QCD physics at heavy–ion collider energies. Results from PHENIX Run–1

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Overview

1. Introduction:
   - Review of QCD properties (confinement, chiral symm., vacuum)
   - High–energy heavy–ion physics topics: QCD phase diagram, quark–hadron phase transition, small–x physics
2. PHENIX experiment:
   - RHIC, Run–1 setup, luminosity
3. Results I: Global observables
   - Energy density, particle multiplicity, net baryon density.
4. Results II: Hard probes
   - High p_T hadron spectra. "Conventional" nuclear vs. QGP effects.
   - Hadron composition at high p_T.
   - Single electrons (open charm).
   - Elliptic flow.
5. Results III: Other observables
   - HBT "puzzle", fluctuations, strange baryons ...
6. PHENIX Run–2 prospects. Summary.

Review of QCD properties

The QCD Lagrangian:

– Degrees of freedom: quarks and gluons

– Non–abelian gauge theory

– Internal symmetry group: $SU(3)_{color}$

$$\mathcal{L} = \frac{1}{4g^2} G^a_{\mu\nu} G^a_{\mu\nu} + \sum_j \bar{q}_j (i\gamma^\mu D_\mu + m_j) q_j$$

where $G^a_{\mu\nu} \equiv \partial_\mu A^a_\nu - \partial_\nu A^a_\mu + i f^a_{bc} A^b_\mu A^c_\nu$

and $D_\mu \equiv \partial_\mu + i t^a A^a_\mu$ $(\alpha_S = g^2/4\pi)$

$\alpha_S(Q^2) \sim 1/\ln(Q^2/\Lambda^2)$, $\Lambda \sim 200$ MeV

Properties of the strong interaction:

1. Confinement: Quarks do not occur isolated in nature: only in hadronic (colorless) bound–states as mesons [$\bar{q}q$] and baryons [qqq]. $\alpha_s(Q^2)$ strong at large distances (low Q^2).
2. Asymptotic freedom: At short distances (high Q^2), $\alpha_\sigma(Q^2)$ decreases logarithmically: quarks & gluons weakly coupled. Perturbative methods applicable (pQCD).
3. Chiral symmetry breaking:
   - Quarks acquire dynamically a mass in a confined medium:

     Current m_q (5–10 MeV) << Constituent m_q (~300 MeV)
   - Non–zero QCD ground–state (non–perturbative vacuum, "sea") filled with quark–antiquark and gluon–gluon virtual pairs :

     quark & gluon condensates: $<\bar{\Psi}\Psi> \approx -(235\text{ MeV})^3$, $<\alpha_s G_{\mu\nu} G^{\mu\nu}> \approx -(500\text{ MeV})^4$

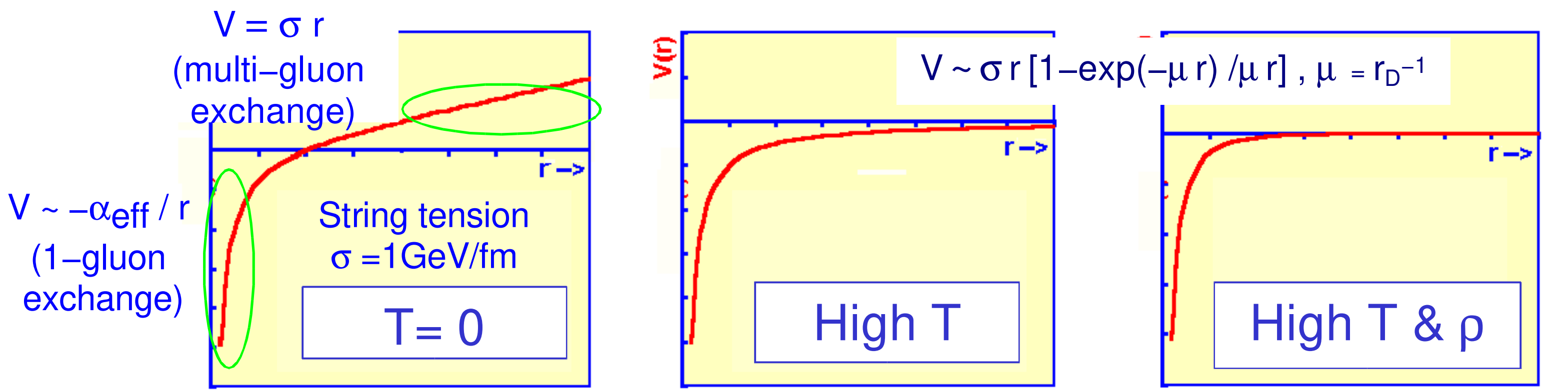
QCD at finite T and ρ

Nuclear matter at high temperatures and densities exhibits:

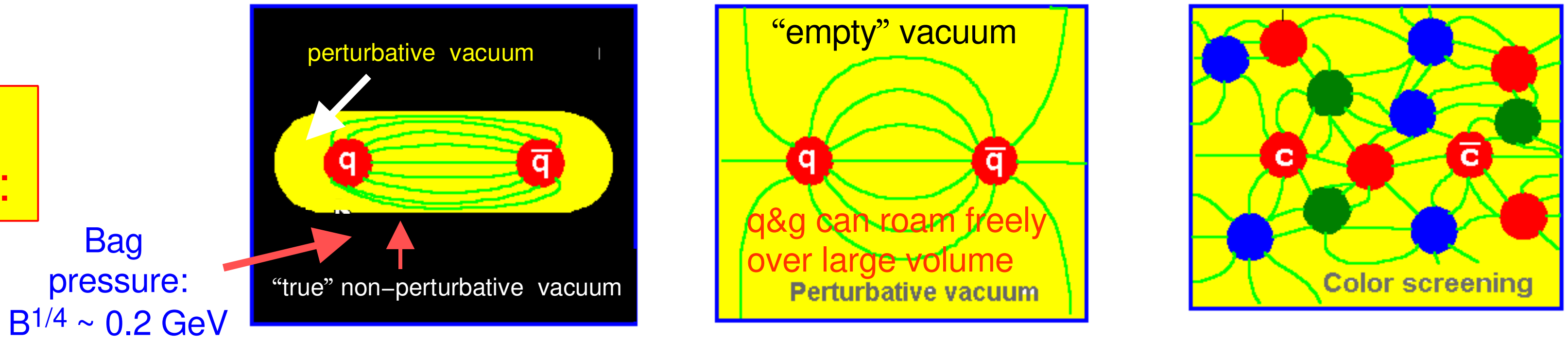
- Color deconfinement: $\alpha_{eff}(T) \rightarrow 0$
- Chiral symmetry restoration: $m_q\,(T,\rho) \rightarrow 0$

} New state of matter

QCD color potential:

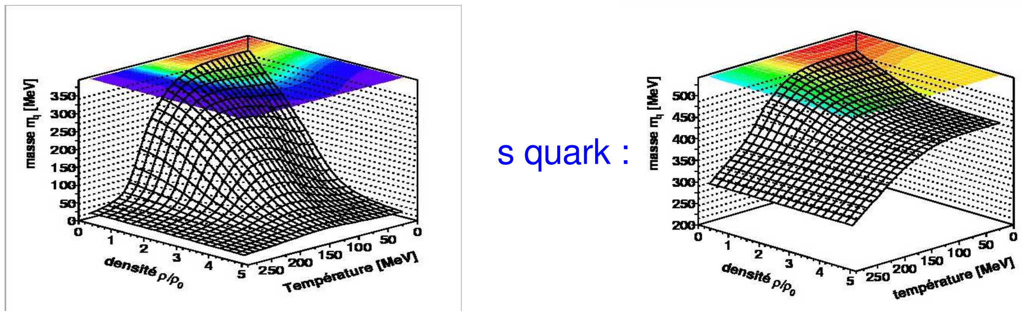


QCD vacuum:



Quark masses:

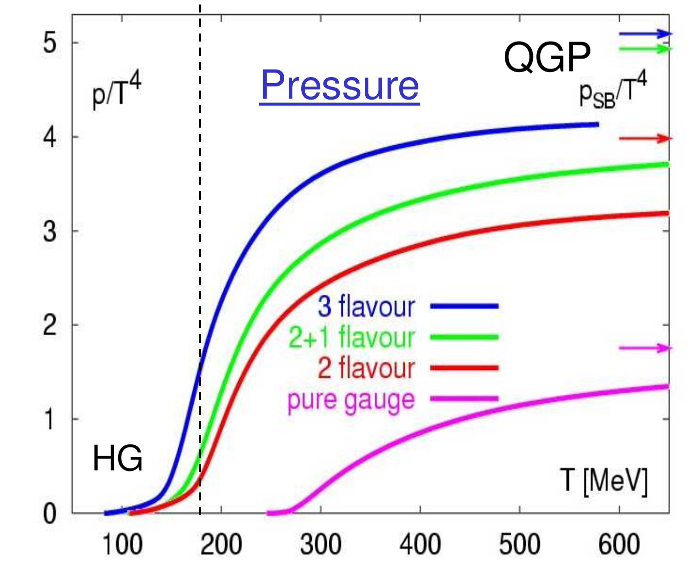
u/d quarks:

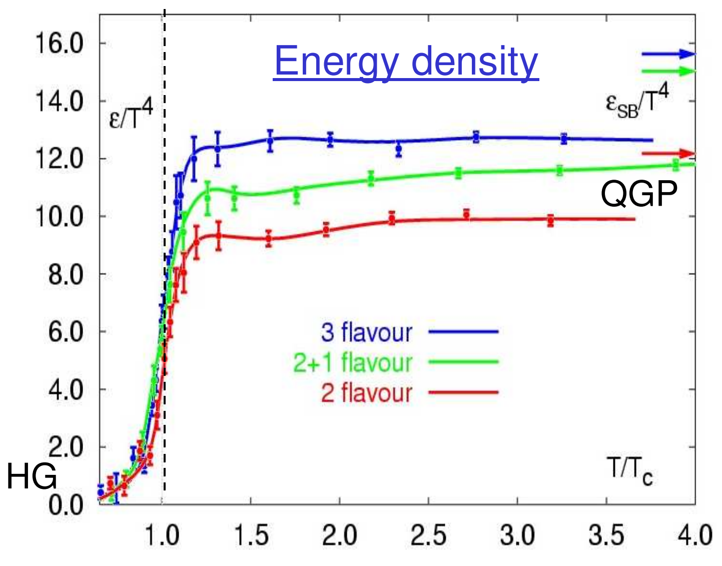


$m_q \sim m_0 + C\langle\bar{\Psi}\Psi\rangle$
(NJL model)

QCD thermodynamics (on the lattice*)

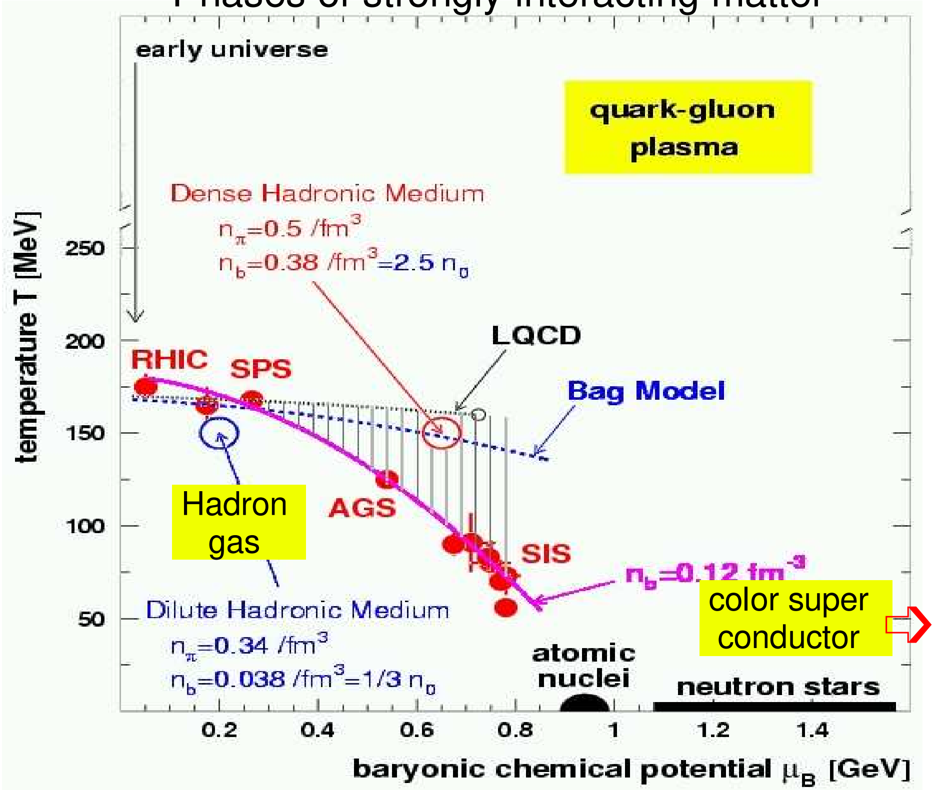
QCD Equation of State [F. Karsch QM2001]





(*) At zero baryon number density (μ_B=0)

Phases of strongly interacting matter



QCD critical temperature:

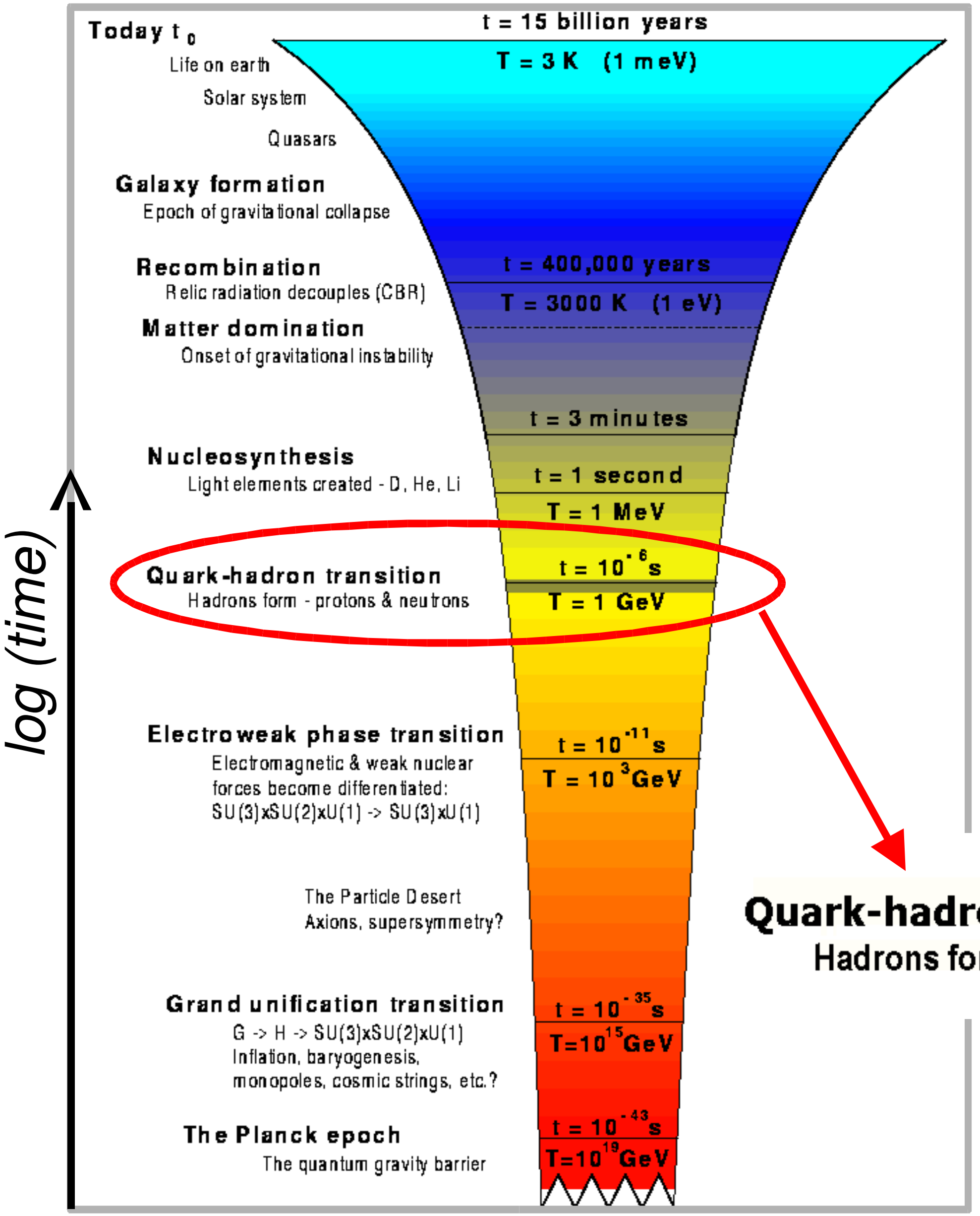
T_c = (173±10) MeV [n_f =2]

T_c = (154±10) MeV [n_f =3]

Critical energy density:

$\varepsilon_c=(6 \pm 2)T_c^4 \Rightarrow \varepsilon_c=(0.7\pm0.3)$ GeV/fm^3

Cosmological QCD transition



The universe was in the QGP state ~10 μs after the “Big Bang”

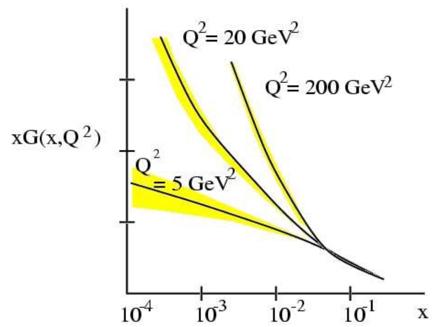
Insights into the cosmology and phase transitions of the early universe

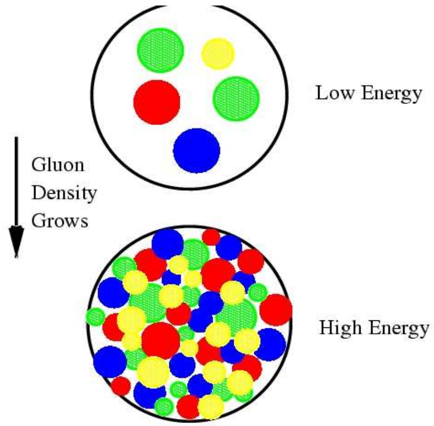
Time duration of the phase transition: O (μs)

High parton density & small–x physics

- Initial conditions at RHIC: High–energies + large nuclei
  - ➡ x_{Bj}<<1: High parton (gluon) densities

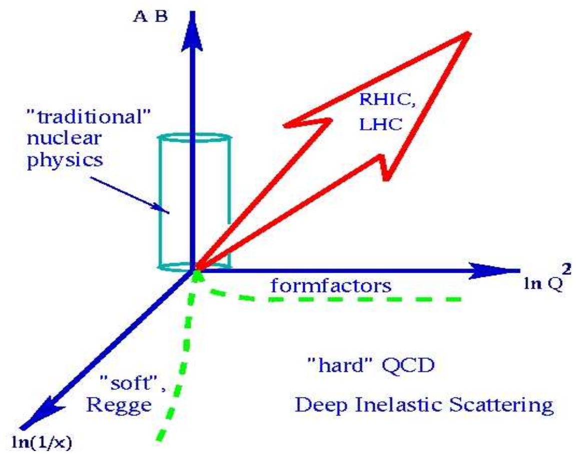
$$\rho_A \simeq \frac{xG_A(x,Q^2)}{\pi R_A^2} \sim A^{1/3}$$





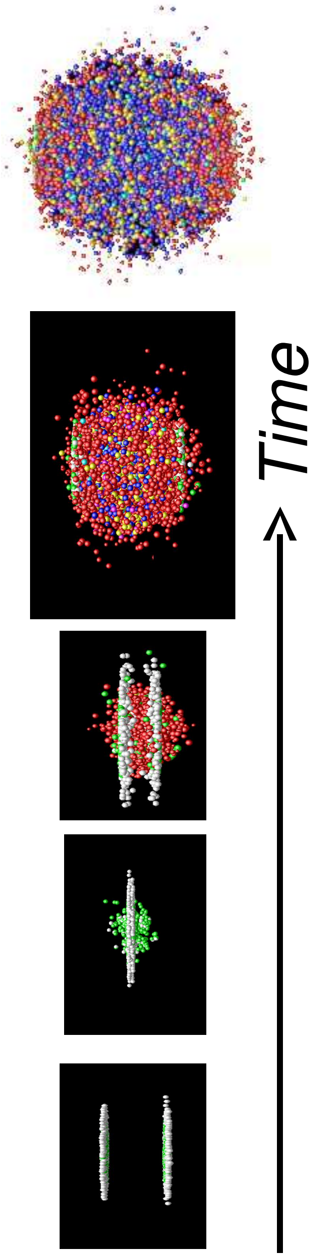
  - ➡ α_s<1: High color field strengths

    weak coupling: "Classical" (Chromo–Dynam.) methods applicable

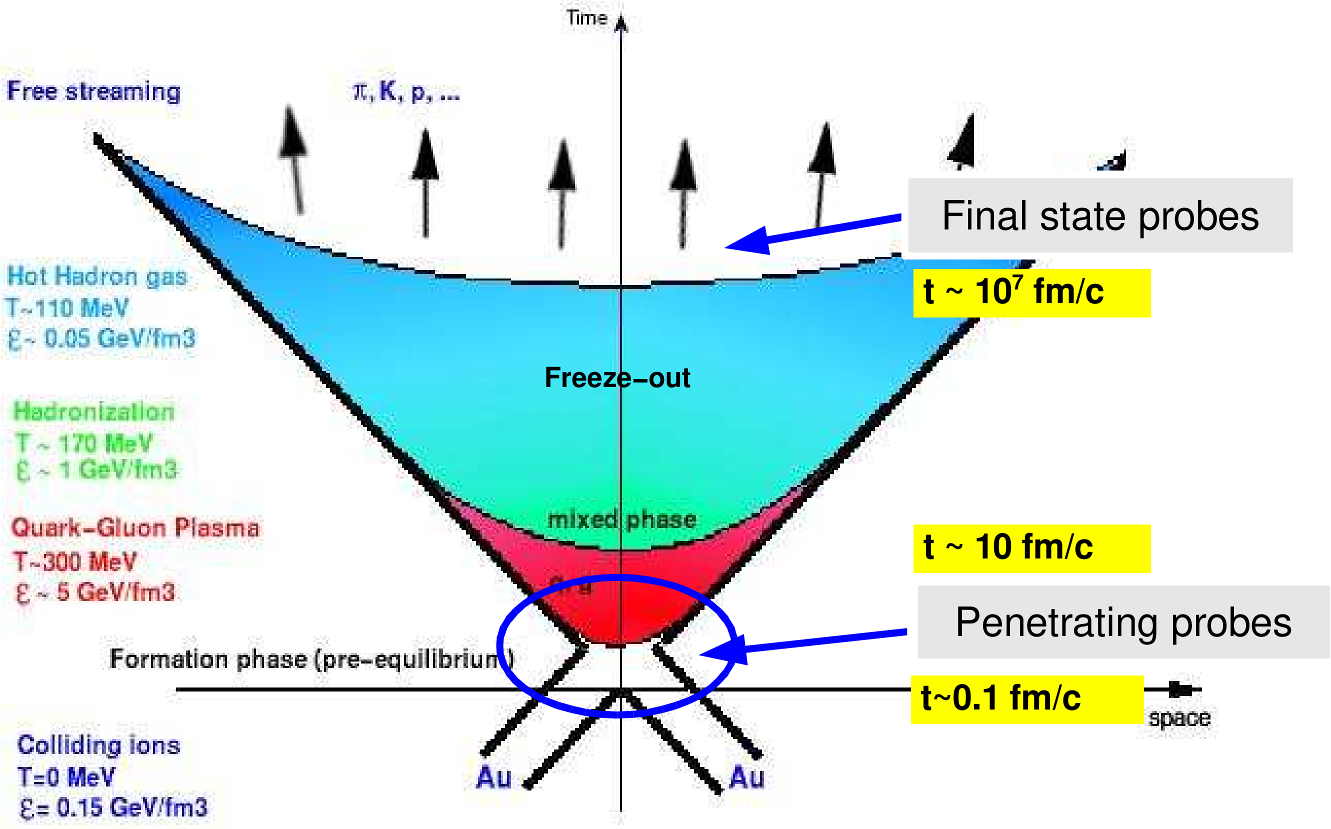


- Unexplored (highly non–linear) QCD regime:
- Keyword 1 – "Saturation scale": $Q_s^2 \sim \alpha_s \dfrac{xG_A(x,Q_s^2)}{\pi R_A^2}$
  - ➡ *"Value of the momentum transfer Q^2 at which the parton system starts looking dense to the probe"*
- Keyword 2 – "Color–Glass–Condensate":
  - ➡ *"Hadron wavefunction described as a state of high–density gluonic (i.e. bosonic and colored) matter, whose distribution is random but frozen over the relevant time scales"*

The "Little Bang" in the lab.



- High–energy nucleus–nucleus collisions: in fixed–target reactions ($\sqrt{s}$~15 GeV, SPS) or in colliders ($\sqrt{s}$~200 GeV, RHIC)
- QGP expected to be formed in a tiny region (~10^{-14} m) and to last very short times (~10^{-23} s).
- Collision dynamics: Diff. exp. observables probe diff. stages



Relativistic Heavy–Ion Collider (RHIC) @ BNL

Specifications:

- 3.83 km circumference
- 2 independent rings:
  - 120 bunches/ring
    - 106 ns crossing time

Au + Au collisions @ 200*A* GeV

(~10 times SPS energy)

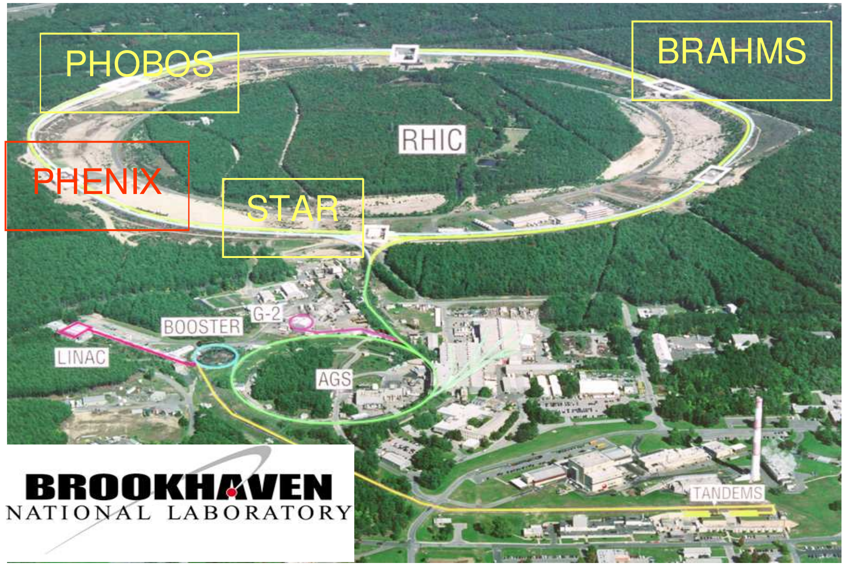
Luminosity: $2\cdot10^{26}$ cm^{-2} s^{-1}

4 experiments:

PHENIX, STAR, PHOBOS, BRAHMS

1st run: June ’00 – Sept. ‘00

2nd run: June ‘01 – Nov. ‘01



The PHENIX collaboration

Pioneering High–Energy Ion eXperiment

11 countries
51 institutions
400+ collaborators

University of São Paulo, São Paulo, Brazil
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KEK, Institute for High Energy Physics,Tsukuba, Japan
Kyoto University, Kyoto, Japan
Nagasaki Institute of Applied Science, Nagasaki-shi, Nagasaki, Japan
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University of Tokyo, Bunkyo-ku, Tokyo 113, Japan
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Cyclotron Application Laboratory, KAERI, Seoul, South Korea
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Korea University, Seoul, 136-701, Korea
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System Electronics Laboratory, Seoul National University, Seoul, South Korea
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Joint Institute for Nuclear Research (JINR-Dubna), Dubna, Russia
Kurchatov Institute, Moscow, Russia
PNPI: St. Petersburg Nuclear Physics Institute, Gatchina, Leningrad, Russia
Lund University, Lund, Sweden
Abilene Christian University, Abilene, Texas, USA
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Georgia State University (GSU), Atlanta, GA, 30303, USA
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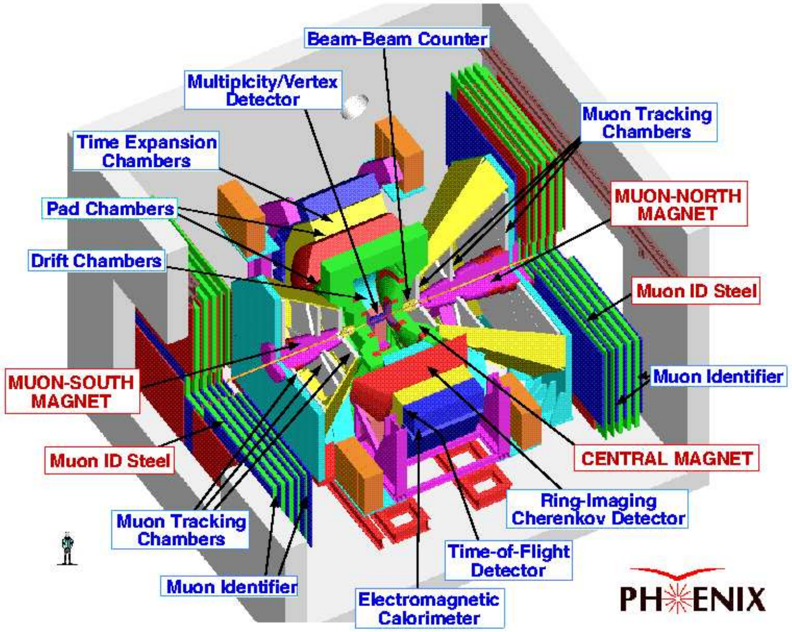
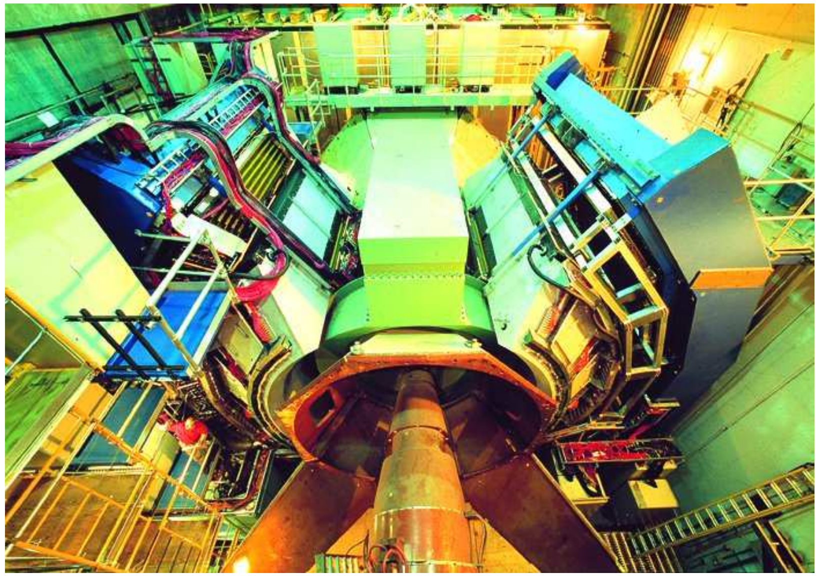
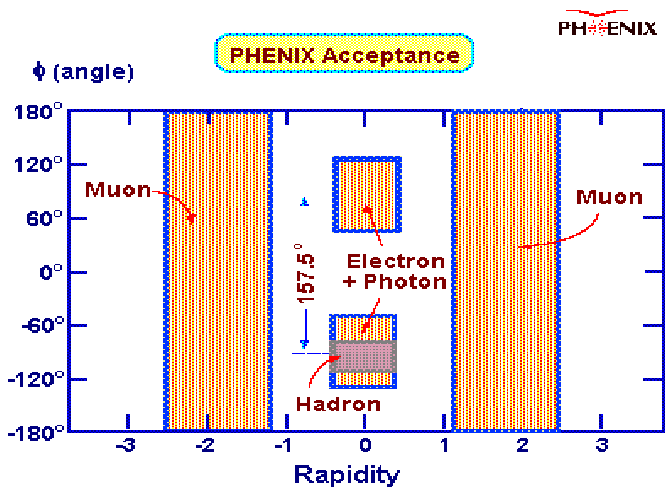
University of Tennessee (UT), Knoxville, TN 37996, USA
Vanderbilt University, Nashville, TN 37235, USA

PHENIX @ RHIC

- 11 detector sub–systems
- 2 Arm central spectrometers:
  - $|\eta| < 0.35$, $\Delta\phi = \pi/2$ (e, γ, hadrons)
  - Open geometry axial field
- 2 forward spectrometers (2nd year)
  - $1.2 < |\eta| < 2.5$, $\Delta\phi = 2\pi$ (muons)
  - Radial magnetic field
- 3 global (inner) detectors: trigger, centrality
- Designed to measure rare probes:
  - + high rate capability & granularity
  - + good mass resolution and PID
  - – limited acceptance

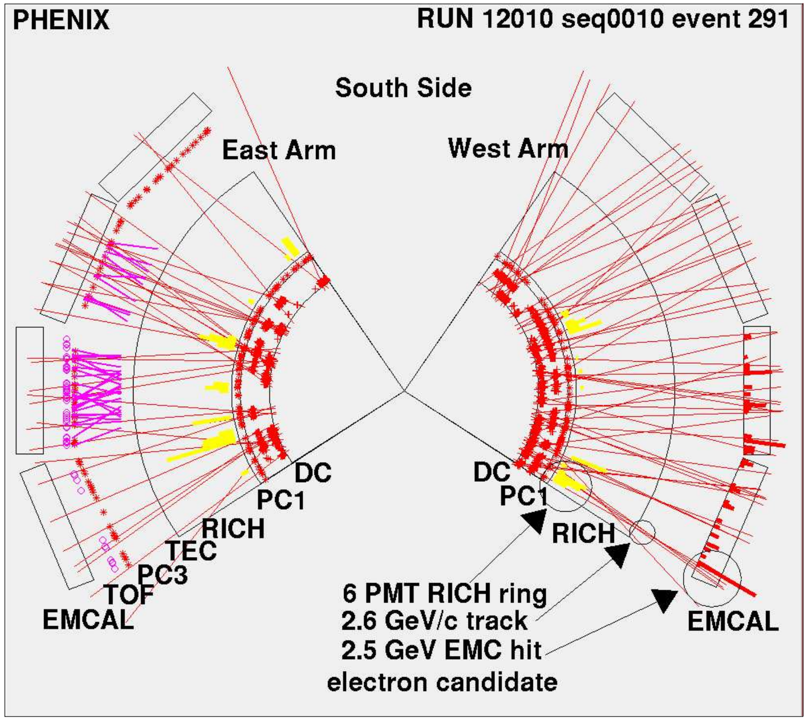


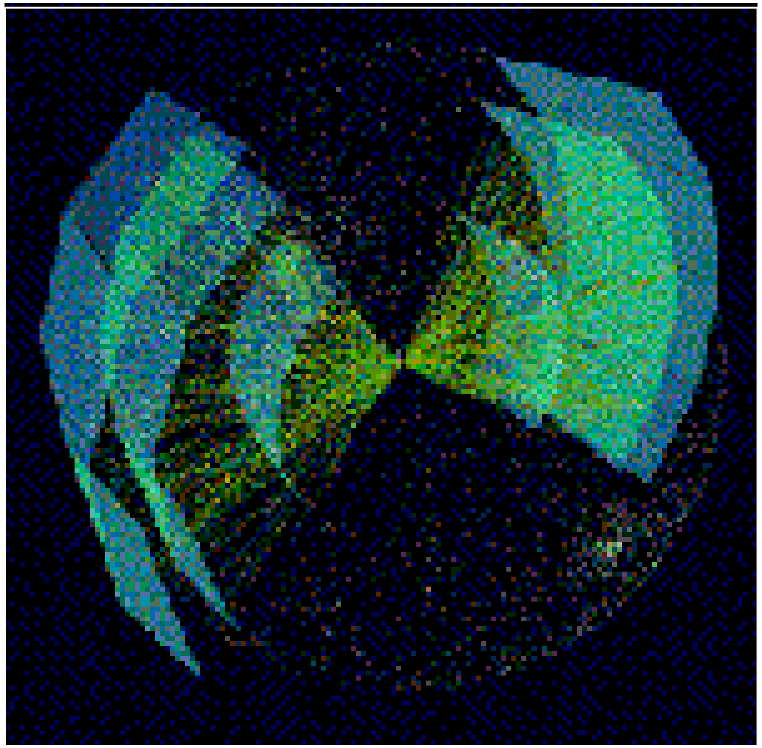




First collisions at PHENIX
(Au+Au @ $\sqrt{s_{NN}}$ = 130 GeV, June 2000)

PHENIX Central Arms



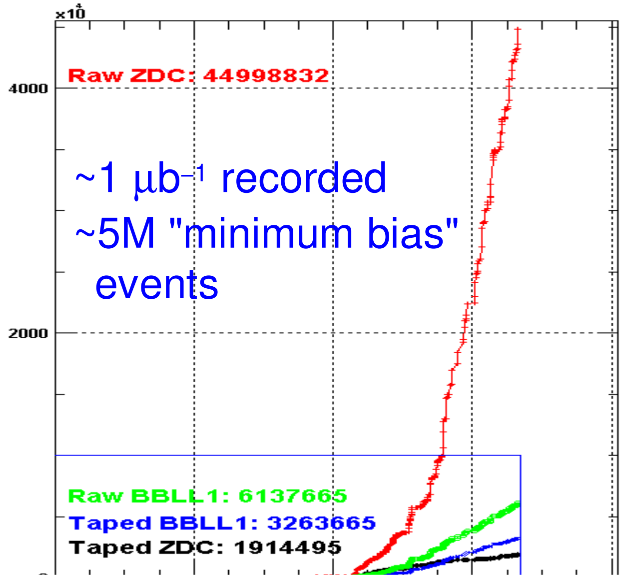


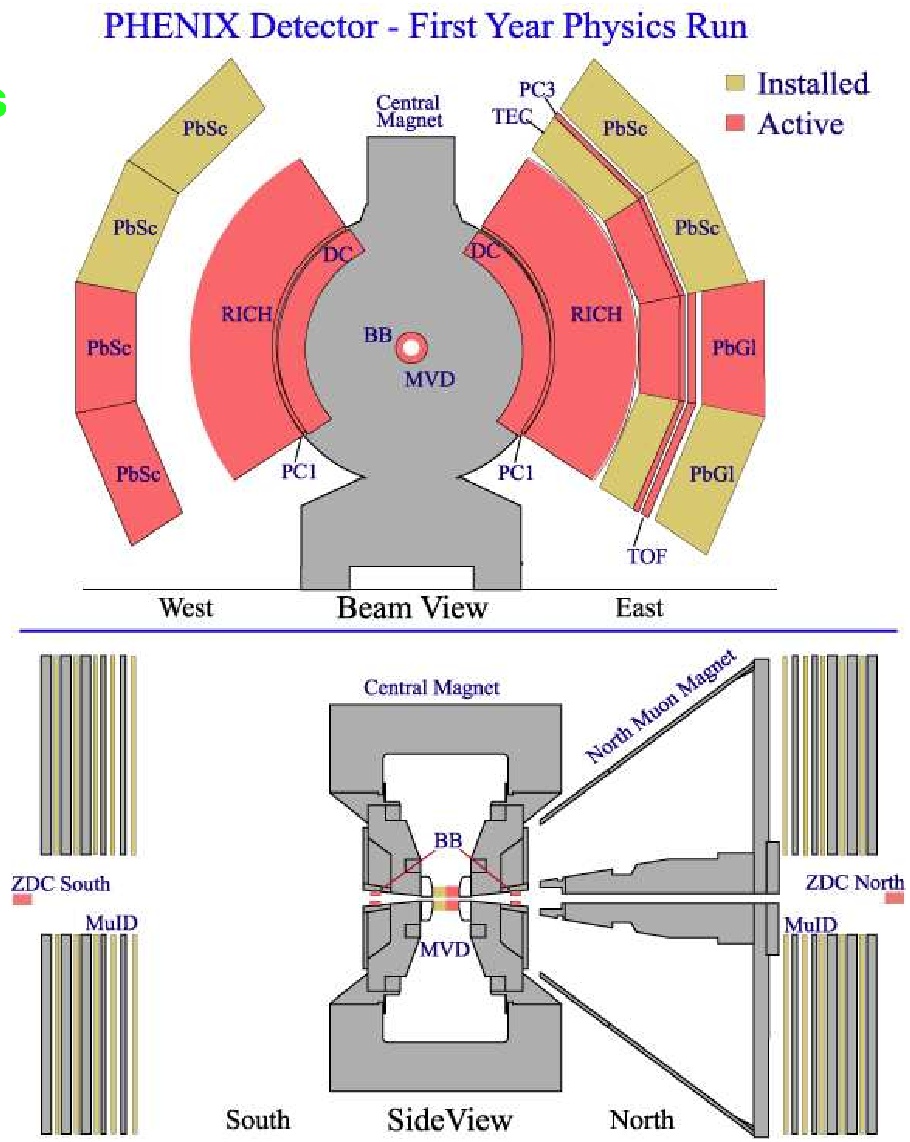
~620 ch. particles per unit rapidity
(in top 5% most central collisions)

PHENIX Run–1 (summer 2000)

ZDC	Zero Degree Calorimeter	**Global detectors**
BB	Beam Beam Counter	
MVD	Multiplicity Vertex Detector	
DC	Drift Chamber	**Tracking**
PC	Pad Chambers	
RICH	Ring Image Cherenkov	**PID**
TEC	Time Expansion Chamber	
TOF	Time Of Flight detector	
PbSc	Lead–Scintillator Cal.	**Calorimetry**
PbGl	Lead–Glas Calorimeter	

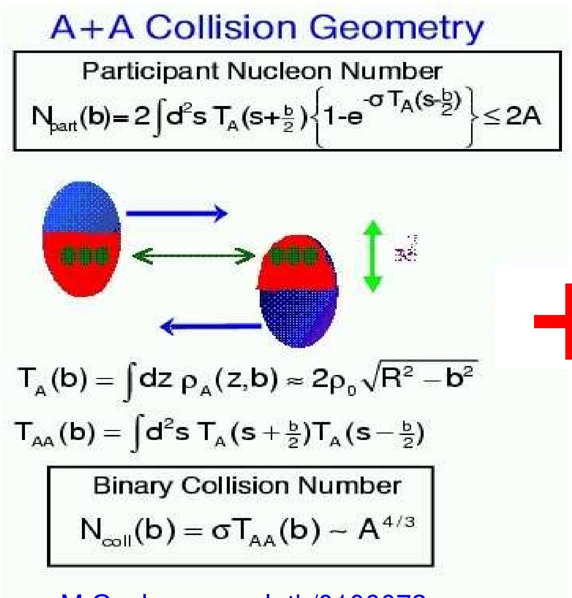
Central magnet (~ 9m high, 500t, B = 0.78 Tm @ 90°)





Reaction centrality & scaling of baseline p+p,p+A observables

- Determination of the properties of the hot strongly interacting medium formed in A+A collisions requires comparing to:
  - No medium data : **p+p** collisions
  - Cold medium data: **p+A** collisions
- Usual particle production observables in p+p,A reactions scale according to:
  - The number of participant ("wounded") nucleons N_{part} : for "soft" processes
  - The number of binary nucleon collisions N_{colls} : for "hard" processes
- N_{colls} & N_{part} are directly related to the centrality of the reaction through: Glauber geometrical model + Global Detectors (ZDC,BBC) response



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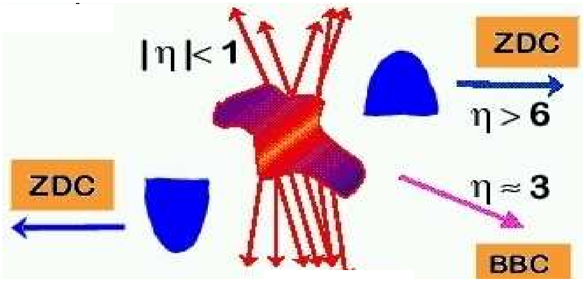

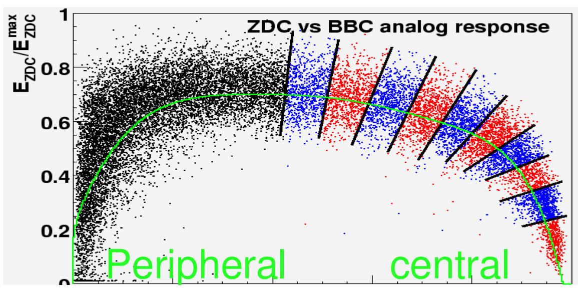

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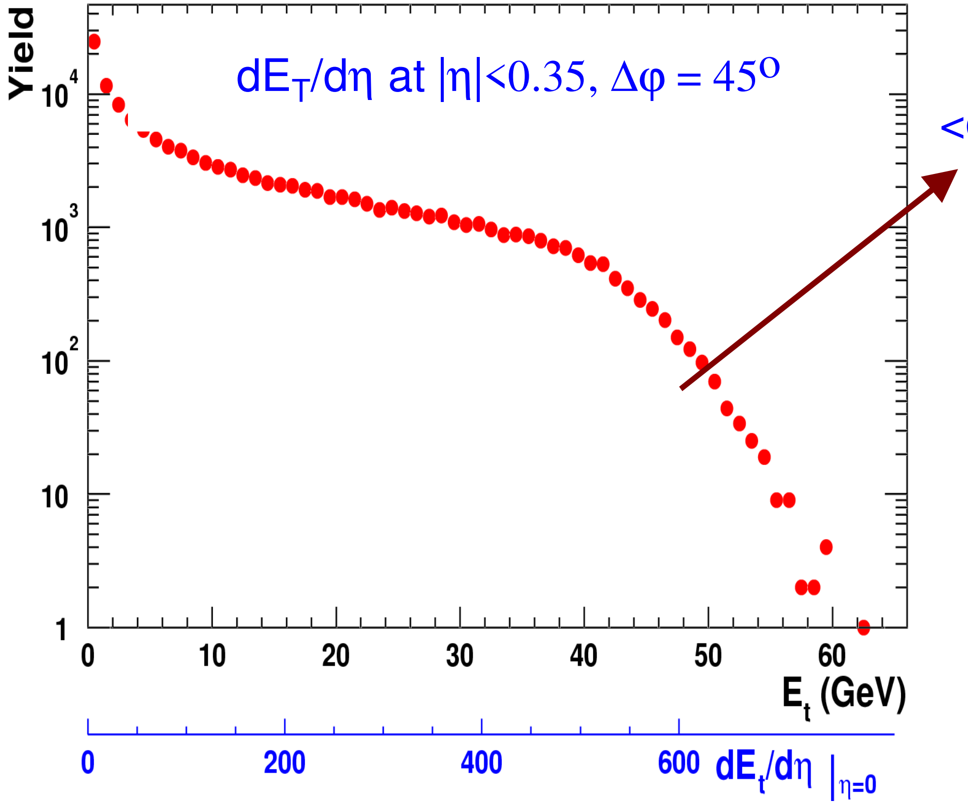
cross section fraction	N_{part}	N_{binary}
0-5	348 ± 10	1009 ± 91
5-15	271 ± 9	712 ± 65
15-30	180 ± 7	406 ± 42
30-60	79 ± 5	131 ± 22
60-92	14 ± 3	14 ± 5

Global Results 1. Energy density [PRL 87, 52301 (2001)]

E_T at mid–rapidity measured by calorimetry: PHENIX EMCal is a good *hadronic* calorimeter: $E_T^{had} = (1.17 \pm 0.05)\ E_T^{EMCal}$

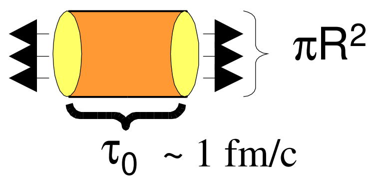


$<dE_T/d\eta>$ ~ 580 GeV (top 2% central)

60% larger than at SPS energies

Bjorken's estimate of the energy density (longitud. expansion):

$$\varepsilon_{Bj}(\tau_0) = \frac{1}{\pi R^2 \tau_0}\frac{dE_T}{d\eta}$$



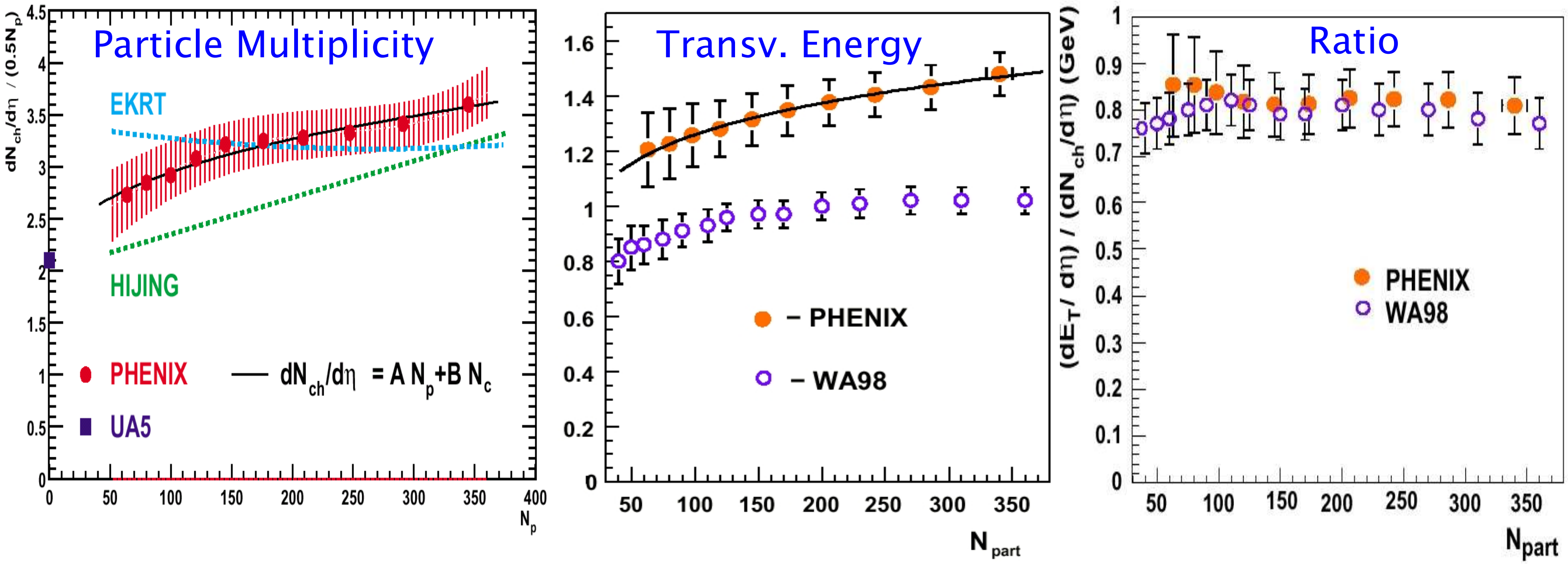
$\varepsilon_{Bjorken}$ ~ 4.6 GeV/fm^3

Energy density (~5 GeV/fm^3) @ RHIC > QCD critical density (~1 GeV/fm^3)

[*modulo: 1D expansion, not fully baryon–free, thermalization time estimate*]

Global Results 2. Particle Mult.iplicity and E_T vs. centrality

[PRL 87, 52301 (2001), PRL 86, 3500 (2001)]

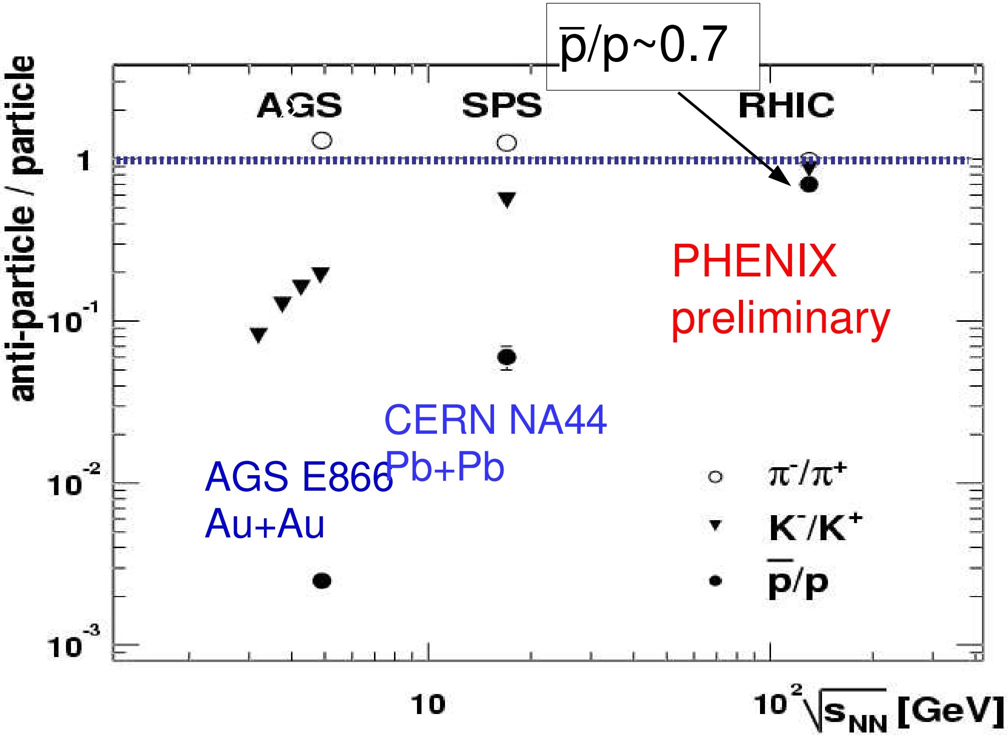


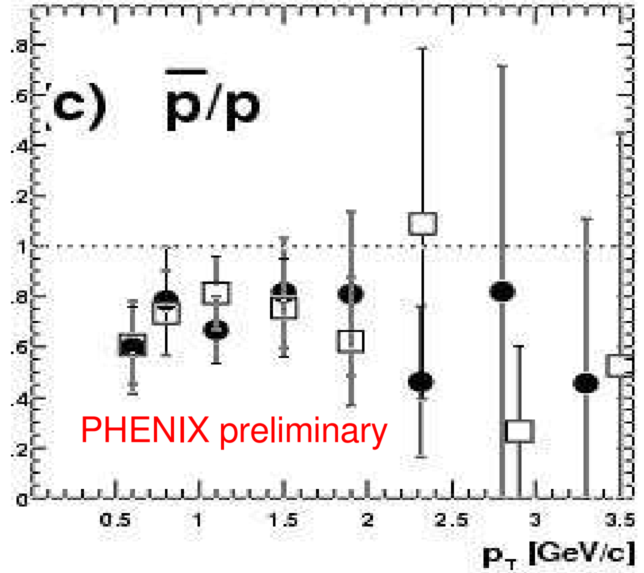
- N_{ch} & E_T increase faster than linearly with N_{part} : onset of hard processes contribution (proportional to # binary inelastic colls.)
- Centrality dependence: Important constraint for particle production models:

  "Soft + hard" (HIJING), initial–state gluon saturation (KLN), final–state gluon sat. (EKRT)
- $\langle E_T \rangle / \langle N_{ch} \rangle \sim 0.8$ GeV independent of centrality (and ~ lower energy WA98 data)

Global Results 3: Net baryon density at midrapidity

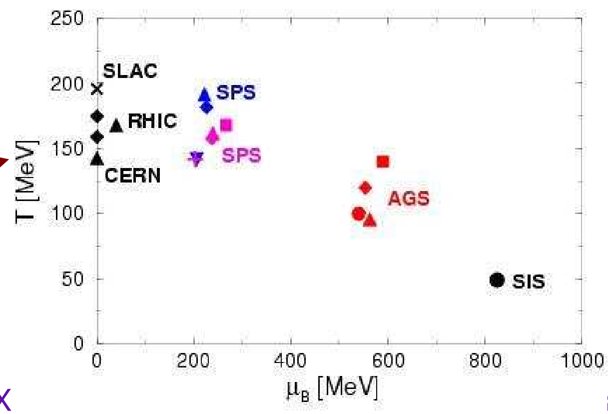
Particle to anti–particle ratios at y=0:





- 2/3 of protons at y = 0 come from pair production
- Much closer to baryon–free region than SPS

- Low baryo–chemical potential at freeze–out (statistical model Redlich *et al*): μ_B ~ 45 MeV



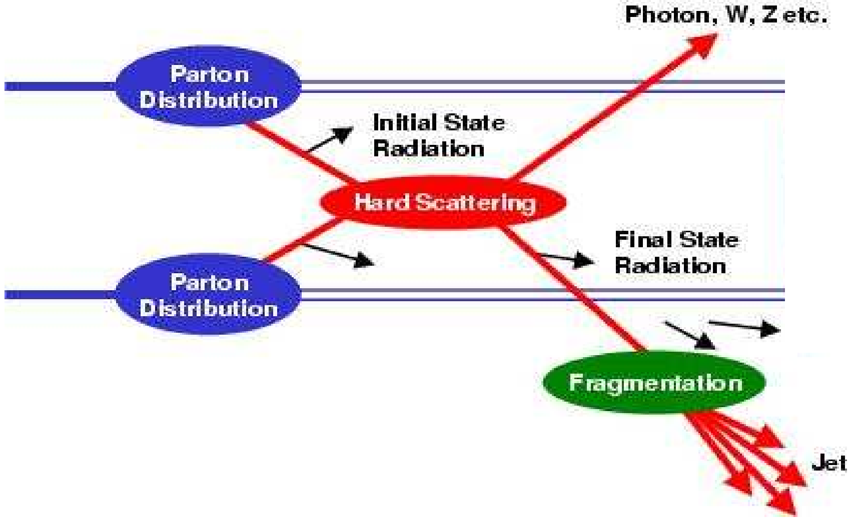
Hard probes observables (*foreword*)

- Early production ($\tau \sim 1/p_T \sim$ 0.1 fm/c) in parton–parton scatterings with large Q^2
- Direct probes of partonic phases ⇒ Sensitive to hot/dense medium (QGP) effects: parton energy loss, color screening ...
- 3 types: High–p_T particles (jets, prompt γ), large mass (D, B, J/Ψ) particles, [Elliptic flow]
- Comparison to available set of baseline "vacuum" data (*pp* ↔ AA) via N_{coll} (# of binary inelastic colls.) scaling:

$$\boxed{\sigma_{AB\,(hard)} = \int d^2b[1-e^{-\sigma_{pp}T_{AB}(b)}] \approx AB*\sigma_{pp\,(hard)}}$$

- Elementary processes calculable via pQCD.

Factorization theorem: $\boxed{\sigma_{AB\rightarrow hX} \propto f_{a/A}(x_a,Q^2_a) \otimes f_{b/B}(x_b,Q^2_b) \otimes \sigma_{ab\rightarrow cd} \otimes D_{h/c}(z_c,Q^2_c)}$



"Hard" results 1: High p_T spectra (central vs. periph.)

[PRL88:022301 (2002)]

- Jet physics in HI collisions ≡ High–p_T hadron physics:
  - Traditional jet algorithms fail in HI collisions below p_T ~ 40 GeV/c (at $\sqrt{s_{NN}}$ = 200 GeV) due to large soft background.
  - High transv. mom. hadrons (p_T>2 GeV/c) ≡ products of parton fragmentation ("leading particle")
- Au+Au $h^{\pm}$ and π^0, $|\eta|$<0.35, compared to scaled *pp* reference (p_T>1.0 GeV/c):

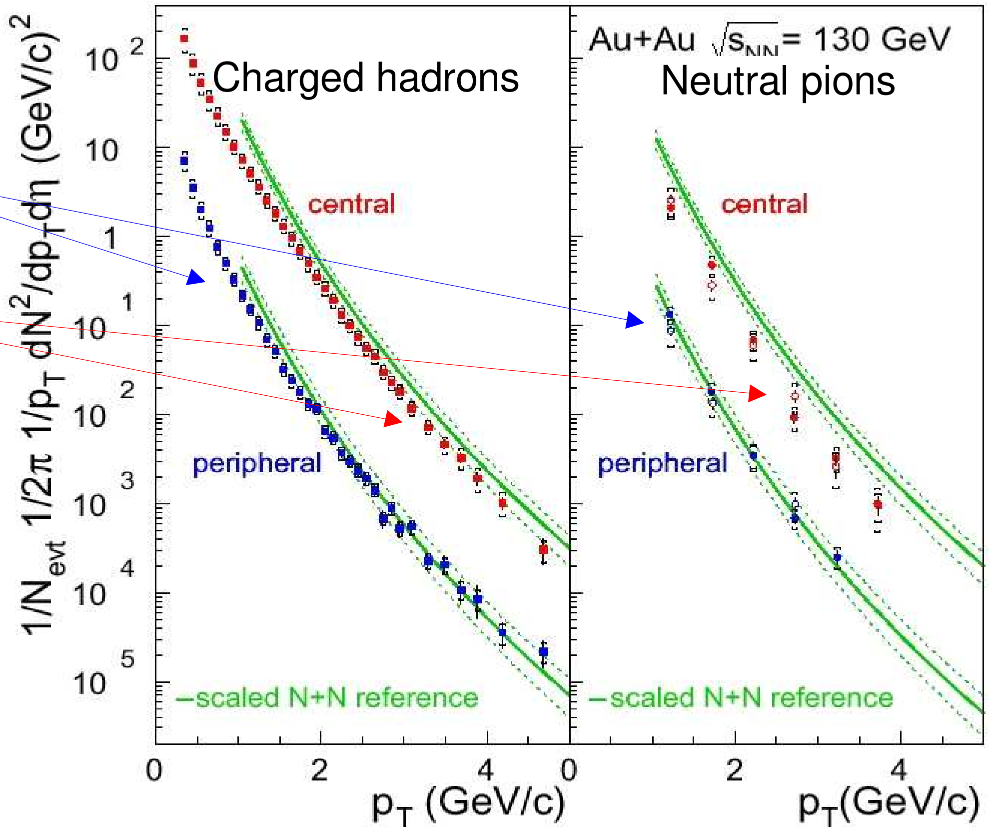
Interpolation ISR, UA1, CDF *p+p,$\bar{p}$*

✔ Peripheral collisions well described

✘ Central colls. not described (×2–3 suppression)

~30–50% systematic errors:

~ 20–35% : *pp* interpolation
~ 16–30% : data
~ 11%: N_{coll} scaling



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"Hard" results 1: High p_T spectra (nuclear modif. factor)

PHENIX Coll. PRL88:022301 (2002)

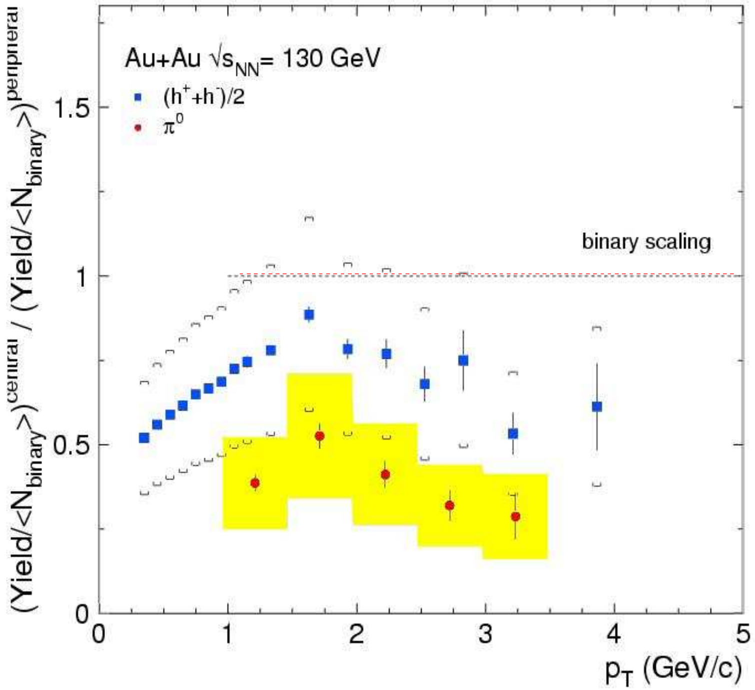
- Nuclear modification factor:

$$R_{AB} = \frac{1}{\langle N_{binary} \rangle} \left(\frac{d^2\sigma_{AB}}{dy dp_t^2} \right) \Big/ \left(\frac{d^2\sigma_{pp}}{dy dp_t^2} \right)$$

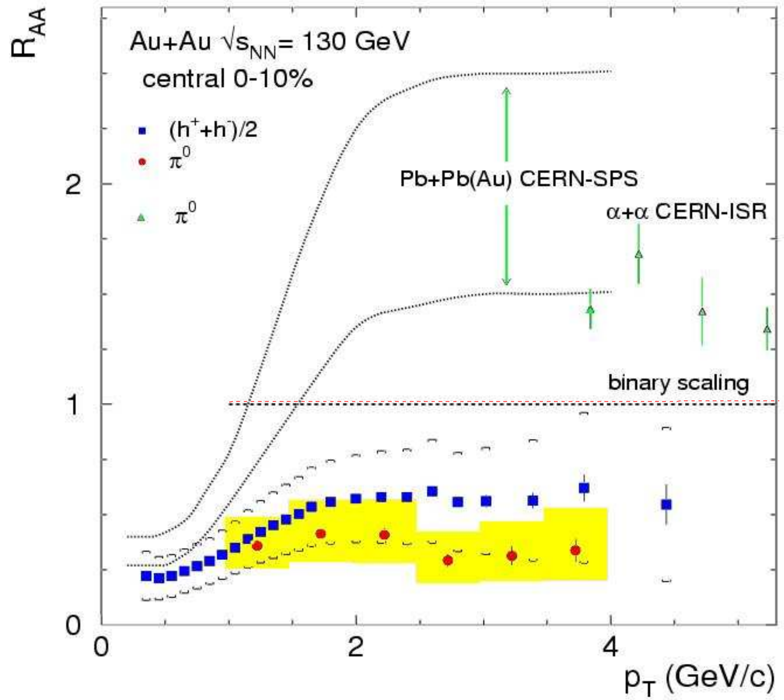
- R_{AB} = 1 : incoherent point–like scaling
- R_{AB} >1 : Cronin effect (SPS)
- R_{AB} ~ 0.4 – 0.6 @ RHIC !

- Deficit of high–p_T particles (esp. π^0) relative to expected N_{coll} scaling:

Ratio AuAu(cent.) / AuAu(periph)



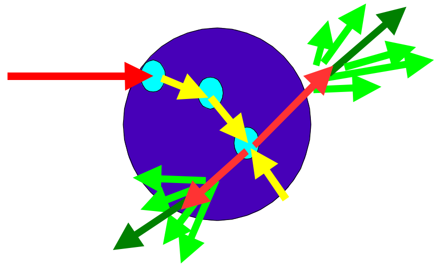
Ratio AuAu / *pp* reference



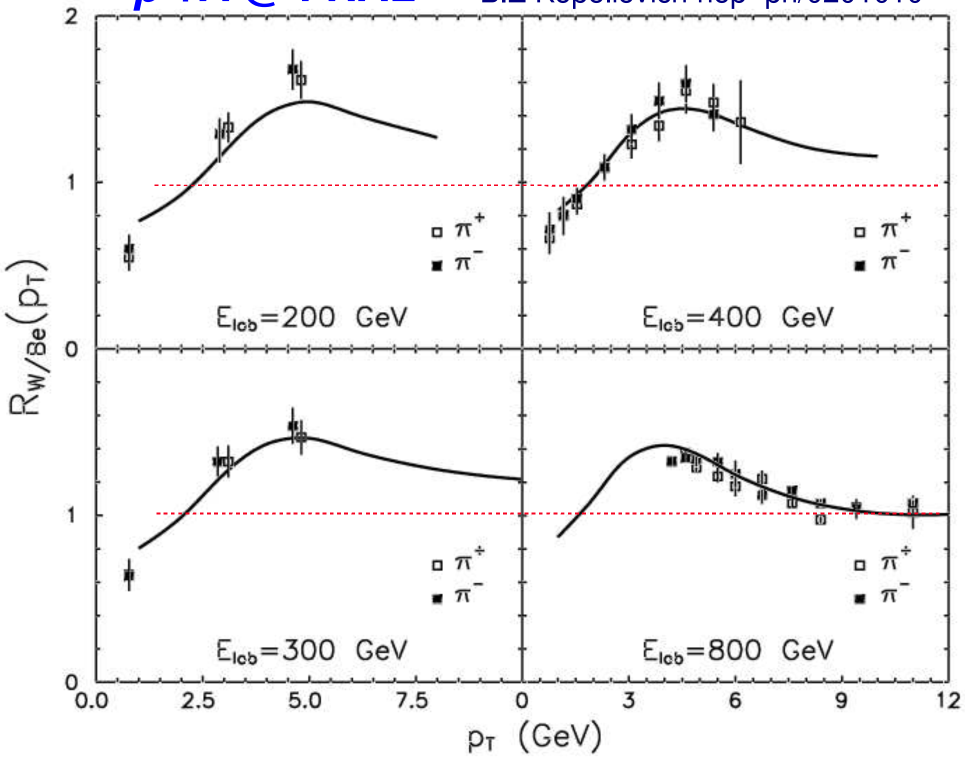
"Conventional" nuclear effects (1) : Cronin enhancement

- Increased high–p_T production in pA, AA collisions: $R_{AB}>1$ (for $p_T > 2$ GeV/c)
- Initial–state multiple (soft & semi–hard) parton interactions (before hard scattering): k_T broadening

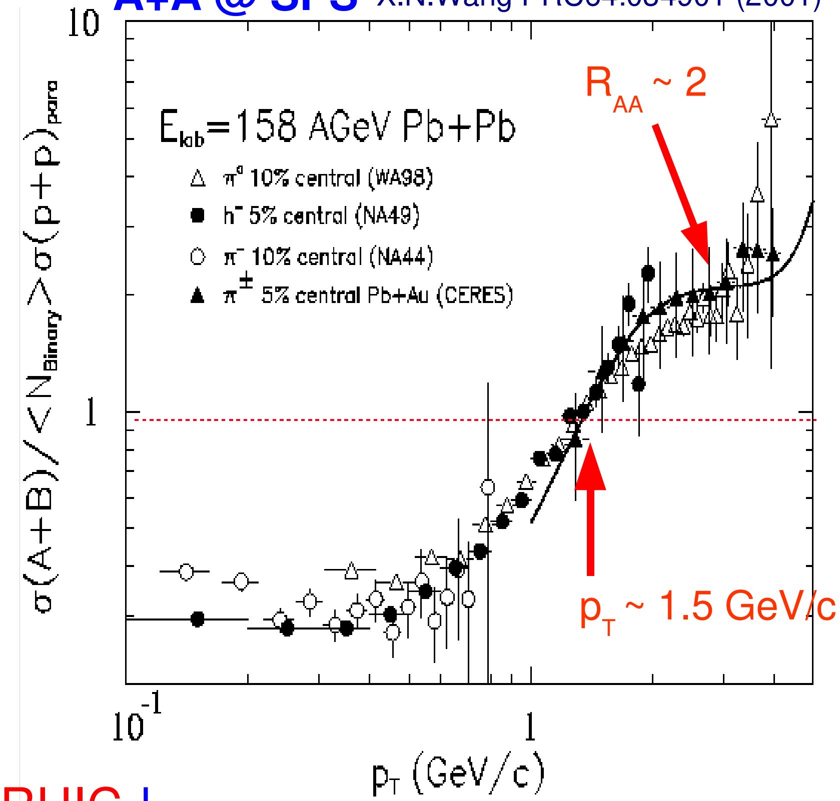
  [*e.g.at $\sqrt{s_{NN}}$ = 200 GeV, broadening ~ 0.4 GeV^2/coll. additional to intrinsic proton k_T^2~2.0 GeV^2*]



p +A @ FNAL B.Z Kopeliovich hep–ph/0201010



A+A @ SPS X.N.Wang PRC64:034901 (2001)



- Exactly the opposite trend is observed at RHIC !

"Conventional" nuclear effects (2): Gluon shadowing

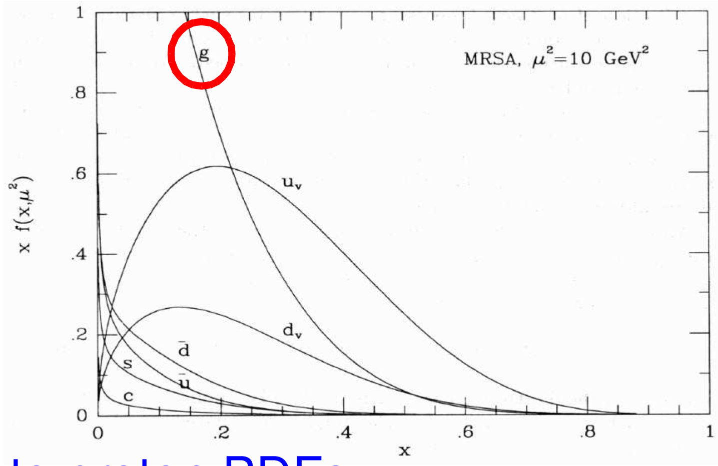
- Relevant x region for high–p_T (2–5 GeV/c) at RHIC:

  $x_T = 2p_T^{parton} / \sqrt{s} = 2\,(p_T^{hadron}/z) / \sqrt{s} \Rightarrow$
  [taking z~1, x~x_T] $\Rightarrow$ $\boxed{x \sim 0.03\text{–}0.08}$

- For x < 0.1: P(arton)DFs ≈ G(luon)DFs: ☞

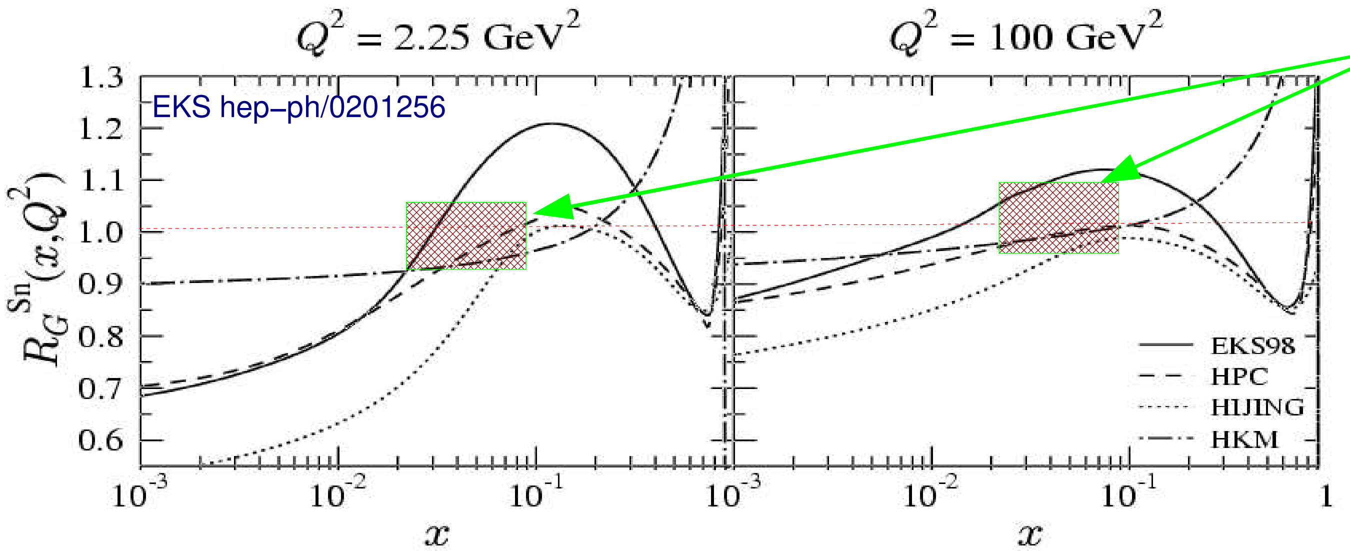
  Specially true for nuclei:

  $xG(x,Q^2) \sim A^{1/3}/x^{\delta}$ (with $\delta \sim 0.2\text{–}0.3$)



- For x<0.1 : Nuclear PDFs depleted compared to proton PDFs

  $R(x,Q^2,A) \equiv f_i^A(x,Q^2) / [A\, f_i^N(x,Q^2)] < 1$ ➔ Shadowing (parton recombination, ...)



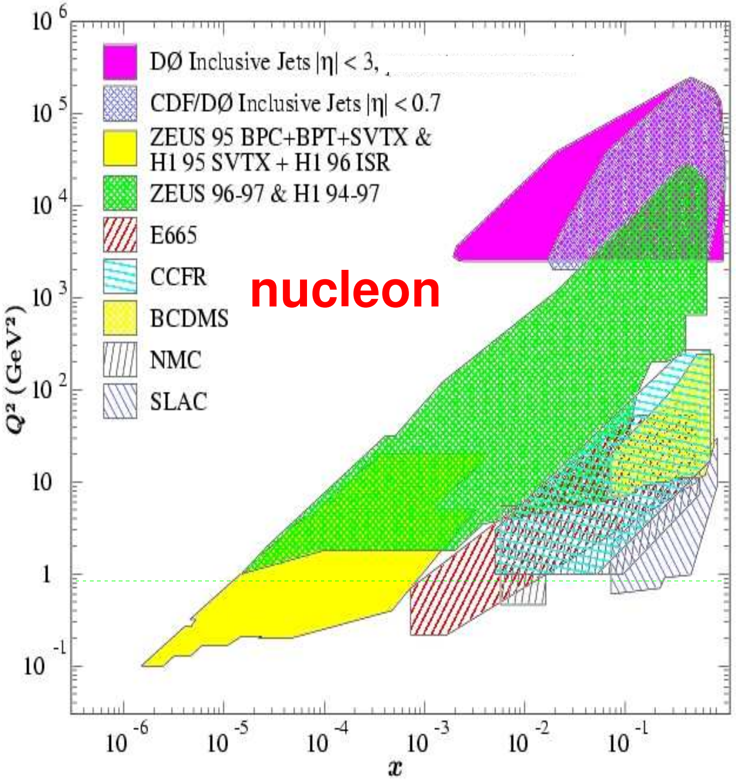
R_G ~ 0.9 for the relevant PHENIX high–p_T kinematics range ⇒

Strong shadowing is ruled out !

"Conventional" nuclear effects (2): Gluon shadowing ...

Note however ...

- (x,Q^2) scale–dependence of nuclear PDFs (specially gluons) less known than for nucleons (limited range of x, Q^2, A covered in available *l*A exp.).



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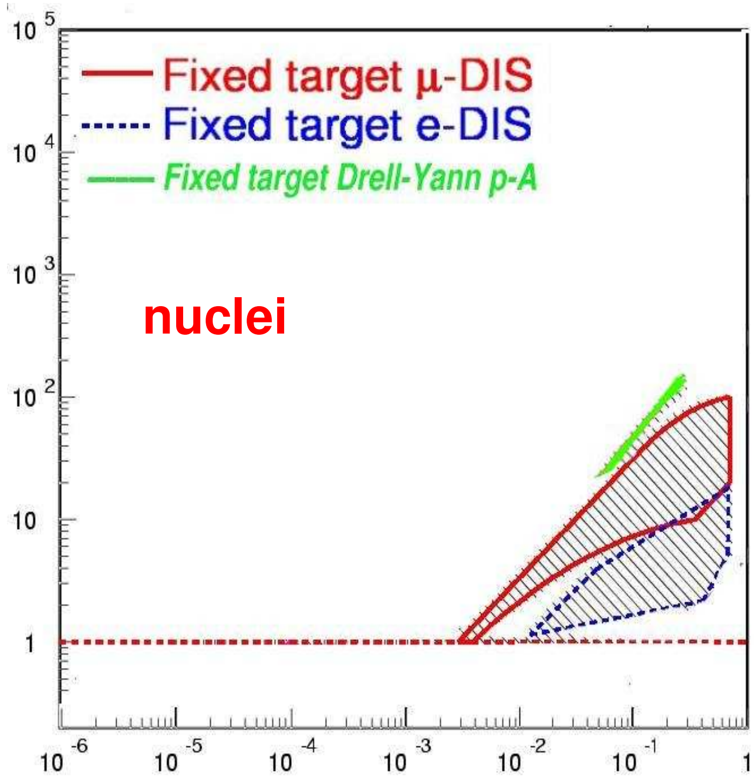
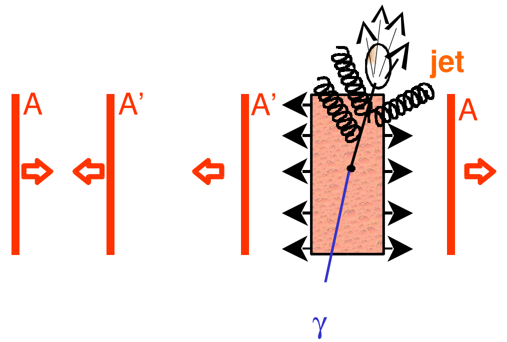


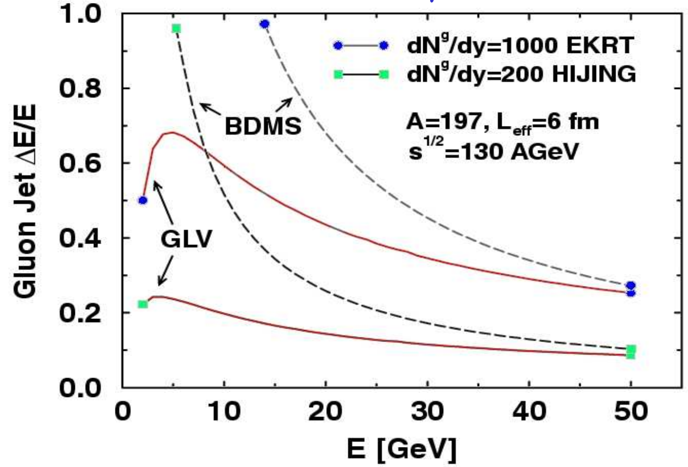
➨ *p,d*+A collisions at the same √*s* needed at RHIC !

"QGP" effects: radiative parton energy loss

- Multiple final–state gluon radiation off the produced hard parton (before hadronization) induced by the traversed (dense and hot) colored medium:
  - Mean parton energy loss: $\Delta E \sim \alpha_s \cdot C_R \cdot \rho_{gluon}(T) \cdot \Delta L^{(2)}$
  - Energy is carried away by gluon bremsstrahung outside jet cone: $dE/dx \sim \alpha_s \langle k_T^2 \rangle$
  - 2 basic formalisms ("thin" and "thick" plasmas):
    – GLV: opacity L/λ expansion
    – BDMPS: gluon transport coeff. $\sim\rho_{gluon}(T)$
  - Expanding vs. static plasma:
    $\Delta E_{1-D} = (2\tau_0/R_A)\Delta E_{stat} \sim 15 \cdot \Delta E_{stat}$ (τ_0=0.2 fm/c, R_A=6 fm)



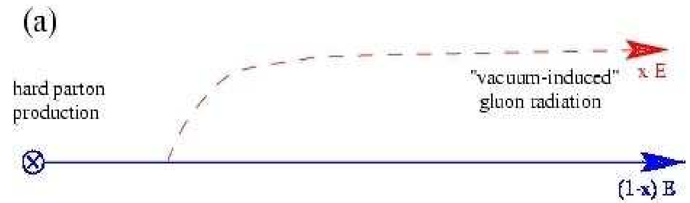
- Observables:
  i) Depletion of leading–particle inclusive high p_T spectra: "jet quenching"
  ii) Photon–tagged jets, direct γ vs fragmentation γ ...



GV & Wang PRL 86, 2537 (2001)

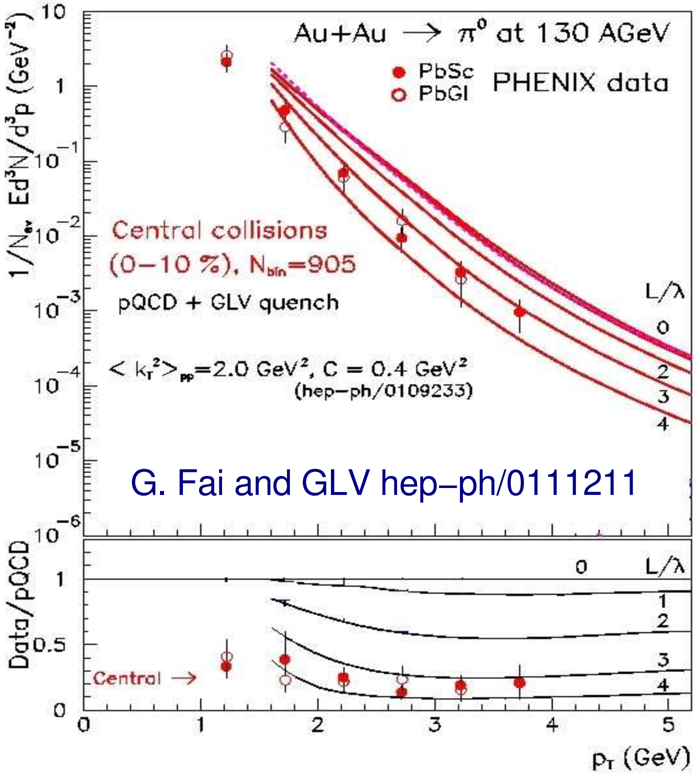
- Well above energy loss in cold nuclear matter:

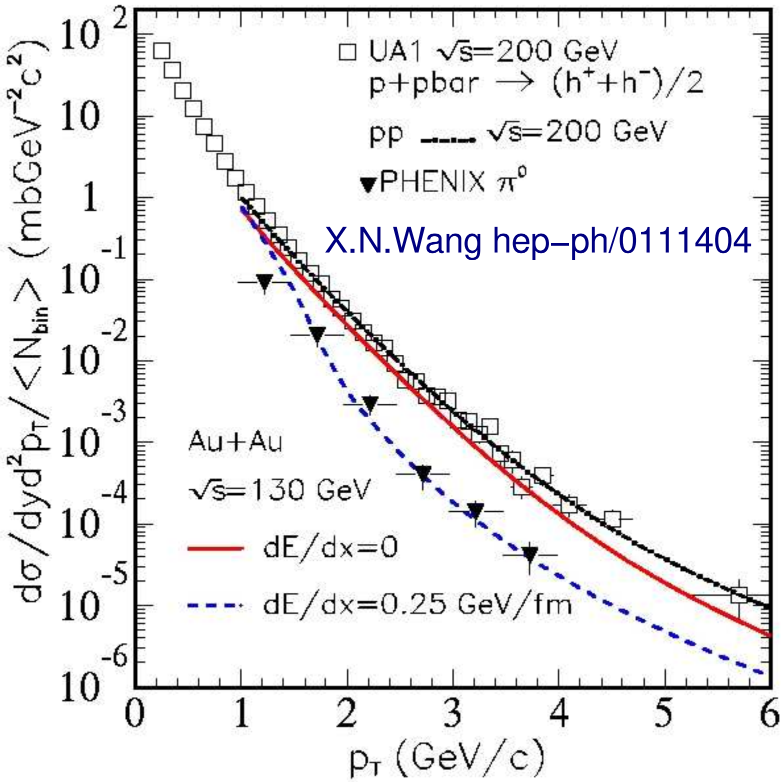
BDMPS: ΔE(T=250 MeV) ~ 15·ΔE(T=0)
X.N.Wang: dE/dx ~0.5 GeV/fm (HERMES *eA* data)
FNAL E772: dE/dx ~0.2 GeV/fm (D.Y. *pA* data)



"QGP" effects: pQCD calculations vs. data

- LO pQCD calculations including: k_T enhancement, nuclear PDFs & modified FFs to take into account medium–induced energy loss.
  - Peripheral collisions well described with L/λ ~1.–1.5 (GLV), dE/dx ~ 0. (X.N.W.)
  - Suppression at p_T>1.5 GeV/c in central collisions described with L/λ ~3.–4. , dE/dx=0.25 GeV/fm (expanding source) ≡ $dE/dx|_{eff}$ ~ 7 GeV/fm (static source)

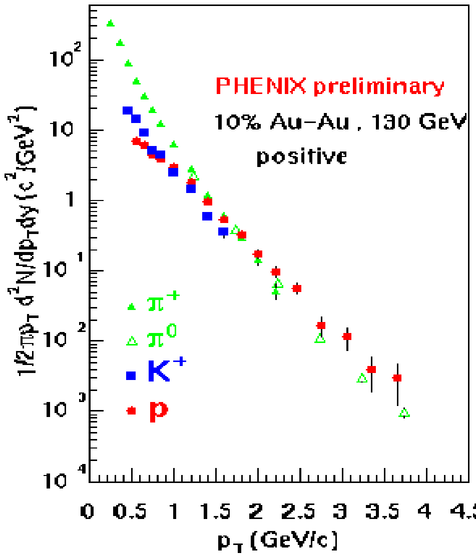


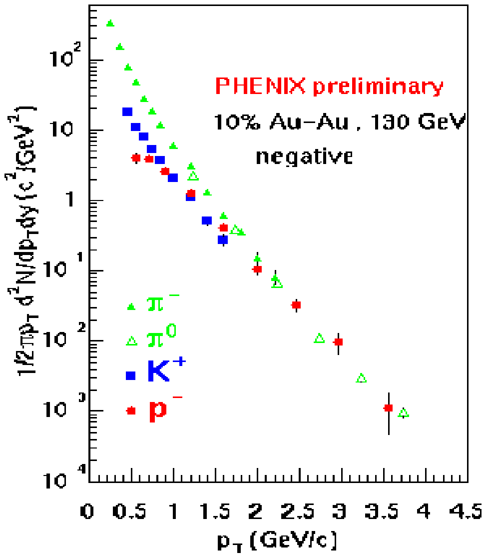


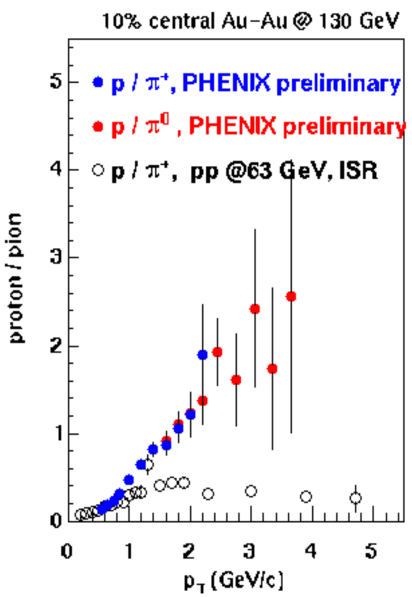
- First hint of final–state medium effect (fast parton energy loss in QGP) ?

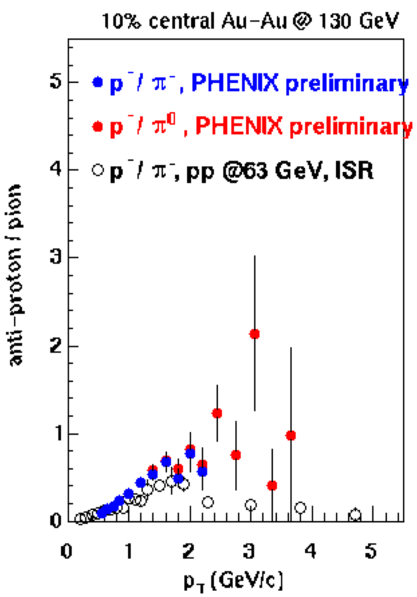
"Hard" results 2: Hadron composition at high–p_T [nucl–ex/0112006]

- Baryon (p, $\bar{p}$) yield larger than pion yield for p_T>2 GeV/c in central colls.
- High–p_T baryon/meson ratio~0.3 in p+p,$\bar{p}$ collisions (ISR,FNAL)
- Supports conclusion of enhanced suppression of pions





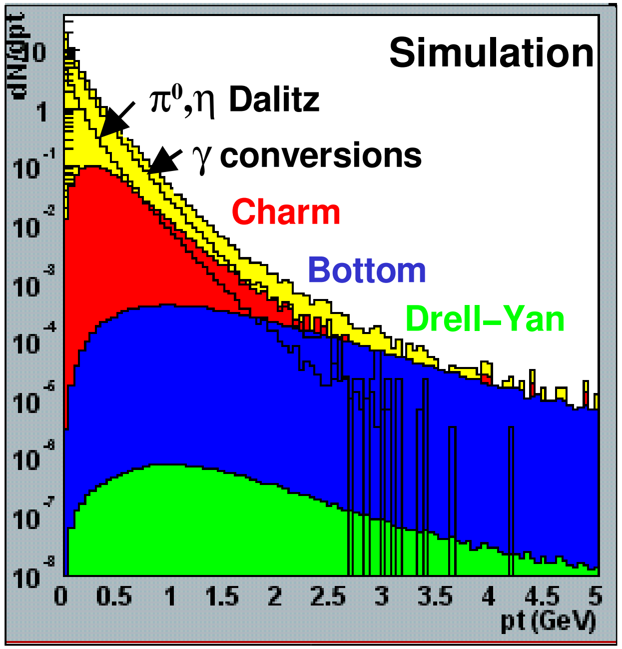




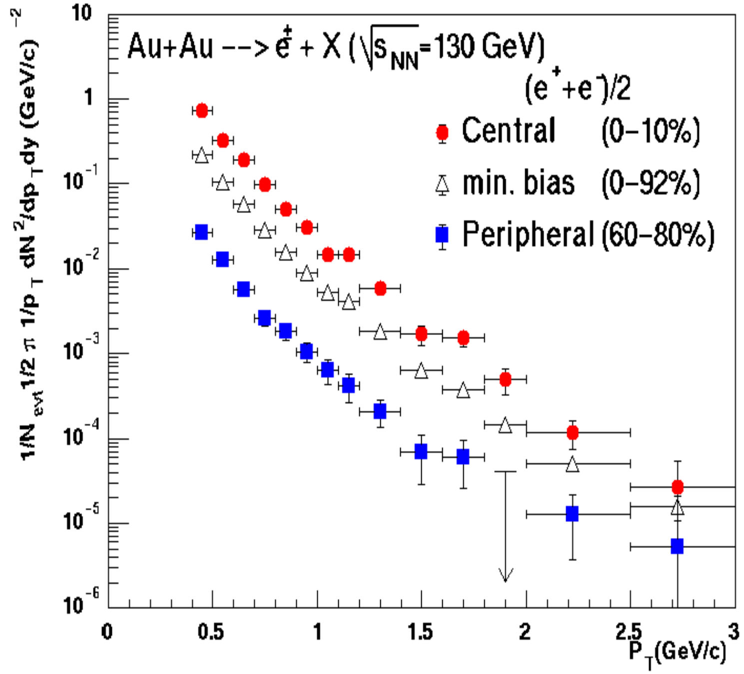
- Different interpretations proposed:
- Hydro (strong collective radial flow) + hadron rescattering
- "Exotic" mechanisms: Baryon junctions + jet quenching in pion channel
- Color–Glass–condensate explains also the observed m_T–scaling ...

"Hard" results 3: Single electron spectrum [nucl–ex/0202002]

- Hard probes signals contributing to electron spectrum:
  - Heavy quark (open charm & bottom via semi–leptonic decays $c \rightarrow eX$, $b \rightarrow eX$): initial gluon density, energy loss of heavy flavors, baseline for J/Ψ suppression ...
  - Thermal dileptons, direct photons (conversion), Drell–Yan.
- Background "cocktail":
  - Dalitz decays of $\pi^0,\eta,\eta',\omega,\phi$
  - γ conversions
  - Di–electron decays of ρ,ω,ϕ
  - Kaon decays

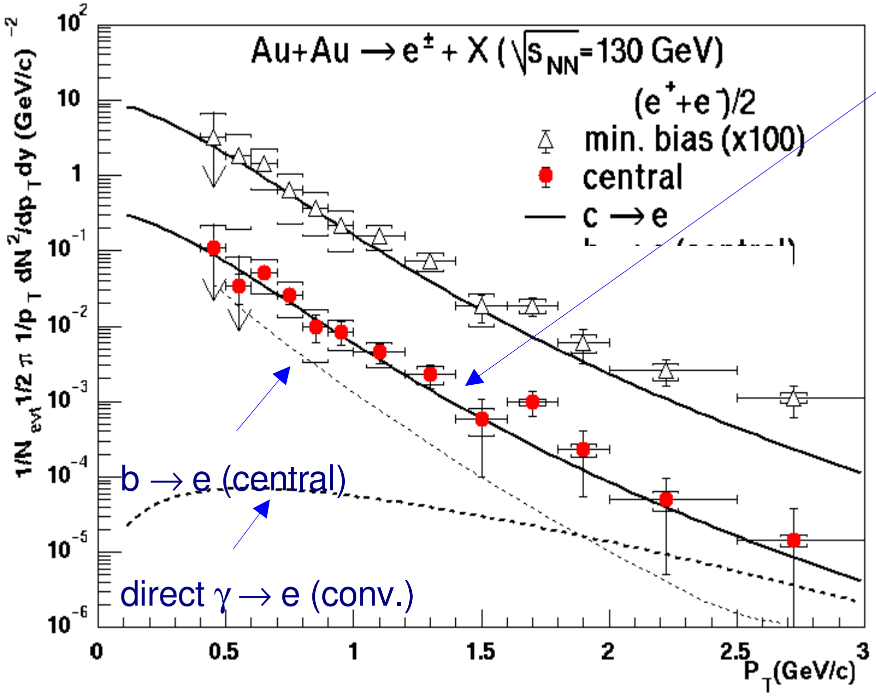


Inclusive $(e^{+}+e^{-})/2$ spectrum:



"Hard" results 3: Open charm from the e⁻ data [nucl–ex/0202002]

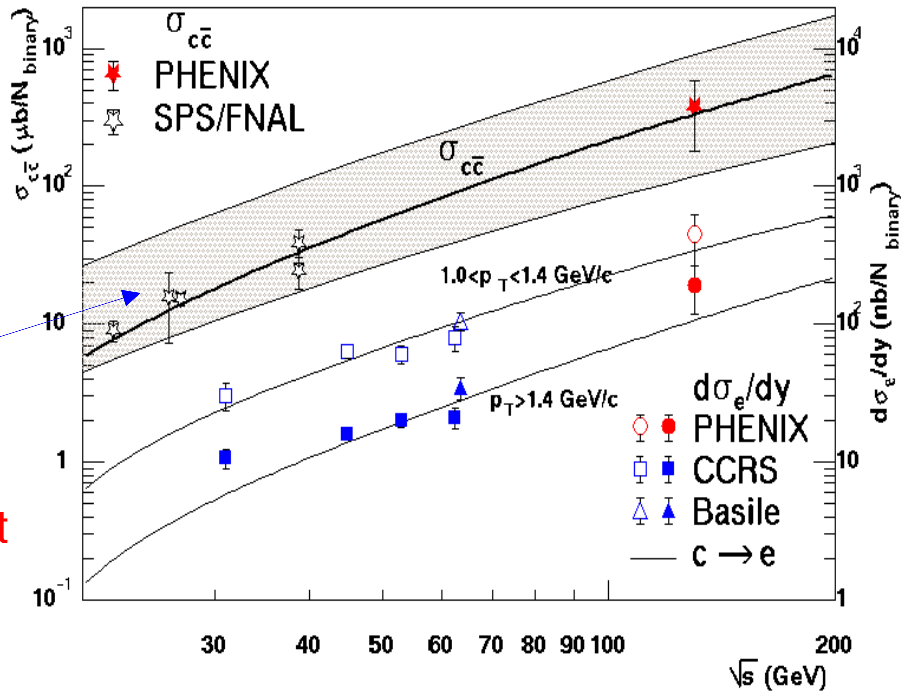
- Background subtracted single electron spectra:



Open charm contribution (scaled *pp* PYTHIA 6.152)

- *Assuming* no thermal radiation contrib. (virtual and/or real+conversion) ⇒

σ_{charm} (cent) = 380 ± 60 ± 200 μb (per NN coll.)

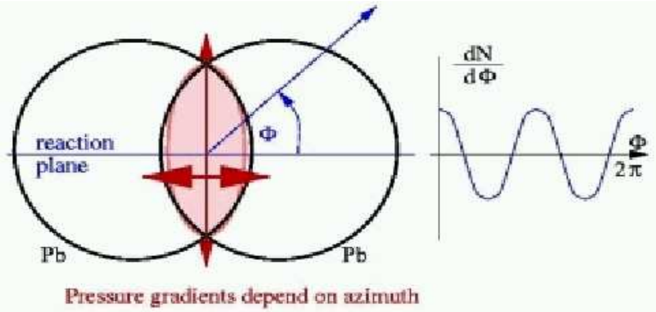


Dashed band = NLO pQCD

- Electron spectrum/cross–section consistent with *pp* scaled charm production (i.e. no nuclear or medium effects), but with large uncertainties.

"Hard" results 4: Elliptic flow [nucl–ex/0204005]

- Initial anisotropy in coord. space (overlap in non–central collisions) translates into final azimuthal asymmetry in momemtum space in the transv. plane



true collective effect: not observed in p+p colls.

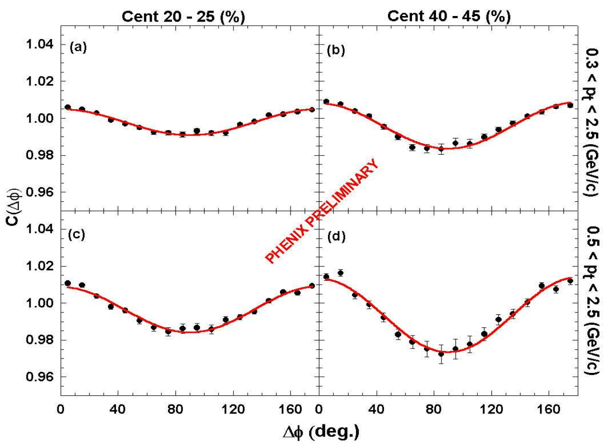
$$\frac{dN}{d^2p_\perp\, d\Phi} = \frac{dN}{d^2p_\perp}\{1 + v_2(\mathbf{p}_\perp)\cos(2\Phi)\}\,.$$

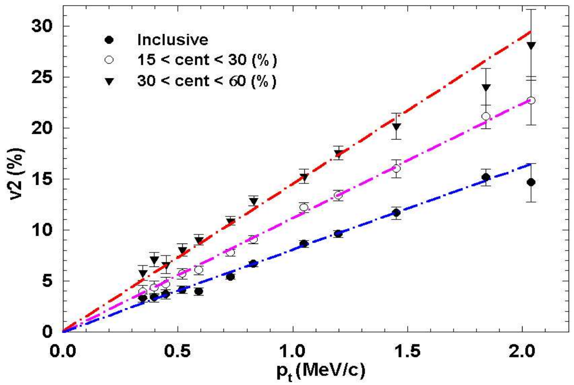
v_2 Fourier coefficient

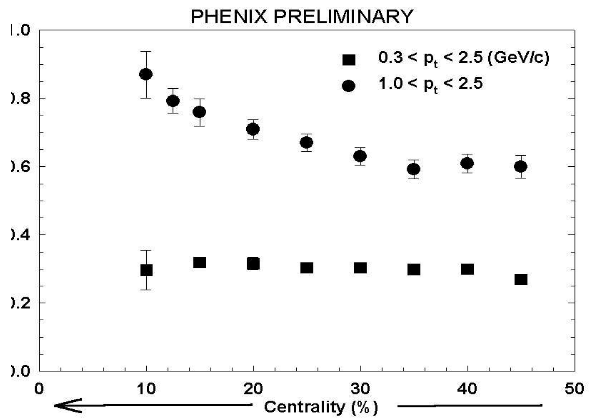
$$\frac{dN}{d\Delta\phi} \propto (1 + \sum_{n=1}^{\infty} 2v_n^2 \cos(n\Delta\phi))$$

- Exp. correlation functions:

p_T and centrality dependence of v_2 (A_2):







- Strong (integrated & differential) elliptic flow signal ⇒ strong (collective) pressure gradients ⇒ large initial state (t<1.0 fm/c) parton rescattering (early thermalization).

PHENIX topics *not* covered in this talk ...

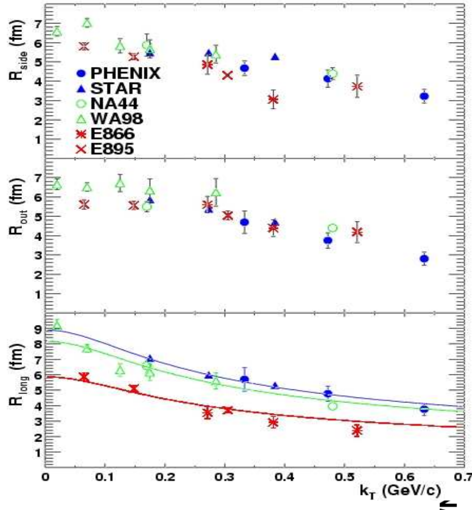
- Two–pion HBT (nucl–ex/0201008) :

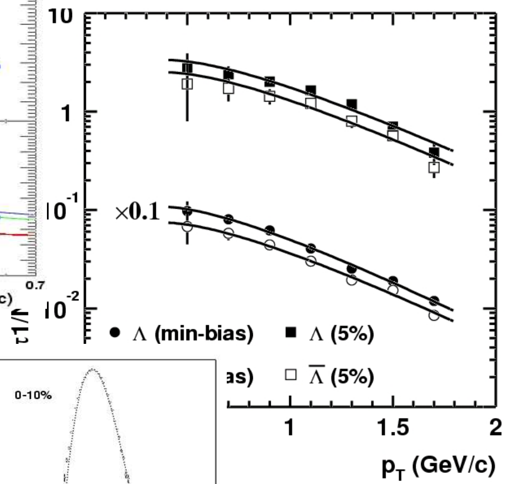
- Lambda baryons (nucl–ex/0204007):

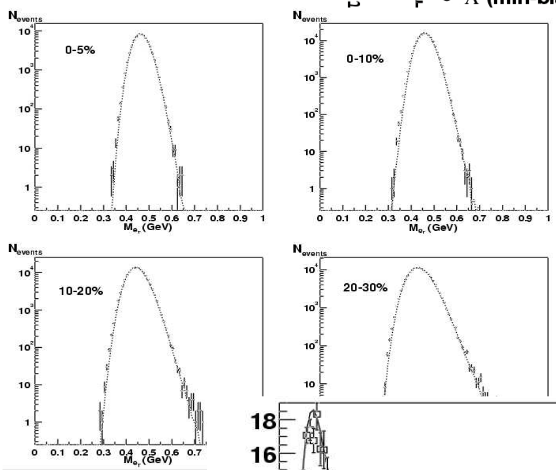
- $\langle p_T \rangle$, E_T fluctuations (nucl–ex/0203015):

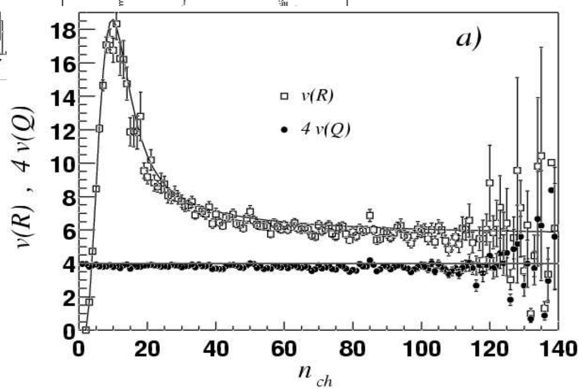
- Net charge fluctuations (nucl–ex/0203014)

- Low p_T hadron spectra (in preparation)



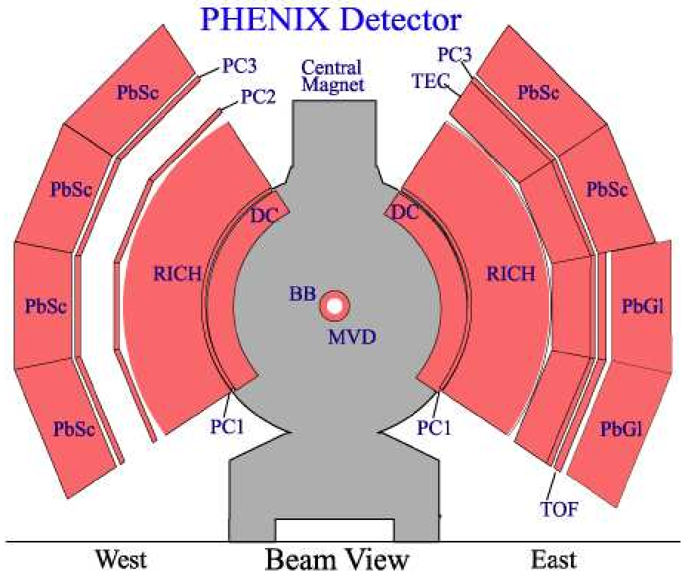


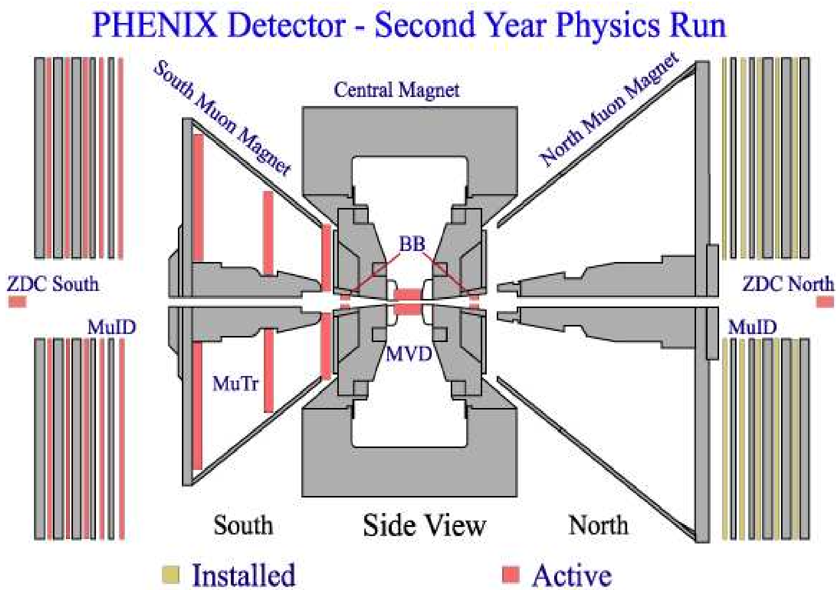




PHENIX Run–2 (2001–2002)

- Configuration: Fully active central arms   South muon arm active:





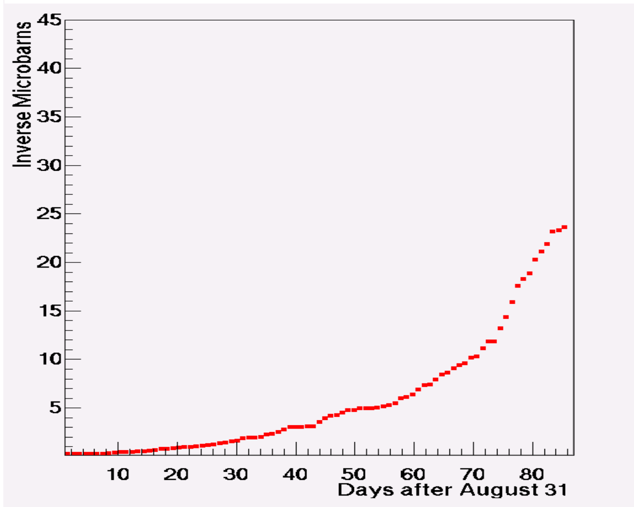
Significant increase in acceptance for most subsystems

- Au+Au, p+p collisions @ $\sqrt{s_{NN}}$ = 200 GeV

AuAu Integrated luminosity: ~24 μb^{-1} recorded

AuAu Statistics: ~200M events "sampled" (LVL2)

Large available set of *pp* baseline data !



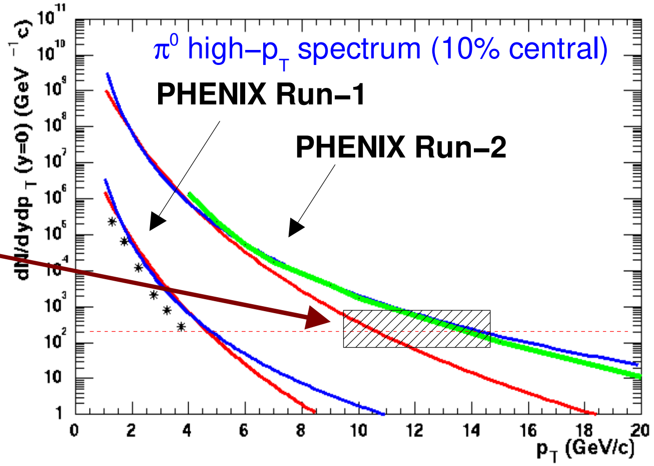
Expected Run–2 (small cross–section) results

1. "Jet quenching" (hot & dense QGP):

Larger quenching @ 200 GeV (hotter medium) ?

Estimated exp. transv. momenta: $(p_T)_{max}$ ~ 10 GeV/c

⇨ Signals: ch. hadrons, π0, γ–tagged jets

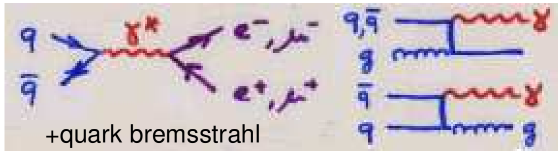


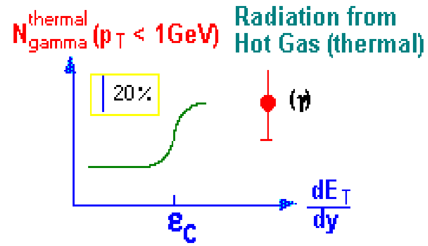
2. Thermal radiation from QGP:

Real and virtual photons convey undistorted info on the thermodynamical state (T) of the medium (EoS)

Thermal direct photons γ, γ* (e^+e^-, $\mu^+\mu^-$)

⇨ Signals: Direct photons, electrons &muon pairs



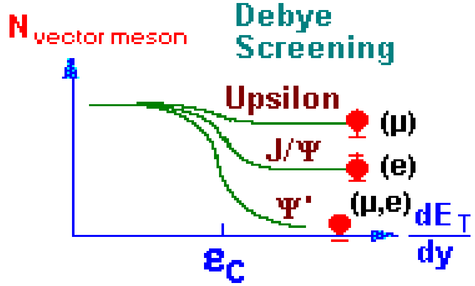


3. "Colour screening" (deconfinement):

Debye–screening in QGP ("onia" dissociation by hard g)

Quarkonia suppression: J/Ψ, Ψ', ϒ

⇨ Signals: electron & muon pairs



4. Open charm & beauty:

D, B mesons enhancement/suppression ?

⇨ Signals: electrons, muons

Summary (I)

- Scientific goals of high–energy heavy–ion physics:
  - Investigate the QCD phase diagram.
  - Produce/study the QGP in the laboratory: color deconfinement & chiral symmetry restoration
  - Probe the quark–hadron phase transition of the early Universe.
  - Study high gluon density & small–x physics.
- Means:
  - Producing the densest and hottest matter ever formed on Earth in high–energy ($\sqrt{s} \sim 200$ GeV) Au–Au collisions.
  - Analyzing the experimental probes (global, hard) that are sensitive to this new state of matter.
- PHENIX Run–1 data:
  - Au+Au @ $\sqrt{s_{NN}} = 130$ GeV. 5M events, L ~ μb^{-1}
  - Charged hadrons, π^0, and $e^\pm$ at mid–rapidity ($|\eta|<0.35$)

Summary (II)

- PHENIX global results for Run–1 :
  - Very high energy density (~60% larger than at SPS) above the expected critical value for QGP.
  - Large particle production, rising faster than number of participant nucleons (onset of hard processes).
  - Closer to baryon–free central region than at SPS.
- PHENIX hard–probes results for Run–1:
  - High–p_T charged hadron and π^0 spectra central collisions: 40–60% suppression (qualitative agreement with energy loss in opaque medium).
  - Increased baryon over meson yield above $p_T \sim 2$ GeV/c (very different from *pp* data).
  - Single electron spectrum/cross–section consistent with *pp* scaled open charm production (no apparent medium effect but large uncertainties yet).
  - Strong elliptic flow signal (early collective rescattering)
- Other PHENIX results: HBT radii, event–by–event fluctuations, lambdas ...
- Many more interesting signals to come (J/Ψ, direct photons, dielectrons, ...) in Run–2 (ongoing analysis of 200 Mevts. collected)