LANL Quark Gluon Plasma and Cold Nuclear Matter Physics

Mike Leitch - January 10, 2012

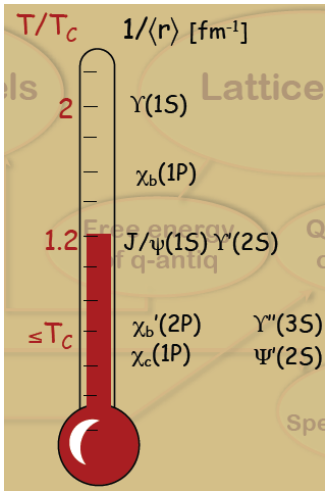
Quark-gluon Plasma (QGP) Physics:

- Quarkonia screening & HQ energy loss
- Heavy-quarks (HQ's) & the FVTX
- Higher energies - CMS

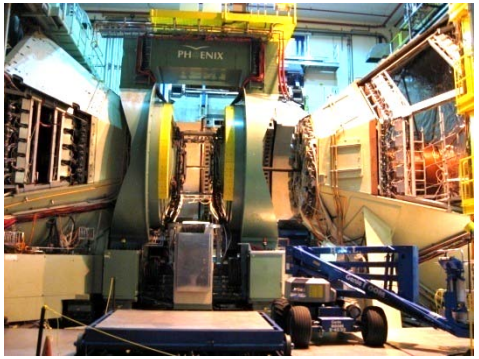
Cold Nuclear Matter (CNM) Physics:

- Gluon saturation & energy loss
- Quarkonia, HQ's, direct photons, Drell-Yan
- Fixed target- FNAL E906

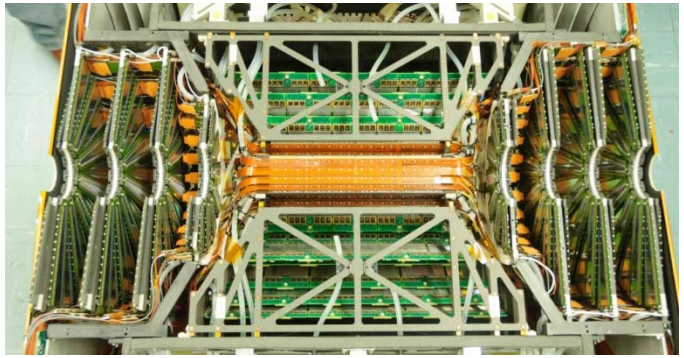
Quarkonia Screening in the QGP



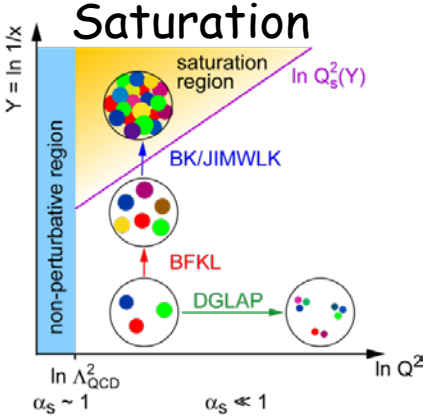
PHENIX Muon Tracker



FVTX

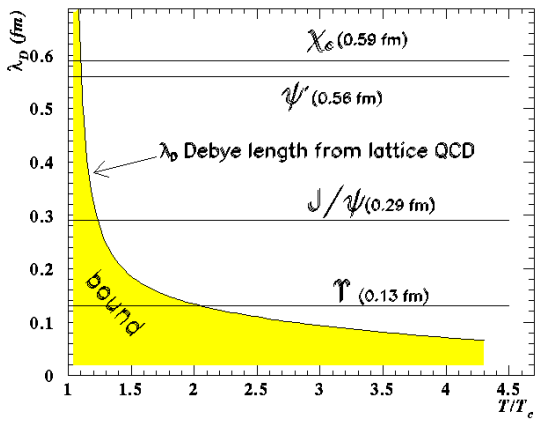


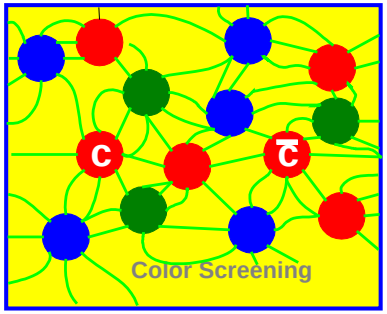
Gluon Saturation



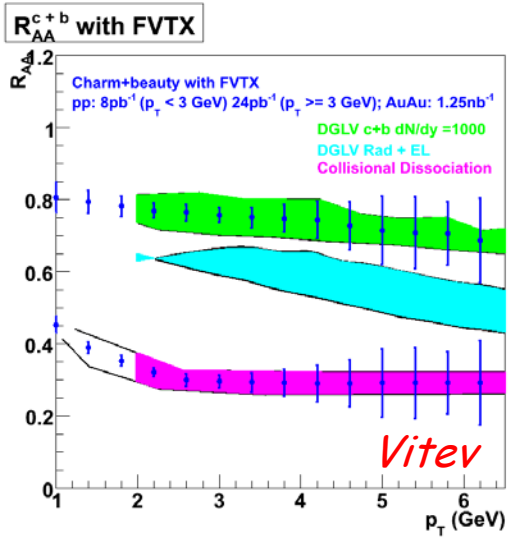
Fundamental QGP Physics Questions

Screening in QGP: NSAC Milestone: DM5 – "Measure the energy and system size dependence of J/Ψ production over the range of ions and energies available at RHIC."



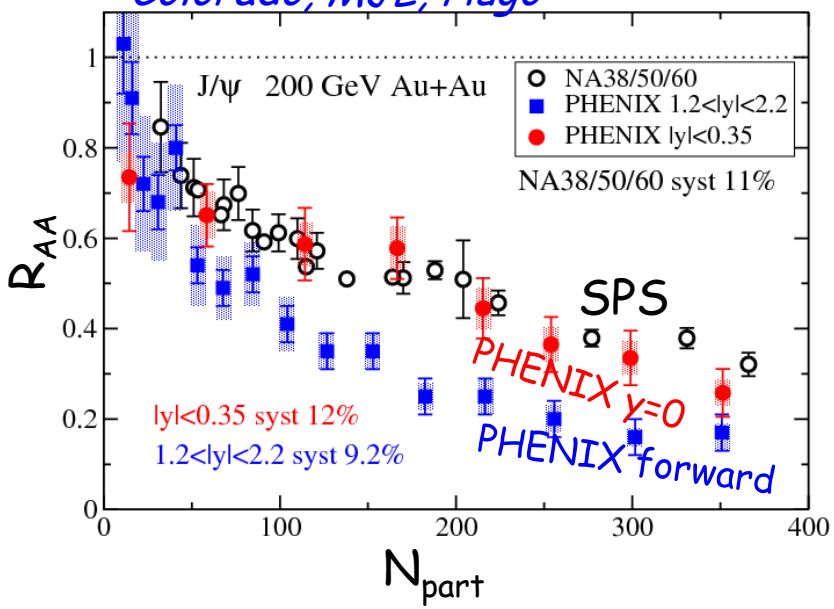


Heavy-quark dE/dx in QGP: NSAC Milestone: DM12 – "Measure production rates, high p_T spectra, and correlations in heavy-ion collisions at $\sqrt{s_{NN}}$ = 200 GeV for identified hadrons with heavy flavor valence quarks to constrain the mechanism for parton energy loss in the quark-gluon plasma."



QGP Physics: Quarkonia Suppression at RHIC

Colorado, MJL, Hugo

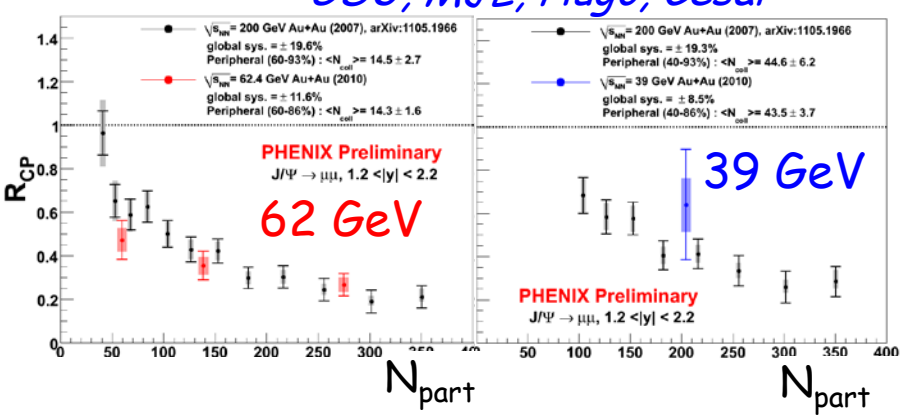


Overall suppression of J/ψ is very similar at SPS (17.2 GeV), RHIC (200,62,39 GeV) and LHC (2.76 TeV)

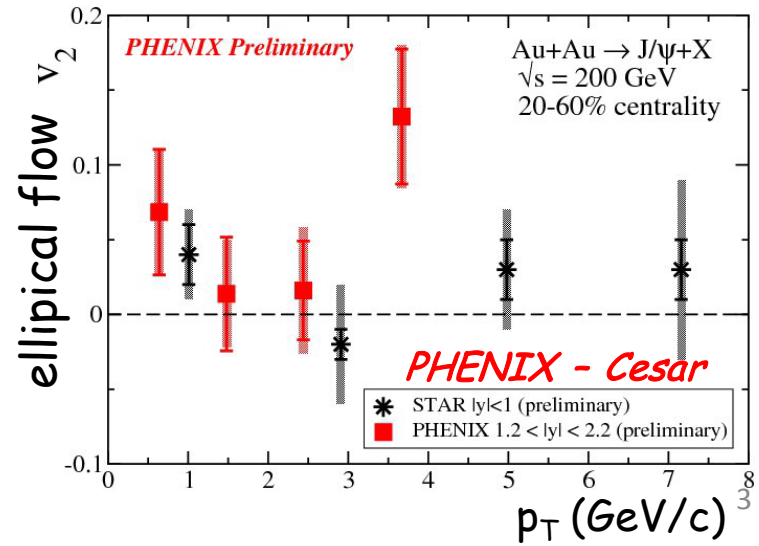
RHIC - Forward-rapidity J/ψ's are suppressed more than Mid-rapidity – Why?

1) Stronger forward rapidity suppression due to CNM effects?
2) Regeneration at mid-rapidity reduces suppression relative to forward (and gives net suppression similar to SPS)?

GSU, MJL, Hugo, Cesar

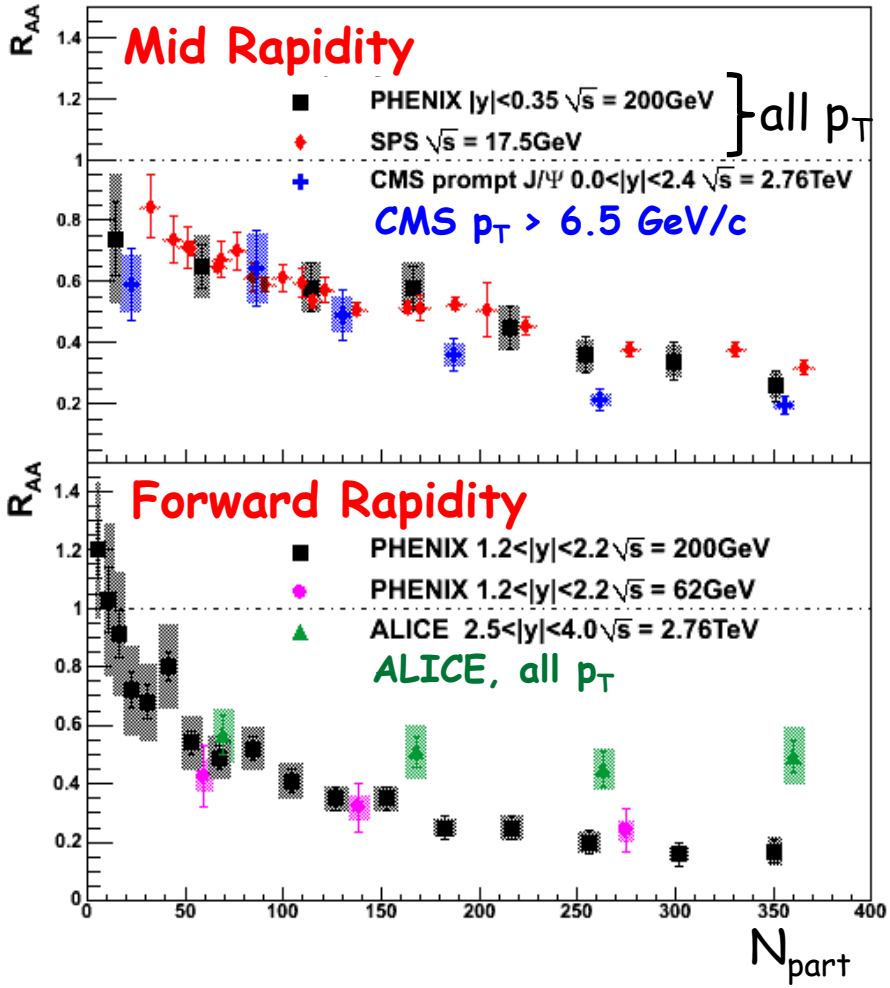


BUT - Small or no J/ψ flow seen at RHIC!



QGP Physics: Quarkonia Suppression – comparing RHIC & LHC

LHC - hotter, longer lived QGP and different CNM effects (all small x)



caution *caution*

- At y~0 LHC suppressed more than RHIC (but CMS is p_T> 6.5 GeV/c)

Catherine (LANL) gave CMS Quarkonia QM11 talk

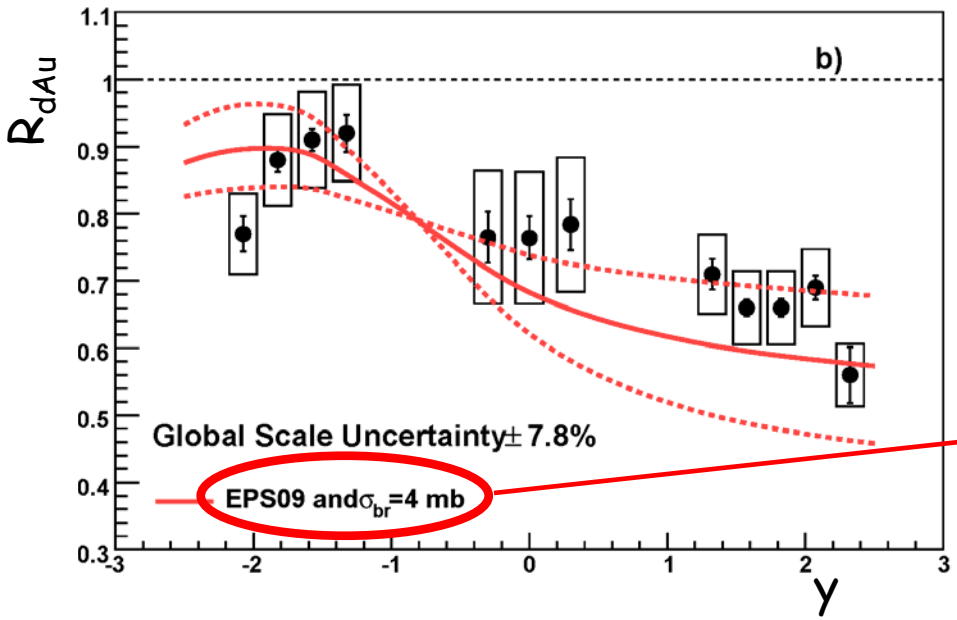
- At forward y LHC suppressed less than RHIC (here ALICE is p_T> 0)

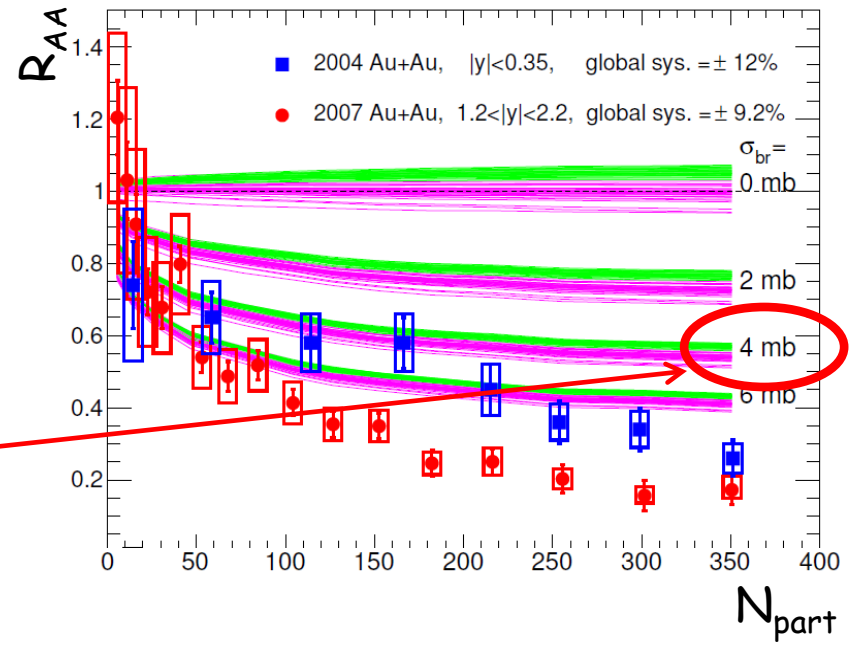
Features expected from regeneration, which is concentrated at small p_T
(need ALICE y=0 data)

QGP Physics: Quarkonia Suppression – Importance of CNM

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

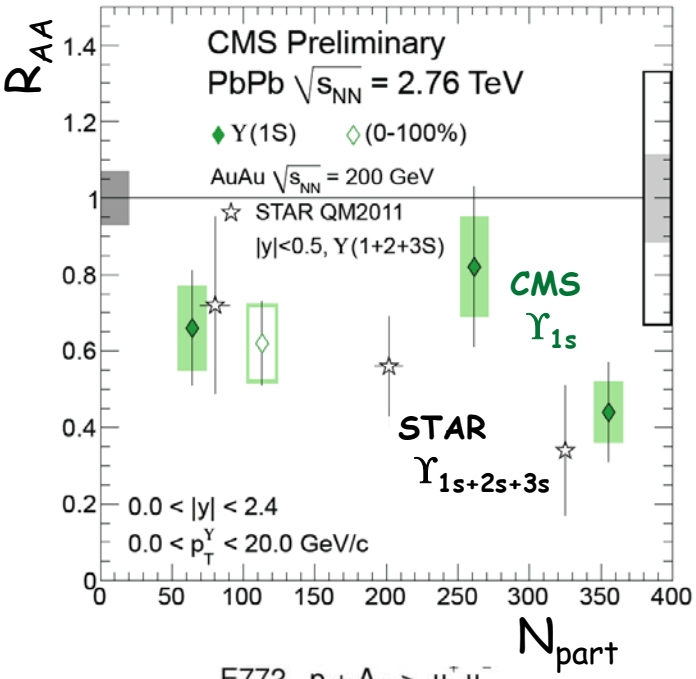
- So difficult to conclude much w/o a thorough (fundamental) understanding of CNM and an informed extrapolation to A+A from d+A





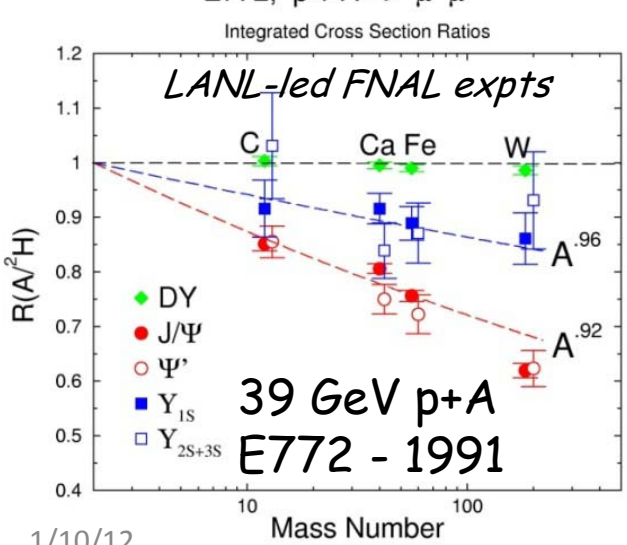
MJL & Vogt began these model comparisons years ago; continuing now with Colorado, FSU working with these in more quantitative and informative ways

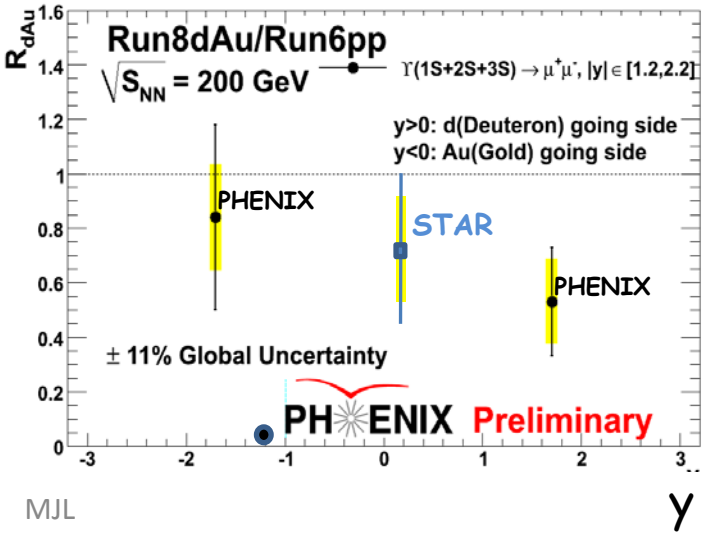
QGP Physics: Heavier Quarkonia - Upsilons



Upsilon suppression at RHIC & LHC similar RHIC – but watch out for CNM suppression (as usual)!

- Our FNAL/E772 saw substantial suppression of Upsilons in p+A
- and PHENIX d+Au forward rapidity suppression observed



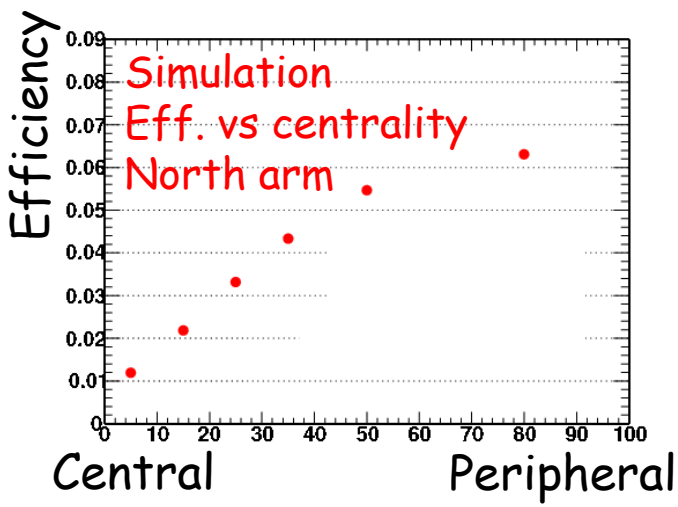


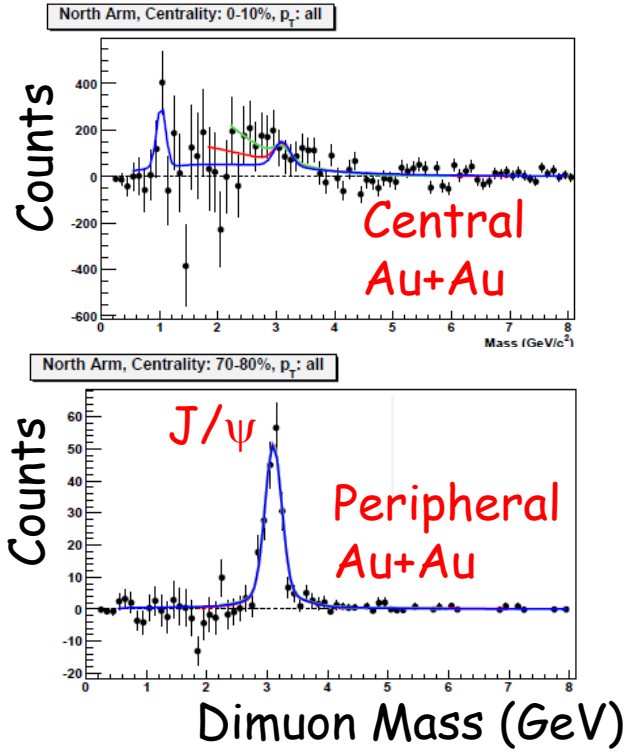
Kwangbok Lee, MJL, …

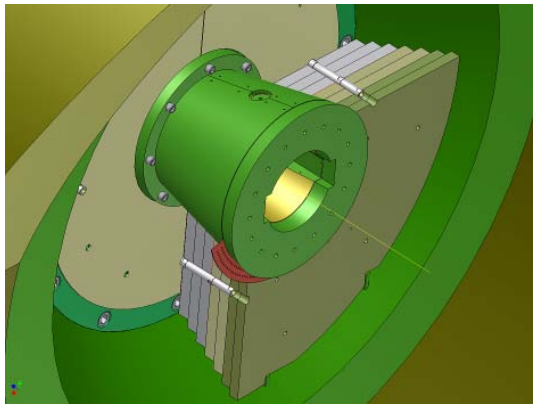
Improving Muon Arm for Central Au+Au Collisions

For Central Au+Au collisions:

- efficiency low , occupancy high
- no J/ψ peak in North arm







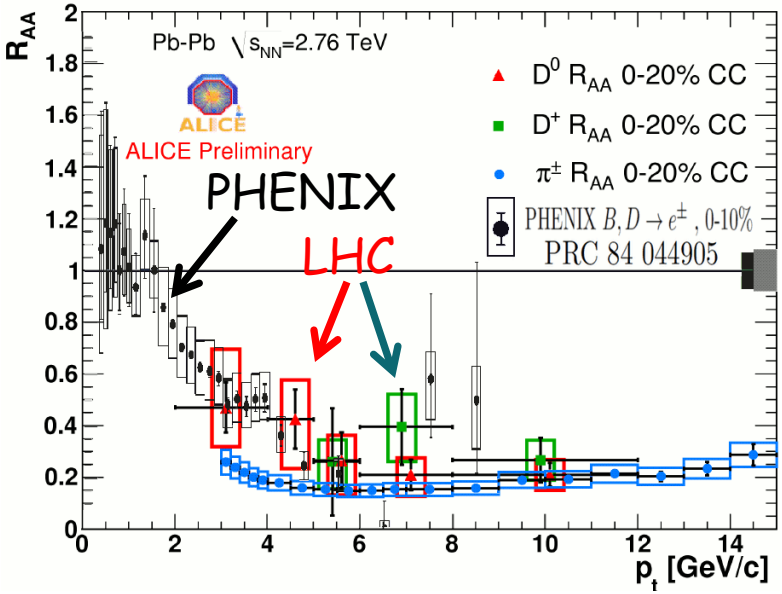
Improvements for Run11:

- addition of absorber
- low-level software improvements
- anode termination

MJL, Hugo, LANL, …

Run11 Analysis in progress: factor of 8 reduction in pions expected (2.1 interaction lengths of Fe absorber)

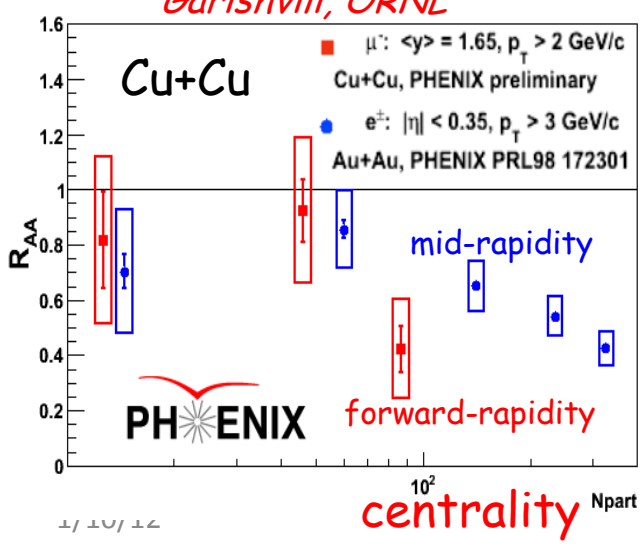
QGP Physics: Energy loss - probing the medium with heavy-quarks



Suppression essentially the same at RHIC & LHC energies & larger than originally expected (similar to $\pi^\pm$)

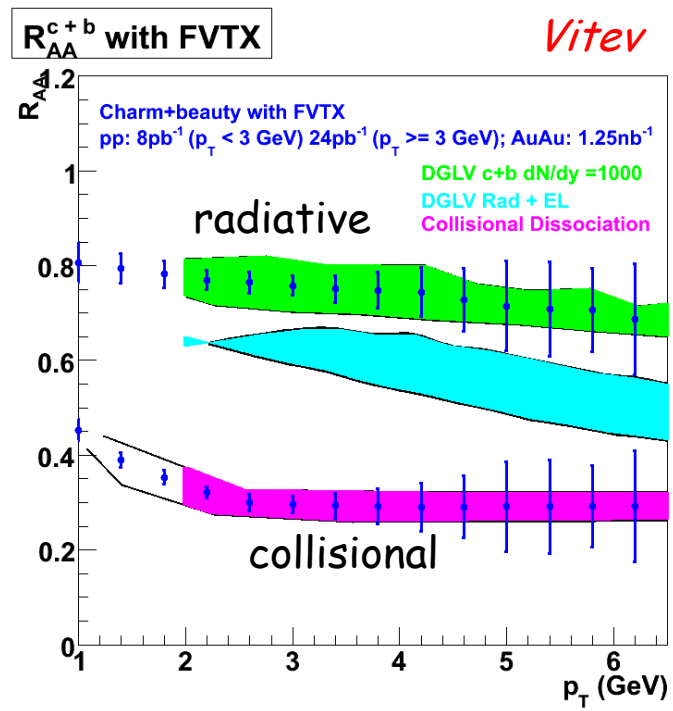
Distinguishing radiative and collisional energy loss & measurement of flow with FVTX at forward rapidity

Garishvili, ORNL



Forward rapidity heavy-q's show suppression in Cu+Cu (very large uncertainties)

Vitev



New Physics Reach with FVTX at PHENIX

Direct identification of D,B -> μ & B -> J/ψ

- energy loss & shadowing for D,B mesons

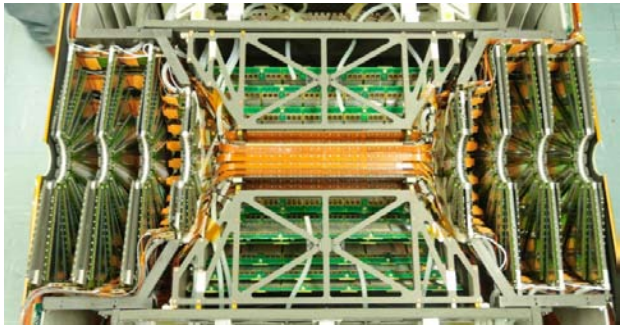
Improved J/ψ and ψ' mass resolution

- enable ψ' as a probe

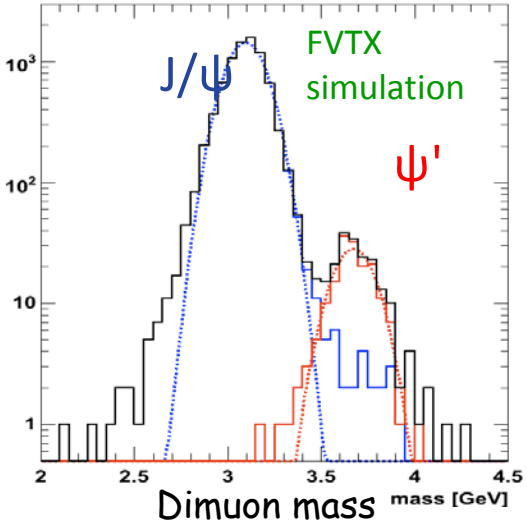
Reduced backgrounds by rejection of π and K

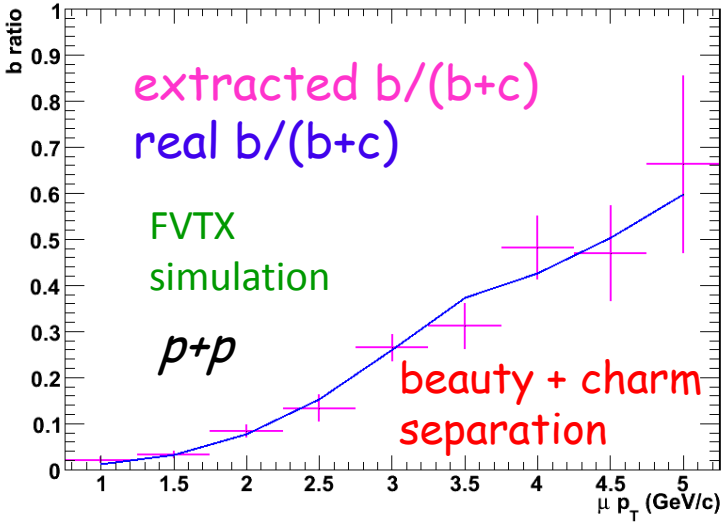
- enable Drell-Yan measurements

Installed & being commissioned now!



Simulations - Z. You, X. Wang, LANL, NMSU



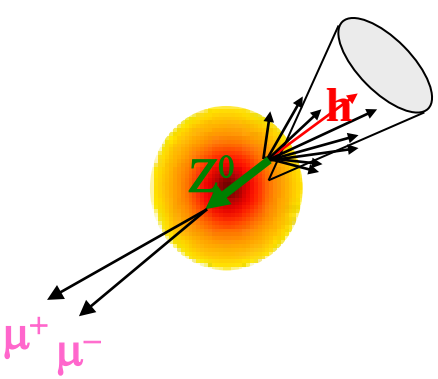


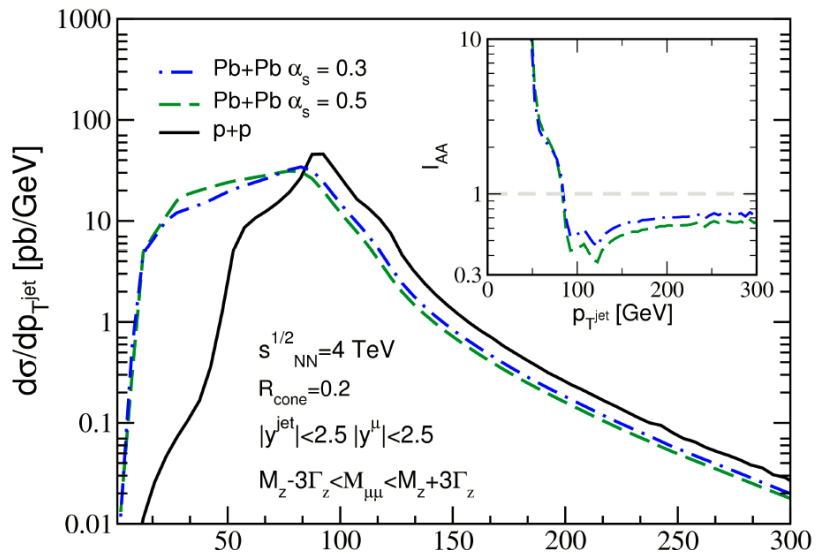
QGP Physics: Probing the QGP with Quark Energy Loss at CMS

Fully reconstructing jet plus tagging with non-interacting Z^0 allows measurement modification of fragmentation & of dE/dx - 3D jet tomography

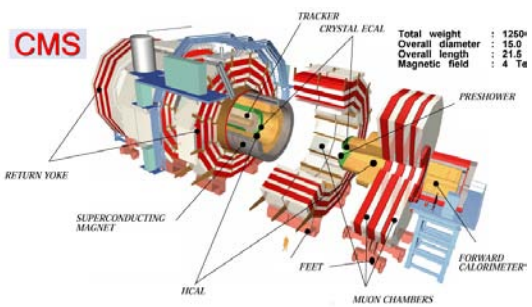
LANL funded LDRD through FY11; now ended

- Produced full simulation of Z^0-tagged jet sensitivity to fragmentation function modifications
- T-2 provided theoretical model development needed to interpret results
- Developed hardware upgrade to CMS Pixel Detector to allow for data-taking in design luminosity Heavy Ion environment





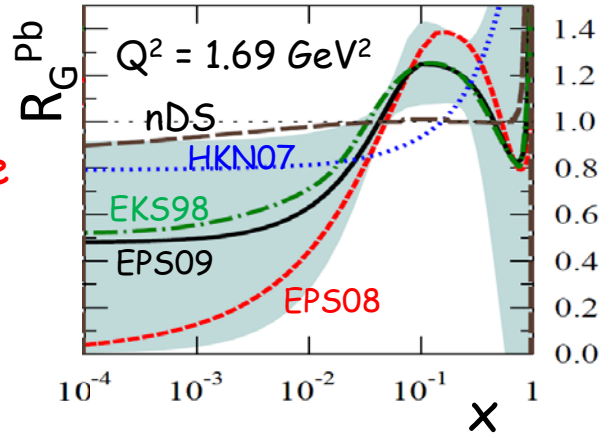
Catherine (LANL) gave CMS Plenary Quarkonia talk at QM11



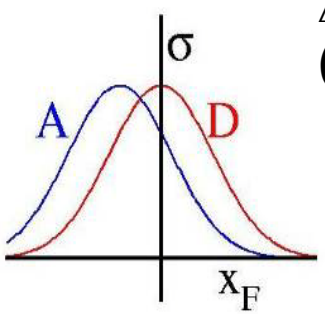
Fundamental CNM Physics Questions

NSAC Milestone: DM8 – "Determine gluon densities at low x in cold nuclei via p + Au or d + Au collisions."

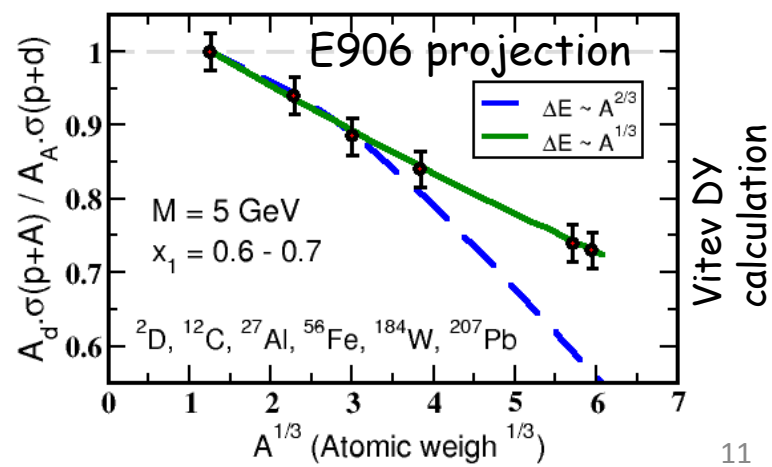
- Leading twist gluon shadowing
- Coherence models & higher-twist (HT) shadowing
- Gluon Saturation: at small-x, 2→ 1 diagrams become important and deplete the low-x region; amplified in a nucleus.



NSAC Milestone: DM12 – "…constrain the mechanism for parton energy loss in the quark-gluon plasma." And what about energy loss in cold nuclear matter?

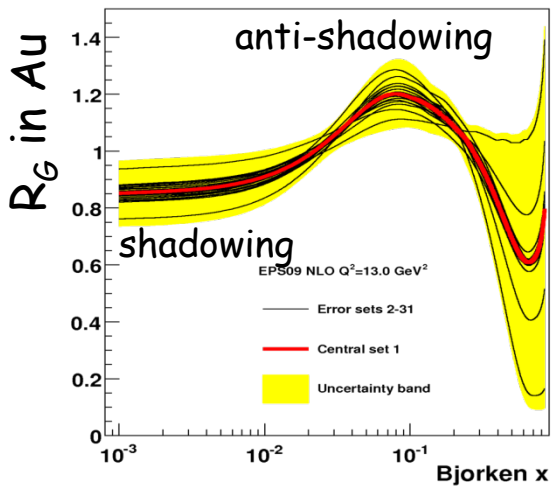


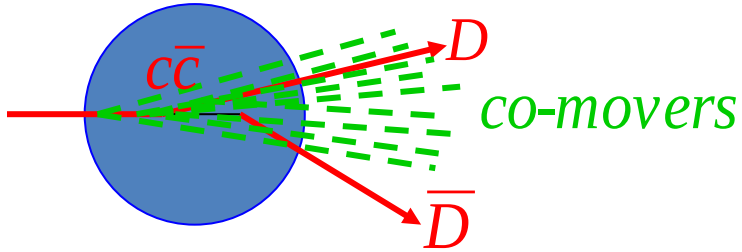
$\Delta E \sim L$ or L^2?
(collisional or radiative?)



CNM Physics: Gluon Saturation, dE/dx, absorption

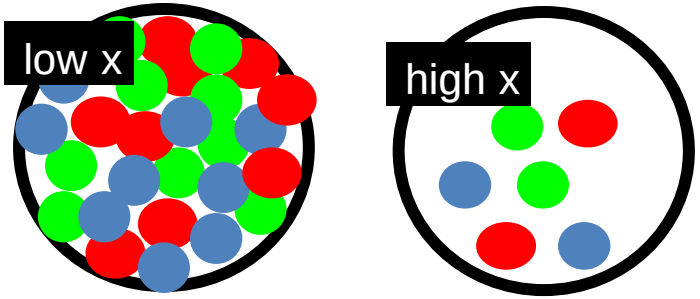
Traditional shadowing from fits to DIS or from coherence models



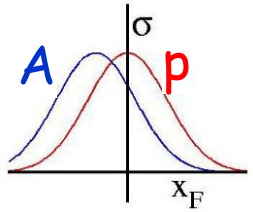


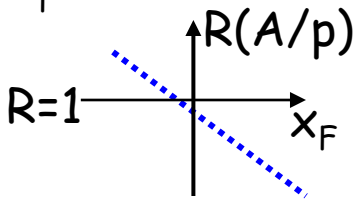
Absorption (or dissociation) of $c\bar{c}$ into two D mesons by nucleus or co-movers

Gluon saturation from non-linear gluon interactions for the high density at small x - Amplified in a nucleus.



Energy loss of incident gluon shifts effective x_F and produces nuclear suppression which increases with x_F





CNM Physics: Scaling between different Energies for J/ψ

Suppression not universal vs x_2 as expected for shadowing

Closer to scaling with x_F or rapidity

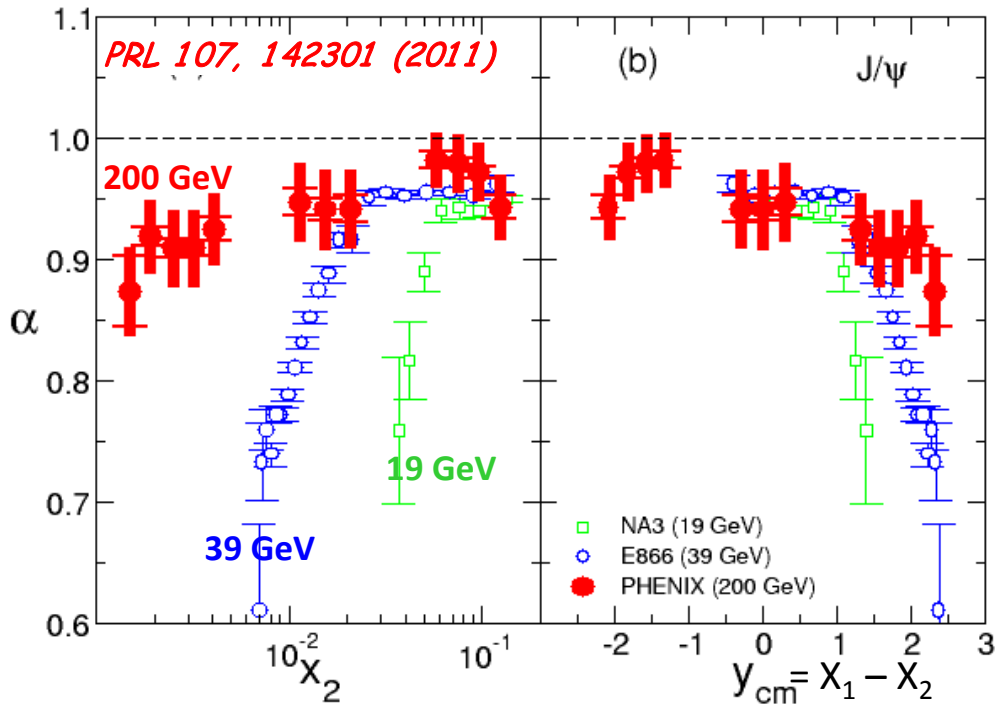
- initial-state gluon energy loss? or gluon saturation?

PHENIX, E866, NA3

Comparison

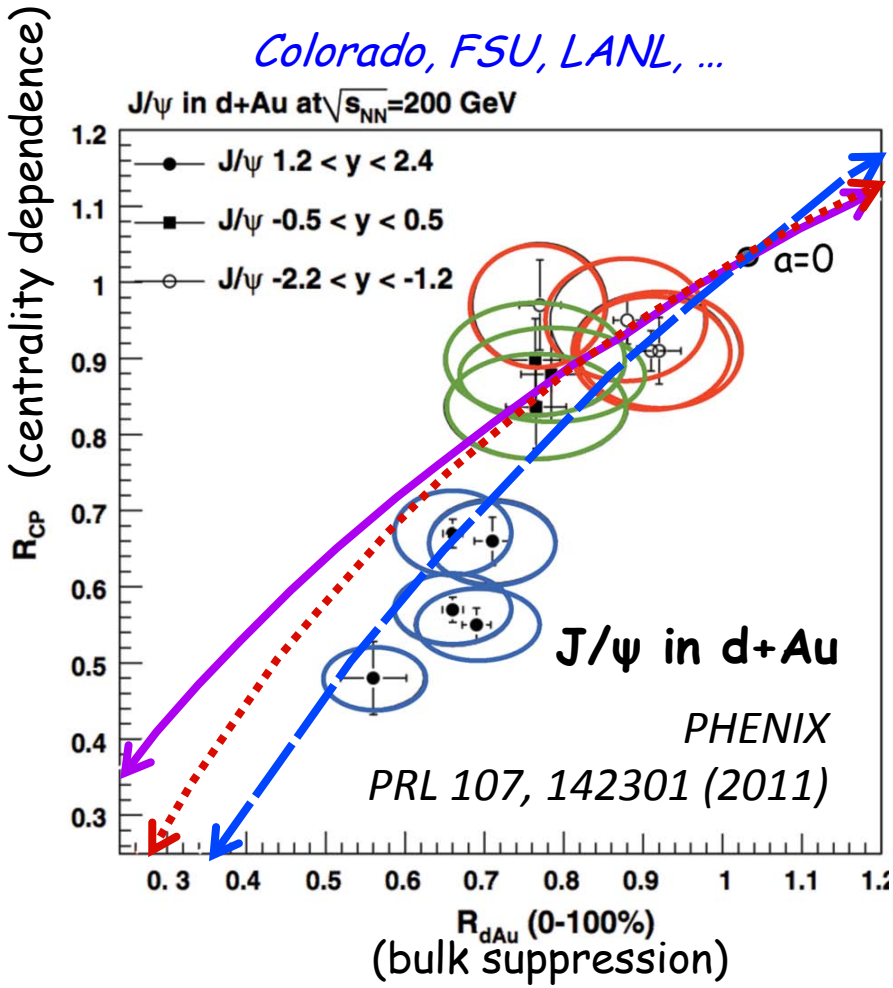
$$\sigma_{pA} = \sigma_{pp} A^{\alpha}$$

1st observed by us in E772 in 1990's: PRL 66, 133 (1991)



(x_2 is x in the nucleus)

CNM Physics: learning about CNM thickness dependence



Vary the strength of suppression & map out relationship between R_{dAu} and R_{CP} as <u>given strictly by Glauber geometry for different dependences on density-weighted thickness</u>

$$\text{Exponential}: M(r_T) = e^{-a\Lambda(r_T)}$$

$$\text{Linear}: M(r_T) = 1 - a\Lambda(r_T)$$

$$\text{Quadratic}: M(r_T) = 1 - a\Lambda(r_T)^2$$

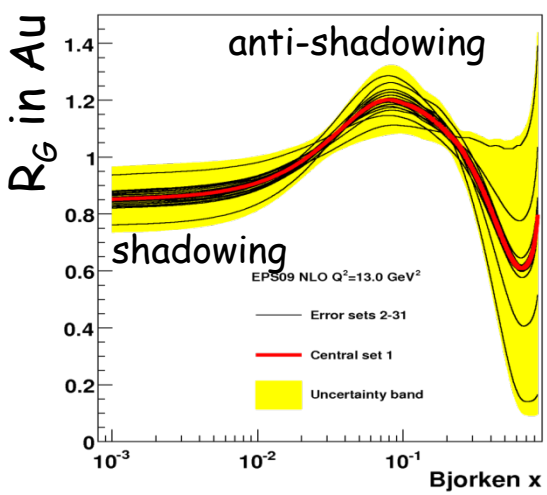
The (blue) forward rapidity points suggests a quadratic or higher geometrical dependence

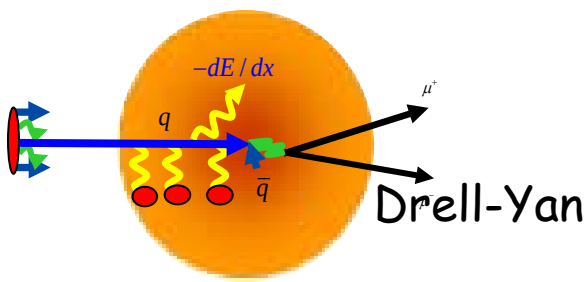
CNM Physics: HQ's, direct photons, Drell-Yan, hadrons

The various CNM effects are difficult to disentangle experimentally – multiple probes, types & energies of collisions, wide kinematic coverage are key

- open-heavy vs quarkonia – isolates initial-state effects
- forward hadron pairs
- direct photons with MPC-EX as "clean" gluon probe
- Drell-Yan to constrain parton energy loss in CNM & measure Q_{sat} via p_T broadening

And strong theoretical guidance & analysis – not just for certain measurements but for the ensemble of measurements

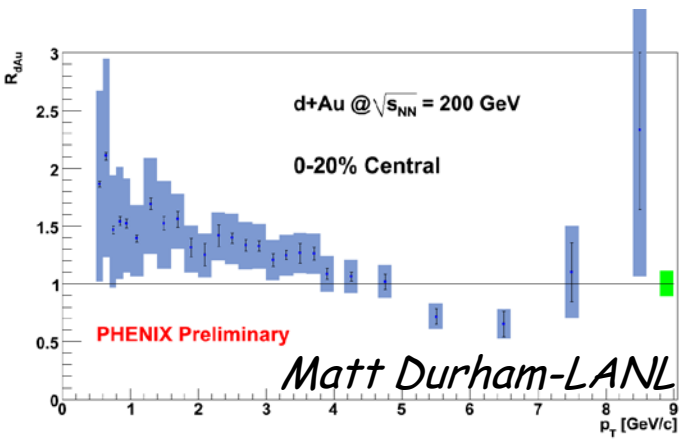




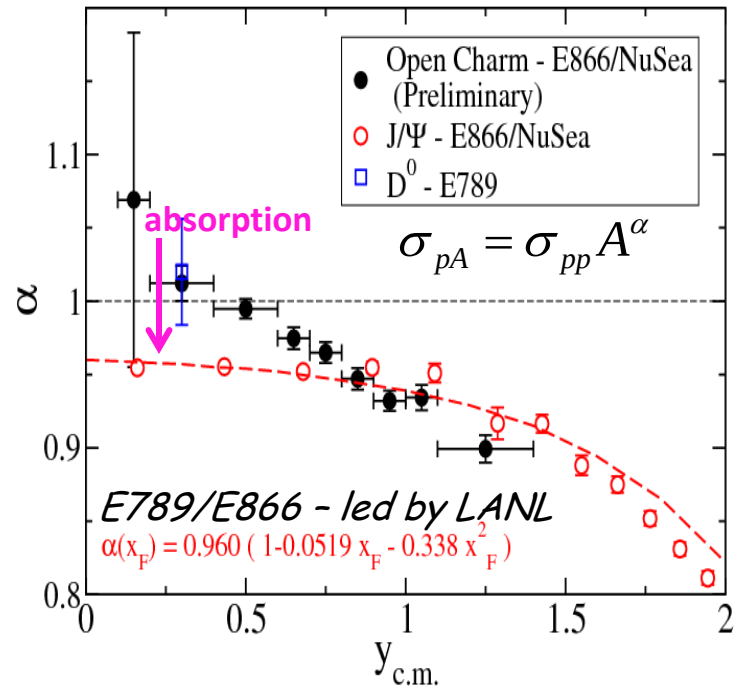
CNM Physics: Open-heavy suppression – Isolating initial-state physics

Open-charm p+A nuclear dependence (single-μ $p_T > 1$ GeV/c) – very similar to that of J/Ψ (E866/NuSea, 39 GeV):

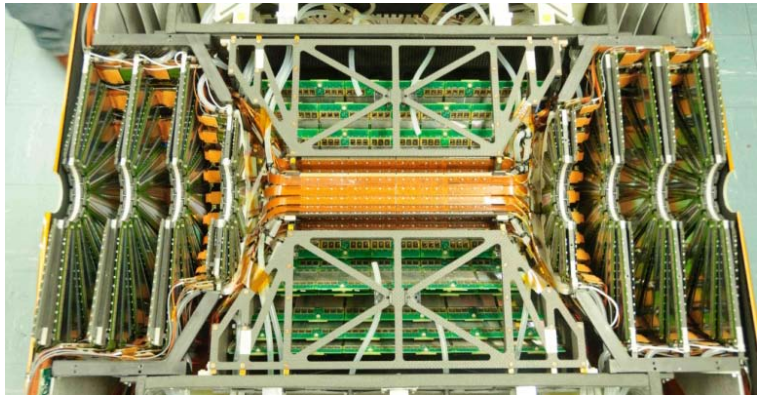
- implies that dominant effects are in the initial state; e.g. dE/dx



Enhancement of open heavy-flavor in d+Au collisions at y=0 & low p_T

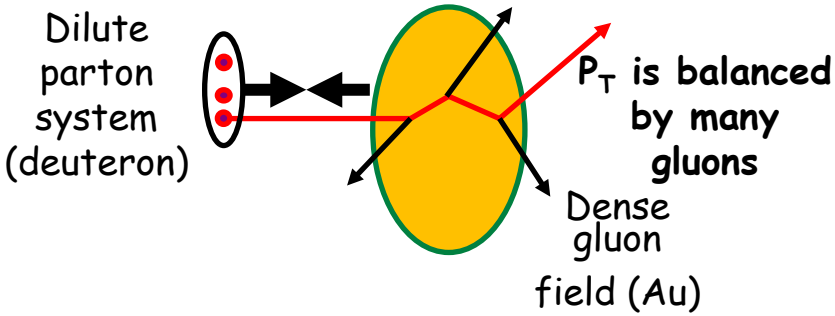


FVTX & VTX



Soon new PHENIX c,b measurements with FVTX/VTX to isolate initial & final-state effects via precision comparisons with Quarkonia

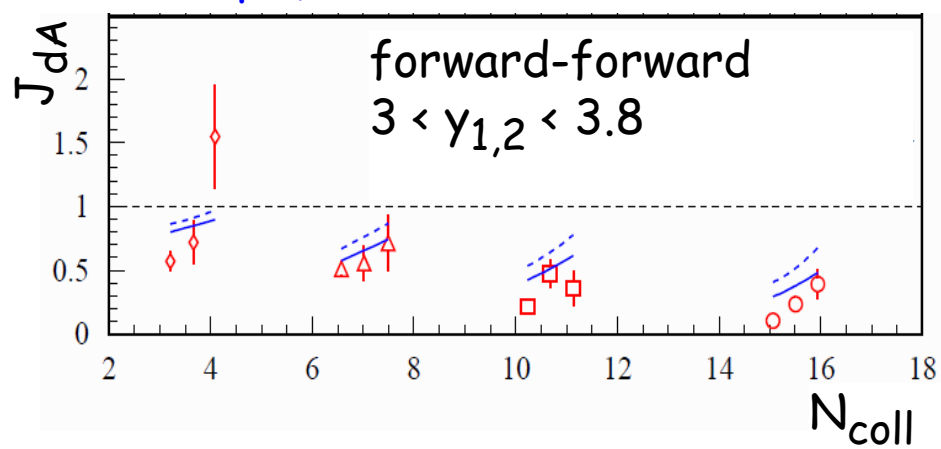
CNM Physics: Shadowing & gluon saturation with Forward hadrons



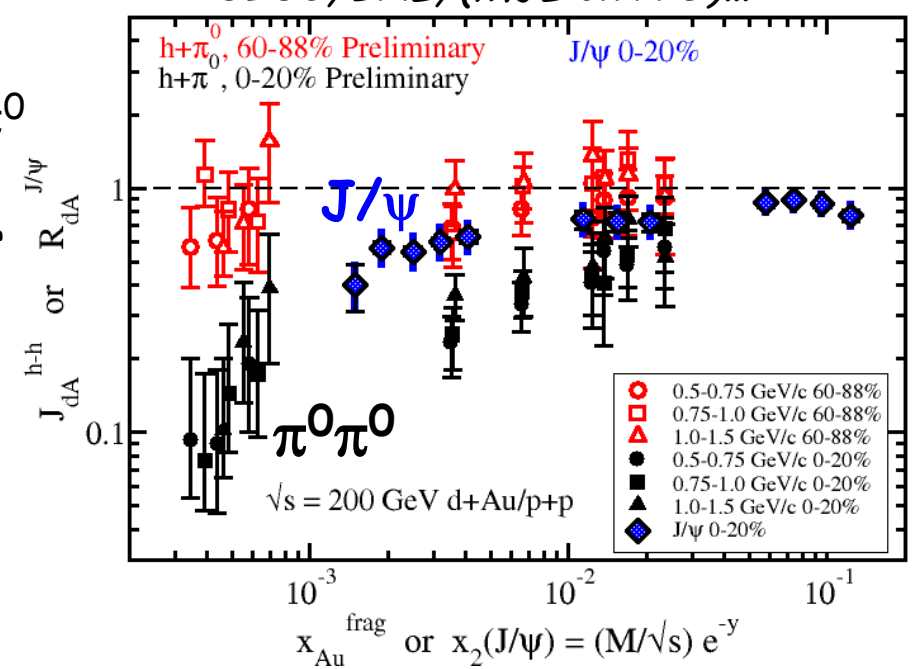
Mono-jets in the gluon saturation (CGC) picture give suppression of pairs per trigger and some broadening of correlation

Kharzeev, NPA 748, 727 (2005)

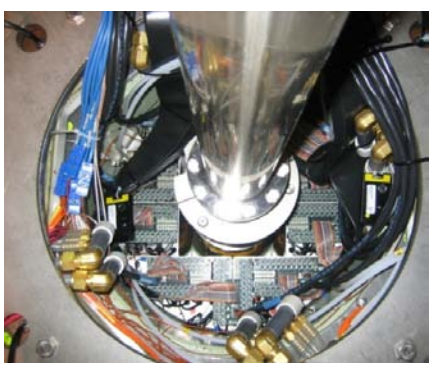
pQCD calc's from Vitev



UIUC, BNL, (MJL on PPG)...



PHENIX MPC

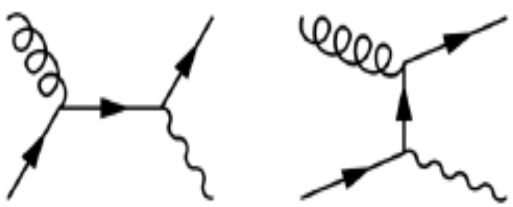


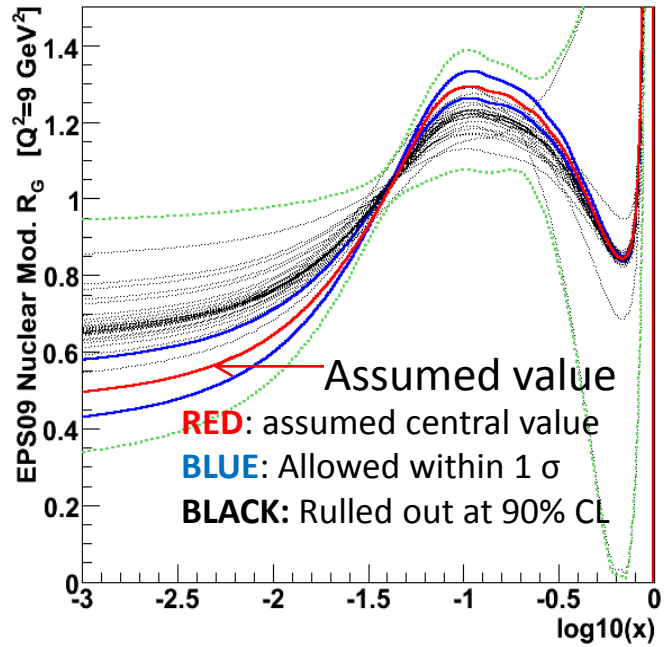
Forward $\pi^0\pi^0$ & J/ψ very similar

CNM Physics: the MPC-EX (extension)

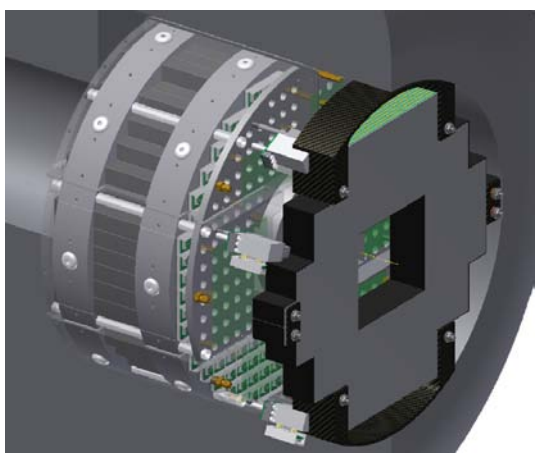
Suppression of gluons in nuclei via direct photon measurements – target 2014 d+Au run

- augmented forward (3.1<y<3.8) calorimeter
- add 8-layer W/Silicon mini-pad preshower

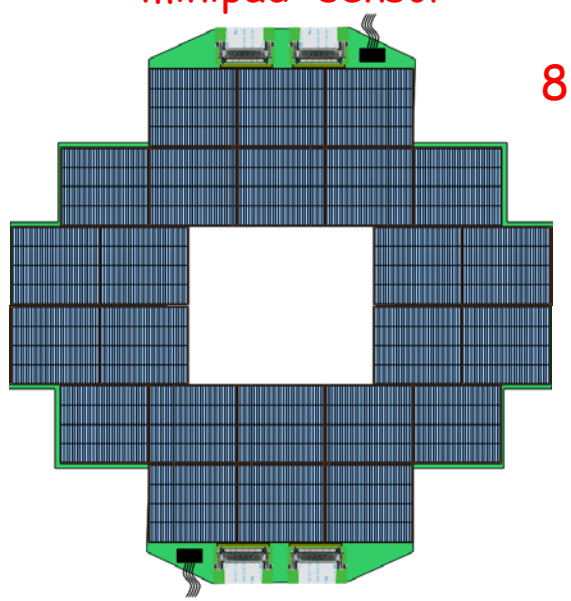




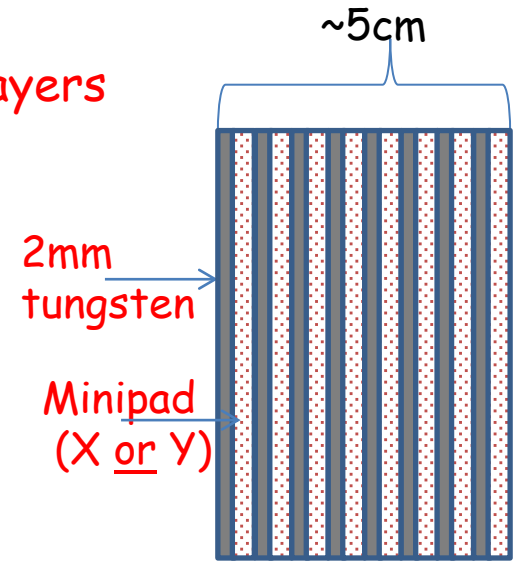
Lajoie, Seto leading; & MJL, Jiang



1.8mm x 15mm "minipad" sensor



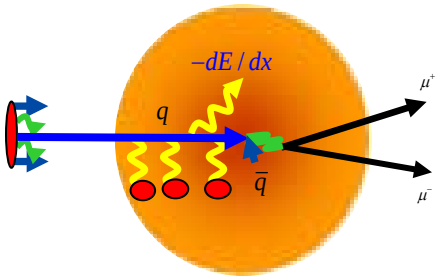
8-layers



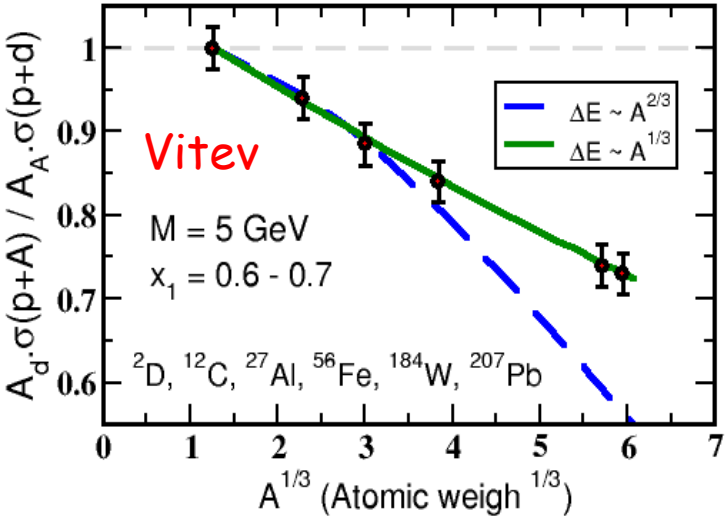
CNM Physics: Drell-Yan to constrain parton energy loss

FNAL E906/Seaquest – Drell Yan

Drell-Yan

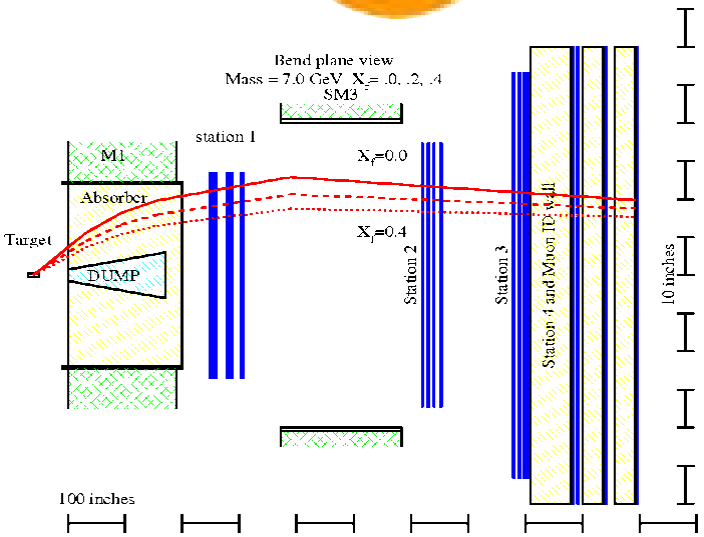


In E906 at 120 GeV, nuclear suppression in Drell-Yan should only be from dE/dx (x_2 > 0.1)



$$\frac{\Delta E}{E} \propto \frac{\mu^2 L^2}{\lambda_g} \frac{\ln E/Q_0}{E}$$

$$\frac{\Delta E}{E} \propto \frac{L}{\lambda_g} \ln \frac{E}{Q_0}$$



Distinguish radiative from collisional (L^2 vs L)

First E906 data expected in 2012

CNM Physics: Connecting to the gluon saturation scale via forward Drell-Yan p_T broadening

Interaction of a propagating parton with the transverse gluonic field in the medium through gluon bremsstrahlung

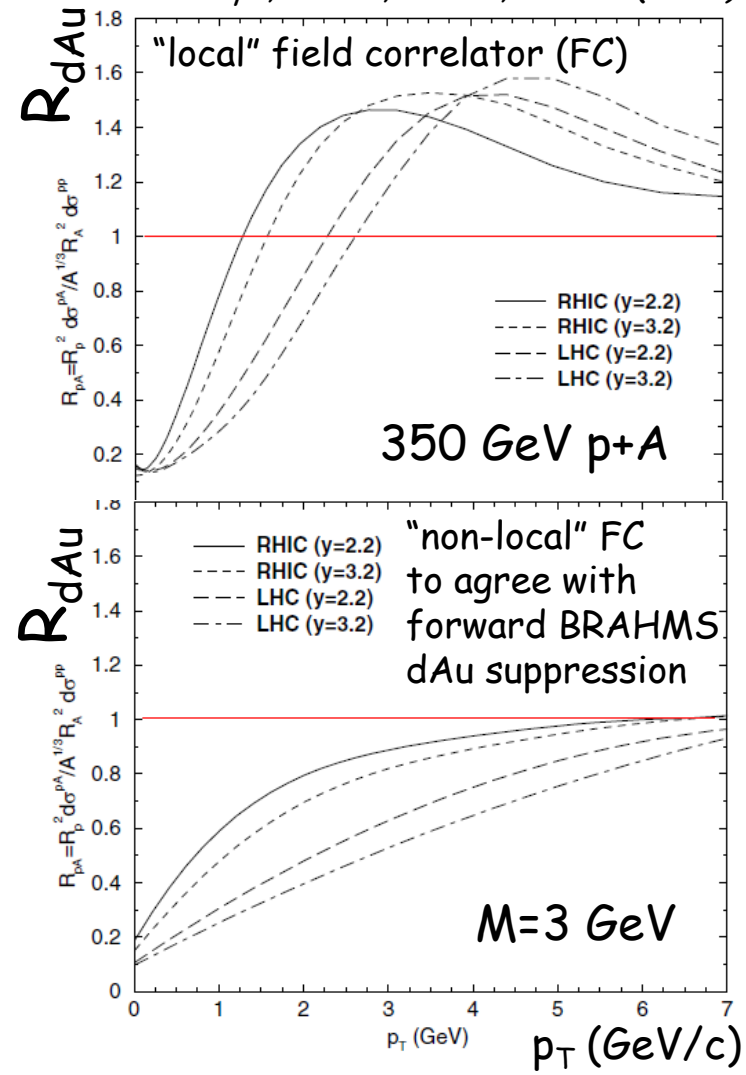
Probability of gluon radiation is proportional to the gluonic density of the medium

For the CGC picture, this broadening is then a direct measure of the saturation scale

$$Q^2_{sat}(b,E) = \Delta p^2_T(b,E)$$

- *Betemps, Ducati, PRD70, 116005 (2004)*
- *Kopeliovich et al., Phys. Rev. C 81, 035204 (2010)*

Betemps, Ducati, PRD70, 116005 (2004)



Summary & Goals – LANL QGP and CNM Physics

QGP physics – quarkonia screening & heavy-quark energy loss

- add ψ' & improved J/ψ, Upsilon
- HQ dE/dx and regeneration constraint
- Cu+Au novel geometry for above
- better measurements at various energies

CNM physics – gluon saturation & parton energy loss in nuclei

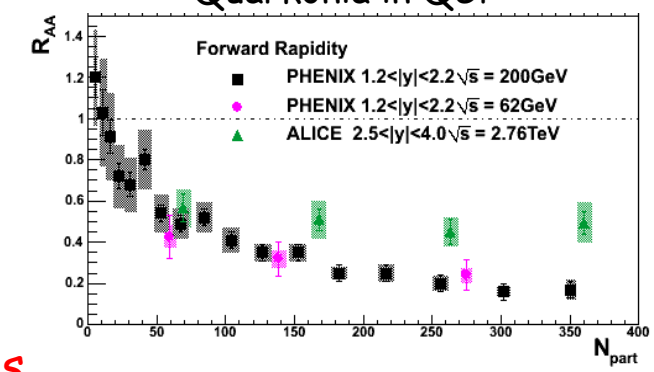
- Quarkonia - ψ', J/ψ , Upsilon
- HQ's vs quarkonia to isolate initial-state phys.
- theoretical extrapolation for QGP studies

- CNM dE/dx from Drell-Yan in E906 p+A
- Probe gluons with direct photons using MPC-EX
- Q_{sat} from Drell-Yan p_T broadening

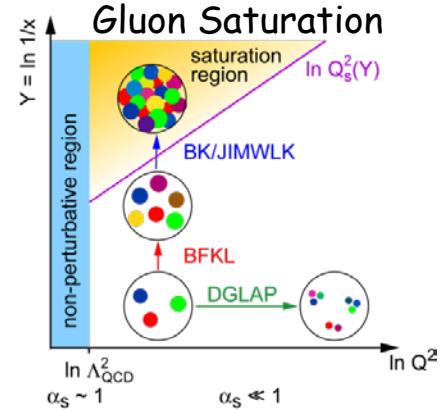
FVTX enables

- accurate open charm & beauty measurements
- isolation of ψ'
- pulling RHIC Drell-Yan out from beneath backgrounds

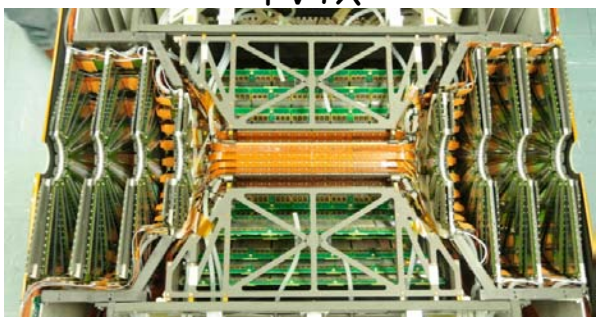
Quarkonia in QGP



Gluon Saturation



FVTX

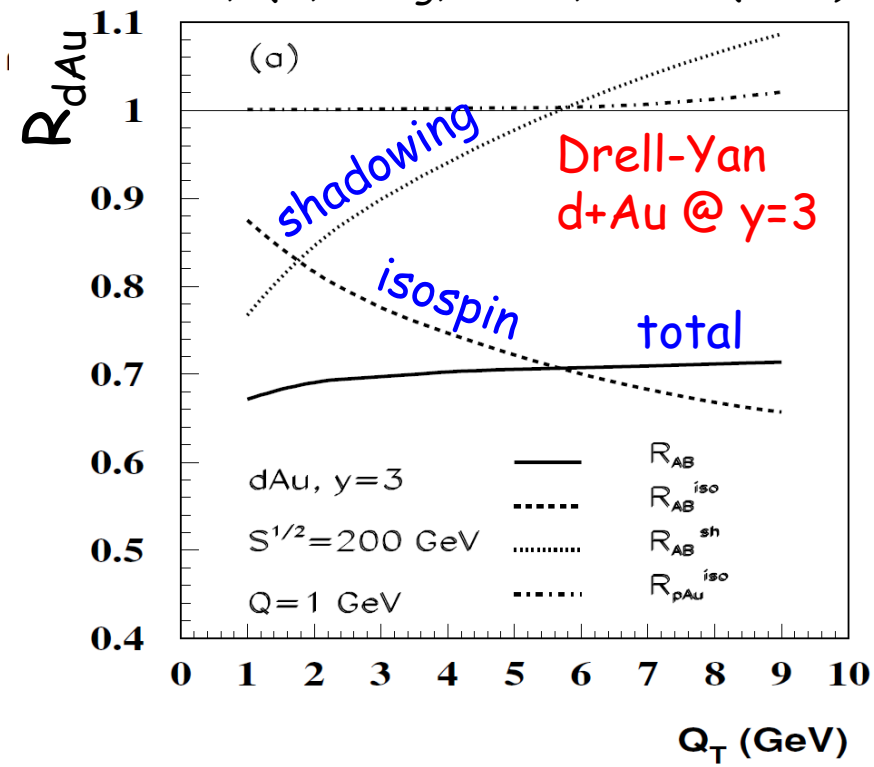


Backup Slides

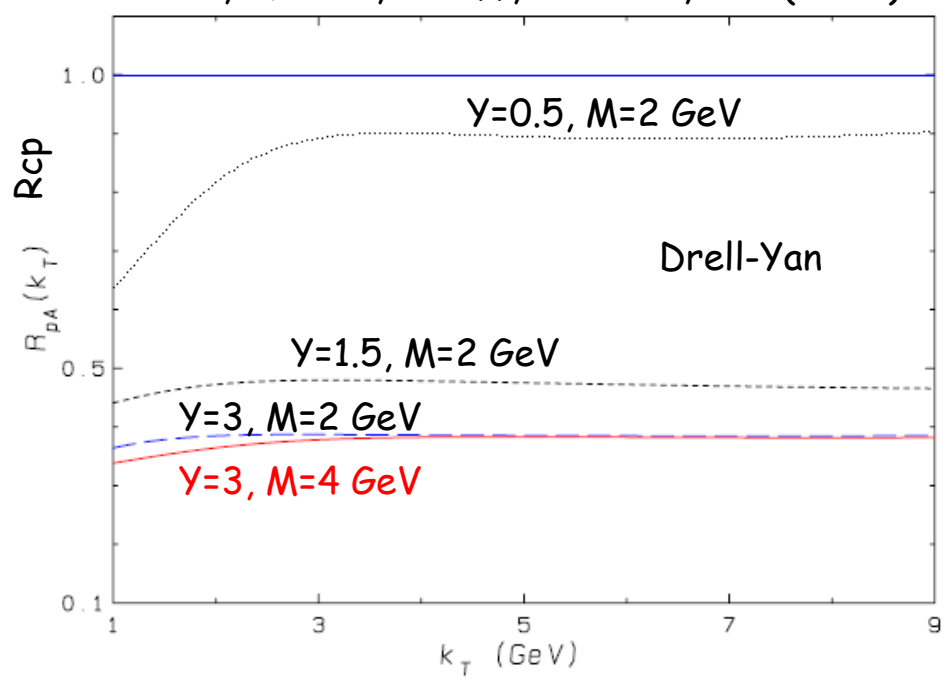
CNM Physics: Connecting to the gluon saturation scale via forward Drell-Yan p_T broadening

LANL Drell-Yan experts
time to bring DY to RHIC

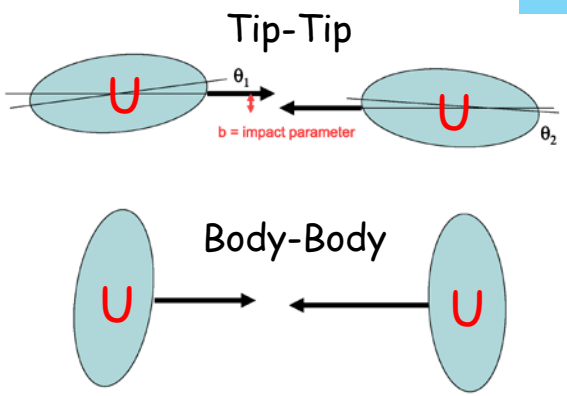
Fai, Qiu, Zhang, PRC 71, 014901 (2004)

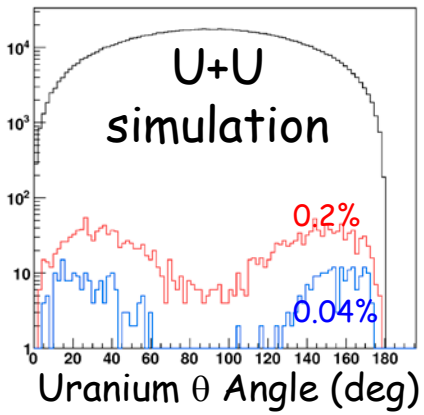


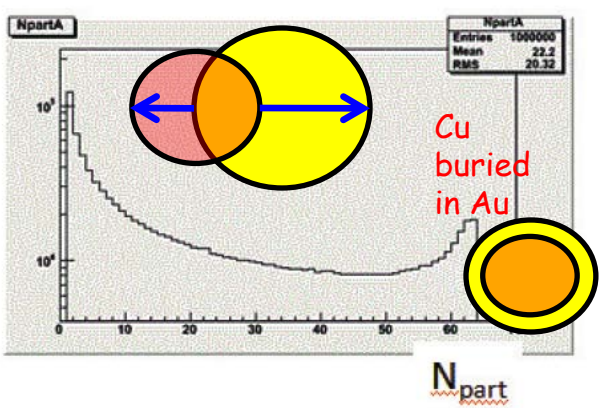
Baier, Mueller, Schiff, NP A741, 358 (2004)



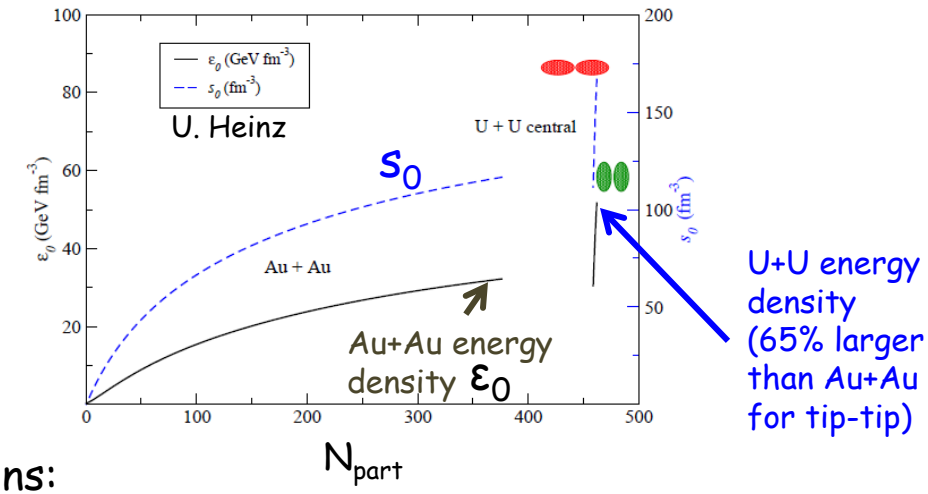
New Geometries – U+U & Cu+Au







Early time dynamics & thermalization
- varying the eccentricity for flow studies
- and path length for suppression studies



U+U collisions:
- higher energy density (top 0.2% tip-to-tip)
- 1st we need initial data to understand how to disentangle the geometry

Cu+Au collisions:
- Cu buried inside Au for most central collisions – minimize periphery (top 3%)
- Eccentricity w/o left-right symmetry for non-central collisions

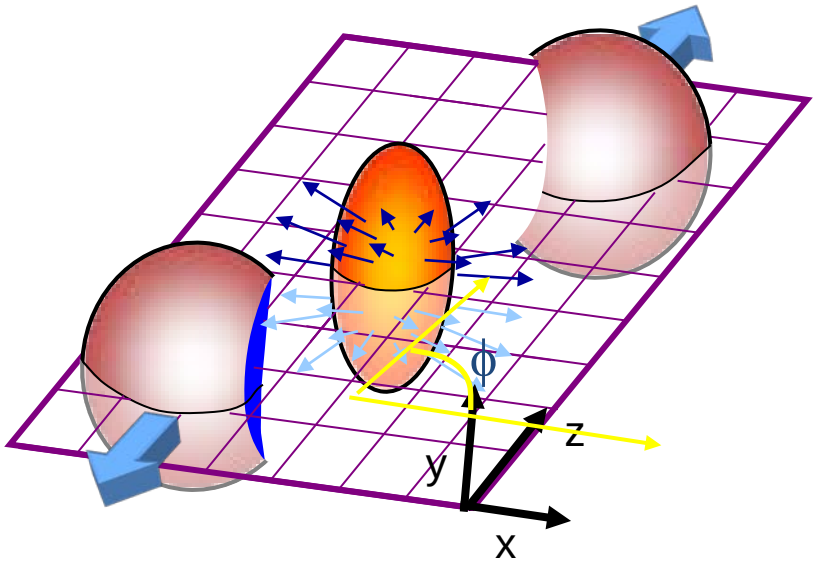
Thermalization
Flow: A collective effect

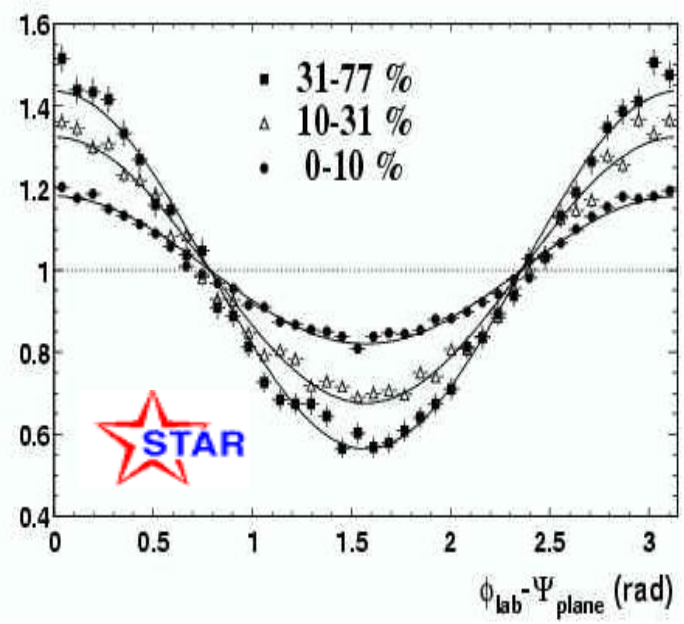
Initial spatial anisotropy converted into momentum anisotropy

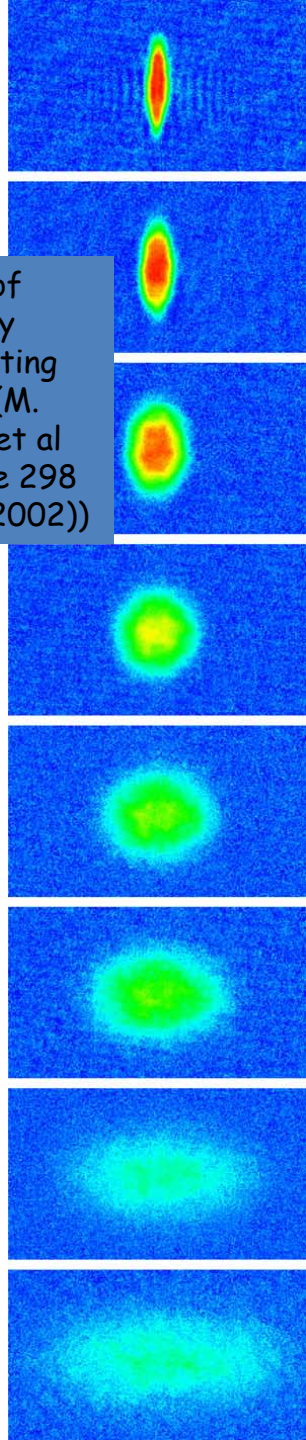
Efficiency of conversion depends on the properties of the medium

Elliptic flow = v_2 = 2nd fourier coefficient of momentum anisotropy

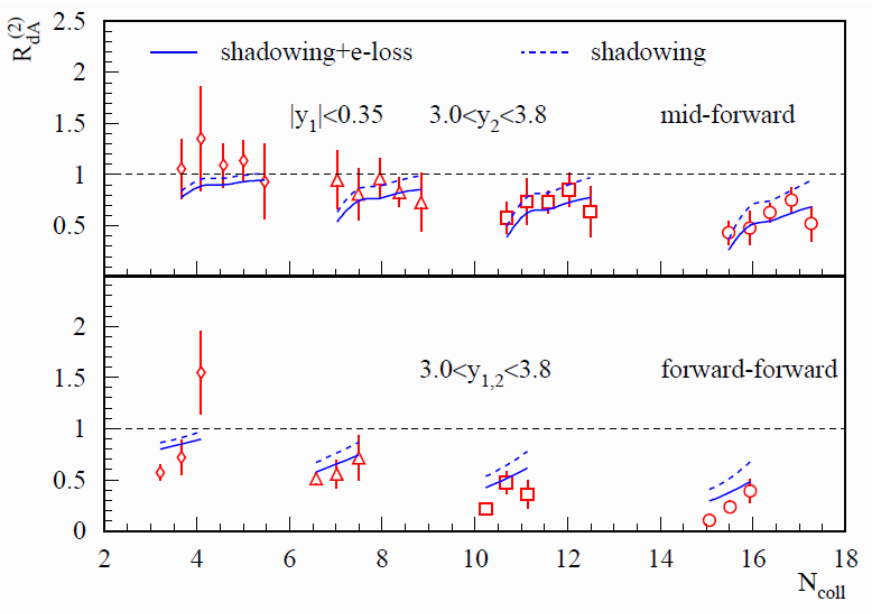
$$dn/d\phi \sim 1 + 2\, v_2(p_T) \cos(2\phi) + \ldots$$



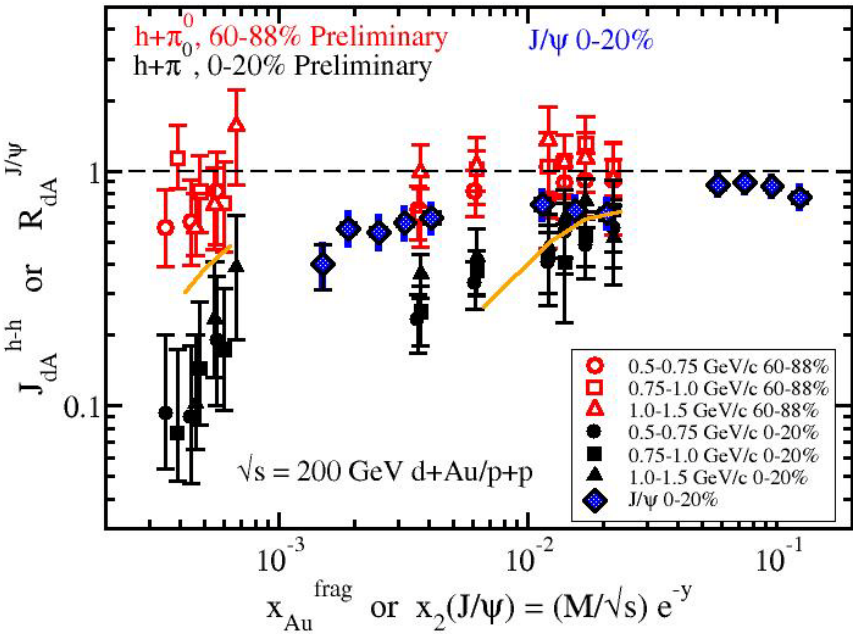




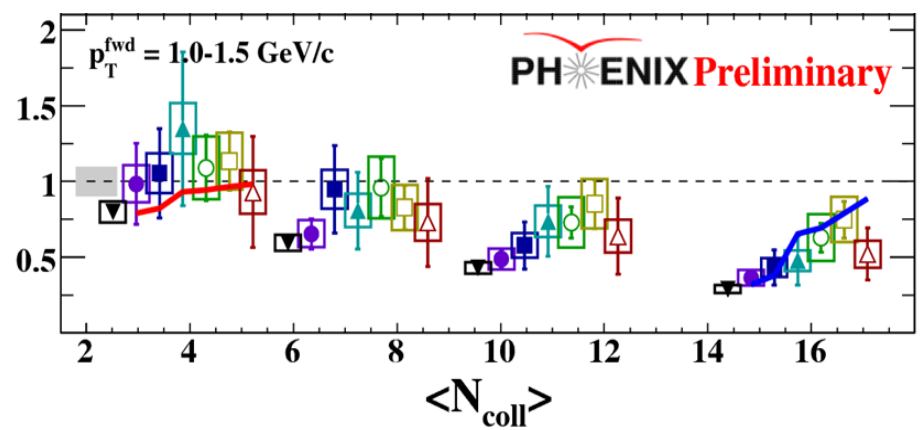
Gases of strongly interacting atoms (M. Gehm, et al Science 298 2179 (2002))



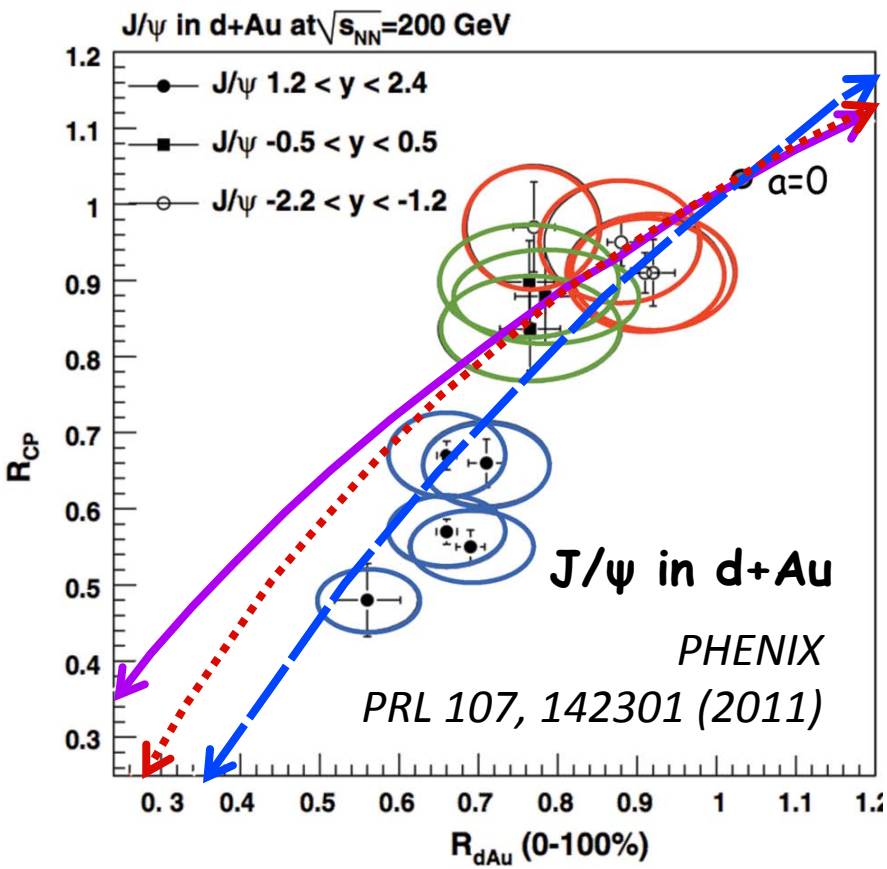
y1	y2	pT1	pT2	xfrag	JdAu
3.4	3.4	1.25	1.25	0.000417	0.305725
3.4	3.4	1.75	1.25	0.000501	0.382914
3.4	3.4	2.53	1.25	0.000631	0.482114
0	3.4	1.29	1.25	0.006659	0.263736
0	3.4	2.43	1.25	0.012359	0.505495
0	3.4	2.71	1.25	0.013759	0.538462
0	3.4	3.35	1.25	0.016959	0.626374
0	3.4	4.67	1.25	0.023559	0.67033



$$x_{Au}^{frag} = (\langle p_{T1}\rangle e^{-\langle\eta_1\rangle} + \langle p_{T2}\rangle e^{-\langle\eta_2\rangle}) / \sqrt{s_{NN}}$$



CNM Physics: learning about CNM thickness dependence



Vary the strength of suppression (a) & see what relationship between R_{dAu} and R_{CP} is given <u>strictly by Glauber geometry for different dependences on density-weighted thickness</u>

$$\Lambda(r_T) = \frac{1}{\rho_0}\int dz\,\rho(z, r_T)$$

Woods-Saxon

$$\text{Exponential}: M(r_T) = e^{-a\Lambda(r_T)}$$

$$\text{Linear}: M(r_T) = 1 - a\Lambda(r_T)$$

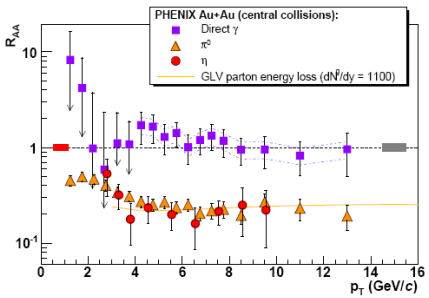
$$\text{Quadratic}: M(r_T) = 1 - a\Lambda(r_T)^2$$

- Break-up has exponential dependence
- EPS09 & initial-state dE/dx have unknown dependences

The forward rapidity points suggests a quadratic or higher geometrical dependence

The Ratio of Fragmentation Functions

We propose to replace the Nuclear Modification Factor R_{AA}



by

Eur. Phys. J. C (2009) 61: 785–788

FIG. 3: $R_{AA}(p_T)$ measured in central Au+Au at $\sqrt{s_{NN}}$ = 200 GeV

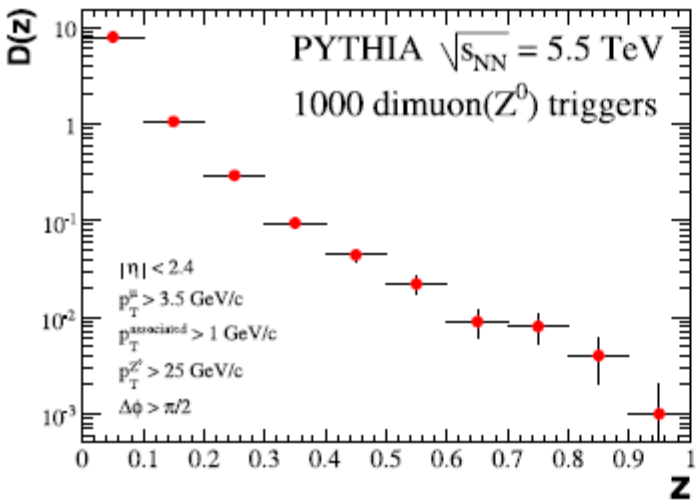


Fig. 6.1 Fragmentation Function $D(Z)$ as determined from the reconstruction of correlated hadrons. The statistical error bars reflect a year-one measurement

Fragmentation Function

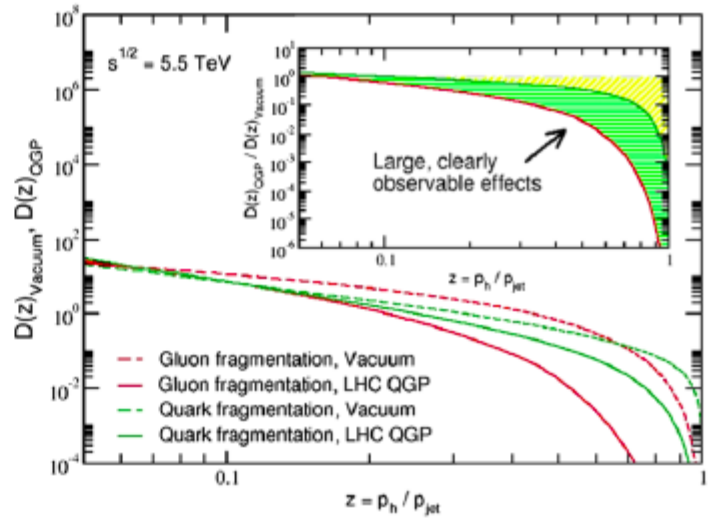


Fig. 6.2 Fragmentation Function $D(Z)$ for quarks and gluons in the vacuum and in a LHC QGP. The fragmentation results for the vacuum case are represented as dashed lines, the QGP result is shown as sold lines. The insert shows the ratio of the fragmentation functions for QGP vs. vacuum. Please note the logarithmic representation

Ratio of Frag. Functions

The Pixel Readout Chain and the Bottle Neck for Design Luminosity Data Taking

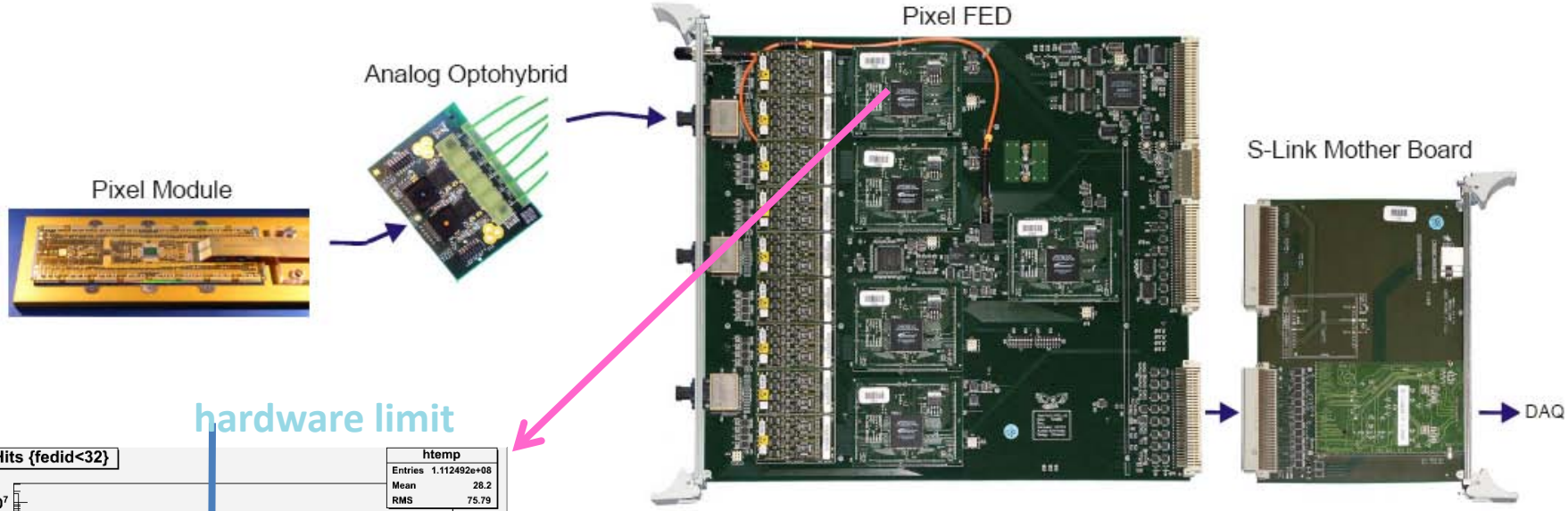
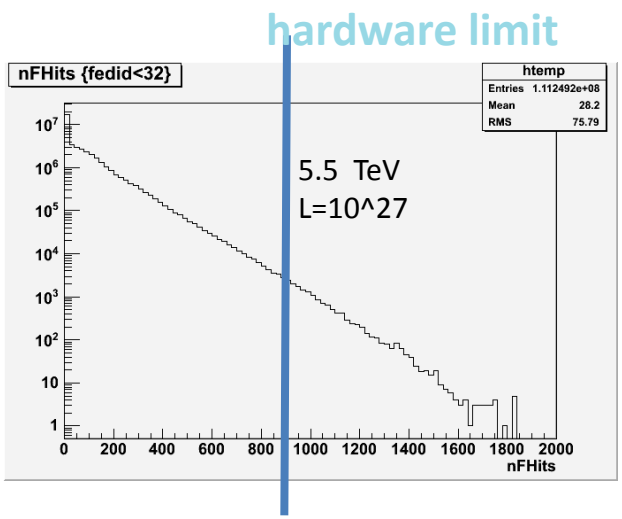


Figure 1: The Pixel Detector Readout Chain



g.j.kunde @ detector readiness 10/14/2009

- Fifo I overflows occur with an average rate of ~600/sec
- Constructed a temporary fix for low luminosity HI running by introducing a dead time of 400 micro seconds (CMS is designed to be dead time free)