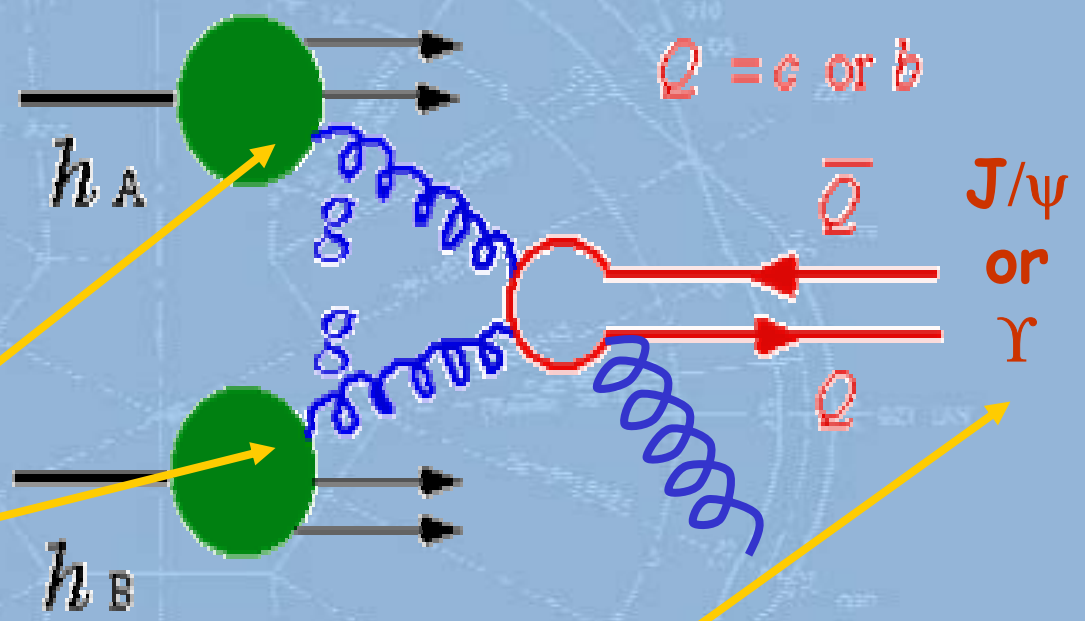
Heavy Flavor Production in PHENIX

O. Drapier
LLR-École Polytechnique, France
for the PHENIX Collaboration

Heavy flavor production

- "Onia" production
  - Leading order at low x = "gluon fusion"

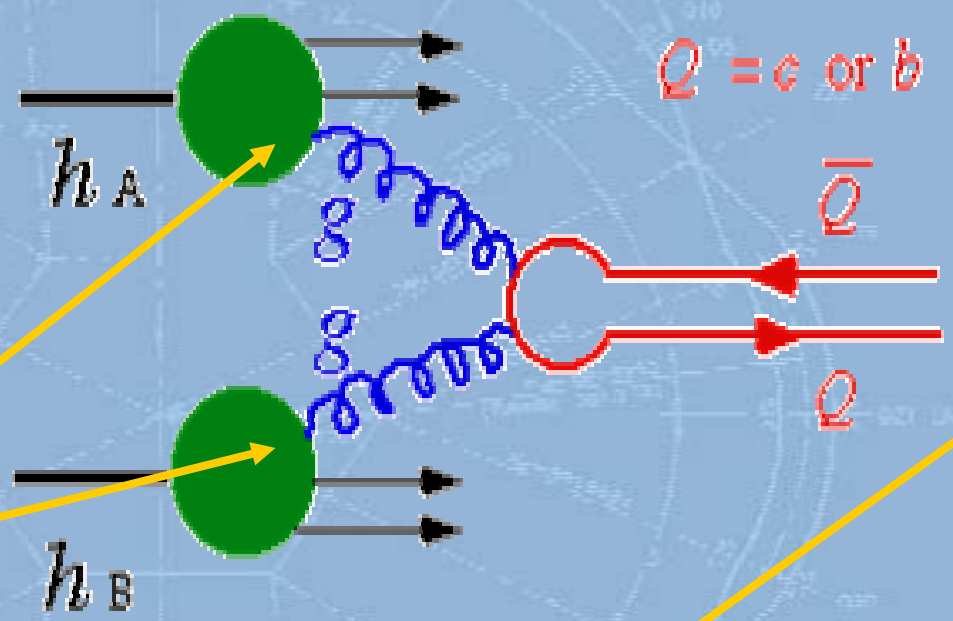


- Sensitive to:
  - Initial state
    - Parton distribution functions
    - p_T broadening
    - Parton energy loss in the initial state ?
    - Polarization ?
  - Final state
    - Parton energy loss in the hot & dense medium ?
    - Thermal enhancement ?
    - Flow ?

+ feed-down (e.g. B or χ_c-> J/ψ)

Heavy flavor production

- Open charm (or beauty) production
  - Leading order at low x = "gluon fusion"



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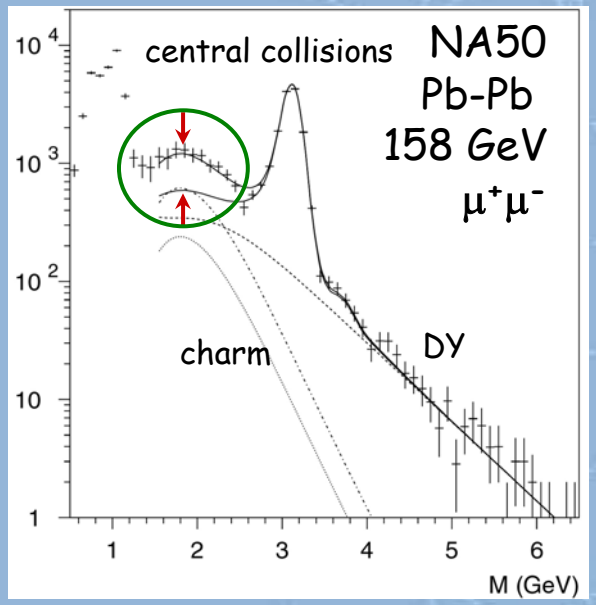
    - Polarization ?
  - Final state
    - Parton energy loss in the hot & dense medium ?
    - Thermal enhancement ?
    - Flow ?

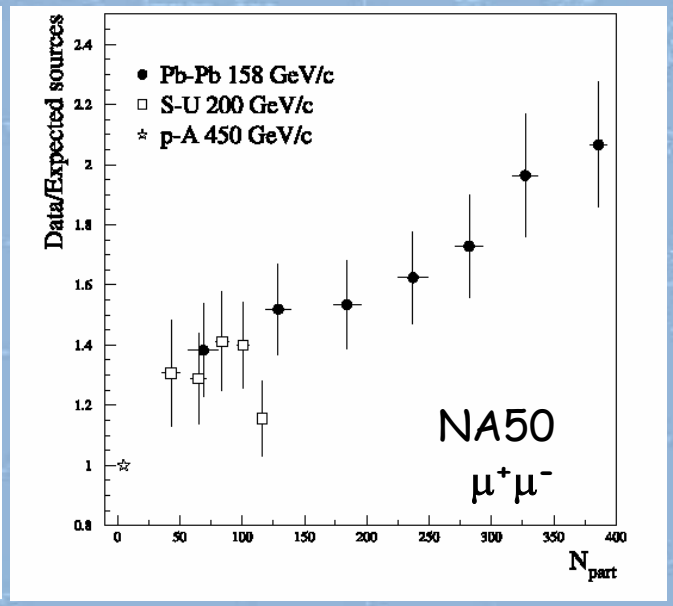
Physics Motivations

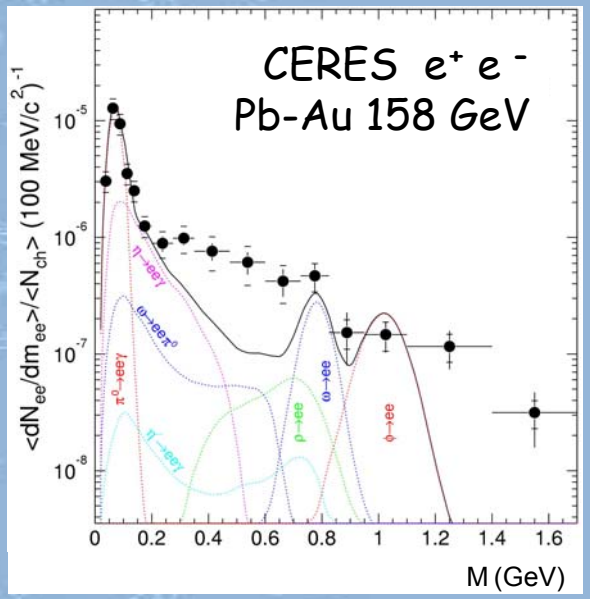
- Open flavors are interesting *per se* :
- Do heavy quark suffer « quenching », as light flavors do ?
  - Higher quark mass -> less gluon radiation ("dead cone effect")
  - D/π modified at moderate p_T due to different quenching
    - Y. L. Dokshitzer & D.E. Kharzeev, Phys.Lett.B519(2001)199-206
- Do heavy quark flow ?
  - Early creation in hard process -> they should not
  - Additional creation, enhancement, "in medium" effects -> they could
  - In any case, OPEN = they're detected once bound to light quarks
    - Influence of light quark flow
    - Influence of decay if detected in semi-leptonic decay channels

Physics Motivations

- ✓ Possible charm enhancement in Heavy Ion collisions ?
  - ✓ "unexpected sources" of dileptons observed at SPS
  - ✓ This contribution doesn't scale as the number of collisions







  - ✓ Is there an enhancement of charm production ?
  - ✓ Ideally, open charm should be used as a reference for J/ψ production, as color screening prevents charmonia bound states

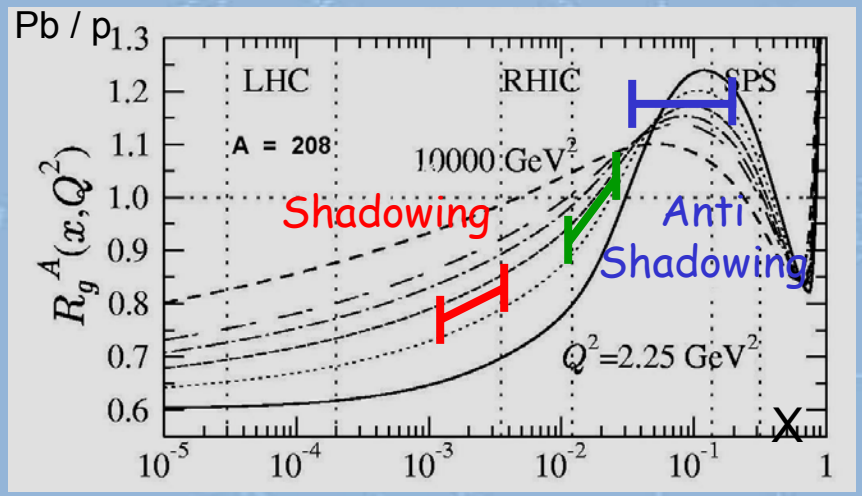
color screening ⇔ bound charmonia / open charm

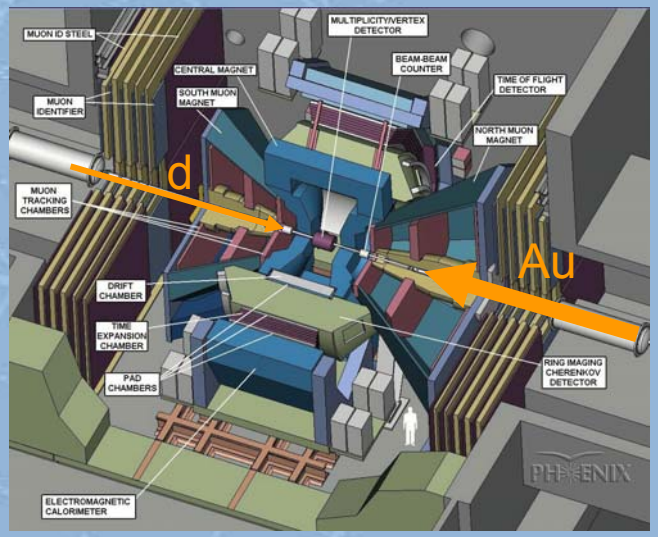
Physics Motivations

- ✓ Heavy flavor = probe for « cold » nuclear effects
  - ✓ Parton distribution functions are modified in nuclei

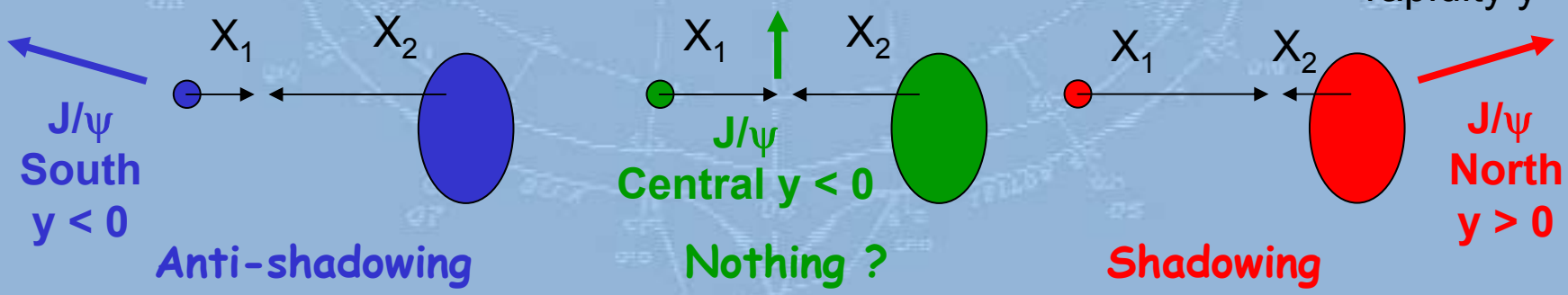
color screening ⇔ bound charmonia / open charm

  - ✓ e.g. in d-Au collisions :



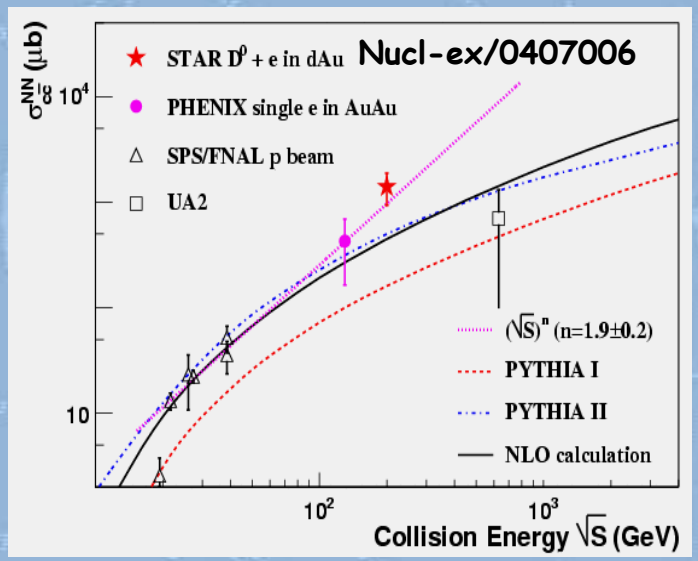


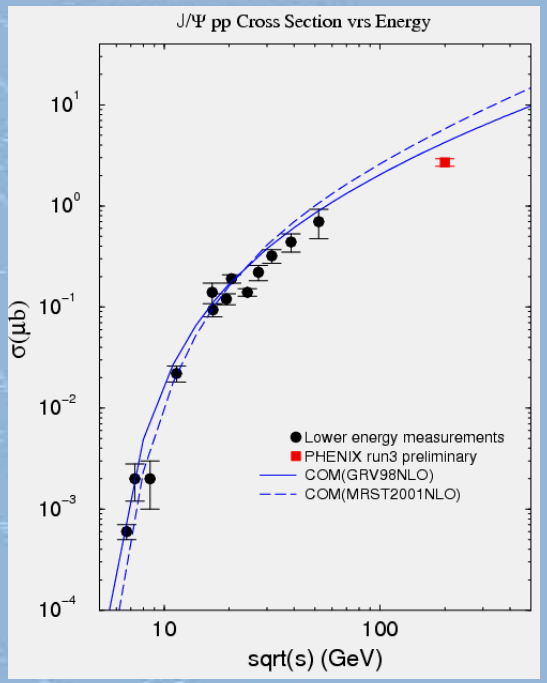
rapidity y

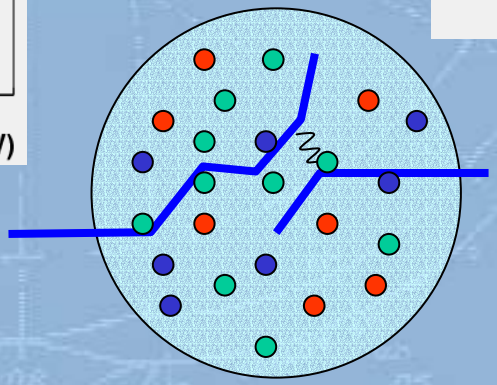


Physics Motivations

- ✓ Charm production is sensitive to incident energy of partons
  - ✓ Possible energy loss in the initial state may affect charmonium production
    - ✓ Holds both for charmonia and open charm, so could be checked with open charm





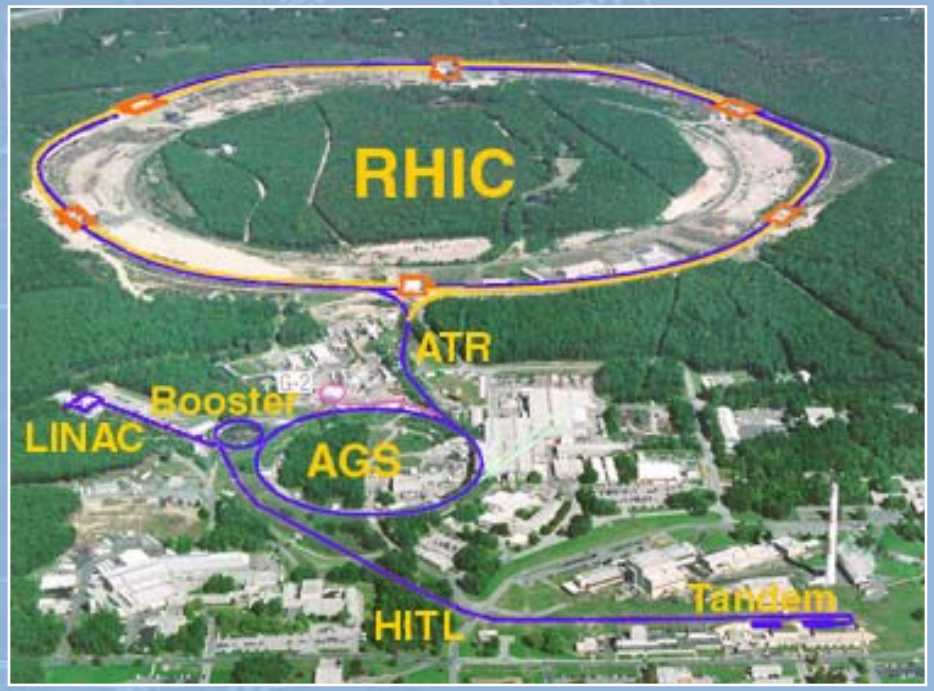


- ✓ Sensitive p_T broadening (e.g.: gluon-nucleon scattering)

color screening ⇔ bound charmonia / open charm

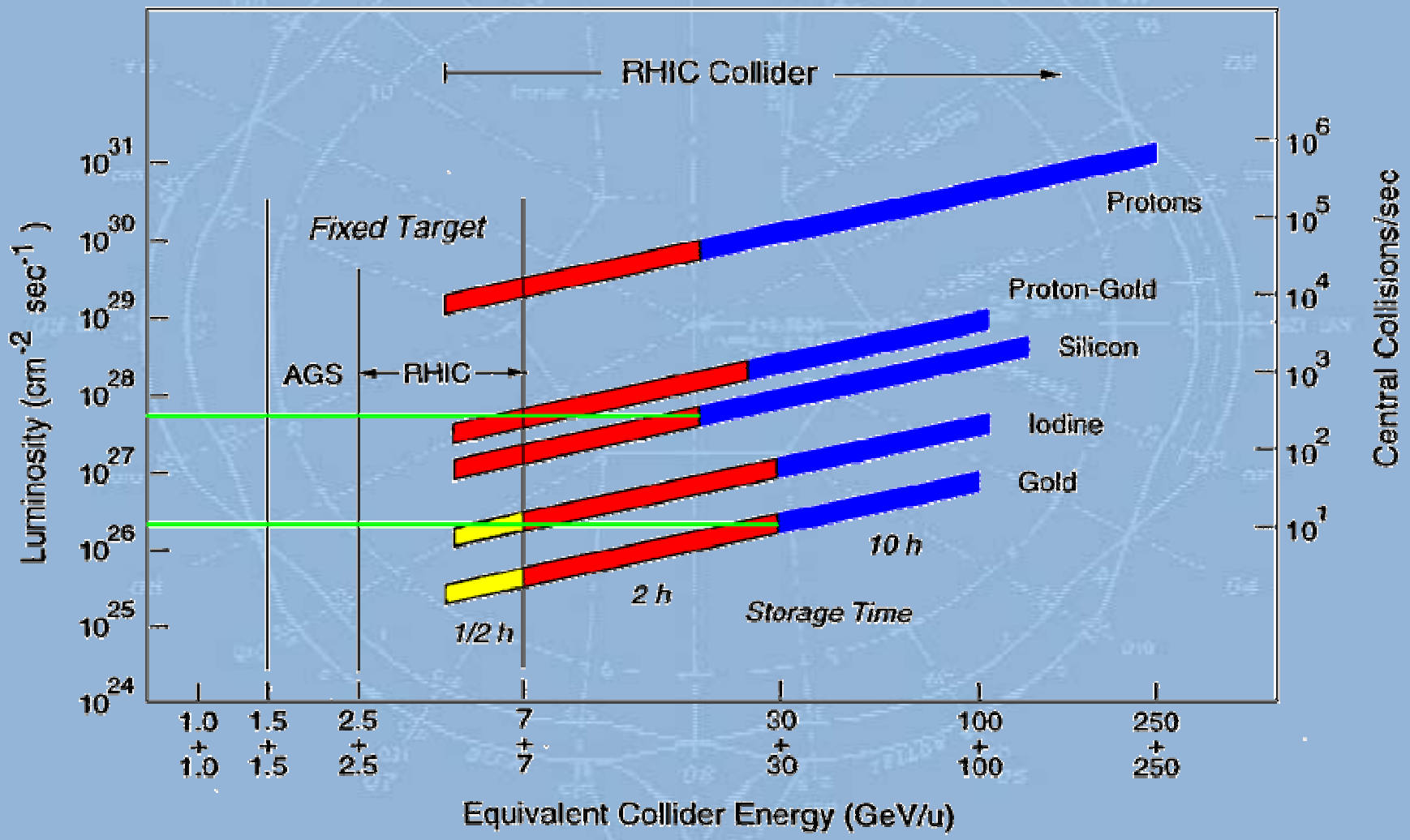
RHIC

- RHIC (Relativistic Heavy Ion Collider)
  - Long Island, not so far from Manhattan ;-)
  - Dedicated to heavy ion physics & spin studies
  - 4 experiments
  - 100+100 GeV/A
  - Variable incident energy
  - p-p up to 500 GeV



RHIC

- ✓ Vast incident energy range
- ✓ Various ion species from p to Au

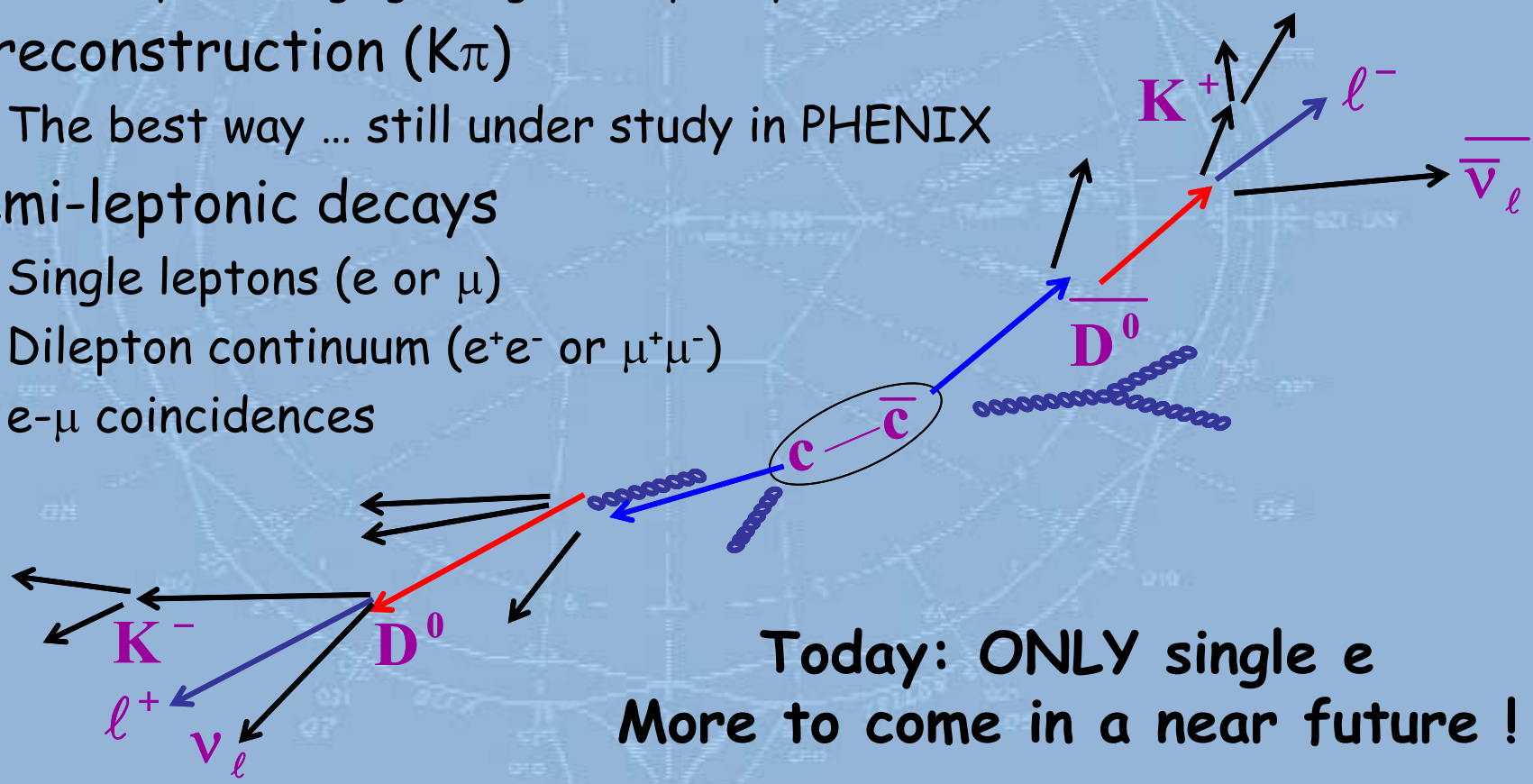


PHENIX

- ✓ Electrons in EM-Cal + RICH
- ✓ Muons in MuTr + MuId

Heavy flavors

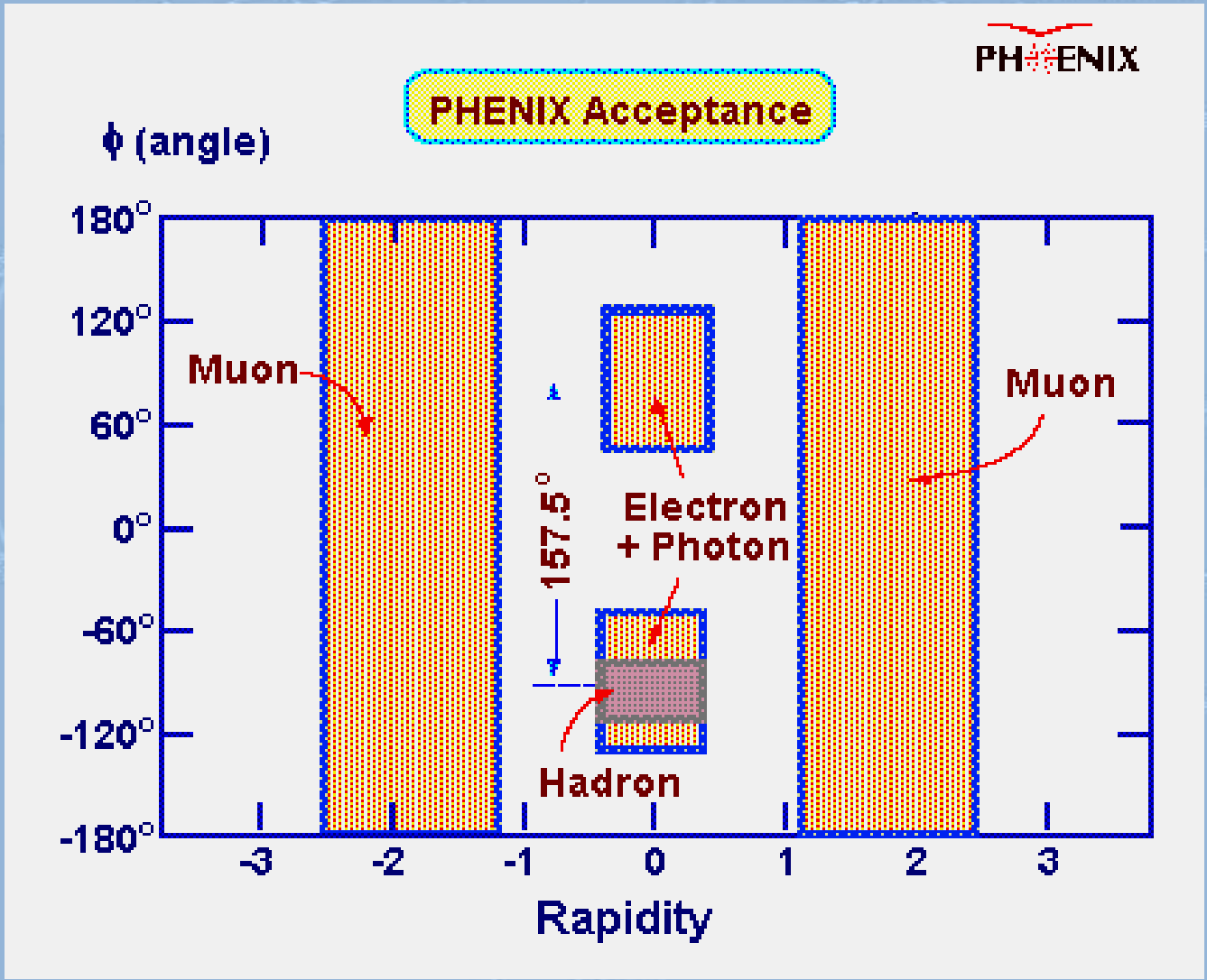
- Secondary decay vertex … long term future ?
  - Needs precise tracking close to IP to see displaced vertex …
    - we have no detector to do this
    - Very challenging in high multiplicity & radiation environment
- D reconstruction (Kπ)
  - The best way … still under study in PHENIX
- Semi-leptonic decays
  - Single leptons (e or μ)
  - Dilepton continuum (e^+e^- or $\mu^+\mu^-$)
  - e-μ coincidences



Today: ONLY single e
More to come in a near future !

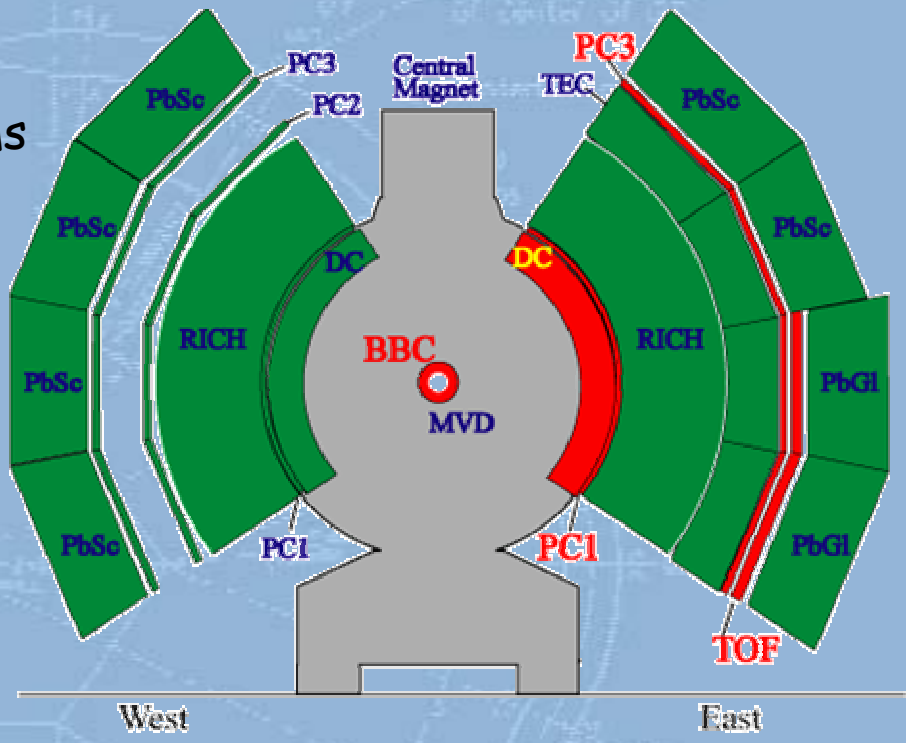
PHENIX

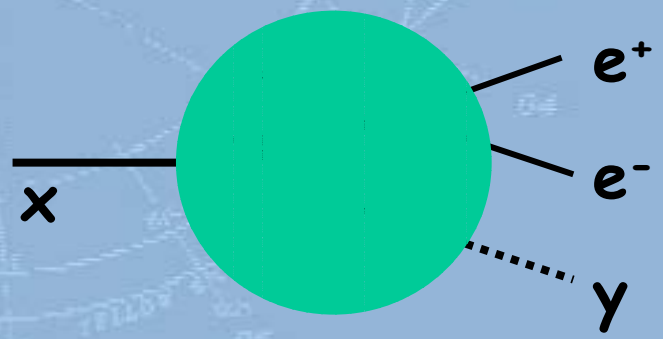
- ✓ Different acceptance domains



Open charm in PHENIX

- For now:
  - Only single electrons in central arms
  - Only open charm
- Electrons
  - $|\eta| < 0.35 \quad \Delta\phi = \pi / 4$
  - Tracks reconstructed with Drift Chamber & PC1
  - EM-Cal matching hit
  - RICH hits + ring shape
  - Timing (EMC or TOF)
- "Photonic" electrons
  - γ conversion
  - π^0 and η/η'Dalitz decay: $\rightarrow \gamma ee$
  - light vector meson decay:
    - $\omega, \varphi \rightarrow (\pi^0,\eta)ee$

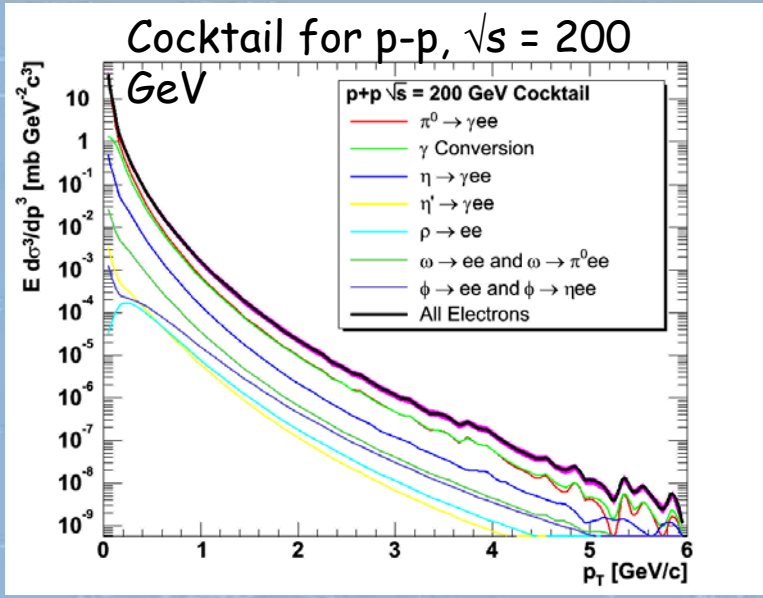


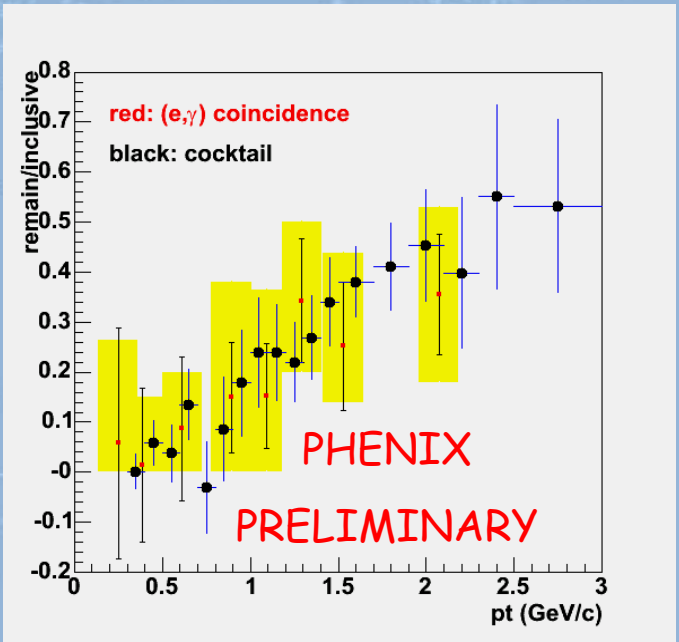


Yield proportional to real γ

Open charm in PHENIX

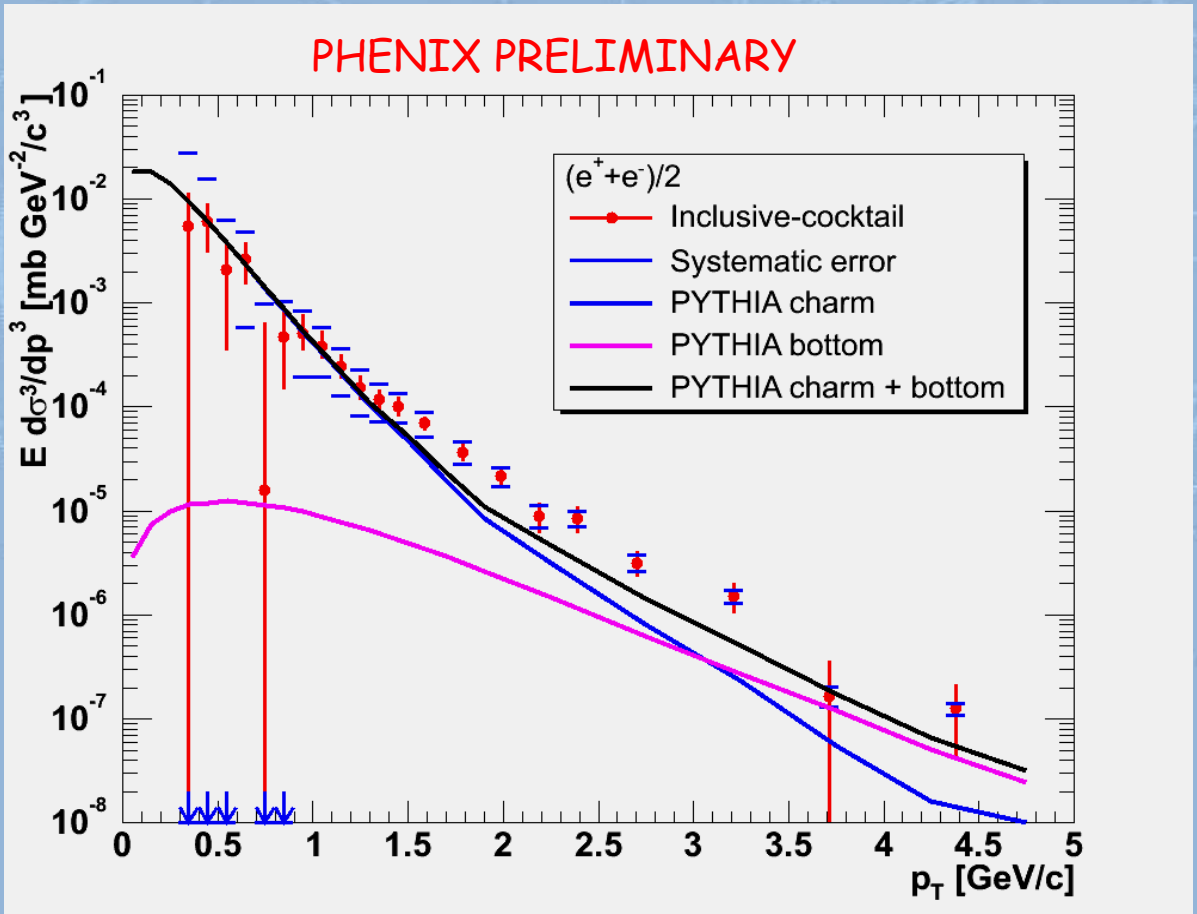
- NON-photonic electrons = ALL - PHOTONIC
  - K decay
  - $\rho, \omega, \varphi \rightarrow ee$
  - $c \rightarrow e$ (dominant)
  - $b \rightarrow e$
- Subtract background by:
  - Cocktail method
  - Converter method
  - Direct measurement of γ e coincidences + event mixing
- Correct for acceptances and efficiencies
- Non-photonic contribution increases with p_T
  - Good agreement between cocktail method and γ e coincidence method





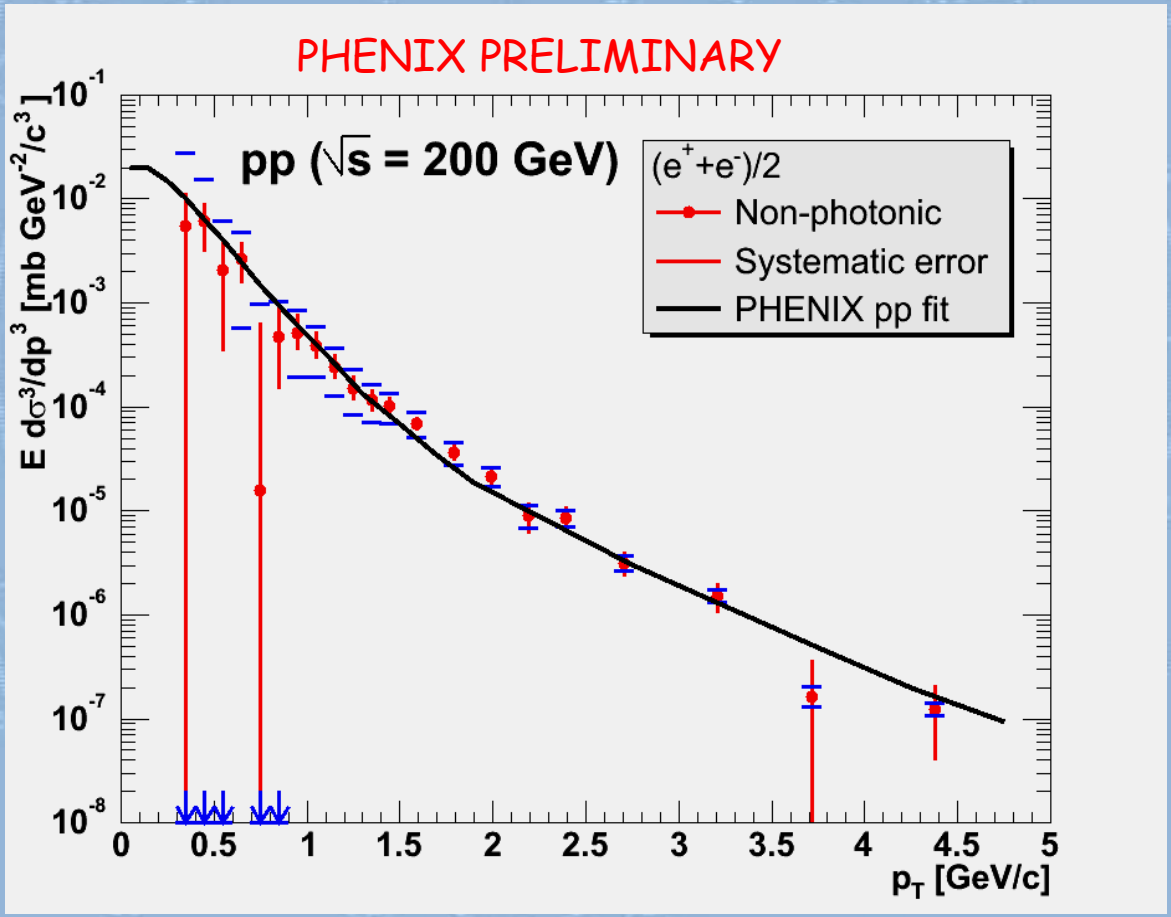
p-p ($\sqrt{s}$ = 200 GeV)

- Non-photonic electrons in p-p as compared to Pythia:
  - Reasonable agreement
    - Charm alone not sufficient at high p_T
    - Bottom -> not enough statistics



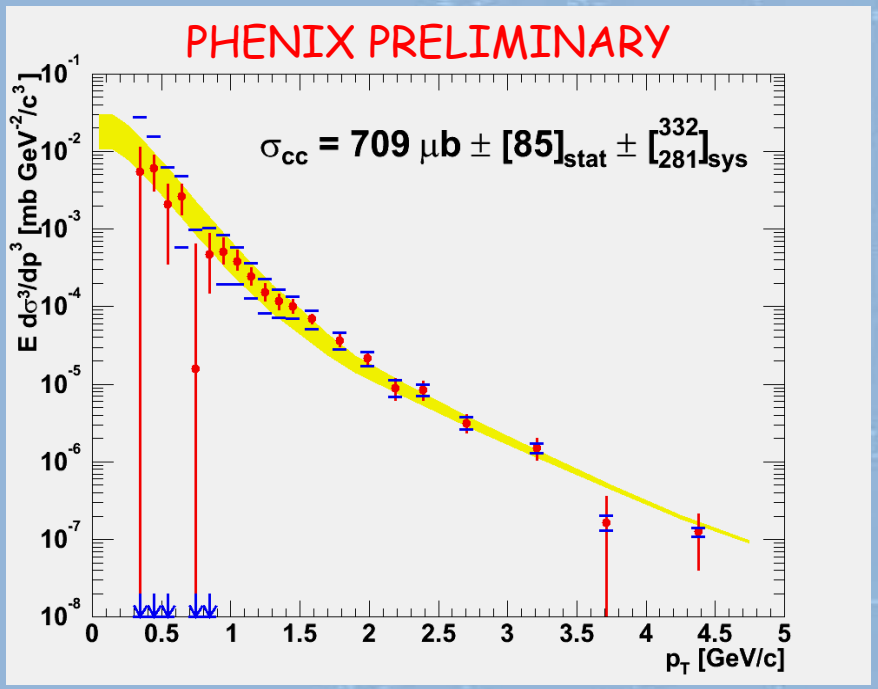
p-p ($\sqrt{s}$ = 200 GeV)

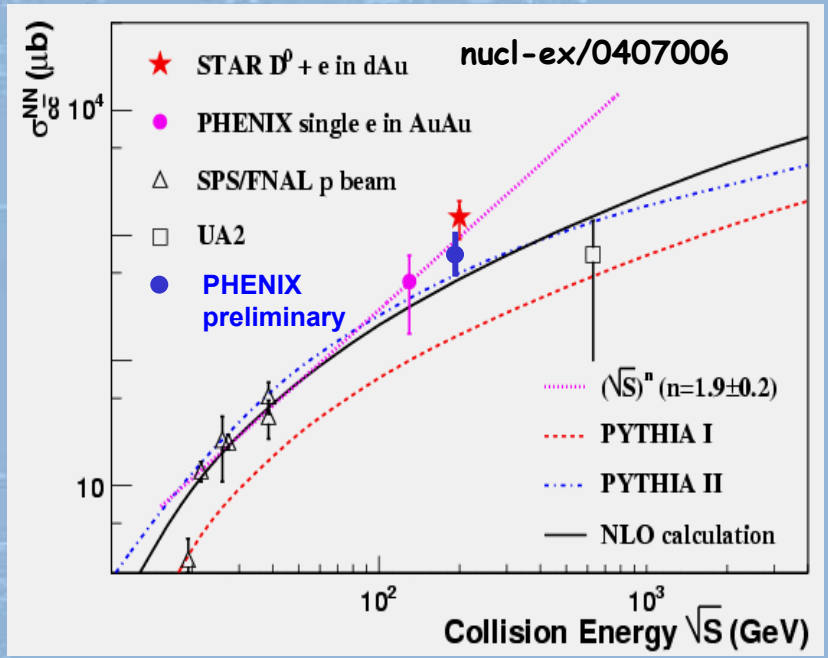
- Phenomenological fit
  - To compare with d-Au and Au-Au …



p-p ($\sqrt{s}$ = 200 GeV)

✓ … and to extract charm cross section

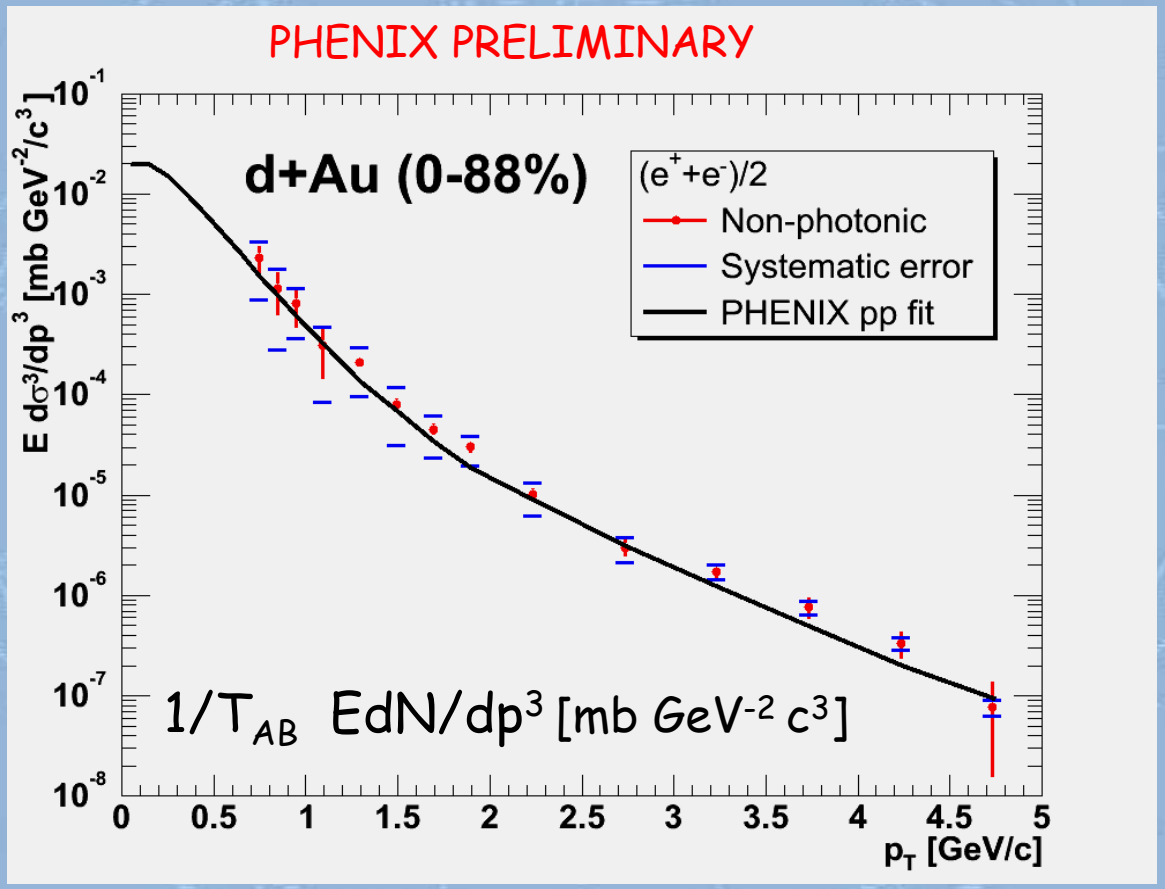




$$\sigma_{cc} = 709\mu b \pm 85(stat)^{+332}_{-281}(syst)$$

d-Au ($\sqrt{s}$ = 200 GeV)

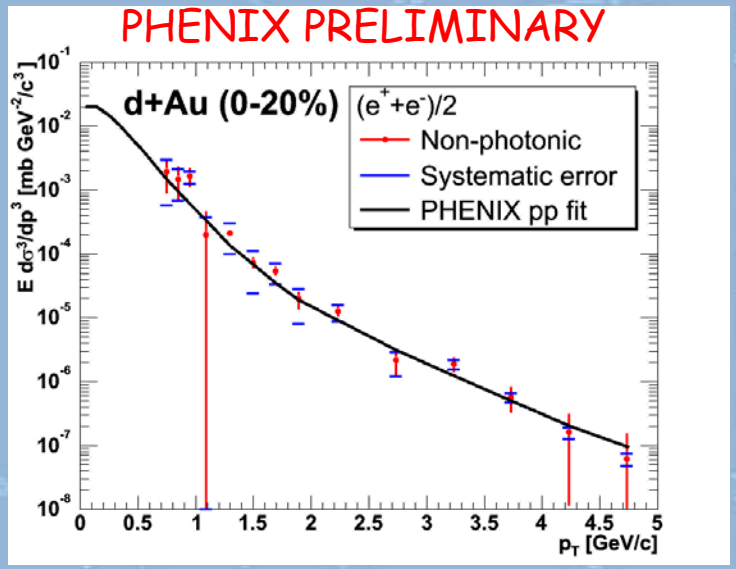
- ✓ d-Au collisions: minimum bias result (binary scaled)

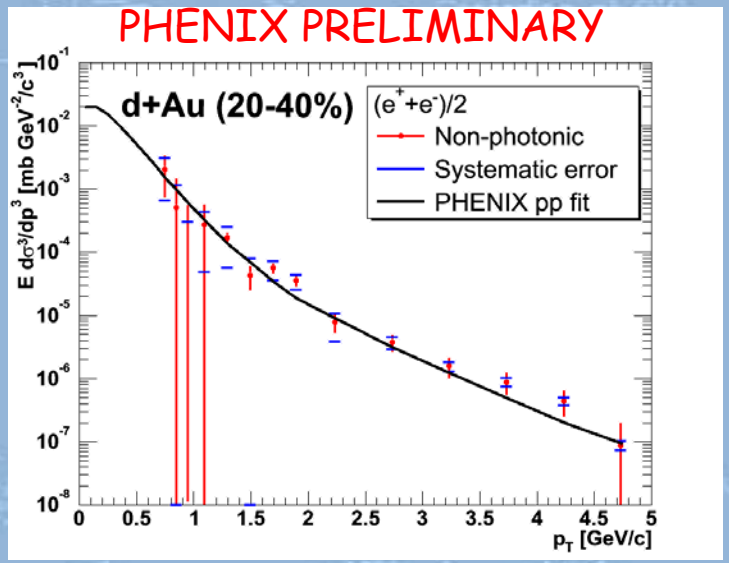


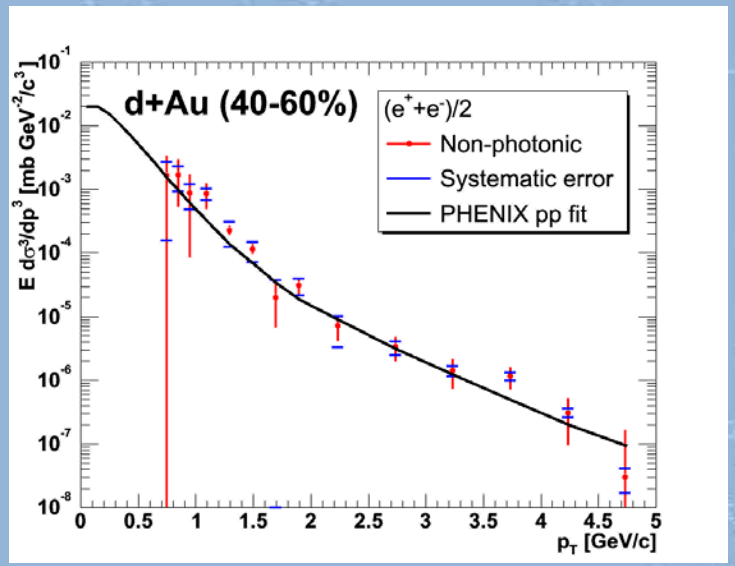
- ✓ COMPATIBLE WITH BINARY SCALING

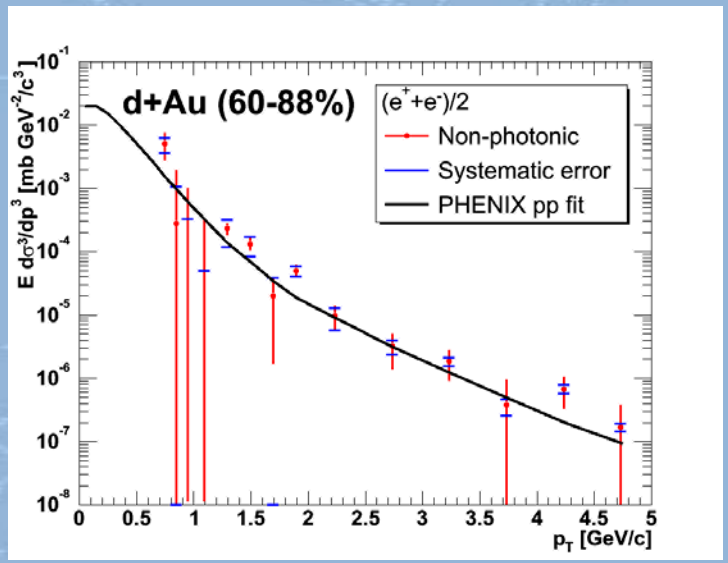
d-Au ($\sqrt{s}$ = 200 GeV)

✓ d-Au: binary scaling also holds for different centralities



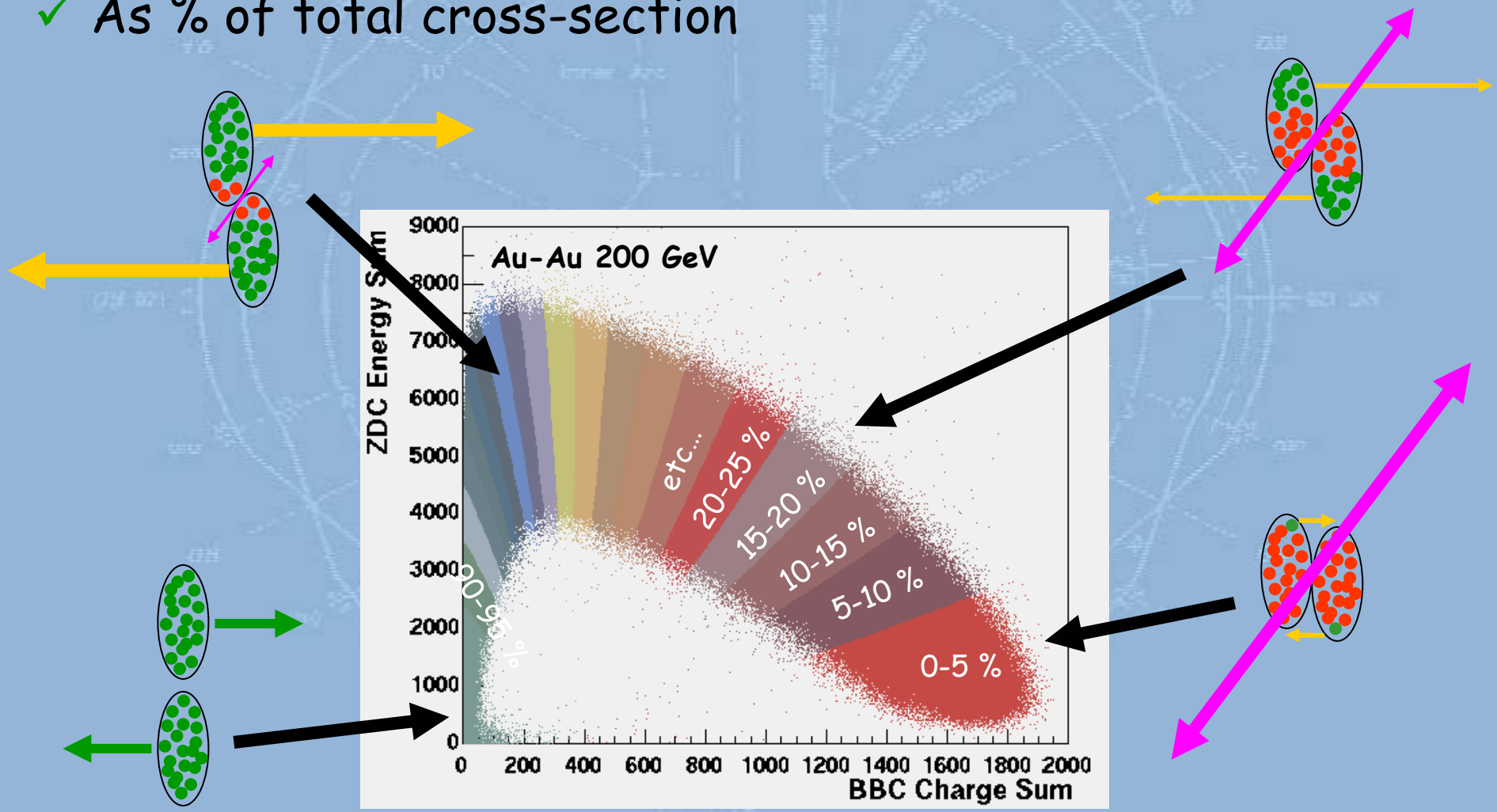




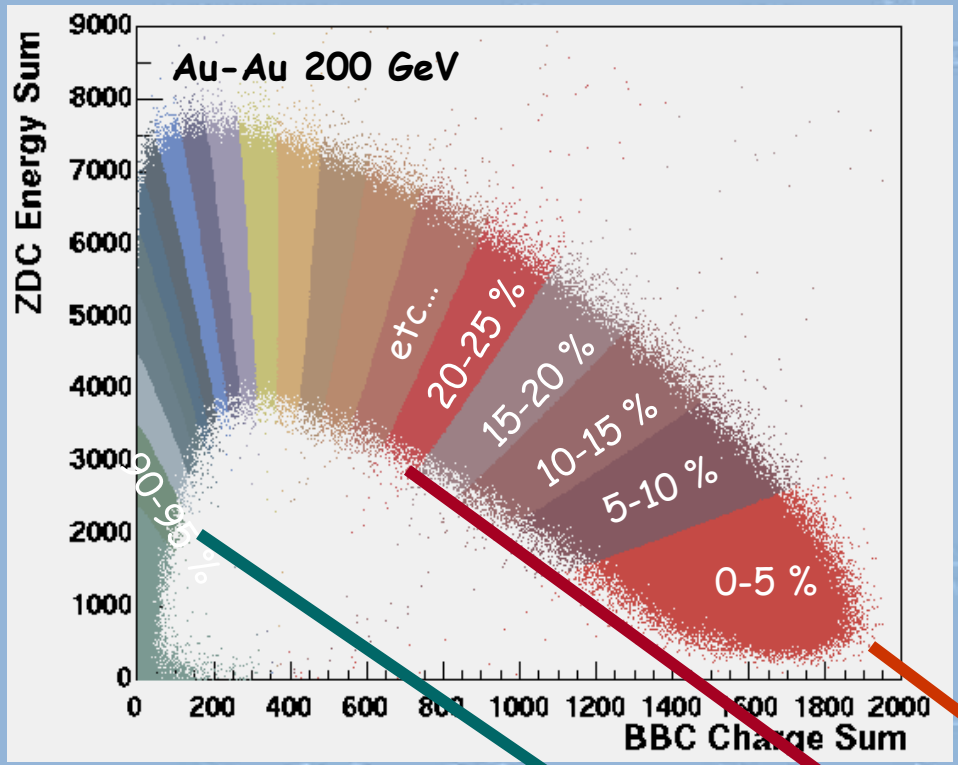


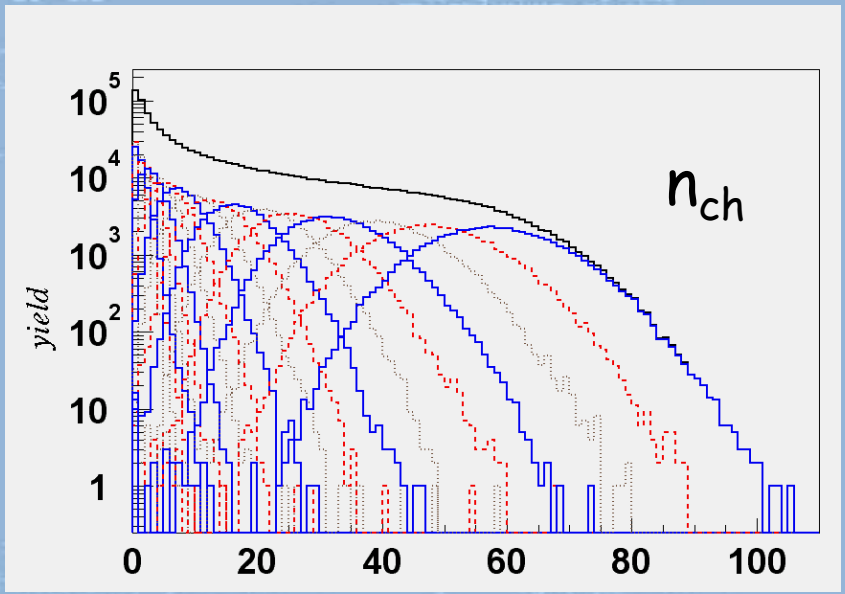
Collision centrality: Au-Au

- ✓ E_{ZDC} (spectators) / BBC (secondary particles) correlation
  - ✓ "zero degree calorimeter" + "beam-beam counter"
- ✓ As % of total cross-section



Collision centrality: Au-Au





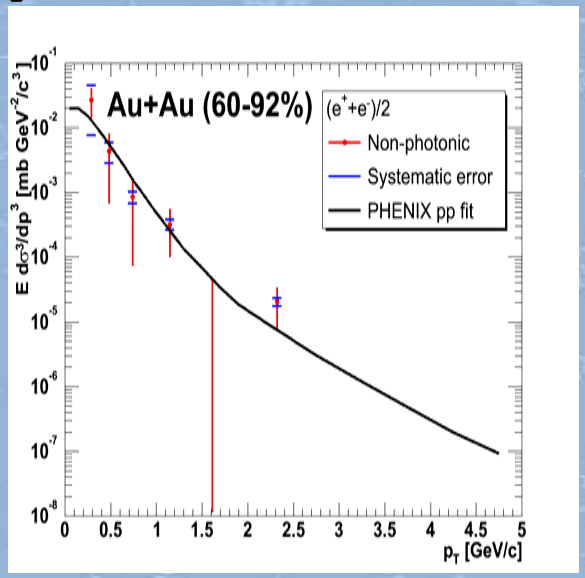
B (fm)	N_{part}	N_{coll}
2,3 ± 0,9	353 ± 19	1091 ± 102
7,1 ± 0,5	181 ± 16	422 ± 65
14,5 ± 0,3	4.1 ± 2.5	2.8 ± 2.2

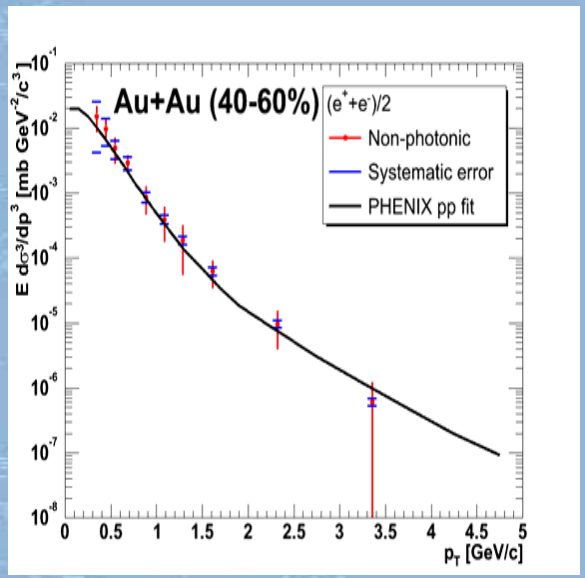
- ✓ Glauber model
  - ✓ Nuclear density profile
  - ✓ Geometry
  - ✓ N-N cross-section

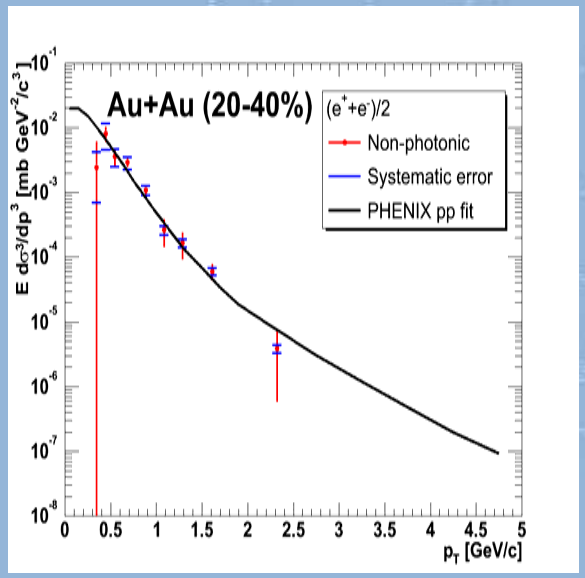
Au-Au ($\sqrt{s}$ = 200 GeV)

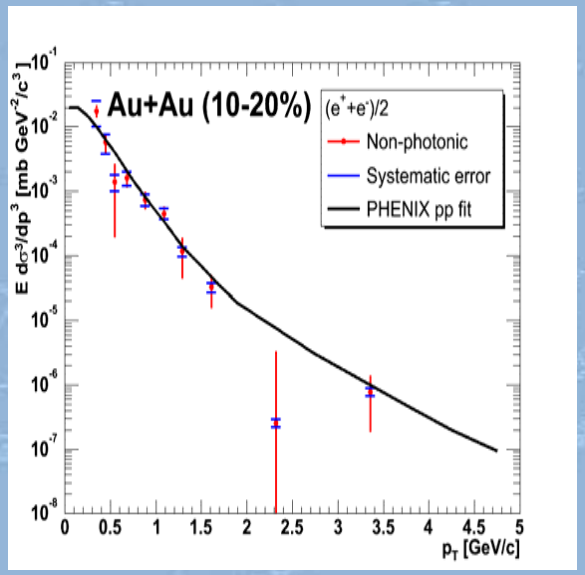
$1/T_{AB}$ EdN/dp^3 [mb GeV^{-2} c^3]

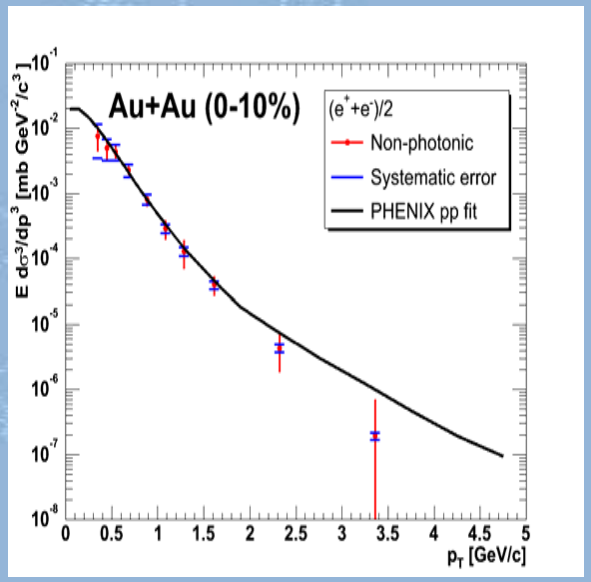
- ✓ Au-Au as a function of centrality
- ✓ Compatible with binary scaling
  - ✓ Need more stat. at high p_T !!!





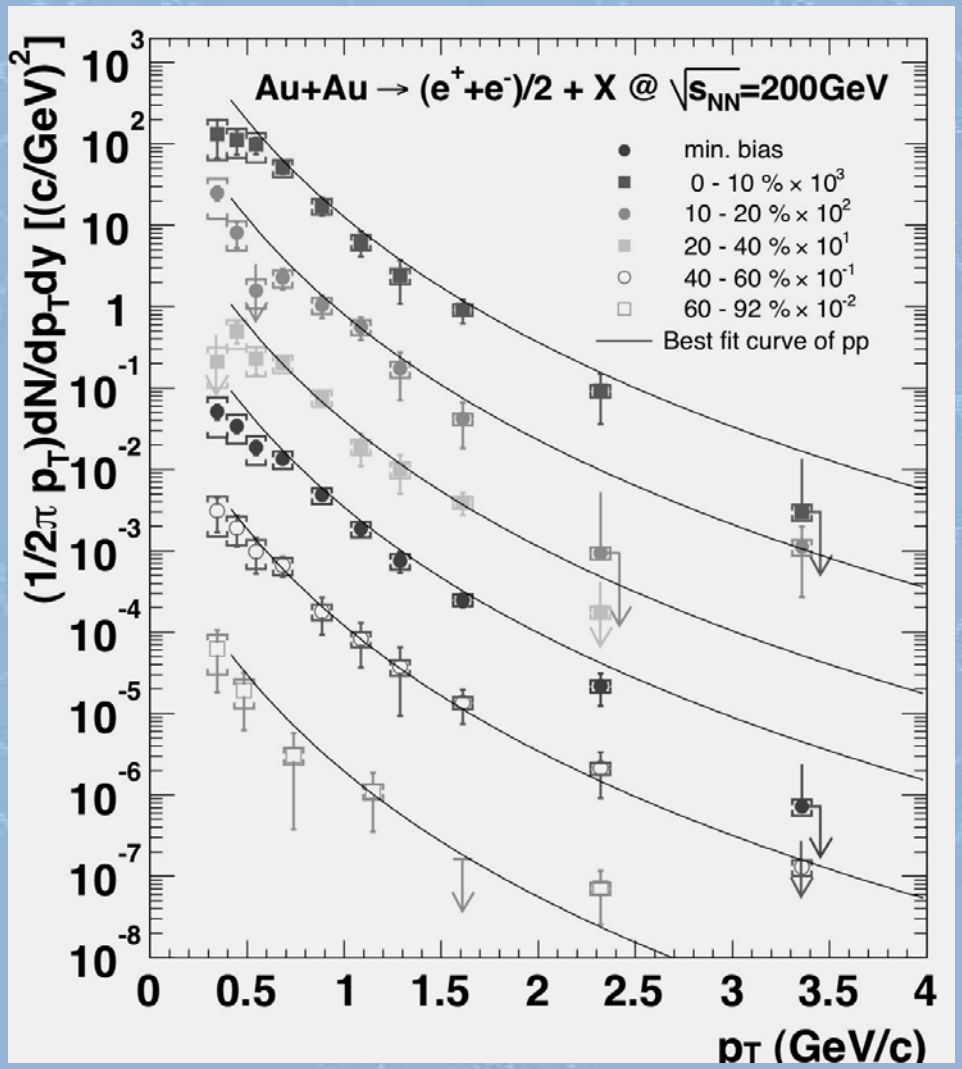






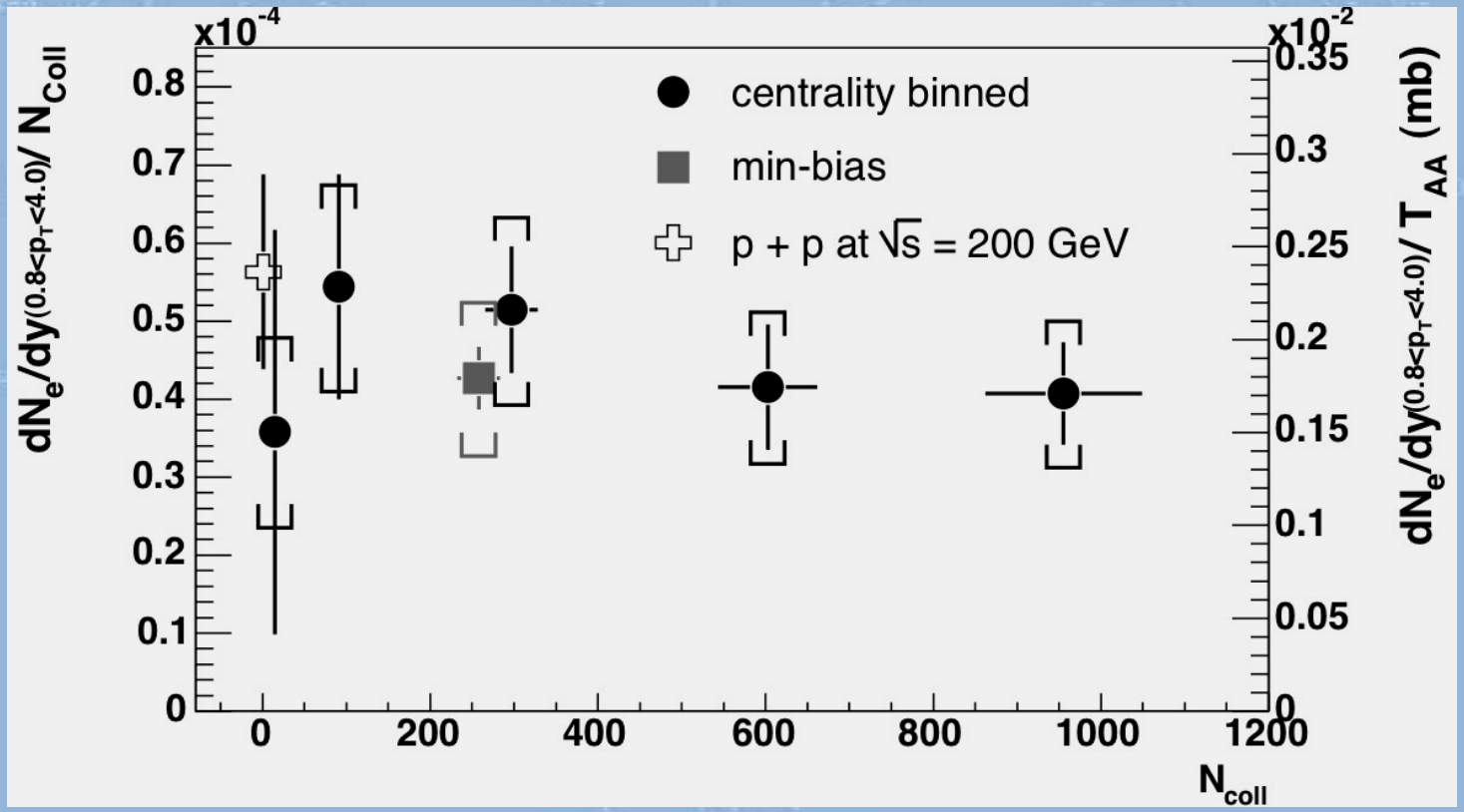
Au-Au ($\sqrt{s}$ = 200 GeV)

- ✓ Au-Au as a function of centrality: summary plot



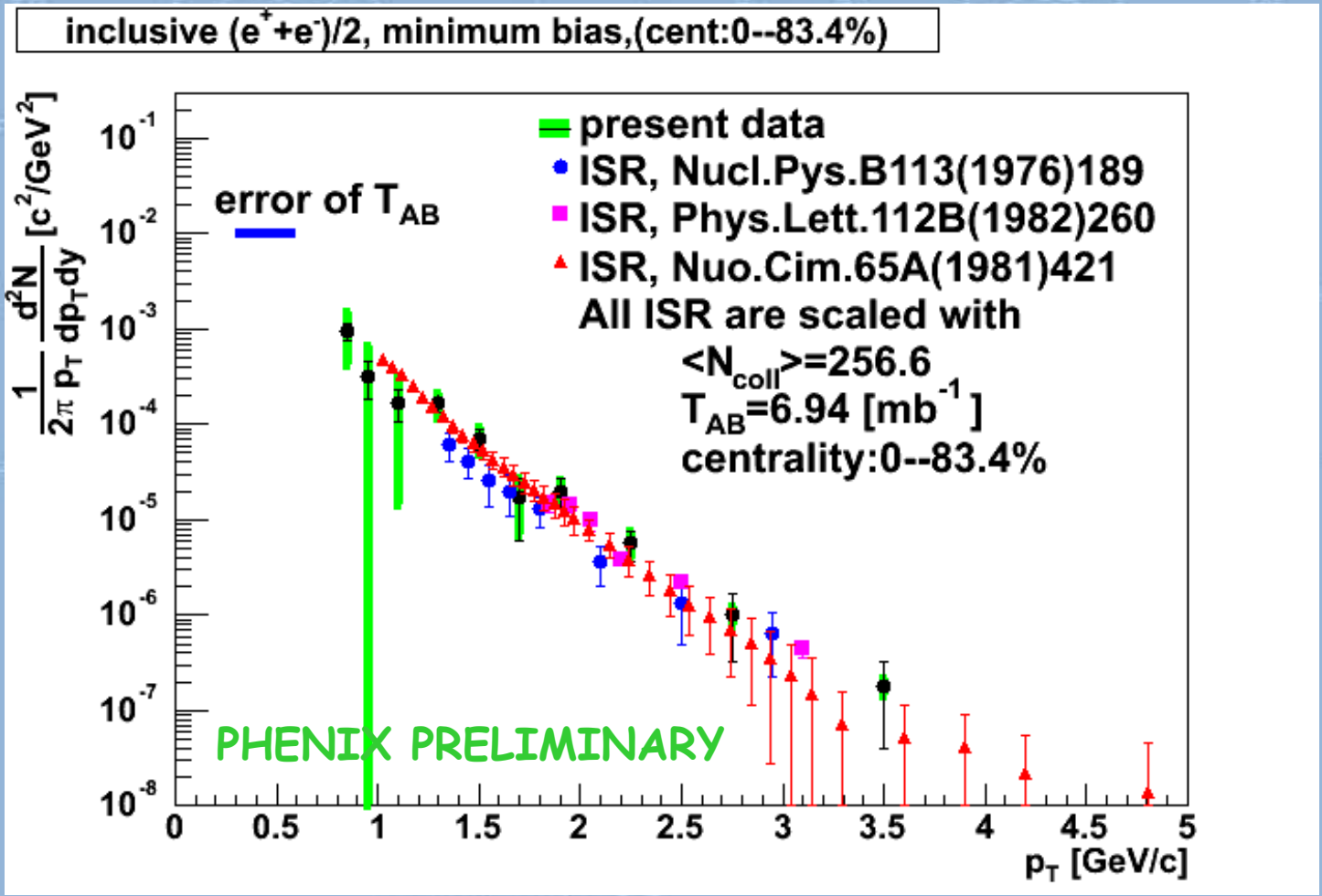
Au-Au ($\sqrt{s}$ = 200 GeV)

- Open charm in Au-Au : consistent with Ncoll scaling
  - 0.8 < pT < 4.0
  - α = 0.938 $\pm$ 0.075 (stat) $\pm$ 0.018 (syst)
  - Together with p-p: α = 0.958 $\pm$ 0.035 (stat)



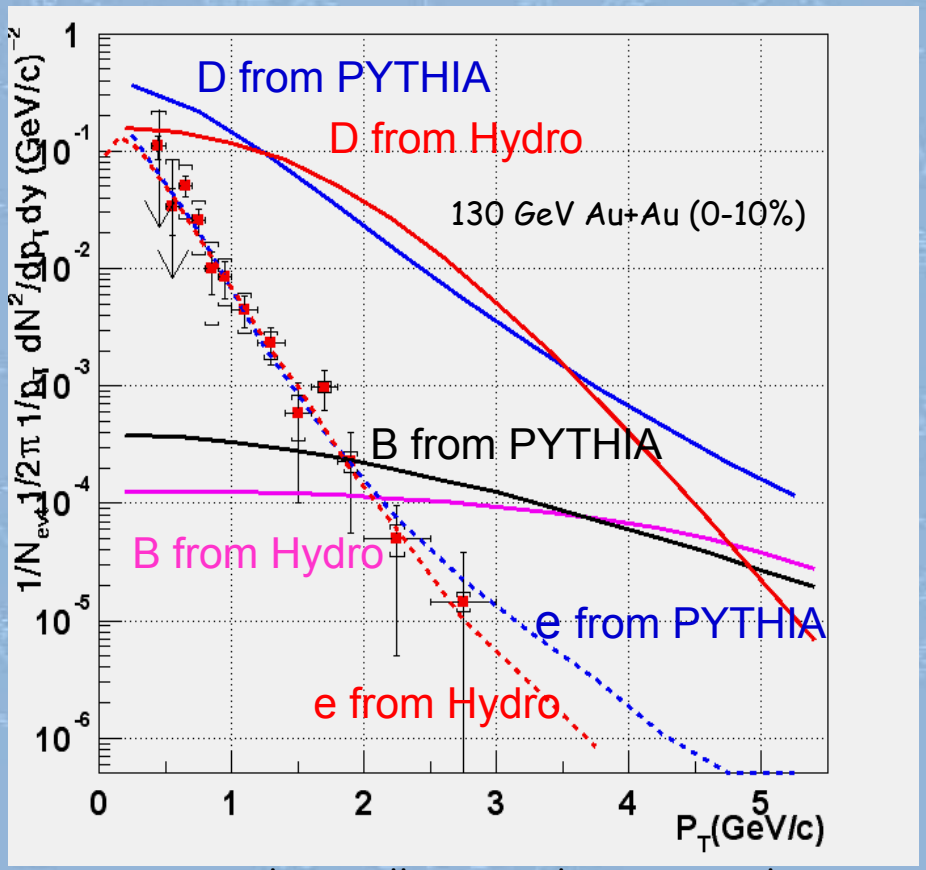
Au-Au ($\sqrt{s}$ = 62.4 GeV)

- Open charm in Au-Au @ 62.4 GeV, as compared to ISR p-p data at the same incident energy
  - Also compatible with <Ncoll> scaling



Flow ?

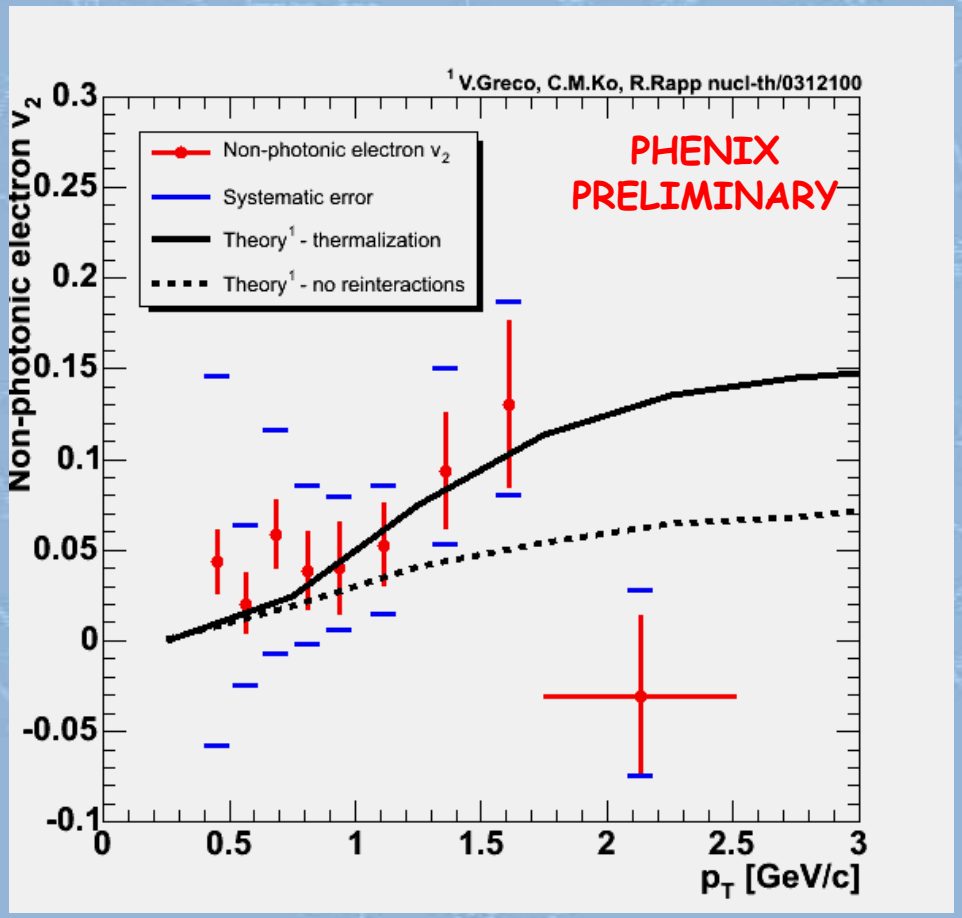
- Undistinguishable scenarios from p_T distributions
  - Would require high statistics at high p_T
  - Difference smoothed by decay



S. Batsouli, S.Kelly, M.Gyulassy, J.Nagle
Phys.Lett. B557 (2003) 26-32

Flow: Au-Au

- What about direct flow measurement … V_2 ?
  - V_2 of non photonic electrons in 200 GeV/A Au-Au (run 2)
    - Need more statistics (run 4)



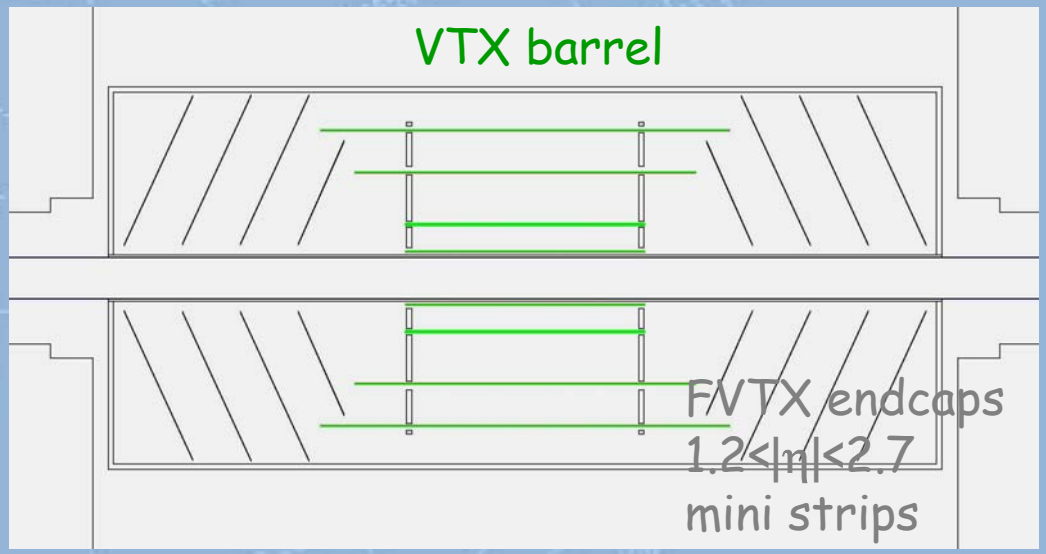
Conclusion

- ✓ PHENIX measures open charm with single electrons
- ✓ Proton-proton : reasonable agreement with PYTHIA
  - ✓ Charm + bottom
  - ✓ σ somewhat lower than reported by STAR
- ✓ d-Au: good agreement with Ncoll scaling for the 4 centrality bins
- ✓ Au-Au : good agreement with Ncoll scaling for the 5 centrality bins: $\alpha = 0.938 \pm 0.075$ (stat) ± 0.018 (syst)
  - ✓ Together with p-p: $\alpha = 0.958 \pm 0.035$ (stat)
- ✓ NO DEVIATION FROM BINARY SCALING OBSERVED SO FAR IN OPEN CHARM PRODUCTION

Outlook

- ✓ Near future: Run4 = much more statistics to come !
  - ✓ + Single muons
  - ✓ + Dilepton continuum
    - ✓ needs high stat + good control of combinatorial background
  - ✓ + Electron-muon coincidences ?

- ✓ PHENIX upgrades:
  - ✓ Barrel VTX
    - ✓ Pixel + strips
  - ✓ Forward VTX
    - ✓ strips



Future heavy flavor detection in PHENIX:

- Beauty and low p_T charm via displaced e and/or μ — $-2.7<\eta<-1.2$, $|\eta|<0.35$, $2.7<\eta<1.2$
- Beauty through displaced $J/\psi \rightarrow ee\ (\mu\mu)$ — $-2.7<\eta<-1.2$, $|\eta|<0.35$, $2.7<\eta<1.2$
- High p_T charm through $D \rightarrow \pi K$ — $|\eta|<0.35$

Thank you !

PHENIX

Brazil	University of São Paulo, São Paulo
China	Academia Sinica, Taipei, Taiwan
	China Institute of Atomic Energy, Beijing
	Peking University, Beijing
France	LPC, University de Clermont-Ferrand, Clermont-Ferrand
	Dapnia, CEA Saclay, Gif-sur-Yvette
	IPN-Orsay, Universite Paris Sud, CNRS-IN2P3, Orsay
	LLR, Ecòle Polytechnique, CNRS-IN2P3, Palaiseau
	SUBATECH, Ecòle des Mines at Nantes, Nantes
Germany	University of Münster, Münster
Hungary	Central Research Institute for Physics (KFKI), Budapest
	Debrecen University, Debrecen
	Eötvös Loránd University (ELTE), Budapest
India	Banaras Hindu University, Banaras
	Bhabha Atomic Research Centre, Bombay
Israel	Weizmann Institute, Rehovot
Japan	Center for Nuclear Study, University of Tokyo, Tokyo
	Hiroshima University, Higashi-Hiroshima
	KEK, Institute for High Energy Physics, Tsukuba
	Kyoto University, Kyoto
	Nagasaki Institute of Applied Science, Nagasaki
	RIKEN, Institute for Physical and Chemical Research, Wako
	RIKEN-BNL Research Center, Upton, NY
	Rikkyo University, Tokyo, Japan
	Tokyo Institute of Technology, Tokyo
	University of Tsukuba, Tsukuba
	Waseda University, Tokyo
S. Korea	Cyclotron Application Laboratory, KAERI, Seoul
	Kangnung National University, Kangnung
	Korea University, Seoul
	Myong Ji University, Yongin City
	System Electronics Laboratory, Seoul Nat. University, Seoul
	Yonsei University, Seoul
Russia	Institute of High Energy Physics, Protovino
	Joint Institute for Nuclear Research, Dubna
	Kurchatov Institute, Moscow
	PNPI, St. Petersburg Nuclear Physics Institute, St. Petersburg
	St. Petersburg State Technical University, St. Petersburg
Sweden	Lund University, Lund

*as of January 2004

12 Countries; 58 Institutions; 480 Participants*

USA	Abilene Christian University, Abilene, TX
	Brookhaven National Laboratory, Upton, NY
	University of California - Riverside, Riverside, CA
	University of Colorado, Boulder, CO
	Columbia University, Nevis Laboratories, Irvington, NY
	Florida State University, Tallahassee, FL
	Florida Technical University, Melbourne, FL
	Georgia State University, Atlanta, GA
	University of Illinois Urbana Champaign, Urbana-Champaign, IL
	Iowa State University and Ames Laboratory, Ames, IA
	Los Alamos National Laboratory, Los Alamos, NM
	Lawrence Livermore National Laboratory, Livermore, CA
	University of New Mexico, Albuquerque, NM
	New Mexico State University, Las Cruces, NM
	Dept. of Chemistry, Stony Brook Univ., Stony Brook, NY
	Dept. Phys. and Astronomy, Stony Brook Univ., Stony Brook, NY
	Oak Ridge National Laboratory, Oak Ridge, TN
	University of Tennessee, Knoxville, TN
	Vanderbilt University, Nashville, TN