Physics with Single Muons

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LANL

– Light & heavy hadrons
– Heavy Ion & Spin Physics

The origin of muons

- Free decay before nose cone, light & heavy hadrons
- Decay inside nose cone
- Decay after nose cone
- Punch-throughs

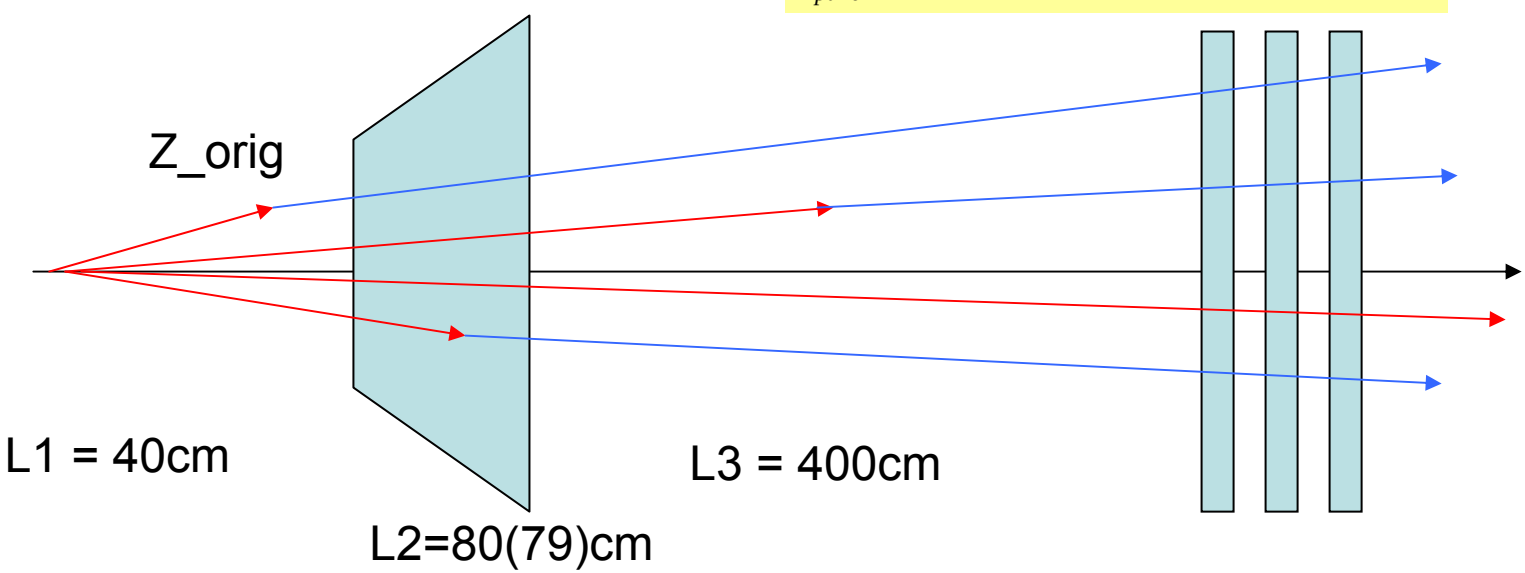
$$P_1 = (1 - e^{-L_1/\lambda}) \approx \frac{L_1}{\lambda} \sim 10^{-2}$$

$$P_2 \approx (1 - e^{-\lambda_I/\lambda}) \approx \frac{\lambda_I}{\lambda} \sim 50\% P_1;$$

$$\lambda_I \approx 20 \sim 30cm$$

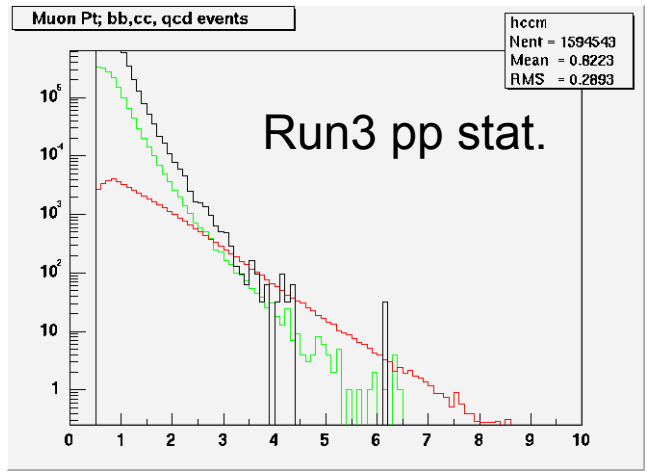
$$P_3 \approx e^{-L_2/\lambda_I}(1 - e^{-L_3/\lambda}) = 10^{-2}\frac{L_3}{\lambda} \sim 10\% P_1$$

$$P_{punch} \approx e^{-L_2/\lambda_I}(a + b \cdot p)$$



Selected Physics Topics

- HI
  - Rcp, RdA, RAA @ forward(backward) rapidity
    - Parton Distributions, CGC
    - Energy loss/multiple scattering, QGP
  - Leading particle and Jet
    - Reaction plane : BBC/MVD/ZDC
  - Open Charm/Beauty
    - QGP enhancement
    - Baseline for J/Psi etc.
- SPIN
  - Polarized gluon distribution
    - Light mesons
    - Open charm

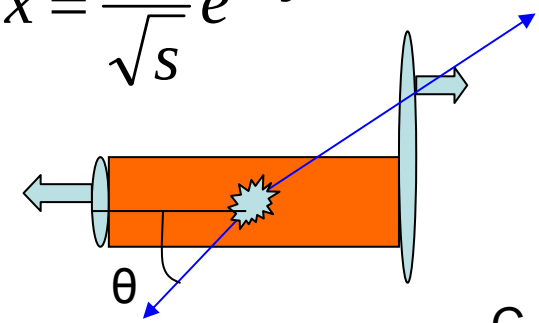


Muon Pt

Physics @ large rapidity

- Different "x" range: initial state
  - (anti)shadowing/CGC
- Final state scattering: energy dependent

$$x = \frac{M}{\sqrt{s}} e^{-y}$$

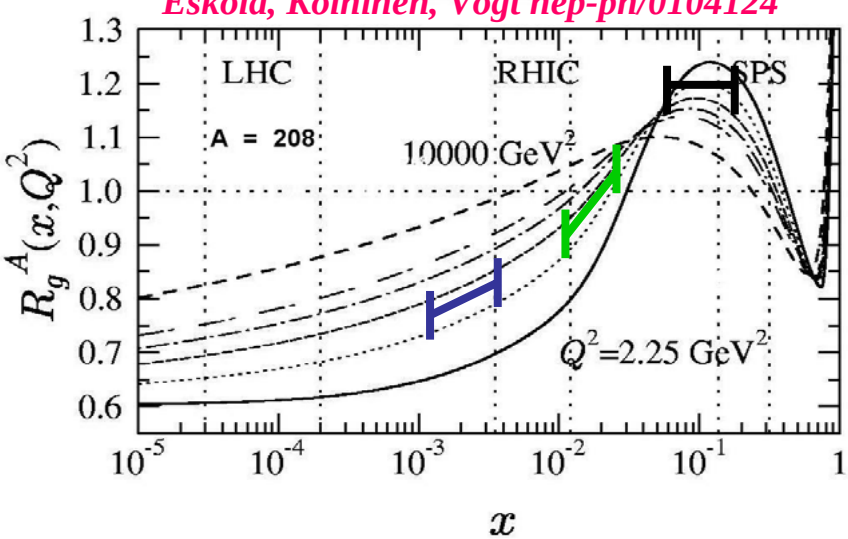


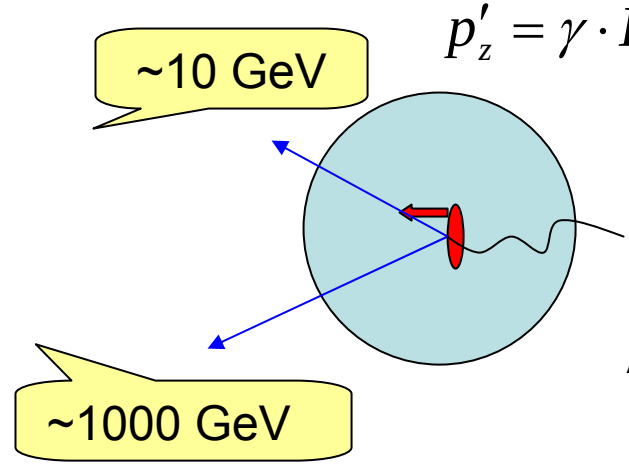
C.M.F.

$$p'_T = p_T$$

$$p'_z = \gamma \cdot E(\cos\theta + \beta)$$

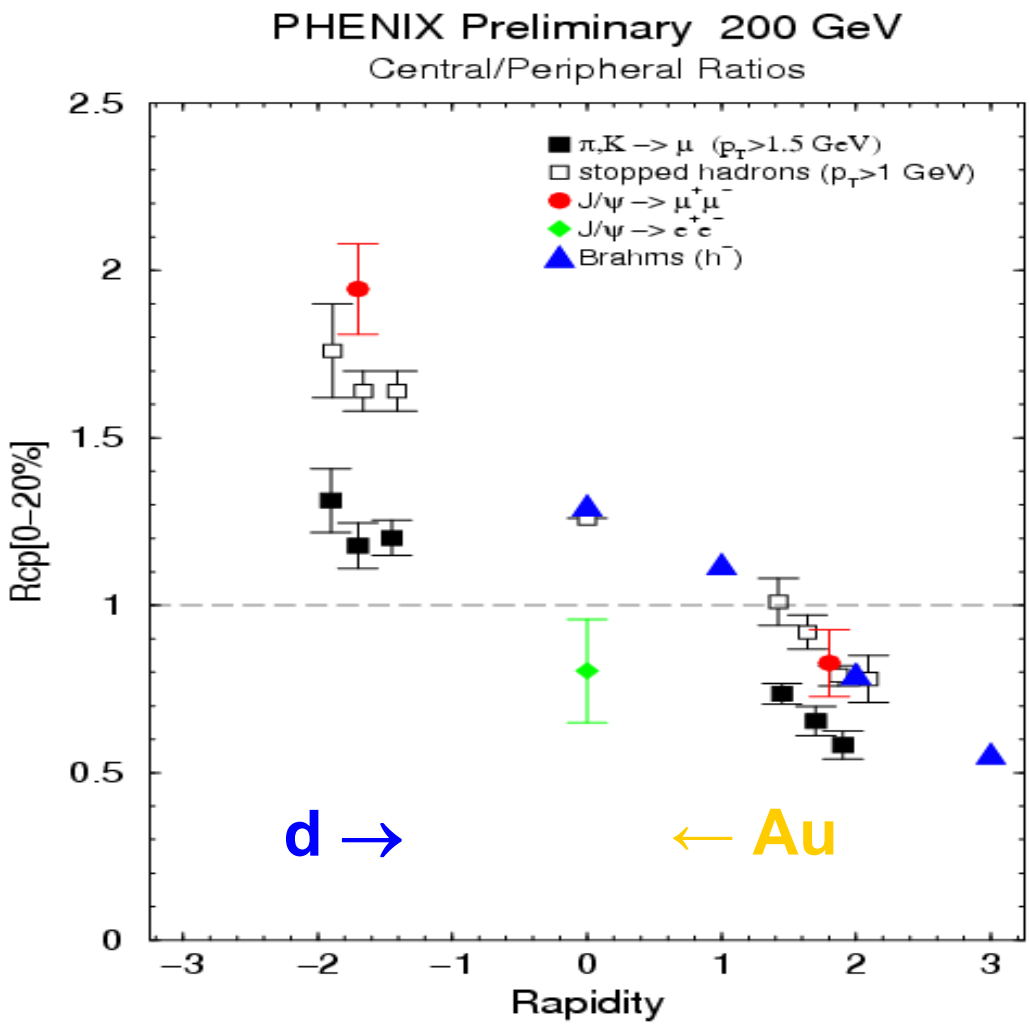
Eskola, Kolhinen, Vogt hep-ph/0104124

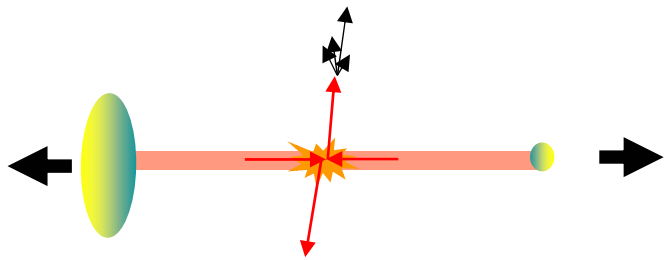




Au rest frame

Rcp w/ light hadrons (QM04)





$$R_{CP} = \frac{dN^{central} / dydp_T / < N_{coll} >}{dN^{60-88\%} / dydp_T / < N_{coll} >}$$

(00-20%)/(60-88%)

See latest update from Chun

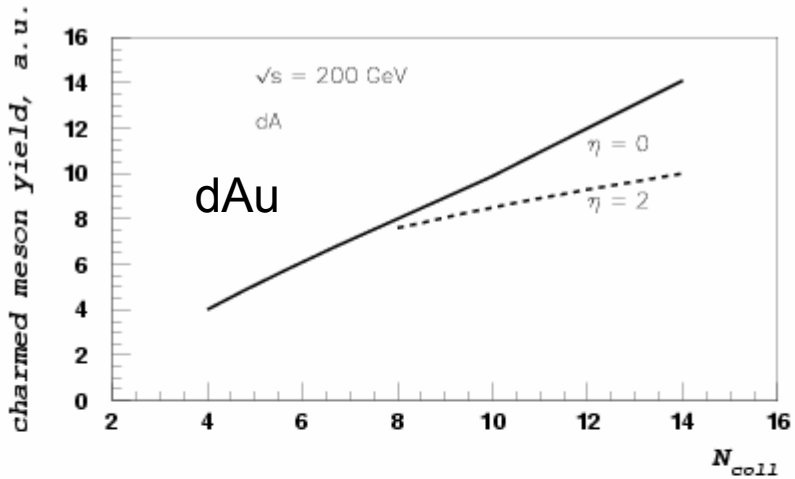
CGC and Open charm at large rapidity

- Gluon saturation/CGC

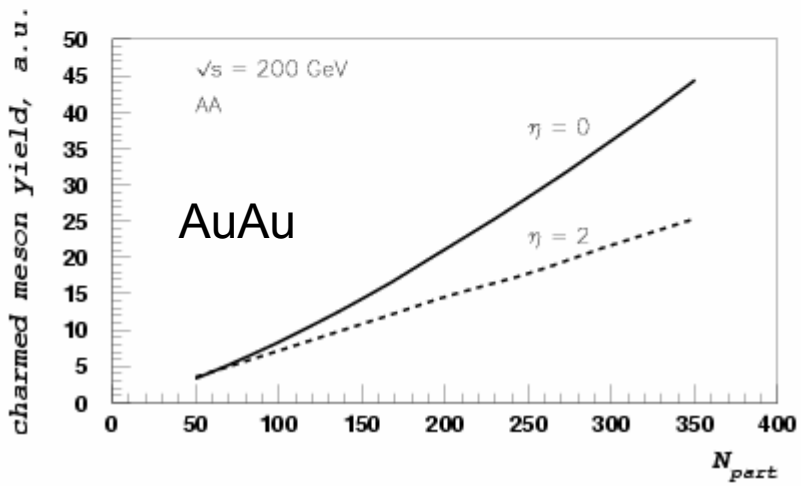
$$y \sim 0: \quad d\sigma \propto N_{coll}$$
$$y \sim 2: \quad d\sigma \propto N_{part}$$

- PHENIX forward prompt muons

$$1.2 < |y| < 2.4$$



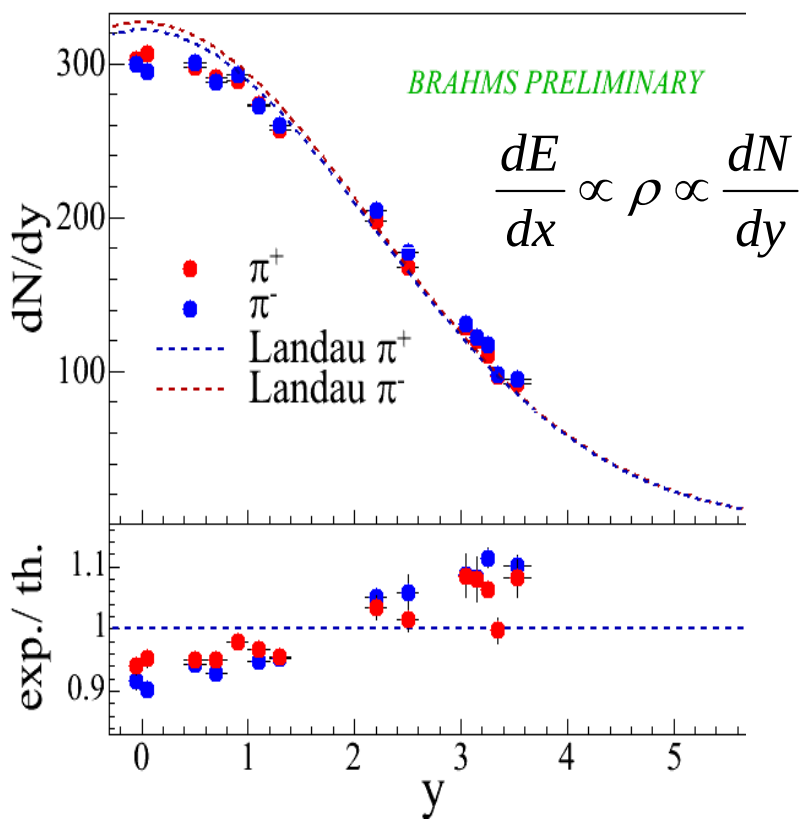
D. Kharzeev & K. Tuchin
hep-ph/0310358

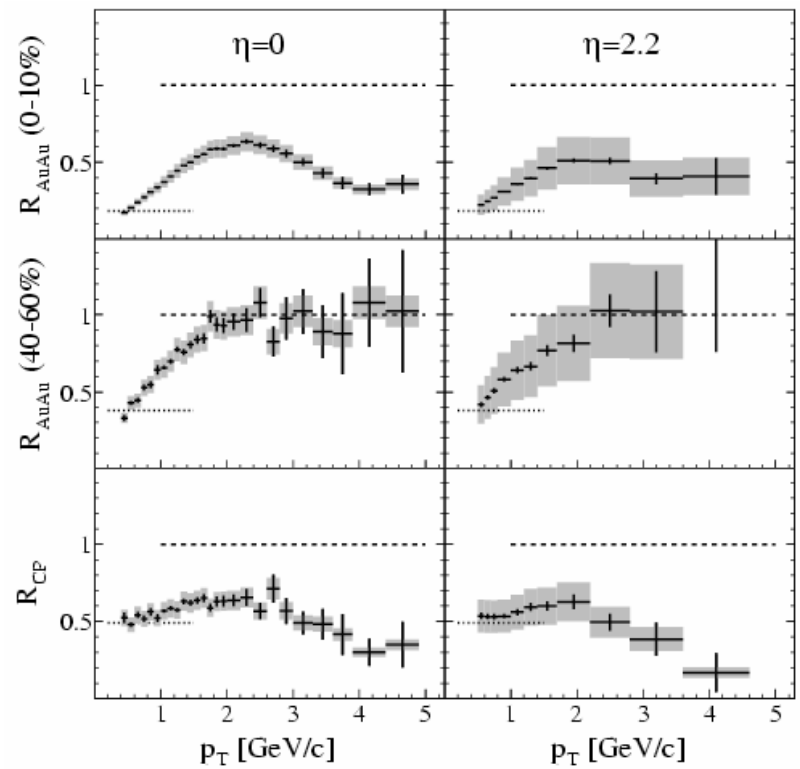


R_AA @ large rapidity (AuAu)

- Energy loss and medium density

$$R_{AuAu} = \frac{N_{AuAu}}{N_{pp} N_{coll}}$$

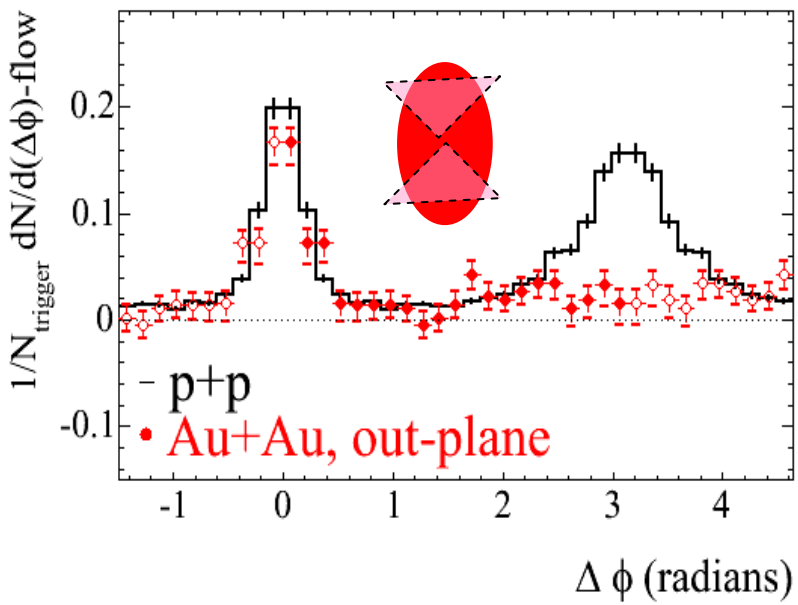




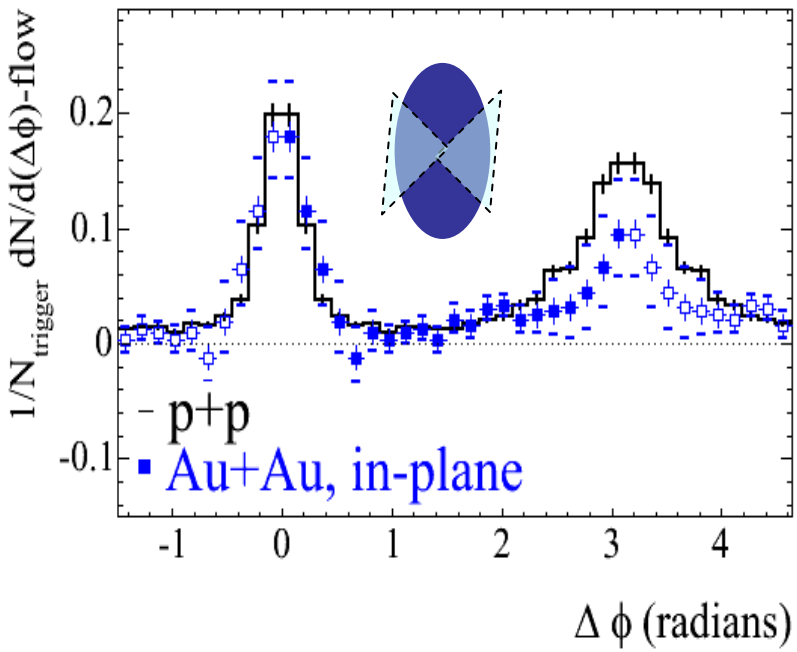
Medium Final state effects

- Reaction Plane (AuAu): MVD/BBC
- Work in progress (Ben's talk)

$$\frac{d^3\sigma}{d\Delta\phi dp_T d\eta}$$



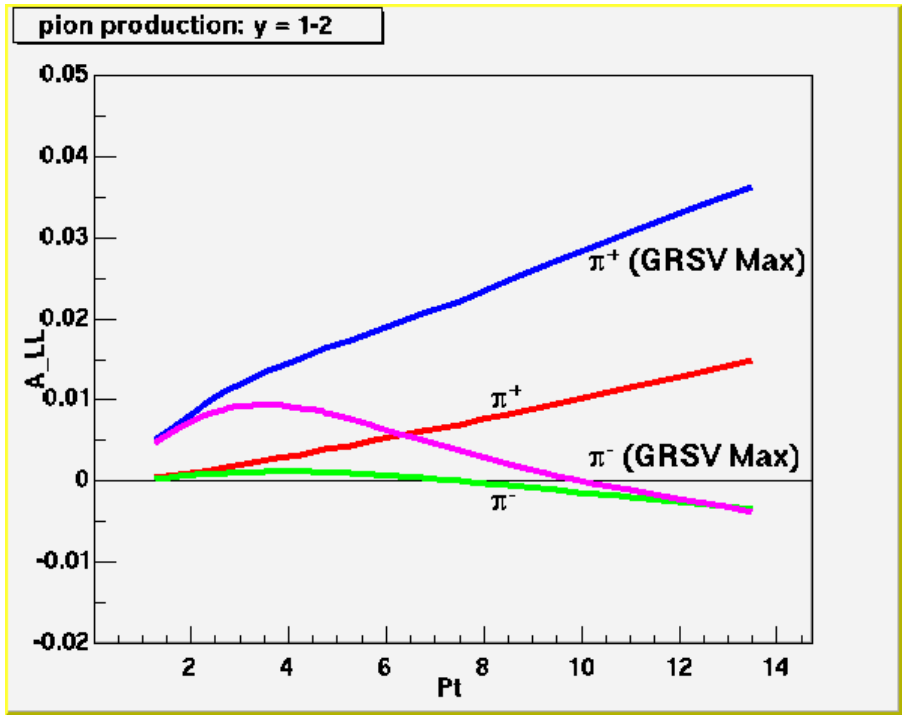
STAR QM04

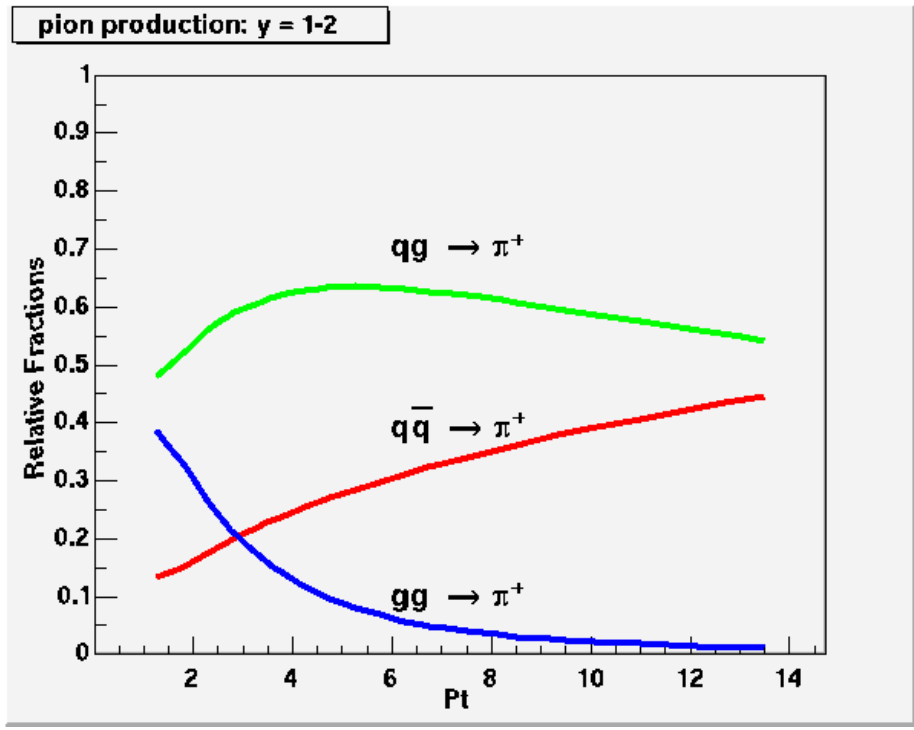


SPIN Physics

- Light & heavy hadrons
- Need people to carry on the analyses

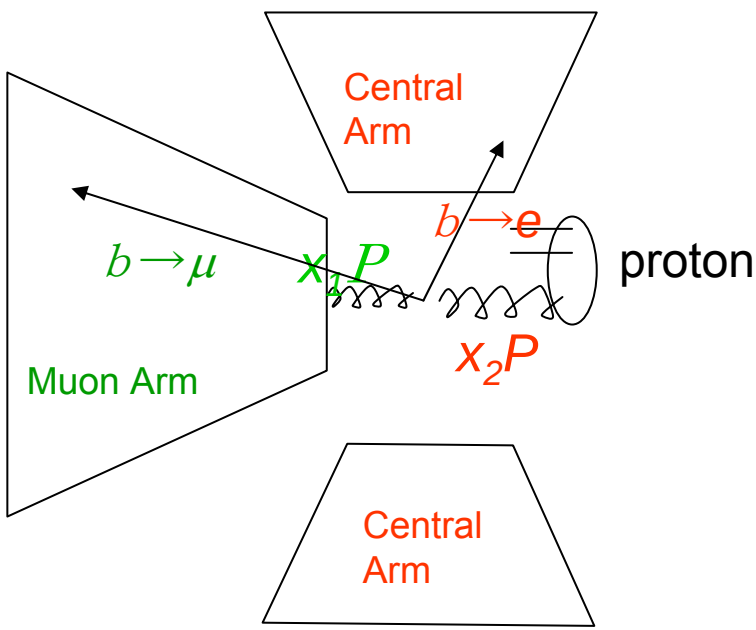
$$A_{LL}(p_T,\eta) = \frac{\sigma(+,+)-\sigma(+,-)}{\sigma(+,+)+\sigma(+,-)} \sim \frac{\Delta f_1}{f_1}\frac{\Delta f_2}{f_2}\frac{\Delta\hat{\sigma}}{\hat{\sigma}}$$

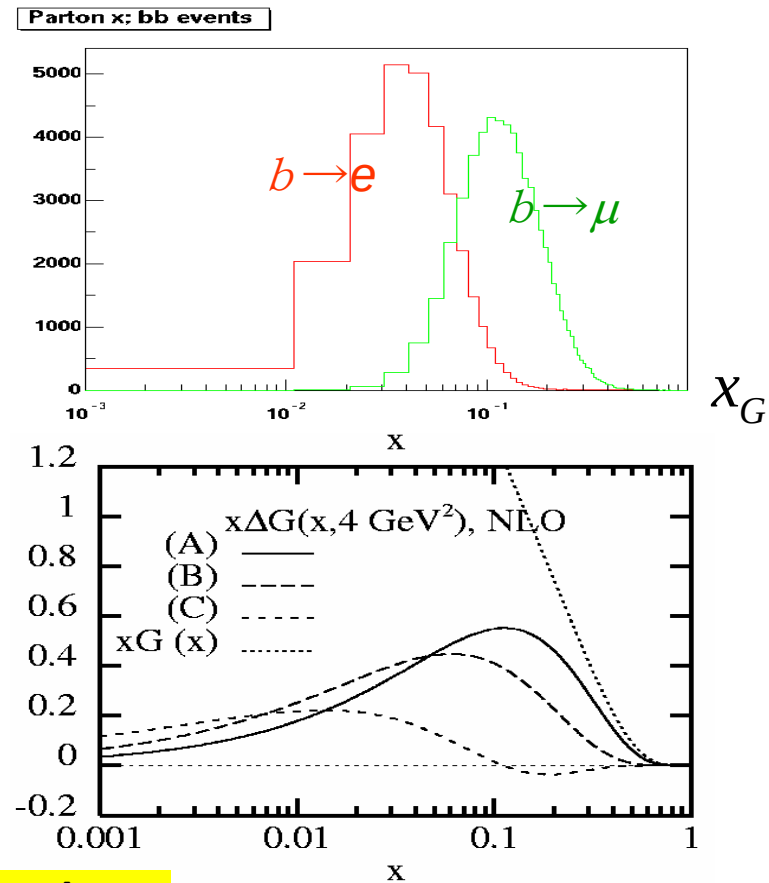




Heavy Quark Production and G(x)

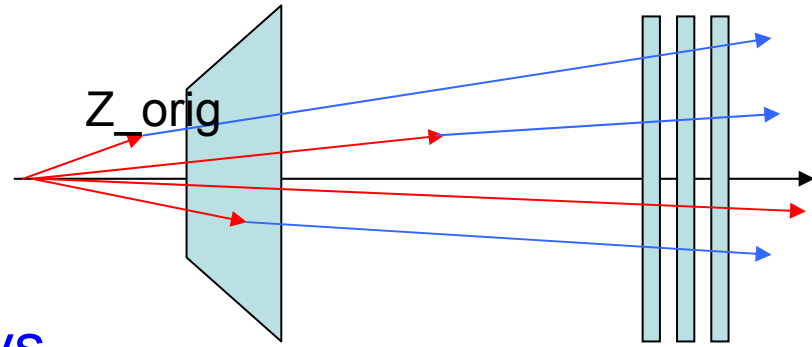
- Gluon's x range





$$A_{LL} = \frac{\Delta\sigma}{\sigma} \approx \frac{\Delta G(x_1)}{G(x_1)} \cdot \frac{\Delta G(x_2)}{G(x_2)} \frac{\Delta\hat{\sigma}_{parton}}{\hat{\sigma}}$$

Experimental Challenge



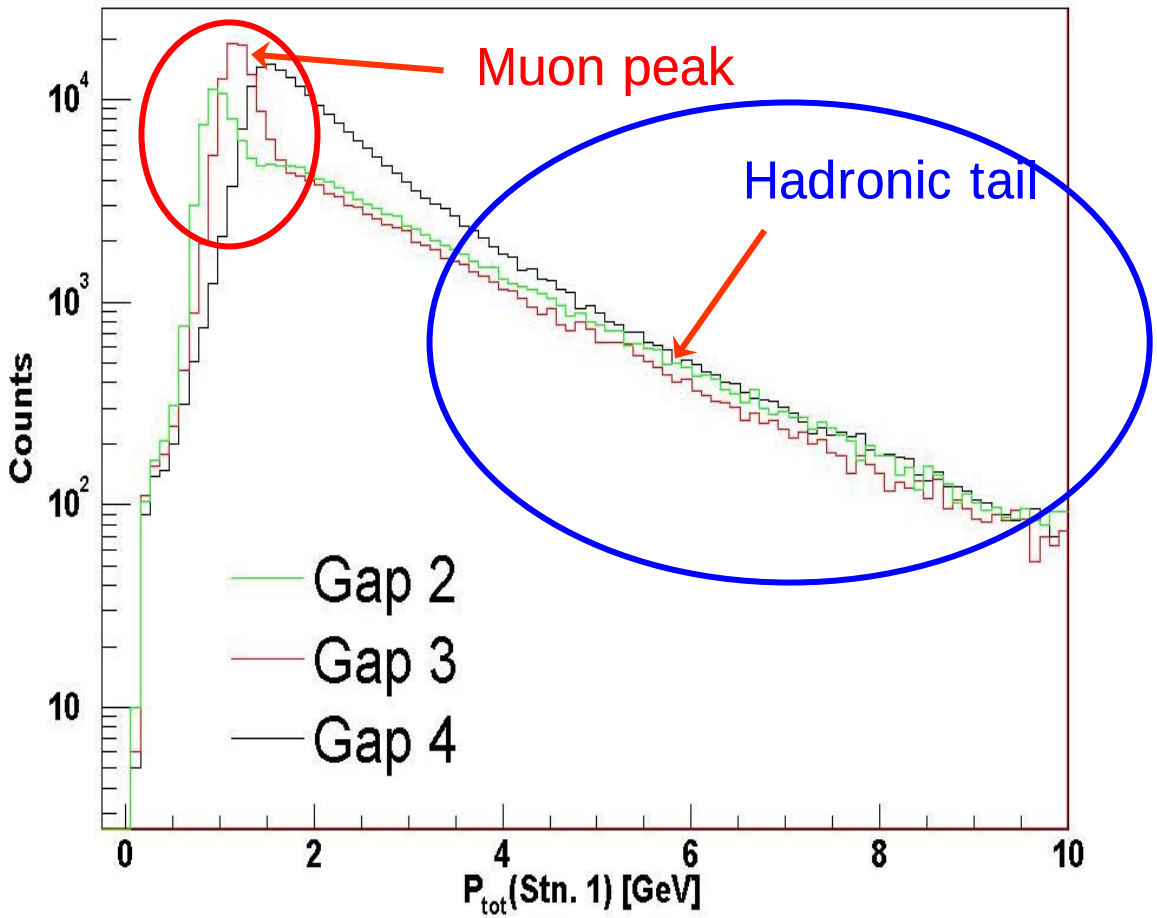
- Stopped hadrons
- Muons from light meson decays
- Muons from heavy hadron decays
  - Hadron punch-throughs (Chun, Youngil's talks)
  - Full MC, Data Driven, semi-analytical (Ken's talk)
- Understanding Detector performance
  - Muon reco performance (Xiaorong's talk)
  - Triggers: BBC & BLT
  - Collisions vertex distributions (WooJin's talk)
- New ideas
  - Heavy flavors with "dimuon" – Pt (Ming et al)
  - Event kinematics (Mikhail et al)

Measurement of Stopped Hadrons

Stopping power:

Use shallow MuID absorber layers to select stopped hadrons

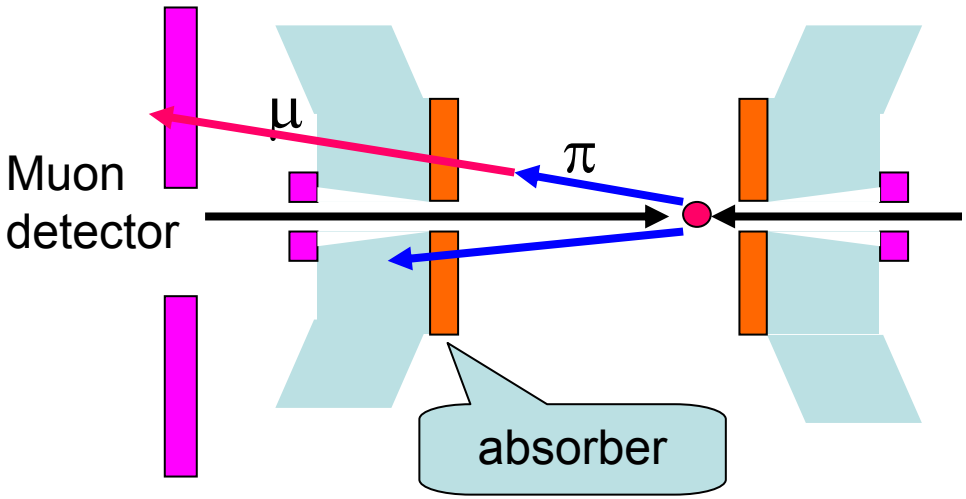
for Ptot > 1.9GeV:
muon contamination < 3%
(Chun'd talk)

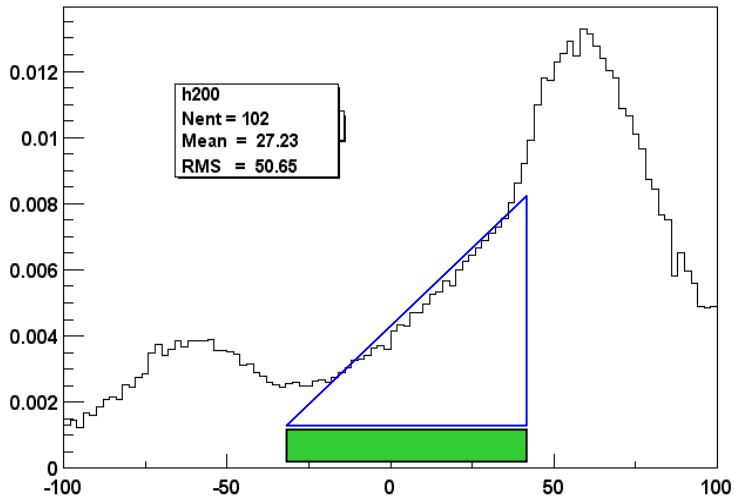


Muons from Light Meson Decays

- Muon event collision vertex distribution

$$\frac{dN^{\mu^{\pm}}}{dz} \sim VTX(z) \cdot P^{h^{\pm} \to \mu^{\pm} + \nu}(p, \theta, z) = VTX(z) \cdot (1 - e^{-\frac{\Delta L}{\lambda}})$$





Collisions Vertex Z

- Ref VTX(z), data QA (WooJin)

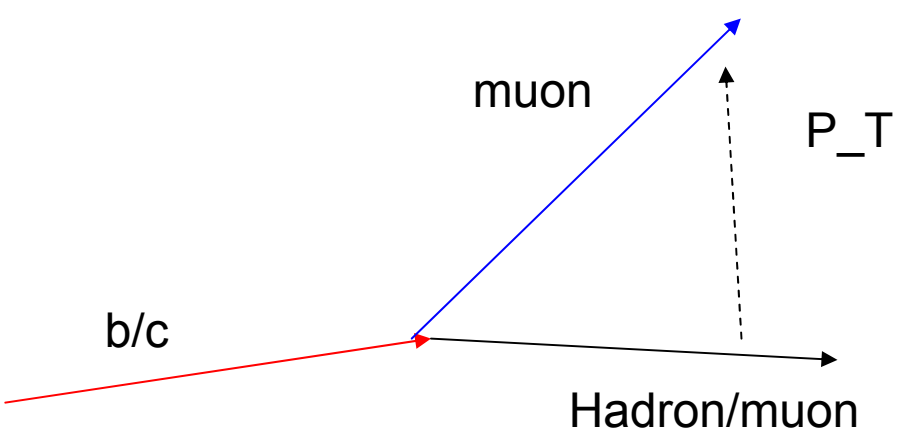
Open Charm/Beauty

- Understanding light hadron punch-thoughs

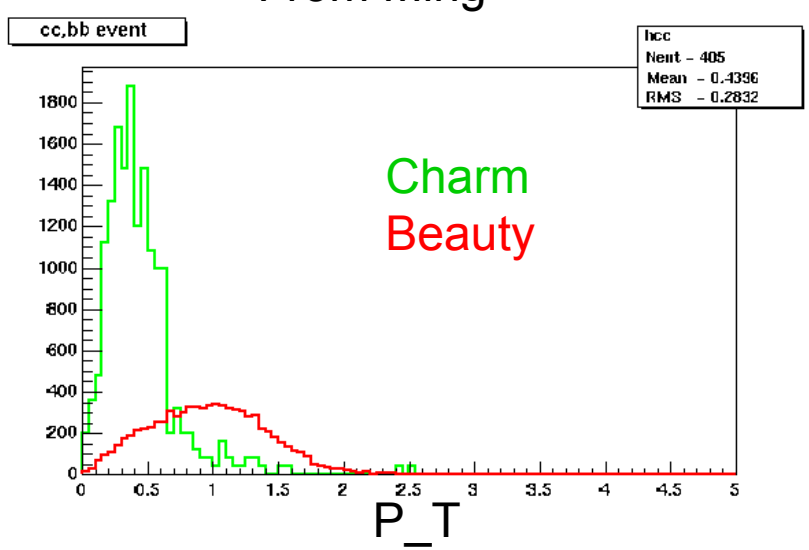
- Single muons – in progress (Youngil/Ken's talk)
- Dimuons – in progress (Sebastien's talk)
- e-mu correlation – in progress (Philippe, Rob)
- Some new ideas
  - Dimuon-jet correlation
  - Event kinematics
  - K-mu correlation – some simulations done
  - K-e correlation – some simulations done

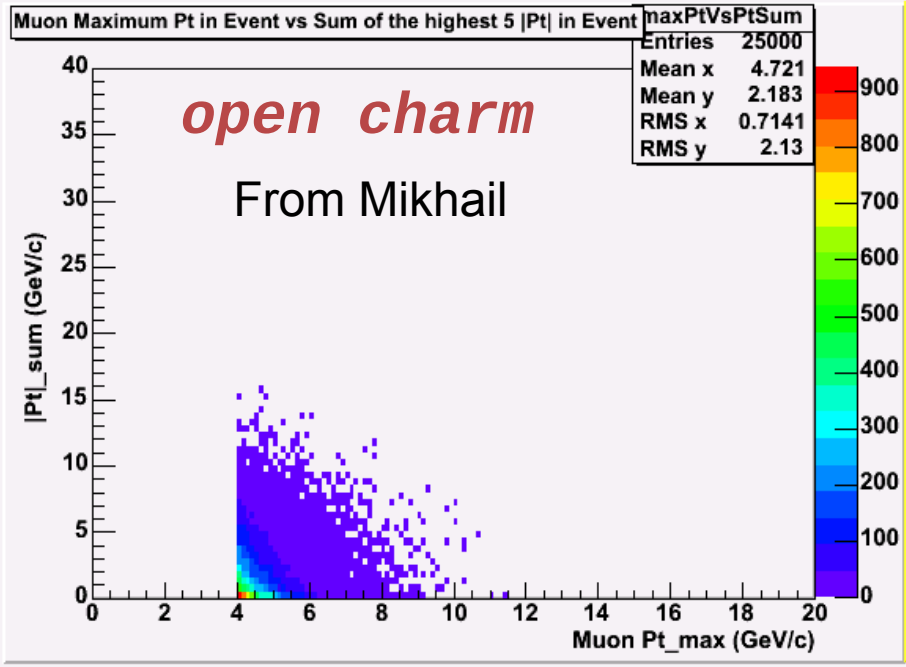
New ideas

- Understanding hadron punch-through
  - Detailed sims + X-check w/ realdata
- New ideas
  - “Dimuons” = muon+”jet” correlation



From Ming

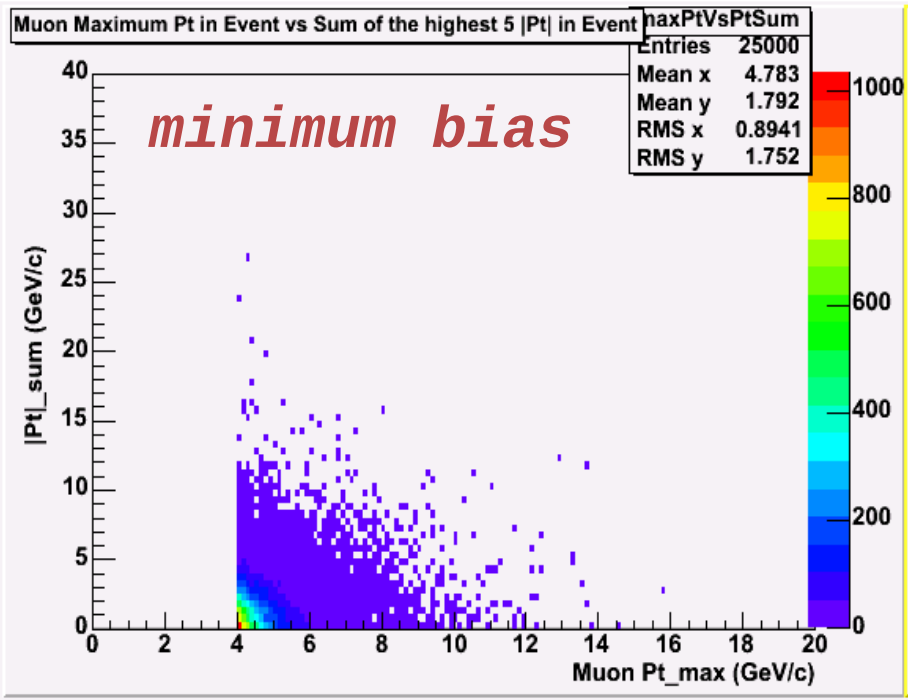




Muon Pt_max (GeV/c)

|Pt|_sum (GeV/c)	>=4.0	>=5.0	>=6.0	>=7.0	>=8.0	>=9.0	>=10.0
>=0.0	100.000%	24.952%	6.012%	1.428%	0.416%	0.108%	0.032%
>=1.0	61.792%	15.320%	3.744%	0.920%	0.268%	0.080%	0.024%
>=2.0	41.796%	10.428%	2.604%	0.660%	0.200%	0.064%	0.020%
>=3.0	28.040%	6.956%	1.700%	0.472%	0.160%	0.056%	0.020%
>=4.0	18.440%	4.696%	1.168%	0.320%	0.100%	0.040%	0.016%
>=5.0	11.704%	3.124%	0.808%	0.232%	0.064%	0.024%	0.008%
>=6.0	6.816%	1.864%	0.480%	0.128%	0.028%	0.016%	0.004%
>=7.0	3.672%	1.064%	0.288%	0.092%	0.020%	0.008%	0.004%
>=8.0	1.800%	0.588%	0.116%	0.040%	0.004%	0.004%	0.000%
>=9.0	0.832%	0.296%	0.048%	0.016%	0.000%	0.000%	0.000%
>=10.0	0.356%	0.132%	0.028%	0.012%	0.000%	0.000%	0.000%
>=11.0	0.196%	0.068%	0.012%	0.008%	0.000%	0.000%	0.000%
>=12.0	0.088%	0.024%	0.004%	0.000%	0.000%	0.000%	0.000%
>=13.0	0.044%	0.012%	0.004%	0.000%	0.000%	0.000%	0.000%
>=14.0	0.016%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
>=15.0	0.012%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
>=16.0	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%

charm predominance



Muon Pt_max (GeV/c)

|Pt|_sum (GeV/c)	>=4.0	>=5.0	>=6.0	>=7.0	>=8.0	>=9.0	>=10.0
>=0.0	100.000%	26.228%	8.496%	3.064%	1.192%	0.532%	0.244%
>=1.0	60.340%	17.032%	5.808%	2.200%	0.856%	0.388%	0.184%
>=2.0	33.600%	10.448%	3.672%	1.408%	0.608%	0.276%	0.124%
>=3.0	18.176%	6.276%	2.348%	0.992%	0.416%	0.216%	0.100%
>=4.0	9.632%	3.716%	1.552%	0.680%	0.304%	0.148%	0.076%
>=5.0	5.476%	2.216%	0.968%	0.456%	0.204%	0.096%	0.048%
>=6.0	3.092%	1.328%	0.644%	0.340%	0.160%	0.080%	0.040%
>=7.0	1.804%	0.812%	0.428%	0.232%	0.096%	0.052%	0.024%
>=8.0	1.052%	0.468%	0.252%	0.132%	0.060%	0.040%	0.020%
>=9.0	0.624%	0.288%	0.156%	0.072%	0.036%	0.032%	0.020%
>=10.0	0.380%	0.172%	0.096%	0.056%	0.032%	0.028%	0.016%
>=11.0	0.228%	0.112%	0.068%	0.036%	0.020%	0.016%	0.012%
>=12.0	0.128%	0.068%	0.048%	0.016%	0.008%	0.004%	0.004%
>=13.0	0.092%	0.040%	0.024%	0.008%	0.004%	0.000%	0.000%
>=14.0	0.076%	0.032%	0.020%	0.008%	0.004%	0.000%	0.000%
>=15.0	0.060%	0.016%	0.012%	0.004%	0.004%	0.000%	0.000%
>=16.0	0.032%	0.004%	0.000%	0.000%	0.000%	0.000%	0.000%

Summary

- A lots of interesting & urgent topics
  - Rcp: light hadron/meson (done)
  - RdA: pp & dA
  - RAA: pp & dA & AuAu
  - Reaction plane: AuAu
  - Open charm/beauty
  - Spin : A_LL - light and heavy in progress
- Tools:
  - Light hadron measurements – pretty mature
  - Heavy – in progress
- Need more people to jump into the analysis!

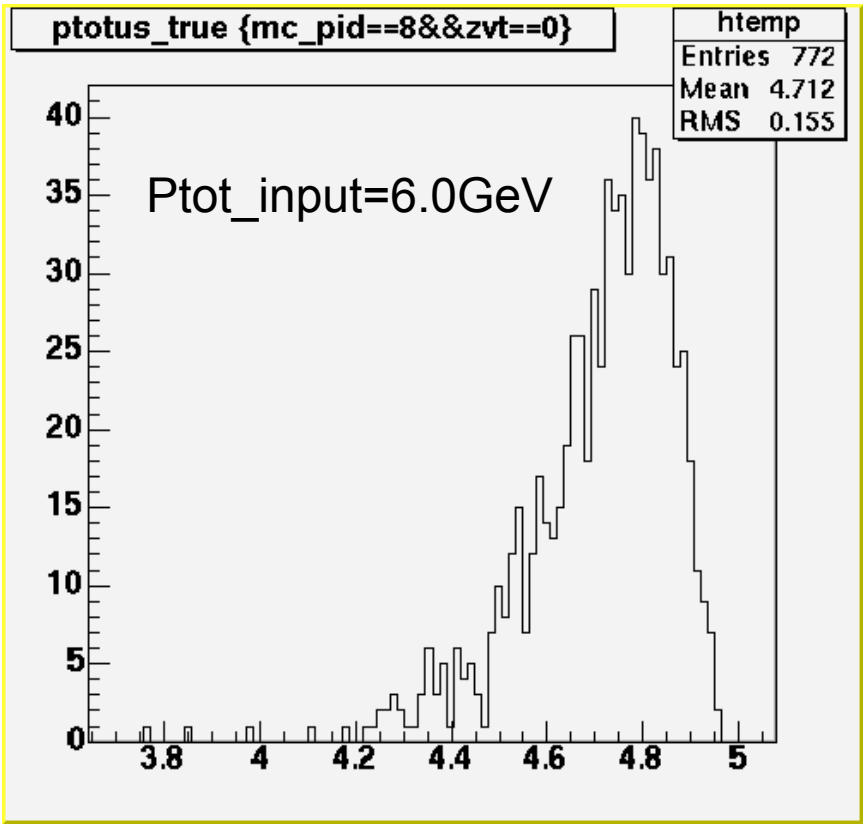
PISA simulations (GHEISHA)

- Hadrons w/o inelastic nuclear interaction with nose cone absorber

$$prob = e^{-L/\cos\theta\cdot\lambda_I} \approx \frac{N^{h^\pm}_{punch}}{N^{h^\pm}_{input}}$$

100K pions(+) and kaons(-)

<cos>=0.916; 15 < theta < 30
L ~ 60 + 19*17.0/15.6
= 80.7 (cm)



Pion Ptot@St-1

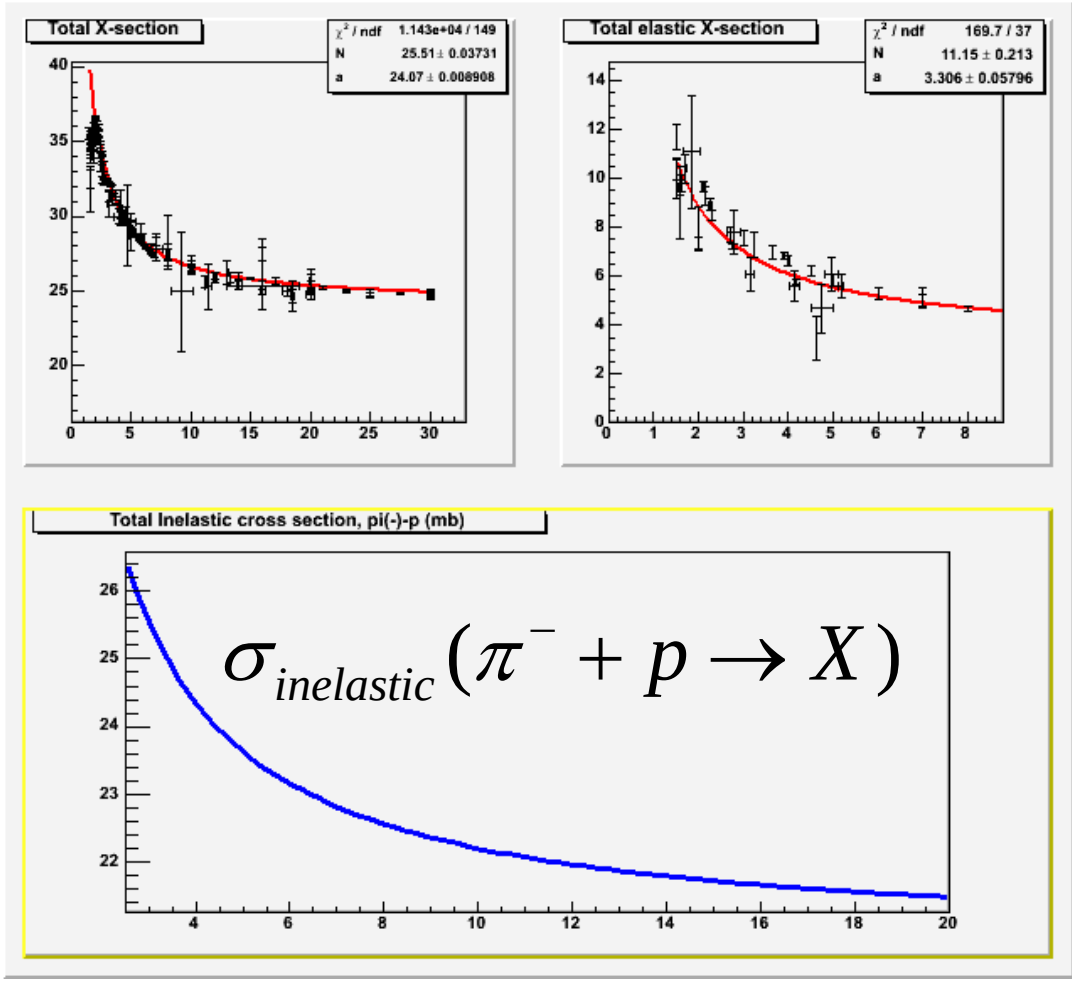
Pi(-)+A cross sections

$$\sigma^{\pi^- p} = \frac{14.36 \pm 0.22}{p} + (20.76 \pm 0.06)$$

$$\sigma^{\pi^+ p} = \frac{3.11 \pm 0.15}{p} + (19.87 \pm 0.03)$$

$$\sigma_A = \sigma_{p/n} \cdot A^{\alpha}$$

$$\lambda_I^{Fe}(p) \approx \lambda_I^{Fe}(p = 20GeV) \frac{\sigma_{\pi p}(20GeV)}{\sigma_{\pi p}(p)}$$



SPIN - Heavy Quarks

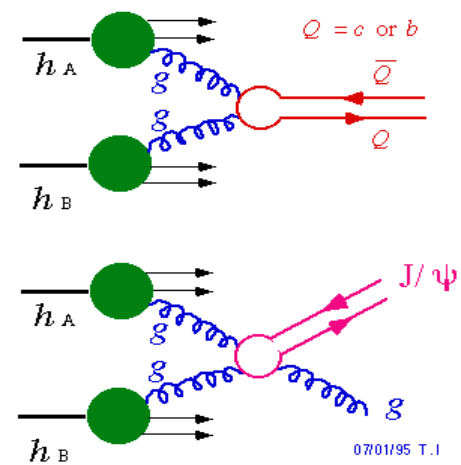
- Heavy Quark production at 200 GeV

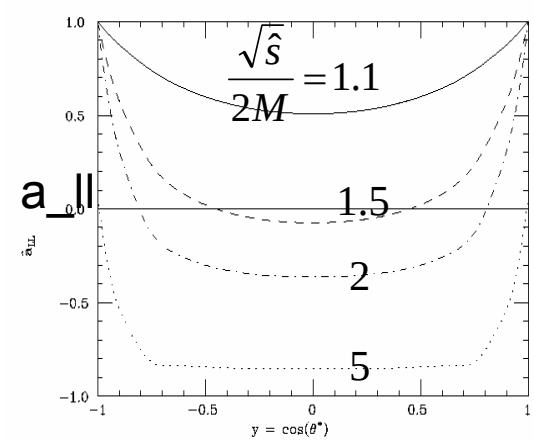
$$c\bar{c}: \; gg \rightarrow c\bar{c} \quad 95\%$$
$$b\bar{b}: \; gg \rightarrow b\bar{b} \quad 85\%$$

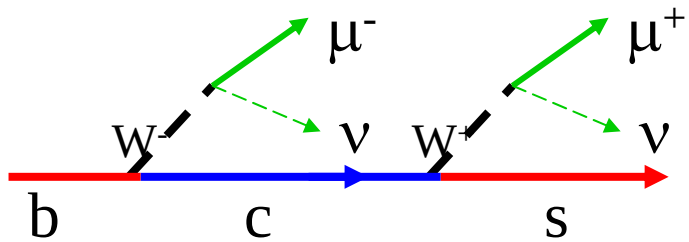
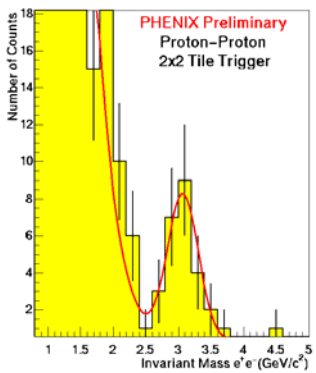
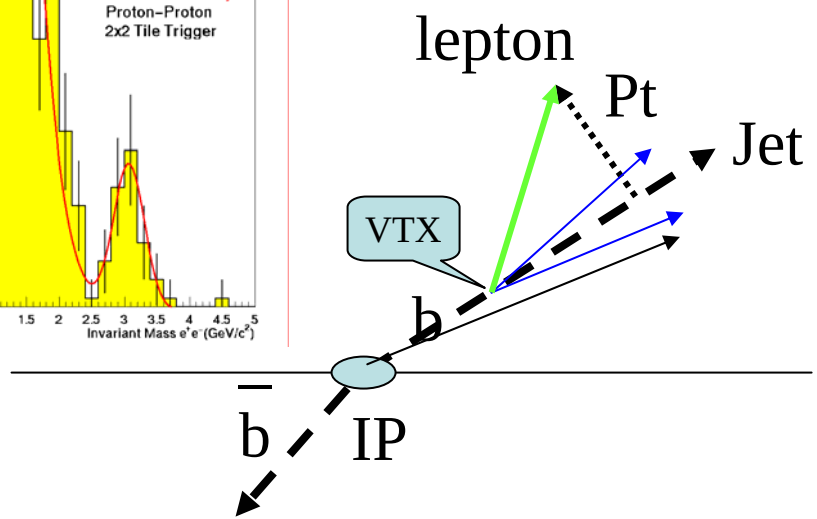
- Distinct Experimental signatures
  - high Pt lepton
  - 2nd vertex
- Large asymmetry and pQCD
  - $M_Q >> \Lambda_{QCD}$
  - $E\frac{d^3\sigma_X}{dp^3} \propto F_A^a(x_a,Q^2) \otimes F_B^b(x_b,Q^2) \otimes \frac{d\sigma_{ab}^{cd}}{dt} \otimes D_X(z)$

$$A_{LL} = \frac{\Delta\sigma}{\sigma} \approx \frac{\Delta G(x_1)}{G(x_1)} \cdot \frac{\Delta G(x_2)}{G(x_2)} \frac{\Delta\hat{\sigma}_{parton}}{\hat{\sigma}}$$

Gluon Fusion





Heavy Quark and Quarkonium @PHENIX

- Exp. Signatures
  - full reconstruction
    - D
    - J/Psi
  - semi-leptonic decay
    - BR ~10% (c, b)
  - charge correlation
  - Long lifetimes*
    - 2nd VTX (Upgrade Plan)