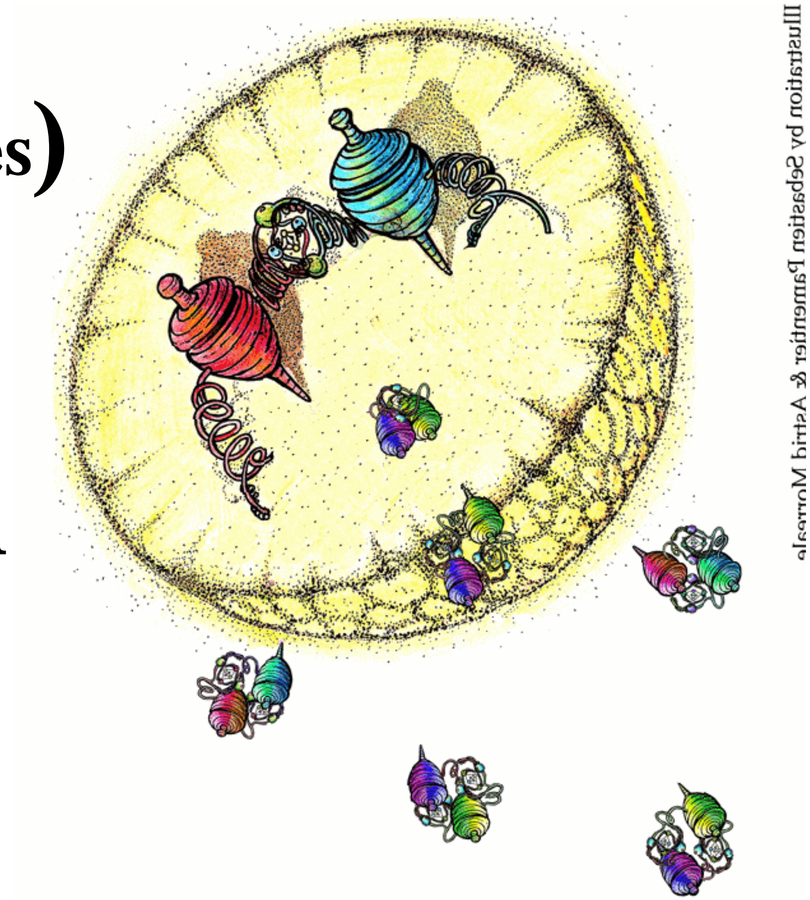
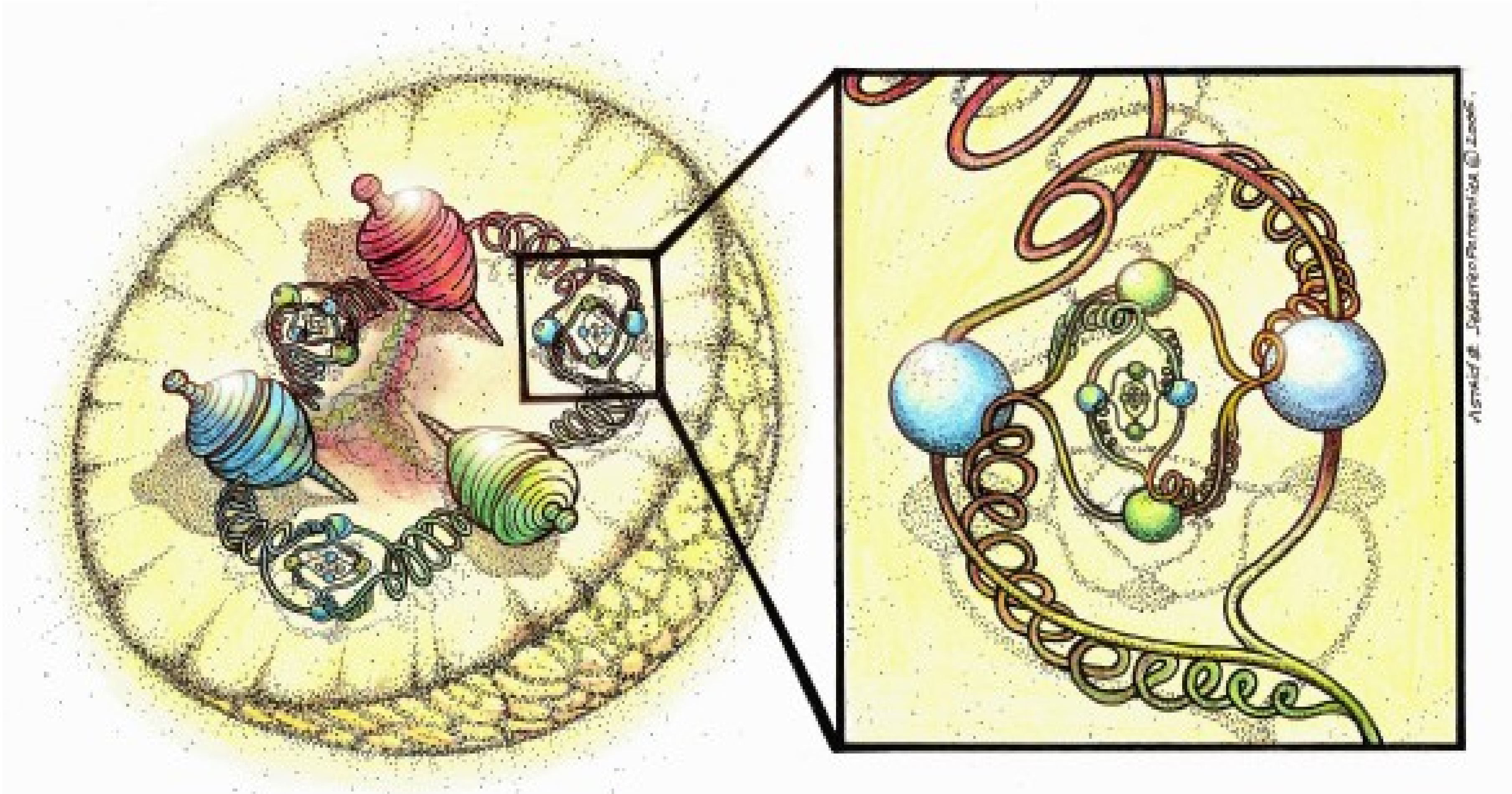
$\pi^{\pm}$ A_{LL} (and Cross Section Studies) in PHENIX central arms.

A “How To” Presentation



Àstrid Morreale

Los Alamos National Lab P-25 Seminar



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PHENIX

Outline

- A (Short) Introduction
- The Detector(PHENIX)
- The Technique
- Some approved Results
- Status/Outlook

INTRODUCTION

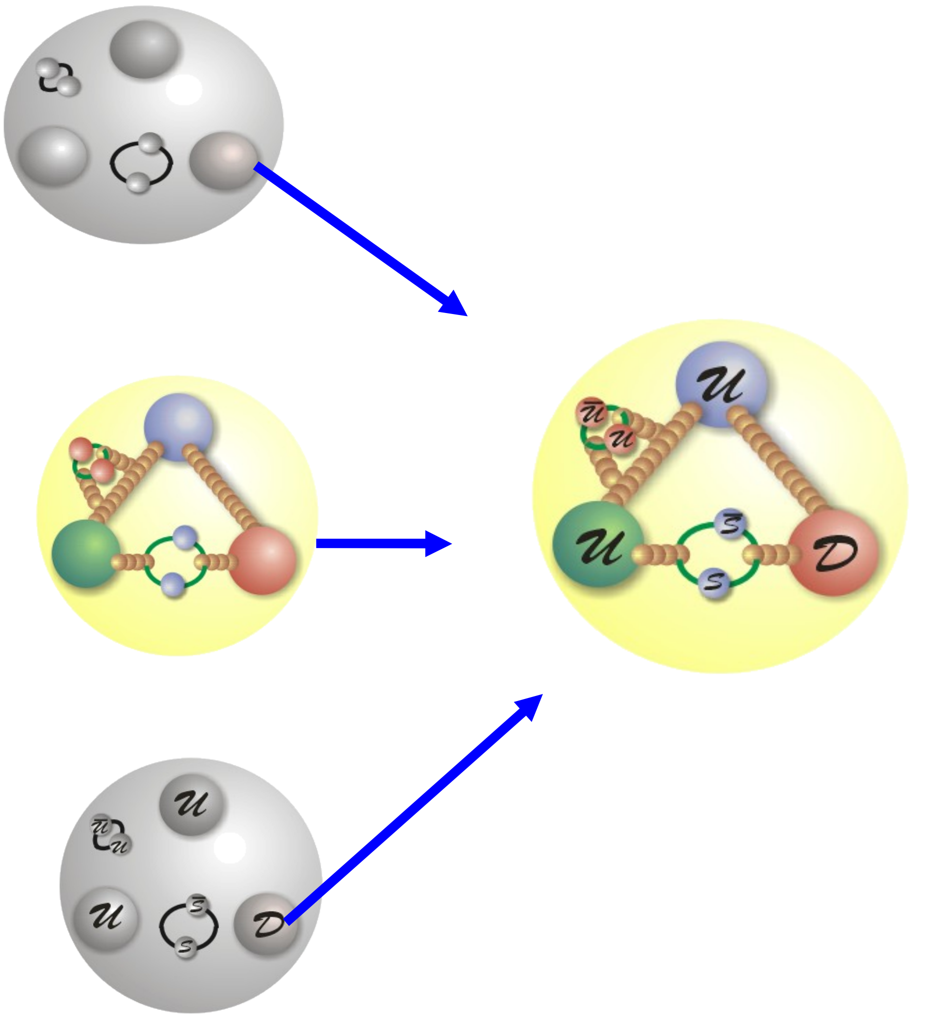
Probing the Proton Structure

- EM interaction-Photon
  - Sensitive to electric charge
  - Insensitive to color charge

- Strong interaction-Gluon
  - Sensitive to color charge
  - Insensitive to flavor
  - Requires longitudinally polarized pp collisions

- Weak interaction-Weak -Boson
  - Sensitive to weak charge ~ flavor
  - Insensitive to color
  - Requires at least one beam Longitudinally polarized (500 GeV in cm)

- Transversity , OAMs:
  - Requires at least one transversely polarized proton beam



GLOBAL ANALYSIS!

The **PI MESON :**

•Zero spin and composed of first generation quarks

•Pseudo scalar under a parity transformation: pion currents couple to the axial vector current.

•Production of pions proceed from **g-g** and **g-q** initiated sub processes on proton-proton collisions

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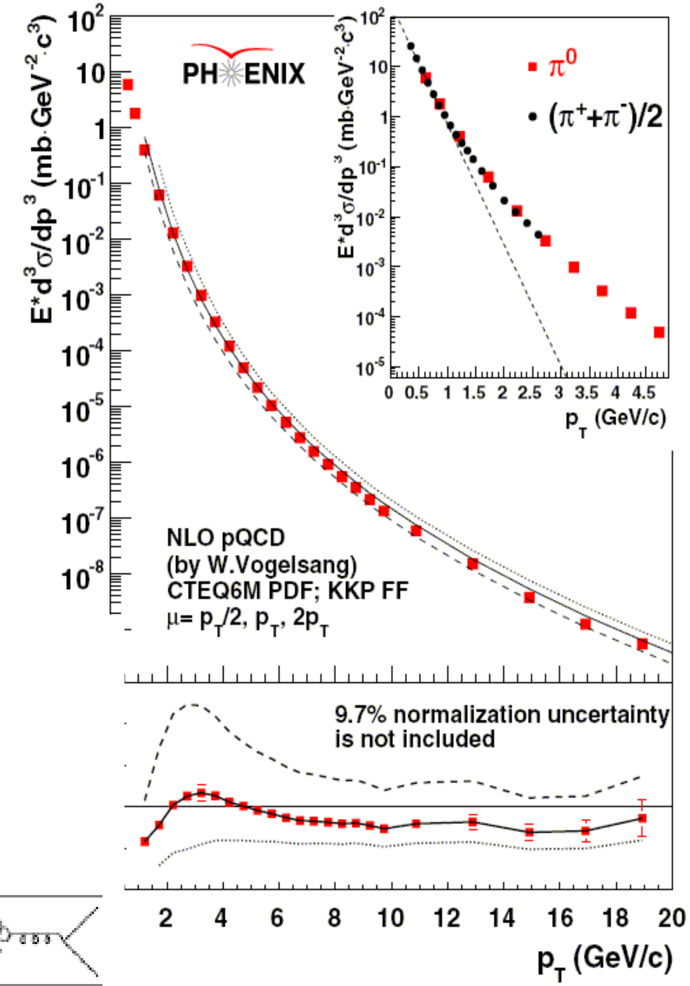
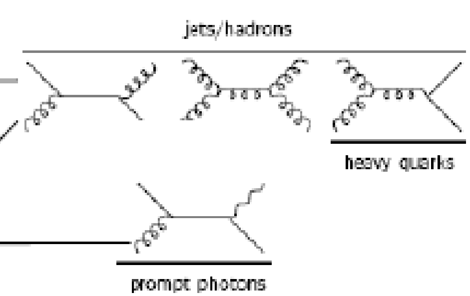
Spin physics at RHIC

-A QCD laboratory: Perturbative description of QCD is valid at RHIC energies (π^0 X-section)



reaction	LO subprocesses	partons probed
$pp \to \text{jets}\, X$	$q\bar{q}, qq, qg, gg \to \text{jet}\, X$	$\Delta q, \Delta g$
$pp \to \pi X$	$q\bar{q}, qq, qg, gg \to \pi X$	$\Delta q, \Delta g$
$pp \to \gamma X$	$qg \to q\gamma, q\bar{q} \to g\gamma$	Δg
$pp \to Q\bar{Q}X$	$gg \to Q\bar{Q}, q\bar{q} \to Q\bar{Q}$	Δg



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PARTONIC CONTRIBUTIONS AT MID-RAPIDITY

The pion's fragmentation function contains all long-distance interactions, they are not calculable but they are **universal**:

$$D^{\pi+}_{u} > D^{\pi 0}_{u} > D^{\pi -}_{u}\,,\quad D^{\pi +}_{g} = D^{\pi -}_{g}$$

q-g starts to dominate for P_T>5GeV , pion production in this pT range is sensitive to both the gluon and the quark distributions, with different flavours having different weights for each pion species

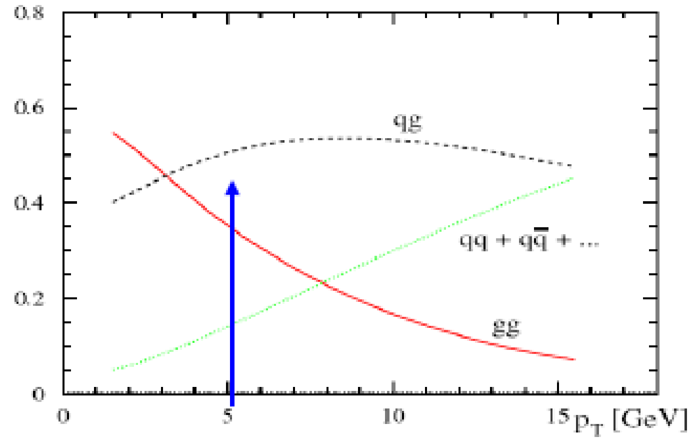

Figure 2: Relative fractional contributions of partonic processes to mid-rapidity pion production at $\sqrt{s} = 200$ GeV, calculated by W. Vogelsang.

$$\sigma(pp \to hX) : f_q(x_1) \otimes f_g(x_2) \otimes \hat{\sigma}^{qg\to \pi X}(\hat{s}) \otimes D^h_q(z)$$

- Structure functions (needs experimental input)
- pQCD hard scattering rates (calculable in pQCD)
- Fragmentation functions (needs experimental input)

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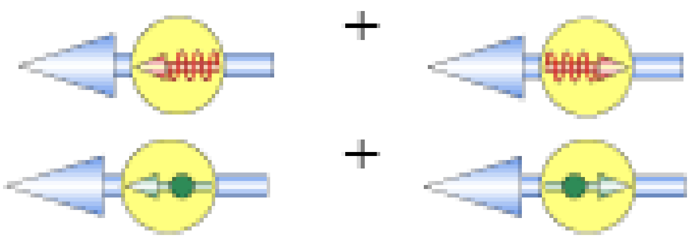
Spin Dependant Parton Density Functions

In a proton with helicity + we can find a parton:

$g(x,Q^2)=$

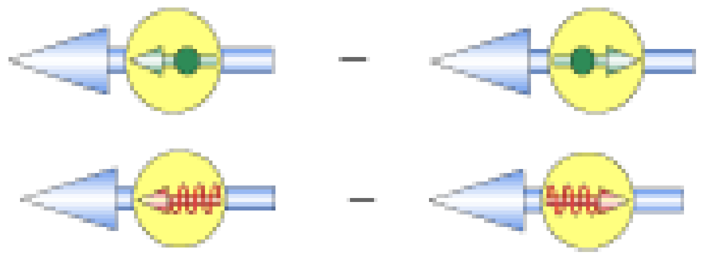
$q(x,Q^2)=$



·We then Define **Δf** as the probability of finding a quark(or gluon) or anti quark with spin parallel or anti parallel to the spin of the nucleon.

$\Delta q(x,Q^2)=$

$\Delta g(x,Q^2)=$



These integrals of Δ f multiplied by the spin of the parton f will give the amount of spin carried by each parton*.

*i.e for gluons : **Amount of carried spin ~ Δ g*1**

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Asymmetries

•Asymmetries are a convolution of the unknown pdf's in both colliding protons w/the elementary scattering asymmetries summed over the different processes that contribute to the observed events.

•In practice what we look is the ratio of the polarized vs the unpolarized cross-section:

$$A_{LL} \equiv d\Delta\sigma / d\sigma$$

Its General Structure:

$$A_{LL} = \frac{\sum_{fq,fg} \Delta f_q \, \Delta f_g \, [d\Delta\sigma^{qg \to \pi X} \quad \hat{a}_{LL}^{qg \to \pi X}] \times D_\pi}{\sum_{fq,fg} f_q \, f_g \, [d\sigma^{qg \to \pi X}] \, D_\pi} \sim \frac{\Delta f}{f}$$

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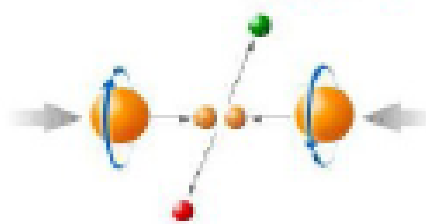
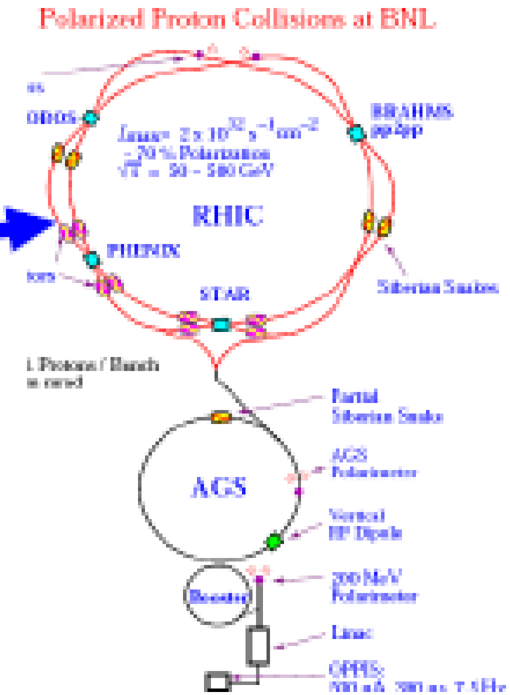
AT the Relativistic Heavy Ion Collider:





Double Spin Asymmetries can be defined and measured for both polarized beams at RHIC as:

$$A_{LL} = \frac{(\sigma_{++}+\sigma_{--})-(\sigma_{+-}+\sigma_{-+})}{(\sigma_{++}+\sigma_{--})+(\sigma_{+-}+\sigma_{-+})}$$

Final state cross section with with initial proton helicities as subscripted.

BUT…
Since our proton beams are not in pure helicity states, we must weight by the polarization

$$P_{beam} = \frac{B_+ - B_-}{B_+ + B_-}$$

$$A_{LL}(p_T) = \frac{\sigma_{++}-\sigma_{+-}}{\sigma_{++}+\sigma_{+-}} \rightarrow \frac{1}{P^2}\frac{N_{++}(p_T)-RN_{+-}(p_T)}{N_{++}(p_T)+RN_{+-}(p_T)}, R = \frac{L_{++}}{L_{+-}}$$

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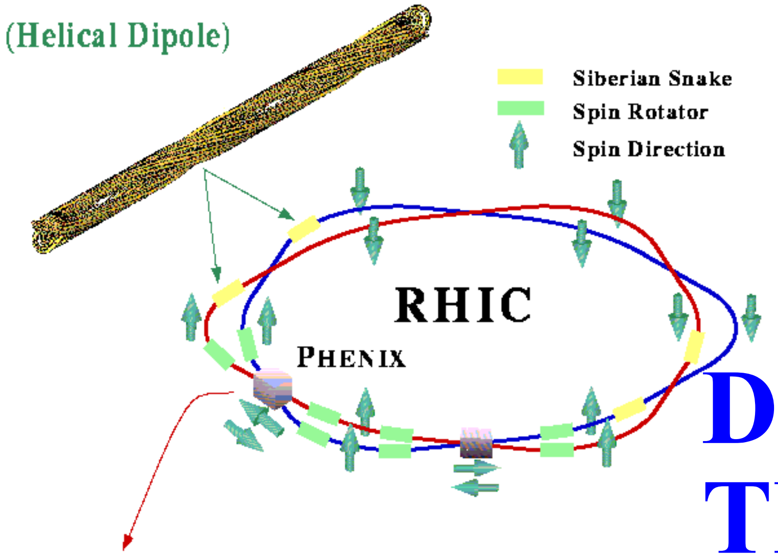
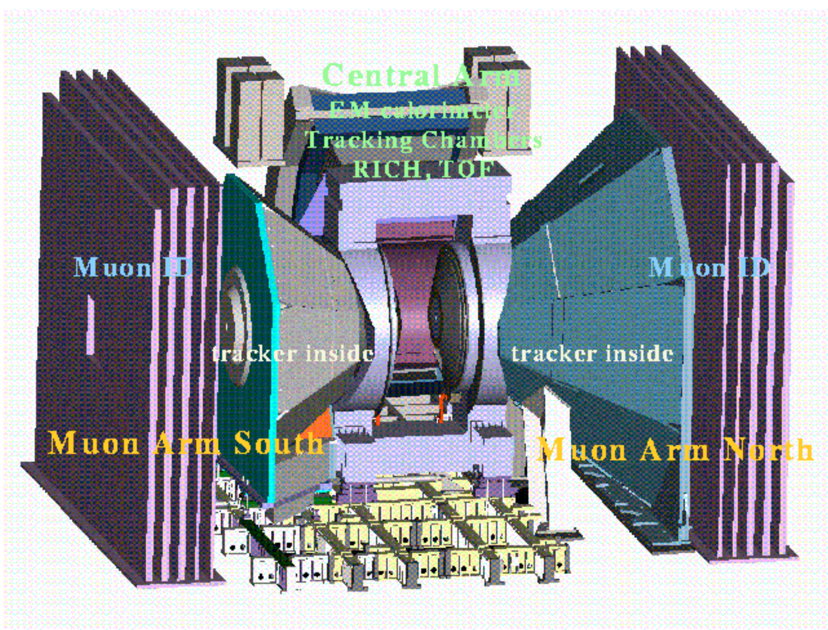
Things to consider

- An asymmetry requires as clean as a sample as possible, sometimes sacrificing pions in the process of background elimination

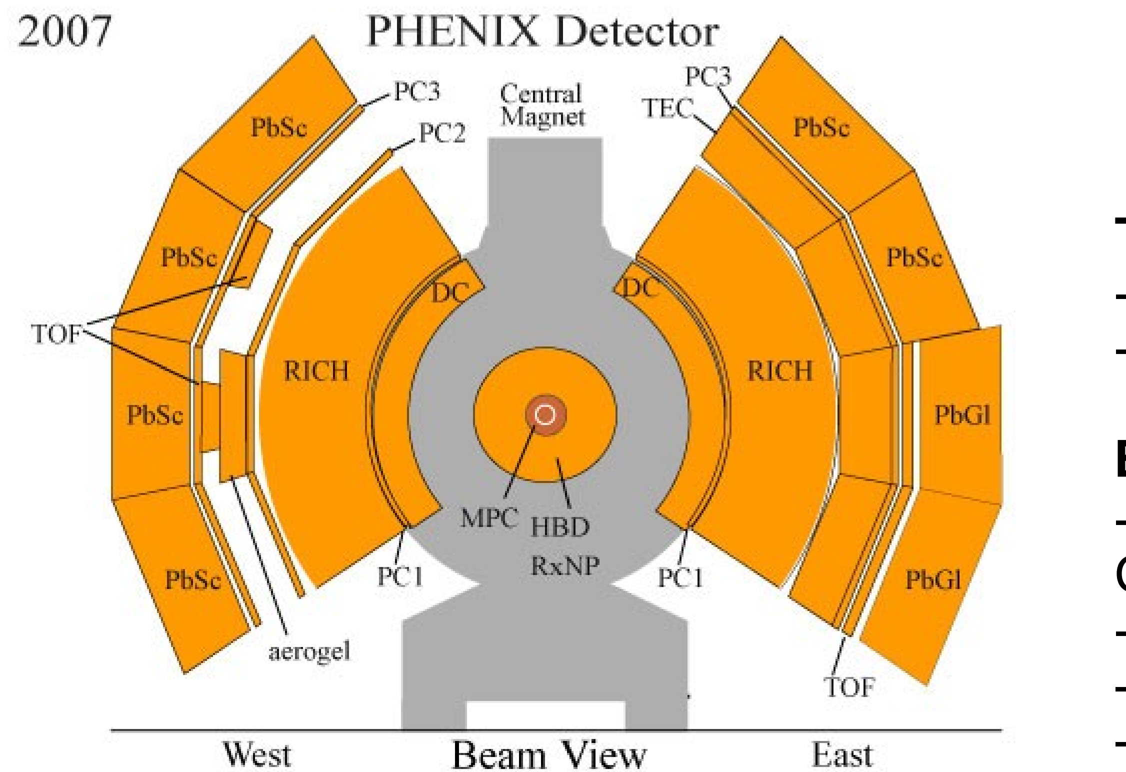
- A cross section requires detailed knowledge of detector and “cut” efficiencies.

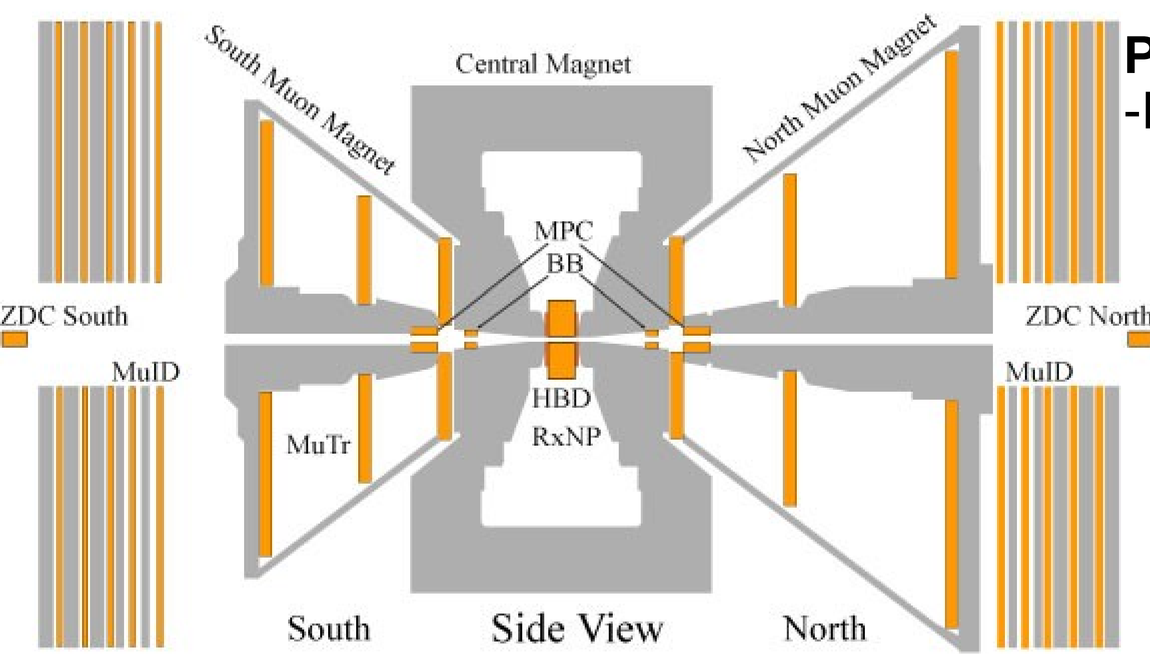


DETECTOR & TECHNIQUE



PHENIX CENTRAL ARMS





Tracking Photons,Hadrons
-Drift Chamber(DC),
-Pad Chambers(PC)

Electron and Hadron Identification
-Ring Imaging Čerenkov Counter(RICH)
-ElectroMagnetic Calorimeter(EMCal)
-Time Expansion Chamber(TEC)
-Time of Flight(TOF)

Photons
-ElectroMagnetic Calorimeter (EMCal)

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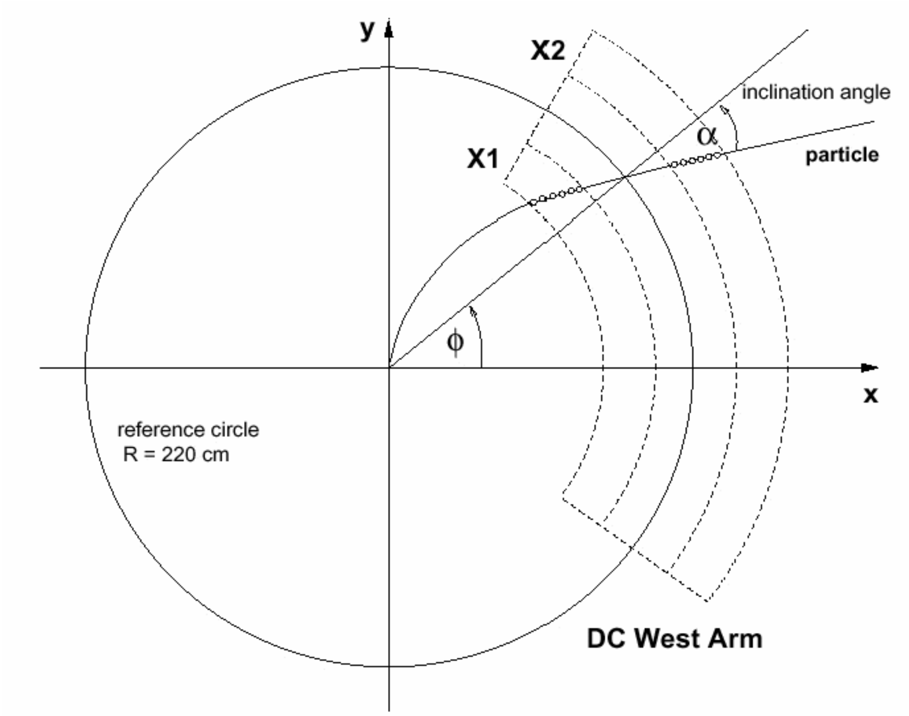
Drift Chamber as a Global Tracker



Drift Chamber:

- Precise measurement of charged particle's momentum
- Gives initial information for the global tracking in PHENIX

Acceptance

- 2 arms 90º in ϕ each
- ±90 cm in Z
- 0.7 units of η

Location:

- Radial :2.02<R<2.48 m
- Angular:
  - West: -34º < $\phi < 56$º
  - East : 125º < $\phi < 215$º

– **To reconstruct charged particle track DC samples a few points in space along the path of the particle. One such point is called a "HIT"**

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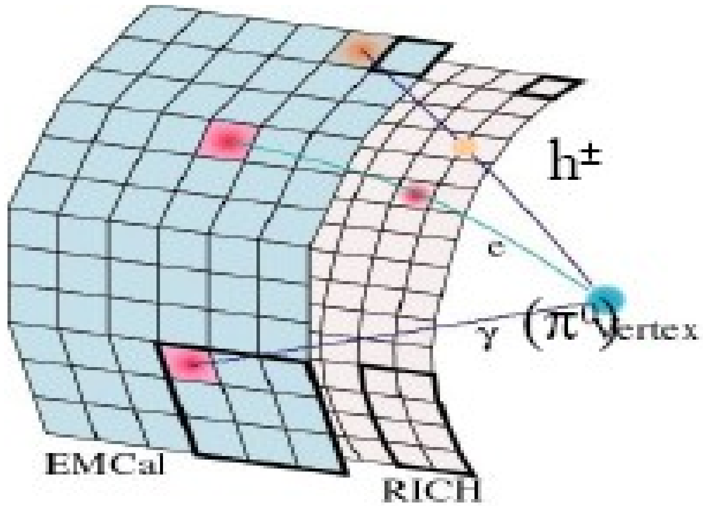
Particle Identification with the RICH

An Emcal-RICH coincidence trigger can be used to select tracks

Tracks can be divided into different categories according to RICH response, i.e.:

- RICH Hit: $e_{\pm}$ background and high-p_T $\pi_{\pm}$
- No RICH Hit: decay background and high-p_T K,p

Particle	**Electron**	**Pion**	**Kaon**	**Proton**
Threshold	30MeV/c	4.7GeV/c	16GeV/c	30GeV/c



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More Details on the RICH

Threshold of light emission

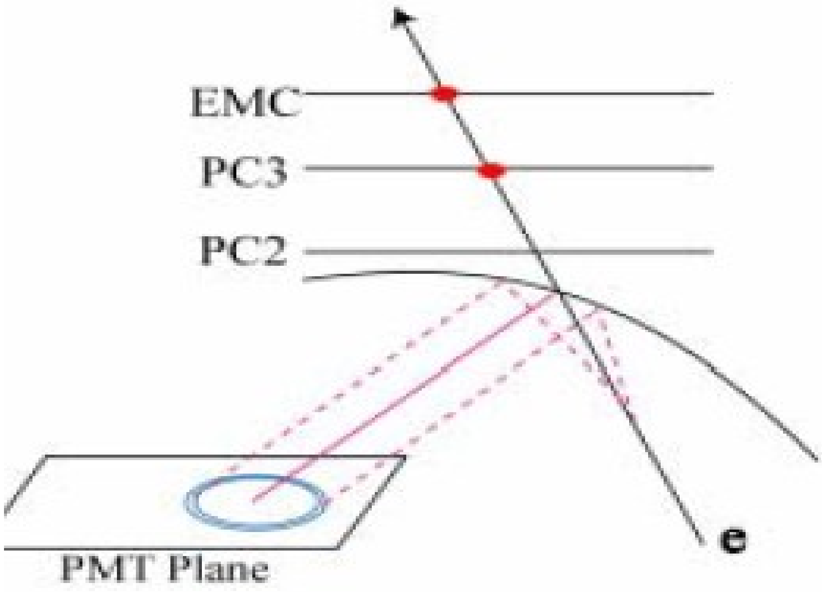
$\beta > 1/n$

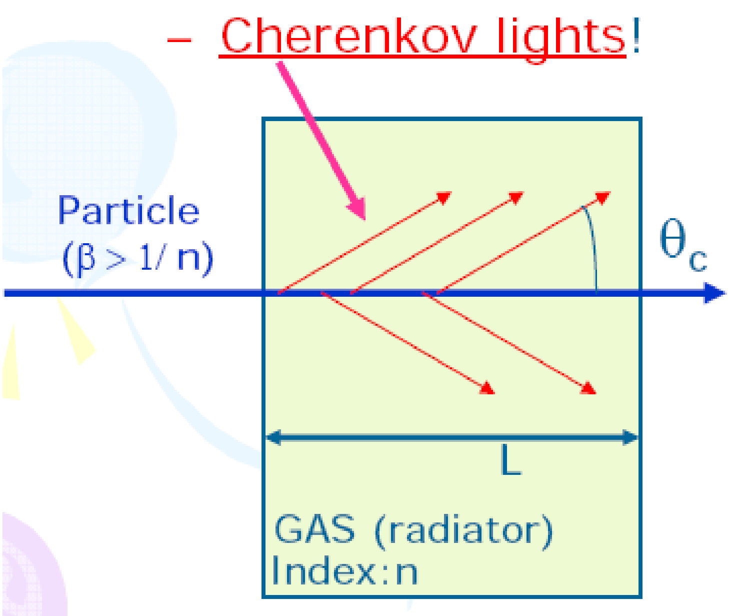
Emission angle

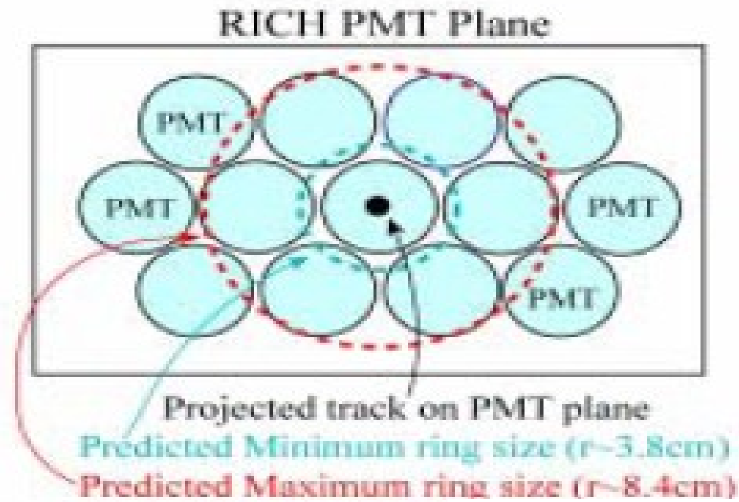
$\cos\theta_c = (\beta n)^{-1}$

Light Yield

Proportional to L and $\sin^2\theta_c$







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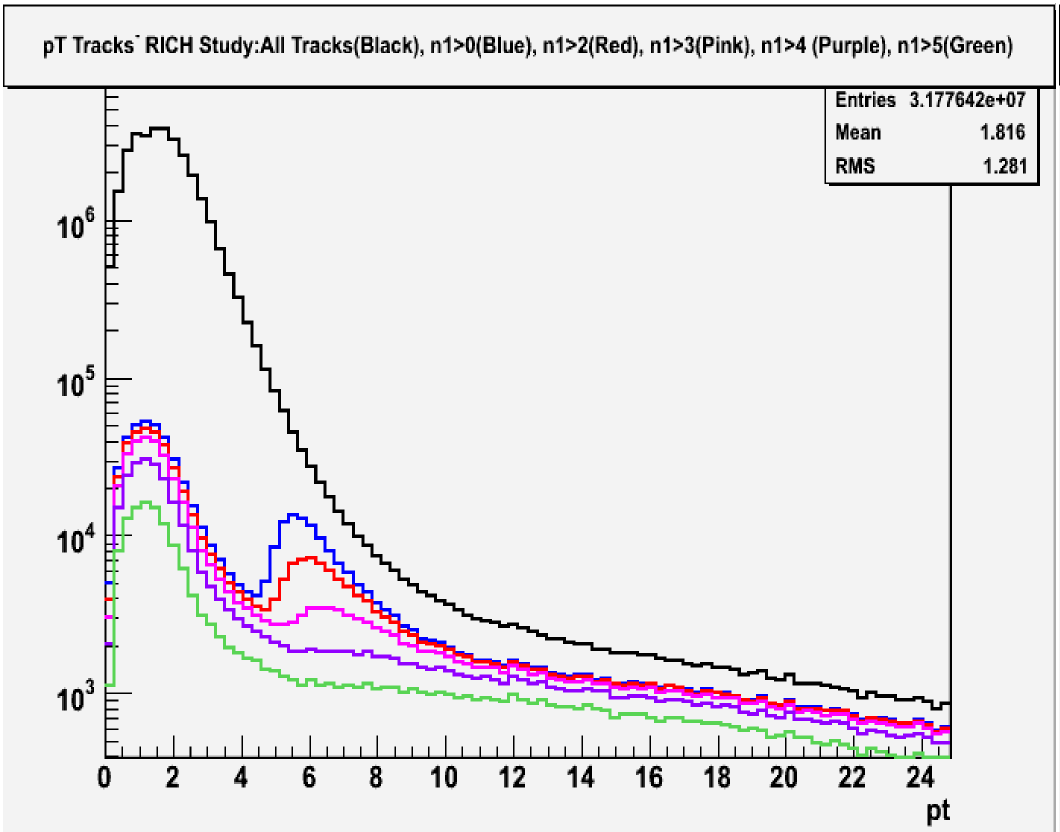
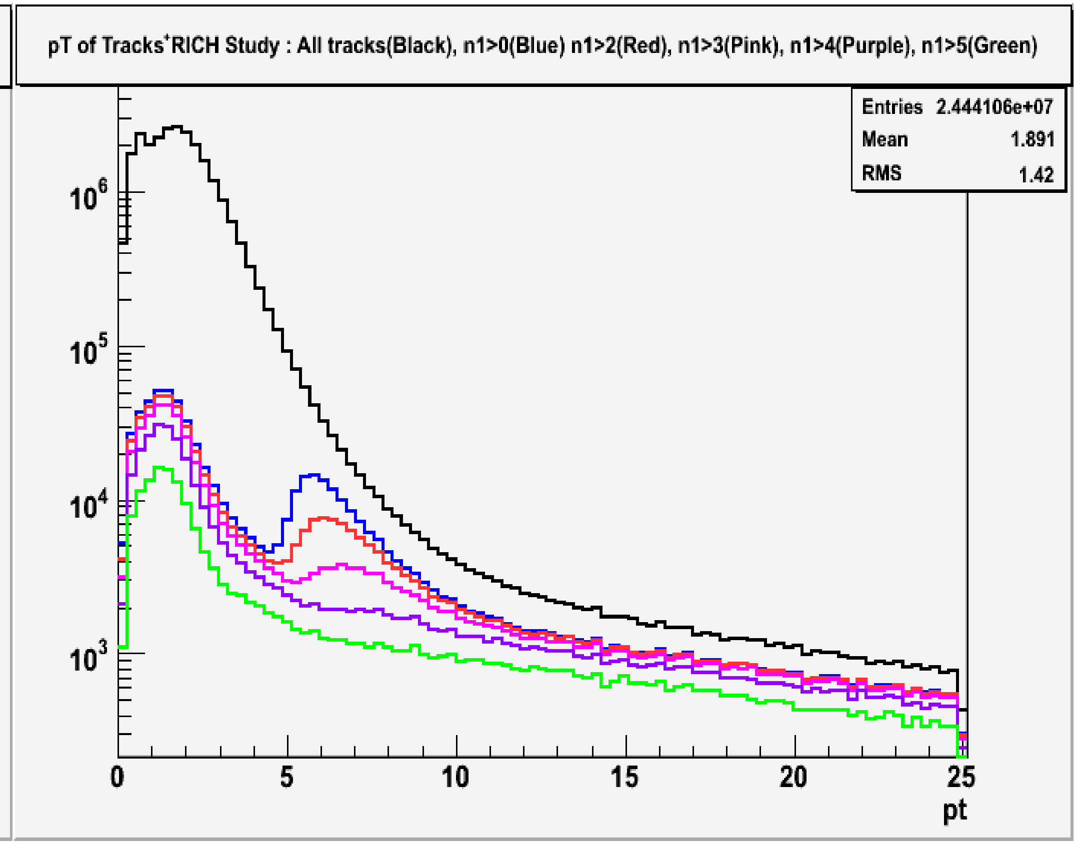
Charged Tracks +RICH Spectra



Negative tracks



Positive Tracks

EMCal

- Electrons and photons interact electromagnetically (bremsstrahlung and pair production) and produce electromagnetic showers.
- Hadrons in this energy range are typically Minimum Ionizing Particles (MIPs) and deposit only part of their energy in hadronic showers(only 1 interaction length -1/e~0.4)
- The calorimeter measures **position**, **energy** and **time of flight** of the incoming particles

- ***Some useful Variables:***
- ***e***: sum of tower energy in the cluster (if above threshold)
- ***ecore***: energy with the assumption that the cluster is a photon; should never be used for MIP or other hadron analysis. It only makes sense for PbSc.

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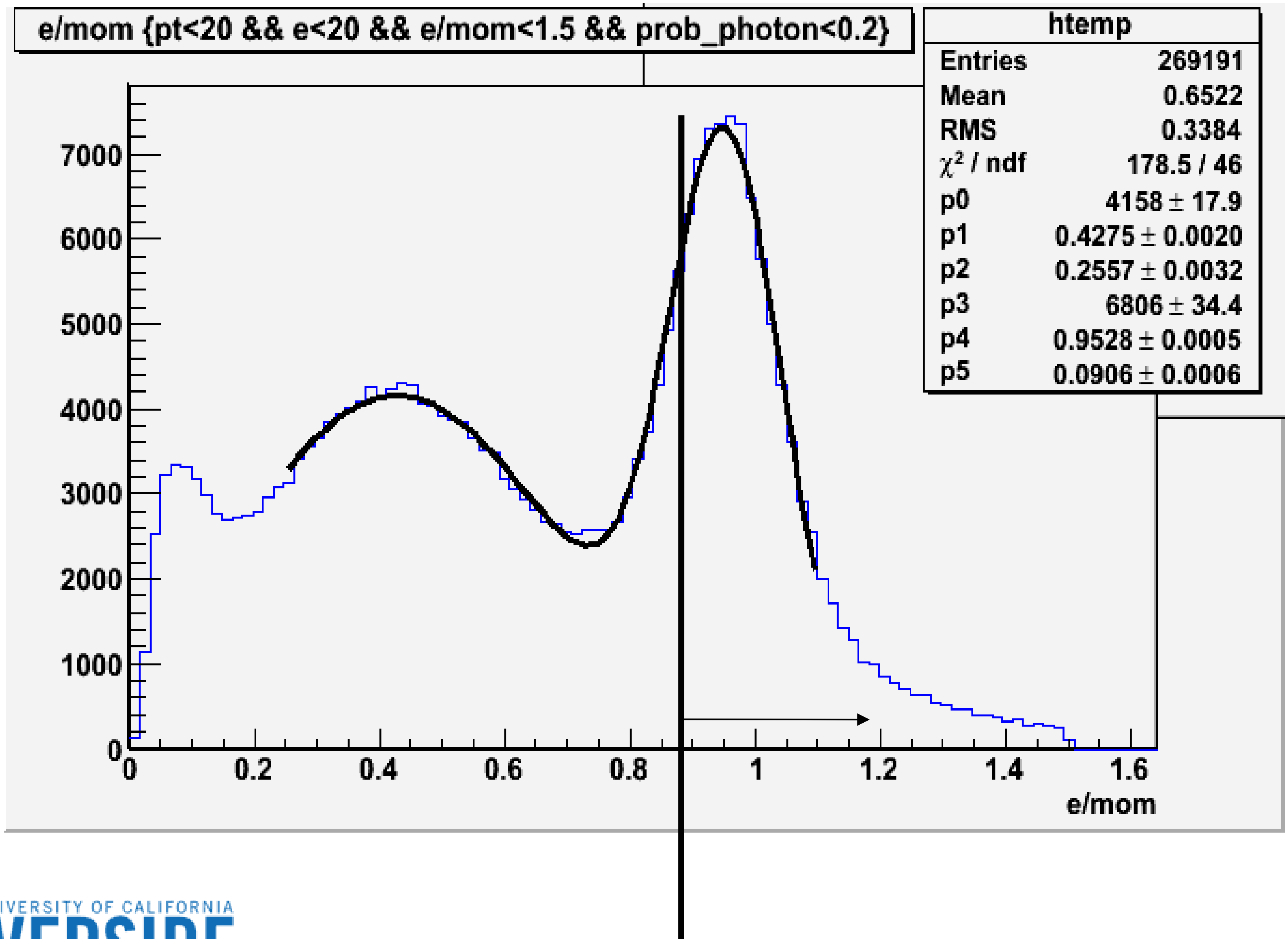
A Quick look at Energy/momentum



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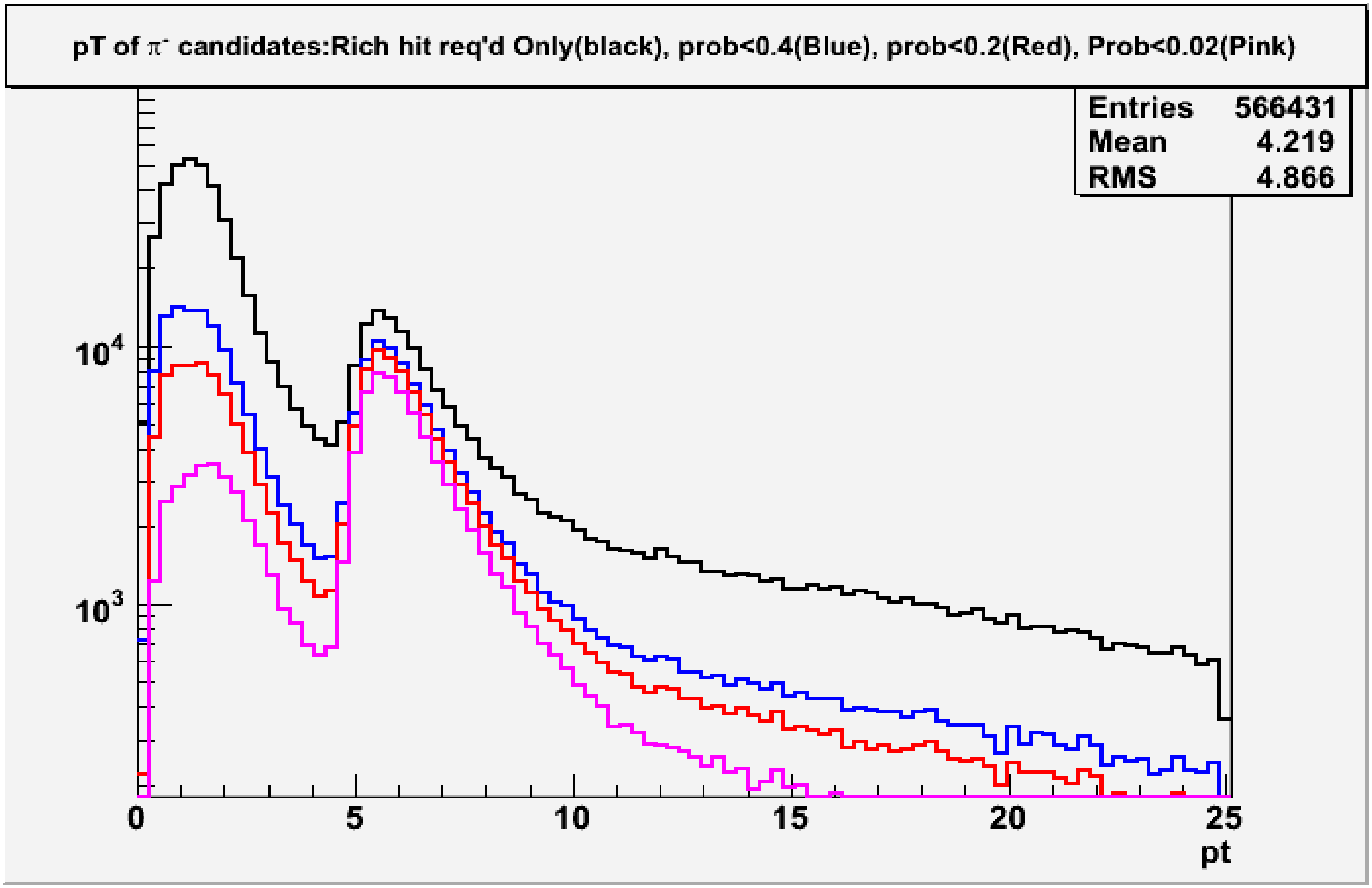
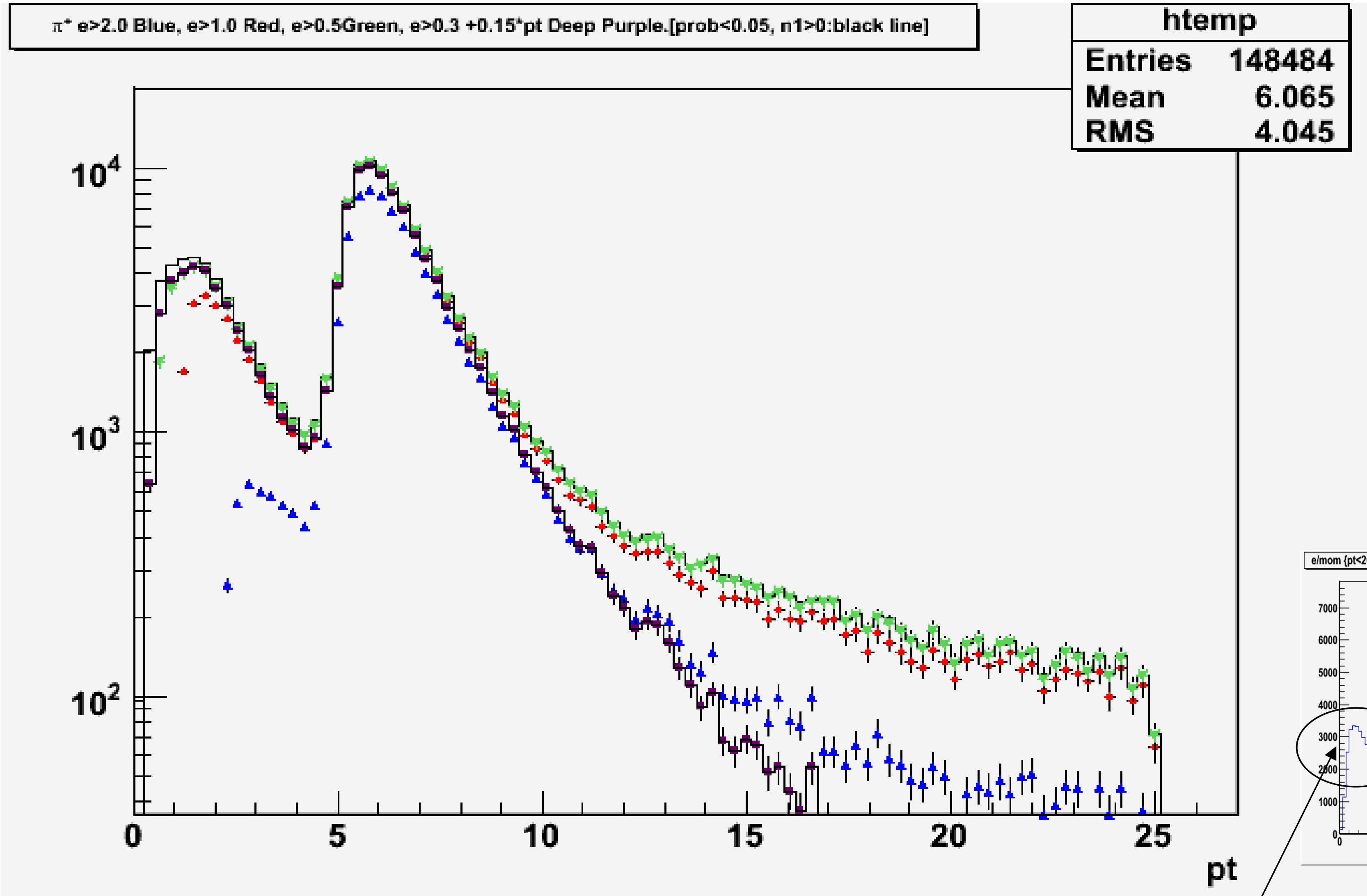
cut all above 0.9

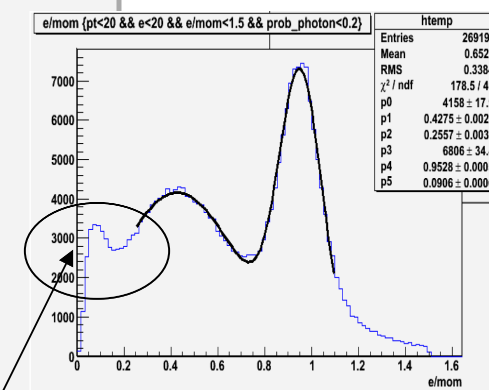
Probability of an E&M shower in pT Spectra



Prob:Normalized photon probability from a reduced chi2 obtained by calculating the predicted energy distribution in the EMCal and comparing it with the measured deposited energy.

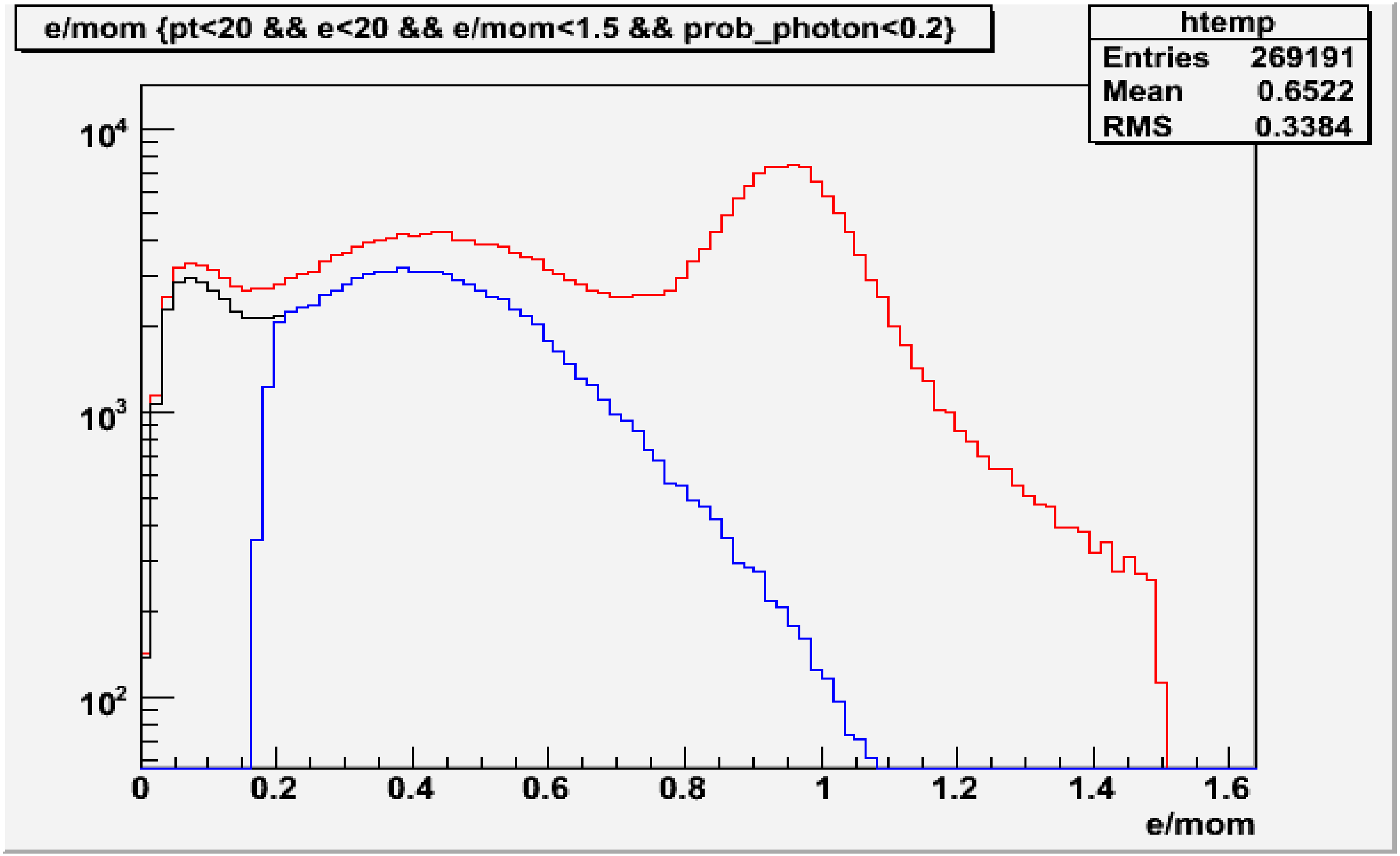
Sliding Energy Cut





By requiring a pT dependant energy cut, we can remove those tracks with very low energy and mis-reconstructed high momenta. (e>0.3+0.15*pT)

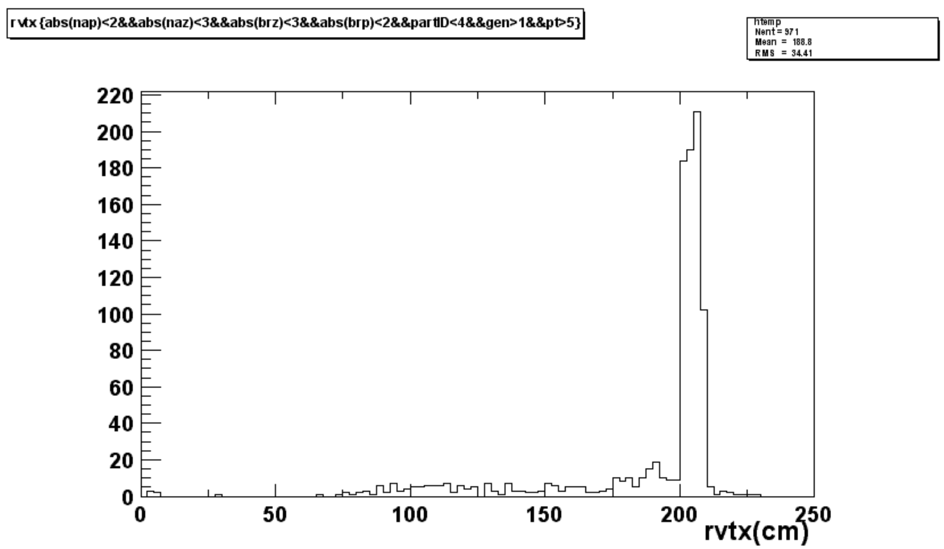
Another Look at e/p



Backgrounds

- *Conversions*: generated in front of the DC or inside the X1 layer, which fire the RICH and are often reconstructed with a false high momentum.
- *Decays* :particles which don't fire the

RICH but are randomly associated with a RICH ring.

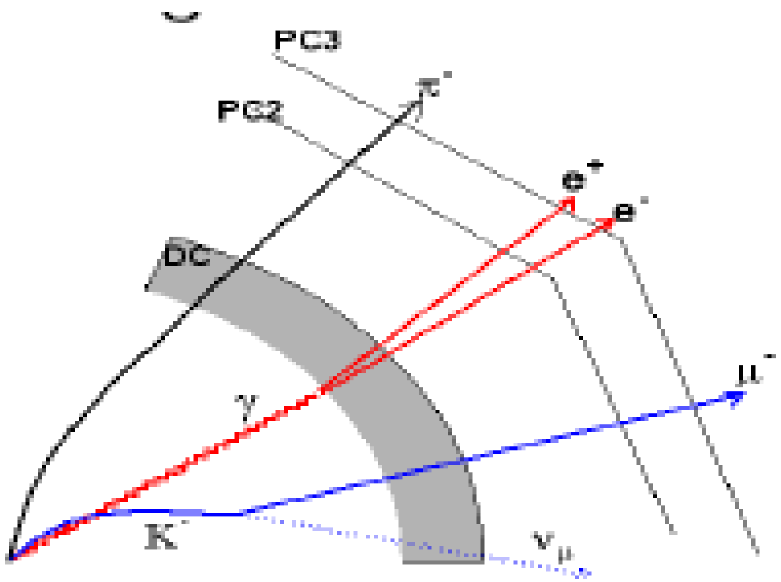


**Because these are actual low mom particles that suffer multiple scattering and are furthermore bent by the residual magnetic field, tight matching cuts and energy cut will remove them

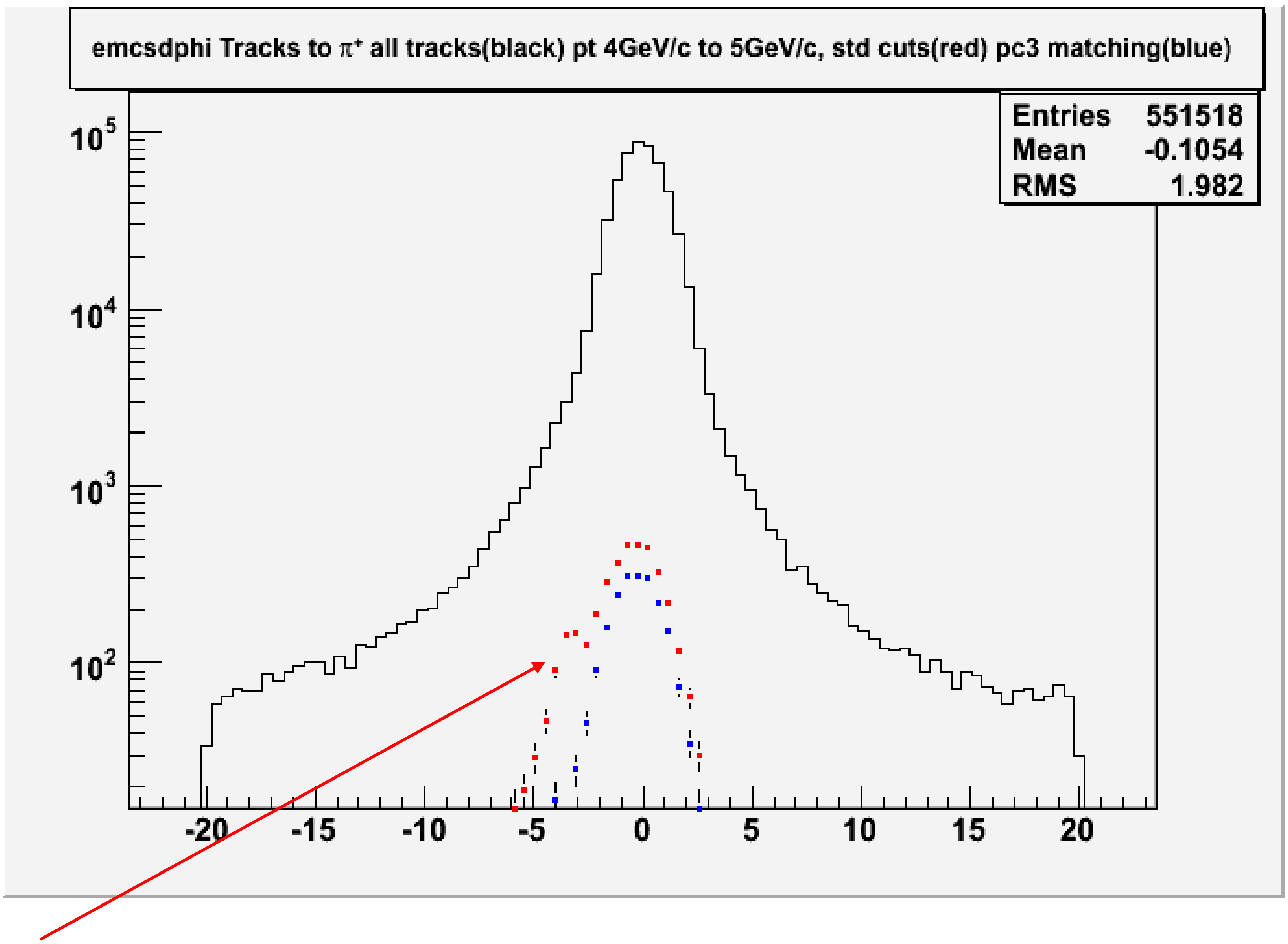
Projections of the reconstructed tracks(Matching)

•Projections of reconstructed DC tracks to the pad chambers or the EMCal.

•These projections can be used to reduce the background from secondary particles (particles not originating from the event vertex) by applying cuts on the deviation of the position of the actual associated hits from the track model projection.

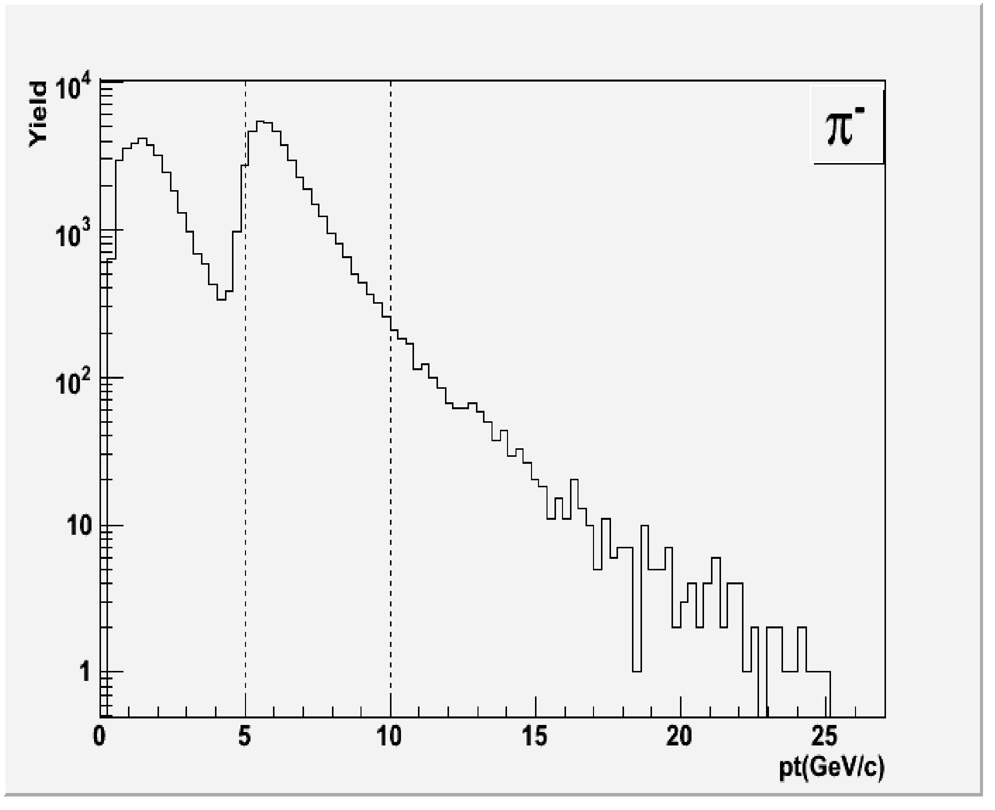


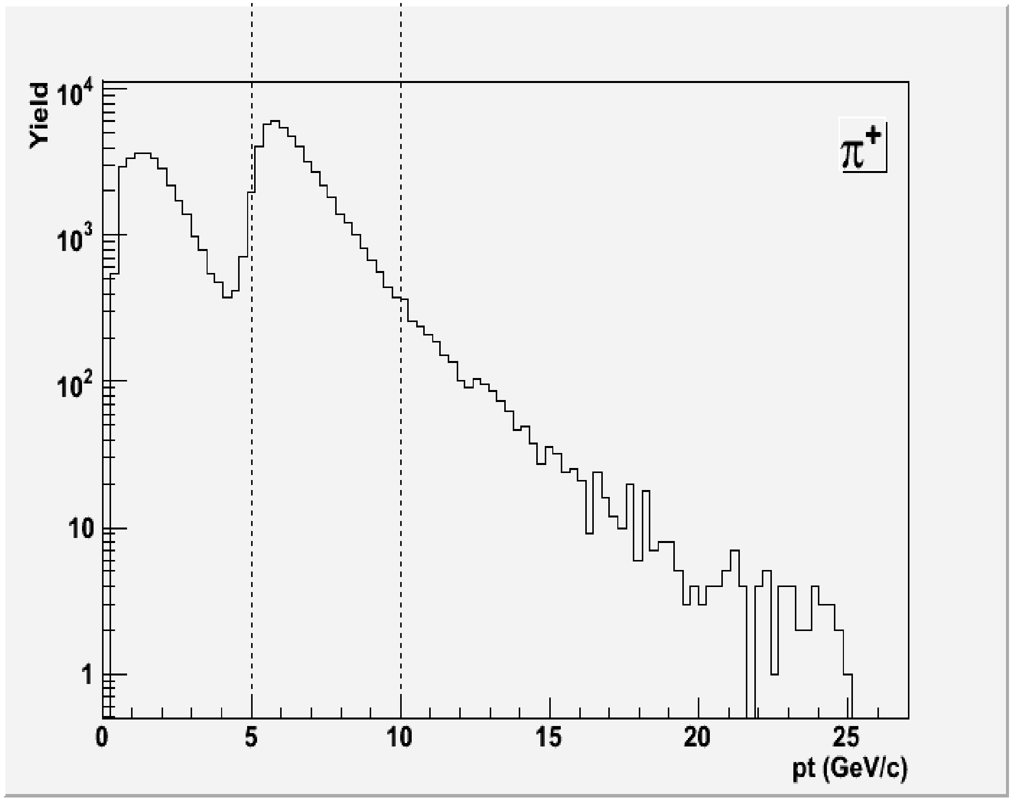
Example - Matching(in sigma)



*similar but opposite side bump can be found on opposite charged tracks

Identified Charged Pion pT Spectrum.





Remaining Background

Matching distributions of Charged pions and Conversion electrons are quite different:

•**Charged pions** Gaussian centered around zero sigma with a width of one

•**Electrons**(from backgrounds) centered off-zero depending on charge.

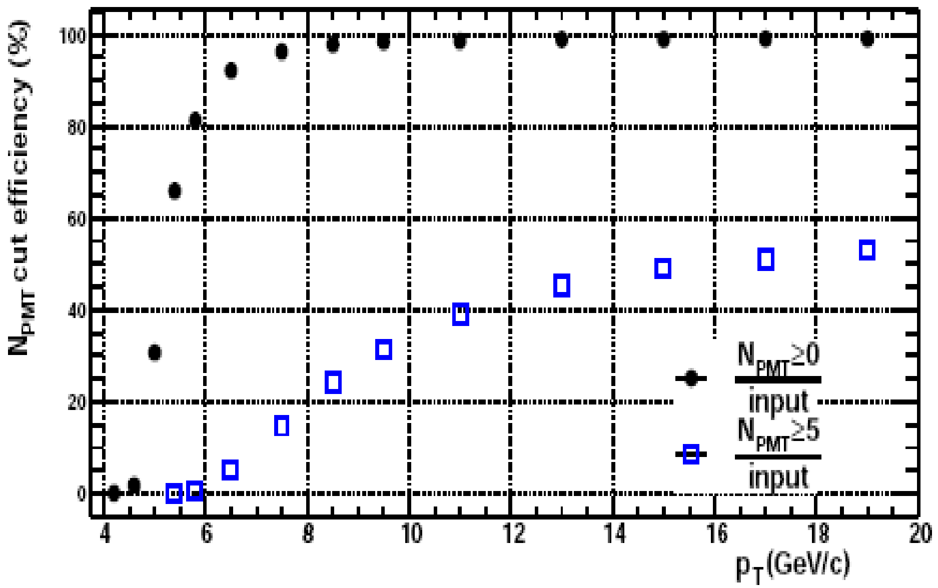
Rich behaviour is also different

•*Charged pions* will begin to emit Čerenkov light around pT 5GeV/c number of pmt's fired will increase rapidly with pT and plateau around 4 pmts

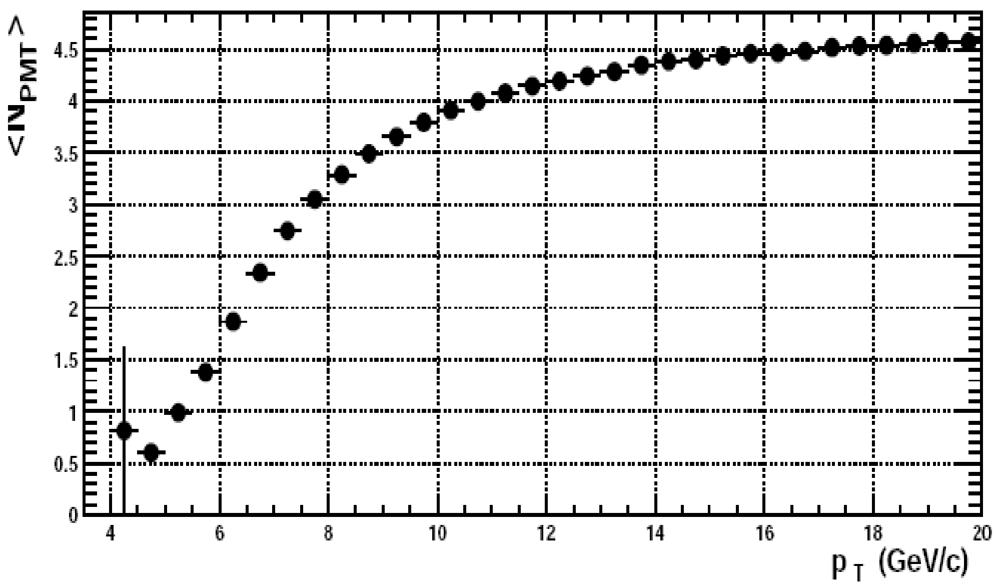
• *Electrons* will in average fire 4-5 pmts

•Requiring more than 4 pmts being fired in the rich should select remaining conversions.

RICH EFFICIENCY from MC

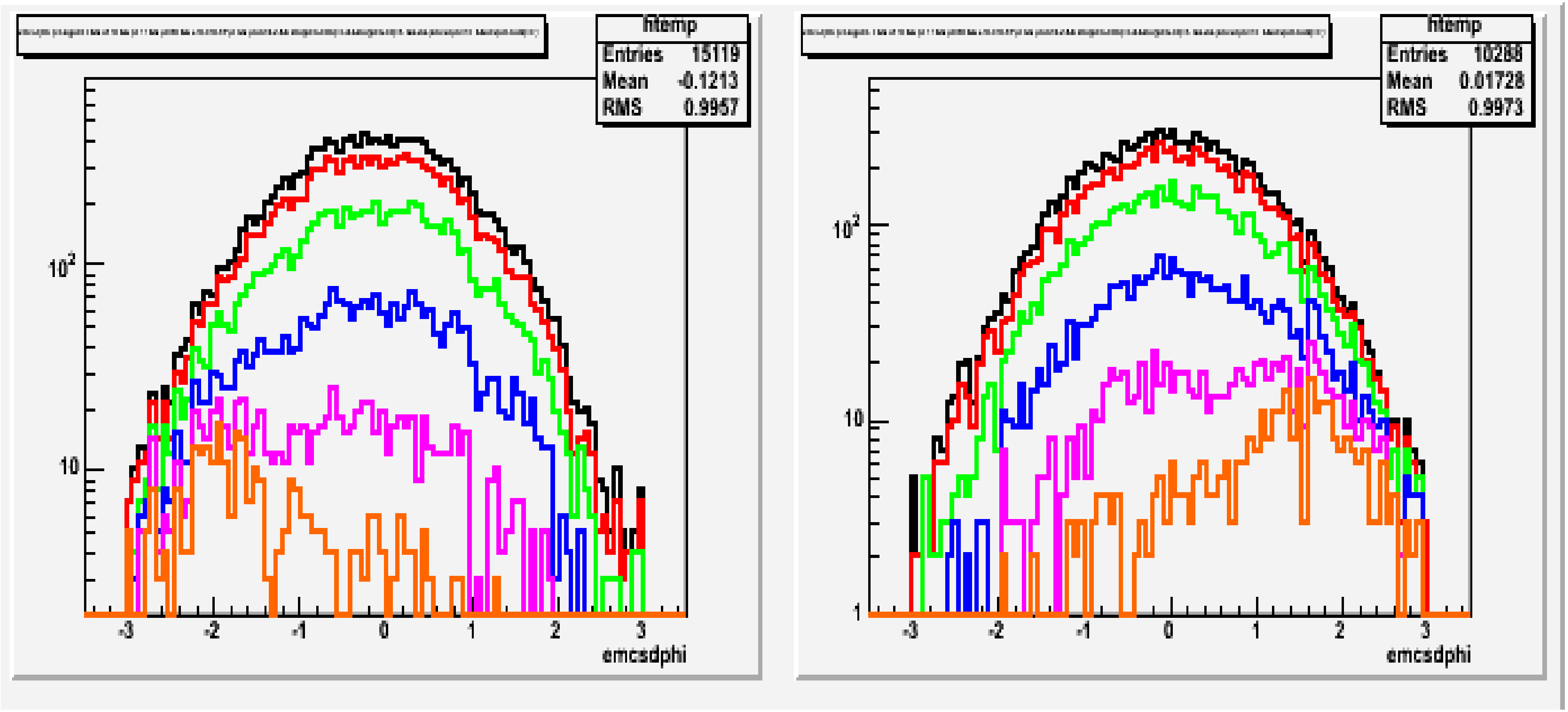


Efficiency of RICH for conversion $\mathbf{e}^{\pm}$ that have reconstructed pT> 5GeV/c.



The <NPMT> as function of pT for $\pi^{\pm}$ from simulation.

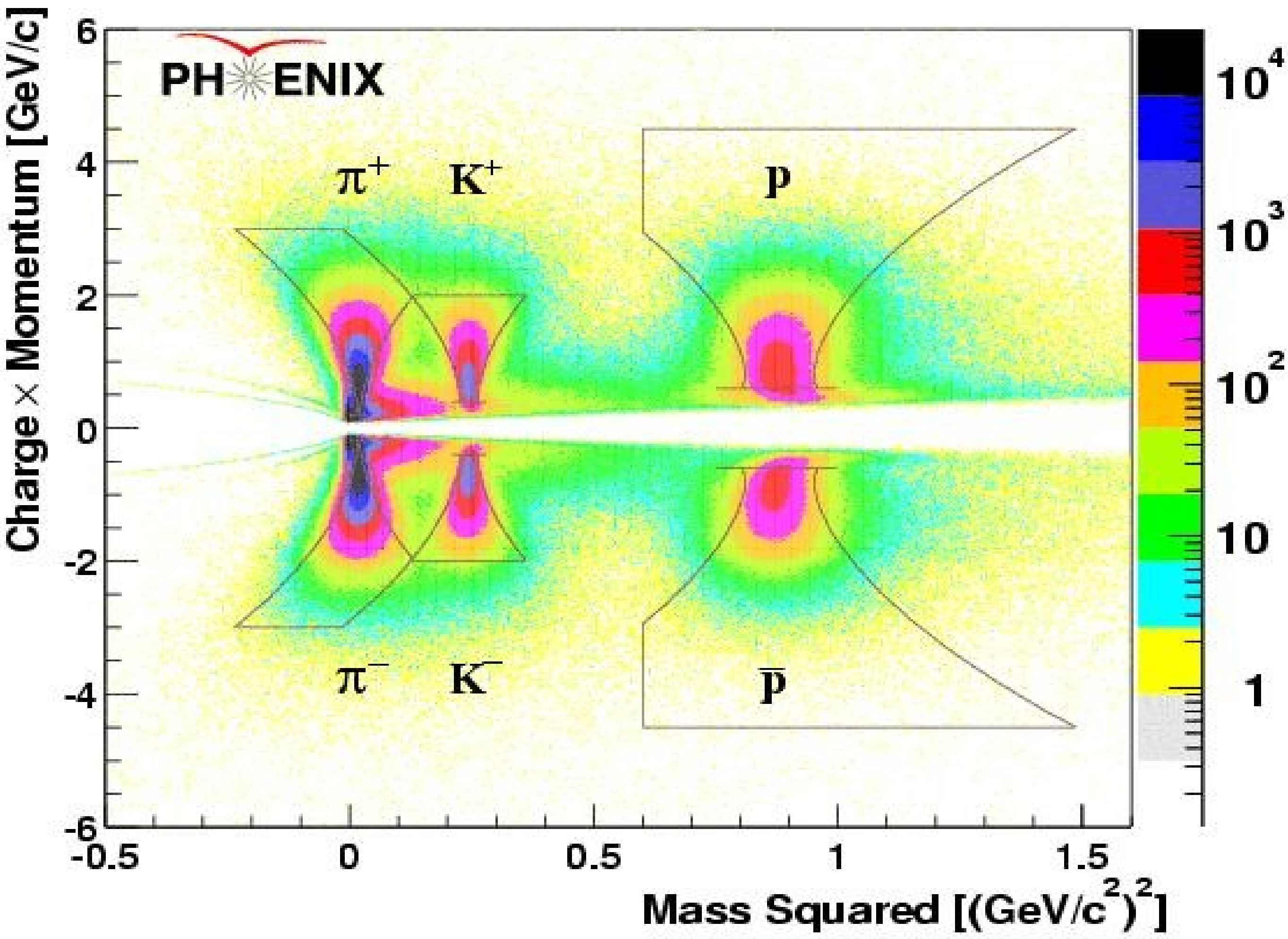
Actual Example:



In this sampled pT bin, background contribution scaled by the RICH efficiency is 1.6%(e+) 1.8%(e-) .

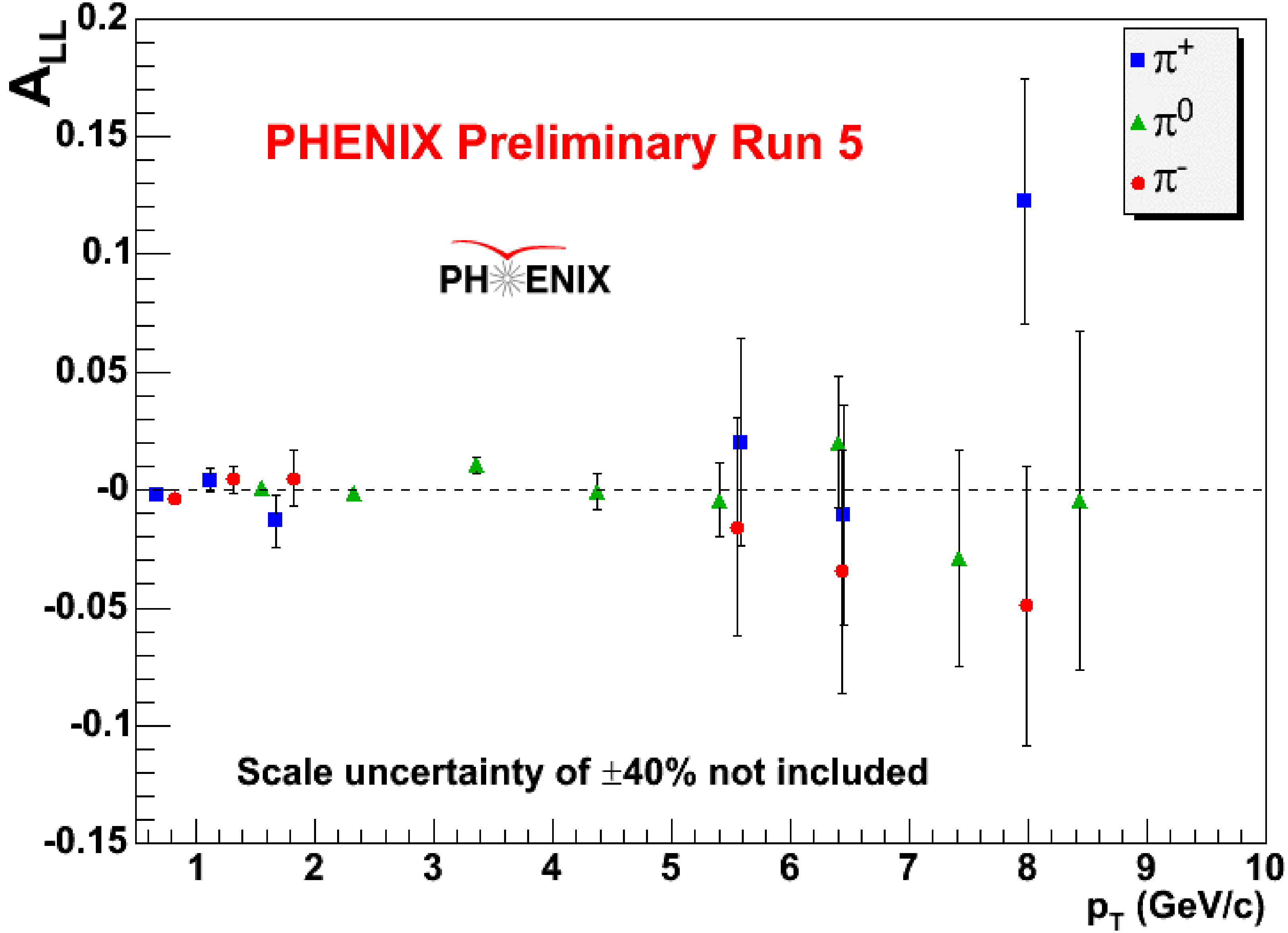
Other pT Ranges

So far we have discussed identifying charged pions at high pT at low pT PHENIX uses time of flight for particle identification.



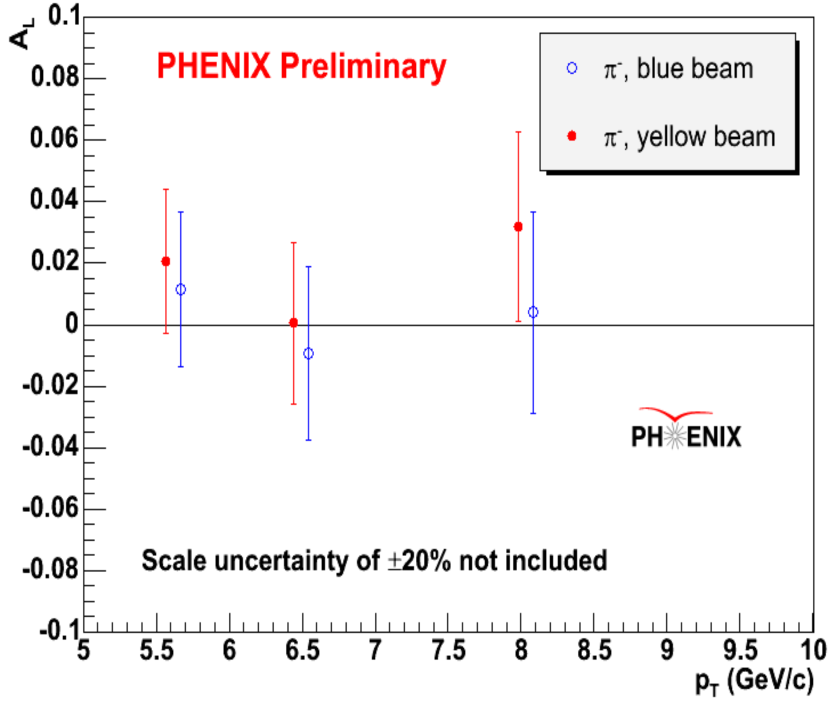
SOME RESULTS & OUTLOOK

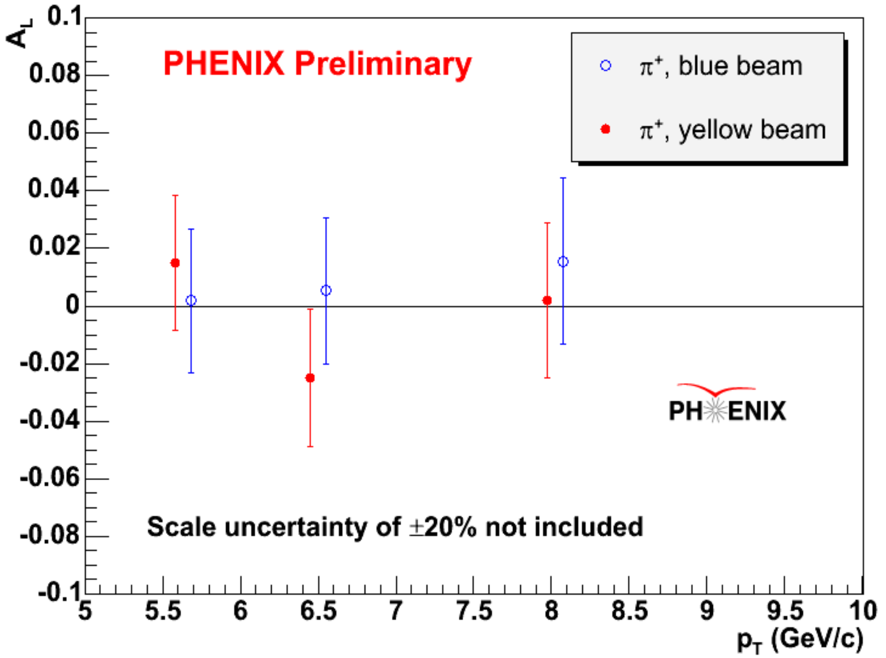
Asymmetries



SINGLE SPIN ASYMETRIES

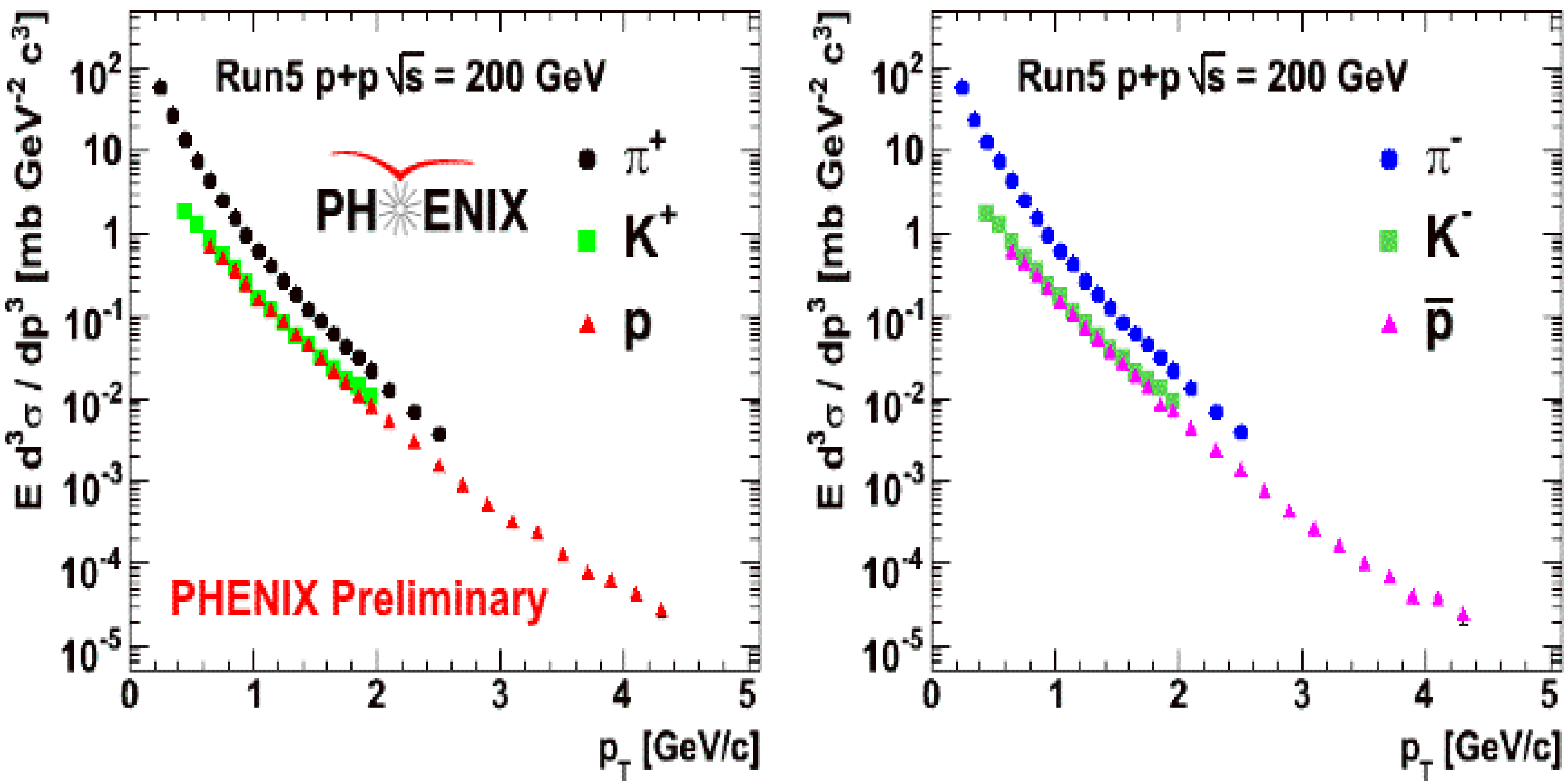
Parity-violating longitudinal spin asymmetries A_L are expected to be consistent with zero



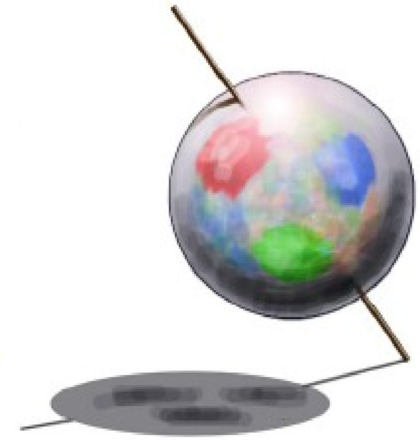


**Approved Run05-Results

Low pT Cross Sections at PHENIX



Status and Outlook



–Global studies aid in the understanding of the gluon's contribution to the proton spin.

–Combined analysis of all three pion species at RHIC can provide valuable information on both the sign and magnitude o Delta-g

–This analysis has been repeated for run6* data , A_{LL} and A_{L} are currently undergoing the approval process.

-High pT Cross section measurement is under way

*Run 2006 was the latest polarized p-p run (longitudinal), next p-p is expected in 2009?

Extra slides

DC Op Principles

- **A HIT:**
- **Registration of one HIT is based on a few physical processes:**
  - **When charged particle transverse the gas volume of the DC it creates clusters of primary ionization on its way**
  - **Electrons of primary ionization drift from the point of ionization to anode wires along electric field lines**
  - **Electrons of primary ionization create avalanches in the vicinity of anode wires**
  - **Back drift of posistively charged ions generate measurable signal on anode wires which is amplified, shaped and discriminated**
- **To register a HIT in the DC:**
  - **Carry out *drift time* measurements: Start - collision time measured by BBC; Stop - time when signal appears on the anode wire**
  - ***Drift time* (t) can be tranformed into *drift distance* (x) if calibration curve is known $x = x(t)$**
  - **Working gas is chosen to have an uniform drift velocity in the active region ➔ linear xt relation can be used $x = V_{dr} \cdot t$**

Track Candidates

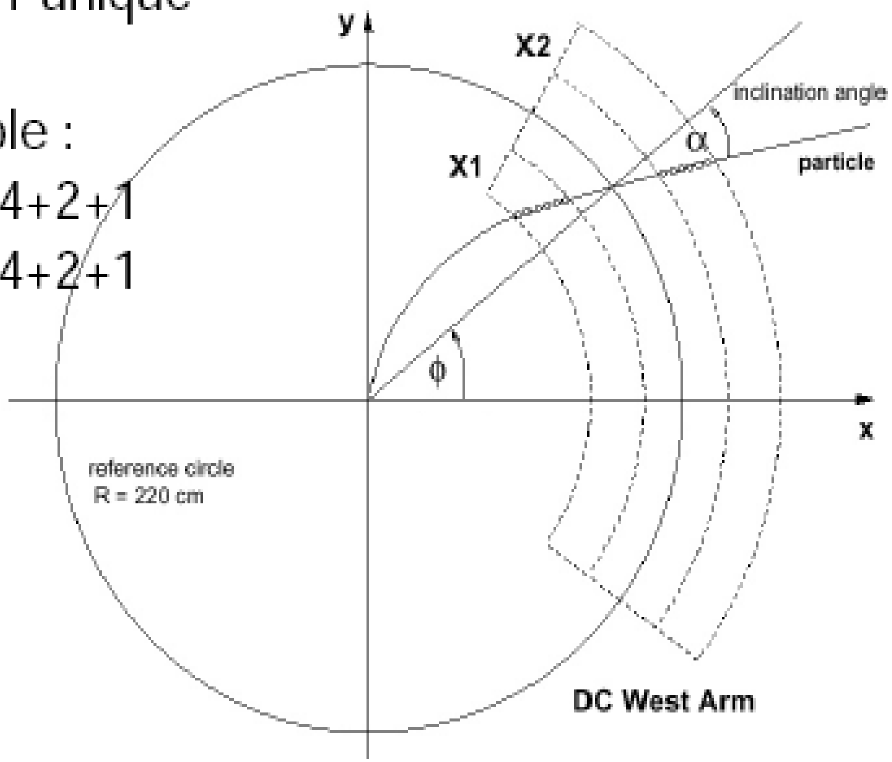
- The results of the hough transform are track candidates
- First we look for tracks with X1 and X2 hits
- Remaining disassociated hits goes into X1 only and X2 only tracking
- Finally we left with the following tracks
- Z coordinates of tracks are defined by PC1-UV-vertex tracking

quality

Quality of the Drift Chamber tracks

0 (1) X1 used
1 (2) X2 used
2 (4) UV found
3 (8) UV unique
4 (16) PC1 found
5 (48) PC1 unique

For example :
63=48+8+4+2+1
31=16+8+4+2+1



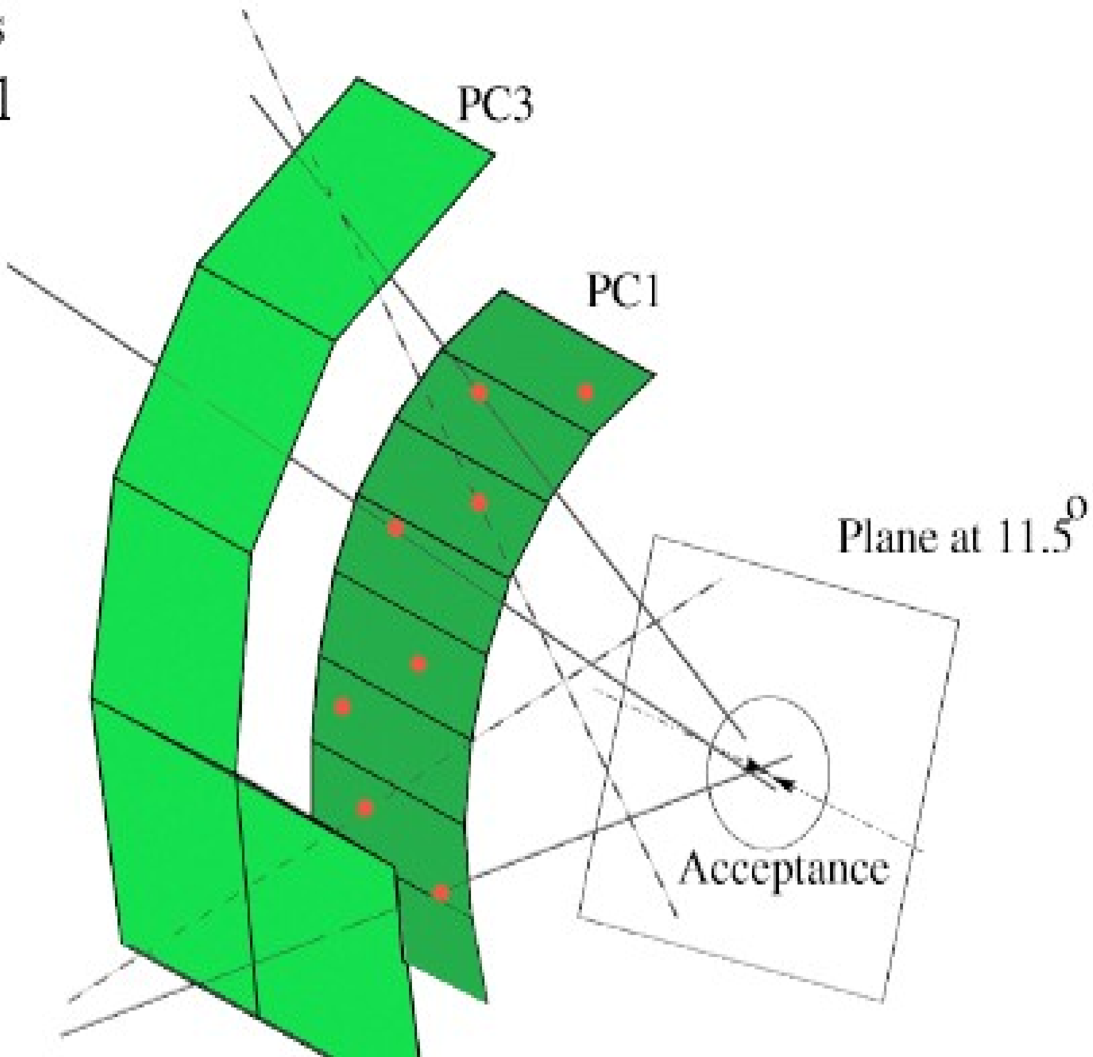
- First look for tracks with X1 and X2 hits
- Remaining unassociated hits go into X1 only and X2 only tracking
- Z coordinates of tracks are defined by PC1-UV-vertex tracking
- When PC choice is unique, stereo wires try to verify. If they do, then UV hits exist and are unique by construction. When they don't, there are no UV hits. If PC has more than one available choice, the UV are consulted for the "best match". In this case one either gets no UV, a best choice, or remaining ambiguity (tied).

zed

Z coordinate at which the track crosses PC1

The vertex position is determined by:

1) Combining all PC1 and PC3 hits to lines
2) Project the lines to the plane and save all within an appropriate X and Y window.
3) Calculate the peak position of the Z distribution.



RICH VARIABLES:

n0: Number of phototubes that fired in the RICH (normally sized ring area.)

The acceptance area of *n0 is 3.4 < r < 8.4* cm, where r is distance between the PMT center and the projected ray of the track.

The RICH n0 cut is used to remove some conversion and most of the real electrons.

n1

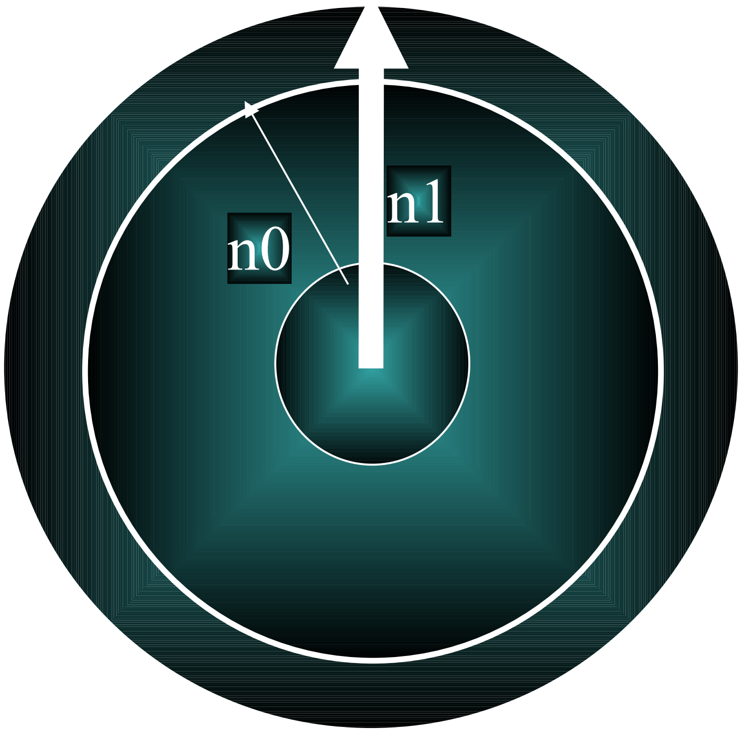
Larger disc area r < 11 cm.

n2

Disc area r < 8.4 cm.

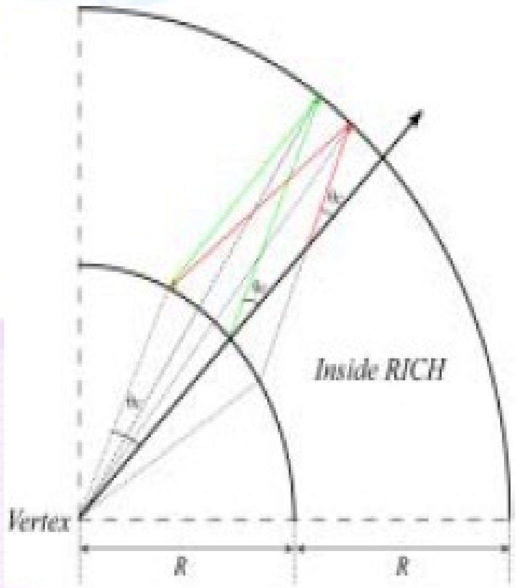
n3

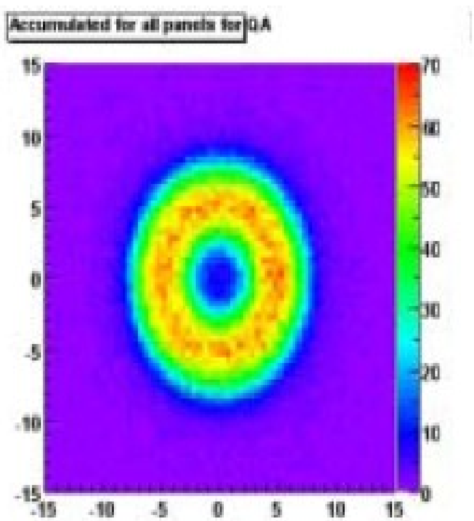
Ring area 3.9 < r < 7.9 cm.



RICH Details

- Cherenkov photons emitted in parallel.
- Using **spherical mirror**, photons are focused on PMT surface.
  - Photons make a **ring**.





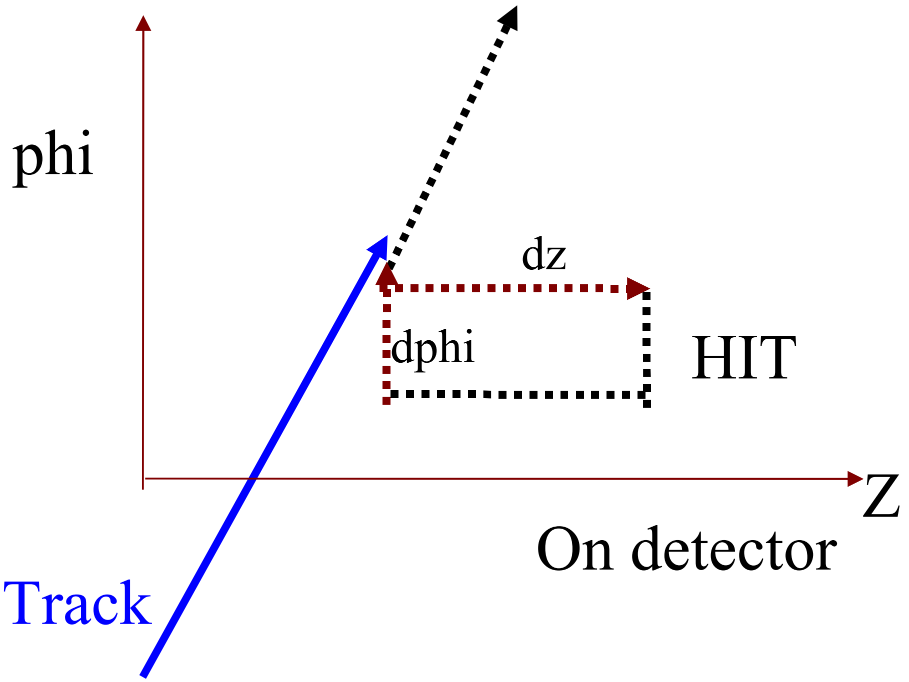
Detector Matching

pc3sdz , pc3sdphi (emcsdz, emcsdphi)

Difference in Z(cm)/phi(rads) between the track model projection and the hit in the pc3 (EMCal) normalized to sigmas. .

spc3sdphi

Difference between the track model projection and the measurement normalized to sigmas, but for the z-swapped projection.



Some Definitions

Pseudorapidity:

Spatial coordinate describing the angle of a particle relative to the beam axis.

It is defined as $\eta = -\ln\left(\tan\left(\frac{\theta}{2}\right)\right)$, where theta is the angle relative to the beam axis.

$$y = \frac{1}{2}\ln\left(\frac{E + p_L}{E - p_L}\right)$$

Rapidity: p_L is the component of the momentum along the beam direction.

Pseudo rapidity does not depend on the energy of the particle, only on the polar angle of its trajectory.

The rapidity is used in some hadron colliders(not in PHENIX) over the polar angle because particle production is constant as a function of rapidity.

The difference in the rapidity of two particles is independent of Lorentz boosts along the beam axis.

Polarizing the Beam:

There are 4 steps to polarize ions:

-Intense high quality beam

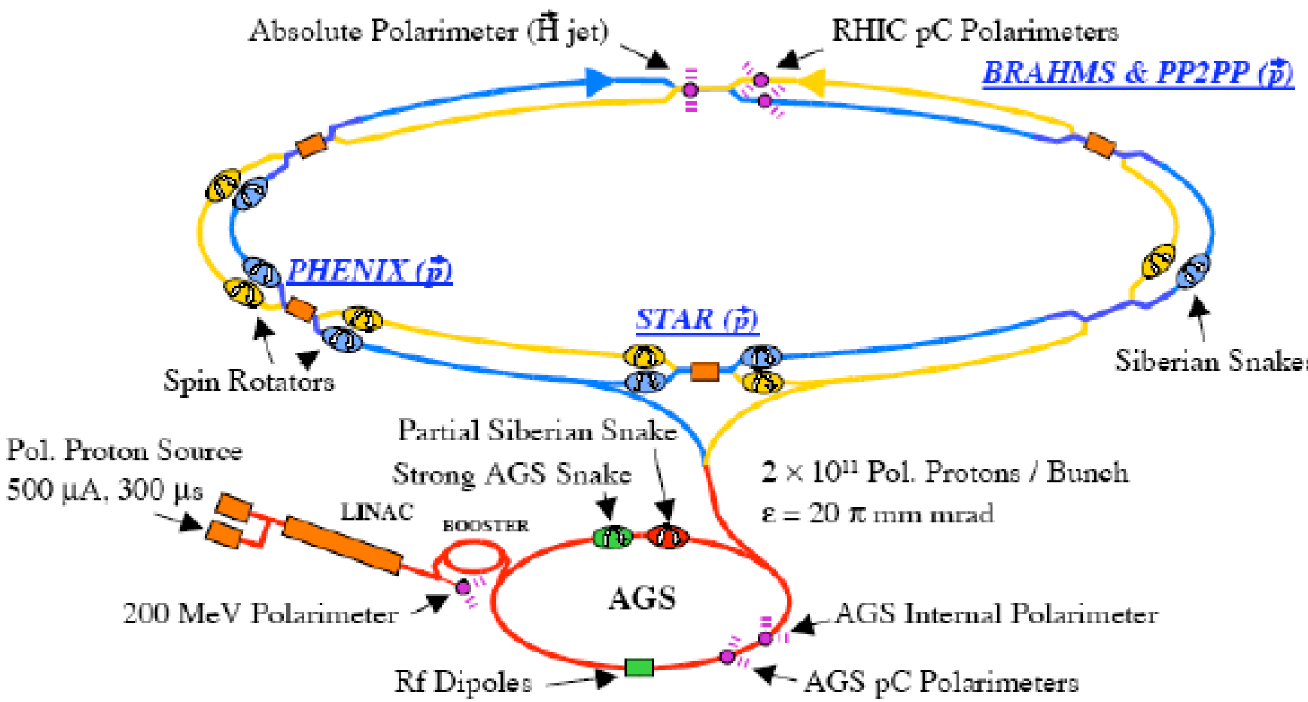
-Polarize in a B-field by selecting the hyperfine states of one of the Zeeman levels.

-Polarization is achieved by inducing transitions from the occupied hyperfine states (undesired spin direction) to the unoccupied hyperfine states (correct spin).

-Finally we ionize it in the presence of a B-field to preserve polarization.

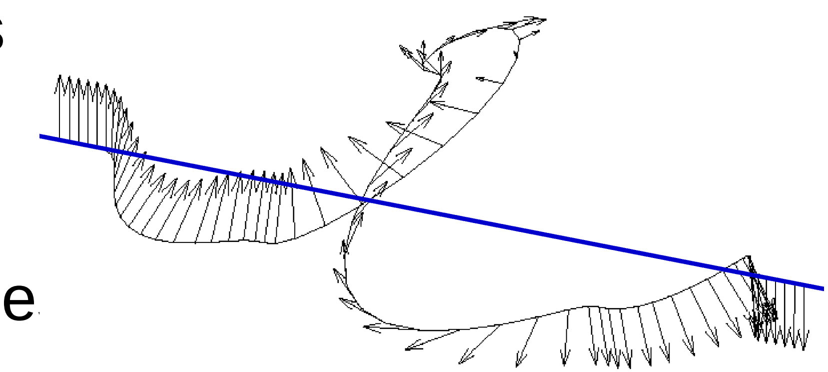
PHENIX

RHIC Relativistic Heavy Ion Collider



2 counter rotating accelerator storage rings with collisions at six interaction points

Siberian Snakes: Depolarized resonances averaged out by rotating spin by 180 degree each turn.



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PHENIX