Future of Heavy Ion Collisions at LHC

Outline:

- where are we now
- expectations and goals

  mainly ALICE

  CMS already addressed by G. Roland

  and

  ATLAS by B. Wosiek

Johanna Stachel, Physikalisches Institut, Universität Heidelberg

EMMI Workshop – Prospects and Challenges for
Future Experiments in Heavy Ion Collisions - GSI, Feb 15/16, 2013

Heavy ion running at LHC and near future

2 PbPb runs

- 2010 $\mathcal{O}(10\ \mu b^{-1})$
- 2011 $\mathcal{O}(150\ \mu b^{-1})$
  - luminosity reached $\mathscr{L}=2\ 10^{26}\ cm^{-2}\ s^{-1}$ twice design lumi at this energy

1 pPb run

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

results see talks of K. Safarik, B. Wosiek, and G. Roland

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

2015-2017 PbPb running at $\sqrt{s_{NN}} = 5.5$ TeV

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

2018 start LS2 – increase of LHC luminosity (timing to be optimized in 9/13)

Achievement with 1nb^{-1}

from data analyzed up to now we can extrapolate:

physics goals with hadrons in the uds section achieved

- abundances, spectra, R_{AA}, flow, correlations

large cross section issues in heavy quark sector solved as well

Future after LS2

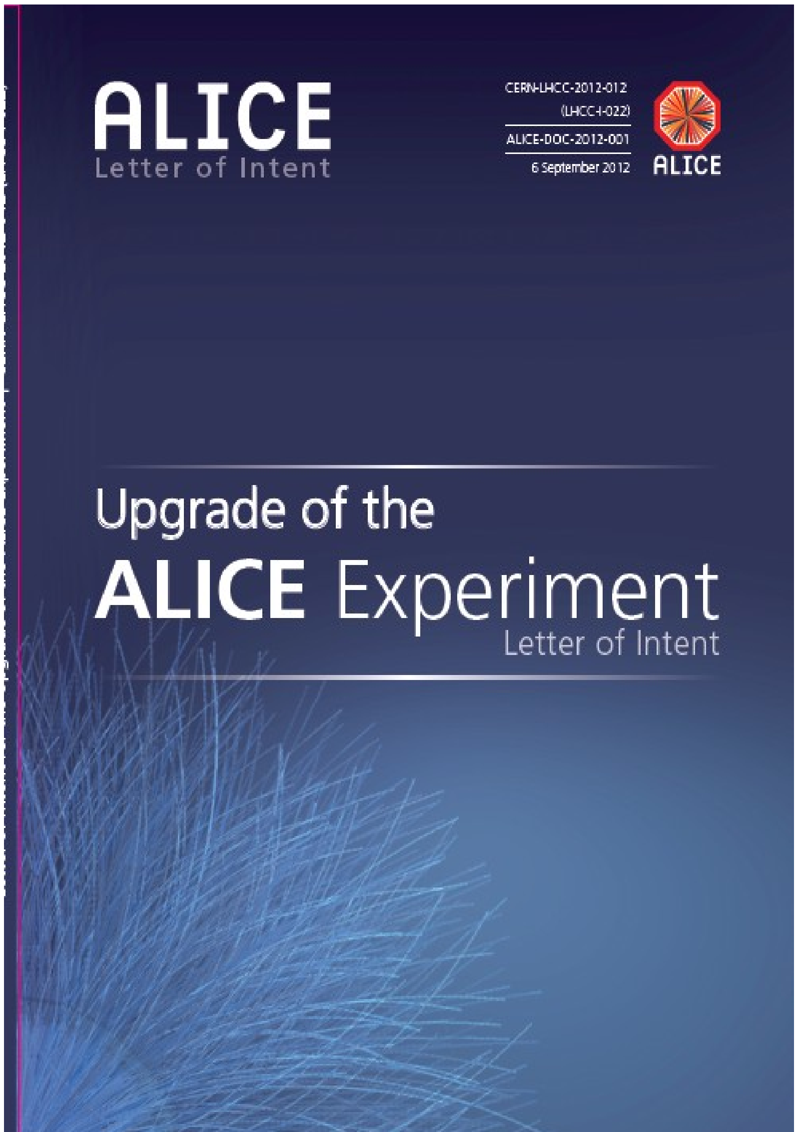
achieve for PbPb 10 nb^{-1} corresponding to 8 10^{10} collisions sampled
plus a low field run of 3 nb^{-1}
pp reference running 6 pb^{-1} or 1.4 10^{11} collisions
pPb sample 50 nb^{-1}

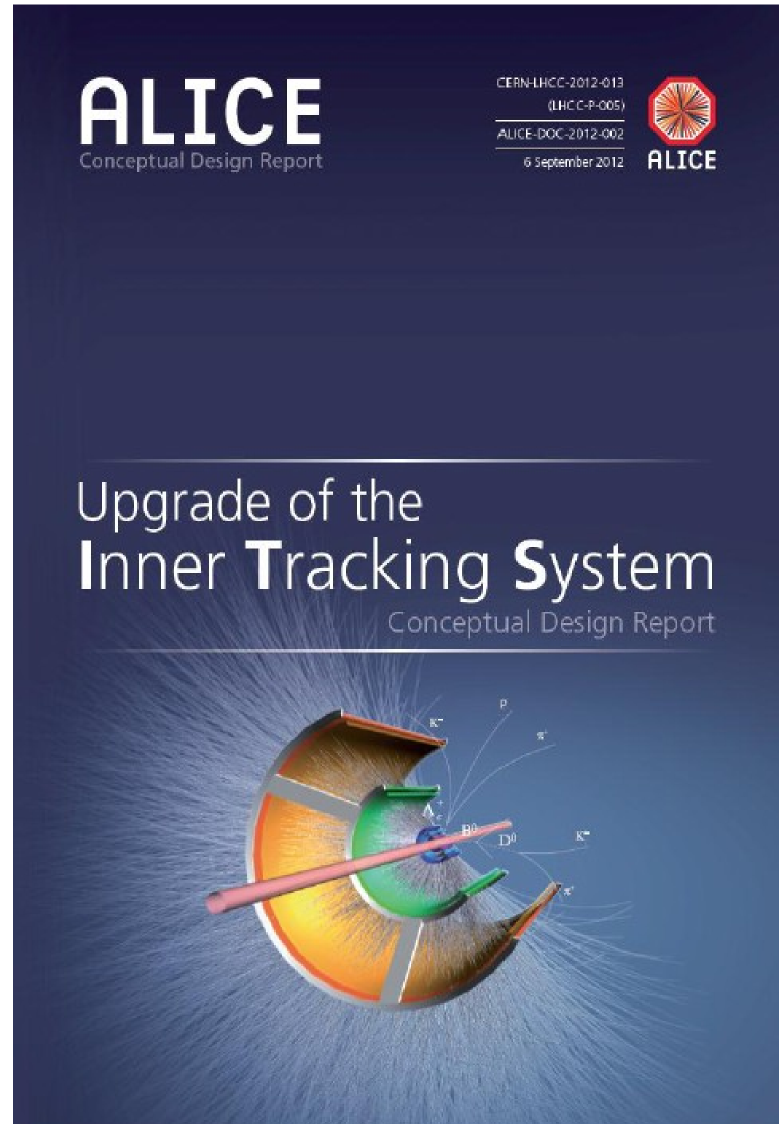
this is a program of about 6 years probably interrupted by another 2 year long shutdown around 2022/23 leading us to 2026 or so

envisage PbPb peak luminosities of $\mathscr{L} = 6\ 10^{27}\ cm^{-2}\ s^{-1}$ corresponding to interaction rates of 50 kHz

detector upgrades
    to cope with this luminosity and
    to achieve physics goals aimed for with this integrated luminosity
for realization see ALICE letters of intent

2 letters of intent
endorsed by LHCC and approved by research board





from draft:

Proposed Update of the European Strategy for Particle Physics

High-priority large-scale scientific activities

After careful analysis of many possible large-scale scientific activities requiring significant resources, sizeable collaborations and sustained commitment, the following four activities have been identified as carrying the highest priority.

c) The discovery of the Higgs boson is the start of a major programme of work to measure this particle's properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this programme. *Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.*

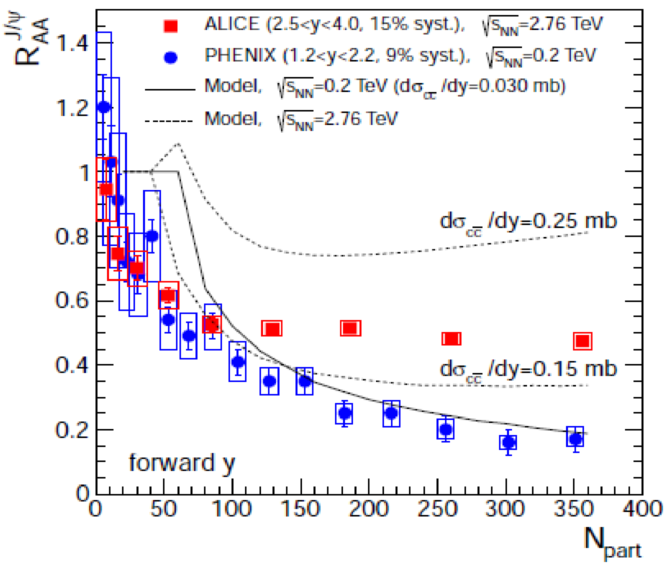
Physics goals for future heavy ion running

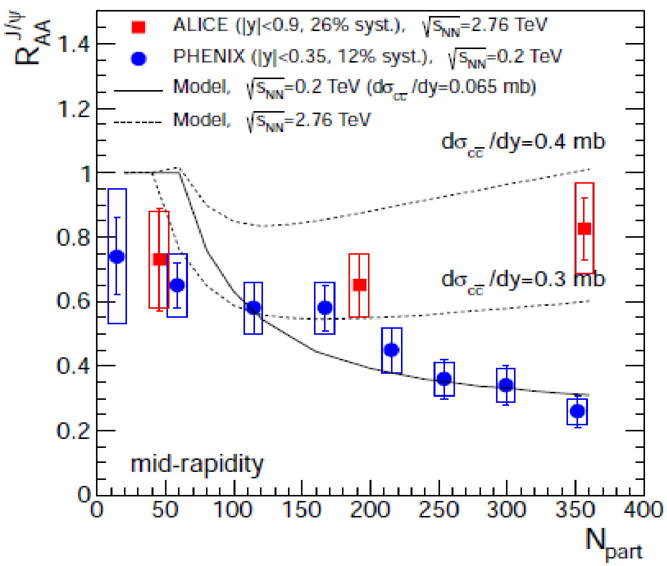
precision measurements in

- charm sector – charmonia, open charm, thermal charm, flow and equilibration, fundamental issues with bound quarks in QGP
- beauty sector – question of thermalization/equilibration
- low mass lepton pairs – chiral restoration and thermal radiation
- real (and virtual) photons – evolution of temperature and quark fugacities, role of hadronic phase
- jets
- ...

important issues will be solved on a quantitative level to give definitive answers at a fundamental level
- aim to reach text book level results

J/psi as probe of deconfinement



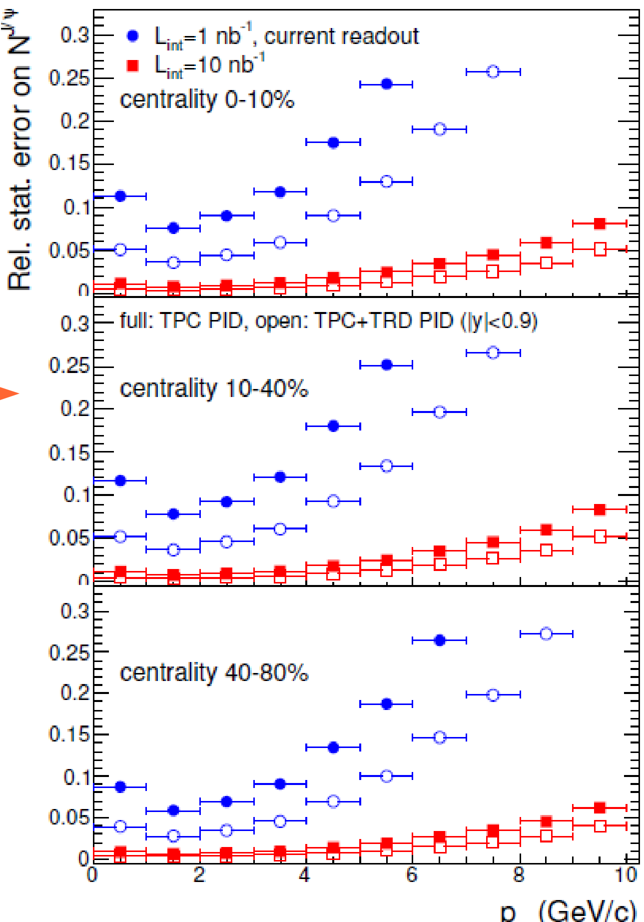


di-electrons statistics limited, 10 nb-1 will have huge effect

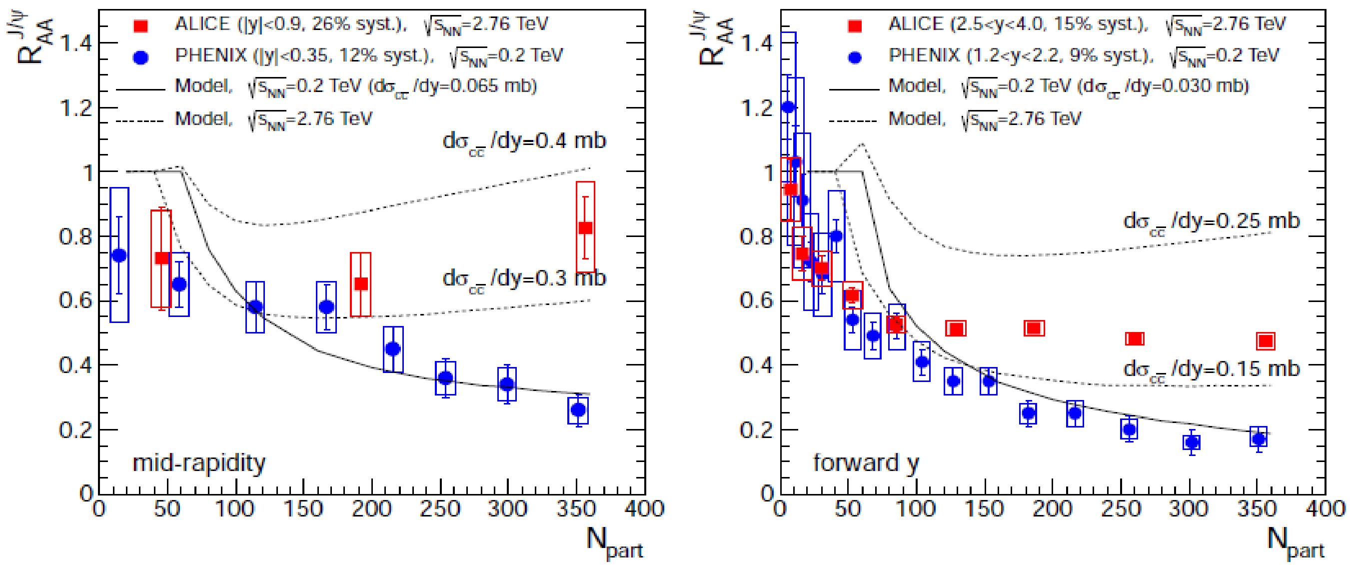
but also syst uncertainties will decrease with upgrade:

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

both affect signal extraction



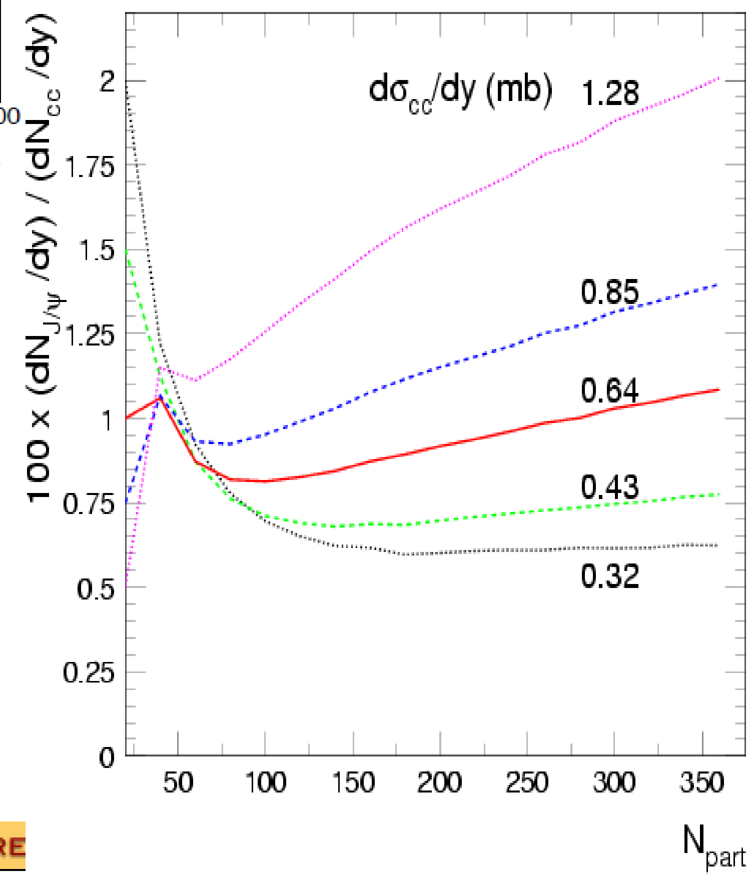
J/psi as probe of deconfinement



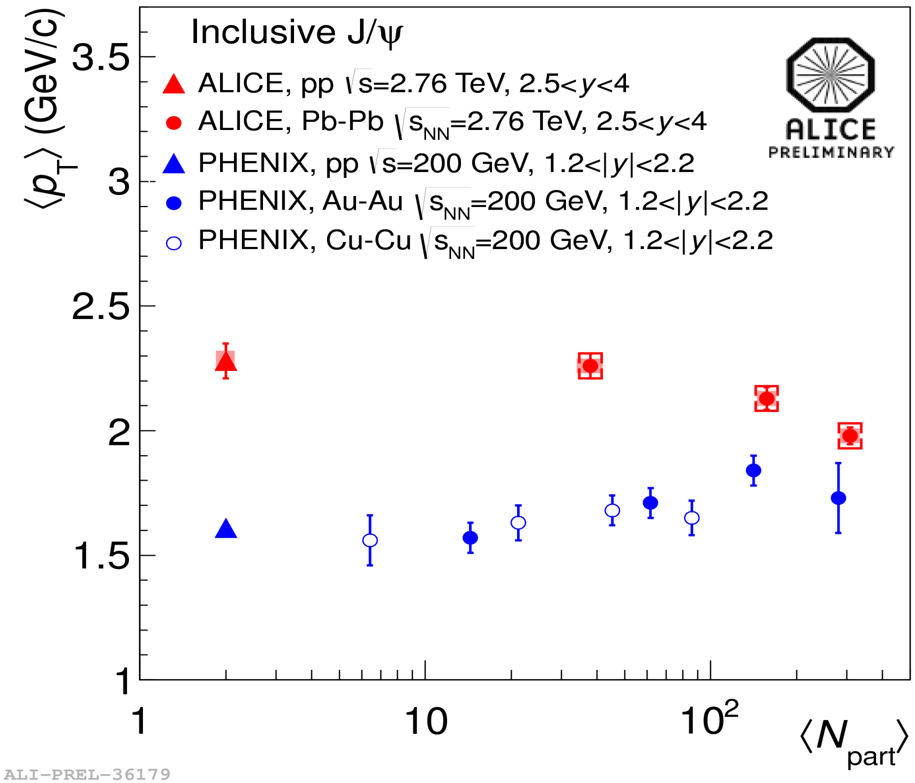
firm physics conclusion needs precise open charm cross section

in statistical hadronization picture this enters quadratically

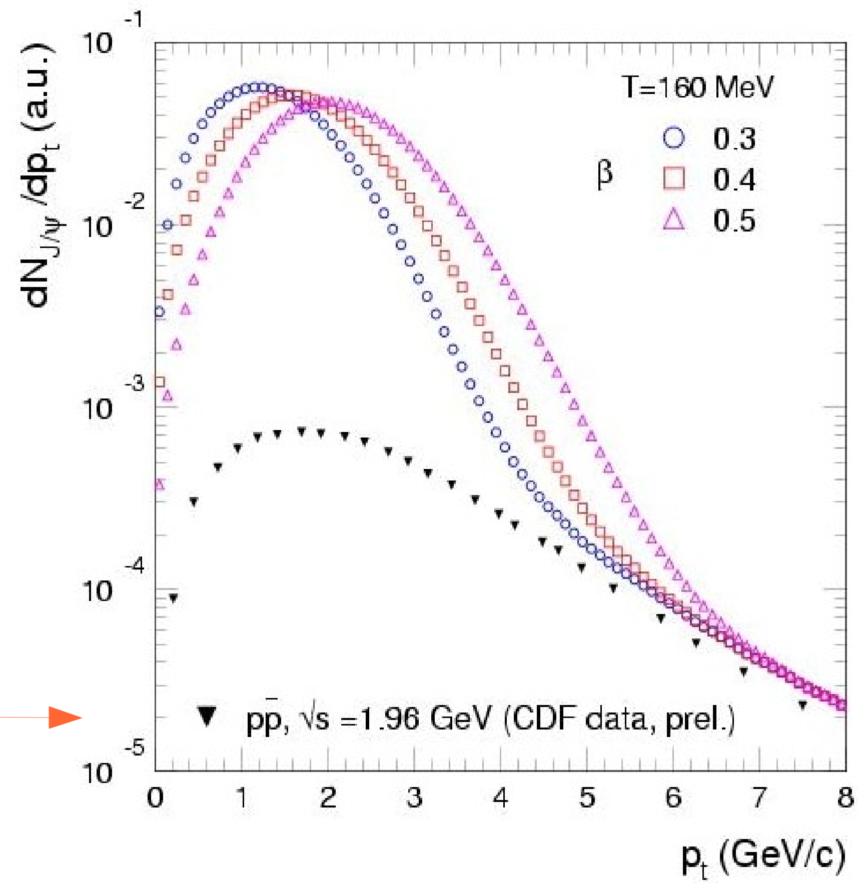
get leaverage from beam energy dependence and rapidity dependence



Spectral distribution is key to thermalization

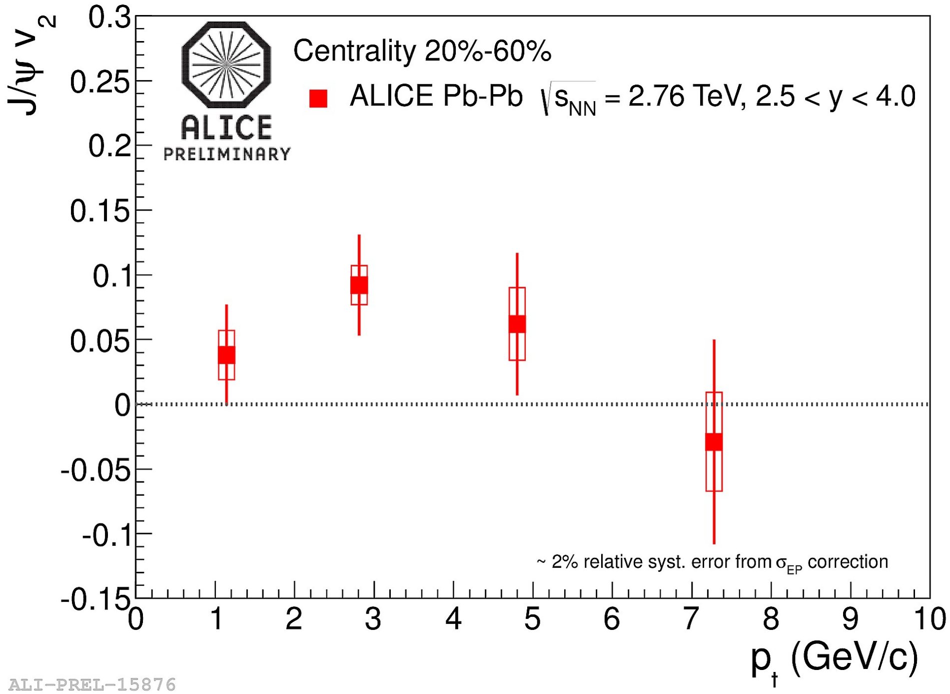


at LHC shift of paradigm: more central collision → narrower momentum distribution
my interpretation: thermalization



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

J/psi from thermalized charm quarks should exhibit collective flow

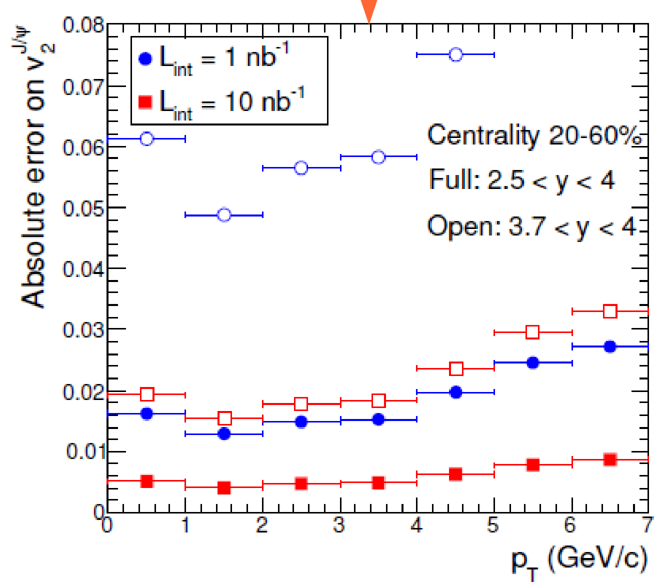


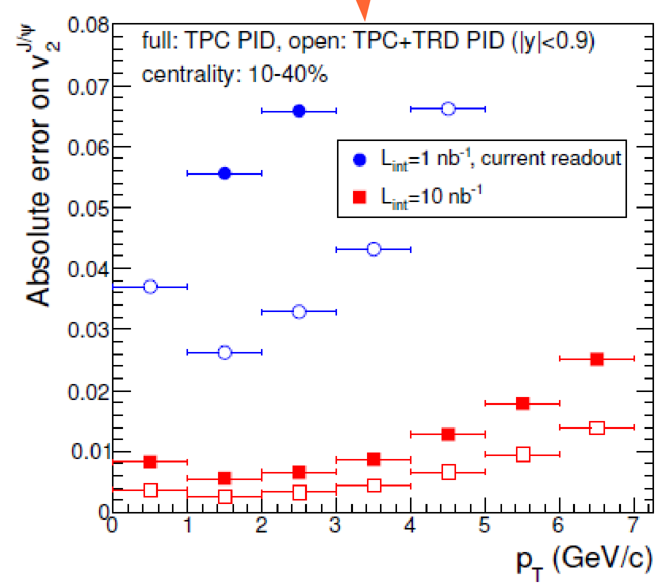
observation of flow with muon arm presently 3 sigma
needs statistics to make model comparison meaningful

future statistical errors

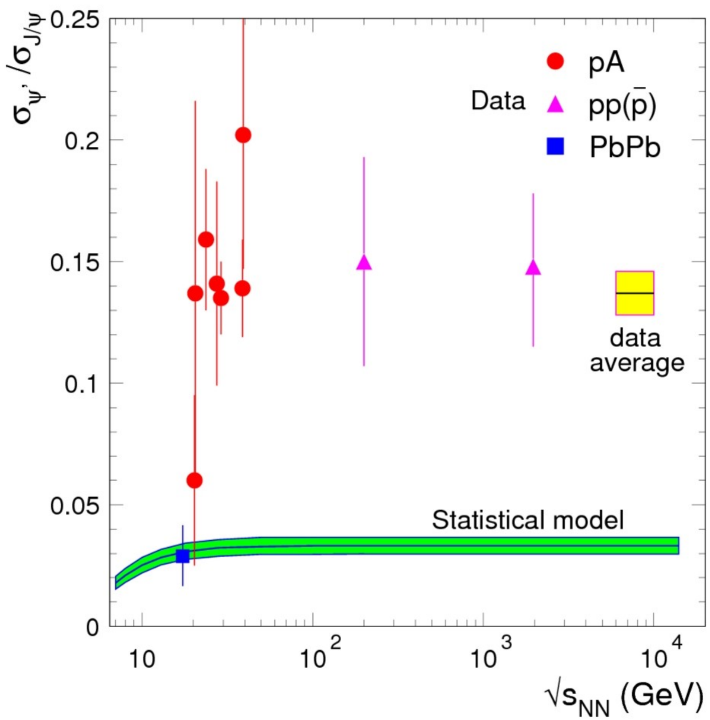
muon arm

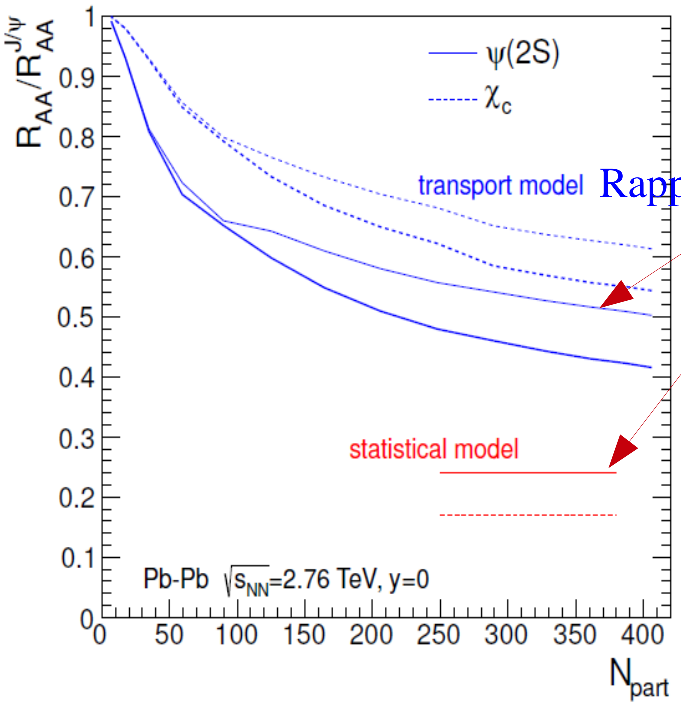
central barrel





formation of charmonia from deconfined quarks: psi' is crucial cornerstone

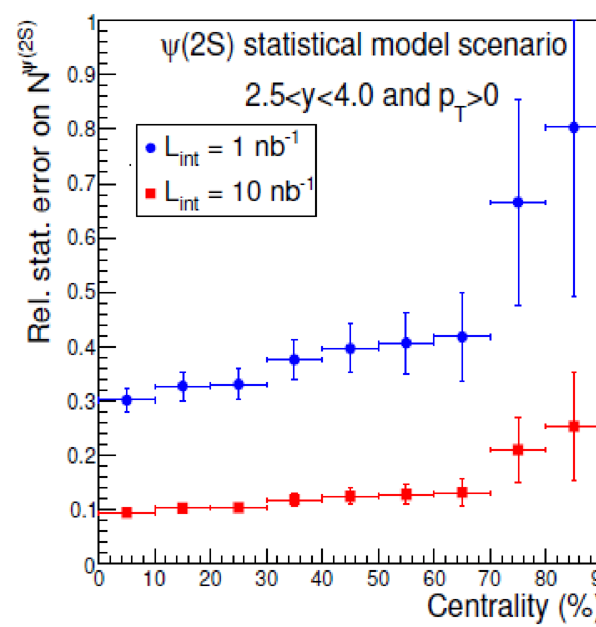




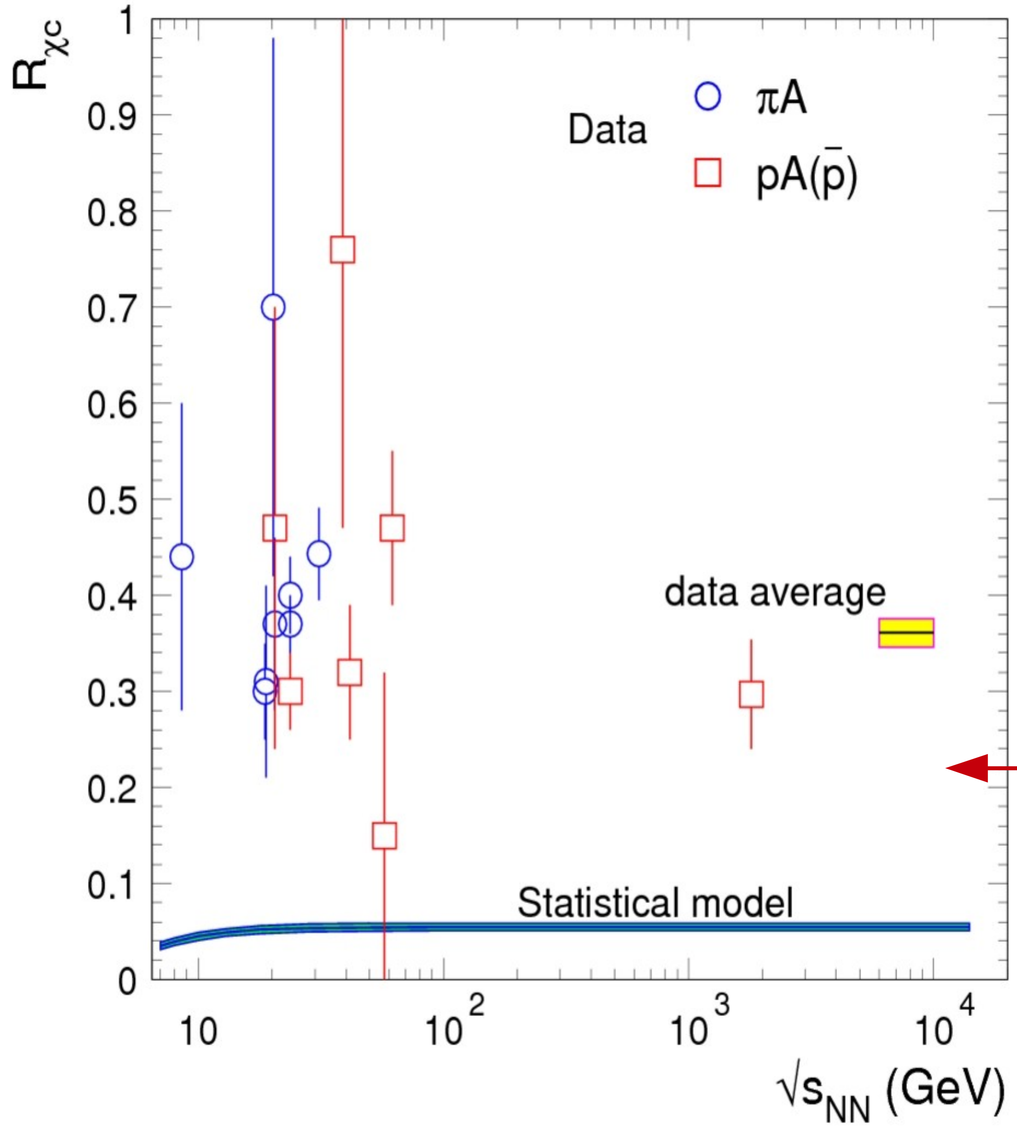
in fact: here one can distinguish between the transport models that form charmonia already in QGP and statistical hadronization at phase boundary!

for statistical hadronization need to see suppression by Boltzmann factor

expected ALICE performance muon arm



chi_c: clear distinction of statistical hadronization mechanism

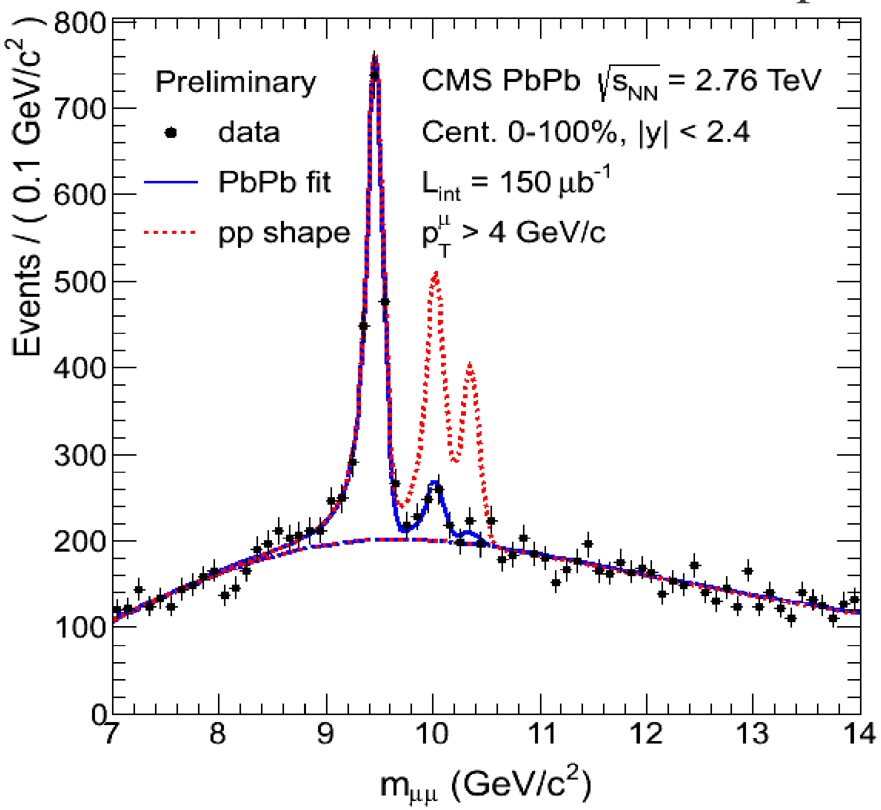


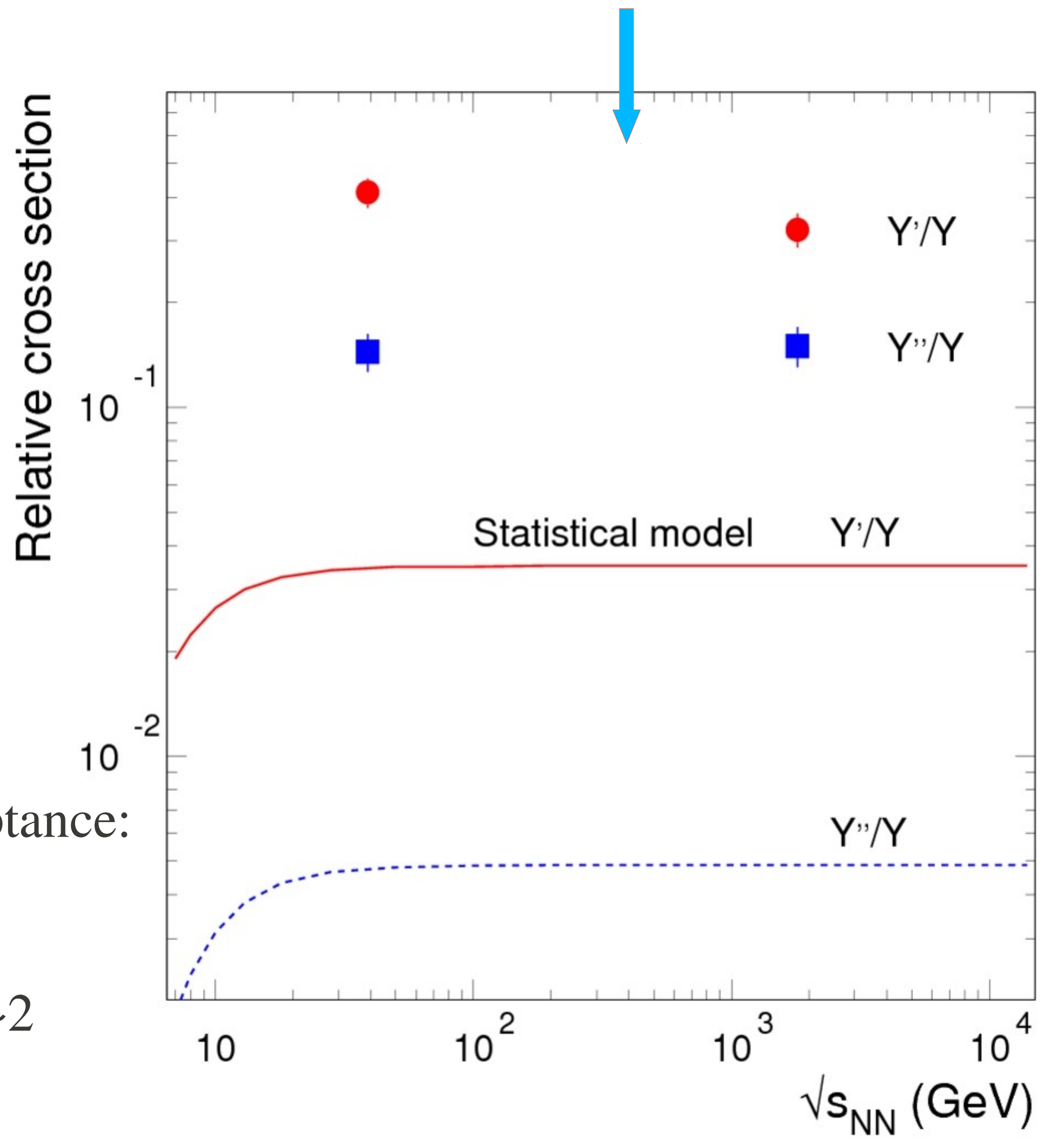
in statistical hadronization of charm (and other) quarks reduction in chi_c by factor 7 expected

Transport model (Rapp)

Upsilon state population indicative of deconfinement?

Sequential melting? story very complicated due to unmeasured feeding
and: also in statistical hadronization picture 2S and 3S strongly supr. by Boltzmann factors

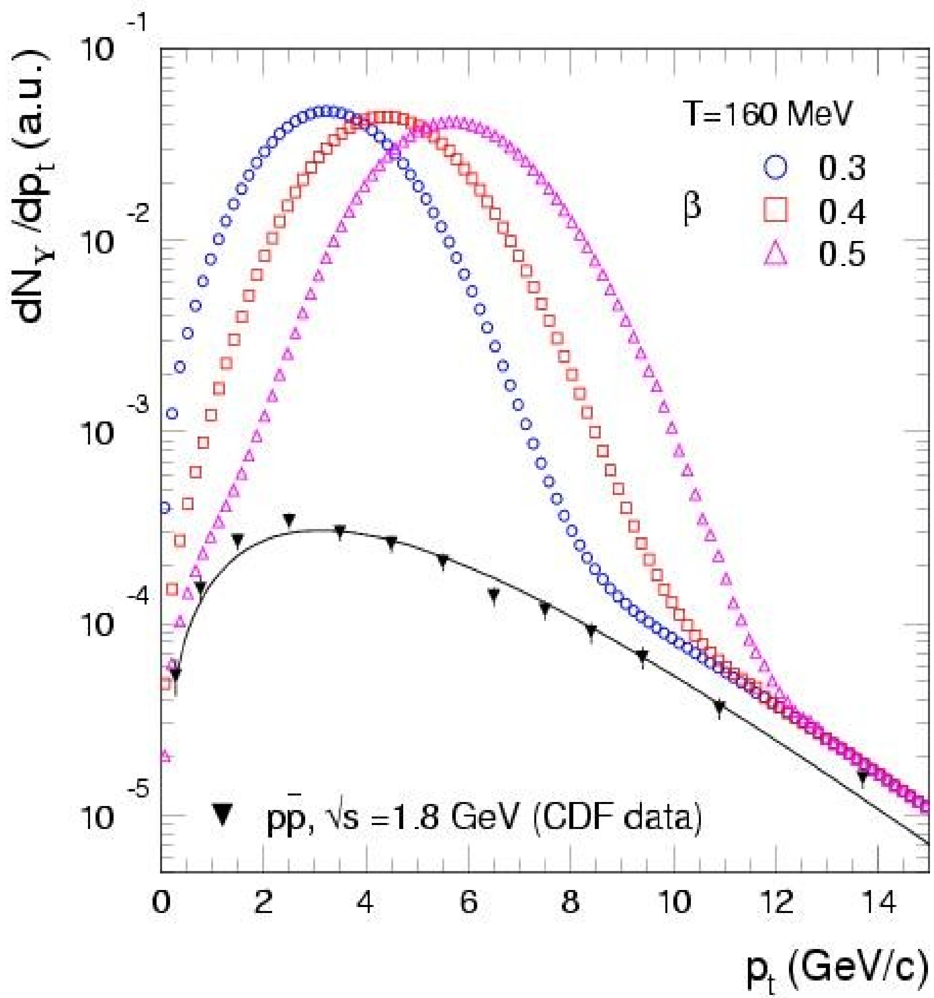




centrality integrated and not corrected for acceptance:
2S/1S PbPb = 0.12+-0.03+-0.02
3S/1S PbPb = 0.02+-0.02+-0.02
both ratios dropping with centrality by factors ~2

Upsilon spectra would resolve the story

for potential picture to apply (and therefore Debye screening), beauty needs to be in equilibrium i.e. thermalized
- in that case, spectra should show global flow of the system



a first try at the total ccbar cross section in pp collisions

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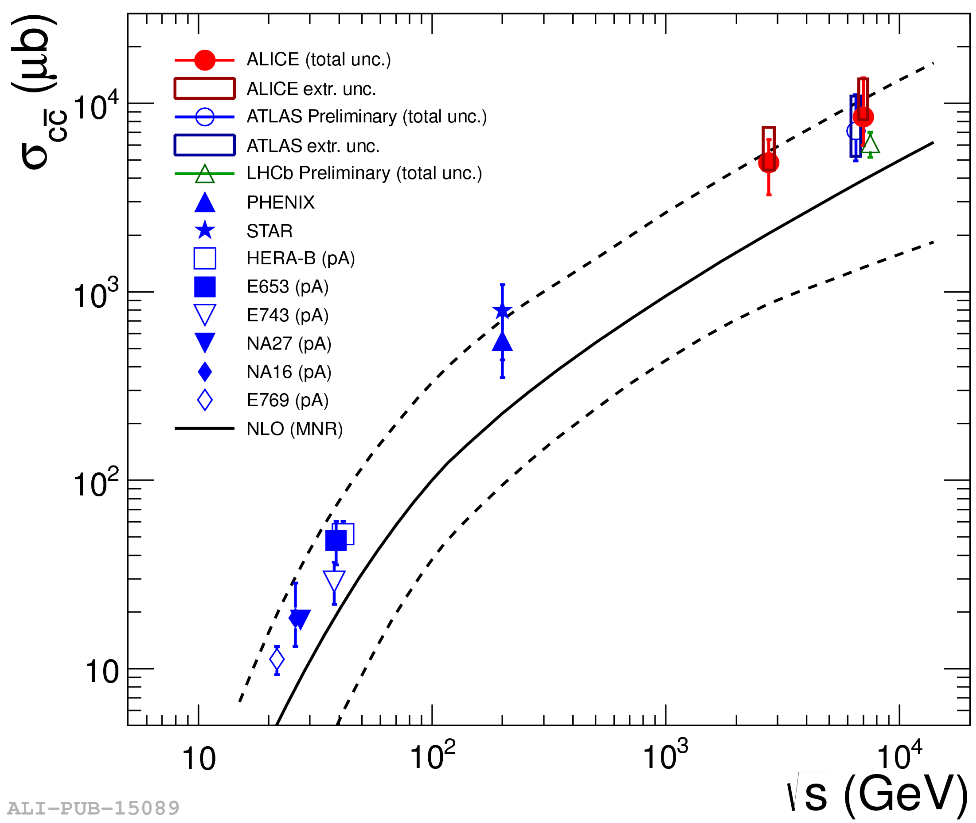
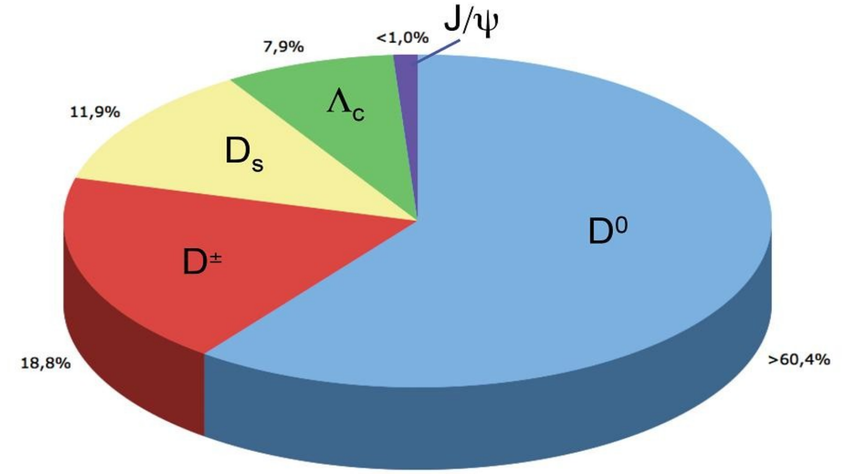


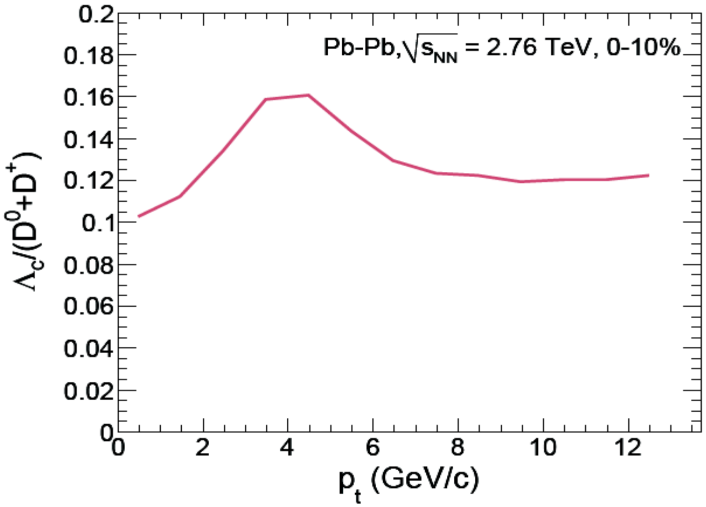
- large syst. error due to extrapolation to low p_t, need to push measurements in that direction
- need to measure all channels including charmed baryons
- need this cross section for PbPb and pPb – here low p_t extrapolation much (!) harder



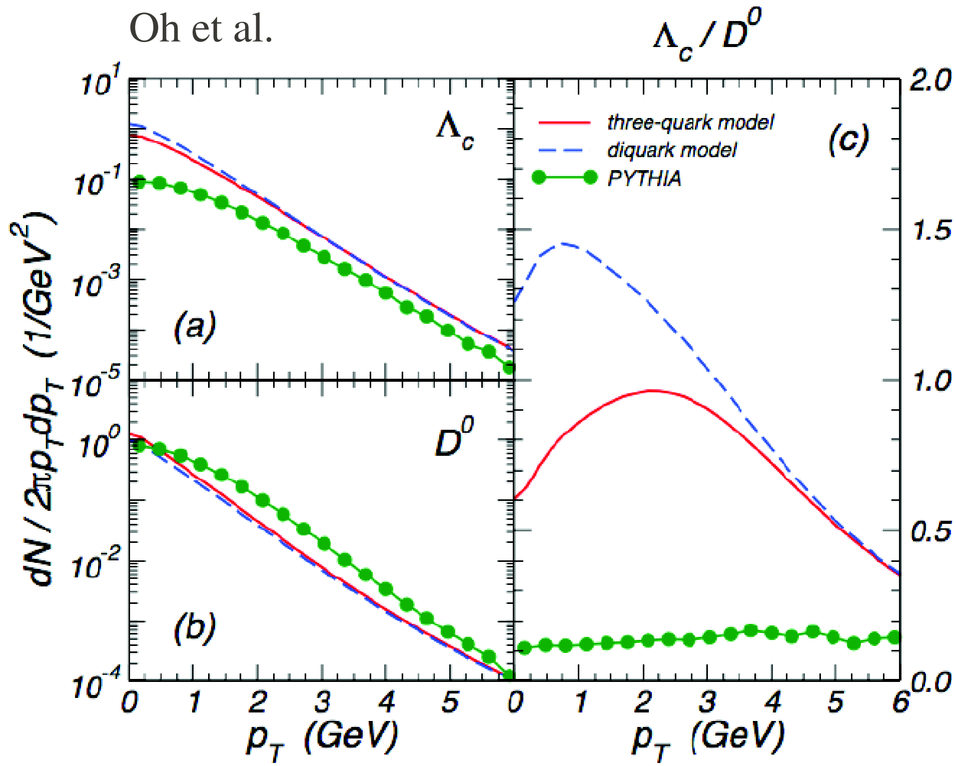
Interesting physics questions related to Lambda_c

baryon anomaly also in charmed baryon sector? cf proton/pion and Lambda/kaon
role of coalescence
diquarks in the QGP? Fundamental issue of bound quarks in QGP

He et al.

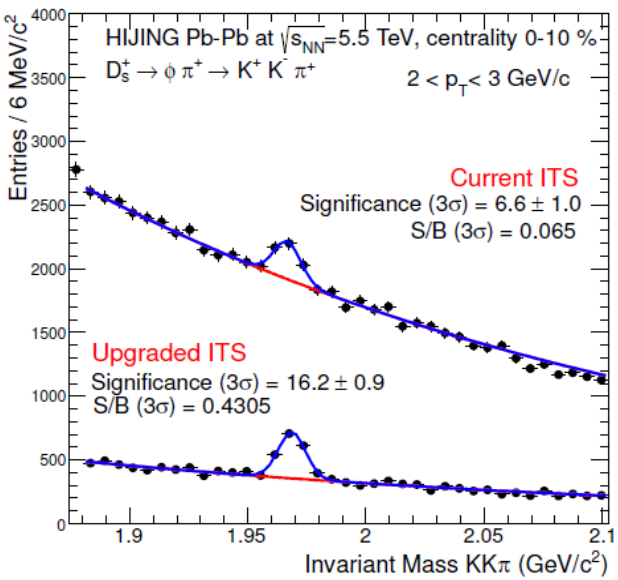


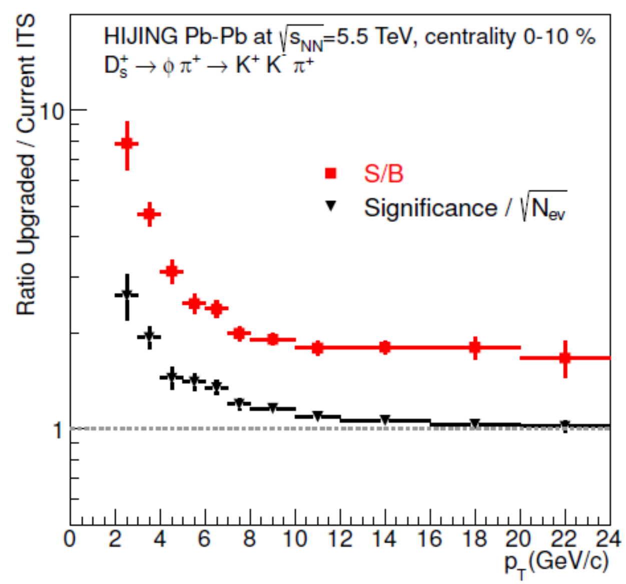
Oh et al.

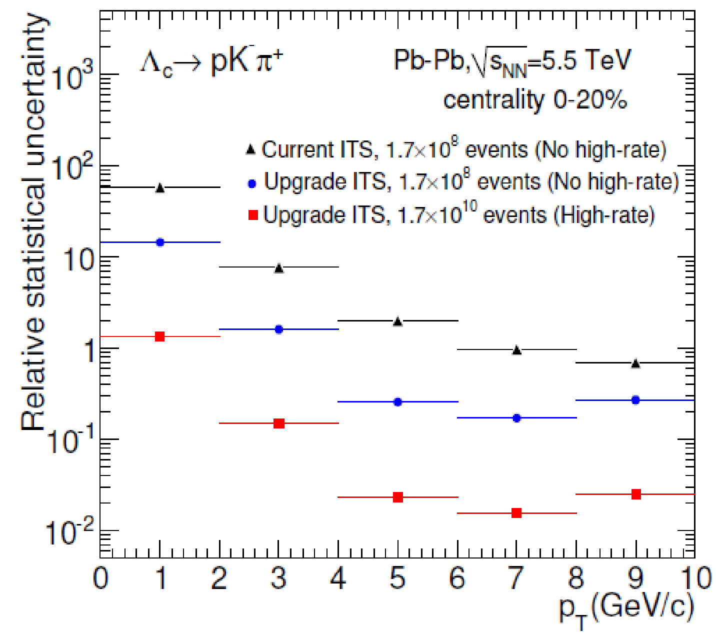


need to measure with O(10%) precision down to low p_t

Expected performance for charmed hadrons with ALICE upgrade

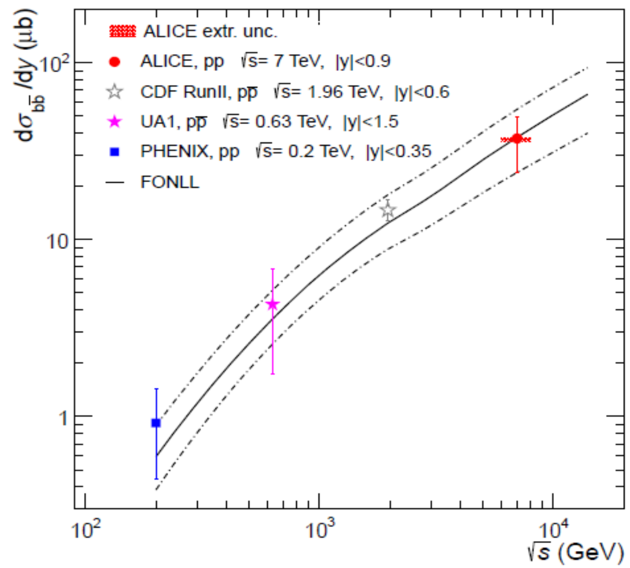






Open Beauty for cross section, R_{AA}, and flow

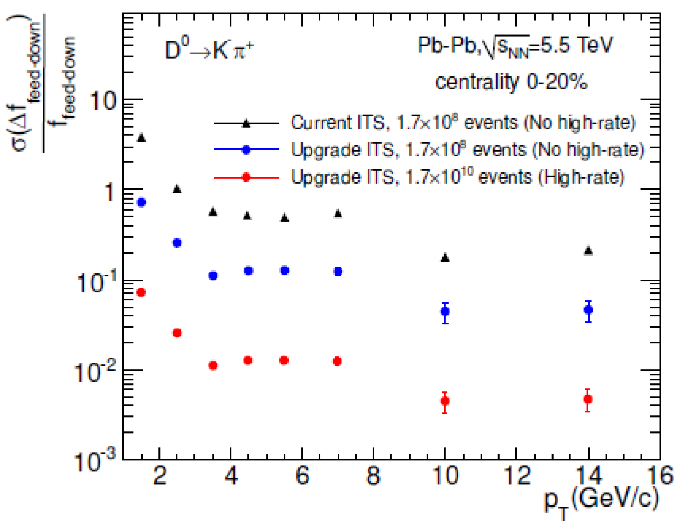
7 TeV pp

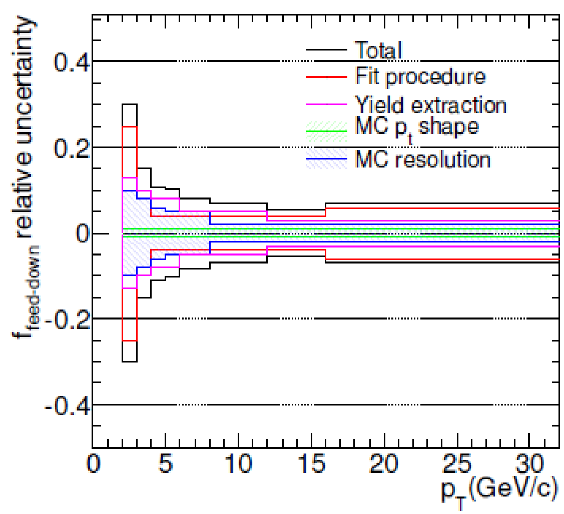


Current methods:

- semi-leptonic decays
- B from secondary J/psi

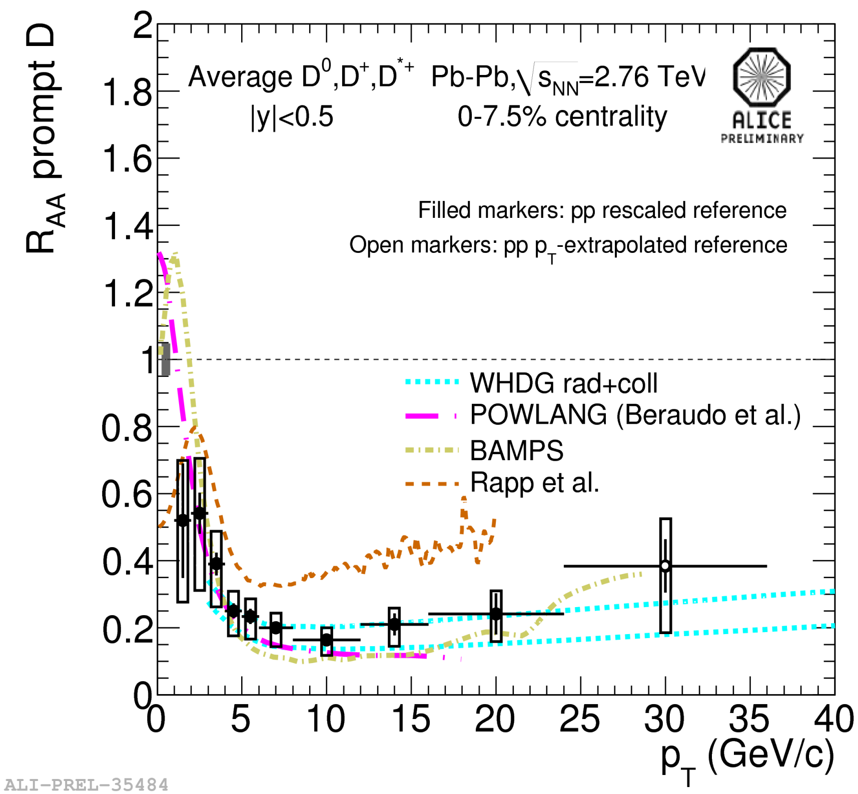
- powerful method for future ALICE:
get beauty from non-prompt D^0

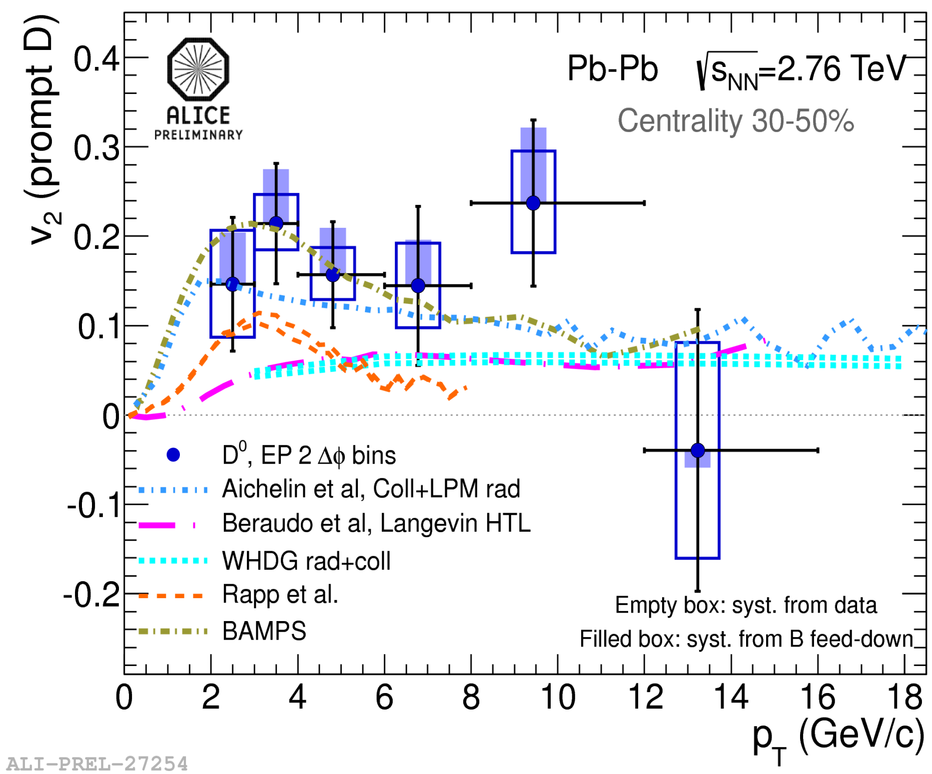




note the p_t coverage down to 1 GeV/c!

Energy Loss and Flow of D-mesons - current status





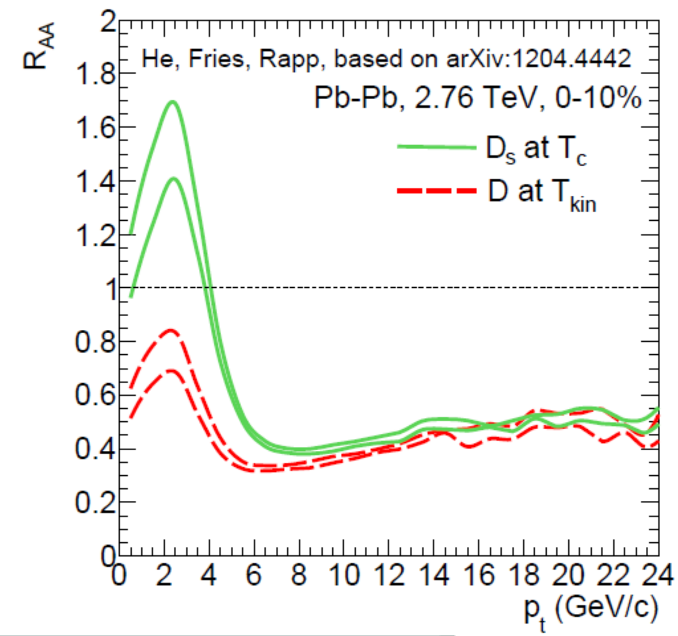
both are determined by transport properties of the medium (QGP)
simultaneous description still a challenge for some models
but also errors of data still too large for precision physics conclusion

what does it take to establish heavy quark thermalization?

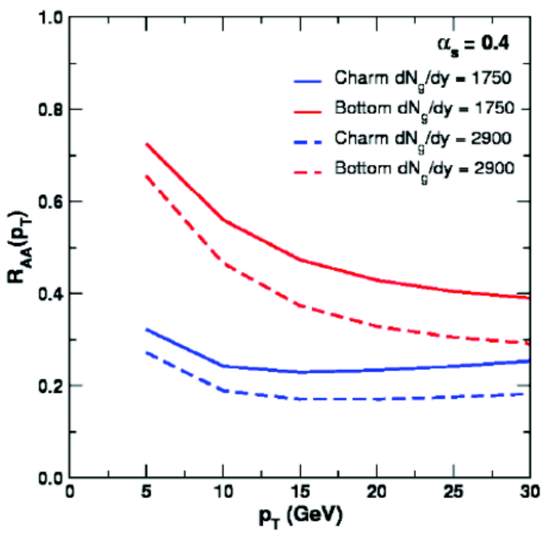
need precise measurements of R_{AA} and v_2 for D and B

sensitivity to gluon density/transport coefficients

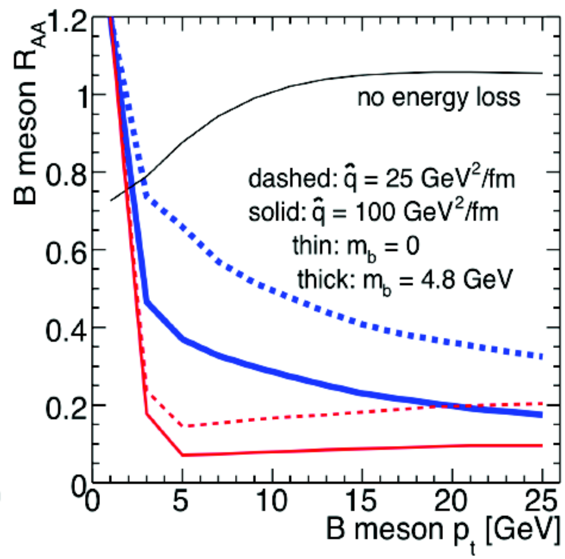
- i.e. medium properties

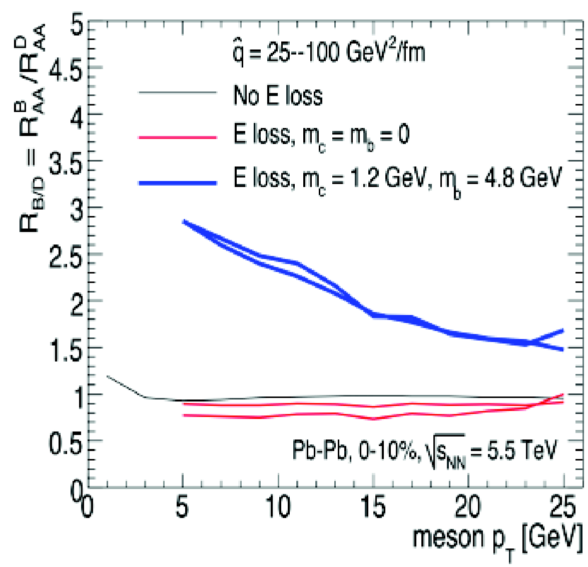


Wicks et al.



Armesto et al.





what does it take to establish heavy quark thermalization?

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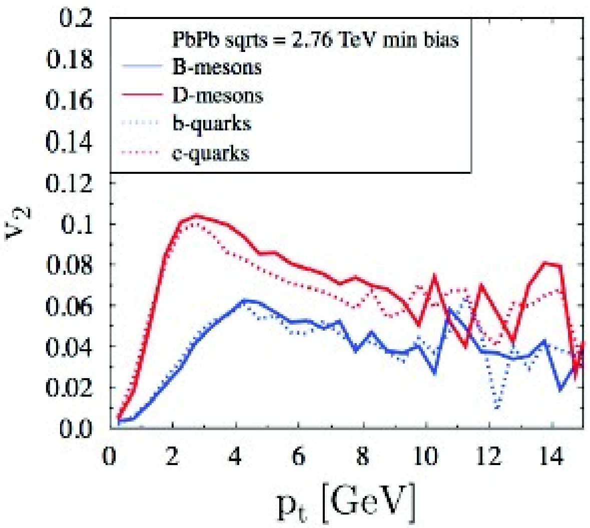
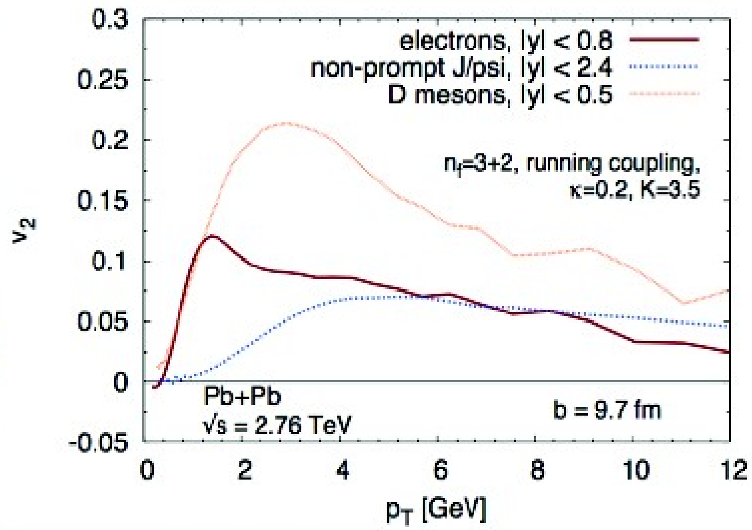
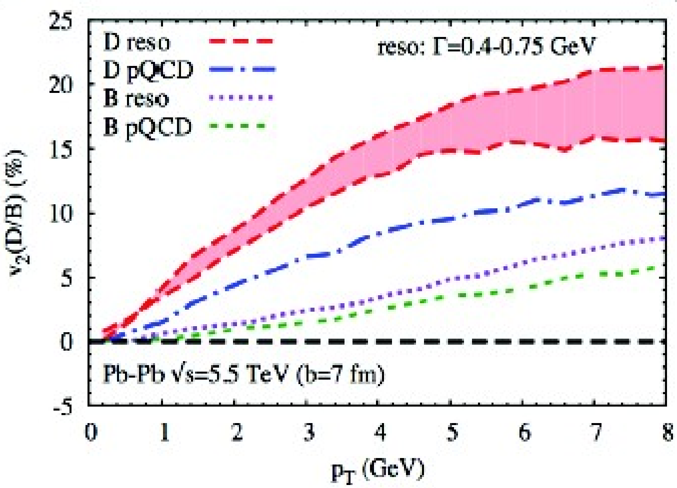
Aichelin et al.



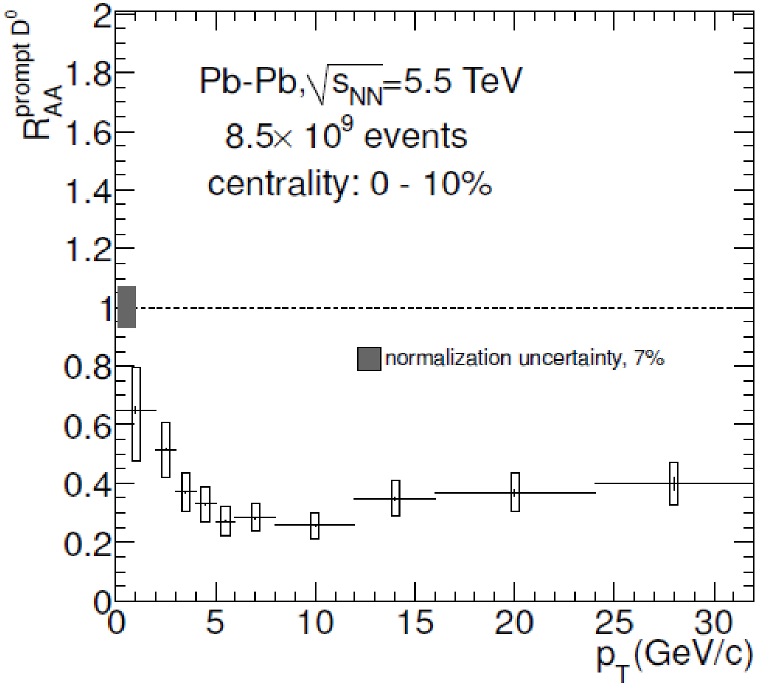
Uphoff et al.

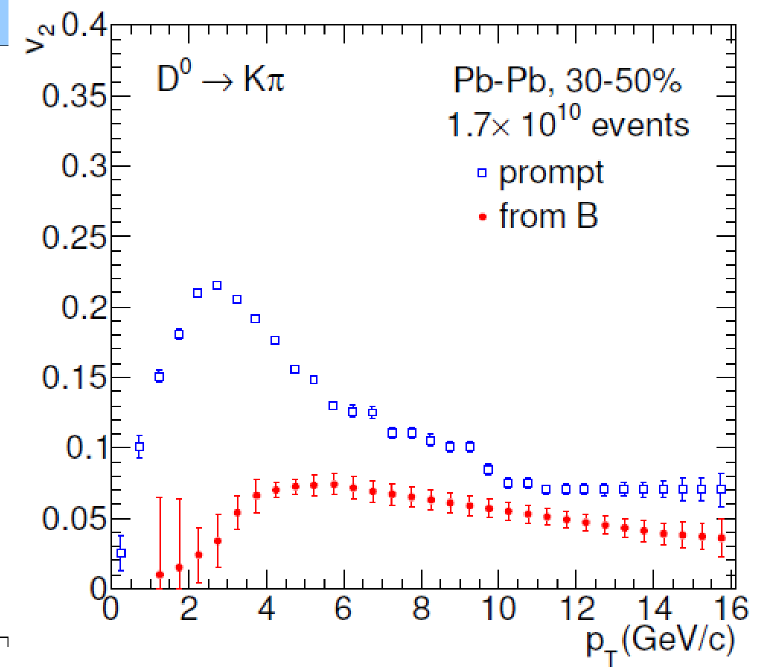


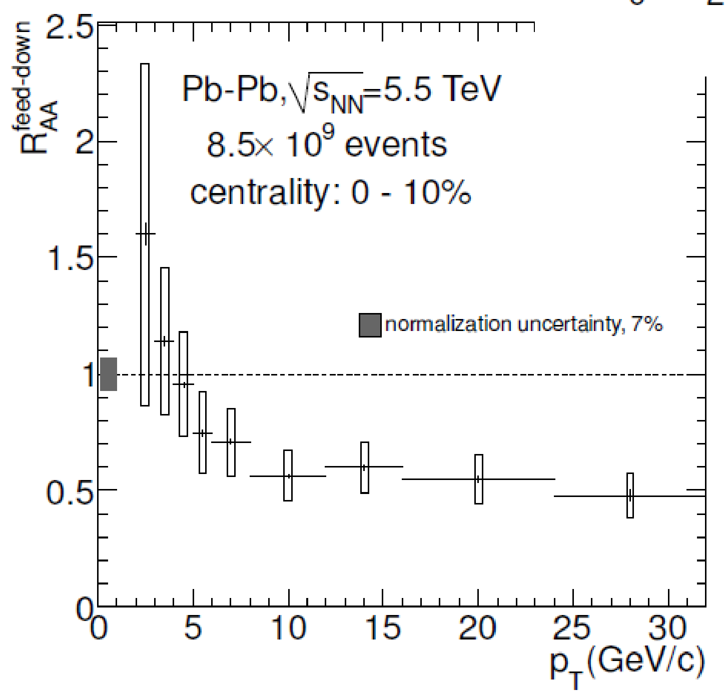
Greco et al.



Expected performance for D^0 and B



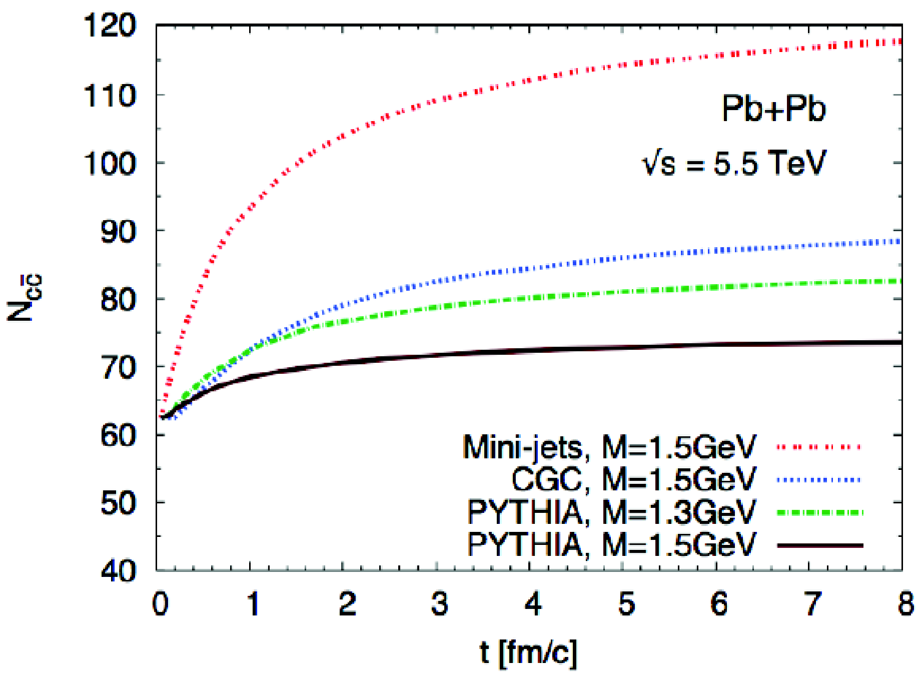




Thermal charm production

first studied by Braun-Munzinger and Redlich (2000): at high T this will be relevant

recent calculation by J. Uphoff et al.
results strongly dependent on
initial gluon density and
charm quark mass



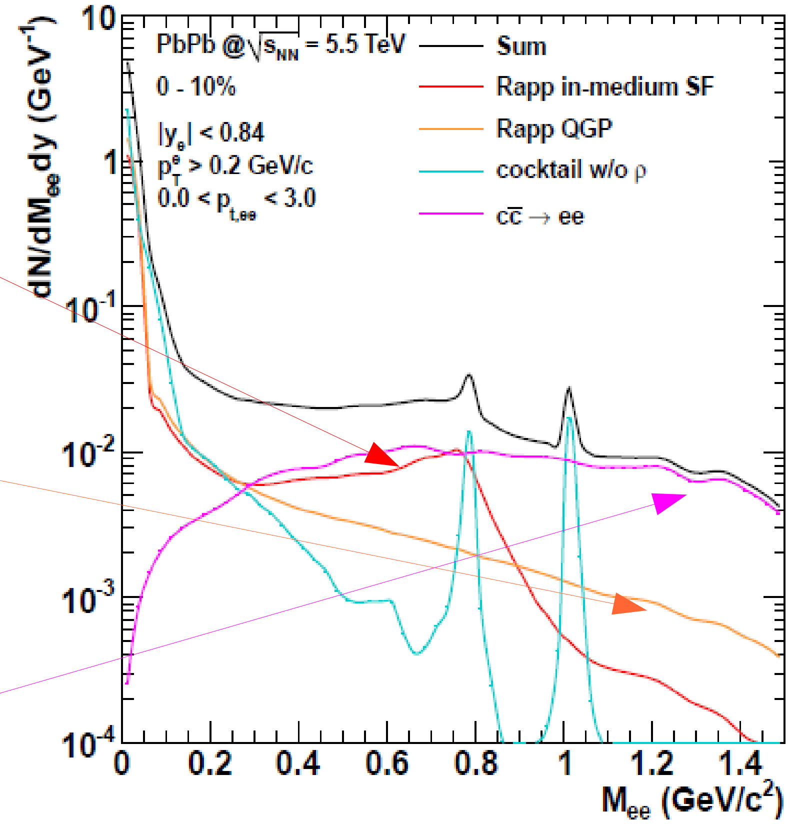
need to measure charm cross section precisely in PbPb collision and as function of centrality

Low mass electron pairs

physics motivation 2-fold: chiral symmetry restoration and thermal history

basically: below 1 GeV/c2 region close to T_c dominates via rho in-medium spectral function - chiral restoration

above 1 GeV (φ) sensitivity the temperature – thermal virtual photons

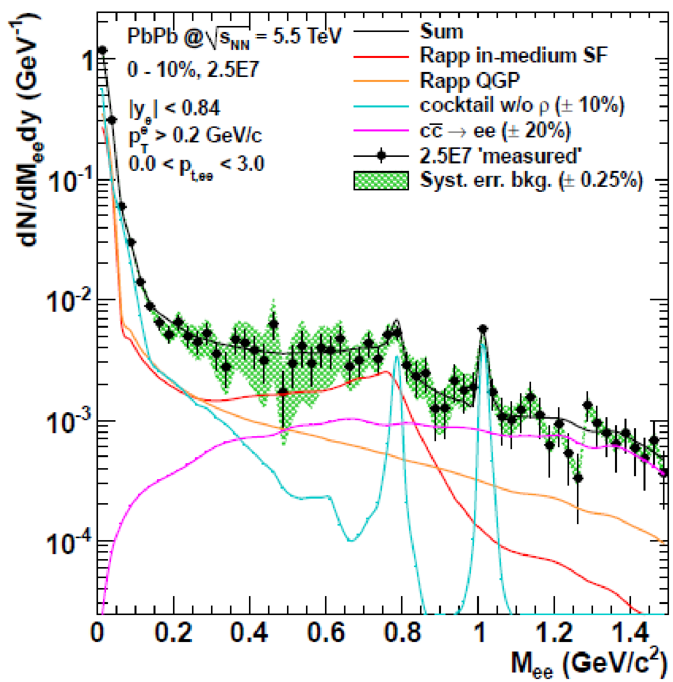


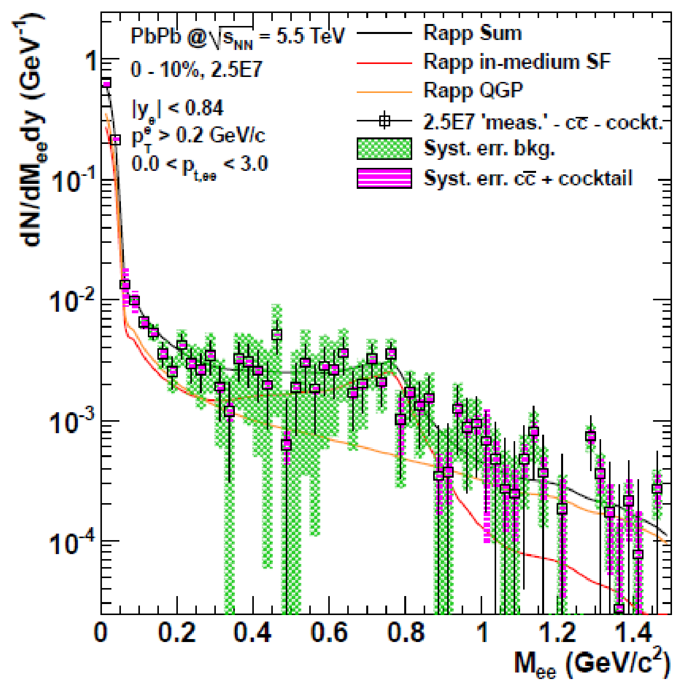
but: need good knowledge of open charm cross section!

a precision measurement will disentangle early and late contributions and hence give detailed access to evolution of collision and fund properties related to transport –coefficients and equation of state

Expected performance for low mass di-electrons before upgrade

excess over hadronic decay cocktail

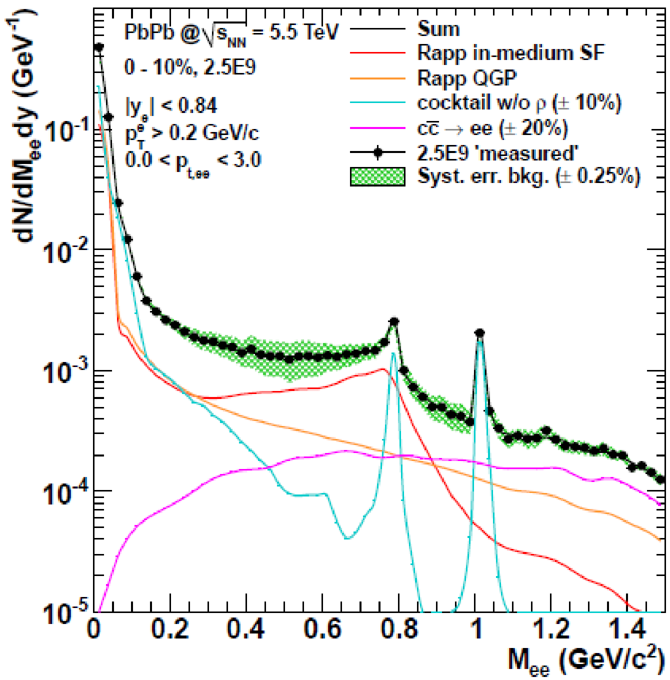


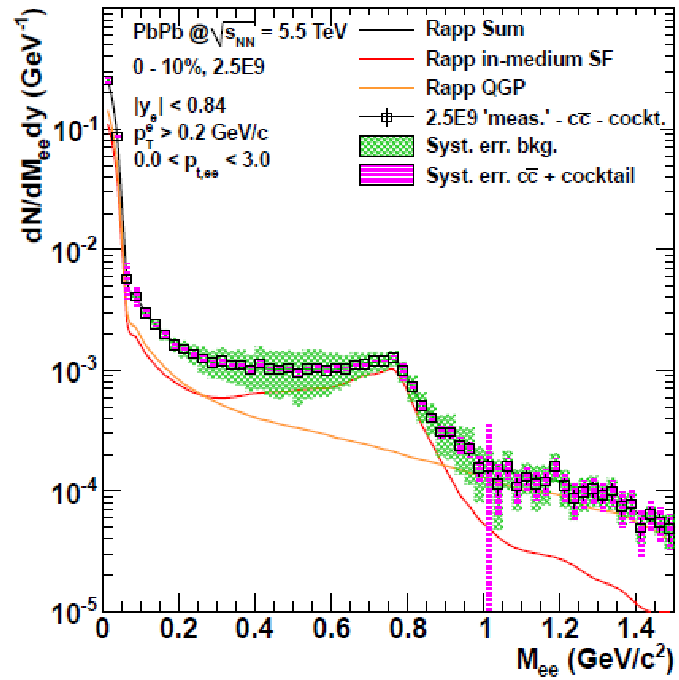


dedicated PbPb run with B=0.2 T sampling 2.5 10^7 collisions

Expected performance for low mass di-electrons

excess over hadronic decay cocktail



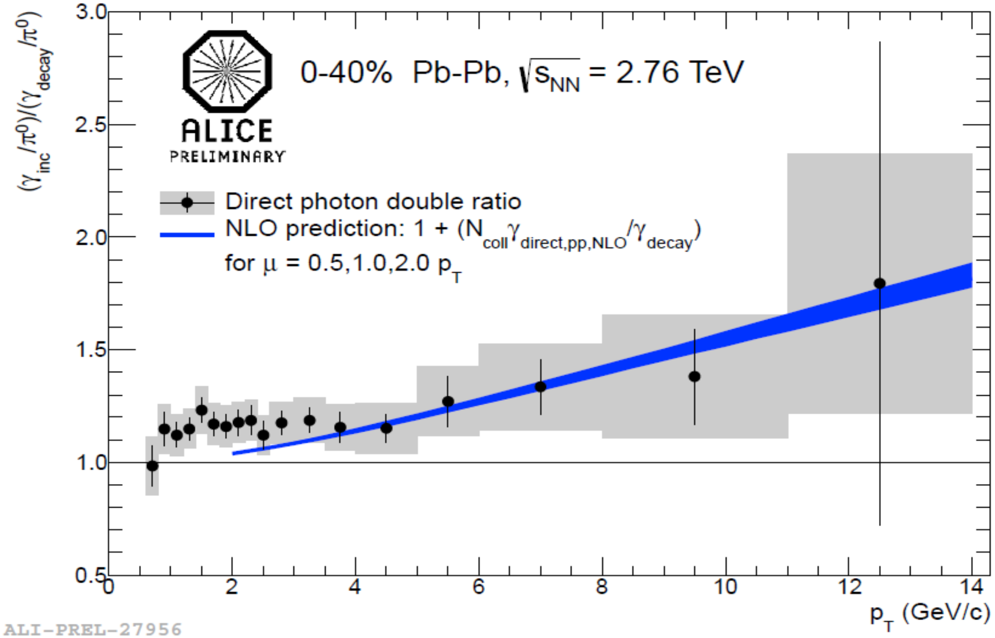


dedicated PbPb run with B=0.2 T sampling 3 nb^{-1}

2.5 10^9 collisions in 0-10% centrality bin

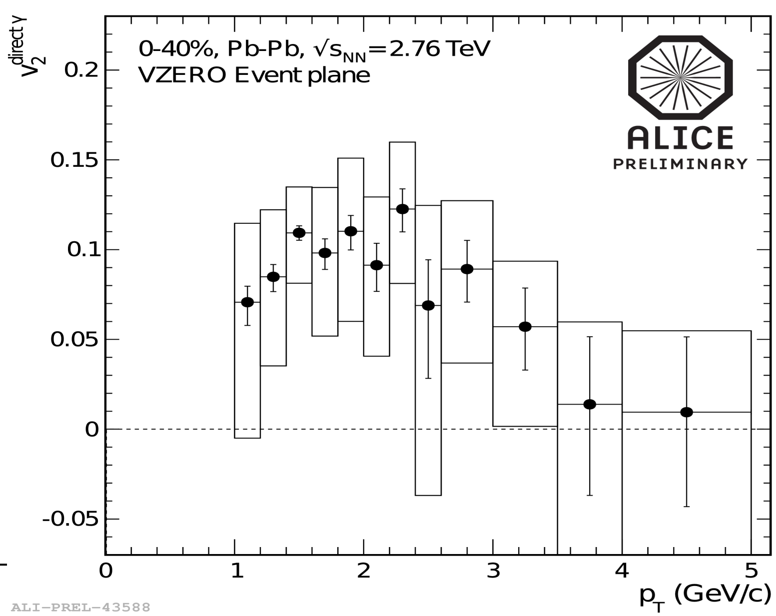
5 10^9 for 40-60%

direct photons - present data from conversion method



2 domains:
- direct photons from hard scattering (above 4 GeV/c)
- thermal photons

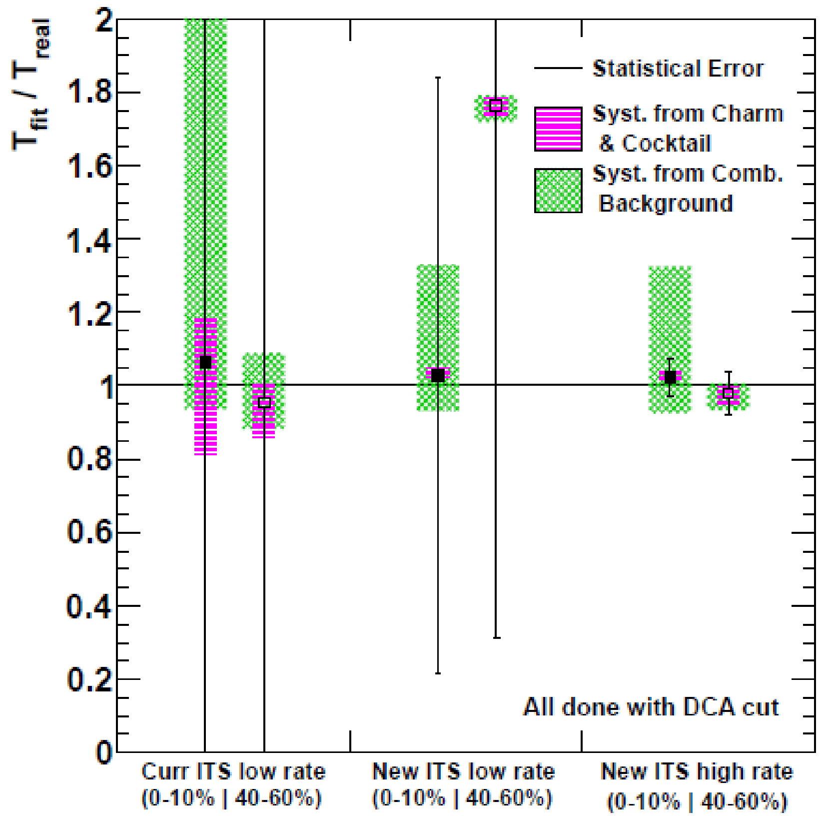
hard scattering looks ok and thermal photons exciting data but in both domains data need to and will improve



<u>future improvements:</u>
more statistics → smaller systematic errors
smaller centrality bins
as well as cross check with virtual photons → e+e-
both at m=0 and m>1 GeV/c^2
thinner inner tracking system by factor 3 means
X/X_0 goes from 11.4±0.5 to 6.2%
possibility to introduce a converter ?

Temperature extraction from thermal di-electrons

ALICE performance before and after upgrade



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

backup

Dielectrons - peformance before and after upgrade