Υ production: an example of heavy-ion physics with the extracted 2.76 TeV lead LHC beam

AFTER @ LHC

Jean-Philippe Lansberg

INSTITUT DE PHYSIQUE NUCLÉAIRE
ORSAY

Probing the Strong Interaction at
A Fixed Target ExpeRiment with the LHC beams
Ecole de Physique des Houches, 12-17 January 2014

Use LHC beams on fixed target :

- LHC 7 TeV proton beam

  $\sqrt{s} \sim 115$ GeV: *pp*, *pd*, *pA*

- LHC 2.76 TeV lead beam

  $\sqrt{s} \sim 72$ GeV: Pb−*p*, Pb*A*

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PDF and nPDF at large x_B

heavy quarkonium prod.
Cold Nuclear Matter effects

W, Z prod. near threshold

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QGP studies, high precision heavy quarkonium observatory, jets

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  - high luminosity, high boost ($y_{cms}^{lab} = 4.84$ @ 115 GeV), target versatility

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- multipurpose experiment, modern detection techniques

More details

- on the website: after.in2p3.fr
- in Physics Reports :

AFTER @ LHC

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Physics opportunities of a fixed-target experiment using LHC beams

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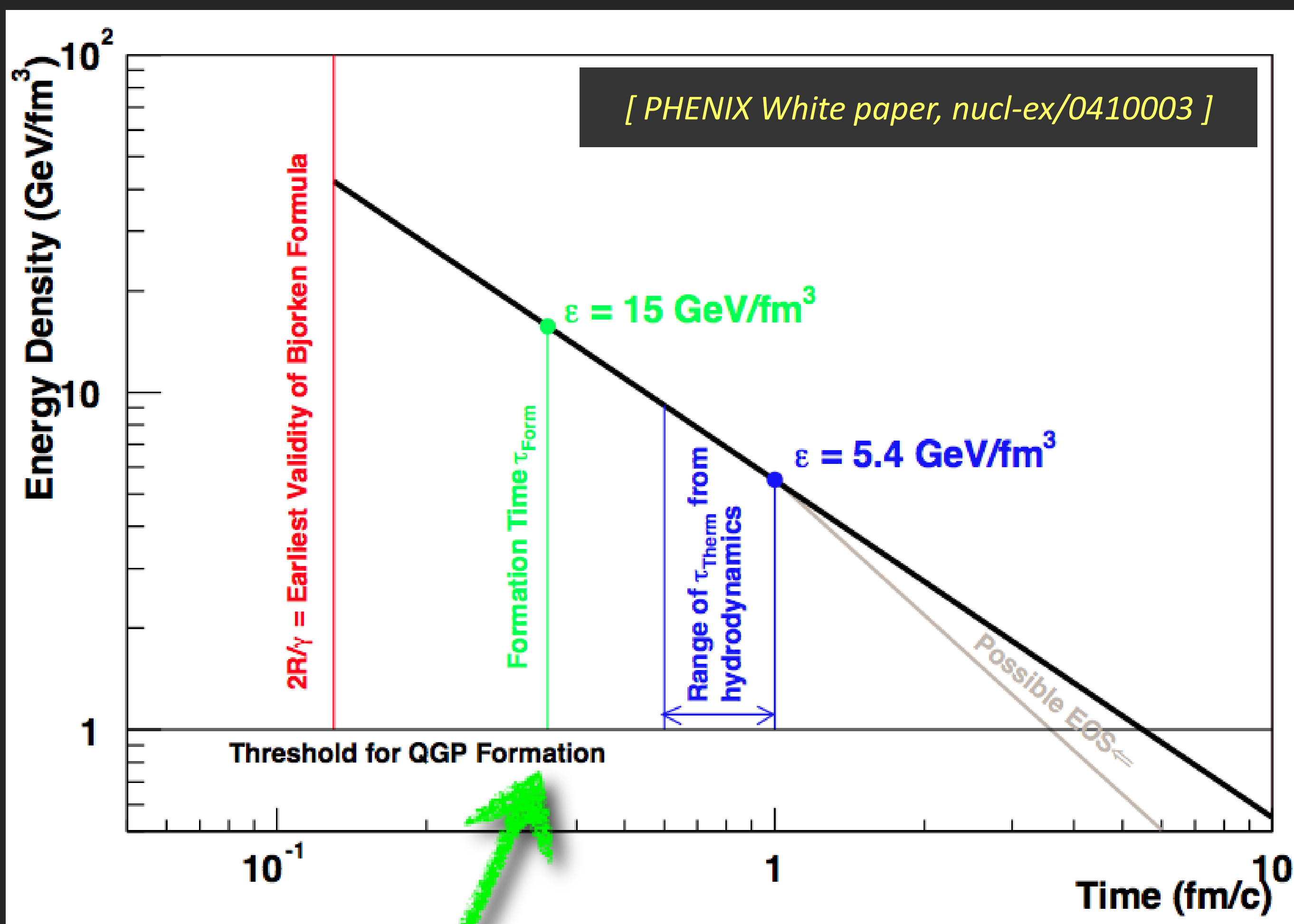
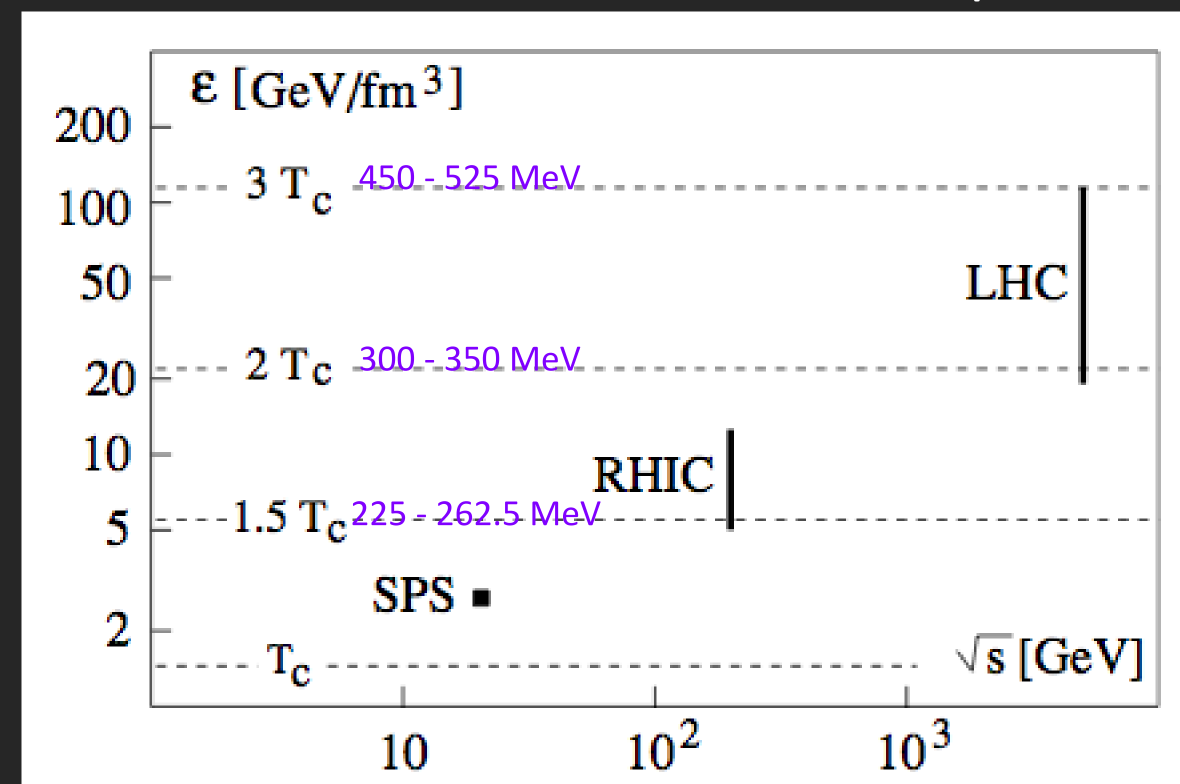
Energy density and temperature

Energy density vs time @ RHIC



Energy density, max. collision energy, and temperature



[Satz, J.Phys. G32 (2006) R25]

T_c ~ 150 - 175 MeV

?

T_{avg} = 221 ± 19 (stat) ± 19 (syst) MeV (0-20% AuAu)

[PHENIX, PRL. 104 (2010) 132301]

$T_{initial}$

370 - 450 MeV

[Strickland et al., NPA 879 (2012) 25-58]

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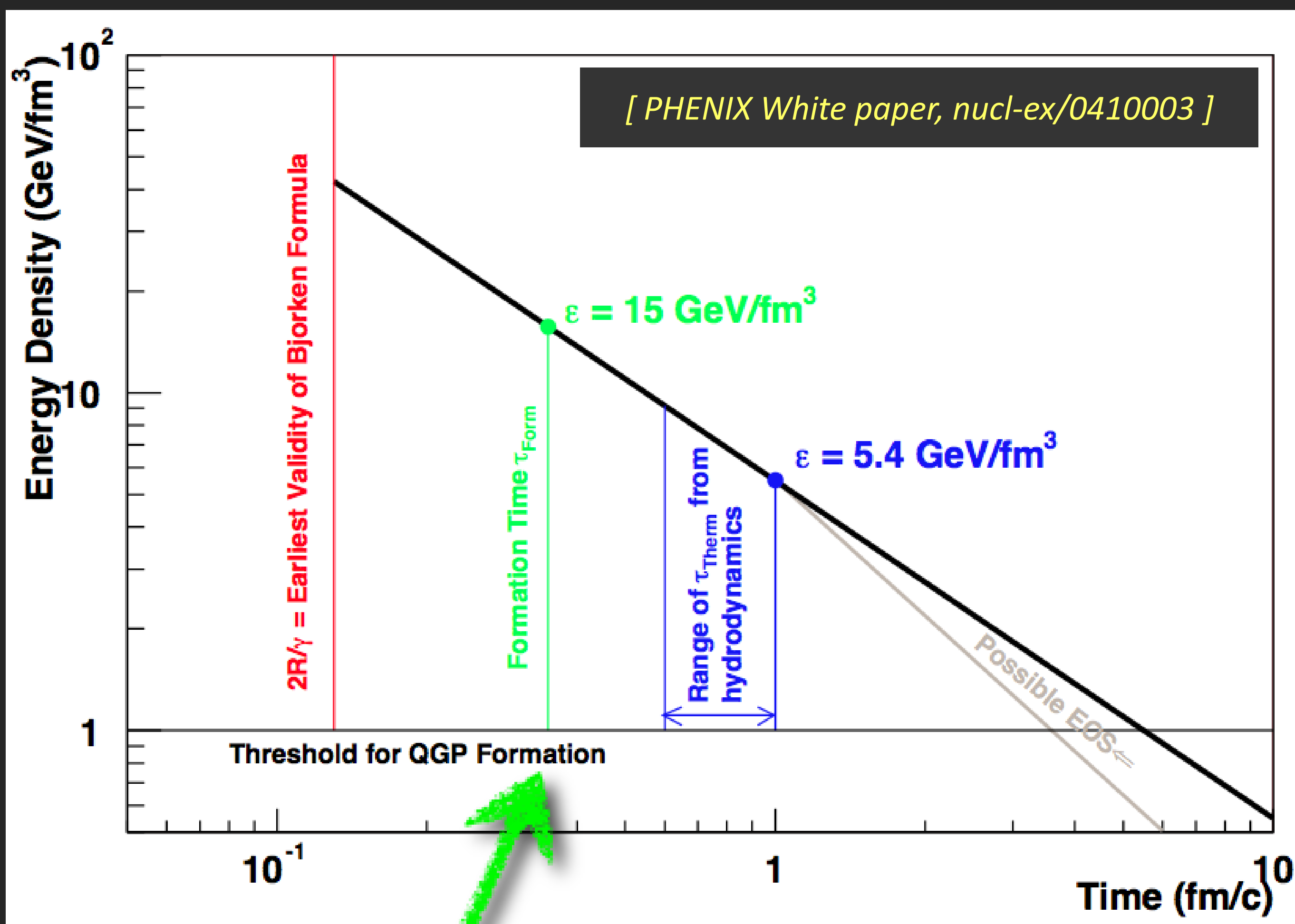

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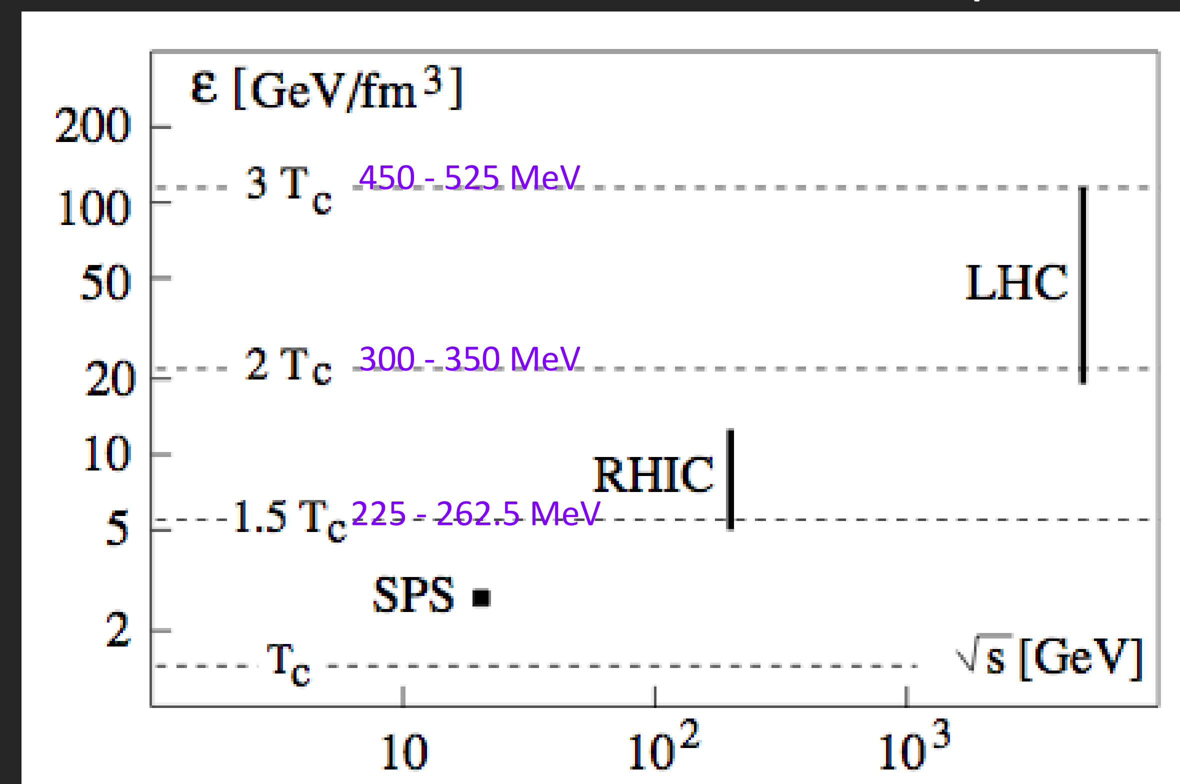

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AFTER in PbA

$\sqrt{s} = 72$ GeV

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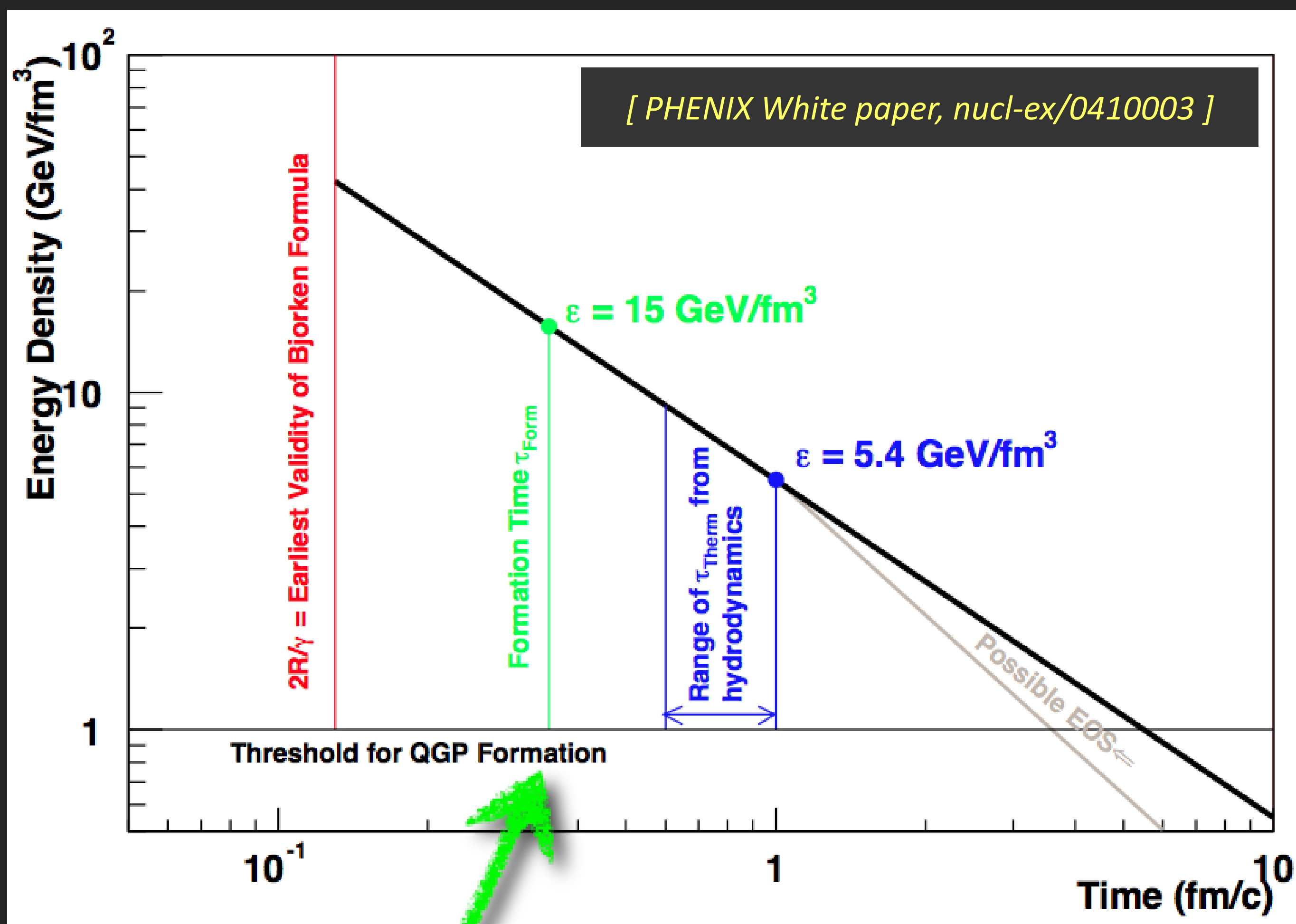

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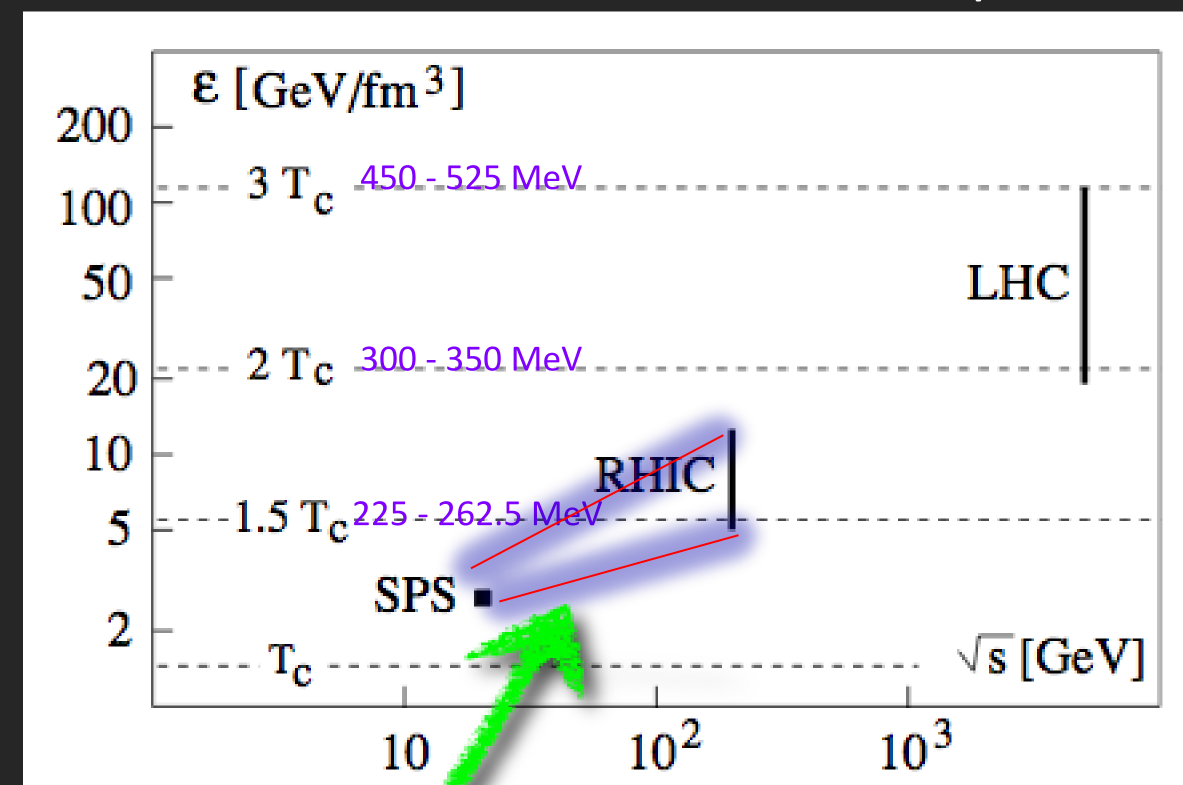

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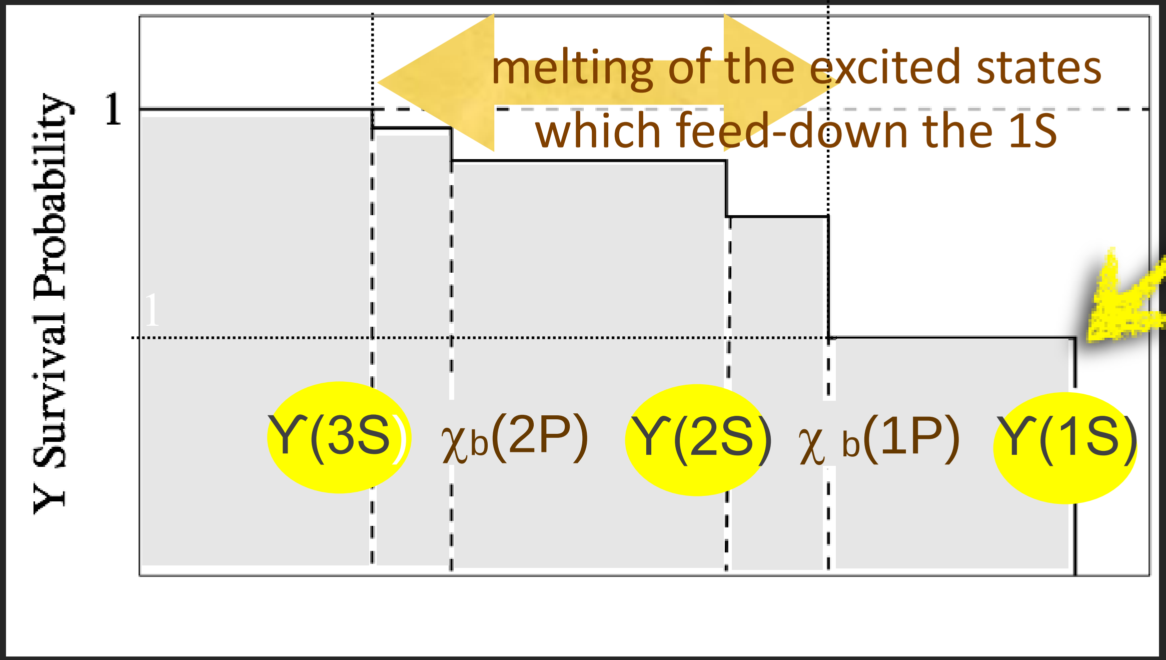
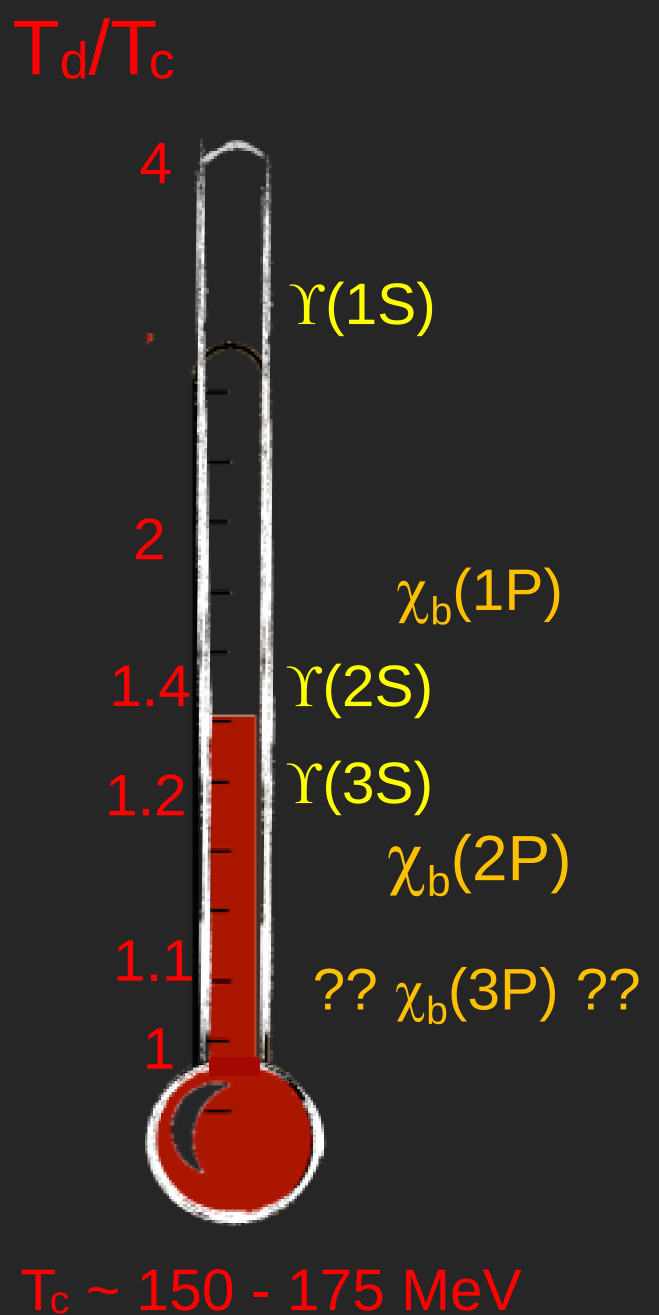
Sequential melting in QGP



melting of the direct Υ(1S)

Dissociation temperatures from lattice QCD (+hydro)



[Mocsy et al., Int.J.Mod.Phys. A28 (2013) 1340012]

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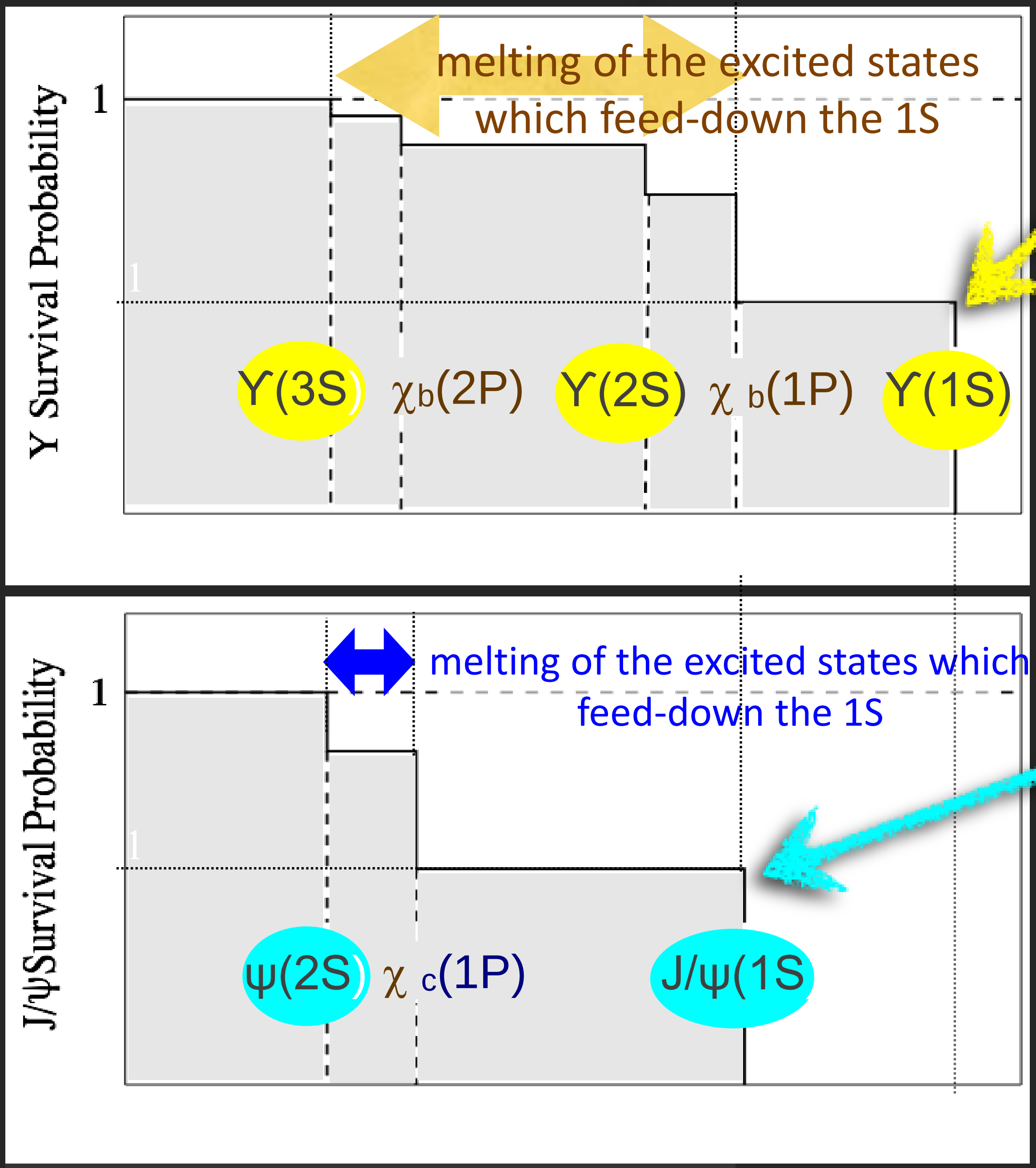

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melting of the direct J/ψ

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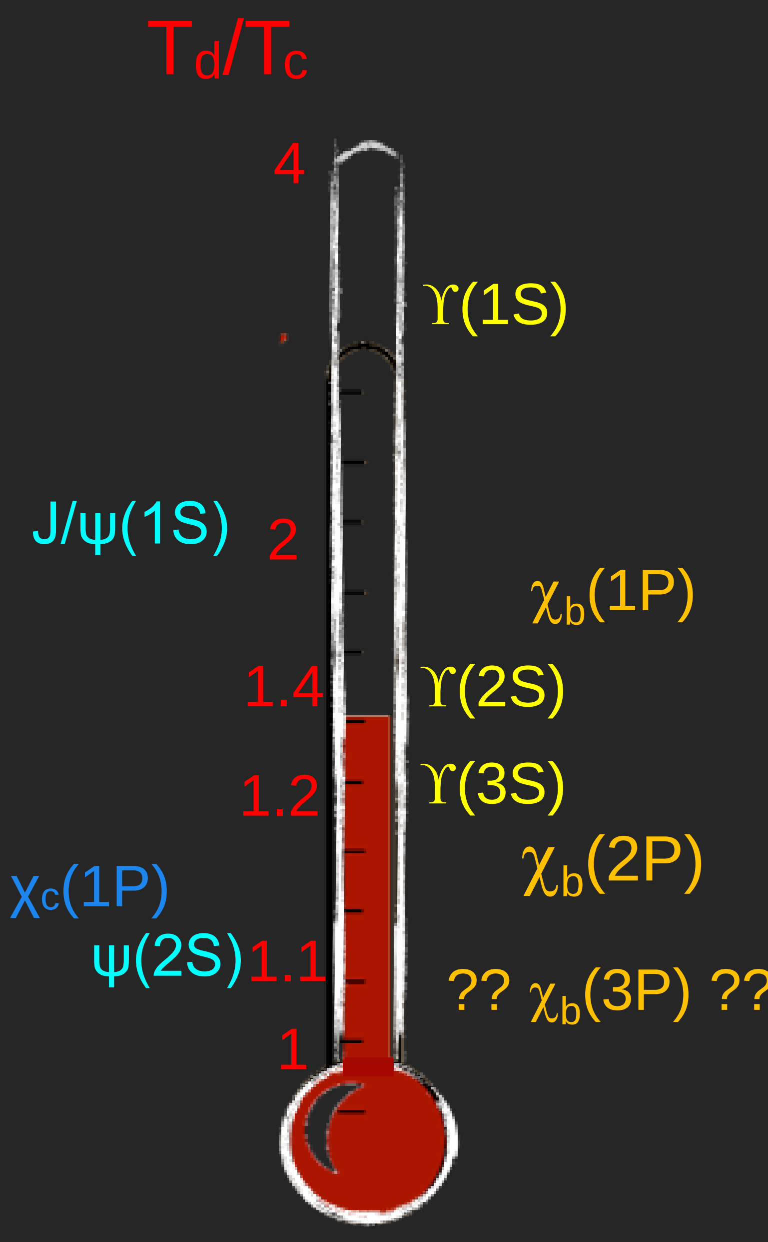

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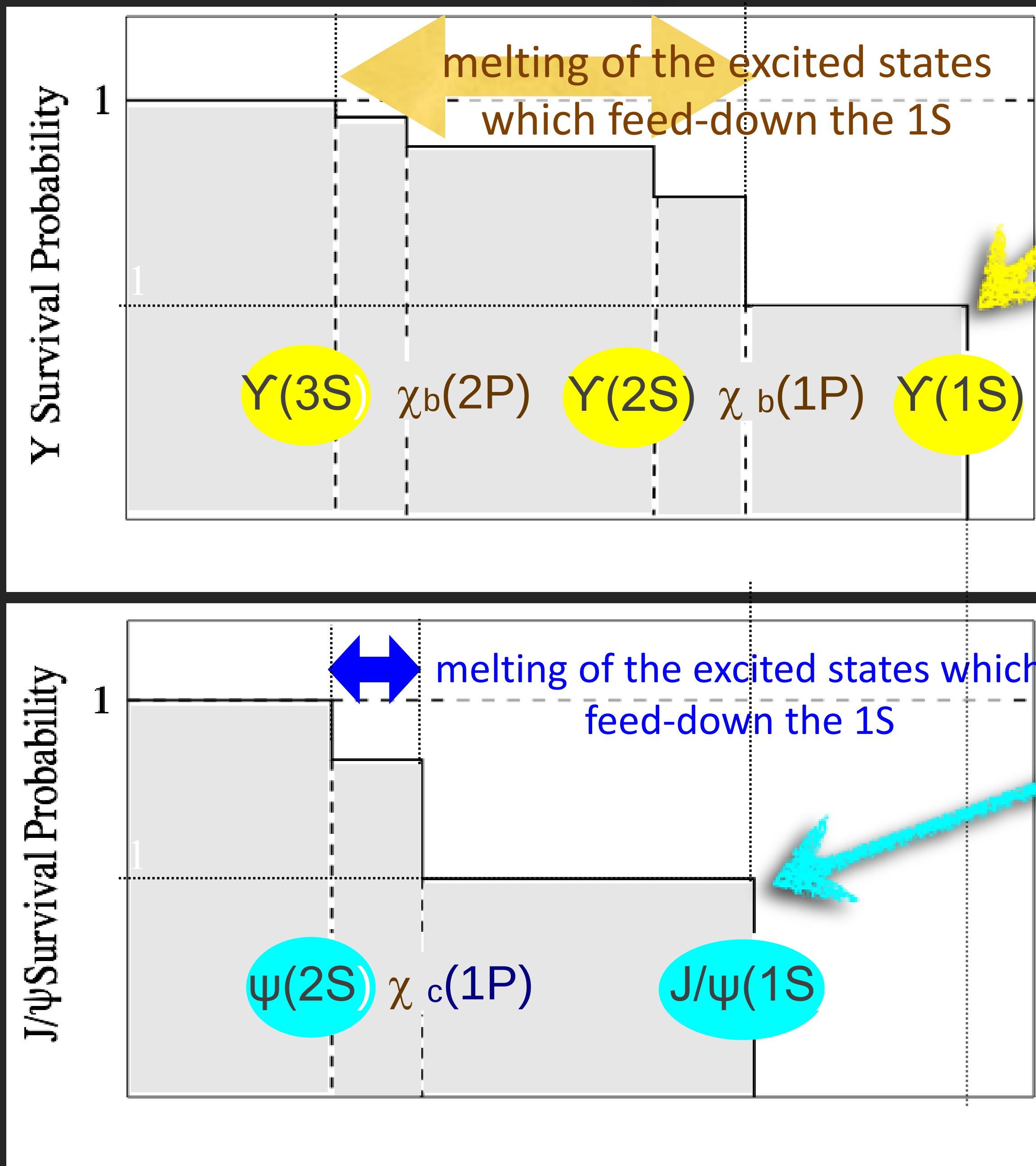

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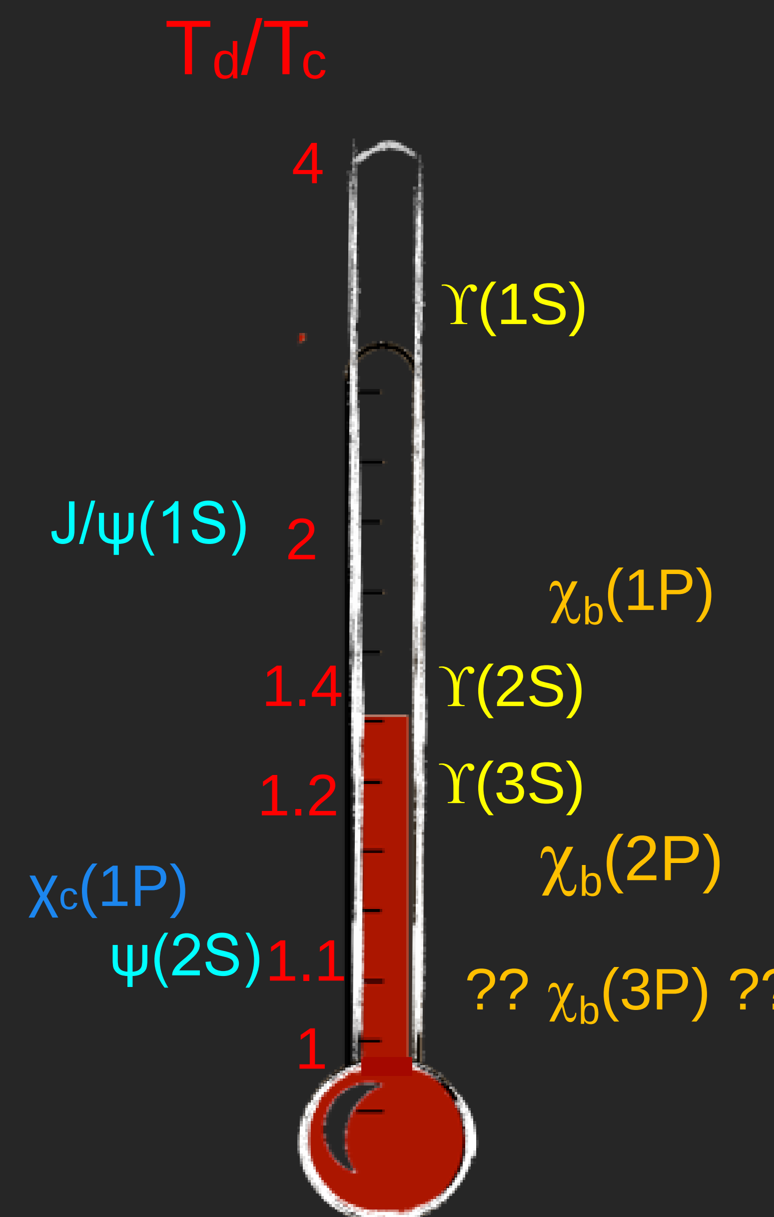

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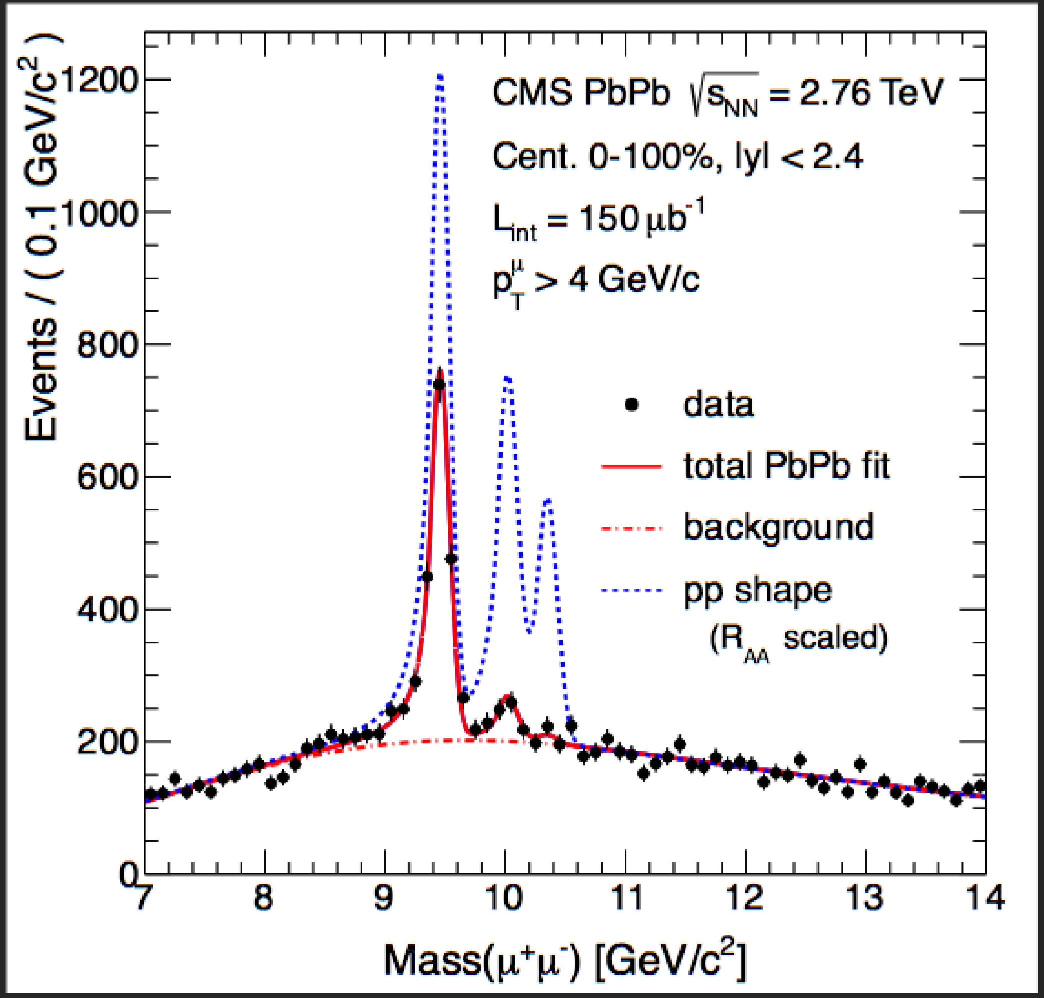
[Mocsy et al., Int.J.Mod.Phys. A28 (2013) 1340012]

- Bottomonium family : richer, broader range in T (compared to charmonium)
- Less necessary to measure the $\chi_b(nP)$

Bottomonium sequential suppression @ LHC

Serious candidate for a « textbook-like » plot at the recent Hard Probes 2013 conference



[CMS, PRL 109 (2012) 222301]

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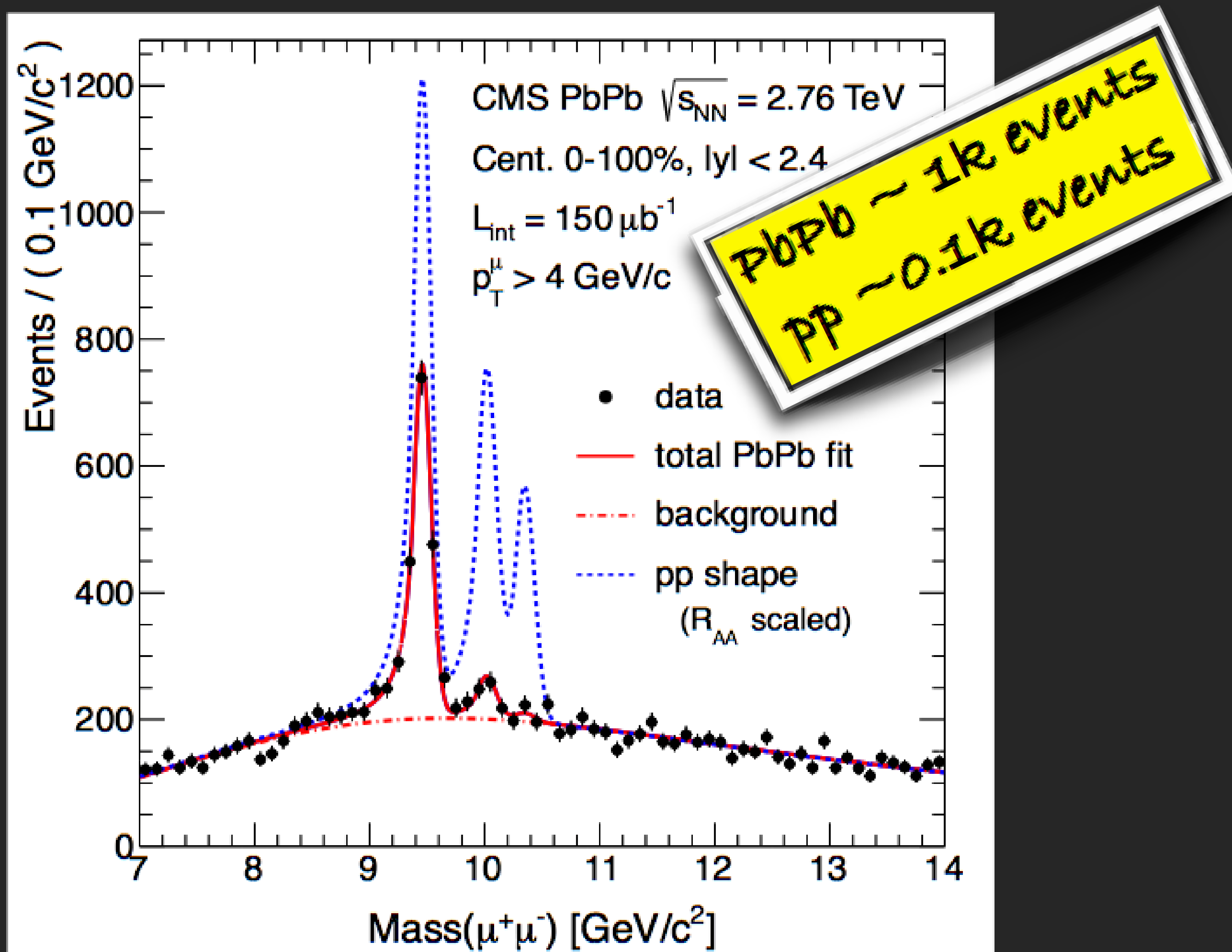

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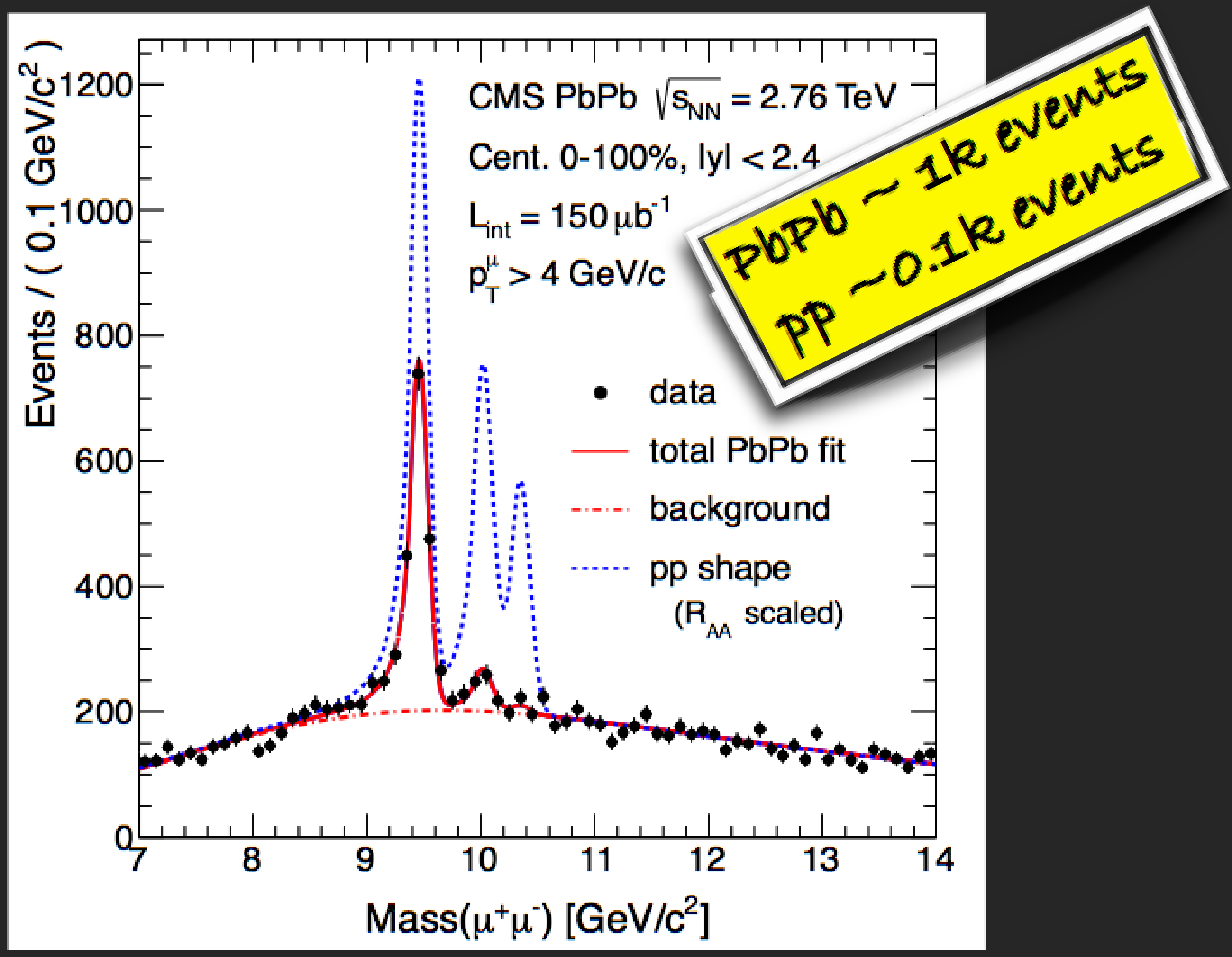

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- necessary ingredients :
- high inv. mass resolution in pp and PbPb + background under control
- Sequential suppression seen :
  - 3S completely melted ?
  - 2S very suppressed
  - direct 1S not affected ?

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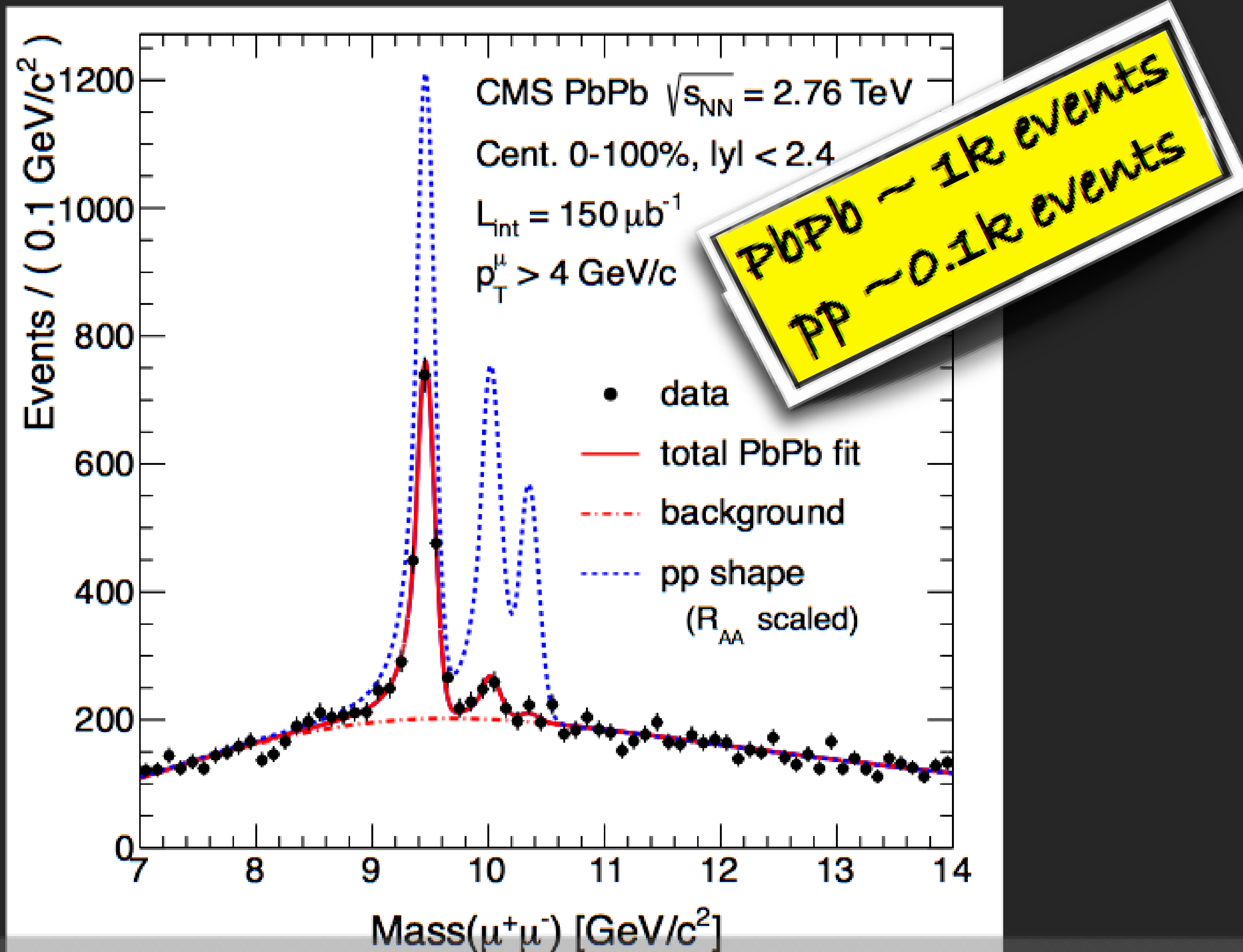

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Selected for a Viewpoint in *Physics*

PRL **109,** 222301 (2012) PHYSICAL REVIEW LETTERS week ending 30 NOVEMBER 2012

Observation of Sequential Υ Suppression in PbPb Collisions

S. Chatrchyan *et al.**
(CMS Collaboration)

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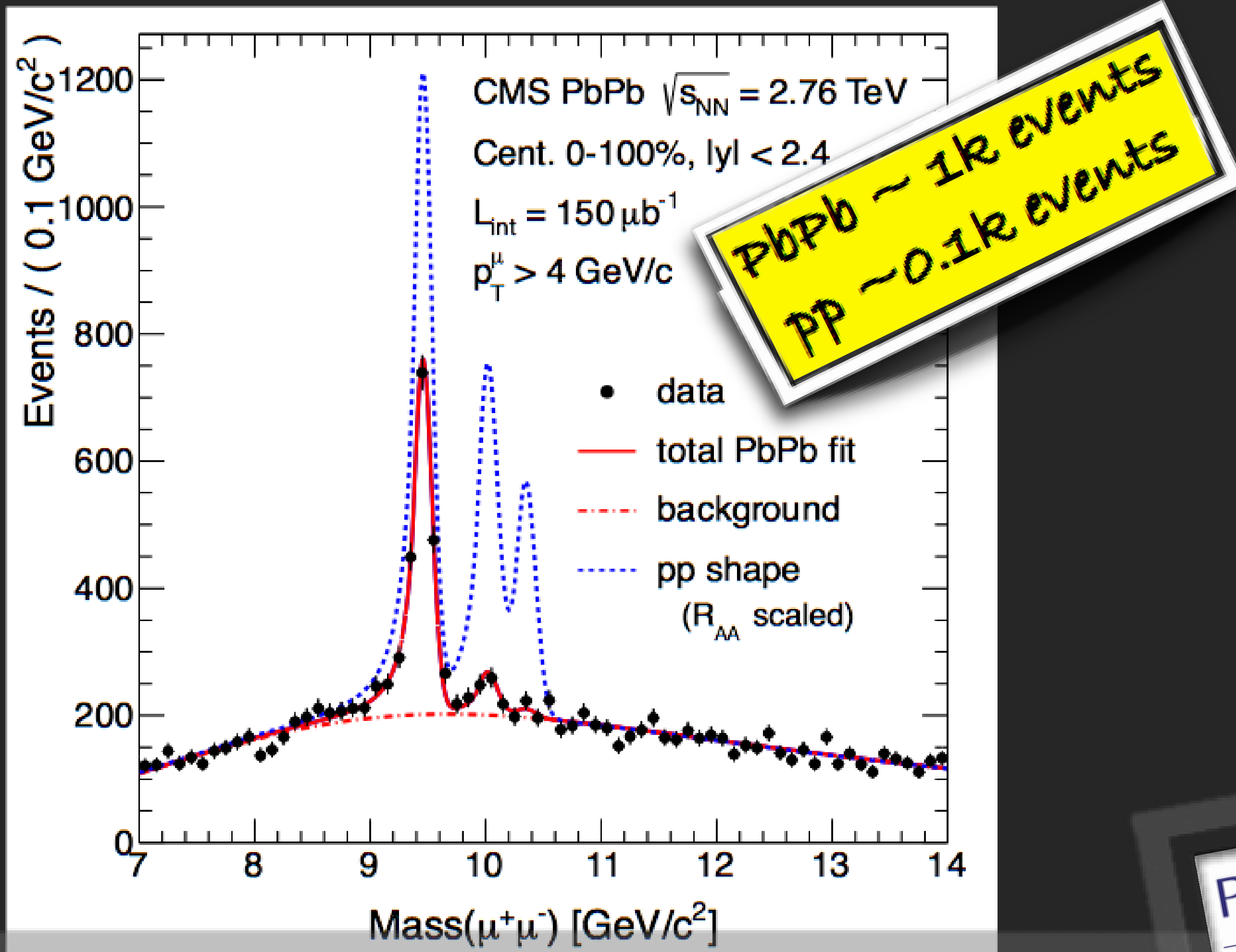

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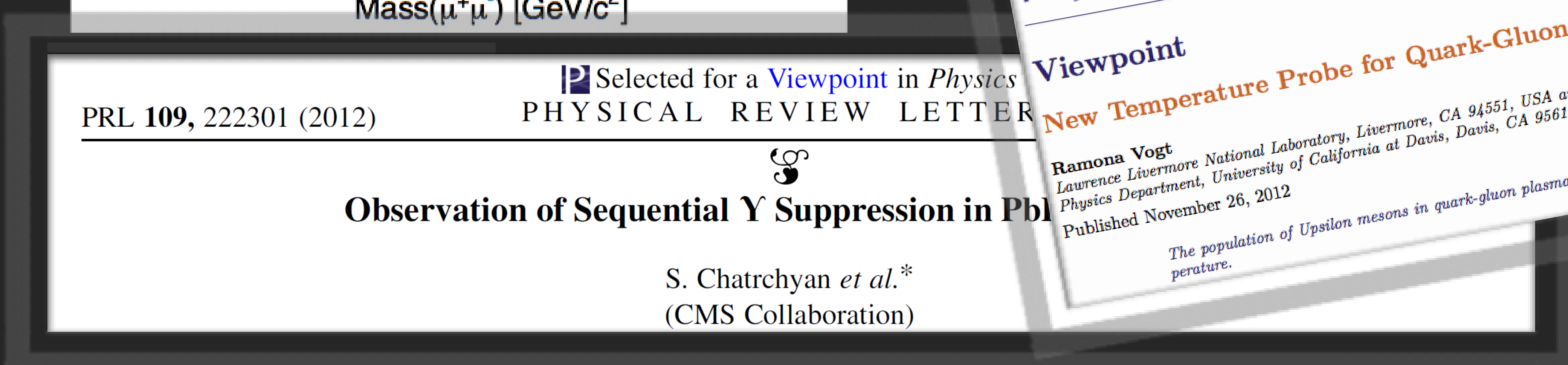
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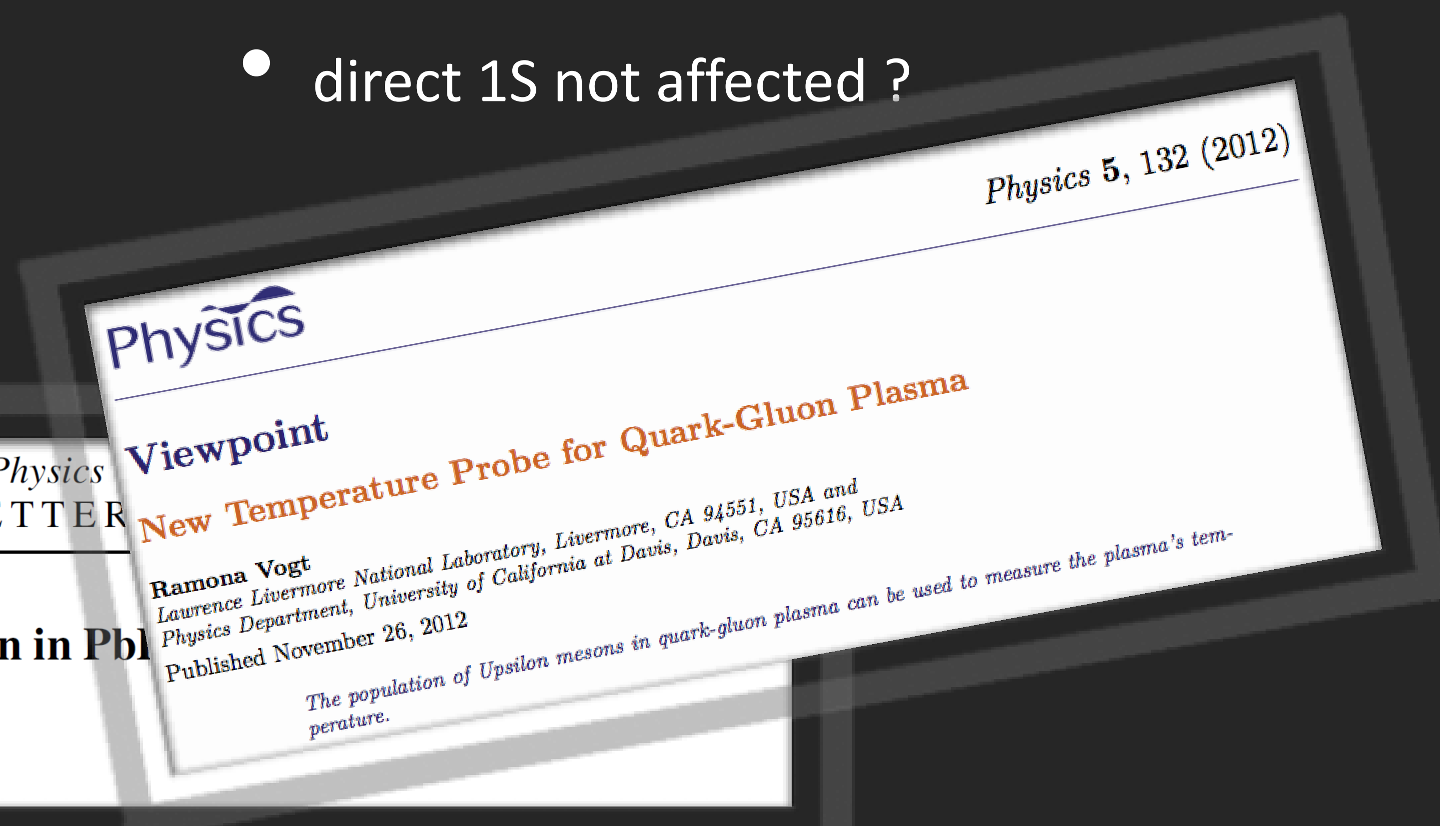

Physics **5**, 132 (2012)

Physics

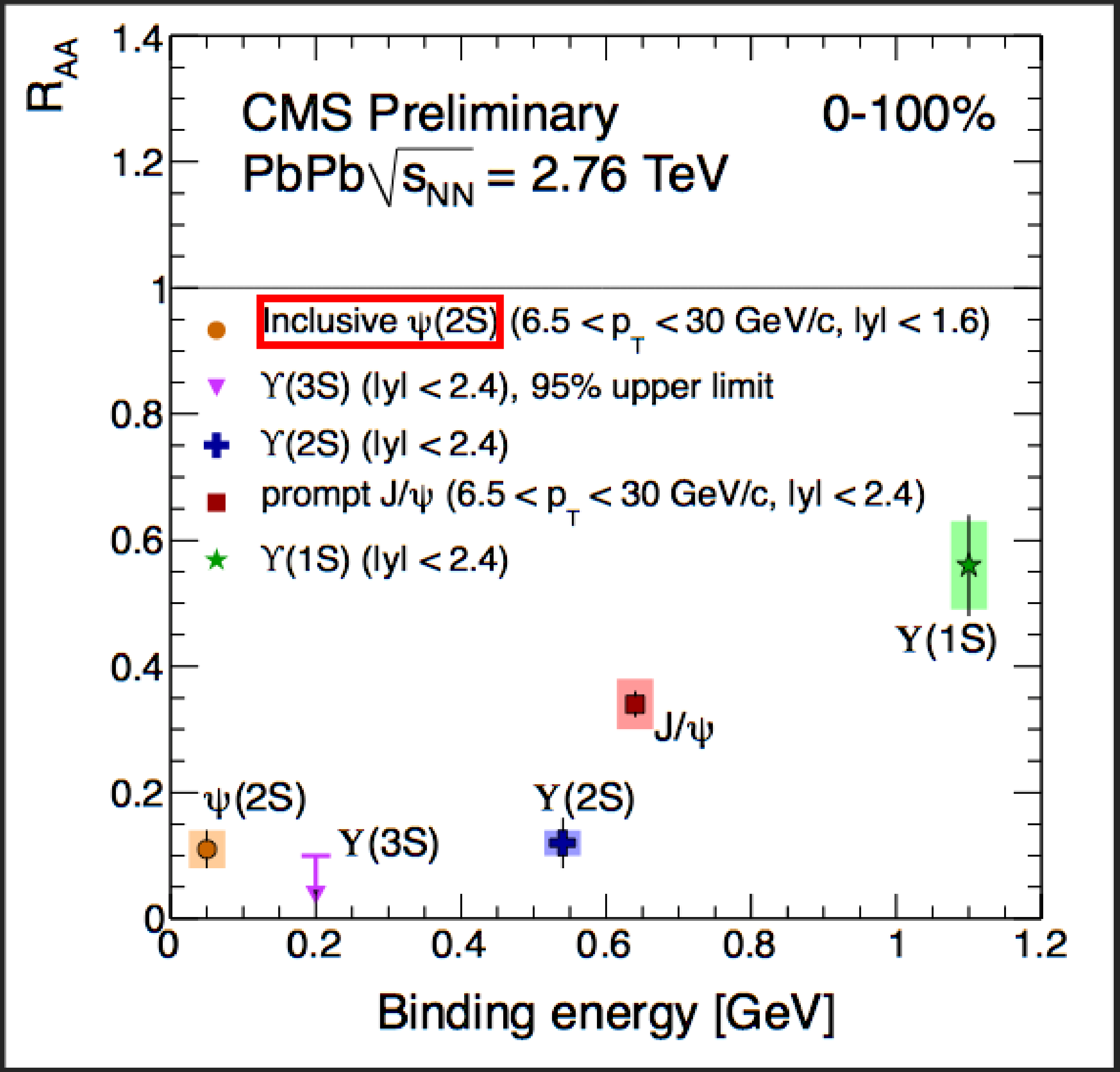
Viewpoint

New Temperature Probe for Quark-Gluon Plasma

Ramona Vogt
Lawrence Livermore National Laboratory, Livermore, CA 94551, USA and
Physics Department, University of California at Davis, Davis, CA 95616, USA
Published November 26, 2012

The population of Upsilon mesons in quark-gluon plasma can be used to measure the plasma's temperature.

Sequential *melting* @ LHC ?



[Velkovska for CMS, HP2013]

$$R_{AA} \equiv \frac{\sigma_{AA}}{\langle N_{coll} \rangle \, \sigma_{pp}}$$

state	R_{AA} ± stat ± syst
Υ(1S)	0.56 ± 0.08 ± 0.07
Υ(2S)	0.12 ± 0.04 ± 0.02
Υ(3S)	<0.10 at 95% CL

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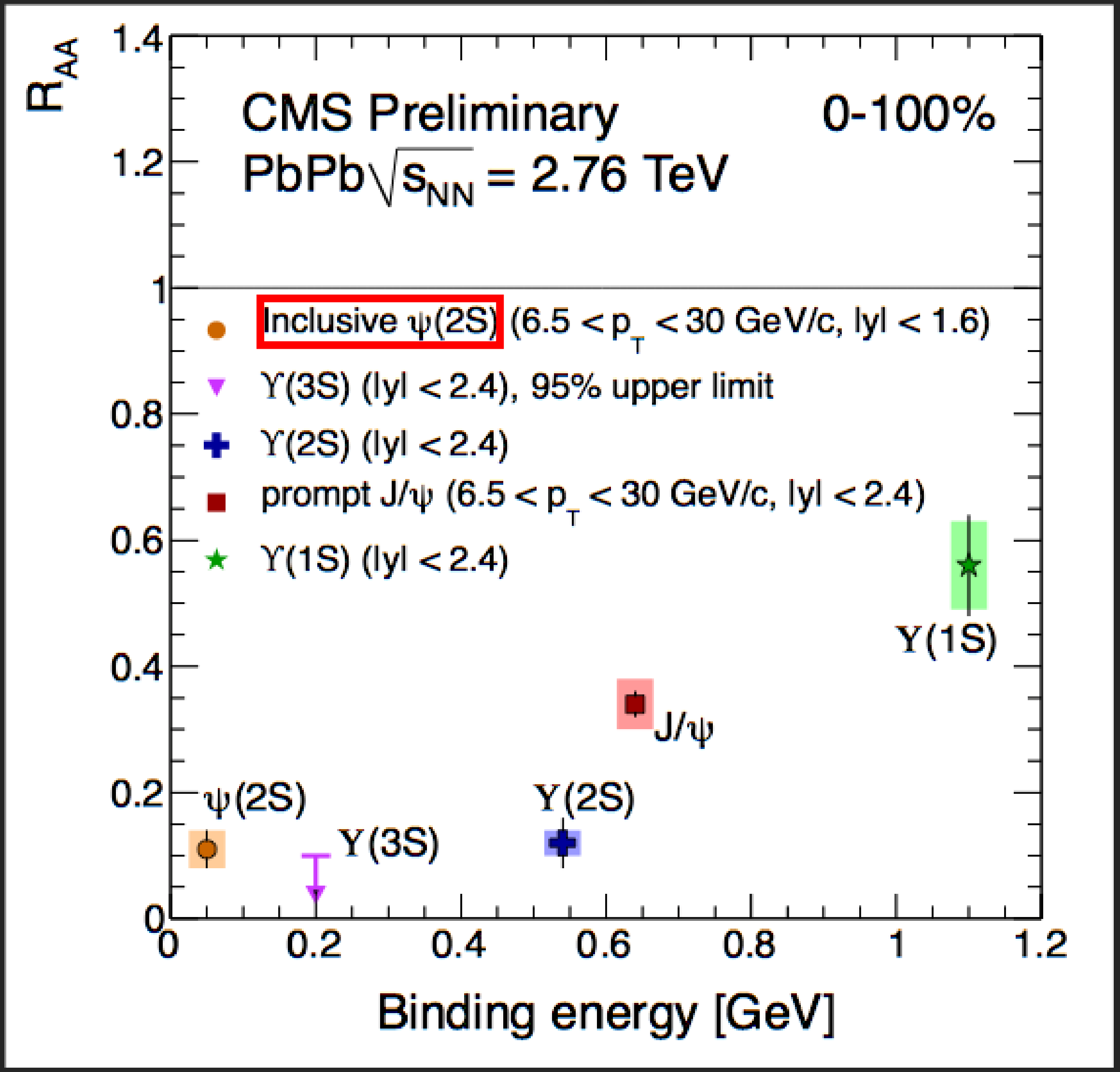

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If the sequential suppression is due to QGP effects *only*, what is the temperature reached @ LHC ?

‣ rough first estimate:

1.4 T_c (~230 MeV) < T< 4 T_c (~600 MeV)

‣ lattice QCD + hydro evolution :

$T_{initial}$ ~ 550 MeV > T

[Strickland et al., NPA 879 (2012) 25-58]

Measurement (thermal photons, dominant at low p_T) : T_{avg} ~ 304 ± 51 MeV

(0-40% PbPb)

[Alice, NPA 904 (2013) 573c]

Lessons from SPS and RHIC

Same J/ψ suppression observed at SPS & RHIC

Two widely spread interpretations:

→ Melting of **excited** states of SPS & RHIC energies (1P & 2S)
→ Induced suppression by feed-down
→ **No** additional **melting** of the **direct** yield at RHIC
→ <u>Temperature between RHIC and SPS is somewhere between 1.2 & 2 T_c</u>

→ Melting of **excited** states of SPS & RHIC energies
→ **Direct** J/*ψ*'s **partially melt**
→ This additional suppression is compensated by **regeneration**
→ <u>Temperature between RHIC and SPS range from 1.2 T_c up to **s**2 T_c</u>

Nota: The fact that the ϒ(2S) would only be partially suppressed at LHC energies does not fit well with the hypothesis that the J/ψ already partially melts at RHIC [Theory predictions (lattice, …) sometimes disagree on this, though]

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In both case, the temperature expected for AFTER@LHC is likely around where the 2S and 3S bb states are expected to melt

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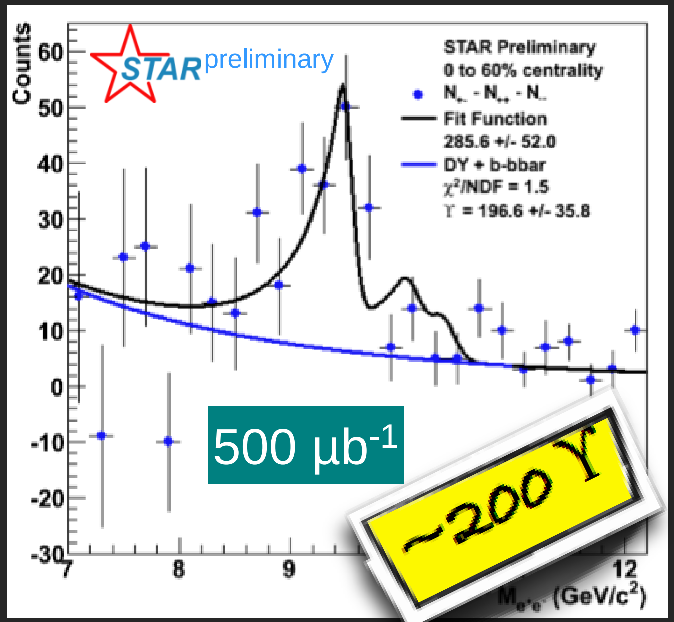
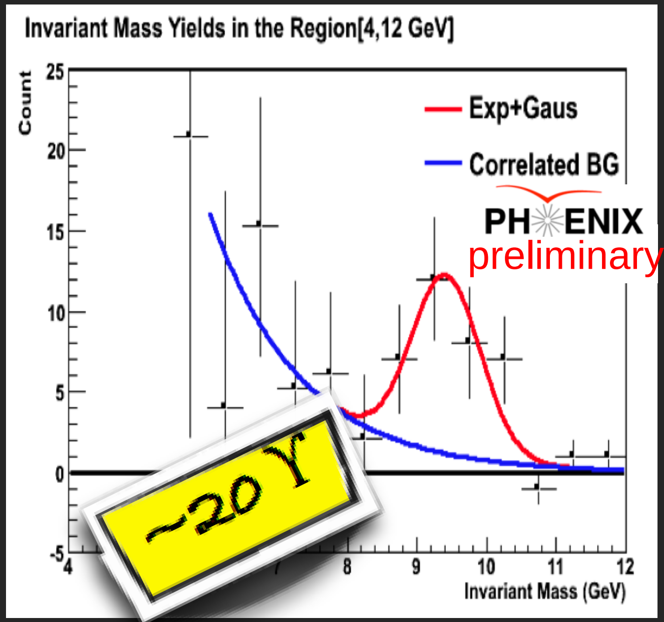
Another hint: Υ(1S + 2S + 3S) suppression @ RHIC

AuAu@200GeV (STAR run 2007, PHENIX run 2010)



[Reed for STAR, JPG 38 (2011) 124185]



[Whitaker for PHENIX, poster at QM2012]

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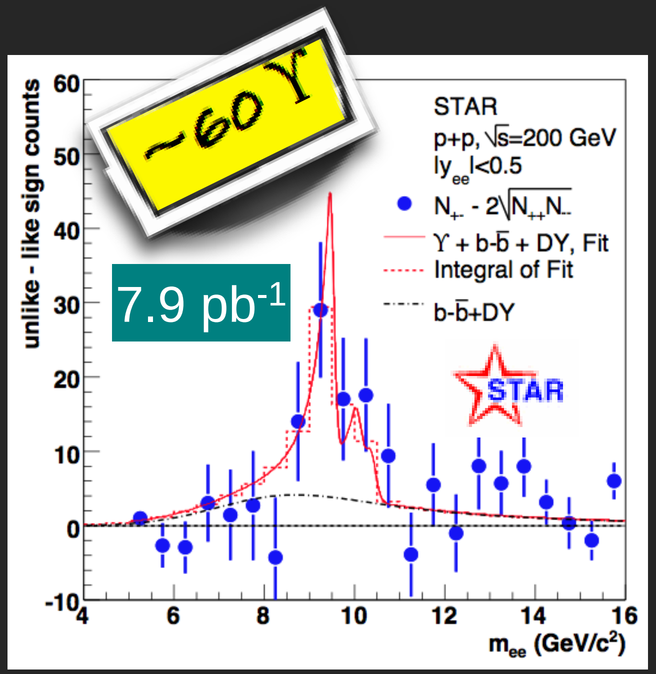
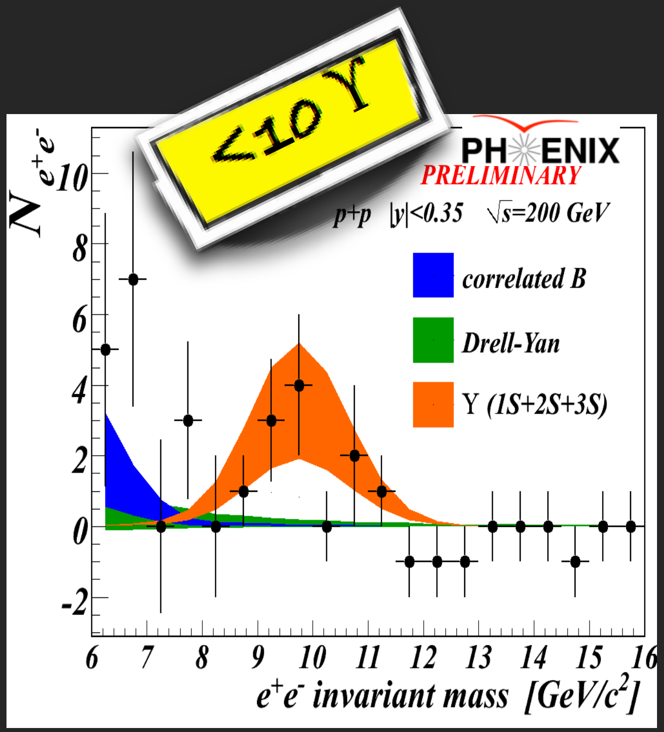


[STAR, PRD 82 (2010) 012004]



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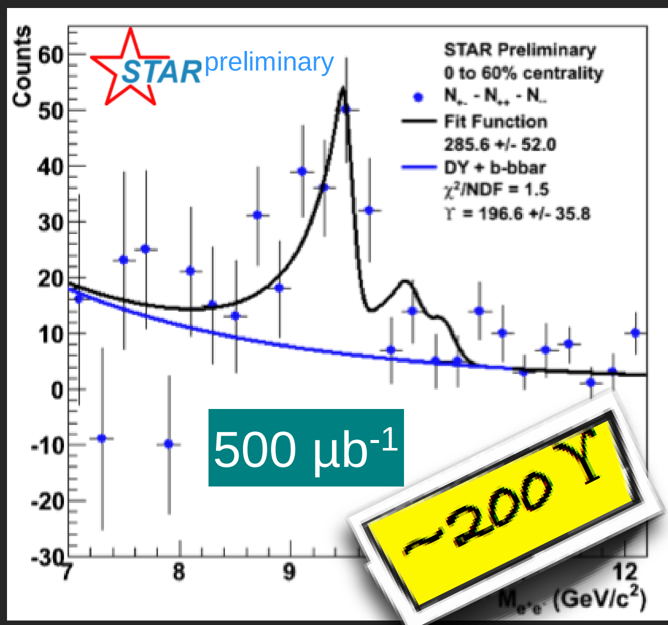

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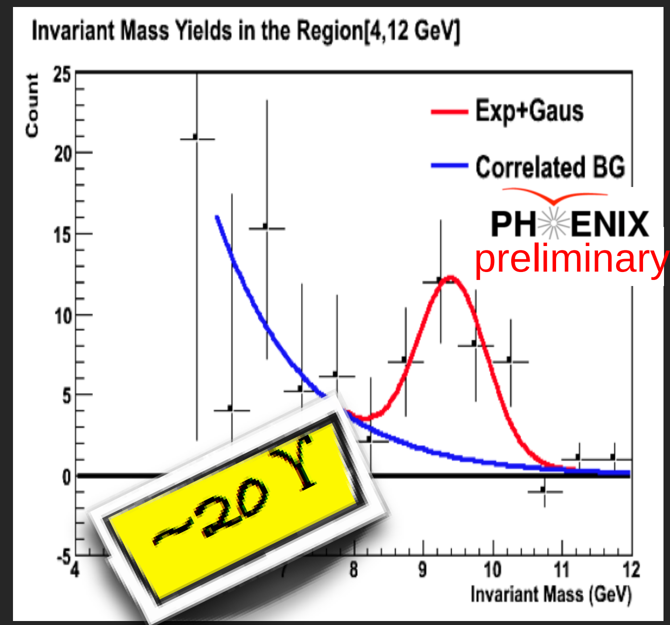

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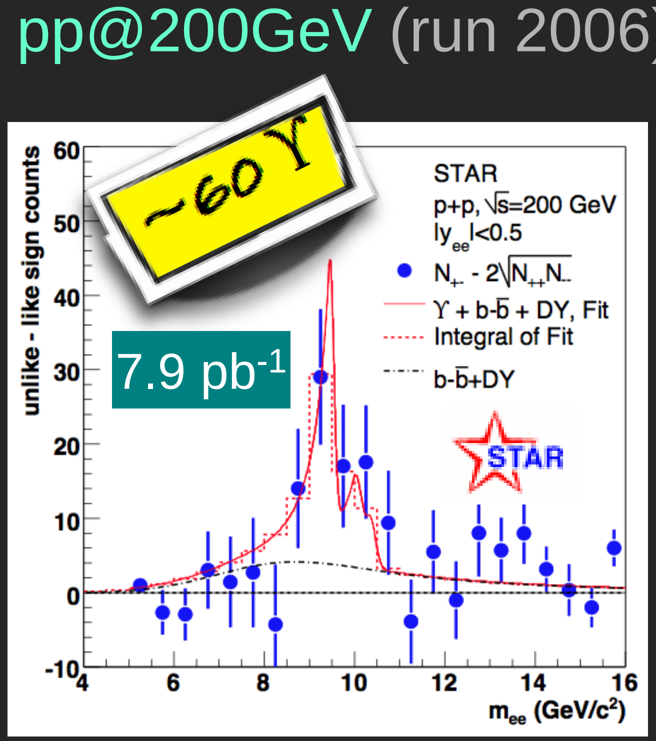

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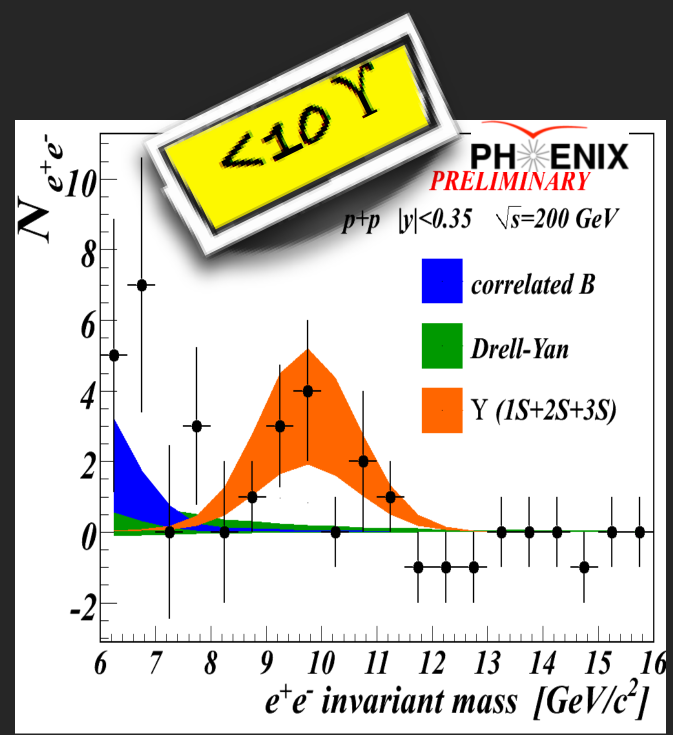

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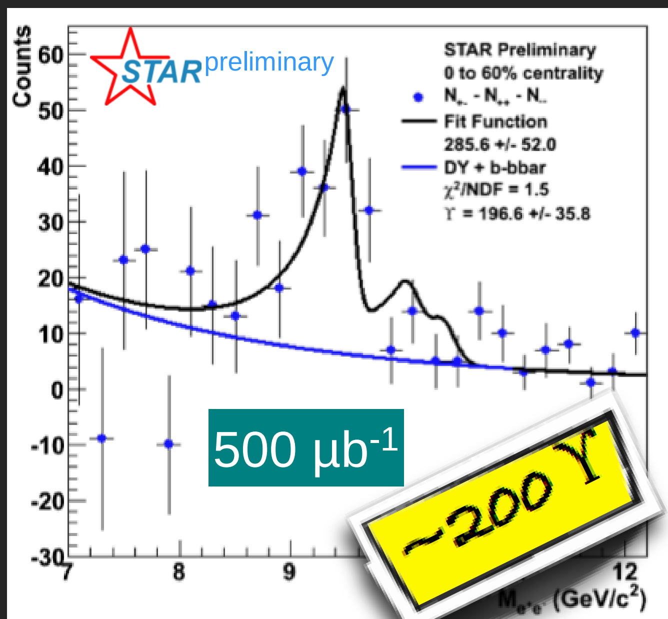

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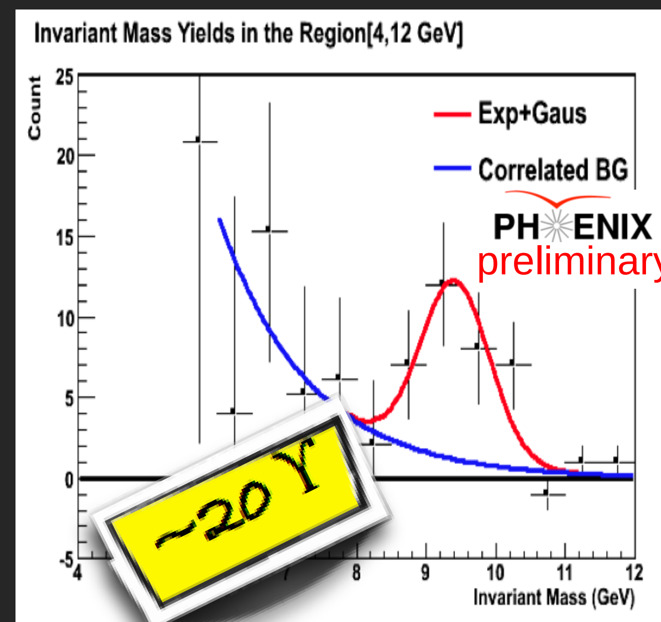

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specific R_{AA} computation for PHENIX :
pp J/ψ, Υ run 2006
AuAu Υ run 2010

$$R_{AA}(\Upsilon) = \frac{[N(\Upsilon)/N(J/\psi)]_{AA}}{[N(\Upsilon)/N(J/\psi)]_{pp}} \times R_{AA}(J/\psi)$$

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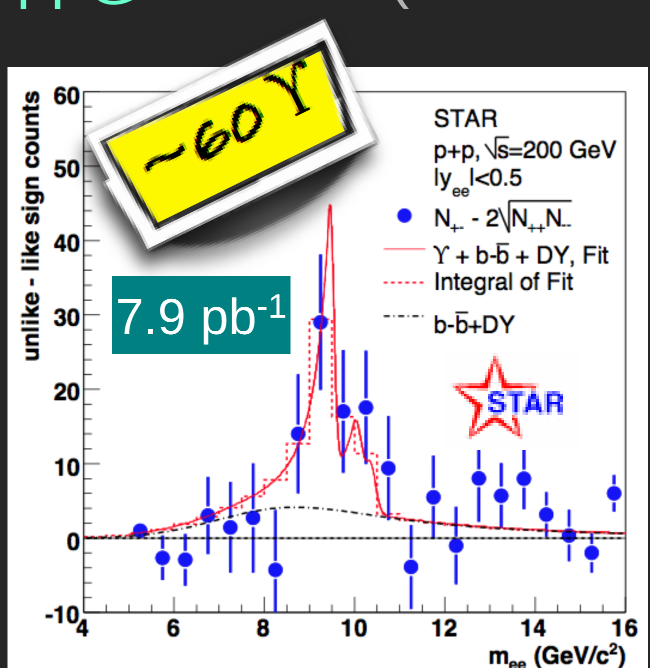

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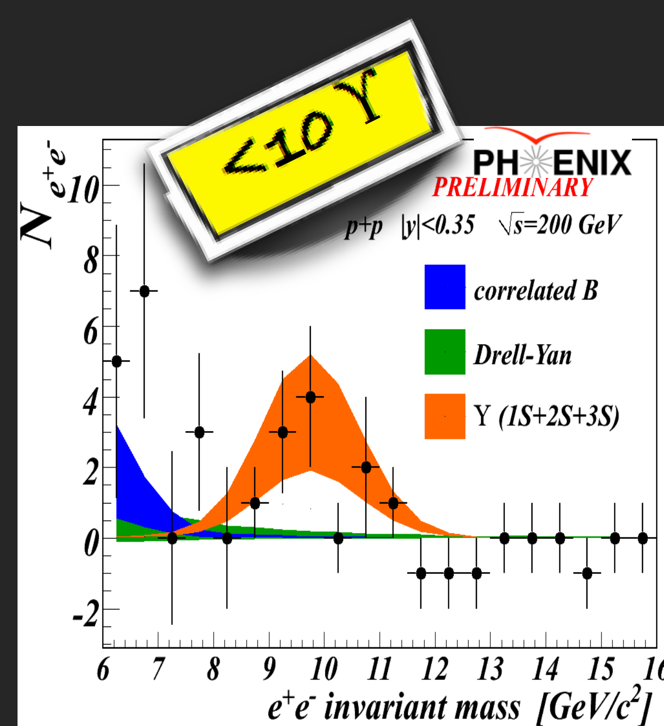

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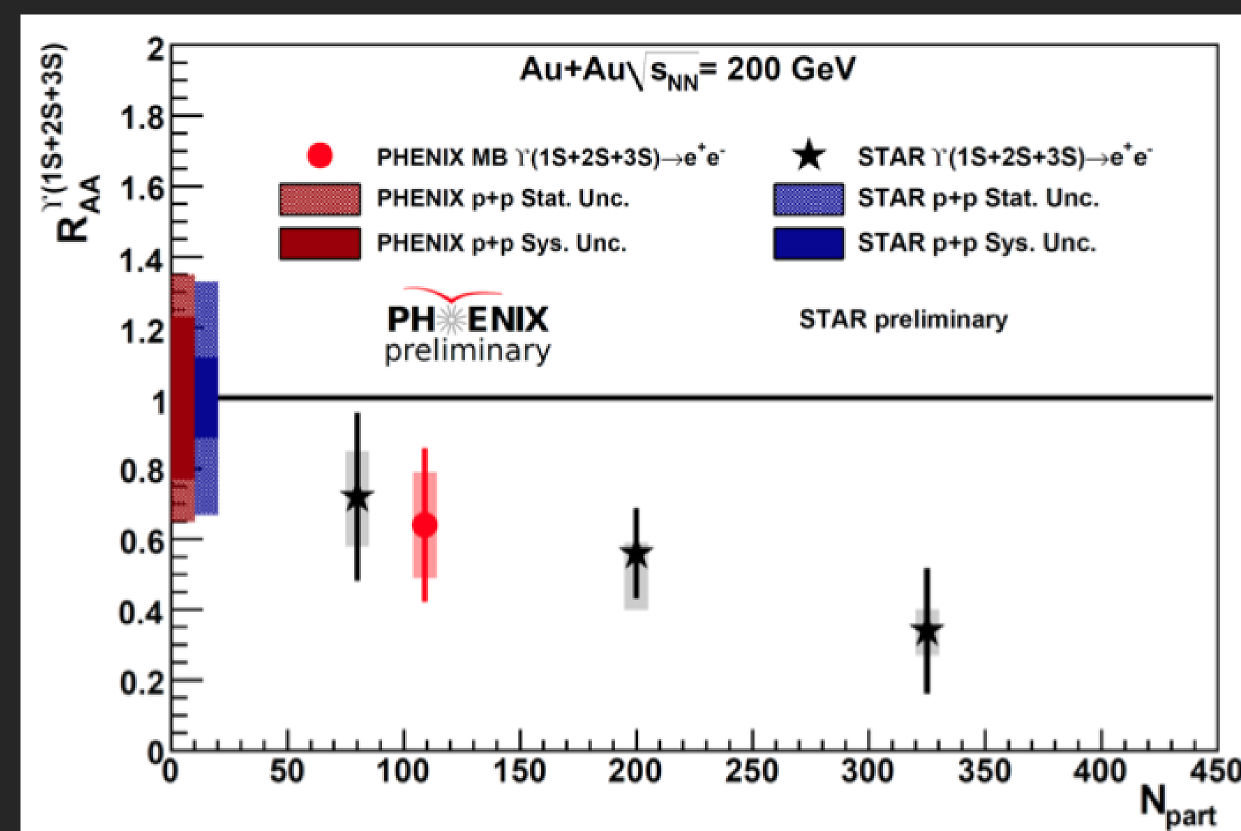

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Luminosities

Instantaneous luminosity :

$\mathcal{L} = N_{beam} \times N_{target} = N_{beam} \times (\rho \,.\, e \,.\, N_A)$ with e = target thickness

Planned luminosity for PHENIX :

- @ 200 GeV run14pp 12 pb^{-1}, run14dAu 0.15 pb^{-1}
- @ 200 GeV run15AuAu 2.8 pb^{-1} (0.13 nb^{-1} @ 62 GeV)

Nominal LHC luminosity PbPb 0.5 nb^{-1}

Luminosities

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$\mathcal{L} = N_{beam} \times N_{target} = N_{beam} \times (\rho \, . \, e \, . \, N_A)$ with e = target thickness

7 TeV proton beam

pp, pd, pA $\sqrt{s}$ = 115 GeV

[S. Brodsky, F. Fleuret, C. Hadjidakis, J.P. Lansberg, Phys. Rep. 522 (2013) 239]

Target (1 cm thick)	ρ (g cm^{-3})	A	$\mathcal{L}$ (μb^{-1} s^{-1})	$\int\mathcal{L}$ (pb^{-1} yr^{-1})
solid H	0.088	1	26	260
liquid H	0.068	1	20	200
liquid D	0.16	2	24	240
Be	1.85	9	62	620
Cu	8.96	64	42	420
W	19.1	185	31	310
Pb	11.35	207	16	160

Table 1: Instantaneous and yearly luminosities obtained with an extracted beam of 5×10^8 p$^+$/s with a momentum of 7 TeV for various 1cm thick targets

extracted beam $N_{beam} = 5 \, .10^8$ p$^+$/s

9 months running / year $\Leftrightarrow 10^7$ s

Planned luminosity for PHENIX :

- @ 200 GeV run14pp 12 pb^{-1}, run14dAu 0.15 pb^{-1}
- @ 200 GeV run15AuAu 2.8 pb^{-1} (0.13 nb^{-1} @ 62 GeV)

Nominal LHC luminosity PbPb 0.5 nb^{-1}

Luminosities

Instantaneous luminosity :

$\mathcal{L} = N_{beam} \times N_{target} = N_{beam} \times (\rho \,.\, e \,.\, N_A)$ with e = target thickness

7 TeV proton beam

pp, pd, pA $\sqrt{s}$ = 115 GeV

2.76 TeV lead beam

Pb*p*, Pb*d*, Pb*A* $\sqrt{s}$ = 72 GeV

[S. Brodsky, F. Fleuret, C. Hadjidakis, J.P. Lansberg, Phys. Rep. 522 (2013) 239]

Target (1 cm thick)	ρ (g cm^{-3})	A	$\mathcal{L}$ (μb^{-1} s^{-1})	$\int\mathcal{L}$ (pb^{-1} yr^{-1})
solid H	0.088	1	26	260
liquid H	0.068	1	20	200
liquid D	0.16	2	24	240
Be	1.85	9	62	620
Cu	8.96	64	42	420
W	19.1	185	31	310
Pb	11.35	207	16	160

Table 1: Instantaneous and yearly luminosities obtained with an extracted beam of 5×10^8 p$^+$/s with a momentum of 7 TeV for various 1cm thick targets

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Cu	8.96	64	17	17
W	19.1	185	13	13
Pb	11.35	207	7	7

Table 2: Instantaneous and yearly luminosities obtained with an extracted beam of 2×10^5 Pb/s with a momentum per nucleon of 2.76 TeV for various 1cm thick targets

extracted beam $N_{beam} = 5 \,.10^8$ p$^+$/s
9 months running / year $\Leftrightarrow 10^7$ s

extracted beam $N_{beam} = 2 \,.10^5$ Pb/s
1 month running / year $\Leftrightarrow 10^6$ s

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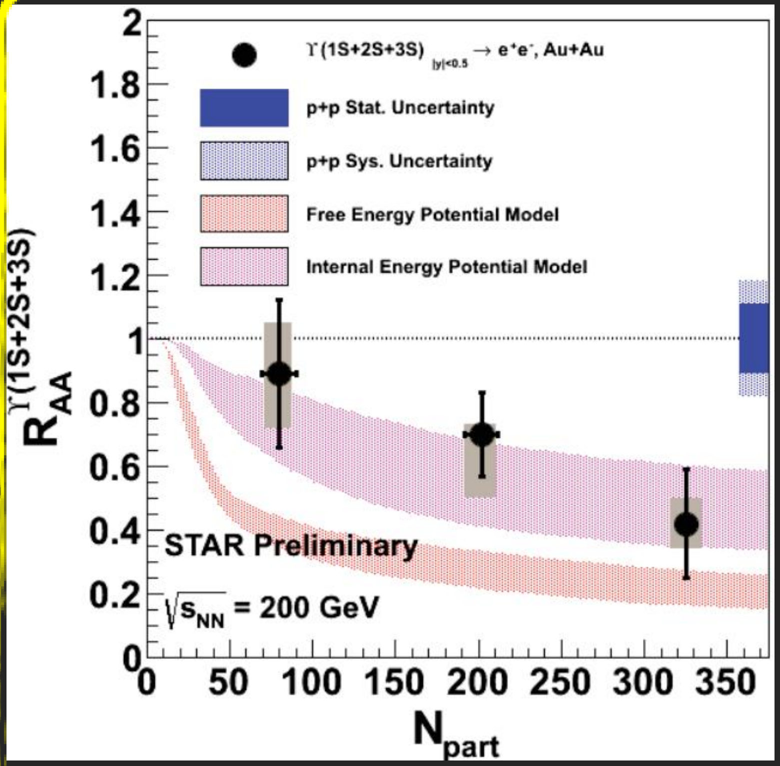
Bottomonium studies: from RHIC to AFTER



[Bielcik for STAR, HP2013]

Today :

- inclusive Υ R_{AA} vs centrality
- the most central point is compatible with a complete melting of 3S and a very strong suppression of 2S, with $T_{initial}$ ~ 430 MeV in this model

From thermal photon p_T spectra :

T_{avg} = 221 ± 19 (stat) ± 19 (syst) MeV (0-20% AuAu)

[PHENIX, PRL. 104 (2010) 132301]

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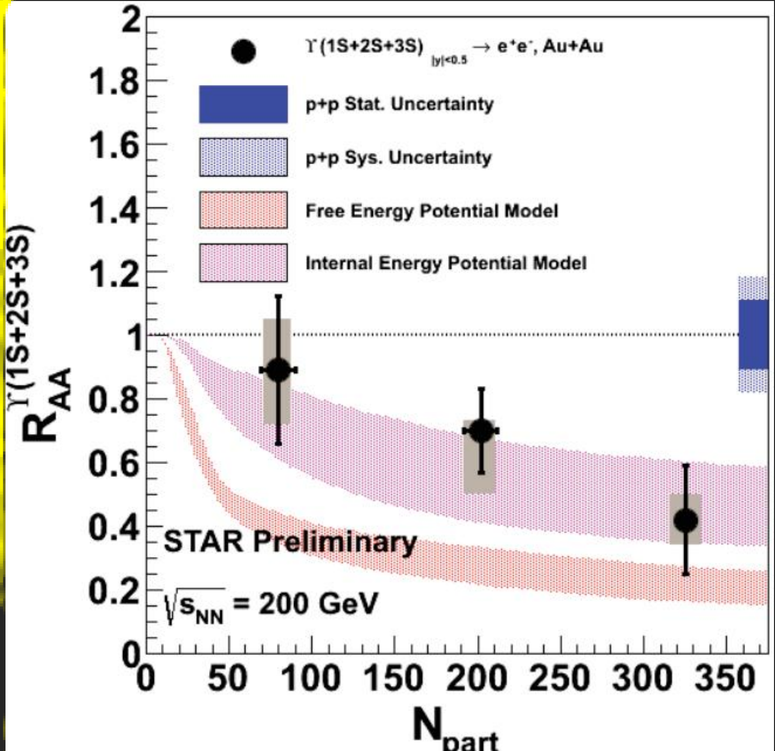

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[PHENIX, PRL. 104 (2010) 132301]

decompose this model into each state

↓

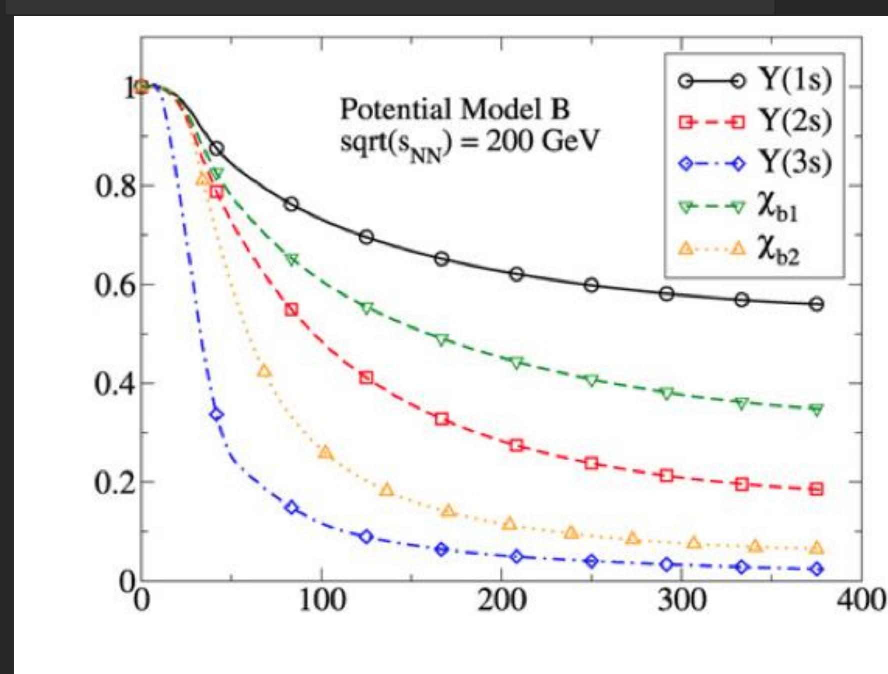
need more stat in AA + very good resolution

reminder

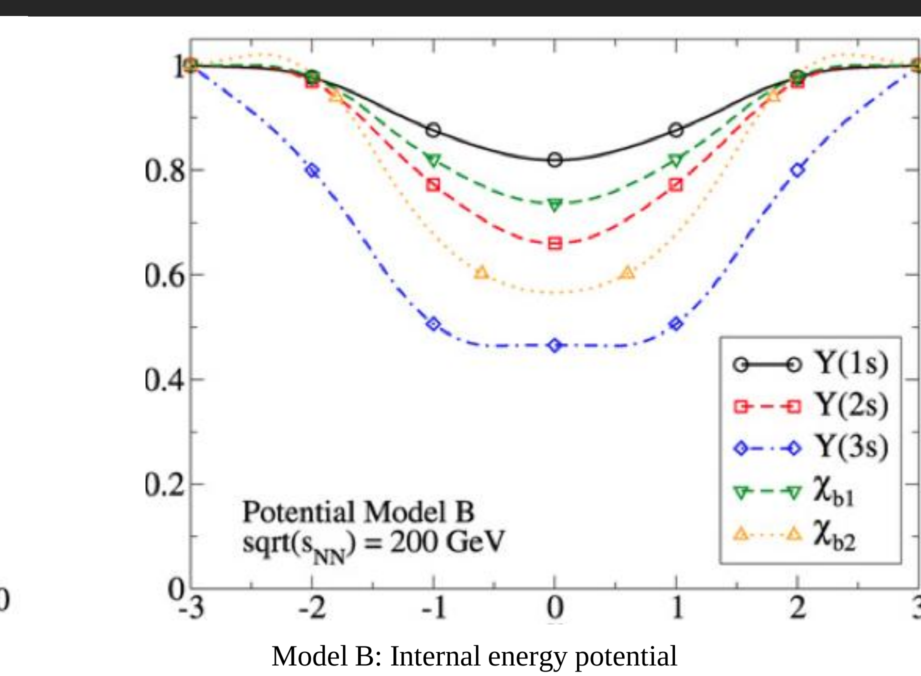
STAR : ~200 Υ

CMS : ~1k Υ

[Strickland et al., NPA 879 (2012) 25-58]



The dream measurements :



High statistics *pA* studies with AFTER: reference for nuclear effects & nPDF *per se*

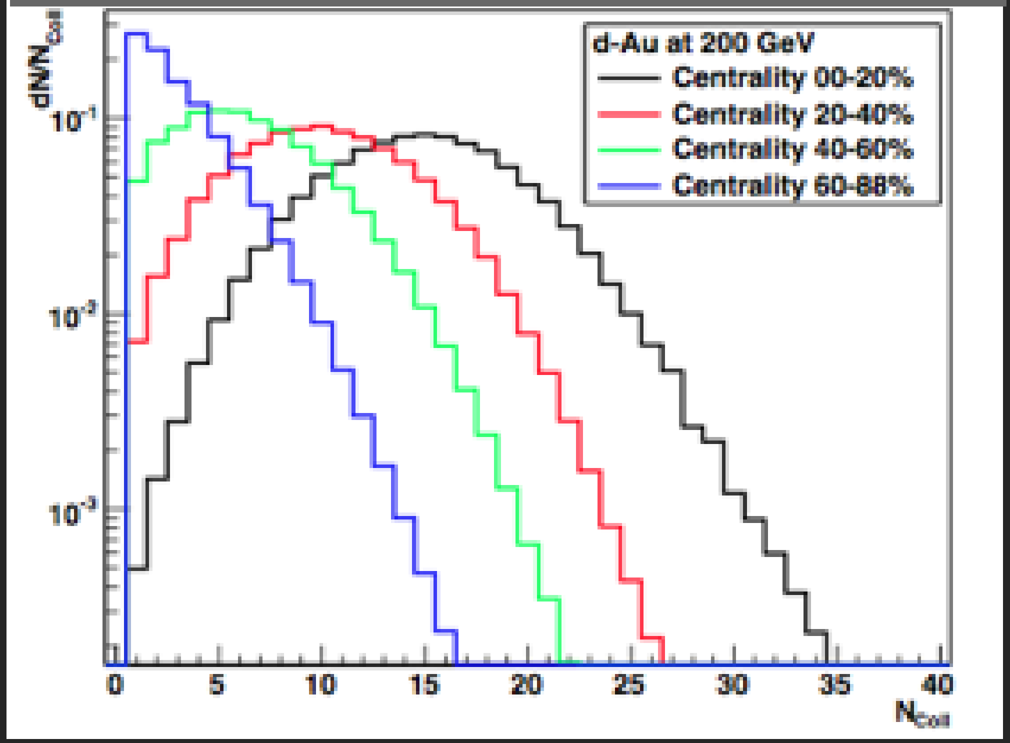
pA

Pb*p*

- A dependence thanks to target versatility

  <N_{coll}> dependence vs. *A* dependence (à la NA50, NA60)

[PHENIX, arXiv:1204.0777]



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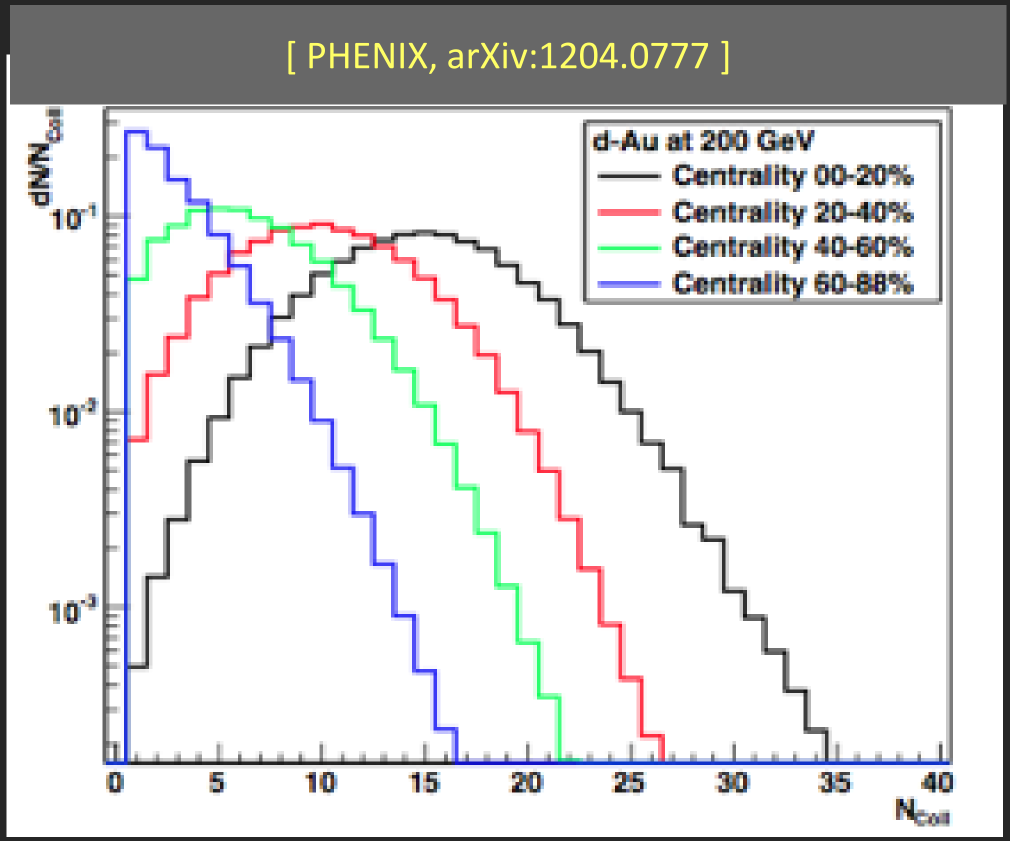

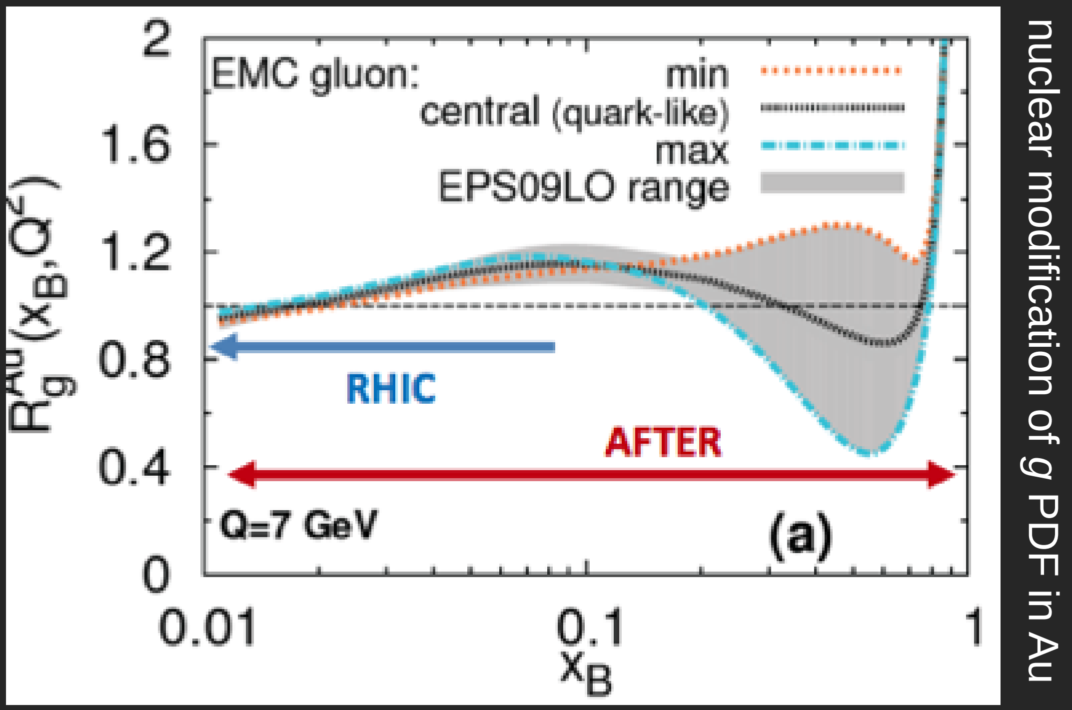

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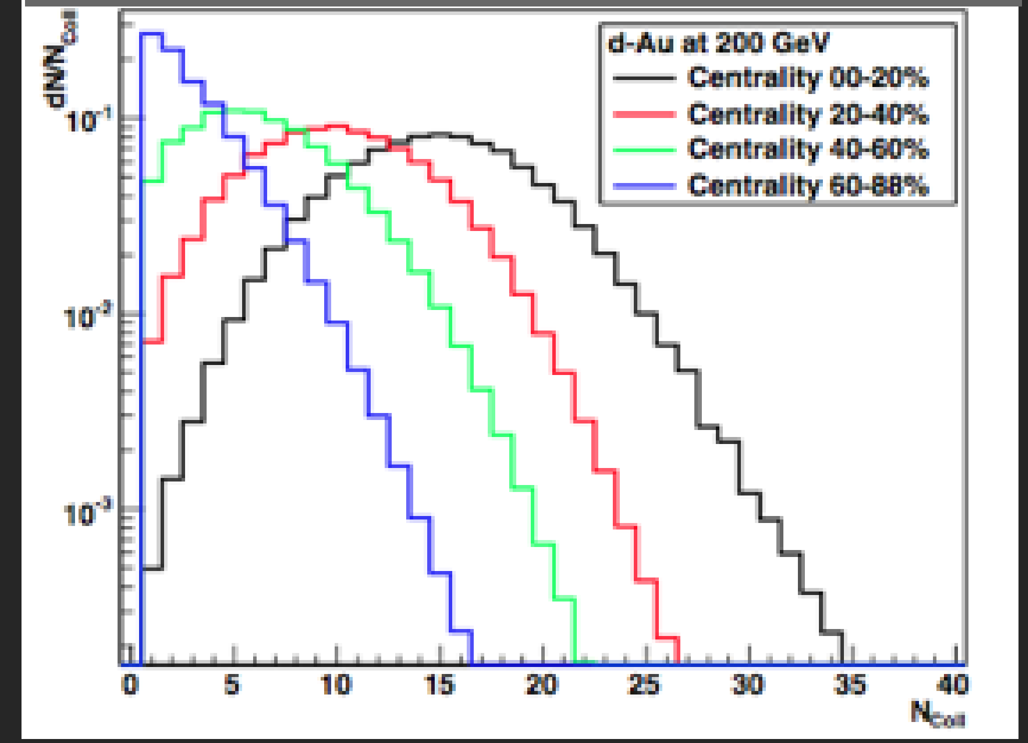
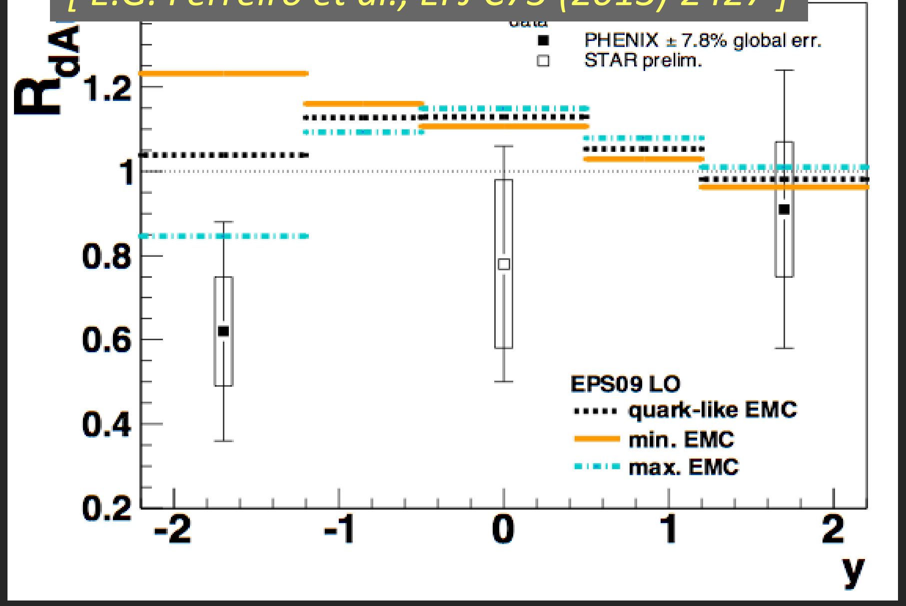
- nuclear PDF from intermediate to high x : antishadowing , EMC region , Fermi motion
- Gluon nPDF extraction using quarkonia (+ correlations), isolated photons, photon-jet correlation
- Strongly limited at RHIC

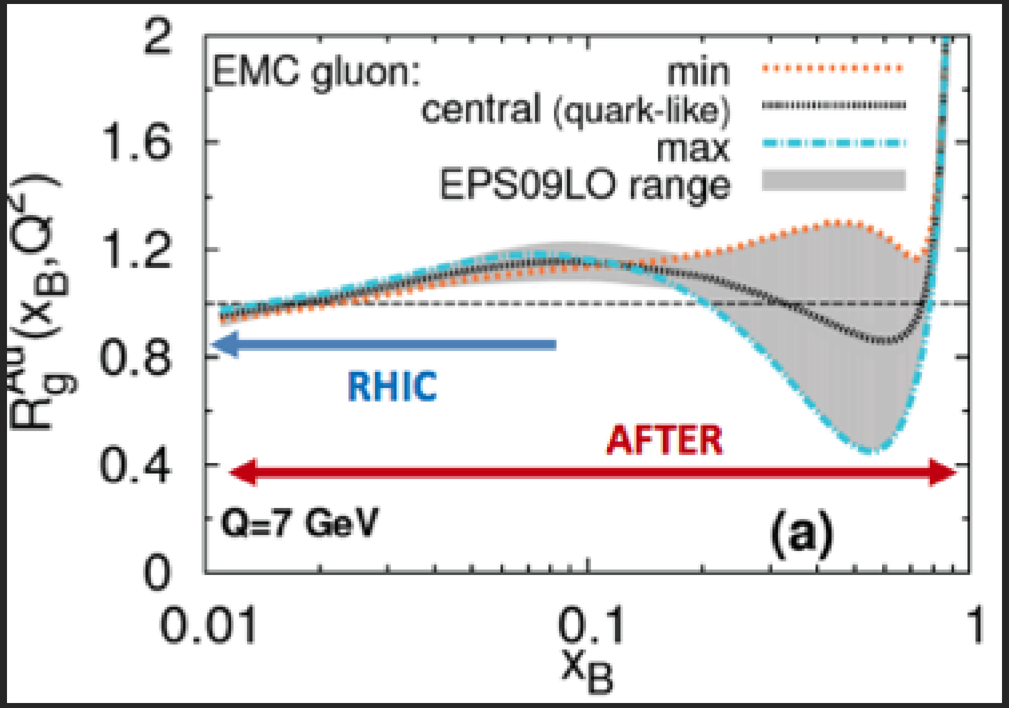
[PHENIX, arXiv:1204.0777]



[E.G. Ferreiro et al., EPJ C73 (2013) 2427]



Υ in dAu @ 200 GeV, STAR and PHENIX



nuclear modification of *g* PDF in Au

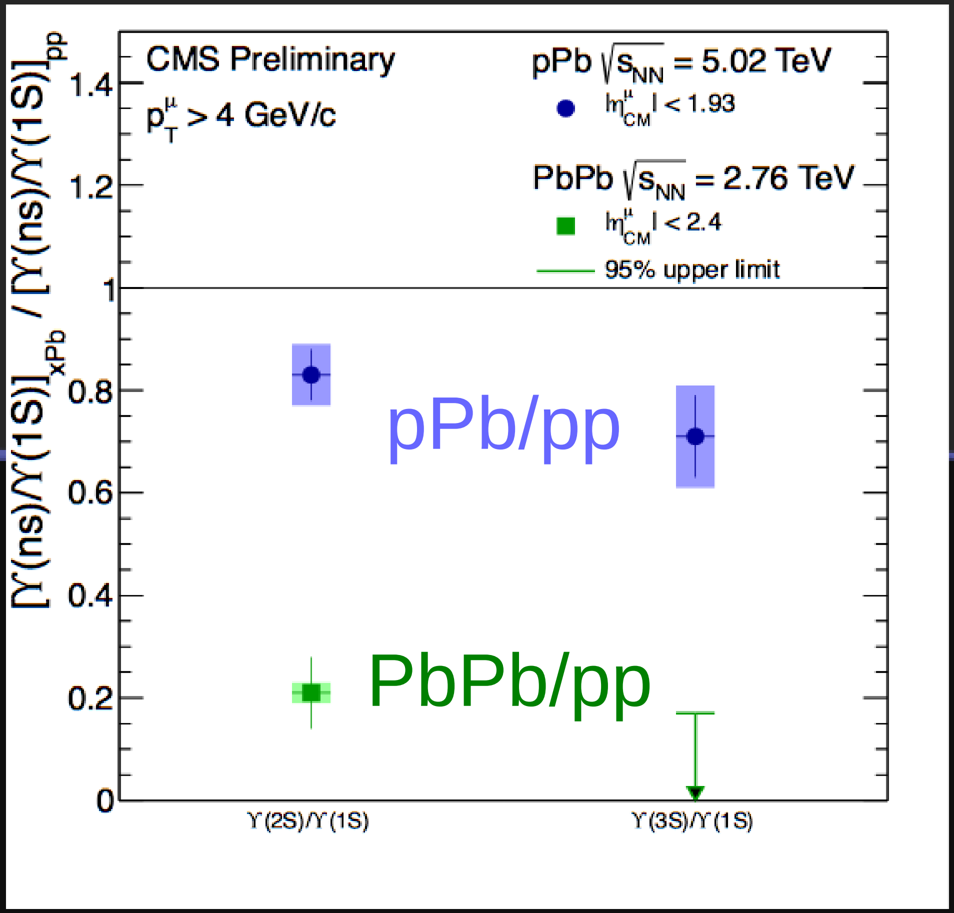
Bottomonium : a cleaner QGP probe ?

- 3 states (2S & 3S not too fragile)
- Better applicability of pQCD w.r.t. J/ψ
- in the QGP : negligible regeneration effects

BUT

Bottomonium : a cleaner QGP probe ?

pPb vs. pp: excited states suppressed more than the ground state in pPb compared to pp collisions (significance < 3σ ?)



[Benhabib for CMS, HP2013]

- 3 states (2S & 3S not too fragile)
- Better applicability of pQCD w.r.t. J/ψ
- in the QGP : negligible regeneration effects

BUT

Cold effects (i.e. not QGP) :

✦ non-trivial effects seen in *pA* collisions

✦ need more studies and high stat *pA* measurements

➡ This is where AFTER cannot be challenged

Summary and outlooks

AFTER @ LHC

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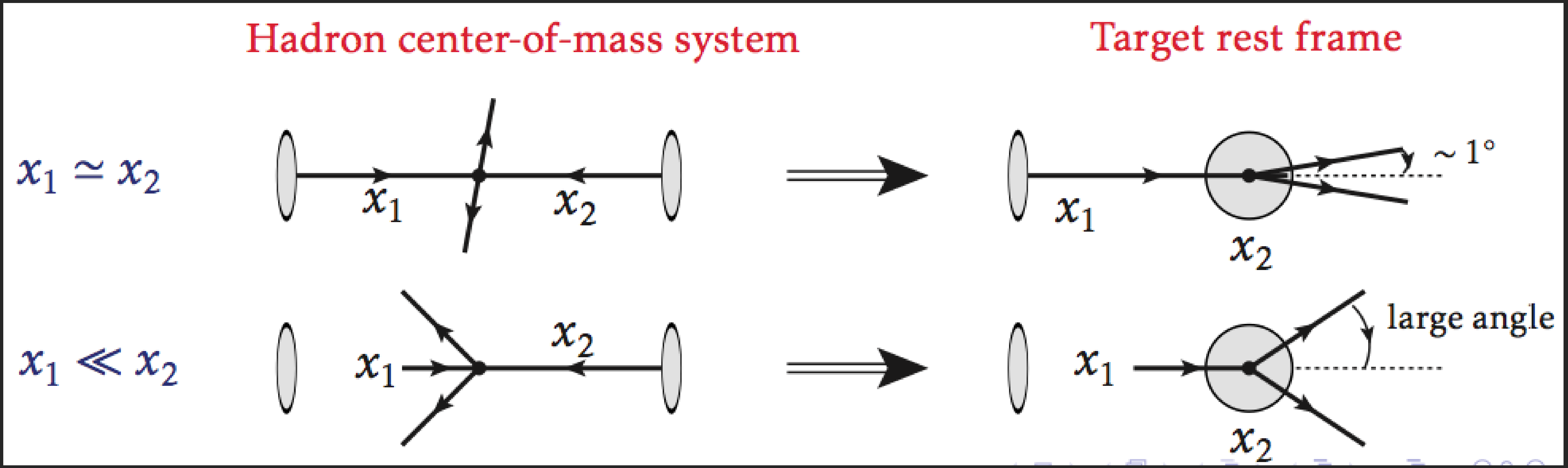
- It can be done with AFTER, with yields as large as those of CMS along with extremely precise measurements of proton-nucleus collisions
- RHIC experiments cannot resolve the 3 states and are limited by the luminosity (stronger limitation at 62 GeV)
- Measurement of χ_b states not required, since we could use all 3Υ(nS) states, but would certainly add very interesting pieces of information.

SPARE SLIDES

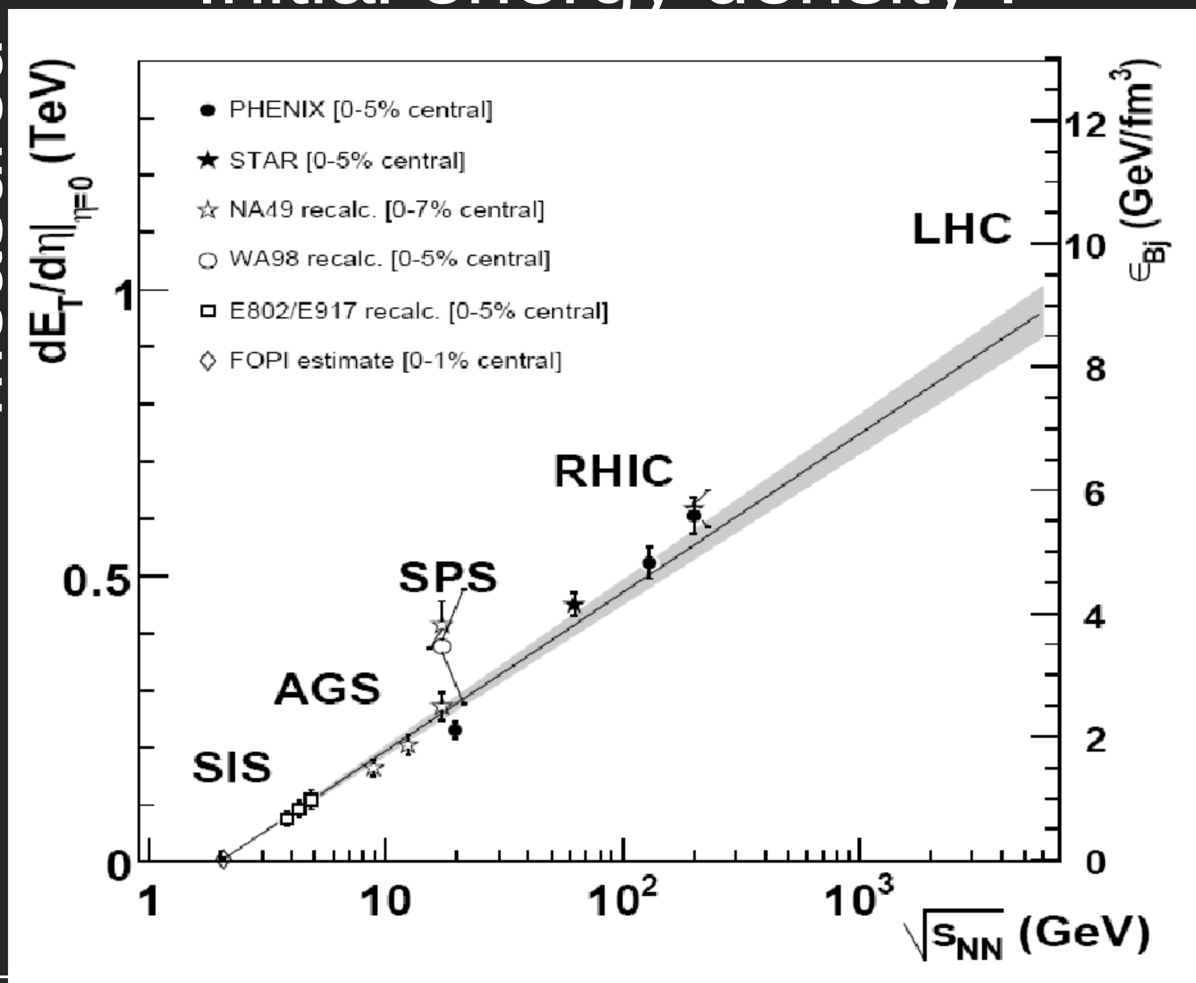
Backward physics



Energy density in heavy ion collisions

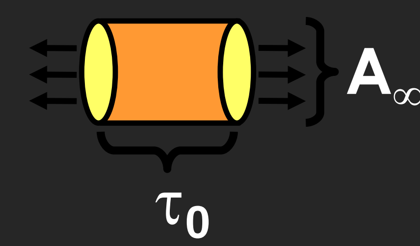
Initial energy density :

measured



computed $\varepsilon_{Bj} \times \tau_0$

Longitudinal QGP expansion :



Bjorken formula :

$$\epsilon_{Bj} = \frac{dE_t}{dy} \frac{1}{A_\perp \tau_0}$$

facility	collision species	$\sqrt{s_{NN}}$ (GeV)	$\varepsilon_{Bj} \times \tau_0$ (GeV/fm^{-3} . fm/c)
AGS (BNL)	Au+Au	5	1,5
SPS (CERN)	Pb+Pb	17	3,9
RHIC (BNL)	Au+Au	200	5,5
LHC (CERN)	Pb+Pb	5500	10