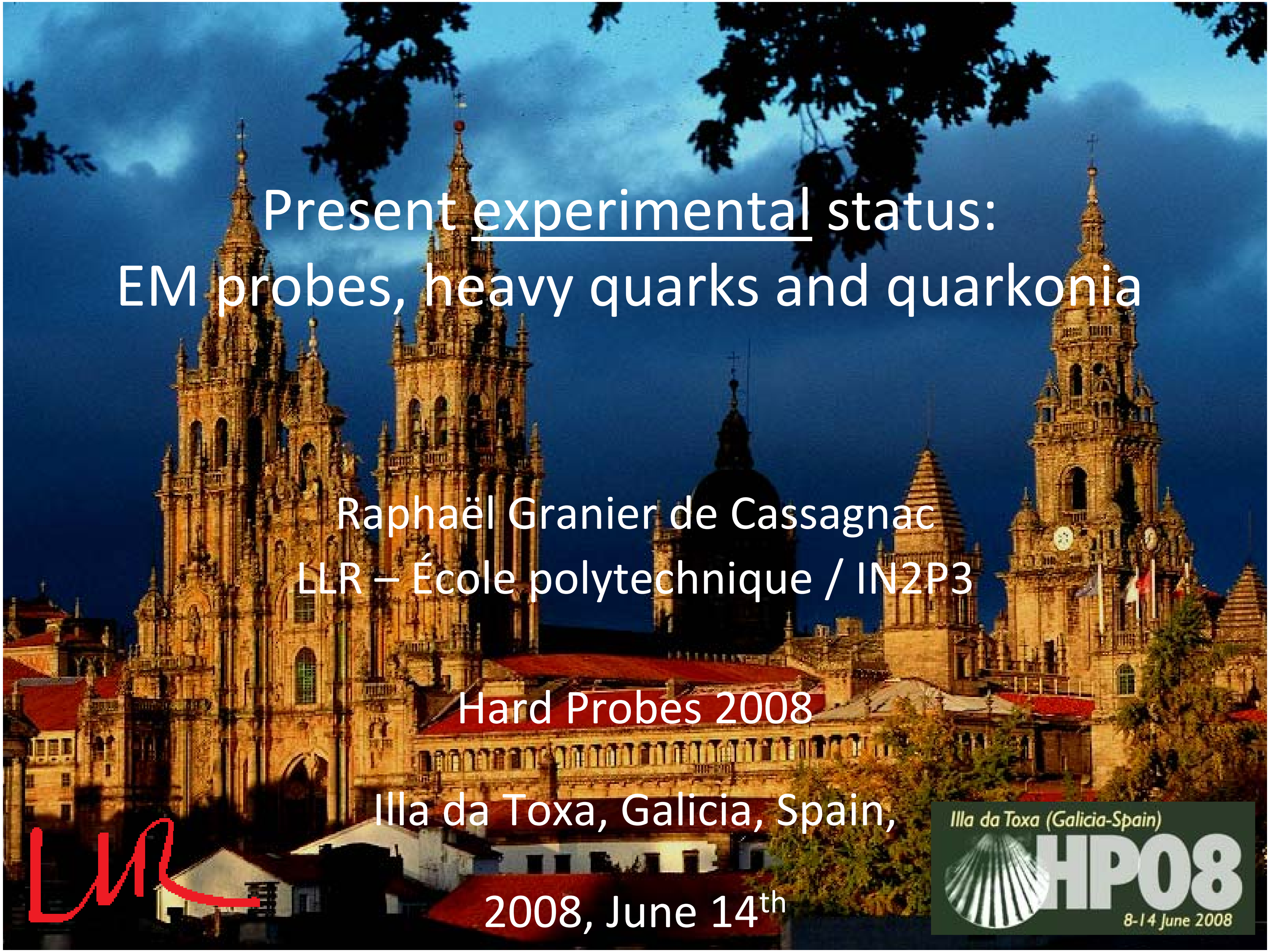


Present experimental status: EM probes, heavy quarks and quarkonia

Raphaël Granier de Cassagnac
LLR – École polytechnique / IN2P3

Hard Probes 2008

Illa da Toxa, Galicia, Spain,

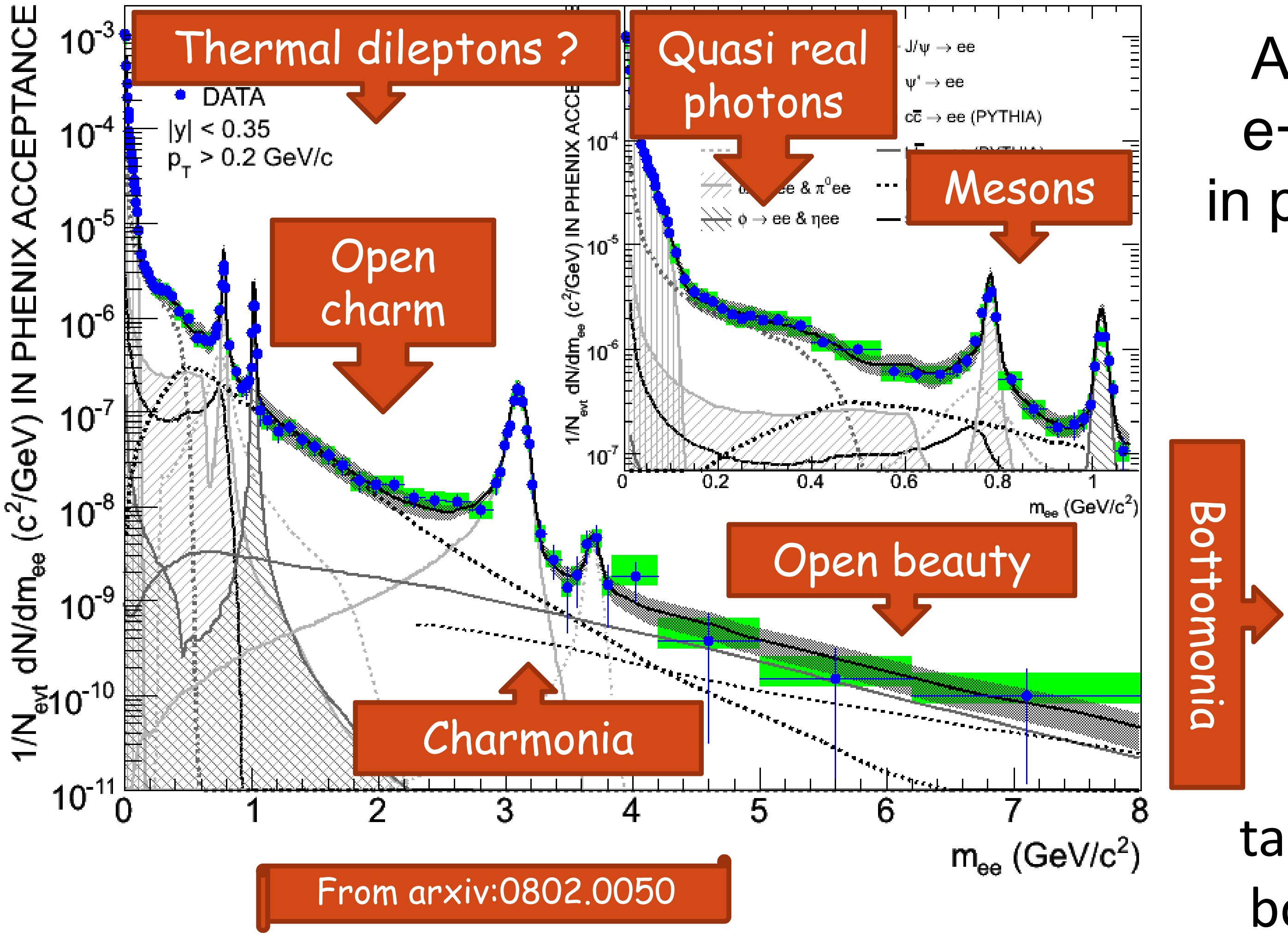
2008, June 14th

Illa da Toxa (Galicia-Spain)
HP08
8-14 June 2008

Disclaimer

- As asked by the organizers, *not a mere summary, but a critical review…*
  - So, apologies to people I will not cite
  - So, apologies to people I will cite
- My biases: rhic, phenix, quarkonia, experimental data and parallel sessions.
- Data related talks ≈ 3 EM probes + 6.5 heavy quarks + 12.5 quarkonia.

EM probes, heavy quark and quarkonia…



An example:
e+e- spectra
in p+p collisions
(PHENIX)

Apologies, this talk is mesons and bottomonia free…

Photons

The historians of heavy ion collisions

Dinesh K. Srivastava

High p_T photons

- Should be THE reference, but they are modified:

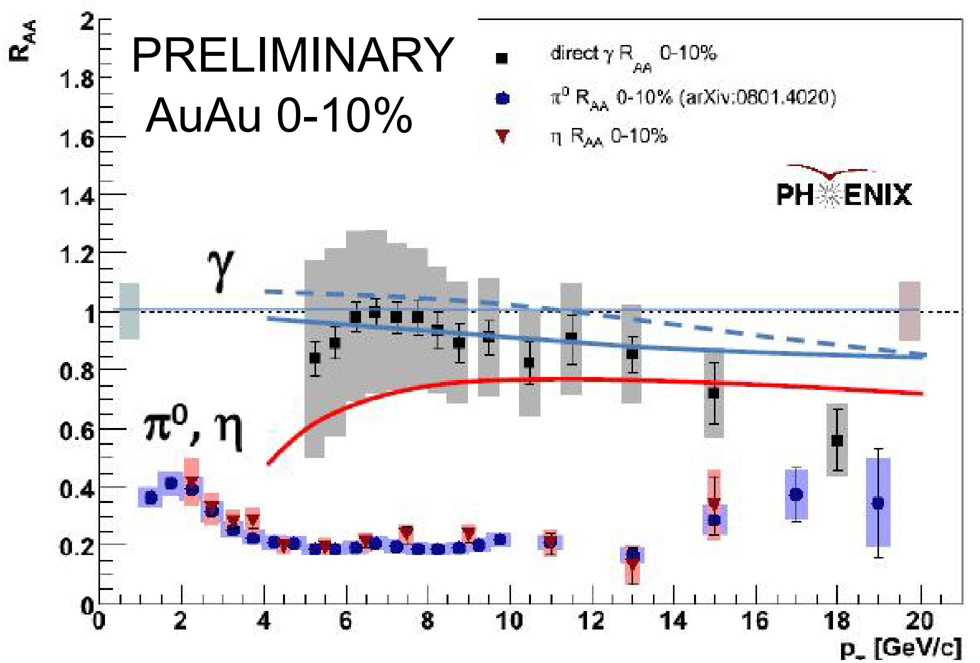
Arleo, JHEP09 (2006) 015

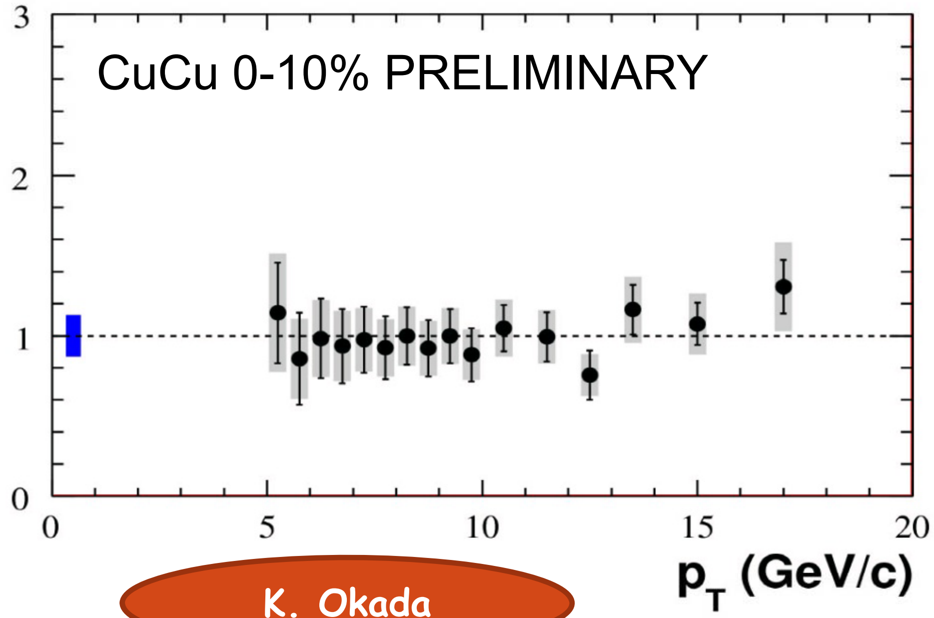
Isospin effect (n≠p)

+ cold nuclear effect (EMC from EKS)

+ eloss 20 < ω_c < 25GeV (from quarks)

- Gauge why it is different from AuAu vs CuCu…
- Wait for final data
- Can be an issue for (high p_T) gamma-jet…

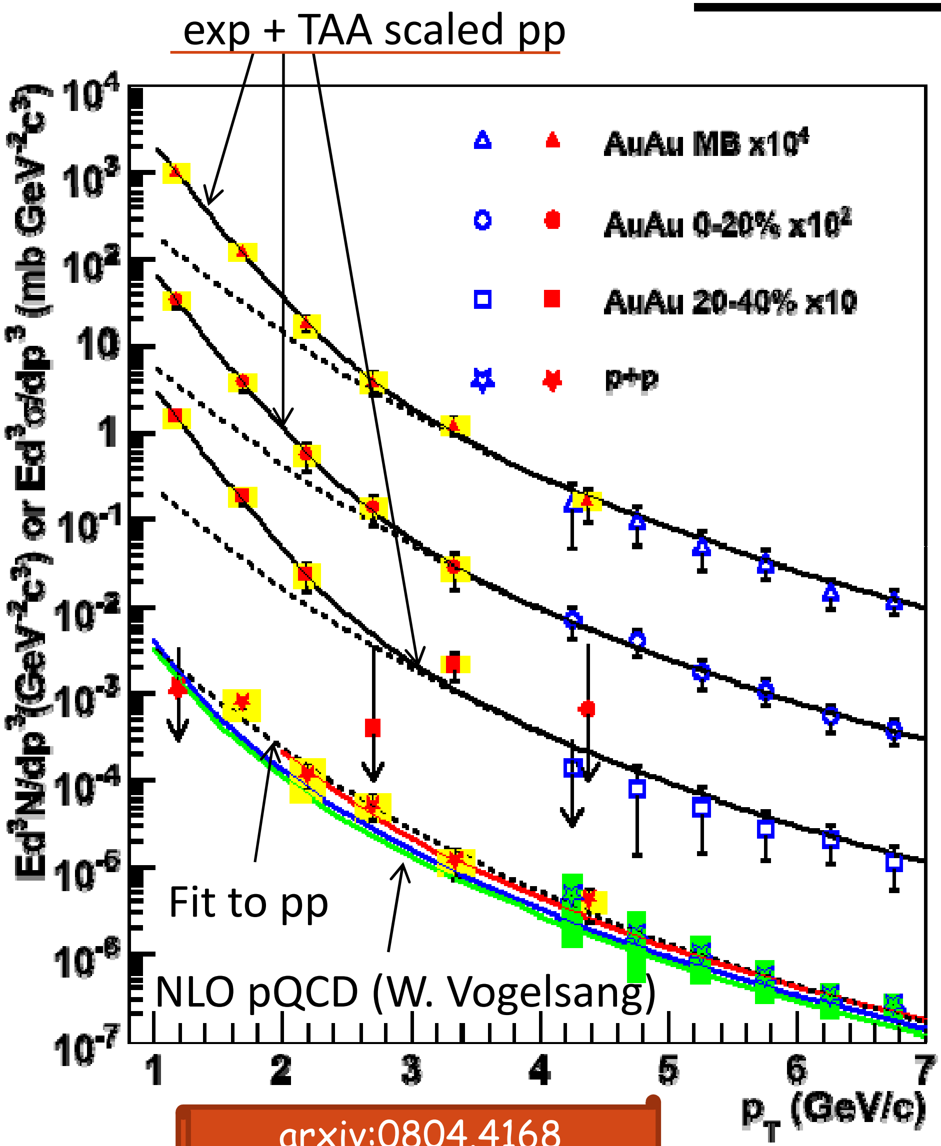




K. Okada

Low p_T photons

K. Okada



arxiv:0804.4168

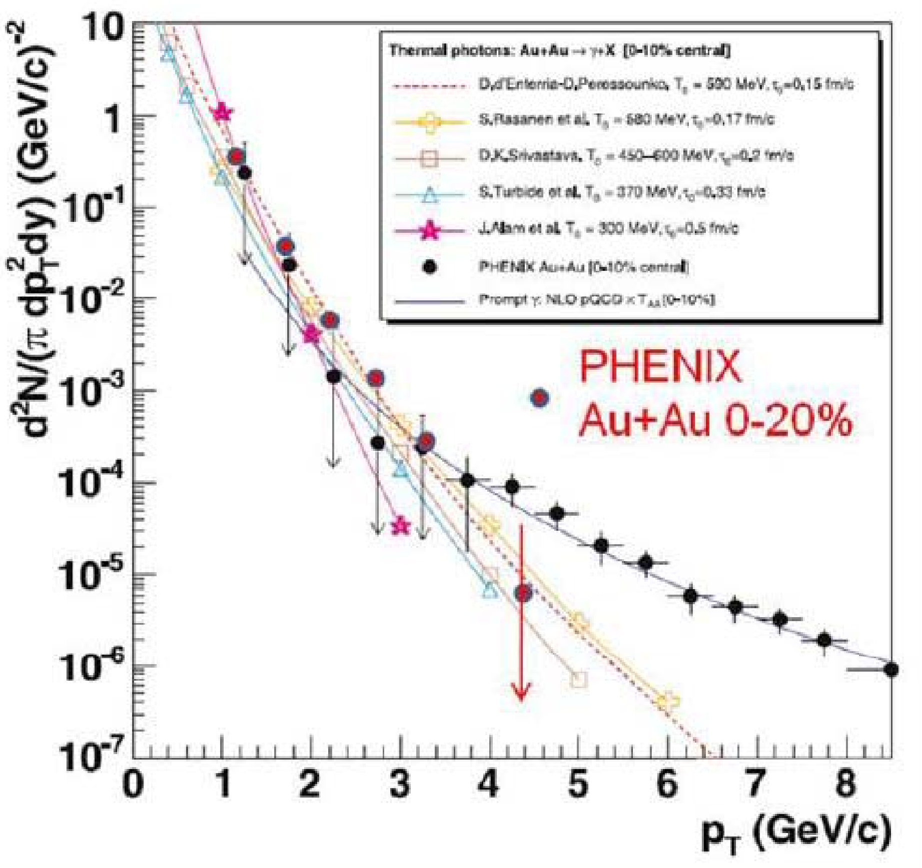
- Direct photon
  - real (p_T > 4 GeV/c) and
  - virtual (1 < p_T < 4 GeV/c & m_{ee} < 300MeV) New pp!
- Good surprise: pQCD consistent with pp down to p_T = 1 GeV/c
- In AuAu above binary scaling for p_T < 2.5 GeV/c

TABLE I: Summary of the fits. The first and second errors are statistical and systematical, respectively.

centrality	$dN/dy(p_T > 1\text{GeV}/c)$	T(MeV)	χ^2/DOF
0-20%	$1.10 \pm 0.20 \pm 0.30$	$221 \pm 23 \pm 18$	3.6/4
20-40%	$0.52 \pm 0.08 \pm 0.14$	$214 \pm 20 \pm 15$	5.2/3
MB	$0.33 \pm 0.04 \pm 0.09$	$224 \pm 16 \pm 19$	0.9/4

Thermal radiation

- New pp reference confirms pQCD baseline that was used and from which various hydro models derived:
  - Initial temperature [300-600 MeV]
  - Time [0.15-0.6 fm/c]
- <u>The matter is hot</u> !
  - T >> Tc

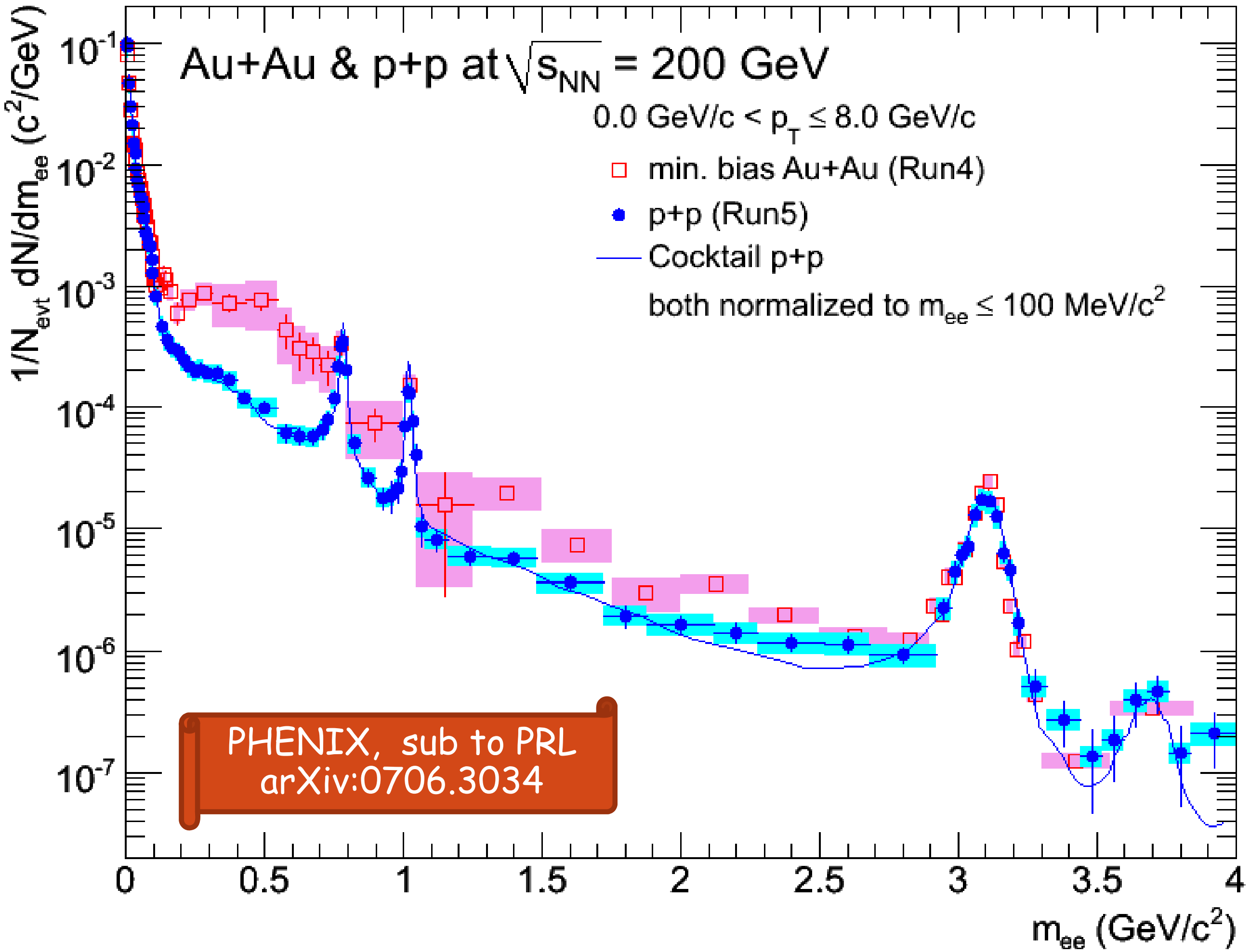


d'Enterria & Peressounko, EPJ. C46 (2006) 451

Dileptons

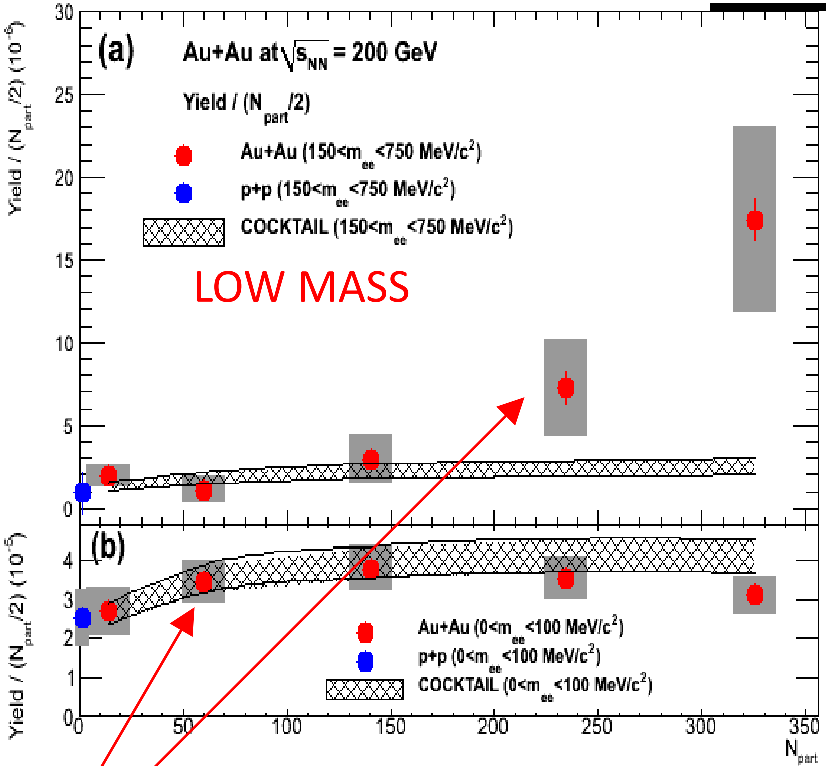
An electromagnetic probe mixed up with hadronic signals (meson modification, charm loss…)

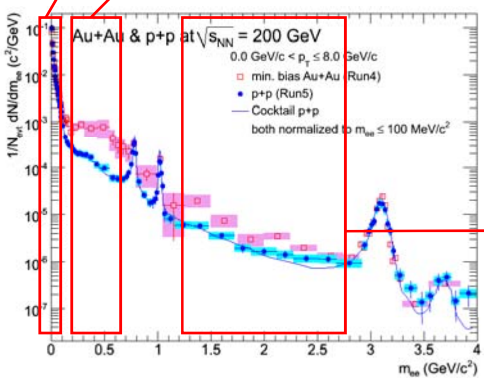
Dielectron pp vs AuAu in PHENIX



Various components of the spectrum

K. Okada





π^0 region:

- Agreement with cocktail

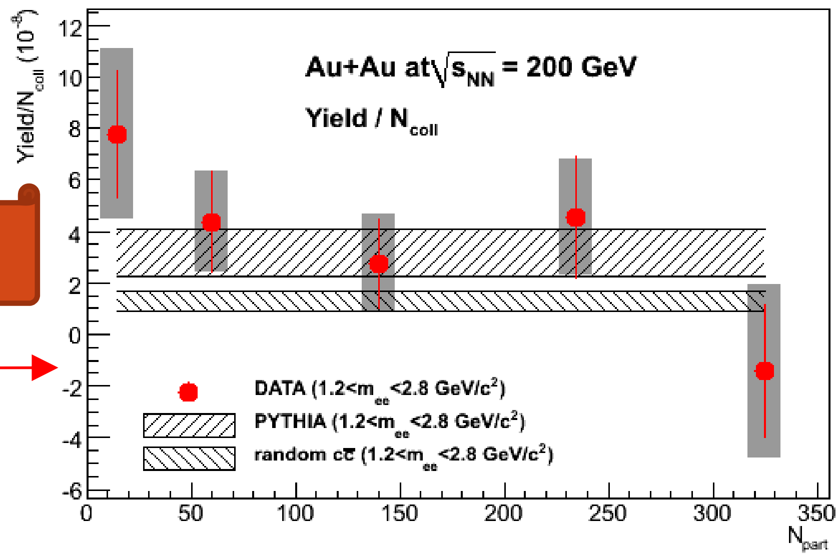
Low Mass:

- yield increases faster than proportional to N_{part}
  → enhancement from binary annihilation (ππ or qq) ?

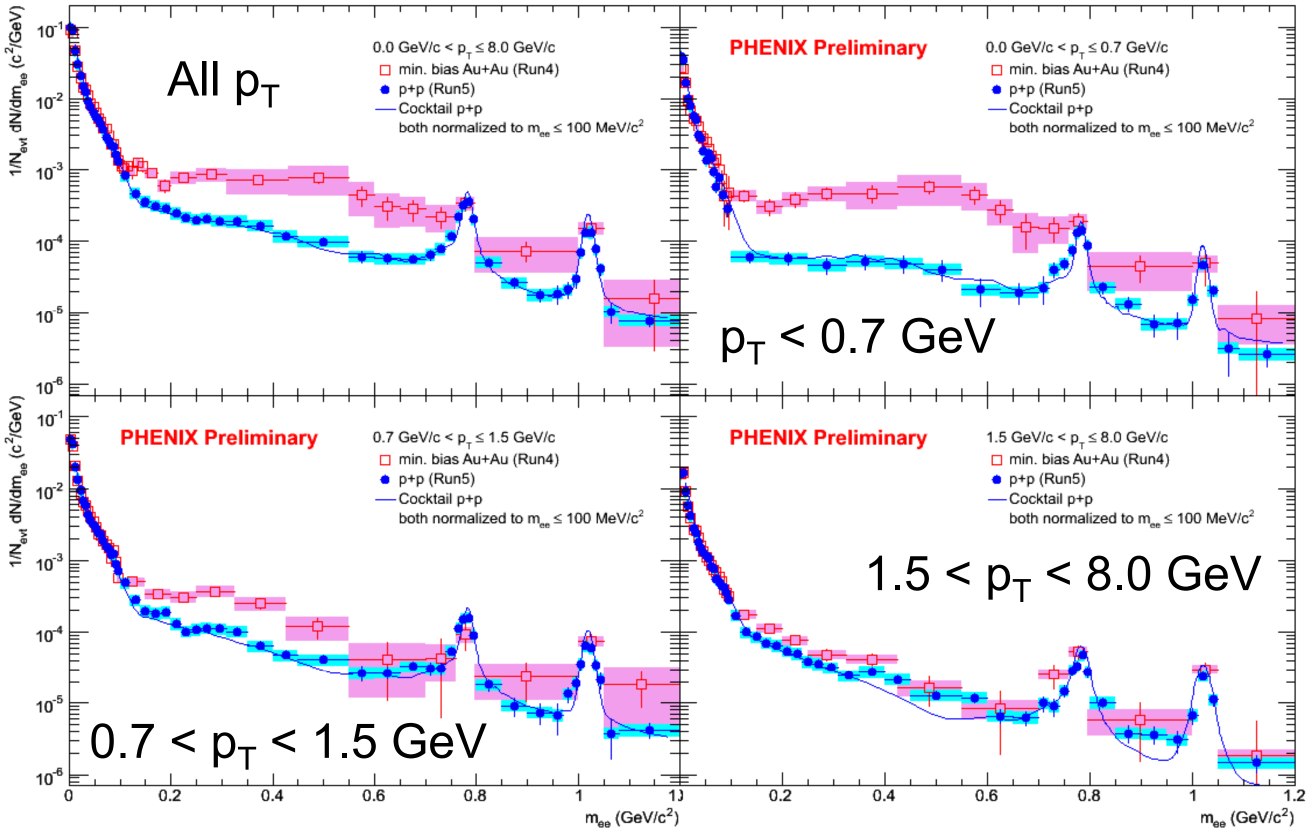
Intermediate Mass:

- yield increase proportional to N_{coll}
  → charm follows binary scaling

PHENIX, sub to PRL
arXiv:0706.3034



p_T dependence in the LMR



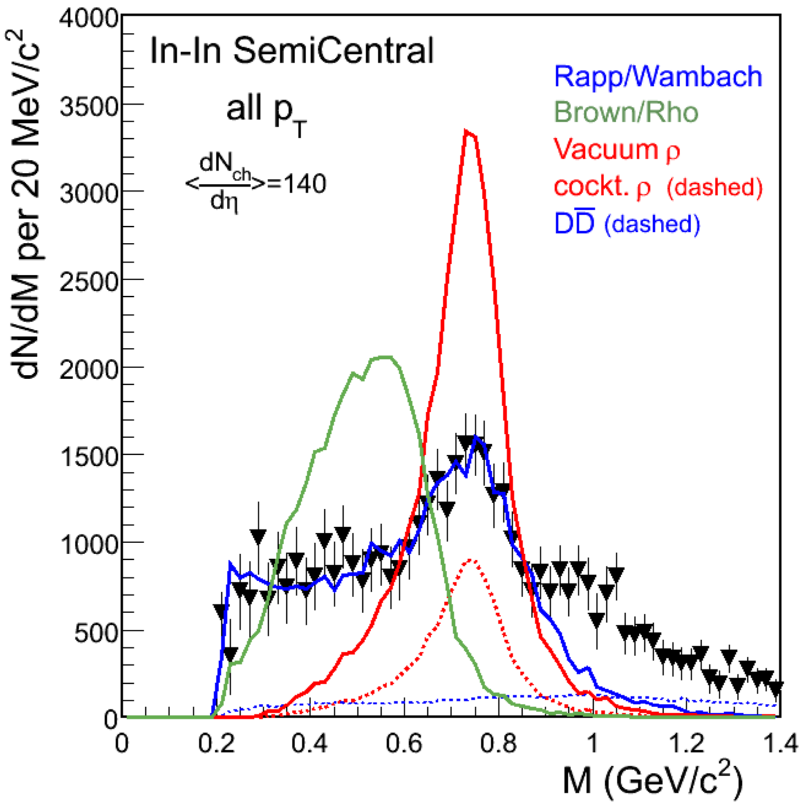
- Phenix sees an enhancement at low p_T and faster than N_{part}
- Thermal radiation? Meson modification? Background systematics?
- Beginning of a long story… That a functional Hadron Blind Detector might help to resolve…

NA60, below J/ψ

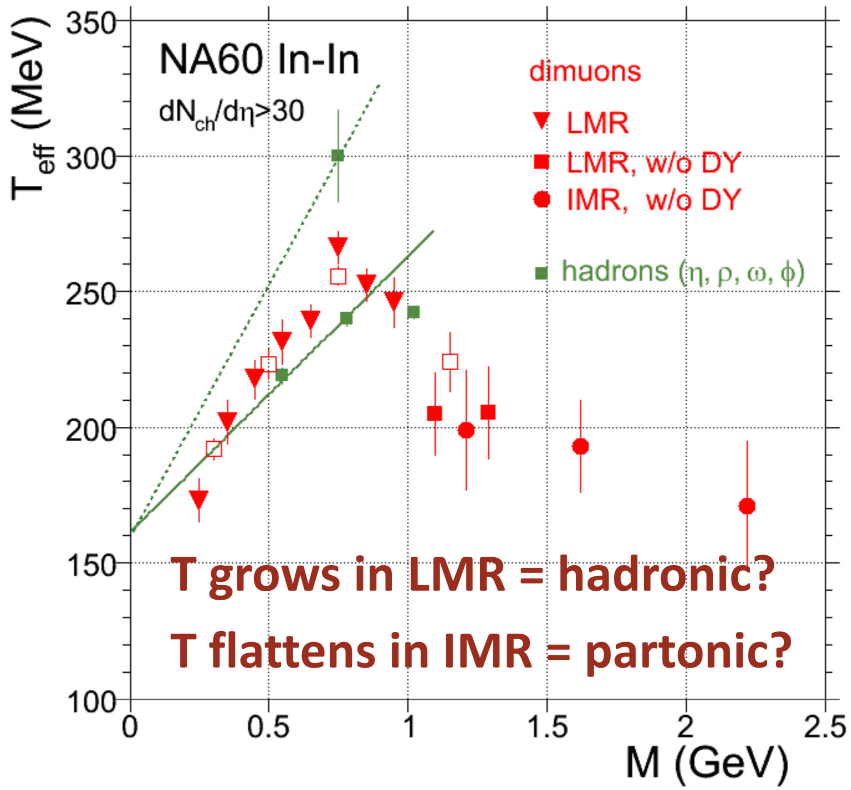
S. Damjanovic

V. Koch

Some ρ broadening (no shift)



Just call them Bob…



→ Dileptons are definitely difficult probes to interpret!

Heavy quarks

"Better behaving observable"

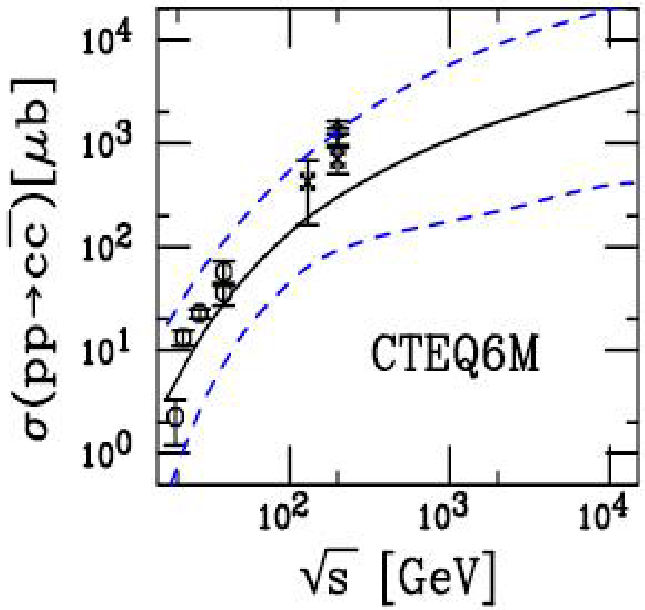
M. Cacciari, Lectures

Do we know the total charm cross-section?

A. Dion
X. Dong

No, say the theorists

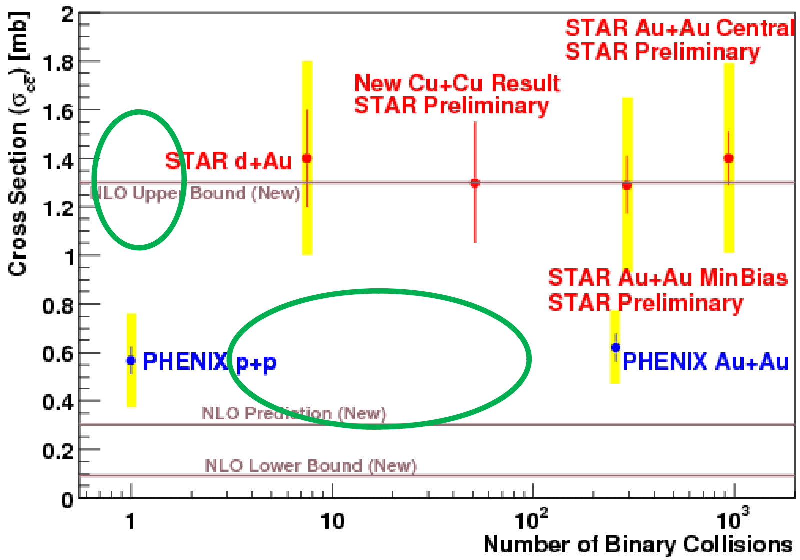
R. Vogt, P4



$$\sigma_{c\bar{c}}^{\mathrm{NLO,\,CTEQ6M}} = 301^{+1000}_{-210}\ \mu\mathrm{b}$$

$$\sigma_{c\bar{c}}^{\mathrm{NLO,\,GRV98}} = 178^{+300}_{-122}\ \mu\mathrm{b}$$

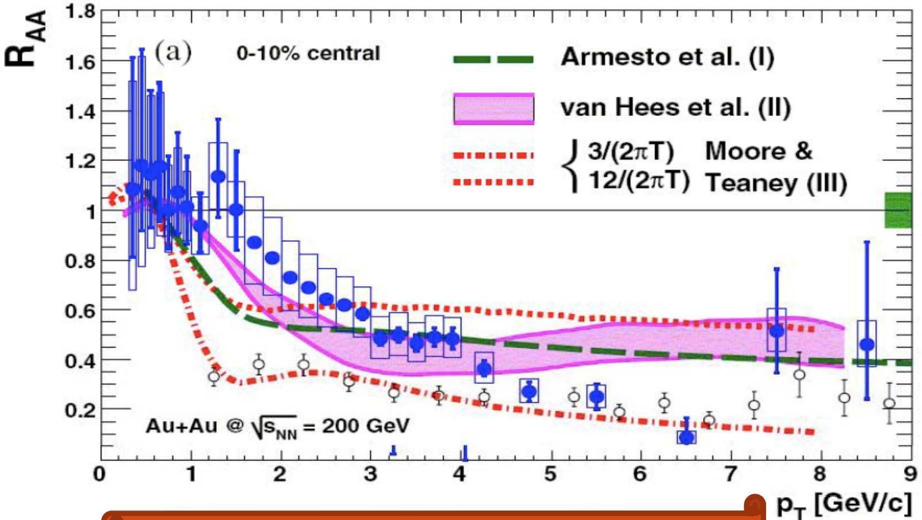
"Yes, but they don't" say the experimentalists…



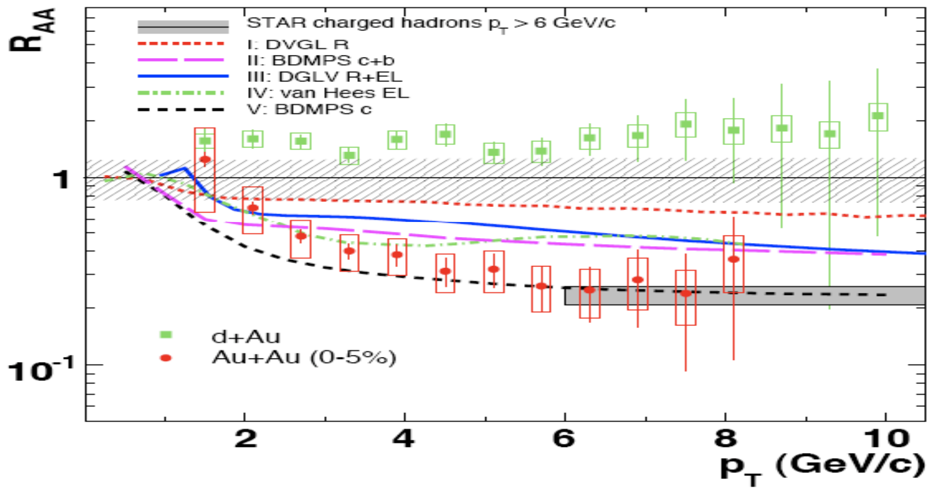
What would be nice…

- D's in PHENIX
- Run8 low material (BG/10) in STAR
- Please, fill these gaps !

Heavy flavour suppression was a surprise



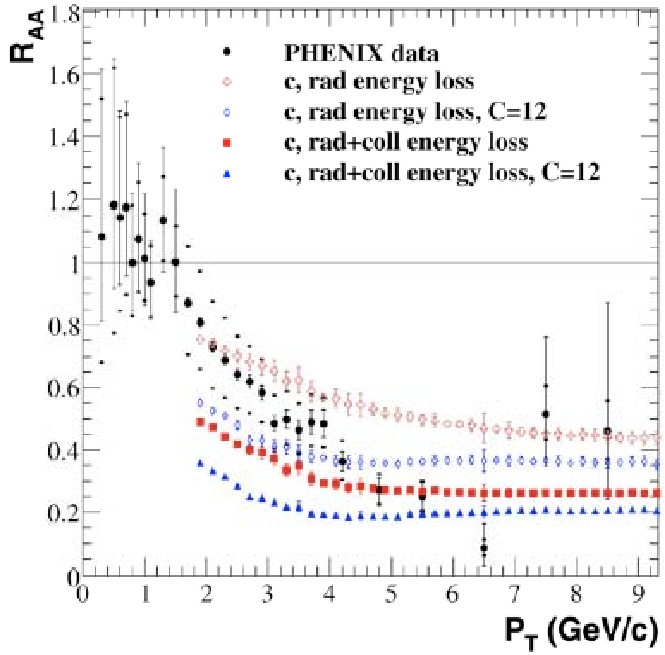
PHENIX, PRL 172301 (2007)
STAR, PRL 192301 (2007)



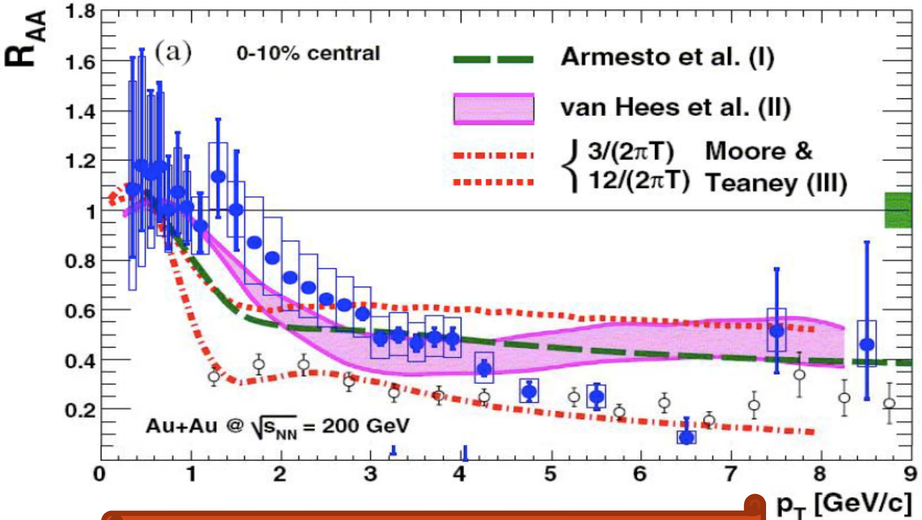
- Radiative is not enough
  Collisional ?

G. Martinez, P4
PLB663 (2008) 55

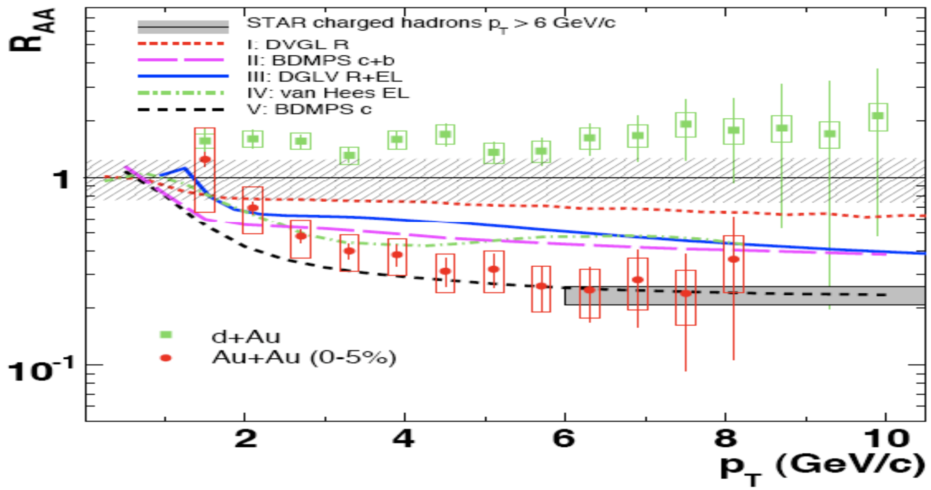
- Baryon/Meson?
  - 10-25% effect even at high p_T



Heavy flavour suppression was a surprise



PHENIX, PRL 172301 (2007)
STAR, PRL 192301 (2007)



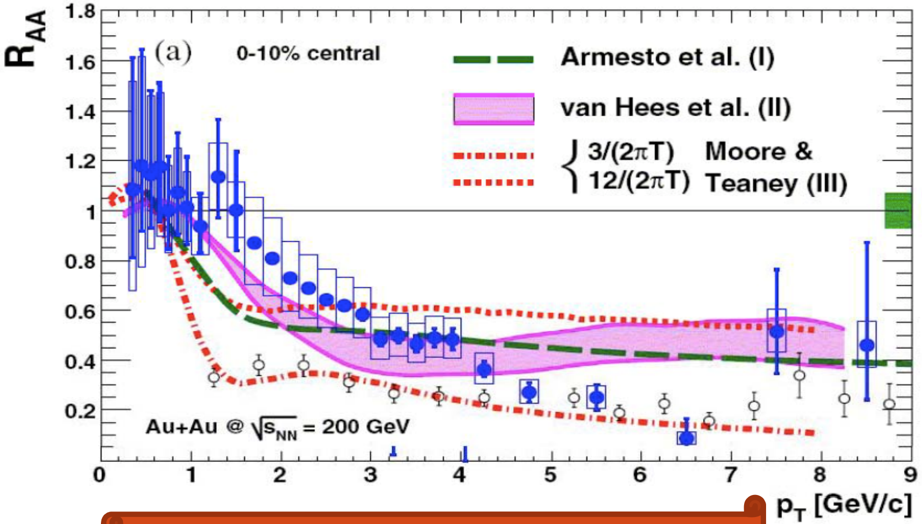
- Radiative is not enough
- Collisional ?

G. Martinez, P4
PLB663 (2008) 55

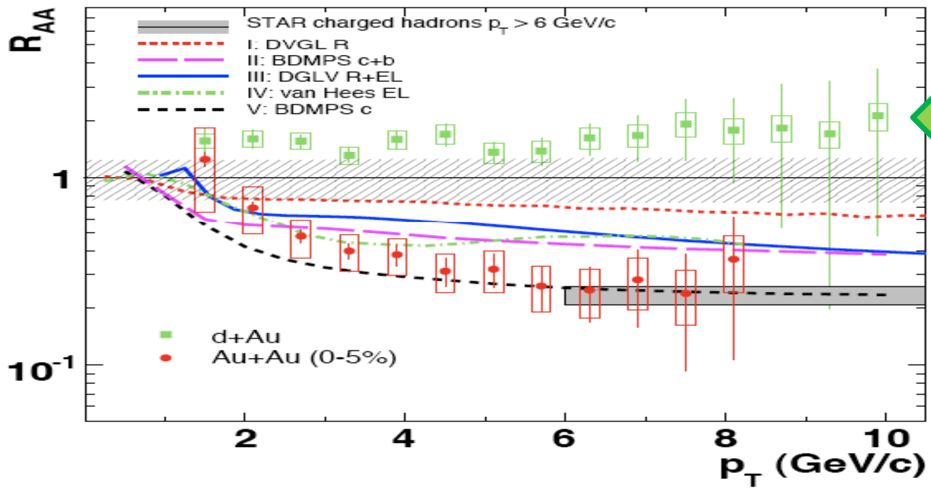
- Baryon/Meson?
  - 10-25% effect even at high p_T
- Charm/beauty? (next slide)
- Or maybe a universal upper bound on energy leaving only room for corona emission…

D. Kharzeev
0806.0358

Heavy flavour suppression was a surprise



PHENIX, PRL 172301 (2007)
STAR, PRL 192301 (2007)



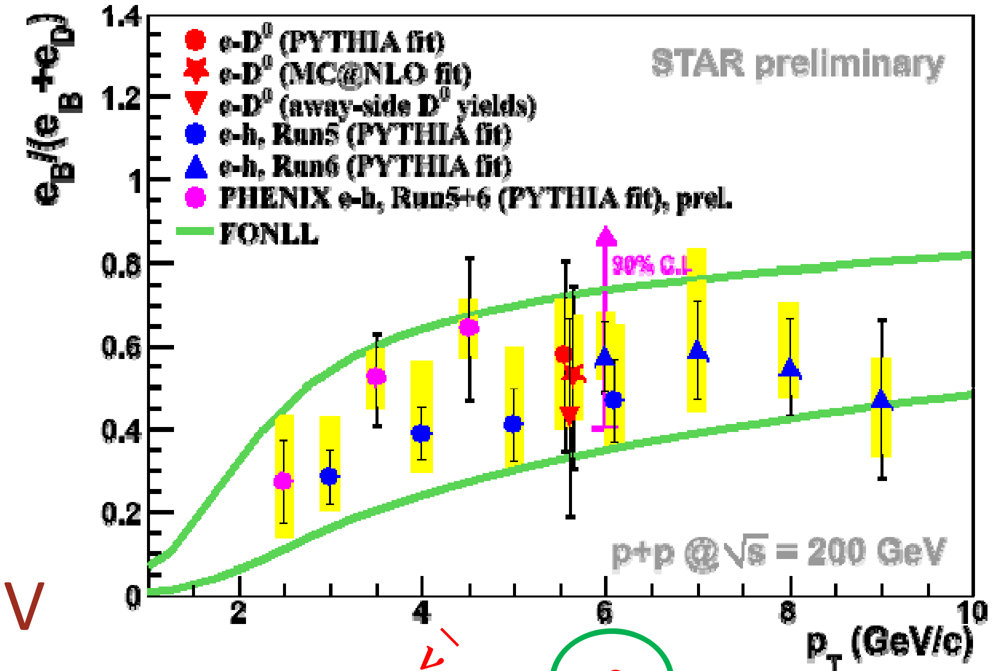
- Interesting d-Au excess, needs confirmation with run8!

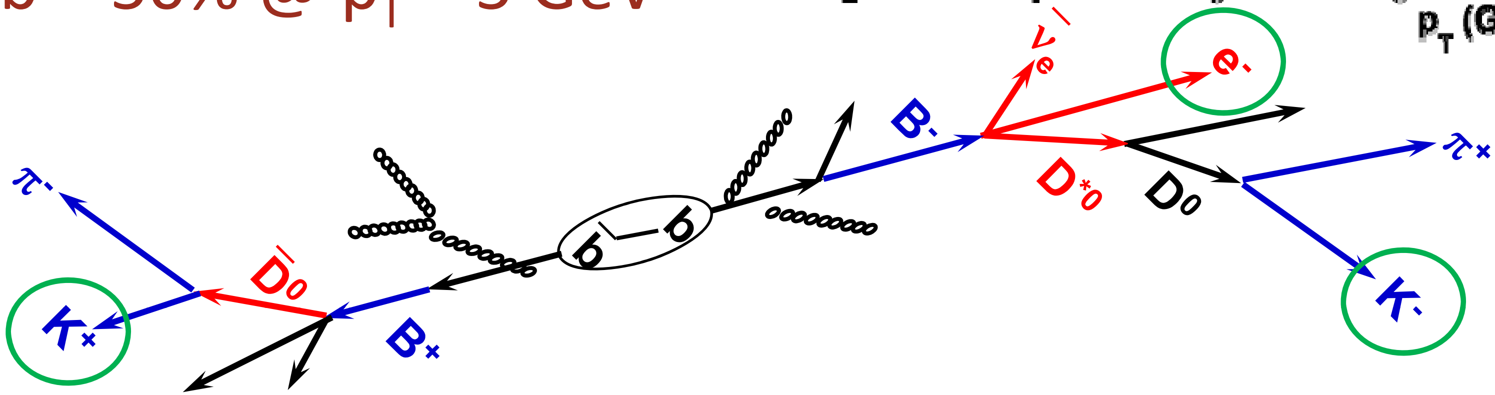
$b \to e/(c \to e + b \to e)$

A. Mischke, P4

- Before the silicon era…
- Making use of various B/D decay kinematical differences…
- For instance:
  - Electron-D azimuthal correlations

→ $b/c+b \approx 50\%$ @ $p_T \approx 5$ GeV

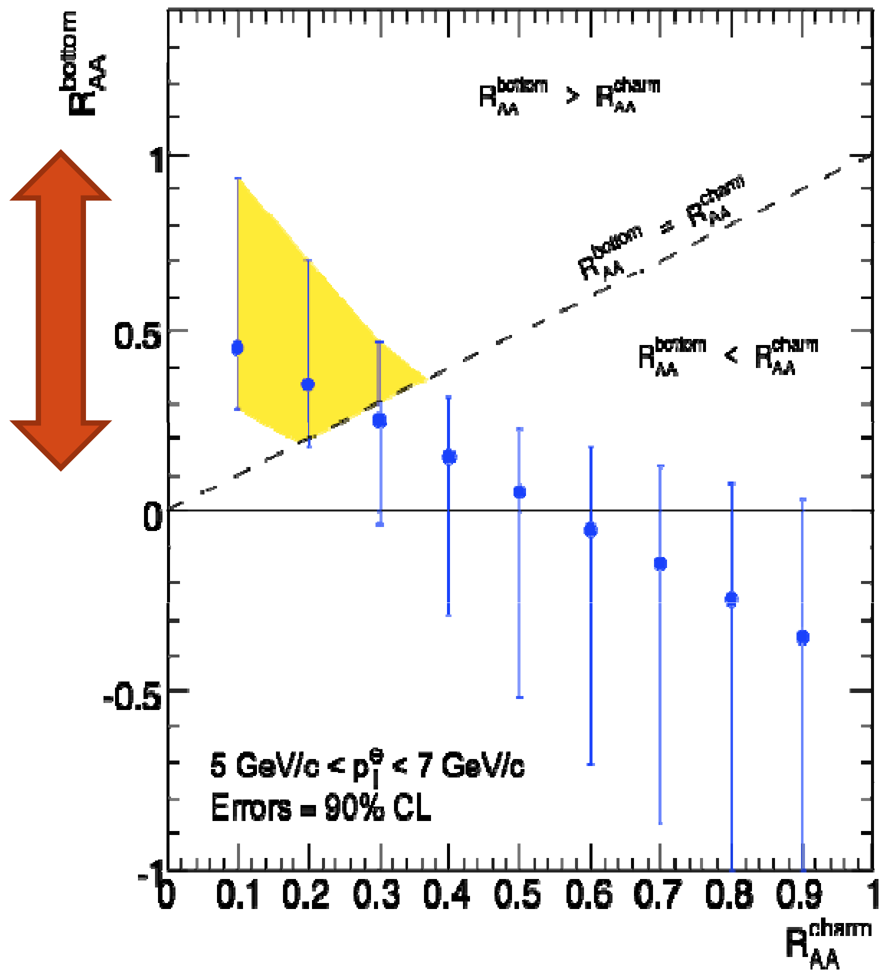




Are bees killed ?

T. Ullrich, lecture for dummies

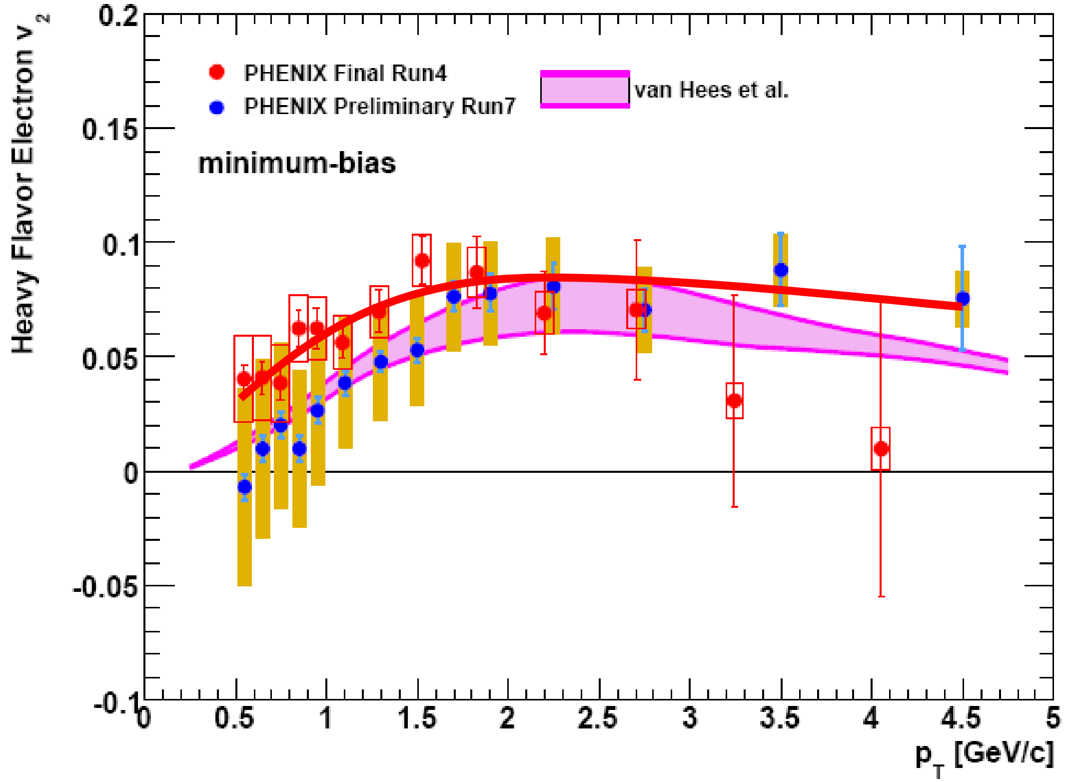
- $R_{AA} = r\,R_{AA}(b) + (1-r)\,R_{AA}(c)$
- Two related unknown nuclear modification factors →
- Nothing is really excluded for $R_{AA}(b)$



Heavy flavor elliptic flow

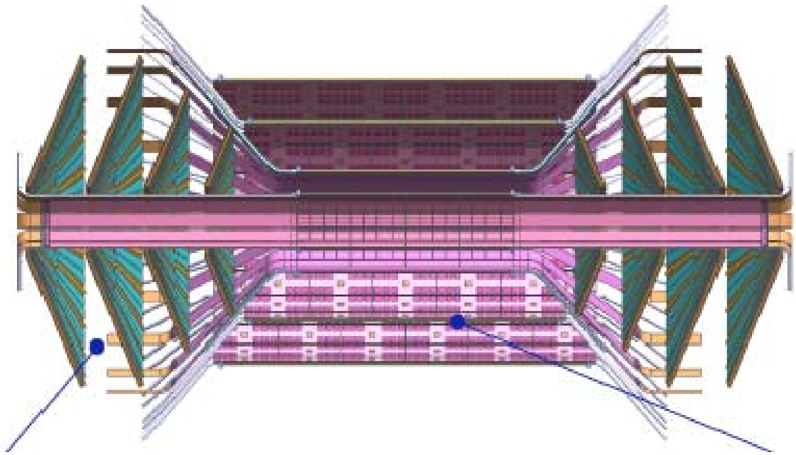
A. Dion
H. Van Hees, P4

- Also a surprise!
- Now, do bees fly?
  - Need the b/c+b in AA to properly estimate the b flow…
- (todo : average the 2 datasets cause they have different stat/syst balance)

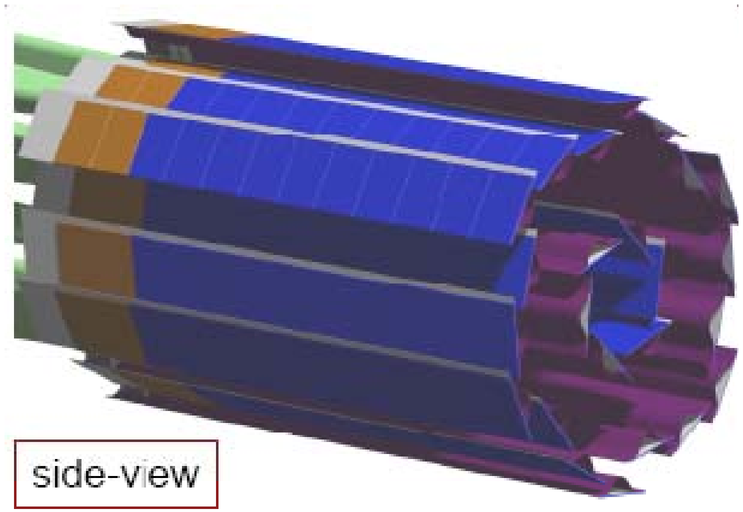


We need to enter in the silicon era…

- PHENIX



- STAR



Quarkonia

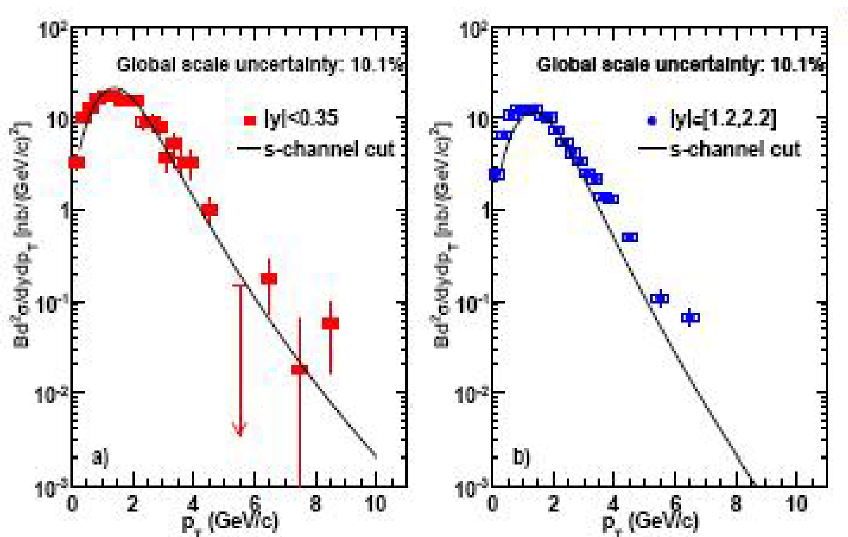
Almost every new piece of experimental information on quarkonium production presents a new "puzzle"

D. Kharzeev

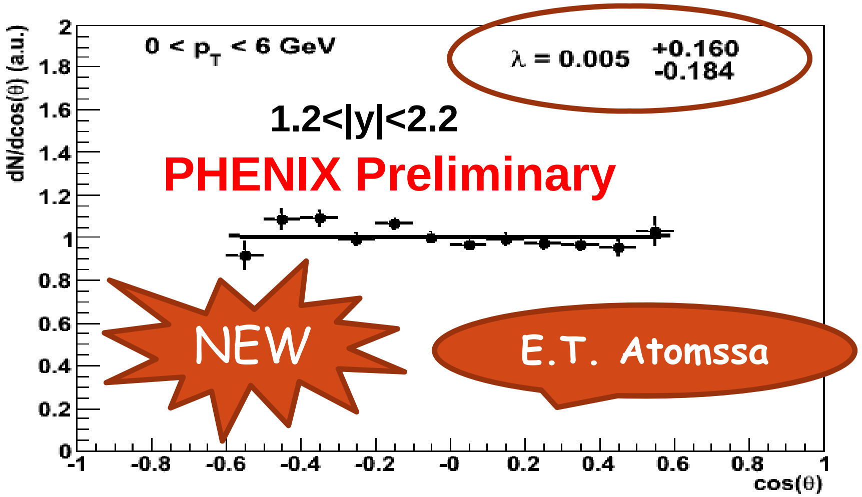
Do we understand quarkonia in vacuum?

J.P. Lansberg

- Better than before! The return of the CSM
  - With off-shell charm quarks (J/ψ @Tevatron and RHIC) →
  - With higher order (NNLO) corrections (Υ @Tevatron)



Possible solution of the J/ψ production puzzle,
Haberzetl & Lansberg PRL100 (2008) 032006

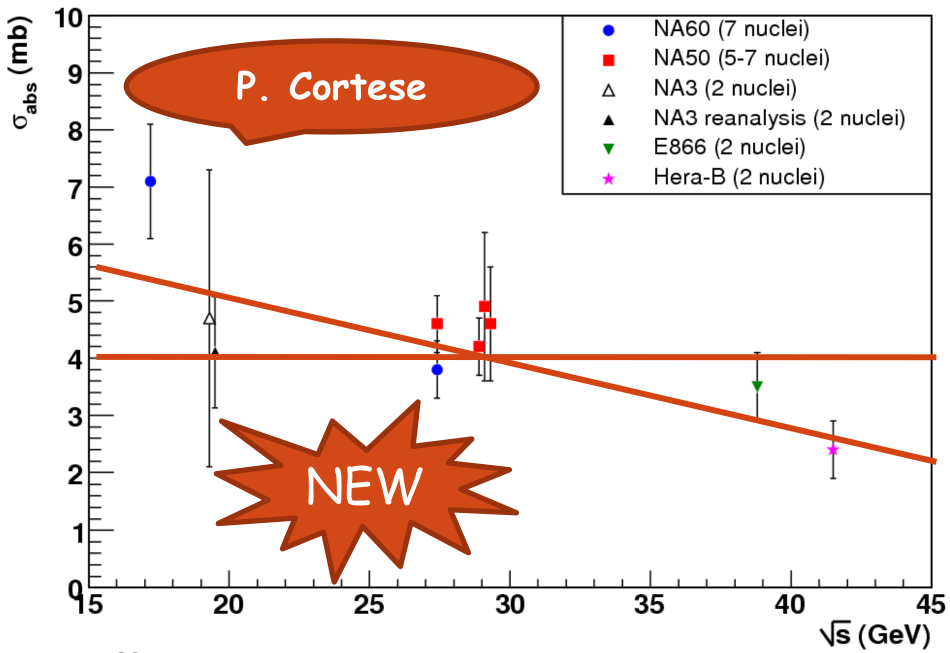


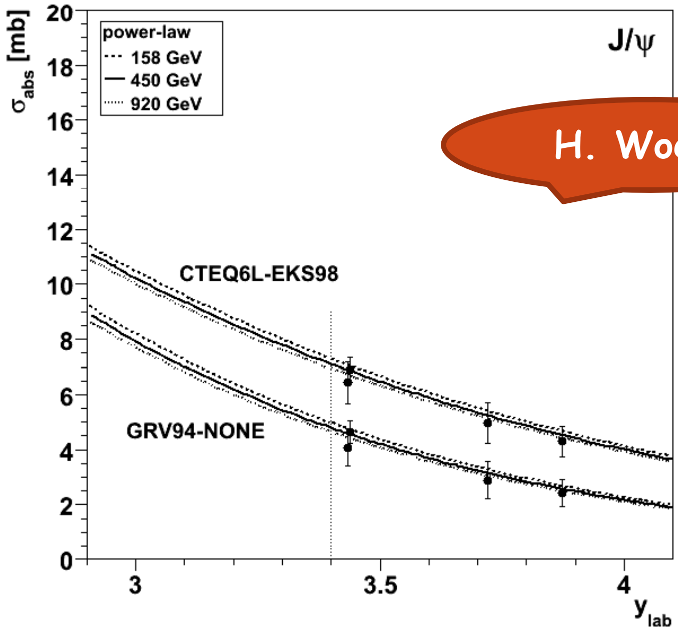
- No room for large polarization @RHIC forward rapidity
  - To be calculated by theorists and compared

Revisiting SPS…

- "Very preliminary" analysis of NA60 pA @ 158 AGeV exhibits three surprises:

1. $\sigma_{abs} = 7.1 \pm 1.0$ mb
   - Was 4.5 ± 0.5 mb from 400/450 AGeV (diff 2.3σ)
   - Which NA60 finds back ☺
   - Seems a rather large jump wrt to higher energies (incl. 200 AGeV) ☹
   - As well as wrt to an energy dependence extrapolation based on a subset of the above data and giving
     - $\sigma_{abs} \approx 5.0$ mb →

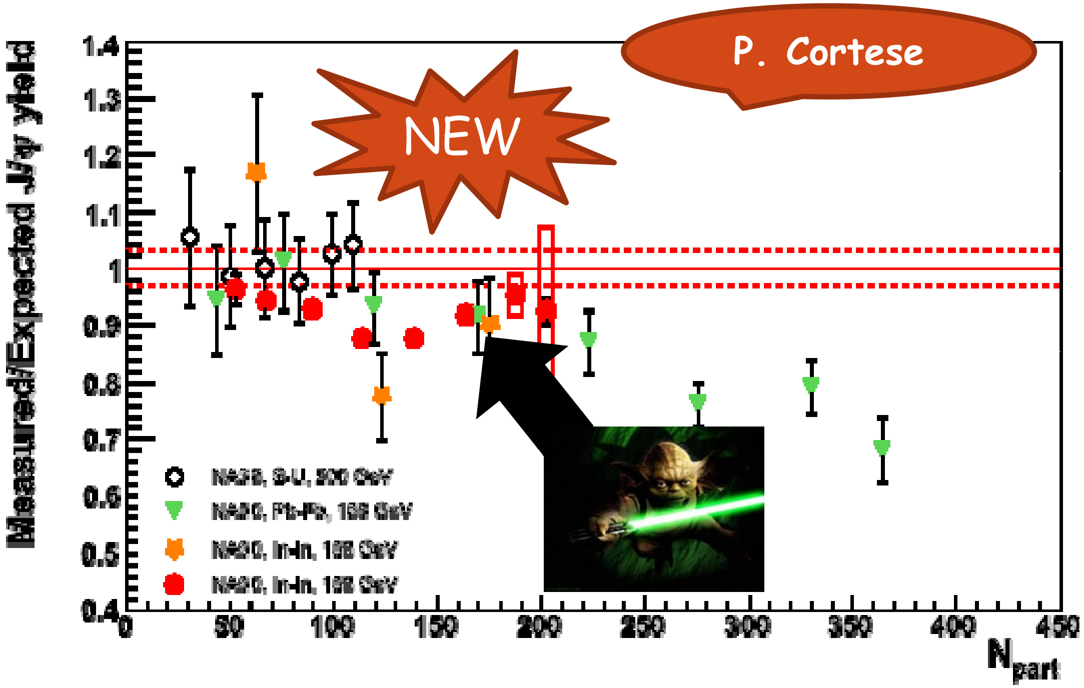


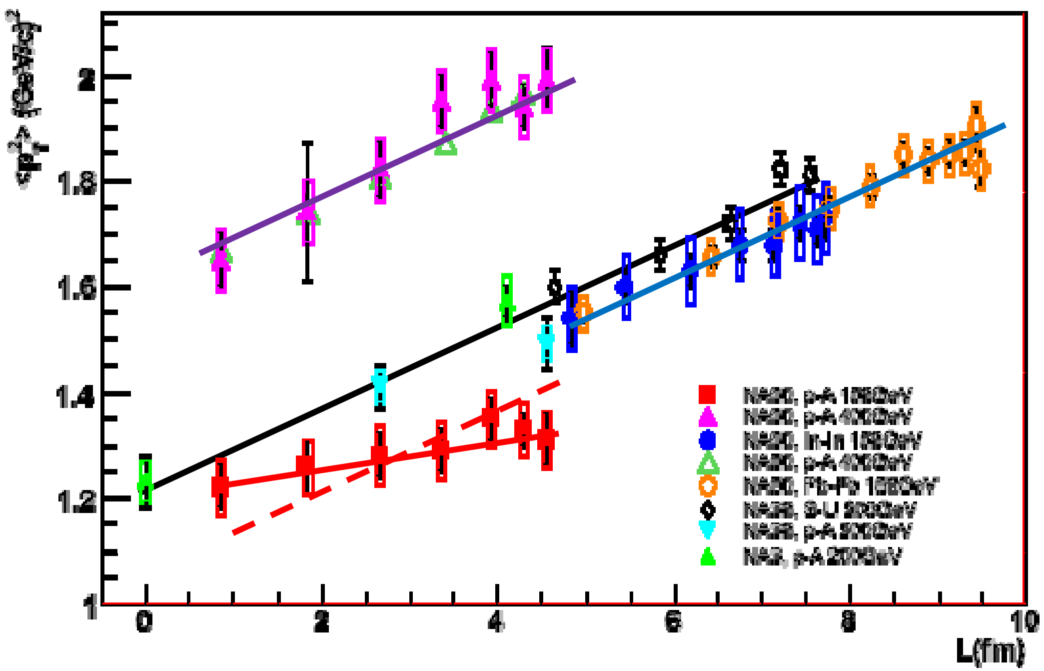


Revisiting SPS…

2. The anomalous suppression pattern exhibits the return of the J/ψ in In-In…
   - Could be related to σ_{abs}
   - Missing systematics ? ☹
   - Doesn't change the qualitative Pb-Pb picture ☺
3. $<p_T^2>$ vs L exhibits a different slope ☹ wrt to
   - A-A @ 158 AGeV
   - p-p to S-U @ 200 AGeV
   - p-A @ 400 AGeV
   - (Found back by NA60 ☺)
   - (statistical analysis needed)

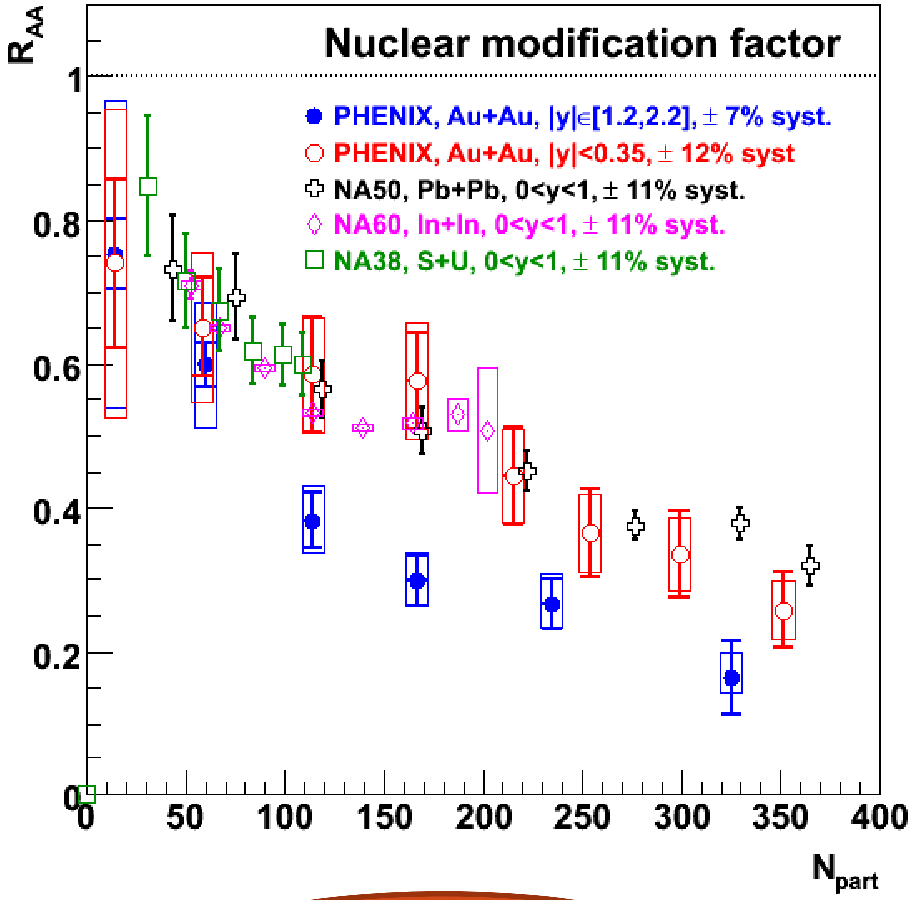
- If confirmed, what's so special about pA @ 158 AGeV?





The Au-Au RHIC J/ψ puzzle(s)

- Two surprises
  - R_{AA} (RHIC,y=0) ≈ R_{AA}(SPS)
  - R_{AA} (y=0) > R_{AA} (y<1.7)
  - While energy density induced suppression mechanisms…
- Two possible solutions
  - Cold nuclear effects?
    - And maybe only the excited states melt…
  - Hot regeneration?



E.T. Atomssa

So now, the question is

COLD EFFECTS ? - ? RECOMBINATION

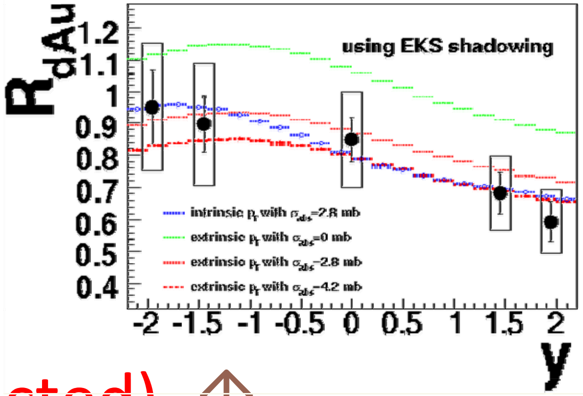
H. Woehri
F. Fleuret, P6
V.N. Tram, P7

K. Tywoniuk, P6
R. Thews, P6

COLD EFFECTS 3 - 2 RECOMBINATION

Cold effects: a trauma for experimentalists

- Woehri, Lourenco and Vogt care for
  - σ_{abs} energy dependence
- Fleuret et al care for
  - the p_T dependence of shadowing
  - extrinsic $g+g \rightarrow J/\psi+g$ (usually neglected) ↑



- Tram and Arleo care for
  - a global (uneasy) fit of σ_{abs} to all available data
  - shadowing scheme dependence of σ_{abs}
  - $\sigma_{abs} = 3.5 \pm 0.2 \pm 1.7$ mb

Tram & Arleo, EPJ. C 55, 449-461 (2008)

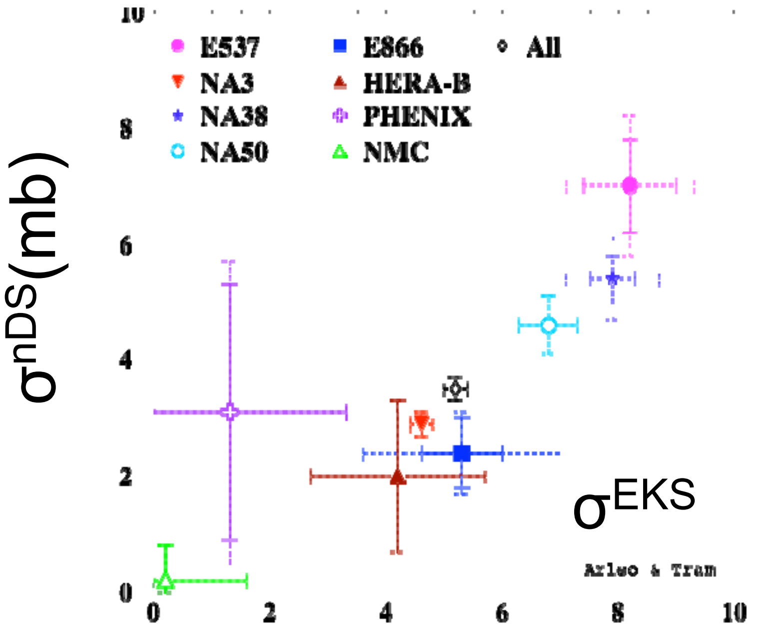
Do we understand J/ψ in nuclear matter?

Tram, P7

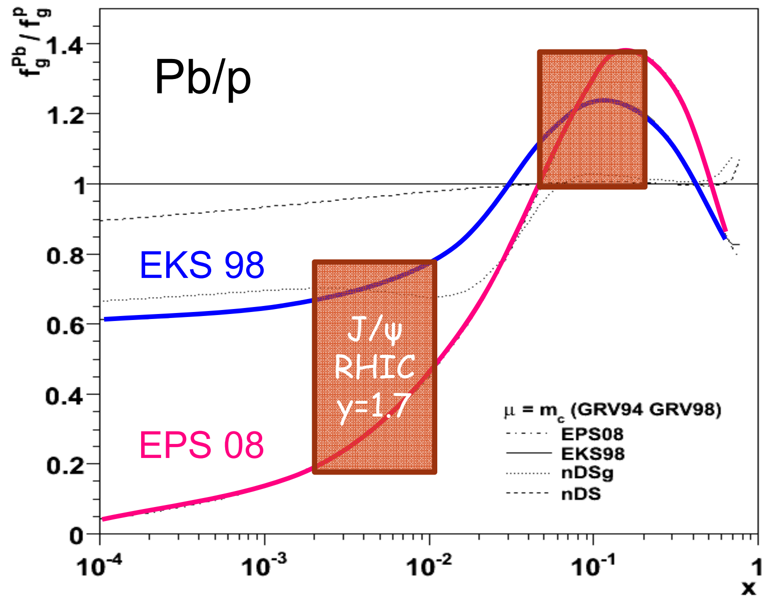
Eskola
Paukkunen, P2

nuclear absorption ⟵ INTERPLAY ⟶ **pdf modifications**

"Use EKS98 & EPS08 in parallel to map out most of such uncertainty"



Tram & Arleo, EPJ. C 55, 449-461 (2008)

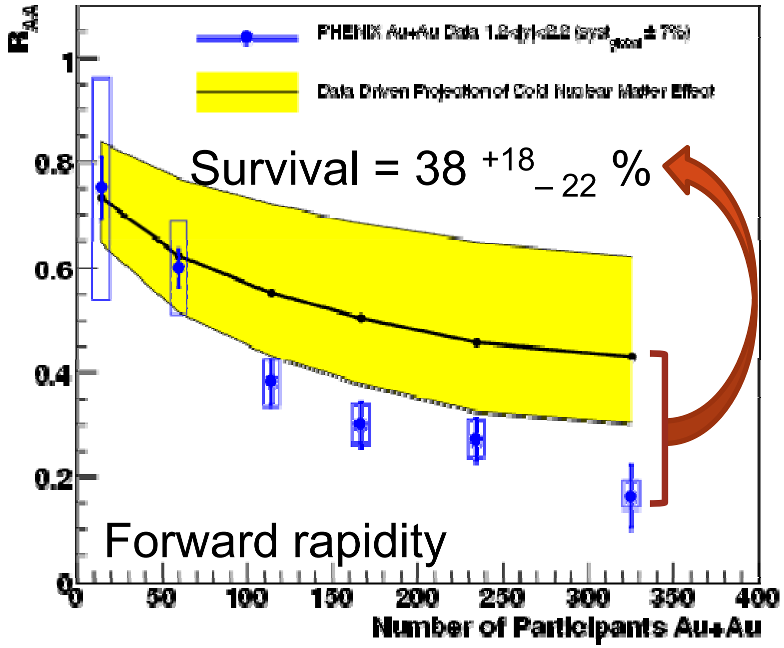


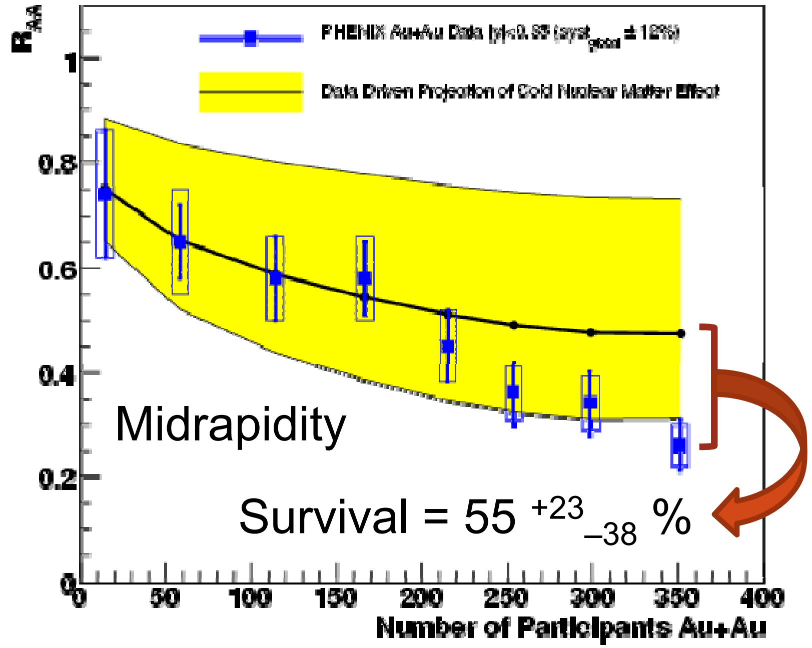
→ Should we really rely on shadowing and σ_{abs}?

A more data driven way…

RGdC, HP06 and QM08
PHENIX, PRC 77, 024912 (2008)

- Plug the centrality and rapidity dependence or RdAu in a Au-Au Glauber model = no need for shadowing or σ_{abs} + proper error propagations…





→ There is anomalous suppression @ RHIC

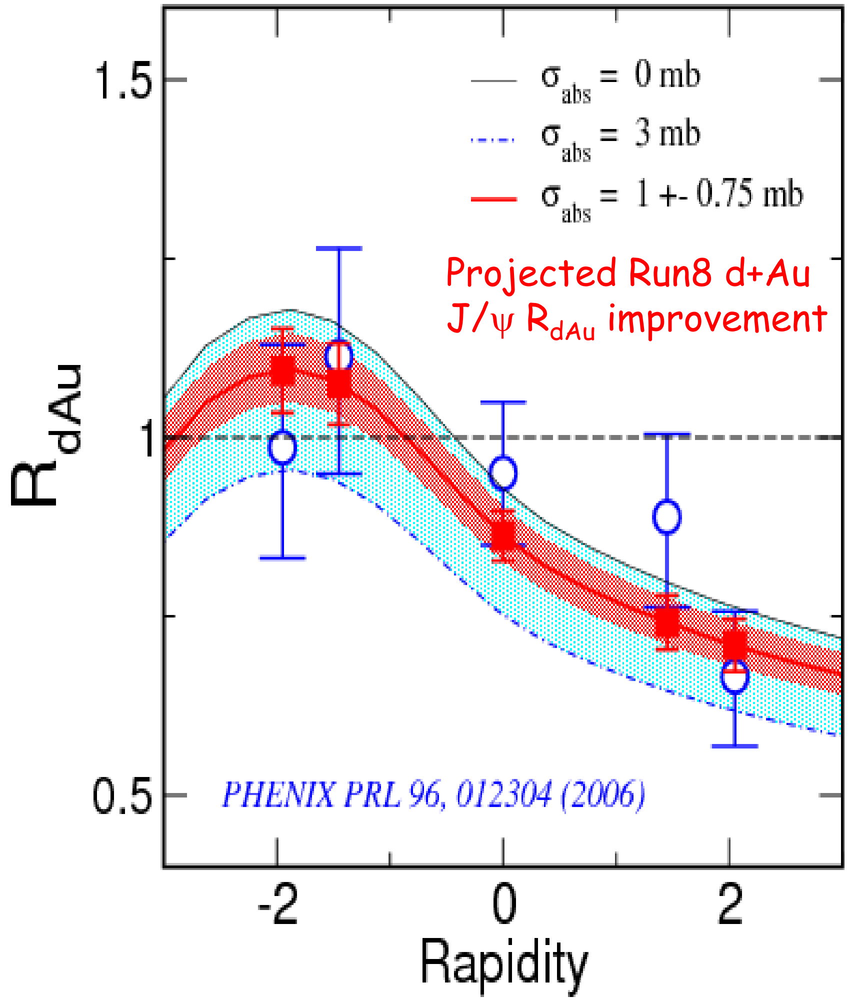
→ It may be the same at mid and forward rapidity

We need/have d-A data !

- New dAu run!
  - 30 times statistics
- Why not dCu?
  - Apply the data driven way to CuCu
- Why not other dA?

K. Tywoniuk, P6

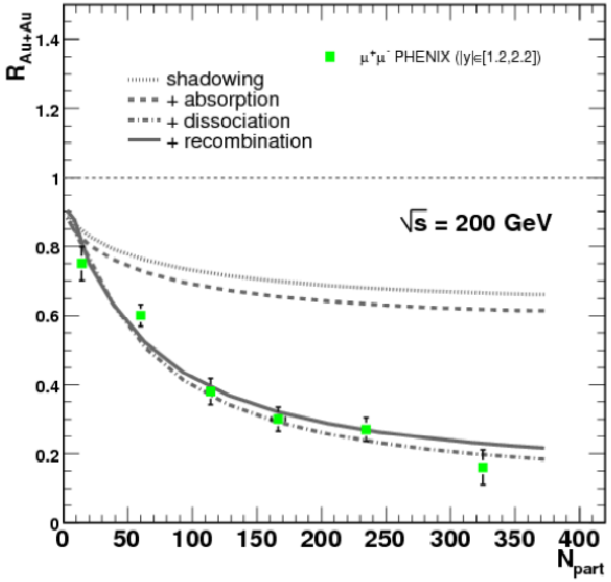
  - **”need several nuclear targets”**

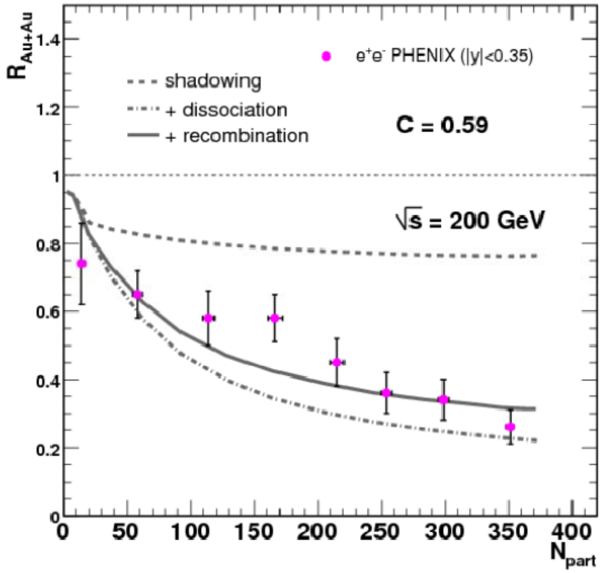


The alternate explanation: regeneration

- A large variety of recombination / coalescence models…
- The two we saw here agree that not more ≈ 20% of the J/ψ comes from recombination
  - Thews study the y and p_T shape
  - Tywoniuk et al don't even really need recombination (but shadowing) →

K. Tywoniuk, P6
R. Thews, P6





Additional little measurements start to shed some light on quarkonia…

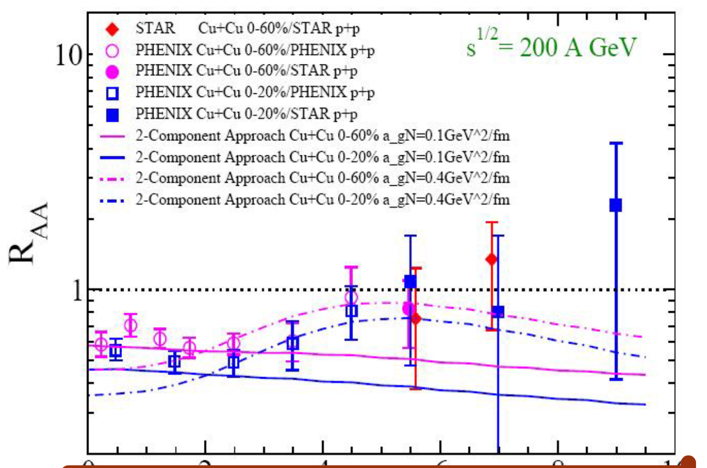
High p_T from STAR, feed-down contributions, and elliptic flow…

STILL THREE SLIDES TO GO…

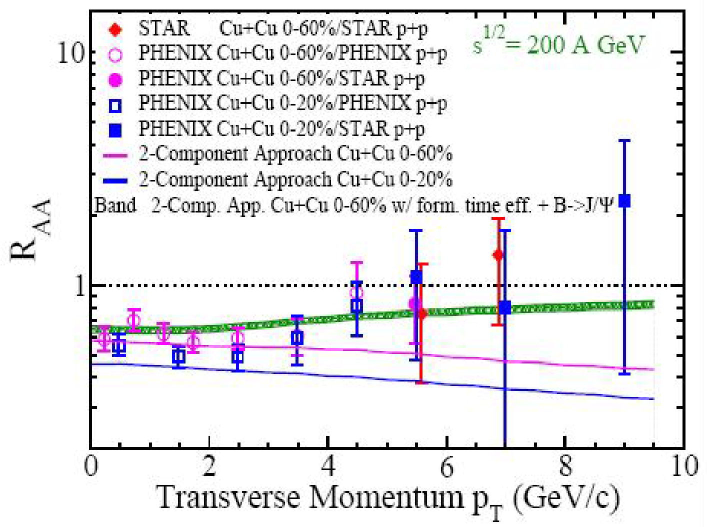
High p_T J/ψ from STAR

T. Ullrich

- R_{CuCu}(high p_T) increase
  - Not new (NA50,NA60…)
- First, it could be due to Cronin →
  - Need to measure this in dAu!
- Then, could also be
  - Leakage (formation time)
  - Bottom contribution



Rapp & Zhao, arxiv:0806.1231

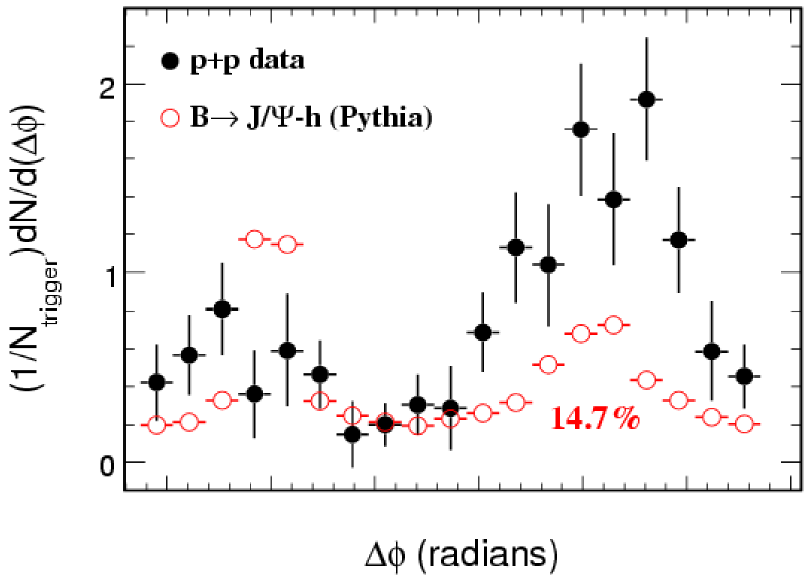


Feed down

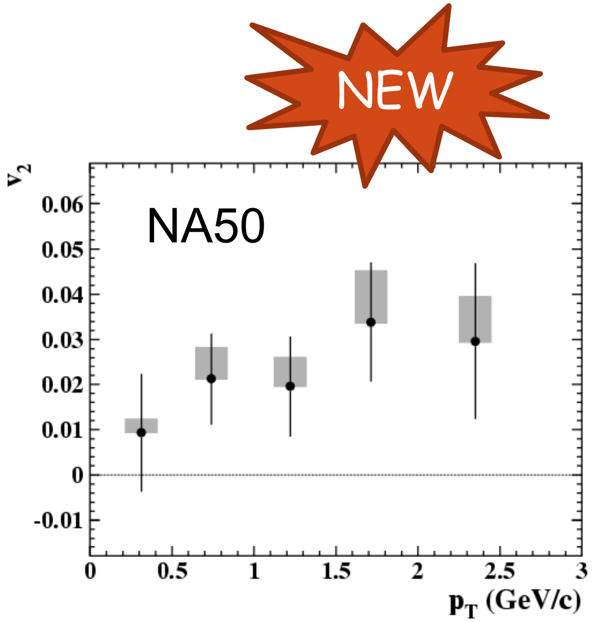
P. Faccioli, P6
T. Ullrich
E.T. Atomssa

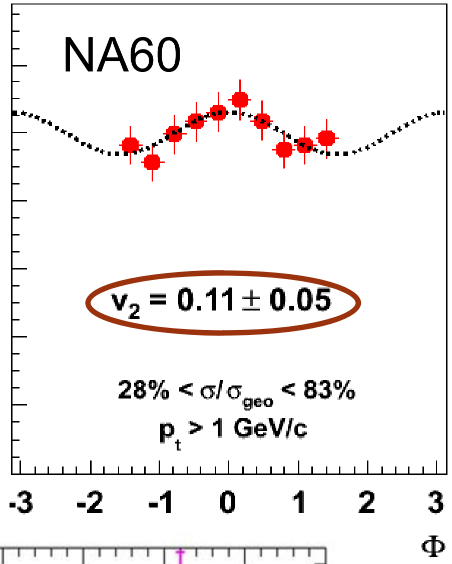
- J/ψ from ψ' from world average 8.1 ± 0.3%
  - 8.6 ±2.5% from PHENIX
- J/ψ from χ_c less precise 26 ±4% (from pA, excluding πA)
  - < 42 % @90 % CL (PHENIX)
- J/ψ from B = 4^{+3}_{-2} % from total b xsection and LEP-Tevatron admixture x BR

- J/ψ-h correlations also points that feed-down from B < 15% for p_T > 5 GeV ↓

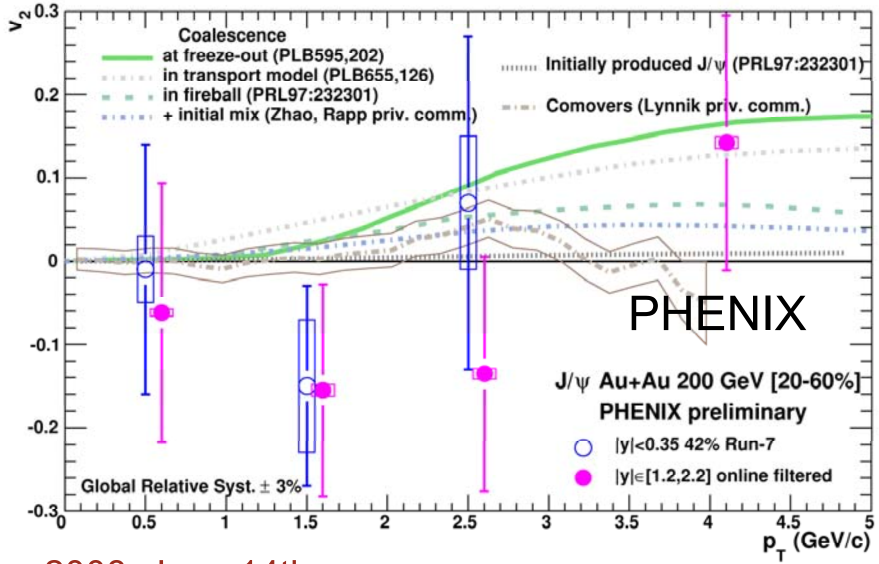


J/ψ elliptic flow, yet another surprise?





E.T. Atomssa
F. Prino, P6
C. Silvestre, P6



- Large uncertainties!
- J/ψ azimuthal anisotropy at SPS!
  - PbPb and InIn
  - Differential absorption?
- While J/ψ (all p_T) have a low probability (6%) to have positive flow at RHIC…

→ Need more data!

→ Difficult interpretation

Conclusions: what's new since HP06?

- How has our understanding progressed?
- Well, not tremendously…
  - Main observations were there!
  - Main puzzles are still here!
  - A few additional surprises!
- However, a lot of little (statistically speaking) but interesting measurements (J/ψ v_2, high p_T, Υ…) or p-p references (photon, ψ', h-J/ψ, b/c+b…)
  - Partly thanks to important upgrades (STAR/EMCAL, PHENIX/RxNP…)
  - Thus, we are progressing!
- But to move forward, we need a step in S/B
  - More luminosity @ RHIC (dAu!) then RHIC2
  - New discriminating detectors (HBD, silicon era…)
  - And probably we also need the LHC, Andrea?