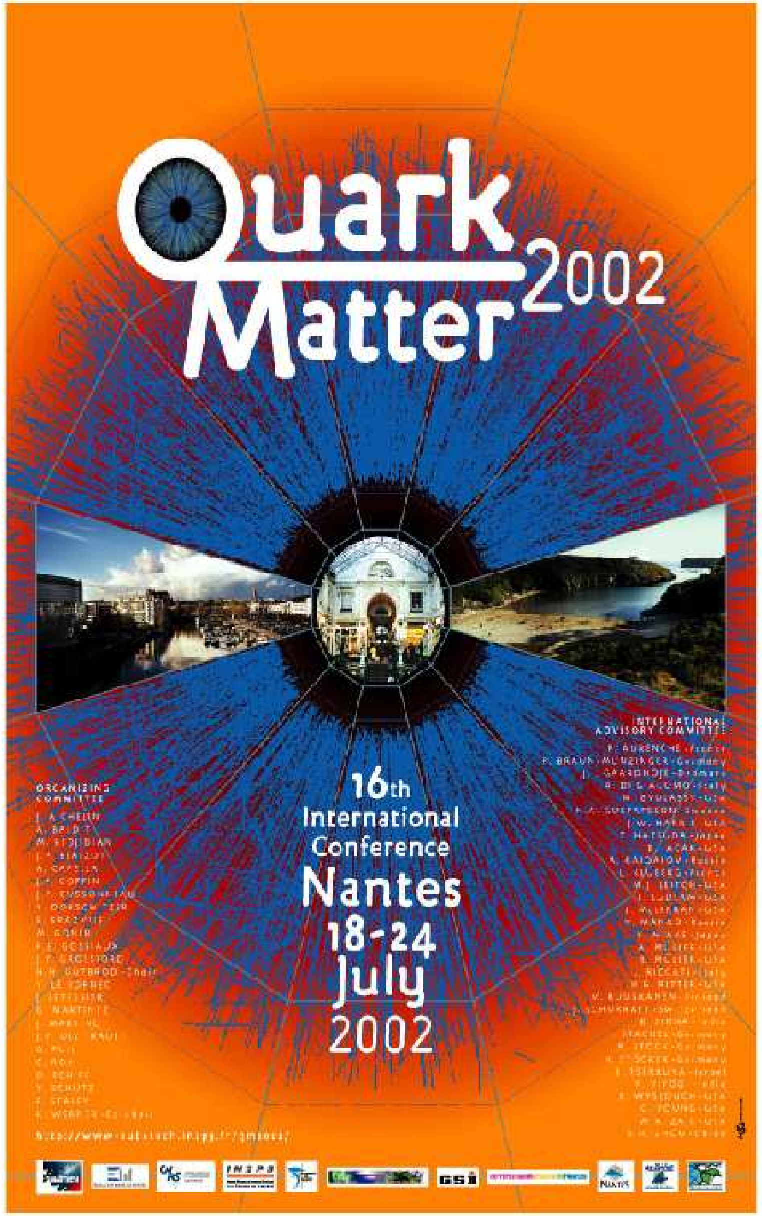


impresje niskoenergetycznego obserwatora

Tomasz Matulewicz

Zakład Fizyki Jądra Atomowego

29 listopada 2002

How many bodies are required before we have a problem? G.E. Brown points out that this case can be answered by a look at history. In XVIII century Newtonian mechanics, the three-body problem was insoluble. With the birth of relativity around 1910 and quantum electrodynamics in 1930, the two- and one-body problems become insoluble. And within modern quantum field theory, the problem of zero bodies (vacuum) is insoluble. So, if we are out after exact solutions, no bodies at all is already too many.

R.D. Mattuck, A guide to Feynmann diagrams
McGraw Hill , NY 1976

Impresje niskoenergetycznego obserwatora

- narzędzia: SPS → RHIC → LHC
- elementarz: y, p_t, detektory
- motywacje
- wyniki „globalne”: krotności, temperatura, potencjał bariochemiczny
- „jet quenching”
- mezony w materii
- jak mierzyć fotony w polu magnetycznym?

Some Pre-Conference Advice

Advice to Experimentalists:

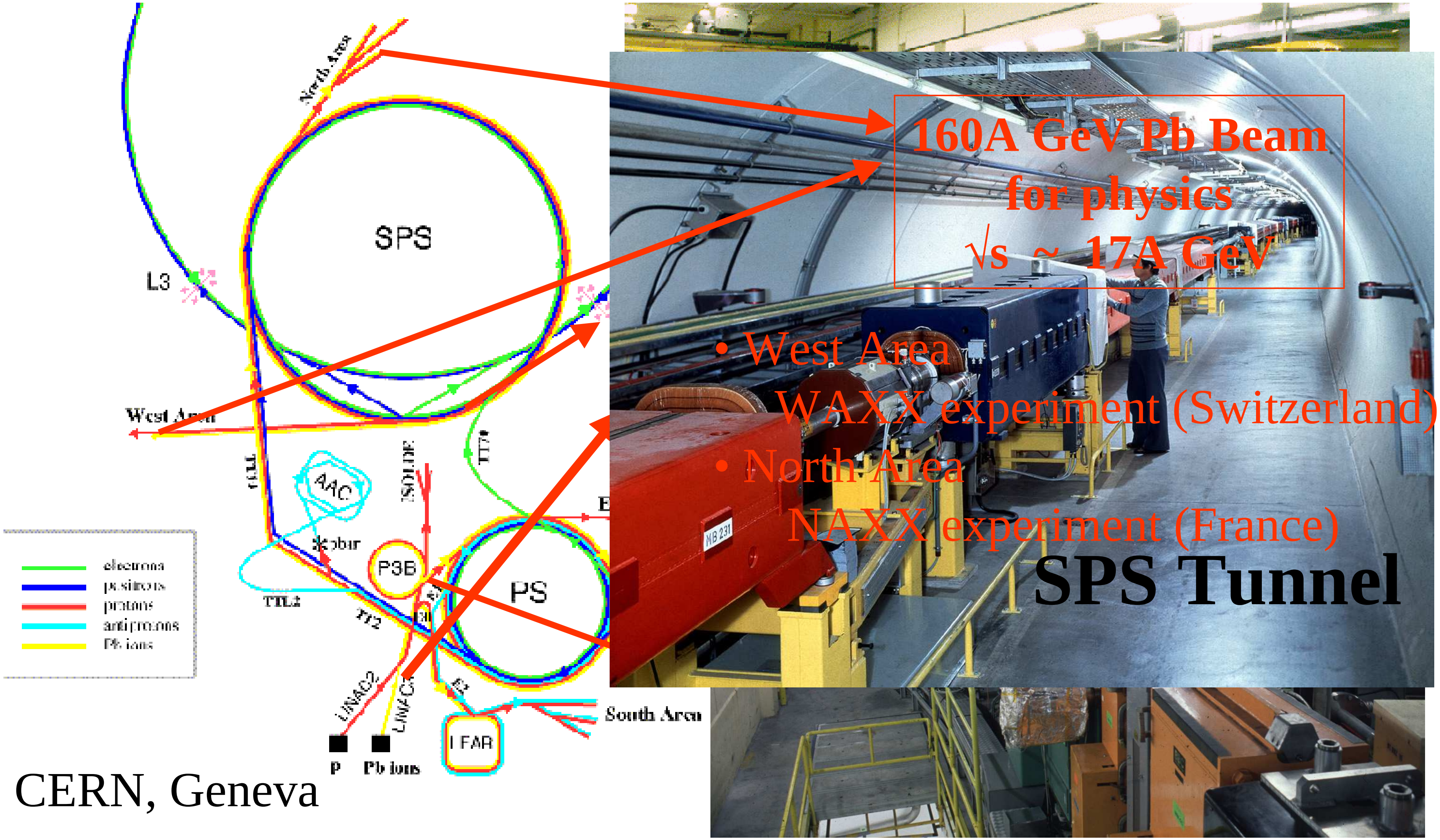
Never let a theorist tell you something is too complicated to explain.

Advice to Theorists:

Never let an experimentalist tell you something is too complicated to explain.

Most all things are really simple once we understand.

Super Proton Synchroton SPS



160A GeV Pb Beam for physics

$\sqrt{s} \sim 17$A GeV

- West Area

  WAXX experiment (Switzerland)
- North Area

  NAXX experiment (France)

SPS Tunnel

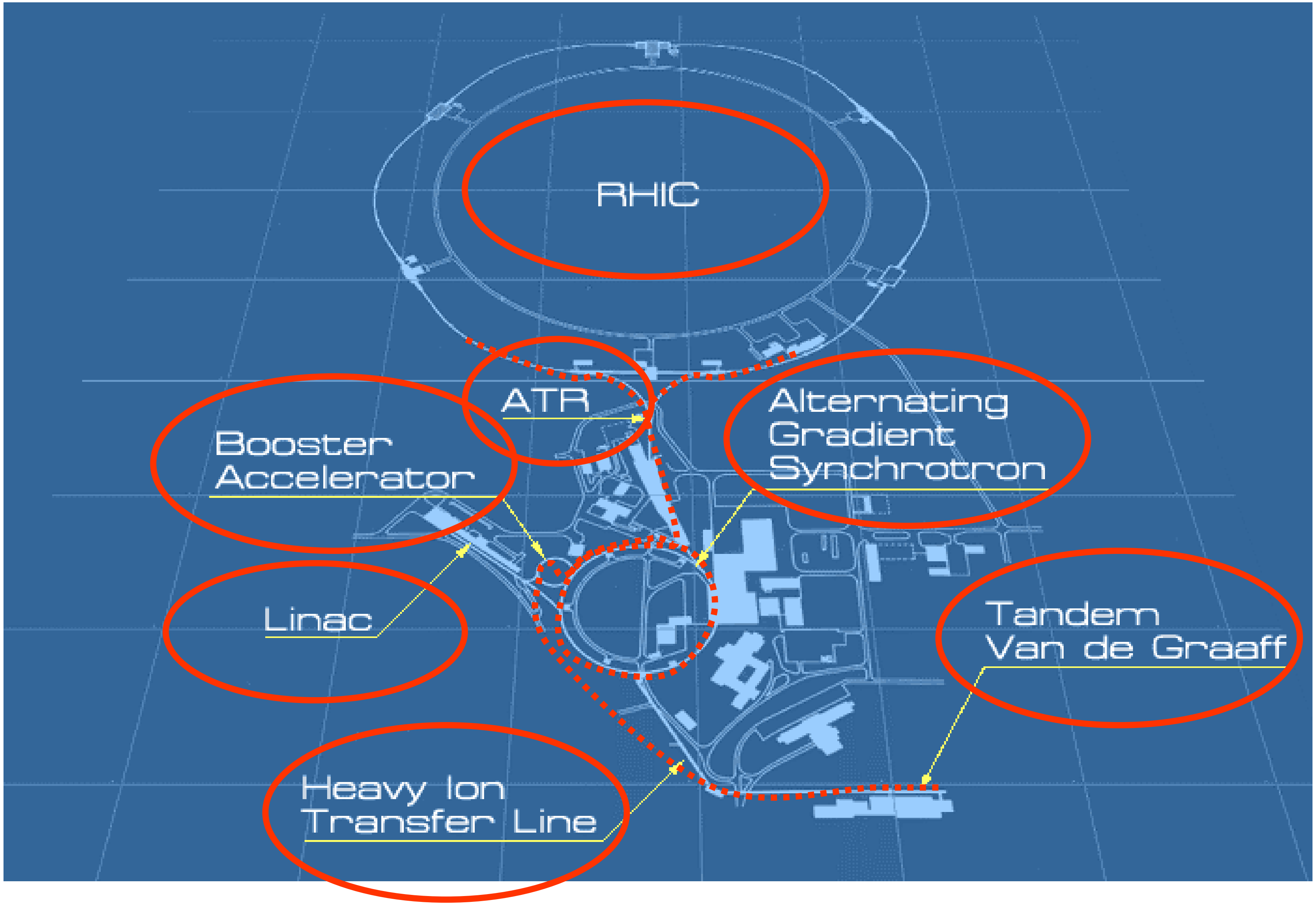
CERN, Geneva

Relativistic Heavy Ion Collider, RHIC

- 3.83 km circumference
- Two *separated* rings
  - 120 bunches/ring
  - 106 ns bunch crossing time
- A+A, p+A, p+p
- Maximum Beam Energy :
  - 500 GeV for p+p
  - 200A GeV for Au+Au
- Luminosity
  - Au+Au: 2×10^{26} cm^{-2} s^{-1}
  - $\vec{p}+\vec{p}$: 2×10^{32} cm^{-2} s^{-1}
- **Mid-rapidity at 90º**
- **Interaction Point**

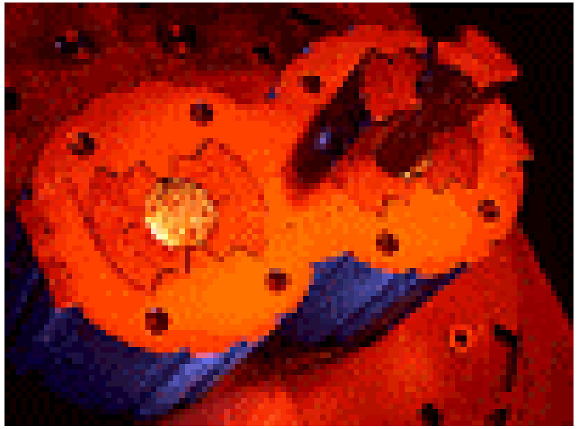
Upton, Long Island, New York

Beam @ RHIC Complex



Large Hadron Collider, LHC

- Pb^{+82} @ 2.76A TeV
- Initial Luminosity 10^{27} $cm^{-2}s^{-1}$
- Luminosity half-life 4.2 h
  - 430b of e.m. processes in Pb+Pb collisions
  - Quench of quadrupoles
- Of course
  - p @ 7 TeV
  - $L_0 = 10^{34}$ $cm^{-2}s^{-1}$



p+p @ 14A TeV in ~2007
Pb+Pb @ 5.5A TeV in ~2008

Why Rapidity?

Kinematical reason:

- The shape of the rapidity distribution, *dn/dy*, is invariant

$$y = 0.5 \times \ln\left(\frac{E+p_z}{E-p_z}\right) \Longrightarrow y^* = y + y_0$$

Dynamical reason:

- The invariant cross-section can be factorized

$$\frac{d^2\sigma}{2\pi p_T dy\, dp_T} = \frac{d\sigma}{2\pi p_T\, dp_T} \times \frac{dn}{dy}$$

Pseudo rapidity

$$\eta = -\ln \tan\left(\frac{\theta}{2}\right)$$

$$y \approx \eta, \quad p >> m, \theta >> 1/\gamma$$

$$y \approx \eta \approx \pi/2 - \theta$$

$\gamma_{SPS} = 9$, $\theta >> 6^o$ // $\gamma_{RHIC} = 100$, $\theta >> 1.6^o$ // $\gamma_{LHC} = 2750$, $\theta >> 0.02^o$

Maximun Rapidity

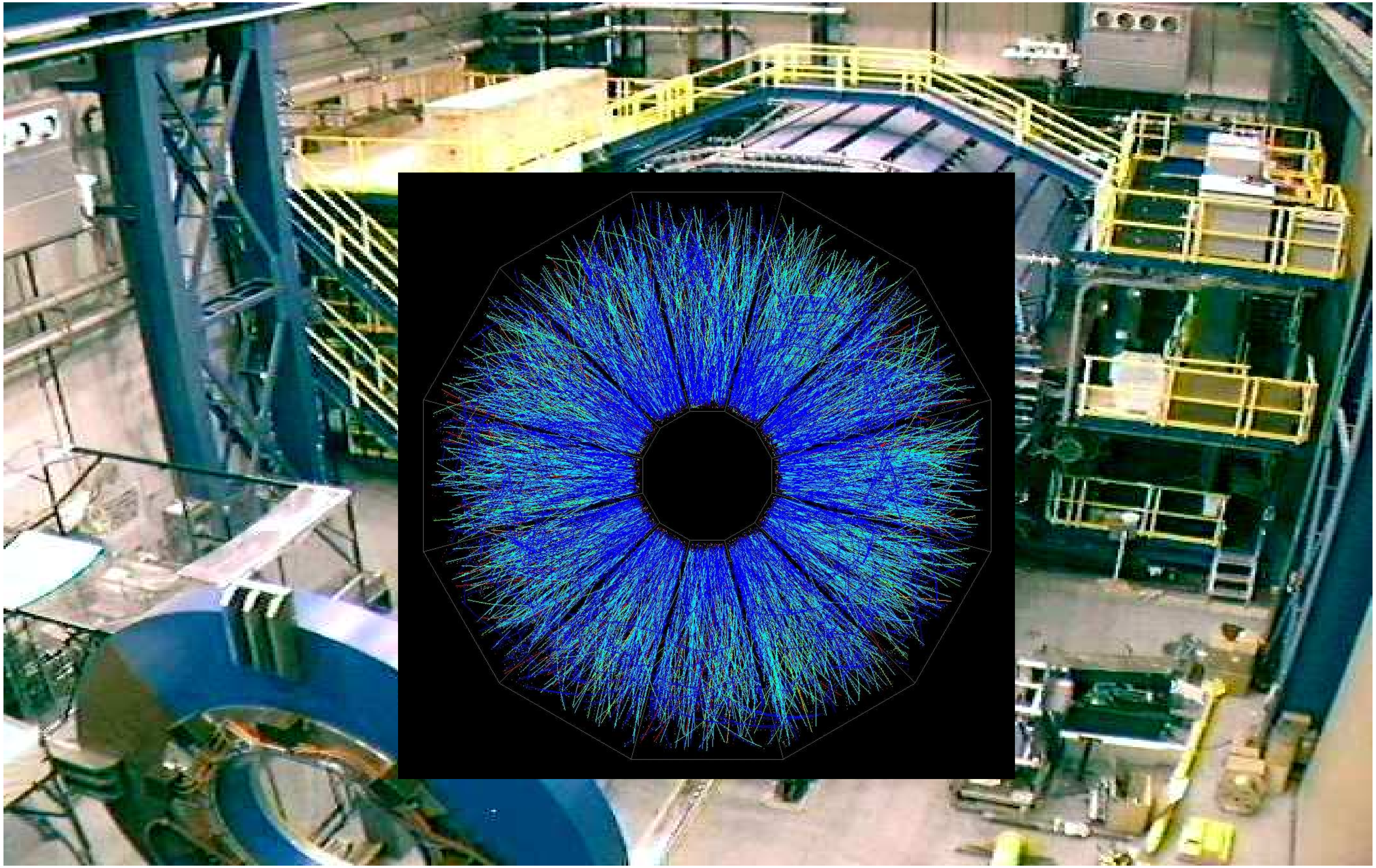
$$y_{\max} = \ln\left(\frac{\sqrt{s}}{m}\right)$$

$$y_{\max}^{SPS} = \pm 2.8$$

$$y_{\max}^{RHIC} = \pm 5.3$$

$$y_{\max}^{LHC} = \pm 8.6$$

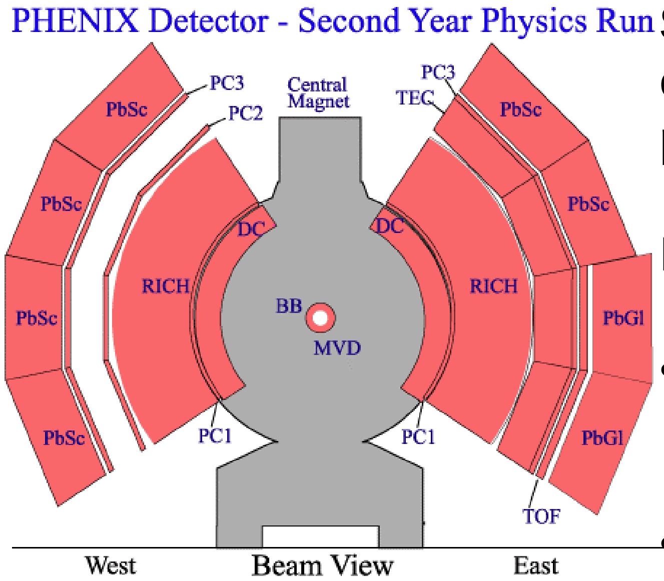
STAR (working) TPC



Charged Particle Identification at PHENIX

HBT analysis
Time-of-Flight
by Calorimeter

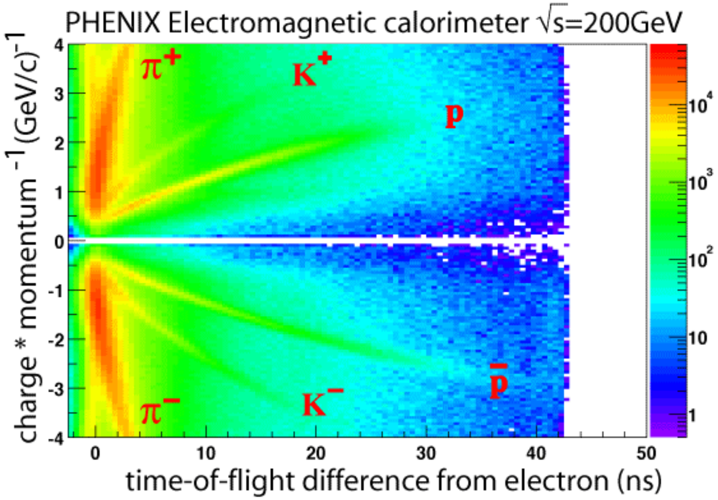
- large acceptance
  ($\Delta\phi = \pi$)

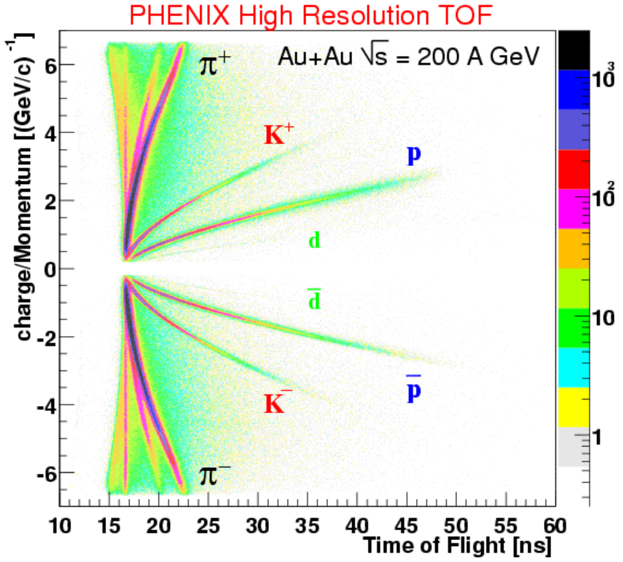


Single particle spectra and elliptic flow w.r.t reaction plane analysis

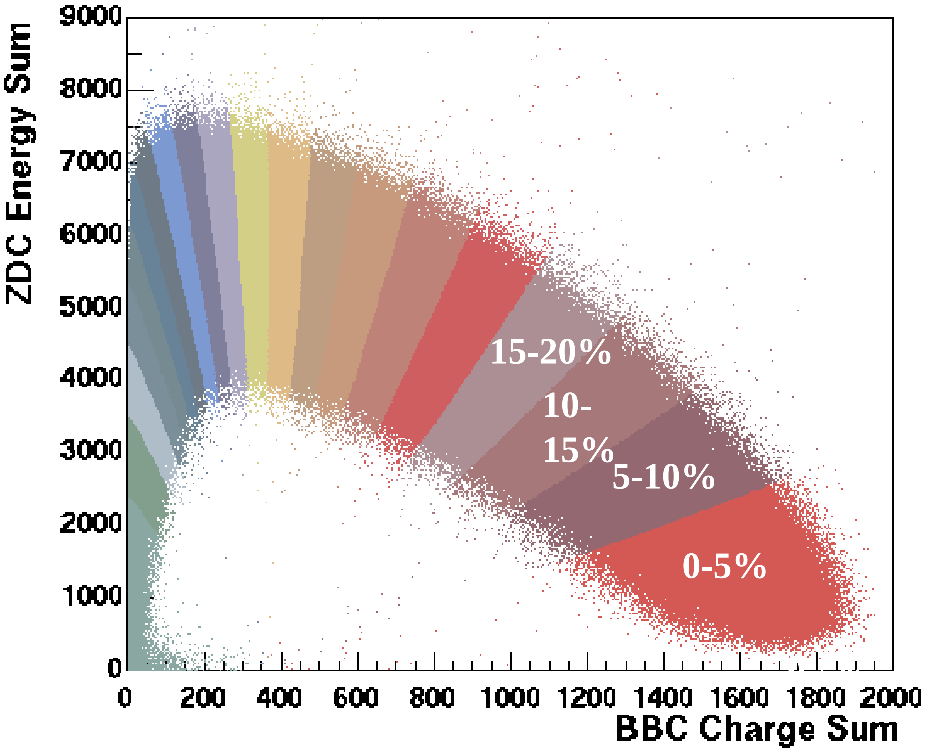
PID by high resolution TOF

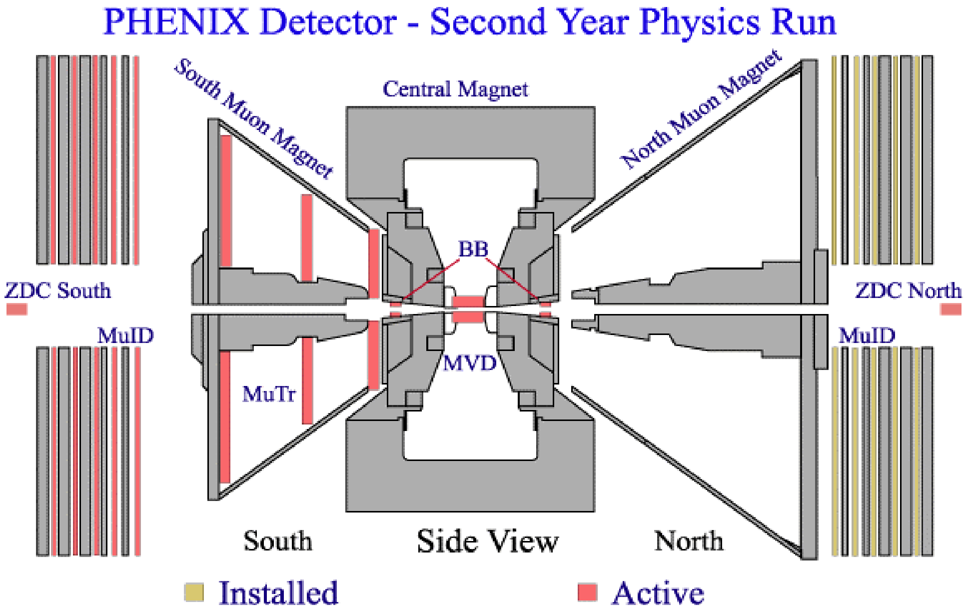
- broad p_T range
  - π, K < 2 GeV
  - proton, anti-proton < 4 GeV
- $\Delta\phi = \pi/4$





Event Selection

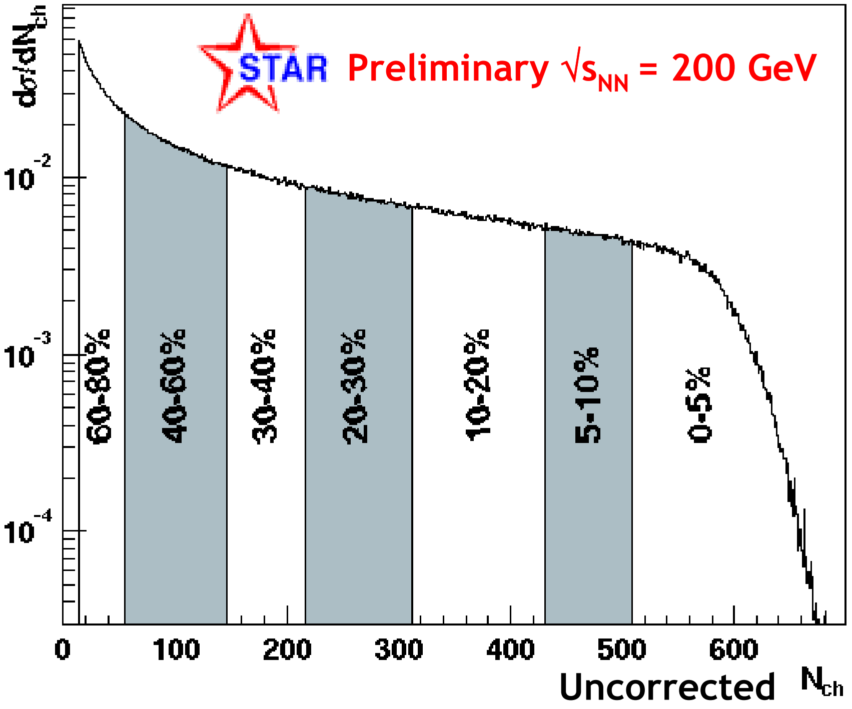




- Centrality selection : Used charge sum of Beam-Beam Counter (BBC, $|\eta|$=3~4) and energy of Zero-degree calorimeter (ZDC) in minimum bias events.
- Extracted N_{part} based on Glauber model.

Au+Au Analysis

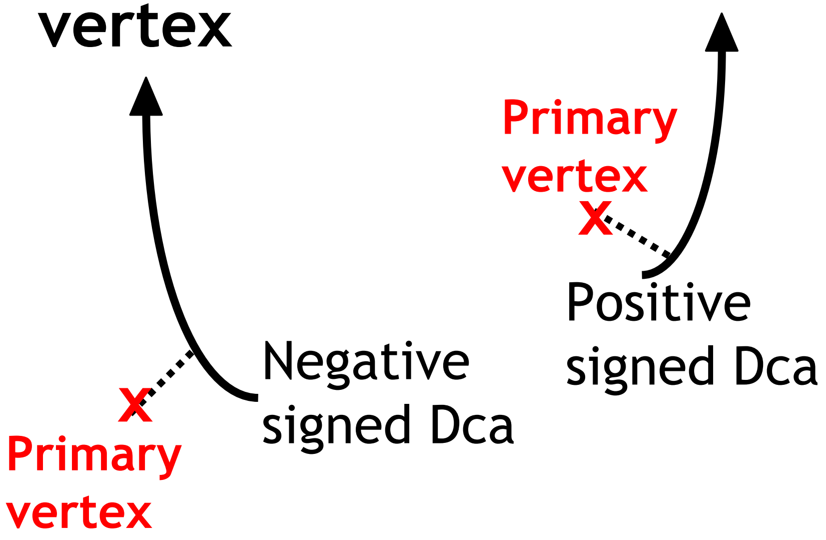
Event Selection:



Centrality classes based on mid-rapidity multiplicity

High p_T Track Selection:

dca ≡ distance of closest approach to the primary vertex



Primary vertex

Positive signed Dca

Negative signed Dca

Primary vertex

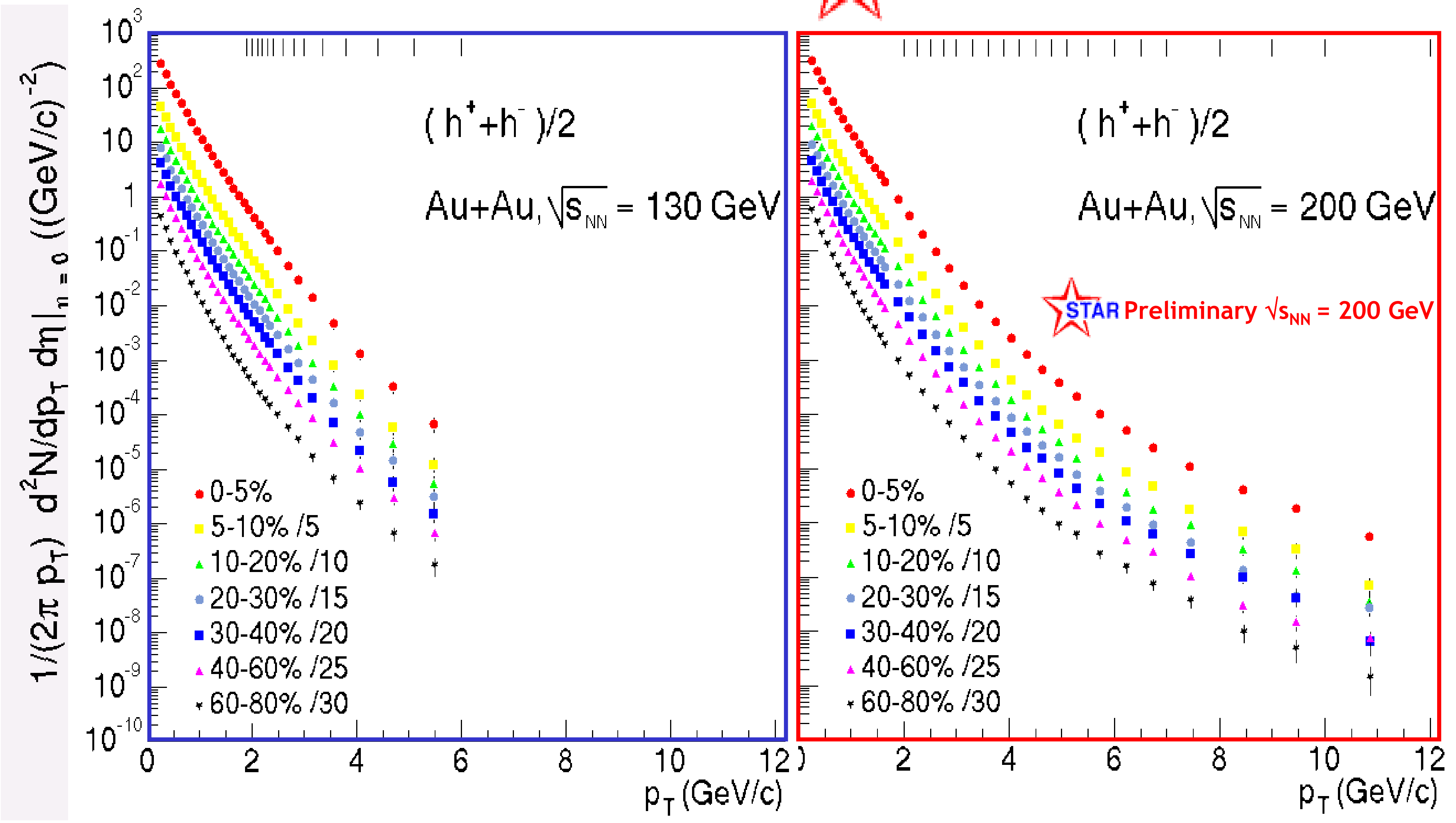
|signed Dca| < 1 cm

$|\eta| < 0.5$

Charged hadron p_t spectra

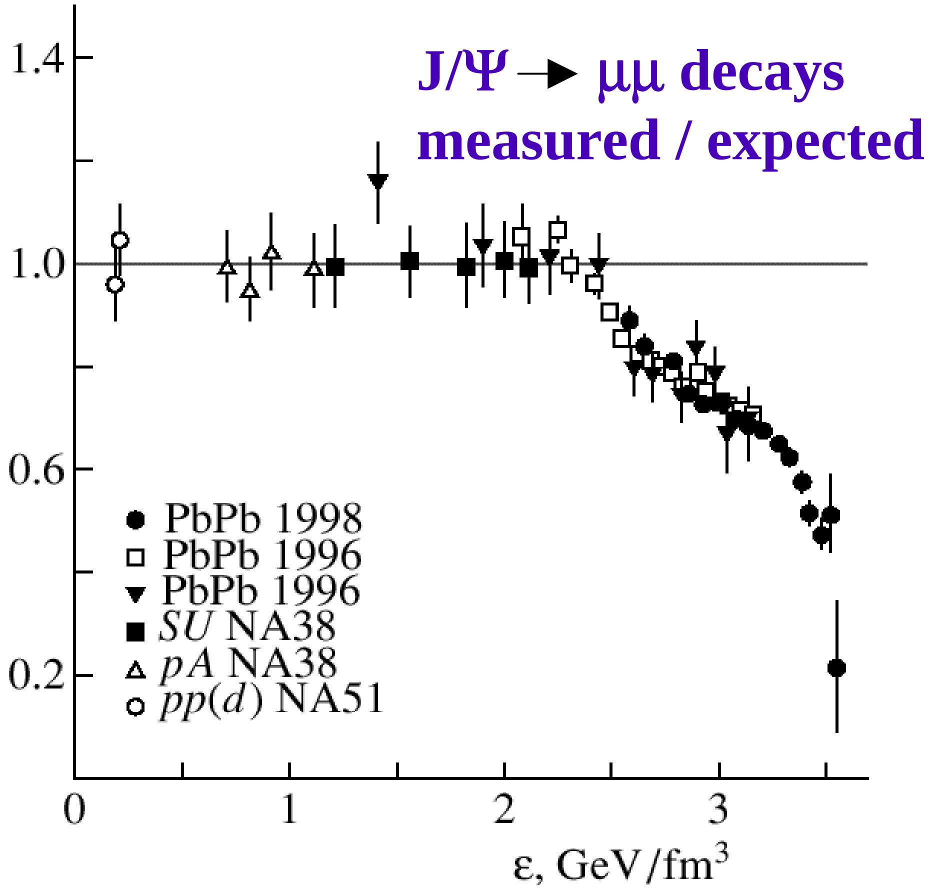
130 GeV nucl-ex/0206011

STAR Preliminary $\sqrt{s_{NN}}$ = 200 GeV



CERN SPS results (NA50, NA38, NA51)

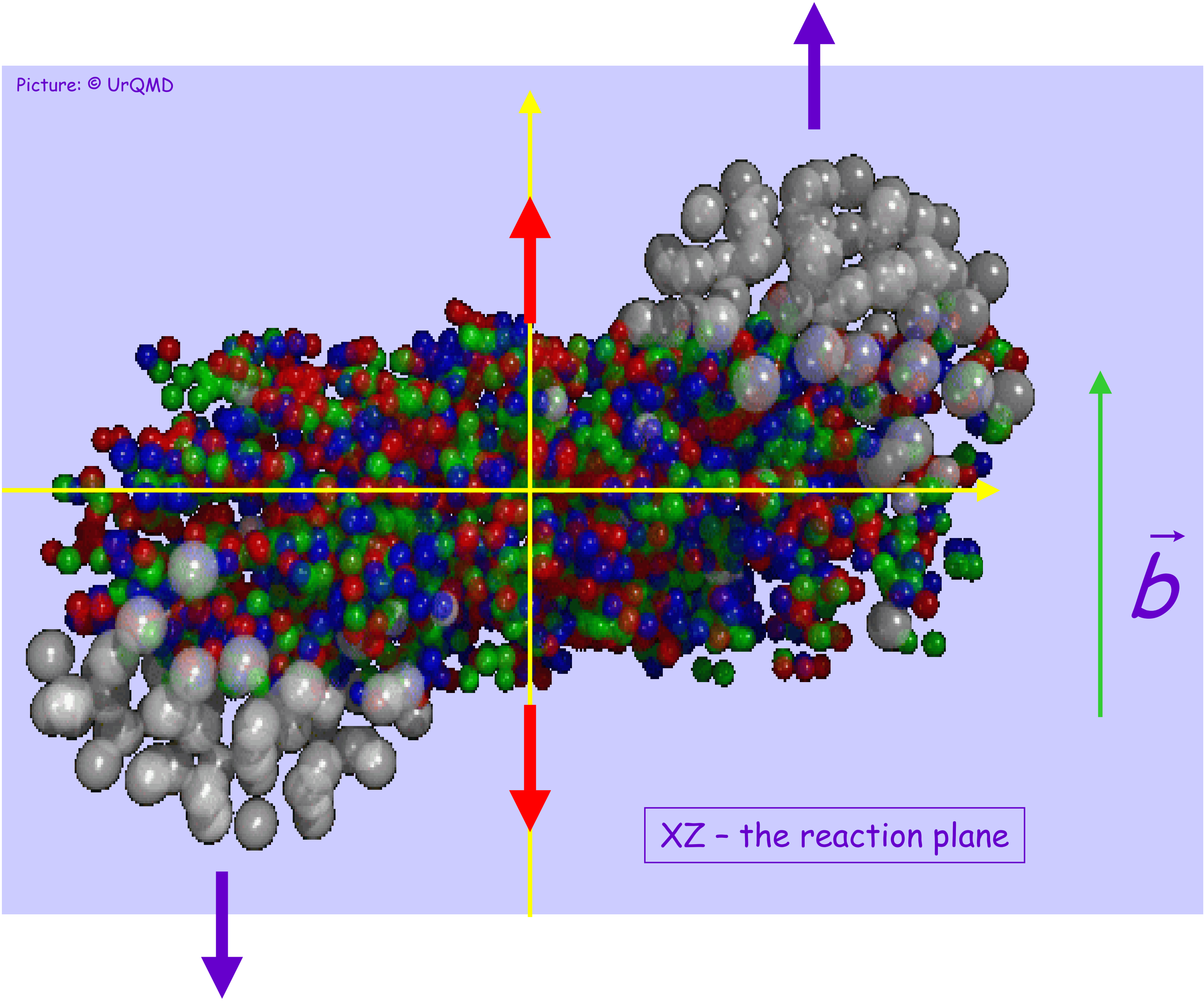
(eg. Physics Of Atomic Nuclei 65, 325 (2002))



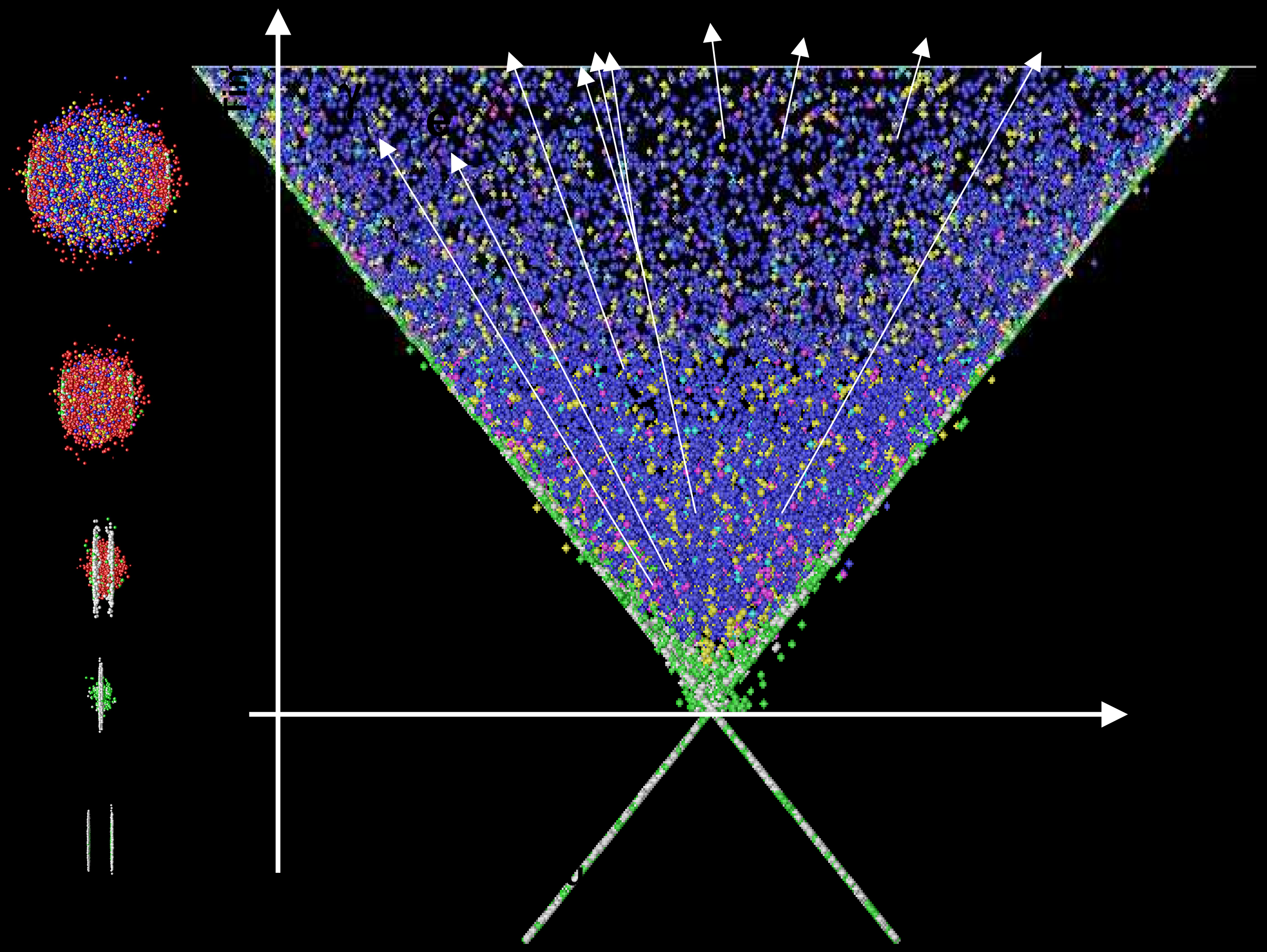
J/Ψ → μμ decays
measured / expected

Expected J/Ψ yields are corrected for "ordinary" nuclear absorption assuming **6.4 mb** absorption cross section

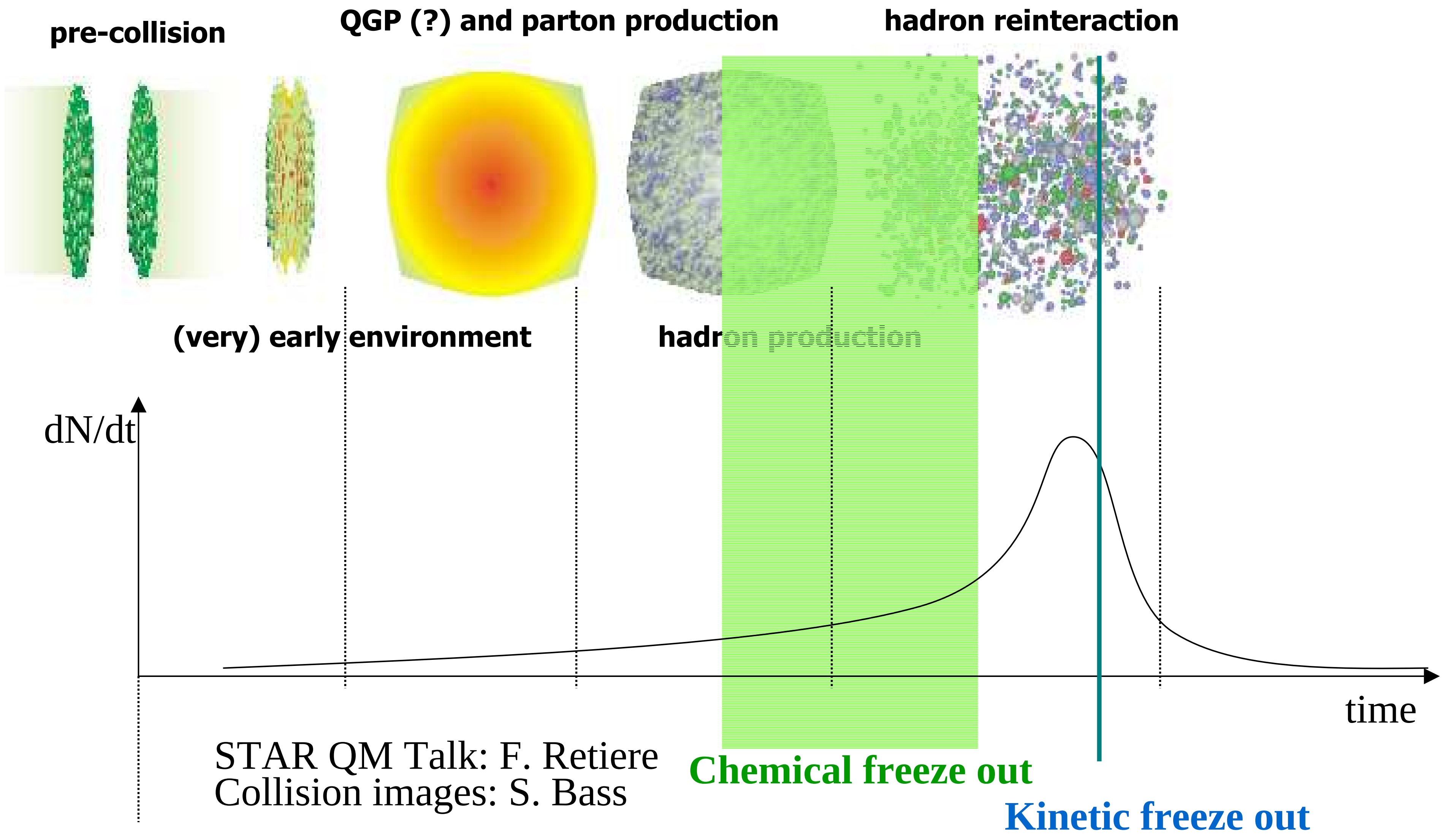
Many arguments about whether this is strong evidence of QGP at SPS energies, but it is clearly VERY interesting!



XZ – the reaction plane


γ
e

Outline of a heavy ion collision



pre-collision

QGP (?) and parton production

hadron reinteraction

(very) early environment

hadron production

dN/dt

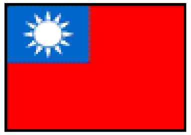
time

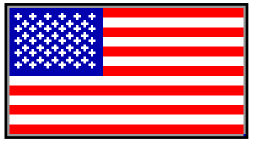
Chemical freeze out

Kinetic freeze out

STAR QM Talk: F. Retiere
Collision images: S. Bass

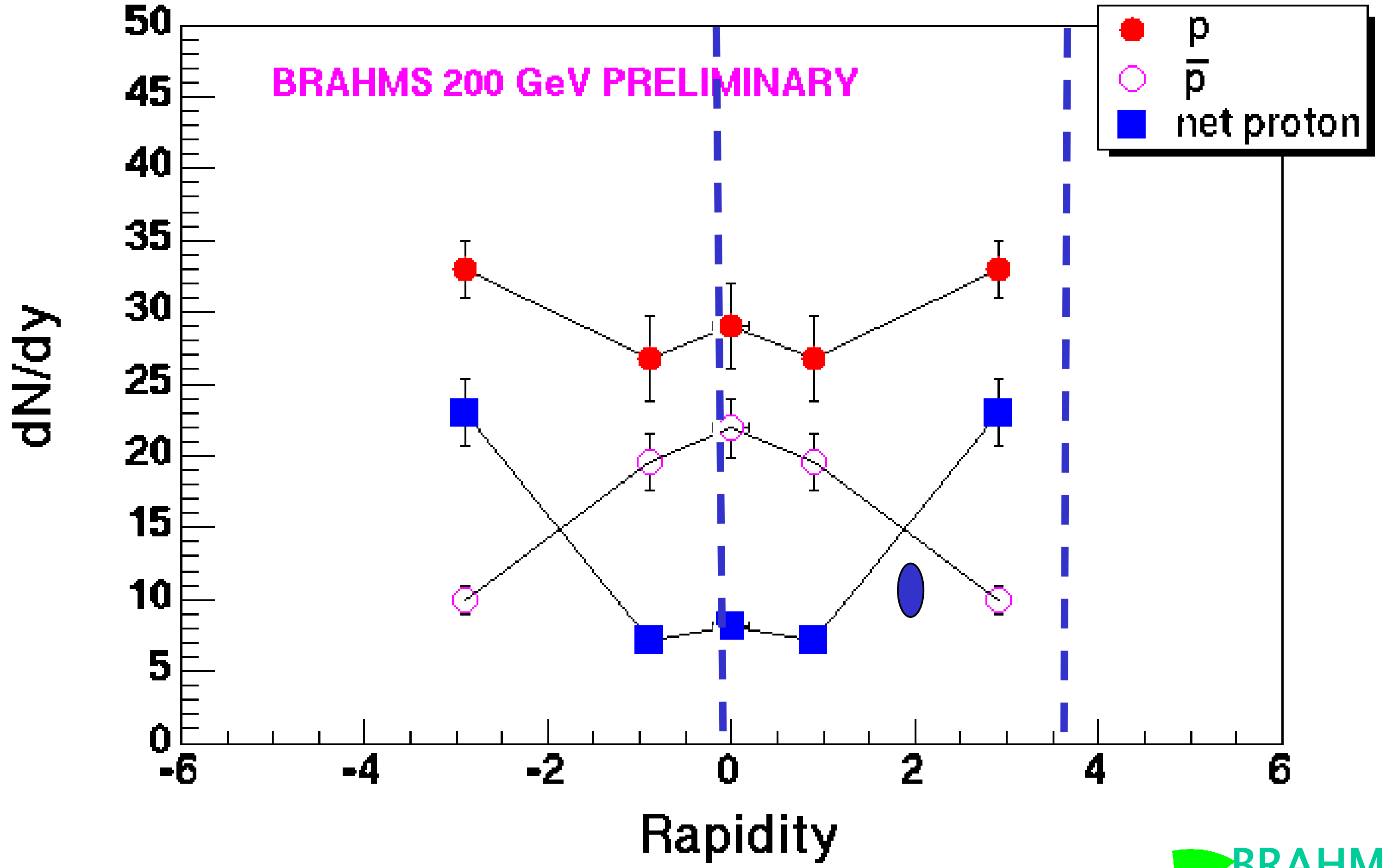
PHOBOS Collaboration



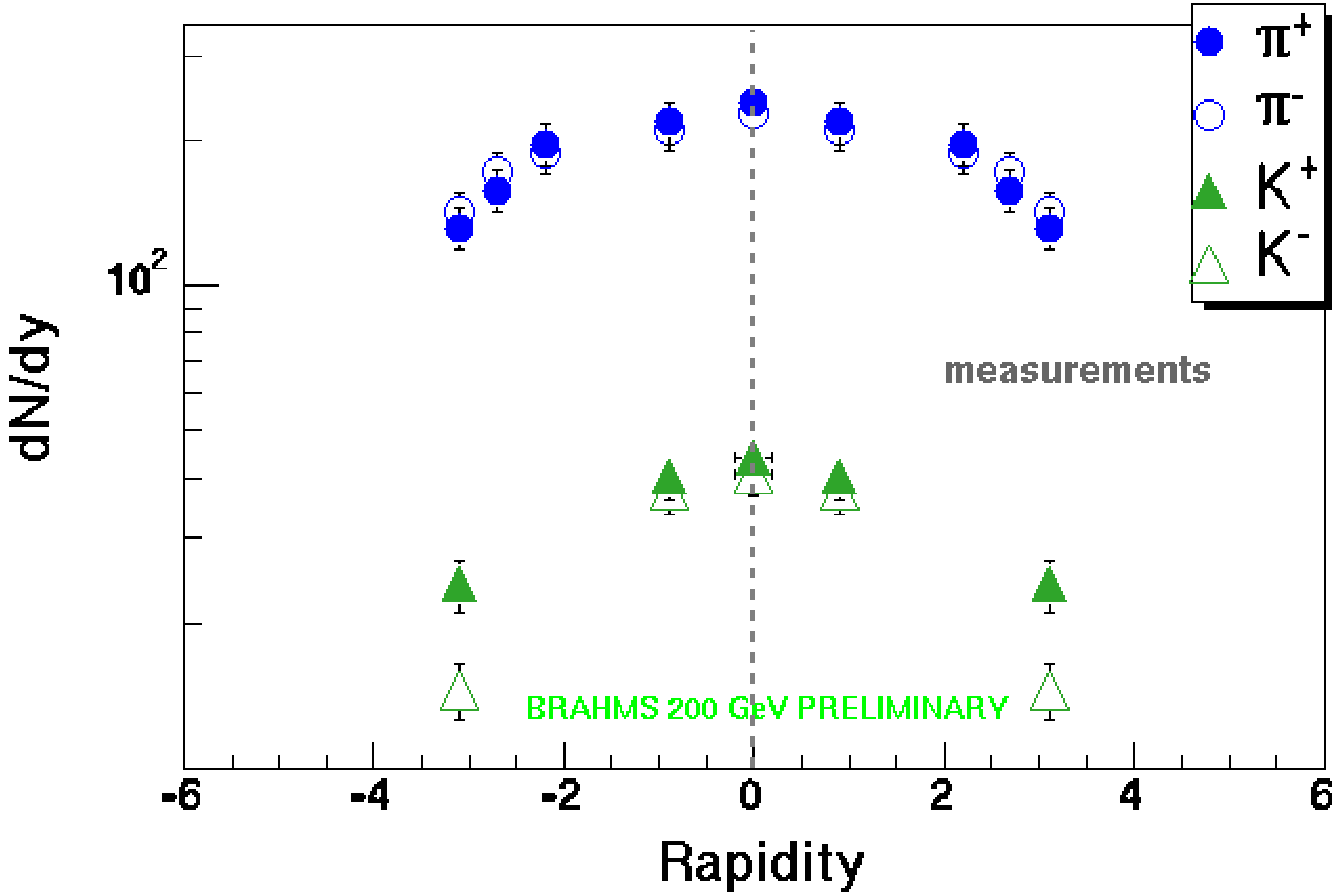


ARGONNE NATIONAL LABORATORY	Birger Back, Alan Wuosmaa
BROOKHAVEN NATIONAL LABORATORY	Mark Baker, Donald Barton, Alan Carroll, Nigel George, Stephen Gushue, George Heintzelman, Burt Holzman, Robert Pak, Louis Remsberg, Peter Steinberg, Andrei Sukhanov
INSTITUTE OF NUCLEAR PHYSICS, KRAKOW	Andrzej Budzanowski, Roman Hołyński, Jerzy Michałowski, Andrzej Olszewski, Pawel Sawicki, Marek Stodulski, Adam Trzupek, Barbara Wosiek, Krzysztof Woźniak
MASSACHUSETTS INSTITUTE OF TECHNOLOGY	Maartin Ballintijn, Wit Busza (Spokesperson), Patrick Decowski, Kristjan Gulbrandsen, Conor Henderson, Jay Kane, Judith Katzy, Piotr Kulinich, Jang Woo Lee, Heinz Pernegger, Corey Reed, Christof Roland, Gunther Roland, Leslie Rosenberg, Pradeep Sarin, Stephen Steadman, George Stephans, Carla Vale, Gerrit van Nieuwenhuizen, Gábor Veres, Robin Verdier, Bernard Wadsworth, Bolek Wysłouch
NATIONAL CENTRAL UNIVERSITY, TAIWAN	Chia Ming Kuo, Willis Lin, Jaw-Luen Tang
UNIVERSITY OF ILLINOIS AT CHICAGO	Russell Betts, Edmundo Garcia, Clive Halliwell, David Hofman, Richard Hollis, Aneta Iordanova, Wojtek Kucewicz, Don McLeod, Rachid Nouicer, Michael Reuter, Joe Sagerer
UNIVERSITY OF MARYLAND	Abigail Bickley, Richard Bindel, Alice Mignerey, Marguerite Belt Tonjes
UNIVERSITY OF ROCHESTER	Joshua Hamblen, Erik Johnson, Nazim Khan, Steven Manly, Inkyu Park, Wojtek Skulski, Ray Teng, Frank Wolfs

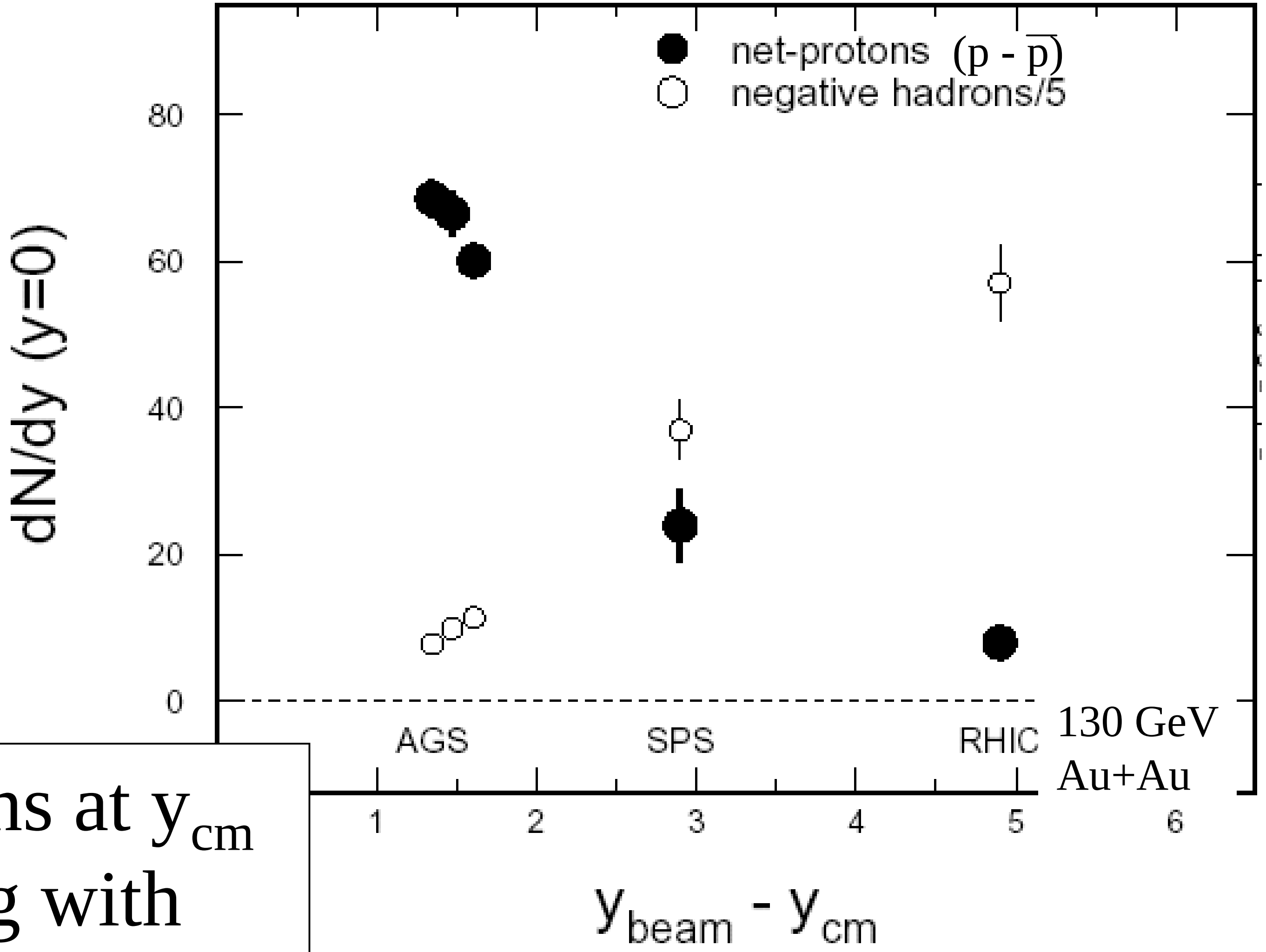
Net protons vs rapidity at RHIC



Rapidity density at RHIC (0-10% central)



Net protons

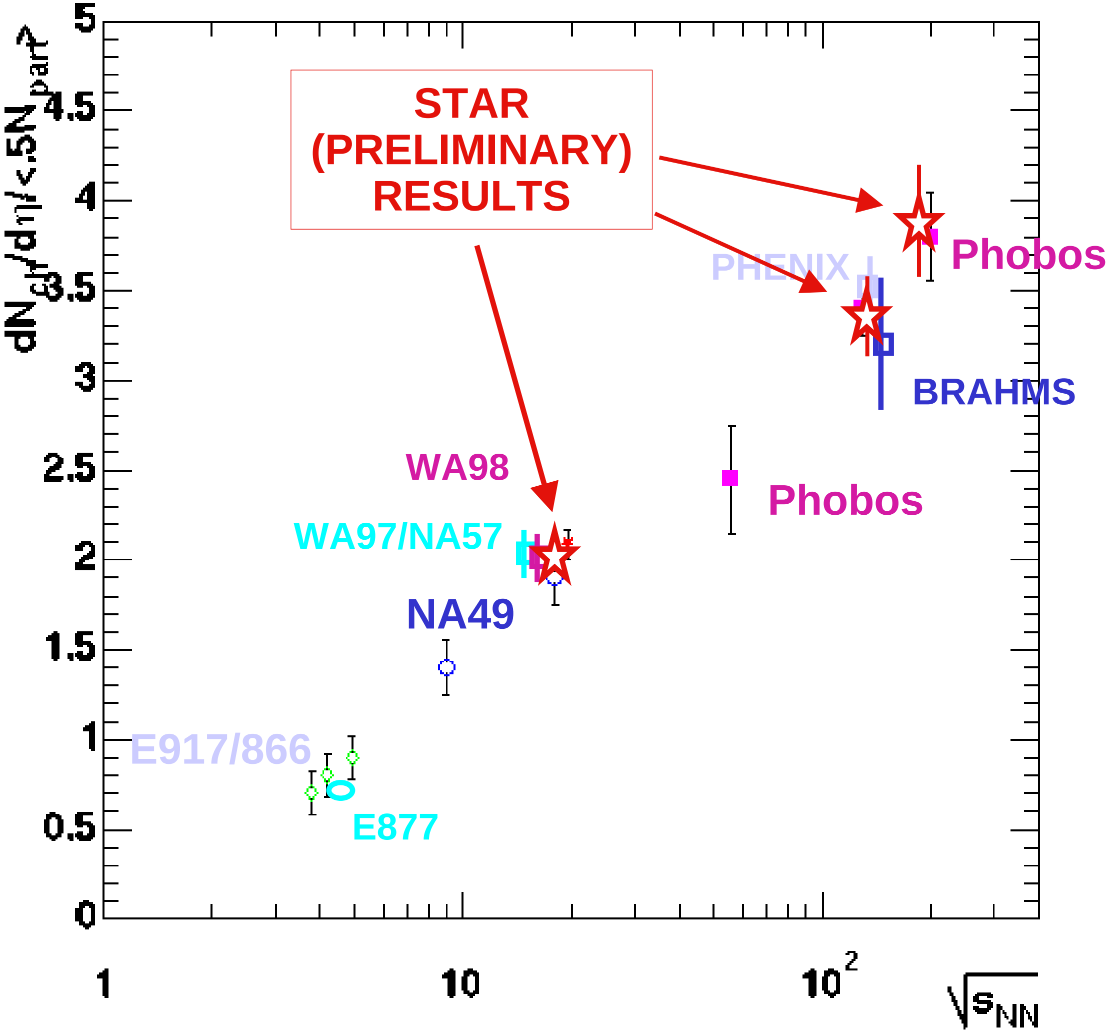


Net protons at y_{cm} decreasing with increasing energy

dN/dη vs. collision energy

~5% central Au+Au (Pb+Pb) collisions

Phobos PRL 85 (2000) 3100
Phobos nucl-ex 018009 (2002)
PHENIX PRL 86 (2001) 3500
STAR(130) nucl-ex 106004 (2001)
BRAHMS QM2001
NA49
WA98 nucl-ex 0008004 (2000)
WA97/NA57 CERN-EP-2000-002
E866/917 PRC59 (1999) 2173
E877 PRC51 (1995) 3309



STAR QM Posters on
19.6 GeV data: D. Cebra
200 GeV data: M. Calderon

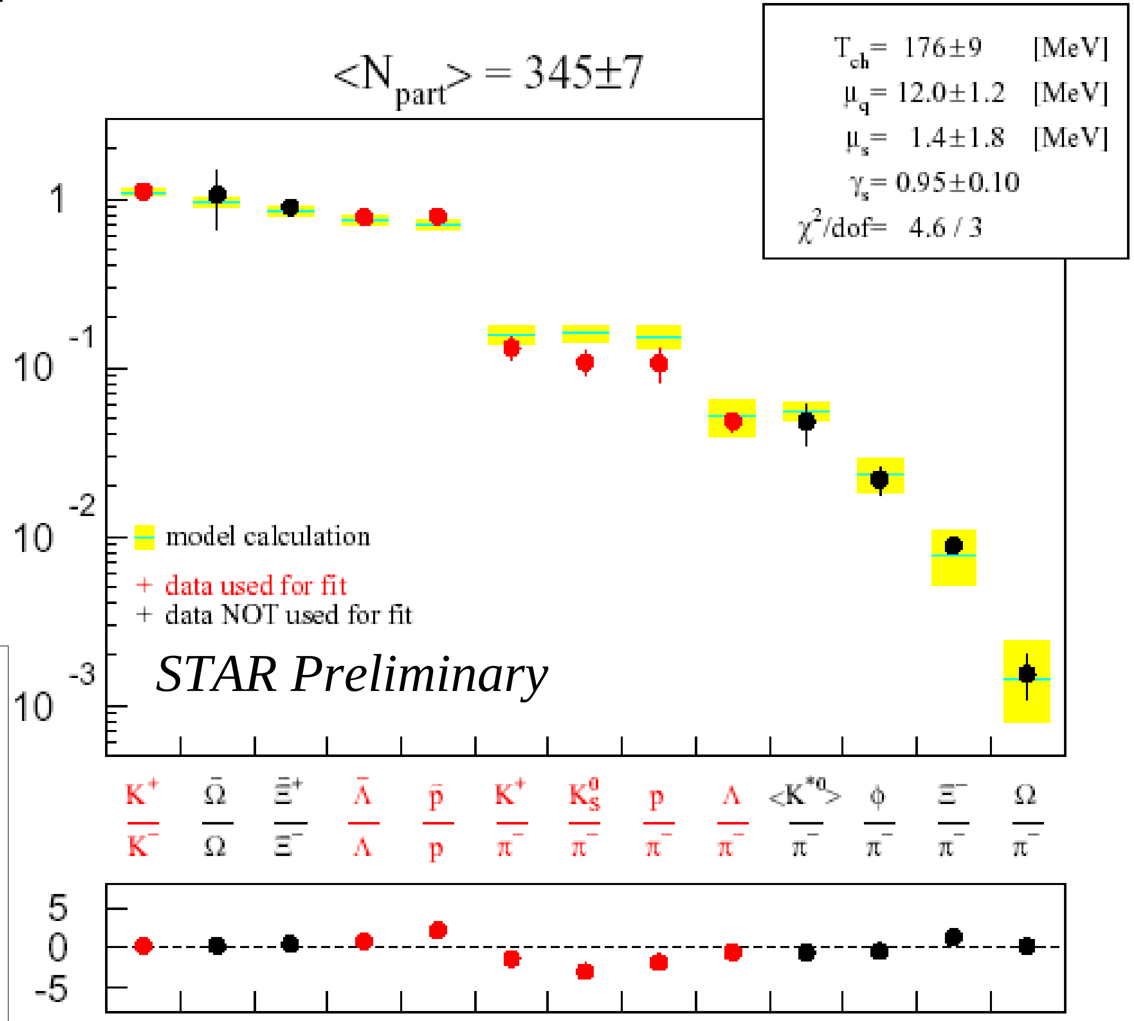
Ratios, experiment vs. a model

Central
130 GeV Au+Au
Preliminary Data

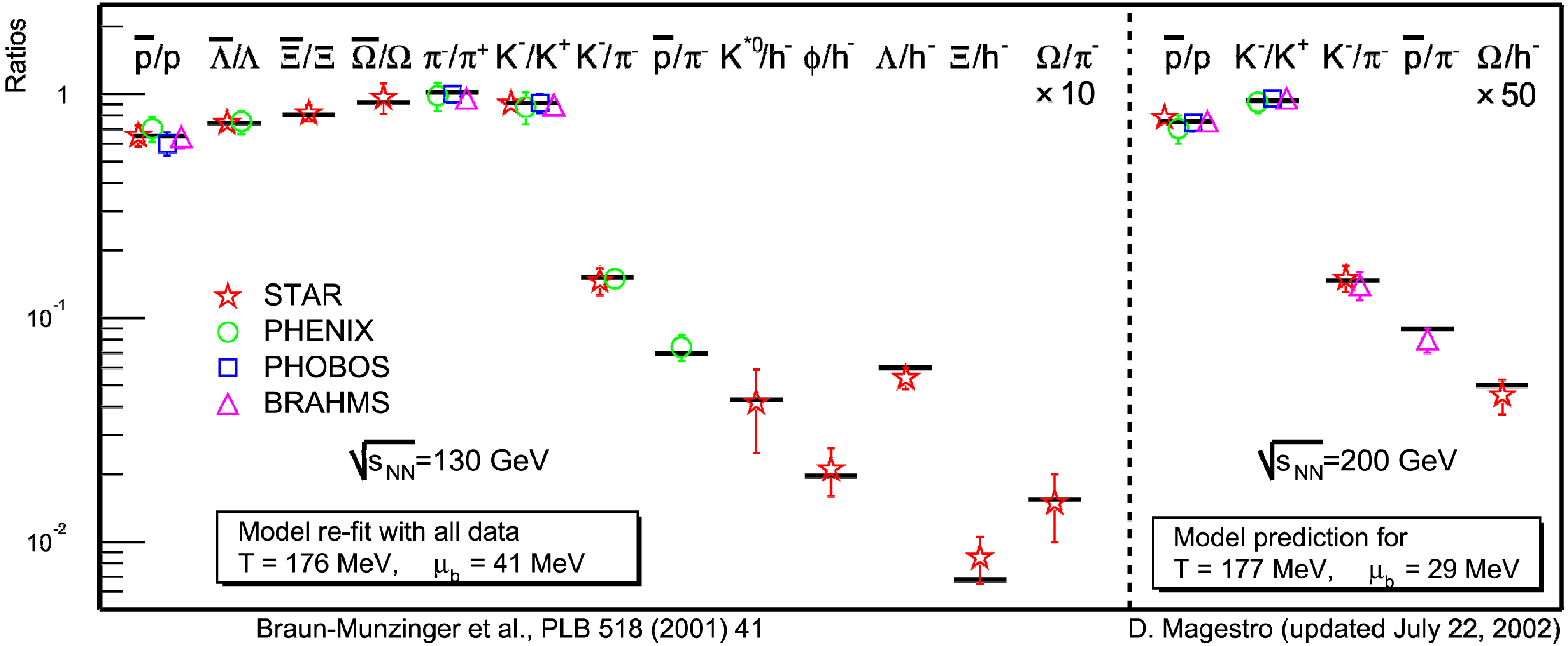
Agreement between model and data is very good!

Thermal fits to mid-rapidity spectra have caveats regarding non-4π measurements (local vs. global equilibrium, boost-invariance).

M. Kaneta and N. Xu,
J. Phys. G**27** (2001) 589



Statistical Model: First Look at AuAu @ 200 GeV



- **All 200 GeV data taken from QM talks:**
- F. Wang (STAR)/G. Van Buren (STAR)/
- T. Chujo (PHENIX)/Ouerdane (BRAHMS)
- J. Lee (BRAHMS)/B. Wosiek (PHOBOS)
- **New 130 GeV data are:**
- C. Suire (STAR)/J. Castillo (STAR)

Predictions:

phenomenologically:

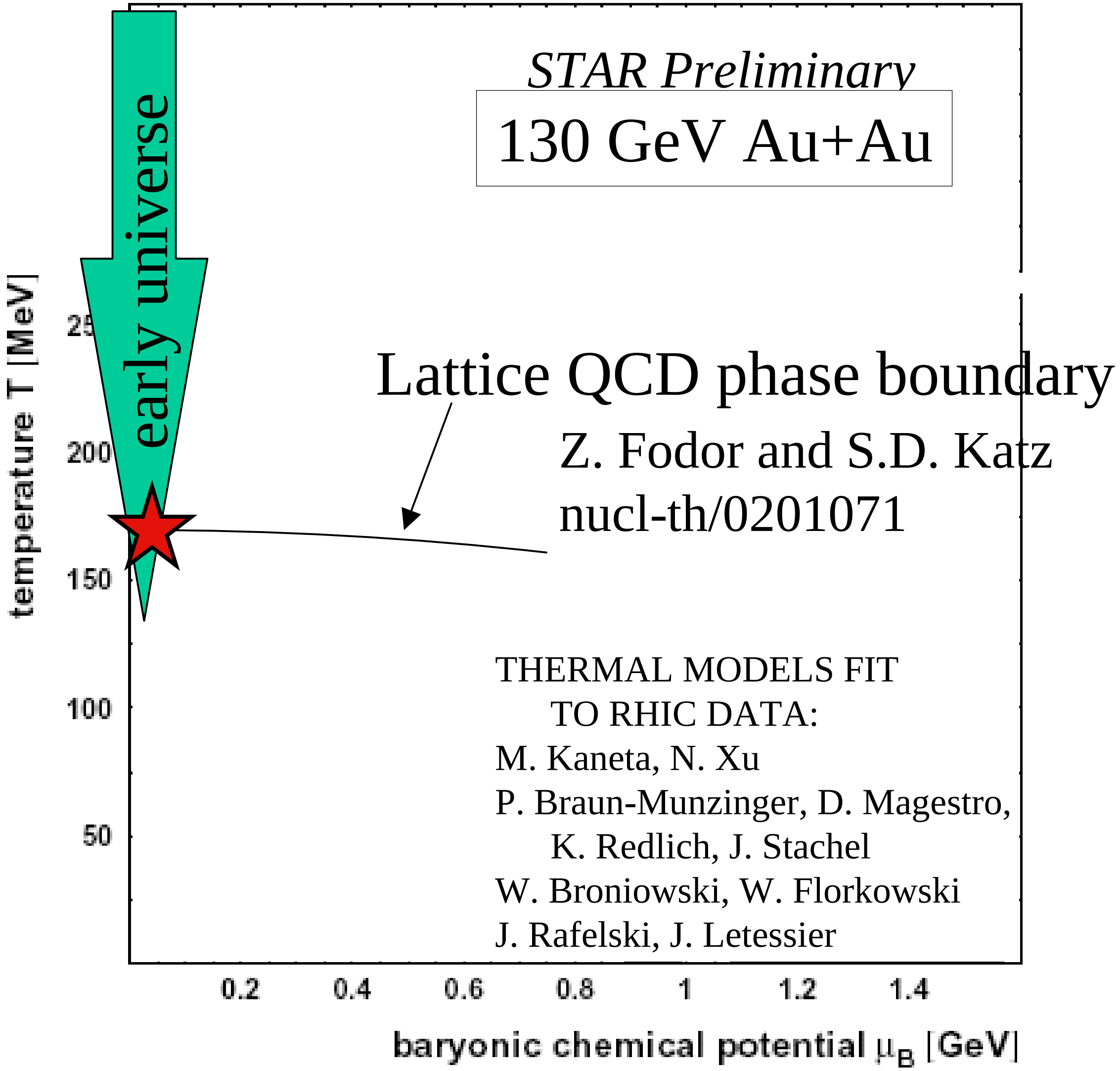
$\mu_B \sim 1.3$ GeV $(1+\sqrt{s}/4.5\text{ GeV})^{-1}$

assume unified freeze-out condition:

$\langle E\rangle/\langle N\rangle \sim 1.1$ GeV $\Rightarrow$ T

Where are we?…Are we there (yet)?

- Chemical, thermal equilibrium description gives high T, low μ_B:
  - Consistent with region of phase boundary from lattice QCD!
  - Similar to early universe!



STAR Preliminary

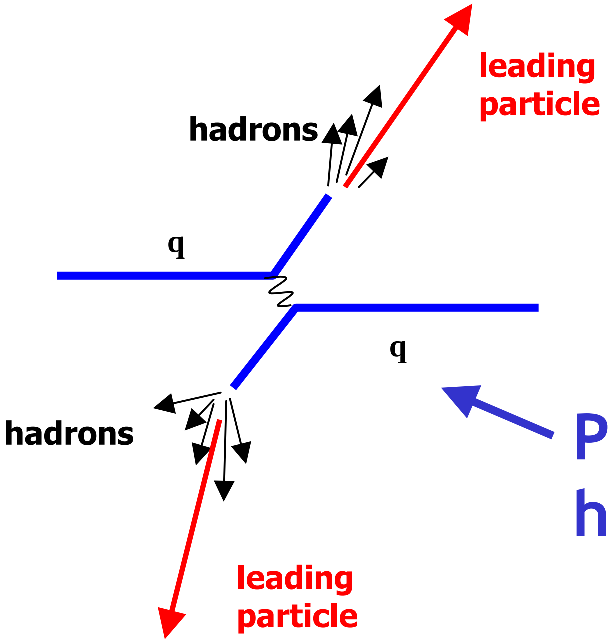
130 GeV Au+Au

Lattice QCD phase boundary

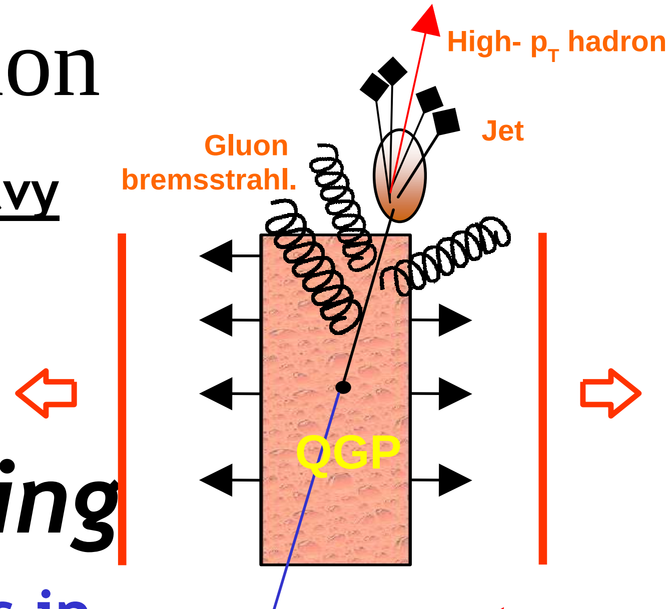
Z. Fodor and S.D. Katz
nucl-th/0201071

THERMAL MODELS FIT
TO RHIC DATA:
M. Kaneta, N. Xu
P. Braun-Munzinger, D. Magestro,
K. Redlich, J. Stachel
W. Broniowski, W. Florkowski
J. Rafelski, J. Letessier

Leading Particle Suppression

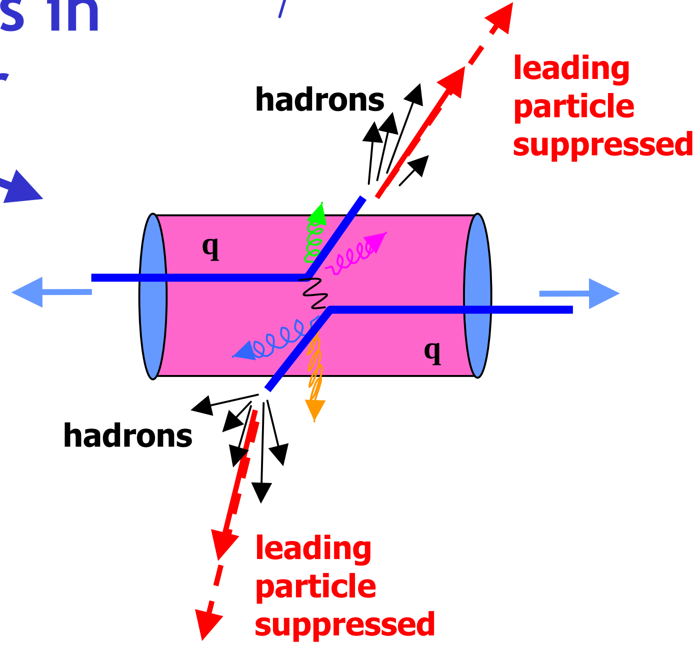


Jets modified in heavy ion collisions?



Jet quenching

Partonic Energy loss in high density matter



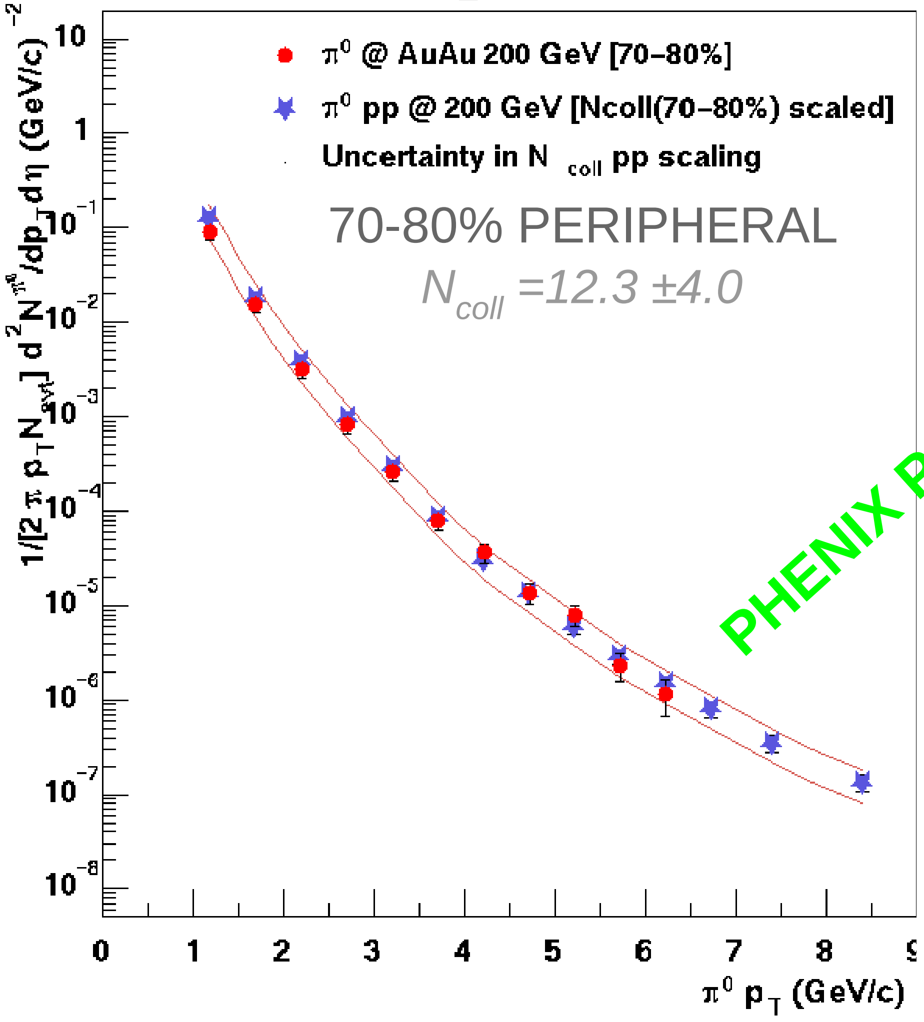
Nuclear Modification Factor:

$$R_{AA}(p_T) = \frac{d^2N^{AA}/dp_T d\eta}{T_{AA} d^2\sigma^{NN}/dp_T d\eta}$$

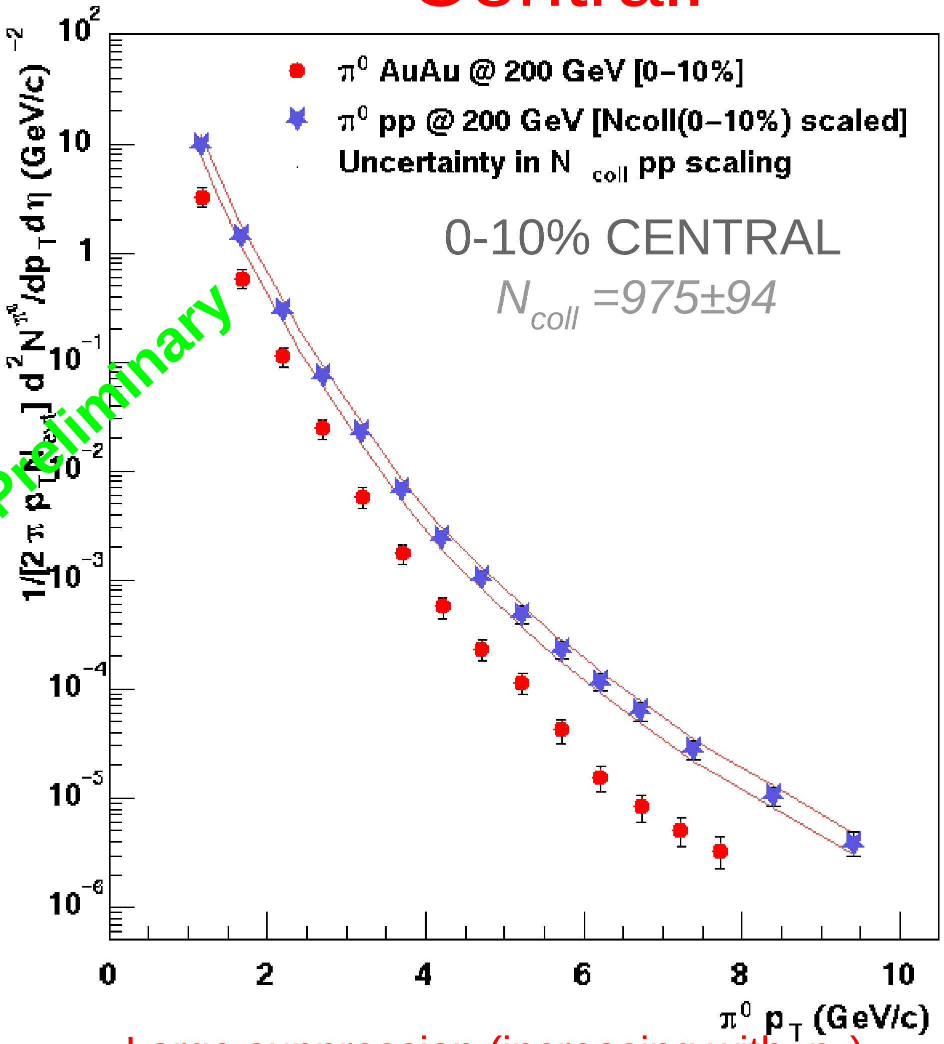
Glauber Model

The results : pp vs AuAu (peripheral & central)

- Peripheral:



- Central:

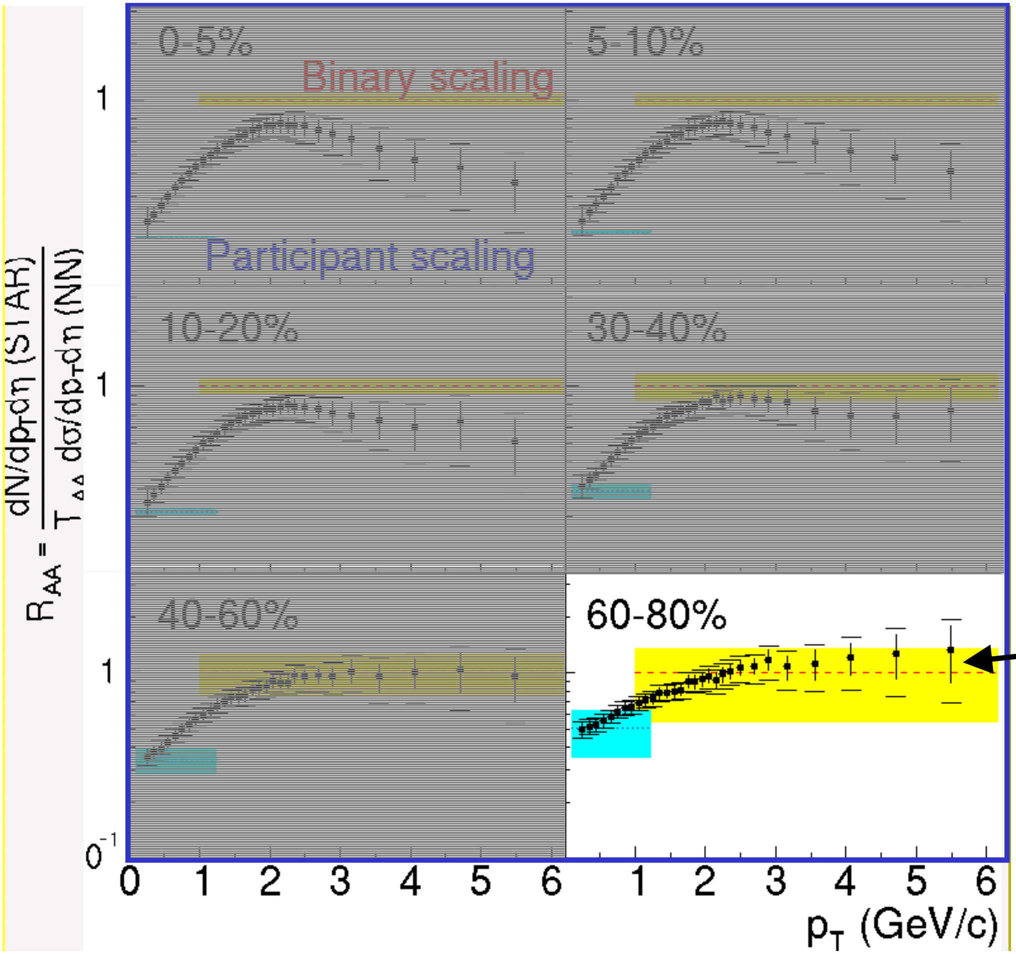


PHENIX

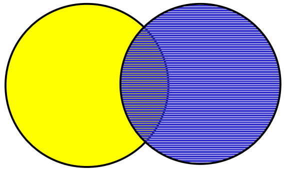
- Large suppression (increasing with p_T) above p_T~1 GeV/c compared to scaled pp.

R_{AA} Comparison to p_T = 6 GeV/c

130 GeV nucl-ex/0206011



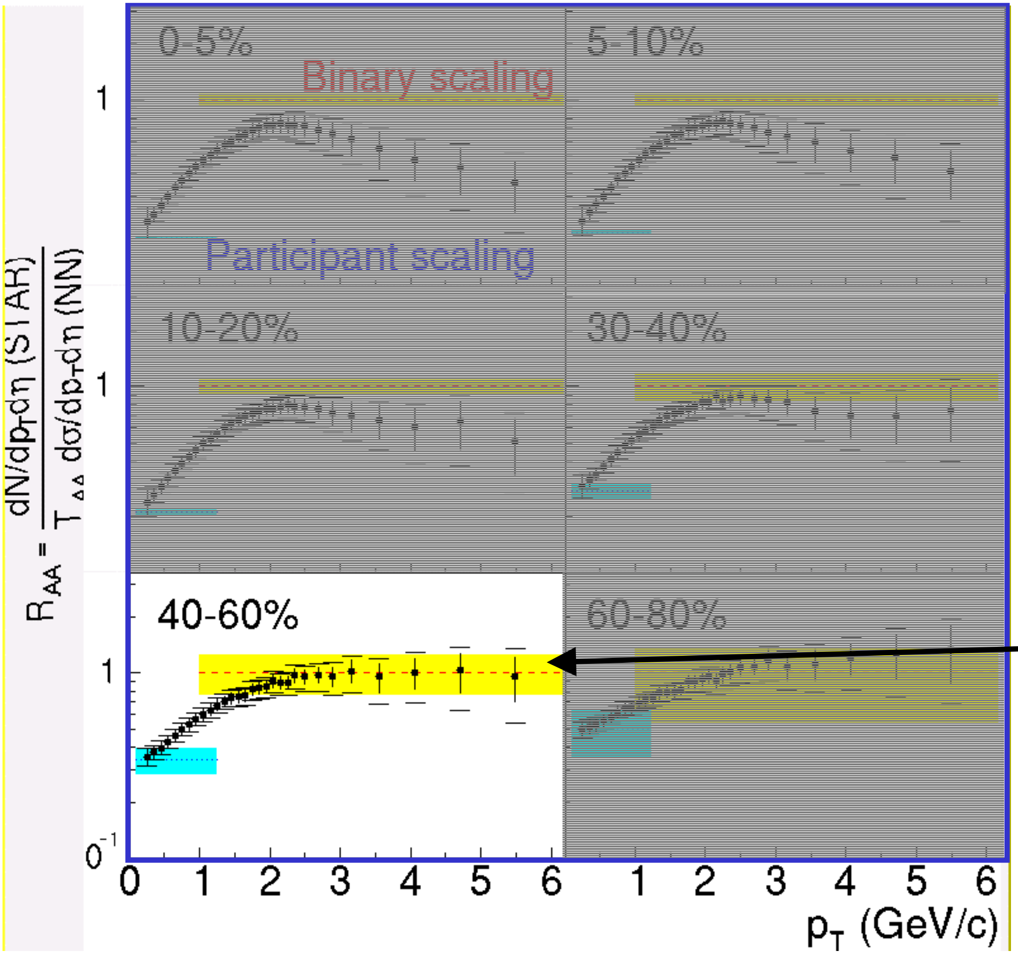
Centrality: 60-80%



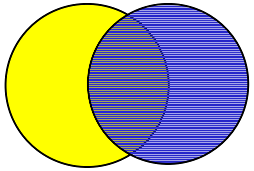
Peripheral R_{AA} scales as N_{binary} above p_T = 2 GeV

R_{AA} Comparison to p_T = 6 GeV/c

130 GeV nucl-ex/0206011



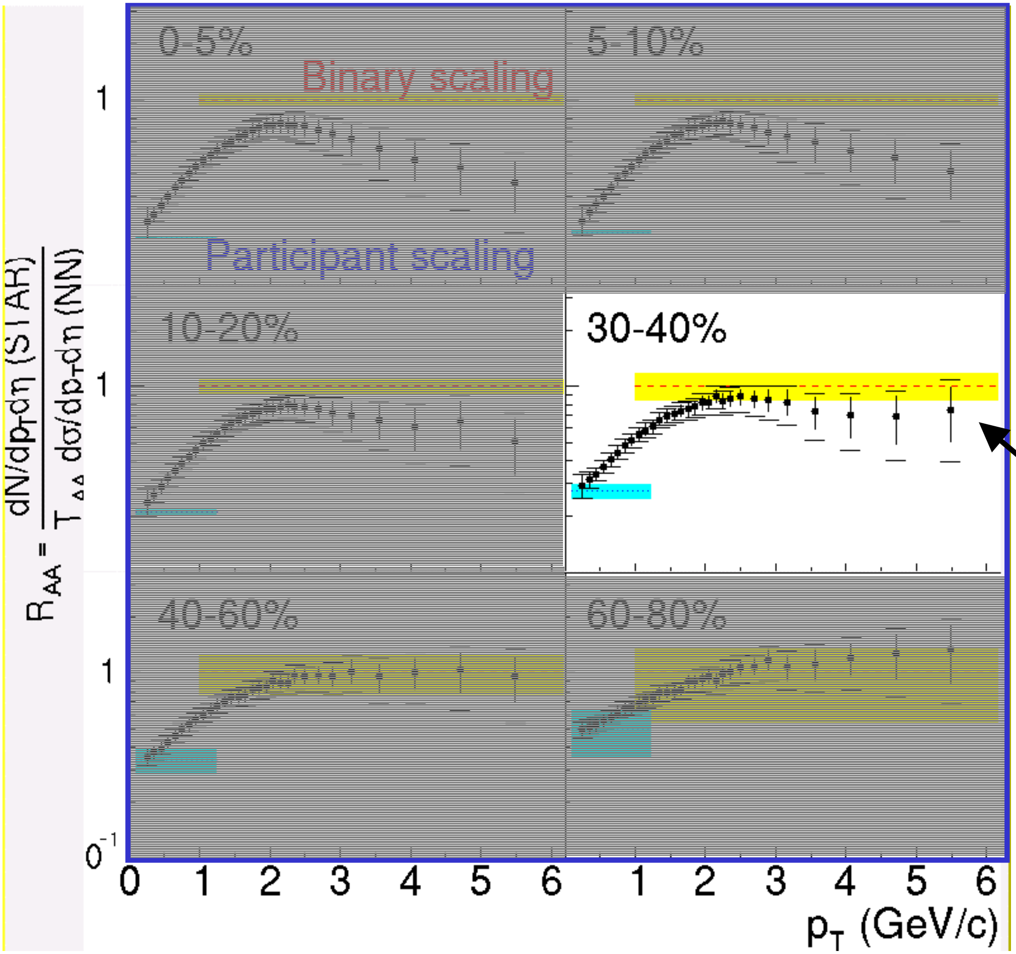
Centrality: 40-60%



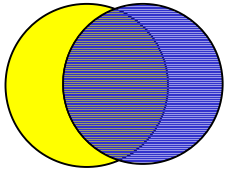
Peripheral R_{AA} scales as N_{binary} above p_T = 2 GeV

R_{AA} Comparison to p_T = 6 GeV/c

130 GeV nucl-ex/0206011



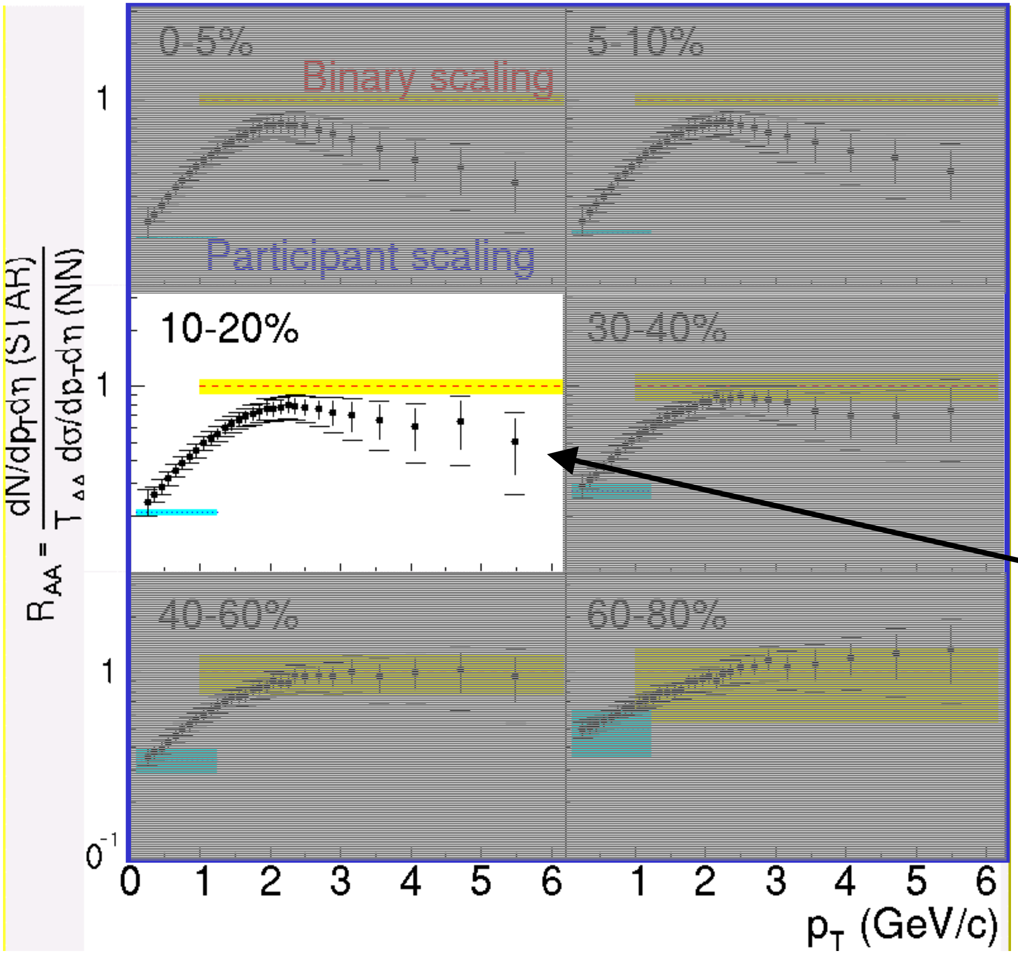
Centrality: 30-40%



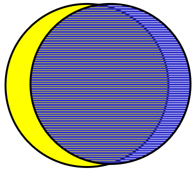
As centrality decreases, suppression sets in above p_T = 2 GeV

R_{AA} Comparison to p_T = 6 GeV/c

130 GeV nucl-ex/0206011



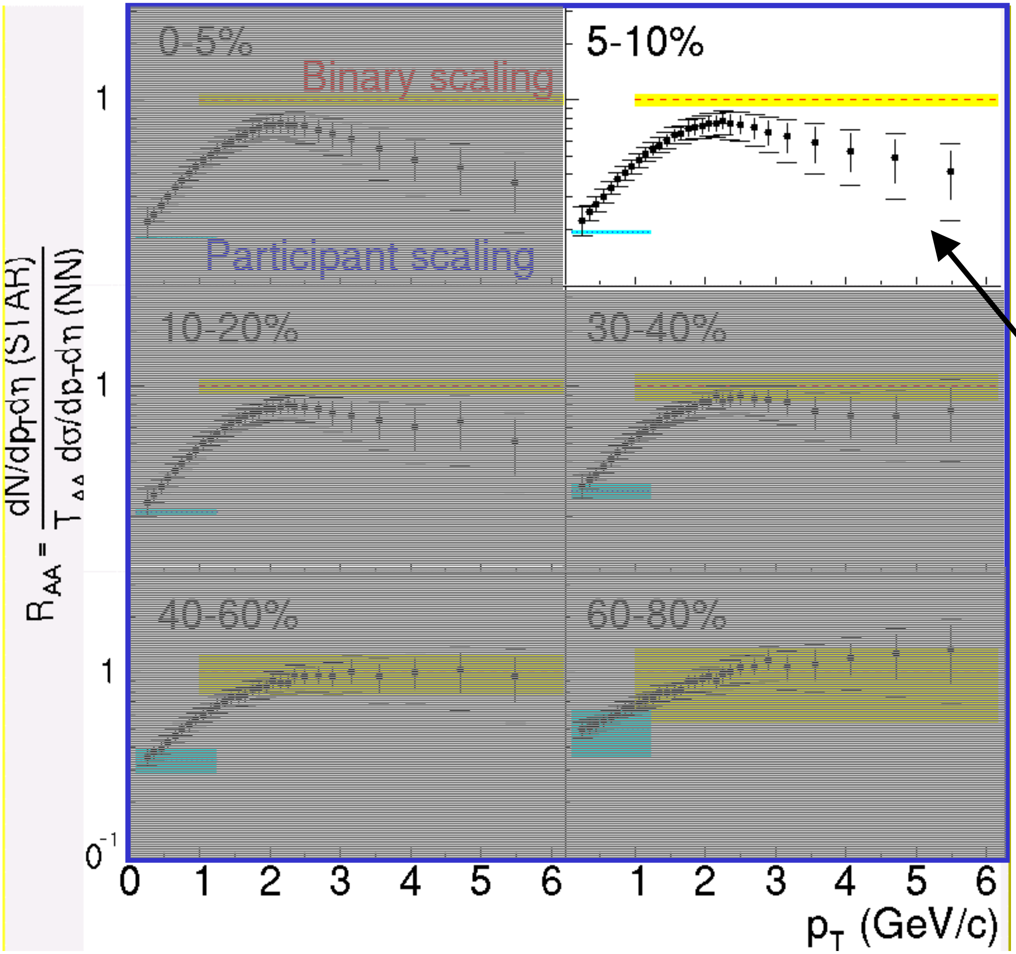
Centrality: 10-20%



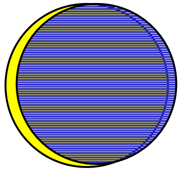
As centrality decreases, suppression sets in above p_T = 2 GeV

R_{AA} Comparison to p_T = 6 GeV/c

130 GeV nucl-ex/0206011



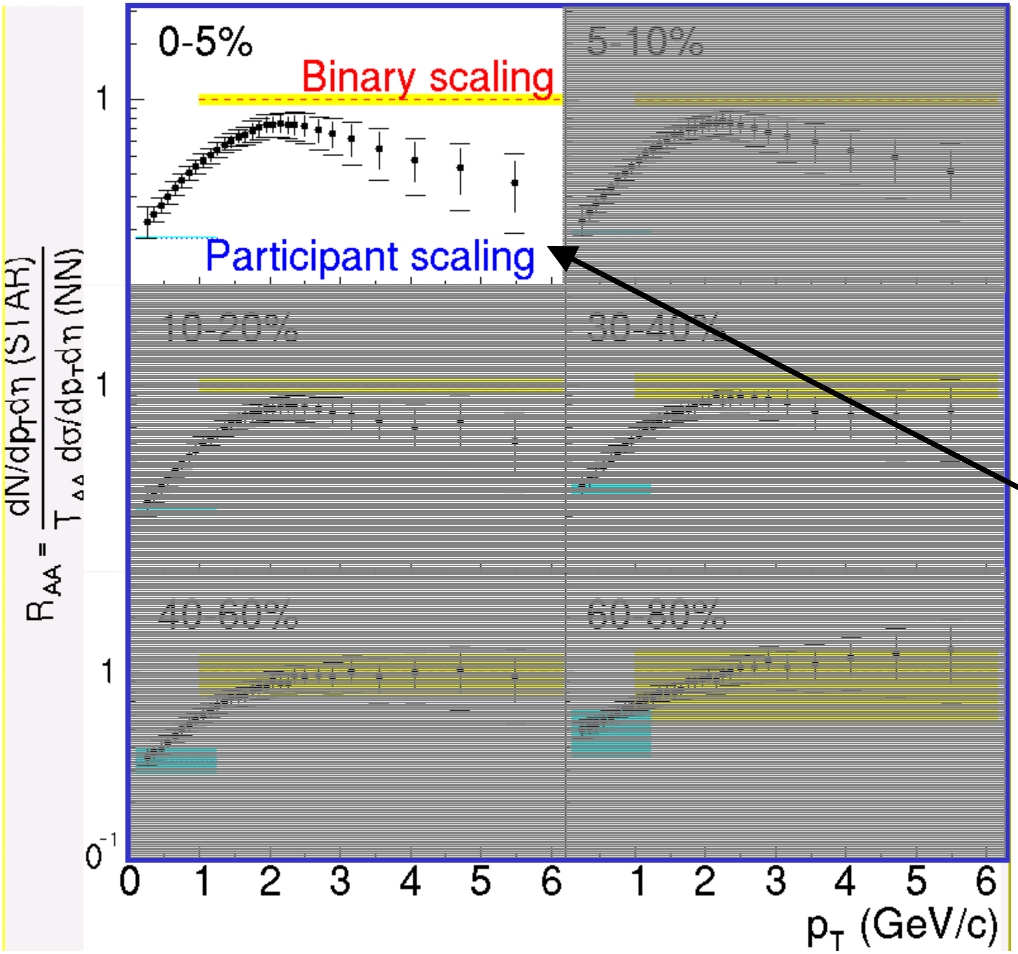
Centrality: 5-10%



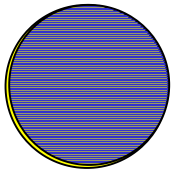
In the most central collisions, suppression is clear

R_{AA} Comparison to $p_T = 6$ GeV/c

130 GeV nucl-ex/0206011

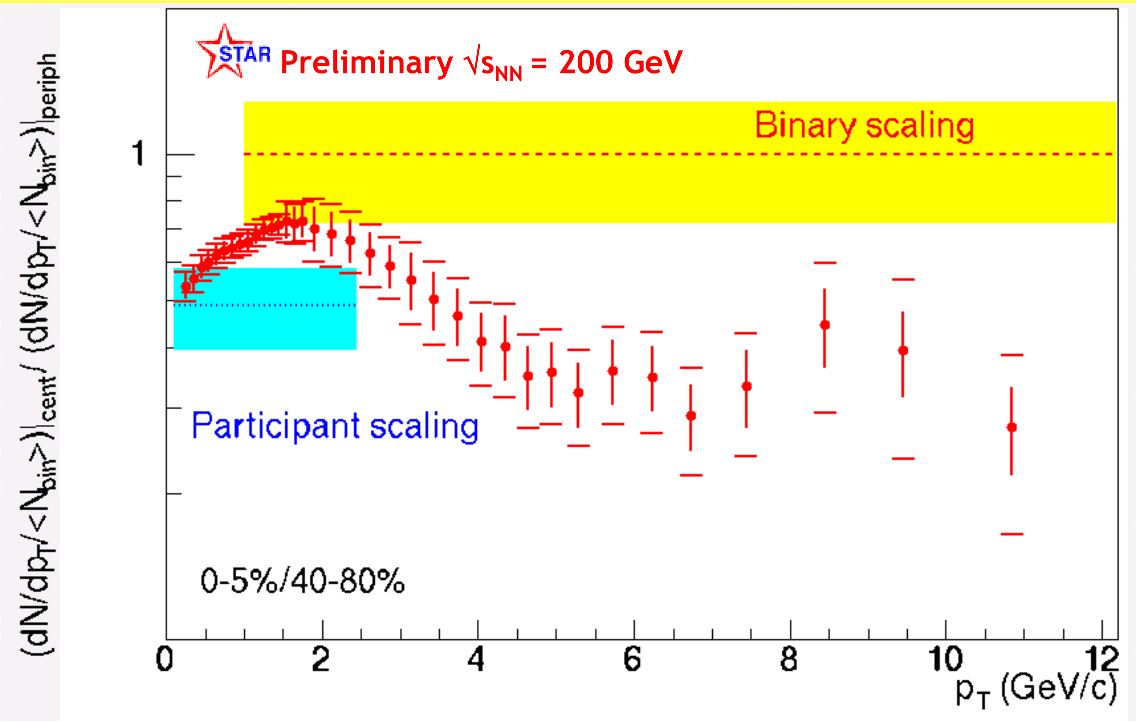


Centrality: 0-5%



In the most central collisions, suppression is strongest

Summary & Outlook

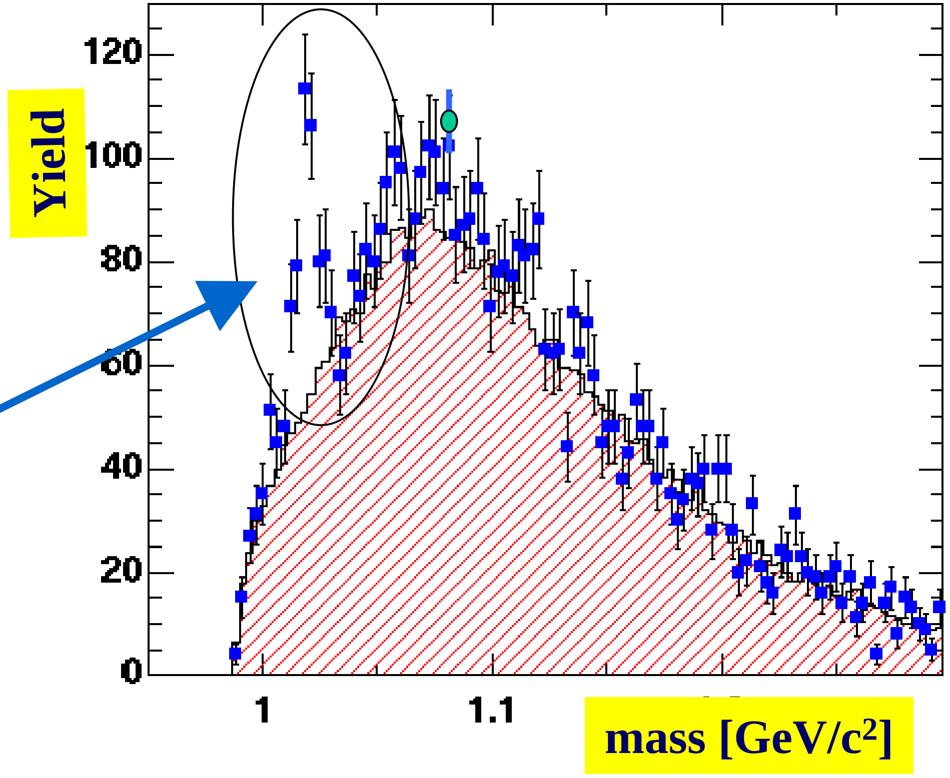


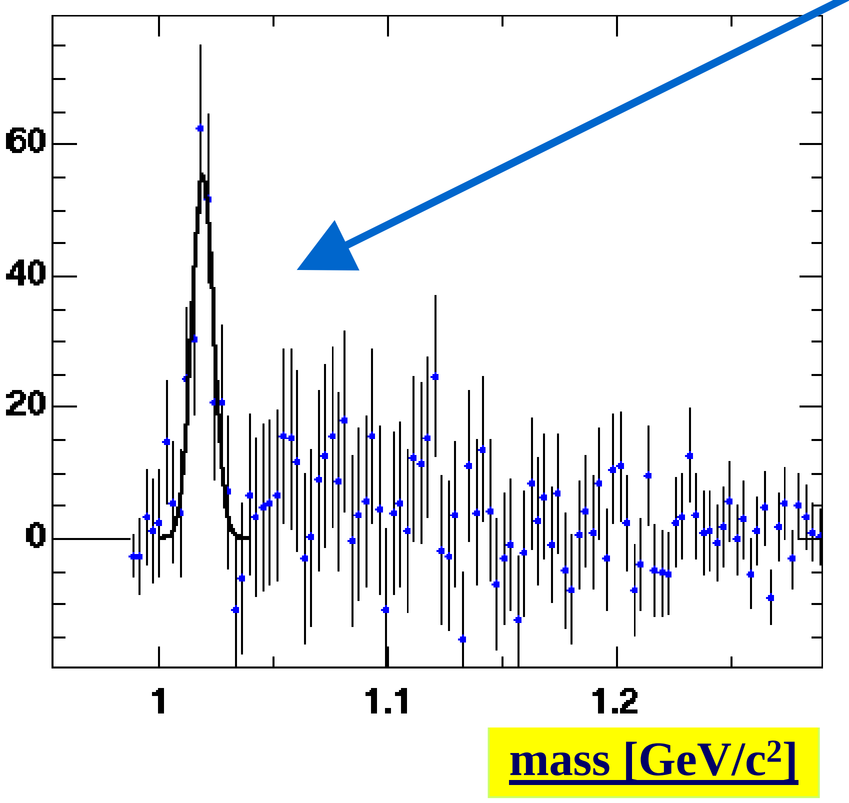
- High p_T hadron suppression saturates above p_T = 6 GeV/c

$\Phi \rightarrow K^+K^-$ Invariant Mass

Au + Au $\sqrt{s_{NN}}$ = 200 GeV

Centrality 40 –80 %



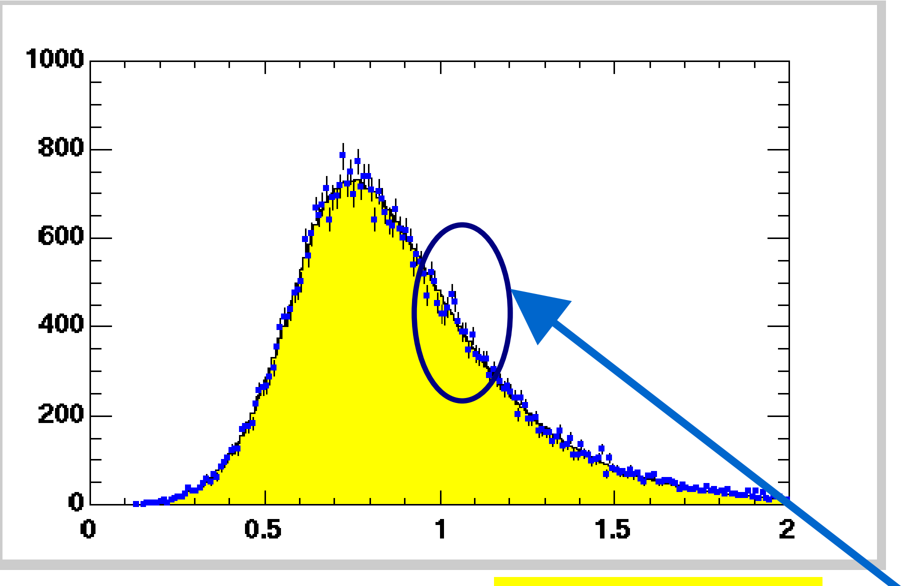


- S = 218 ± 24
- S/B = 1/2

Preliminary

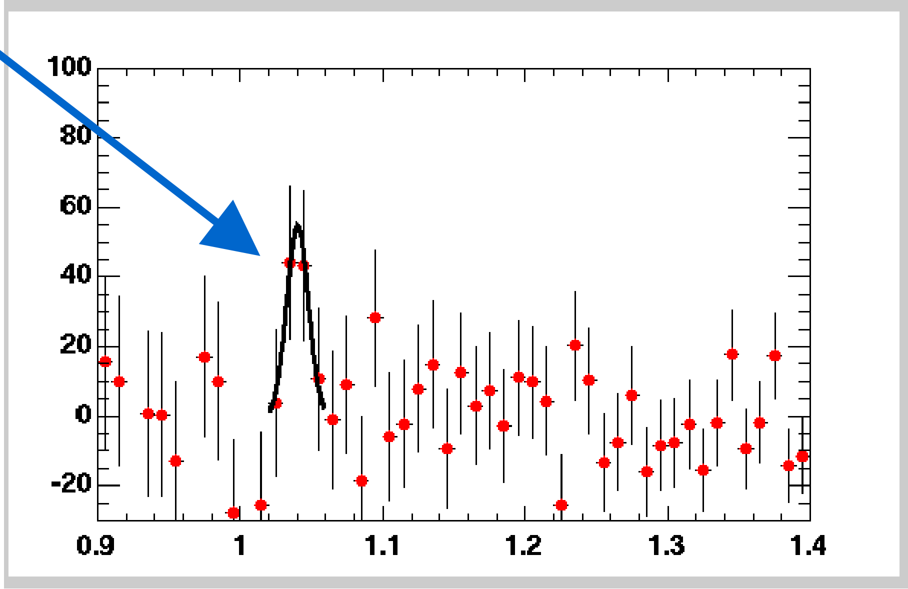
PHENIX

$\Phi \rightarrow e^+e^-$ Mass Spectrum



Au + Au $\sqrt{s_{NN}}$ = 200 GeV

Minimum bias



$$S = 101 \pm 47\,(\mathrm{stat})^{+56}_{-20}\,(\mathrm{syst})$$

S/B = 1/20

Preliminary

PHENIX

Minimum bias dN/dy

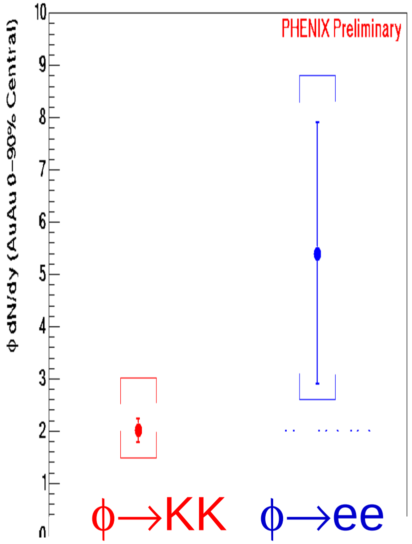
- **$\Phi \rightarrow K^+K^-$ (TOF)**

$$\frac{dN}{dy} = \underset{\text{stat}}{2.01 \pm 0.22}\,{}^{+1.01}_{-0.52}\ \text{syst}$$

- **$\Phi \rightarrow e^+e^-$**

$$\frac{dN}{dy} = \underset{\text{stat}}{5.4 \pm 2.5}\,{}^{+3.4}_{-2.8}\ \text{syst}$$

- **only** probe at RHIC for chiral symmetry restoration (until PHENIX upgrade)
- STAR & PHENIX can (in principle) measure both channels
- requires high statistics, high precision measurement

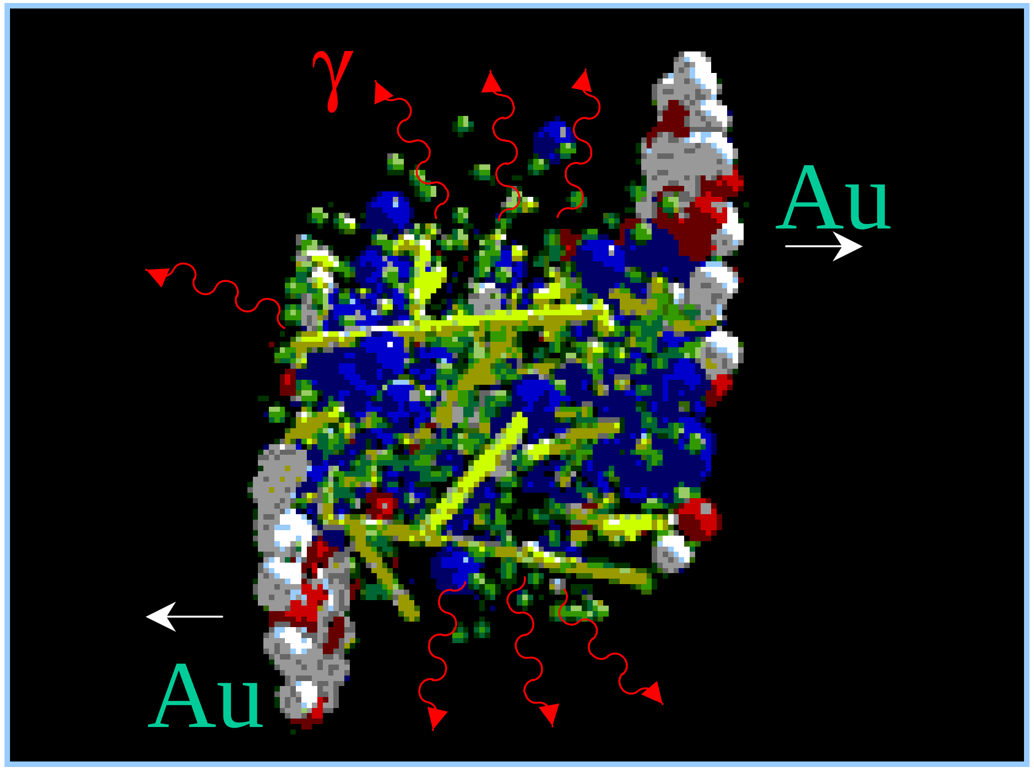


Data are consistent with free vacuum PDG branching fraction values within 1σ statistical errors.

Preliminary

PHENIX

Why are photons interesting?



- To Study Hot Dense Matter

  Long mean free path in dense matter – much larger than the transverse size of matter created in Heavy Ion Collisions

- Probe the Partonic Stages of Heavy Ion Collisions

  Partonic Interactions - Compton ($qg \rightarrow q\gamma$) and Annihilation ($q\bar{q} \rightarrow g\gamma$, $q\bar{q} \rightarrow \gamma\gamma$)

  Electromagnetic Bremsstrahlung ($q \rightarrow q\gamma$)

How do we measure photons?

By reconstructing photon conversions

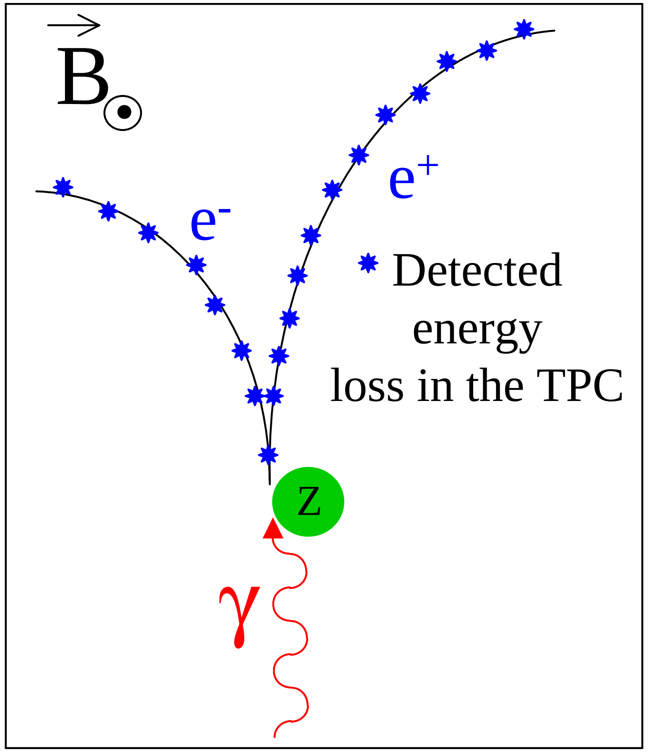
- $\gamma Z \rightarrow e^+ e^- Z$

TPC was used as a Pair Spectrometer

- low efficiency (1%)
- but large acceptance
- excellent energy resolution

$\Delta p_t/p_t \sim 2\%$ at p_t=0.5GeV/c

$\Delta p_t/p_t \sim 4\%$ at p_t=3.0GeV/c



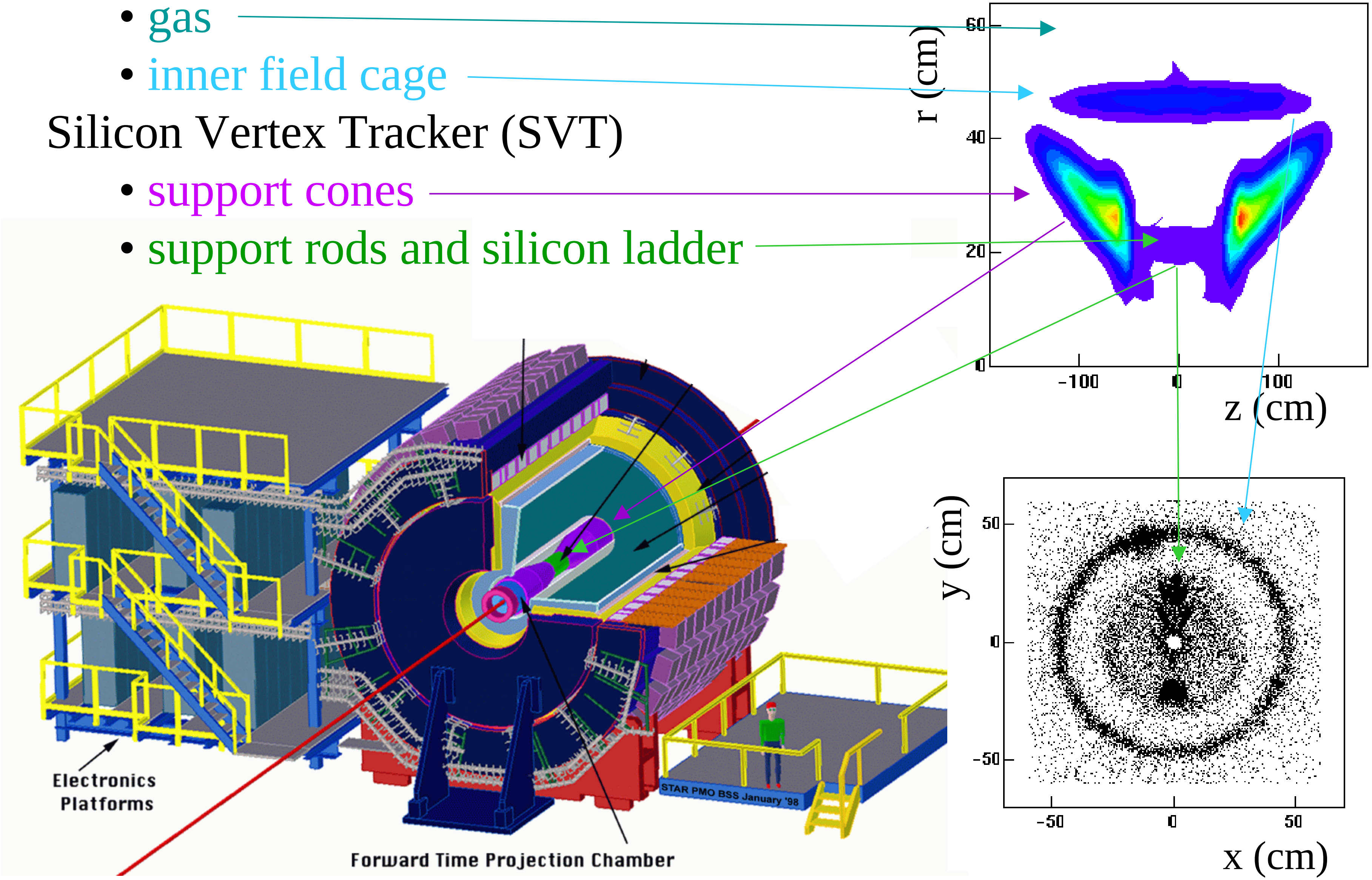
Converters in STAR

TPC

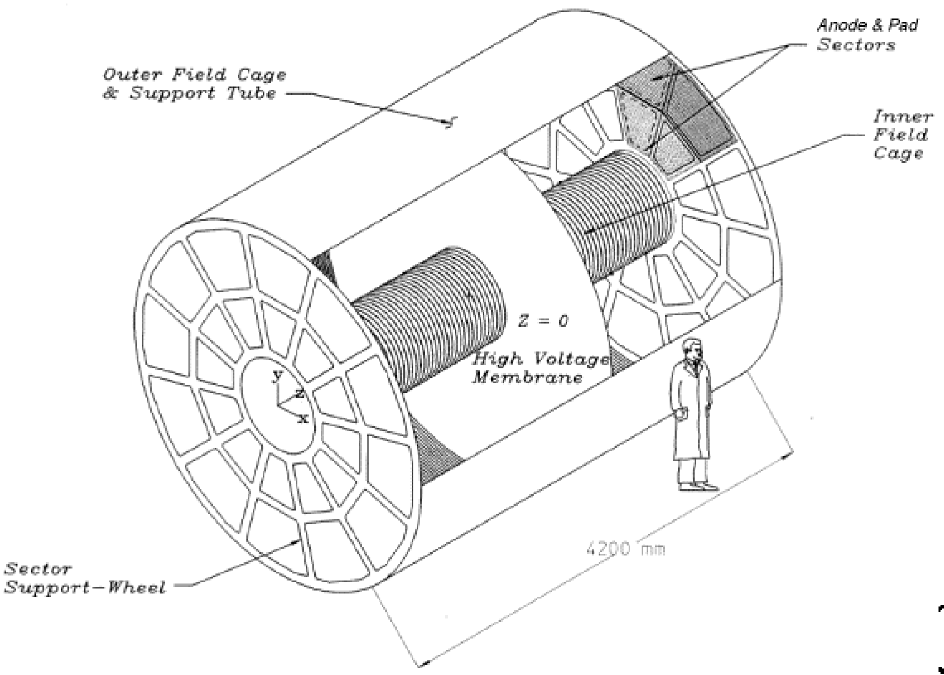
- gas
- inner field cage

Silicon Vertex Tracker (SVT)

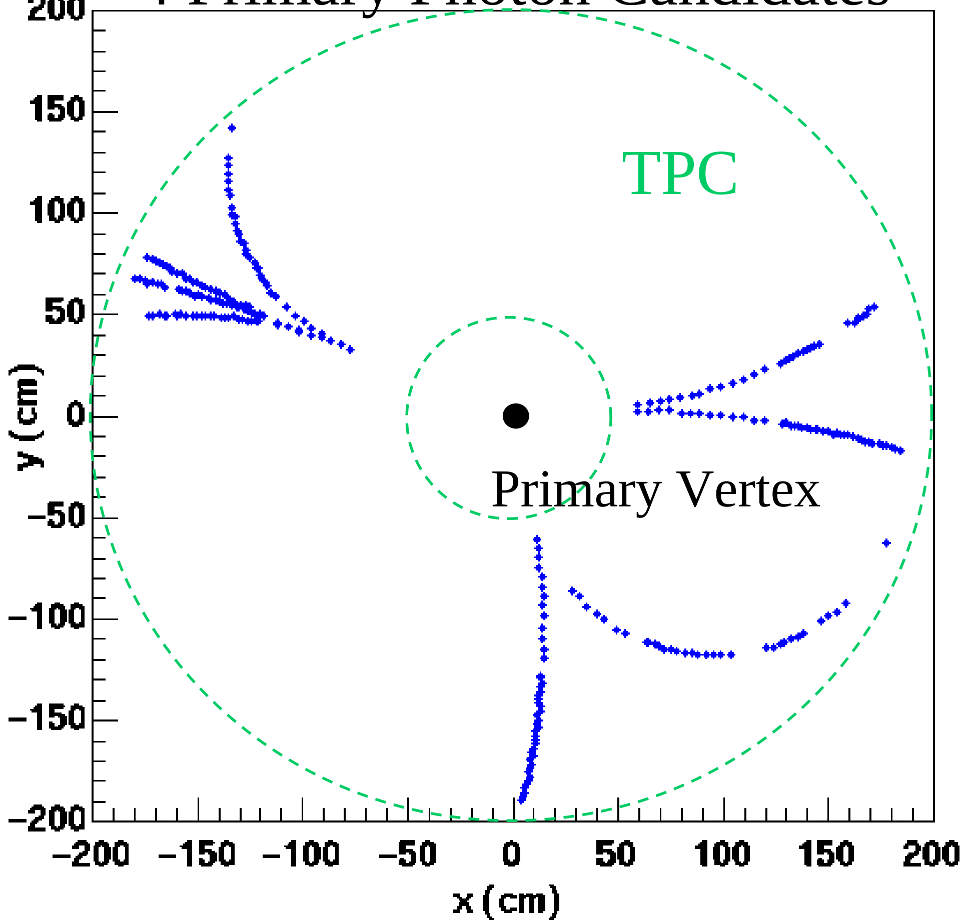
- support cones
- support rods and silicon ladder

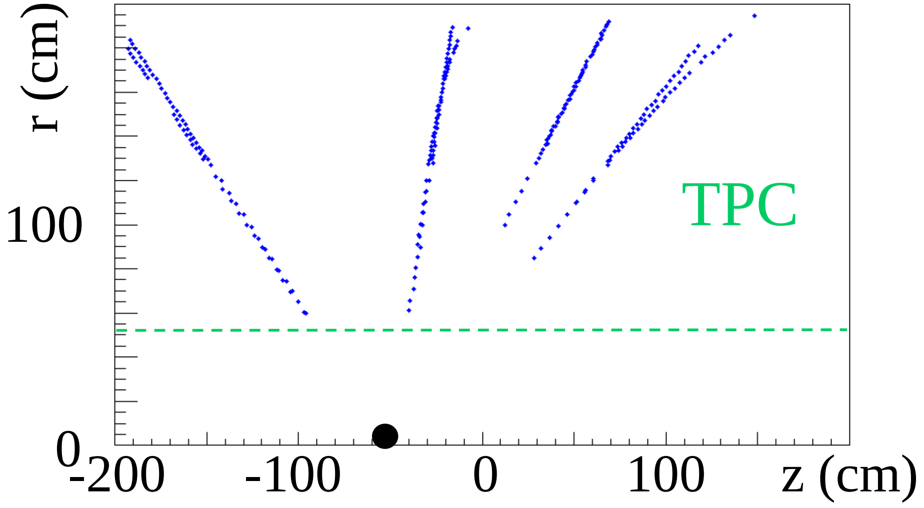


A Typical STAR Event



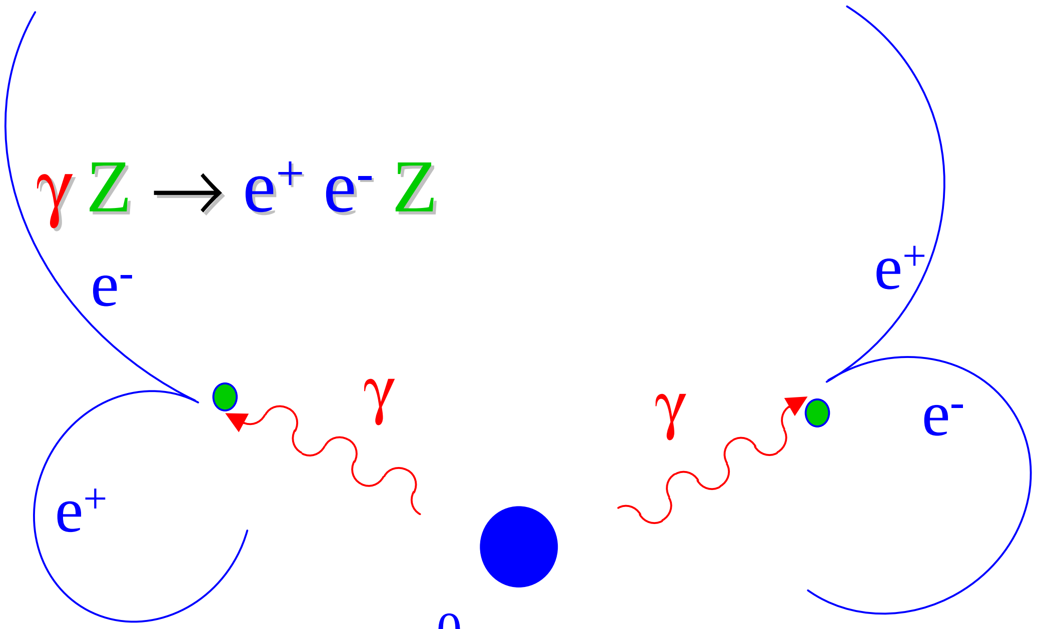
4 Primary Photon Candidates





Note: Most tracks are not shown

Two Photon Decays



$\gamma\, Z \rightarrow e^+ e^- Z$

$\pi^0 \rightarrow \gamma\,\gamma$

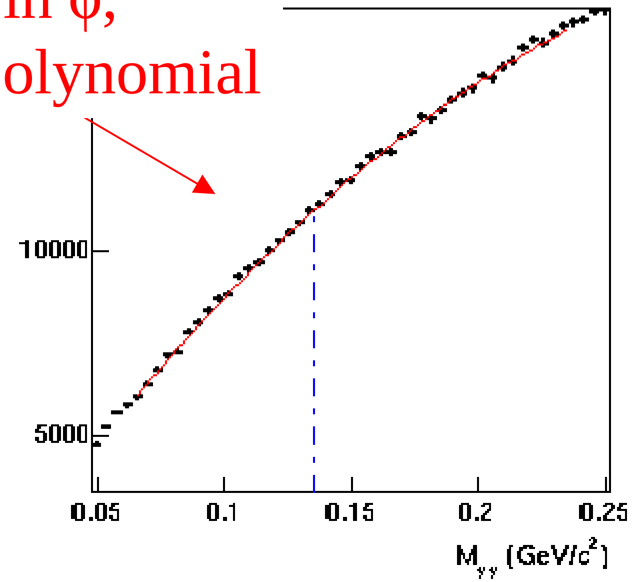
$\eta \rightarrow \gamma\,\gamma$

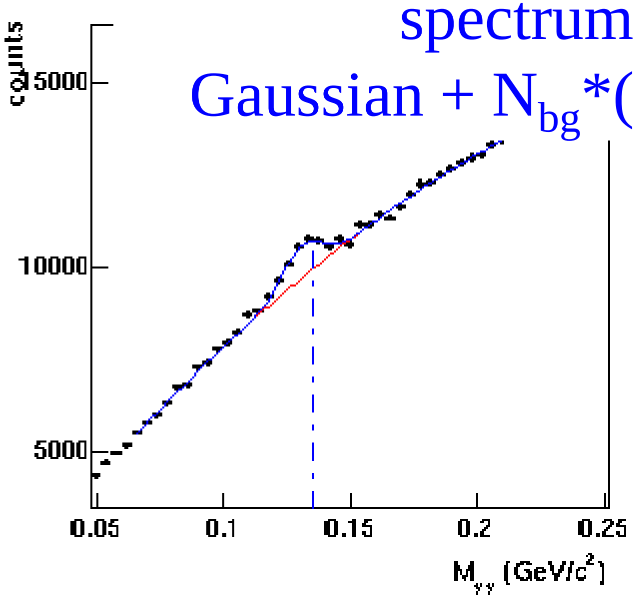
$\pi^0 \rightarrow \gamma\,\gamma$	Branching Ratio	98.80 %
$\gamma\, Z \rightarrow e^+ e^- Z$	Conversion Probability	~ 1%
e^+ and e^-	Tracking Efficiency	60 - 90%
Overall π^0	Reconstruction probability	~ 10^{-4}

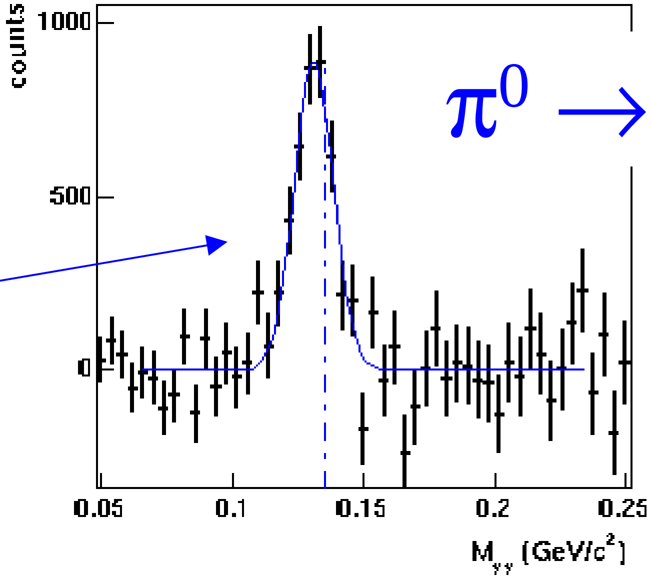
Extracting $\pi^0 \rightarrow \gamma\,\gamma$ Yields

One photon rotated
by π in ϕ,
2^{nd} order polynomial

Two photon invariant mass
spectrum,
Gaussian + N_{bg}*(2^{nd} poly)





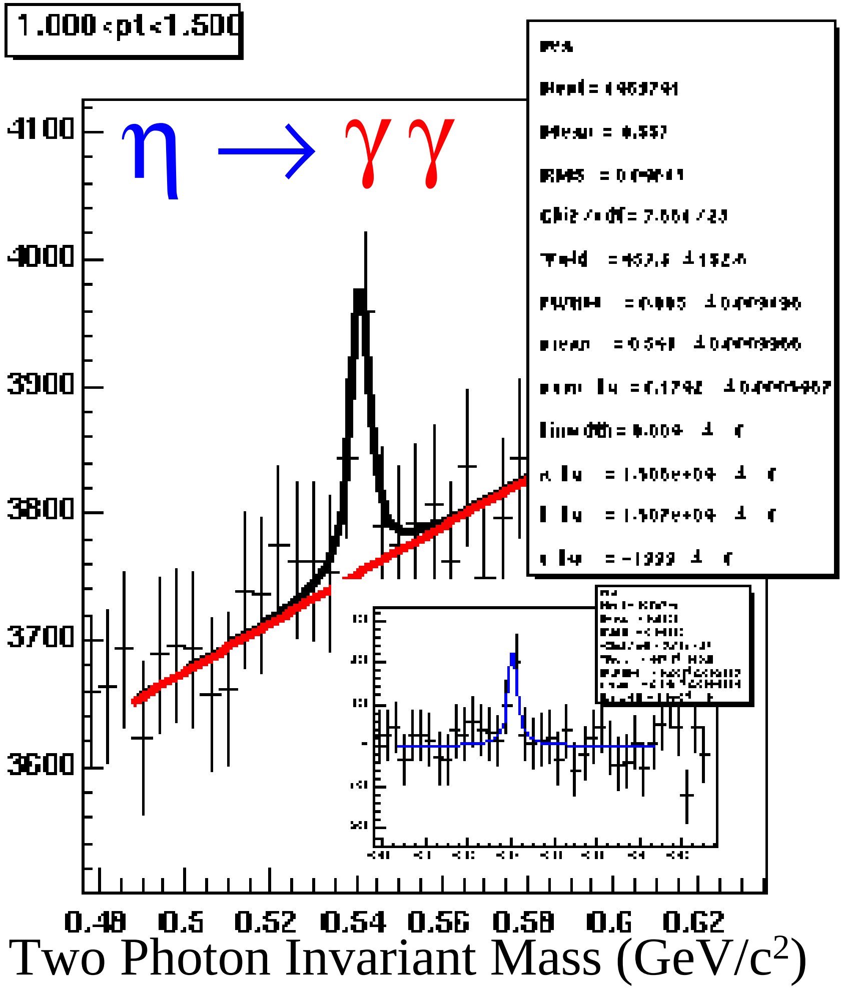


$\pi^0 \rightarrow \gamma\,\gamma$

After background subtraction,
Gaussian (σ~10 MeV/c^2)

Outlook

- Measure the η Cross Section
  - η→γ γ was observed! (2000)
- With photon, π^0 and η measurements
  - extract a cross section for direct photon production at $\sqrt{s_{NN}} = 200$ GeV
  -



Conclusions

We are excited about the first results.

We are working on systematic errors.