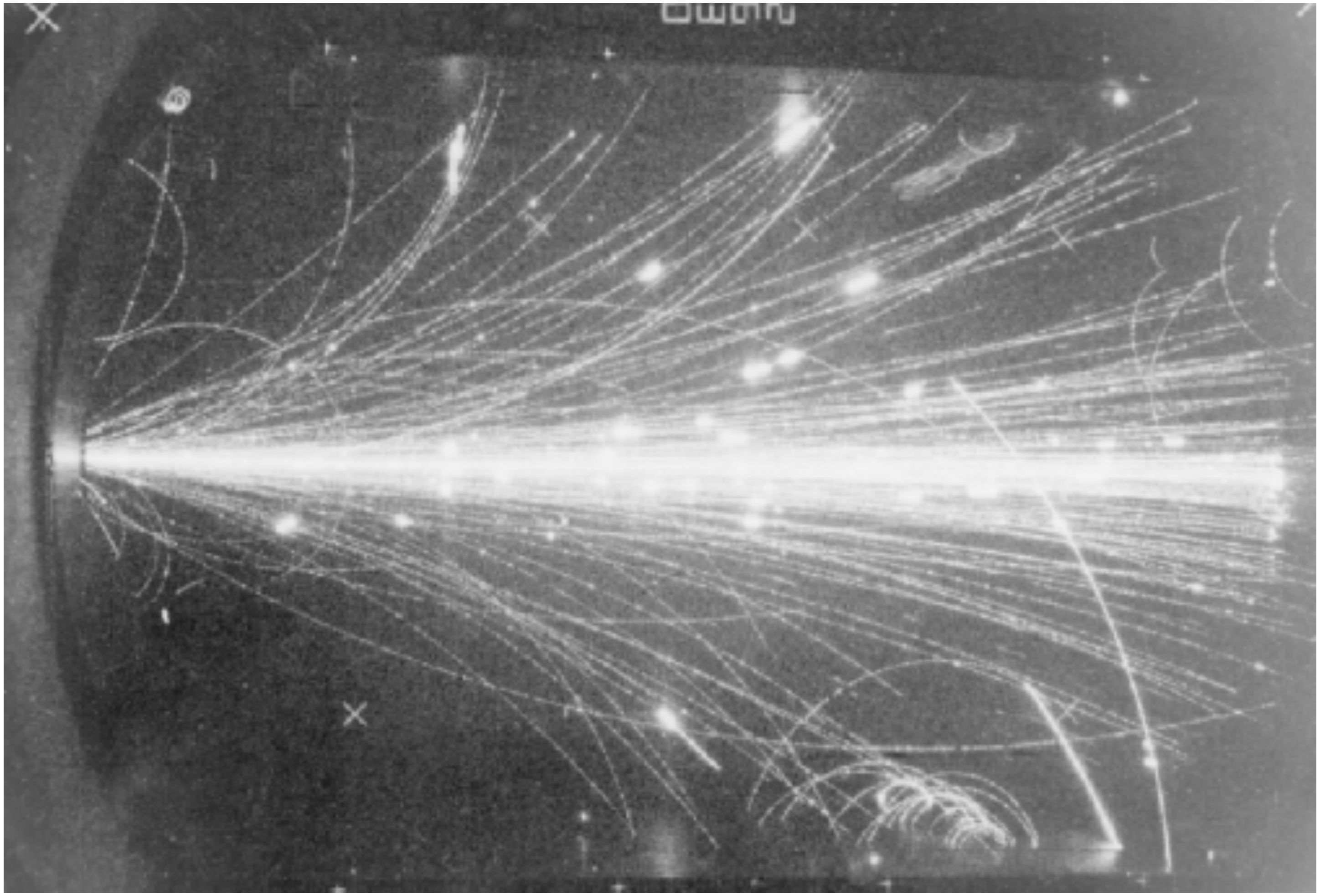
The Future

Gunther Roland
MIT

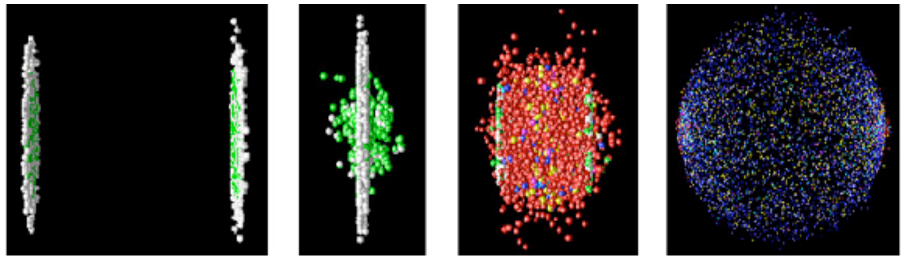
Heavy Ion Collisions in 1989



NA35 Streamer chamber picture of S+Ag collision

The Future is bright…

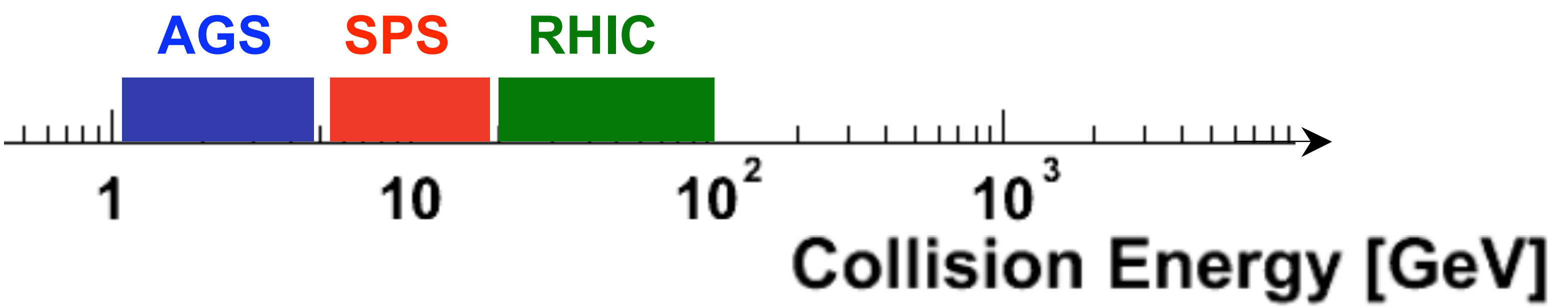
The Present



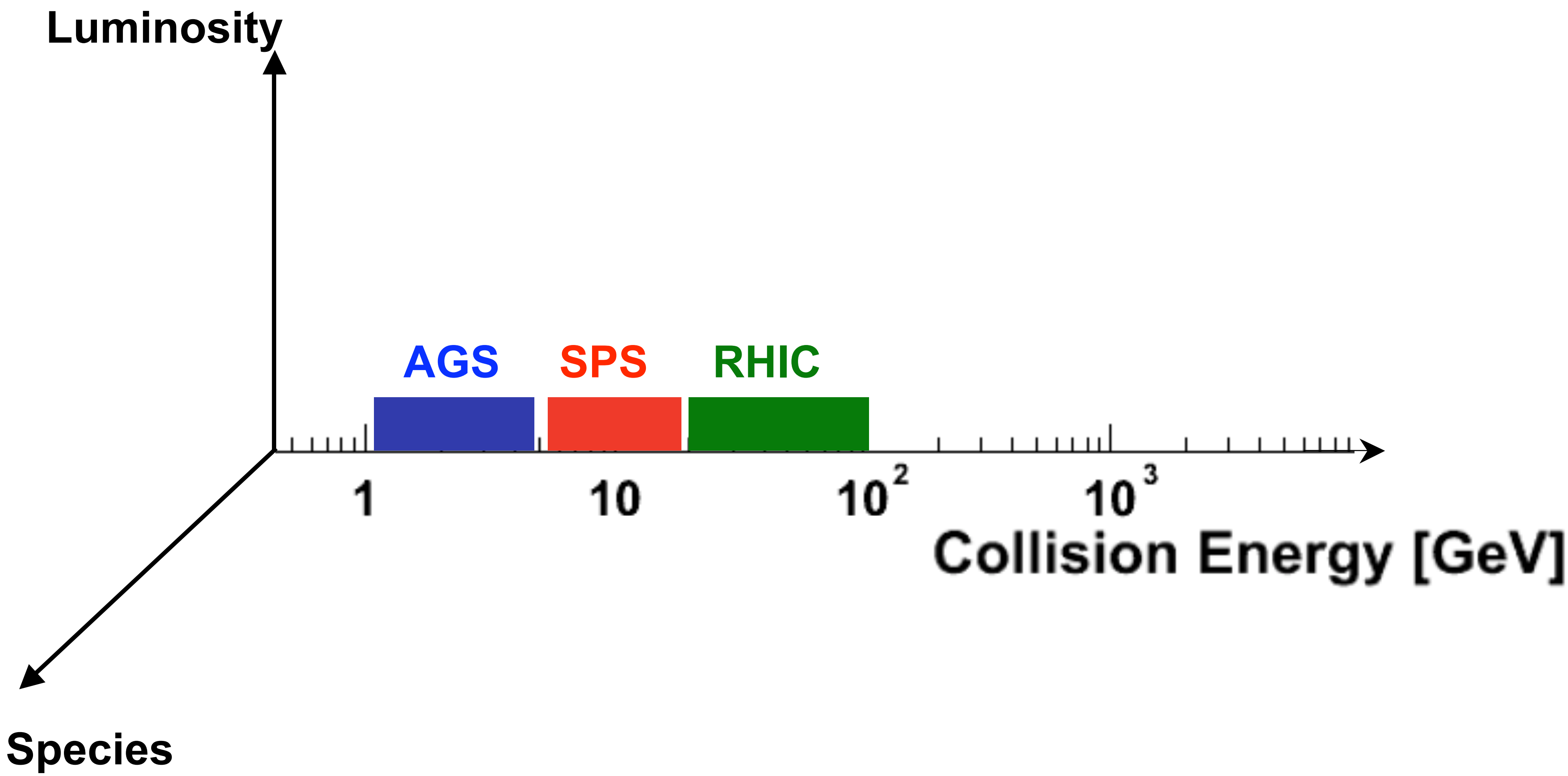
- What we know
  - Dense, ‘coherent’ initial state
  - Early thermalization
  - Highly interactive ‘liquid’ medium
  - Opaque to fast partons
  - Simple, but subtle ‘scaling rules’:
    - Quark number scaling of v_2, +spectra
    - Statistical particle ratios
    - Energy independence of $v_2(p_T)$
    - $\langle N_{part} \rangle$ scaling of multiplicity
    - Limiting fragmentation
    - Universality of $\langle N_{ch} \rangle$

- What we want to learn
  - How is thermalization achieved?
  - What is the initial temperature?
  - What is the nature of the medium?
  - What is the location and nature of the phase transition?
  - Origin of scaling rules?

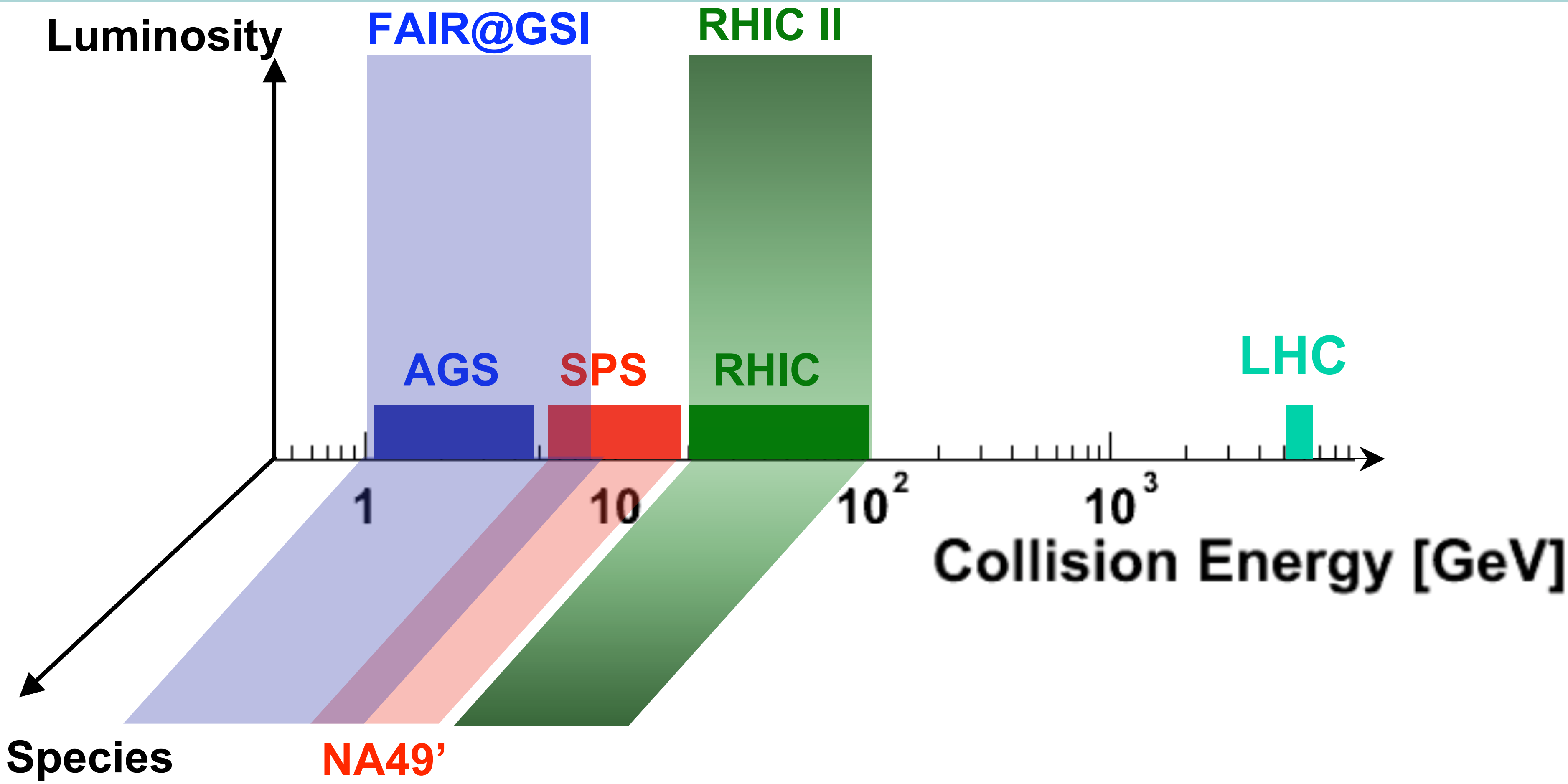
Where we've been



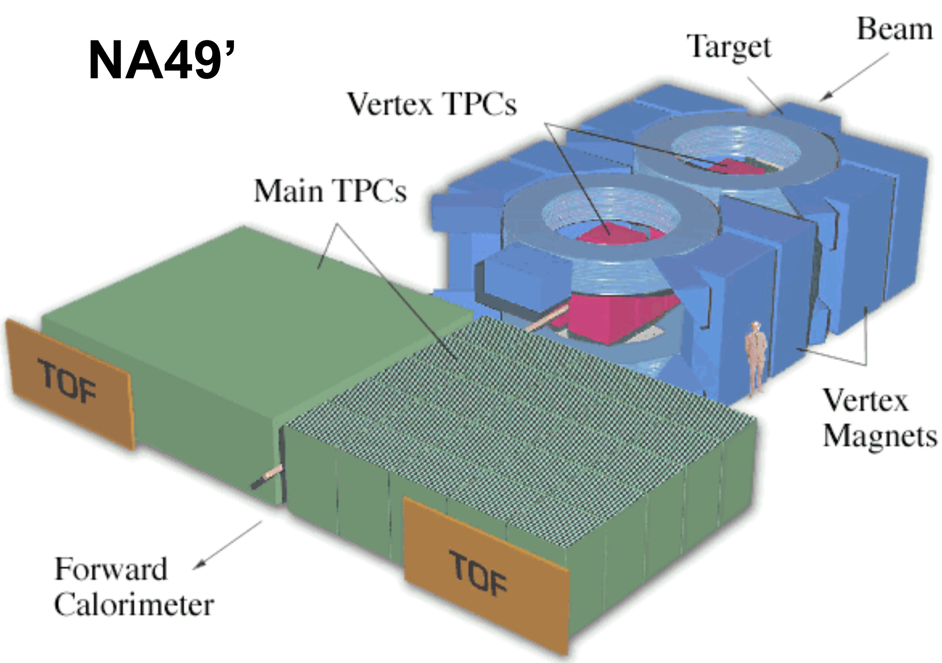
Where we're going

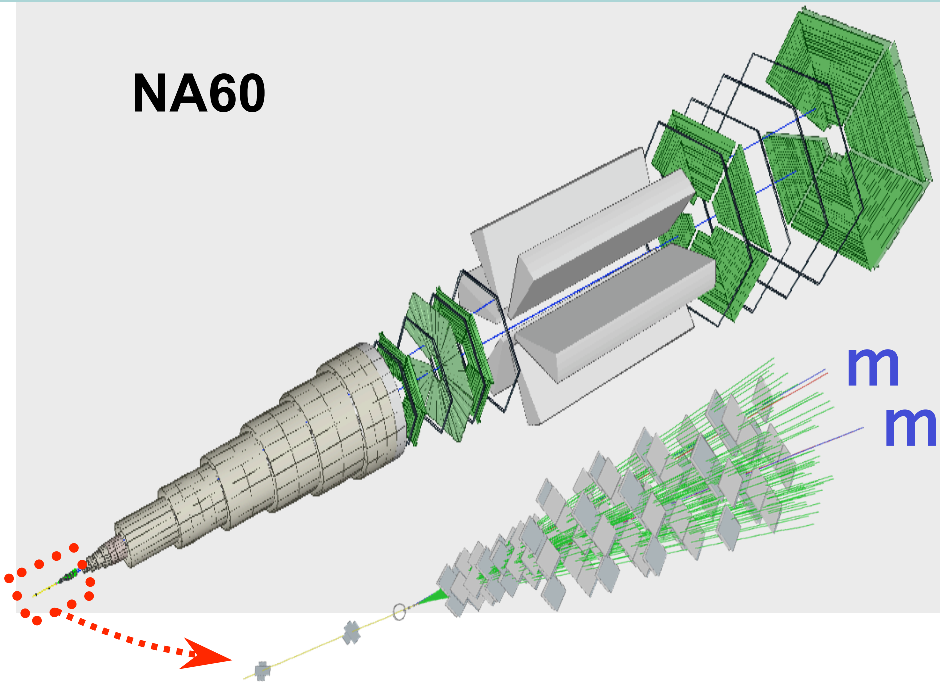


Where we're going



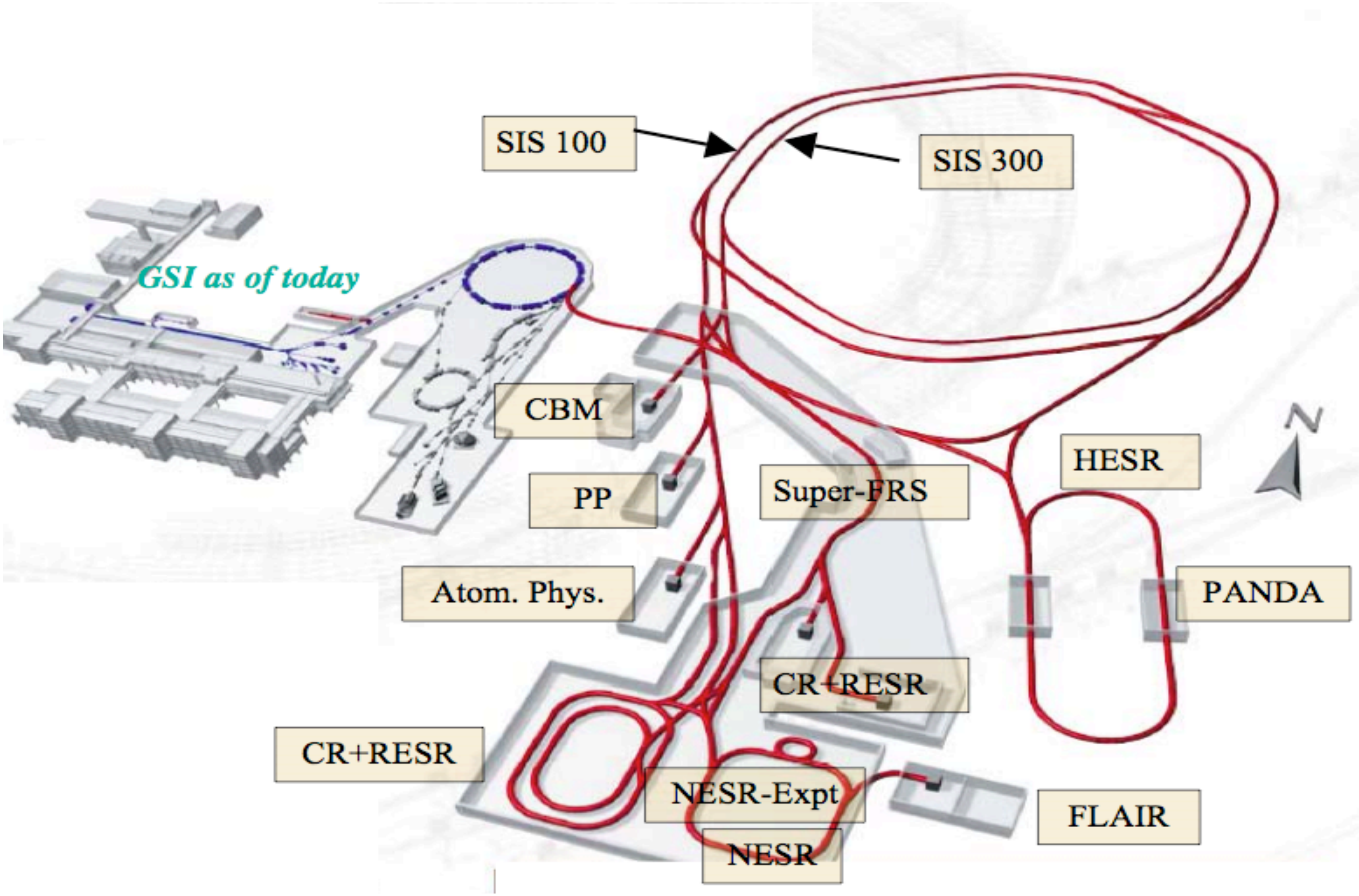
Low Energy Frontier: 2006 - ?



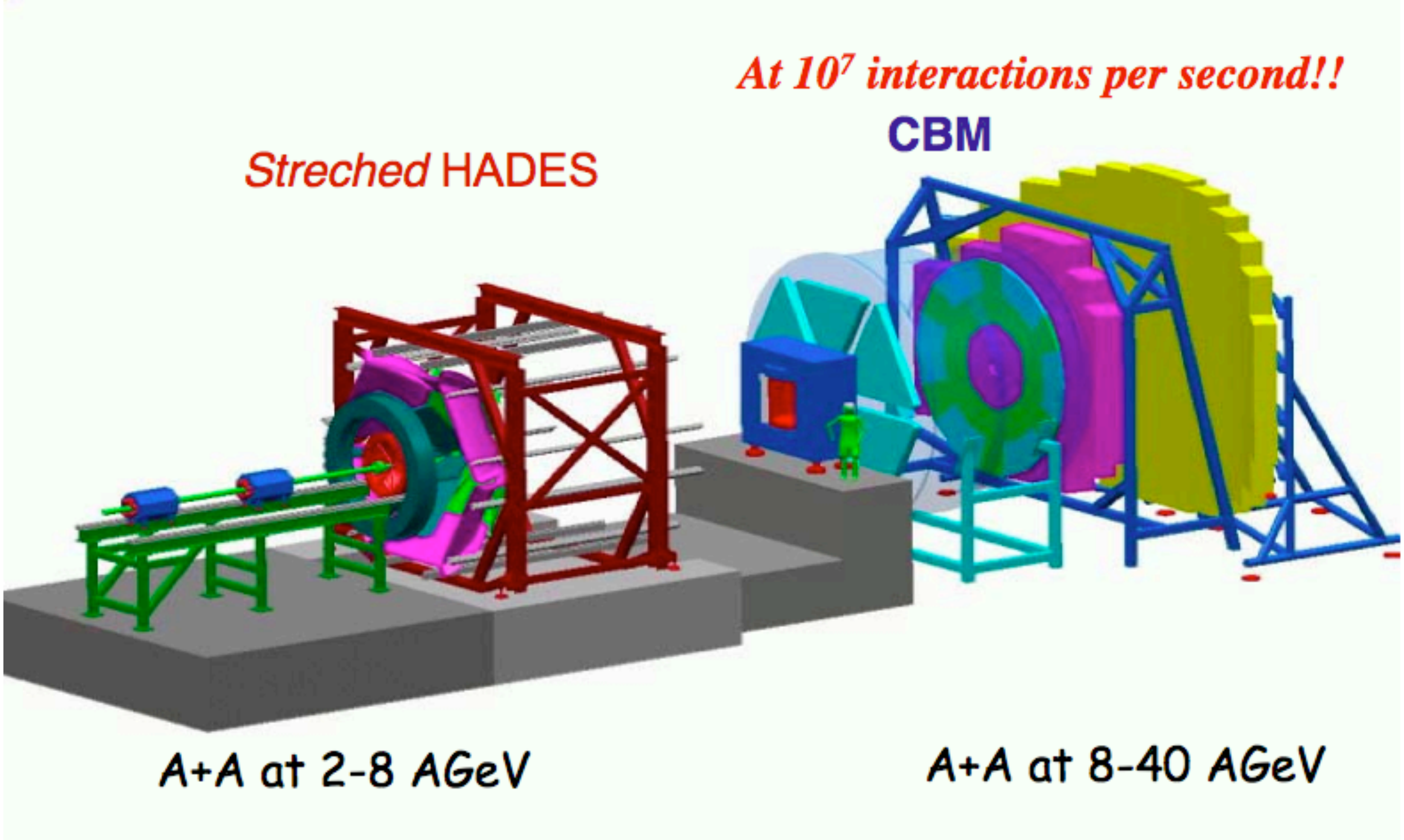


Possible SPS running 2006?

FAIR@GSI: 2012-beyond

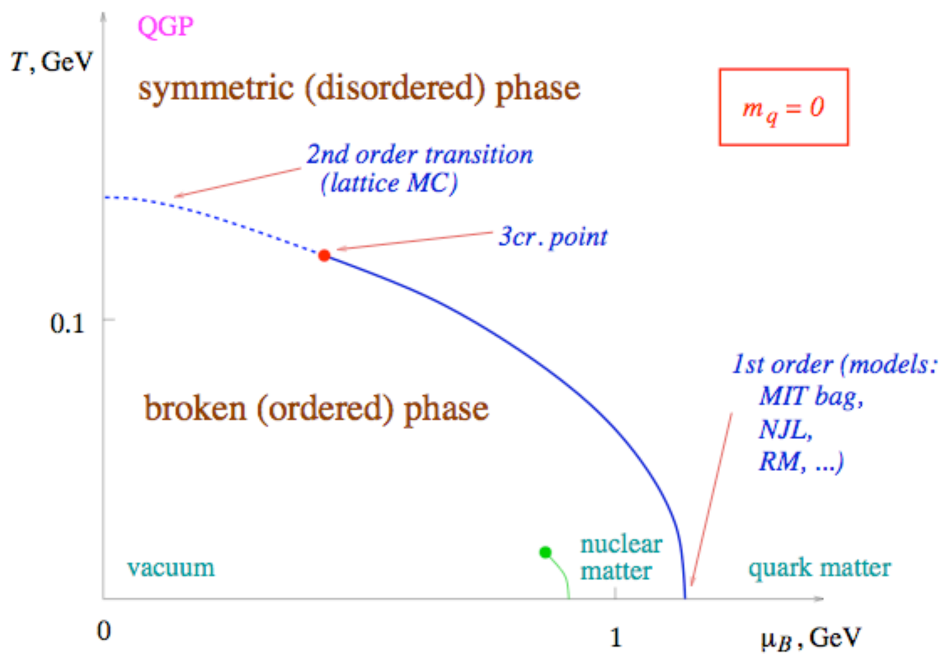


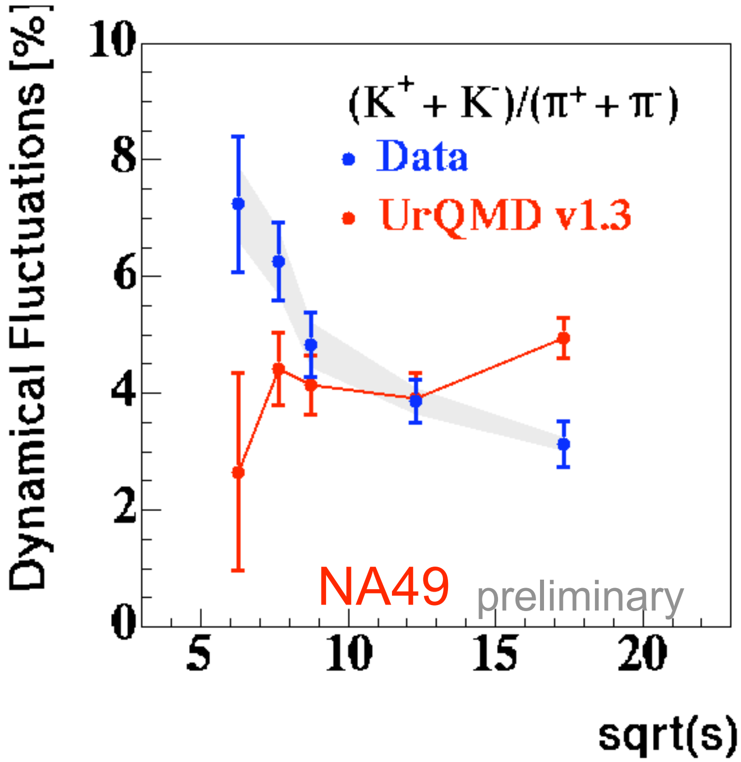
Compressed Baryonic Matter



Critical Fluctuations

Stephanov hep-ph/0402115

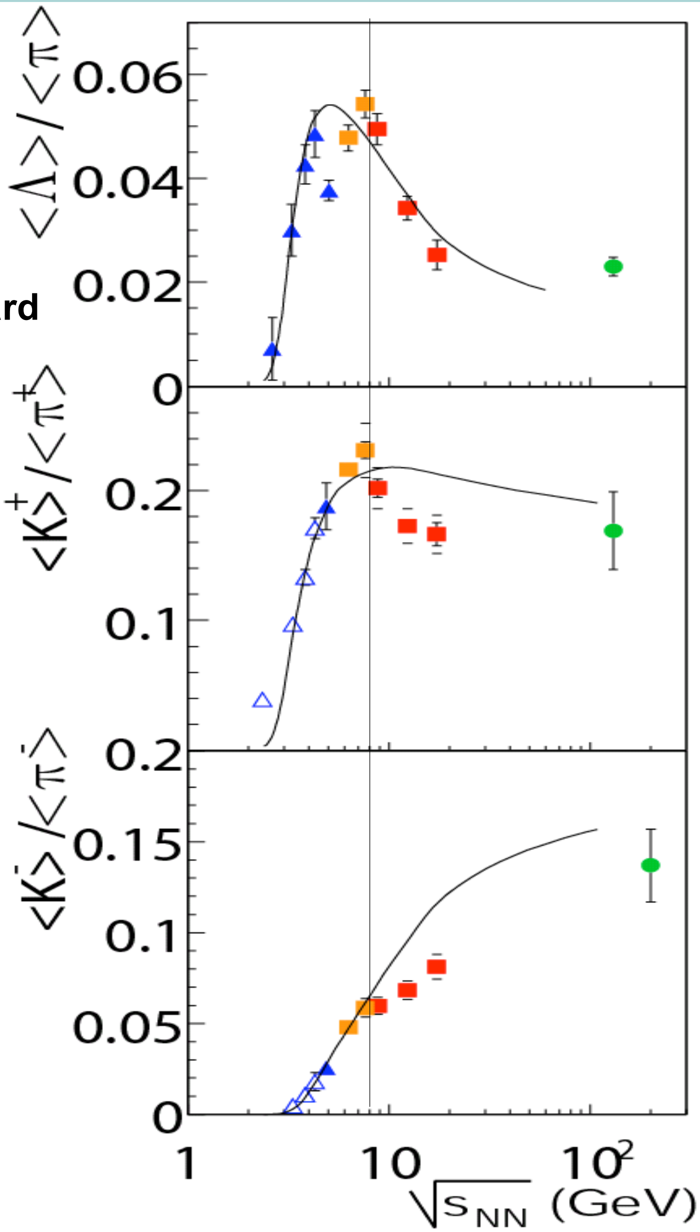




Location of Phase Transition?

NA49

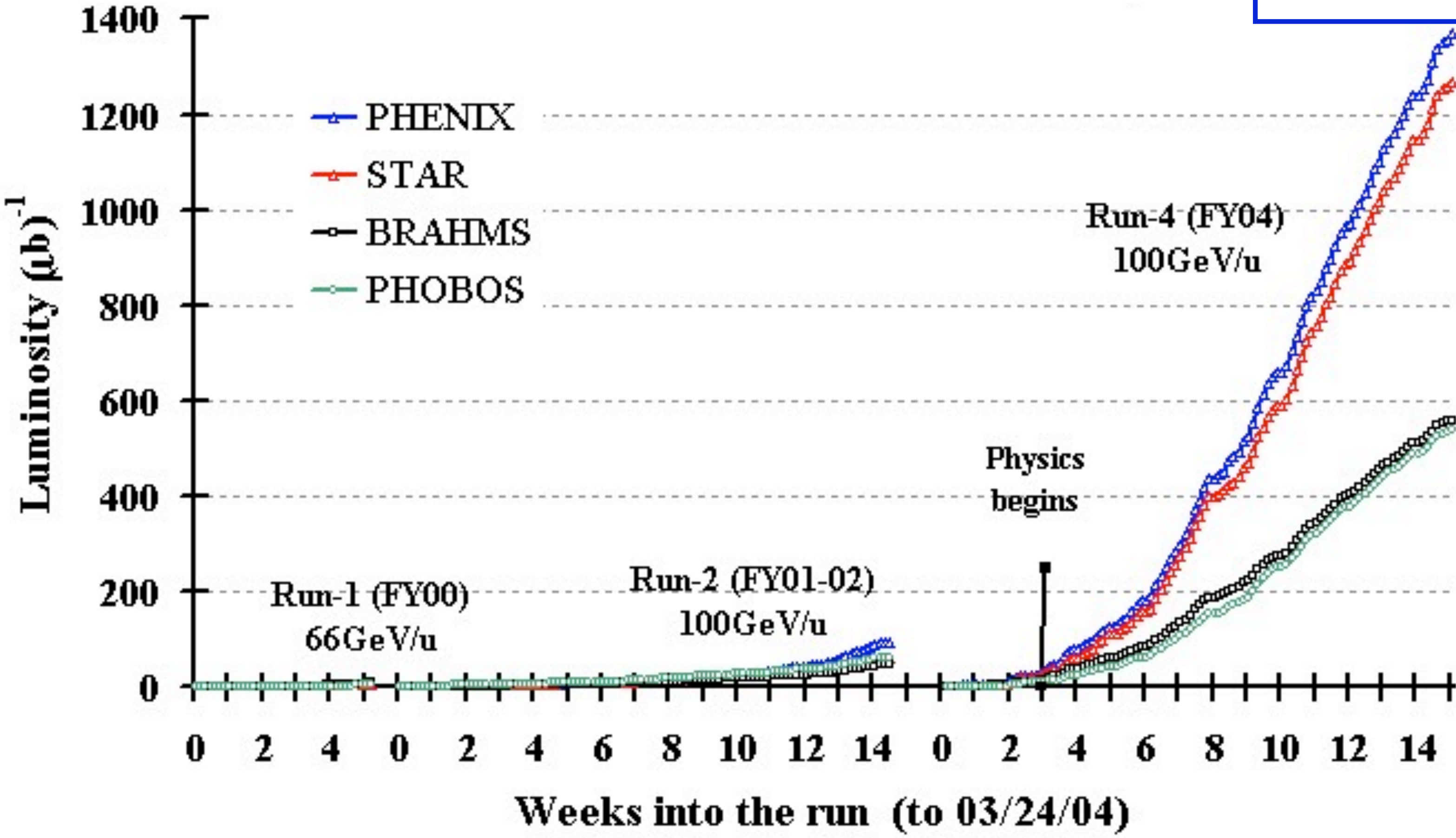
Agnes Richard



- Is this the phase transition?
  - maybe, maybe not…
  - But: No other candidate between AGS and RHIC!
  - No model even close to data
  - Confirmation?

RHIC Status and Future

Phenix	1370 mb^{-1}
Star	1270 mb^{-1}
Phobos	560 mb^{-1}
Brahms	540 mb^{-1}



physics target

From RHIC towards RHIC II

'04 **RHIC** → **Excitation function**

- vs Energy
- vs Systemsize

→ **Properties of the Medium**

- 6-D jet tomography
- Heavy Quark suppression
- Charm elliptic flow
- Thermal QGP photons
- J/psi, upsilon
- Low mass di-leptons
- g-Jet correlations
-

Need:

Higher Luminosity
Faster DAQ
Larger Acceptance
Extended PID
Micro-vertexing

'14 **RHIC II**

From RHIC towards RHIC II

2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018

RHIC operation at and
beyond design luminosity

eRHIC
e-ion

RHIC II 40x design luminosity for Au-Au
via electron cooling

RHIC baseline program
- Au-Au ~ 1 nb^{-1} at 200 GeV
- Species scan at 200 GeV
- Au-Au energy scan
- Polarized protons ≥ 150 nb^{-1}

Completion of
- BRAHMS & PHOBOS

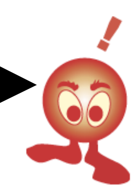
Studies of dense nuclear matter
with rare probes: jet tomography, open flavor,
J/ψ, ψ', χc, $\Upsilon(1s)$, $\Upsilon(2s)$, $\Upsilon(3s)$
Polarized protons at 500 GeV
p-A physics

Near & medium term detector upgrades
of PHENIX and STAR
Proposals submitted or in preparation

New eRHIC experiment

Long term upgrades
of PHENIX and STAR
related to RHIC II

from Axel Drees

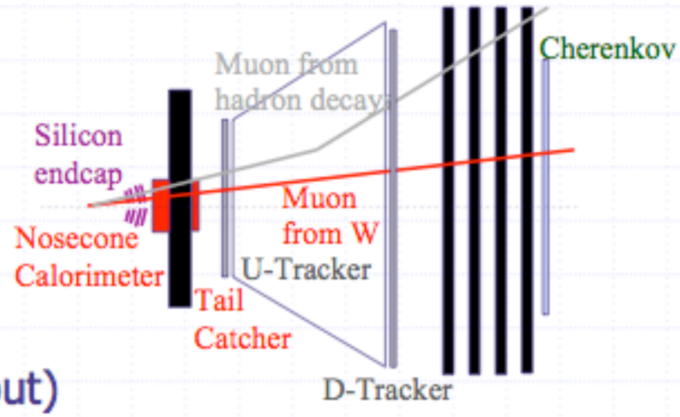


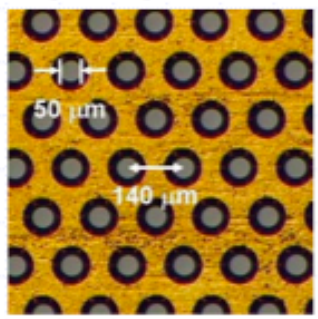
new RHIC experiments ?

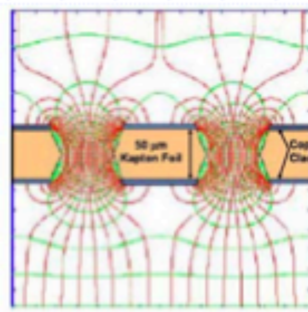
Medium term: 2008 and beyond

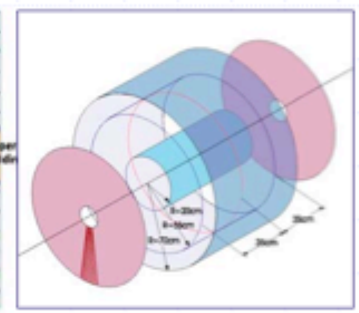
RHIC II Detector Upgrades

- PHENIX
  - Compact TPC (GEM readout)
  - Forward Upgrade (Si-W cal.)
  - DAQ
- STAR
  - TPC replacement (GEM readout)
  - Forward Tracking Upgrade
  - DAQ



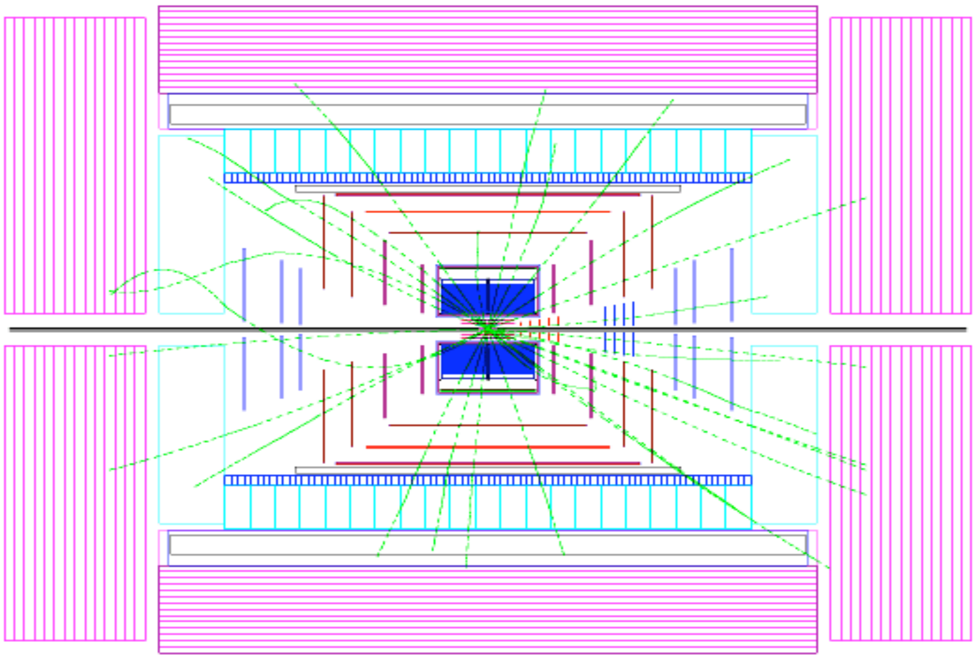






NSAC H.I. Review S. Aronson

New Comprehensive Detector for RHIC II ?



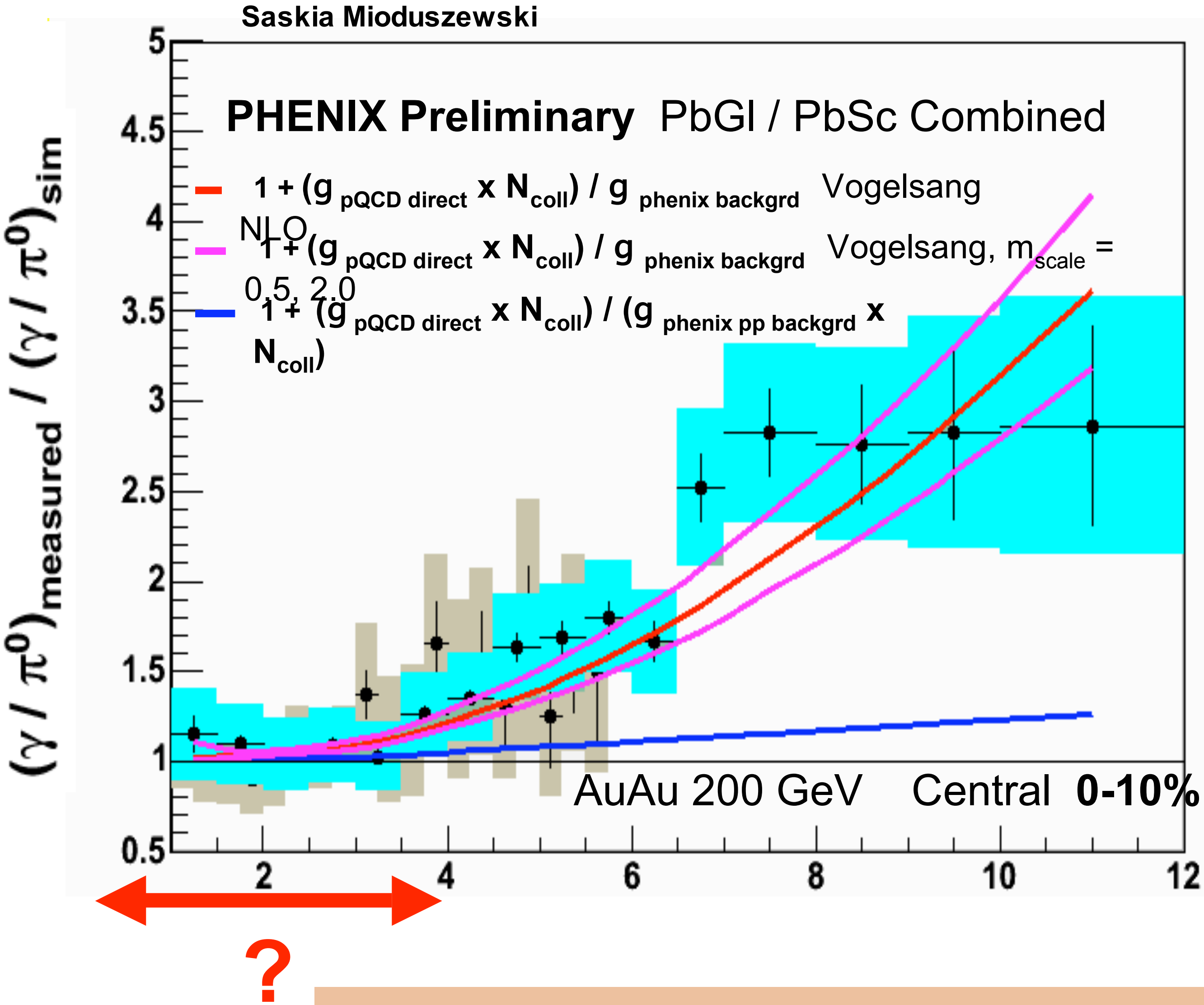
Specs:

- High field
- Fast DAQ
- Fast Detectors
- Triggers
- Si-vertexing
- High p_T PID
- Calorimetry

c.f. R.Bellwied, J.Harris, P.Steinberg, N. Smirnov, B.Surrow, T.Ullrich, J.Vavra, H.Wieman, C.Woody

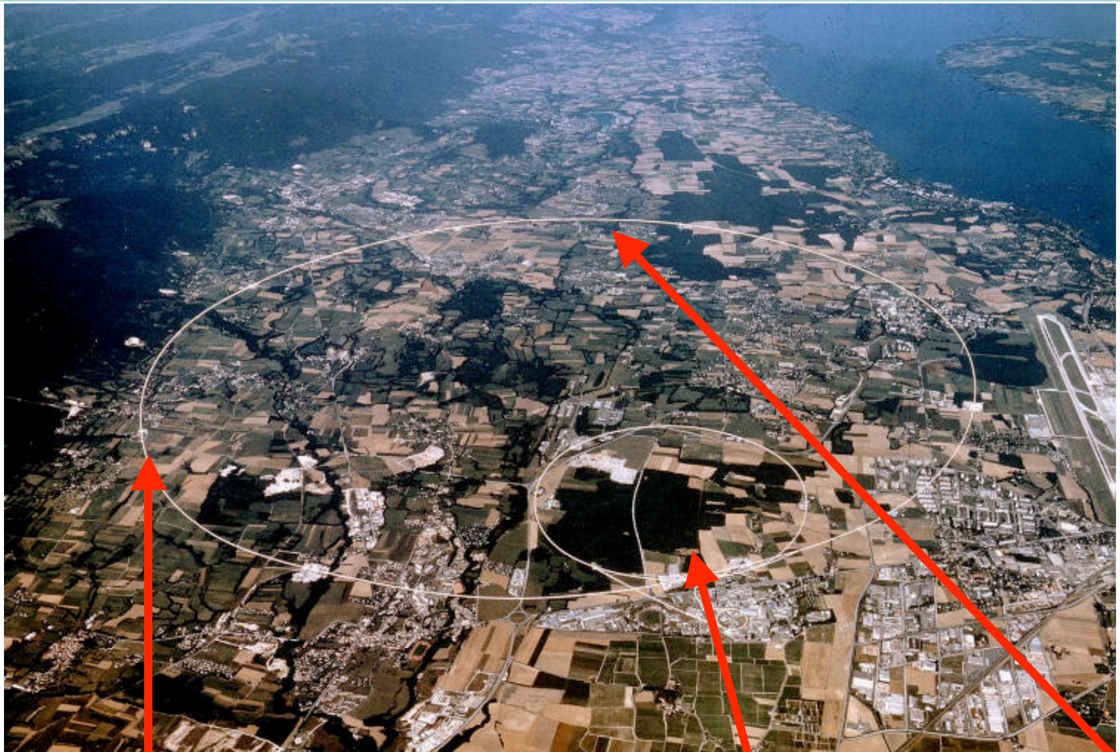
ł, Taos

From Direct to Thermal Photons



Can we see beyond the hadronic veil?

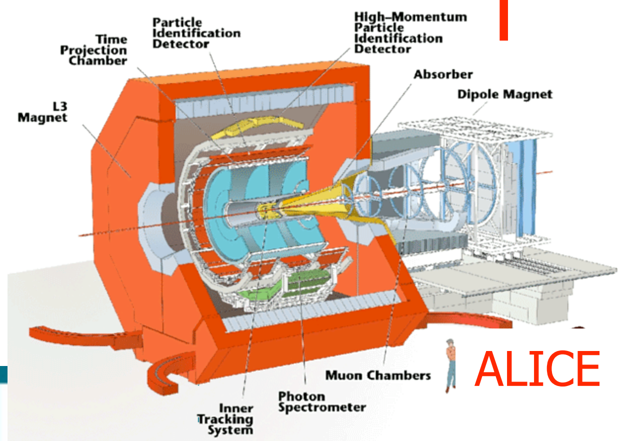
High Energy Frontier: LHC



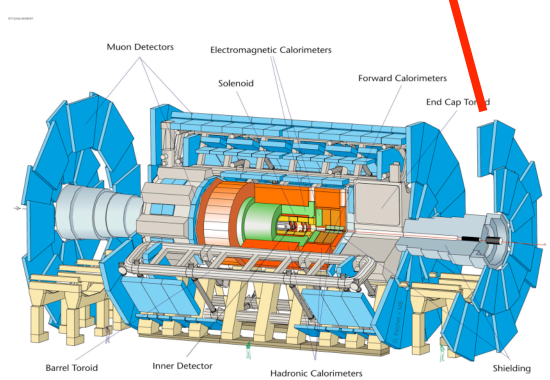
Startup:

p+p: 2007

Pb+Pb: 2007/08

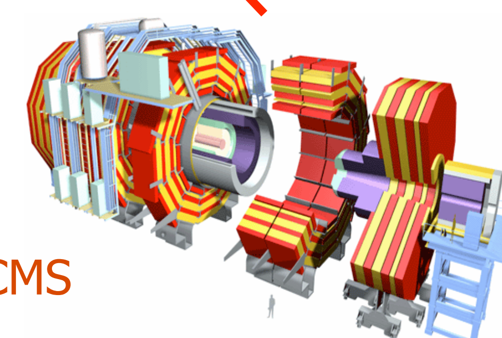


ALICE



ATLAS

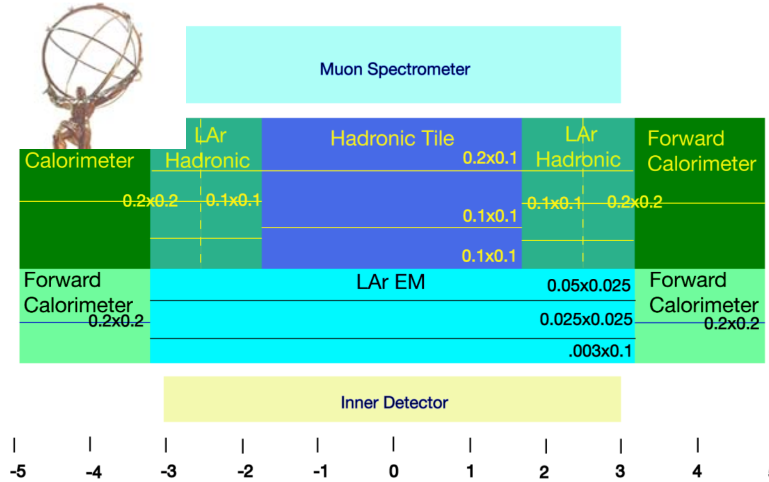
CMS

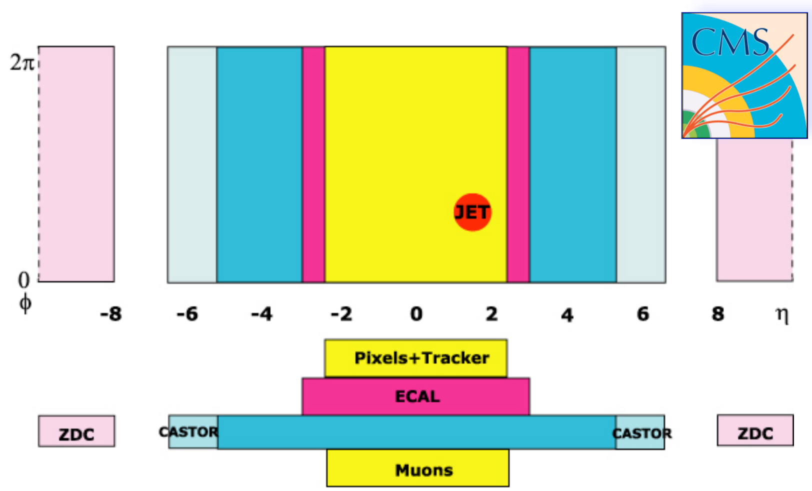


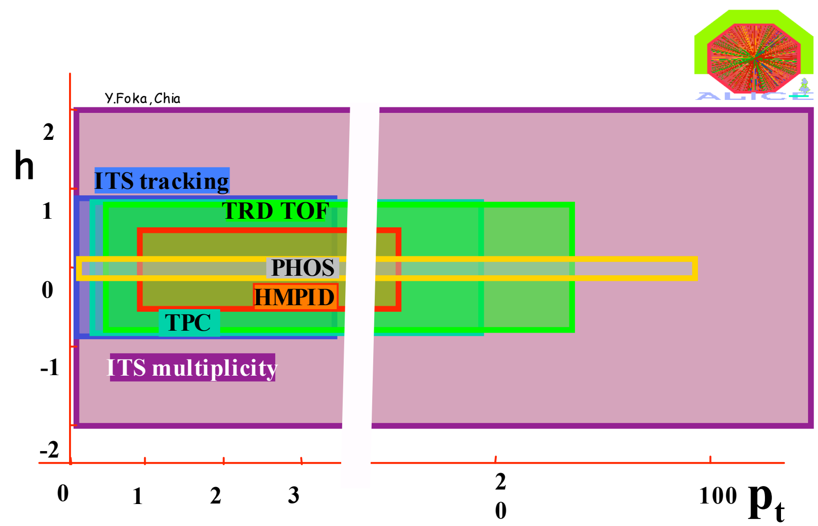
Gunther Roland - Hot Quarks ‘04, Taos

LHC Detector Capabilities

- Different B field: 0.5T, 2T, 4T
- Different emphasis on hermeticity
- Different emphasis on particle ID
- Different DAQ capabilities
- Different detector technologies



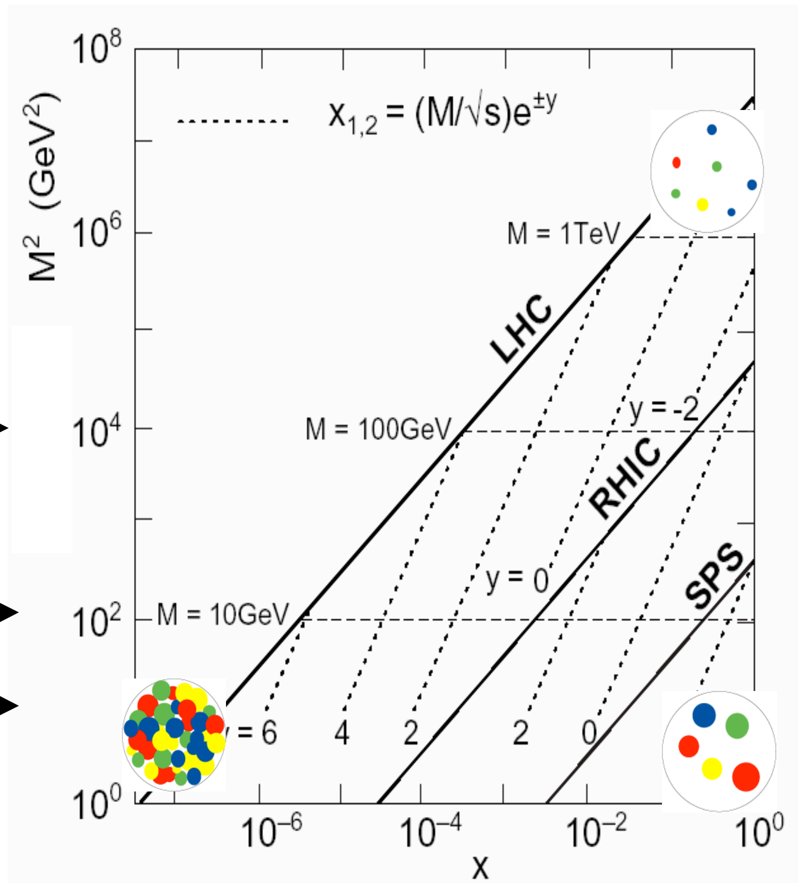


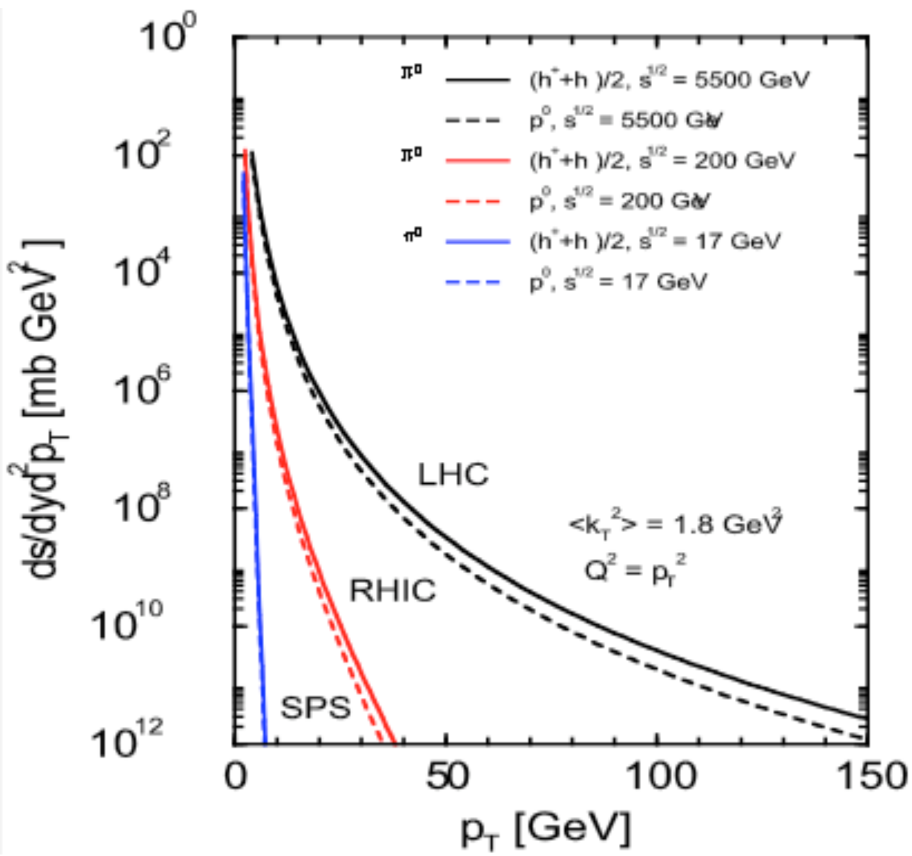


Kinematics at the LHC

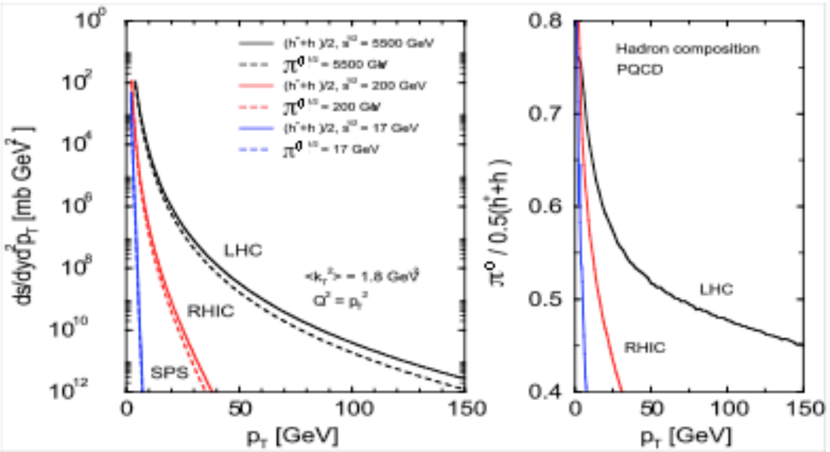
Access to widest range of Q^2 and x

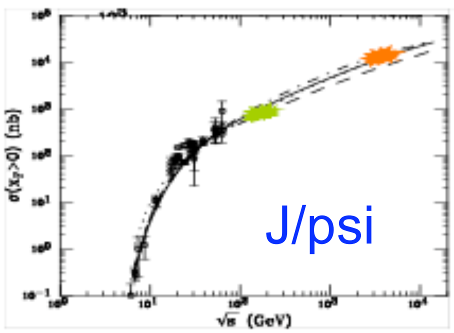
Z0 →
Υ →
J/y →

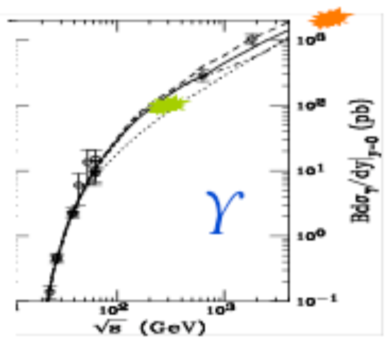


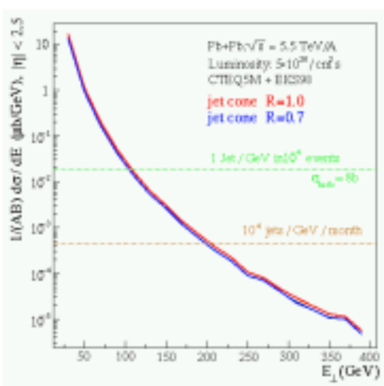


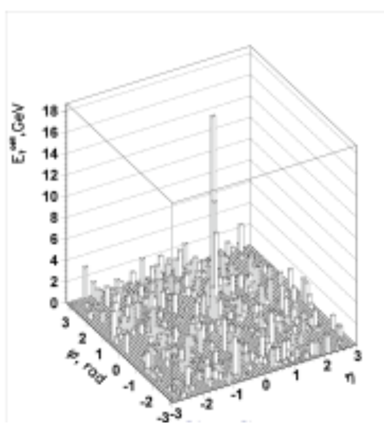
Heavy Ion Physics at the LHC











- Medium modification at high p_T
  - Copious production of high p_T particles
- Different "melting" for members of Υ family
  - Large cross section for ***J/psi*** and Υ family production
- Detailed studies of medium effects on jets
  - Jets shape and fragmentation modified by the medium
  - Jet tomography
  - Dijet/monojet ratio
  - Jet-g
  - Jet-Z^0
  - Multi jets

from Bolek Wyslouch

· Hot Quarks '04, Taos

Bulk Matter at LHC?

Sharon Millstein, Numerologist and Psychic Counselor:

“Friends Can Advise You,

Numerology Directs You!”

I. Spectrum of Produced Hadrons at LHC

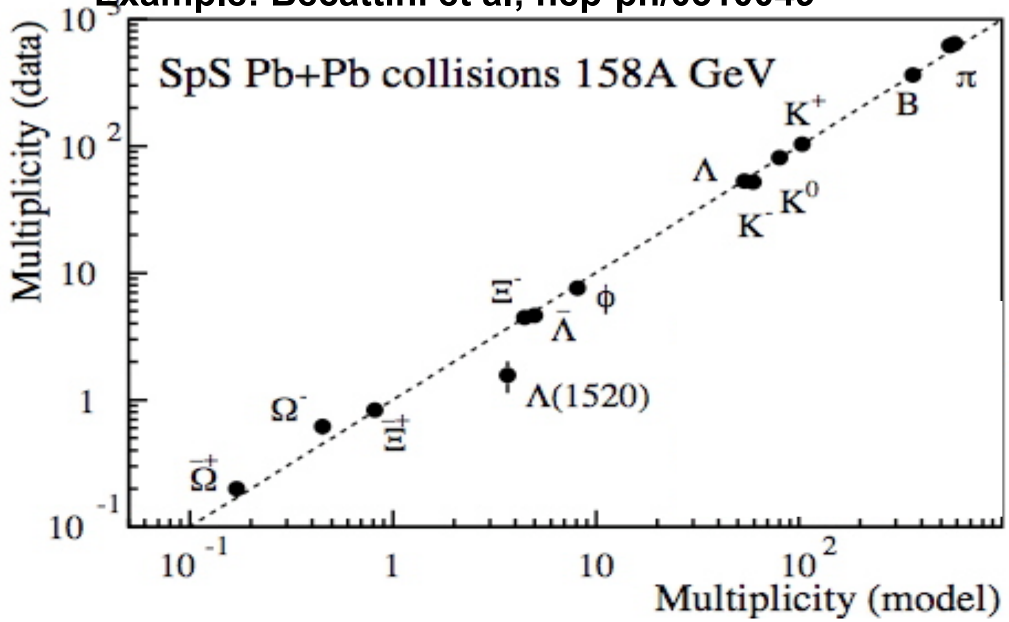
Temperature Chemical Potential

$$\langle n_j \rangle = \frac{(2J_j+1)V}{(2\pi)^3} \int \mathrm{d}^3\mathrm{p} \left[\mathrm{e}^{\sqrt{\mathrm{p}^2+m_j^2}/T + \boldsymbol{\mu}\cdot\mathbf{q}_j/T} \pm 1 \right]^{-1}$$

Yield

Mass Quantum Numbers

Example: Becattini et al; hep-ph/0310049



NA49 data,

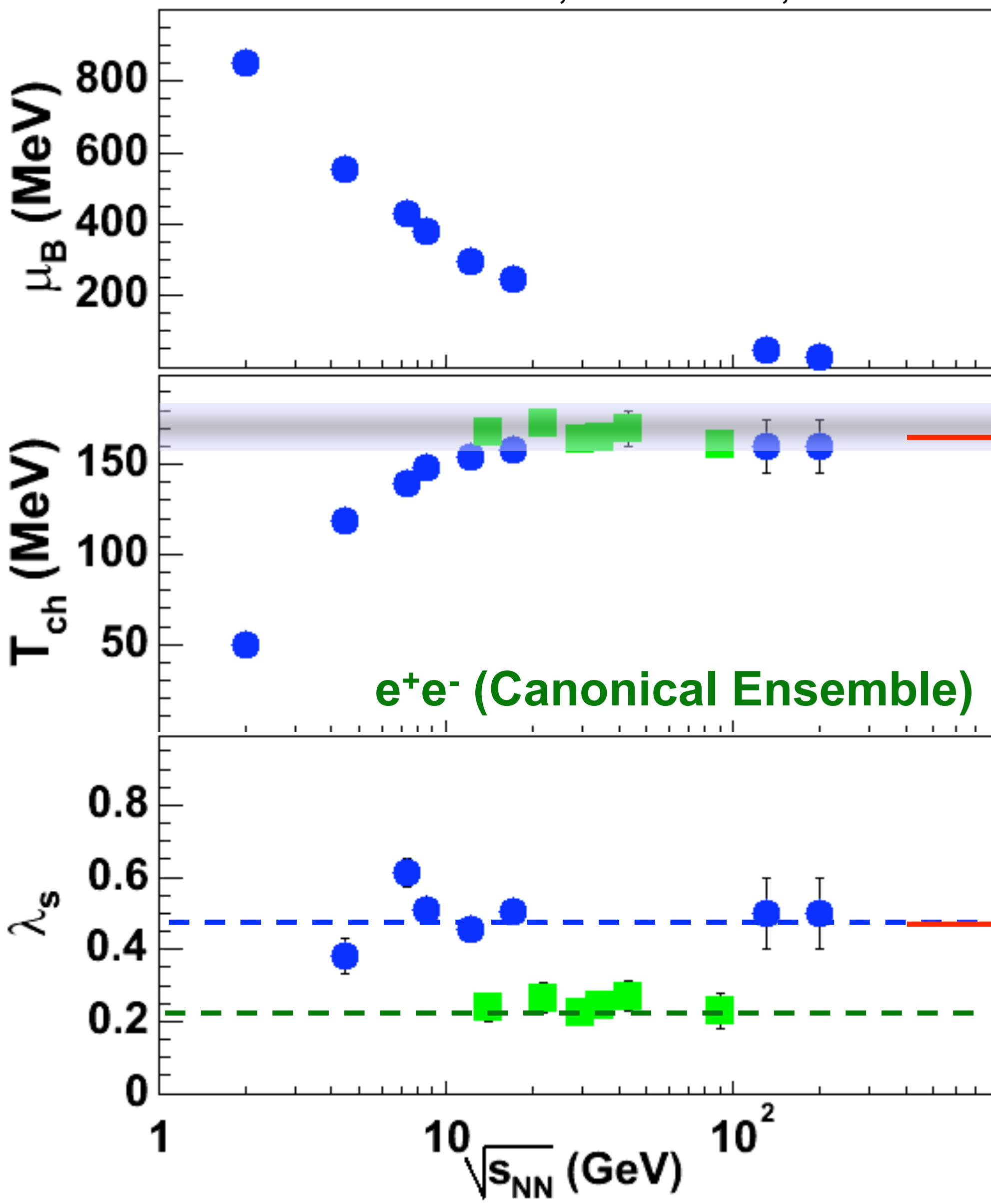
4-p yields,

g_s ~ 0.85

c.f. Hagedorn, Becattini, Braun-Munzinger, Cleymans, Heinz, Letessier, Mekijan, Rafelski, Redlich, Sollfrank, Stachel, Tounsi + many others

I. Spectrum of Produced Hadrons at LHC

Calculations: Redlich et al, Becattini et al, Braun-Munzinger et al, Rafelski et al



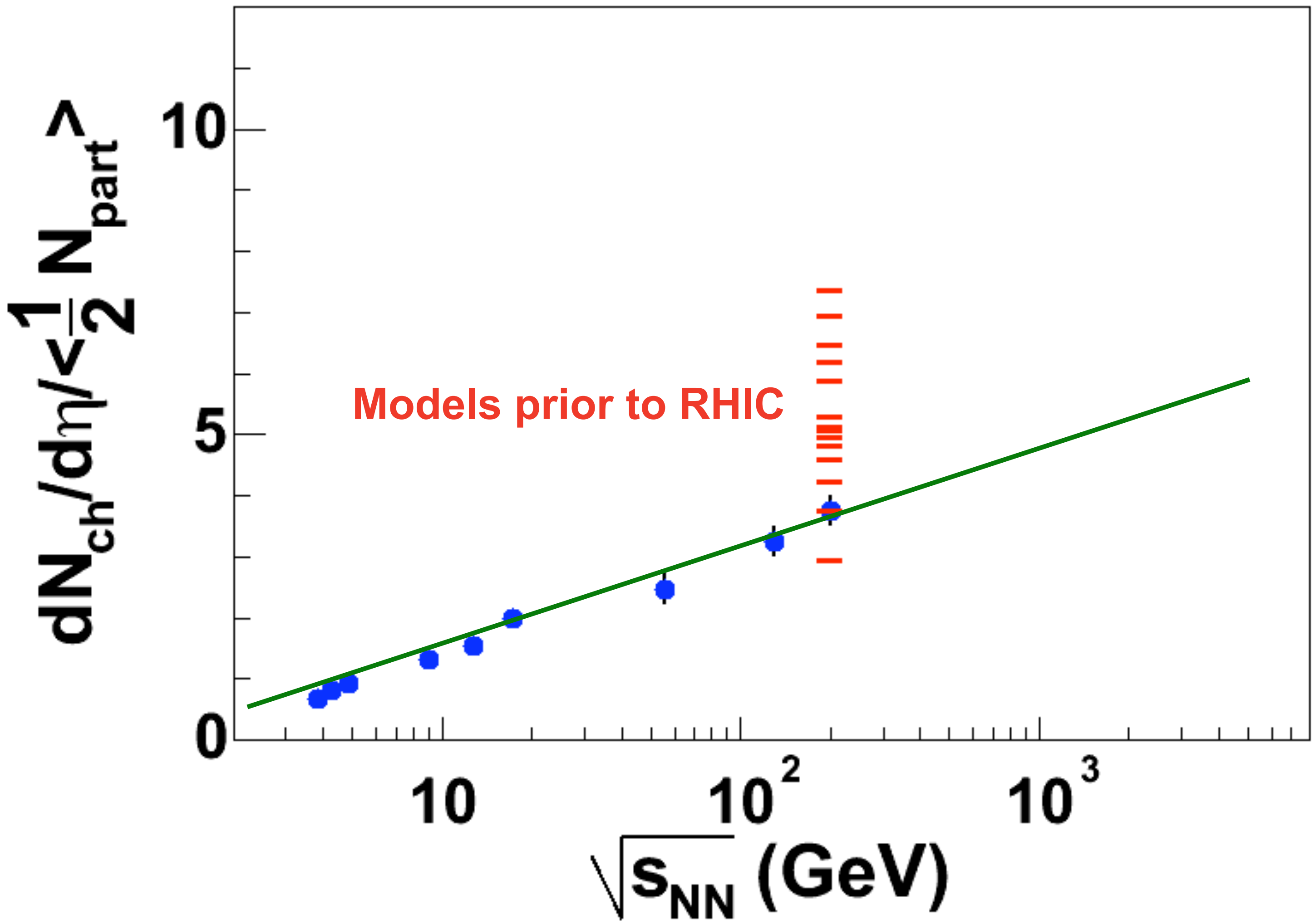
m_B drops with collision energy

LHC

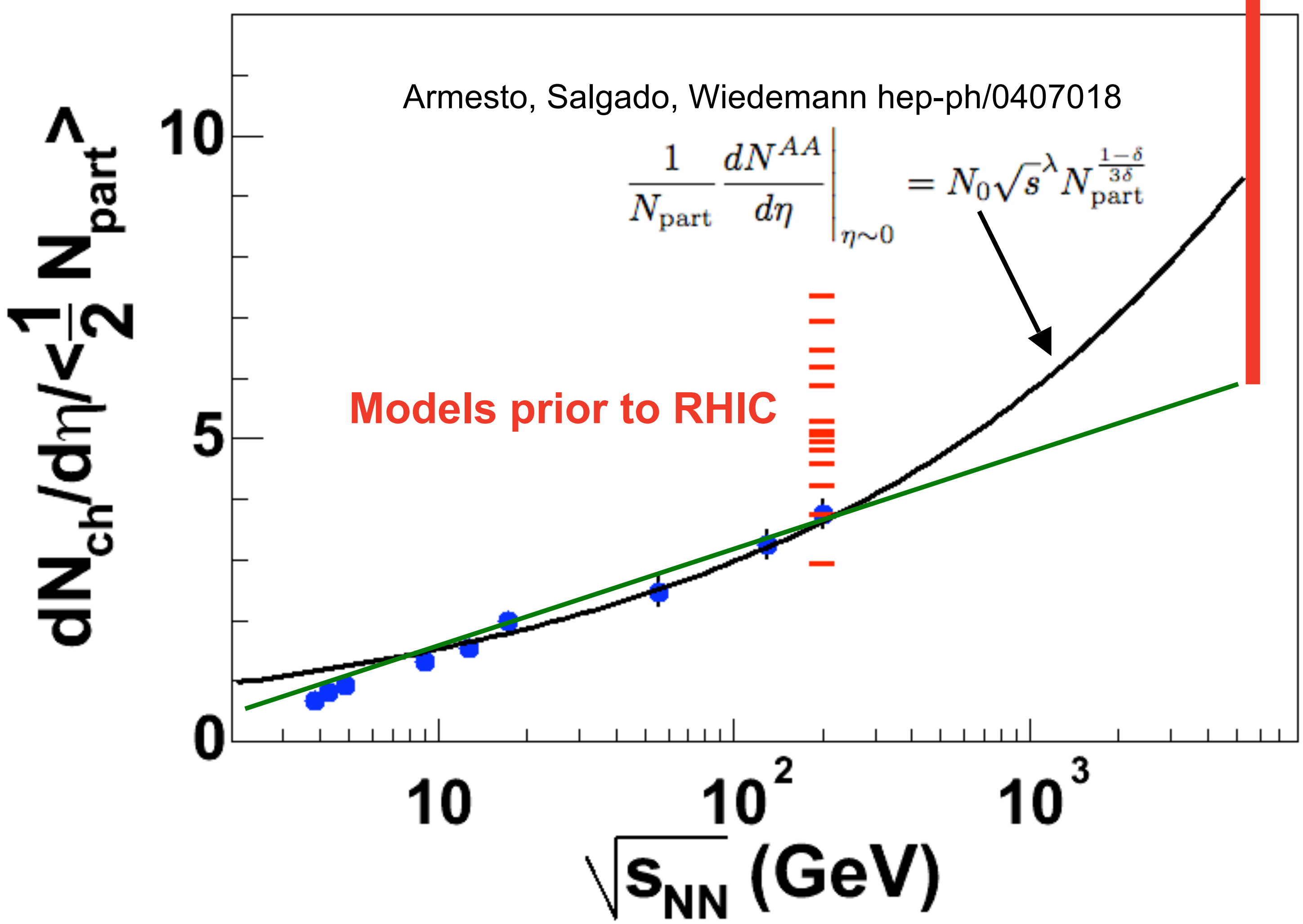
T_{ch} approaches limiting value

LHC

II. Particle Density at LHC

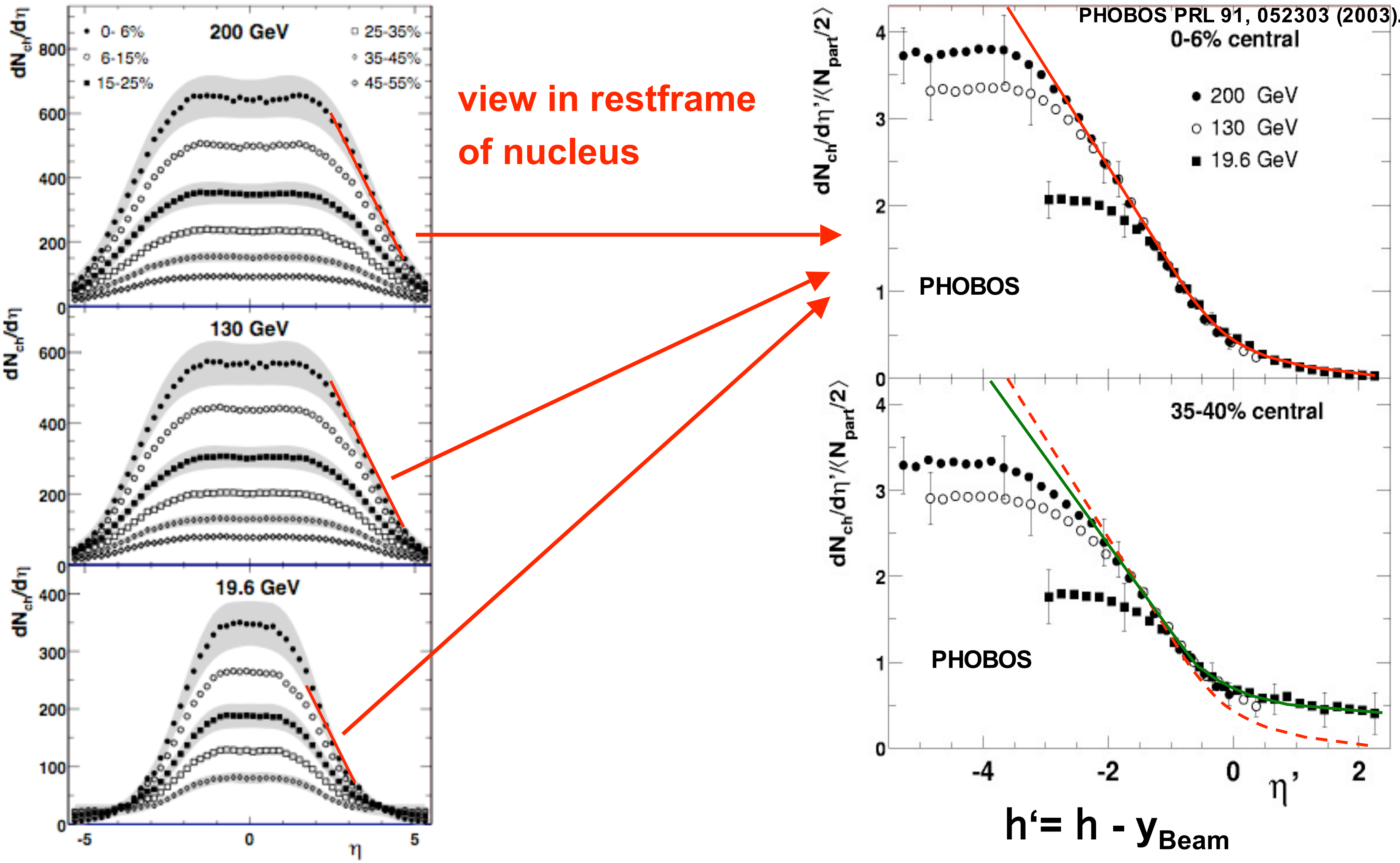


II. Particle Density at LHC

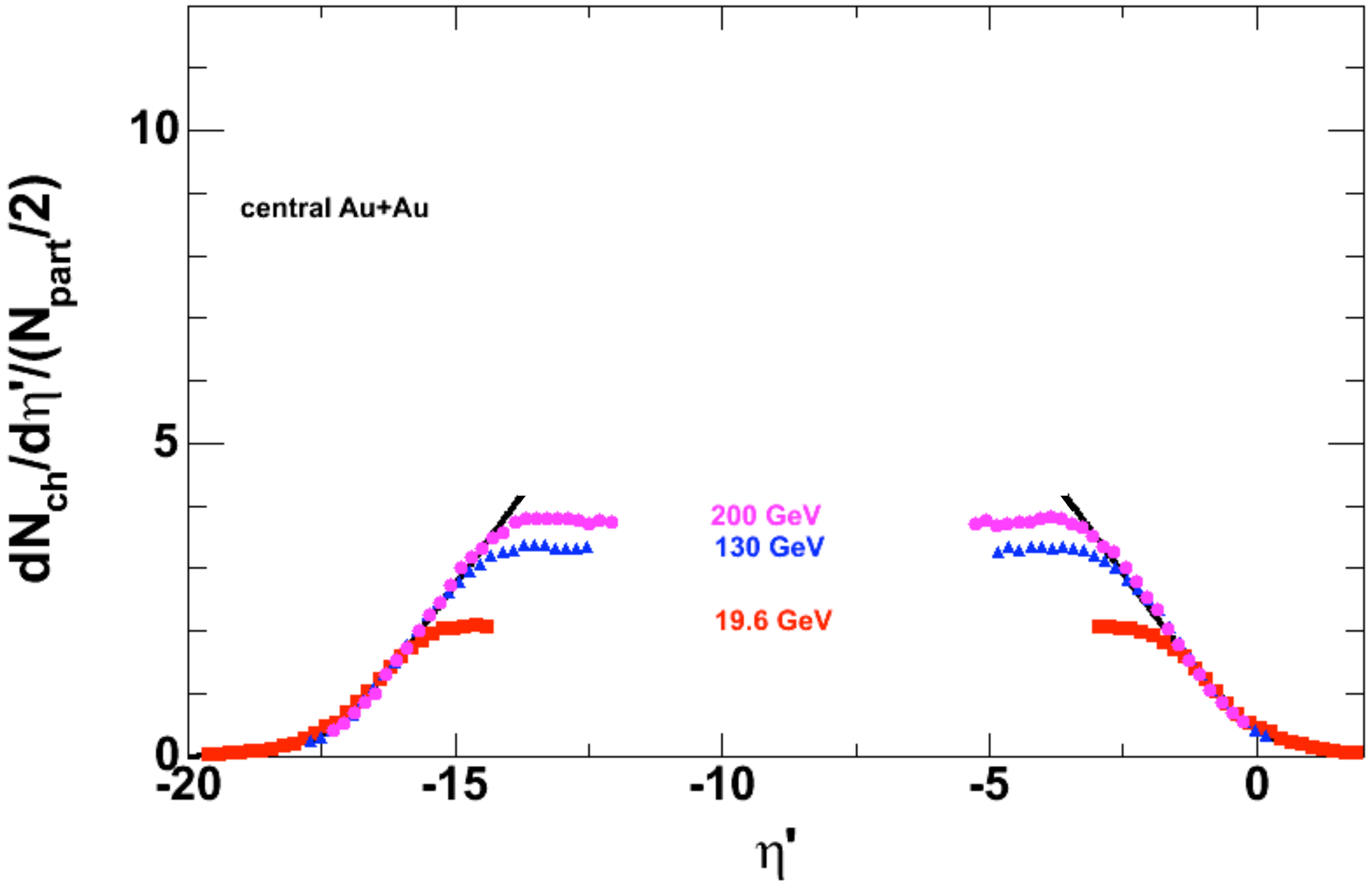


Detectors planned for dN/dy > 5000!

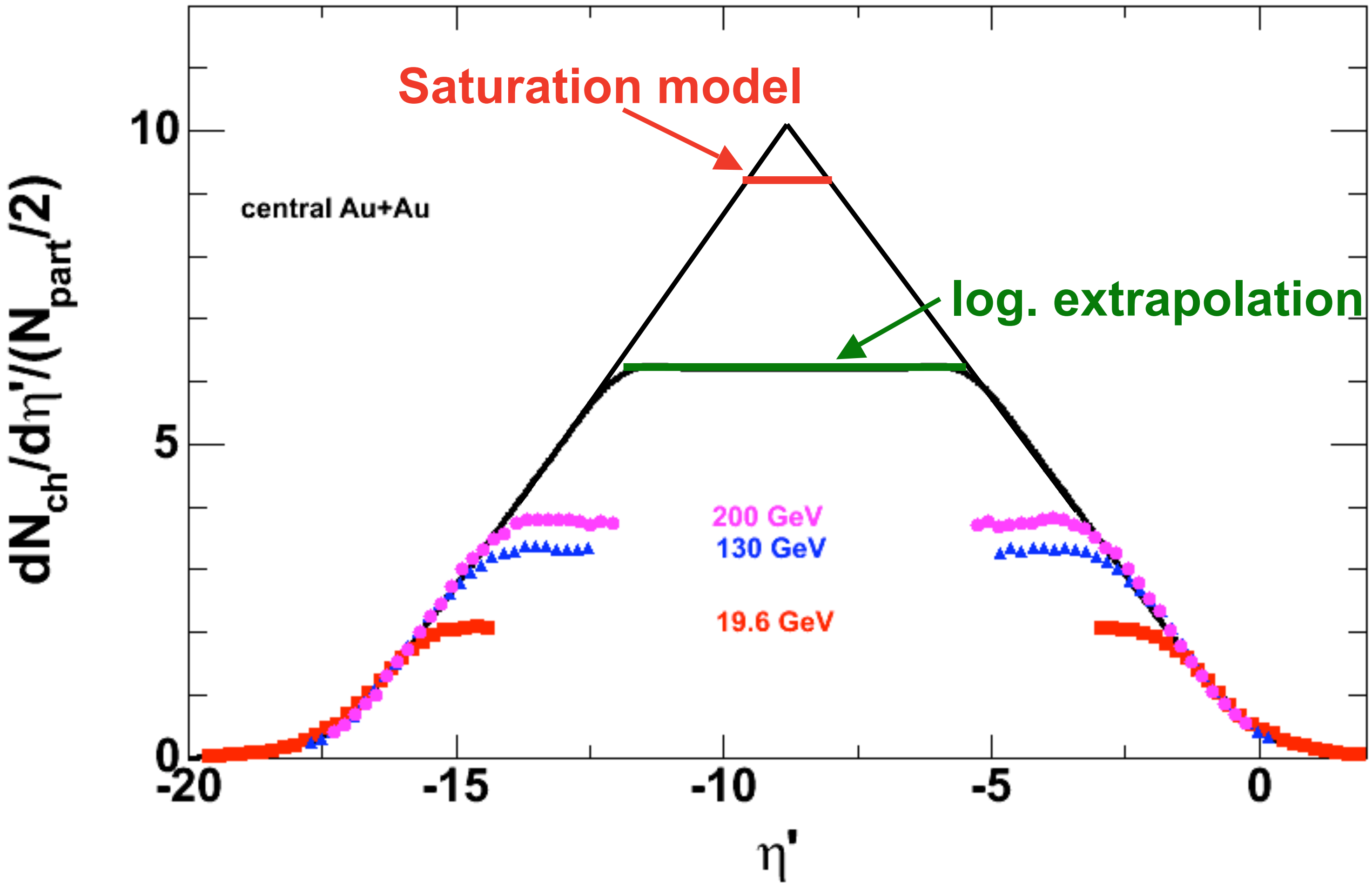
Limiting Fragmentation



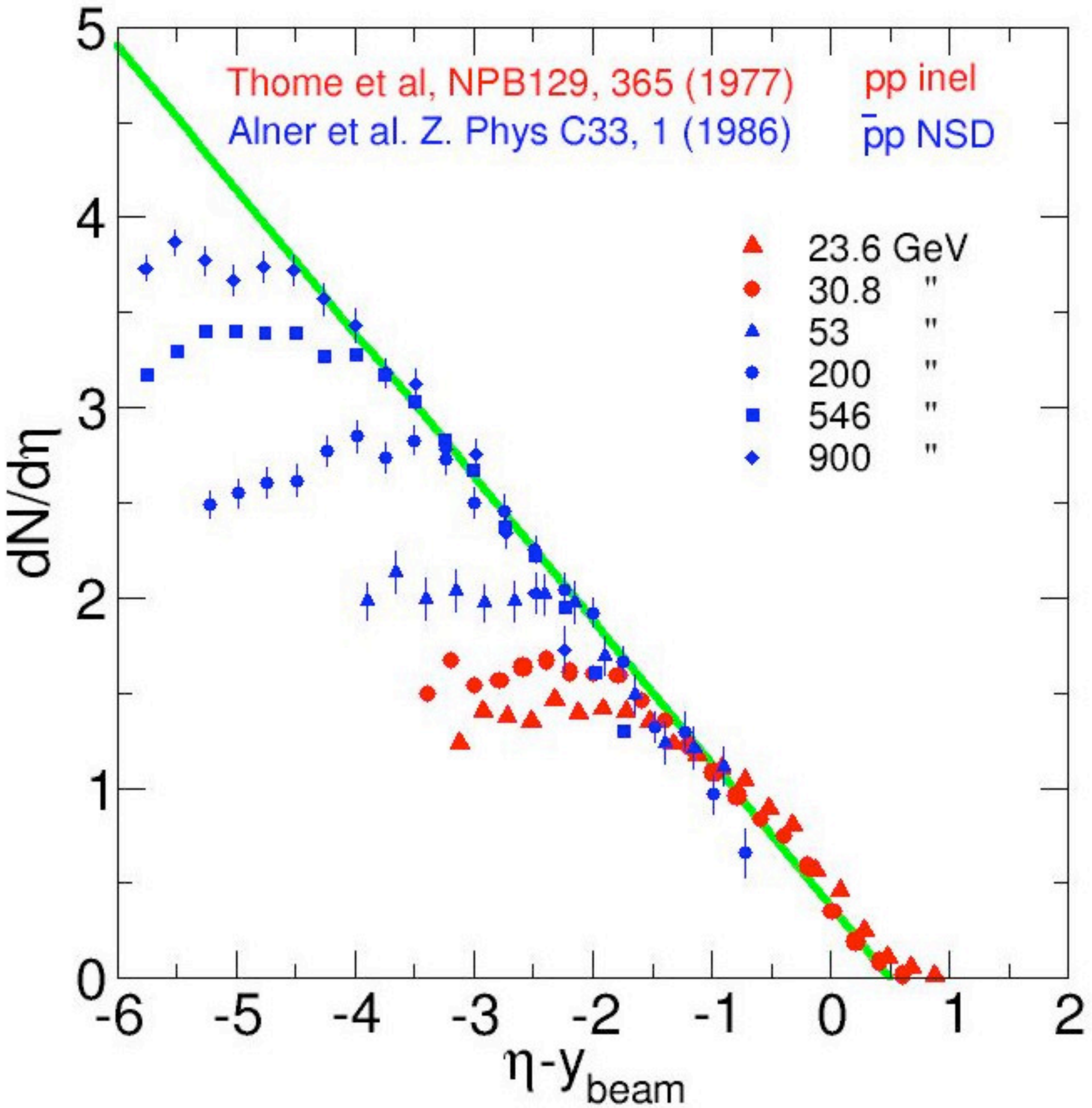
Limiting Fragmentation and LHC



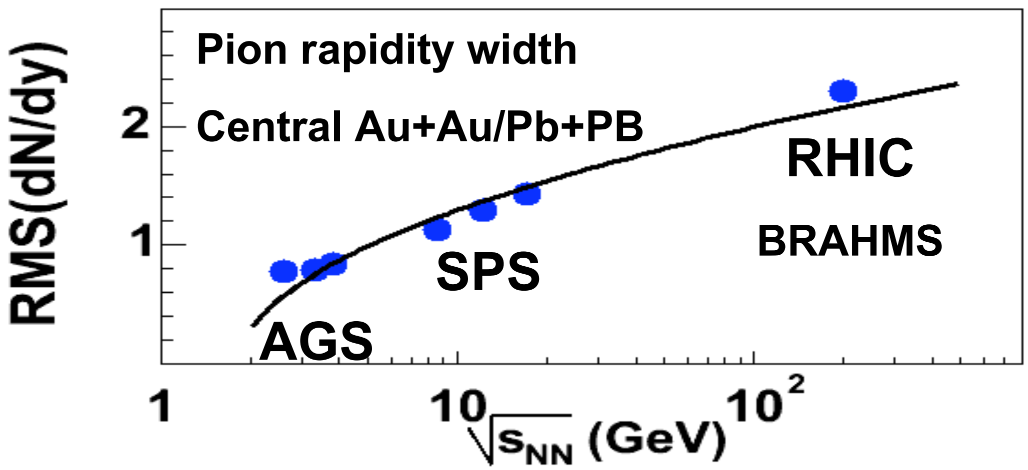
Limiting Fragmentation and LHC



Limiting Fragmentation in p+p



Landau Hydrodynamics



surprisingly well described by Landau's energy-dependent Gaussian rapidity distribution [see Eq. (2.1) for the definition of y]

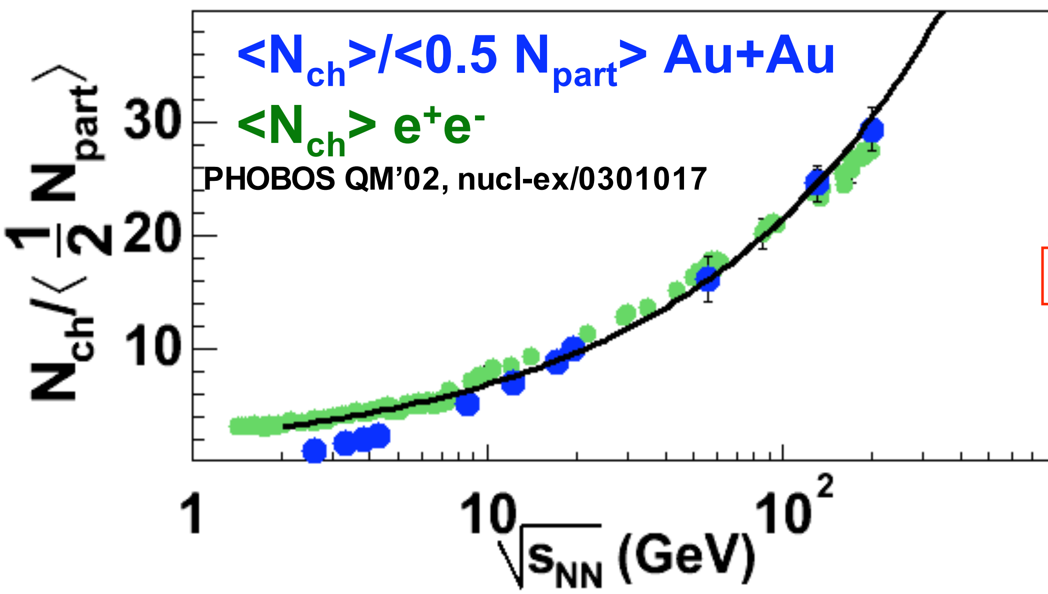
$$\frac{1}{\sigma_{in}}\frac{d\sigma}{dy}=\frac{dN}{dy}$$

$$=N\exp(-y^2/2L)/(2\pi L)^{1/2}, \qquad (1.5)$$

where the parameter L is

$$L=\tfrac{1}{2}\ln(s/4m_p{}^2), \qquad (1.6)$$

where s is the squared total c.m. energy.



Secondly, we wish to stress that as a function of *available energy* W_{had} the hadronic multiplicity varies as $N\approx 2.2\ W_{had}{}^{1/2}$ over a vast range of initial energies.[25]

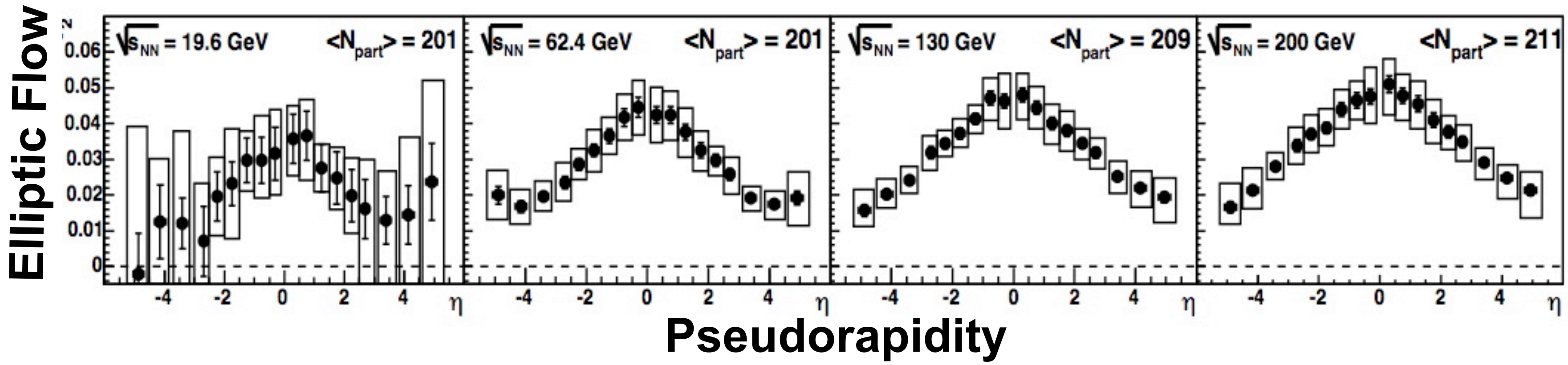
Carruthers, Duong-Van

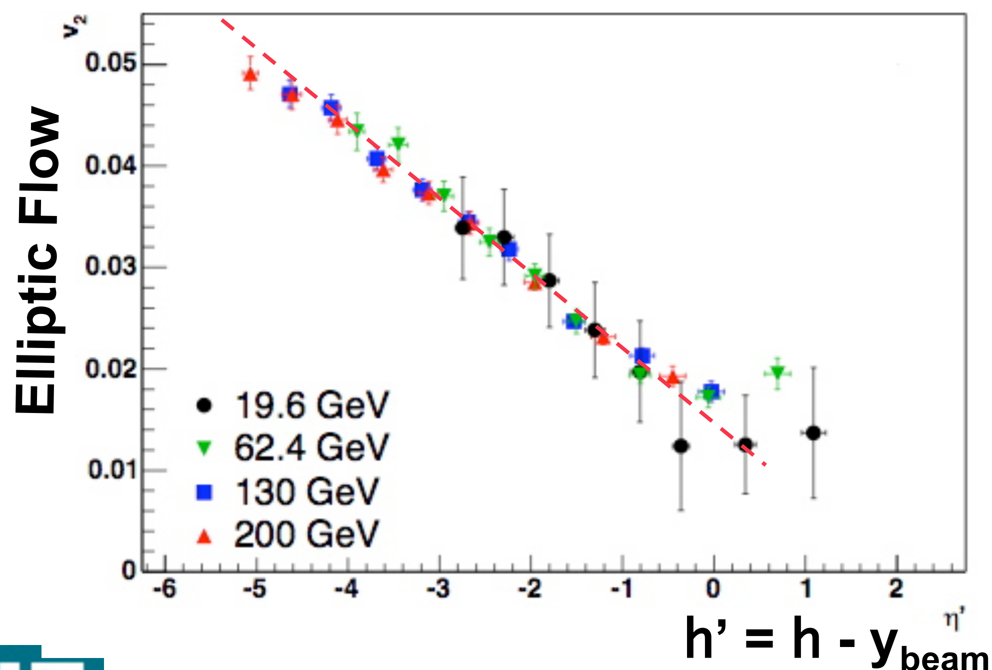
on pp and e^+e^- data in 1983

Much faster rise of mid-y multiplicity density

III. Elliptic Flow at LHC

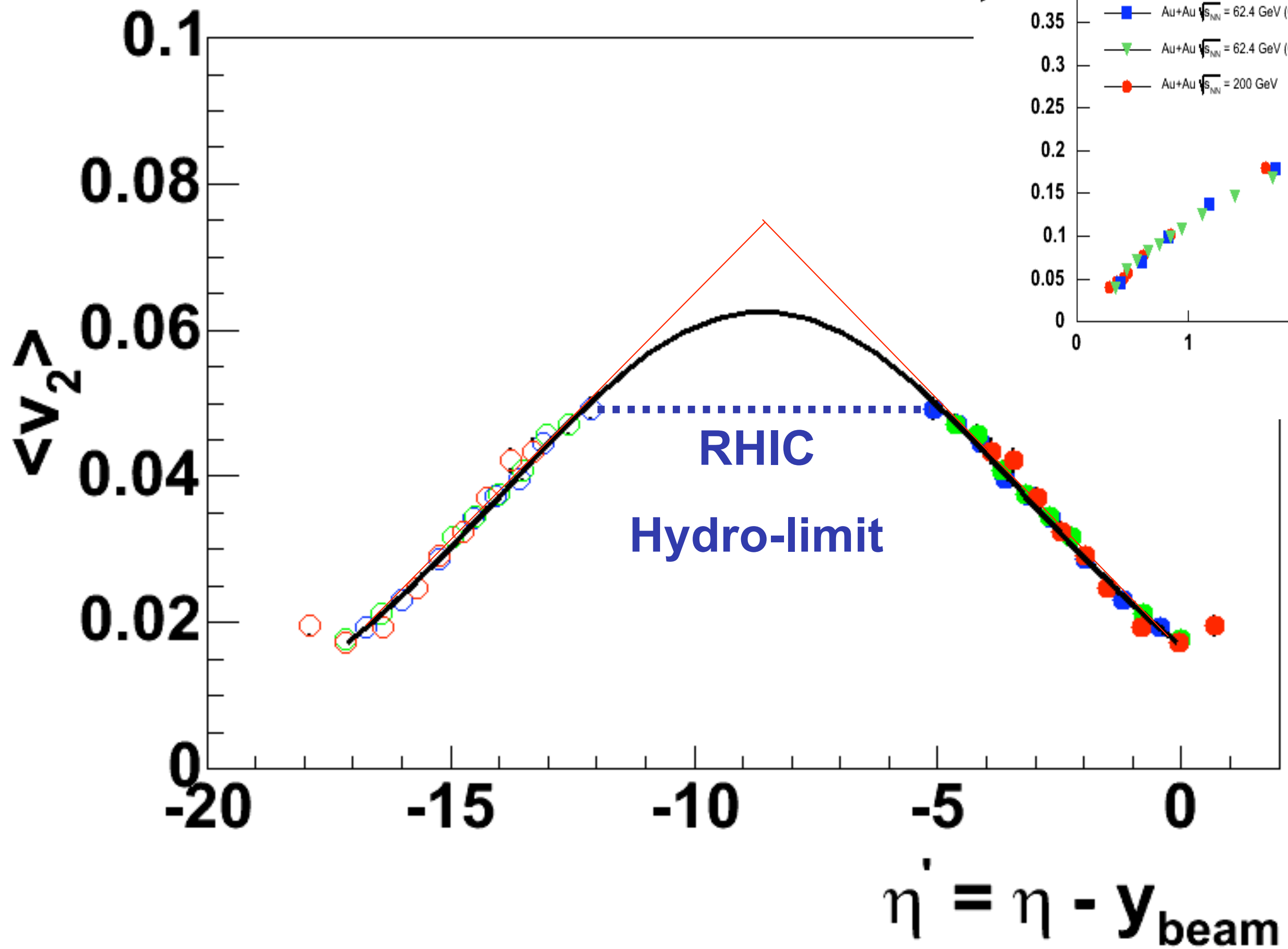
PHOBOS nucl-ex/0406021 Au+Au 0-40%

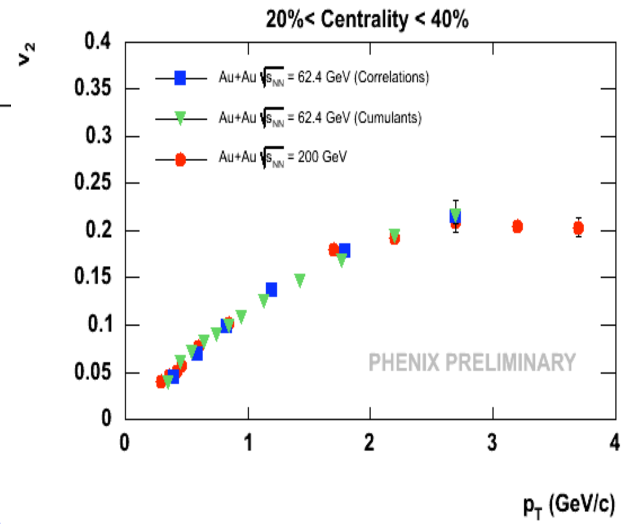




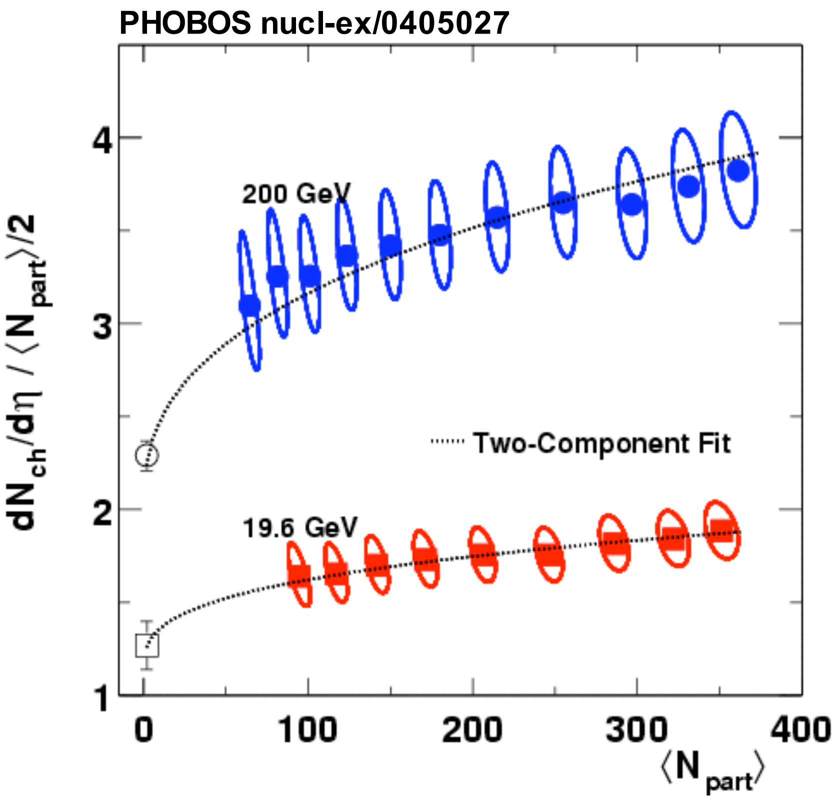
$v_2(h')$ is energy-independent

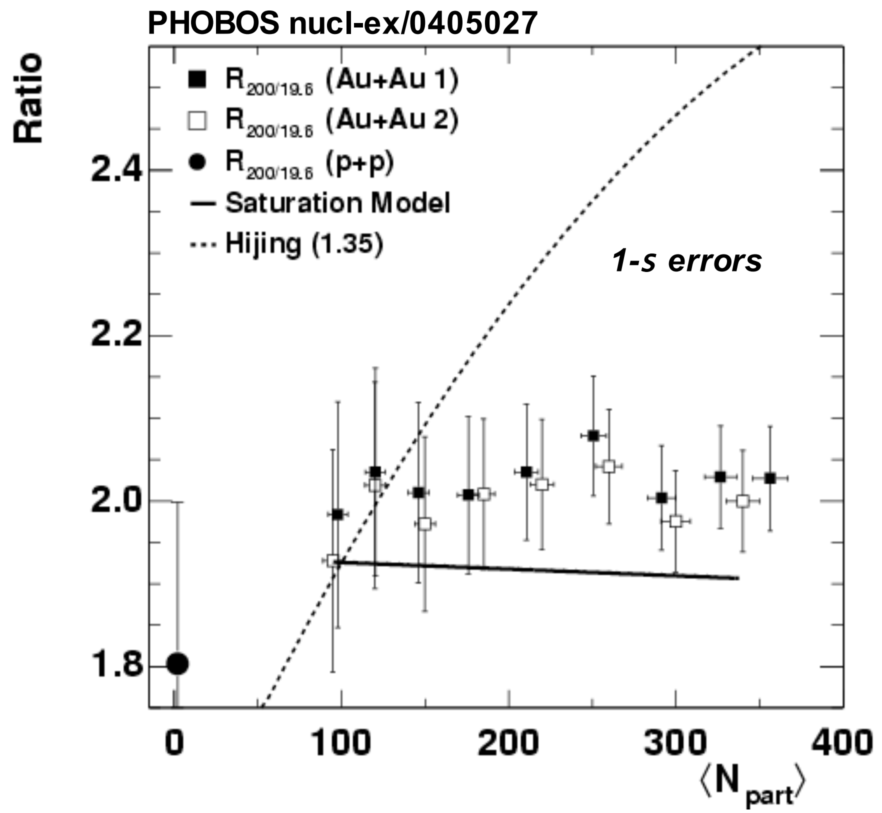
III. Elliptic Flow at LHC





IV. Factorization of Energy/Centrality Dependence





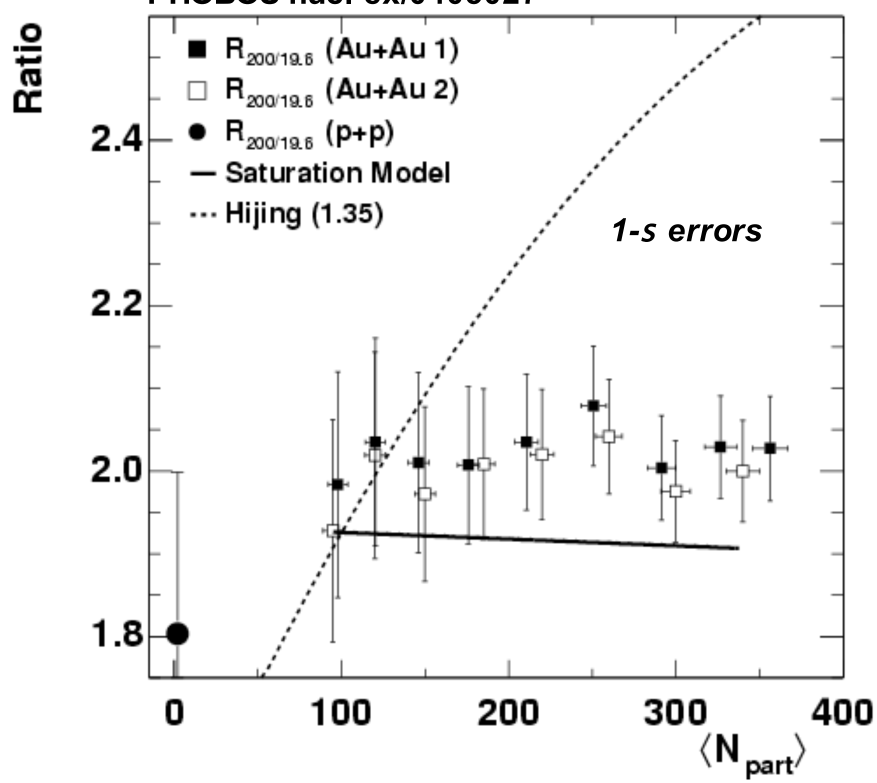
- dN/dh / $<N_{part}/2>$ changes with sqrt(s), $<N_{part}>$
- Energy and Centrality Dependence Factorize

IV. Factorization of Energy/Centrality Dependence

Armesto, Salgado, Wiedemann hep-ph/0407018

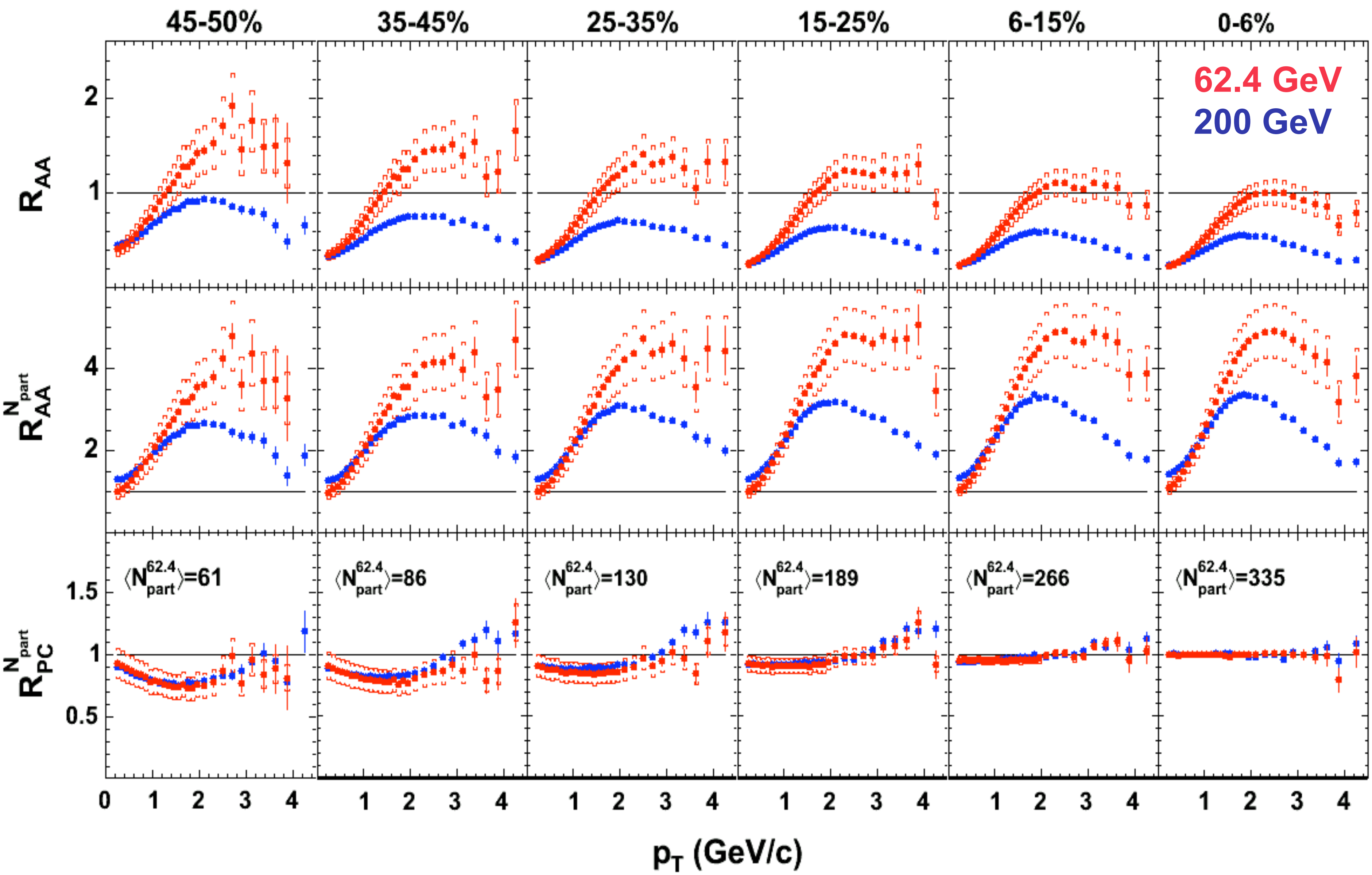
$$\frac{1}{N_{\rm part}} \frac{dN^{AA}}{d\eta}\bigg|_{\eta\sim 0} = N_0 \sqrt{s}^{\lambda} N_{\rm part}^{\frac{1-\delta}{3\delta}}$$

PHOBOS nucl-ex/0405027



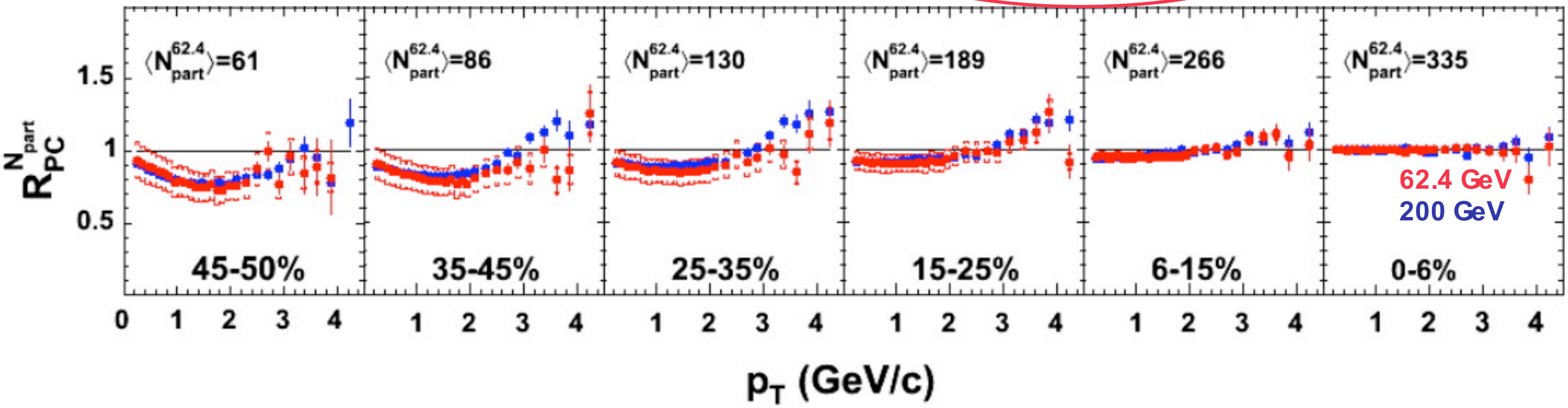
- dN/dh / <N_{part}/2> changes with sqrt(s), <N_{part}>
- Energy and Centrality Dependence Factorize

IV. Factorization of Energy/Centrality Dependence



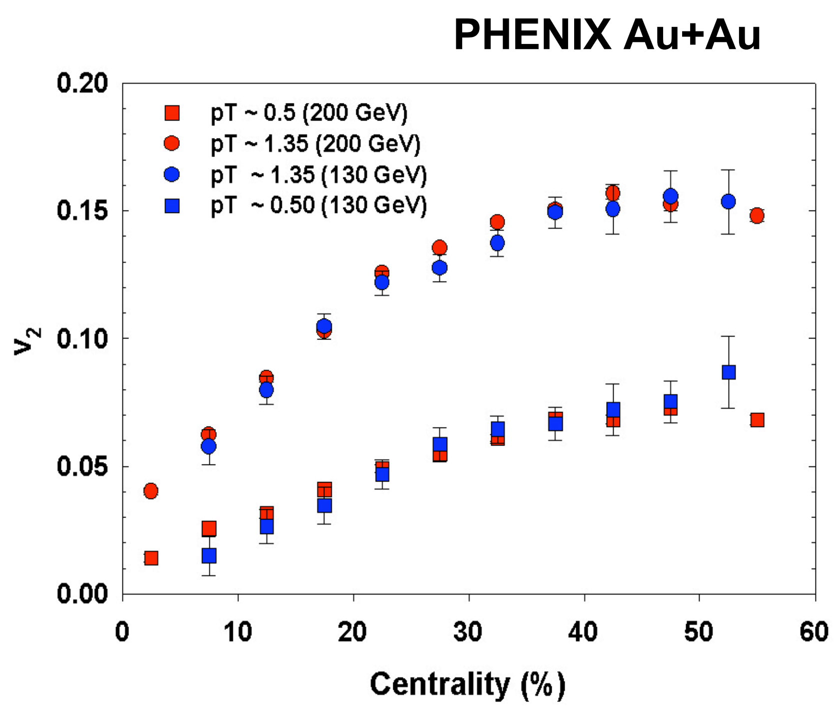
IV. Factorization of Energy/Centrality Dependence

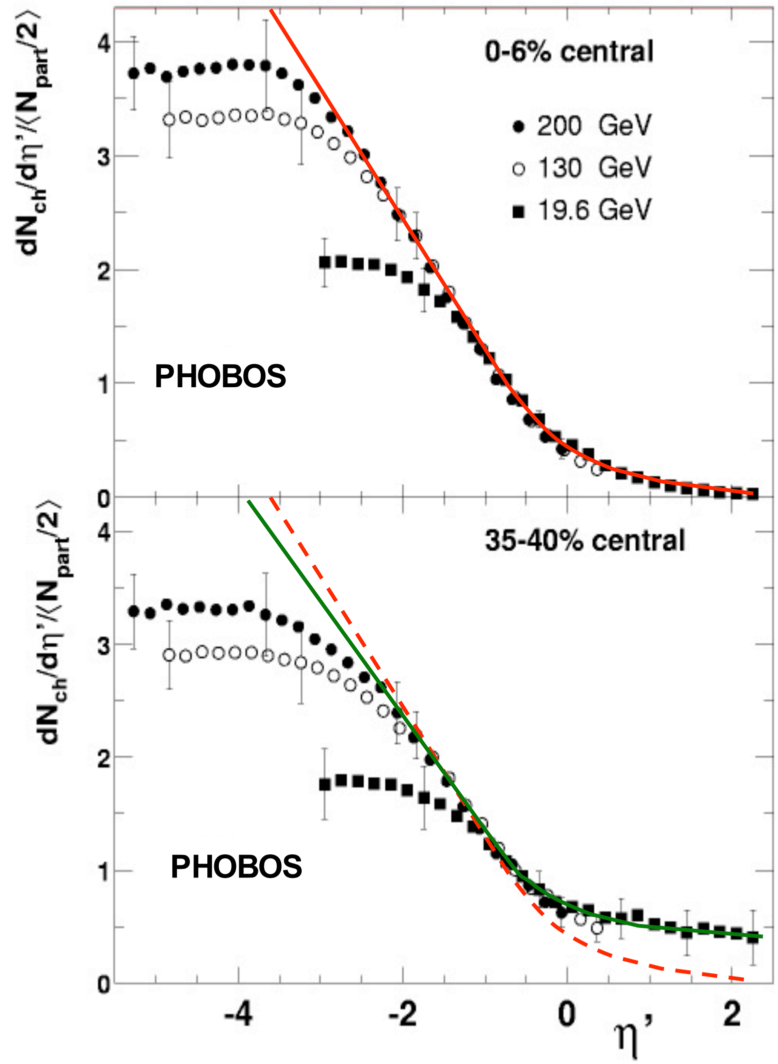
$$R_{PC}^{N_{part}} = \frac{\langle N_{part}^{0-6\%} \rangle}{\langle N_{part} \rangle} \frac{d^2 N_{AA}/dp_T d\eta}{d^2 N_{AA}^{0-6\%}/dp_T d\eta}$$



- Yield/participant changes by less than 25% for all p_T
- Factorization of energy and centrality dependence

Other examples of factorization





Summary

T D Lee, May ‘04

- QGP will be produced at LHC abundantly, and will dominate LHC physics ∵ its strong interaction.
- Need early RHIC II to supplement LHC. Also, e-RHIC to differentiate QED vs QCD

… and it’s up to you guys to make it happen