

# the STAR Physics Program



The STAR Collaboration logo is centered on a background of particle tracks. The word "STAR" is written in large, bold, red-outlined white letters. Below it, the word "Collaboration" is written in a smaller, white, italicized font. To the left of "STAR", the word "the" is written in a smaller, white, italicized font. The background features a dense field of colorful particle tracks (red, blue, green, yellow) radiating from a central point, set against a dark background. A list of names is visible in the background, partially obscured by the logo.

...dman,<sup>2</sup> M.M. Aggarwal,<sup>20</sup> Z. Ahsanullah,<sup>45</sup> J. Amoretti,<sup>26</sup> B.D. Anderson,<sup>20</sup> D. Arhipkin,<sup>13</sup> G.S. Averchev,<sup>12</sup>  
K. Baidya,<sup>29</sup> Y. Bai,<sup>27</sup> J. Balawski,<sup>17</sup> O. Baranikova,<sup>22</sup> L.S. Barnby,<sup>2</sup> J. Basile,<sup>12</sup> S. Bekele,<sup>20</sup> V.V. Belaga,<sup>12</sup>  
R. Bellwied,<sup>46</sup> J. Berger,<sup>14</sup> B.I. Bezverkhny,<sup>46</sup> S. Bharadwaj,<sup>32</sup> A. Bhasin,<sup>19</sup> A.K. Bhati,<sup>29</sup> V.S. Bhatia,<sup>29</sup>  
H. Bichsel,<sup>48</sup> A. Billmeier,<sup>46</sup> L.C. Bland,<sup>4</sup> C.O. Blyth,<sup>3</sup> B.F. Bowen,<sup>34</sup> M. Bojic,<sup>27</sup> A. Bouchaou,<sup>28</sup> A.V. Brandin,<sup>7</sup>  
A. Bravar,<sup>4</sup> M. Bystrzycki,<sup>11</sup> R.V. Cadman,<sup>1</sup> X.Z. Cai,<sup>37</sup> H. Caines,<sup>48</sup> M. Calderón de la Barca Sánchez,<sup>17</sup>  
J. Castillo,<sup>21</sup> D. Celis,<sup>7</sup> Z. Chajczyk,<sup>44</sup> P. Chaloupka,<sup>11</sup> S. Chattopadhyay,<sup>43</sup> H.F. Chen,<sup>36</sup> Y. Chen,<sup>8</sup> J. Chereu,<sup>8</sup>  
M. Cherney,<sup>30</sup> A. Chikanian,<sup>44</sup> W. Christie,<sup>4</sup> J.P. Coffin,<sup>15</sup> T.M. Cormier,<sup>46</sup> J.G. Craxson,<sup>46</sup> H.J. Crawford,  
D. Das,<sup>42</sup> S. Das,<sup>43</sup> M.M. de Moura,<sup>28</sup> A.A. Derevchikov,<sup>31</sup> L. Didenko,<sup>4</sup> T. Dietel,<sup>14</sup> S.M. Dogra,<sup>19</sup> W.J. D  
X. Dong,<sup>26</sup> J.E. Draper,<sup>7</sup> F. Du,<sup>42</sup> A.K. Duley,<sup>15</sup> V.R. Durkin,<sup>12</sup> J.C. Dunlop,<sup>4</sup> M.R. Dutta Mazumdar,  
V. Edvardi,<sup>23</sup> W.R. Edwards,<sup>21</sup> L.G. Efimov,<sup>12</sup> V. Enkelianov,<sup>26</sup> J. Engelage,<sup>8</sup> G. Eppky,<sup>24</sup> B. Erazru,  
M. Estienne,<sup>38</sup> P. Fachini,<sup>4</sup> J. Faivre,<sup>18</sup> R. Fazio,<sup>17</sup> J. Fedorisin,<sup>13</sup> K. Filimonov,<sup>20</sup> P. Filip,<sup>11</sup> E. Fisch,<sup>48</sup>  
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M. Heinz,<sup>2</sup> T.W. Heary,<sup>38</sup> S. Heppelmann,<sup>36</sup> B. Hippolyte,<sup>18</sup> A. Hirsch,<sup>32</sup> E. Hjort,<sup>21</sup> G.W. Hoff  
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M. Jaak,<sup>44</sup> H. Jiang,<sup>8</sup> P.G. Jones,<sup>8</sup> E.G. Judd,<sup>6</sup> S. Kabana,<sup>2</sup> K. Kang,<sup>41</sup> M. Kaplan,<sup>9</sup> D. K  
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A.I. Kulkov,<sup>12</sup> A. Kumar,<sup>29</sup> R.K.K. Kuzuu,  
F. Laus,<sup>4</sup> J. Lauret,<sup>4</sup> A. Lebedev,<sup>4</sup> R. Lednicki,  
S.J. Lindenbaum,<sup>26</sup> M.A. Lisa,<sup>28</sup> F. Liu,<sup>14</sup>  
R.S. Longacre,<sup>4</sup> M. Lopez-Noriega,  
Y.G. Ma,<sup>27</sup> D. Magosto,<sup>28</sup> S. M  
S. Margolin,<sup>29</sup> C. Markert,<sup>21</sup> N. Marz,<sup>2</sup>  
T.S. McShane,<sup>16</sup> F. Meiser,<sup>21</sup> A. Meehan,  
A. Mischke,<sup>27</sup> D.K. Mishra,<sup>21</sup> A. Mochizuki,  
M.G. Munhoz,<sup>26</sup> B.K. Nandi,<sup>21</sup> T.K. Nayak,<sup>42</sup>  
L.V. Nogués,<sup>31</sup> S.B. Nurunhev,<sup>21</sup> A. Ogawa,<sup>4</sup> V. O  
Y. Pachratsev,<sup>12</sup> S.Y. Paritosh,<sup>12</sup> T. Pawlak,<sup>44</sup> T. Peitzmann,<sup>27</sup> v  
W. Peryt,<sup>44</sup> V.A. Petrov,<sup>12</sup> R. Picha,<sup>7</sup> M. Planinic,<sup>49</sup> J. Pluta,<sup>44</sup>  
A.M. Poskanzer,<sup>21</sup> M. Poteraj,<sup>12</sup> S. Prasad,<sup>12</sup> B.V.K.S. Potluri,<sup>10</sup> D.  
J. Putzke,<sup>22</sup> G. Rakness,<sup>30</sup> R. Rapp,<sup>12</sup> O. Ravin,<sup>28</sup> R.L. Ray,<sup>40</sup>  
J.G. Reid,<sup>40</sup> G. Renak,<sup>28</sup> F. Roesler,<sup>12</sup> R. Röttger,<sup>21</sup> J.B. Roberts,  
J.L. Romero,<sup>7</sup> A. Rose,<sup>46</sup> C. Roy,<sup>38</sup> L. Roca,<sup>12</sup> S. Saha,<sup>4</sup>  
I. Sovin,<sup>13</sup> P.S. Sazhin,<sup>12</sup> J. Schambach,<sup>43</sup> R.P. Schenck,<sup>22</sup> K. Sch  
E. Shabaliev,<sup>12</sup> M. Shao,<sup>38</sup> W. Shao,<sup>38</sup> M. Sharma,<sup>21</sup> K.E. Shest  
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P. Sorensen,<sup>21</sup> J. Soucha,<sup>17</sup> J. Speltz,<sup>16</sup> H.M. Spinka,<sup>12</sup> A. Stachura,<sup>32</sup> A.  
R. Stock,<sup>14</sup> A. Stolton,<sup>12</sup> M. Strikhanov,<sup>20</sup> B. Stirling,<sup>12</sup> A.A.P. Sua  
M. Sunberg,<sup>14</sup> B. Surrow,<sup>12</sup> T.J.M. Symons,<sup>21</sup> A. Szarek,<sup>12</sup> P. S  
A.H. Tang,<sup>27</sup> T. Tani,<sup>12</sup> D. Thein,<sup>3</sup> J.H. Thomas,<sup>12</sup> I. Tomaszek,  
S. Thakur,<sup>8</sup> R.B. Thaler,<sup>12</sup> O.D. Tsai,<sup>3</sup> J. Ullrich,<sup>12</sup> D.G. U  
B. Van der Venter,<sup>18</sup> M. Vanzade,<sup>12</sup> G. Van Veen,<sup>18</sup>  
J.C. Wang,<sup>12</sup> W. Wang,<sup>41</sup> Z. Wang,<sup>41</sup> C. Whitten Jr.,<sup>12</sup> P. Witt,<sup>2</sup>  
T. Wu,<sup>4</sup> J. Wu,<sup>12</sup> H. Wu,<sup>12</sup> Z. Xiang,<sup>12</sup> E. Yamamoto,<sup>12</sup> P. V. Vasiliev,<sup>12</sup> V.I. Turevich,<sup>12</sup> V. Zanevsky,<sup>12</sup>  
H. Zhang,<sup>4</sup> W.M. Zhang,<sup>29</sup> Z.P. Zhang,<sup>38</sup> R. Zoukarnine,<sup>13</sup> Y. Zoukarnine,<sup>13</sup> and A.N. Zubarev<sup>12</sup>

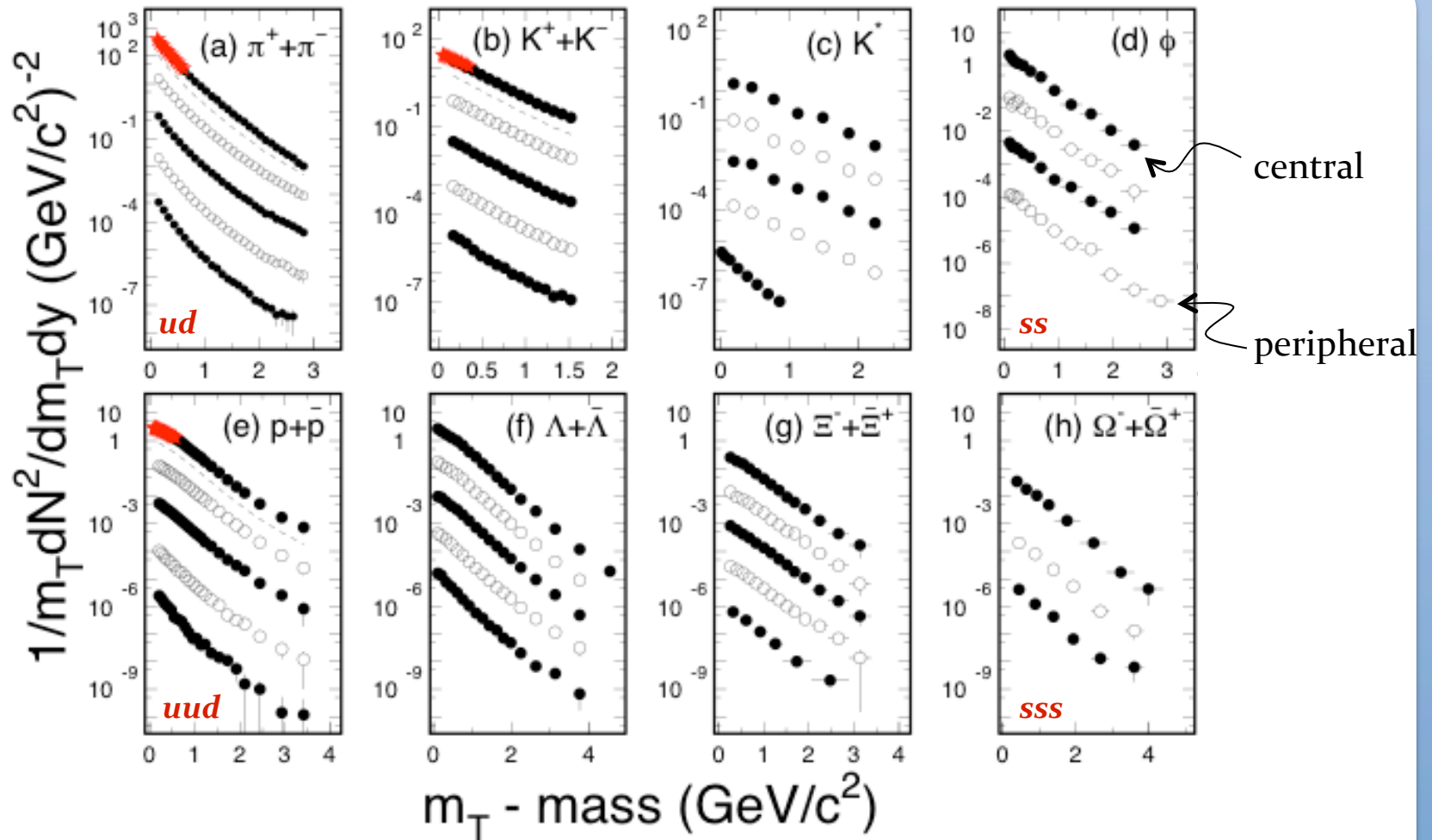
Highlights, Goals and the Future for STAR

# Outline

- Highlights from the STAR experiment
  - Spectra and nuclear modification
  - Flow coefficients:  $m_T$  and quark number scaling
  - Di-hadrons and the ridge
- Heavy-Ion goals for the second decade of RHIC
  - Critical Point
  - Onset of Deconfinement
  - Characterization of QGP
- Timely, goal focused, and shovel-ready upgrades
  - DAQ Upgrade: DAQ1000
  - Barrel Time of Flight: TOF
  - Heavy Flavor Tracker: HFT
  - Forward Gem Tracker: FGT

# Highlights: Hadron Spectra

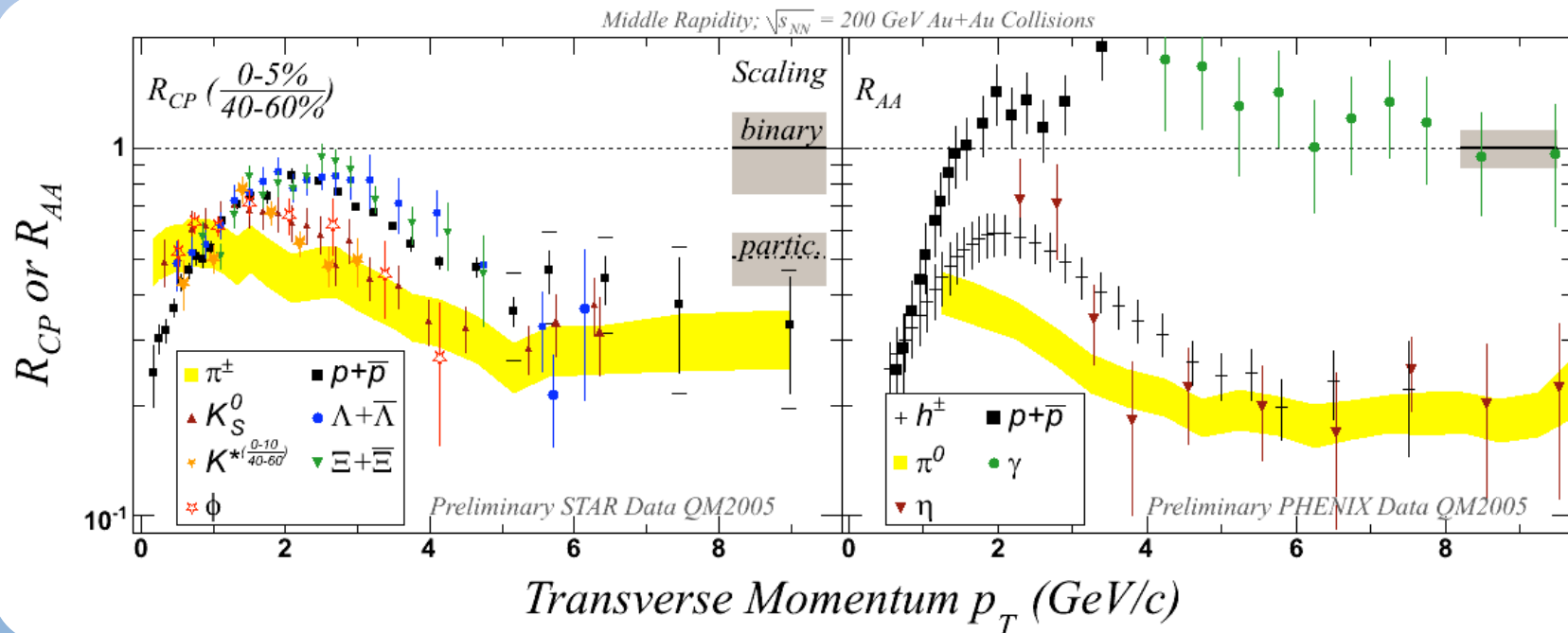
*p+p and Au+Au collisions at 200 GeV*



**Spectra from light hadrons up to multi-strange hadrons**

STAR white papers - Nucl. Phys. A757, 102(2005).

# Highlights: Nuclear Modification



*Phys.Rev.Lett.*92:052302,2004

## Key Features:

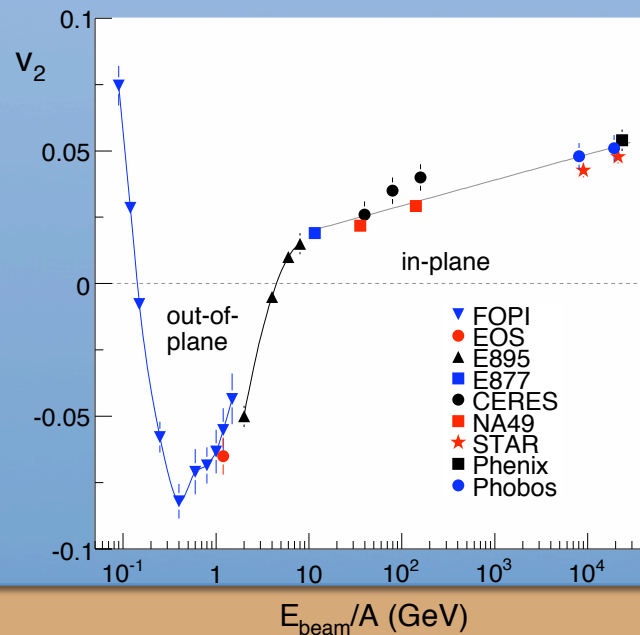
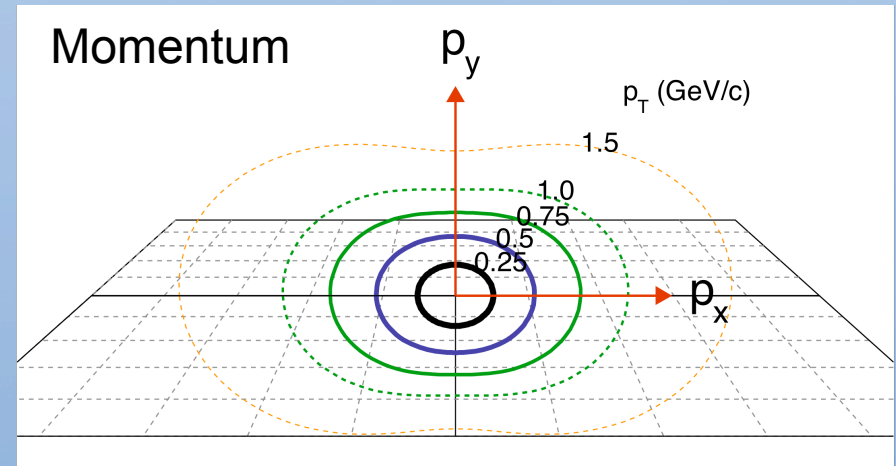
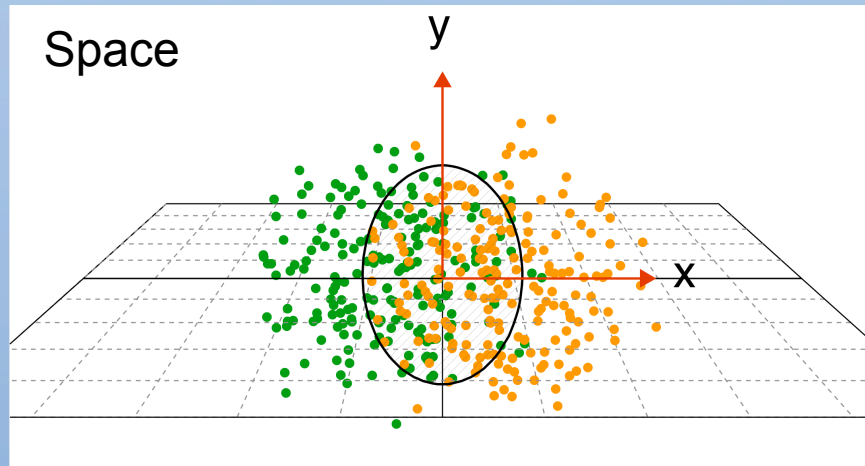
Suppression by a factor of 5 at  $p_T > 6$  GeV/c

Centrality dependence at low  $p_T$  is governed by mass

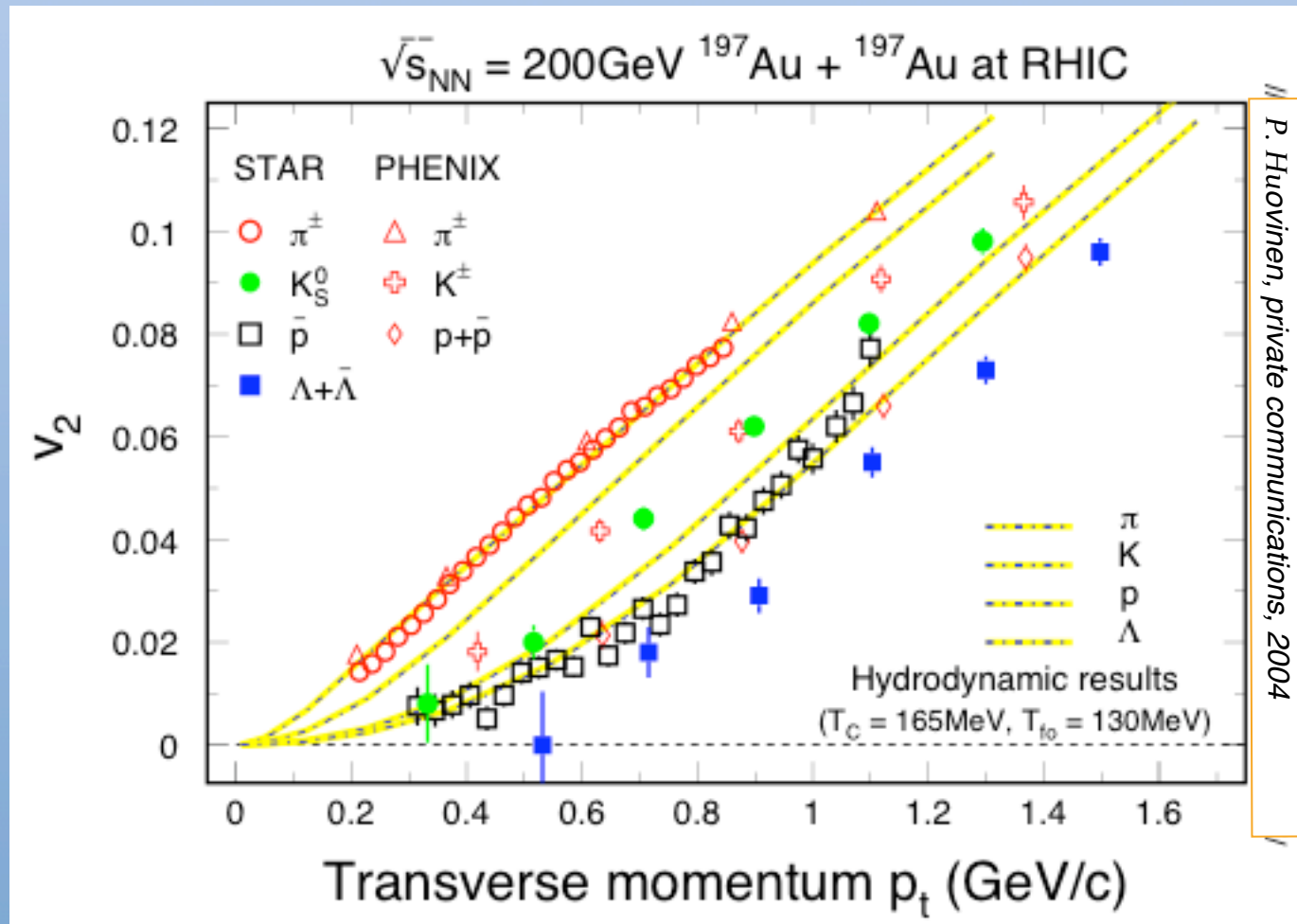
At intermediate  $p_T$ , centrality dependence governed by  
**number of constituent quarks**

# Highlight: Elliptic Flow at RHIC

Large Elliptic Flow: A Signal of Strong Space-Momentum Correlations



# Highlights: Elliptic Flow



P. Huovinen, private communications, 2004

*Phys.Rev.Lett.92:052302,2004*

Mass ordering of  $v_2(p_T)$ : consistent with emission from a boosted source

# Highlights: Flow Scaling

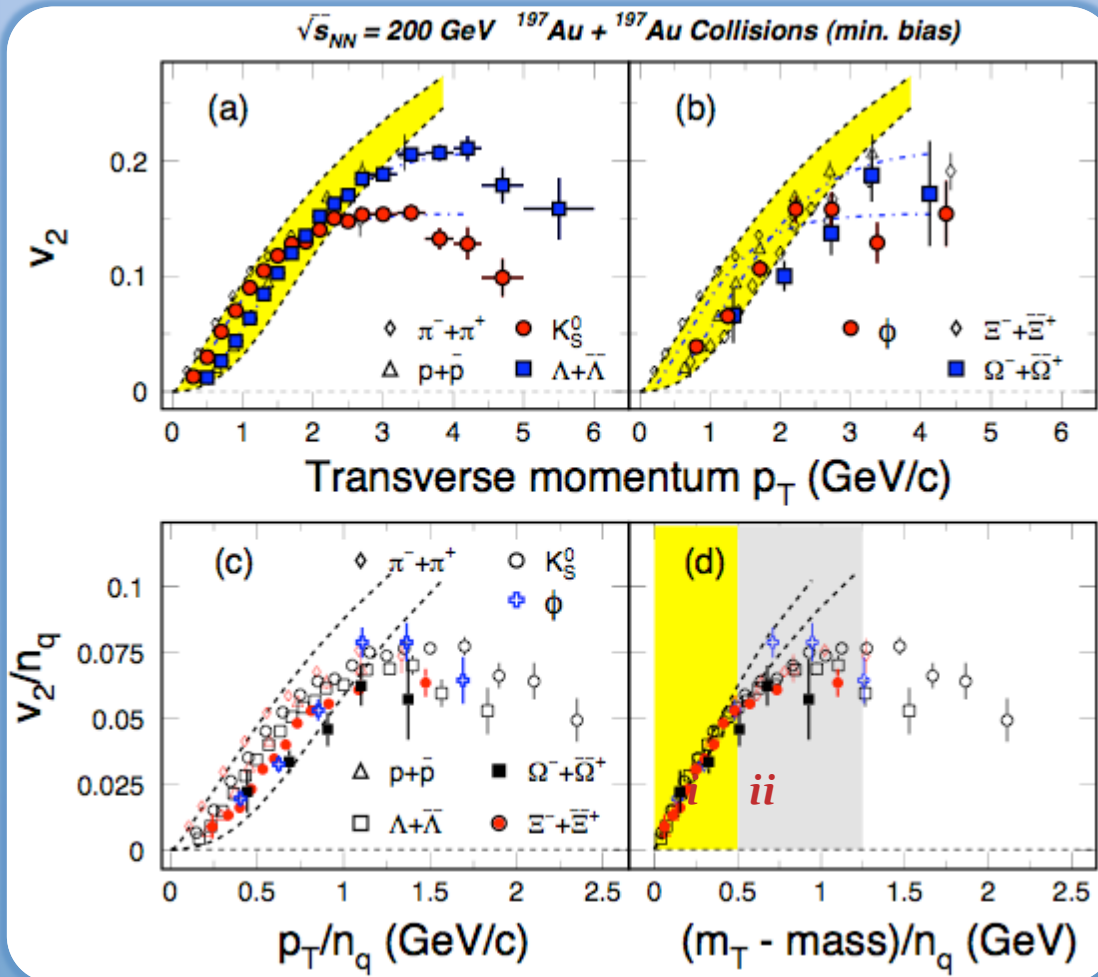
- $v_2$  of light hadrons and multi-strange hadrons
- scaling by the number of quarks

At RHIC:

- ⇒  **$N_q$  scaling**  
novel hadronization process
- ⇒  **$\phi$  and  $\Omega$  flow**  
De-confinement

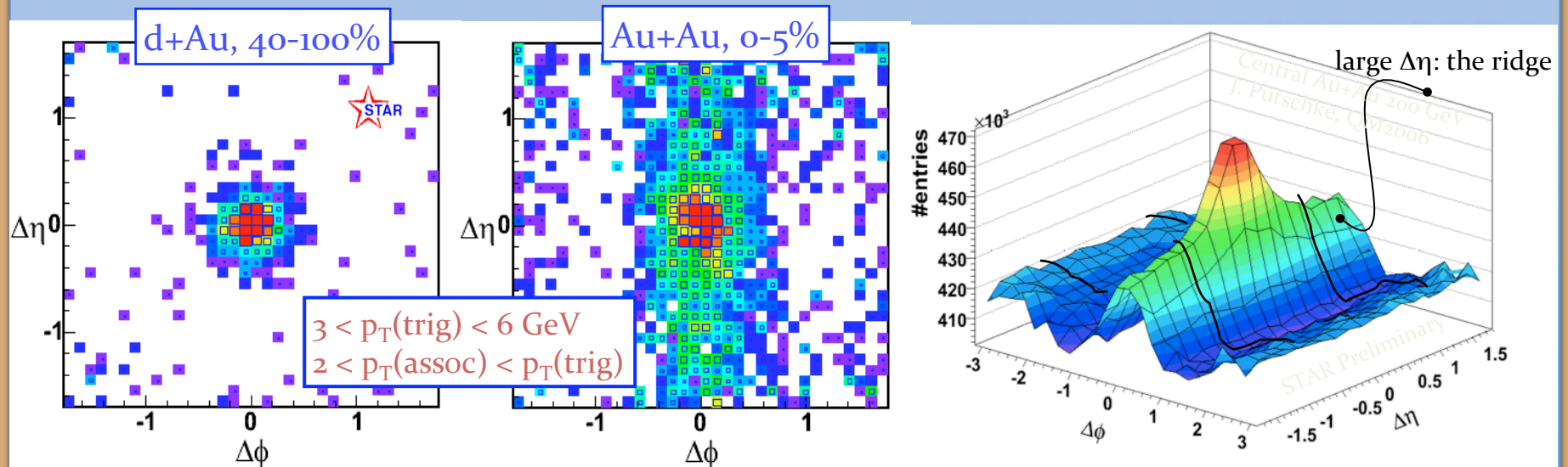
*PHENIX*: PRL**91**, 182301(03)  
*STAR*: PRL**92**, 052302(04), **95**, 122301(05)  
 nucl-ex/0405022, QM05

S. Voloshin, NPA**715**, 379(03)  
 Models: Greco et al, PRC**68**, 034904(03)  
 Chen, Ko, nucl-th/0602025  
 Nonaka et al. *PLB***583**, 73(04)  
 X. Dong, et al., Phys. Lett. **B597**, 328(04).  
 Fries, Greco, Sorensen, Ann.Rev.Nucl.Part.Sci **58**



# Highlights: The Ridge

A structure unique to Au+Au collisions!



A “model independent” *conclusion*:

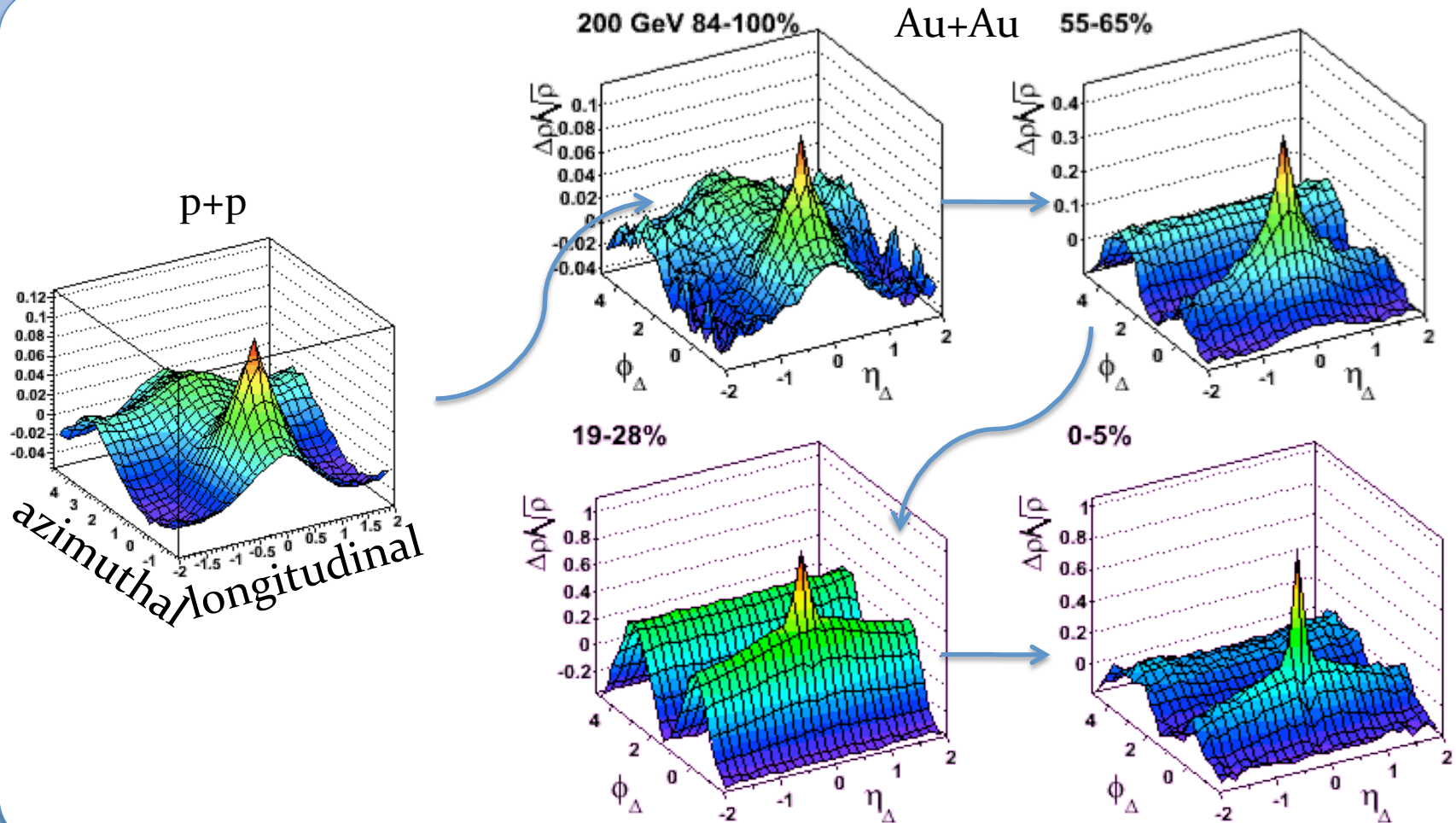
- $\Delta\eta$  width of the ridge points to correlations from very early times
- short range bulk correlations would imply late/phase-boundary (*cross-over at RHIC...*)



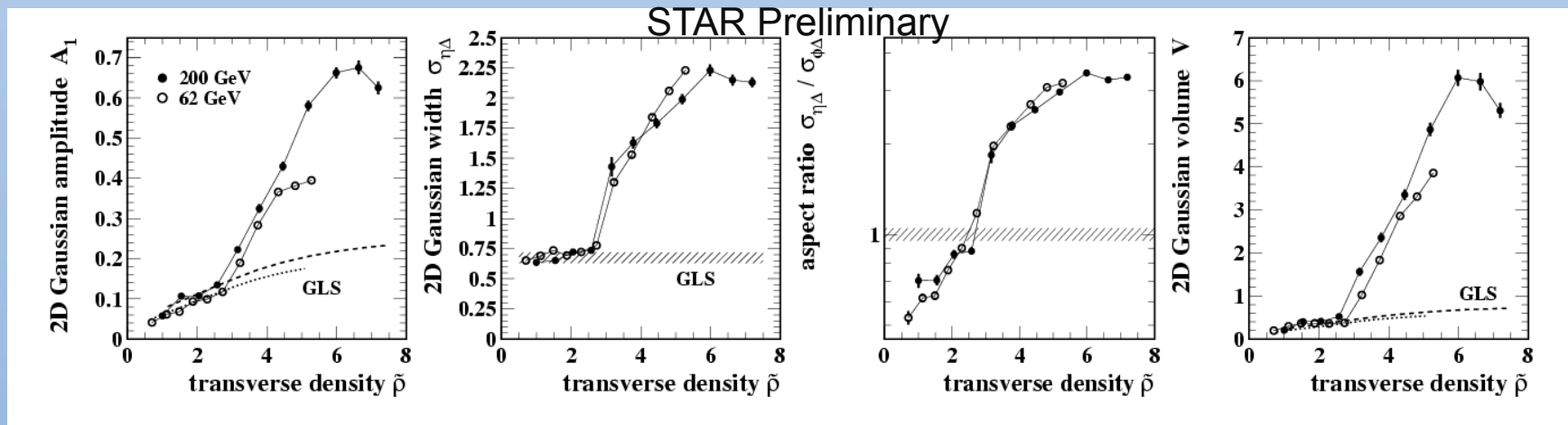
# Highlights: 2-D Correlations

Correlations of all unique pairs of charged particles:

STAR can measure the *charge sign*, *momentum*, and *particle-type* dependence



# Highlights: Transition



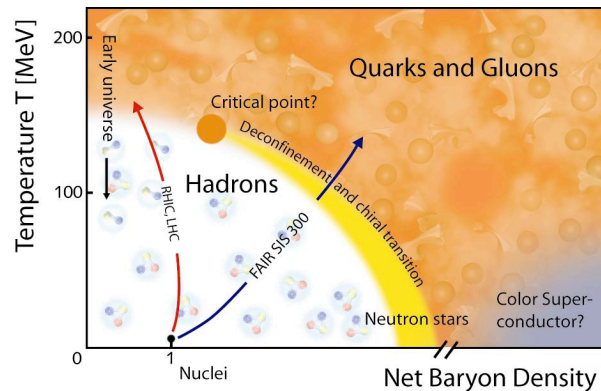
$$\tilde{\rho} = \frac{3}{2} \frac{dN_{ch}}{d\eta} / S$$

$$\varepsilon_{BJ} = \frac{dE_T / dy|_{y=0}}{\pi R^2 \tau_0}$$

**Apparent transition** occurs at a fixed particle density,  
*perhaps related to the energy density*

Indicates the **onset** of new physics: QGP? Deconfinement?  
Glasma? Minijets? *Explanation not yet established.*

# STAR's Focus in the 2<sup>nd</sup> Decade

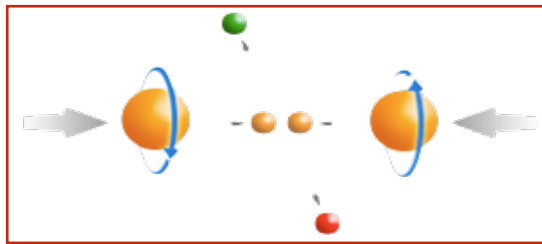


## 1) Heavy-ion program

- Study *medium properties, EoS*
- pQCD in hot and dense medium

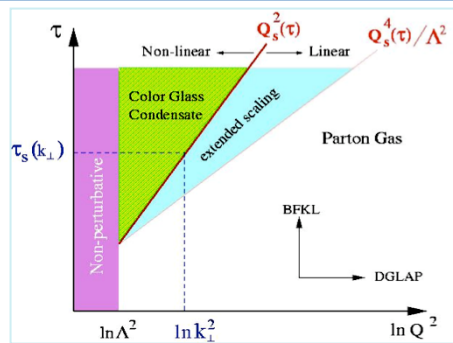
## 2) RHIC beam energy scan

- Search for *critical point*
- Chiral symmetry restoration



## Polarized spin program

- Study *intrinsic properties of the proton*

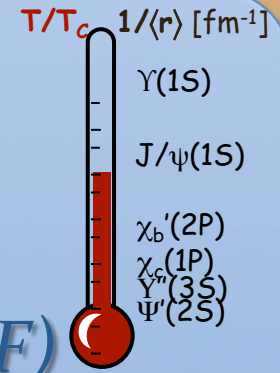


## Forward program

- Low-x properties, search for *CGC*
- Elastic (inelastic) processes (pp2pp)
- Investigate *gluonic exchanges*

# Studies of sQGP

- Next Steps in Quantifying the sQGP
  - **Quarkonium: *the QGP Thermometer***
  - **Open Heavy-Flavor: *Transport Properties***
  - **Jet Finding: *Understanding Energy Loss (FF)***
  - **Fluctuations and Correlations: *Viscosity and Quantifying Incomplete Equilibration***
- Possible with Timely and Focused Upgrades
  - **TOF: *Full Barrel PID (75% complete)***
  - **DAQ1000: *Take advantage of RHICs Luminosity***
  - **HFT: Open Heavy Flavor**
  - **FGT: Forward Tracking for W charge to access polarized sea**



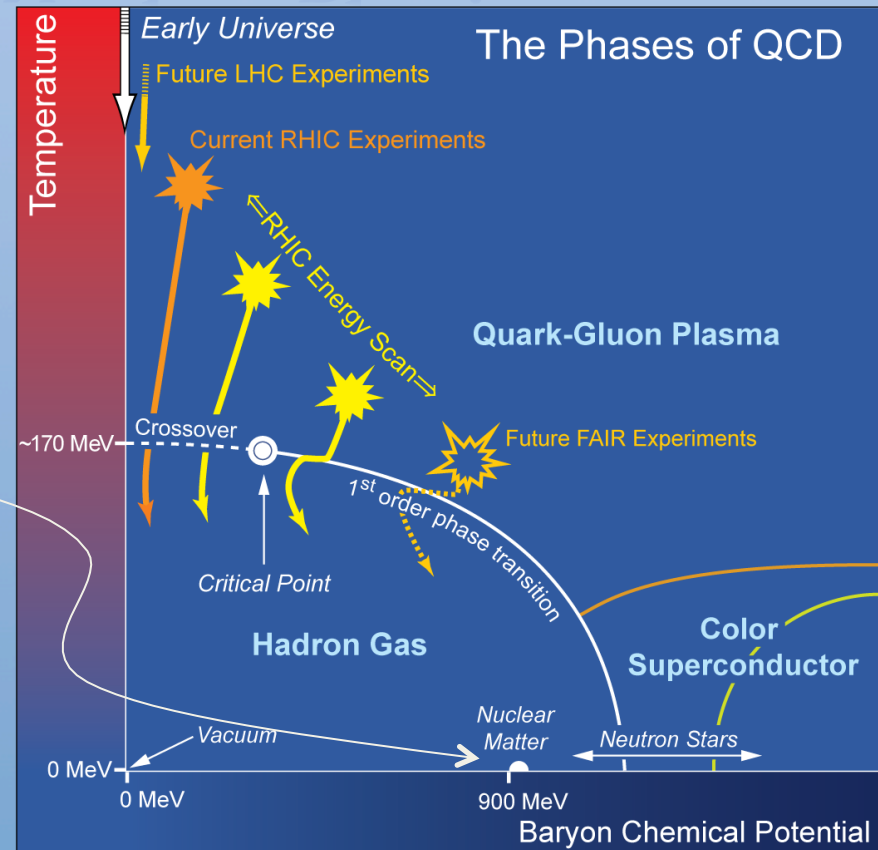
# RHIC Beam Energy Scan

## One Century of Nuclear Physics



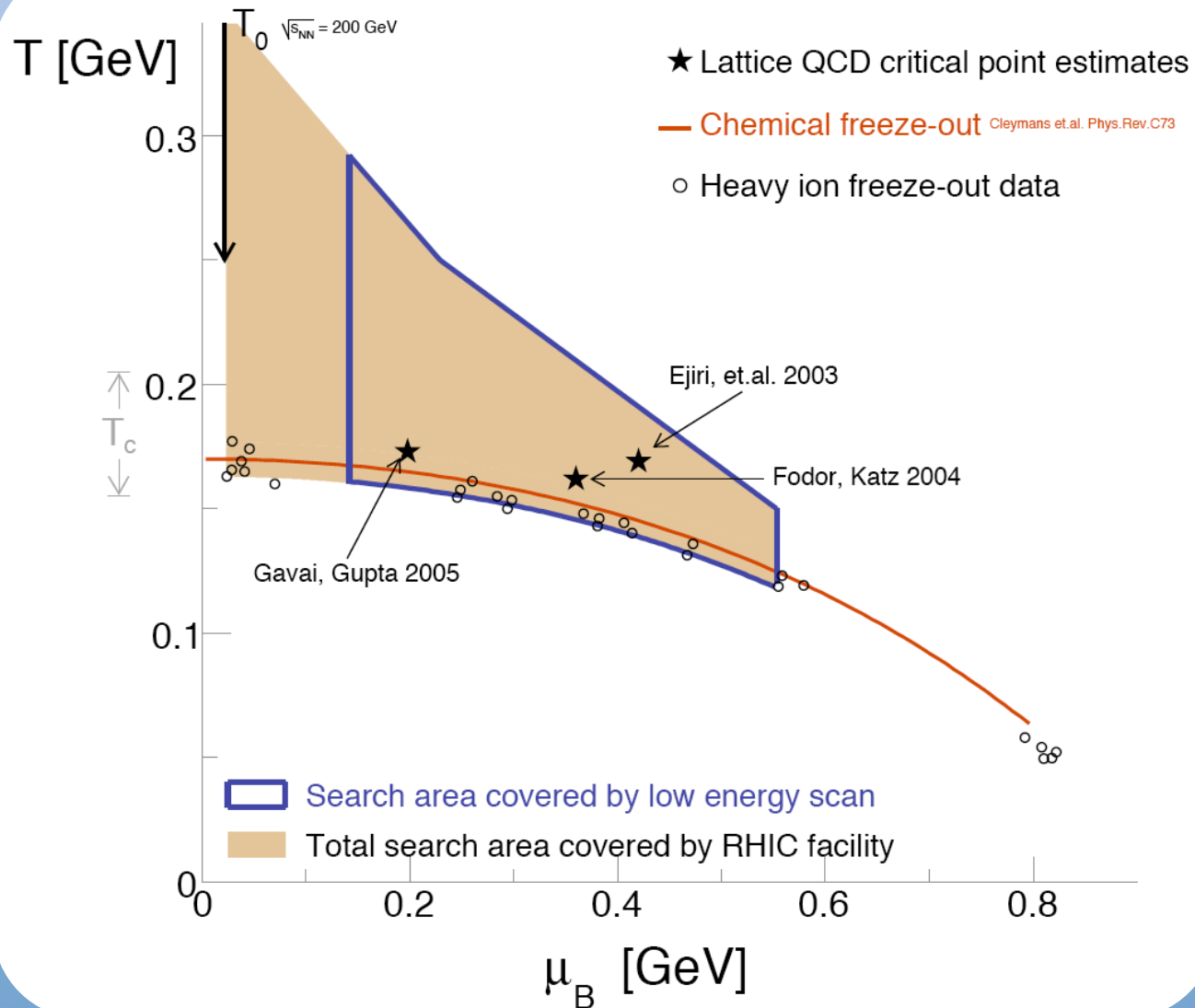
In 1911, Rutherford discovered the nucleus, making him the first nuclear physicist

100 years later, RHIC will scan for the next landmark on the nuclear matter phase diagram: **the critical point**

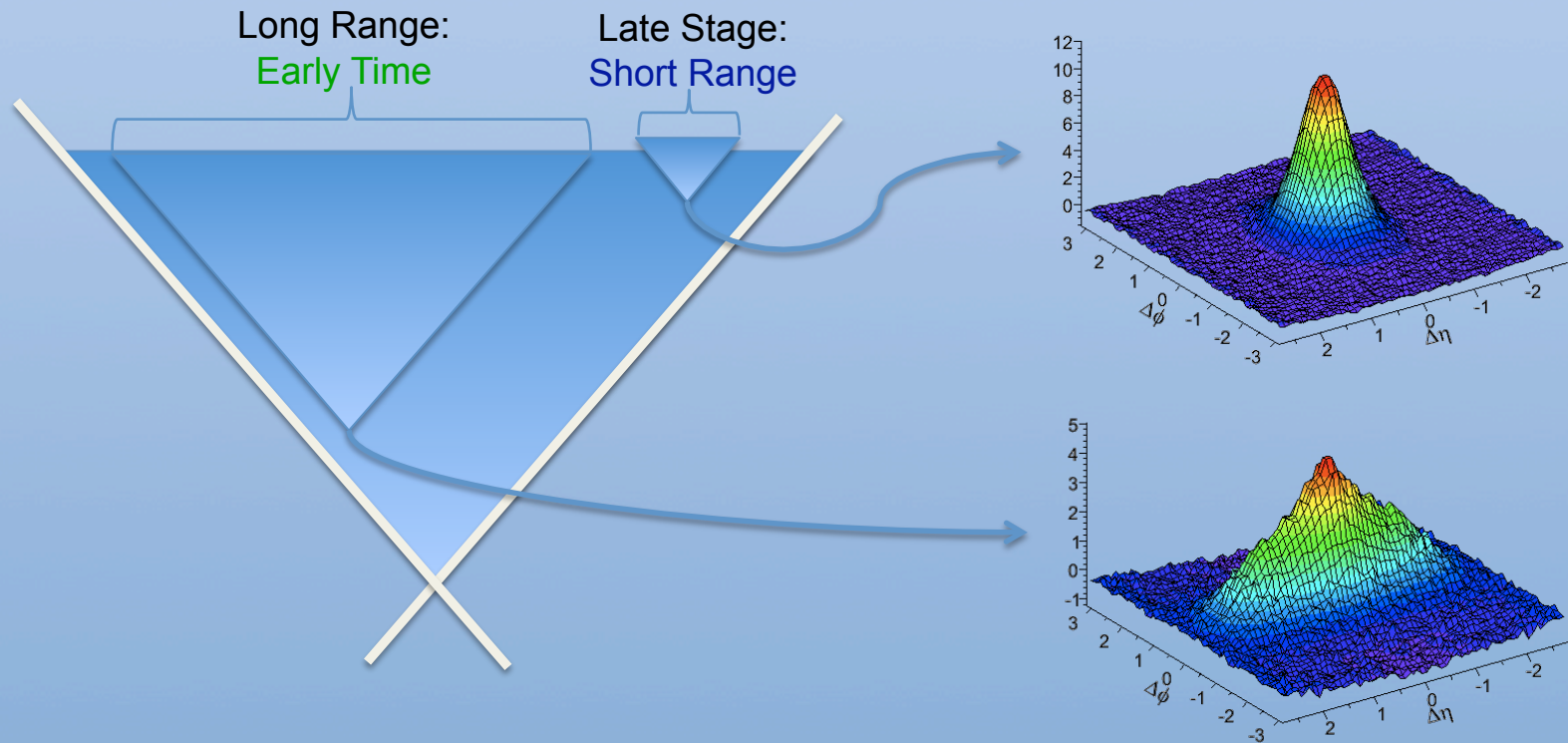


See Declan Keane's Talk Tomorrow

# RHIC: Ideally Suited



# Size Matters: Origin of Correlations



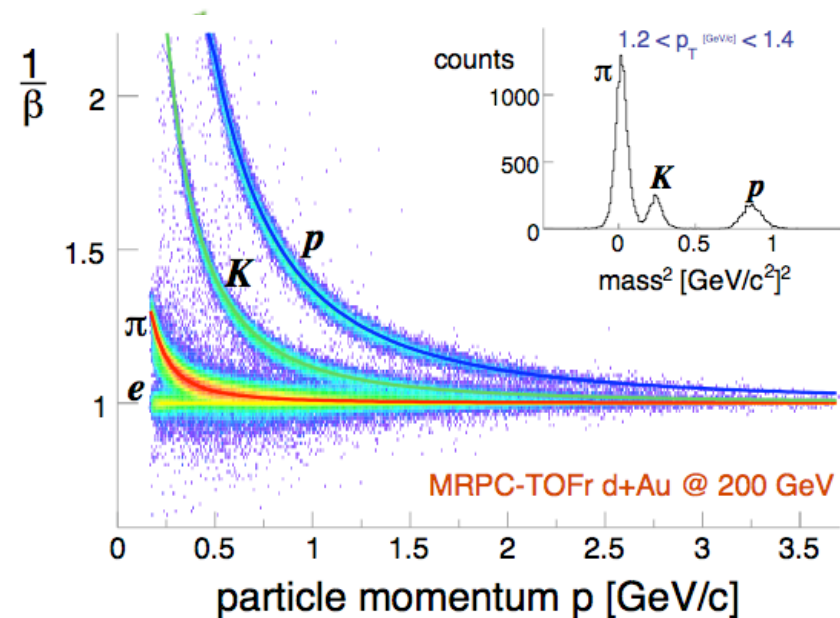
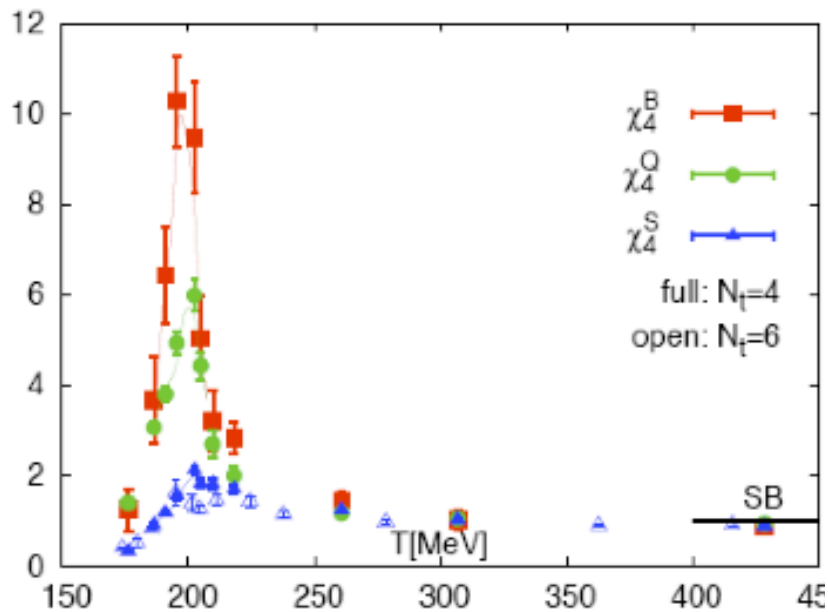
Unlike the ridge, *related by causality arguments*<sup>★</sup> to early times, phase boundary correlations will be narrower in  $\Delta\eta$

★Dumitru, Gelis, Venugopalan,  
McLerran: Nucl. Phys.A 810:91,2008

Good  $\Delta\phi$   $\Delta\eta$  coverage needed to identify the source of correlations and fluctuations

# PID matters: Phase Transitions

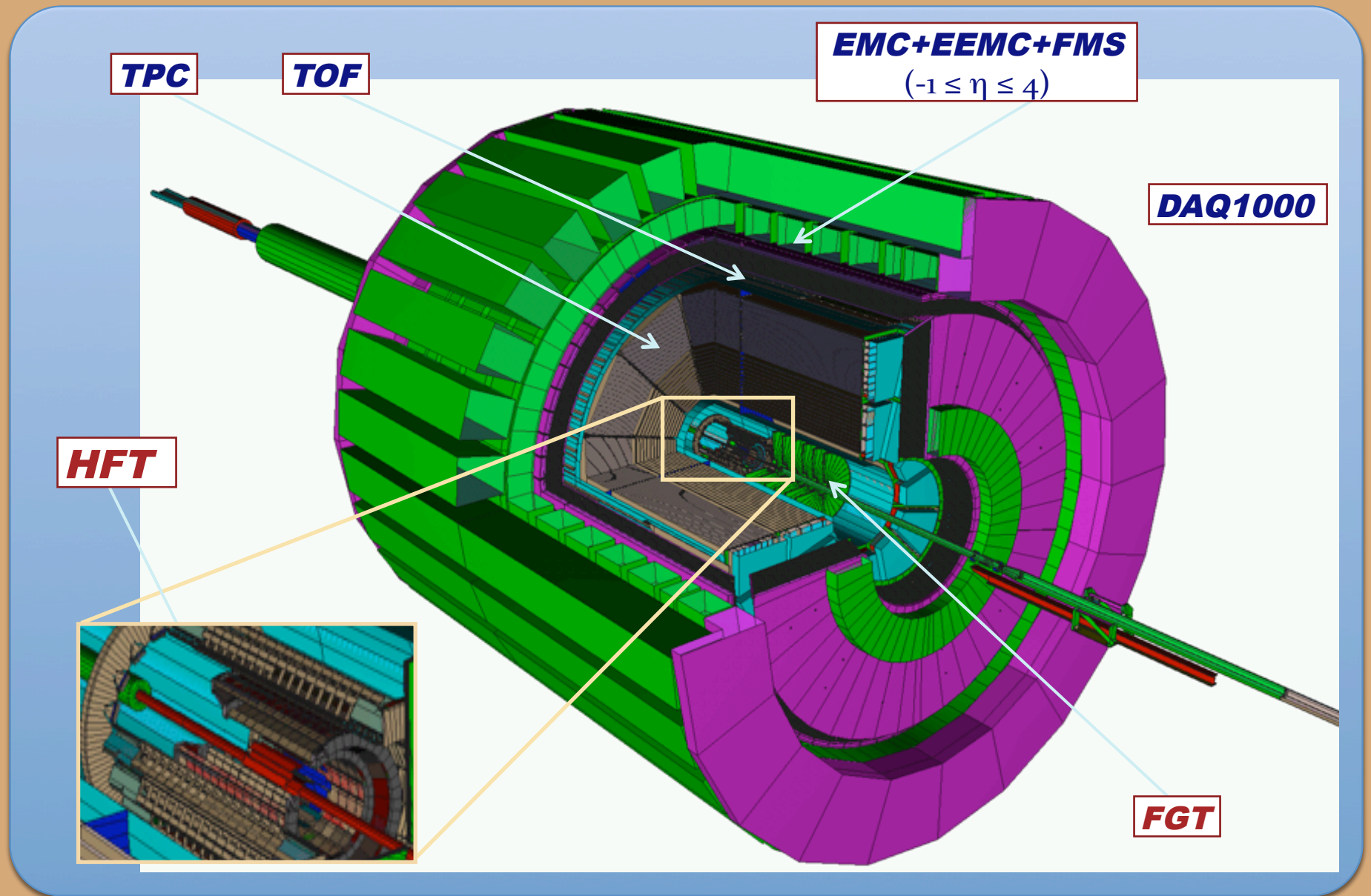
Rutherford's discovery of the nucleus in 1911 relied on state-of-the-art technology developed by Hans Geiger to count alpha particles. The state-of-the-art technology at the heart of STAR's Time-of-Flight upgrade increases the possibility that STAR will locate that other landmark on the nuclear matter map: the critical point.



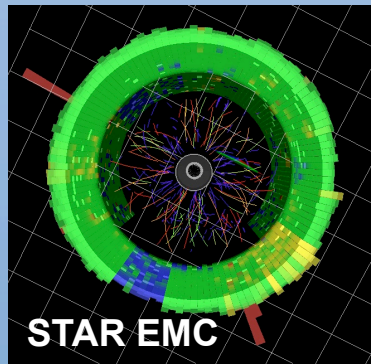
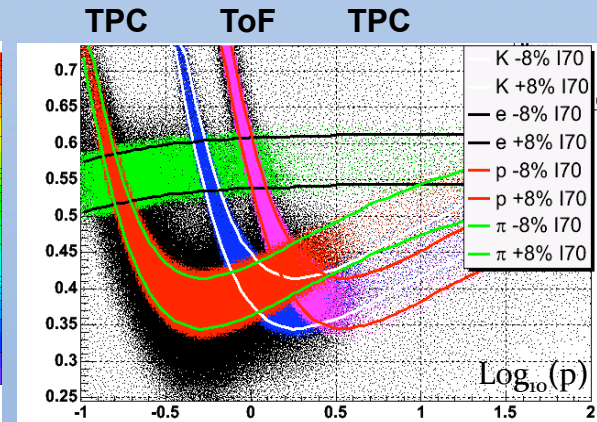
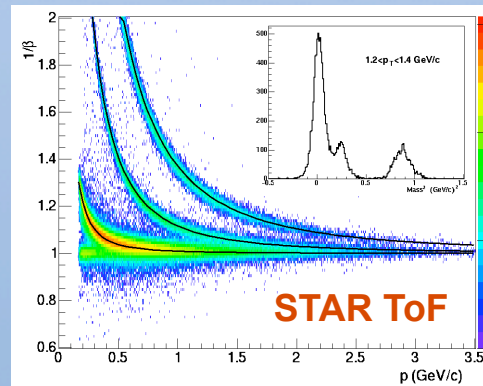
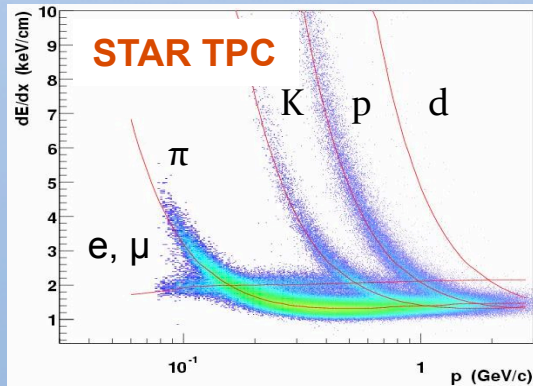
PID to measure moments of the distributions of conserved quantities



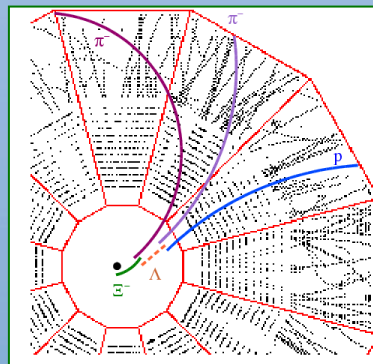
# STAR Detectors: *Full $2\pi$ particle identification!*



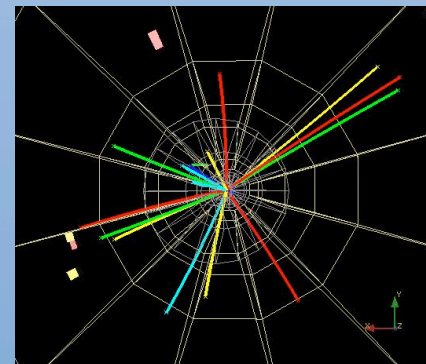
# PID and Acceptance at STAR



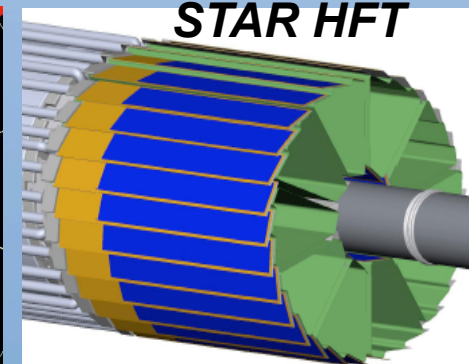
Neutral  
Particles



Strange  
Hyperons



Jets



Open Heavy Flavor

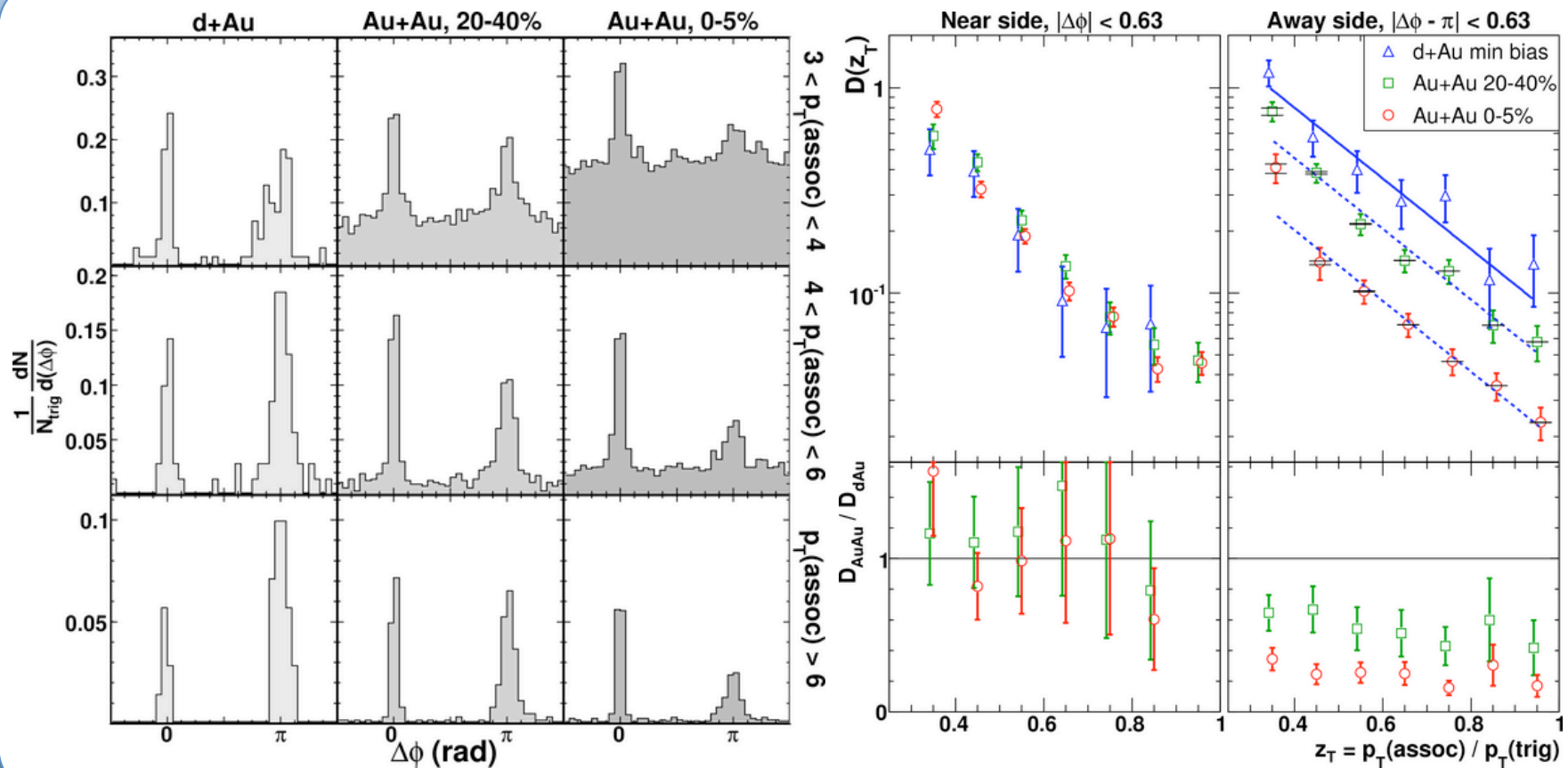
**Multiple-fold correlations identified for particles over large acceptance!**

# Summary

- **THE FIRST DECADE OF RESEARCH AT STAR**
  - Strongly Interacting Hot and Dense Matter Produced in 200 GeV Au+Au collisions
- **THE NEXT DECADE**
  - Characterize the Matter
  - Explore the QCD Landscape
  - RHIC Provides the Luminosity and Flexibility
  - STAR Detector Upgrades are Focused on Accomplishing Our Goals



# Highlights: Dijet Suppression



Direct observation of Dijets through dihadron correlations  
 Away-side peak suppressed by a factor of 5