Possibilities of New data in Hadroproduction

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Fermilab

- Review the non-perturbative QCD theory status.
  - » Status of particle production data
- Difficulties in using shower simulation models in experiments such as MINOS, MiniBoone, Atmospheric neutrino production, Hadron Calorimetry (ILC in particular)
- Review plans to obtain higher quality data- MIPP Upgrade
- Ways to use new data directly in simulators—Hadron libraries

We have a theory of the strong interaction—in theory

- Why study non-perturbative QCD? Answer:- We do not know how to calculate a single cross section in non-perturbative QCD! This is >99% of the total QCD cross section. Perturbative QCD has made impressive progress. But it relies on structure functions for its calculations, which are non-perturbative and derived from data.
- Feynman scaling, KNO scaling, rapidity plateaus are all violated. We cannot predict elastic cross sections, diffractive cross sections, let alone inclusive or semi-inclusive processes. Regge "theory" is in fact a phenomenology whose predictions are flexible and can be easily altered by adding more trajectories.
- Most existing data are old, low statistics with poor particle id.
- QCD theorist states- We have a theory of the strong interaction and it is quantum chromodynamics. Experimentalist asks– what does QCD predict? Almost as bad as the folks who claim string theory is the theory of everything! Experimentalist asks-what does it predict?

Elastic scattering

- The entire strong interaction problem can be reduced to our ignorance in describing the very simple process of elastic scattering.- By the optical theorem

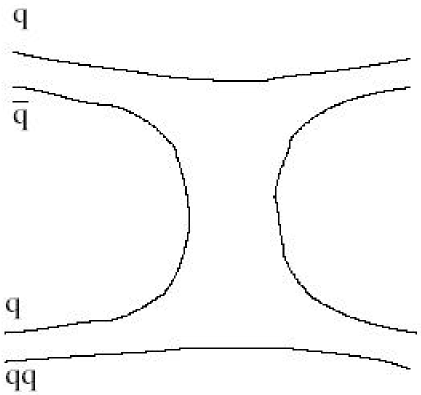
$$\sigma_{tot} \propto \text{Im(forward elastic scattering amplitude)}$$

$$\sigma_{tot} \propto s^{\alpha(0)-1}$$

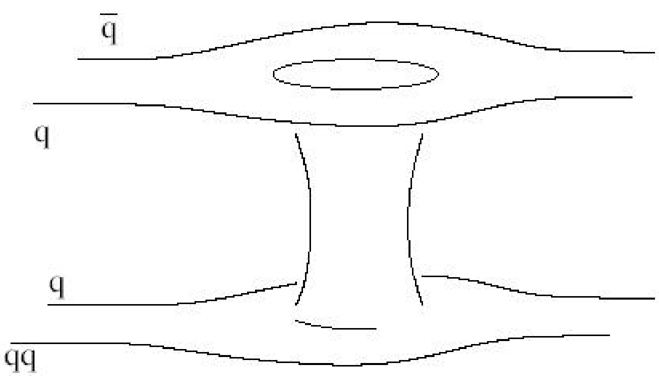
- Where $\alpha(0)$ is the intercept of the leading Regge trajectory, commonly known as the Pomeron. In the era when total cross sections were thought to asymptote to a constant value, this intercept was taken to be unity. Since it has been shown conclusively that the cross sections rise with energy, this intercept is now thought to be ~1.095
- This leads to a power law rise in total cross sections, which will eventually violate unitarity-Froissart bound states cross sections should not grow faster than $\log^2 s$!

Hard and Soft scattering

Reggeon exchange. Can either be thought of as a sum of t channel exchanges or as a sum of s channel resonances- Hence Dual.

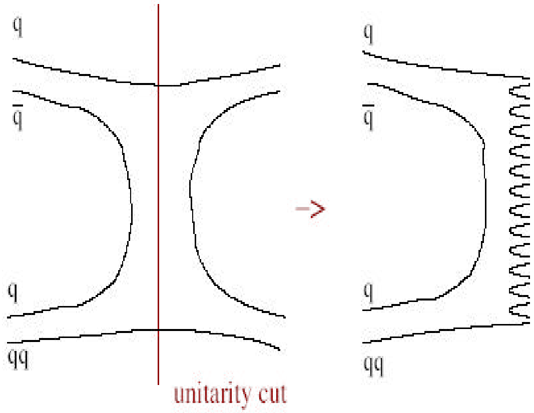


Pomeron exchange Does not depend on flavor of scattering particles.

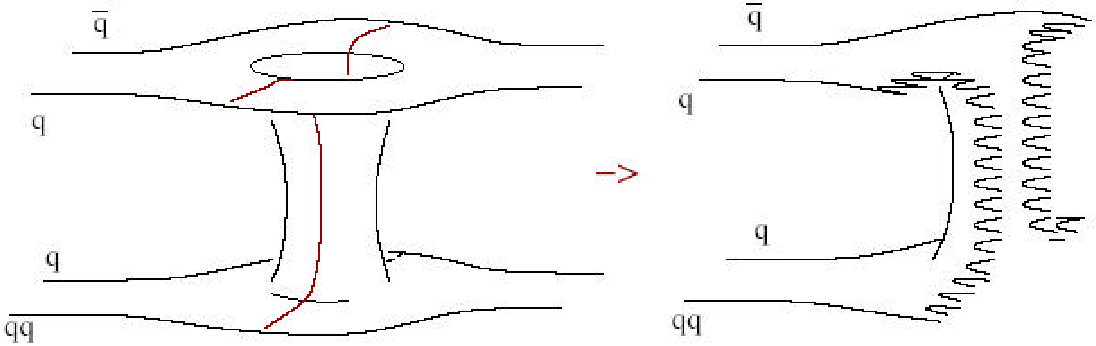


Concepts-Optical theorem

Reggeon Exchange-Single string of hadrons

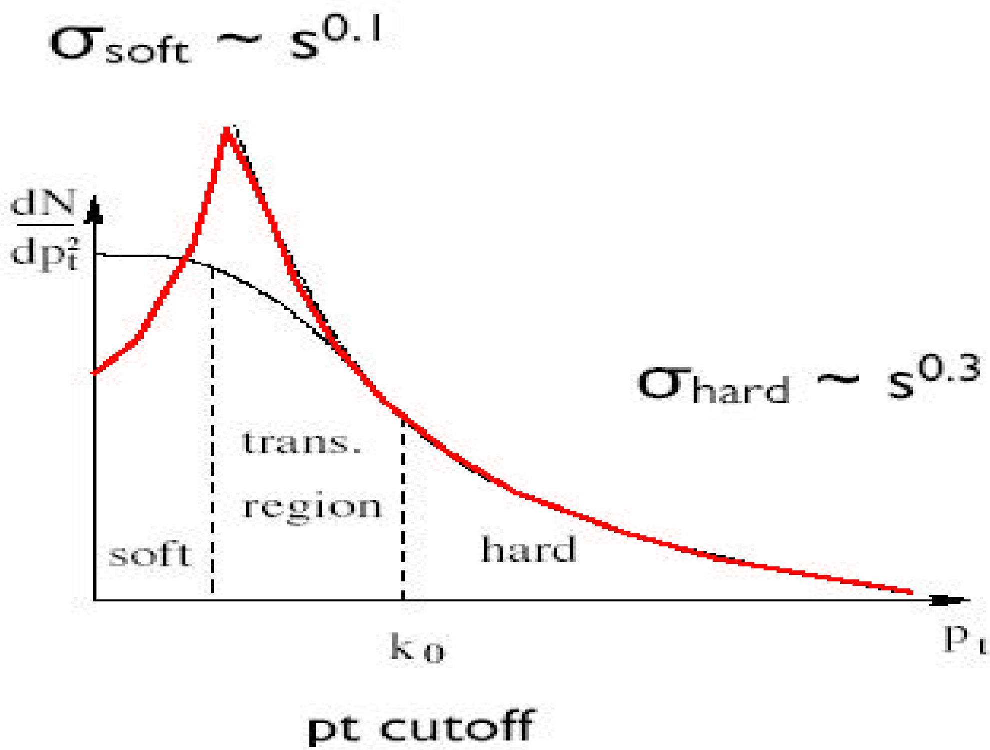


Pomeron Exchange-Two strings of hadrons



Conceptual problem- Matching soft and hard processes.

This is done by tuning the transition region carefully!

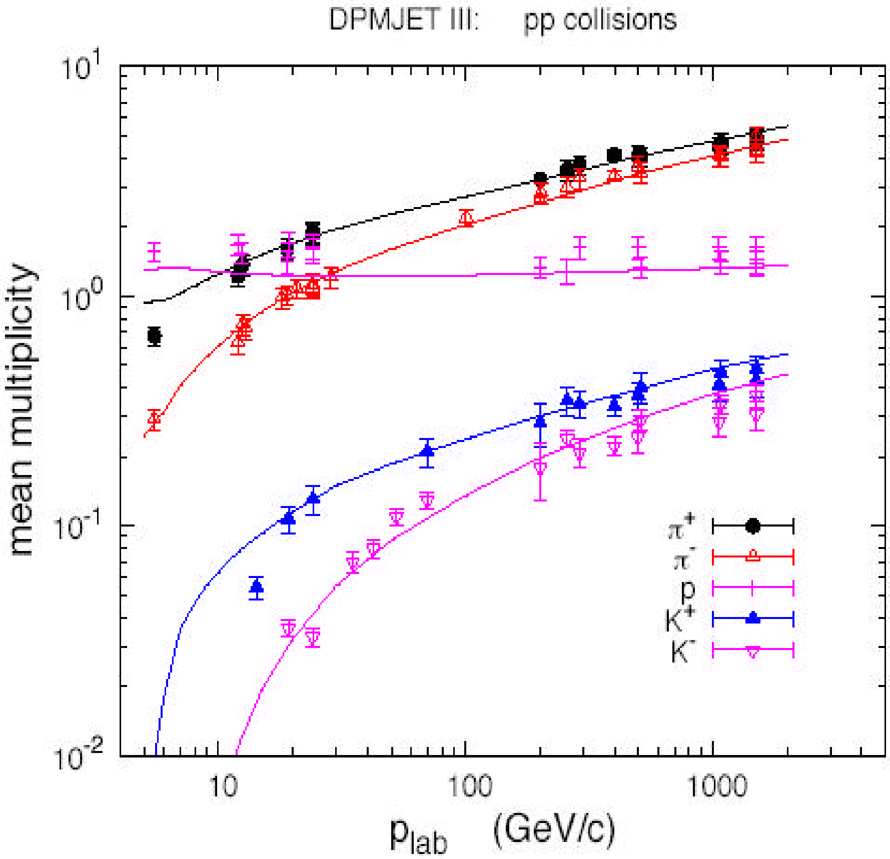


DPMJET-Multiplicities-Slides from R.Engel

DPMJET in p-p mode:
simulation of particle production from energy threshold on

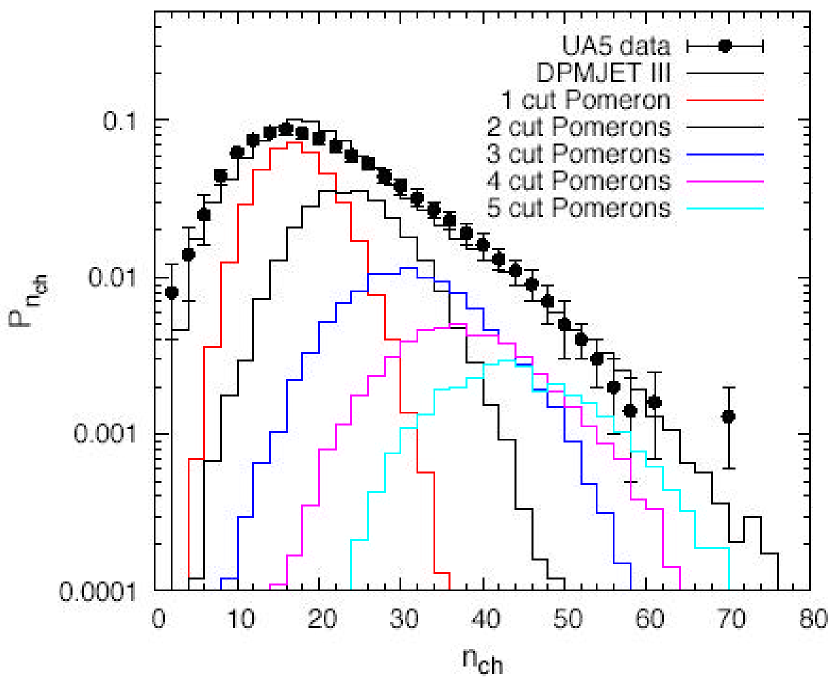
proton - proton, $E_{lab} = 200GeV$

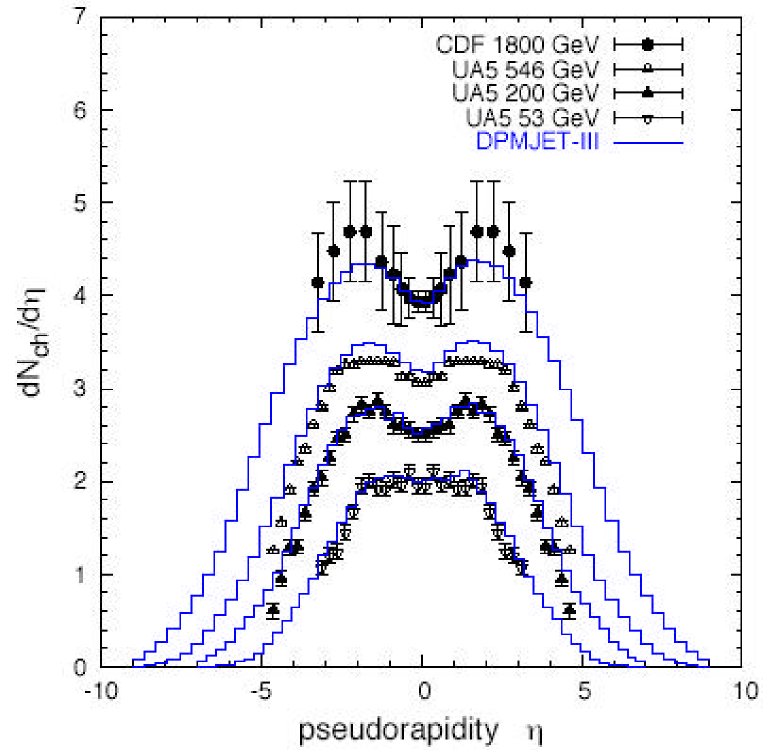
	Exp.	DPMJET-III
charged	7.69 ± 0.06	7.64
neg.	2.85 ± 0.03	2.82
p	1.34 ± 0.15	1.26
n	0.61 ± 0.30	0.66
π^+	3.22 ± 0.12	3.20
π^-	2.62 ± 0.06	2.55
K^+	0.28 ± 0.06	0.30
K^-	0.18 ± 0.05	0.20
Λ	0.096 ± 0.01	0.10
$\bar{\Lambda}$	0.0136 ± 0.004	0.0105



DPMJET- Collider distributions (R.Engel)

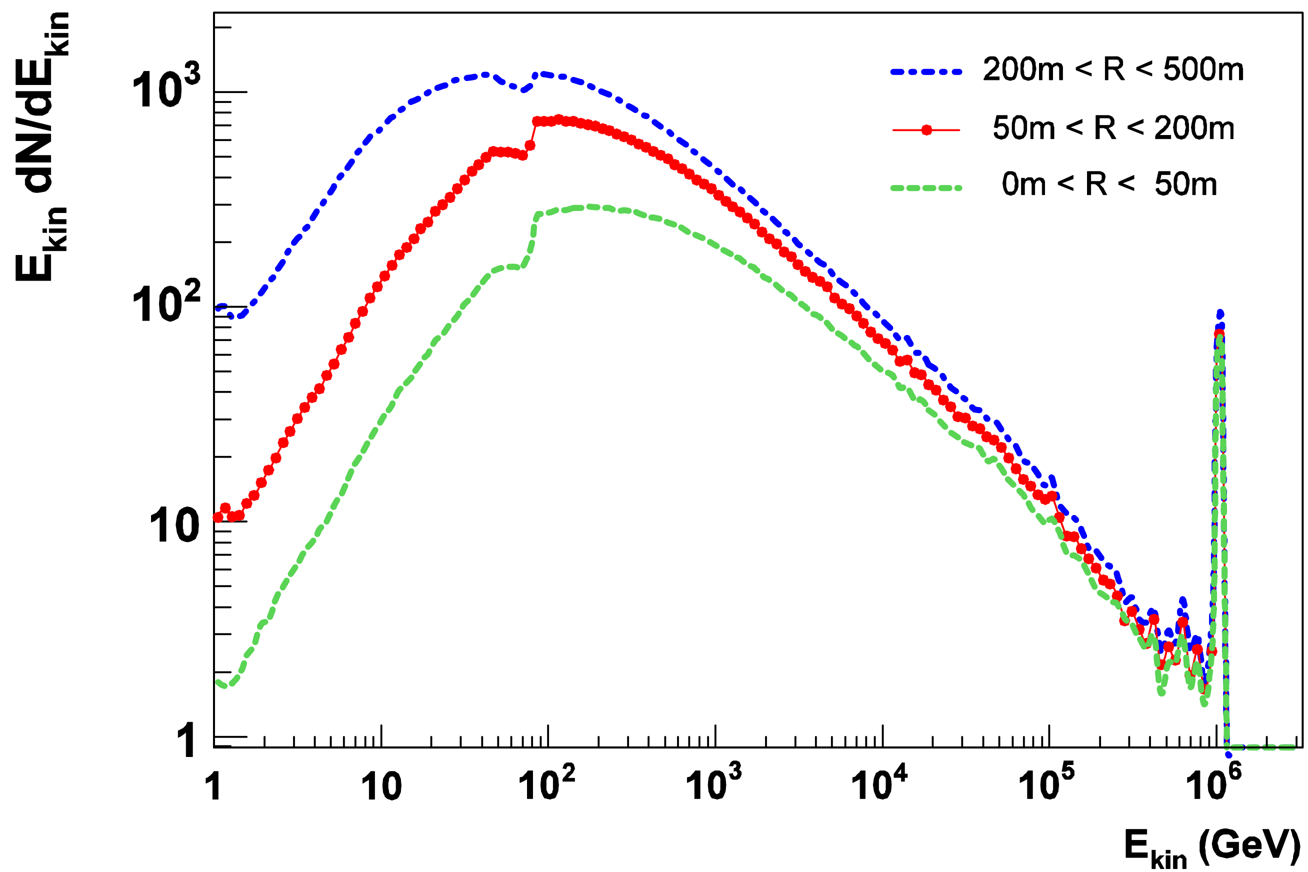
Charged particle multiplicity distribution at 200 GeV cms.





Charged particle pseudorapidity distributions

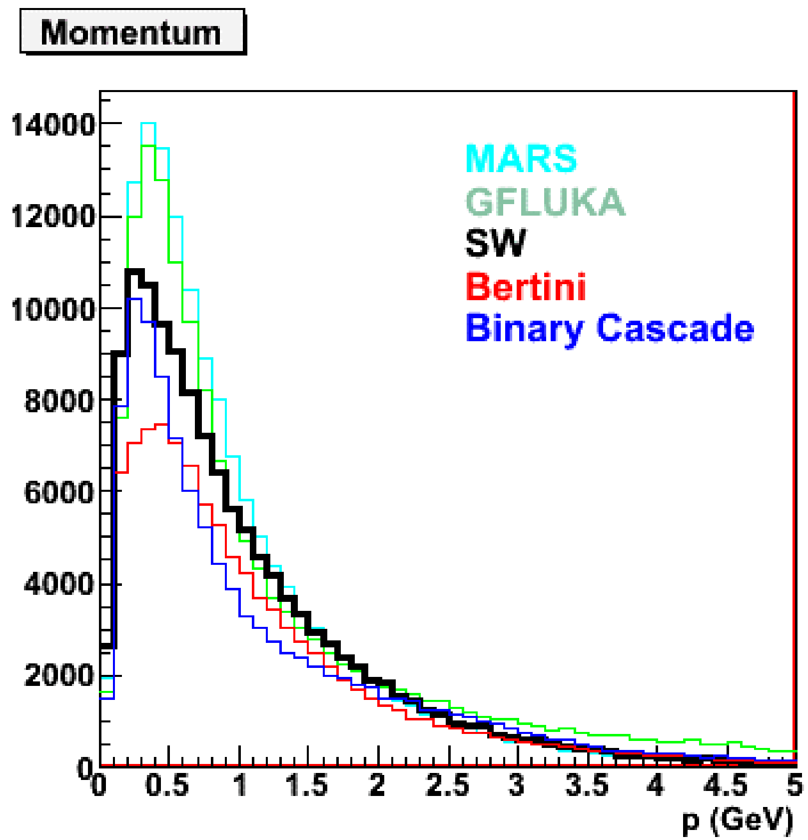
Meurer et al –Cosmic ray showers Discontinuity-Gheisha at low energies and QGSJET at higher energies-Simulation of air showers

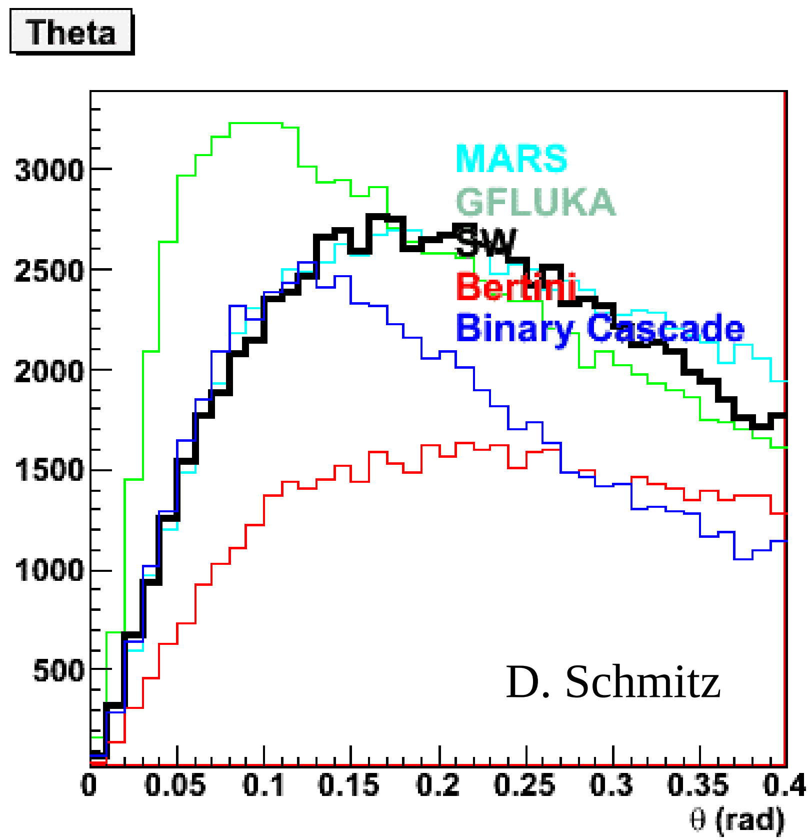


Plethora of models

- No complete theory exists-unlike in QED/EGS case
- A plethora of models exists. Not all can be correct. In fact none can describe all data. All models tuned to single particle inclusive cross sections. We are now asking questions where particle correlations are important—Eg How wide is the shower from a particle.
- So the approach of "Validating models and tuning them with data" will only have limited success. Anytime we open up new territory, we will need to re-validate. Unless we take a new tack, and maximize the use of data and minimize the use of theory in the shower simulation. I will describe this approach towards the end.

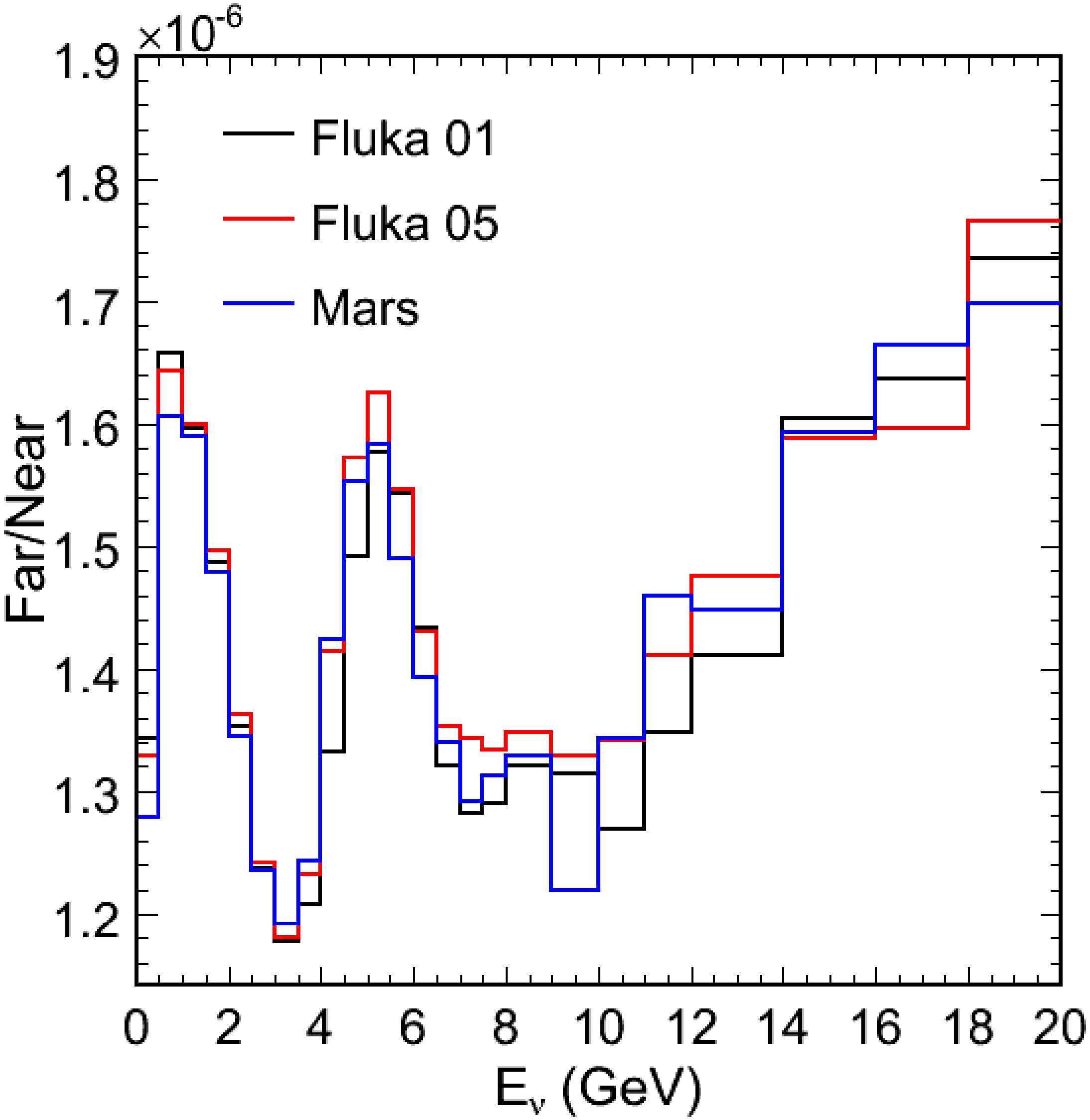
Miniboone-Sanford-Wang (SW) parametrizaion of E910 and HARP compared to other models





The differences are dramatic in the p spectra as well! But the E910 and HARP cross sections determine the correct model, which is very close to MARS.

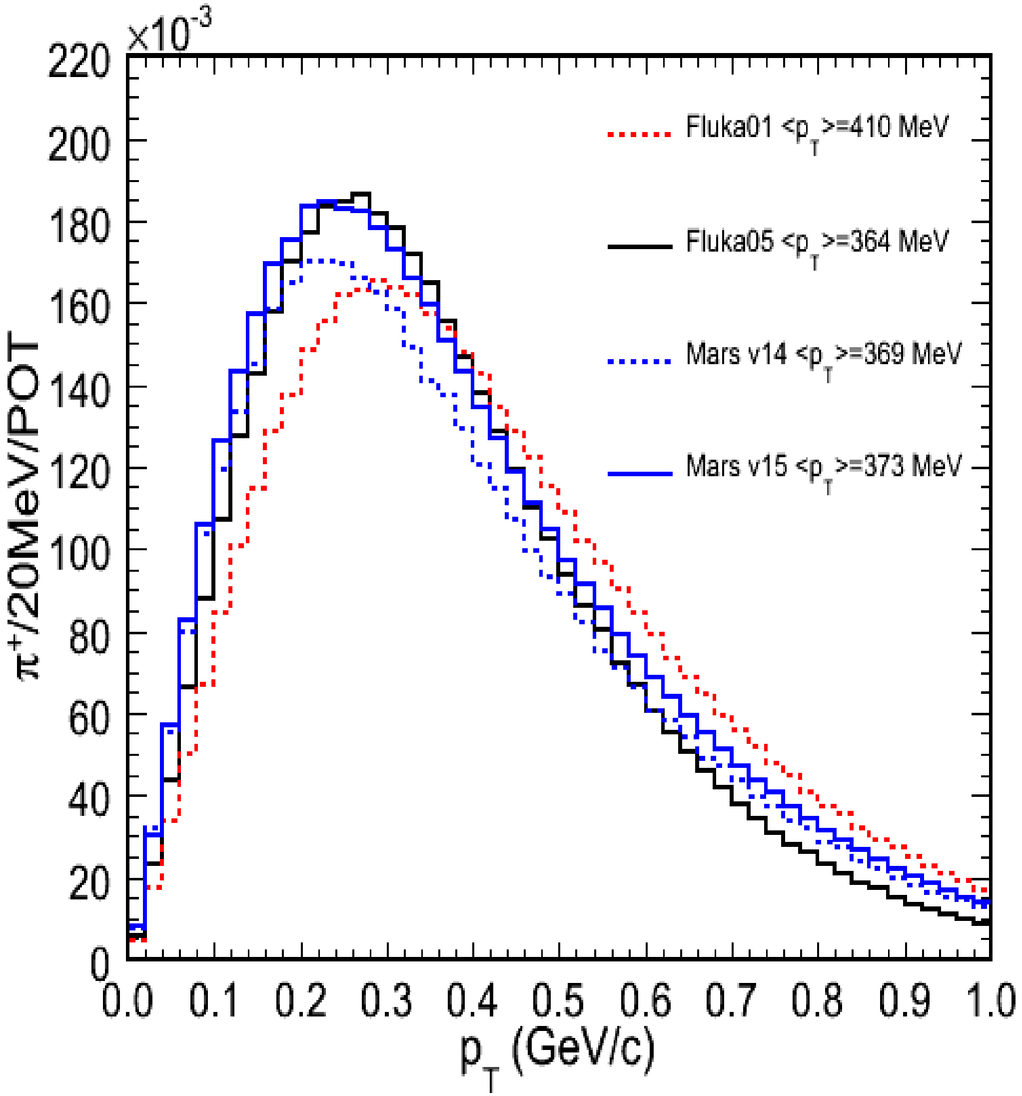
Why Hadron Production Is Important to NuMI-slides from S.Kopp



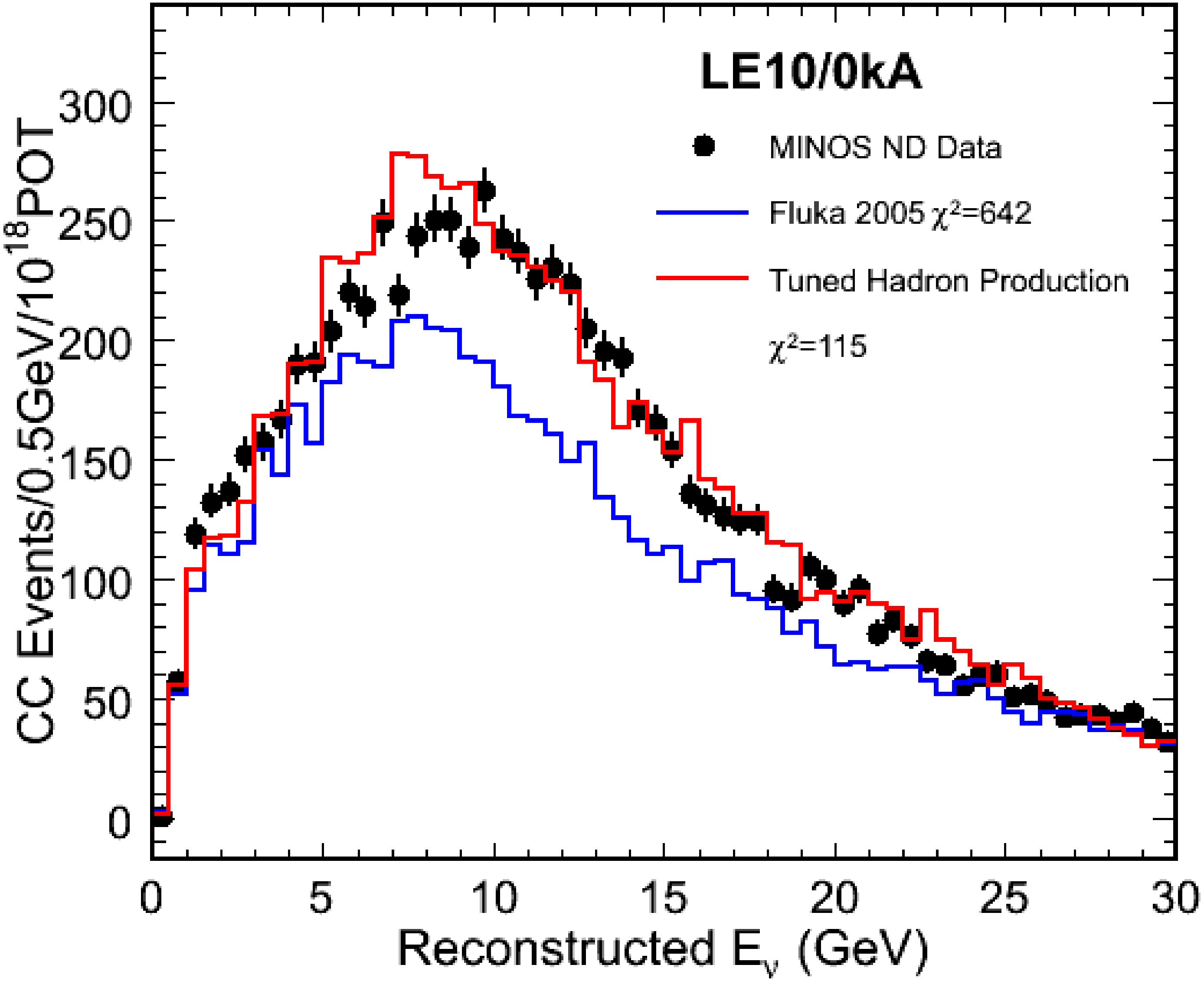
- Two-detector experiment for ν_μ disappearance measurement.
- Agreement 'OK' in ND, within model spread.
- But what should we use as error in predicted beam spectrum? (model correlation?)

Compare Hadron Production Models-S.Kopp

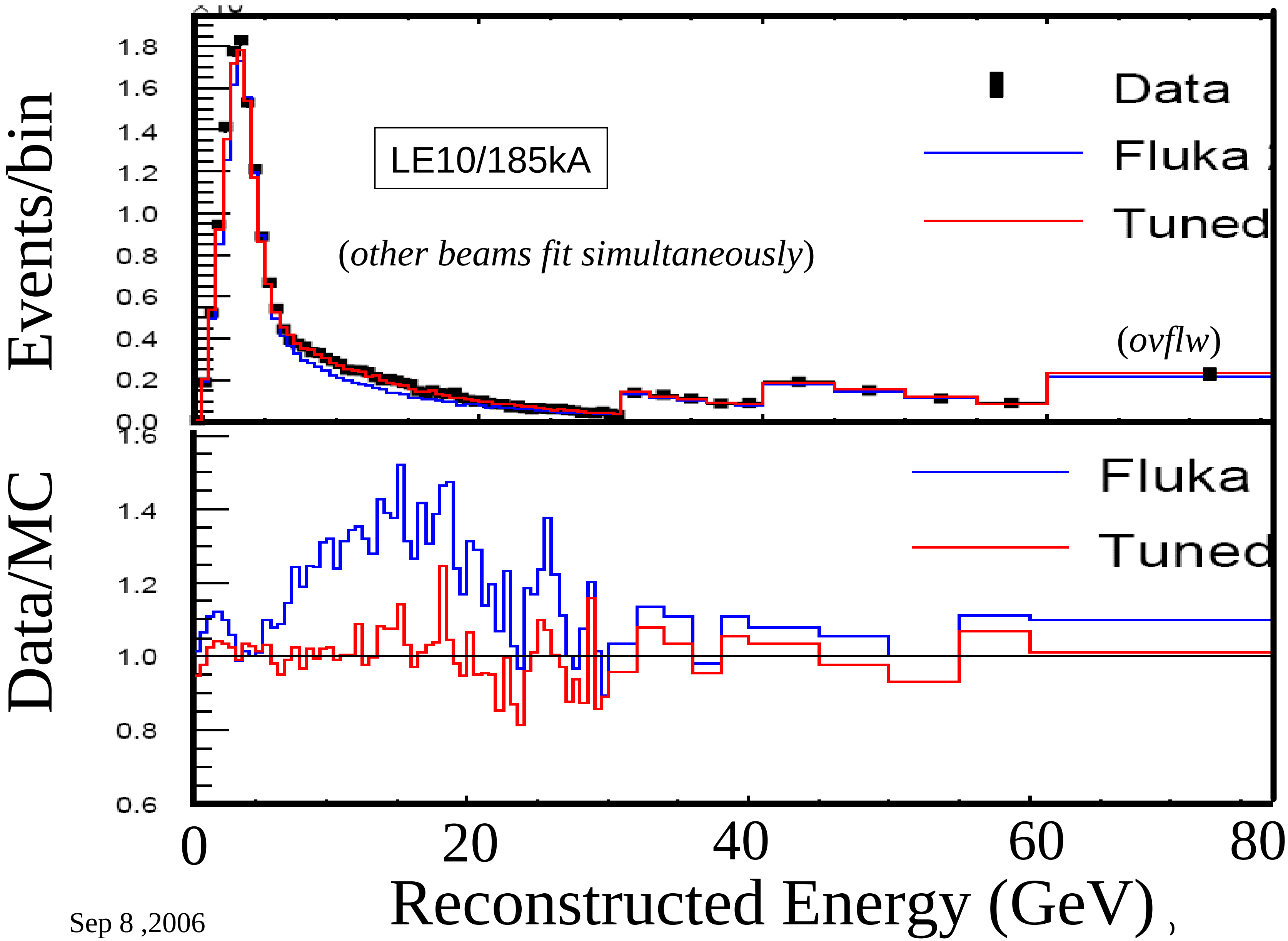
Model	$\langle p_T \rangle$ (GeV/c)
GFLUKA	0.37
Sanf.-Wang	0.42
CKP	0.44
Malensek	0.50
MARS – v.14	0.38
MARS – v.15	0.39
Fluka 2001	0.43
Fluka 2005	0.36



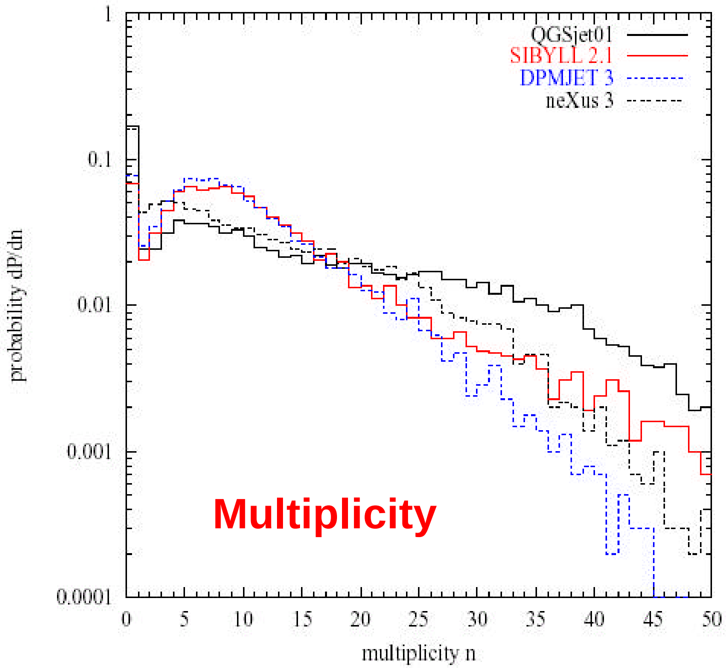
ND Spectra After Reweighting (VI)-S.Kopp



Results (Including >30 GeV)-S.Kopp

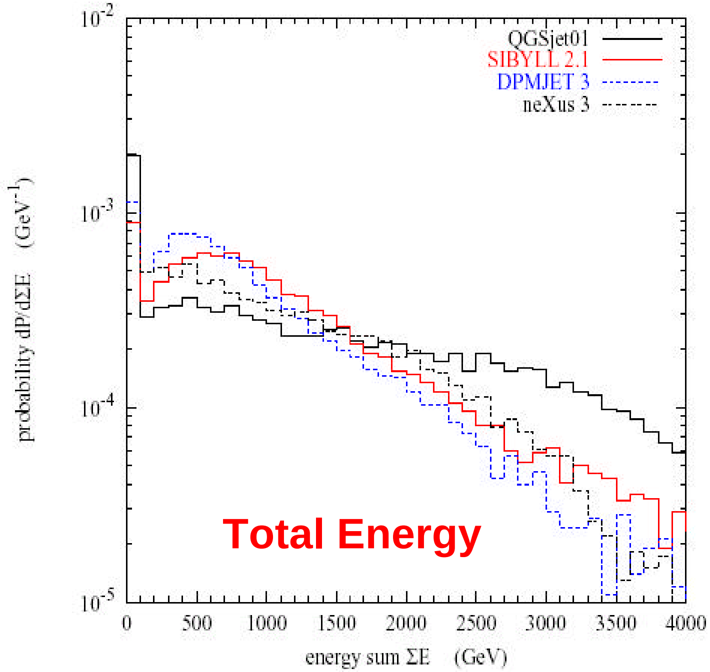


Model Predictions: proton-proton at the LHC –Totem Expt- S.Lami



total multiplicity in forward detector

$(5 \leq \eta \leq 7)$



total energy in forward detector

$(5 \leq \eta \leq 7)$

Predictions in the forward region within the CMS/TOTEM acceptance

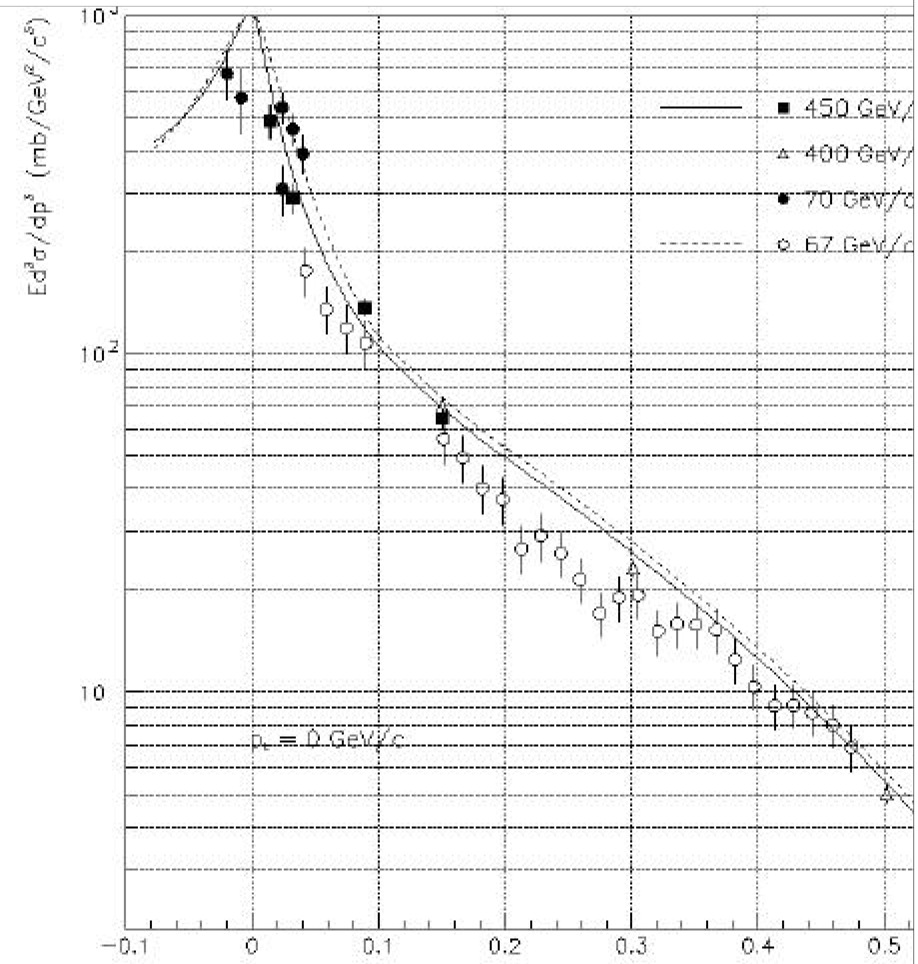
(T1 + T2 + CASTOR)

Hadron Shower Simulator problem

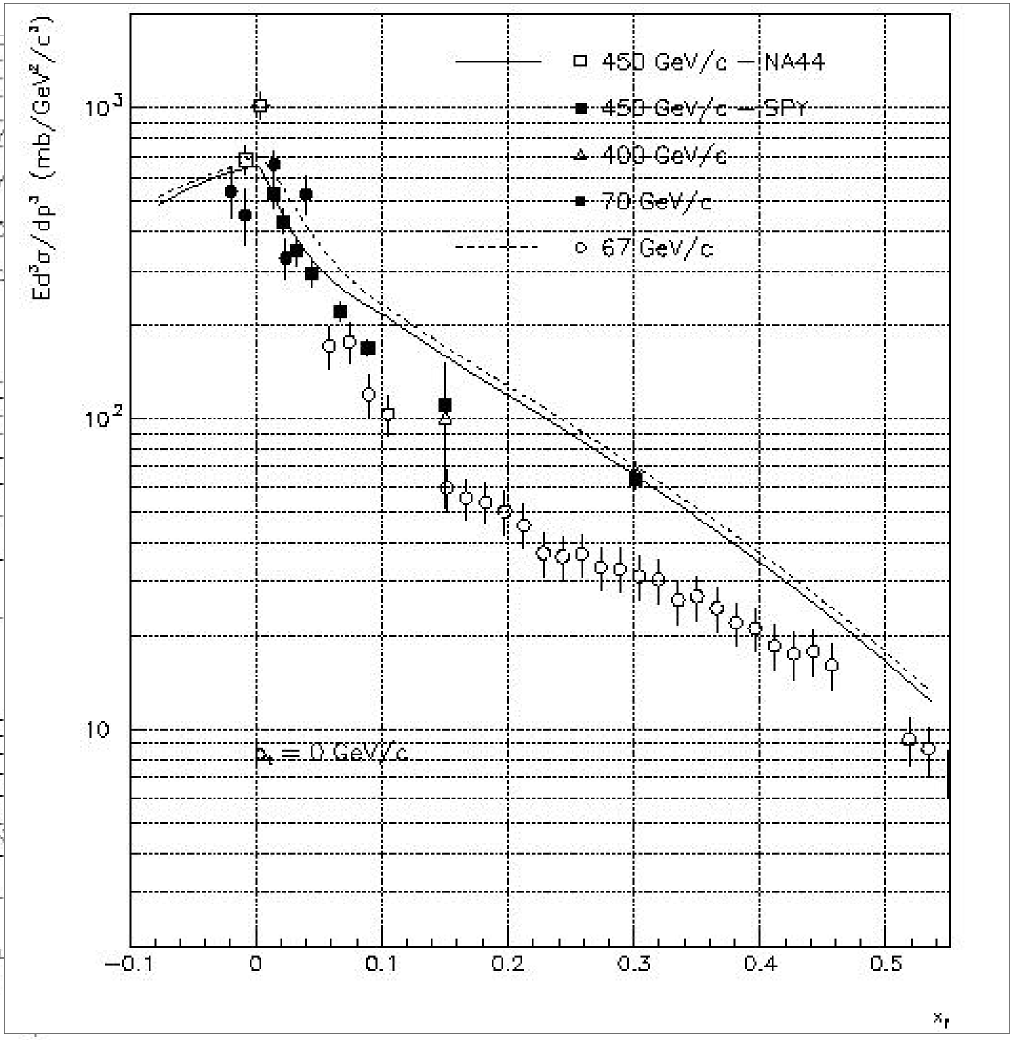
- All neutrino flux problems (NUMI, MiniBoone, K2K, T2K,Nova, Minerva) and all Calorimeter design problems and all Jet energy scale systematics (not including jet definition ambiguities here) can be reduced to one problem- the current state of hadronic shower simulators.
- Timely completion of MIPP upgrade progam can help CDF/D0 systematics, CMS/ATLAS, CALICE and all neutrino experiments.
- Myth-I Put designed calorimeter in test beam and use the data to tune the simulator_-D0 experience. You need test beam to test the hardware.
- Myth-II Take test beam data at various incident angles and use it to interpolate –H-matrix experience
- In order to have better simulator, we need to measure event by event data with excellent particle ID using 6 beam species (pi,K,P and antiparticles) off various nuclei at momenta ranging from 1 GeV/c to ~100 GeV/c. MIPP upgrade is well positioned to obtain this data.
- MIPP can help with the nuclear slow neutron problem.
- Current simulators use a lot of „Tuned theory“. Propose using real library of events and interpolation.

Quality of existing data

Invariant π^- cross section pBe interactions vs models

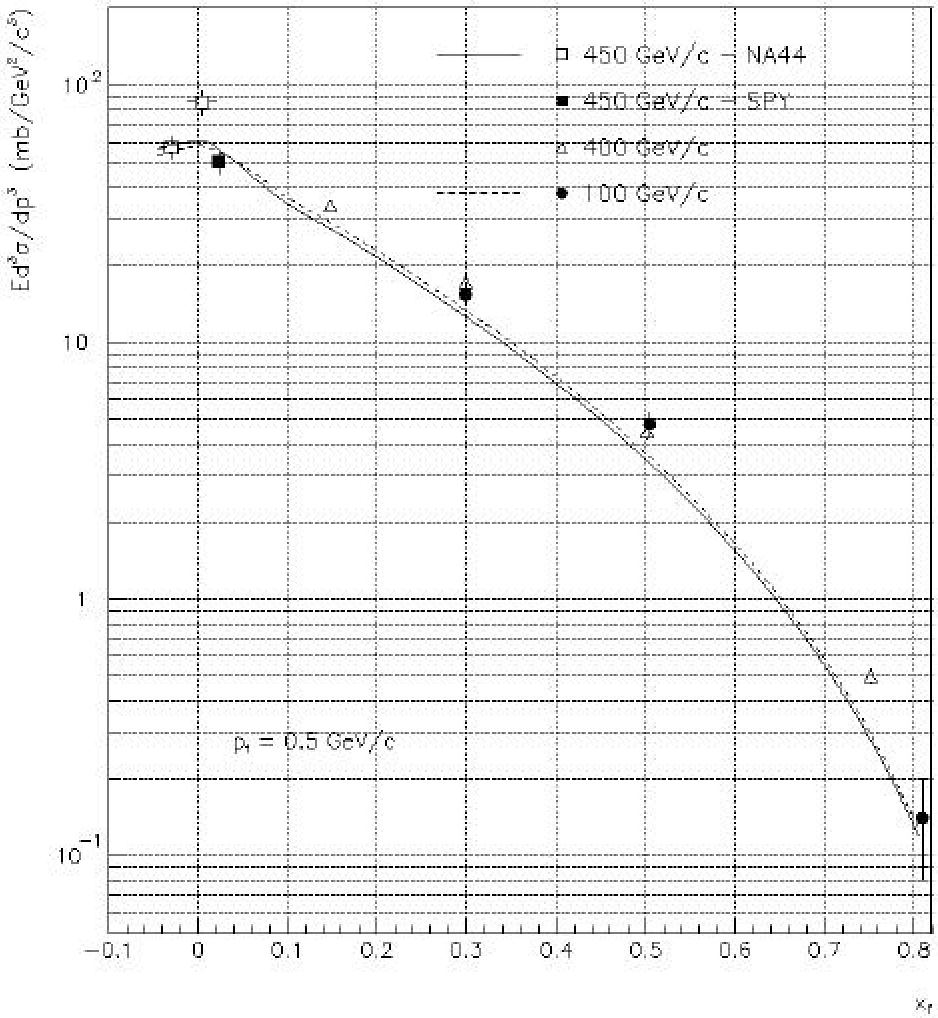


Invariant π^+ cross section pBe interactions vs models

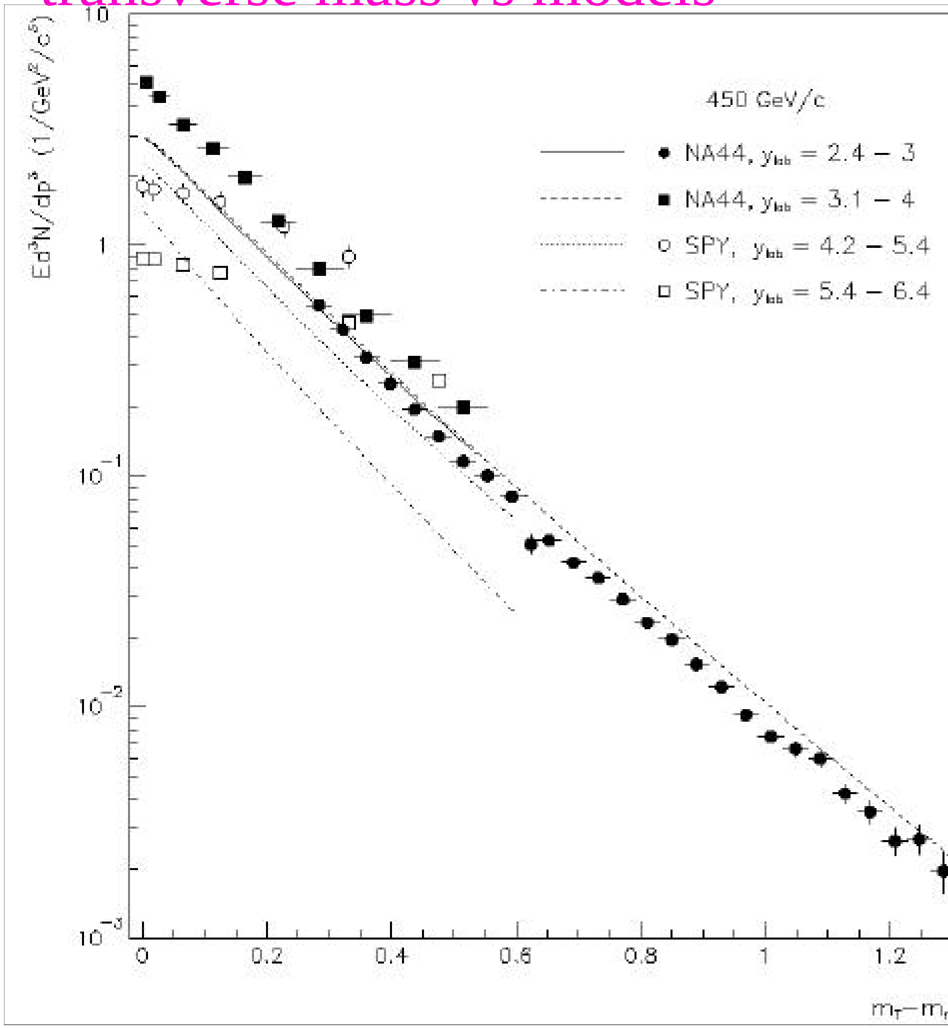


Quality of existing data

Invariant π^+ cross section pBe interactions $p_T = 0.5$ GeV/c vs models



Invariant π^+ cross section pBe interactions vs transverse mass vs models

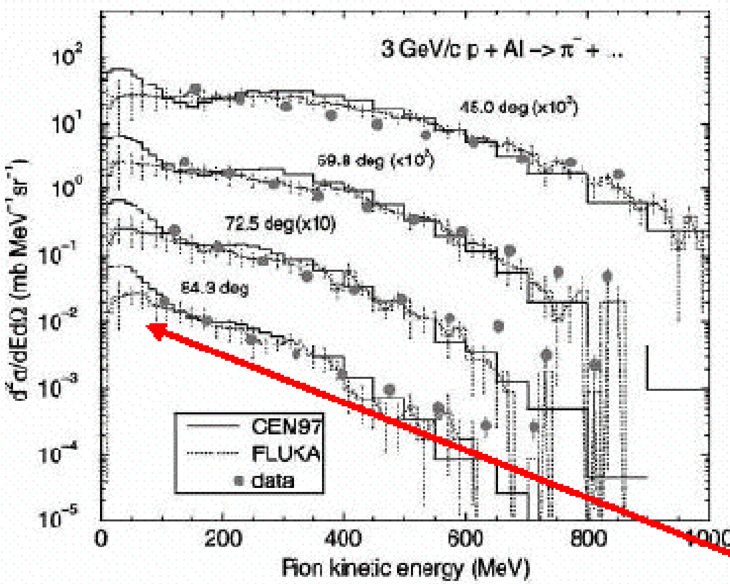


Discrepancies between hadronic generators

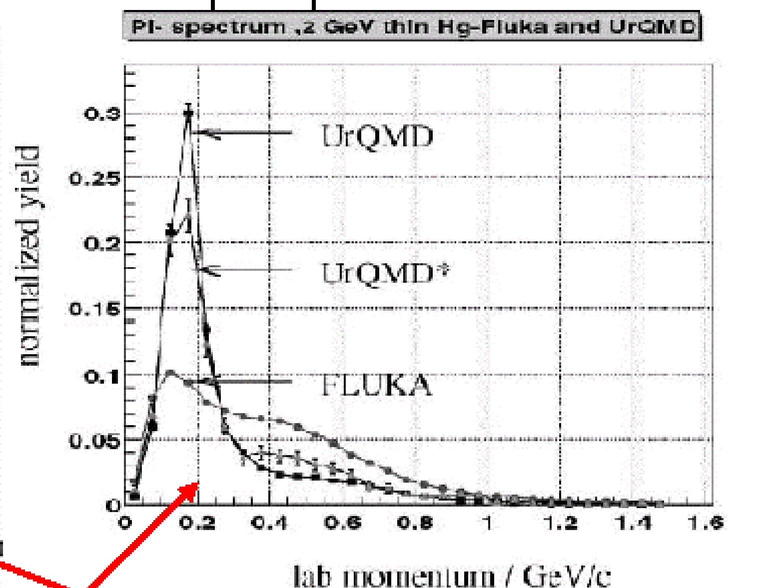
Lack of experimental data and large uncertainties in the calculations,

in particular for thick and high Z target materials

Differential distributions for pion production:



NIMA451(2000)327



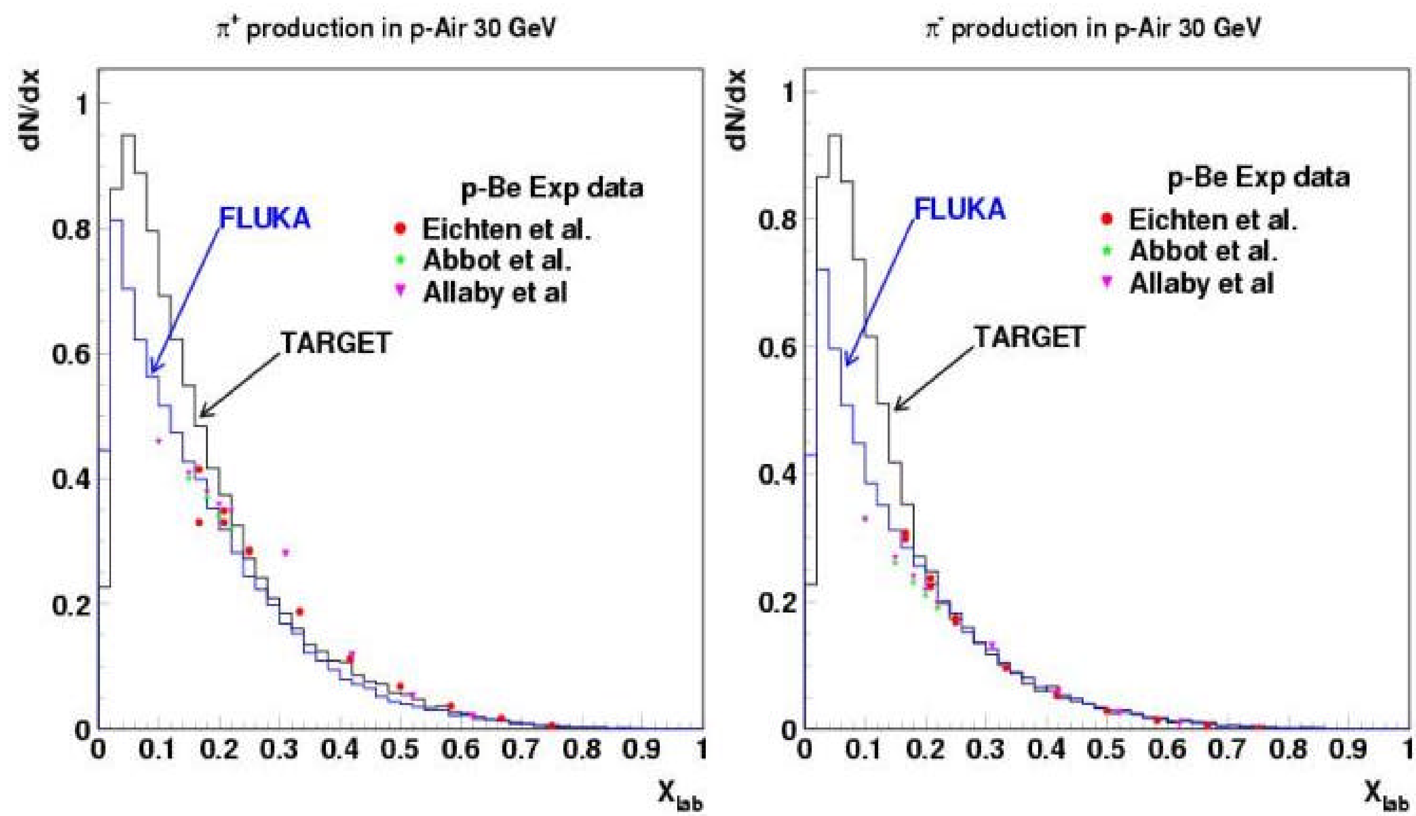
NIMA472(2001)5

NO DATA !

➔ Thin and thick targets, scan in Z

Discrepancies between hadronic generators- Testing particle production off nitrogen(Be extrapolated)

27



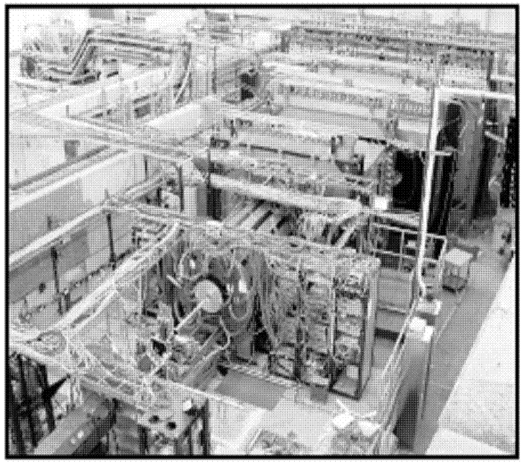
G.Battistoni

Possibilities of New Experimental data

- HARP experiment- Published p-Al at 12.9 GeV/c. NUFACT06- New data presented. More targets to come. Proton and pion beams max beam momentum 15 GeV/c.

HARP – PS214 at CERN

HARP is a large angle spectrometer to measure hadron production from various nuclear targets and a range of incident beam momenta



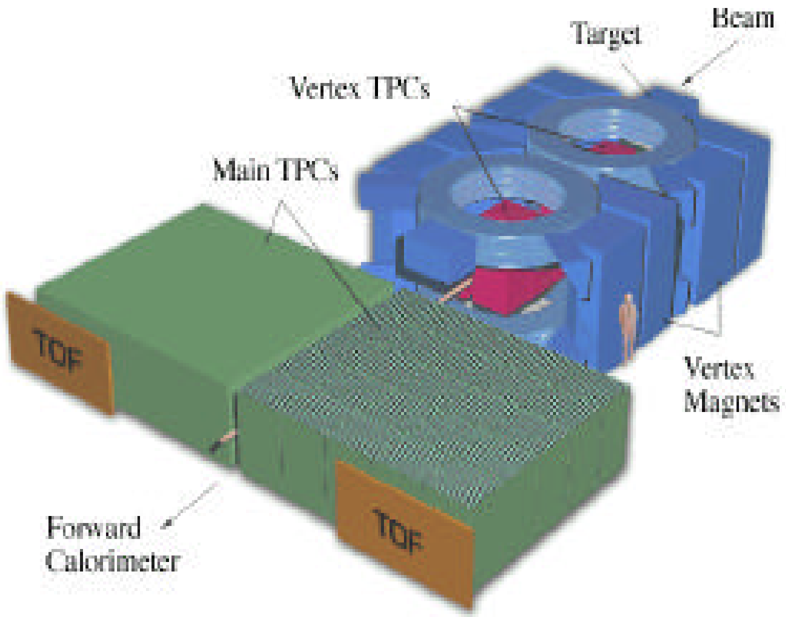
- Nuclear target materials : A = 1 – 200
- Nuclear target thickness : λ = 2 – 100%
- Beam particles : h = p, π^{+-},e^{+-}
- Beam momenta : p_{beam} = 1 – 15 GeV/c
- Secondaries measured : h = p, π^{+-},K^{+-}
- Kinematic acceptance of forward spectrometer

  p = 0.5 – 8.0 GeV/c

  θ = 20 – 250 mrad

hadron production measurements in *"seven dimensions"*

NA49 Experiment Upgrade LoI



Run Expt at 20 Hz

2007-30days of proton beam at 30GeV. 3E6 events on p+c

2008 45 days of proton, pion beams at 30,40,50 and 158 geV/c. 75E6 pp, pC and πC events.

MIPP collaboration list

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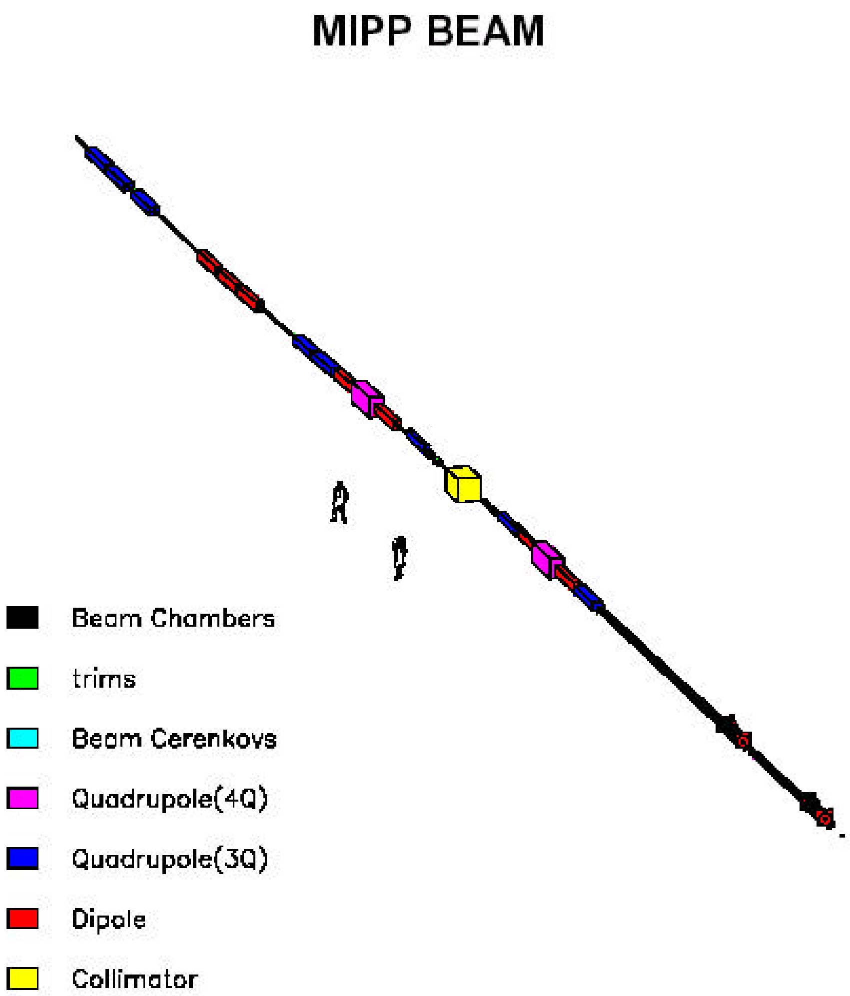
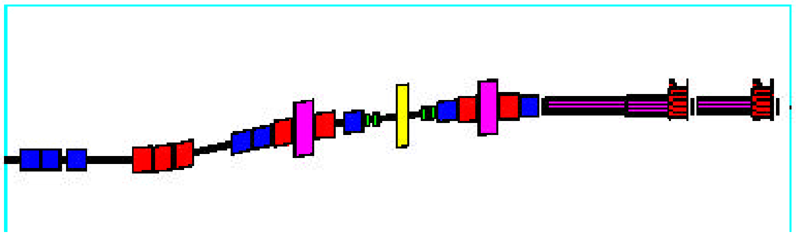
University of Virginia

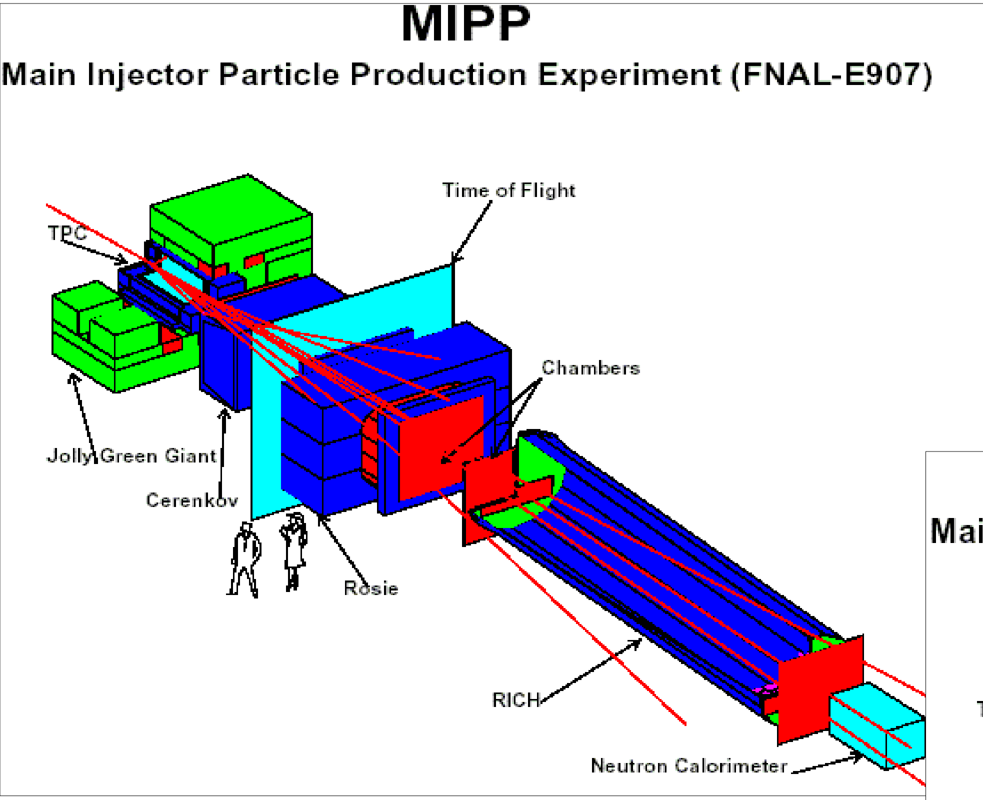
More have joined. Wisconsin, GSI/KVI

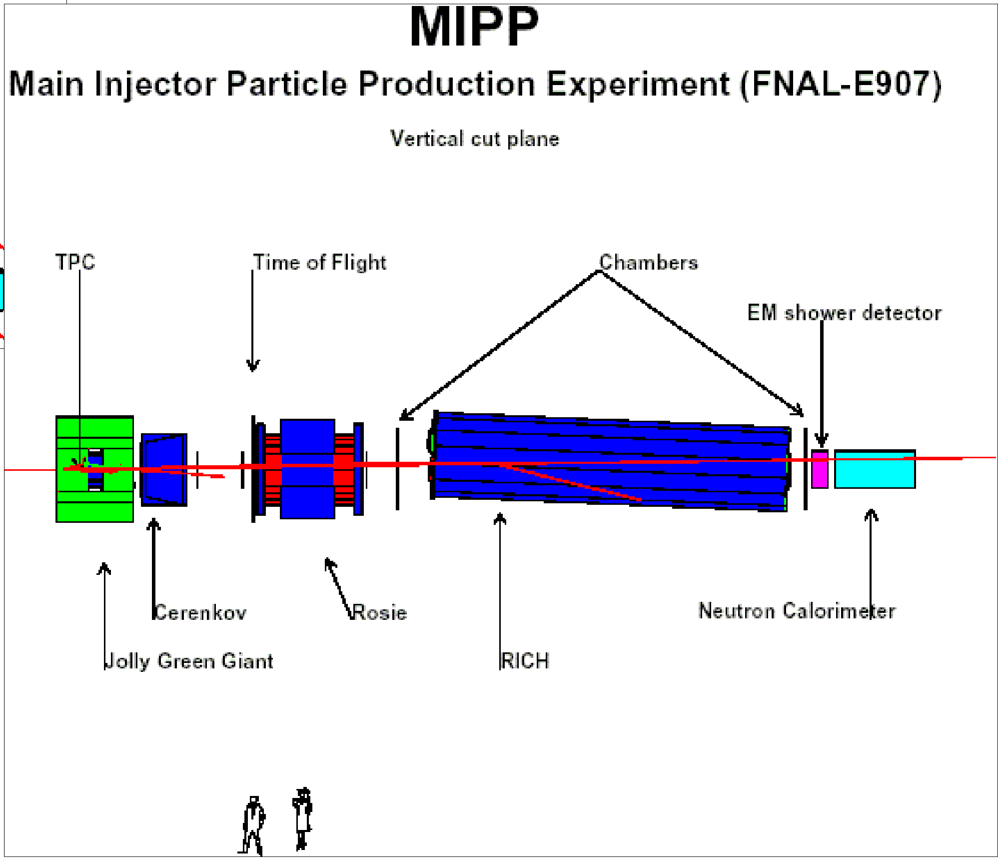
MIPP Secondary Beam

Installed in 2003. Delivering slow spill commissioning beam (40GeV/c positives since in 2004). Finished Engineering run in Aug 2004. Data taking run All of 2005. Ended February 2006. Acquired 18million events on various nuclear targets.






MIPP
Main Injector Particle Production Experiment (FNAL-E907)
Time of Flight
TPC
Chambers
Jolly Green Giant
Cerenkov
Rosie
RICH
Neutron Calorimeter


MIPP
Main Injector Particle Production Experiment (FNAL-E907)
Vertical cut plane
TPC
Time of Flight
Chambers
EM shower detector
Cerenkov
Rosie
Neutron Calorimeter
Jolly Green Giant
RICH

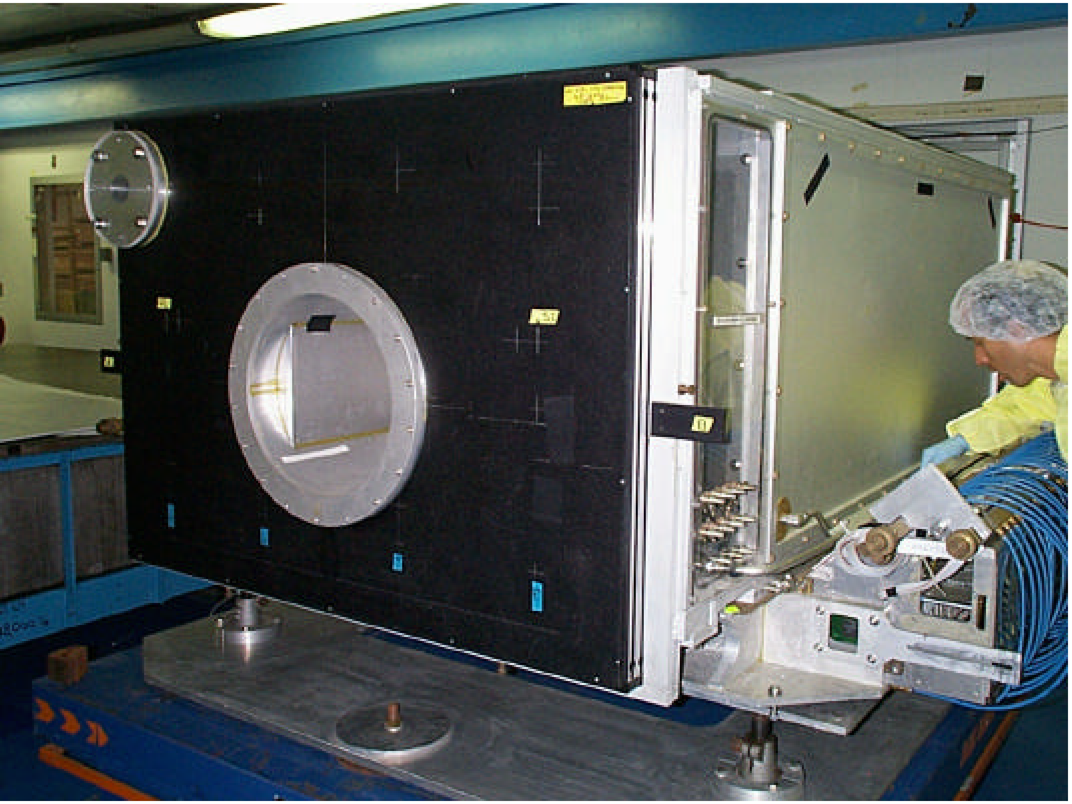
Installation in progress- Collision Hall

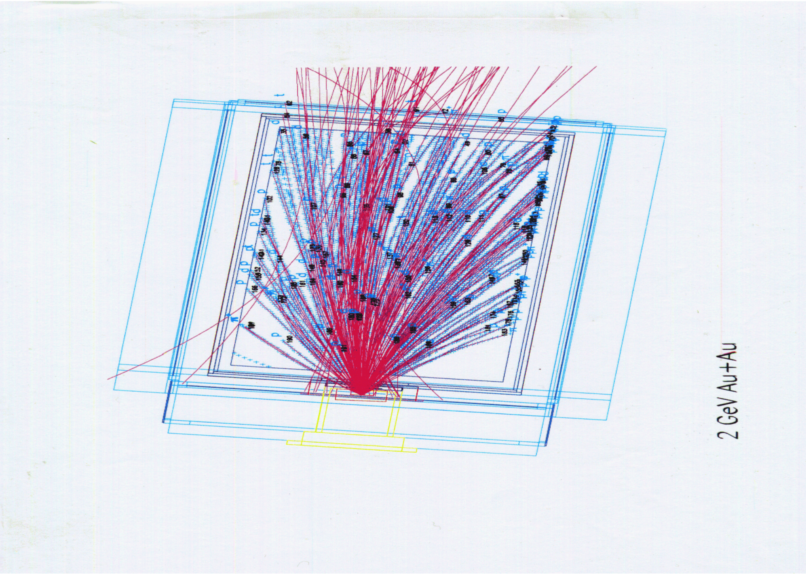
Brief Description of Experiment

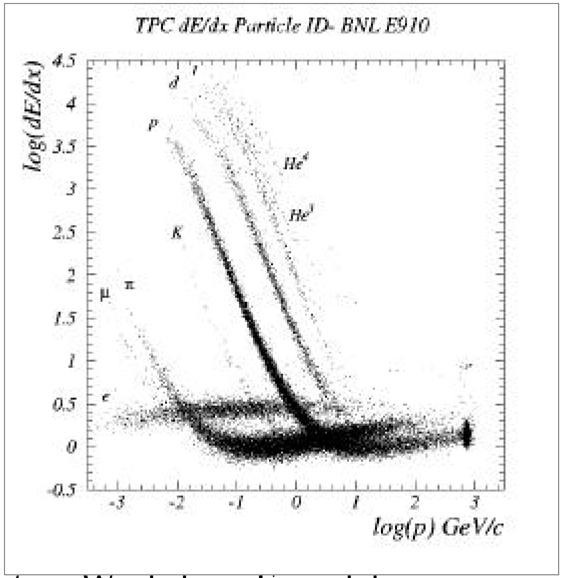
- Approved November 2001
- Situated in Meson Center 7
- Uses 120GeV Main Injector Primary protons to produce secondary beams of $\pi^{\pm}$ K $^{\pm}$ p $^{\pm}$ from 5 GeV/c to 100 GeV/c to measure particle production cross sections of various nuclei including hydrogen.
- Using a TPC we measure momenta of ~all charged particles produced in the interaction and identify the charged particles in the final state using a combination of dE/dx, ToF, differential Cherenkov and RICH technologies.
- Open Geometry- Lower systematics. TPC gives high statistics. Existing data poor quality.
- First Physics run- 18 million events 2005. Ended Feb 2006

TPC

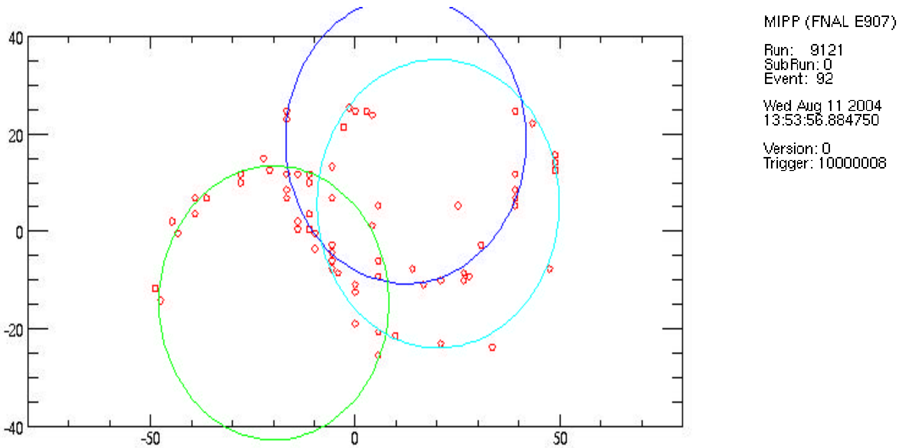
•

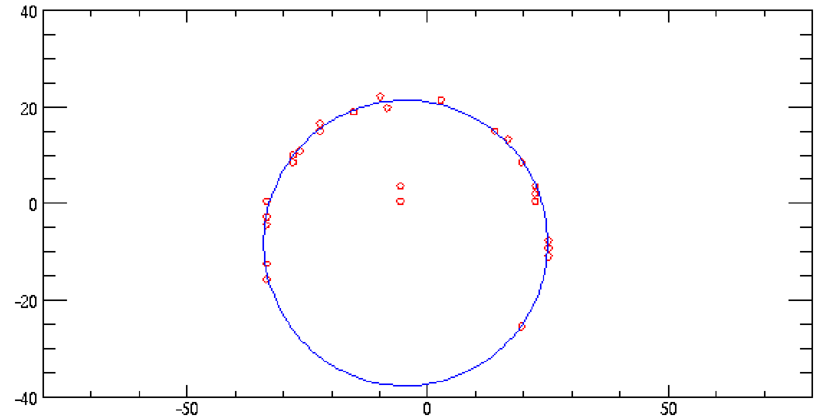


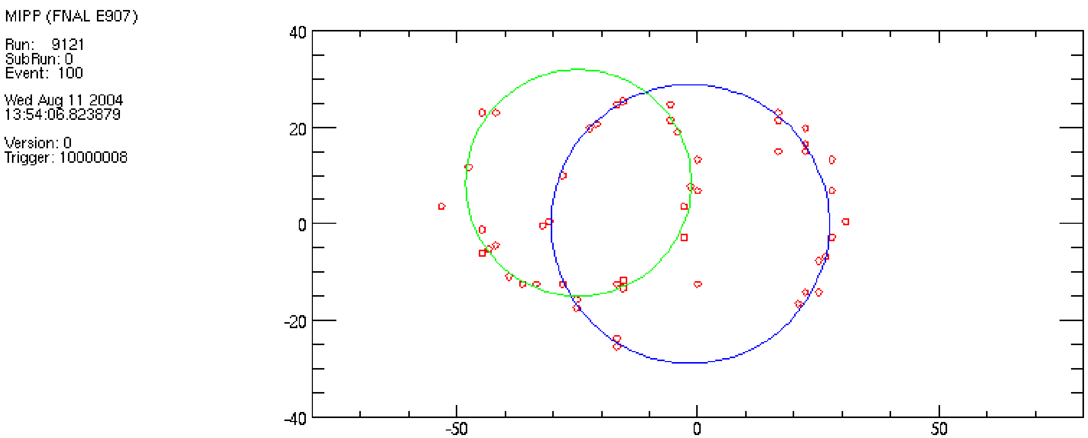

2 GeV Au+Au


TPC dE/dx Particle ID- BNL E910
log(dE/dx)
log(p) GeV/c
d
t
p
He4
He3
K
μ
π
e

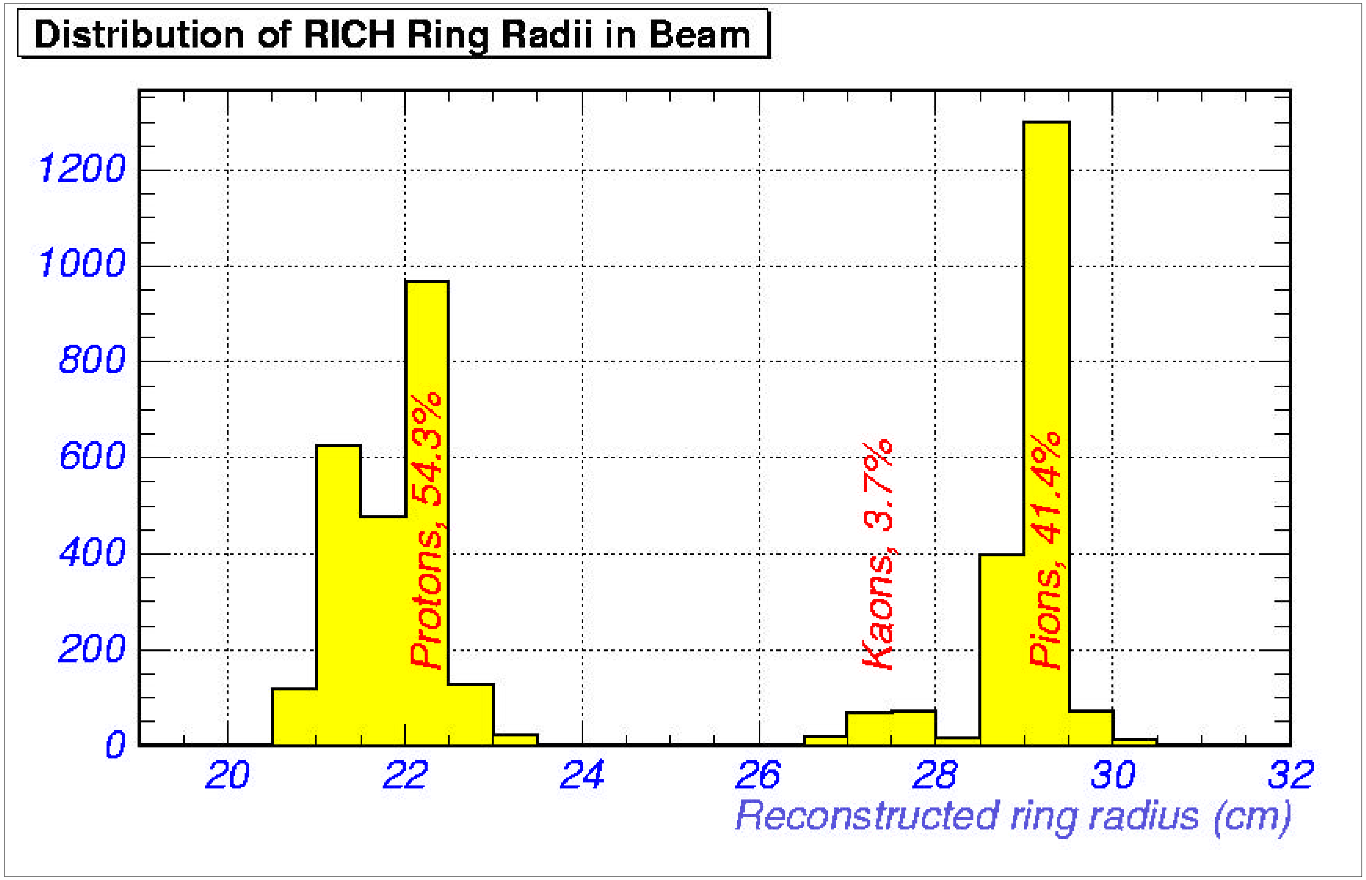
RICH rings pattern recognized





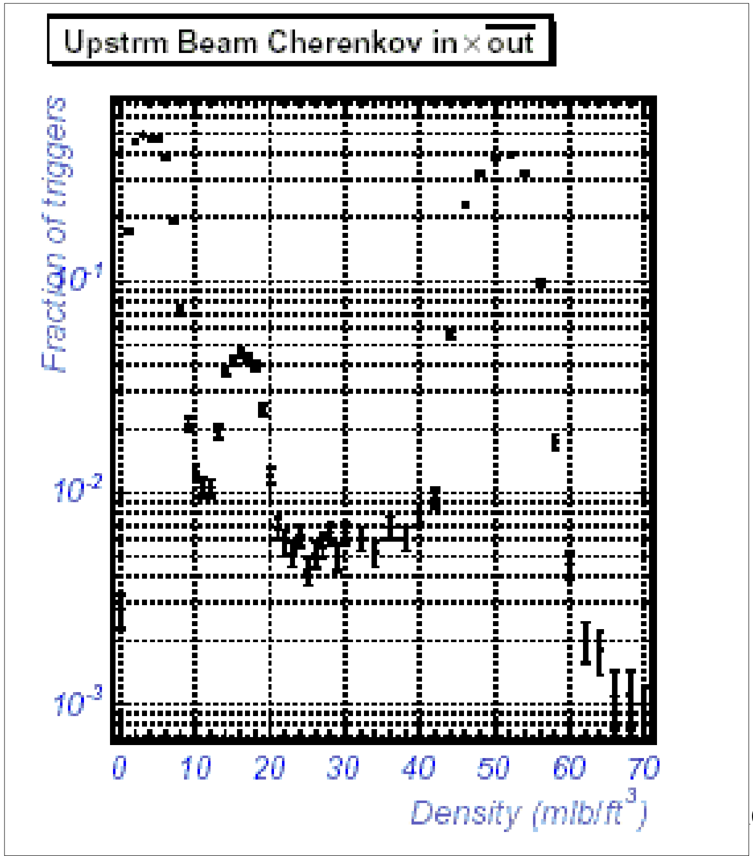


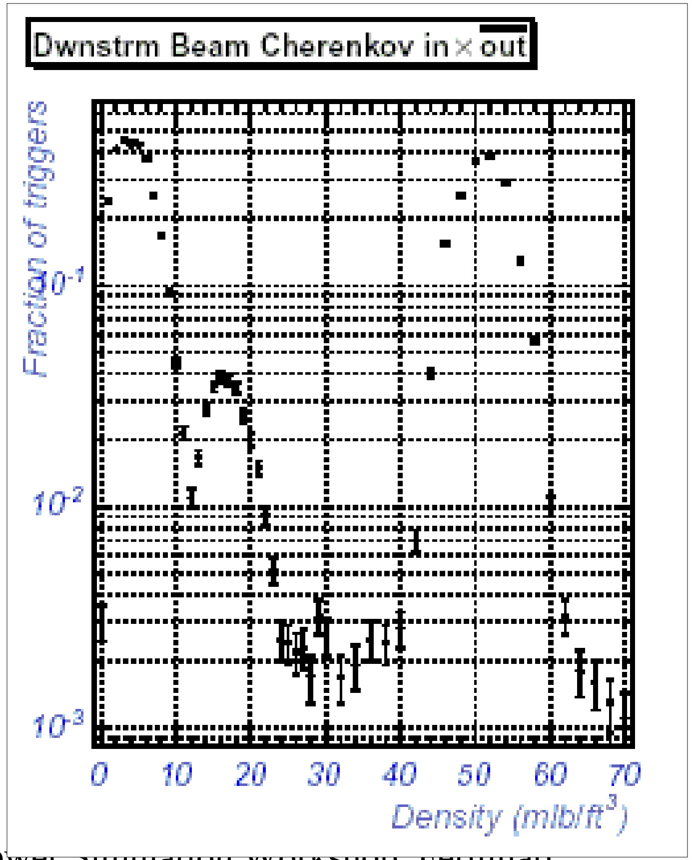
RICH radii for + 40 GeV beam triggers



Beam Cherenkovs

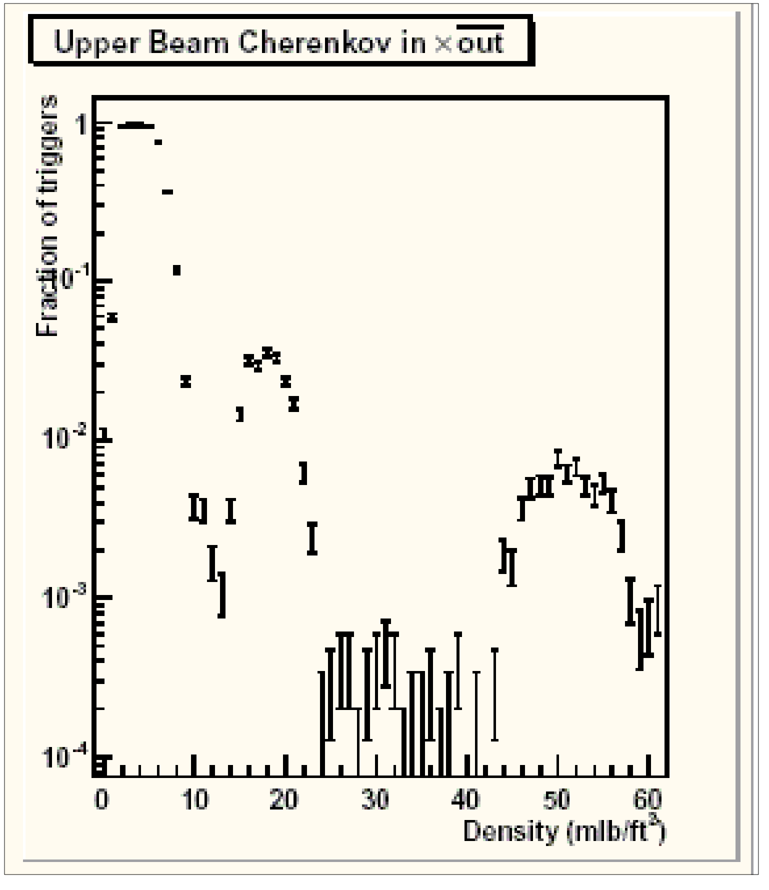
- Pressure curve Automated- Mini-Daq-APACS 30 minutes per pressure curve.+40GeV/c beam.

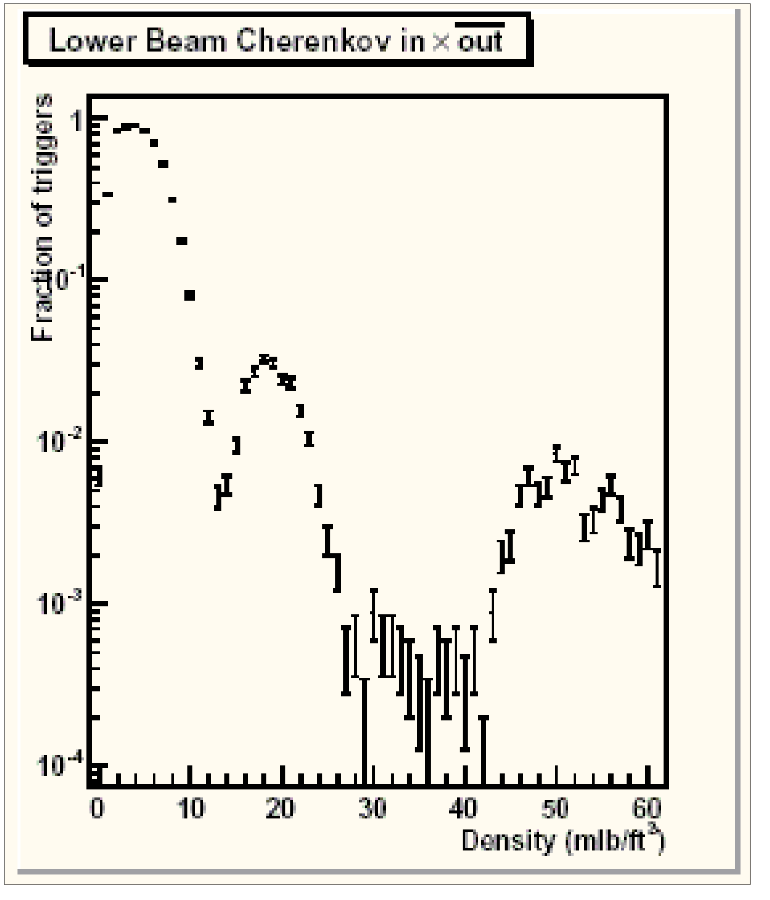




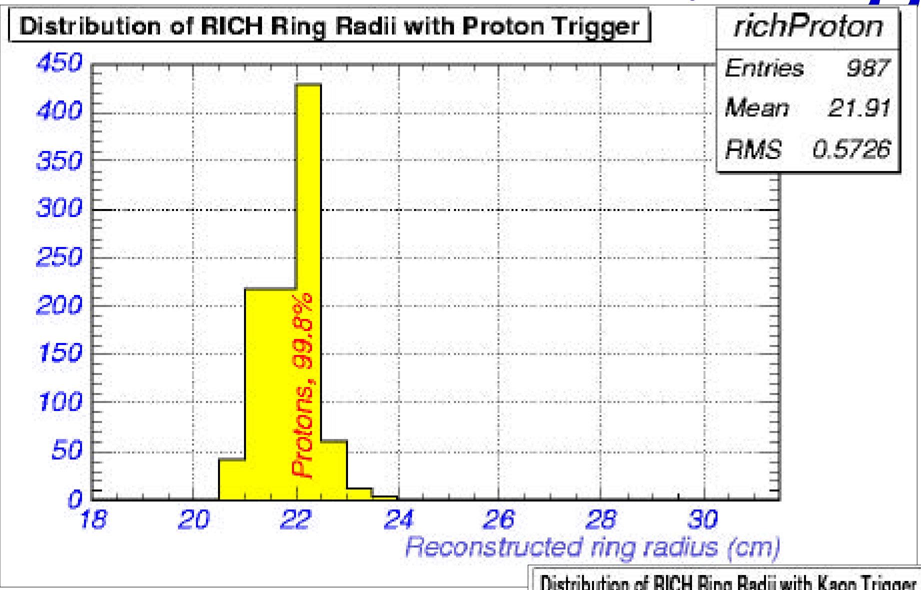
Beam Cherenkovs

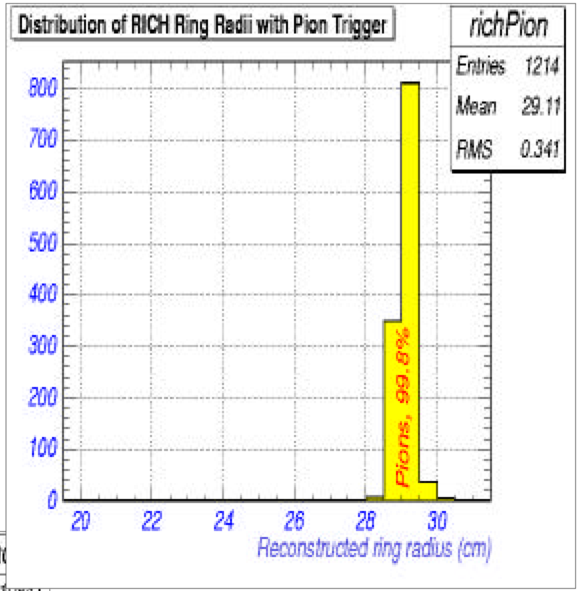
- 40 GeV/c negative beam

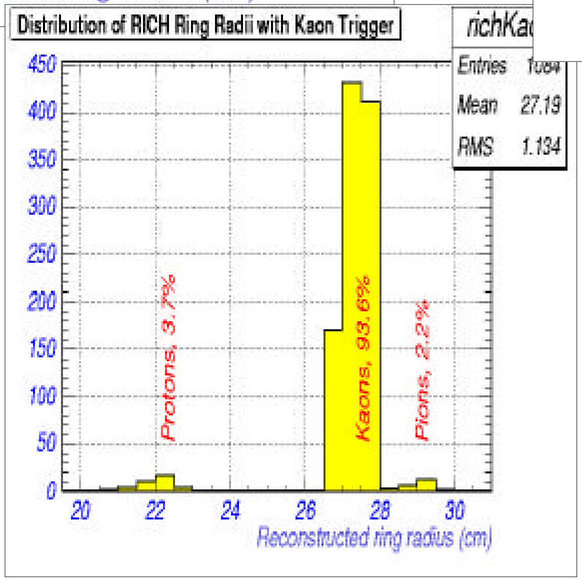




Comparing Beam Cherenkov to RICH for +40 GeV beam triggers-No additional cuts!

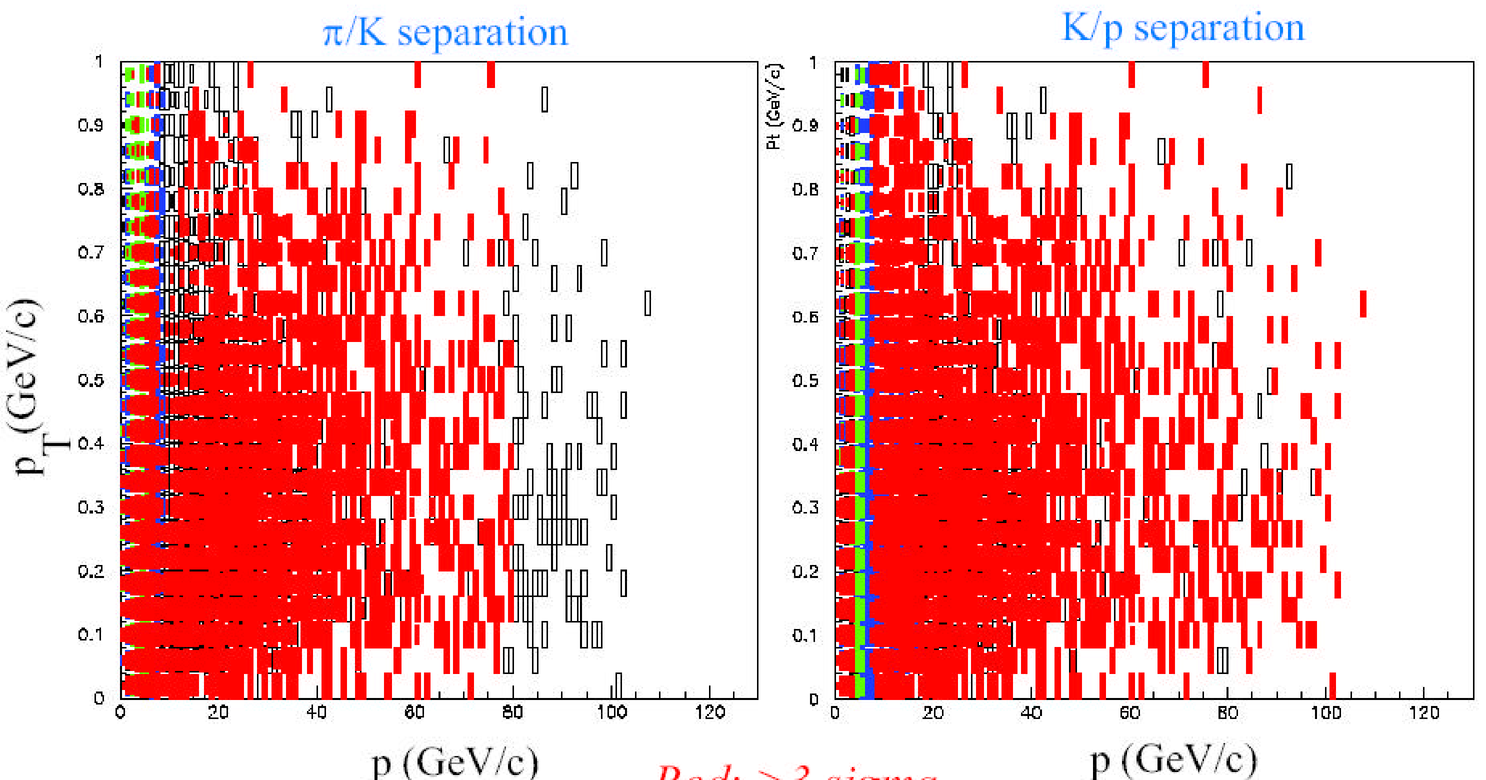






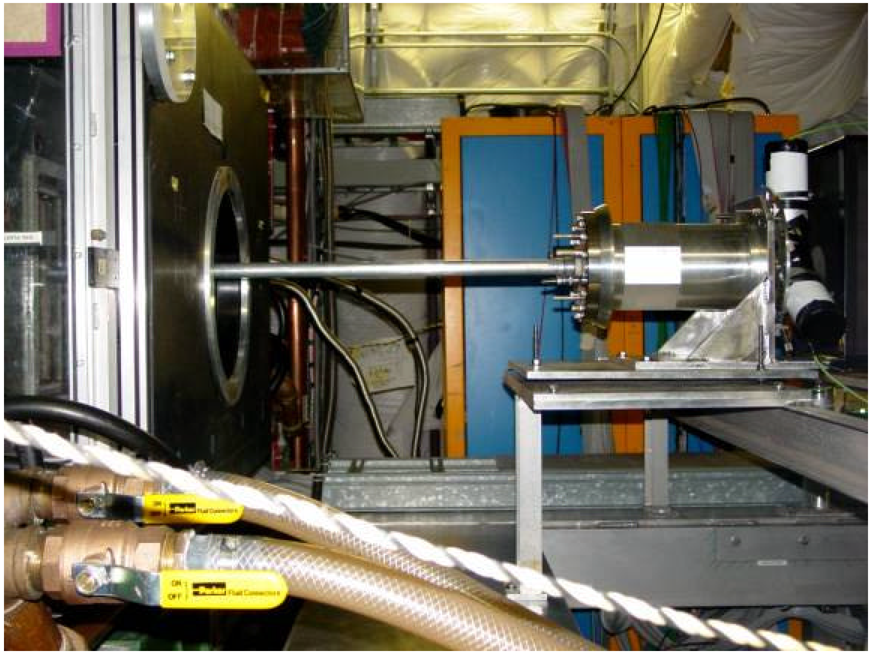
MIPP Particle ID

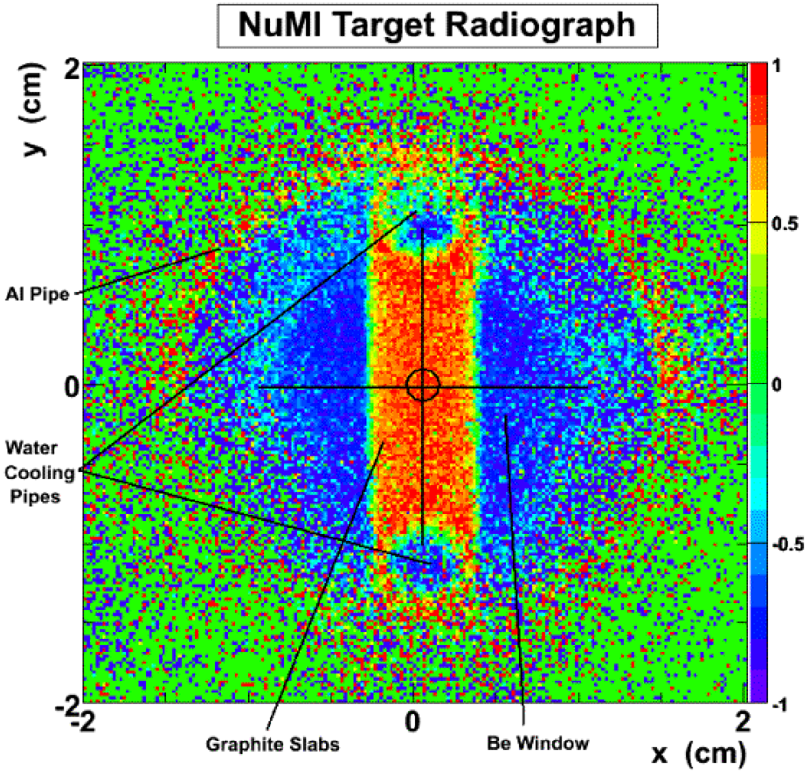
Particle ID Performance



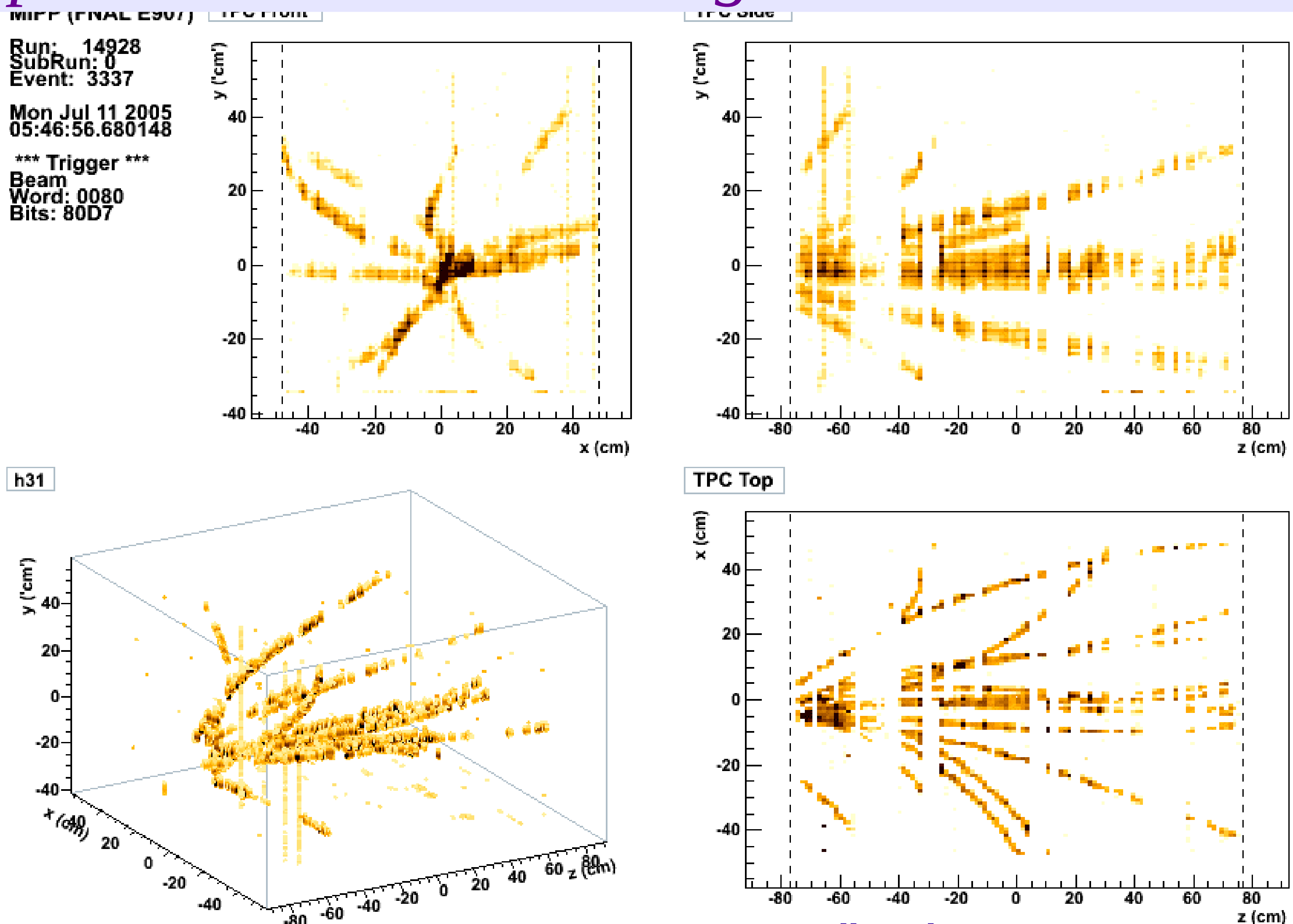
Red: >3 sigma
Green: 2-3 sigma
Blue: 1-2 sigma
White: <1 sigma

NUMI target pix





Sample Event On NuMI Target



- Collected 1.5M events
- NuMI target ran in July'05
- Target returned to NuMI

Data Taken In current run

Data Summary 27 February 2006			Acquired Data by Target and Beam Energy Number of events, x 10^6									
Target			E									Total
Z	Element	Trigger Mix	5	20	35	40	55	60	65	85	120	
0	Empty[1]	Normal		*0.10*	*0.14*			*0.52*			*0.25*	***1.01***
	K Mass[2]	No Int.				*5.48*	*0.50*	*7.39*	*0.96*			***14.33***
	Empty LH[1]	Normal		*0.30*				*0.61*		*0.31*		**7.08**
1	LH	Normal	0.21	**1.94**				**1.98**		**1.73**		
4	Be	*p* only									1.08	**1.75**
		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**	**13.97**	**0.96**	**2.04**	**4.63**	**31.38**

General scaling law of particle fragmentation

- States that the ratio of a semi-inclusive cross section to an inclusive cross section

$$\frac{f(a+b \to c+X_{subset})}{f(a+b \to c+X)} \equiv \frac{f_{subset}(M^2,s,t)}{f(M^2,s,t)} = b_{subset}(M^2)$$

- where M^2,s and t are the Mandelstam variables for the missing mass squared, CMS energy squared and the momentum transfer squared between the particles a and c. PRD18(1978)204.
- Using EHS data, we have tested and verified the law in 12 reactions (DPF92) but only at fixed s.
- The proposed experiment will test the law as a function of s and t for various particle types a ,b and c for beam energies between ~5 GeV/c and 120 GeV/c to unprecedented statistical and systematic accuracy in 36 reactions.

MIPP Upgrade program

- MIPP has been asked to submit a proposal in Oct 2006 to the PAC by Fermilab management.
- Speed up TPC DAQ by using ALICE ALTRO/PASA chips. We have been given he green light to acquire these chips from CERN ($80K).
- Jolly Green Giant Magnet repair money approved.
- Speed up rest of DAQ.
- Is important for

CDF/D0, CMS/Atlas (hadronic Energy scale)
PIERRE AUGER/ICE CUBE(hadronic Energy scale)
Super K/Hyper K (Neurino Spectra)
MINOS/MINERvA/NOvA. (Neutrino spectra)
CALICE (hadronic energy scale/resolutions)

Upgrade the beam to run at lower energies

- Currently, we can run reliably in the beam momentum range 10 GeV/c-90 GeV/c. With the installation of trim element power supllies that regulate at lower currents and by installing Hall probes in the magnets to measure the actual field (hysterisis), we feel we can get secondary beams as low as 1 GeV/c. Kaon beams as low as 3 GeV/c are possible.
- This allows measurements crucial for the hadronic shower simulation problem.
- Missing Baryon Resonances (F.Wilczek interest). Coupled channel partial wave analyses
- Pbar-P annihilation studies

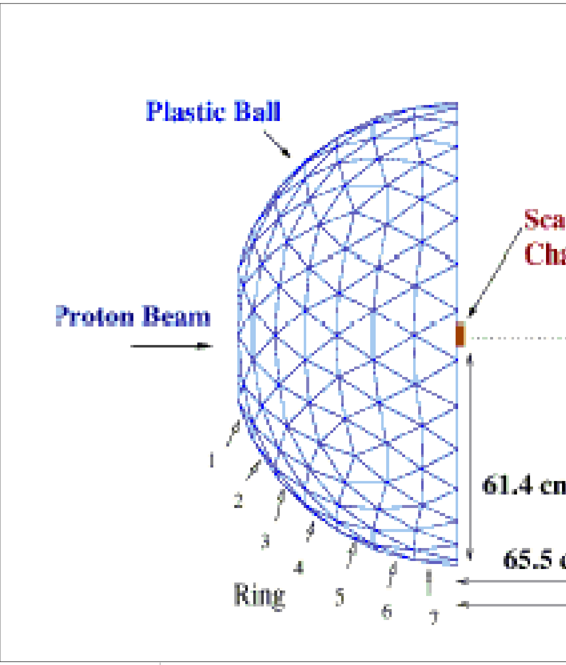
Proposal to upgrade the TPC DAQ speed

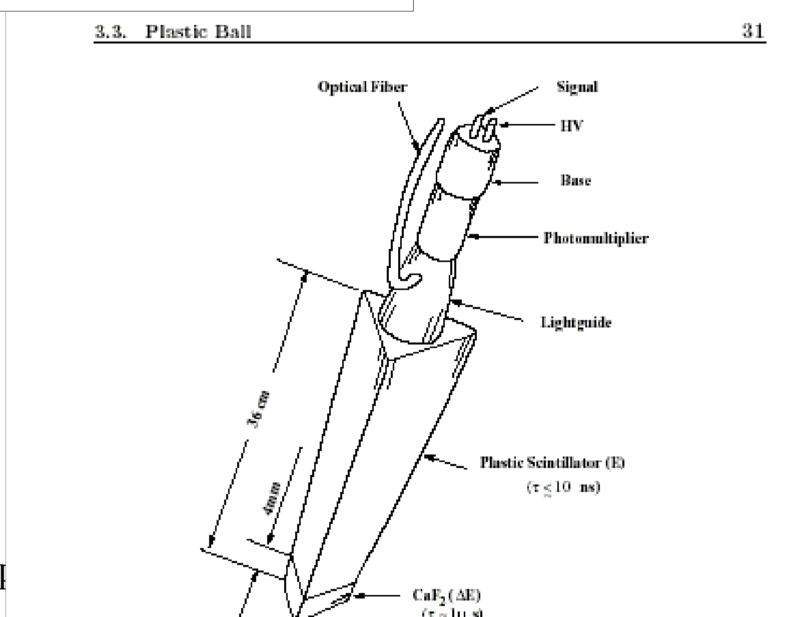
- The MIPP TPC electronics if 1990's vintage. It is highly multiplexed and can run at a maximum of 60HZ for simple events and 20Hz for events of our complexity. There are 15,360 channels on the TPC.
- With more modern electronics (those developed for the ALICE collaboration at the LHC (PASA/ALTRO), we can speed this rate up to 3000HZ. I.e. a factor of 100.
- We propose to join a chip order along with STAR and TOTEM collaborations . This will reduce the cost by (sharing the overhead) to ~$8/channel.
- With this upgrade (and the rest of the systems can also be upgraded to run at 3KHZ), and assuming one 4 second spill every 2 minutes and a 50% duty factor, we can obtain 5 million events per day.

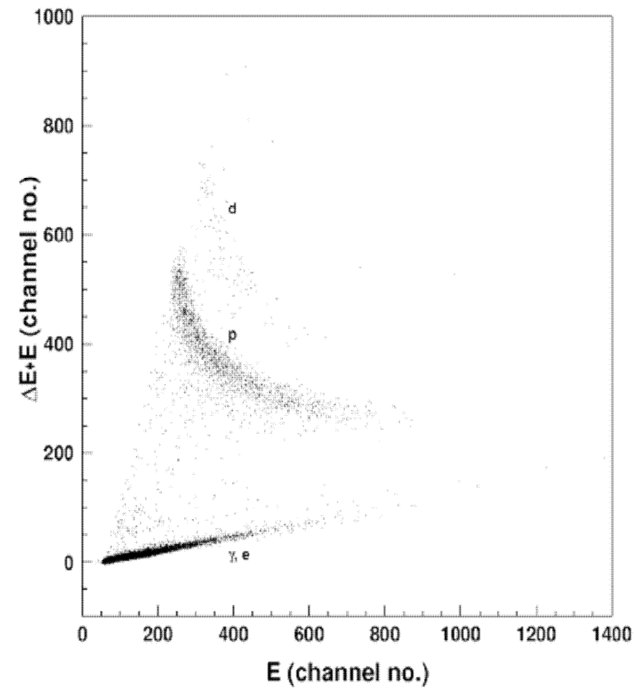
Nuclei of interest- 1st pass list

- The A-List
- H_2,D_2,Li,Be,B,C,N_2,O_2,Mg,Al,Si,P,S,Ar,K,Ca,,Fe,Ni,Cu,Zn,Nb,Ag,Sn,W,Pt,Au,Hg,Pb,Bi,U
- The B-List
- Na, Ti,V, Cr,Mn,Mo,I, Cd, Cs, Ba
- On each nucleus, we can acquire 5 million events/day with one 4sec beam spill every 2 mins and a 50% downtime.
- We plan to run several different momenta and both charges.
- The libraries of events thus produced will be fed into shower generator programs which currently have 30 year old single arm spectrometer data with high systematics

The recoil detector







Detect recoil protons, neutrons, pizeros and charged pions,kaons

Spallation products

- Such a recoil detector coupled with the TPC can detect spallation products such as "grey" and "Black" protons, and neutrons as well as nuclear fragments.
- Table from Textbook on Calorimetry by Wigmans

	Binding Energy	Evaportion n (# neutrons)	Cascade n (# neutrons)	Ionization (#cascade p)	Target recoil
Before first reaction				(250)(π_{in})	
First reaction	126	27(9)	519 (4.2)	350(2.8)	28
Generation 2	187	63(21)	161(1.7)	105(1.1)	3
Generation 3	77	24(8)	36(1.1)	23 (0.7)	1
Generation 4	24	12(3)			
Total	414	126(41)		478(4.6)	32

TABLE I: Destination of 1.3 GeV total energy carried by an average pion produced in hadronic shower development in lead. Energies are in MeV.

Can we reduce our dependence on models?

- Answer- Yes- With the MIPP Upgrade experiment, one can acquire 5 million events per day on various nuclei with six beam species ($\pi^{\pm}$,$K^{\pm}$,$p^{\pm}$) with beam momenta ranging from 1 GeV/c-90 GeV/c. All final state particles can be identified to ~ 3sigma over most of phase space. Full acceptance over phase space.
- This permits one to consider random access event libraries that can be used to generate the interactions in the shower.

Random Access Data Libraries

- Typical storage needed

Nuclei	beam species	momentum bins	events/bin	tracks/event	words/track
30	6	10	100000	10	5

Number of events	1.80E+08	Number of days	36
Total number of words	9.00E+09	to take data	
Bytes	3.60E+10		

- Mean multiplicities and total and elastic cross section curves are parametrized as a function of s.
- When in the simulation program, one wants to simulate an interaction, one computes the mean multiplicity. Then the multiplicity of interaction is generated by the KNO curve (known to work at these energies).

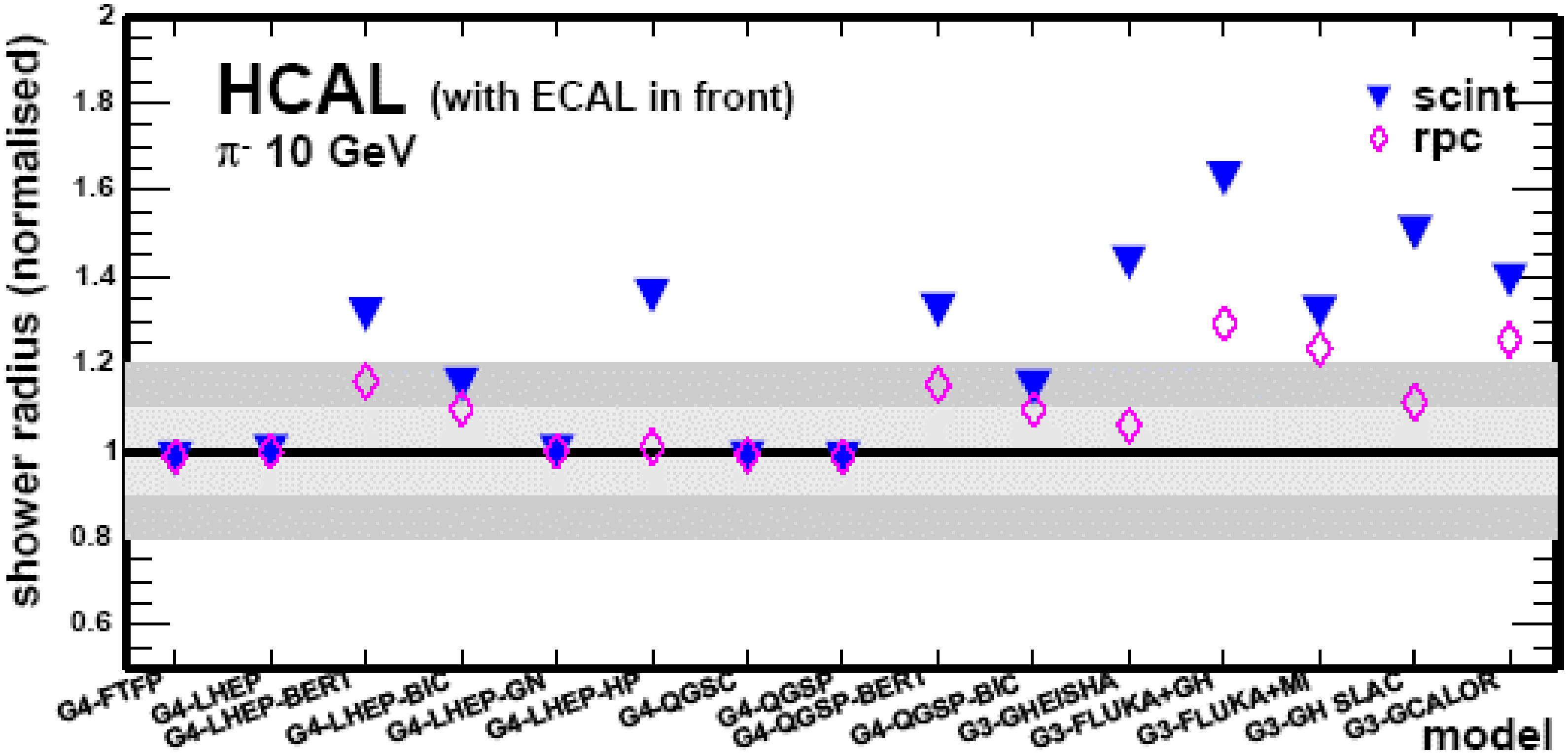
Random Access Data libraries

- Note the Mean Charged Multiplicity and KNO curves are measured again with high statistics using MIPP.
- Then one generates the charged multiplicity for the event in question according to the KNO curve. One then loks up an appropriate event (closest beam momentum, nucleus) and rescales the momenta slightly as per the exact beam momentum of the scatter being simulated. This generates the charged particle event. Event has all the correlations built in since it is measured from data on the nucleus in question.
- What about neutral particles?

Neutral particle algorithm

- All events in library are characterized by their overall baryon number, strangeness, and missing mass. There will be a class of events with next to zero missing mass.
- In the event picked from the library, if the missing mass is substantial, we must turn that missing mass into missing neutrals. Since the overall quantum numbers of the event is known and also that of the charged particles, one can then assign quantum numbers to the missing mass.
- The neutral particle algorithm then involves picking up from the library an event with appropriate center of mass energy and quantum numbers (with zero missing mass) and turning the charged particles in the event to neutral particles.
- Proton-> neutron, pi+,pi- to pizero etc.
- The event thus obtained has to be transformed to the appropriate Lorentz frame of the missing mass in the event question .
- Such a scheme will get most of the correlations in the event.
- It can be tested using existing generators (before we get the data).

ILC- Particle Flow Algorithm- Neutral Particle shower sizes.



Tagged neutron and K-long beams in MIPP-For ILC Particle flow algorithm studies

- MIPP Spectrometer permits a high statistics neutron and K-long beams generated on the LH2 target that can be tagged by constrained fitting. The neutron and K-long momenta can be known to better than 2%. The energy of the neutron (K-long) can be varied by changing the incoming proton(K^+) momentum. The reactions involved are

$$pp \rightarrow pn\pi^+$$

$$K^+p \rightarrow pK_L^0\pi^+$$

$$K^-p \rightarrow pK_L^0\pi^-$$

$$\bar{p}p \rightarrow \bar{n}\pi^-p$$

See R.Raja-MIPP Note 130

~50K tagged neutrons per day

Conclusions

- MIPP has already acquired data of unprecedented quality on particle production using 6 beam species on several nuclei and the MINOS target.
- More data is needed for the neutrino program on their targets-MINOS, MINERVA, NOVA.
- MIPP Upgrade will obtain 10 times more data than MIPP with 10 times less beam time..
- Hadronic shower systematics can be significantly improved with MIPP upgrade data.
- Excellent training ground for students.