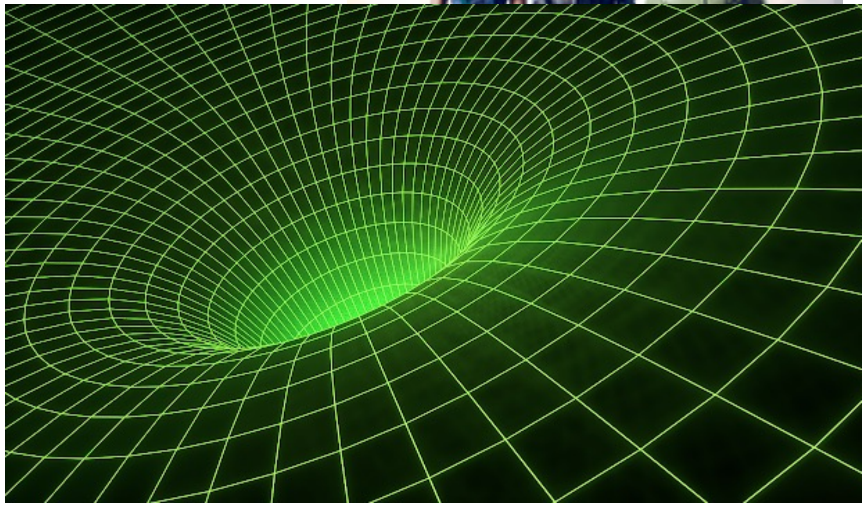
HIDDEN degrees of freedom in heavy-ion collisions

Zhangbu Xu (BNL)

- Global Spin Polarization
- Other polarizations in heavy-ion collisions
- Spin Interference Enabled Nuclear Tomography
- Connections among the polarizations?
- Do gluons carry baryon number?
  What are the evidence against it?
  Propose three ways of testing



60大寿生日快乐，新年！

中国STAR组成立10th十周年纪念

ph by the China-STAR Collaboration

重要事件和人物照片

International Workshop of Relativistic Heavy Ion Collision and Quark Matter Physics , April 5-8, 1999, Wuhan. Dr. Tim Hallman visited China for the first time.

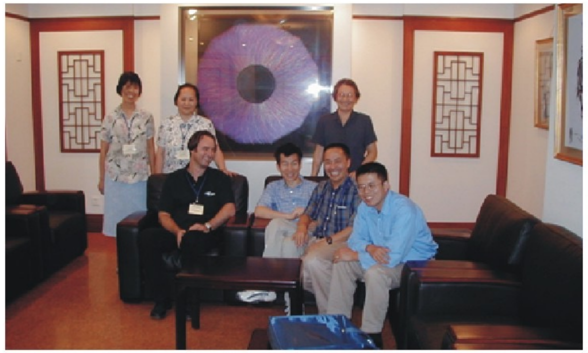
Prof. Naiyan Wang (Academician of CAS and the former deputy director of NNSFC), Dr. Qing Chang (Director general of International Cooperation Bureau of NNSFC), Dr. Peiwen Ji (Director general of the Department of Mathematics and Physics of NNSFC) visited Prof. T. D. Lee at BNL.

Photo for the representatives of NNSFC, Prof. Xin-nian Wang and Prof. Feng Liu at LBNL

中国STAR组成立10th十周年纪念

各种会议照片

June 17–18, 2002 The international workshop "QCD Theory and RHIC Physics"workshop was held by CCNU in Wuhan.

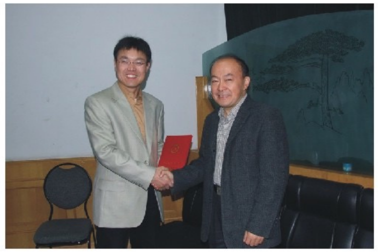


Aug.2002 The first international workshop "QCD and RHIC Experimental Physics" was held by CCAST. Later this meeting became an annual workshop in this field, alternately organized by the institutions or universities with STAR membership every year. Participants visited the CCAST.

Aug.2004, "Relativistic Heavy–Ion Collisions and Low Energy Hadron Physics" Workshop at Weihai.

中国STAR组成立10th十周年纪念

授聘教授与讲习班



Oct.2006 USTC Vice–President Ding Li awarded LBNL Prof. Xin–nian Wang the certificate of USTC Guest Professor.

June 2006 USTC Secretary Wu Xu awarded BNL Dr. Zhangbu Xu the certificate of USTC Guest Professor.

Although we do not overlap in terms of physics interests, we do share many other common interests.

He is one of the facilitators for China-STAR TOF Project, on which I have worked in last 20 years.

Connection to Xin-Nian and this workshop

Globally Polarized Quark-Gluon Plasma in Noncentral $A + A$ Collisions

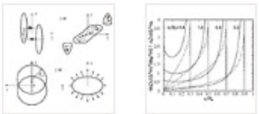
Zuo-Tang Liang and Xin-Nian Wang

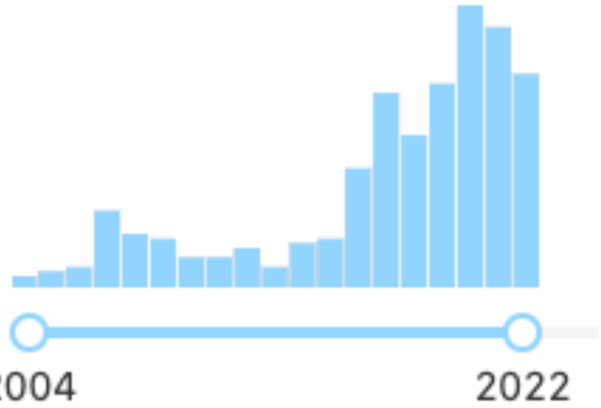
Phys. Rev. Lett. **94**, 102301 – Published 14 March 2005; Erratum Phys. Rev. Lett. **96**, 039901 (2006)

Article | References | Citing Articles (251) | PDF | HTML | Export Citation

ABSTRACT

Produced partons have a large local relative orbital angular momentum along the direction opposite to the reaction plane in the early stage of noncentral heavy-ion collisions. Parton scattering is shown to polarize quarks along the same direction due to spin-orbital coupling. Such global quark polarization will lead to many observable consequences, such as left-right asymmetry of hadron spectra and global transverse polarization of thermal photons, dileptons, and hadrons. Hadrons from the decay of polarized resonances will have an azimuthal asymmetry similar to the elliptic flow. Global hyperon polarization is studied within different hadronization scenarios and can be easily tested.





ELSEVIER

Physics Letters B

Volume 443, Issues 1–4, 10 December 1998, Pages 45-50

Baryon number transport via gluonic junctions

Stephen E. Vance a, Miklos Gyulassy a, Xin-Nian Wang b

Show more

\+ Add to Mendeley Share Cite

https://doi.org/10.1016/S0370-2693(98)01338-0

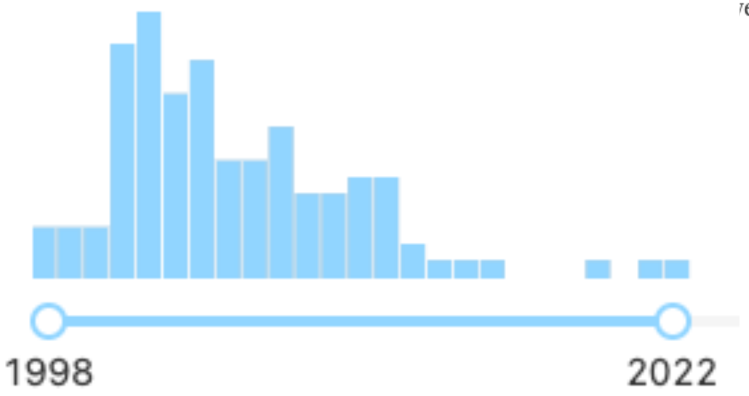
Get rights and content

Abstract

A novel non-perturbative gluon junction mechanism is introduced within the HIJING/B nuclear collision event generator to calculate baryon number transport and hyperon production in pA and AA collisions. This gluonic mechanism can account for the observed large mid-rapidity valence baryon yield in Pb+Pb at 160 AGeV and predicts high initial baryon densities at RHIC. However, the highly

e ... ved in this

re



"Science, however, is never conducted as a popularity contest..." --- Michio Kaku

BUT citations ARE

The early days of Global Polarization (2005-2008)

Two plenary and one parallel talks

Quark Matter 2006 Conference

Yu-Gang Ma, En-Ke Wang, Xu Cai, Huan-Zhong Huang, Xin-Nian Wang and Zhi-Yuan Zhu

− Close abstract   View article   PDF

The Quark Matter 2006 conference was held on 14–20 November 2006 at the Shanghai Science Hall of the Shanghai Association of Sciences and Technology in Shanghai, China. It was the 19th International Conference on Ultra-Relativistic Nucleus–Nucleus Collisions. The conference was organized jointly by SINAP (Shanghai Institute of Applied Physics, Chine Academy of Sciences (CAS)) and CCNU (Central China Normal University, Wuhan). Over 600 scientists from 32 countrie

Global polarization of QGP in non-central heavy-ion collisions at high energies

Zuo-tang Liang

+ Open abstract   View article   PDF

Spin alignment of K^{*0}(892) and φ(1020) mesons in Au+Au and p+p collisions at $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$

J H Chen and (forthe STAR Collaboration)

+ Open abstract   View article   PDF

Centrality dependence of hyperon global polarization in Au+Au collisions at RHIC   S1099

I Selyuzhenkov and (for theSTAR Collaboration)

The early days of Global Polarization (2005-2008)

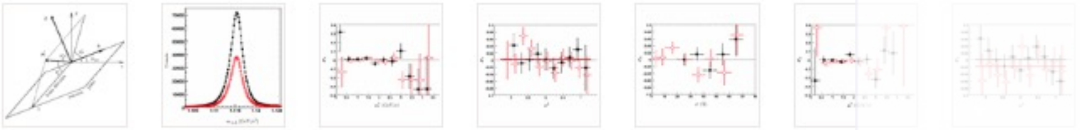
Global polarization measurement in Au+Au collisions

B. I. Abelev *et al.* (STAR Collaboration)
Phys. Rev. C **76**, 024915 – Published 29 August 2007; Erratum Phys. Rev. C **95**, 039906 (2017)

Article | References | Citing Articles (91) | PDF | HTML | Export Citation

ABSTRACT

The system created in noncentral relativistic nucleus-nucleus collisions possesses large orbital angular momentum. Because of spin-orbit coupling, particles produced in such a system could become globally polarized along the direction of the system angular momentum. We present the results of Λ and $\bar{\Lambda}$ hyperon global polarization measurements in Au+Au collisions at $\sqrt{s_{NN}} = 62.4$ and 200 GeV performed with the STAR detector at the BNL Relativistic Heavy Ion Collider (RHIC). The observed global polarization of Λ and $\bar{\Lambda}$ hyperons in the STAR acceptance is consistent with zero within the precision of the measurements. The obtained upper limit, $|P_{\Lambda,\bar{\Lambda}}| \leqslant 0.02$, is compared with the theoretical values discussed recently in the literature.



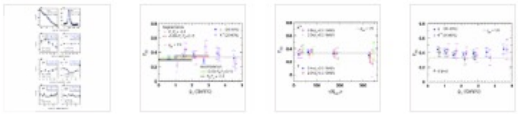
Spin alignment measurements of the $K^{*0}(892)$ and $\phi(1020)$ vector mesons in heavy ion collisions at $\sqrt{s_{NN}} = 200$ GeV

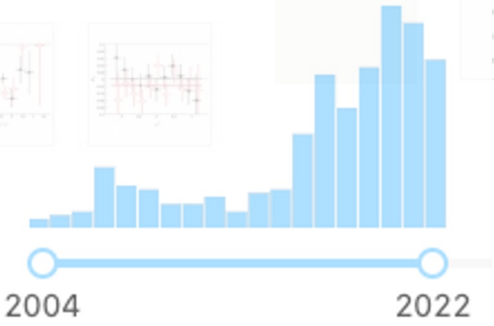
B. I. Abelev *et al.* (STAR Collaboration)
Phys. Rev. C **77**, 061902(R) – Published 12 June 2008

Article | References | Citing Articles (32) | PDF | HTML | Export Citation

ABSTRACT

We present the first spin alignment measurements for the $K^{*0}(892)$ and $\phi(1020)$ vector mesons produced at midrapidity with transverse momenta up to 5 GeV/c at $\sqrt{s_{NN}} = 200$ GeV at RHIC. The diagonal spin-density matrix elements with respect to the reaction plane in $\mathrm{Au}+\mathrm{Au}$ collisions are $\rho_{00} = 0.32 \pm 0.04$ (stat) ± 0.09 (syst) for the K^{*0} $(0.8 < p_T < 5.0$ GeV/$c)$ and $\rho_{00} = 0.34 \pm 0.02$ (stat) ± 0.03 (syst) for the ϕ $(0.4 < p_T < 5.0$ GeV/$c)$ and are constant with transverse momentum and collision centrality. The data are consistent with the unpolarized expectation of 1/3 and thus no evidence is found for the transfer of the orbital angular momentum of the colliding system to the vector-meson spins. Spin alignments for K^{*0} and ϕ in $\mathrm{Au}+\mathrm{Au}$ collisions were also measured with respect to the particle's production plane. The ϕ result, $\rho_{00} = 0.41 \pm 0.02$ (stat) ± 0.04 (syst), is consistent with that in $p+p$ collisions, $\rho_{00} = 0.39 \pm 0.03$ (stat) ± 0.06 (syst), also measured in this work. The measurements thus constrain the possible size of polarization phenomena in the production dynamics of vector mesons.



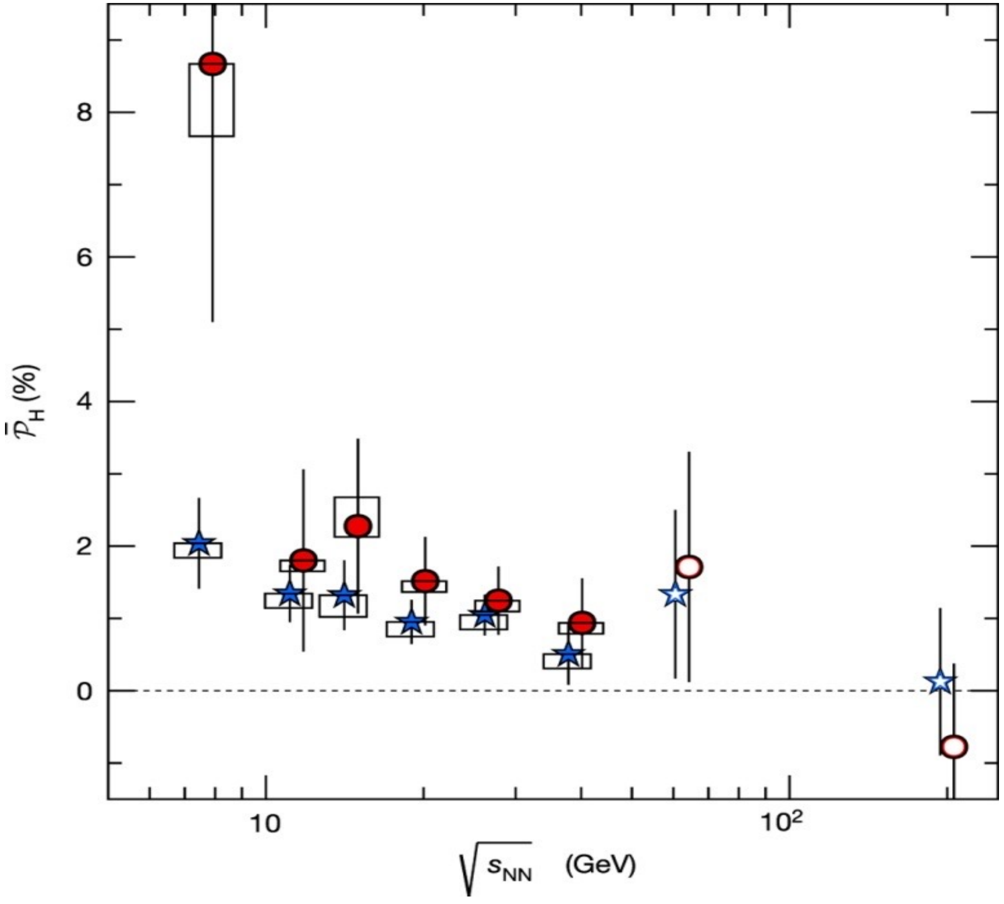


Observation of Global Hyperon Polarization (2017)

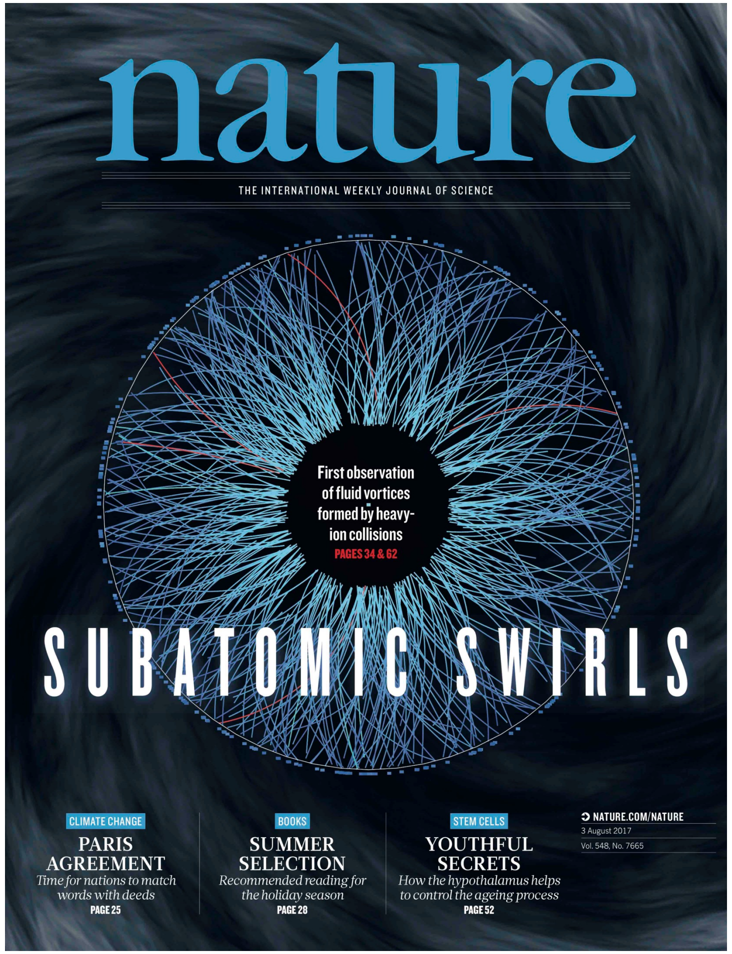
nature

This is quite a significant achievement

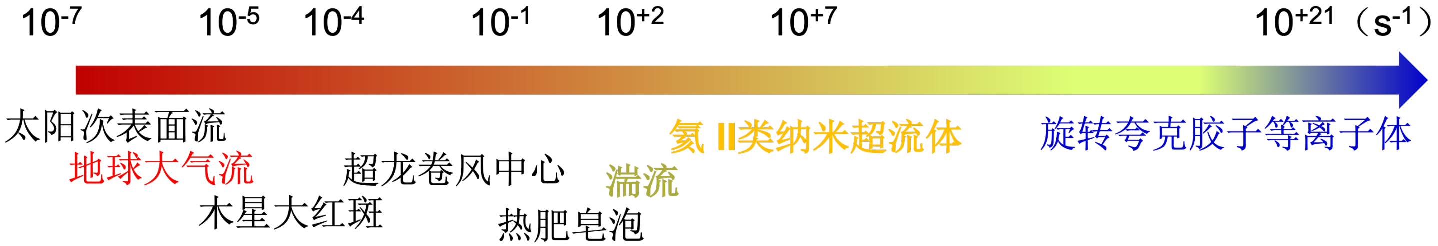
When I was invited to talk about GHP at this workshop,
I am clearly not an expert on this and my only connection to this is that
I was the spokesperson at that time.



L Adamczyk *et al.* *Nature* **548,** 62–65 (2017) doi:10.1038/nature23004

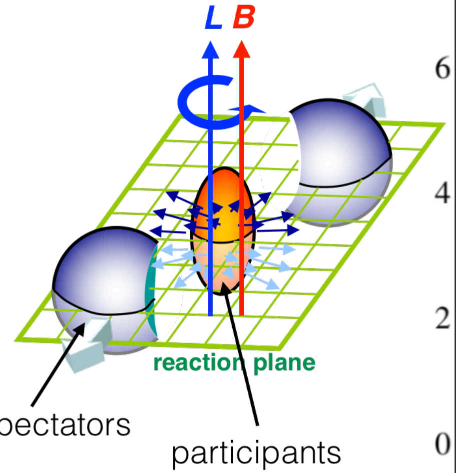


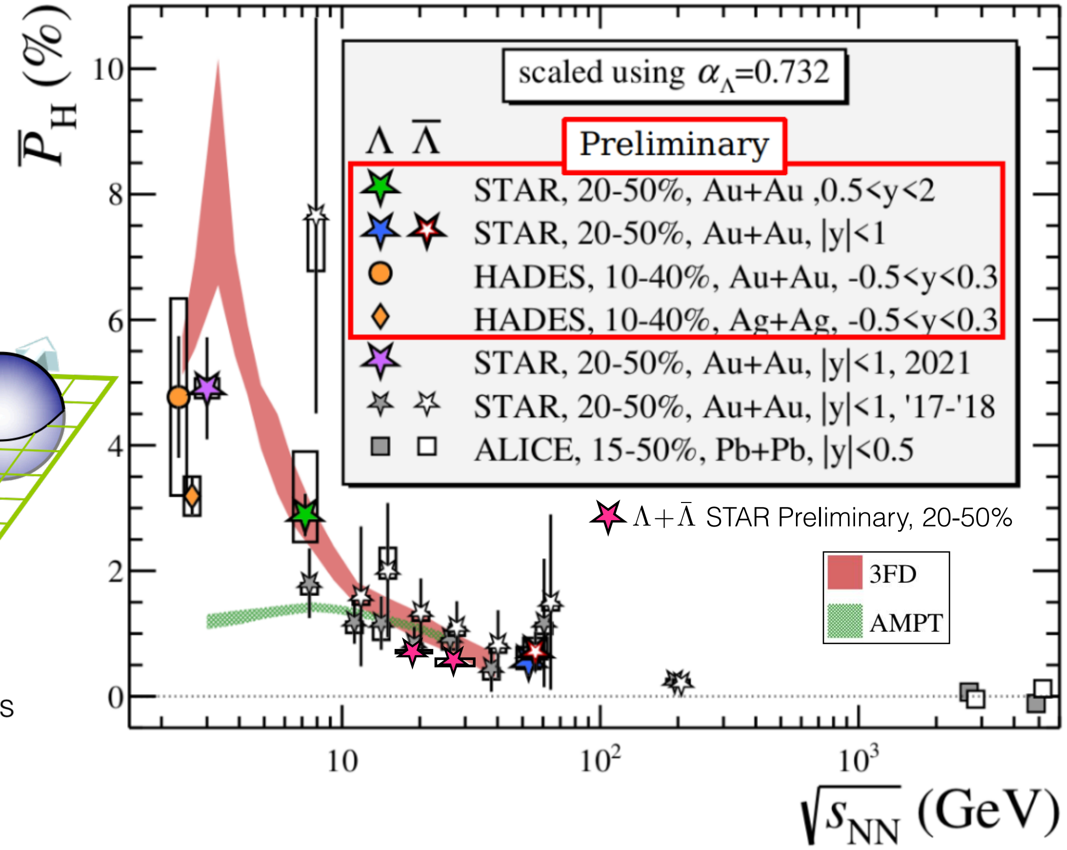
最旋流体



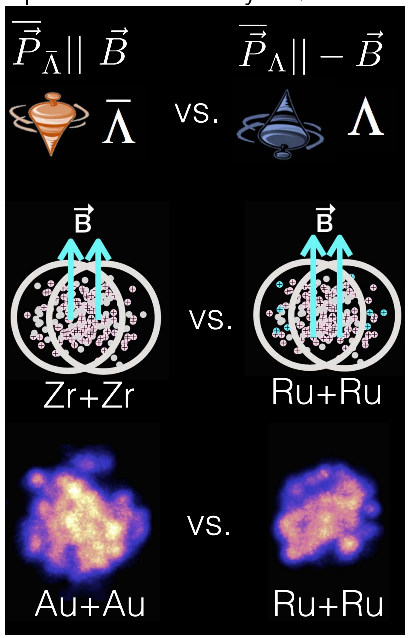
Global polarization

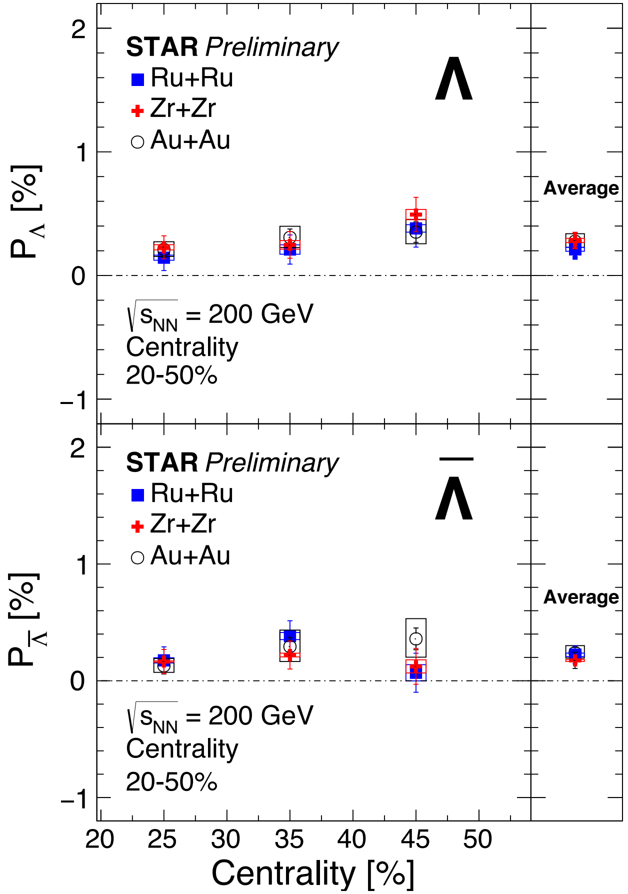
STAR, PRC104.L061901 (2021)
HADES, SQM2021





picture: P. Tribedy@QM2022

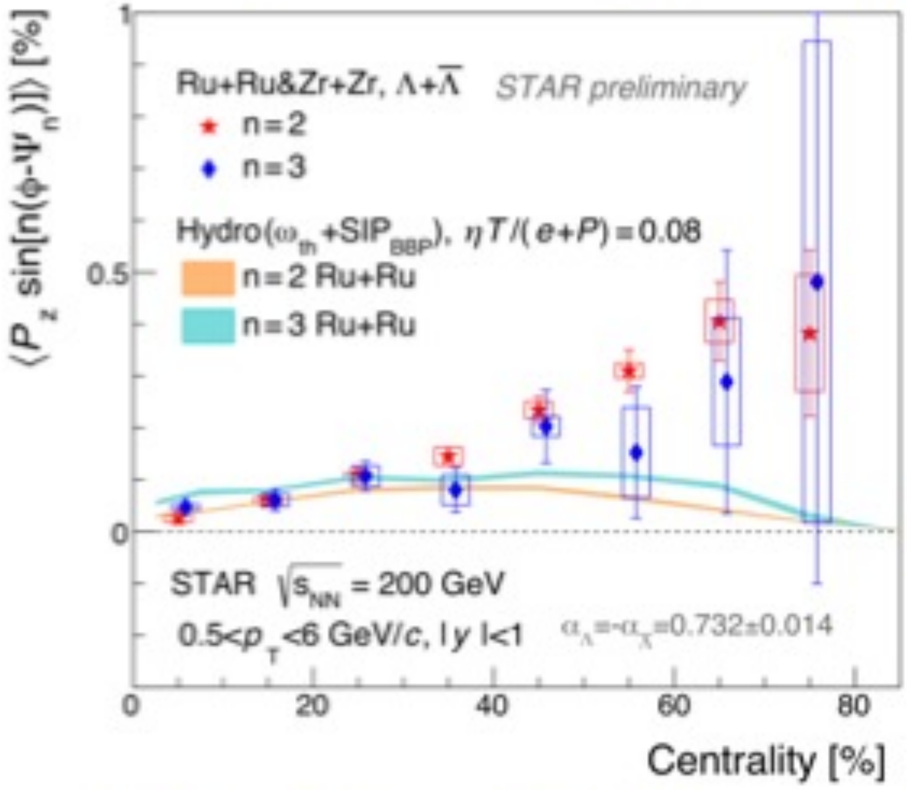


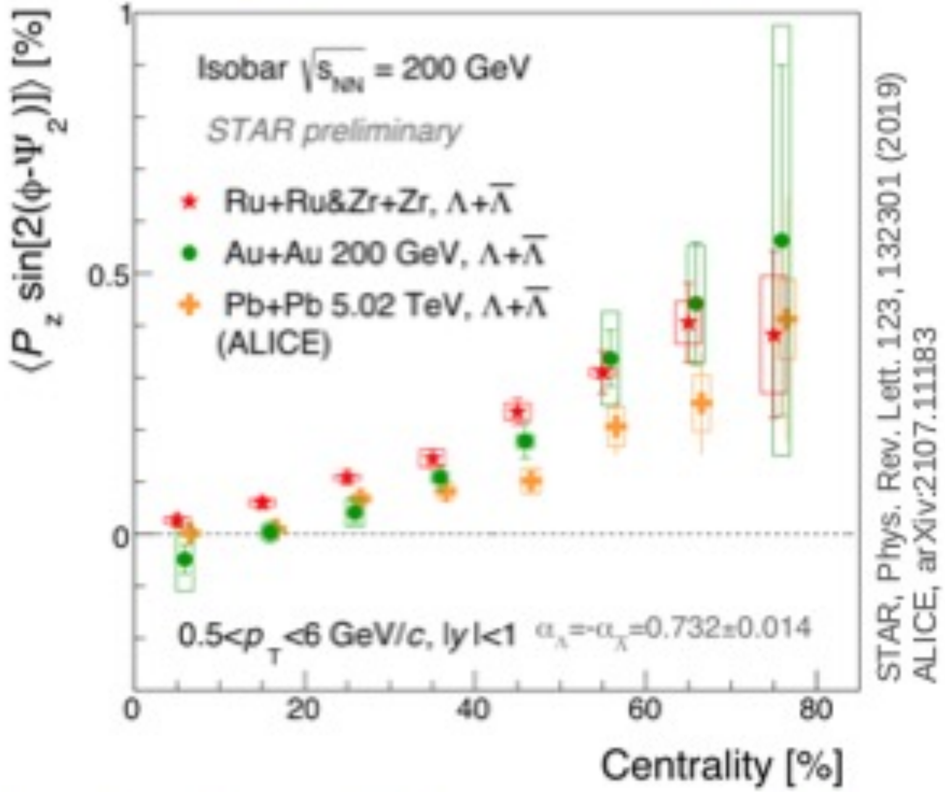


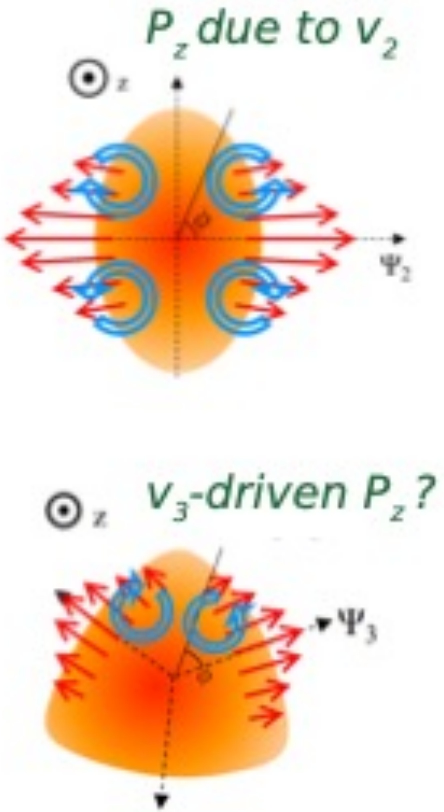
- Still increasing trend down to $\sqrt{s_{NN}}$ = 3 GeV (FXT). Results from BES-II (3, 7.2, 19.6, 27, 54.4 GeV) follow the global trend. More results will come!
- No colliding system size dependence nor splitting between Λ and anti-Λ in isobar collisions

Local hyperon polarization

- Anisotropic flow → Longitudinal polarization P_z (thermal vorticity + shear term)







→ 2nd and **3rd order** P_z increase with centrality and have comparable magnitude

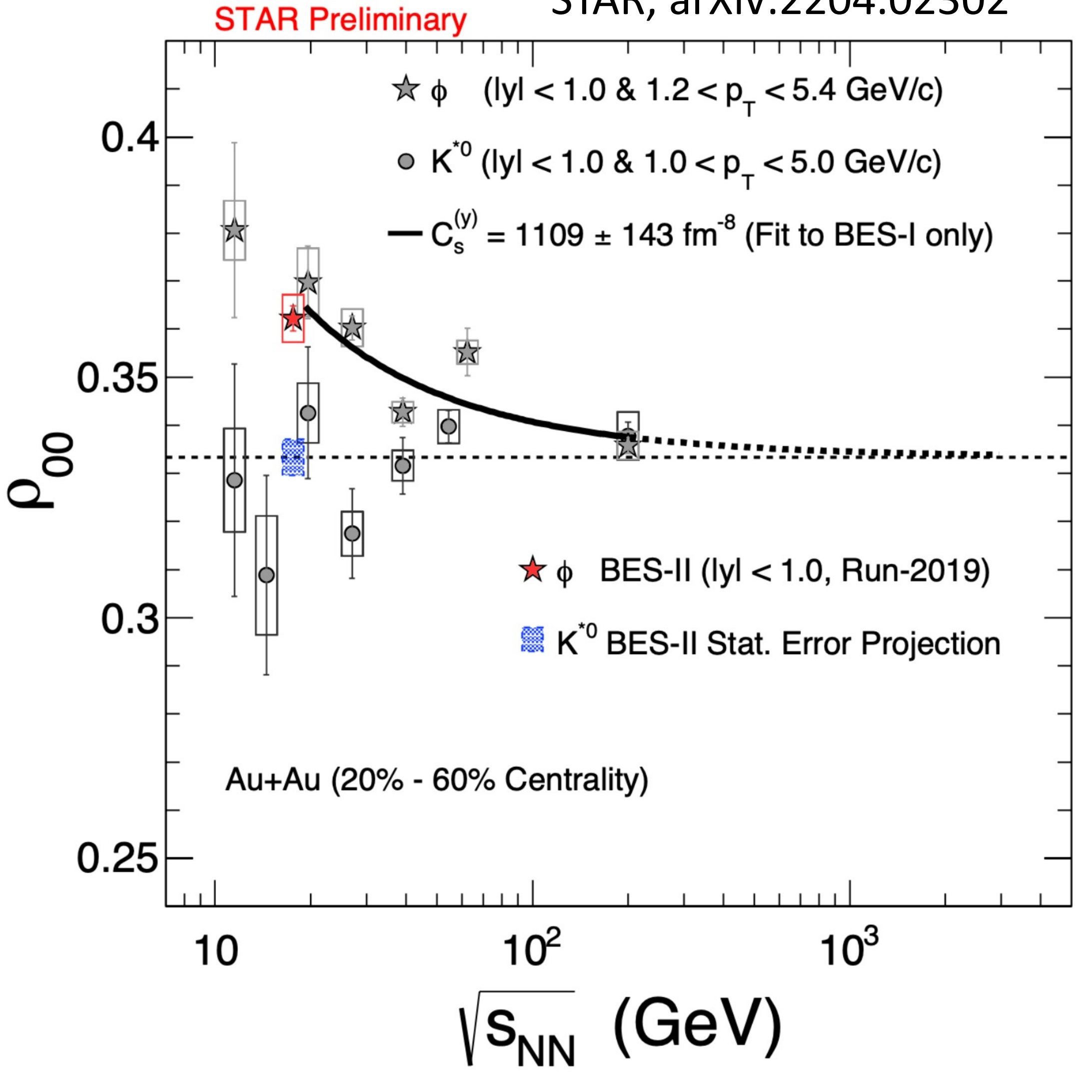
→ Additional constraint on shear viscosity

→ Similar P_z in isobar, Au+Au and Pb+Pb → hint of system size dependence rather than energy dependence ?

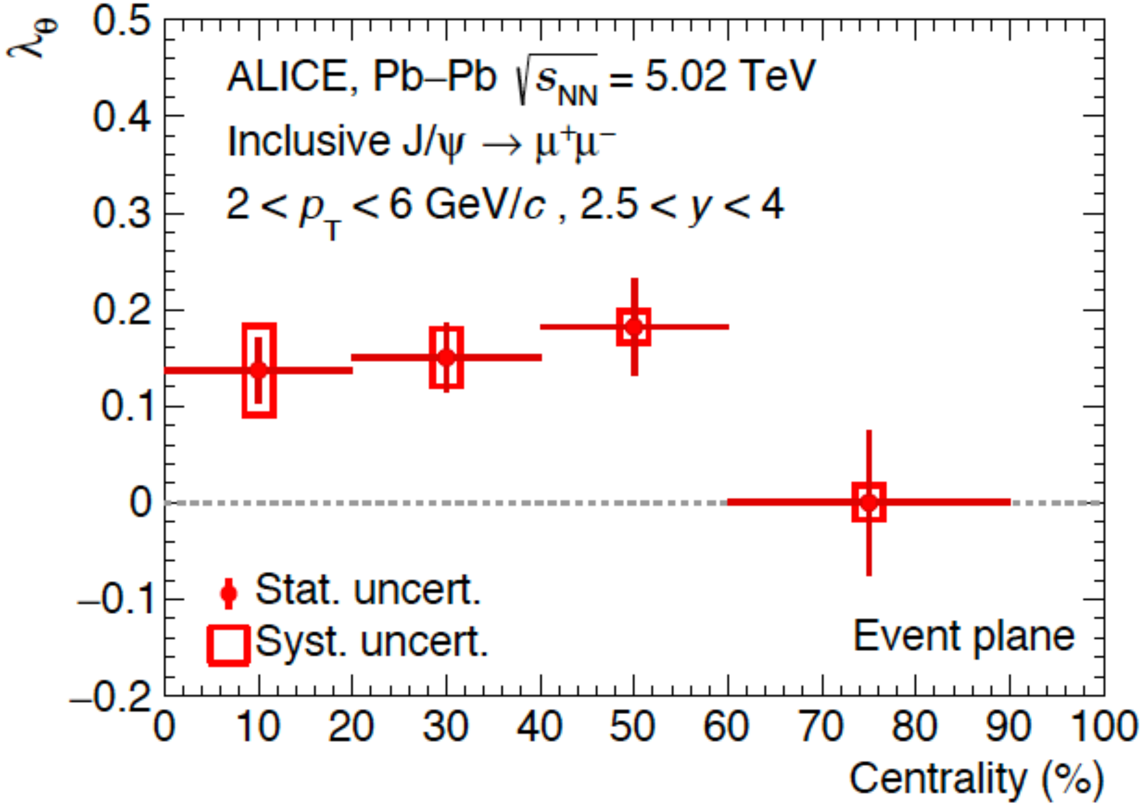
Xingrui Gou 14.6 2:20pm

Vector Meson Global Spin Alignment (2022)

STAR, arXiv:2204.02302



ALICE, arXiv:2204.10171



A zoo of Global Polarization Effects

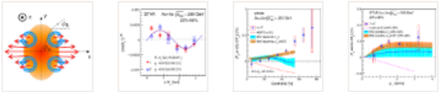
Polarization of Λ ($\bar{\Lambda}$) Hyperons along the Beam Direction in $\mathrm{Au}+\mathrm{Au}$ Collisions at $\sqrt{s_{NN}} = 200\ \mathrm{GeV}$

J. Adam *et al.* (STAR Collaboration)
Phys. Rev. Lett. **123**, 132301 – Published 27 September 2019

Article | References | Citing Articles (63) | PDF | HTML | Export Citation

ABSTRACT

The Λ ($\bar{\Lambda}$) hyperon polarization along the beam direction has been measured in $\mathrm{Au}+\mathrm{Au}$ collisions at $\sqrt{s_{NN}} = 200\ \mathrm{GeV}$, for the first time in heavy-ion collisions. The polarization dependence on the hyperons' emission angle relative to the elliptic flow plane exhibits a second harmonic sine modulation, indicating a quadrupole pattern of the vorticity component along the beam direction, expected due to elliptic flow. The polarization is found to increase in more peripheral collisions, and shows no strong transverse momentum (p_T) dependence at p_T greater than $1\ \mathrm{GeV}/c$. The magnitude of the signal is about 5 times smaller than those predicted by hydrodynamic and multiphase transport models; the observed phase of the emission angle dependence is also opposite to these model predictions. In contrast, the kinematic vorticity calculations in the blast-wave model tuned to reproduce particle spectra, elliptic flow, and the azimuthal dependence of the Gaussian source radii measured with the Hanbury Brown–Twiss intensity interferometry technique reproduce well the modulation phase measured in the data and capture the centrality and transverse momentum dependence of the polarization signal.



W

Fine structu

Nobel L

When the Nobel Prizes we
something of just two objects
the electron and the proton. A deluge of other « elementary » particles appeared after 1930; neutron, neutrino, μ meson, π meson, heavier mesons, and various hyperons. I have heard it said that « the finder of a new elementary particle used to be rewarded by a Nobel Prize, but such a discovery now ought to be punished by a $10,000 fine ».

Polarization of Λ and $\bar{\Lambda}$ Hyperons along the Beam Direction in Pb-Pb Collisions at $\sqrt{s_{NN}}$=5.02 TeV #6
ALICE Collaboration • Shreyasi Acharya (Calcutta, VECC) et al. (Jul 23, 2021)
Published in: *Phys.Rev.Lett.* 128 (2022) 17, 172005 • e-Print: 2107.11183 [nucl-ex]

Global polarization of $\Lambda\bar{\Lambda}$ hyperons in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 and 5.02 TeV #11
ALICE Collaboration • Shreyasi Acharya (Calcutta, VECC) et al. (Sep 3, 2019)
Published in: *Phys.Rev.C* 101 (2020) 4, 044611 • e-Print: 1909.01281 [nucl-ex]

Measurement of the J/ψ polarization with respect to the event plane in Pb-Pb collisions at the LHC #2
ALICE Collaboration (Apr 21, 2022)
e-Print: 2204.10171 [nucl-ex]

Measurement of global polarization of Λ hyperons in few-GeV heavy-ion collisions #1
HADES Collaboration • R. Abou Yassine (Darmstadt, Tech. U. and IJCLab, Orsay) et al. (Jul 11, 2022)
e-Print: 2207.05160 [nucl-ex]

Observation of Global Spin Alignment of phi and K*0 Vector Mesons in Nuclear Collisions
Submitted Apr. 4, 2022
e-Print Archives (2204.02302) : **Abstract | PS | PDF**
Data and figures (pub id: 377): click here

Global Lambda-hyperon polarization in Au+Au collisions at sqrt{sNN} =3 GeV
Submitted Aug. 4, 2021 , published Dec. 21, 2021
Phys. Rev. C **104** (2021) 61901
e-Print Archives (2108.00044) : **Abstract | PS | PDF**
SLAC-Spires HEP: **Entry**
Journal article: **Phys. Rev. C server**
Data and figures (pub id: 359): click here

Global polarization of Xi and Omega hyperons in Au+Au collisions at sqrt{s_{NN}} = 200 GeV
Submitted Dec. 28, 2020 , published Apr. 22, 2021
Phys. Rev. Lett. **126** (2021) 162301
e-Print Archives (2012.13601) : **Abstract | PS | PDF**
SLAC-Spires HEP: **Entry**
Journal article: **Phys. Rev. Lett. server**
Data and figures (pub id: 344): click here

Global polarization of Lambda hyperons in Au+Au collisions at sqrt(sNN)=200 GeV
Submitted May. 11, 2018 , published Jul. 23, 2018
Phys. Rev. C **98** (2018) 14910
e-Print Archives (1805.04400) : **Abstract | PS | PDF**
SLAC-Spires HEP: **Entry**
Journal article: **Phys. Rev. C server**
Data and figures (pub id: 279): click here

Erratum: Global polarization measurement in Au + Au collisions
Submitted Jan. 24, 2017 , published Mar. 23, 2017
Phys. Rev. C **95** (2017) 039906
SLAC-Spires HEP: **Entry**
Journal article: **Phys. Rev. C server**

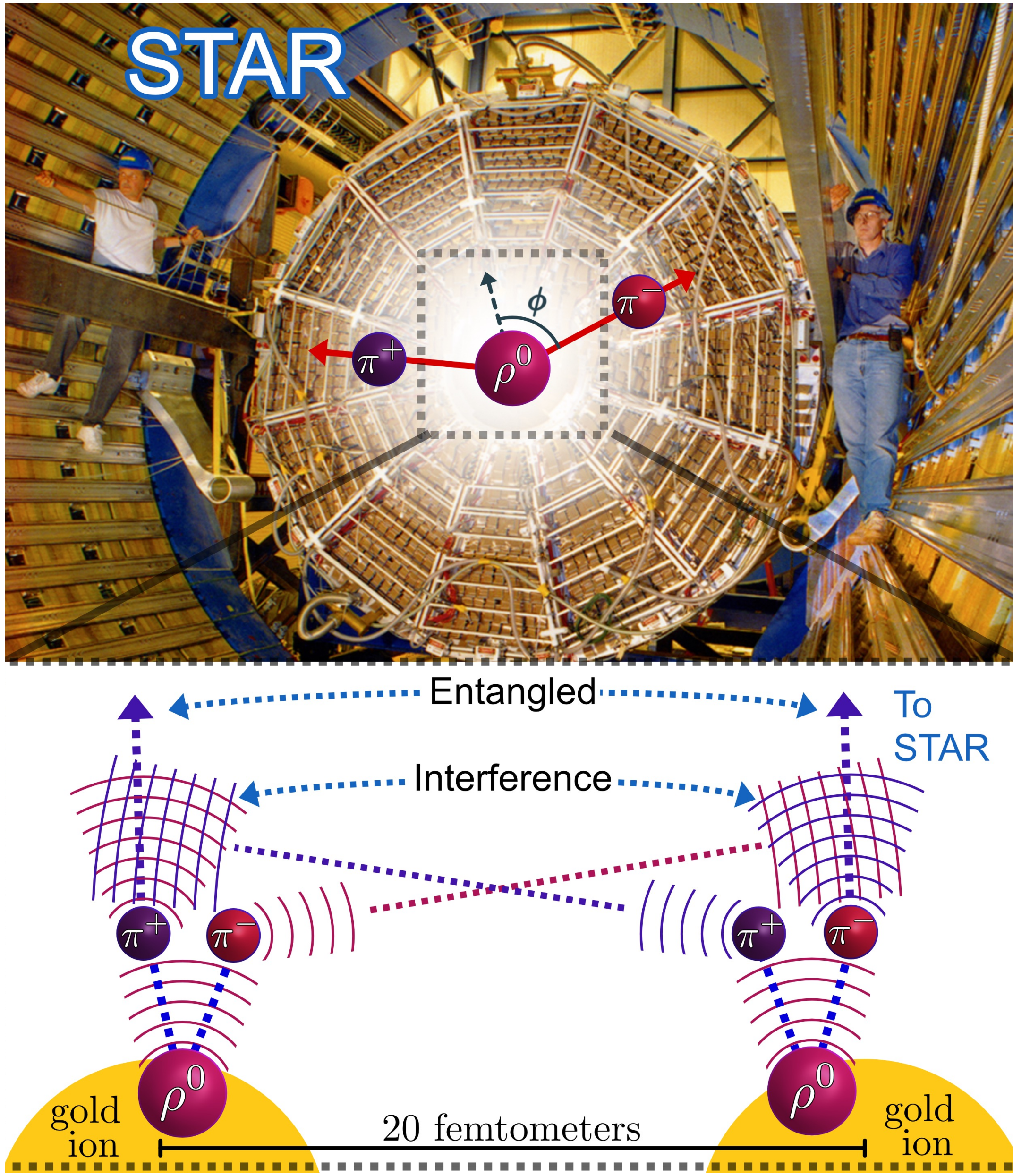
Global Lambda hyperon polarization in nuclear collisions: evidence for the most vortical fluid
Submitted Jan. 21, 2017 , published Aug. 2, 2017
Nature **548** (2017) 62
e-Print Archives (1701.06657) : **Abstract | PS | PDF**
SLAC-Spires HEP: **Entry**
Journal article: **Nature server**
Data and figures (pub id: 260): click here

Every Effect requires a different explanation

phenomenon	facility	feature	Theory		
Global Hyperon Polarization vs beam energy	RHIC, LHC, SIS	~1% decrease with energy	OAM, Vorticity	Reasonable agreement	Hadron, QGP, same effect?
GHP vs centrality	RHIC, LHC	Increase toward peripheral	Not explained		
GHP vs pt					
Pz polarization	RHIC, LHC	Positive Sine modulation	Additional shear viscosity	Resolve the sign puzzle	
Vs v2, v3 polarization	RHIC	Increase toward peripheral			
VM Alignment	RHIC	K*=0, ϕ positive	Additional strong force field	Qualitative	
VM alignment	LHC	ϕ=0, K* negative			
J/Ψ alignment	LHC	Few %			
Rapidity	Not measured		Different predictions		

There seems to lack a consistent picture

Spin Interference Enabled Nuclear Tomography

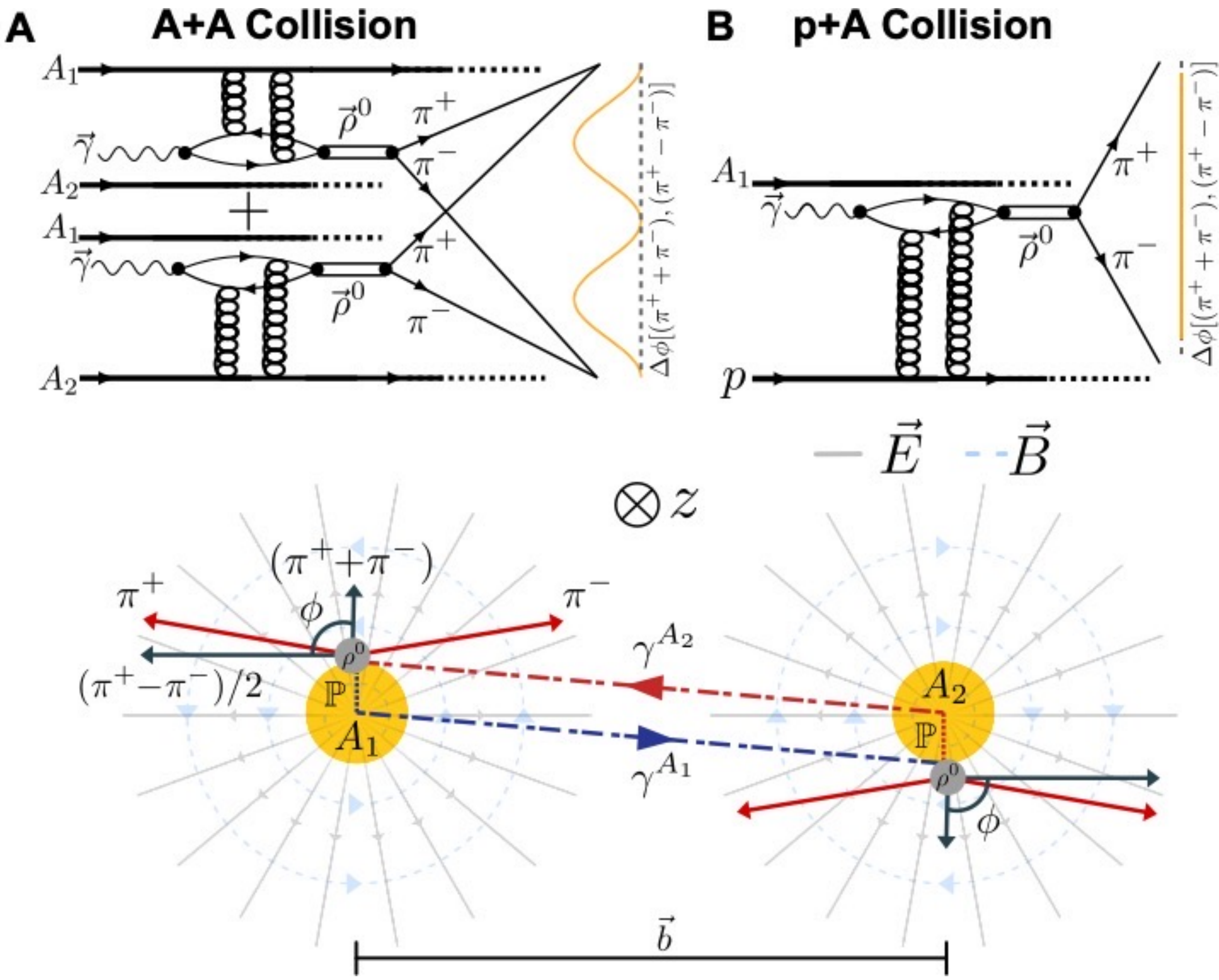


- Teaser:
  Polarized photon-gluon fusion reveals quantum wave interference of non-identical particles and shape of high-energy nuclei

STAR, arXiv:2204.01625

Three Ingredients

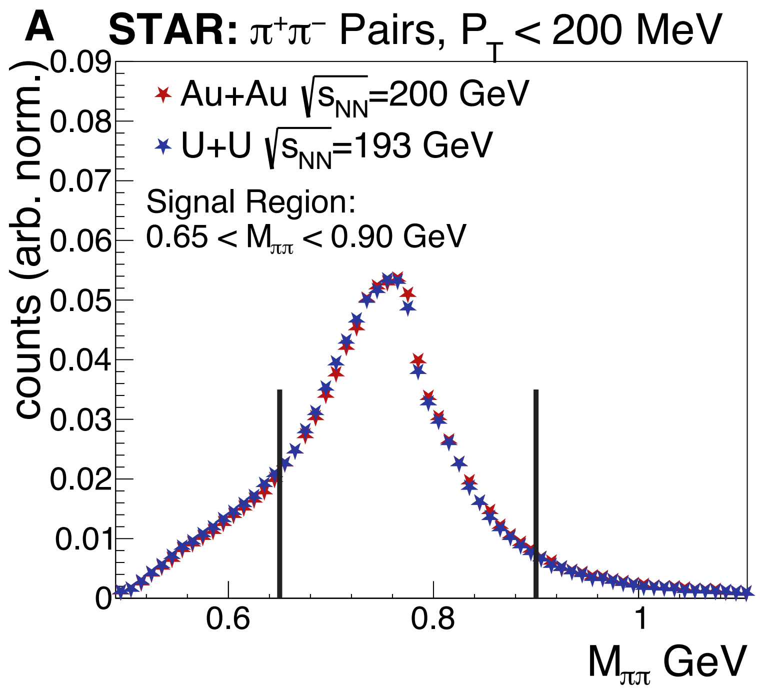
- Linearly Polarized photoproduction of vector meson
- At a distance with two wavefunctions (180^{o} rotation symmetry)
- Entanglement between $\pi^{\pm}$ from ρ decay and interference between identical pion wavefunction

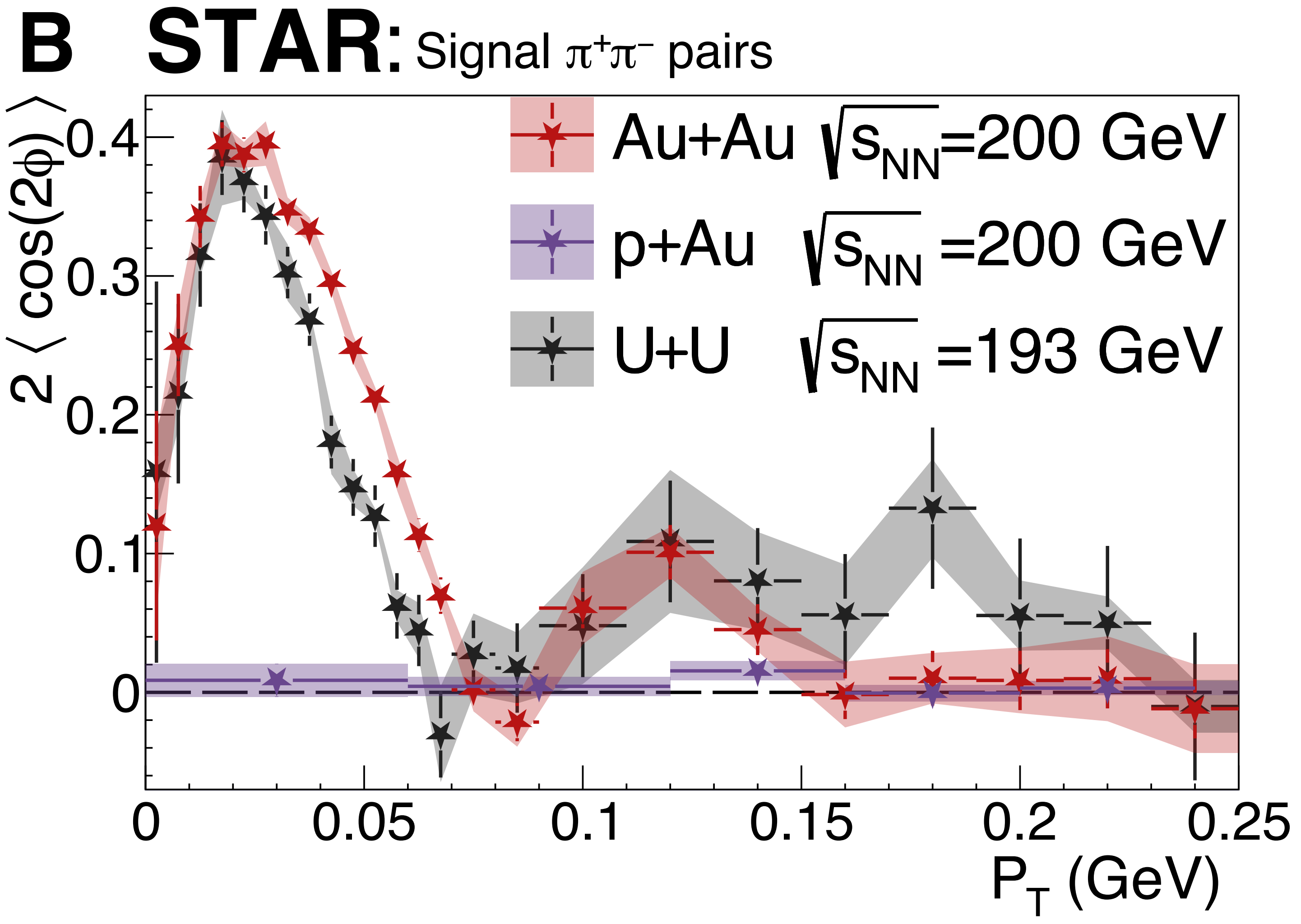


IF I have said that this is what reality is without any experimental evidence, most people would have thought that I am crazy.

> "Truth is Stranger than Fiction,
> but it is because Fiction is obligated
> to stick to possibilities; Truth isn't."
> – Mark Twain

$\Delta\phi$ in Au+Au and U+U Collisions





Quantify the difference in strength for Au+Au vs. U+U via a fit:

$$f(\Delta\phi) = 1 + a\ \cos 2\Delta\phi$$

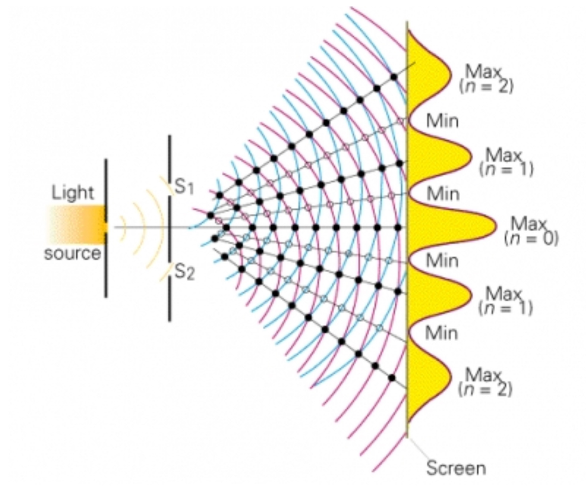
Au+Au : $a = 0.292 \pm 0.004$ (stat) ± 0.004 (syst.)
U+U : $a = 0.237 \pm 0.006$ (stat) ± 0.004 (syst.)
Difference of 4.3σ (stat. & syst.):

arXiv:2204.01625

- Interference effect is sensitive to the nuclear geometry (gluon distribution) – difference between Au and U

Novel Form of Quantum Interference

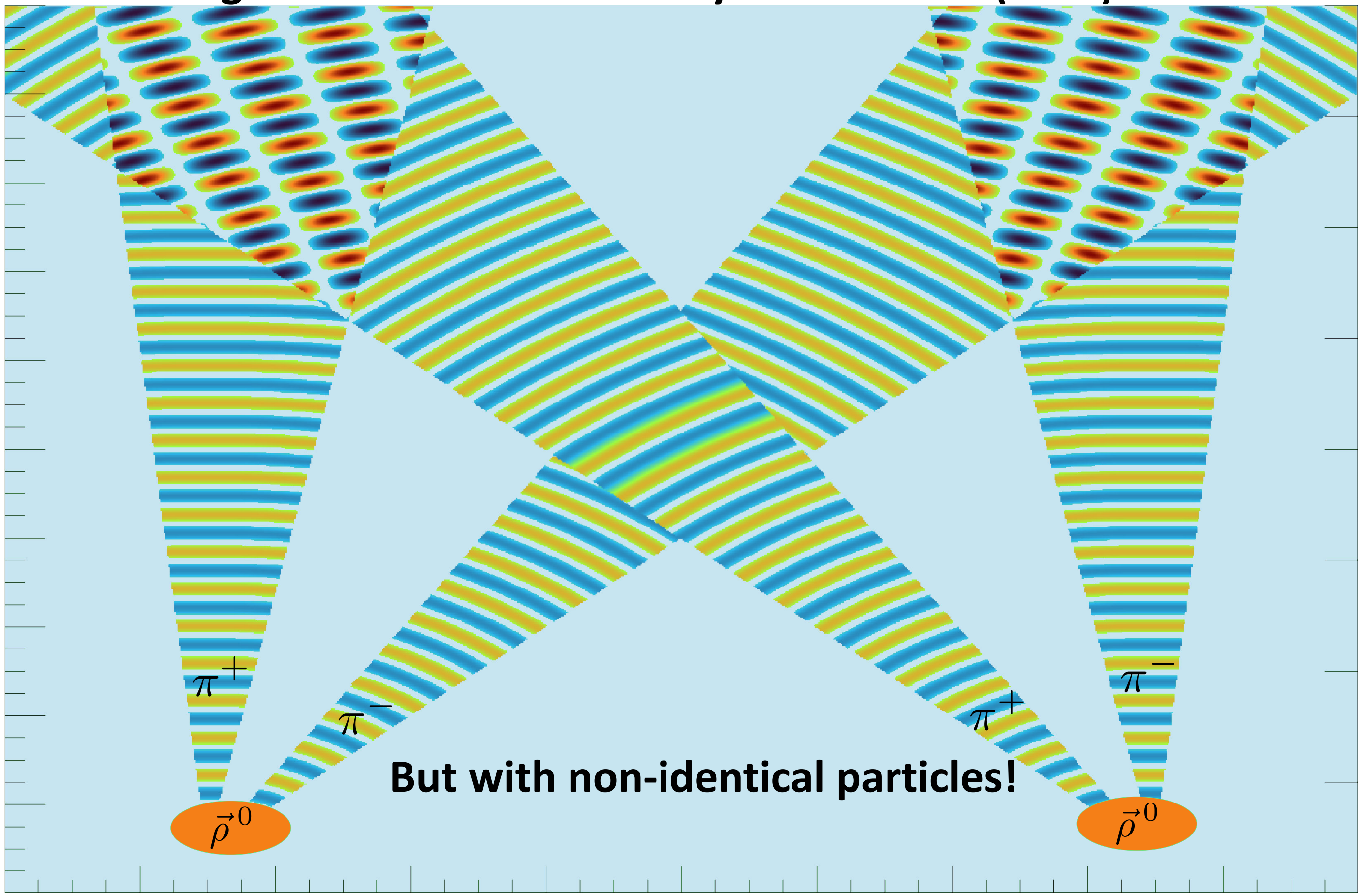
Similar to double-slit experiment



BUT

Interference occurs between **distinguishable** particles

Entanglement Enabled Intensity Interference (E^2I^2)

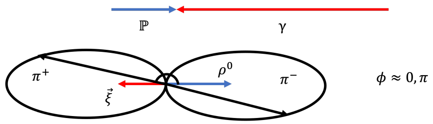


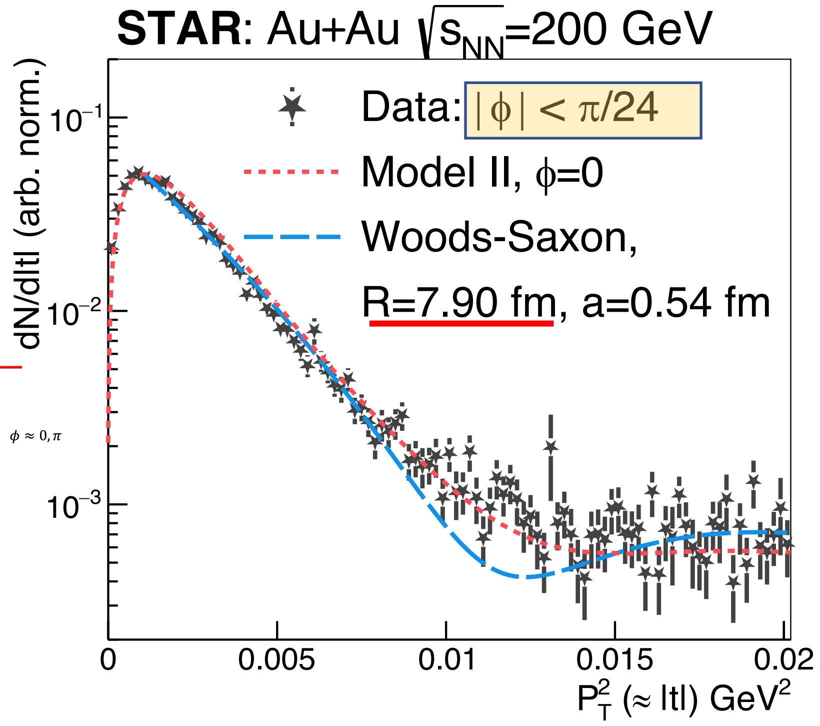
Possible theoretical explanation from Frank Wilczeck's group at MIT – Entanglement enabled interference of amplitudes from non-identical particles

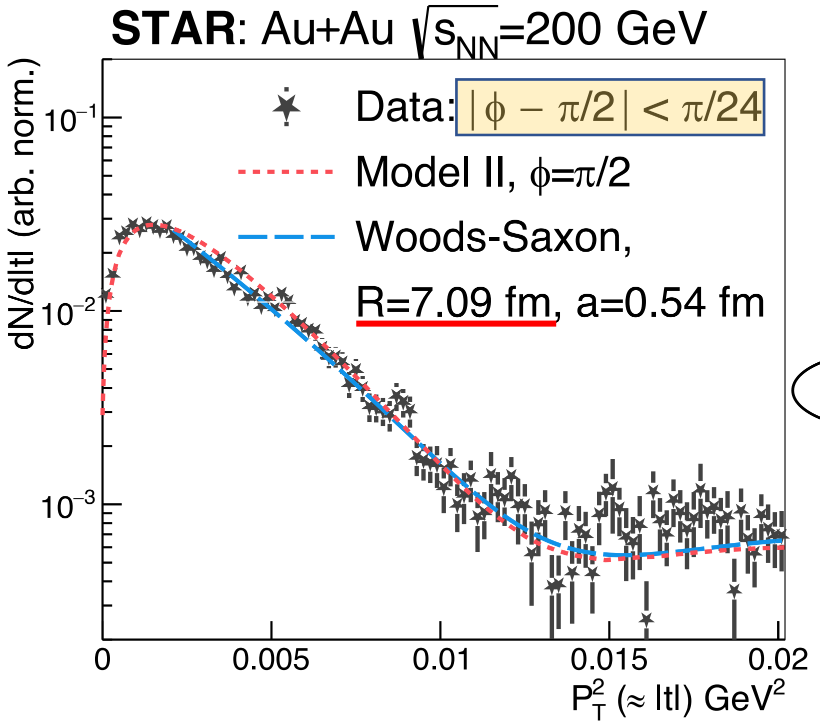
J. Cotler, F. Wilczek, and V. Borish, Annals of Physics **424**, 168346 (2021).

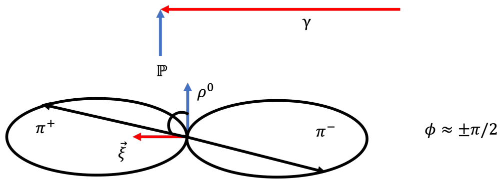
|t| vs. ϕ, which radius is 'correct'?

Now instead of p_x and p_y lets look at $|t|$ with a 2D approach









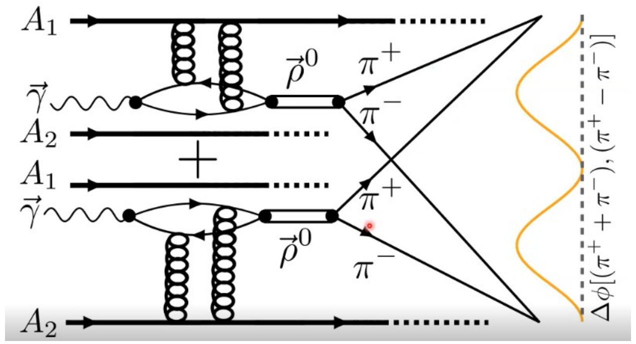
- Drastically different radius depending on ϕ, still way too big
- Notice how much better the Woods-Saxon dip is resolved for $\phi = \pi/2$ -> experimentally able to **remove photon momentum, which blurs diffraction pattern**
- **Can we extract the 'true' nuclear radius from |t| vs. ϕ information?**

arXiv:2204.01625

Precise Nuclear Tomography

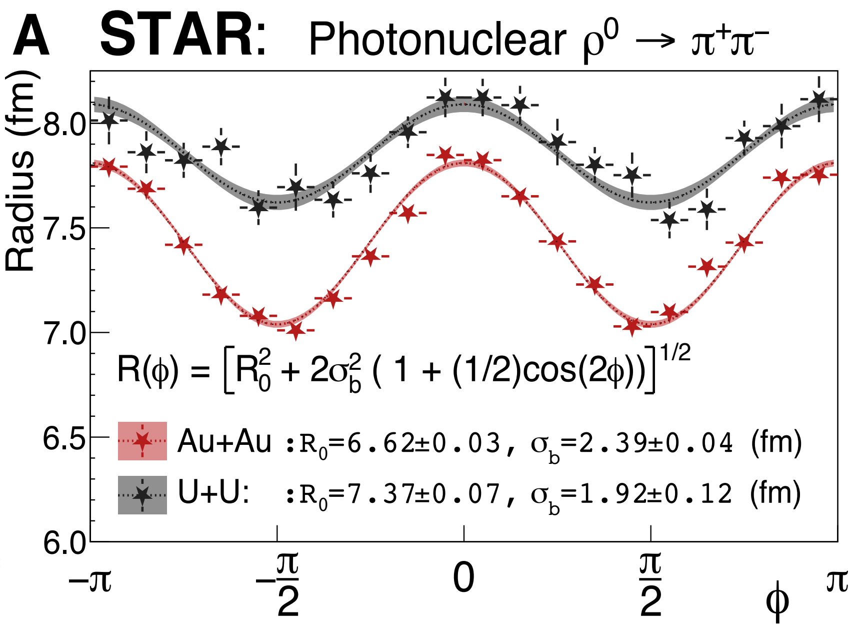
Neutron skin physics at RHIC.

Ultra-peripheral collisions.



$$f(t) = A_c |\mathcal{F}\left[\rho_A(r; R, a)\right](|t|)|^2 + \frac{A_i/Q_0^2}{(1+|t|/Q_0^2)^2}$$

FT of gluon density
(Woods-Saxon)



[STAR Collaboration, arXiv:2204.01625]

neutron skins:

$0.44 \pm 0.05(\text{stat.}) \pm 0.08(\text{syst.})$ fm for ^{238}U

$0.17 \pm 0.03(\text{stat.}) \pm 0.08(\text{syst.})$ fm for ^{197}Au

Neutron skin physics at RHIC.

The neutron skin in atomic nuclei, Δr_{np}, is proportional to the slope L of symmetry energy.

Accurate measurement of Δr_{np} of ^{208}Pb from neutral weak form factor at JLab (PREX-II experiment):

$\Delta r_{np} = 0.283 \pm 0.071$ fm

$L = (106 \pm 37)$ MeV

[PREX-II experiment, PRL **126** (2021) 17, 172502]

Stiffer EoS than expected. [Reed et al., PRL **126** (2021) 17, 172503] [Fattoyev et al., PRL **120** (2018) 17, 172702]

From GW170817

of $\Lambda_{1.4} \lesssim 580$ [44], we eagerly await the next generation of terrestrial experiments and astronomical observations to verify whether the tension remains. If so, the softening of the EOS at intermediate densities, together with the subsequent stiffening at high densities required to support massive neutron stars, may be indicative of a phase transition in the stellar core [42].

Can we get an independent estimate at RHIC?

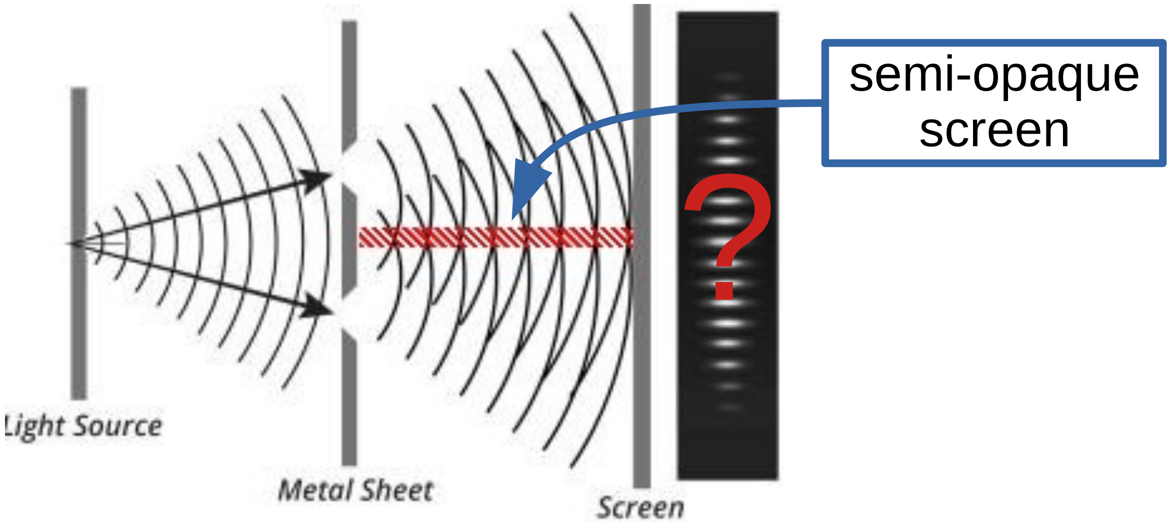
GIULIANO GIACALONE, July 22, 2022

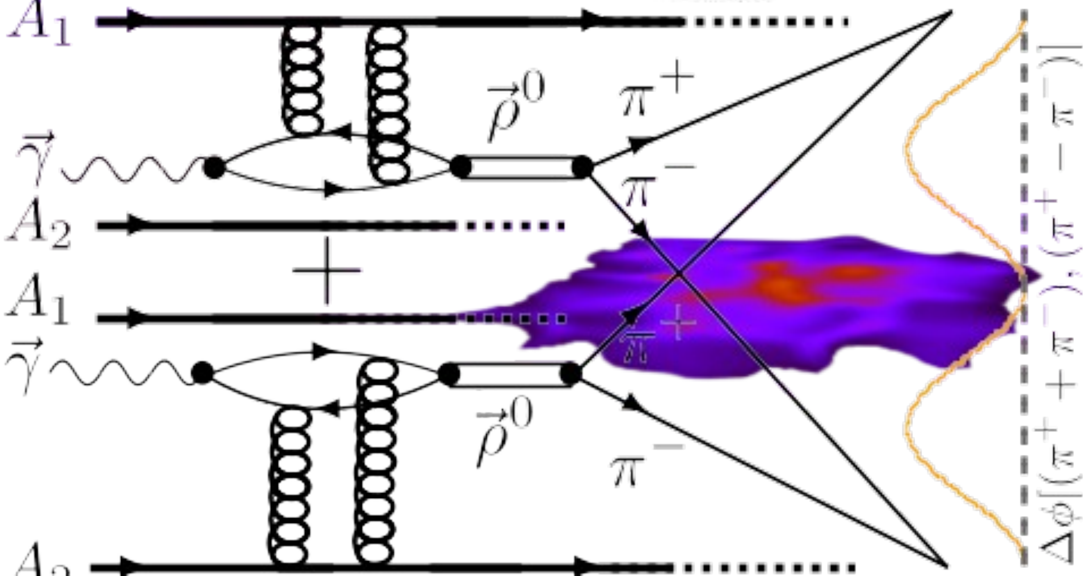
^{208}Pb: Jlab, RHIC?, LHC and EIC

Two weeks of RHIC Pb run

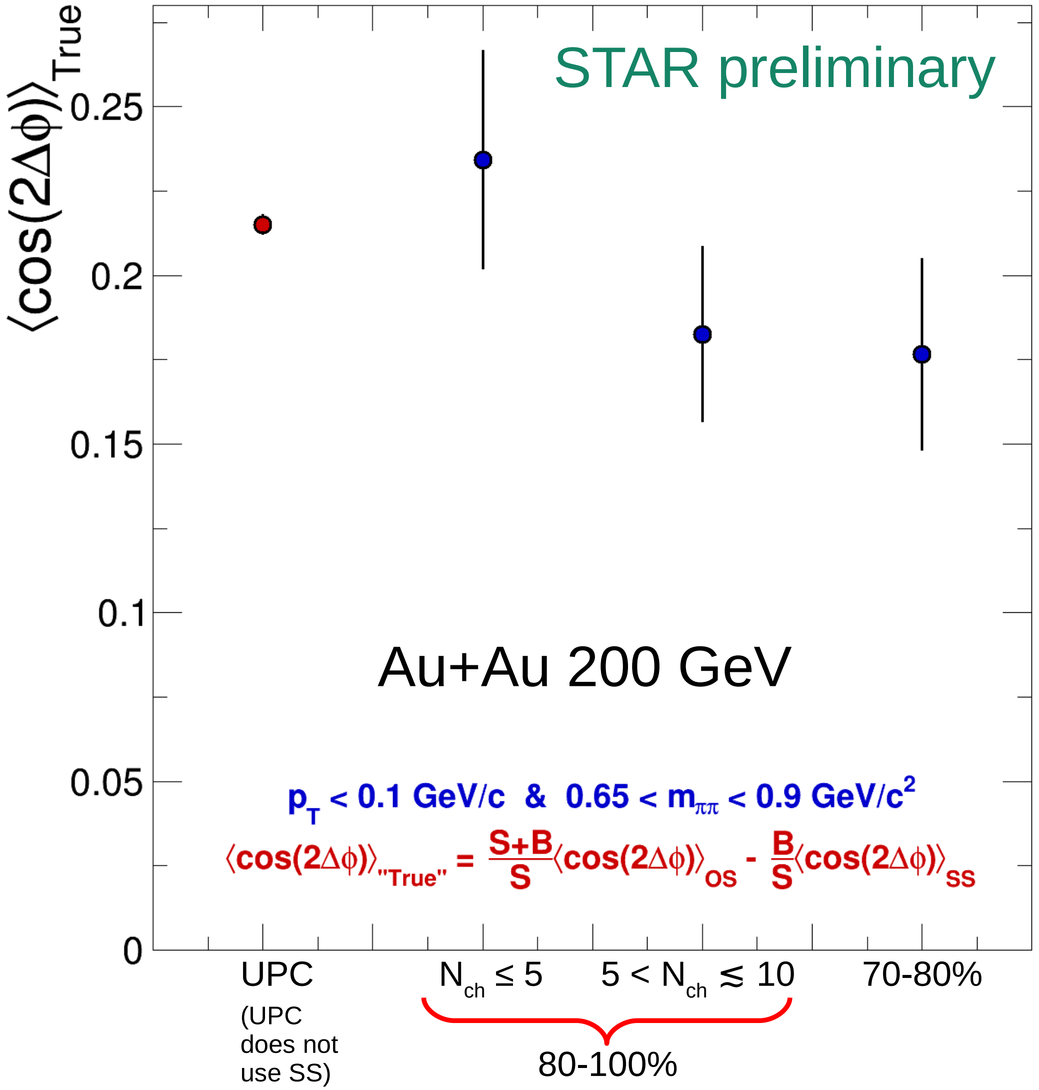
Modification of double-slit

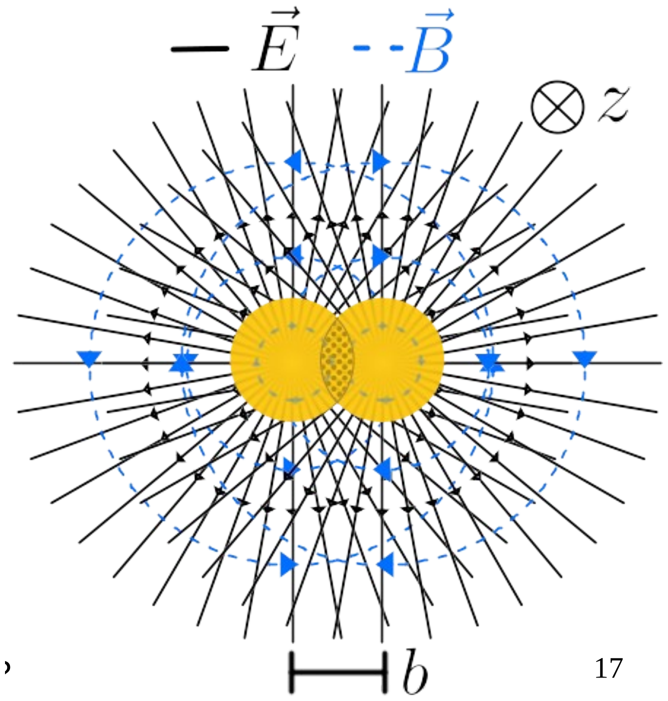
- In double-slit analogy hadronic interactions might be semi-opaque screen dividing the holes
- J/Ψ measurements demonstrate coherent photoproduction in central collisions, but do not investigate how these hadronic interactions affect the wave function





The magic of spin alignment in photoproduction





The alignments along impact-parameter cancel

The spin alignment becomes along the B-field direction

Analog to Hagedorn temperature vs thermalization: Where hadrons are born into the available phase space instead of dynamically achieving thermalization

Global Polarization is required by rotation symmetry instead of dynamically achieving polarization

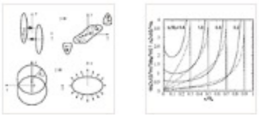
Connection to Xin-Nian and this workshop

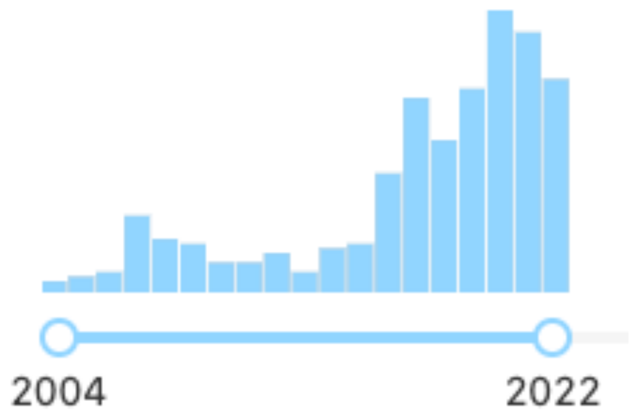
Globally Polarized Quark-Gluon Plasma in Noncentral $A+A$ Collisions

Zuo-Tang Liang and Xin-Nian Wang
Phys. Rev. Lett. **94**, 102301 – Published 14 March 2005; Erratum Phys. Rev. Lett. **96**, 039901 (2006)

ABSTRACT

Produced partons have a large local relative orbital angular momentum along the direction opposite to the reaction plane in the early stage of noncentral heavy-ion collisions. Parton scattering is shown to polarize quarks along the same direction due to spin-orbital coupling. Such global quark polarization will lead to many observable consequences, such as left-right asymmetry of hadron spectra and global transverse polarization of thermal photons, dileptons, and hadrons. Hadrons from the decay of polarized resonances will have an azimuthal asymmetry similar to the elliptic flow. Global hyperon polarization is studied within different hadronization scenarios and can be easily tested.





Physics Letters B
Volume 443, Issues 1–4, 10 December 1998, Pages 45-50

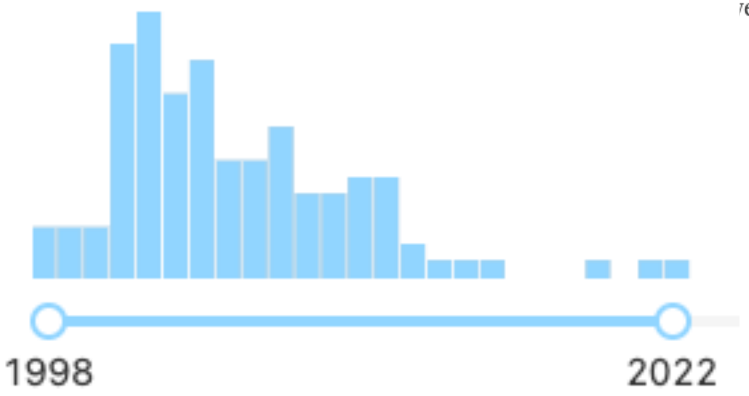
Baryon number transport via gluonic junctions

Stephen E. Vance a, Miklos Gyulassy a, Xin-Nian Wang b

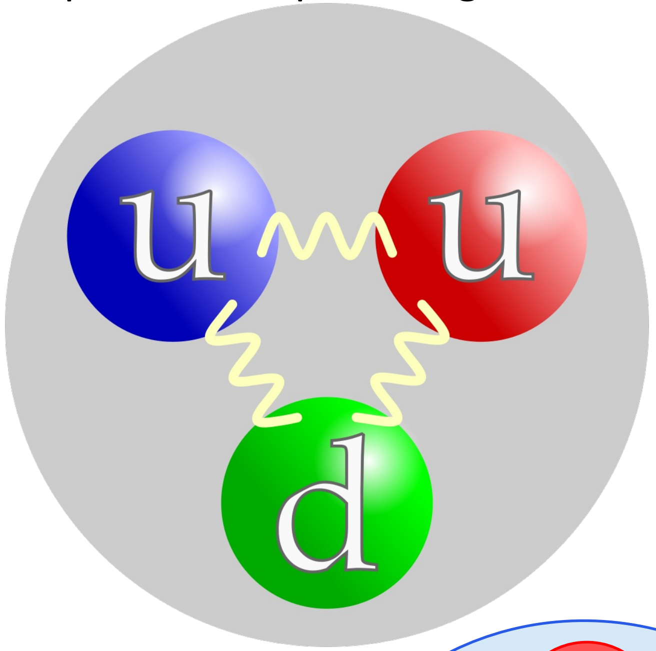
https://doi.org/10.1016/S0370-2693(98)01338-0

Abstract

A novel non-perturbative gluon junction mechanism is introduced within the HIJING/B nuclear collision event generator to calculate baryon number transport and hyperon production in pA and AA collisions. This gluonic mechanism can account for the observed large mid-rapidity valence baryon yield in Pb+Pb at 160 AGeV and predicts high initial baryon densities at RHIC. However, the highly ... ved in this ...



Baryon Junction



- Many of the models used for heavy-ion collisions at RHIC (HIJING, AMPT, UrQMD) have implemented a nonperturbative baryon stopping mechanism

  V. Topor Pop, *et al,* Phys. Rev. C **70**, 064906 (2004)

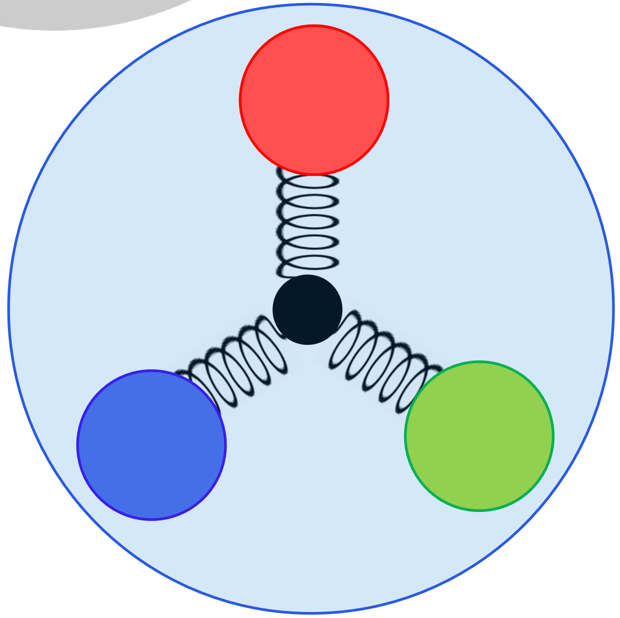
  Zi-Wei Lin, *et al*, Phys. Rev. C **72**, 064901 (2005)

  M. Bleicher, *et al,* J.Phys.G **25,** 1859-1896 (1999)

- Baryon Junction: nonperturbative configuration of gluons linked to all three valence quarks
  - Carries the baryon number
  - Theorized to be an effective mechanism of stopping baryons in pp and AA

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

- But no signature of baryon junction has been cleanly identified in the experiment
  1. proton rapidity shift vs beam energy
  2. baryon rapidity asymmetry in γ+A
  3. charge vs baryon stoppings



Do gluons carry baryon number?

•e-Print: 2205.05685

Model implementations of baryons at RHIC

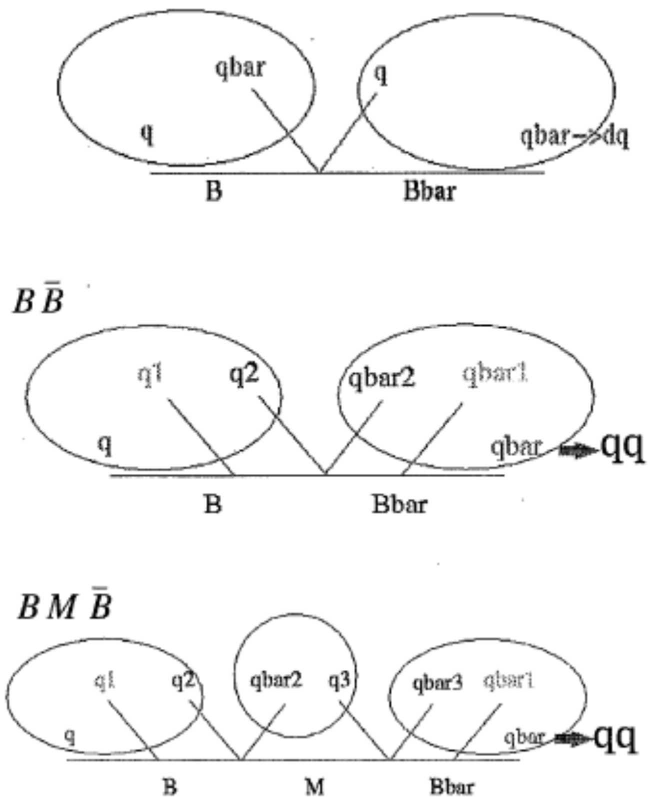
HIJING/$B\bar{B}$ v 1.10 Outline

Experimental data at CERN-SPS on p+A and A+B interactions has revealed a large degree of stopping and strange hyperon production in the heavy nuclear systems. The stopping is significantly under-predicted by models which assume that the primary mechanism for baryon transport is diquark-quark hadronic strings (Gyulassy,Topor,Vance,97).

- Baryon junction mechanism, a novel non-equilibrium hadronic mechanism derived from the Y-shaped ($SU_c(3)$) gluon structure of the baryon, has been introduced within HIJING/B to explain these observations.(Vance and Gyulassy,98). Abandoned?
- The valence baryon junction exchange mechanism has been extended by including junction-antijunction ($J\bar{J}$) loops that naturally arise in Regge phenomenology. HIJING/$B\bar{B}$ v1.10, (Vance, Gyulassy and Wang,99) is now available.
- Fitting $\bar{p}$ and $\bar{\Lambda}$ data from p+p and p+S interactions, the cross section for $J\bar{J}$ exchange is found to be $\sigma_{B\bar{B}} = 6$ mb. The threshold cutoff mass $m_c = 6$ GeV, provides sufficient kinematical phase space for fragmentation of the strings and for $B\bar{B}$ pair production. This kinematic constraint severely limits the number of allowed $J\bar{J}$ configurations, reducing its effective cross section to ≈ 3 mb. at SPS.

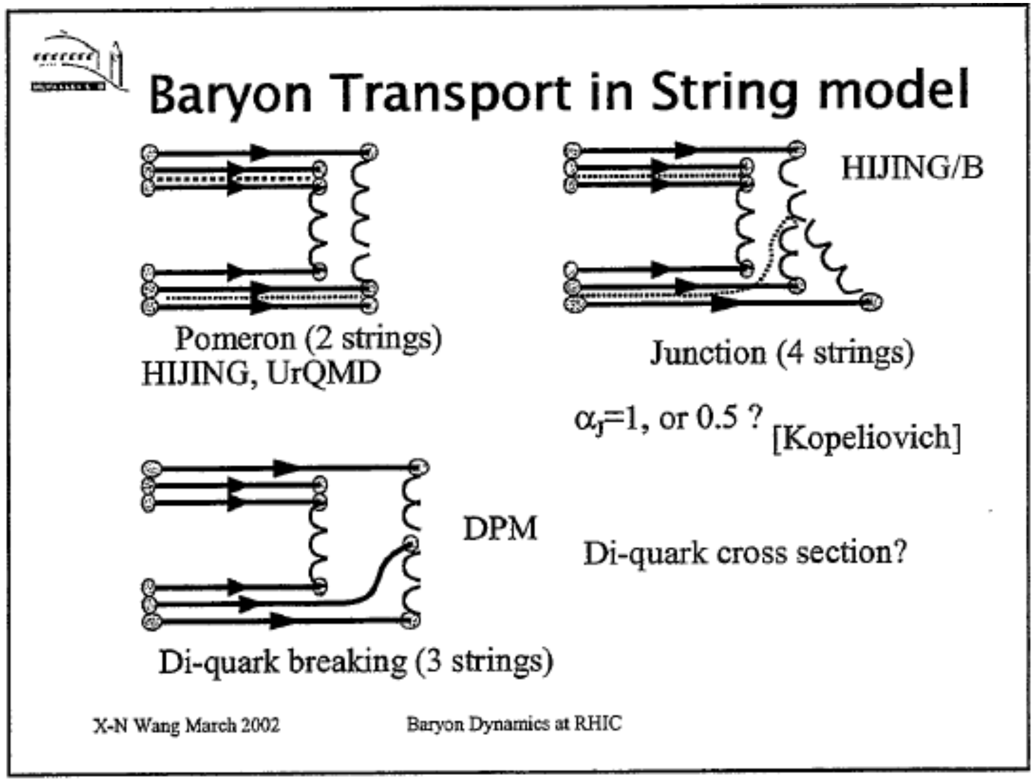
V. Topor Pop

With popcorn scheme:



Z.W. Lin (AMPT)

2002 RBRC Workshop: Baryon Dynamics at RHIC



X.N. Wang (theory summary)

Confusing Evidence AGAINST junction

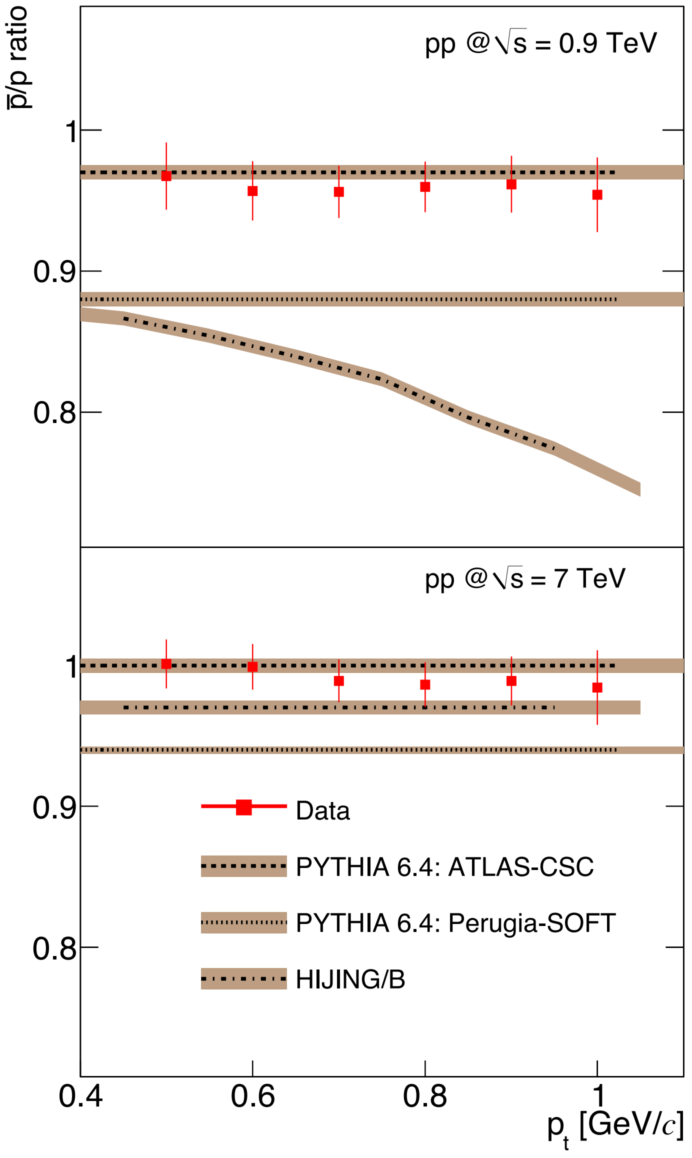


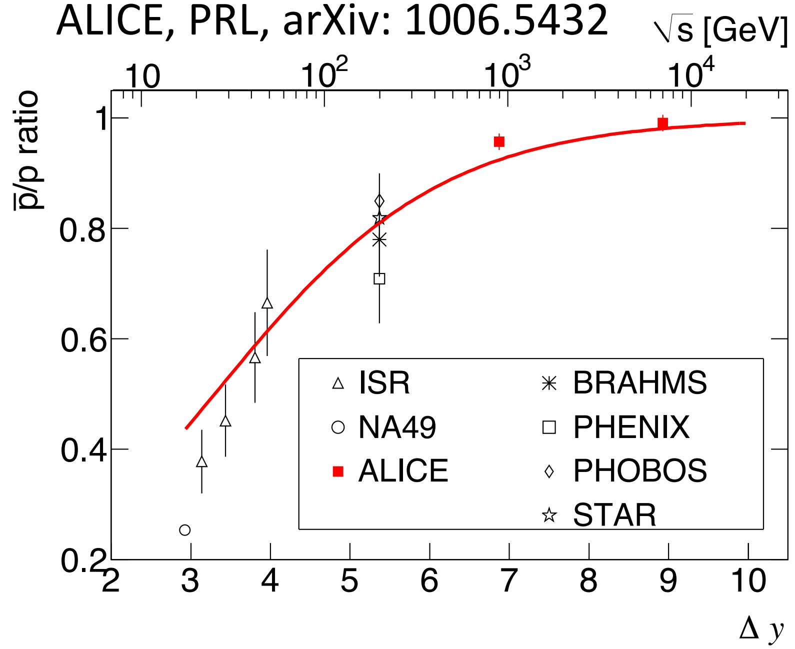
FIG. 3. (Color online) The p_t dependence of the $\overline{\mathrm{p}}/\mathrm{p}$ ratio integrated over $|y| < 0.5$ for pp collisions at $\sqrt{s} = 0.9$ TeV (top) and $\sqrt{s} = 7$ TeV (bottom). Only statistical errors are shown for the data; the width of the Monte Carlo bands indicates the statistical uncertainty of the simulation results.

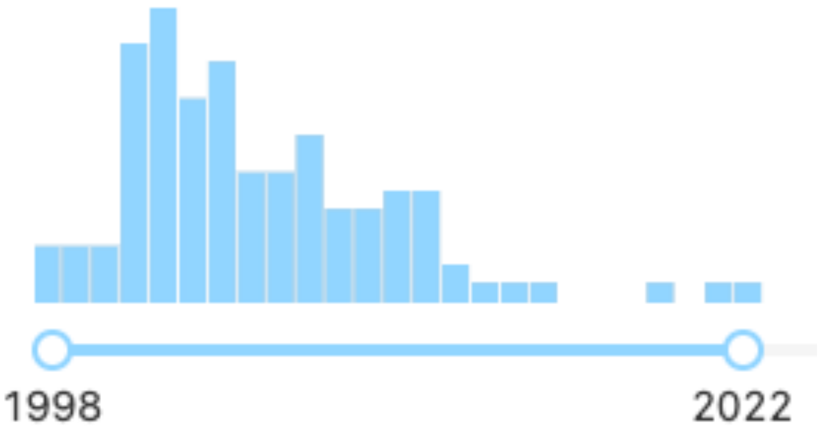
Abstract:
The results are consistent with the conventional model of baryon-number transport and set stringent limits on any additional contributions to baryon-number transfer over very large rapidity intervals in pp collisions.

It rules out α_B=0.5

A rough approximation of the Δy dependence of the ratio R can be derived in the Regge model, where baryon pair production at very high energy is governed by Pomeron exchange and baryon transport by string-junction exchange [5]. In this case the p/p̄ ratio takes the simple form $1/R = 1 + C \exp[(\alpha_J - \alpha_P)\Delta y]$. We have fitted such a function to the data, using as value for the Pomeron intercept $\alpha_P = 1.2$ [23] and $\alpha_J = 0.5$, whereas C, which determines the relative contributions of the two diagrams, is adjusted to the measurements from ISR, RHIC, and LHC. The fit, shown in Fig. 4, gives a reasonable description of the data with only one free parameter (C), except at lower energies, where contribu-

ALICE, PRL, arXiv: 1006.5432





Different ways of quantifying baryon rapidity loss

STAR, Phys. Rev. C **79** (2009) 34909; **96** (2017) 44904

Keep in mind that the exponential slope is close to ½

BESI data continues with the trend

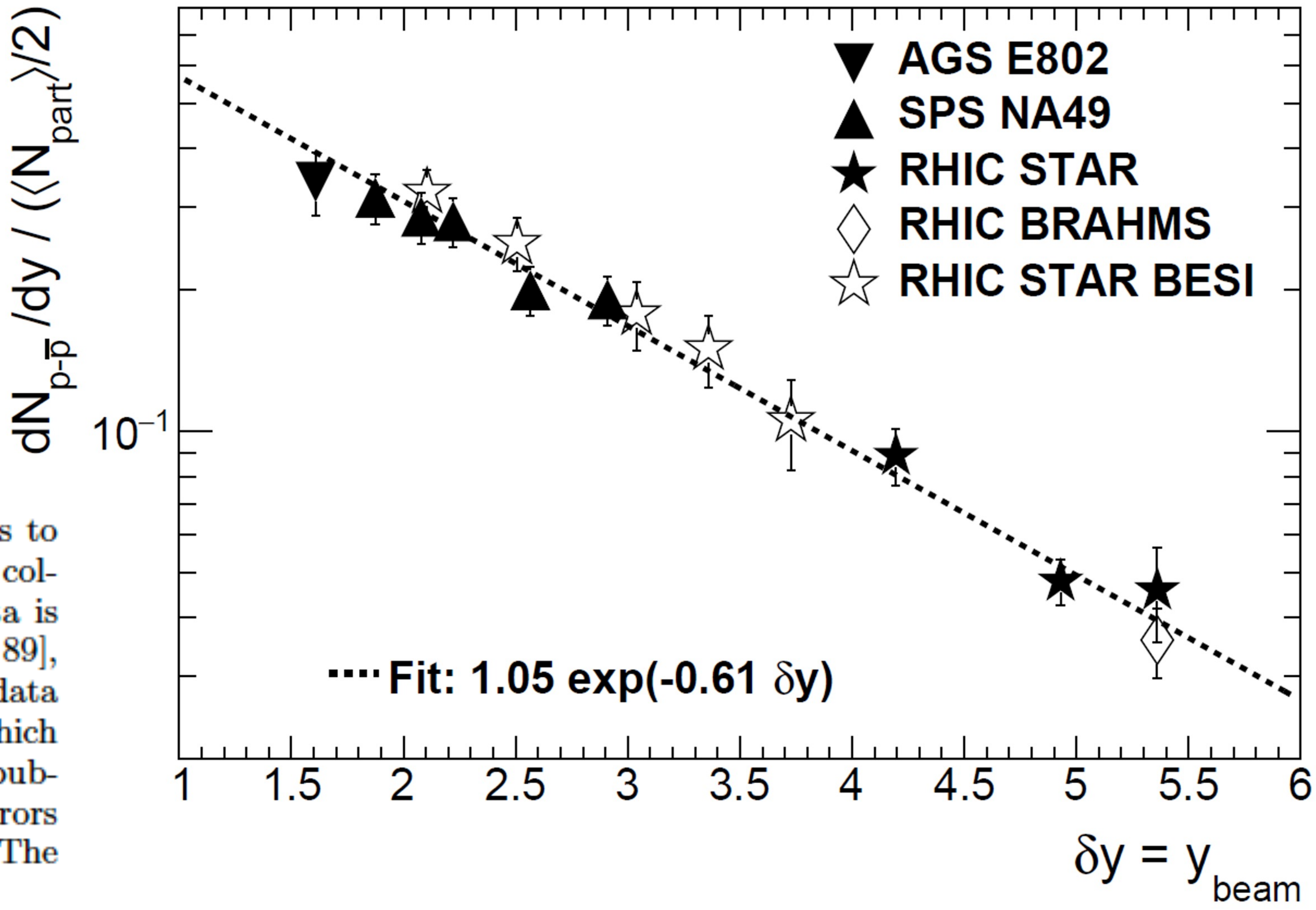
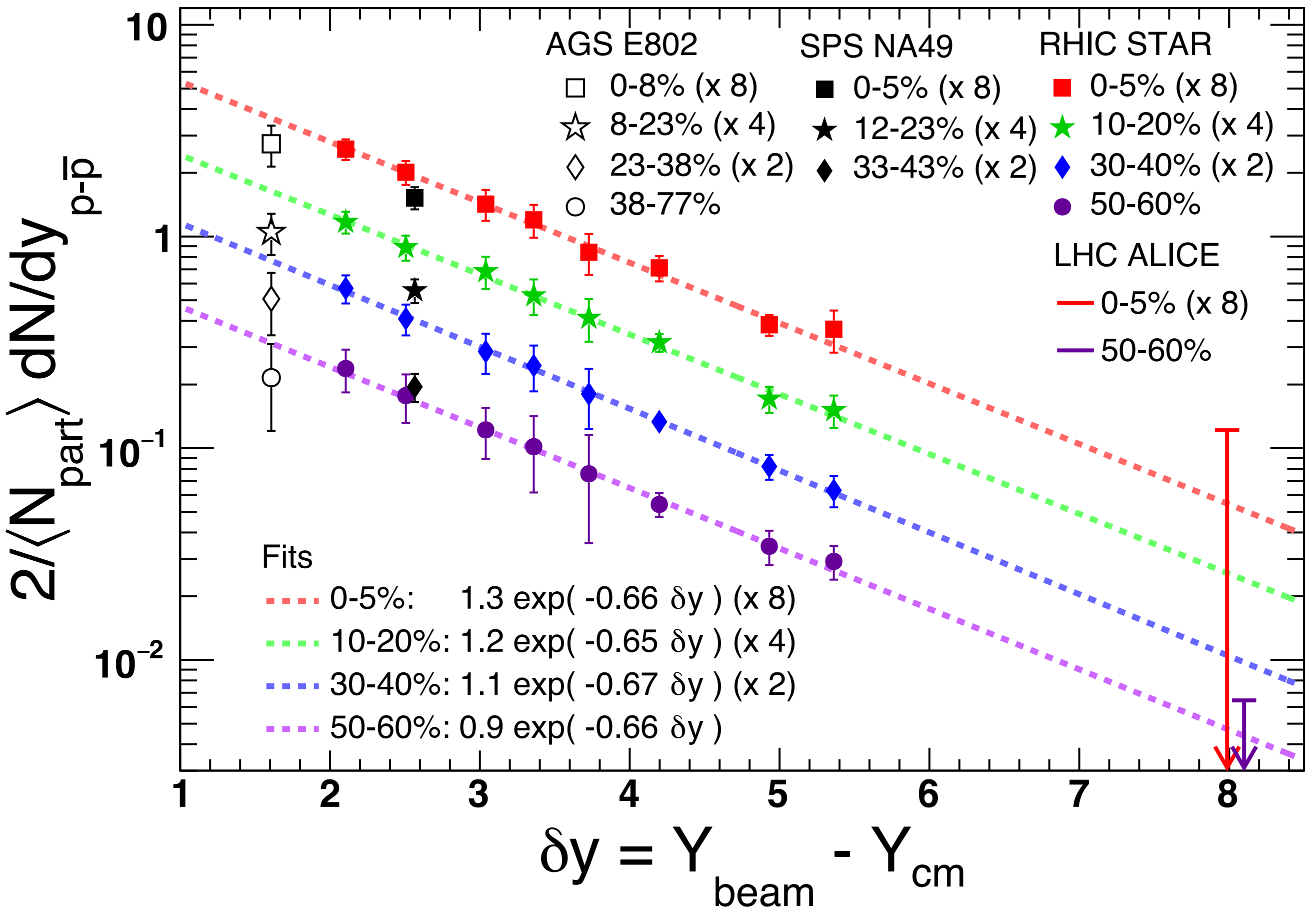


FIG. 29: The ratio of mid-rapidity inclusive net-protons to half of the number of participants in central heavy-ion collisions as a function of the rapidity shift. The AGS data is taken from Refs. [75, 86], SPS data from Refs. [87, 88, 89], and BRAHMS data from Ref. [90]. The published SPS data have already been corrected for weak-decays, the size of which is of the order 20-25% [88], so we have added 25% to the published net-proton yields to obtain the inclusive ones. Errors shown are total statistical and systematic uncertainties. The dashed line is an exponential fit to the data.

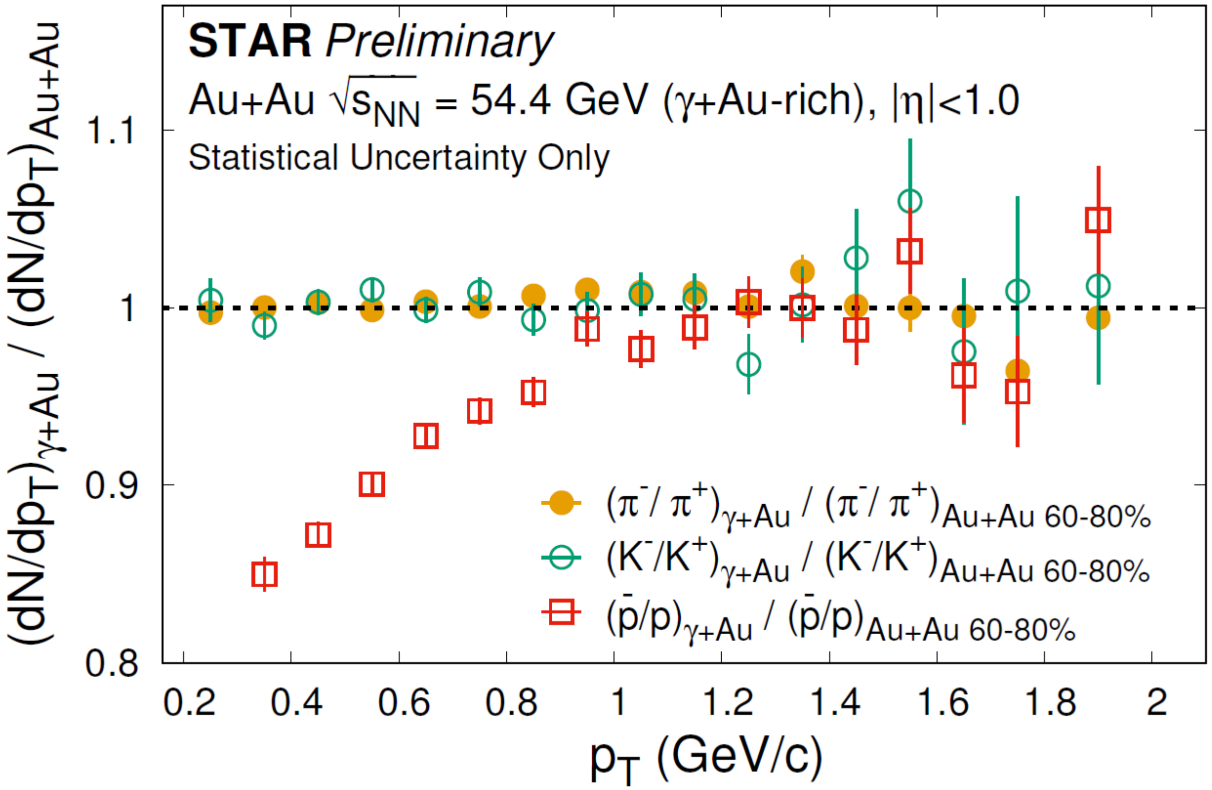
Best ways of probing baryon carrier

STAR, Phys. Rev. C **79** (2009) 34909; **96** (2017) 44904
JDB, NL, PT and XZB, arXiv:2205.05685

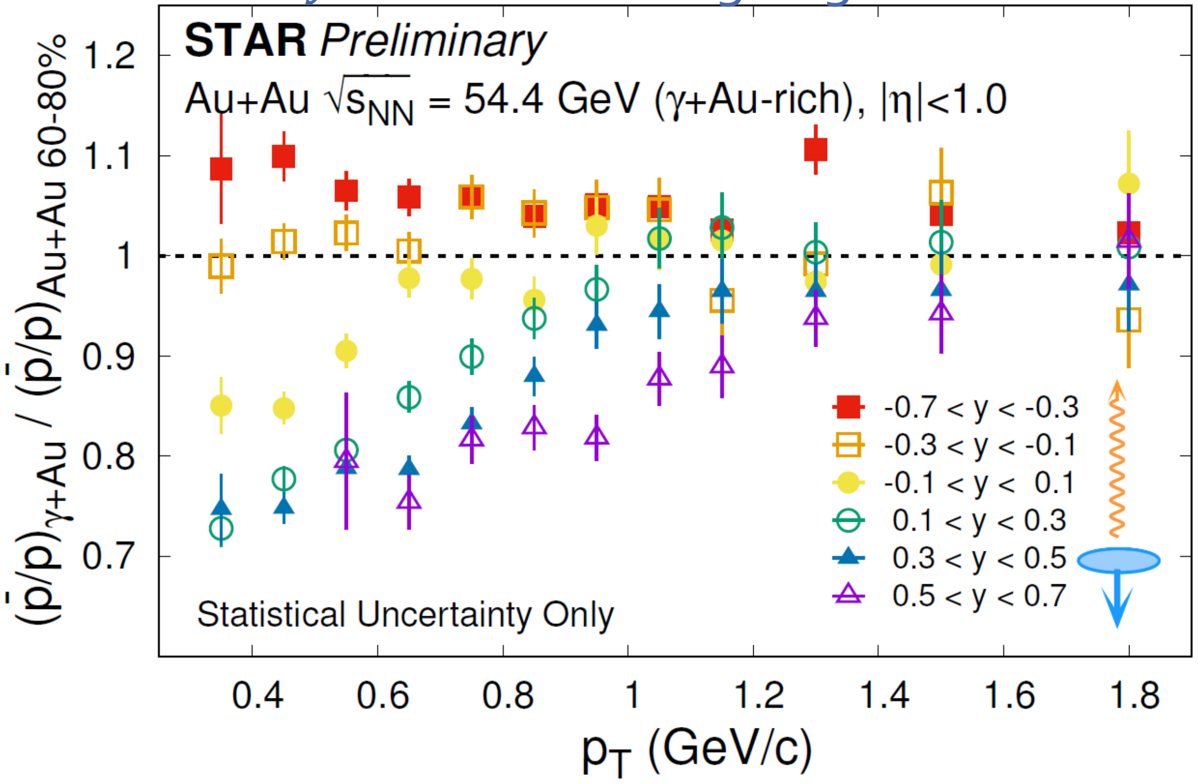
- Beam Energy Dependence of net baryon yields at midrapidity in A+A collisions
- Net Charge (quark) vs Net Baryon (gluon) at midrapidity in isobar collisions
- Rapidity asymmetry in γ+A (e+A) Regge theory predicts exp(-0.5*y)



Low p_T Baryon Enhancement in γA



$y > 0$ is in the A-going direction

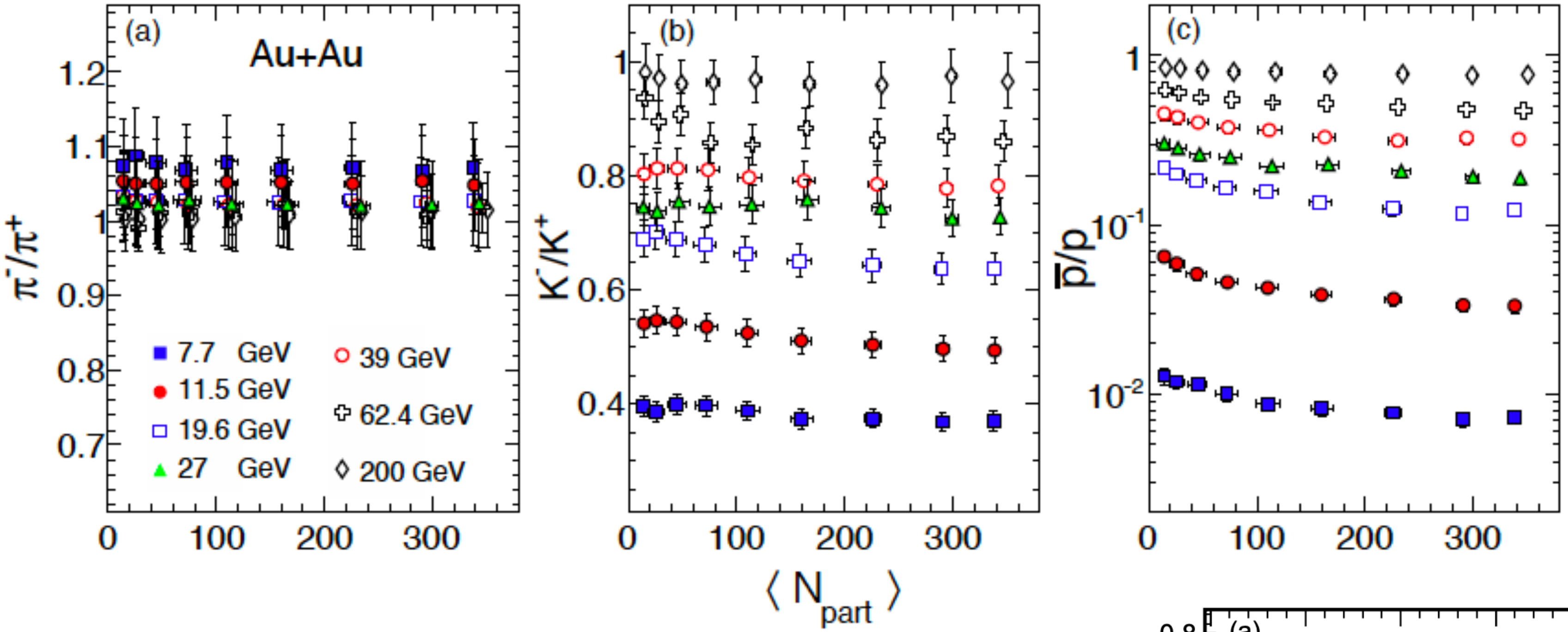


Double ratio: $\bar{p}/p < 1$ at lower p_T

- Soft baryon stopping that is **stronger** in γA compared to peripheral AA
- Ratio is smaller at higher rapidity (A-going side)

Measure charge stopping

STAR, Phys. Rev. C **96** (2017) 44904

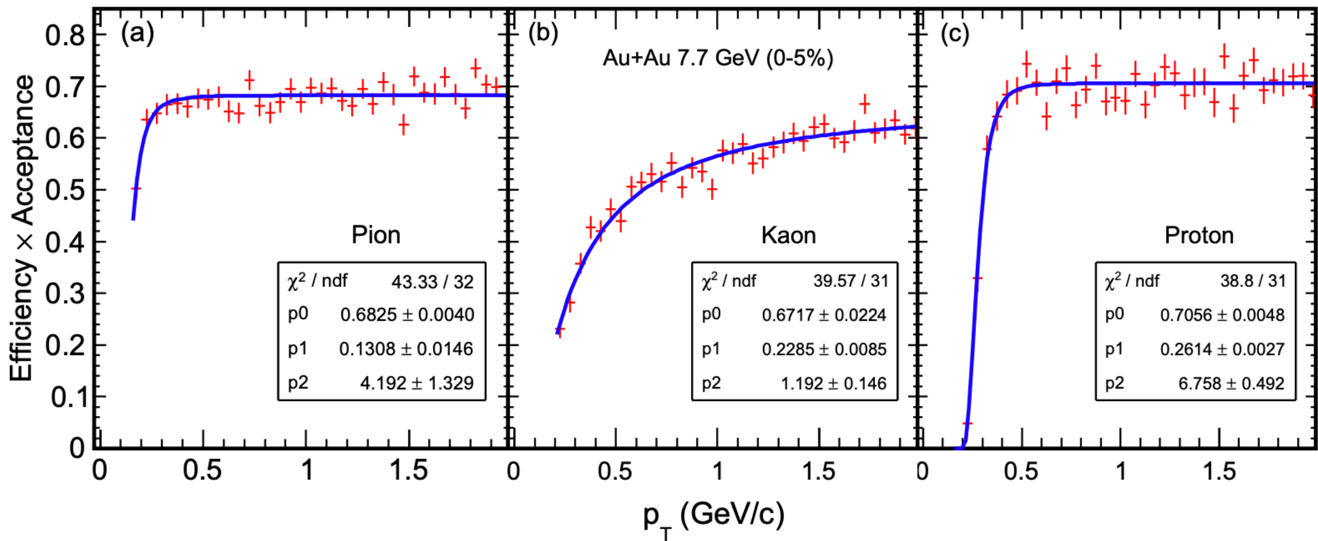


In conventional Au+Au collisions:
pbar/p ratio @ **54.4GeV** is ~0.4, and decreases with multiplicity
K^-/K^+ ~=0.8—0.9

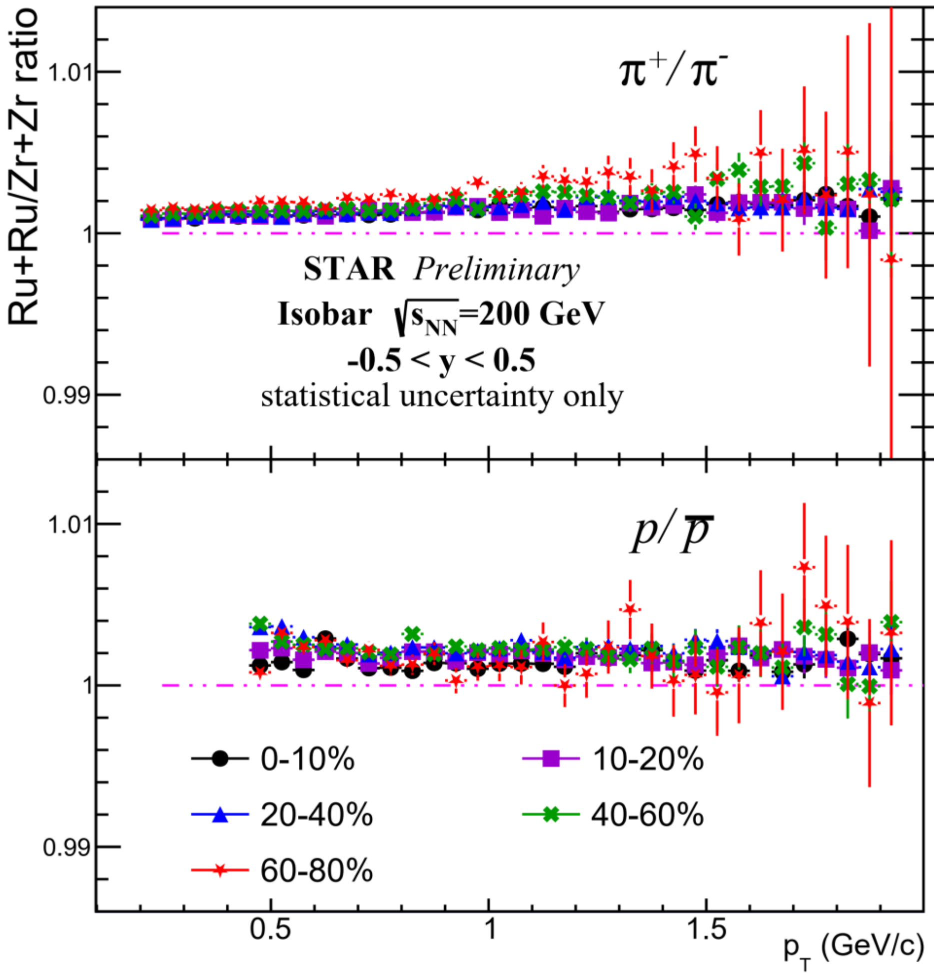
Errors are too large to determine charge net charge at 200GeV

Isobar data can cancel many of the detector effects
net baryon B: (p-pbar)*(1+d/dbar*(pbar/p)^2)
net charge Q: π^++K^++p – (π^-+K^-+pbar)

Q=B*(Z/A) if baryon number carried by valence quark
Q<<B*(Z/A) if gluon junction carries baryon number
Isobar: ΔQ =? B*(ΔZ/A)



Double ratios between Ru+Ru and Zr+Zr collisions



- The double ratios of π^+/π^- and $p/\bar{p}$ are larger than 1. Due to extra charge in Ru?
- The double ratios of K^-/K^+ is consistent with unity within uncertainties.

From baryon stopping:
$B*(\Delta Z/A)$~=2x10^{-3}

Charge stopping:
ΔQ ~=1x10^{-3}

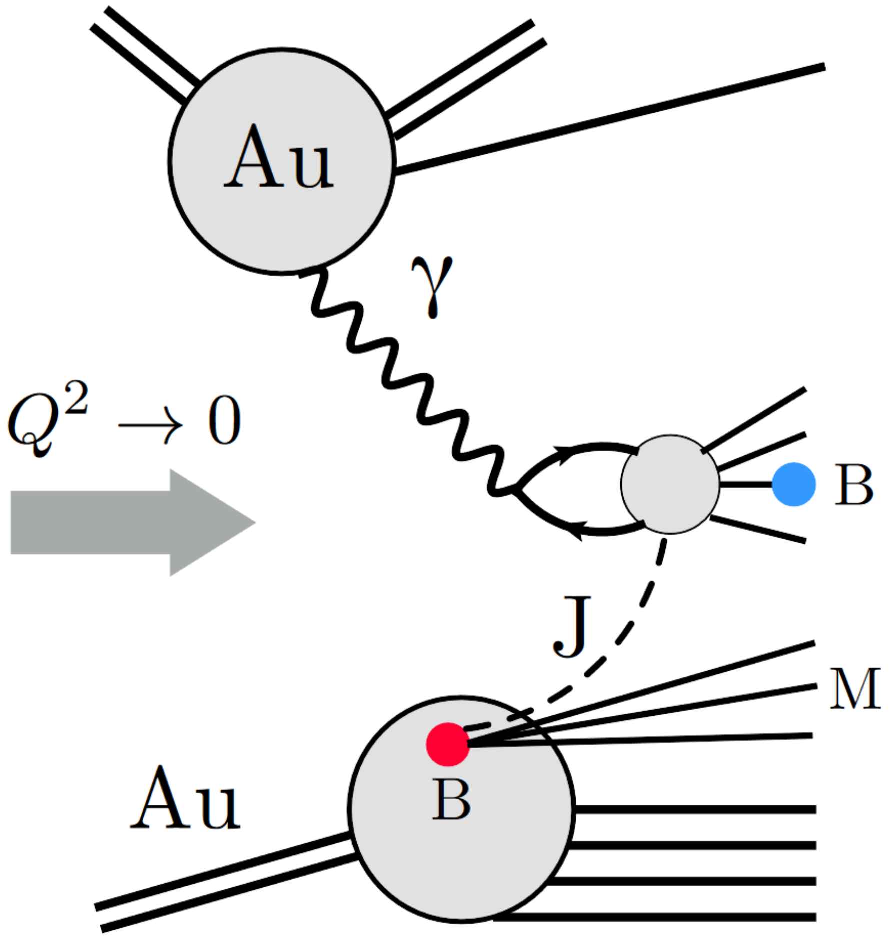
Summary

- Polarization effect is an exciting phenomenon in heavy-ion collisions
- Pioneering work two decades ago finally validated last 5 years
- Many new experimental results and unexplained features

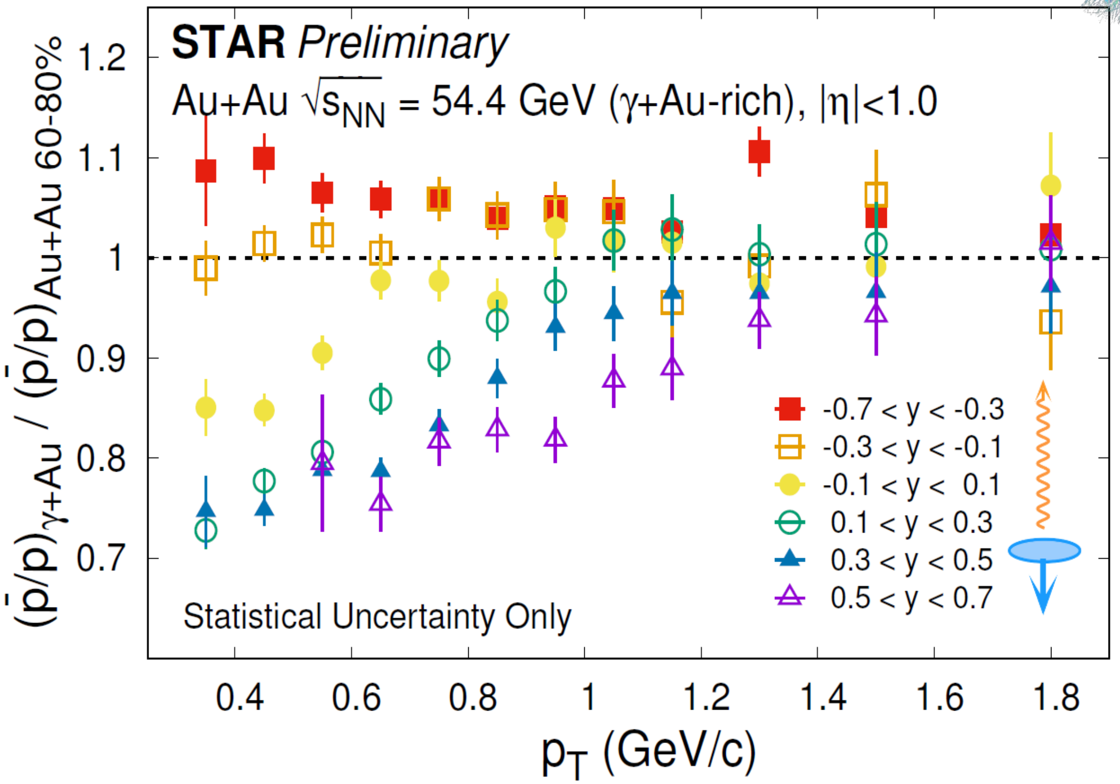
- Whether Baryon Junction is a valid physical object still waiting for experimental confirmation
- We have proposed three ways of testing the hypersis

- RHIC, LHC and future EIC experiments can provide further experimental insights into these phenomena

Low p_T Baryon Enhancement in γA



J. D. Brandenburg *et al*, arXiv 2205.05685



- Double ratio: $\bar{p}/p < 1$ at lower p_T
  - Soft baryon stopping that is **stronger** in γA compared to peripheral AA
  - Ratio is smaller at higher rapidity (A-going side)

Baryon Junction Distribution Function (JDF)

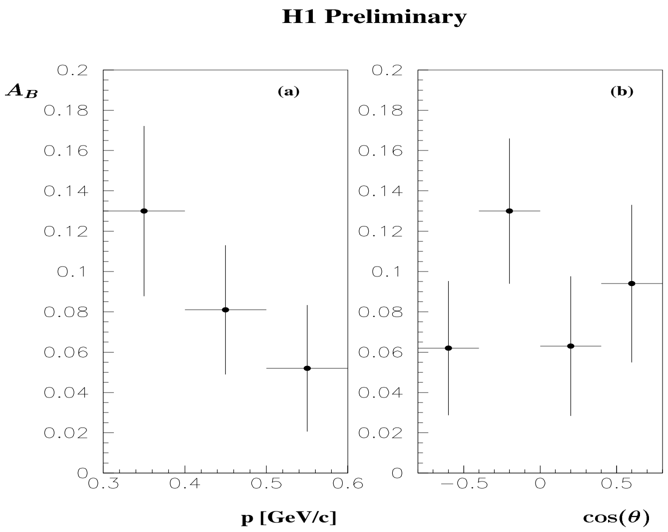
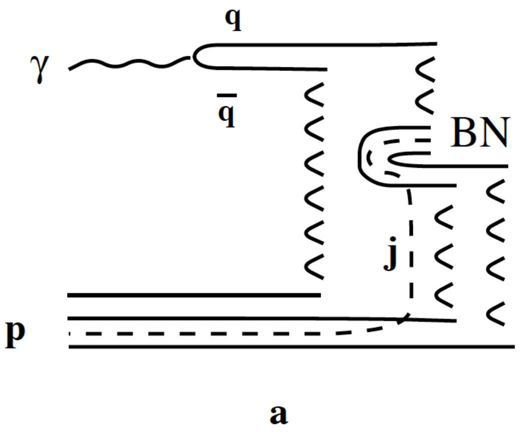
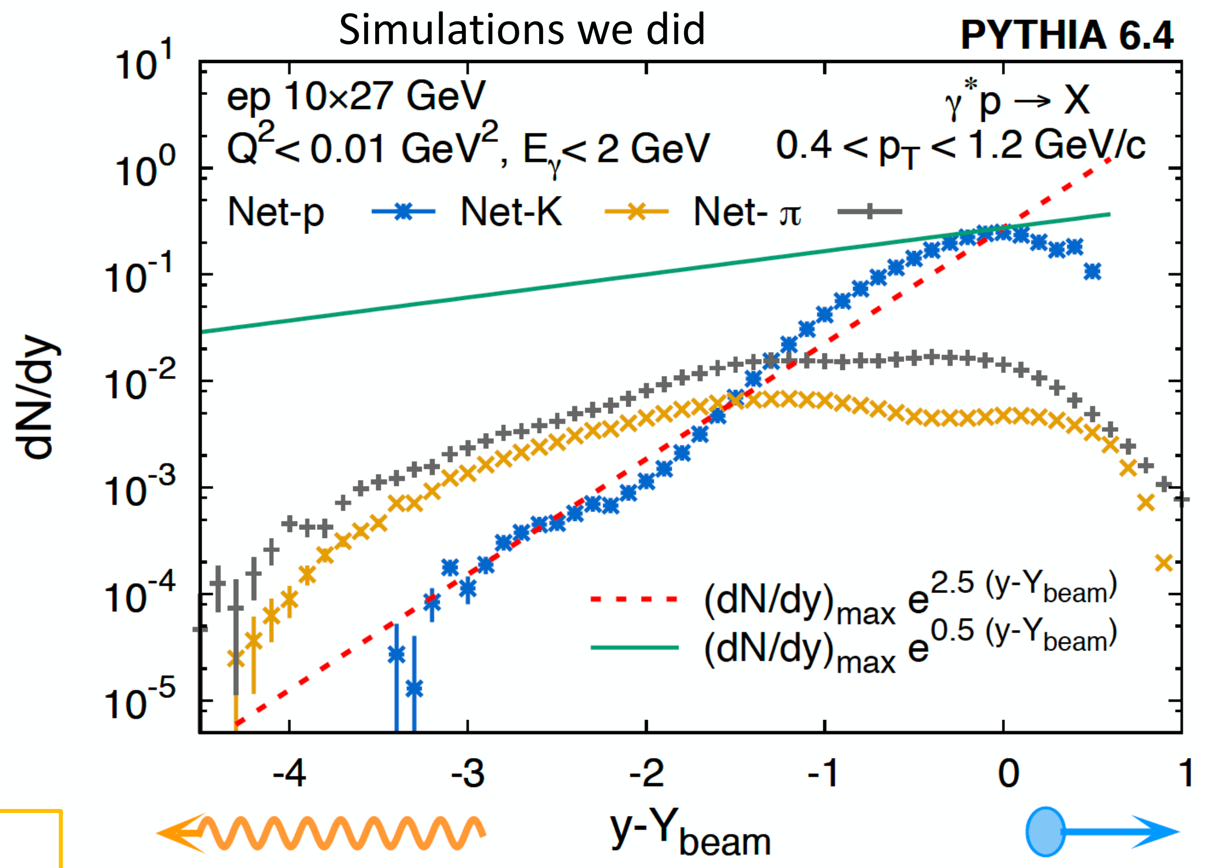


Figure 7: Baryon asymmetry as function of the proton momentum (a) and the polar angle (b).



Our final result for the baryon asymmetry is

$$A_B = (8.0 \pm 1.0 \pm 2.5)\% .$$



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]

Many theory papers cited this result even as late as 2008

What is clear from STAR and other new measurements:
At HERA kinematics, A_B~=<1%, H1 is x10 too large
PYTHIA6.4 would predict almost 0%.
HERA is at wrong kinematics without good PID detector

EIC is the best to address this fundamental science at DAY 1 with TOF