Future of Hard & Electromagnetic Probes

at

RHIC

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Hard and Electromagnetic Probes at RHIC

- "Near"-term (2005-2010) RHIC physics & plans

  PHENIX & STAR: "continue to establish the presence and properties of the QGP"

  - Systematic study (vs. …) of soft observables (& establish spin program*)
  - Electromagnetic Probes
    - Direct γ – thermal radiation, shadowing
    - Virtual γ (e^+e^-) - chiral restoration via low mass di-leptons
  - Heavy Flavors
    - Open charm, charmonium spectroscopy
    - Open beauty, bottomonium spectroscopy
    - flavor-tagged jets
  - Hard Probes - jets
    - via leading particles
    - γ-jet, D-jet, B-jet, topology!

  PHENIX & STAR: "must continue upgrading detector capabilities"

  - Increase triggering capabilities and DAQ rates
  - Expand apertures
  - Add new capabilities (micro-vertexing, low-mass di-leptons, PID)

  PHENIX MVTX | PHENIX HBD | PHENIX Aerogel | STAR ToF | STAR μVTX

- Low σ physics require RHIC upgrade in luminosity

Hard and Electromagnetic Probes at RHIC

- "Long"-term (2012 $\rightarrow$ …..) RHIC II Luminosity Upgrade
  - Current RHIC Luminosity for Au+Au
    - $L_o = 2 \times 10^{26}$ cm^2 s^{-1}
    - Recent performance $\rightarrow$ 2 L_o
    - $\int L \cdot dt$ per RHIC year (20 wks) ~ 2 - 3 nb^{-1}

Need similar statistics to Au + Au for
✓ p+p reference data
✓ d+Au comparison/control data

  - RHIC II Luminosity for Au+Au
    - Many crucial Au + Au measurements require > 10 nb^{-1}
    - For vital program must increase $\int L \cdot dt$ $\rightarrow$ RHIC II = 40 x L_o ~ 80 - 90 nb^{-1}

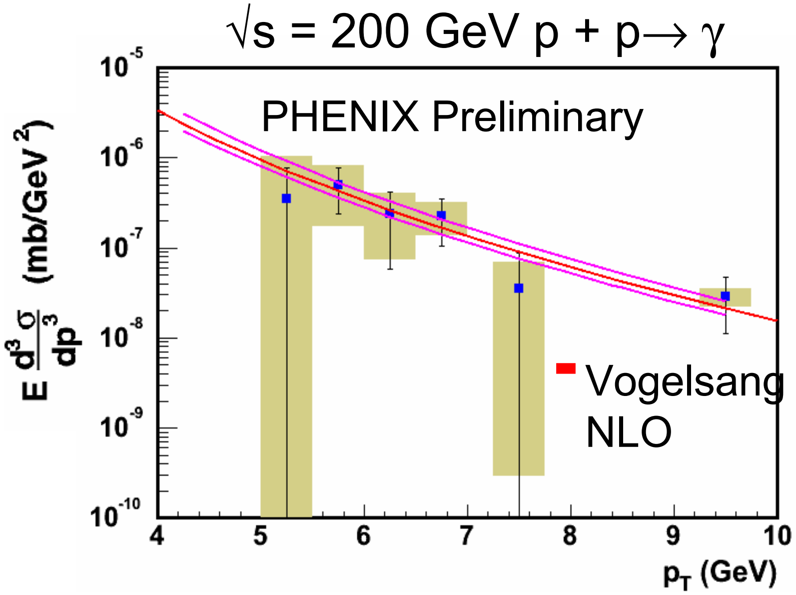
“Near”-Term Data Taking at RHIC

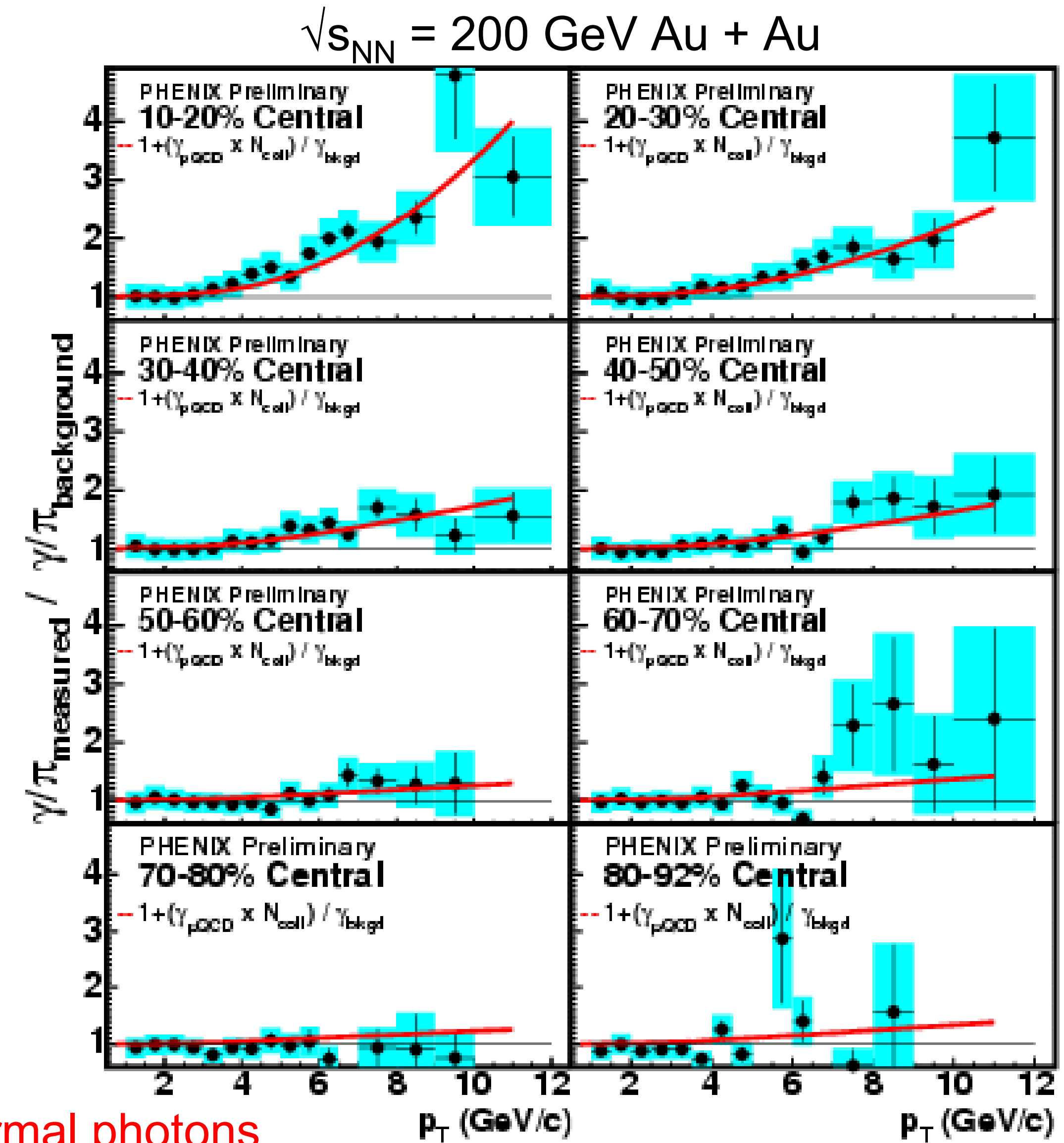
- “Near” -term (2005-2010) Anticipated RHIC Run Plan
  - 2005 – Cu + Cu, pol. p + p at 200 GeV
  - 2006 – Au + Au at 62 GeV, p + p at 200 GeV
  - 2007 – pol. p + p at 200 GeV – spin + reference data
  - 2008 – Au + Au at 200 GeV with new detectors complete
  - 2009 – pol. p + p at 500 GeV – spin / W production
  - 2010 – d + Au at 200 GeV – reference data

EM Probes (Direct Photons)

- EM Probes in
  - A+A (thermal radiation)
  - p+A (shadowing)
  - p+p (reference)

Benefit from larger $\int L \cdot dt$





from K. Reygers talk

I. Tserruya talk: "will know about thermal photons for sure from RHIC Run 4!" – done?

EM Probes (Virtual Photons via e^+e^-)

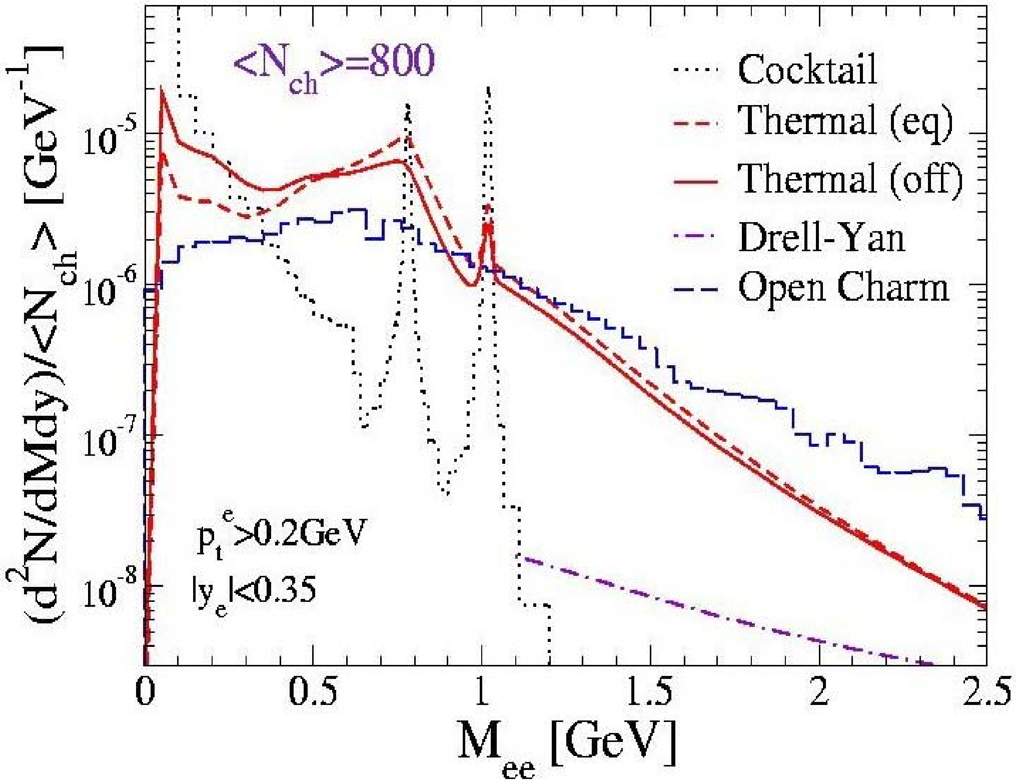
- Medium modifications of vector mesons
  - Chiral symmetry breaking
  - Bound states in sQGP ?
- Thermal radiation
- PHENIX requires
  - Hadron-blind TPC (HBD)

    and
  - $\int L \cdot dt$ for charm
- STAR requires ToF
  - allows electron capabilities

    $p_T > 0.2$ GeV/c

    and
  - $\int L \cdot dt$ for charm
- Significant background issues!

R. Rapp nucl-th/0204003



see I. Tserruya talk

Heavy Flavor (Quarkonium)

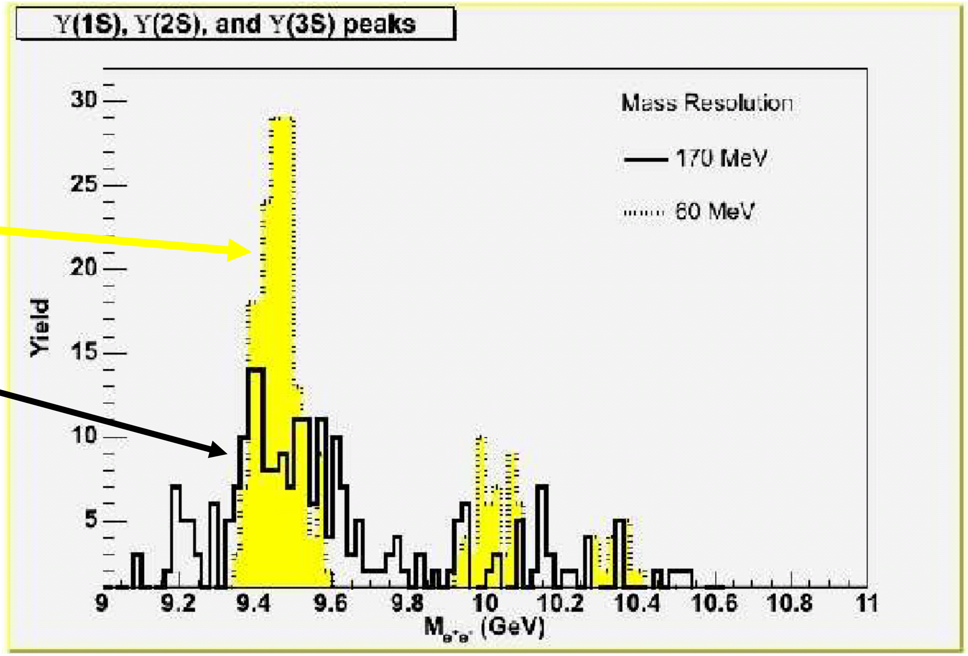
- PHENIX quarkonium program Au+ Au statistics for

	RHIC (1.5 nb^{-1})	RHIC II (30 nb^{-1})	
$J/\psi \rightarrow ee$	2800	56000	
$\psi' \rightarrow ee$	100	2000	
$\Upsilon \rightarrow ee$	8	155	VTX
$J/\psi\ (\psi') \rightarrow \mu\mu$	38,000 (1400)	760,000 (28,000)	
$\Upsilon \rightarrow \mu\mu$	35	700	μ-trigger

- Need measurements with similar p_T or x_T reach in p+p, d+A, lighter systems.

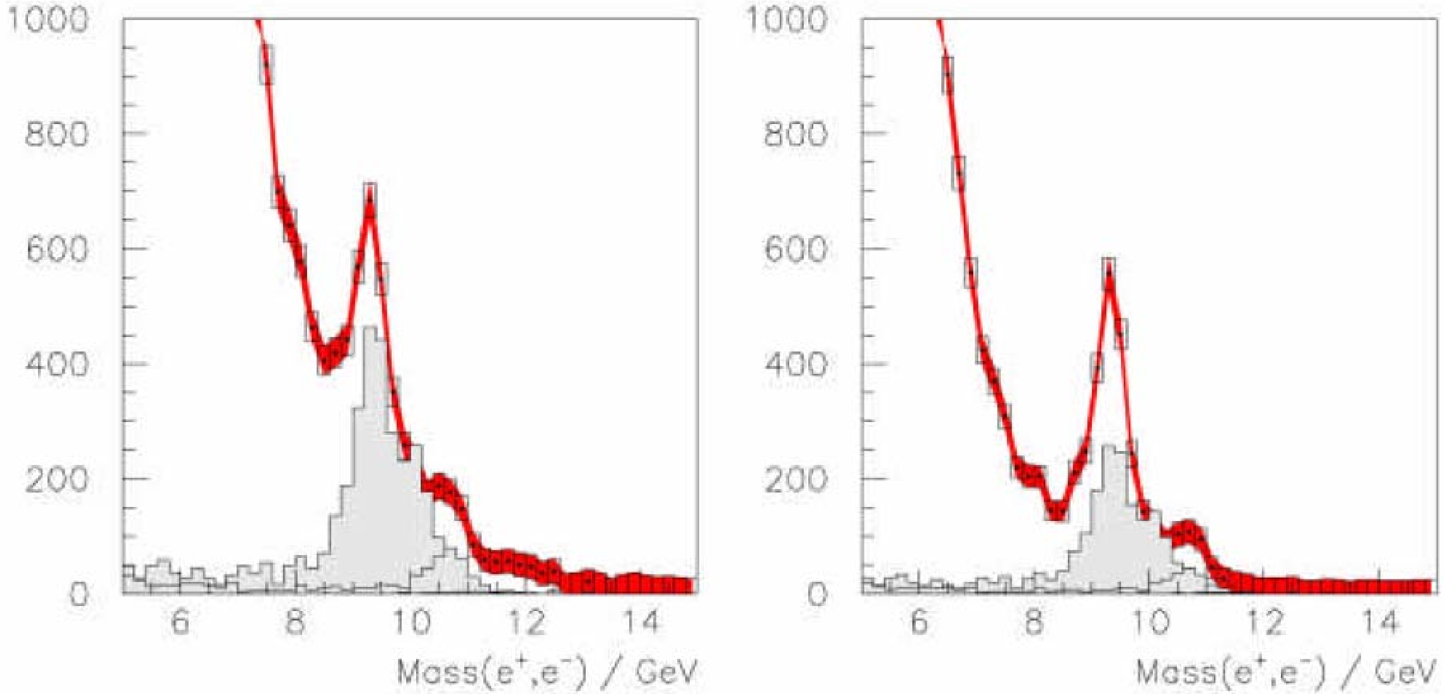
- PHENIX (10 nb^{-1} from RHIC)
  - with VTX
  - w.o. VTX

➡ *Bottomonium require RHIC II luminosities*



Heavy Flavor (Quarkonium)

- Trigger on J/ψ difficult in STAR
- Triggered Υ
  - Expect 3500 Υ for 3 nb^{-1} luminosity (next long Au + Au run)
  - Without trigger (1.6% rate), without DAQ upgrade (0.3% rate)
  - $p_{e+, e-}$ > 3.5 GeV/c
- Resolution
  - Δm = 340 MeV for 1s
  - μVTX improves resolution by factor 2

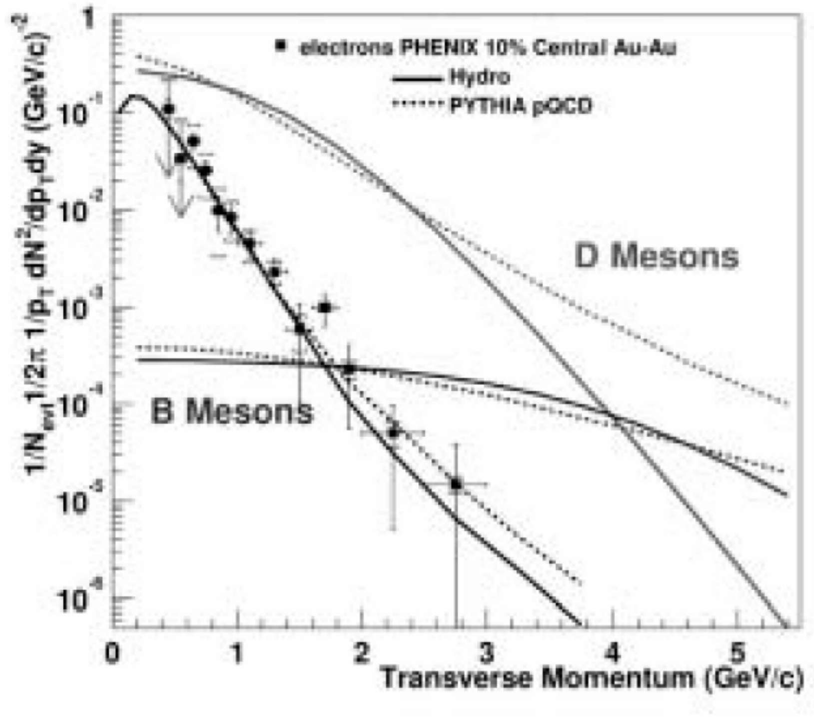


2 different hadron suppression factors (tradeoff - efficiency vs background)

Heavy Flavor in PHENIX

- Significant open charm & open beauty with ~ few nb^{-1}
  - Open charm to p_T ~ 6 GeV/c

➡ *Require Vertex Detector*



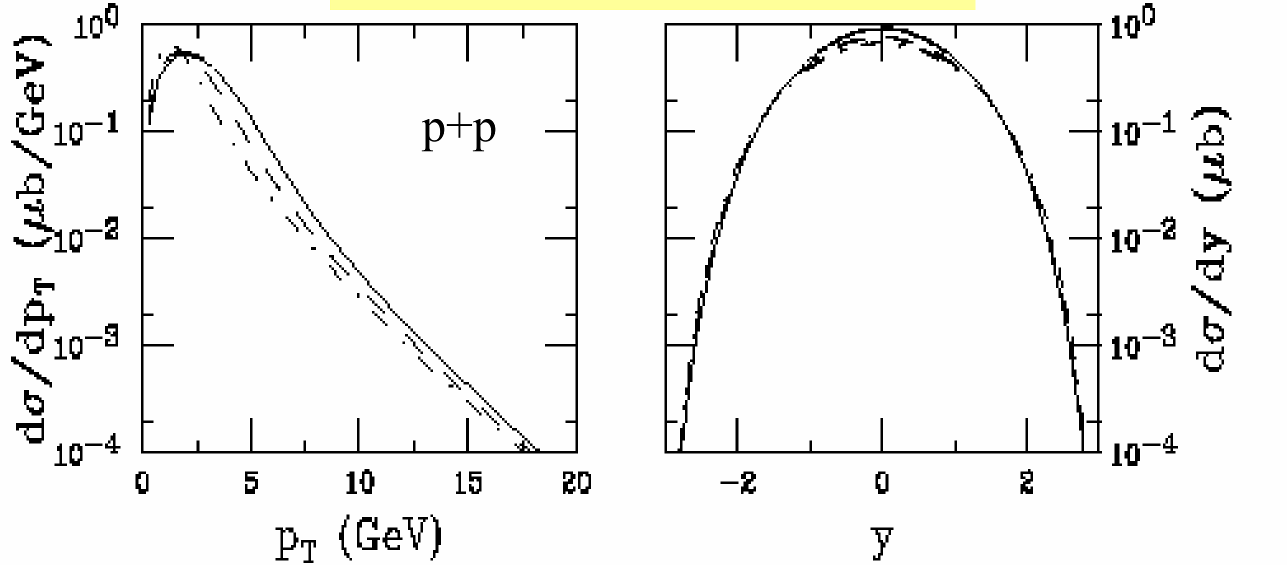
Topic	Signals	p_T (GeV/c)	RHIC L/3 (μb^{-1})	Requires
open charm	$D \rightarrow \mu, e \; + \; X$	$0.5 - 2.5$	300	
(energy loss, $\sigma(c\bar{c})$, *flow*)	$D \rightarrow \mu, e \; + \; X$	$0.3 - 6$	1000	VTX
	$D \rightarrow K \; + \; \pi$	> 2	1000	VTX
open beauty	$B \rightarrow \mu, e \; + \; X$	$1 - 6$	1000	VTX
(energy loss, $\sigma(b\bar{b})$)	$B \rightarrow J/\psi \rightarrow e^+e^-, \mu^+\mu^- + X$	all	1000	VTX

from PHENIX Decadel Plan

Heavy Flavor & Flavor-tagged Jets in STAR

- Open Charm Flow (10 nb^{-1} of RHIC Au+Au)

Ramona Vogt, hep-ph/0111271

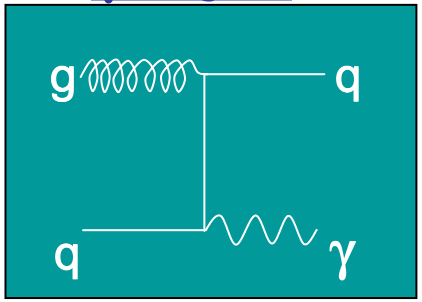


- $p_T \sim 15$ GeV/c: σ (p+p) $\sim 5 \times 10^{-4}$ μb/GeV
  $\Rightarrow \sigma$ (Au+Au) $\sim 20\mu$b/GeV centrally produced

10 nb^{-1} of RHIC Au+Au $\Rightarrow$ 200K $b\bar{b}$ pairs

➡ *These measurements require μvertex + ToF + RHIC II luminosities*

γ + jet



Direct photons

- $p_T \geq 10$ GeV/c for 1 nb^{-1}
- $p_T \geq 15$ GeV/c for 10 nb^{-1}
- ➡ *Issues of fragmentation γ's*
  - ➡ *Distinguish direct from frag. γ's*
  - ➡ *How does energy loss affect this?*

γ+jet

- 0.1% jets have leading hadron > bkgd
- Measure away-side frag. function

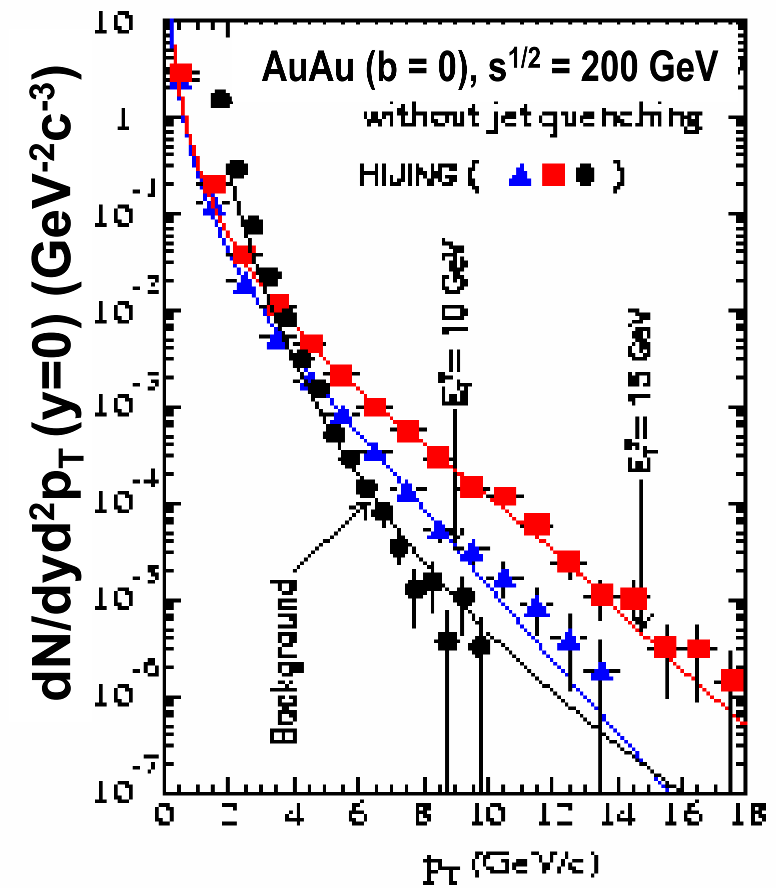
γ+jet yields in STAR

(central Au+Au – 20 weeks):

E_γ = 10 GeV: ~8K ch. hadrons in spectrum

E_γ = 15 GeV: ~1K ch. hadrons in spectrum

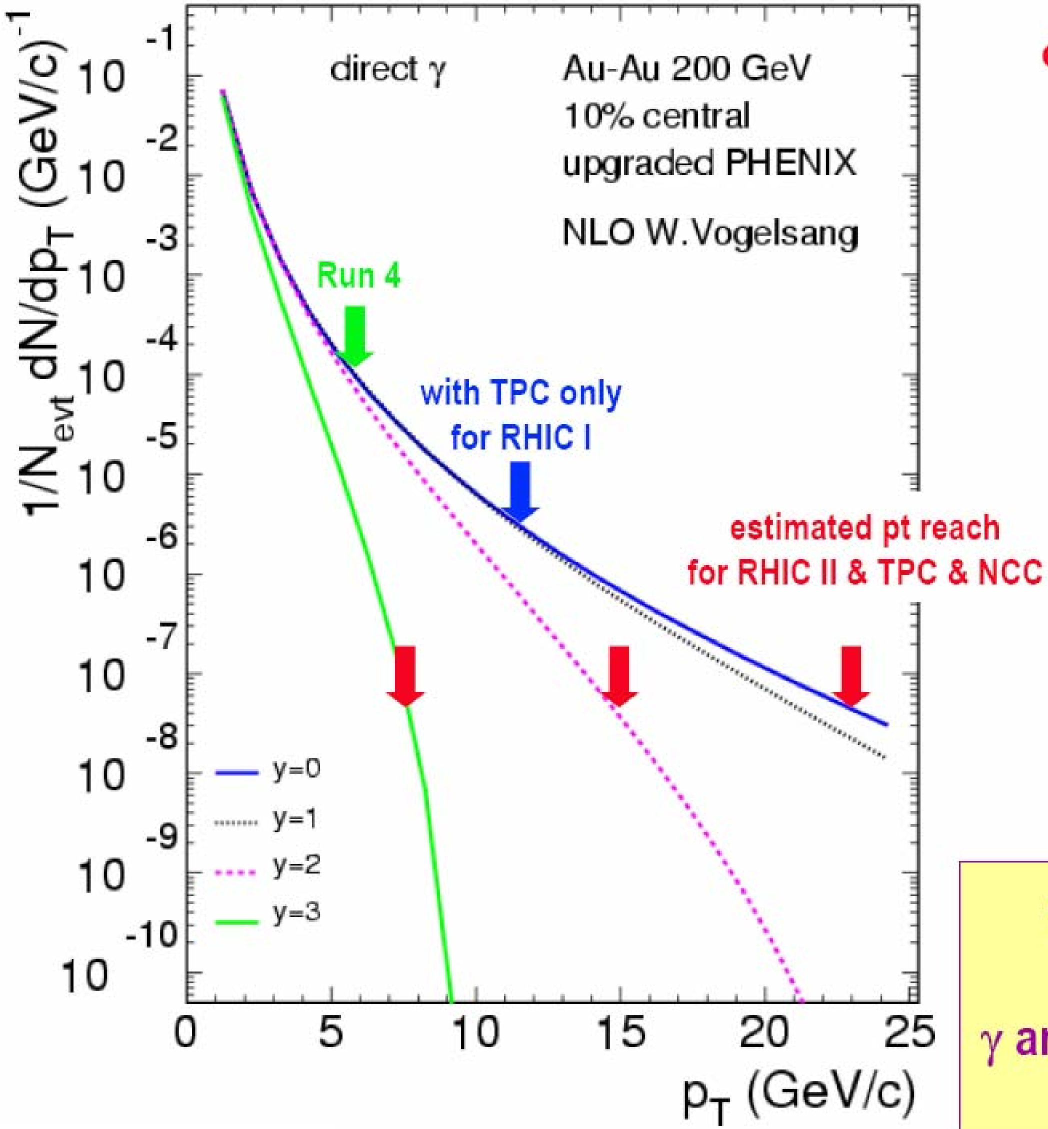
➡ *γ - jet measurements require RHIC II*



XN Wang et al

Rate Estimates for γ-jet Tomography

PHENIX



- **Rapidly falling cross section with rapidity:**
  - Assume ~ 1000 events required for statistical γ-jet correlation
  - RHIC II luminosity
  - PHENIX acceptance (TPC & NCC)

y	max γ-p_T (GeV)
0	23
1	21
2	15
3	8

γ-jet tomography at RHIC requires RHIC II luminosity
γ and jet reconstruction in central region
($-2 < \eta < 2$)

Hard & EM Probes with STAR & PHENIX at RHIC II

- STAR Hard/EM Probe Physics Capabilities at RHIC II
  - Upsilon Yields and Spectra – T melting sequence
  - Heavy quark jets (D,B) high pt spectra – quark energy loss

    [TOF, fast DAQ, μ–vertex tracker]
  - γ-tagged jets – parton energy loss

- PHENIX Hard/EM Probe Physics Capabilities at RHIC II
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Future of Hard & Electromagnetic Probes

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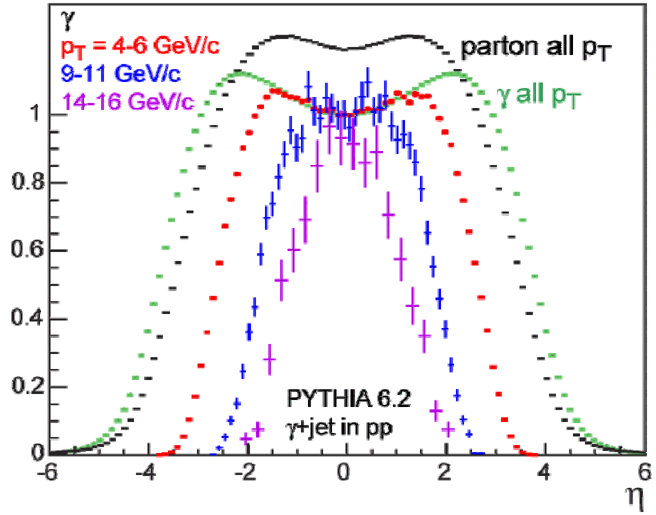
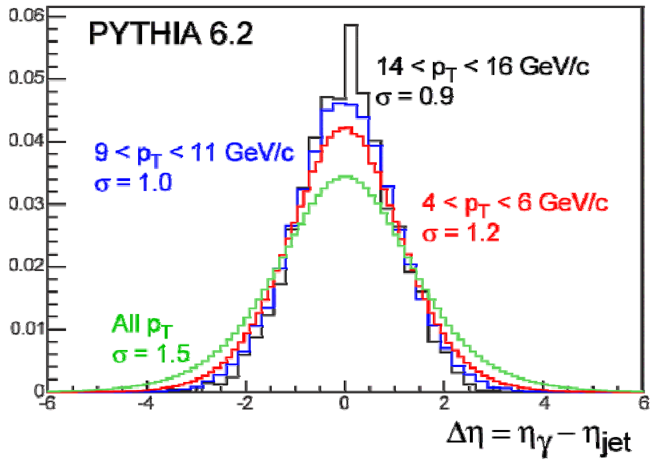
Part 2:

Some Real Experimental Challenges Ahead!

Jet Broadens Significantly in Pseudorapidity!

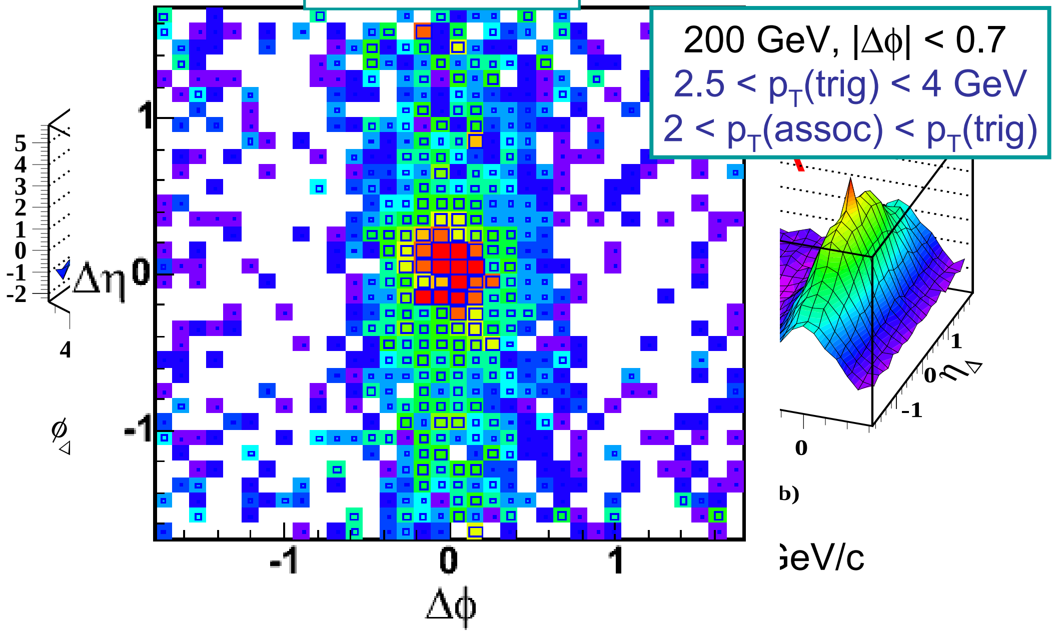
Kinematics in η and p_T in pp (γ+jet)





Broadening in η and φ pp → AA

Au+Au, 0-5%



D. Magestro (STAR) talk

Δη elongation even on near-side!

Large acceptance becomes essential to understand jets, high p_T correlations and for x-dependence (esp. forward - low x)

⇒ with tracking + EMCAL (+ ….)

Understanding Hadronization, Fragmentation & Medium Modification from Jet Quenching?

Measure fragmentation functions in pp & modifications in AA.

Study $z = p_{hadron}/p_{jet}$ and x dependence :

$0.2 < z < 1 \rightarrow 7 < p < 30$ GeV/c

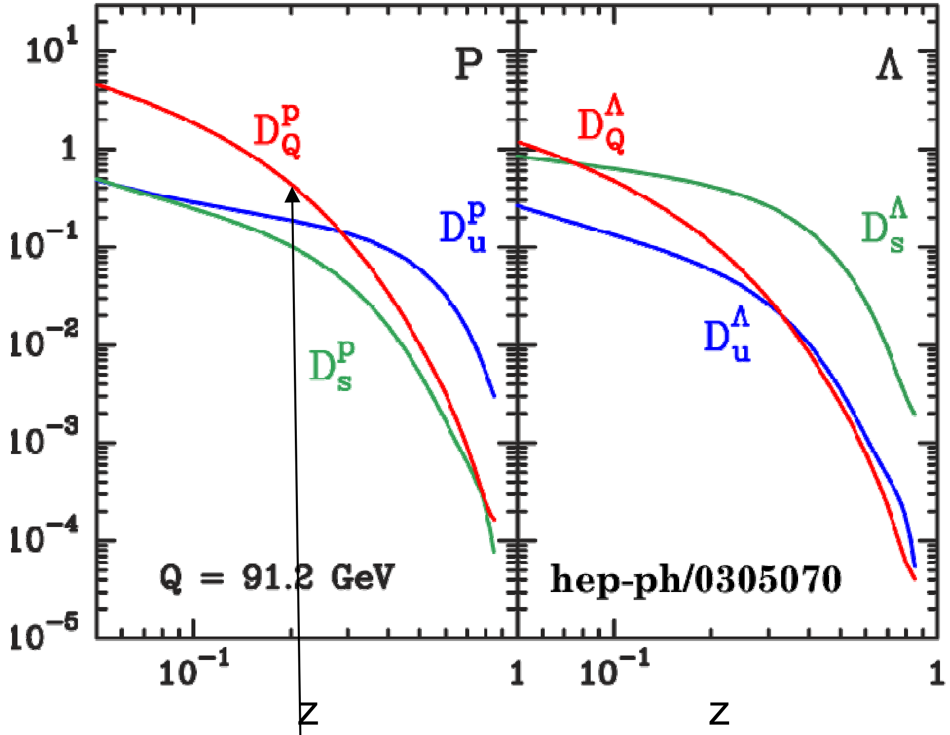
$0.1 < x < 0.001 \rightarrow 0 < \eta < 3$

High p_T
Identified particles
Intra- and inter-jet particle correlations
Large η acceptance
γ-tagged jets

$\Rightarrow$ Essential for real "jet tomography"

Each flavor parton contributes differently to fragmentation function
(see Bourrely & Soffer, hep-ph/0305070)

should lose different amounts of energy in opaque medium.



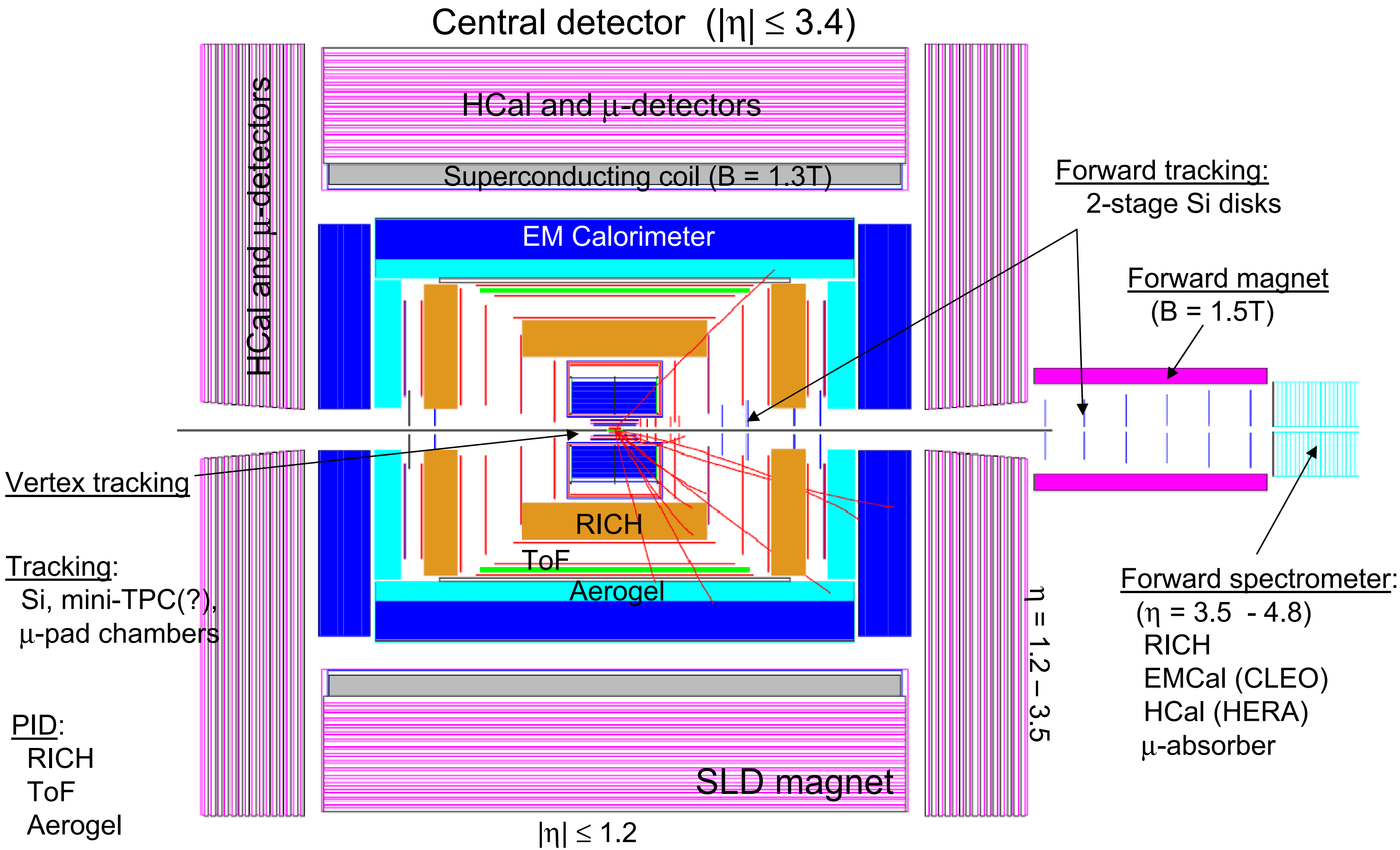
2 GeV/c proton in 10 GeV jet
Aside – effect of heavy quark propagation p/π ratio?

Expression of Interest - A Comprehensive New Detector at RHIC II

P. Steinberg, T. Ullrich (Brookhaven National Laboratory)
M. Calderon (Indiana University)
J. Rak (Iowa State University)
S. Margetis (Kent State University)
M. Lisa, D. Magestro (Ohio State University)
R. Lacey (State University of New York, Stony Brook)
G. Paic (UNAM Mexico)
T. Nayak (VECC Calcutta)
R. Bellwied, C. Pruneau, A. Rose, S. Voloshin (Wayne State University)
and
H. Caines, A. Chikanian, E. Finch, J.W. Harris, M. Lamont, C. Markert,
J. Sandweiss, N. Smirnov (Yale University)

EoI Document at http://www.bnl.gov/henp/docs/pac0904/bellwied_eoi_r1.pdf

Comprehensive New Detector at RHIC II



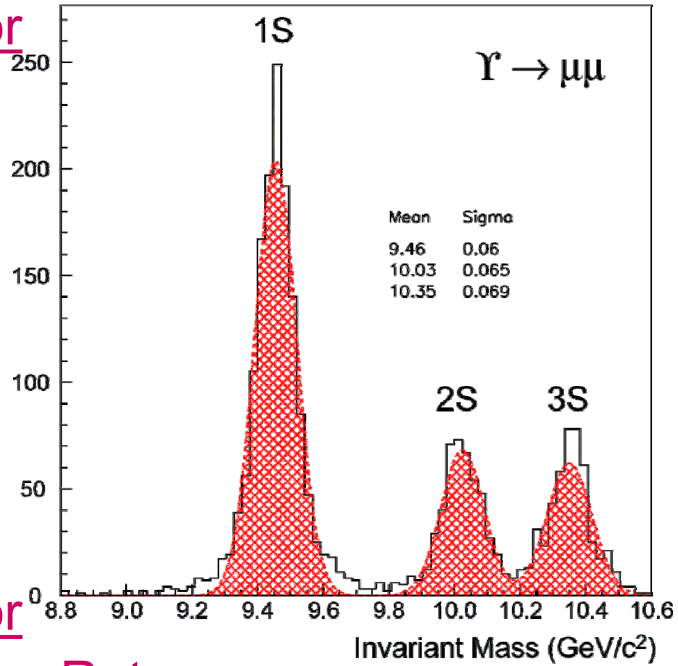
A Quarkonium Physics Program at RHIC II

Quarkonium melting T's → Suppression (AA)

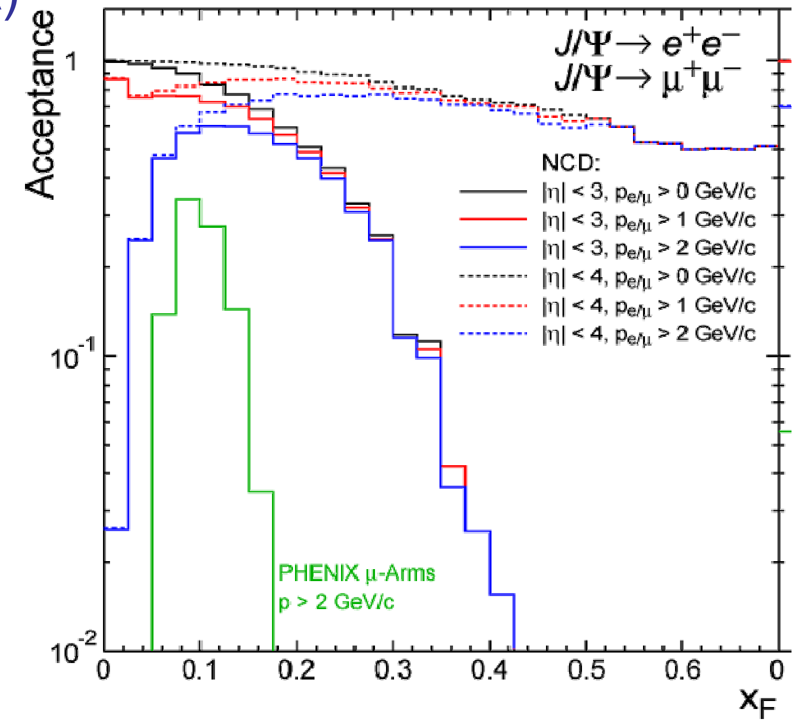
$T_{melt}(\Psi') < T_{melt}(\Upsilon(3S)) < T_{melt}(J/\Psi) \approx T_{melt}(\Upsilon(2S)) < T_{RHIC} < T_{melt}(\Upsilon(1S))$?

- Measure χ_c feed-down to J/ψ
- Production mechanism studies (pp, pA)
- Nuclear absorption/shadowing studies (pA)

New Detector Resolution:



x_F dependence:



New Detector Acceptance → Rates

Precision Tracking + Muon Detectors + EMCAL + PID

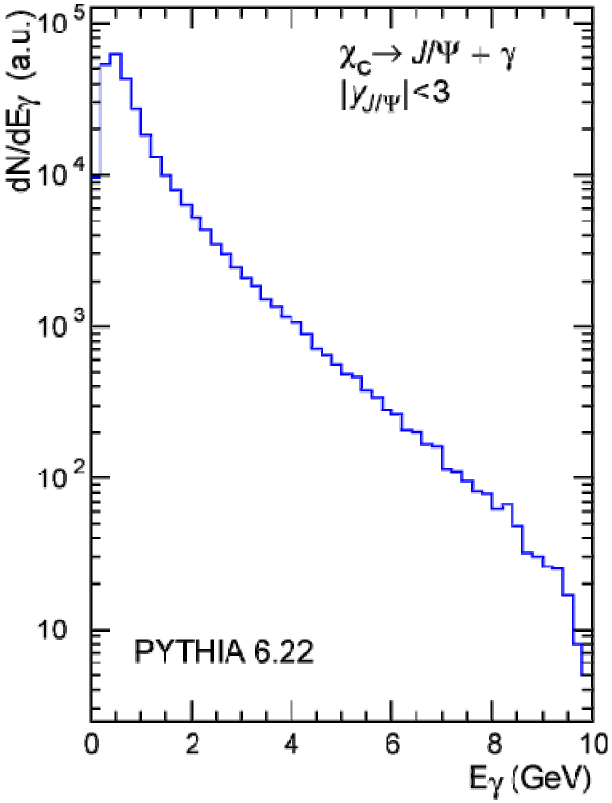
electrons and muons $|\eta| < 3.4$, $\Delta\phi = 2\pi$

x_F coverage

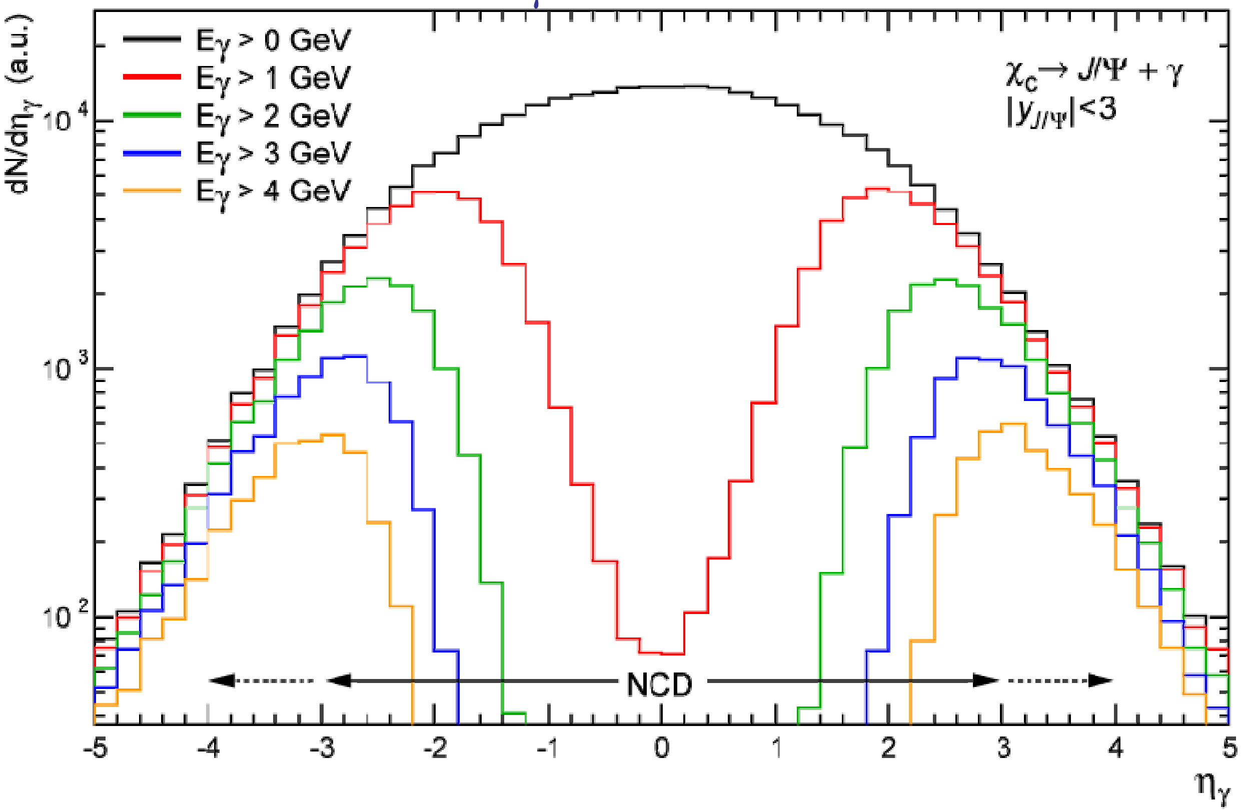
Charmonium χ_c Feed-down in this Detector

$\chi_c \rightarrow J/\psi + \gamma$

γ spectrum



η_γ distribution



To measure χ_c decay & determine feed-down to J/ψ
$\chi_c \rightarrow J/\psi + \gamma$, must have large forward acceptance for γ

Foundations of RHIC II Physics Program

- Degrees of Freedom of sQGP (Deconfinement)
  - Quarkonium Resolution, Acceptance, Rates & Feed-down Acceptance
  - Jet and PID High Pt Measurements (γ-jet, jet-jet)
- Origin of Mass (Hadronization & Chiral Symmetry)
  - PID at High p_T, Correlations, Large η acceptance, γ-tagged jets
- Origin of Spin (of Proton)
  - Large η acceptance, jets, γ-jet, High p_T identified particles, correlations
- Phase(s) of Matter (CGC $\leftrightarrow$ QGP)
  - High-p_T identified particle yields to large η
  - Multi-particle correlations over small & large $\Delta\eta$ range

Future of Hard & Electromagnetic Probes

at

RHIC

"Alive and well" → much to uncover, to do (new data!) and discuss

Exact timescales unknown → due to need for construction (& funding)

Significant capabilities added with RHIC II (~2012) & new detector(s)

RHIC II Physics and Detectors to be determined in the next 1 ½ years
(RHIC Community discussions and decision)