E910, HARP, and E907 Results, Status, and Plans

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NUFACT03

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Columbia University

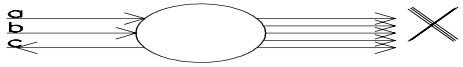
- Three Hadroproduction experiments
- All Open Geometry, using TPC's and good particle ID capabilities. High statistics. What the bubble chamber experiments always wanted but couldn't in the 70's and 80's. Made possible by the "new" technologies of TPC, RICH etc.
- BNL-E910– Recent results
- CERN-HARP- Data taken and status
- Fermilab E907 (MIPP- Main Injector Particle Production)- Status and Plans

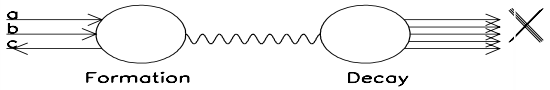
Purposes of the experiments

- Particle Physics-To acquire unbiased high statistics data with complete particle id coverage for hadron interactions.
  - » Study non-perturbative QCD hadron dynamics, scaling laws of particle production(E910,HARP,MIPP)
  - » Investigate light meson spectroscopy (HARP,MIPP)
- Nuclear Physics
  - » Investigate strangeness production in nuclei- RHIC connection (E910,MIPP)
  - » Nuclear scaling
  - » Propagation of flavor through nuclei (MIPP)
- Service Measurements
  - » Atmospheric neutrinos – Cross sections of protons and pions on Nitrogen from 5 GeV- 120 GeV (HARP,MIPP)
  - » Improve shower models in MARS, Geant4 (E910,HARP,MIPP)
  - » Make measurements of production of pions for neutrino factory/muon collider targets (E910,HARP,MIPP)
  - » Proton Radiography– Stockpile Stewardship- National Security (MIPP)
  - » K2K and MiniBoone target measurements(HARP)
  - » MINOS target measurements – pion production measurements to control the near/far systematics (MIPP)

Scaling Law

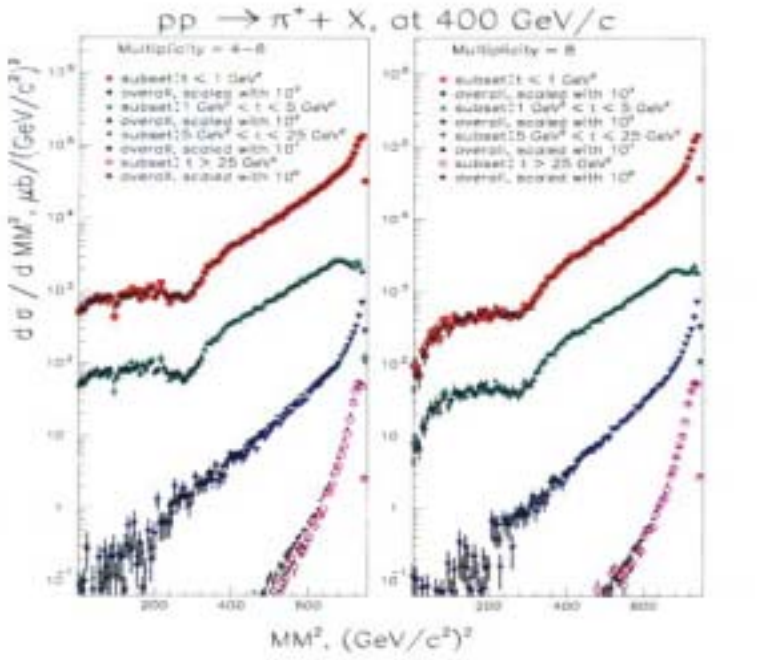
- Physics behind law is the factorization of 3 body scattering cross section.



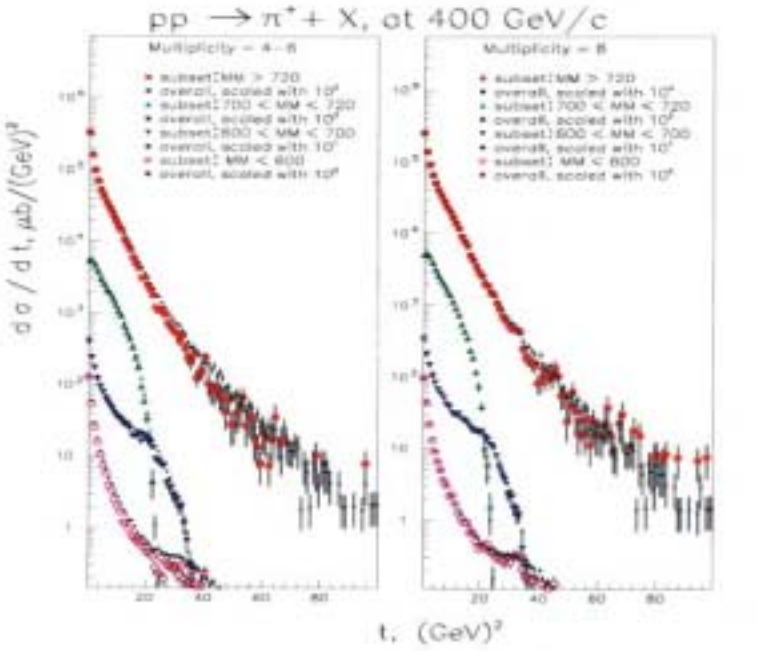


- We will be able to test the scaling law for 36 reactions as a function of s and t for various subsets with unprecedented accuracy.
- For each subset, we will be able to test the equality of the branching function for sets of crossed reactions. E.g $\pi^- p \longrightarrow p + X$ and $p^- p \longrightarrow \pi^+ + X$ should have the same set of branching functions $\beta_{subset}(M^2)$! One is a diffractive process and the other a central process.

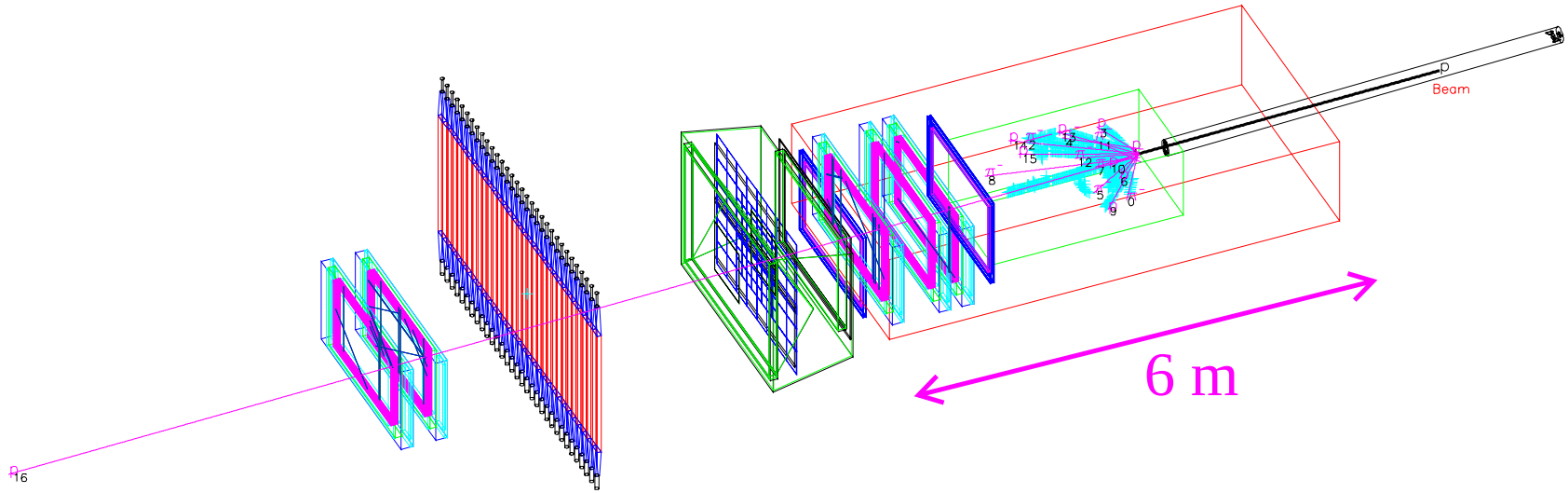
Scaling Law-EHS results



Scaling law -EHS results



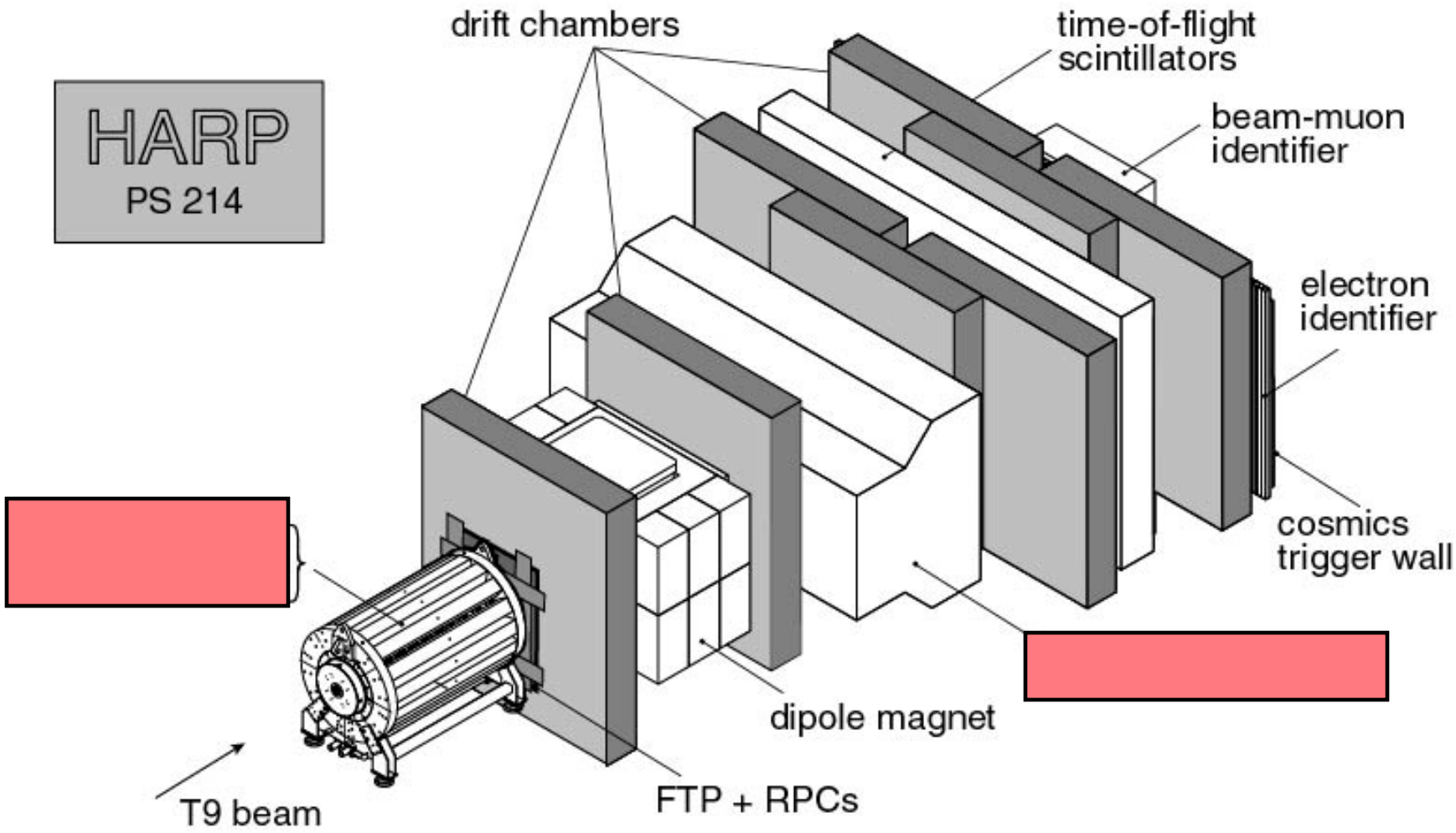
E910 Spectrometer
at the
MPS Facility of the AGS



- MPS Magnet
- EOS TPC
- Downstream tracking:
  - MPS Drift Chambers, Wire Chambers
- PID:
  - TPC dE/dx, TOF, Segmented Cherenkov

- Spring 96 Proton Run at AGS
- Be, Cu, Au, U targets
- 6, 12.5, 18 GeV/c Beam Momenta
- O(15) Million Central and MinBias Triggers

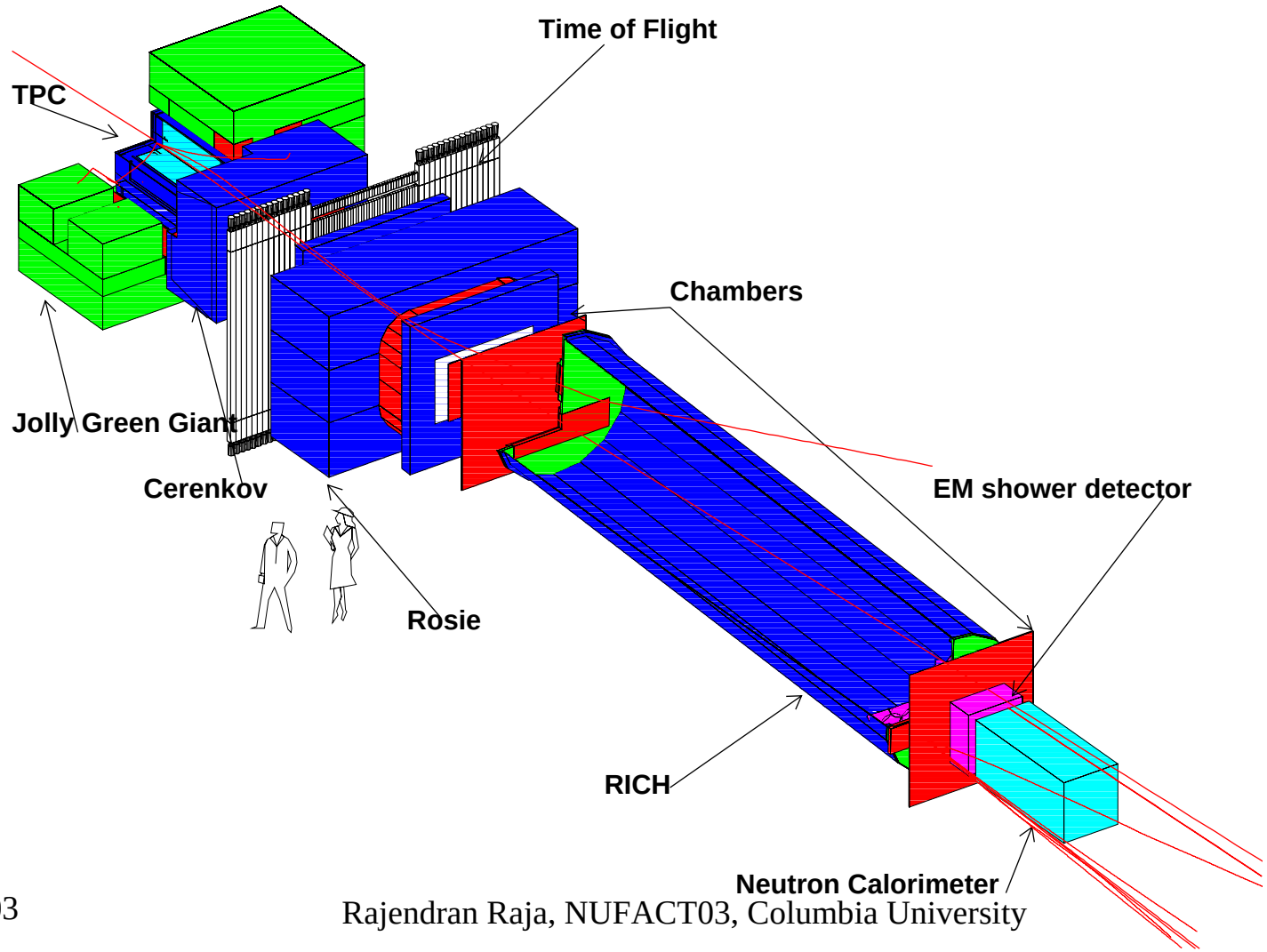
The HARP Detector



MIPP

Main Injector Particle Production Experiment (FNAL-E907)

Horizontal cut plane



Beam species, momenta and targets- E910

-

		E910 Dataset	
Beam	Target		Total events
Protons GeV/c			
12.5	Be		1446K
	Cu		1536K
	Au		4544K
17.5	Be		49K
	Cu		49K
	Au		3690K
6	Be		8K
	Cu		9K
	Au		12K

Beam species, momenta and targets- HARP -Solid target program

Be	C	Al	Cu	Sn	Ta	Pb	H_2O	Empty
2% 5% 100%	2% 5% 100%	2% 5% 100%	2% 5% 100%	2% 5% 100%	2% 5% 100%	2% 5% 100%	10% 100%	0%
+3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c	+3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c	+3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c	+3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c	+3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c	+1.5, +3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c	+1.5, +3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c	+1.5,+8 GeV/c	+1.5, +3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c

- ~ 190 settings measured
- Typically 1 - 4 million trigger/setting (depending on target and momentum)
- 100k – 400k (good) proton (pion) interactions for final physics analysis (after selection)

HARP- The cryogenic target programme

H	D	N	O	Empty
0.8% 2.4%	2.1%	5.5%	7.5%	0%
+3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c	+3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c	+3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c	+3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c	+3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c

About 80 settings
Typically 0.5 - 4 million trigger/setting
-> about 100k - 200k proton (pion) interactions
for final physics analysis after cuts

Targets: 2cm diameter, 6 (18) cm long.
Filling takes 4-6 hours. Emptying takes ~1 hour.

MIPP secondary beamline

Primary Proton Budget

Table 5 Primary beam rates, secondary beam rates and event yields for a positive secondary beam

p GeV/c	Primary p/spill	p Hz	K Hz	π Hz	Total Hz	p events	K events	π events	total events
5	9.66E+09	7404	1583	116013	125000	1000000	340391	1000000	2340391
15	2.10E+09	16968	4651	74886	96505	1000000	1000000	1000000	3000000
25	1.08E+09	28457	4651	60948	94055	1000000	1000000	1000000	3000000
30	8.92E+08	36365	4651	56926	97942	1000000	1000000	1000000	3000000
40	7.19E+08	59890	4651	50114	114655	1000000	1000000	1000000	3000000
50	5.76E+08	84327	3854	36820	125000	1000000	828519	1000000	2828519
60	4.37E+08	100367	2601	22032	125000	1000000	559231	1000000	2559231
70	3.43E+08	111720	1575	11705	125000	1000000	338524	1000000	2338524
80	2.86E+08	118639	861	5500	125000	1000000	185184	1000000	2185184
90	2.67E+08	122354	422	2224	125000	1000000	90714	645042	1735755
100	3.07E+08	124115	176	709	125000	1000000	37818	205646	1243464
110	5.82E+08	124819	51	130	125000	1000000	11007	37783	1048790

Table 6 Primary beam rates, secondary beam rates and event yields for a negaitive secondary beam

p GeV/c	Primary p/spill	pbar Hz	K Hz	π Hz	Total Hz	pbar events	K events	π events	total events
5	1.49E+10	7747	1726	115527	125000	1000000	431391	1000000	2431391
15	3.78E+09	4192	4651	99287	108130	1000000	1000000	1000000	3000000
25	2.77E+09	2613	4651	82580	89843	1000000	1000000	1000000	3000000
30	2.73E+09	2192	4651	79822	86666	1000000	1000000	1000000	3000000
40	3.94E+09	2000	5683	101496	109179	1000000	1000000	1000000	3000000
50	5.73E+09	1520	5626	117855	125000	858621	1000000	1000000	2858621
60	8.24E+09	910	4449	119641	125000	514056	1000000	1000000	2514056
70	1.38E+10	481	3241	121278	125000	271690	810316	1000000	2082006
80	2.80E+10	215	2145	122640	125000	121342	536302	1000000	1657644
90	7.62E+10	74	1237	123688	125000	41906	309340	1000000	1351246
100	2.00E+11	9	327	72576	72913	5322	81839	1000000	1087161
110	2.00E+11	0	6	4867	4873	25	1394	1000000	1001420

MIPP secondary beamline

Primary Proton Budget

Table 1 Physics request and proton needs

Target	Physics	Data Points	Primary proton Average Intensity/spill	Total number of Primary Protons
Numi 1	MINOS	3.3	125000	2.06E+10
NUMI 2	MINOS	3.3	125000	2.06E+10
H2	Scaling	6	9.76E+09	2.93E+15
N2	Atmospheric ν	4	9.76E+09	1.95E+15
Be	pA	2	9.76E+09	9.76E+14
Be	Survey	1	9.76E+09	4.88E+14
C	Survey	1	9.76E+09	4.88E+14
Cu	pA	2	9.76E+09	9.76E+14
Cu	Survey	1	9.76E+09	4.88E+14
Pb	pA	2	9.76E+09	9.76E+14
Pb	Survey	1	9.76E+09	4.88E+14
Total		26.6		9.76E+15

1 data point = 3 million events.

5,15,25,50,70,90 GeV/c positive and negative momenta

Total number of spills 1330000 Total number of protons 1E16

Number of spills/minute 3

Total time for experiment 308 days No Pi factor

Double slow spill will help considerably.

E910 Collaboration

PHYSICAL REVIEW C, VOLUME 65, 024904

Inclusive soft pion production from 12.3 and 17.5 GeV/*c* protons on Be, Cu, and Au

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Differential cross sections are presented for the inclusive production of charged pions in the momentum range 0.1–1.2 GeV/*c* in interactions of 12.3 and 17.5 GeV/*c* protons with Be, Cu, and Au targets. The measurements were made by Experiment 910 at the Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory. The cross sections are presented as a function of pion total momentum and production polar angle θ with respect to the beam.

The HARP Collaboration

- 24 Institutes
- 9 countries
- 120 physicists

- Also:
  - » K2K
  - » MiniBooNE

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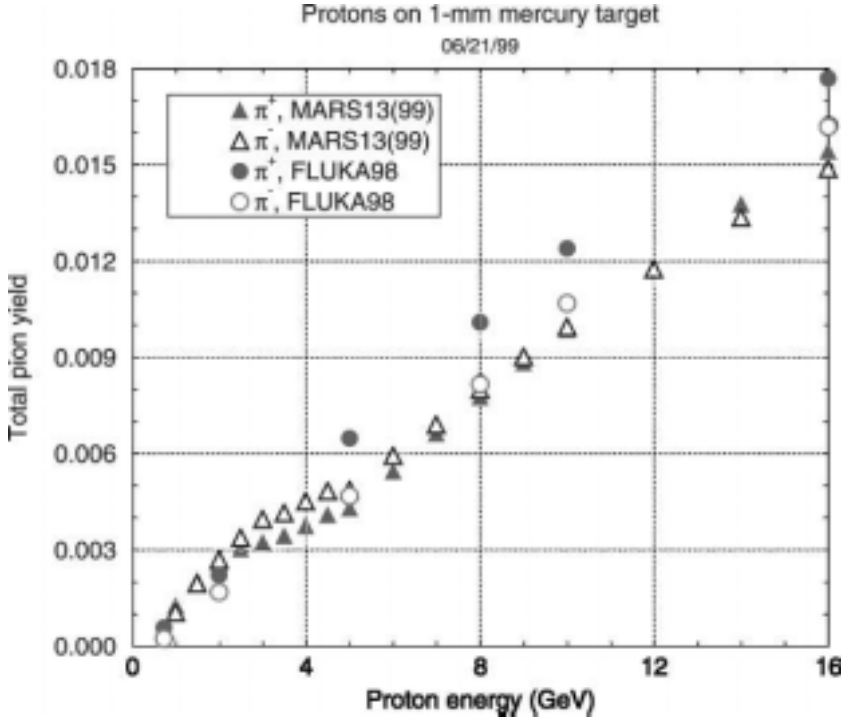
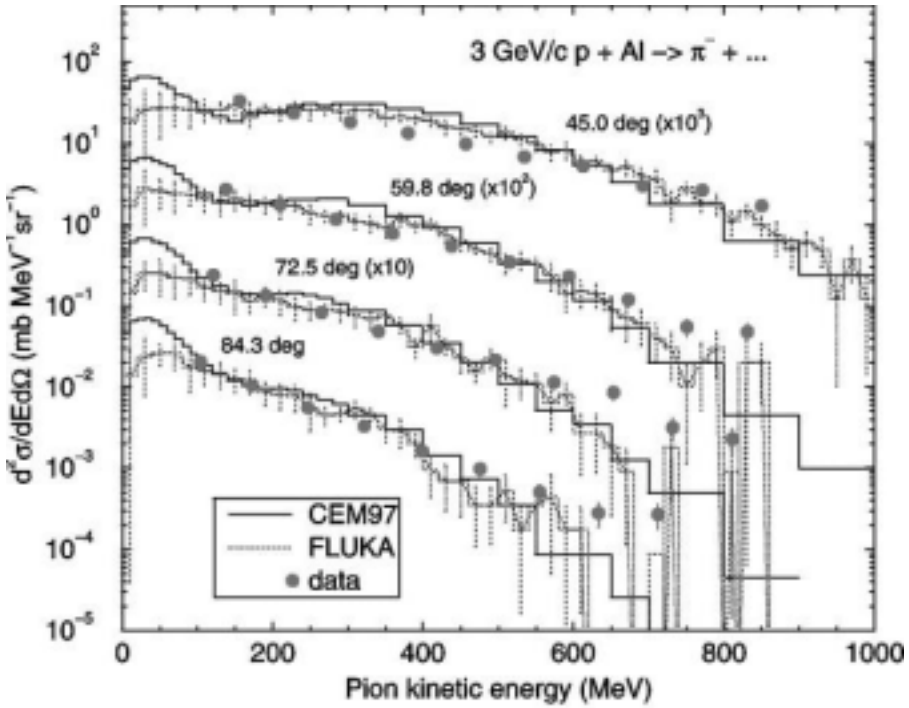
Hadronic generators

General problem: little experimental data, large uncertainties in calculations

NIM-A 451 (2000) 327-330

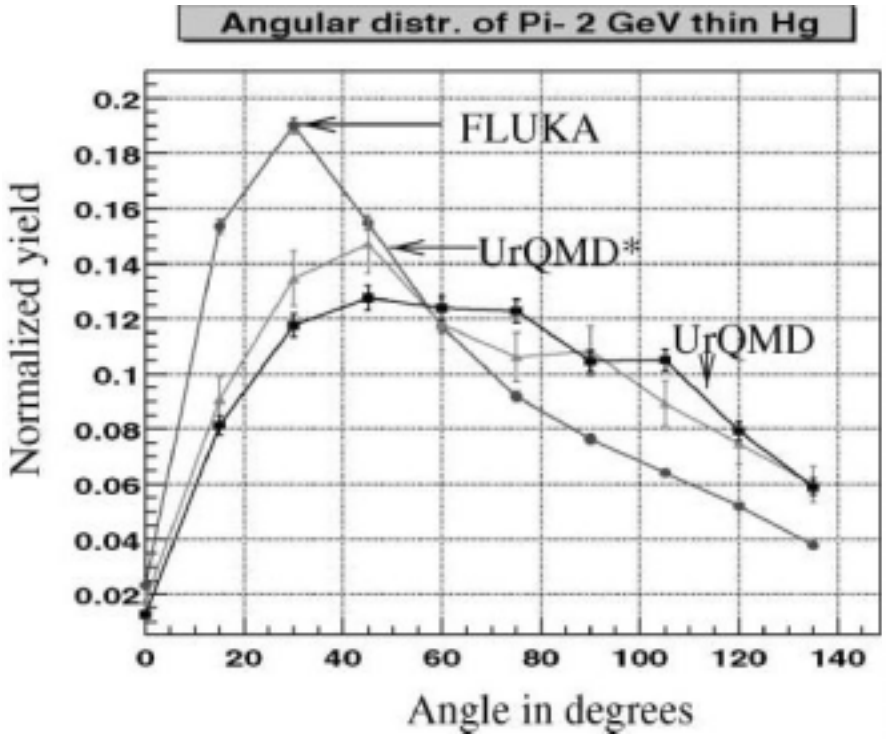


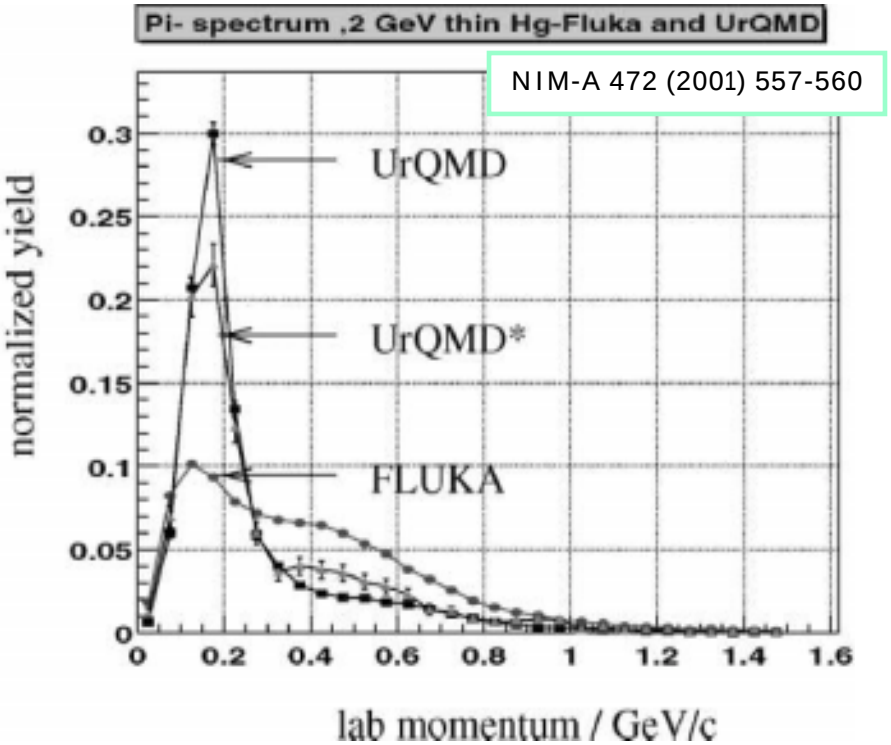


→ **Thin and thick targets, scan periodic system**

Hadronic Monte Carlos

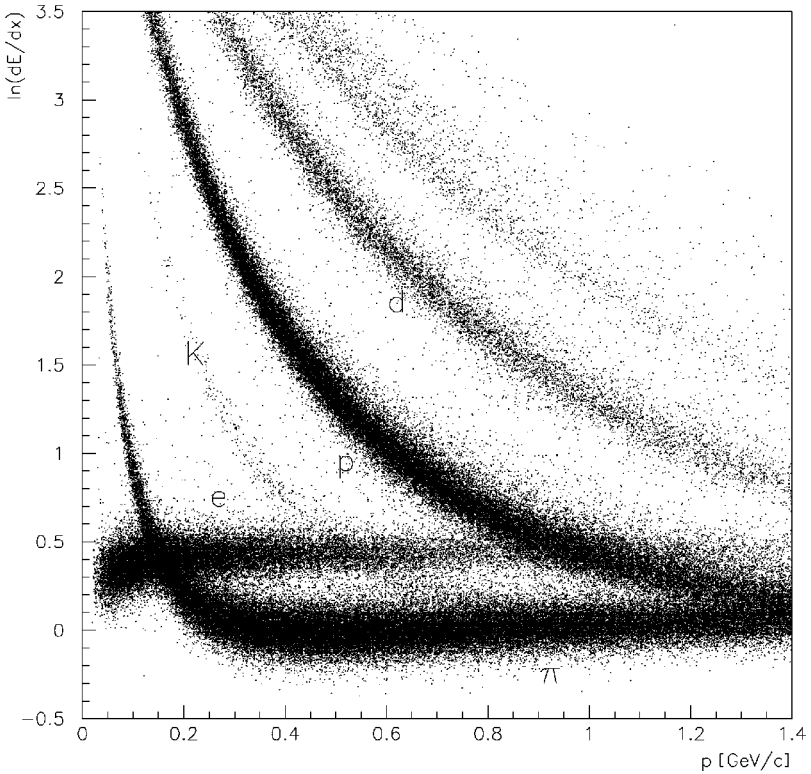
Little experimental data and large uncertainties in calculations in particular for thick and high z target materials and very low primary energies





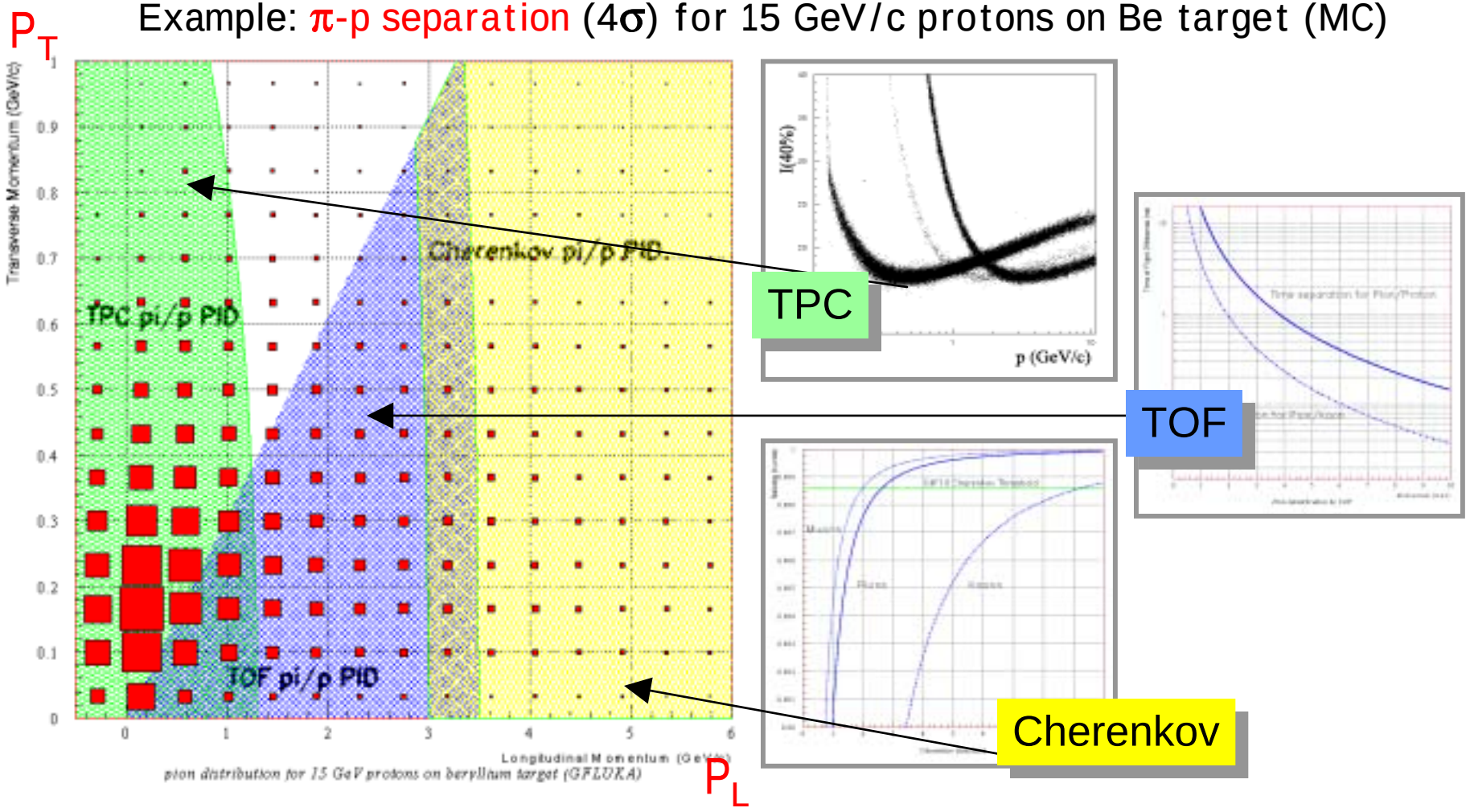
→ **Thin and thick targets, scan periodic system and momenta**

E910 TPC particle ID capabilities



HARP Particle ID coverage

Example: π-p separation (4σ) for 15 GeV/c protons on Be target (MC)

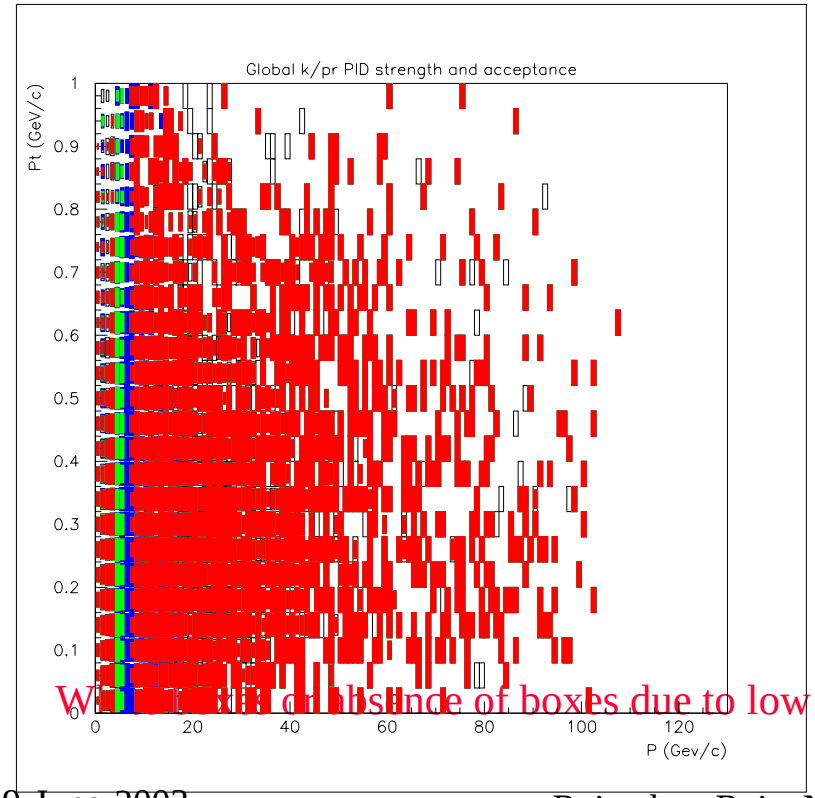


MIPP Particle ID capabilities

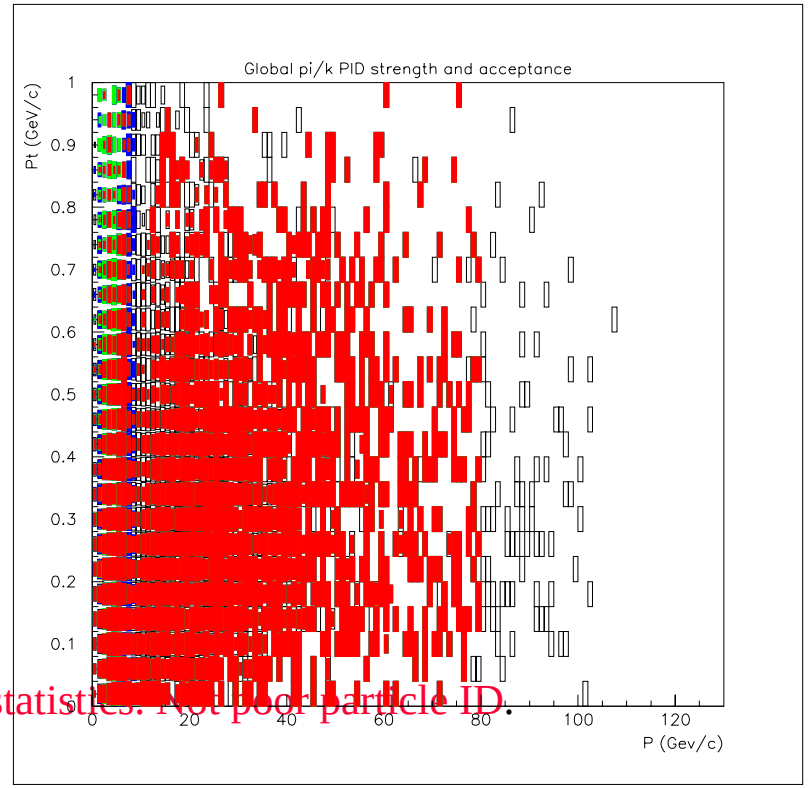
K/Proton separation analysis using all systems.

- Red = 3σ or better.
- 3σ < Green < 2σ
- 2σ < Blue < 1σ

  0σ < White < 1σ
- K/P separation

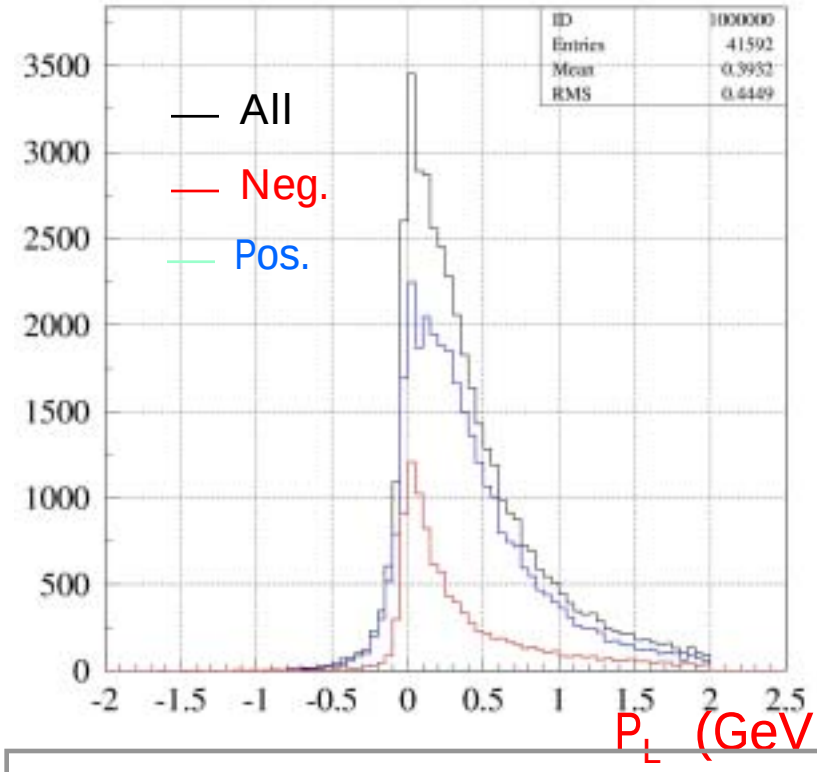


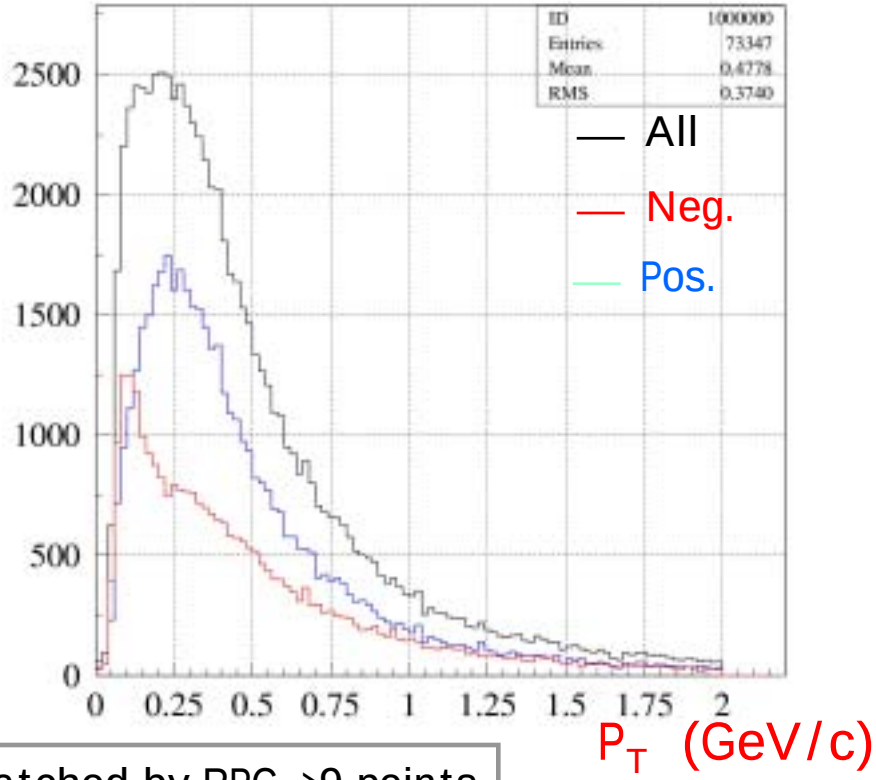
π/K separation



White = 1σ, but abundance of boxes due to low statistics. Not poor particle ID.

HARP Prel. distribution of P_T and P_L



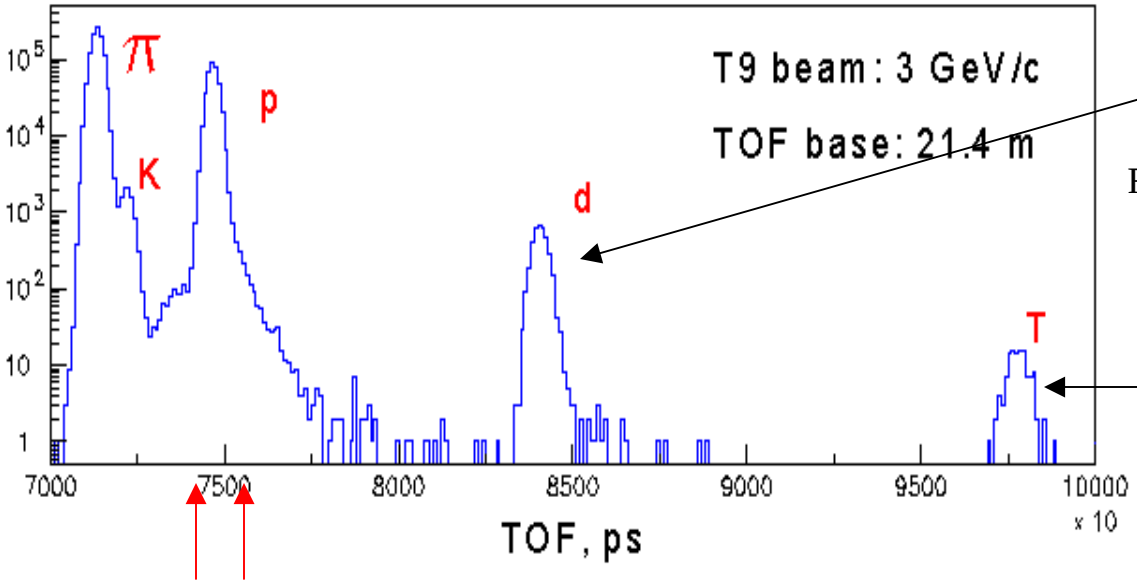


3GeV/c protons on 100% Ta target, tracks matched by RPC, >9 points

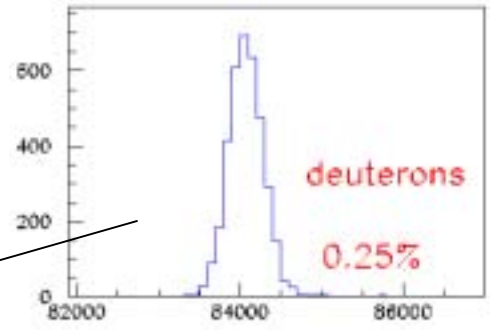
All particles, no corrections on cross-talk, momentum-resolution and efficiencies

Beam particle selection

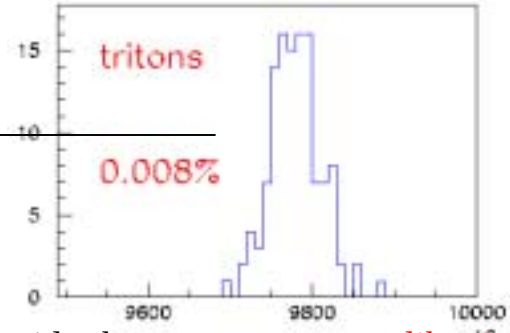
- Beam particles are measured by 4 MWPC 's (accuracy <1 mm)
- Particle identification by:
  Beam Cherenkov, TOF(21 m), Mu-identifier (6.5λ)
- Example: Proton selection in the 3 GeV/c beam



Proton selection: purity > 98.7%



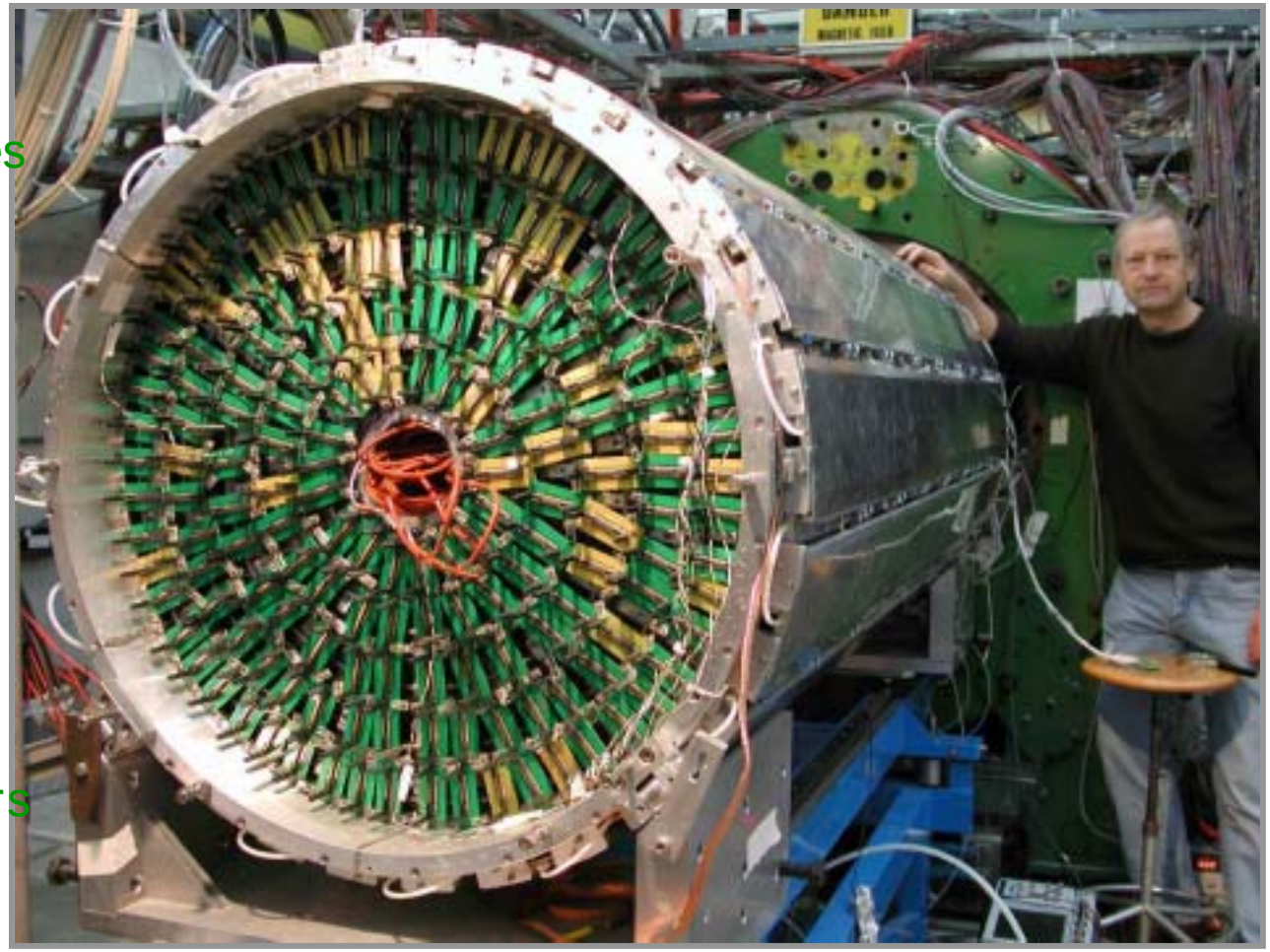
For measurements of total cross section



Provides beam momentum calibration

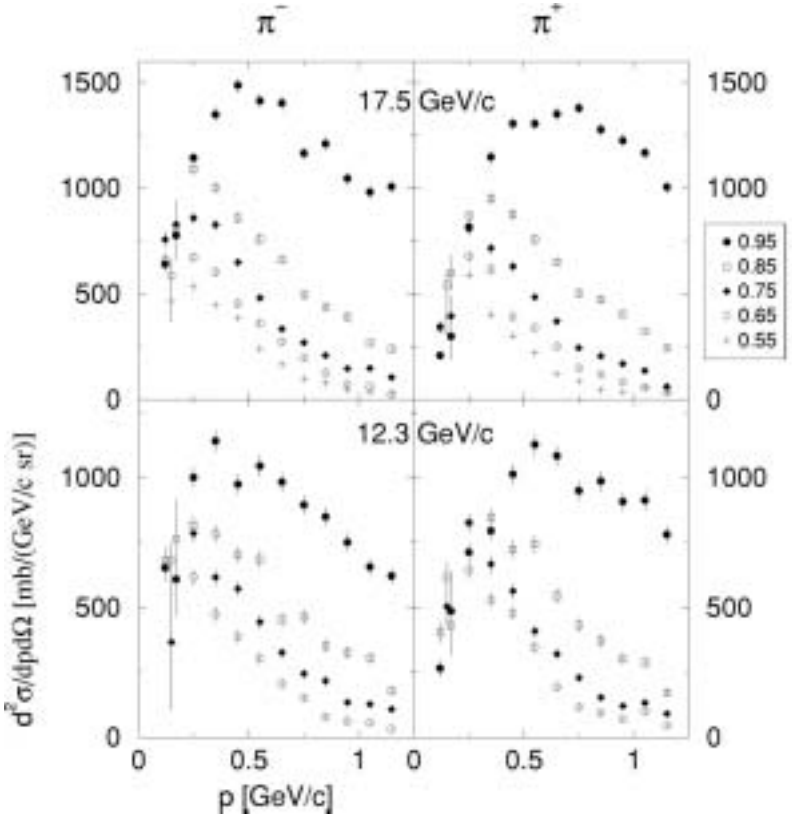
Large Angle region

- **Solenoid**
  - » 0.7 Tesla
- **ITC**
  - » Scint. fibres
  - » around target
- **TPC**
  - » R=0.41 m
  - » L=1.56 m
  - » 4000 pads
- **RPCs**
  - » TOF
  - » 30 chambers
  - » around TPC

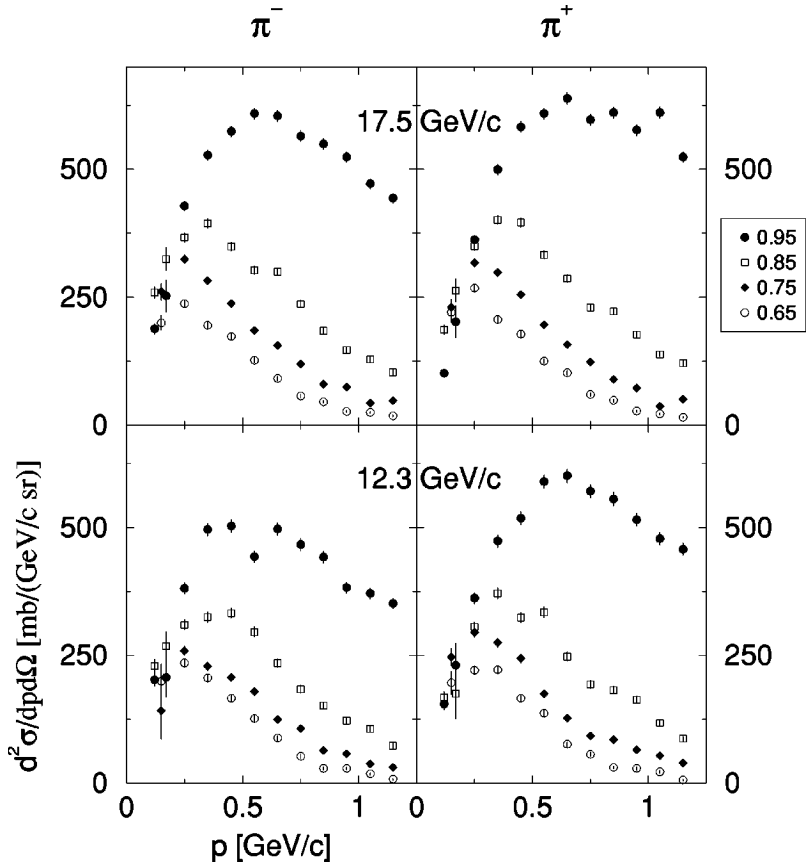


E910-Protons PRC65 (2002) 024904

Gold

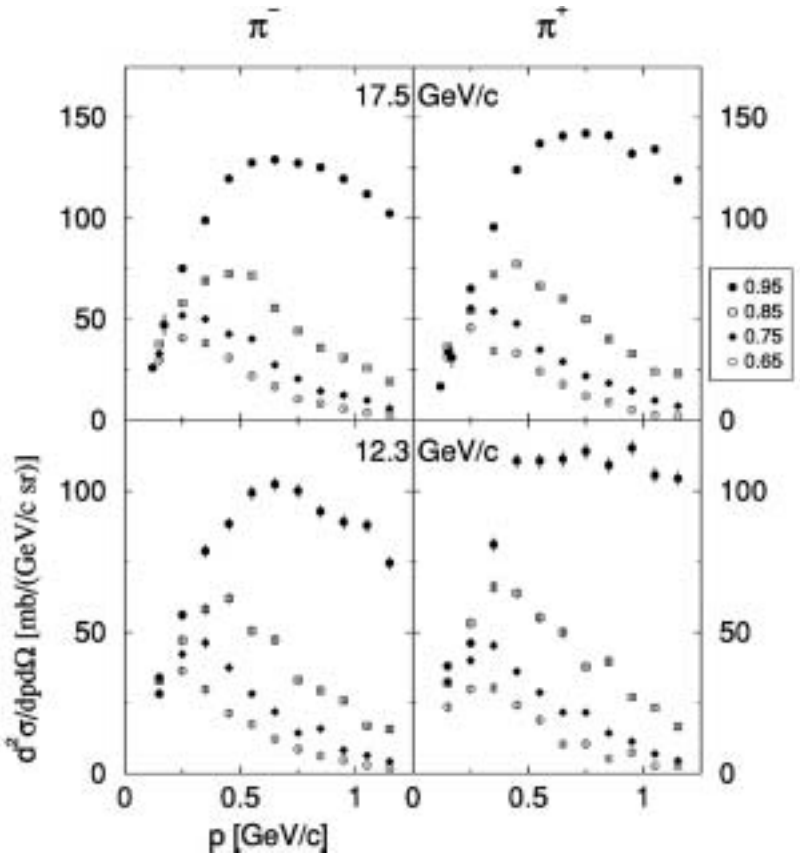


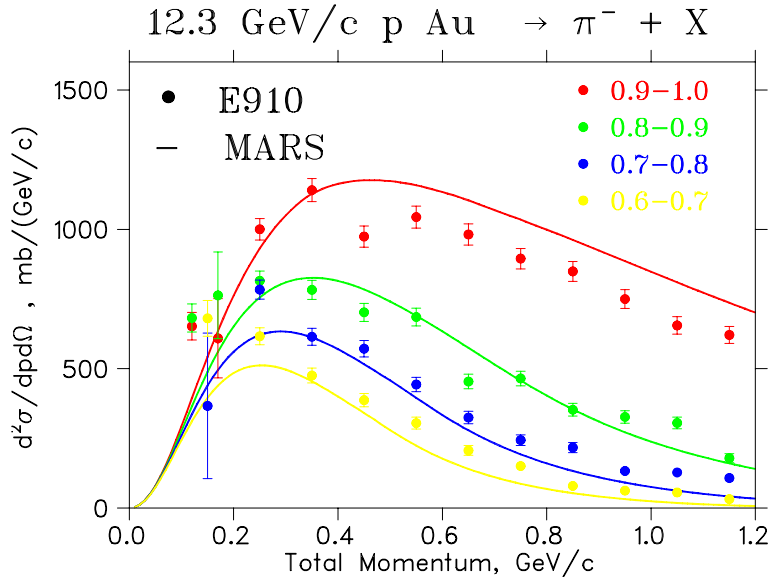
Copper

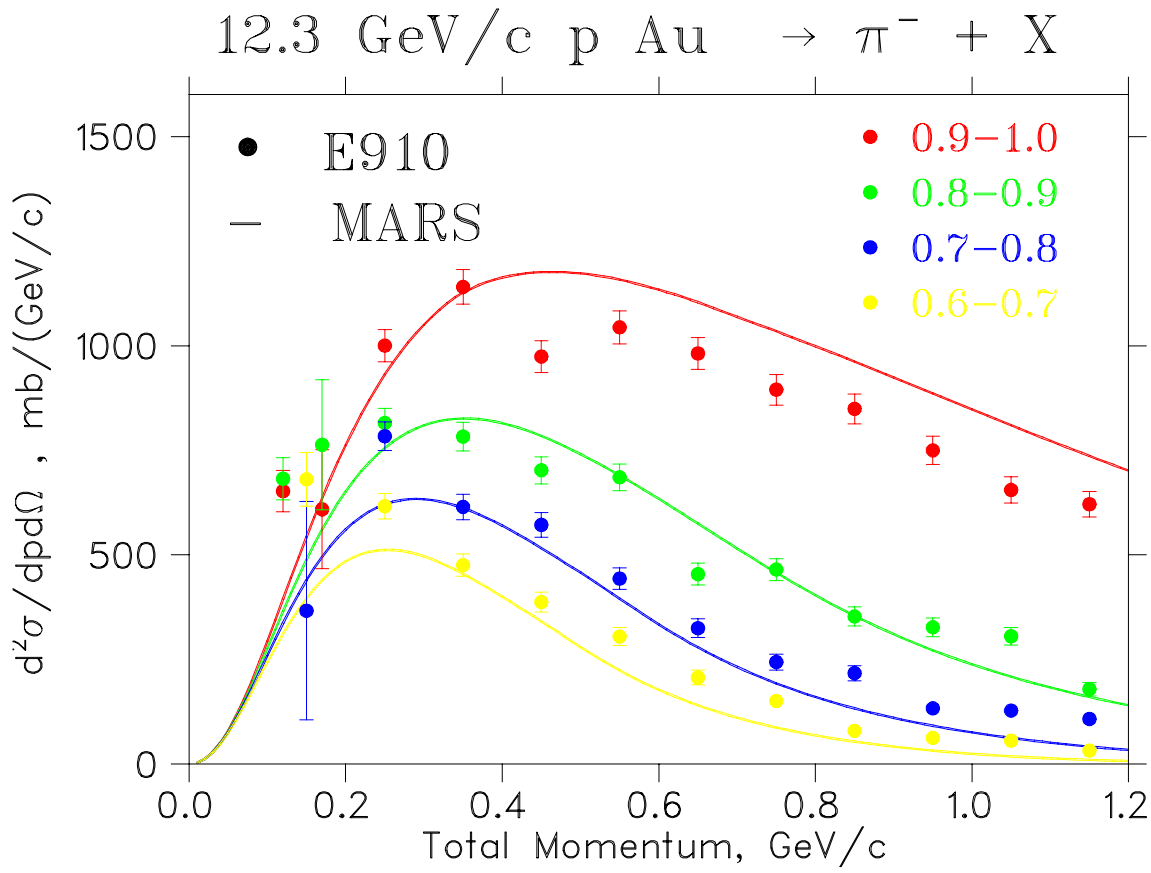


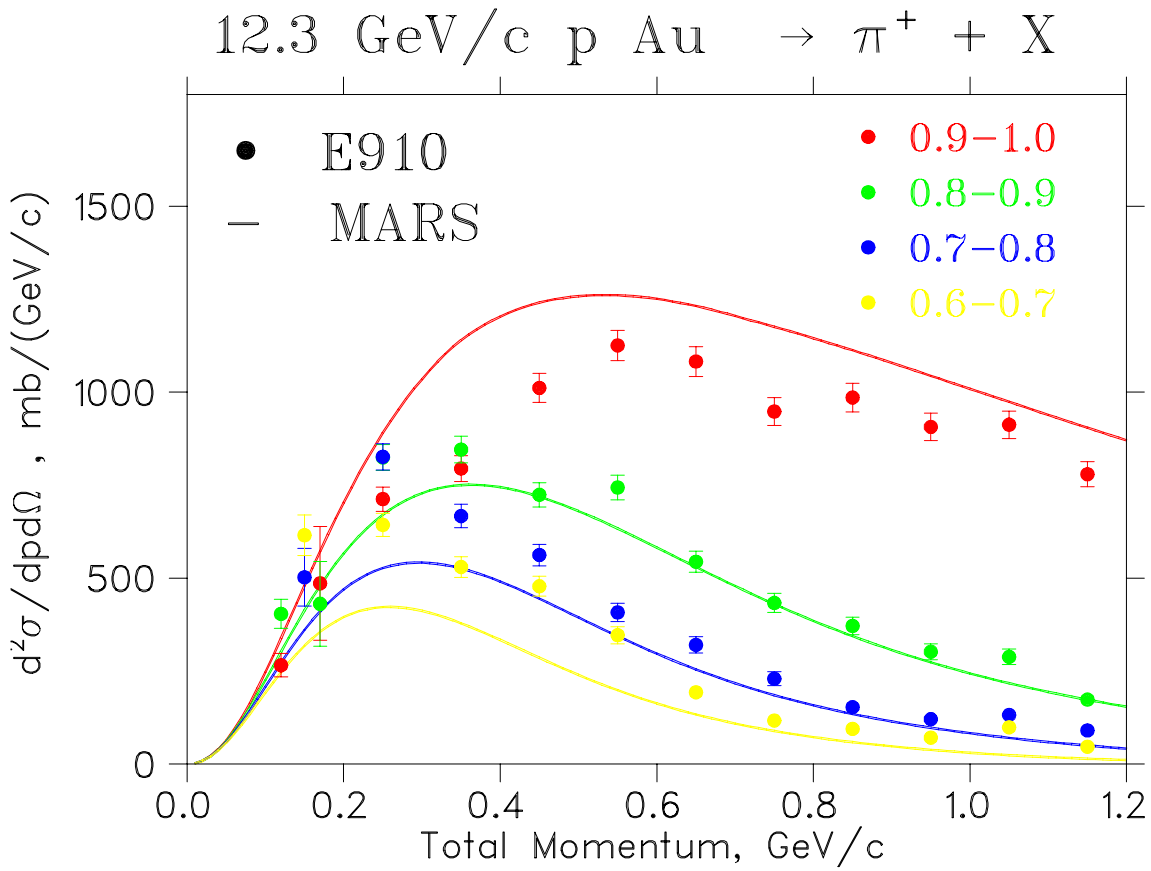
E910-protons on Beryllium

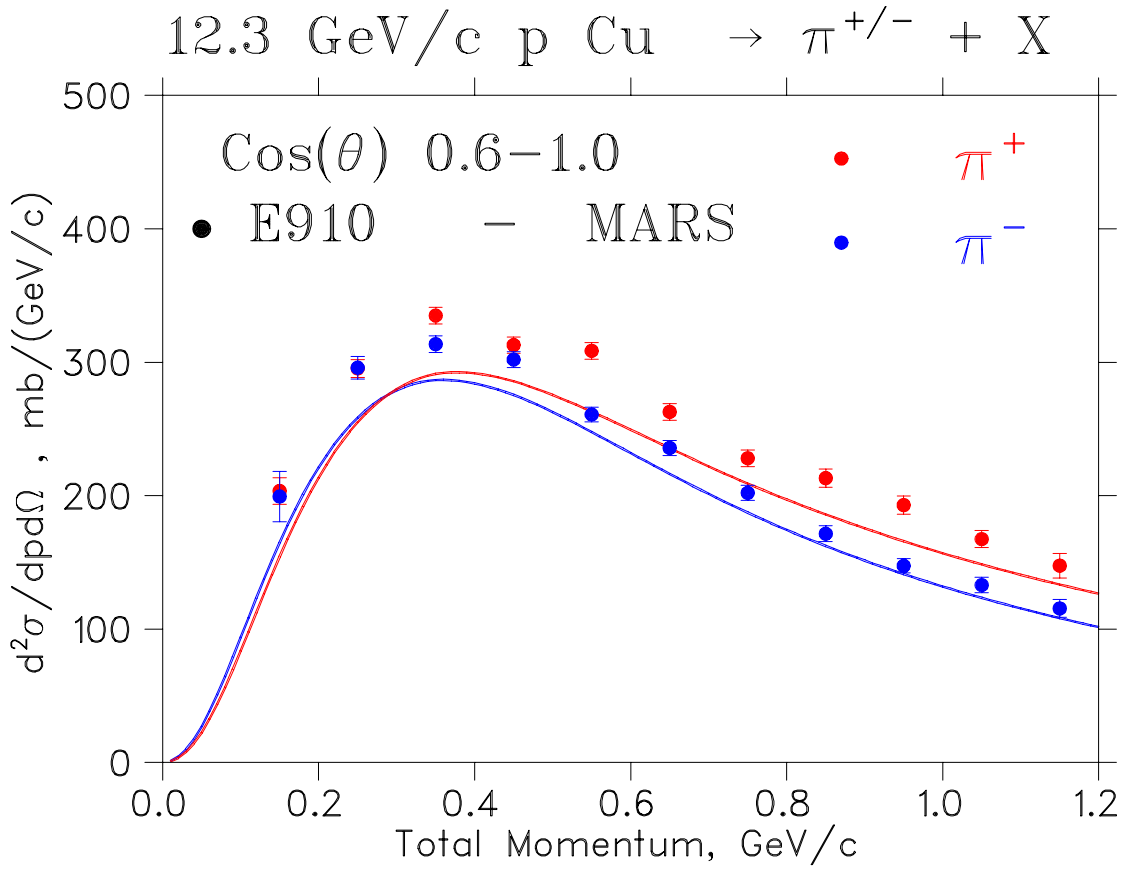
- Beryllium

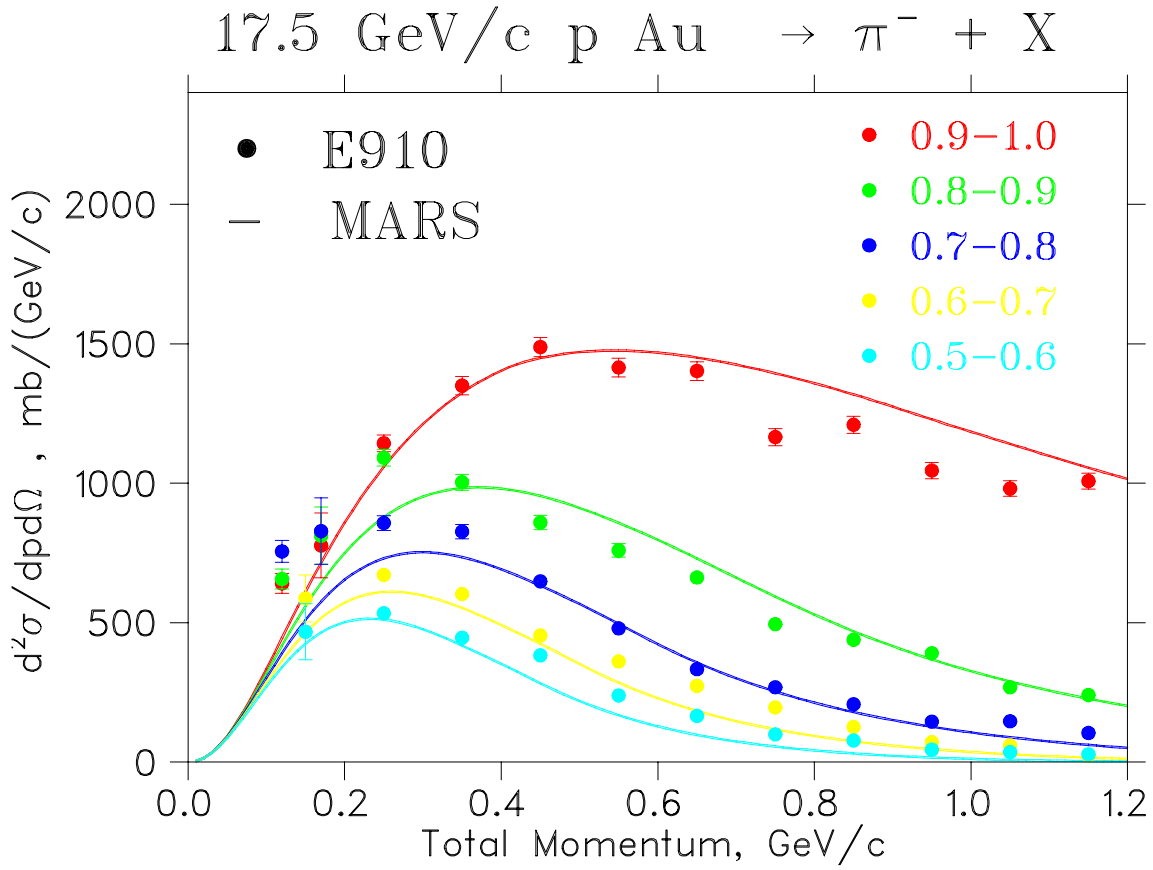


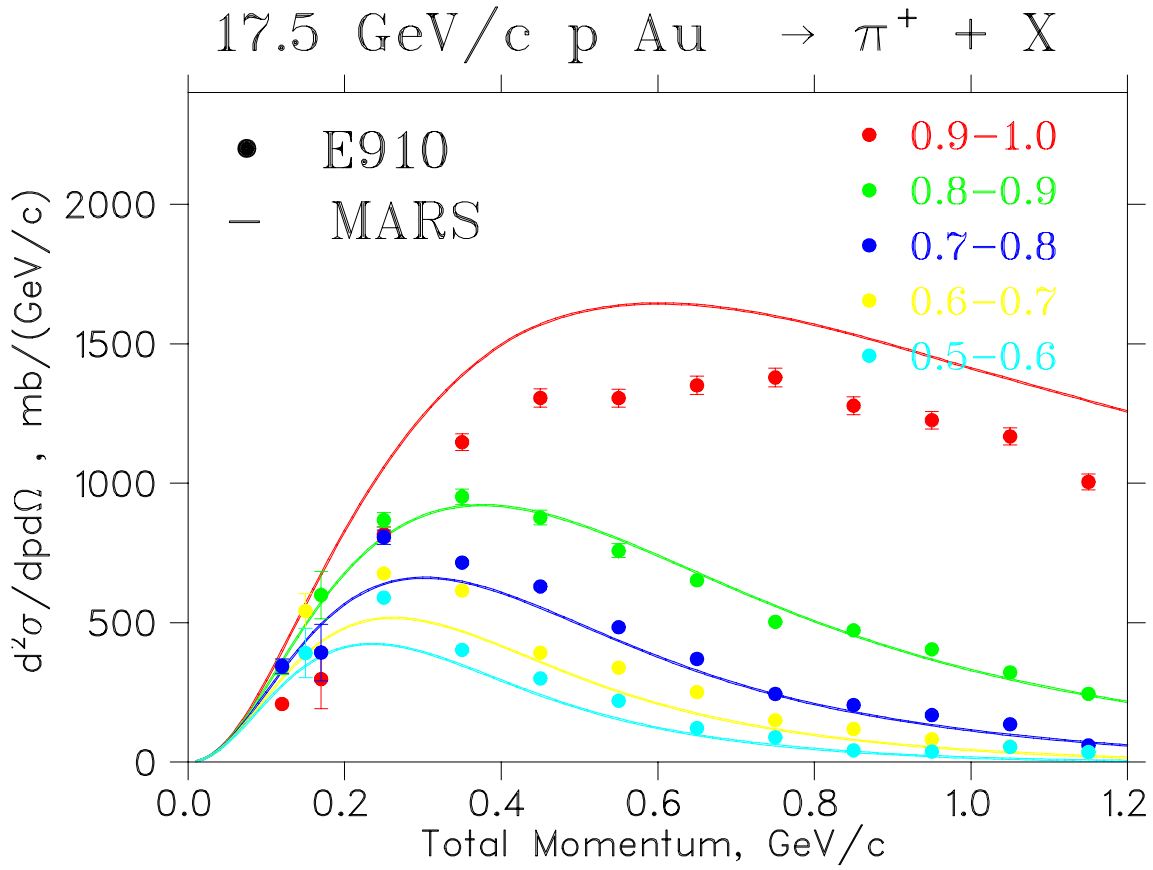



12.3 GeV/c p Au → π⁻ + X
E910
MARS
0.9−1.0
0.8−0.9
0.7−0.8
0.6−0.7
d²σ/dpdΩ , mb/(GeV/c)
1500
1000
500
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Total Momentum, GeV/c


12.3 GeV/c p Au → π+ + X
E910
MARS
0.9−1.0
0.8−0.9
0.7−0.8
0.6−0.7
d²σ/dpdΩ , mb/(GeV/c)
1500
1000
500
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Total Momentum, GeV/c


12.3 GeV/c p Cu → π+/− + X
Cos(θ) 0.6−1.0
E910 − MARS
π+
π−
d²σ/dpdΩ , mb/(GeV/c)
Total Momentum, GeV/c
0
100
200
300
400
500
0.0
0.2
0.4
0.6
0.8
1.0
1.2


17.5 GeV/c p Au → π⁻ + X
E910
MARS
0.9−1.0
0.8−0.9
0.7−0.8
0.6−0.7
0.5−0.6
d²σ/dpdΩ , mb/(GeV/c)
2000
1500
1000
500
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Total Momentum, GeV/c


17.5 GeV/c p Au → π+ + X
E910
MARS
0.9−1.0
0.8−0.9
0.7−0.8
0.6−0.7
0.5−0.6
d²σ/dpdΩ , mb/(GeV/c)
2000
1500
1000
500
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Total Momentum, GeV/c

HARP Summary

- HARP was conceived to measure hadron production on different materials, with solid and cryogenic targets, at beam energies of 1.5 – 15 GeV/c
- The experiment was built in 15 months, took data for 2 years, stopped in Nov. 2002 ... and is dismantled now
- The detector worked extremely well and stable (only known major problem: TPC cross-talk)
- 350 M triggers and 30 Tbyte of data recorded
- Detector performance well understood
- Analysis in progress - first physics results in summer (?)

MIPP-Brief Description of Experiment

- Approved November 2001
- Situated in Meson Center 7
- Uses 120GeV Main Injector Primary protons to produce secondary beams of $\pi^{\pm} K^{\pm} p^{\pm}$ from 5 GeV/c to 100 GeV/c to measure particle production cross sections of various nuclei including hydrogen.
- Using the EOS-TPC(Same as in E910) we measure momenta of ~all charged particles produced in the interaction and identify the charged particles in the final state using a combination of dE/dx, ToF, threshold Cherenkov and RICH technologies.
-

MIPP Situation at PAC approval (Nov 2001)

- We had cleaned up the previous experiment in MC7 Hyper-CP.
- We had designed and constructed iron struts to support the weight of the magnets Jolly Green Giant and Rosie and installed it in M-Bottom.
- We had installed a 1' high concrete platform in MC7 to support the magnets.
- We had fixed the Jolly Green Giant coil

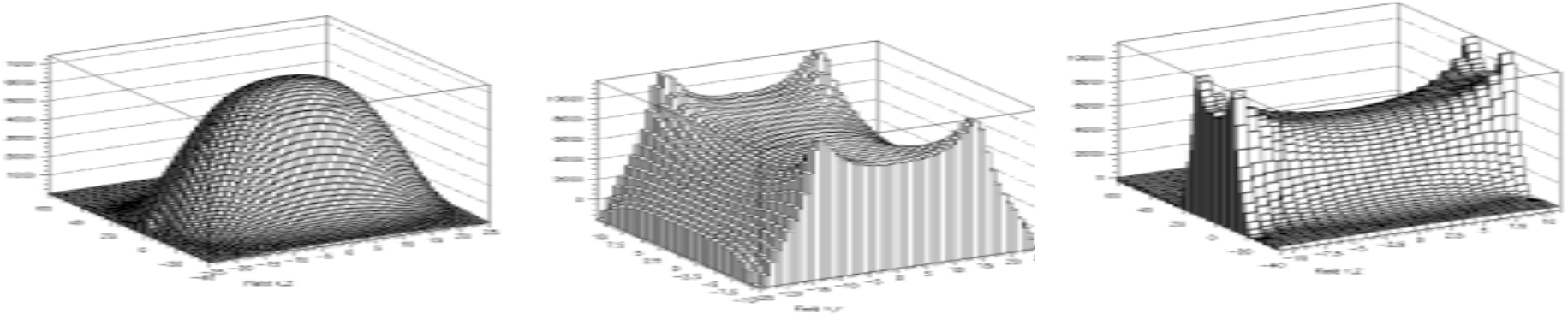
Status of MIPP Now- Collision Hall

Status of MIPP Now- Collision Hall

Ziptrack of magnets complete

- We resurrected the Ziptrack system
  - » Software recovered by sending out crashed disk to California.
  - » Missing Hall probe cart re-made. Measured B_x, B_y, B_z in a 2" cube grid of points for both JGG and ROSIE over full aperture.
  - » Ziptrack now available for CKM and BTeV.

JGG B_y component in projections y=0, z=0 and x=0



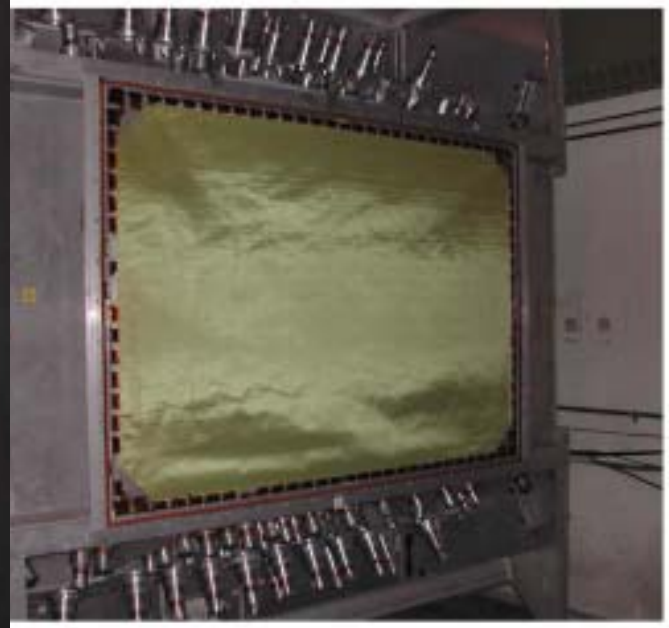
Installation schedule

- MIPP running time June 2003- Summer Shutdown 2005 (~ two years)
- Experiment will be ready by end of June 2003

	Fermilab E907 MIPP			
	Installation Schedule			
WBS	Task Name	Duration	Start	Finish
5.2.4	Beam Cerenkov	37 days	4/7/03	5/27/03
5.5	Cerenkov	52 days	3/27/03	6/6/03
5.7.1	Target Wheel	35 days	4/7/03	5/23/03
5.8.5	TPC Installation	33 days	4/7/03	5/21/03
5.1	Time of Flight	99 days	4/14/03	8/28/03
5.11	RICH	54 days	3/20/03	6/3/03
5.12	Drift Chambers	65 days	3/20/03	6/18/03
5.13	Hadron Calorimeter	52 days	4/7/03	6/17/03
5.16	EM Calorimeter	67 days	3/20/03	6/20/03
5.15	DAQ	30 days	5/5/03	6/13/03

- See above chart in detail at http://ppd.fnal.gov/experiments/e907/Project/E907_v2.05_Install.det.pdf

MIPP Cherenkov

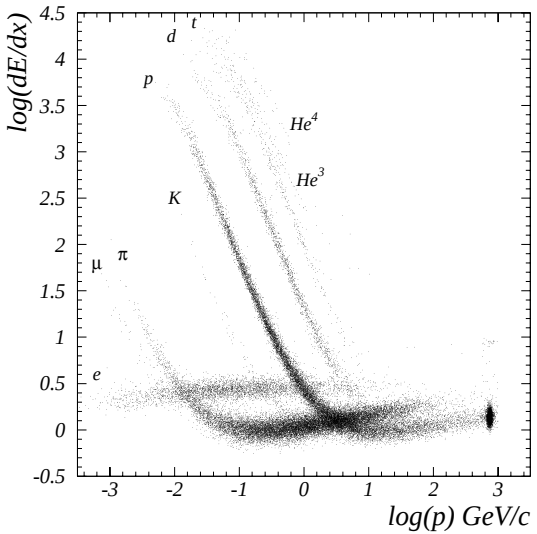


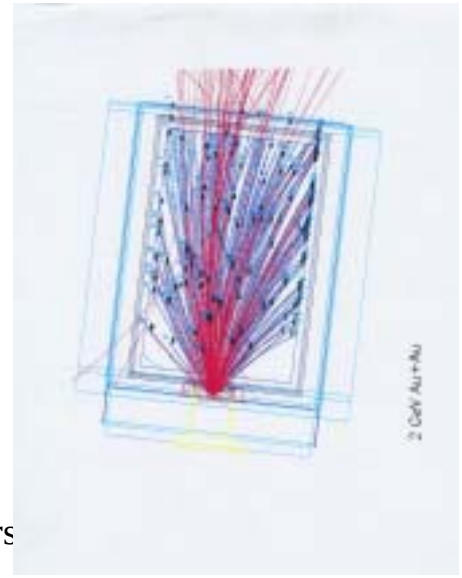
- Alignment of mirrors complete. PMT's need to be tested, installed and wired up. Completion by end of June 2003
-

TPC installation

- TPC in the Jolly Green Giant magnet this week. Cabling up will proceed shortly. Will be completed in June 2003

TPC dE/dx Particle ID- BNL E910



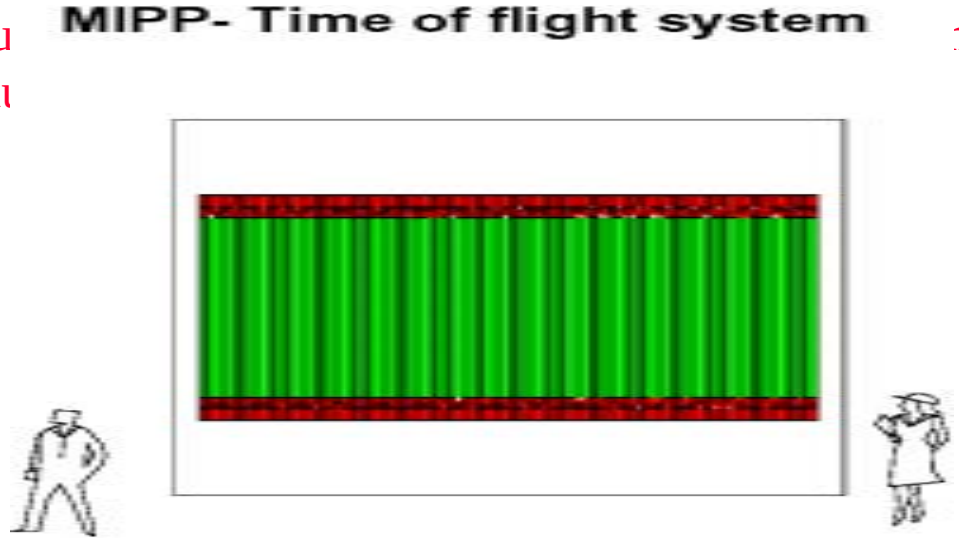


Time of Flight

- Time of flight ($220K) . Univ. S. Carolina responsility. Scintillator and tubs on order.

5.10 Time-of-Flight (TOF)	**99 days**	**4/14/03 8/28/03**
5.10.1 TOF Module Frame Design	10 days	4/14/03 4/25/03
5.10.2 TOF Module Fabrication	4 mons	4/28/03 8/15/03
5.10.3 TOF Module Installation	5 days	8/18/03 8/22/03

5cmx 5cm squ n outside. ~
150ps resolu



Ring Imaging Cherenkov

- Selex RICH-We acquired all phototubes from the Russians- total of ~ 3000 phototubes
- The old electronics, with its Russian chips had a high death rate. Completely redesigned the front end electronics– 5 VME boards and ~100 (32 channel) readout boards. VME boards complete.
- 100 (32 channel boards) manufactured and delivered.
- Ready for beam in June 2003

Calorimeters and Wire Chambers

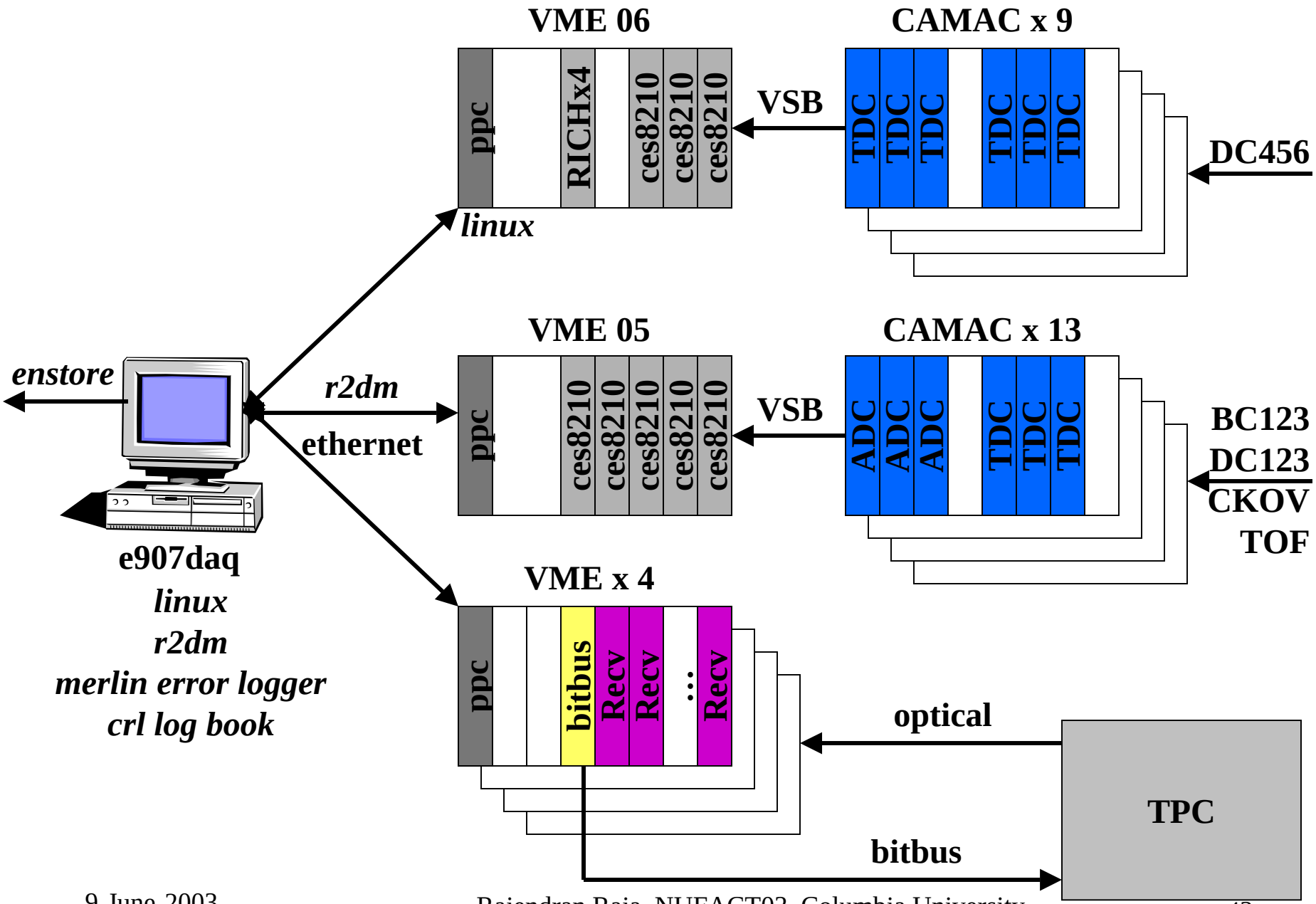
Hadron Calorimeter schedule

EM calorimeter schedule

We are building a lead sheet- gas tube EM calorimeter. Assembly to be completed in June.

Re-using E690 Drift Chambers. 4 have been refurbished. 3 beam chambers from E690 will also be used. Being installed and cabled up currently. U. Of Iowa large wire chambers being installed and cabled up currently.

MIPP DAQ Hardware



Monte Carlo

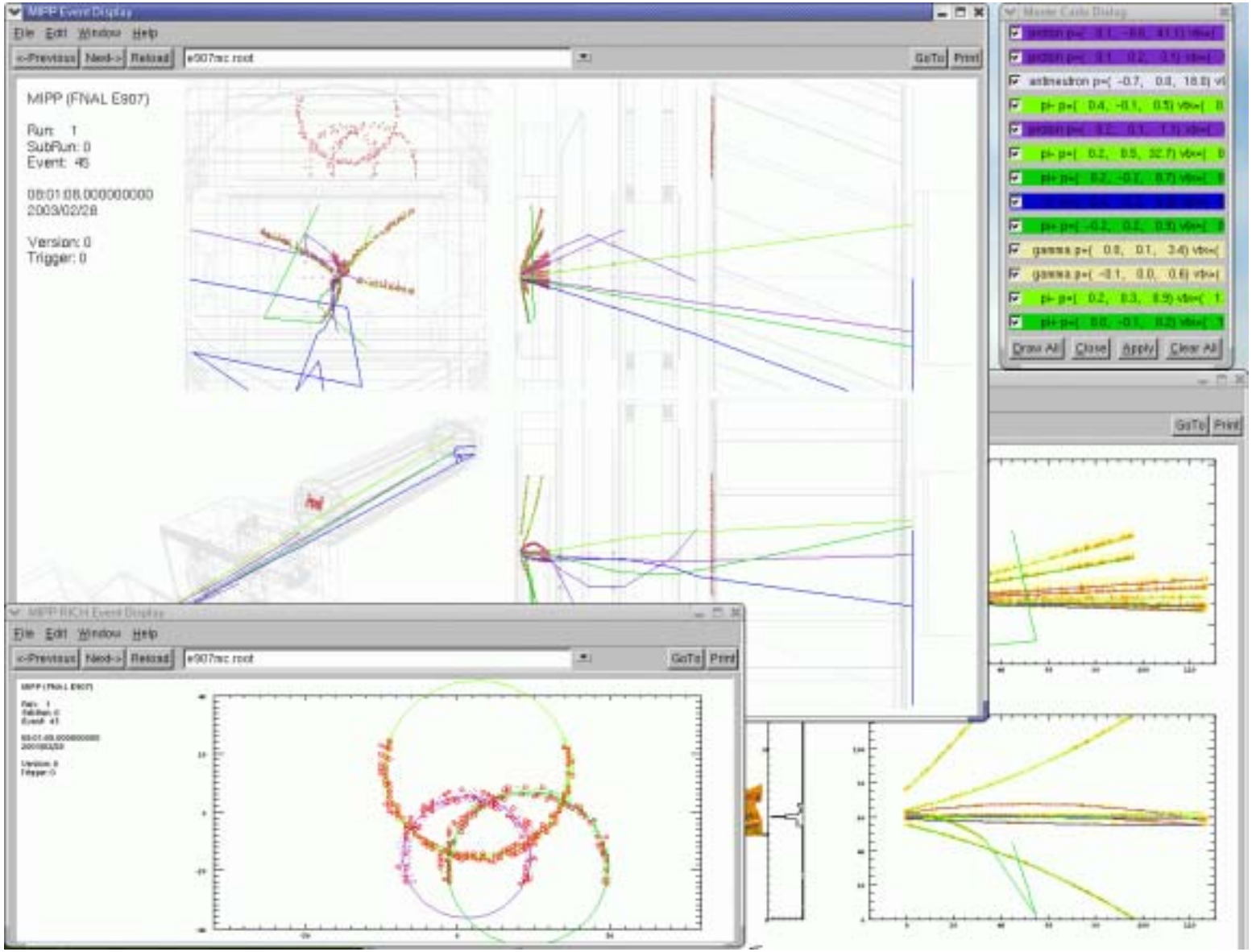
- Geant3.21 based data driven Geometry. Details can be found at http://ppd.fnal.gov/experiments/e907/MC/e907mc.htm
- Have used it to study acceptances, resolutions and ToF design.
- Work to be done- Digitize wire chambers, Implement calorimeters and beam Cherenkovs.

Offline Software

Monte Carlo Geometry transported to ROOT.

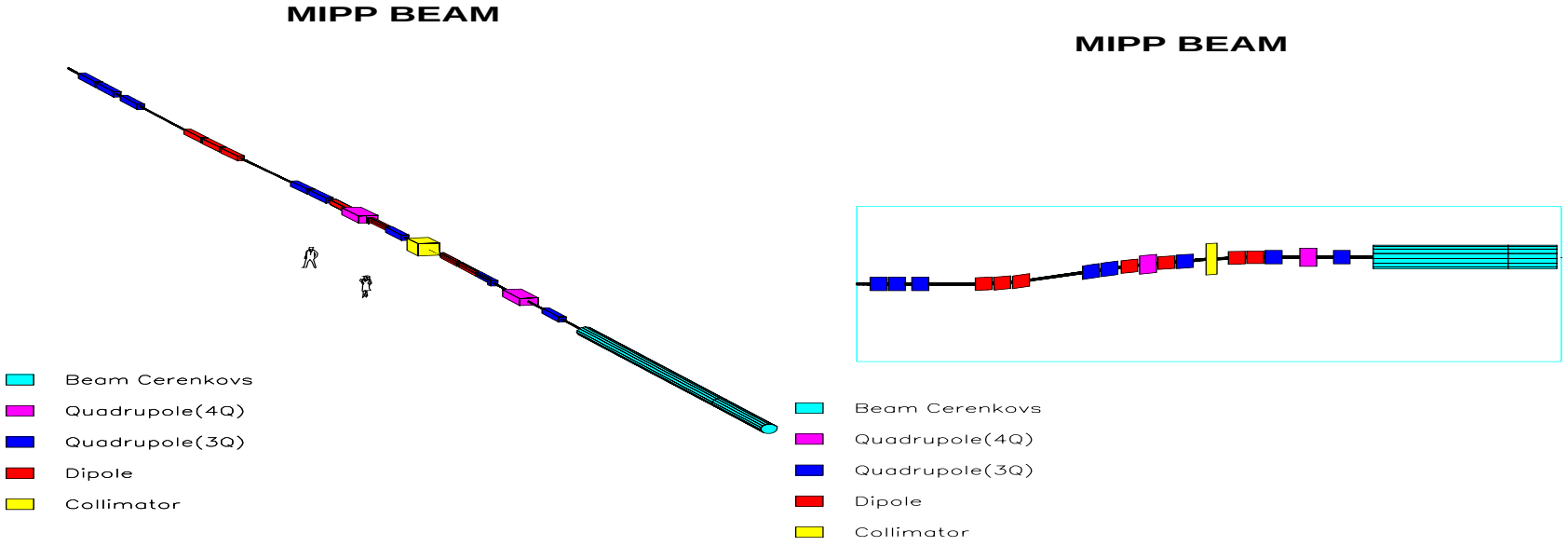
Offline C++, ROOT IO. MIPP has benefited enormously from the ability to use the same geometrical data-base in Monte Carlo and Reconstruction. Result of discussions during ACAT2000 conference held at Fermilab.

Event Display



MIPP Secondary Beam

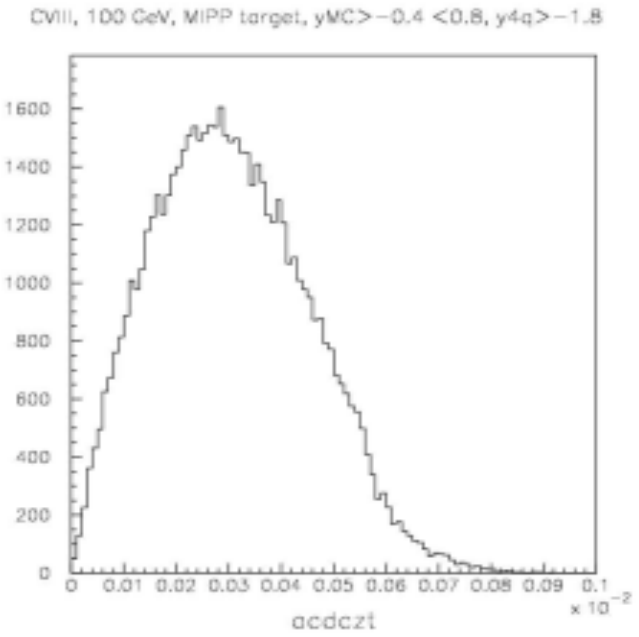
- MC7 Hyper CP beam line removed. Target pile cleaned up.
- Beamline group of MIPP collaborators and Switchyard 120 personnel. Have examined 4 beam designs (using TRANSPORT, MAD and MARS (calculates showering backgrounds). Have decided on a design. MIPP beamline installation has started and will be complete by end of June- Beginning of July.- Safety Assessment still needs passing.

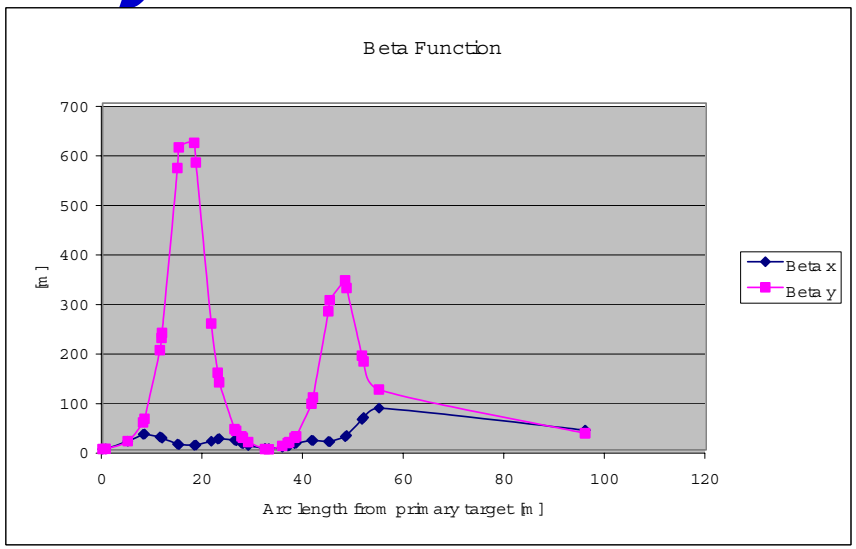


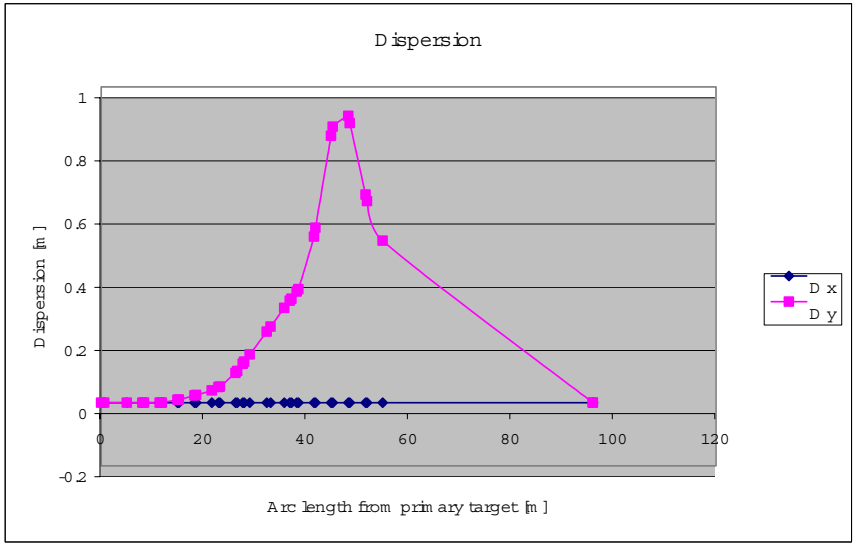
Mars study of beam

$\delta p/p = 0.0$

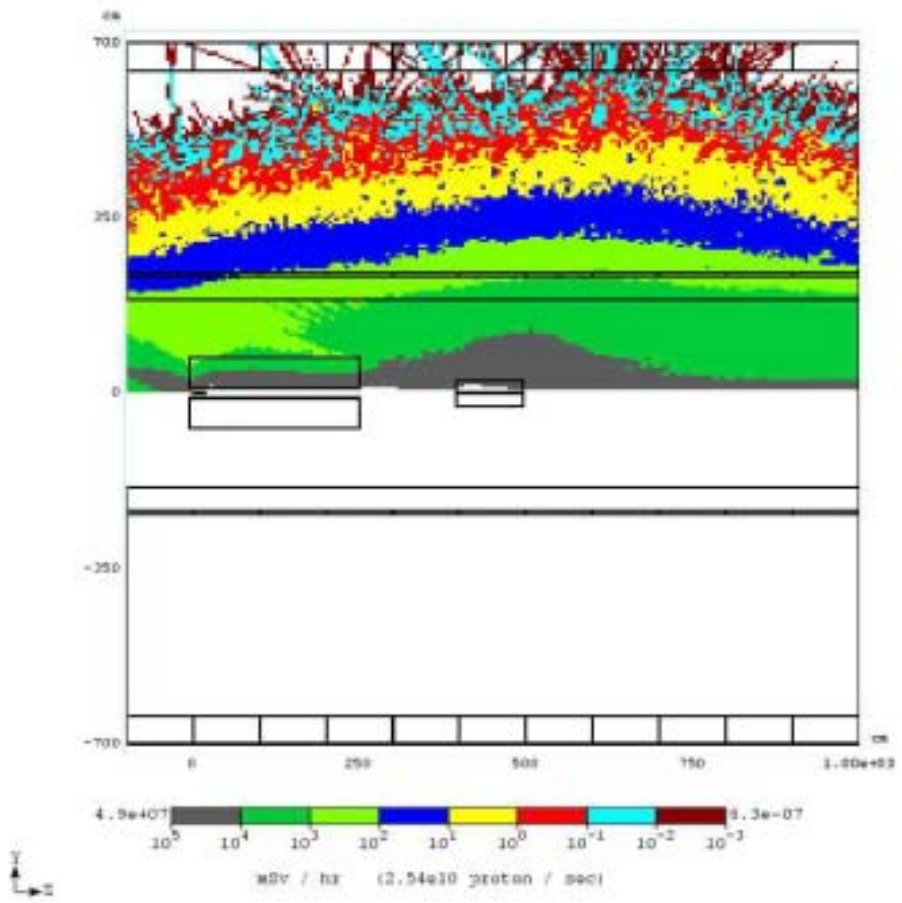
Angle at secondary target







Prompt Dose



Estimated from a simplified model prompt dose after 15' of soil = 4 mrem / hr (+− 50%)

Main contribution from scraper 1. Dose will be reduced to be below the radiation area limit (5 mrem/hr) by putting the scrapper inside of the target shielding and adding one extra steel plate to the top of shielding.

Expected prompt dose in the Meson Building 20 mrem / hr with 2m of concrete and 0.8m of steel around hot spot (scraper 2).

Conclusions

- MIPP will complete data taking my middle of 2005. MIPP data along with HARP and E910 will add significantly to our understanding of MINBIAS non-perturbative QCD interactions (>99% of cross section)