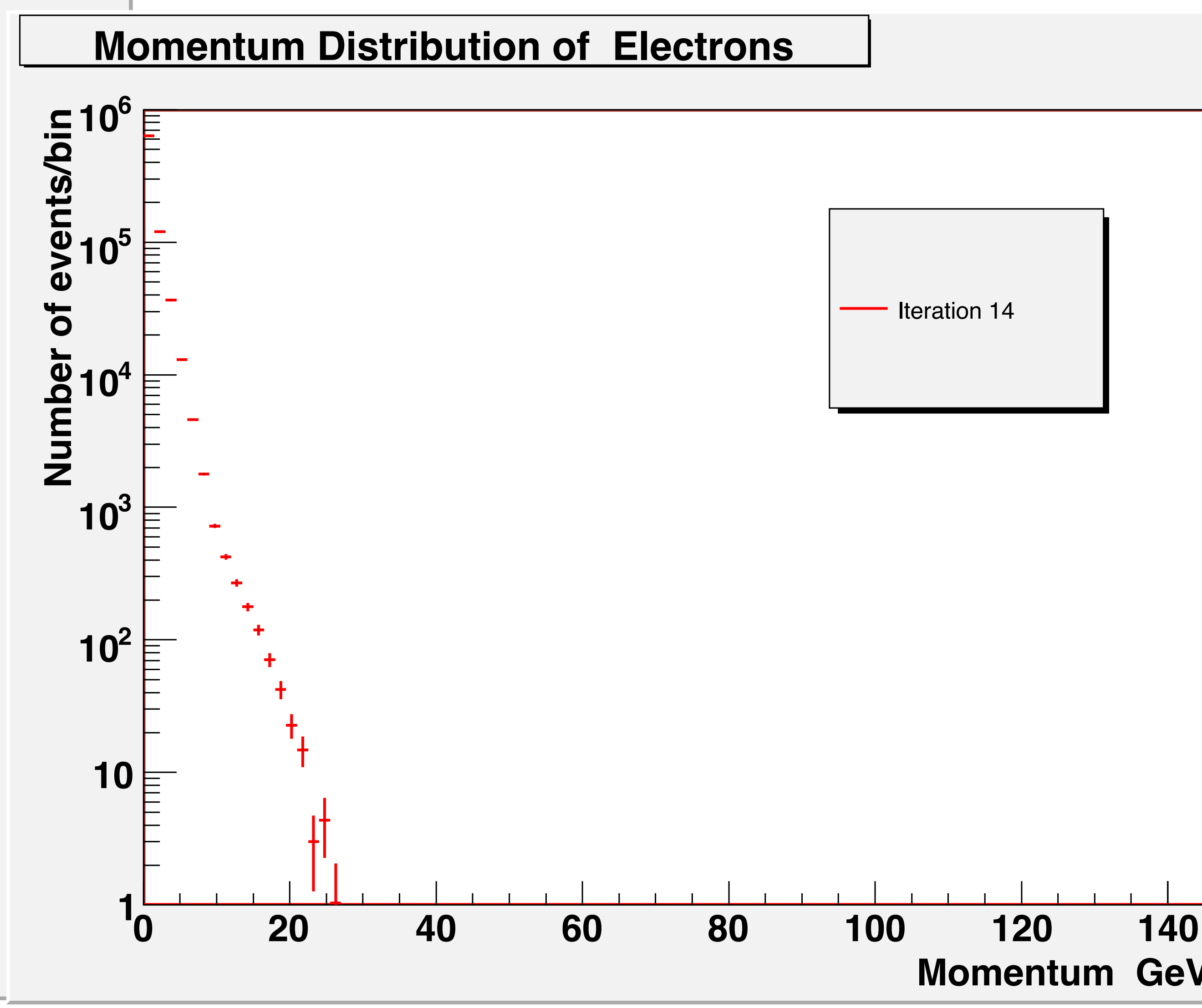
Global PID

- 4-Hypotheses for Each charged track: e π K P
- ID: dE/dx ToF Ckov Rich Cal
- Max LH fit for each hypothesis; iterate





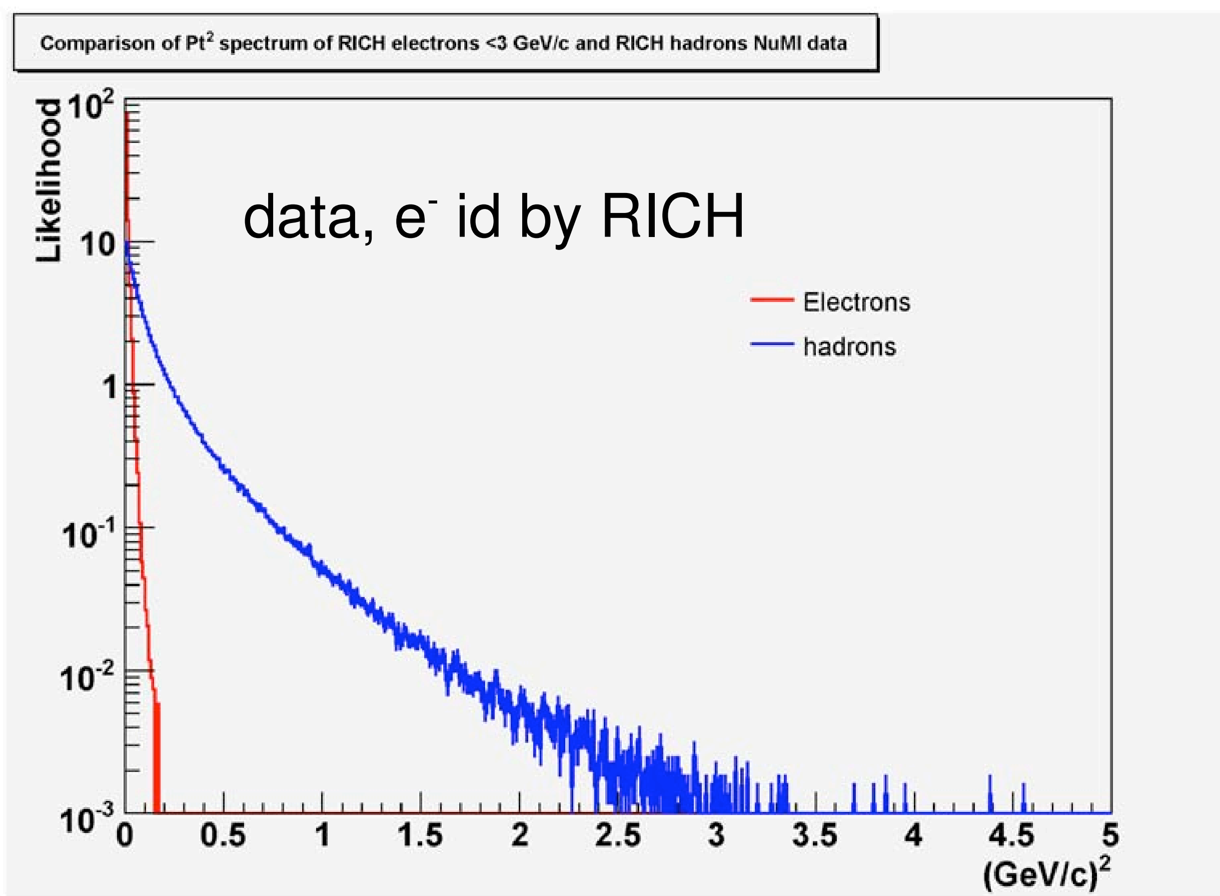

Momentum Distribution of Protons
Iteration 14
Number of events/bin
Momentum GeV/c

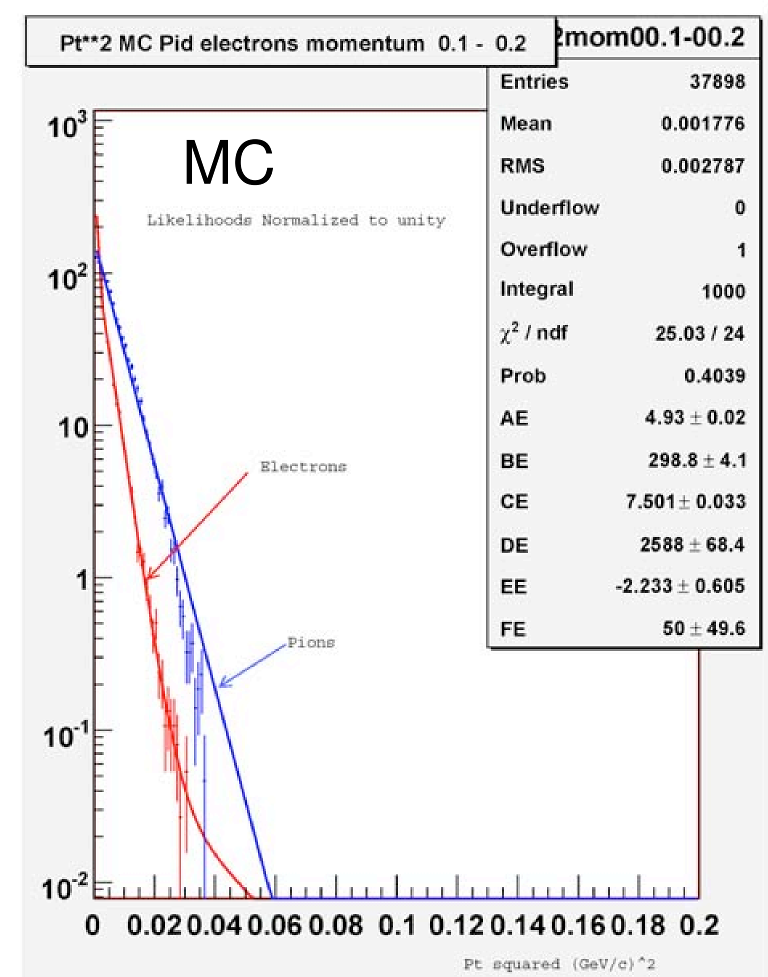

Momentum Distribution of Electrons
Iteration 14
Number of events/bin
Momentum

Separation of Electrons and Pions in MIPP – p_t^2 as a discriminant

MIPP

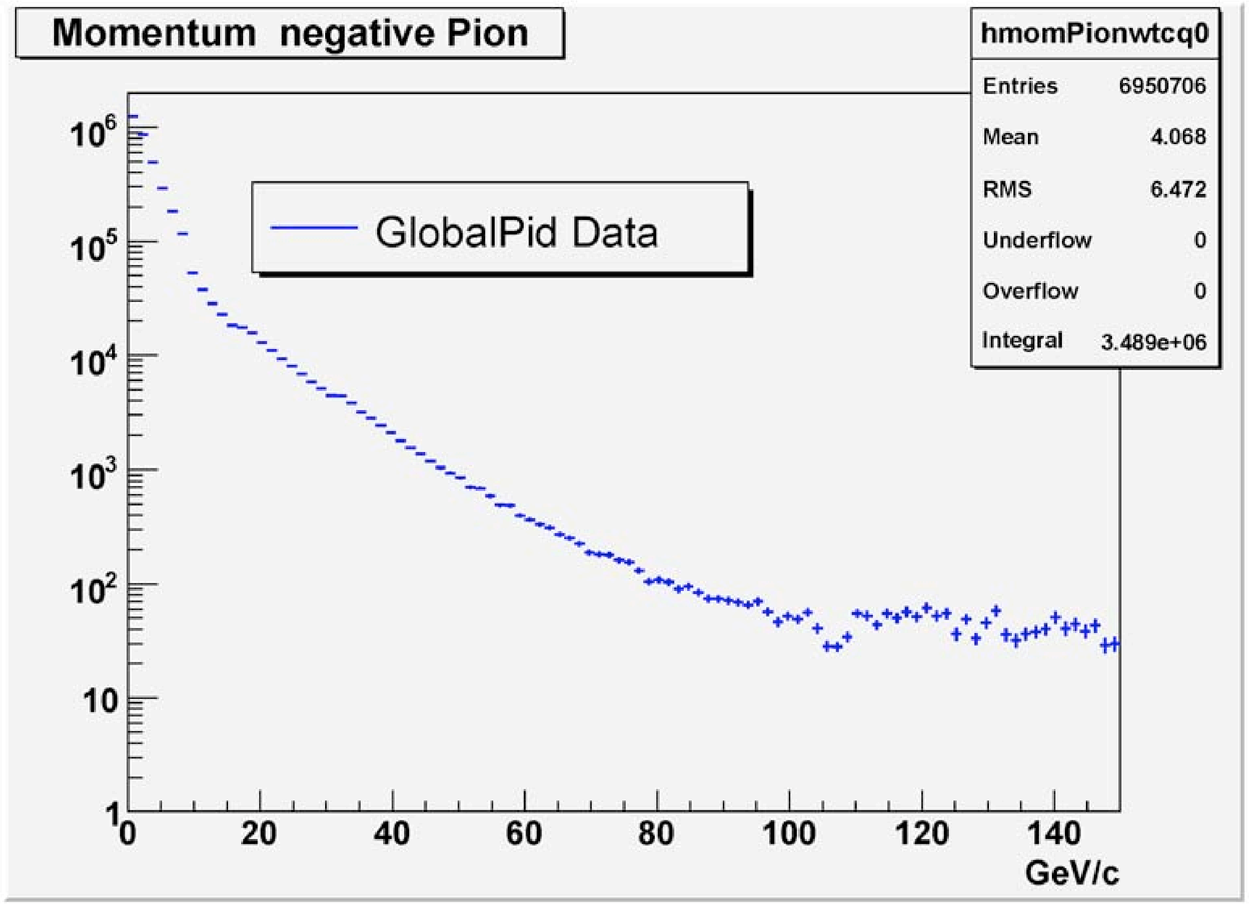
- There is some distinction between electrons and pions in the TPC dE/dx and in the RICH below the pion threshold at 4.6 GeV/c. Pretty much everywhere else they are indistinguishable since they are both β~1 particles.
- However, electrons arise from π^0 which decay to two photons which then convert again. At each stage the average p_t of the final state particle is lowered by ~ a factor of two. So for any given momentum an electron will have approximately a factor 4 less p_t than a charged pion. Verified in data and MC. Use p_t^2 likelihood as an added discriminant – R. Raja, MIPP-Doc 993

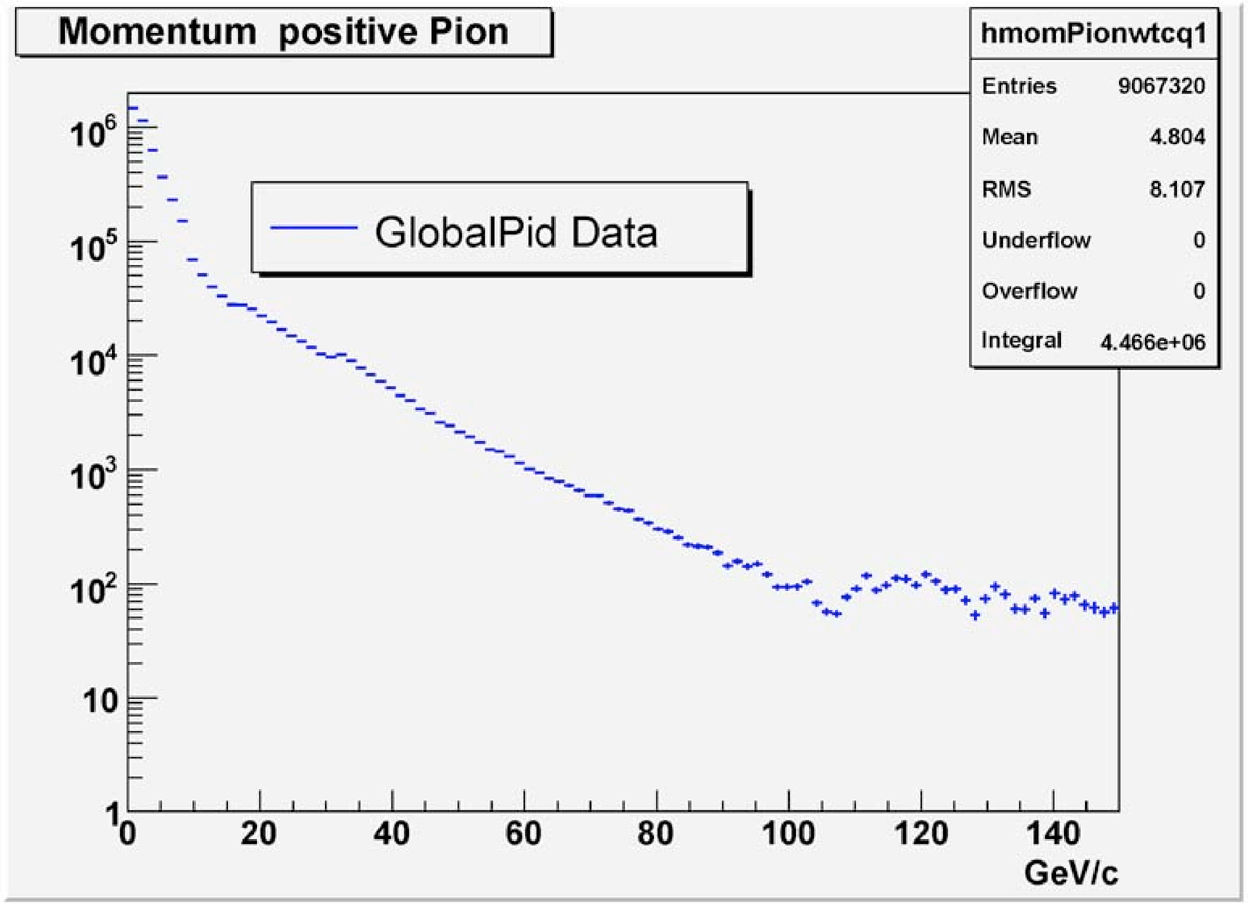




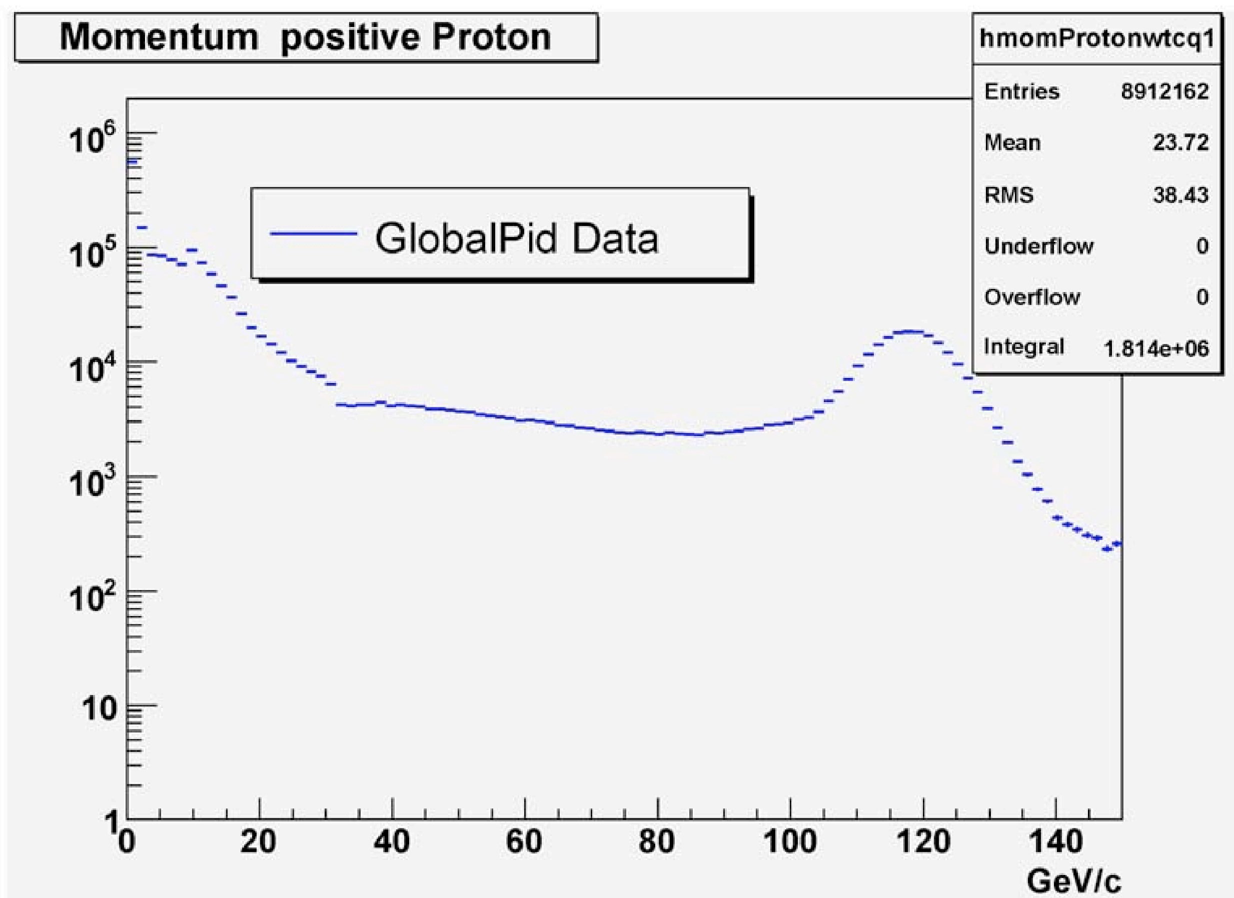
NuMI target analyzed by GlobalPid

MIPP





NuMI target analyzed by GlobalPid



- Further work to be completed
  - Tweak various algorithms
  - As p_t increases, we lose acceptance. This results in a dilution of analysis power of algorithm. P_t dependence has to be studied before we make detailed MC data comparisons.
  - Estimate systematic errors
  - Do momentum smearing corrections
  - Minority particles (K, p-bar) after further study

Forward Neutron Production

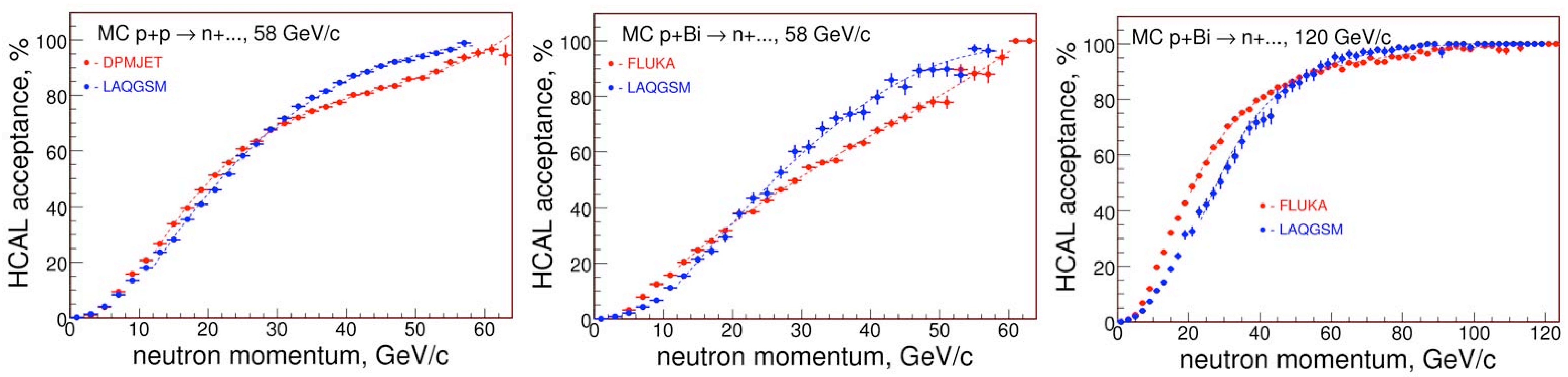
- What we measure: *p + A ⇒ n + X* [n ➽ Excess energy in Cal]

- Beam Energy: *20, 58, 84, & 120* GeV

- Targets: *H, Be, C, Bi, U*

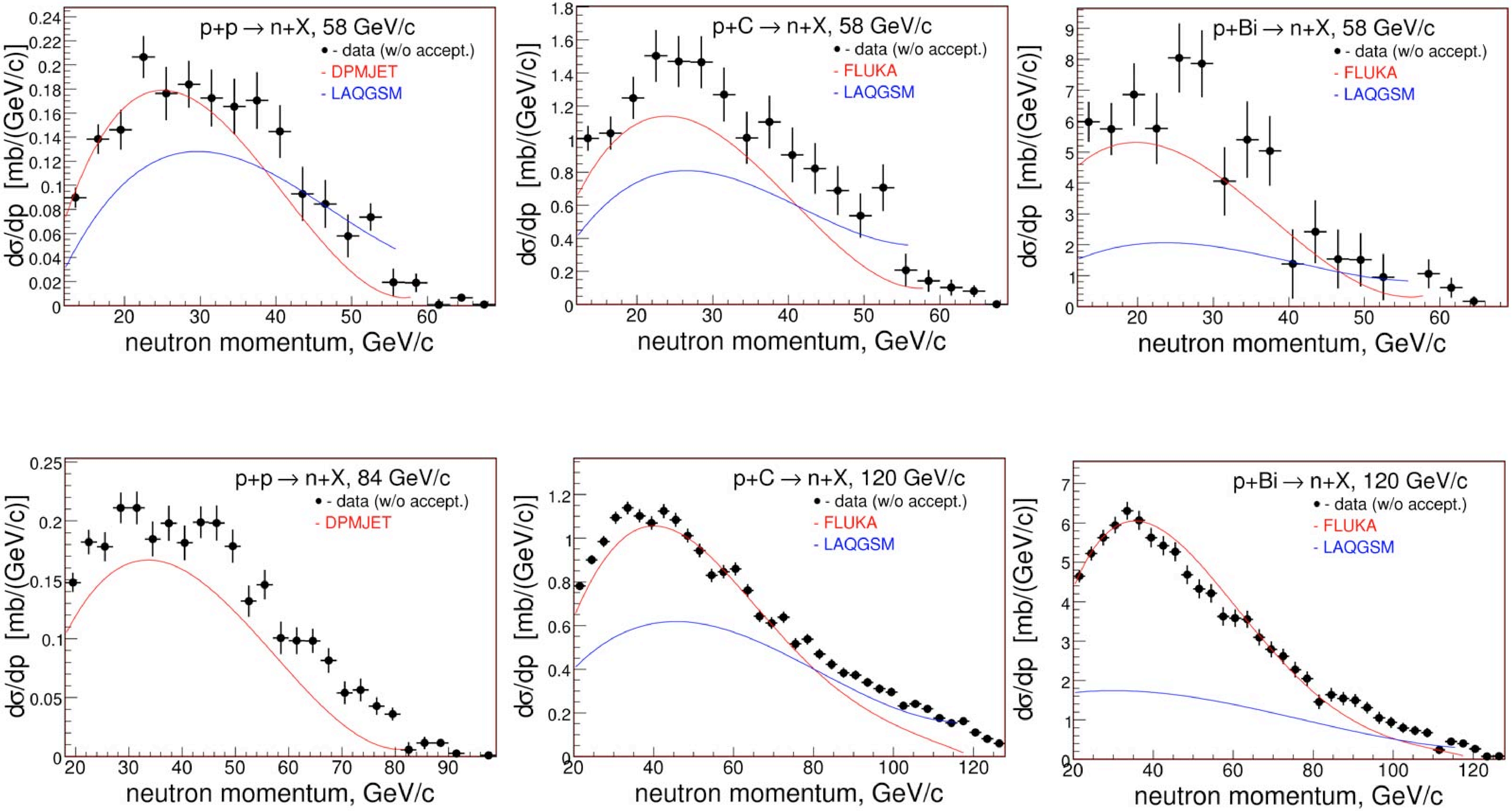
- Cross-Checks: *Use known p-p cross-section to check*
  ➢Beam Flux ➢Reconstruction ➢Acceptance

- Acceptance: *MC Estimations* [Large differences]



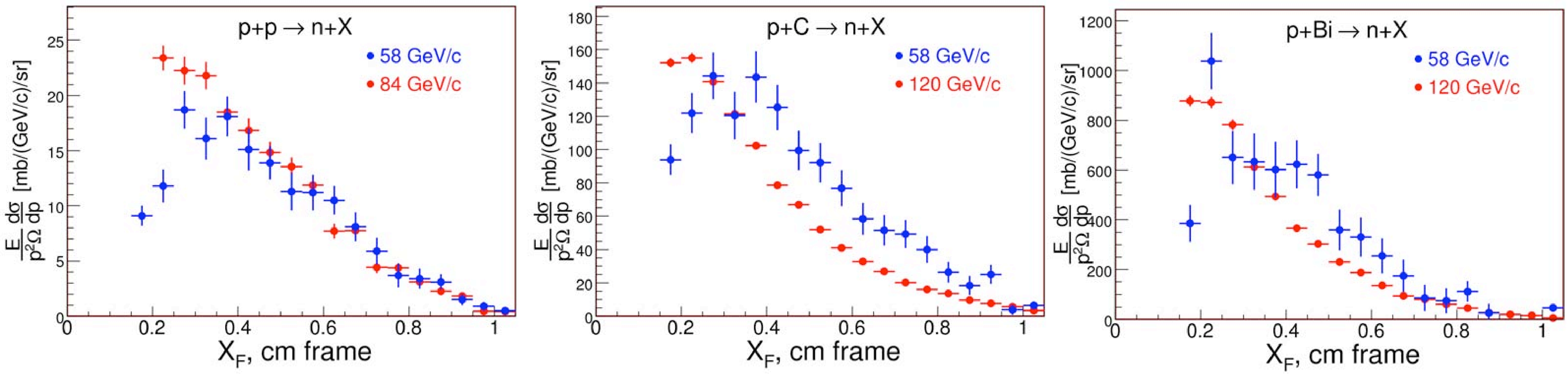
Neutron cross sections
some cross section results

MIPP

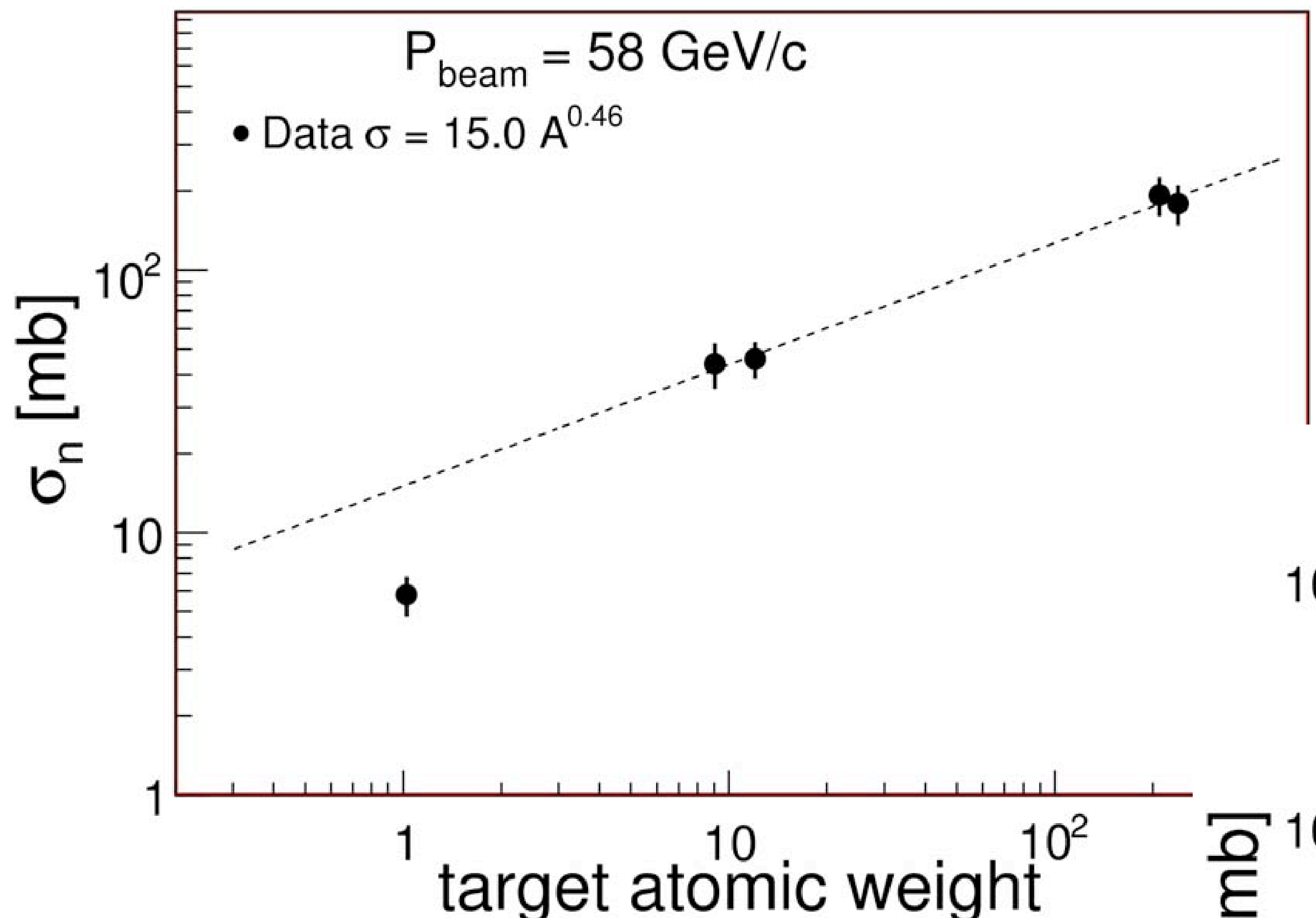


Neutron cross sections
invariant cross section scaling

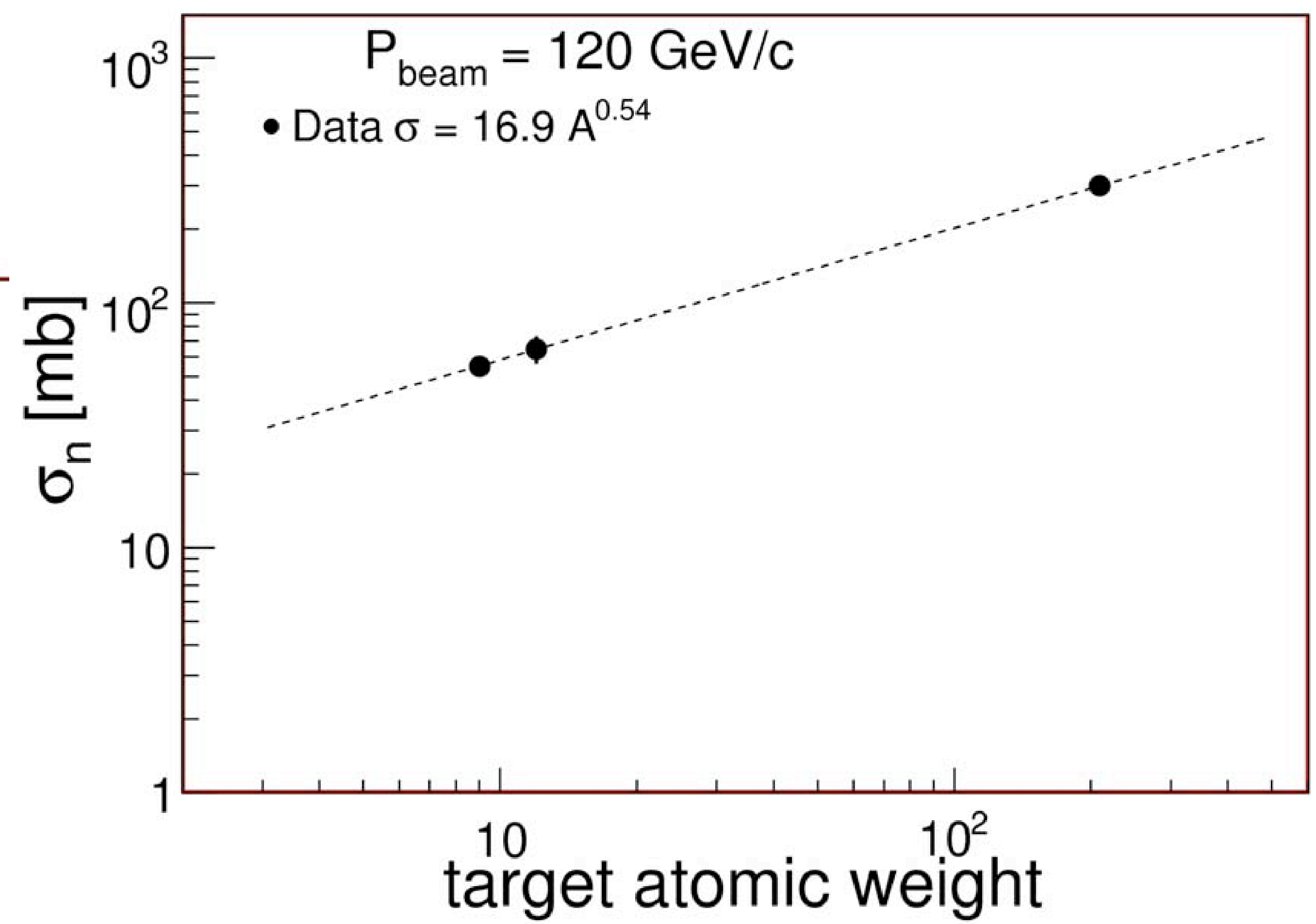
- Scaling of the Lorentz invariant cross section
  - Observed for p+p
  - Not observed for p+A



Neutron cross sections Results as a function of A

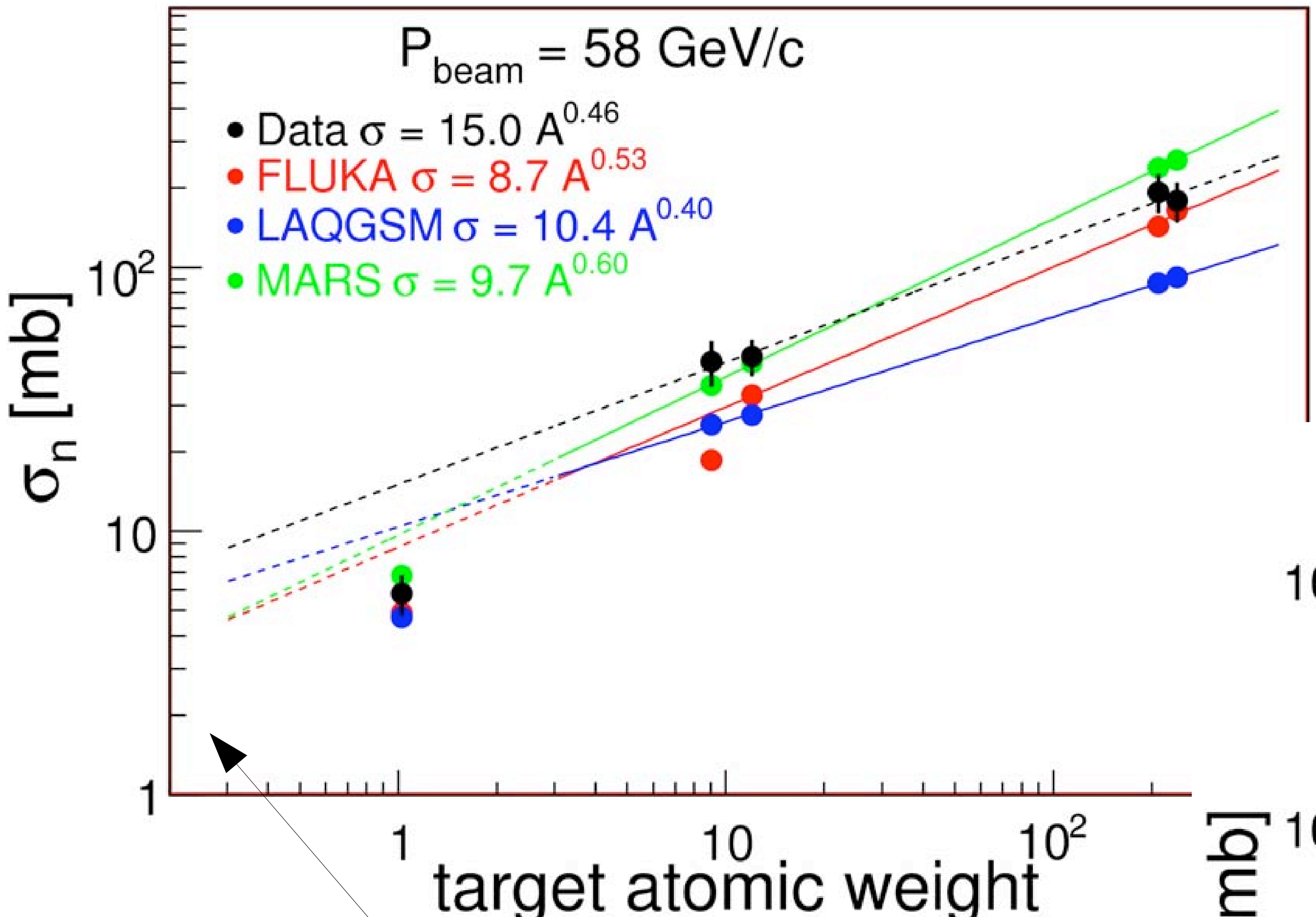


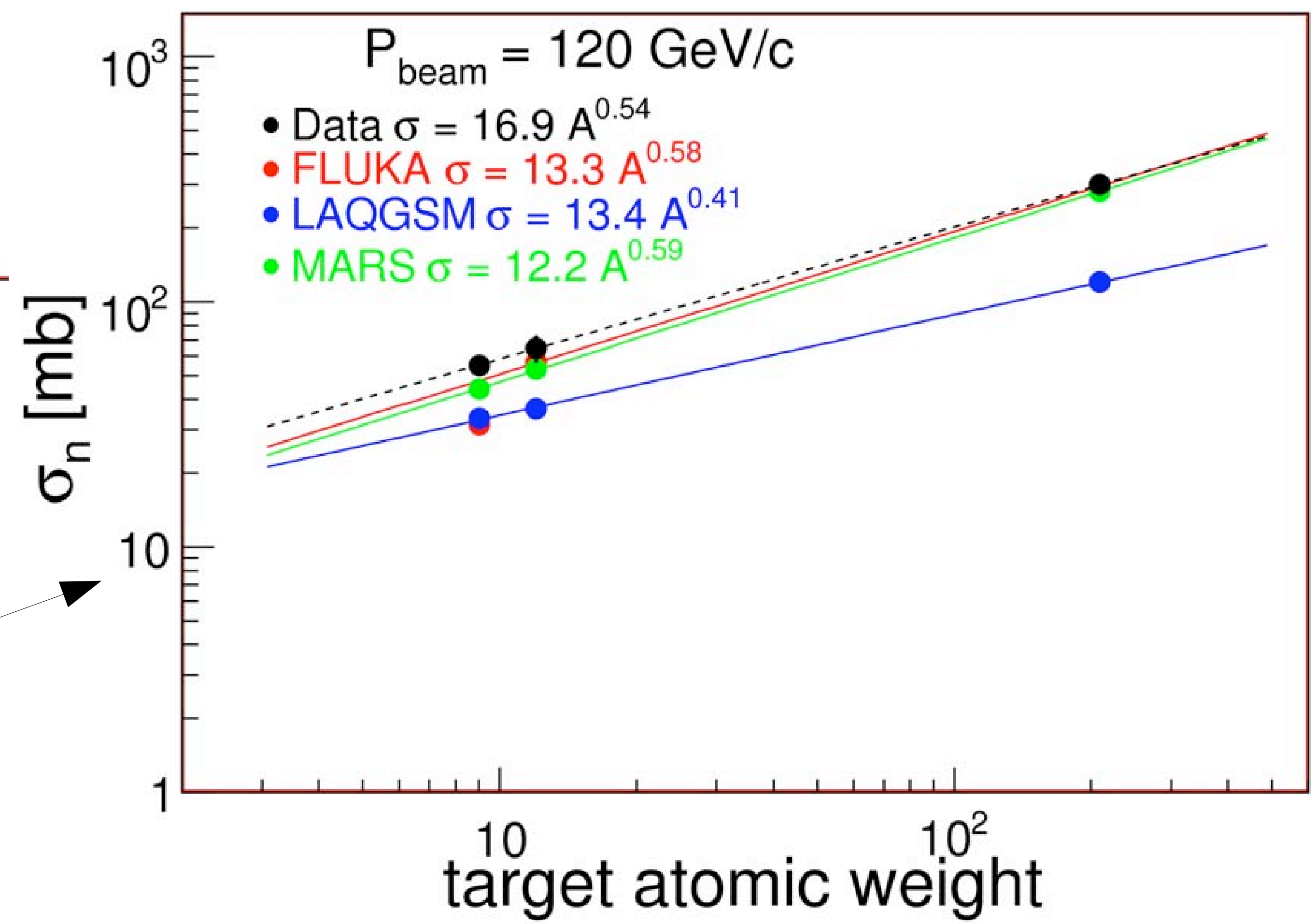
- MIPP neutron cross section measurements on nuclei show consistent behavior
  - $A^{0.5}$ dependence
  - LH_2 data point is lower



Neutron cross sections
Results as a function of A

- MARS predictions





log scale

MIPP Upgrade

Proposed Data

- x100 times more data: ≃ 5 Million events/day/nucleus
- Nuclear Targets:
  - *H, D, Li, Be, B, C, N, O, Mg, Al, Si, P, S, Ar, K, Ca, Fe, Ni, Cu, Zn, Nb, Ag, Sn, W, Pt, Au, Hg, Pb, Bi, U*
  - Thick & Thin targets
  - Targets for NuMI, LBNE, ν-Factory & elements used in ν beam-line

Solve the Hadron Shower Simulation problem

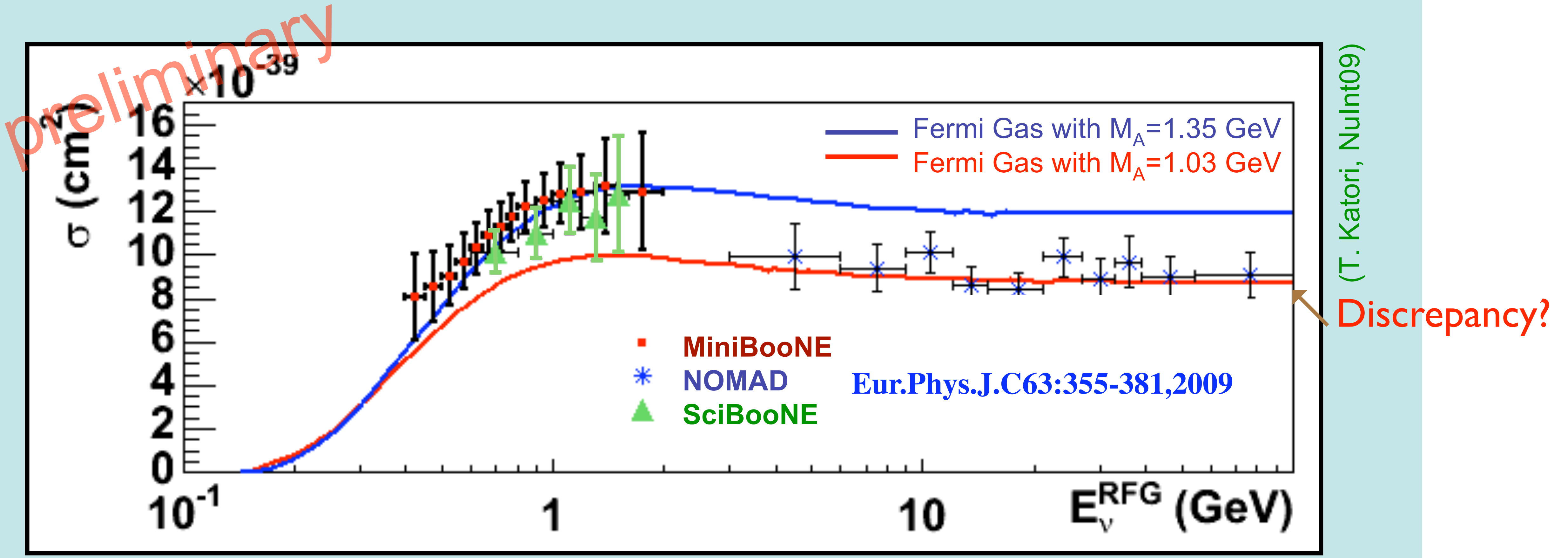
⇒ Constraint on ν-Flux

- Baryon Resonance, Scaling,
- Nuclear Physics

QE

Quasi-Elastic Scattering

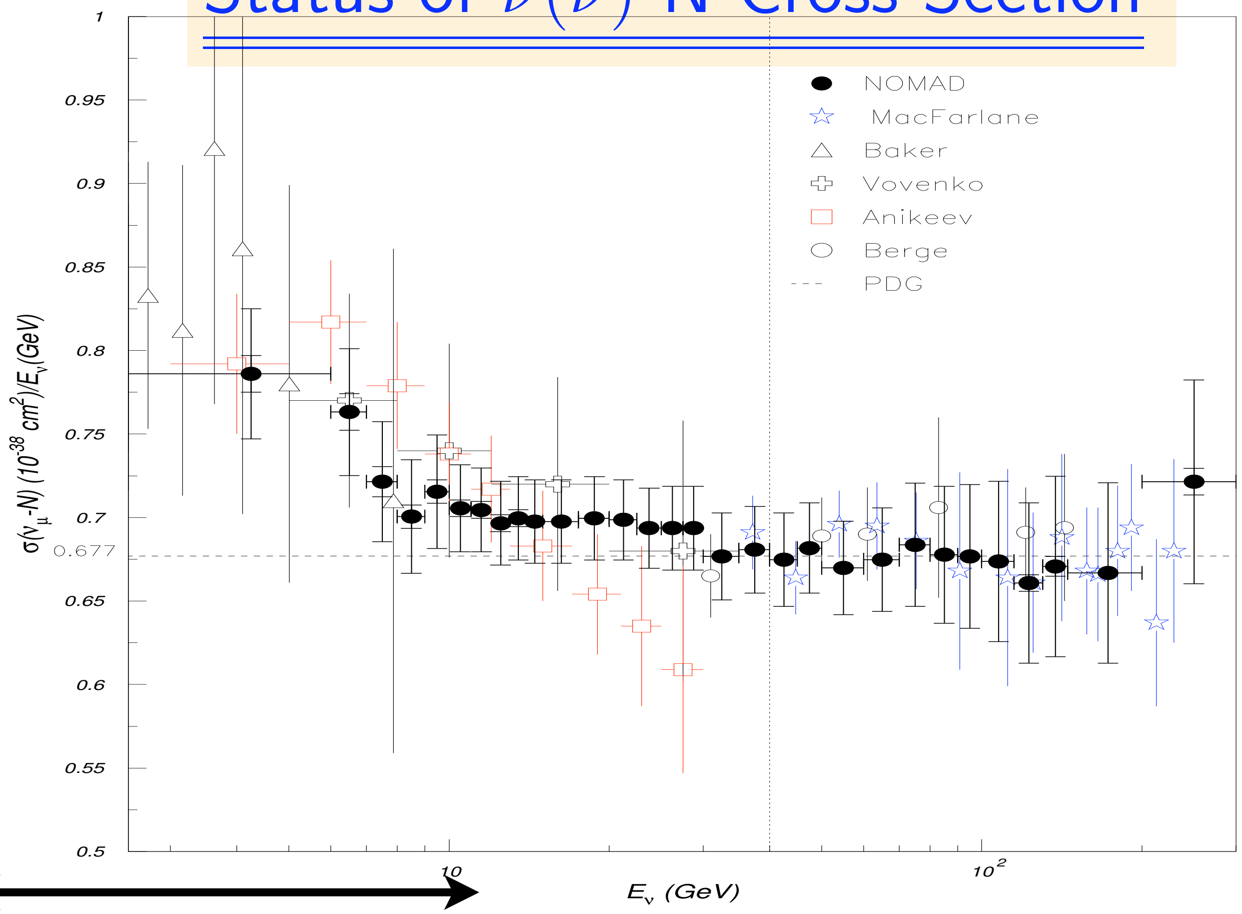
• new, modern measurements of QE σ at these energies (on ^{12}C)

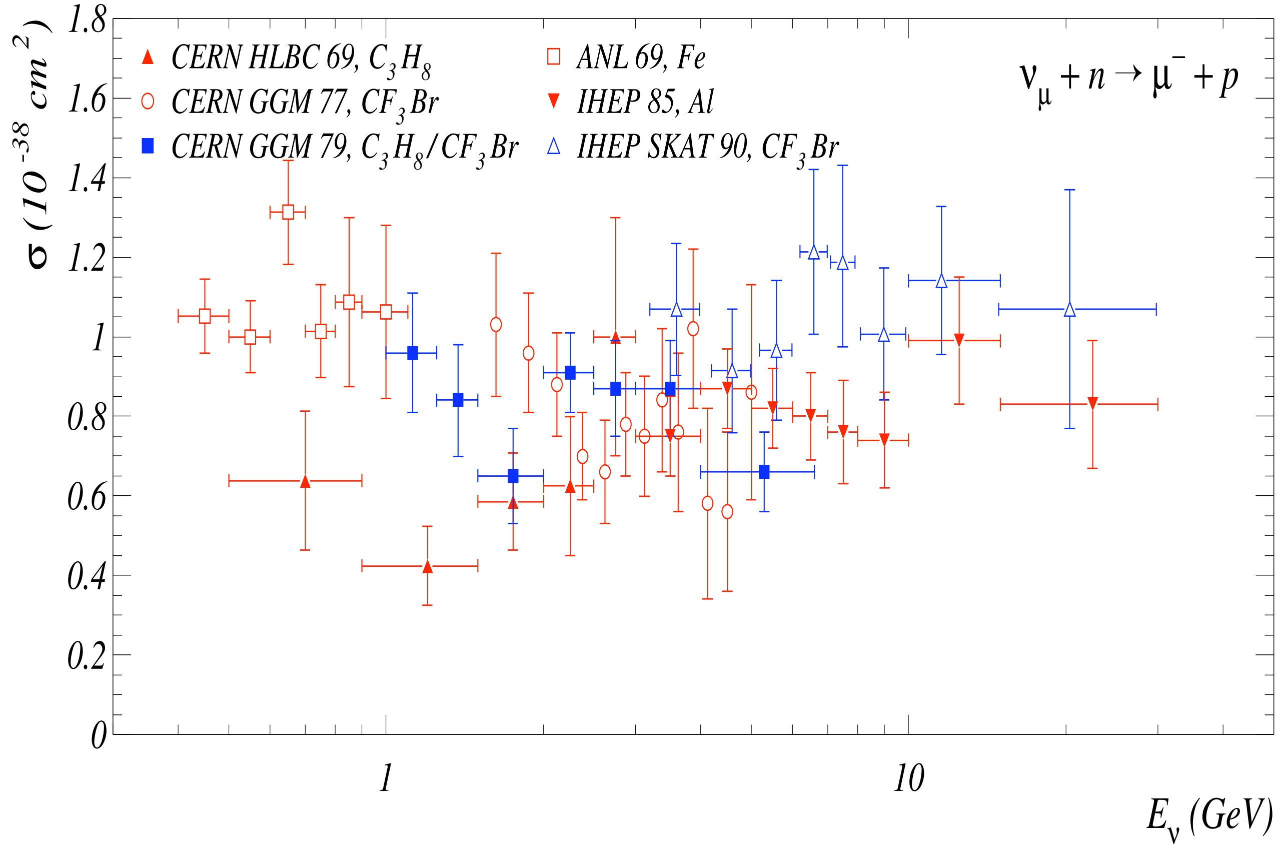


~ 30% difference between QE σ measured at low & high E on ^{12}C ?!

?

Status of $\nu(\bar{\nu})$-N Cross-Section





Flux: … Always the Flux

σ(νN) ⇒ ***Absolute-*ϕ**(ν)-Flux // Poorer precision in σ(anti-νN)

MIPP is not a `be-all/end-all' for ϕ(ν)

MIPP *will* provide an invaluable constraint, currently missing, on the flux

REQUIREMENTS FROM EXTERNAL MEASUREMENTS

Search for Large Δm**2 *Oscillation:* P($\nu_\mu \rightarrow \nu_e$) & *anti*-P($\nu_\mu \rightarrow \nu_e$)

- *We need the following external measurements from p-production experiments (e.g. MIPP at Fermilab):*
  - K^+/π^+ *as a function of* $P(2 \leq P \leq 20\ GeV)$ & $P_T(\leq 0.4\ GeV)$ *of* K^+ *and* π^+
  - K^-/π^- *as a function of* $P(2 \leq P \leq 20\ GeV)$ & $P_T(\leq 0.4\ GeV)$ *of* K^- *and* π^-
  - K^0/K^+ *ratio*

- *We need these measurements off:*
  - *LBNE neutrino target;*
  - *Thin/Thick Al, Cu, etc. targets that compose horn/beam-elements;*
  - *Air (N)*

MIPP Upgrade ...cont.

- **Detector Upgrade** {Most elements from 1990's}
  - TPC Readout upgrade: *30 Hz* ➸ *3000 Hz* {Chips delivered}
  - JGG Coil Replacement: Done
  - Recoil Detector: DGSI Plastic-Ball {wide angle *p, n,* γ}
  - Beam Veto Wall: Assembled at FNAL {Sadler et al.}
  - BDC/Ckov/ToF/Calo Readout: Prototypes built {Compatible with 3kHz rate}

- **Beam Upgrade**
  - Tagged Neutral Beam {*n*, $K0_L$}

- **New Institutions have joined the proposal**
  - Indian Physicists in the Indo-US ν-Collaboration

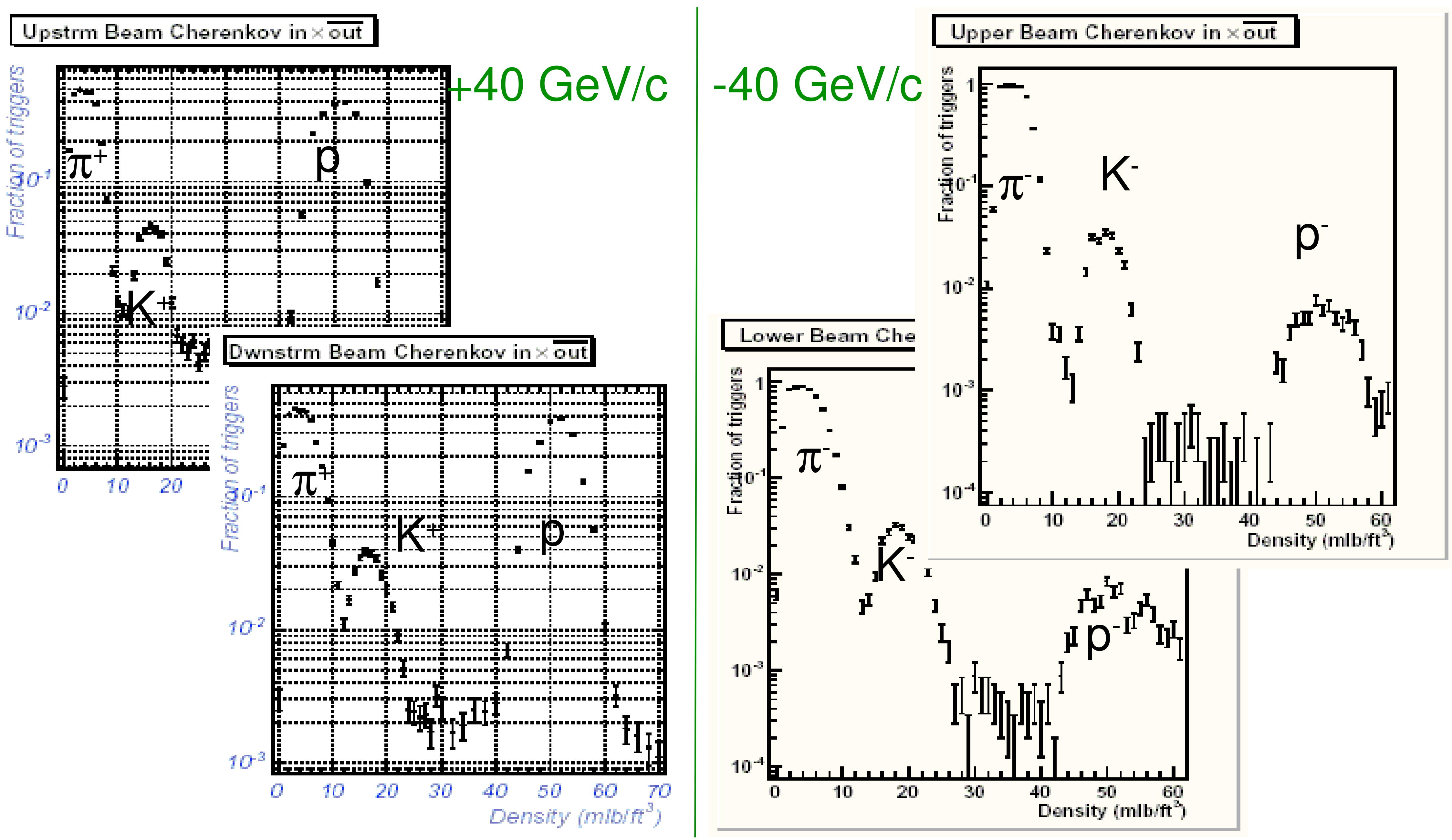
- **Cost of the Upgrade:**
  - $2M {*$0.5M spent*}

Backup Slides

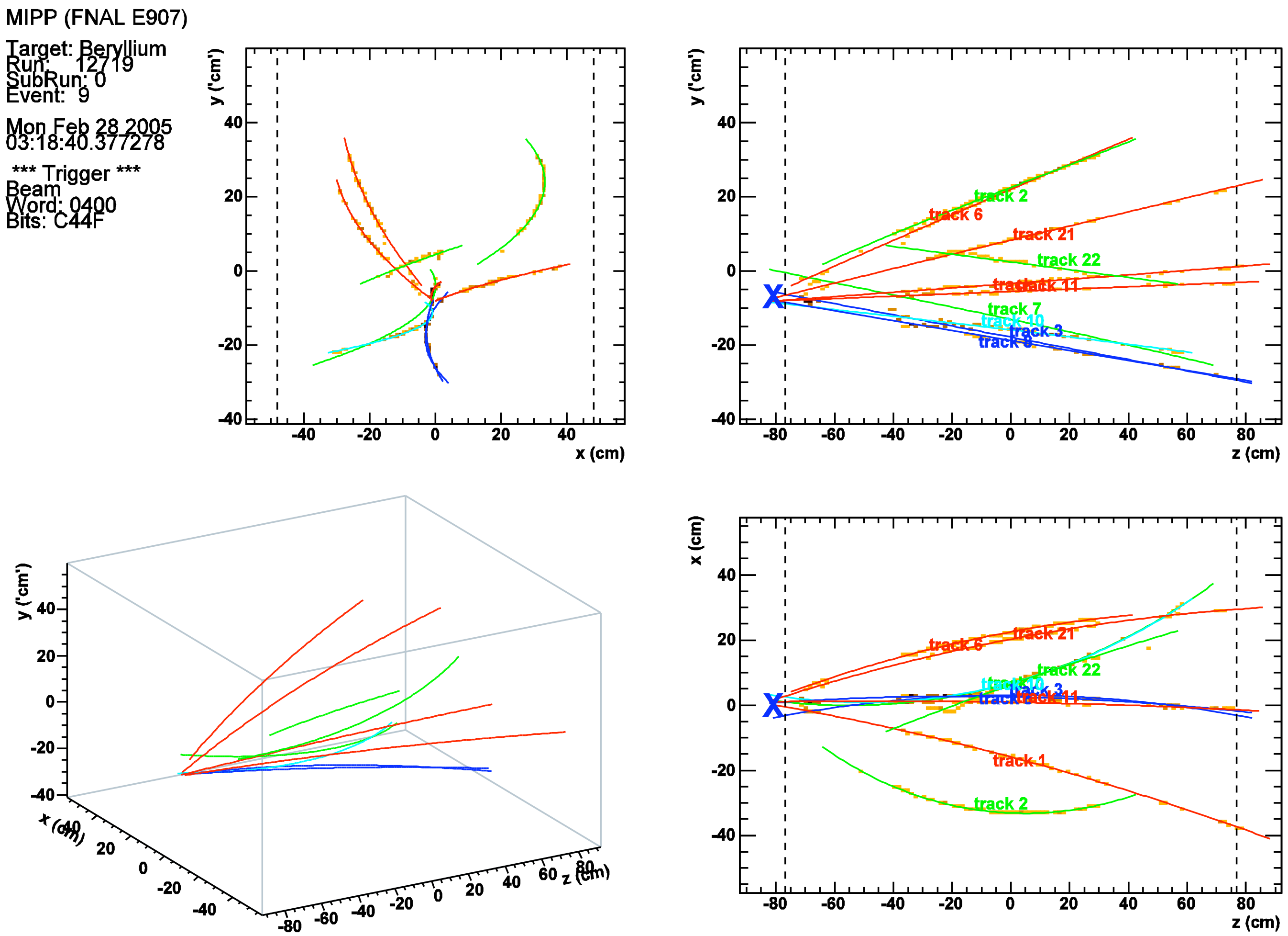
Beam Cherenkov Pressure Curve

MIPP

- Two differential Ckovs separate π/K or K/p depending on N_2 radiator pressure



MIPP TPC – Reconstructed tracks



TPC (Bevalac/E910):

- Gas: P10
- Readout:

X-Z via 120x128 pads(≃1cm**2);

drift ⇛ Y

- Magnet: 0.7T JGG
- Can handle much larger multiplicity than MIPP

Global PID

- 4-Hypotheses for Each charged track: e π K P
- ID: dE/dx ToF Ckov Rich Cal
- Max LH fit for each hypothesis; iterate