Relativistic Heavy Ion Physics at RHIC

Korean Physical Society Meeting
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at KNU in Taegu, Korea

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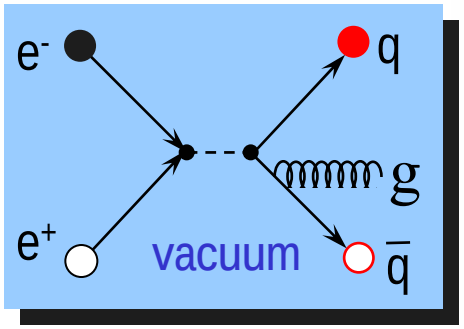
Outline of the talk

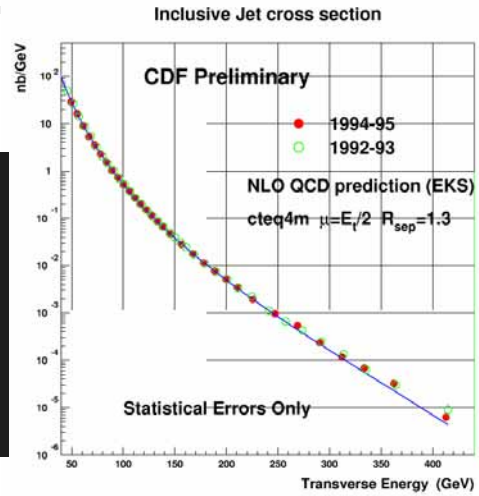
- Motivation and physics goals of Relativistic Heavy Ion programs
- Relativistic Heavy Ion Collider at BNL
- Programs at BNL-RHIC
  - hadrons and quarkonia in Au+Au, d+Au and p+p up to $\sqrt{s_{NN}}$ = 200 GeV
  - leptons and photons
- Another RHI program at CERN-LHC
- Where we are? - as summary -

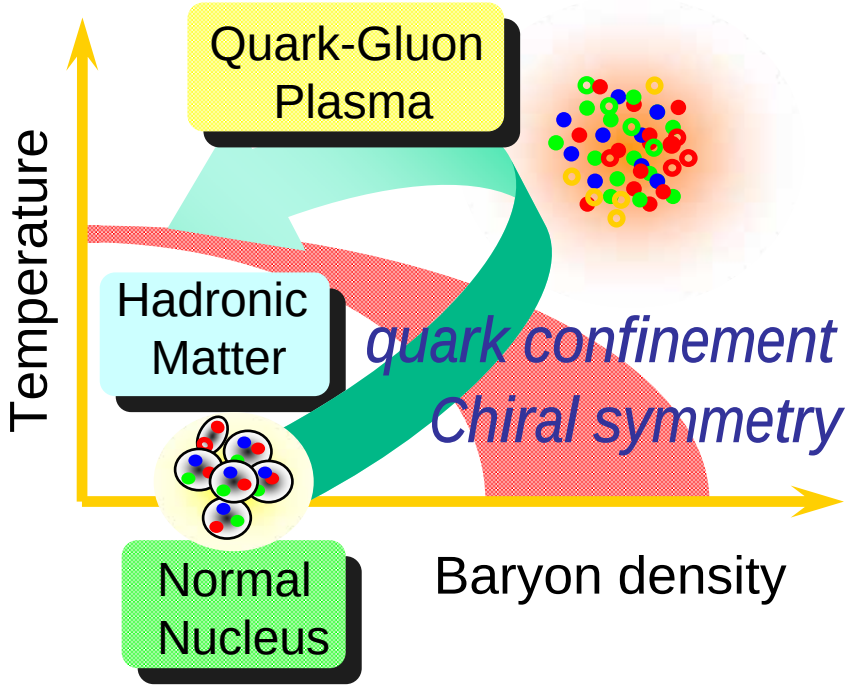
Motivation of RHI programs

- We know the QCD lagrangian, but can handle only at large energy scale.
- Search for partonic matter and understand the *non-perturbative* nature of quarks and gluons;
  - equilibration and EOS
  - color and mass in partonic medium
  - de-confinement and Chiral symmetry
- Look for new physics beyond QCD and/or SM.

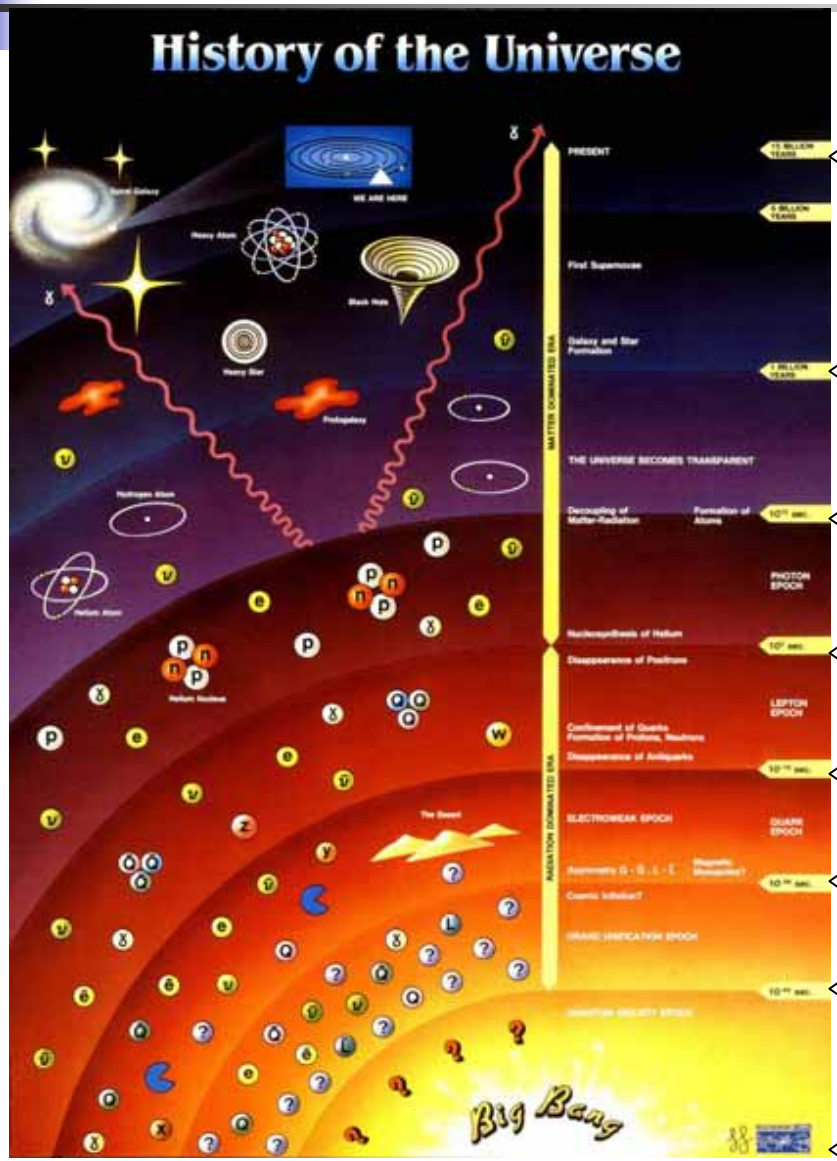
perturbative QCD world







Creating matter in the early Universe

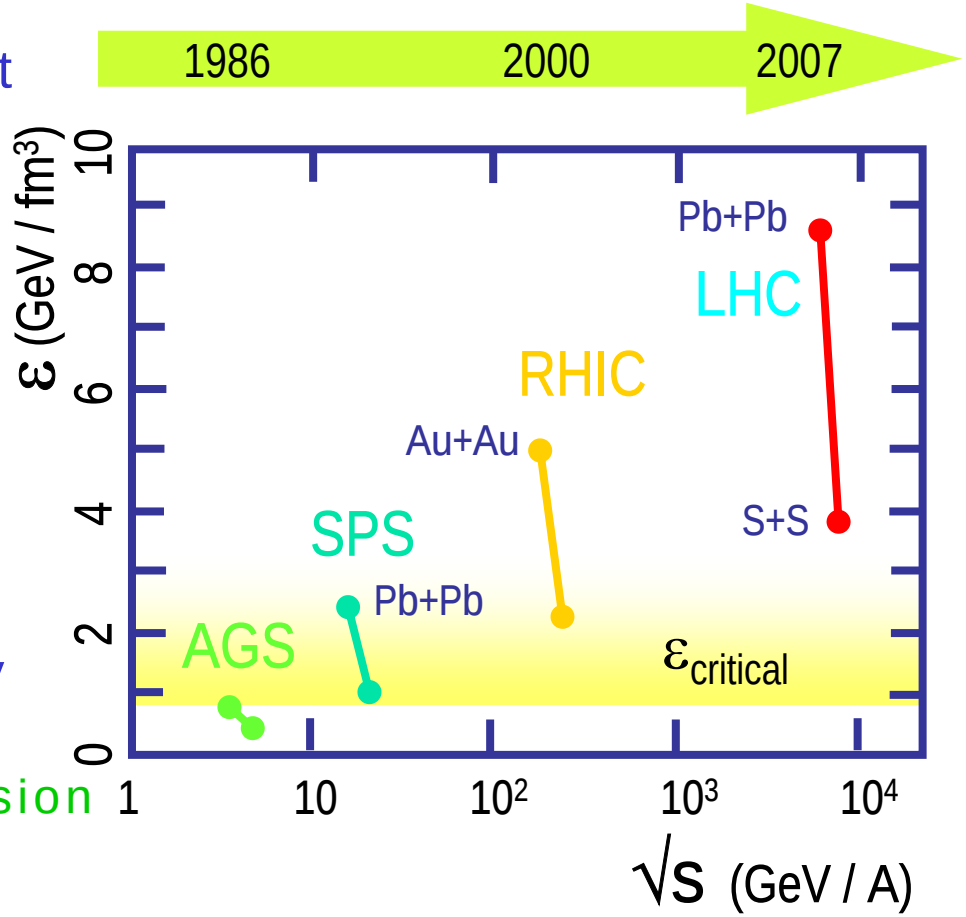


宇宙の歴史

15by	生命の誕生：現在 太陽系の誕生 超新星爆発 重い元素の合成
1by	原始星の誕生 宇宙背景放射 宇宙の晴れ上がり
10^{13}s	原子の生成
10^{2}s	ヘリウム原子核の生成
10^{-10}s	クォークの閉じ込め 物質・反物質の対称性破れ
10^{-34}s	クォークの生成
10^{-43}s	インフレーションの発生
0.00s	宇宙誕生（ビッグバン）

Lessons from AGS and SPS

- Hadrons probe dynamics at the final stage;
  - high baryon density
  - chemical and thermal equilibration
  - multi-strange baryon enhancement
  - explosive hydro-dynamical expansion
- Leptons probe EOS in early stages;
  - J/psi "anomalous" suppression
  - Intermediate-mass dimuon enhancement
  - low-mass dielectron enhancement

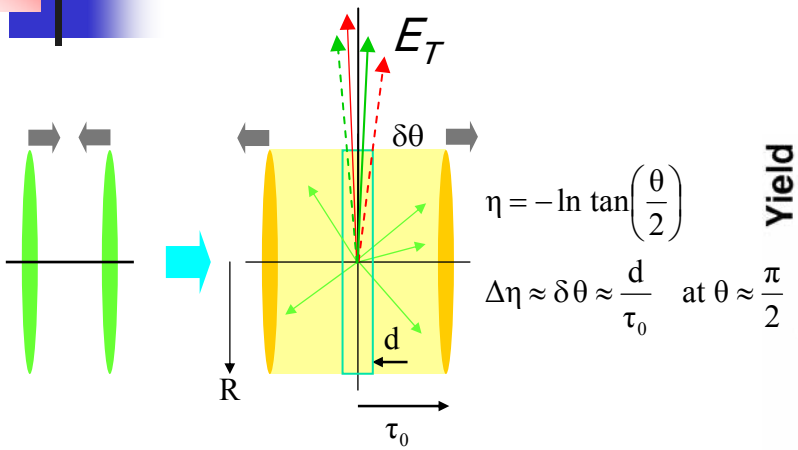


Original picture by U.Heinz, Proceedings of LHC Physics, 1992 CERN

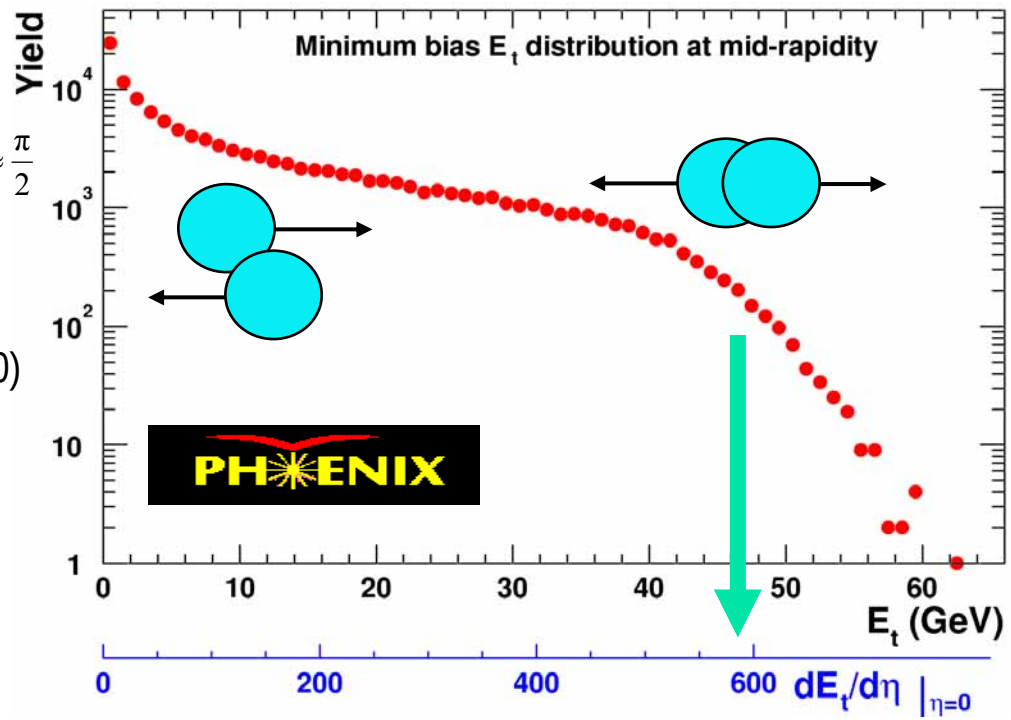
Relativistic Heavy Ion Collider at BNL

- 2 independent super-conducting rings
- 3.83 km circumference
- AGS complex as injector
- up to 100 A GeV Au and/or 250 GeV (polarized) p
- 6 intersections; 4 complimentary experiments
  - BRAHMS – PHENIX – PHOBOS – STAR –

Initial energy density ε achieved



PRL87, 052301 (2001)



Bjorken energy density (PR D27(83)140)

$$\varepsilon_{Bj} = \frac{dE_T}{dy}\frac{1}{\tau_0 \pi R^2}$$

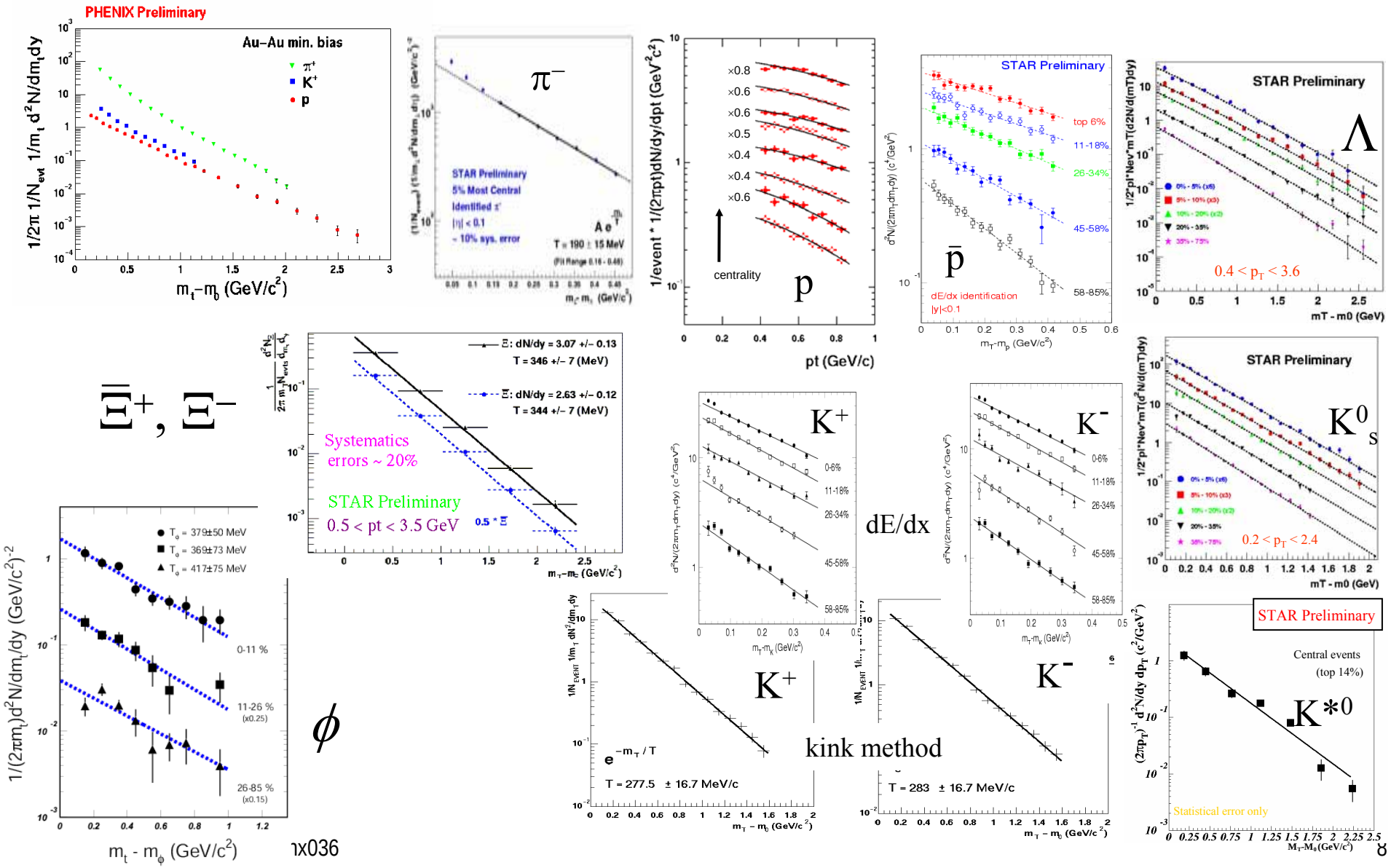
ε ~ 4.6 and 5.5 GeV/fm^3
in Au+Au at $\sqrt{s_{NN}}$=130 and 200 GeV

compared with;

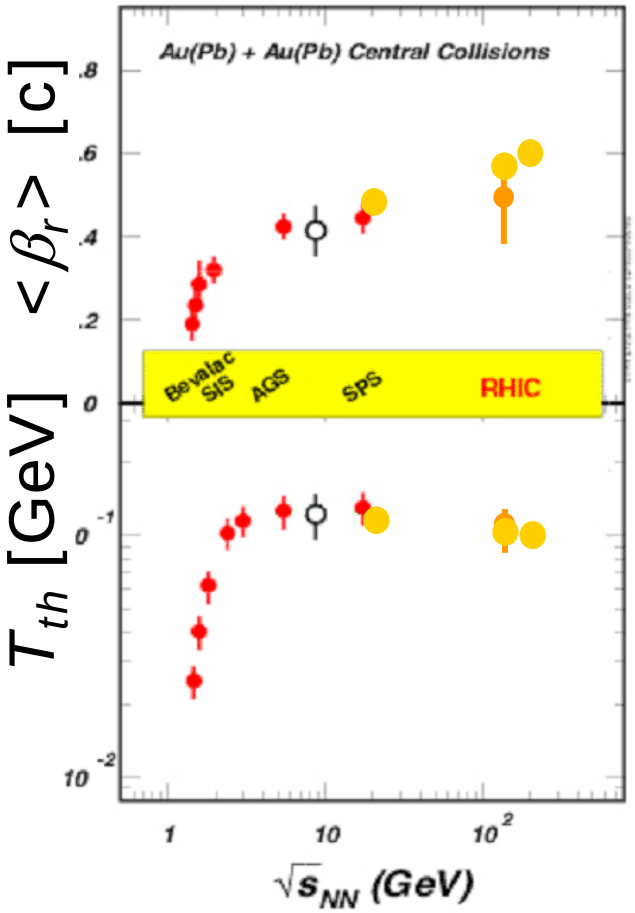
$\varepsilon^{critical} \cong$ 1 ~ 2 GeV/fm^3 by theories and

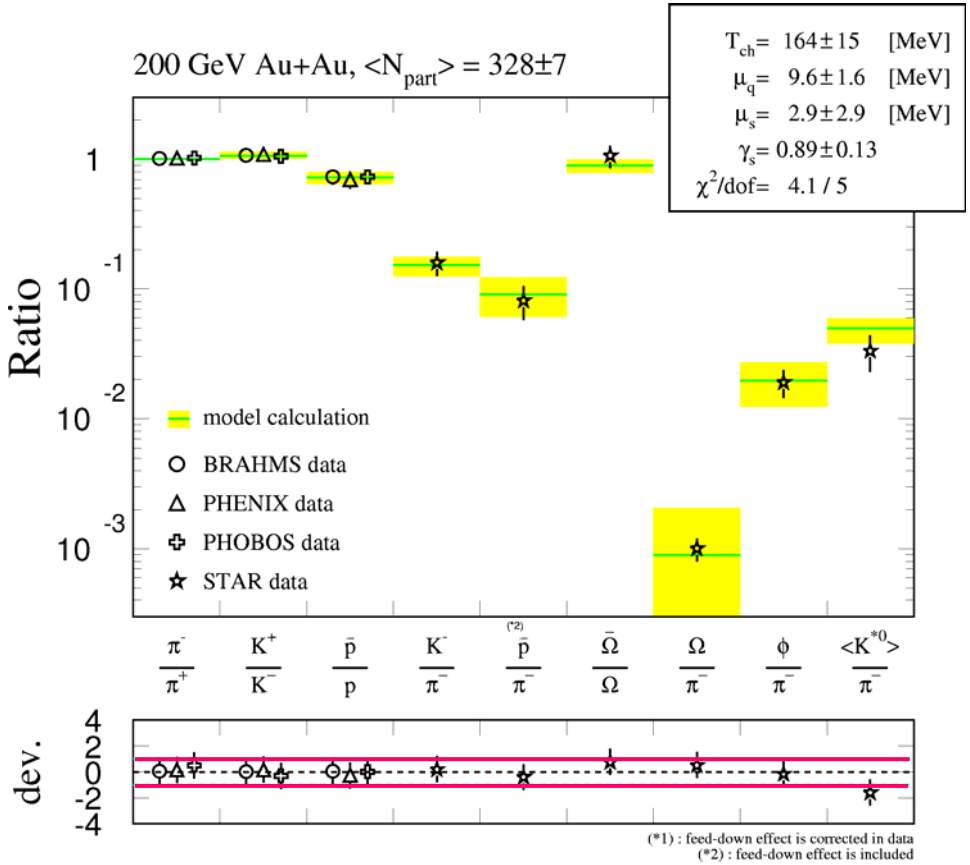
ε ~ 3.2 GeV/fm^3 in Pb+Pb at SPS

Hadron measurements by 4 exp's



Equilibration achieved





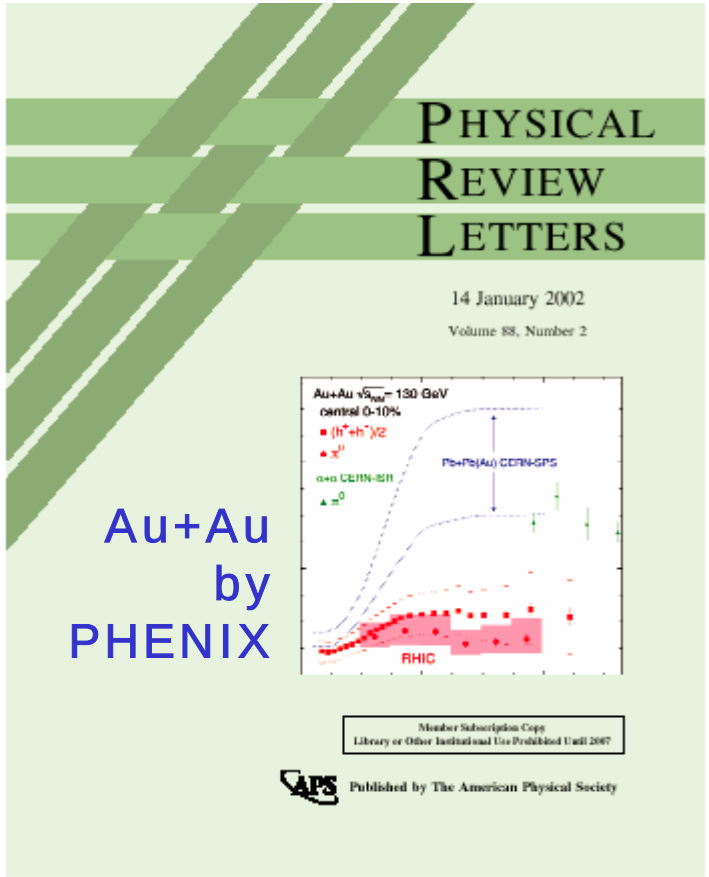
M.K.'s poster for international conference Strangeness in Quark Matter 2003

Distributions are parameterized with; T_{th} and β_r
Yields are parameterized with; T_{ch}, μ_B, μ_s and γ_s

The SPS scenario works again for hadrons, but..

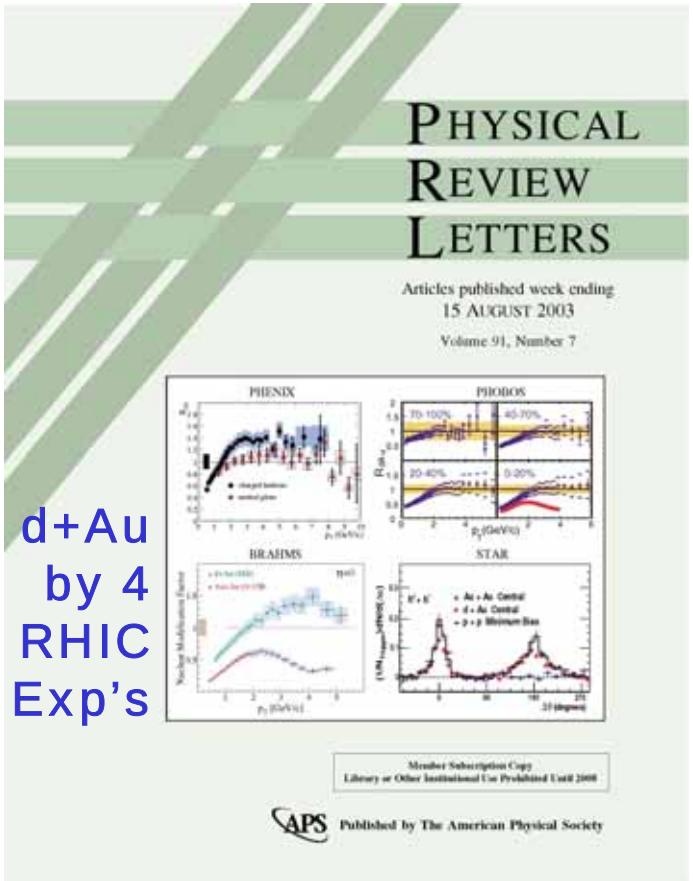
Discovery of jet quenching

PRL 88, Num. 2 (Jan. 2002)



Au+Au by PHENIX

PRL 91, Num. 7 (Aug. 2003)

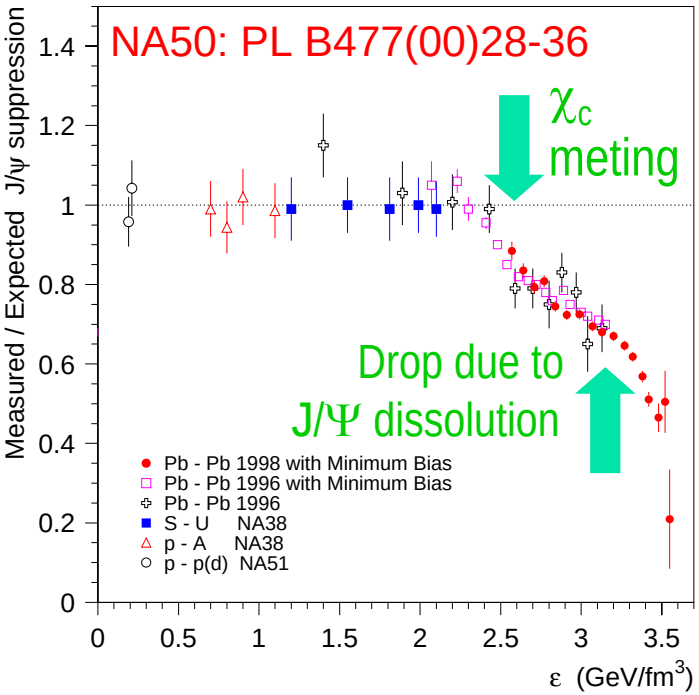


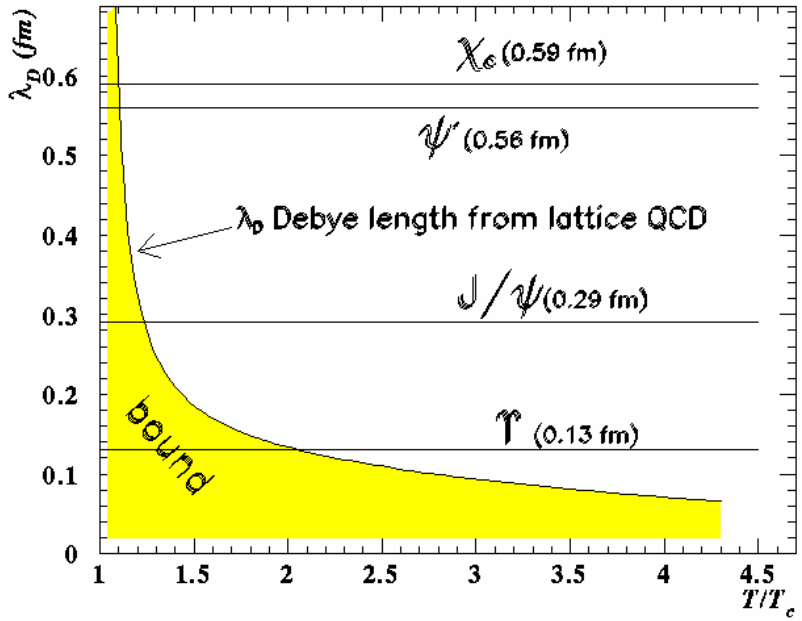
d+Au by 4 RHIC Exp's

This topics will be focused by the next speaker, Prof. J. H. Kang (Yonsei Univ.)

Quarkonia and color force in medium

- T. Matsui & H. Satz predict "melting" Charmonium in QGP; PL 178(86)416.
- penetrating probe of EOS in early stages.
- lattice QCD agrees no bound-states above T_c.





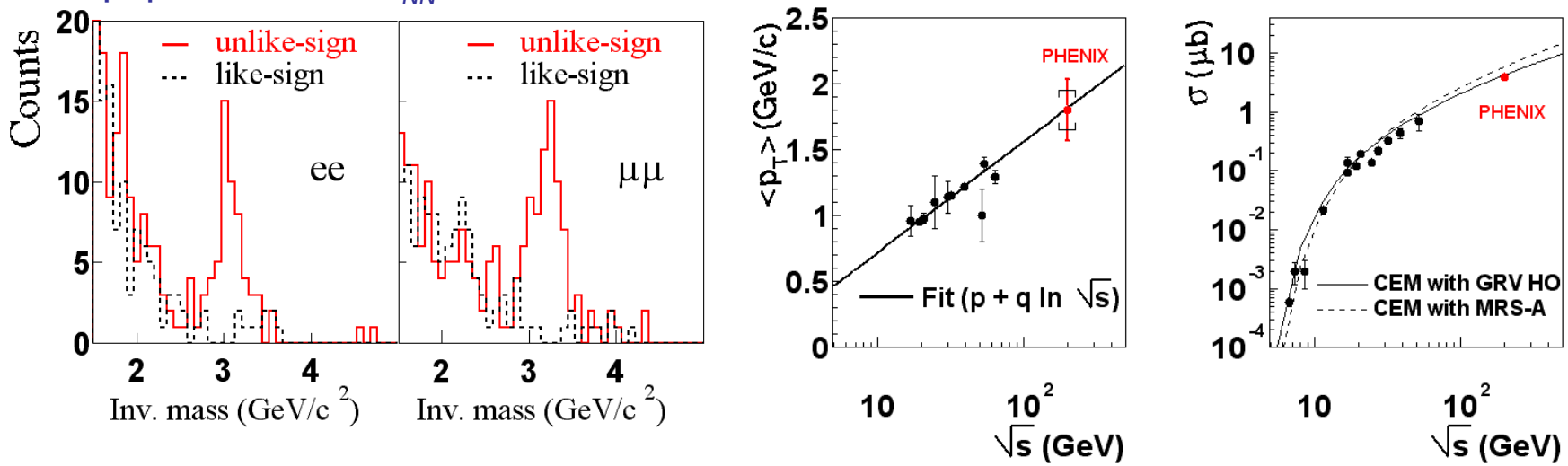
- NA50 at SPS observed "anomalous" suppression of J/Ψ and Ψ(2S).

  Two-step suppression of J/Ψ due to χ_c melting first , and then J/Ψ dissolution at a higher density.
- seems not easy to explain these suppression only from hadronic perspective so far.

The PHENIX J/Ψ's in p+p

p+p→J/Ψ+X at $\sqrt{s_{NN}}$ = 200 GeV

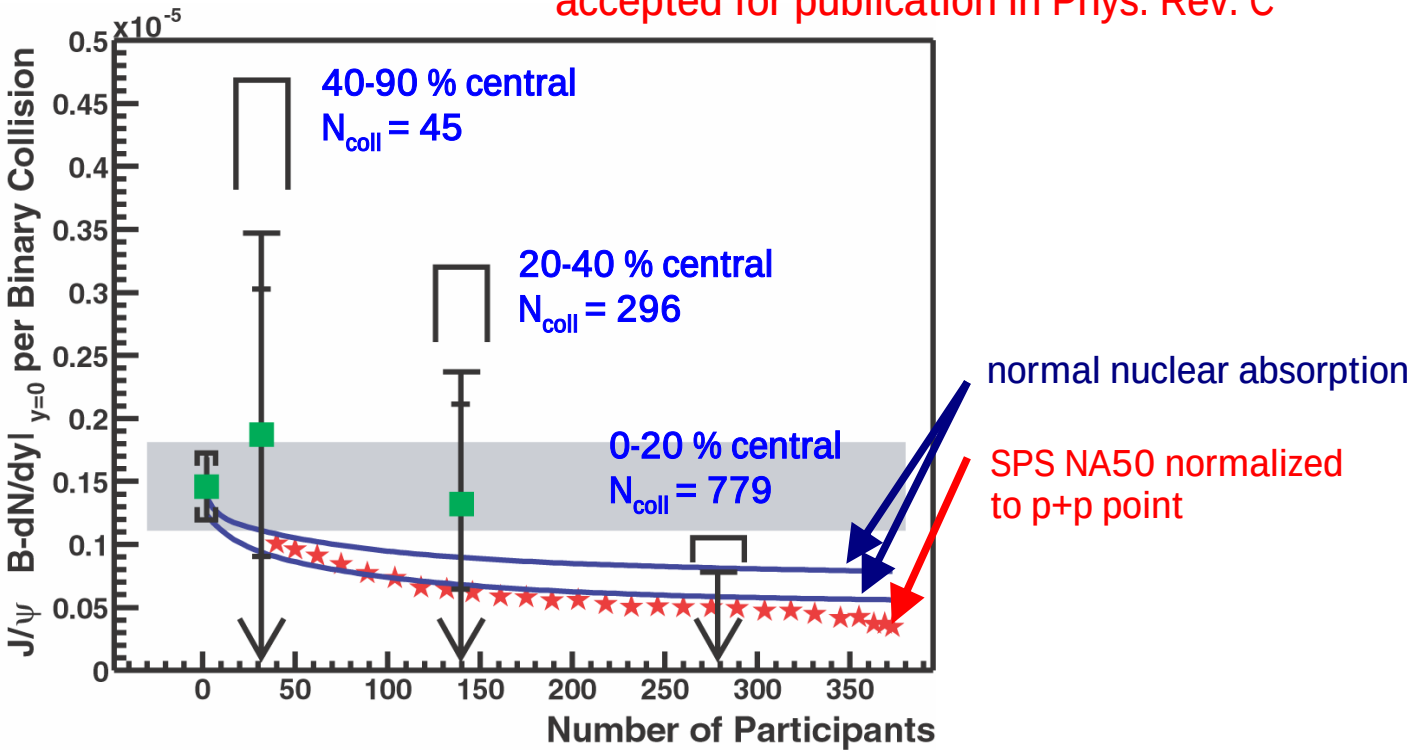
nucl-ex/0307019; submitted to PRL



- clear J/Ψ signals in both central and forward arms
  - expected mass resolutions
  - mean transverse momentum:
    1.80 ± 0.23 (stat.) ± 0.16 (sys.) GeV/*c*
  - integrated cross section:
    3.99 ± 0.61 (stat.) ± 0.58 (sys.) ± 0.40 (abs.) μb
- good agreement with
  - lower $\sqrt{s}$ data and phenomenological extrapolation
  - color evaporation models

The PHENIX J/Ψ's in Au+Au

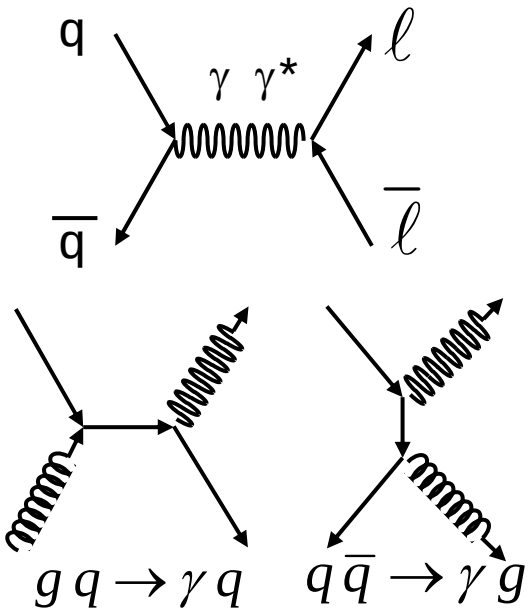
nucl-ex/0305030
accepted for publication in Phys. Rev. C



- not much statistics, but we can say that;
  - binary scaling disfavored
  - inconsistent with enhancement scenarios
    - *e.g.* Phys. Rev. C63 054905 (2001)

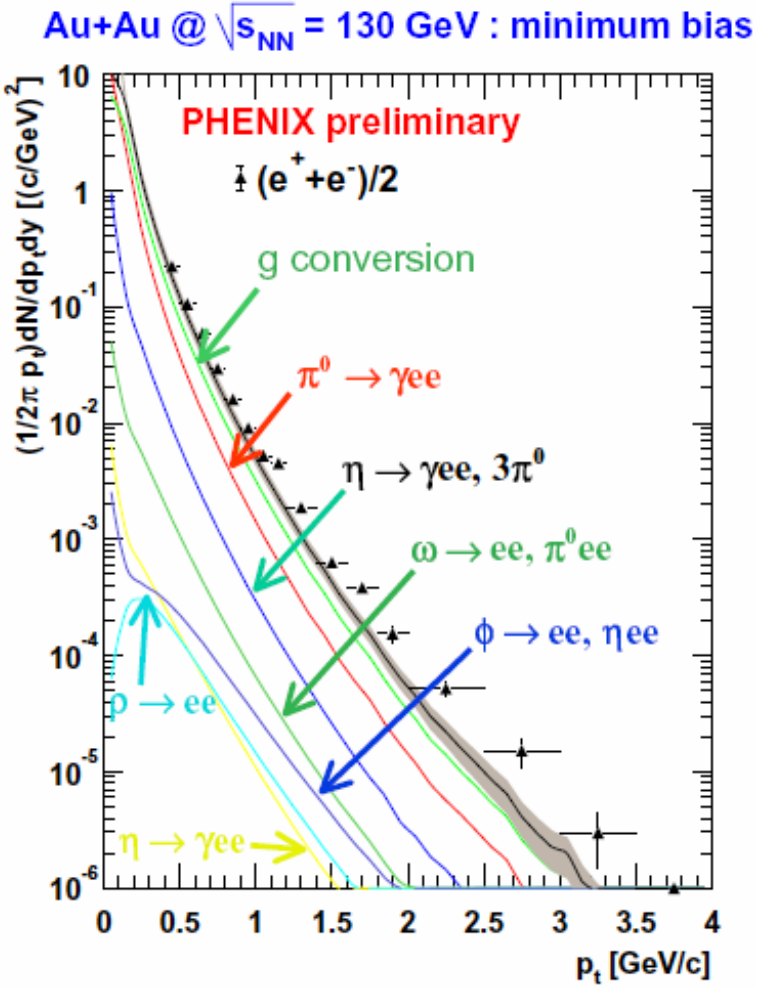
More leptons and Photons

- open heavy flavor (charm, bottom) production
  - probe of initial state and good reference to J/Ψ production
  - jet quenching effects to heavy quarks
- light vector mesons (ϕ, ω, ρ)
  - probe of chiral symmetry restoration
- thermal dileptons
  - possible mass window at 1-2 GeV;
  - *cf.* direct photons
- direct photons
  - probe initial parton distribution and
  - final state parton/hadron re-scattering

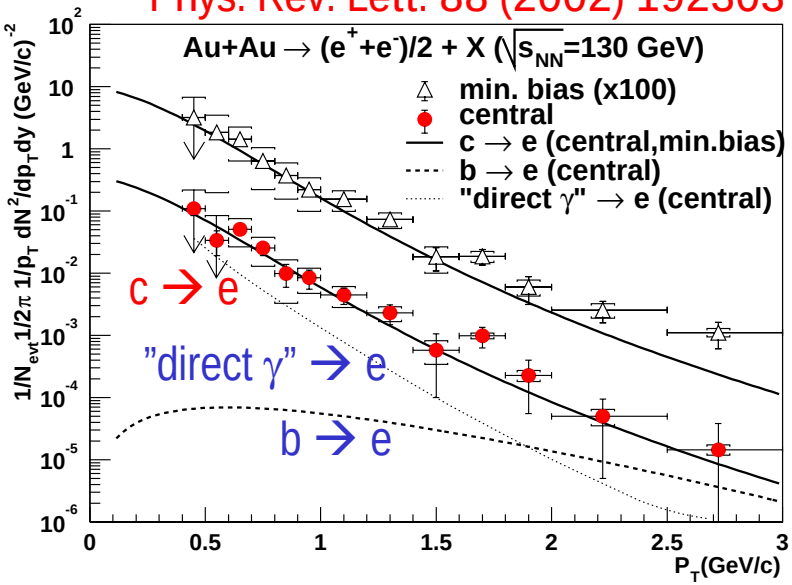


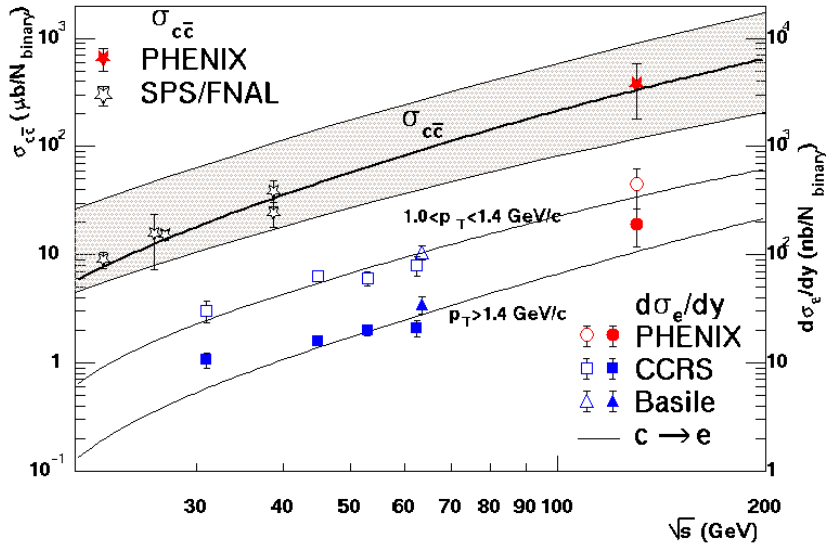
- These measurements are scheduled in the coming Au+Au run starting in a month.
- More activities are ongoing, including hardware upgrades, to complete the goals.

Open charm production by single e±



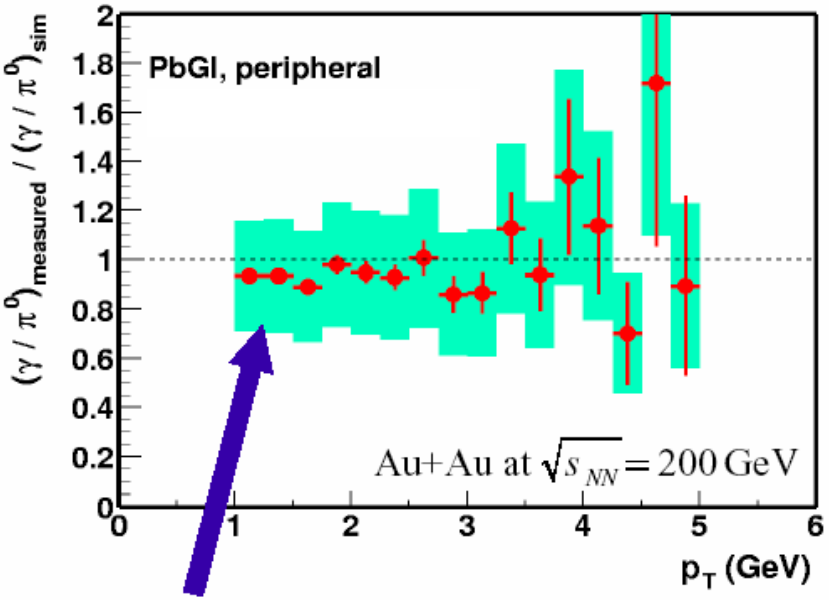
Phys. Rev. Lett. 88 (2002) 192303



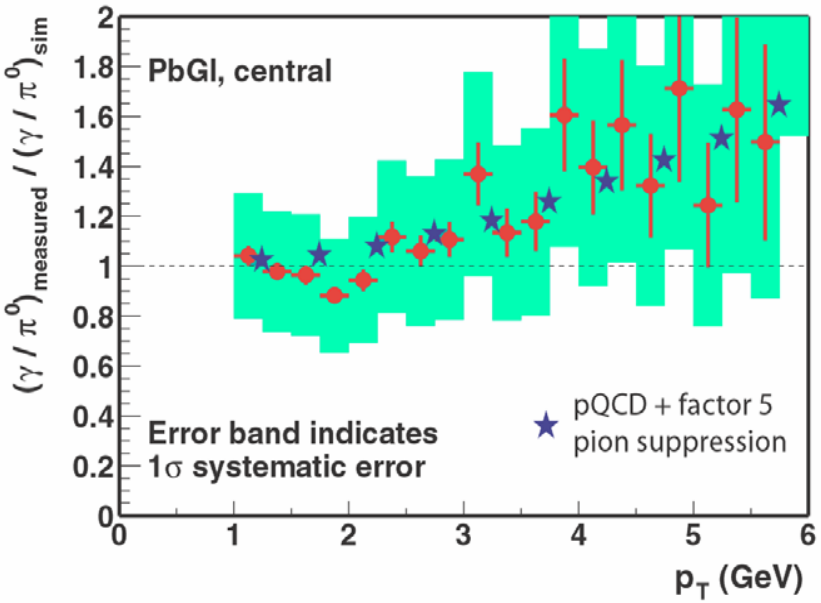


Looks "*no large suppression*"
- unlike light quarks! -

Direct photons in PHENIX



Boxes: 1σ systematic error

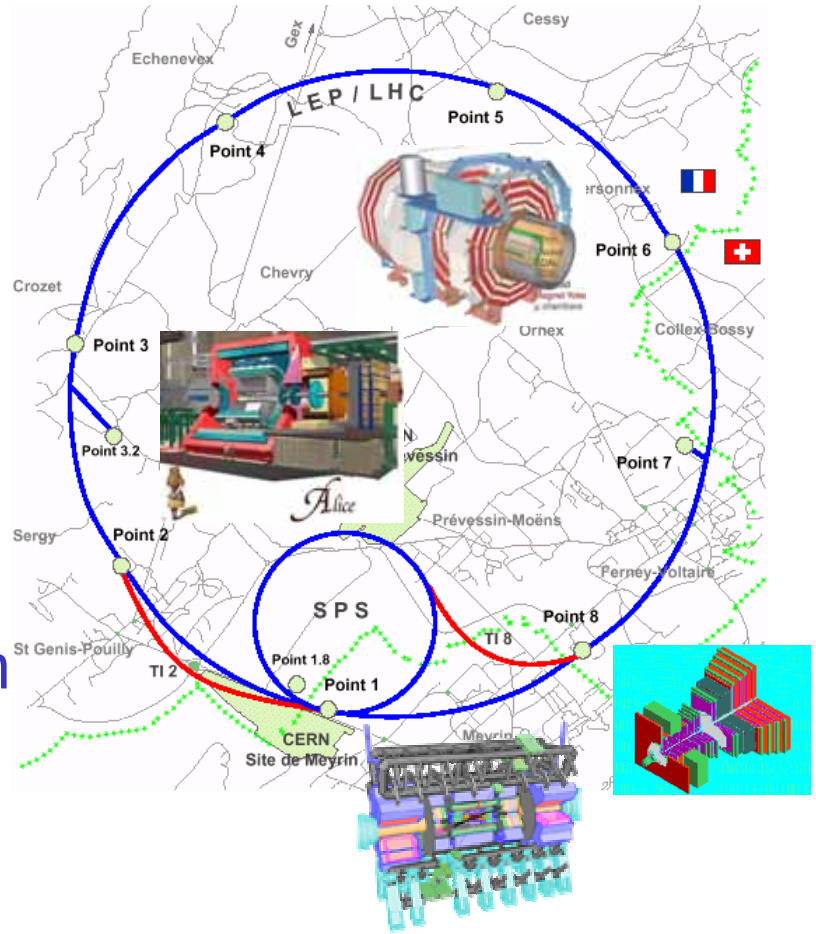


Au+Au→γ+X at $\sqrt{s_{NN}}$ = 200 GeV
PHENIX preliminary

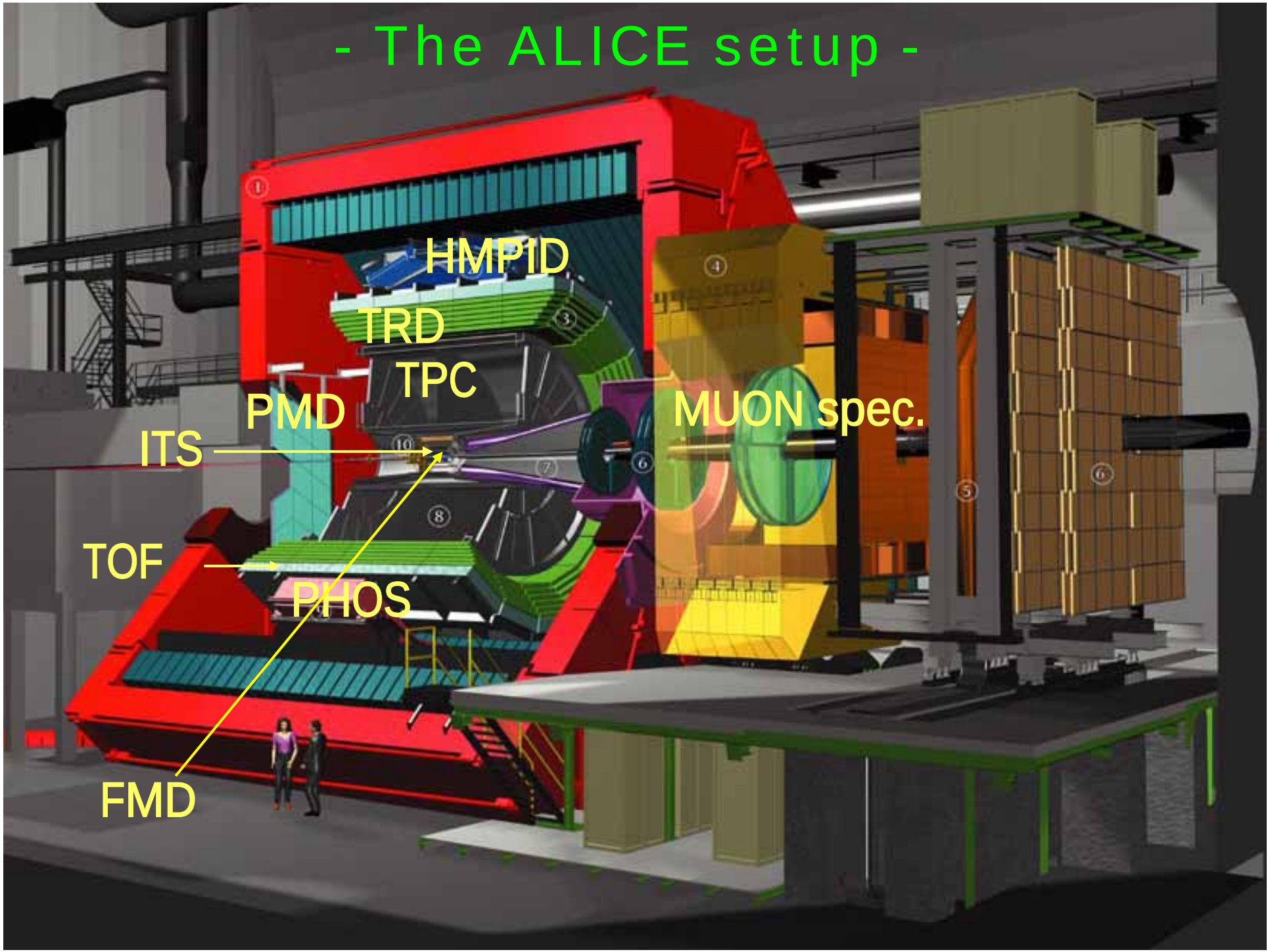
- no direct photon excess seen within errors
  - based on measured neutral pion spectrum
- systematic error to be reduced in further analysis

Next generation of a RHI collider

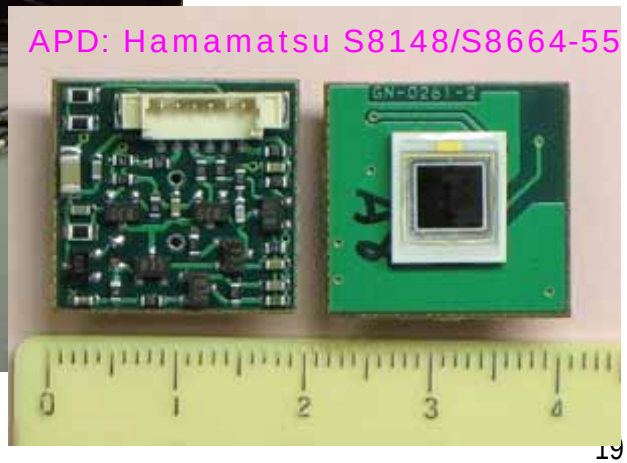
- LHC is a RHI Collider
  - former LEP tunnel
  - 27 km circumference
  - up to 2.8 A TeV Pb
  - a factor of 28 times higher $\sqrt{s_{NN}}$ than RHIC
- ALICE only the one
  - cover in single experiment what is by 4 at RHIC and by several at SPS and AGS
- Goals of the RHI program
  - examine the *QGP* state after the "discovery" at RHIC
  - fully understand the non-perturbative QCD nature of quarks and gluons
  - look for what *NOT* expected



- The ALICE setup -



The ALICE status



- L3 magnet has been reformed for ALICE at the point 2.
- the Muon magnet will be installed soon.
- various detectors are in R&D/testing/production

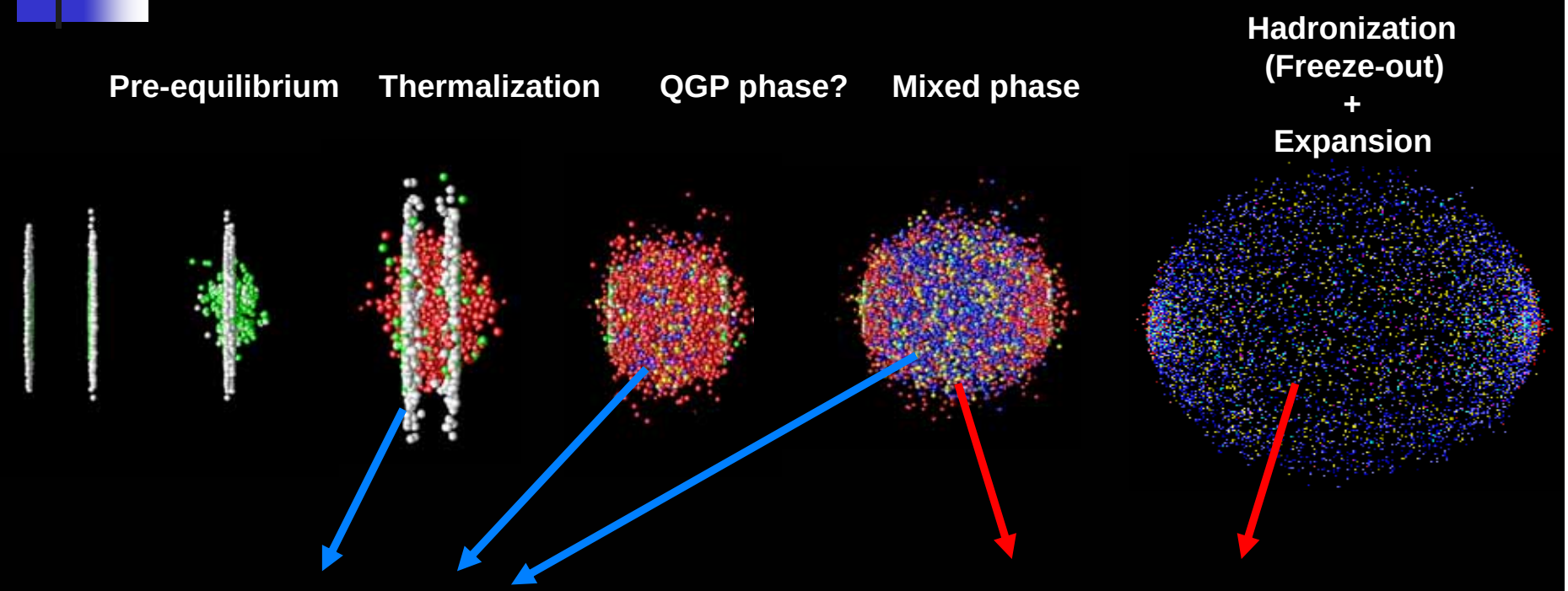
Where we are? - as summary -

- Do we see anything exciting at RHIC?
  - Yes, we do: *e.g.* see the next talk and recent PR(L)'s
- Have we discovered *Quark-Gluon-Plasma*?
  - "it's a quark-gluon plasma. period." (M. Gyulassy)
  - "maybe premature to claim triumph." (~experimentalists)
- What's up in the next runs?
  - probe of deconfinement via rare processes
    - light vector mesons and quarkonia: J/Ψ, Ψ'
    - low- and intermediate-mass dileptons
  - probe EOS in early stages
    - direct photons and heavy quarks
- Will RHI physics/program ends at RHIC?
  - RHIC presenting rich harvest;
  - even more fruitful physics ahead of us at BNL and CERN

Stay tuned.

backup

Relativistic Heavy Ion Collision



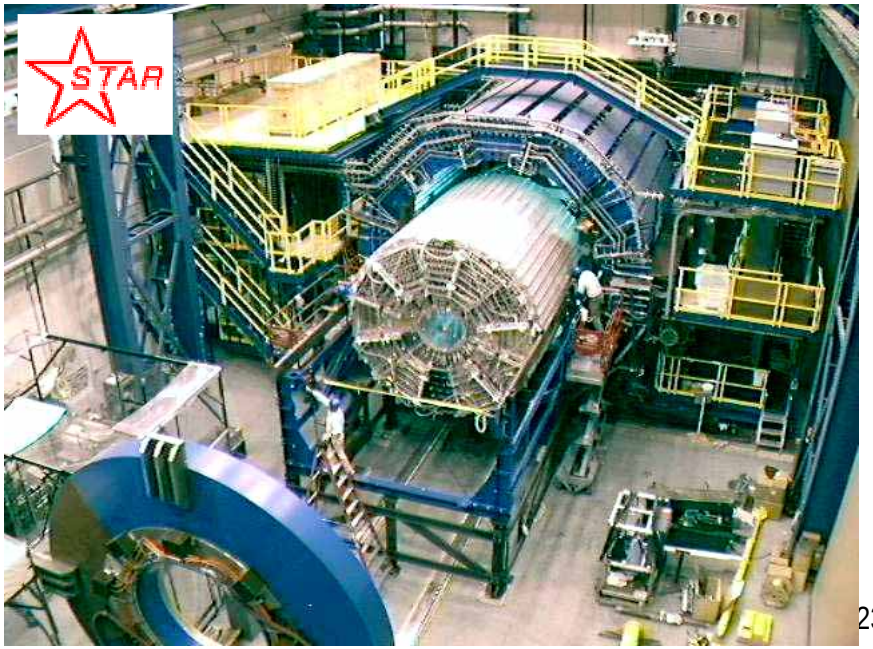
$\gamma, \gamma^* \rightarrow e^+e^-, \mu^+\mu^-$

$\pi, K, p, n, \phi, \Lambda, \Delta, \Xi, \Omega, d, \ldots$

Real and virtual photons from q scattering sensitive to the early stages (penetrative probes).

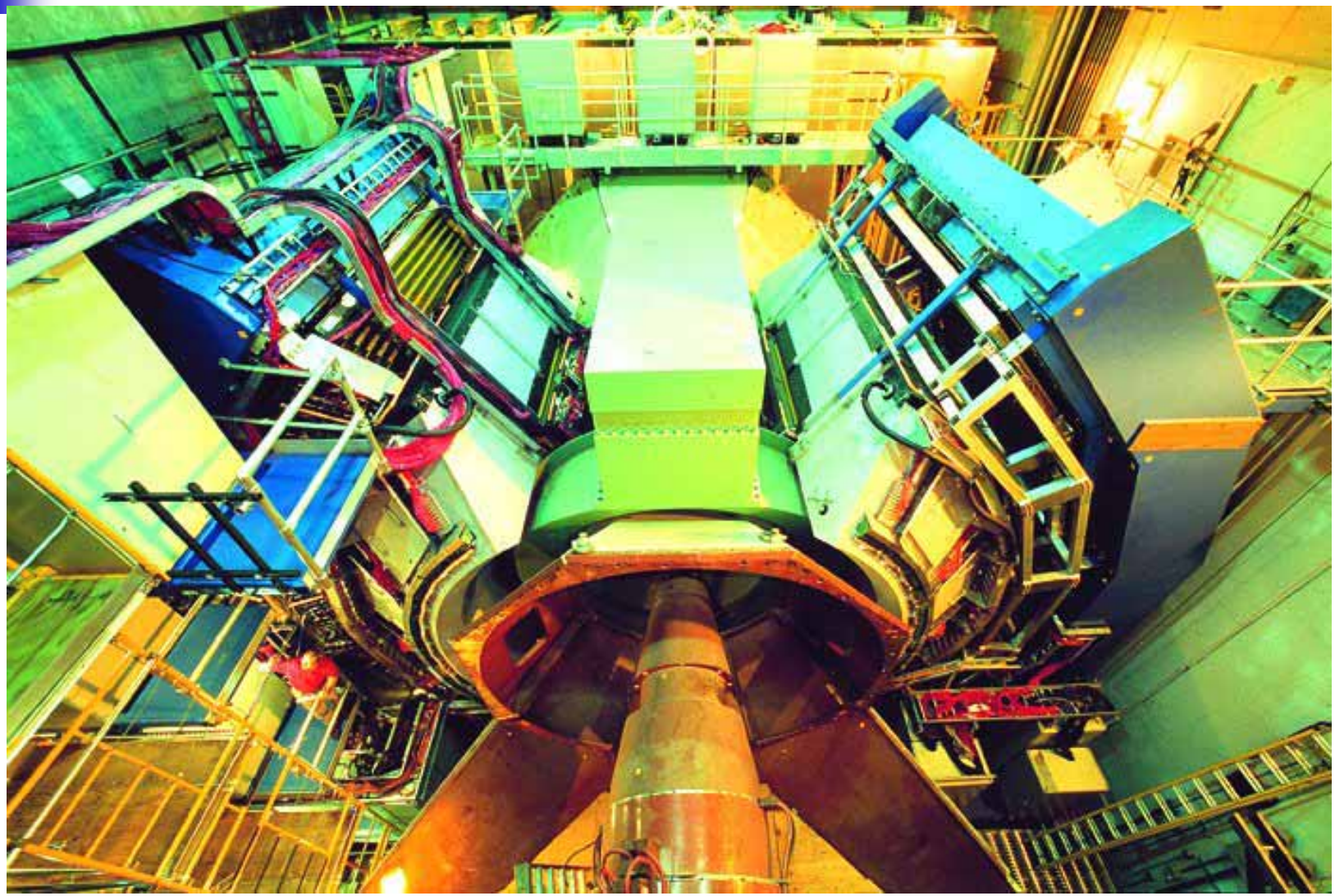
Hadrons reflect medium properties when inelastic collisions stop (chemical freeze-out).

The RHIC Experiments

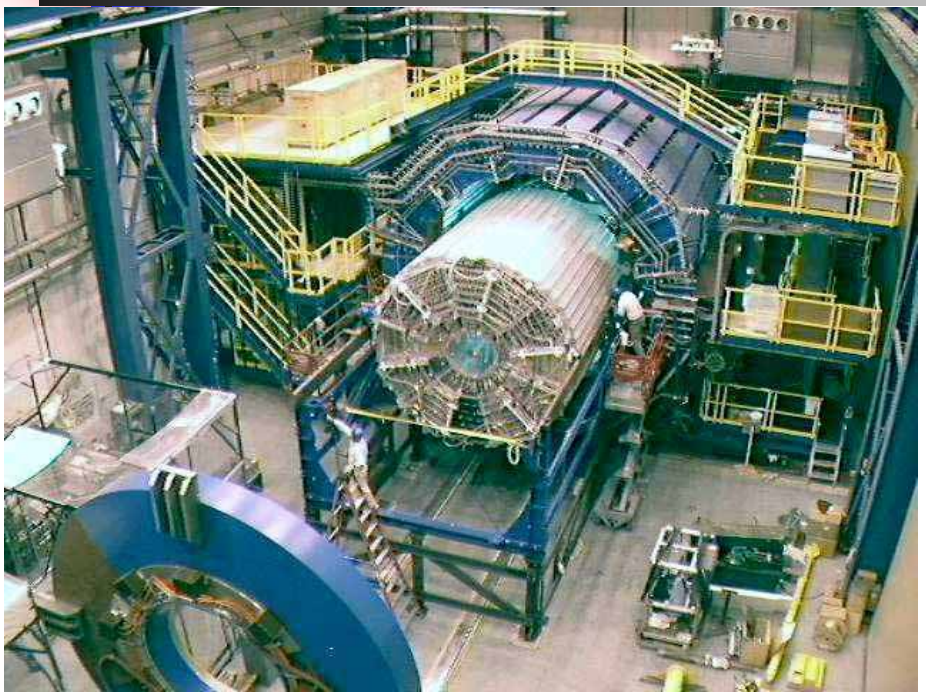


Pioneering High Energy Nucl. Interaction Exp.

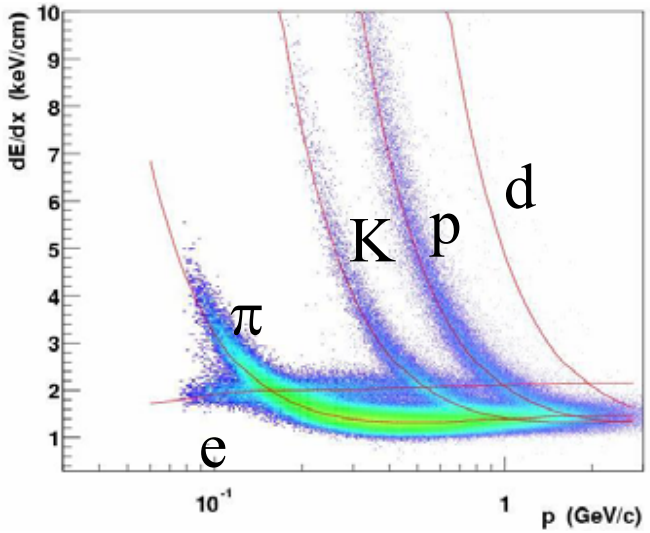
- maximal set of probes and physics channels
  - photons/electrons/muons/hadrons
  - unique emphasis on penetrating probes
- high quality measurement
  - good particle identification
  - high resolution
  - wide kinematical coverage
- access to rare processes
  - high rate capability
  - selective multi-level triggering

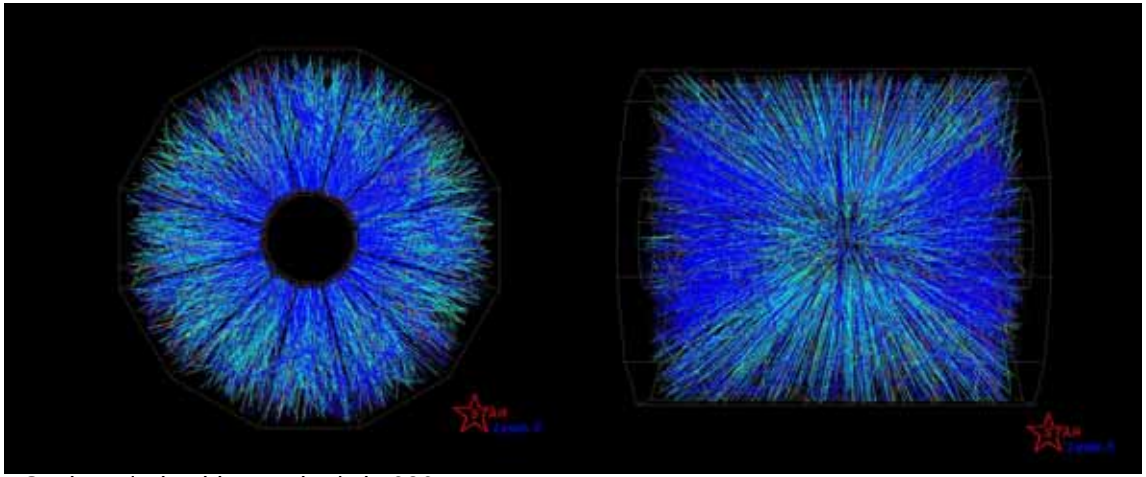


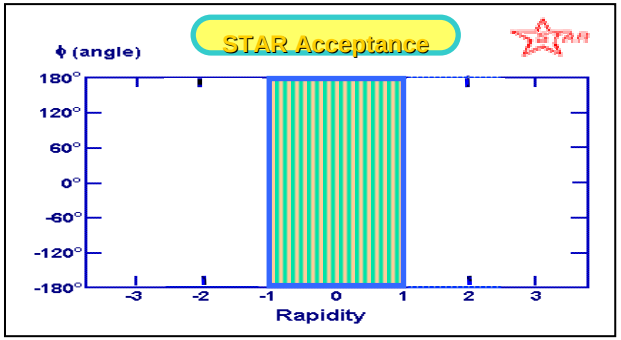
STAR (Solenoidal Tracker at RHIC)



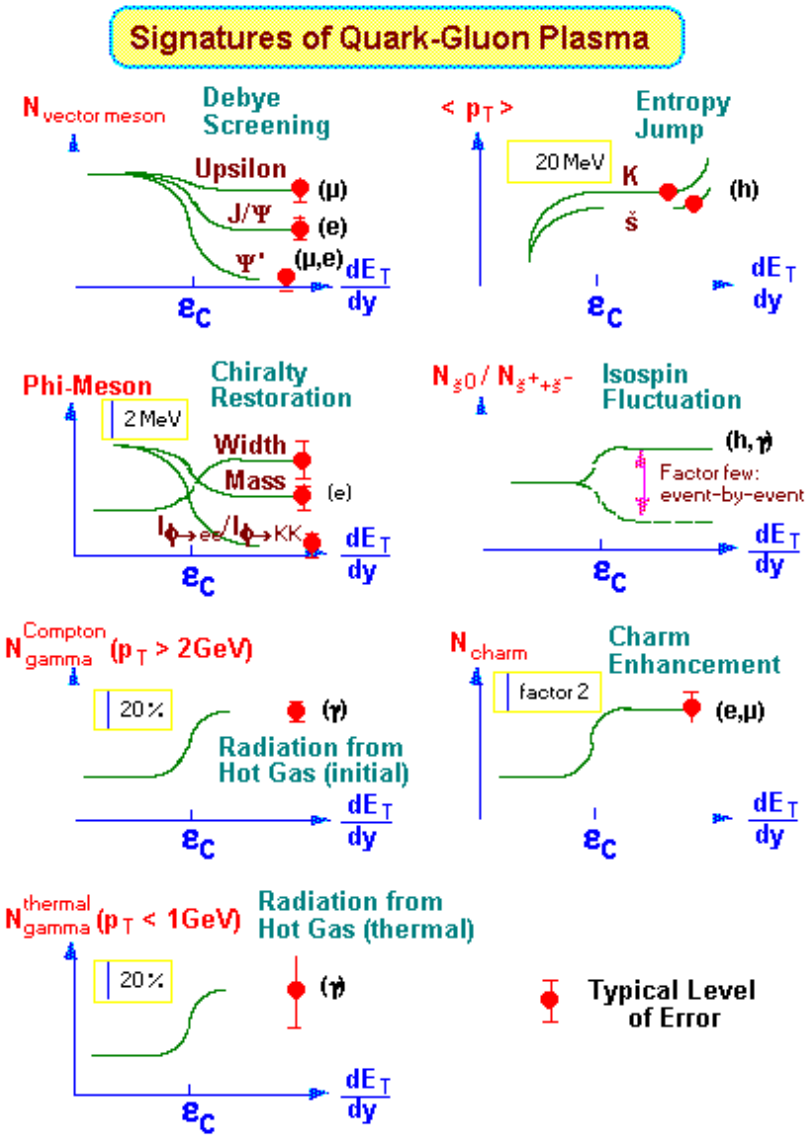
- A large volume TPC covers $|\eta| < 1$ with a full azimuthal coverage.
- PID capability of TPC - dE/dx and RICH.
- Topological PID technique for short lived and/or neutral particles.







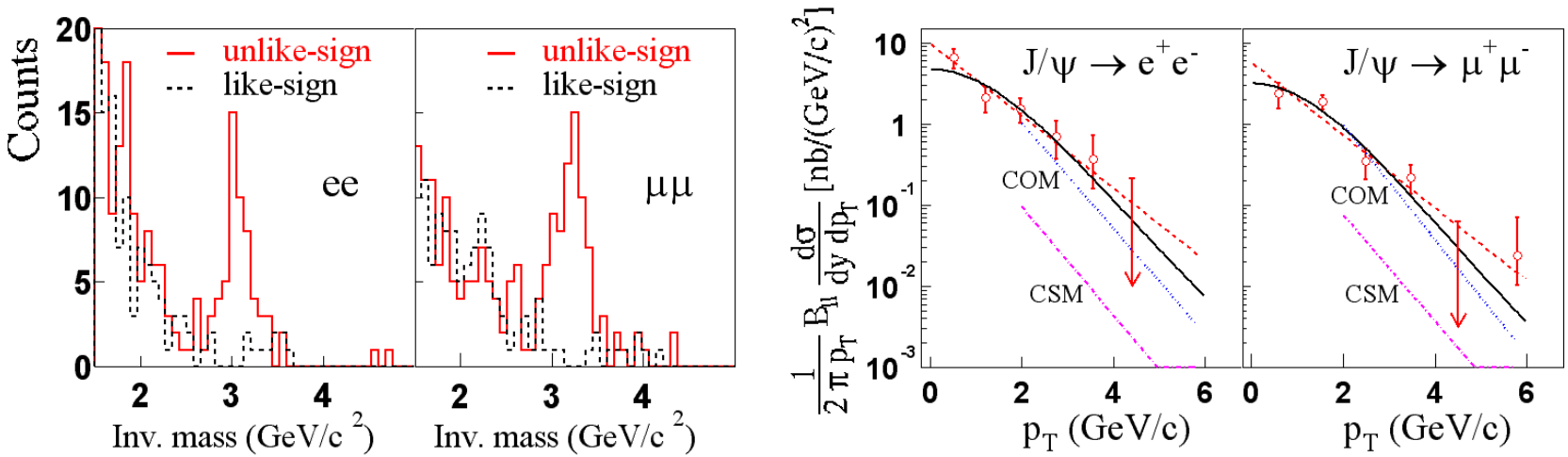
PHENIX Physics Strategies



various signatures; essentially all time scales

- initial hard process
  - jets, high *pt* hadrons/photons
- deconfinement
  - heavy vector mesons
- chiral symmetry restoration
  - light vector mesons, disoriented chiral condensation
- thermalization
  - thermal photons/dileptons, open charms/bottoms
- hadronization
  - hadron spectra, strangeness, HBT interferometry
- hydro-dynamics
  - transverse energy, *dN/dy*

The PHENIX J/Ψ's in p+p



p+p→J/Ψ+X at $\sqrt{s_{NN}}$ = 200 GeV
nucl-ex/0307019; submitted to PRL

- clear J/Ψ signals in both central and forward arms
  - expected mass resolutions
  - mean transverse momentum:
    1.80 ± 0.23 (stat.) ± 0.16 (sys.) GeV/*c*
  - integrated cross section:
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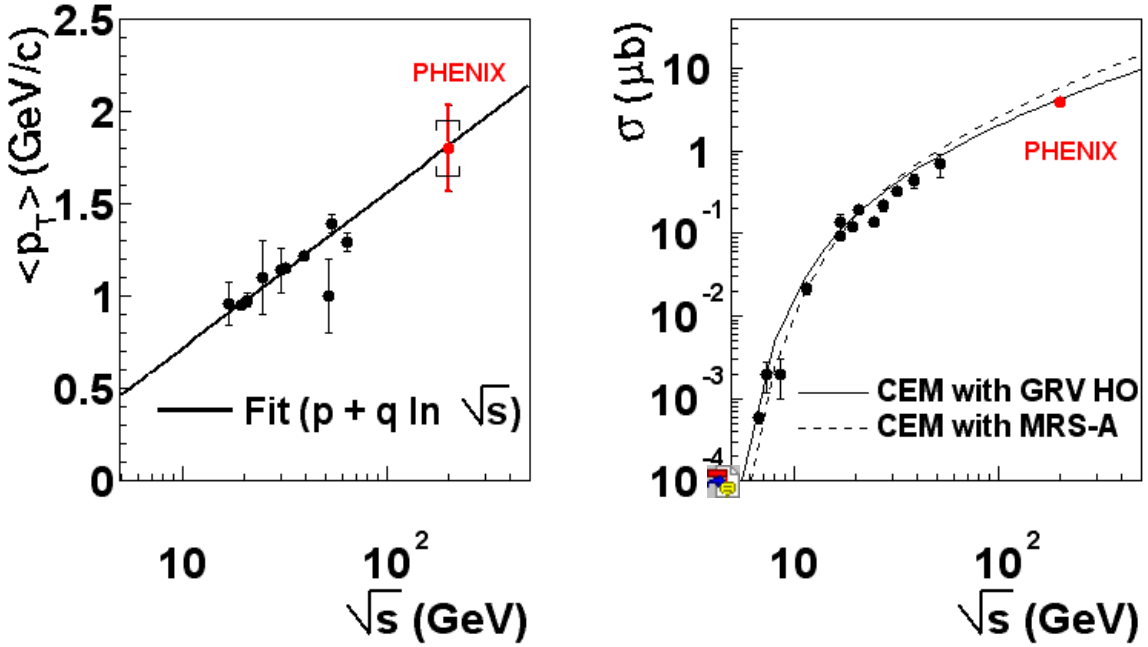
The PHENIX J/Ψ compared with data



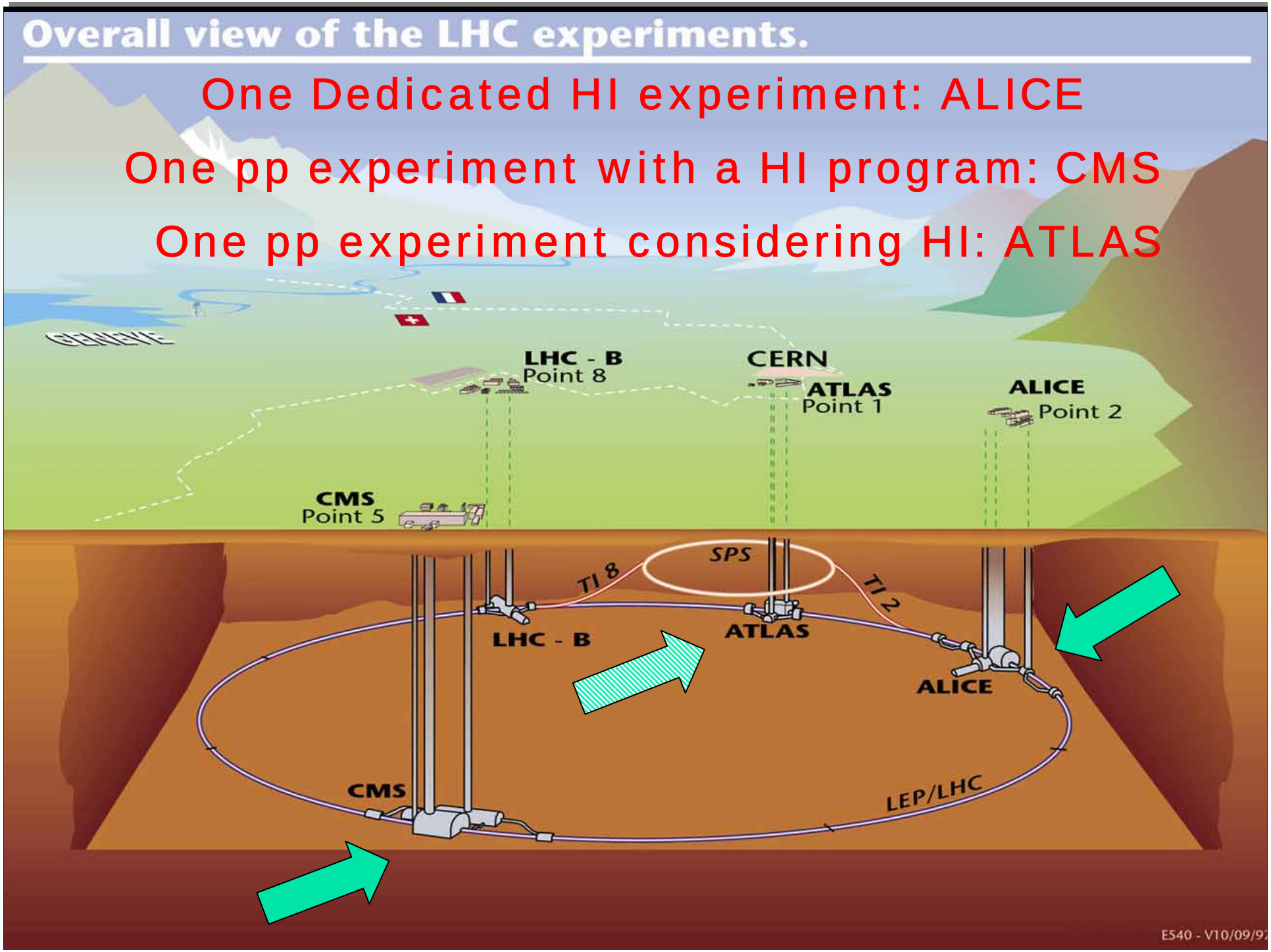
nucl-ex/0307019; submitted to PRL

- Good agreement with
  - lower √s data and phenomenological extrapolation
  - color evaporation model

ready to go!

Overall view of the LHC experiments.

One Dedicated HI experiment: ALICE

One pp experiment with a HI program: CMS

One pp experiment considering HI: ATLAS