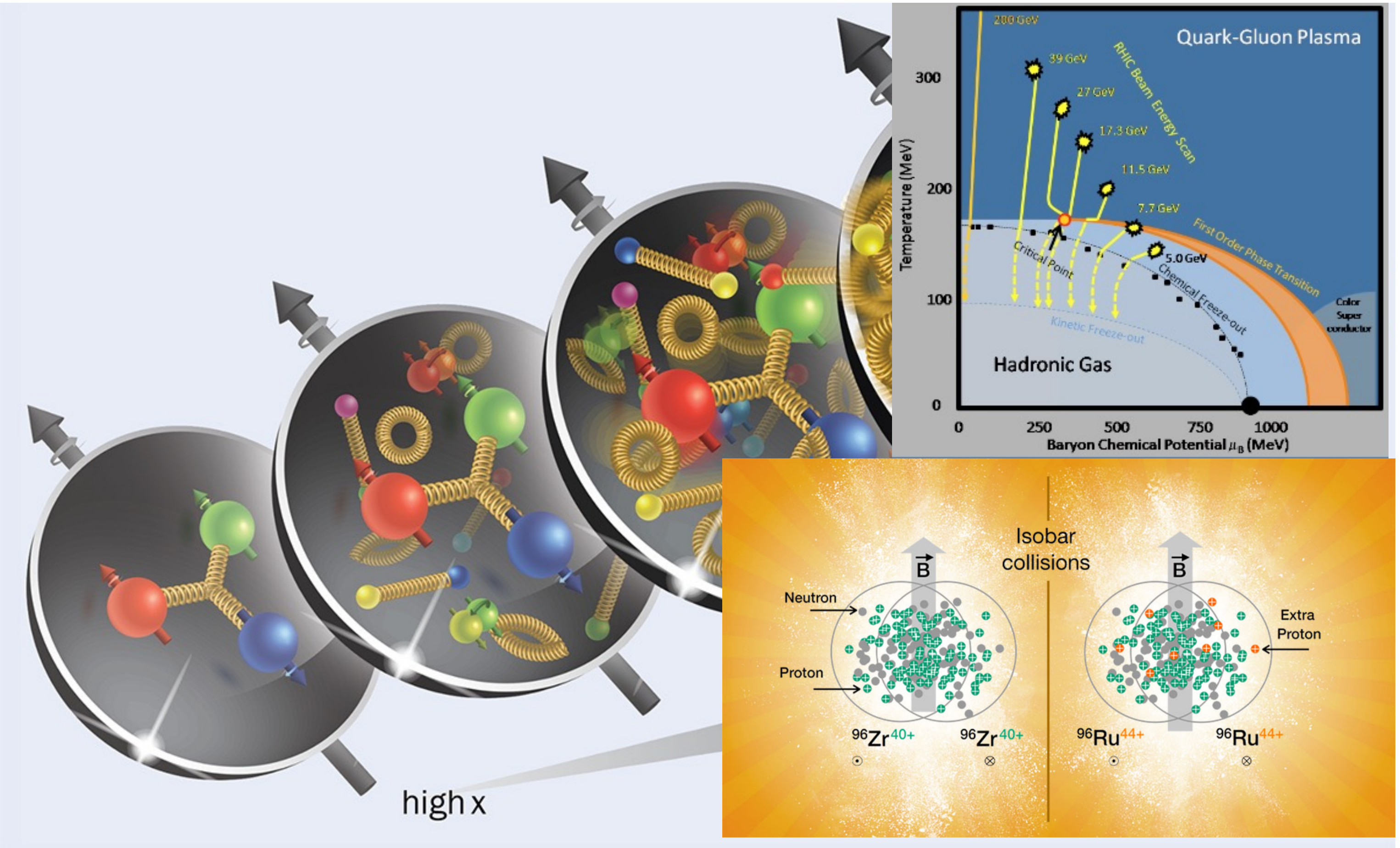
Short Remarks: Baryon Stopping in photo-processes from EMC to UPC to LHC



Zhangbu Xu
(Brookhaven National Lab)

CFNS workshop on Baryon Dynamics, 01/23/2024

In part supported by

RBRC Workshop on "Baryon Dynamics at RHIC" March 2002

20 years later,
IMHO

There is some consensus on production of baryons and hyperons at high [intermediate] pT due to flow and coalescence

There is still very confusing picture on large rapidity shifts of baryon numbers

One of the striking observations at RHIC is the large valence baryon rapidity density observed at mid rapidity in central Au+Au at 130 A GeV. There are about twice as many valence protons at mid-rapidity than predicted based on extrapolation from p+p collisions. Even more striking PHENIX observed that the high pt spectrum is dominated by baryons and anti-baryons. The STAR measured event anisotropy parameter v2 for lambdas are as high as charged particles at pt ~ 2.5 GeV/c. These are completely unexpected based on conventional pQCD parton fragmentation phenomenology.

One exciting possibility is that these observables reveal the topological gluon field origin of baryon number transport referred to as baryon junctions. Another is that hydrodynamics may apply up to high pt in A+A. There is no consensus on what are the correct mechanisms for producing baryons and hyperons at high pt and ~~large rapidity shifts~~ and the new RHIC data provide a strong motivation to hold a meeting focusing on this class of observables. The possible role of junctions in forming CP violating domain walls and novel nuclear bucky-ball configurations would also be discussed.

In this workshop, we focused on all measured baryon distributions at RHIC energies and related theoretical considerations. To facilitate the discussions, results of heavy ion collisions at lower beam energies, results from p+A /p+p/e+e collisions were included. Some suggestions for future measurements have been made at the workshop.

M. Gyulassy, D. Kharzeev, and N. Xu

N·H
ELSEVIER

20 June 1996

PHYSICS LETTERS B

Physics Letters B 378 (1996) 238–246

Can gluons trace baryon number?

D. Kharzeev

Theory Division, CERN, CH-1211 Geneva, Switzerland
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Received 15 March 1996
Editor: R. Gatto

Abstract

QCD as a gauge non-Abelian theory imposes severe constraints on the structure of the baryon wave function. We point out that, contrary to a widely accepted belief, the traces of baryon number in a high-energy process can reside in a non-perturbative configuration of gluon fields, rather than in the valence quarks. We argue that this conjecture can be tested experimentally, since it can lead to substantial baryon asymmetry in the central rapidity region of ultra-relativistic nucleus-nucleus collisions.

In QCD, quarks carry colour, flavour, electric charge and isospin. It seems only natural to assume that they also trace baryon number. However, this latter assumption is not dictated by the structure of QCD, and there- [illegible] the baryon number $B = 1/3$ to quarks is based merely on the naive quark model classification. But any phys- [illegible] state vector which is gauge-invariant – the constraint which is ignored in most of the naive quark model formulations. This constraint turns out to be very severe; in fact, there is only one way to construct a gauge-invariant state vector of a baryon from quarks and gluons [1] (note however that there is a large amount of freedom in choosing the paths connecting x to x_i):

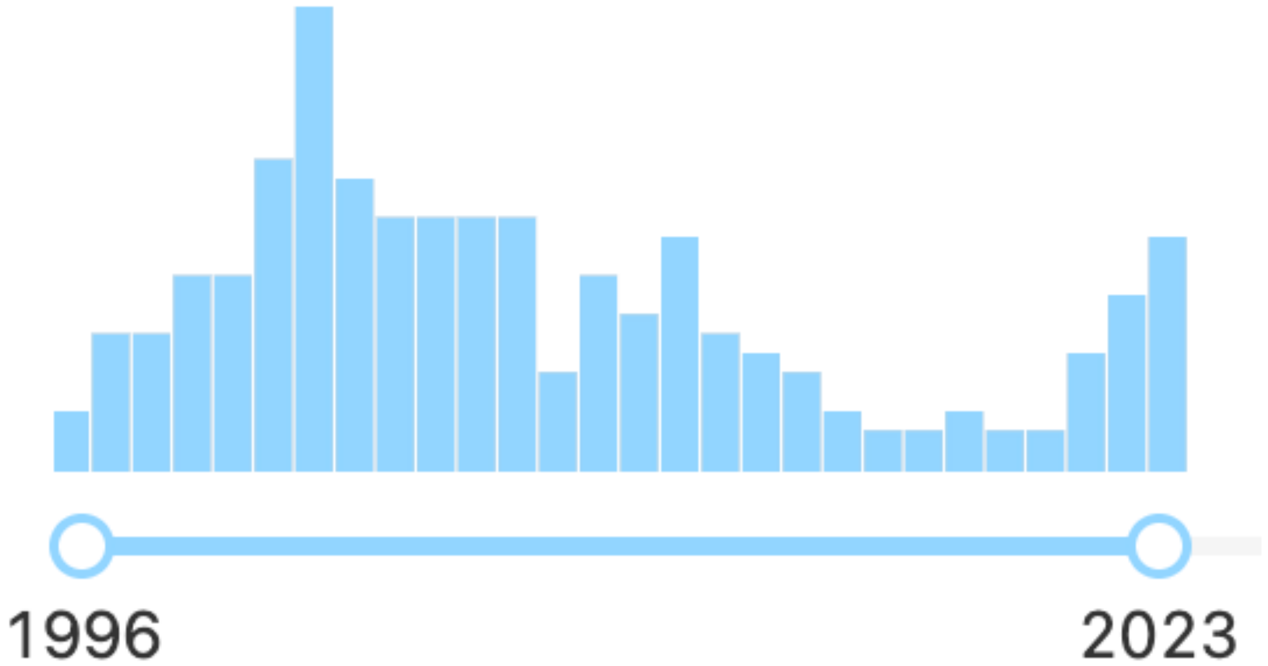
$$B = \epsilon^{ijk}\left[P\exp\left(ig\int_{x_1}^{x} A_\mu dx^\mu\right)q(x_1)\right]_i \times \left[P\exp\left(ig\int_{x_2}^{x} A_\mu dx^\mu\right)q(x_2)\right]_j \times \left[P\exp\left(ig\int_{x_3}^{x} A_\mu dx^\mu\right)q(x_3)\right]_k . \quad (1)$$

There is only one way to construct a gauge-invariant state vector of a baryon from quarks and gluons

[illegible] $q(x_n)$ make it transform as a quark field at point x instead of at x_n. The [illegible] tensor then constructs a local [illegible] quark fields (see Fig. 1a). The B in Eq. (1) is a set of gauge invariant operators representing a baryon in QCD. With properly optimised parameters it is used extensively in the first principle computations [illegible] lattice Monte Carlo attempting to determine the nucleon mass. The purpose of this work is to study [illegible] phenomenological impact on baryon number production in the central region of nucleus-nucleus collisions.

It is evident from the structure of (1) that [illegible] of baryon number should be associated not with the valence quarks, but with a non-perturbative configuration of gluon fields located at the point x – the [illegible] junction" [1]. This can be nicely illustrated in the string picture: let us pull all of the quarks aw[illegible]

PII S0370-2693(96)00435-2



following. The string junction, connected to all three of the valence quarks, is confined inside the baryon, whereas pp collisions become on the average more and more peripheral at high energies. Therefore, in a typical high-energy collision, the string junctions of the colliding baryons pass far away from each other in the impact parameter plane and do not interact. One can however select only central events, triggering on high multiplicity of the produced hadrons. In this case, we expect that the string junctions will interact and may be stopped in the central rapidity region. [illegible]

It is evident from the structure of (1) that the trace of baryon number should be associated not with the valence quarks, but with a non-perturbative configuration of gluon fields located at the point x - the “string junction” .

[illegible] can be represented through a t-channel exchange of the quarkless junction-antijunction state with the wave function given by

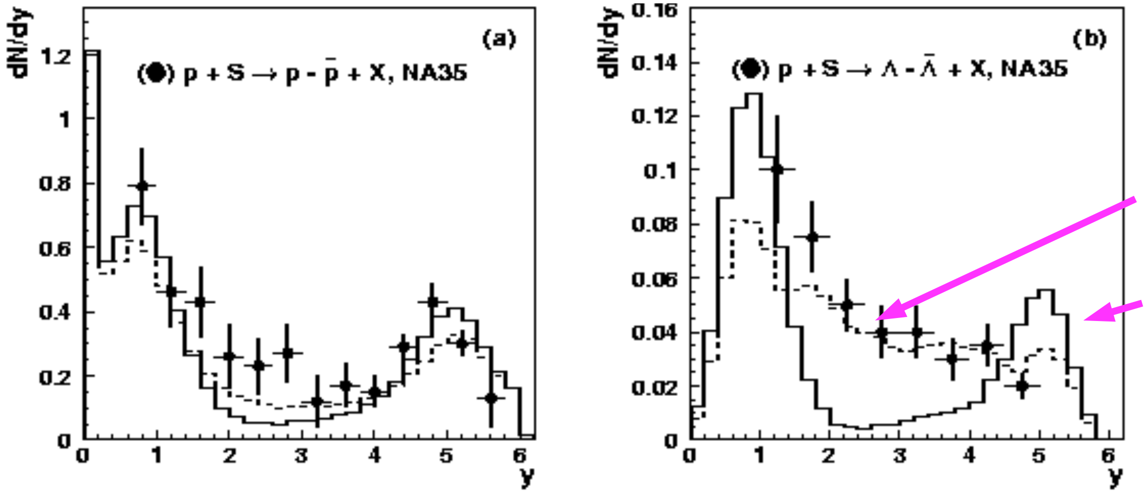
$$M_0^J = \epsilon_{ijk}\epsilon^{i'j'k'}\left[P\exp\left(ig\int_{x_1}^{x_2} A_\mu dx^\mu\right)\right]_{i'}^{i} \times \left[P\exp\left(ig\int_{x_1}^{x_2} A_\mu dx^\mu\right)\right]_{j'}^{j} \times \left[P\exp\left(ig\int_{x_1}^{x_2} A_\mu dx^\mu\right)\right]_{k'}^{k} . \quad (5)$$

The structure of the wave function (5) is illustrated in Fig. 1b – it is a quarkless closed string configuration composed from a junction and an antijunction. In the topological expansion scheme, the states (5) lie on a Regge trajectory; its intercept can be related to the baryon and reggeon intercepts [1]:

$$\alpha_0^J(0) \simeq 2\alpha_B(0) - 1 + 3(1-\alpha_R(0)) \simeq \frac{1}{2}, \quad (6)$$

NET BARYON NUMBER TRANSPORT VIA GLUONIC JUNCTIONS vs SPS data

S Vance, MG, XN Wang Phys.Lett.B443:45-50,1998



HIJING/B dashed

HIJING   solid

Distribution of final Y=rapidity of proton = $\tanh^{-1}(v_z)$

Miklos Gyulassy
Prepared in 08/18/2022

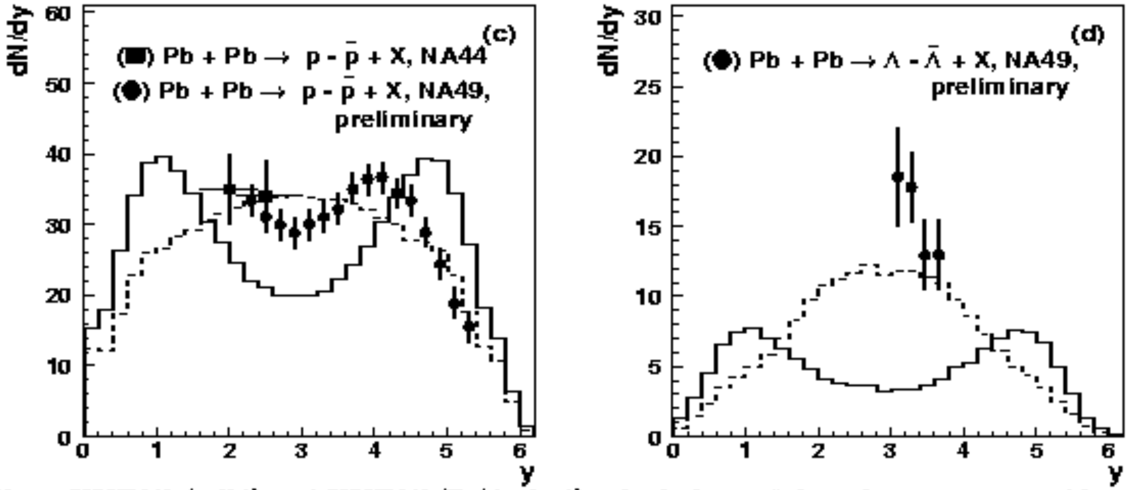


FIG. 1. HIJING (solid) and HIJING/B (dashed) calculations of the valence proton and hyperon rapidity distributions are shown for minimum bias $p+S$ collisions at 200 AGeV and central $Pb+Pb$ collisions at 160 AGeV. The data are from measurements made by the NA35 [1,2], NA44 [3] and NA49 [5] collaborations.

What do we know about μ+p collisions

Same plot, opposite conclusion!

Benchouk (EMC), ISMD1984

At this point it should be noted that, if they were significantly contributing, protons coming from scattering on diquark clusters (higher twist)[10] would also present such behaviours as those of Figs. 2 and 3d. However those protons must exhibit a strong decrease with Q^2, which is obviously not the case as shown by Fig. 4 and their contribution to our sample can be excluded.

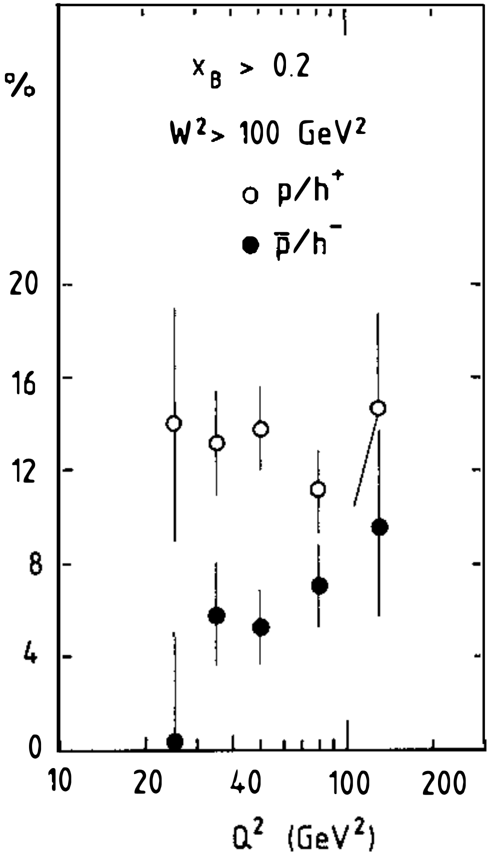
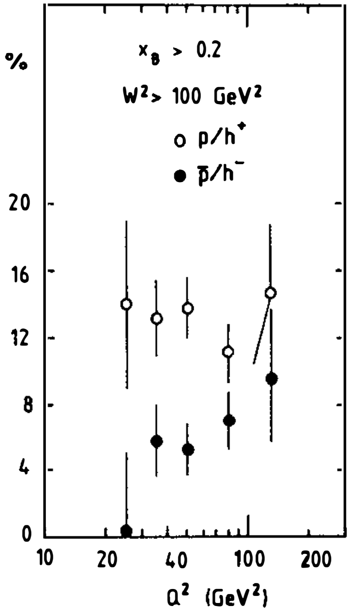
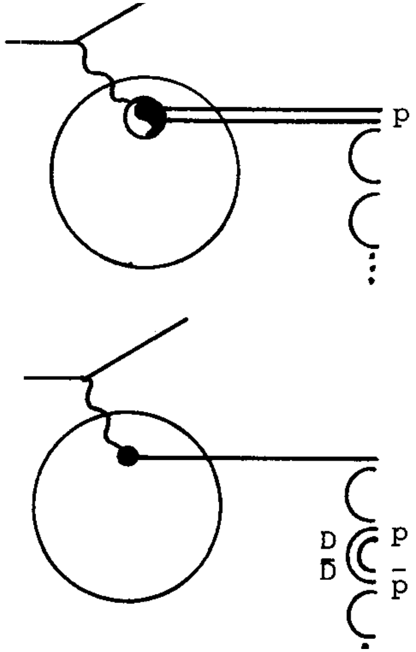


Fig. 4 - The ratio of the proton (antiproton) multiplicity to the overall positive (negative) hadron multiplicity as a function of Q^2 for $W^2 > 100\ GeV^2$ and $x_B > 0.2$.

Fredrikasson, “Hello Diquark, Goodbye Gluon!”, Moriond 1984

Fig.3 Ratio of proton (antiproton) multiplicity to the overall positive (negative) multiplicity in μp scattering according to Ref.7 (EMC). Part of the difference between p and $\bar{p}$ might be explained by the diquark process in the upper reaction, while large-Q^2 events come from knocked-out quarks, as shown in the lower reaction. The two processes give rise to completely different p-$\bar{p}$ correlations.





~~They~~ only SEE what ~~they~~ want to see!
We we

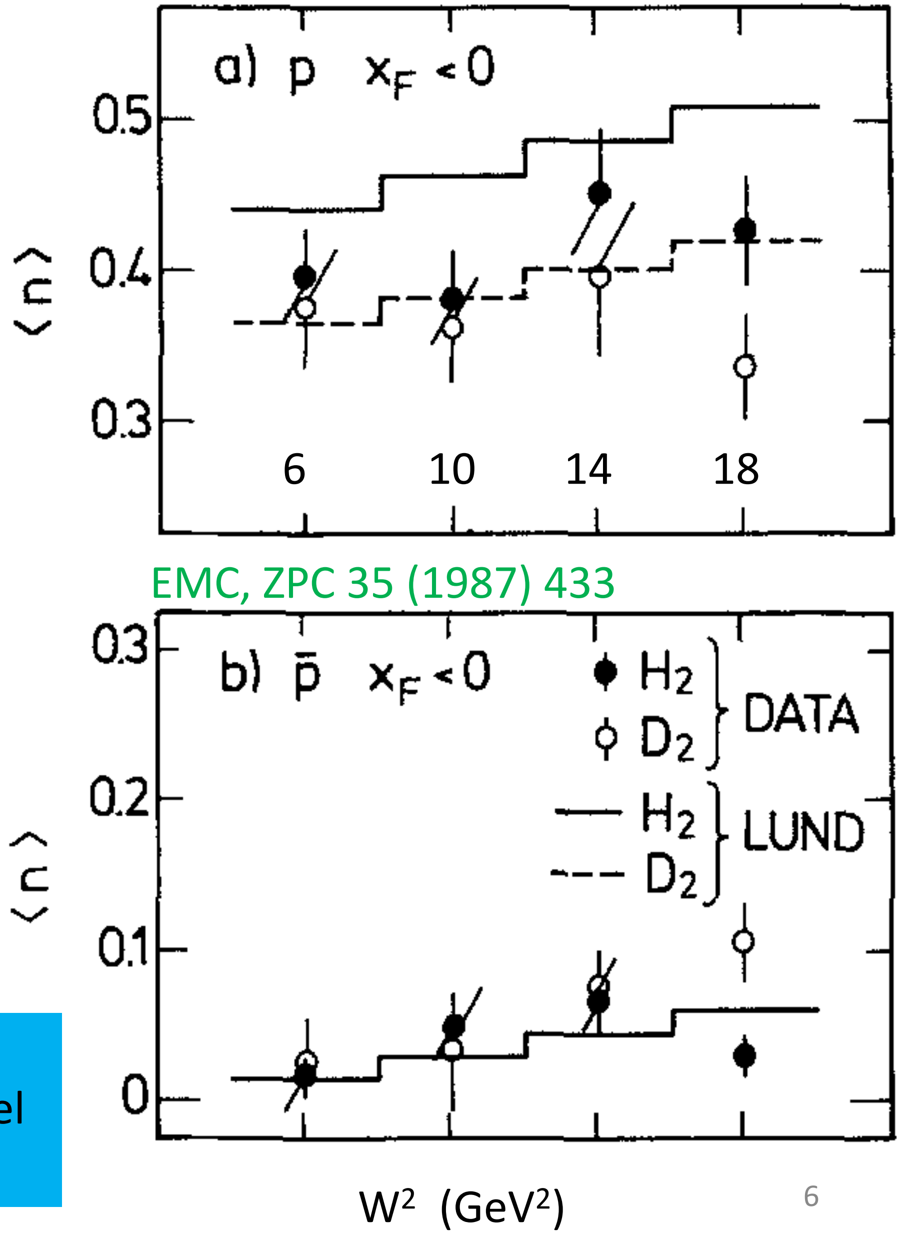
280GeV muon on target:
EMC, PLB 103 (1981) 388;
last cited in 1992
EMC, PLB 135 (1984) 225

What do we know about μ+p (d) collisions

Diquark Lund model predicts a flavor dependence of backward proton production (20%) while data shows little-to-no dependence

Fig. 5a-d. Average multiplicities from the H_2 (full circles) and the D_2 target (open circles) vs. W for backward protons a, backward antiprotons b. The histograms show the Lund model predictions (full line: H_2 target, dashed line: D_2 target, full line only where both are the same)

the Lund model (JETSET62) predicts a higher yield of backward going protons from hydrogen than from deuterium, an effect which is less pronounced in the data.



Total citations: 19

Niseem Magdy's talk for EIC;
we are able to reproduce model prediction 35 years later

What do we know about π+p collisions

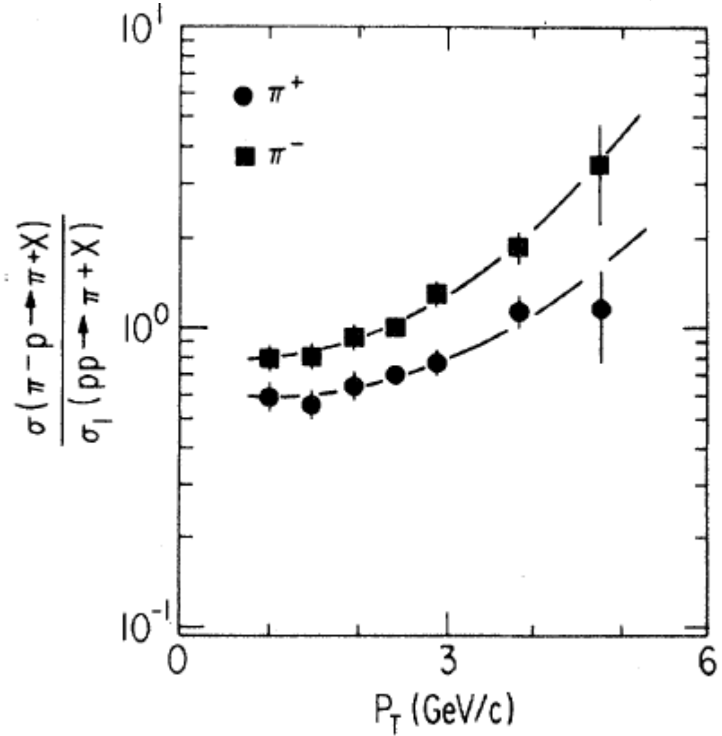
Two mechanisms are probably involved in this effect. The first is that the π^- has constituents with higher average momenta than does a proton. The second, which is relevant only to π^- production, is that the initial π^- clearly has the right ingredients to make another π^-, whether by a valence-quark scatter or a process which involves both quarks.

The "beam ratio" for K^+ and K^- production is shown in Fig. 29. K^- are produced three times more copiously by π^- than by protons at a P_T of $\sim$4 GeV/c. K^+ production rises to be at least equal in π^-p and pp collisions.

The beam ratios for p and $\bar{p}$ productions are shown versus P_T in Fig. 30. Antiproton production is strongly enhanced in π^-p collisions over pp collisions in a fashion very much like the K^- production of Fig. 29.

Proton production in π^-p collisions, however, is a little less than half that of pp collisions at all values of p_T. Proton production in pp collisions at these energies has always seemed anomalously large, with more protons produced at large P_T than pions.[8] It is interesting that replacing one of the two colliding protons with a π^- reduces the proton production by approximately one half.

The beam ratios for the six particle types are tab-



Frisch, et al., PRD 27 (1983) 1001

FermiLab, 200-300GeV pion and proton beams

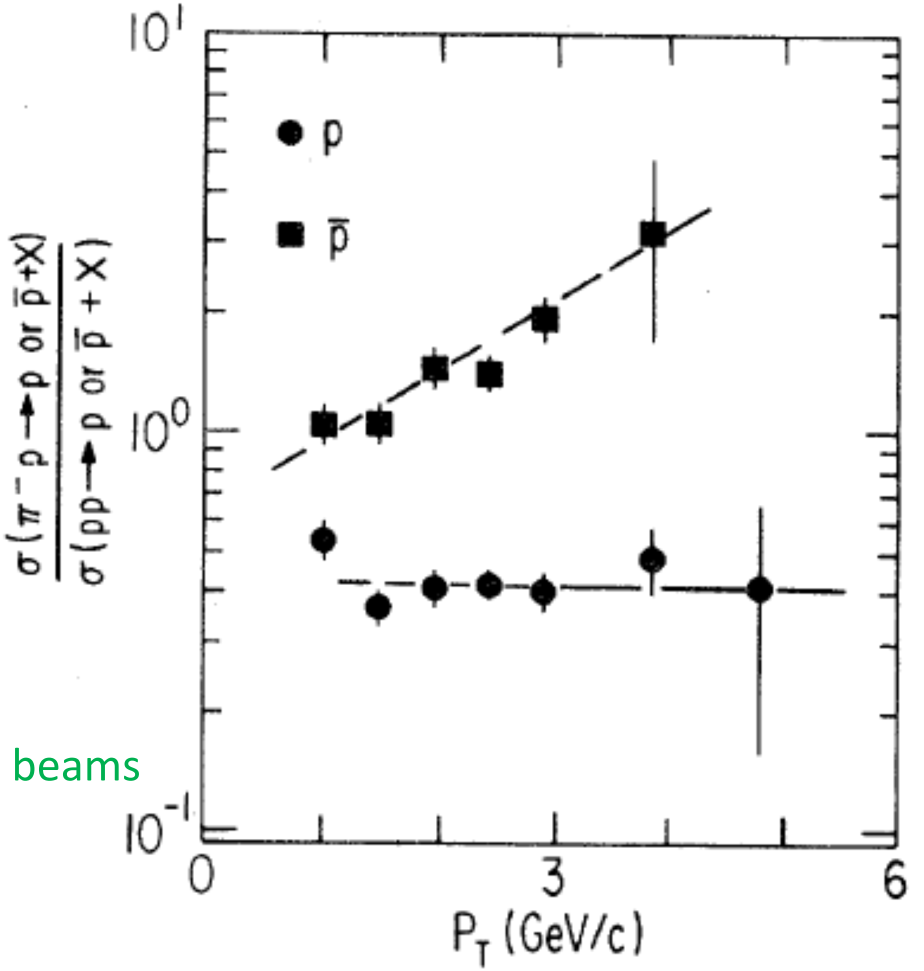


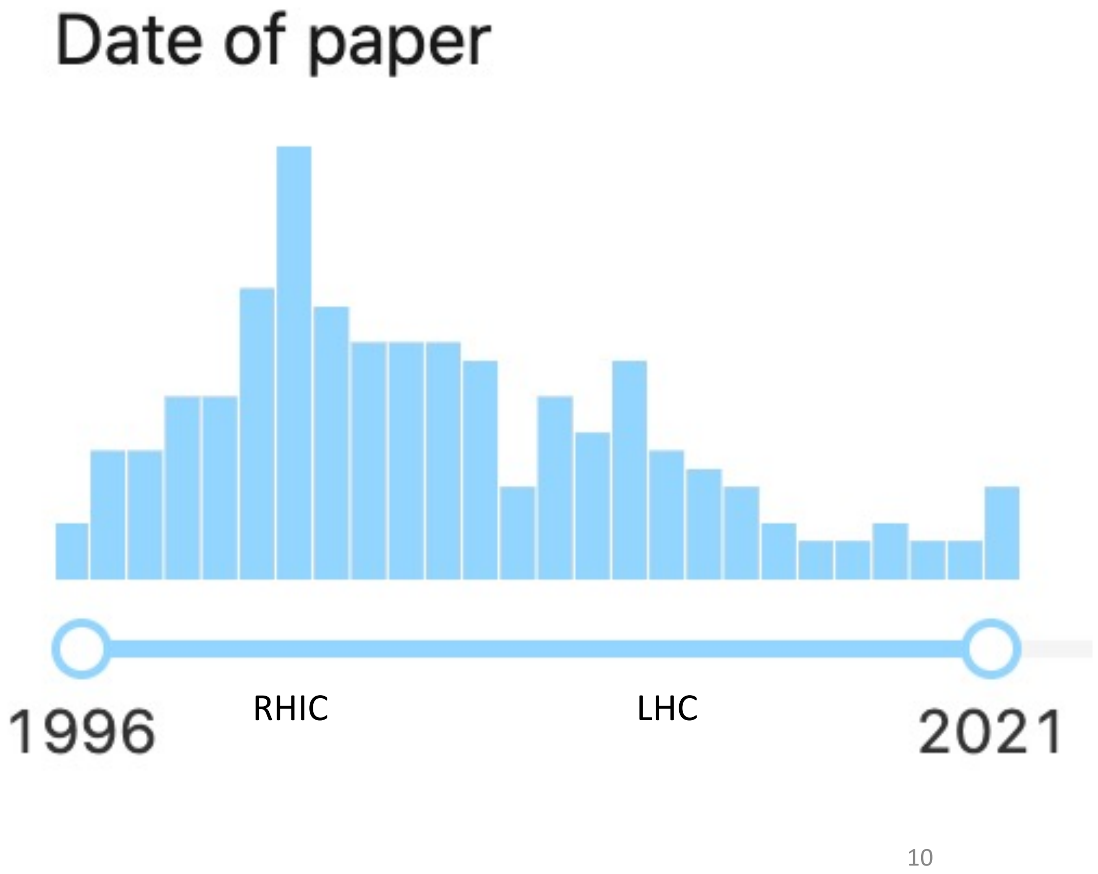
FIG. 30. The ratios of invariant cross sections for p and $\bar{p}$ production in 200 GeV π^-p collisions to those in pp collisions, versus p_T. The lines are only to guide the eye.

What can we do for a decisive test?

- It seems that what works still works, what does not work, remains broken
- Is there a decisive way to test the baryon transport, or ultimately what really carries the baryon number?
- One of the arguments is that if gluon junction carries baryon number, one can stop baryons without stopping the valence quarks or charges!!!
  3K+Ω, or ϖ+p

H.Z. Huang (UCLA) talk

D. Kharzeev, Physics Letters B **378**, 238-246 (1996)



Study charge stopping is much much harder

Nucleus-nucleus bremsstrahlung from ultrarelativistic collisions

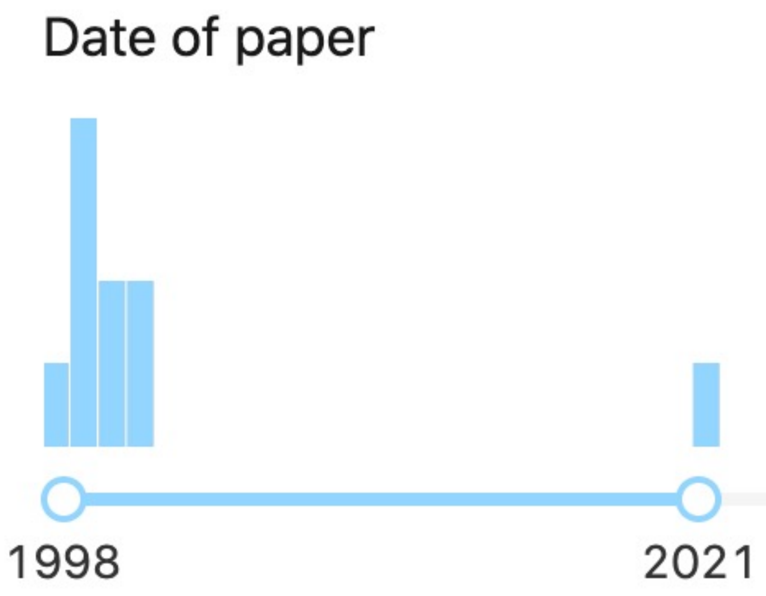
Sangyong Jeon, Joseph Kapusta, Alexei Chikanian, and Jack Sandweiss
Phys. Rev. C **58**, 1666 – Published 1 September 1998

Article | References | Citing Articles (11) | PDF | Export Citation

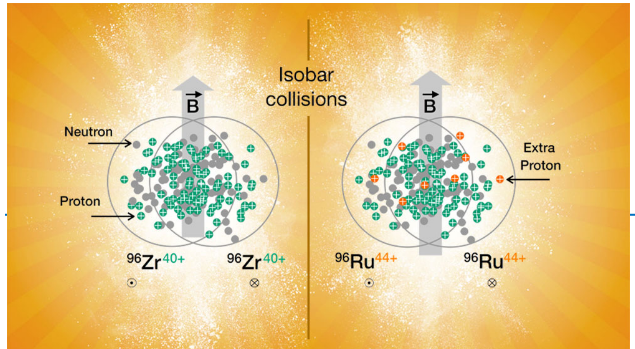
ABSTRACT

The bremsstrahlung produced when heavy nuclei collide is estimated for central collisions at the Relativistic Heavy Ion Collider. Soft photons can be used to infer the rapidity distribution of the outgoing charge. An experimental design is outlined.

Received 13 March 1998



In fact, no one succeeded!



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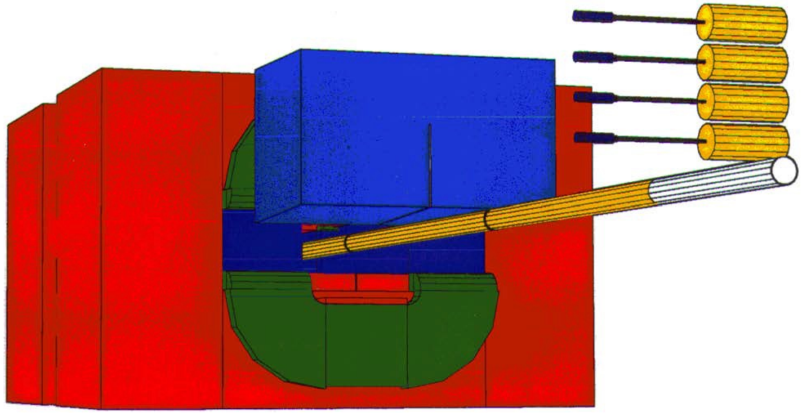
Until STAR used isobar collisions to directly measure charge transport
See Rongrong Ma's talk
We had not proposed the idea when I gave the talk in 2021

Nucleus - Nucleus Bremsstrahlung and measurement of charge* stopping at RHIC

* Perhaps also measurement of the time history of charge acceleration in the heavy ion collision

Berkeley workshop Jan. 10 '99
J. Sandweiss

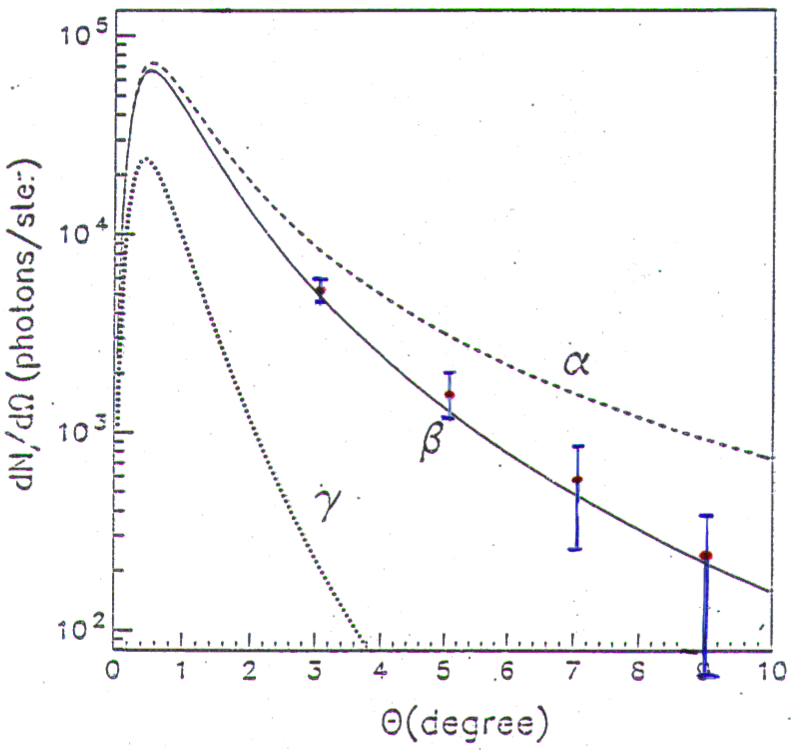


Nominal 6 weeks @ 100 hrs. / week

1% of design luminosity = 10 ev/s
Live time and "diamond cut" (50%)
included.

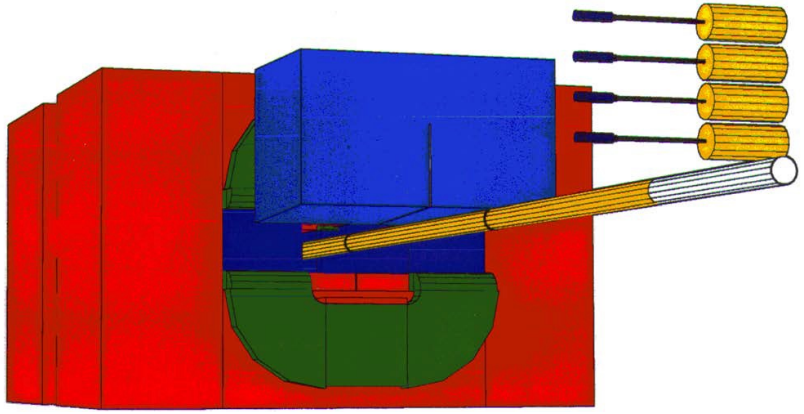
Run plan 7/8/1 No plug / $\frac{1}{8}$" in" Pb. / 1mm Pb.

SOFT π SPECTRUM



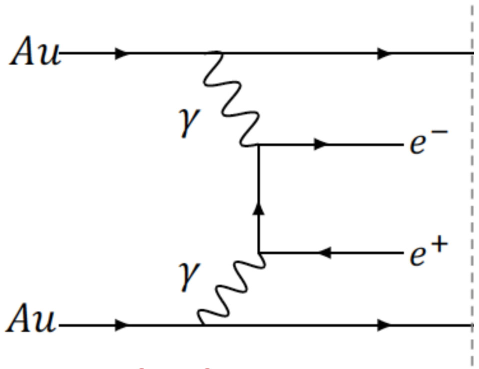
200 keV

Figure 2: The number of bremsstrahlung photons with energies between 10 keV and ~~3~~ MeV, per steradian in the laboratory system for the three different stopping models α, β, and γ of figure 1.

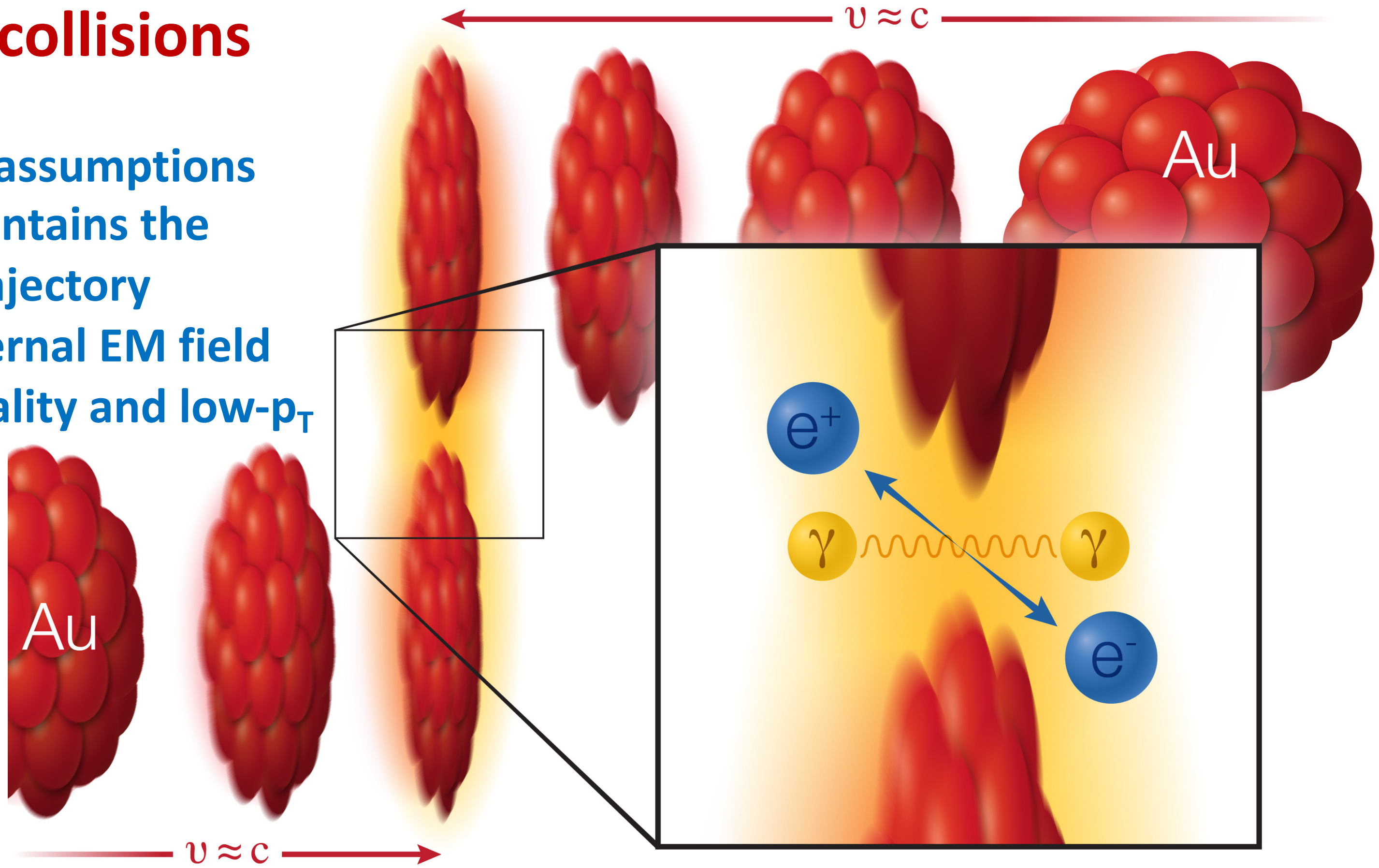


UPC AND peripheral collisions

One of the most important assumptions is that the ions (charge) maintains the velocity and straight-line trajectory
One can them quantize external EM field as photons with small virtuality and low-p_T



The Breit-Wheeler process, 1934



Two gold (Au) ions (red) move in opposite direction at 99.995% of the speed of light (v, for velocity, = approximately c, the speed of light). As the ions pass one another without colliding, two photons (γ) from the electromagnetic cloud surrounding the ions can interact with each other to create a matter-antimatter pair: an electron (e^-) and positron (e^+).

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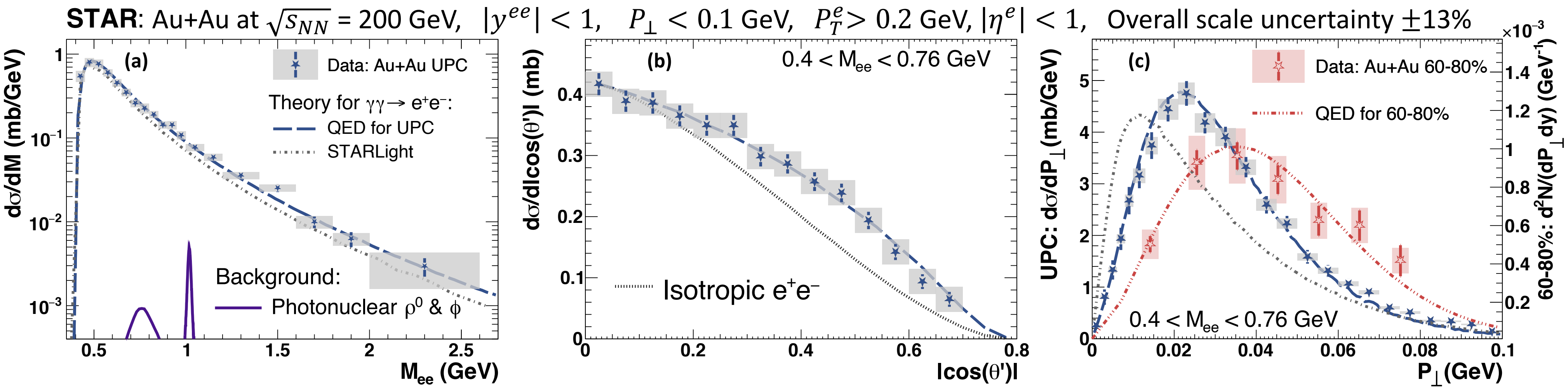
Well understood kinematics



ρ,ϕ,ω<±0.2%

<±2%

<±2%

STAR, Phys. Rev. Lett. **127** (2021) 52302

STAR, Phys. Rev. Lett. 121 (2018) 132301, 60-80%

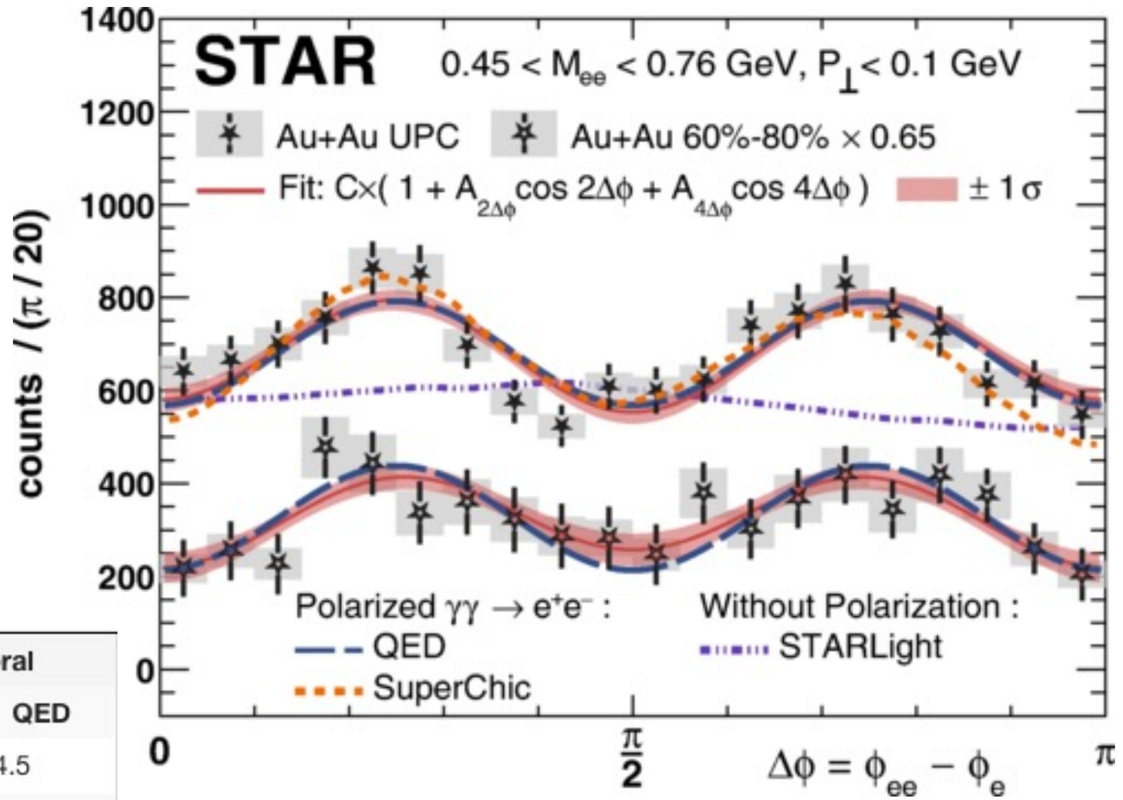
15

THE cos(4ϕ) modulation

It was quite shocking to me that such a large effect exists.

Remember that the large elliptic flow in perfect QGP liquid is 5%

Peripheral collisions also agrees with QED, which does not have to.



STAR, Phys. Rev. Lett. **127** (2021) 52302

	Ultraperipheral				Peripheral	
	Measured	QED	SC	SL	Measured	QED
$\lvert A_{4\Delta\phi}\rvert$ (%)	16.8 ± 2.5	16.5	19	0	27 ± 6	34.5
$\lvert A_{2\Delta\phi}\rvert$ (%)	2.0 ± 2.4	0	5	5	6 ± 6	0
$\sqrt{\langle P_{\perp}^2 \rangle}$ (MeV)	38.1 ± 0.9	37.6	35.4	35.9	50.9 ± 2.5	48.5

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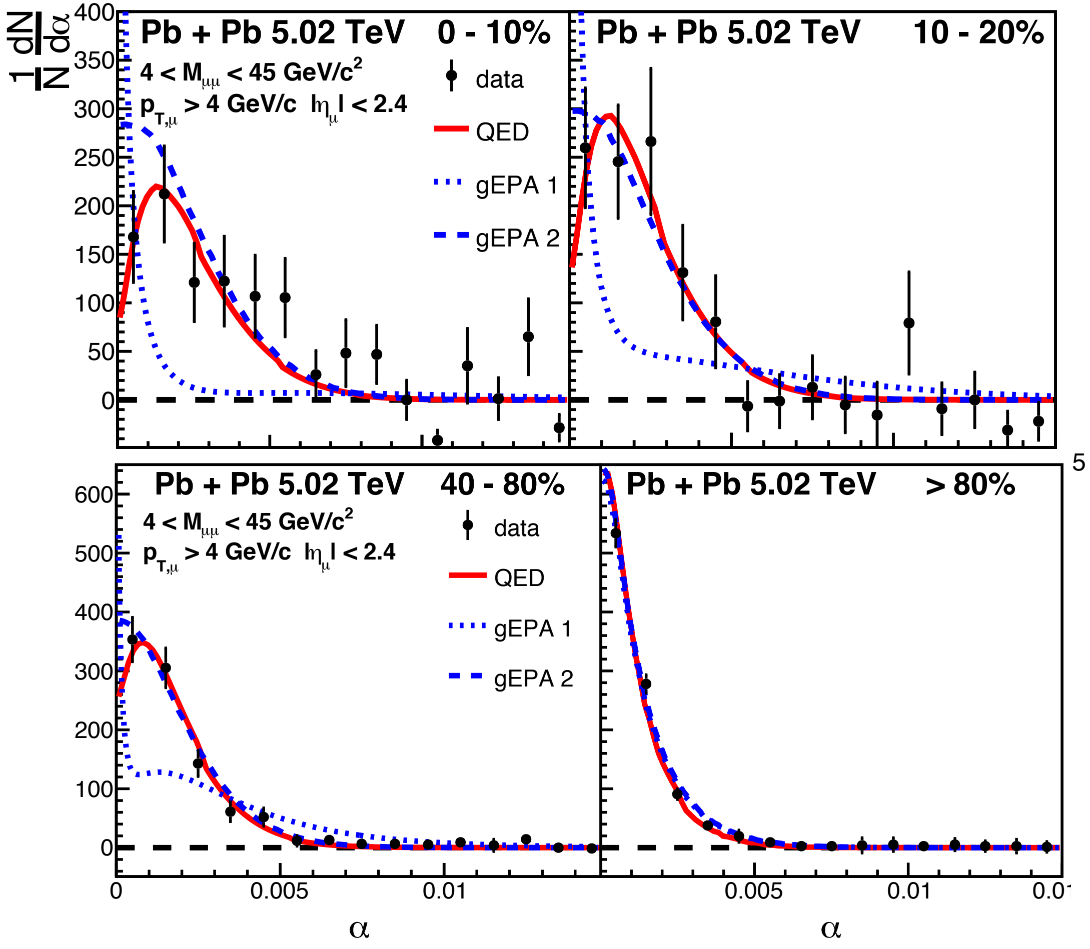
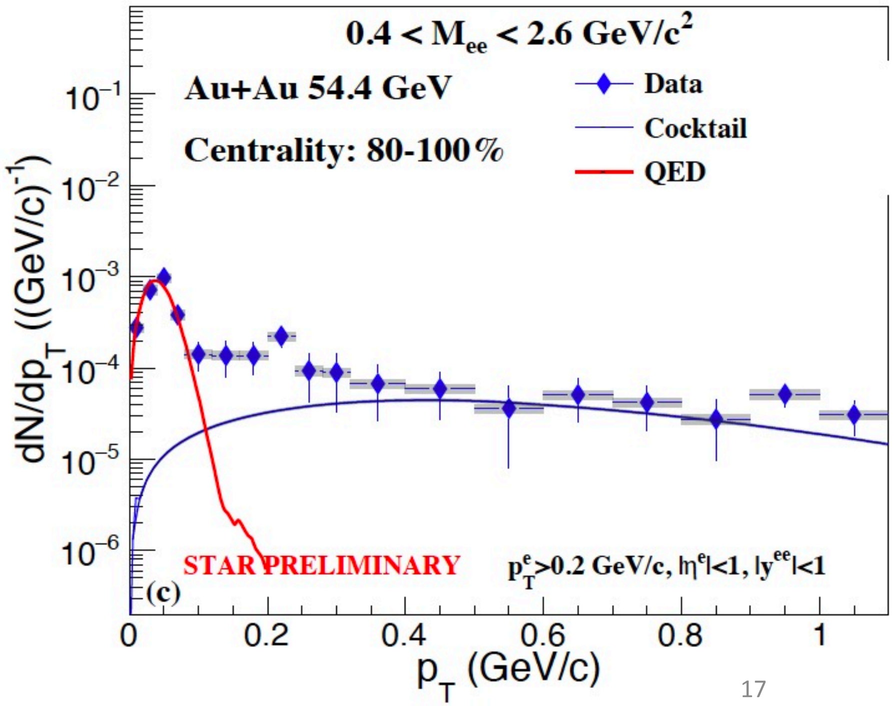
Other RHIC and LHC energies and centralities

ATLAS data: PRL 121 (2018) 212301

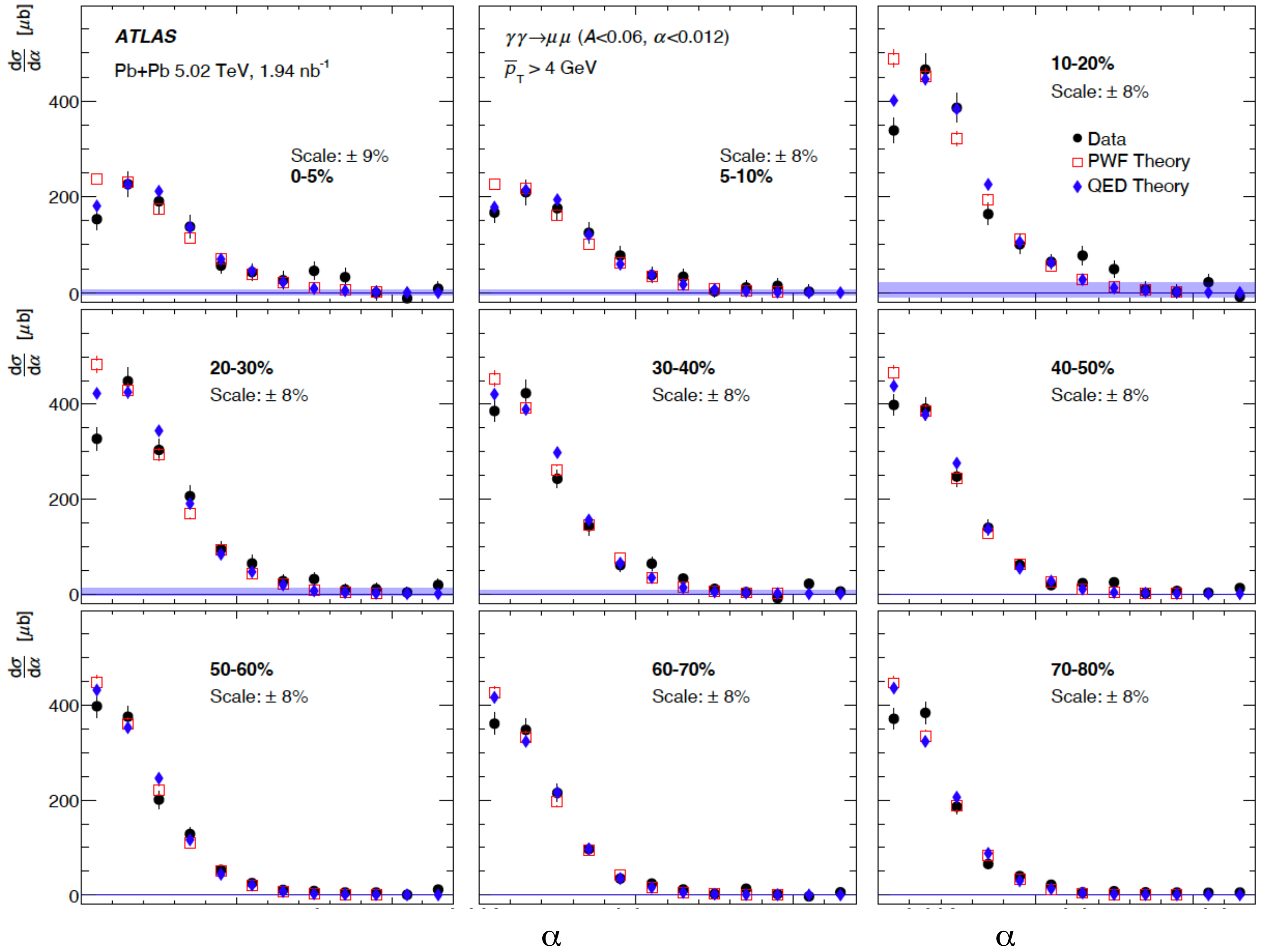


If straight-line and velocity of charges do not maintain, there is not reason to have low-pt, cos(4phi) and cross section as predicted by QED which assumes those
And the J/Psi photoproduction …

Xiaofeng Wang for STAR, IS 2021



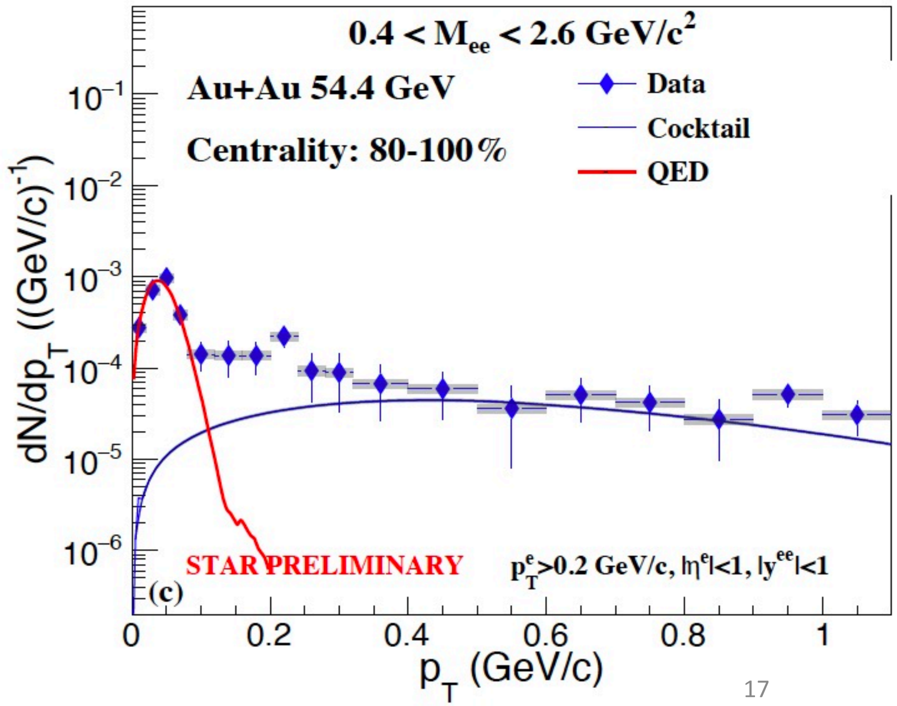
Other RHIC and LHC energies and centralities



ATLAS, arXiv:2206.12594; PRC

If straight-line and velocity of charges do not maintain, there is not reason to have low-pt, cos(4phi) and cross section as predicted by QED which assumes those
And the J/Psi photoproduction …

Xiaofeng Wang for STAR, IS 2021



Interesting proposals in 1990s and 2020s

Quantifying baryon stopping in high energy nuclear collisions

S.M.H. Wong [1, 1]

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Received 18 February 2000, Accepted 23 March 2000, Available online 17 May 2000.

Editor: R. Gatto

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https://doi.org/10.1016/S0370-2693(00)00408-1   Get rights and content

Abstract

We propose a numerical definition for baryon stopping in relativistic heavy ion collisions that is obtainable from final hadron rapidity distributions as well as from bremsstrahlung measurements. Thus a new channel of communication is opened between the two methods.

Bremsstrahlung photons from stopping in heavy-ion collisions

Sohyun Park and Urs Achim Wiedemann
Phys. Rev. C **104**, 044903 – Published 4 October 2021

Article | References | No Citing Articles | PDF | HTML | Export Citation

ABSTRACT

We examine the spectrum of bremsstrahlung photons that results from the stopping of the initial net charge distributions in ultrarelativistic nucleus-nucleus collisions at the CERN Large Hadron Collier (LHC). This effect has escaped detection so far since it becomes sizable only at very low transverse momentum and at sufficiently forward rapidity. We argue that it may be within reach of the next-generation LHC heavy-ion detector ALICE-3 that is currently under study, and we comment on the physics motivation for measuring it.

How about studying charge no-stopping?

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Not as a measure of baryon transport, but as an important measure of charge transport at LHC

Stopping of charge at LHC

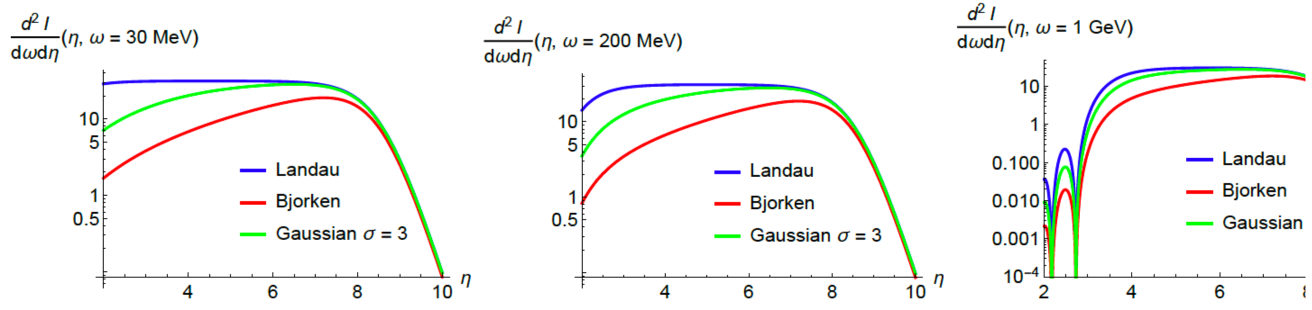


FIG. 3. The double-differential photon energy distribution $\frac{d^2 I}{d\omega\, d\eta}$ for different photon energies ω as a function of pseud
η. Results are shown for the three different stopping scenarios (12) in central PbPb collision at $\sqrt{s_{\rm NN}} = 5.02$ TeV.

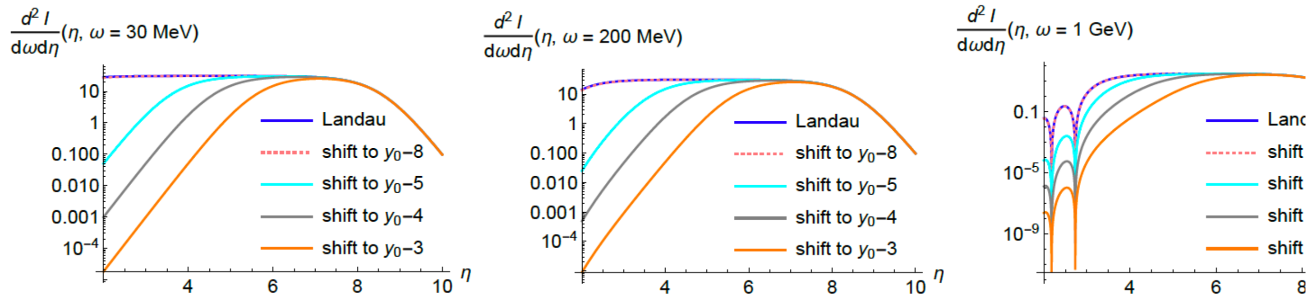


FIG. 4. Same as Fig. 3, but for the stopping scenarios of Eq. (16).

S. Park, U. Wiedemann, Phys.Rev.C 104 (2021) 4, 044903

The ALICE collaboration plans to develop a new detector (ALICE-3) with experimental acceptance in a previously uncharted, ultrasoft regime 10 MeV $< p_T <$ 100 MeV and up to relatively forward pseudorapidity. As demonstrated here (Fig. 6), photon bremsstrahlung due to stopping of the incoming net charge distributions is an expected phenomenon that leaves characteristic signatures in this newly accessible experimental regime. As such, it is useful for illustrating the novel opportunities of a detector design with ultrasoft acceptance. Its centrality- and p_T-dependence is characteristically different from that of expected backgrounds.

Can we put baryon transport, charge transport, Breit-Wheeler process and Bremsstrahlung together?

Conclusions and Perspectives

- Baryon number is a strictly conserved quantum number,
  keeps the Universe as is
- We did not know what its carrier is;
  It has not been experimentally verified one way or the other until now
- RHIC Beam Energy Scans provide unique opportunity in studying baryon number transport over large unit of rapidity
- RHIC Isobar collisions provide unique opportunity in studying charge and baryon transport
- Experimental verification of the simplest QCD topology

- Baryon junction is a non-perturbative object
- Need small Q^2, large rapidity coverage and low-momentum hadron particle identification

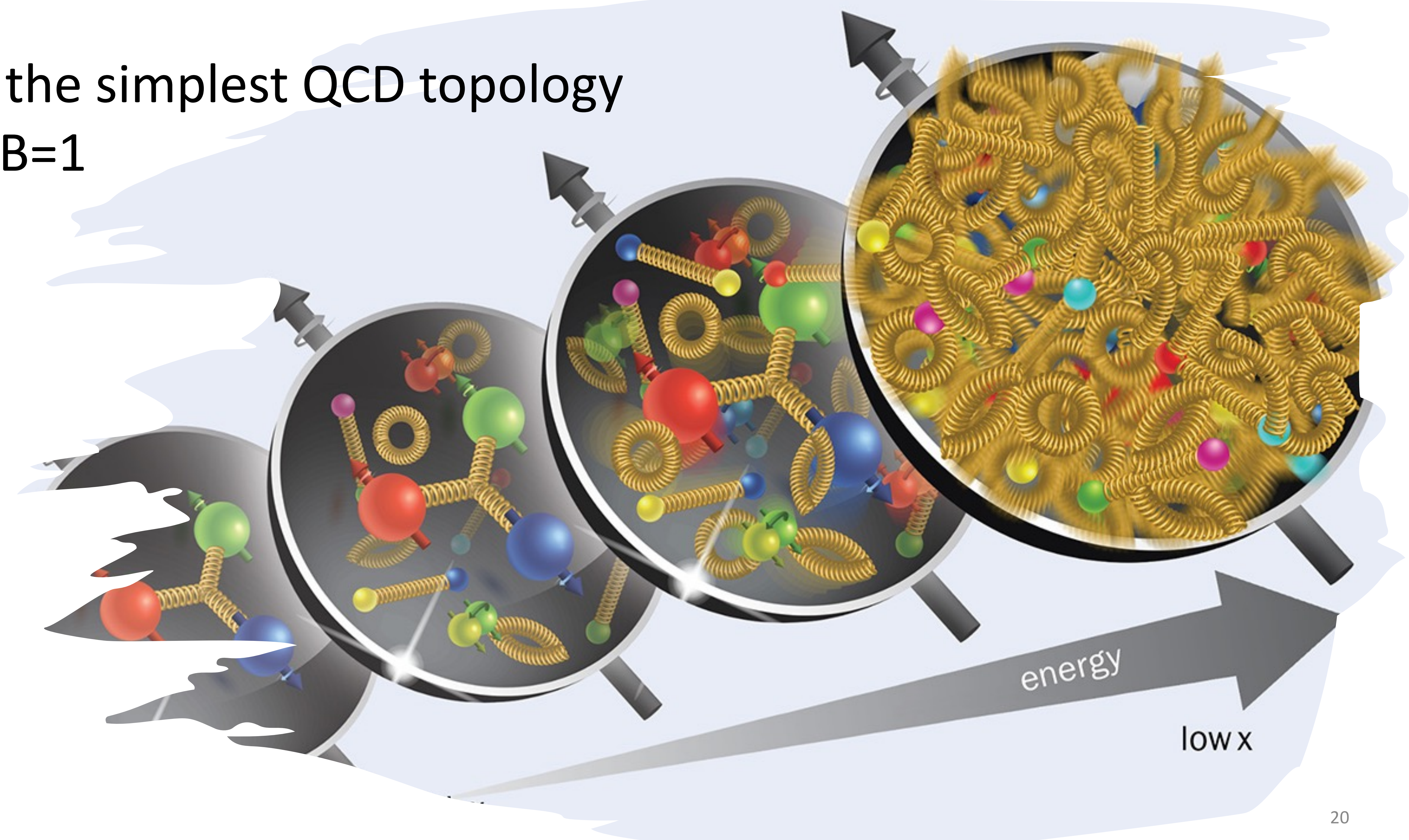
$$Q^2 \leq 1\ GeV^2$$

$$\pi\text{/k/p PID } p_t \geq \sim 100\ MeV$$

- Isobar collisions to measure charge transport (quark transports),
  Zr/Ru; ^{7}Li/^{7}Be
- EIC can measure the baryon junction distribution function
- Explore other signatures at RHIC,LHC,Jlab & EIC

the simplest QCD topology

B=1

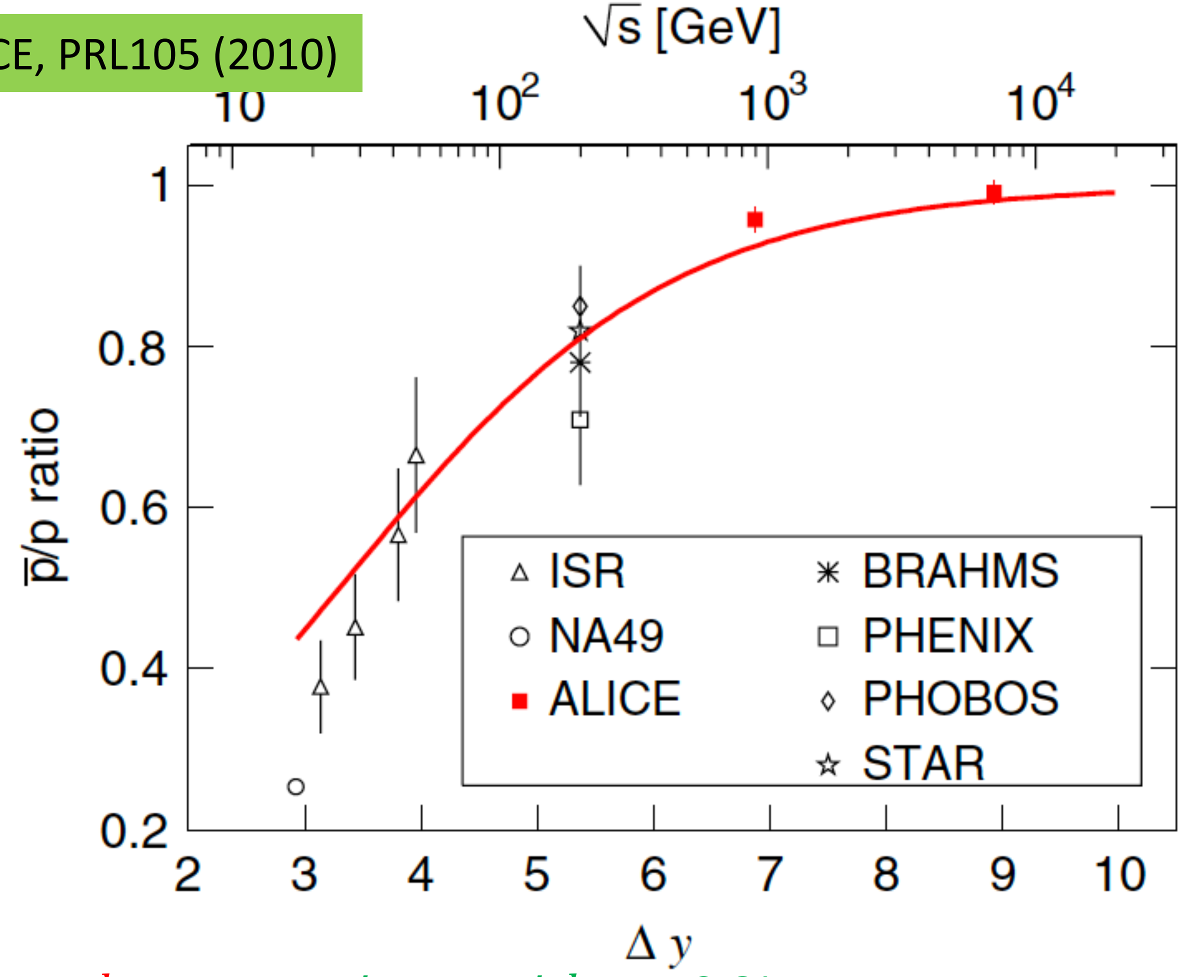


backup

What do we know about pp collisions?

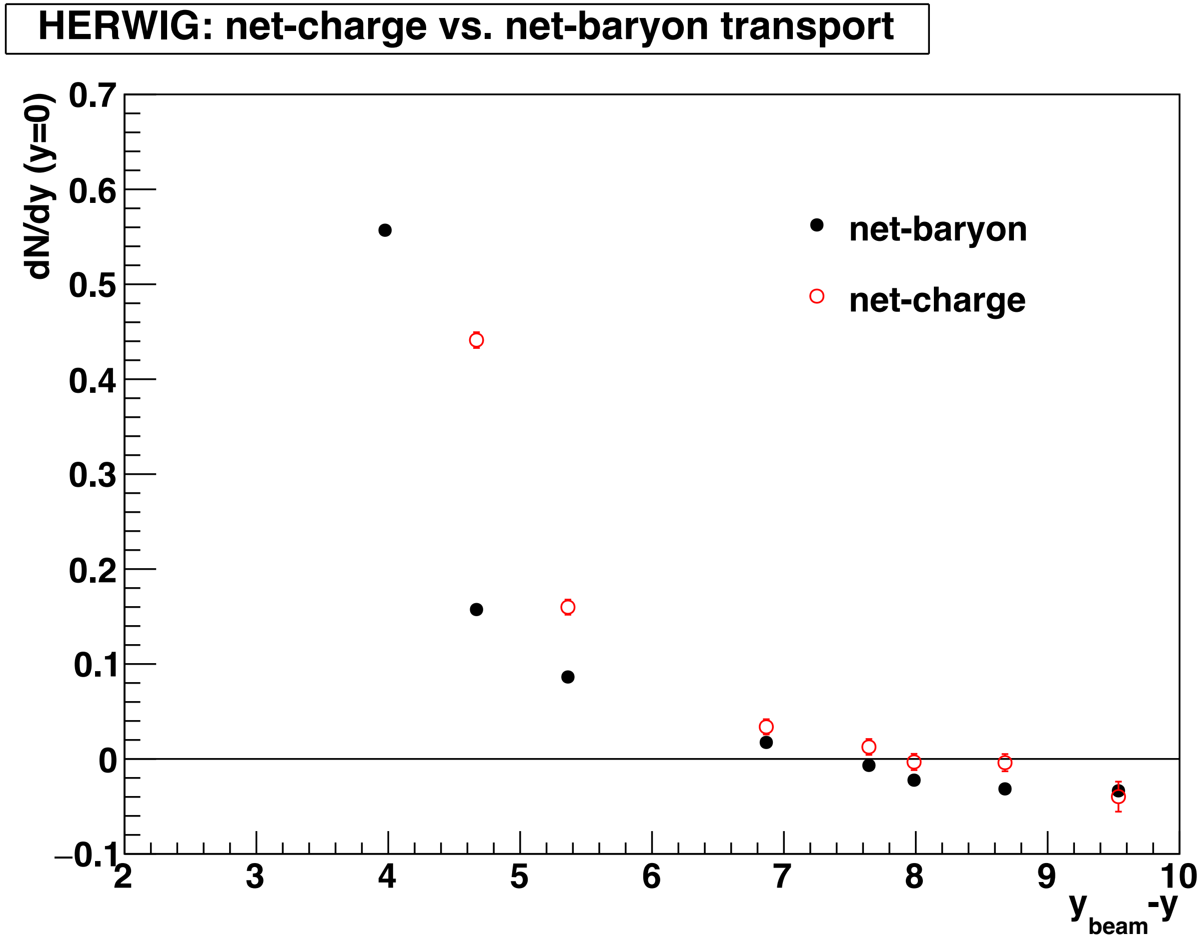
"These results are consistent with standard models of baryon-number transport and set tight limits on any additional contributions to baryon-number transfer over very large rapidity intervals in pp collisions."

ALICE, PRL105 (2010)



red curve consistent with α_B =0.61

Rongrong Ma (BNL)



HERWIG and PYTHIA 6: α_B ~=1.6-2.5

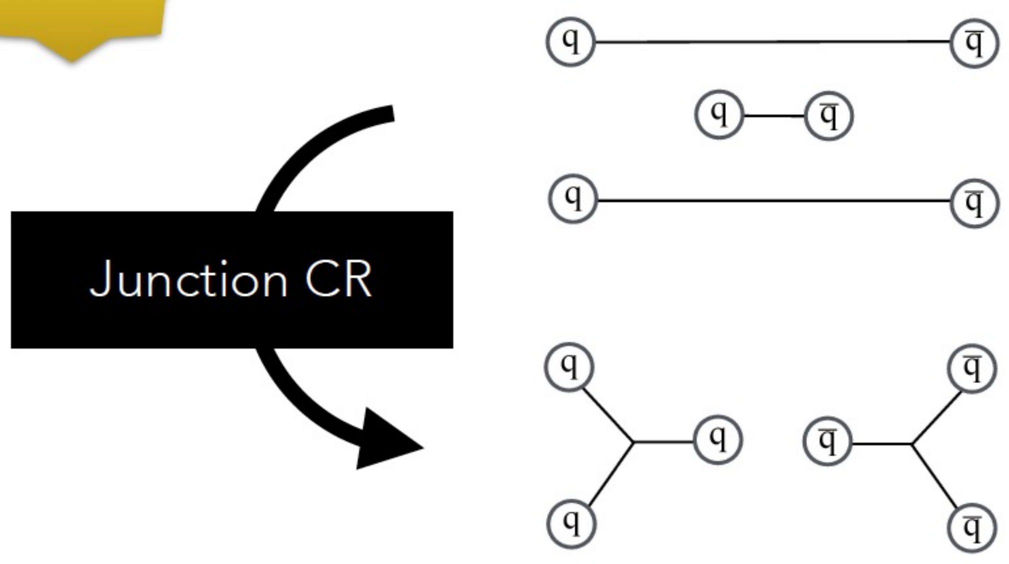
Negative (pbar>p) at LHC energy

“Final-State” baryon junction in PYTHIA 8.x

new!

Peter Skands, 2021

Illustrations by J. Altmann



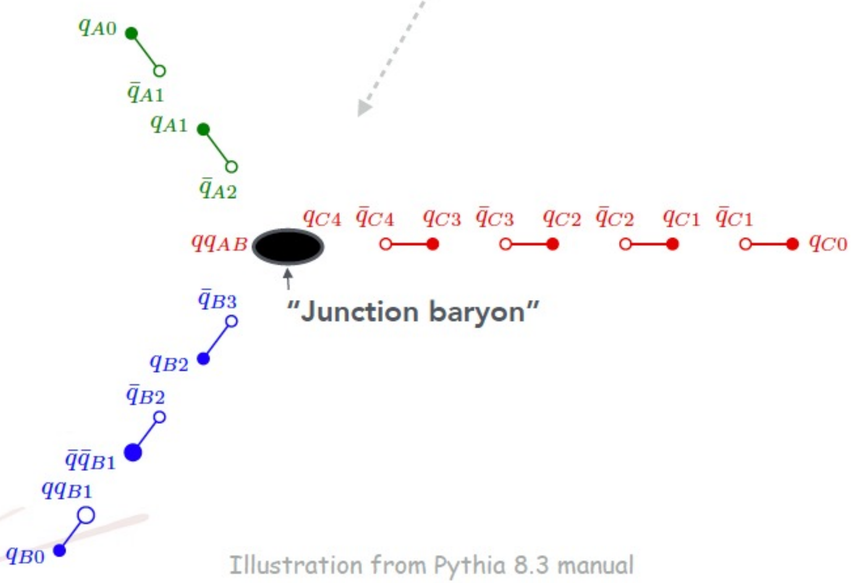


Illustration from Pythia 8.3 manual

Junction treatment (PYTHIA MANUAL 8.x)

A junction topology corresponds to an Y arrangement of strings i.e. where three string pieces have to be joined up in a junction. Such topologies can arise if several valence quarks are kicked out from a proton beam, or in baryon-number-violating SUSY decays. Special attention is necessary to handle the region just around the junction, where the baryon number topologically is located. The junction fragmentation scheme is described in [Sjo03, 2003]. The parameters in this section should not be touched except by experts.

What do we know about e+p collisions?

- RHIC nuclear energy is at a sweet spot
  - U+U, Au+Au, O+O, Cu+Au, Cu+Cu, He3+Au, d+Au,p+Au, p+p
- LHC and HERA energy are too high with small baryon excess (<1%)
- Isobar collisions at EIC with low Q^2 and low-p_t PID to study the charge and baryon transports

Artru & Mekhfi, NPA 1991

"unpolarized and polarized electroproduction of fast baryons

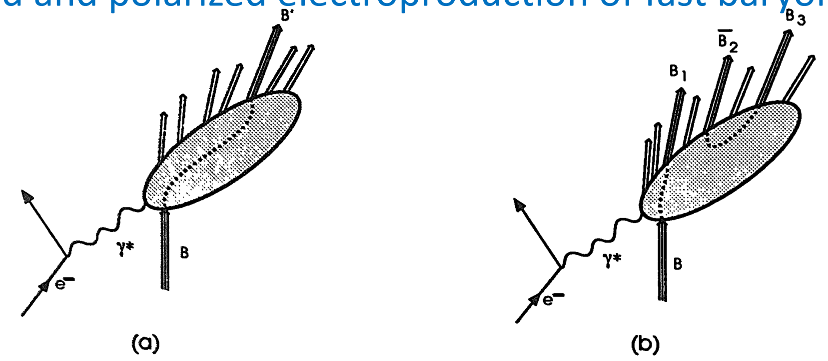


Figure 1. Main mechanisms of electroproduction of fast baryons.

The first mechanism dominates in the region (see Fig. 2)

$$Y < Y_C \simeq \beta^{-1} \ln(\beta/b) \qquad (3)$$

(Y_C corresponds to Δ_1 in Ref.1). The second one dominates for $Y > Y_C$. In this talk I will show that both mechanisms can reveal interesting features of hadronic physics (I shall consider only events with low transverse momenta).

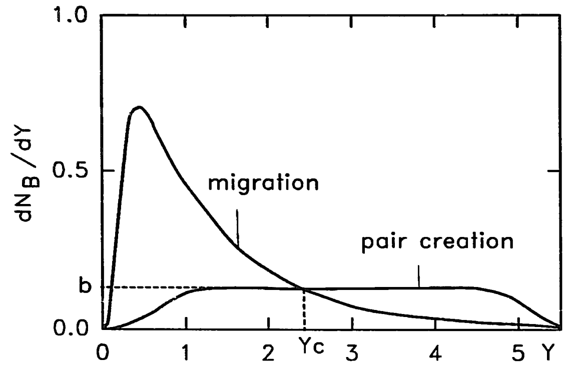


Figure 2. Rapidity spectrum: (a) of the migration mechanism, (b) of the pair creation mechanism.

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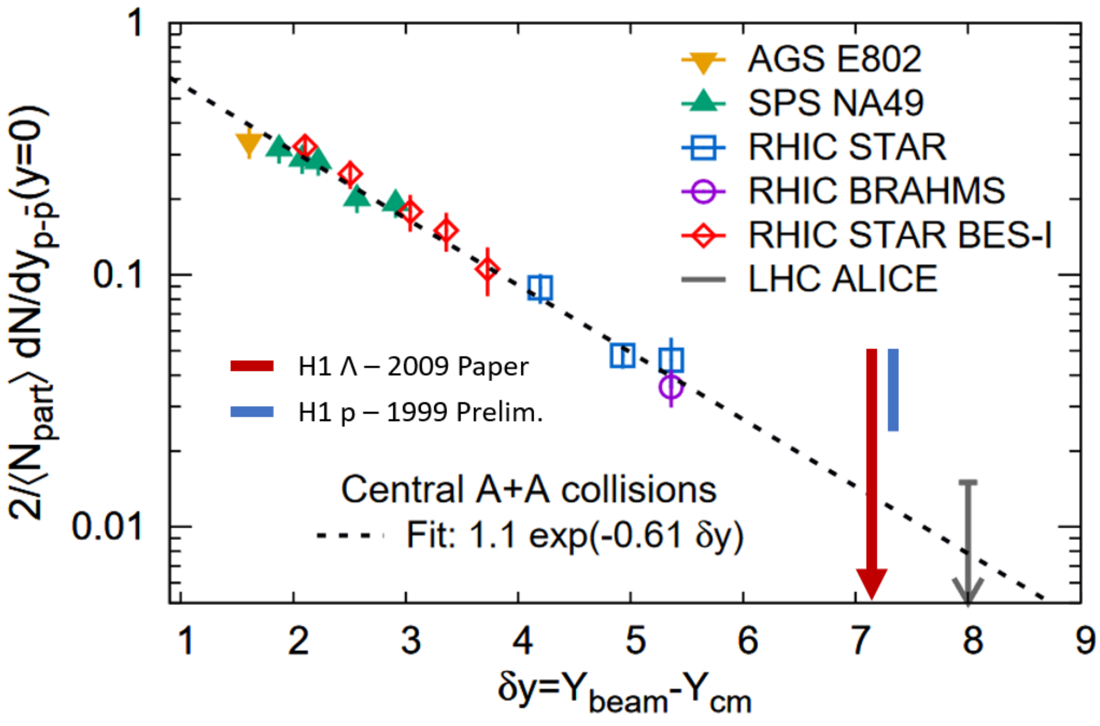
D. Brandenburg, N. Lewis, P. Tribedy, Z. Xu, arXiv:2205.05685; Henry Klest (SBU) HERA data



Measurement of the Baryon-Antibaryon Asymmetry in Photoproduction at HERA
C. Adloff et al. (H1 Collaboration), ICHEP 1998

Baryon stopping at HERA: Evidence for gluonic mechanism
Boris Kopeliovich (Heidelberg, Max Planck Inst. and Dubna, JINR), Bogdan Povh (Heidelberg, Max Planck Inst.)
Published in: *Phys.Lett.B* 446 (1999) 321-325 • e-Print: hep-ph/9810530 [hep-ph]