Quarkonia as probes of deconfinement

- quarkonia and deconfinement
- charmonium data (run1 and run2 of LHC)
- pPb data
- bottomonium

work done over the past 18 years in collaboration with Peter Braun-Munzinger, Anton Andronic, Krzysztof Redlich
see article in Nature 561 (2018) 321, Sept. 20

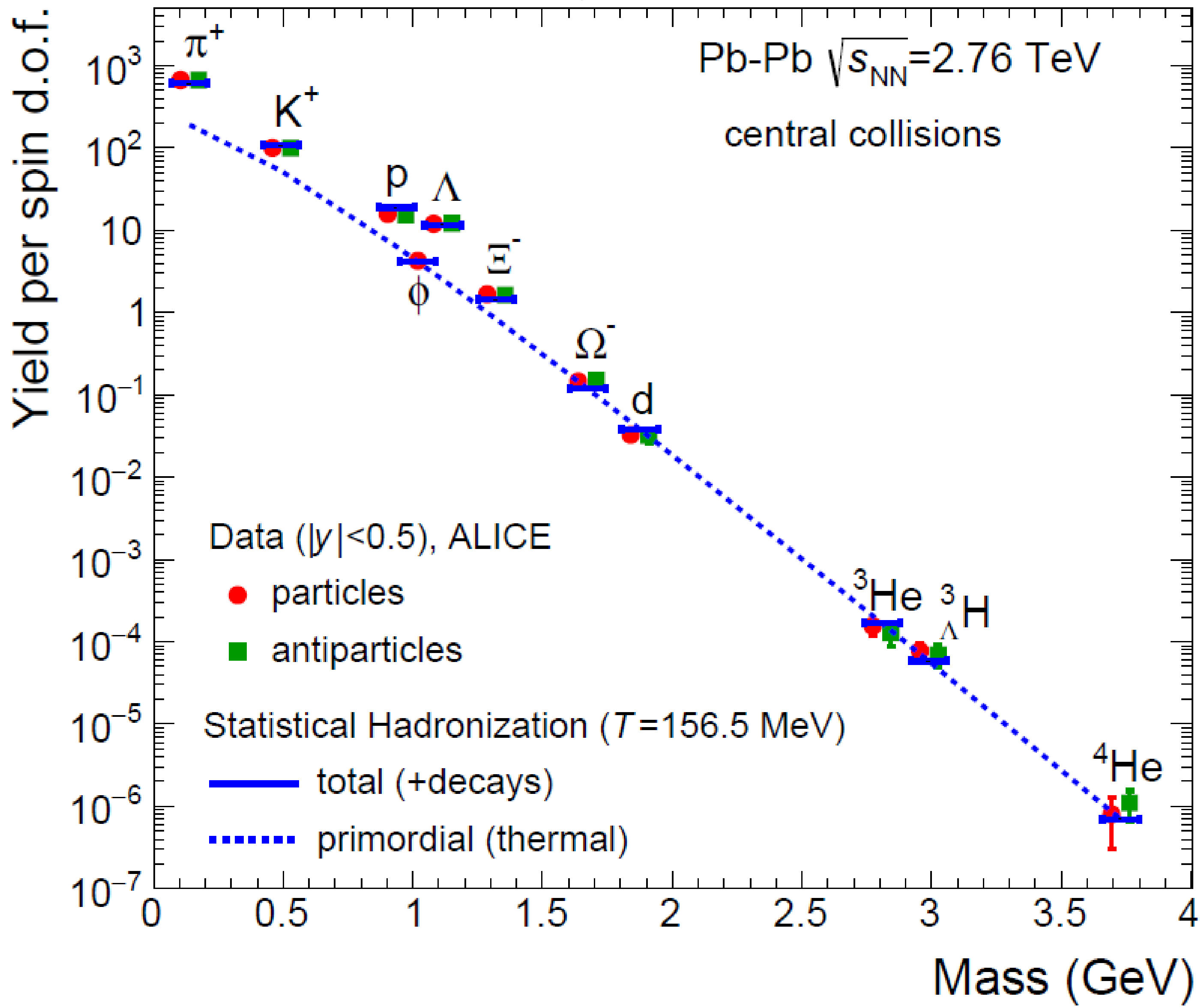
Johanna Stachel, Universität Heidelberg
Workshop on 'Observables of Hadronization and the QCD Phase Diagram in the Cross Over Domain'
ECT* Trento, October 15 - 19, 2018

Success of statistical hadronization approach

Peter's talk: yields of light flavor hadrons and (anti-)nuclei well consistent with QCD statistical operator as captured by the HRG

does this approach extend to heavy flavor hadrons?

A. Andronic, P. Braun-Munzinger, K. Redlich, JS Nature 561 (2018) 321



Charmonia and statistical hadronization

assume QGP screens all charmonia (as proposed by Matsui and Satz), but charmonium and charmed hadron production takes place at the phase boundary (Braun-Munzinger, J.S. 2000):

→ enhanced J/ψ production at colliders – signal for deconfinement
production probability from thermalized charm quarks scales with N_{ccbar}^2

yields of charmonia (and open charm hadrons) directly linked to phase boundary and hadronization temperature
still probe of deconfinement, but notion of 'thermometer' obsolete

Extension of statistical model to include charmed hadrons

- assume: all charm quarks are produced in initial hard scattering; number not changed in QGP

  $N_{c\bar{c}}^{direct}$ from data (total charm cross section) or from pQCD

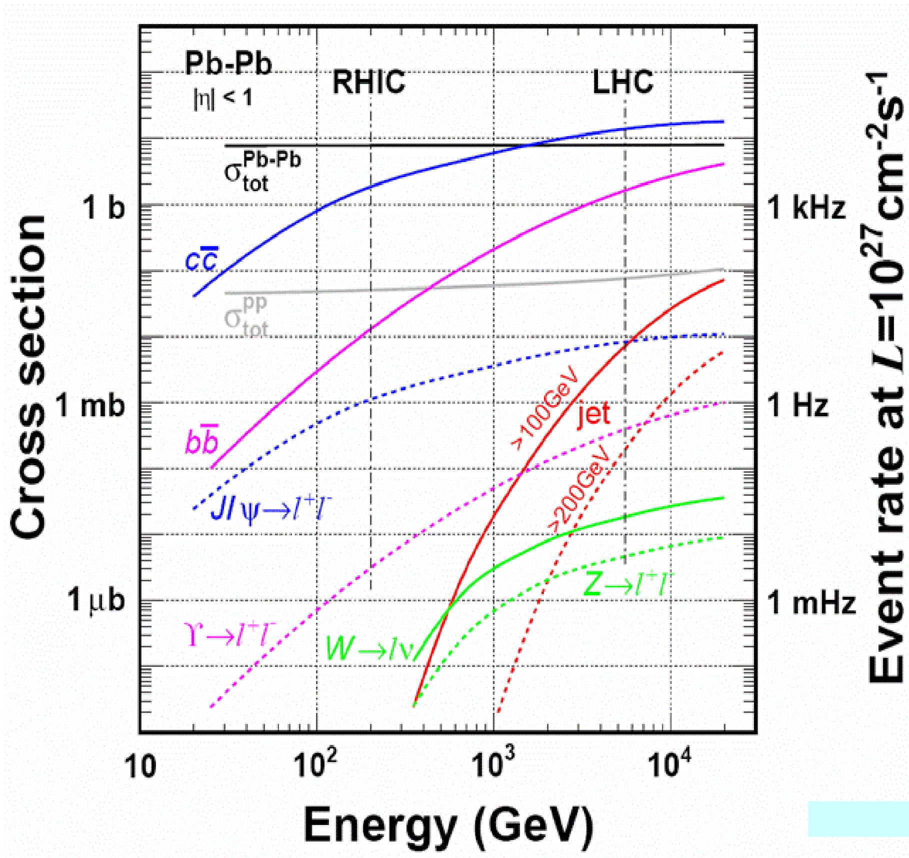
- hadronization at T_c following grand canonical statistical model used for hadrons with light valence quarks (canonical corr. if needed)
  technically number of charm quarks fixed by a charm-balance equation containing fugacity g_c

$$N_{c\bar{c}}^{direct} = \frac{1}{2} g_c V (\sum_i n_{D_i}^{therm} + n_{\Lambda_i}^{therm}) + g_c^2 V (\sum_i n_{\psi_i}^{therm}) + \ldots$$

↑

the only additional free parameter

Cross sections as function of collision energy



from SPS to RHIC to LHC
strong growth in charm and beauty
procution cross sections

Alternative - generation and formation in QGP

implementation of screening into space-time evolution of the fireball

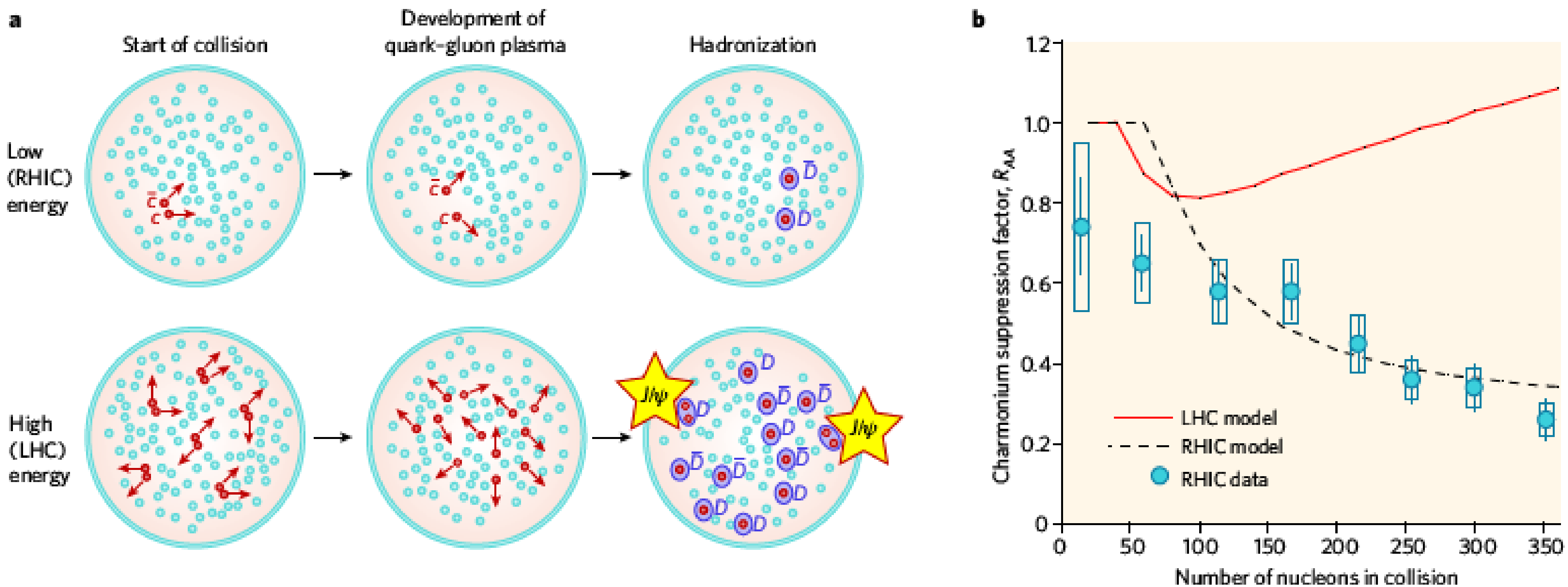
→ continuous destruction and (re)generation in QGP

Thews et al., 2001, Rapp et al. 2001, Gorenstein et al. 2001, P.F. Zhuang et al. 2005

enhancement at colliders possible

notion of hadron-like states in QGP
make use of modified spectral functions and gluon distribution
again no direct link to phase boundary, no 'thermometer' either

Quarkonium as a probe for deconfinement at the LHC the statistical hadronization picture

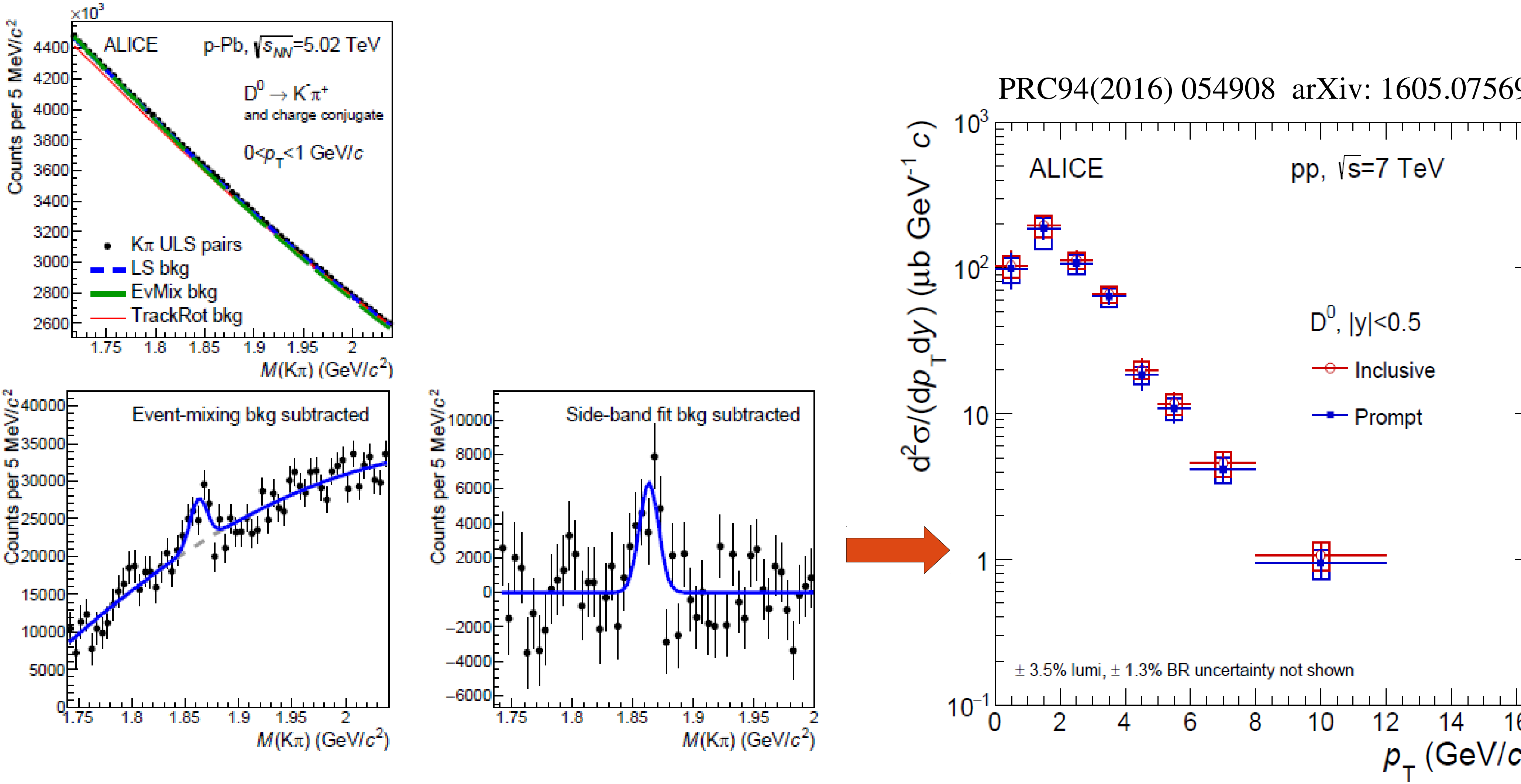


charmonium enhancement as fingerprint of deconfinement at LHC energy - a prediction!

Braun-Munzinger, J.S. Phys. Lett. B490 (2000) 196

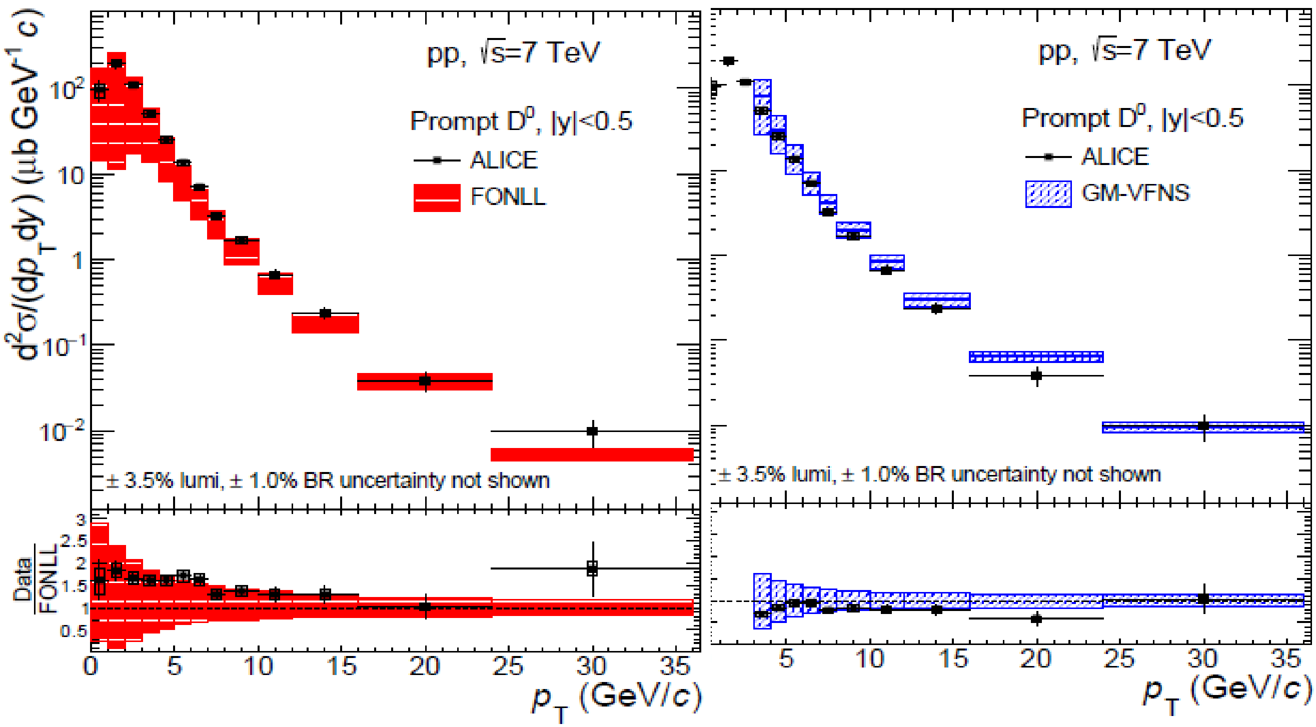
Andronic, Braun-Munzinger, Redlich, J.S., Phys. Lett. B652 (2007) 659

First measurements of open charm cross section down to p_t = 0 at mid-rapidity



very hard struggle to deal with (irreducible) combinatorial background, successful

measurements in pp at 7 TeV agree well with state of the art pQCD calculations



ALICE: 1702.00766
FONLL: Cacciari et al., arXiv:1205.6344
GM-VFNS: Kniehl et al., arXiv:1202.0439

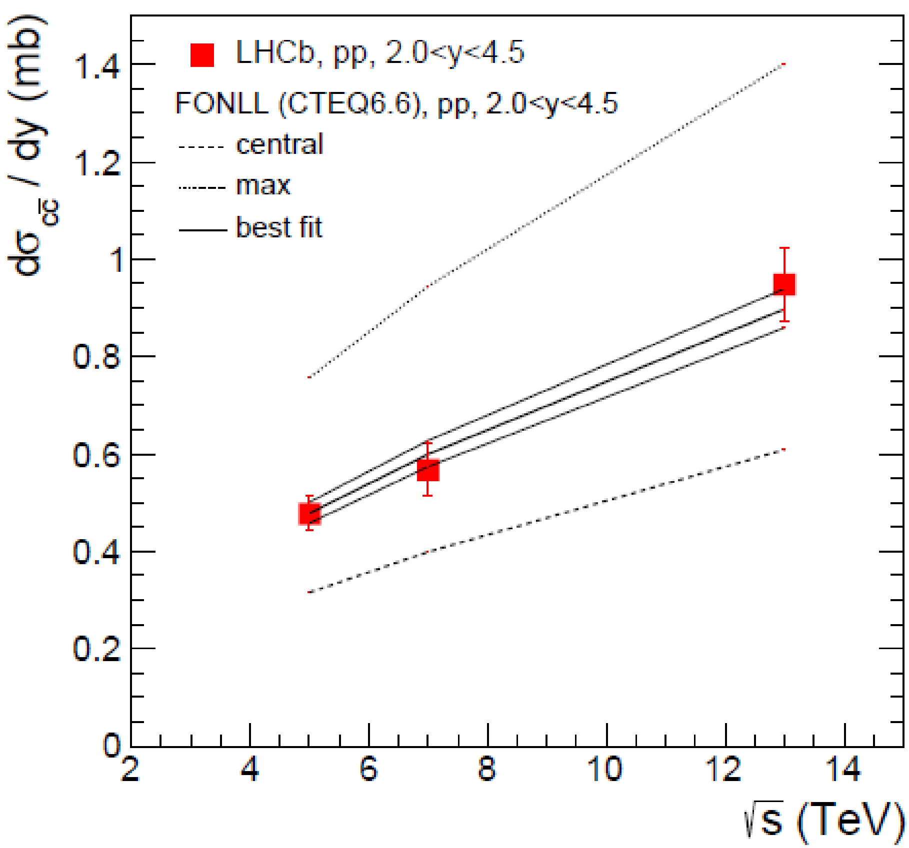
data are compared to perturbative QCD calculations
reasonable agreement
- at upper end of FONLL and
  at lower end of GM-VFNS

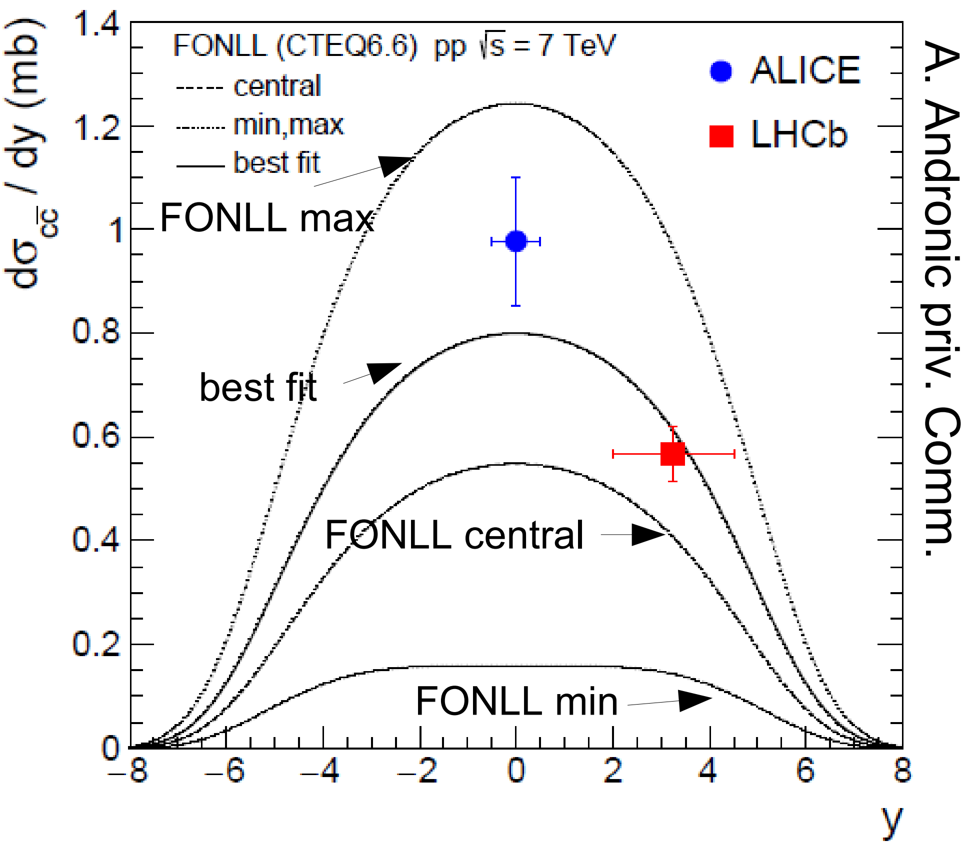
mid-y cross sections

	Extr. factor to $p_T > 0$	$\mathrm{d}\sigma/\mathrm{d}y\,|_{|y|<0.5}$ (μb)
D^0	$1.0002^{+0.0004}_{-0.0002}$	$512 \pm 37(\mathrm{stat}) \pm 39(\mathrm{syst}) \pm 18(\mathrm{lumi}) \pm 5(\mathrm{BR})$
D^+	$1.25^{+0.29}_{-0.09}$	$235 \pm 19(\mathrm{stat}) \pm 26(\mathrm{syst}) \pm 8(\mathrm{lumi}) \pm 6(\mathrm{BR})^{+54}_{-16}(\mathrm{extrap})$
D^{*+}	$1.21^{+0.28}_{-0.08}$	$251 \pm 29(\mathrm{stat}) \pm 24(\mathrm{syst}) \pm 9(\mathrm{lumi}) \pm 3(\mathrm{BR})^{+58}_{-16}(\mathrm{extrap})$
D_s^+	$2.23^{+0.71}_{-0.65}$	$89 \pm 18(\mathrm{stat}) \pm 11(\mathrm{syst}) \pm 3(\mathrm{lumi}) \pm 3(\mathrm{BR})^{+28}_{-26}(\mathrm{extrap})$

the baseline for the interpretation of PbPb data

use shape of FONLL to interpolate to proper √s and y-interval

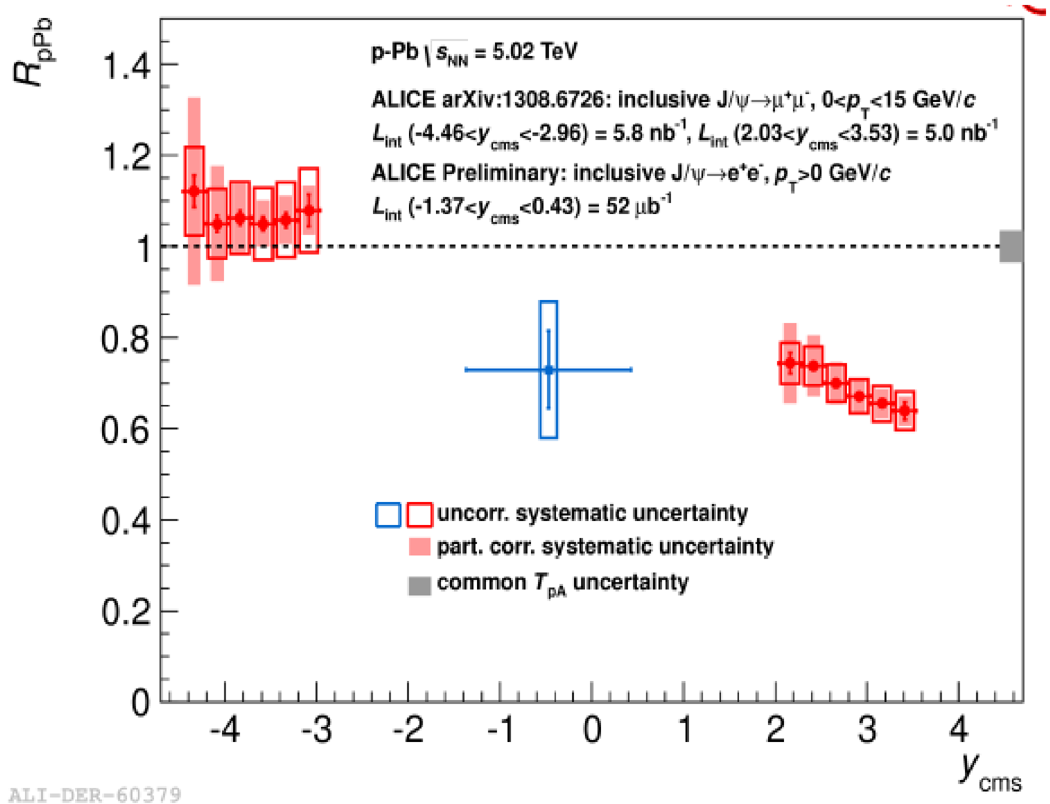




LHCb: 5 TeV arXiv:1610.02230
7 TeV NPB 871 (2013) 1
13 TeV JHEP 03 (2016) 159
plus erratum

ALICE: 7 TeV PRC94(2016) 054908
and 1702.00766

J/ψ rapidity distribution in pPb compared to pp

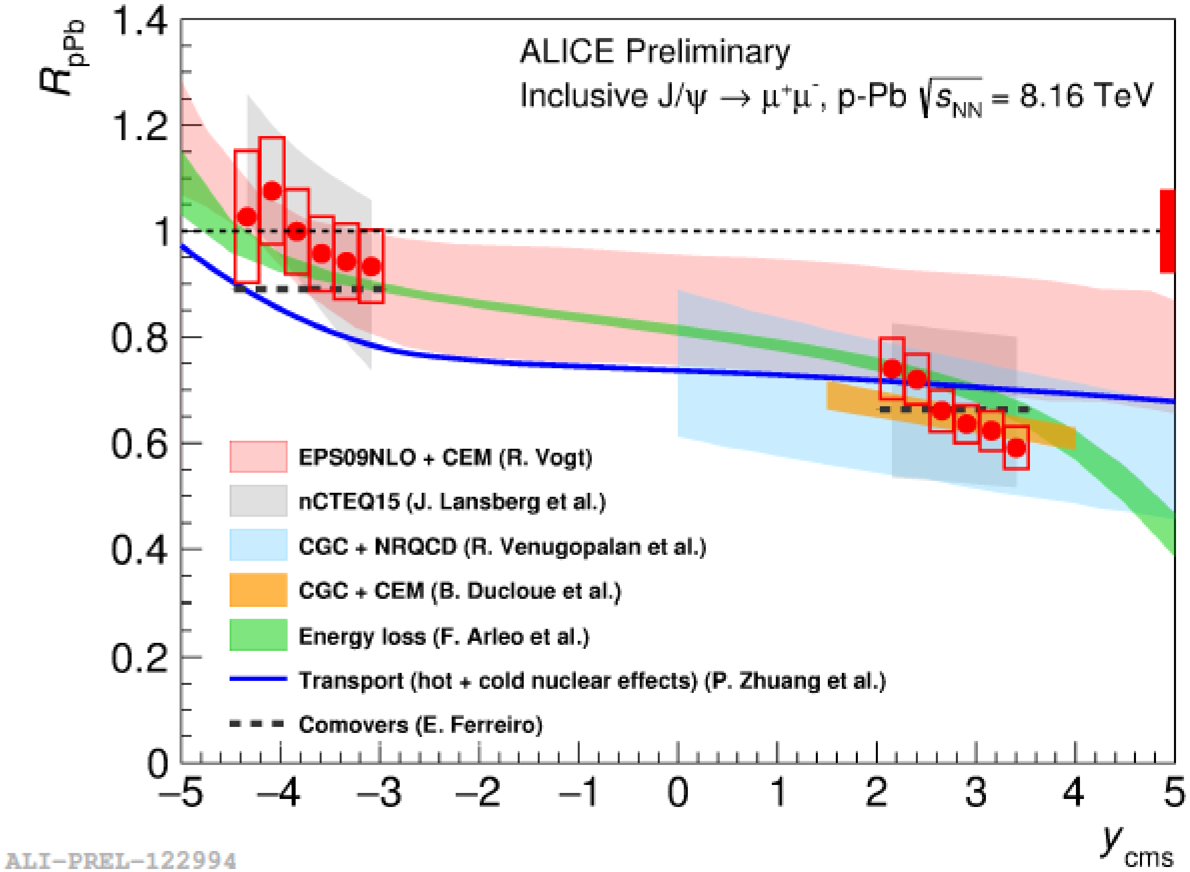


ALICE forward/backward arXiv:1308.6726

good agreement with LHCb arXiv:1308.6729

ALICE mid-y Nucl. Phys. A932 (2014) 472c

J/ψ rapidity distribution in pPb compared to pp



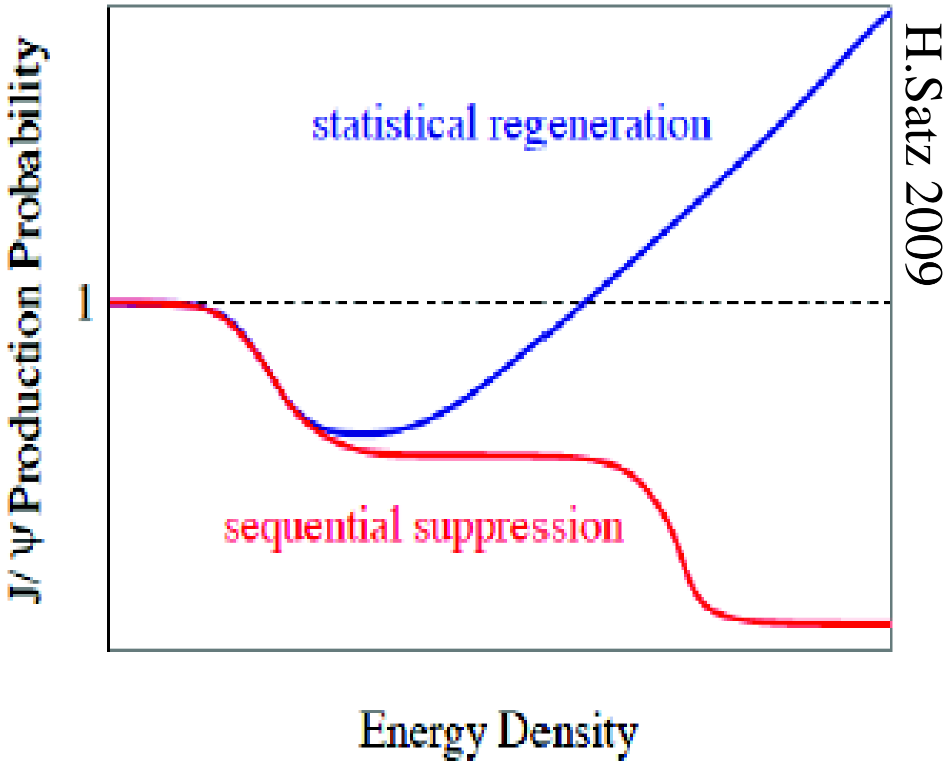
ALICE new 8.16 TeV data

pp open charm dσ/dy plus nuclear effects from J/ψ in pPb form current baseline for charmonia in PbPb

good agreement with shadowing calculations
also with energy loss models wo shadowing
and CGC calculation

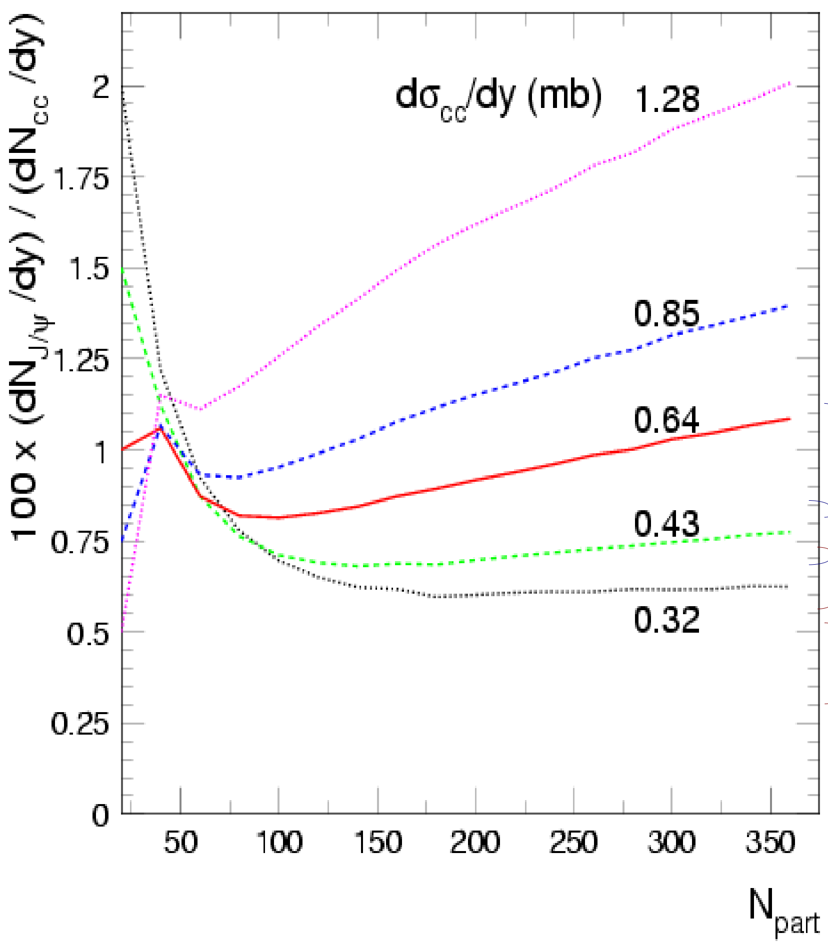
Expectations for LHC

2 possibilities:



Expectations for LHC from measured ccbar cross section in pp collisions

A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel Phys. Lett. B652 (2007) 259



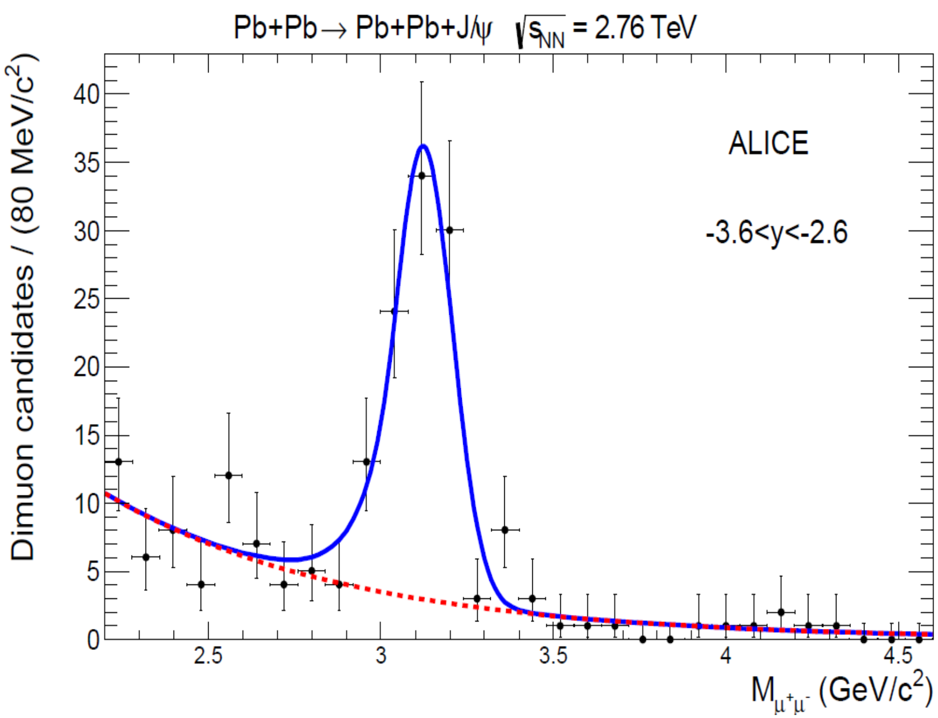
mid-y LHC 2.76 and 5.02 TeV including shadowing

forward-y LHC 2.76 and 5.02 TeV including shadowing

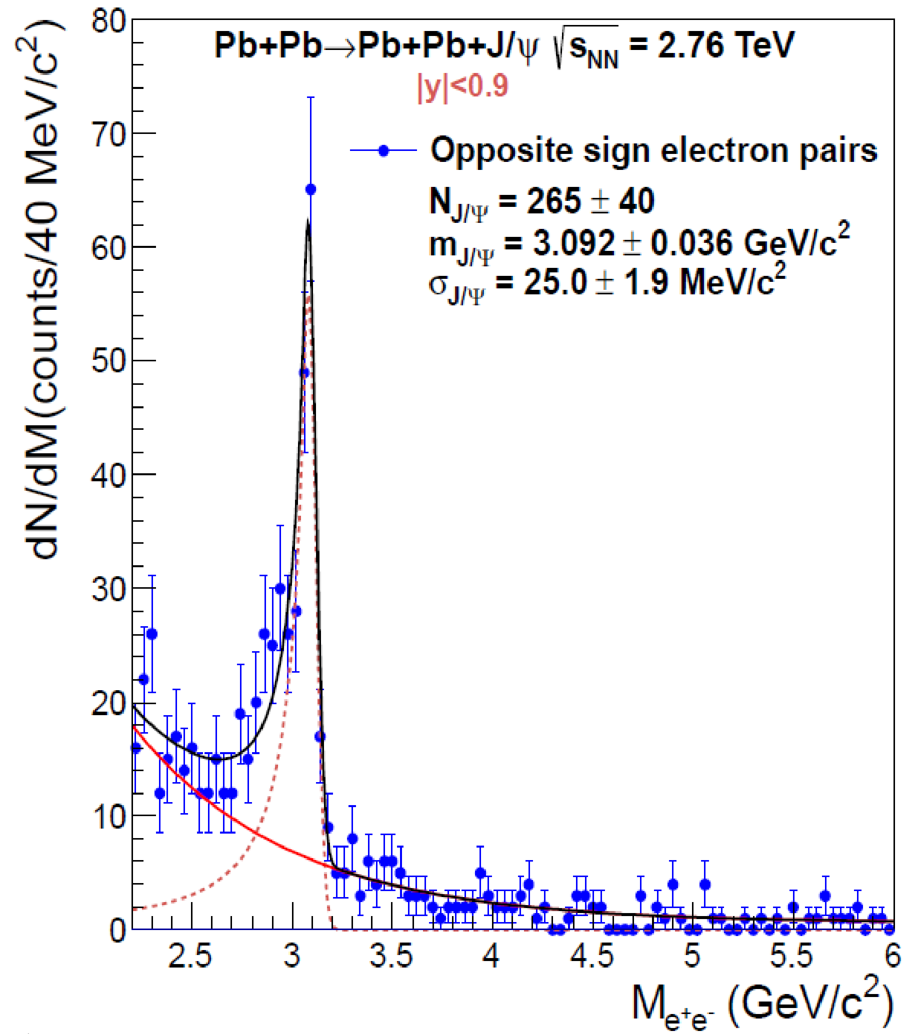
measured ccbar cross sections at appropriate rapidity by ALICE and LHCb and shadowing from measured J/psi production in pPb collisions compared to pQCD

Reconstruction of J/ψ via $\mu^+\mu^-$ and e^+e^- decays

PLB 718 arXiv:1209.3715



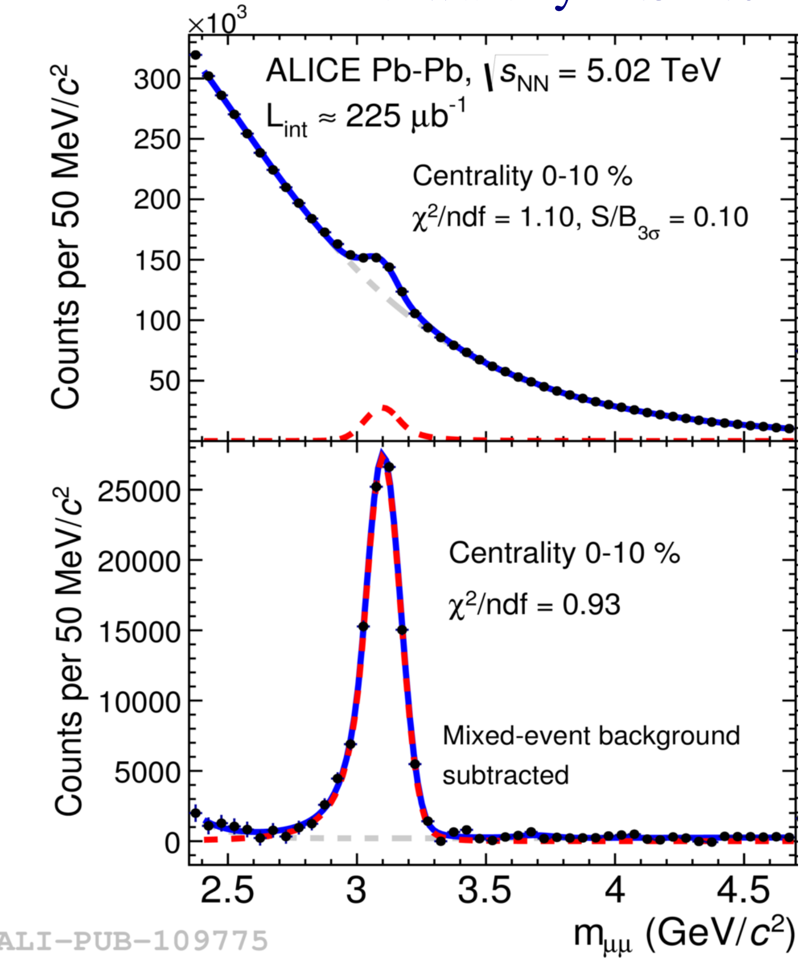
ALICE EPJ C73 arXiv:1305.1467



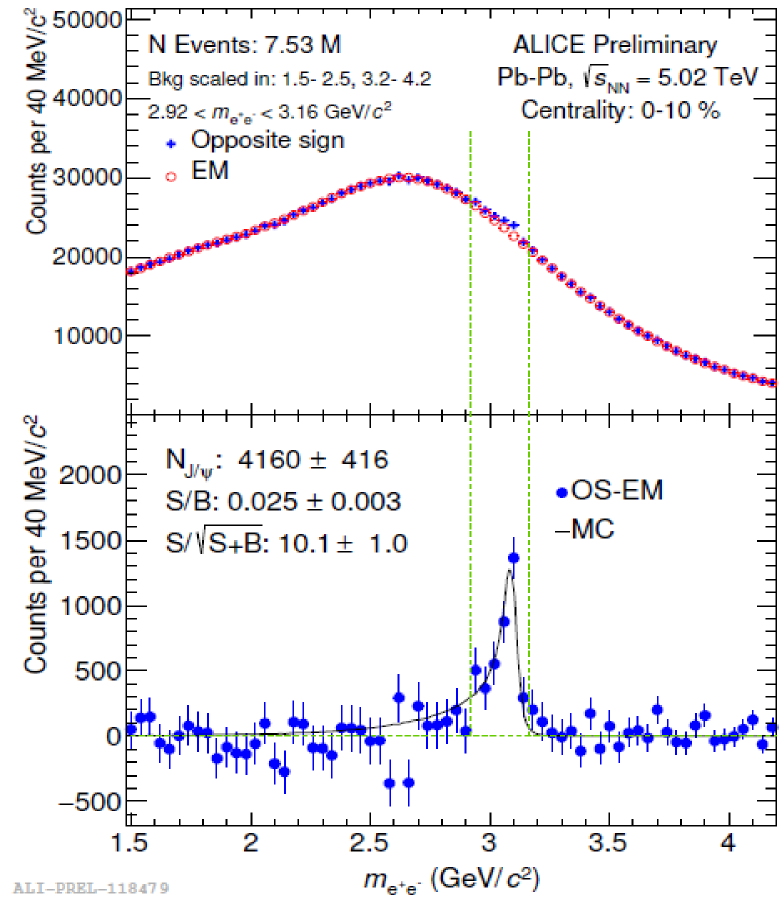
photoproduction in ultra-peripheral PbPb collisions – excellent signal to background very good understanding of line shape
(probes nuclear gluon shadowing, not discussed here)

Reconstruction of J/ψ via $\mu^+\mu^-$ and e^+e^- decays

forward y=2.5-4.0



mid |y| < 0.8



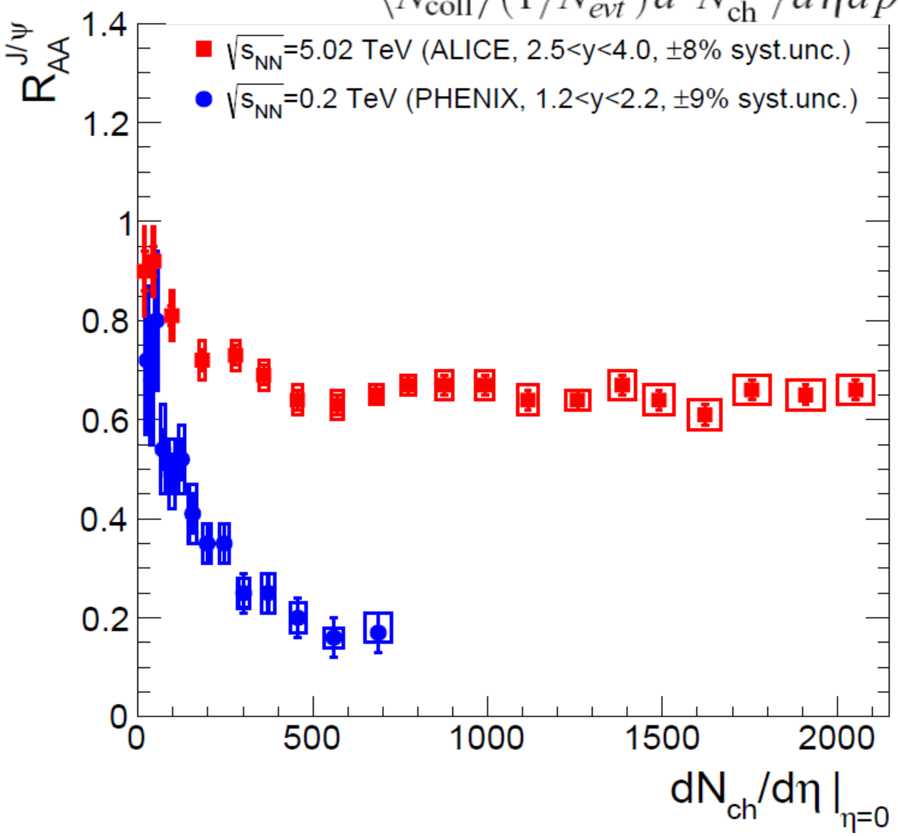
<u>most challenging:</u> central PbPb collisions

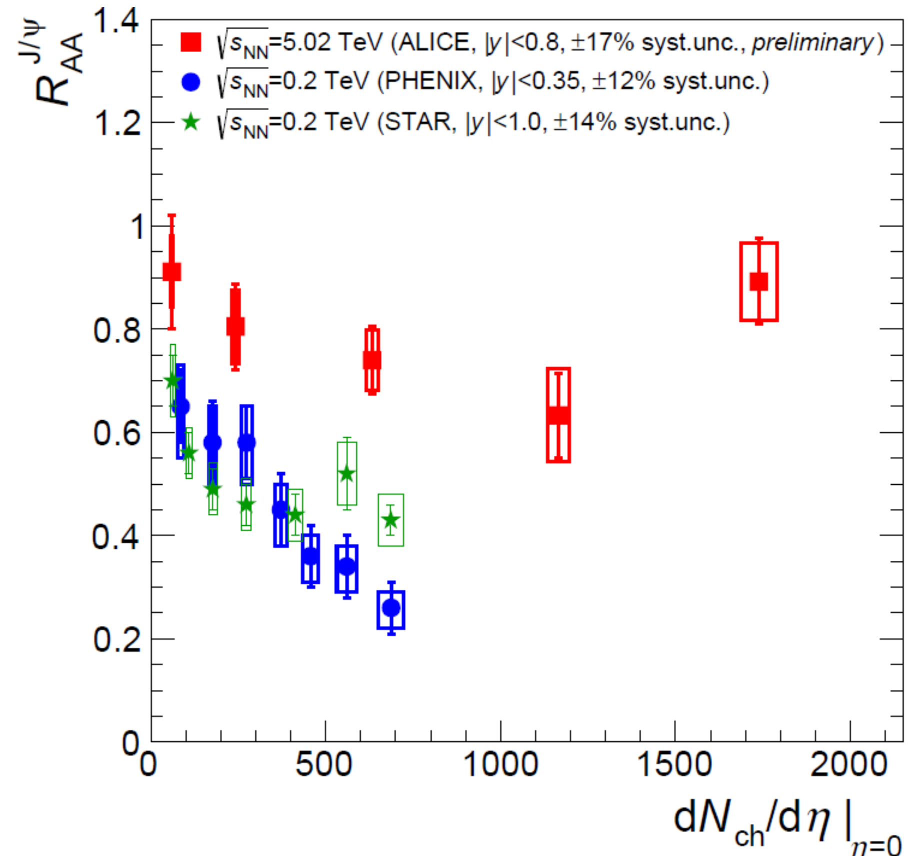
in spite of formidable combinatorial background

(true electrons, not from J/ψ decay but e.g. D- or B-mesons) resonance well visible

J/ψ production in PbPb collisions: LHC rel. to RHIC

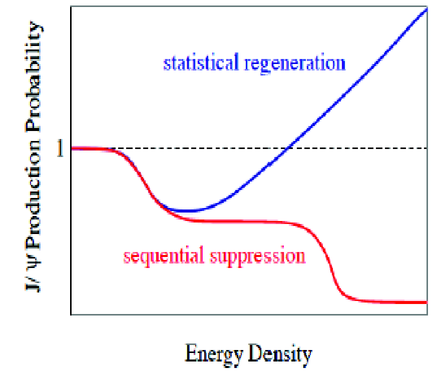
$$R_{AA}(p_T) = \frac{(1/N_{evt}^{AA})\, d^2N_{ch}^{AA}/d\eta dp_T}{\langle N_{coll}\rangle\,(1/N_{evt}^{pp})\, d^2N_{ch}^{pp}/d\eta dp_T}$$



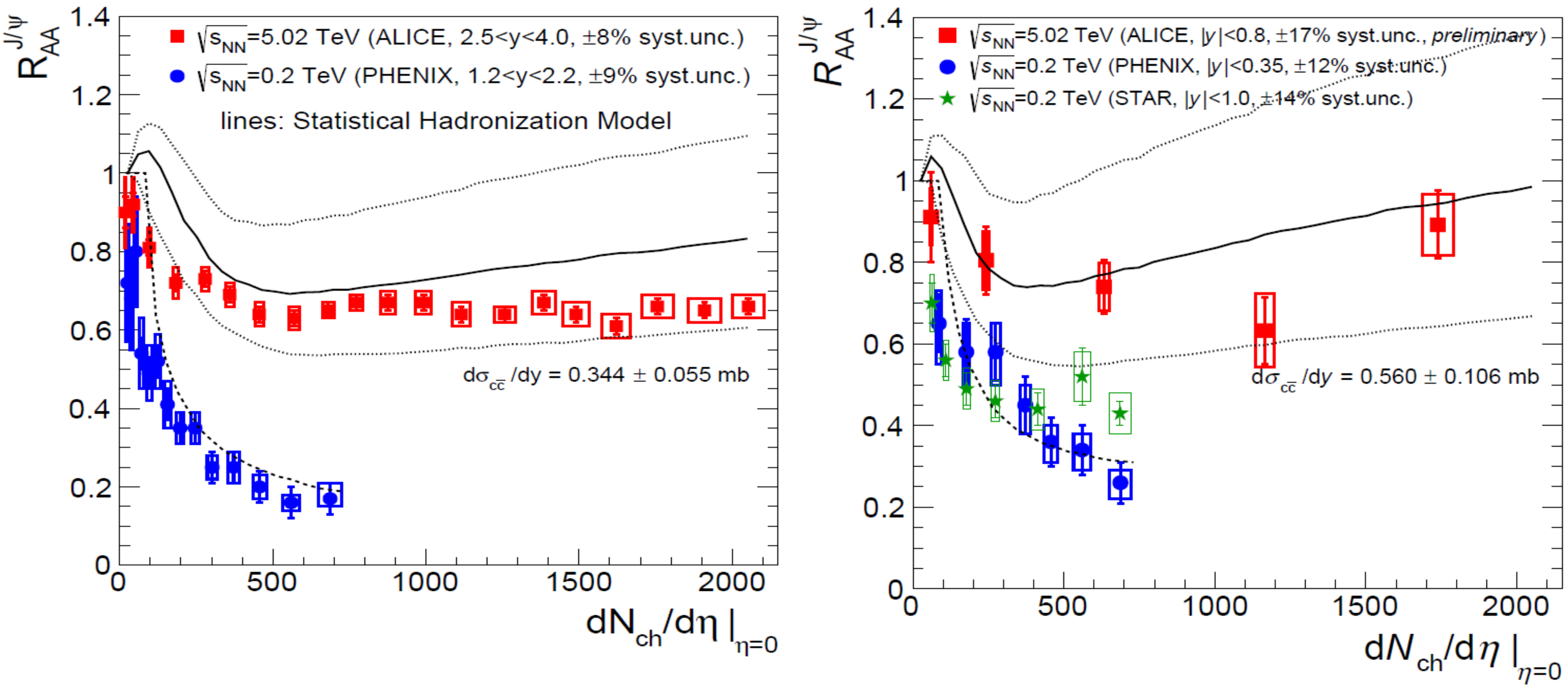


energy density -->

sequential melting scenario not observed
rather: enhancement with increasing energy density!
(from RHIC to LHC and from forward to mid-rapidity)

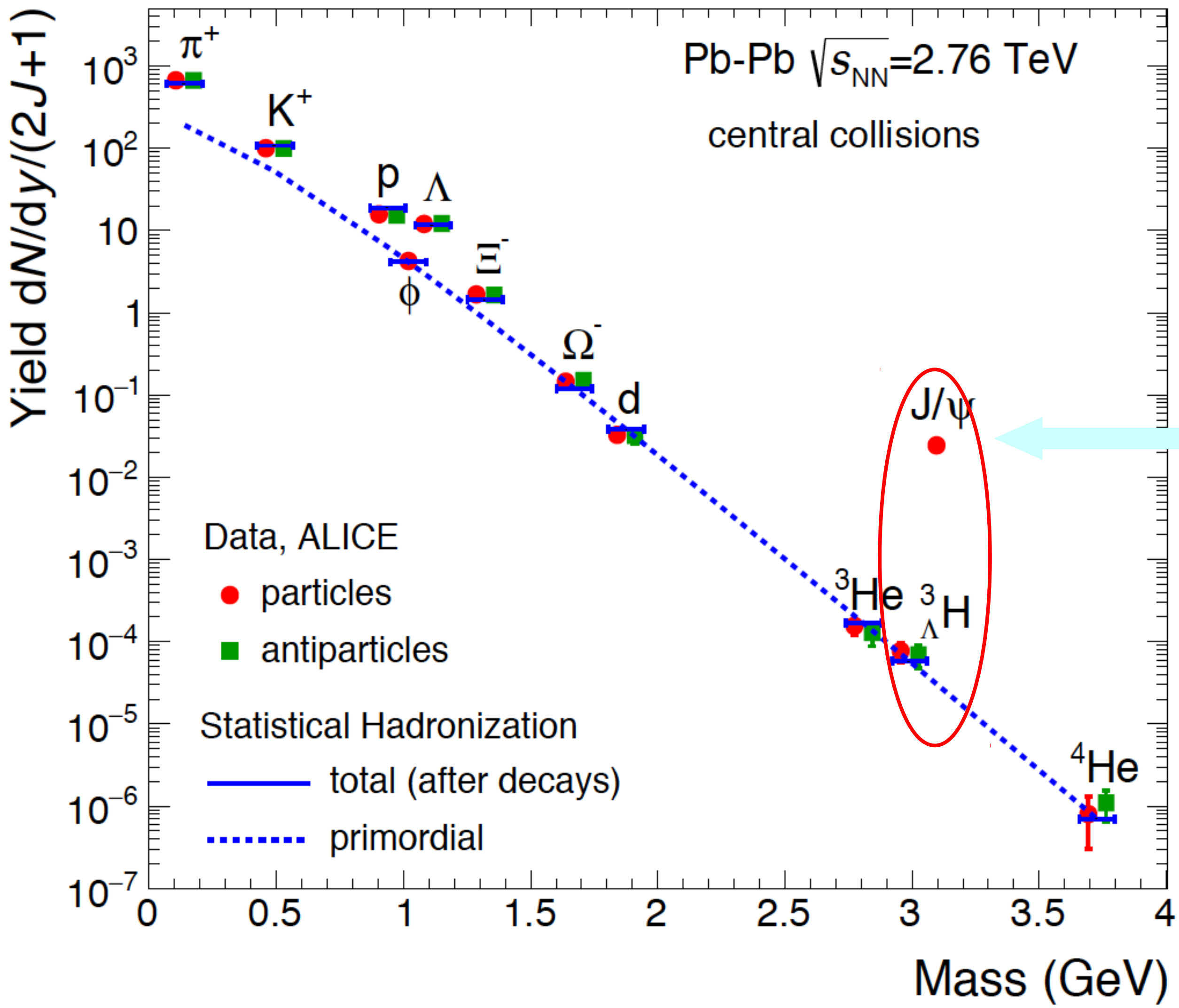


J/ψ and statistical hadronization



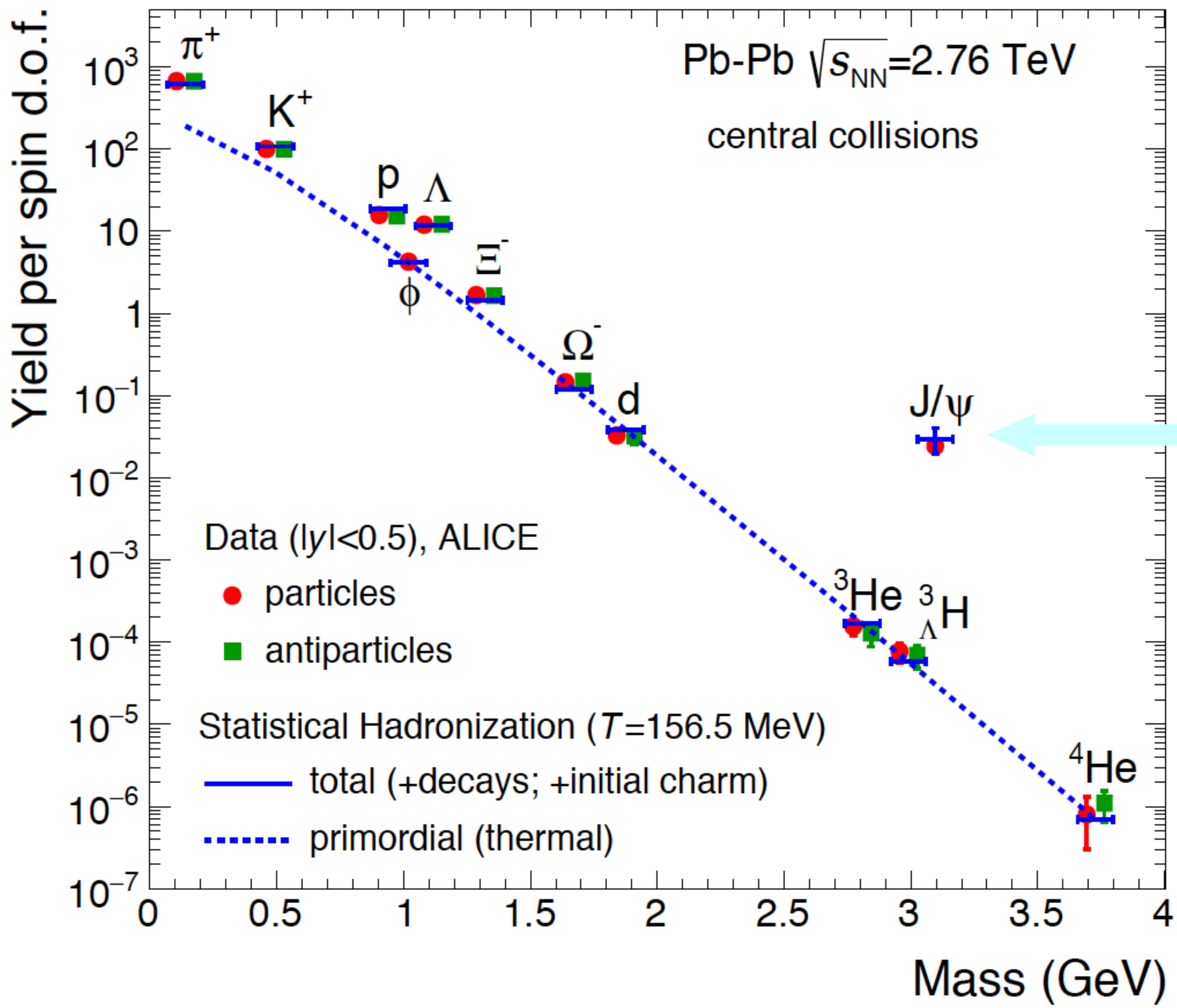
production in PbPb collisions at LHC consistent with deconfinement and subsequent statistical hadronization within present uncertainties
main uncertainties for models: open charm cross section due to shadowing in Pb

Systematics of hadron production in SHM



J/psi mass close to hypertriton where does 3 oom enhancement come from?

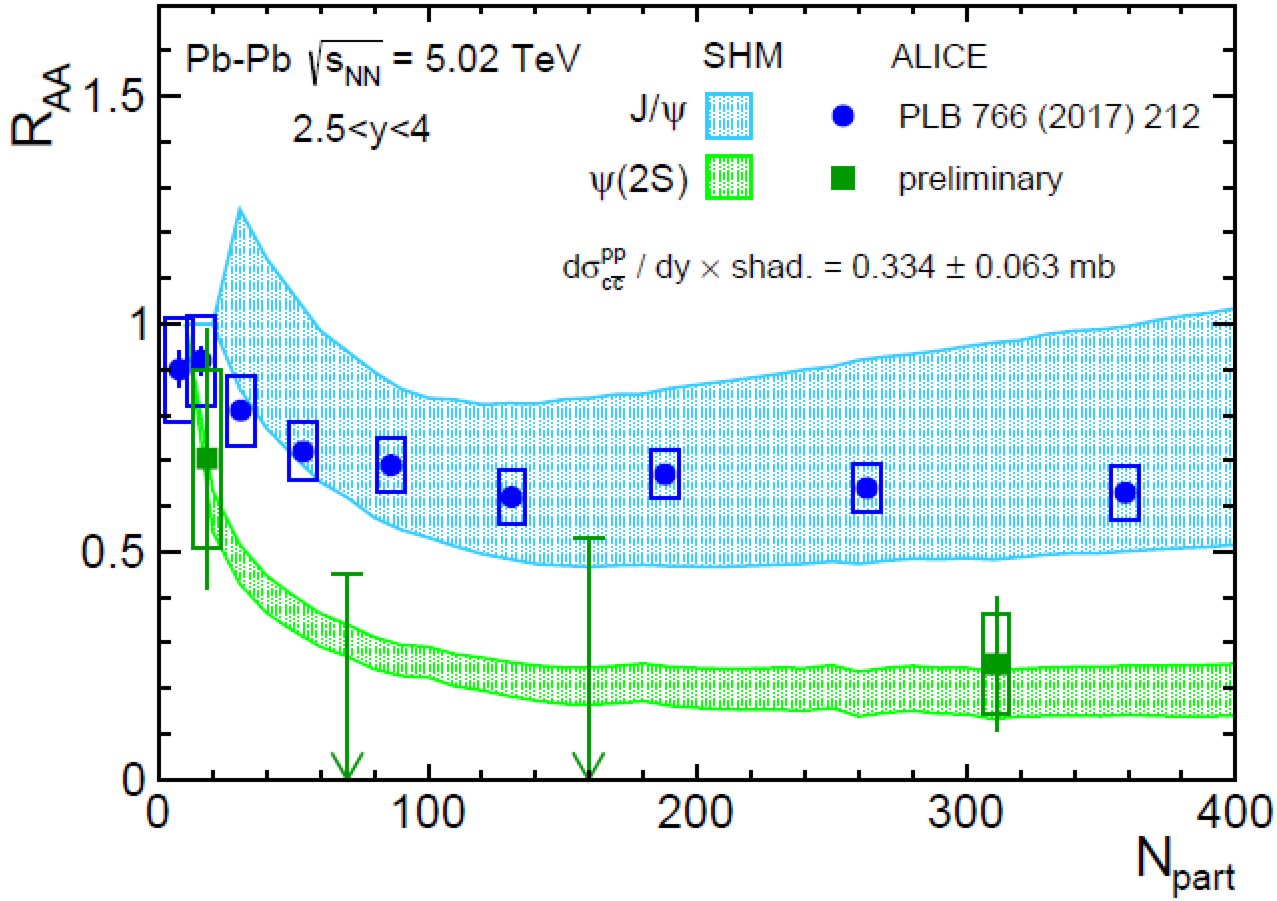
Systematics of hadron production in SHM



yield exactly reproduced with stat hadr. of deconfined and thermalized c-quarks from initial hard scattering (fugacity)

What about ψ(2S)?

M. Köhler, A. Andronic, P. Braun-Munzinger, JS, arXiv:1807.01236



also excited state completely in line, suppressed by Boltzmann factor
errors will decrease with more data

Open charm hadron yields

ALICE mid-y cross sections pp 7 TeV:

	Extr. factor to $p_T > 0$	$d\sigma/dy\,|_{|y|<0.5}$ (μb)
D^0	$1.0002^{+0.0004}_{-0.0002}$	$512 \pm 37(\text{stat}) \pm 39(\text{syst}) \pm 18(\text{lumi}) \pm 5(\text{BR})$
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	pp 7 TeV	SHM	STAR AuAu	ALICE PbPb	
D^+/D^0	0.46 (0.10)	0.44	0.44 (0.10)	LHC run3/4	✔
D_s^+/D^+	0.38 (0.15)	0.81	0.83 (0.30)	LHC run3/4	✔
Λ_c/D^0	LHC run3/4	0.22	1.9 (0.79)	LHC run3/4	??

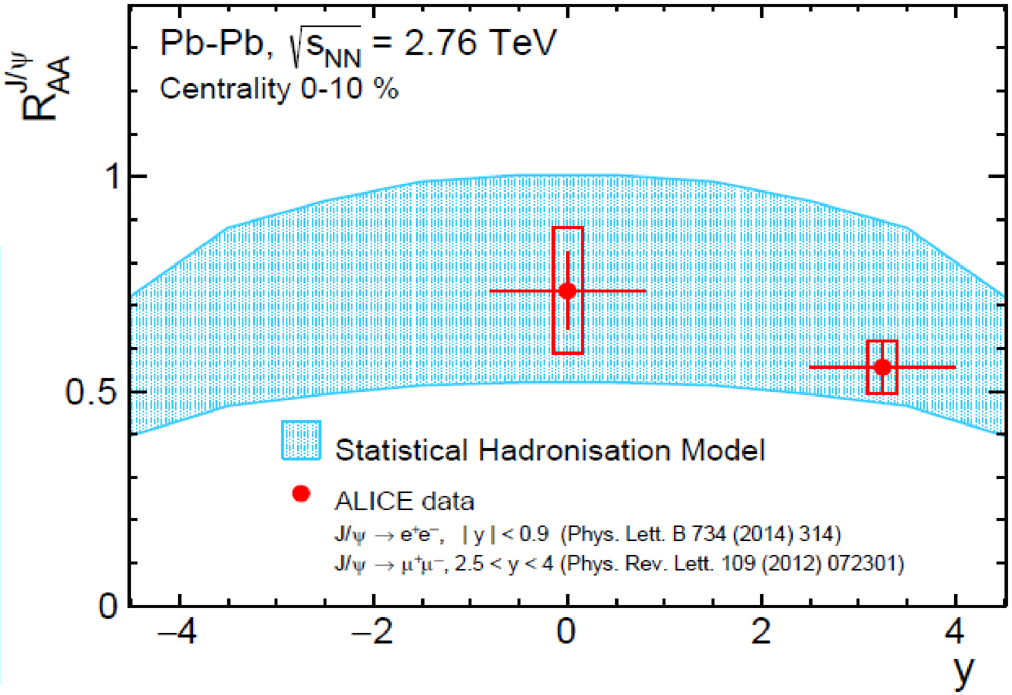
charmed hadron yields on a good way, conclusive data to come in run3/4

Rapidity dependence of R_{AA}

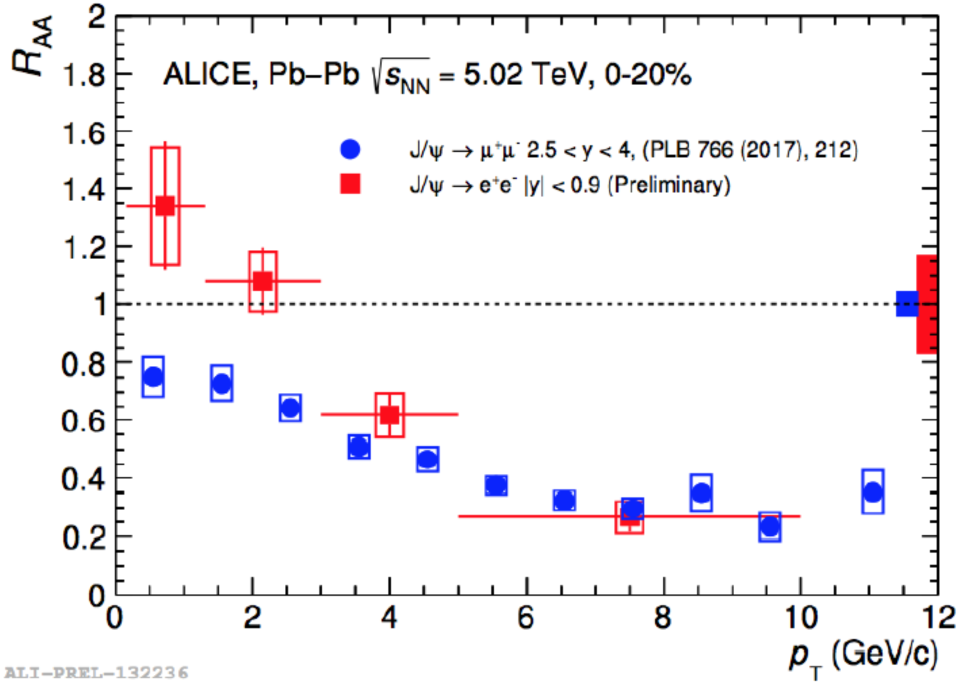
yield in PbPb peaks at mid-y
where energy density is largest
?

for statistical hadronization J/ψ yield proportional to N_c^2 - higher yield at mid-rapidity predicted in line with observation
(at RHIC and LHC)

M. Köhler, A. Andronic, P. Braun-Munzinger, JS
arXiv:1807.01236



Transverse momentum dependence



compared to pp collisions enhancement at small p_t!

– was predicted for statistical hadronization component

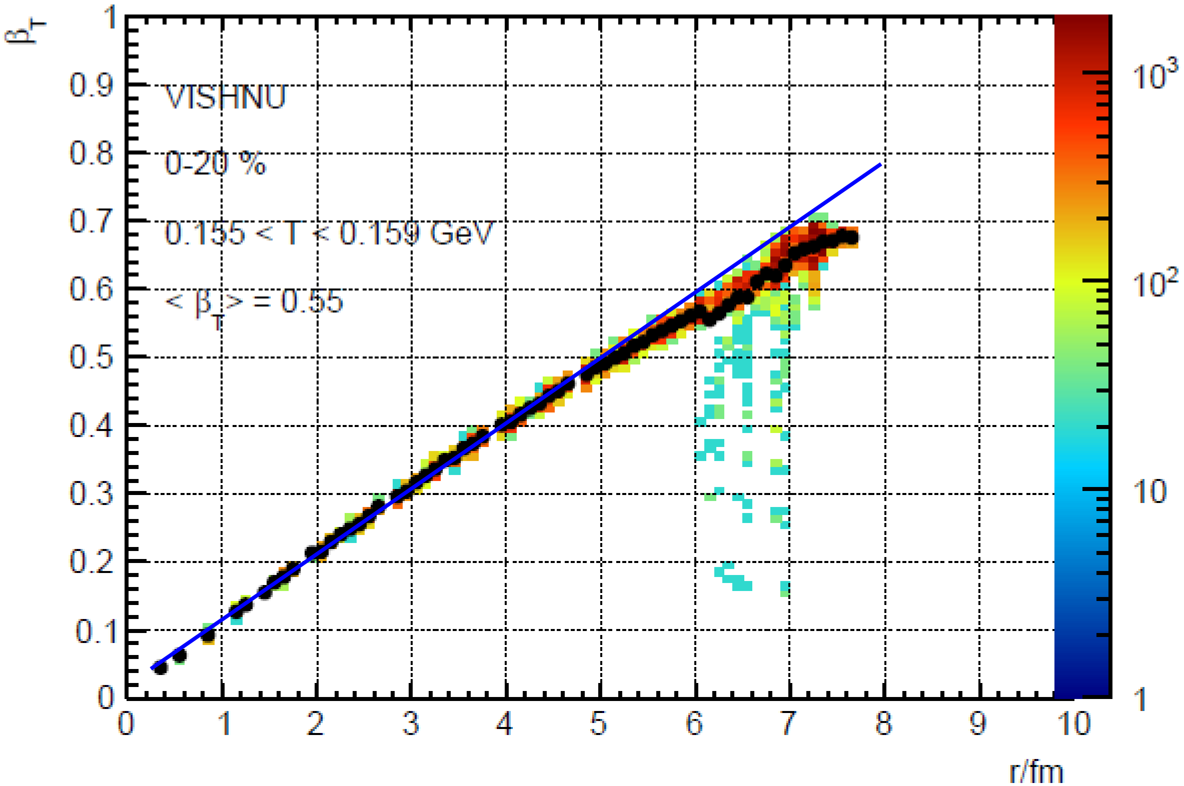
what does statistical hadronization have to say about p_t spectrum?

<u>the physical picture:</u> charmonia are formed at hadronization from charm quarks in the medium

<u>implies:</u> they should exhibit – as other hadrons – a spectrum characterized by the temperature and the flow of the surrounding medium

<u>recipe:</u> take flow characteristics at T_c from a good hydro describing the other light flavor observables, normalization given by ccbar cross section ¬ no free parameter

Transverse hydro velocity profile at T_c

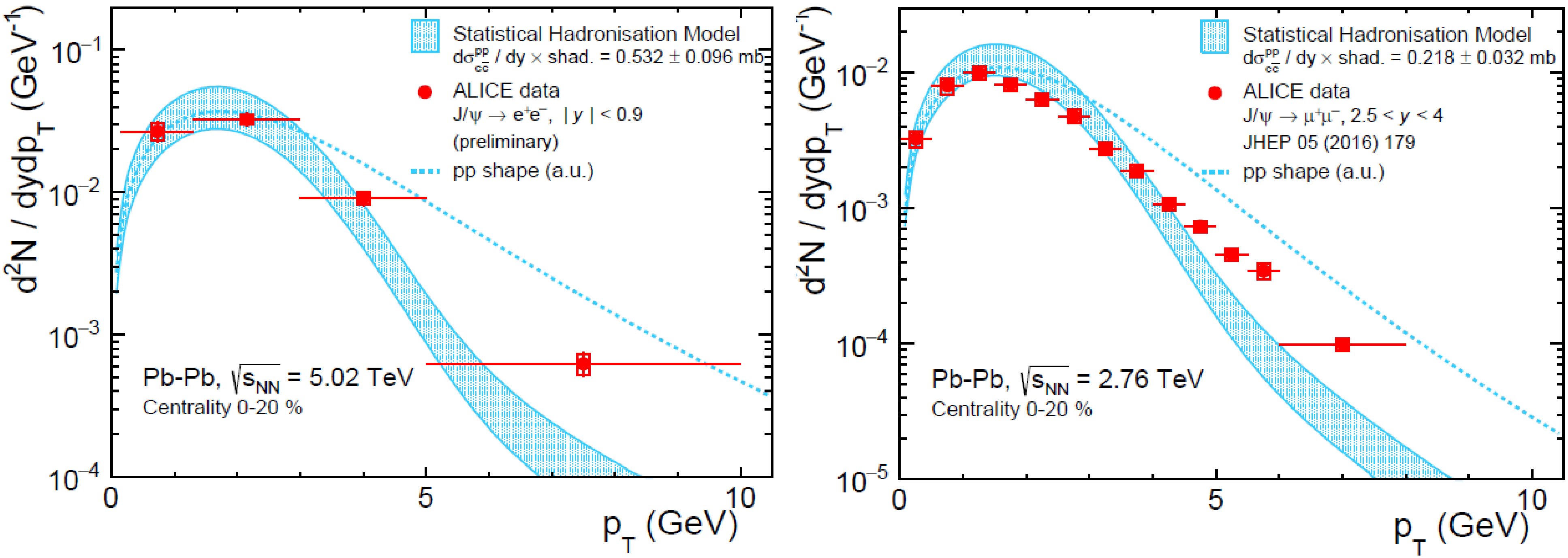


- velocity profile linear in r
- average transverse velocity: 0.55 c

<u>first approach:</u> use blast wave parameterization with hydro input, i.e. linear velocity profile and correct mean velocity and $T=T_c$ and $m=m(J/\psi)$ for core and pp spectrum for corona

J/ψ transverse momentum spectra from stat. hadr.

M. Köhler, A. Andronic, P. Braun-Munzinger, JS, arXiv:1807.01236

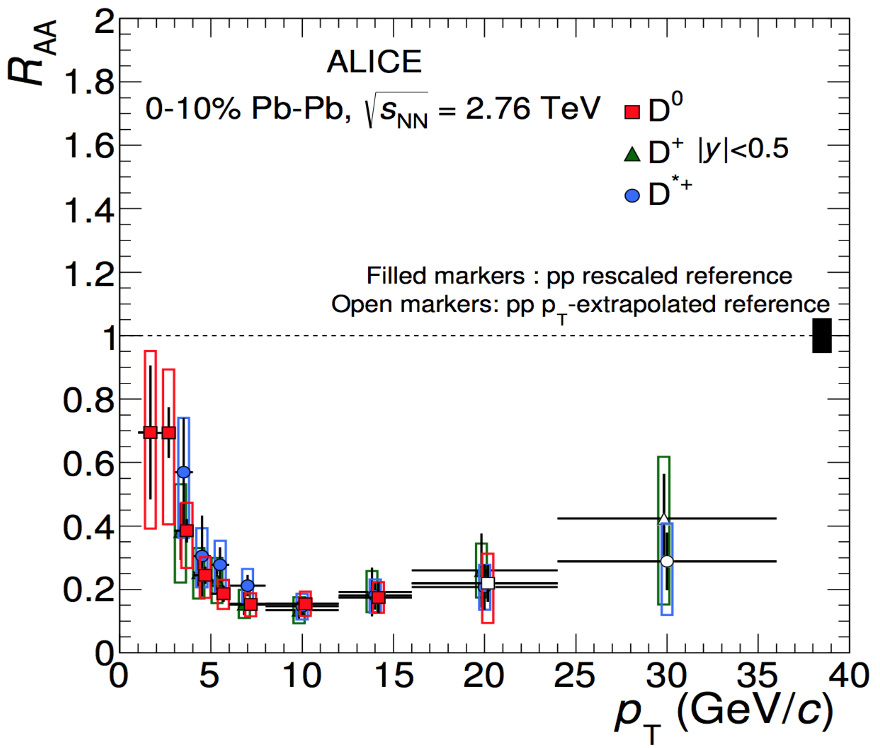


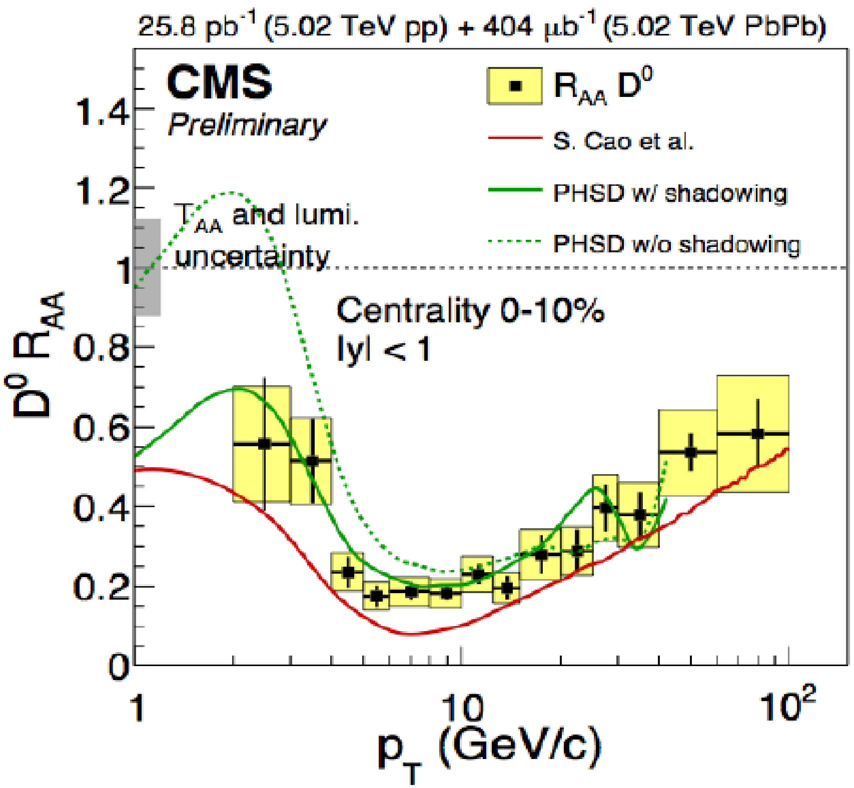
quite reasonable agreement without any free parameters

J/ψ formed at hadronization at T_c from thermalized charm quarks flowing with the rest of the medium

D^0 R_{AA} compared to models

0-10% Central

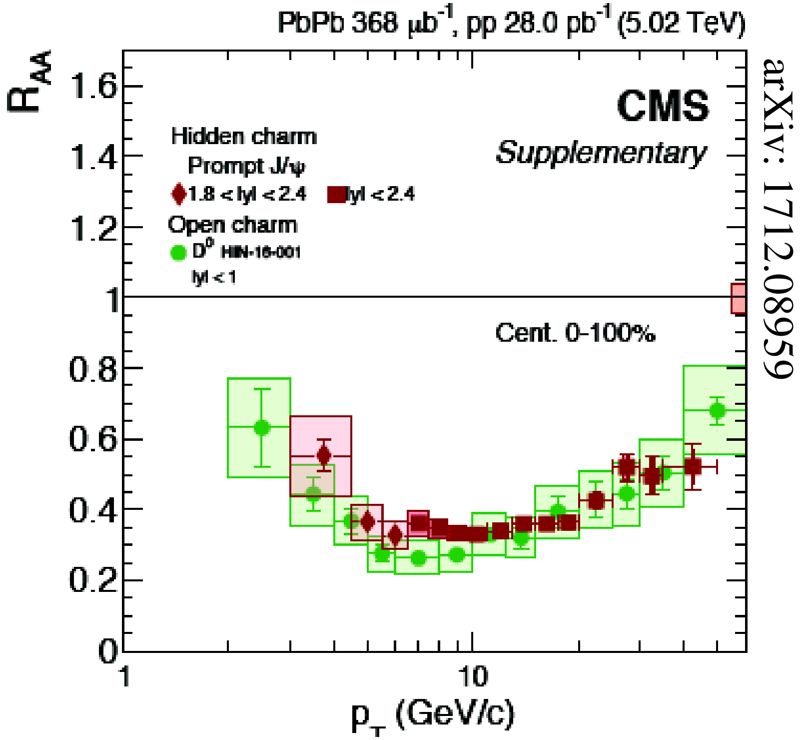


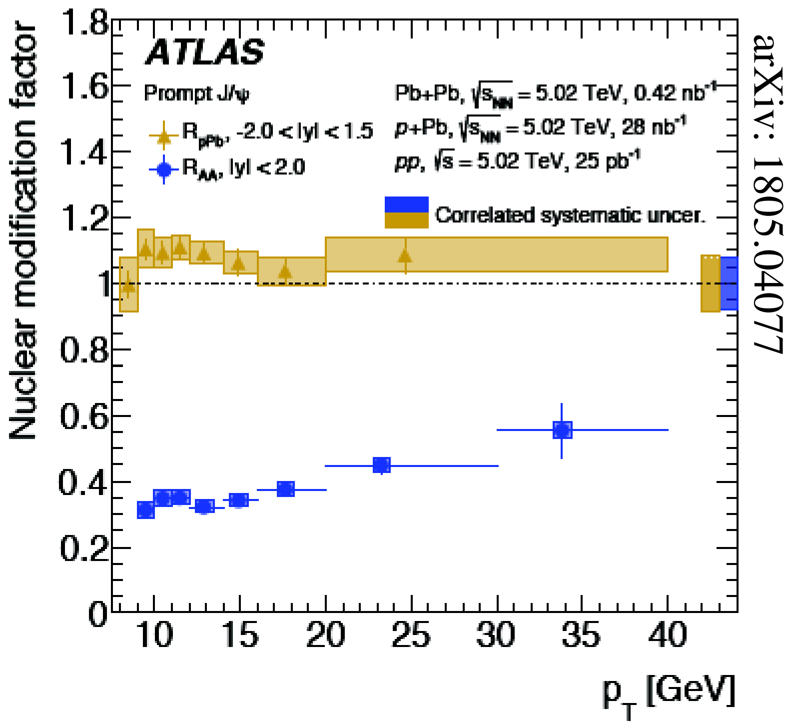


models: predictions before run2 data

- PHSD (Parton-Hadron-String Dynamics model[2])
- S.Cao et al. (Linearized Boltzmann transport model + hydro) arXiv:1605.06447v1
- M. Djordjevic (QCD medium of finite size with dynamical scattering centers with collisional and radiative energy loss) Phys. Rev. C 92 (Aug, 2015) 024918

J/psi R_{AA} in central PbPb like open heavy and light flavor hadrons



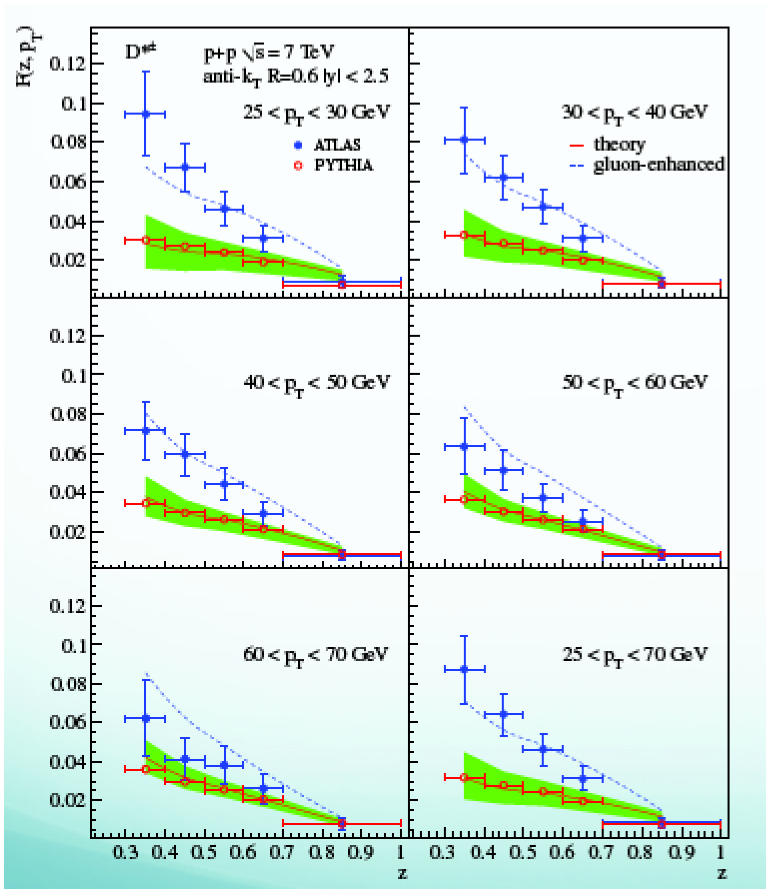


prompt J/ψ suppression in PbPb collision – R_{AA} rising at high p_t

same shape and magnitude as D-mesons charged particles

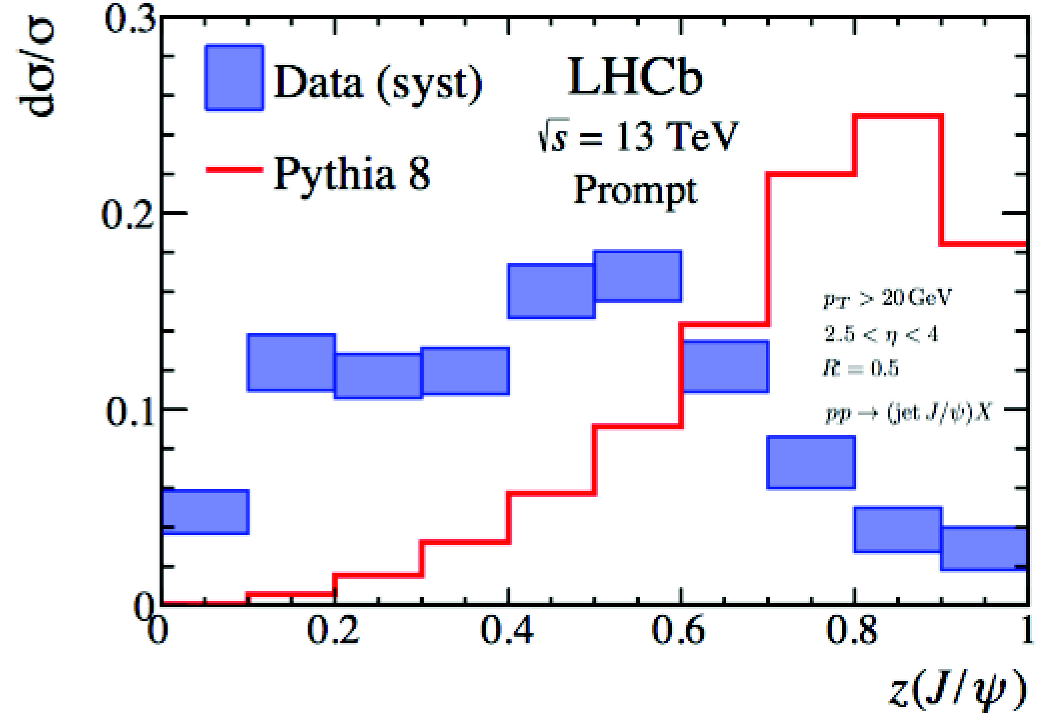
J/ψ from gluon fragmentation?

D meson and J/ψ fragmentation functions surprizing



Using ZM-VFNS scheme:
Chien, Kang, Ringer, Vitev, Xing,
1512.06851, JHEP 16

$D_g^D(z,\mu) \to 2D_g^D(z,\mu)$



H.Xing (Wuhan 10/2018) : data prefers that jet was initiated by a single parton fragmentation, while PYTHIA starts from a ccbar

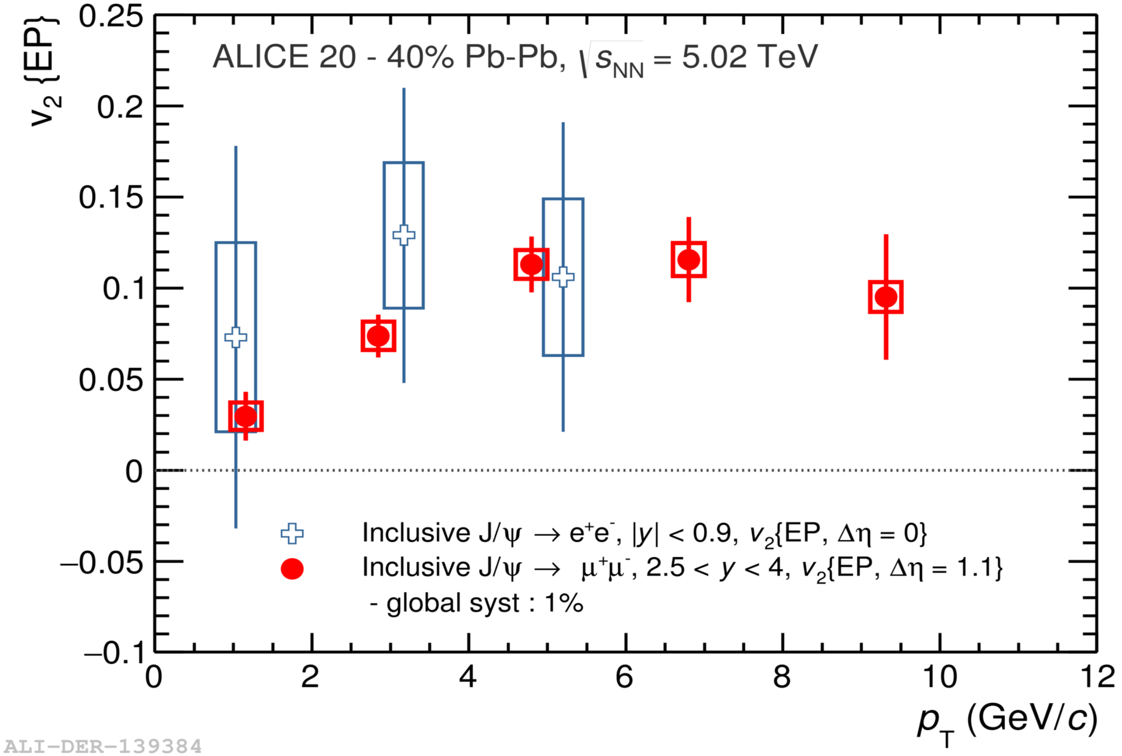
Gluon fragmentation into J/ψ could well be the mechanism explaining the high p_t R_{AA}

Elliptic flow of J/ψ vs p_t

semi-central collisions: asymmetric overlap region → asym expansion velocity profile

charm quarks thermalized in the QGP should exhibit the elliptic flow generated in this phase

PRL119 (2017) 242301, arXiv:1709.05260

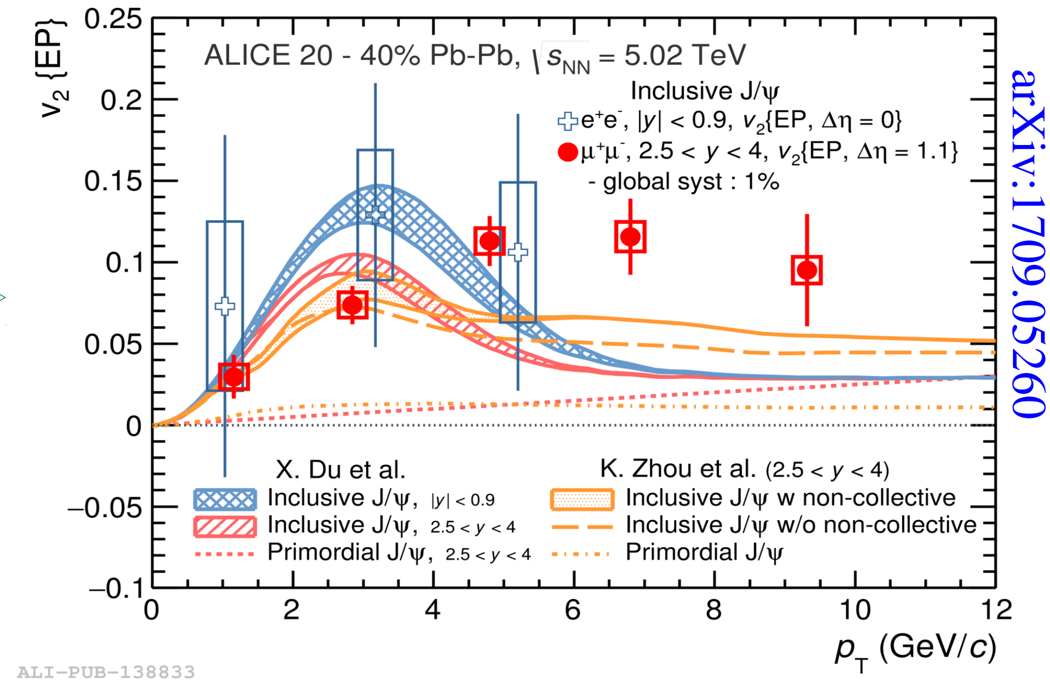


- expect build-up with p_t as observed for π, p. K, Λ, … and vanishing signal for high p_t region not dominated by flow

first observation of significant J/ψ v_2 at mid and forward y in line with expectation from statistical hadronization

Elliptic flow of J/ψ

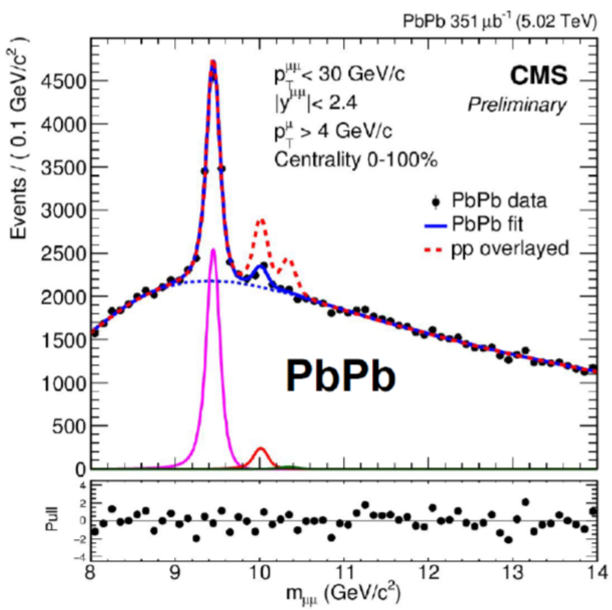
charm quarks thermalized in the QGP should exhibit the elliptic flow generated in this phase

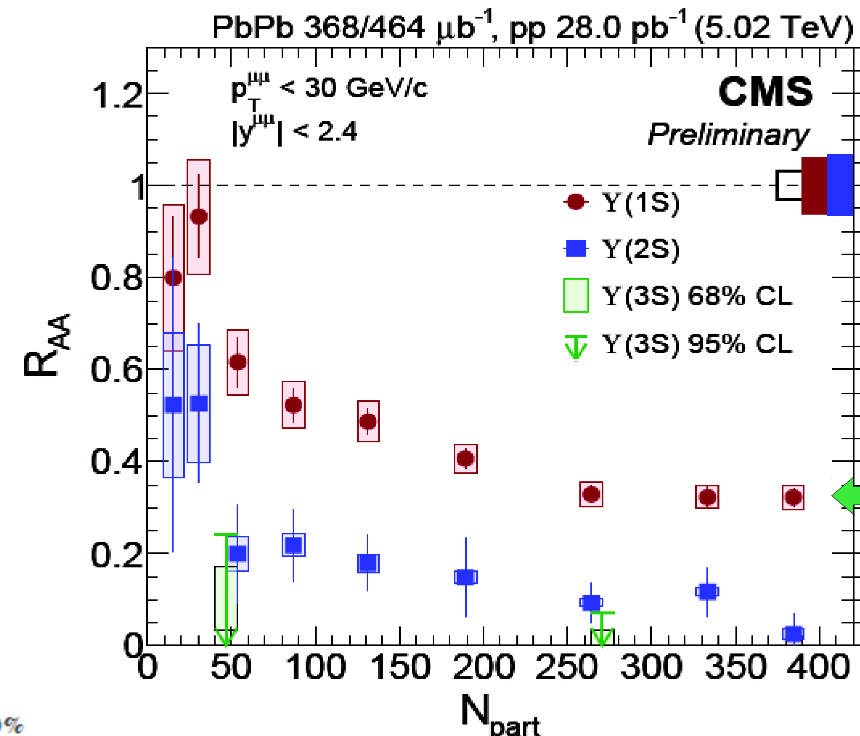


J/ψ elliptic flow in line with expectation from recombination
at high pt room for additional effects

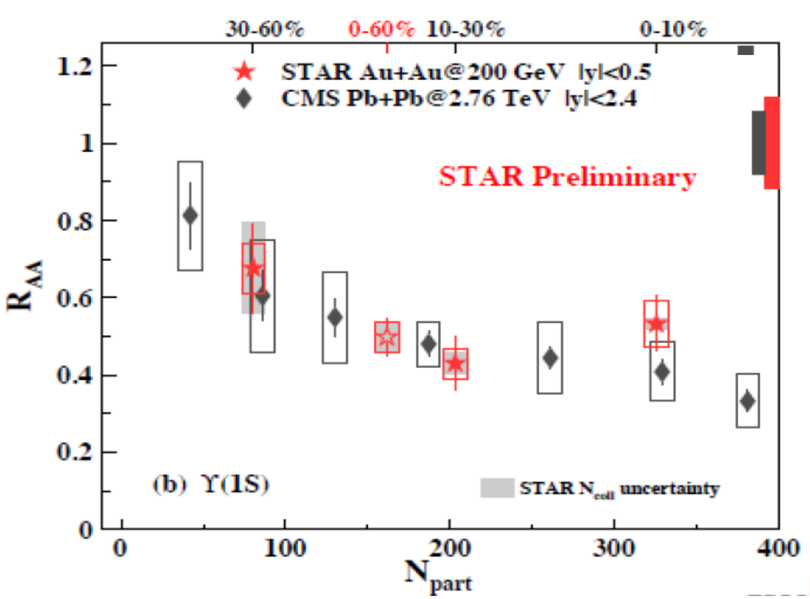
Bottomonia

Suppression of Upsilon states



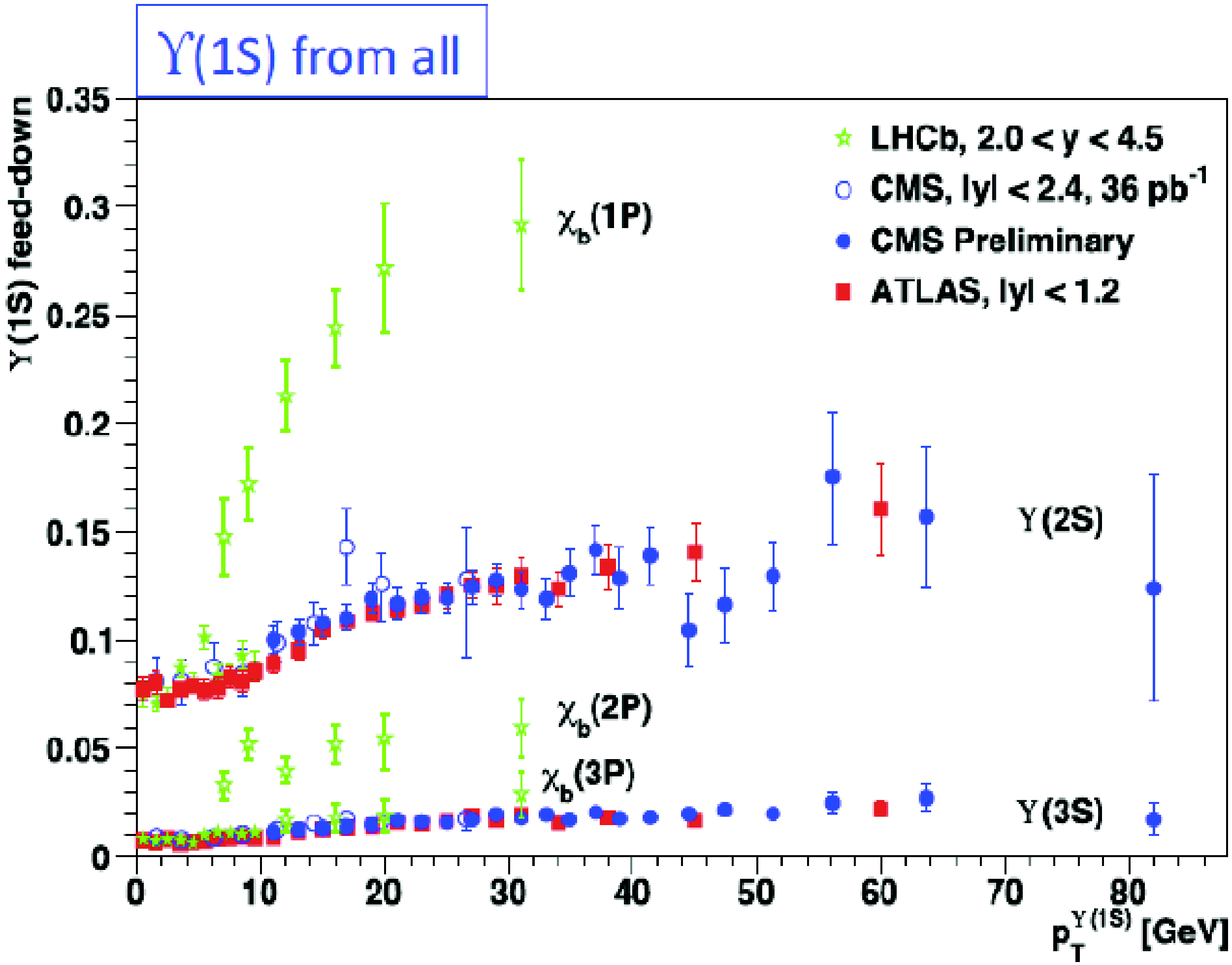


not consistent with just excited state suppression (LHCb data: only 25 % feed-down in pp at LHC)

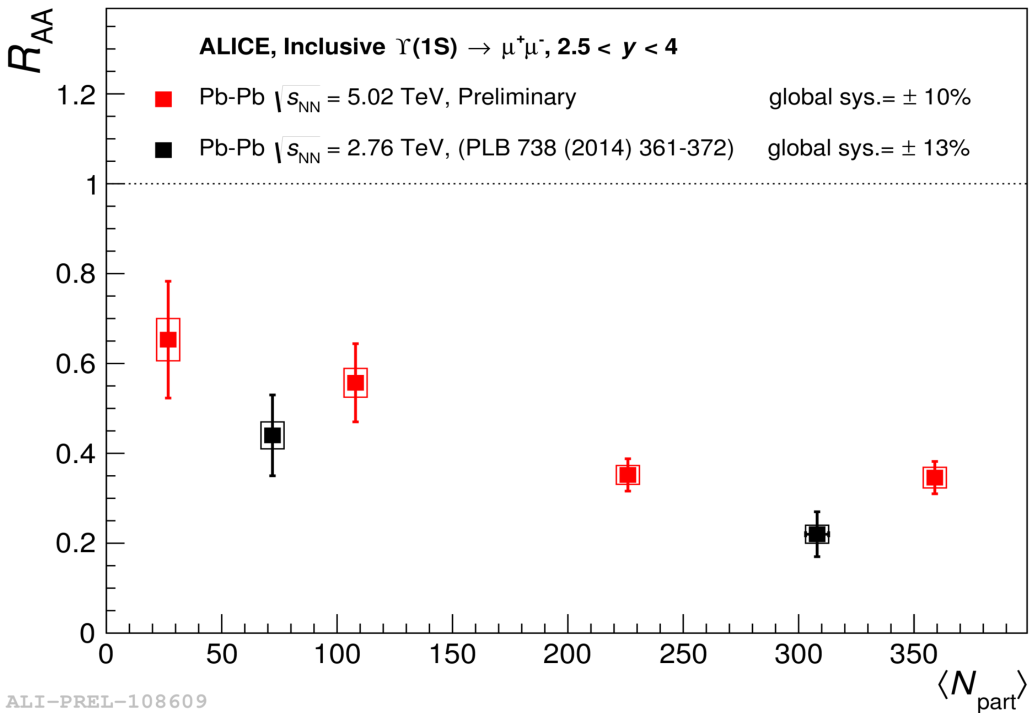


genuine Upsilon suppression
- real and imaginary part of potential at finite temperature play a role
- similarity of RHIC and LHC suppression reminiscent of SPS and RHIC for J/ψ
- possibility of statistical hadronization?

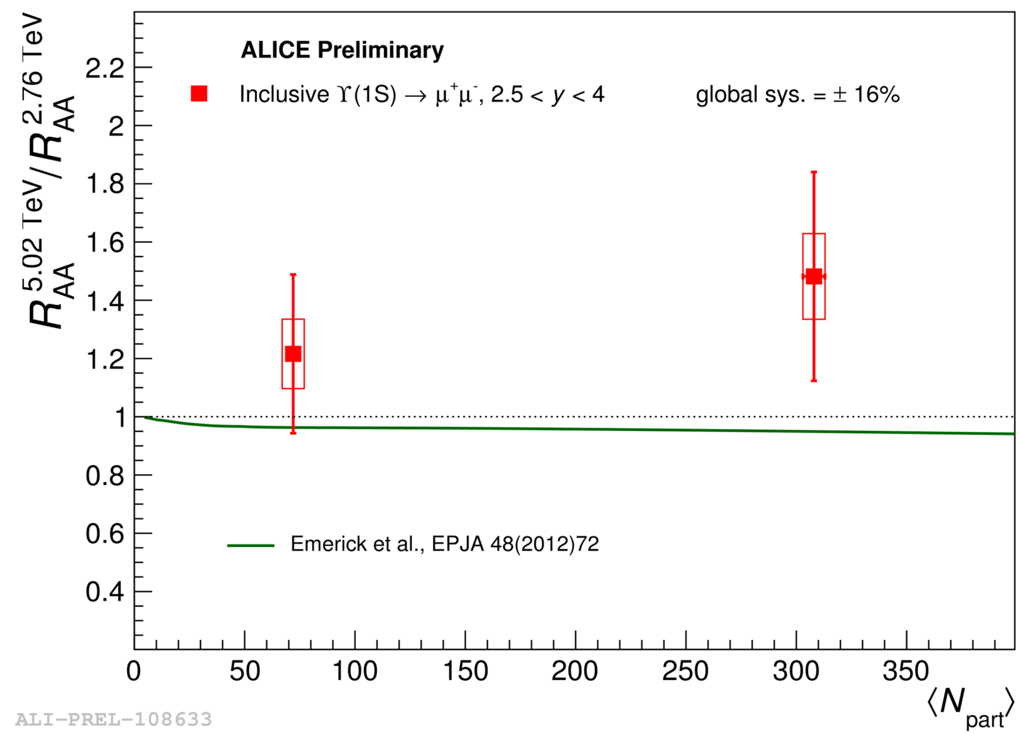
Feeding into Upsilon (1S)



Upsilon in PbPb at 5 TeV compared to 2.76 TeV



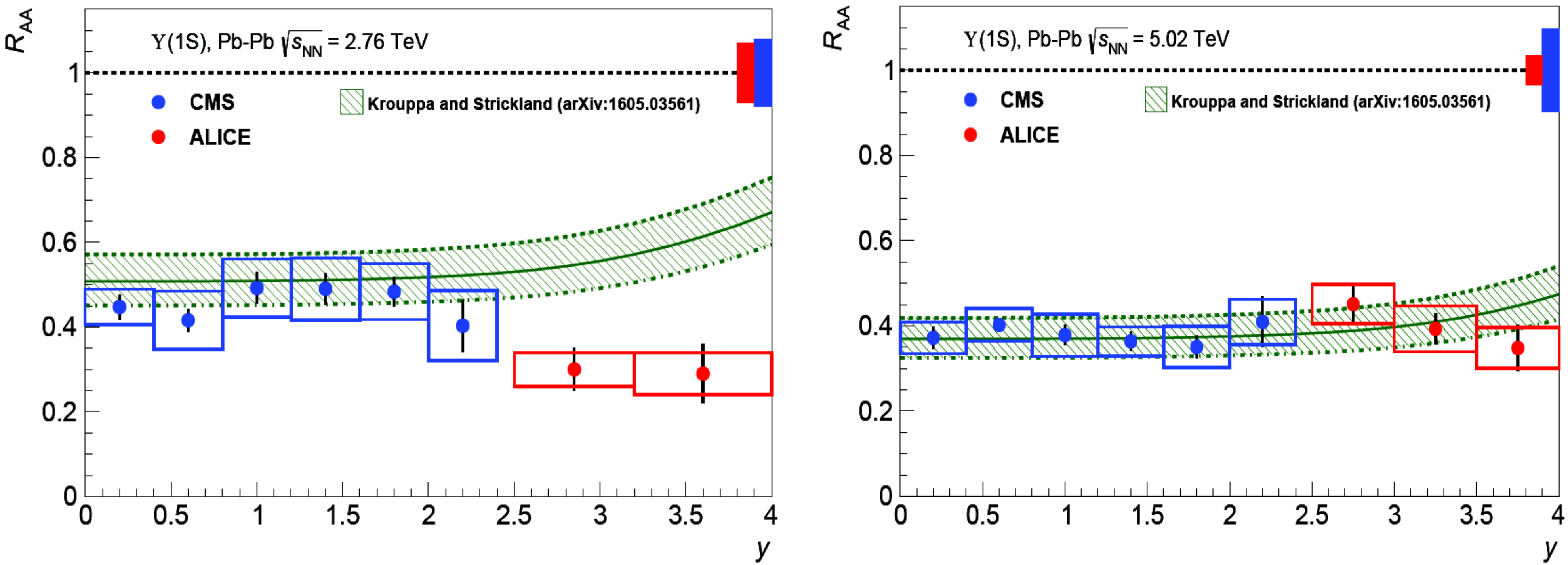
yield of Upsilon(1S) increases with beam energy



dissociation of Upsilon in a hydrodynamically medium will not produce an increase with increasing energy density

$R_{AA}^{0\text{-}90\%}$(5.02 TeV) / $R_{AA}^{0\text{-}90\%}$(2.76 TeV) = 1.3 ± 0.2(stat) ± 0.2(syst)

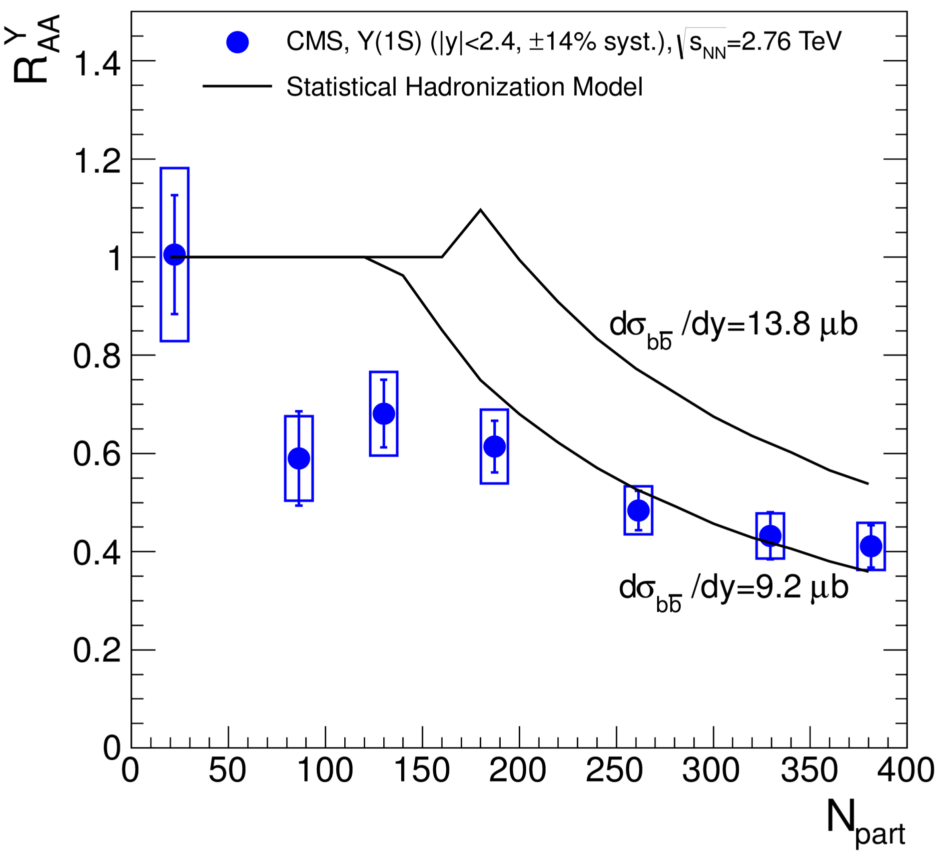
Upsilon R_{AA} rapidity dependence

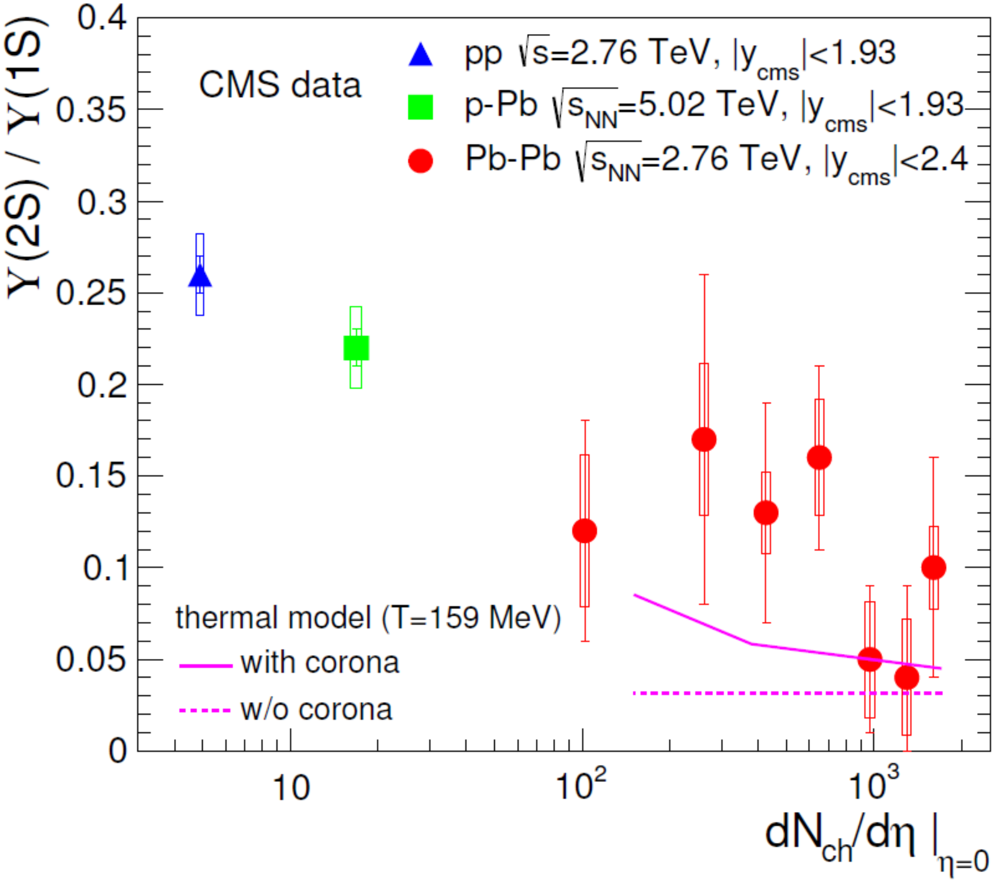


Indication: R_{AA} peaked at mid-y like for J/ψ
not in line with collisional damping in expanding medium

the Upsilon could also come from statistical hadronization

SHM/thermal model: Andronic et al.





in this picture, the entire Upsilon family is formed at hadronization
but: need to know first – do b-quark thermalize at all? spectra of B
- total b-cross section in PbPb

Summary

- lots of new experimental data
- clear indication of new producion mechanism for charmonia at LHC
  supported by yields, spectra, rapidity distribution, v2
- data consistent with statistical hadronization model and transport model approaches
- limitation in interpretation:
  precision measurement of open charm cross section in PbPb
  statistics of charmonium observables
- bottomonium data not in line with simple screening picture
  statistical hadronization as well? Does beauty thermalize in QGP?

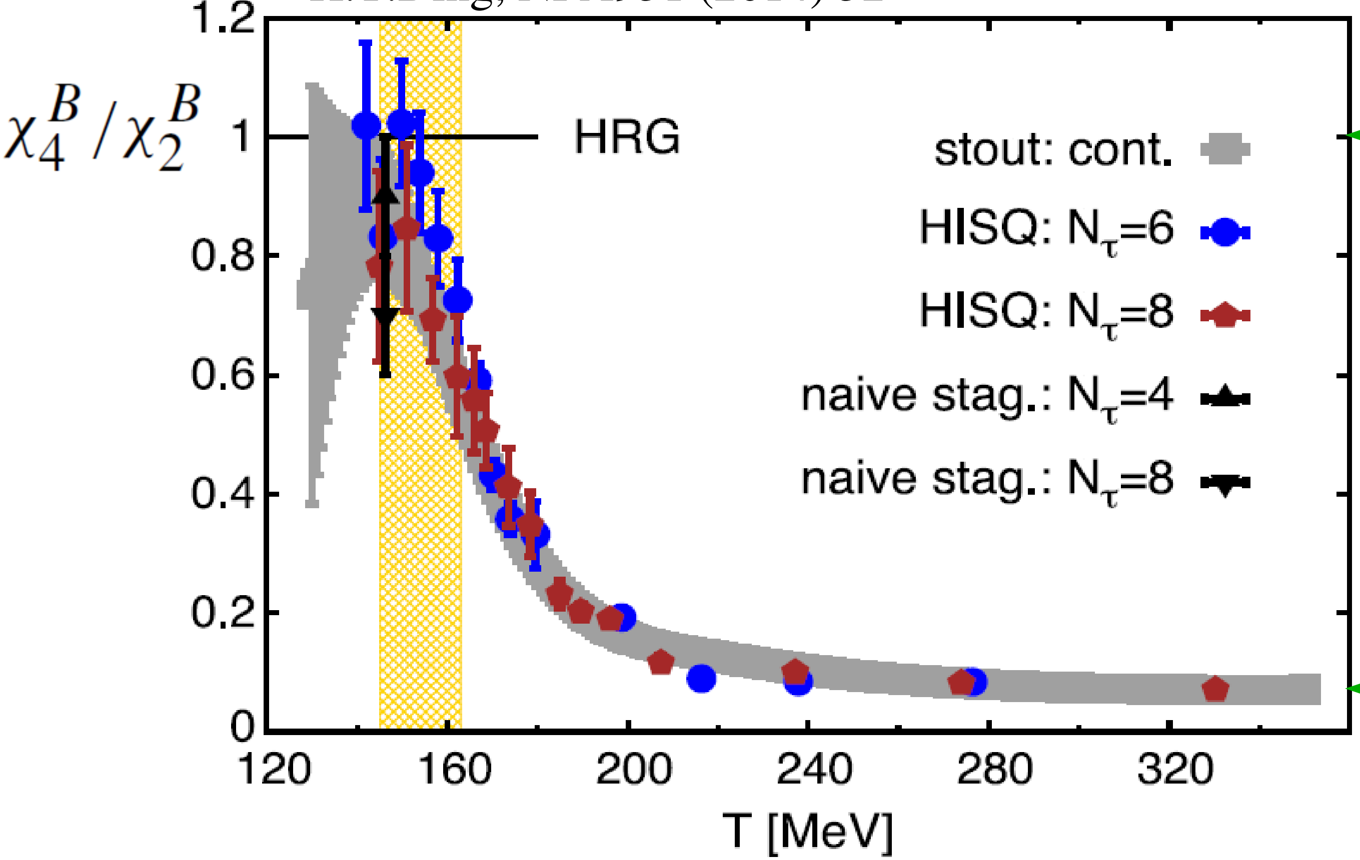
- expect significant progress from run2 and run3 LHC data from all experiments

backup

Measure of deconfinement in lQCD

$\chi_4^B / \chi_2^B \propto \text{baryon number}^2$

H.T.Ding, NPA931 (2014) 52



confined: 1

deconfined: $6/9\pi^2$

measure suggested by Ejiri, Karsch, Redlich (2006)

rapid drop suggests: chiral cross over and deconfinement appear in the same narrow temperature range

Charmonia as probe of deconfinement

the original idea (Matsui and Satz 1986): implant charmonia into the QGP and observe their modification (Debye screening of QCD), in terms of suppressed production in nucleus-nucleus collisions with plasma formation

in the QGP, the screening length $\lambda_{Debye}(T)$ decreases with increasing T

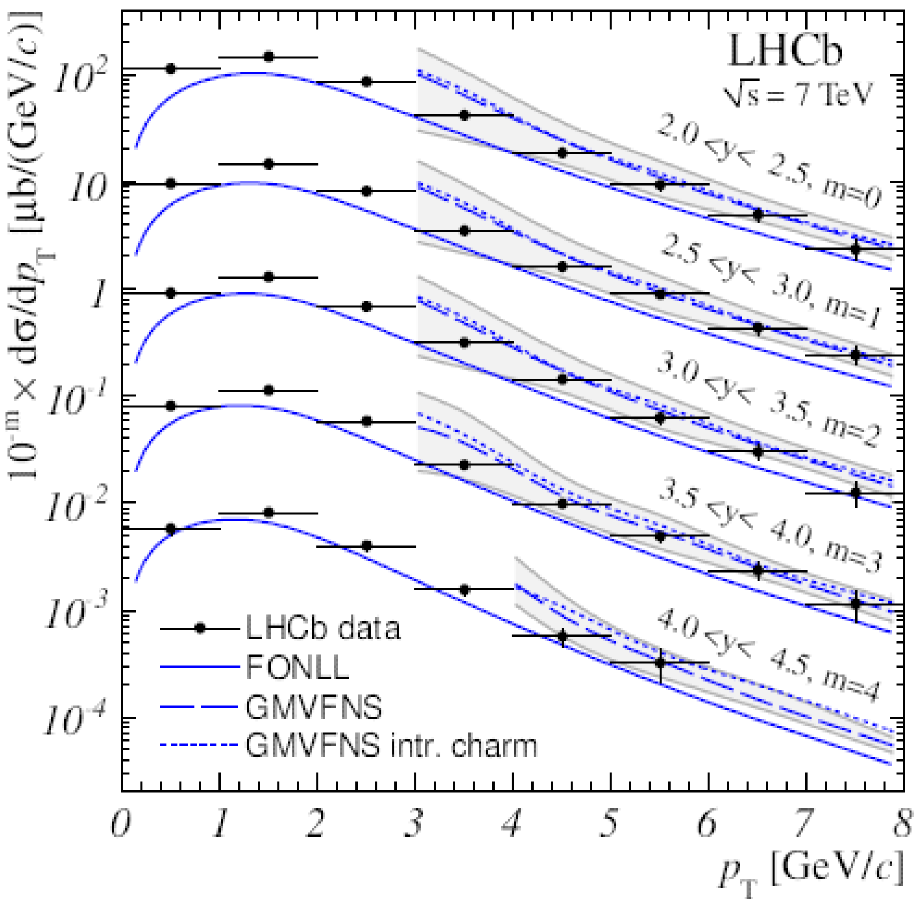
if $\lambda_{Debye}(T) < r_{quarkonium}$ the system becomes unbound

→ notion of charmonia as thermometer – sequential melting

signature of deconfinement, but no direct link to phase boundary

Open charm

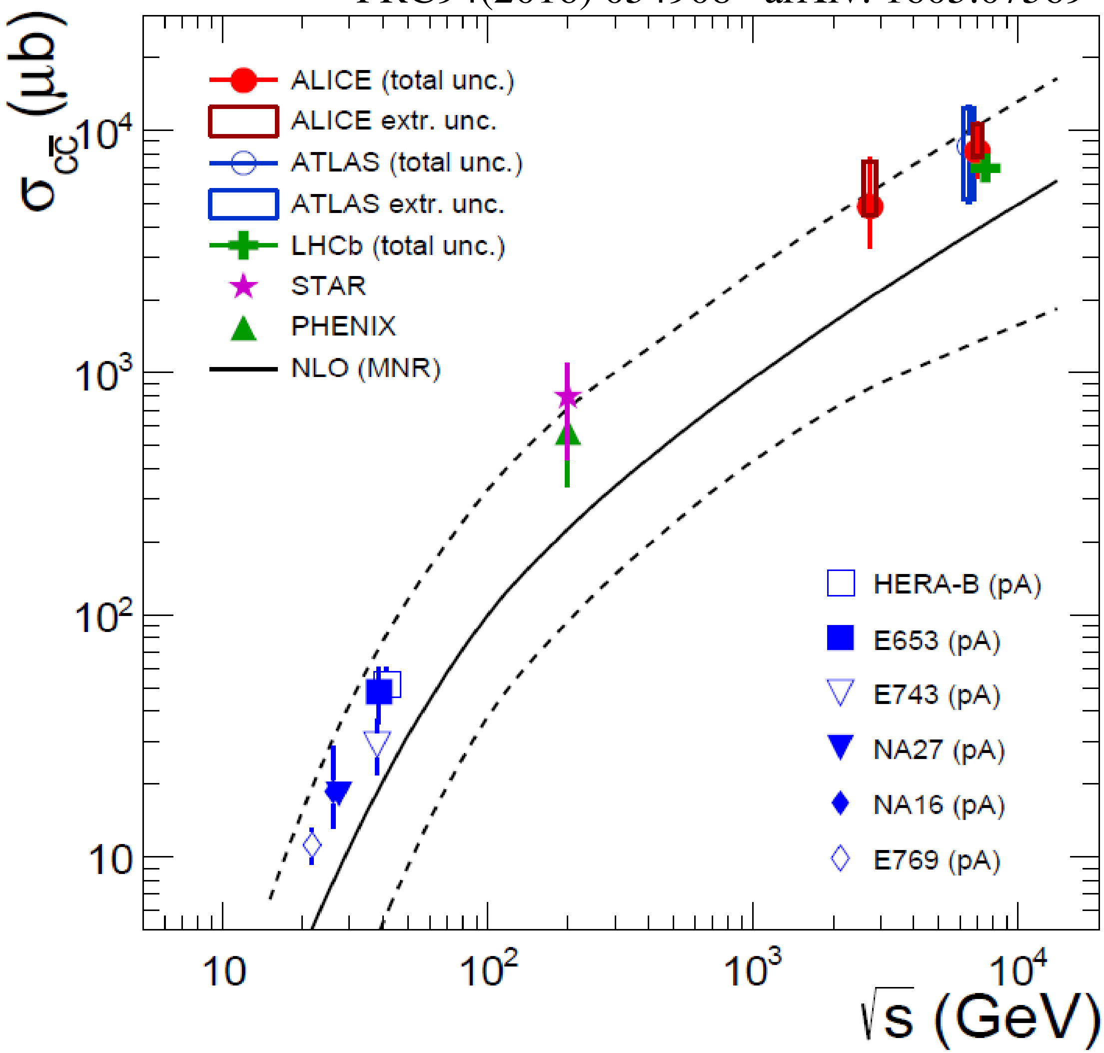
Charm production in pp and pQCD LHCb data



for a recent summary of data and pQCD predictions see:
Beraudo, 1509.04530
Guzzi, Geiser, Rizatdinova, 1509.04582

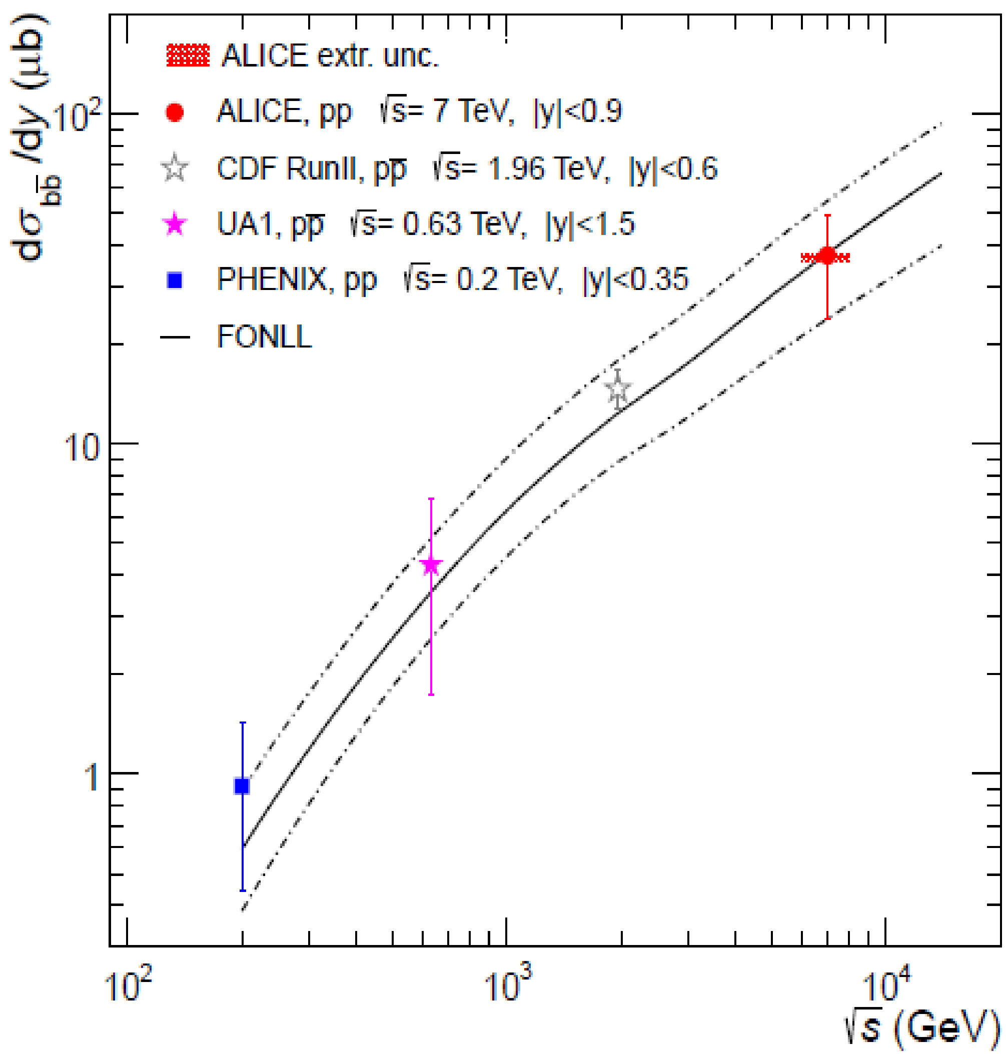
Currently best measurement of the total ccbar cross section in pp at LHC

PRC94(2016) 054908 arXiv: 1605.07569



- good agreement between ALICE, ATLAS and LHCb
- ALICE and LHCb at 7 TeV measurement down to zero p_t, much reduced syst. error
- data at upper edge of NLO pQCD band but well within uncertainty
- beam energy dependence follows well NLO pQCD

Beauty cross section in pp and ppbar collisions



rapidity density of beauty cross section in excellent agreement with pQCD

total bbar cross section

$$\sigma_{b\bar{b}} = 280 \pm 23(\mathrm{stat})^{+81}_{-79}(\mathrm{sys})^{+7}_{-8}(\mathrm{extr}) \pm 10(\mathrm{BR})\ \mu b$$

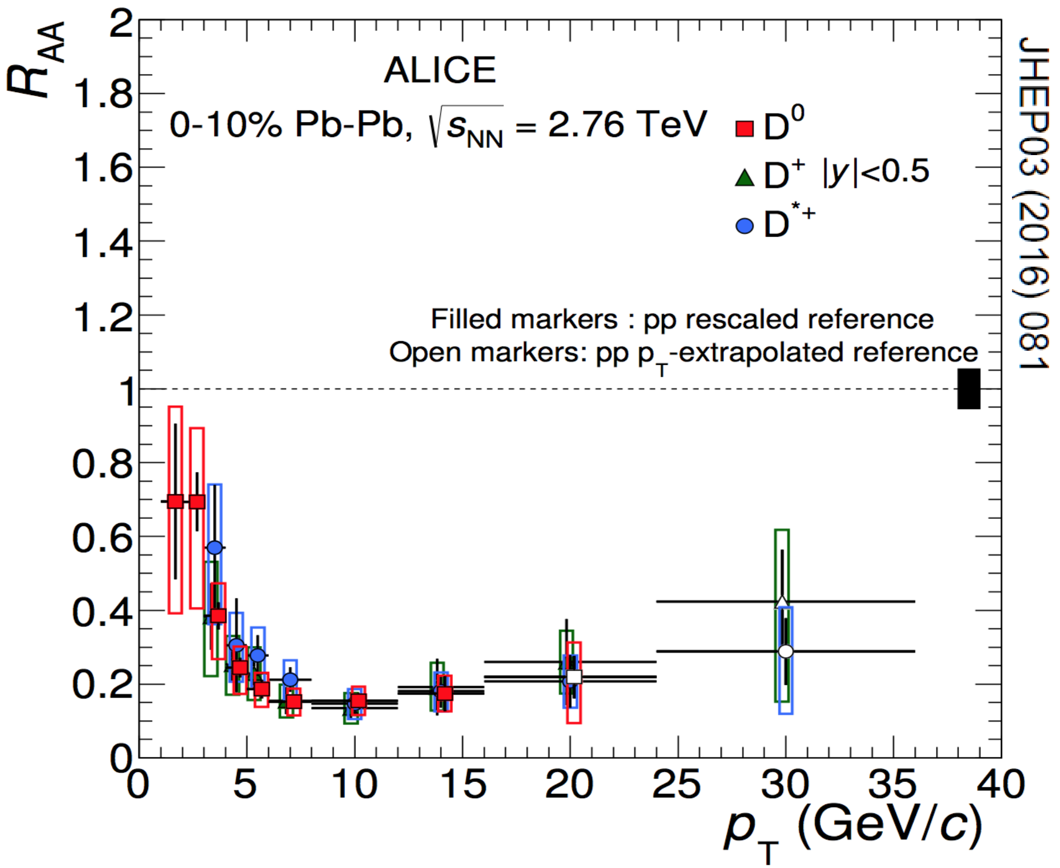
well consistent with ALICE measurement of J/psi from displaced secondary vertices

$$\sigma_{b\bar{b}} = 282 \pm 74(\mathrm{stat})^{+58}_{-68}(\mathrm{sys})^{+8}_{-7}(\mathrm{extr})\ \mu b$$

compared to FONLL

$$\sigma_{b\bar{b}} = 259^{+120}_{-96}\ \mu b$$

Suppression of charm at LHC energy

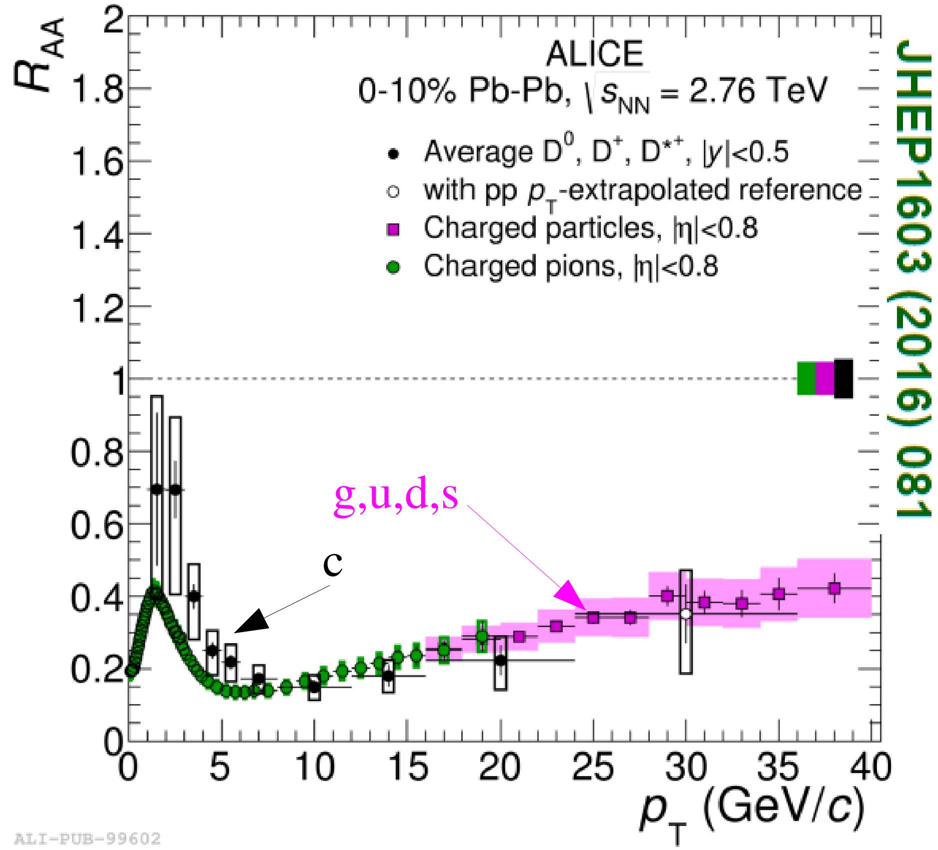


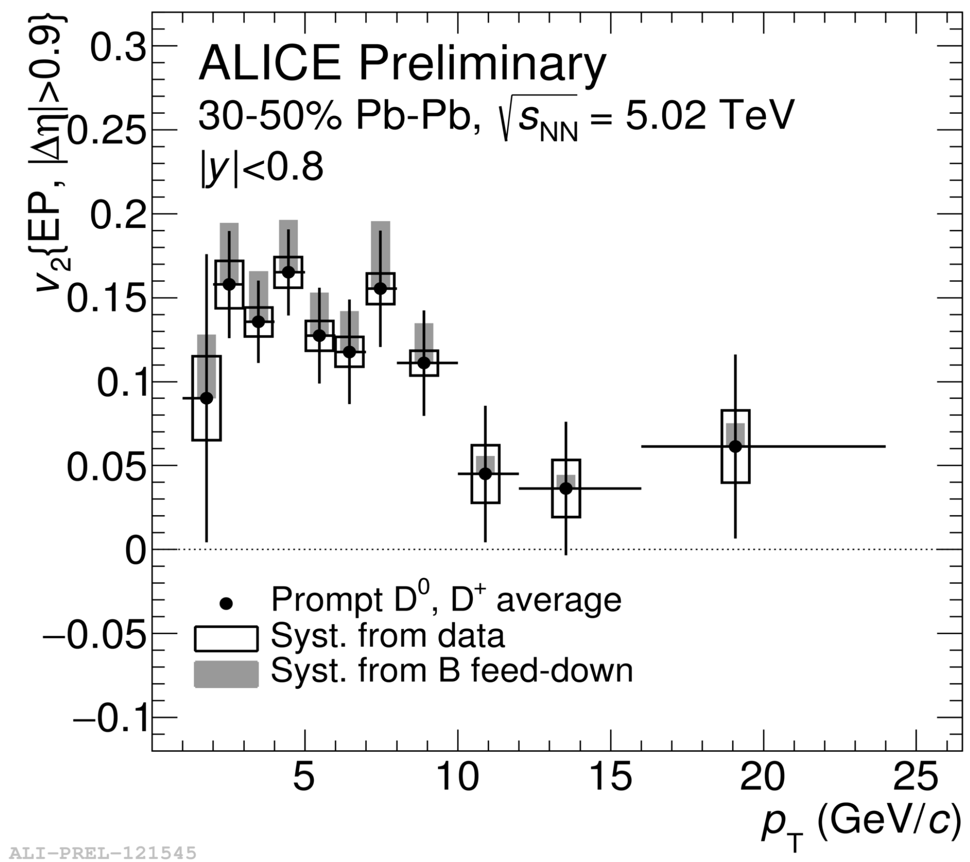
energy loss for all species of D-mesons within errors equal - not trivial
energy loss of central collisions very significant - suppr. factor 5 for 5-15 GeV/c

charm quarks thermalize to large degree in QGP

strong energy loss of charm quarks

elliptic flow for charm – participation in coll. flow

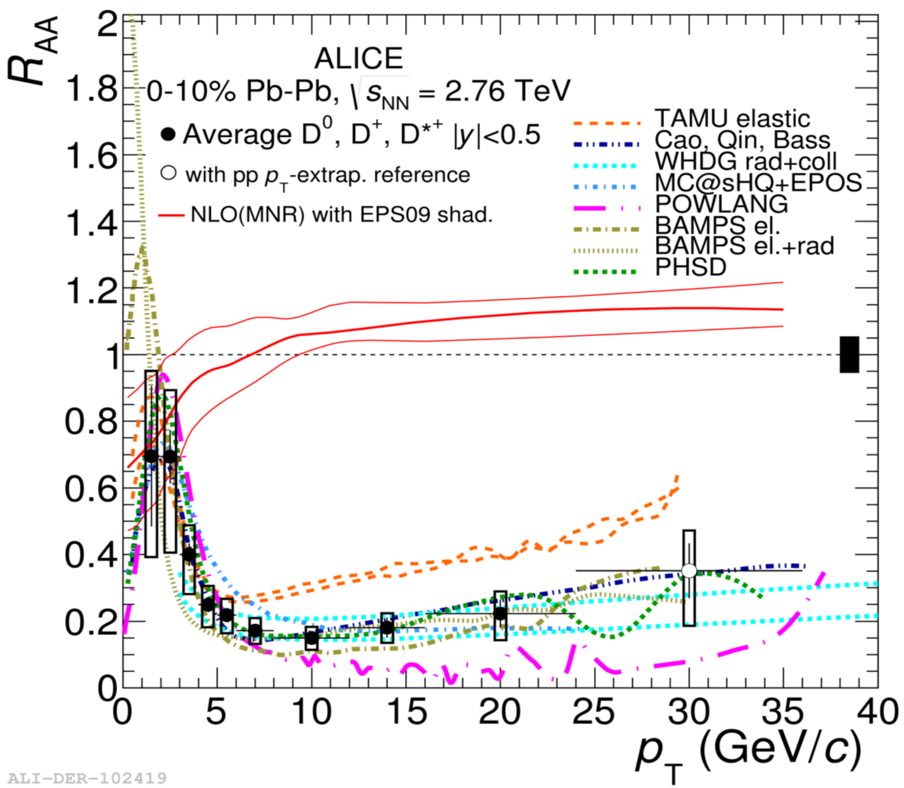


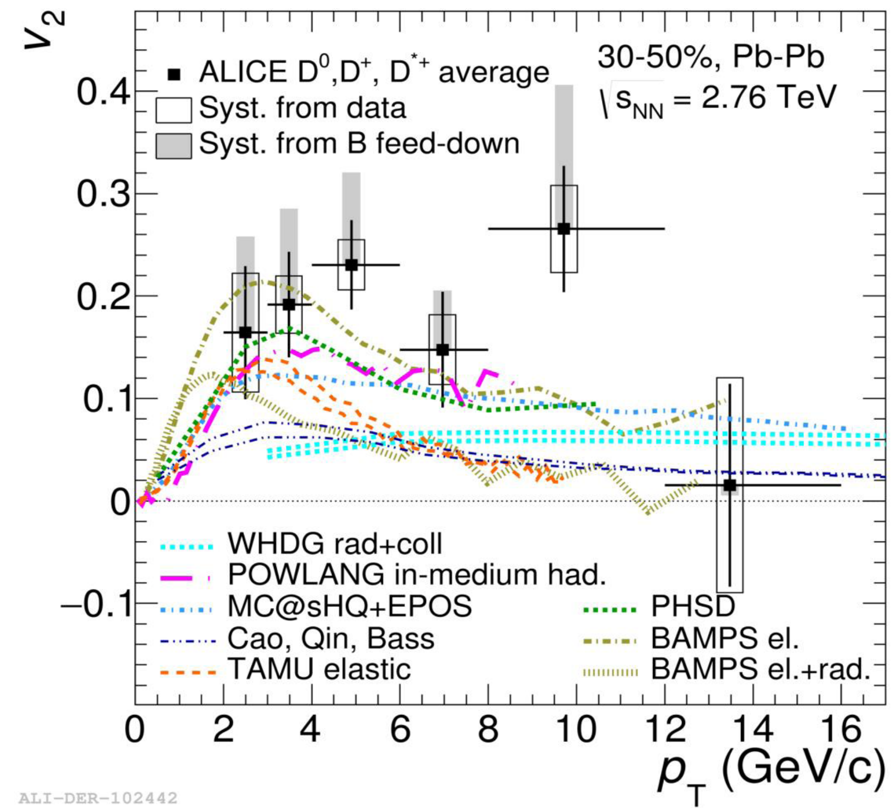


M.Djordjevic, arXiv:1307.4098:
equal R_{AA} is a conspiracy of different fragmentation functions of light quarks, gluons, charm and different color factors in energy loss

models constrained by simultaneous fit of R_{AA} and v_2

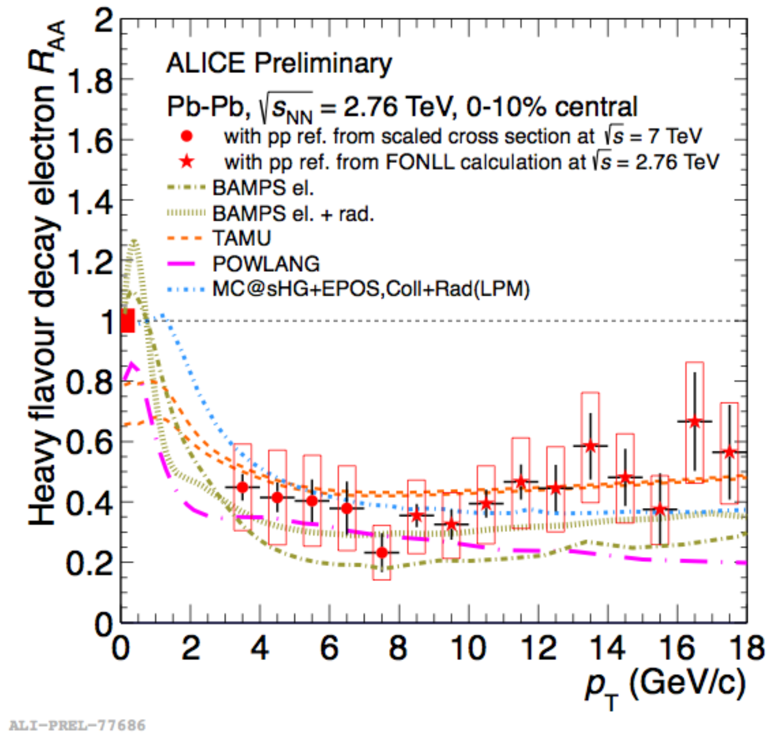
PRL 111 (2013) 102301, PRC 90 (2014) 034904

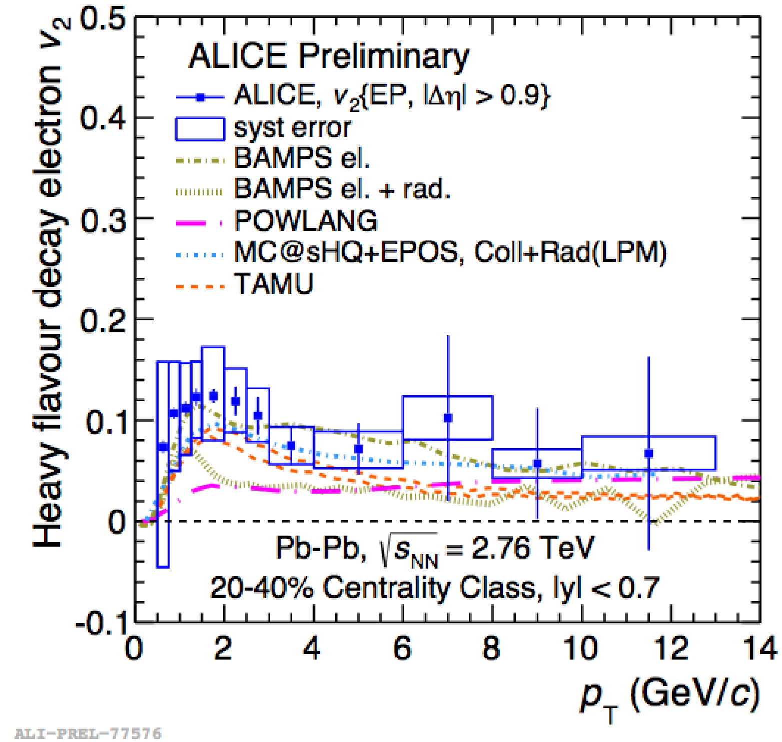




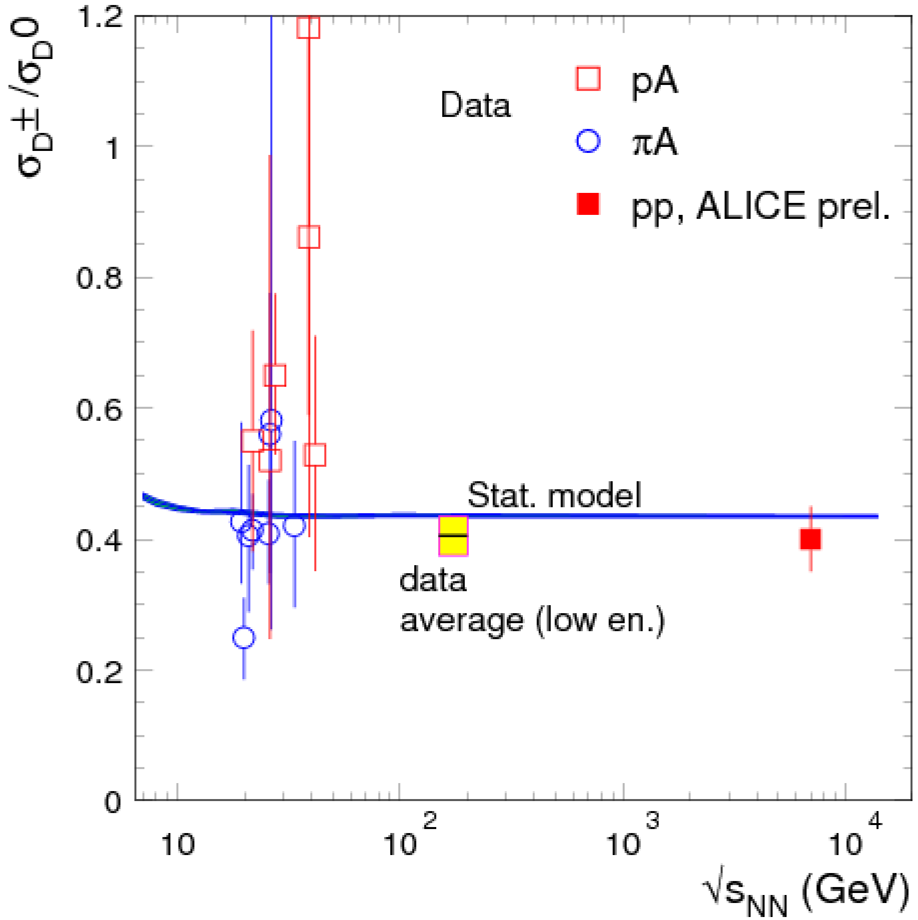
models capture various relevant aspects leading to thermalization of charm
– serious need to put together a coherent picture
- a difficult theoretical challenge, that is being addressed
- recently an EMMI rapid reaction task force took up the issue
(Andronic, Averbeck, Gossiaux, Masciocchi, Rapp)

models constrained by simultaneous fit of R_{AA} and v_2





Charged to neutral D-mesons



also in pp collisions c quarks hadronize at about T = 165 MeV
what about PbPb collisions? To come soon!

charmonia

Formation time of quarkonia

heavy quark velocity in charmonium rest frame:

v = 0.55 for J/ψ see, e.g. G.T. Bodwin et al., hep-ph/0611002

Implies minimum formation time: t = separation/v = 0.45 fm

see also:

Hüfner, Ivanov, Kopeliovich, and Tarasov, Phys. Rev. D62 (2000) 094022

J.P. Blaizot and J.Y. Ollitrault, Phys. Rev. D39 (1989) 232

formation time of order 1 fm

formation time is not short compared to QGP formation time

→ if J/ψ forms at all, it does so in QGP

→ if high color densith QGP screens interaction, J/ψ never forms until screening seizes

Extension of statistical model to include charmed hadrons

- assume: all charm quarks are produced in initial hard scattering; number not changed in QGP
- hadronization at T_c following grand canonical statistical model used for hadrons with light valence quarks (A. Andronic, P. Braun-Munzinger, J.S. or J. Cleymans, K. Redlich or F. Becattini)

number of charm quarks fixed by a charm-balance equation containing fugacity g_c

$$N_{c\bar{c}}^{direct} = \frac{1}{2} g_c V (\sum_i n_{D_i}^{therm} + n_{\Lambda_i}^{therm}) + g_c^2 V (\sum_i n_{\psi_i}^{therm}) + \ldots$$

and for $N_{c,\bar{c}} << 1 \rightarrow$ canonical: $N_{c\bar{c}}^{dir} = \frac{1}{2} g_c N_{oc}^{therm} \frac{I_1(g_c N_{oc}^{therm})}{I_0(g_c N_{oc}^{therm})}$

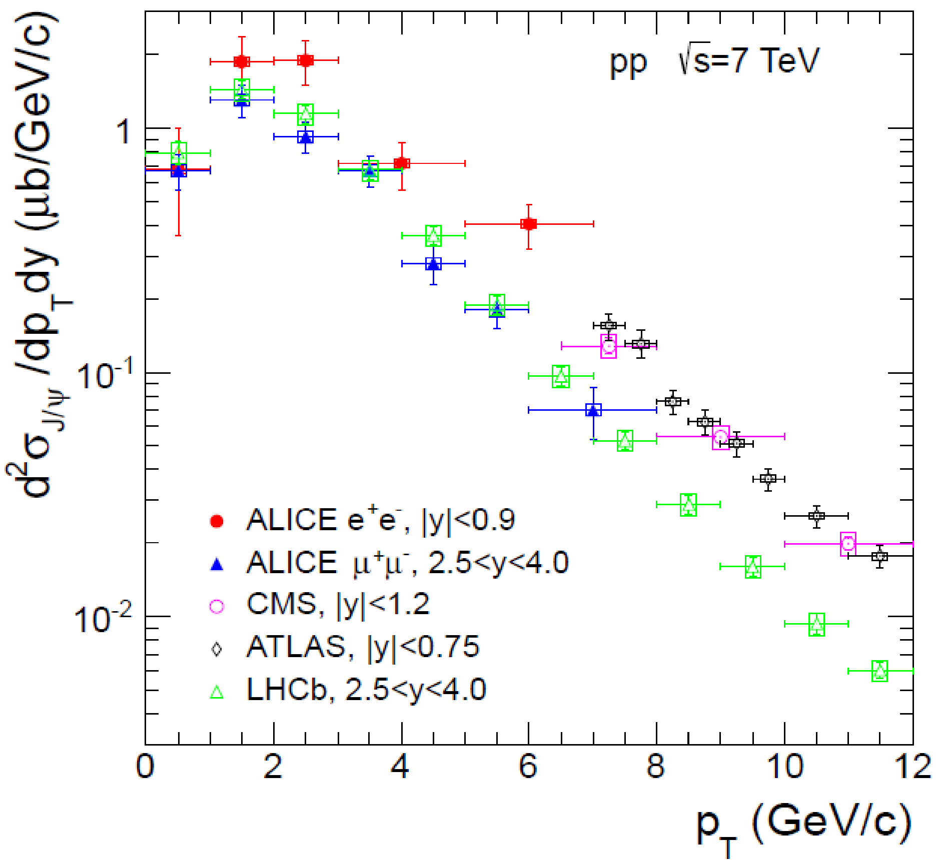
obtain: $N_D = N_D^{therm} \cdot g_c \cdot \frac{I_1}{I_0}$ and $N_{J/\psi} = N_{J/\psi}^{therm} \cdot g_c^2$ and same for all other charmed hadrons

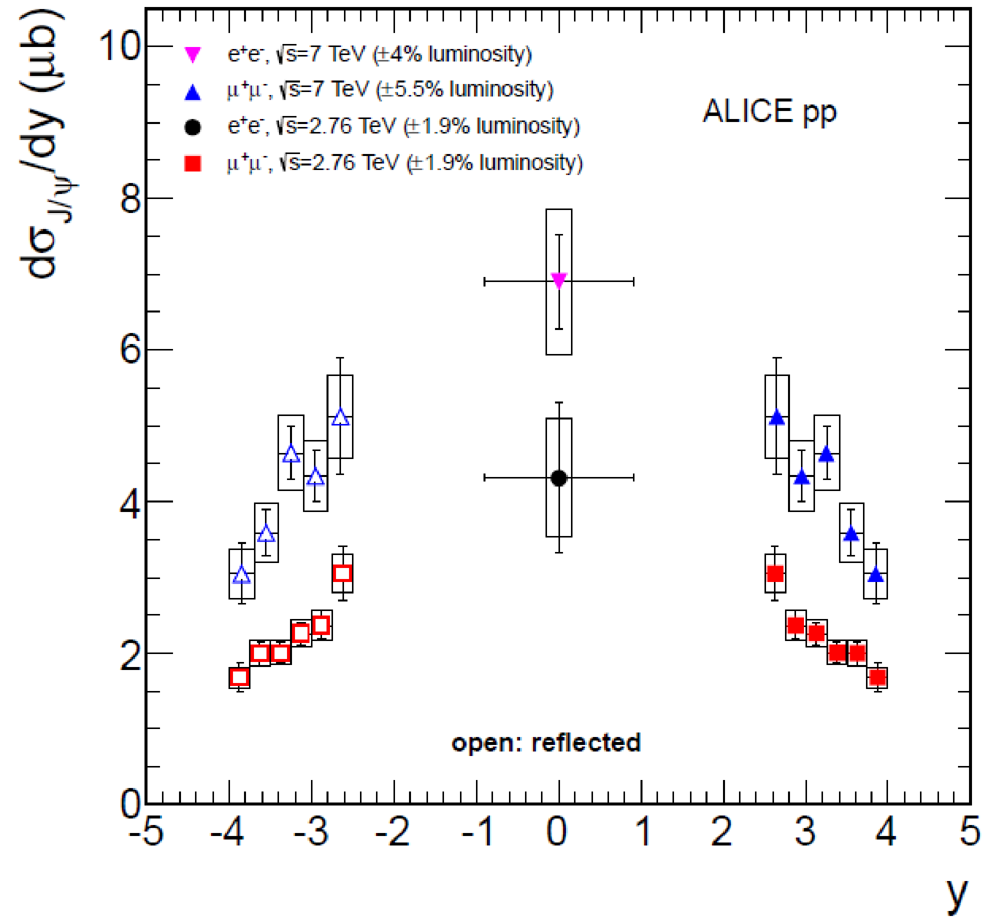
additional input parameters (beyond T, μ_b
fixed by fitting light flavor hadron yields: $V, N_{c\bar{c}}^{direct}$

- volume V fixed by $dN_{ch}/d\eta$
- $N_{c\bar{c}}^{direct}$ from pQCD as long as precision data are lacking
- causally connected region – use 1 unit y (but tested a range)
- core-corona: treat overlap with the tails of nuclear density distribution as pp physics

J/psi spectrum and cross section in pp collisions

ALICE PLB704 (2011) 442 arXiv:1105

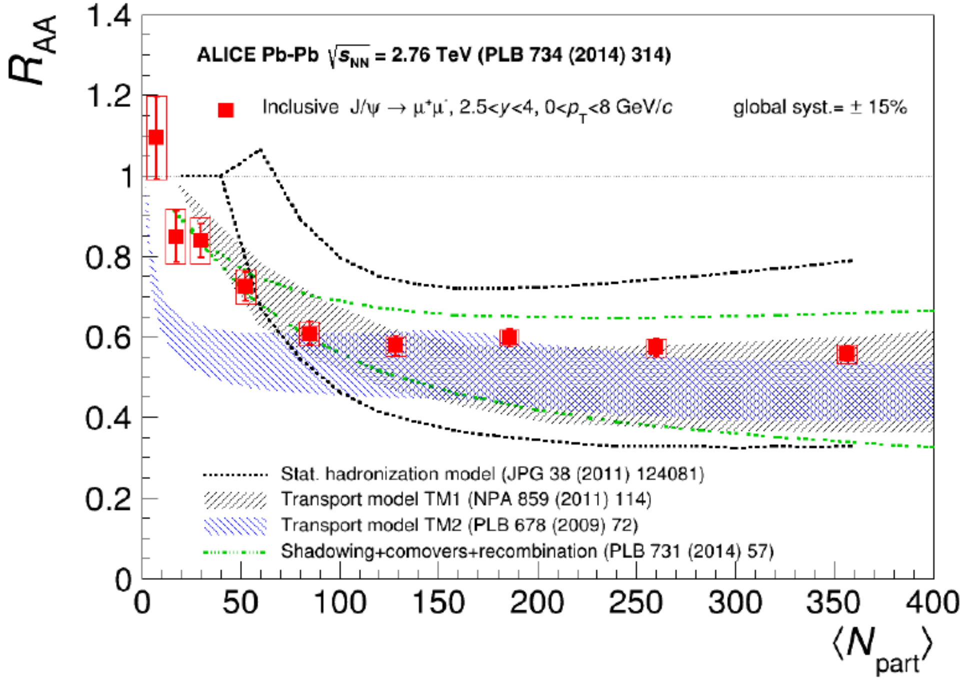


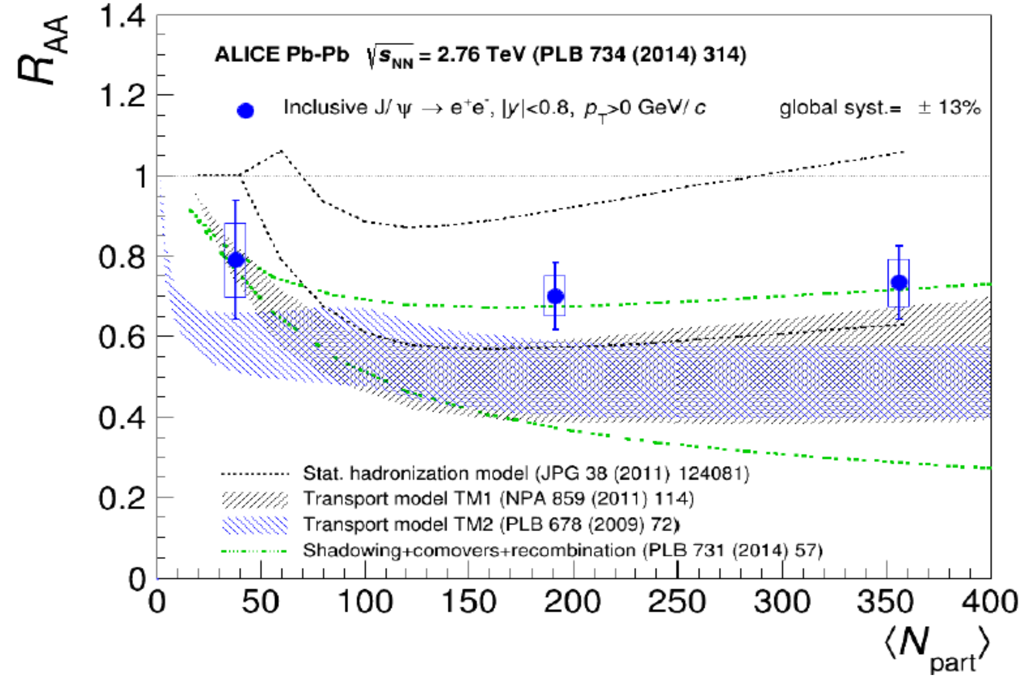


- good agreement between experiments
- complementary in acceptance: only ALICE has acceptance below 6 GeV at mid-rapidity

measured both at 7 and 2.76 TeV
<u>open issues:</u> statistics at mid-rapidity
polarization (biggest source of syst error)

J/psi and transport models (and stat hadronization)

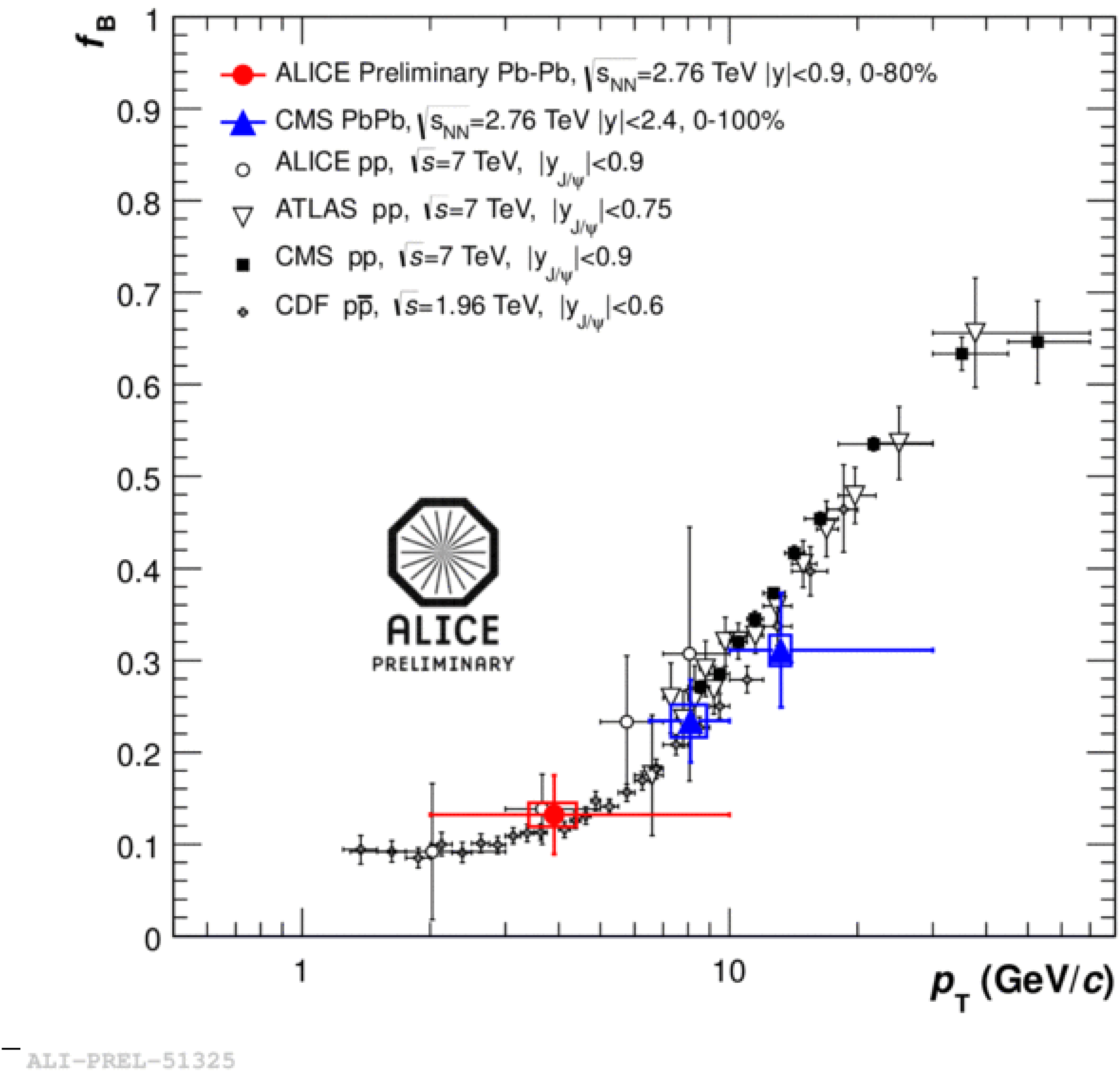




in transport models (Rapp et al. & Zhuang et al.) J/psi generated both in QGP and at hadronization

- transport models also in line with R_{AA}
  part of J/ψ from direct hard production, part dynamically generated in QGP, part at hadronization, but different open charm cross section used
  (0.5-0.75mb TAMU and 0.65-0.8 mb Tsinghua vs. 0.3-0.4 mb SHM) more below

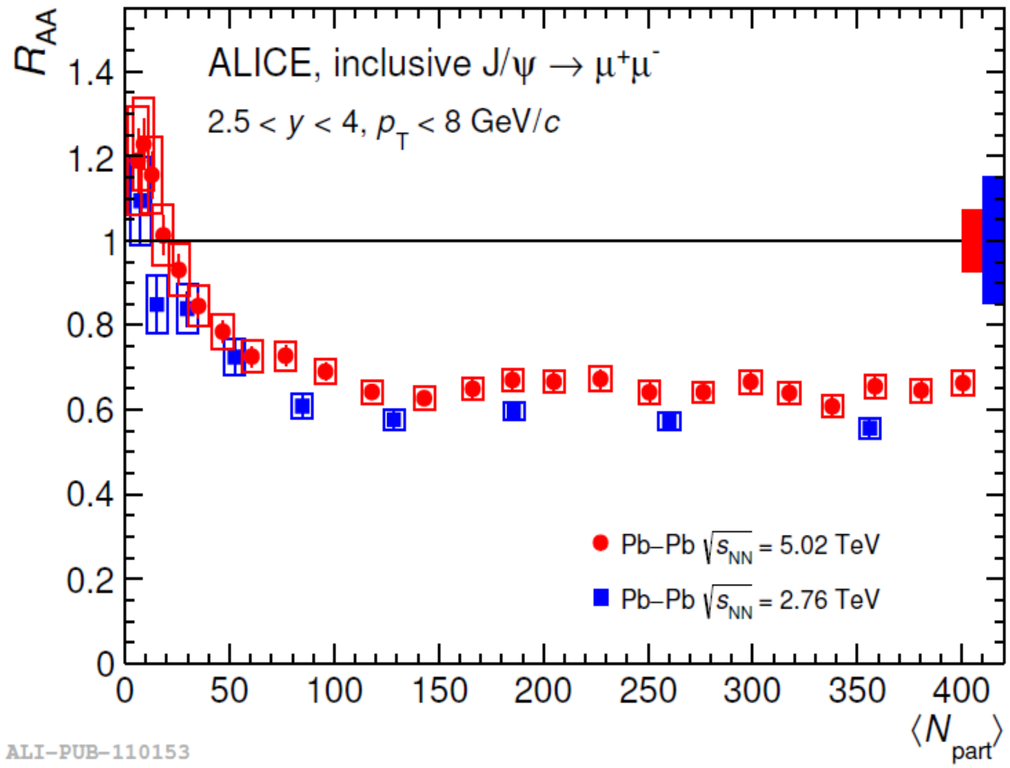
Fraction of J/psi from B-decays



p_t integrated non-prompt B-fraction of small
within current errors no significant difference in pp and PbPb collisions

J/ψ in PbPb at $\sqrt{s_{NN}}$ = 5.02 TeV

arXiv:1606.08197 [nucl-ex]



$R_{AA}^{0\text{-}90\%}$(5.02 TeV) / $R_{AA}^{0\text{-}90\%}$(2.76 TeV) = 1.13 ± 0.02(stat) ± 0.18(syst)

increase of J/ψ R_{AA} for all centralities and over large range of p_t (but within 1 σ)

Attempt to determine Debye mass from data

J/ψ formation via statistical hadronization at T_c implies in classical picture:

$\lambda_D < r_{J/\psi} \simeq$ 0.5 fm at T = 156 MeV or $\omega_D/T > 2.5$

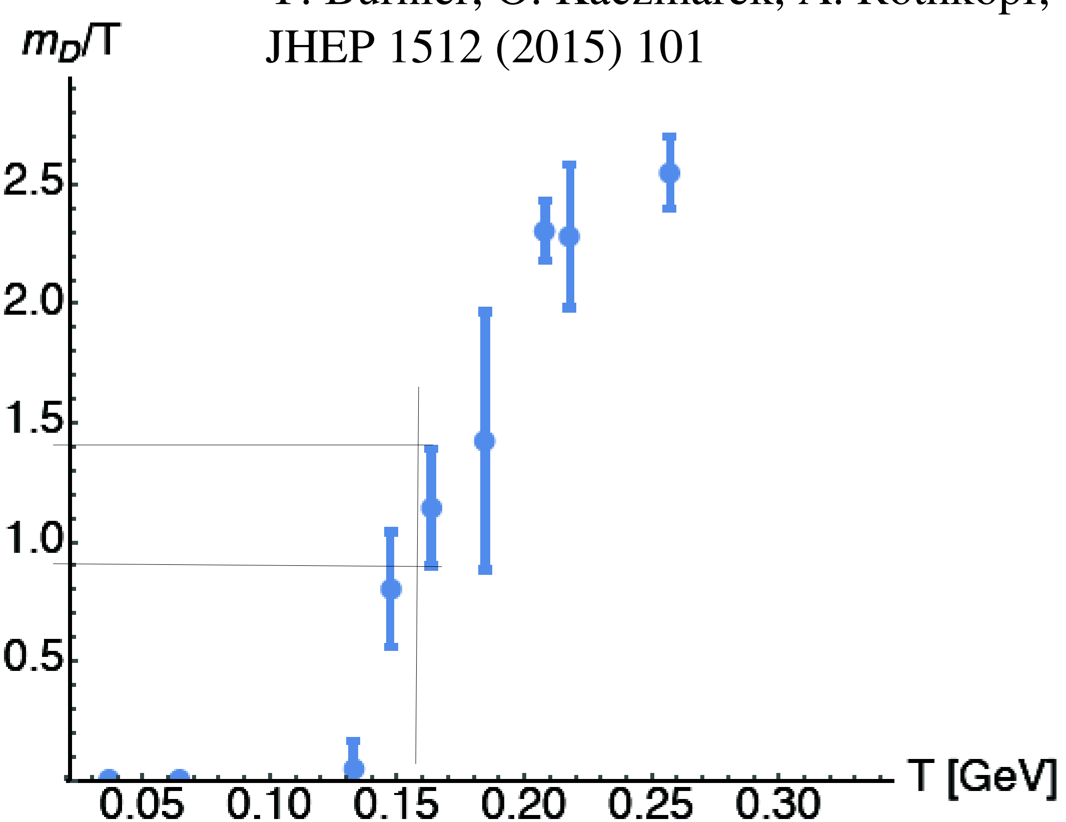
compare to recent finite temperature lQCD potential result:

- value at T_c lower
- systematics?
- and: lattice potential has real and imaginary part, both contribute to screening

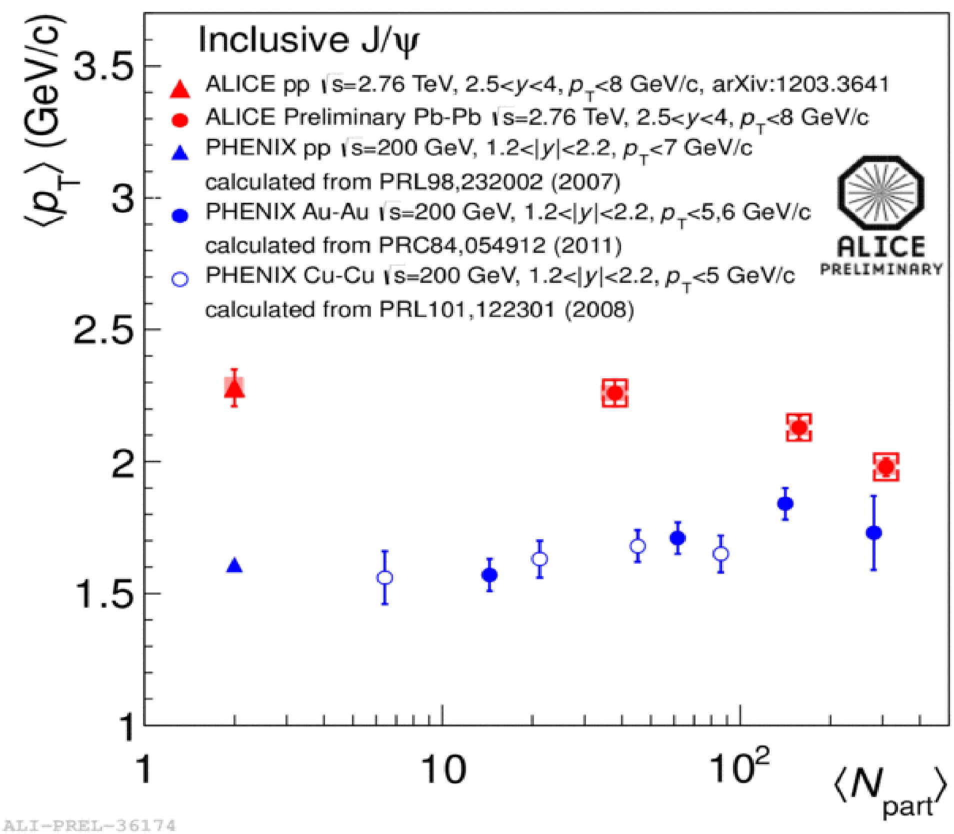
other observable to determine λ_D ?

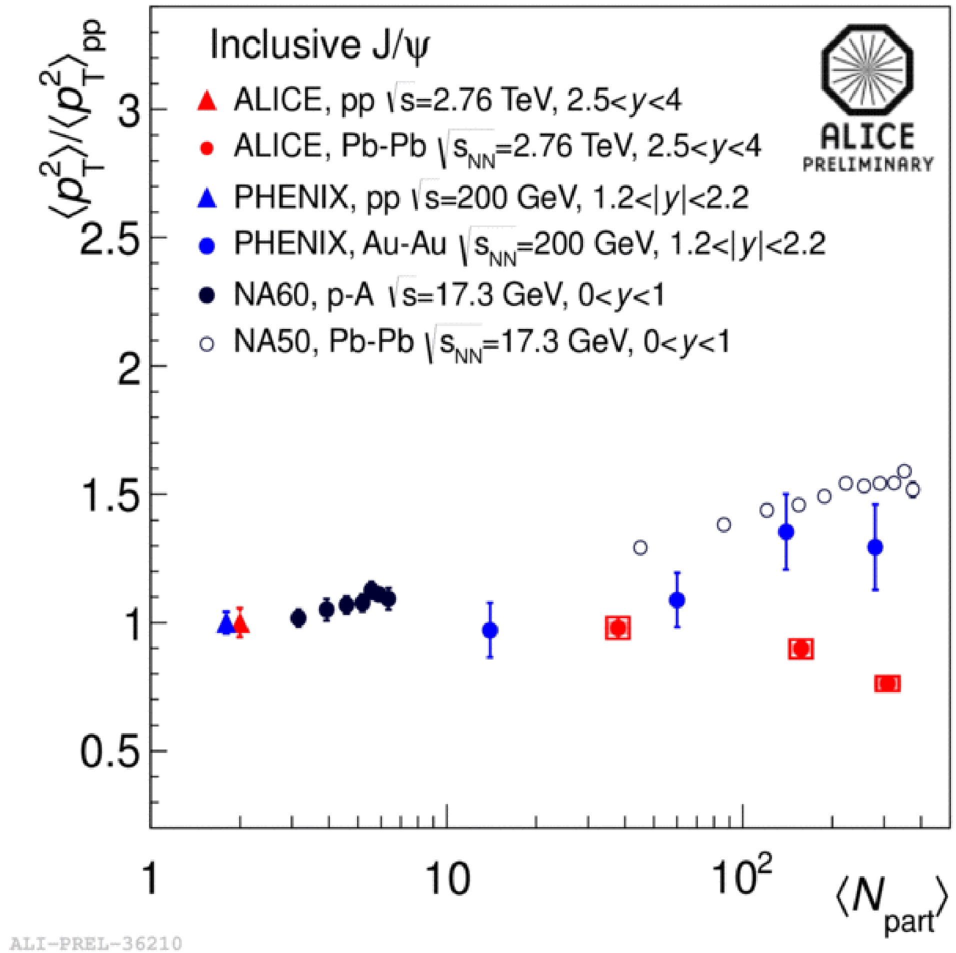
e.g. ψ' vs J/ψ

Y. Burnier, O. Kaczmarek, A. Rothkopf, JHEP 1512 (2015) 101



softening of J/psi p_t distributions for central PbPb coll

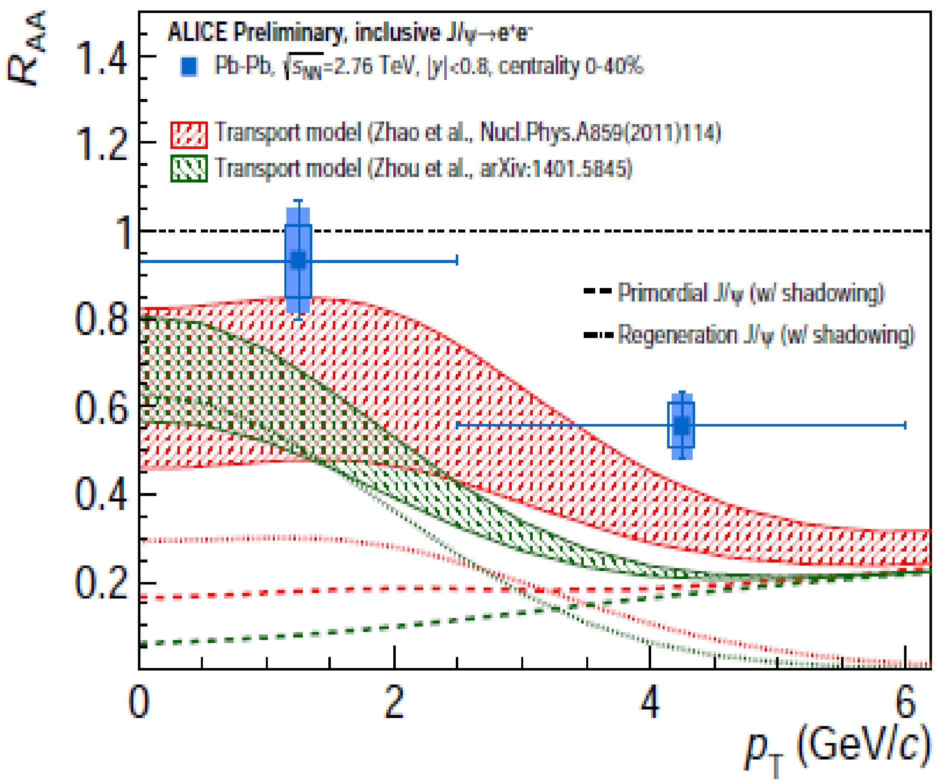




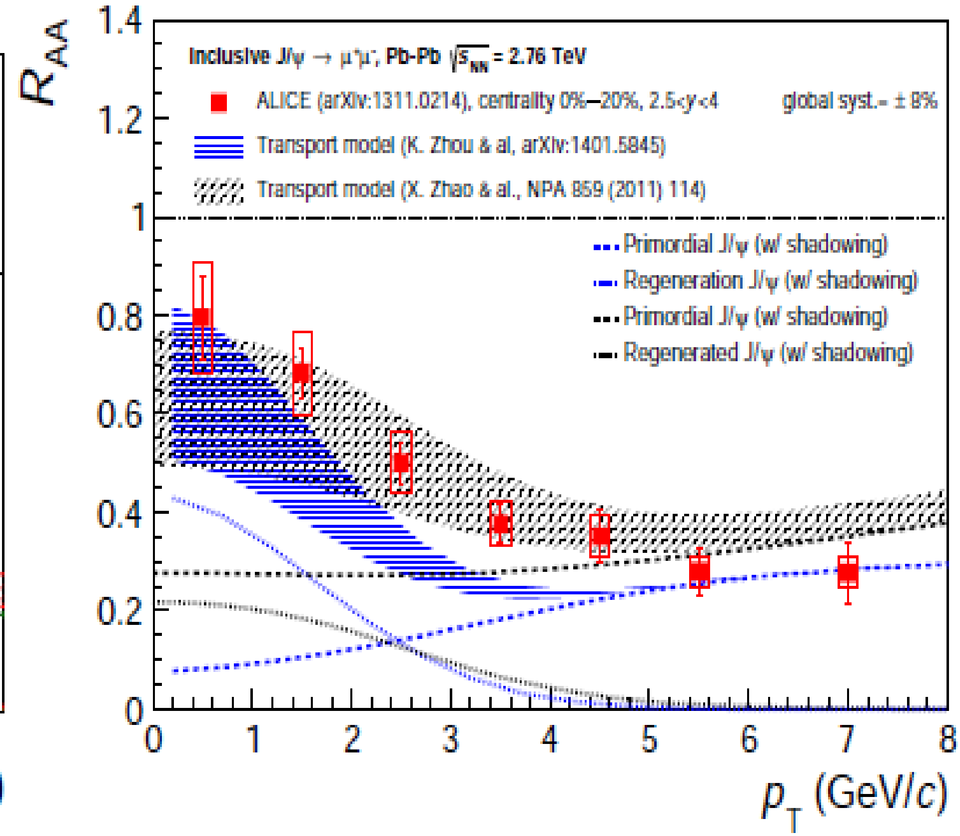
At LHC for central collisions softening relative to peripheral collisions and relative to pp (opposite trend to RHIC) - consistent with formation of J/psi from thermalized c-quarks

comparison with (re-)generation models

midrapidity



forward rapidity



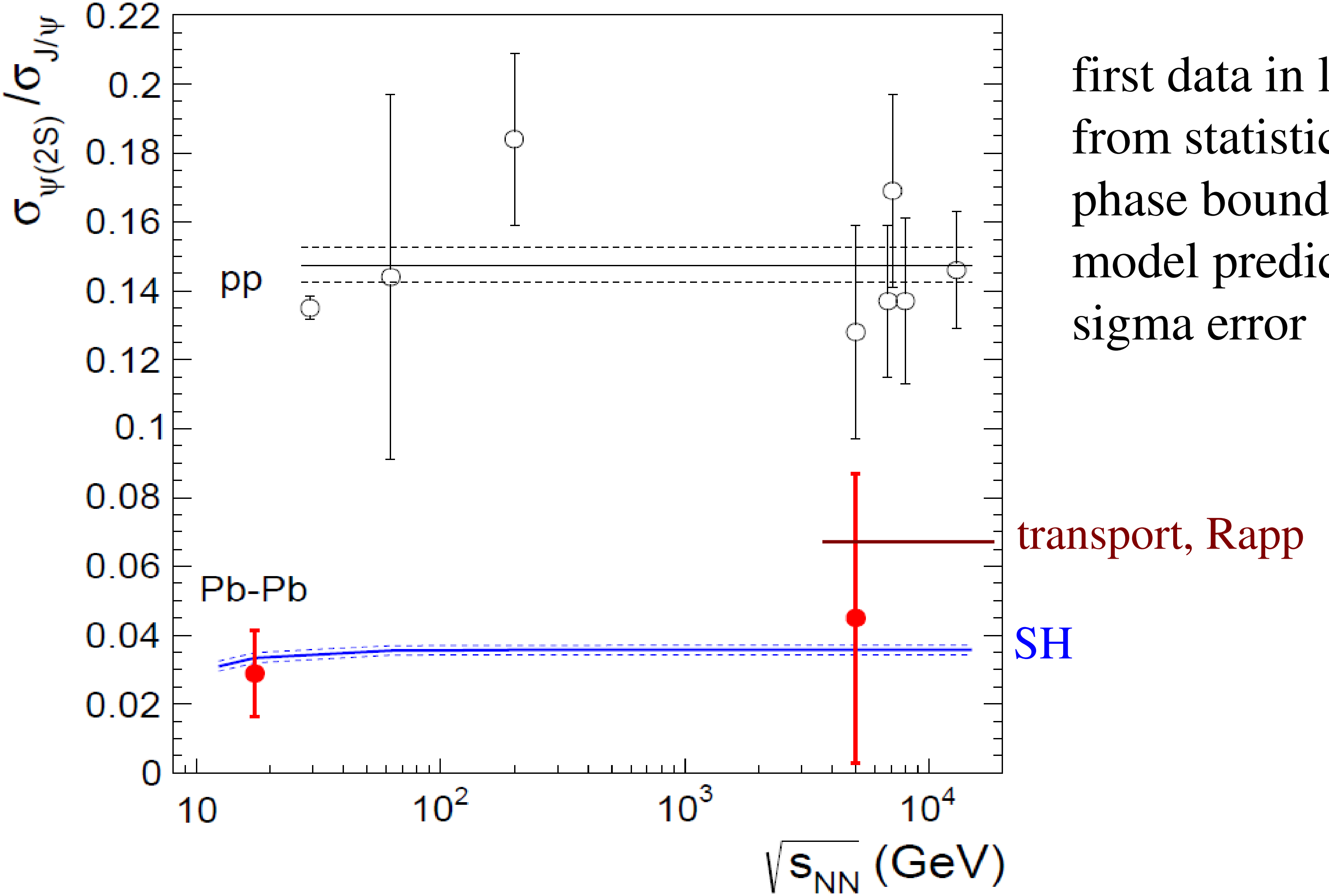
good agreement lends further strong support to the 'full color screening and late J/psi production' picture

How to distinguish between statistical hadronization and transport models with J/ψ beyond T_c?

not a detail, which model is right, but fundamental question
link to phase boundary and existence of bound states beyond T_c at stake

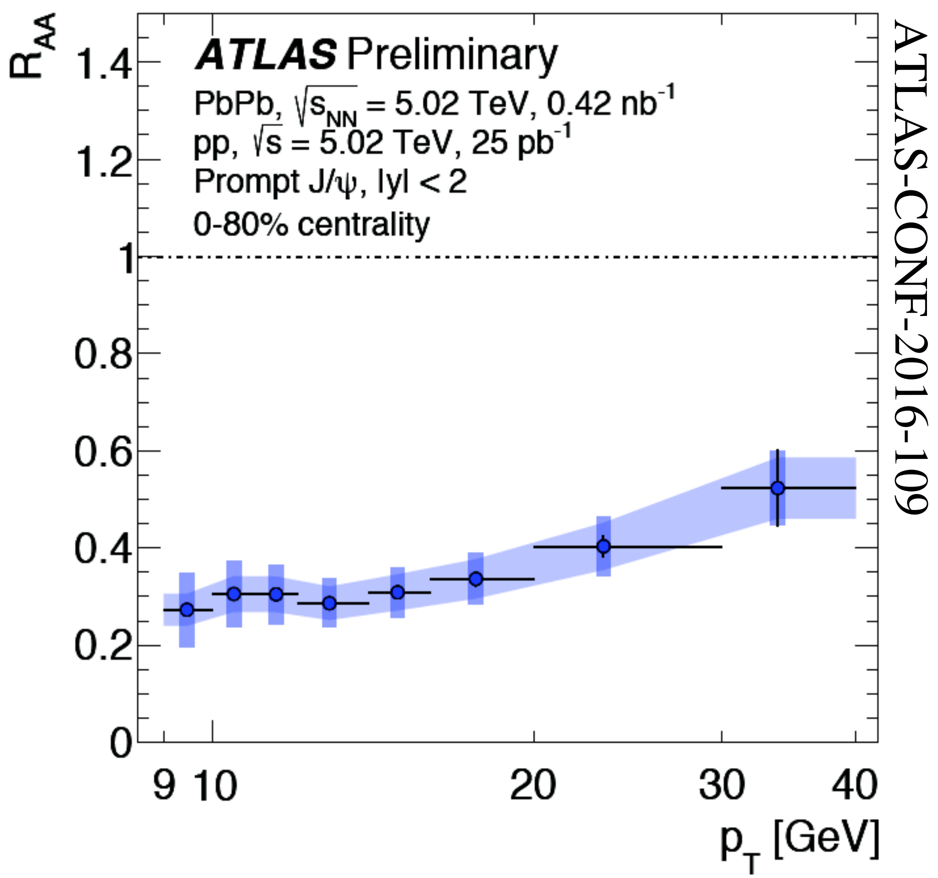
- R_{AA} can be reproduced by both, albeit with different charm cross sections
  go away from R_{AA}, normalize to open charm cross
- spectra: transport models start to be challenged, need more precise data
  and more refined hydro based computation
- similar: v_2 of J/ψ
- maybe decisive: excited state population

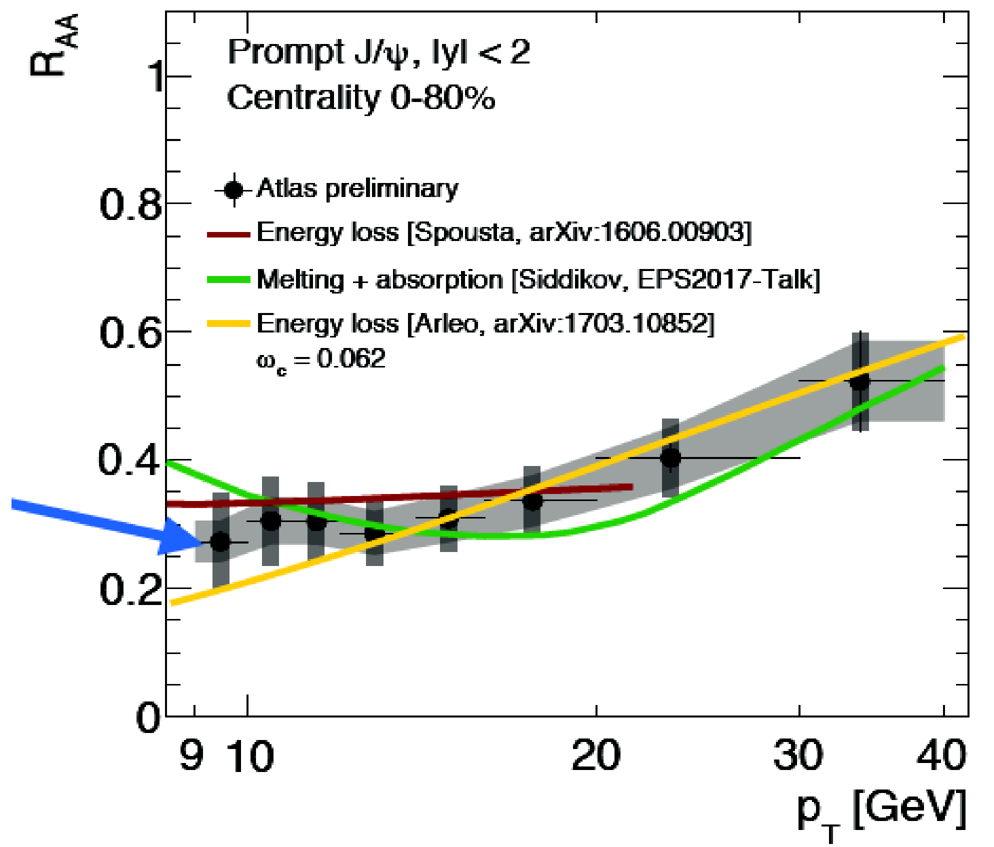
ψ(2S)



first data in line with expectation from statistical hadronization at phase boundary but transport model prediction also inside 1 sigma error

J/ψ in PbPb to high p_t





looks like R_{AA} of other hadrons, understood in terms of energy loss

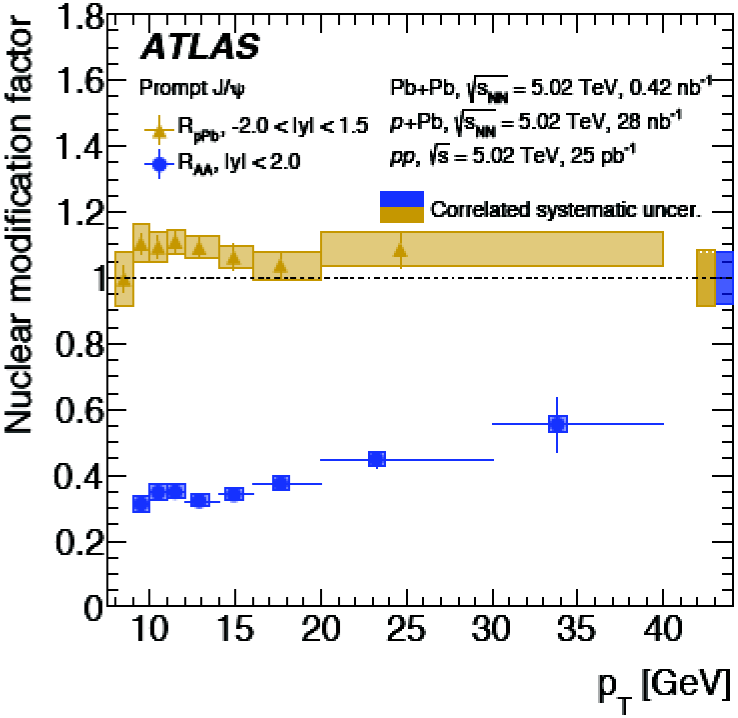
very implausible that this is primordial J/ψ

how far out does statistical hadronization mechanism reach?

1b. J/psi R_{AA} in central PbPb like open heavy flavor and ligh flavor hadrons

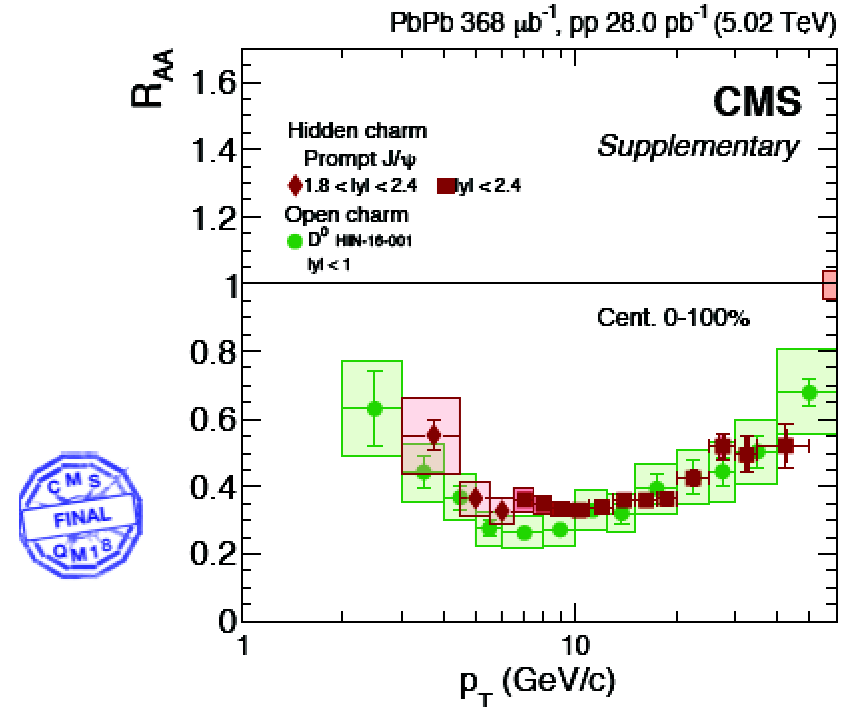
CMS-PAS-HIN-18-012
arXiv:1712.08959

arXiv:1805.04077



Jorge López for the ATLAS Collaboration
Universidad Técnica Federico Santa María, Valparaíso, Chile

PbPb: prompt J/ψ suppression



J/ψ suppression similar to D^0 suppression
Jet quenching for charmonia?

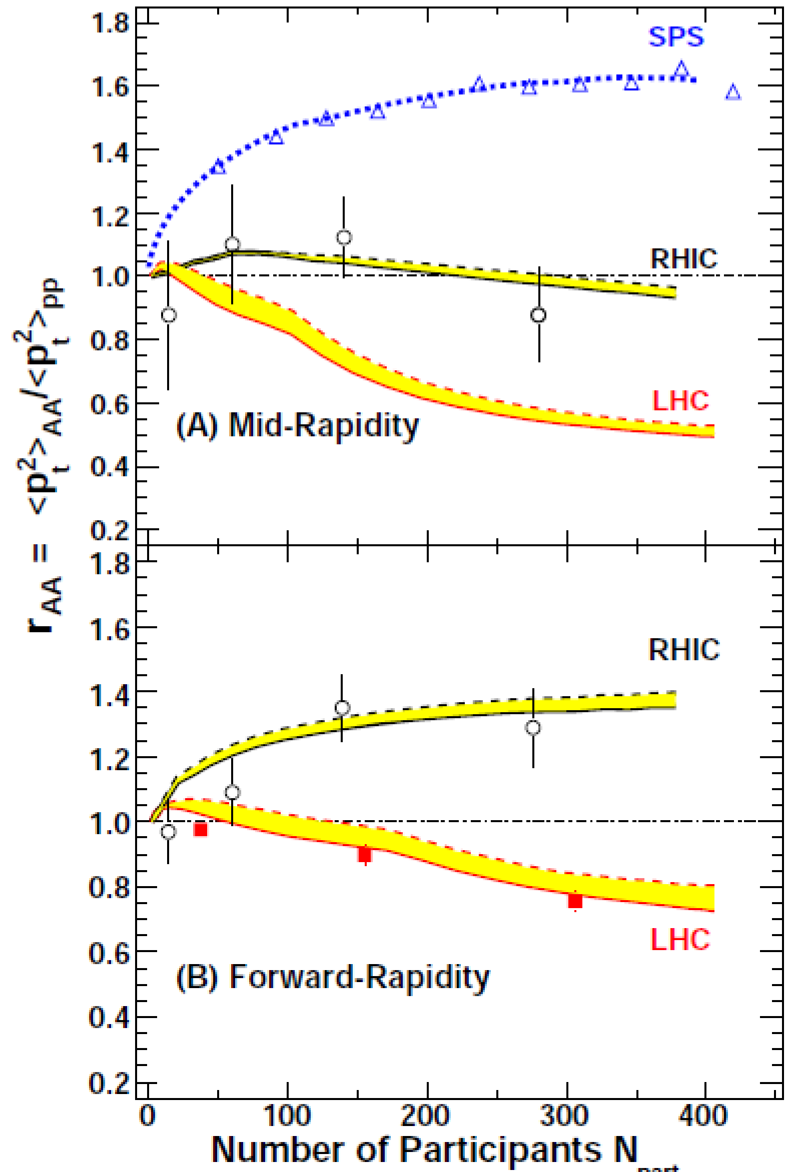
Talk, Quarkonia, Wed. 17:10, G. Oh

analysis of transverse momentum spectra

arXiv:1309.7520v1 [nucl-th] 29 Sep 2013

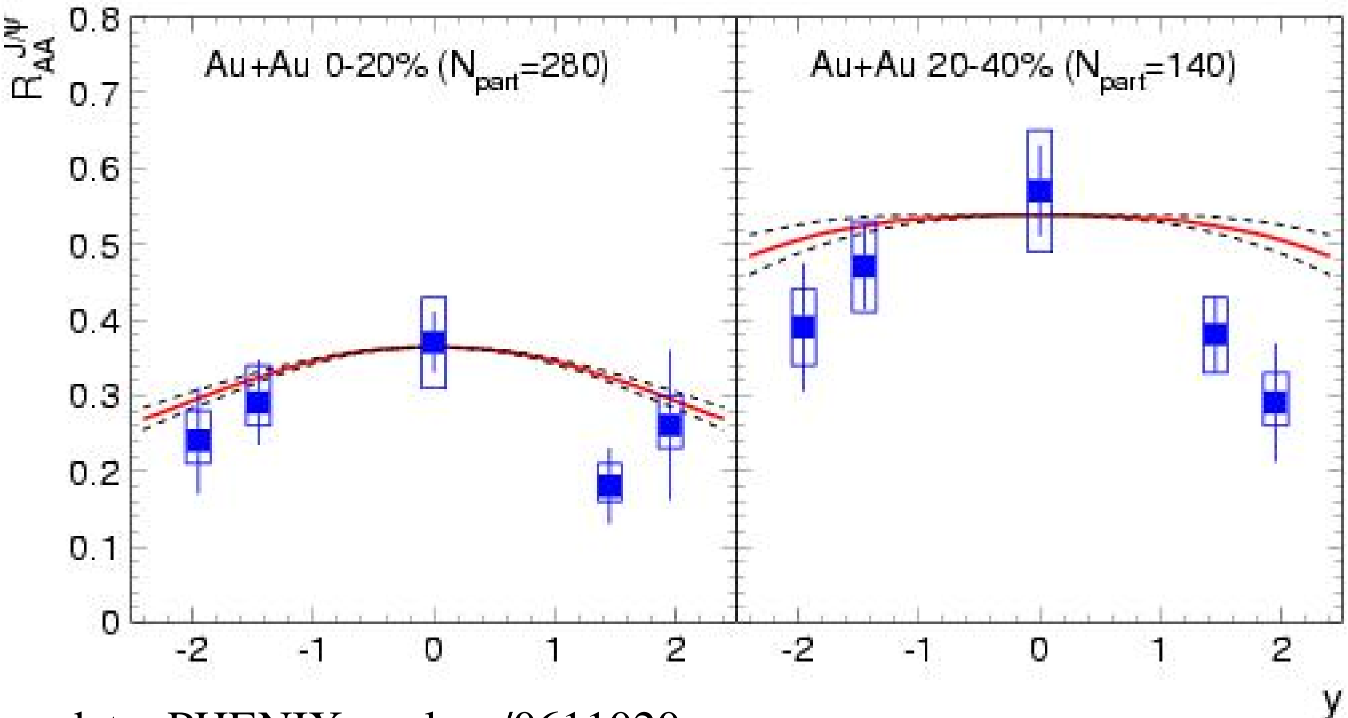
Zhou, Xu, Zhuang

at LHC energy, mostly (re-) generation of charmonium, p_t distribution exhibits features of strong energy loss and approach to thermalization for charm quarks



comparison of model predictions to RHIC data:

R_{AA}: J/ψ yield in AuAu / J/ψ yield in pp times N_{coll}



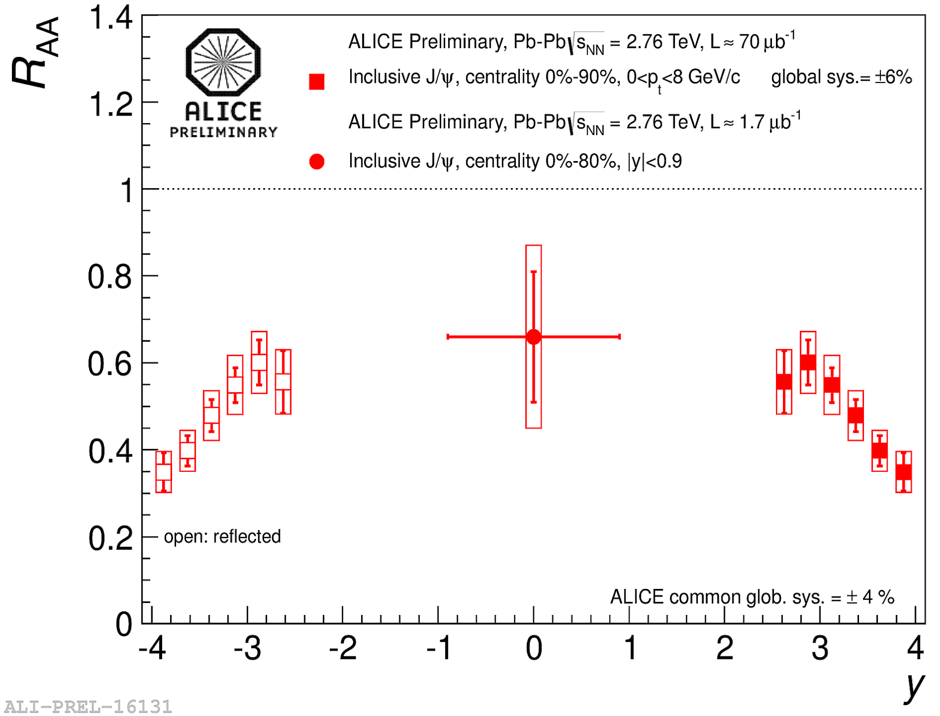
data: PHENIX nucl-ex/0611020
additional 14% syst error beyond shown

model: A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel Phys. Lett. B652 (2007) 259

good agreement, no free parameters
same holds for centrality dependence

remark: y-dep opposite in 'normal Debye screening' picture; suppression strongest at midrapidity (largest density of color charges)

rapidity dependence of J/psi R_{AA}

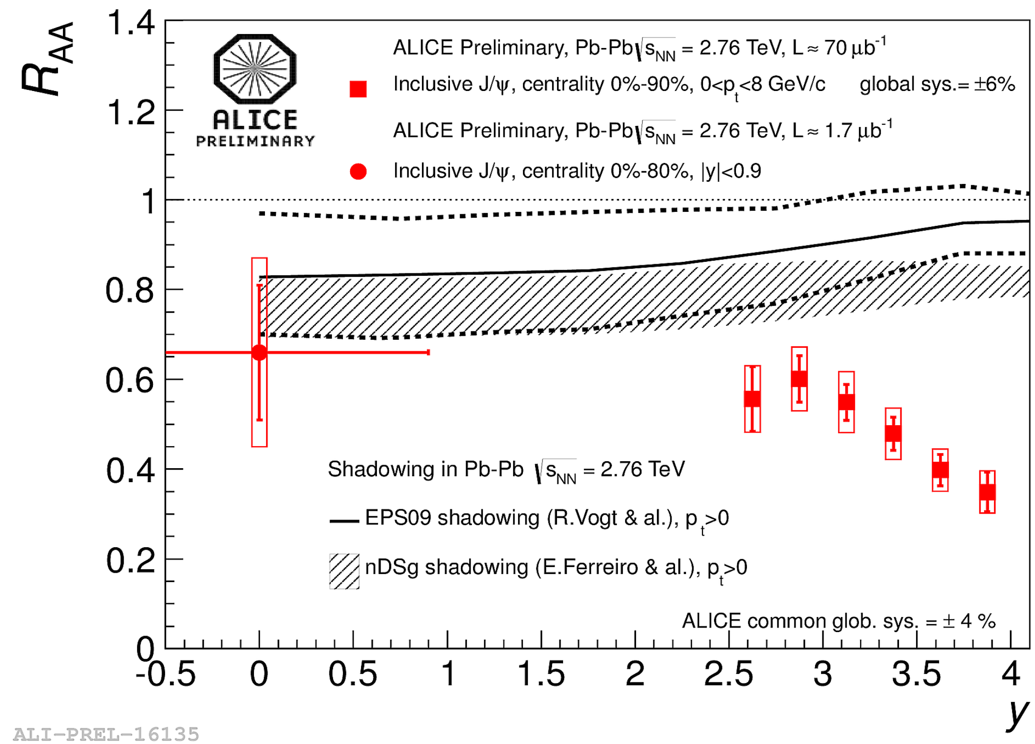


for statistical hadronization J/ψ yield proportional to N_c^2

higher yield at mid-rapidity predicted in line with observation

comparison to shadowing calculations:

- at mid-rapidity suppression could be explained by shadowing only
- at forward rapidity there seems to be additional suppression
- need to measure shadowing

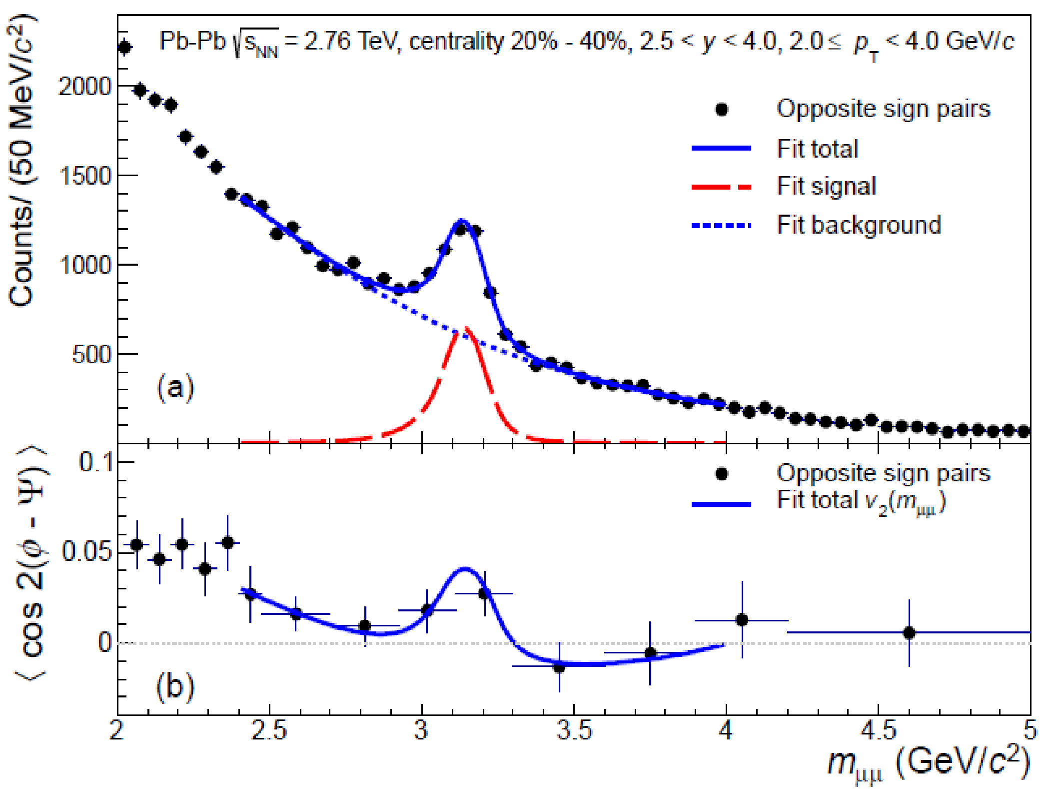


elliptic flow of J/psi

charm quarks thermalized in the QGP should exhibit the elliptic flow generated in this phase

Centrality	$\langle N_{part} \rangle$	EP resolution ± (stat.) ± (syst.)
5%–20%	283 ± 4	0.548 ± 0.003 ± 0.009
20%–40%	157 ± 3	0.610 ± 0.002 ± 0.008
40%–60%	69 ± 2	0.451 ± 0.003 ± 0.008
60%–90%	15 ± 1	0.185 ± 0.005 ± 0.013
20%–60%	113 ± 3	0.576 ± 0.002 ± 0.008

ALICE data analysis in 4 centrality bins



analyze opposite sign muon pairs relative to the V0 event plane as function of mass and for each pt bin

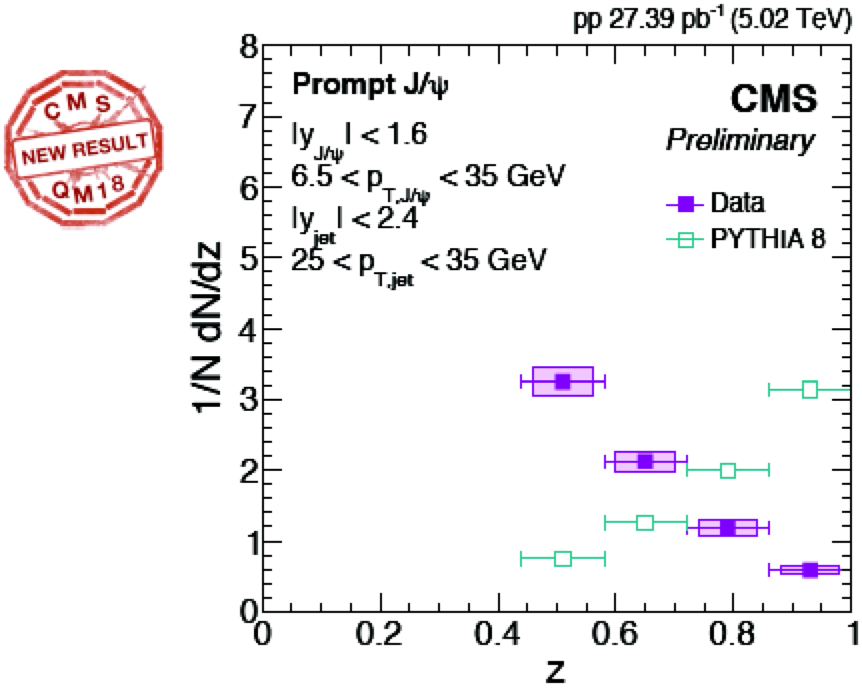
- fit distribution with

$$v_2(m_{\mu\mu}) = v_2^{sig}\alpha(m_{\mu\mu}) + v_2^{bkg}(m_{\mu\mu})[1-\alpha(m_{\mu\mu})]$$

where $\alpha(m_{\mu\mu})$ = S / (S+B) fitted to the mass spectrum

1c. J/psi fragmentation function surprizing

pp: Prompt J/ψ fragmentation

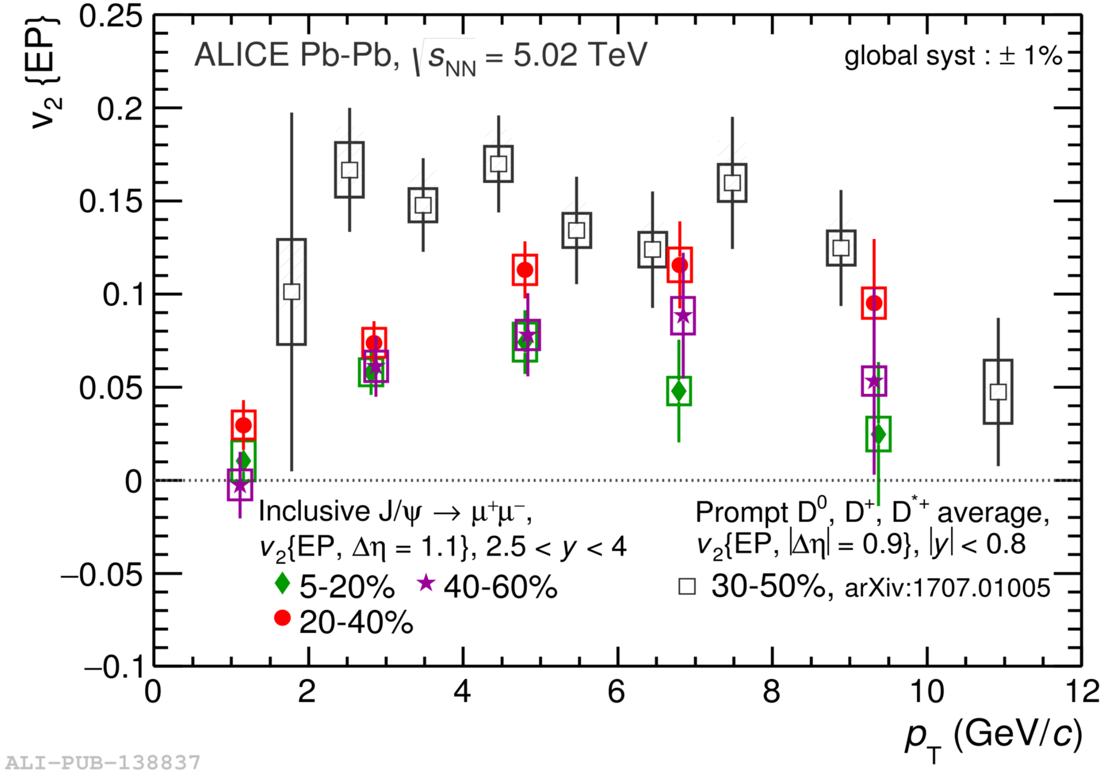


Prompt J/ψ in jet fragmentation function not well described by PYTHIA

Poster, B. Diab (J/Psi in jet), QRK-06

Elliptic flow of J/ψ vs p_t

arXiv:1709.05260



Strength of J/ψ v_2 similar to D-mesons

outlook – what ALICE can do in the future

LHC run1:

2 PbPb runs

- 2010 $O(10\ \mu b^{-1})$
- 2011 $O(150\ \mu b^{-1})$

luminosity reached $\mathscr{L}=2\ 10^{26}\ cm^{-2}\ s^{-1}$ twice design lumi at this energy

1 pPb run

- 2012/2013 $O(30\ nb^{-1})$

from 2/2013 until end of 2014 LS1: consolidation of LHC to allow full energy

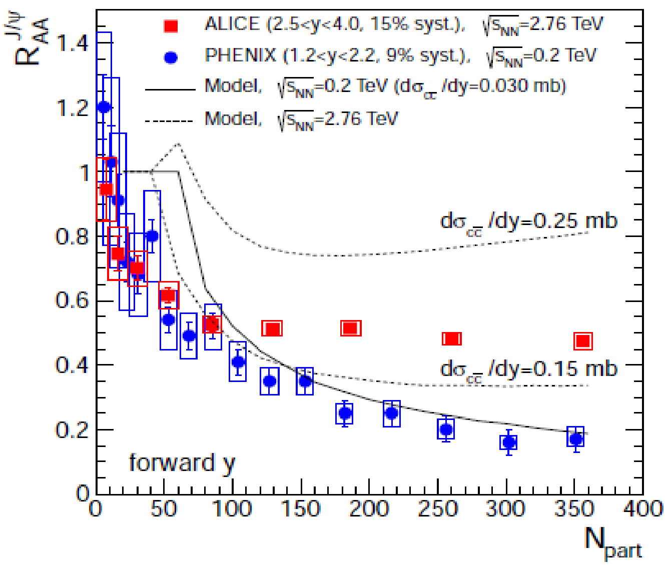
LHC run2: 2015-2018 PbPb running at $\sqrt{s_{NN}} = 5.5$ TeV

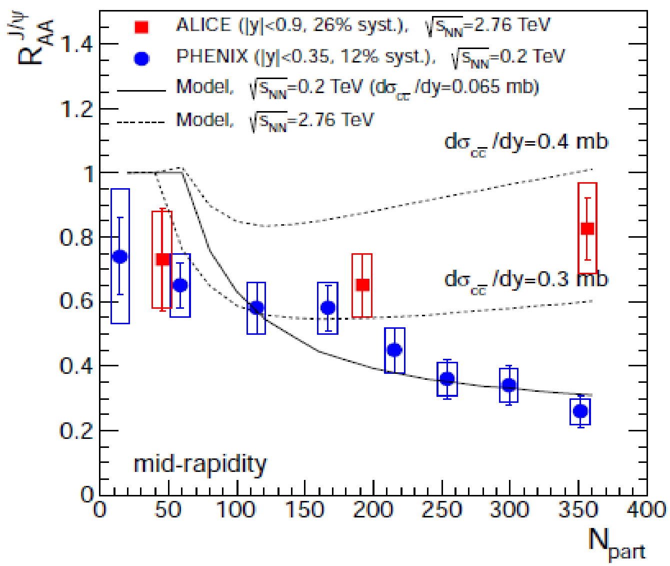
to achieve approved initial goal of 1 nb^{-1}

late 2018 start LS2 – increase of LHC luminosity und experiment upgrade

LHC run3: 2020 onwards - expect $\mathscr{L}=6\ 10^{27}\ cm^{-2}\ s^{-1}$ or PbPb interactions at 50 kHz
achieve for PbPb 10 nb^{-1} corresponding to 8 10^{10} collisions sampled
plus a low field run of 3 nb^{-1} + pp reference running + pPb - a program for about 6 years

J/psi as probe of deconfinement



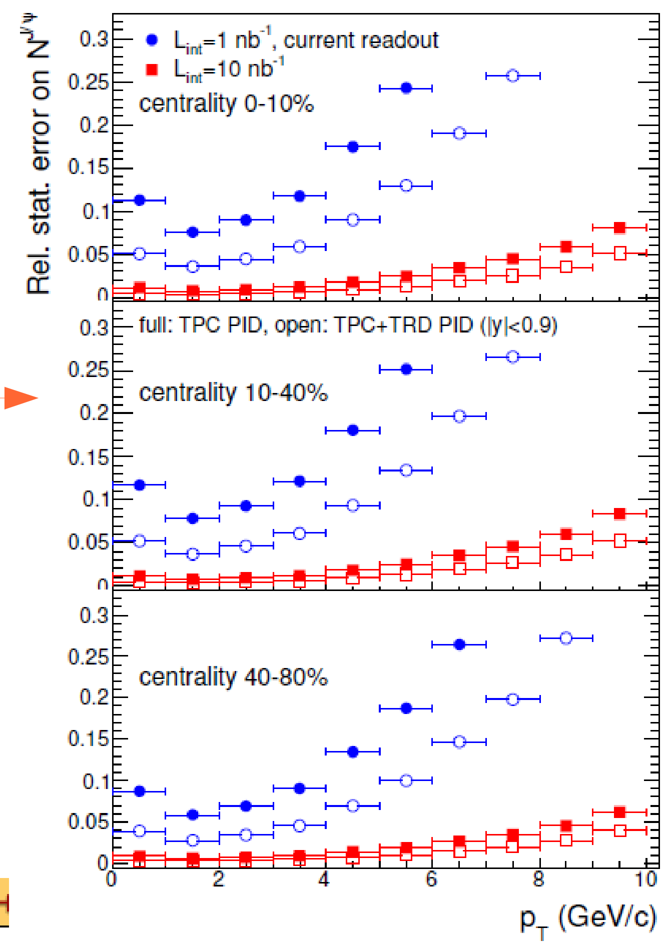


di-electrons statistics limited, 10 nb-1 will have huge effect

but also syst uncertainties will decrease with upgrade:

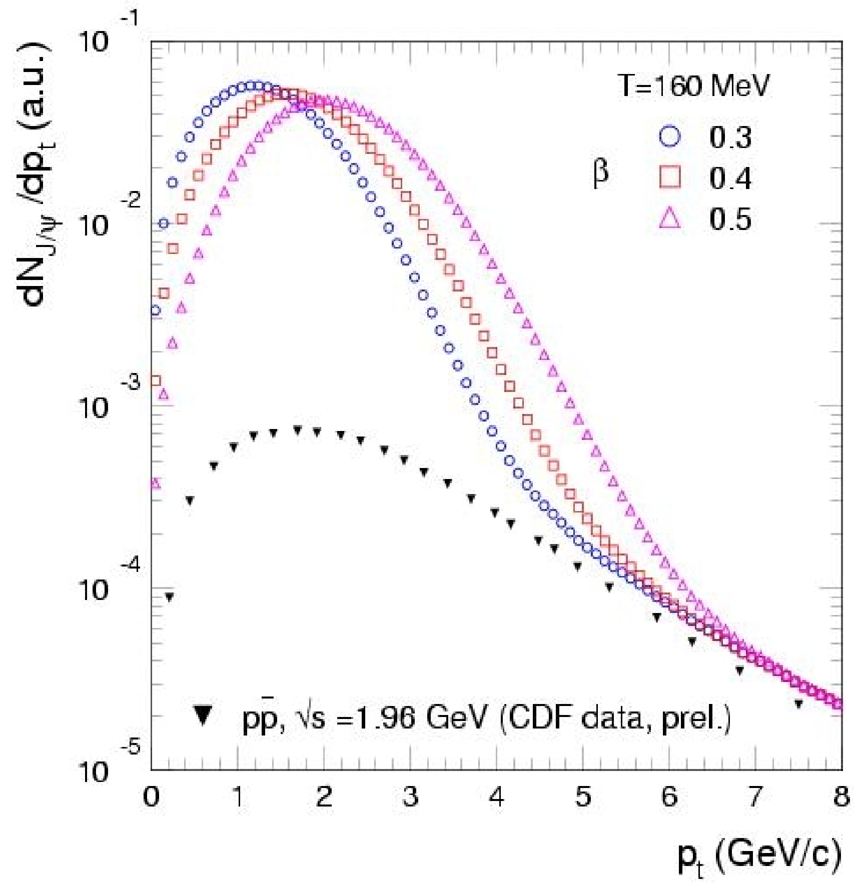
- will also add TRD for electron id - reduced comb background
- thinner ITS reduced radiation tail

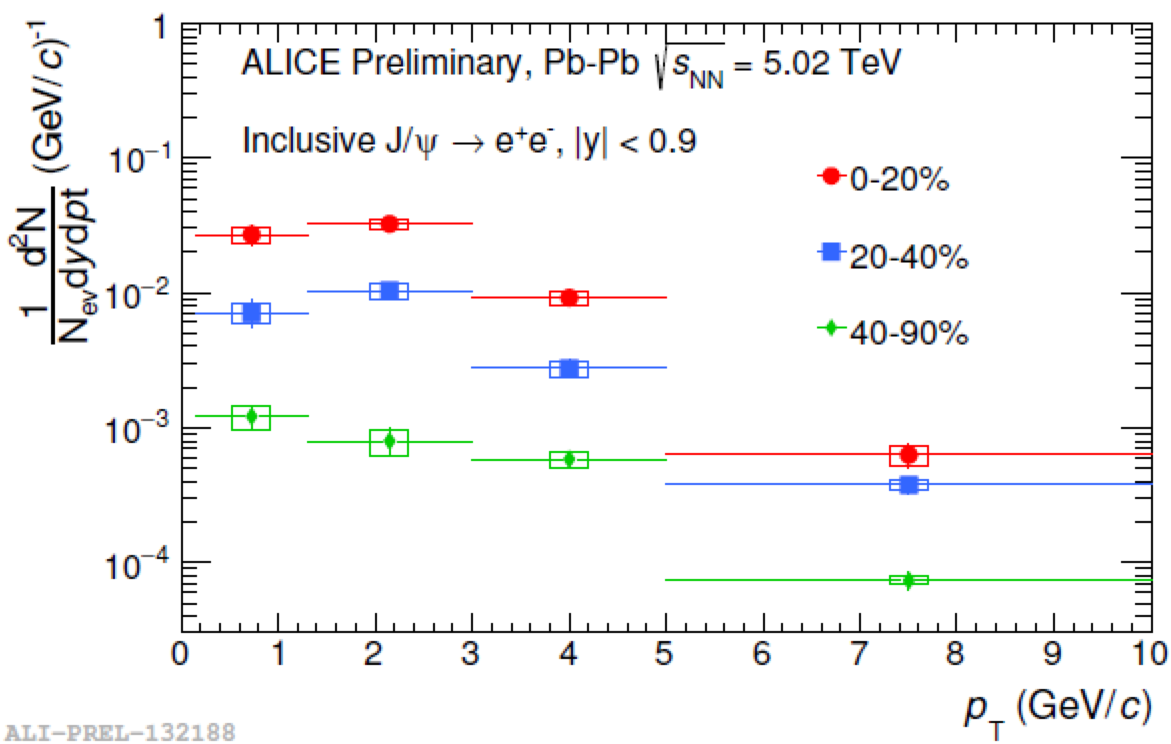
both affect signal extraction



spectral distribution is key to thermalization

if charm quark thermalize, their spectral distributions should also reflect collective flow of liquid

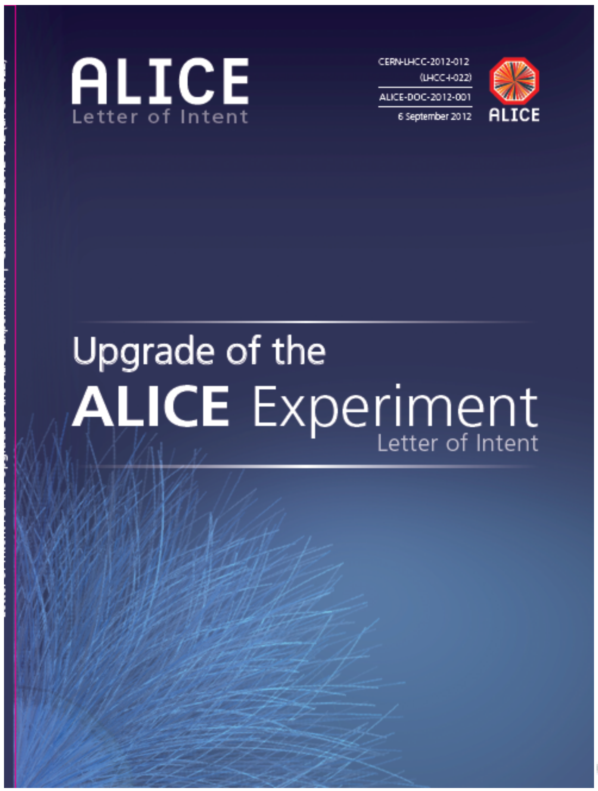




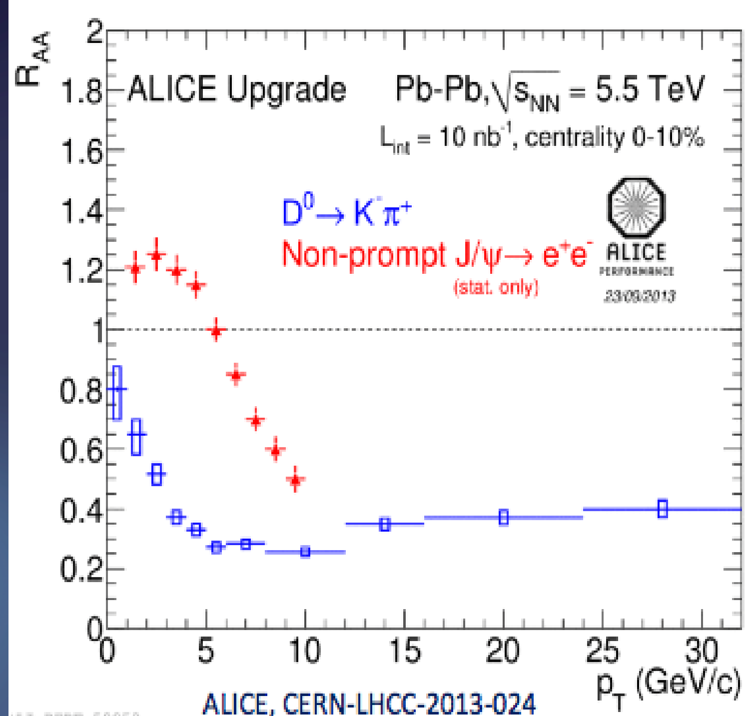
first spectra a mid-y appearing
much more to come
we are computing spectra

outlook open heavy flavor – LHC run3

new high performance ITS plus rate increase (TPC upgrade)



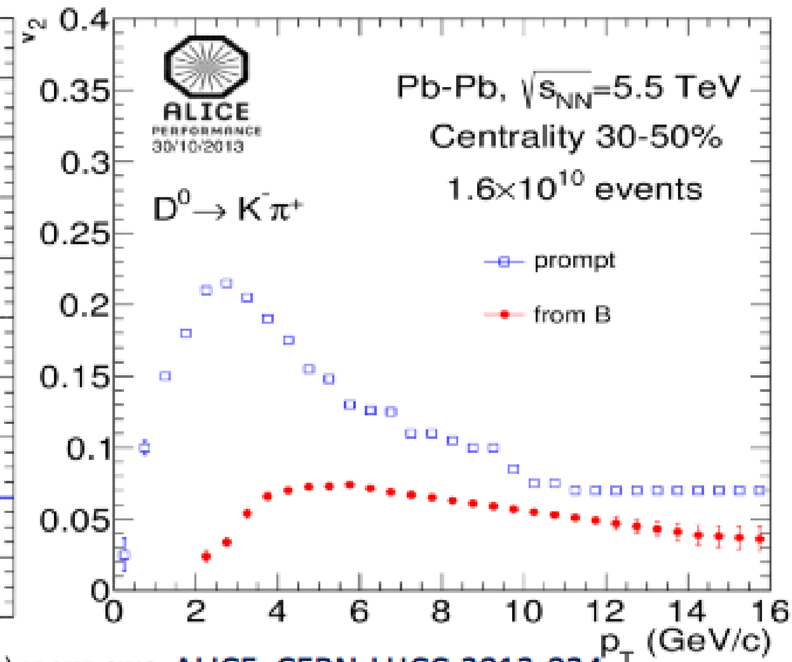
Upgrade



ALICE, CERN-LHCC-2013-024

Charm and beauty R_{AA} down to p_T~0 using D^0 and B-decay J/ψ

Upgrade



ALICE, CERN-LHCC-2013-024

Input values from BAMPS model: C. Greiner et al. arXiv:1205.4945

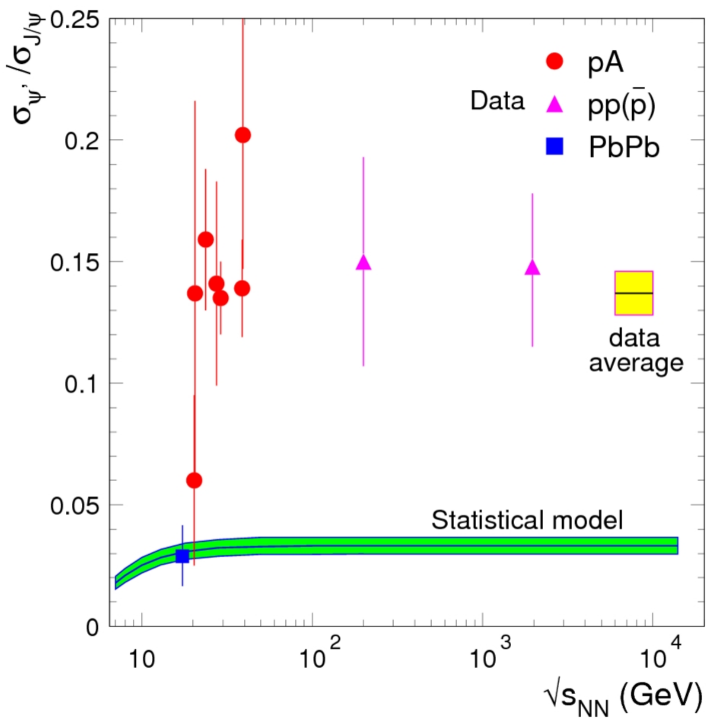
Charm v_2 down to p_T~0 using prompt and beauty v_2 down to B p_T~0 using B-decay D^0

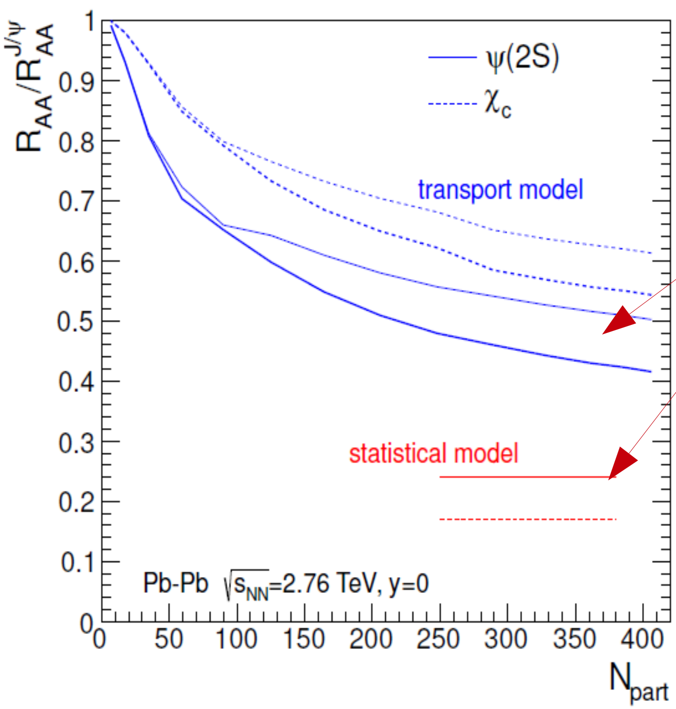
physics reach after ALICE upgrade

Topic	Observable	Approved (1/nb delivered, 0.1/nb m.b.)	Upgrade (10/nb delivered, 10/nb m.b.)
Heavy flavour	D meson RAA	pT>1, 10%	pT>0, 0.3%
	D from B RAA	pT>3, 30%	pT>2, 1%
	D meson elliptic flow (for v2=0.2)	pT>1, 50%	pT>0, 2.5%
	D from B elliptic flow (for v2=0.1)	not accessible	pT>2, 20%
	Charm baryon/meson ratio (Λc/D)	not accessible	pT>2, 15%
	Ds RAA	pT>4, 15%	pT>1, 1%
Charmonia	J/ψ RAA (forward y)	pT>0, 1%	pT>0, 0.3%
	J/ψ RAA (central y)	pT>0, 5%	pT>0, 0.5%
	J/ψ elliptic flow (forward y, for v2 =0.1)	pT>0, 15%	pT>0, 5%
	ψ'	pT>0, 30%	pT>0, 10%
Dielectrons	Temperature IMR	not accessible	10% on T
	Elliptic flow IMR (for v2=0.1)	not accessible	10%
	Low-mass vector spectral function	not accessible	pT>0.3, 20%
Heavy nuclei	hyper(anti)nuclei, H-dibaryon	35% (4ΛH)	3.5% (4ΛH)

stat. error at min pt

excited charmonia crucial to distinguish between models



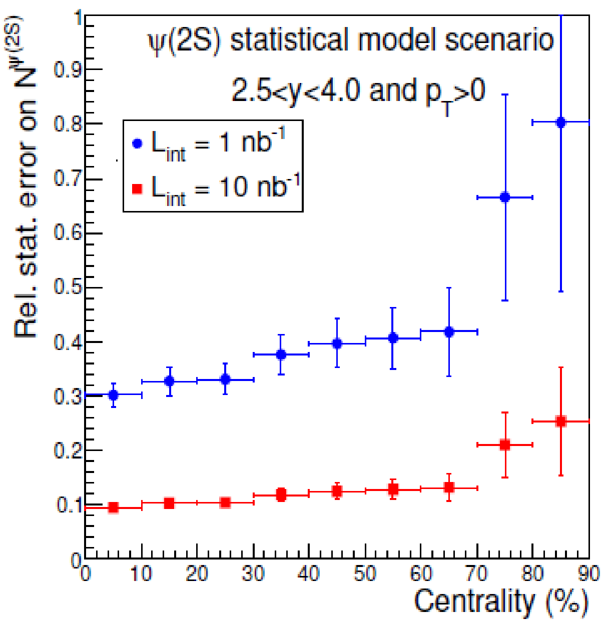


in fact here one can distinguish between the transport models that form charmonia already in QGP and statistical hadronization at phase boundary!

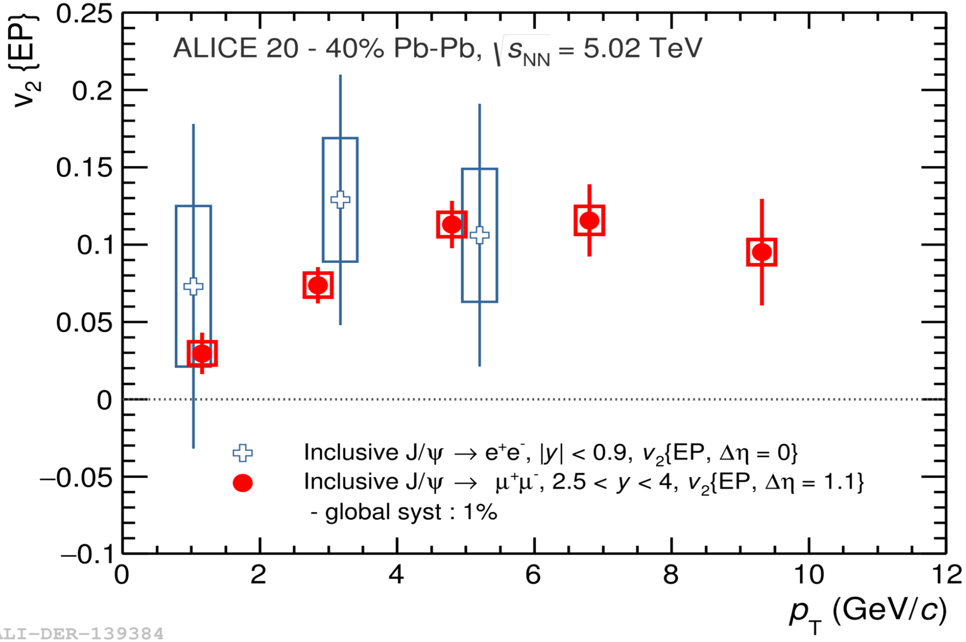
for statistical hadronization need to see suppression by Boltzmann factor

χ_c even bigger difference

expected ALICE performance muon arm run2 and run3



J/psi elliptic flow



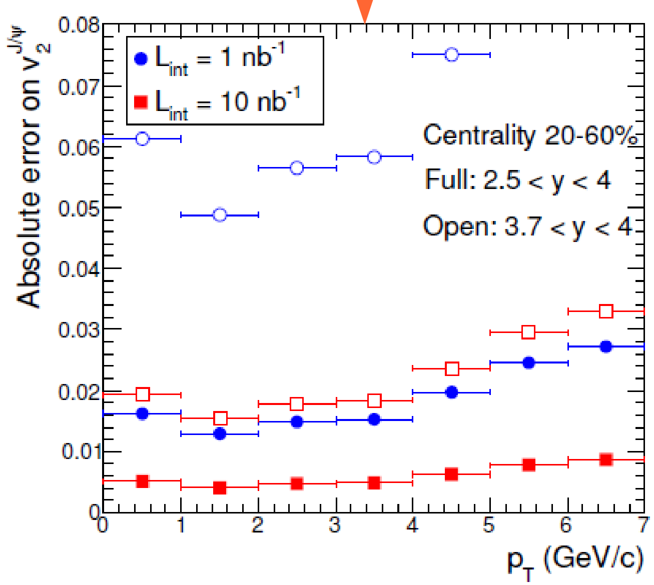
ALI-DER-139384

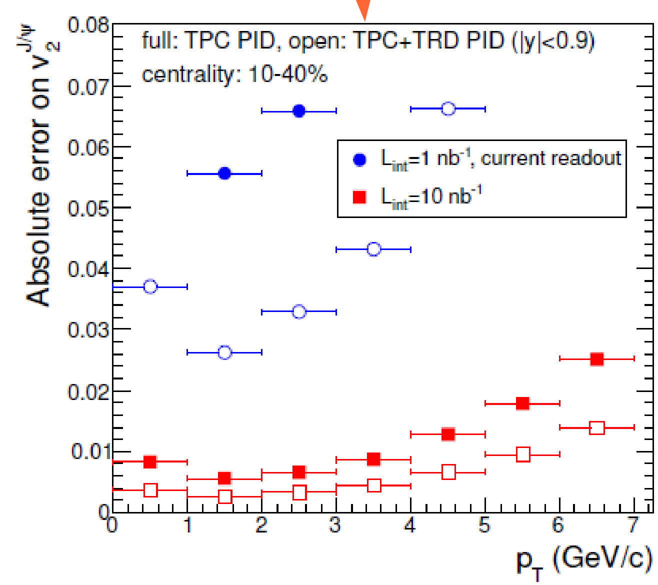
goal for run2 in muon arm already achieved
for e+e- at mid-y getting there

future statistical errors

muon arm

central barrel





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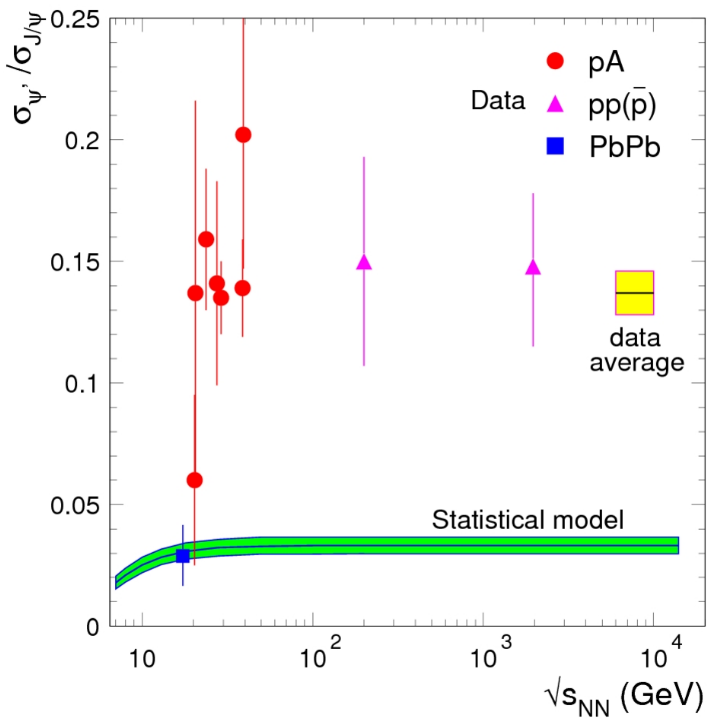

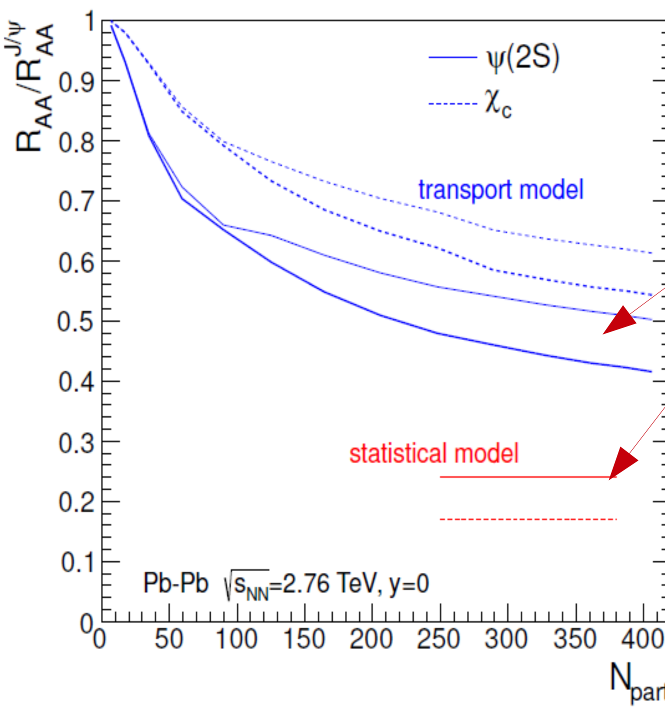

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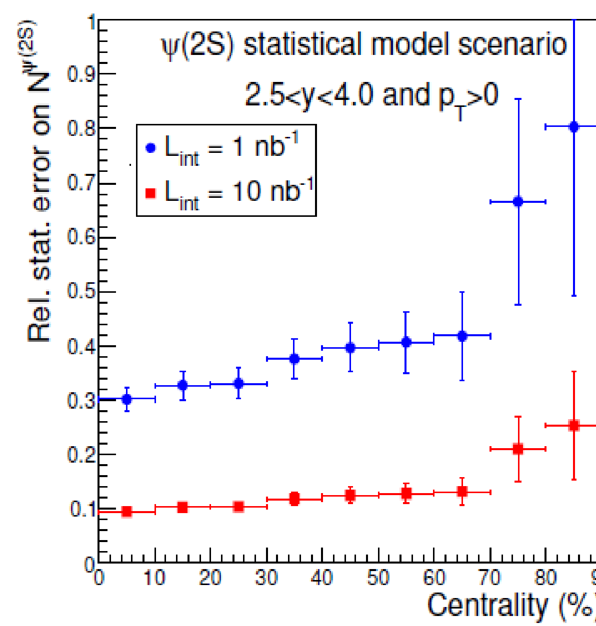
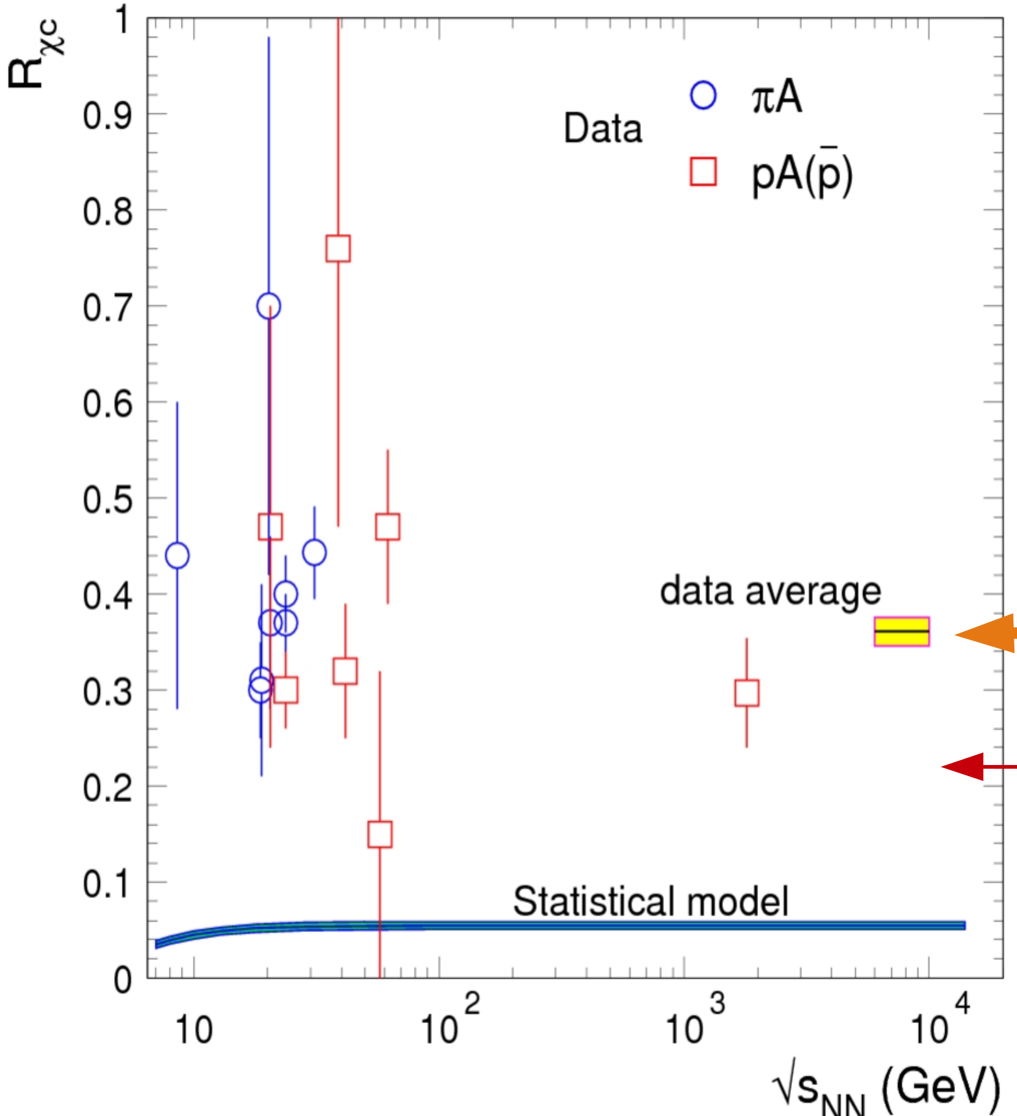


Situation even more dramatic for P-states

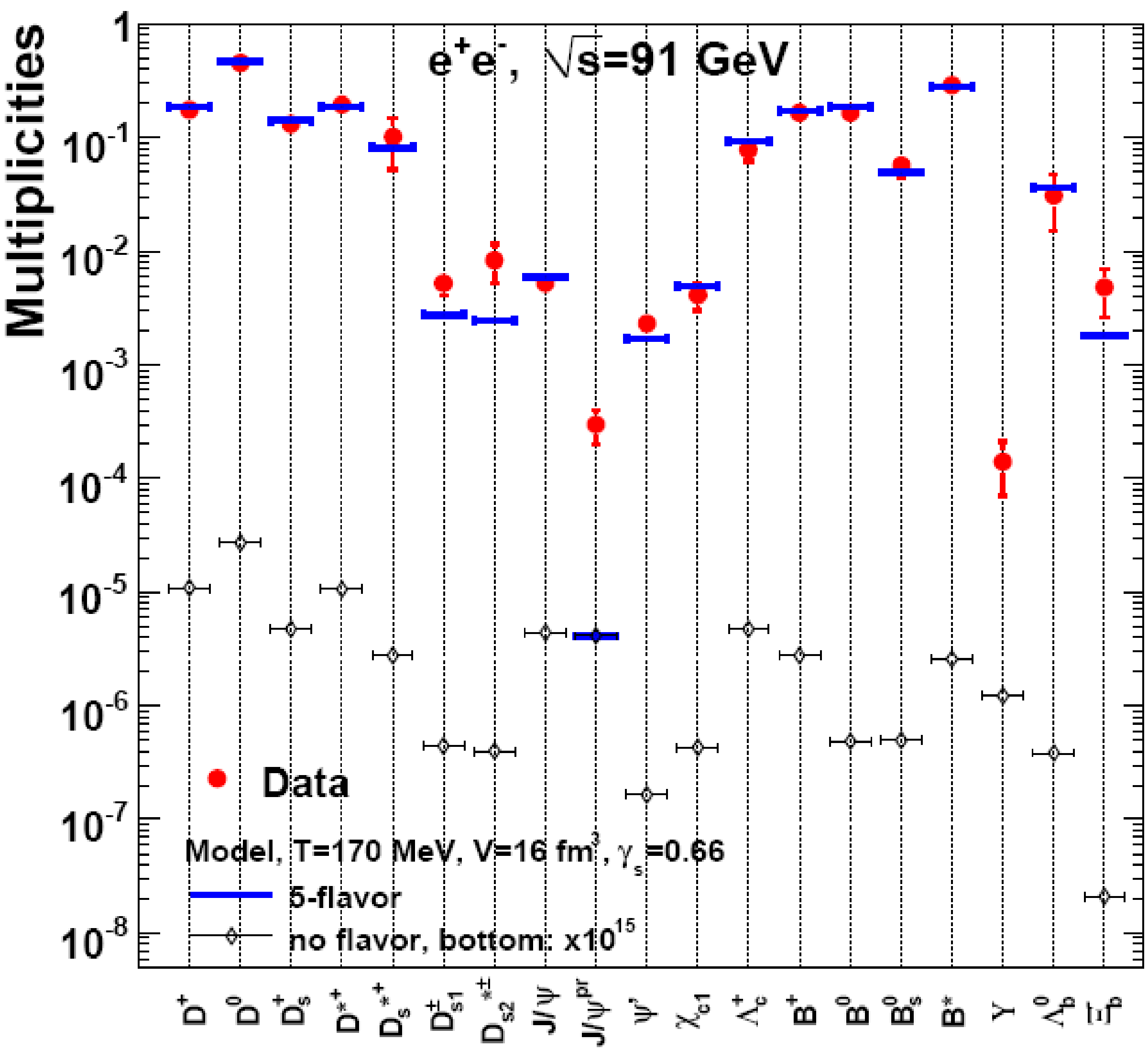


pA and πA data on average factor 7 avove statistical model prediction

Transport model (Rapp)

A. Andronic, F. Beutler, P. Braun-Munzinger, K. Redlich, J. Stachel Phys. Lett. B678 (2009) 350

heavy quark and quarkonium production in e+e- collisions



Comparison of stat. model calcs. with data

Phys. Lett. B678 (2009) 350, arXiv:0903.1610 [hep-ph]

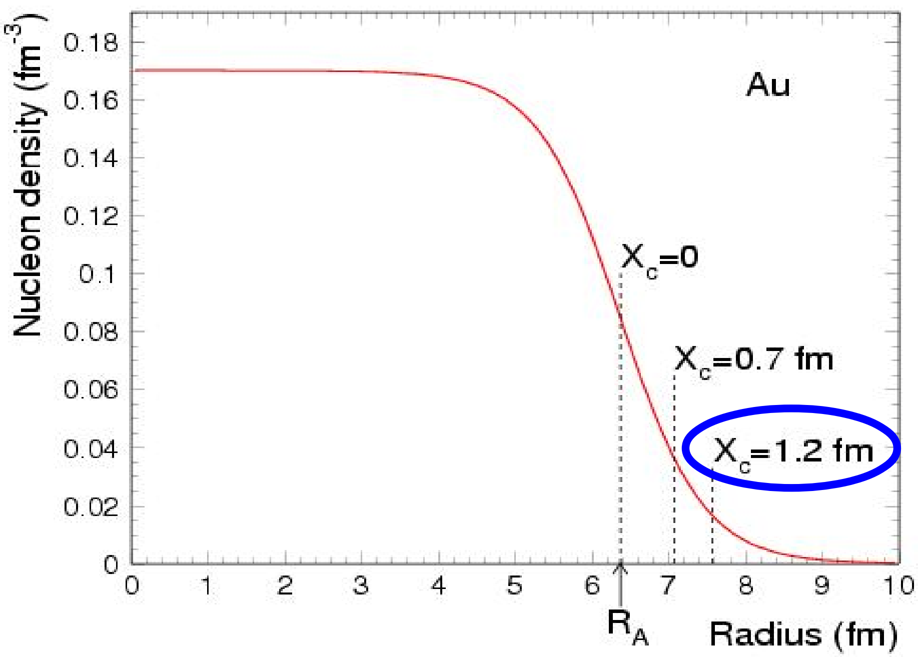
charmonium cannot be described at all in this approach

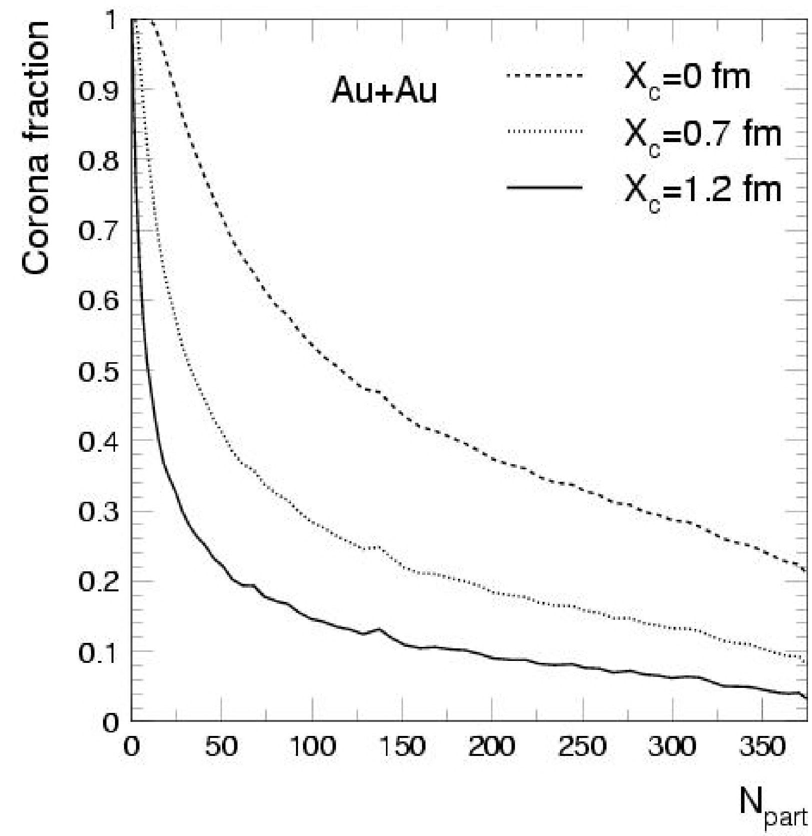
But: all charm quarks hadronize at 170 MeV

extension of statistical model to include charmed hadrons

core-corona effect considered: important for more peripheral collisions

"core" up to $R_A + X_c$ "corona" outside





$$N_{part}(b) = N_{core}(b) + N_{corona}(b)$$

Collisions in corona region treated as in pp,   core: medium, e.g. QGP

$dN_{ch}/d\eta/N_{part}(b) = dN_{ch}/d\eta/N_{core}(b) + dN_{ch}^{pp}/d\eta/N_{corona}(b)$ and same for J/psi

core-corona effect