Measurement of the Collins Asymmetry in Mid-Rapidity Jets at STAR

Robert Fersch
University of Kentucky
for the STAR Collaboration

Presentation for the High-p_T Physics at RHIC RBRC Workshop

Goals of this Presentation:

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- Present a survey of quark transversity (δq) and partonic spin degrees of freedom (Motivation)

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- Demonstrate kinematic coverage of the data and physics in terms of p_T
- Show statistical expectations of measured asymmetries and summarize systematic concerns

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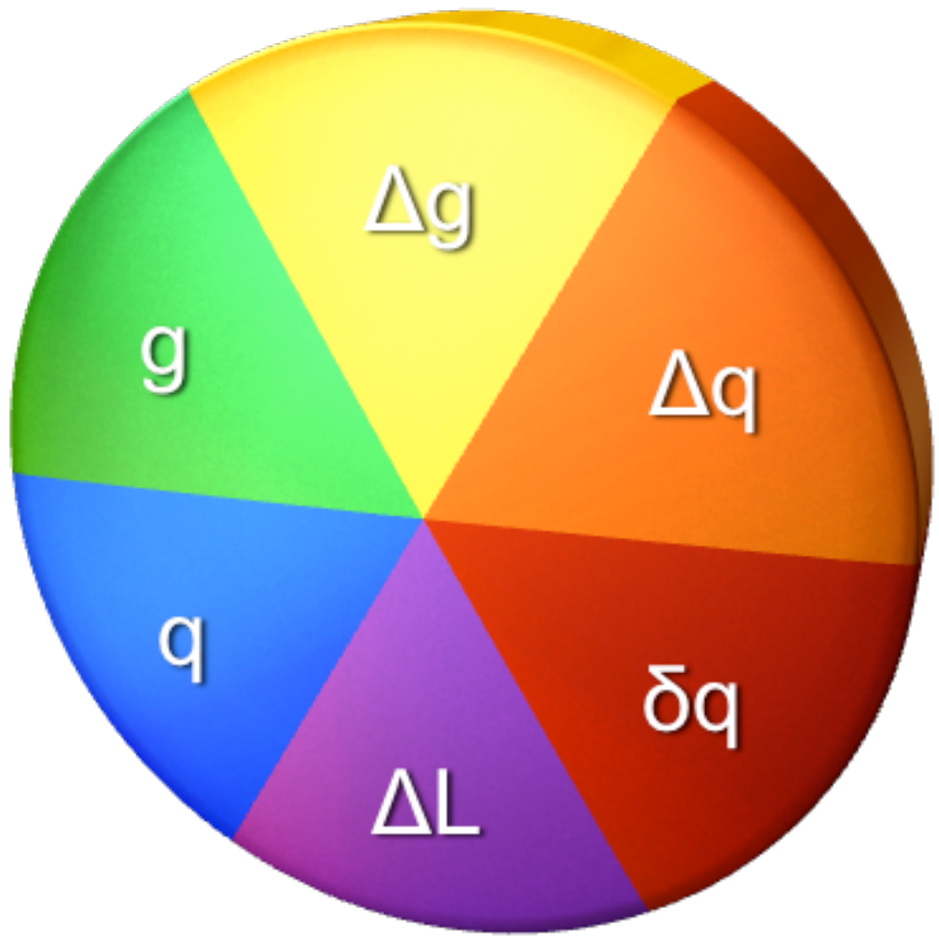
Degrees of Freedom in the Proton



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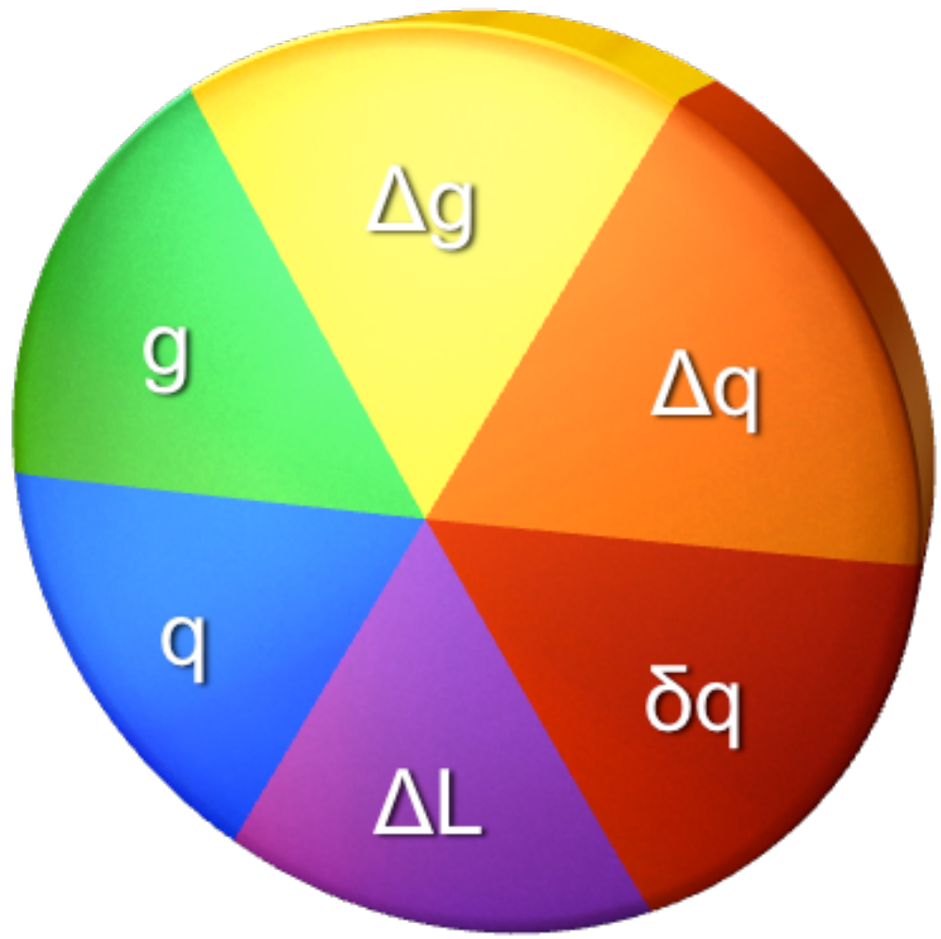

quark density

Degrees of Freedom in the Proton

gluon density

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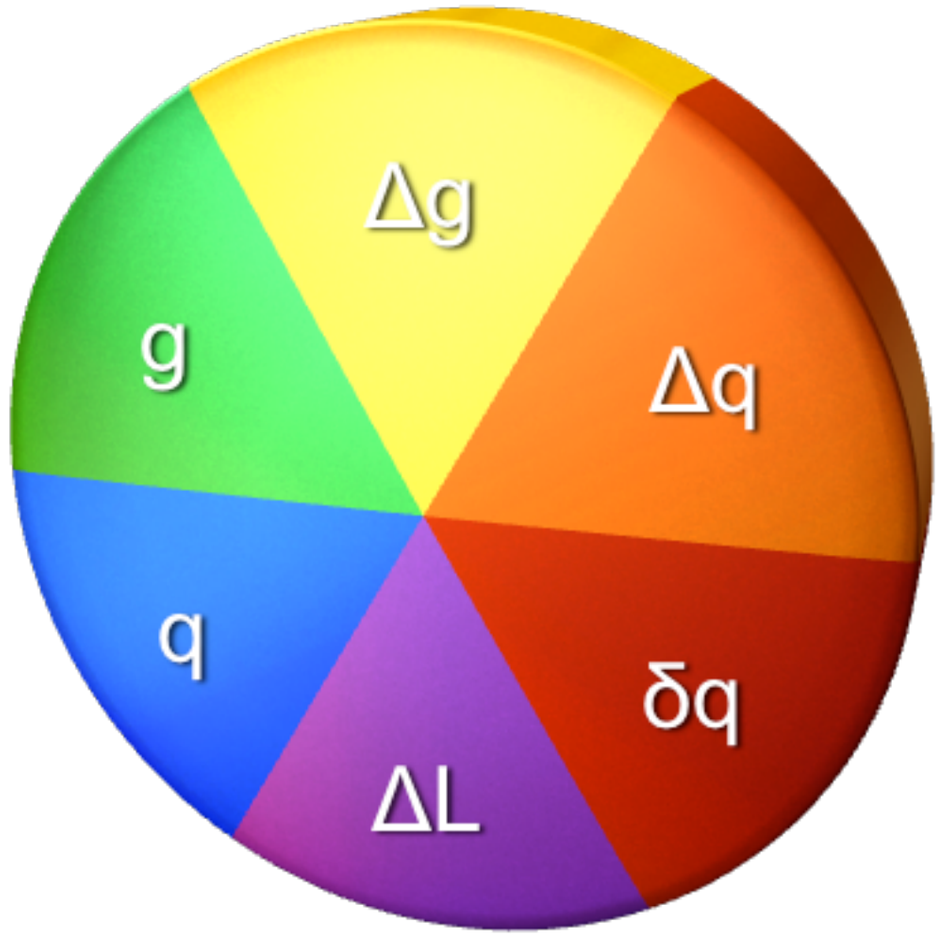

Degrees of Freedom in the Proton

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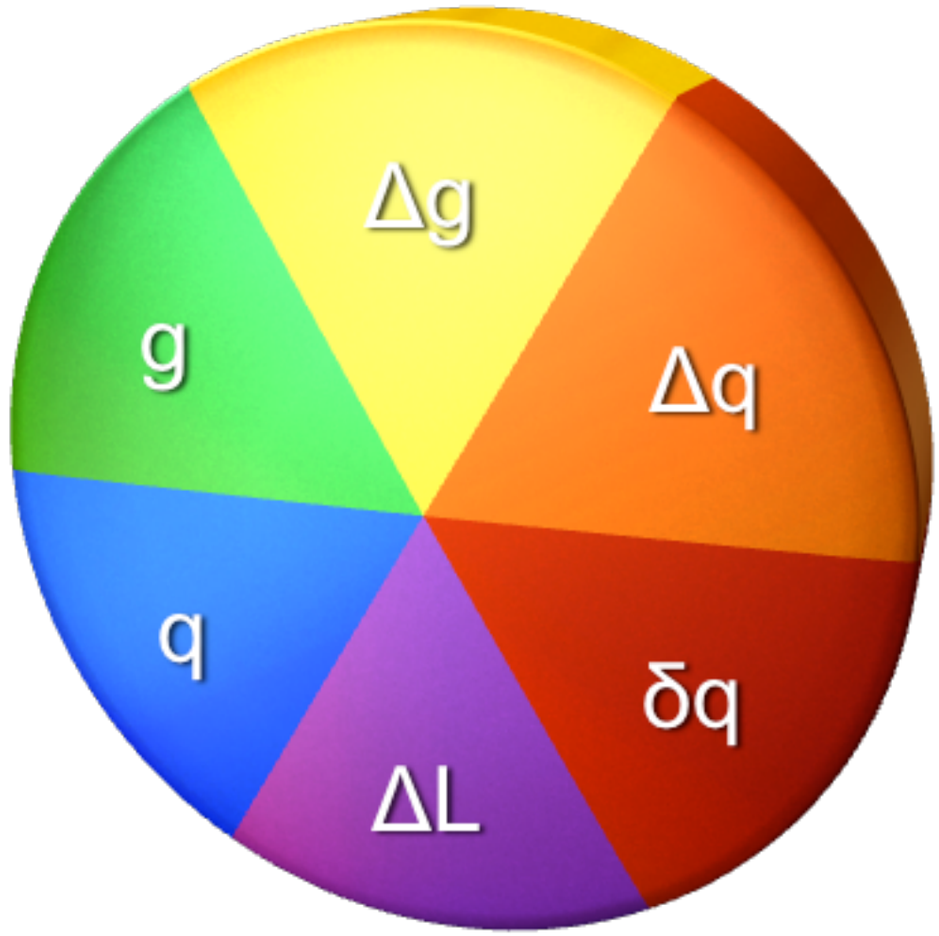

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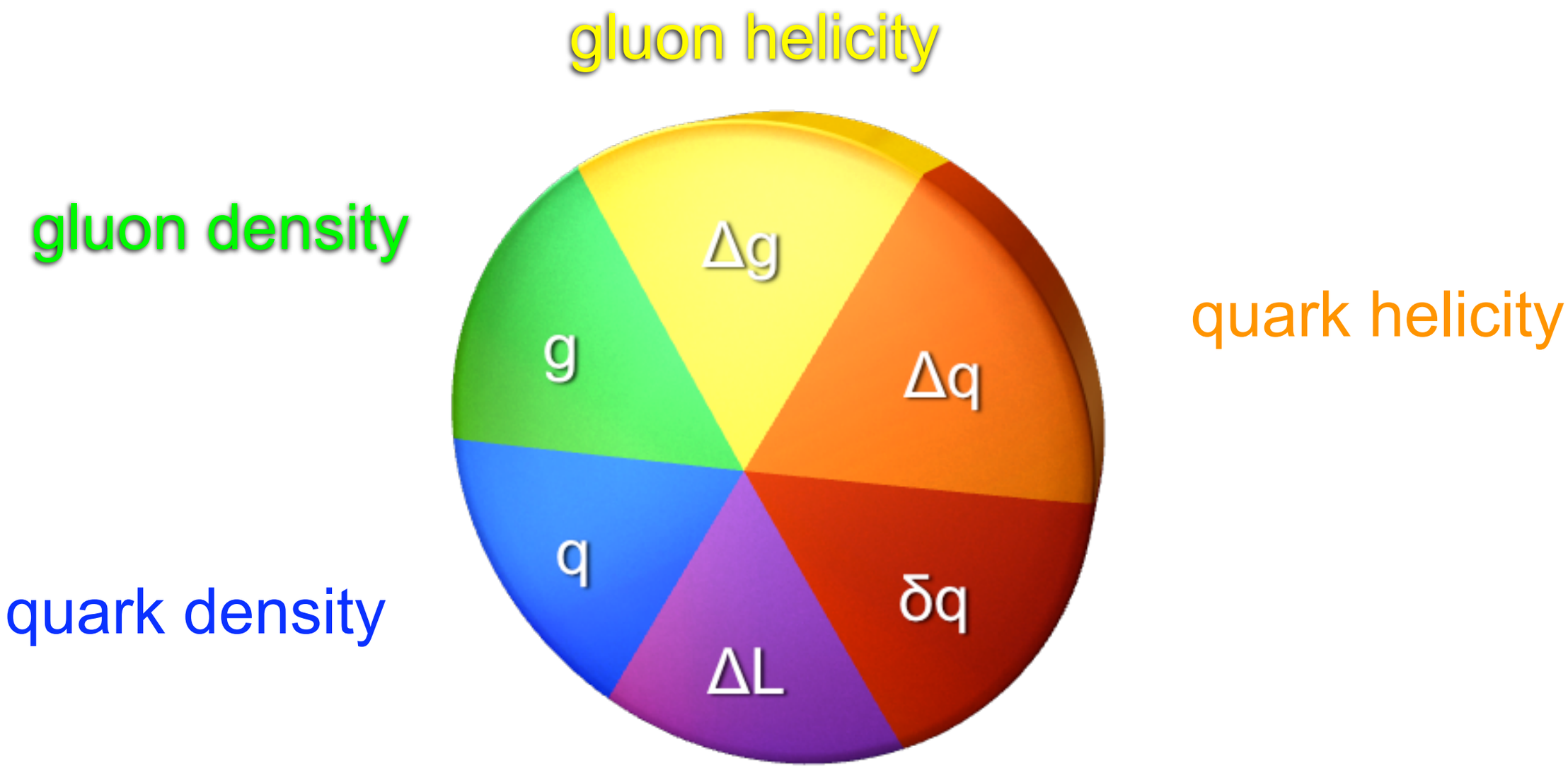

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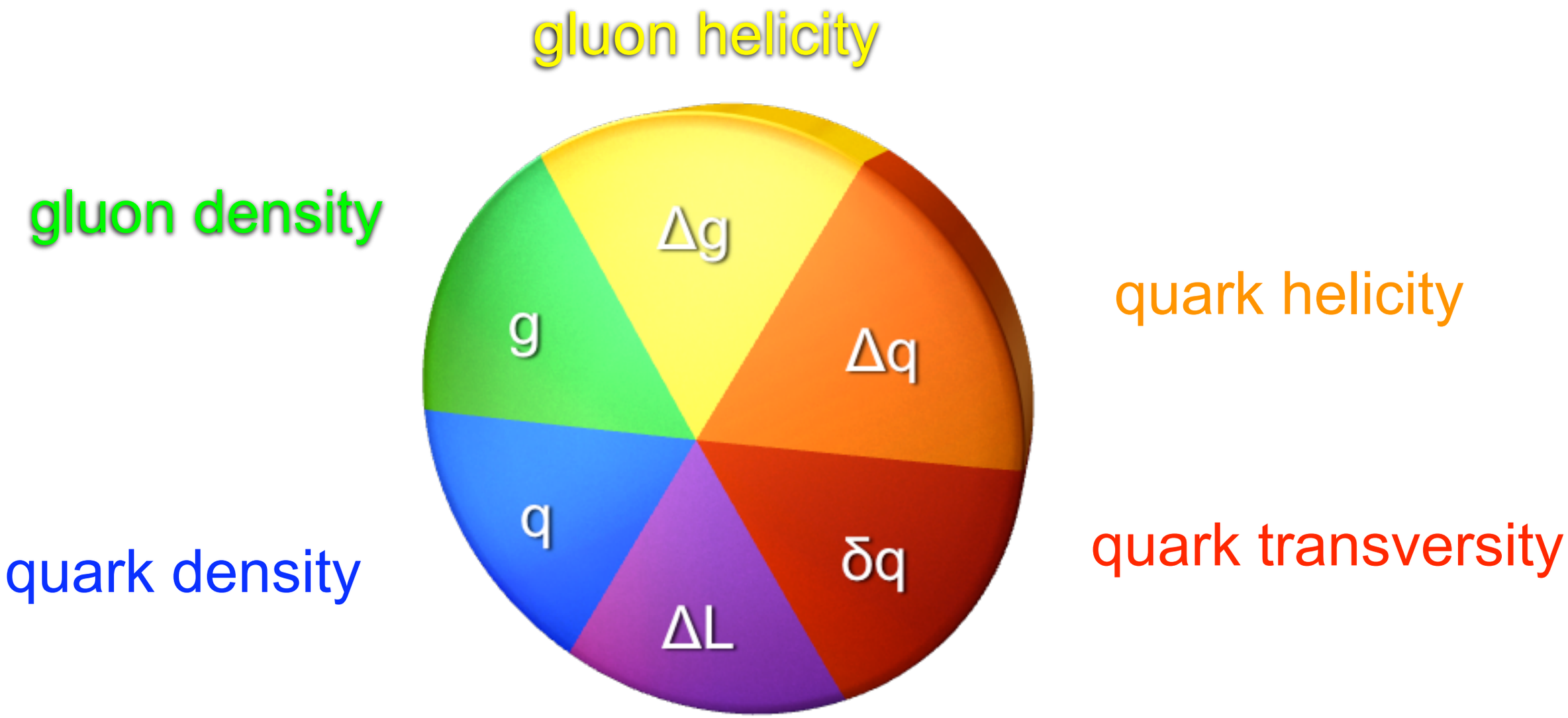

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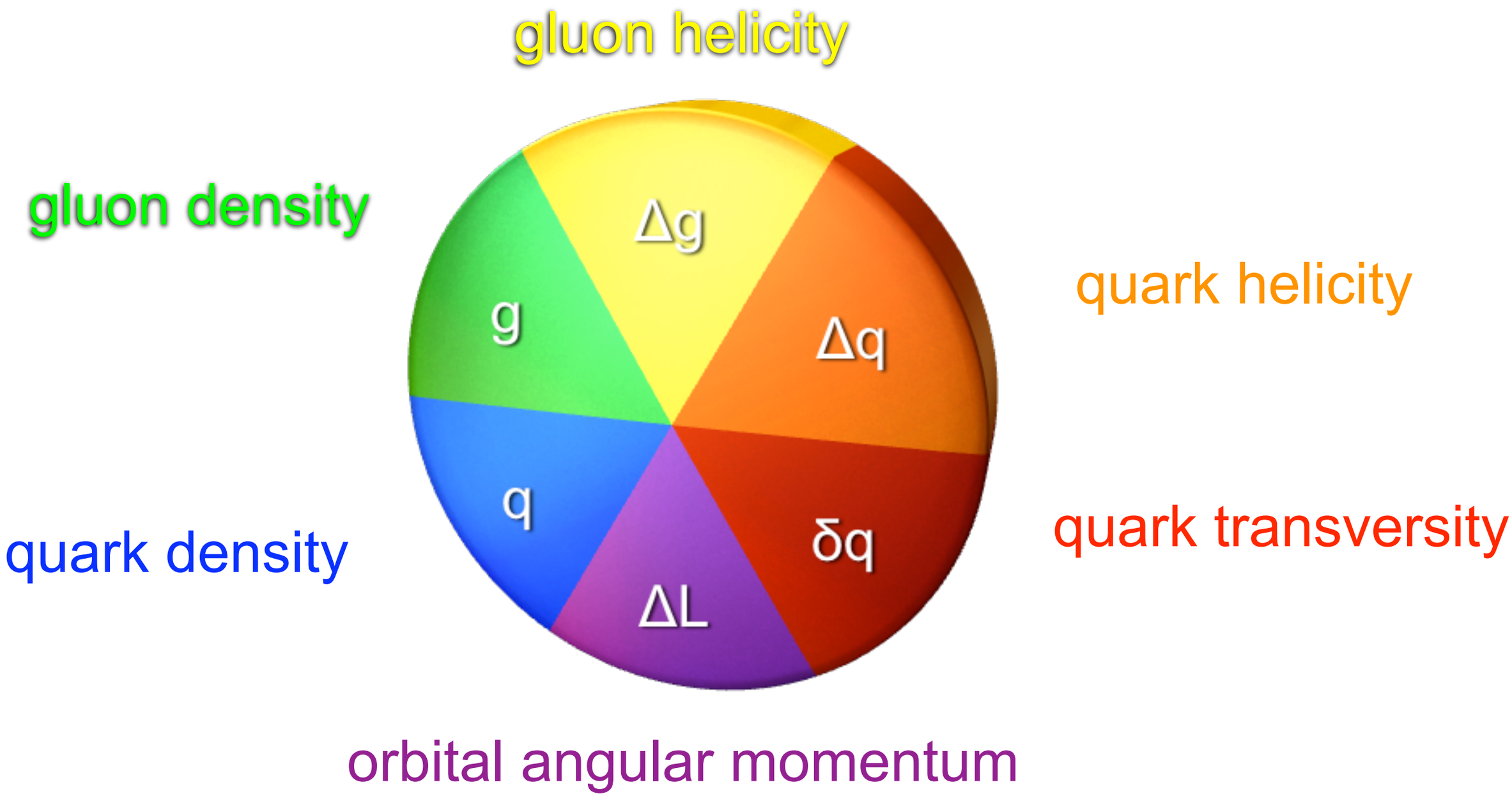

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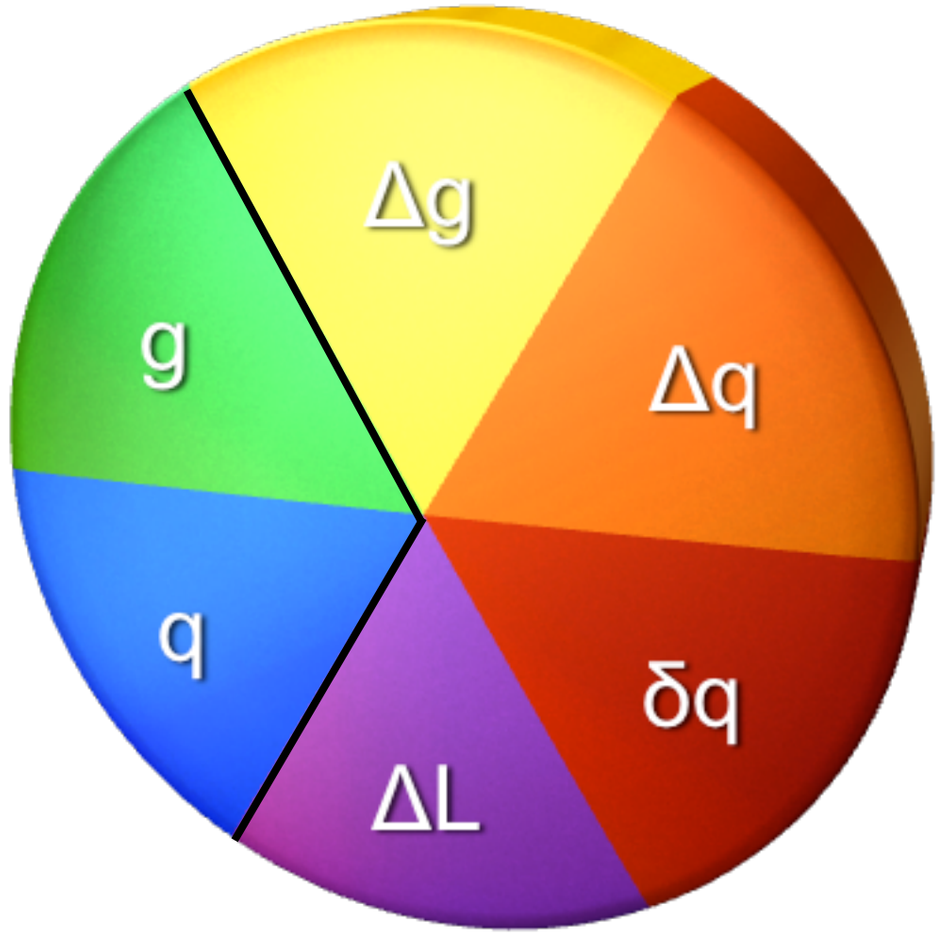
(unpolarized scattering experiments)



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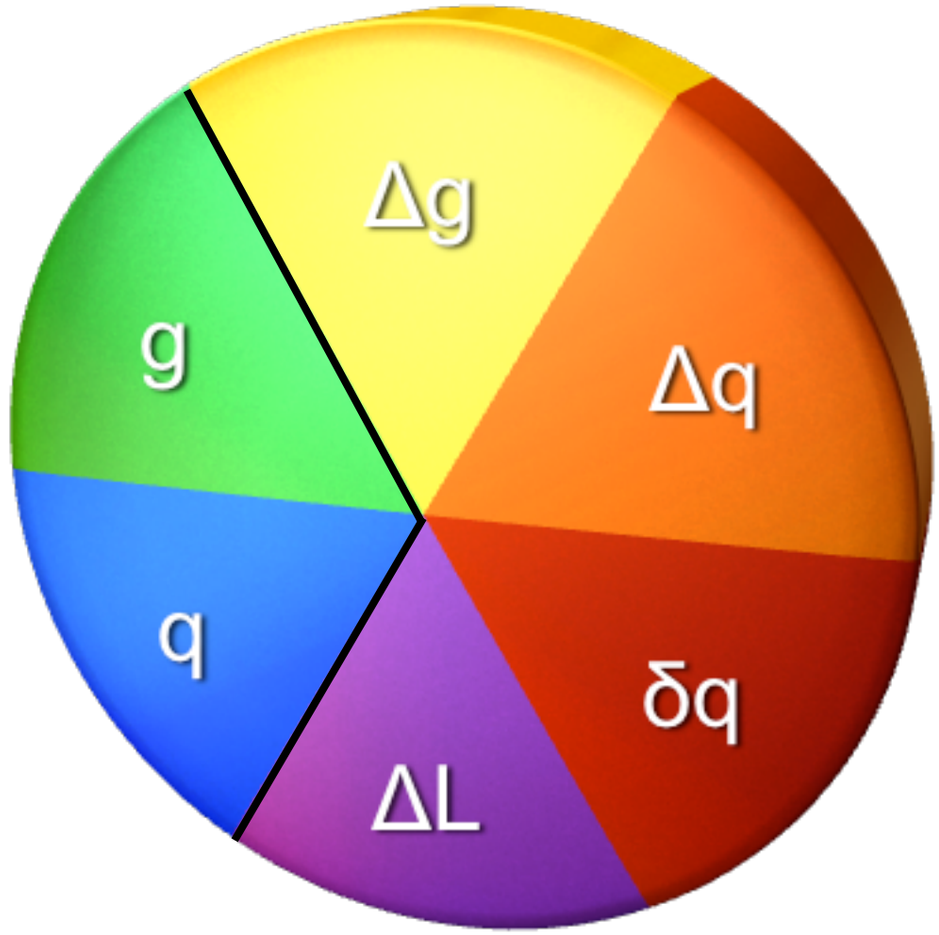

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longitudinal and transverse degrees of freedom

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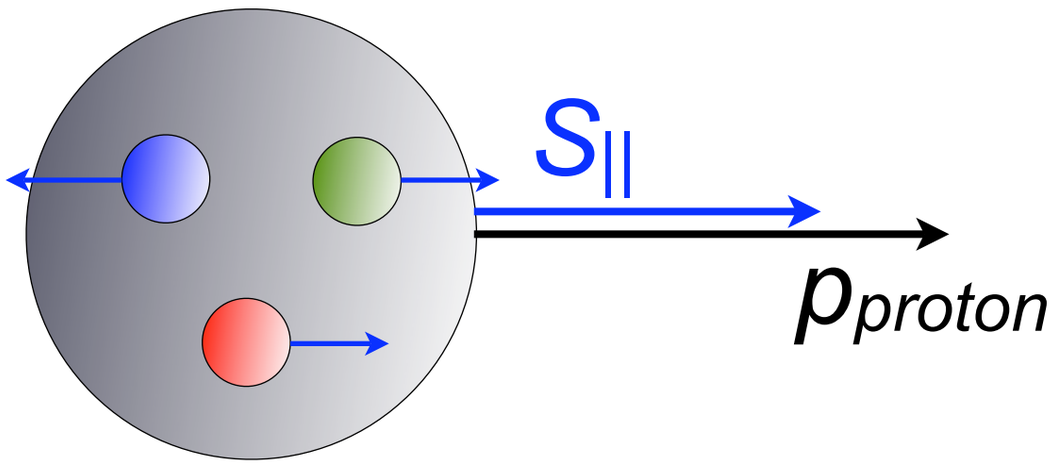

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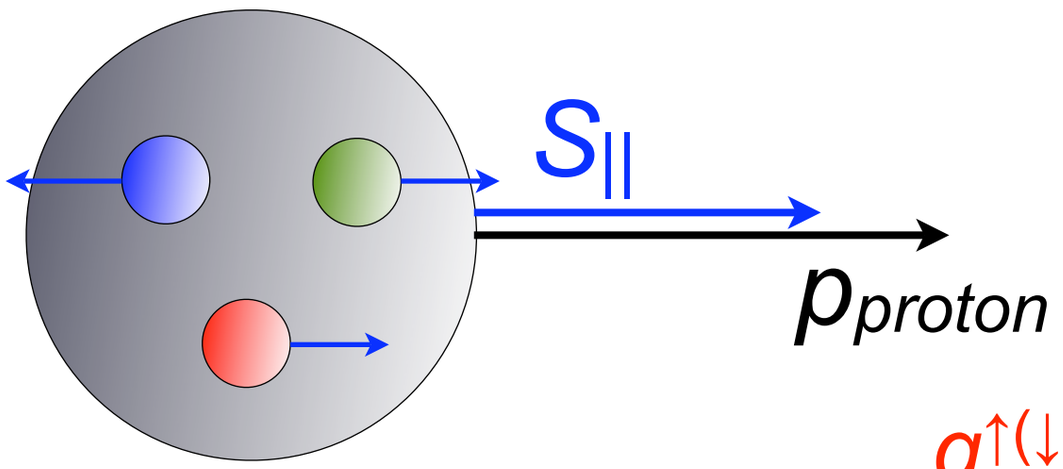

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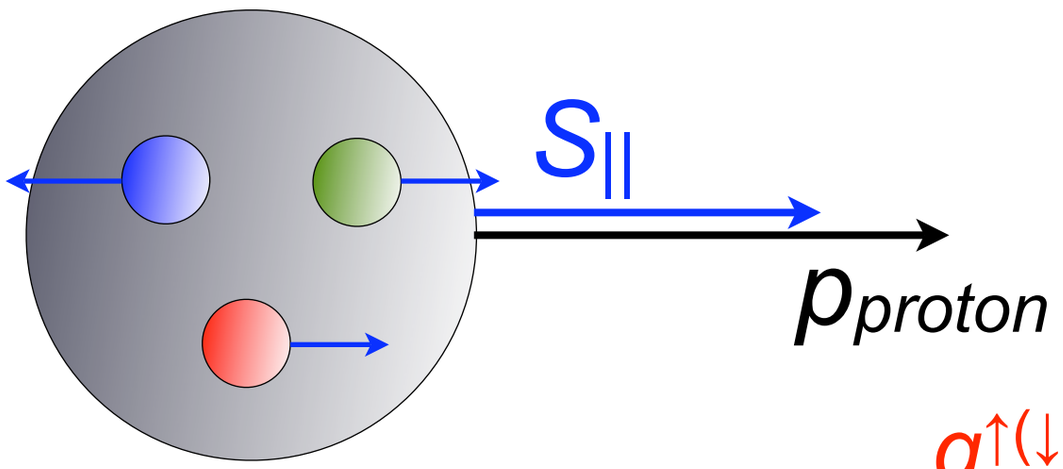

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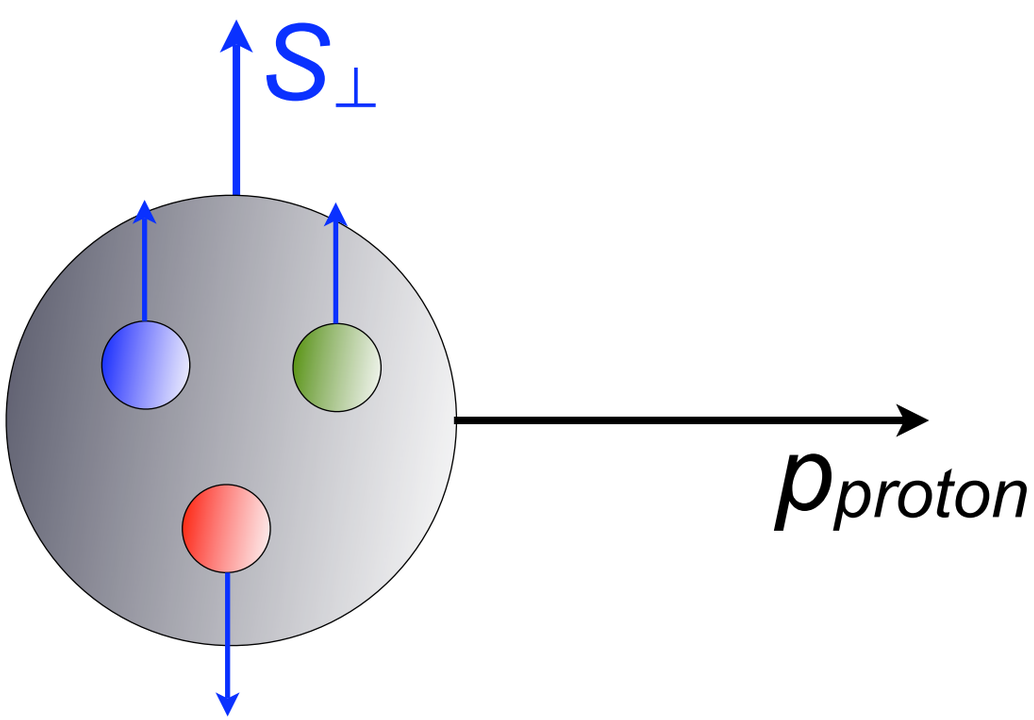

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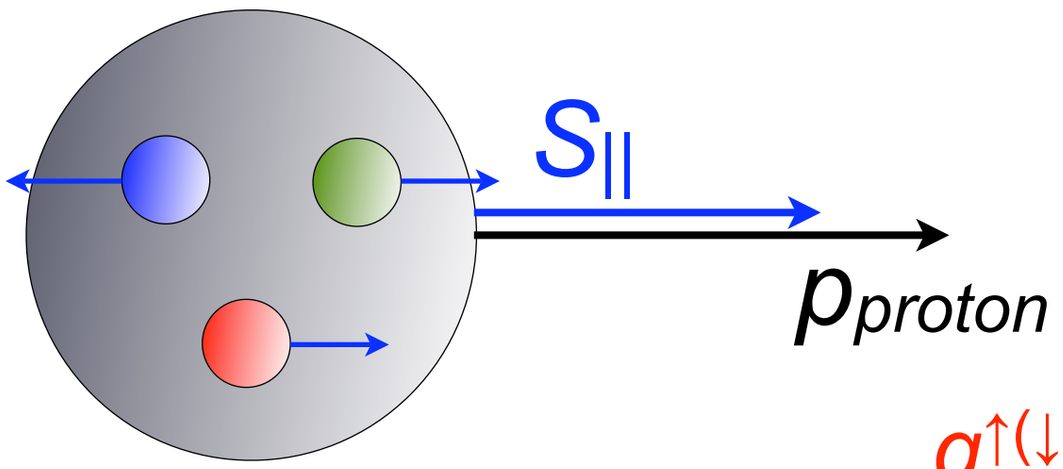

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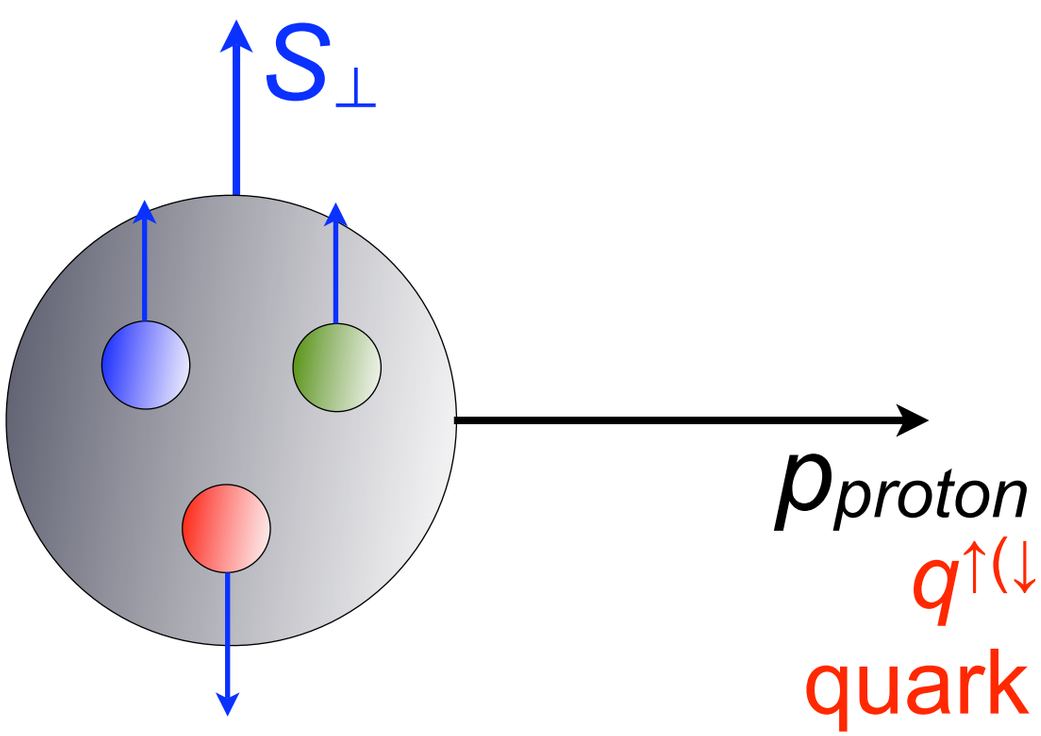

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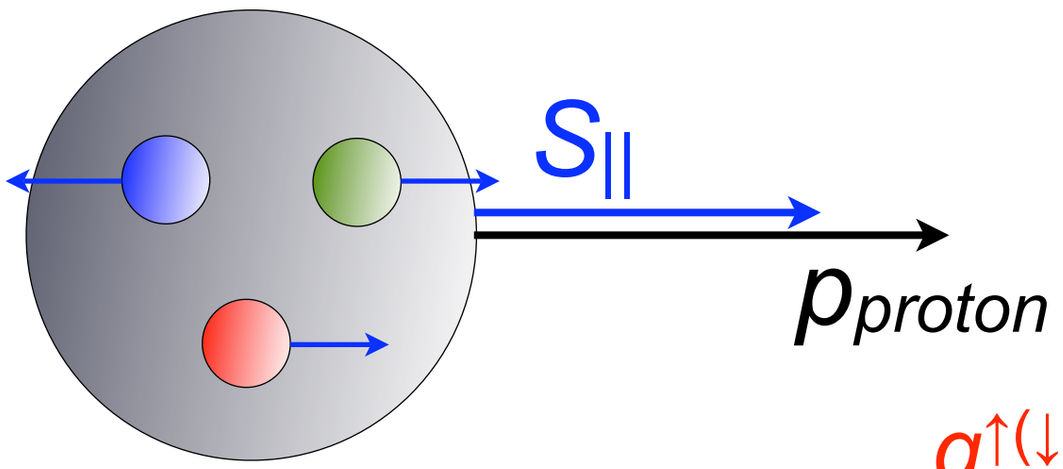

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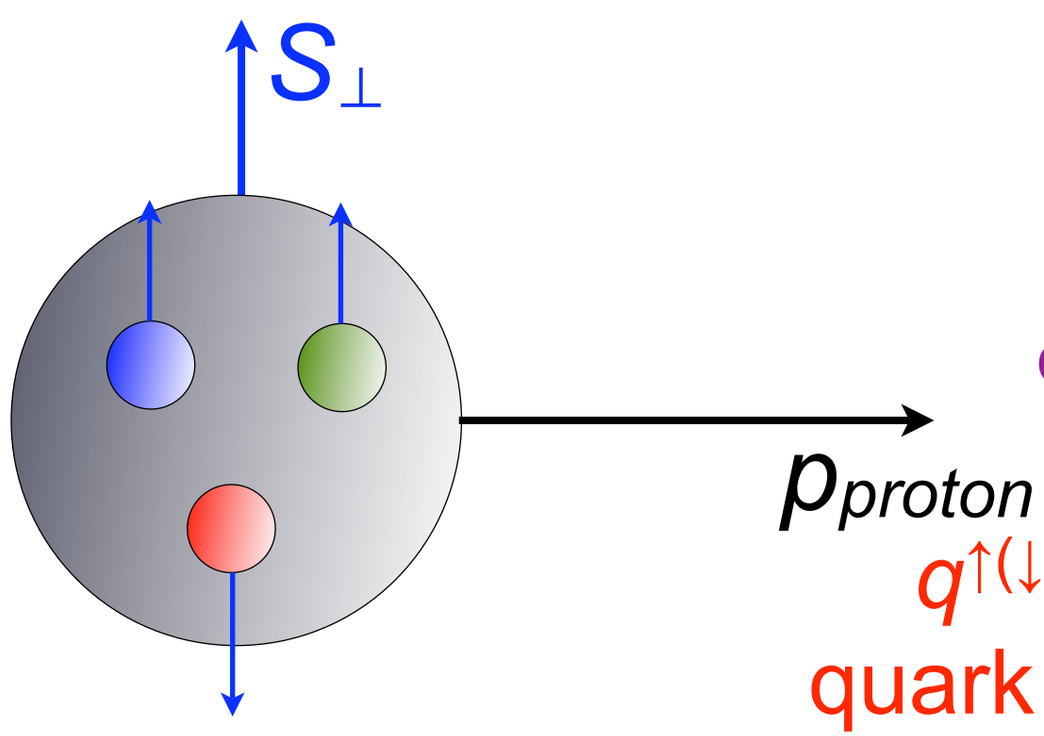

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***q, Δq, δq* all required for a complete basis in spin-density matrix representation**

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Existing Measurements of Spin Degrees of Freedom

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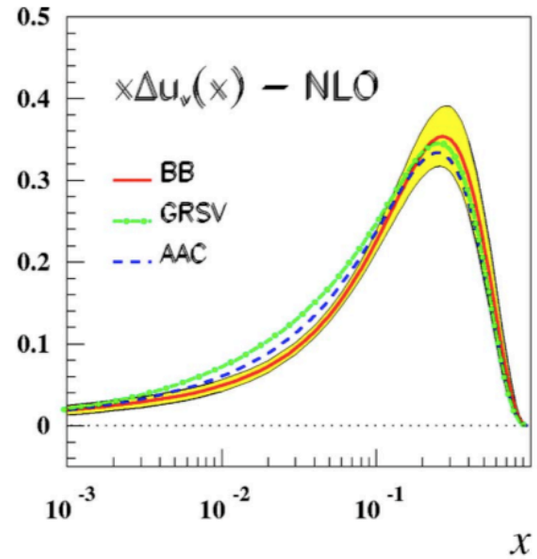

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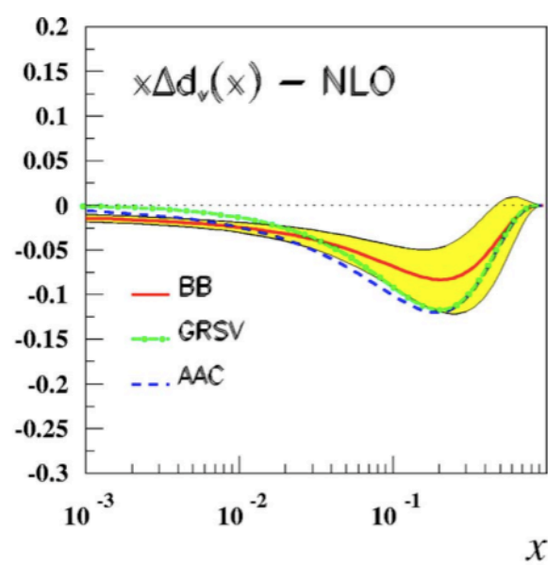

Rev. Mod. Phys. **77,** 1257(2005) Bass

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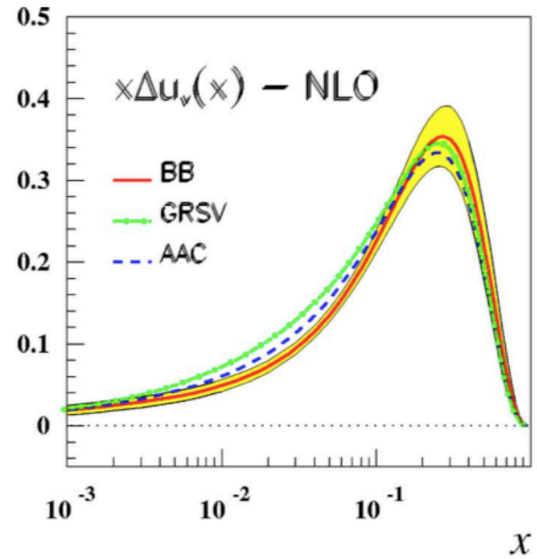

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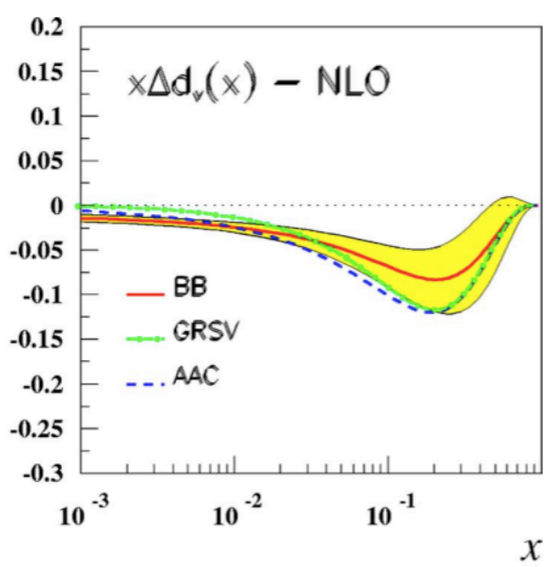

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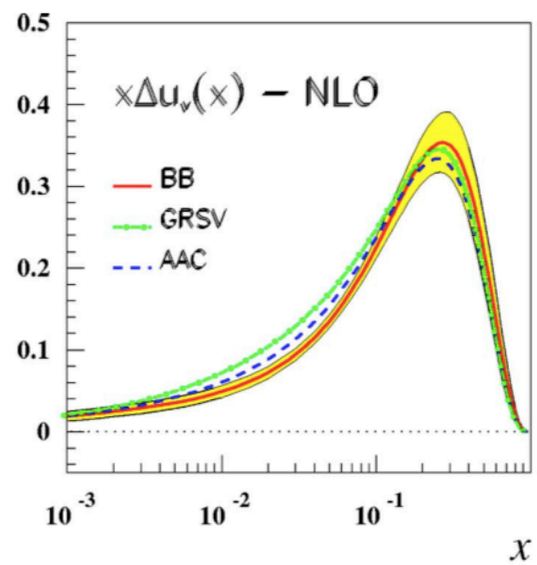
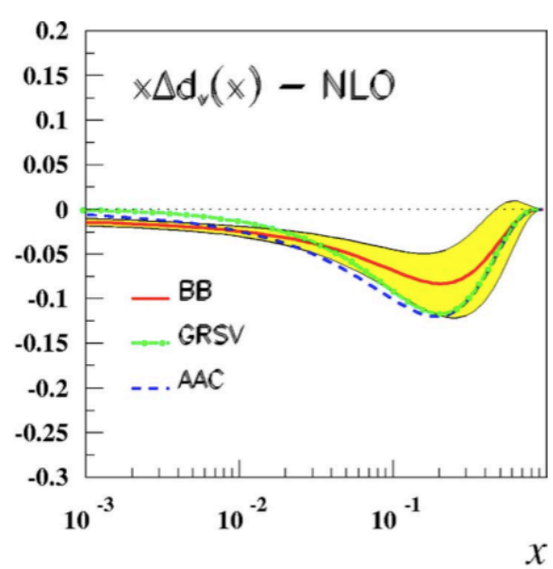


x ≡ Bjorken x (0<x<1); 1 = elastic limit

x Δd



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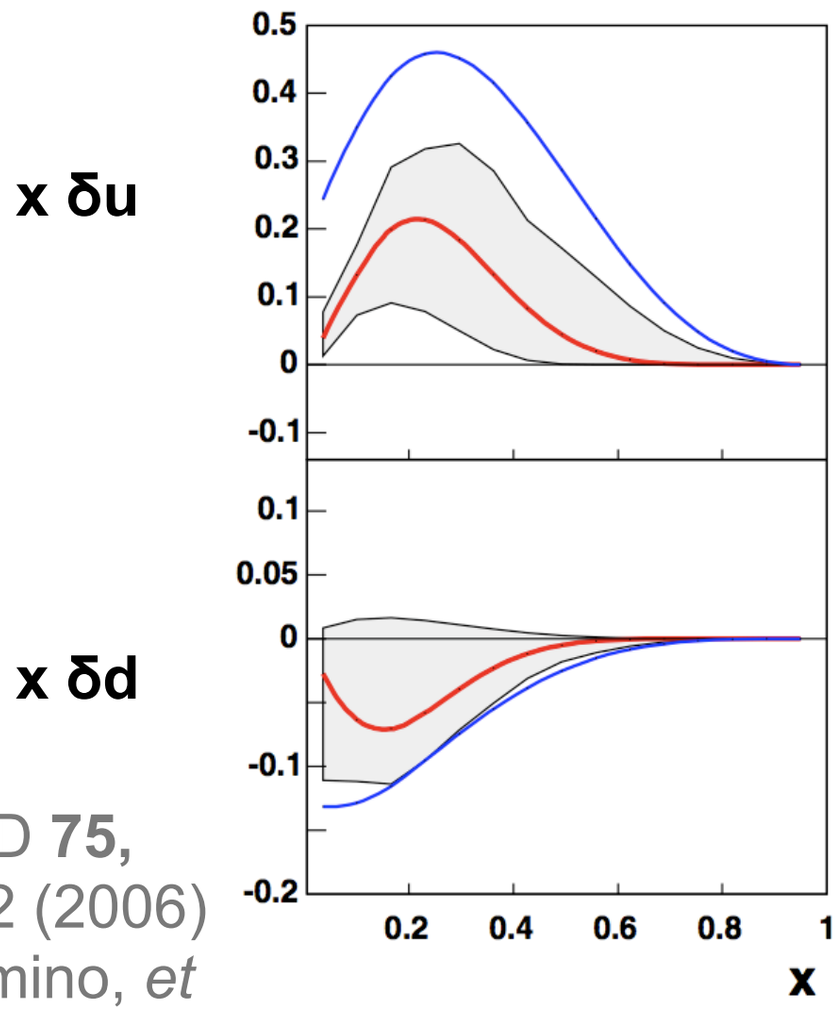

PRD **75,** 054032 (2006) Anselmino, *et al.*

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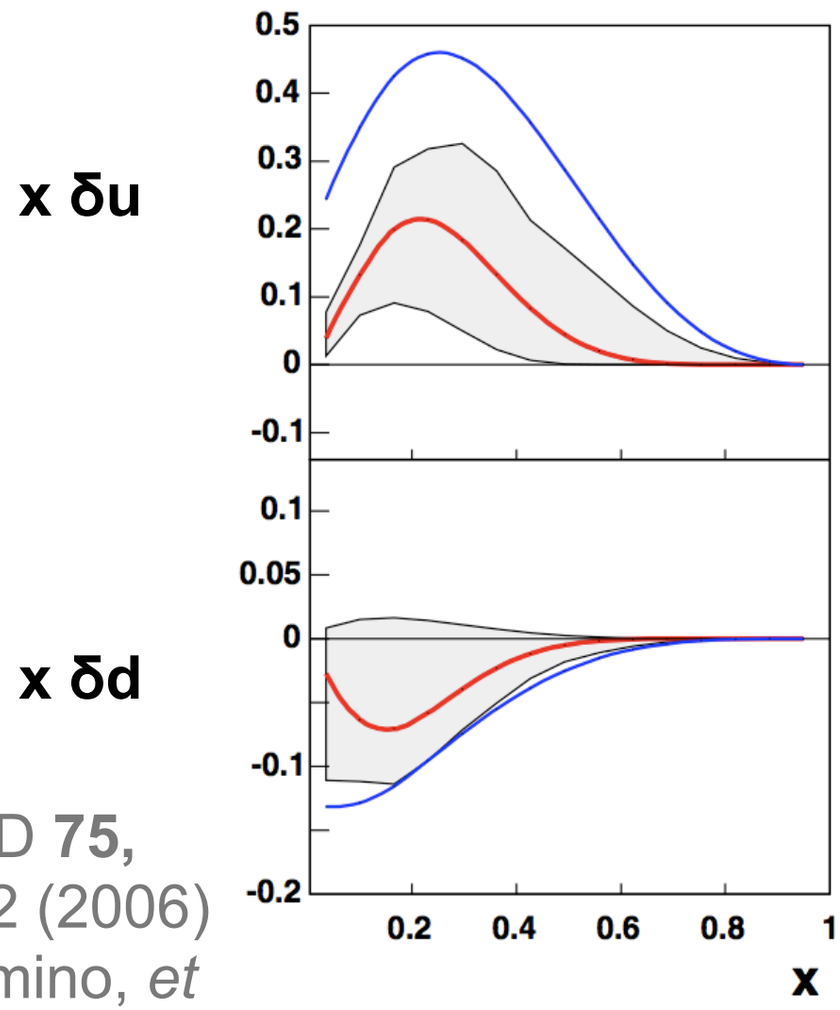

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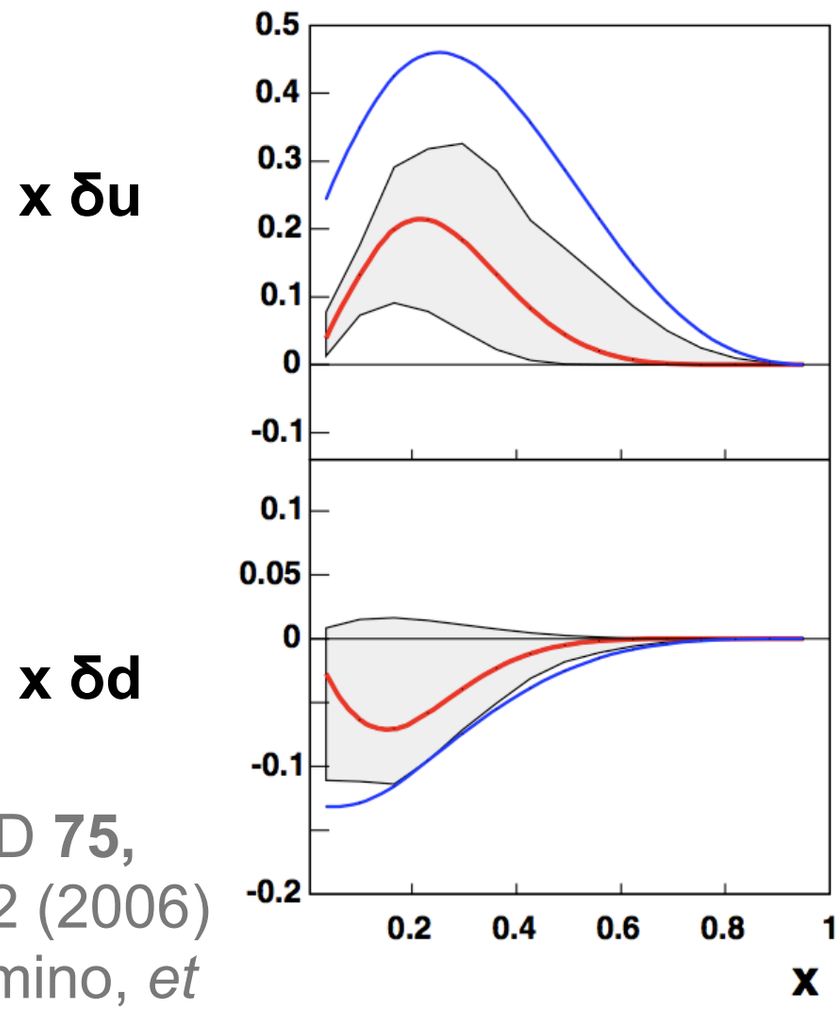

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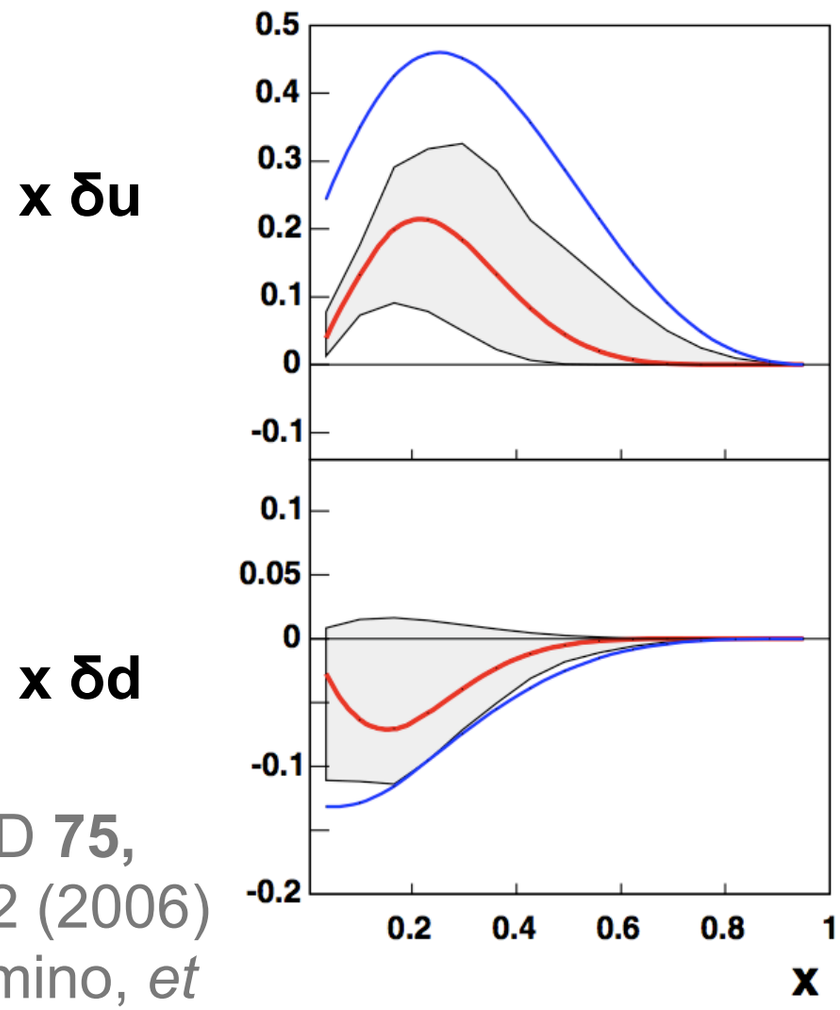

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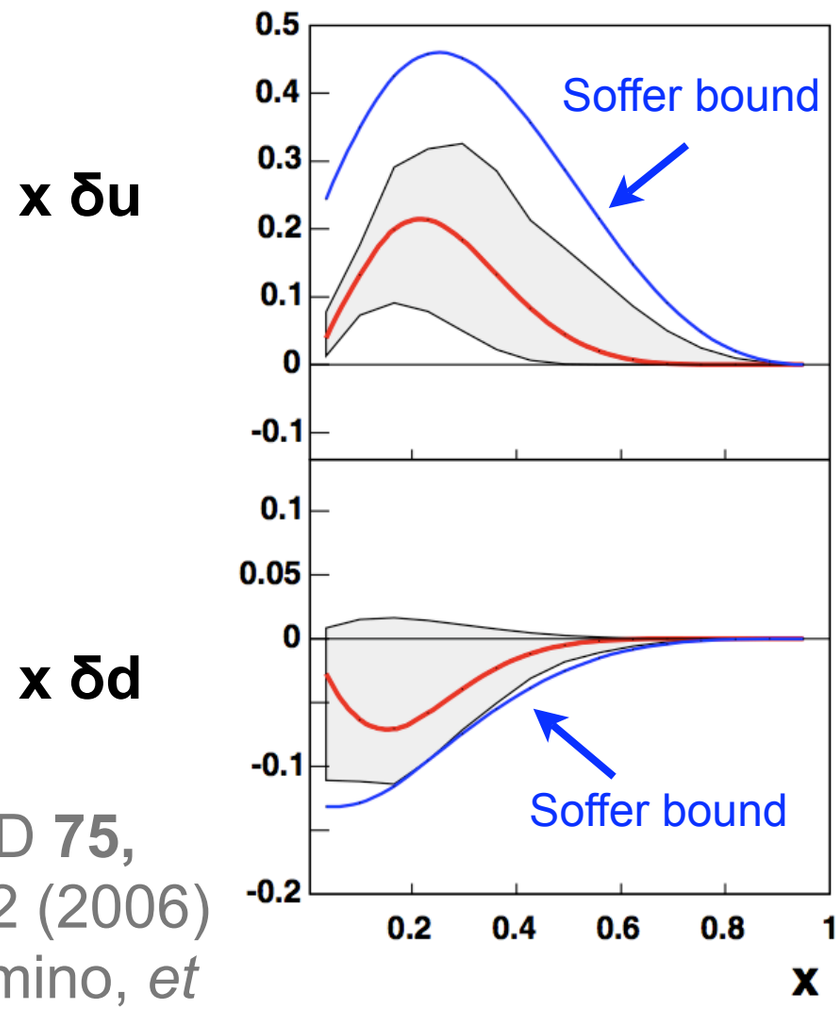

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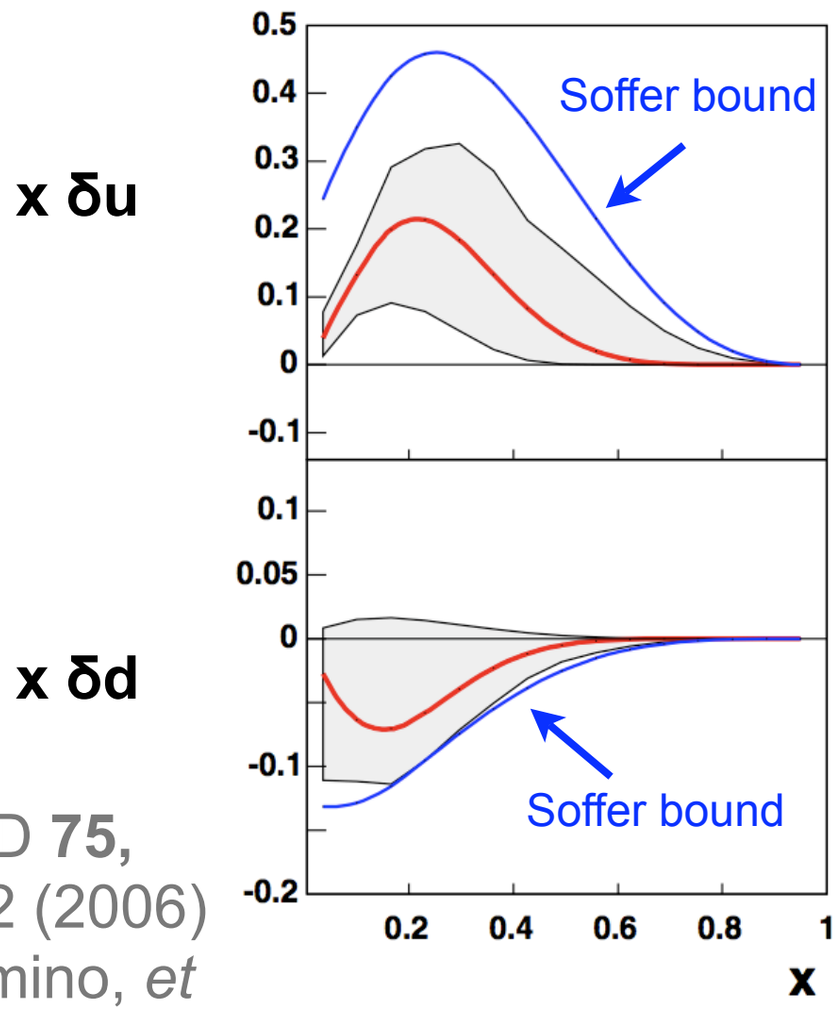

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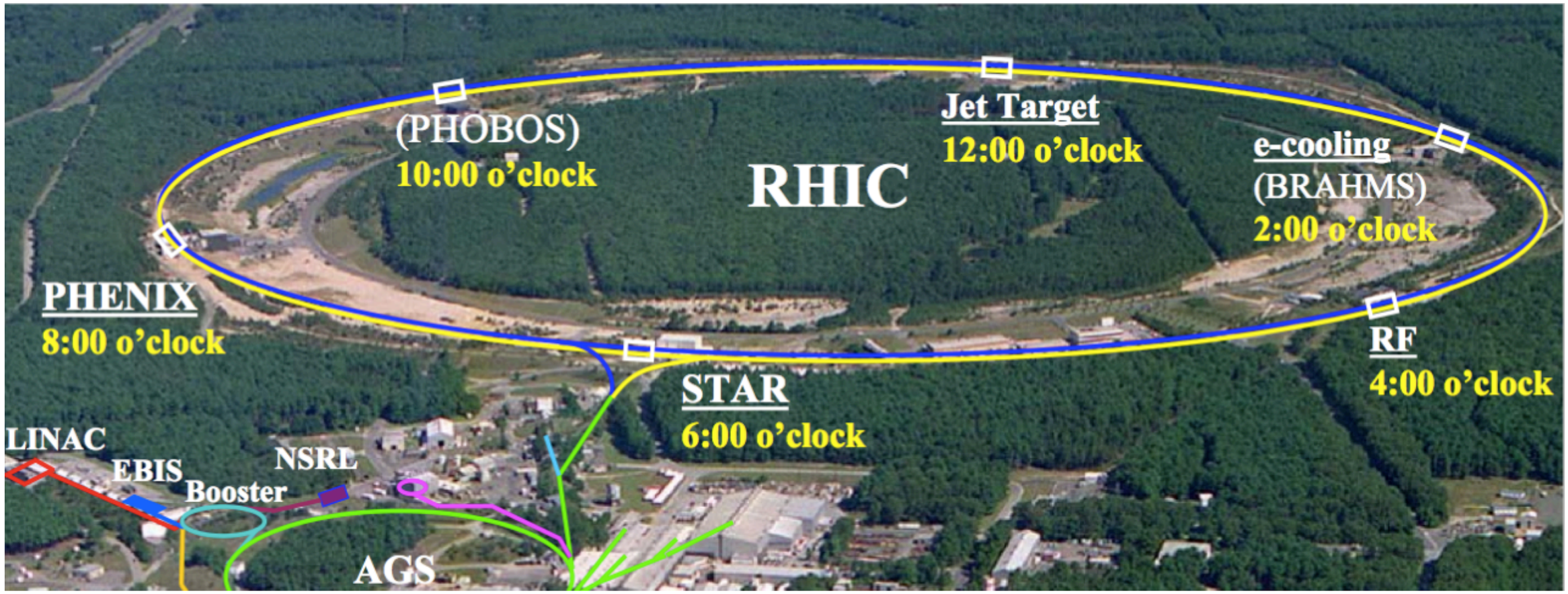
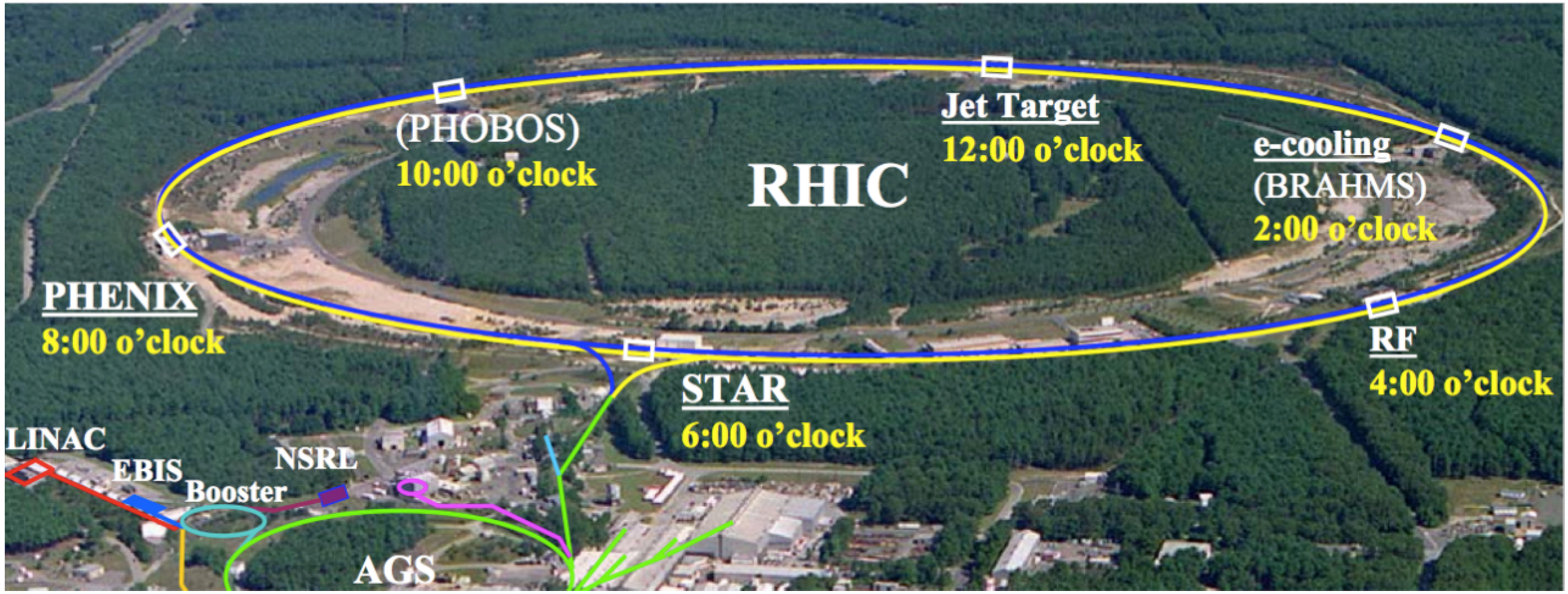
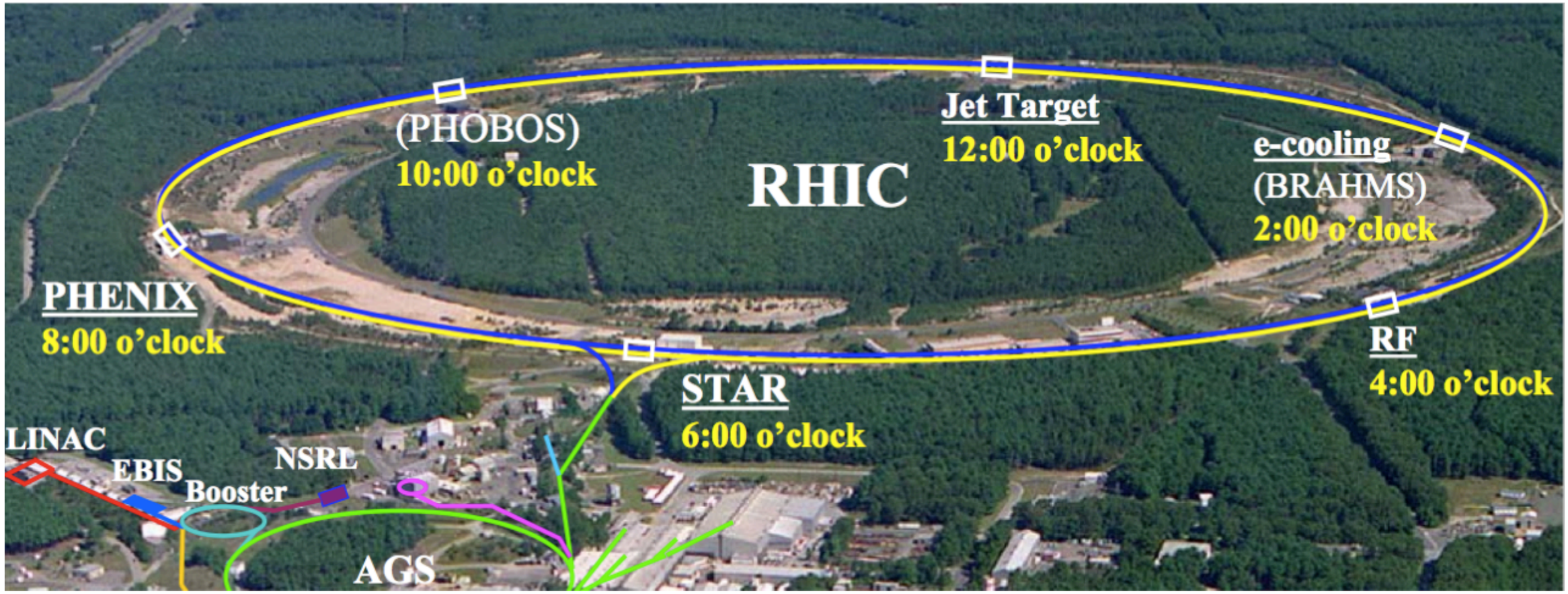

(PHOBOS)
10:00 o'clock
RHIC
Jet Target
12:00 o'clock
e-cooling
(BRAHMS)
2:00 o'clock
PHENIX
8:00 o'clock
RF
4:00 o'clock
STAR
6:00 o'clock
LINAC
EBIS
Booster
NSRL
AGS



Proton-proton collisions at $\sqrt{s}$ = 200 GeV



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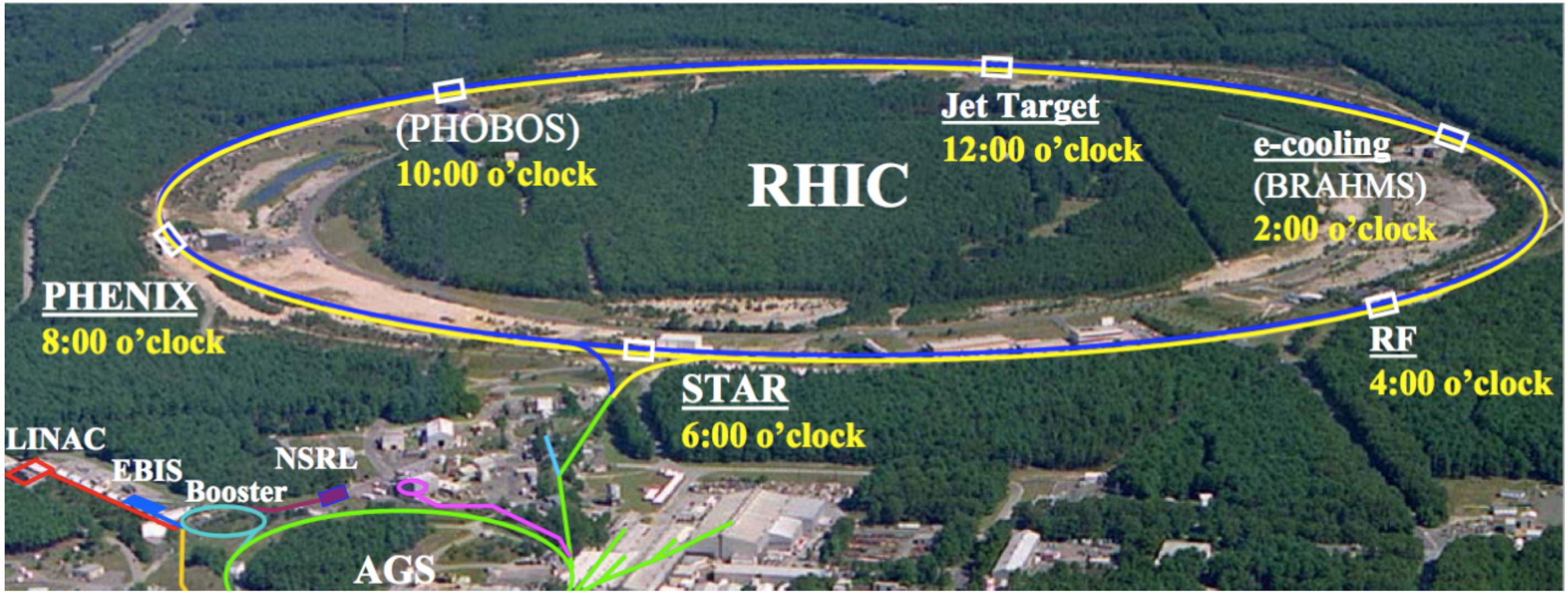
Beam polarizations as high as ~60%



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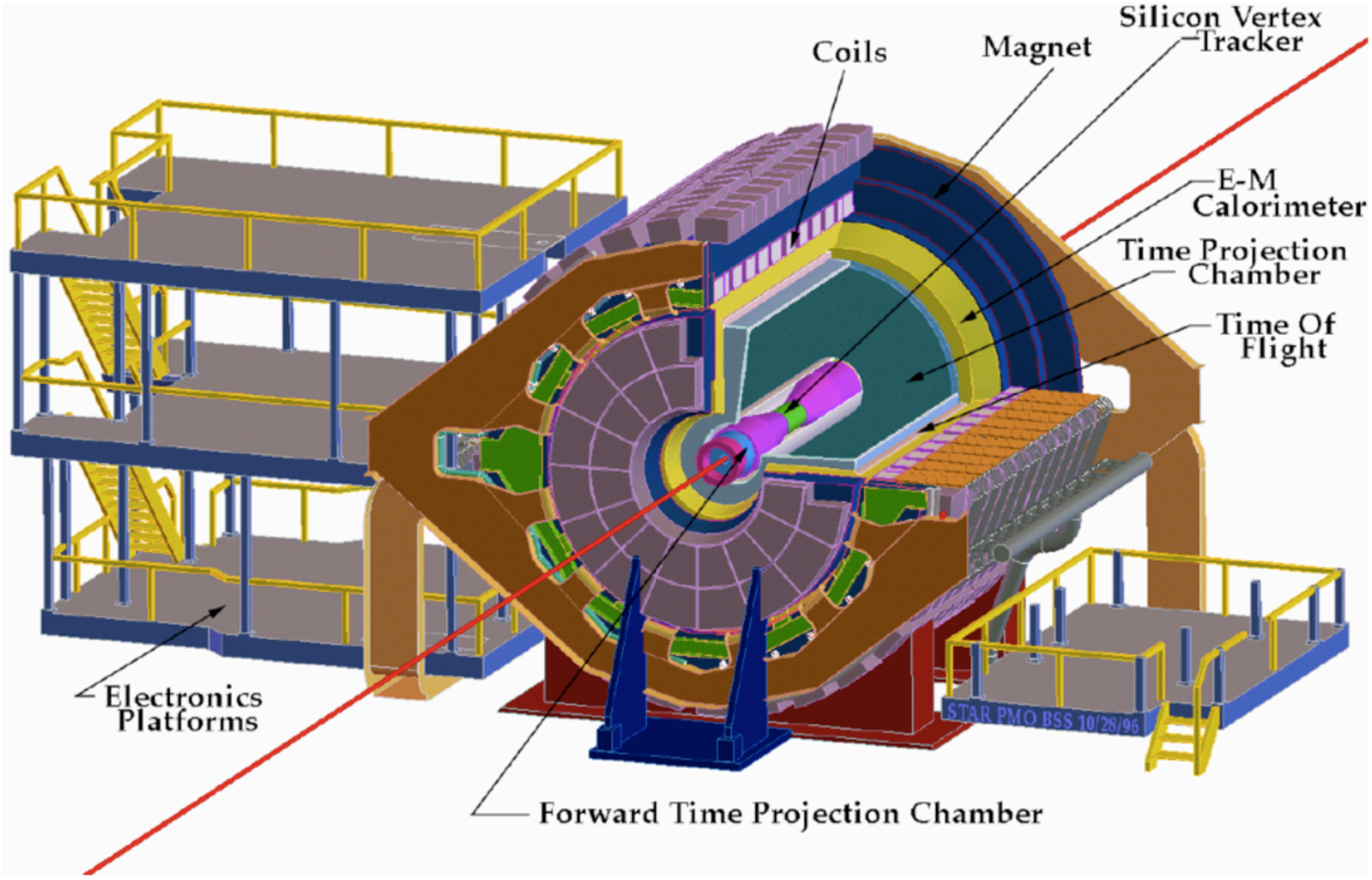

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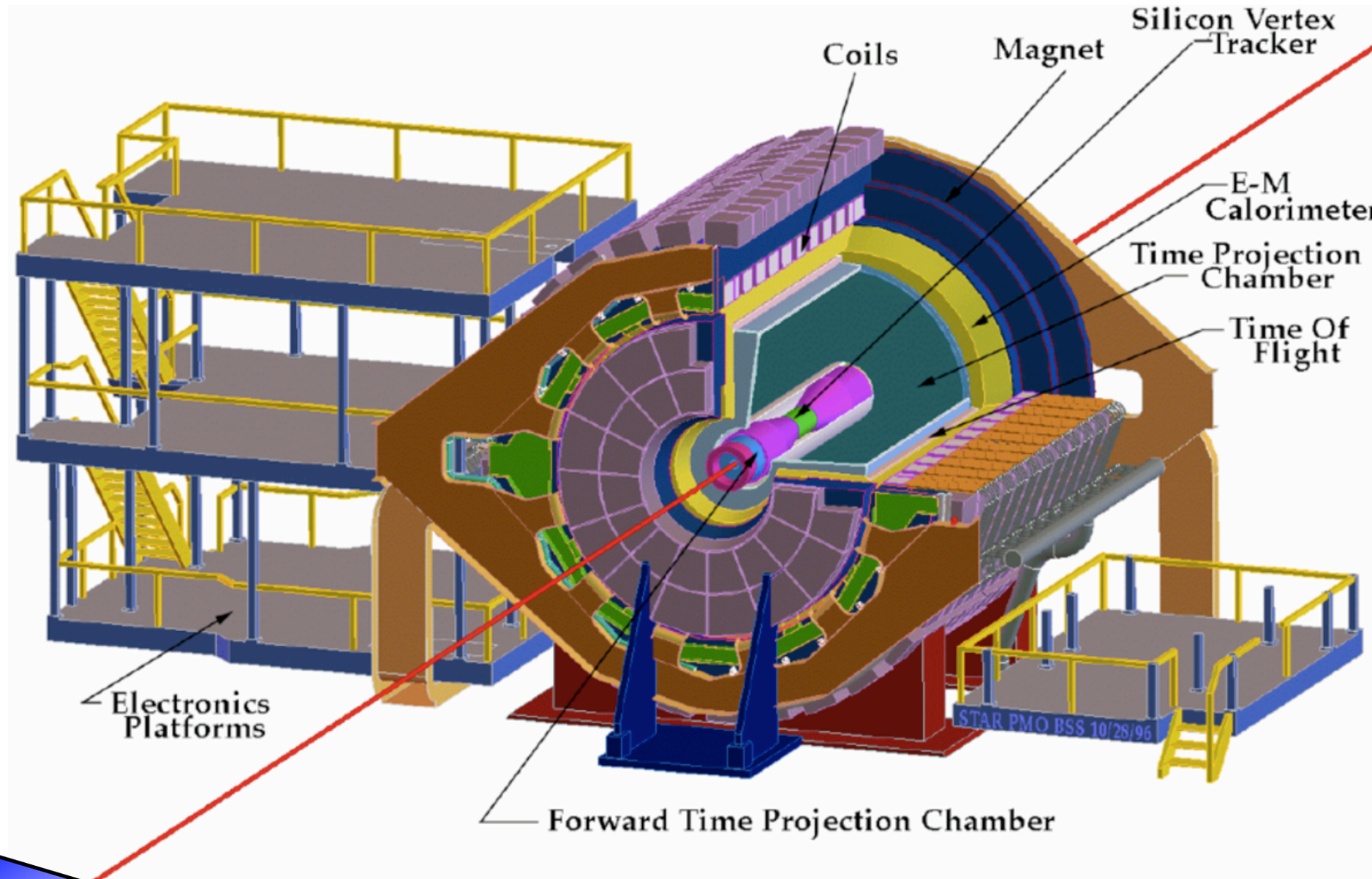

Transversely polarized (~50%) protons from RHIC

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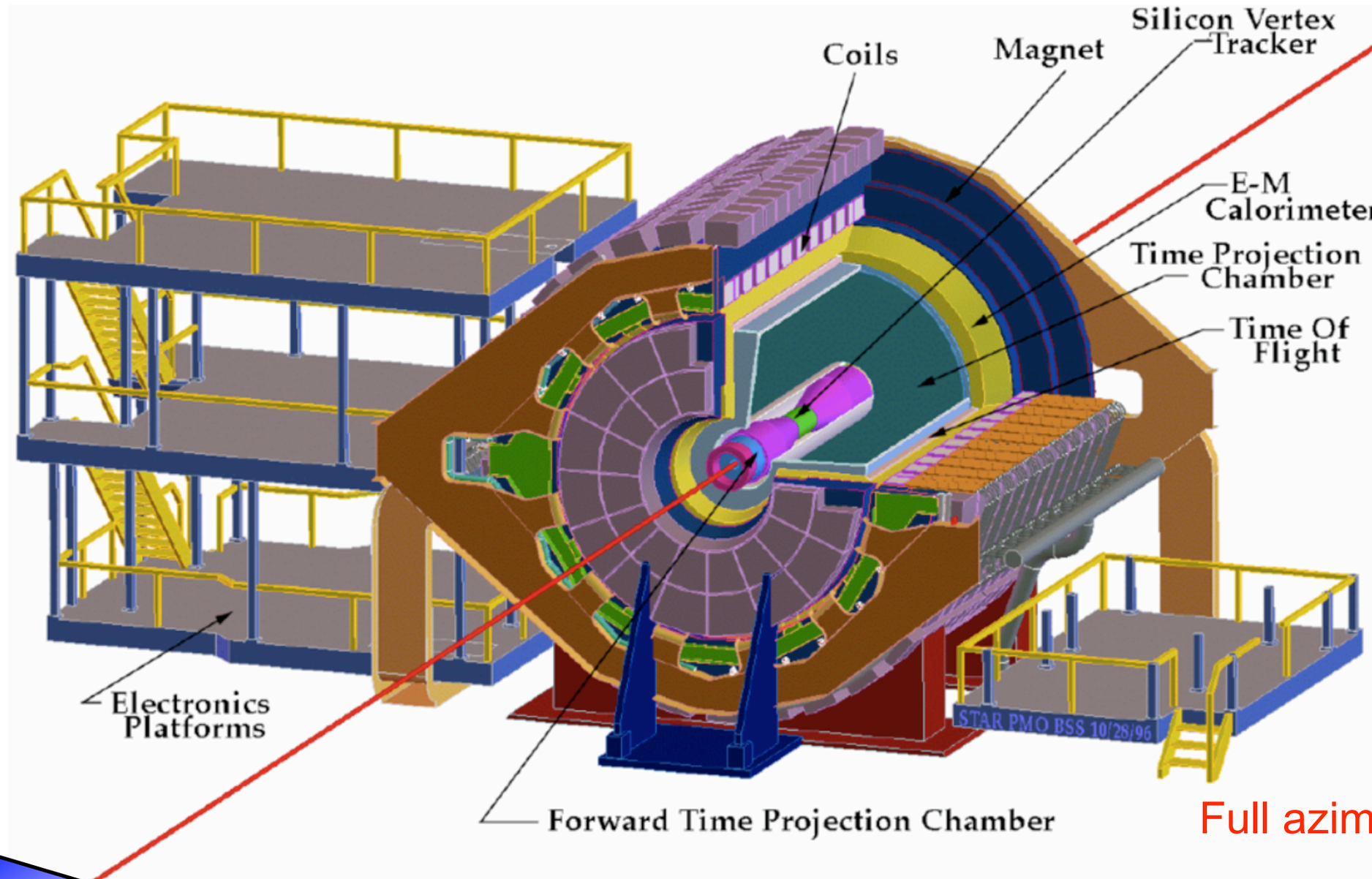

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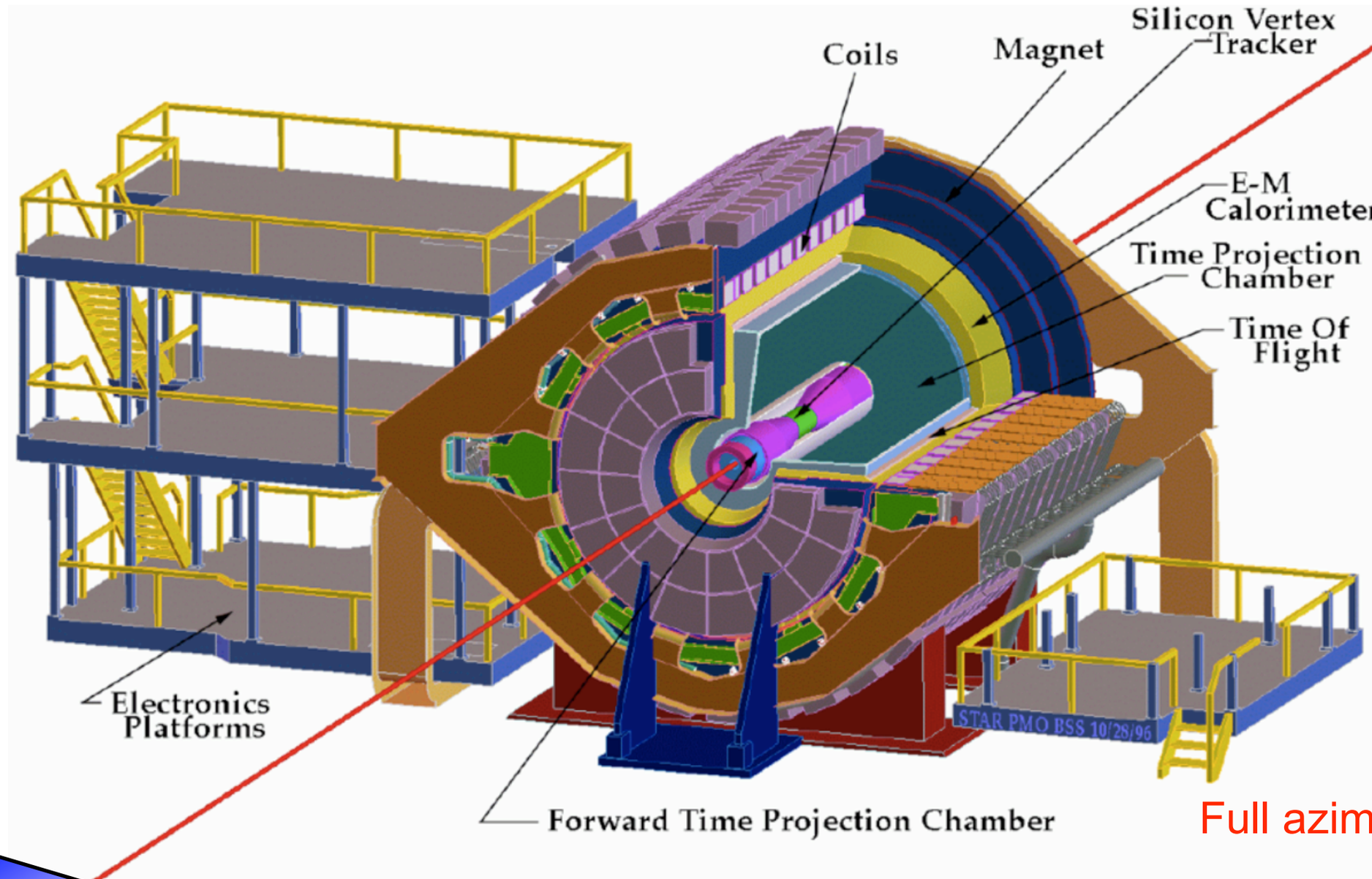

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Data analyzed at mid-rapidity ($-1 < \eta < 1$)

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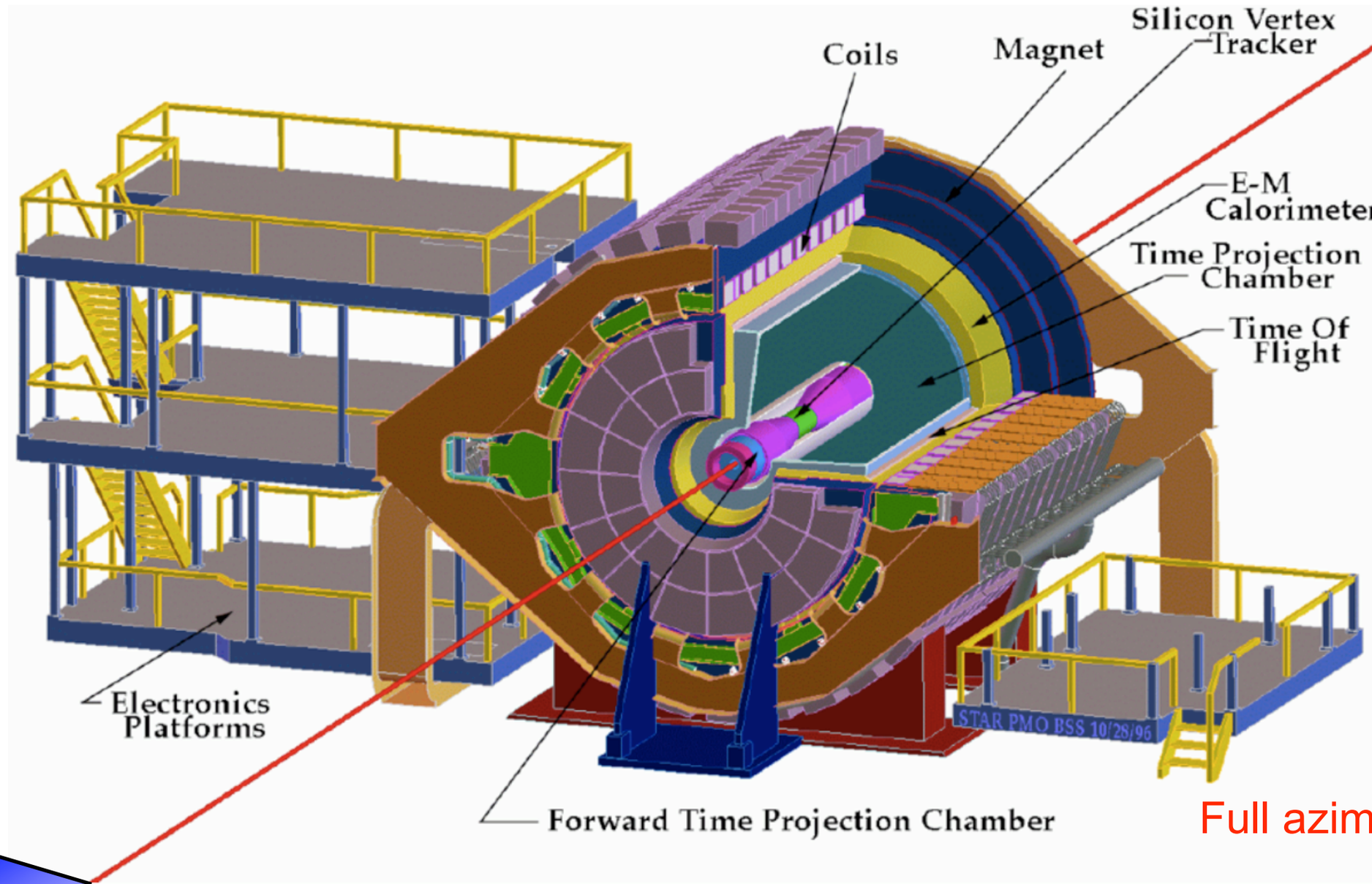

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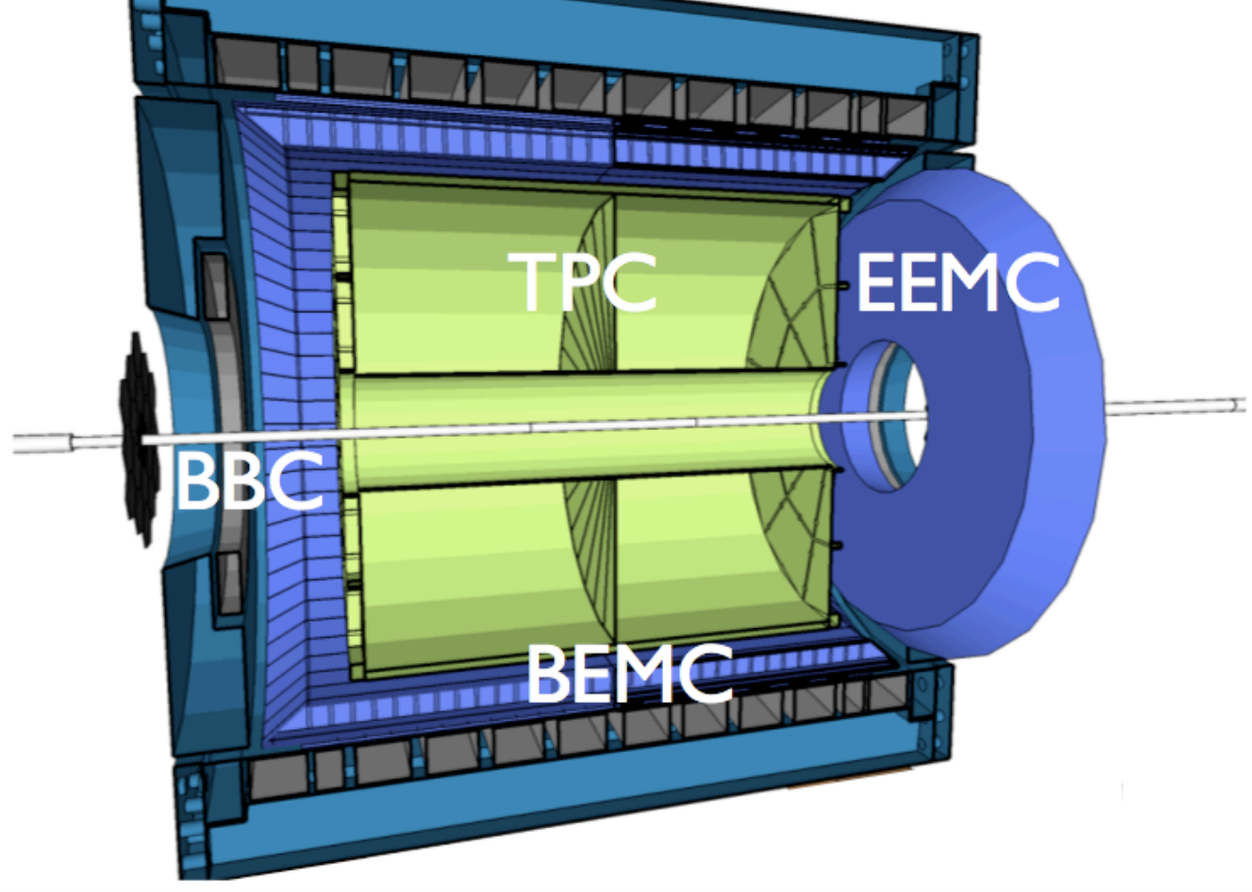
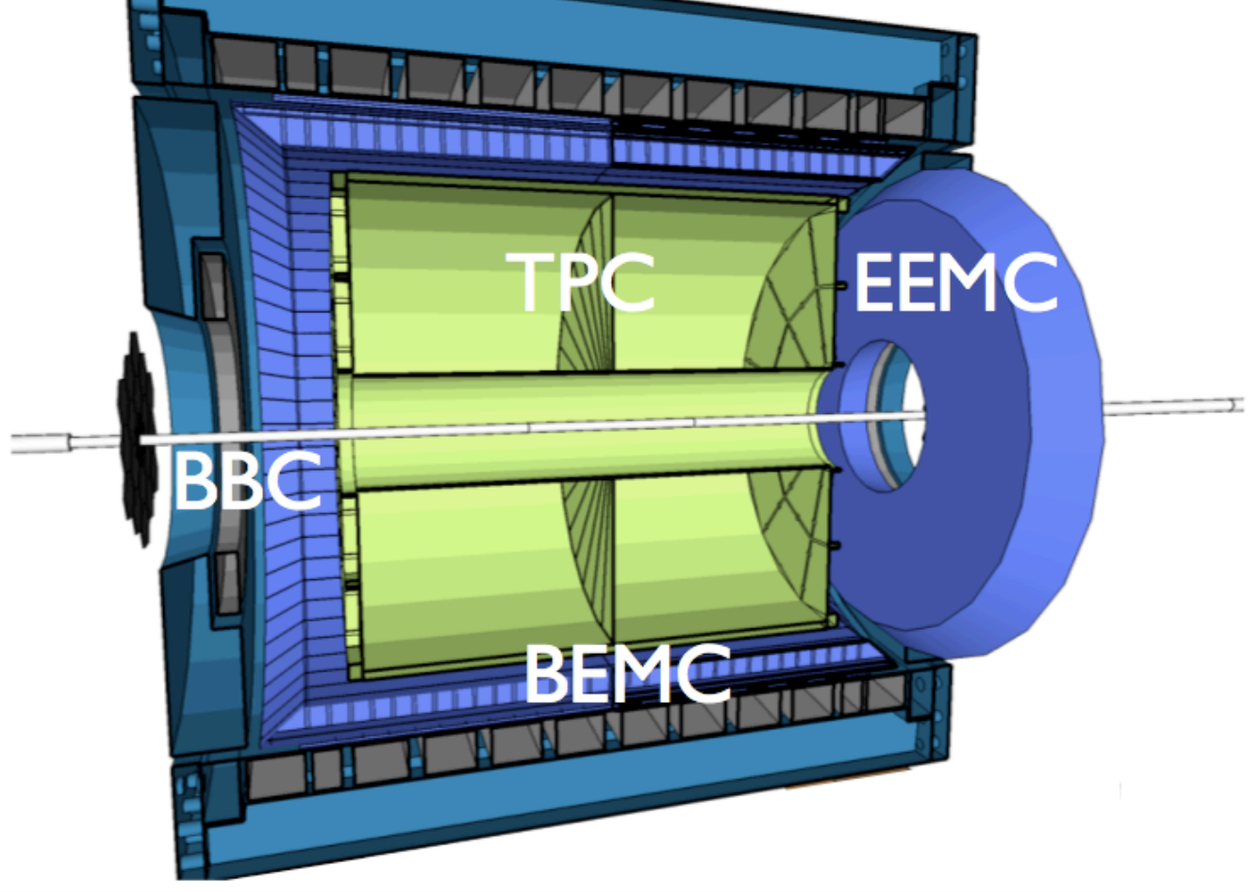
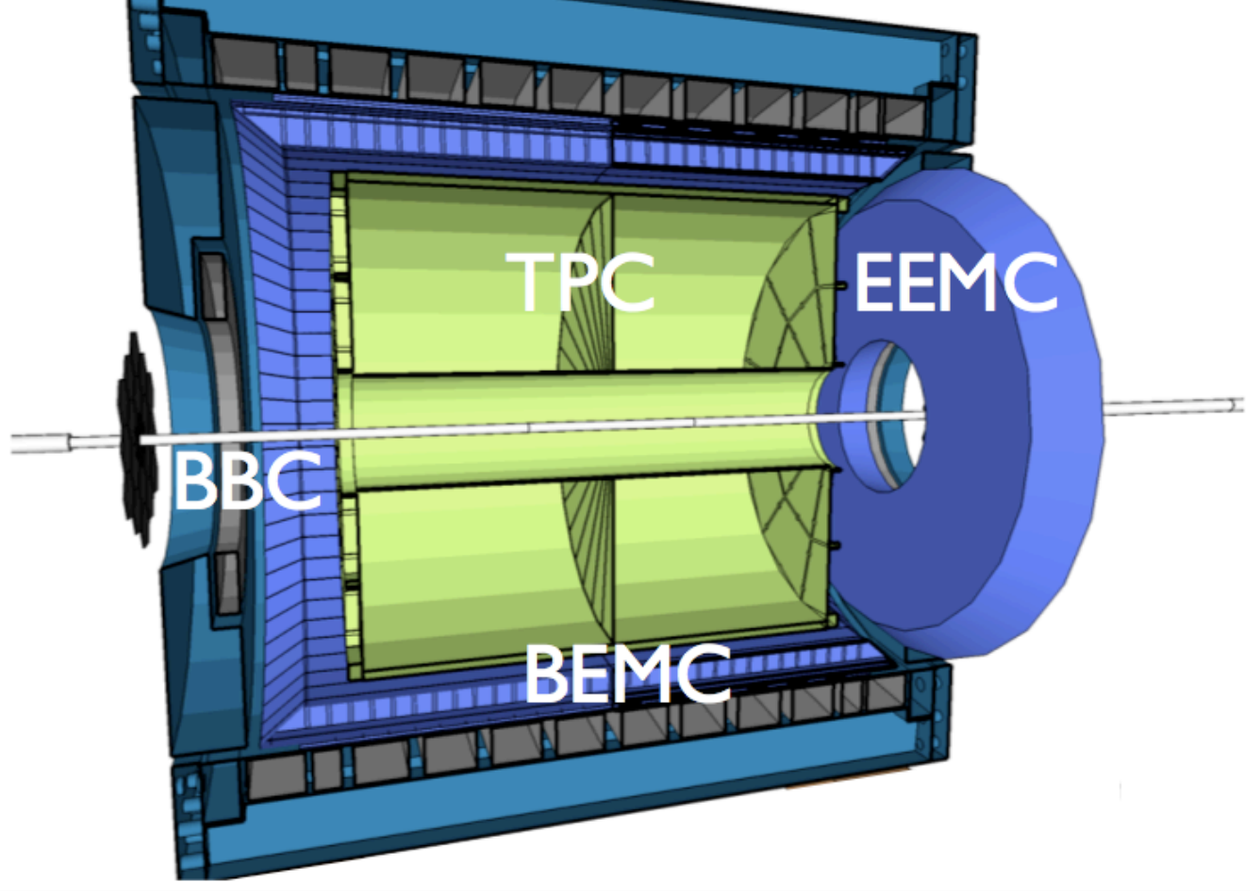
Reconstruction of jets and component charged particle trajectories reconstructed


TPC
EEMC
BBC
BEMC



BBC: relative polarization luminosities; minimum bias trigger; determines local polarimetry



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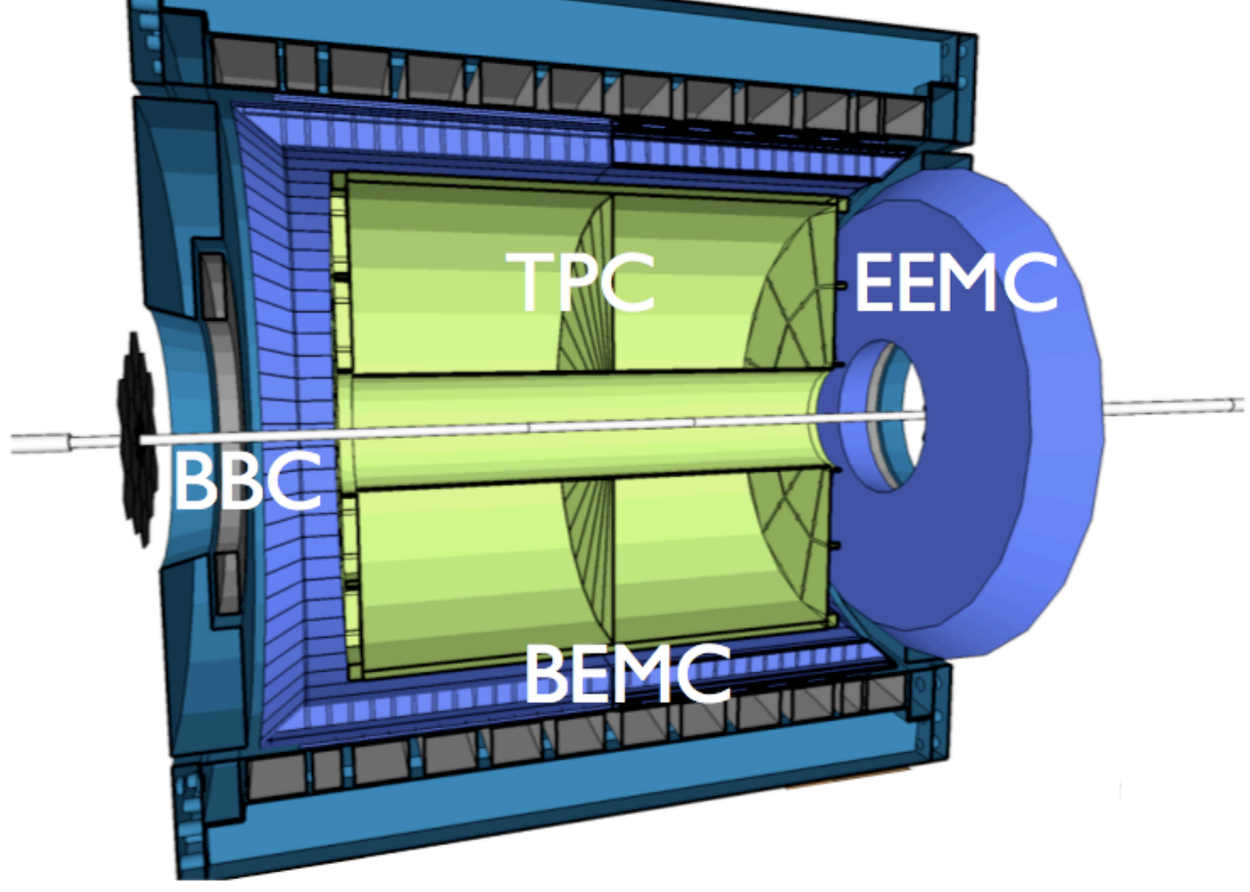
TPC: charged particle tracking; dE/dx PID (p<15 GeV)



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BEMC, EEMC: barrel/endcap calorimeters for triggering, jet reconstruction

Jet Reconstruction

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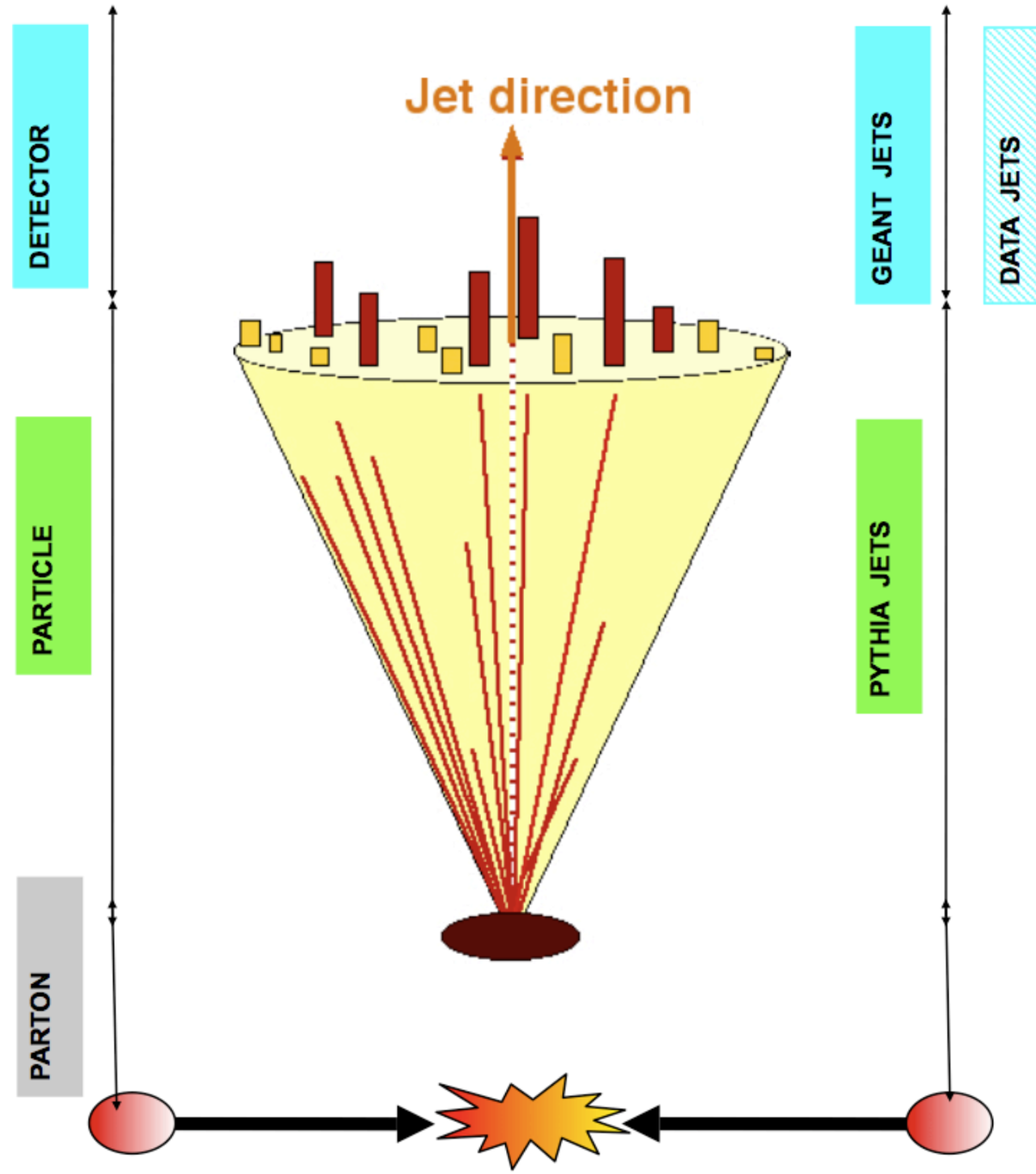

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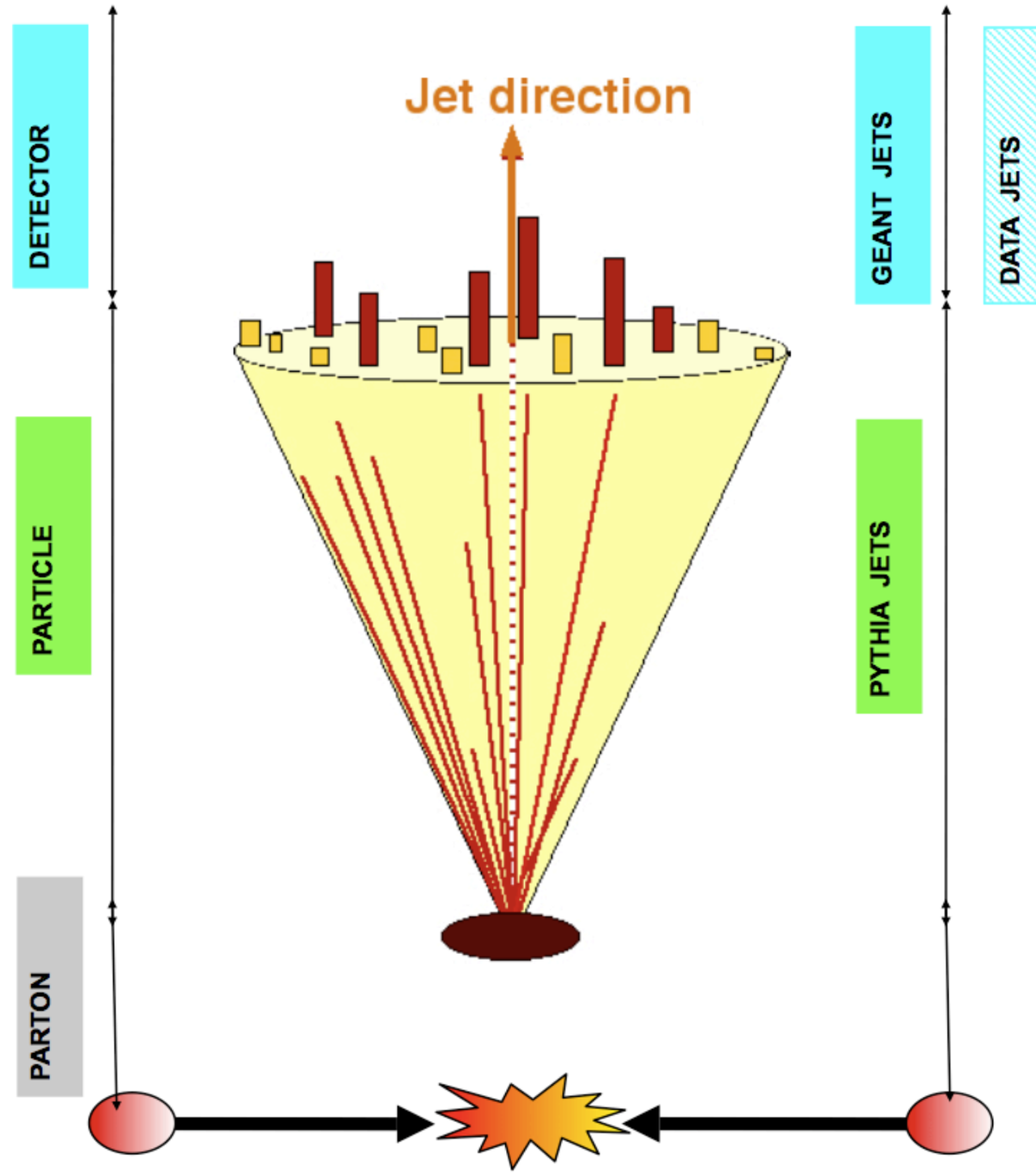
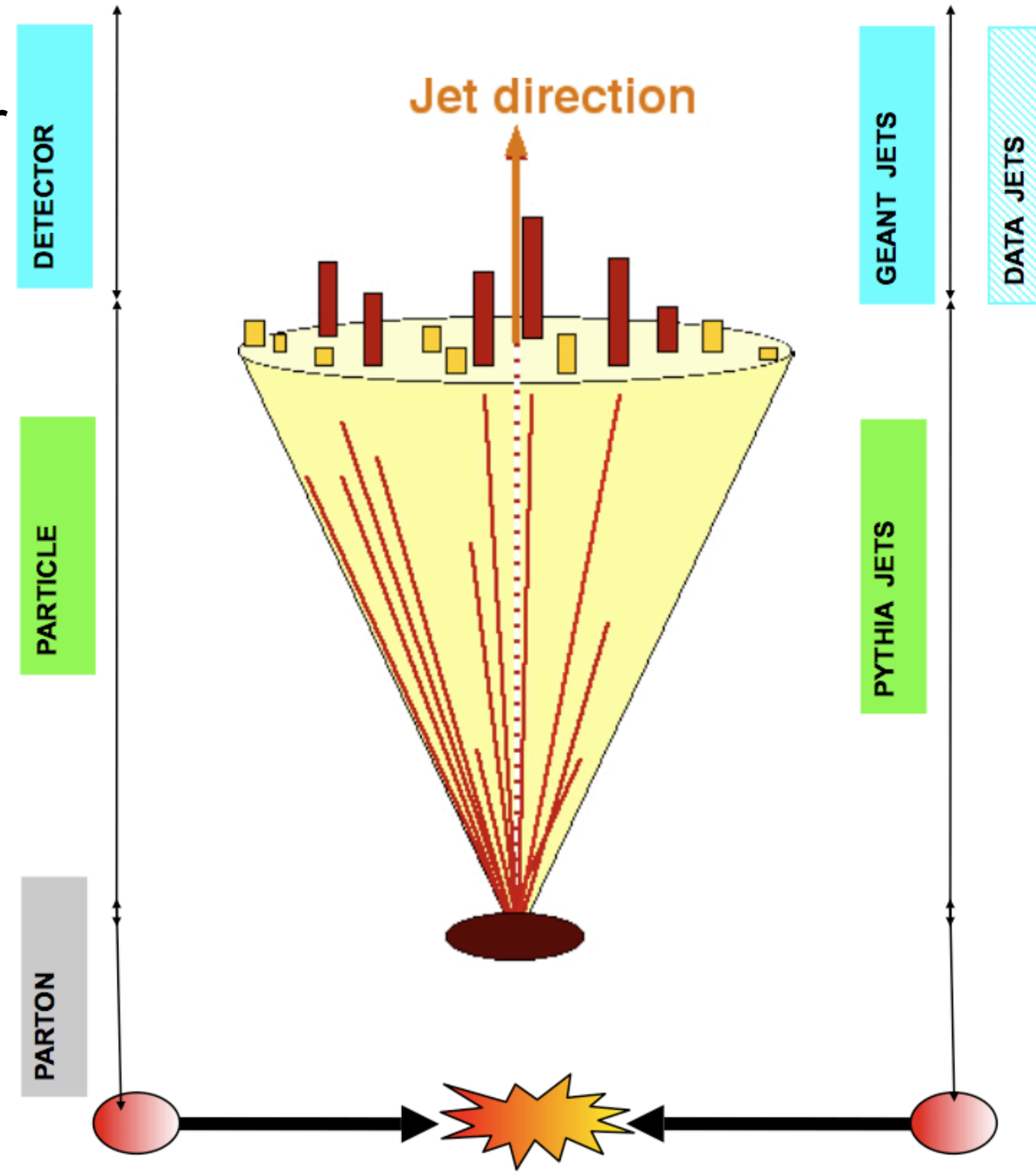


Midpoint Cone Algorithm

(hep-ex/0005012)

Jet Reconstruction

1) TPC track or EMC tower used as “seed”
2) hits inside fixed radius determine cluster energy
3) neighboring clusters calculated & merged if energy overlap > 50%



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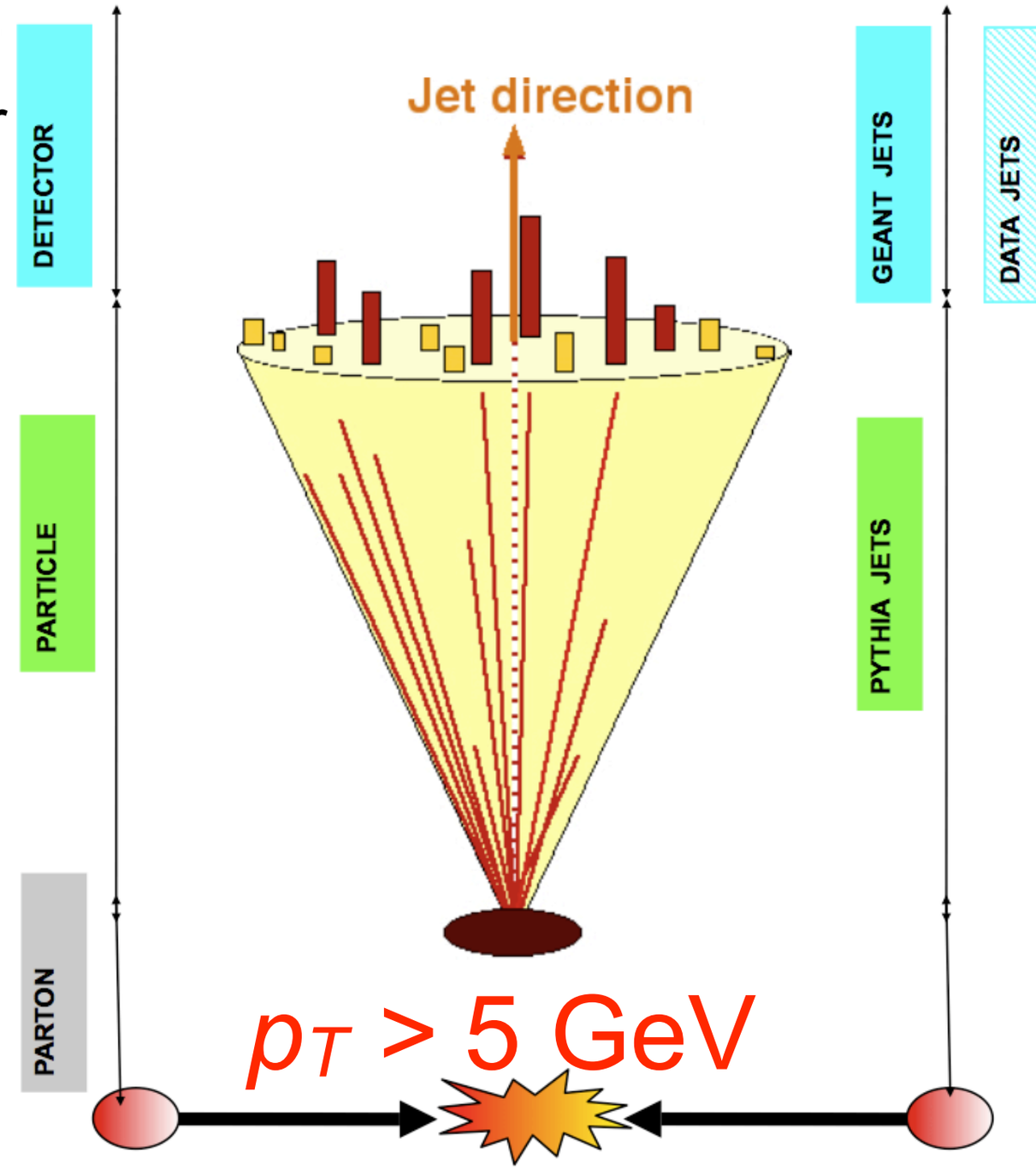

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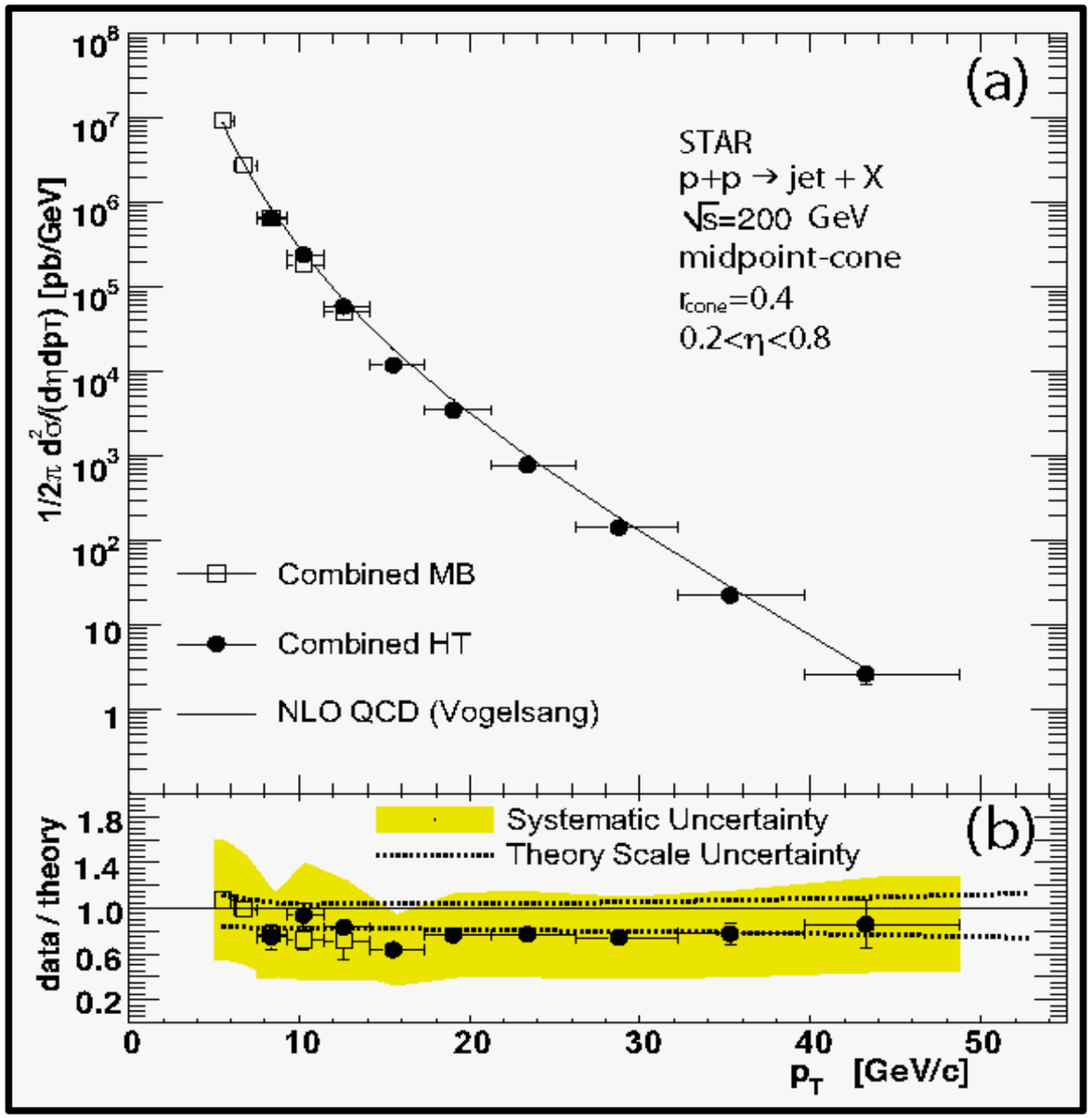
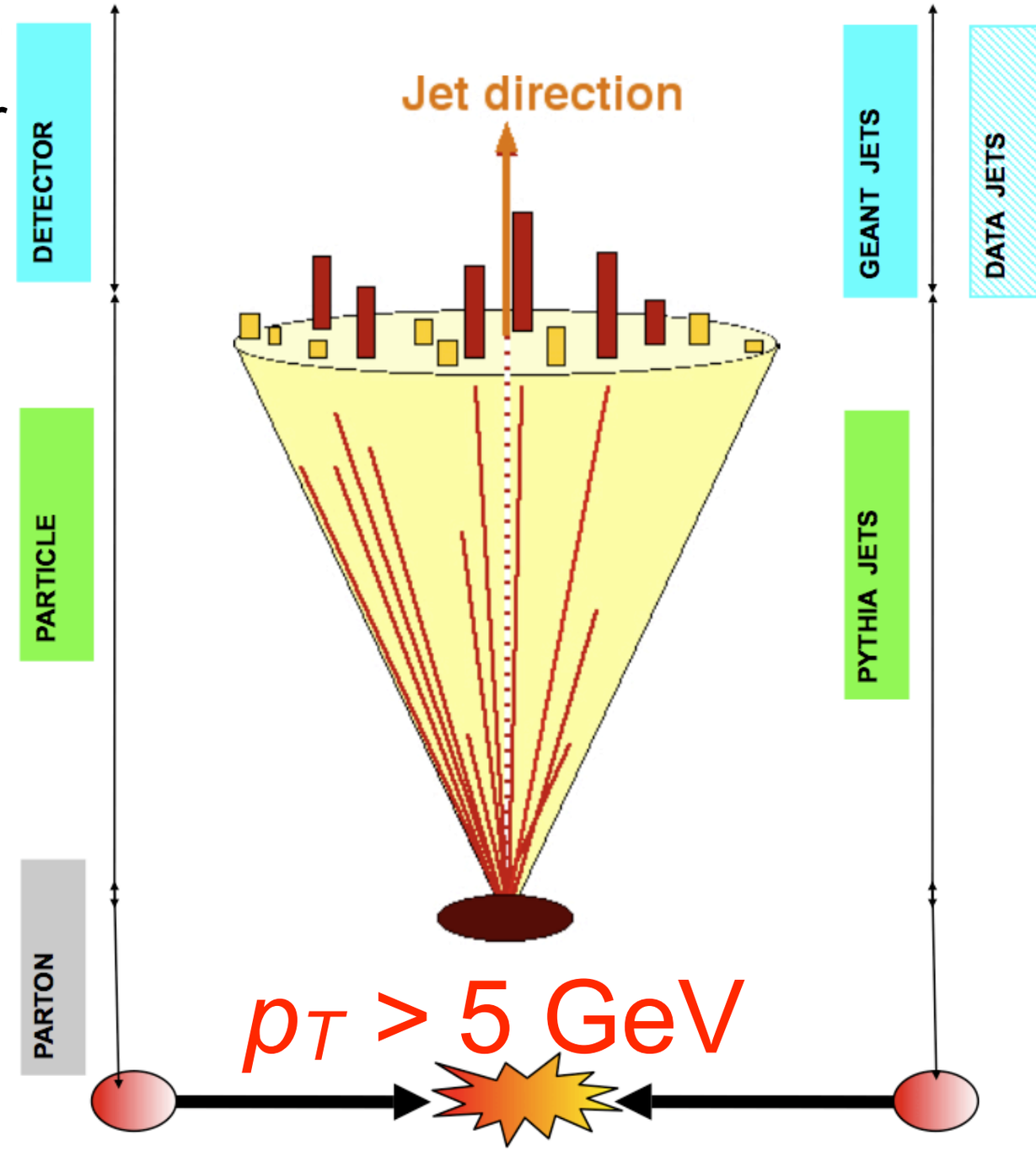




Midpoint Cone Algorithm

(hep-ex/0005012)

Goals of this Presentation:

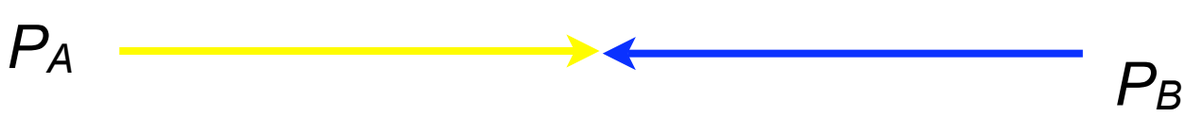
- Relate δq to the experimentally measurable Collins asymmetry

Experimental access to δq

Experimental access to δq

proton-proton scattering:

$$p(P_A, S_\perp) + p(P_B) \rightarrow jet(P_J) + X \rightarrow \pi^{\pm} \quad + X$$



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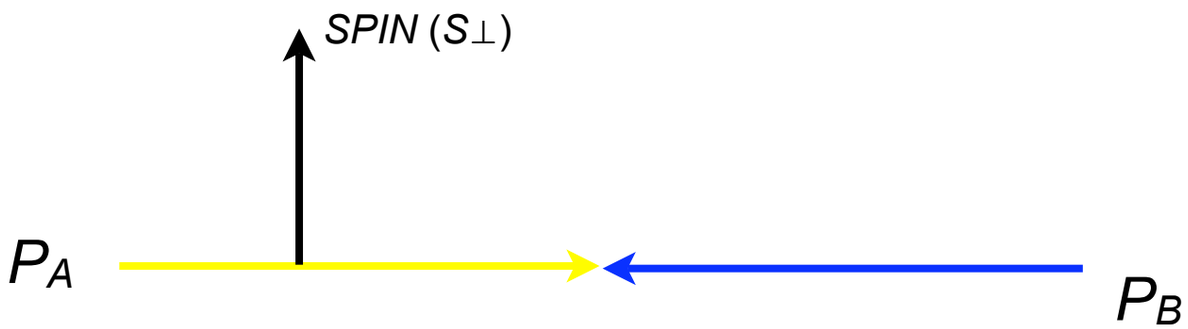

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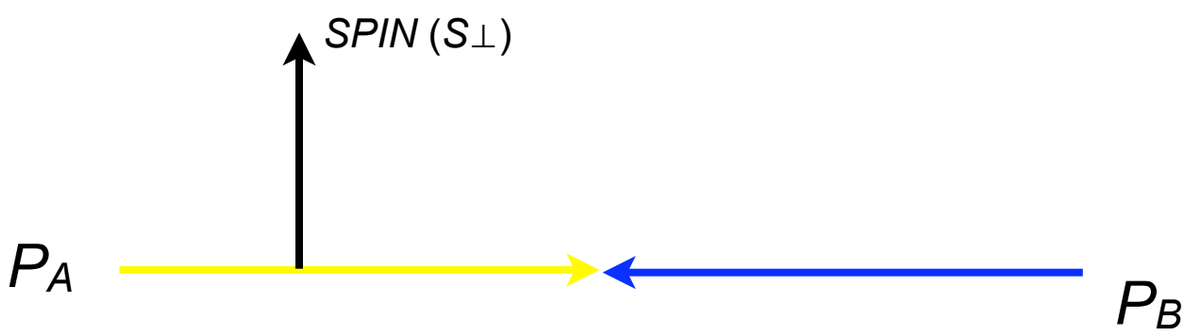

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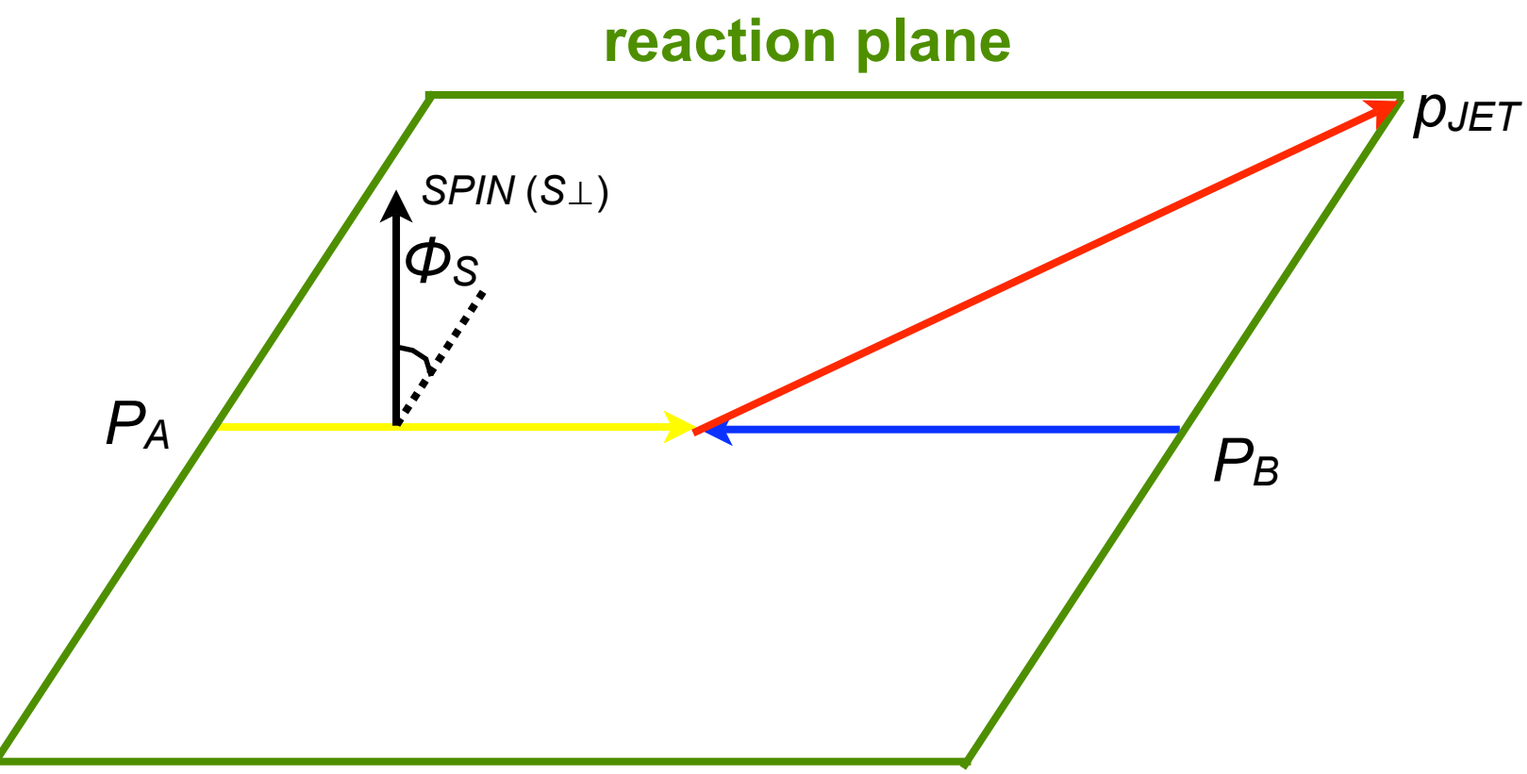

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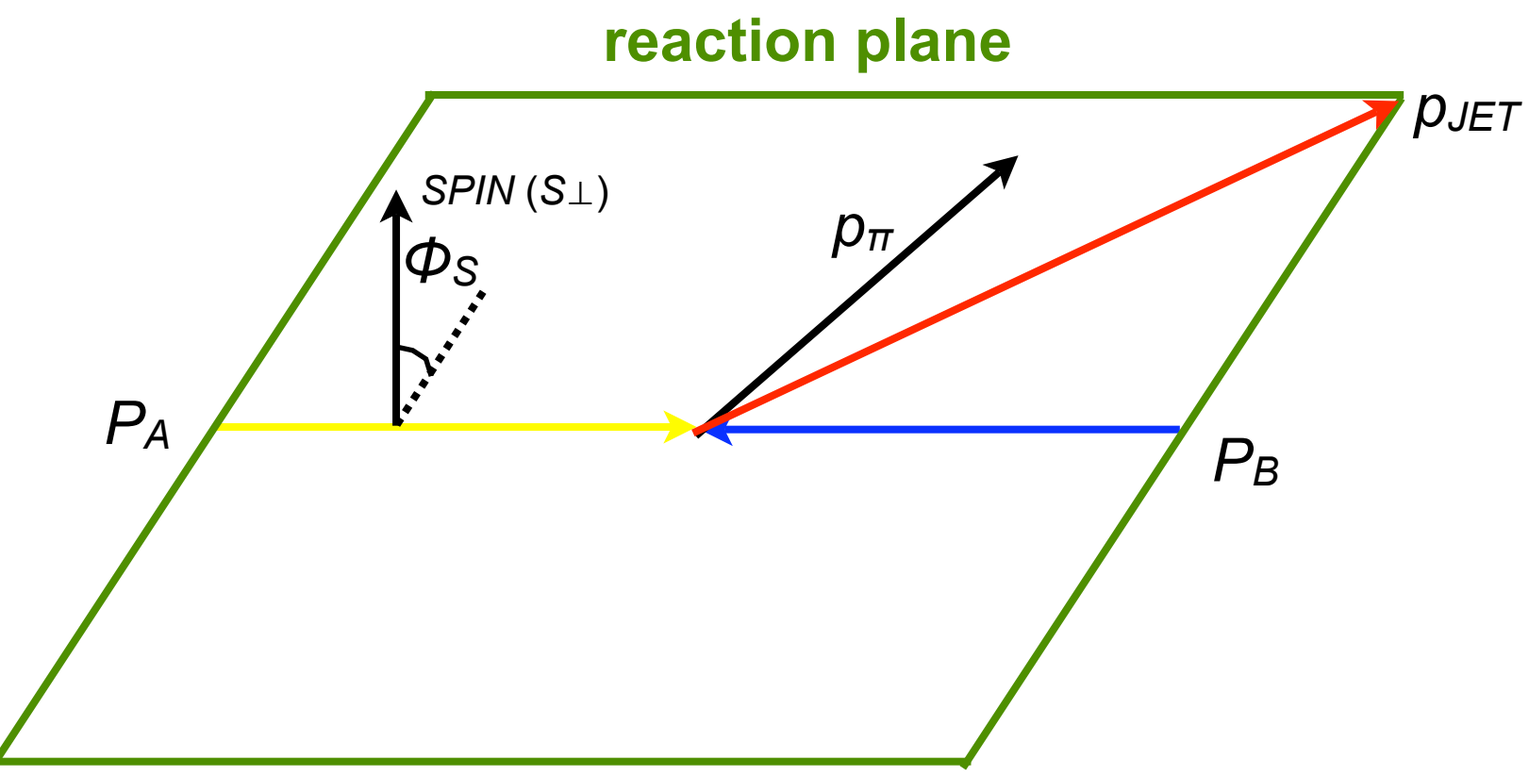
Leading pions give us the most direct access to the quark initiating the event.



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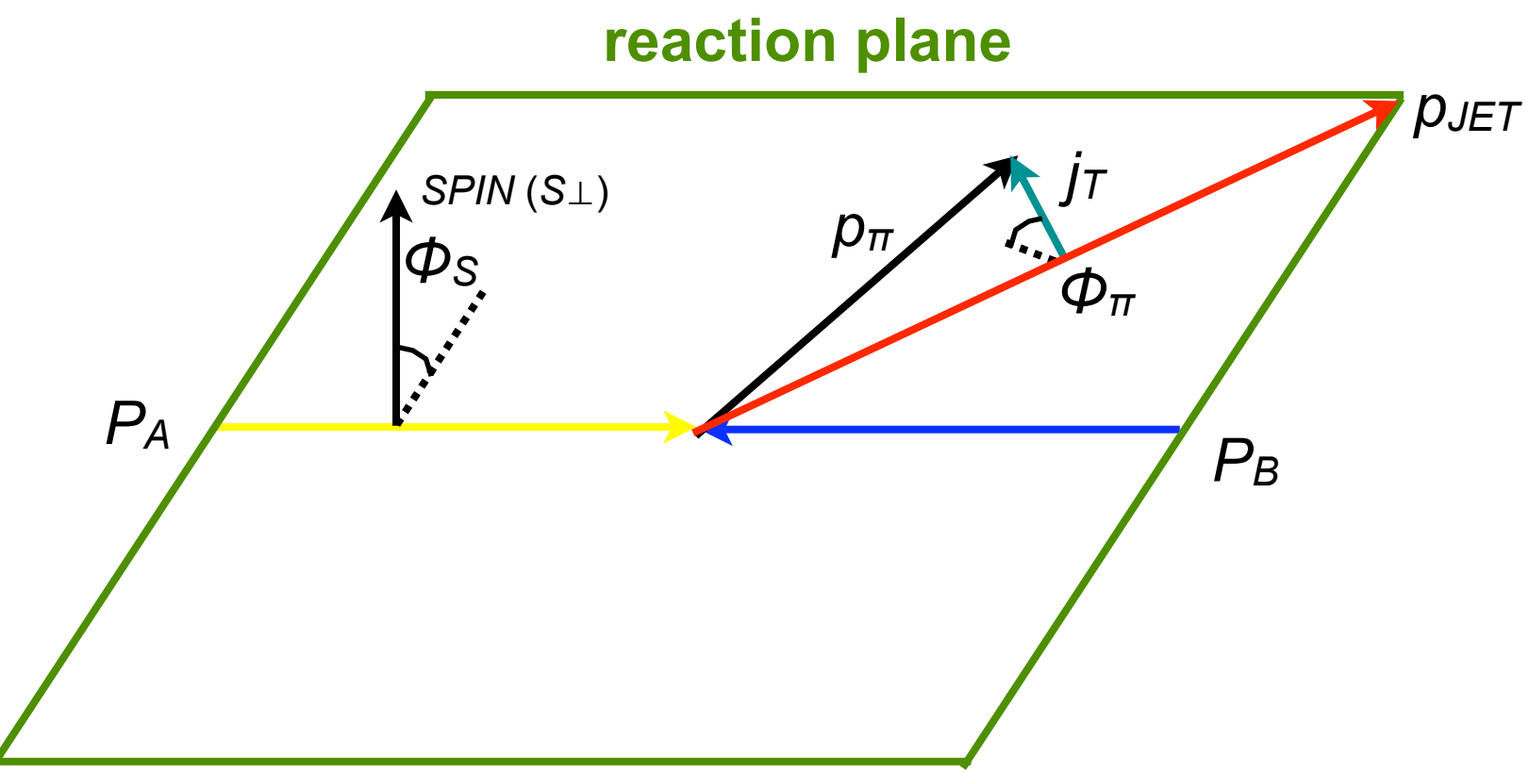

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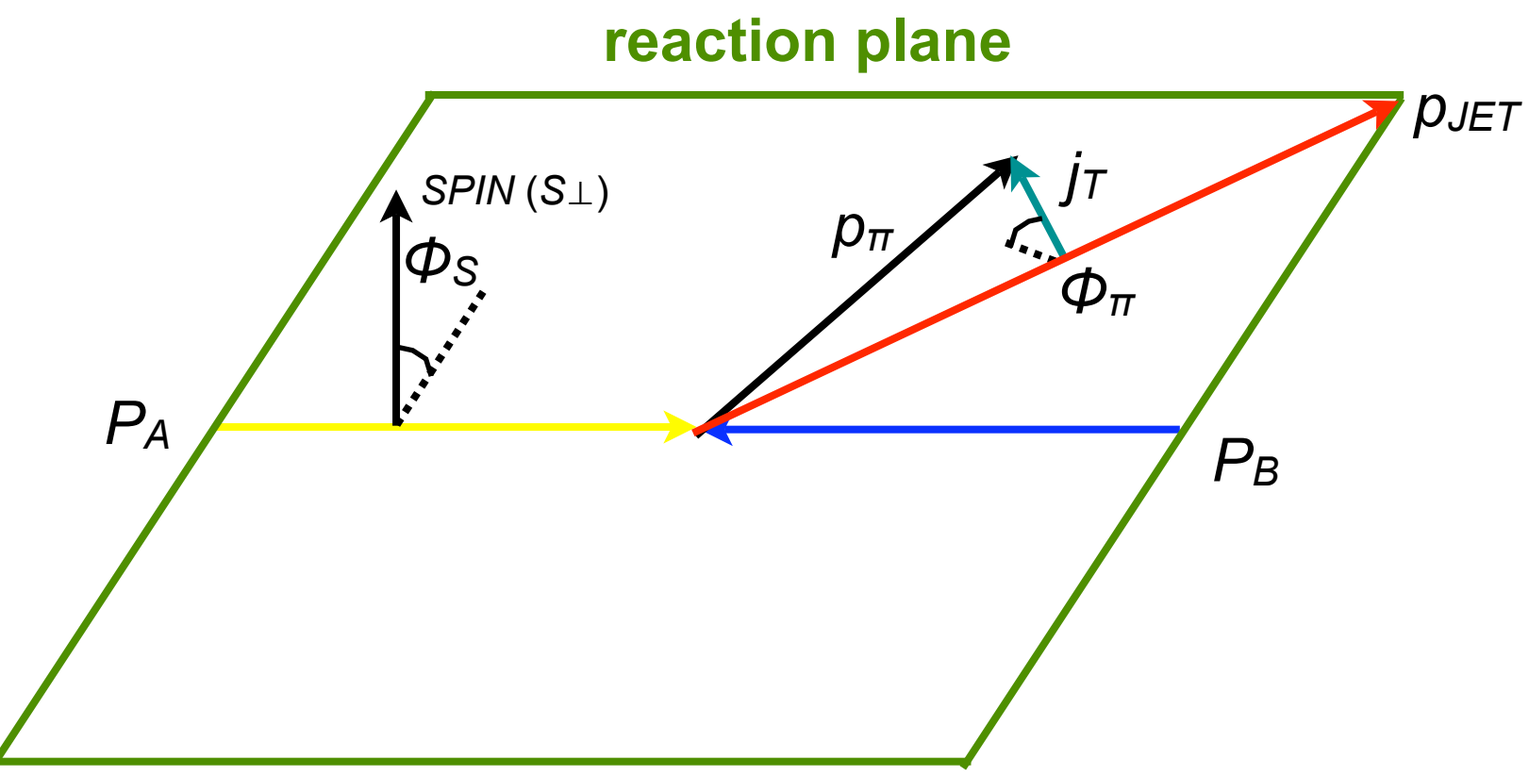

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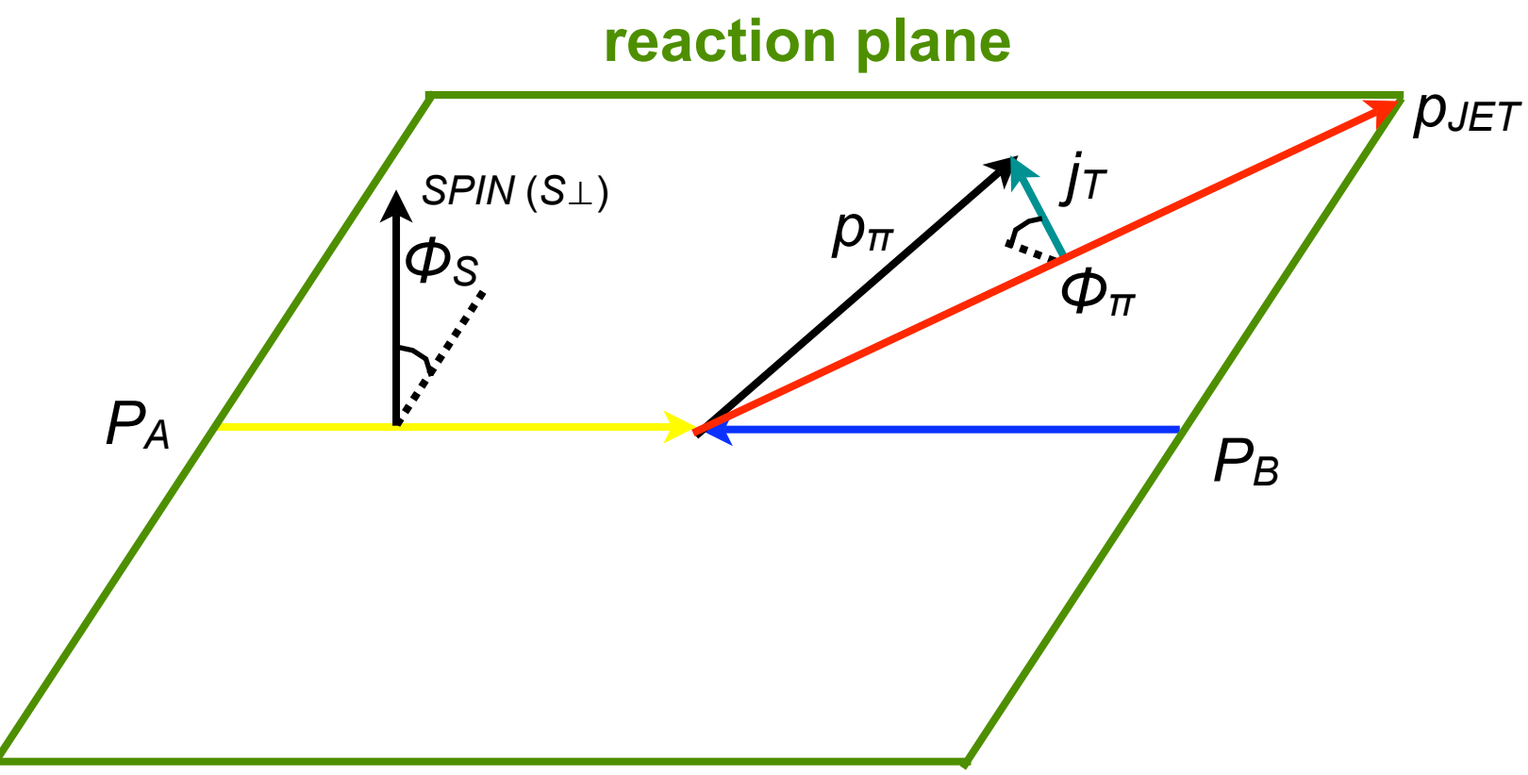

Collins Mechanism:

polarized quark → jet ⇒

spin-dependence in fragmentation of the polarized quark ⇒

Φ_π-dependence of pion production rate, relative to $S_\perp^\pm$

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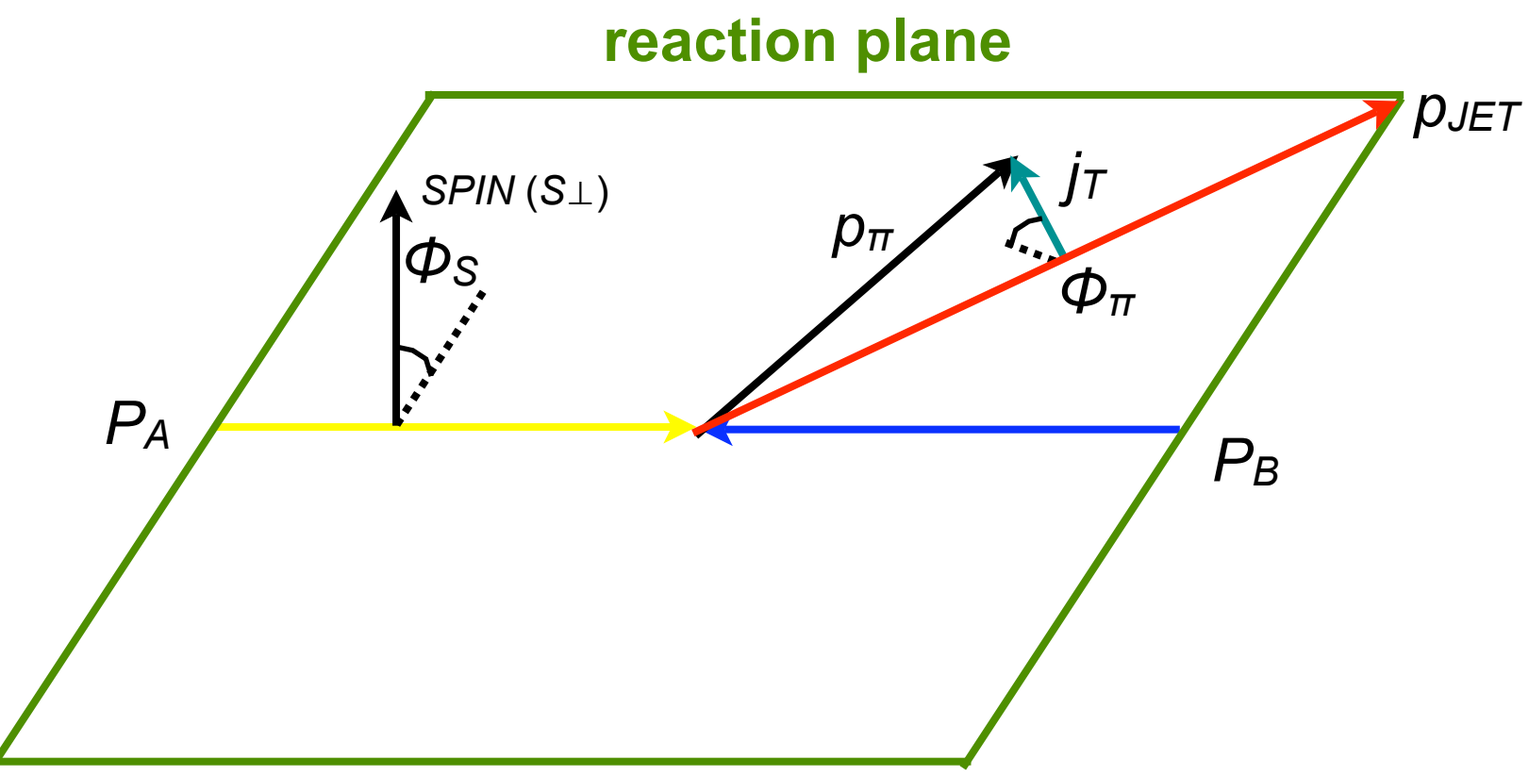

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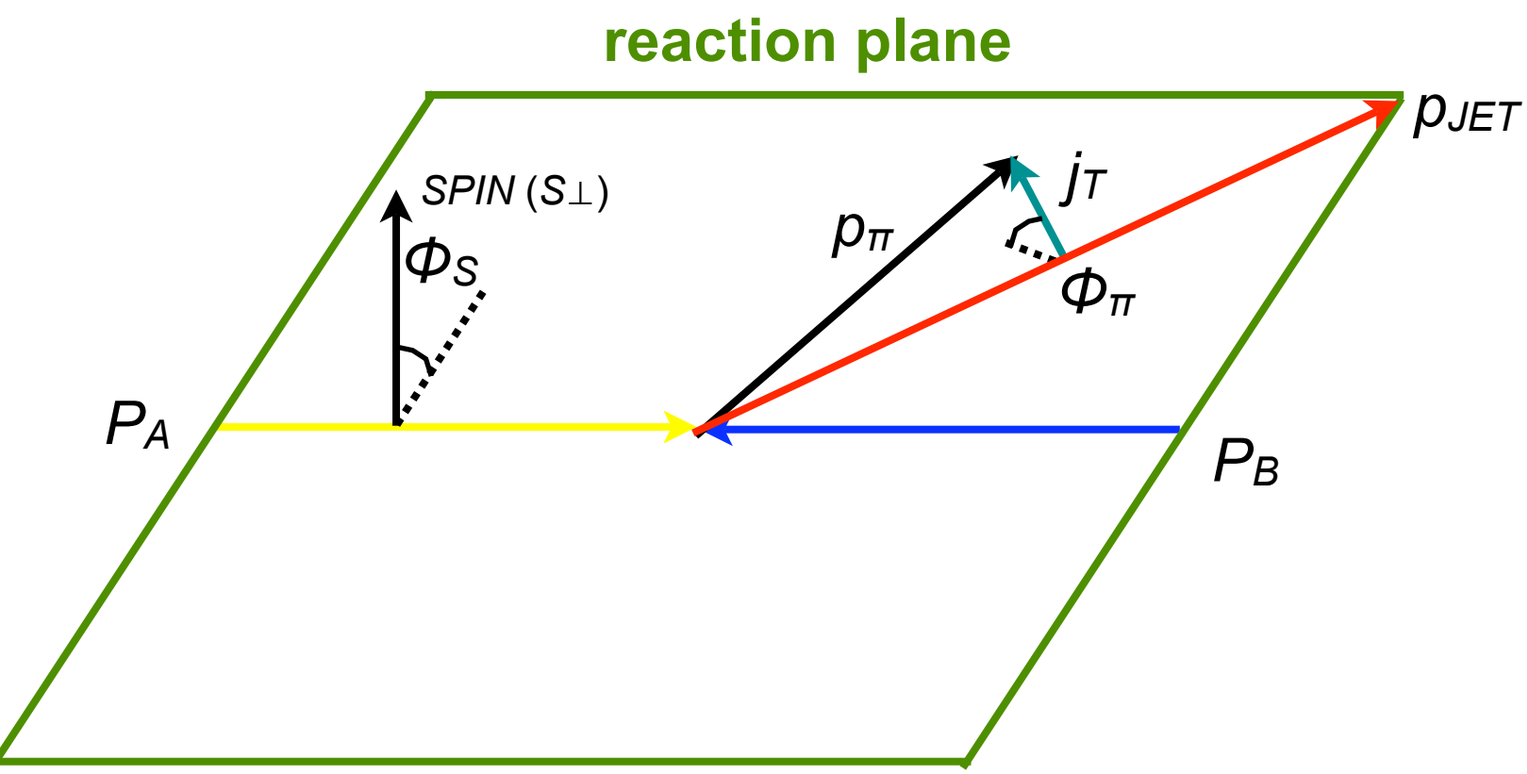

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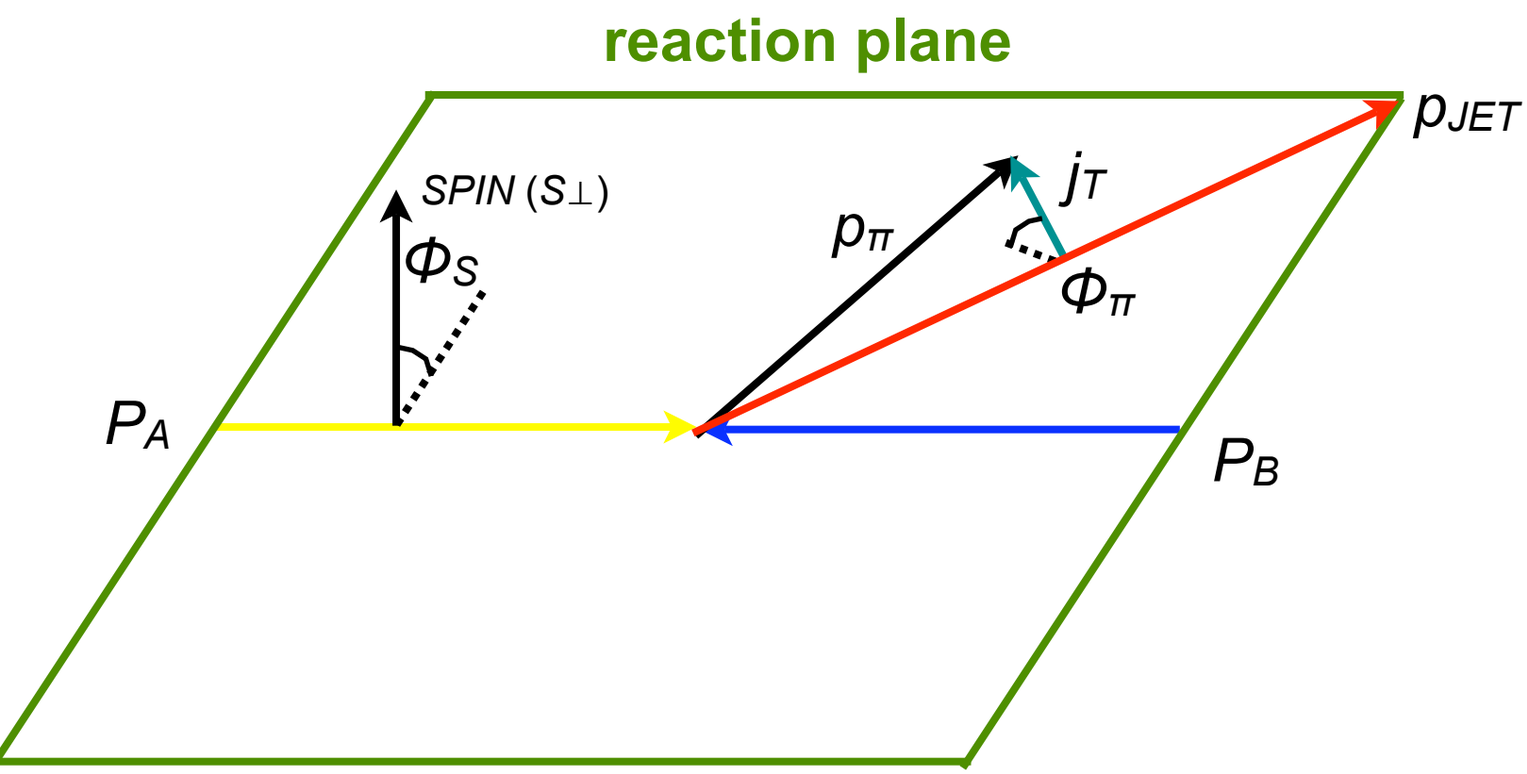

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total number of jets

How is Δu, Δd constrained by this asymmetry?

Measured asymmetry

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Spin transfer coefficient

unpolarized quark distribution

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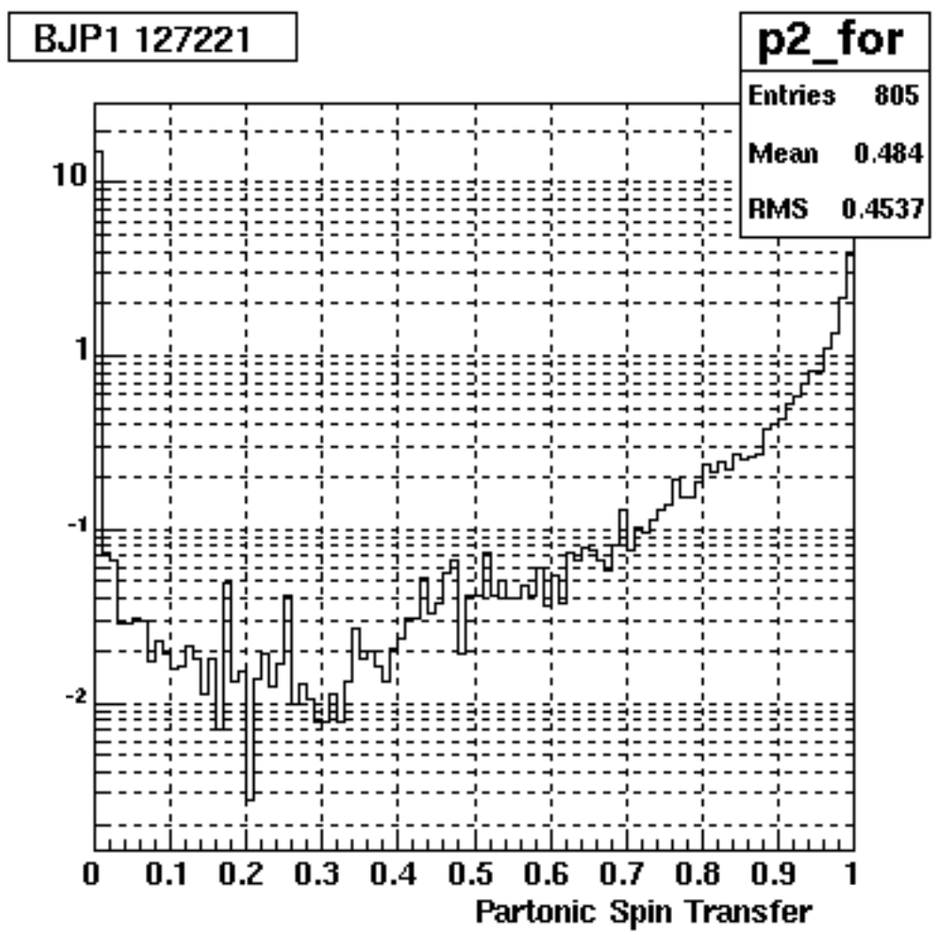

(GEANT + PYTHIA) simulation

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Collins, Sivers *fragmentation functions*

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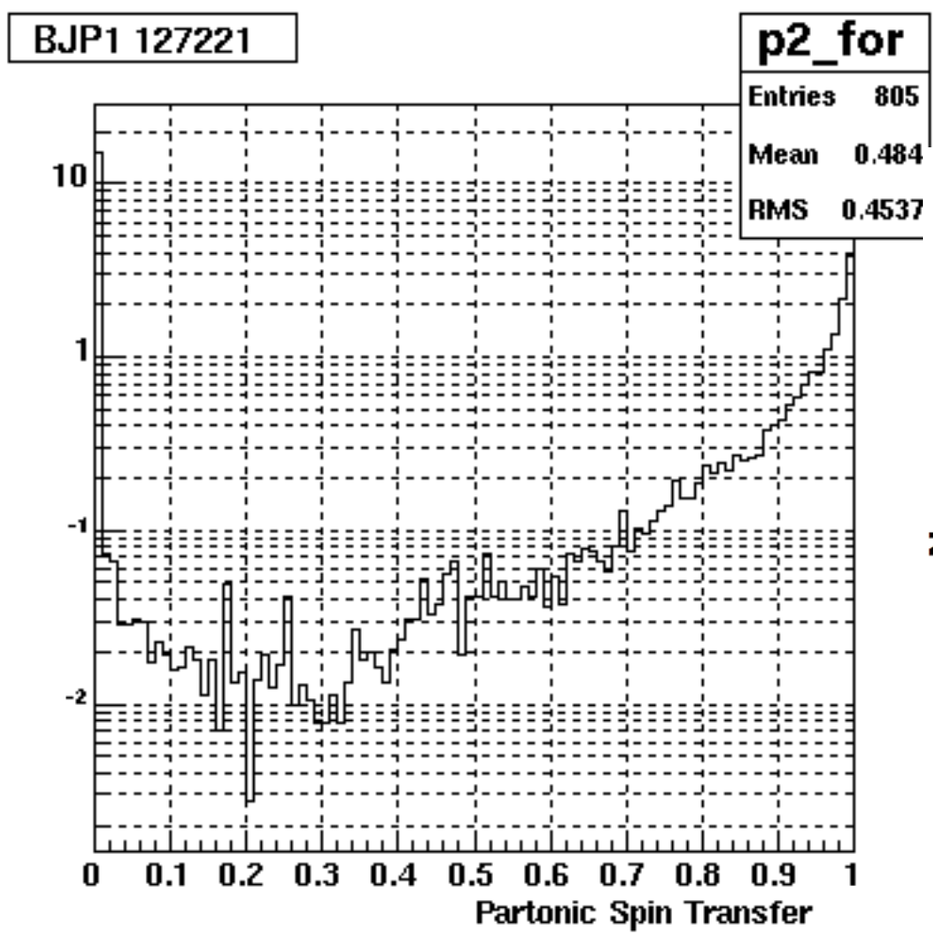

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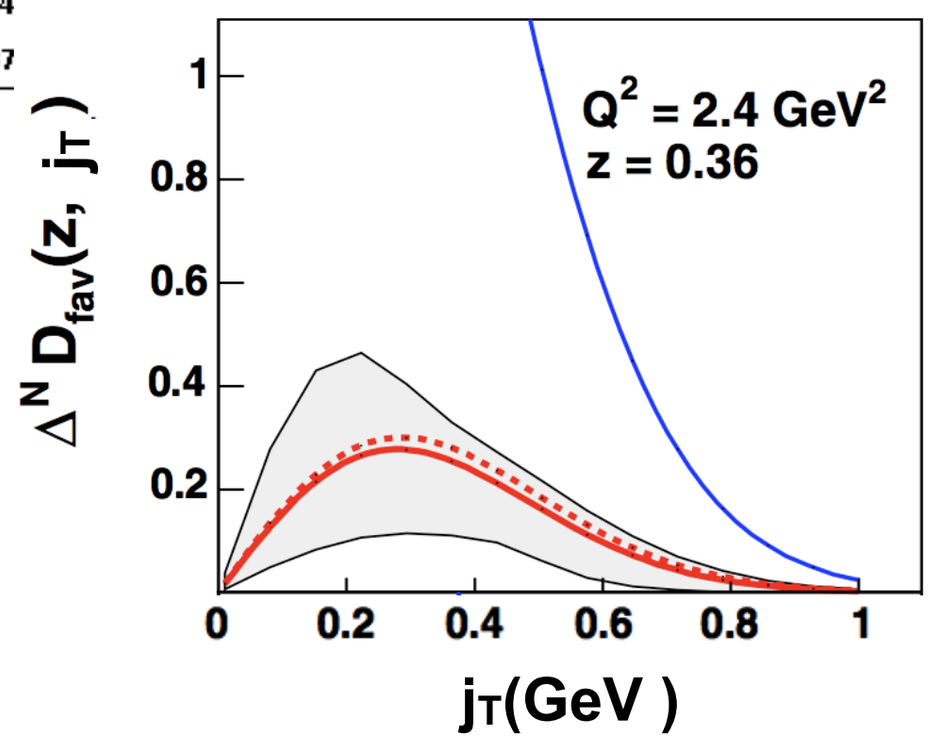

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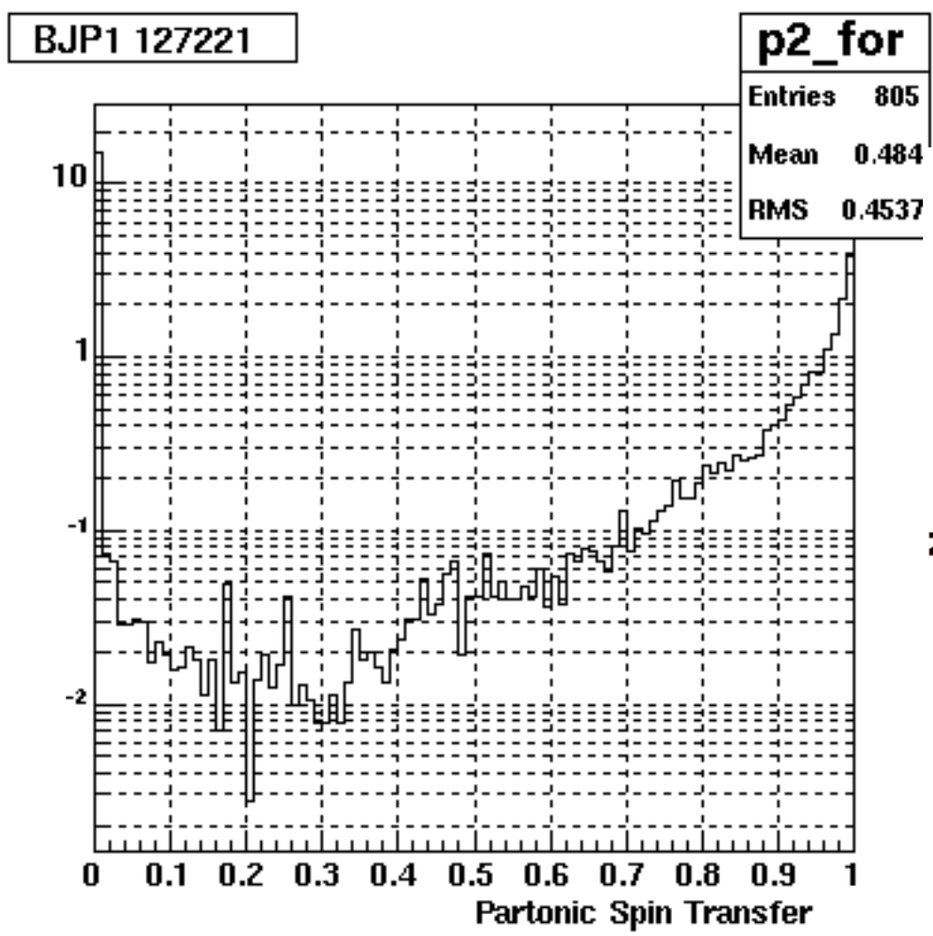

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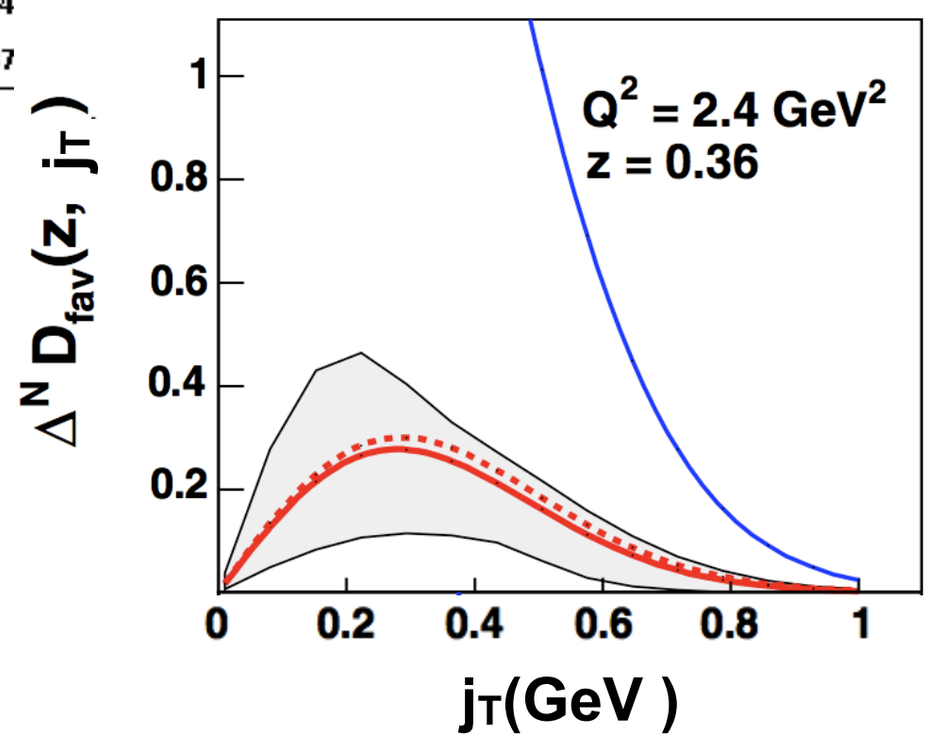

Extraction of Collins fragmentation function from fit to SIDIS data (HERMES, COMPASS) and Belle Collab. data (KEK) (Anselmino, *et al.*, 2008)

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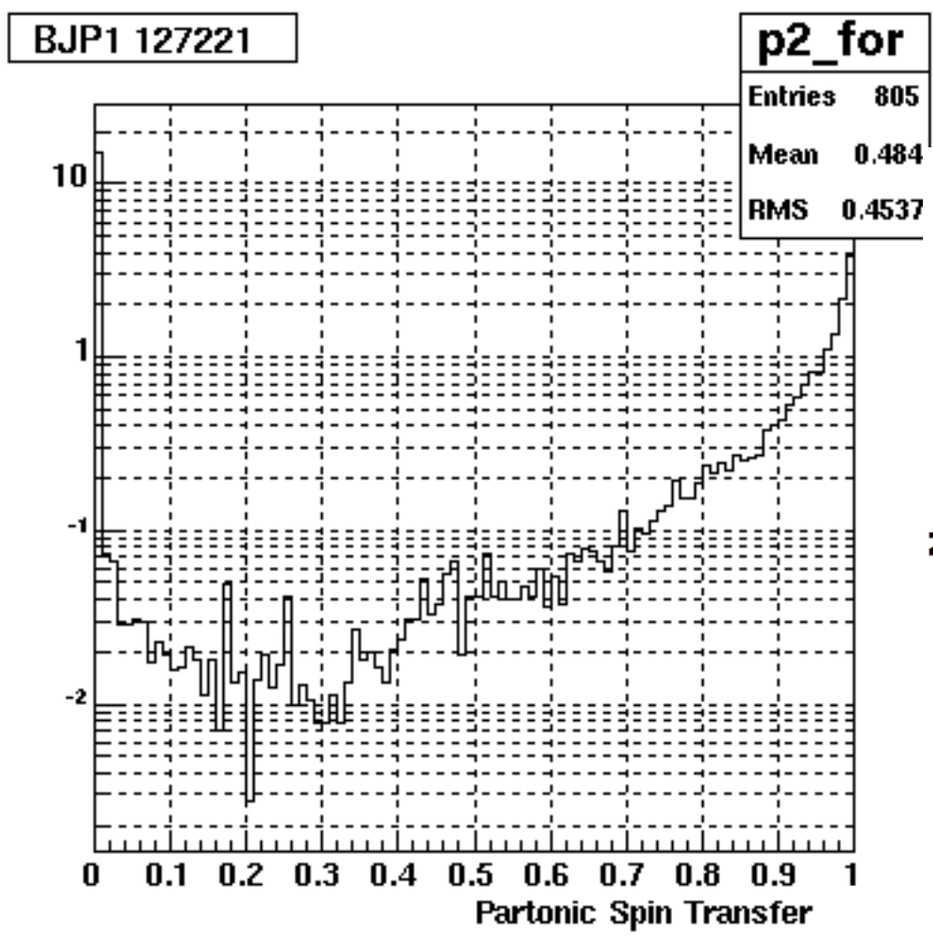

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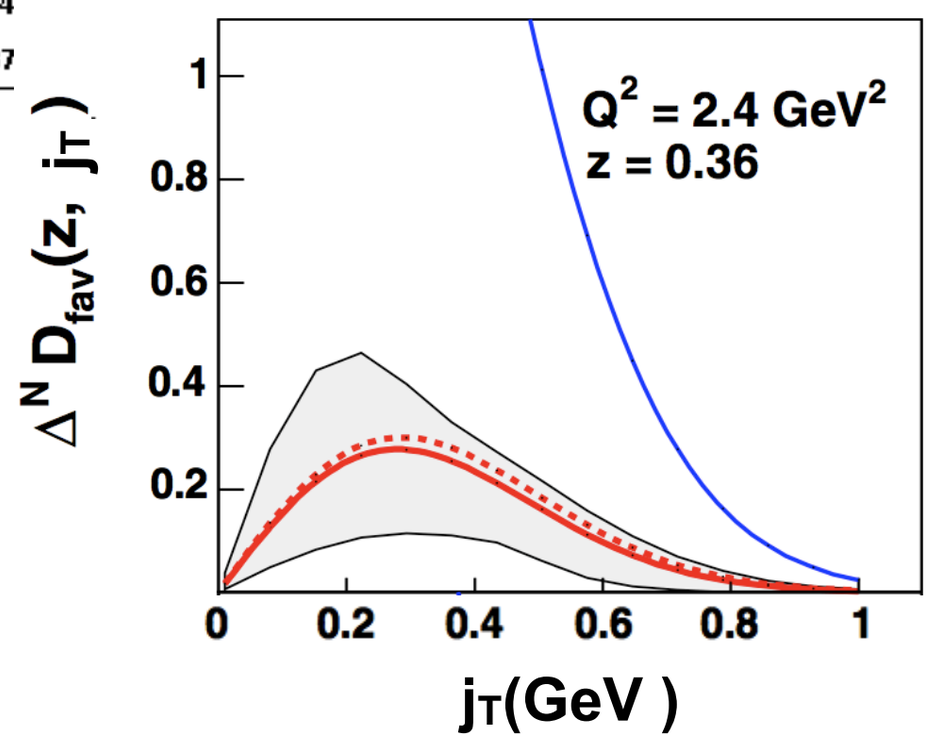

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Prediction (estimate): $A \quad (\pi^\pm) \approx \pm 0.03$

The Collins Asymmetry

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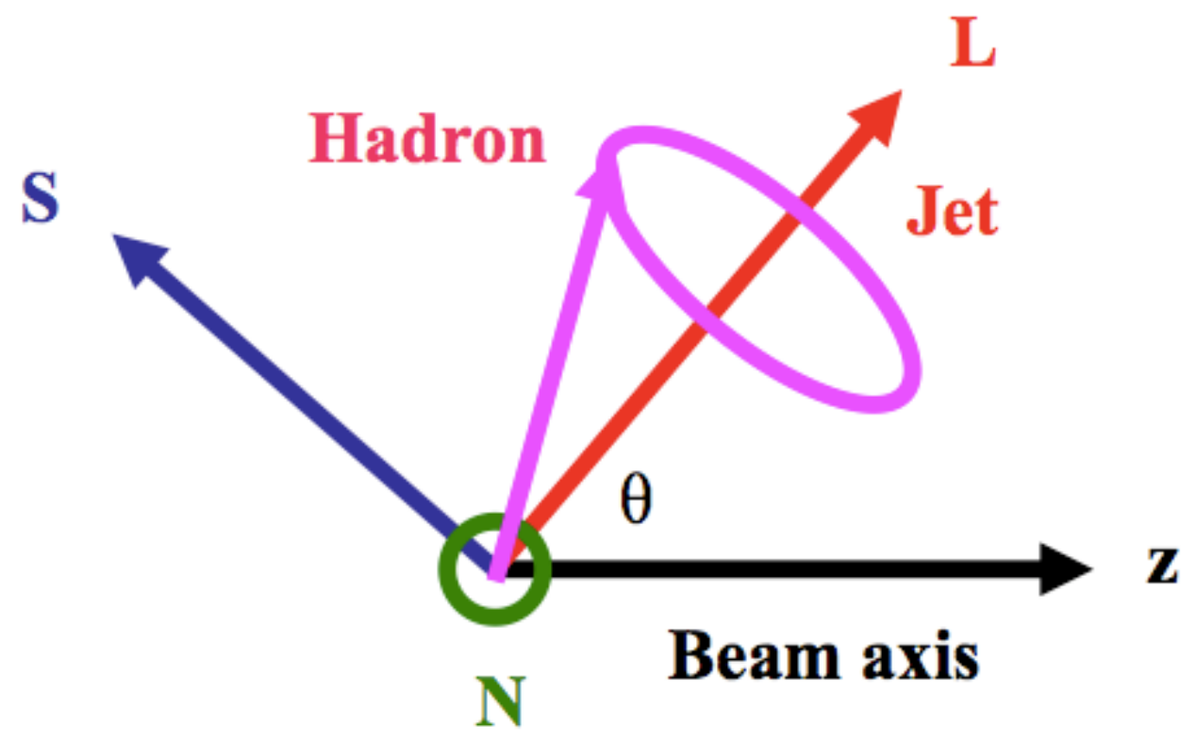
Φ_π is defined in NLS coordinates



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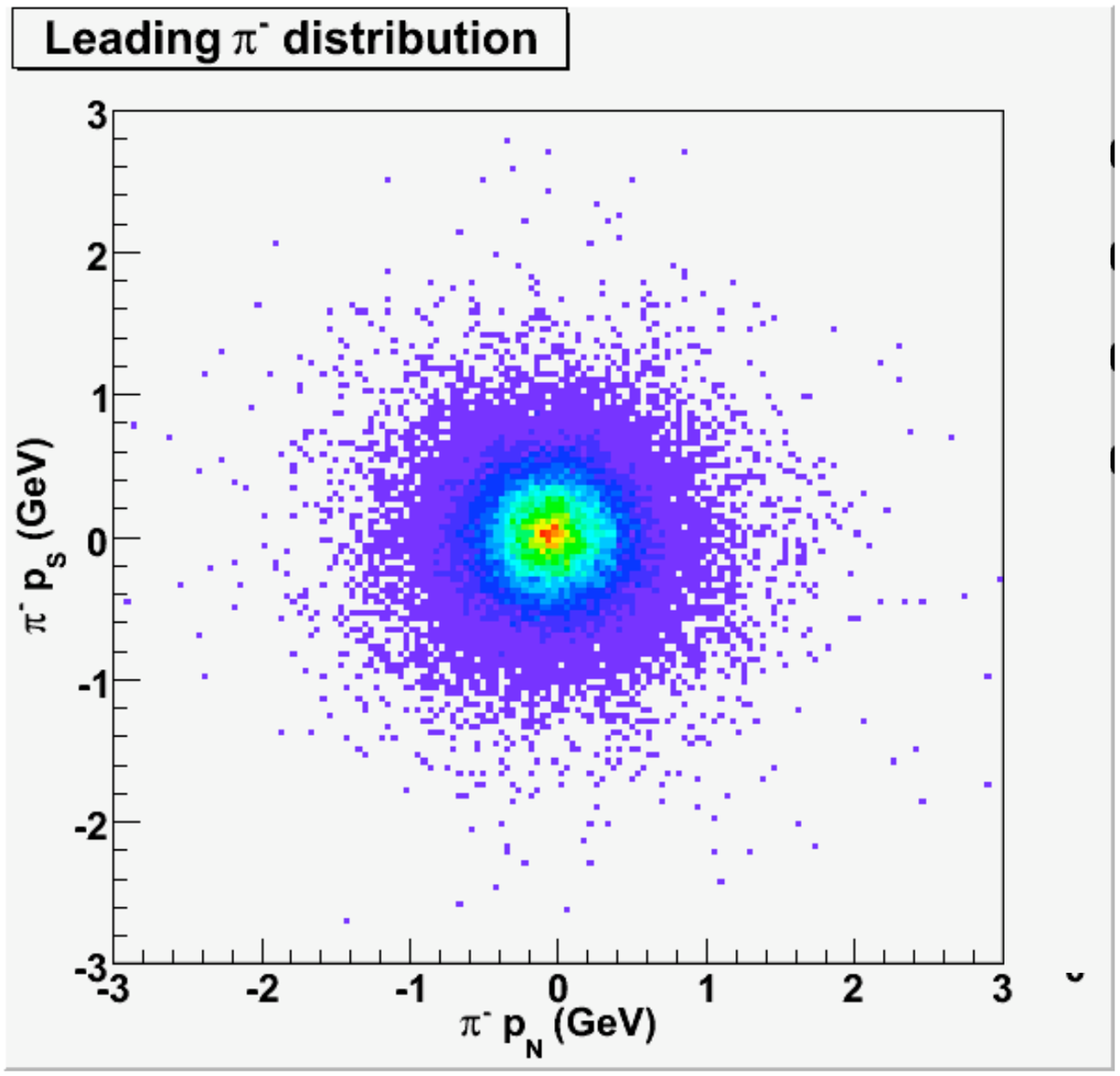

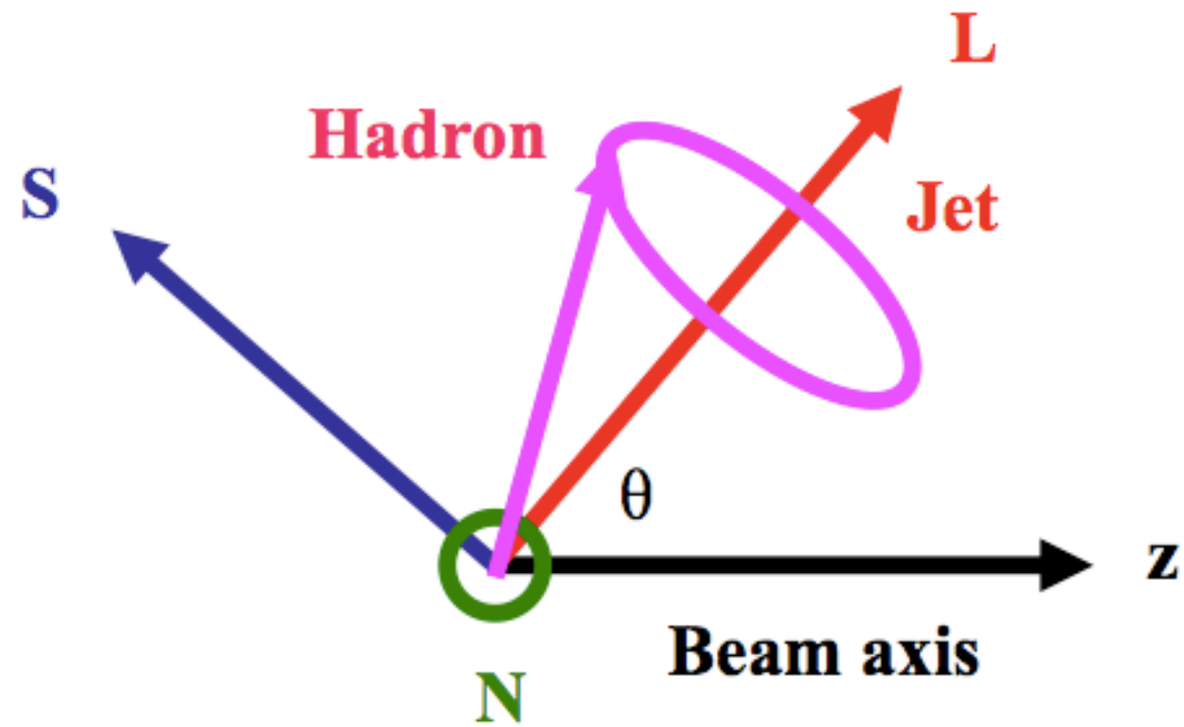

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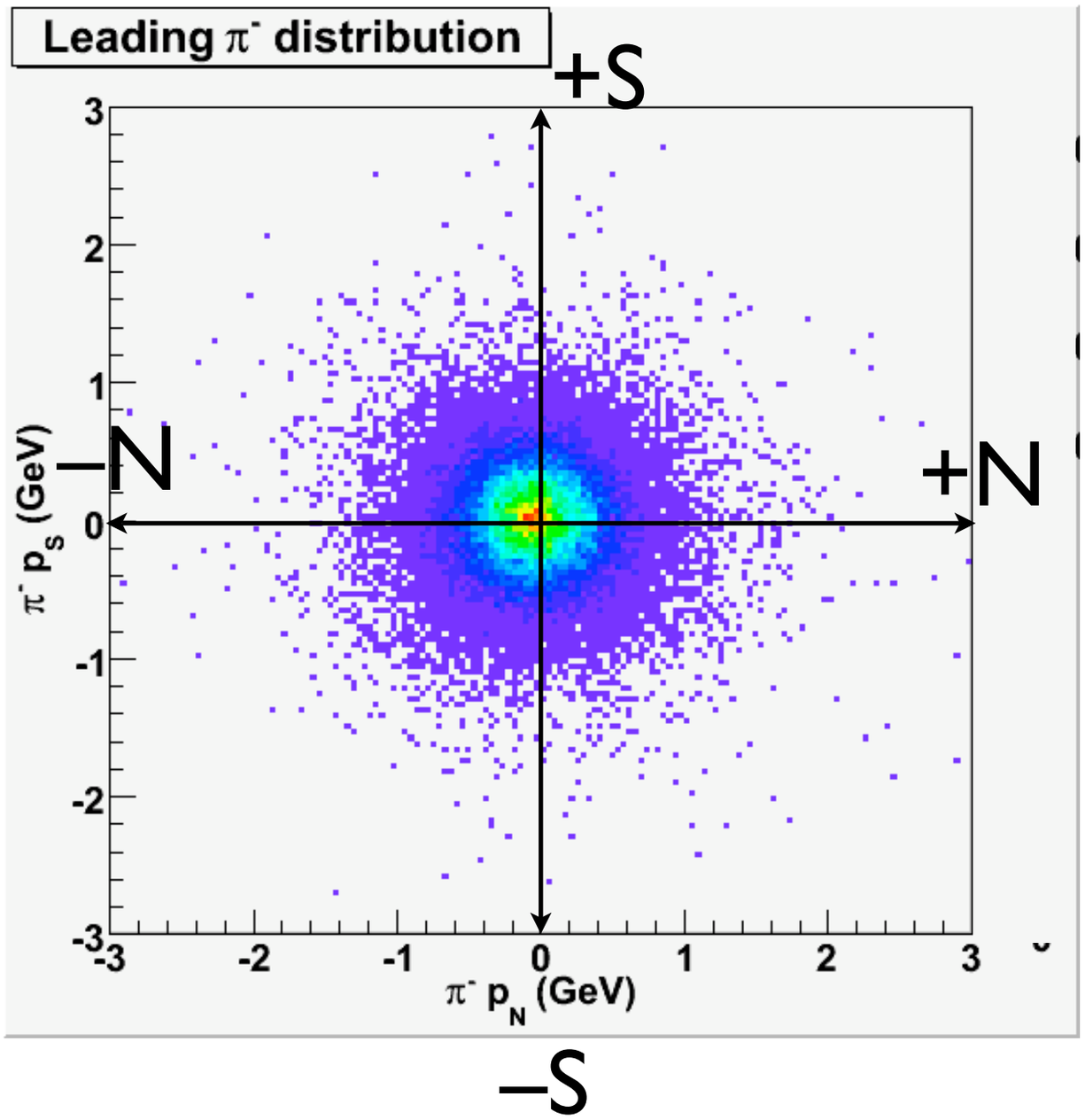

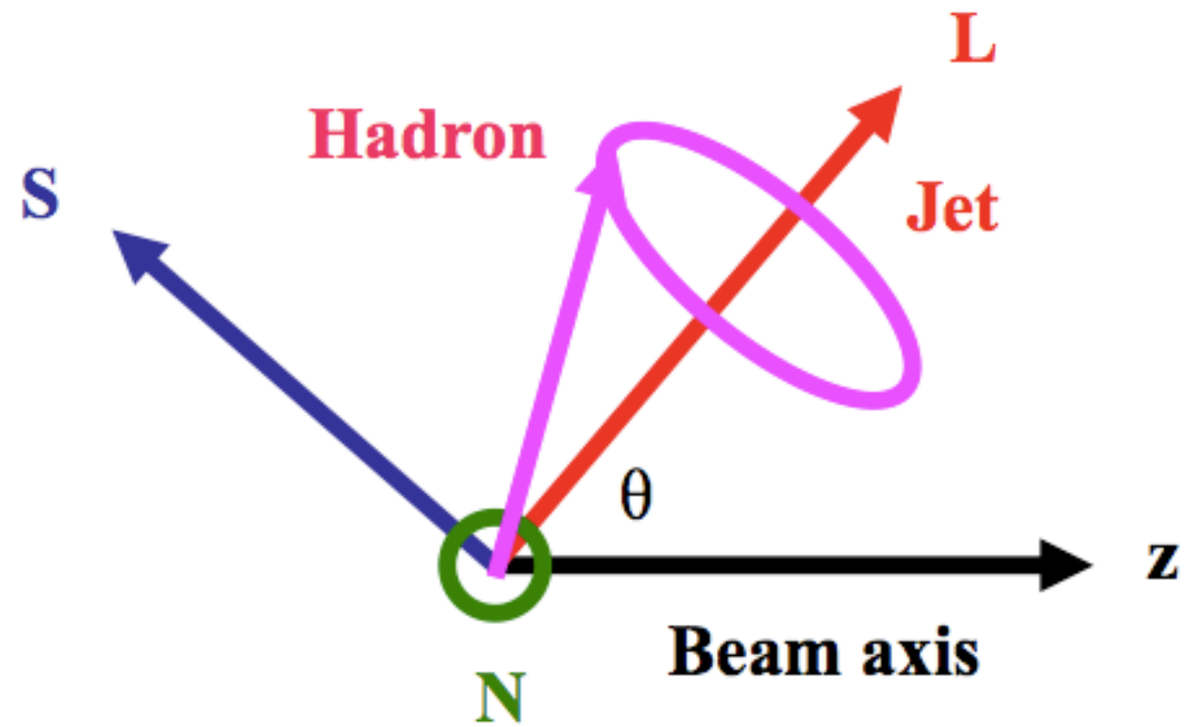

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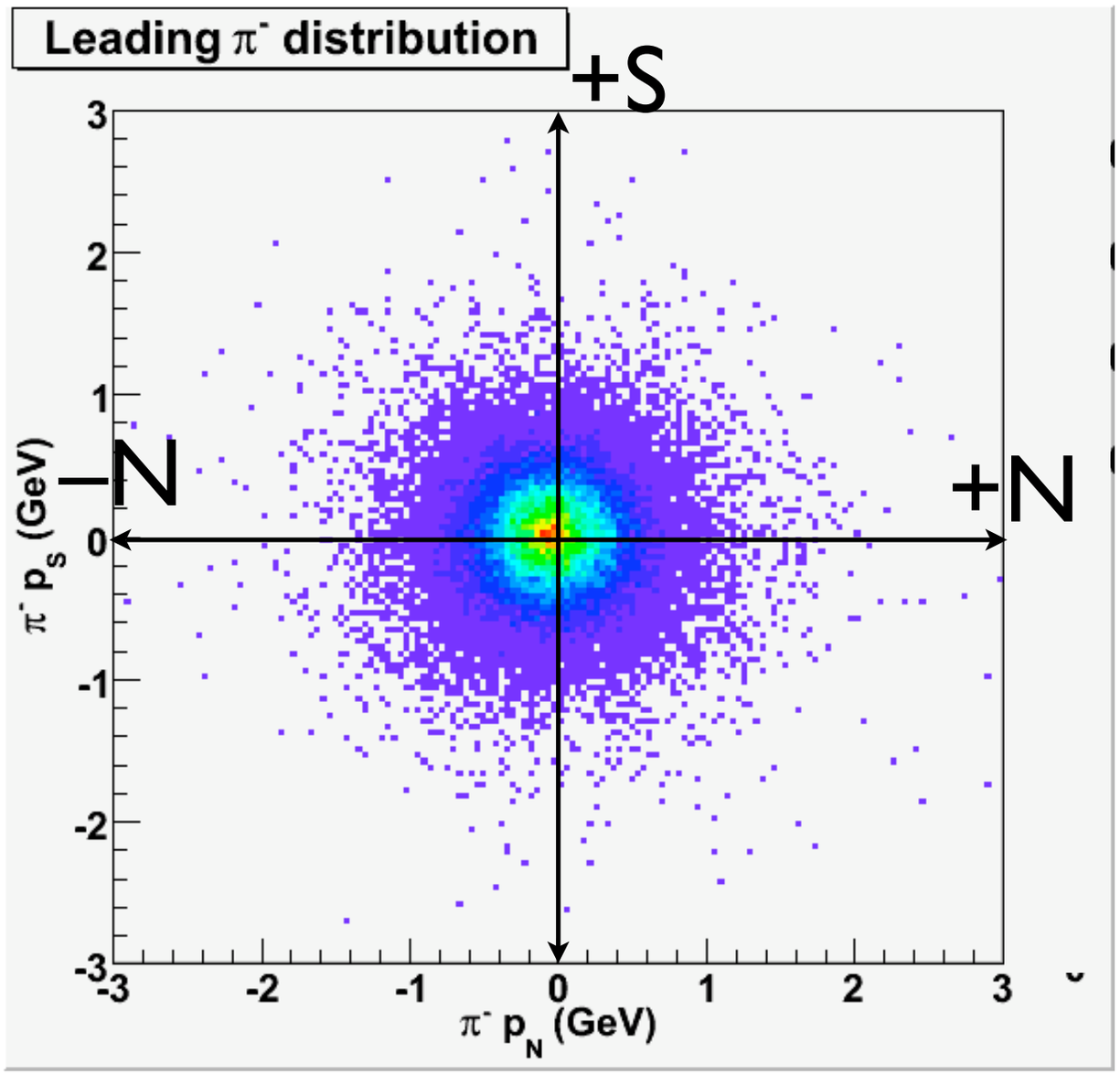

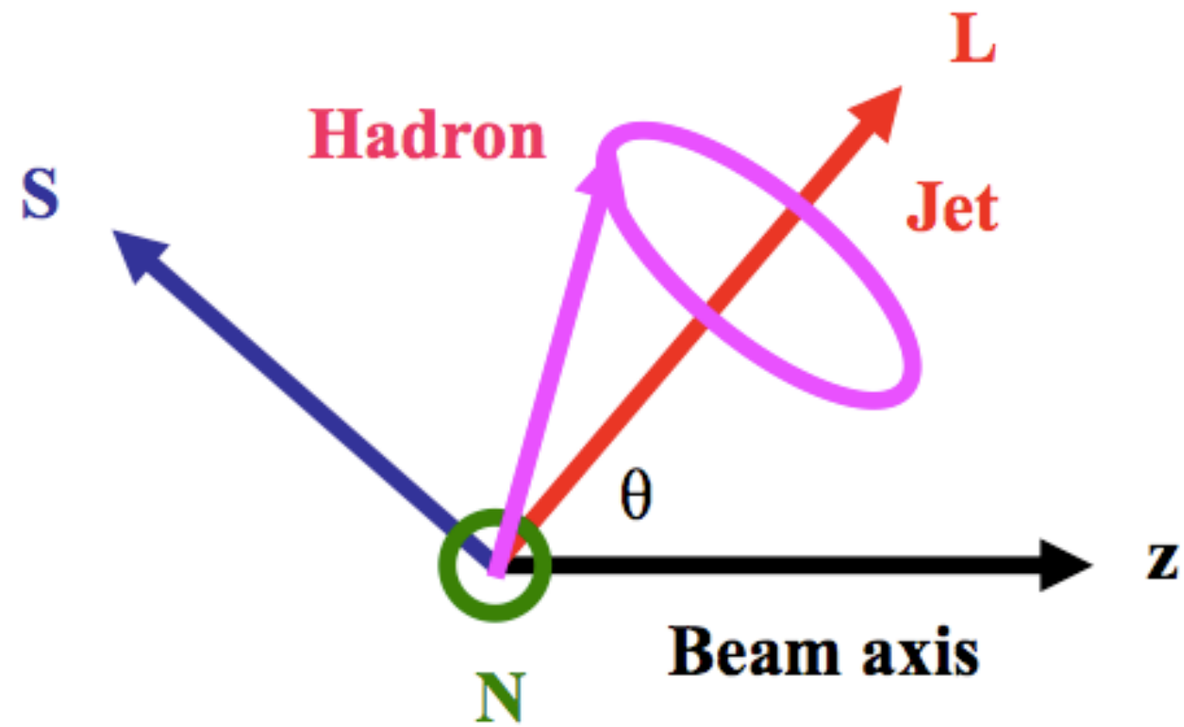

(L is 3rd axis; L = S × N)

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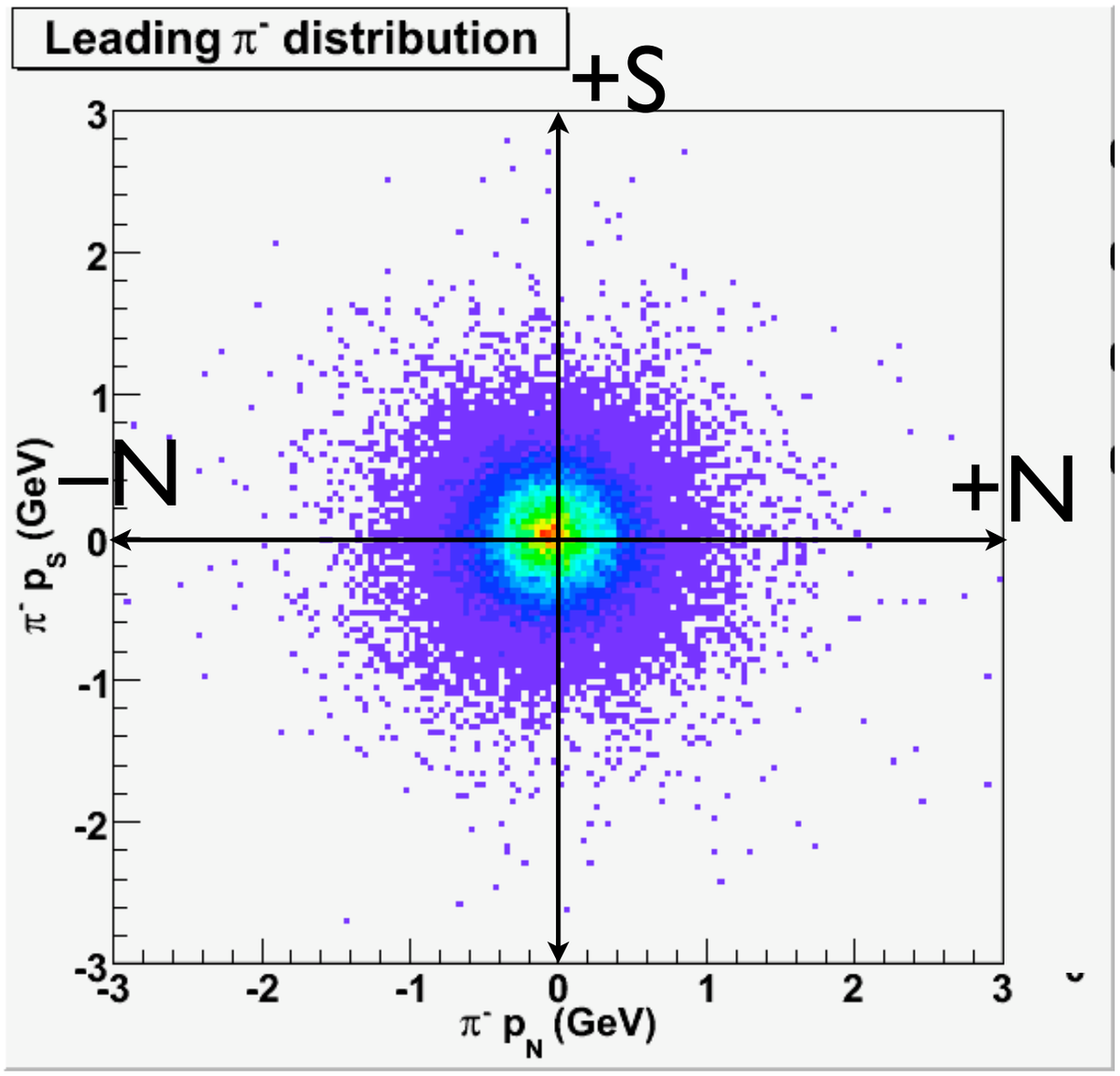

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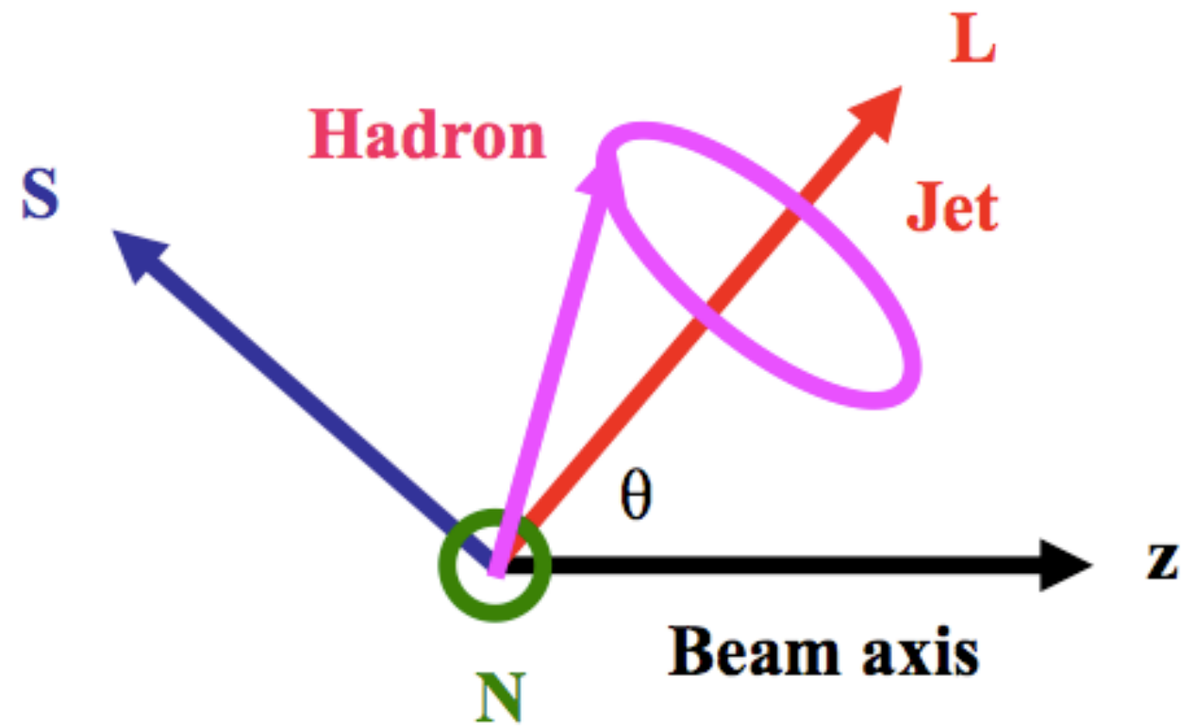
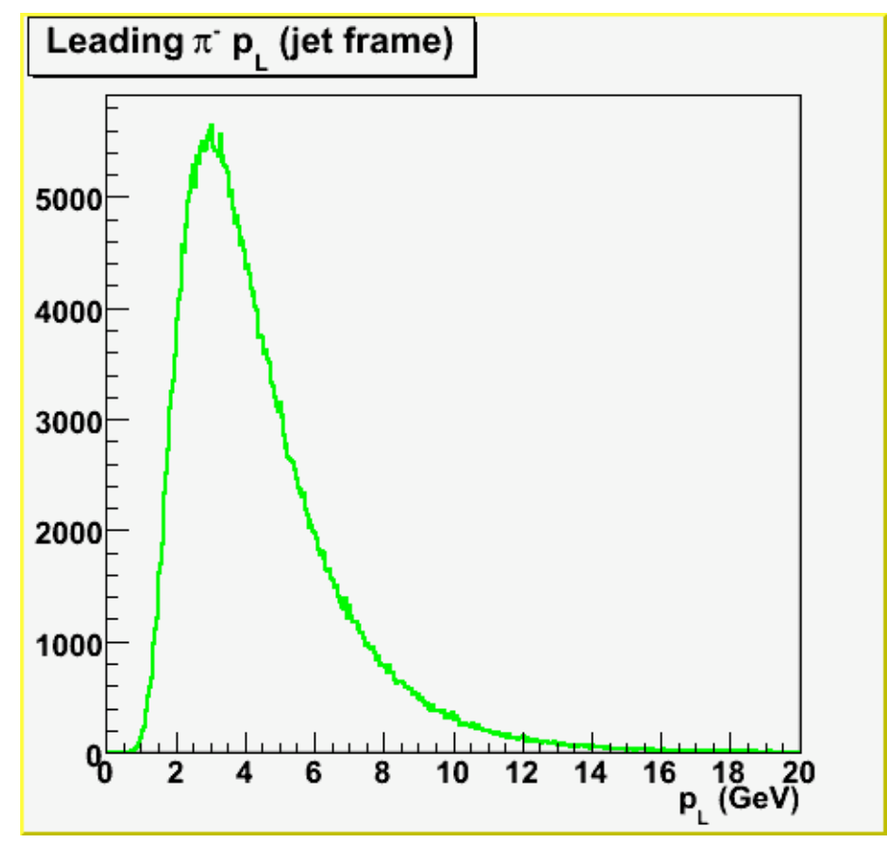
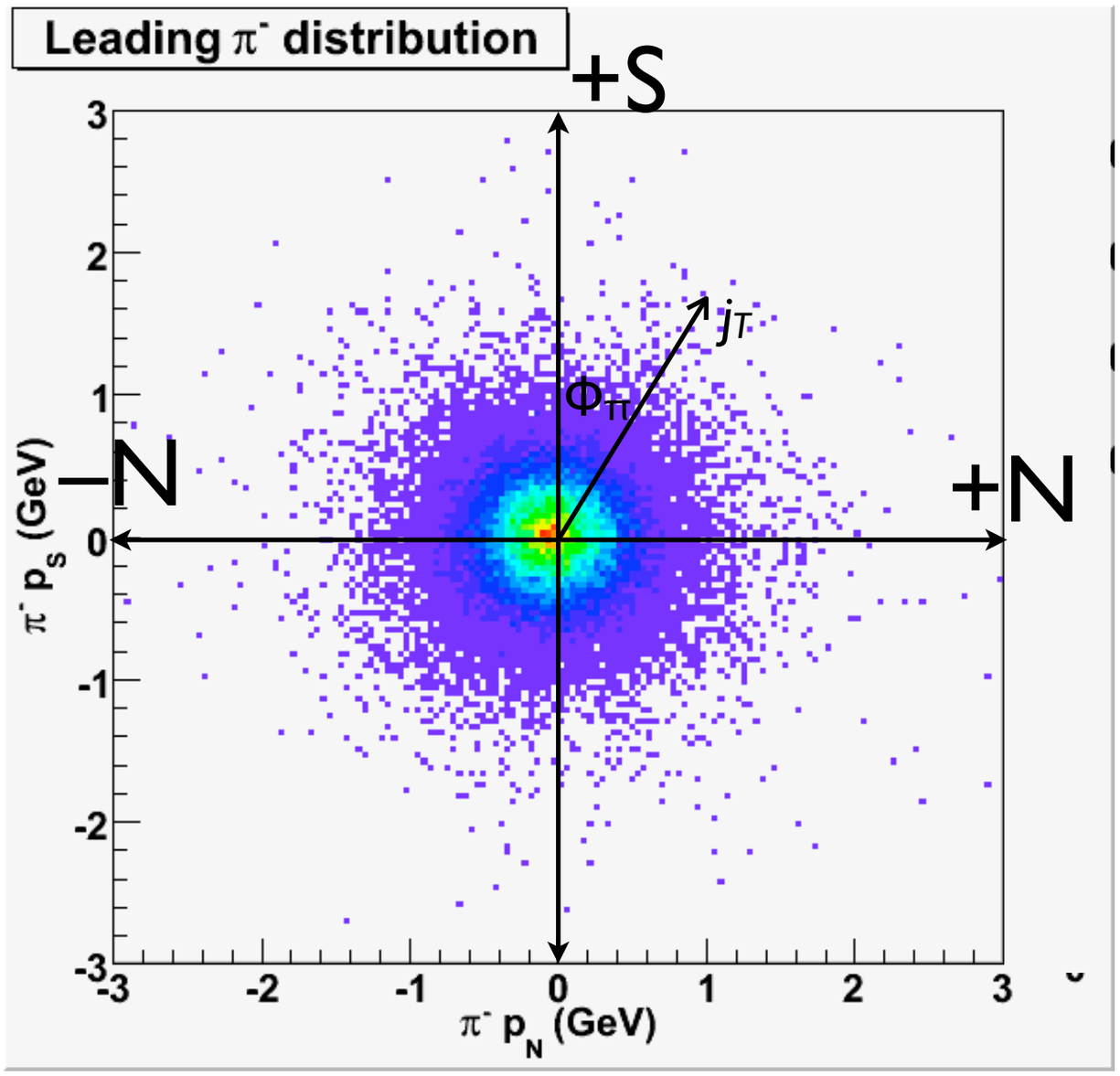
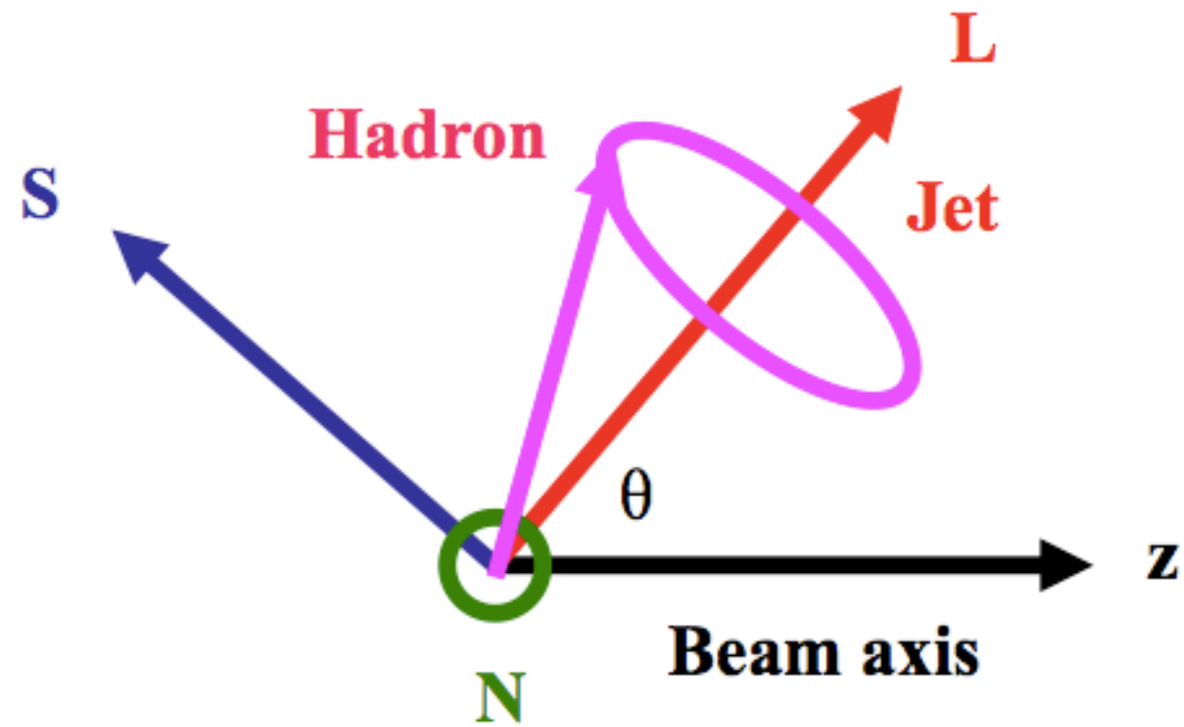


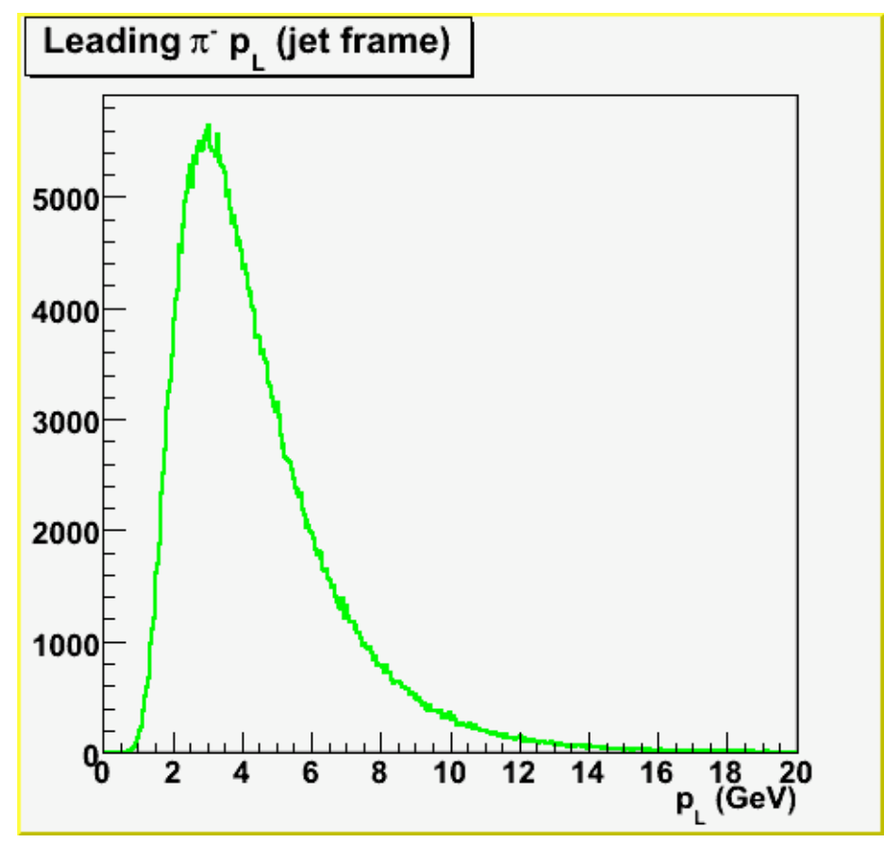


The Collins Asymmetry

Φ_π is defined in NLS coordinates







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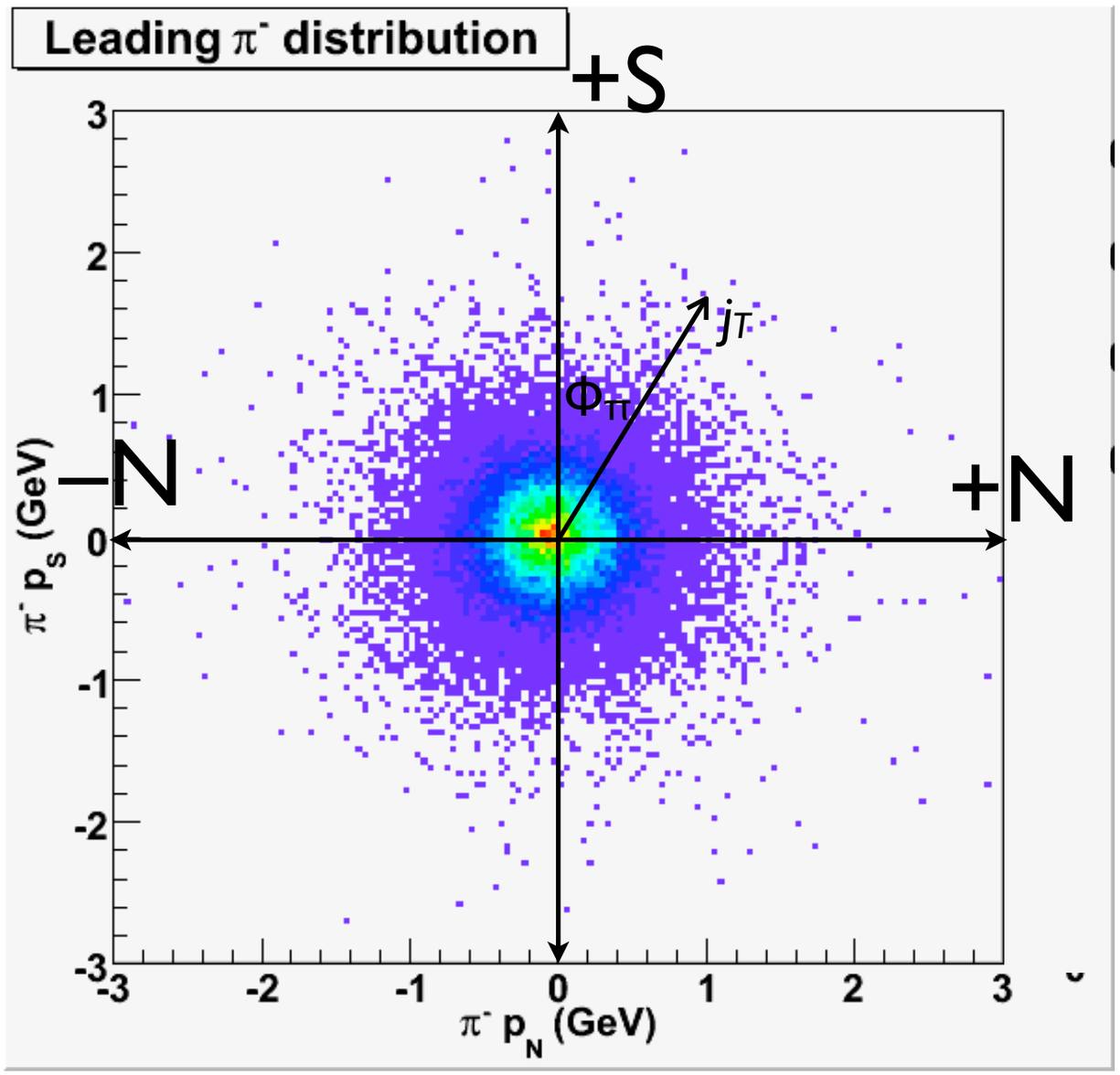

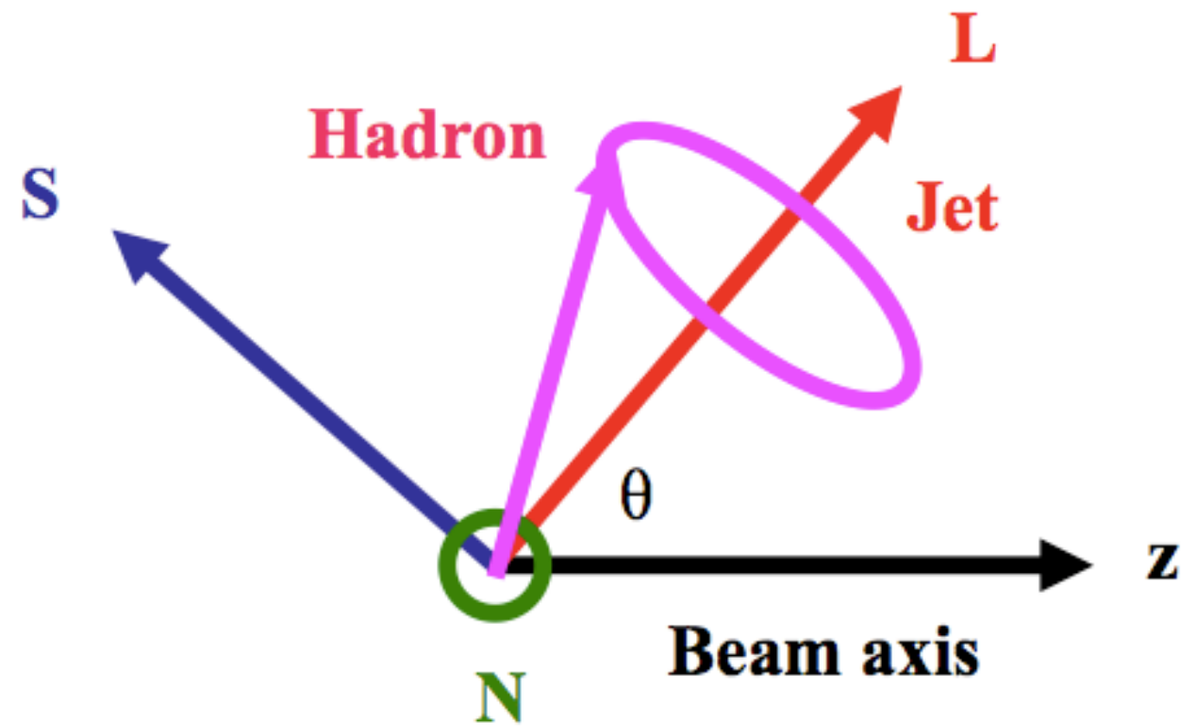

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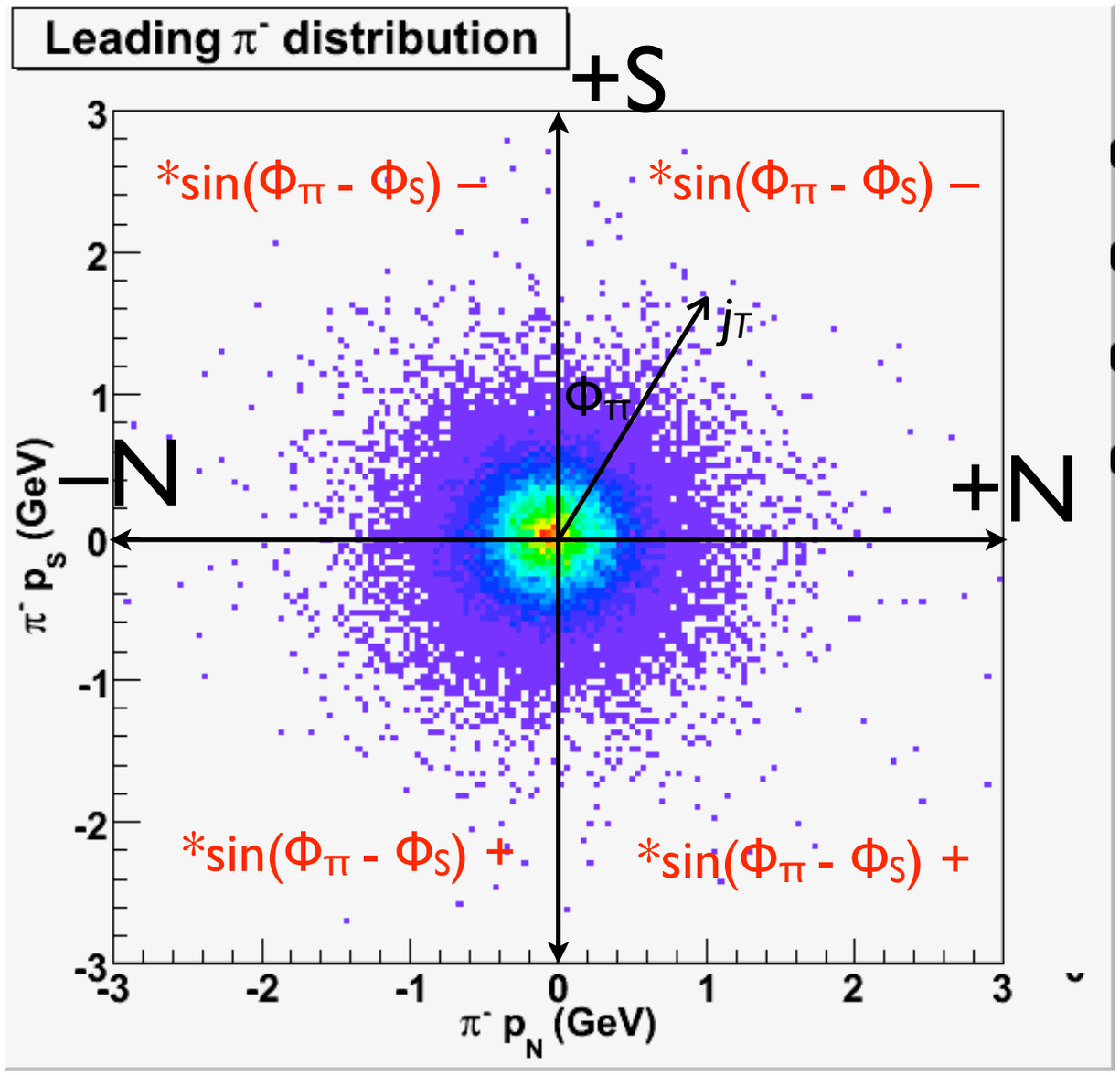

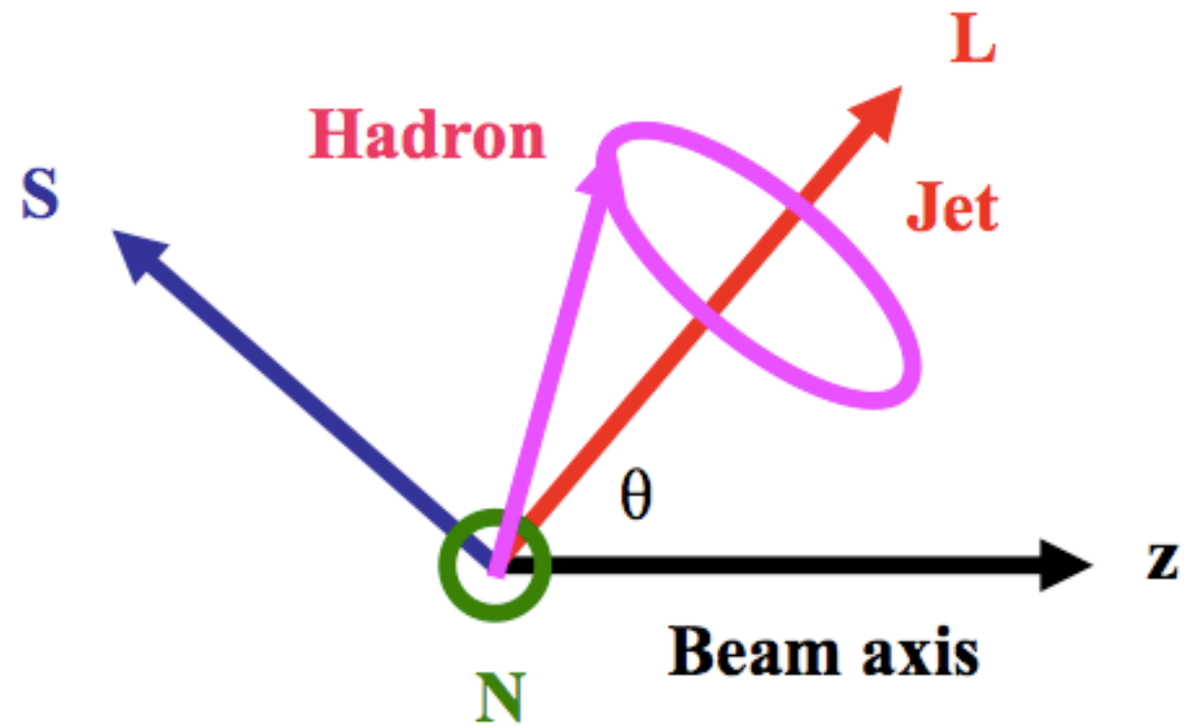

*For proton spin ↑↑ N axis, $\Phi_S = 90°$

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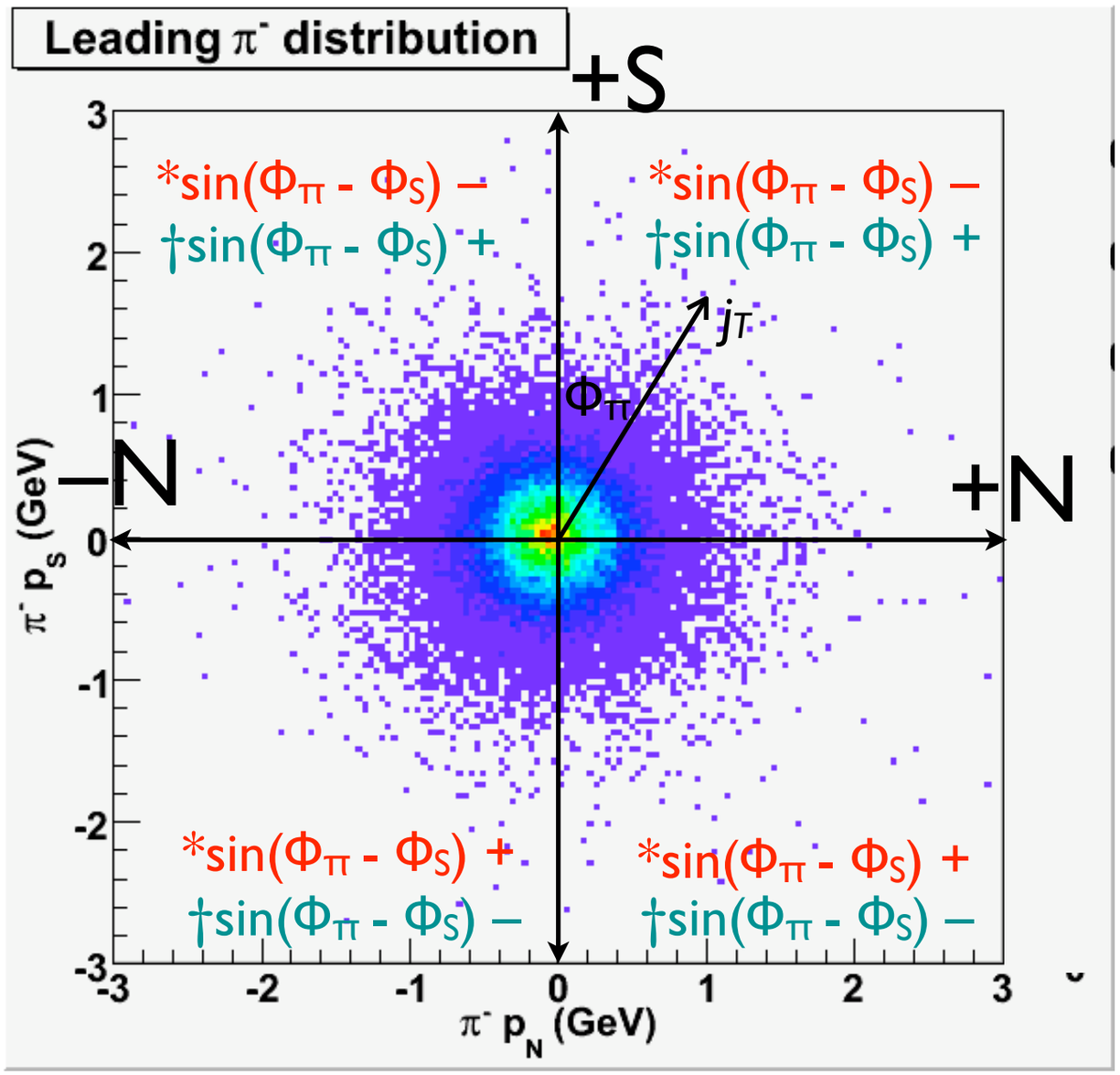

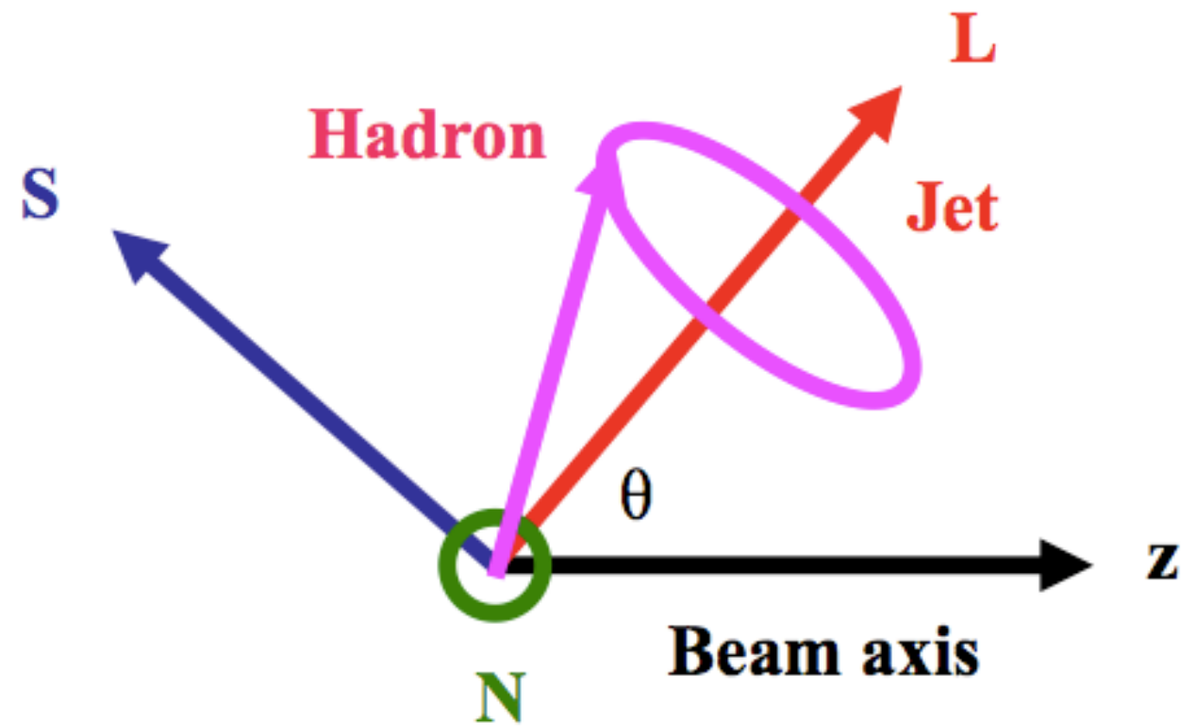

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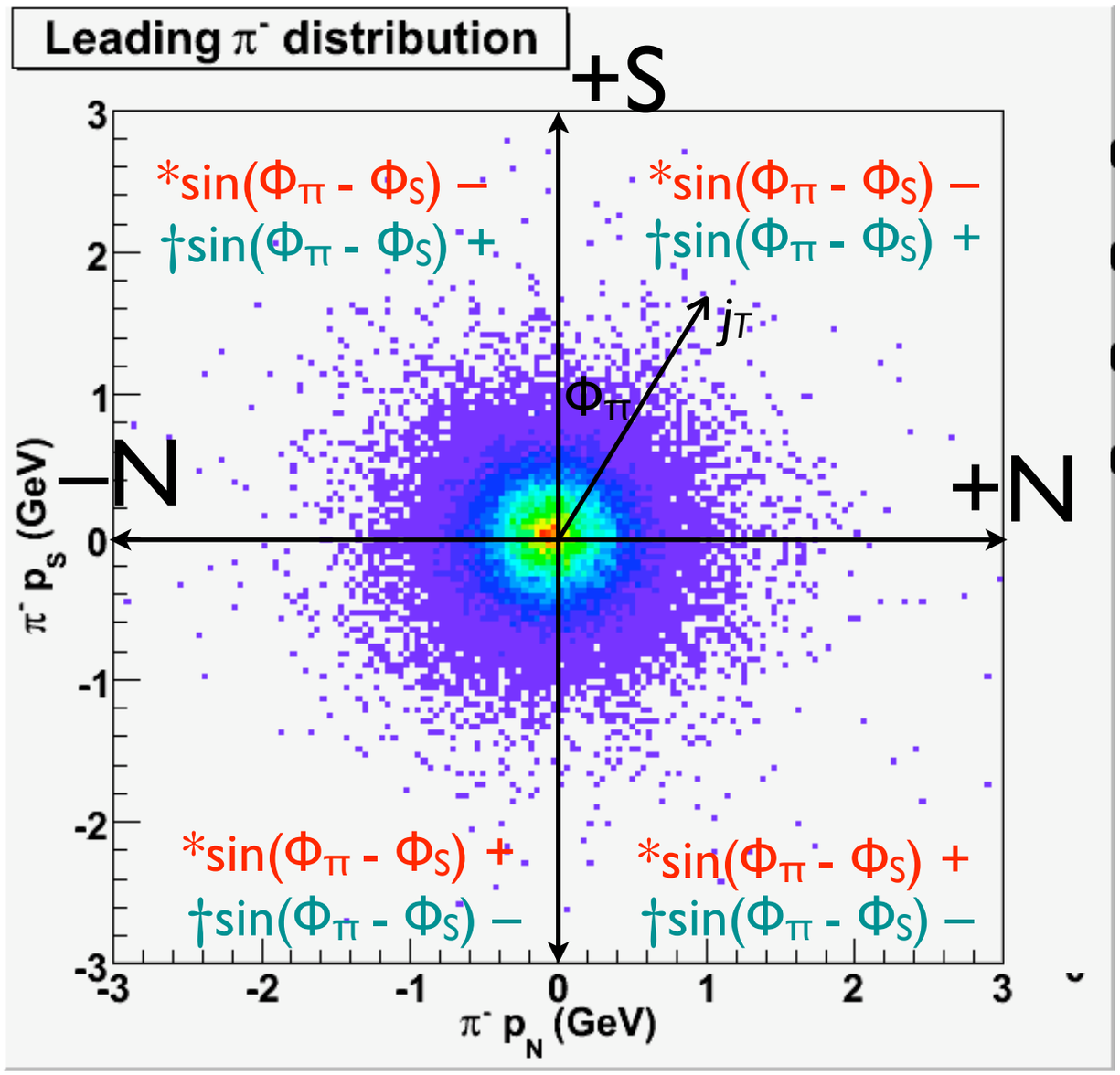

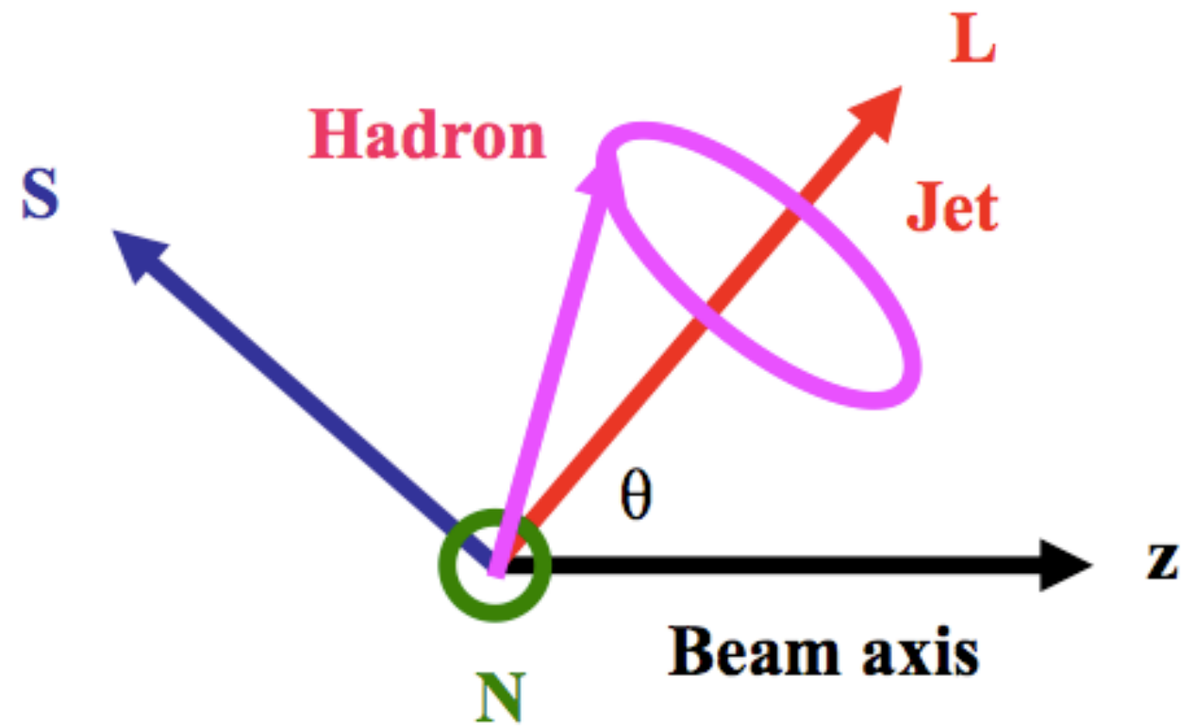

*For proton spin ↑↑ N axis, $\Phi_S = 90°$

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Geometry dictates these cancel along the N-axis; leaving a possible top-bottom asymmetry *A* along the S-axis

(L is 3rd axis; L = S × N)

Data analyzed separately for blue and yellow beams in forward hemisphere only:

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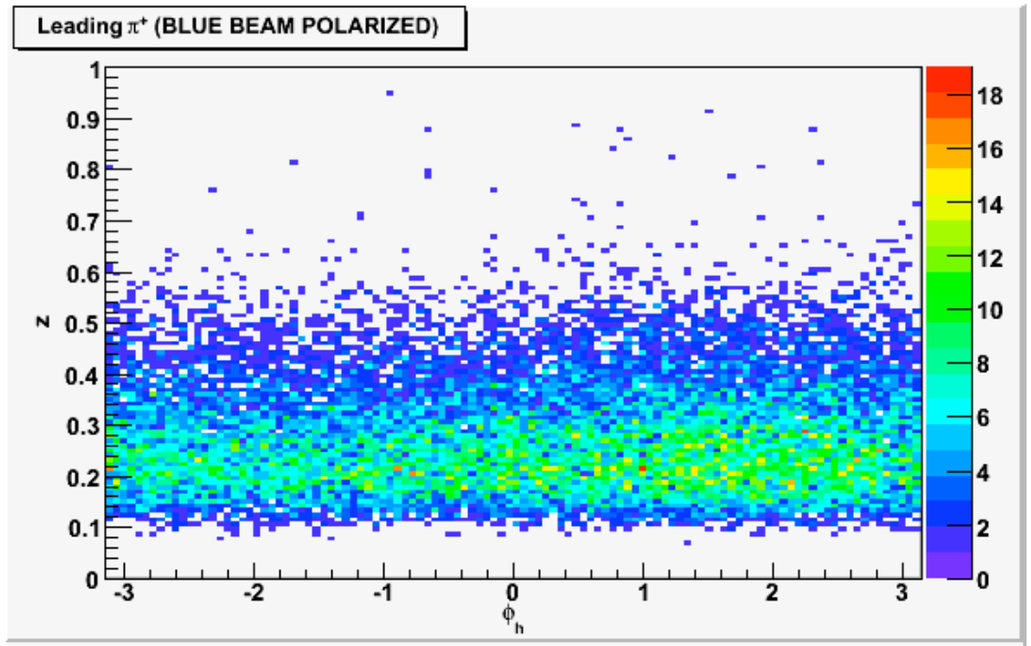

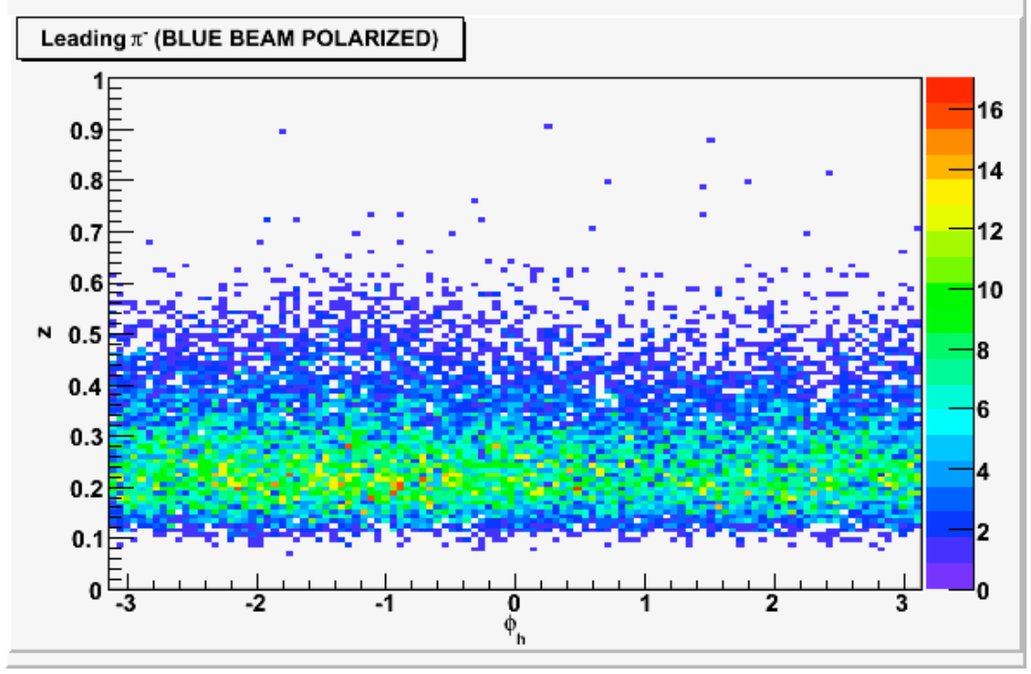

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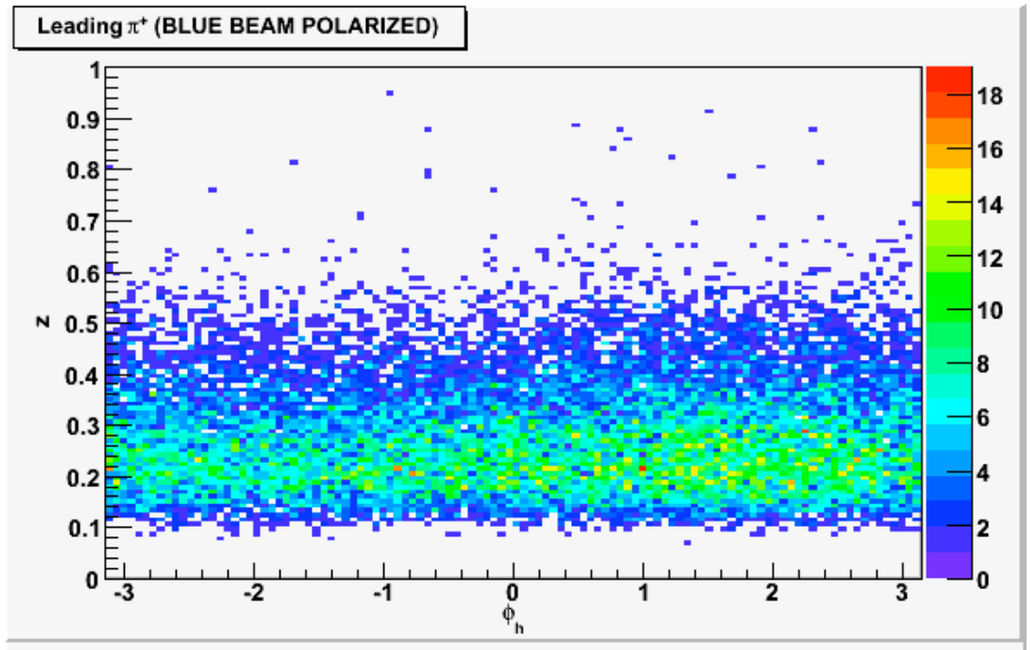

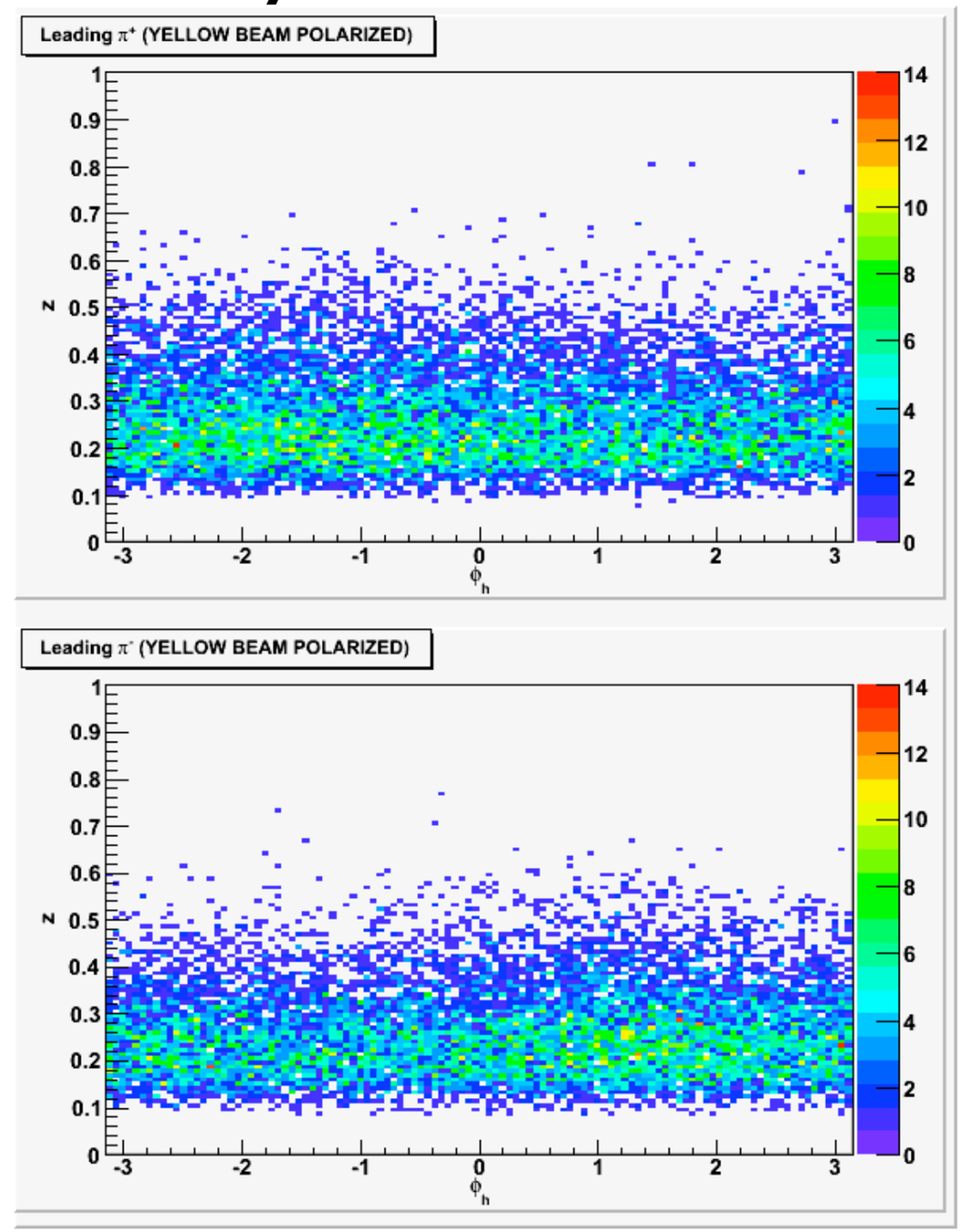

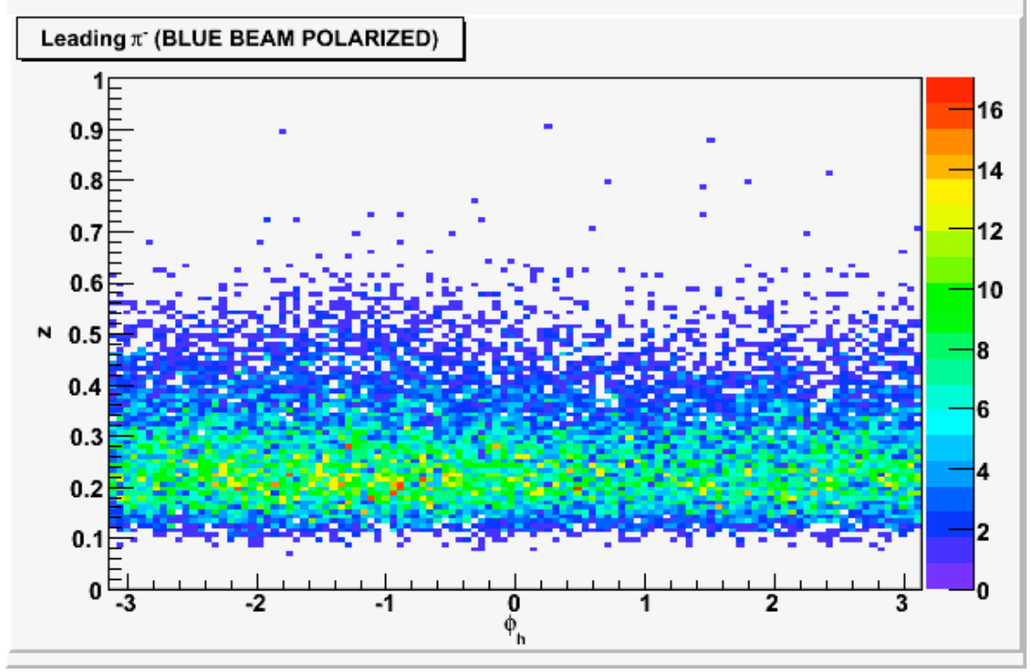

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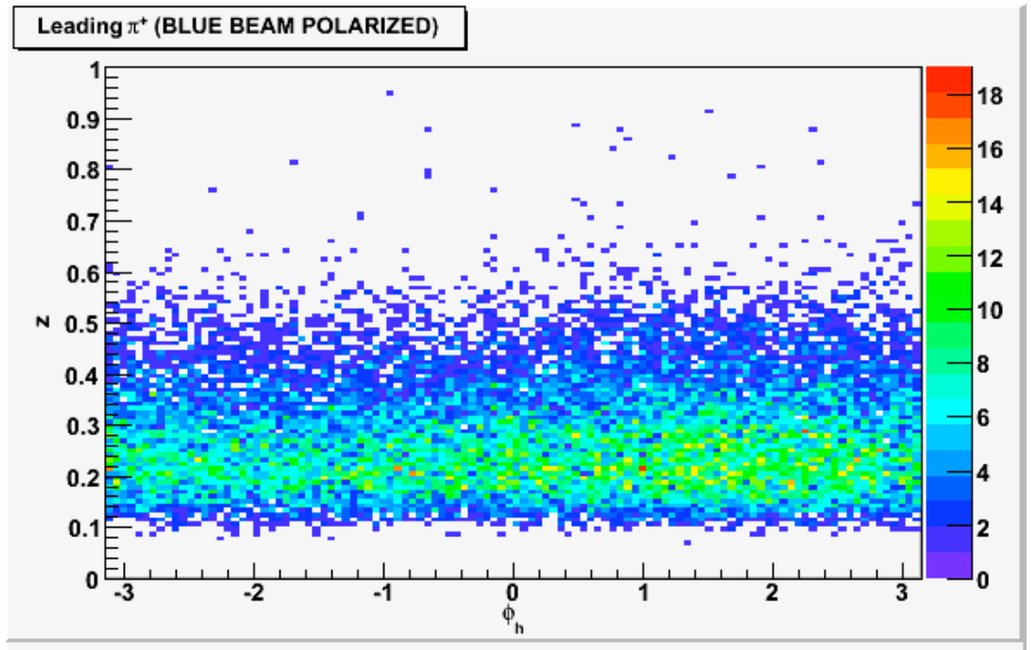
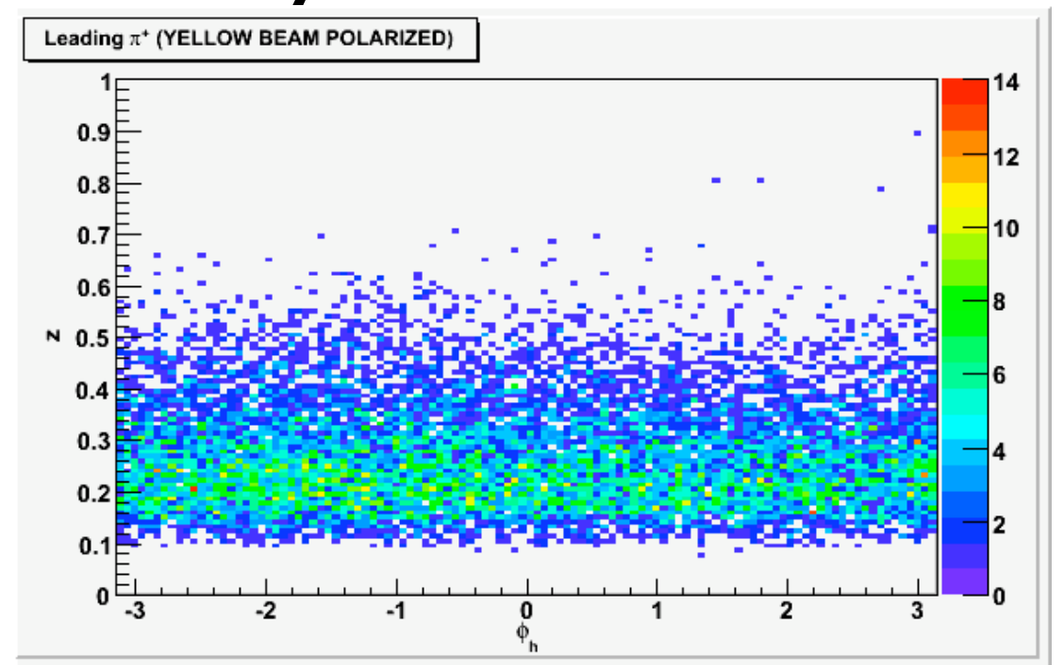
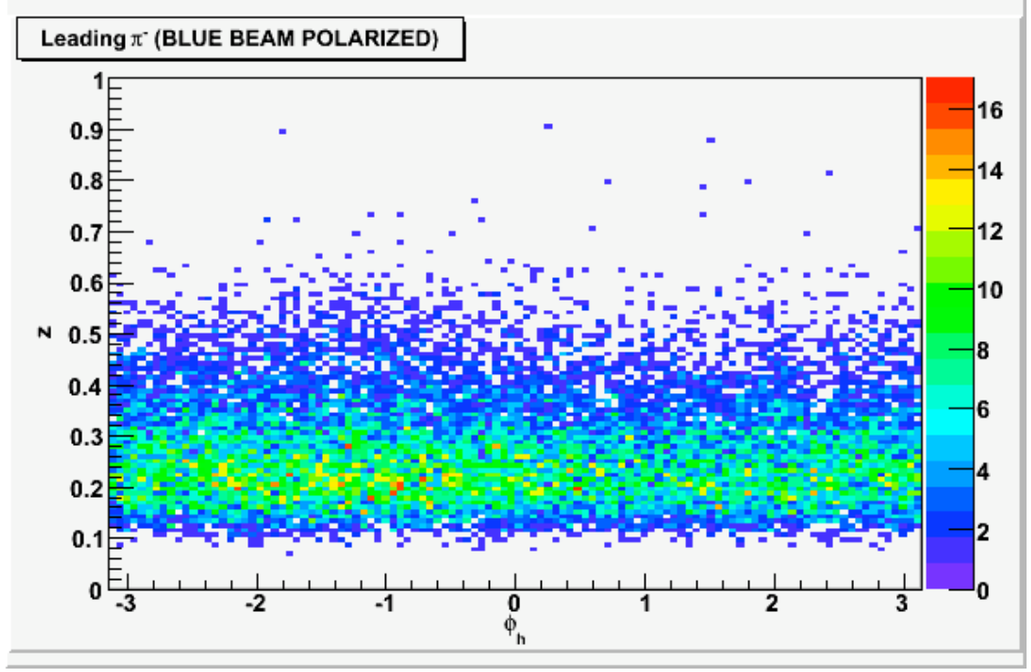
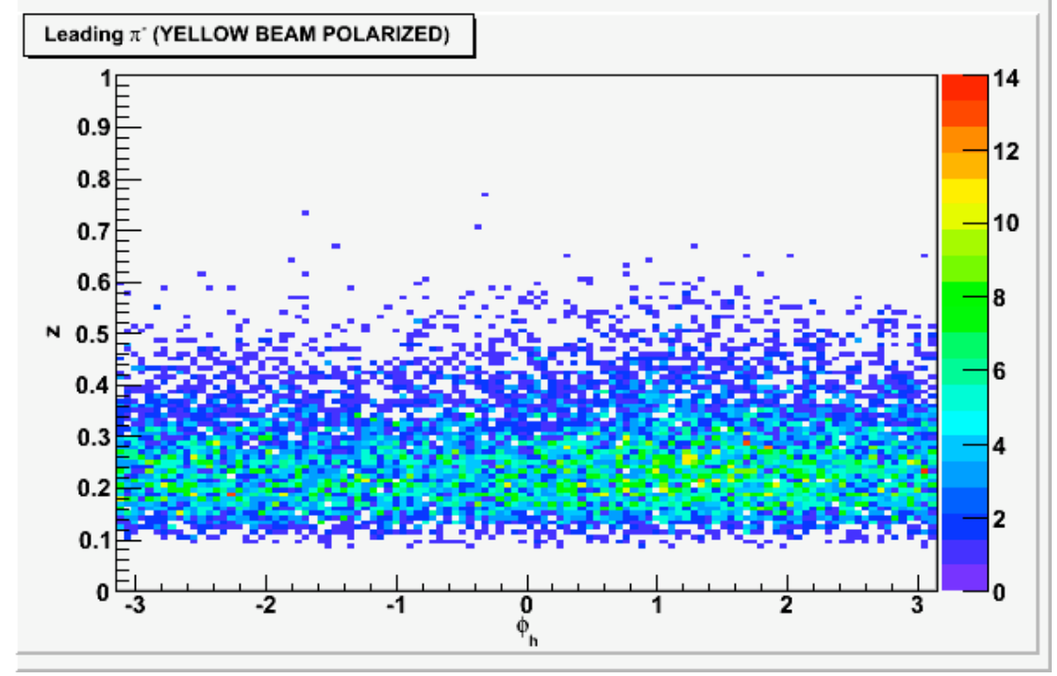






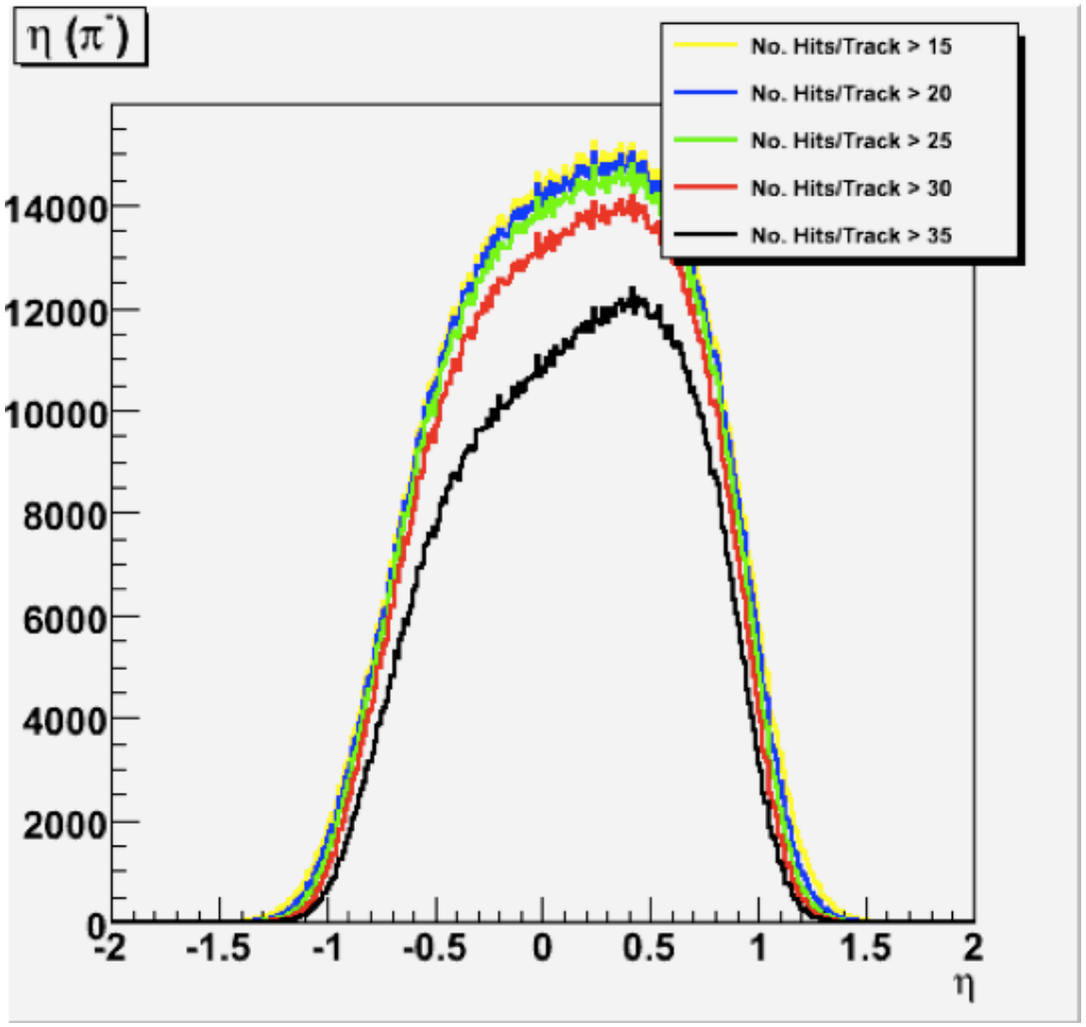


* Asymmetric distributions shown here are NOT a result of the Collins Asymmetry, they are a relic of track curvatures between TPC sectors; they are opposite for blue, yellow beam measurements & are symmetric with respect to the S-axis

Goals of this Presentation:

- Demonstrate kinematic coverage of the data and physics in terms of p_T

Charged $\pi^{\pm}$ reconstruction



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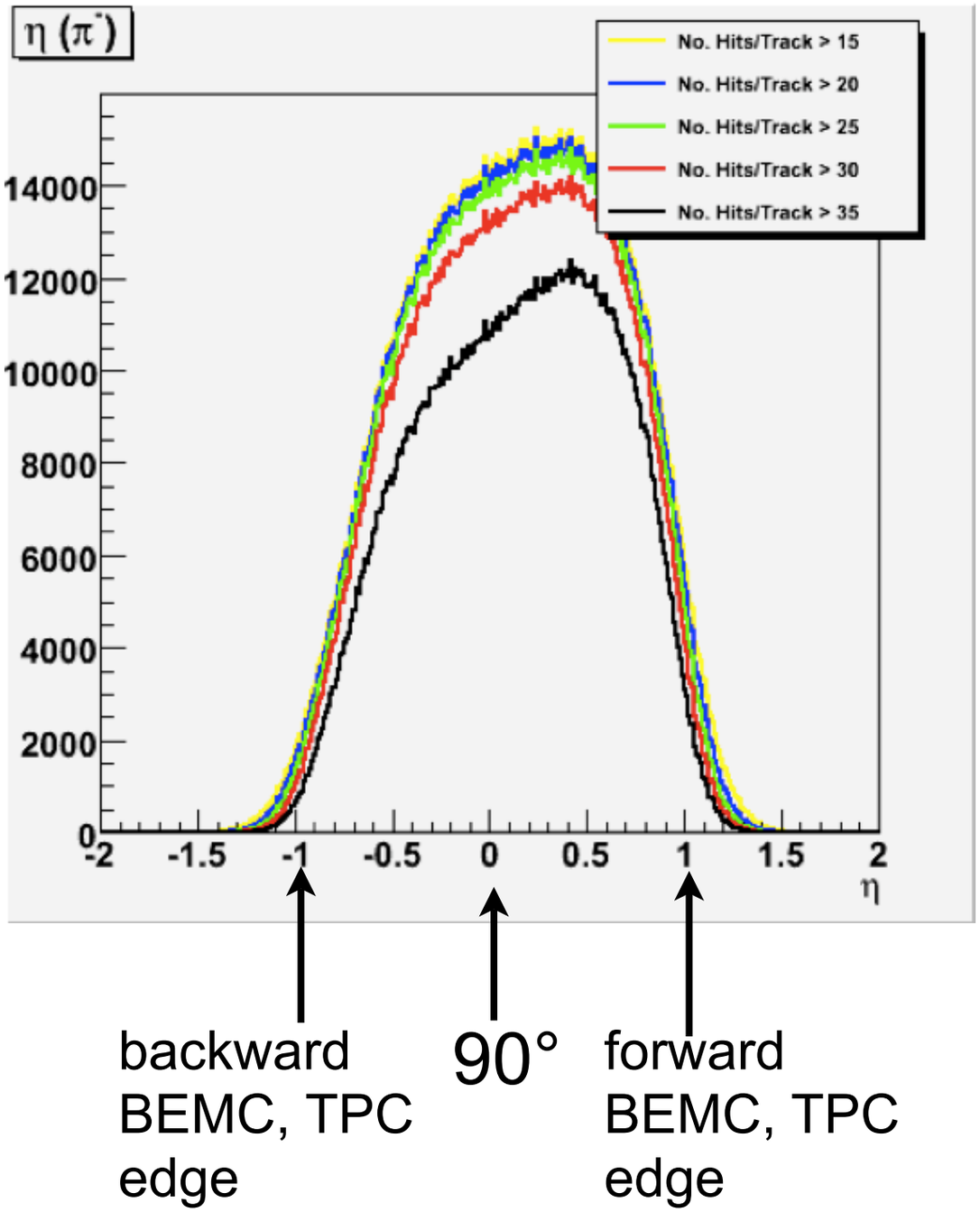

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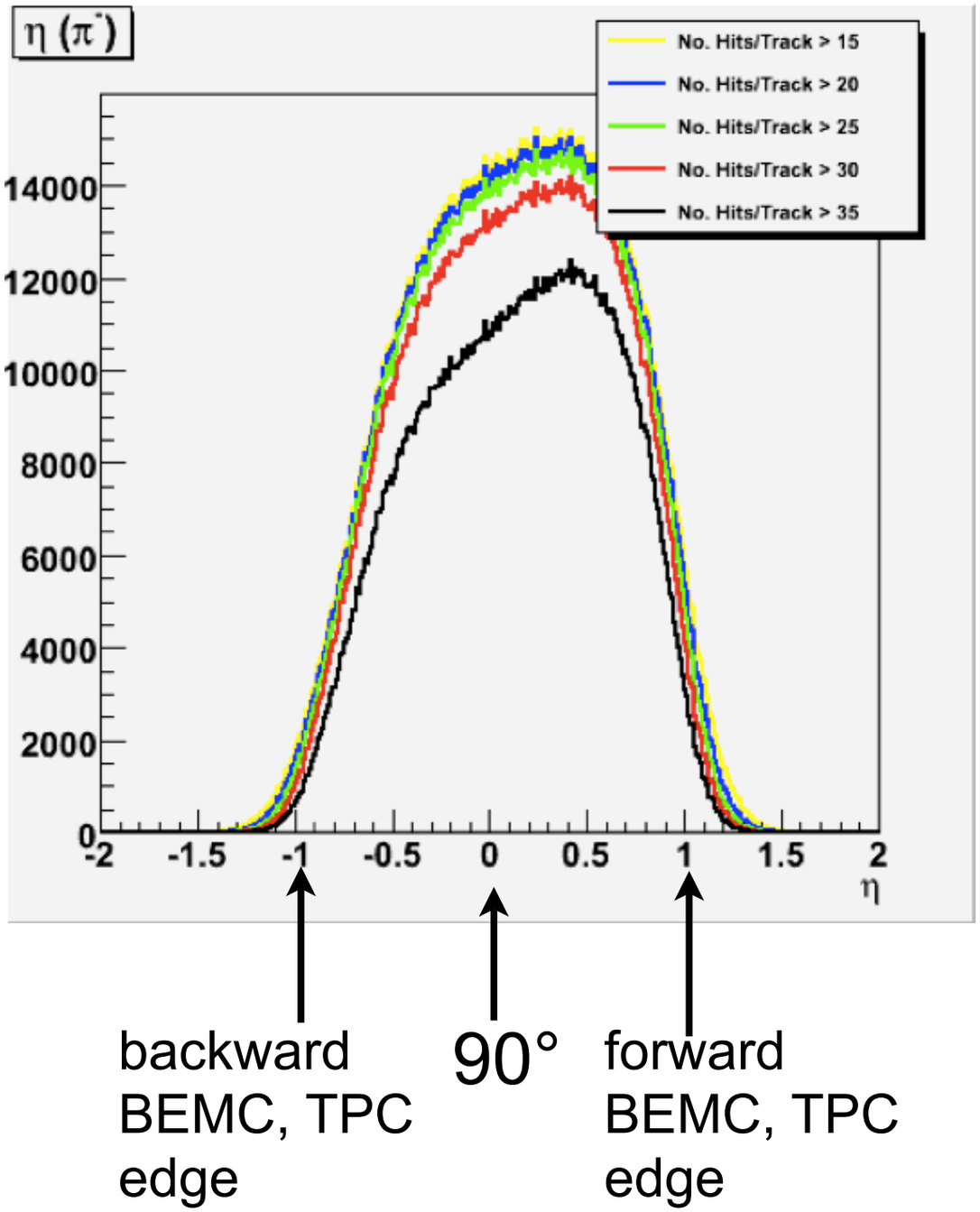

Determined by momentum and dE/dx in the TPC (≥25 fit points required)

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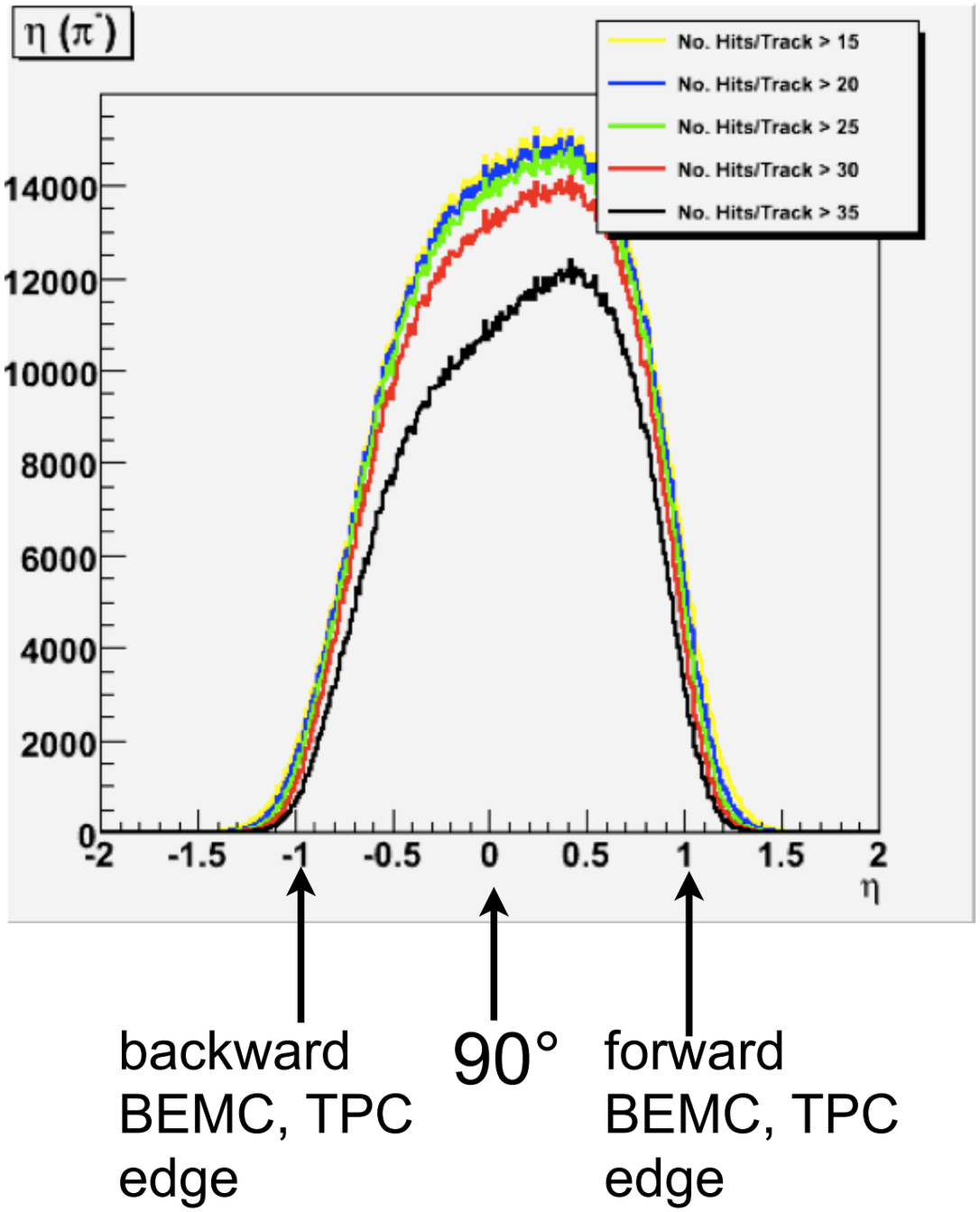

Determined by momentum and dE/dx in the TPC (≥25 fit points required)

Only *Leading* pions (highest momentum fraction *z*) are kept

Jet reconstruction

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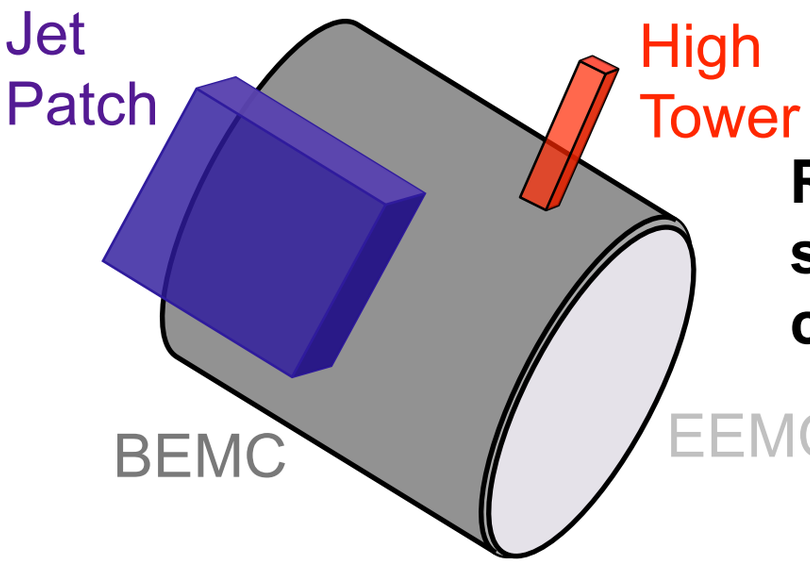
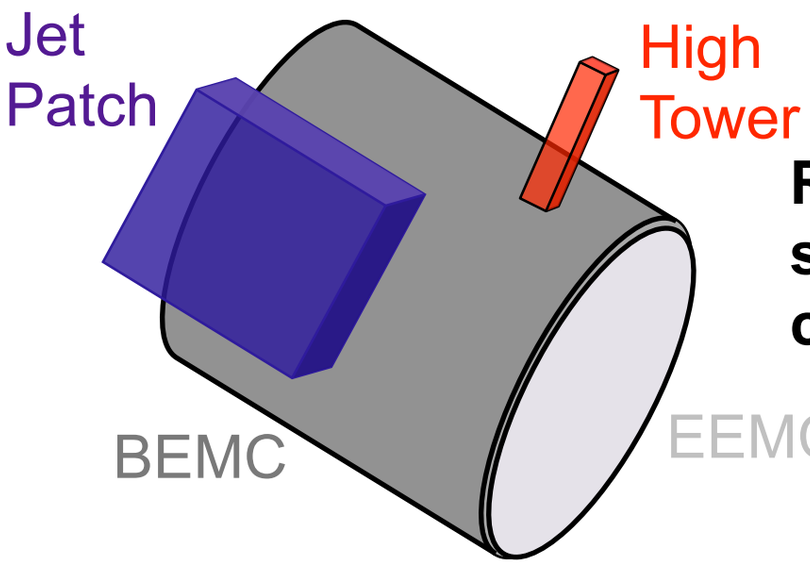


Results from several triggers compared

Jet reconstruction



Results from several triggers compared

Jet Patch trigger:
Requires sum of 400 localized "patches" above a threshold as a cluster for soft fragmentation (total coverage $\Delta\Phi = \Delta\eta = 1$)

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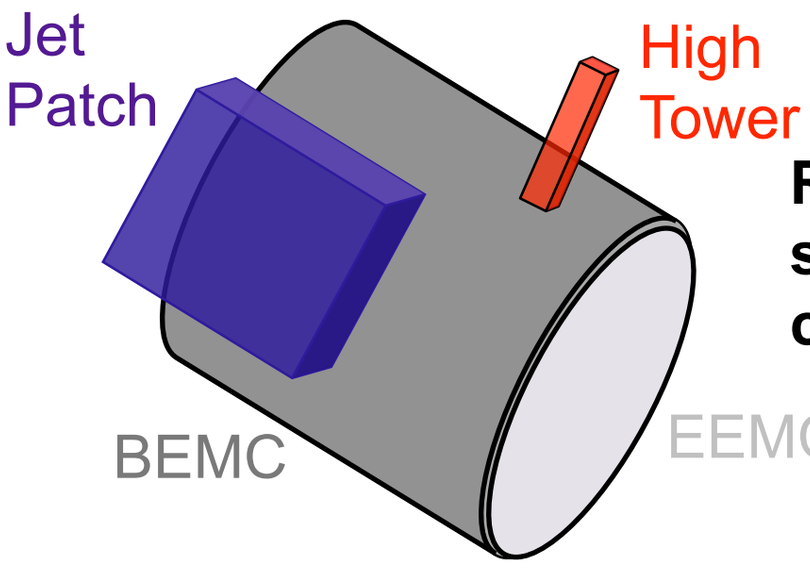

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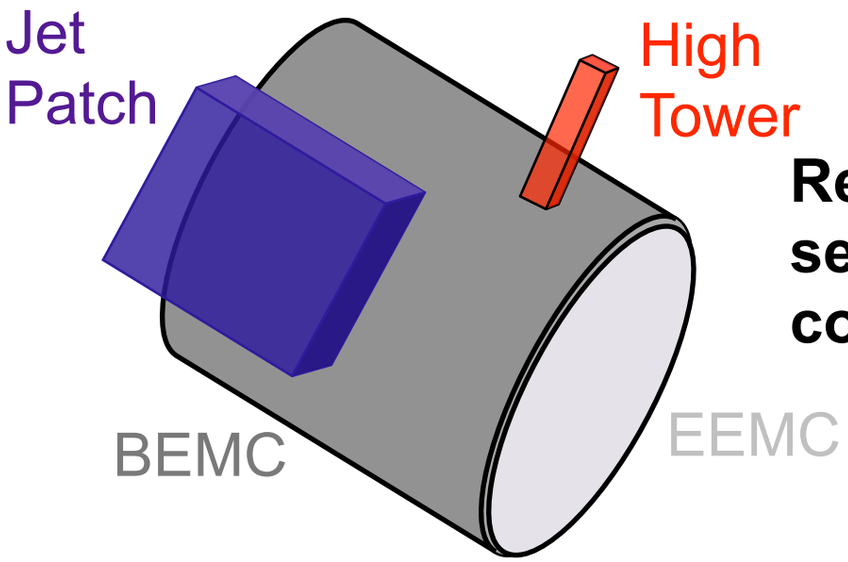

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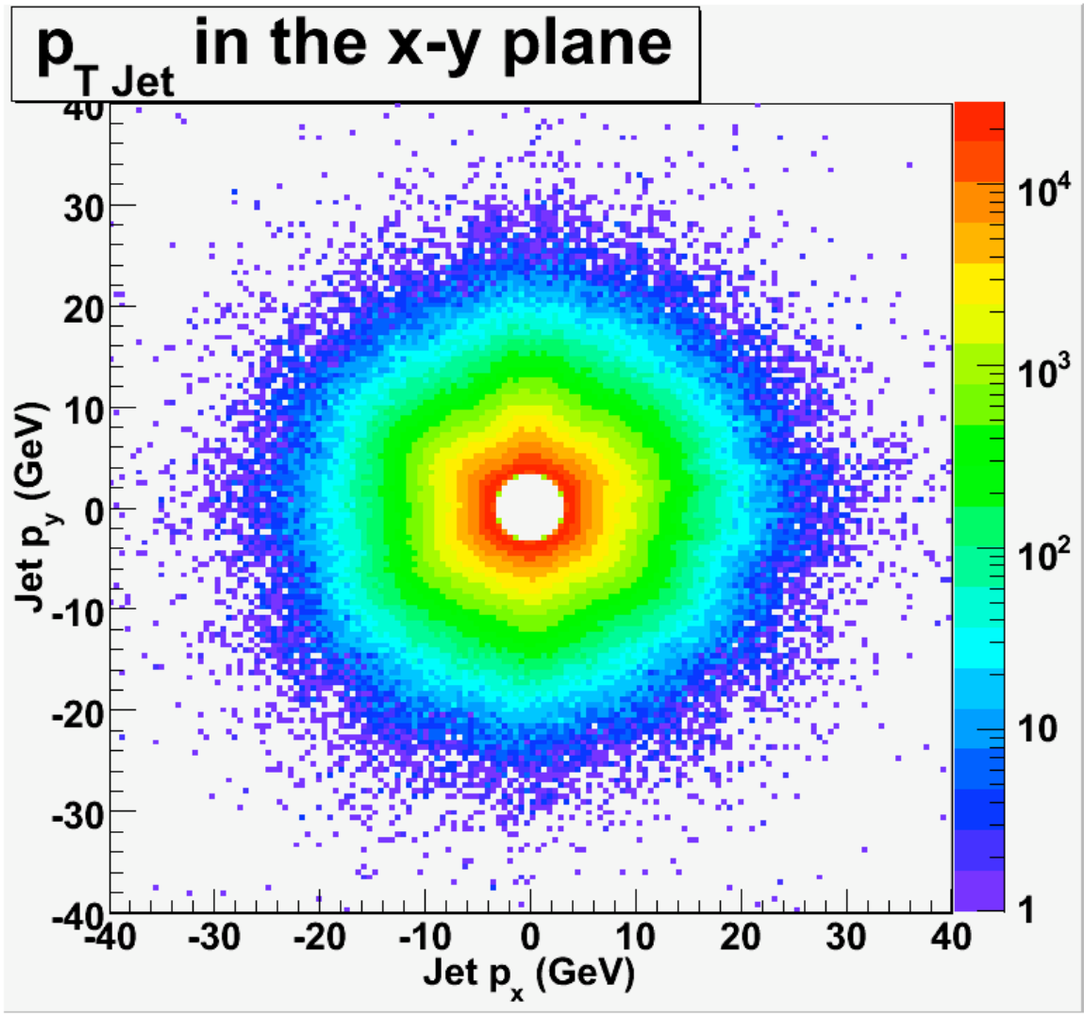

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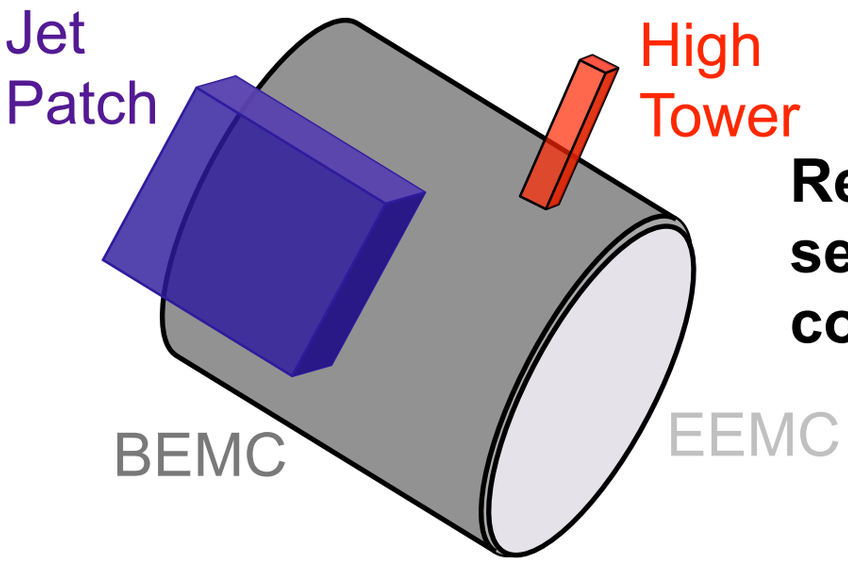

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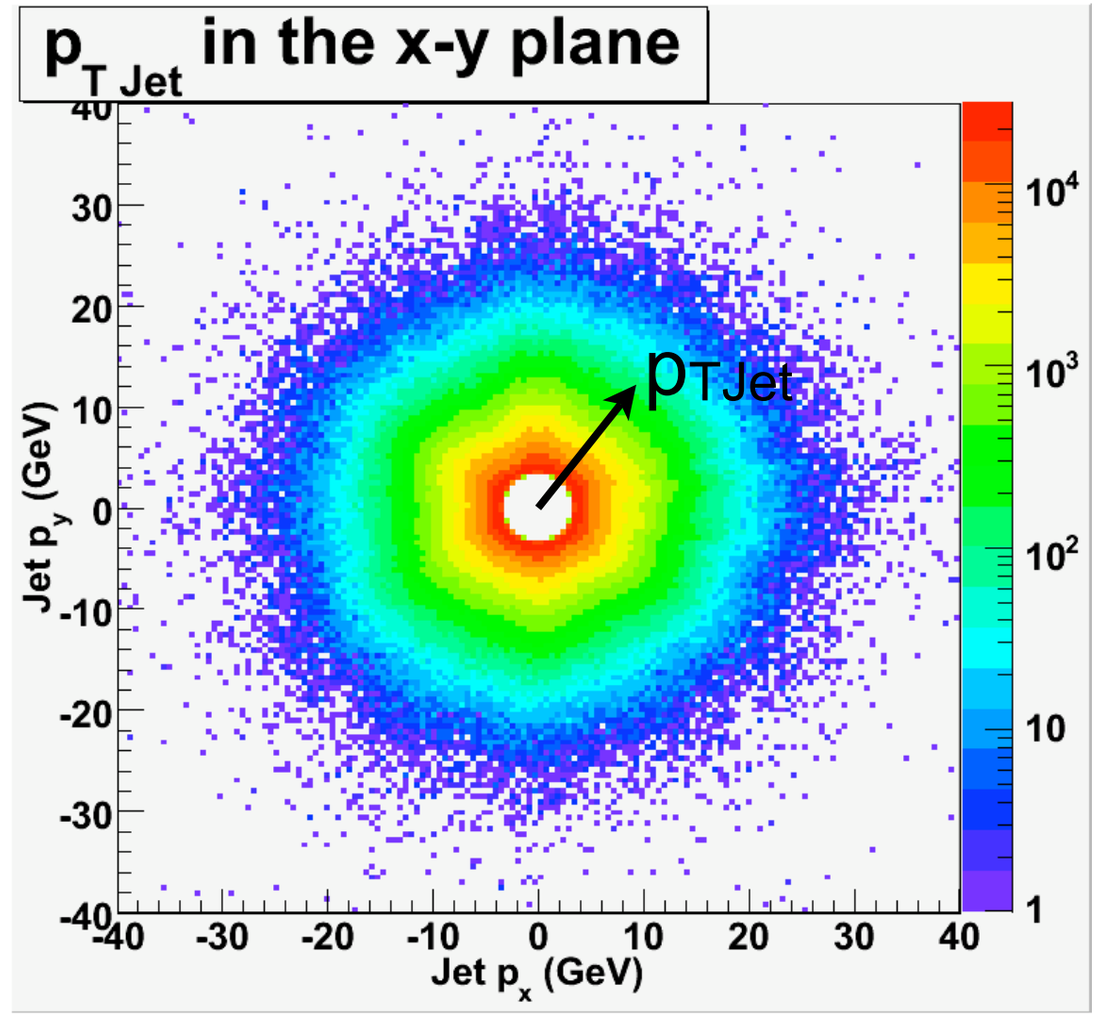

full azimuthal (Φ) coverage

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Jet physics in terms of p_T

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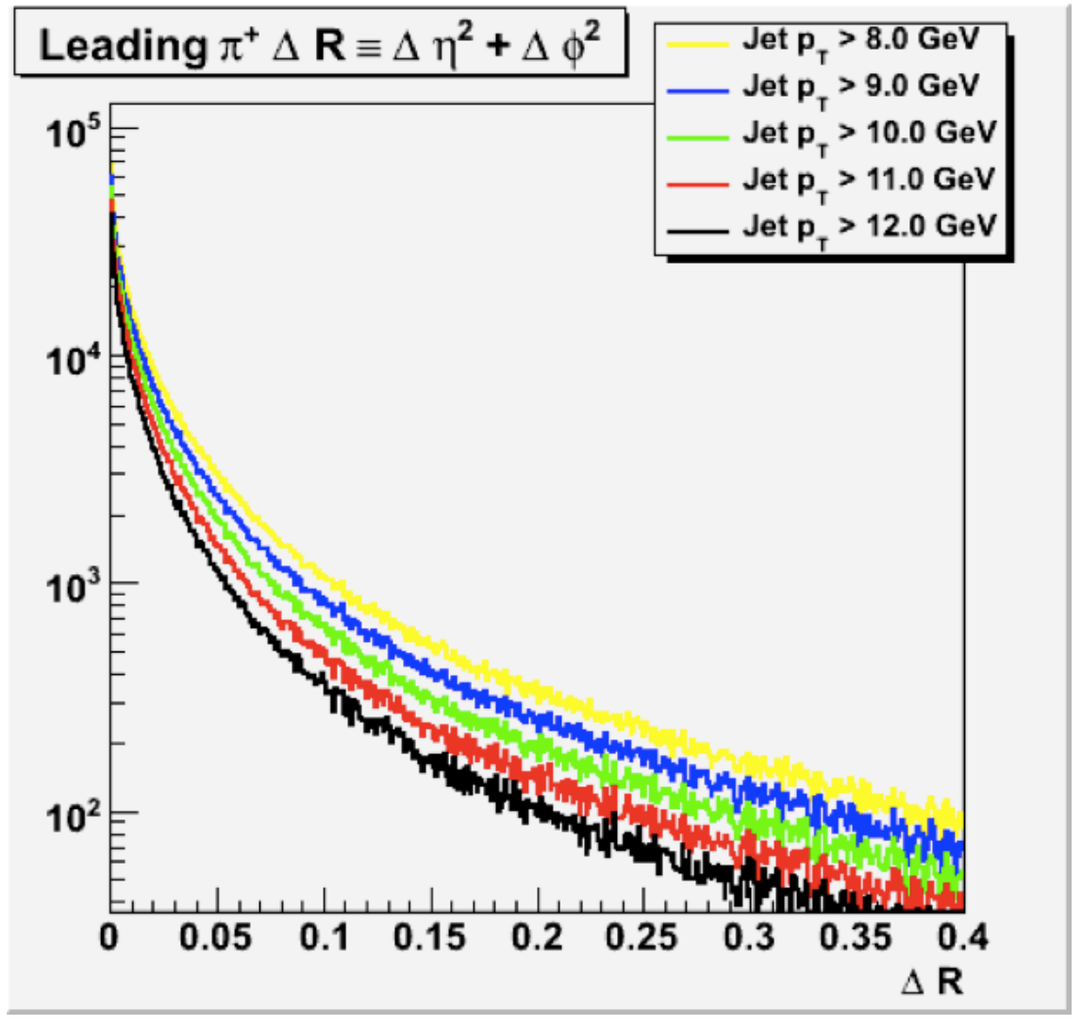
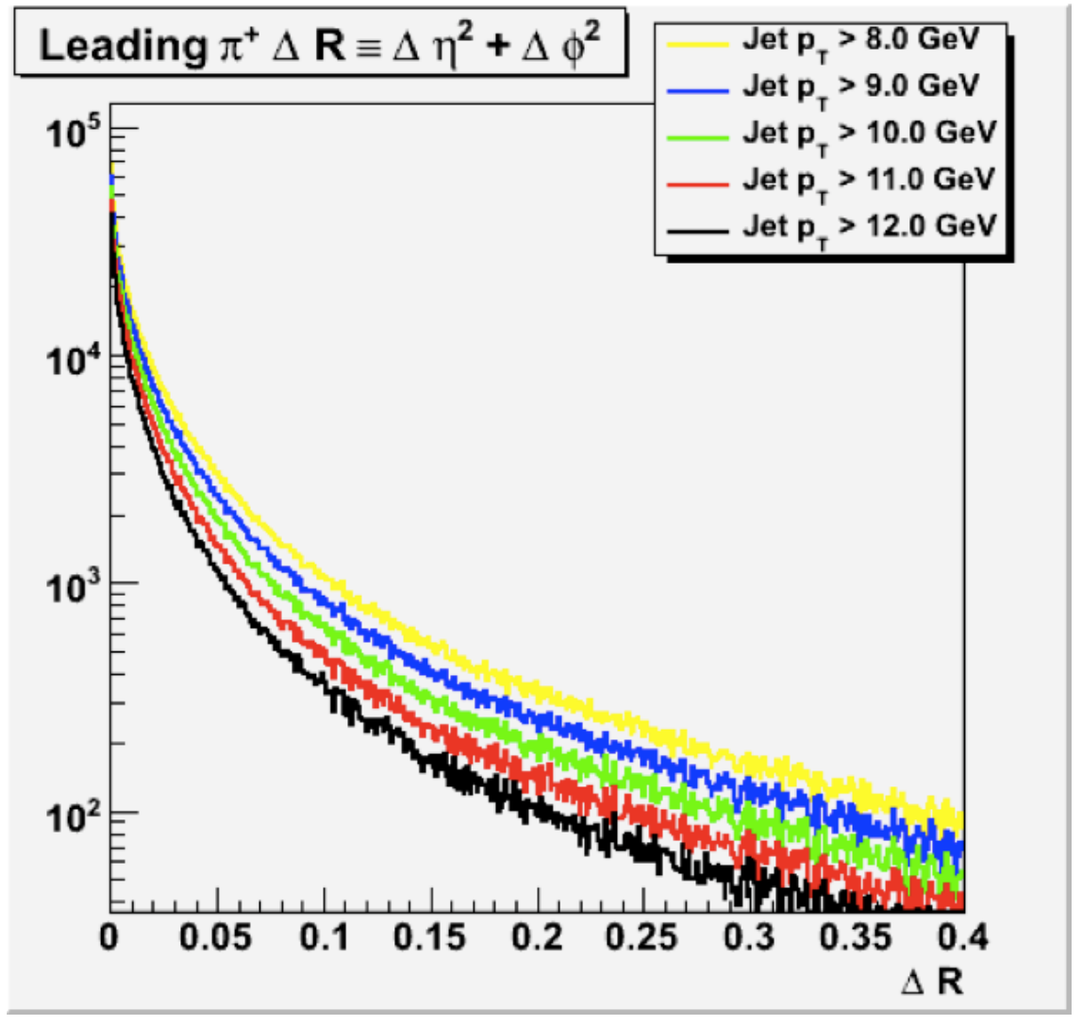


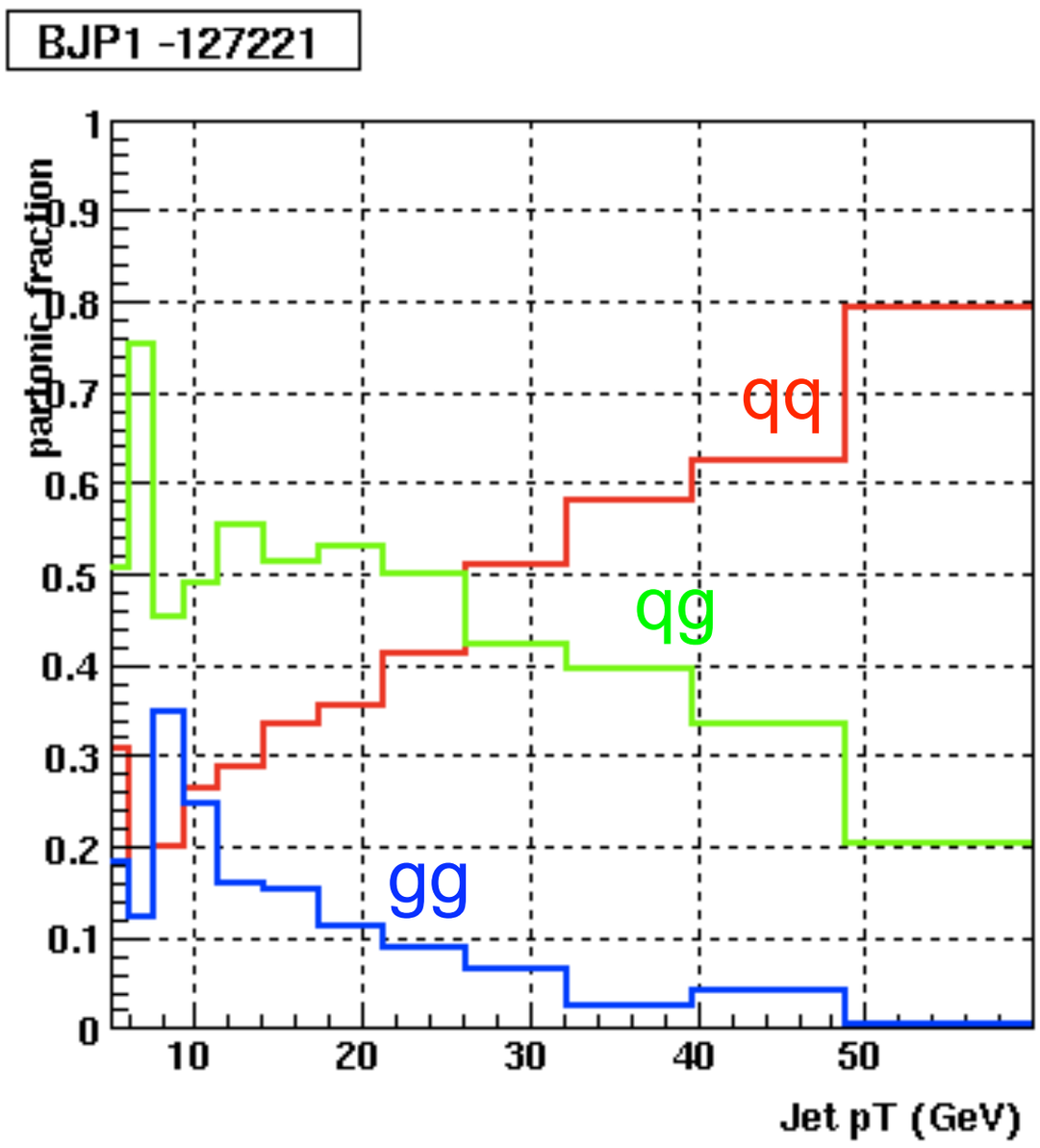
ΔR measures collimation of particles within jet

Jet physics in terms of p_T



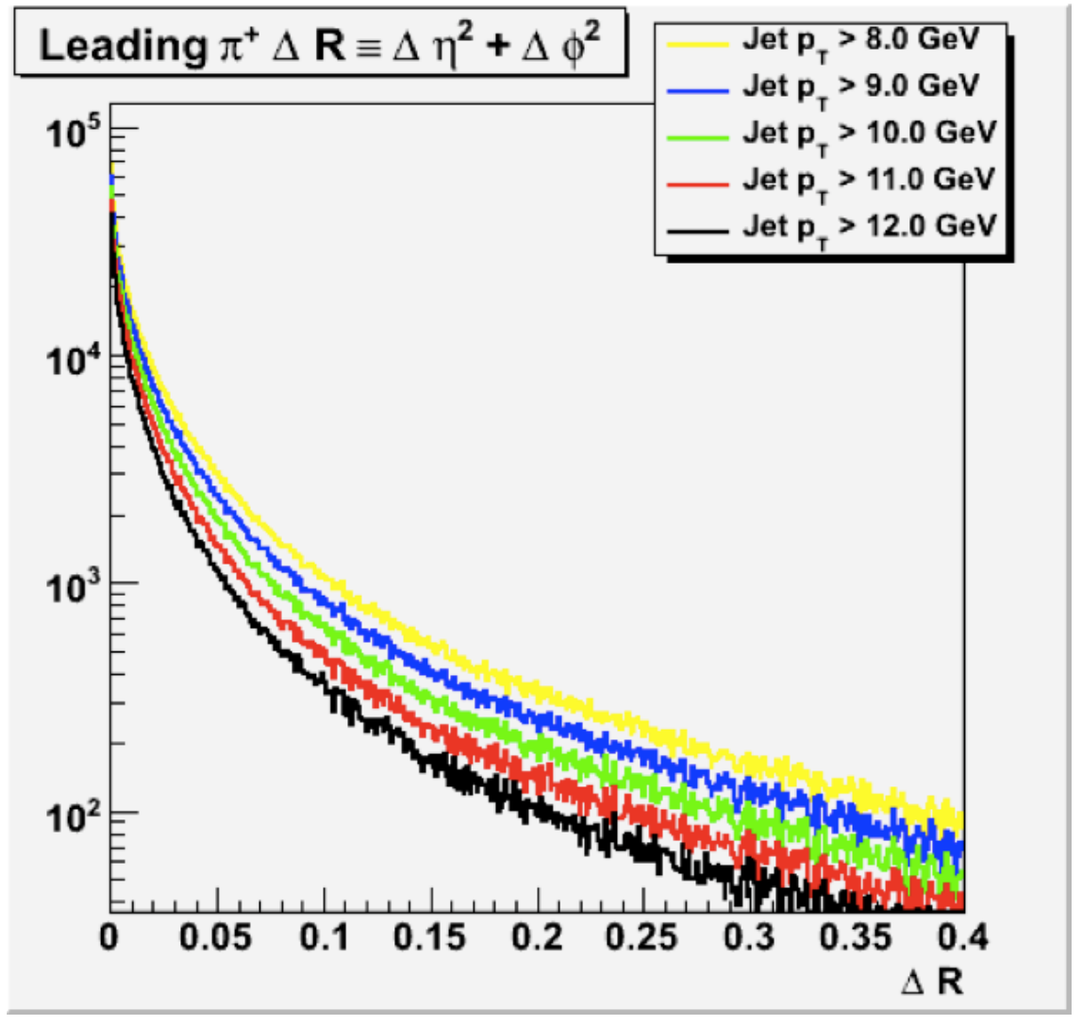
ΔR measures collimation of particles within jet

Lower p_T cut is a tradeoff between statistics and gluon event contamination:



STAR simulation (PYTHIA + GEANT) at $\sqrt{s}$ = 200 GeV

Jet physics in terms of p_T



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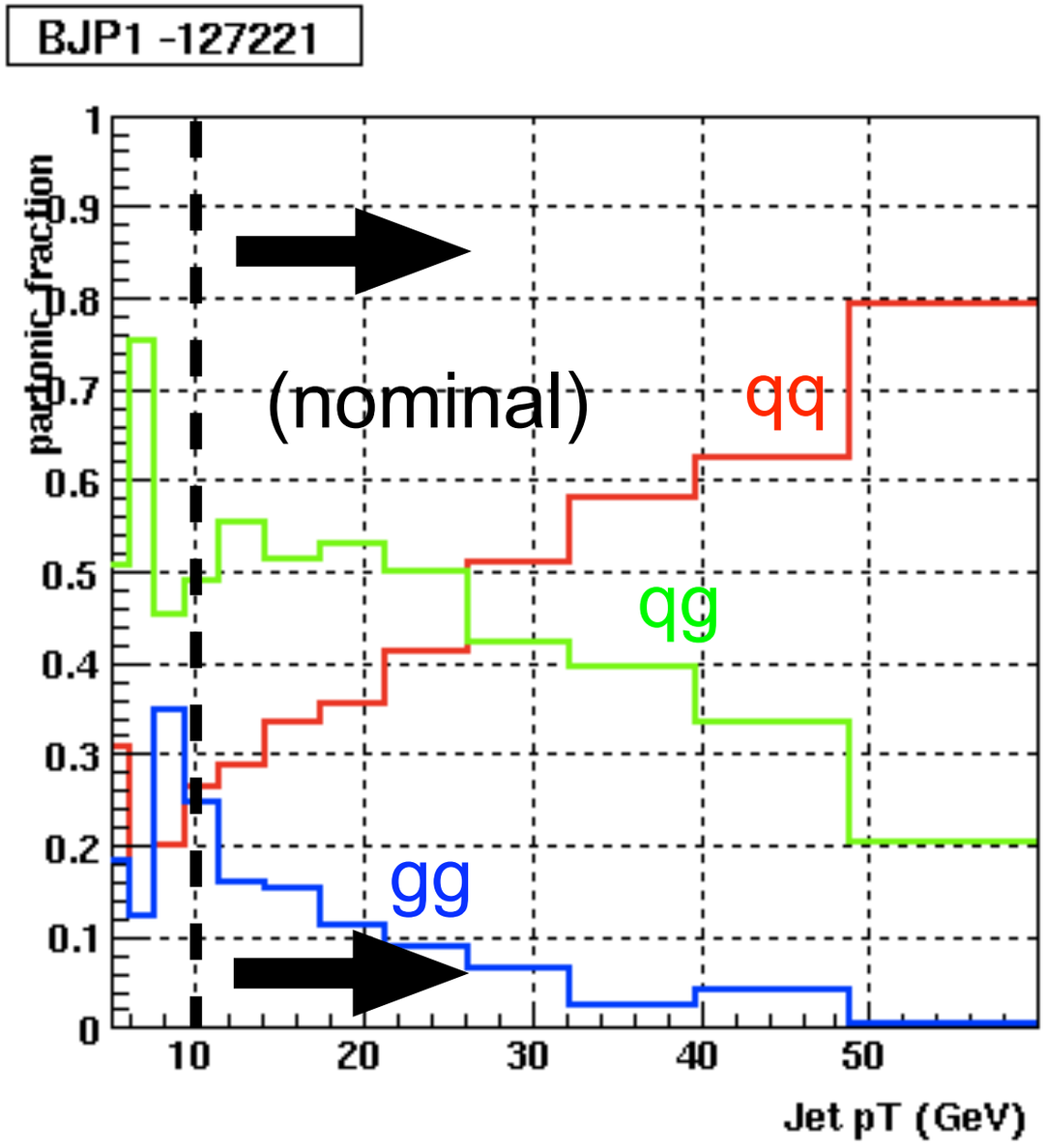
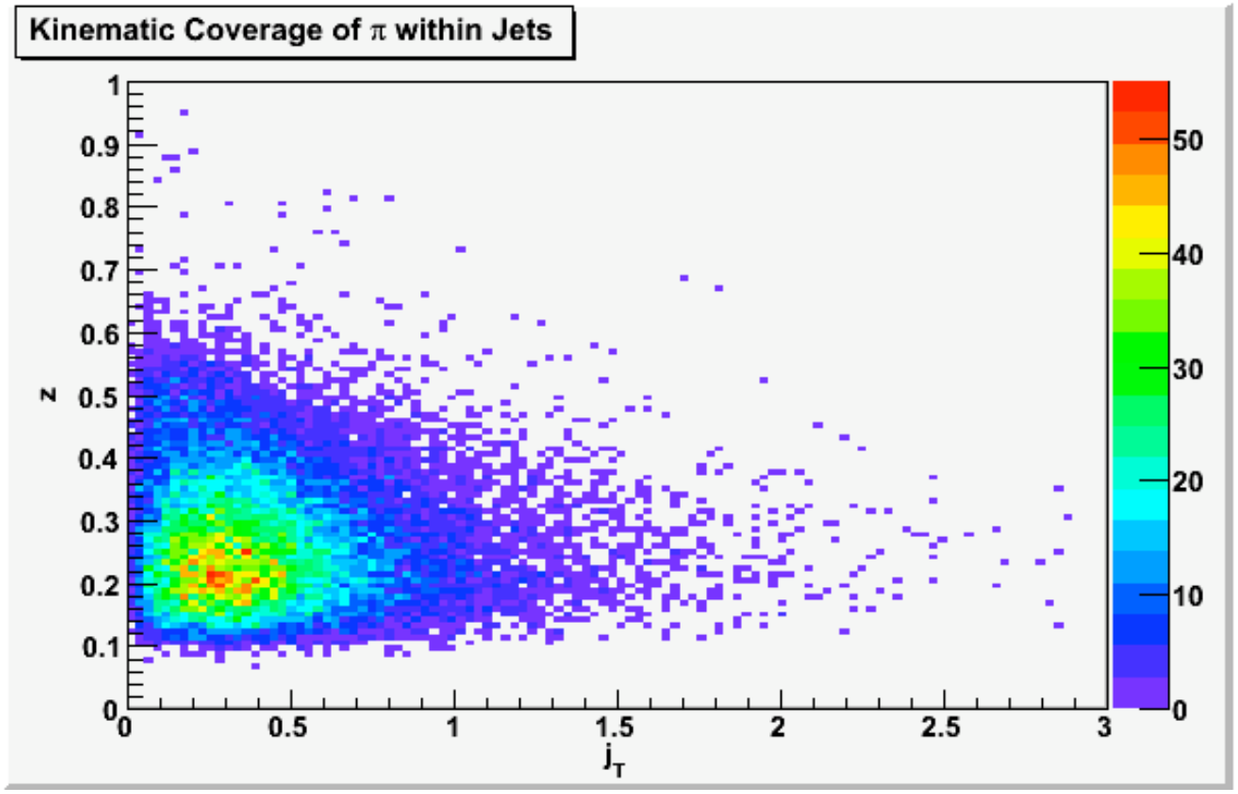


STAR simulation (PYTHIA + GEANT) at $\sqrt{s}$ = 200 GeV

Data separated by z and j_T ;



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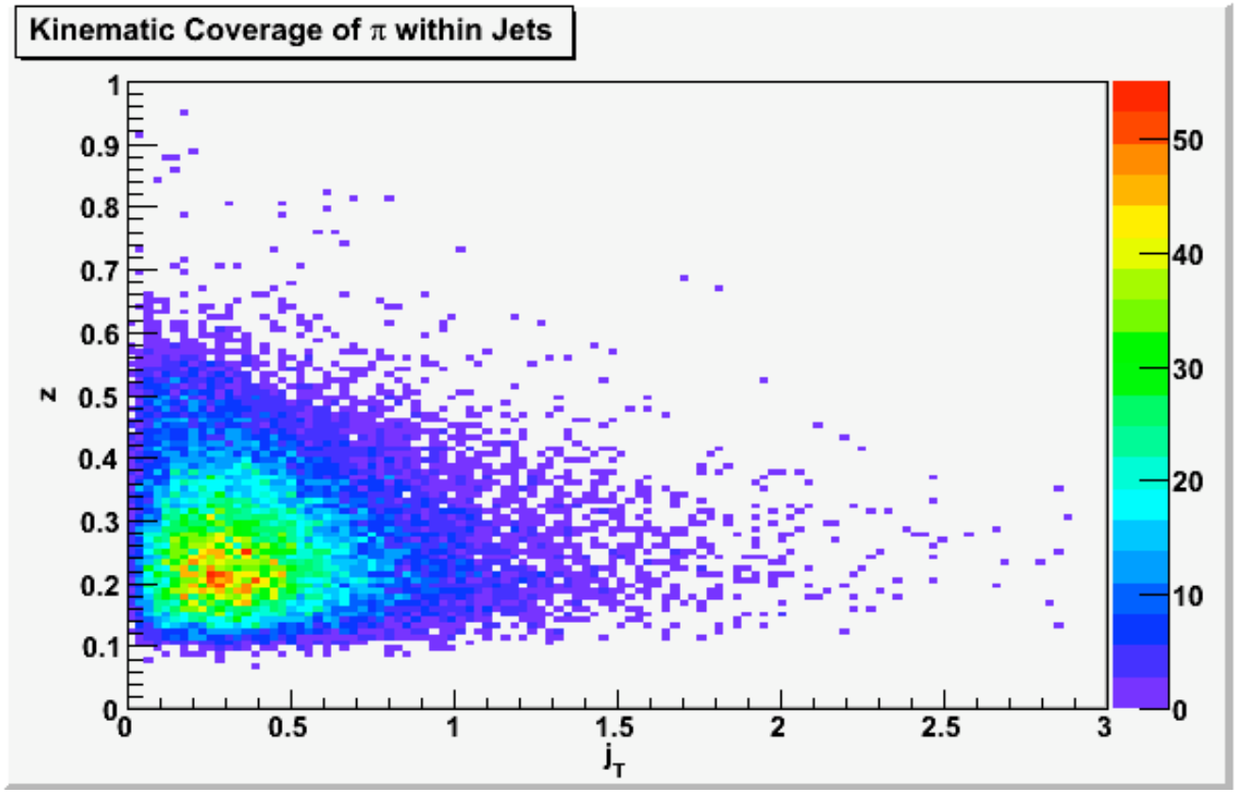
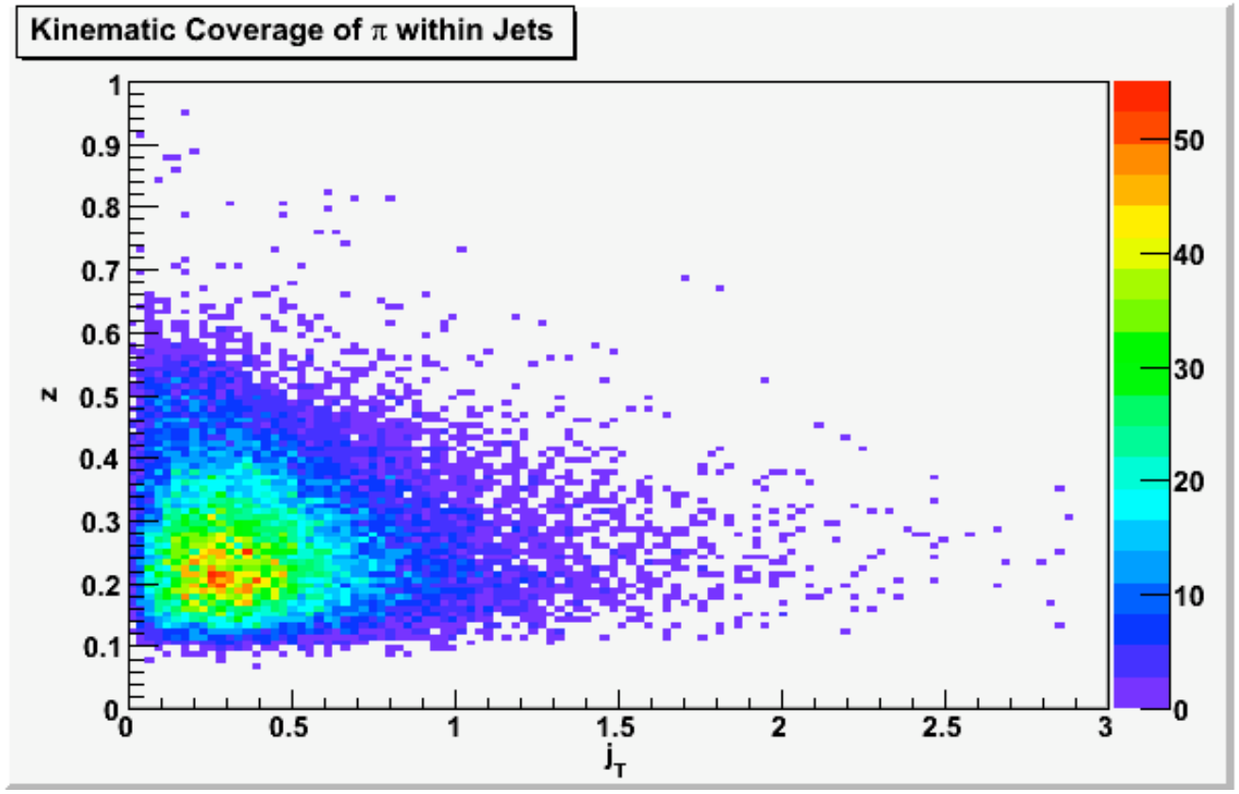


Asymmetry can be measured in terms of either z or j_T

(z = hadron/jet momentum fraction;
j_T = hadron momentrum transverse to jet)

Data separated by z and j_T; azimuthal angles calculated:



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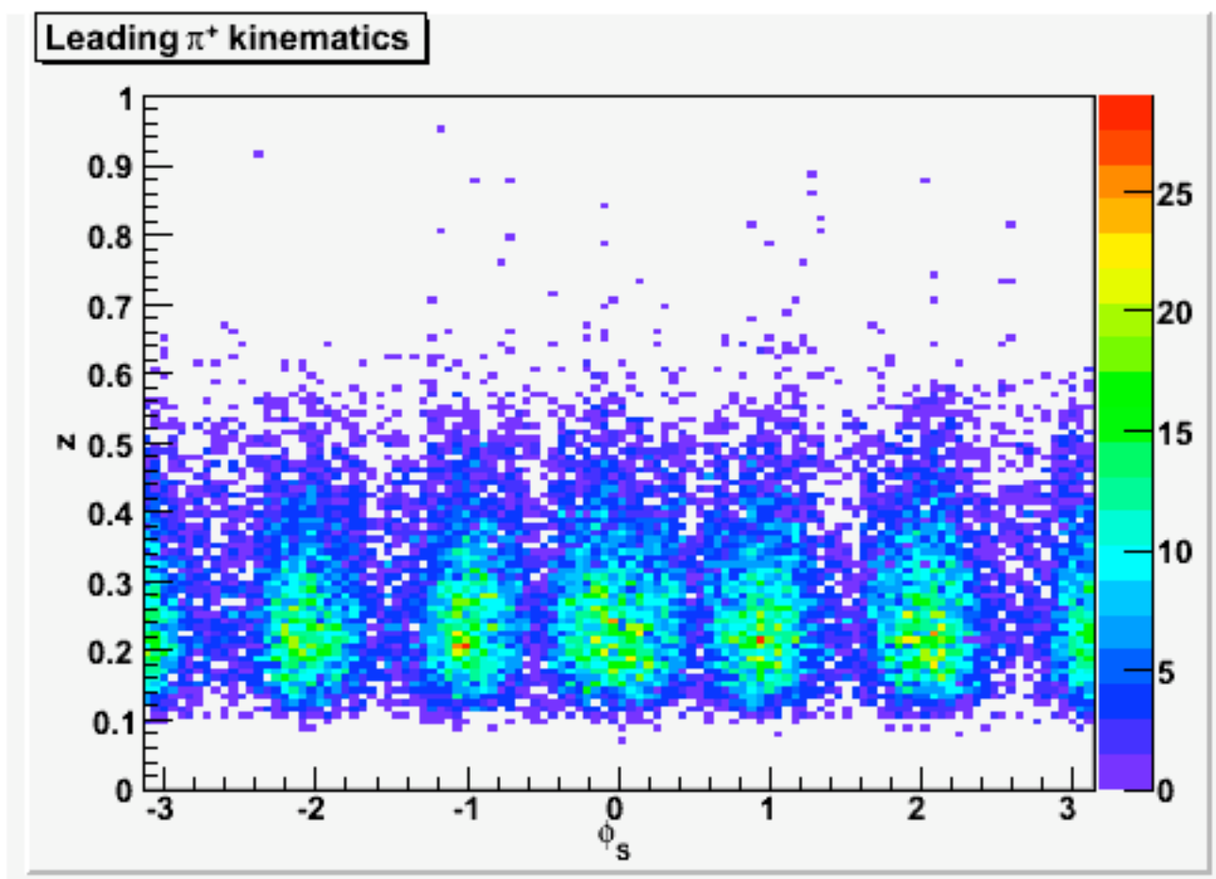
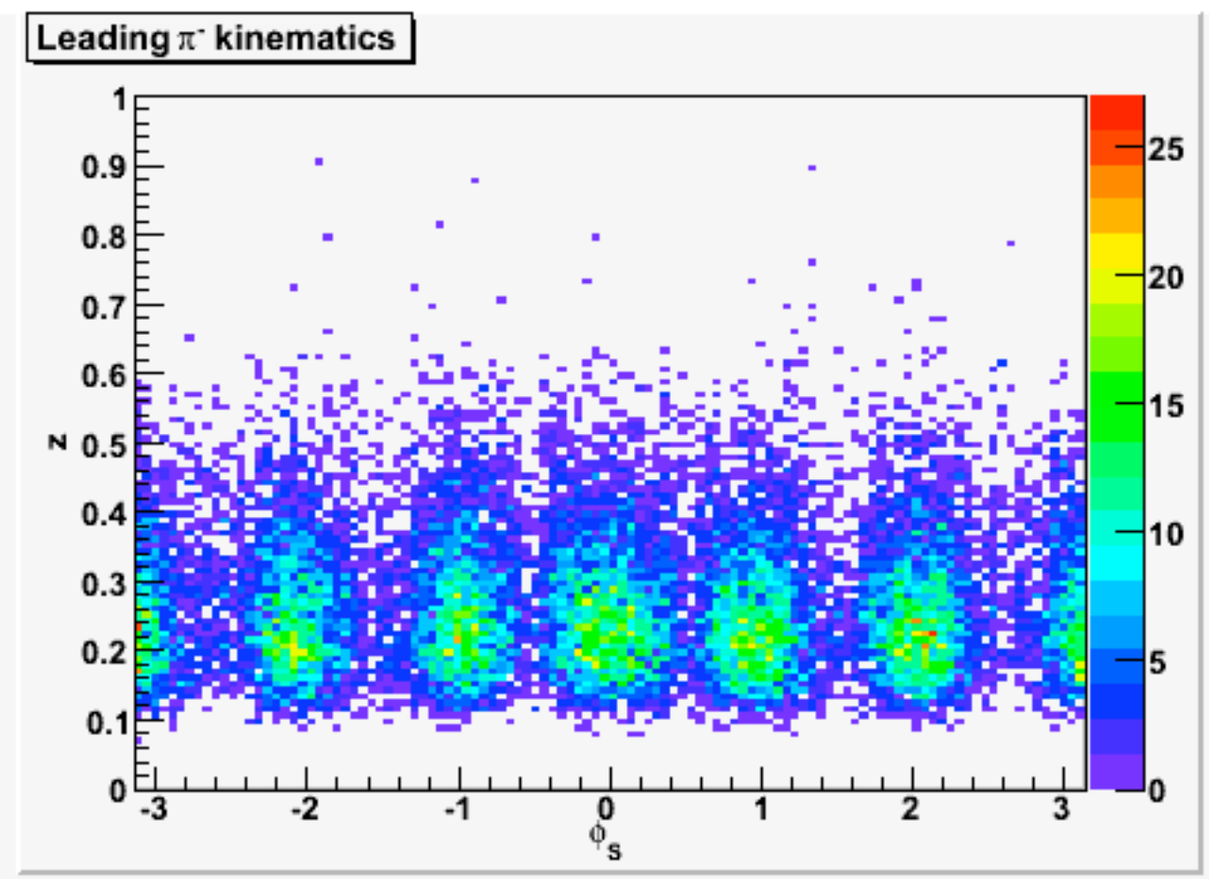




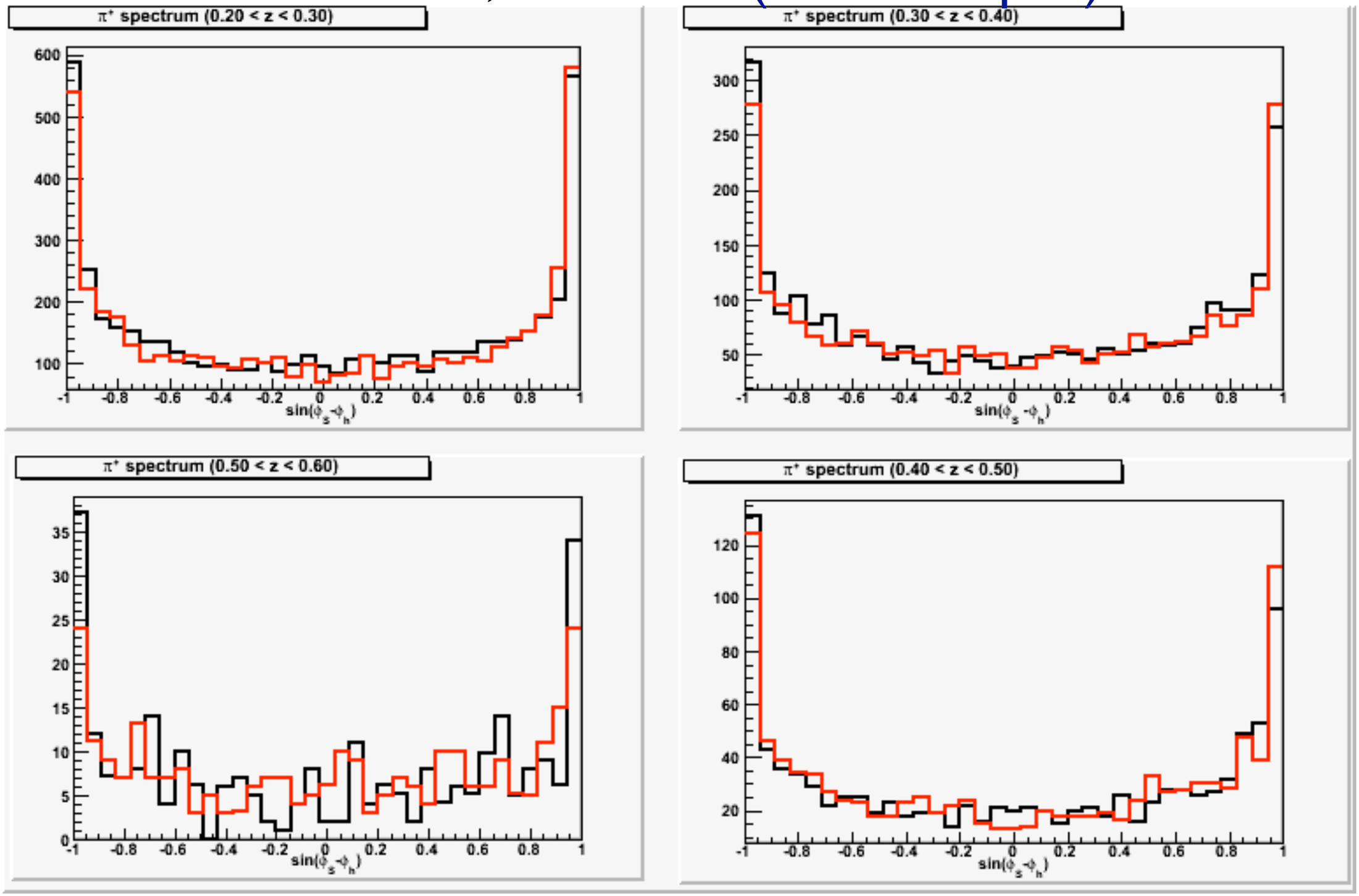
Goals of this Presentation:

- Show statistical expectations of measured asymmetries and summarize systematic concerns

$\sin(\Phi_s - \Phi_\pi)$ spectrum

$\sin(\Phi_s - \Phi_\pi)$ spectrum

Red = ↑ , Black = ↓ (lab frame pol.)



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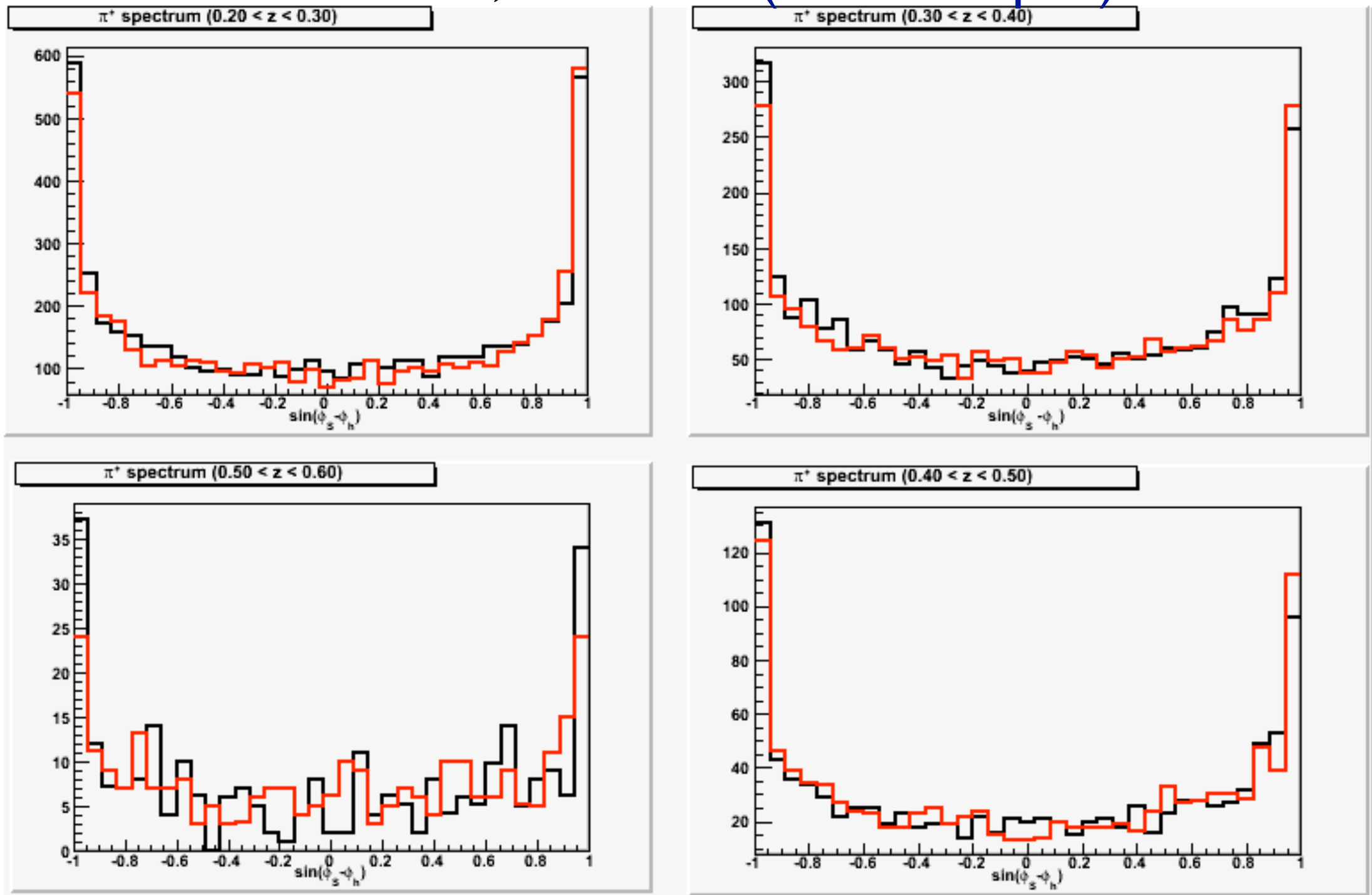

(Use of opposing polarizations, weighted by beam luminosity, ensures that detector acceptances cancel in the asymmetry.)

Asymmetry Statistics

Asymmetry Statistics

“blue” beam polarized

“yellow” beam polarized

(jets in forward hemisphere of each beam analyzed)

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Asymmetry should be opposite in sign for + vs. – pions

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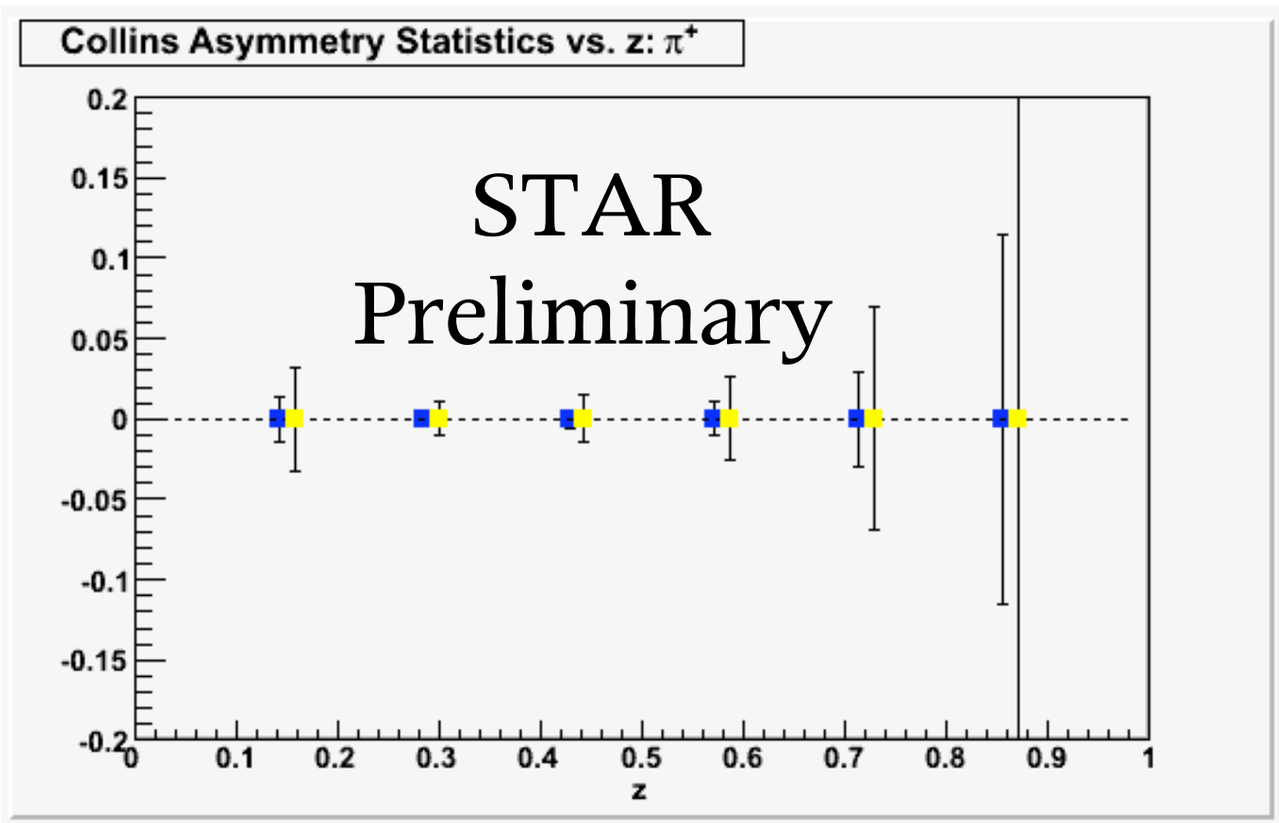

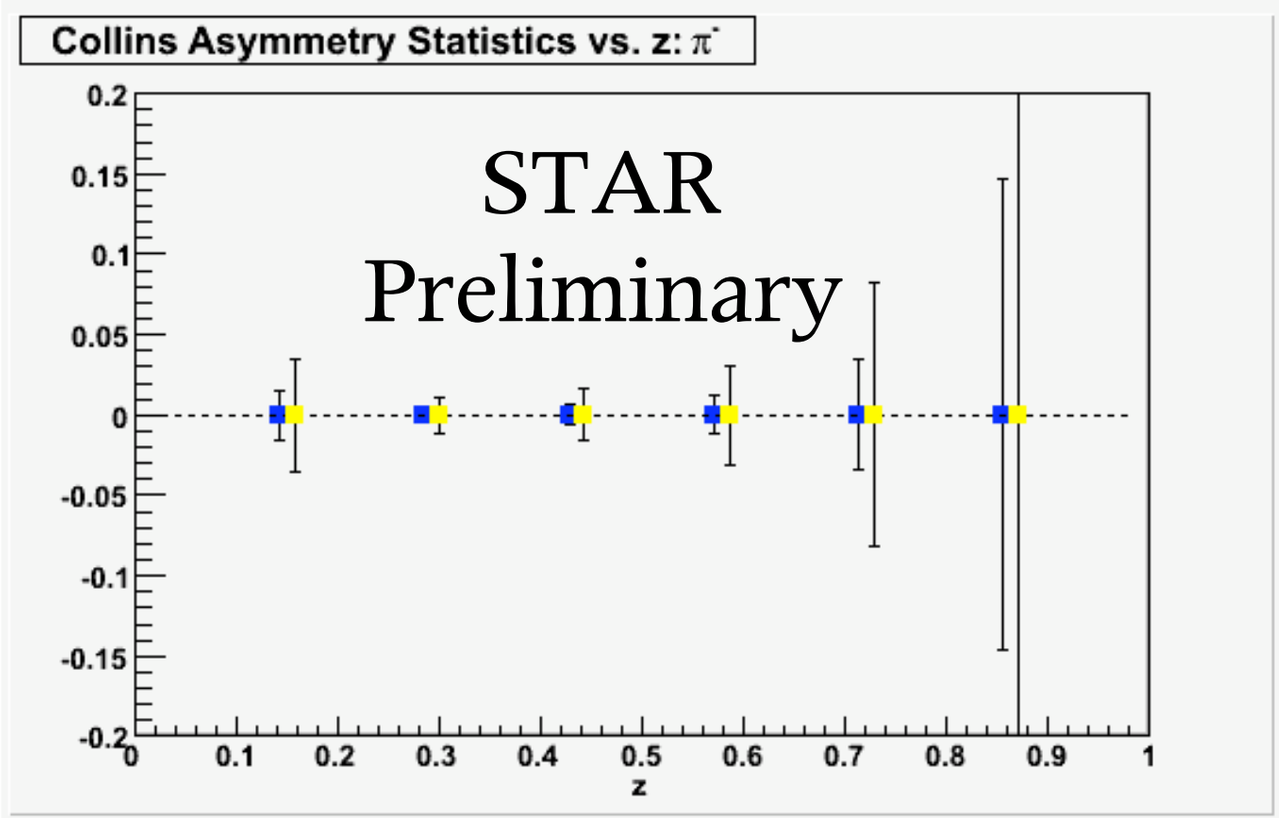

"blue" beam polarized

"yellow" beam polarized

(jets in forward hemisphere of each beam analyzed)

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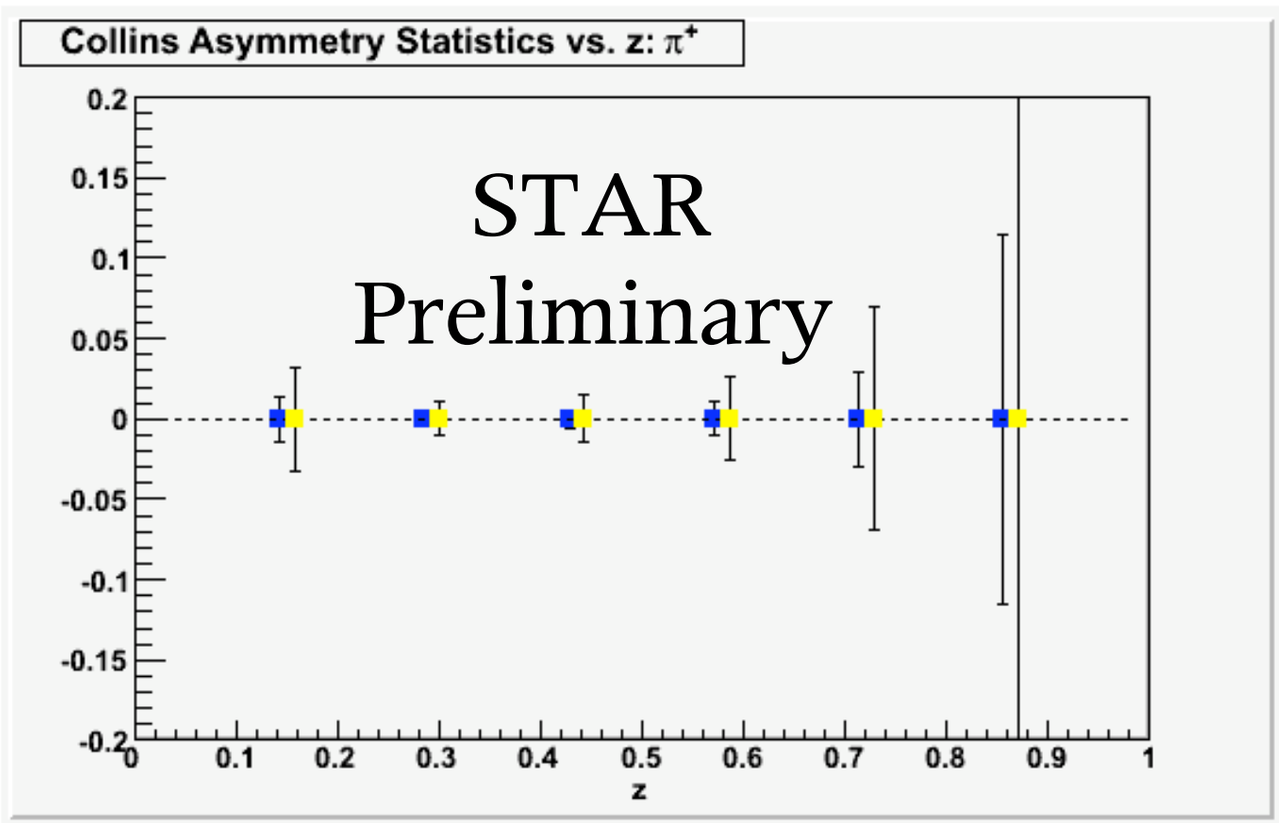
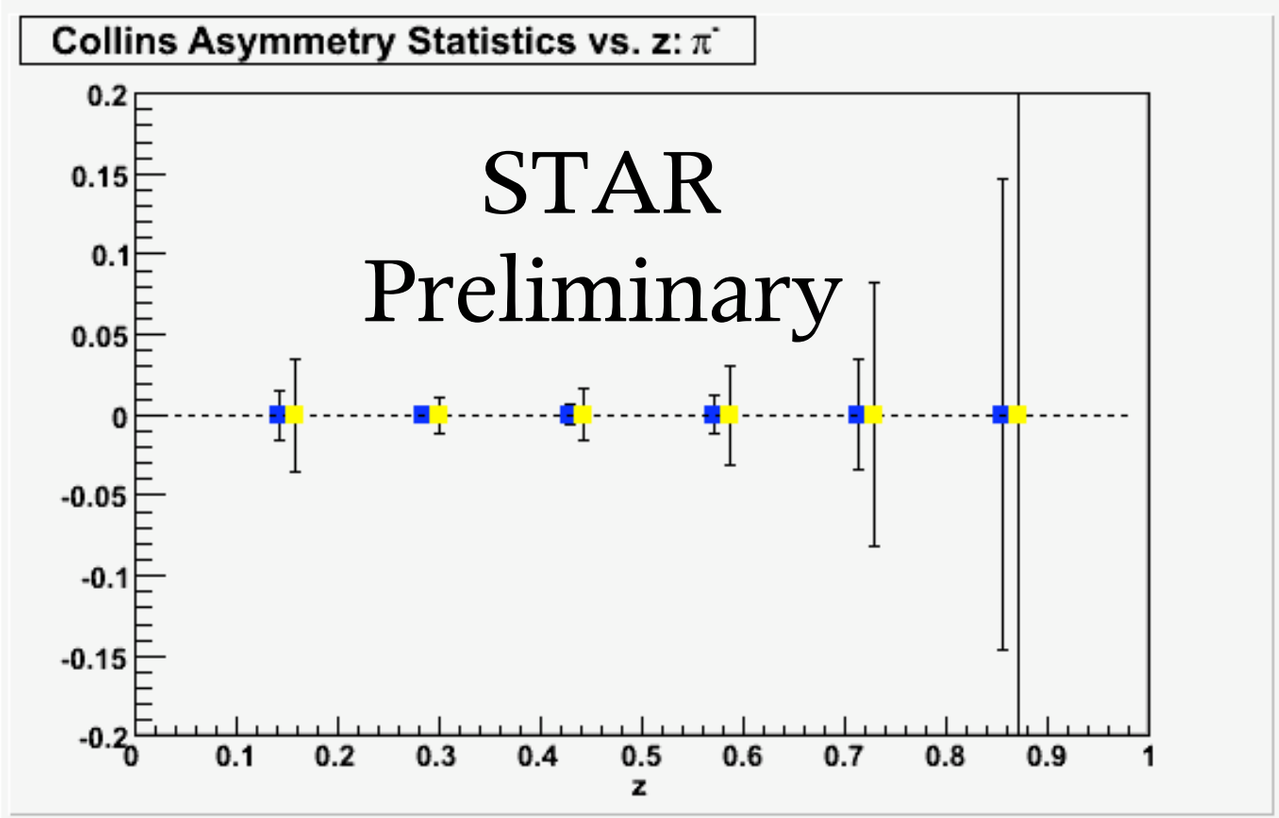




"blue" beam polarized

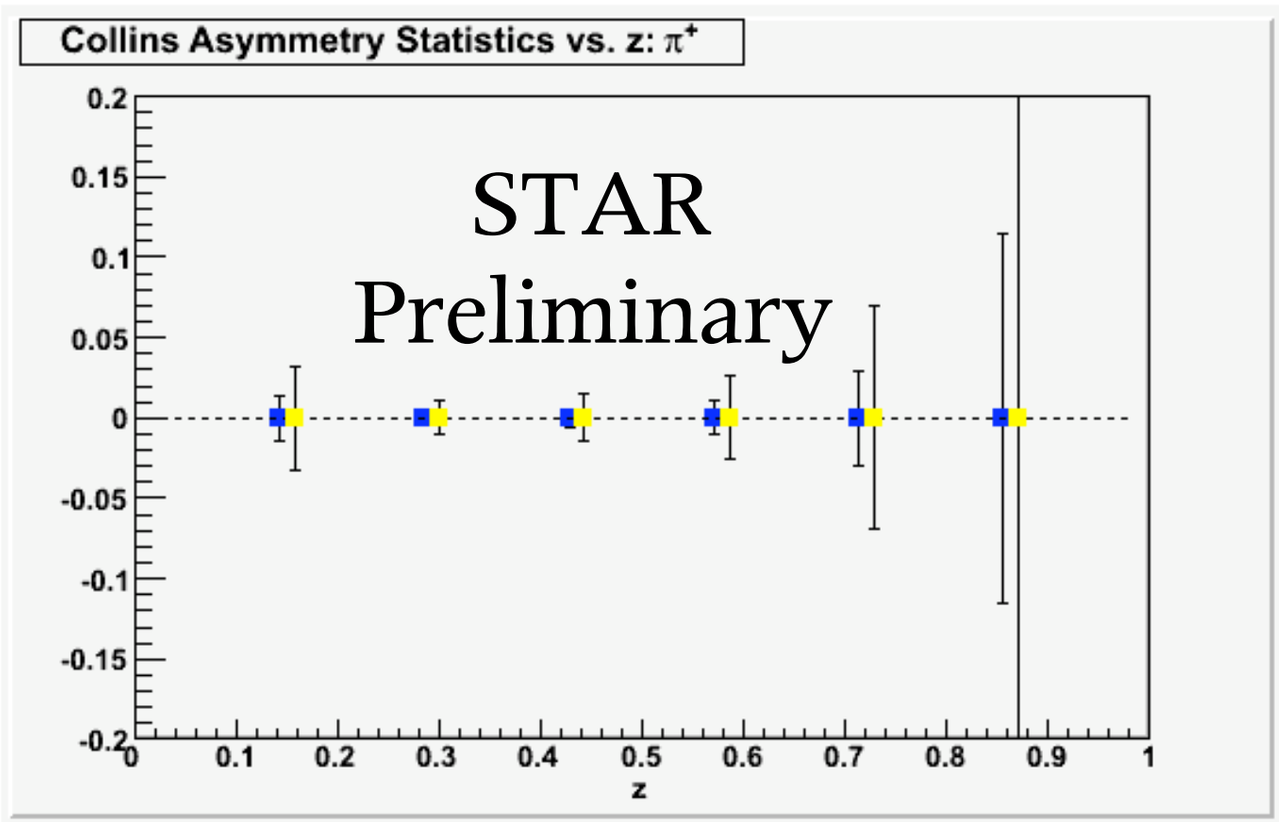
"yellow" beam polarized

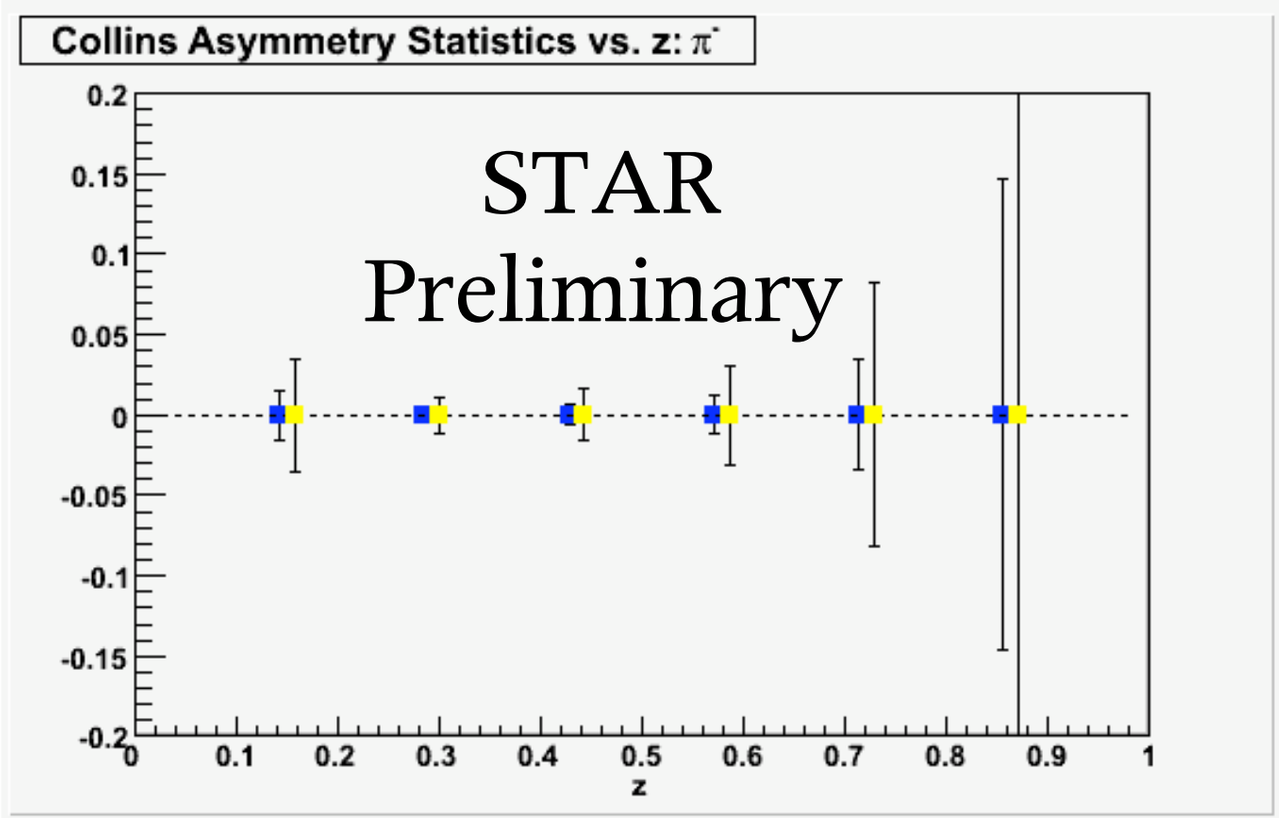
(jets in forward hemisphere of each beam analyzed)

Asymmetry should be opposite in sign for + vs. – pions

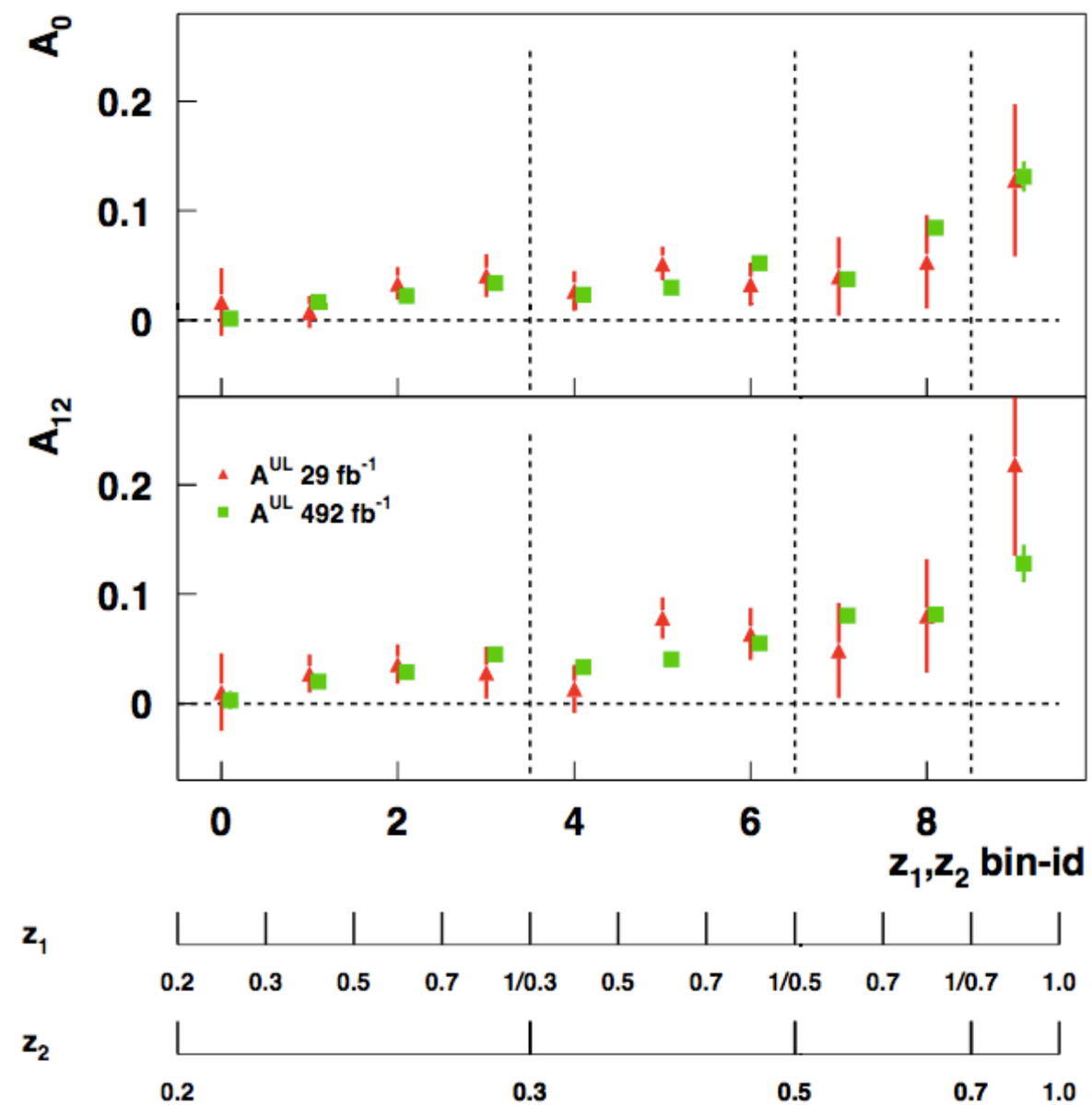
Simulation/theory (estimate): $A \quad (\pi^{\pm}) \approx \pm 0.03$

Asymmetry Statistics





R. Seidl et.al. **Phys.Rev.D78:032011,2008**.



Published e^+e^- results from Belle

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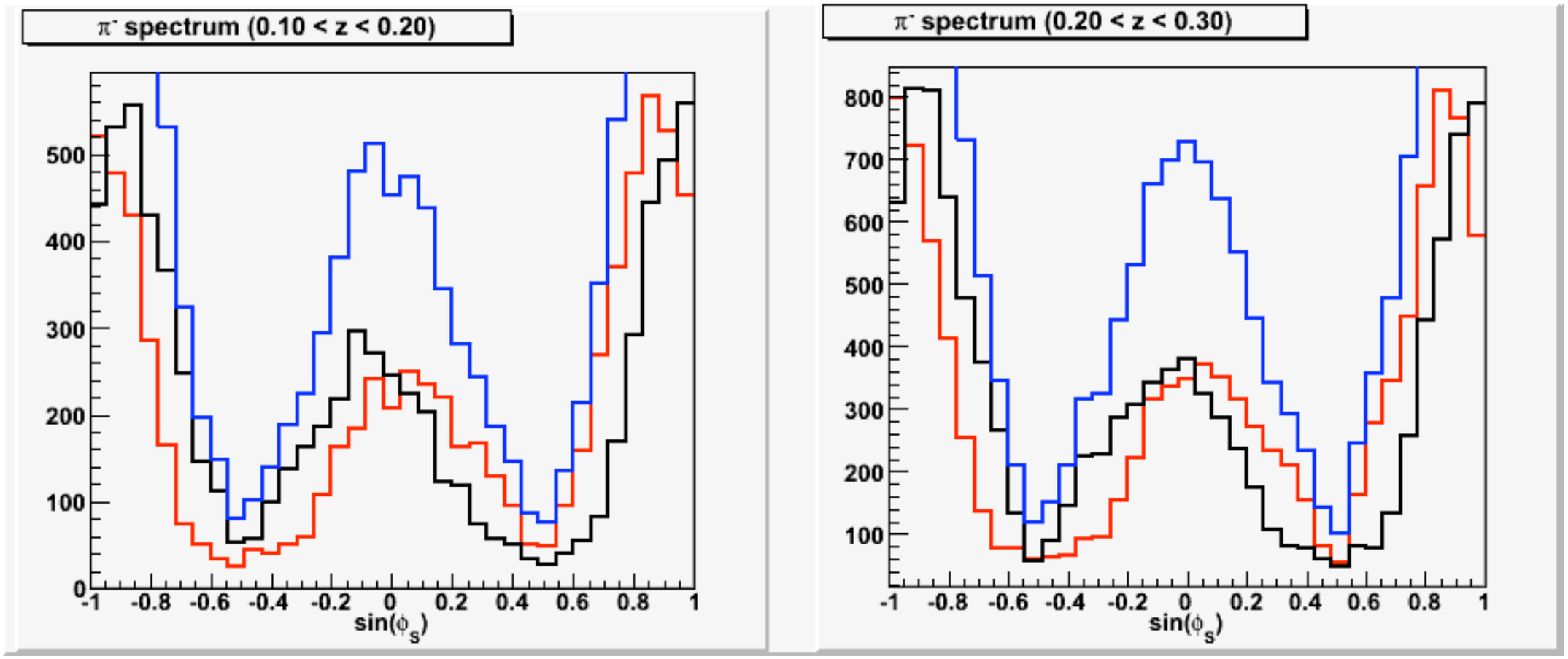
Extra Reference Slides

...after acceptances cancel when ↑ and ↓ polarizations are added



red = up pol., black = down pol., blue = added

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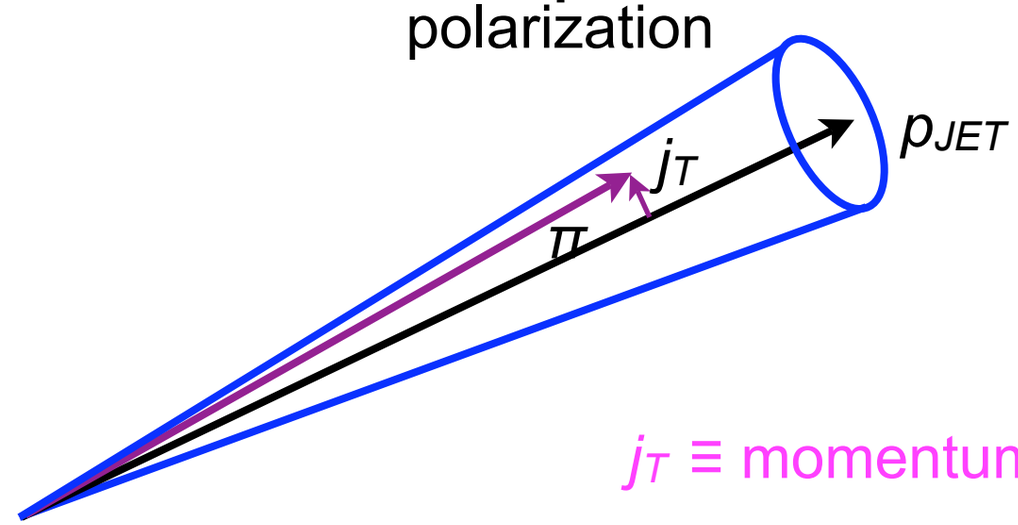

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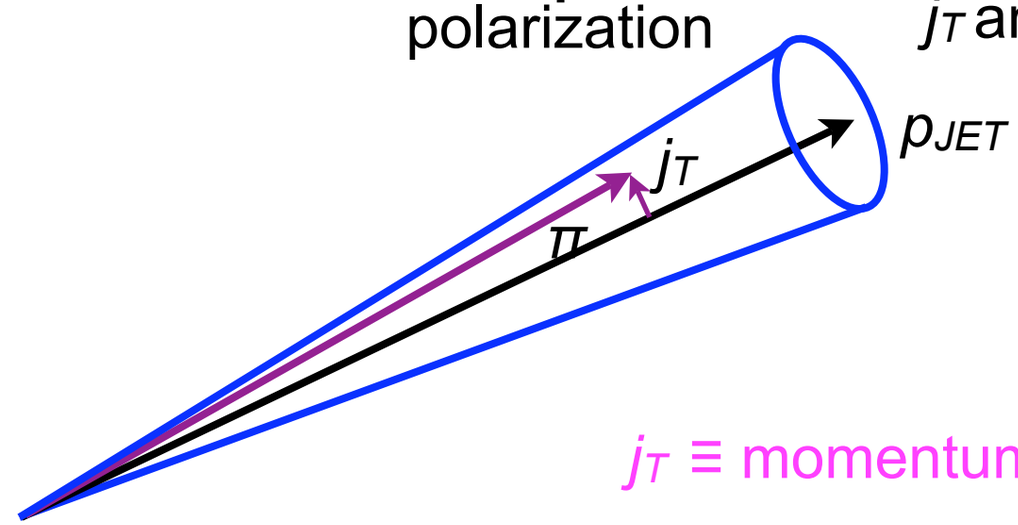
pol. angle



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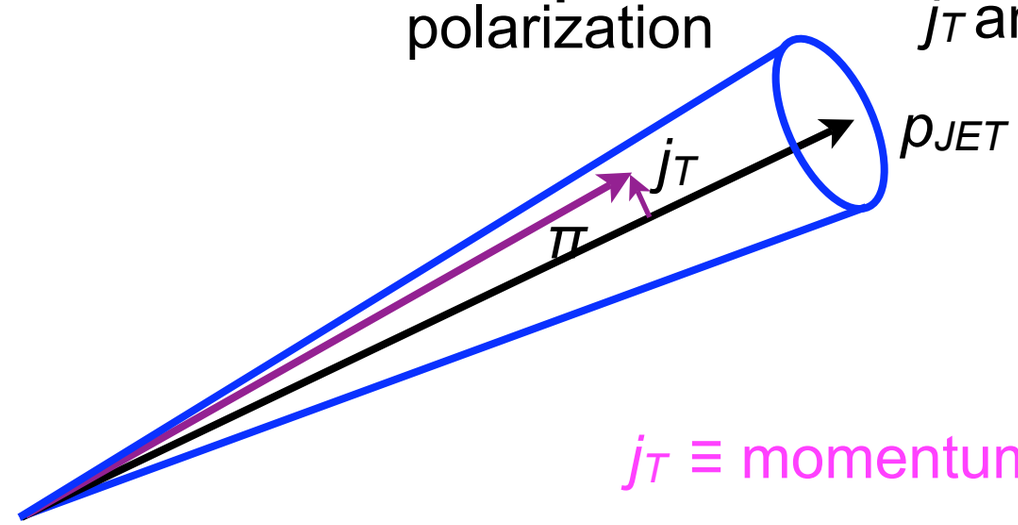

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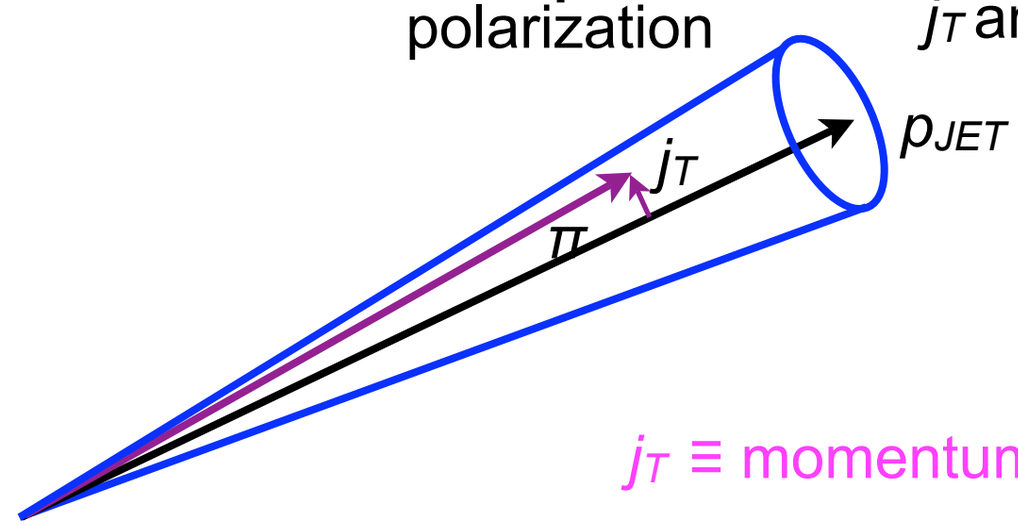

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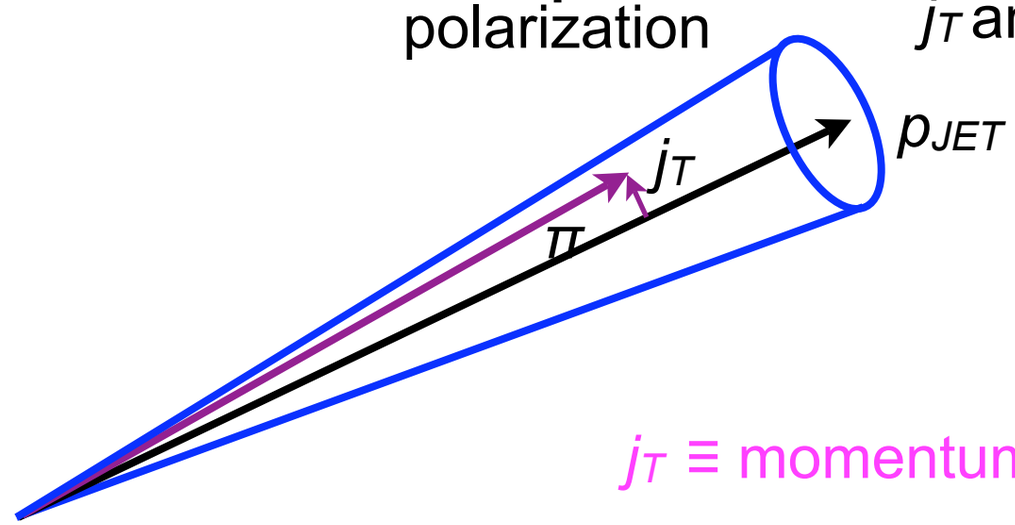

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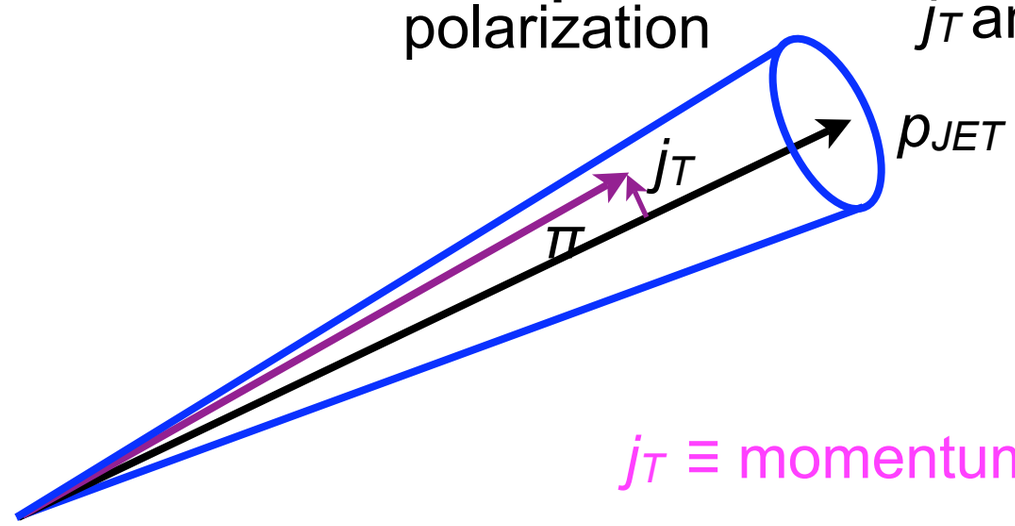

Extraction of Collins fragmentation function from fit to SIDIS data (HERMES, COMPASS) and Belle Collab. data (KEK) (Anselmino, *et al.*, 2008)

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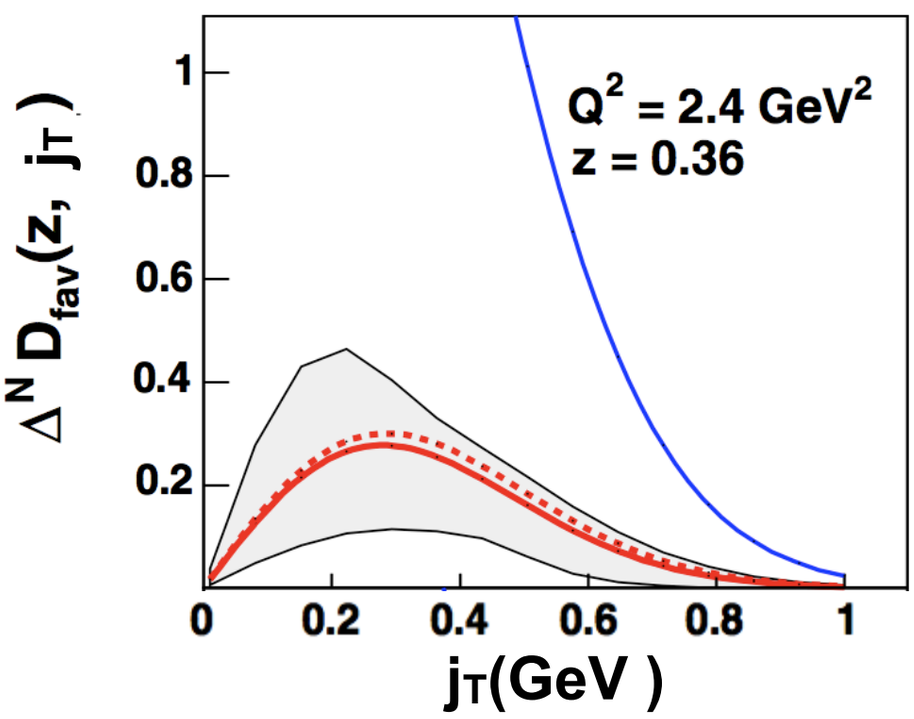

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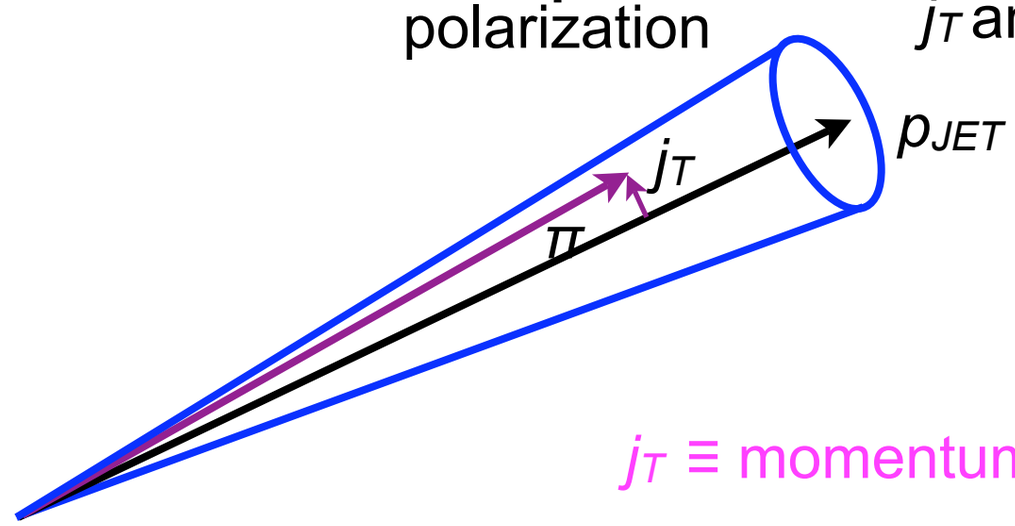

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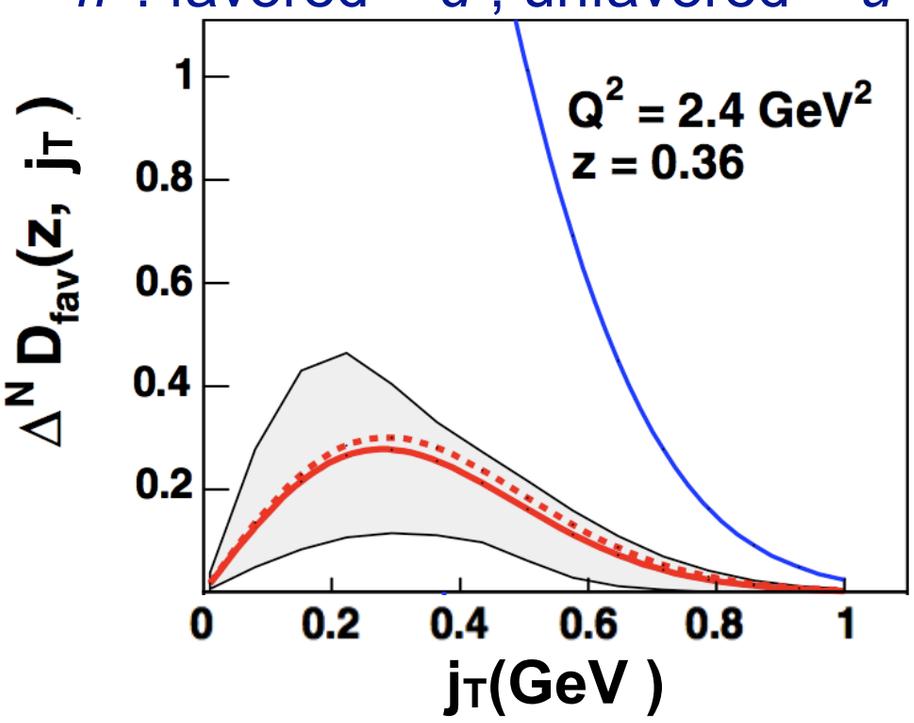

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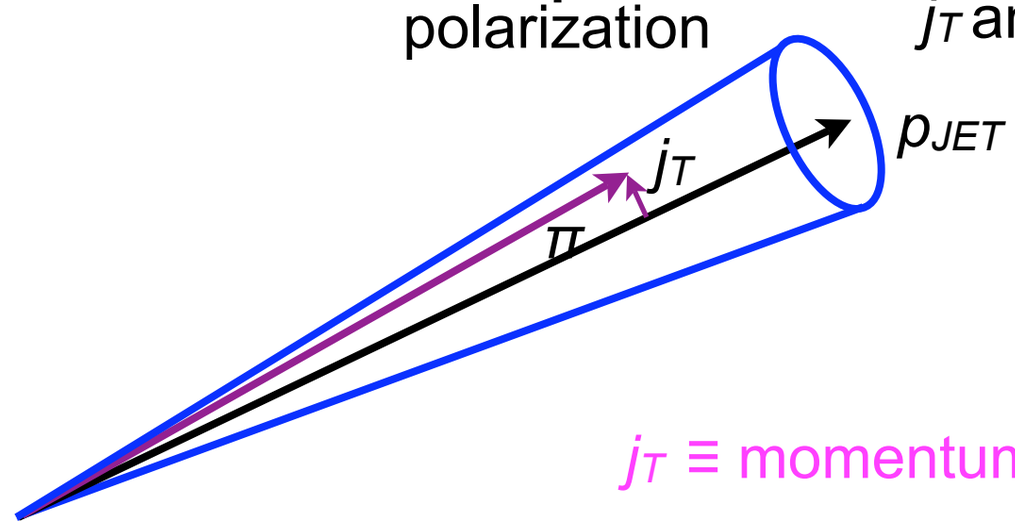

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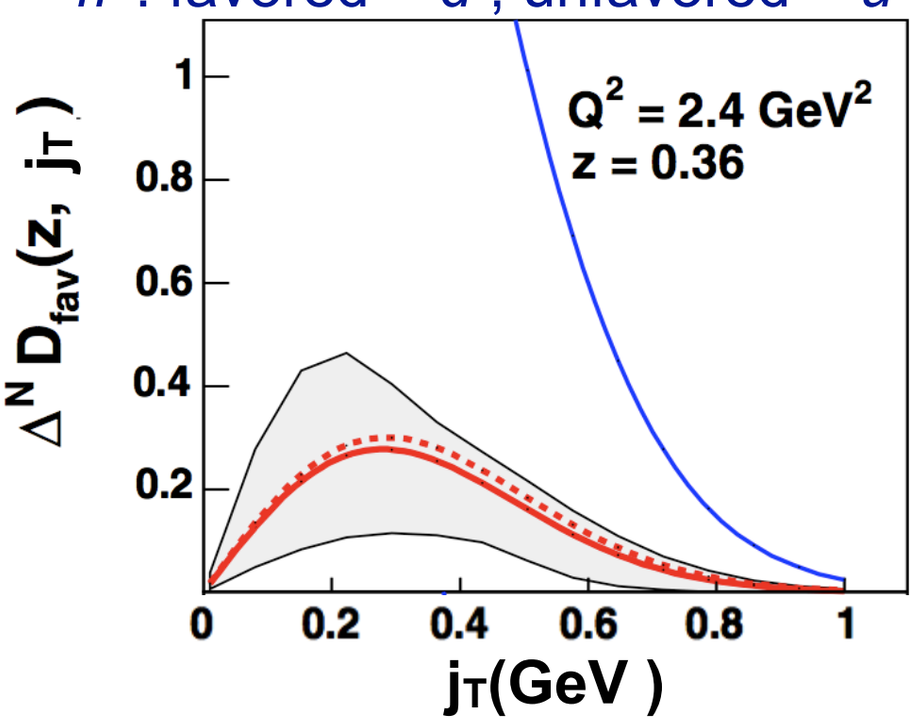


$$\frac{d\sigma_{UU}}{d\mathbf{P.S.}} = \sum_{a,b,c} x' f_b(x') x f_a(x) D_c^h(z, j_T) H_{ab\to cd}$$

$$\frac{d\sigma_{TU}}{d\mathbf{P.S.}} = \sum_{b,q} x' f_b(x') x \delta q(x) \Delta^N D_q(z, j_T) H^{\text{Collins}}_{qb\to qb}$$

(Unpolarized) quark distributions at x ≈ 0.2

Fragmentation functions (Collins, Sivers)

Isospin-favored Collins frag. function

Hard scattering term ~0.4-0.5

Extraction of δq

F. Yuan, arXiv:0804.3047 [hep-ph] (2008)

unpolarized, polarized cross-sections

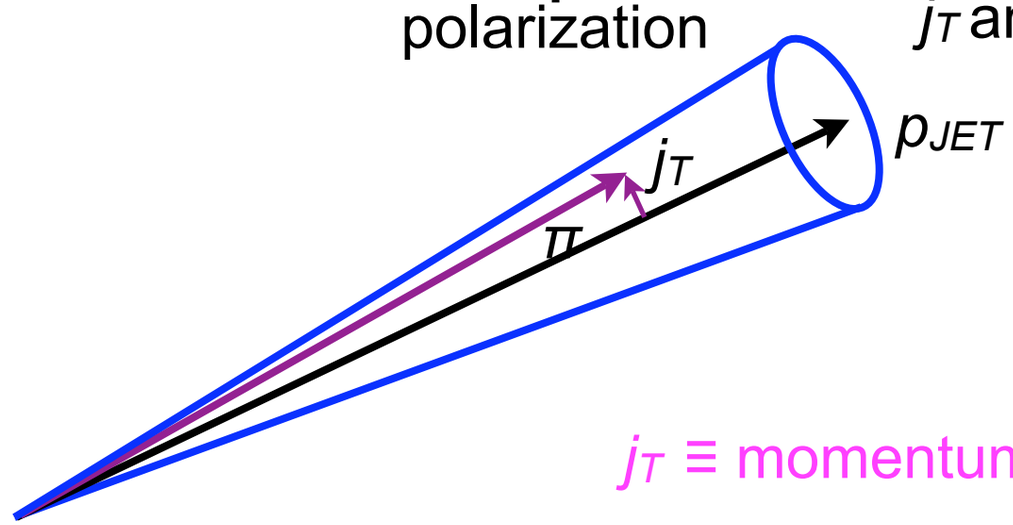
$$\frac{d\sigma}{dy_1\,dy_2\,dp_T^2\,dz\,d^2 j_T} \equiv \frac{d\sigma}{d\mathbf{P.S.}} = \frac{d\sigma_{UU}}{d\mathbf{P.S.}} + |S_\perp| \frac{|j_T|}{m_\pi} \sin(\phi_\pi - \phi_S) \frac{d\sigma_{TU}}{d\mathbf{P.S.}}$$

phase space

polarization

j_T angle

pol. angle



$j_T \equiv$ momentum of π transverse to jet

Extraction of Collins fragmentation function from fit to SIDIS data (HERMES, COMPASS) and Belle Collab. data (KEK)
(Anselmino, *et al.*, 2008)

π^+: favored = u , unfavored = d
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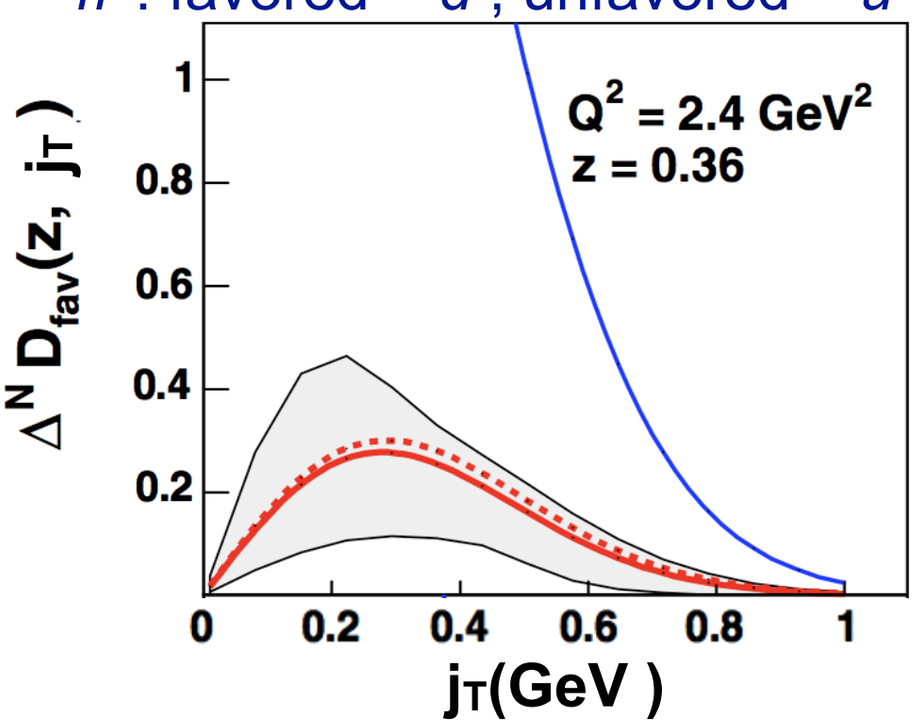

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(Unpolarized) quark distributions at x ≈ 0.2

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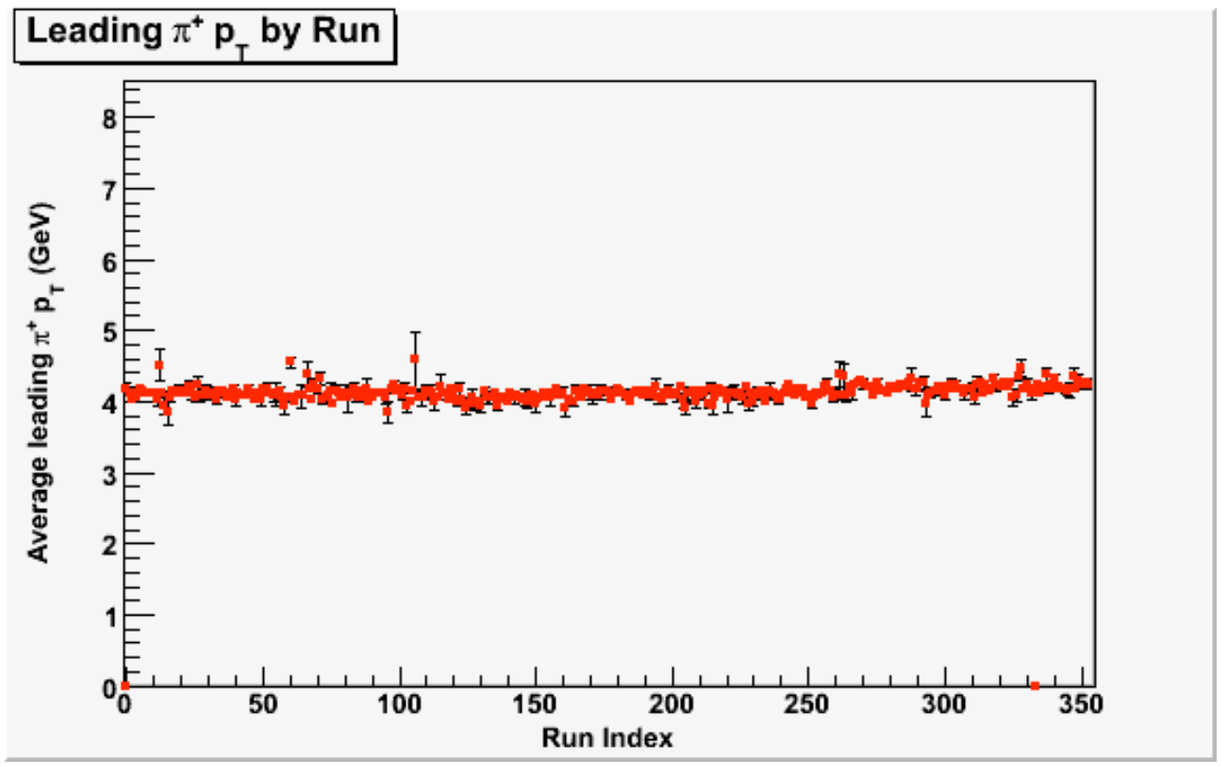
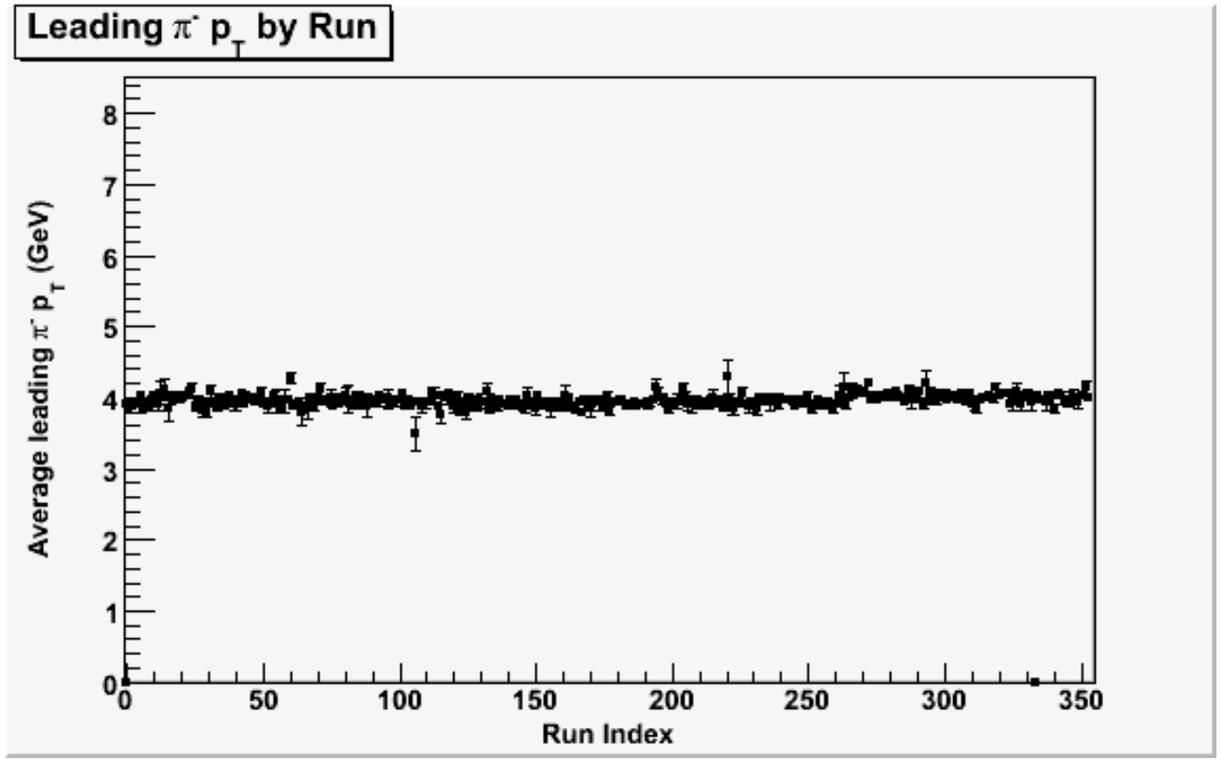
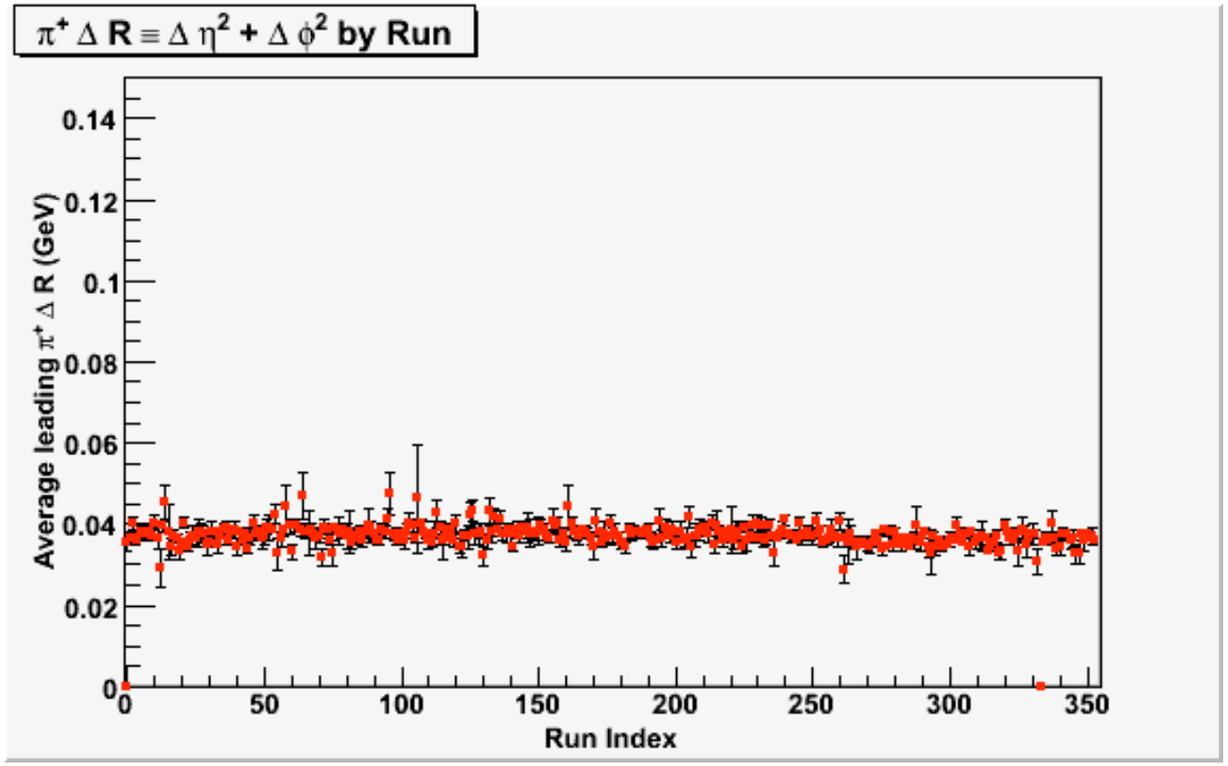
Quark transversity

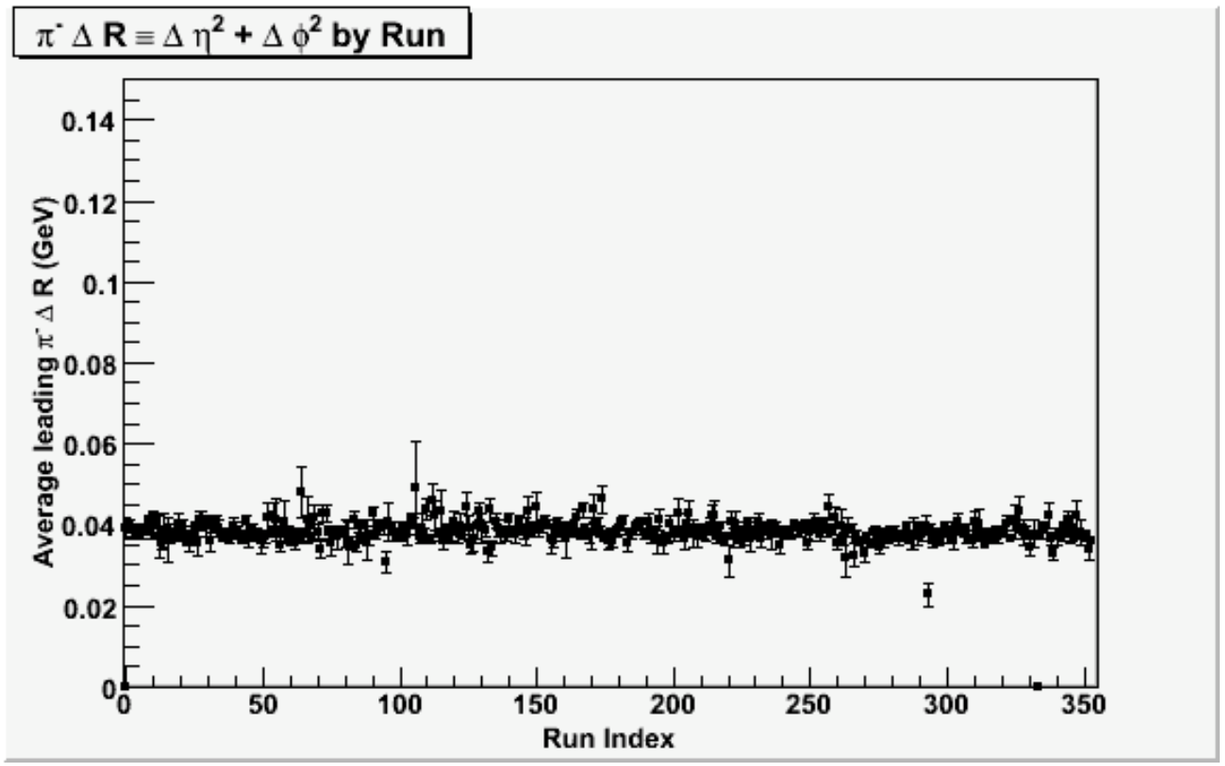
Quality Assessment:

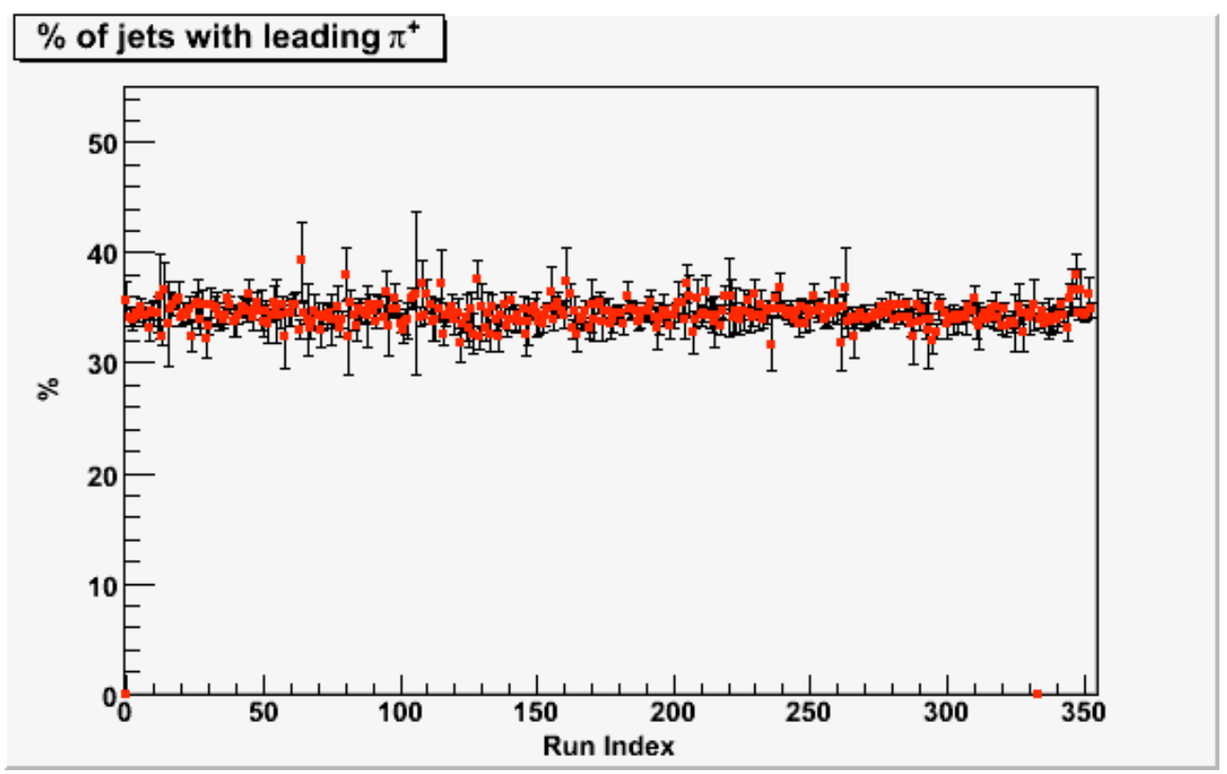


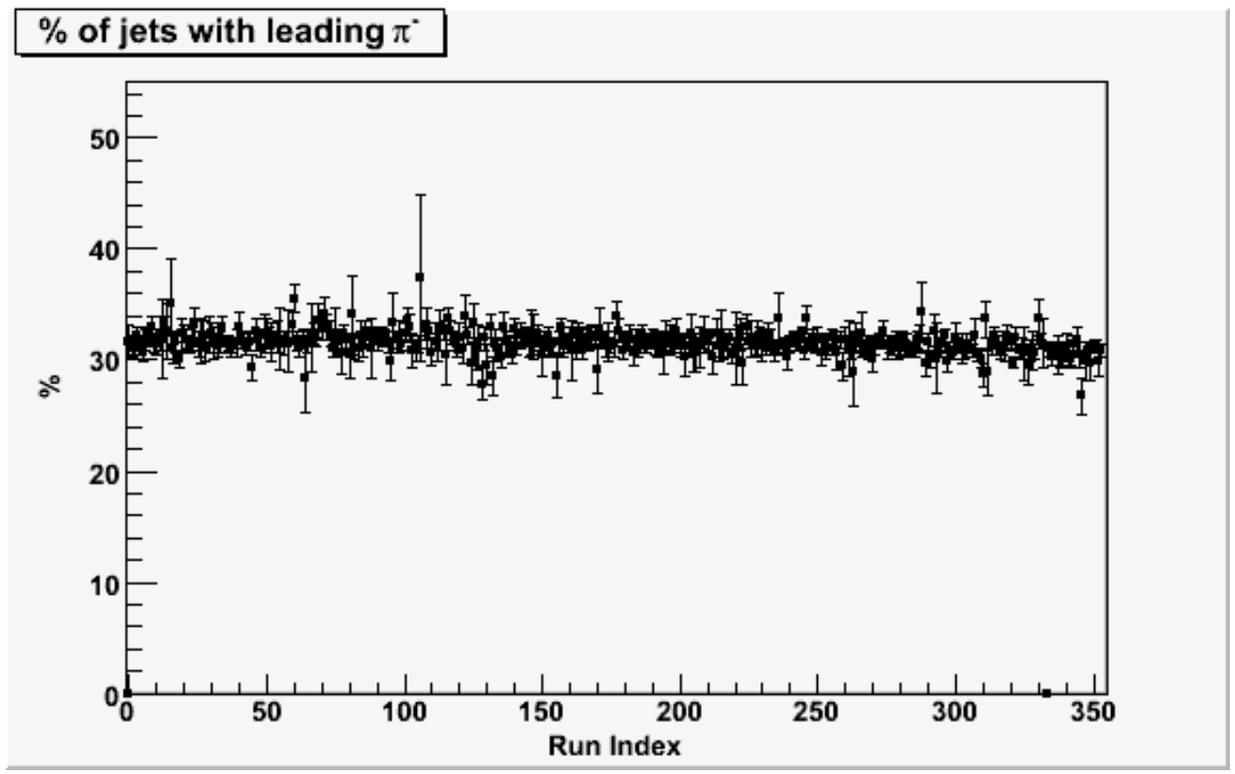
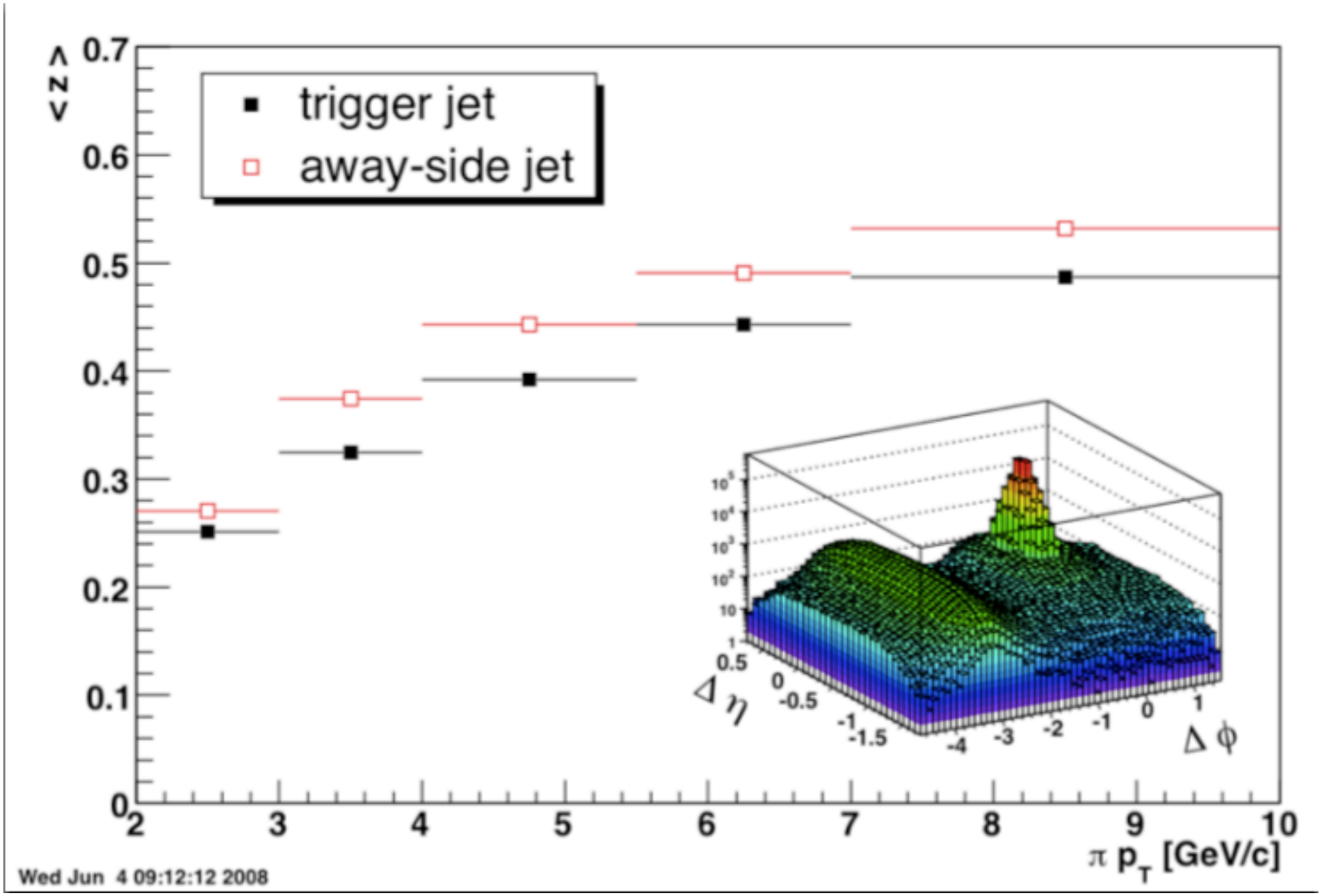


Quality Assessment:









Effect on z due to triggering on neutral particles