What pA (may) tell us about AA

Berndt Mueller
Brookhaven National Laboratory
& Duke University

International Conference
on the Initial Stages of
High Energy Nuclear Collisions
Illa de Toxa, Spain
8-14 September 2013

BROOKHAVEN NATIONAL LABORATORY
a passion for discovery

Office of Science
U.S. DEPARTMENT OF ENERGY

Disclaimers

I doubt that I will be able to
answer the "charge" for my talk
but
I also doubt that this is what
the organizers expected :-)

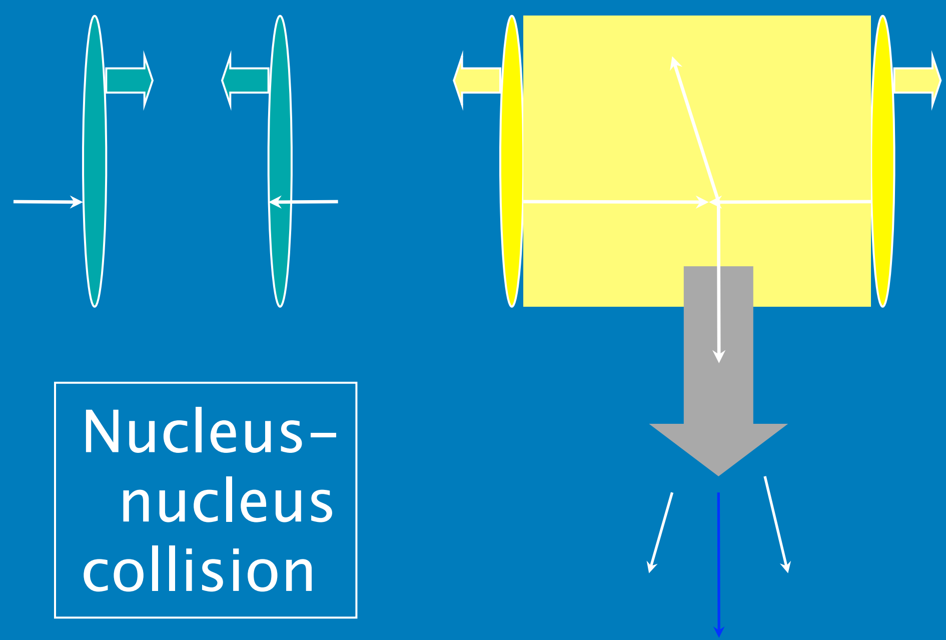
I apologize in advance to those
(Y. Kovchegov, J. Albacete, C. Salgado, F. Gelis, J. Qiu...)
whose brilliant work on pA I will not cover

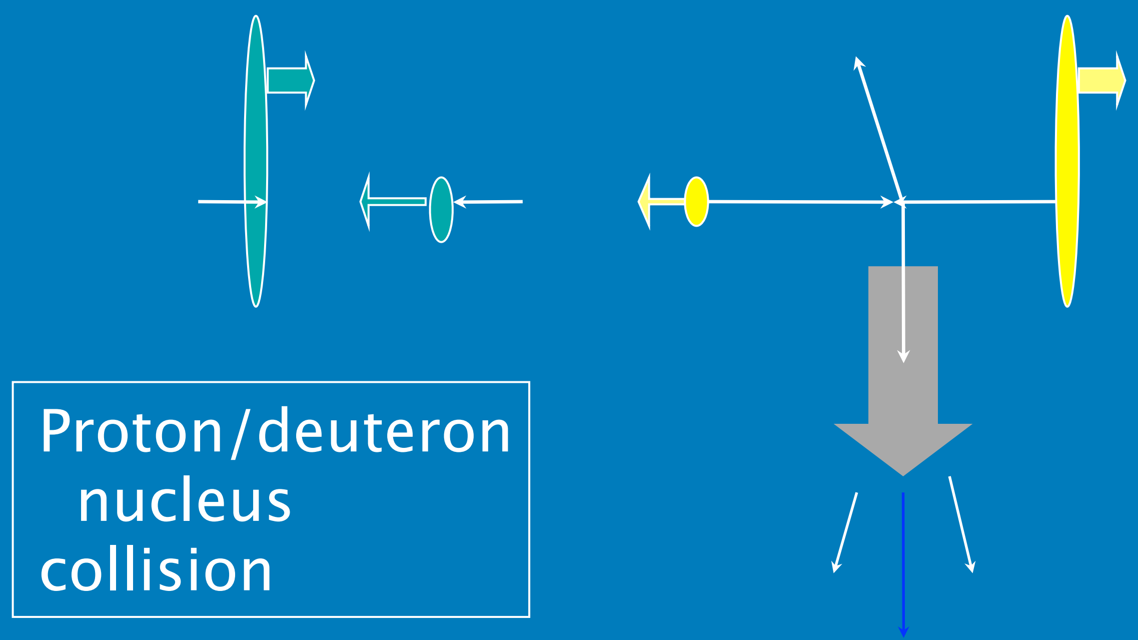
The common view before 2013

p+A (d+A) collisions serve as a control experiment to separate initial-state effects from final-state effects in A+A collisions

Flashback to 2003:

d+Au Control Experiment





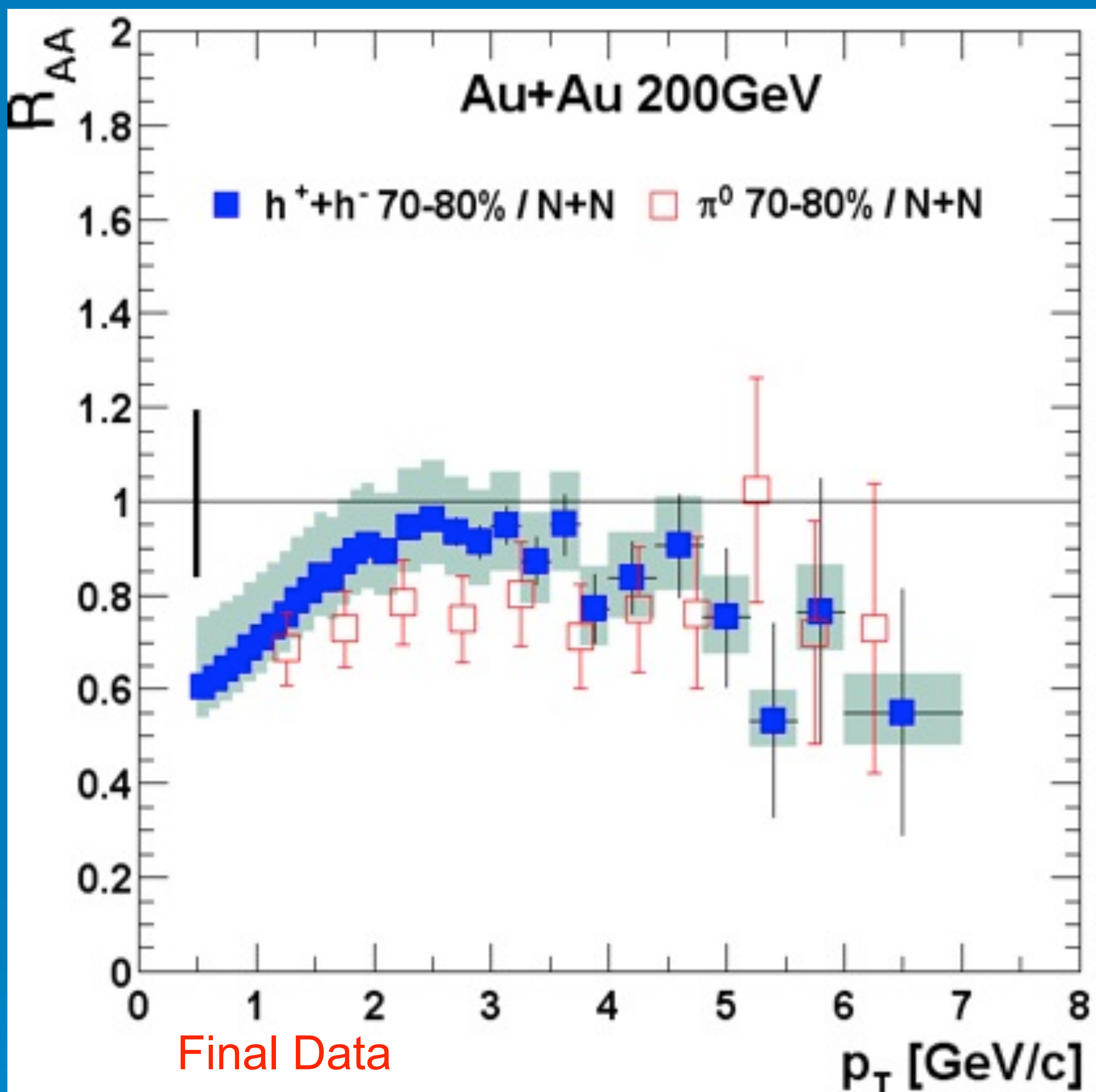
- Collisions of small with large nuclei were always foreseen as necessary to quantify cold nuclear matter effects.
- Recent theoretical work on the "Color Glass Condensate" model provides alternative explanation of data:
  - Jets are not quenched, but are a priori made in fewer numbers.
- Small + Large distinguishes all initial and final state effects.

June 18, 2003 Workshop at BNL

T.K. Hemmick

Centrality Dependence

Au + Au Experiment



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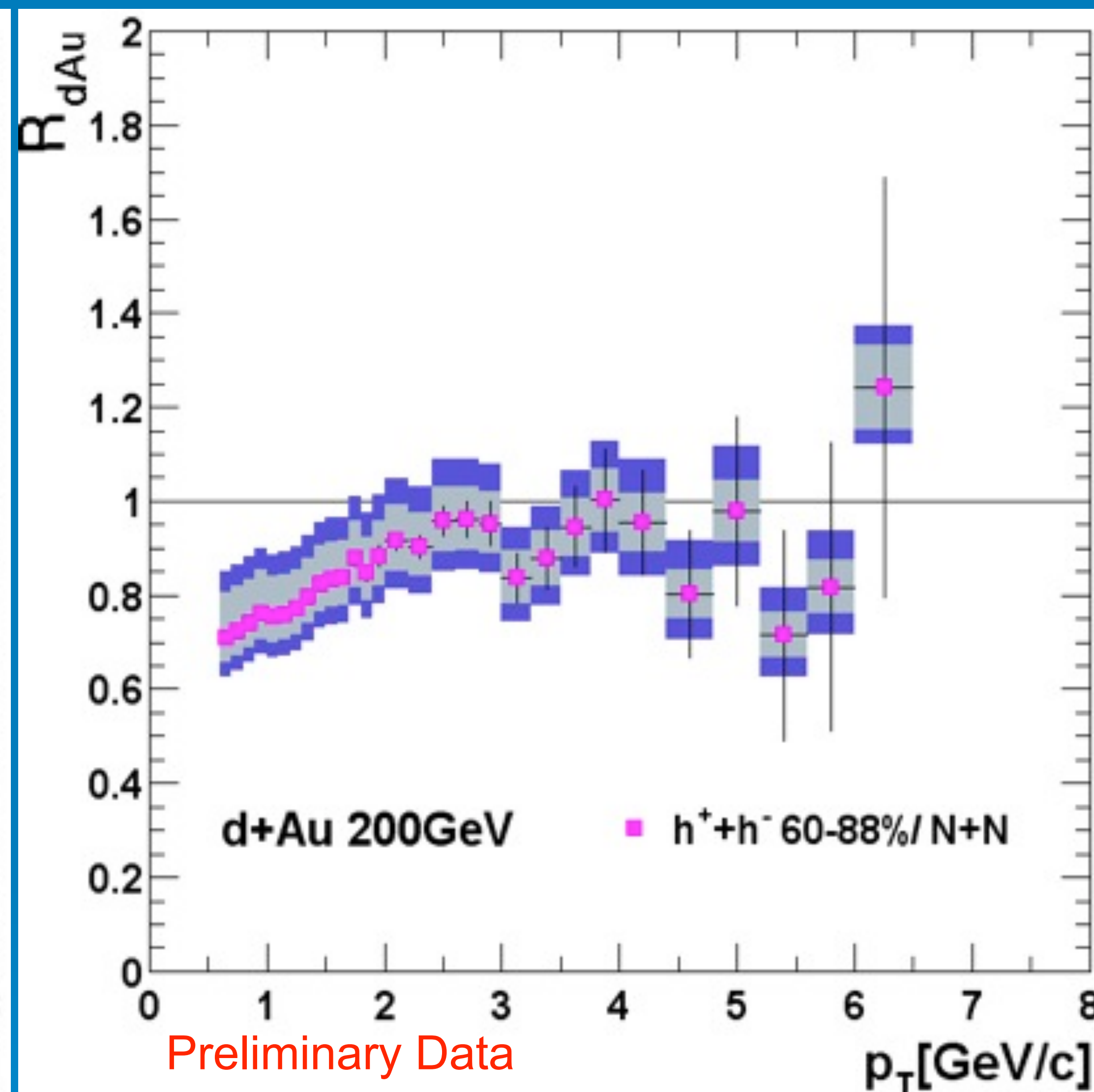

"PHENIX Preliminary" results, consistent with PHOBOS data in ***submitted paper***

- Dramatically different and opposite centrality evolution of Au+Au experiment from d+Au control.
- Jet Suppression is clearly a final state effect.

T.K. Hemmick

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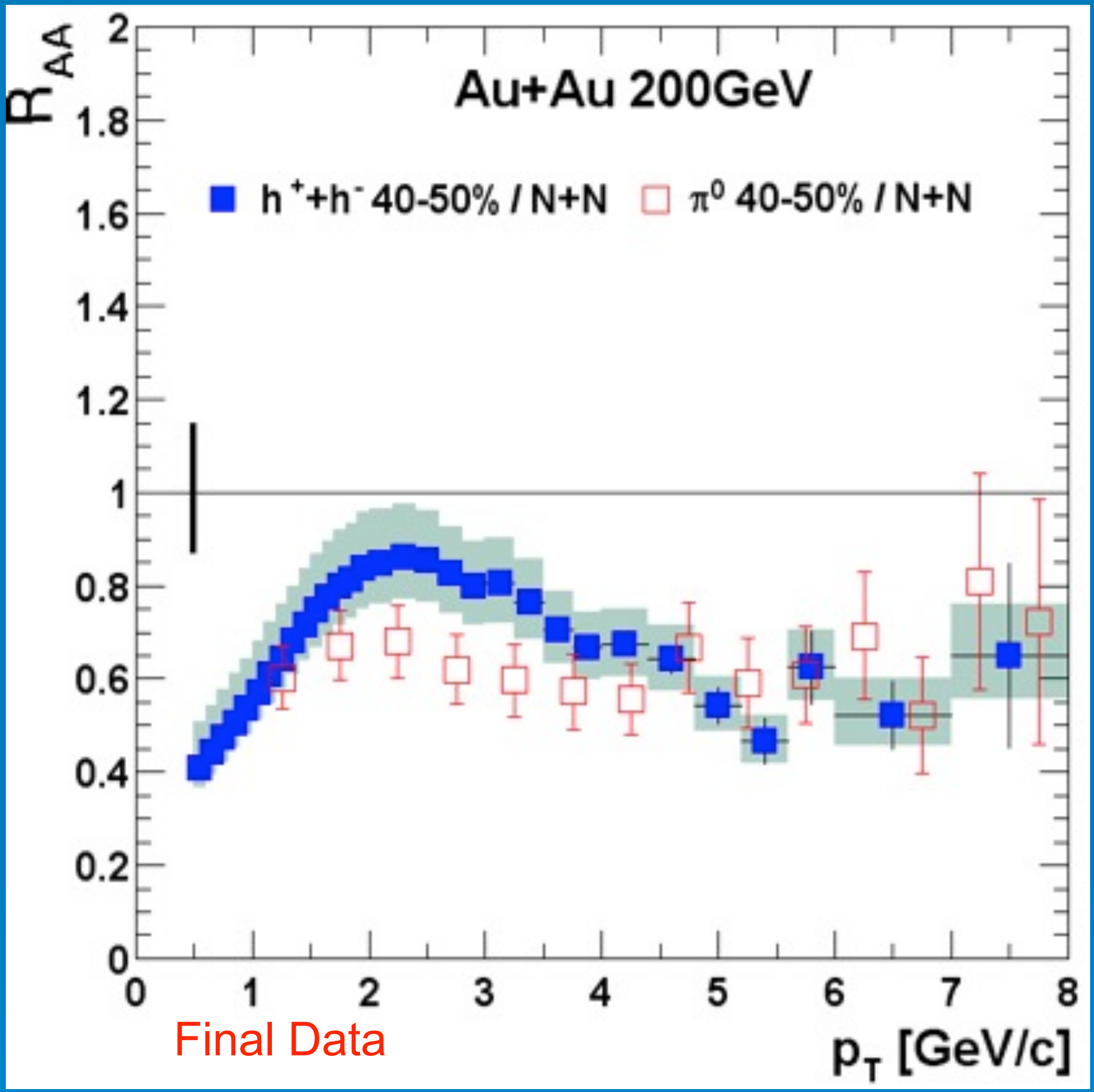

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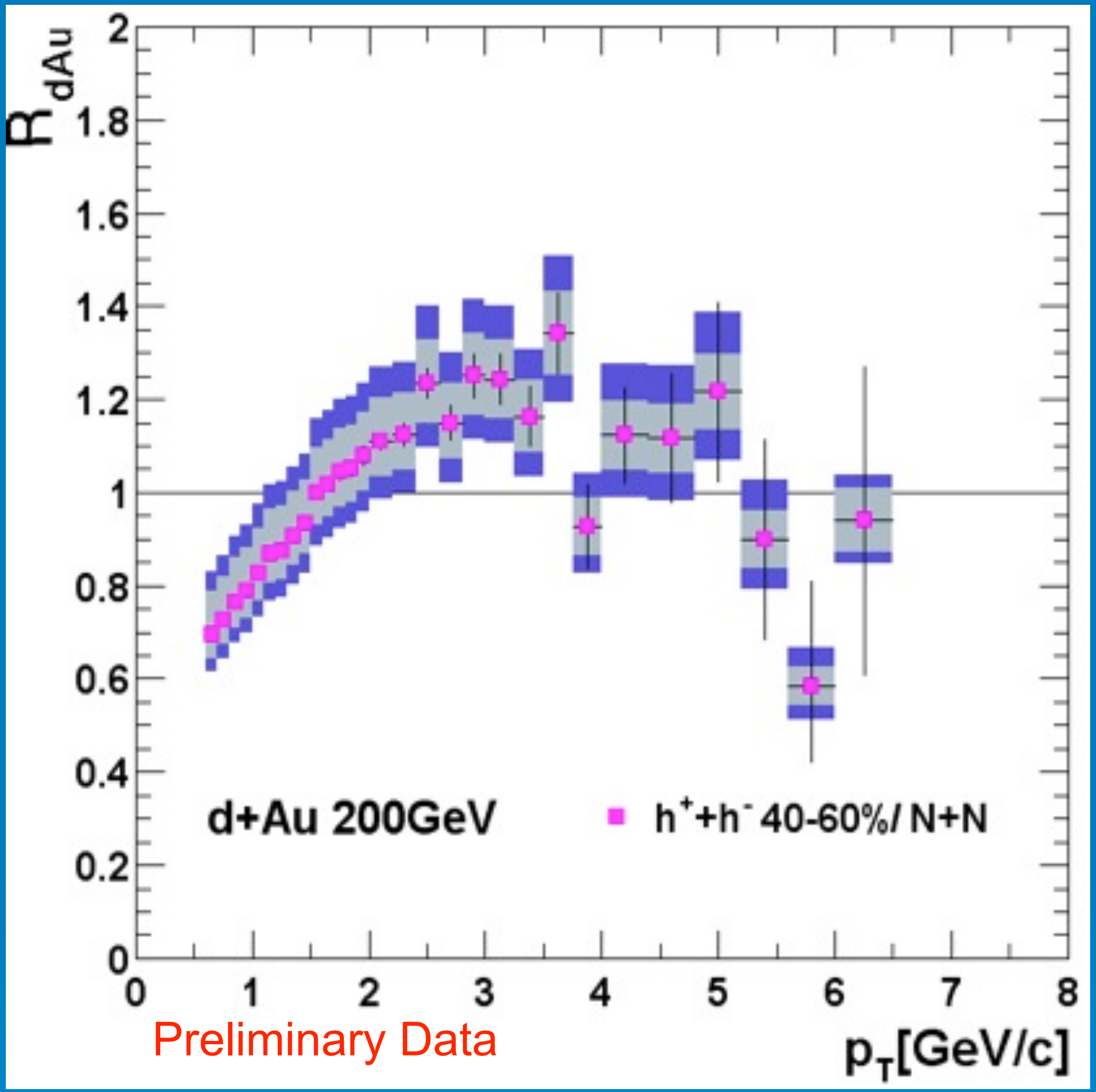

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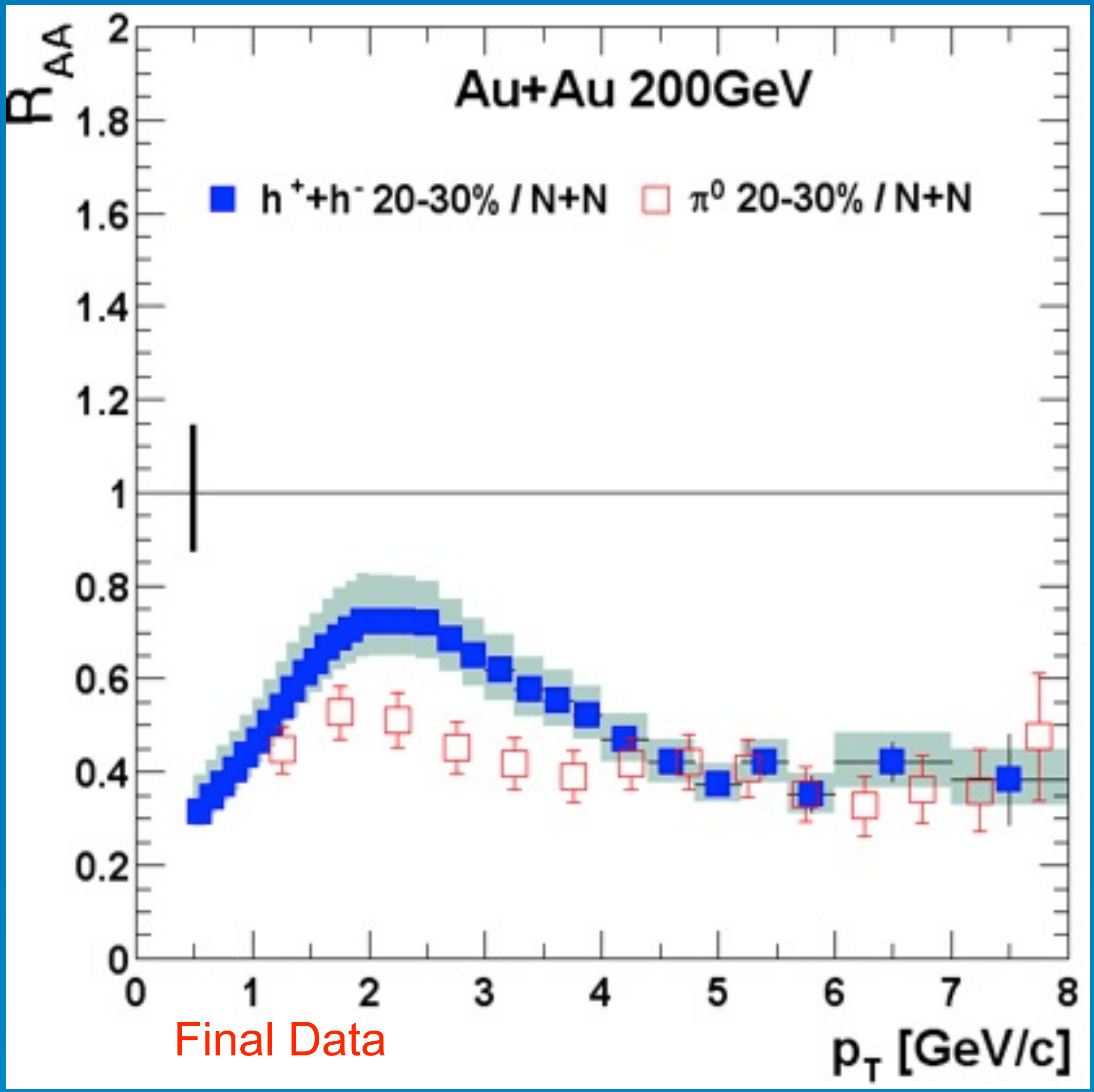

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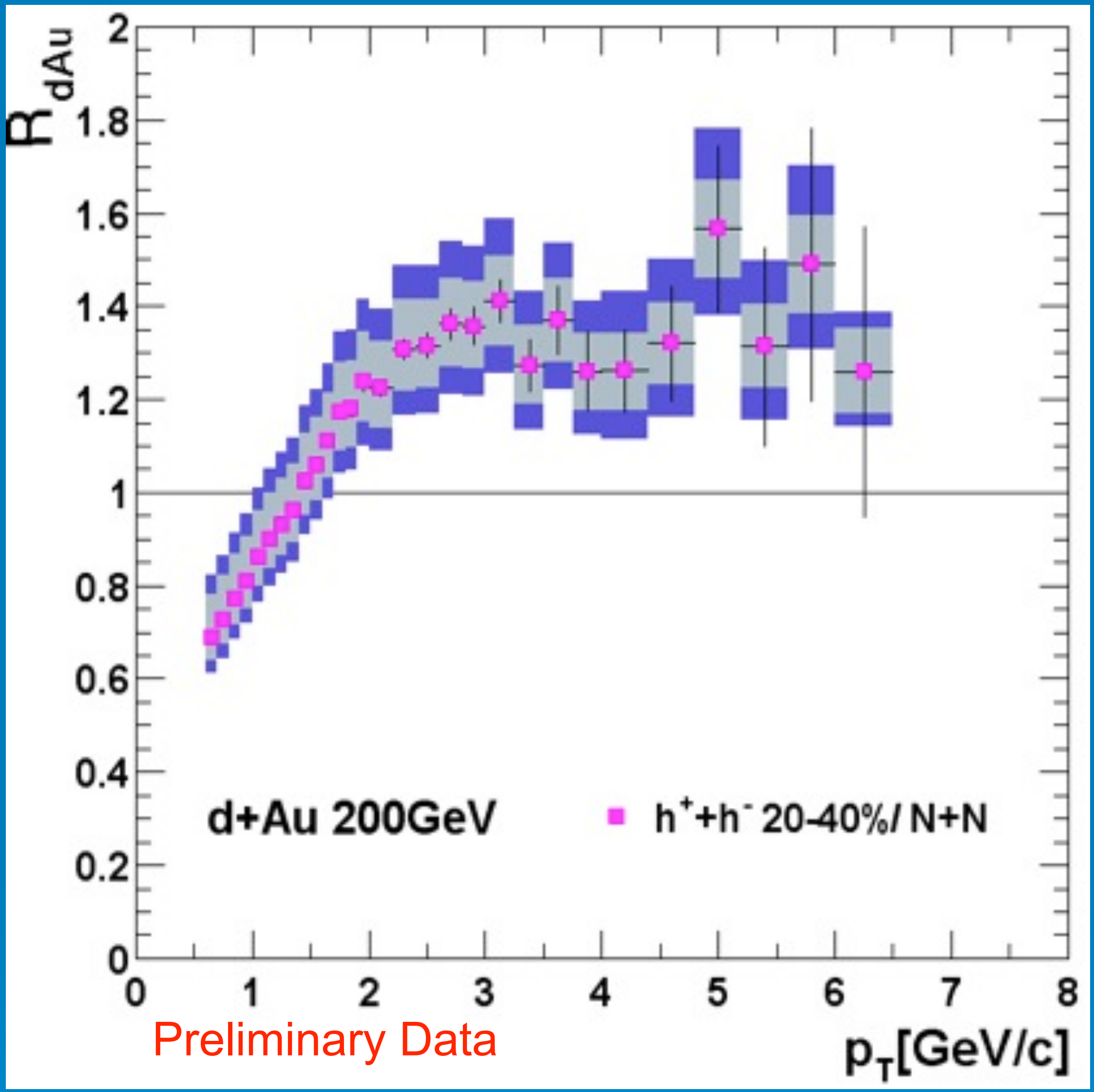

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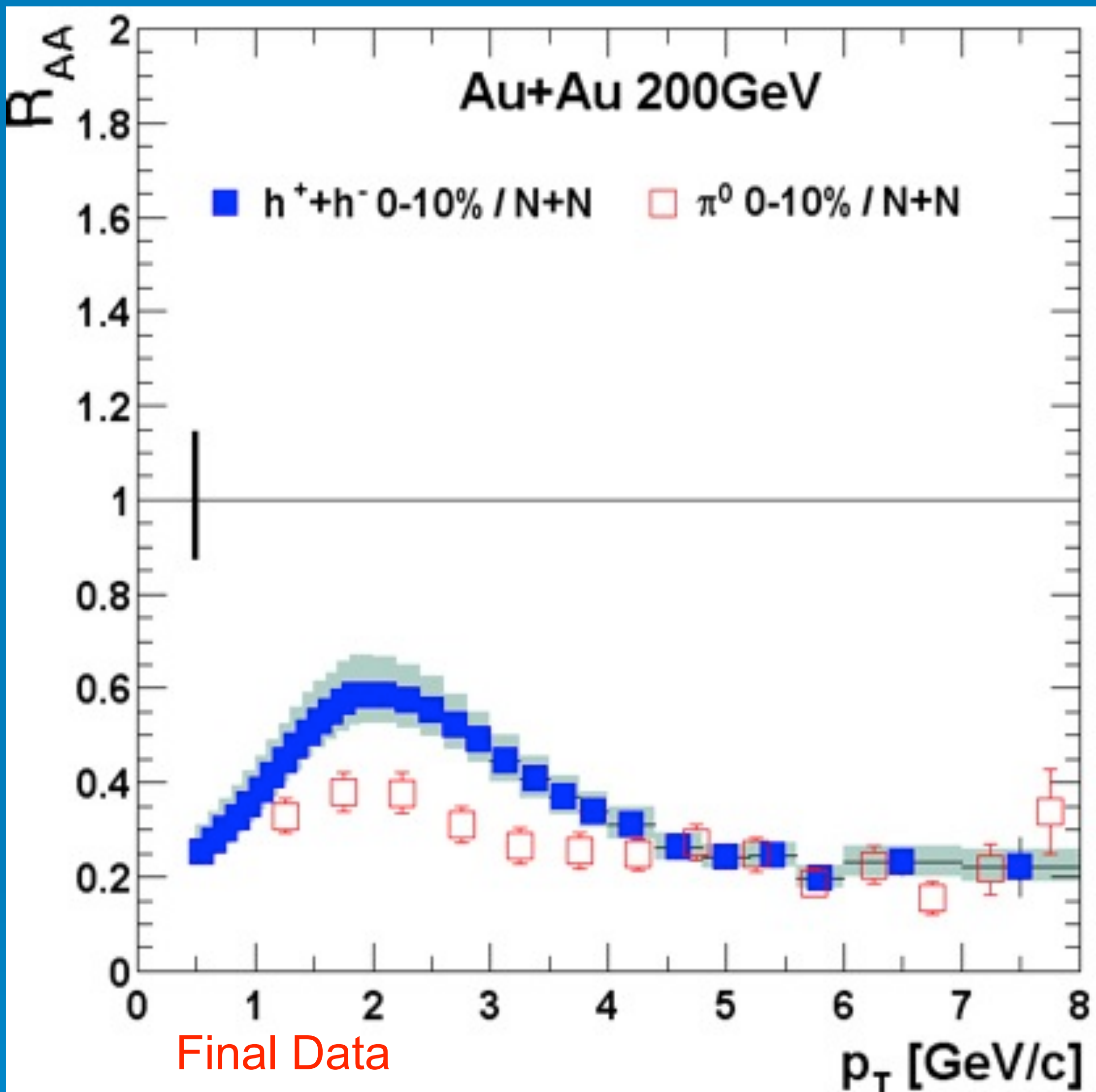

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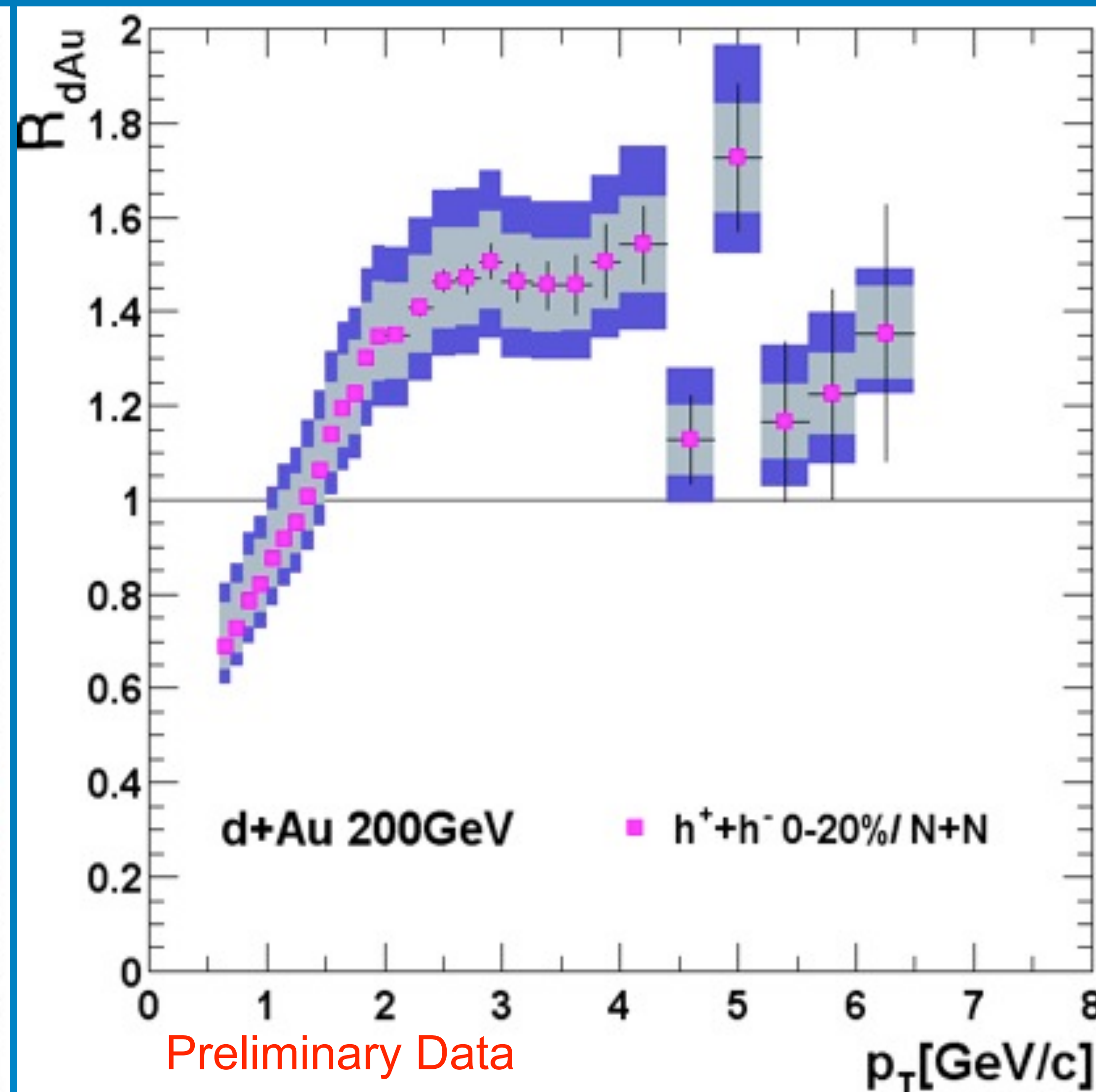

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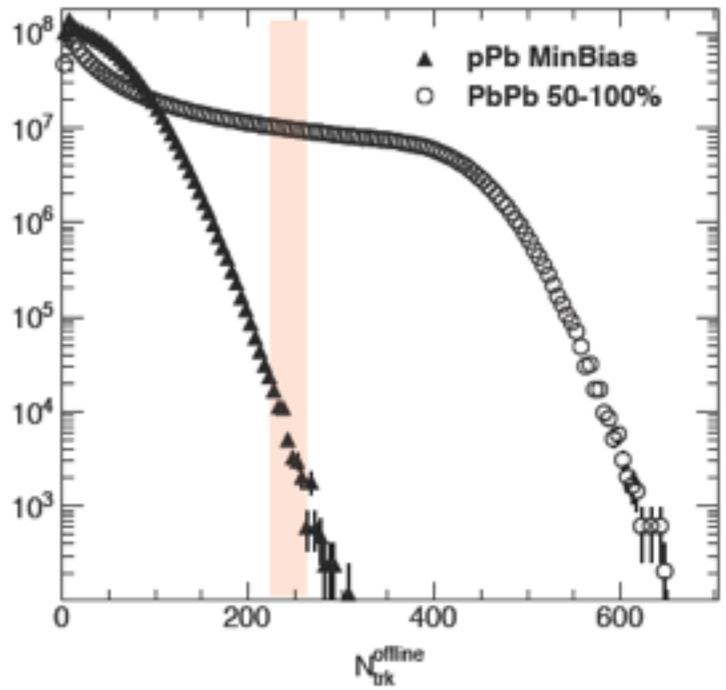
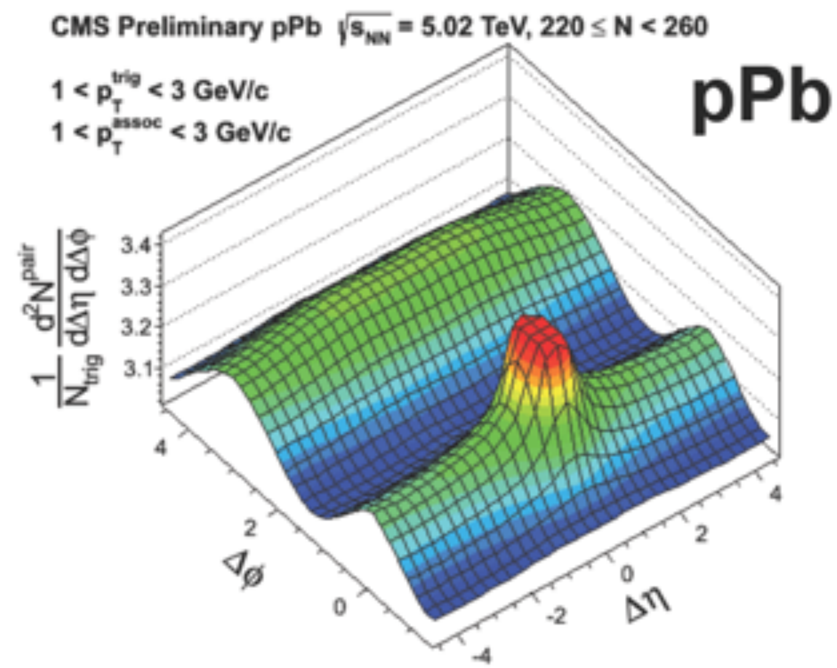
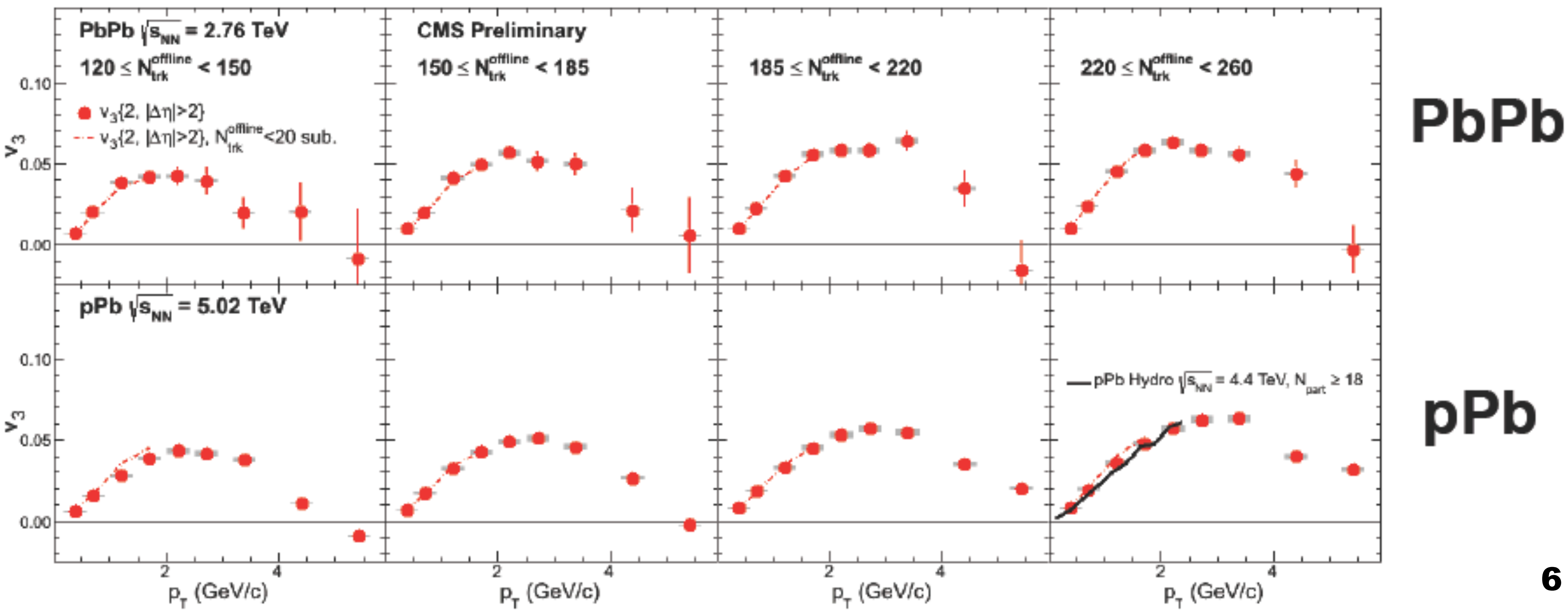
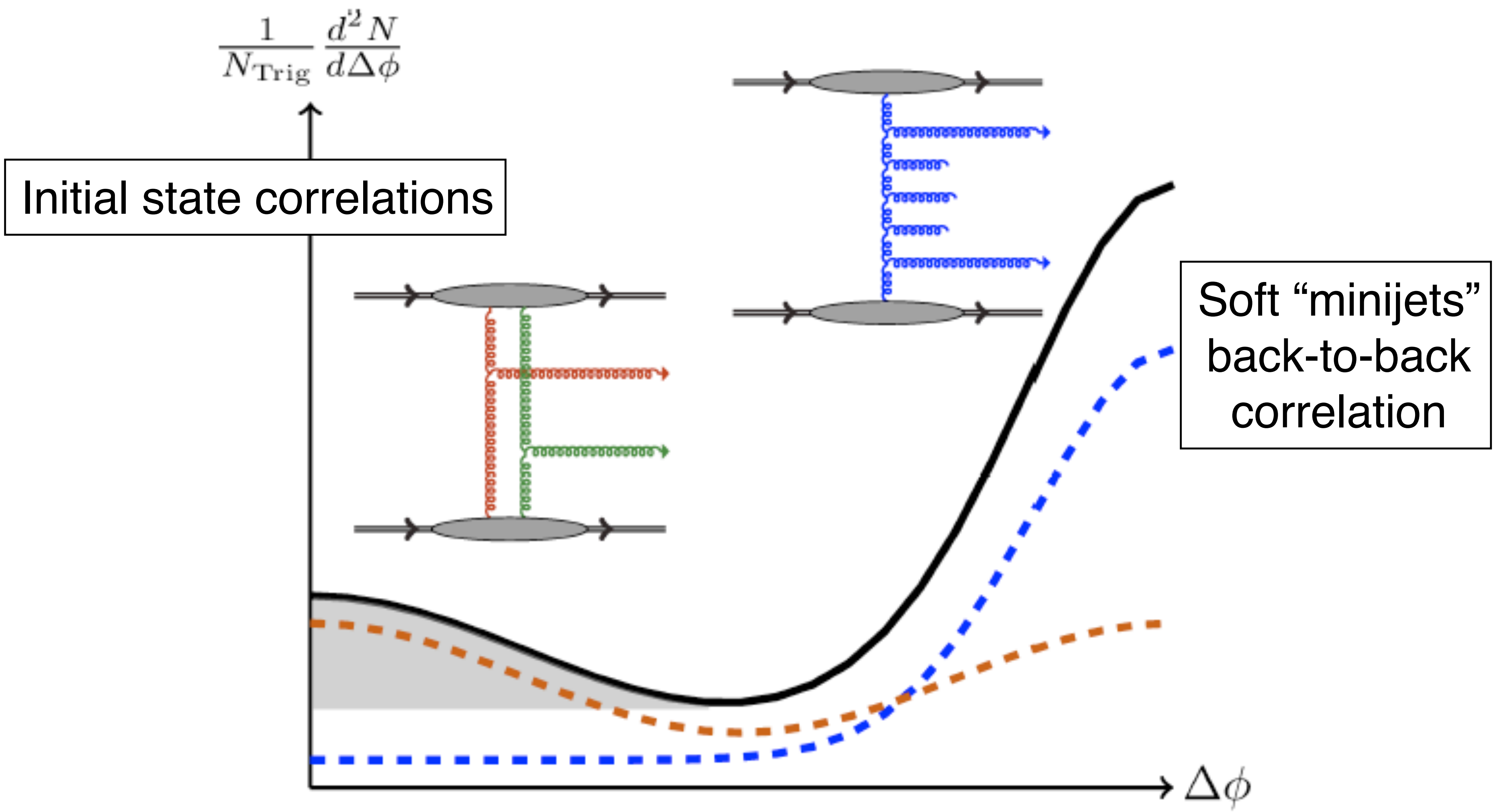
The p+Pb shock





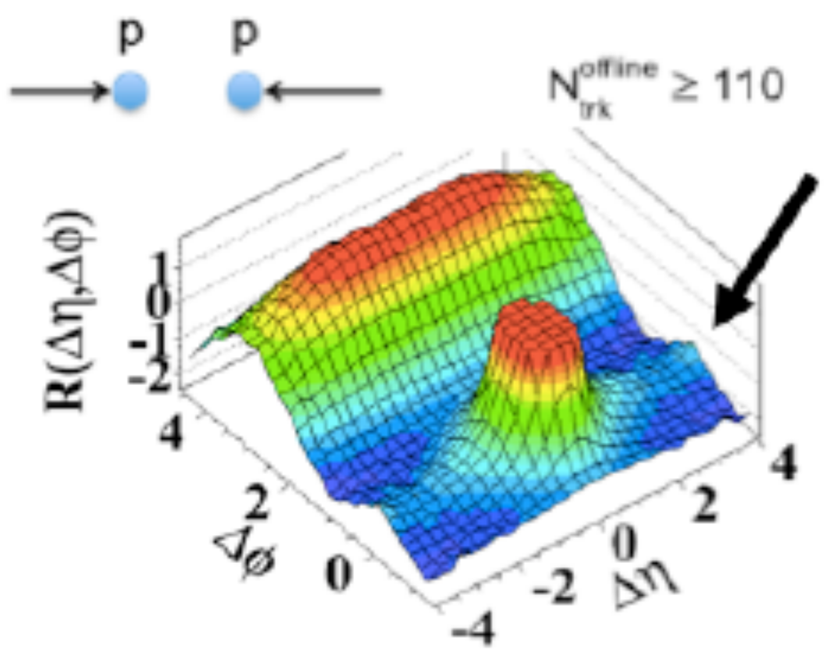


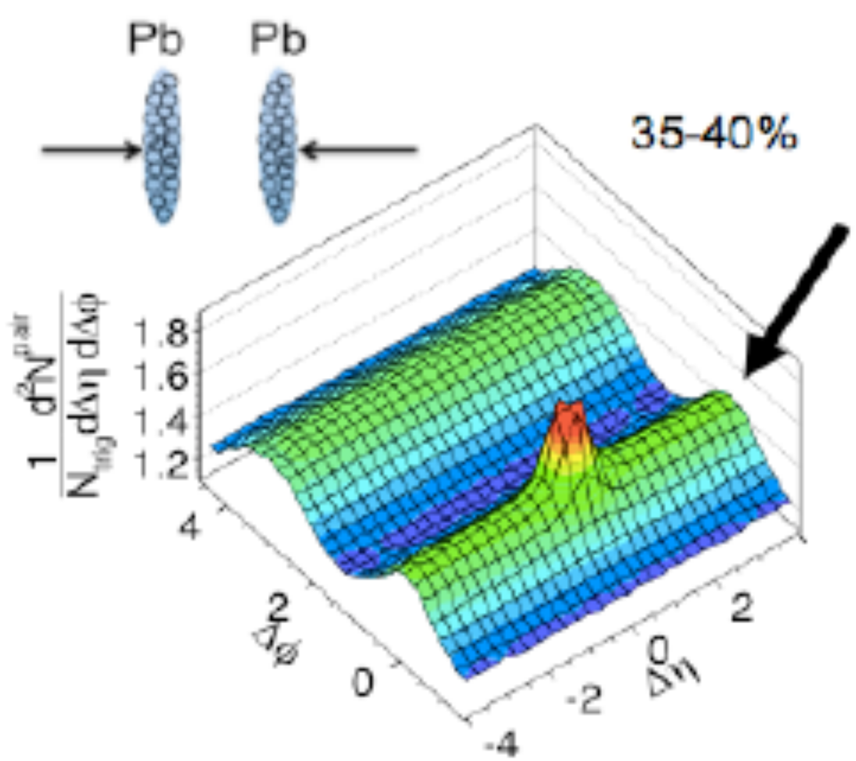
“Initial state” effects

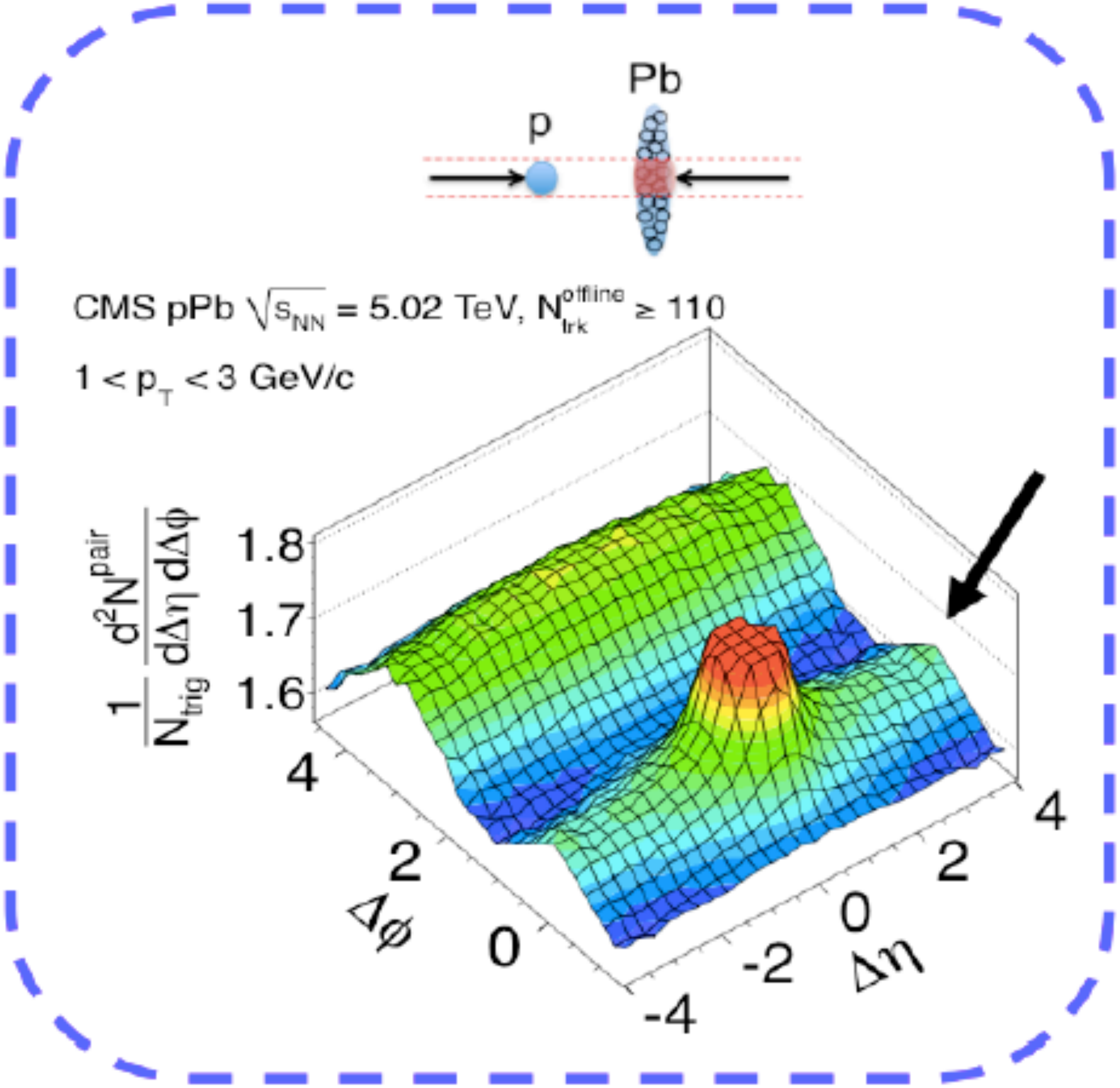


Dusling & Venugopalan 1211.3701, 1302.7018

Continuity pp → pA → AA







The ultimate train wreck?

In perspective...

Claiming that pA (dA) collisions
can probe **cold** nuclear matter effects
does **not** imply that there are
no hot matter effects present in pA (dA).

But it does require that we understand
where **hot** nuclear matter effects show up
and where they are **negligible**!

This is our present challenge.

Final-state effects
were not completely unanticipated,
even in p+p(bar) collisions....

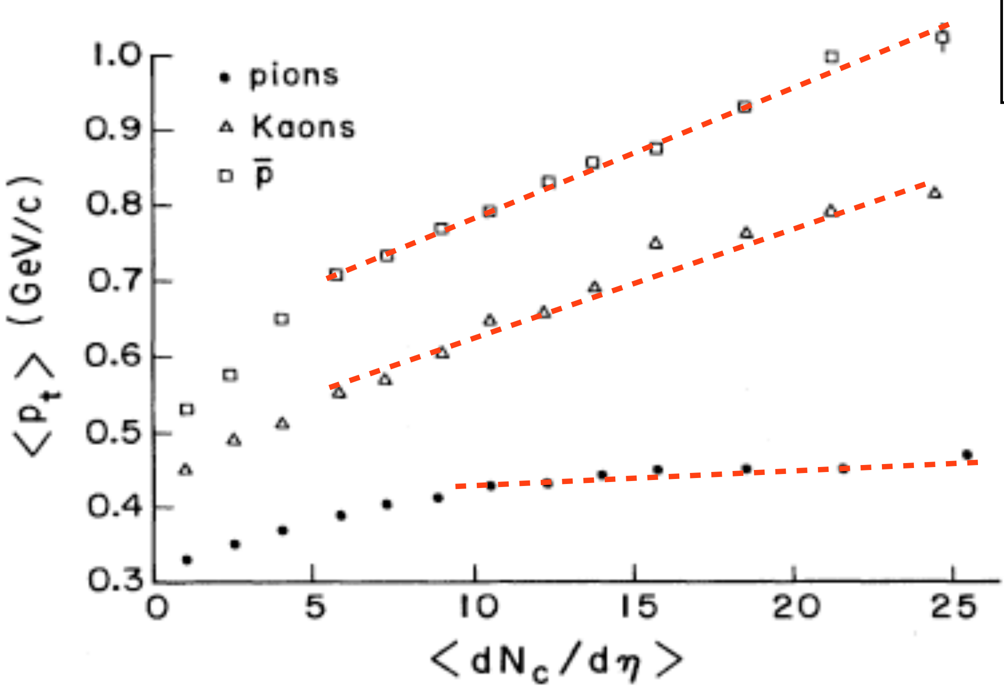
E735 data

VOLUME 67, NUMBER 12 PHYSICAL REVIEW LETTERS 16 SEPTEMBER 1991

Transverse Baryon Flow as Possible Evidence for a Quark-Gluon-Plasma Phase

Péter Lévai[(a)] and Berndt Müller
Department of Physics, Duke University, Durham, North Carolina 27706
(Received 13 March 1991)

In order to investigate the coupling between the collective flow of nucleons and pions in hot pion-dominated hadronic matter, we calculate the pion-nucleon drag coefficient in linearized transport theory. We find that the characteristic time for flow equalization is longer than the time scale of the expansion of a hadronic fireball created in high-energy collisions. The analysis of transverse-momentum data from $p+\bar{p}$ collisions at $\sqrt{s}=1.8$ TeV reveals the same flow velocity for mesons and antinucleons. We argue that this may be evidence for the formation of a quark-gluon plasma in these collisions.



E735 - T. Alexopoulos, PRD84, 984 (1993)

Ambiguity:
Instead of being caused by collective flow, the increase of <pt> with hadron mass could be the result of a minijet production mechanism (Xin-Nian Wang)

E735 claims QGP !

Evidence for hadronic deconfinement in $\bar{p}$-p collisions at 1.8 TeV

T. Alexopoulos,[1*] E. W. Anderson,[2] A. T. Bujak,[3] D. D. Carmony[3] A. R. Erwin,[1] L. J. Gutay,[3] A. S. Hirsch,[3] K. S. Nelson,[1**] N. T. Porile,[4] S. H. Oh,[6] R. P. Scharenberg,[3] B. K. Srivastava,[4] B. C. Stringfellow,[3] F. Turkot,[7] J. Warchol,[5] W. D. Walker[6]

arXiv:hep-ex/0201030v1 18 Jan 2002

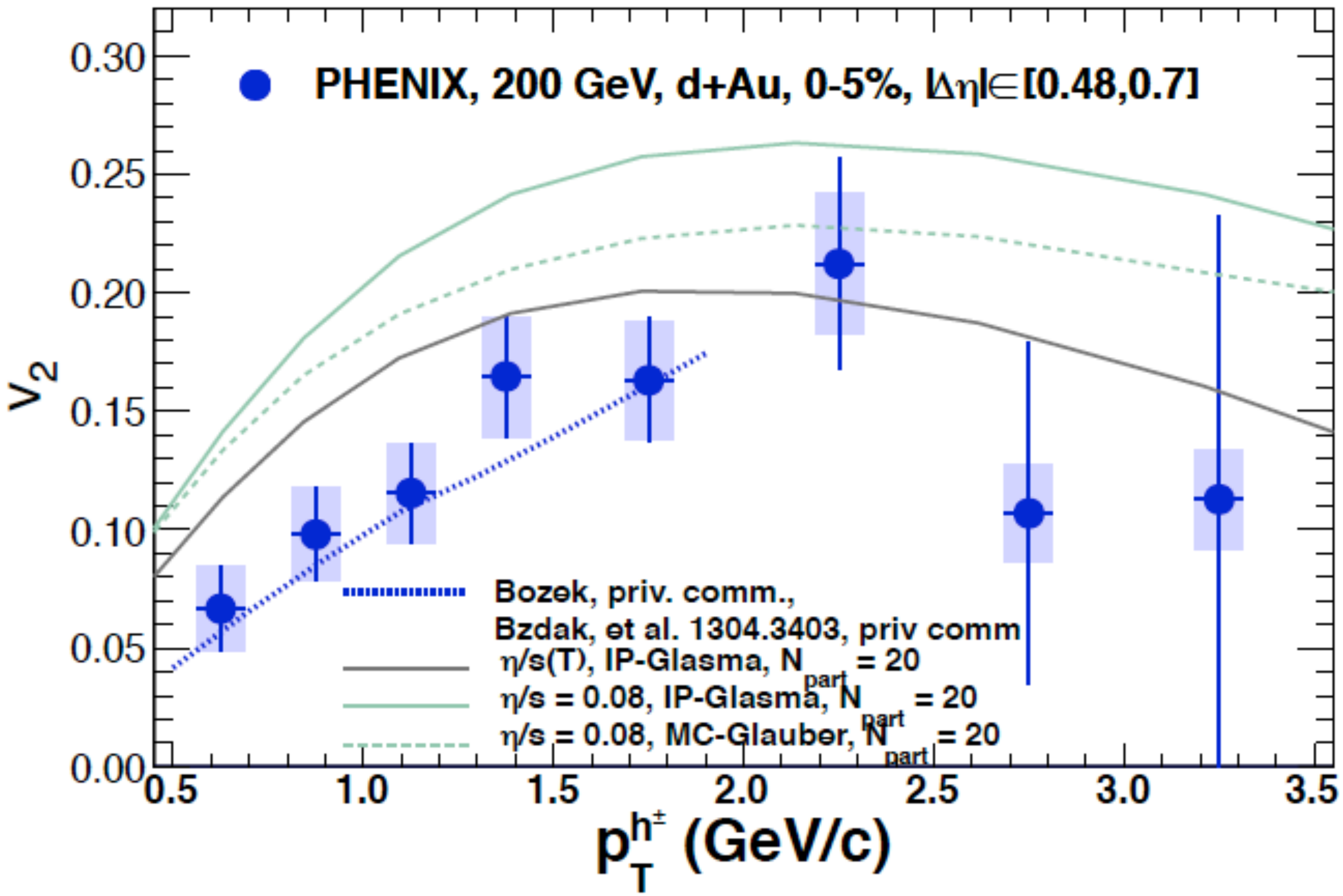
Abstract

We have measured deconfined hadronic volumes, $4.4 < V < 13.0$ fm^3, produced by a one dimensional (1D) expansion. These volumes are directly proportional to the charged particle pseudorapidity densities $6.75 < dN_c/d\eta < 20.2$. The hadronization temperature is $T = 179.5 \pm 5$ (syst) MeV. Using Bjorken's 1D model, the hadronization energy density is $\epsilon_F = 1.10 \pm 0.26$ (stat) GeV/fm^3 corresponding to an excitation of 24.8 ± 6.2 (stat) quark-gluon degrees of freedom.

$n_\pi^{exp} = 1.6/\text{fm}^3 \gg n_\pi^{th}$

Experimental cross checks: d+Au (^{3}He+Au ?)

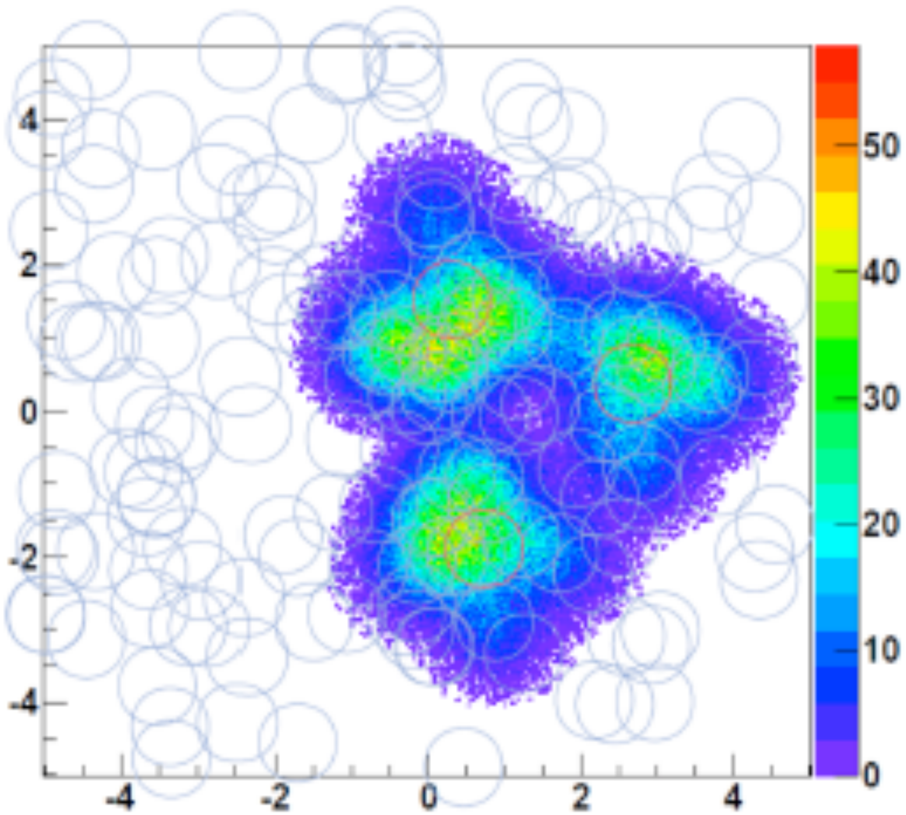
d+Au has larger v_2

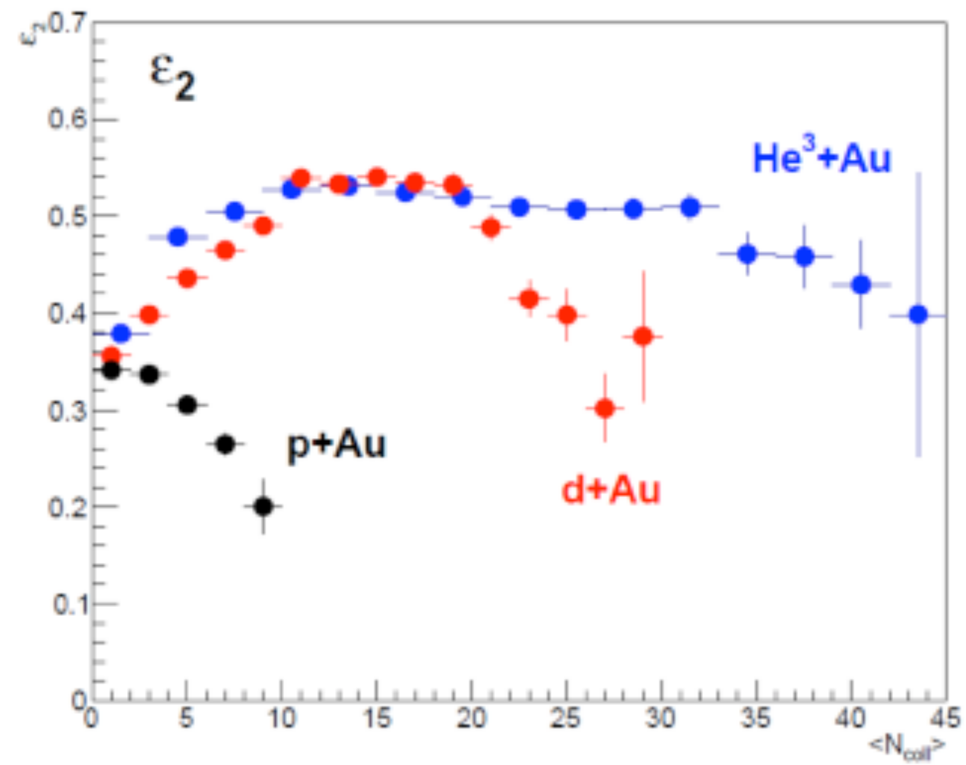


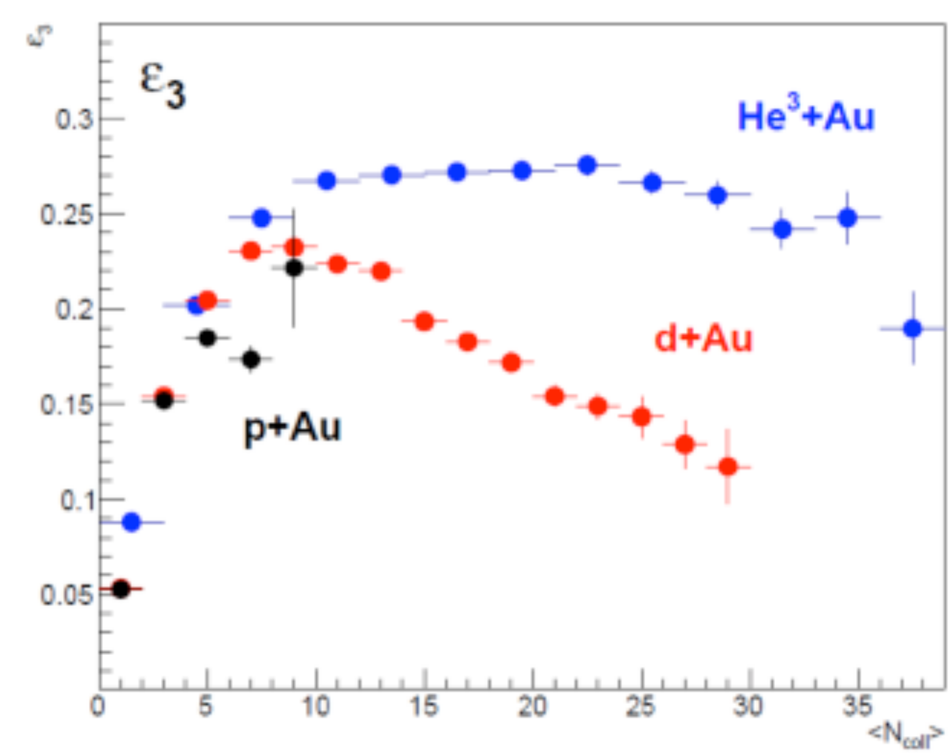
p vs. d vs. ^{3}He

^{3}He should generate a large ε_3
RHIC could do it!

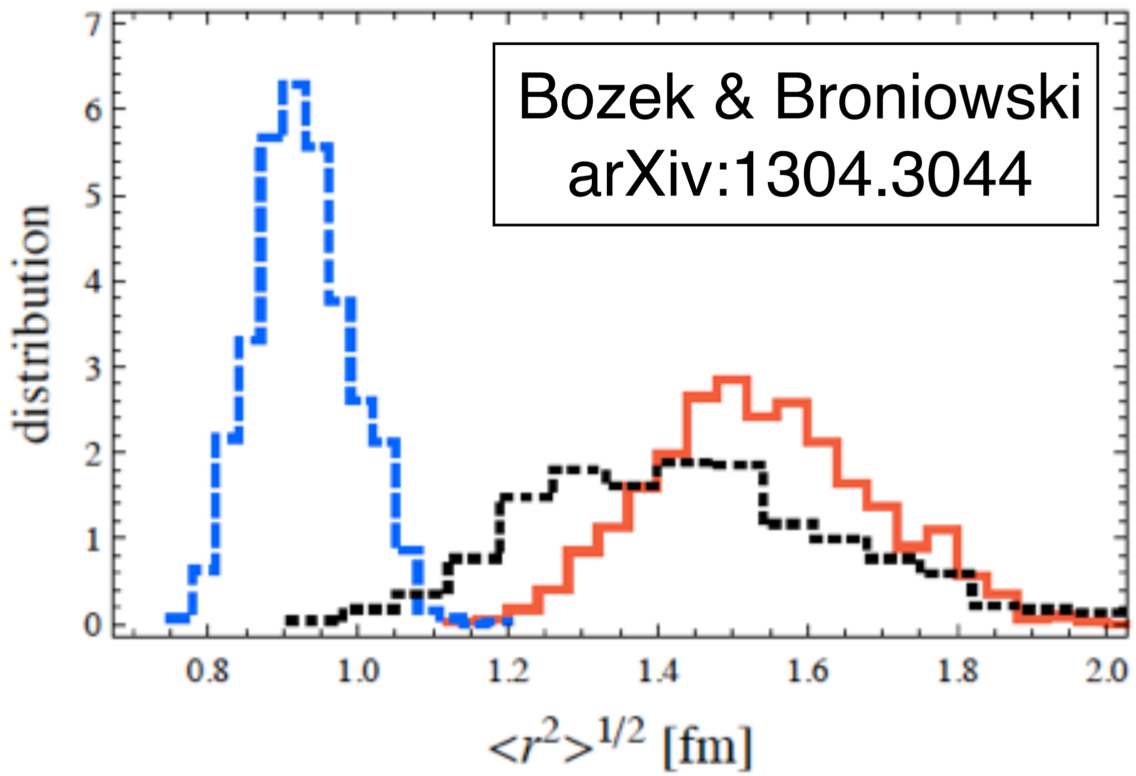
He3 + Au



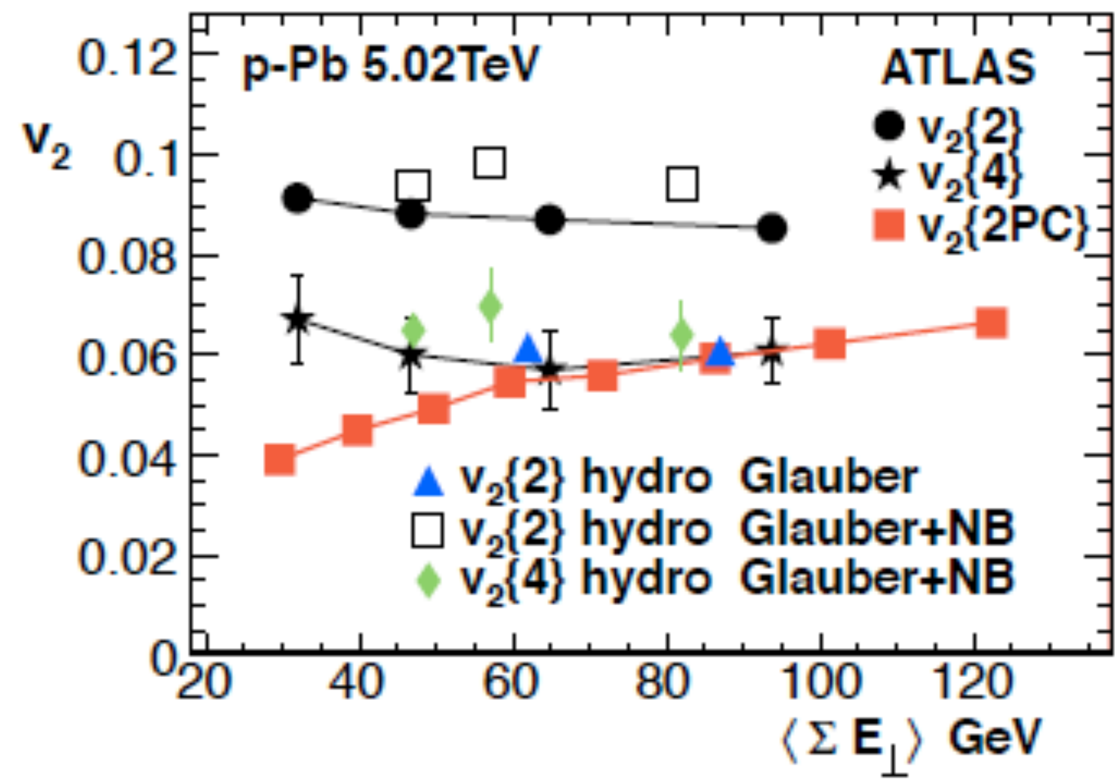


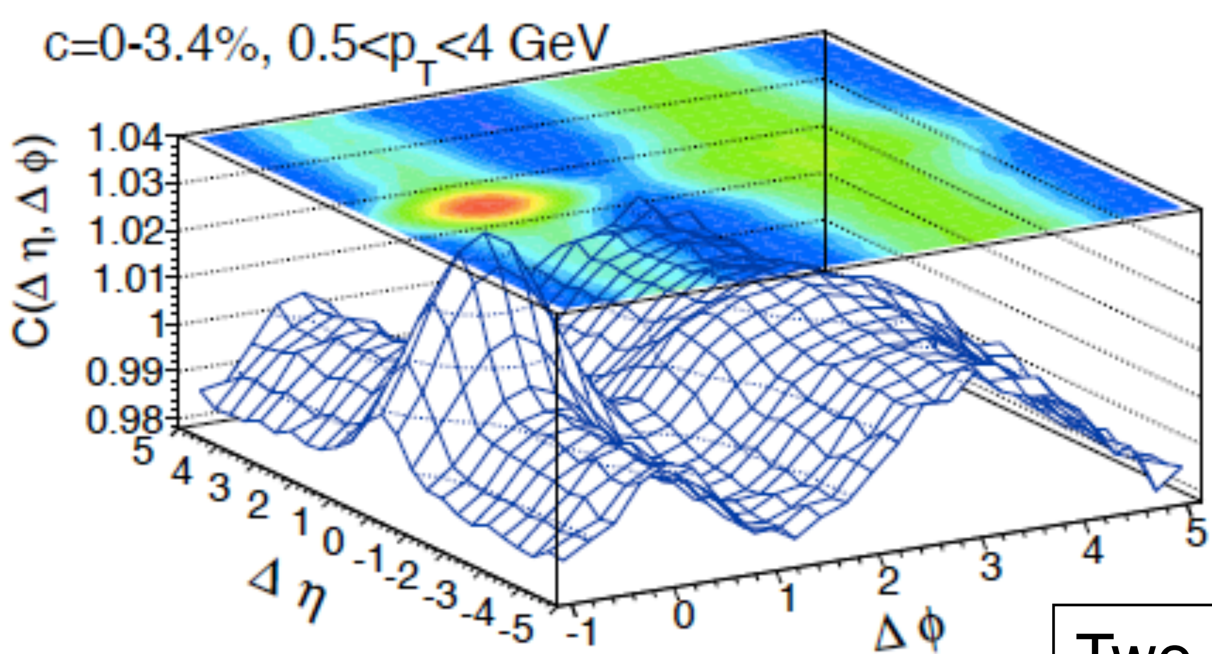


Hydrodynamics



Assumptions about spatial location of the interactions make a difference

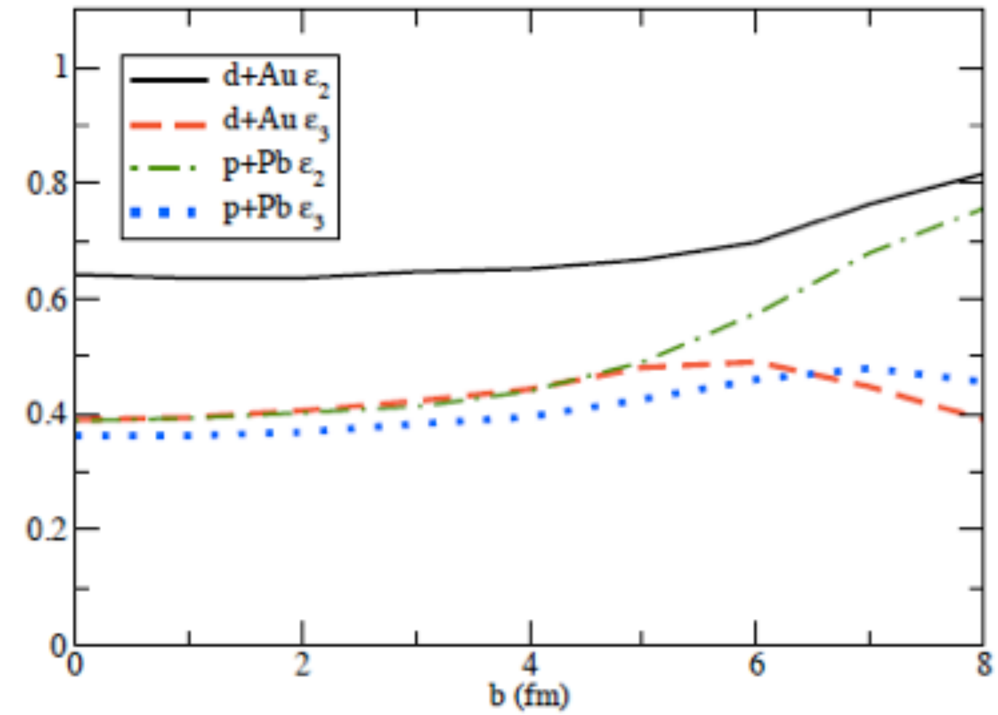


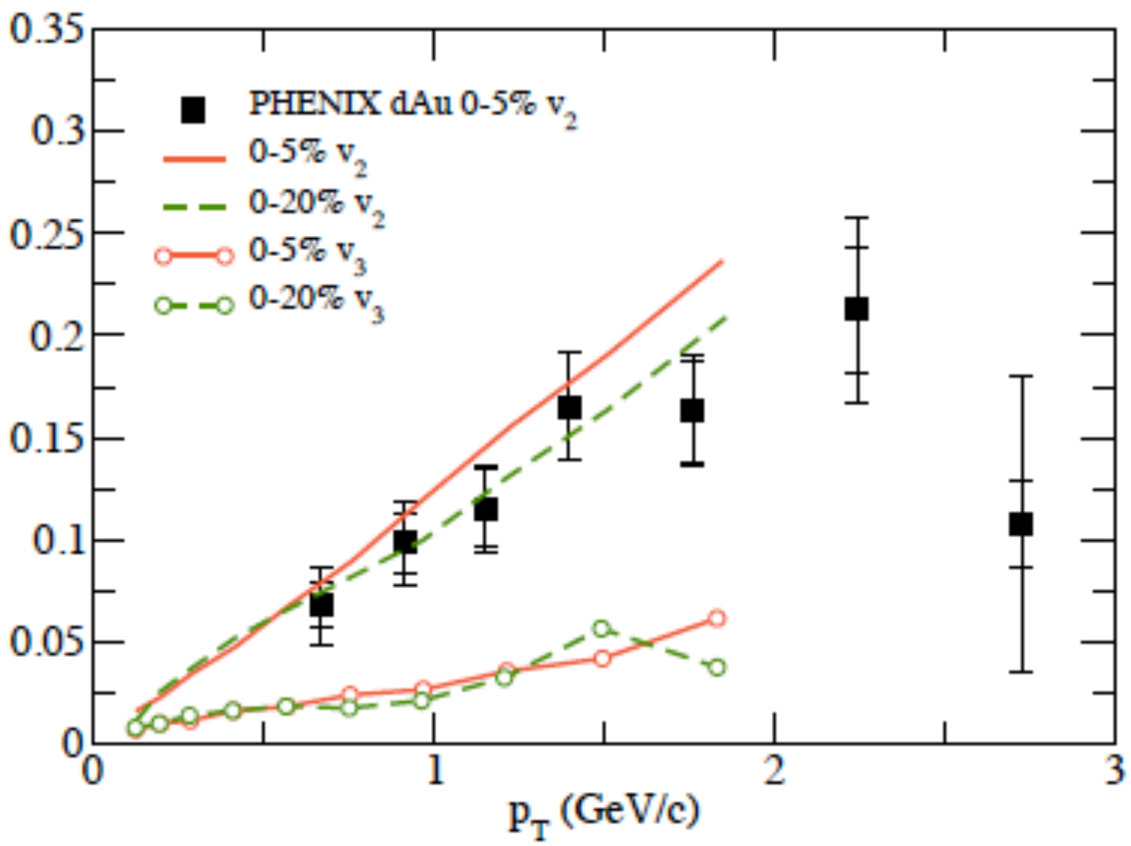


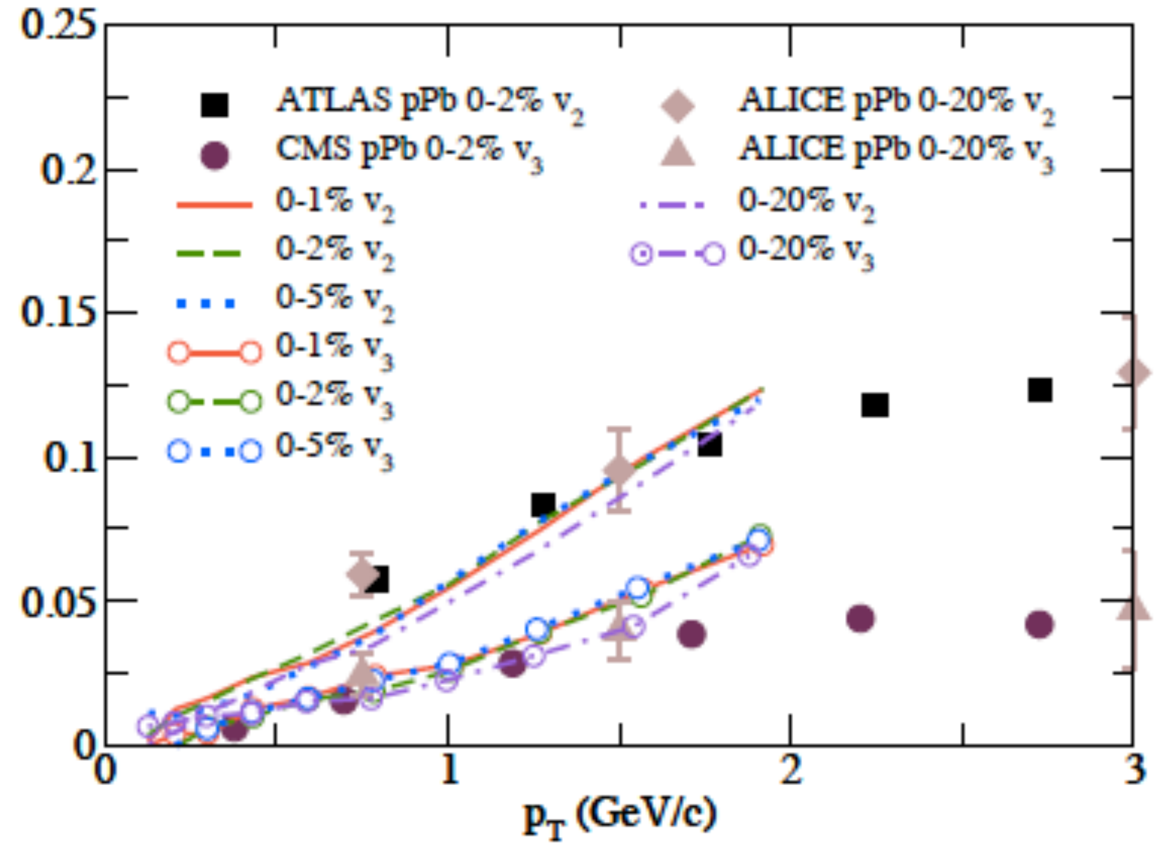
Two particle correlations resemble data

Au+Au → d+Au, p+Pb

Guangyou Qin & BM (arXiv:1306.3439) using E-by-E initial state + hydro model developed for Au+Au collisions at RHIC (ideal fluid!) find remarkable agreement







The nagging question

Can it really be hydrodynamics?

The standard folklore (before 2012): Protons are small.

But are they really?   Compared to what?

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$\eta/s = 1/4\pi$ together with kinetic theory $\eta = np\lambda/3$ implies

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When they are tiny, we call it "color transparency."
But what can be tiny, also can be "fat" !

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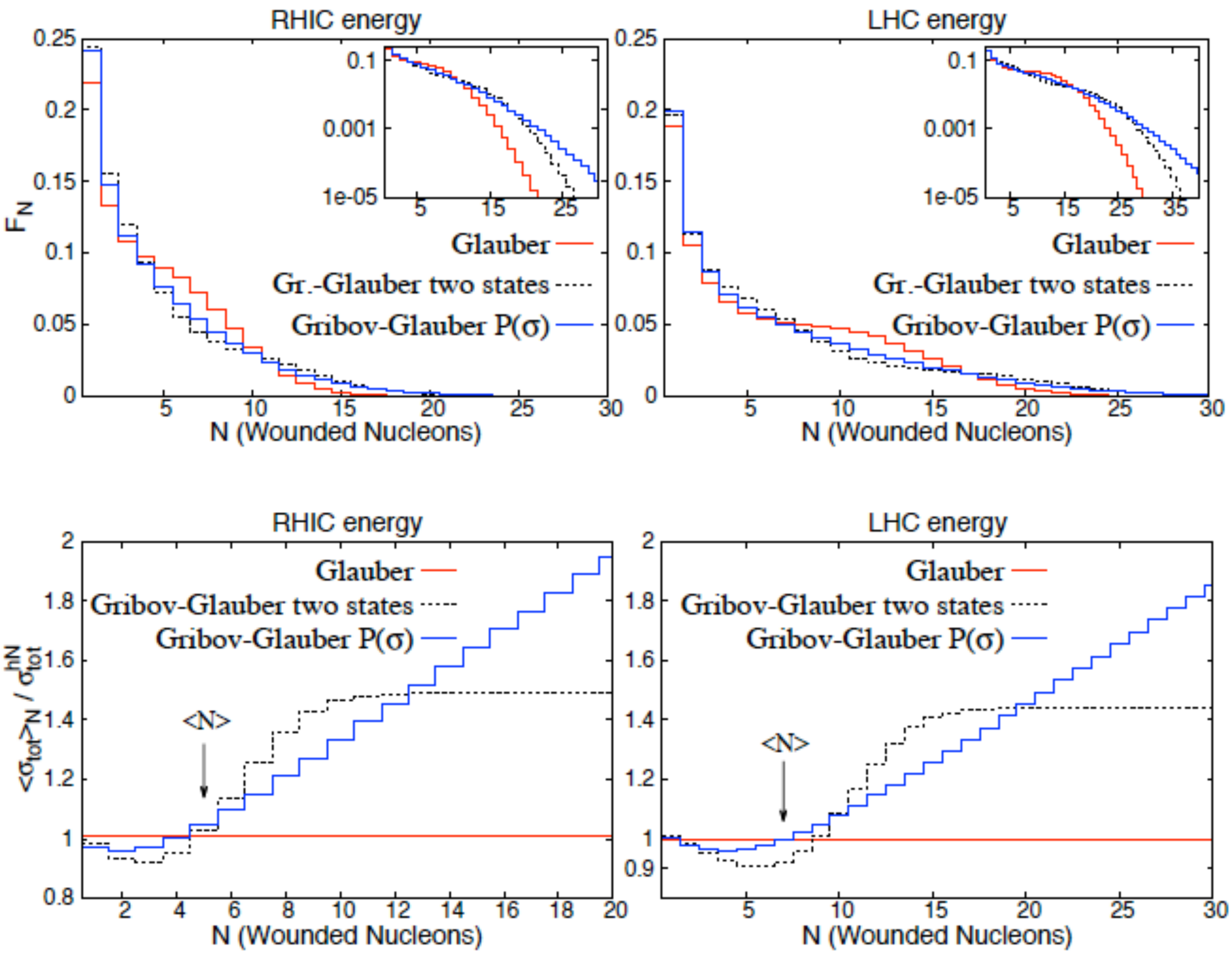
How to catch "fat" protons? A heavy nucleus acts as a **net**.

σ_{NN} fluctuations



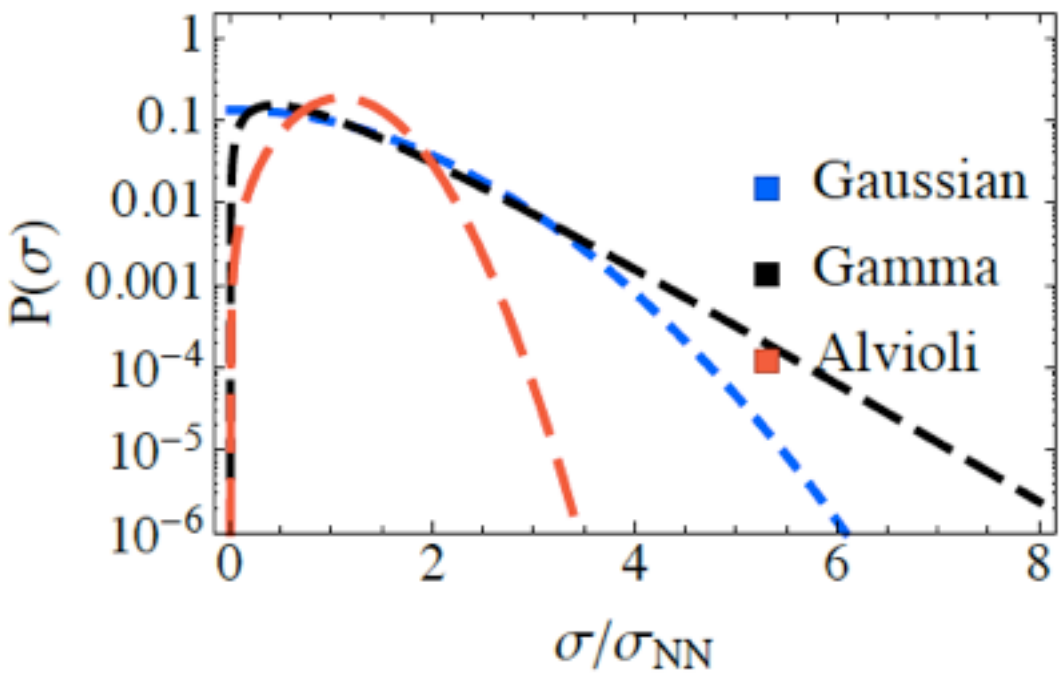
Blättel, Baym, Frankfurt, Heisel-berg & Strikman PRD47, 2761 (93)

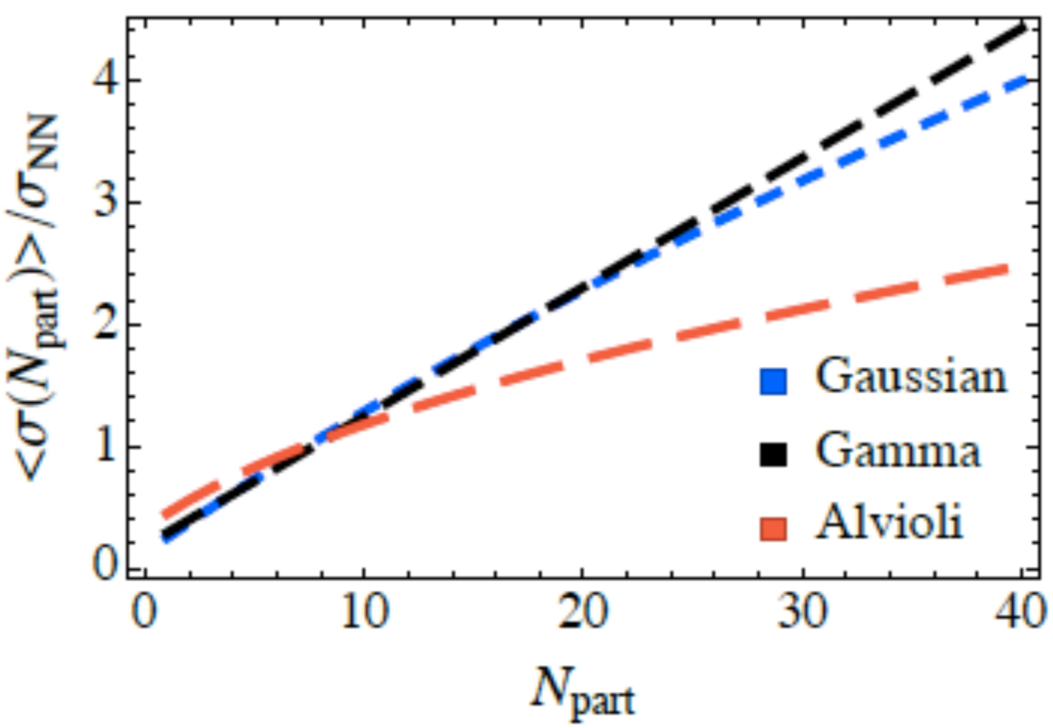
Alvioli & Strikman 1301.0728:

Large N_{WN} picks out **large σ**

Fat proton "net"

Some models of P(σ):





N_{part} depends on σ:

$$W(N,\sigma) = e^{-\bar{n}(\sigma)} \frac{\bar{n}(\sigma)^N}{N!}$$

$$\sigma_{eff}(N_{part}) = \frac{\int \sigma \, d\sigma \, W(N_{part},\sigma) P(\sigma)}{\int d\sigma \, W(N_{part},\sigma) P(\sigma)}$$

C. Coleman-Smith & BM, 1307.5911

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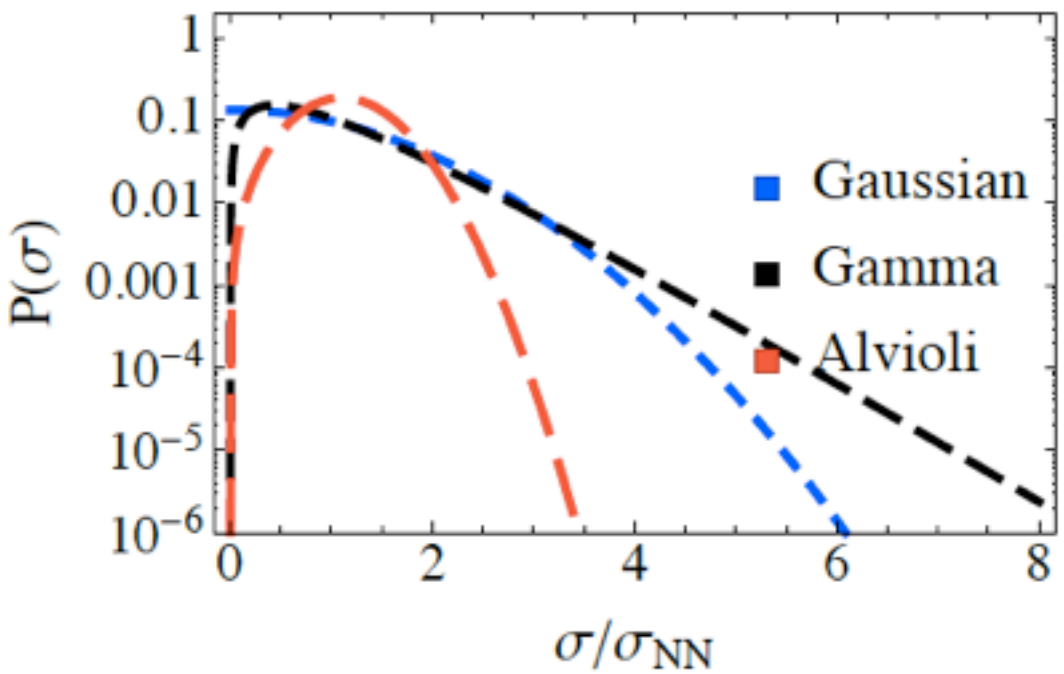

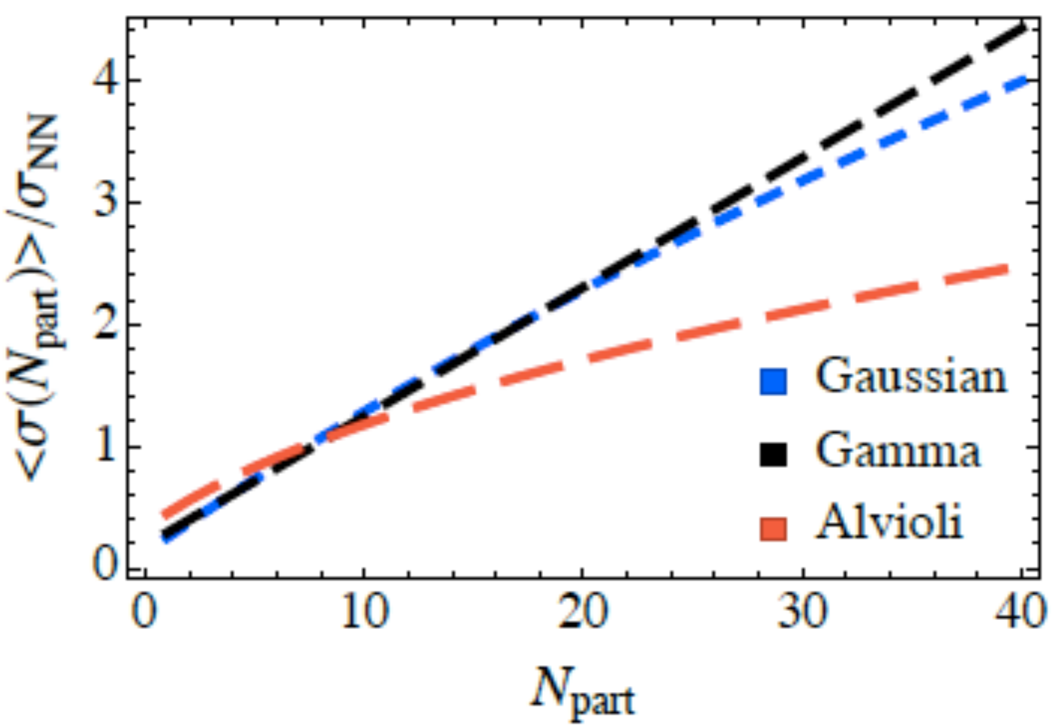

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C. Coleman-Smith & BM, 1307.5911

N_{part} serves as a "net" catching "fat" protons

What does a “fat” proton look like?

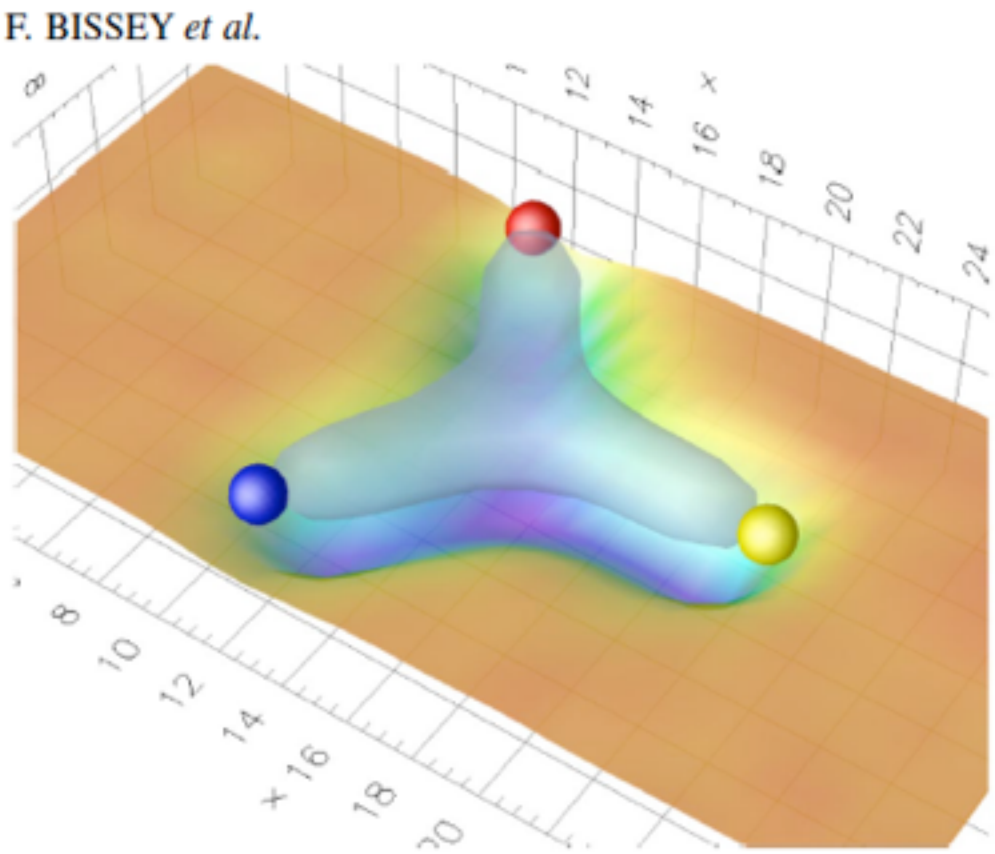
“Obese” protons

Two extreme models

“Obese” protons

Two extreme models

The “stringy” proton



"Obese" protons

Two extreme models

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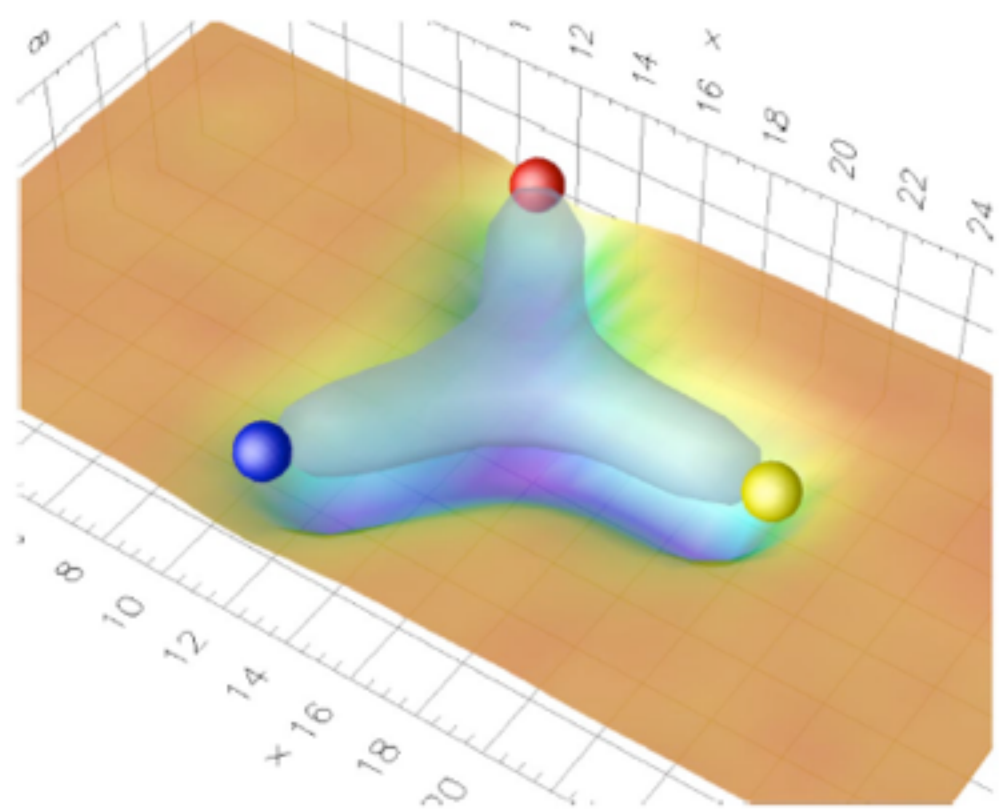
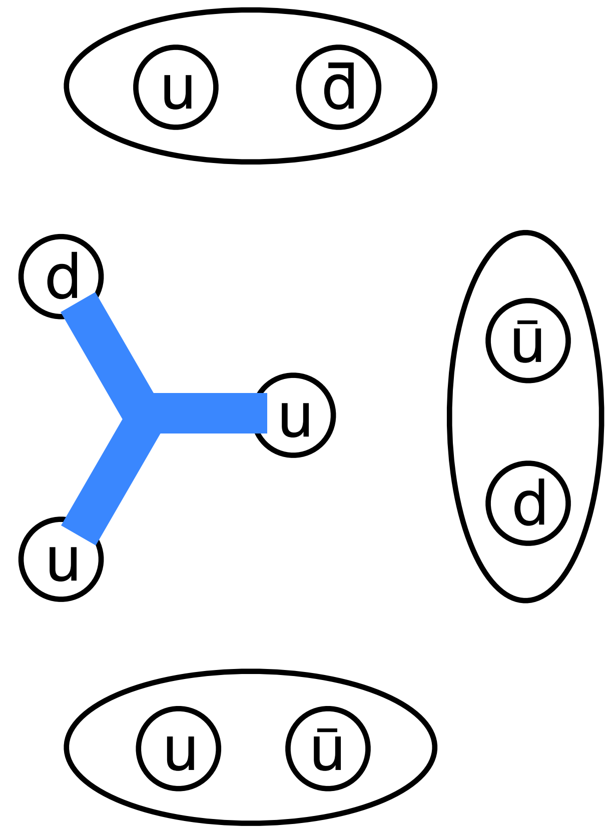


The "cloudy" proton



Pictures*

The “stringy” proton

*Thanks to Chris Coleman-Smith

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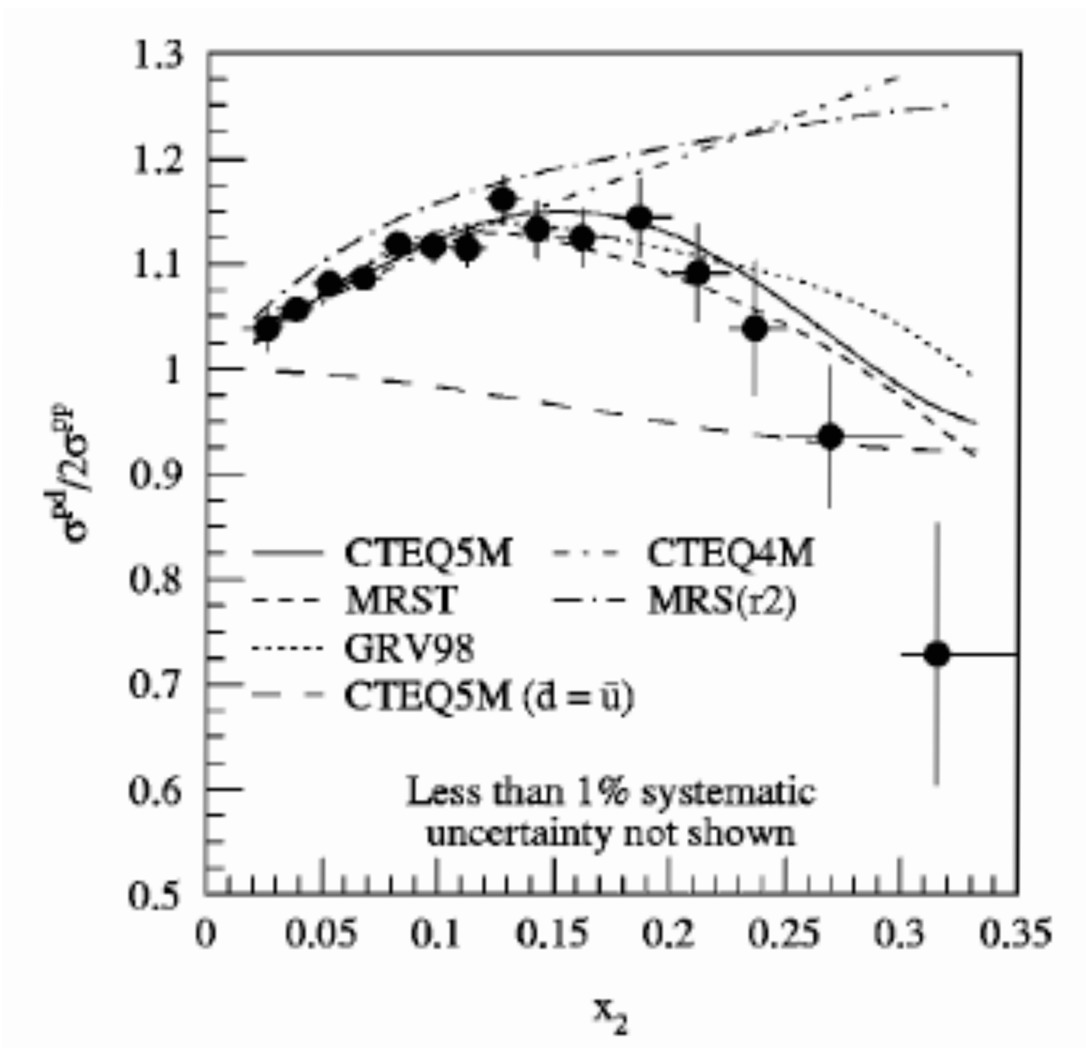
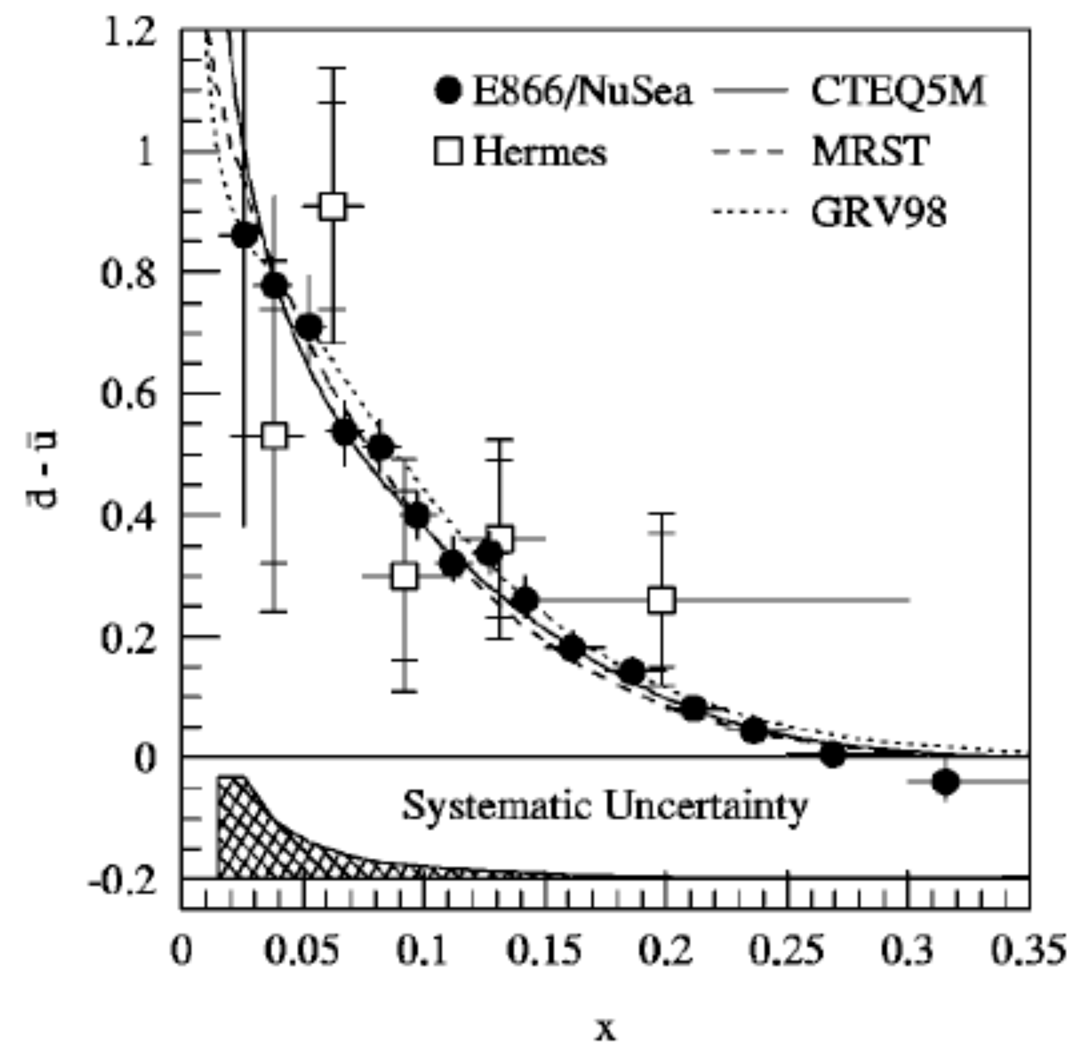
pion cloud: exp. evidence

R.S. Towell et al. (E866/NuSea Collaboration), PRD64, 052002 (2001)



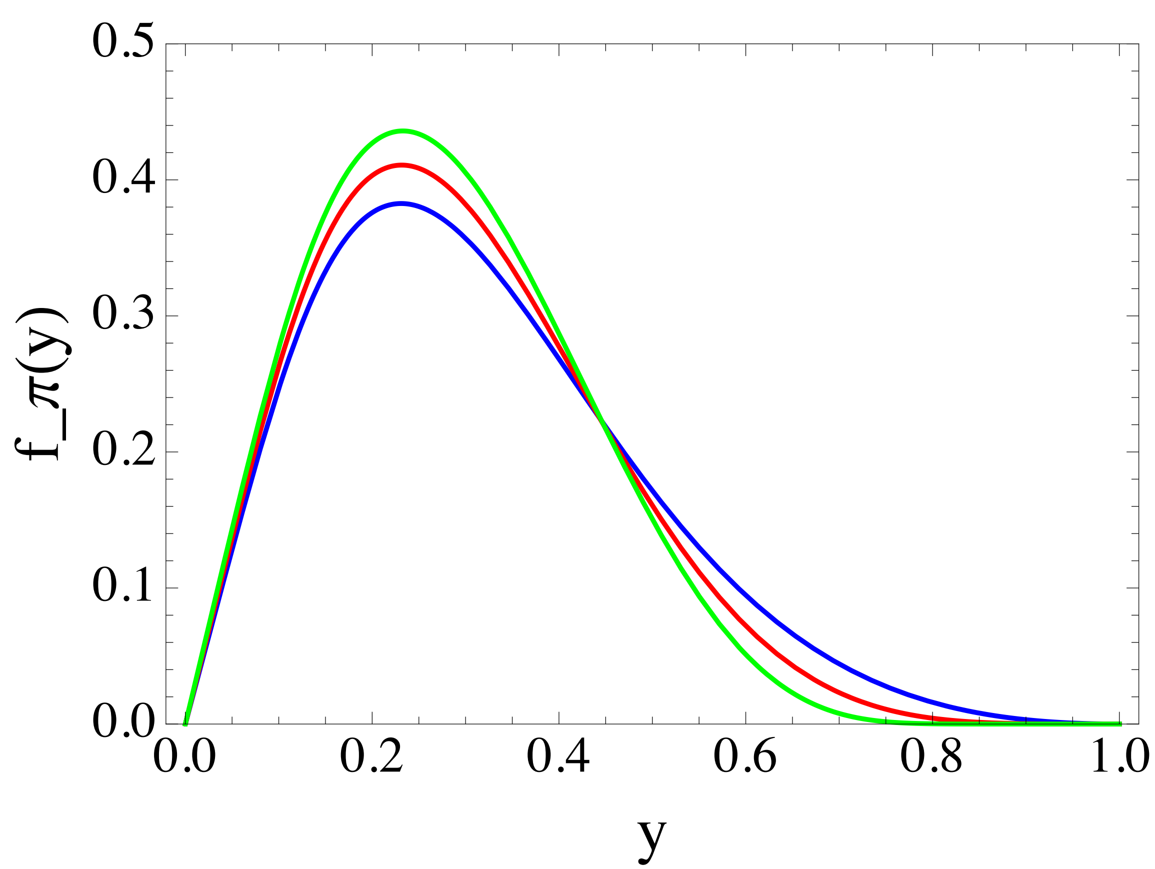


$$\int dx(\bar{d}-\bar{u}) = 0.118 \pm 0.012$$

Pion cloud models

Kumano, PRD 43, 59 (1991)

$$f_\pi(y) \sim \frac{g_{\pi NN}^2}{(4\pi)^2} y \int_{-\infty}^{t_{\max}} dt \frac{-t}{(-t+m_\pi^2)^2} F_{\pi NN}(t)^2$$



P_N = probability for a proton to be accompanied by N virtual pions
N_Q = number of "valence" quarks

N	P_N	$N_Q/3$
0	0.89	1
1	0.104	1.67
2	0.0062	2.33
3	2.4×10^{-4}	3
4	7.2×10^{-6}	3.67

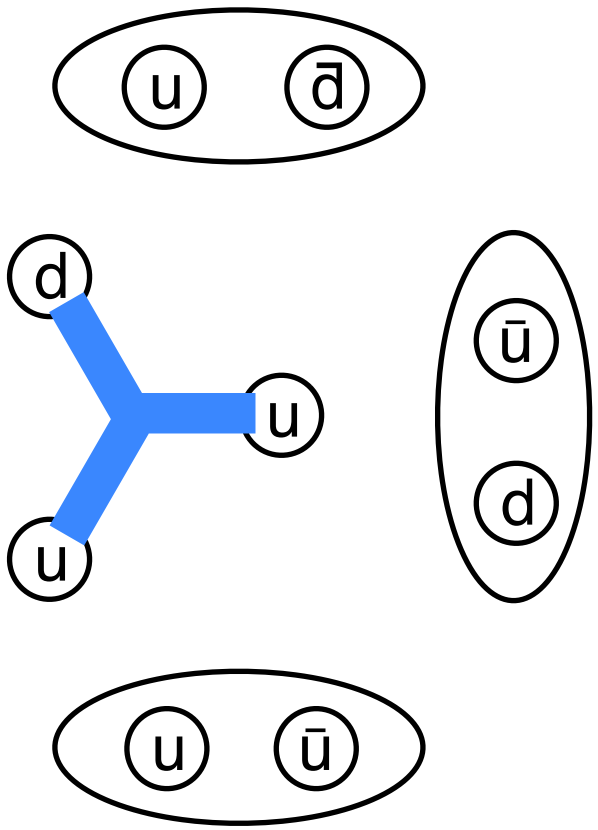
"Obese" protons

We have estimated the probability of finding a fat "cloudy" proton.

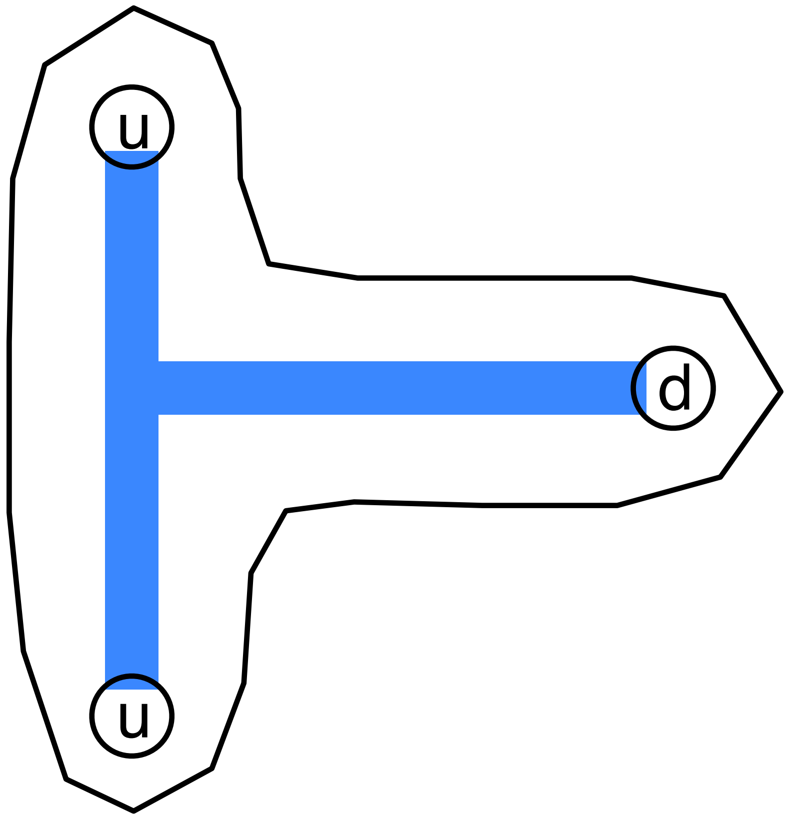
Can we estimate the probability of finding a fat "stringy" proton?

The "cloudy" proton

$\sim 10^{-4}$



The "stringy" proton



Wednesday, September 11, 13

Stringy proton model

$$u = x_2 - x_1$$
$$v = (x_2 + x_1)/2 - x_3$$

$$\left[p_1^2 + p_2^2 + p_3^2 + V(x_1, x_2, x_3)^2\right] \Psi = E^2 \Psi$$

$$V(x_1, x_2, x_3)^2 = k^2(u^2 + v^2)$$

$$\Psi(u, v) = N \exp\left(-\frac{ku^2}{2\sqrt{2}} - \frac{kv^2}{\sqrt{6}}\right)$$

$$\langle r^2 \rangle = 2.285/k \qquad k \approx 1 \text{ GeV/fm} = 5 \text{ GeV}^{-2}$$

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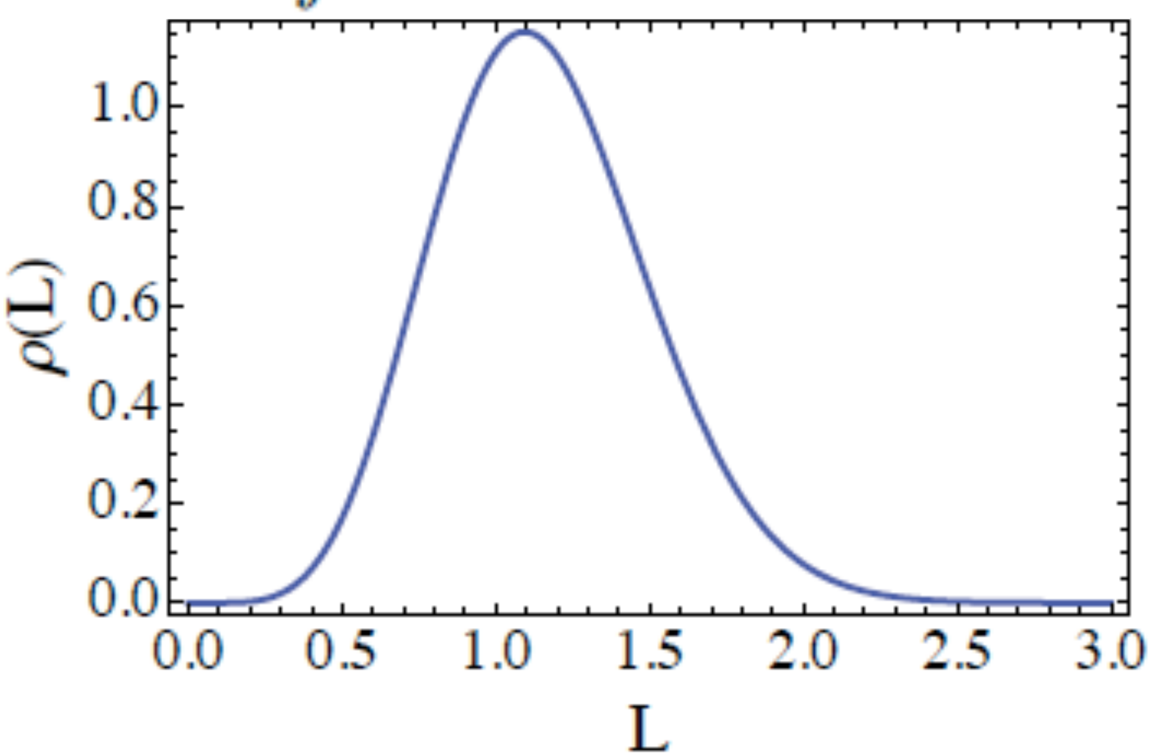
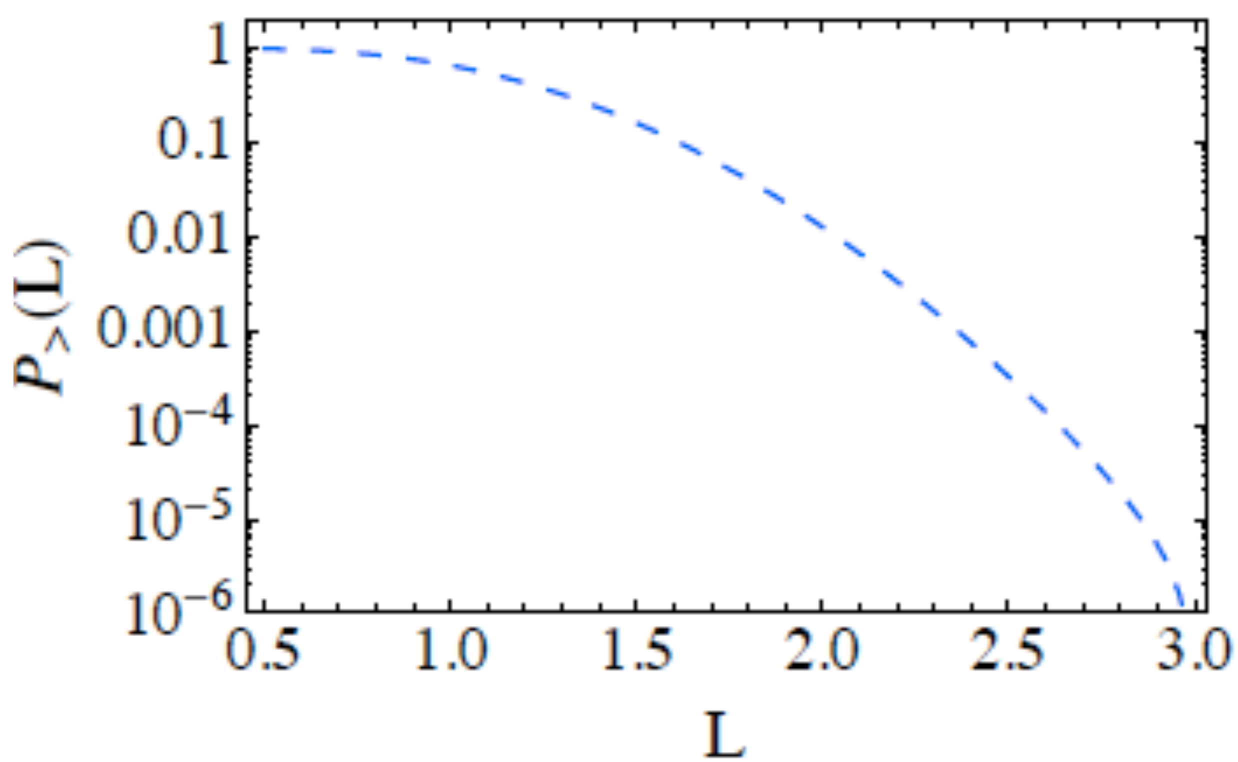
$$\langle r^2\rangle = 2.285/k \qquad k \approx 1\ \mathrm{GeV/fm} = 5\ \mathrm{GeV}^{-2}$$

$$\rho(L) = \int \Psi^2 \delta(u + v - L)\ u^2 v^2 du dv$$

L = total length of flux tube





Experimental checks?

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- Fat “stringy” protons should have a surplus of soft gluons with similar x-distribution as a normal proton.
- Fat “cloudy” protons have an enhanced quark sea in the range $x \approx 0.1$.
- This should lead to a suppression of very high-pt mesons in high-multiplicity p+A and d+A events, and hard di-jets should be shifted downstream (towards y_A) in c.m. rapidity.

Wounded nucleon (MC-Glauber) model

vs.

IP-Glasma (CGC) model

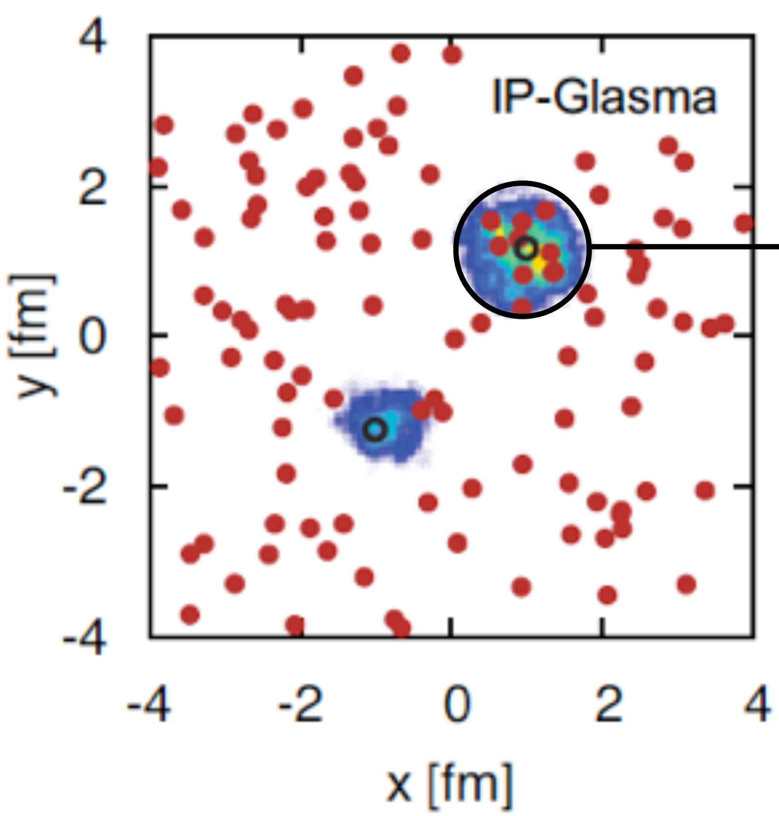
IP Dipole model

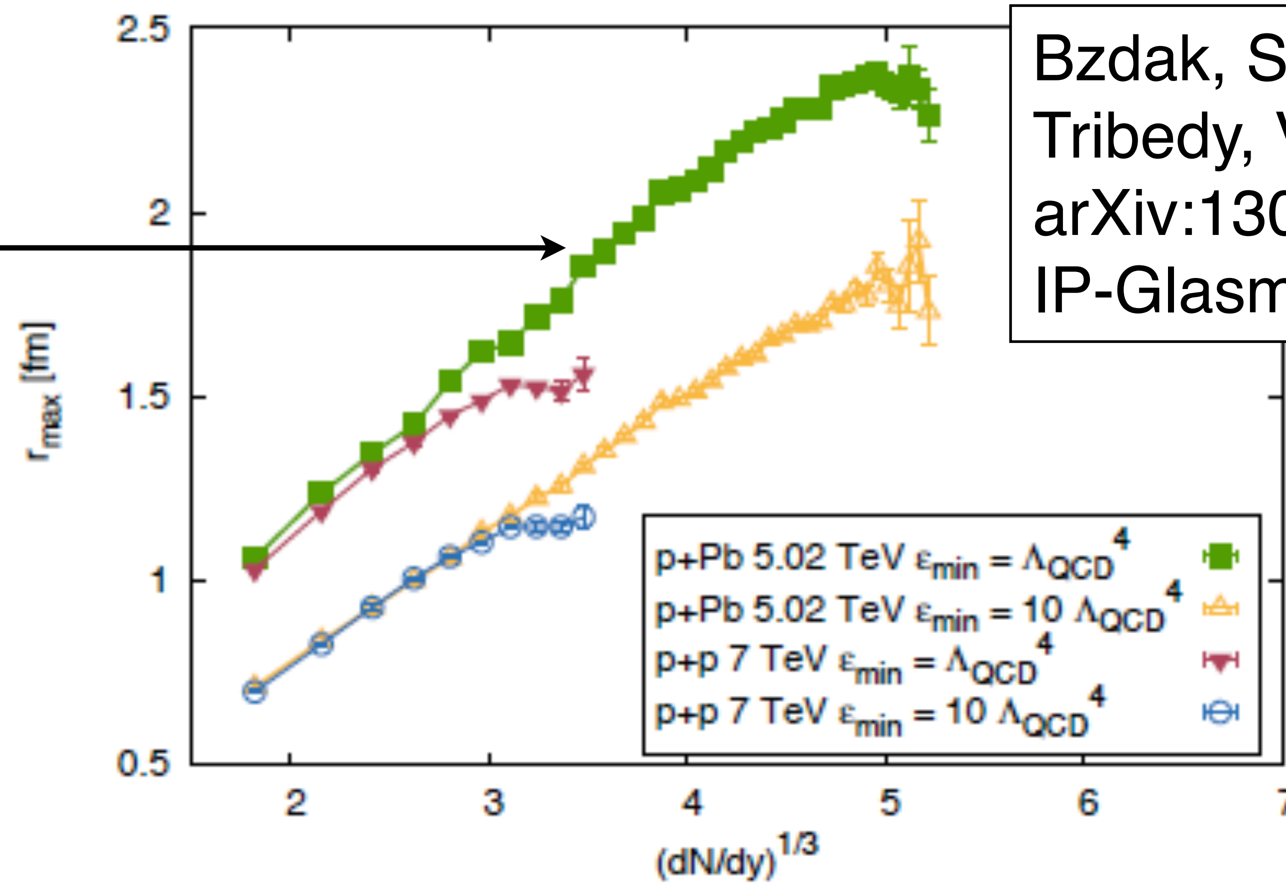
Nucleon thickness function:

$$T(b) = \int_{-\infty}^{\infty} dz\, \rho(b, z)$$

Kowalski & Teaney, hep-ph/0304189

Gaussian model: $T_G(b) = \dfrac{1}{2\pi B_G} \exp(-b^2/2B_G)$ $\quad B_G = 4.25\ \mathrm{GeV}^{-2}$

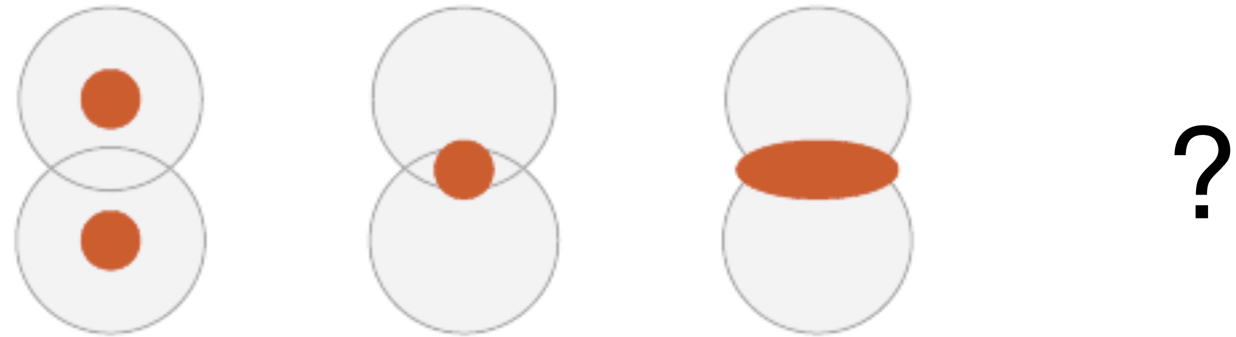


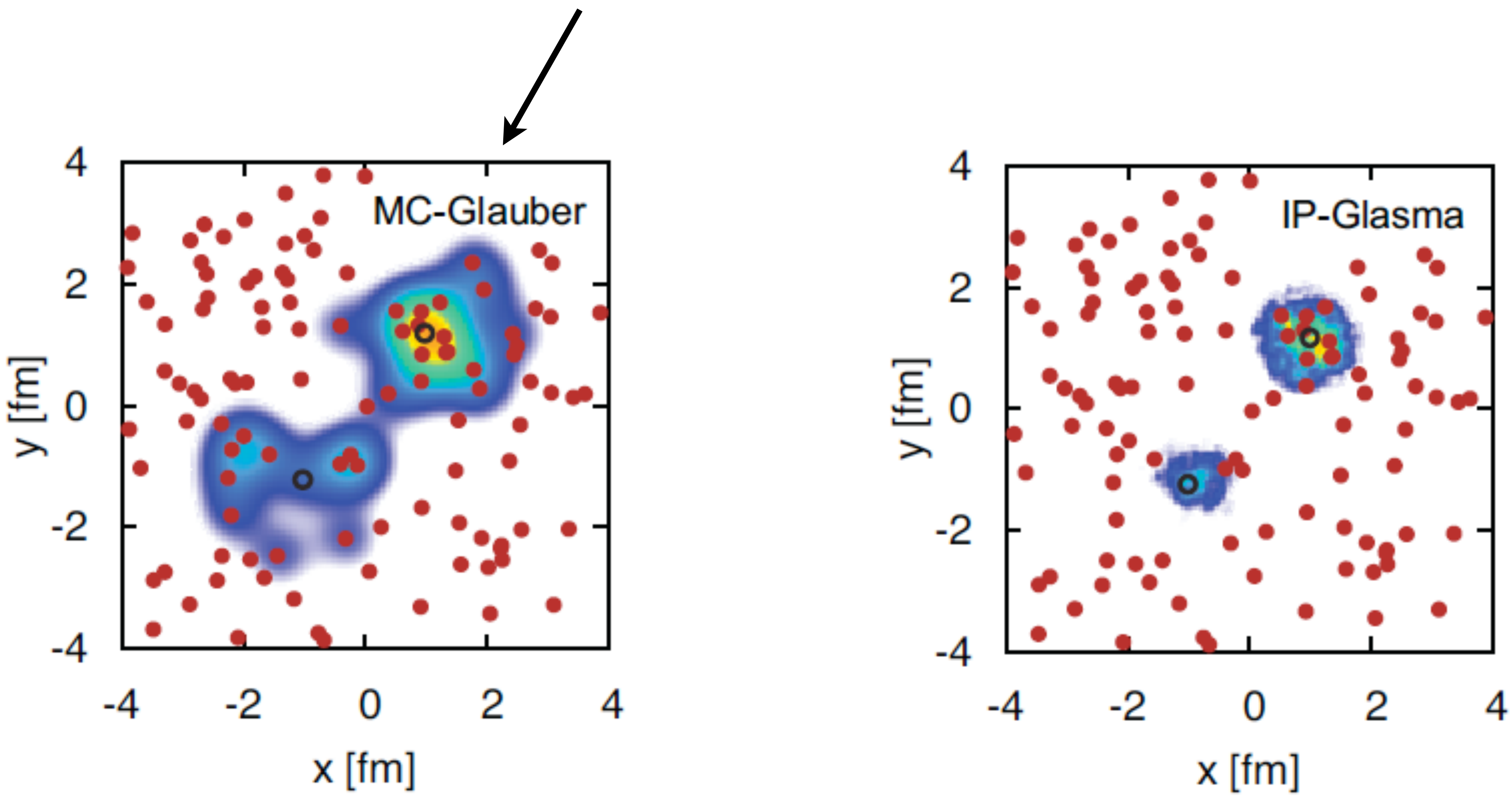


Bzdak, Schenke, Tribedy, Venugopalan arXiv:1304.3403 IP-Glasma model

Energy deposition

Energy deposition in the MC-"Glauber" model is conceptually uncertain





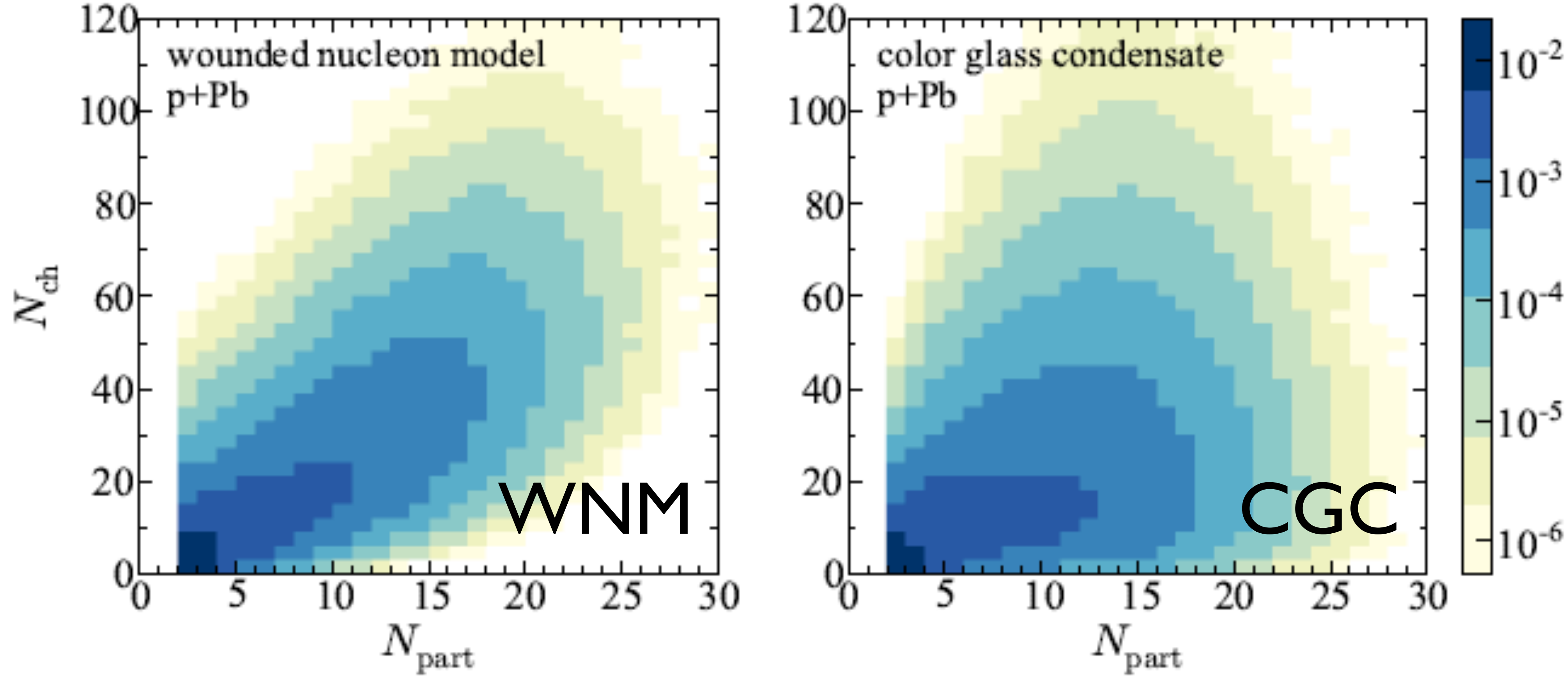
WNM vs. CGC ?

Wounded nucleon model: $N_{ch}^{pA} \sim N_{part}$

Bzdak & Skokov, arXiv:1307.6168

CGC/Glasma: $N_{ch}^{pA} \sim \ln(N_{part})$

Problem: Fluchtuations in N_{ch} in the CGC model are large!



Problem: How to determine N_{part} experimentally ?

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- Can initial state explanation of double ridge be excluded?

Final thoughts

Tentative Run Schedule for RHIC

Years	Beam Species and Energies	Science Goals	New Systems Commissioned
2013	• 510 GeV pol p+p	• Sea quark and gluon polarization	• upgraded pol'd source • STAR HFT test
2014	• 200 GeV Au+Au • 15 GeV Au+Au	• Heavy flavor flow, energy loss, thermalization, etc. • Quarkonium studies • QCD critical point search	• Electron lenses • 56 MHz SRF • full STAR HFT • STAR MTD
2015-2016	• p+p at 200 GeV • p+Au, d+Au, ^{3}He+Au at 200 GeV • High statistics Au+Au	• Extract η/s(T) + constrain initial quantum fluctuations • More heavy flavor studies • Sphaleron tests	• PHENIX MPC-EX • Coherent electron cooling test
2017	• No Run		• Electron cooling upgrade
2018-2019	• 5-20 GeV Au+Au (BES-2)	• Search for QCD critical point and deconfinement onset	• STAR ITPC upgrade
2020	• No Run		• sPHENIX installation
2021-2022	• Long 200 GeV Au+Au w/ upgraded detectors • p+p, p(d)+Au at 200 GeV	• Jet, di-jet, γ-jet probes of parton transport and energy loss mechanism • Color screening for different QQ states	• sPHENIX
2023-24	• No Runs		• Transition to EIC (eRHIC)

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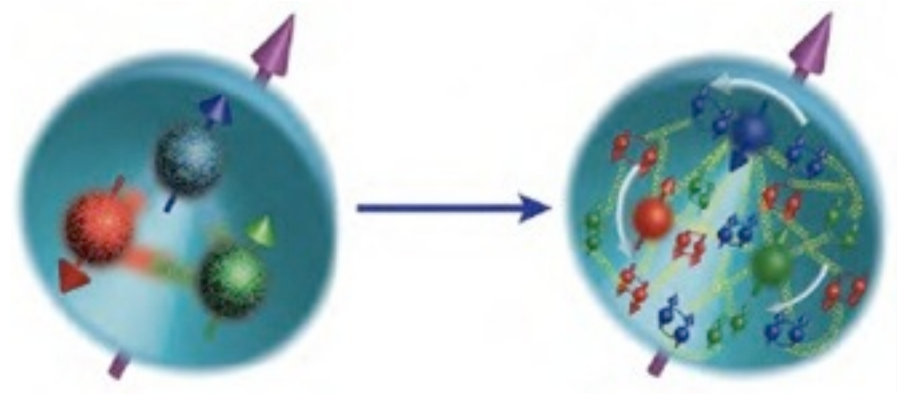
Gluon and sea quark structure of the proton,
or what gives matter (most of) its mass ?



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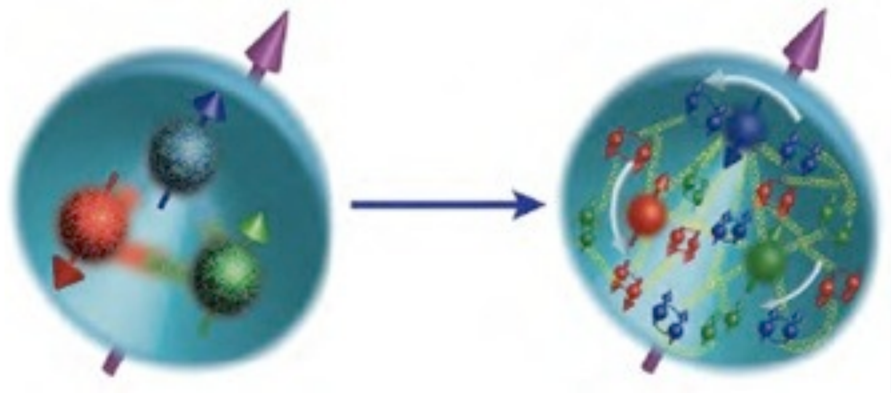
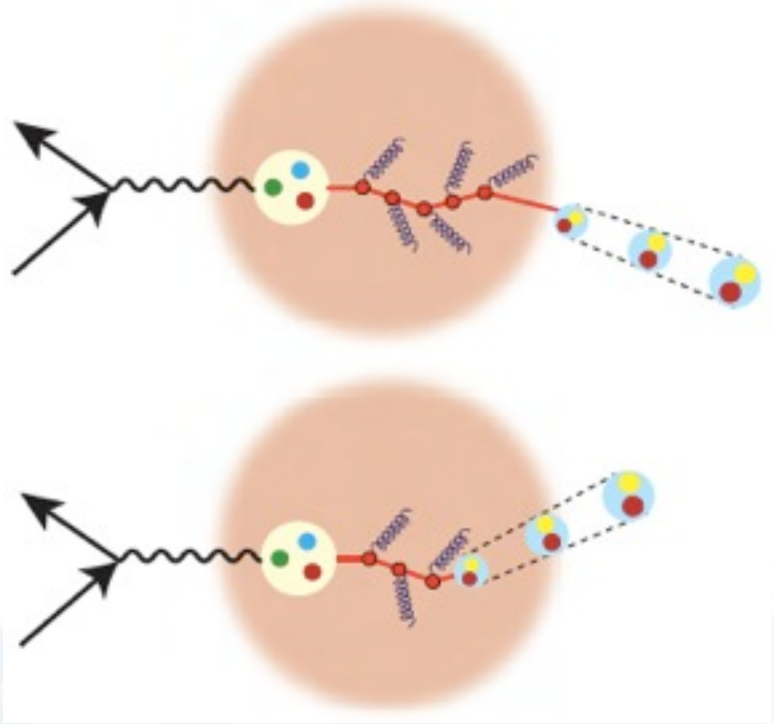


Use the nucleus as a fm-scale vertex detector to probe confinement



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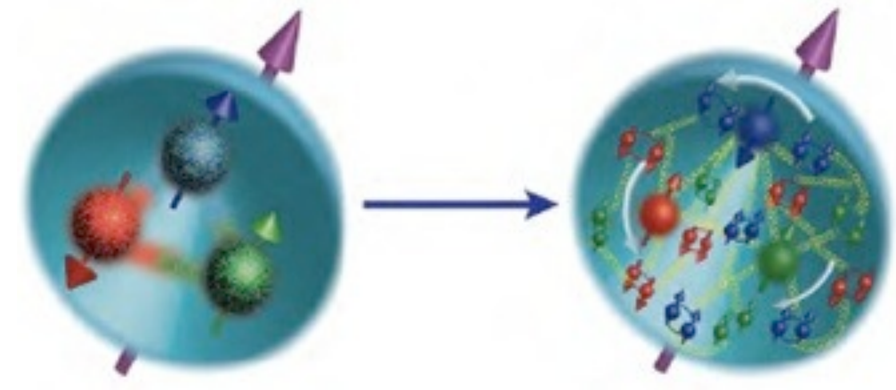

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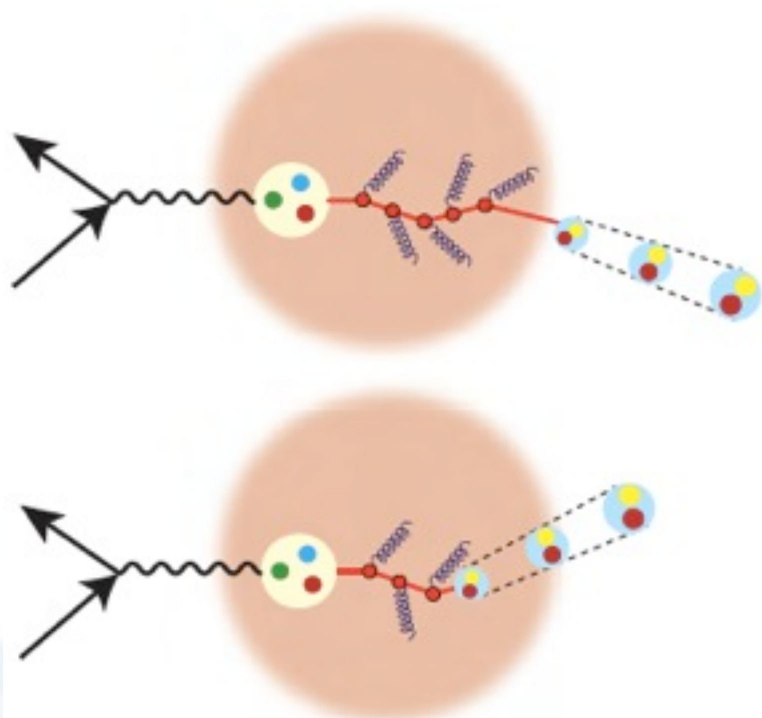
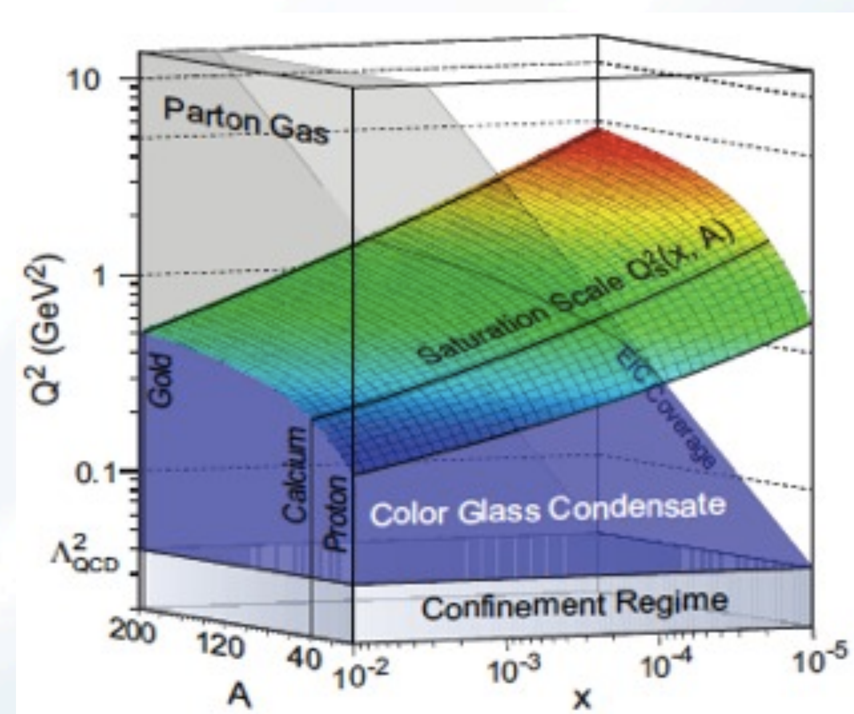


Is there a universal saturated gluon ocean (CGC) at low x ?



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Input from theoretical (and experimental) community is needed as we plan and justify the future physics program of RHIC.

Back-up slides

e-RHIC overview

Add an electron accelerator to the existing RHIC accelerator complex:

5-10 GeV e-beam accelerated with an Energy Recovery Linac (ERL) inside the existing RHIC tunnel and colliding with RHIC beams (250 GeV polarized protons or 100 GeV/n heavy ions)

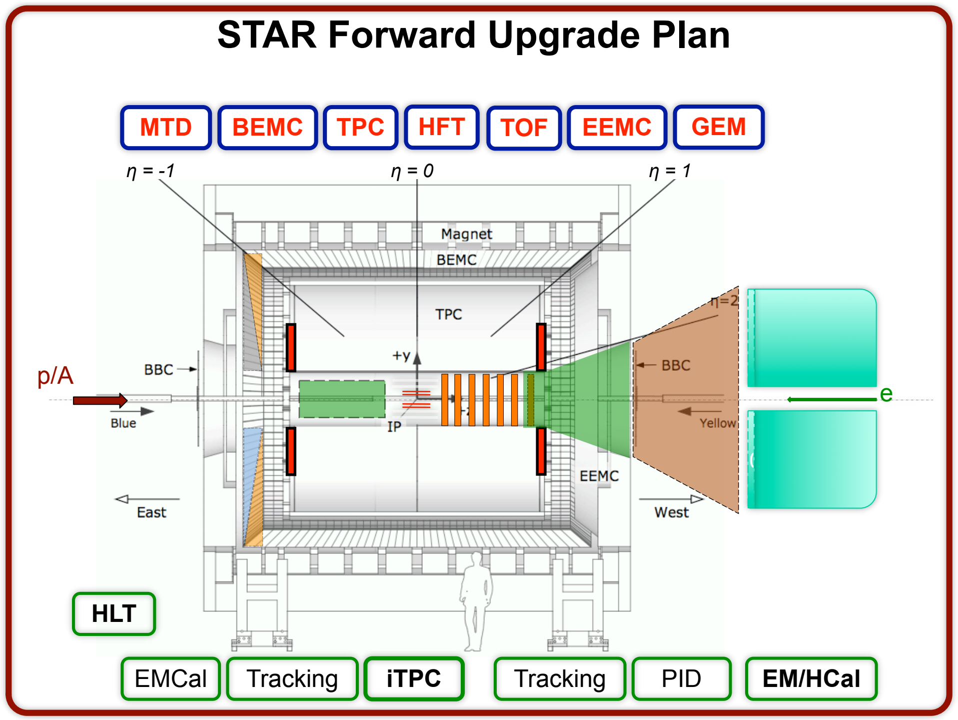
ERL provides fresh electron bunches for each collision resulting in high luminosity (10^{33} cm^{-2} s^{-1}) and high electron polarization over a wide kinematic range

Preliminary cost estimate for 5 GeV e-beam: $550M (FY12$) w/o detector. Work on a design that will allow us to reach 10 GeV electron energy for similar cost is ongoing.

STAR and PHENIX will soon submit LoI for e-RHIC Day-1 upgrades.

Comprehensive e-RHIC design document by year-end 2013.

From RHIC to e-RHIC



The 2013 NSAC *Subcommittee on Future Facilities* identified the physics program for an Electron-Ion Collider, as it was described in the 2013 EIC White Paper, as ***absolutely central*** to the U.S. nuclear science program in the next decade.