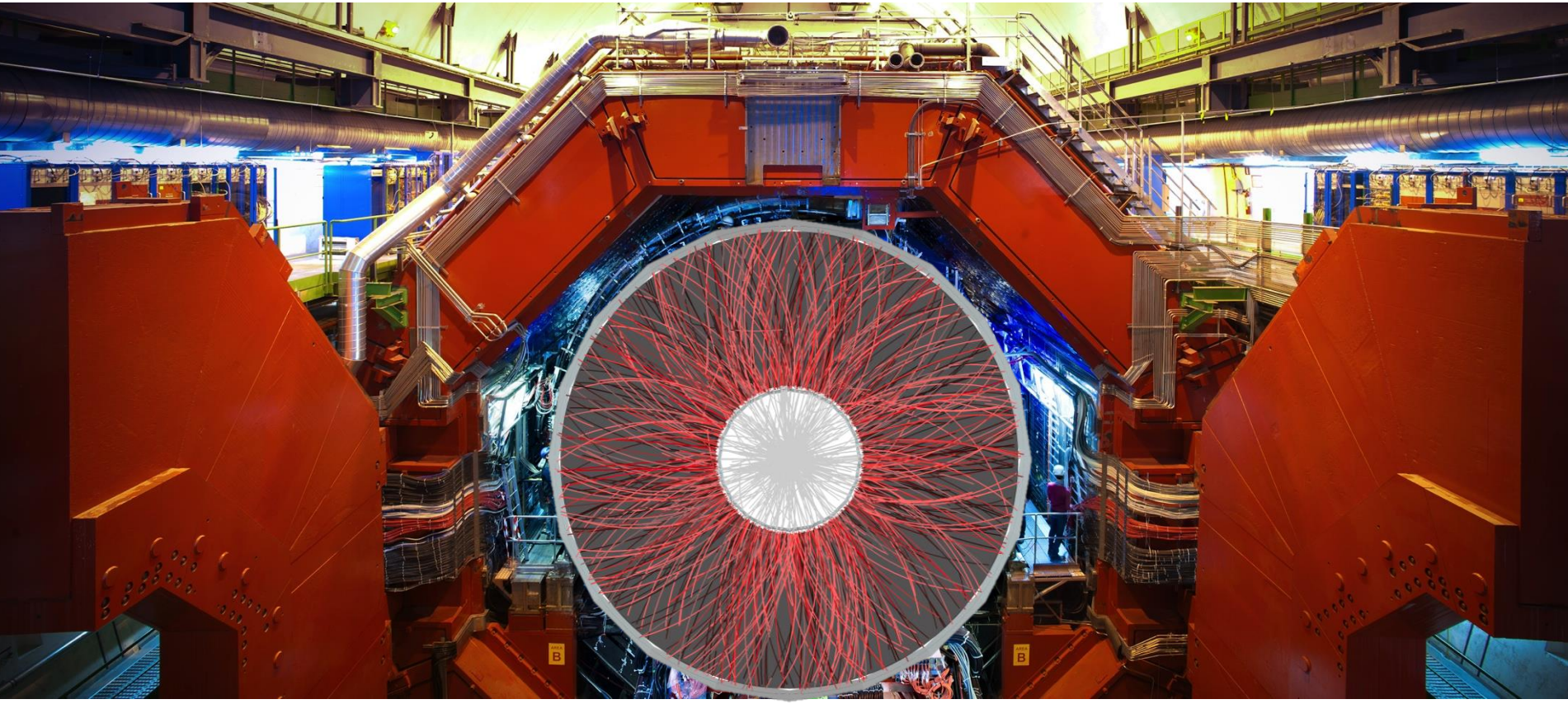
Physics with the upgraded ALICE



Michael Weber (University of Houston)
for the ALICE collaboration

ICTDHEP 2013 – *Jammu, India – 10.09.2013*

ALICE approved programme

- ALICE heavy-ion programme approved for ~ 1 nb^{-1}:
  - 2013–14 Long Shutdown 1 (LS1)
    - completion of TRD and CALs
  - 2015 Pb–Pb at $\sqrt{s_{NN}}$ = 5.1 TeV
  - 2016–17 (maybe combined in one year) Pb–Pb at $\sqrt{s_{NN}}$ = 5.5 TeV
  - 2018 Long Shutdown 2 (LS2)
  - 2019 probably Ar–Ar high-luminosity run
  - 2020 p–Pb comparison run at full energy
  - 2021 Pb–Pb run to complete initial ALICE programme
  - 2022 Long Shutdown 3 (LS3)

Order/choice of nuclei may change

- This will improve statistical significance of our main results by a factor about 3
  - physics reach extended by the new energy and completion of TRD and CALs

ALICE future plans

Precision measurement of the QGP parameters at $\mu_b = 0$
to fully exploit scientific potential of the LHC – unique in:

- large cross sections for hard probes
- high initial temperature

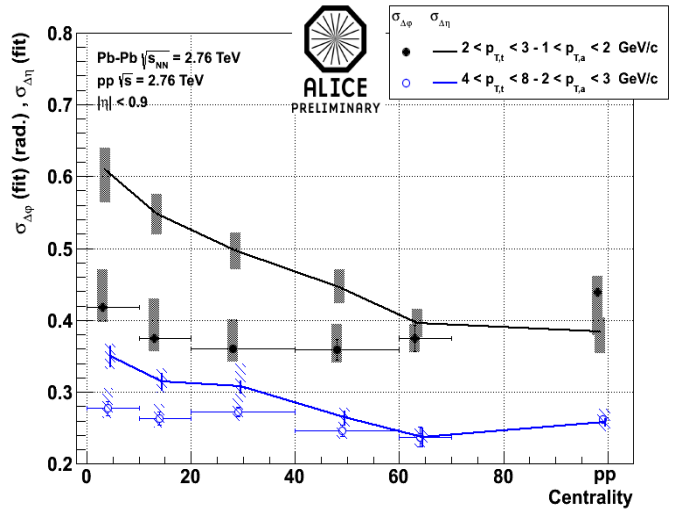
Main physics topics, uniquely accessible with the ALICE detector:

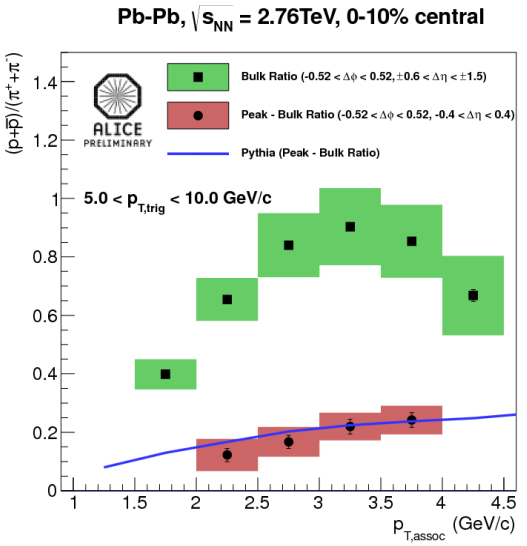
- measurement of heavy-flavour transport parameters
  - study of QGP properties via transport coefficients (η/s, q)
- measurement of low-mass and low-p_T di-leptons
  - study of chiral-symmetry restoration
  - space-time evolution and equation of state of the QGP
- J/ψ , ψ', and χ_c states down to zero p_T in wide rapidity range
  - statistical hadronization versus dissociation/recombination

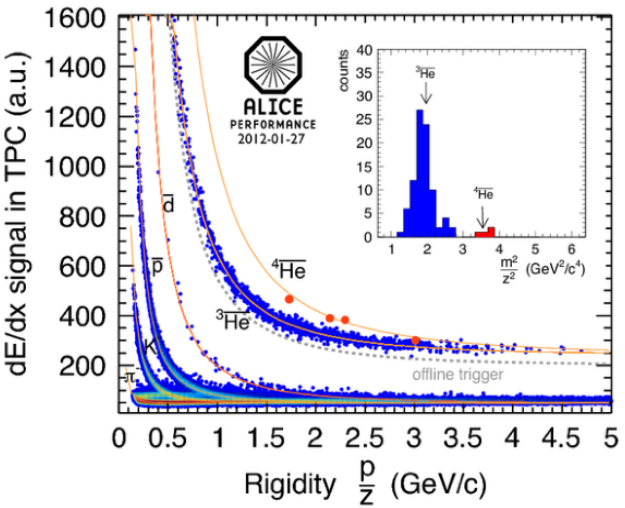
- for main physics programme factor > 100 increase in statistics
  (maximum readout with present ALICE ~ 500 Hz)
  for triggered probes increase in statistics by factor > 10

… and more

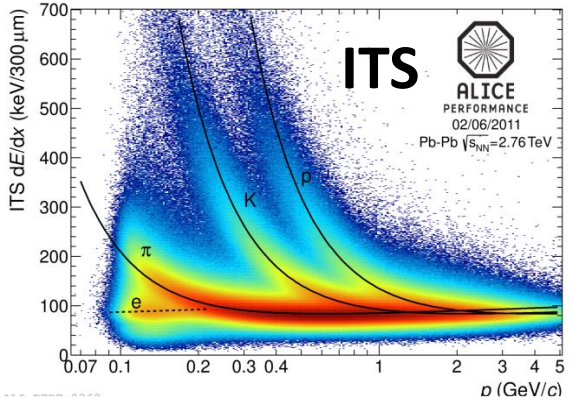
- Jet quenching and fragmentation
  - jet energy recuperation at very low p_T
  - heavy-flavour tagged jets, gluon vs. quark induced jets
  - heavy-flavour produced in fragmentation
  - particle identified fragmentation functions
- Heavy nuclear states
  - high statistics mass-4 and -5 (anti-)hypernuclei
  - search for H-dibaryon, Λn bound state, etc.

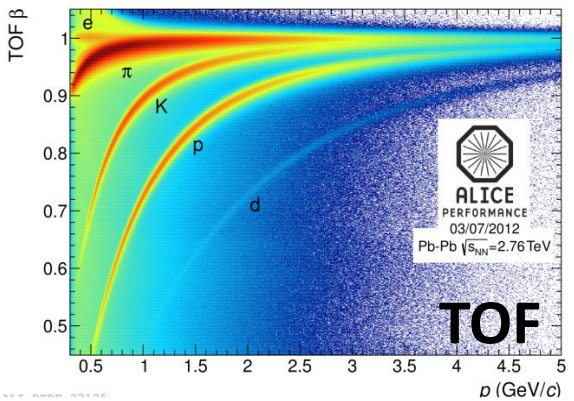


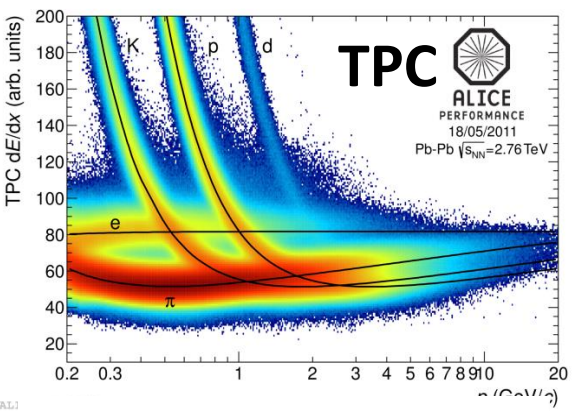


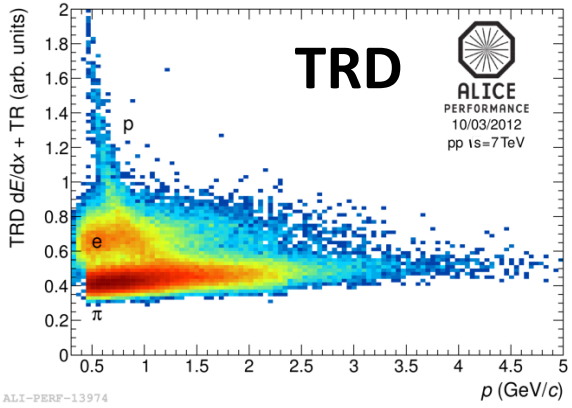


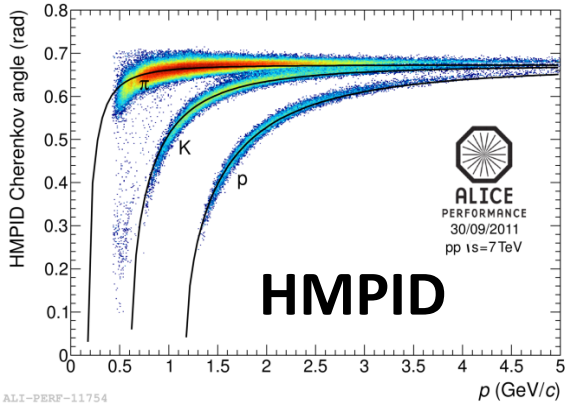
ALICE Upgrade – build on demonstrated strengths…

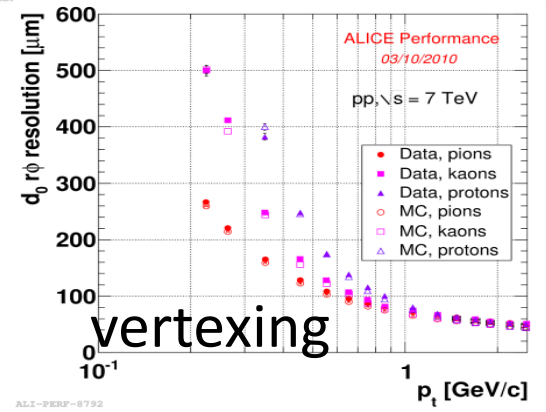












- particle identification (practically all known techniques)
- extremely low-mass tracker ~ 10% of X_0
- excellent vertexing capability
- efficient low-momentum tracking – down to ~ 100 MeV/*c*

ALICE Upgrade strategy

Luminosity upgrade – target 50 kHz minimum bias rate for Pb–Pb
run ALICE at this high rate, inspecting all events
corresponds to Pb–Pb luminosity 6×10^{27} cm^{-2}s^{-1} – achievable at LHC

Upgrade heavy-ion programme already after LS2 (2018)
collect more than 10 nb^{-1} of integrated luminosity
implies running with heavy ions few years after LS3

- Improved vertexing and tracking at low p_T
- Preserve particle-identification capability
- High-luminosity operation without dead-time

- New, smaller radius, beam pipe
- New inner tracker (ITS) (performance and rate upgrade)
- High-rate upgrade for the readout of the TPC, TRD, TOF, CALs, DAQ-HLT, Muon-Arm and Trigger detectors

Additional proposal to be submitted: Muon Forward Tracker (MFT)
postponed: Forward Calorimeter (FoCal)

Heavy-flavour production

Two main topics under study:

- thermalization of heavy quarks in the medium
  - baryon-to-meson ratio, i.e. Λ_c/D, Λ_b/B
  - azimuthal anisotropy v_2
  - possible thermal charm production?
- in-medium energy loss
  - separately for D and B mesons
  - wide p_T range, and especially low p_T

•Two topics connected via transport coefficient

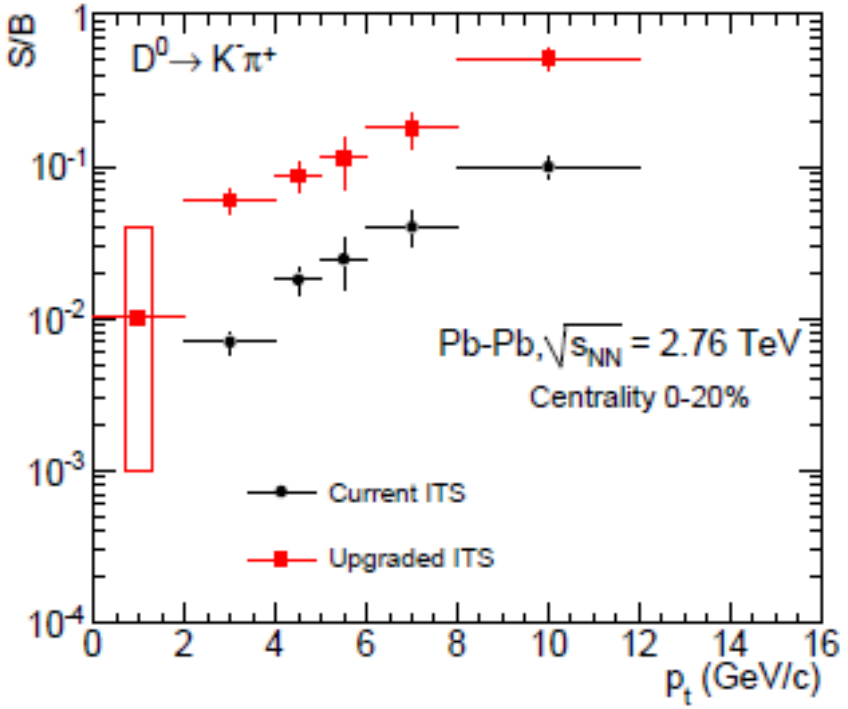
•Significant differences between c and b predicted

Benchmark analyses:

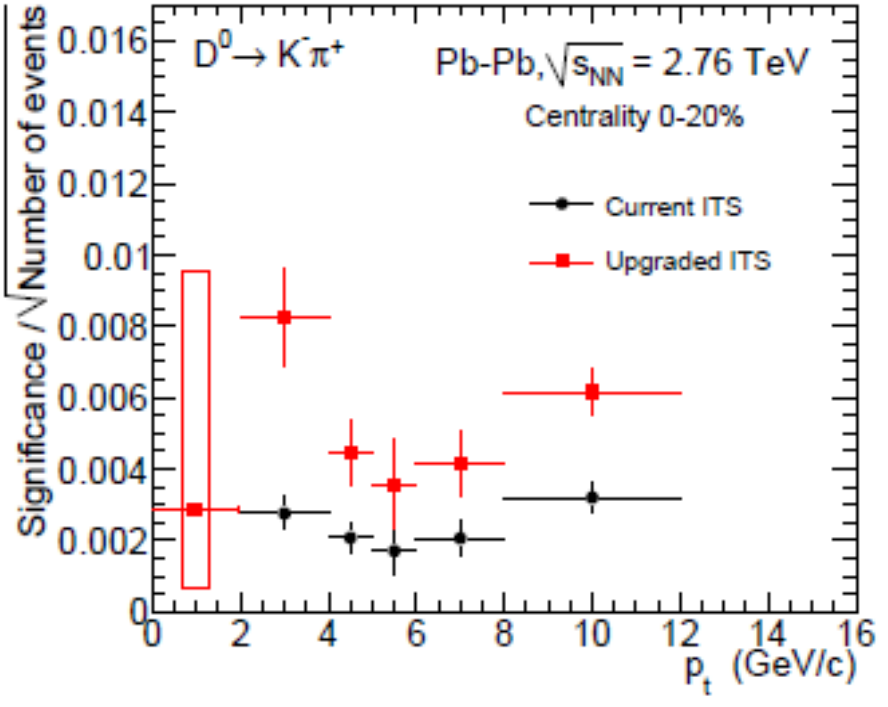
- charm meson production $D^0 \rightarrow K^-\pi^+$
- charm-strange meson $D_s^+ \rightarrow K^+K^-\pi^+$
- beauty meson production $B \rightarrow D^0(\rightarrow K^-\pi^+) + X$; $B \rightarrow J/\psi(\rightarrow l^+l^-) + X$
- charm baryon production $\Lambda_c \rightarrow pK^-\pi^+$

$D^0 \rightarrow K^-\pi^+$

Signal-to-background ratio



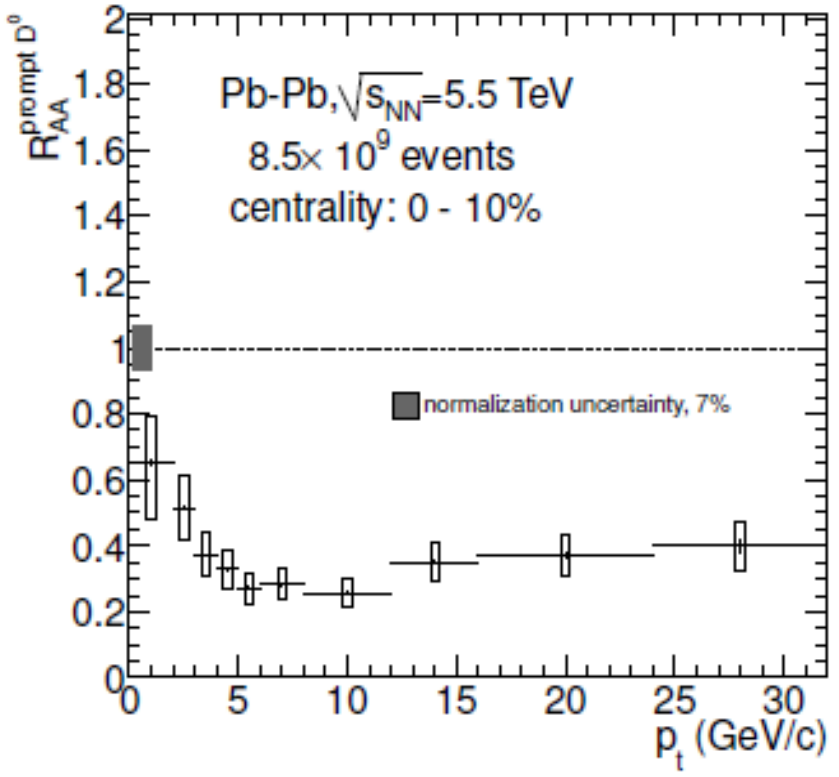
Significance (multiply by ~10^5)



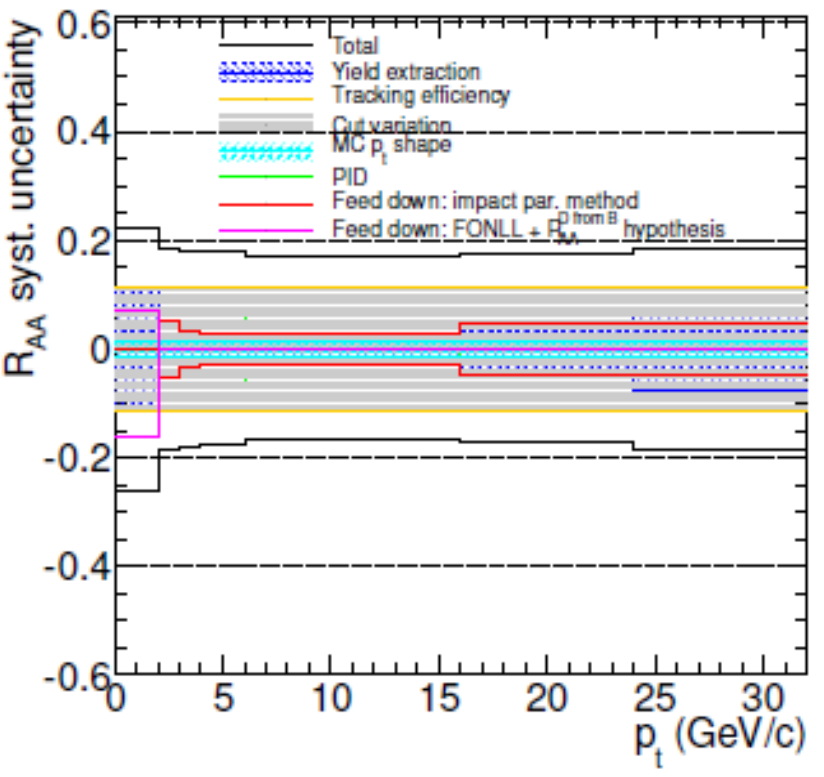
With new ITS: signal-to-background improved by one order of magnitude
significance per event improved by factor 2–4
(additional factor 10 due to event statistics)

Systematic uncertainties: $D^0 \rightarrow K^-\pi^+$

D-meson R_{AA} for 10 nb^{-1}

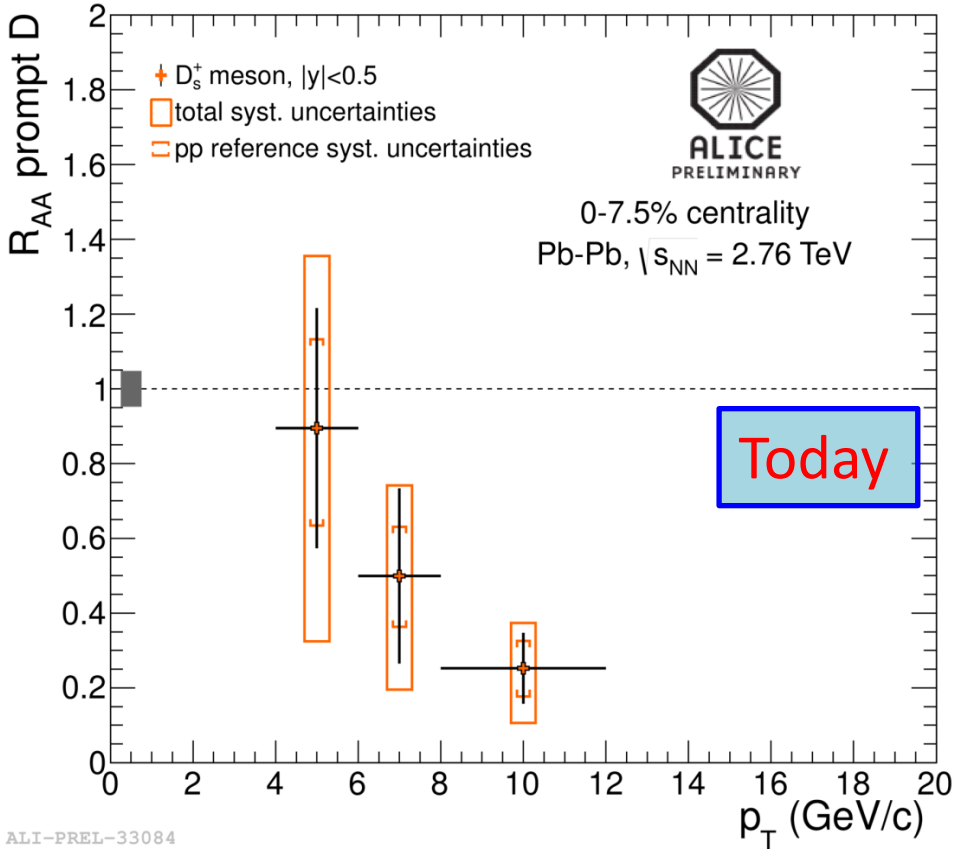


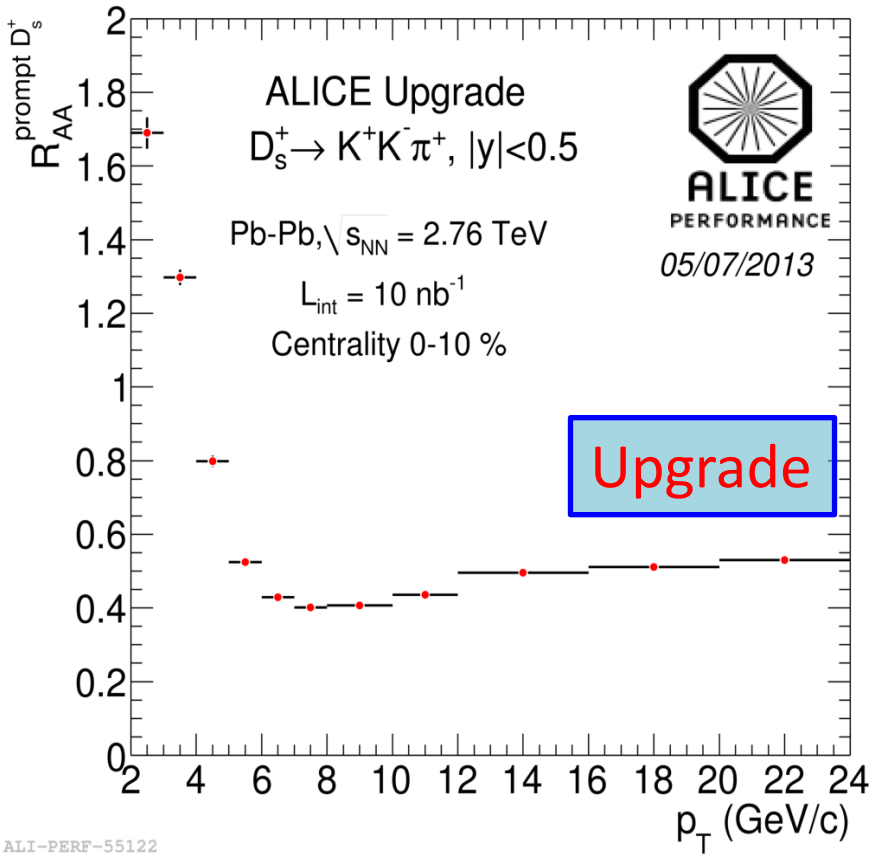
Contributions to systemic error



High precision measurement of D meson !

$D_s^+ \rightarrow K^+K^-\pi^+$

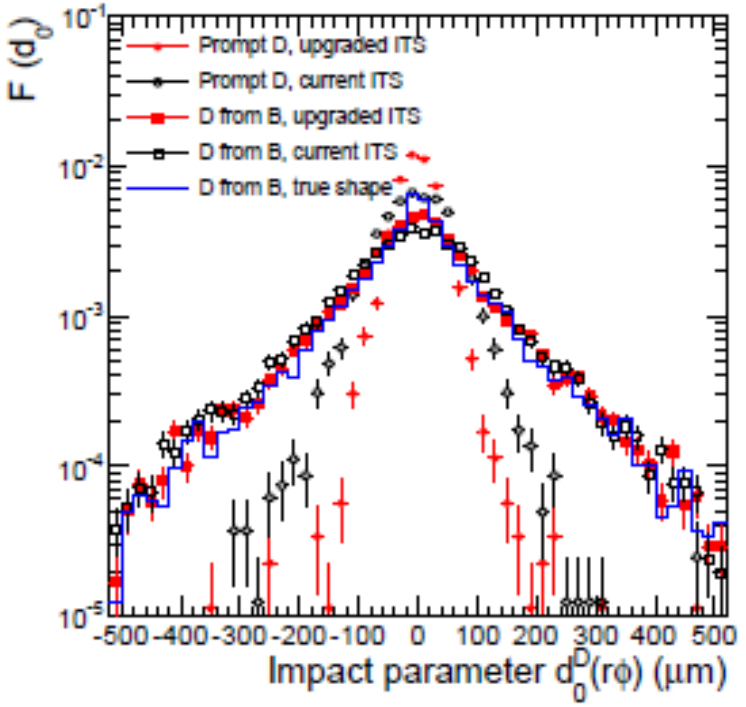




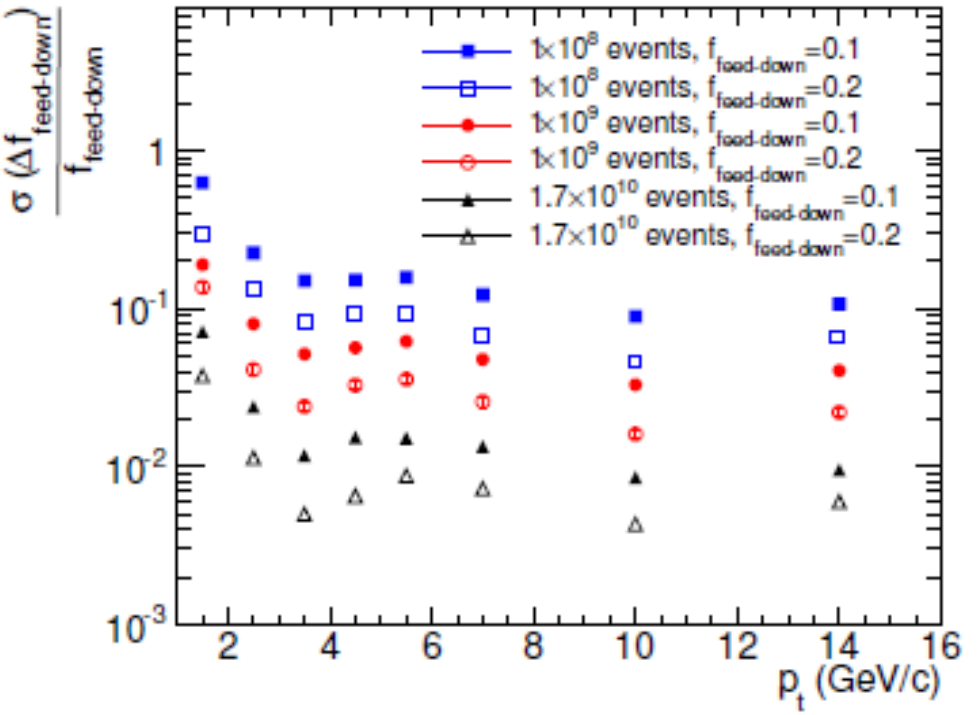
With new ITS: significant improvement for D_s^+
high-precision measurement down to p_T = 2 GeV/*c*

$B \rightarrow D^0 (\rightarrow K^-\pi^+) + X$

Impact parameter distribution for D and B



Relative statistical error on B fraction (new ITS)

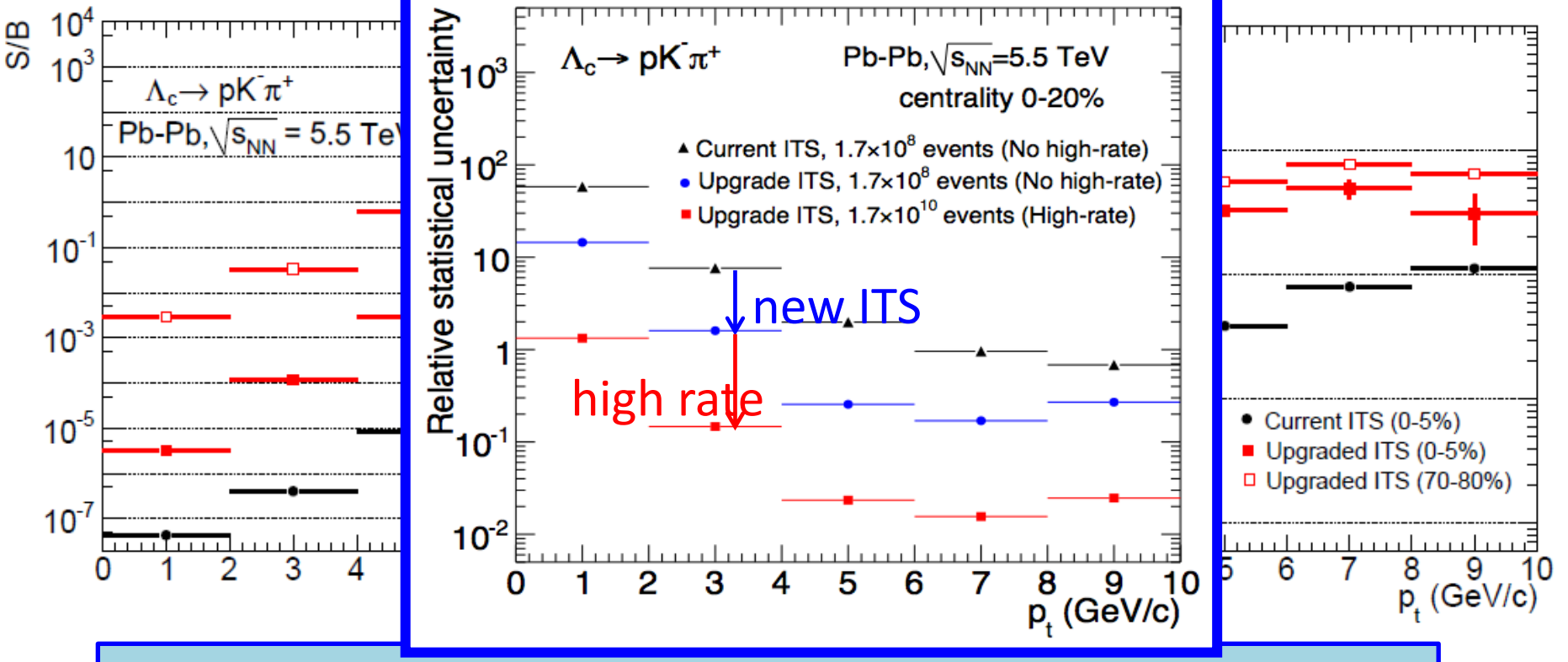


Significantly improved resolution for prompt D meson with new ITS
For B-meson measurement high statistics necessary
Study of systemic uncertainties presented in LoI

$\Lambda_c \rightarrow pK^-\pi^+$

Signal-to-background ratio

Significance (multiply by ~10^5)



With new ITS: signal-to-background ratio improved by more than two orders of magnitude!

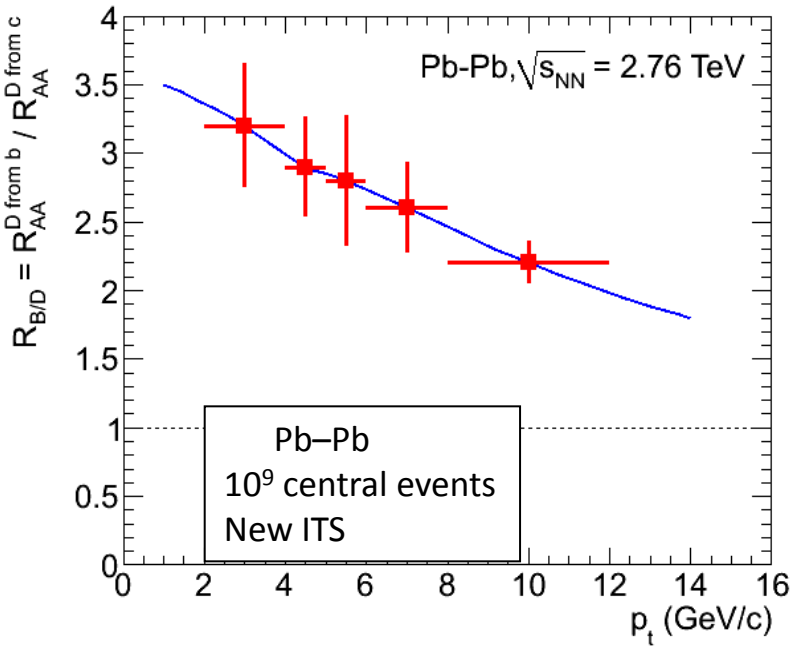
significance improvement ~ one order, statistics bring another order

For Λ_c-baryon measurement – high statistics necessary

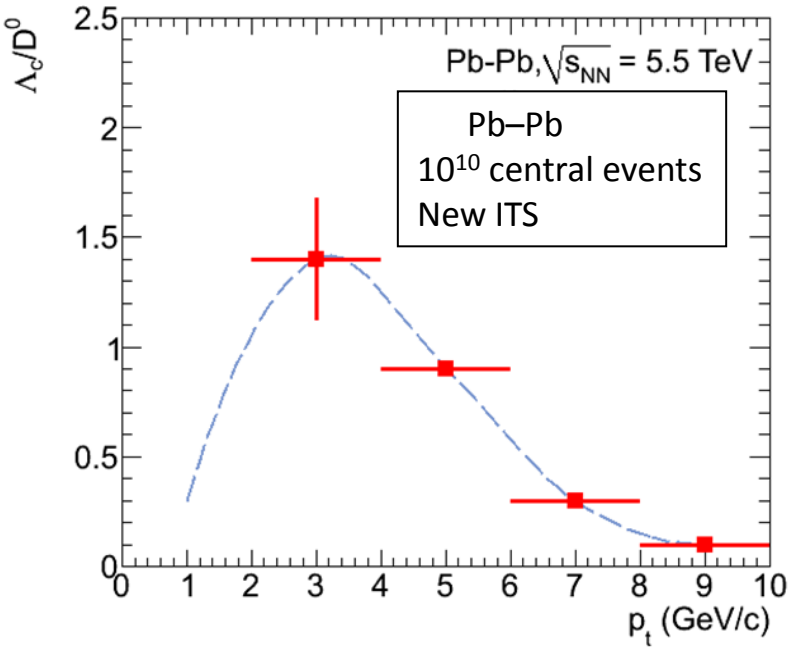
Heavy-flavour "results"

- Beauty via non-prompt D^0 -> $K\pi$ – mass dependence of energy loss
  - needs precision of the new ITS
- Λ_c – charm in-medium hadronization, baryon-to-meson ratio
  - needs both: new ITS and luminosity ~ 10 nb^{-1}

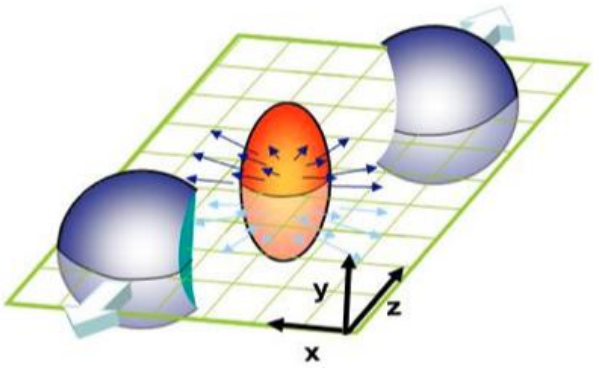
B/D R_{AA} suppression



Λ_c/D enhancement

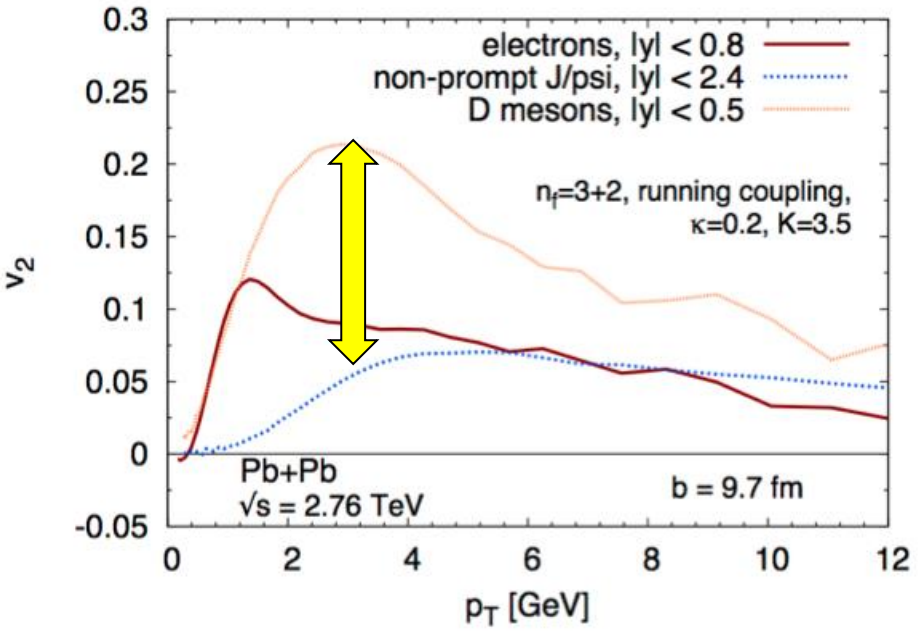


Heavy-flavour elliptic flow (v_2)

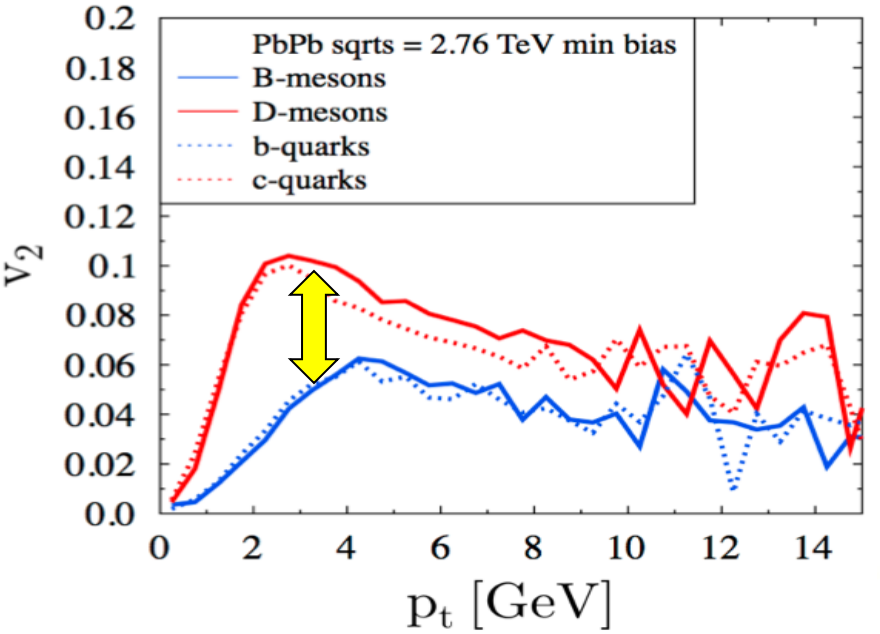


sensitive to:

- Thermalization of c and b quarks in the QGP
- Heavy-quark diffusion coefficient of the QGP, which characterizes its coupling strength, and is related to its η/s (viscosity/entropy-density)

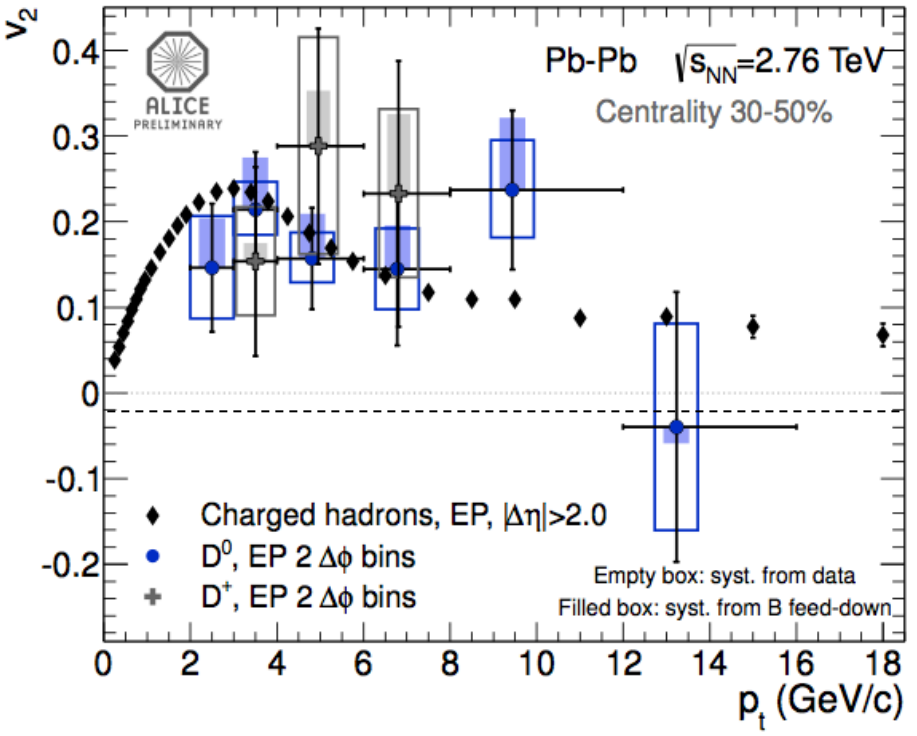


J. Uphoff et al. arXiv:1205.4945



J. Aichelin et al. in arXiv:1201:4192

Heavy-flavour elliptic flow (v_2)



- New: ALICE preliminary results with full 2011 sample (10^7 events in 30-50%)
- Indication of non-zero v_2
- But uncertainties are substantial
- Factor 3 larger statistics 2015-16 data?

→ Need precise measurement of v_2 of D and B mesons to answer these questions:
- is v_2 of **charm the same as of pions**?
- is v_2 of **beauty smaller than of charm**?
- comparison with models → **HF transport coefficient of QGP**

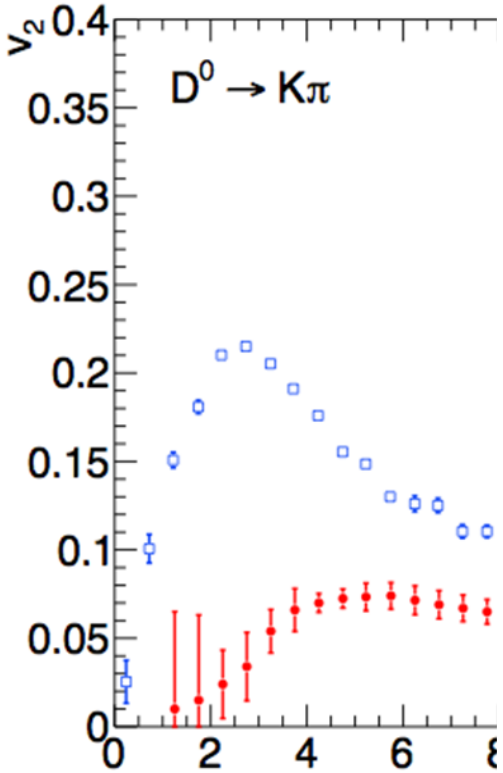
Heavy-flavour elliptic flow (v_2)

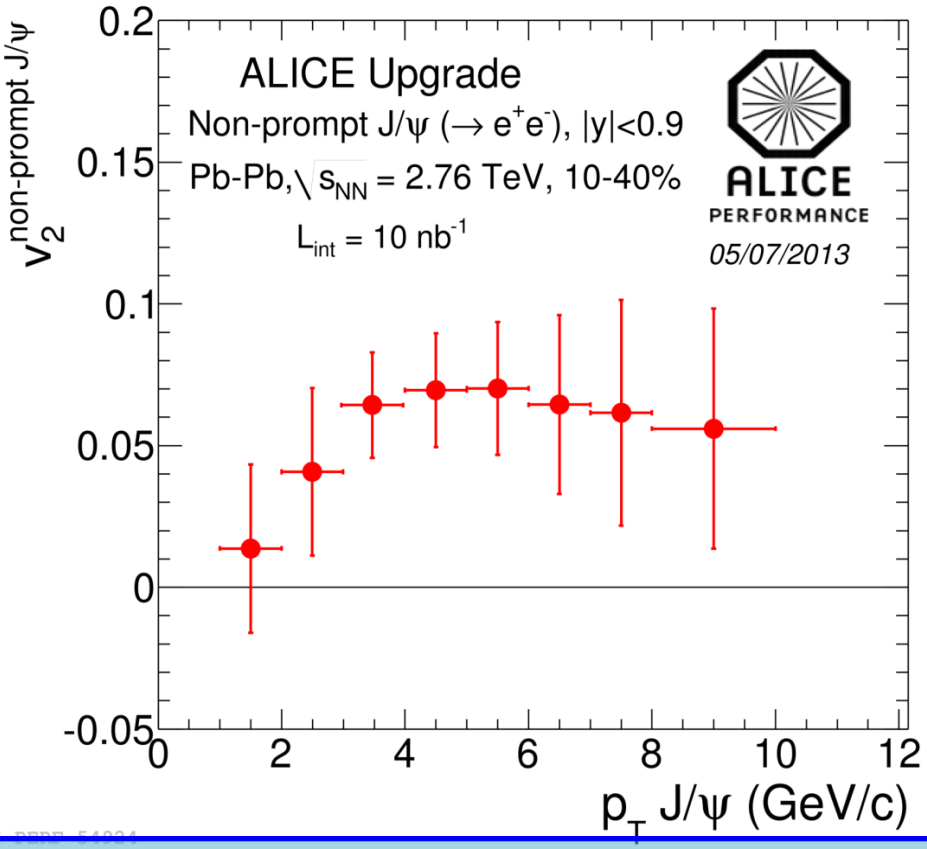
Thermalization of heavy quarks

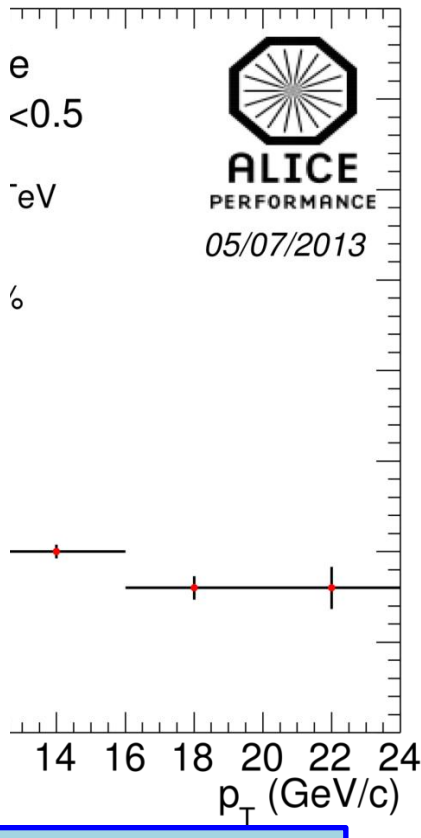
v_2 D^0 and $B \rightarrow D^0 + X$

v_2 $B \rightarrow J/\psi(e^+e^-) + X$

v_2 D_s^+







- need high statistics for precise measurement of charm and beauty v_2
- systematic uncertainties and corrections mostly cancel in v_2

Production of quarkonia

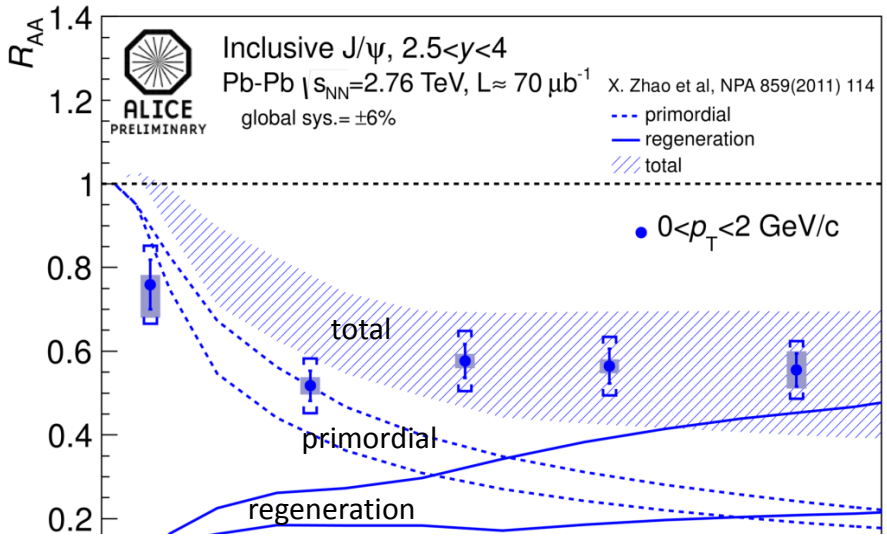
Measurement proposed:

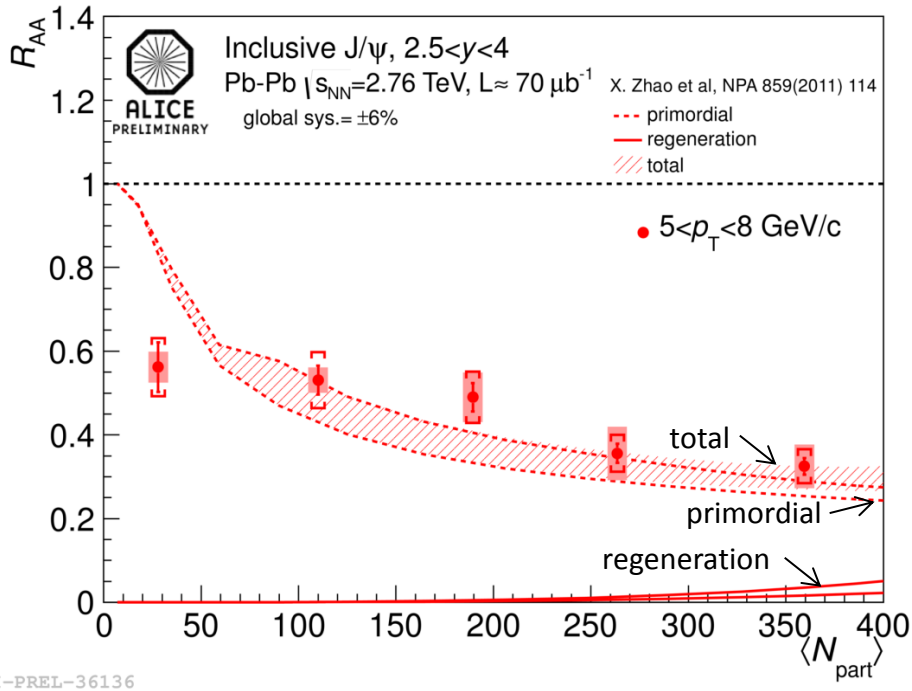
- high-statistics measurement of J/ψ in wide rapidity range
  - nuclear modification factor R_{AA}
  - azimuthal anisotropy v_2
  - dissociation (re)generation ?
  - J/ψ polarization
  - low-p_T J/ψ excess
- ψ(2S) production – nuclear modification factor
- access to χ_c under study

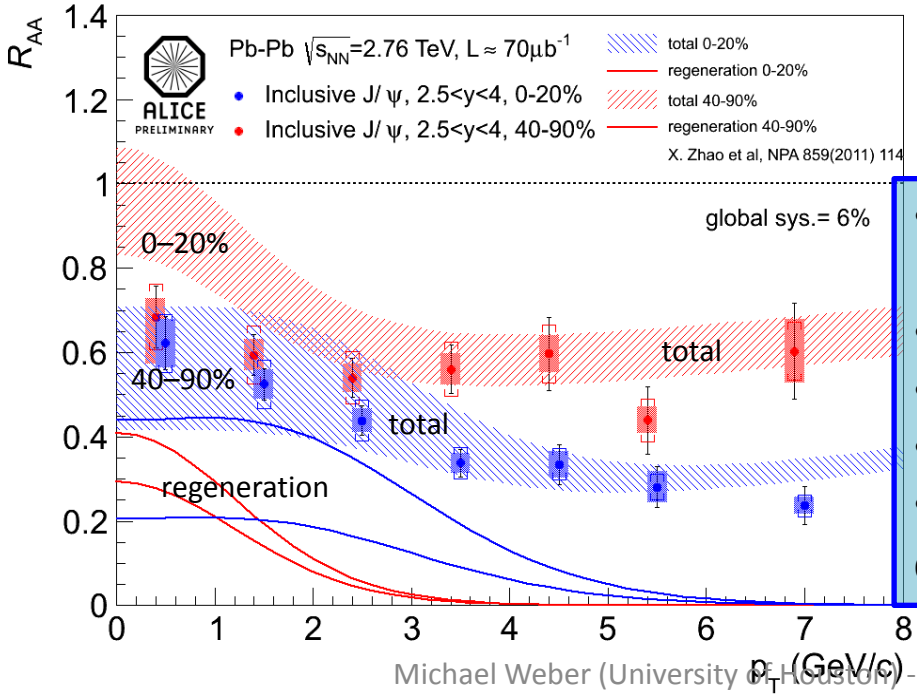
Measurement both in e^+e^- (barrel) and in
$\mu^+\mu^-$ (forward muon spectrometer) channels

Complementary measurement of Υ family in forward region

J/ψ R_{AA} vs. centrality and p_T

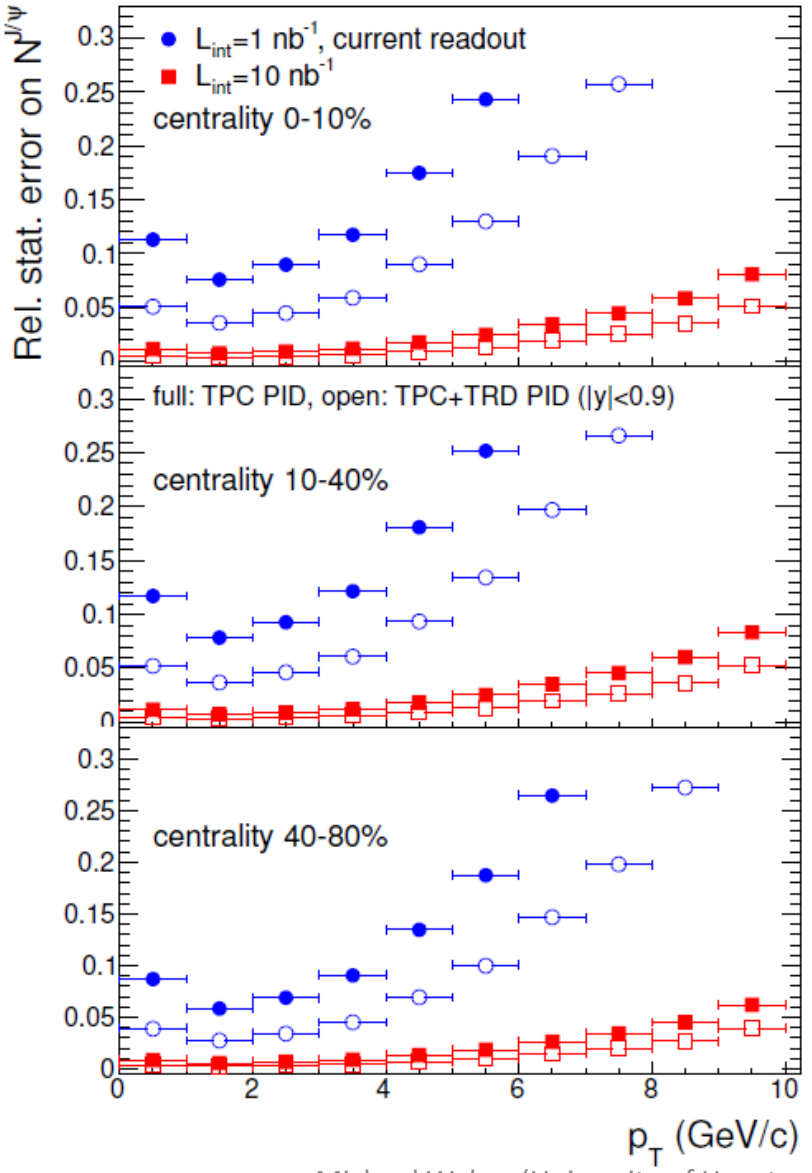






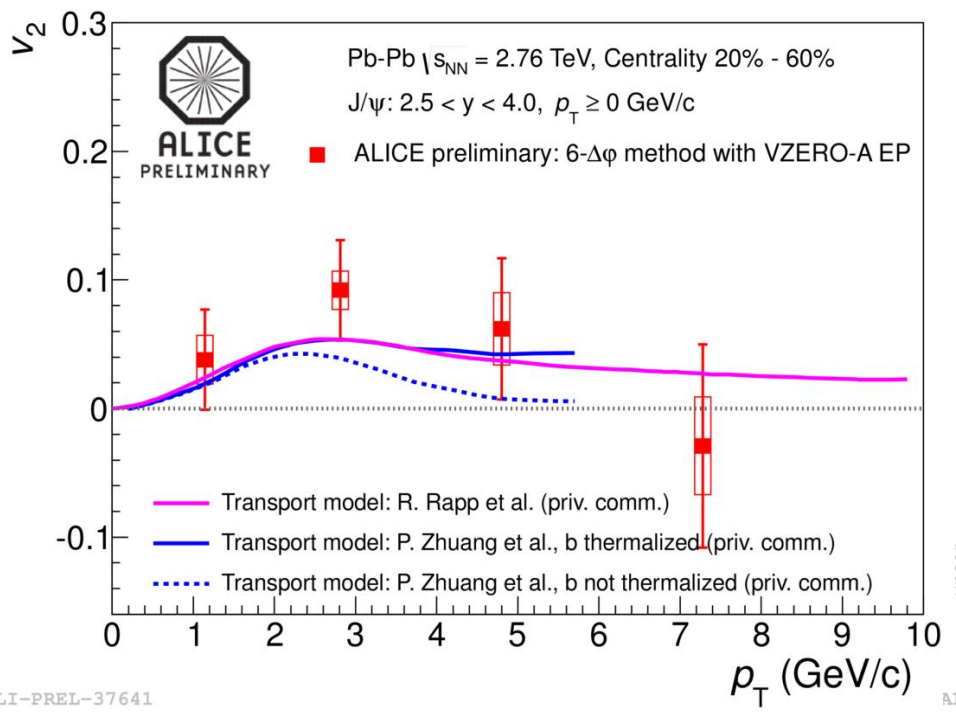
- Comparison to regeneration model:
  X.Zhao, R.Rapp NPA 859 114
- Different suppression pattern at low/high-p_T
- At low p_T ~50% J/ψ from recombination
- Fair agreement for different centralities
- Statistical hadronization model also describes the data: *P.Braun-Munzinger et al.*

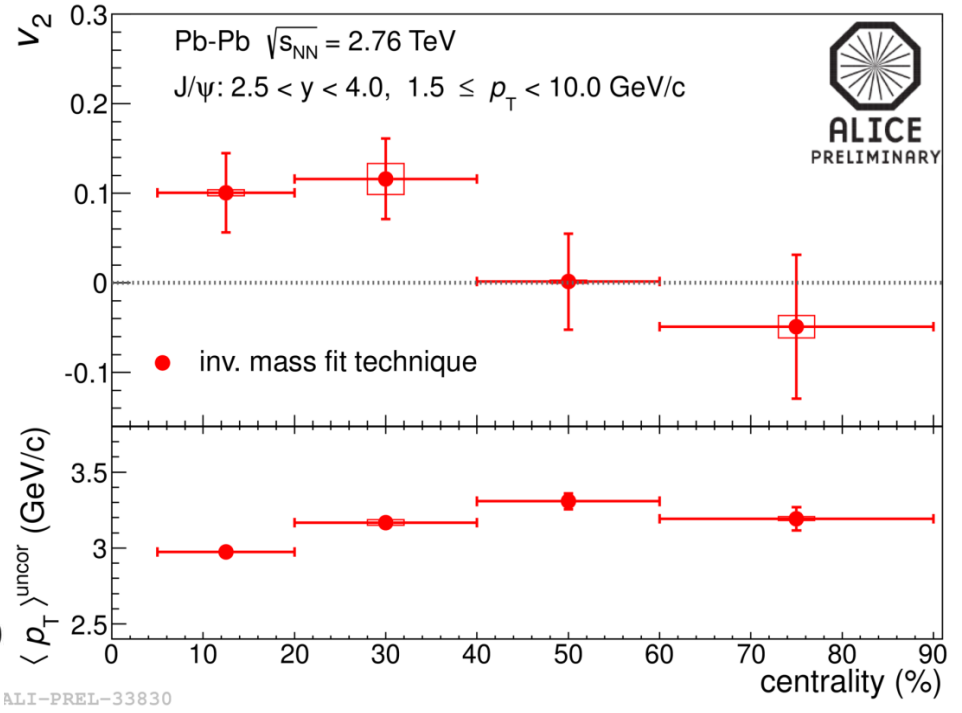
$J/\psi \rightarrow e^+e^-$ (barrel)



High-rate – significant improvement at high p_T

J/ψ elliptic flow





J/ψ produced by recombination of thermalized c-quarks should have non-zero elliptic flow

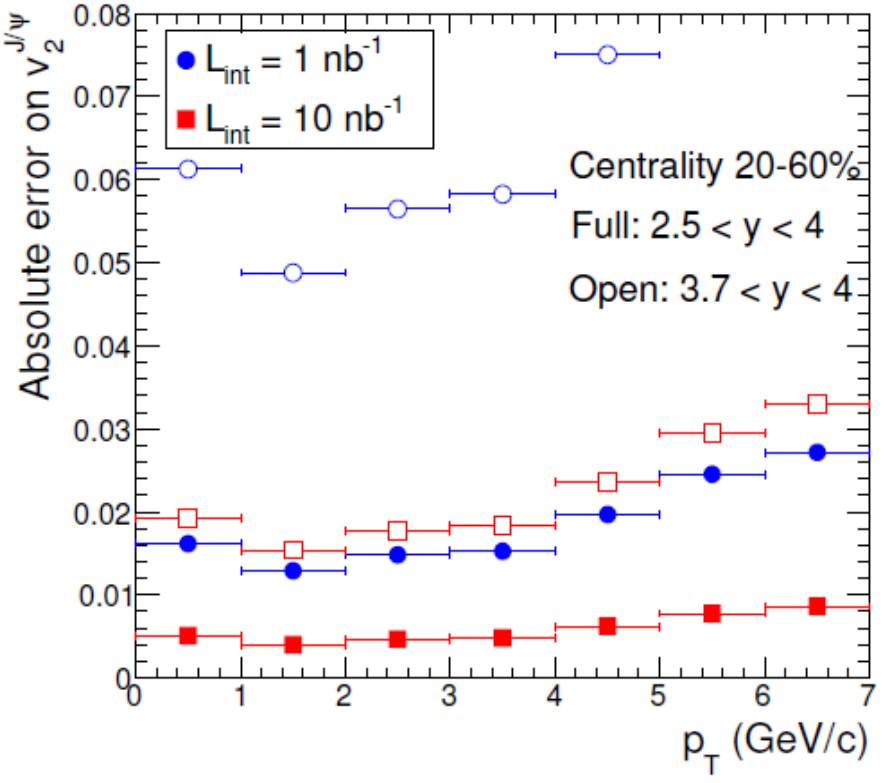
– measurements give a hint for non-zero v_2

– qualitative agreement with transport models, including regeneration

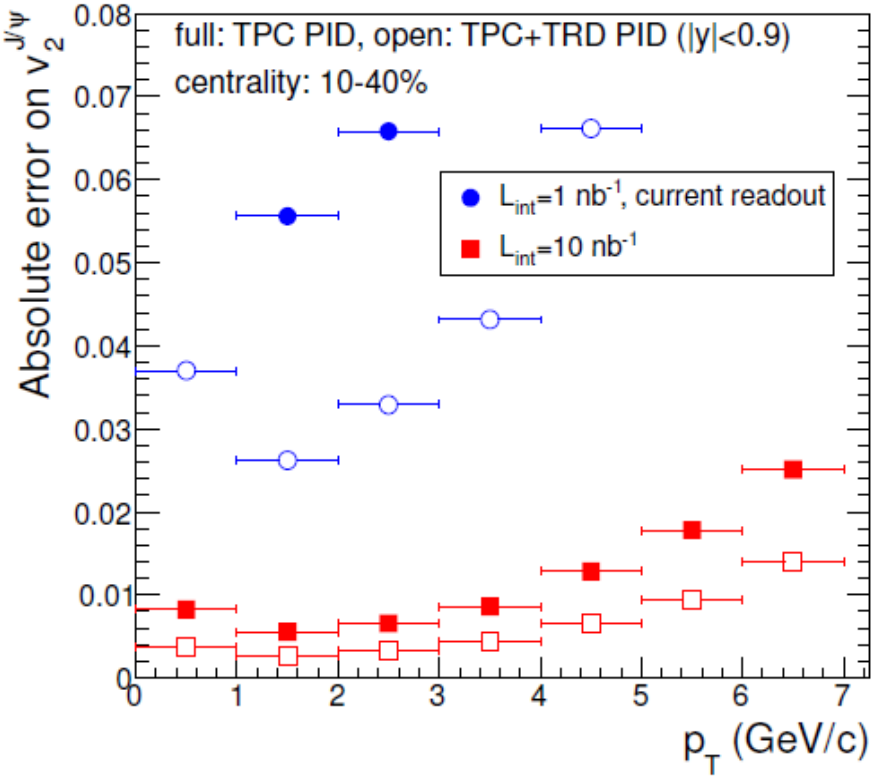
– complementary to indications obtained from J/ψ R_{AA} studies

J/ψ elliptic flow

J/ψ in muon channel, forward region



J/ψ in electron channel, central region



Azimuthal anisotropy – even more demand for high-rate upgrade…

Low-mass dileptons

One of the most fundamental (and difficult) measurements, potentially giving access to:

- chiral-symmetry breaking mechanism by modification of ρ-meson spectral function
- direct photon thermal emission extrapolating to zero dilepton mass
- partonic equation of state studying space–time evolution with invariant-mass and p_T distributions of dileptons

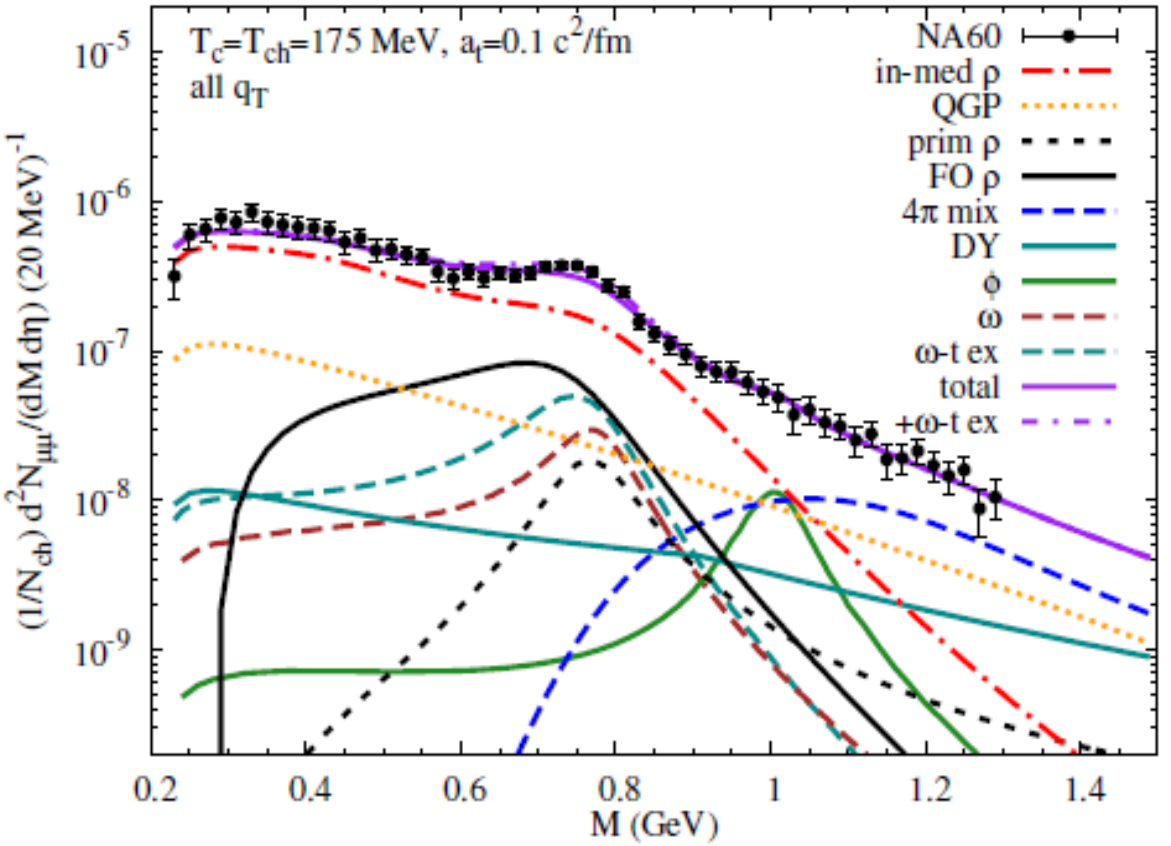
Measurements to be done:

- mapping of dilepton yields in invariant mass and p_T
- elliptic flow of dileptons
- (after experimentally driven subtraction of all backgrounds…)

Need for special run at lower magnetic field (B = 0.2T) to enhance acceptance at low p_T, thus integrated luminosity of 3 nb^{-1} assumed

NA60 dimuon measurement

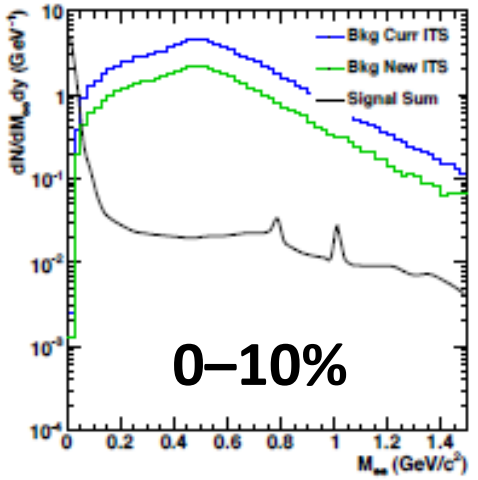
… probably the best dilepton result to date…

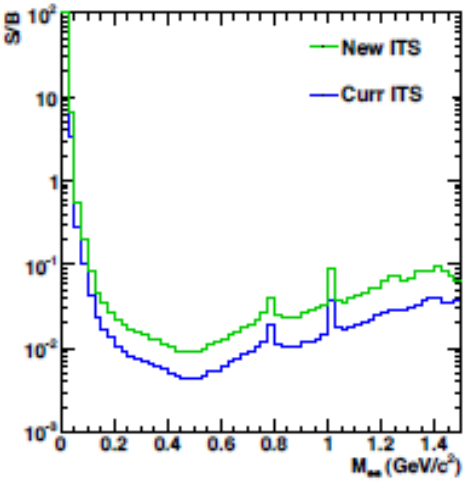


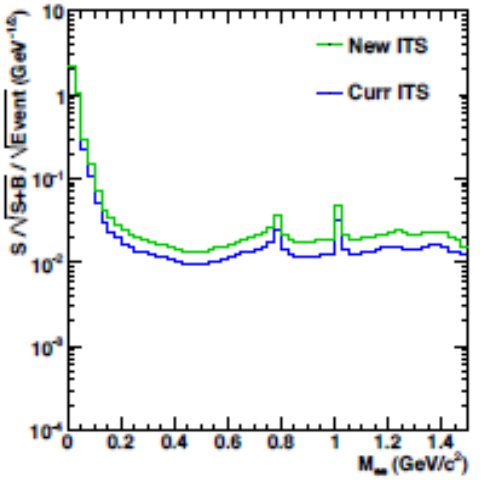
- … but at quite high baryon density …
- measurements at RHIC still in tension…

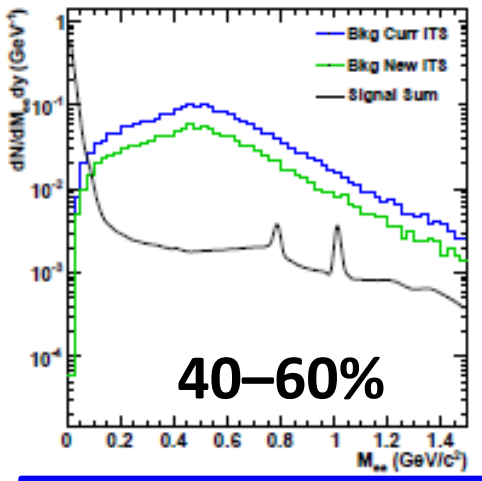
Signal and Background(s)…

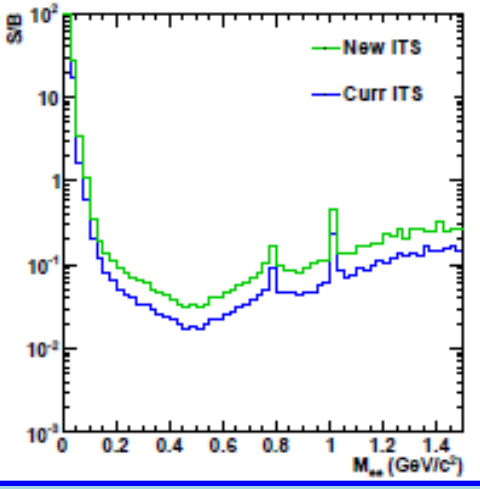
Signal & background	Signal-to-background ratio	Significance: multiply by ?

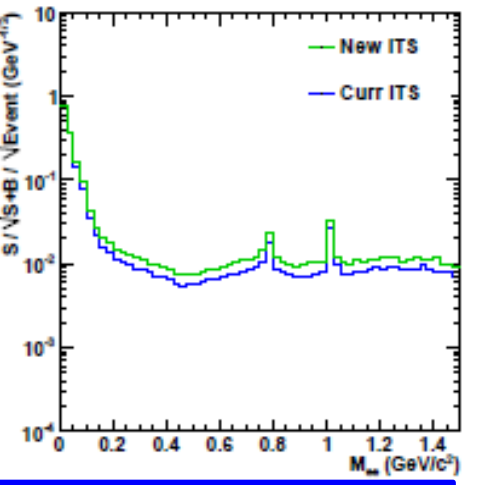








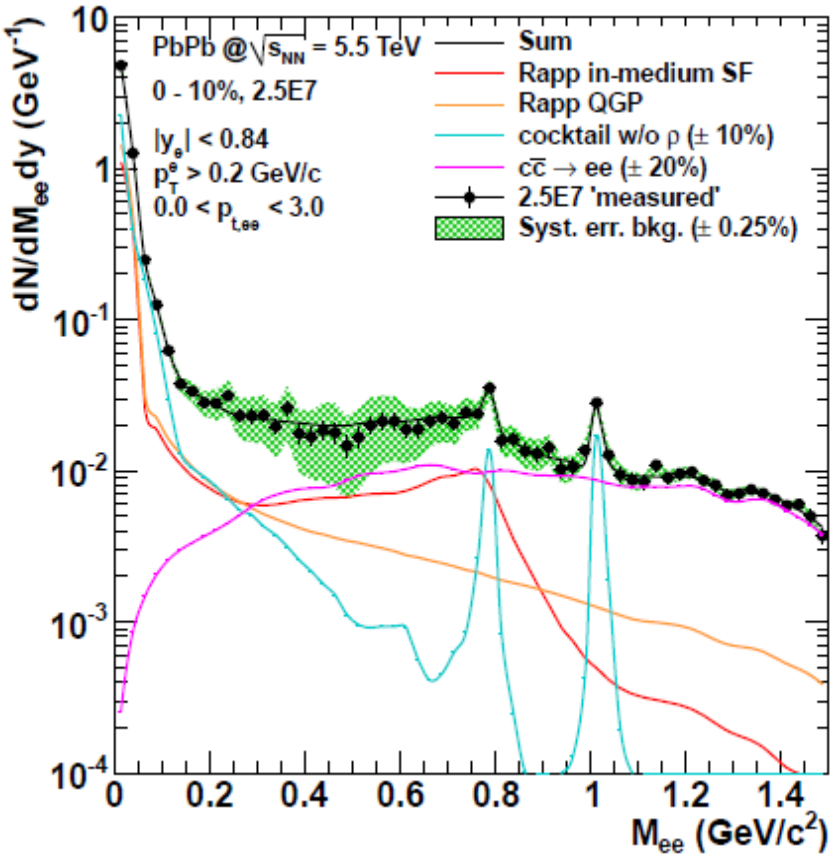




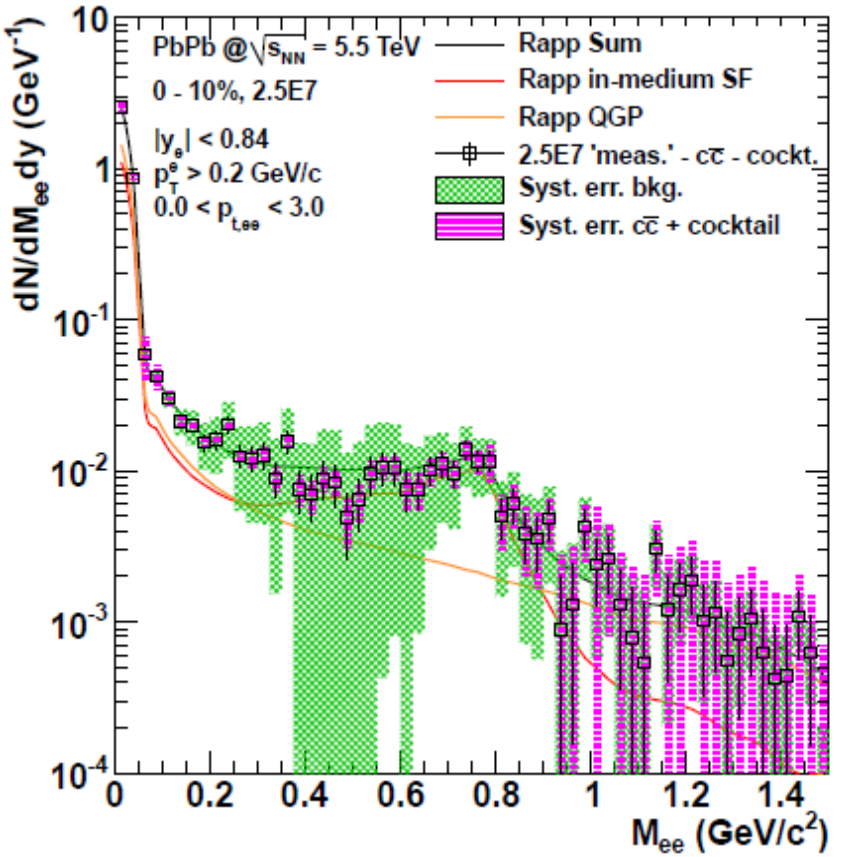
In general: new ITS helps to suppress background by a factor of ~2

ALICE dielectrons

inclusive dielectron invariant mass



… excess after subtraction

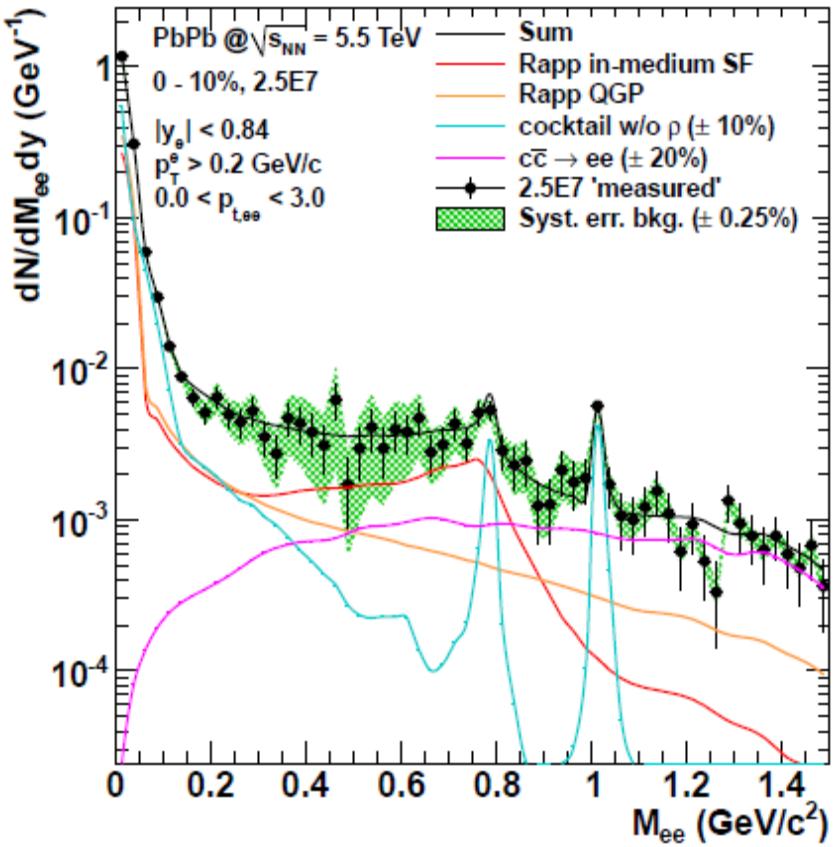


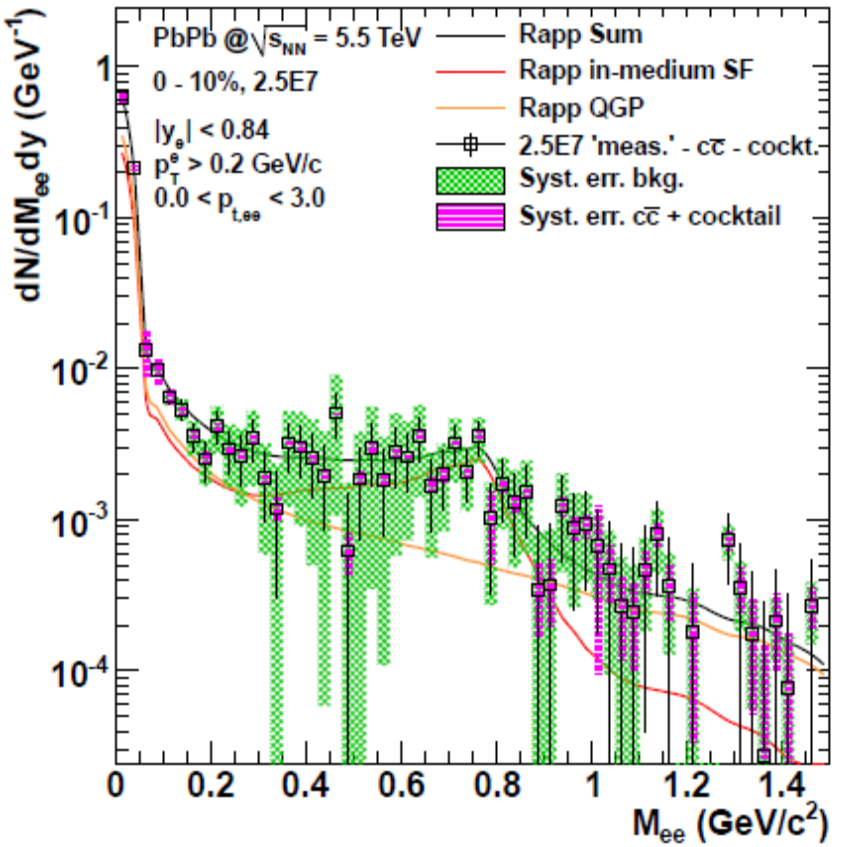
current ITS and event rate, no cut on impact parameter…

ALICE dielectrons

inclusive dielectron invariant mass

… excess after subtraction



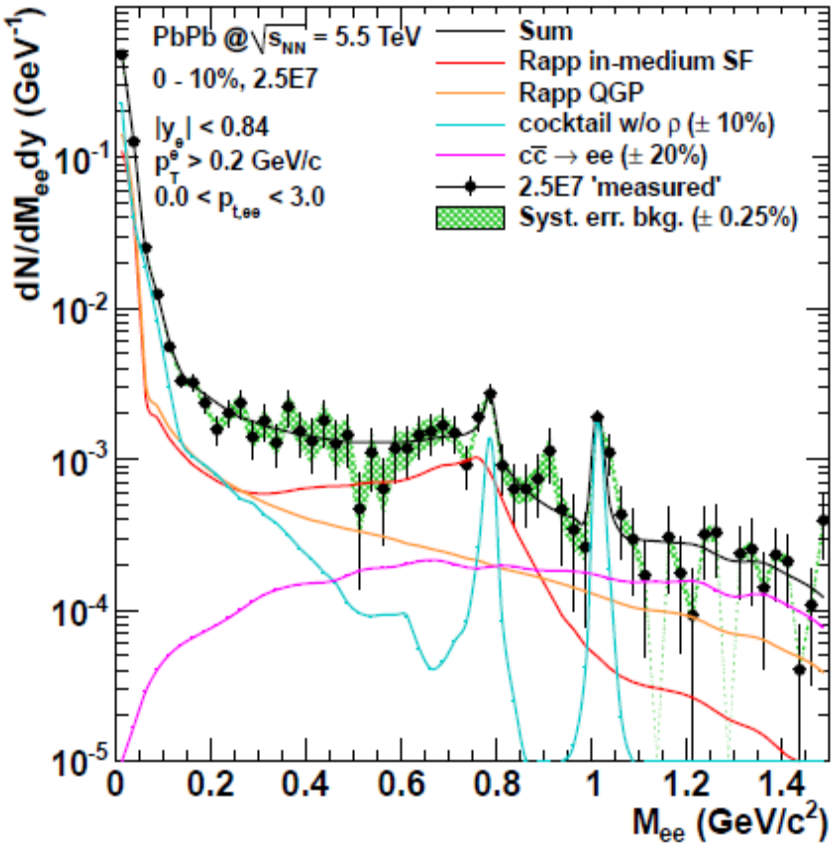


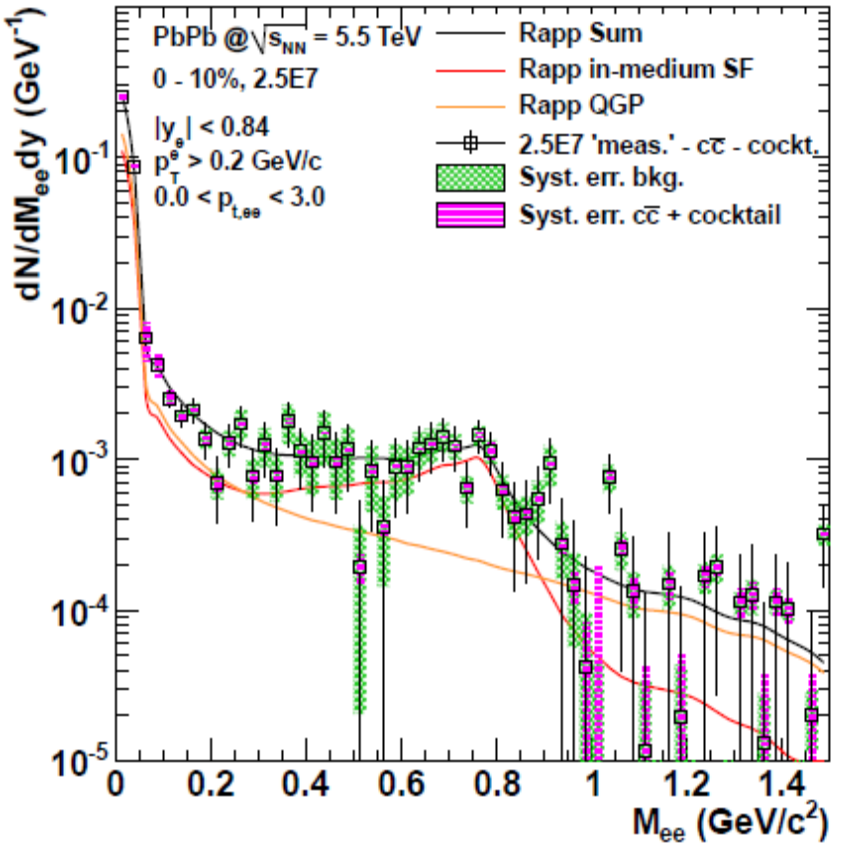
current ITS and event rate, with “tight” impact parameter cut…

ALICE dielectrons

inclusive dielectron invariant mass

… excess after subtraction



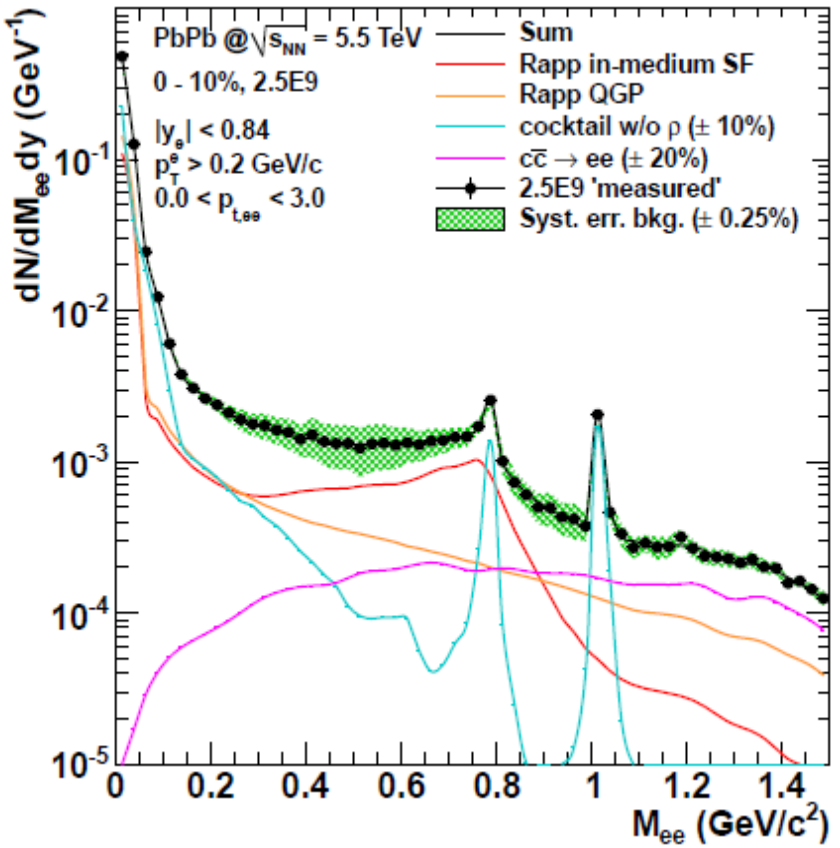


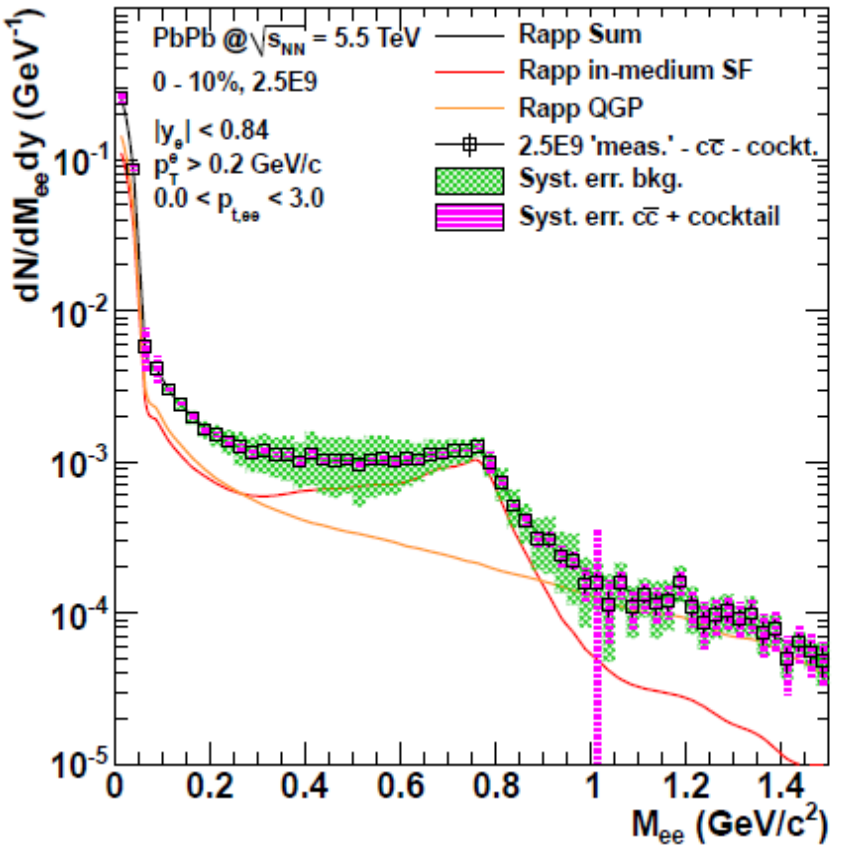
new ITS but no high-rate upgrade, with “tight” impact parameter cut…

ALICE dielectrons

inclusive dielectron invariant mass

… excess after subtraction



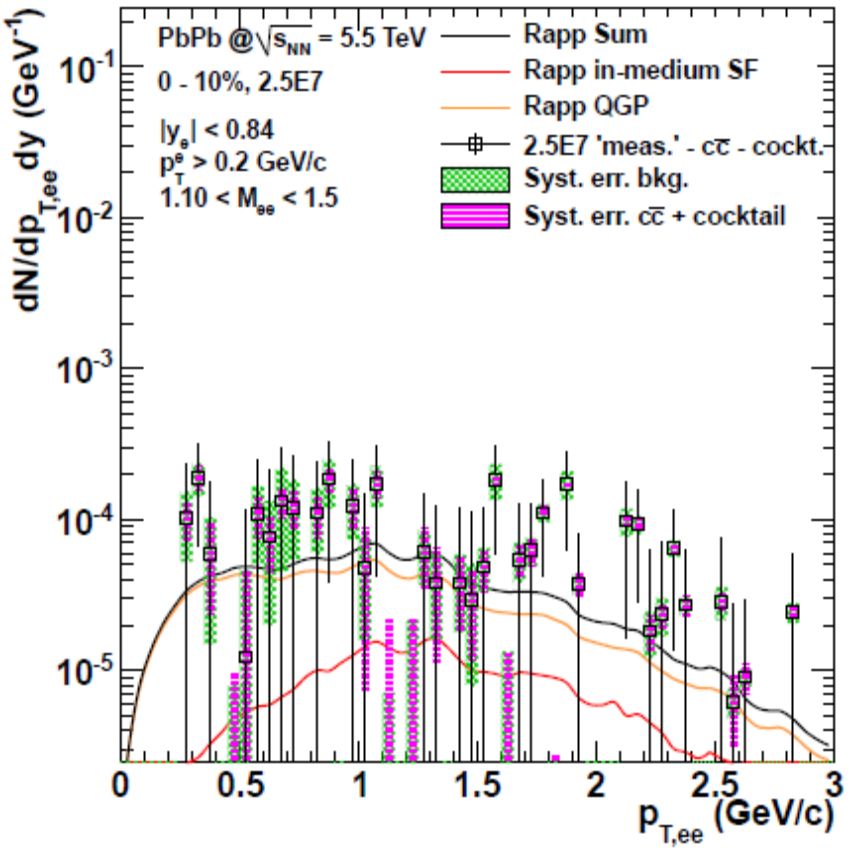


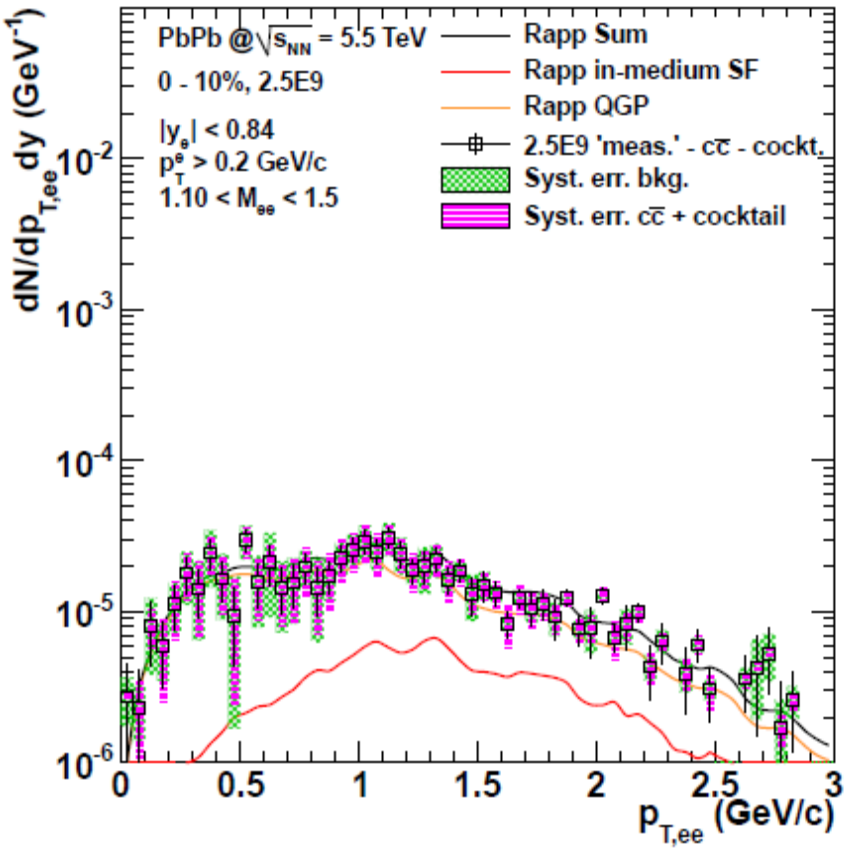
new ITS and high-rate upgrade, with “tight” impact parameter cut…

Dielectron p_T spectra

current ITS, no hight-rate upgrade

new ITS, high-rate upgrade



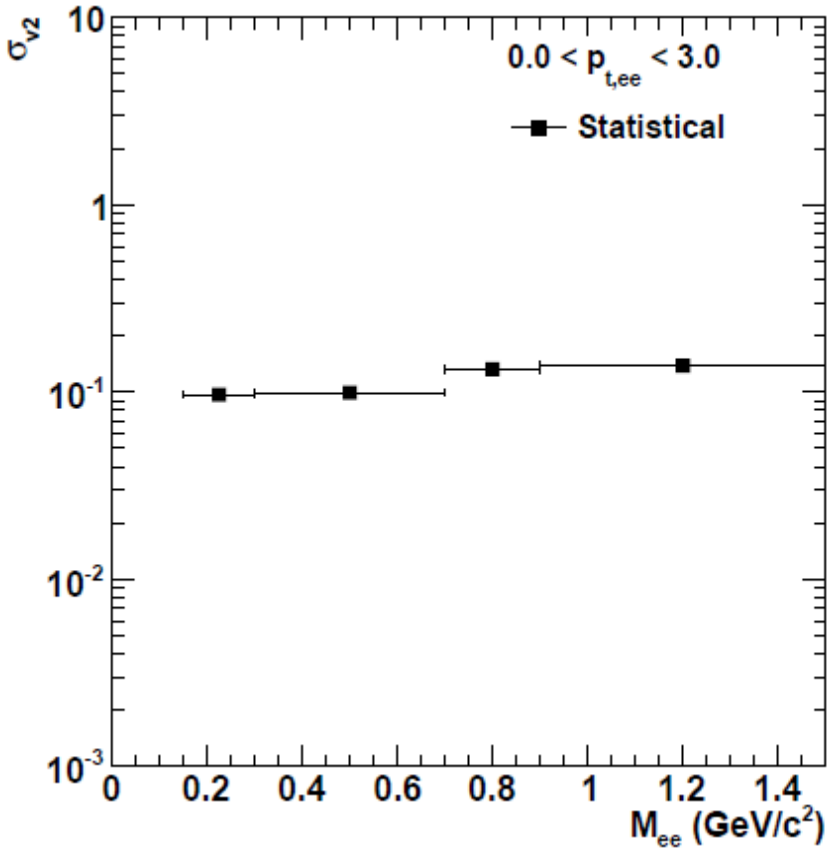


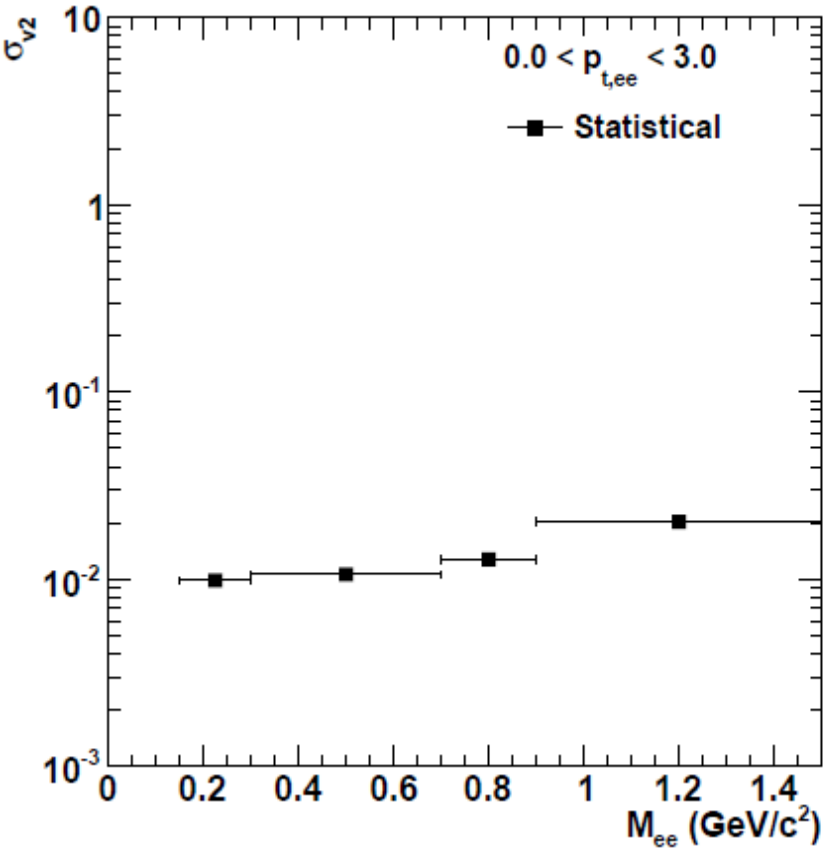
new ITS and high-rate: significant improvement…

Dielectron v_2

current ITS, no hight-rate upgrade

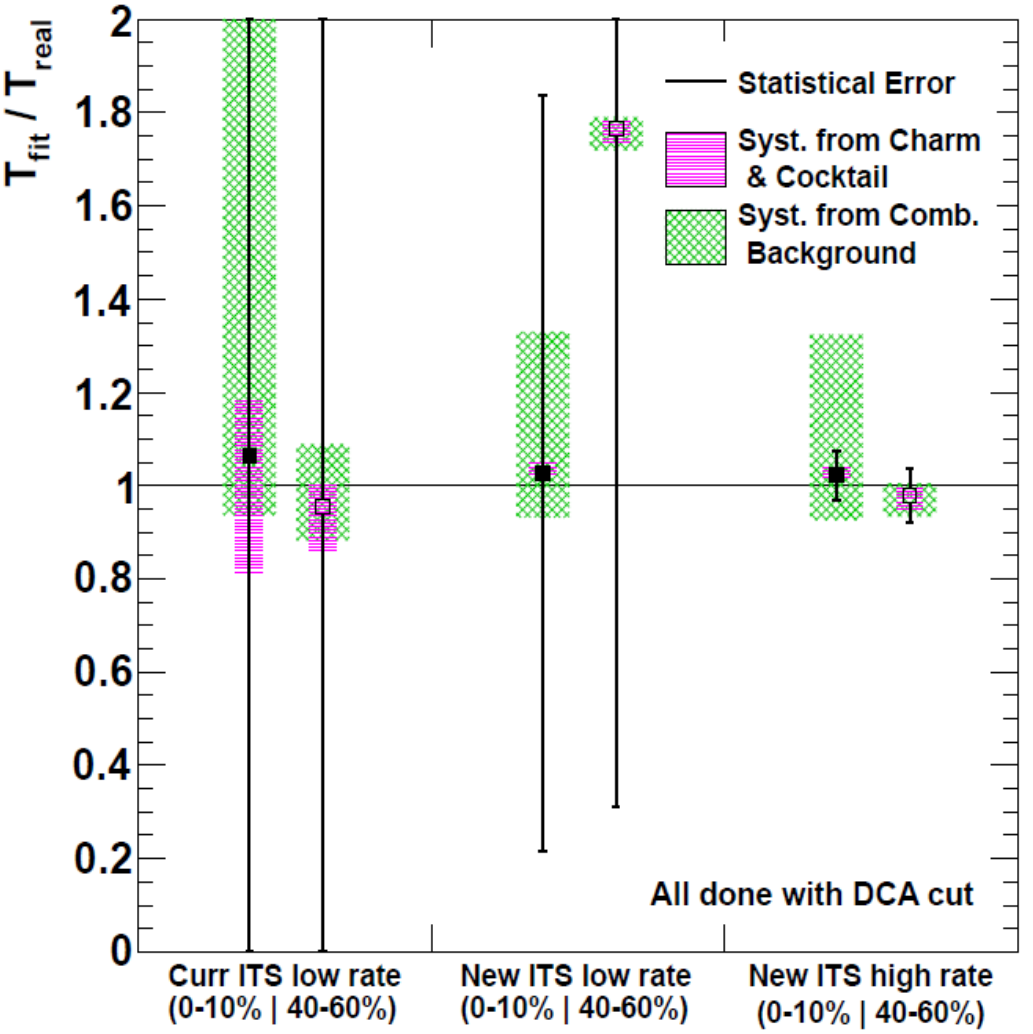
new ITS, high-rate upgrade





new ITS and high-rate: significant improvement (one order of magnitude)…

Temperature from dielectrons



new ITS and high-rate: significant improvement in precision…

Summary

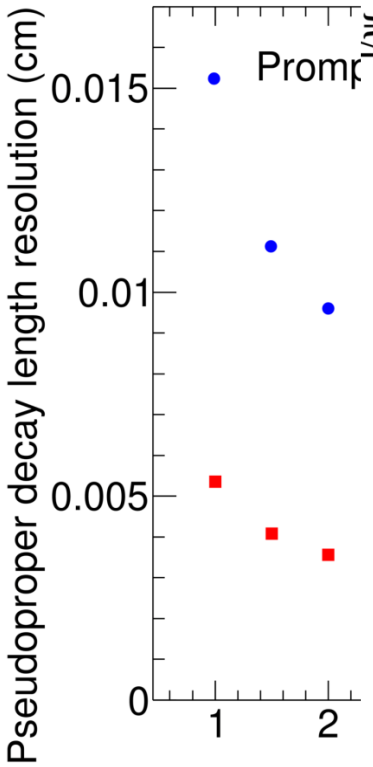
- High-energy heavy-ion physics :
  - transition from exploratory phase to high-precision measurement era
  - charmed and beauty era of the QGP
  - before LS2 (2018): p–Pb and Pb–Pb, higher energy and complete approved ALICE detector
- ALICE Upgrade Letter of Intent presents long-term plan for high-luminosity LHC, based on:
  - ambitious physics programme
  - clear detector upgrade plan for improved vertexing and tracking
  - high-rate capability of all subdetectors

Backup

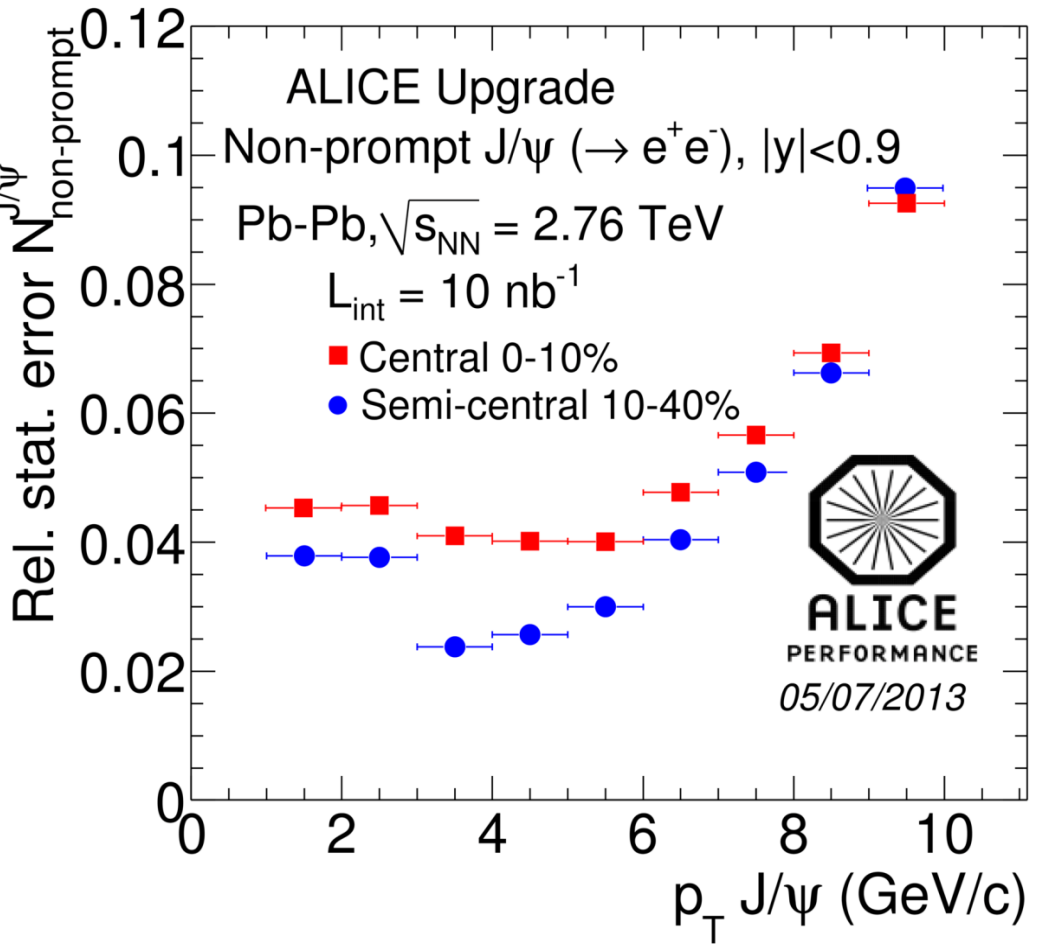
$B \rightarrow J/\psi\ (\rightarrow e^+e^-) + X$

Resolution
decay lengt

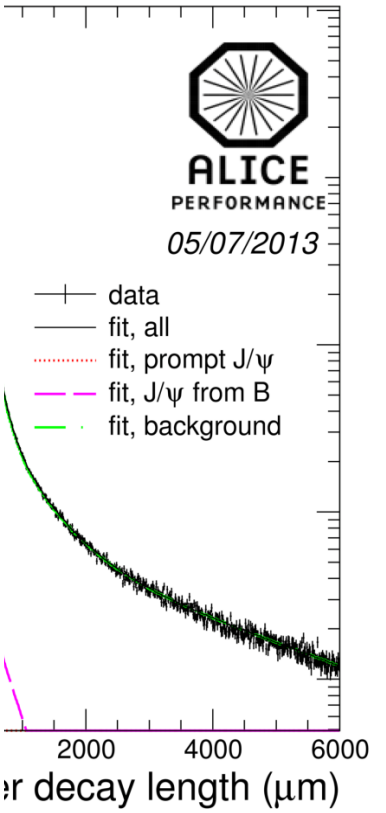
do-proper



ALI-PERF-54905



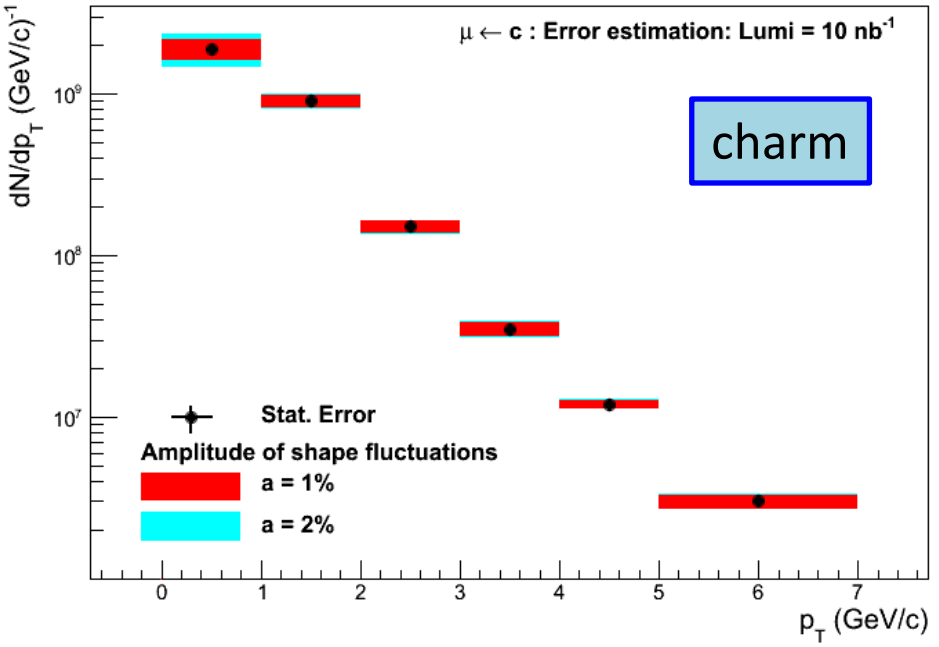
ALI-PERF-54917

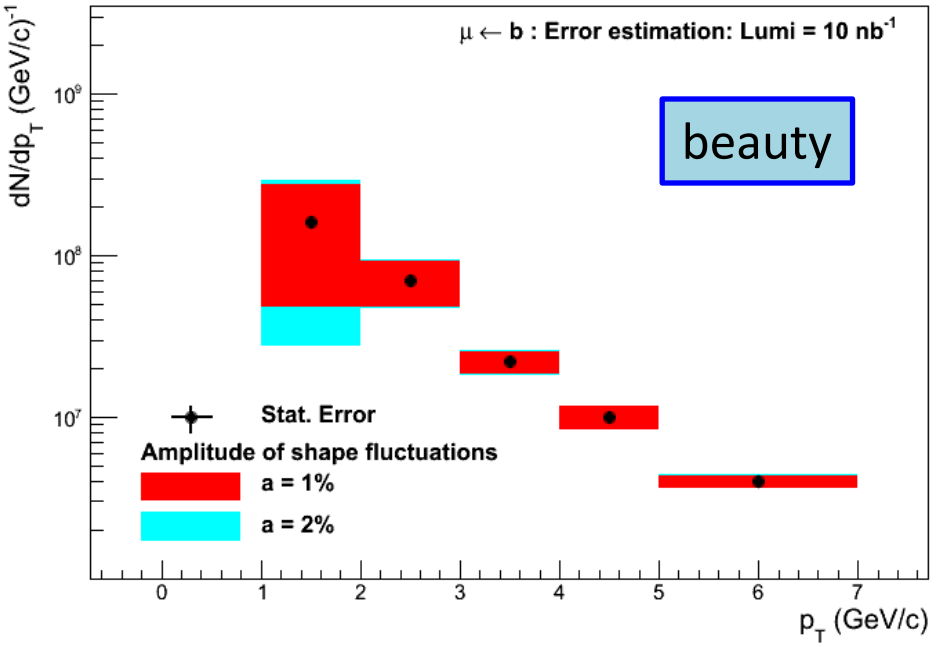


Improved resolution of pseudo-proper decay length with new ITS by factor ~ 3
Statistical error on J/ψ from B ~ few %

c, b via μ decays

- MC templates for impact parameter distribution in p_T bins of
  – μ←c μ←b μ–background
- Fit templates to data

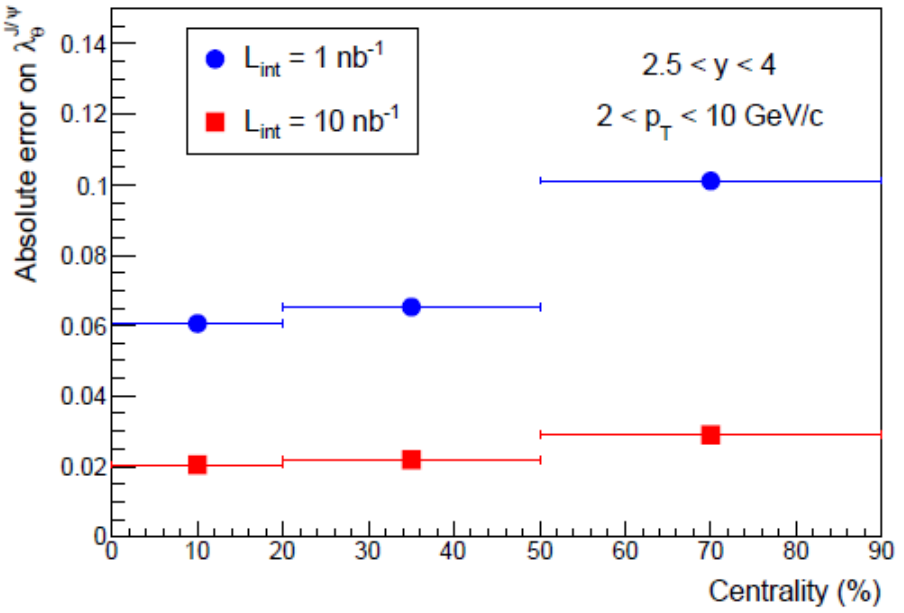




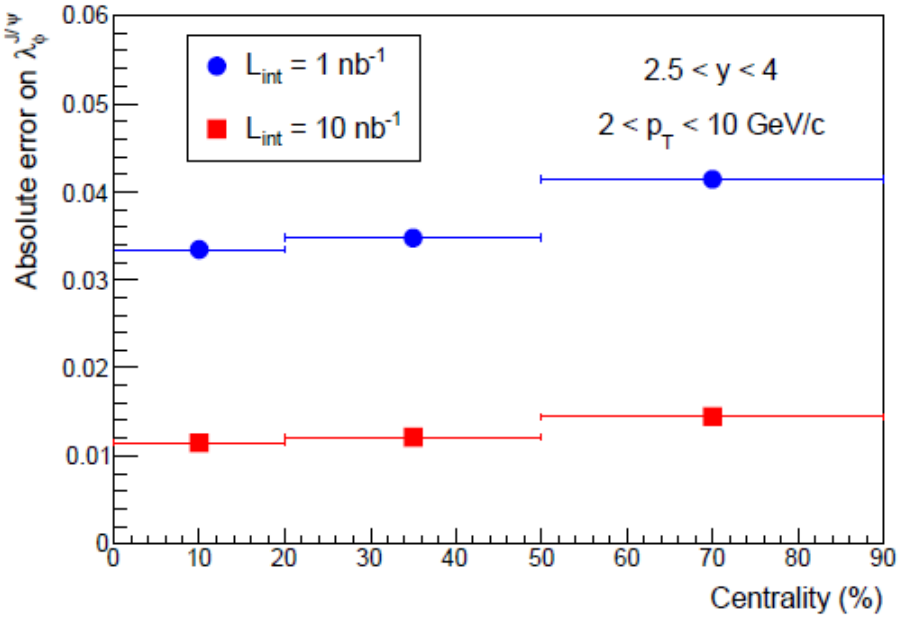
With new MFT: μ impact parameter resolution ~ 60 μm

J/ψ polarization

J/ψ in muon channel, λ_θ

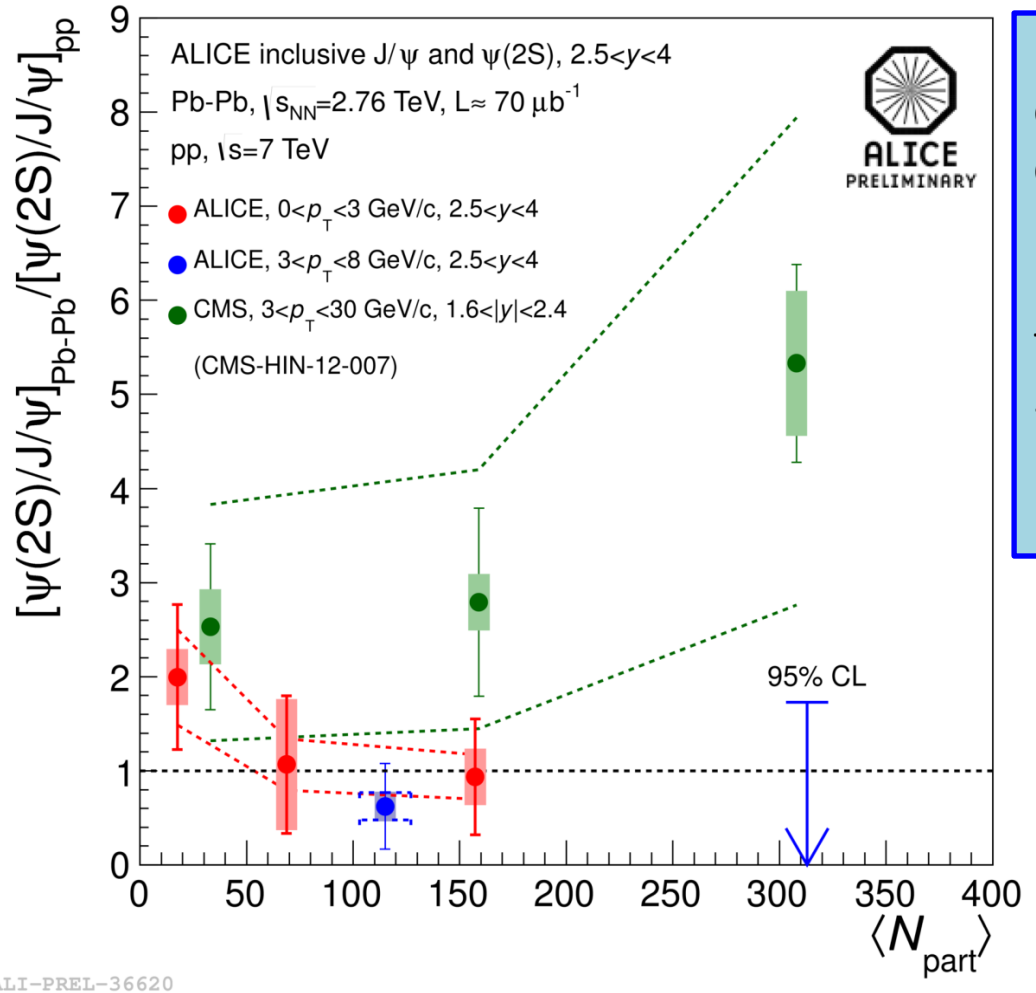


J/ψ in muon channel, λ_ϕ



Polarization parameters – factor 3–4 improvement with high-rate upgrade…

ψ(2S) to J/ψ double ratio



No firm conclusion on ψ' enhancement or suppression with centrality within current *stat.* and *syst.* uncertainties

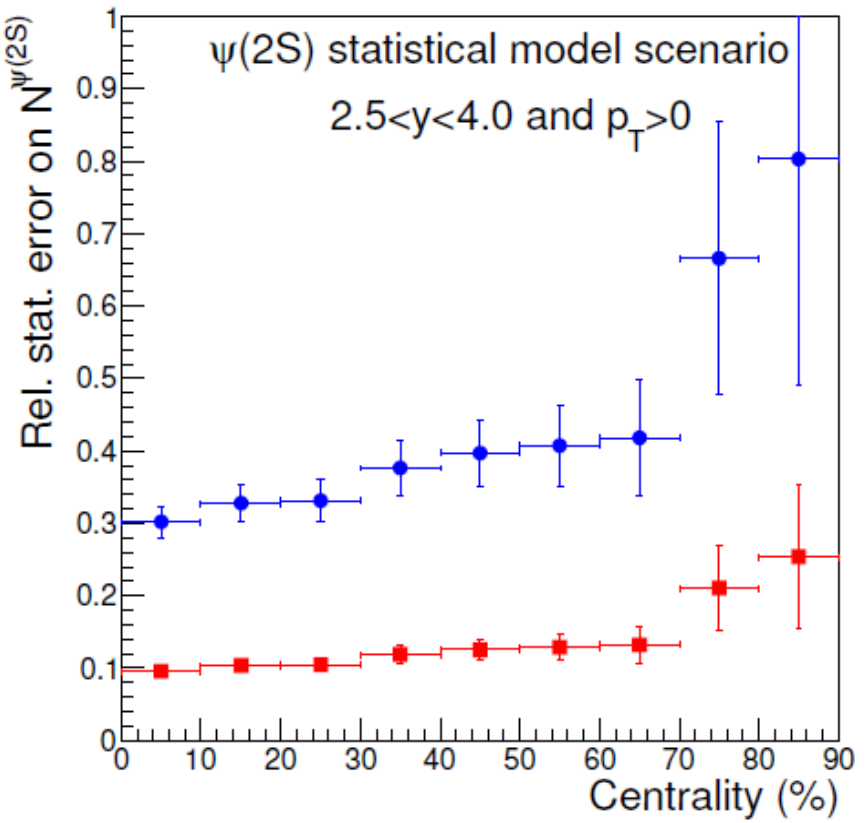
Large ψ(2S) enhancement with respect to J/ψ reported by CMS at p_T above 3 GeV/*c* not confirmed

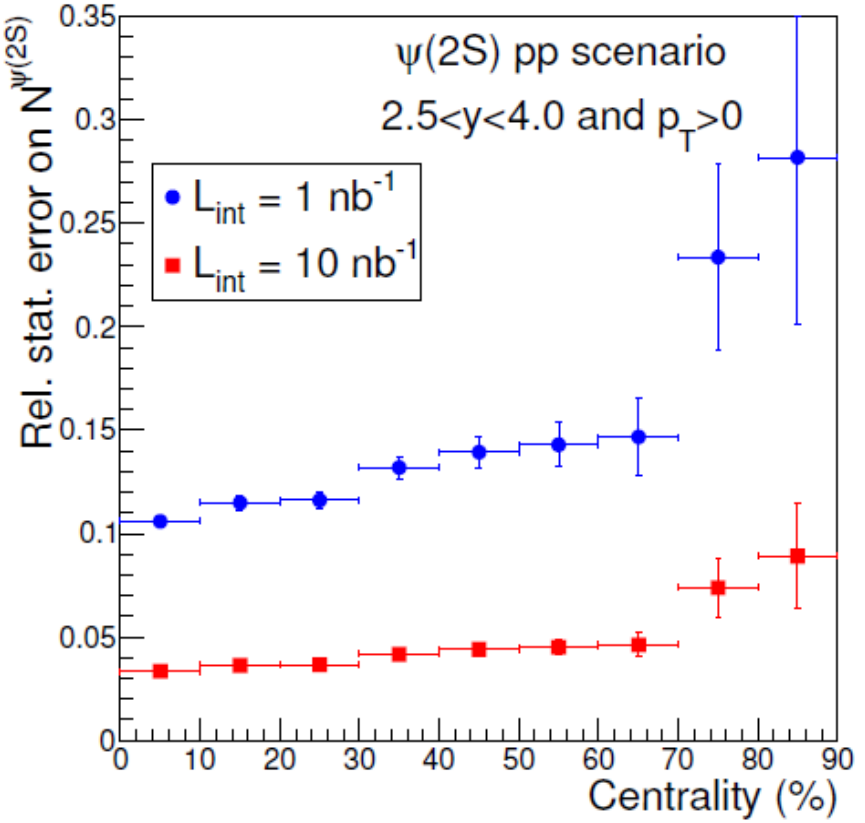
Is this a tension ?

ψ(2S) in muon channel

ψ(2S) according statistical model prediction

ψ(2S) according to pp rate with N_{coll} scaling

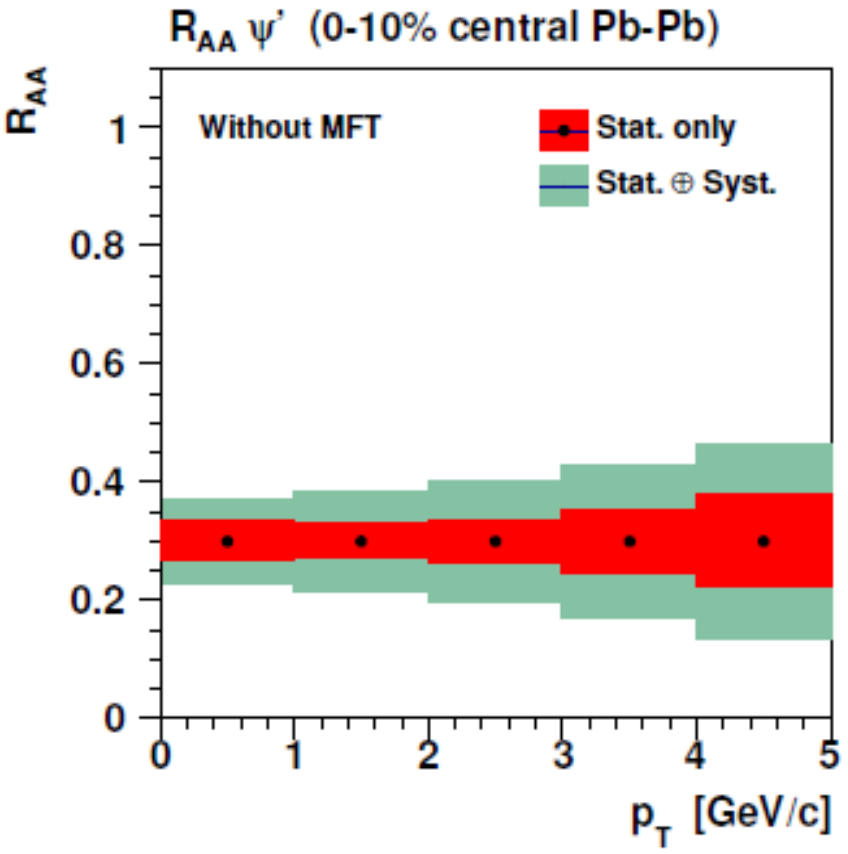




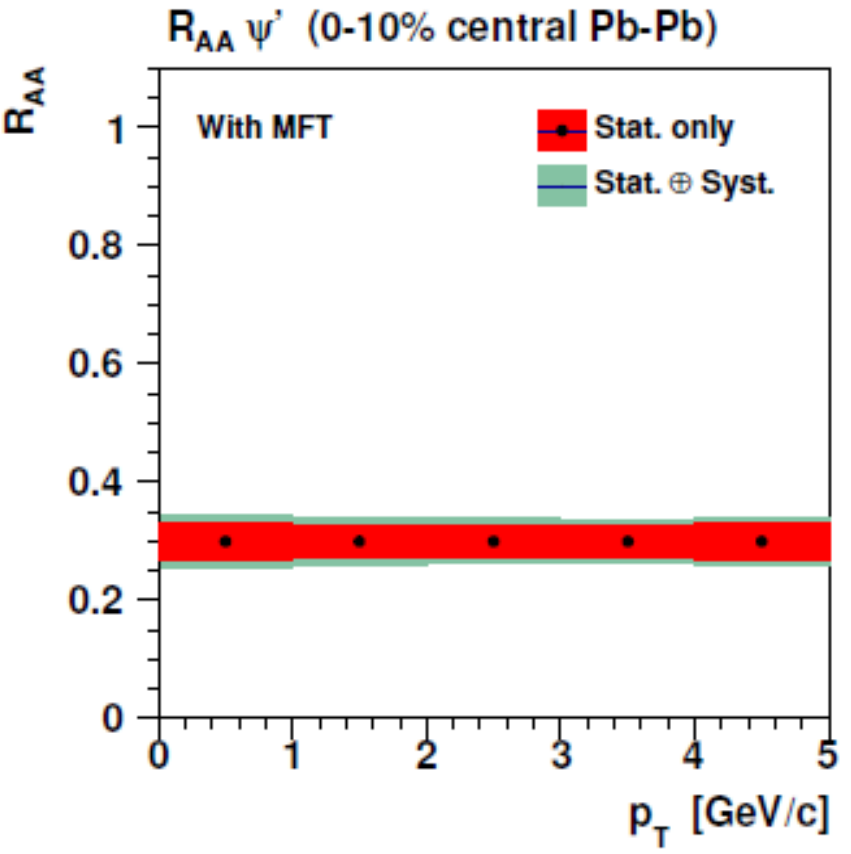
ψ(2S) statistical error – factor 3 improvement with high-rate upgrade…

ψ(2S) in muon channel with MFT

ψ(2S) without MFT



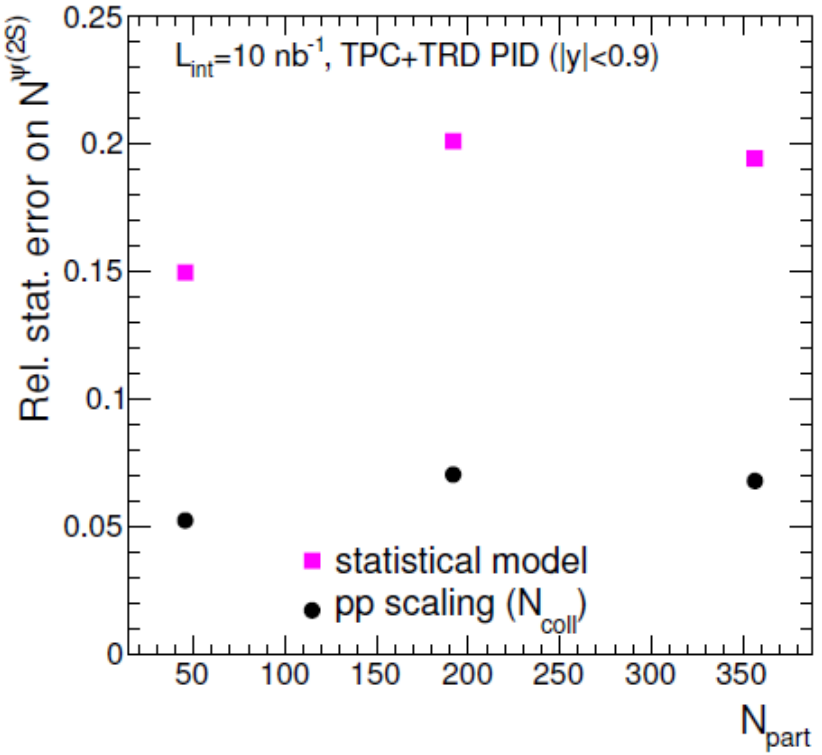
ψ(2S) with MFT



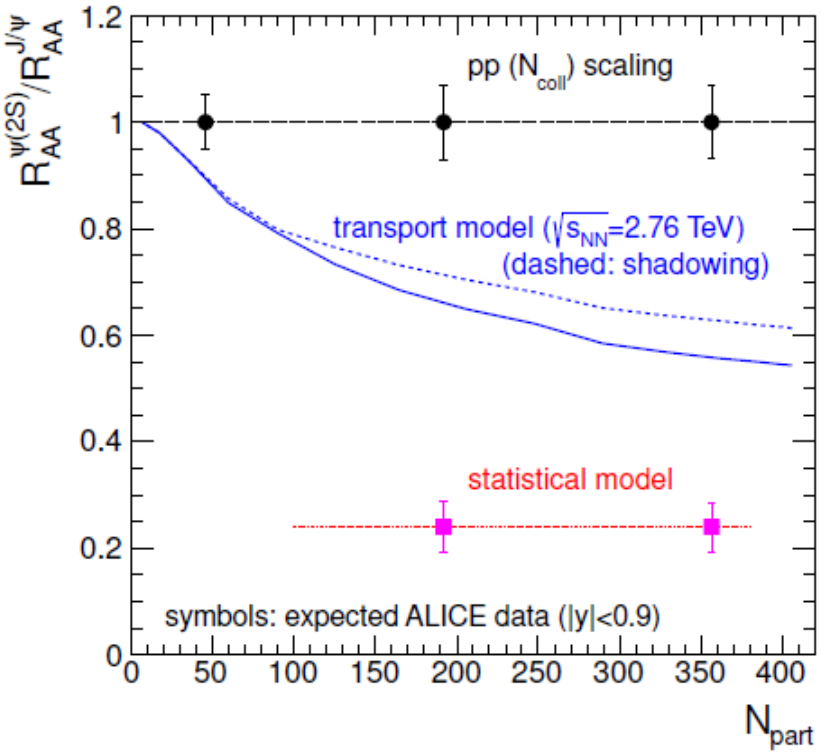
ψ(2S) statistical and systematic error large improvement with MFT

ψ(2S) in electron channel

ψ(2S) according two scenarios



ψ(2S) to J/ψ RAA ratio (or double ratio)



With high-rate upgrade – good discrimination power for different models

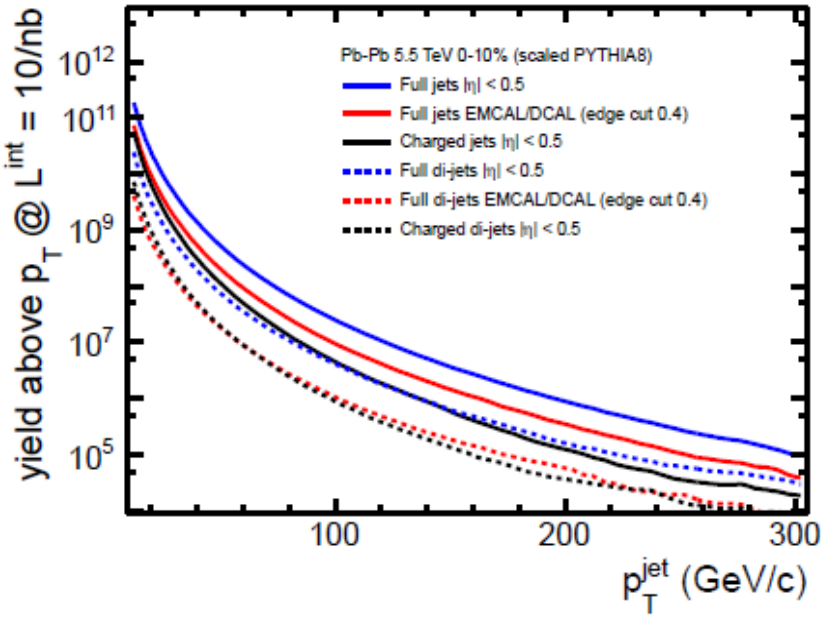
Jet measurements

Other LHC experiments participating in heavy-ion programme have larger acceptance and calorimetry coverage – ALICE will complement jet studies with:

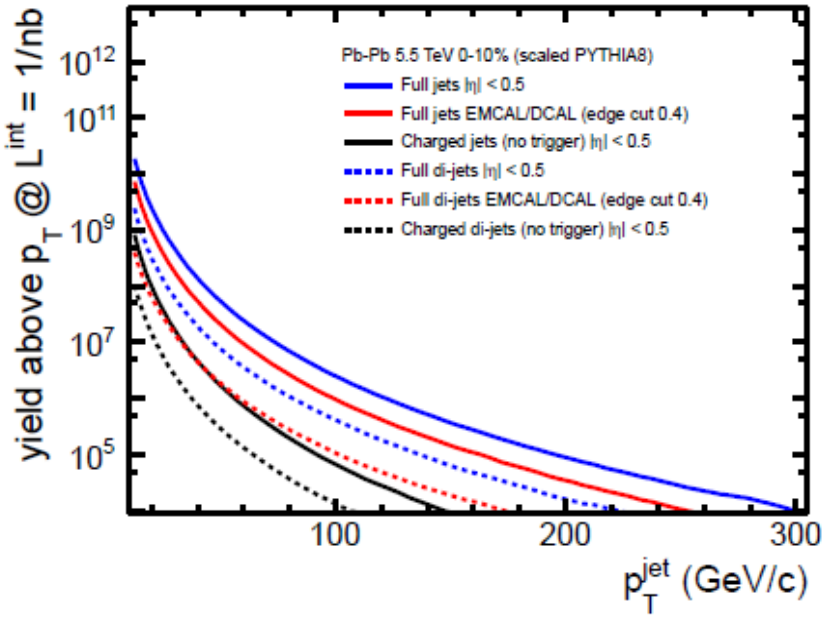
- particle-identified fragmentation functions – and their modifications with respect to pp collisions
- heavy-flavour production in jet fragmentation
- utilizing low-momentum particles to reconstruct the total jet energy
- investigating jet-like correlations, such as identified-particle–jet and γ–jet correlations

Jet and dijet yields

high-rate upgrade



no high-rate upgrade

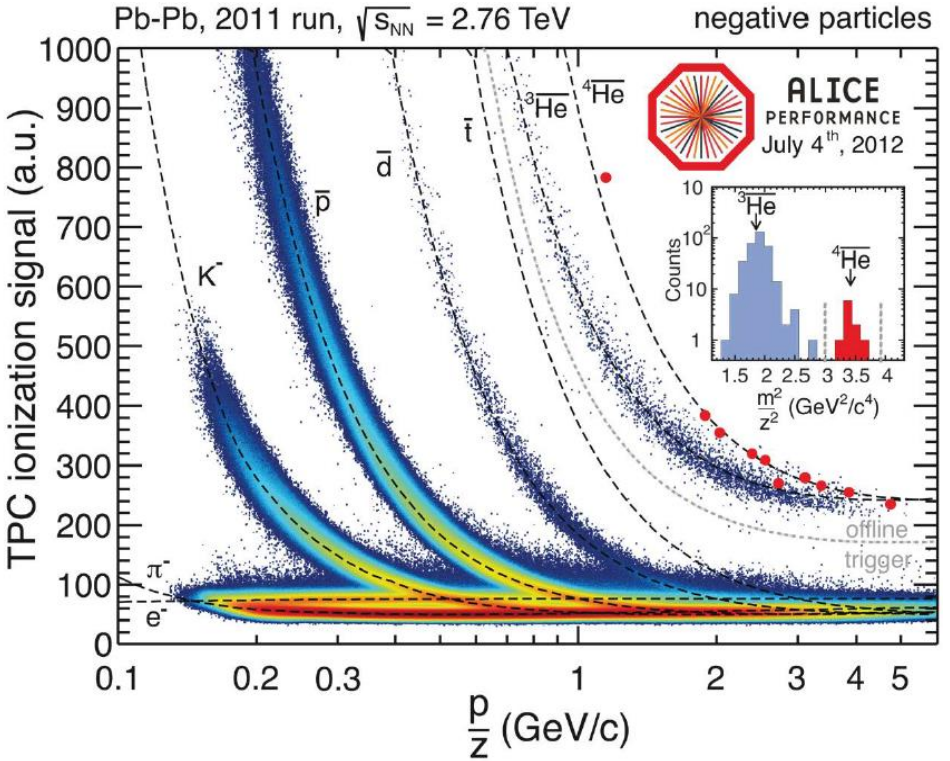


significant increase in statistics for “charged” jets

Heavy nuclear states

With ALICE PID and high event statistics search for rare heavy nuclear states:

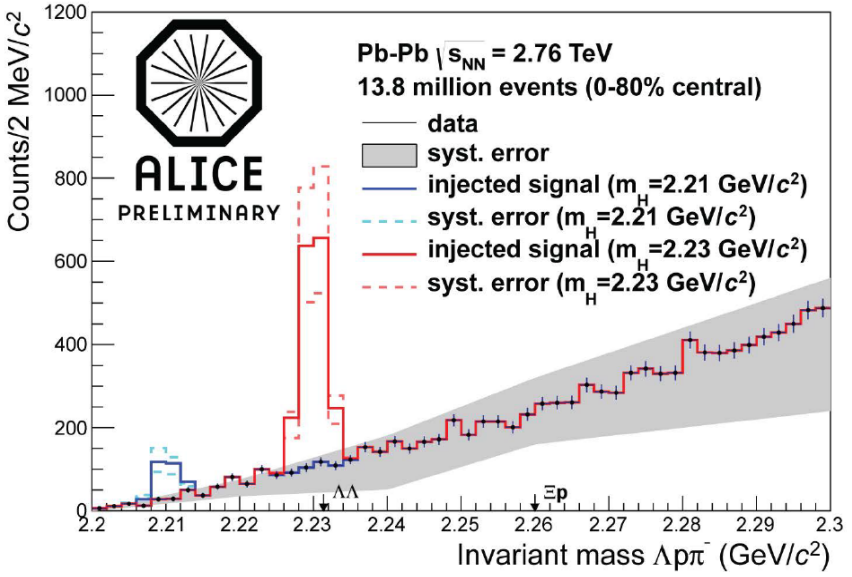
- anti-^{4}He already observed
- search for ($\Lambda\Lambda$) (H-dibaryon) and (Λn) states
- $_{\Lambda\Lambda}{}^5$H sill accessible
- study of decay properties

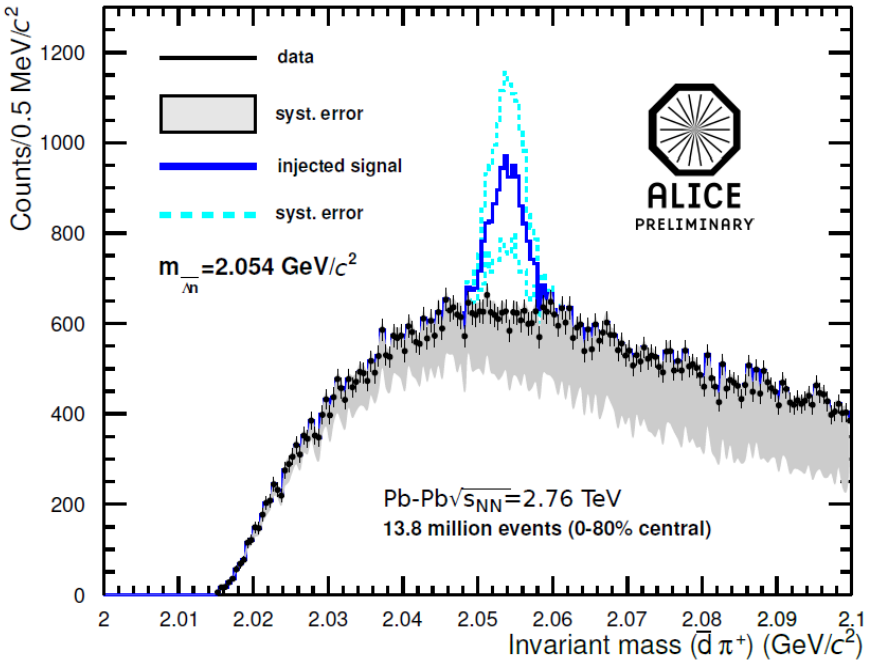


Search for ($\Lambda\Lambda$) and (Λn)

H-dibaryon ($\Lambda\Lambda$)

anti-(Λn) state





statistics increased by factor ~ 10^3…