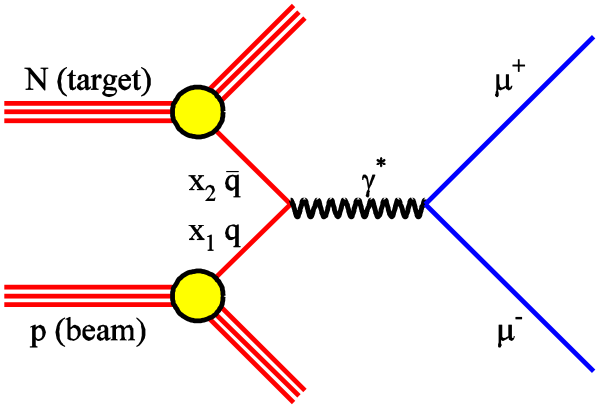
Possible Topics for First Year Physics

Ming Liu
Los Alamos National Lab

- Drell-Yan and J/Psi productions @120 NN
- Quark energy loss via DY in p+A
- CNM J/Psi production in p+A



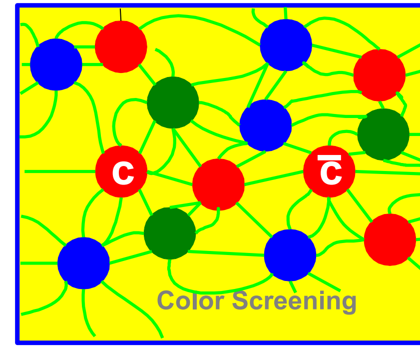
Quark-Gluon Plasma (QGP)
Cold Nuclear Matter Effects (CNM)

Outline

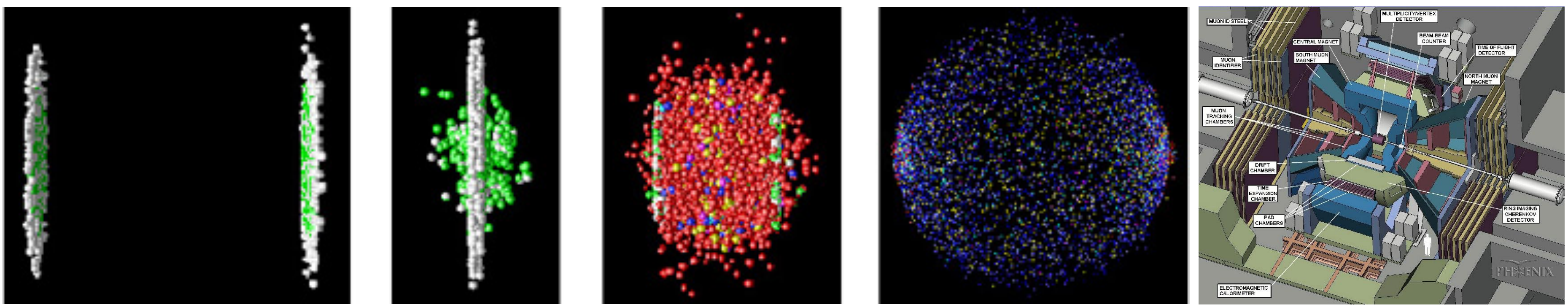
- Physics Motivations
  - Drell-Yan suppression in p+A
- Year-1 E906 statistics
  - Drell-Yan production
- J/Psi suppression in p+A
  - J/Psi CNM absorption and breakup
- DY cos(2phi) type modulation (B-M type)
  - Expect samll asymmetries

Physics of Heavy Ion Collisions

- Understand the Properties of QGP
- Explore the QCD phase diagram
- Novel CNM physics & QGP baseline



- Before collision
- Initial state CNM effects
- QGP
- Hadron gas
- Hadrons detected

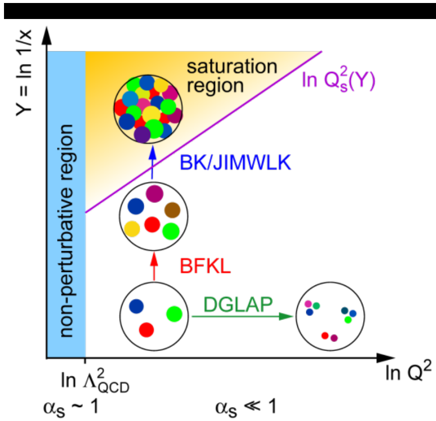


Heavy Ion Collision – Time Evolution

Time (fm/c)

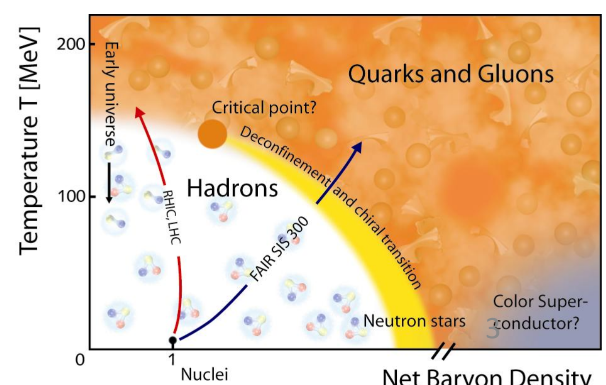
1

10



- Gluon saturation
- Parton shadowing
- CNM Parton energy loss

Ming Liu @E906 Collab. Mtg.

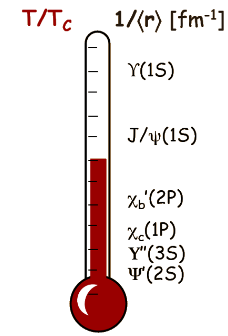


Outstanding Questions in Heavy Ion Physics

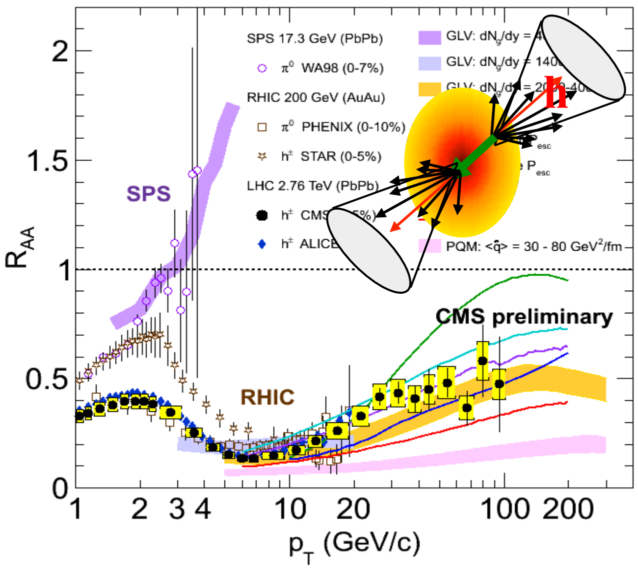
LHC ~ RHIC!

- Parton dE/dx & QGP properties
  (NSAC DM10, 12)
  – Radiation & collisional dE/dX
    - Light vs heavy quarks
  – CNM effects

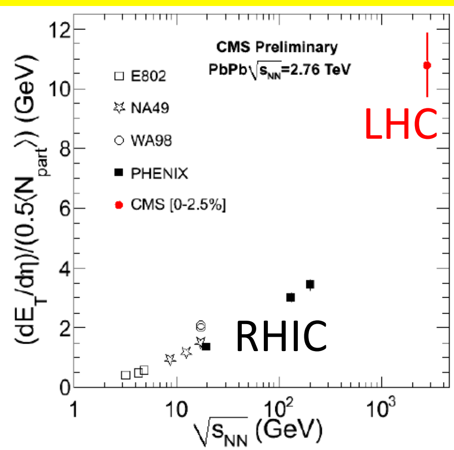
- QGP color screening & heavy quarkonia "melting"
  (NSAC DM5)
  – Color screening & recombination
  – CNM effects



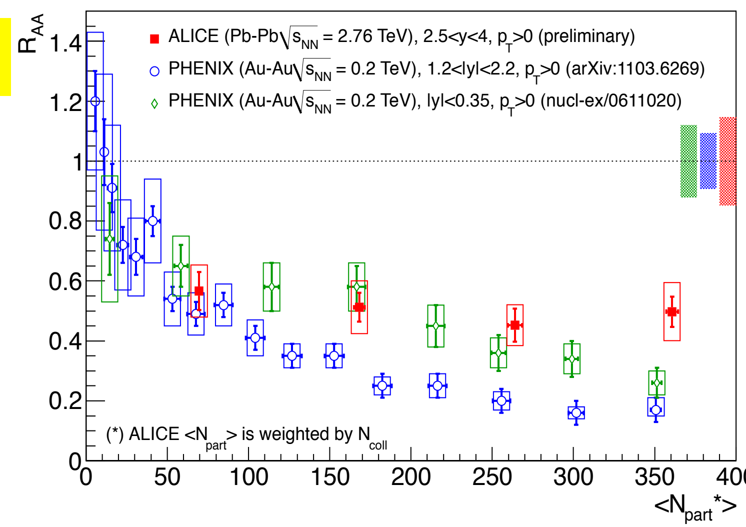
Jet suppression



Achieved QGP Densities



J/Psi suppression



Topic I

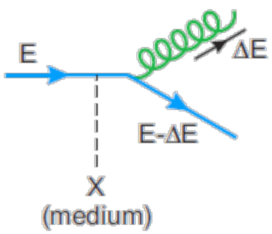
Drell-Yan and Quark Energy Loss in p+A

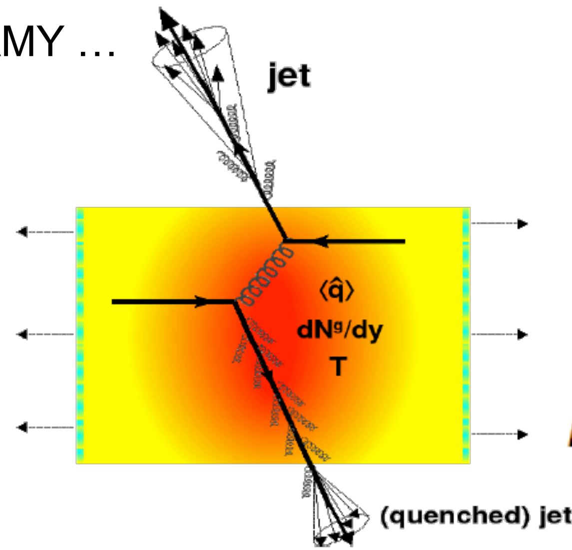
The first unambiguous determination of quark dE/dx with DY at E906!

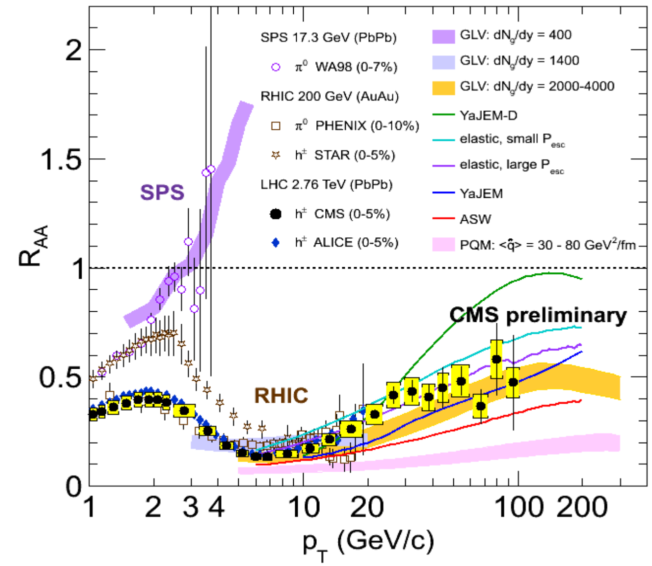
Outstanding Questions in Heavy Ion Physics

Jet Quenching and QGP Properties

- Various parton energy loss mechanisms
  - Radiative energy loss
    - e.g. DGLV, BDMPS, AMY …

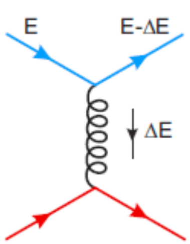






$$R_{AA} = \frac{1}{\langle n_{coll} \rangle} \frac{\pi^0 \text{ in AuAu collisions}}{\pi^0 \text{ in pp collisions}}$$

  - Collisional energy loss



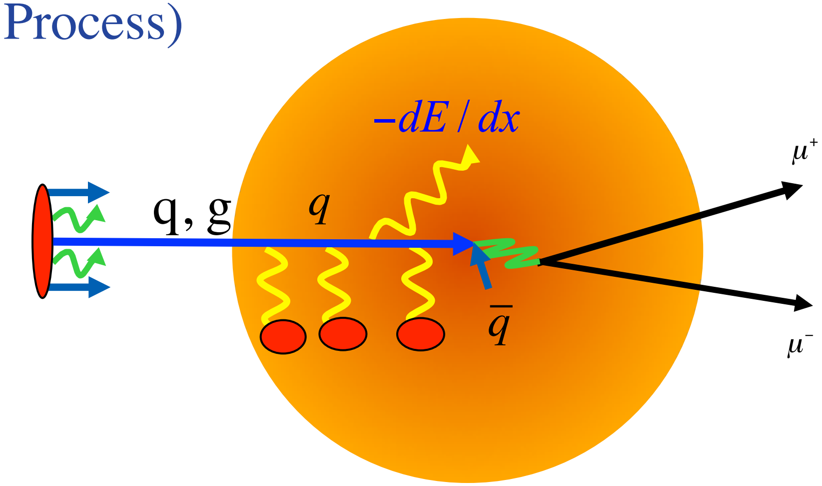
Theoretical quenching factor
- much model dependent!

$$R_{AA} \sim \int \rho_{QGP}(x) \cdot [\frac{dE}{dx}(\hat{q})] \cdot dx$$

$$<\hat{q}> = \frac{\langle k_T^2 \rangle}{L} \approx \frac{\mu^2}{\lambda} = \quad 2 \sim 20\, GeV^2/fm$$

Determine and Calibrate dE/dx with DY in p+A

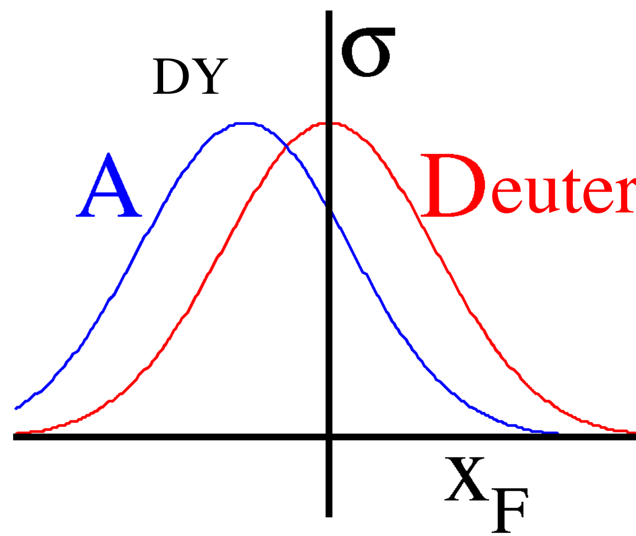
$$q + \bar{q} \rightarrow \gamma^* \rightarrow \mu^+ + \mu^-$$ (Drell-Yan Process)



- Known initial state nuclear parton density;
- Minimal final-state interactions of the detected particles.
- E906: No shadowing correction at moderate X_t

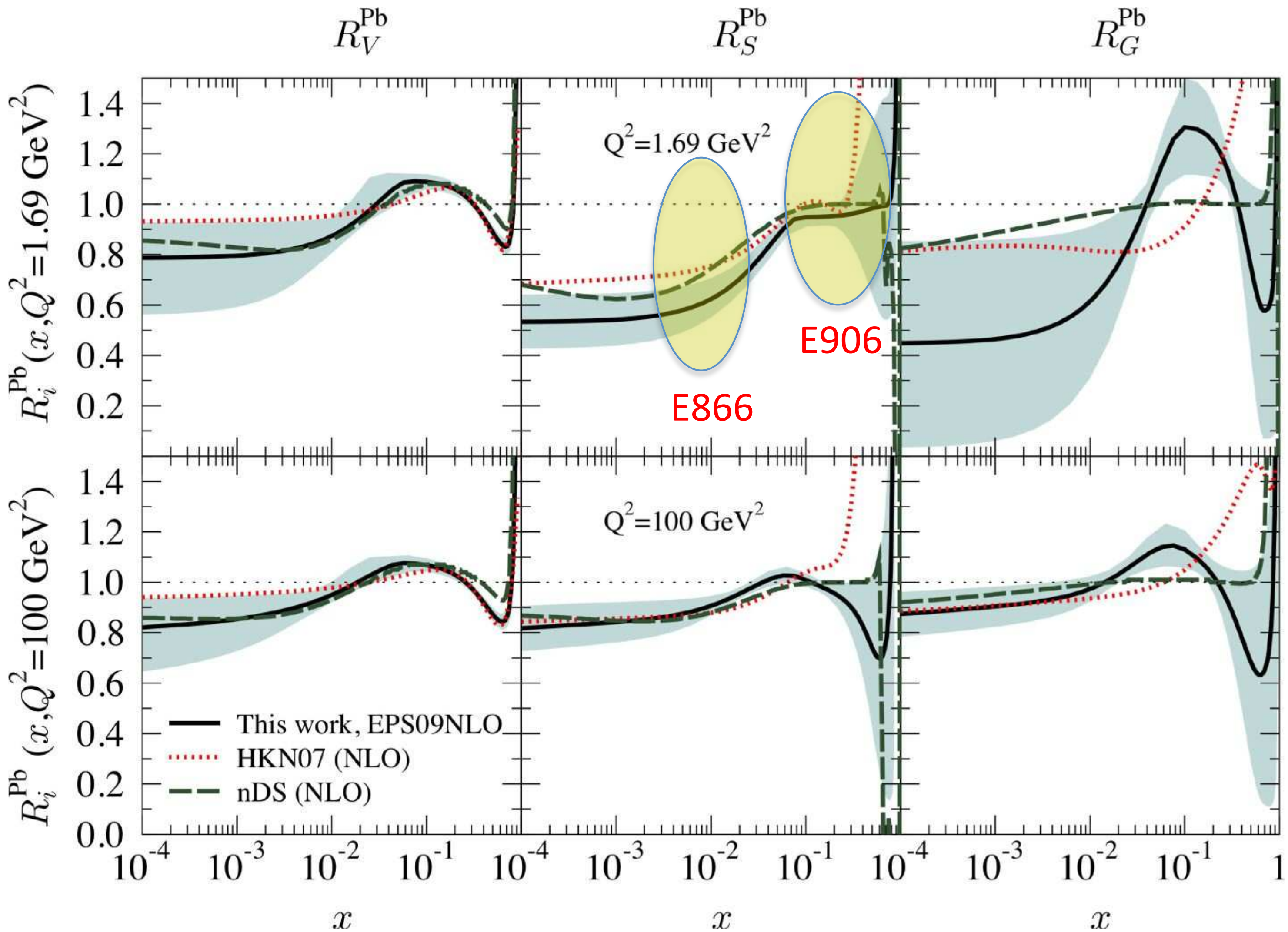
Energy loss reduces x_b and x_F in nuclei versus proton ($x_F = x_b - x_t$)

$$\frac{d^2\sigma}{dx_t dx_b} \approx \frac{4\pi\alpha^2}{9x_1x_2s}\sum e^2[q_b(x_b)\bar{q}_t(x_t)]$$



Possible sea-quark shadowing effects

Sea Quark Shadowing and Nuclear PDFs



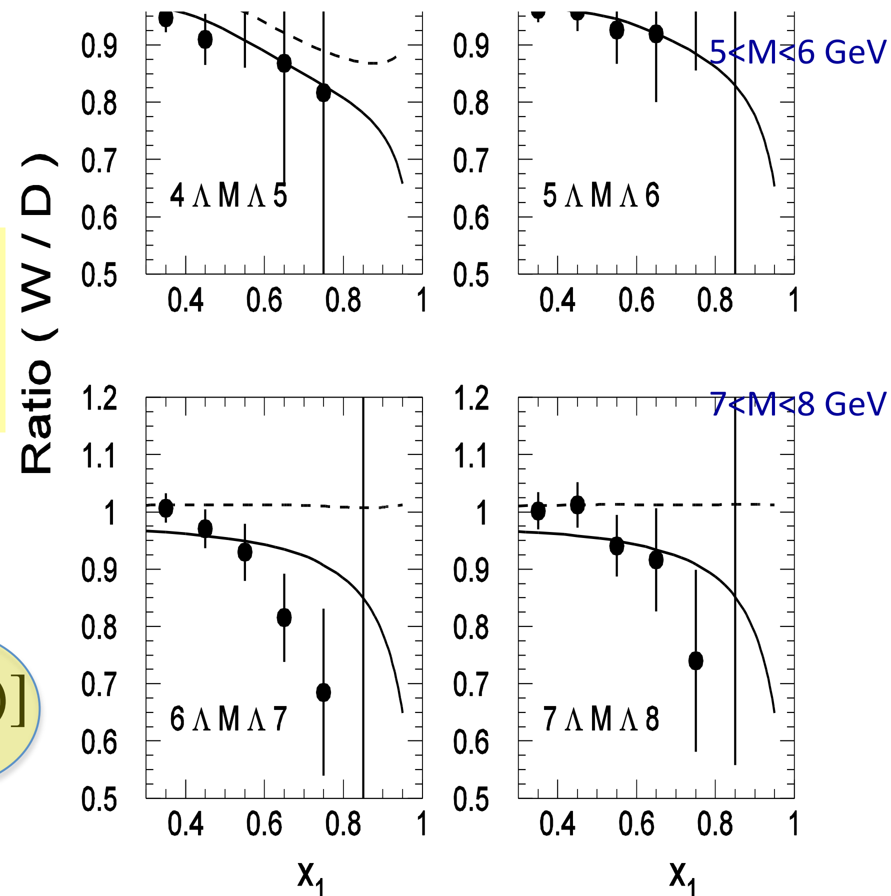
Quark Energy Loss in Cold Nuclear Medium

Drell-Yan @E866

(PRL 86 (2001) 4483)

- Drell-Yan Suppression ~20% in p+W
- <dE/dx> strongly depends on shadowing correction
- $x_t \sim 10^{-2}$ @ 800GeV p+A

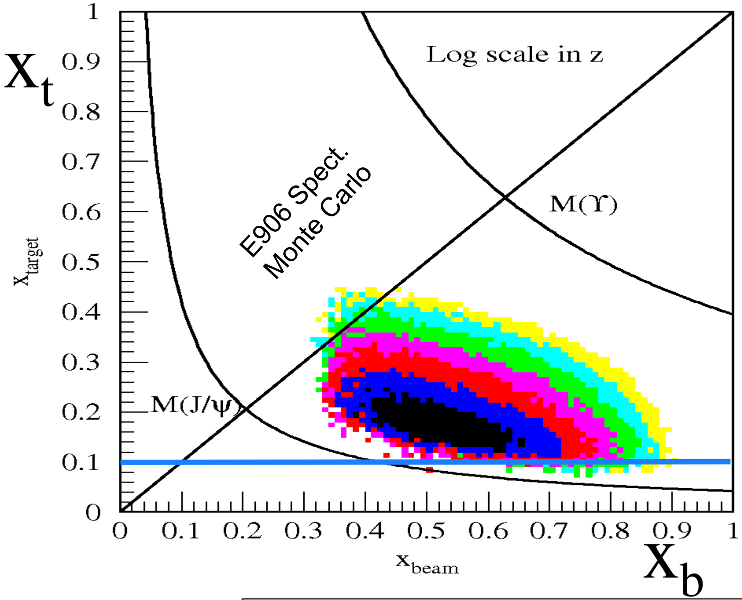
800GeV p + A



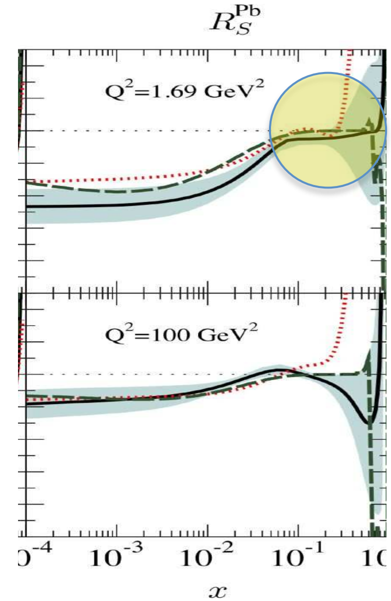
$$\frac{dE}{dx} = 0 \sim 2.5 \quad GeV / fm$$

$$\frac{d^2\sigma}{dx_t dx_b} \approx \frac{4\pi\alpha^2}{9x_1x_2s}\sum e^2[q_b(x_b)\bar{q}_t(x_t)]$$

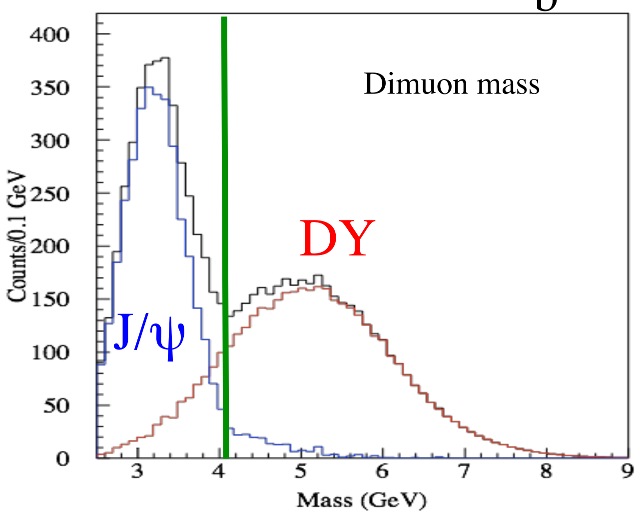
E906 Acceptance and Dimuon Mass Distributions

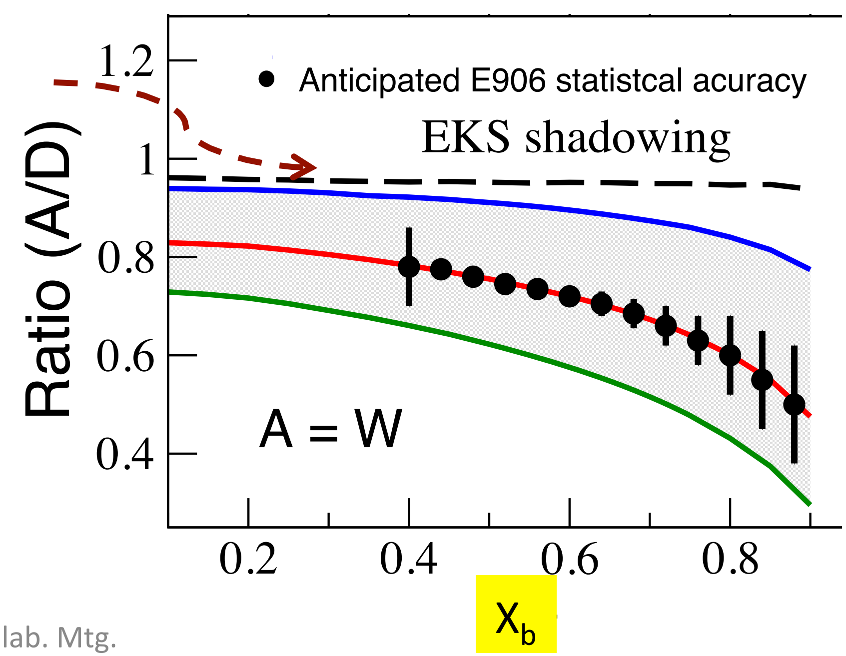


E_{beam} 120 GeV:
No shadowing
correction
since $x_t = 0.1 \sim 0.4$



20~30% effect @xF~0.6!





Experimental Sensitivity to Quark Energy Loss

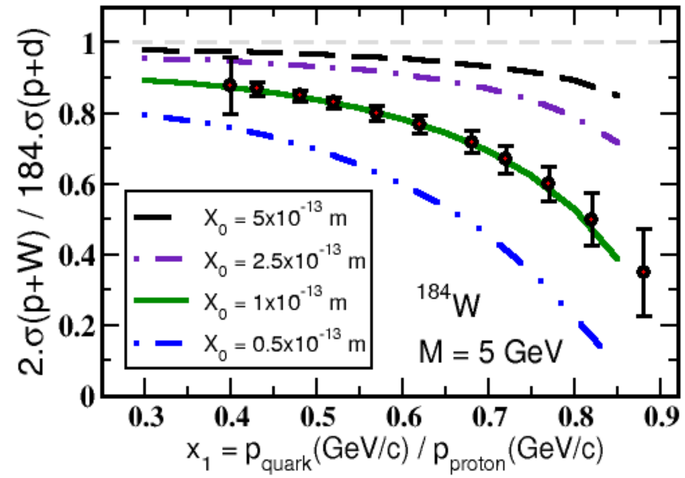
$$-\frac{dE}{dx} = \frac{E}{X_0}$$

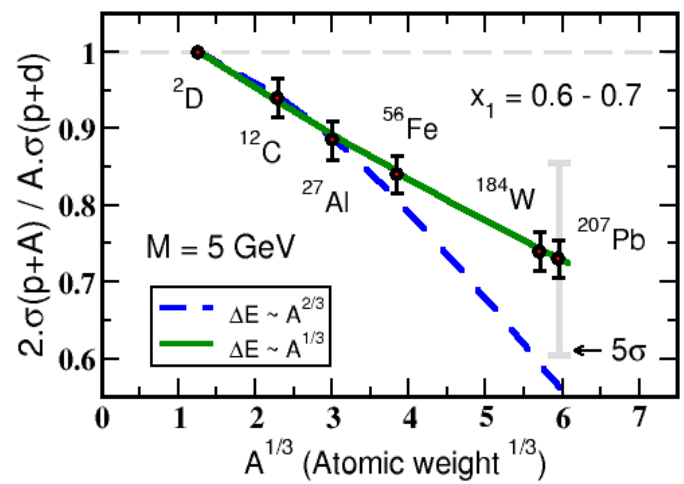
- Shortest radiation length in nature $X_0 = 1 \times 10^{-13}$ m
- Clearly distinguish between leading models for L dependence of E-loss

$$\boxed{\begin{array}{lll} -\Delta E & \propto & A^{1/3} \ (\text{or} \propto L) \\ -\Delta E & \propto & A^{2/3} \ (\text{or} \propto L^2) \end{array}}$$

- Benchmark dE/dx models

Quark energy loss only I. Vitev et al





Reality

E906 2012 Run: Expected Statistics

- Run plan: 4~5 weeks of physics run
  - p+A and p+d ?
  - p+H and p+d?
- Beam conditions
  - 2.5 x 10^11/ sec for 4 sec per minute
  - E906 efficiency 50%
  - If lower field for J/Psi, expect higher rate in detectors, need to reduce beam intensity to 1x10^11/sec
- Protons on targets
  - (1x10^11) x (4 sec) x (4 weeks x 7 x 24 x 60 minutes) x 50%
    = 1x10^11 x 1.6x10^5 x 0.5
    = 0.8 x 10^16
- Effective Target thickness
  - Target: ~10% interaction length
  - 0.8 x 10^15 p+(p/n) collisions

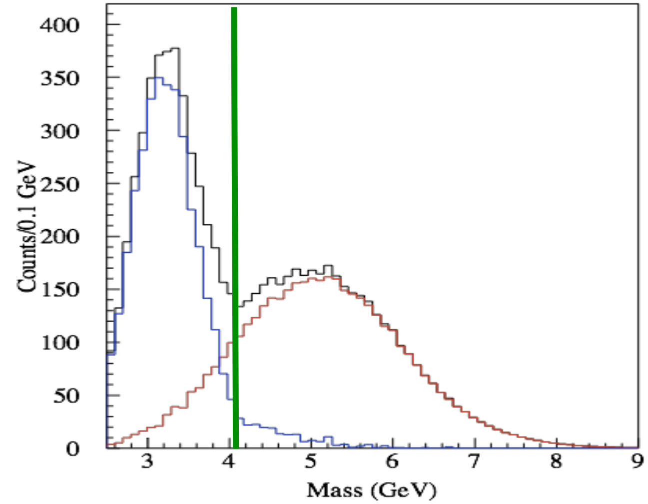
$$N = L \times \sigma = 10\% \times 0.8 \times 10^{16} = 0.8 \times 10^{15}$$

$$\sigma_{NN} \approx 40mb$$

$$\sqrt{s} = 15.1GeV$$

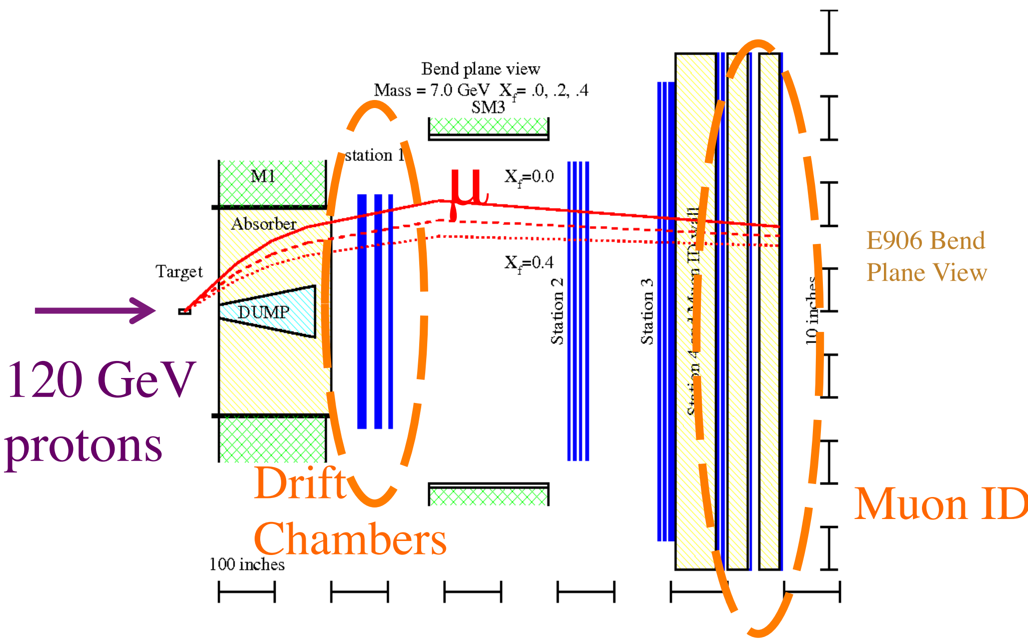
$$L = 0.8 * 10^{15} / 40mb = 20\ fb^{-1}$$

Expected Detector Performance

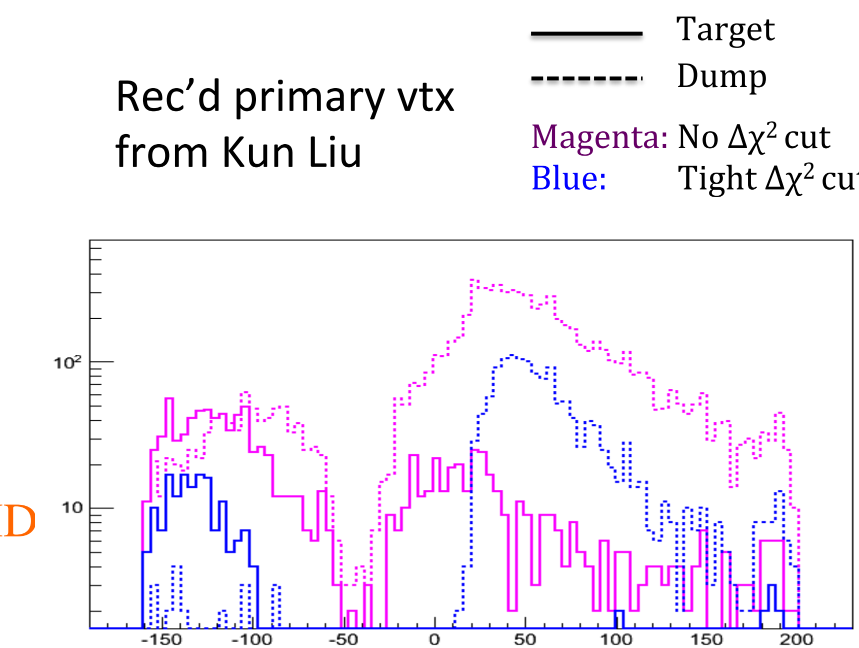


- Reasonable J/Psi and Drell-Yan separation
  - Drell-Yan: M>4GeV

- Improved tracking to separate tracks from target and beam dump



Rec'd primary vtx from Kun Liu

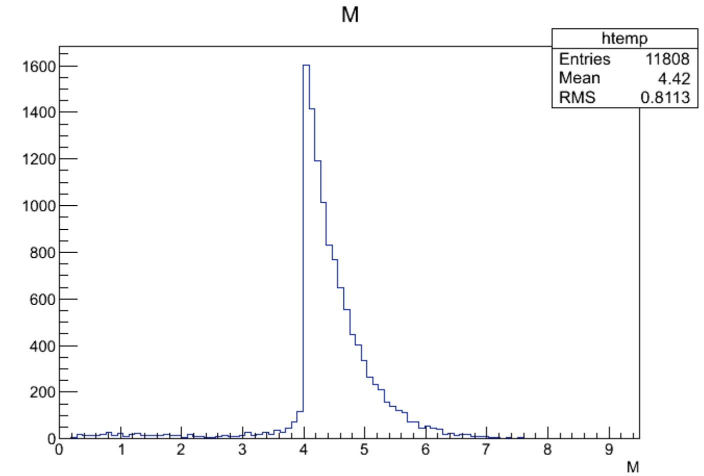


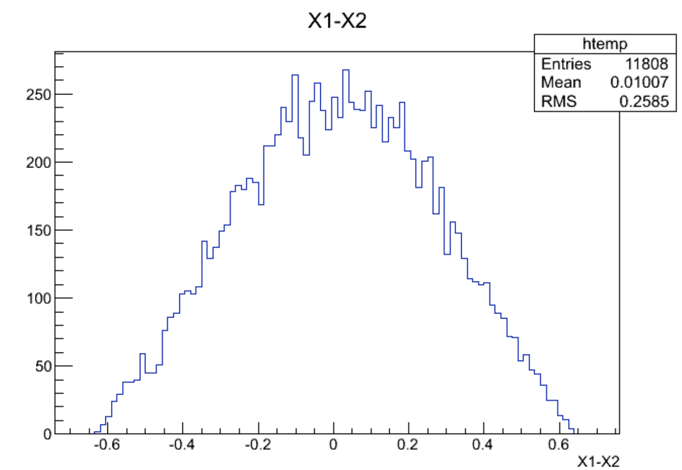
DY Production p+p

PYTHIA @LO, K = 2.5

- DY cross section: M >4 GeV @120 GeV: (PYTHIA LO)
  - 1 f + fbar -> gamma*/Z0,
    - Sigma = 5.442D-08 mb, M > 4GeV
  - K = 2.5,
    - sigma = 2.5 x 5.5 x 10^-8mb
      = 13.8 x 10^-11b
  - N = 20 fb^-1 * 13.8x 10^-11b
    = 2.8 x 10 ^6
  - 80K pythia events -> 11,808 dimuons (M>4 GeV), (BR~15%)

DY_dimuons = 2800k/80k*11800
= 410 k



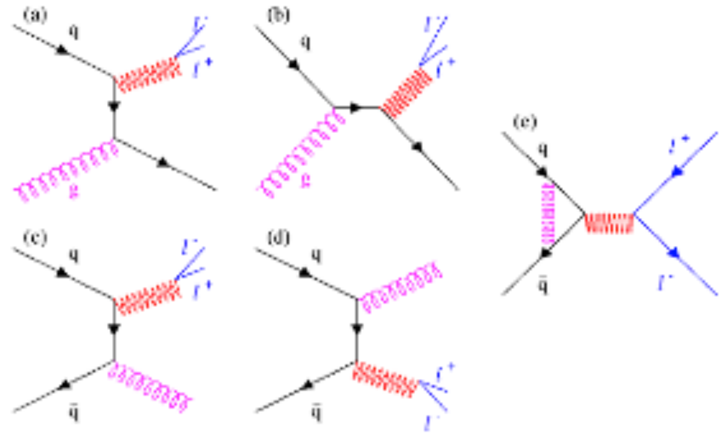


xF

QCD Correction

K factors

$$d\sigma^{DY}_{NLO} = K(s, M^2) d\sigma^{DY}_{LO}$$

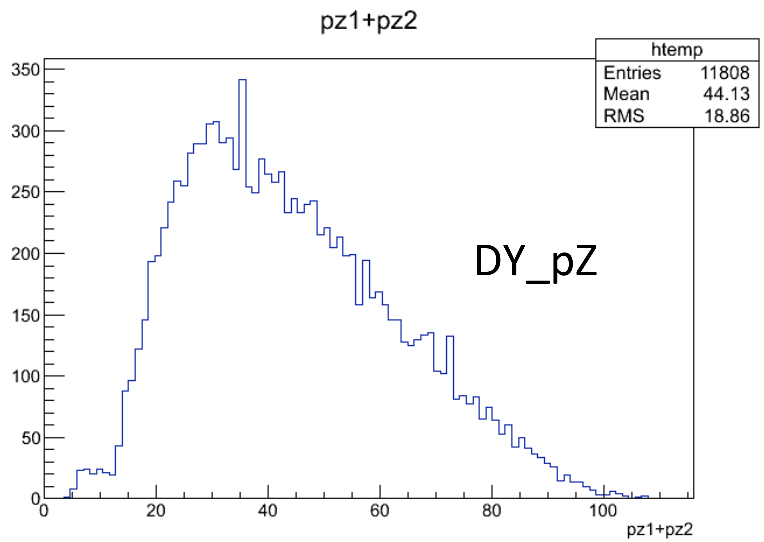


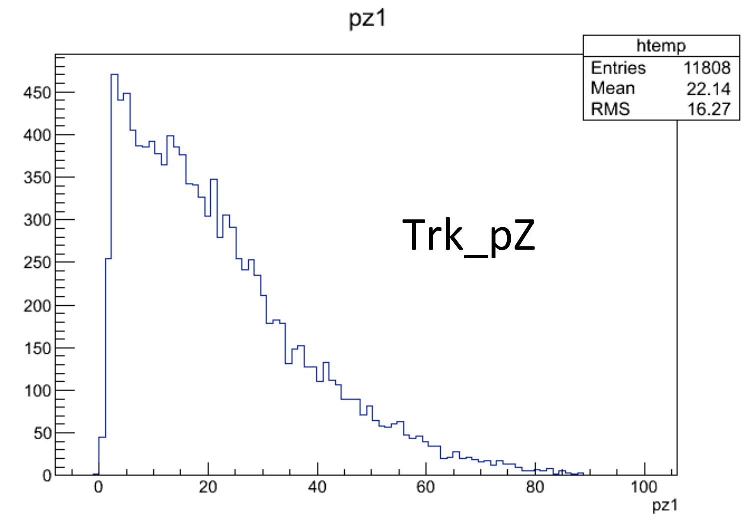
Group	Beam/target	cm Energy	K
E288	p/Pt	27.4	1.7
E439	p/W	27.4	1.6±0.3
CHFMNP	p/p	44,63	1.6±0.2
AABCSY	p/p	44,63	1.7
NA3	p/Pt	27.4	3.1±0.5±0.3
E537	$\bar{p}$/W	15.3	2.45±0.12±0.20
NA3	(p-$\bar{p}$)/Pt	16.8	2.3±0.4
NA3	π/Pt	16.8	2.49±0.37
		22.9	2.22±0.33
E326	π/W	20.6	2.70±0.08±0.40
NA10	π/W	19.1	2.8±0.1
Goliath	π/Be	16.8,18.1	2.5
Omega	π/W	8.7	2.6±0.5

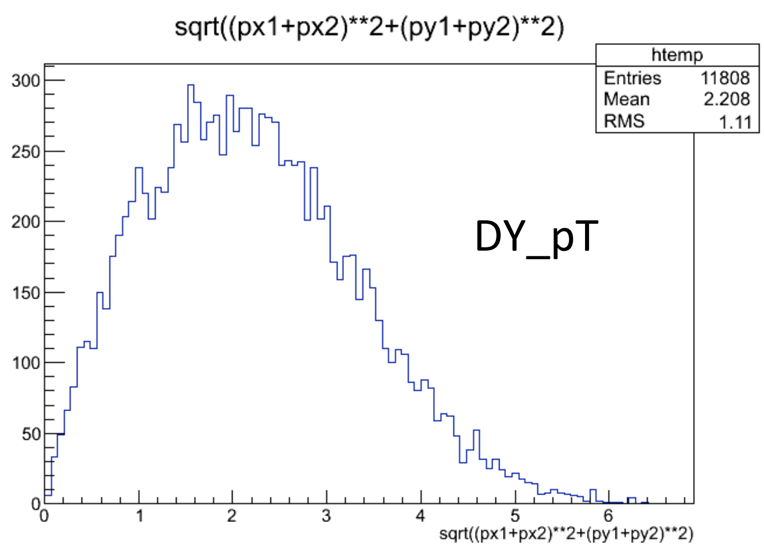
K = 2.5 @120GeV p+p

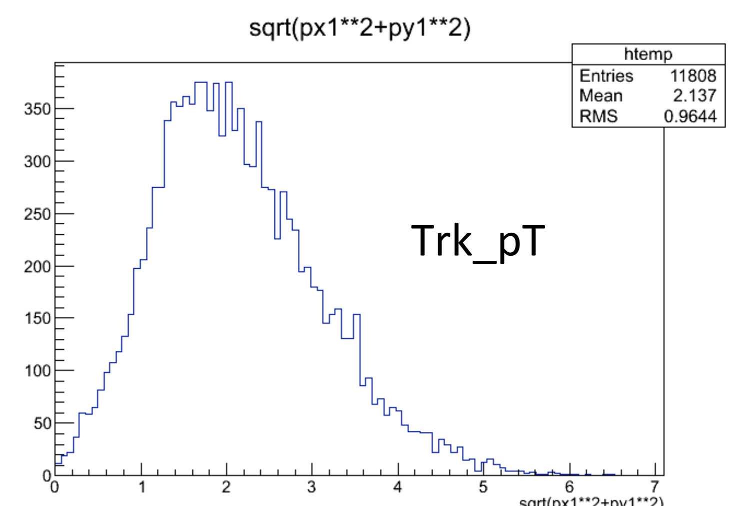
Table VII..2. *K* Factors for dilepton experiments (Grosso-Pilcher and Shochet, 1986).

DY and Muon Kinematics w/o E906 Acceptance @PYTHIA LO







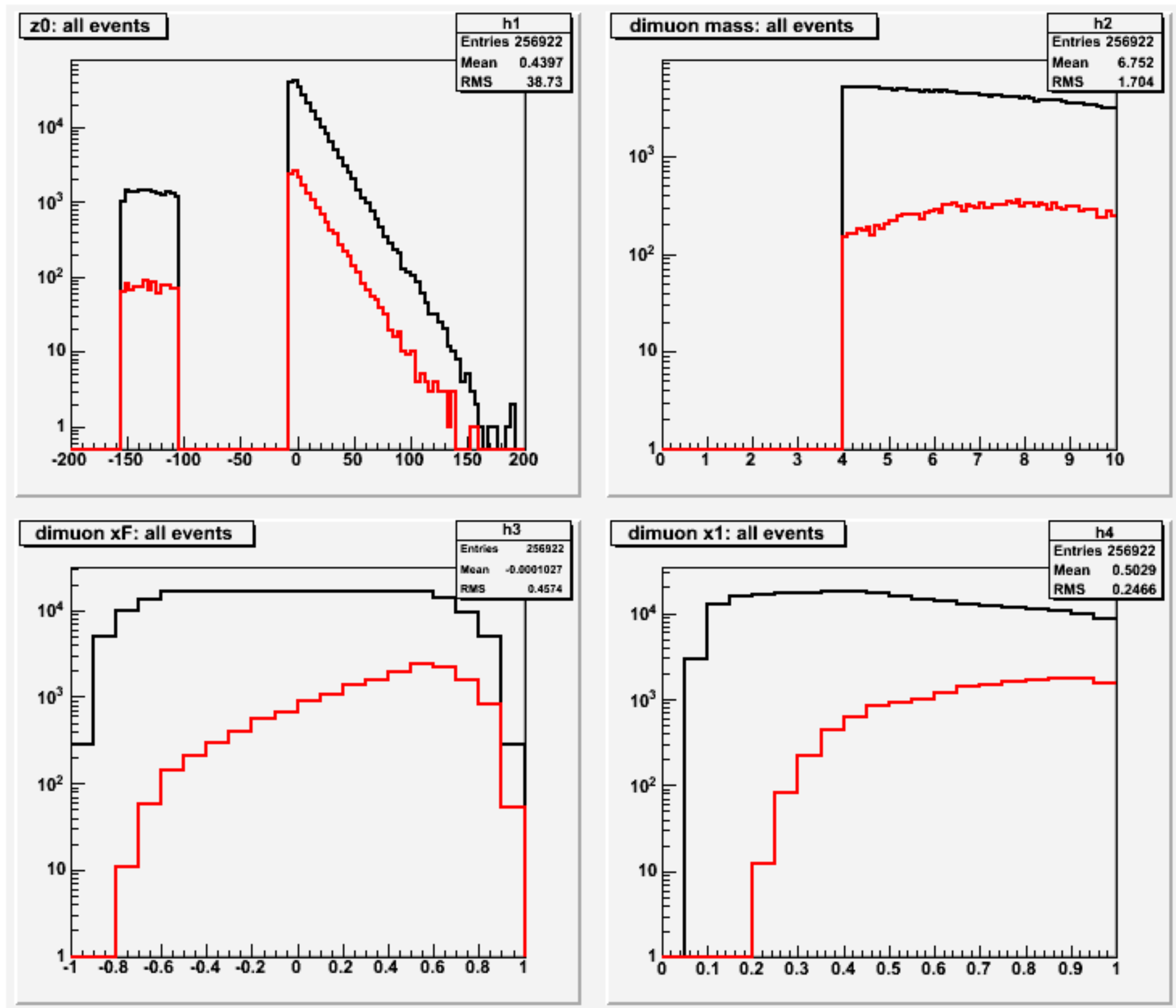


E906 Drell-Yan Dimuon Acceptances

Black: generated
Red: detected

E906 Efficiencies:
DY (M>4) = 6.4%

DY-> dimuons
N = 410K x 6.4%
= 26000



xF

x_b

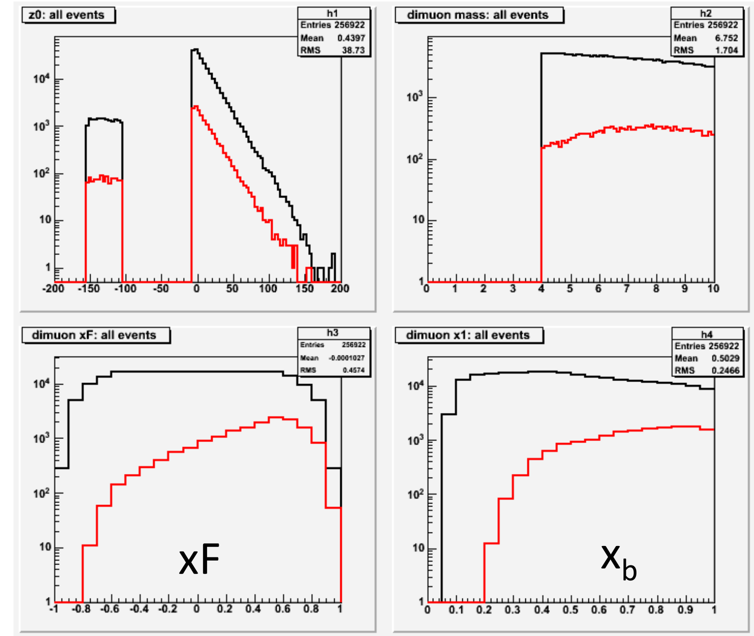
Drell-Yan Summary

$$A = \frac{N_1}{N_2}, \quad N_1 \sim N_2 \sim N/2$$

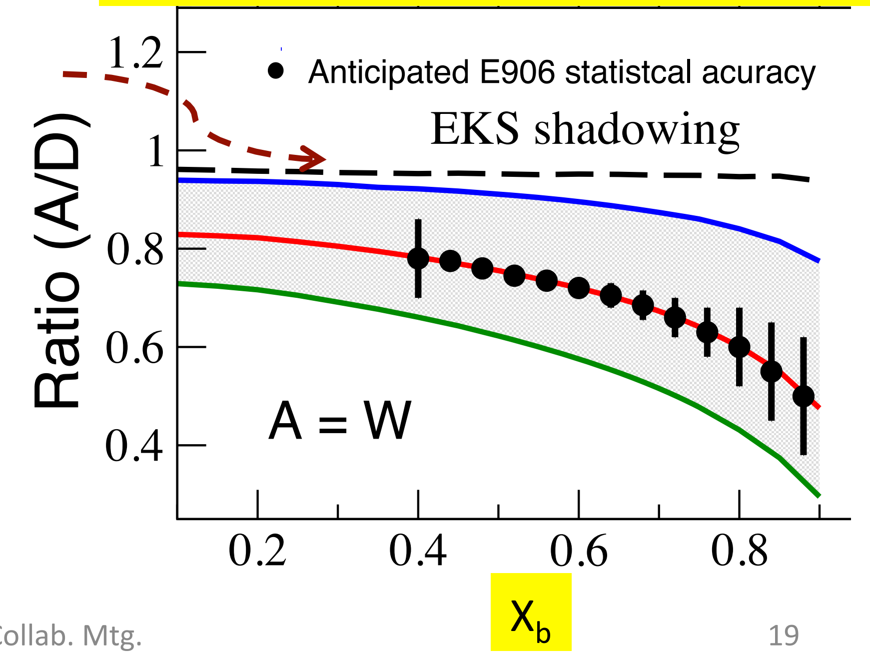
$$\delta A / A = \frac{1}{\sqrt{N_1}} \oplus \frac{1}{\sqrt{N_2}} \approx \frac{2}{\sqrt{N}}$$

$$\delta A / A = \frac{2}{\sqrt{26000}} = 1.2\%$$

- Prefer W target
  - 20~30% suppression
  - but Fe is OK, smaller effect
- p+d and p+W
  - 50% split in beams
- DY: Dimuon_mass > 4GeV



Expectation: ~20% suppression effect!



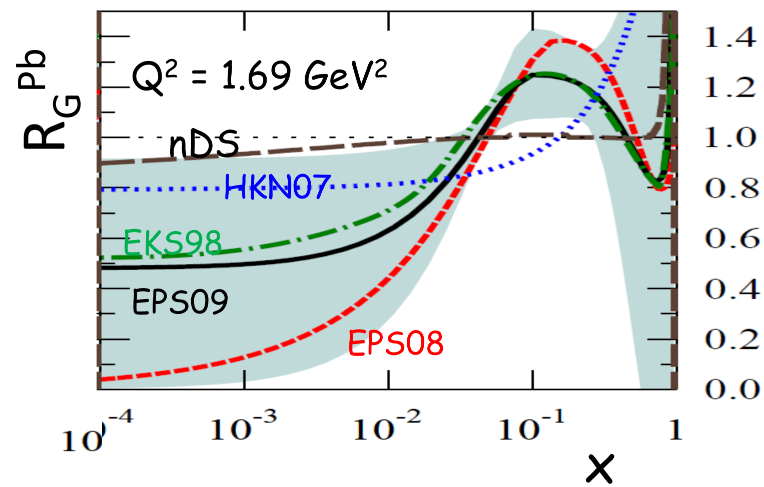
Topics II

J/Psi Production and CNM Effects

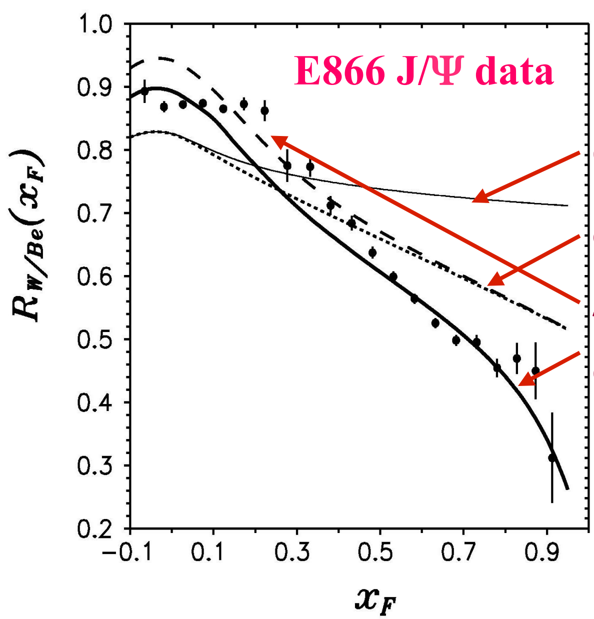
Novel CNM Effects and QGP Baseline

- Parton (anti)shadowing
- Gluon saturation physics
  (NSAC DM08)
- Parton energy loss in CNM
  (NSAC DM10,12)

Gluon shadowing



Kopeliovich etal Nucl Phys A696 (2001) 669-714

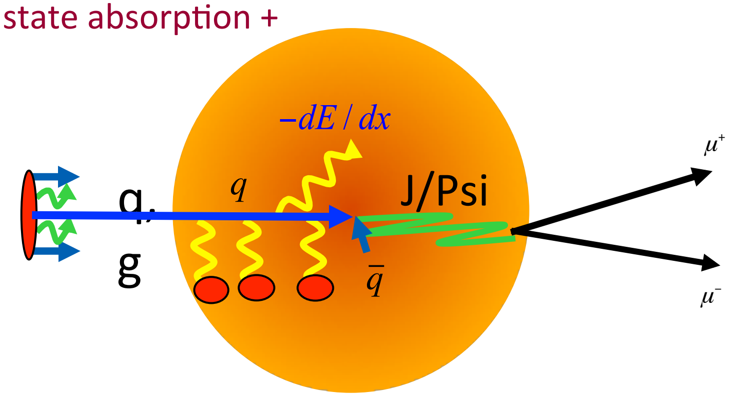


Quark shadowing and final state absorption +

Gluon shadowing +

Anti-shadowing +

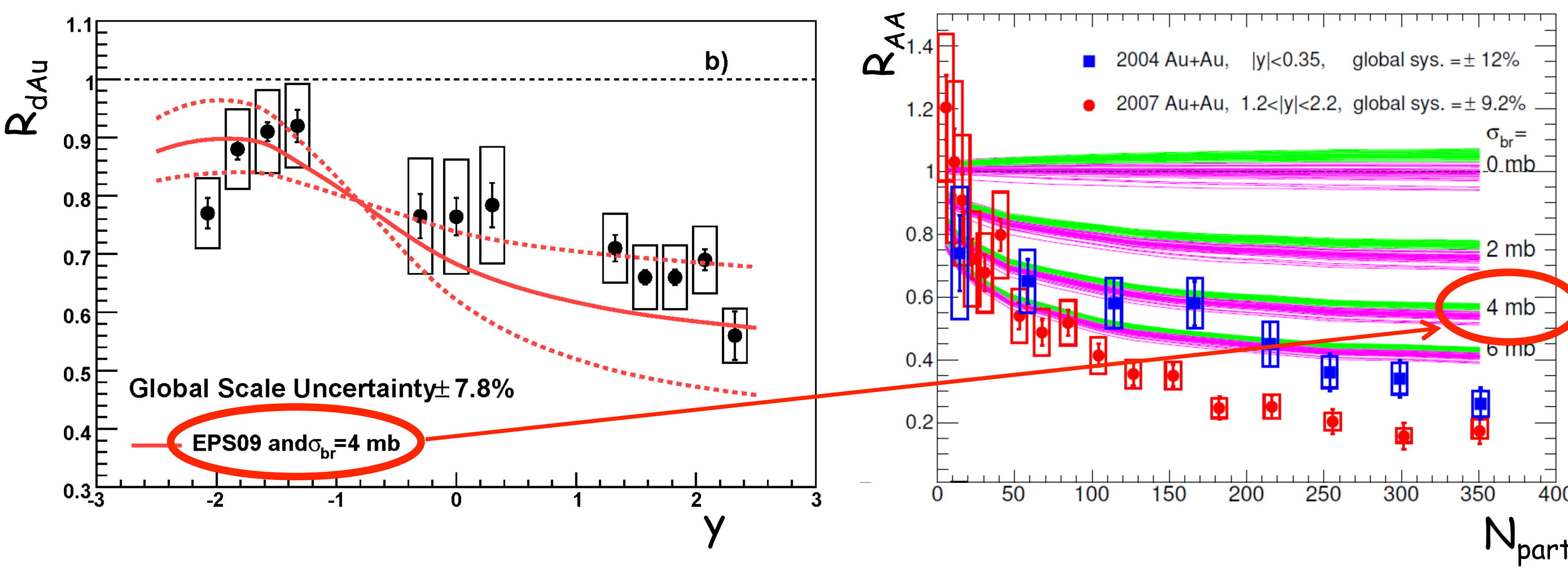
dE/dx



QGP Physics: Quarkonia Suppression – Importance of CNM

CNM effects appear to provide a large fraction of the observed suppression

- So difficult to conclude much w/o a thorough (fundamental) understanding of CNM and an informed extrapolation to A+A from d+A



MJL & Vogt began these model comparisons years ago; continuing now with Colorado, FSU working with these in more quantitative and informative ways

J/Psi Production in p+p @120 GeV

- J/Psi cross section: J/Psi -> dimuon
  - Data: ~ 50 nb @120GeV p+p
  - N_J/Psi = 20 fb^-1 x 50nb
    = 1K x 10^6
  - Total J/Psi->dimuon = 1K x 10^6 x6%
    = 60 x 10^6
  - @800 GeV: 442 +/-88 nb

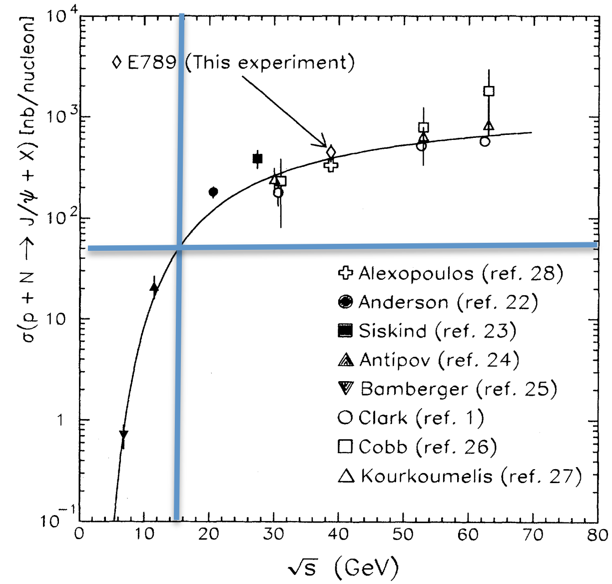
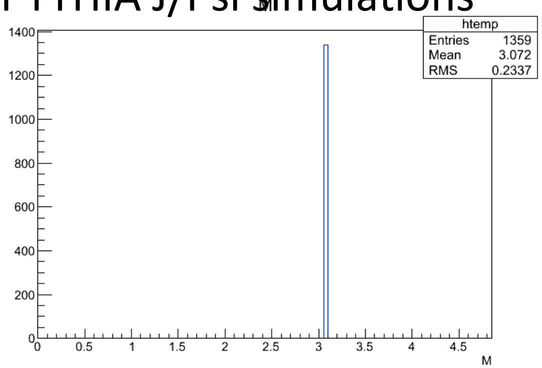
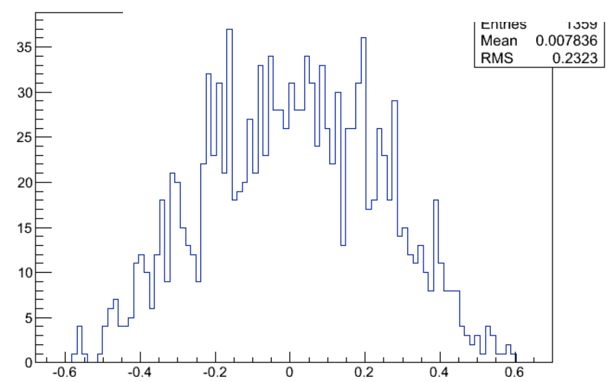


FIG. 11. Total cross section for J/ψ production vs center-of-mass energy. The solid curve is a fit to the data using the functional form $Ae^{-B\sqrt{\tau}}$ where $\tau = M^2_{J/\psi}/s$. See text for details.

PYTHIA J/Psi simulations

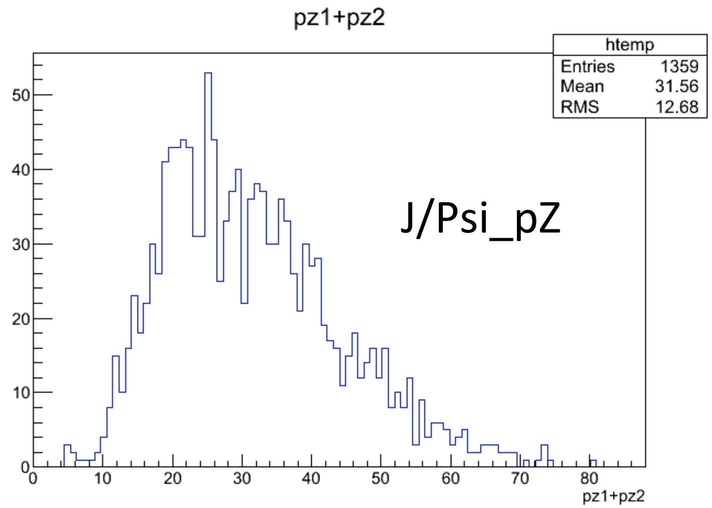


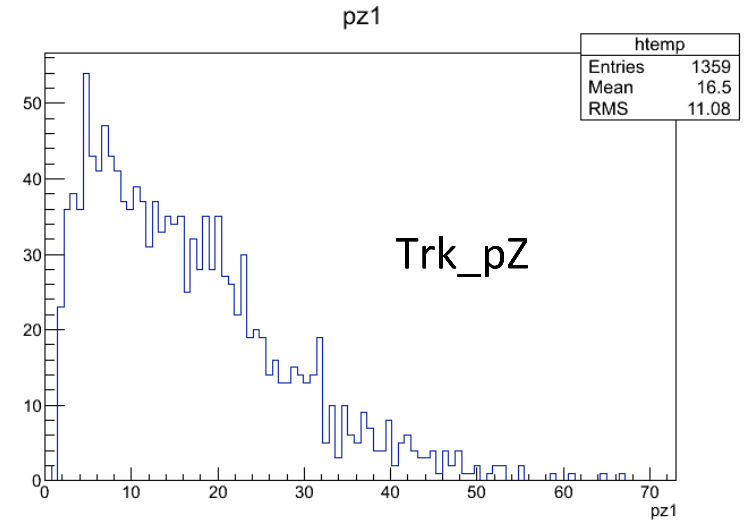


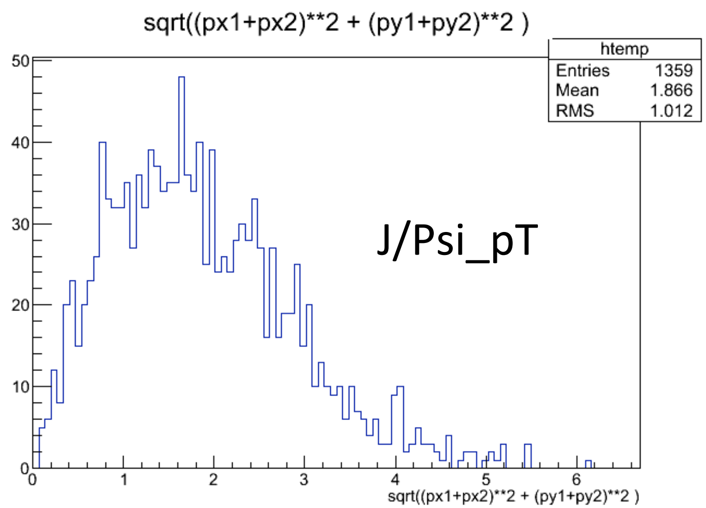
xF_J/Psi

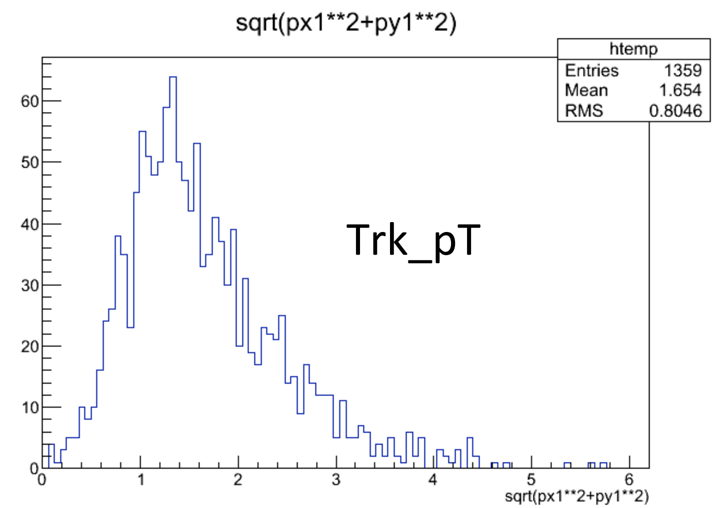
J/Psi and Muon Kinematics

PYTHIA Simulations







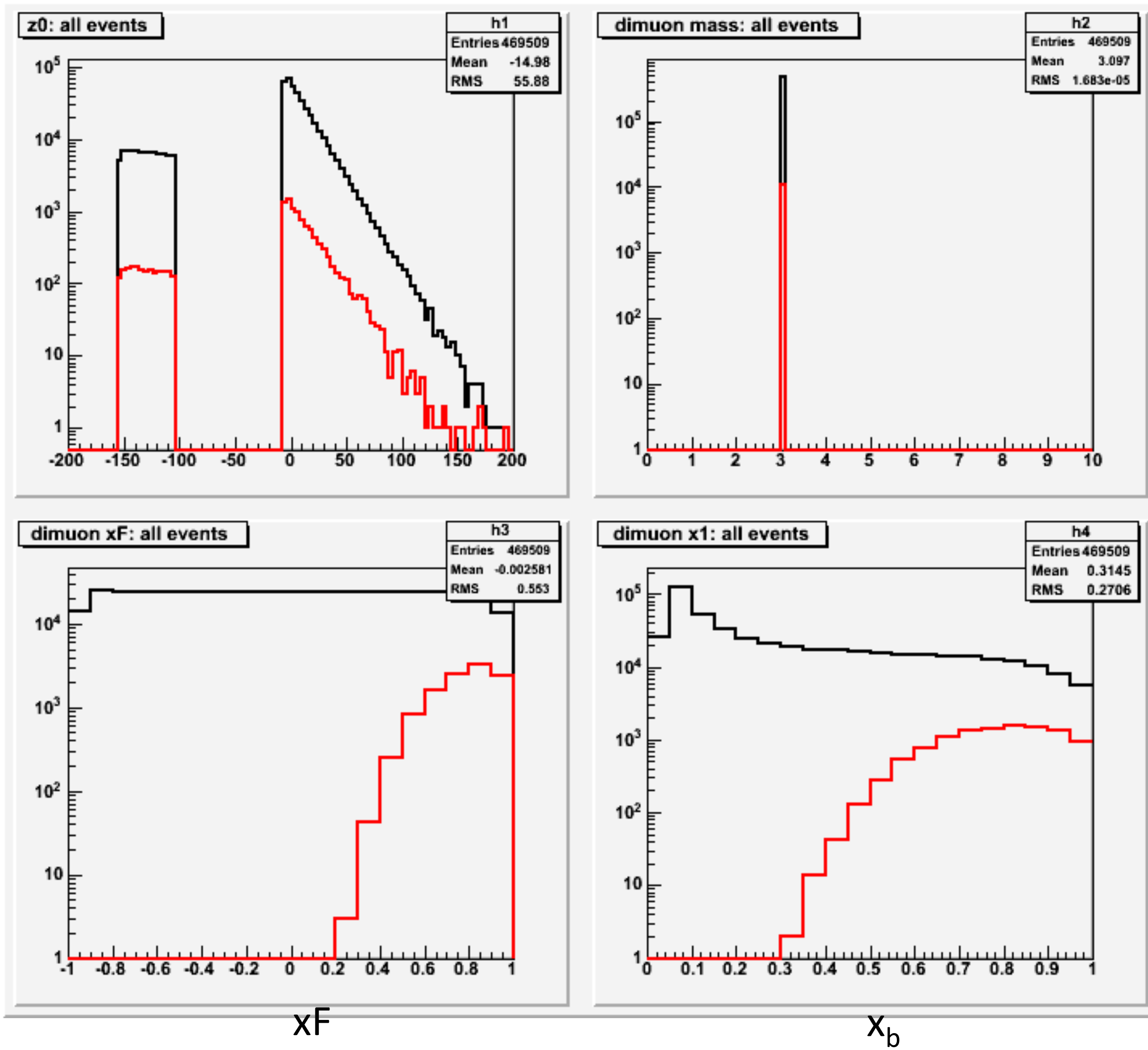


E906 J/Psi Dimuon Acceptance

Black: generated
Red: detected

E906 Efficiencies:
J/Psi = 2.4%

J/Psi->Dimuons
N = 60M x 2.4%
= 1.4M

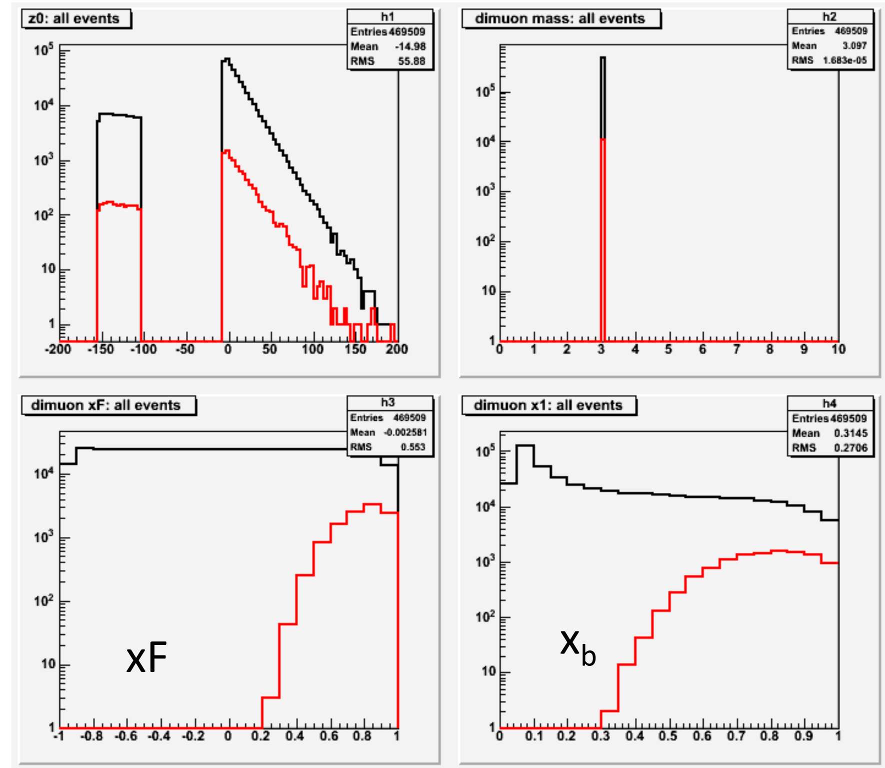


J/Psi Summary

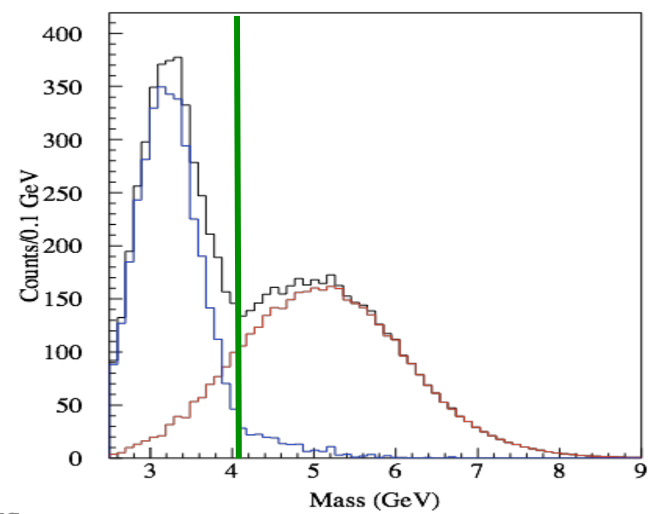
$$A = \frac{N_1}{N_2}, \quad N_1 \sim N_2 \sim N/2$$

$$\delta A / A = \frac{1}{\sqrt{N_1}} \oplus \frac{1}{\sqrt{N_2}} \approx \frac{2}{\sqrt{N}}$$

$$\delta A / A = \frac{2}{\sqrt{1.4 \times 10^6}} = 0.17\%$$



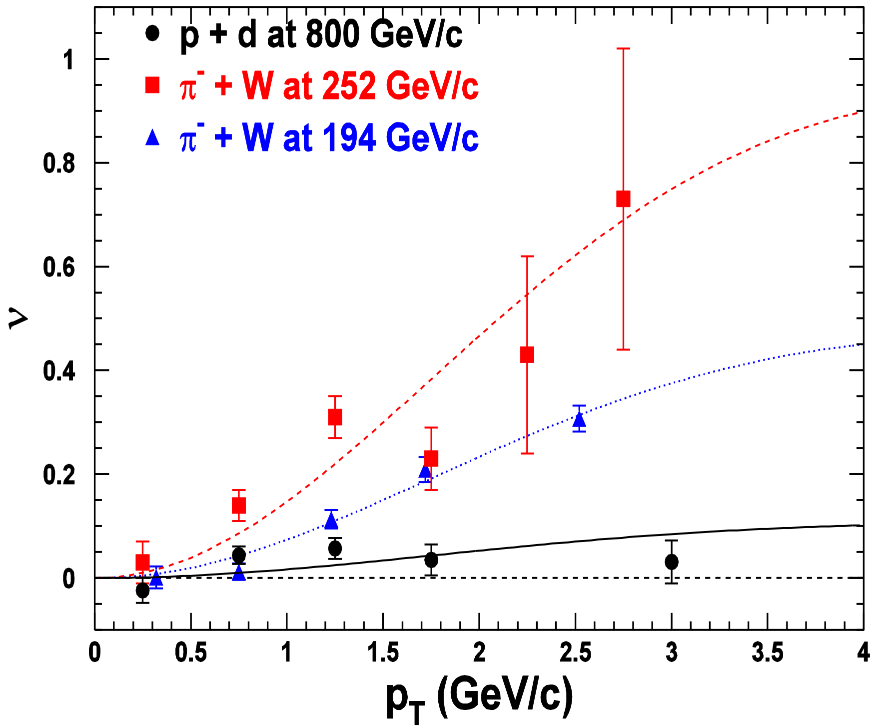
- Prefer W, larger effects
  - but Fe is OK
- p+d and p+W
  - 50% split in beams
- J/Psi: Dimuon_mass < 4GeV



Azimuthal cos2Φ Distribution in π+W and p+d Drell-Yan

E866 Collab., Lingyan Zhu et al.,
PRL 99 (2007) 082301; PRL 102 (2009) 182001

J.C. Peng



Small ν is observed for p+d D-Y

With Boer-Mulders function $h_1^{\perp}$:

$\nu(\pi^- W \to \mu^+\mu^- X) \sim$ [valence $h_1^{\perp}(\pi)$] * [valence $h_1^{\perp}(p)$]

$\nu(pd \to \mu^+\mu^- X) \sim$ [valence $h_1^{\perp}(p)$] * [sea $h_1^{\perp}(p)$]

Sea-quark BM functions are much smaller than valence quarks

Backup

E906 Sensitivity to Quark Energy Loss

- For radiation lengths X_0 = 1 x 10^{-13} cm can achieve sensitivity ~ 20%

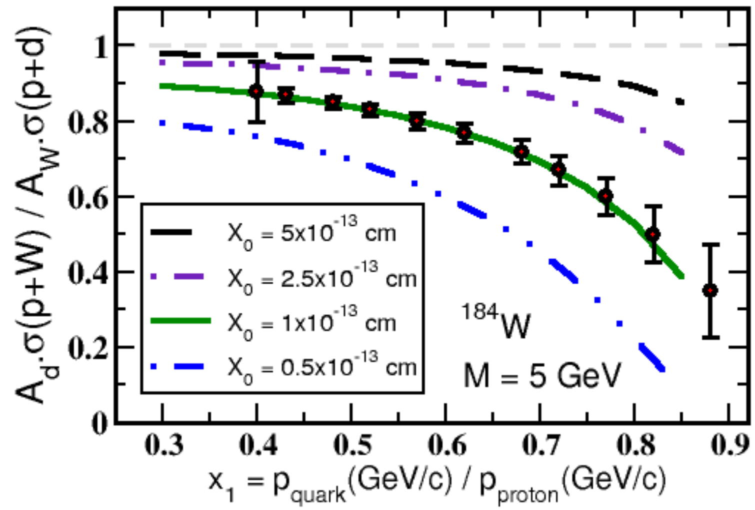
$$\frac{dE}{dx} = -\frac{E}{X_0}$$

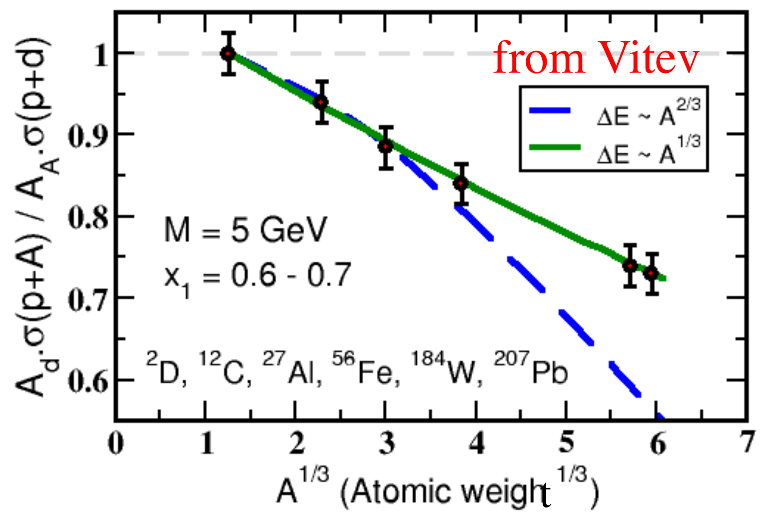
- Clearly distinguish between leading models for L dependence of E-loss (5σ)

$$-\Delta E \sim A^{1/3} \quad (\text{or} \ \sim L)$$

$$-\Delta E \sim A^{2/3} \quad (\text{or} \ \sim L^2)$$

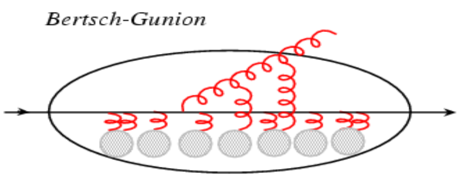
Simulated Quark energy loss only



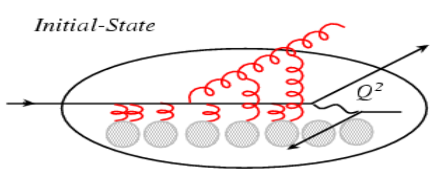


Process Dependence of Parton Energy Loss

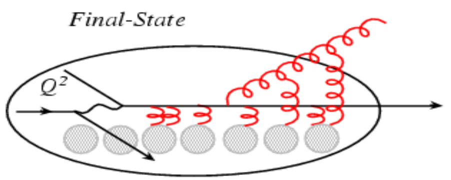
- E-loss in three cases



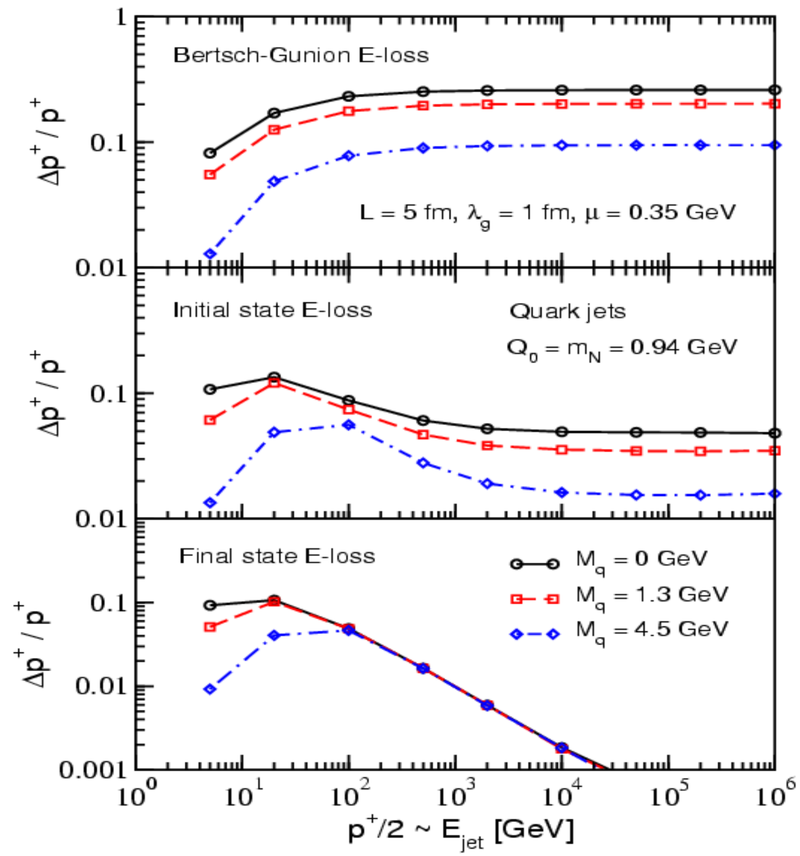
Academic case
(probably inapplicable)



Initial-state E loss:
DY process



Final-state E loss:
SDIS, QGP



I. Vitev, PRC 75(2007)064906.