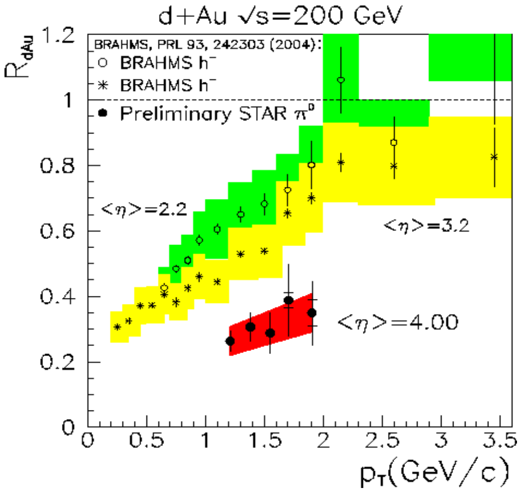
RHIC II Science - Forward & pA Physics

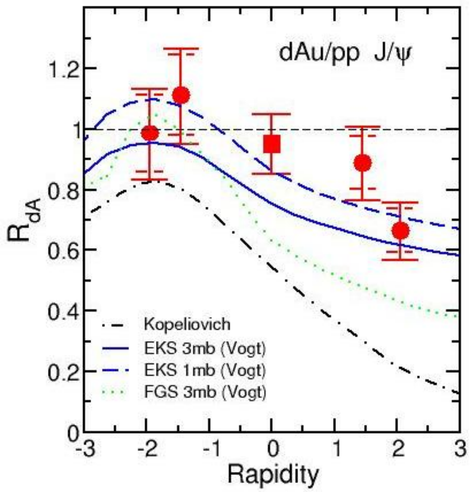
Conveners: Carl Gagliardi, Mike Leitch, Kirill Tuchin

Mike Leitch – LANL (*leitch@lanl.gov*)

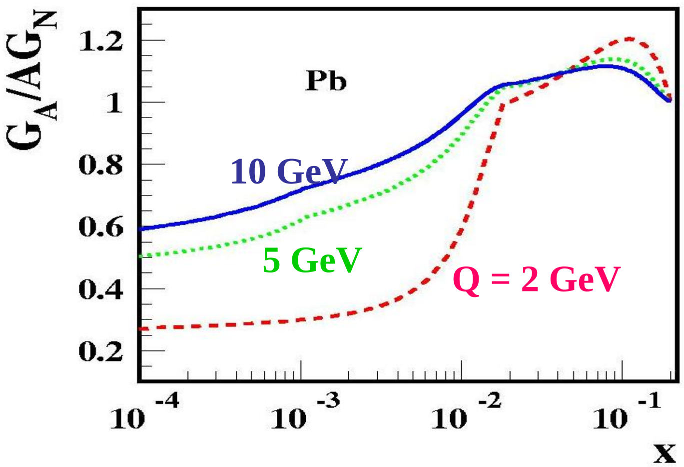
BNL PAC – 4 November 2005

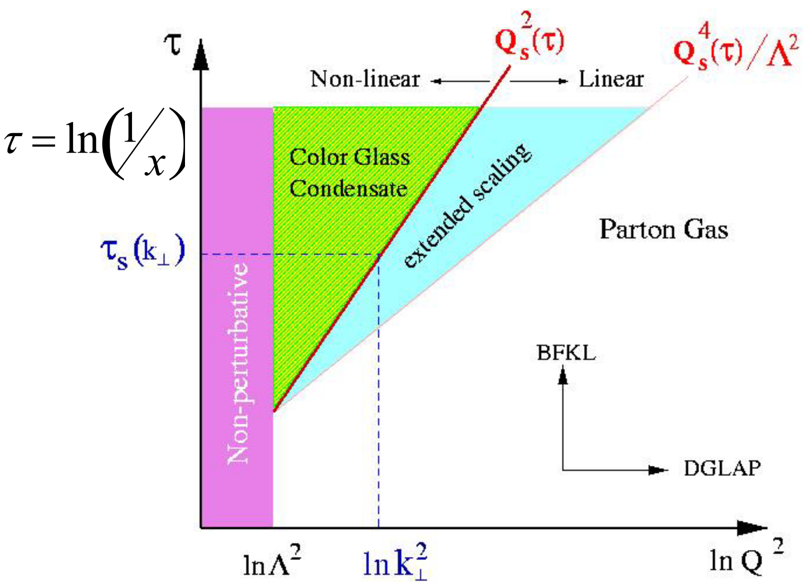
- Small-x and shadowing in nuclei
  - leading twist, saturation, mass renormalization, etc.
  - contrast with LHC
  - forward hadrons
  - heavy quarks & onia
  - Sudakov suppr, limiting fragmentation
  - "mono"-jets
- Anti-quarks in the nucleon and nuclei
  - shadowing of sea anti-quarks
  - tagged Drell-Yan
- other forward-proton tagged reactions
- not discussed: direct photons; polarized pA (need theor. input), & …?
- Accelerator issues for pA





Gluon Shadowing and Saturation





Iancu and Venugopalan hep-ph/0303204

Leading twist gluon shadowing, e.g.:
- Gerland, Frankfurt, Strikman, Stocker & Greiner (hep-ph/9812322)
- phenomenological fit to DIS & DY data, Eskola, Kolhinen, Vogt hep-ph/0104124
- and many others

Amount of gluon shadowing differs by up to a factor of three between diff models!

Saturation or Color Glass Condensate (CGC)
- At low x there are so many gluons, that the quantum occupation numbers get so large that the situation looks classical
- Nuclear amplification: $x_A G(x_A) = A^{1/3} x_p G(x_p)$, i.e. gluon density is ~6x higher in Gold than the nucleon

Contrasting small-x physics at RHIC-II and the LHC

At RHIC/RHIC-II measurements explore the onset of shadowing or saturation, while at the LHC most measurements will be deep into the saturation region

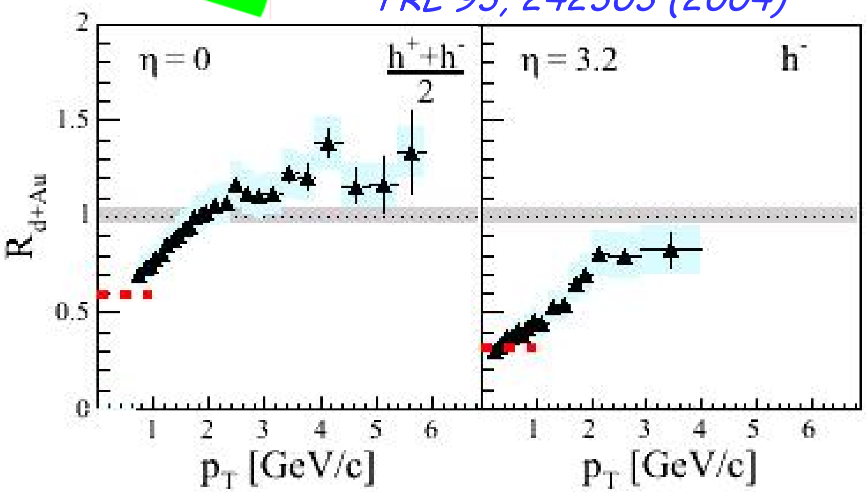
- exploring the onset at RHIC-II will be key to understanding saturation
- studies at RHIC will be complimentary to those at the LHC

From the LHC pA Workshop:
(http://wwwth.cern.ch/pAatLHC/pAworkshop2.html)

- p+A at the LHC is still officially an upgrade
- First year that LHC might run p+Pb: 2010
- Possible "target" luminosity: 10^{29} cm^{-2}s^{-1} (RHIC-II: 2x10^{30} cm^{-2}s^{-1} avg)
- Can't use the constant frequency solution that worked well at RHIC
- N-N CM not at lab y=0 (Δy=-0.46 for 8.8 TeV p+A)
- "Company line": no need for p+p reference. Will come from interpolation between Tevatron and 14 TeV
  - Probably okay for "really hard" processes
  - May be problematic for measurements focused on small-x saturation effects
  - If the accelerator turn-on goes well, even getting the 14 TeV reference data may be a challenge

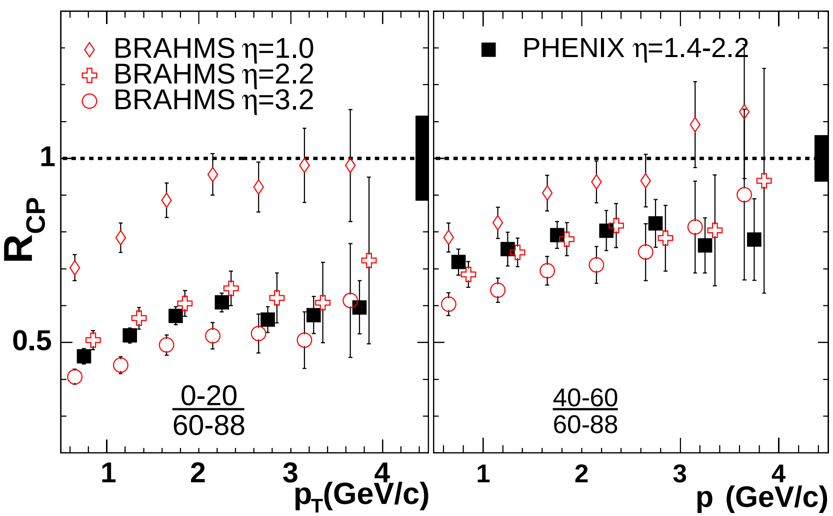
Forward hadrons

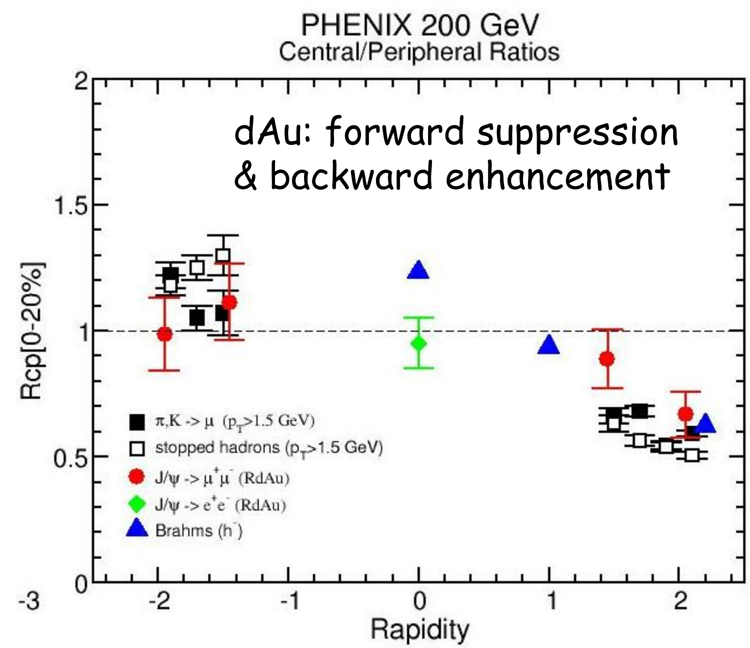
BRAHMS *PRL 93, 242303 (2004)*



Charged particles are suppressed in the forward direction in d+Au collisions

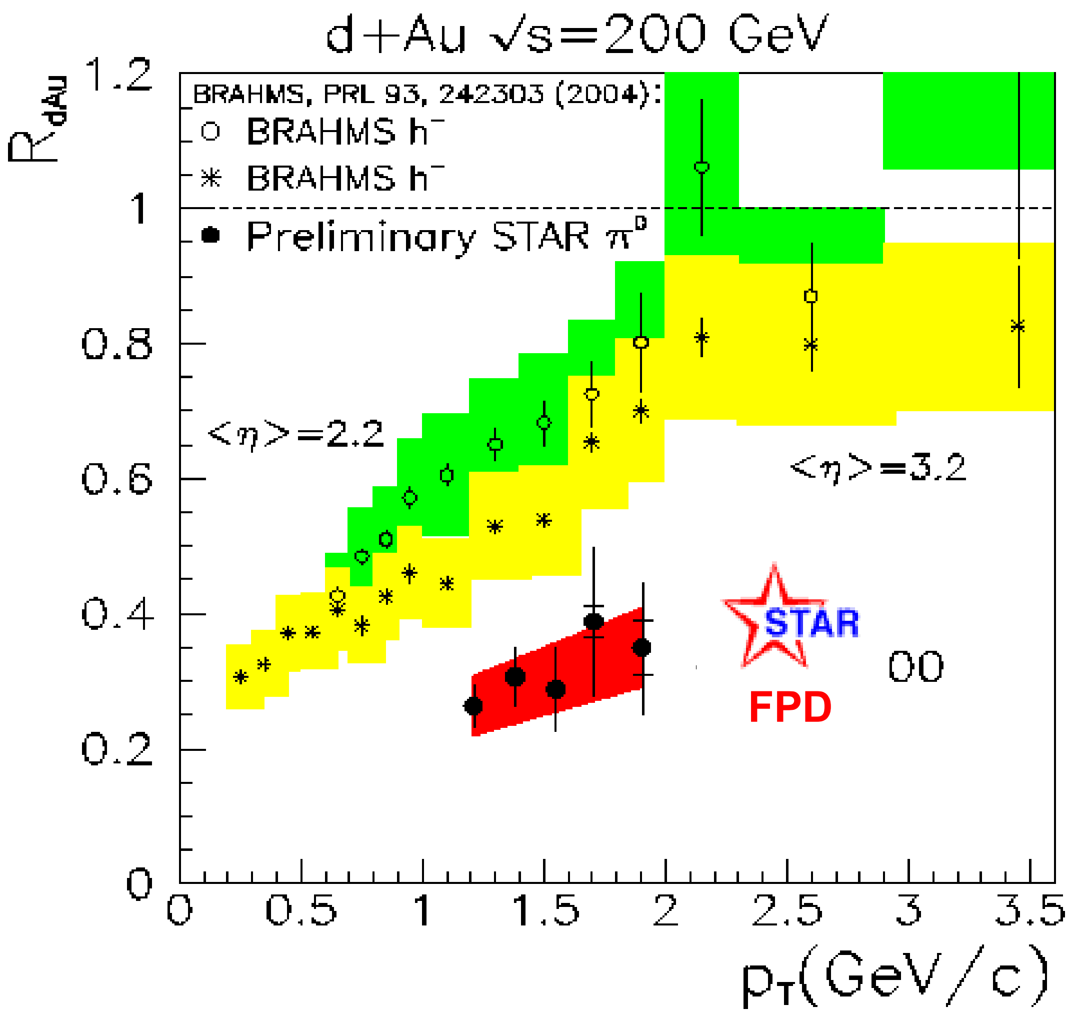
PRL 94, 082302 (2005)
& nucl-ex/0507032





η dependence of R_{dAu}

Very forward π^0's



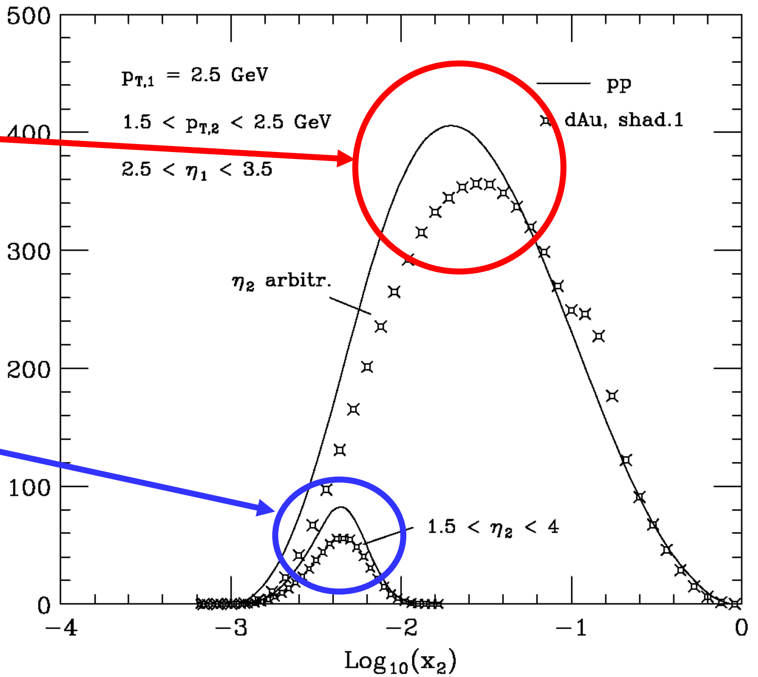
Observe **significant rapidity dependence**, similar to BRAHMS measurements and expectations from saturation framework.

But forward hadron production does not probe such small momentum fraction: $\langle x_g \rangle \sim 0.02$ in NLO pQCD calculations so leading twist shadowing & CGC saturation regions may not be probed

Guzey, Strikman, and Vogelsang
PL B603, 173

Only one π^0 detected

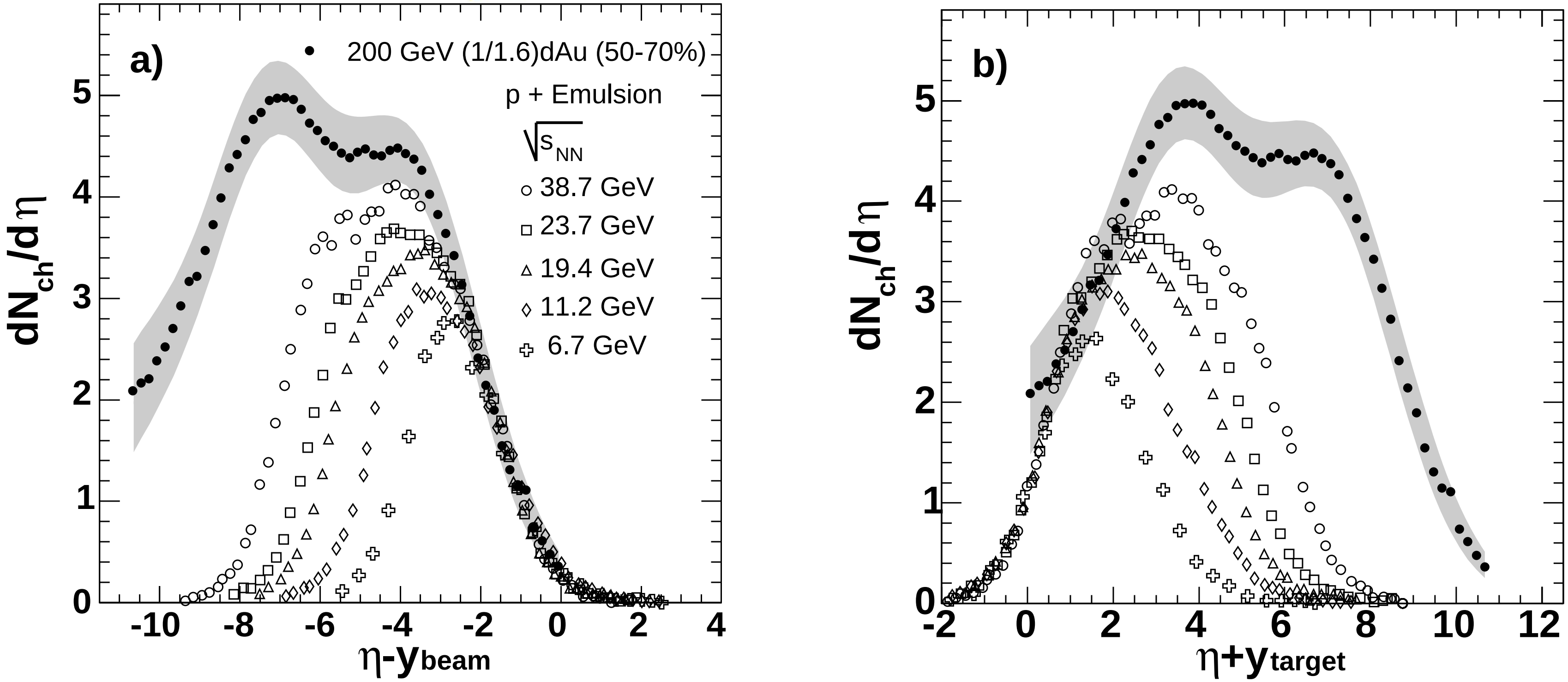
Both π^0's detected at forward rapidity



However, as shown by Guzey et al., if one measures two forward hadrons (π^0's) then one CAN pin down x_2 to small values

Comparing d+Au dN/dη to p+emulsion

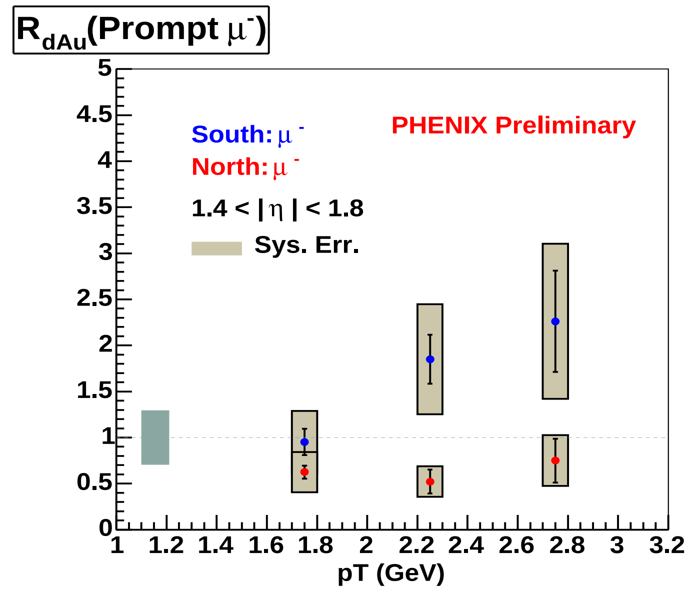
nucl-ex/0409021



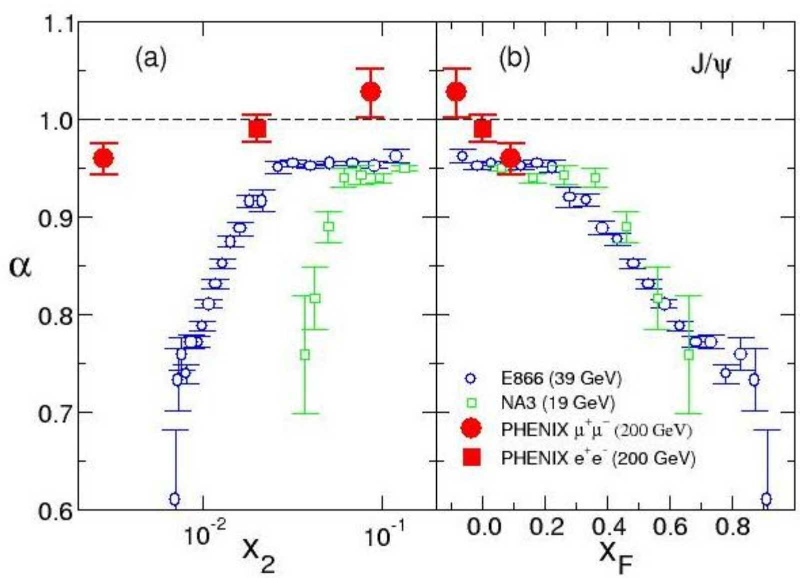
PHOBOS attributes effects to limiting fragmentation

Heavy quarks at forward rapidity & small-x

First forward rapidity **prompt** muon results (charm & beauty)

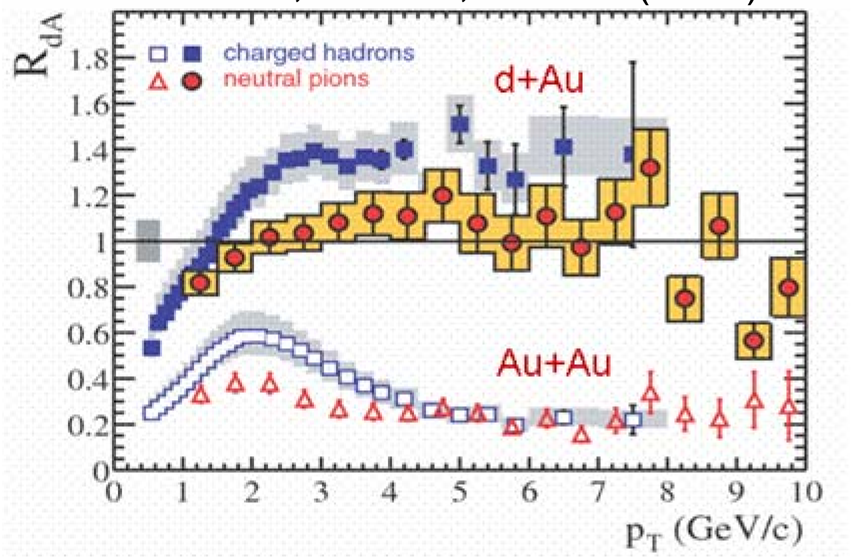


- J/ψ nuclear dependence does not scale with x_2 so appears to NOT have a dominant effect from shadowing *PHENIX, nucl-ex/0507032*
- Apparent scaling with x_F is similar to limiting fragmentation phenomena seen for hadron production (see previous slide)
- but other models involving Sudakov suppression (energy conservation) *Kopeliovich et al, hep-ph/0501260 (2005)*
- or (large) initial-state gluon energy loss could also explain this x_F scaling

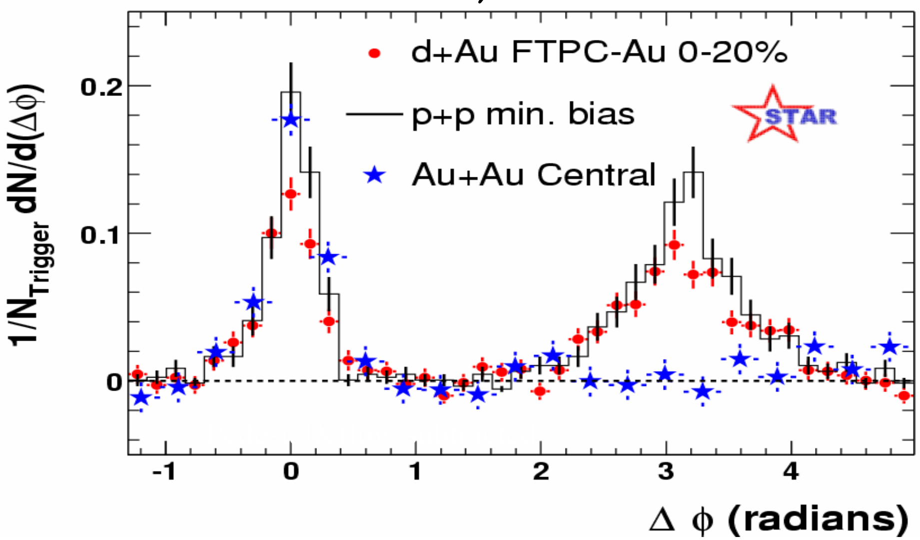


dAu provides an essential baseline for the jet quenching and correlation modifications observed in AuAu collisions

PHENIX, PRL 91, 072303 (2003)



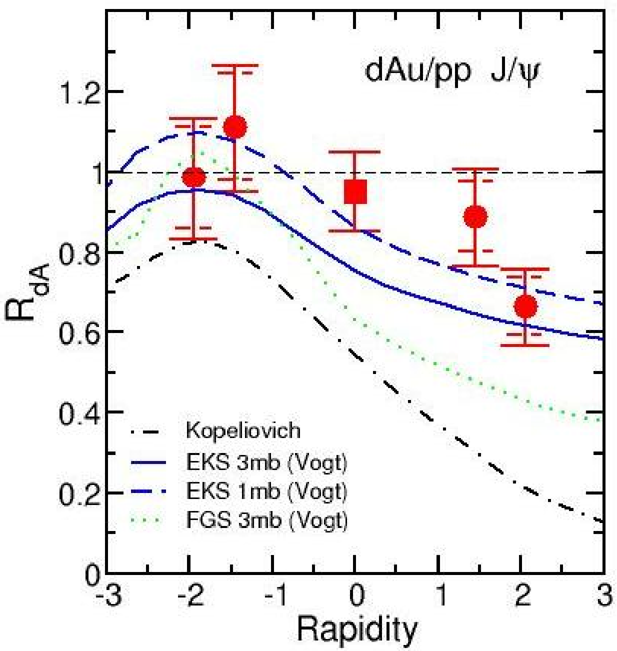
PRL 91, 072304

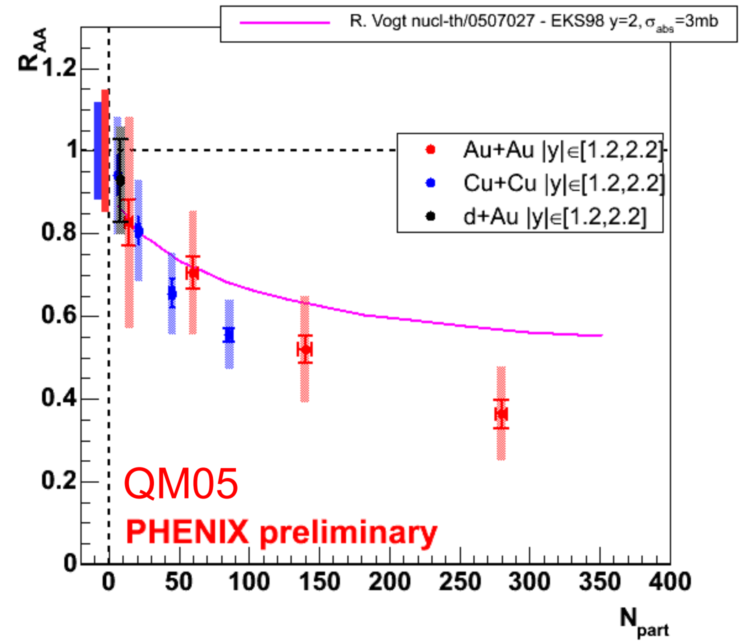


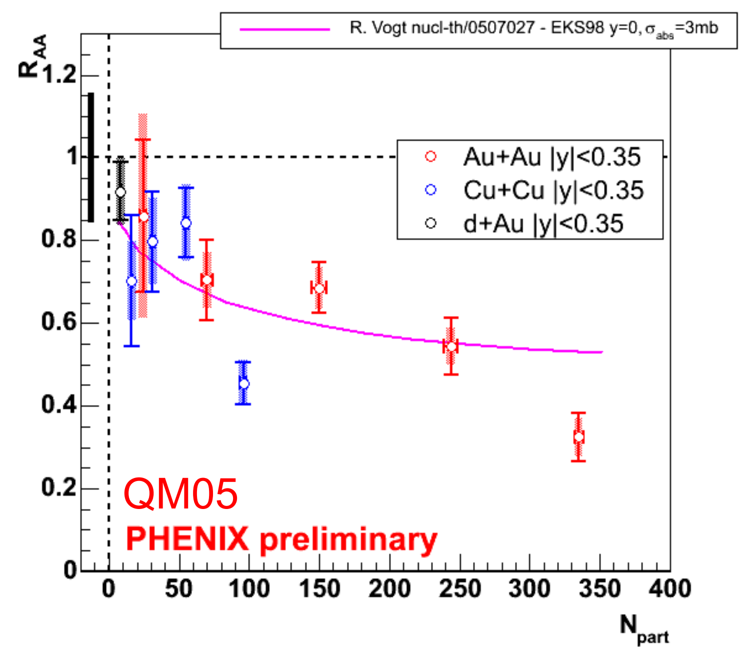
J/ψ nuclear modification factor R_{AA}

It also provides a CNM (cold nuclear matter) baseline for normal J/ψ absorption and shadowing; although not very precise with dAu luminosities obtained so far

PHENIX, nucl-ex/0507032





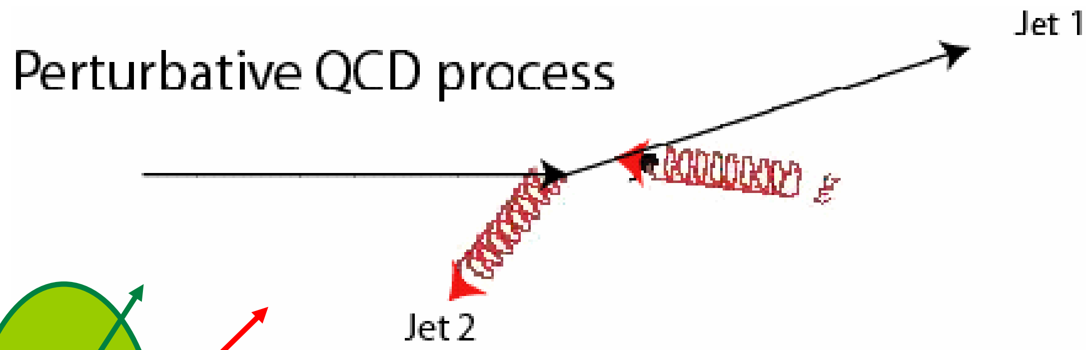


Any difference between p+p and d+Au?

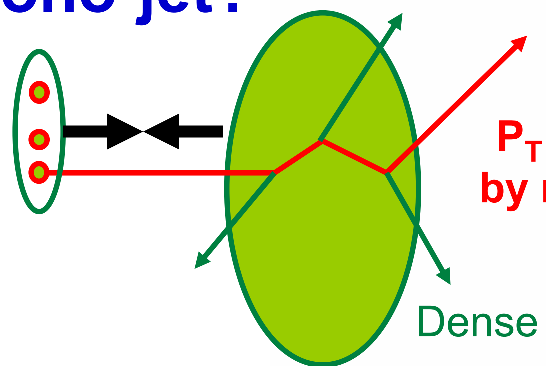
(Next 3 slides from Les Bland)

http://www.phenix.bnl.gov/phenix/WWW/publish/leitch/rhicii-forward/apr05_workshop/les_bland_FMS_RHIC2.ppt

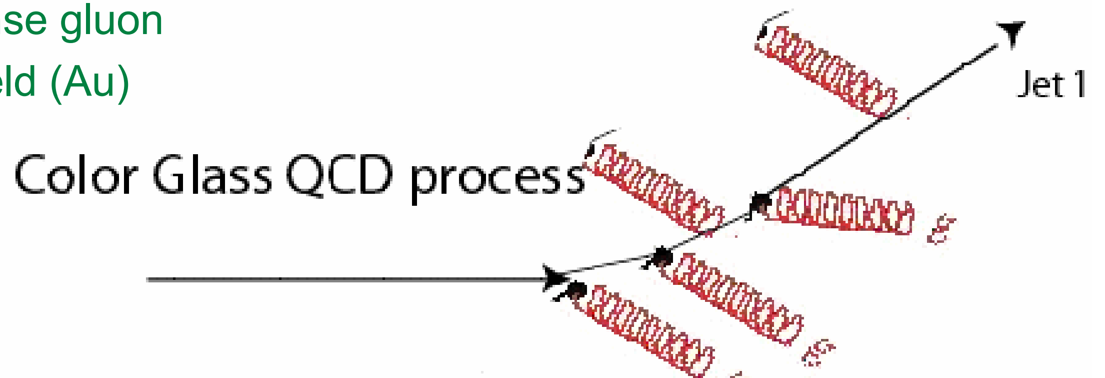
p+p: **Di-jet**



d+Au: **Mono-jet?**

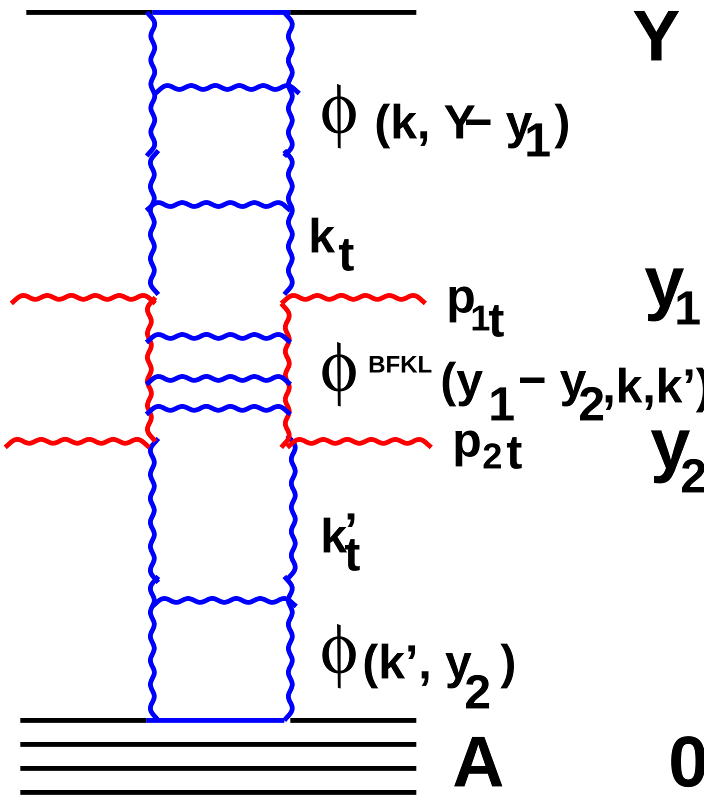


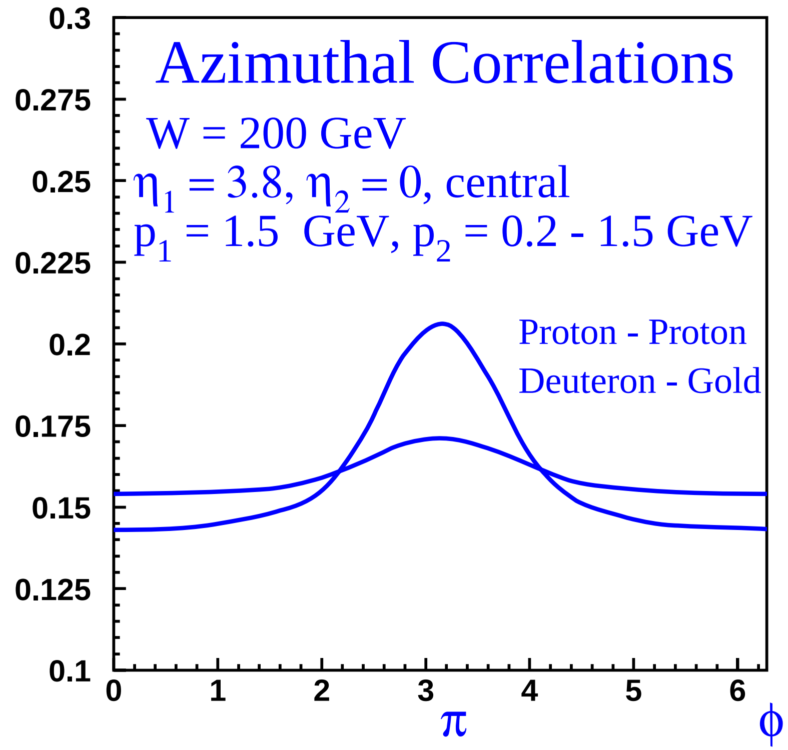
Kharzeev, Levin, McLerran gives physics picture (NPA748, 627)



Color glass condensate predicts that the **back-to-back correlation** from p+p **should be suppressed**

Back-to-back correlations with the color glass

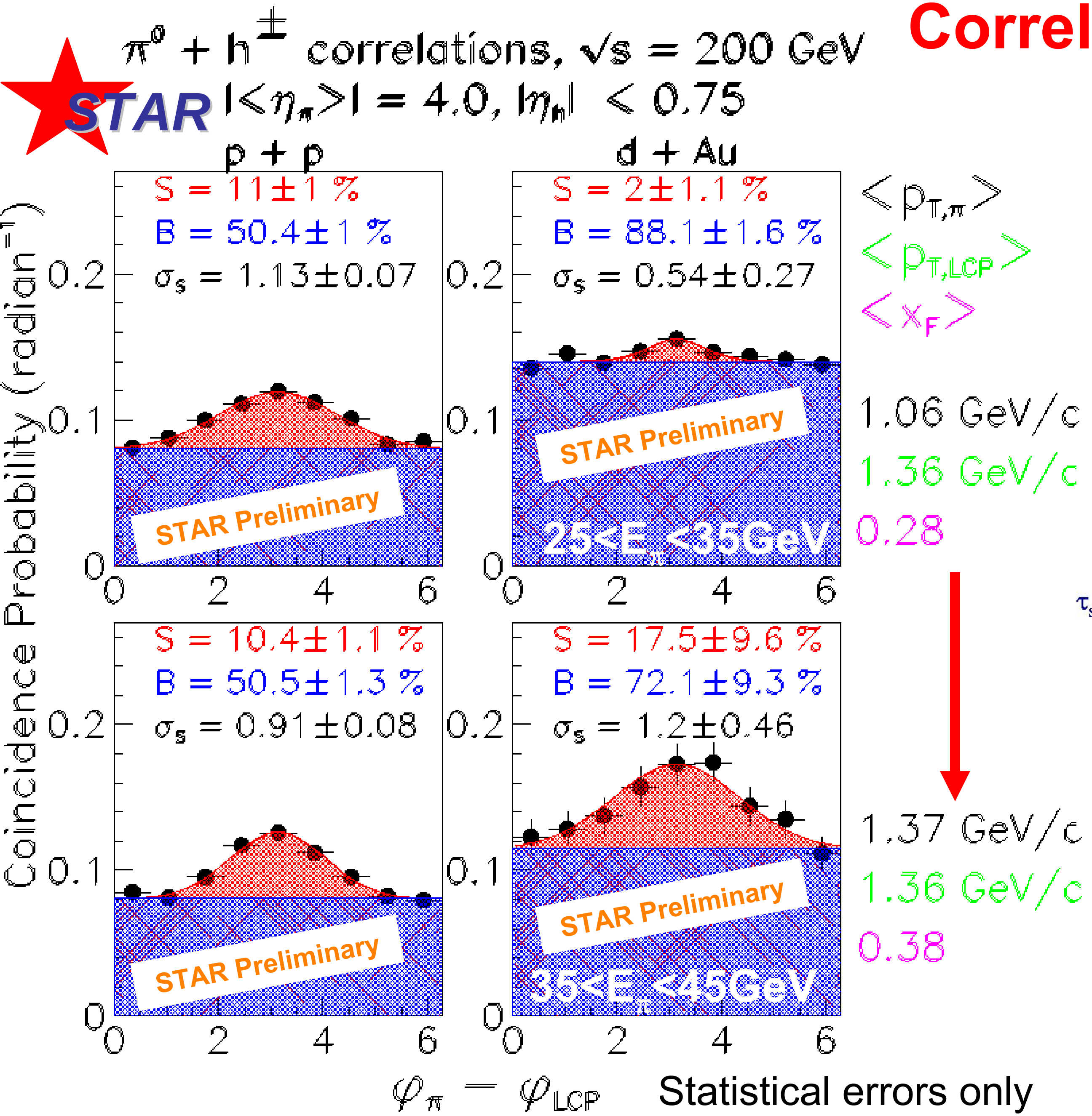




The evolution between the jets makes the correlations disappear.

(Kharzeev, Levin, and McLerran, NP A748, 627)

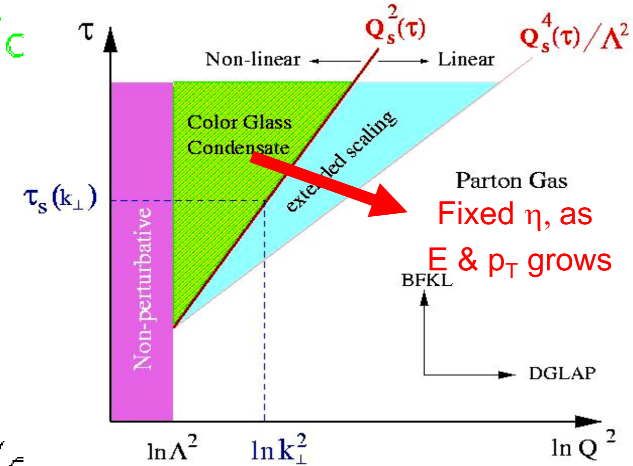
Correlations in d+Au



- are suppressed at small $\langle x_F\rangle$ and $\langle p_{T,\pi}\rangle$

S_{pp}-S_{dAu}= (9.0 ± 1.5) %

consistent with CGC picture

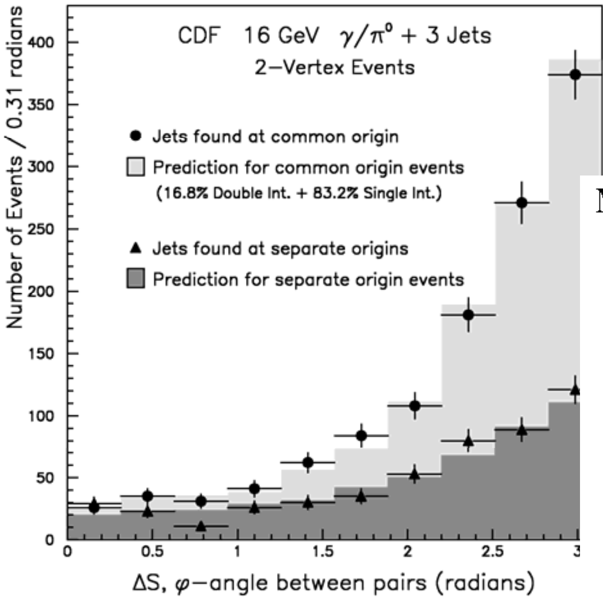


- are consistent in d+Au and p+p at larger $\langle x_F\rangle$ and $\langle p_{T,\pi}\rangle$

as expected by HIJING

Double parton correlations

CDF, PRL 79, 584



PRL 88, 031801

Measuring Double-Parton Distributions in Nucleons at Proton-Nucleus Colliders

M. Strikman*
Department of Physics, Pennsylvania State University, University Park, Pennsylvania 16802

D. Treleani†
Università di Trieste, Dipartimento di Fisica Teorica, Strada Costiera 11, Miramare-Grignano, and INFN, Sezione di Trieste, I-34014 Trieste, Italy

(Received 11 June 2001; published 2 January 2002)

We predict a strong enhancement of multijet production in proton-nucleus collisions at collider energies, as compared to a naive expectation of a cross section $\propto A$. The study of the process would allow one to measure, for the first time, the double-parton distribution functions in a nucleon in a model-independent way and hence to study both the longitudinal and the transverse correlations of partons.

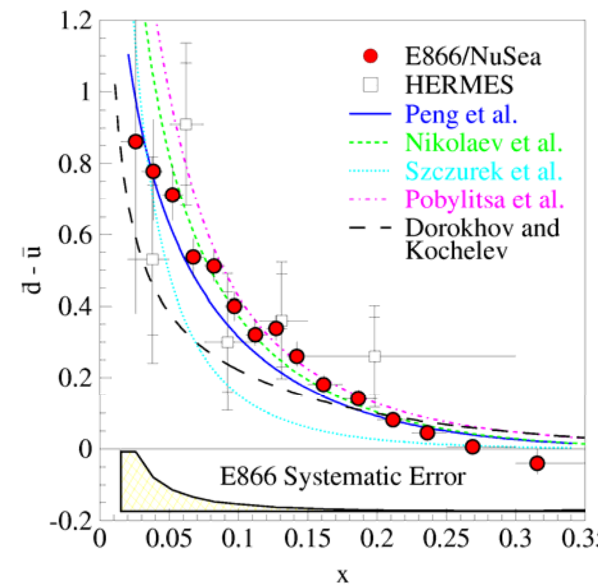
A-dependence of 4-jet yields in p+A collisions can be used to measure $x_1 - x_2$ momentum correlations within the proton.

- This would require pA, not dA collisions!

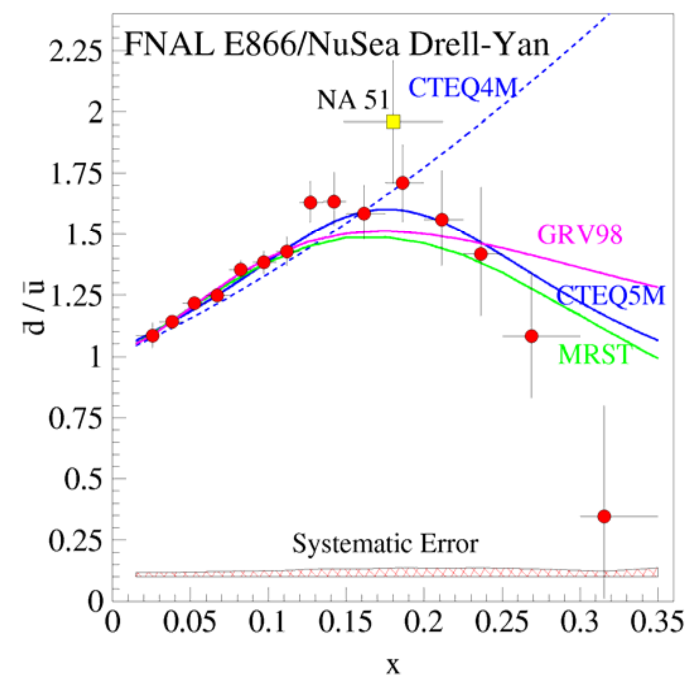
Flavor asymmetry of the nucleon anti-quark sea

E866/NuSea
Phys. Rev. Lett. **80**, 3715 (1998)

$$\left.\frac{\sigma^{pd}}{2\sigma^{pp}}\right|_{x_b \gg x_t} \approx \frac{1}{2}\left[1+\frac{\bar{d}(x_t)}{\bar{u}(x_t)}\right]$$



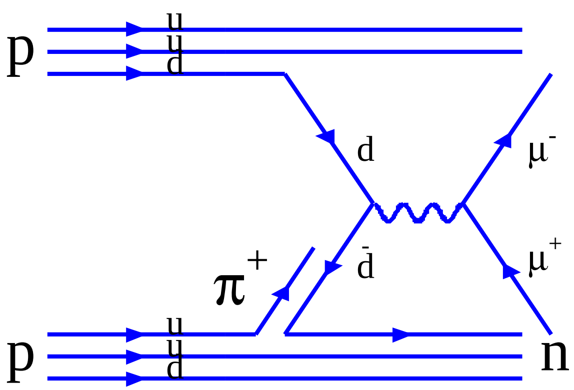
- pQCD Gluon splitting? $\bar{d}(x) = \bar{u}(x)$
- Meson Cloud? Chiral Solitons? Instantons? $\bar{d}(x) > \bar{u}(x)$
- Models describe $\bar{d}(x) - \bar{u}(x)$ well, but not $\bar{d}(x)/\bar{u}(x)$ — pQCD becoming dominant?



(from Jen-Chieh Peng)

Tagged Drell-Yan production at RHIC?

(from Jen-Chieh Peng)



One can tag on forward-going proton, neutron, Δ, Λ in coincidence with lepton-pair

Assuming factorization, then

$d\sigma^{DY}/dy\, dm\, dx_F\, (p+p \to n+\mu^+ \mu^- + x)$

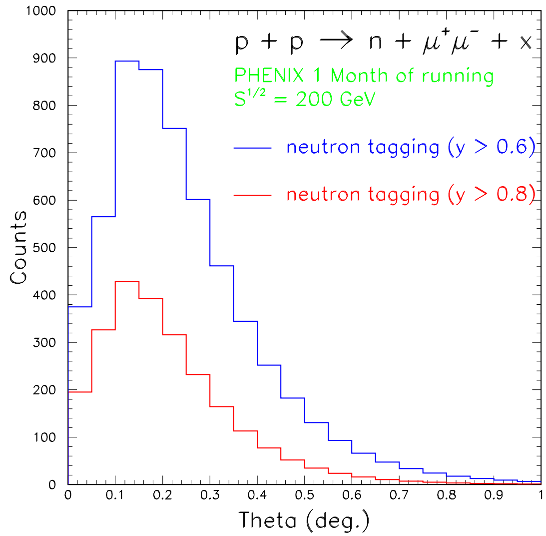
$\quad = d\sigma^{DY}/dm\, dx_F\, (p+\pi^+ \to \mu^+\mu^- + x) \cdot f_{MB}(y)$

and $f_{MB}(y)$ is the probability for $p \to \pi^+ + n$, where n carries a fraction y of the proton momentum

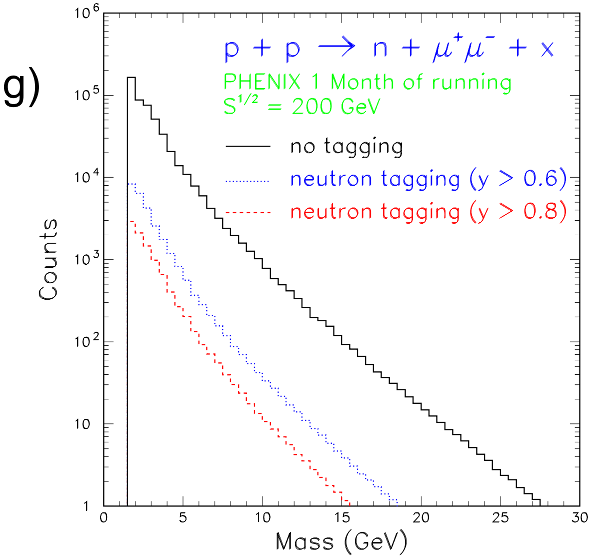
Tagged Drell-Yan production could provide information on the antiquark distribution in the mesons of the nucleon sea and on $f_{MB}(y)$

Tagged DY with forward neutrons

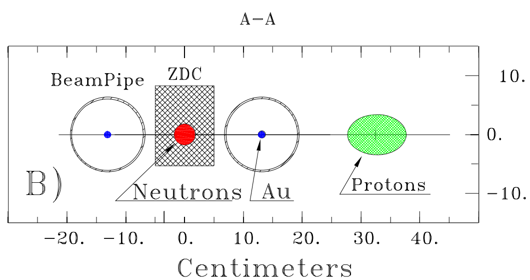
Or with tagged protons

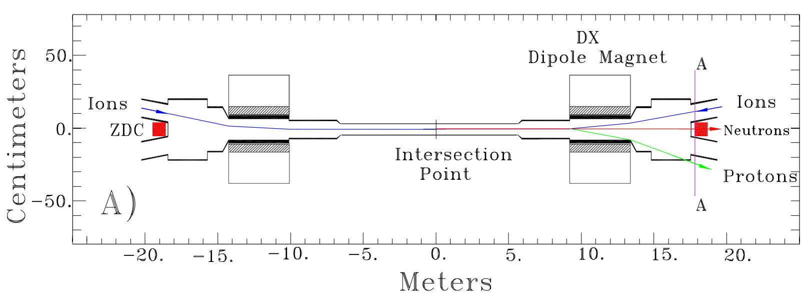


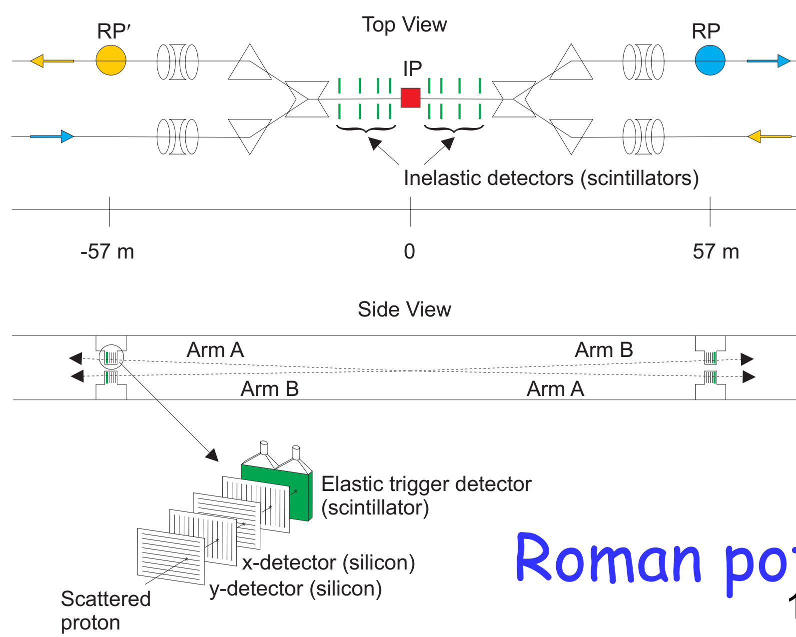
(from Jen-Chieh Peng)



ZDC







Roman pots

Other possible tagged Drell-Yan measurements

(from Jen-Chieh Peng)

- $p + p \rightarrow \Lambda + \ell^+ \ell^- + x$

  Probe the $p \rightarrow \Lambda + K^+$ component, and the strange quark contents in the proton
- $\vec{p} + \vec{p} \rightarrow n + \ell^+ \ell^- + x$

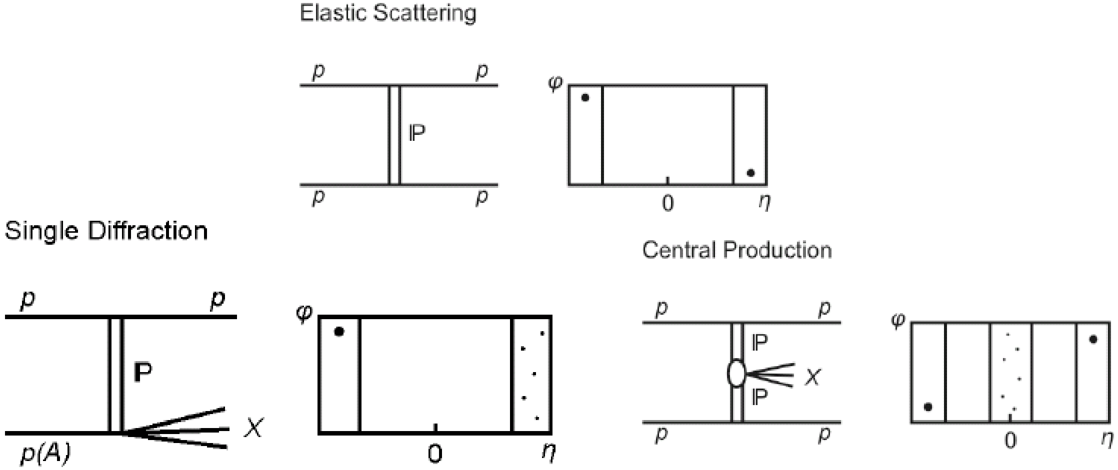
  Measure helicity asymmetry A_{LL} due to the meson cloud (expect $A_{LL} \sim 0$)
- $p + A \rightarrow A + \ell^+ \ell^- + x$
  - probe "pion excess" in nuclei via the A-dependence measurement
- Doubly-tagged Drell-Yan: $p + p \rightarrow p + p + \ell^+ \ell^- + x$
  - meson-meson annihilation (or pomeron interactions)?
- Other hard-diffractive processes at RHIC?
  - tagged J/ψ production?
  - tagged jet production?

  (gluon content of the meson cloud)

Physics with tagged forward protons at RHIC-II

from Wlodek Guryn

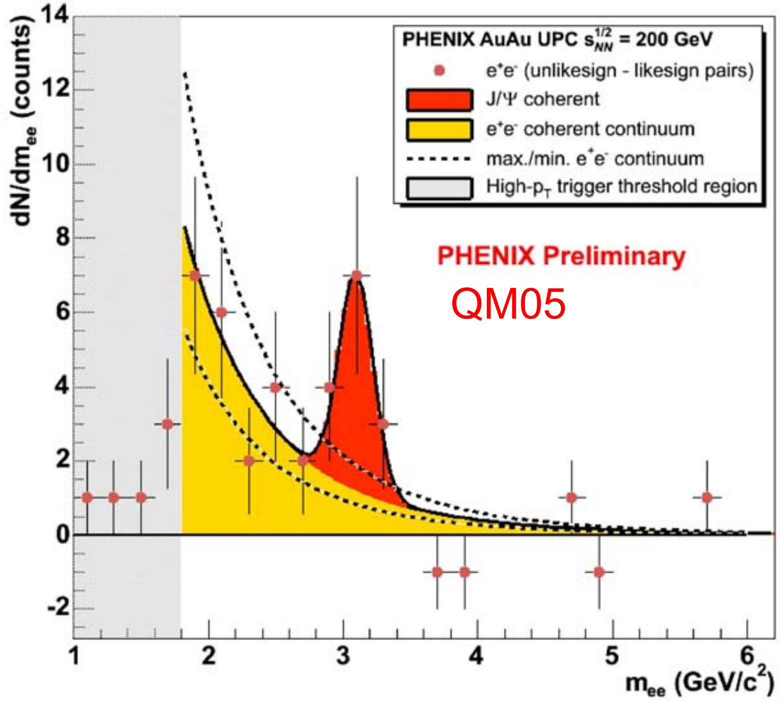
- processes with forward tagged protons select exchanges mediated by gluon-rich objects
- color-singlet objects with vacuum quantum numbers – Pomerons
- double Pomeron exchange can produce massive systems – glueballs and other gluon-rich states



Ultra-peripheral Collisions (UPC's)

Can Ultra-peripheral reactions (UPC's) at forward rapidity probe small-x gluon shadowing or saturation?

- e.g. J/ψ production probes gluon distributions of nuclei (private comm. Mark Strikman)



Asymmetric collisions at RHIC

From Wolfram Fischer – Santa Fe RHIC-II mtg
http://www.phenix.bnl.gov/WWW/publish/abhay/panic05/fischer.ppt

- For p-Au collisions need to move DX magnets, not necessary for d-Au collisions
- Need to have same revolution frequencies (≈g) for both beams
  injection/ramp: no modulated beam-beam
  (problem for LHC, although smaller bunch intensity)
  store : maintains luminosity and vertex
- 250GeV p on 100GeV/n Au: not possible
  equal f_{rev} not possible, expect luminosity reduction of at least 1000×
- Can possibly collide 120GeV p on 100GeV/n Au
  expect considerable operational difficulties

Method for pA (from Thomas Roser):

- inject A at 10 GeV/u and ramp to proton injection energy
- inject protons at normal injection energy
- ramp both up together to full energy

Question: pA or dA?

- Not prepared to give a detailed answer here – but a few comments:
- Physics processes are cleaner theoretically for pA
- Impact parameter resolution should be better in pA (no loose 2-nucleon projectile system)
  - but calculations need to be done to check this for actual experimental centrality measurements
- Trigger efficiencies would be a little lower for pA than dA, but probably not much (e.g. PHENIX dAu MB eff in run3 was ~88%)

Extra Slides

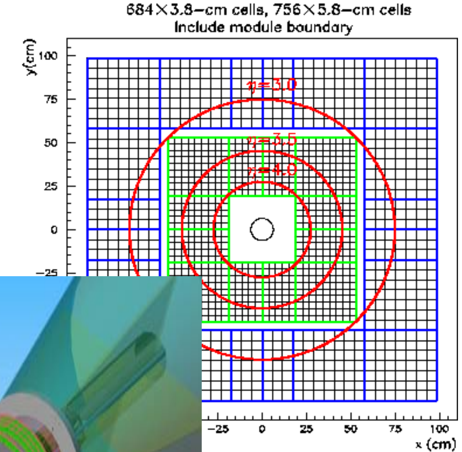
Upgrades

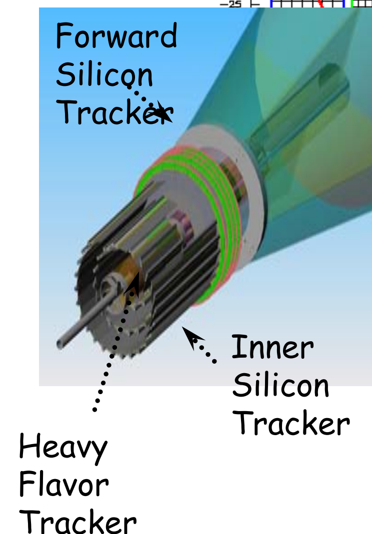
STAR

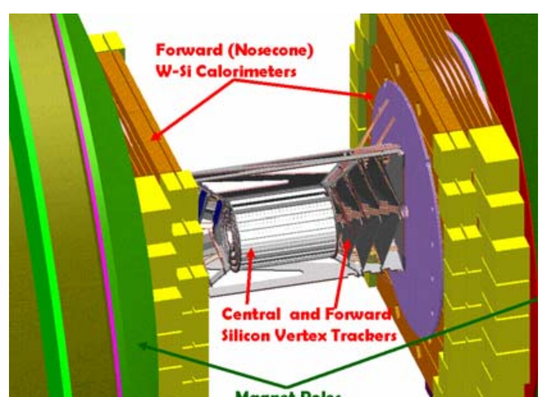
- Forward Meson Spectrometer
- Forward tracker upgrade (GEM)

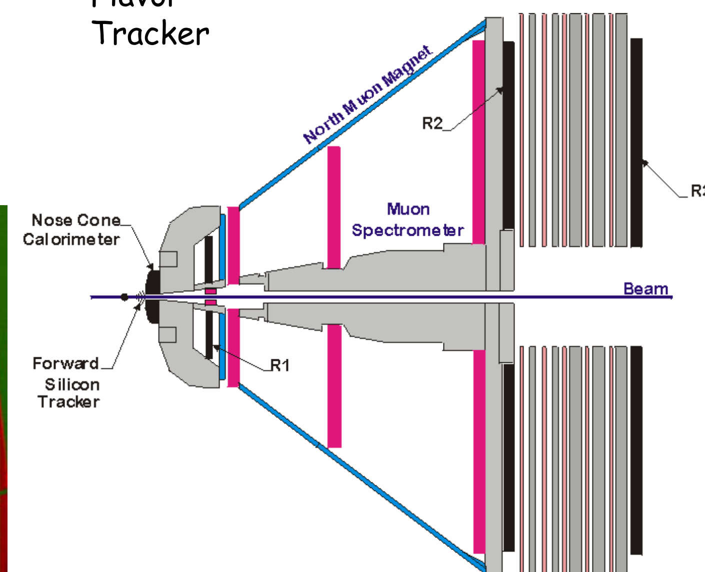
PHENIX

- Nosecone calorimeter (W-Si)
- forward muon trigger (RPC)
- Forward Silicon Vertex detector (mini-strips)









RHIC-II & LHC rate comparisons (RHIC: 12 weeks of AuAu; LHC: 1 month of PbPb). From Tony Frawley, Santa Fe RHIC Planning Meeting, 29-30 Oct 2005 http://www.phenix.bnl.gov/WWW/publish/abhay/panic05/frawley.pdf

	RHIC-II				LHC Heavy Ions					
Signal	PHENIX	$\|\eta\|$	STAR	$\|\eta\|$	ALICE	$\|\eta\|$	CMS	$\|\eta\|$	ATLAS	$\|\eta\|$
$J/\psi \to ee$	45k	<0.35	220k	<1	9.5k	<0.9				
$J/\psi \to \mu\mu$	395k	1.2-2.4			380k	2.5-4	40k	<2.4	8-100k	<2.5
$\psi' \to ee$	800	<0.35	4k	<1	190	<0.9				
$\psi' \to \mu\mu$	7.1k	1.2-2.4			6.9k	2.5-4	731	<2.4	140-1800	<2.5
$\chi_C \to ee\gamma$	2.8k	<0.35								
$\chi_C \to \mu\mu\gamma$	117k	1.2-2.4								
$\Upsilon \to ee$	400	<0.35	11.2k	<1	1.9k	<0.9				
$\Upsilon \to \mu\mu$	1.04k	1.2-2.4			4.2k	2.5-4	8.2k	<2.4	15k	<2
$B \to J/\psi \to ee$	570	<0.35	2.5k	<1						
$B \to J/\psi \to \mu\mu$	5.7k	1.2-2.4								
$D \to K\pi$	?		30k	<1	8k	<0.9				

Gluon saturation at small x & shadowing in nuclei

RHIC allows study of transition. LHC always saturated (except very high pT and y<-3)

LHC only 1-month/yr shared between pp, pA and AA – earliest pA 2010?

polarized and diffractive pA are useful - need theoretical calculations.

Models:
- gluon saturation, CGC
- leading twist shadowing (coherence)
- mass renorm. (Vitev)
- Sudakov suppr. (Kopeliovich)
- limiting fragmentation

Also important for AA initial state

Especially for LHC where always saturated at midrapidity

How to distinguish??
- correlations
- energy,rapidity dependence
- universality

need hard processes sensitive to gluons

Forward hadrons
- need forw. $\pi^0 \rightarrow$ STAR FMS
- hadron PID for $|y|>1$

compare open & closed

Heavy-quarks (c,b) & bound states

need cleaner way to get open-c, -b

vertex detectors!

wide kinematic range to understand physics & differentiate models

separating D & B in single-lepton spectra?
- use $B \rightarrow J/\psi X$ measurement
- very high statistics could allow seeing 2 $c\tau$'s

$D \rightarrow K\pi$ nice but difficult!

Direct photons for $|y|>1 \rightarrow$ PHENIX NCC

Onia – rare processes
- PHENIX onia
- Need STAR forward $J/\psi \rightarrow ee$

High Luminosities needed!

Antiquark distribution in nucleon and nuclei

Flavor structure of parton distribution in nuclei is practically unknown.

Models:
- Enhancement of antiquark in nuclei due to meson cloud
- Leading twist shadowing of antiquark at low-x
- Meson cloud explains the d-bar, u-bar asymmetry in nucleon

Also important for understanding gluon distribution in nuclei

Nuclear shadowing of antiquark sea can be measured at RHIC in pA

Spin structure of the nucleon is closely connected to the flavor structure of the nucleon

need hard process sensitive to antiquarks

Polarized Drell-Yan can probe seaquark polarization complementary to W-production

Drell-Yan process in pA and pp is ideal for probing antiquarks

Forward-tagging in p-p Drell-Yan can probe the pion cloud directly

High Luminosities needed!

Roman pot and forward neutron tagging are required

Many recent descriptions of low-*x* suppression

A short list (probably incomplete)

Saturation (color glass condensate)

- Jalilian-Marian, NPA **748** (2005) 664.
- Kharzeev, Kovchegov, and Tuchin, PLB **599** (2004) 23; PRD 68 (2003) 094013.
- Armesto, Salgado, and Wiedemann, PRL **94** (2005) 022002.

Multiple scattering

- Qiu and Vitev, PRL **93** (2004) 262301; hep-ph/0410218.

Factorization breaking

- Kopeliovich, *et al*., hep-ph/0501260.
- Nikolaev and Schaefer, PRD **71** (2005) 014023.

Shadowing

- R. Vogt, PRC **70** (2004) 064902.
- Guzey, Strikman, and Vogelsang, PLB **603** (2004) 173.

Parton recombination

- Hwa, Yang, and Fries, PRC **71** (2005) 024902.

Others?

- ...