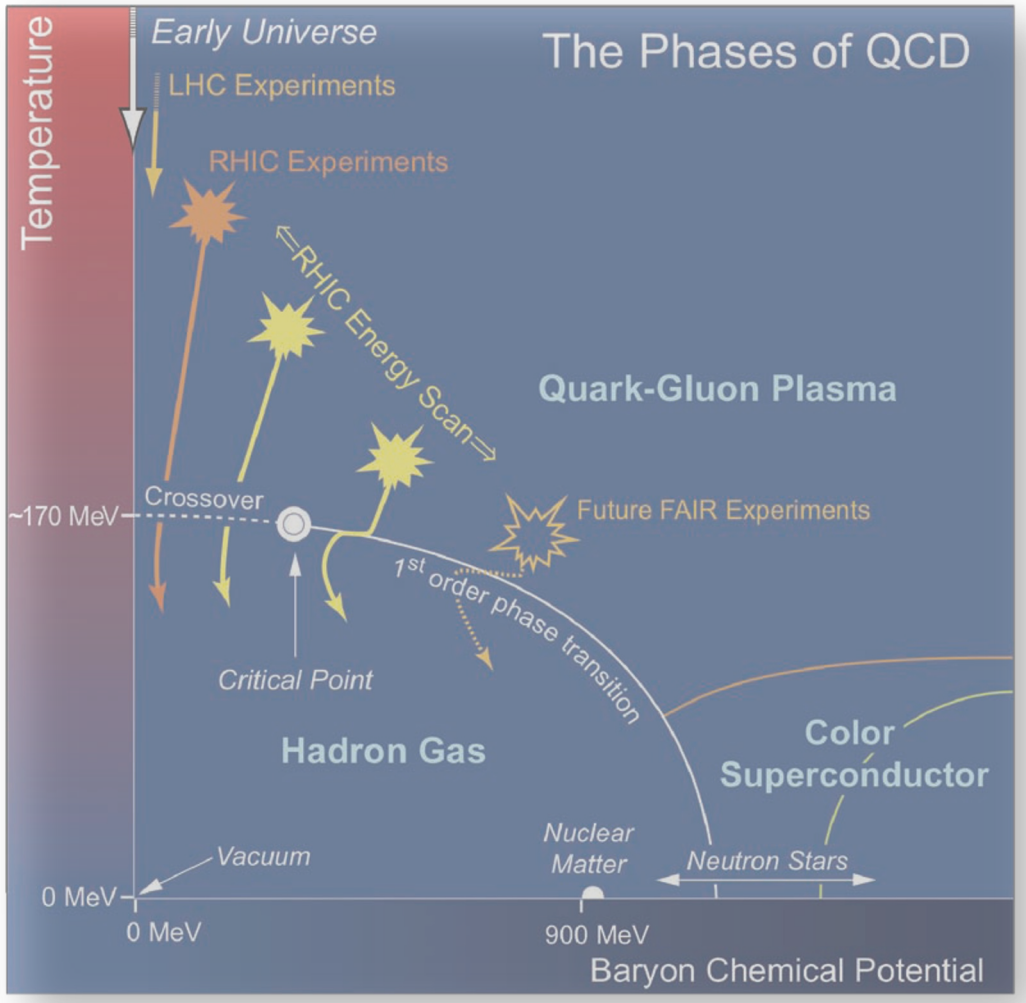
Two decades in the past, and a look into the future



Zhangbu Xu
(Brookhaven National Lab)

Keane Fest 12/01/2023

In part supported by
Brookhaven National Laboratory
U.S. DEPARTMENT OF ENERGY | Office of Science

Declan's impact on STAR Collaboration Science in one table

ID	Title of Paper	Title of published/submitted paper	Publ. ID	Inspire ID	Ana. ID	Date GPC Formed	GPC Chairperson	GPC Members	Date to Collaboration	Institution Readers	Date Submitted for publication	Referee Report	Date Published (Accepted)	Journal Published	Principal Authors
1	Elliptic Flow in Au+Au Collisions at sqrt(snn) = 130 GeV	Elliptic Flow in Au+Au Collisions at $\sqrt{s_{NN}}$ = 130 GeV	1	533414 (HepData)			Declan Keane	Mike Lisa, Art Poskanzer, Tom Trainor	14-Aug-00		12-Sep-00		18-Jan-01	PRL	Art Poskanzer, Raimond Snellings, Sergei Voloshin
51	Pseudo-rapidity Asymmetry and Centrality Dependence of Charged Hadron Spectra in d+Au Collisons at sqrt(s)=200 GeV	Pseudorapidity Asymmetry and Centrality Dependence of Charged Hadron Spectra in d+Au Collisions at $\sqrt{s_{NN}}$ = 200 GeV	47	656934 (HepData)		21-Apr-04	Declan Keane	Olga Barannikova, Johan Gonzalez, Kirill Filimonov, Joern Putschke	24-Jun-04		16-Aug-04		23-Dec-04	PRC	Johan Gonzalez, Zhangbu Xu
70	Strangelet search at RHIC	Strangelet Search in AuAu collisions at 200 GeV	59	698939 (HepData)		10-Jun-05	Jack Sandweiss	Haibin Zhang, Aihong Tang, Richard Majka, Huan Huang	13-Oct-05		27-Nov-05		25-Jul-07	PRC	Hank Crawford, Declan Keane, Brandon Szeliga, Aihong Tang, Sergei Voloshin, Gang Wang, Zhangbu Xu
129	Observation of anti-hypertriton and hypertriton in a relatively symmetric system of matter and anti-matter	Observation of an Antimatter Hypernucleus	156	848409 (HepData)	498 (note, cvs)	1-Jul-09	Alejandro Szanto de Toledo	Michael Lisa, Jim Thomas (Analysis Code QA), W.J. Llope (English QA), Jinhui Chen(PA rep), Lijuan Ruan(PWG rep)	12-Sep-09		28-Oct-09		4-Mar-10	Science	Jinhui Chen, Hank Crawford, Declan Keane, Hao Qiu, Zebo Tang, Zhangbu Xu
148	Observation of the antimatter Helium-4 nucleus	Observation of the antimatter Helium-4 nucleus	171	893021 (HepData)	536 (note, cvs)	5-Jan-11	Bedangadas Mohanty	Robert Tribble, Richard Majka, Joseph Seele (English QA), Lokesh Kumar (Code QA), Aihong Tang (PA rep) Anthony Timmins (PWG rep)	11-Feb-11	TAMU, BNL, LBNL, Purdue, Rice, UCLA	14-Mar-11		24-Apr-11	Nature	J. Chen, H. Crawford, Y. Fisyak, F. Geurts, Q. Hao, B. Huang, C. Jena, H. Ke, D. Keane, T. Kollegger, J. Landgraf, T. Ljubicic, M. Naglis, X. Sun, A. Tang, G. Van Buren, Z. Xu, L. Xue, J. Zhao
206	Observation of interaction between anti-nucleons	Measurement of interaction between antiprotons	240	1385105 (HepData)	616 (note, cvs)	05-Jan-15	Declan Keane	Neha Shah, Spencer Klein, Saskia Mioduszewski (English QA), John Campbell (Code QA), Daniel McDonald (PWG rep), Zhengqiao Zhang (PA rep)	30-May-15	Valparaiso, CTU, Sao Paulo, Yale, USTC	25-Jul-15		04-Nov-15	Nature	Andrew Peterson, Alex Schmah, Qi-Ye Shou, Kefeng Xin, Yan Yang, Zhengqiao Zhang, Mike Lisa, Yu-Gang Ma, Aihong Tang, Hanna Zbroszczyk
228	Observation of Global Hyperon Polarization in Ultrarelativistic Heavy Ion Collisions	Global Λ hyperon polarization in nuclear collisions: evidence for the most vortical fluid	260	1510474 (HepData)	659 (note, cvs)	28-Jun-16	Declan Keane	Huan Huang, Evan Finch (English QA), Xu Sun (Code QA), Bill Llope (PWG rep), Isaac Upsal (PA rep)	14-Nov-16	BNL, LBNL, SDU, CTU, Pusan	21-Jan-17		02-Aug-17	Nature	Isaac Upsal, Mike Lisa, Sergei Voloshin
269	Precise measurement of the mass difference and the binding energy B_Lambda of hypertriton and anti-hypertriton (Webpage)	Precise measurement of the mass difference and the binding energy of hypertriton and antihypertriton	304	1731117 (HepData)	714 (note, cvs)	30-Dec-18	Hank Crawford	Rongrong Ma, Evan Finch (English QA), Maksym Zyzak (Code QA), Chi Yang (PWG Rep), Jinhui Chen (PA Rep), Peng Liu (PA Rep)	15-Mar-19	AGH, Heidelberg, NCKU, NISER, WSU	24-Apr-19		09-Mar-20	Nature Physics	Irakli Chakaberia, Jinhui Chen, Xin Dong, Wlodek Guryn, Declan Keane, Peng Liu, Yugang Ma, Zhangbu Xu
277	Probing Extreme Electromagnetic Fields with the Breit-Wheeler Process (Webpage)	Measurement of e+e- Momentum and Angular Distributions from Linearly Polarized Photon Collisions	317		724 (note, cvs)	05-Jun-19	Declan Keane	Mariusz Przybycien, Hank Crawford (English QA), Te-chuan Huang (Code QA), Jaroslav Adam (PWG Rep), Daniel Brandenburg (PA Rep)	02-Sep-19	UIC, LBNL, MEPhi, TAMU, Yale	06-Jan-21	RefereeReport (Reply)	27-Jul-21	PRL	Daniel Brandenburg, Zhangbu Xu, Lijuan Ruan, Shuai Yang, Chi Yang, Frank Geurts, Janet Seger, Wangmei Zha
298	Observation of Global Spin Alignment of ϕ and K^{*0} Vector Mesons in Nuclear Collisions (Webpage)	Observation of Global Spin Alignment of phi and K*0 Vector Mesons in Nuclear Collisions	377	2063245 (HepData)	748 (note, cvs)	15-Jun-20	Lanny Ray	Anders Knospe (English QA), Shaowei Lan (Code QA), Xiaofeng Luo (PWG Rep), Prithwish Tribedy (PWG Rep), Xu Sun (PA Rep), Chensheng Zhou (PA Rep), Subhash Singha (PA Rep), Takafumi Niida (Ex officio)	02-Feb-22	LBNL, NISER, TAMU, TUD, Yale (Reply)	04-Apr-22	RefereeReport (Reply) RefereeReport_R2 (Reply_R2)	18-Jan-23	Nature	Jinhui Chen, Declan Keane, Yugang Ma, Subhash Singha, Xu Sun, Aihong Tang, Chensheng Zhou
360 (Mailing List)	Accessing the Temperature of the Quark-Gluon Plasma at Different Stages (Webpage)				816 (note, cvs)	15-Jun-23	Xin Dong	Saehanseul Oh, Declan Keane (English QA), Hao Huang (Code QA), Yue-Hang Leung (PWG Rep), Zaochen Ye (PA Rep)							Daniel Brandenburg, Frank Geurts, Lijuan Ruan, Tetyana Galatyuk, Zhangbu Xu, Zhen Wang, Xiaofeng Wang, Chi Yang, Shuai Yang, Zaochen Ye

GPC chair of first STAR paper (2001)
First paper Declan chair and me PA (2004)
First paper both as PAs (2005)
First STAR Science paper as PA (2010)
First STAR Nature paper as PA (2011)
Chair of 2 Nature papers (2015, 2017)
PA of Nature Physics (2019)
PA of Nature paper (2023)

GPC review committee or Principal Author of
66 STAR papers (20%)
Only two collaborators 60+ papers

First Project with Declan

version 2.5, November 4, 2003
Revised December 2, 2003

Proposed Addition of a Shower Max Detector to the STAR Zero Degree Calorimeters

Hank Crawford[1], Declan Keane[2], Spencer Klein[3], Mikhail Kopytine[2], Bernd Surrow[4], Aihong Tang[4,5], Sergei Voloshin[6], Gang Wang[2], Zhangbu Xu[4]

[1] *UC Berkeley Space Sciences Laboratory*
[2] *Kent State University*
[3] *Lawrence Berkeley National Laboratory*
[4] *Brookhaven National Laboratory*
[5] *NIKHEF*
[6] *Wayne State University*

I. EXECUTIVE SUMMARY

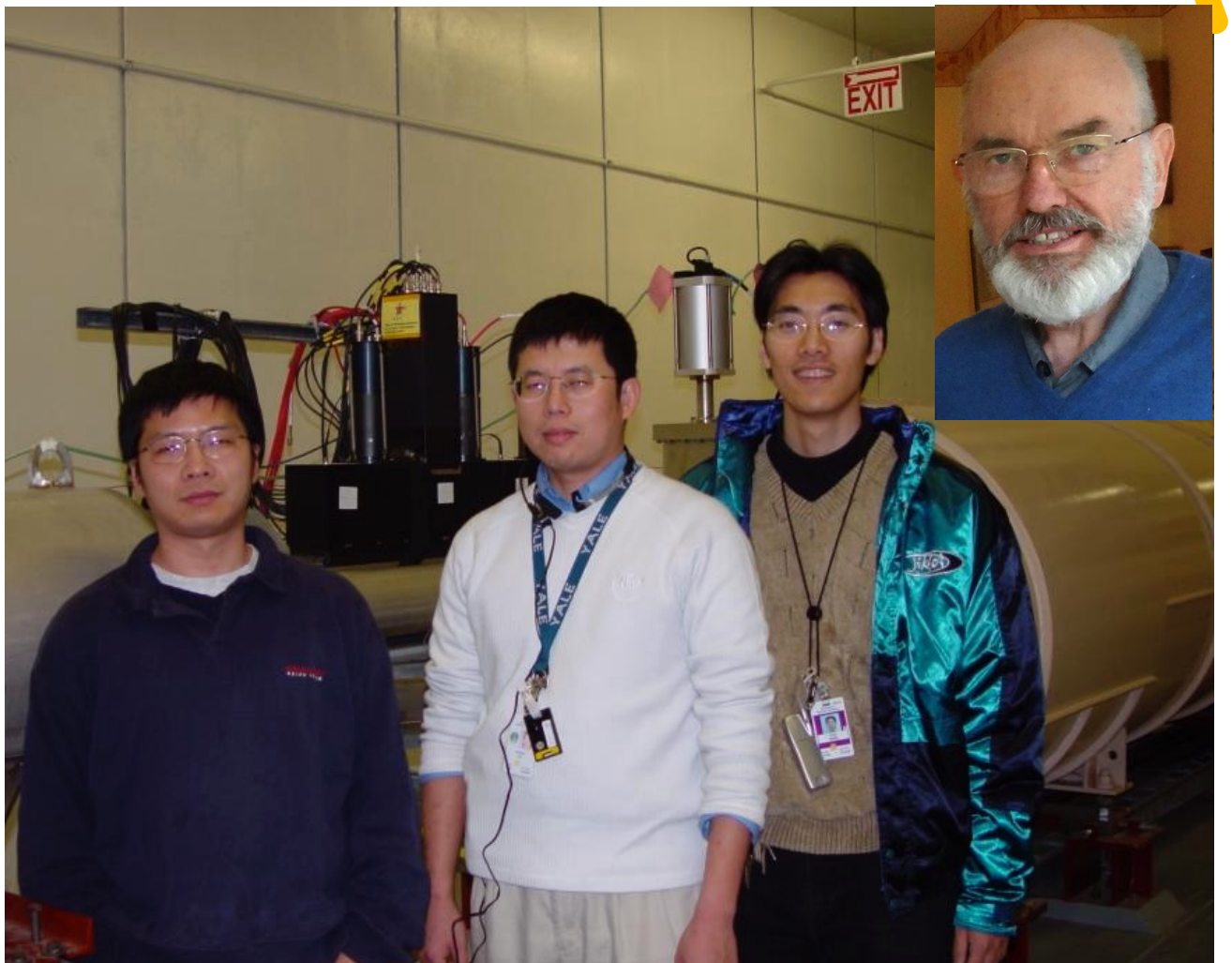
We propose the addition of a Shower Maximum Detector (one plane of 7 vertical slats and another of 8 horizontal slats) to the STAR Zero Degree Calorimeters, closely resembling the ZDC-SMD already used by PHENIX in RHIC run III. The SMD would add significant capability to STAR in four areas of physics: anisotropic flow, strangelet searching, ultra-peripheral collisions, and spin physics. The modest funding needed to implement this upgrade has been identified, and an ample manpower effort is available to complete the installation in time for RHIC run IV.

VI. MANPOWER CONSIDERATIONS

Graduate student Gang Wang, who has carried out the flow simulations, has relocated to BNL and is available to devote 100% of his time to this project. Mikhail Kopytine, Aihong Tang, and Zhangbu Xu will devote whatever fraction of their effort is needed during review, installation and shakedown. Gang Wang will analyze the flow data, Aihong Tang will analyze the strangelet search, and members of the UPC and Spin PWGs yet to be identified will pursue the other physics directions. Bernd Surrow is contributing to this project during the review and implementation phase, and will ensure that STAR spin physics interests are understood and accomodated. Spencer Klein will ensure that STAR UPC physics interests are understood and accomodated. Jim Thomas will provide oversight as needed during review and installation of the detector.

Formally, the ZDC is part of the trigger subsystem, and Hank Crawford is the project leader for all trigger subsystems. Declan Keane and Zhangbu Xu will share direct responsibility for the SMD upgrade.

Tree of Life



Tree of Life

Physics, “Unambition”, and **Seventy** is a rarity

- 唐代杜甫的《曲江二首》

细推物理须行乐，何用浮名绊此身。

酒债寻常行处有，**人生七十古来稀**。

Fu Du (Tang Dynasty, Year 758):

Working hard on physics is a happy time,
Do not need ambition and fame to burden yourself.

So often we cannot afford food and drinks,
It is a rarity to reach seventy years of age.

HAPPY 70th (古稀之年) BIRTHDAY, DECLAN!

Search for heavy antimatter and baryon objects

2003—2007 Gang Wang, PhD
KSU/BNL built ZDC SMD in 2003

Rapid Communication

Strangelet search

B. I. Abelev *et al.* (STAR Collab
Phys. Rev. C **76**, 011901(R) – Pu

nature

2011 Aihong Tang, PhD

Explore content · About the journal · Publish with us

nature > letters > article

Published: 24 April 2011

Observation of the antimatter helium-4 nucleus

The STAR Collaboration

Nature **473**, 353–356 (2011) | Cite this article

nature physics

2020, Declan Keane, Professor

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nature > nature physics > letters > article

Letter | Published: 09 March 2020

Measurement of the mass difference and the binding energy of the hypertriton and antihypertriton

The STAR Collaboration

Nature Physics **16**, 409–412 (2020) | Cite this article

Science

HOME > SCIENCE > VOL. 328, NO. 5974 > OBSERVATION OF AN ANTIMATTER HYPERNUCLEUS

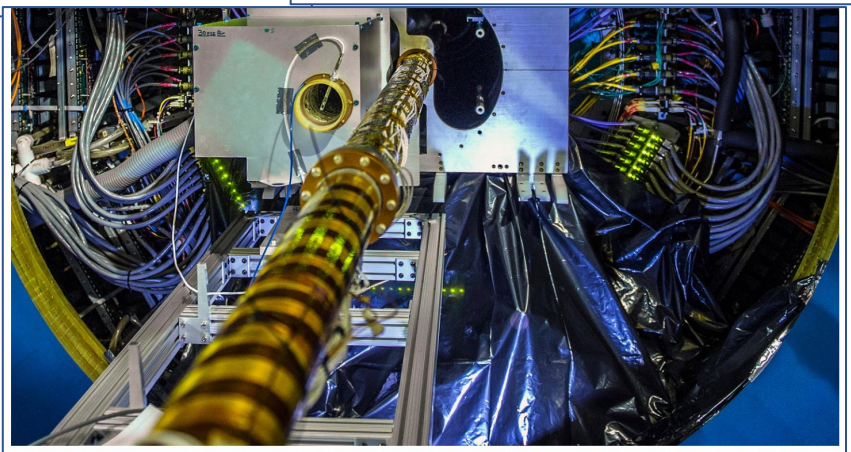
RESEARCH ARTICLE

2010, Jinhui Chen, Postdoc

Observation of an Antimatter Hypernucleus

THE STAR COLLABORATION , B. I. ABELEV, M. M. AGGARWAL, Z. AHAMMED, A. V. ALAKHVERDYANTS, I. ALEKSEEV, B. D. ANDERSON, D. ARK
Y. ZOULKARNEEVA +382 authors Authors Info & Affiliations

SCIENCE · 4 Mar 2010 · Vol 328, Issue 5974 · pp. 58-62 · DOI: 10.1126/science.1183980



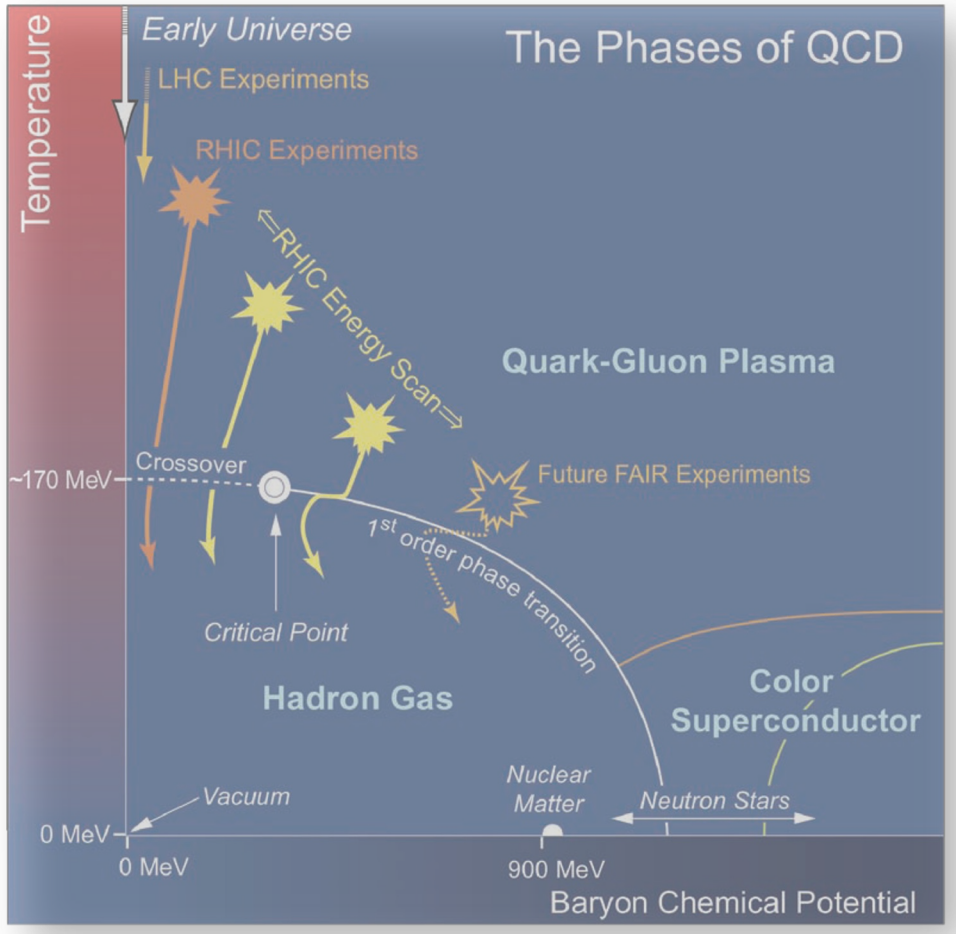
DEPARTMENT OF ENERGY SELECTS KENT STATE NUCLEAR PHYSICS DOCTORAL STUDENT FOR PRESTIGIOUS RESEARCH PROGRAM

Thursday, October 7, 2021 - 02:16pm

Edwin Duckworth, a physics doctoral student in the College of Arts and Sciences at Kent State University, is among 65 students from 29 states recently selected for funding by the Department of Energy's (DOE) Office of Science Graduate Student Research (SCGSR) program. The...

Emmy Duckworth,
2021 DOE SCGSR

A look into the future (from Kent Perspective)



HEAVY ION COLLISIONS OVER A RANGE OF RELATIVISTIC ENERGIES

Zhangbu Xu, Kent State University (Principal Investigator)

Declan Keane, Kent State University (Co-Investigator)

Spyridon Margetis, Kent State University (Co-Investigator)

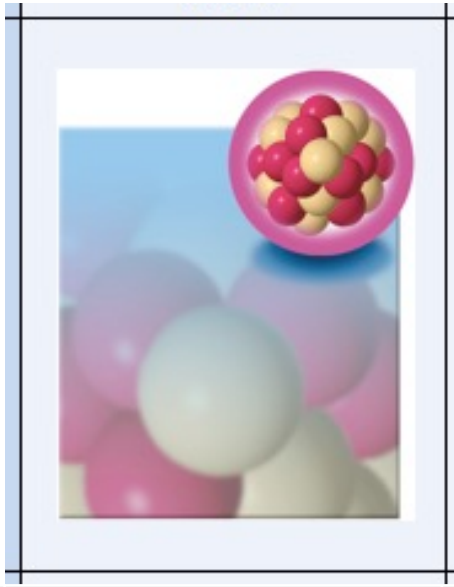
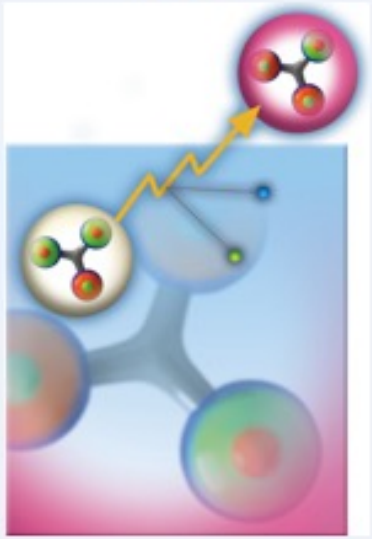
- **Introduction to the QCD phase diagram**
- **Temperatures of the Quark-Gluon Plasma**

  thermal “blackbody” radiation
- **Baryons**

  baryon number carrier
- **When QED meets QCD**

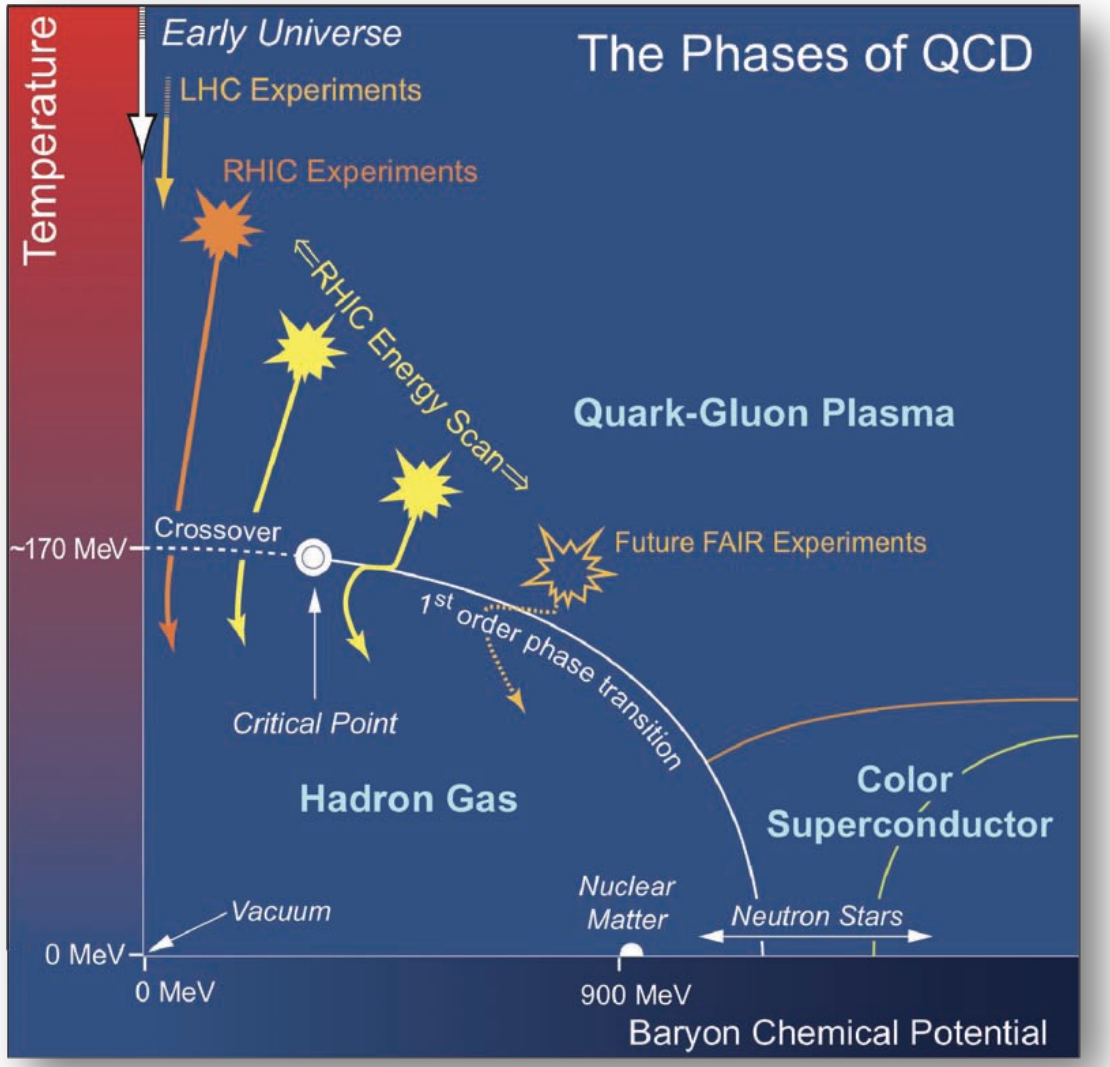
  photon-induced process
- **Further Future Perspectives**

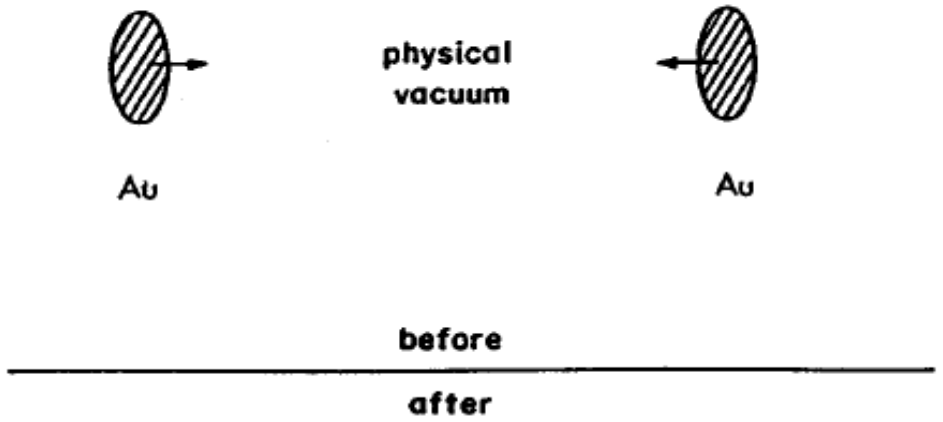
The four fundamental interactions in Nature

Interaction	Strong Interaction	Electromagnetism	Weak Interaction	Gravitation
Year Formulated	1970s	1860s	1960s	1680s
				
Relative strength at 2 proton distance	**1**	**10^{-2}**	**10^{-6}**	**10^{-38}**
Interaction range (m)	10^{-15}	∞	10^{-18}	∞
Mediator	gluons	photon	Z/W Bosons	graviton

Free quarks in excited vacuum

2007 NSAC Long Range Plan





T.D. Lee (1970s)

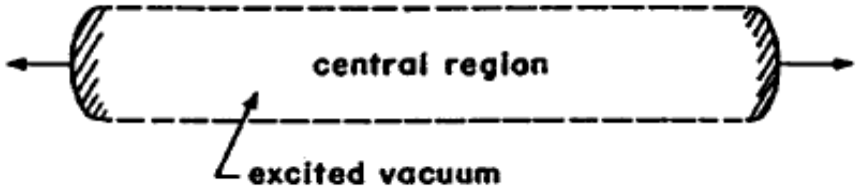
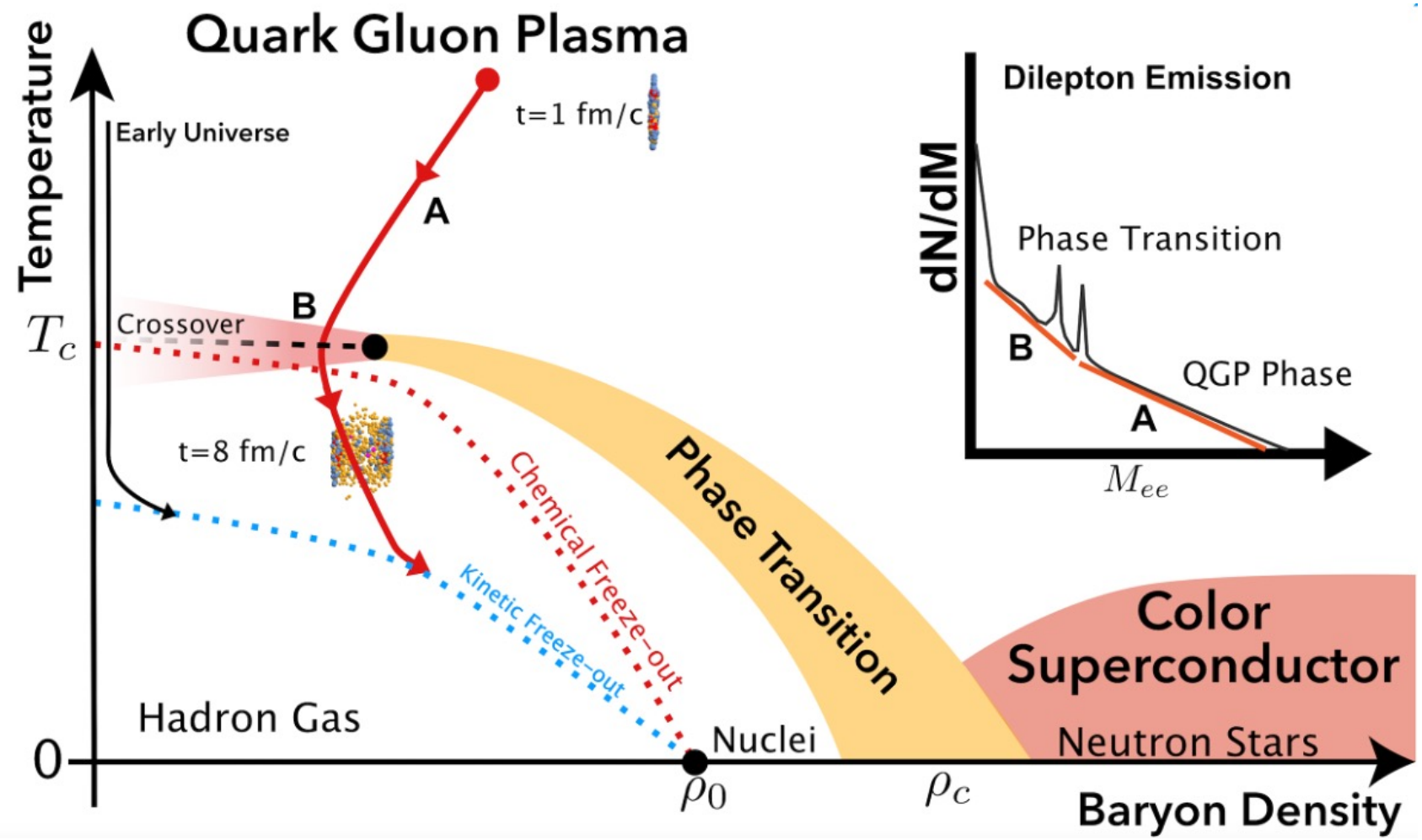


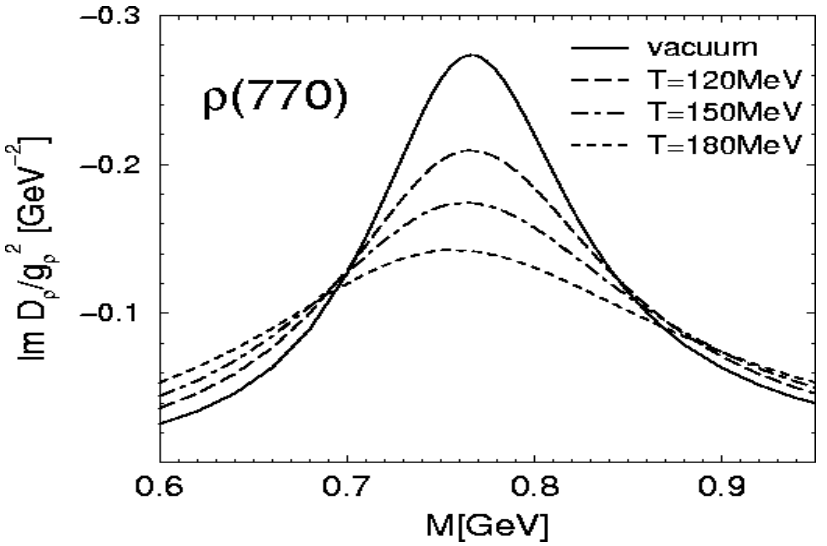
Figure 2. Vacuum excitation through relativistic heavy ion collisions.

Fireball Spectroscopy



The hot fireballs also emit real and virtual photons, which — contrary to hadrons — penetrate the QCD medium and thus carry information on the interior of the fireball

R. Rapp, Nature Physics, 15 (2019) 990



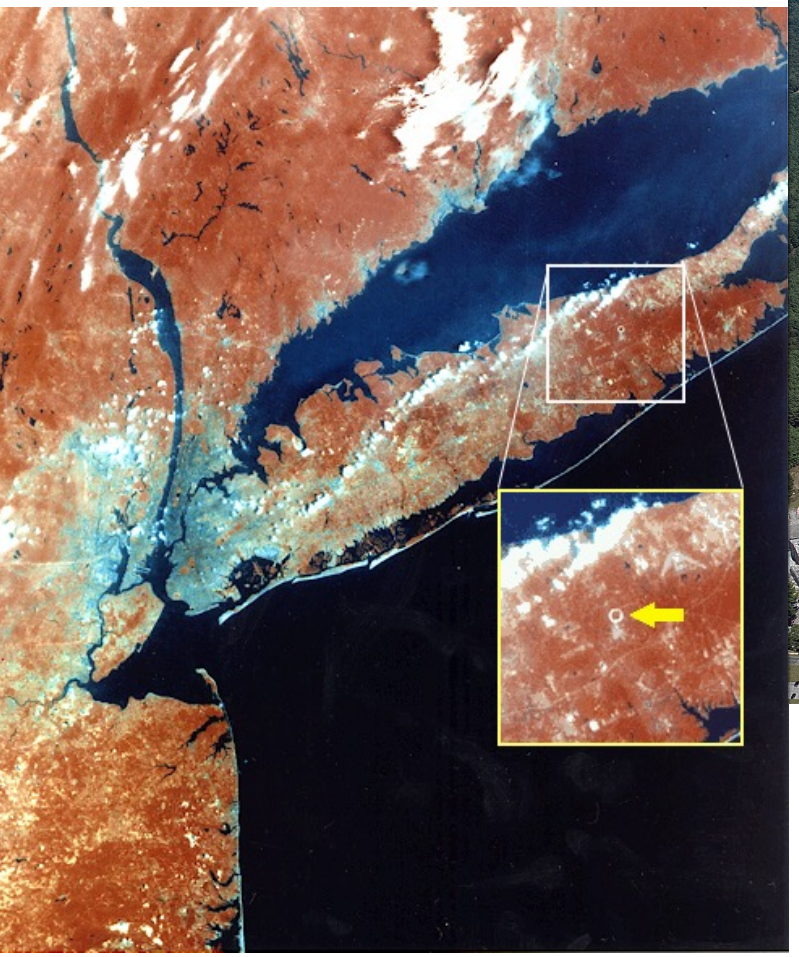
QUARK–GLUON PLASMA AND HADRONIC PRODUCTION OF LEPTONS, PHOTONS AND PSIONS

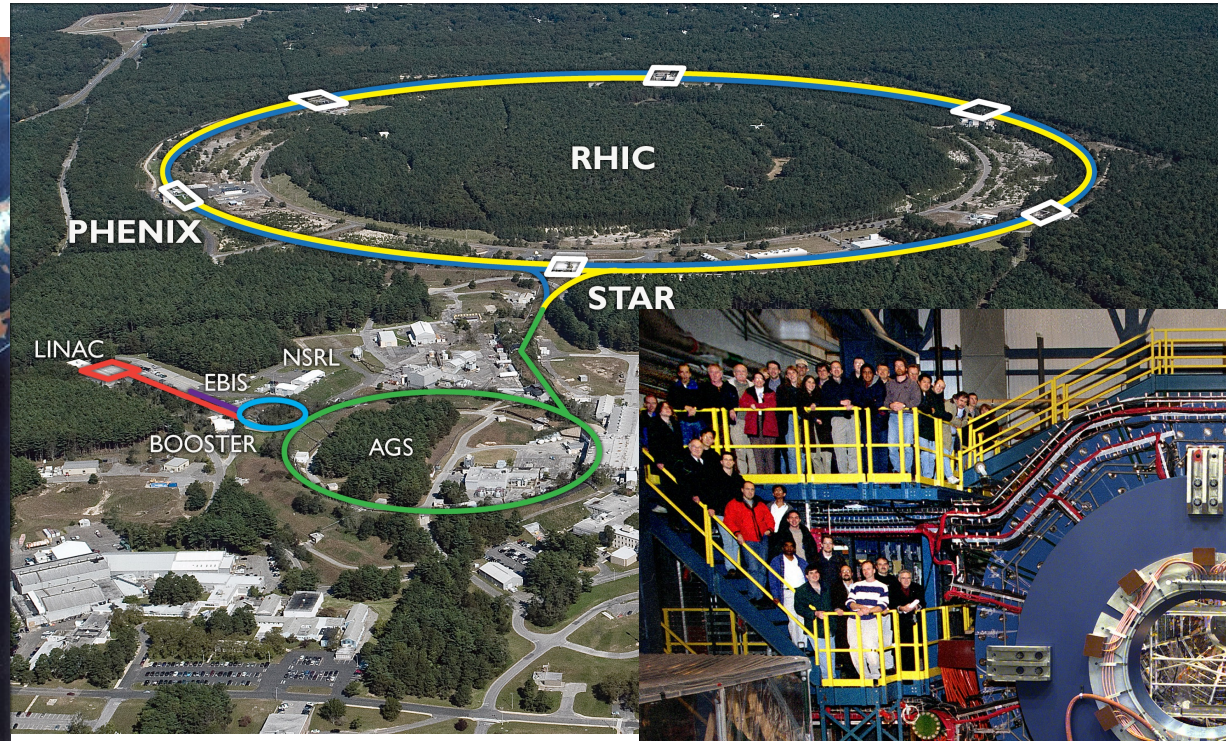
E.V. SHURYAK
Institute of Nuclear Physics, Novosibirsk, USSR

Received 16 March 1978

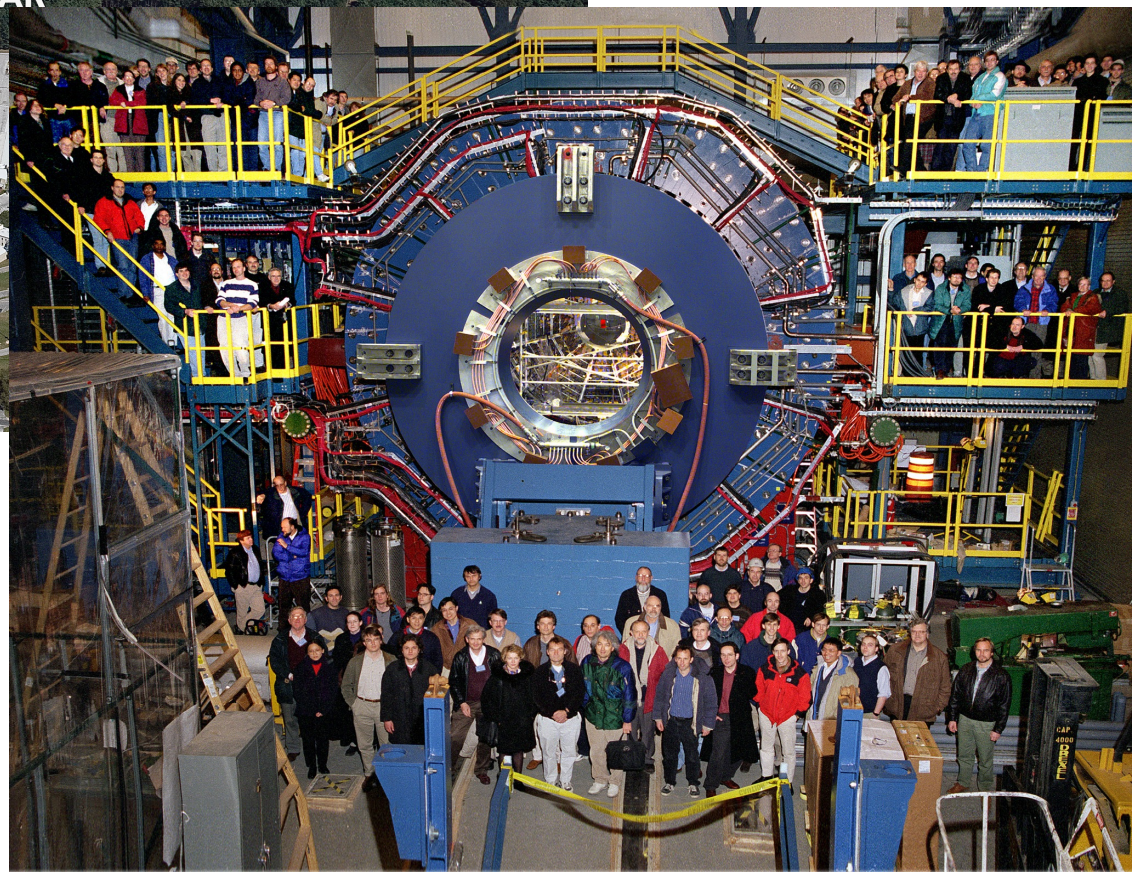
$$e^{-\frac{m}{T}}$$

Our Experiment: the STAR Collaboration at RHIC





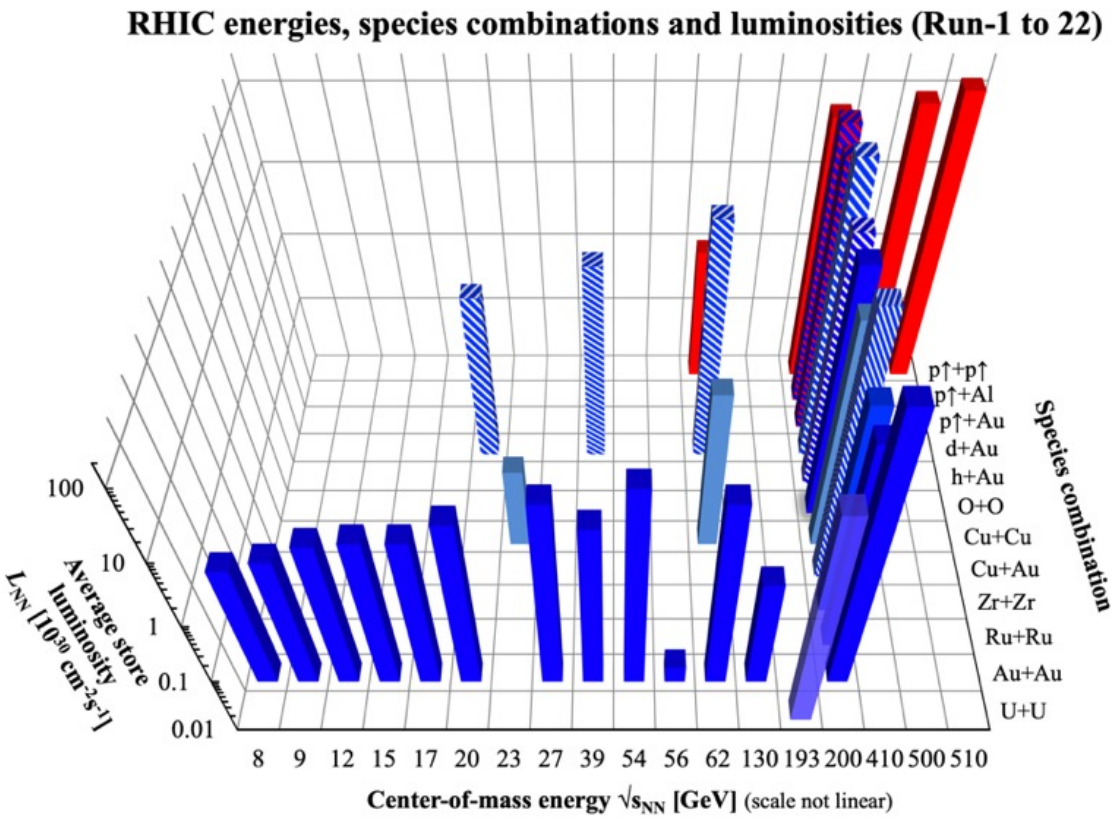
My term as spokesman (2014-17) ,
co-spokesperson (17-20),
institutions from 48-> 70



Relativistic Heavy Ion Collider (RHIC) is 3.8km in length
STAR Collaboration: 700+ scientists from 14 countries
Established in 1993, and operational since 2000
www.star.bnl.gov

Example of versatile colliders and detectors

major upgrades over the last twenty years to improve particle identification and vertex reconstruction and is still evolving with an extension to forward rapidity as of today. pioneered in using new technologies: MRPC, MAPS, GEM and siPM.
Estimate 35M(initial) +75M(upgrades)$.



Detector	primary functions	DOE+(in-kind)	year
TPC+Trigger	$\|\eta\|$ <1 Tracking		1999-
Barrel EMC	$\|\eta\|$ <1 jets/γ/π^0/e		2004-
FTPC	forward tracking	(Germany)	2002-2012
L3	Online Display	(Germany)	2000-2012
SVT/SSD	V0/charm	(France)	2004-2007
PMD	forward photons	(India)	2003-2011
EEMC	1< η <2 jets/π^0/e	(NSF)	2005-
Roman Pots	diffractive		2009-
TOF	PID	(China)	2009-
FMS/Preshower	2.5< η <4.2	(Russia)	2008-2017
DAQ1000	x10 DAQ rate		2008-
HLT	Online Tracking	(China/Germany)	2012-
FGT	1< η <2 $W^{\pm}$		2012-2013
GMT	TPC calibration		2012-
HFT/SSD	open charm	(France/UIC)	2014-2016
MTD	muon ID	(China/India)	2014-
EPD	event plane	(China)	2018-
RHICf	η >5 π^0	(Japan)	2017
iTPC	$\|\eta\|$ <1.5 Tracking	(China)	2019-
eTOF	-2< η <-1 PID	(Germany/China)	2019-
FCS	2.5< η <4 calorimeter	(NSF)	2021-
FTS	2.5< η <4 Tracking	(NCKU/SDU)	2021-

8 new detectors added to STAR since 2014

Electron Identification at STAR

TPC dE/dx: large hadron background

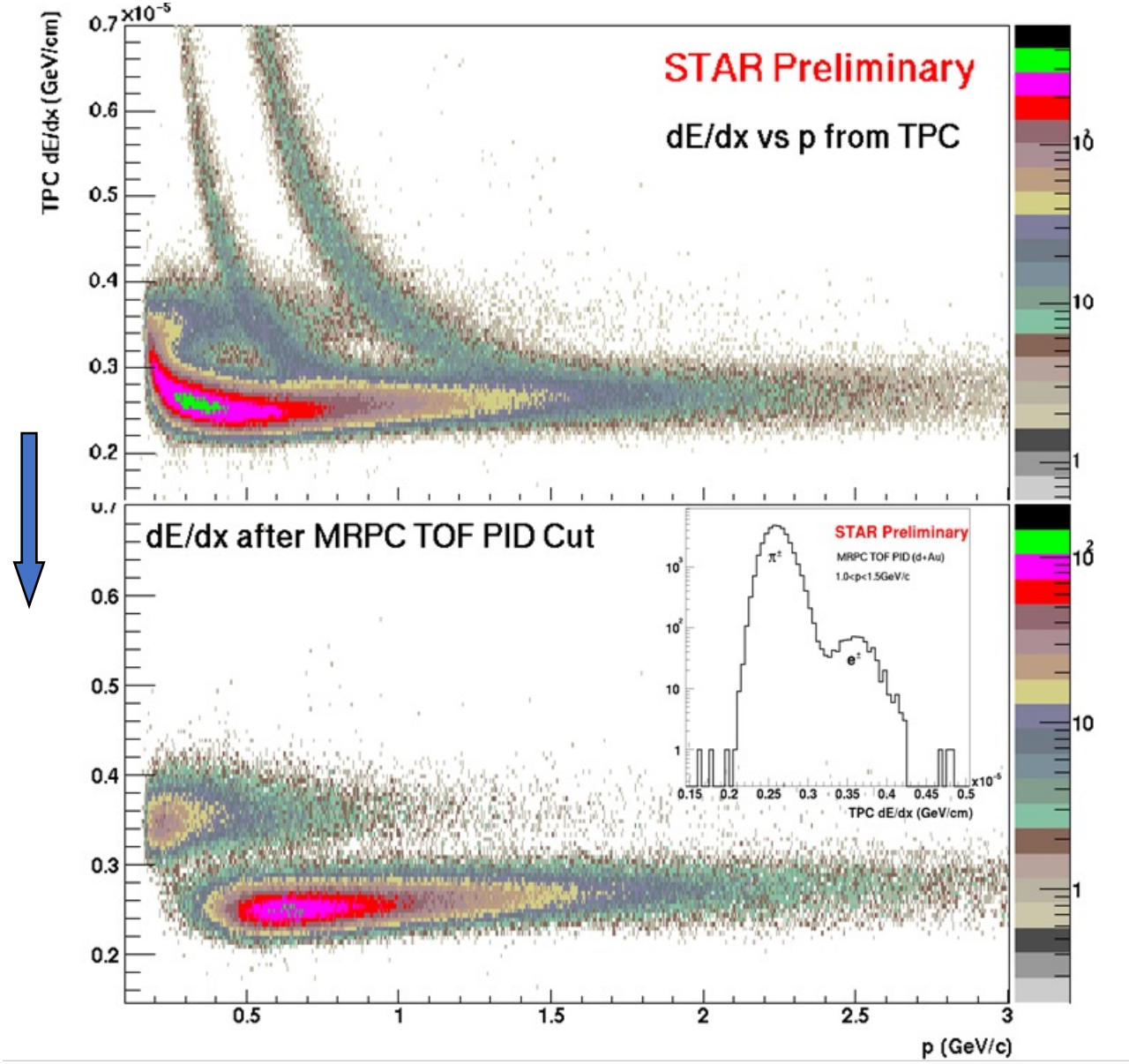
EMC: p_T>~2.0 GeV/c

A prototype TOF tray (TOFr) in 2003

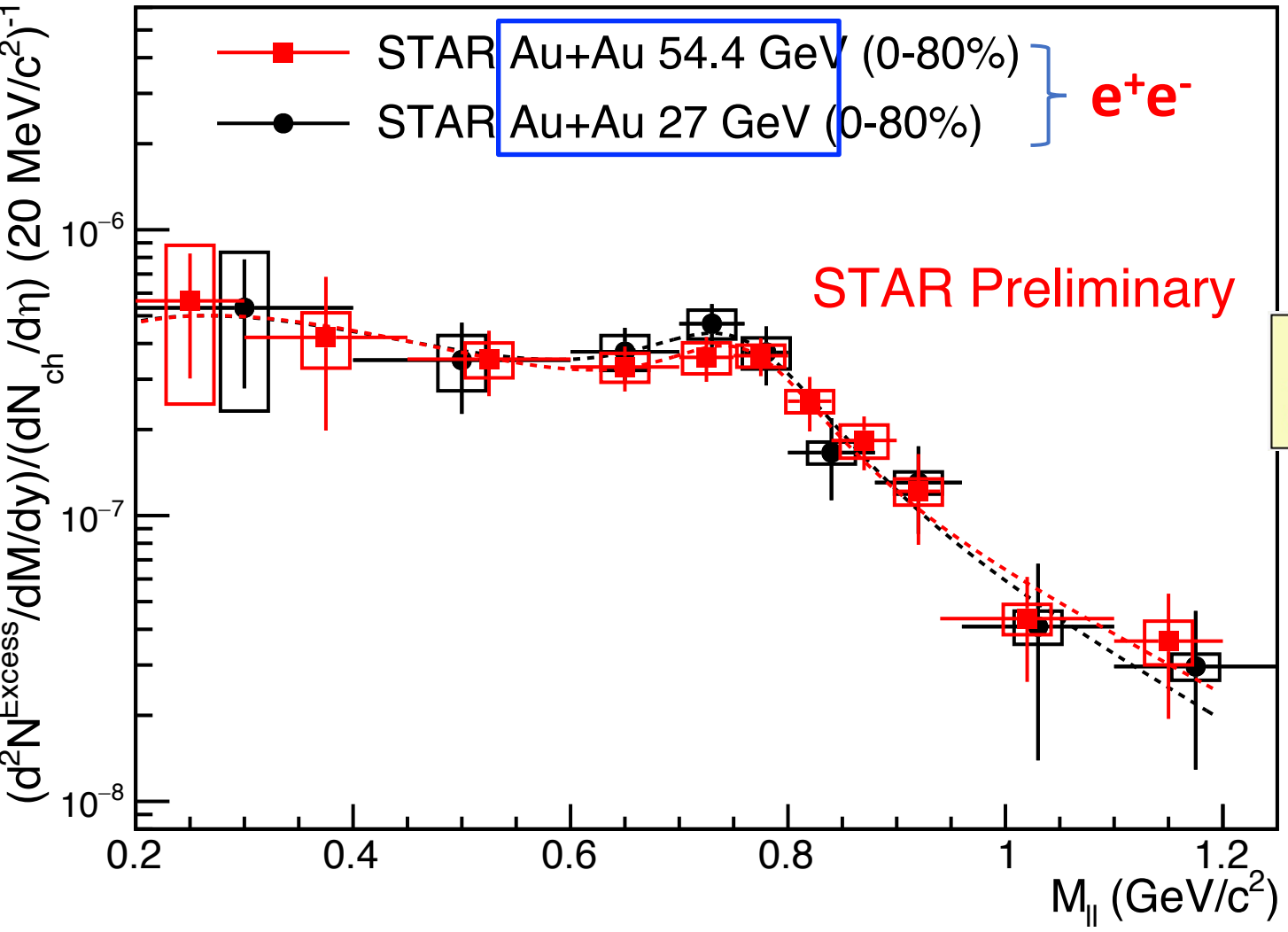
$|1/\beta-1|<0.03$

Not able to do without TOF!

NIMA2005, nucl-ex/0505026, M. Shao et al.
Xin Dong PHD Thesis (USTC 2005)
Lijuan Ruan PHD Thesis (USTC 2004)



Low-mass thermal dielectron



In-medium ρ dominated

Thermal dilepton rate (R. Rapp):

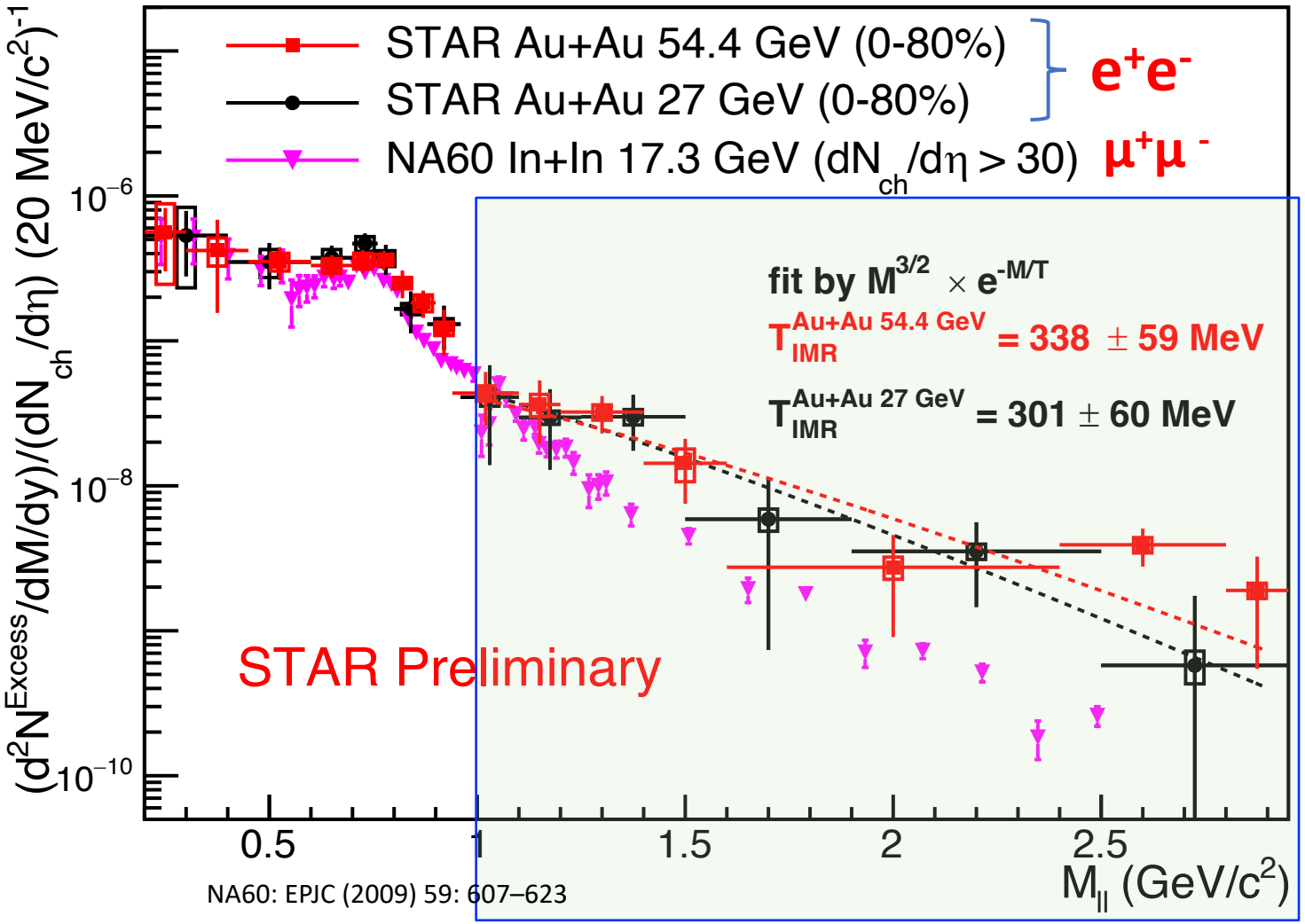
$$\frac{dR}{d^4q} = \frac{-\alpha^2}{\pi^3 M^2} f^B(q_0, T)\ \mathrm{Im}\,\Pi_{\mathrm{em}}(M, q; \mu_B, T)$$

Traditionally focus on the ρ spectral function
use model parametrization for Boltzmann factor

NEW: focus on the Boltzmann factor
use model parametrization for ρ spectral function

Zaochen Ye (STAR), SQM2022
Zhen Wang, PhD thesis, SDU, 2023

Intermediate-Mass Thermal Dilepton



QGP dominated

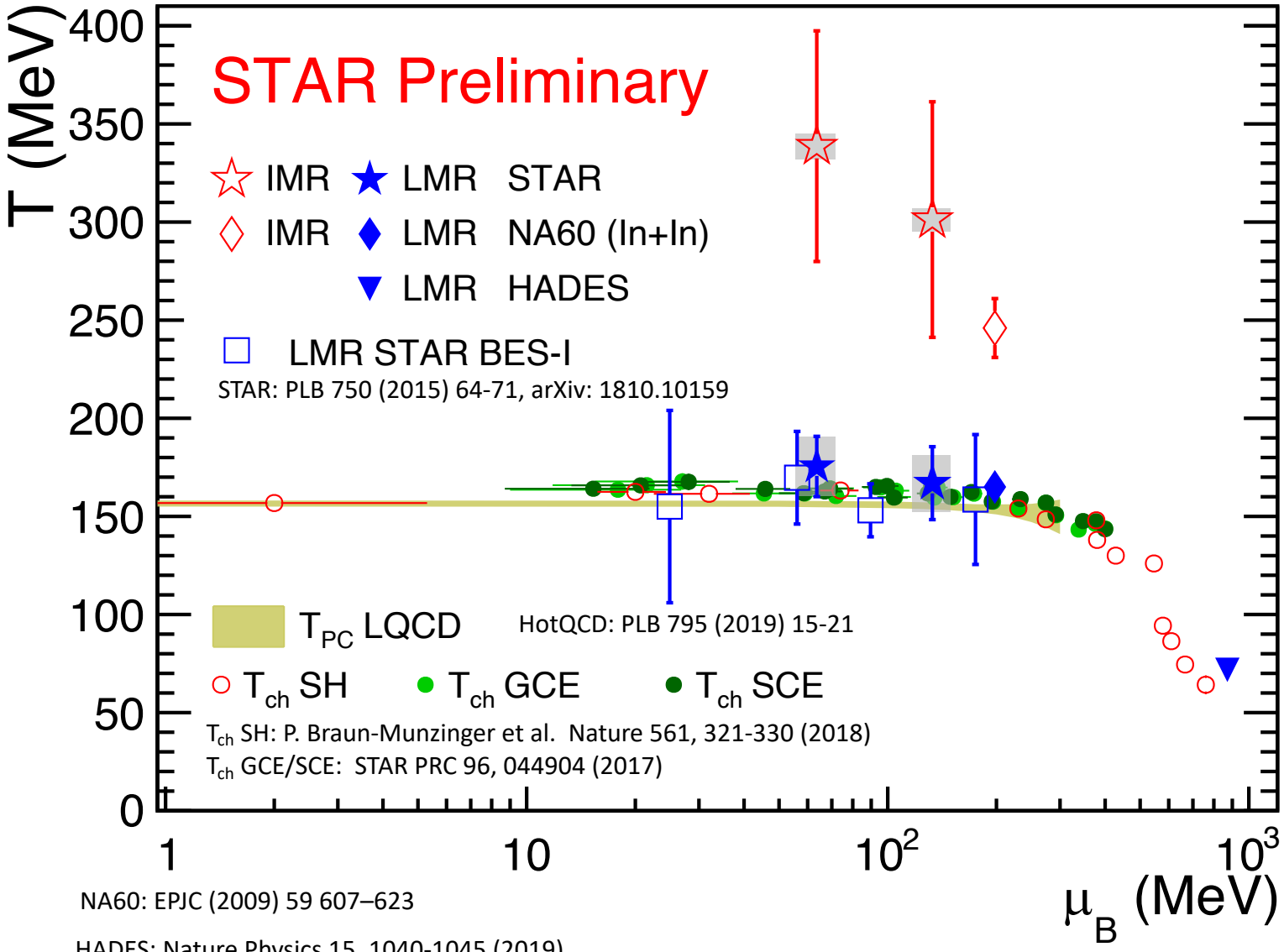
T_{IMR} from STAR data: ~ 320 MeV

T_{IMR} from NA60 data:

- 246 ± 15 MeV ($1.2<M<2.5$ GeV/c^2) [2]

$T_{IMR} > T_{pc}$ (156 MeV) indicating: emission source is dominantly the partonic phase

Temperatures of QGP at different stages



NA60: EPJC (2009) 59 607–623

HADES: Nature Physics 15, 1040-1045 (2019)

Thermal dileptons in LMR

- T close to both T_{ch} and T_C
- Emission dominantly around phase transition

Thermal dileptons in IMR

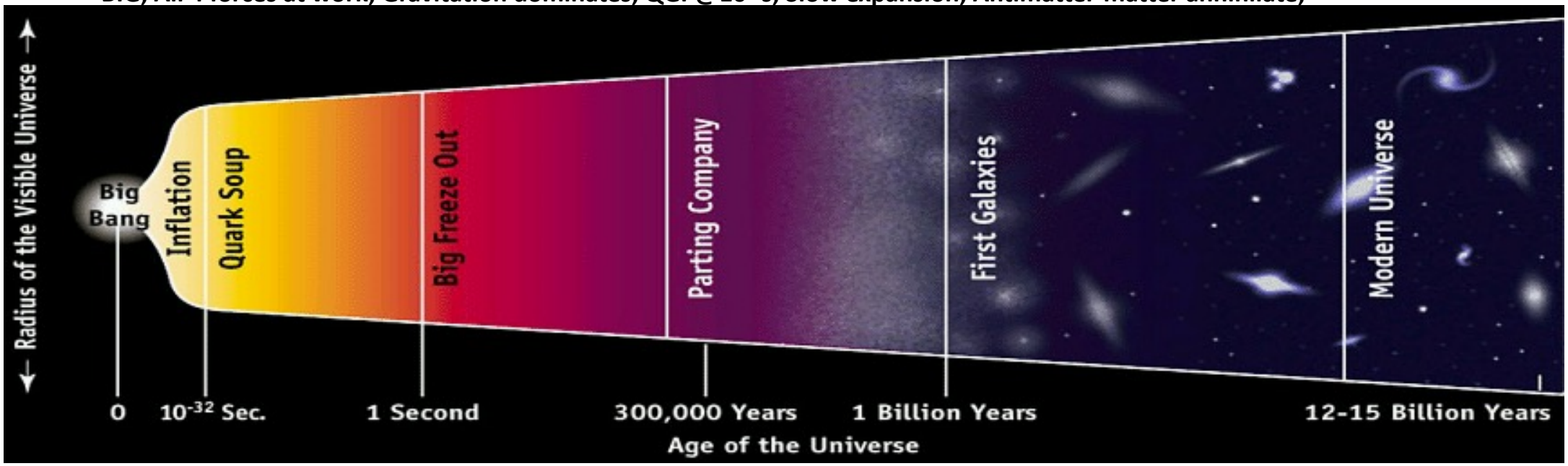
- T is higher than T_c
- Emitted from QGP phase and earlier

Note: μ_B (QGP) ≠ μ_B (Ch. freeze-out)

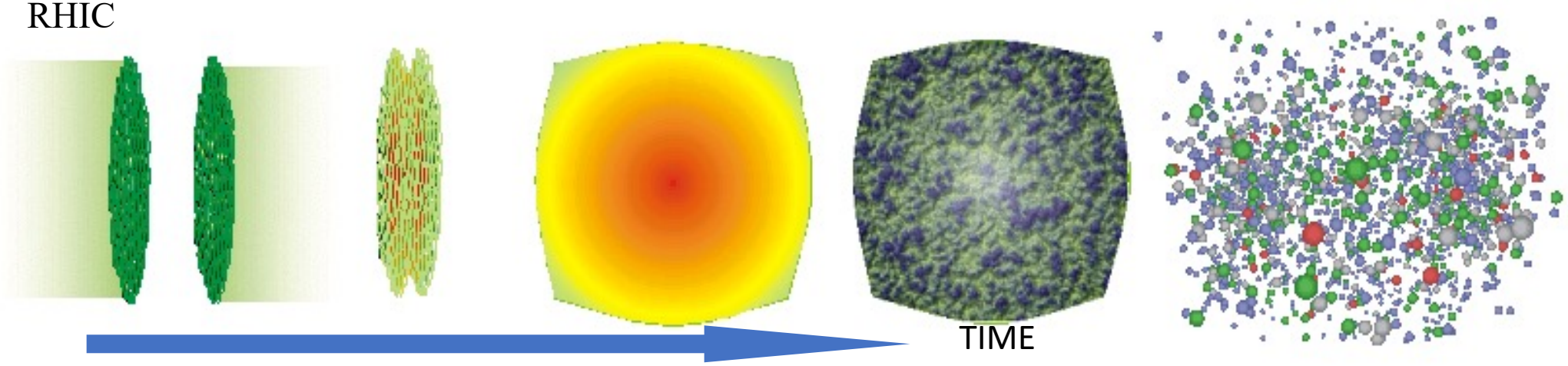
Declan as member of the GPC review committee, paper prepared to submit to Nature

Little Big Bang

BIG; All 4 forces at work; Gravitation dominates; QGP@10^{-6}s; Slow expansion; Antimatter-matter annihilate;



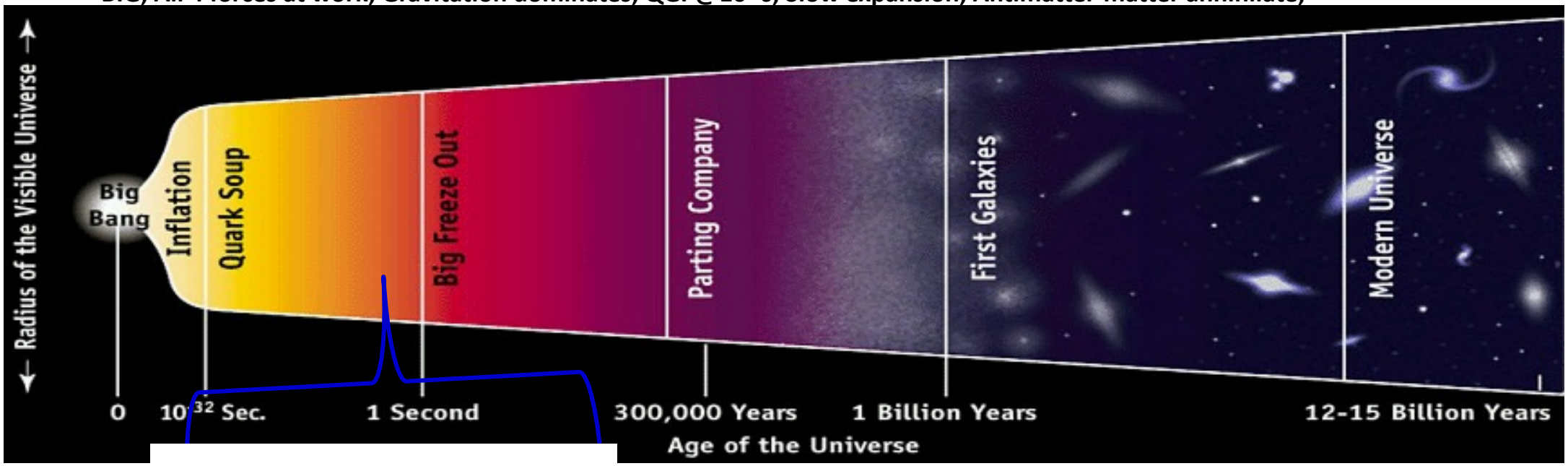
RHIC

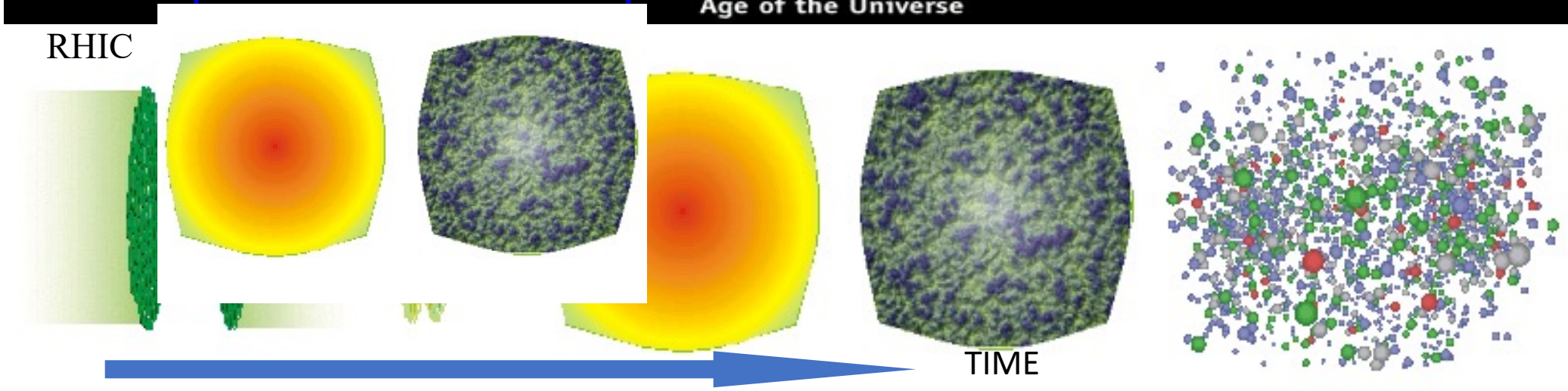


Little; Strong force at work; QGP@10^{-23}s; Fast expansion; Antimatter-matter decouple; repeat trillion times

Little Big Bang

BIG; All 4 forces at work; Gravitation dominates; QGP@10^{-6}s; Slow expansion; Antimatter-matter annihilate;

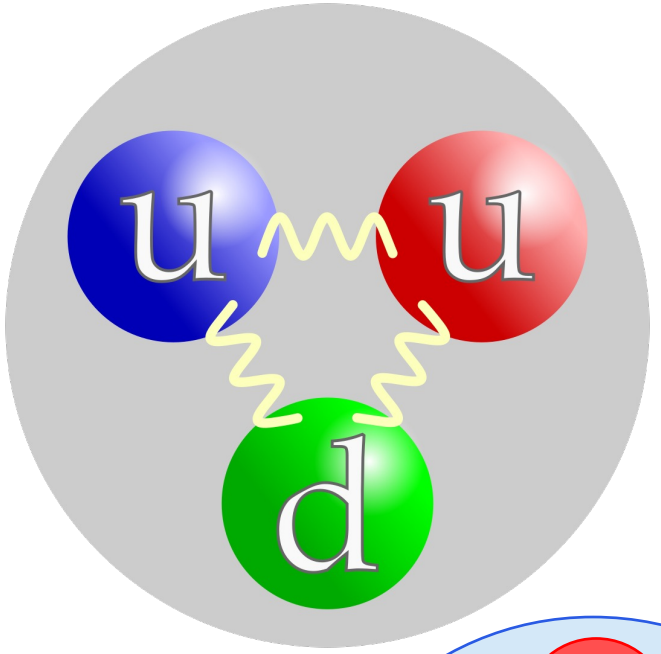




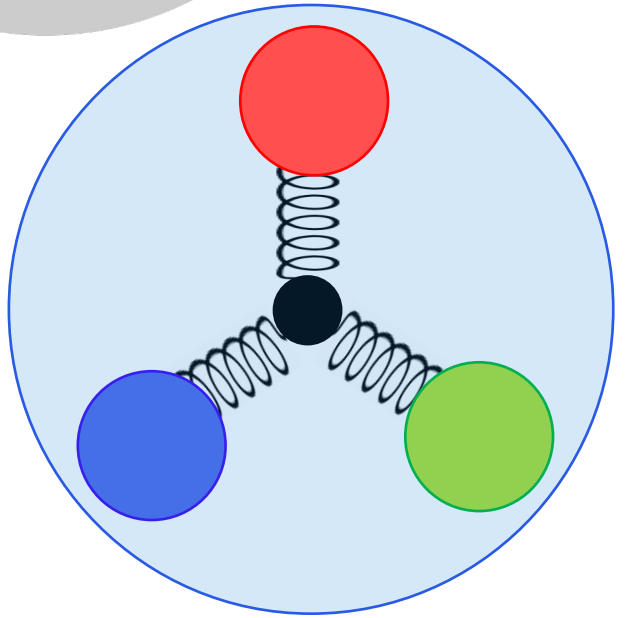
Little; Strong force at work; QGP@10^{-23}s; Fast expansion; Antimatter-matter decouple; repeat trillion times

Baryon Number (B) Carrier

https://en.wikipedia.org/wiki/Quark



- Textbook picture of a proton
  - Lightest baryon with strictly conserved baryon number
  - Each valence quark carries 1/3 of baryon number
  - Proton lifetime >10^{34} years
  - Quarks are connected by gluons
- Alternative picture of a proton
  - Proposed at the Dawn of QCD in 1970s
  - A Y-shaped gluon junction topology carries baryon number (B=1)
  - The topology number is the strictly conserved number
  - Quarks do not carry baryon number
  - Valence quarks are connected to the end of the junction always
- Neither of these postulations has been verified experimentally



[1]: Artru, X.; String Model with Baryons: Topology, Classical Motion. Nucl. Phys. B 85, 442–460 (**1975**).
[2]: Rossi, G. C. & Veneziano, G. A; Possible Description of Baryon Dynamics in Dual and Gauge Theories. Nucl. Phys. B 123, 507–545 (**1977**)

Baryon Number (B) Carrier

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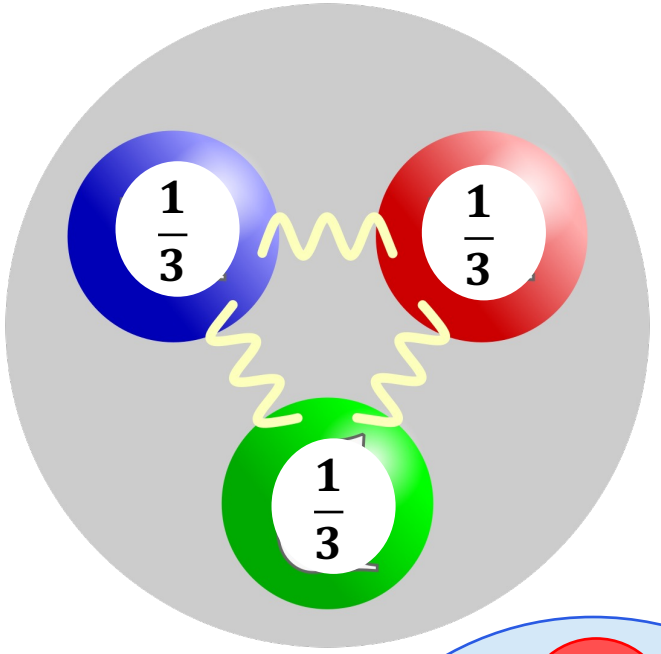

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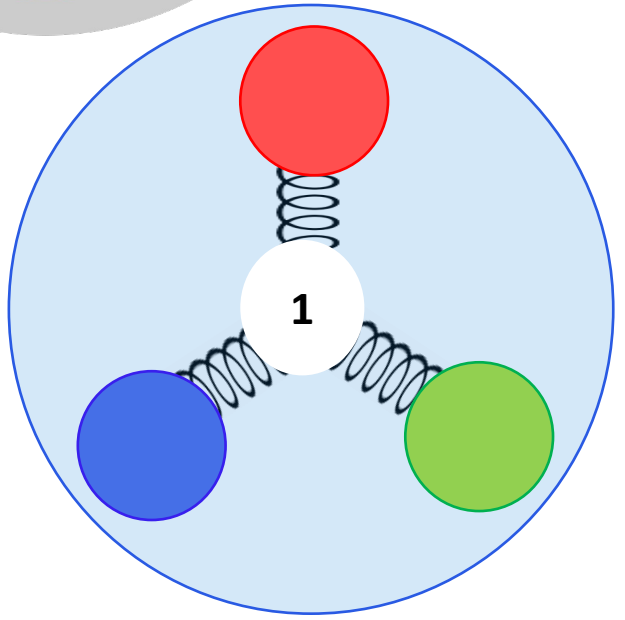


[1]: Artru, X.; String Model with Baryons: Topology, Classical Motion. Nucl. Phys. B 85, 442–460 (**1975**).
[2]: Rossi, G. C. & Veneziano, G. A; Possible Description of Baryon Dynamics in Dual and Gauge Theories. Nucl. Phys. B 123, 507–545 (**1977**)

Model implementations of baryons at RHIC

- 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 Stopping
  - Theorized to be an effective mechanism of stopping baryons in pp and AA

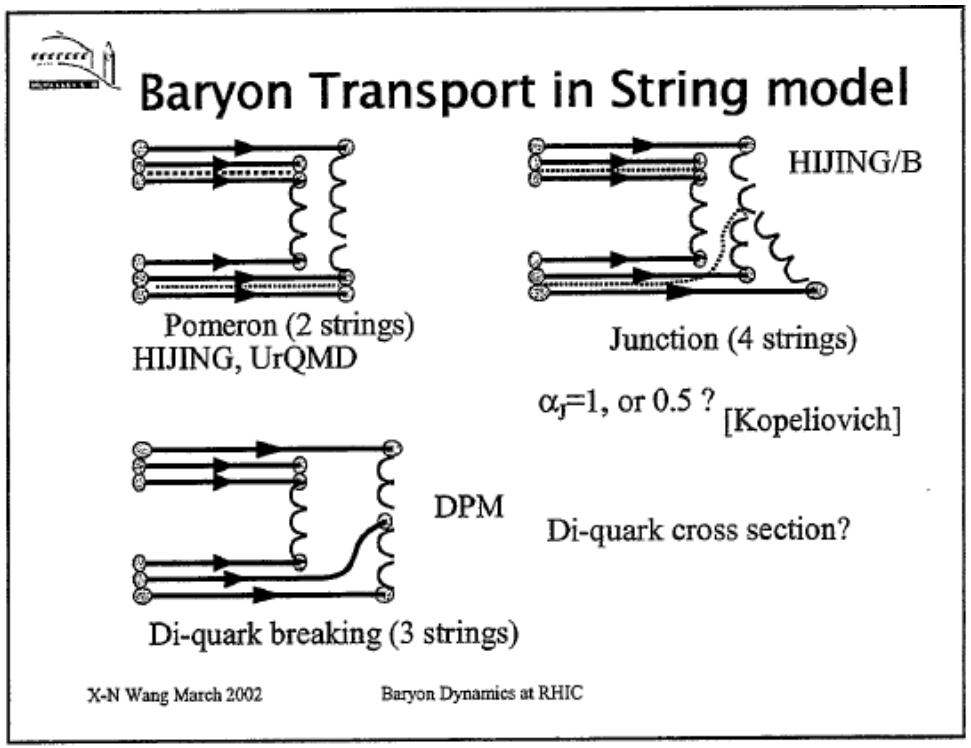
  D. Kharzeev, Physics Letters B **378**, 238-246 (1996)

- Specific rapidity dependence is predicted:

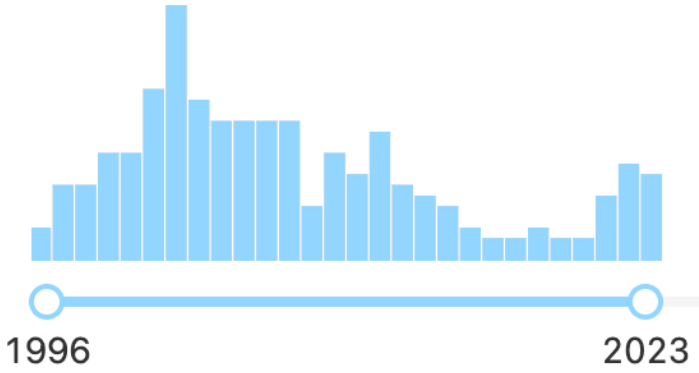
$$p = \sim e^{-\alpha_B y}$$

α_B ~=0.5

2003 RBRC Workshop on "Baryon Dynamics at RHIC"



D. Kharzeev, Physics Letters B **378**, 238-246 (1996)
"Can gluons trace baryon number?"



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

BUT citations ARE

Three approaches toward tracking the origin of the baryon number

1. Charge (Q) stopping vs baryon (B) stopping:
   if valence quarks carry Q and B,
   Q=B at middle rapidity

2. If gluon topology (J) carries B as one unit, it should show scaling according to Regge theory

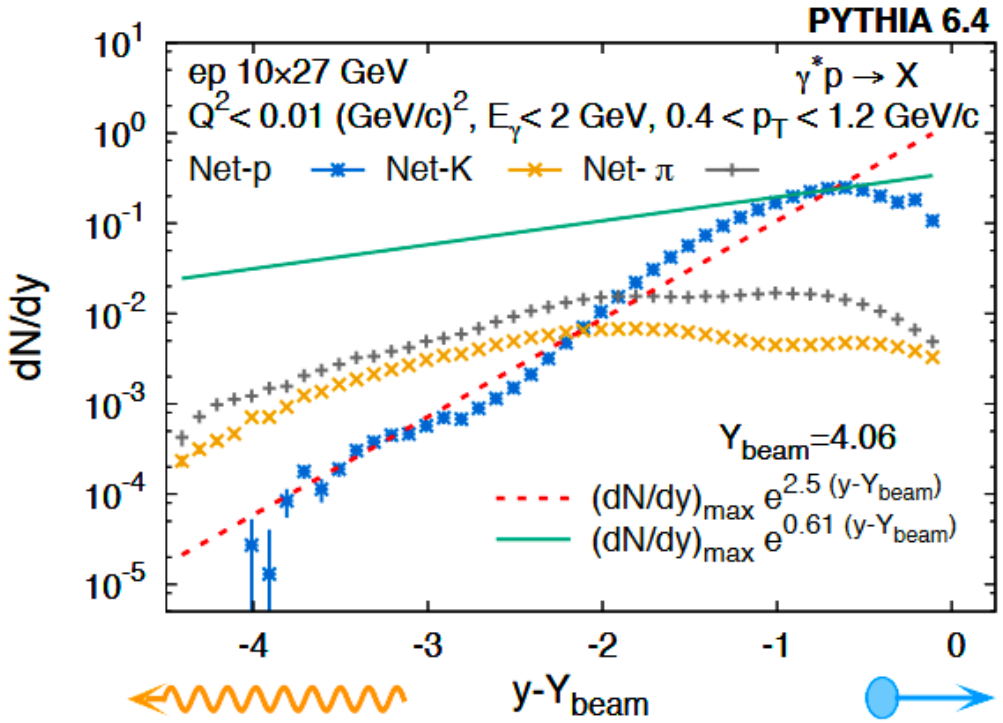
$$p = \sim e^{-\alpha_B y}$$

α_B ~=0.5

3. In γ+Au collision, rapidity asymmetry can reveal the origin

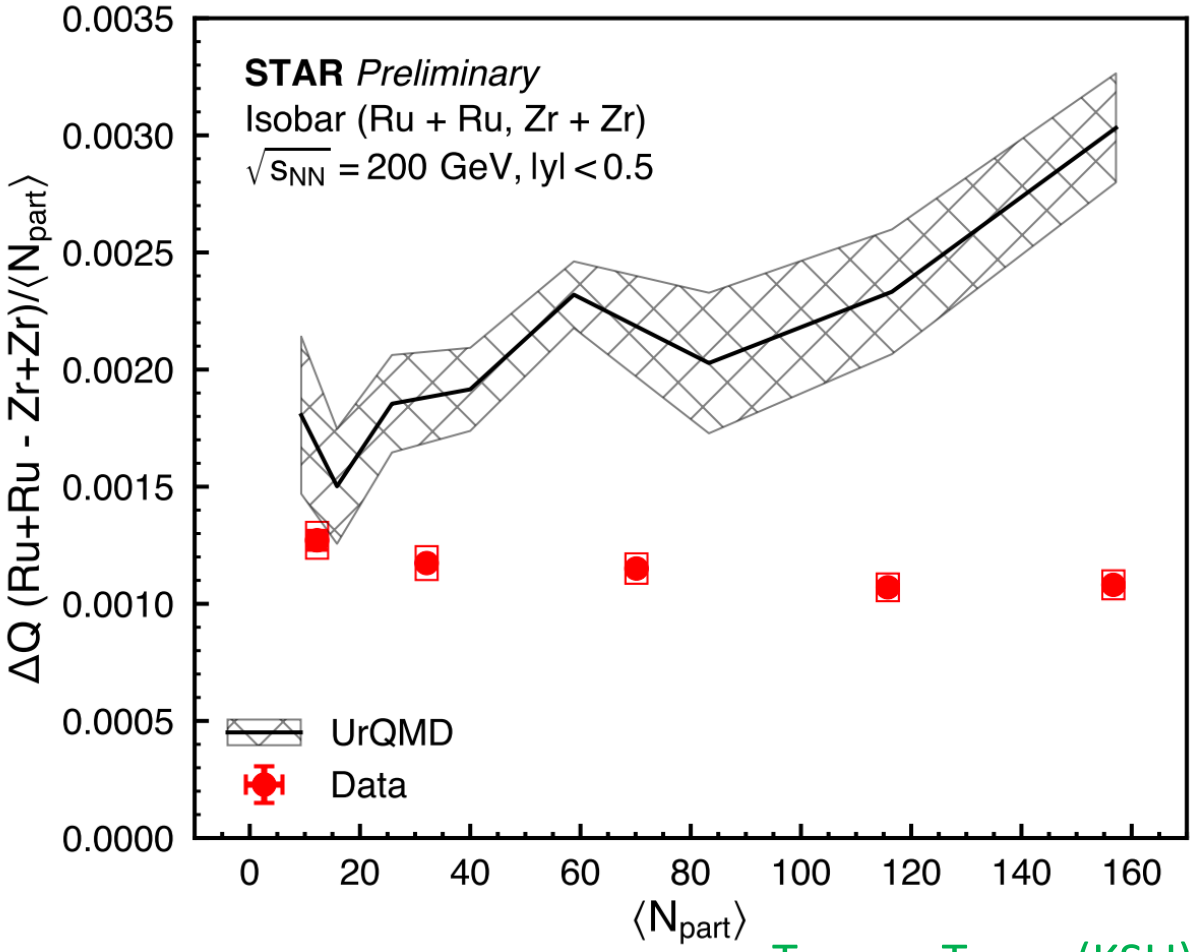
D. Brandenburg, N. Lewis, P. Tribedy, Z. Xu, arXiv:2205.05685

Proposed to use double ratio in Zr+Zr and Ru+Ru isobar collisions to cancel al the detector effects, the signal is at the level of 10^{-3}

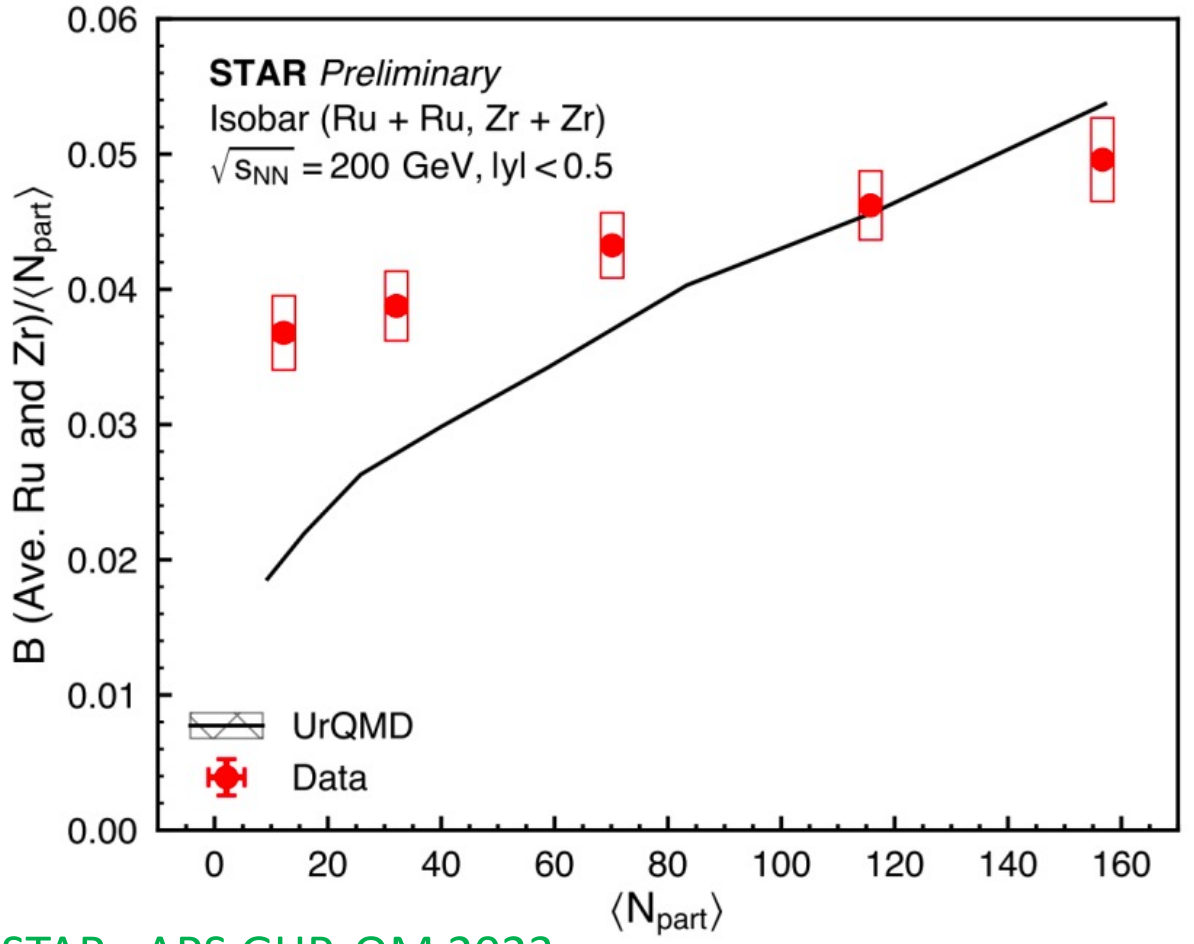


Separate charge and baryon transports

Charge number transport



Baryon number transport



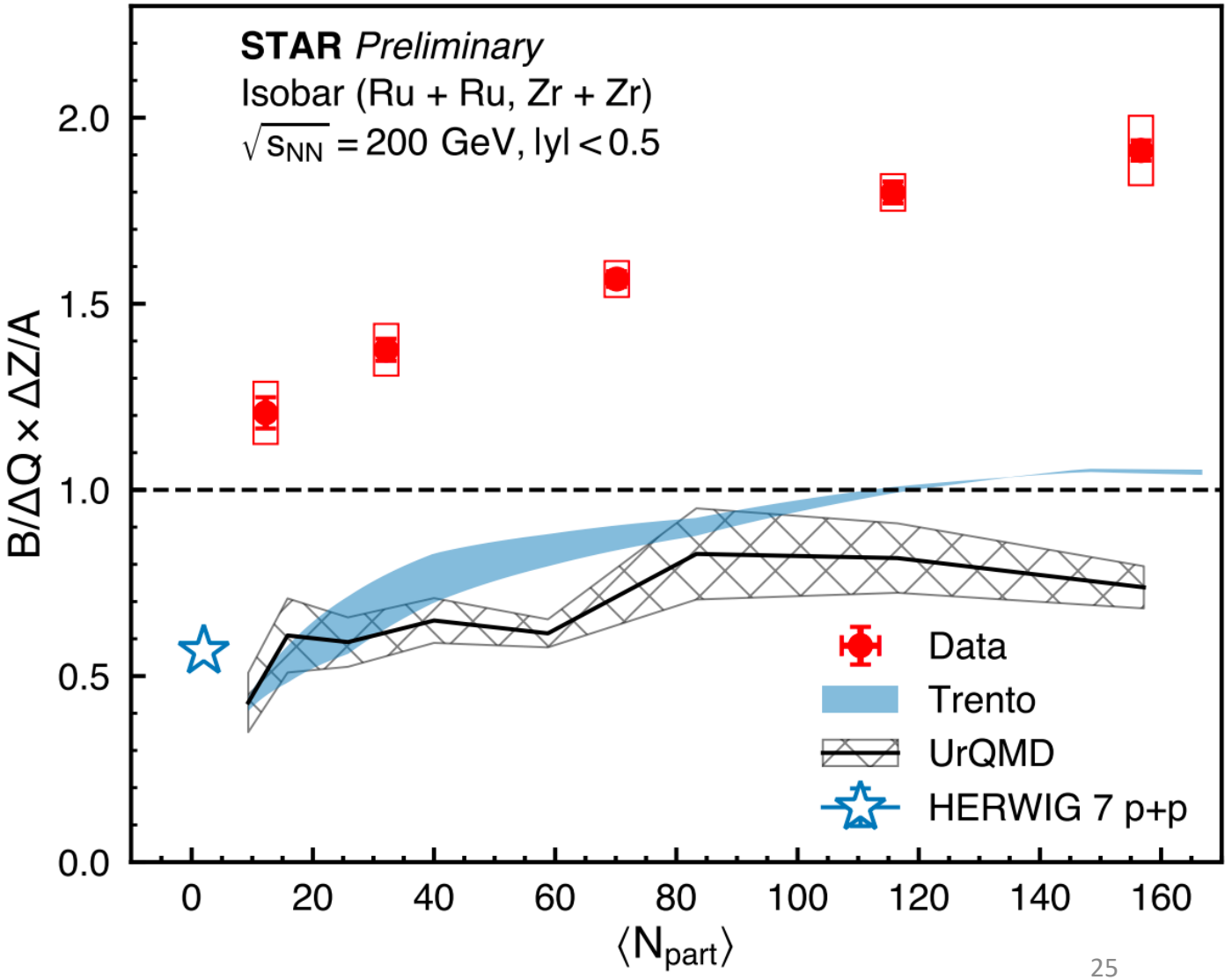
Tommy Tsang (KSU) for STAR, APS GHP, QM 2023

UrQMD matches data on charge stopping better in peripheral; better on baryon stopping in central
overpredicts charge stopping in central; underpredicts baryon stopping in peripheral

Ratio of baryon over charge transports

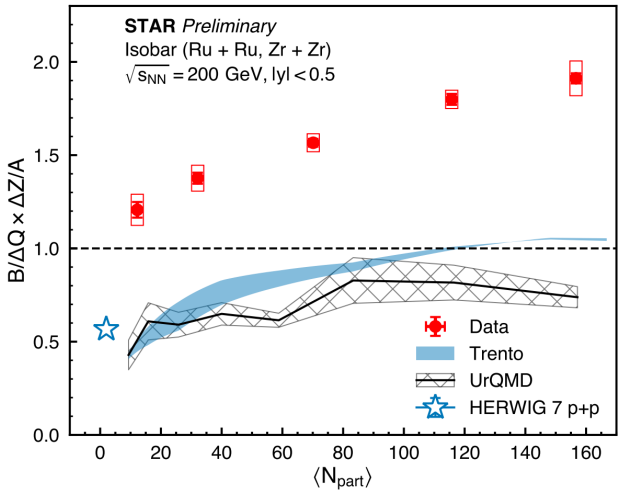
Tommy Tsang (KSU) for STAR, APS GHP, QM 2023

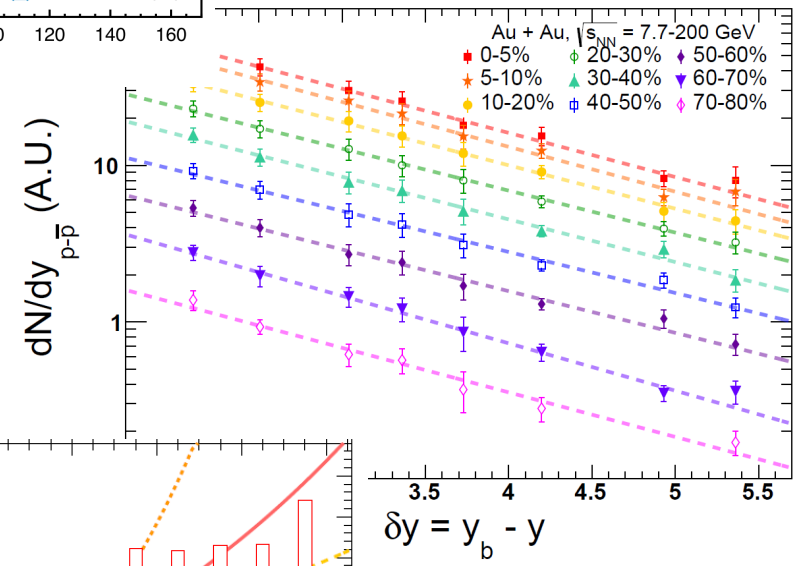
- **Experimental data:**
  More baryon transported to C.O.M than charge by about a factor of 2
- **Model simulations**:
  Less baryon transported to C.O.M frame than charge
- Pure geometry:
  with neutron skin predicts the right centrality dependence (Trento)

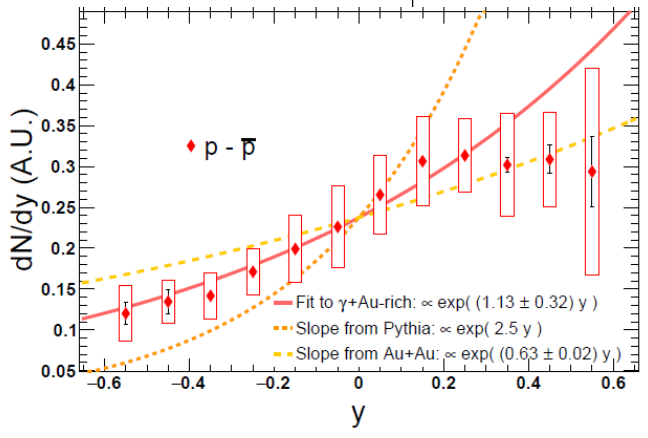


Three approaches toward tracking the origin of the baryon number

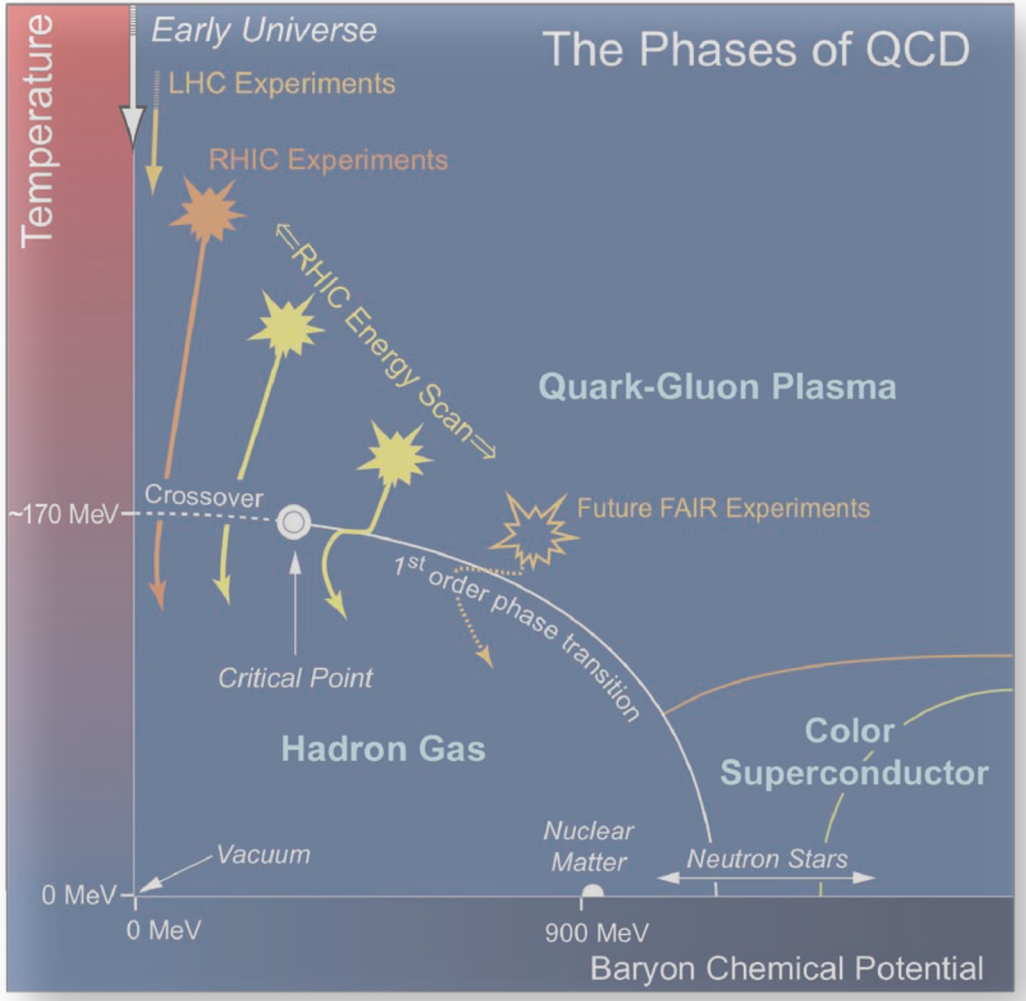
1. STAR Method:
   Charge (Q) stopping vs baryon (B) stopping:
   if valence quarks carry Q and B,
   Q=B at middle rapidity
   B/Q=2
2. Kharzeev-STAR Method:
   If gluon topology (J) carries B as one unit, it should show scaling according to Regge theory
   α_B=0.61
   $p = \sim e^{-\alpha_B y}$
   α_B ~=0.5
3. Artru Method:
   In γ+Au collision, rapidity asymmetry can reveal the origin
   α_B(A+A)=0.61< α_B(γ+A)=1.1< α_B(PYTHIA)







Explore the phase diagram of nuclear matter and beyond



- **Introduction to the QCD phase diagram**
- **Temperatures of the Quark-Gluon Plasma**

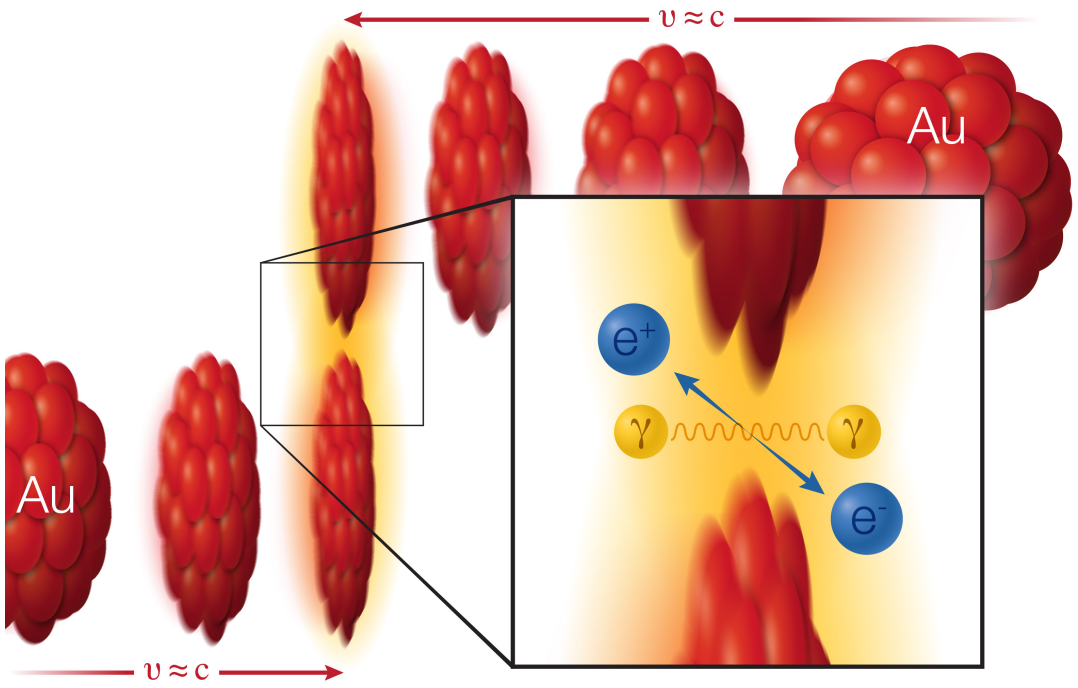
  thermal “blackbody” radiation
- **Baryons**

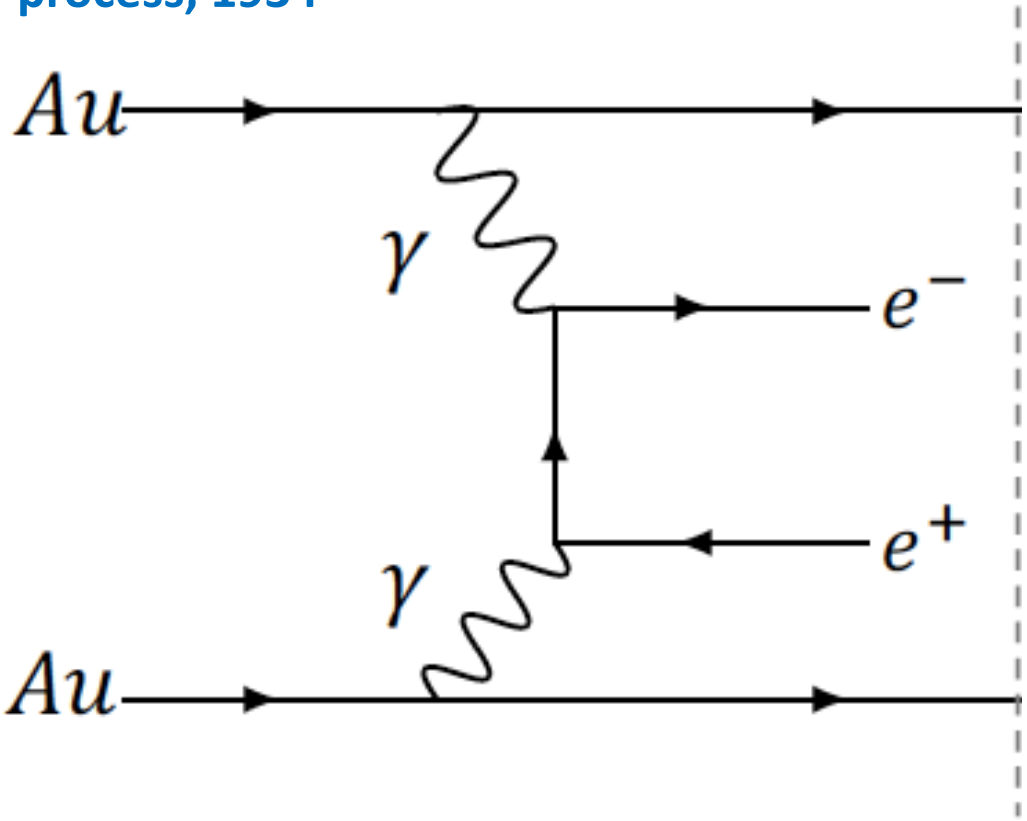
  antimatter, baryon number carrier
- **When QED meets QCD**

  polarized photon collisions; Diffractive VM production
- **Future Perspectives**

A different class of pure electromagnetic interactions

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^+).

Characteristics of photon collisions

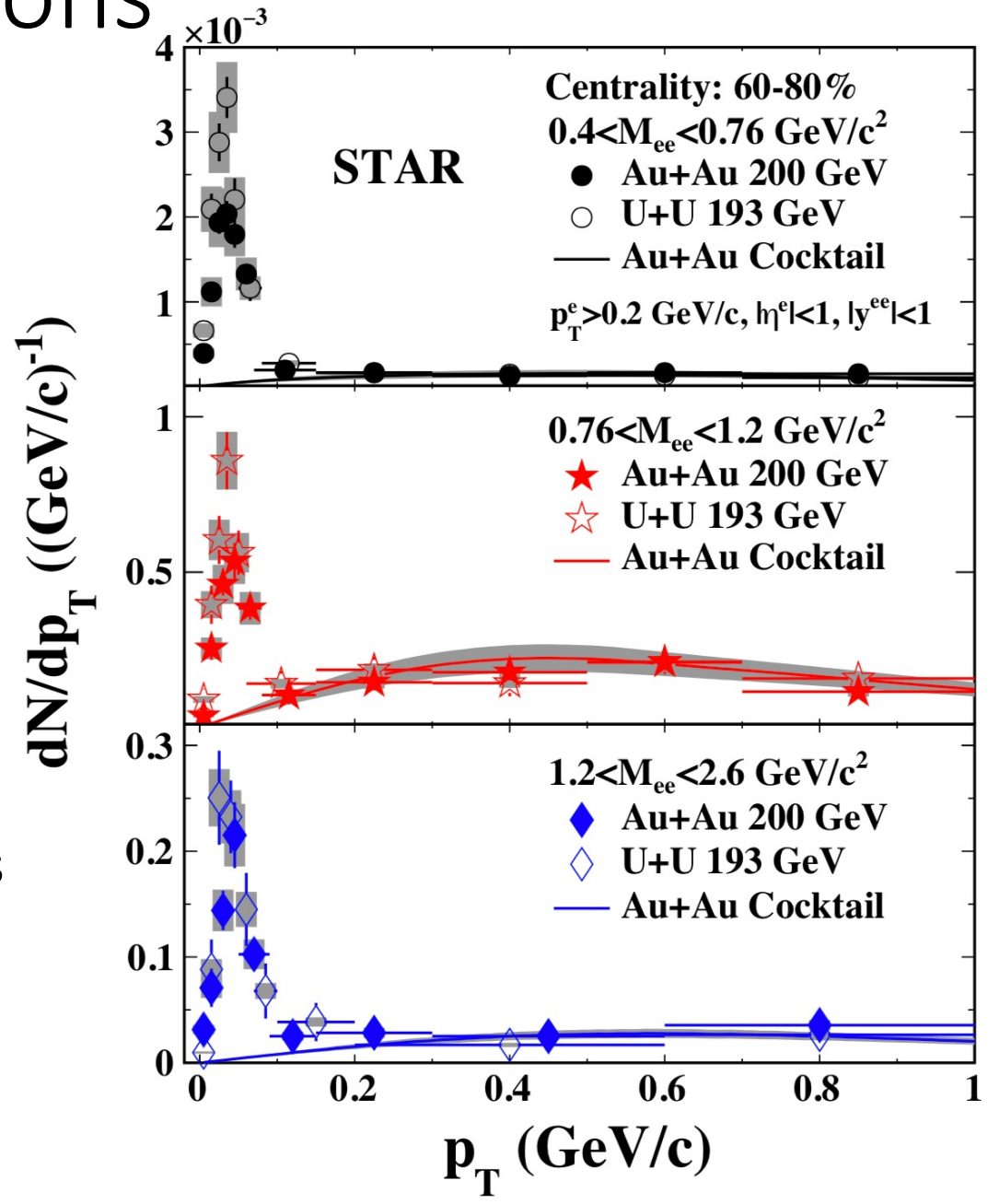
Photon-interactions:
Peak at low p_T ~= 30MeV
Prominent above background

Hadronic and QGP radiation production:
$\langle p_T \rangle$~=500MeV/c

Datasets:
Au+Au 2010+2011
U+U 2012

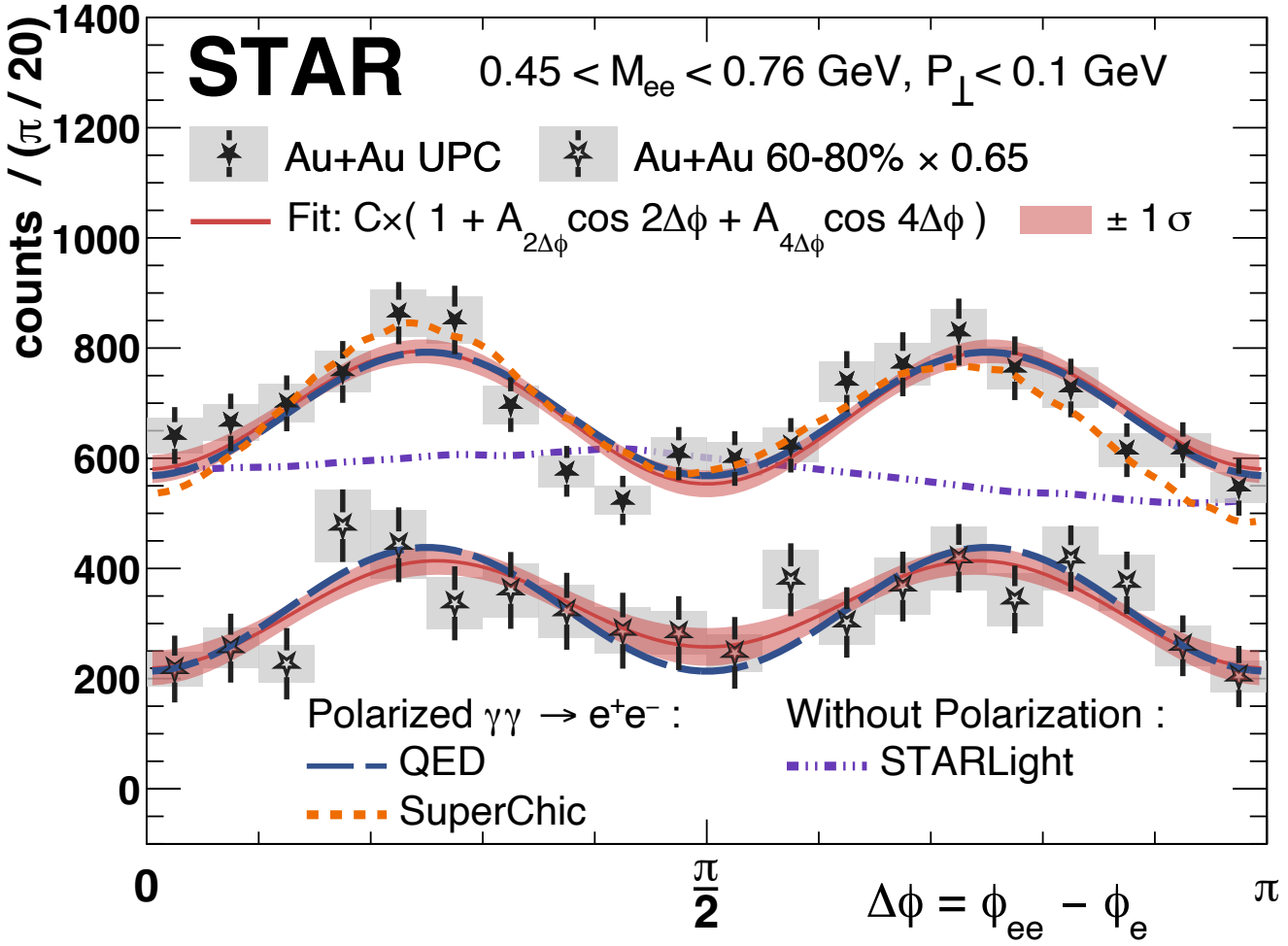
Linear Scale
Signal-to-background ratio is about 17:1

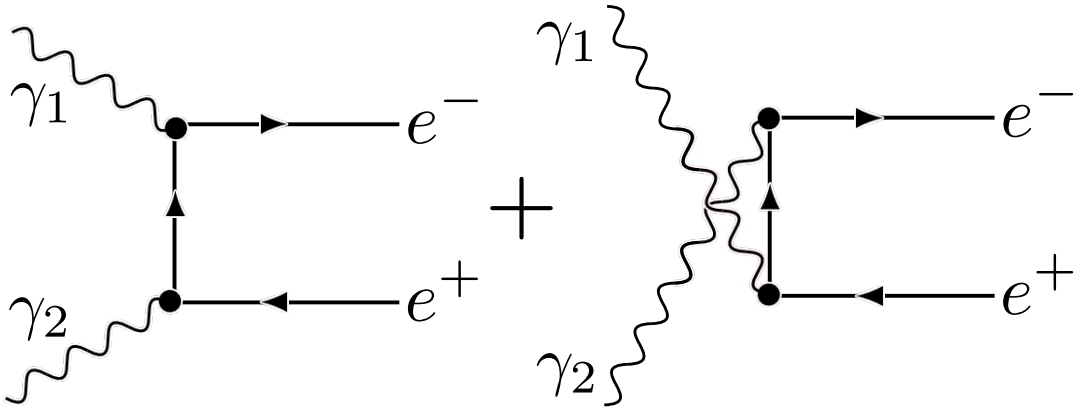
Shuai Yang, PhD, 2016
USTC PhD Thesis:
https://drupal.star.bnl.gov/STAR/files/Thesis_ShuaiYang.pdf
PRL2018



Polarized photons from boosted Coulomb field

How do we know photons are polarized?



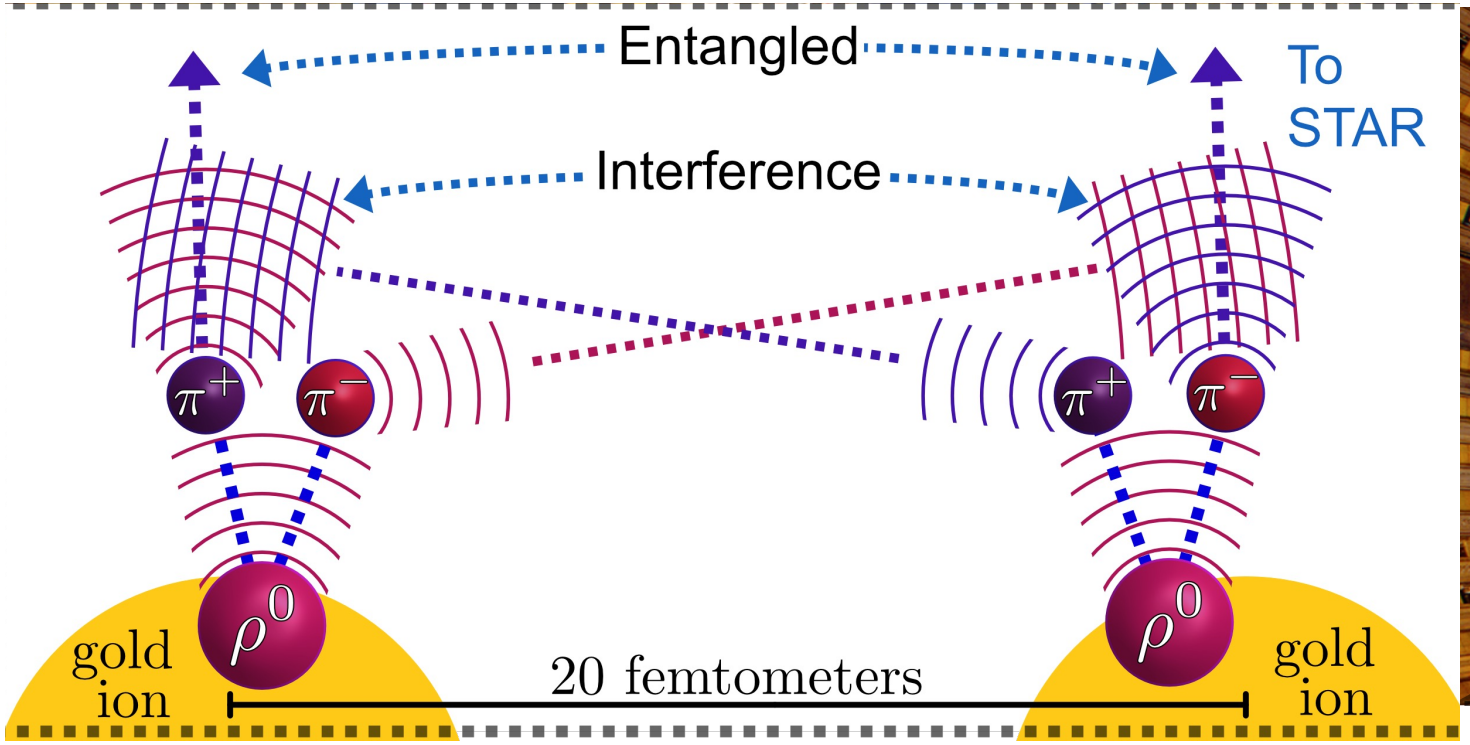


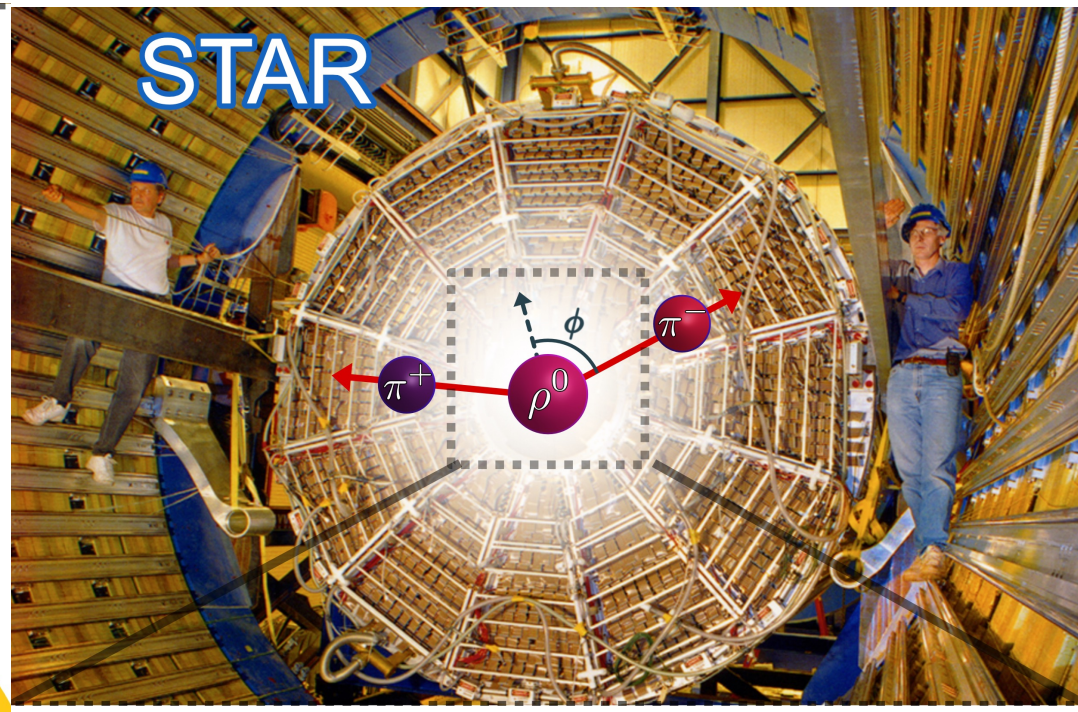
The Breit-Wheeler process (1934): $\gamma\gamma \rightarrow e^+e^-$ angular distribution from 100% linearly polarized photon collisions

STAR, Phys. Rev. Lett. **127** (2021) 52302
e-Print Archives (1910.12400)

Daniel Brandenburg, BNL (now OSU)

Quantum interference enabled nuclear tomography





The experimental detection is a pair of pion+-, ONLY ONE pair.
Similar to double-slit experiment, there is ONLY ONE photon each time.

Possible similarity proposed by Frank Wilczek's group at MIT:
"Entanglement Enabled Intensity Interference of different wavelengths of lasers"
J. Cotler, F. Wilczek, V. Borish, Annals of Physics, 424 (2021) 168346

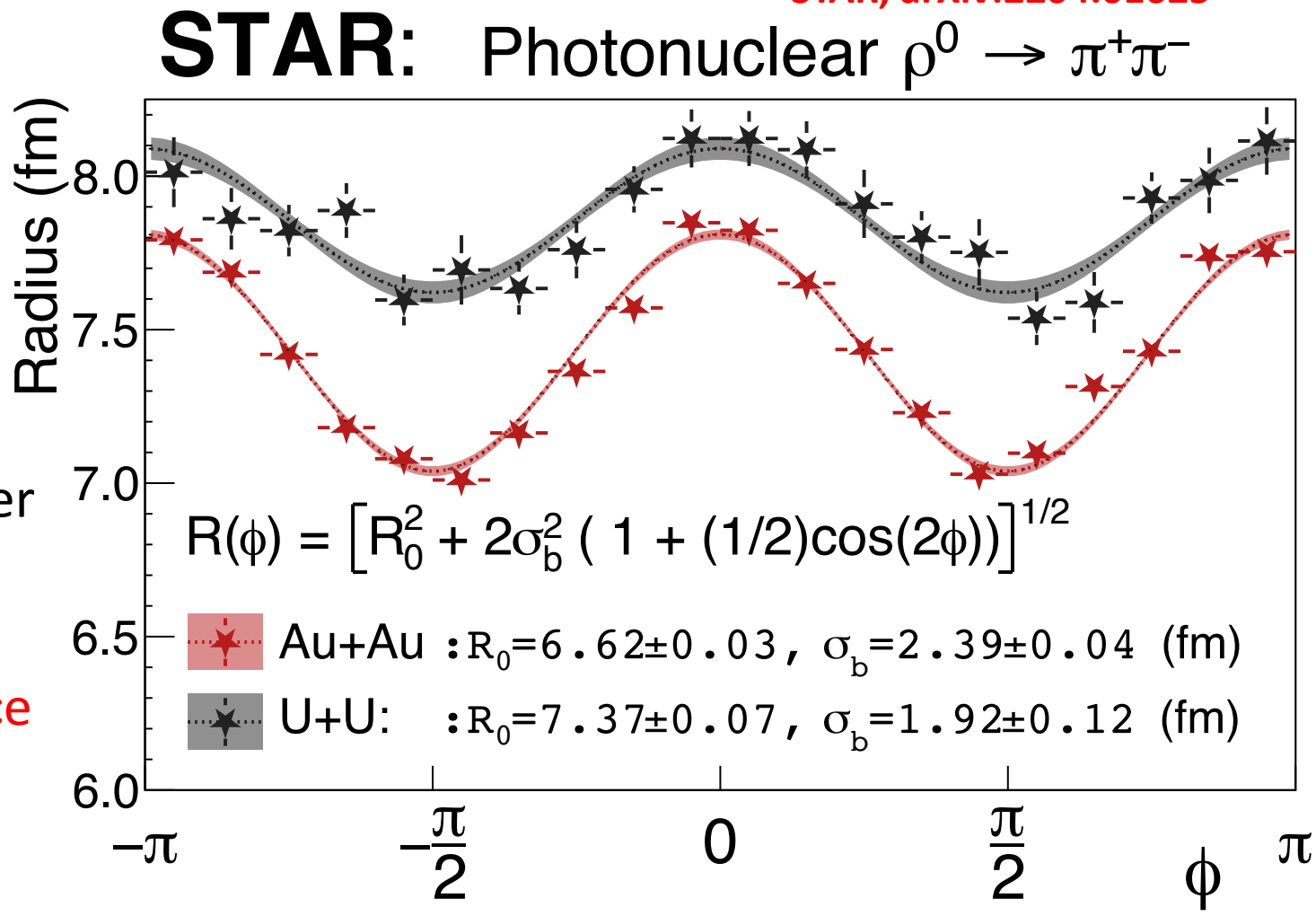
Precision radius measurement with interference

Azimuthal variation due to:

- Photon linear polarization,
- Spin transfer to VM
- Photon finite k_T
- VM spin 1 decay to spin 0 pions
- Interference along impact parameter

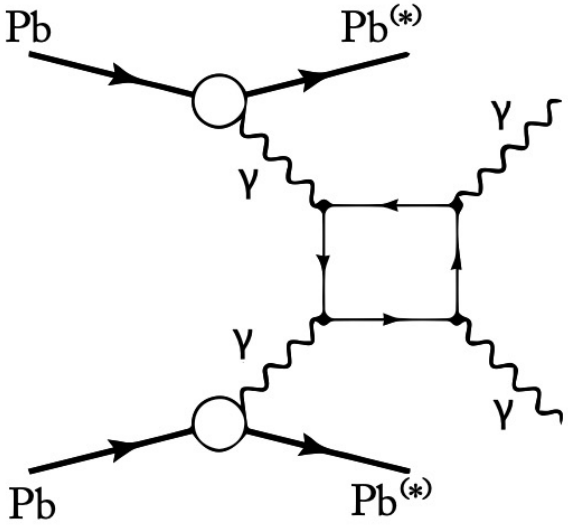
These image blurring effects can be improved with the angular dependence

STAR, arXiv:2204.01625



Recent Discoveries in Ultra-peripheral collisions:

2017: Light-by-Light



Open Access | Published: 14 August 2017

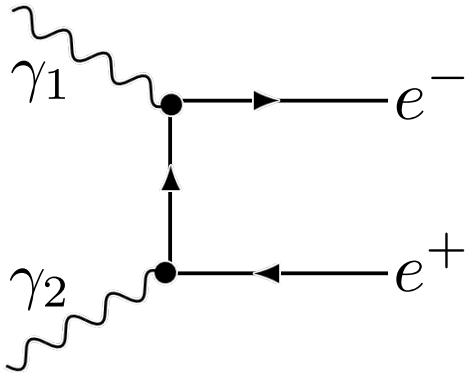
Evidence for light-by-light scattering in heavy-ion collisions with the ATLAS detector at the LHC

ATLAS Collaboration

Nature Physics **13**, 852–858 (2017) | Cite this article

41k Accesses | **185** Citations | **521** Altmetric | Metrics

2021: Breit-Wheeler



OUTPUTS FROM PHYSICAL REVIEW LETTERS

#42

of 37,322 outputs

2023: Entanglement Enabled Interference

Science Advances

AAAS

Article Metrics

? What is this page? | Embed badge | Share

Tomography of ultrarelativistic nuclei with polarized photon-gluon collisions

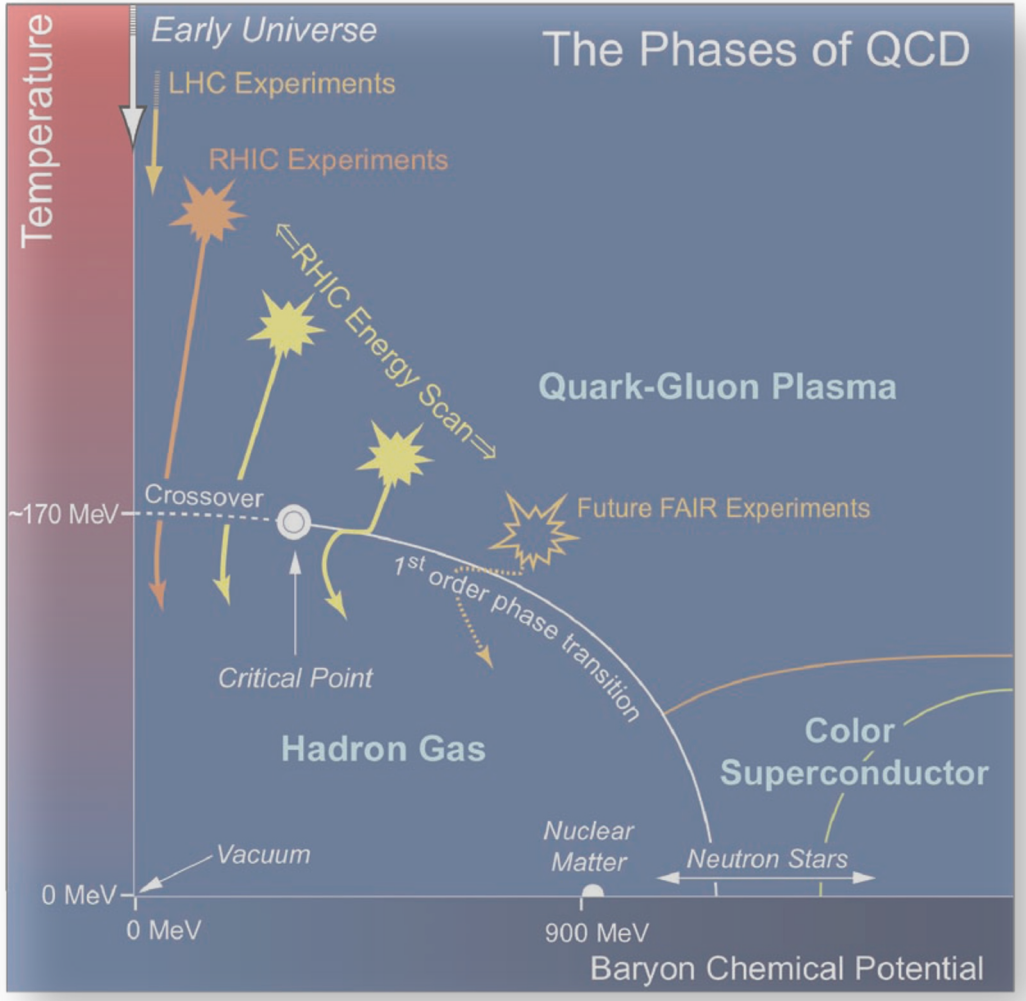
Overview of attention for article published in Science Advances, January 2023

Scientists See Quantum Interference between Different Kinds of Particles for First Time

A newly discovered interaction related to quantum entanglement between dissimilar particles opens a new window into the nuclei of atoms

Declan as chair of the GPC review committee

Explore the phase diagram of nuclear matter and beyond



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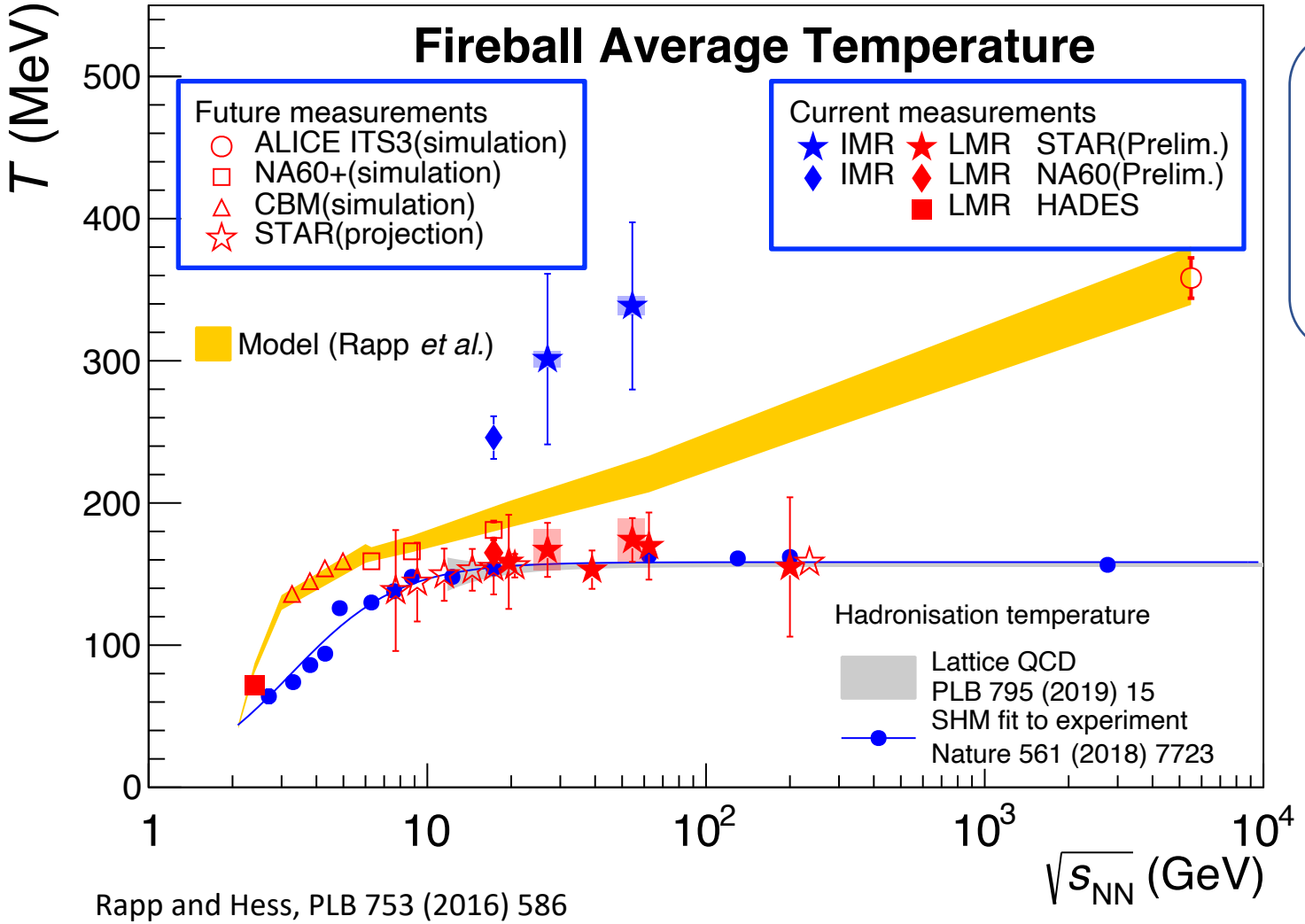
  photon-induced process
- **Future Perspectives**

Future Thermal Dilepton Measurements



Rapp and Hess, PLB 753 (2016) 586
TG *et al.,* EPJA 52 (2016) 131
https://github.com/tgalatyuk/QCD_caloric_curve

- **STAR BES-II/FXT, Run23+Run25@RHIC**
- **ALICE ITS3**
- **NA60+@SPS**
- **HADES, CBM@FAIR**
- **MPD@NICA**

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ScienceDirect
Nuclear Physics A 967 (2017) 712–715
NUCLEAR PHYSICS A
www.elsevier.com/locate/nuclphysa

Structure of virtual photon polarization in ultrarelativistic heavy-ion collisions

Gordon Baym,[a,b] Tetsuo Hatsuda,[b,c] and Michael Strickland[d]

[a]Department of Physics, University of Illinois, 1110 W. Green Street, Urbana, IL 61801-3080, United States
[b]iTHES Research Group and iTHEMS Program, RIKEN, Wako, Saitama 351-0198, Japan
[c]Nishina Center, RIKEN, Wako, Saitama 351-0198, Japan
[d]Department of Physics, Kent State University, Kent, OH 44242, United States

EIC simulation of baryon vs charge transports

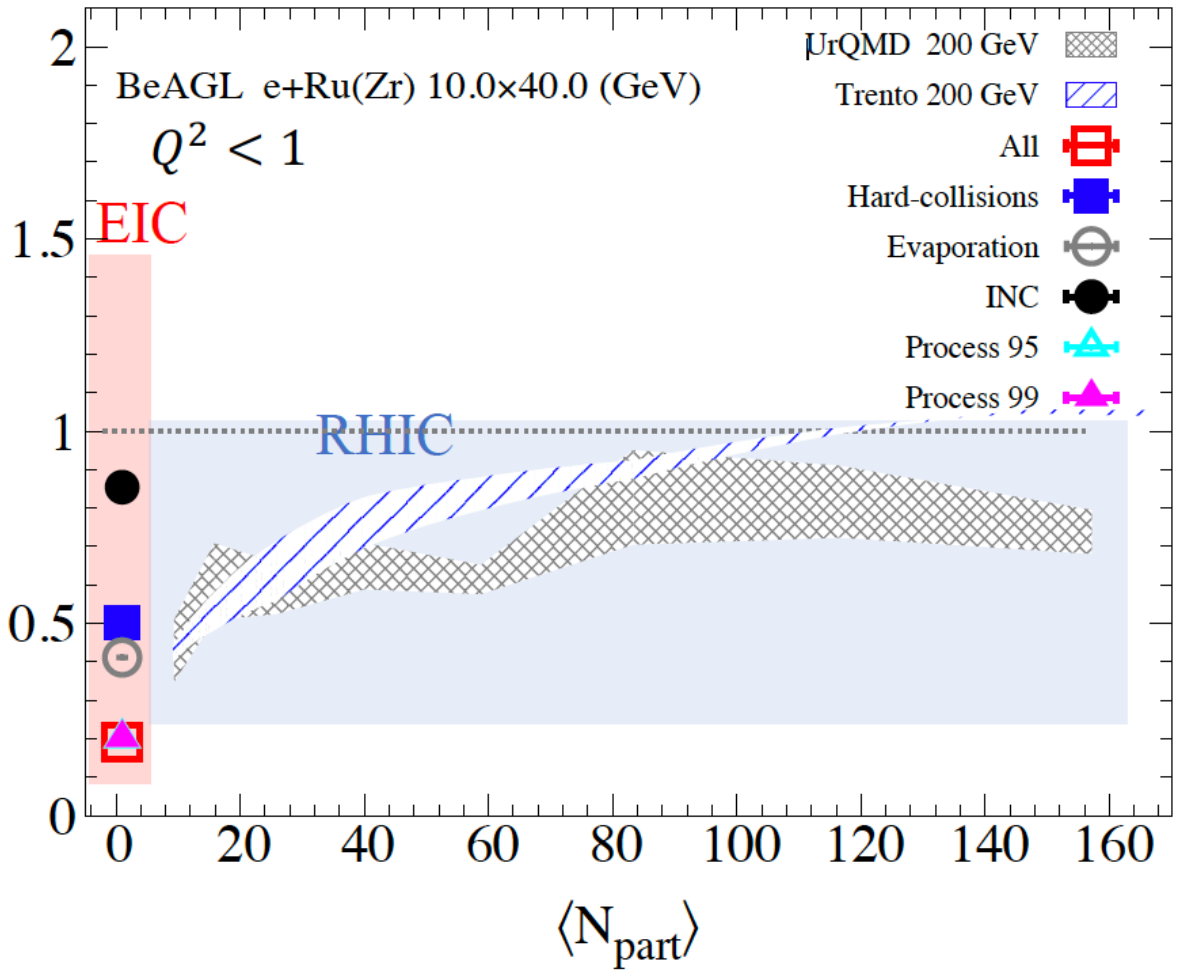
Niseem Magdy (SBU)

Summary of the 1st workshop on 2nd EIC detector (05/15/23)

Golden Channels Strawman

CHANNEL	PHYSICS	DETECTOR II OPPORTUNITY
Diffractive dijet	Wigner Distribution	detection of forward scattered proton/nucleus + detection of low p_T particles
DVCS on nuclei	Nuclear GPDs	High resolution photon + detection of forward scattered proton/nucleus
Baryon/Charge Stopping	Origin of Baryon # in QCD	PID and detection for low p_T pi/K/p
F_2 at low x and Q^2	Probes transition from partonic to color dipole regime	Maximize Q^2 tagger down to 0.1 GeV and integrate into IR.
Coherent VM Production	Nuclear shadowing and saturation	High resolution tracking for precision t reconstruction

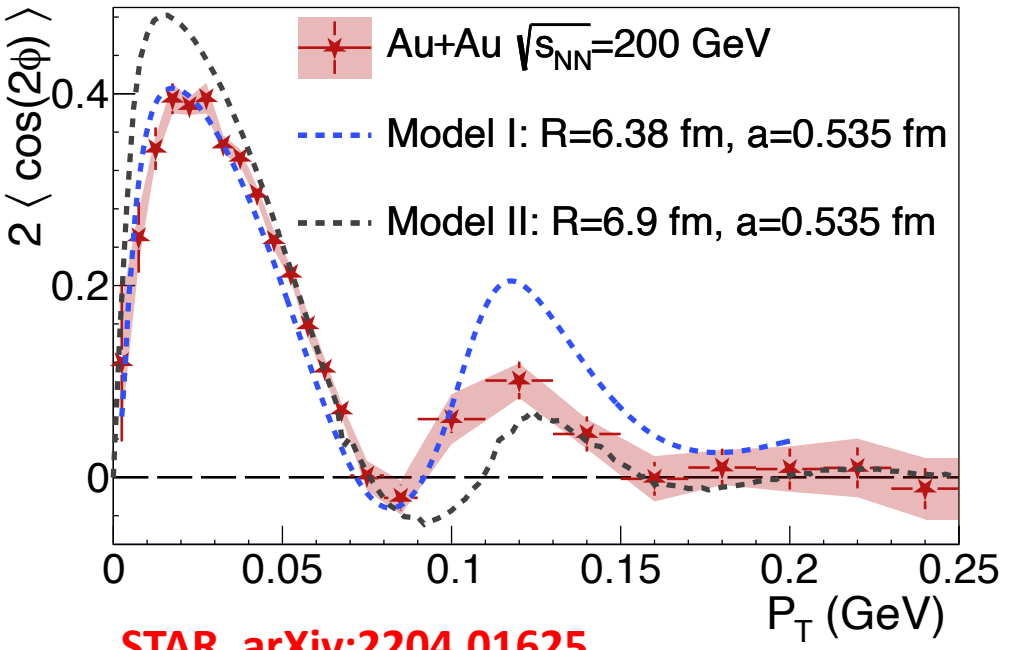
These channels are just a starting point, a way to initially focus activities within the group. Additional ideas and efforts are welcome!



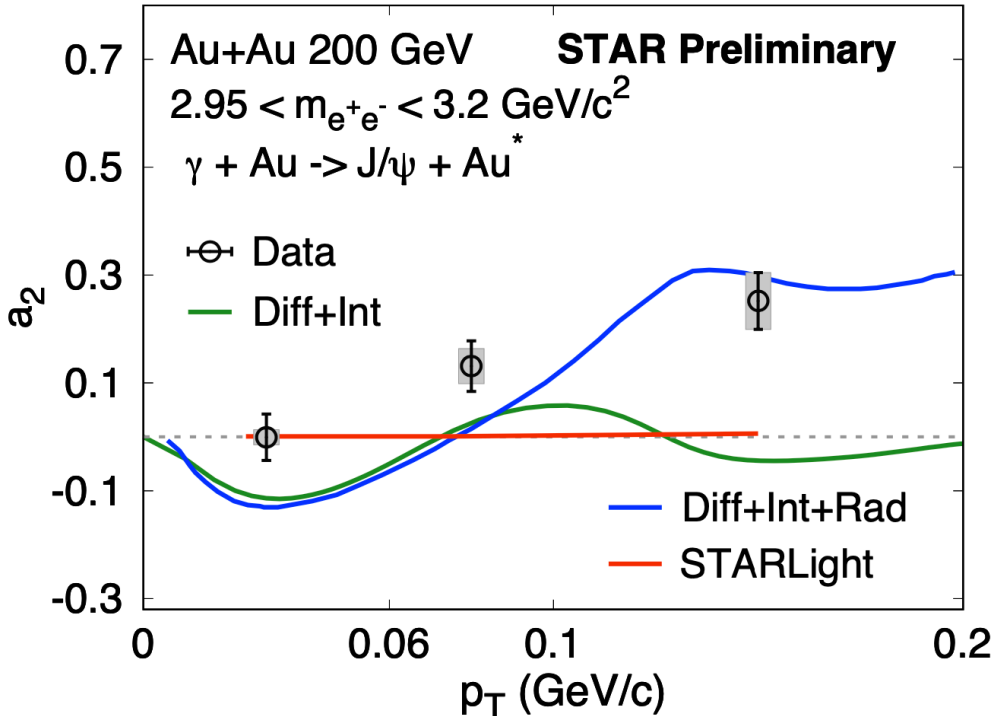
Improvements of nuclear tomography

- Both interference and Woods-Saxon models only describe the first peak well
- The neutron skin syst. uncertainty mainly due to WS vs Gaussian,
  and the actual distribution seems to be flatter (more prominent second peak)
- Heavier vector mesons (ϕ,J/Ψ)

Ashik Ikbal Sheikh (KSU, postdoc) QM2023



STAR, arXiv:2204.01625



W. Zha, L. Ruan, Z. Tang, Z. Xu, S. Yang, *Phys. Rev. C* **99**, 061901 (2019).

W. Zha, J. D. Brandenburg, L. Ruan, Z. Tang, *Phys. Rev. D* **103**, 033007 (2021).

H. Xing, C. Zhang, J. Zhou, Y.-J. Zhou, *JHEP* **10**, 064 (2020).

Declan's impact on STAR Collaboration Science in one table

ID	Title of Paper	Title of published/submitted paper	Publ. ID	Inspire ID	Ana. ID	Date GPC Formed	GPC Chairperson	GPC Members	Date to Collaboration	Institution Readers	Date Submitted for publication	Referee Report	Date Published (Accepted)	Journal Published	Principal Authors
1	Elliptic Flow in Au+Au Collisions at sqrt(snn) = 130 GeV	Elliptic Flow in Au+Au Collisions at $\sqrt{s_{NN}}$ = 130 GeV	1	533414 (HepData)			Declan Keane	Mike Lisa, Art Poskanzer, Tom Trainor	14-Aug-00		12-Sep-00		18-Jan-01	PRL	Art Poskanzer, Raimond Snellings, Sergei Voloshin
51	Pseudo-rapidity Asymmetry and Centrality Dependence of Charged Hadron Spectra in d+Au Collisions at sqrt(s)=200 GeV	Pseudorapidity Asymmetry and Centrality Dependence of Charged Hadron Spectra in d+Au Collisions at $\sqrt{s_{NN}}$ = 200 GeV	47	656934 (HepData)		21-Apr-04	Declan Keane	Olga Barannikova, Johan Gonzalez, Kirill Filimonov, Joern Putschke	24-Jun-04		16-Aug-04		23-Dec-04	PRC	Johan Gonzalez, Zhangbu Xu
70	Strangelet search at RHIC	Strangelet Search in AuAu collisions at 200 GeV	59	698939 (HepData)		10-Jun-05	Jack Sandweiss	Haibin Zhang, Aihong Tang, Richard Majka, Huan Huang	13-Oct-05		27-Nov-05		25-Jul-07	PRC	Hank Crawford, Declan Keane, Brandon Szeliga, Aihong Tang, Sergei Voloshin, Gang Wang, Zhangbu Xu
129	Observation of anti-hypertriton and hypertriton in a relatively symmetric system of matter and anti-matter	Observation of an Antimatter Hypernucleus	156	848409 (HepData)	498 (note, cvs)	1-Jul-09	Alejandro Szanto de Toledo	Michael Lisa, Jim Thomas (Analysis Code QA), W.J. Llope (English QA), Jinhui Chen(PA rep), Lijuan Ruan(PWG rep)	12-Sep-09		28-Oct-09		4-Mar-10	Science	Jinhui Chen, Hank Crawford, Declan Keane, Hao Qiu, Zebo Tang, Zhangbu Xu
148	Observation of the antimatter Helium-4 nucleus	Observation of the antimatter Helium-4 nucleus	171	893021 (HepData)	536 (note, cvs)	5-Jan-11	Bedangadas Mohanty	Robert Tribble, Richard Majka, Joseph Seele (English QA), Lokesh Kumar (Code QA), Aihong Tang (PA rep) Anthony Timmins (PWG rep)	11-Feb-11	TAMU, BNL, LBNL, Purdue, Rice, UCLA	14-Mar-11		24-Apr-11	Nature	J. Chen, H. Crawford, Y. Fisyak, F. Geurts, Q. Hao, B. Huang, C. Jena, H. Ke, D. Keane, T. Kollegger, J. Landgraf, T. Ljubicic, M. Naglis, X. Sun, A. Tang, G. Van Buren, Z. Xu, L. Xue, J. Zhao
206	Observation of interaction between anti-nucleons	Measurement of interaction between antiprotons	240	1385105 (HepData)	616 (note, cvs)	05-Jan-15	Declan Keane	Neha Shah, Spencer Klein, Saskia Mioduszewski (English QA), John Campbell (Code QA), Daniel McDonald (PWG rep), Zhengqiao Zhang (PA rep)	30-May-15	Valparaiso, CTU, Sao Paulo, Yale, USTC	25-Jul-15		04-Nov-15	Nature	Andrew Peterson, Alex Schmah, Qi-Ye Shou, Kefeng Xin, Yan Yang, Zhengqiao Zhang, Mike Lisa, Yu-Gang Ma, Aihong Tang, Hanna Zbroszczyk
228	Observation of Global Hyperon Polarization in Ultrarelativistic Heavy Ion Collisions	Global Λ hyperon polarization in nuclear collisions: evidence for the most vortical fluid	260	1510474 (HepData)	659 (note, cvs)	28-Jun-16	Declan Keane	Huan Huang, Evan Finch (English QA), Xu Sun (Code QA), Bill Llope (PWG rep), Isaac Upsal (PA rep)	14-Nov-16	BNL, LBNL, SDU, CTU, Pusan	21-Jan-17		02-Aug-17	Nature	Isaac Upsal, Mike Lisa, Sergei Voloshin
269	Precise measurement of the mass difference and the binding energy B_Lambda of hypertriton and anti-hypertriton (Webpage)	Precise measurement of the mass difference and the binding energy of hypertriton and antihypertriton	304	1731117 (HepData)	714 (note, cvs)	30-Dec-18	Hank Crawford	Rongrong Ma, Evan Finch (English QA), Maksym Zyzak (Code QA), Chi Yang (PWG Rep), Jinhui Chen (PA Rep), Peng Liu (PA Rep)	15-Mar-19	AGH, Heidelberg, NCKU, NISER, WSU	24-Apr-19		09-Mar-20	Nature Physics	Irakli Chakaberia, Jinhui Chen, Xin Dong, Wlodek Guryn, Declan Keane, Peng Liu, Yugang Ma, Zhangbu Xu
277	Probing Extreme Electromagnetic Fields with the Breit-Wheeler Process (Webpage)	Measurement of e+e- Momentum and Angular Distributions from Linearly Polarized Photon Collisions	317		724 (note, cvs)	05-Jun-19	Declan Keane	Mariusz Przybycien, Hank Crawford (English QA), Te-chuan Huang (Code QA), Jaroslav Adam (PWG Rep), Daniel Brandenburg (PA Rep)	02-Sep-19	UIC, LBNL, MEPhi, TAMU, Yale	06-Jan-21	RefereeReport (Reply)	27-Jul-21	PRL	Daniel Brandenburg, Zhangbu Xu, Lijuan Ruan, Shuai Yang, Chi Yang, Frank Geurts, Janet Seger, Wangmei Zha
298	Observation of Global Spin Alignment of ϕ and K^{*0} Vector Mesons in Nuclear Collisions (Webpage)	Observation of Global Spin Alignment of phi and K*0 Vector Mesons in Nuclear Collisions	377	2063245 (HepData)	748 (note, cvs)	15-Jun-20	Lanny Ray	Anders Knospe (English QA), Shaowei Lan (Code QA), Xiaofeng Luo (PWG Rep), Prithwish Tribedy (PWG Rep), Xu Sun (PA Rep), Chensheng Zhou (PA Rep), Subhash Singha (PA Rep), Takafumi Niida (Ex officio)	02-Feb-22	LBNL, NISER, TAMU, TUD, Yale (Reply)	04-Apr-22	RefereeReport (Reply) RefereeReport_R2 (Reply_R2)	18-Jan-23	Nature	Jinhui Chen, Declan Keane, Yugang Ma, Subhash Singha, Xu Sun, Aihong Tang, Chensheng Zhou
360 (Mailing List)	Accessing the Temperature of the Quark-Gluon Plasma at Different Stages (Webpage)				816 (note, cvs)	15-Jun-23	Xin Dong	Saehanseul Oh, Declan Keane (English QA), Hao Huang (Code QA), Yue-Hang Leung (PWG Rep), Zaochen Ye (PA Rep)							Daniel Brandenburg, Frank Geurts, Lijuan Ruan, Tetyana Galatyuk, Zhangbu Xu, Zhen Wang, Xiaofeng Wang, Chi Yang, Shuai Yang, Zaochen Ye

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