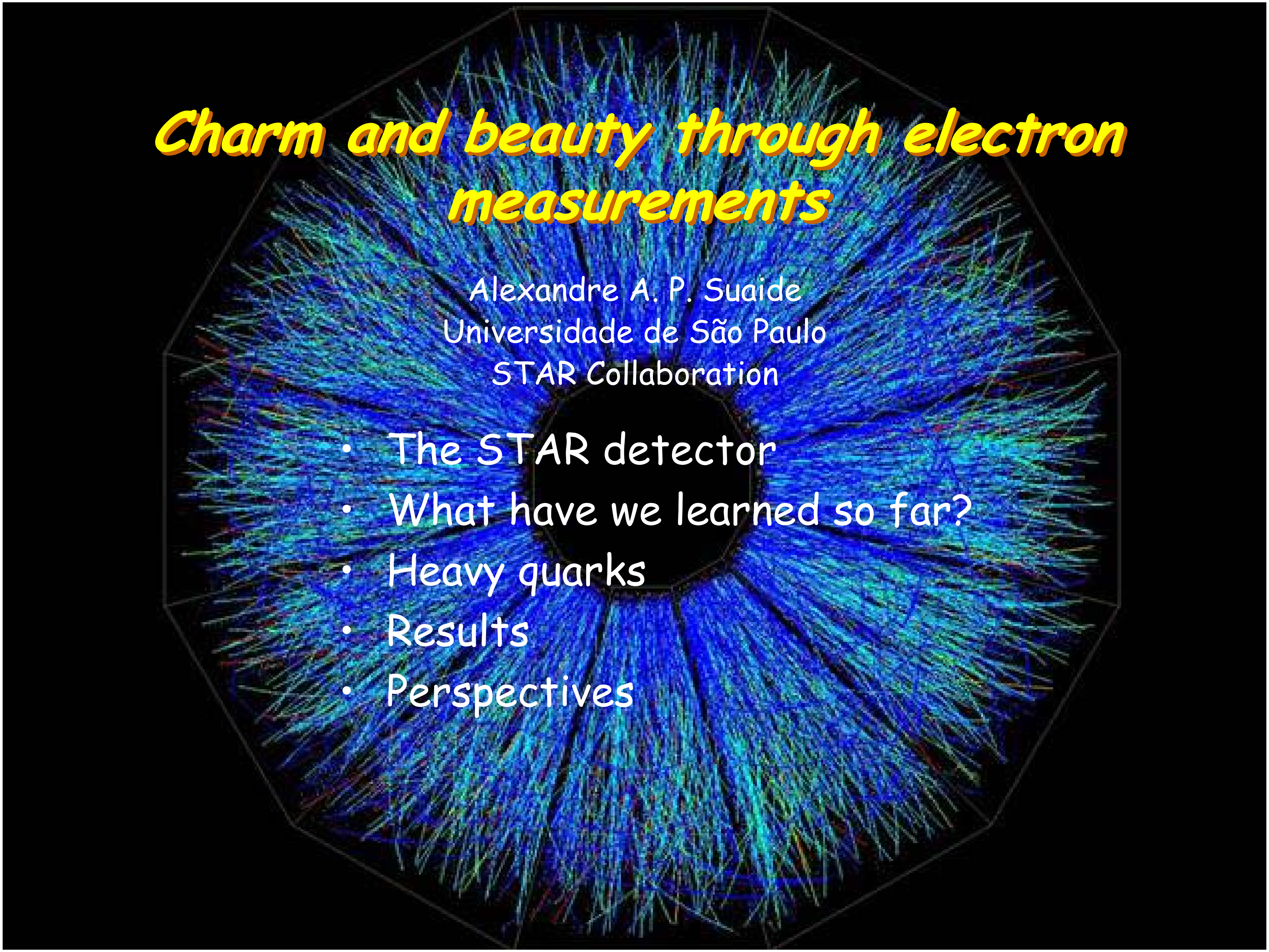
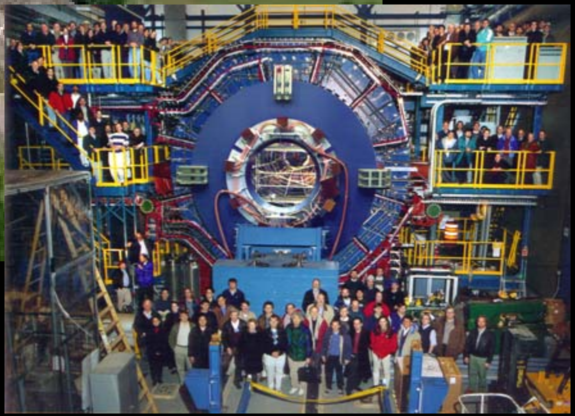


Charm and beauty through electron measurements

Alexandre A. P. Suaide
Universidade de São Paulo
STAR Collaboration

- The STAR detector
- What have we learned so far?
- Heavy quarks
- Results
- Perspectives

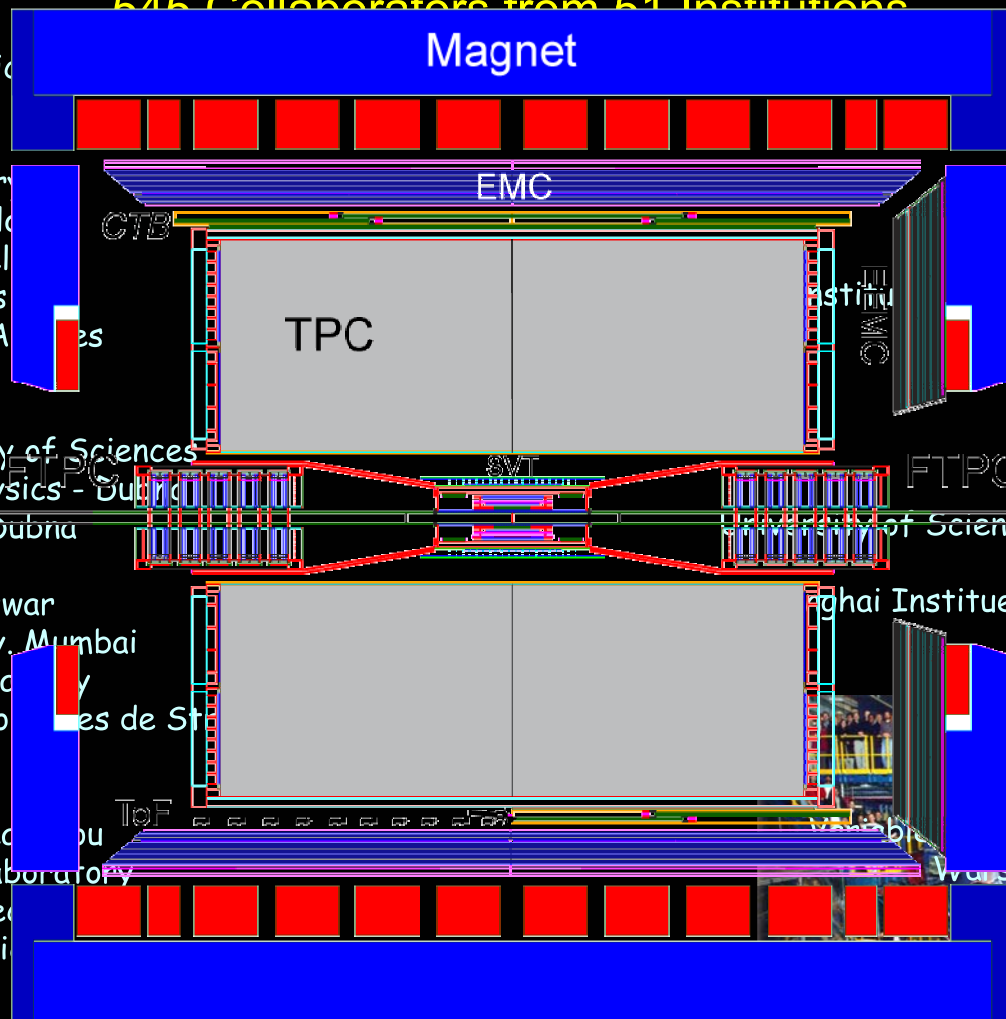
How do we do it?



How do we do it?

545 Collaborators from 51 Institutions

Argonne National Laboratory
Institute of High Energy Physic
University of Bern
University of Birmingham
Brookhaven National Laborator
California Institute of Technol
University of California, Berkel
University of California - Davis
University of California - Los A es
Carnegie Mellon University
Creighton University
Nuclear Physics Inst Academy of Sciences
Laboratory of High Energy Physics - Dubna
Particle Physics Laboratory - Dubna
University of Frankfurt
Institute of Physics. Bhubaneswar
Indian Institute of Technology. Mumbai
Indiana University Cyclotron F y
Institut de Recherches Subato es de St
University of Jammu
Kent State University
Institute of Modern Physics. L ou
Lawrence Berkeley National Laboratory
Massachusetts Institute of Te
Max-Planck-Institut fuer Physi



Michigan State University
ngineering Physics Institute
City College of New York
NIKHEF
Ohio State University
Panjab University
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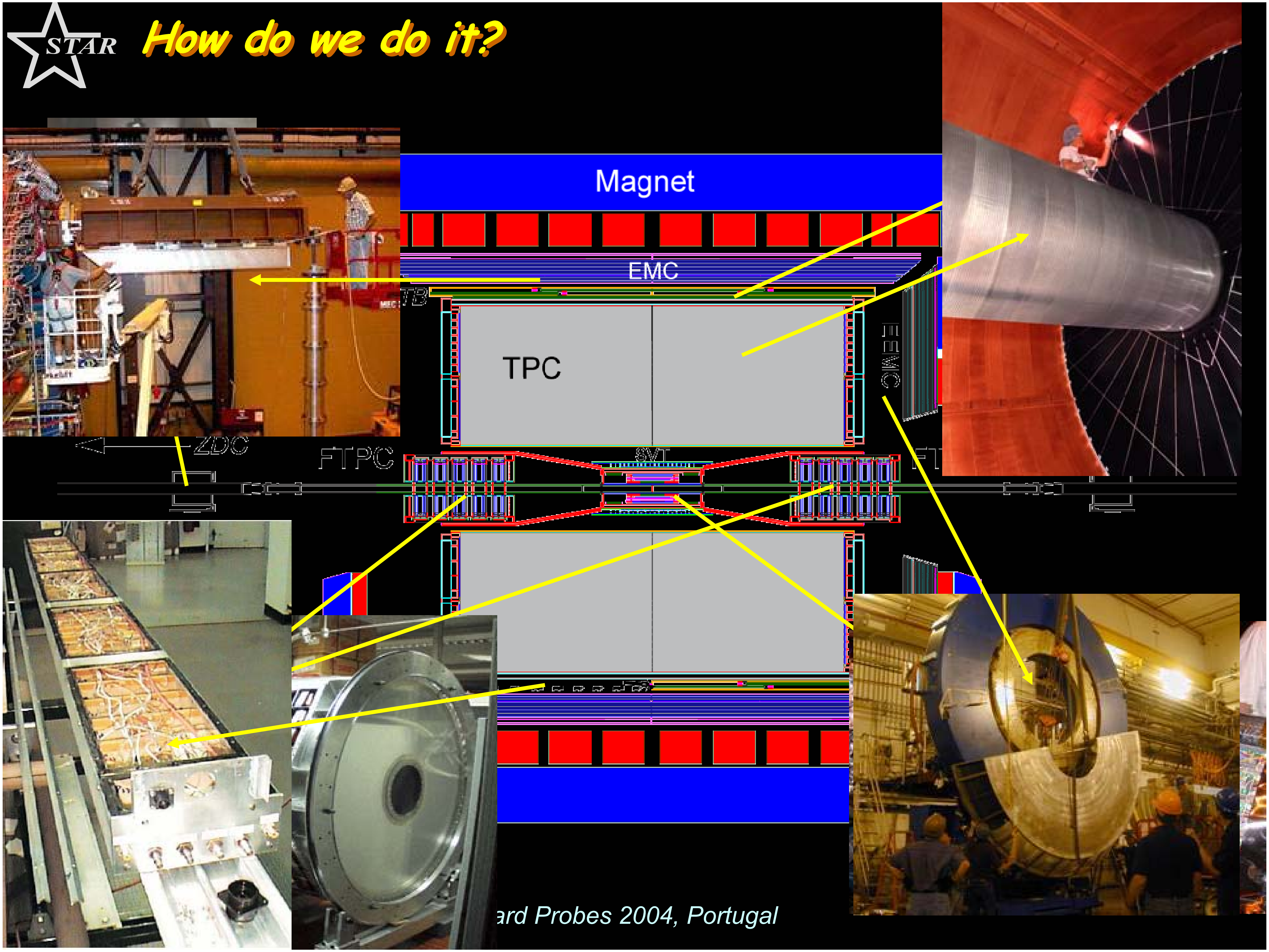
Purdue University
University of Rajasthan
Rice University
Instituto de Fisica da
Universidade de Sao Paulo
University of Science and Technology of China -
USTC
ghai Institue of Applied Physics - SINAP
SUBATECH
Texas A&M University
University of Texas - Austin
Tsinghua University
Valparaiso University
gy Cyclotron Centre. Kolkata
Warsaw University of Technology
University of Washington
Wayne State University
Institute of Particle Physics
Yale University
University of Zagreb

How do we do it?



What have we measured so far?

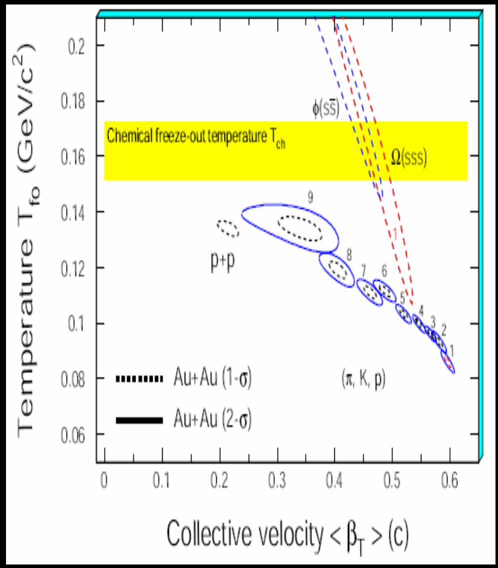
- RHIC has been exploring nuclear matter at extreme conditions over the last few years
  - 2000 – first run (Au+Au @ 130 GeV/NN)
  - 2001 – small Au+Au and p+p runs @ 200 GeV/NN
  - 2003 – d+Au and polarized p+p runs @ 200 GeV/NN
  - 2004 – large Au+Au run @ 200 GeV/NN and Au+Au run @ 62 GeV/NN

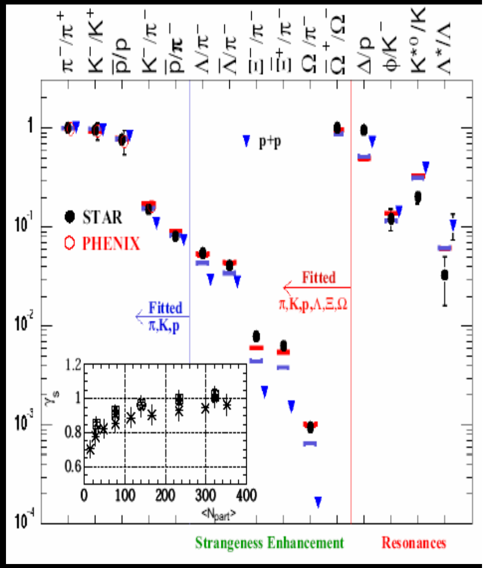
The soft sector: the bulk of produced particles

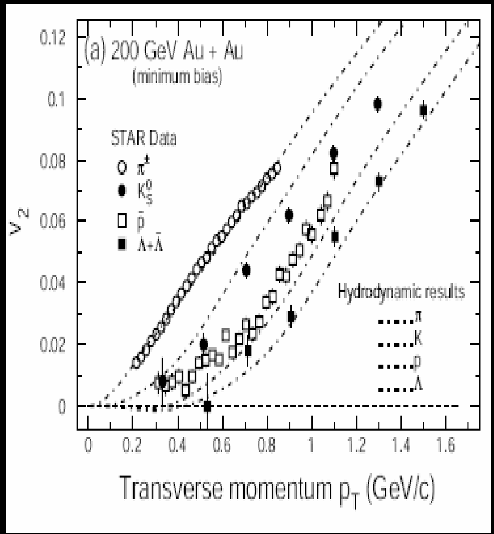
- The matter produced show strong collective flow
- The relative yield of different particles is in relative good agreement with Thermal Model
  - T_{ch}~ 160-170 MeV
  - μ_{ch} ~ 25 MeV
- Mass and p_T dependence, as well eliptic flow are consistent with Hydro expectations for an ideal relativistic fluid
- Very high initial energy density
  - Aprox 30 times cold nuclear matter

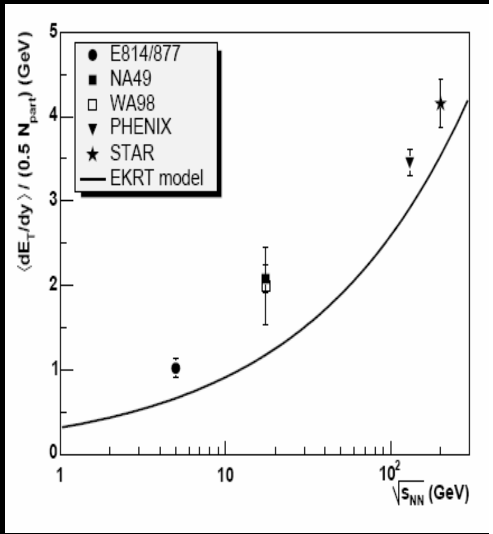
$$\varepsilon_{BJ} = \frac{1}{\pi R^2 \tau}\frac{dE_T}{dy} \sim 4.5 - 5.0\ \text{GeV/fm}^3$$

$$\varepsilon_{cold} = 0.13\ \text{GeV/fm}^3$$



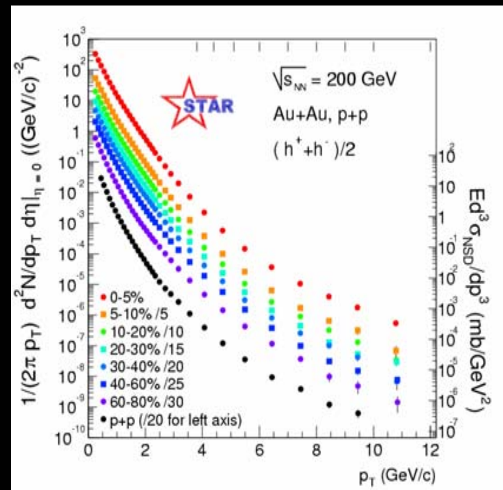


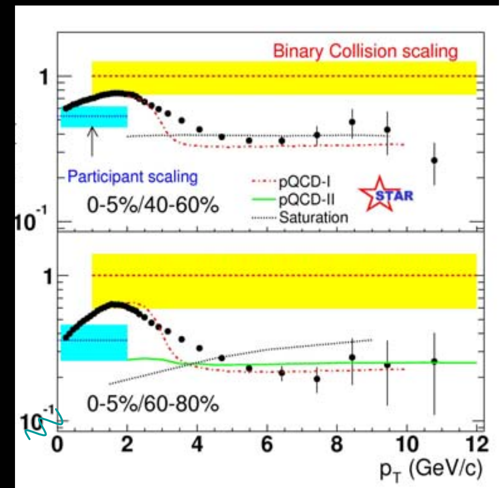


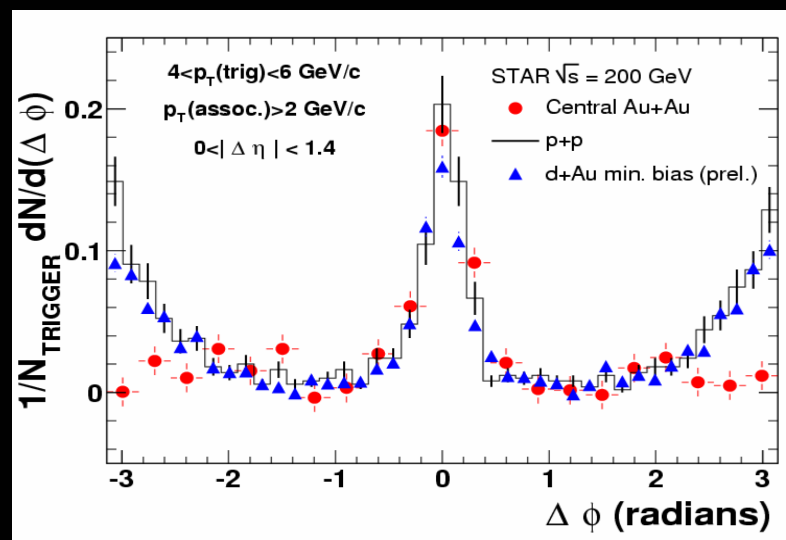


The high-p_T sector – sensitive to the initial stages of the system evolution

- Strong hadron suppression in central Au+Au collisions
  - Compared to p+p and peripheral events
  - Not seen in d+Au
    - Final state effect
- Magnitude of suppression indicates an initial gluon density much larger than normal nuclear matter
- Suppression of away side jets
  - Strong interactions with the matter produced
- **A new physics at RHIC era!**





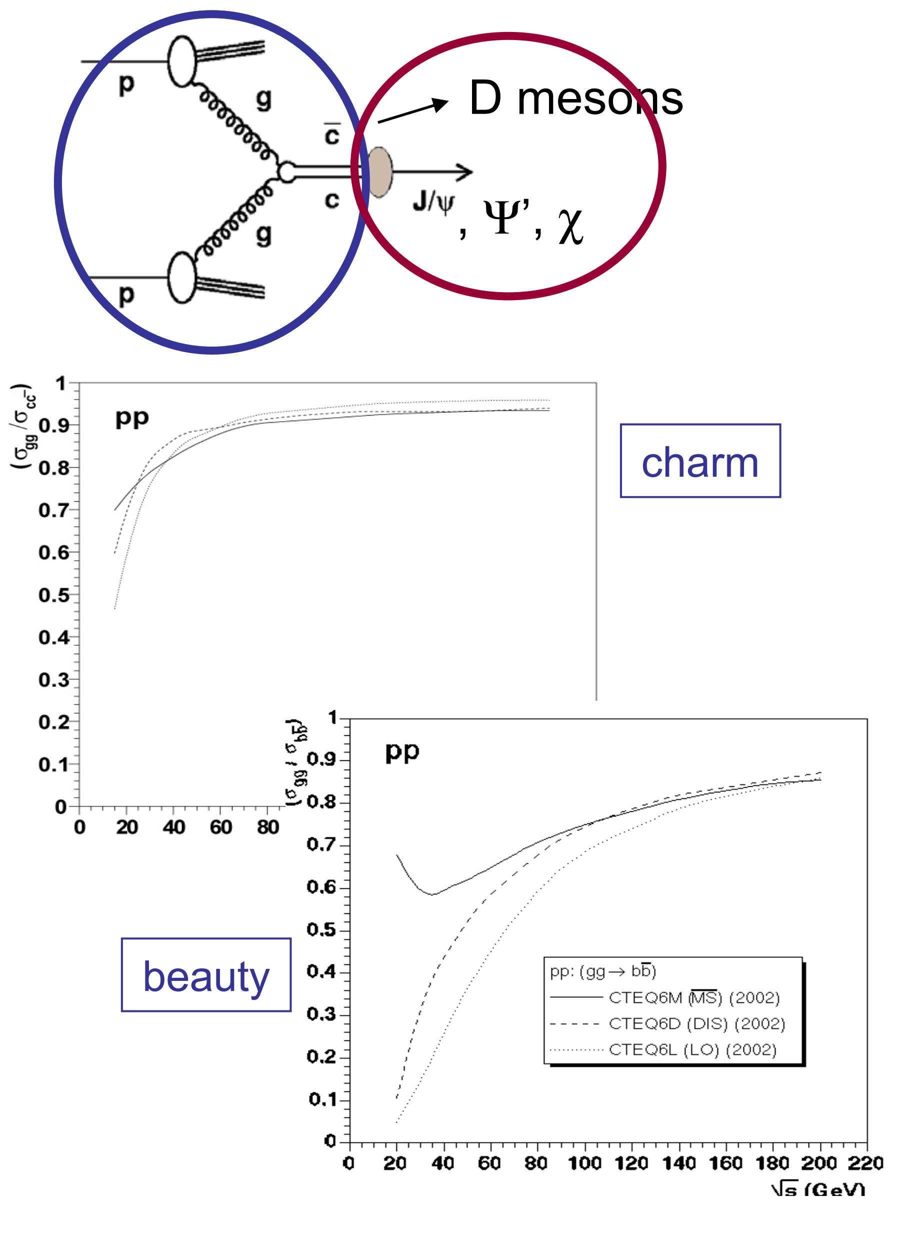


What we already know...
... and what we don´t.

- RHIC has produced matter that behaves differently from anything we had seen previously...
  - Is this the QGP?
  - Can we see the phase transition?
    - Lower energies, different system sizes?
- ... is dense (many times cold nuclear matter density)...
- ... is dissipative...
- ... exhibits strong collective behavior...
  - Does dissipation and collective behavior both occur at the partonic stage?
- ... and seems to be thermally equilibrated
  - Is it?

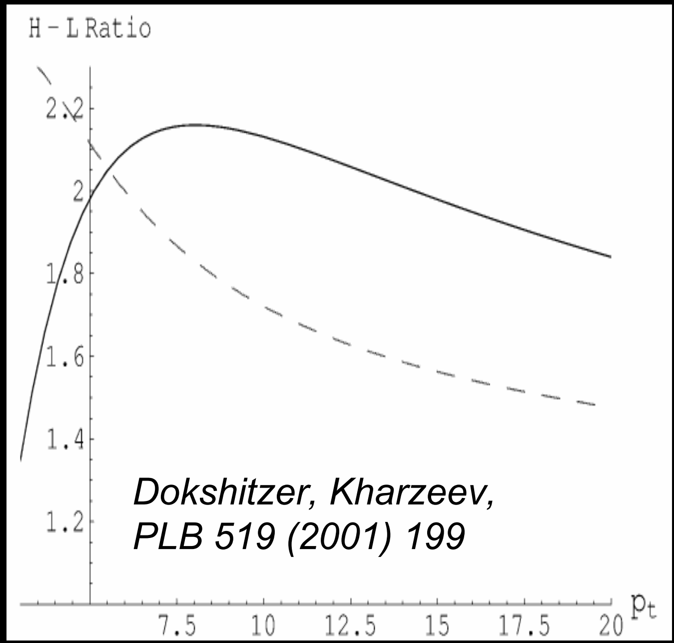
What could heavy quarks give us?

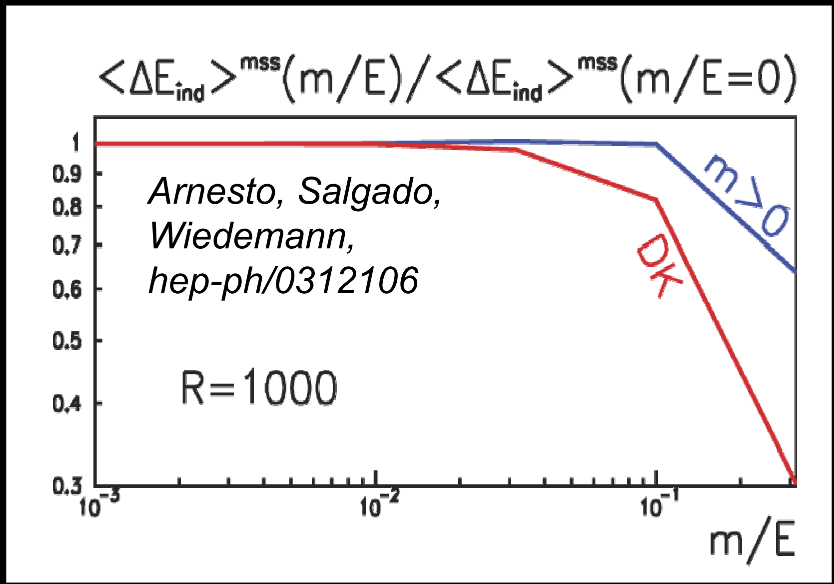
- Heavy quark production
  - Charm produced in early stage, mostly from initial gluon fusion
    - Sensitive to early conditions:
      - initial gluon density
      - nuclear effects
      - medium effects
    - Are heavy-quarks mesons suppressed as well as light quarks ones?
      - Probe of energy loss mechanism
    - Thermalization probe?
      - Eliptic flow.



Heavy quark suppression?

- Propagation of heavy quarks in QCD matter
  - Energy loss through gluon radiation
  - dead cone effect
    - Gluon radiation suppressed for $\theta < M/E$ (Dokshitzer & Kharzeev, PLB 519 (2001) 199)
  - Medium induced radiation reduces effect but still sizeable (Arnesto, Salgado, Wiedemann, hep-ph/0312106)
  - large enhancement of D/π ratio at moderate high p_T (5-10 GeV/c)





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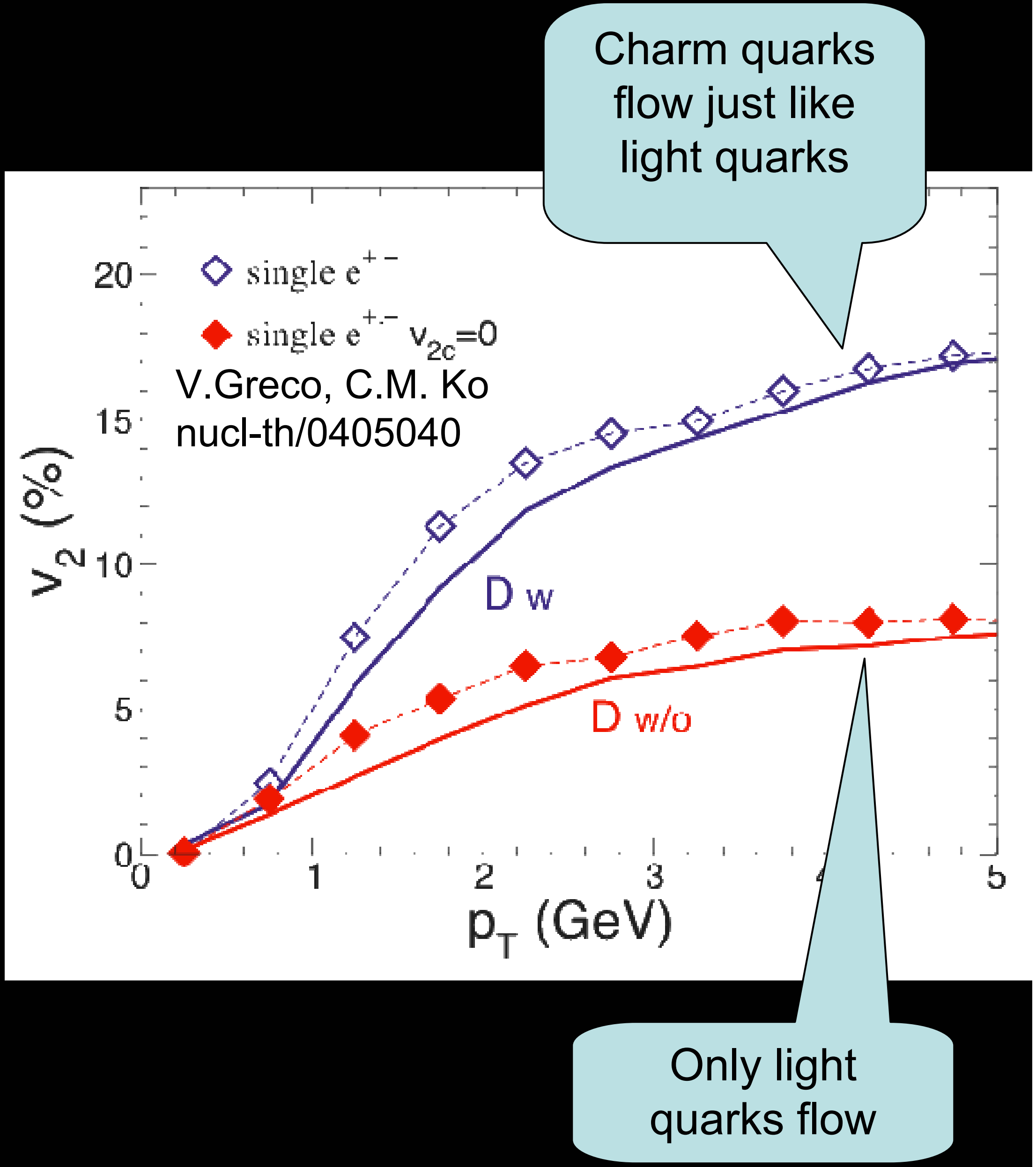
Heavy-quark flow

- Elliptic flow of D-Meson and their decay electrons is a sensitive probe for thermalization
  - Charm flow extremely interesting, because of the c-quark's mass (m=1.5GeV). If the c-quarks flow, there must have been enough interactions to easily thermalize light quarks.



Electrons: information from heavy quark production

Citation: K. Hagiwara *et al.* (Particle Data Group), Phys. Rev. D **66**, 010001 (2002) (URL: http://pdg.lbl.gov)

CHARMED MESONS
($C = \pm 1$)

$D^+ = c\overline{d}$, $D^0 = c\overline{u}$, $\overline{D}^0 = \overline{c}\,u$, $D^- = \overline{c}\,d$, similarly for D^*'s

$D^\pm$ $I(J^P) = \frac{1}{2}(0^-)$

Mass $m = 1869.3 \pm 0.5$ MeV (S = 1.1)
Mean life $\tau = (1051 \pm 13) \times 10^{-15}$ s
$c\tau = 315\ \mu$m

c-quark decays

$\Gamma(c \to \ell^+ \text{anything})/\Gamma(c \to \text{anything}) = 0.096 \pm 0.004$ [nn]
$\Gamma(c \to D^*(2010)^+ \text{anything})/\Gamma(c \to \text{anything}) = 0.255 \pm 0.017$

CP-violation decay-rate asymmetries

$A_{CP}(K^0_S \pi^\pm) = -0.016 \pm 0.017$
$A_{CP}(K^0_S K^\pm) = 0.07 \pm 0.06$

BOTTOM MESONS
($B = \pm 1$)

$B^+ = u\overline{b}$, $B^0 = d\overline{b}$, $\overline{B}^0 = \overline{d}\,b$, $B^- = \overline{u}\,b$, similarly for B^*'s

B^0 DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\ell^+ \nu_\ell$ anything	[qq]	(10.5 ±0.8) %		–
$D^- \ell^+ \nu_\ell$	[qq]	(2.11±0.17) %		–
$D^*(2010)^- \ell^+ \nu_\ell$	[qq]	(4.60±0.21) %		–
$\rho^- \ell^+ \nu_\ell$	[qq]	($2.6\ ^{+0.6}_{-0.7}$) $\times 10^{-4}$		–
$\pi^- \ell^+ \nu_\ell$		(1.8 ±0.6) $\times 10^{-4}$		–

Electron PID with MRPC TOF/TPC and EMC

Inclusive electron spectra

ToF

1. use TPC a
2. works for

EMC

dE/dx

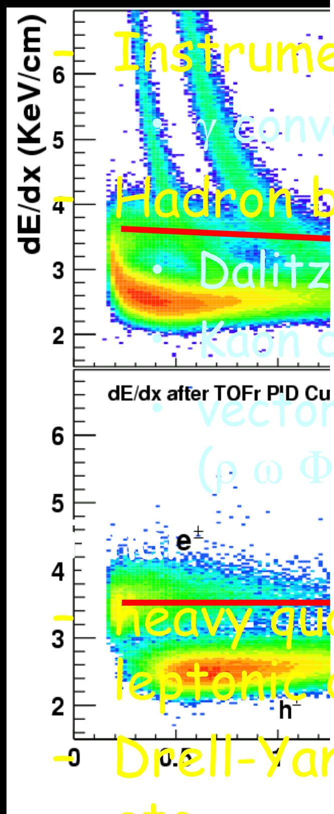
/E

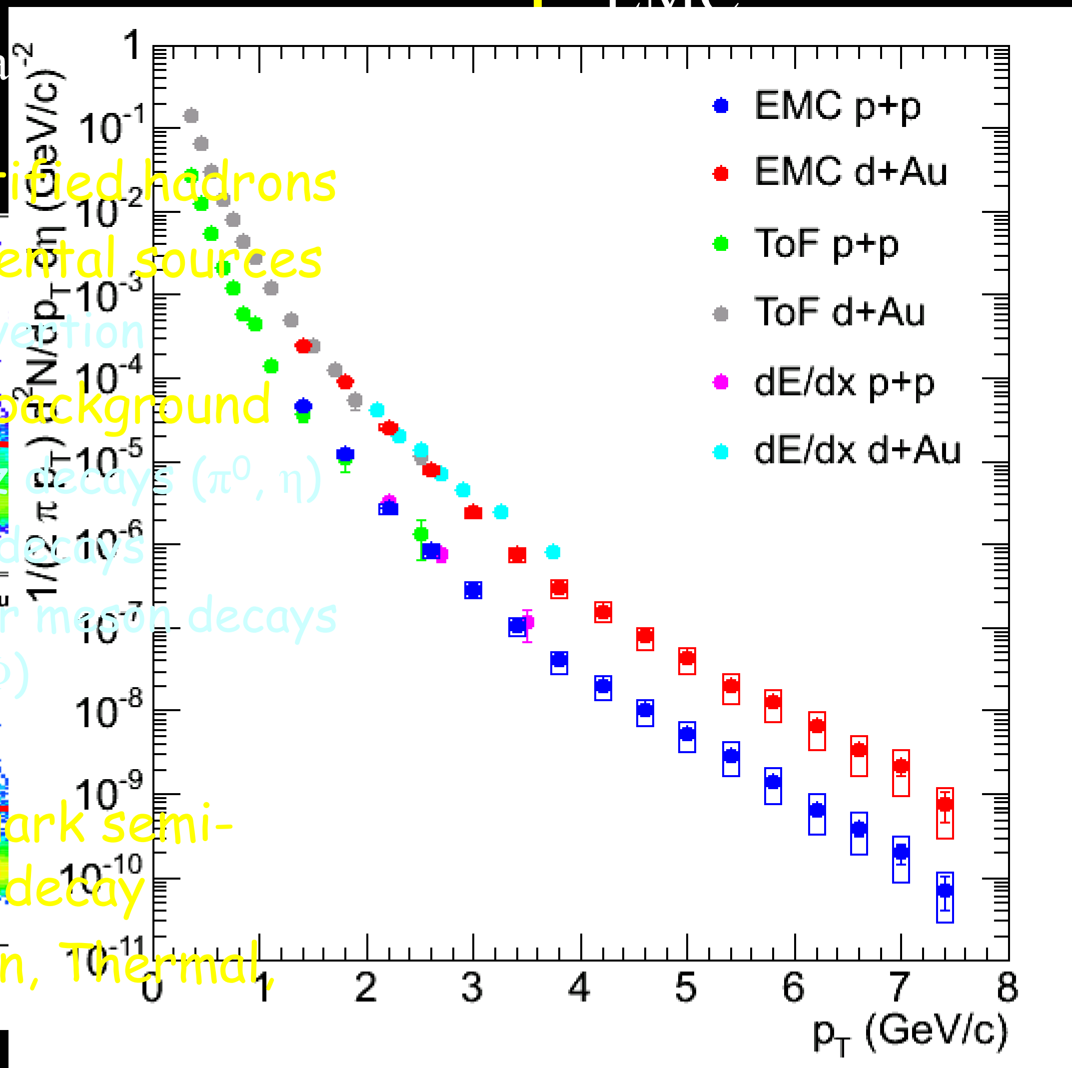
reject hadrons

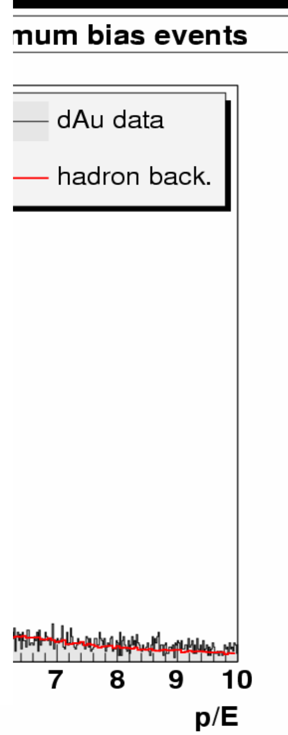
power ~ 10^5

GeV/c

- Background
  - Misidentified hadrons
  - Instrumental sources
    - γ conversion
  - Hadron background
    - Dalitz decays (π^0, η)
    - Kaon decays
    - vector meson decays (ρ ω Φ)
-
  - heavy quark semi-leptonic decay
  - Drell-Yan, Thermal, etc





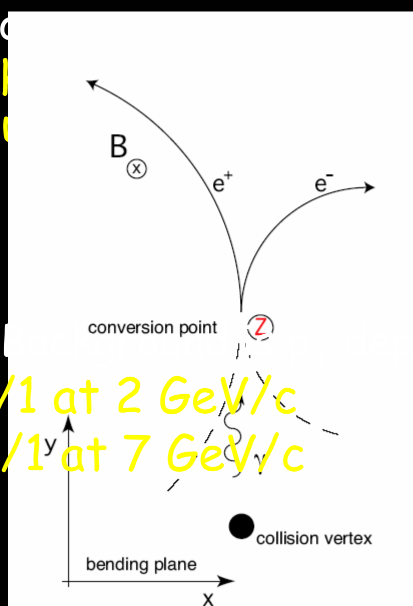


Electron background

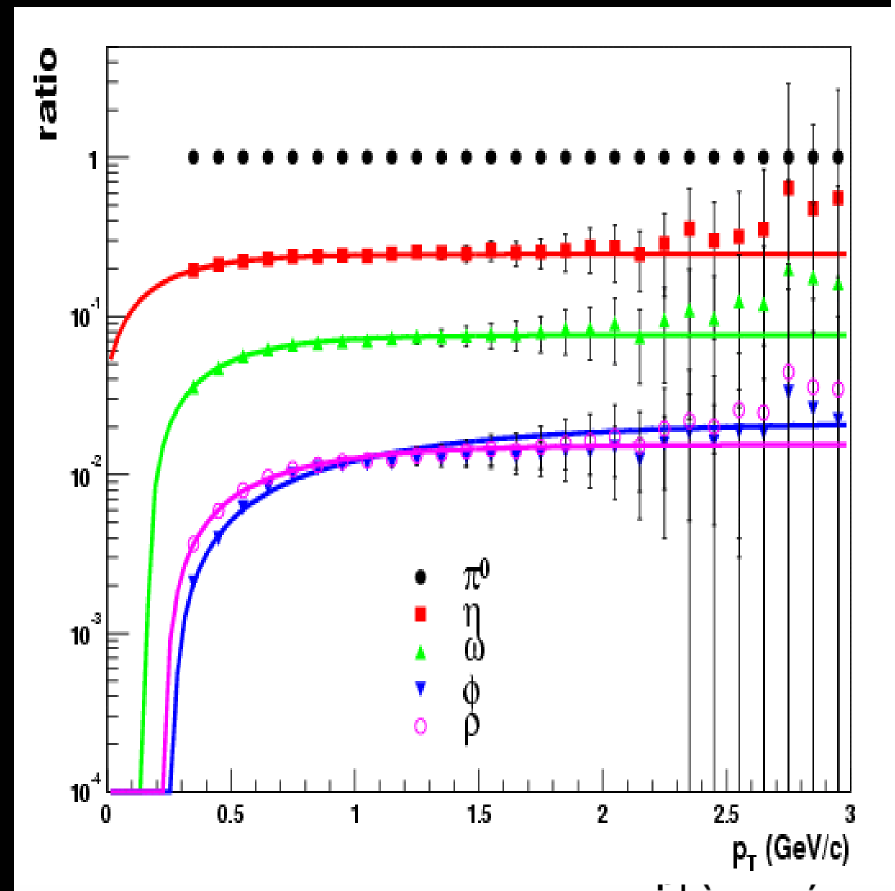
- Misidentified hadrons
  - Obtained by shifting the TPC dE/dx selection over the hadrons region

- γ convertion and Dalitz decays
  - Di-electron mass reconstruction
  - High efficiency

- Other so
  - Pyth ANT simu
    - to π^0

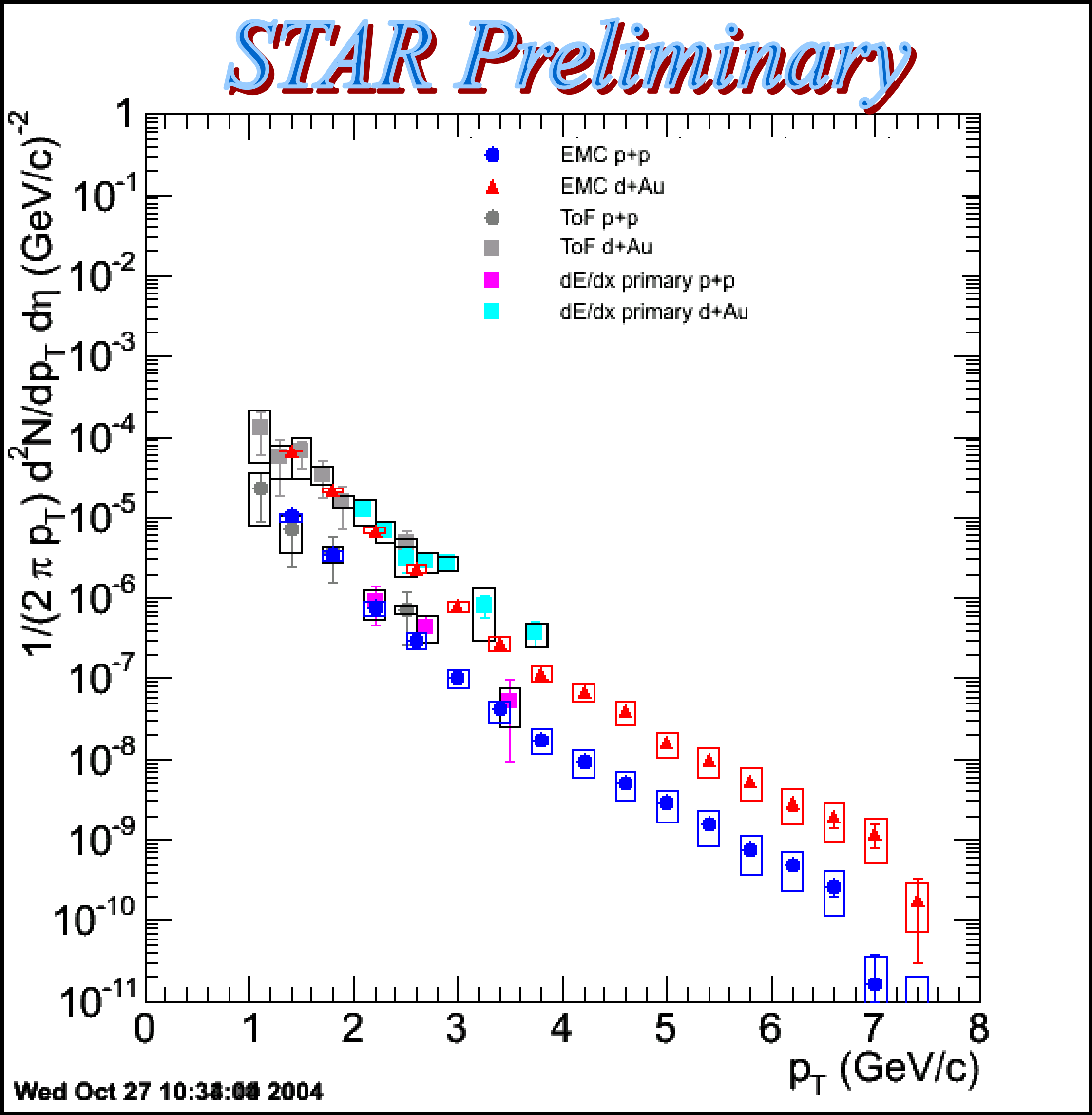


- Signal/ endent
  - ~1/1 at 2 GeV/c
  - ~2/1 at 7 GeV/c



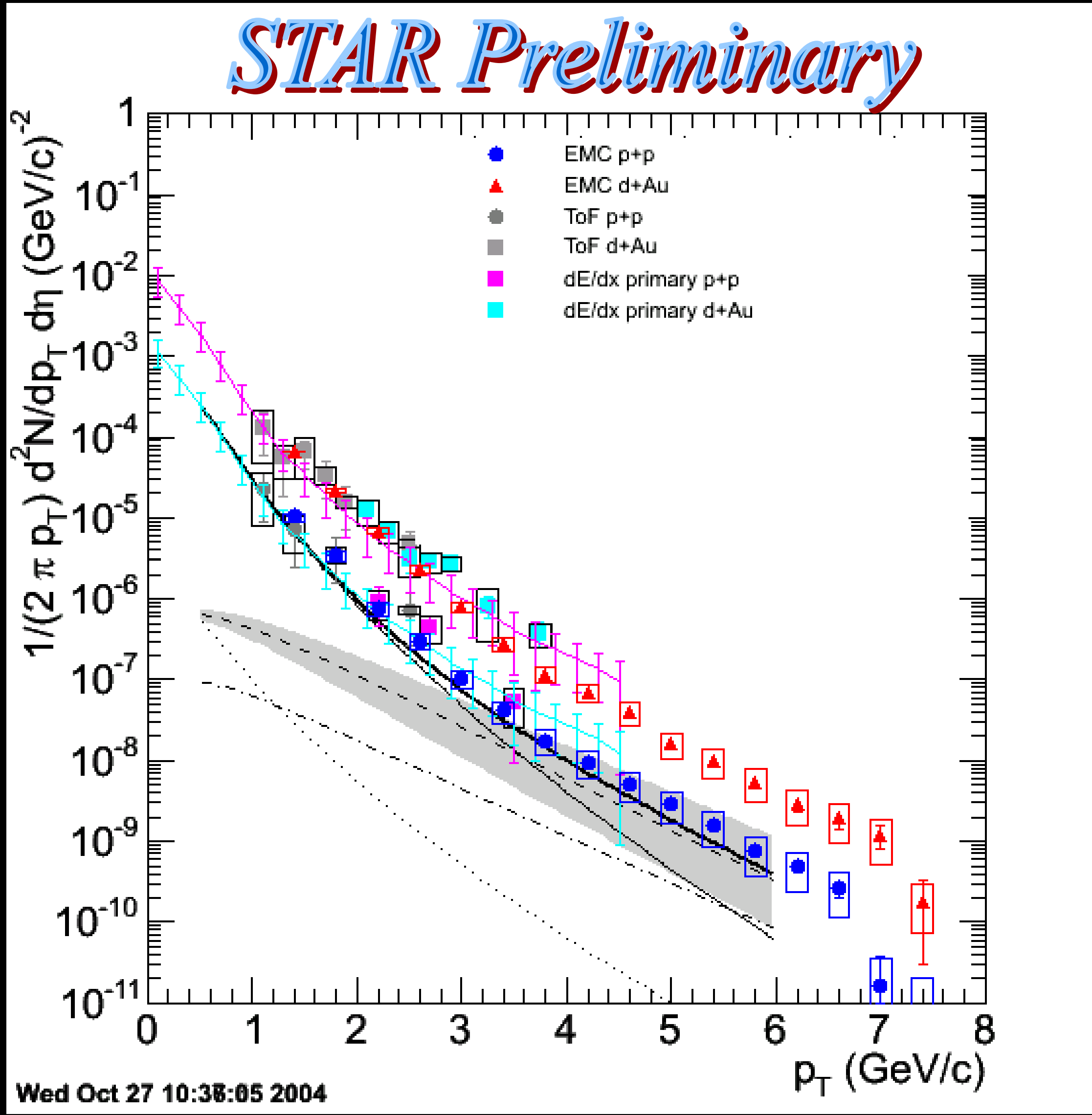
Background subtracted electron spectra

- STAR has measured electrons up to $p_T = 8$ GeV/c
- EMC, ToF and dE/dX electrons agree within errors
- Systematic uncertainties
  - Trigger bias ~ $0.5\sigma_{sys}$
  - Efficiency ~ $0.2\sigma_{sys}$
  - Other sources ~ $0.3\sigma_{sys}$



Where these electrons come from?

- Are they from heavy-quark decay?
- Electrons calculated from D-mesons measurements indicate that a significant fraction are from charm
  - See Manuel Calderon's talk
- Pythia suggest that high-p_T electrons may have a significant contribution from beauty decays.



Charm Cross-Section

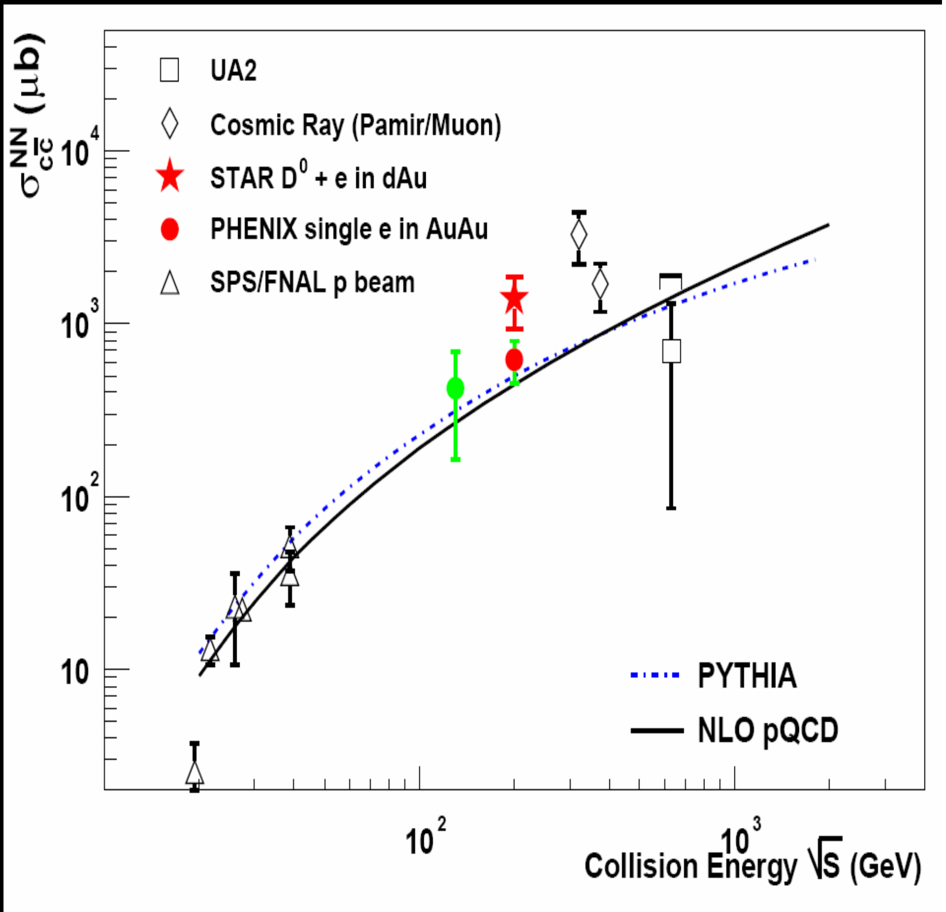
Measured D combined with measured electron spectra

$$\sigma_{c\bar{c}}^{NN} = 1.4 \pm 0.2(stat) \pm 0.4(sys)\ \text{mb}$$

- Pythia and NLO pQCD calculations
  - Underpredicts cross-section by at least a factor of 3.

Ramona Vogt
hep-ph/0203151

			40 GeV	200 GeV	5.5 TeV
		$c\bar{c}$			
PDF	m_c (GeV)	μ/m_c	σ (μb)	σ (μb)	σ (mb)
MRST HO	1.4	1	37.8	298	3.18
MRST HO	1.2	2	43.0	382	5.83
CTEQ 5M	1.4	1	40.3	366	4.52
CTEQ 5M	1.2	2	44.5	445	7.39
GRV 98 HO	1.3	1	34.9	289	4.59
		$b\bar{b}$			

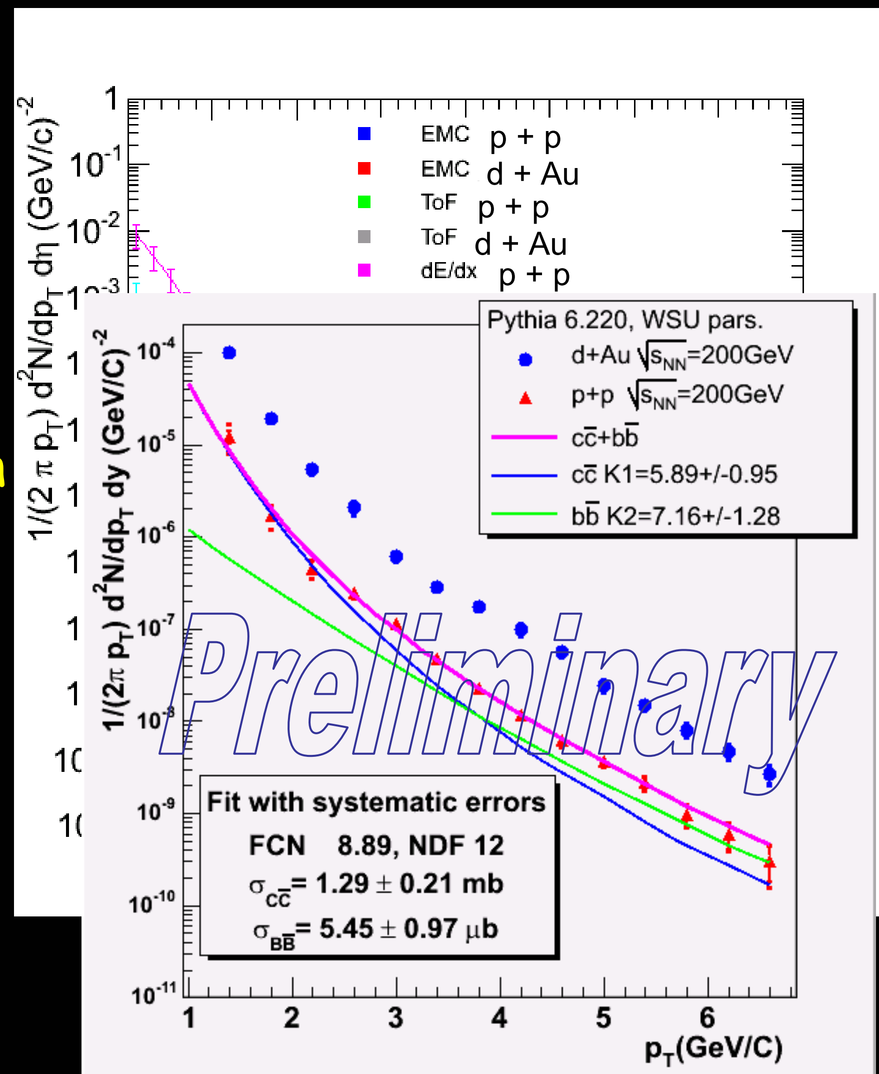


  - Other processes like *flavor excitation, gluon splitting, parton showers* et al. are needed
  - To understand Au+Au need to understand this first.

What about beauty?
... an exercise on Pythia simulation...

- Pythia simulations suggest that high-p_T electrons above 3.5 GeV/c are sensitive to beauty
- Obtaining beauty cross section
- Use Pythia to ESTIMATE a limit on beauty production
  - Intensive study on the systematics of c cross section
  - Only c-cbar gives too much cross section
  - Use D-mesons as constrain
    - $\sigma_{bbar} = 5.45 \pm 0.97^{stat} \pm 2.2^{sys}$ μb

The ideal way
- Measure D-mesons and subtract the electron yield from D-meson decay
- Current measurement
  - Needs very large extrapolation with current measurements
  - Huge uncertainties

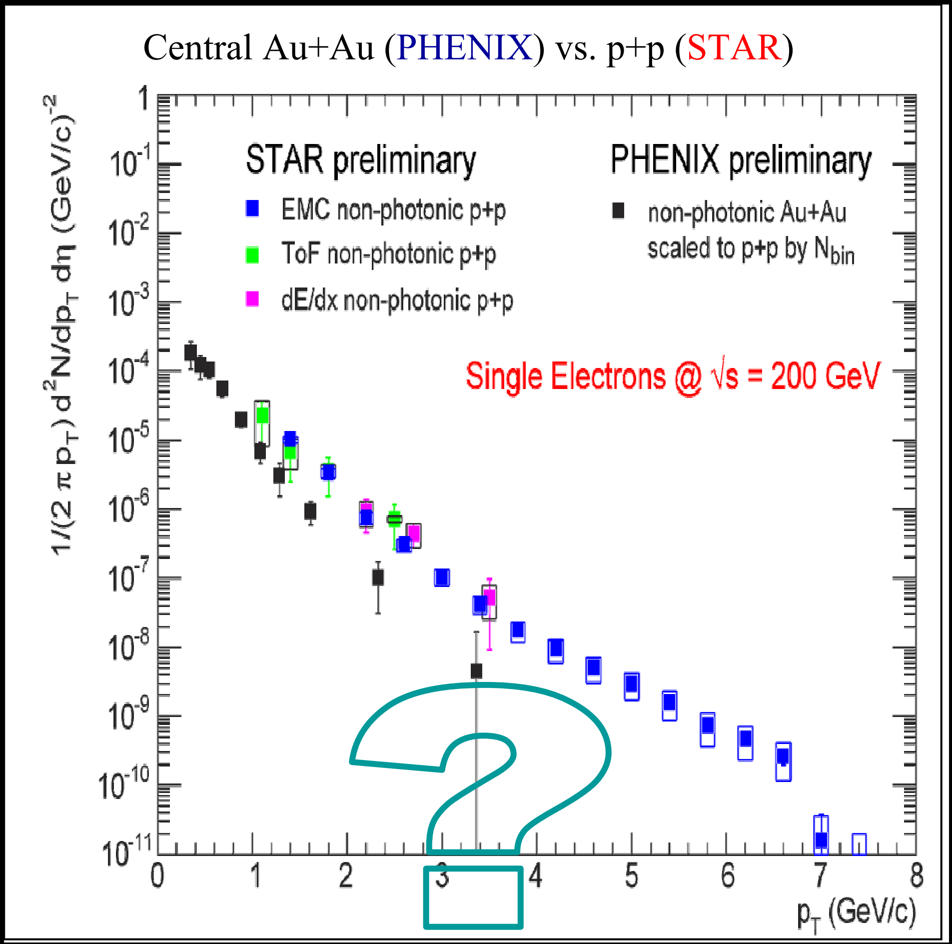


Ramona Vogt hep-ph/0203151

PDF	m_b (GeV)	μ/m_b	σ (nb)	σ (μb)	σ (μb)
MRST HO	4.75	1	9.82	1.90	185.2
MRST HO	4.5	2	8.73	1.72	193.2
MRST HO	5.0	0.5	10.96	2.16	184.8
GRV 98 HO	4.75	1	13.40	1.65	177.6
GRV 98 HO	4.5	2	12.10	1.64	199.0
GRV 98 HO	5.0	0.5	14.80	1.73	166.0

Comparison between p+p, d+Au and Au+Au?

- d+Au collisions
  - R_{dAu} is compatible with binary collision scalling
  - Maybe a small Cronin enhacement
- Au+Au collisions
  - Too early to call
  - But it seems we have some modification
- Do we really understand quark energy loss?
  - Need to extend AuAu to higher p_T
    - STAR results will be available in the next few months



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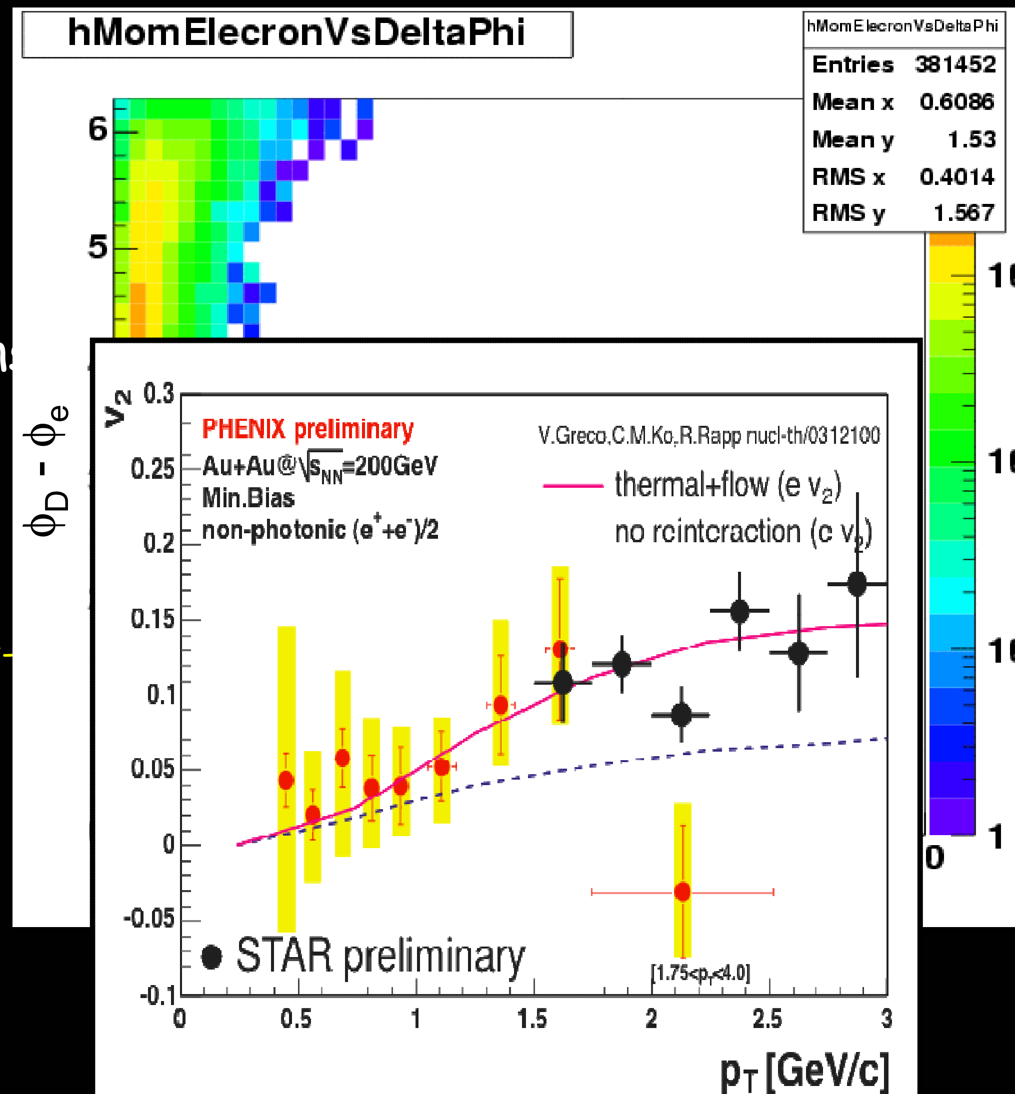
Does heavy-quark flow?

- Elliptic flow of D-Meson is a sensitive probe for thermalization
  - c mass (~1.5 GeV). If c-quarks flow, there must have been a lot of interactions to easily thermalize light quarks.
- How we measure it?
  - Direct measurement is not possible at this point
  - Does electron flow reflect D's flow?
- Electron v_2 in Au-Au collisions @ 200 GeV
  - Indication of non-zero non-photonic electron v_2
  - consistent with $v_{2c} = v_{2light}$- theory calculations
- Still a long way to go
  - Centrality dependence
  - Understand systematics
  - Improve statistics



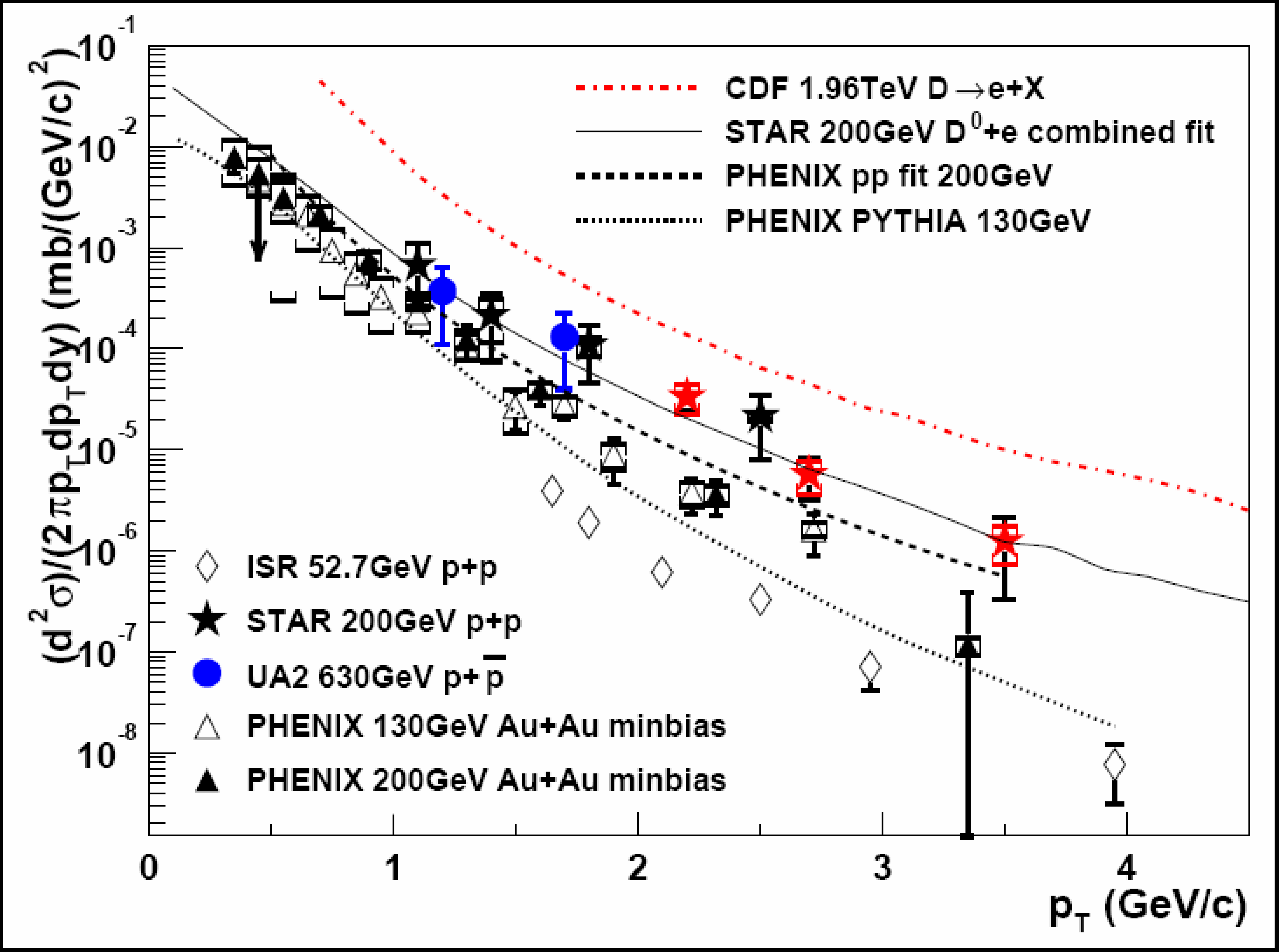
Final remarks

- STAR has measured electrons from heavy-quark decays up to 8 GeV/c in p+p and d+Au collisions
  - Heavy-quark cross sections underestimated by pQCD calculations
  - R_{dAu} suggests Cronin enhancement in electrons but is consistent with N_{bin} scaling within present errors
  - There are indications of strong heavy-quark suppression in central Au+Au
    - Need to extend to higher p_T and minimize systematics
    - Do we understand heavy-quark energy loss (dead cone effect)?
- Preliminary results show non-zero v_2 for electrons from heavy-quark decays
  - Results are compatible with $v_{2c} = v_{2light-q}$ theoretical calculations
- It seems that there are strong interactions between heavy-quarks and the medium created in RHIC.
  - Y2004 data will provide enough statistics to confirm these results.

Backup slides

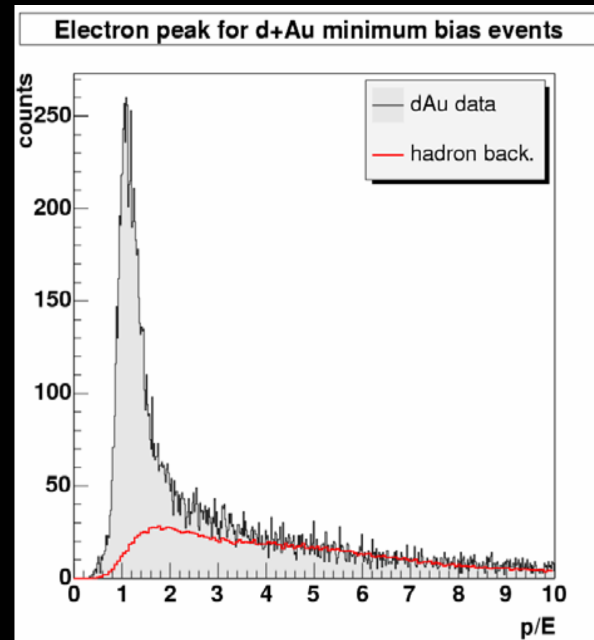
- Not ready yet, but...
  - Phenix AA electrons / Npart
  - Electron id in detail

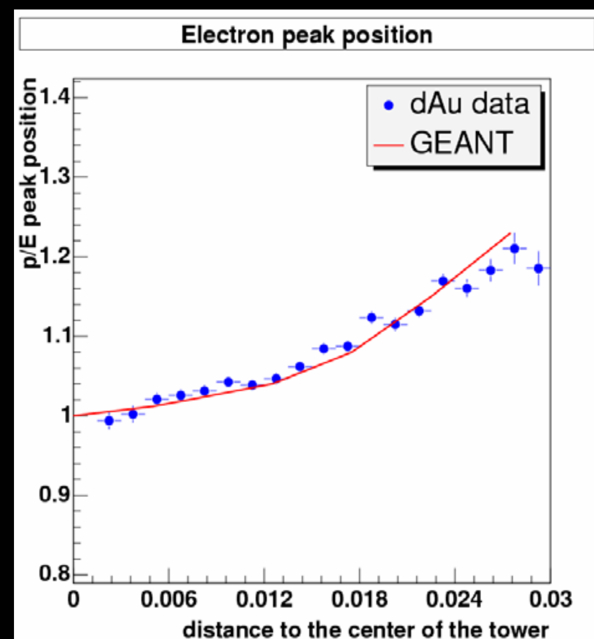
Electron spectra from many experiments



Electron id in detail

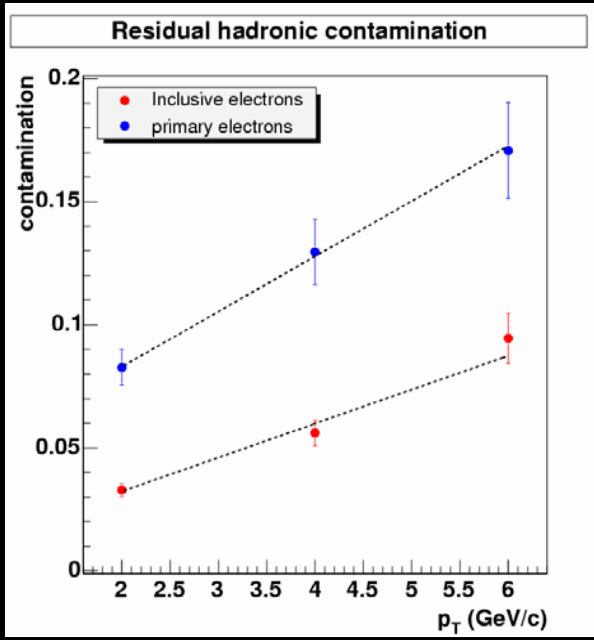
- TPC as a candidate selector
  - dE/dX for p > 1.5 GeV/c
    - Electrons can be discriminated from hadrons up to 8 GeV/c
- EMC
  - Towers
    - **p/E for electron and hadron candidates**
      - p is the track momentum
      - E is the tower energy
      - Peak position depends on the distance to the center of the tower
  - SMD (Shower Max Detector)
    - **Shower cluster type**
      - **Type 3 = both SMD planes**
    - **Track-SMD cluster distance**
      - Hadrons have a wider distribution
- e/h discrimination power ~ 10^5
  - **TPC ~ 500**
  - **EMC ~ 250**



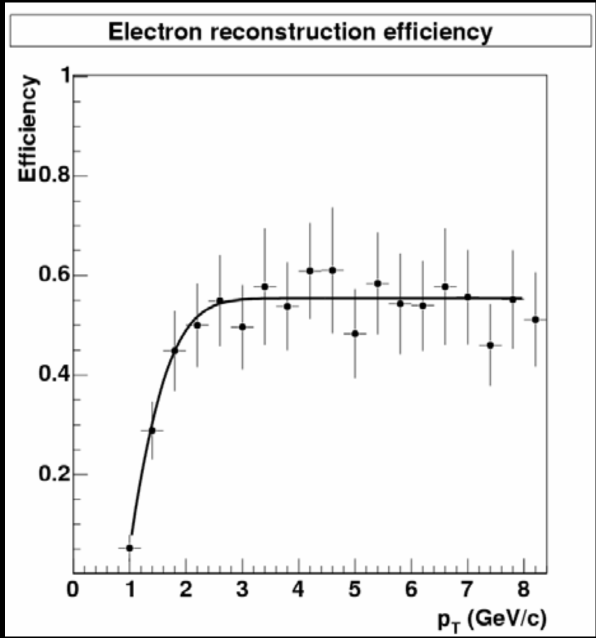


Electron id in detail (cont)

- Remaining hadronic contamination (hadrons misidentified as electrons)
  - Obtained by selecting hadrons using TPC dE/dX
    - **Larger for primary electrons**



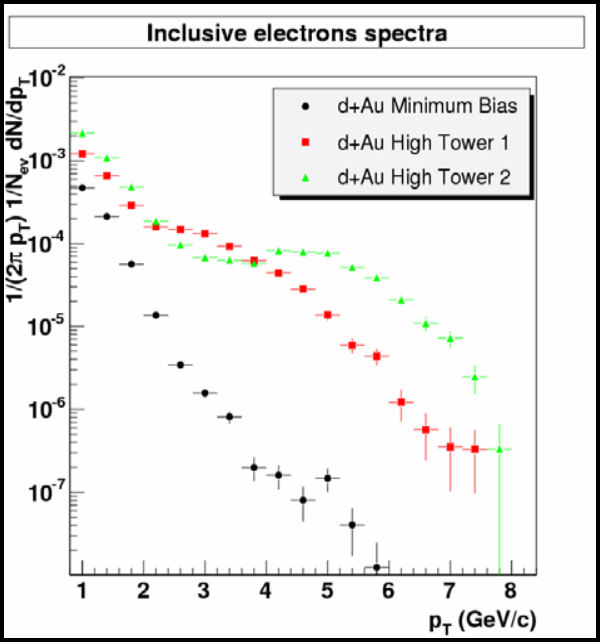
- Reconstruction efficiency
  - From embeddig simulated electrons into real events
    - **Aprox. 50% for p_T > 2 GeV/c**

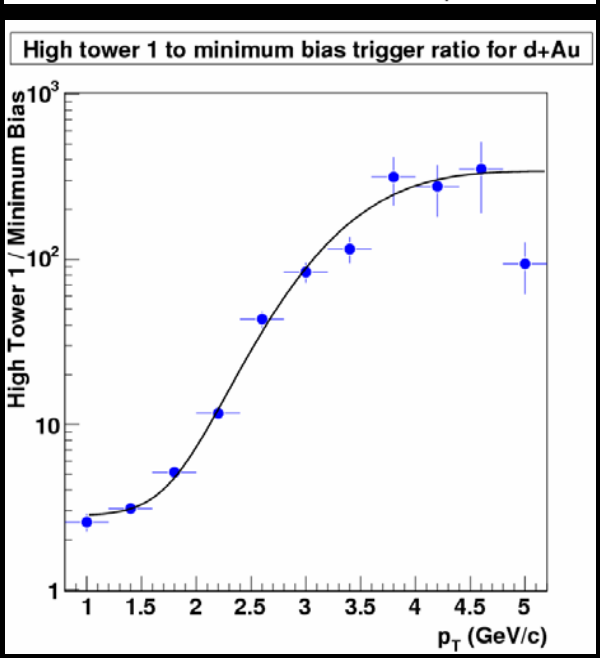


High-p_T electron trigger

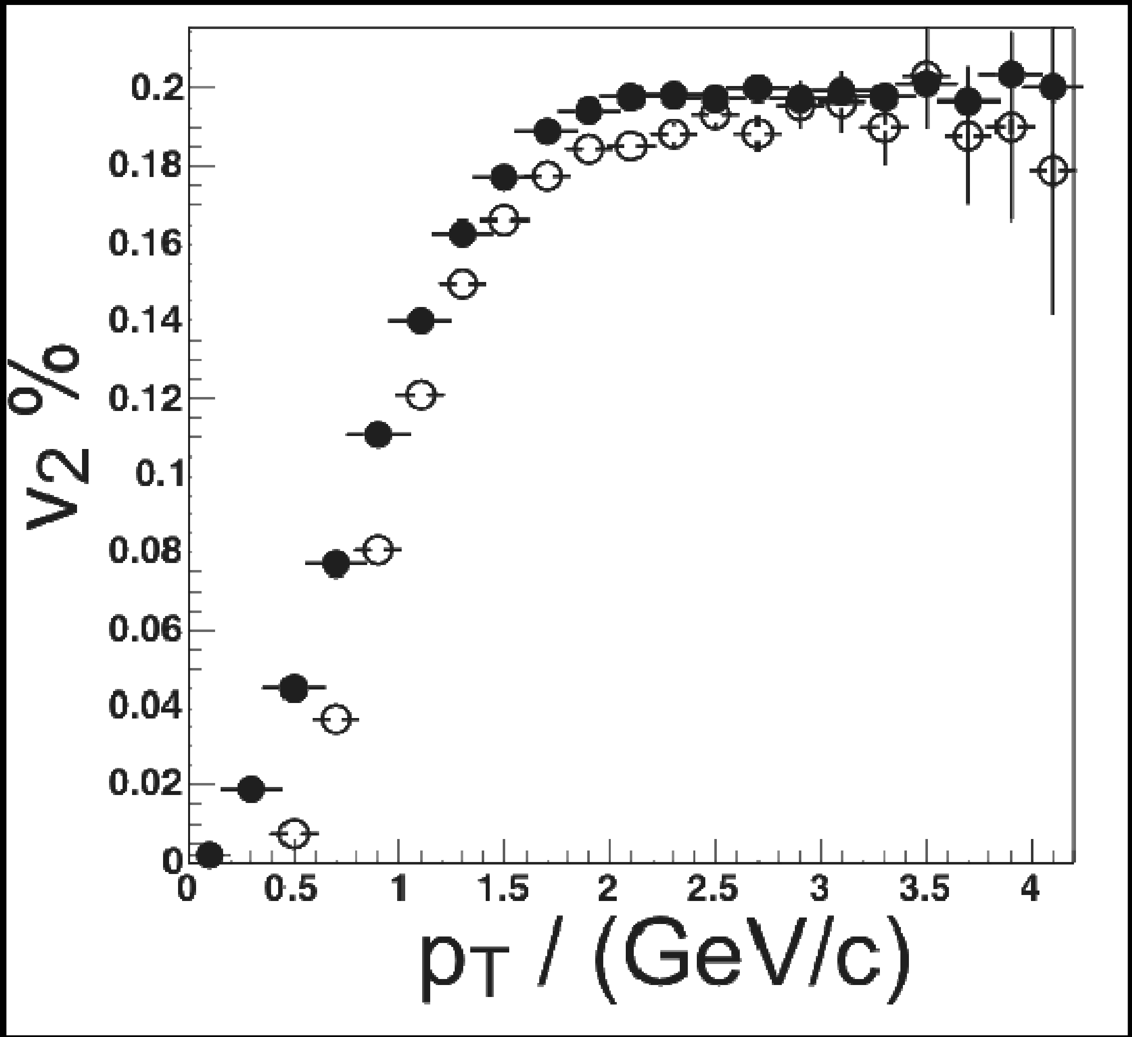
- EMC provides a Level 0 high-p_T electron trigger
  - Runs for every RHIC crossing (10 MHz)
  - Two E_T thresholds
    - 2.5 and 5 GeV
  - Enhancement as high as 1000 for p_T > 5 GeV/c

- Trigger bias
  - Suficient overlap between the minimum bias and the EMC triggered data

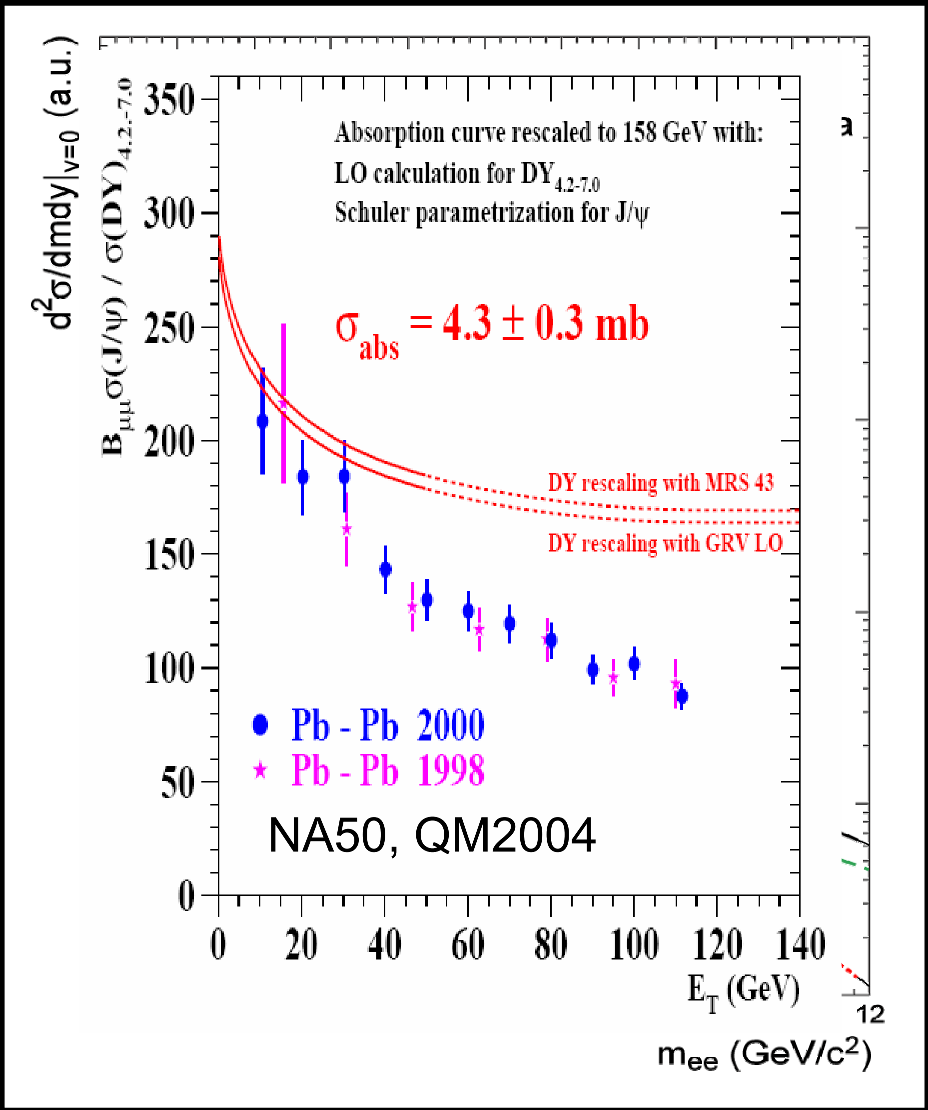




Electron v_2 and D v_2
Pythia/Mevsim Simulation



Hidden (Quarkonium) and Open Charm?



- NA38/NA50: measurement of J/Ψ, Ψ′ suppression at CERN/SPS:
- Suppression with respect to
  - continuum (Drell-Yan)
    - Low statistics
  - N_{bin}/N_{part} from Glauber
    - Model dependent
    - Fluctuations!
- RHIC: Continuum dominated by open charm
- also: Statistical models: relative chemical equilibrium between open charm and J/Ψ?

Open charm production provides a good reference and may be the only mean to understand charmonium suppression (same gluon conditions in the initial stage)