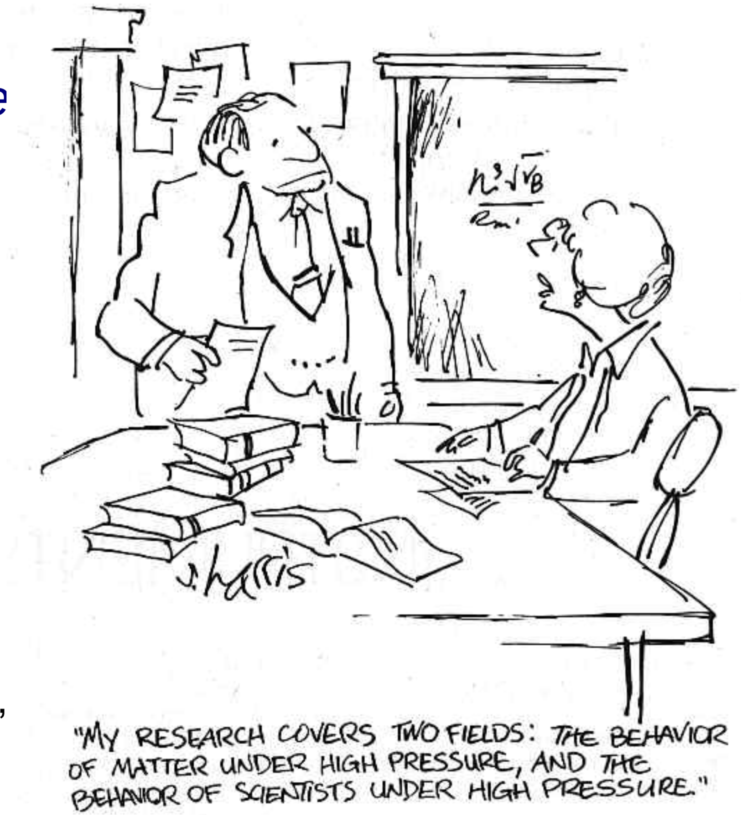
A Comprehensive New Detector for RHIC II Physics

Thomas Ullrich

for

Exploratory Working Group on a Comprehensive New Detector for RHIC-II Physics

L. Bland, P. Steinberg, T. Ullrich (BNL),
M. Calderon (BNL/Indiana),
S. Margetis (Kent State),
B. Surrow (MIT),
J. Rak (New Mexico),
M. Lisa, D. Magestro (Ohio State),
R. Lacey (Stony Brook),
G. Paic (UNAM Mexico),
T. Nayak (VECC Calcutta),
R. Bellwied, C. Pruneau, A. Rose, S. Voloshin (Wayne State),
H. Caines, A. Chikanian, E. Finch, J.W. Harris, C. Markert,
J. Sandweiss, N. Smirnov (Yale)



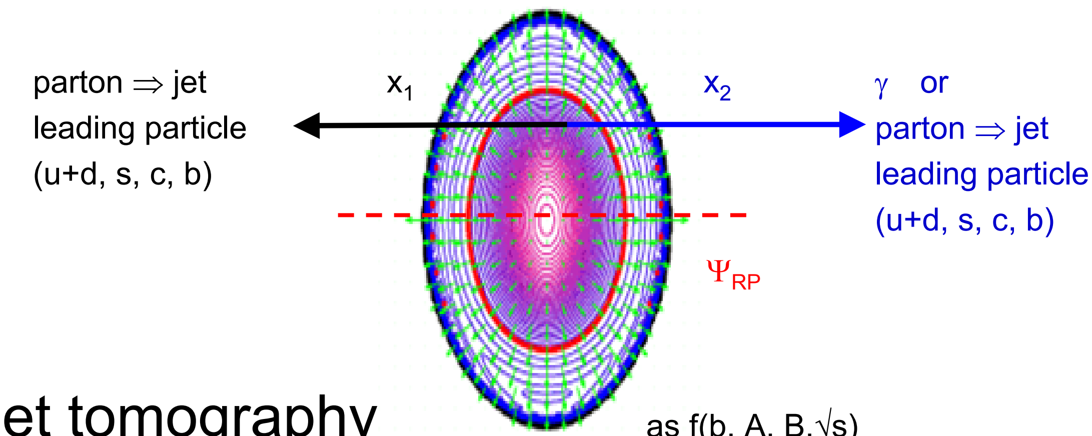
NSAC Review, BNL, June 3, 2004

The Physics Pillars of a New RHIC-II Detector

- What are the detailed properties of the sQGP and can we probe a weakly interacting plasma state ?
- How do particles acquire mass and is chiral symmetry restored in the dense medium ?
- Is there another phase (CGC) of matter at low x, what are its features (how does it melt into the QGP) ?
- What is the structure and dynamics inside the proton (parton spin, L) and is parity violation important ?

What are the features of the matter created ?

- Why strongly interacting (expected weakly) ?
- Initial temperatures, system evolution, EOS ?



Study: using …

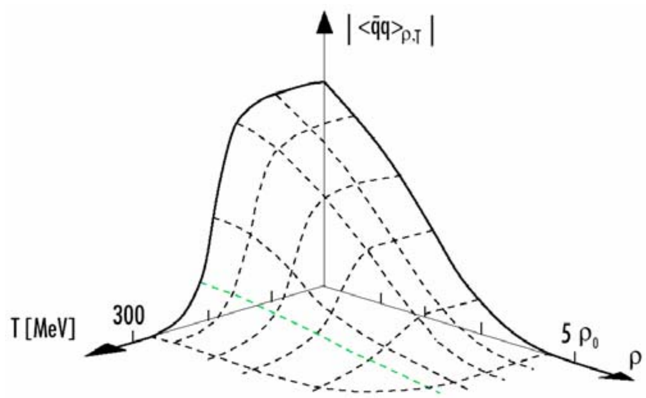
- Initial T: γγ-HBT
- Parton Density: γ+jet, jet-jet tomography
- Frag. Function: identified leading particles
- Deconfinement: quarkonium states
  - $T_{diss}(\Psi') < T_{diss}(\Upsilon(3S)) < T_{diss}(J/\Psi) \approx T_{diss}(\Upsilon(2S)) < T_{RHIC} < T_{diss}(\Upsilon(1S))$?
- Energy-loss: heavy quark jets (dead cone)
- Quark vs. Gluon Matter: jets as f(√s), 3 jet events

all as a function of b, A, B, √s, reaction plane

How do particles acquire mass ?

- Hadron formation
  - Quark Coalescence ?
  - Chiral Symmetry

$$m_\pi^2 f_\pi^2 = -\tfrac{1}{2}(m_u + m_d)\langle\psi\overline{\psi}\rangle$$

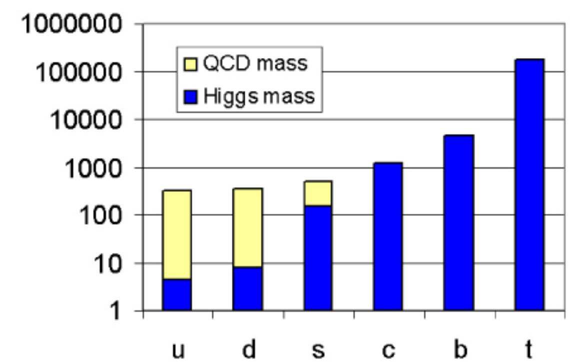


Study using:

- Quarkonium absorption threshold
  - Chiral symmetry restoration:
    heavy mesons lose light quark current mass

$$Q\overline{Q} \rightarrow (\overline{Q}q) + (Q\overline{q})$$

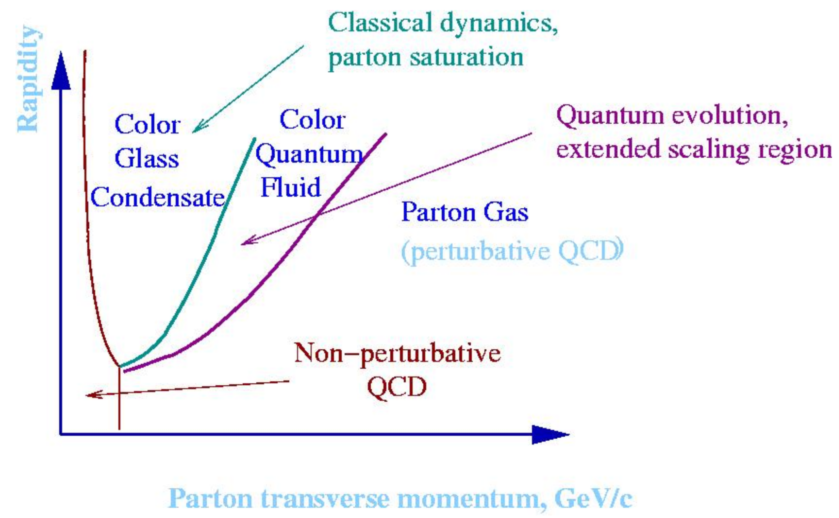
    - Grandchamp, Rapp et al. hep-ph/0403204



- D-meson production to explore chiral dynamics
  - Chiral doubling scenario: $m(0^+)-m(0^-) \rightarrow 0$ as $\langle qq\rangle \rightarrow 0$
    - M. Harada et al., hep-ph/0312182, Nowak et al., hep-ph/0307102
  - D_s/D ratio (pp ~ 0.3, AA thermal models ~ 0.3, CSS > 0.3)
- $m_\rho(p_T)$, $\Gamma_\rho(p_T)$ near- versus away-side jet cone
- Particle identified fragmentation functions

Is there a distinct phase (CGC) of matter at low x?

- Gluon saturation and color glass condensate
- What are its features ?
- How does it evolve into the QGP



Study using (see D. Kharzeevs talk)

- low-x $\Rightarrow$ forward physics
- Mid–forward rapidity correlations (Mueller-Navelet dijets)
- Direct photons at forward rapidities
- $\gamma\gamma$ HBT (coherence of sea-quark source?)
- Drell-Yan in forward region (hep-ph/040321)
- R_{pA}, R_{AA} of heavy mesons in forward direction (hep-ph/0310358)

What is the dynamical structure of the proton?

Polarized p+p

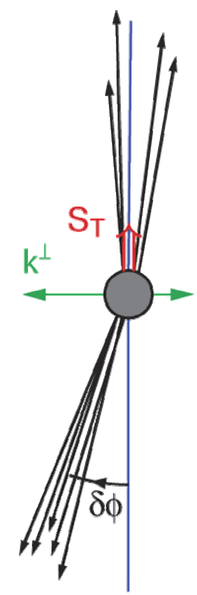
- Gluon polarization in proton
- Polarization of sea?
  - Parity violating longitudinal single-spin asymmetry A_L
- Transverse spin structure
- Physics beyond the Standard Model
  - Parity violation in qq scattering (interference of *g* and Z exchange) and through baryon polarization (Taxil, Virey PLB364, 181, PRD55, 4480)
  - Contact interactions, leptophobic Z' models ? (Taxil, Virey hep-ph/9604331, 9607390)

Study using:

- Heavy quark production
  - via semileptonic & hadronic D decays, and $B \to J/\Psi + X$

  $\Rightarrow$ constrains gluon polarization in LO (NLO corrections essential)
- Single transverse-spin asymmetry in $\Delta\phi$ of jets in dijet

  $\Rightarrow$ directly sensitive to Sivers function
- γ+jet
- Drell-Yan
- W production: $W \to e(\mu) + \nu$, $W \to$ jet + jet

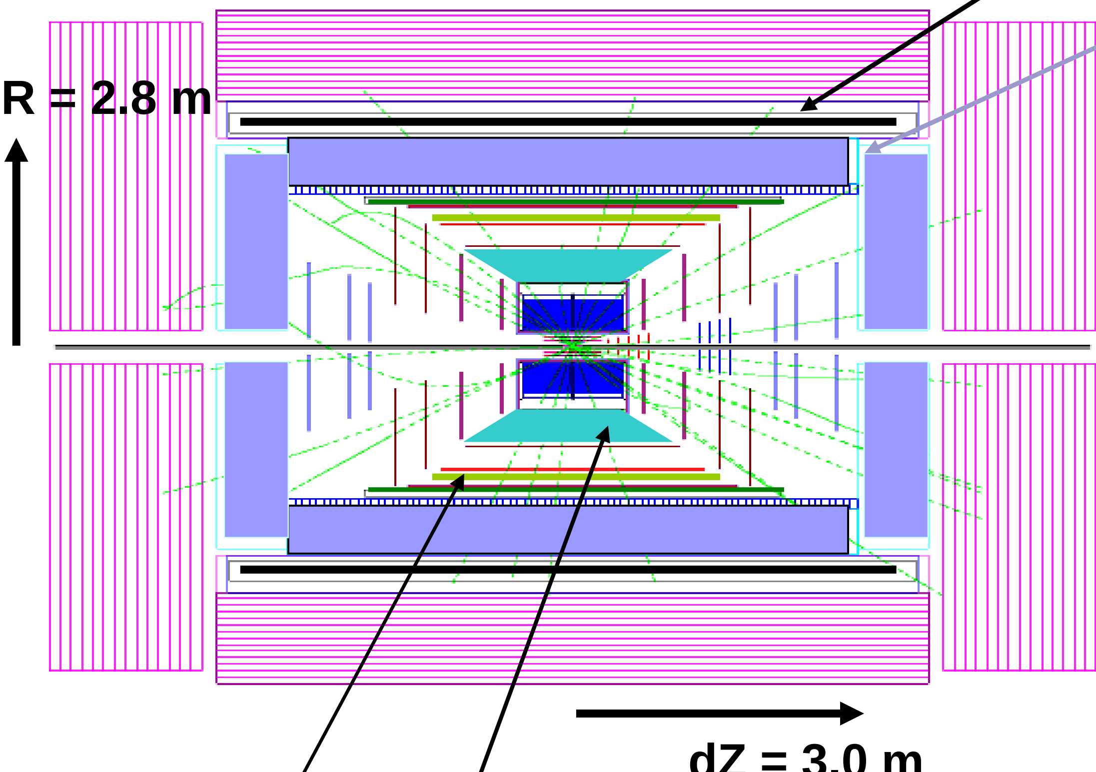


Detector Concept: central $|\eta| < 3$

SC Magnet Coil, 1.5 T
("available") $p_T > 0.5$ GeV/c

HCAL & muon detector. 15 planes,
(5 cm Fe, streamer tubes, 0.3 x 4 cm resolution)
(available)

EMC; Crystals + Fe(Pb)/Sc
(accordion type)
or LAr variant, 6x6 mrad towers
(available)



"Very Forward Direction"
(see next slide)

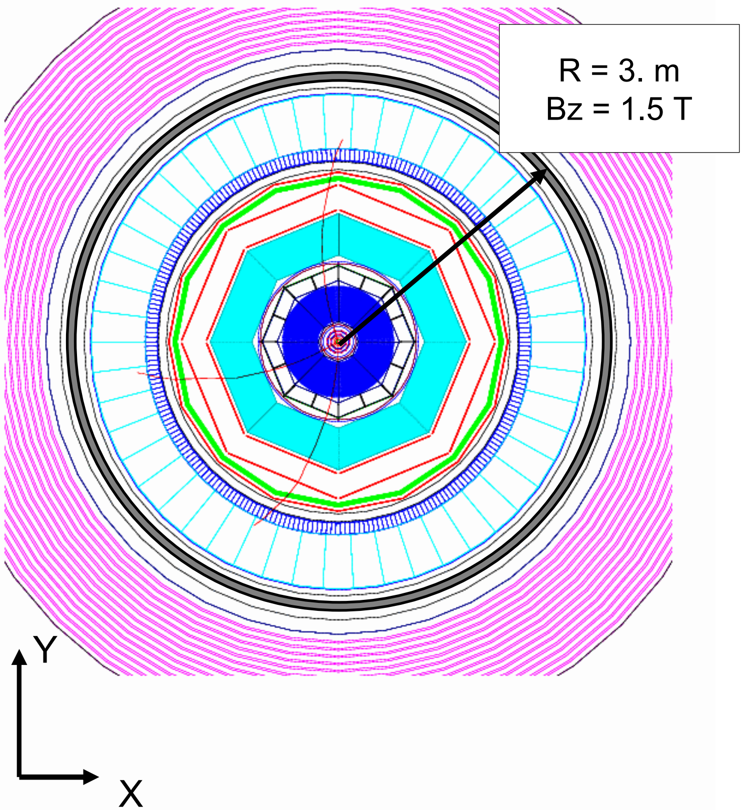
Tracking:

- Si Vertex Detector (Si Pixel)
- Primary Tracker: multi-layer Si strip or miniTPC
- µPattern Pad Detectors in Barrel and End Caps

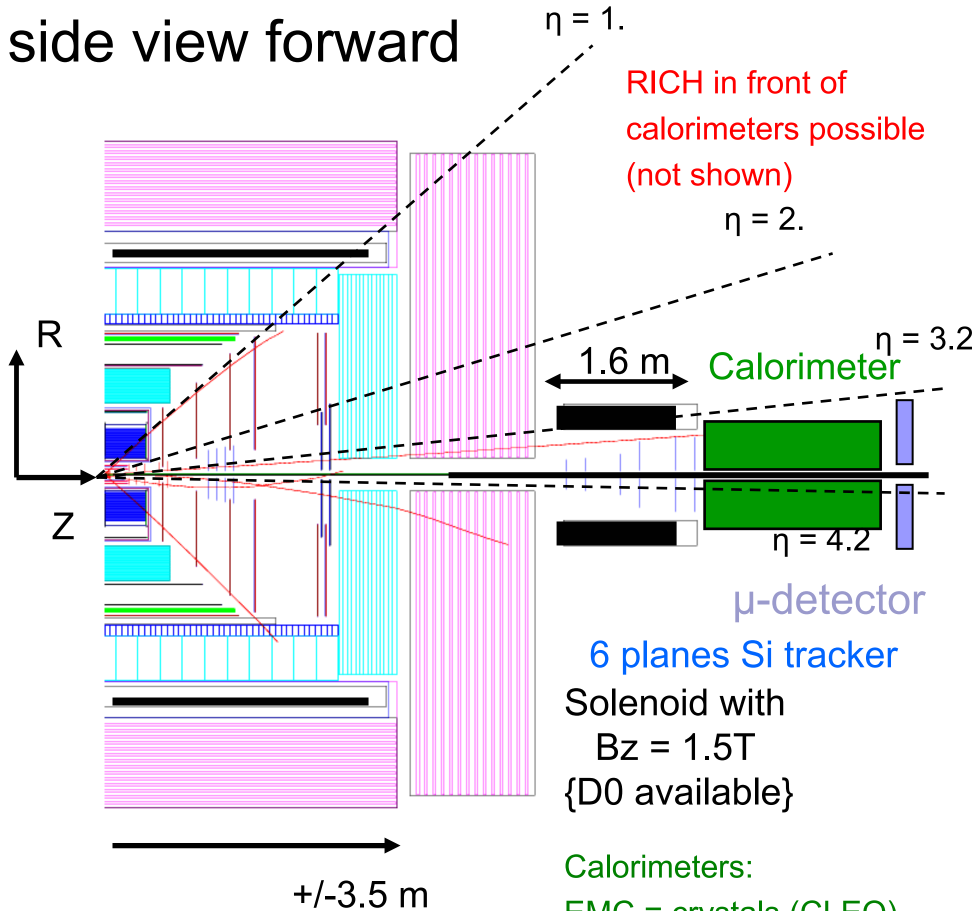
PID Detectors:
Cherenkov threshold (aerogel), RICH, Photon Converters, ToF (STAR clone?)

Detector Concept: forward (3.2 < η < 4.2)

front view central



side view forward



Calorimeters:
EMC = crystals (CLEO)
HCAL = HERA

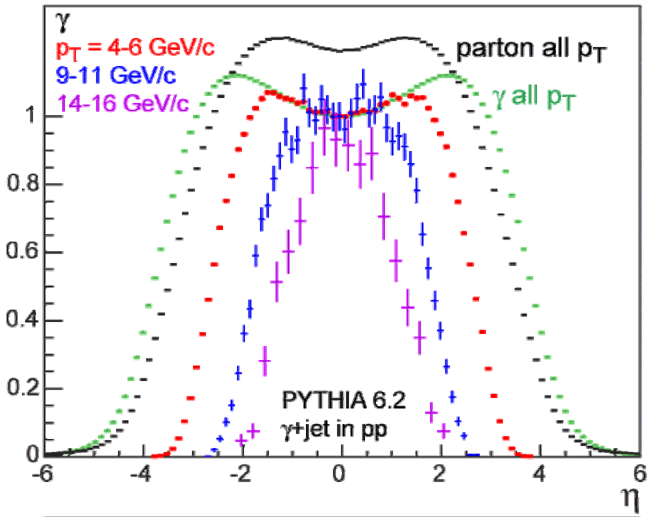
Forward-backward symmetry and |η|>4 under discussion

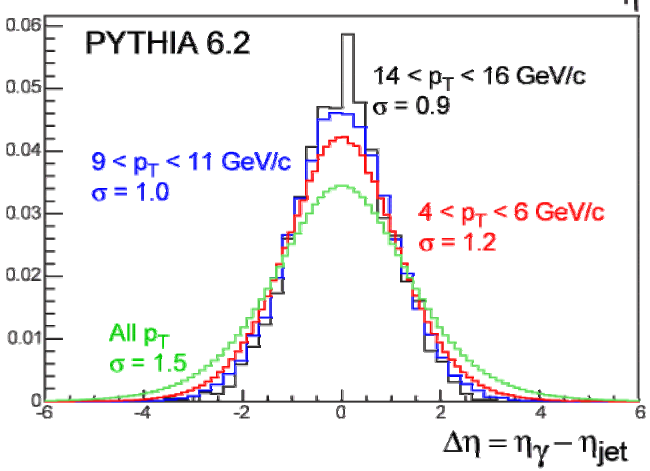
Why Acceptance ?

Large acceptance essential for jet tomography

⇒ requires: tracking + HCAL + ECAL

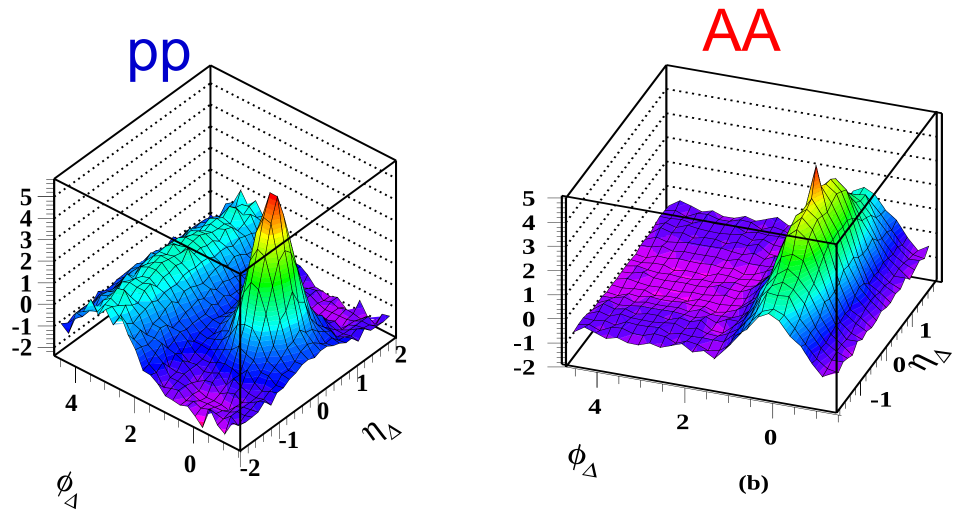
- pp (PYTHIA γ+jet)





- pp → AA

Preliminary STAR results on number correlations for p_T < 2 GeV/c



parton fragmentation modified in dense color medium:

$\Delta\eta$ elongation already on near side

Example: 40 GeV dijets for 30 nb^{-1}: 120k

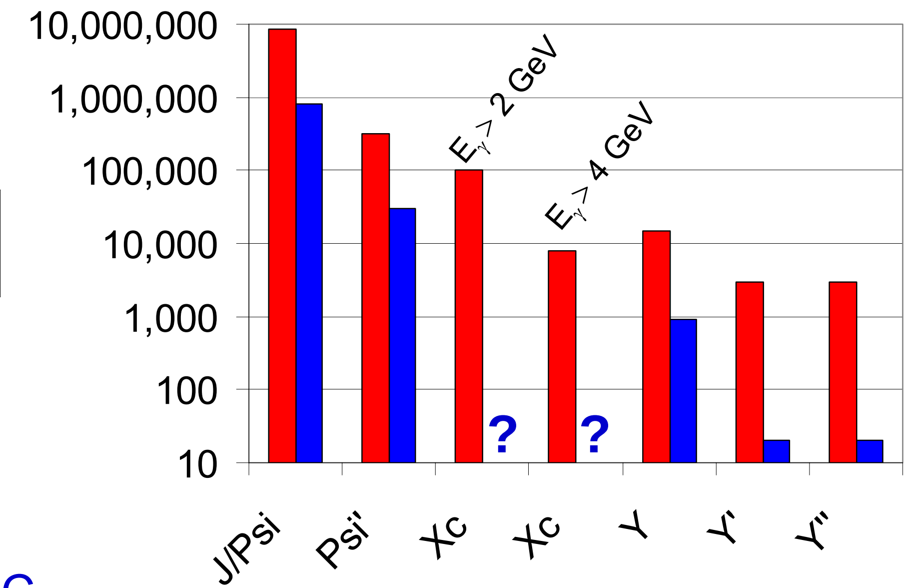
Rates in Acceptance

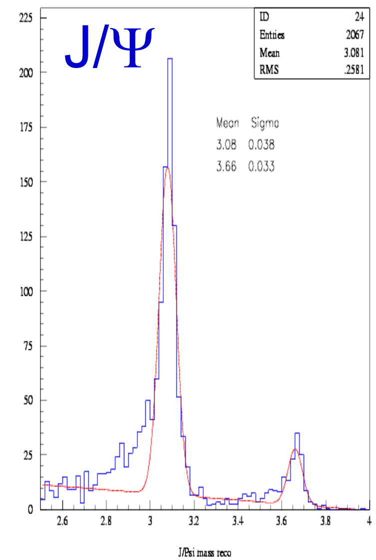
Large acceptance for electrons **and** muons $|\eta|<3$, $\Delta\phi = 2\pi$

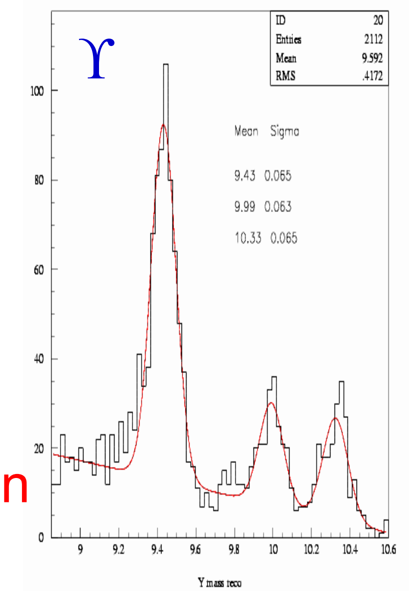
Precision Tracking + Muon Detectors + ECAL + PID

Au+Au min bias:

- 30 nb^{-1} p_{lepton} > 2 GeV/c for J/Ψ (4 GeV/c for Υ)







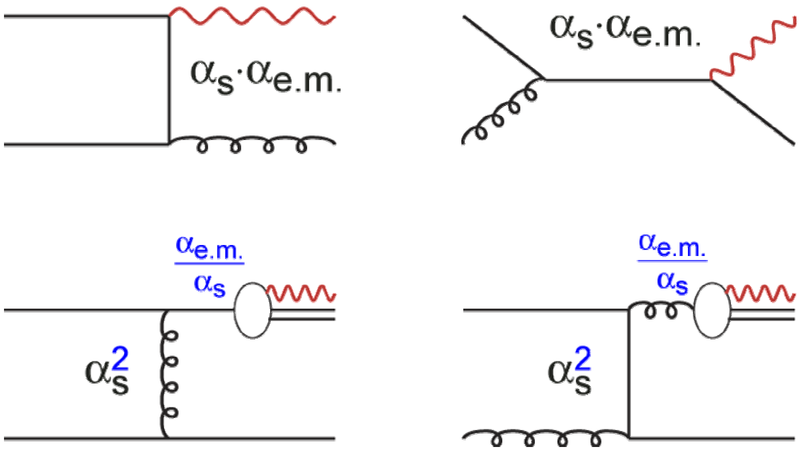
Comparison to LHC

- σ(LHC)/σ(RHIC) = 9 (GRV-HO) – 25 (MRS-D1)
- but ∫Ldt (RHIC) / ∫Ldt(LHC) > 10-20

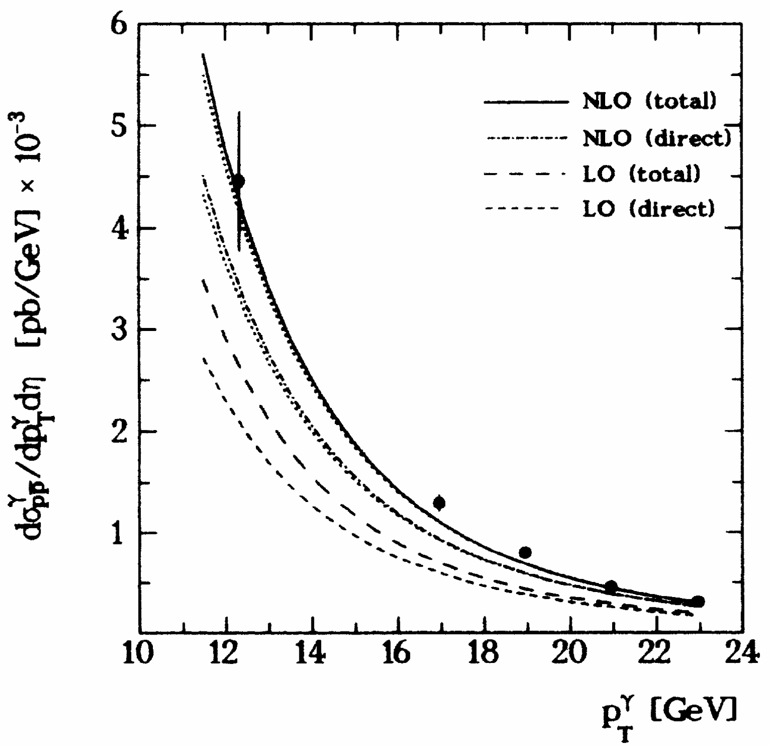
High rates + large acceptance ⇒ x_F coverage, √s and A scan

Why Hadronic Calorimetry ?

- γ+jet
  - direct
  - fragmentation (background)
  - $D_{\gamma/q,g}(z)$ not well known



Vogelsang, Whalley JPG 23 (1997) A1



Glueck et al., PRL 73, 388

- pp (pp spin)

isolation cuts $E_{had} < \varepsilon\, E_\gamma$ in cone

requires HCAL (see CDF)

- AA

$z_{medium} = E_{jet}/E_\gamma \neq E_{jet}/(zE_\gamma)$

isolation cuts not as effective

Need to go to **very** high E_T^γ

$\Rightarrow$ high rate, large acceptance

Hadronic Calorimetry

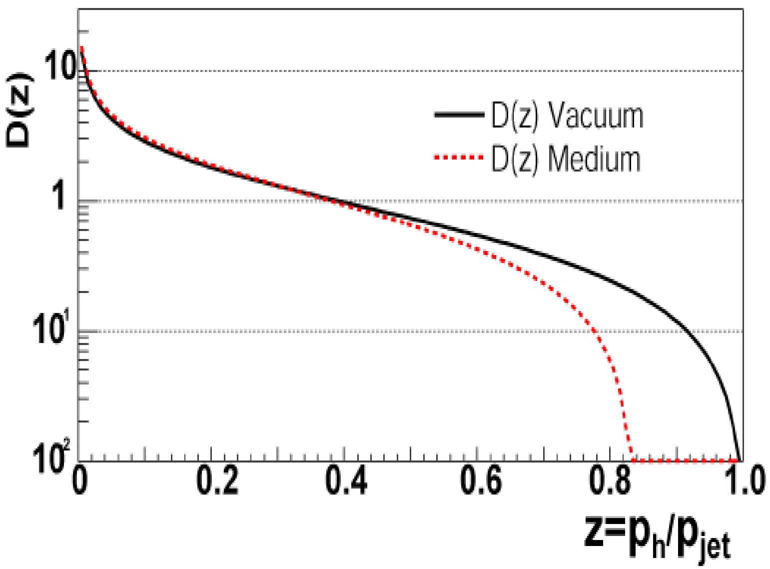
- AA: γ+jet at high E_T^{γ}
  - for 30 nb^{-1}: E_T^{γ} = 20 GeV $\rightarrow$ 33k γ+jet event (1500 @ 30 GeV)
    - numbers similar as PHENIX since $-3 < \eta < 3$
    - new detector: PID for leading parton over full acceptance $-3 < \eta < 3$

- General HCAL:
  - improves jet energy resolution (neutral component)
  - removes trigger bias of EMC
  - proven essential in all HEP detectors for jet physics
  - not available at any RHIC experiment

- Hermetic detector (4π HCAL) $\Rightarrow$ missing energy
  - W production: $W \rightarrow e(\mu) + \nu$ (Nadolsky, Yuan, NPB666 31)
  - $W \rightarrow$ jet + jet

Why Particle ID to High-p_T ?

Presently: modification of fragmentation function is non-specific, *i.e.*, same for all quarks and gluons (e.g.Gyulassy et al.,nucl-th/0302077)

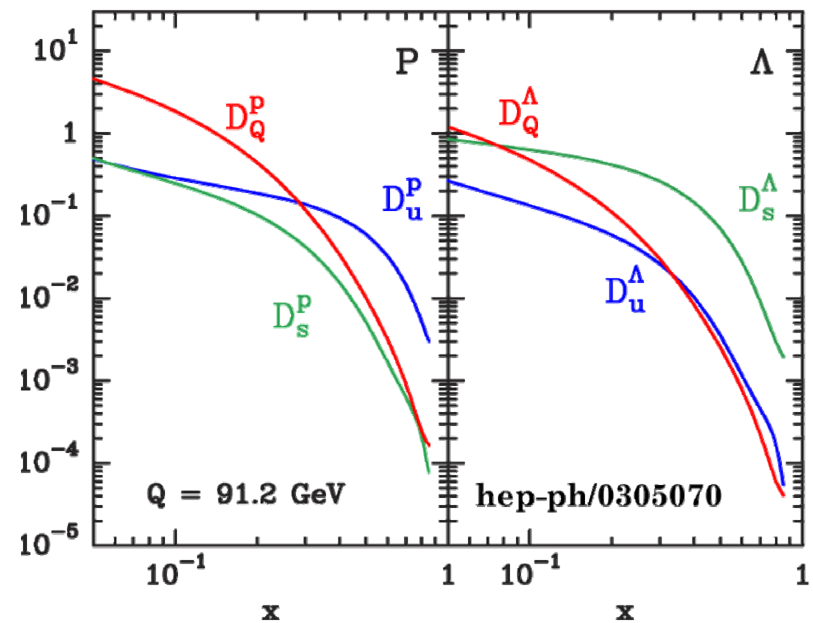


Induced Gluon Radiation

~collinear gluons in cone

"Softened" fragmentation

But: each parton contributes to basic fragmentation function differently (statistical approach (Bourelly & Soffer, hep-ph/0305070)) and is expected to lose different amounts of energy in opaque medium.

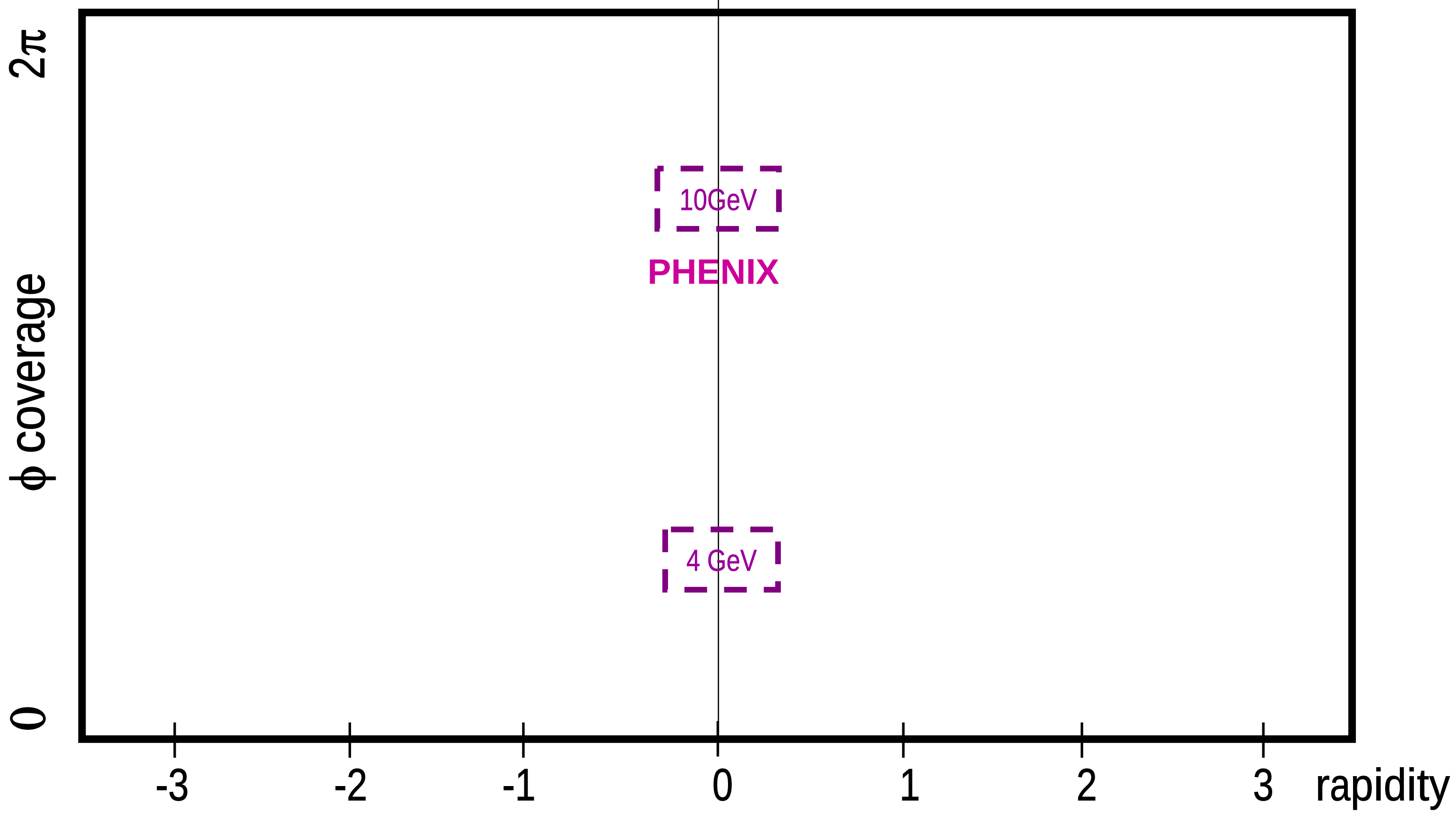


Determine identified fragmentation functions and high p_T PID two particle correlations in pp and AA

⇒ **Essential for "tomography" of medium**

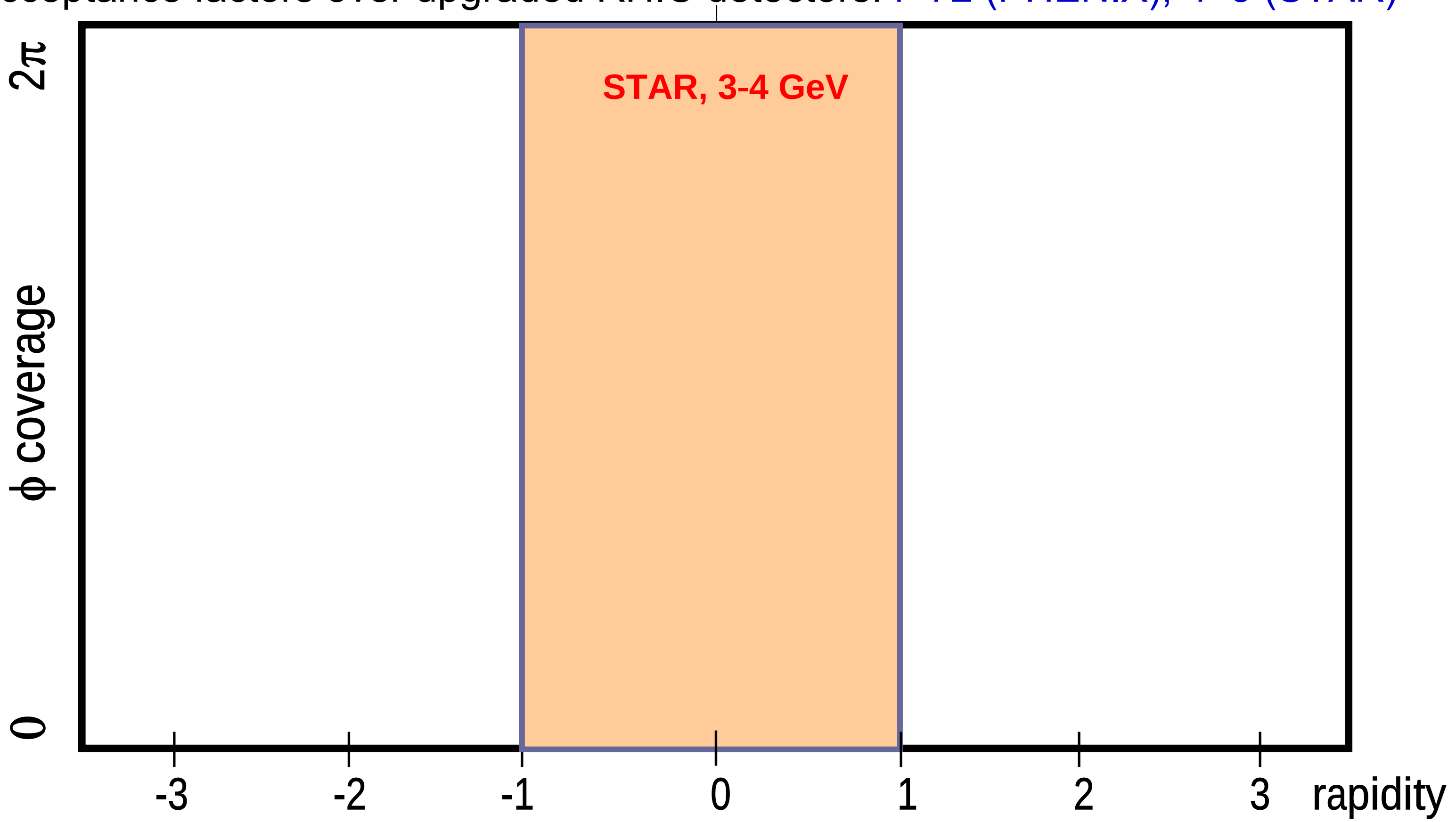
Particle ID to High-p_T (π, K, p)

PID acceptance factors over upgraded RHIC detectors: f=72 (PHENIX), f=3 (STAR)



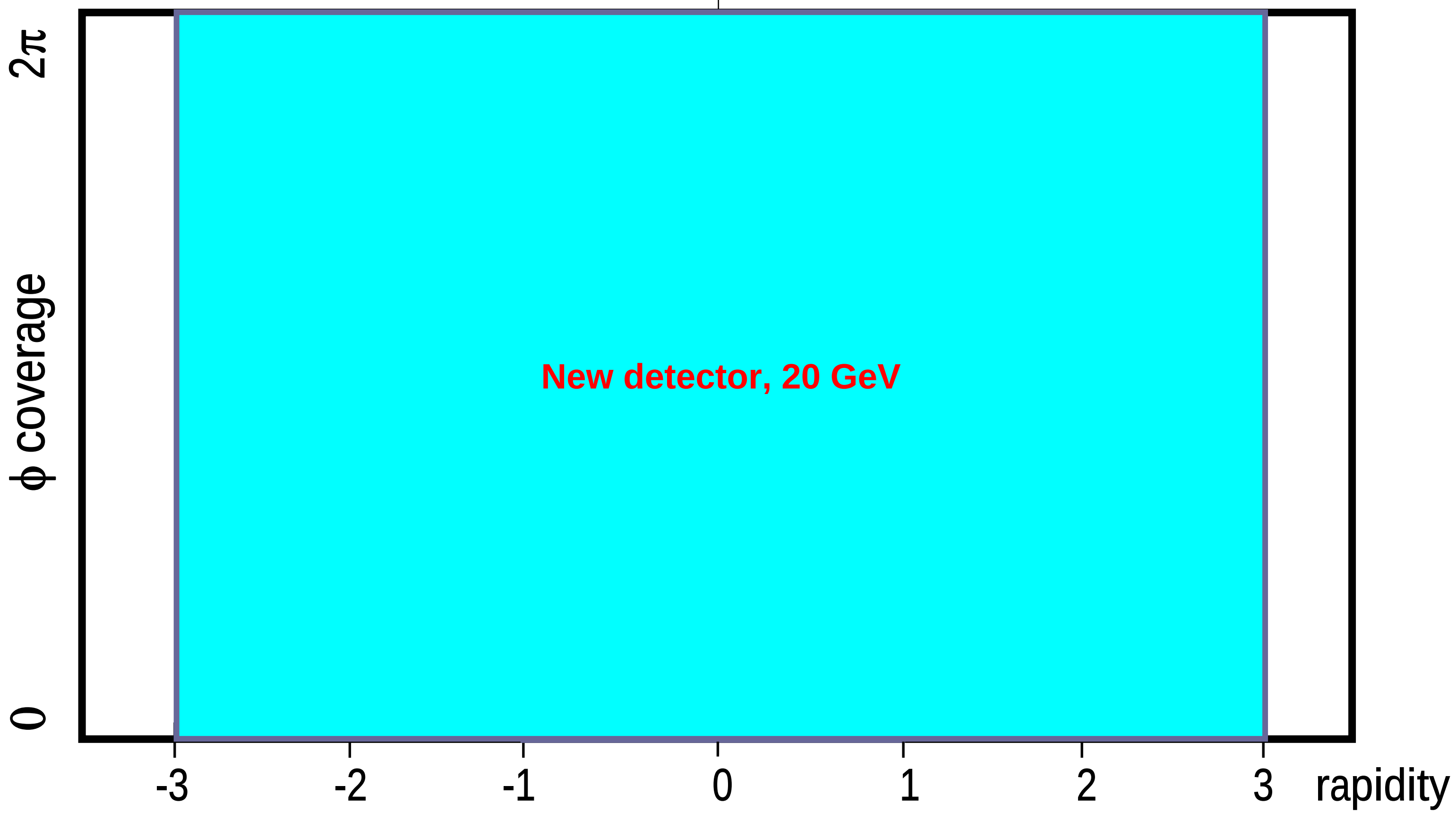
Particle ID to High-p_T (π, K, p)

PID acceptance factors over upgraded RHIC detectors: f=72 (PHENIX), f=3 (STAR)



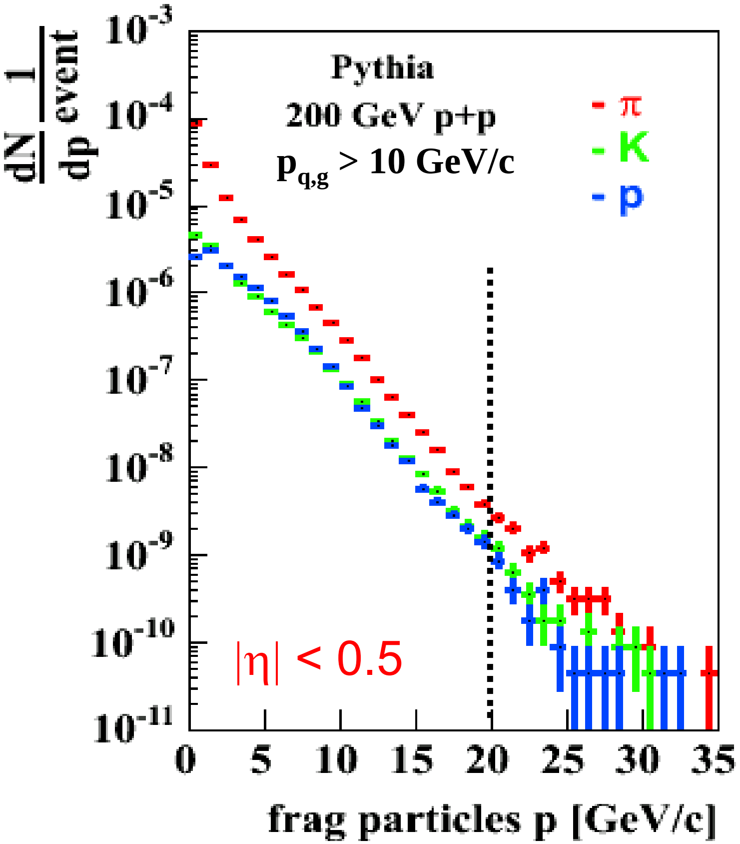
Particle ID to High-p_T (π, K, p)

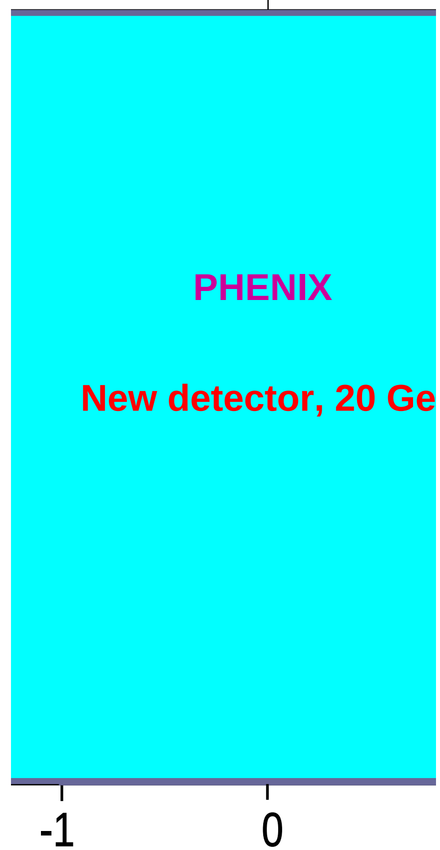
PID acceptance factors over upgraded RHIC detectors: f=72 (PHENIX), f=3 (STAR)

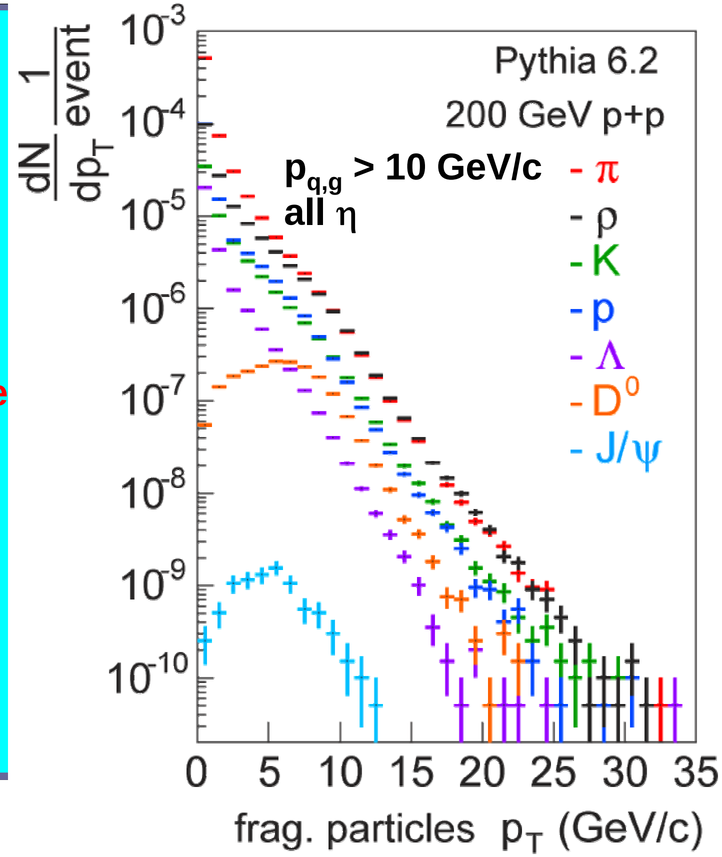


Particle ID to High-p_T (π, K, p)

PID acceptance factors over upgraded RHIC detectors: f=72 (PHENIX), f=3 (STAR)







Singles measurements in AA ($30 nb^{-1}$)

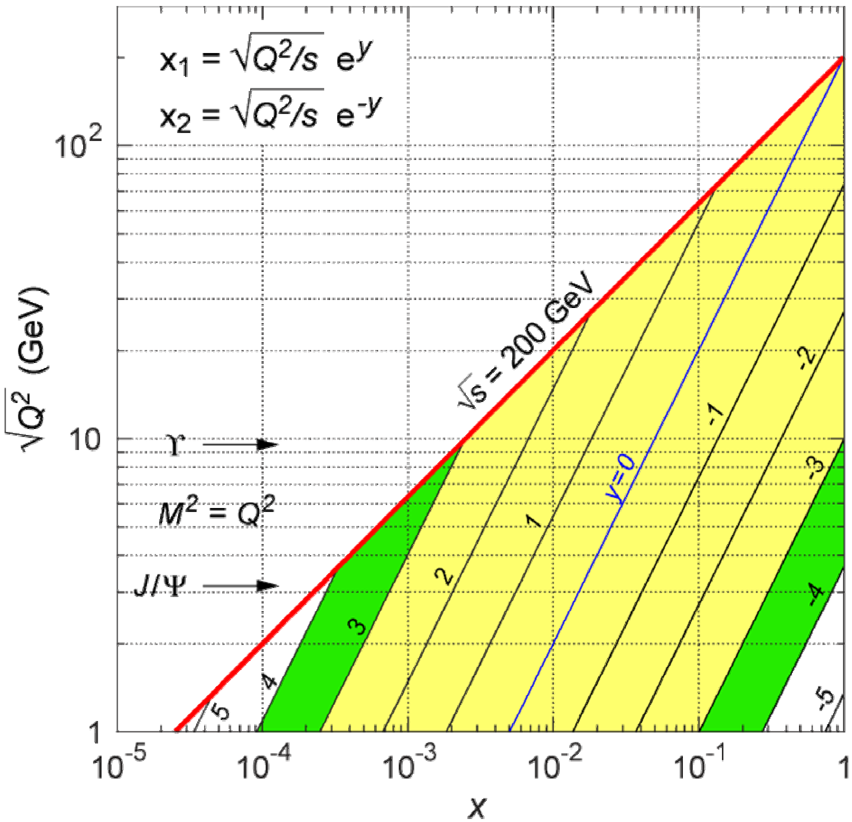
jet-jet leading particles: e.g. 10 GeV proton = 30 M; 20 GeV proton = 60,000

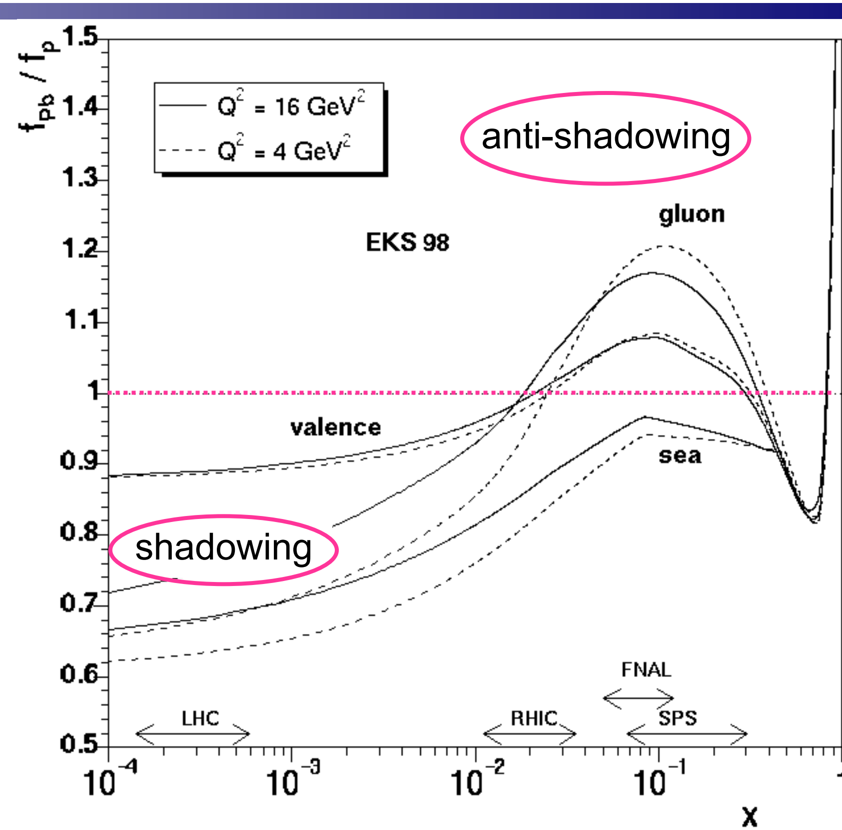
γ-jet leading particles: e.g. 10 GeV proton = 10,000; 15 GeV proton = 200

Two particle correlations in AA ($30 nb^{-1}$)

both above 4 GeV/c: 50,000 $\Lambda\Lambda$ pairs above 10 GeV/c: 5,000 pp pairs

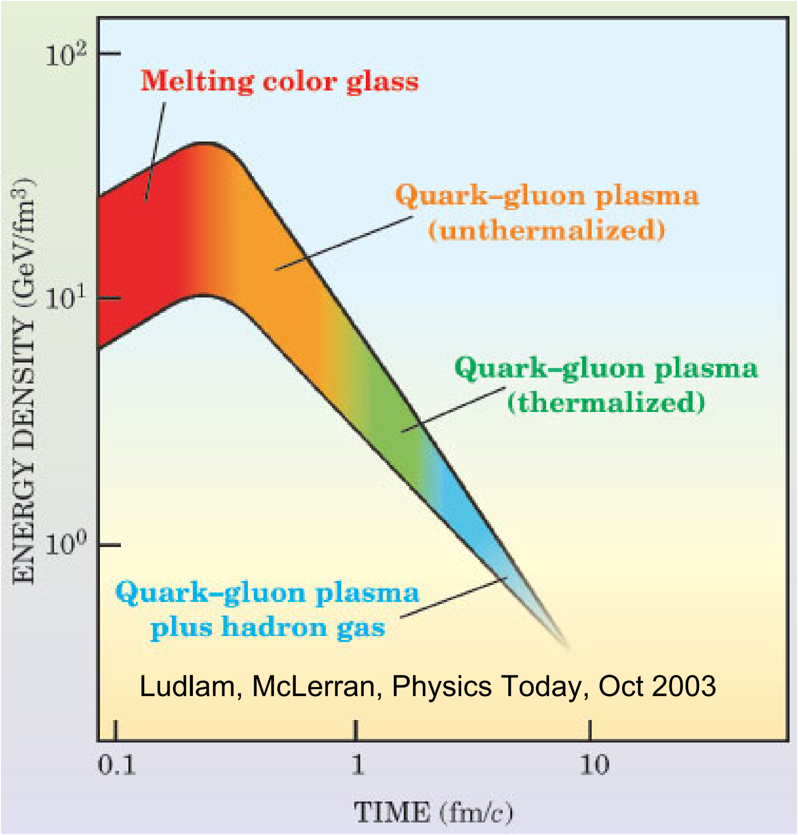
Why Forward Coverage in d+A and A+A ?



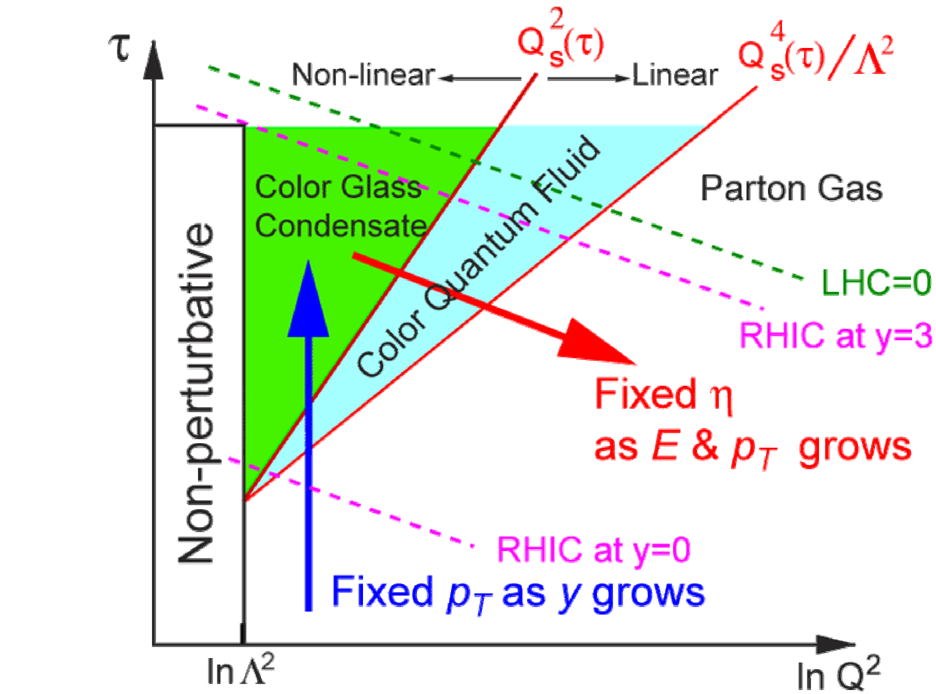


- RHIC at a "Sweet Spot" (M. Gyulassy)
  - models predict undistorted window at *y=0* (shadowing negligible)
  - RHIC might be able to 'dial in' saturation by varying x through rapidity window.
  - Measure flavor dependent R_{dA} and R_{AA} and high-p_T correlations

Why Forward Coverage in d+A and A+A ?



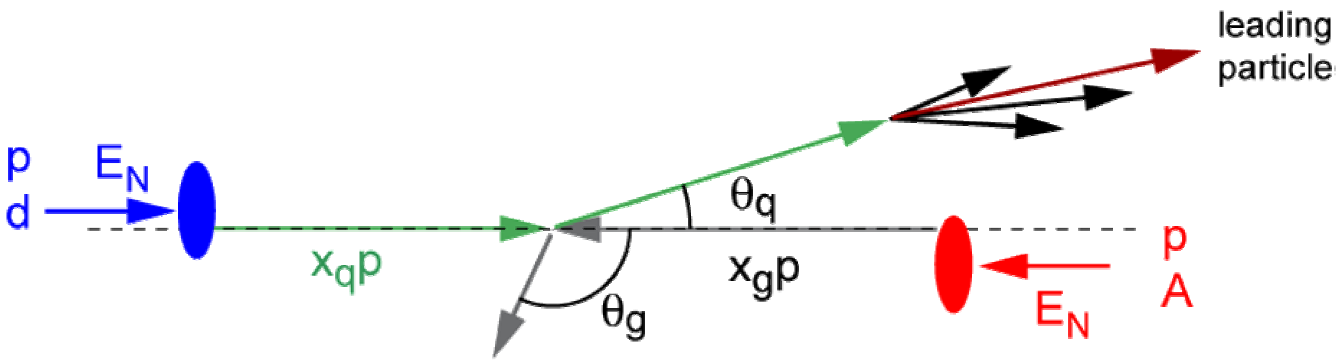
τ = ln (1/x) related to rapidity of produced hadrons



- RHIC at a “Sweet Spot” (M. Gyulassy)
  - models predict undistorted window at *y=0* (shadowing negligible)
  - RHIC might be able to ‘dial in’ saturation by varying x through rapidity window.
  - Measure flavor dependent R_{dA} and R_{AA} and high-p_T correlations

Why Forward Coverage in p(d)+A ?

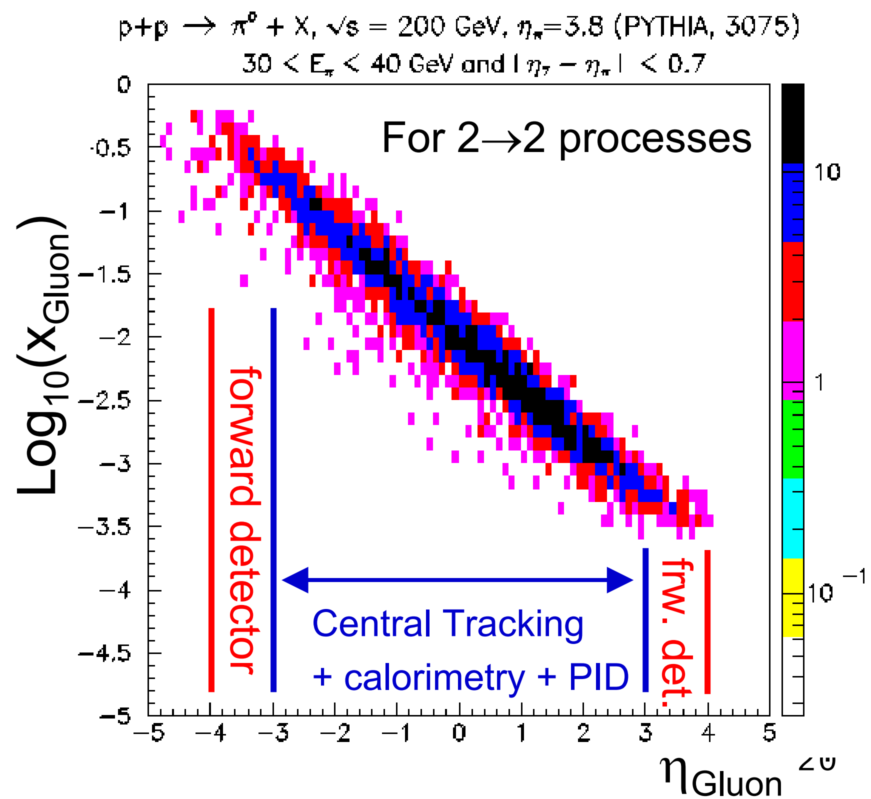
Forward emission in hadron collider: QCD analog of low-x deep-inelastic scattering



- Mostly high-x valence quark + low-x gluon
- $0.3 < x_q < 0.7$
- $0.001 < x_g < 0.1$

Rapidity interval (forward - mid rapidity) correlations (Mueller-Navelet Jets)

- Wide acceptance mid-rapidity detector (|η|<3) & unobstructed view at forward rapidity (3 < |η| < 4)
- Large acceptance enables full coverage of recoil parton and PID
- Spin effects with rapidity interval correlations?



Preliminary Budget and Anticipated Contributions

Central detector (|η| < 3)	**$ 65 M**
Magnet	$ 2 M + in kind (SLD)
Coil (replace to superconducting)	$10 M
Tracking (Silicon or Gas)	$17 M
Vertex (APS)	$ 5 M (STAR tech.)
HCAL (streamer tube exchange)	$ 2 M(SLD)
Muon chambers	in kind SLD
EMCAL	
Central	$ 1 M + in kind (SLD, D0)
Endcap	$ 10 M
PID	
RICH (mirrors from SLD)	$ 8 M
TOF	$ 8 M (STAR tech.)
Aerogel	$ 2 M
Forward detector (η = 3–4)	**$ 8 M**
Magnet	$ 1 M + in kind D0
Tracking (Silicon)	$ 3 M
HCAL	$ 1 M + in kind HERA
PID – RICH	$ 2 M
EMCAL	$ 1 M + in kind CLEO
Combined DAQ/TRG	**$ 10 M**
Detector TOTAL	**$ 83 M**

Next Steps …

- Continued interaction with theory and CAD
  - … has already stimulated new ideas (theory & machine aspects)
    - Yale workshop: http://star.physics.yale.edu/users/bump/April2004RHICworkshop/
- Continue simulations to refine physics capabilities
- Letter of Intent for PAC review this year
- Aim to be included in NSAC long range plan in 2006
  - Should yield R&D funding for specific detector systems
  - Join certain ongoing RHIC-II upgrade R&D efforts
- Proposal to BNL/DoE: Summer 2005
- Construction should begin in 2009 together with RHIC-II
  - Staging of construction possible
    - HCAL+ECAL+μ-Detector+Tracking
    - Vertex Detector+PID
    - Forward Detectors
- Aiming for 2013 as start date

Summary

The New Comprehensive Detector Presents

Unique New Physics Programs at RHIC II:

- γ - jet/leading particle physics program
  - flavor dependent modification of fragmentation due to medium
- Quarkonium physics program
  - deconfinement, initial conditions, nuclear effects

Unique Physics Contributions to:

- Gluon saturation (CGC)
- Chiral symmetry restoration
- Structure and dynamics of the proton

New (as yet) undetermined physics