JOINT WORKSHOP "GDR-QCD/QCD@short distances and STRONG2020/PARTONS/FTE@LHC/NLOACCESS"

May 31 to June 4 2021

Visioconference

Heavy-flavour projections for pA and flow decorrelation predictions for PbA with ALICE-FT setup

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Joint workshop "GDR-QCD@short distances and STRONG2020/PARTONS/FTE@LHC/NLOAccess"

May 31 – June 4 2021

Fixed-target experiment at LHC

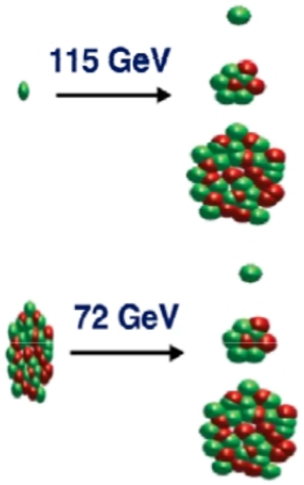
Energy range

7 TeV proton beam on a fixed target

c.m.s. energy:	$\sqrt{s} = \sqrt{2m_N E_p} \approx 115\,\mathrm{GeV}$	**Rapidity shift:** $y_{c.m.s.} = 0 \rightarrow y_{lab} = 4.8$
Boost:	$\gamma = \sqrt{s}/(2m_N) \approx 60$	

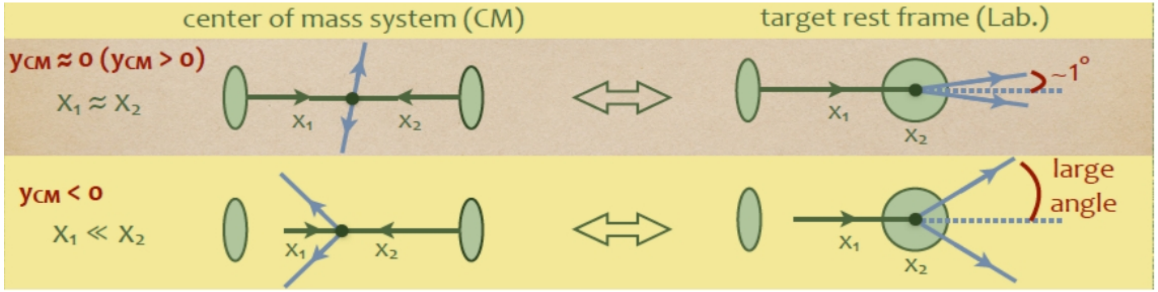
2.76 TeV Pb beam on a fixed target

c.m.s. energy:	$\sqrt{s_{NN}} = \sqrt{2m_N E_{Pb}} \approx 72\,\mathrm{GeV}$	**Rapidity shift:** $y_{c.m.s.} = 0 \rightarrow y_{lab} = 4.3$
Boost:	$\gamma \approx 40$	



- √s in-between SPS and top RHIC

Effect of boost



- Entire forward hemisphere, $y_{cms} > 0$, within 1 degree
- **Easy access to (very) large backward rapidity range, $y_{cms} < 0$**
- **And large parton momentum fraction $x_2 \rightarrow 1$ ($x_F \rightarrow -1$)**

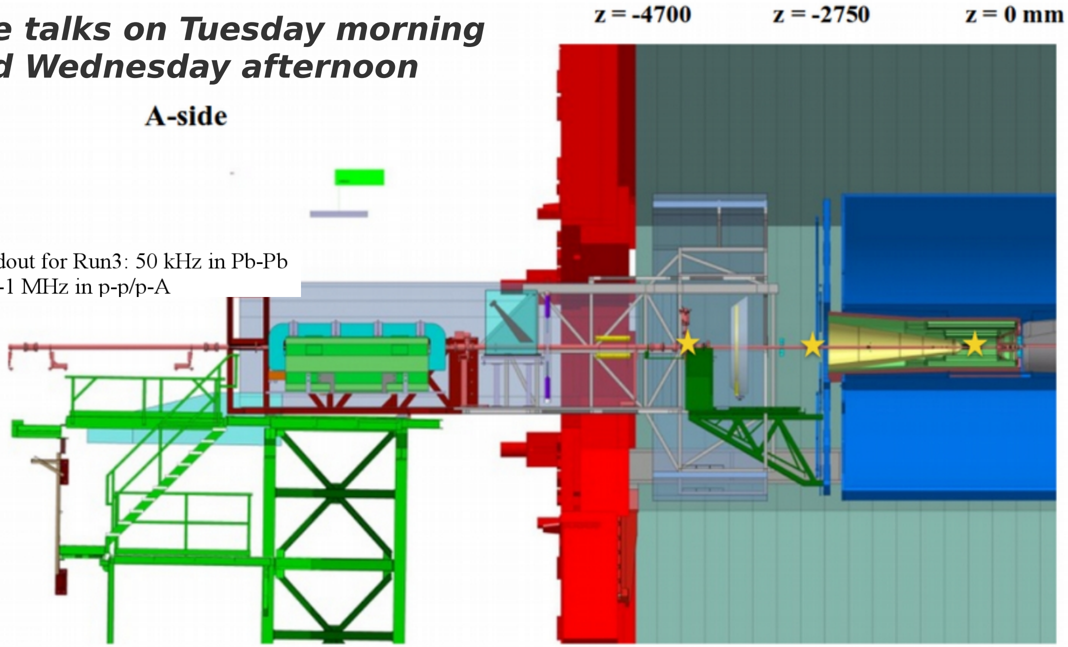
$$[|x_F| \equiv \frac{|p_z|}{p_{z\,max}} \rightarrow 1]$$

ALICE-FT setup

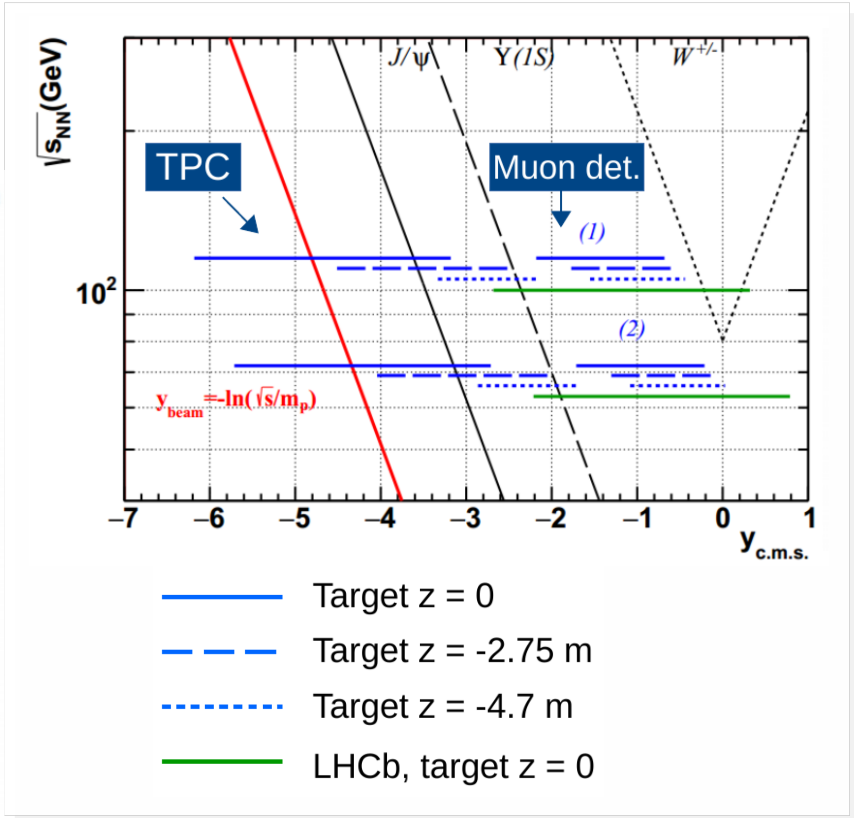
Beam splitting with bent crystal + internal target

- Crystal installed prior of the IP2, deviates the beam halo onto a target
- Target position: ~4.8 m from the IP on A-side
- Various target type: from Be to W
- Target length from ~100μm to 1 cm
- ***Feasibility studies ongoing***

See talks on Tuesday morning and Wednesday afternoon

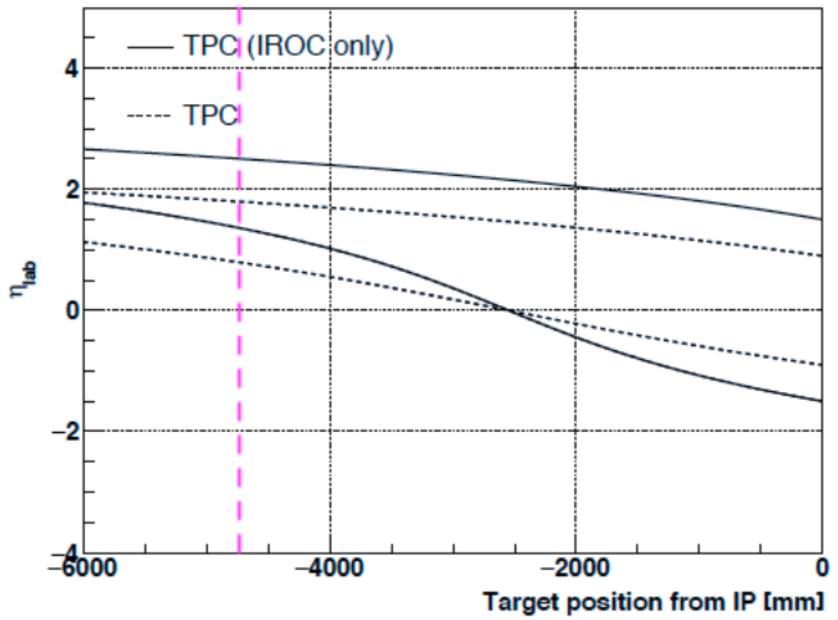


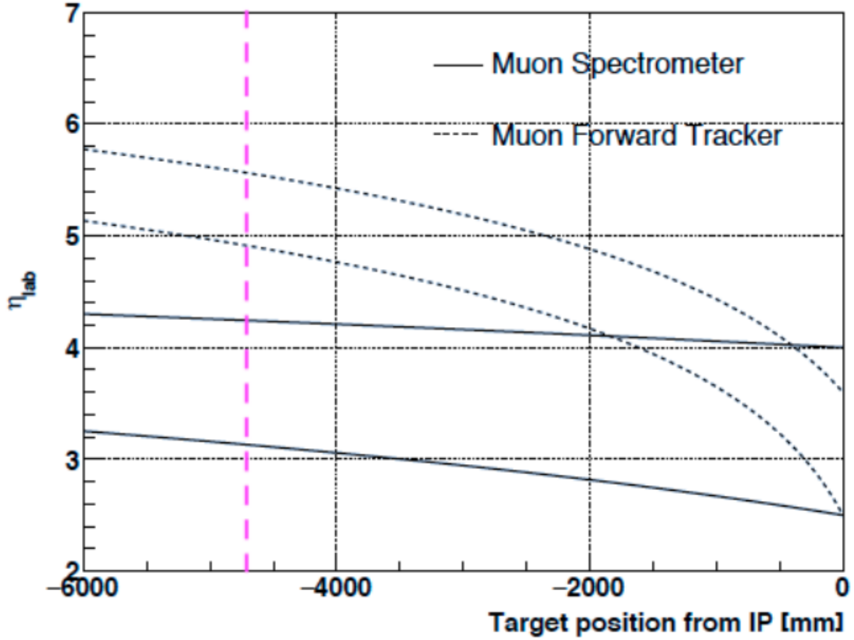
ALICE Readout for Run3: 50 kHz in Pb-Pb and 200kHz-1 MHz in p-p/p-A



Acceptance vs target position

- **Acceptance vs target position for ALICE muon and TPC detectors**





Open heavy-flavour projections

ALICE-FT Simulation setup

- Pythia 8 simulations, Monash 2013 tune, HardQCD, pp at 115 GeV
- Total ccbar cross-section: 2.29×10^{-1} mb (HELAConia)

- Target at z = -4.7 m from the nominal interaction point
- 1 cm long solid targets, C, Ti, W, with a vertex detector close to the target
- Rapidity coverage for D mesons in the ALICE central barrel: $-3.5 < y_{CMS} < -2.3$

- $D^0 \rightarrow \pi^+ K^-$, BR = 3.89%
- Efficiency x acceptance: 2%
- Event plane Ψ_2 resolution for v_2 studies $Res(\Psi_2) = 0.2$

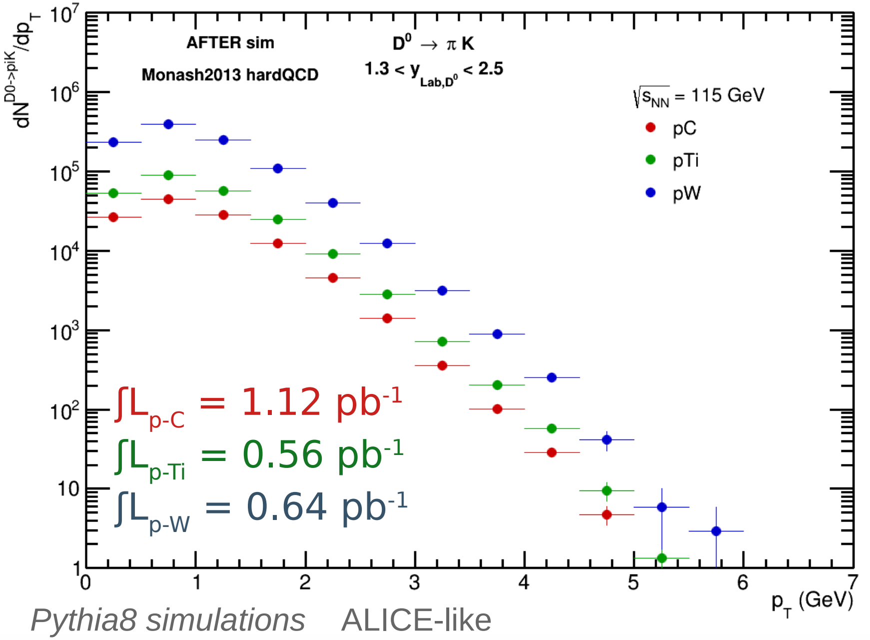
- Expected yearly integrated luminosities:

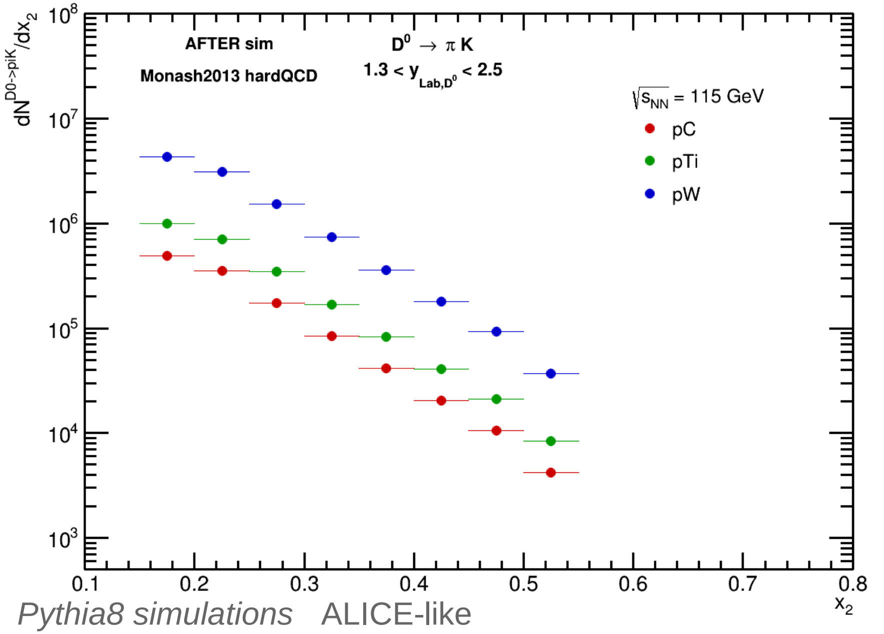
p-C: $\int L_{p\text{-}C} = 1.12\ pb^{-1}$
p-Ti: $\int L_{p\text{-}Ti} = 0.56\ pb^{-1}$
p-W: $\int L_{p\text{-}W} = 0.64\ pb^{-1}$

- Potential of measuring HF μ with ALICE muon arms closer to mid-rapidity

D^0 meson yields in pA

- Gluon PDFs and nuclear PDFs now well know at large x > 0.1
  - Expected yearly yields for $D^0 \rightarrow \pi^+ K^-$ in pA collisions at 115 GeV
  - Precise measurements from p_T = 0 up to ~5 GeV/c
  - x_2 coverage: 0.15 – 0.55



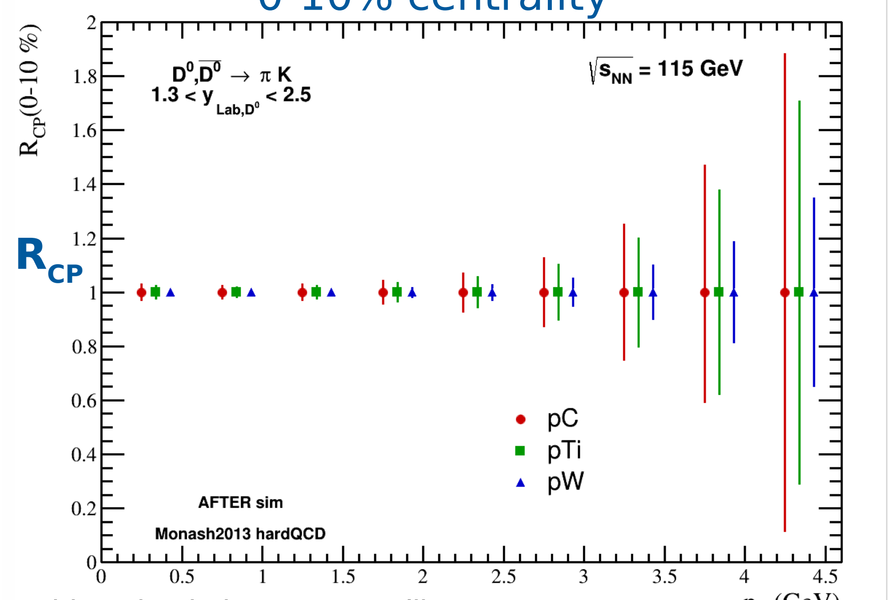


Pythia8 simulations ALICE-like *Pythia8 simulations* ALICE-like

D^0 meson R_{AA} in pA

- pA collisions: Cold Nuclear Matter effects, possible collectivity in small systems
- Simultaneous measurements of D R_{AA} and v_2 in different systems

0-10% centrality



Pythia8 simulations ALICE-like

- $D^0 \rightarrow \pi^+ K^-$ and c.c. in p-A collisions at 115 GeV
- Nuclear modification factor, $R_{CP} = N_{raw}^{central}/N_{raw}^{per}$
- Peripheral bin: 60-100%

$$N_{raw}^{D,cent} = < T_{pA} >^{cent} \times \sigma_{pp}^{D} \times N_{evt}^{cent}$$

Per 10%-wide centrality bin:
$25 \ast 10^9$ events
$30 \ast 10^9$ events
$80 \ast 10^9$ events

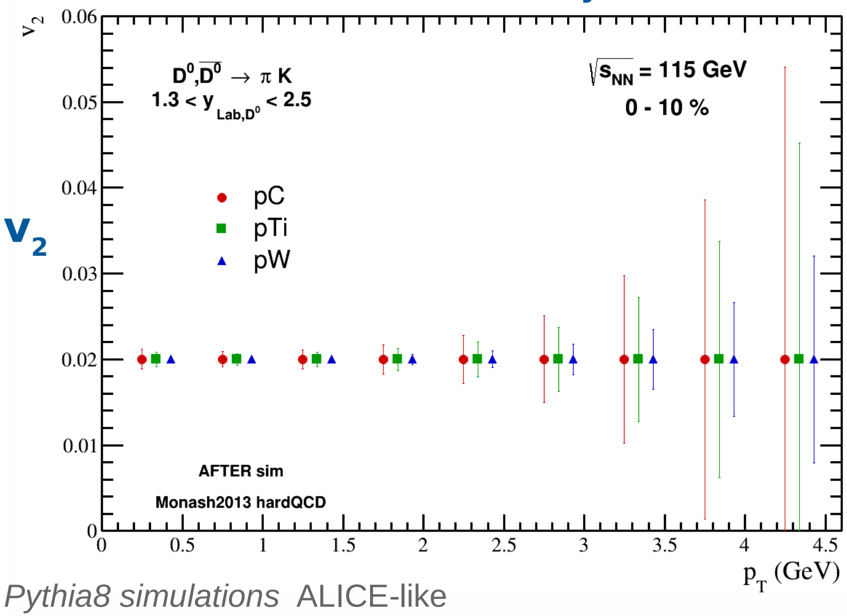
For 0-10% centrality
$\int L_{p\text{-}C} \approx 92\ nb^{-1}$
$\int L_{p\text{-}Ti} \approx 43\ nb^{-1}$
$\int L_{p\text{-}W} \approx 47\ nb^{-1}$

- Similar precision expected in 10-20, 20-40% centrality intervals

D^0 meson v_2 in pA – 0-10%

- pA collisions: Cold Nuclear Matter effects, possible collectivity in small systems
- Simultaneous measurements of D R_{AA} and v_2 in different systems

0-10% centrality



Pythia8 simulations ALICE-like

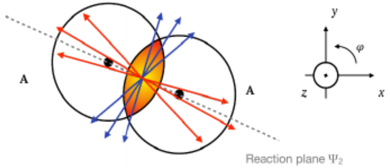
Azimuthal momentum space anisotropy of particle emission

$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1+\sum_{n=1}^{\infty} 2v_n cos(n(\phi-\Psi_{RP}))\right)$$

$$v_n^{obs} = \langle\cos\left[n\left(\phi-\Psi_n\right)\right]\rangle \qquad v_n = \frac{v_n^{obs}}{Res(\Psi_n)}$$

- Elliptic flow v_2 measurement using Event Plane method
- Event plane resolution $Res(\Psi_2) = 0.2$ – enters to the uncertainties

$$\frac{dN}{d\phi} = A(1+2v_2\cos(2\Delta\phi))$$



Per 10%-wide centrality bin:

$25*10^9$ events

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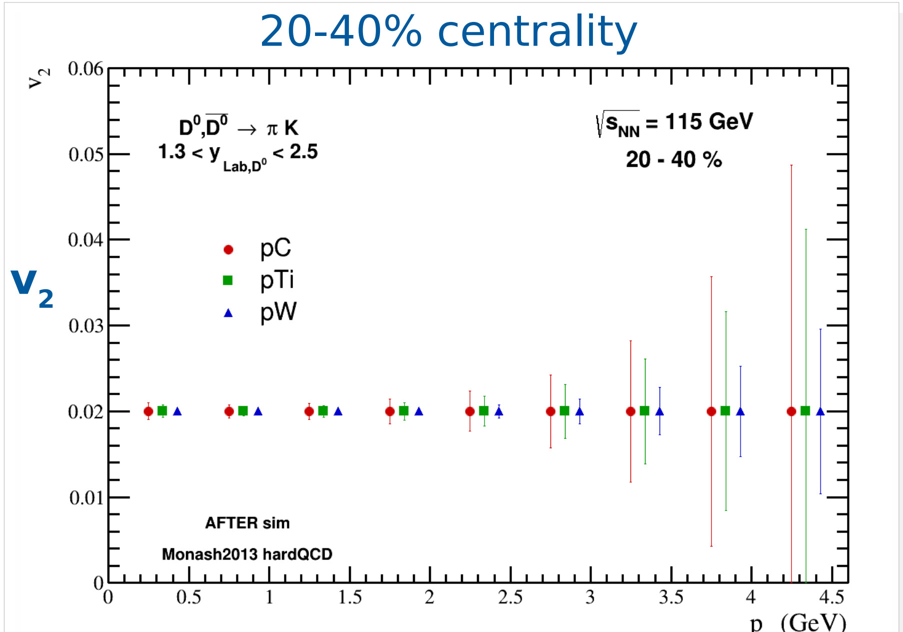
$80*10^9$ events

D^0 meson v_2 in pA – 20-40%

- pA collisions: Cold Nuclear Matter effects, possible collectivity in small systems
- Simultaneous measurements of D R_{AA} and v_2 in different systems



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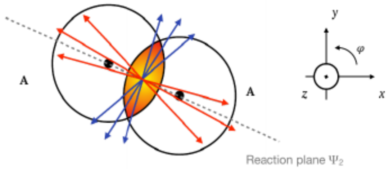

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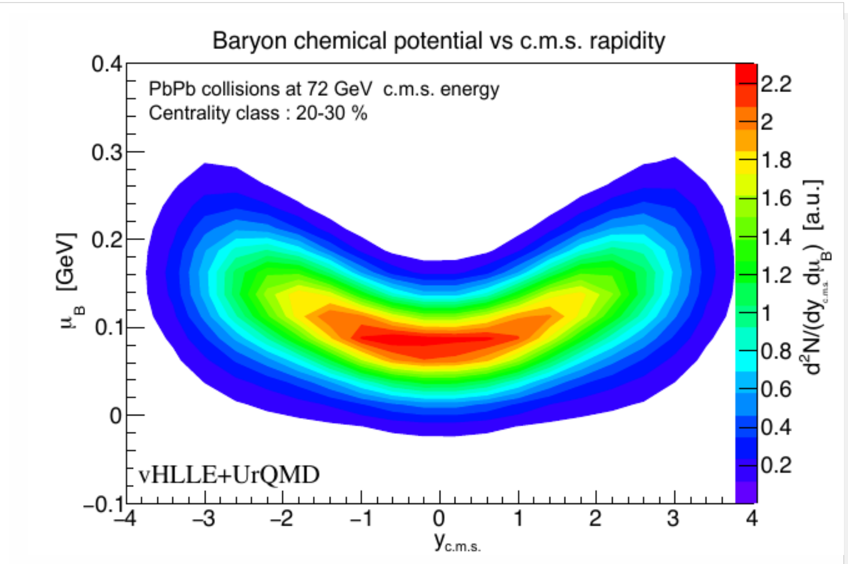
$80*10^9$ events

Anisotropic flow decorrelation

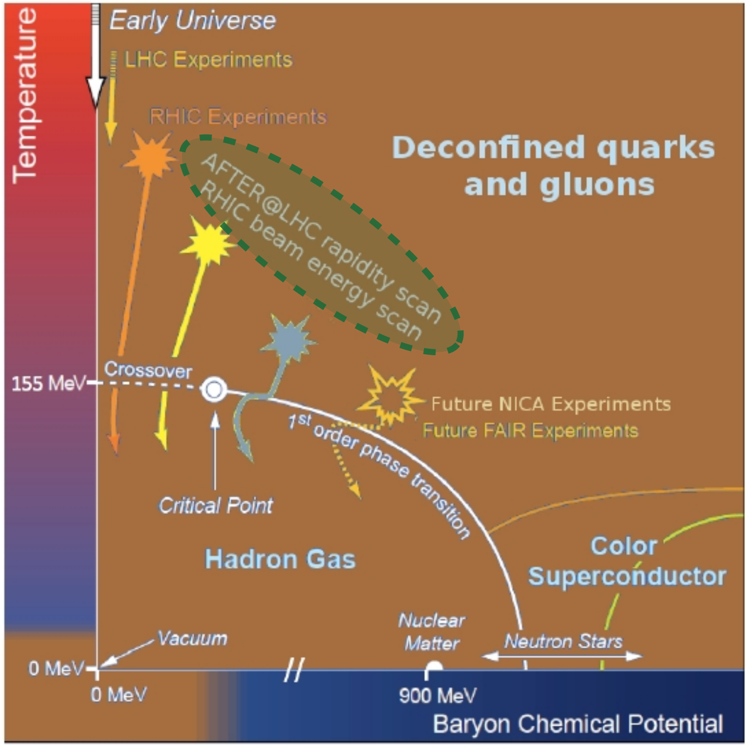
Jakub Cimerman, *Iurii Karpenko, Boris Tomasik, BT*
arXiv: 2104.08022

Physics case: QGP

- Study of the **quark-gluon plasma** between SPS and top RHIC energies of $\sqrt{s_{NN}}$ = 72 GeV over broad rapidity range
- Complete studies as a function of rapidity, centrality and system size → **scan in μ_B** complementary to RHIC BES programme



I.Karpenko, Acta Phys. Polon. B50 (2019), 141-148



arXiv: 1807.00603

Physics case: QGP

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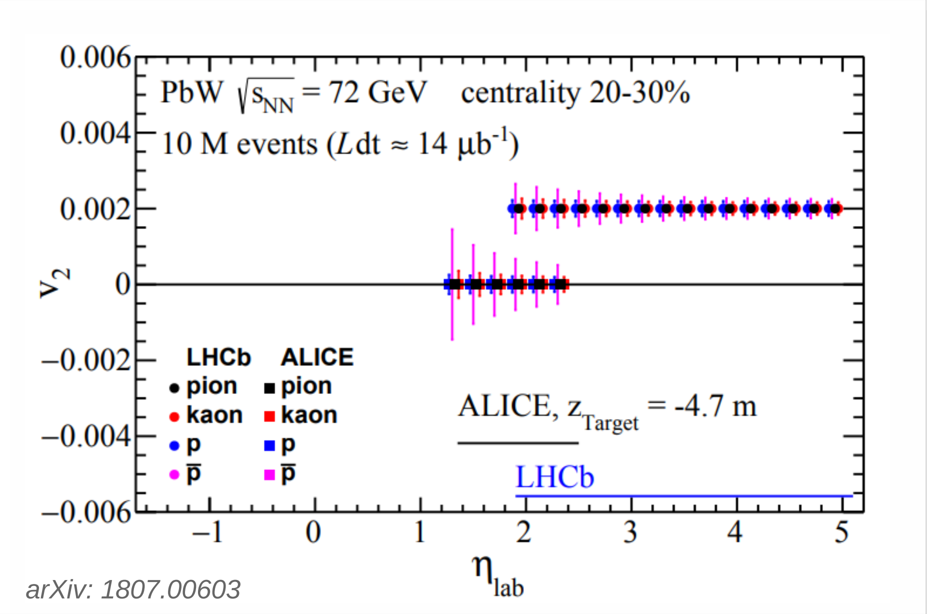
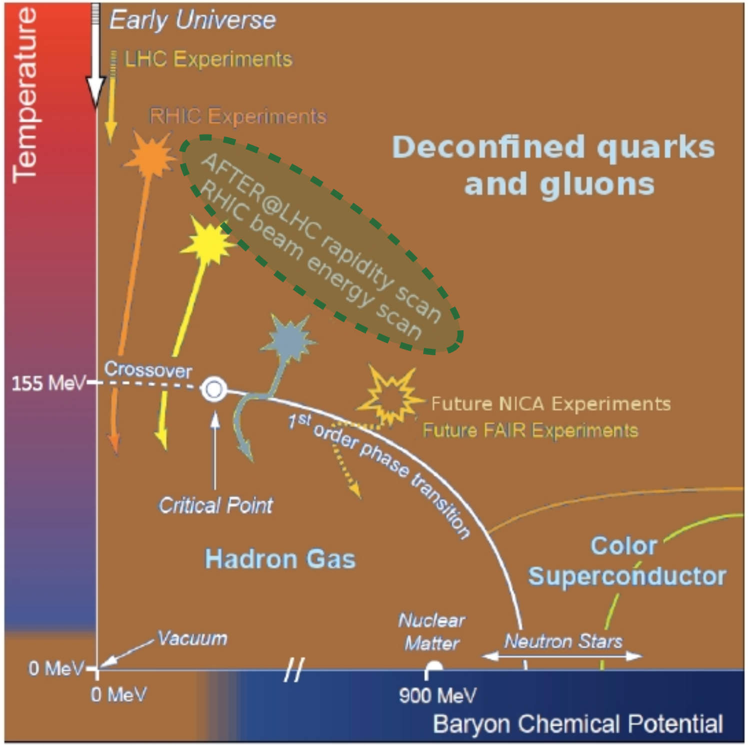


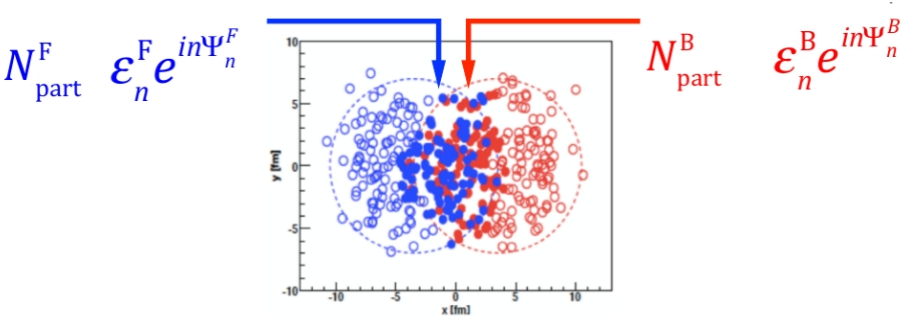
arXiv: 1807.00603



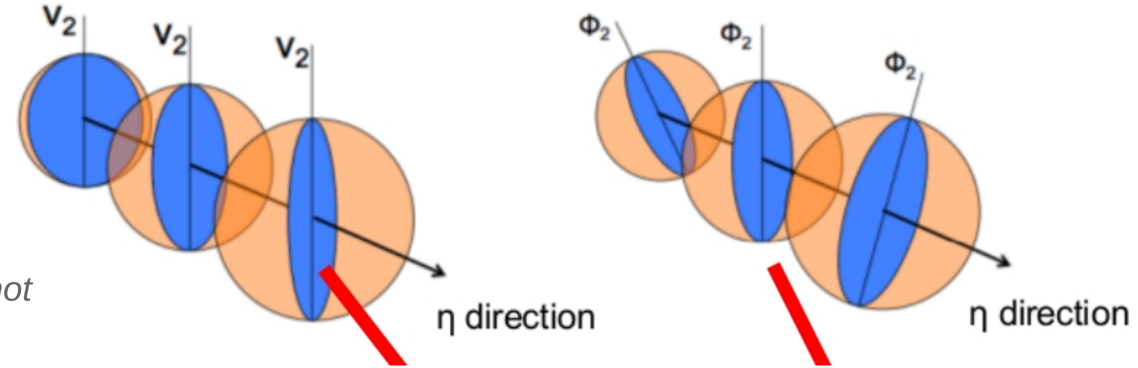
- v_n vs y → determination of η/s temperature dependence

Longitudinal flow decorrelation

- **Longitudinal dynamics of heavy-ion collisions**
  - Modeling: full (3+1)D QGP evolution, source fluctuations
  - Longitudinal fluctuations → EbE flow fluctuations in magnitude and direction
  - Information about initial state
  - Long. structure of flow → transport properties of QGP, *Phys.Rev. C 98, 024913 (2018)*



Forward & backward going participant distributions are not symmetric



Also, linear twist of the event-plane angle $\Psi_n(\eta)$ in the longitudinal direction was suggested in CGC model

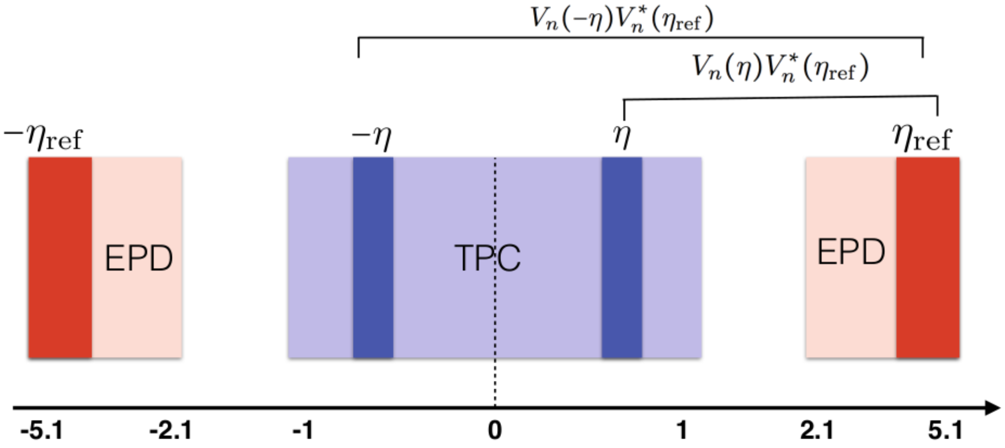
S.Mohapatra, QM17

Factorization ratio r_n

➔ **Factorization ratio r_n – measure of flow decorrelation**

$$r_n(\eta) = \frac{\langle q_n(-\eta) q_n^*(\eta_{\mathrm{ref}})\rangle}{\langle q_n(\eta) q_n^*(\eta_{\mathrm{ref}})\rangle}$$

$$r_n(\eta) = \frac{\langle v_n(-\eta) v_n(\eta_{\mathrm{ref}}) \cos[n(\Psi_n(-\eta) - \Psi_n(\eta_{\mathrm{ref}}))]\rangle}{\langle v_n(\eta) v_n(\eta_{\mathrm{ref}}) \cos[n(\Psi_n(\eta) - \Psi_n(\eta_{\mathrm{ref}}))]\rangle}$$

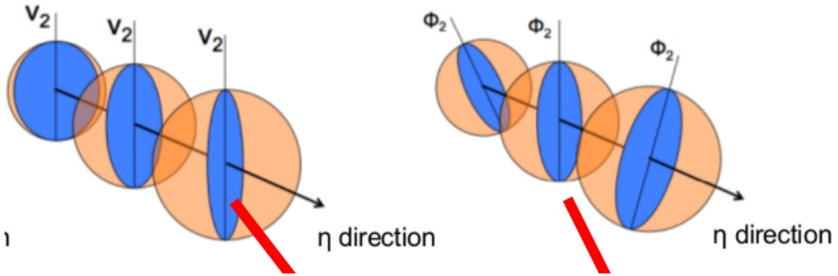


A large η gap is imposed to avoid short-range correlations.

M.Nie, QM19

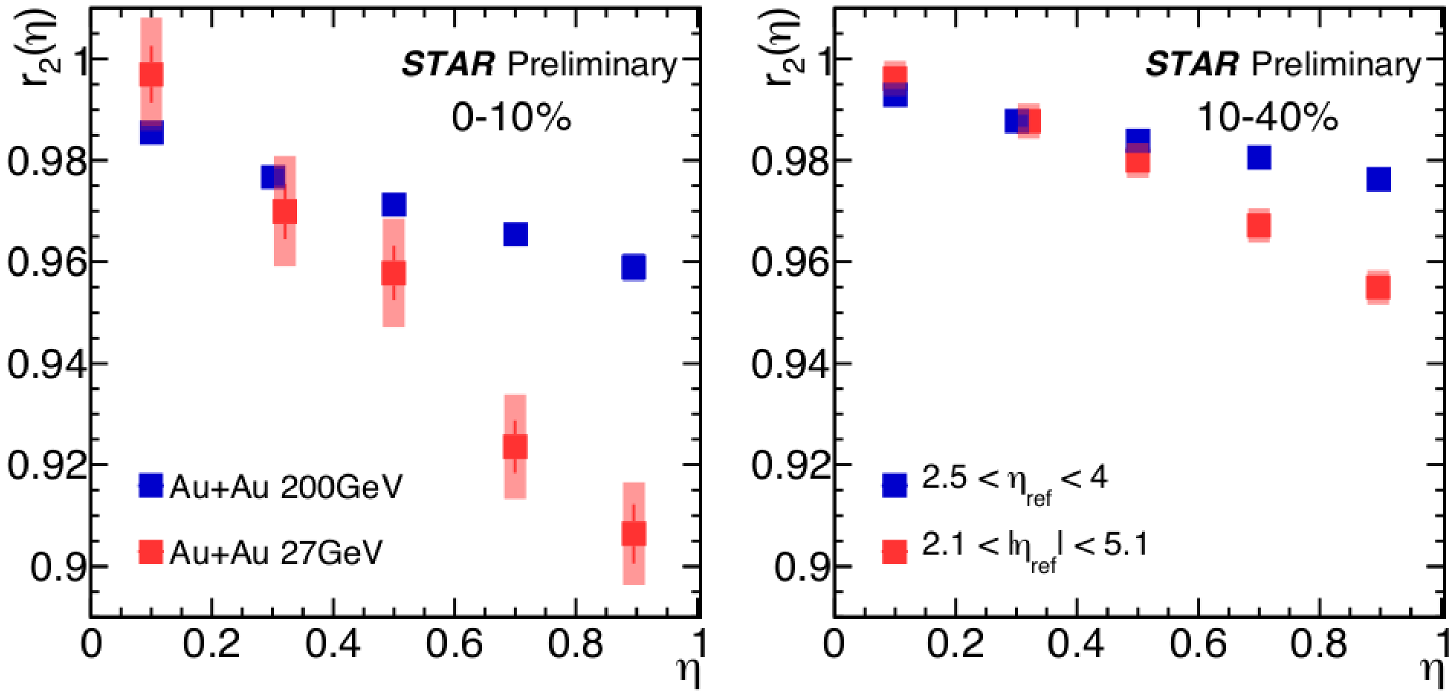
➔ Two effects:

- *flow magnitude decorrelation*
- *flow angle decorrelation*



Flow decorrelation factorization

- **STAR**: r_2, r_3 measured at 200 and 27 GeV
  - Stronger decorrelation with decreasing energy

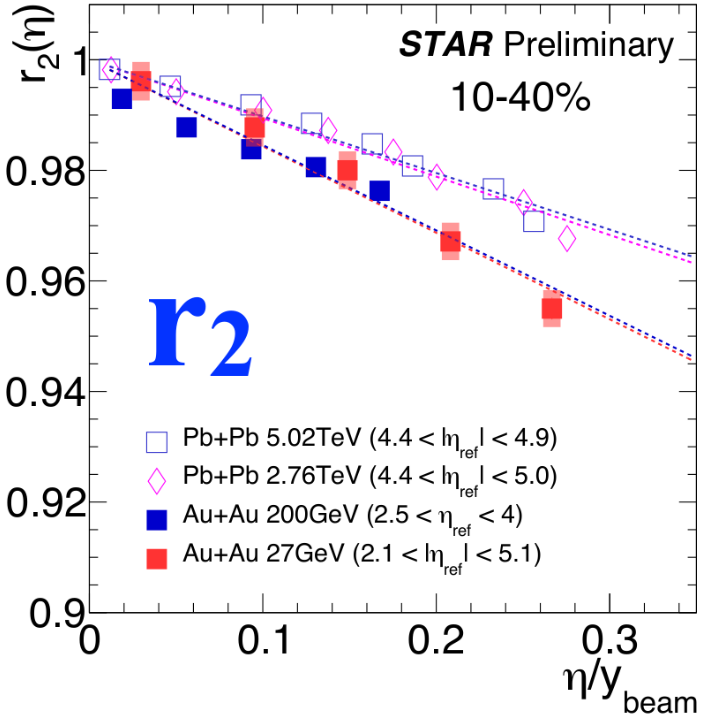


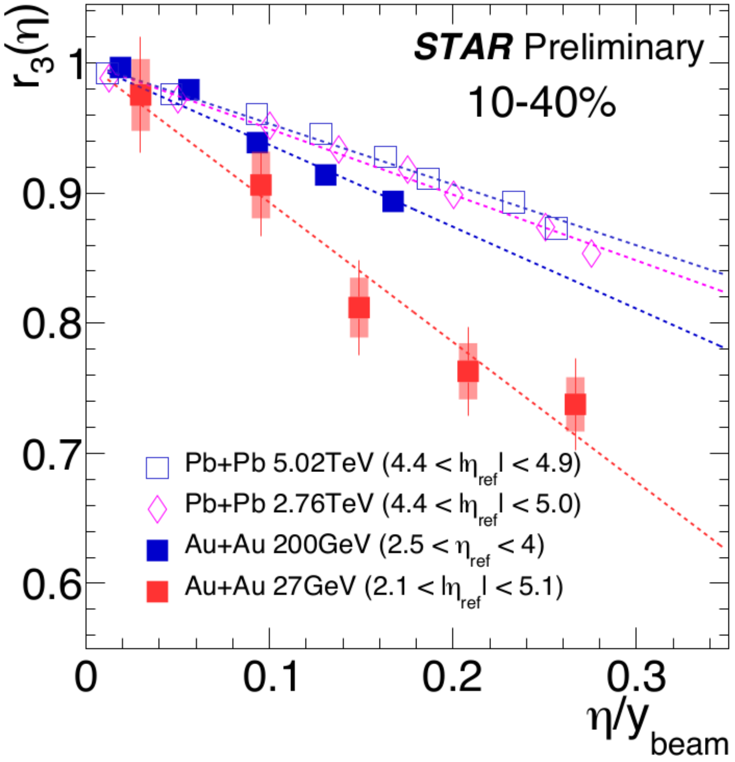
- **LHC:**
  - CMS: Phys. Rev. C92 (3) (2015) 034911, ATLAS: Eur. Phys. J. C (2018) 78:142

M.Nie, QM19
QM18

Flow decorrelation factorization(2)

- **STAR**: $r_{2,}$ r_3 measured at 200 and 27 GeV
  - Scaling of r_2 vs η/y_{beam} not understood





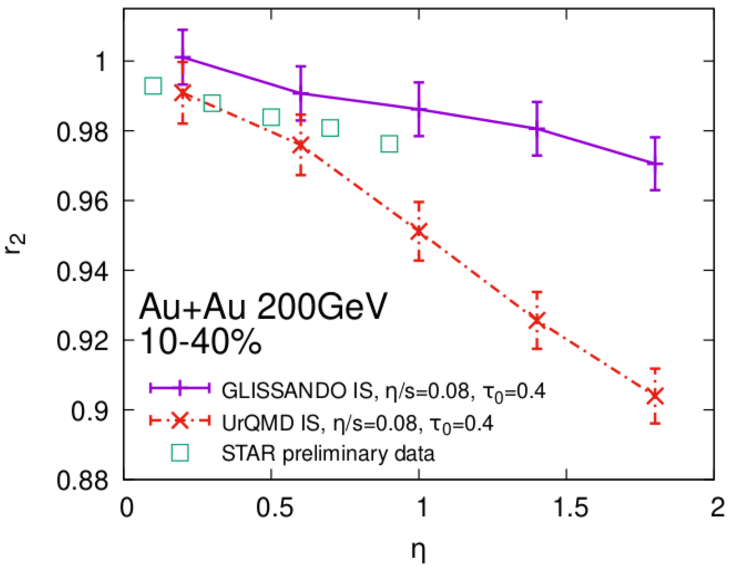
- **Energy and system size studies of interest**

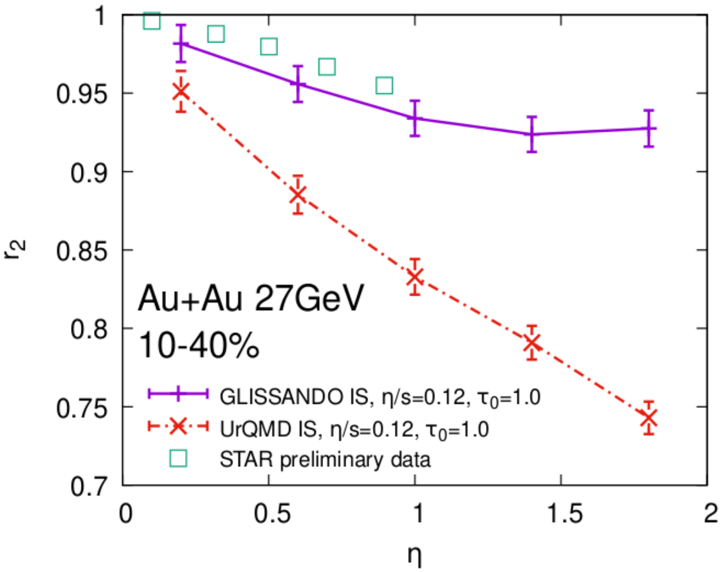
M.Nie, QM19

Decorrelation with hydro model

- **Event-by-event viscous hydrodynamic model**
  - Initial states: UrQMD and 3D GLISSANDO 2, Prog. Part. Nucl. Phys. 41, 255 (1998), Comput. Phys. Commun. 185, 1759 (2014), 1310.5475
  - 3D viscous code: vHLLE, Phys. Rev. C 91, 064901 (2015), 1502.01978
  - Hadronic rescatterings: UrQMD cascade
  - Model tuned on basics observable from RHIC at 27 and 62 GeV and 200 GeV, Phys. Rev. C 103, 034902 (2021)

- **r_2 for STAR:**

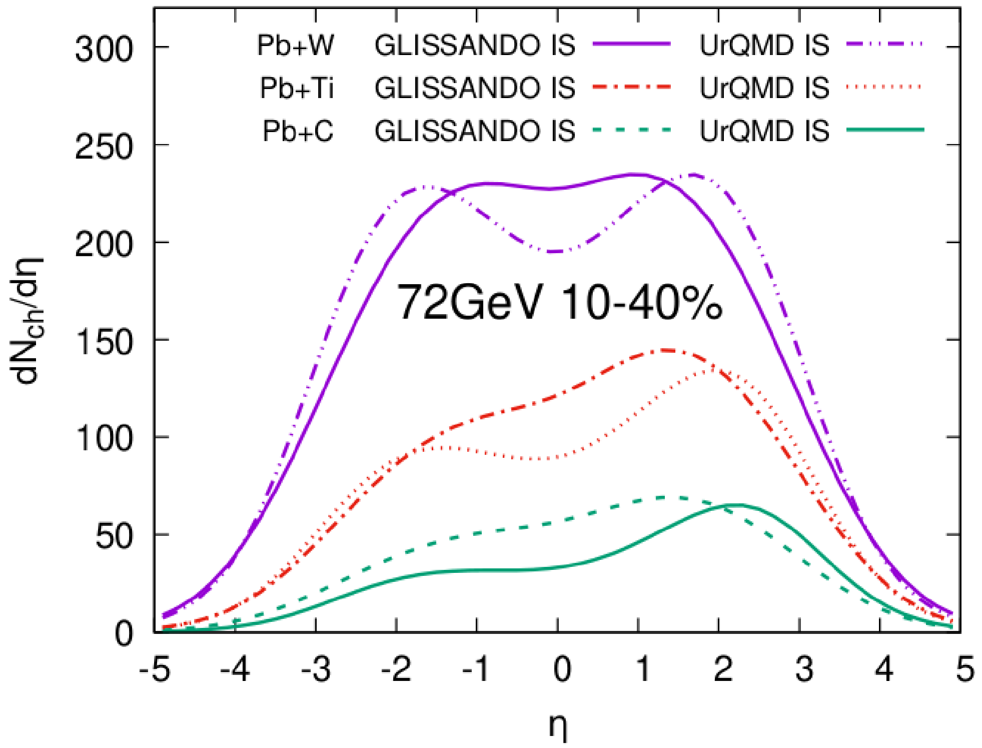


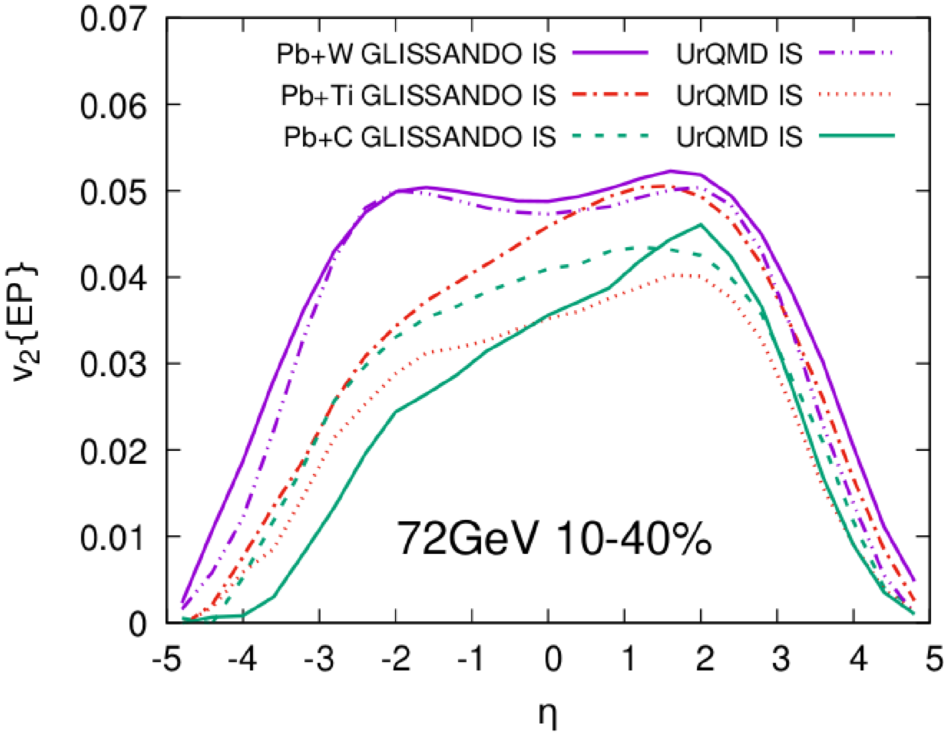


arXiv: 2104.08022 J.Cimerman, I.Karpenko, B.Tomasik, BT

Predictions for AFTER

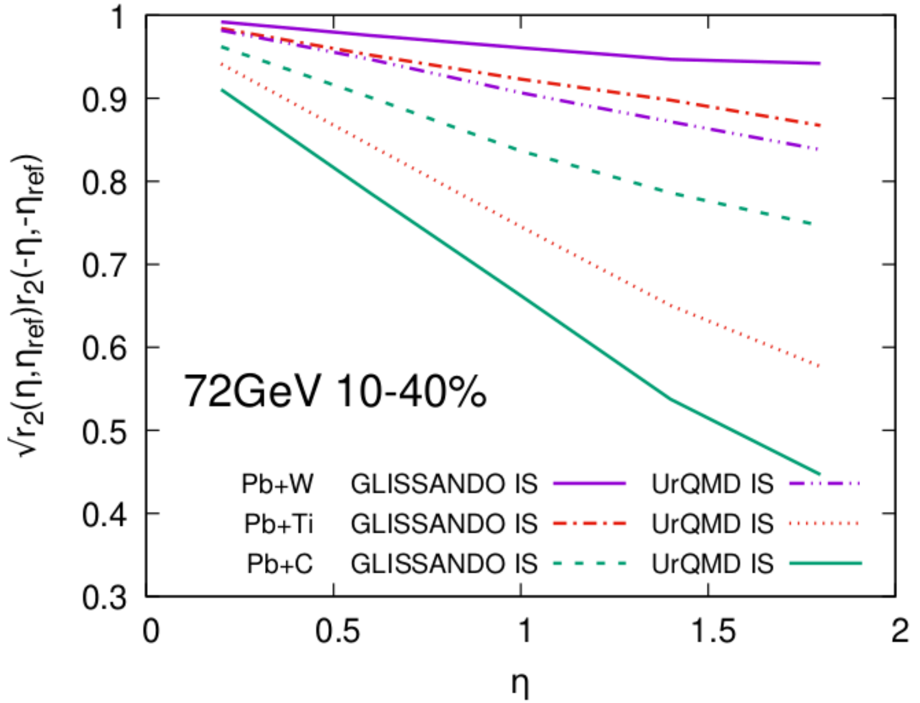
- Event-by-event viscous hydrodynamic model
- Pb-W, Pb-Ti, Pb-C at 72 GeV





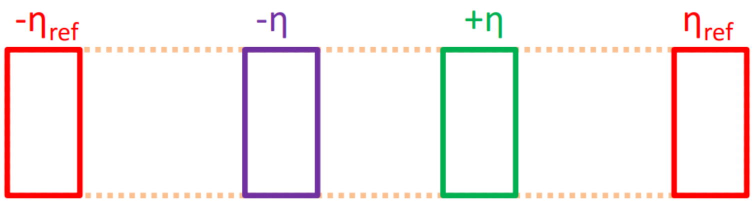
Decorrelation predictions FT

- Event-by-event viscous hydrodynamic model
- Pb-W, Pb-Ti, Pb-C at 72 GeV



- **r_n definition**
  - Asymmetric system
    (CMS, Phys. Rev. C92 (3) (2015) 034911):

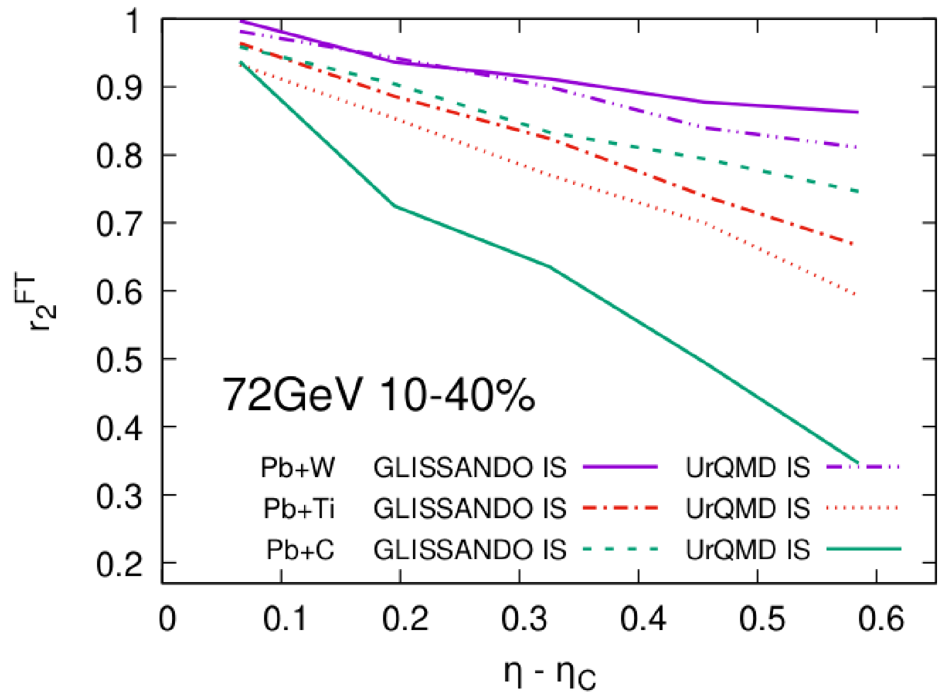
$$\sqrt{\frac{\langle q_n(-\eta)q_n^*(\eta_{ref})\rangle}{\langle q_n(\eta)q_n^*(\eta_{ref})\rangle}\frac{\langle q_n(\eta)q_n^*(-\eta_{ref})\rangle}{\langle q_n(-\eta)q_n^*(-\eta_{ref})\rangle}}.$$



- **Strong decorrelation, increasing with decreasing system size**
- **Significant differences between different IS models**

Decorrelation predictions FT (2)

- Event-by-event viscous hydrodynamic model
- Pb-W, Pb-Ti, Pb-C at 72 GeV, ALICE-like setup



- **r_n definition**
  - Fixed-target with two acceptance windows

$$r_n^{\mathrm{FT}}(\eta - \eta_C) = \frac{\langle q_n(-\eta + 2\eta_C) q_n^*(\eta_{\mathrm{ref}}) \rangle}{\langle q_n(\eta) q_n^*(\eta_{\mathrm{ref}}) \rangle}$$

  - TPC: $-2.9 < \eta < -1.6$
  - Muon det: $-1.0 < \eta_{\mathrm{ref}} < -0.5$
  - Decorrelation around the center of the pseudo-rapidity bin:

$$\eta_C = -2.25$$

- **Strong decorrelation, increasing with decreasing system size**
- **Significant differences between different IS models**

Summary

- Good precision for D^0 meson measurements in pA systems
  - Yield, nuclear modification factor, v_2 – down to low p_T
  - Statistical projections can be updated with more realistic ALICE detector performance figures – FT simulations within ALICE framework ongoing

- Longitudinal flow decorrelation
  - Great tool to discriminate between initial state models
  - Studies can be extended to pA systems (decorrelation measurements performed in p-Pb at LHC)
  - Doesn't required large statistics – feasibility studies to be performed with ALICE simulation framework

Thank you!

A Fixed-Target Programme at the LHC:
arXiv: 1807.00603

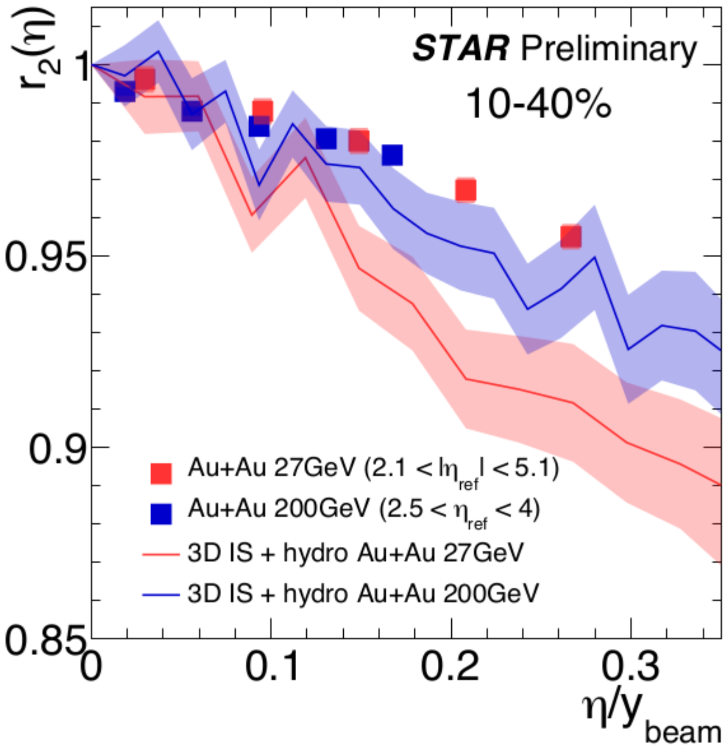
This work was supported by grant from The Czech Science Foundation, grant number: GJ20-16256Y

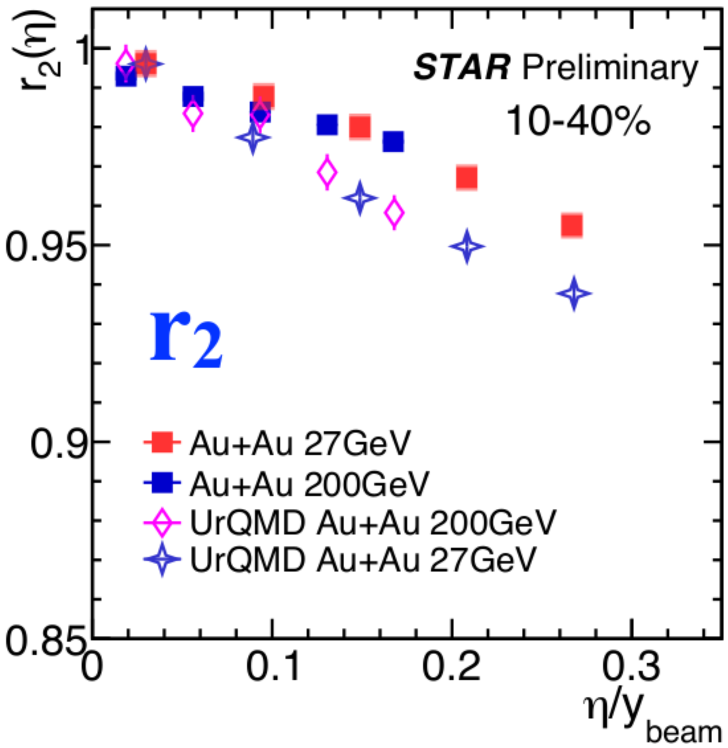
GRANTOVÁ AGENTURA ČESKÉ REPUBLIKY

Backup

STAR r_2 vs models

➔ **STAR r_2 vs models**

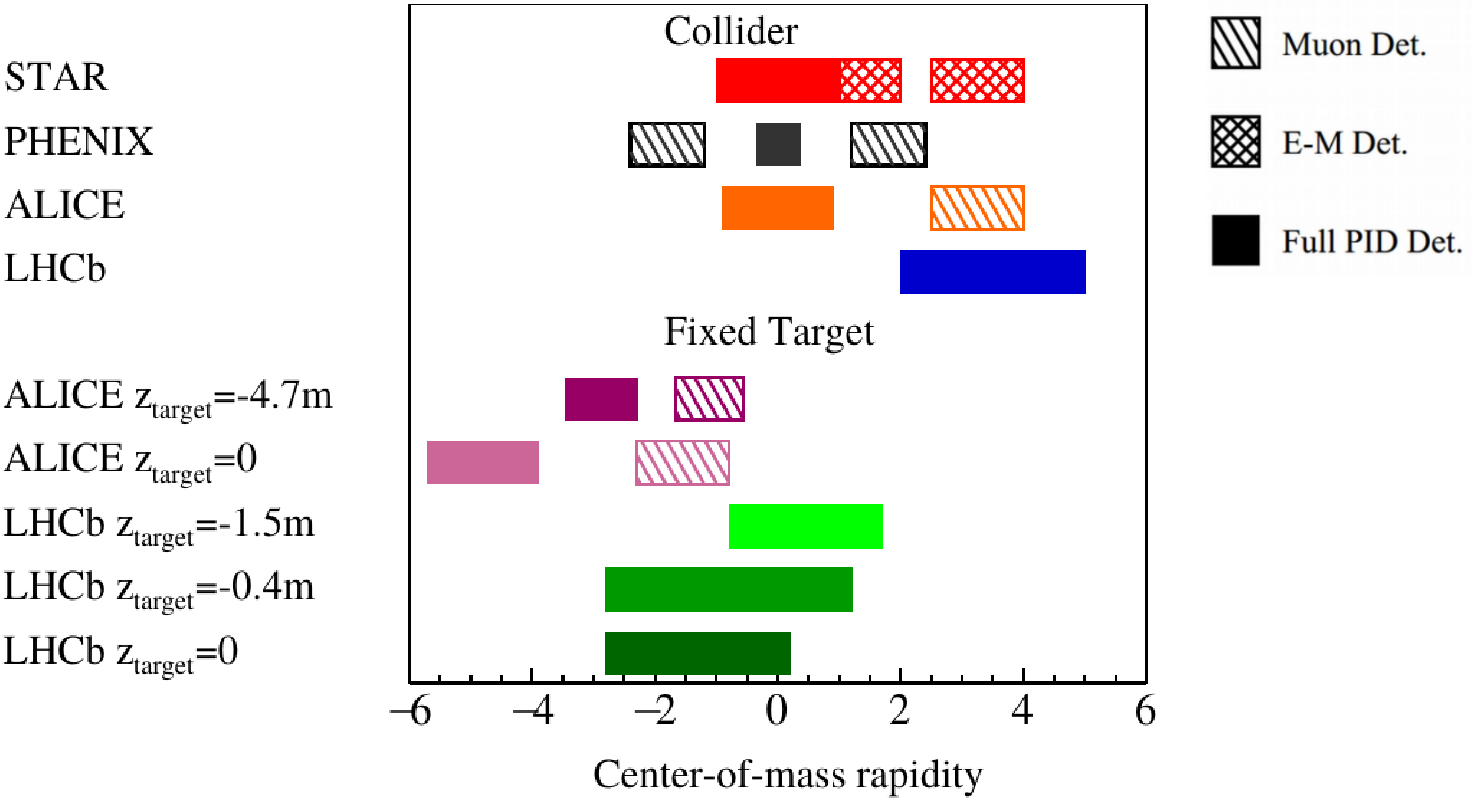




M.Nie, QM19

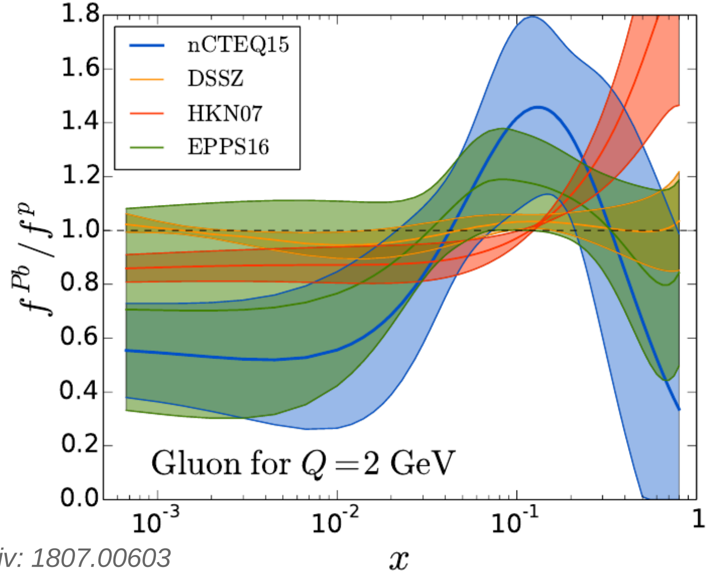
Acceptance in centre-of-mass y

- With7 TeV proton beam
  $\Delta y = 4.8$

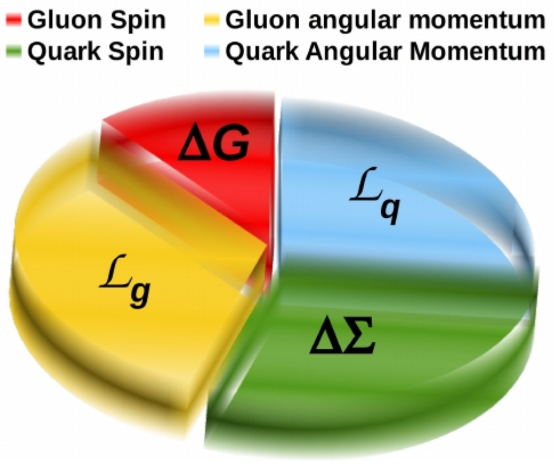


Physics motivations

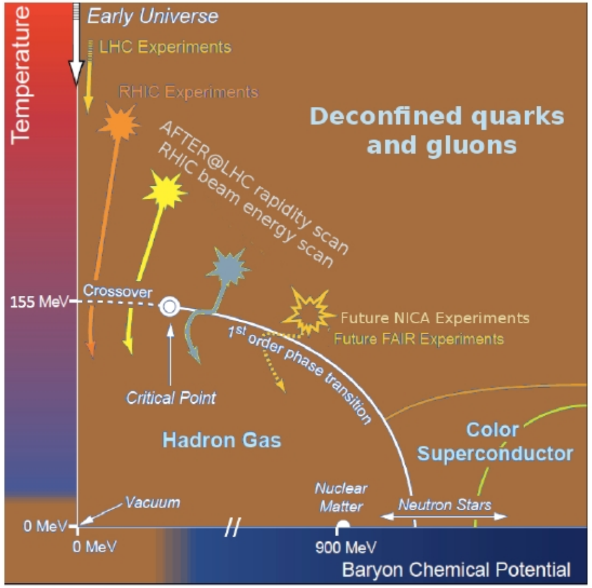
- Advance our understanding of the **high-x frontier in nucleons and nuclei** (gluon and heavy-quark content) **and its connection to astroparticle physics**
- Unravel the **spin of the nucleon**: dynamics and spin distributions of quarks and gluons inside (un)polarised nucleons
- Studies of the **quark-gluon plasma** in heavy-ion collisions at a new energy domain down to the target-rapidity region



arXiv: 1807.00603



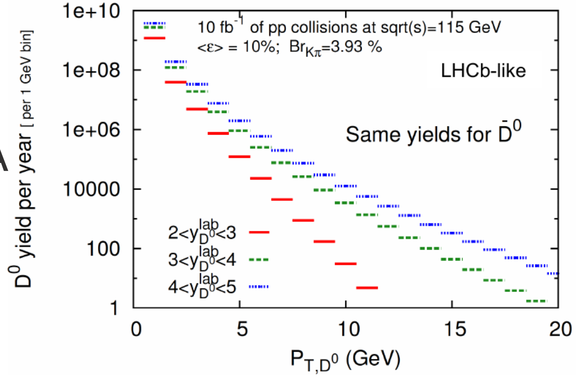
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \mathcal{L}_g + \mathcal{L}_q$$

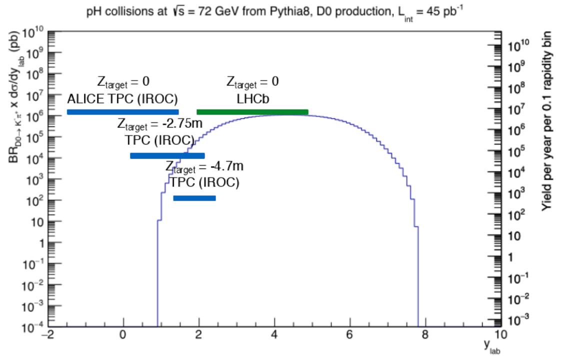


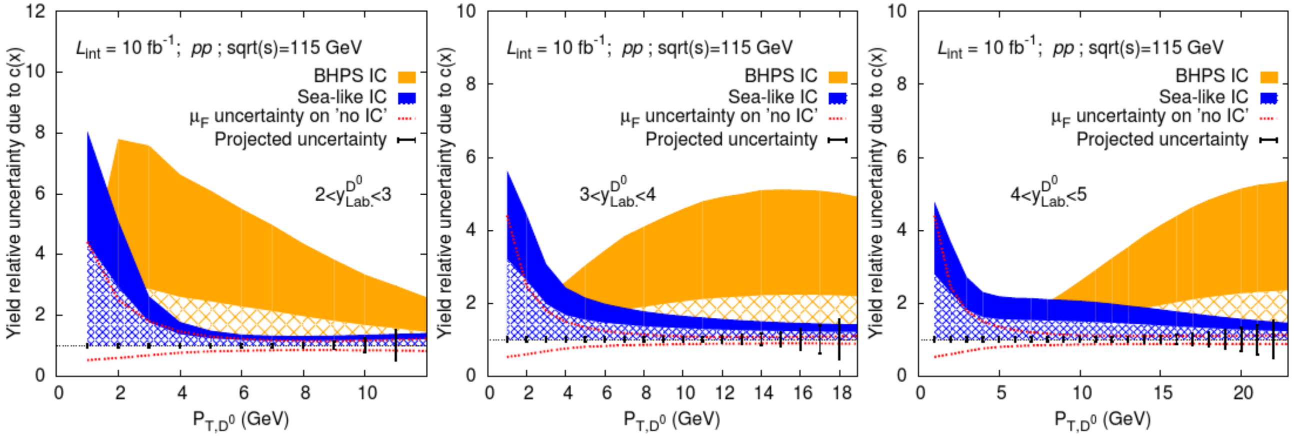
charm PDF (IC) with D

- Extremely good prospects for charm
  - Down to 0 p_T → total charm x-section
  - Wide rapidity coverage, x_F → -1
  - High statistical precision in pp, p-A, A-A
  - With LHCb background well under control
- Intrinsic charm modifies significantly D meson yields at large p_T or forward rapidity
- Large-x → large charm PDF uncertainty
  - Perturbative via gluon splitting vs non-perturbative from intrinsic charm
- Impact on neutrino flux and cosmic-ray physics

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





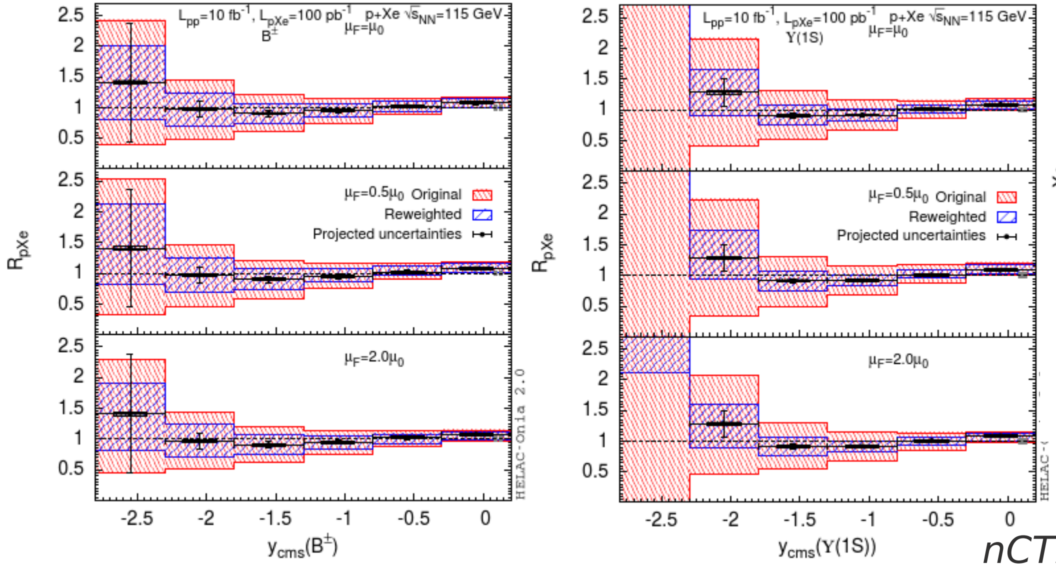


(a) $2 < y_{Lab} < 3$ (b) $3 < y_{Lab} < 4$ (c) $4 < y_{Lab} < 5$

arXiv: 1807.00603

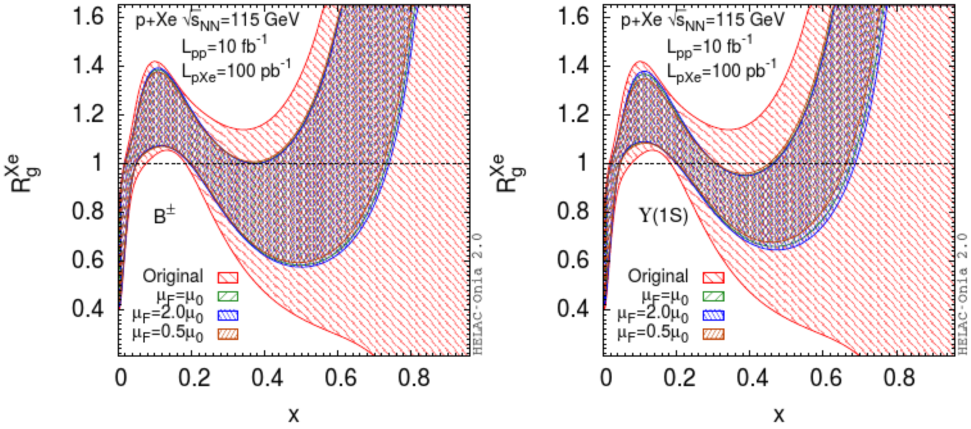
gluon nPDF with heavy-flavour

- Constraining gluon nPDF with D, B and quarkonium measurements
- Almost unknown for x > 0.1; anti-shadowing, EMC effect ?
  - Reweigting analysis with pseudo data on R_{pA}
- Large reduction on the gluon nPDF uncertainty: unique constraints at large x and low scales
- Other nuclear effects in play: nuclear absorption, …



LHCb-like

nCTEQ15

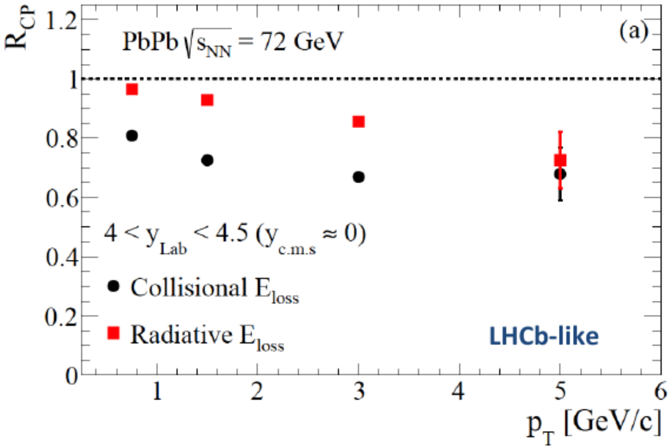


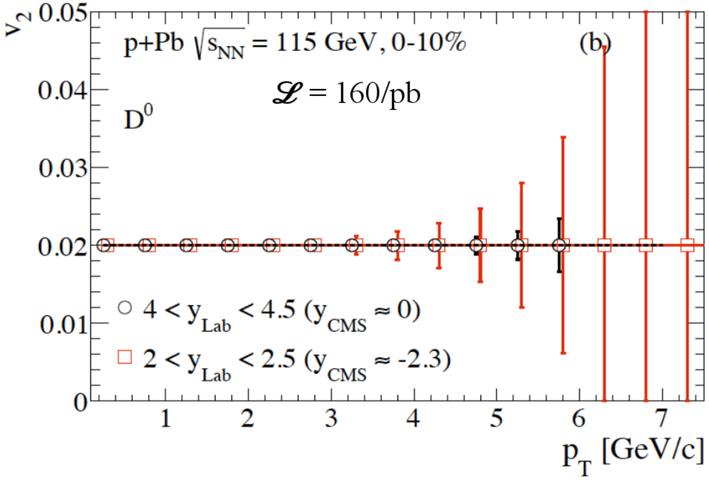
Impact on gluon nPDFs

arXiv: 1807.00603

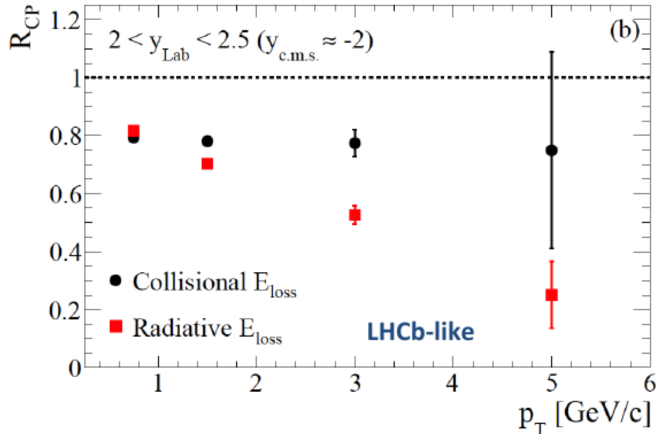
QGP: Open Heavy-Flavour

- Open heavy-flavour in A-A → heavy-quark energy loss in the medium
- Precise suppression measurements of charm and beauty vs rapidity and p_T → medium transport coefficient
- Useful reference for charmonium studies
- p-A: study collective-like effects in small systems
- Precise D meson v_2 measurement
  - Studies with different target type





LHCb-like



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