Heavy-flavour-production studies in a new energy and rapidity domain with AFTER@LHC

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Outline

- **Physics Motivations**
- **Detector Requirements**
- **Selected Physics Projections**

[Based on the Review of the AFTER physics case: **arXiv:1807.00603**]

See also the other AFTER presentations at HP2018:

- Future heavy-ion facilities: FT LHC (AFTER) (J.P. Lansberg)
- High-luminosity fixed-target experiments at the LHC (C. Hadjidakis)
- Probing the high-x content of the nuclei in the FT mode (A. Kusina)
- UPC studies in the fixed-target mode with the proton and Pb LHC beams (N. Yamanaka)

A Heavy-Ion Fixed-Target Program at the LHC?

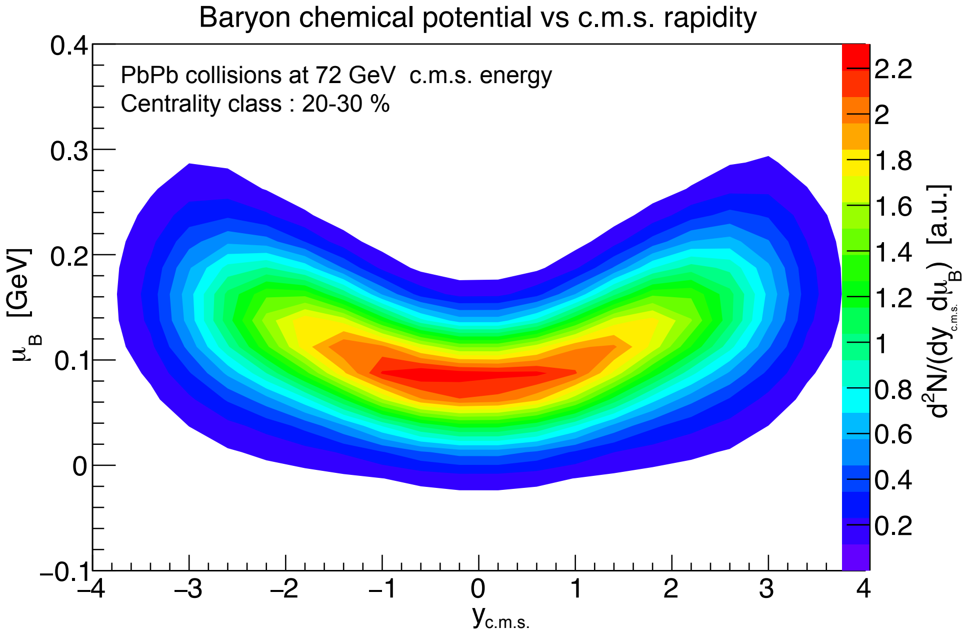
AFTER@LHC is a proposal for a multi-purpose fixed target experiment using the multi-TeV proton or heavy ion beams of the LHC

Heavy Ions at AFTER@LHC: high-statistics measurements in an energy domain between the SPS and RHIC experiments, in an unexplored rapidity domain

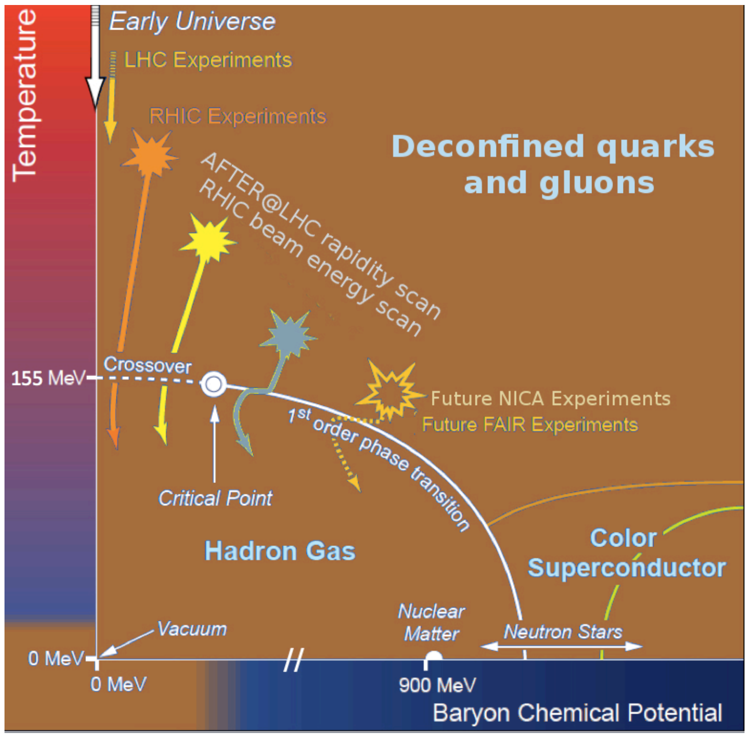
- **High density of the target → high luminosity** (achievable at no cost and negligible interference for the LHC collider-mode experiments)
- **Large rapidity acceptance accessible** with standard detectors ($1 < \eta_{lab} < 5$, down to −1 with ALICE central barrel), allowing one to measure any probe down to the very end of the backward phase space
- **Extended number of species for the target**, with the possibility to change them in a reduced amount of time for short runs

A Heavy-Ion Fixed-Target Program at the LHC?

- AFTER@LHC will study Pb-A collisions at a **c.m.s. energy of 72 GeV** (complementary to RHIC and SPS)



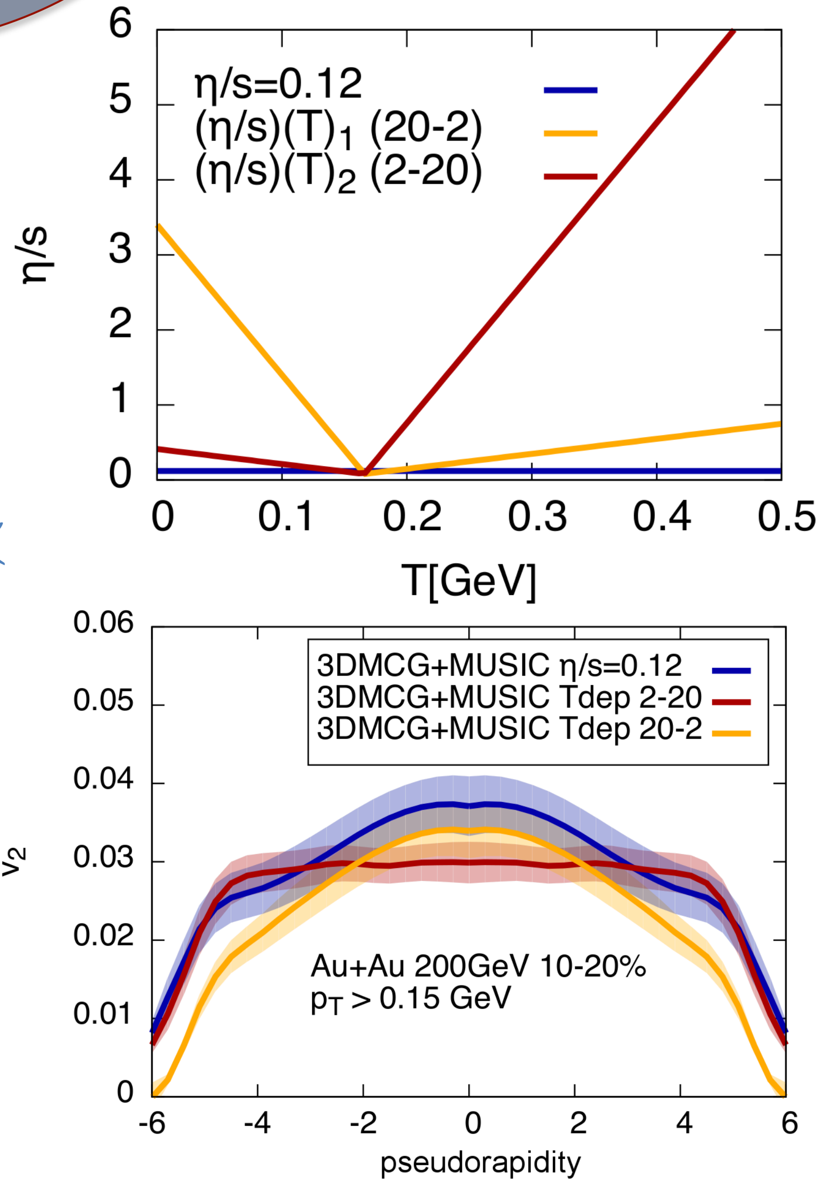
arXiv:1805.11998



- **AFTER@LHC will exploit the dependence of the baryonic chemical potential μ_B and the temp. T on the rapidity** (with some model dependence!)

➡ New approach to investigate the QCD phase diagram, complementary to the RHIC Beam Energy Scan (BES) program

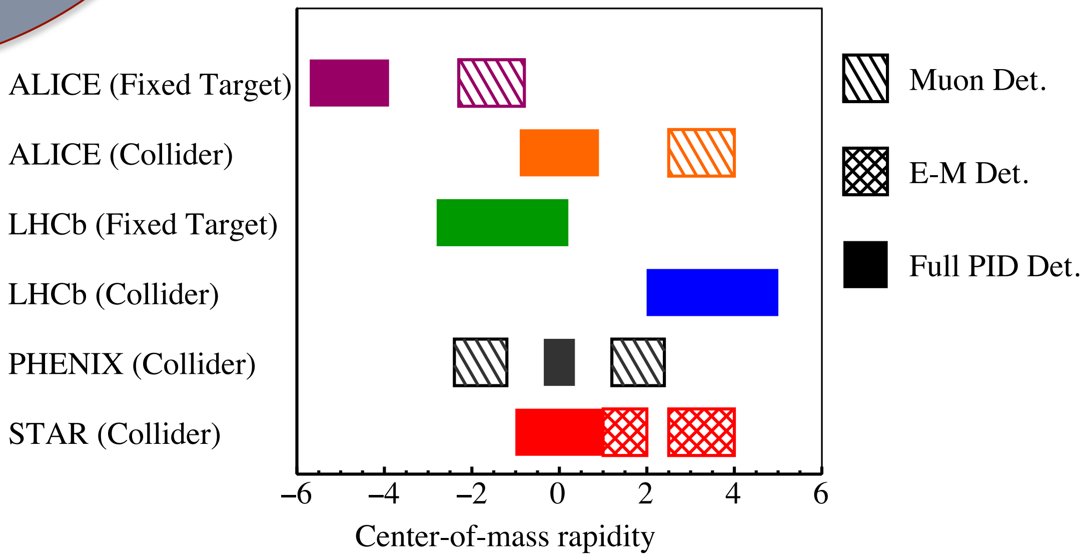
A Heavy-Ion Fixed-Target Program at the LHC?

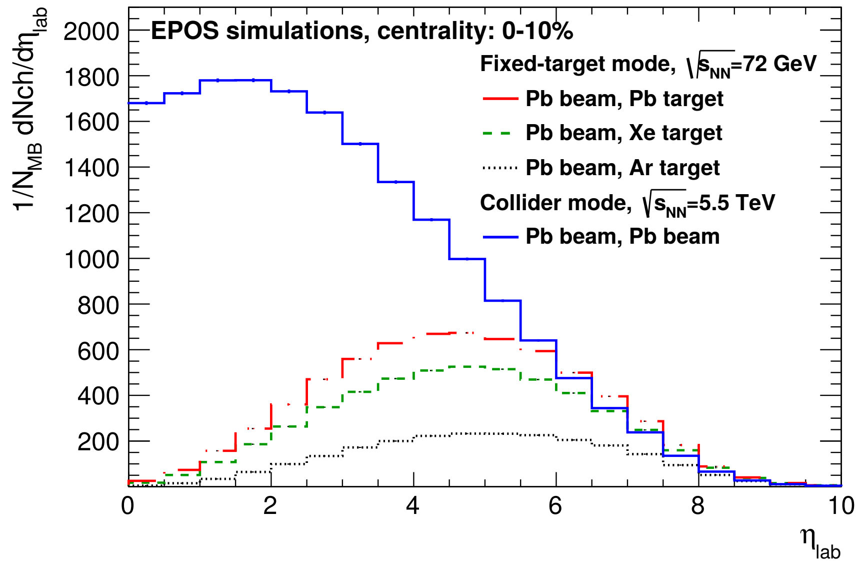


B. Schenke, QM 2015

- **Temperature dependence of the shear viscosity to entropy density ratio η/s of the medium** → by measuring the rapidity dependence of the anisotropic flow
- **Collective effects in small systems with heavy quarks** (v_2 of D mesons in p-Pb and high-multiplicity pp collisions)
- **Heavy quarks energy loss mechanisms** (collisional/radiative) through high-precision measurement of D meson R_{AA} and v_2
- **Drell-Yan** → control probe due to its insensitivity to QGP formation

Detector Requirements

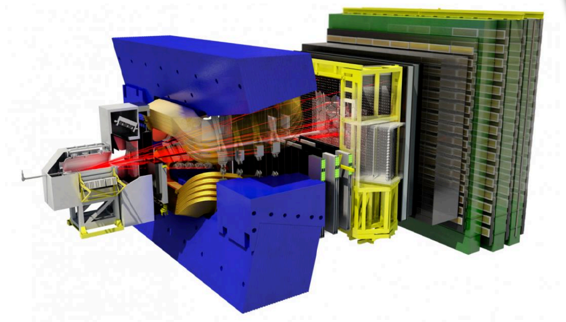




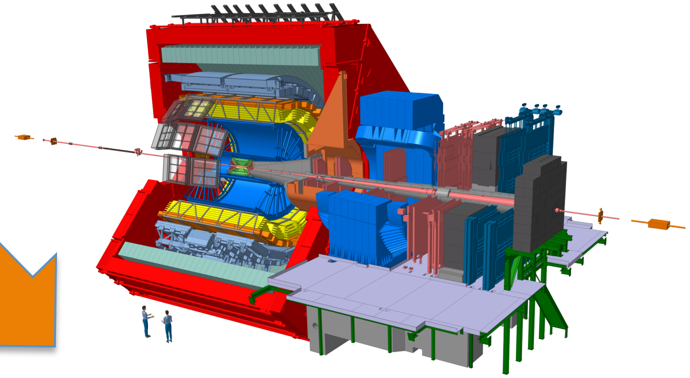
- **Fixed-target mode at LHC:** rapidity shifts Δy = 4.2 and 4.8 for a beam energy per nucleon of 2.76 and 7 TeV, respectively. Particle production easily measurable at very large values of negative y_{cms} with standard detector technologies
- **Instantaneous luminosity with LHC beams:** up to 3×10^{28} cm^{-2} s^{-1} in Pb-A, and up to 10^{33} cm^{-2} s^{-1} in pp and p-A collisions
- **Largest multiplicities** expected in central Pb-Xe collisions at 72 GeV, at η_{lab} = 4.2: $dN_{ch}/d\eta \approx 600$, below central Pb-Pb collisions at 5.5 TeV in collider mode

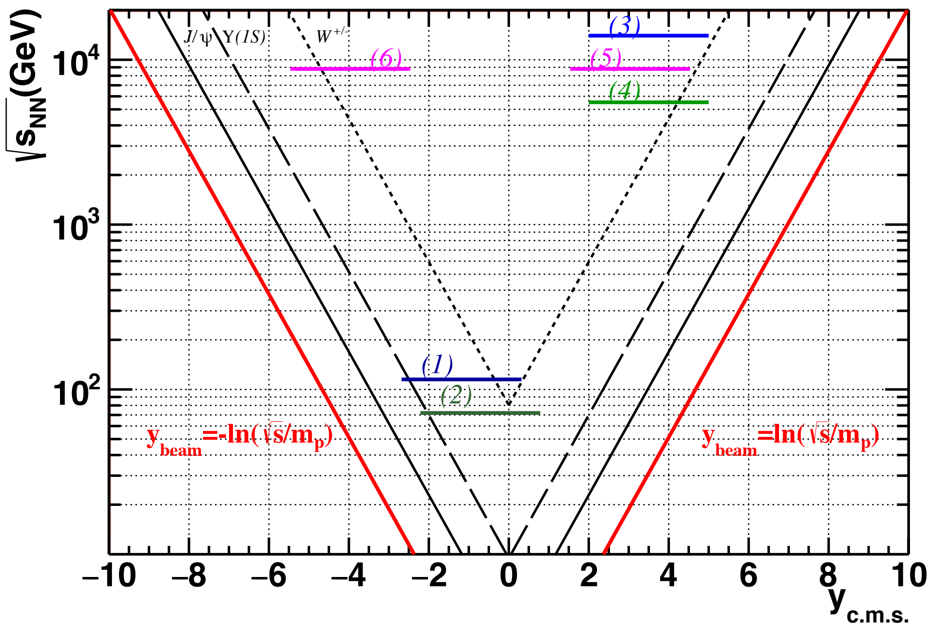
Detector Requirements

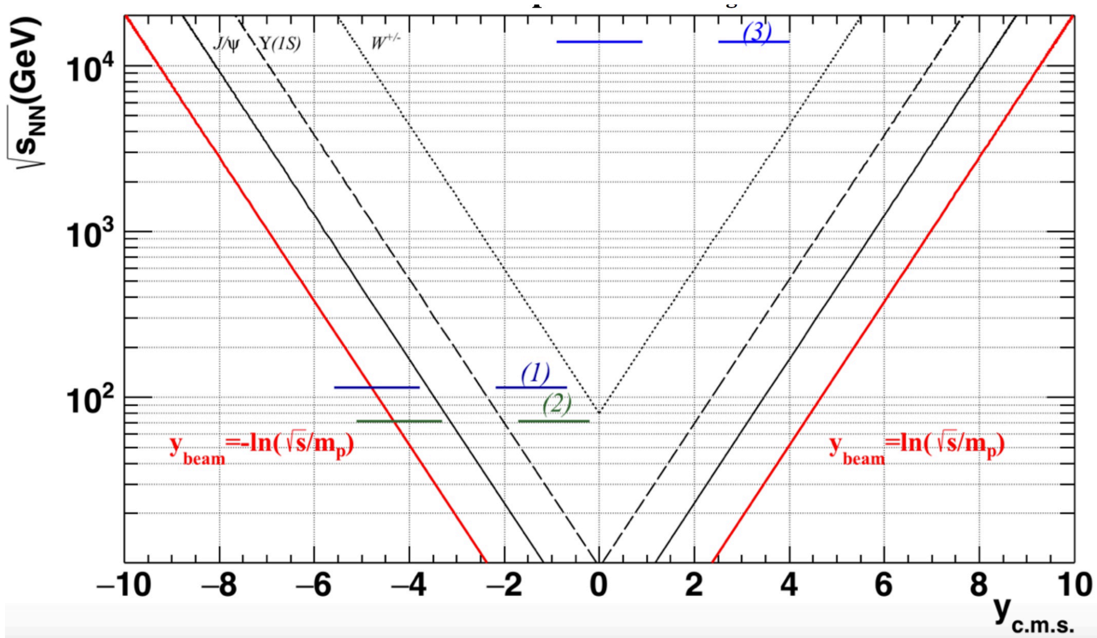
LHCb acceptance would cover the backward hemisphere up to mid-rapidity (approx. CMS and ATLAS acceptance in collider mode)



ALICE central barrel would measure particles at the very end of the backward hemisphere



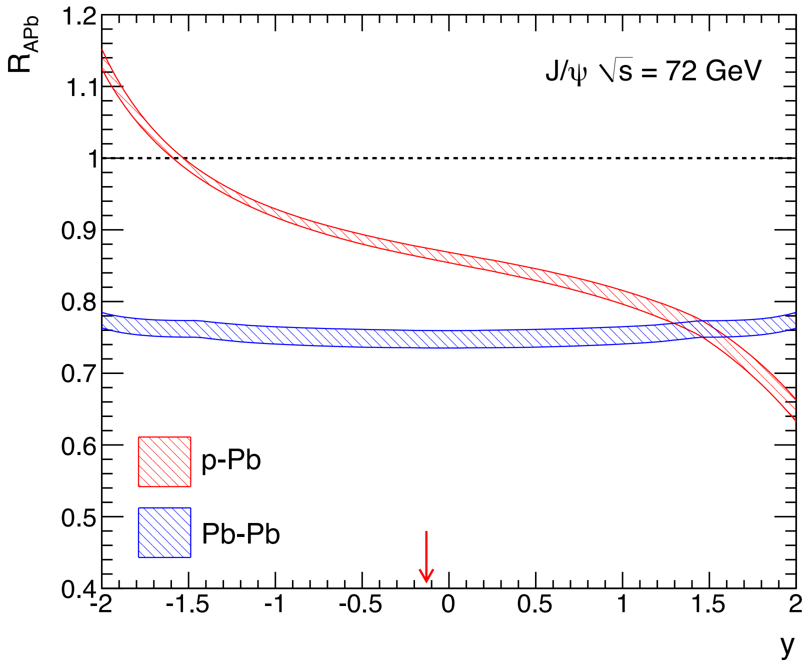


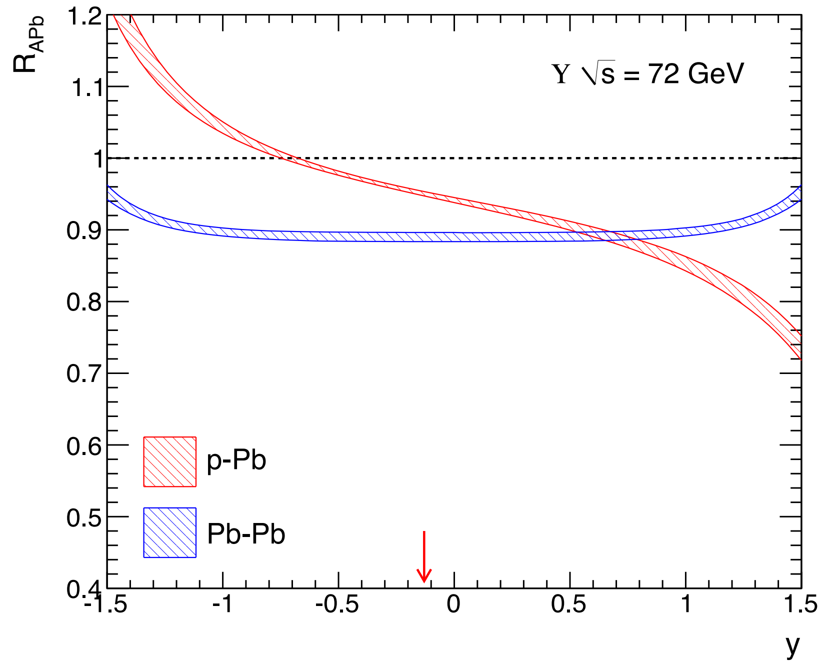


Quarkonium Measurements

- **Quarkonium production measurements** will constrain **cold nuclear matter effects** (p-A collisions) and probe **QGP properties** (Pb-A collisions). From zero p_T to $p_T \approx 15$ GeV/c, in a wide rapidity range

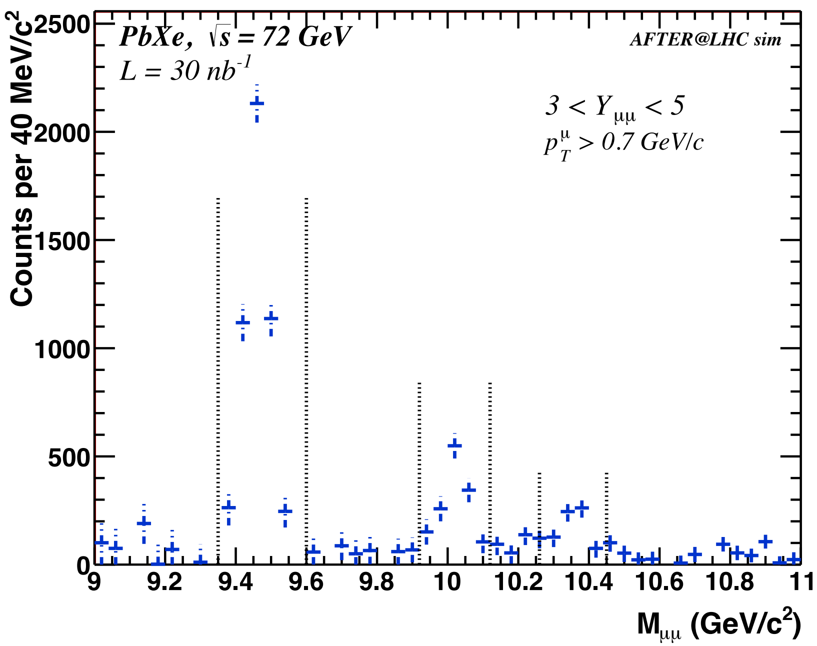
- In particular, **gluon PDFs** must be studied in p-A to understand effects where gluons are involved, like **coherent energy loss**, predicting a suppression of p-A and A-A cross-sections compared to the pp one



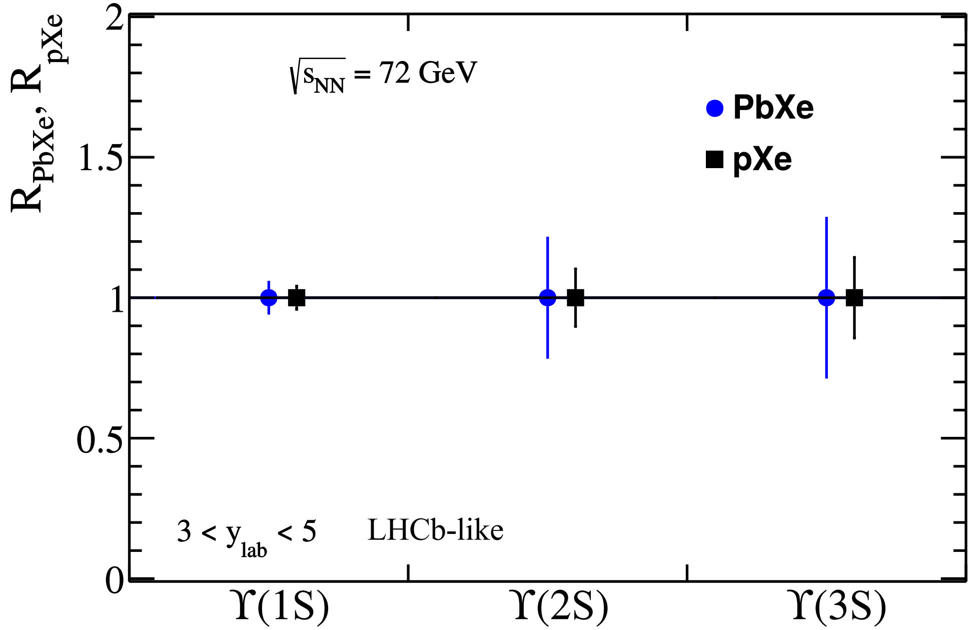


Adv. High Energy Phys. 2015 (2015) 961951

- **Y(nS) production in pp, p-A, A-A:** thermodynamic properties of QGP, cold nuclear matter effects
- **Y(nS) suppression as a function of rapidity and system size:** good calibration of the "QGP thermometer" (no bb recombination expected)
- **Large Y(nS) yields in one LHC year of Pb-Xe data taking** with LHCb-like performances: ***o*(450) Y(3S)**



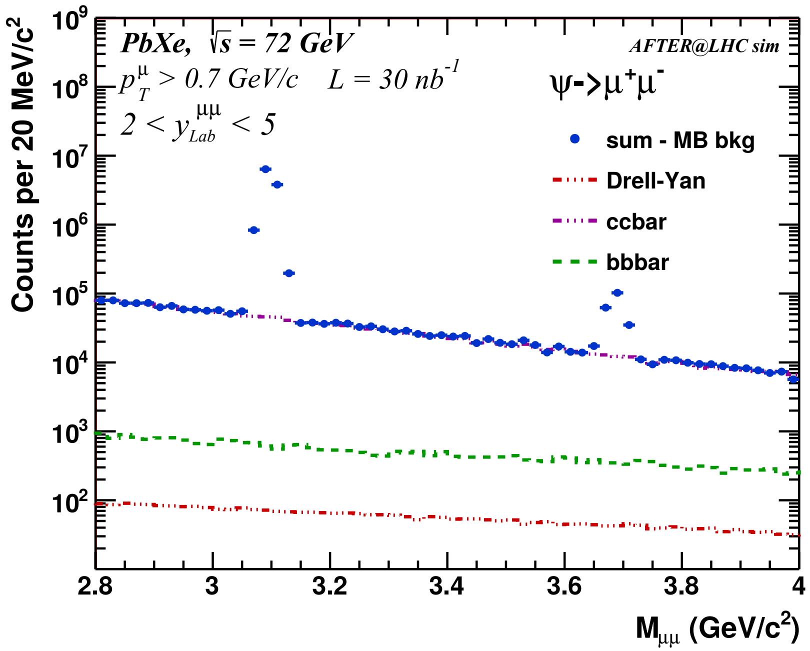
Few Body Syst. 58 no. 5, (2017) 148



- **LHCb-like detector:** excellent control of the background, precise measurement of J/ψ and ψ(2S) in p-A and Pb-A in the dimuon channel

- **LHCb: no absorber** → possibility of performing **χ_c and η_c suppression** studies in p-A collisions and, possibly, in the most backward part of the acceptance, in semi-central or central A-A collisions

- **J/ψ + J/ψ** and **J/ψ + D** correlation measurements also within reach



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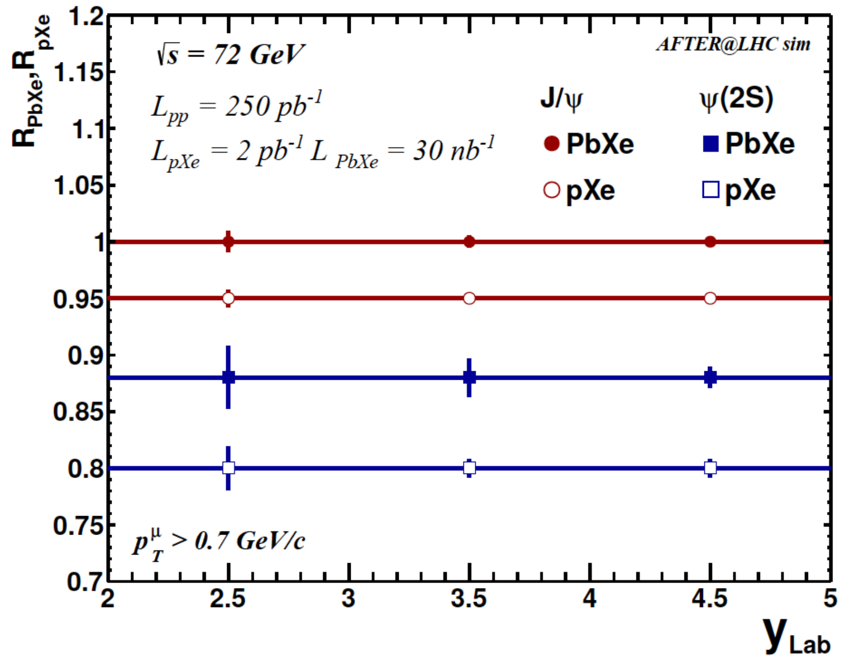
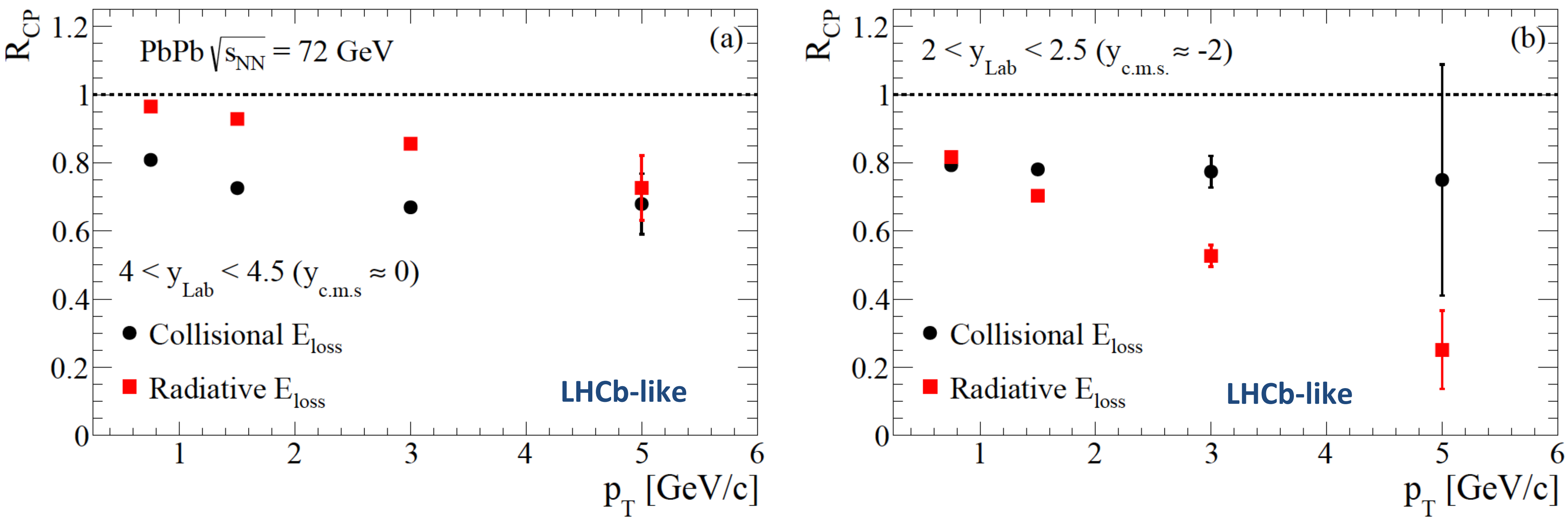


Open Heavy Flavor Measurements: Energy Loss

- **Open heavy-flavor measurements in A-A collisions:** heavy-quark energy loss mechanisms in the medium

- **Precise suppression measurements** of charm and beauty (through prompt-displaced D^0 and/or J/ψ separation) **versus rapidity and p_T** can help to disentangle **collisional versus radiative E_{loss} mechanisms** and measure the **transport coefficients.** Useful **reference for charmonium studies**

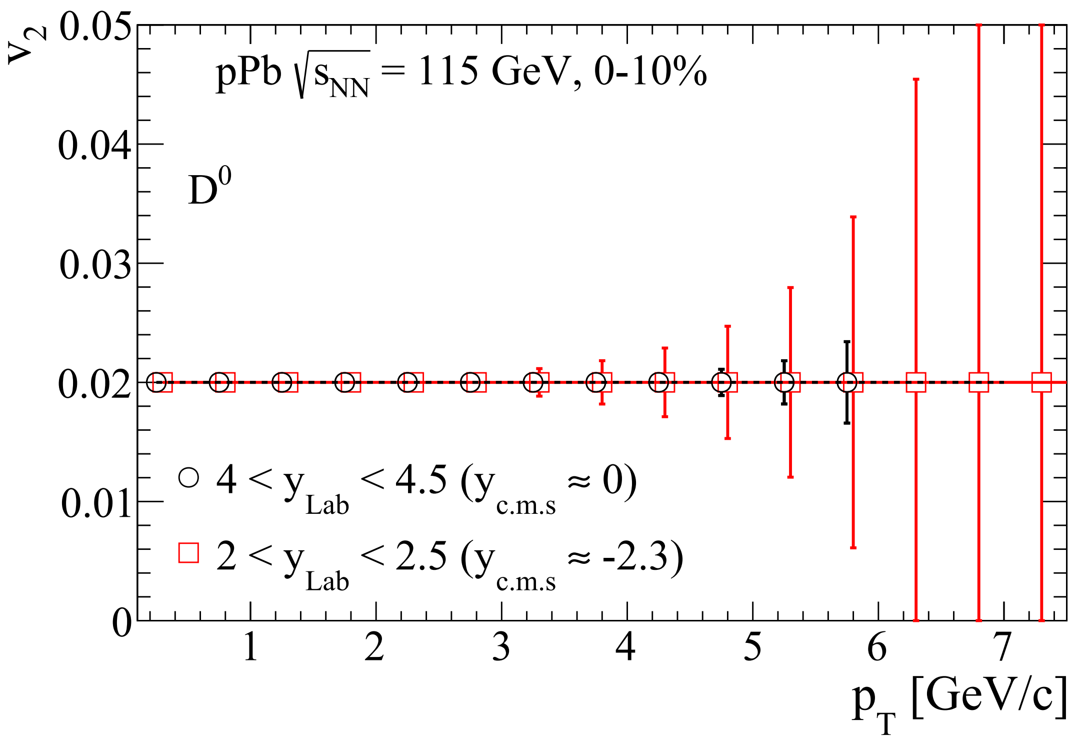


Adv. High Energy Phys. 2015 (2015) 783134.

- **Open heavy-flavor measurements in A-A collisions:** do heavy-quark participate to the collective expansion of the medium?

- **Precision measurements of elliptic flow of charm and beauty mesons:** insights into degree of thermalization of the created nuclear matter, discrimination between different models of **heavy-quark interactions with the QGP**

Adv. High Energy Phys. 2015 (2015) 783134.



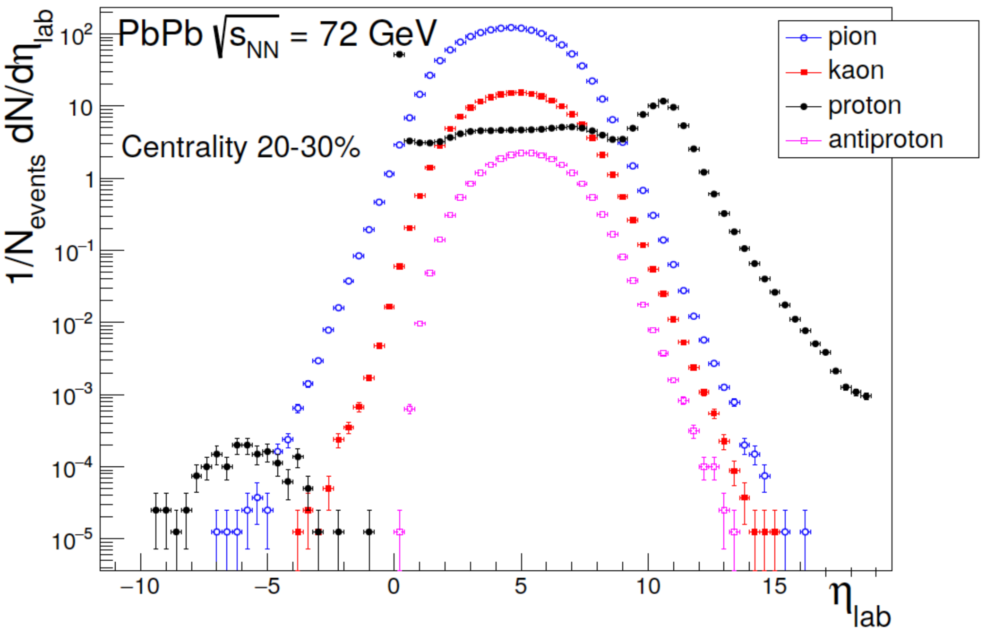
- **Simultaneous measurements of the D-meson elliptic flow and nuclear modification factor** will allow for a precise determination of the QGP transport properties

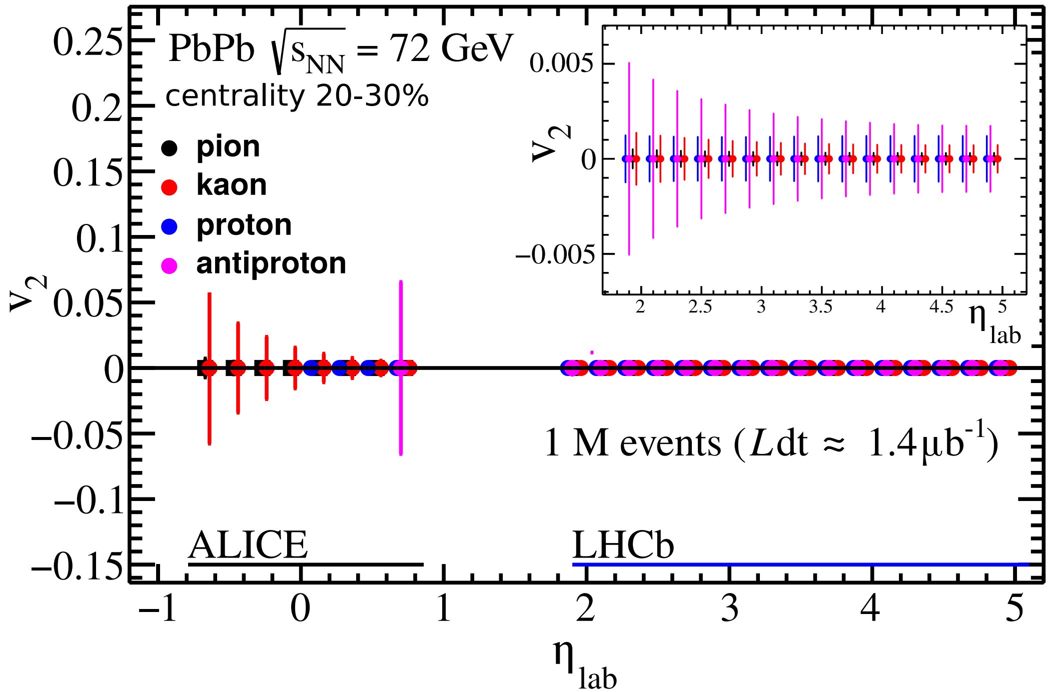
- AFTER@LHC will contribute to the study of the **energy dependence of the QGP transport coefficients**

The Underlying Picture: QGP Hydrodynamics

- **The AFTER@LHC program will include QGP hydrodynamic studies:** large rapidity coverage to measure particle azimuthal asymmetries, possibility to obtain large statistics for different targets

- Precision study of v_n over a very broad rapidity range → **accurate determination of the temperature dependence of the shear viscosity to entropy ratio η/s**





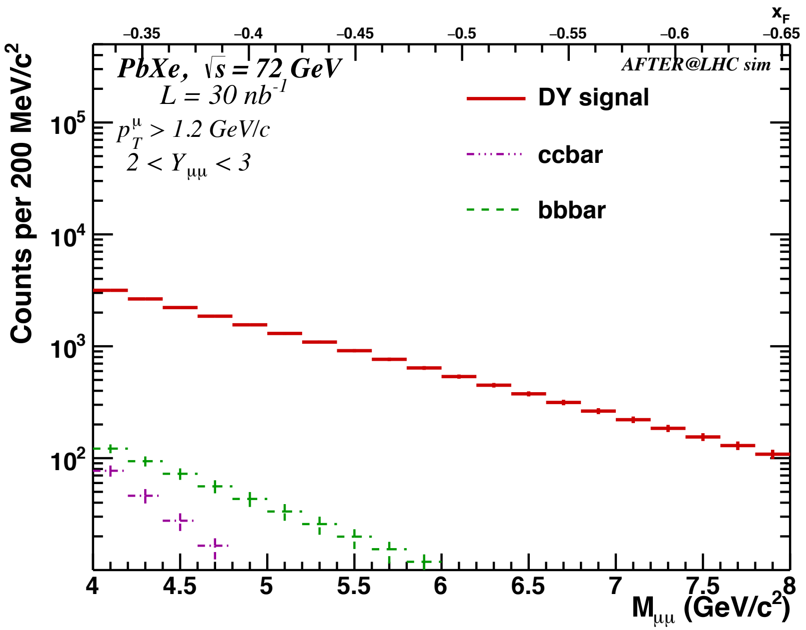
Phys. Rev. C92 no. 3, (2015) 034906

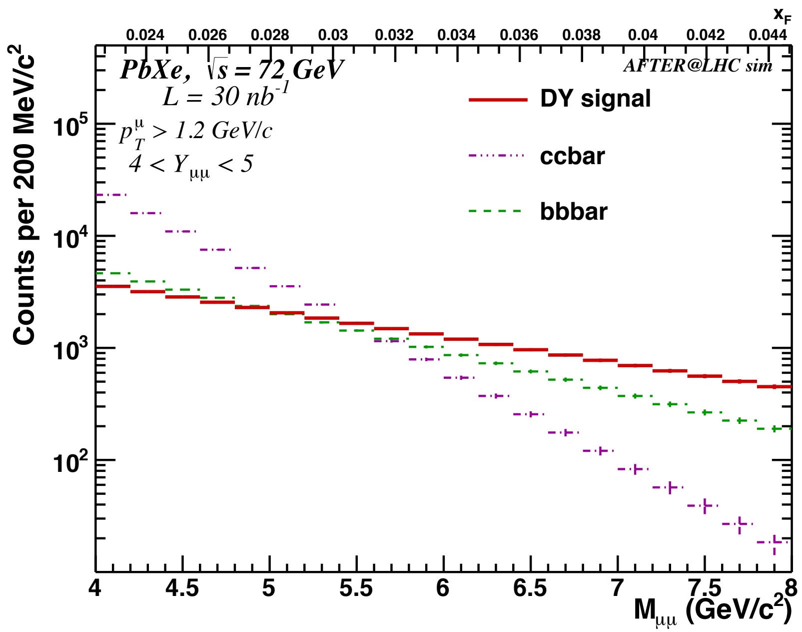
Testing Factorization of Initial State Effects

- **Drell-Yan production** can be effectively used to test the **extrapolation of initial state effects** observed in p-A collisions, to A-A collisions

- **Drell Yan dileptons** directly come from interactions of **initial-state partons** and are not perturbed by the nuclear medium

- **Low correlated background from HF pairs at AFTER@LHC energies:** S/B ratio ≈ 10^{-2} in the most backward rapidity bin



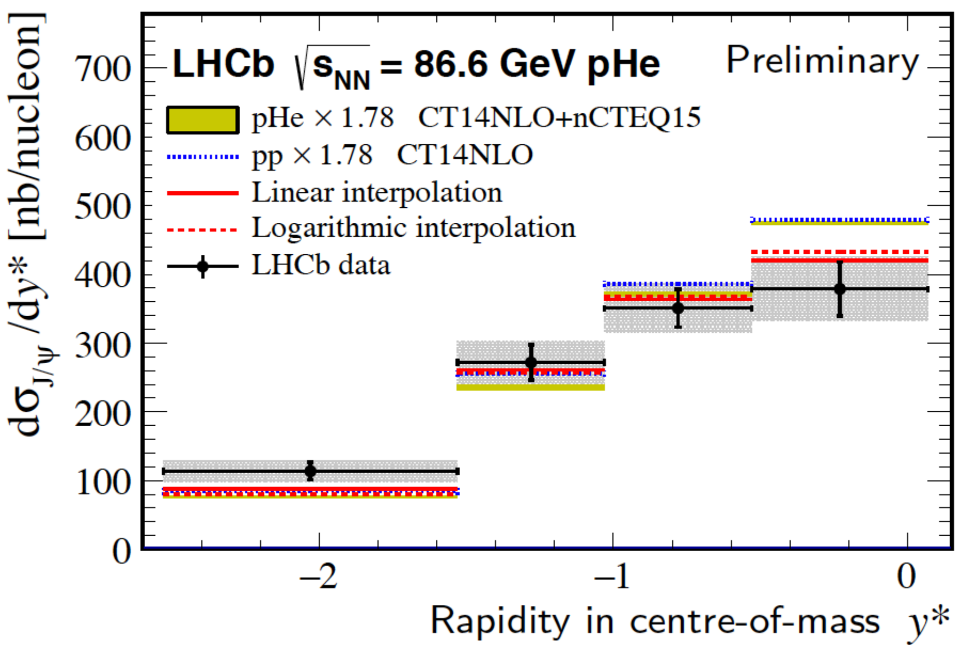


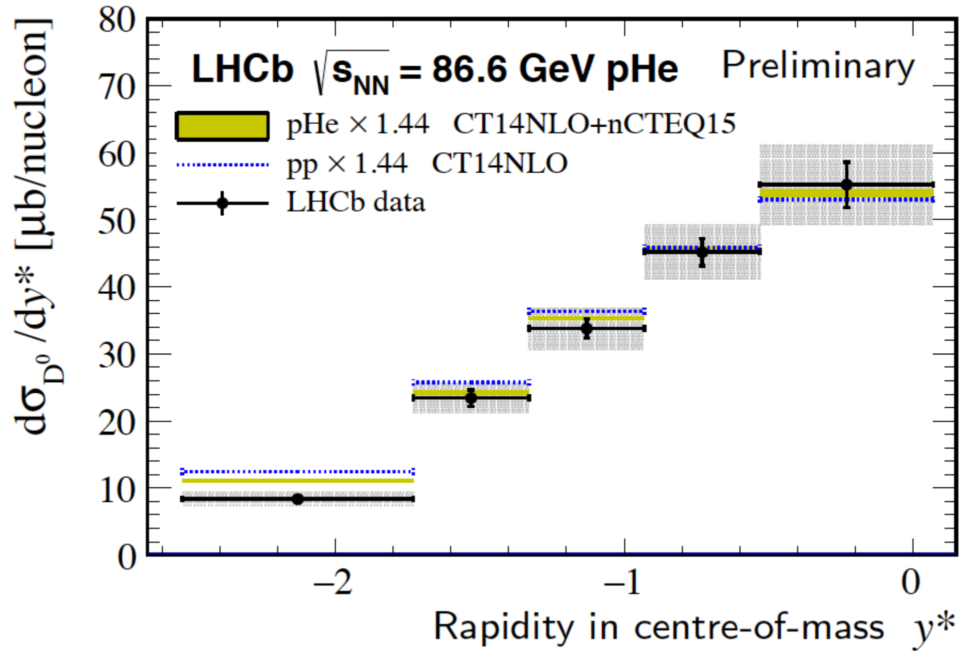
- **LHCb already take data in fixed-target mode using its SMOG system** (but only for light systems and with low luminosity)

- **Successful reconstruction of J/ψ and D-mesons:** paper under preparation with p-He results at 86.6 GeV

See talks by F. Fleuret and E. Maurice

LHCb-PAPER-2018-023, in preparation





Conclusions

- AFTER@LHC: **high-statistics measurements in an energy domain between the SPS and RHIC experiments**, in an unexplored rapidity domain

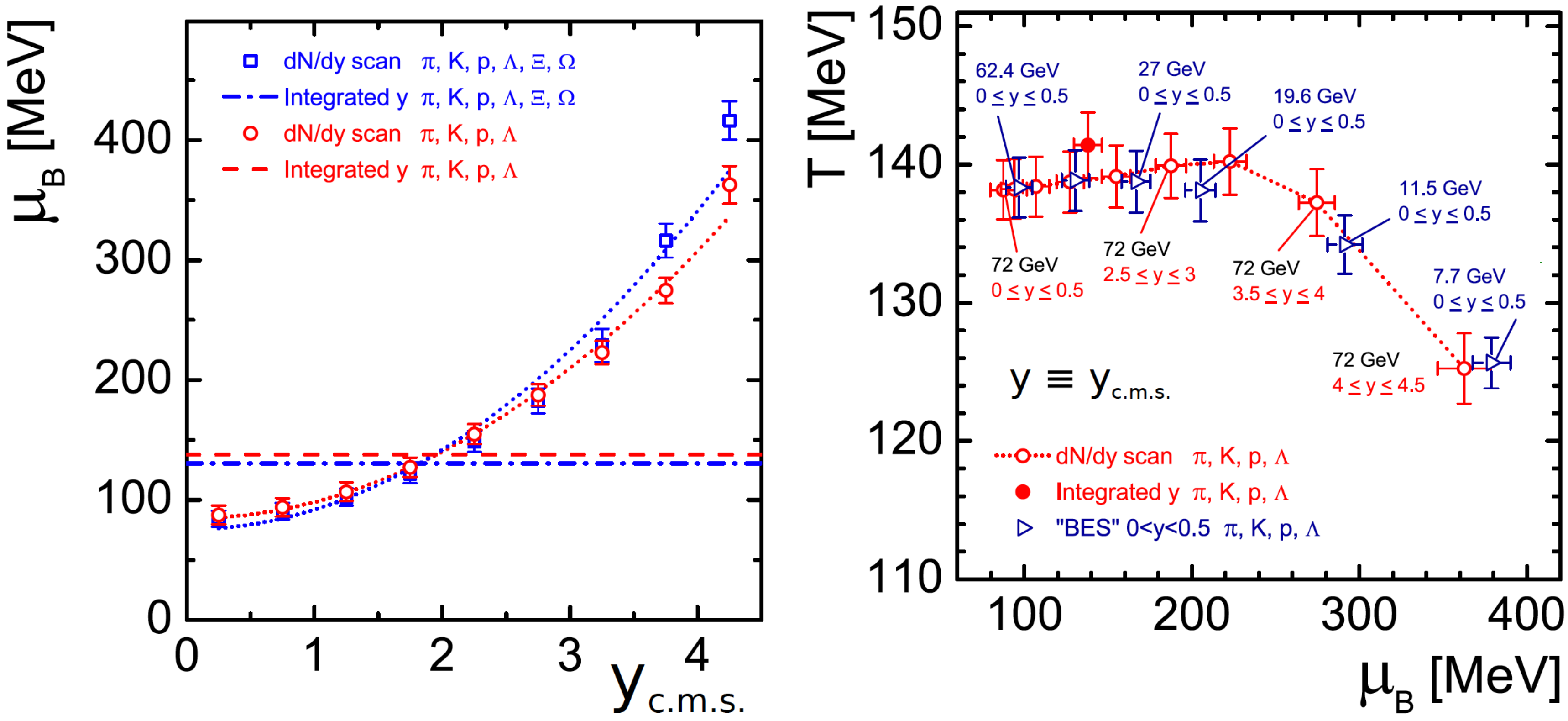
- **Experimental implementation** possibly based on the **existing LHCb** (fixed-target mode already implemented in SMOG) and **ALICE detectors**

- **Large yields for quarkonia and open heavy flavor signals in pA and AA**
  - CNM effects
  - Collectivity in small systems
  - Energy loss in the QGP and coupling with the medium

- **Underlying event characterization:** measurement of identified particle bulk. **Testing extrapolation of initial state effects with Drell-Yan**

Backup Slides

The Rapidity Scan: Exploring the QCD Phase Diagram



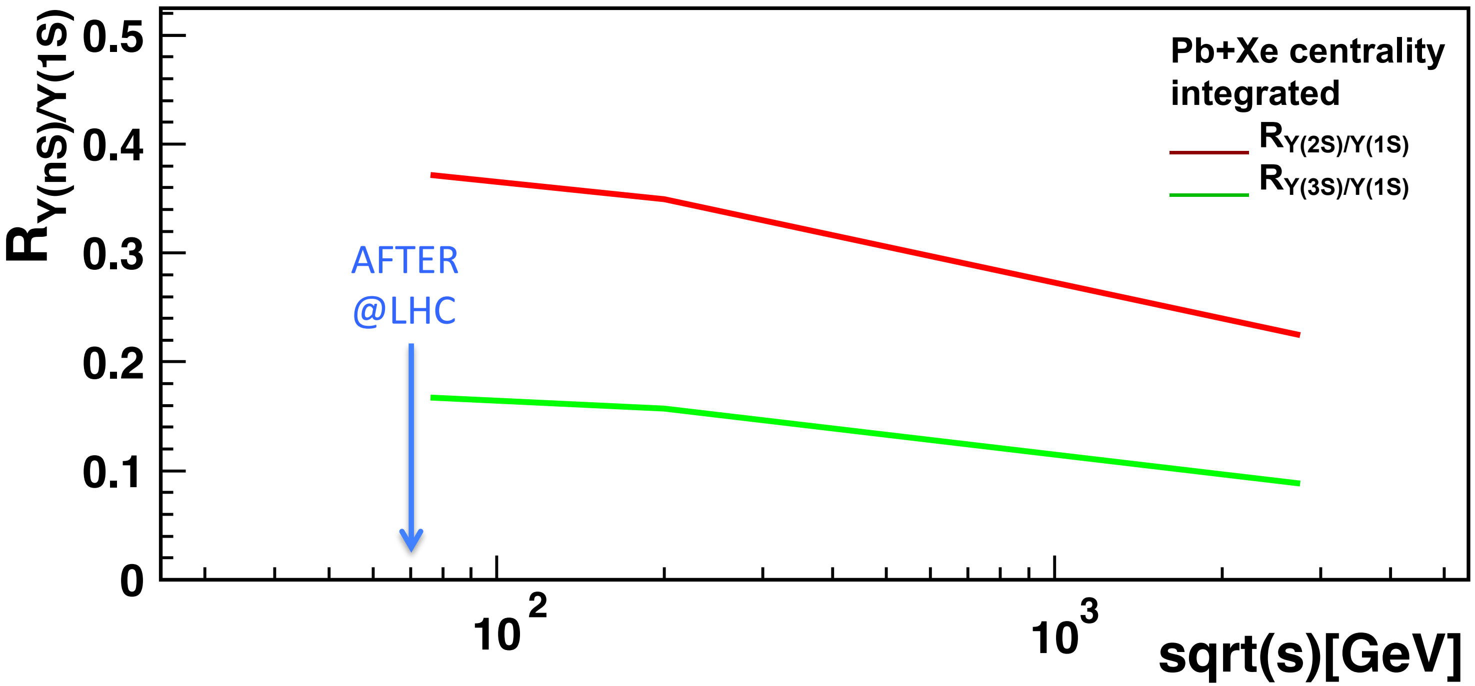
(a) μ_B vs. $y_{c.m.s.}$ (b) T vs. μ_B ($y \equiv y_{c.m.s.}$)

Figure 44: The baryonic chemical potential μ_B (a) and (b) the temperature T in 0-10% most central PbPb collisions at $\sqrt{s_{NN}}$ = 72 GeV from the Hadron Resonance Gas model calculations [75]. The two series of results represent calculations that uses two sets of particle densities as the input (with or without the Ξ and Ω baryons). The uncertainties on the points follows from the assumed relative uncertainties of 10% on the particle yields measured in AFTER@LHC.

Quarkonium Measurements: Bottomonium

- **Expected relative suppression $R_{\Upsilon(nS)/\Upsilon(1S)}$ in the improved Comover Interaction Model (iCIM)** recently applied to describe the ϒ(nS) suppression at the LHC

- Given the foreseen accuracy of ϒ(nS) measurements, the AFTER@LHC program will allow to verify such predictions in a completely new energy domain



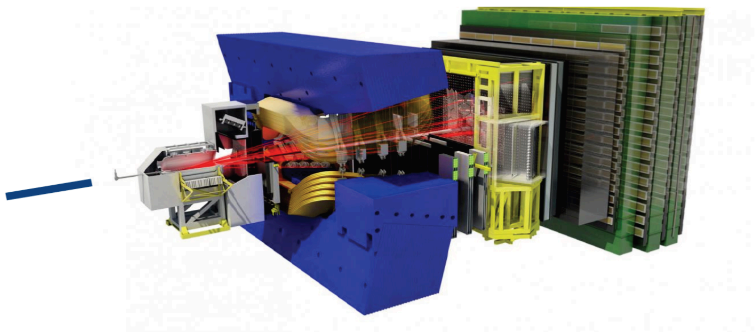
arXiv:1804.04474

AFTER@LHC Implementation in LHCb and ALICE

LHCb-like

$\sqrt{s_{NN}}$ = 115 GeV, L_{int} (p-H) = 10 fb^{-1} / year
$\sqrt{s_{NN}}$ = 115 GeV, L_{int} (p-Xe) = 100 pb^{-1} / year
$\sqrt{s_{NN}}$ = 72 GeV, L_{int} (Pb-Xe) = 30 nb^{-1} / year
(Ref at same energy: L_{int} (p-H) = 250 pb^{-1}
L_{int} (p-Xe) = 2 pb^{-1})

$2 < \eta < 5$



HERMES-type polarized target + LHCb – like acceptance and performance

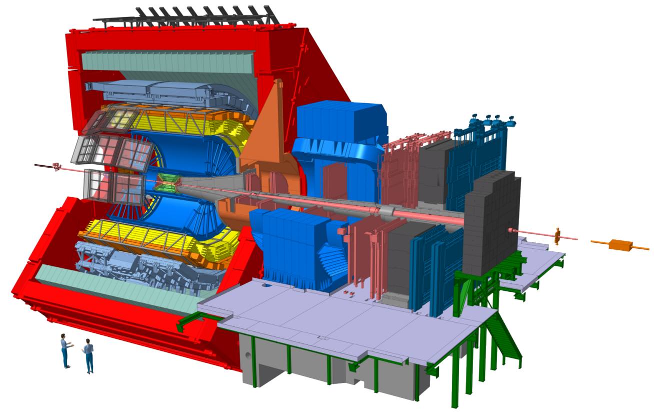
Resolution, efficiencies, microvertexing, particle ID, μ ID, electromagnetic and hadonic cal.

ALICE-like

$\sqrt{s_{NN}}$ = 72 GeV, L_{int} (Pb-Pb) = 1.6 nb^{-1} / year

$-0.87 < \eta^{TPC} < 0.95$

Bent crystal



+ internal solid target:
  Z ~ 13 cm from IP (A side)
+ ALICE like acceptance

AFTER@LHC Implementation in LHCb and ALICE

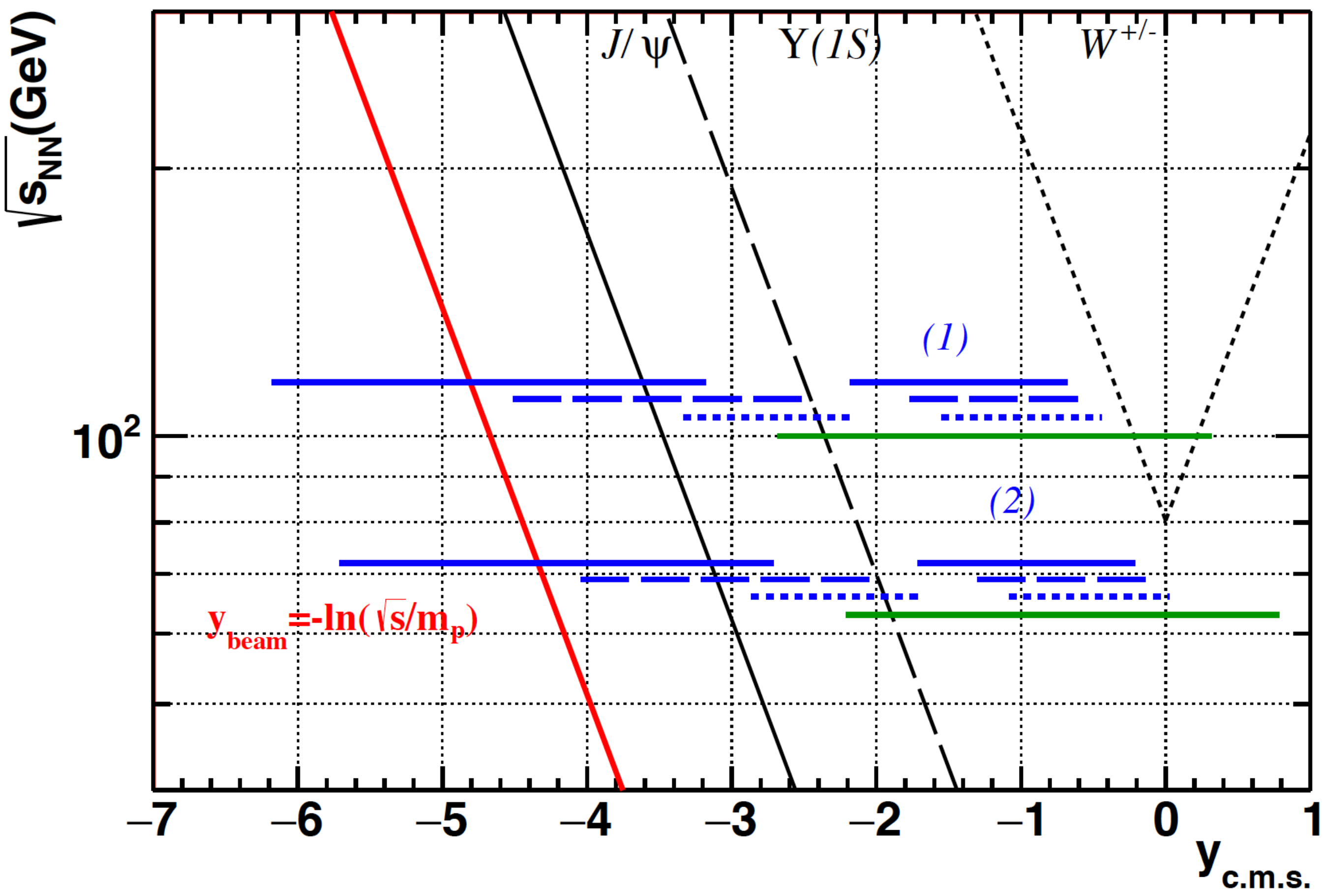


Figure 11: Center-of-mass-rapidity ($y_{c.m.s.}$) coverage as a function of the colliding energies per nucleon pair ($\sqrt{s_{NN}}$) as in Fig. 8. The blue lines represent the acceptance of the TPC and MS of ALICE. The full, long-dashed and short-dashed lines correspond to targets located at the IP, upstream of the IP by z_{target} = 2.75 and 4.7 m, respectively. The green lines represent the acceptance of the LHCb detector with a target at the IP. The long-dashed and short-dashed blue lines as well as the green lines are shifted in energy for a better visibility.