

LHCb Upgrade 2 for heavy-ion physics

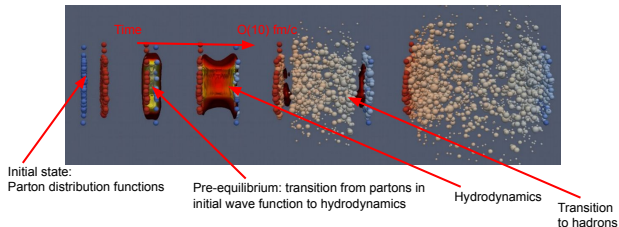
Michael Winn

DPhN IRFU-CEA

Etretat QGP France, July 7, 2021

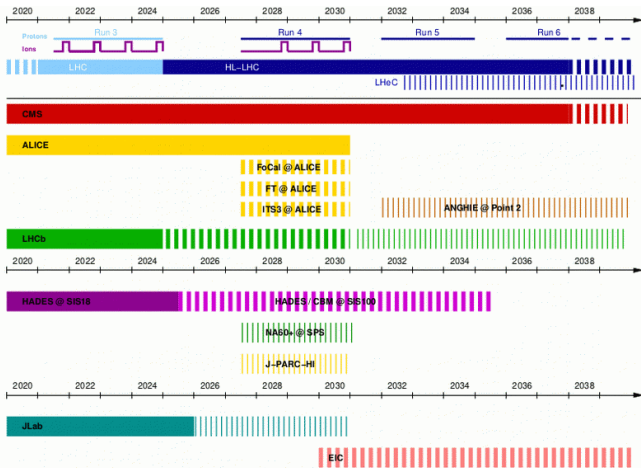


Quark-Gluon-Plasma physics



- ▶ characterize the macroscopic long-wavelength properties of the QGP
→ determine thermodynamic quantities & transport coefficients
- ▶ access the microscopic parton dynamics
→ Degrees of freedom and their coupling at which energy scale and temperature?
- ▶ Develop a unified picture of QCD particle production from small to larger systems
→ How is hadronisation modified? Limits of hydrodynamics and how do we approach it?
- ▶ Constrain the initial conditions: input for heavy-ions and hadron structure

Heavy-ion physics future after 2030



- ▶ after ALICE upgrade, sPhenix (Run 3), ATLAS/CMS upgrades (Run 4), during FAIR/EIC running
- ▶ key: precise & broad & flexible

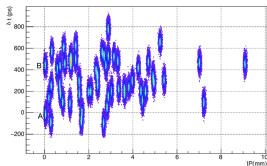
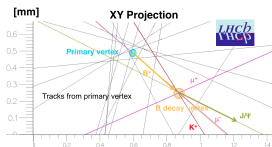
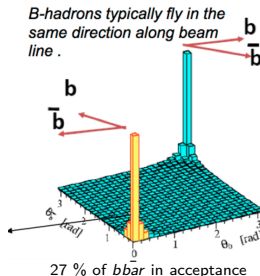
Scientific questions in 2030

- ▶ Characterizing the macroscopic long-wavelength properties of the QGP
→ precise temperature and time evolution of the system
Thermal and preequilibrium radiation
- ▶ Accessing the microscopic parton dynamics underlying QGP properties
→ precise experimental assessment of heavy-flavour transport, of in-medium QCD force and hadronization mechanism
→ **Heavy-flavour & quarkonium in nucleus-nucleus collisions**
- ▶ Developing a unified picture of QCD particle production and initial state from small (pp, γ p, γ Pb) to larger (pA and AA)
→ **high-luminosity pp, pA and fixed-target programmes**

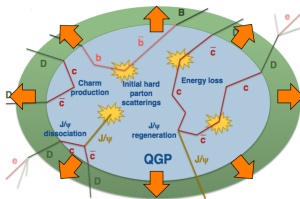
LHCb Upgrade II

LHCb Upgrade II including fixed-target programme

- ▶ longitudinal boost, fully instrumented in $2 < \eta < 5$
 - Access to low p_T at moderate momenta
 - secondary vertexing
- ▶ Precision
 - High rate capability including pp with vertex association
 - Excellent vertex and track resolution
 - good particle identification
- ▶ Flexibility
 - Full software trigger

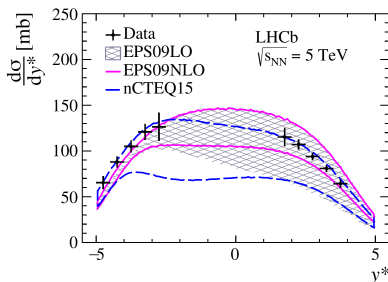


Nucleus-Nucleus collisions with LHCb



- ▶ nucleus-nucleus collisions require Upgrade 2:
Pile-up $O(40)$ in pp \rightarrow conditions become more similar to nucleus-nucleus collisions
- ▶ a unique chance for heavy-ion physics:
feasibility studies: 'worst' case: 0-10% PbPb
- ▶ focus on heavy-flavour and prompt dileptons as highlights
 \rightarrow interesting light-flavour production & correlation programme due to forward acceptance and PID

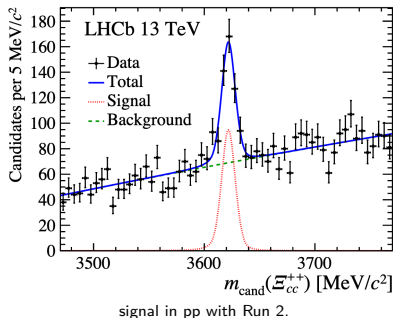
Charm and beauty from midrapidity to forward rapidity



JHEP 1710 (2017) 090.

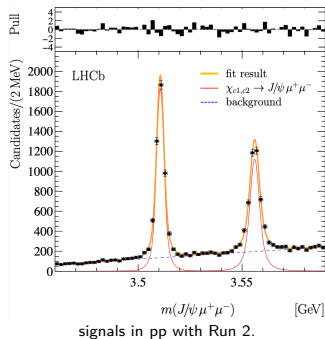
- ▶ hadronisation: limitation to use charm for material properties
- ▶ change heavy quark doping of the QGP crucial to (de)validate picture of heavy-quark hadronisation
→ [arXiv:2104.12754](https://arxiv.org/abs/2104.12754): quark density enters as power
- ▶ charm production in LHCb acceptance:
≈ midrapidity plateau to forward rapidity
- ▶ measure single charm/beauty charm-charm correlations, quarkonium and multi-charm baryons in this rapidity range

Multi-heavy flavour baryons



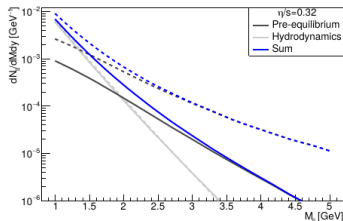
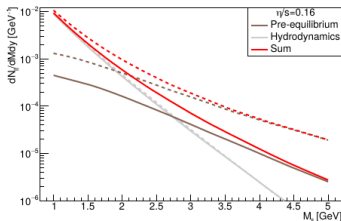
- ▶ first fast simulation study with observed channels by LHCb
- ▶ background reduced via BDT by 8 orders of magnitude via 2ndary and tertiary vertex in PbPb most central, rejection simulation statistics limited
→ so far too low S/B for detection
- ▶ feasibility to be studied in smaller collision systems and with new anticipated decay channels

χ_c to 4 muons



- feasibility study of χ_c : with J/ψ + photon/dielectron/dimuon
- 4-muon channel best: at the edge in 0 – 10% PbPb with about 1% S/B in worst case model
→ promising for smaller collision system with large luminosity

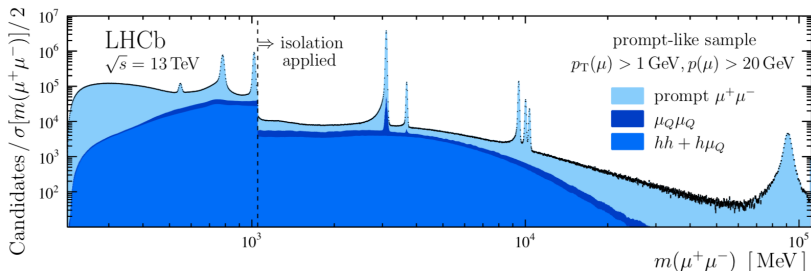
Pre-equilibrium dileptons



Coquet, Du, Schlichting, Ollitrault, Winn [arXiv:2104.07622](https://arxiv.org/abs/2104.07622)

- ▶ how fast do we thermalise?
- ▶ When do charges emerge from the initial state?
→ questions for dileptons at relatively high masses at the LHC
- ▶ window of opportunity at the LHC since DY dominant only at relatively high mass

Nucleus-nucleus: preequilibrium dileptons



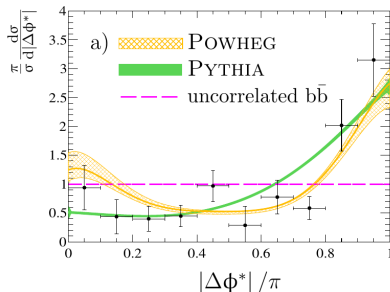
[arxiv:1710.02867](https://arxiv.org/abs/1710.02867)

- ▶ fast simulation studies indicate very good potential in a forward geometry
S/B ≈ 1 : longitudinal boost for muon-ID, large longitudinal vertex displacements for charm/beauty semileptonic decays
 \rightarrow follow-up studies planned with charm tagging
- ▶ measure directly where factorisations breaks in nucleus-nucleus collisions!

High-luminosity pp and pA programme

- ▶ constrain the initial state at low and high- x extremes in parallel to electron-ion collider running
- ▶ probe hadronisation in high-multiplicity
- ▶ precision QCD at intermediate scales with UPC and inclusive probes

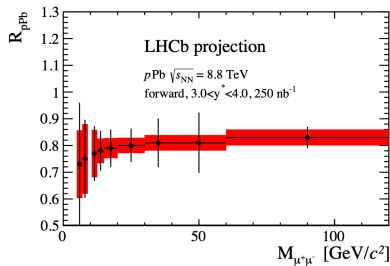
High-luminosity pp programme



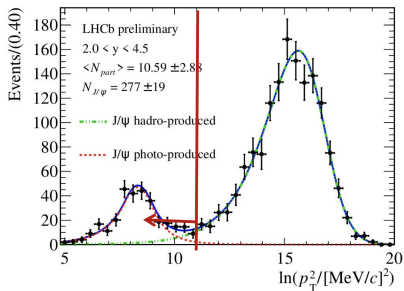
[arXiv:1708.05994](https://arxiv.org/abs/1708.05994) with 3/fb.

- ▶ heavy-flavour physics programme requires:
vertex association, full software trigger, luminosity: 300 /fb
- ▶ unique programme to constrain hadronisation at high-multiplicity
- ▶ discover multiple heavy-flavour as benchmark for ion-ion studies
- ▶ constrain parton heavy-flavour kinematics for heavy-ion studies

Collider QCD measurements for initial state and hadron structure

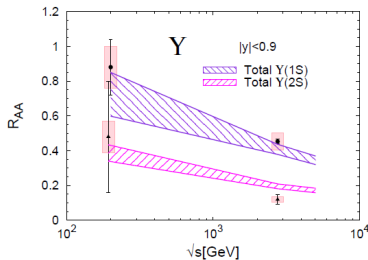
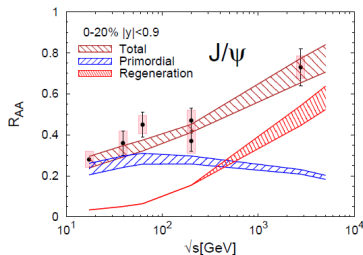


Left: LHCb-CONF-2018-005, right: LHCb-CONF-2018-005



- ▶ forward acceptance: fully-instrumented for low- x physics frontier in parallel with EIC running
- ▶ pA low-mass DY statistically limited in Run 3/4: clean low- x physics with larger lumi
- ▶ γ production and correlations in p-nucleus and pp
- ▶ high statistics UPC in pA/AA for gluon tomography at low- x : exclusive vector mesons (from phi to Upsilon), continuum dimuons, χ_c states for hadron structure
more inclusive photo-production channels to be explored

Addressing open questions with LHCb U2: fixed-target as energy lever arm



Rapp QM 2017

- ▶ energy lever arm: crucial for nucleus-nucleus studies
 - one of keys for our current understanding of heavy-flavour dynamics
 - RHIC: precision limitations for heavy-flavour
- ▶ LHCb well adapted due to forward geometry for fixed-target at $\sqrt{s_{NN}} = 100$ GeV
- ▶ proton-nucleus studies for high- x physics, polarised target: from Run 4 on
 - physics case by AFTER consortium

Interesting areas of research not covered

- ▶ light-flavour production collider as well as fixed target: complementary acceptance to midrapidity collider
→ connection to astroparticle physics and dark matter searches
- ▶ $g - 2$ of tau in UPC:
boosted taus in empty events
- ▶ ultra-low-pt photon measurement with conversions in pp/pA:
Low-theorem
- ▶ push down light-by-light scattering in mass at forward rapidity

Summary

- ▶ broad programme for heavy-ion physics in 2030ies with LHCb:
 - heavy-flavour in nucleus-nucleus with the dedicated heavy-flavour experiment at the LHC
 - a detector for fixed-target ion-ion studies with high-luminosity
 - small collision systems with high-lumi pp, pA to address collectivity, jet universality breaking and precision QCD
 - a low-x frontier programme in parallel to EIC in UPC (pA, AA) and pA
- ▶ open for unidentified areas of interest with unique kinematics, full software triggering and vertex association
- ▶ crucial and unique contributions to heavy-ion physics:
heavy-flavour and quarkonium transport, hadronisation, initial state
→ as function of rapidity and collision energy

Conclusions

- ▶ a detector optimised for intermediate scales at the interplay between soft and hard: a joker card for QCD
 - U2 unique opportunity to make LHCb fit for ion-collisions
 - make tracking work for nucleus-nucleus including PbPb as worst case
 - use calorimeter for unique exclusive decays and pA studies
- ▶ first physics feasibility & detector studies with our colleagues: LLR, Subatech, Saclay, LPNHE, IJCLab and other LHCb colleagues!