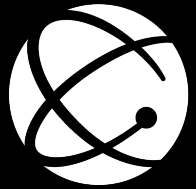


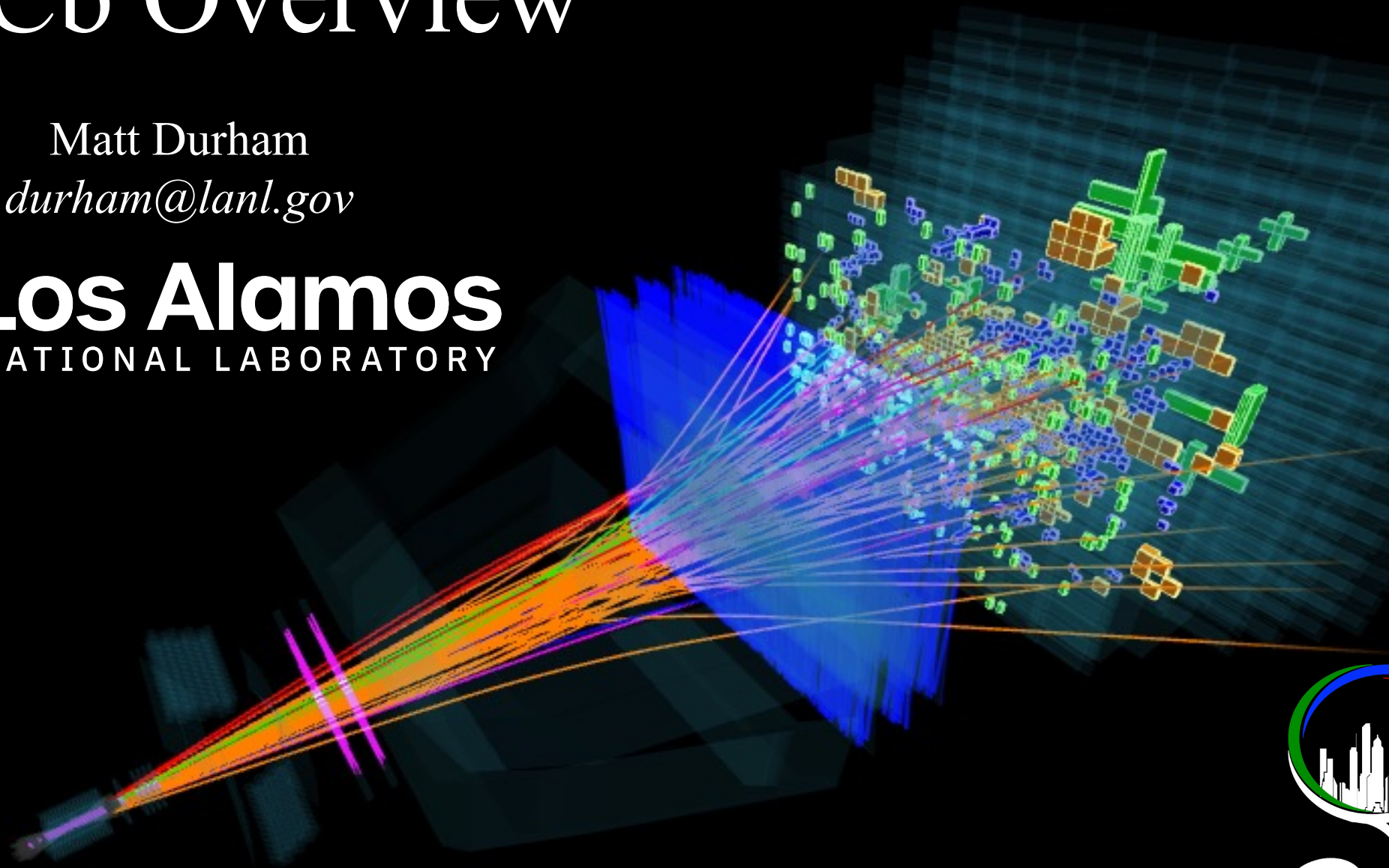
LHCb Overview



Matt Durham
durham@lanl.gov



Los Alamos
NATIONAL LABORATORY



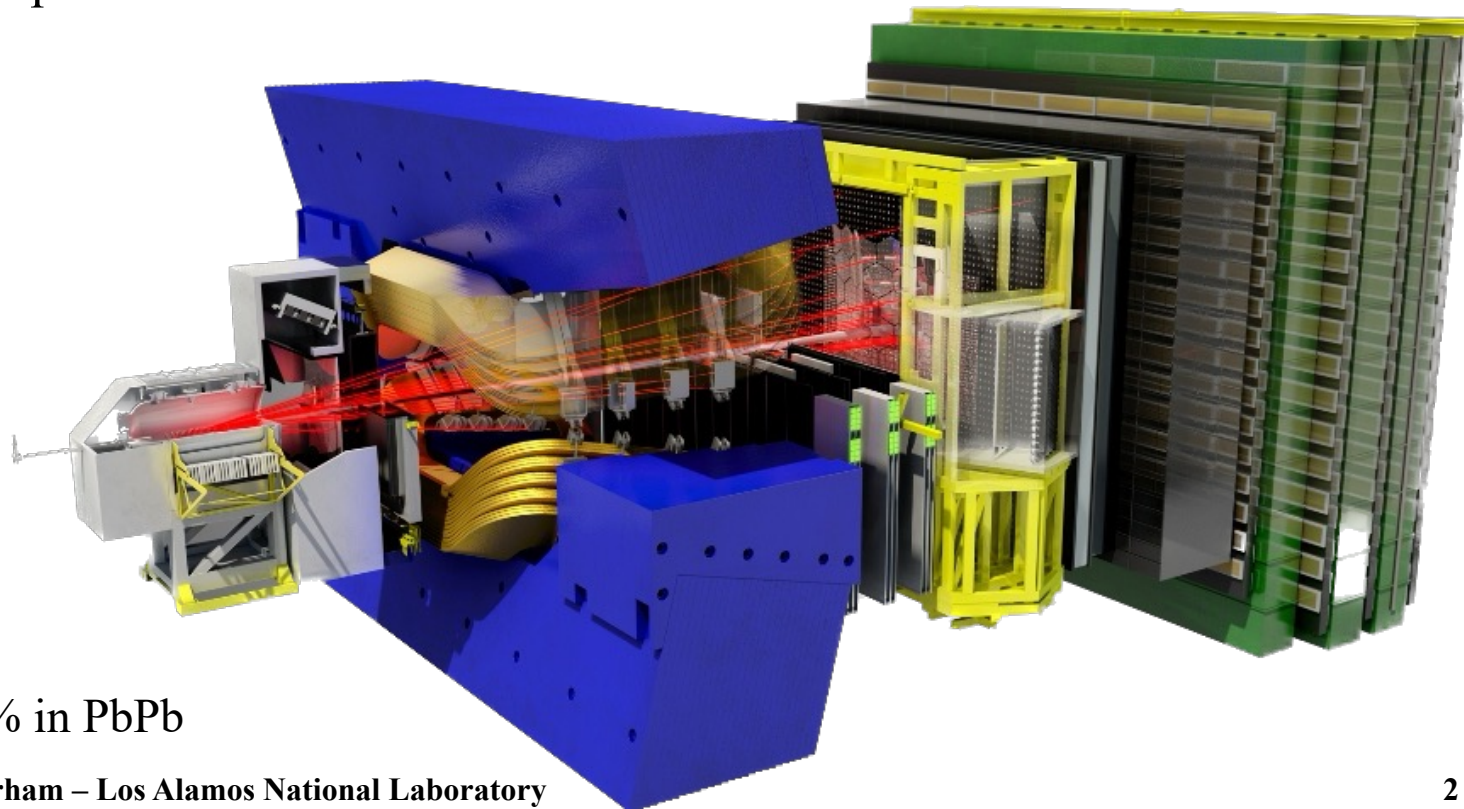
2023

LHCb – a unique place in heavy ion physics



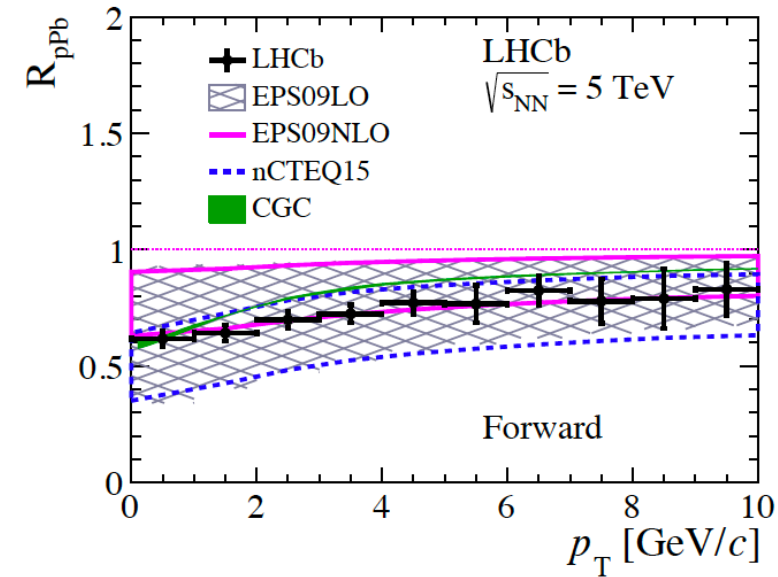
- **Unique forward rapidity coverage**
 - Unparalleled access to low- and high-x regions inside the nucleus
- **Large forward momentum boost**
 - Full PID, reconstruct resonances to $p_T = 0$
 - Clear separation between primary and displaced vertices
- **Fast DAQ and detectors**
 - Access to rare probes:
higher quarkonia, exotic states
- **Upgraded fixed-target system**
 - Explore p+gas and Pb+gas collisions
 - Hugely versatile physics program
- **Major upgrades underway**
 - Increase centrality reach from ~60% to ~30% in PbPb

**A general purpose detector
at forward rapidity**



Constraining nPDFs with D mesons

JHEP 1710 (2017)

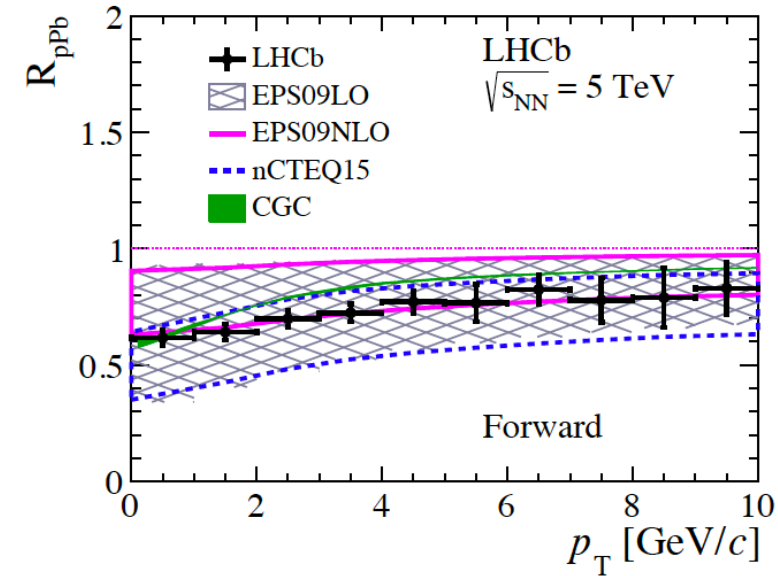


- LHCb D meson data: significantly more precise than calculations from older nPDF sets



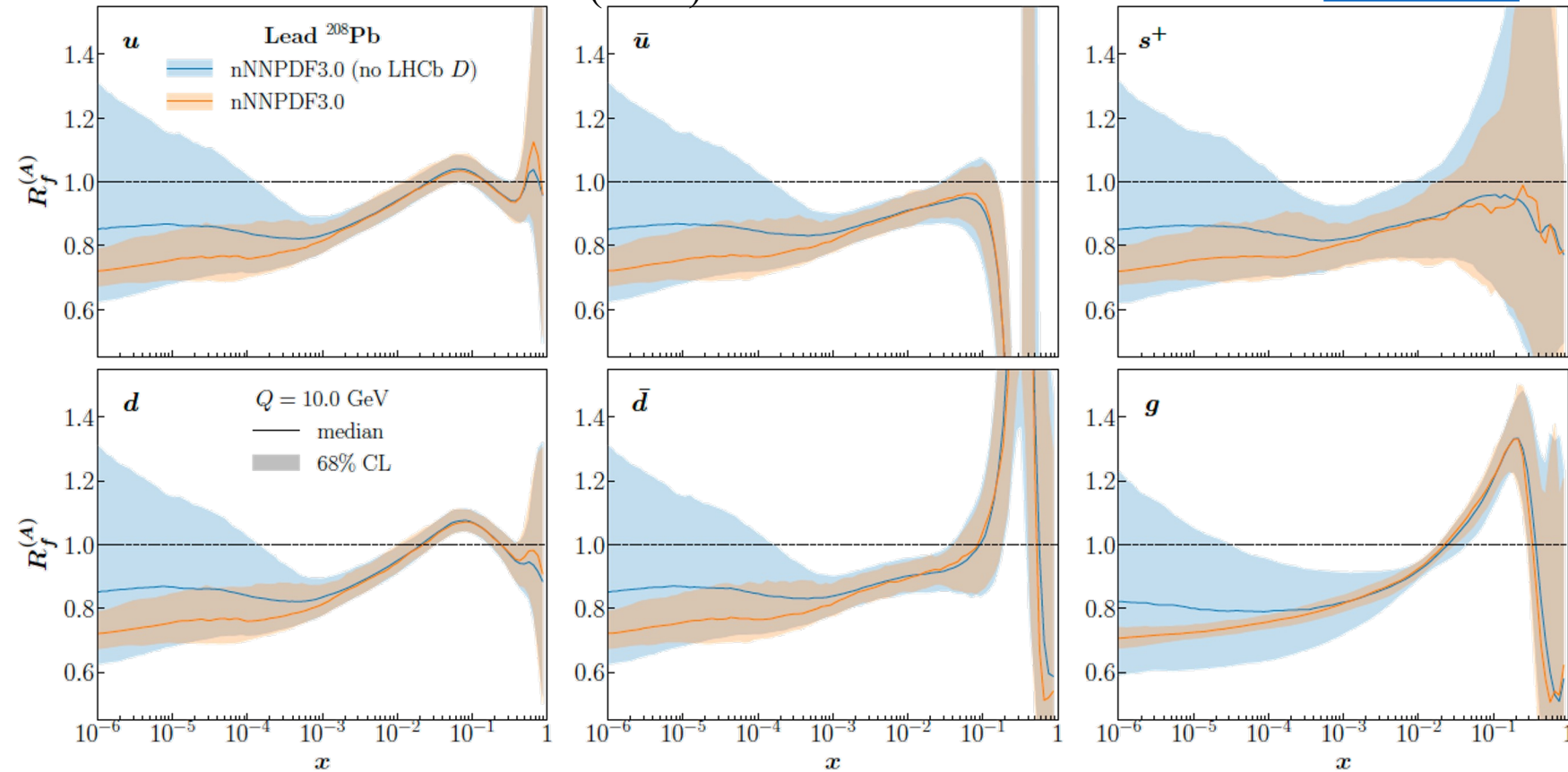
Constraining nPDFs with D mesons

JHEP 1710 (2017)



- LHCb D meson data: significantly more precise than calculations from older nPDF sets
- Now included as constraint in updated nPDF sets

nNNPDF3.0 *EPJC* 82 507 (2022)



LHCb data currently constrains nPDFs down to $x \sim 10^{-6}$
Places especially stringent bounds on gluon nPDF



NEW! Identified particles at low-x

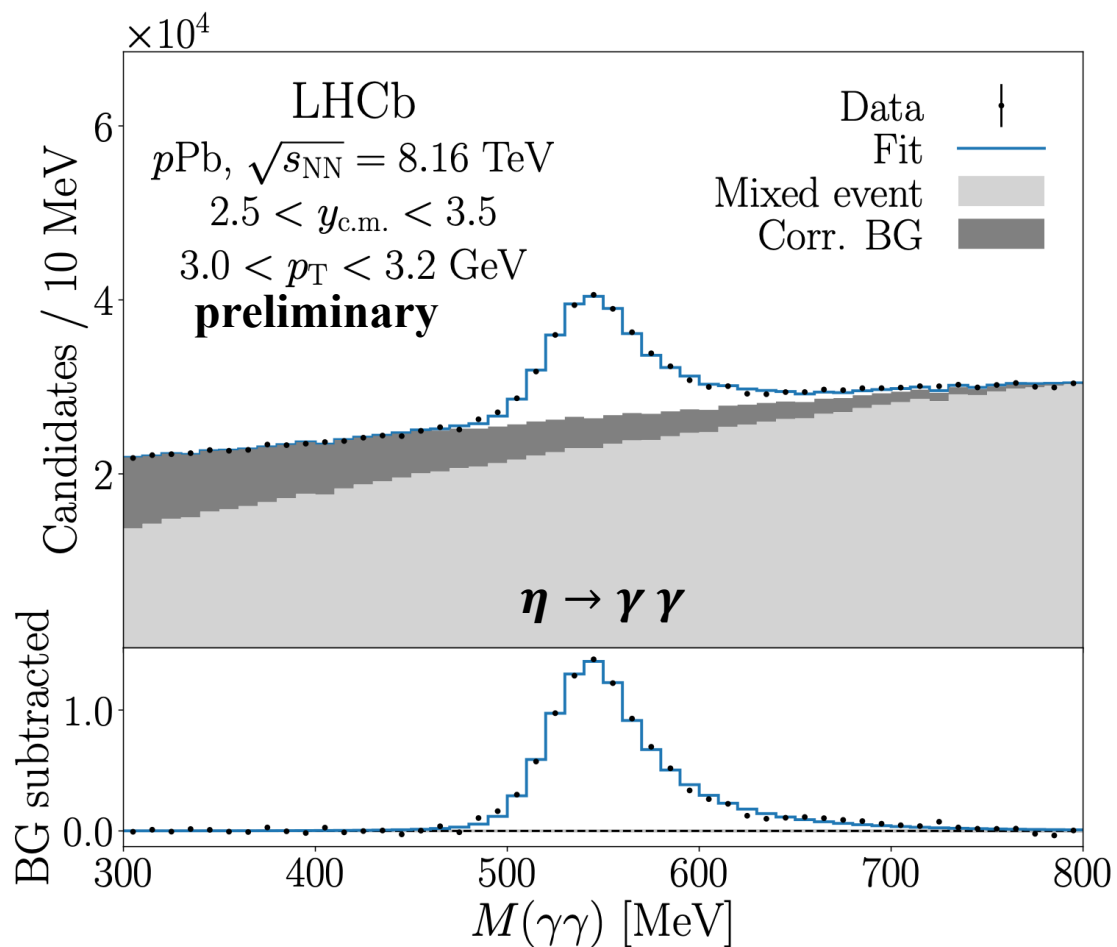
LHCb-PAPER-2023-030
in preparation



Tom Boettcher

Tues 16:30

- Nuclear modification of identified particles allows us to probe mass-dependent effects



NEW! Identified particles at low-x

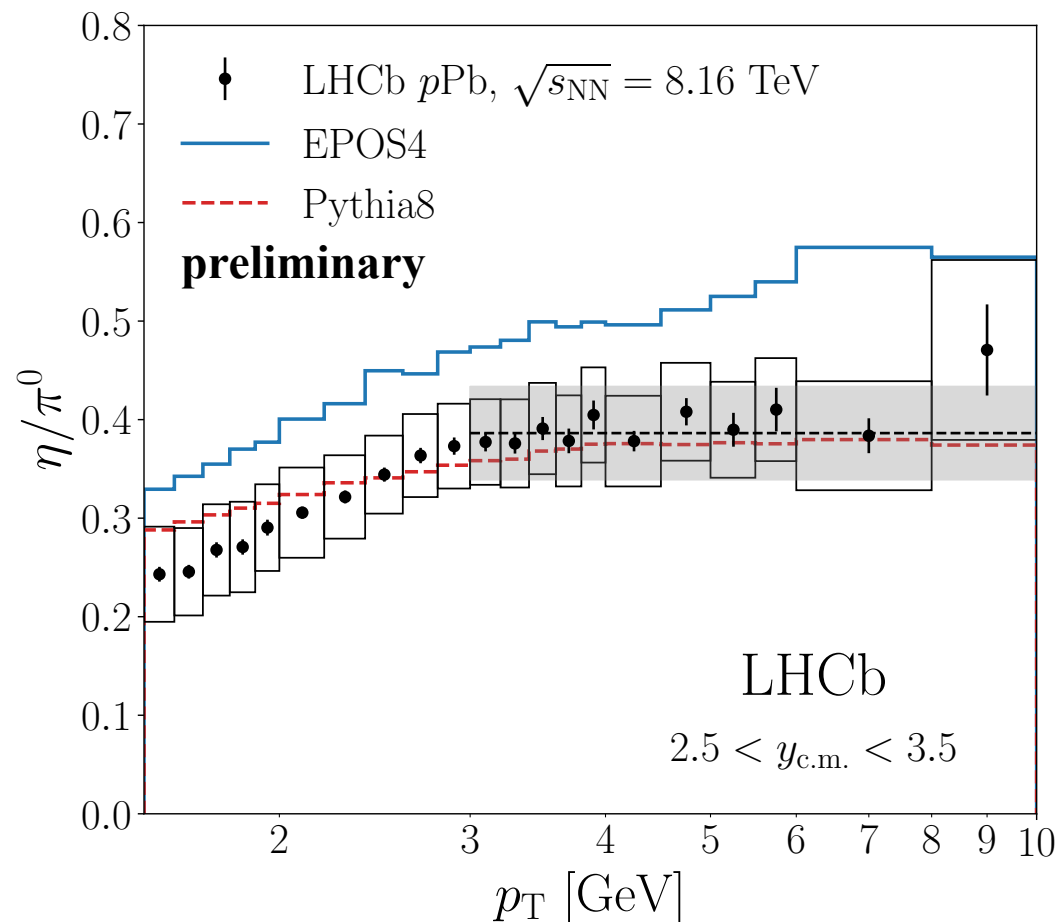
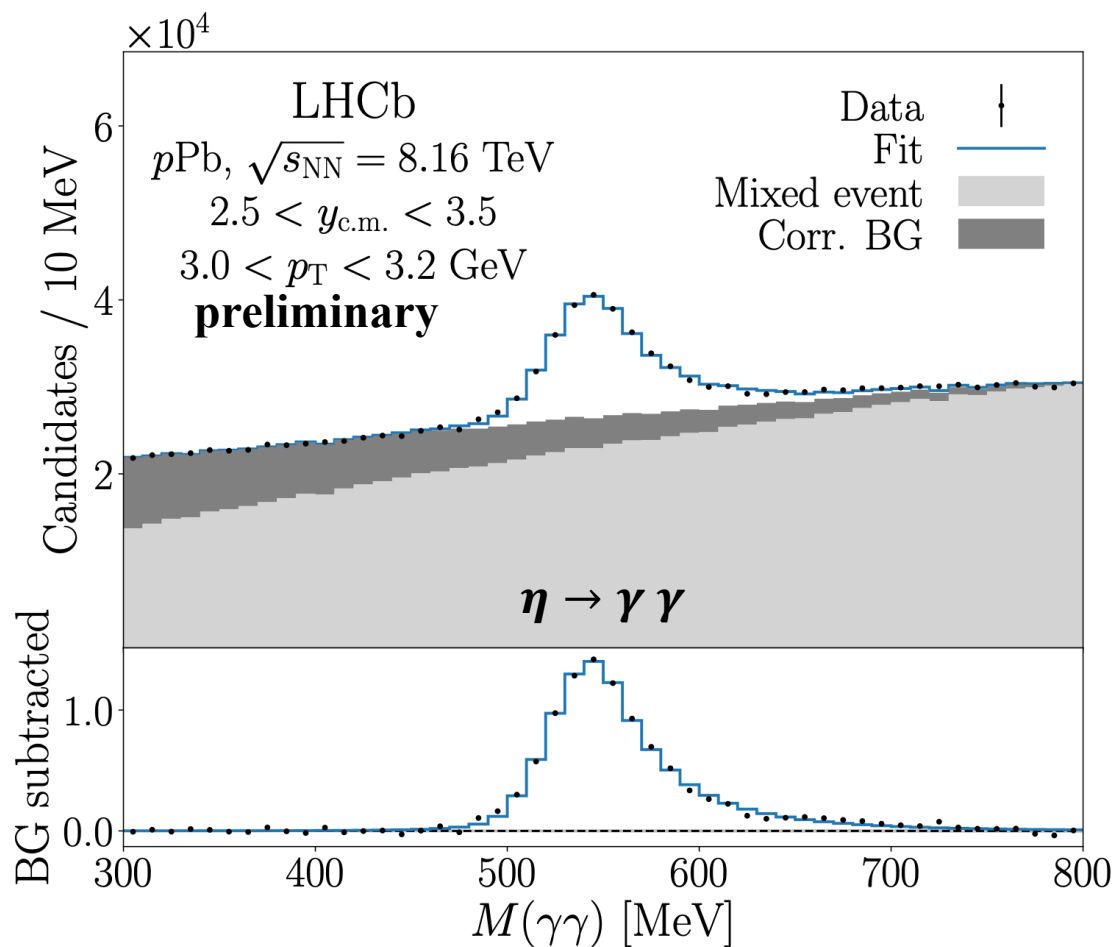
LHCb-PAPER-2023-030
in preparation



Tom Boettcher

Tues 16:30

- Nuclear modification of identified particles allows us to probe mass-dependent effects



NEW! Identified particles at low-x

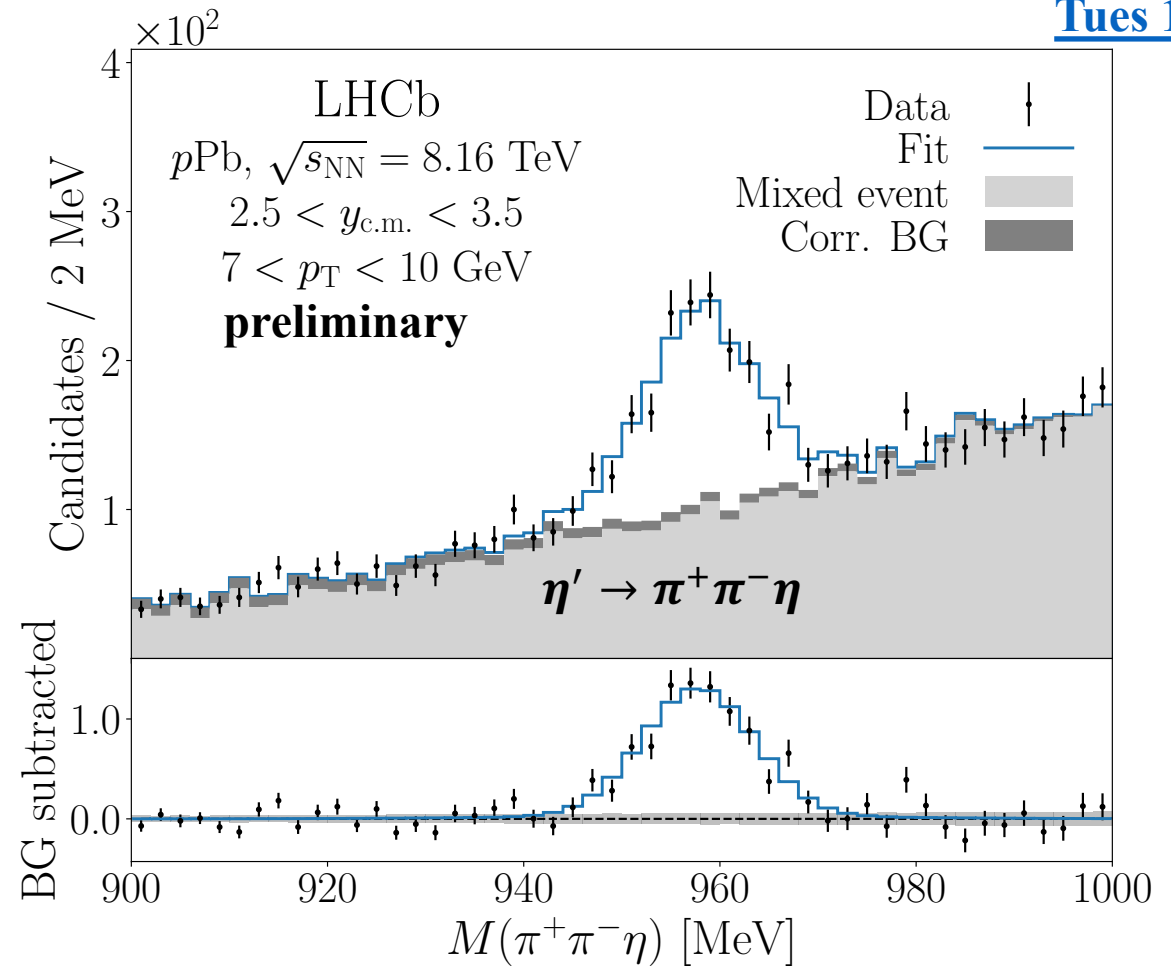
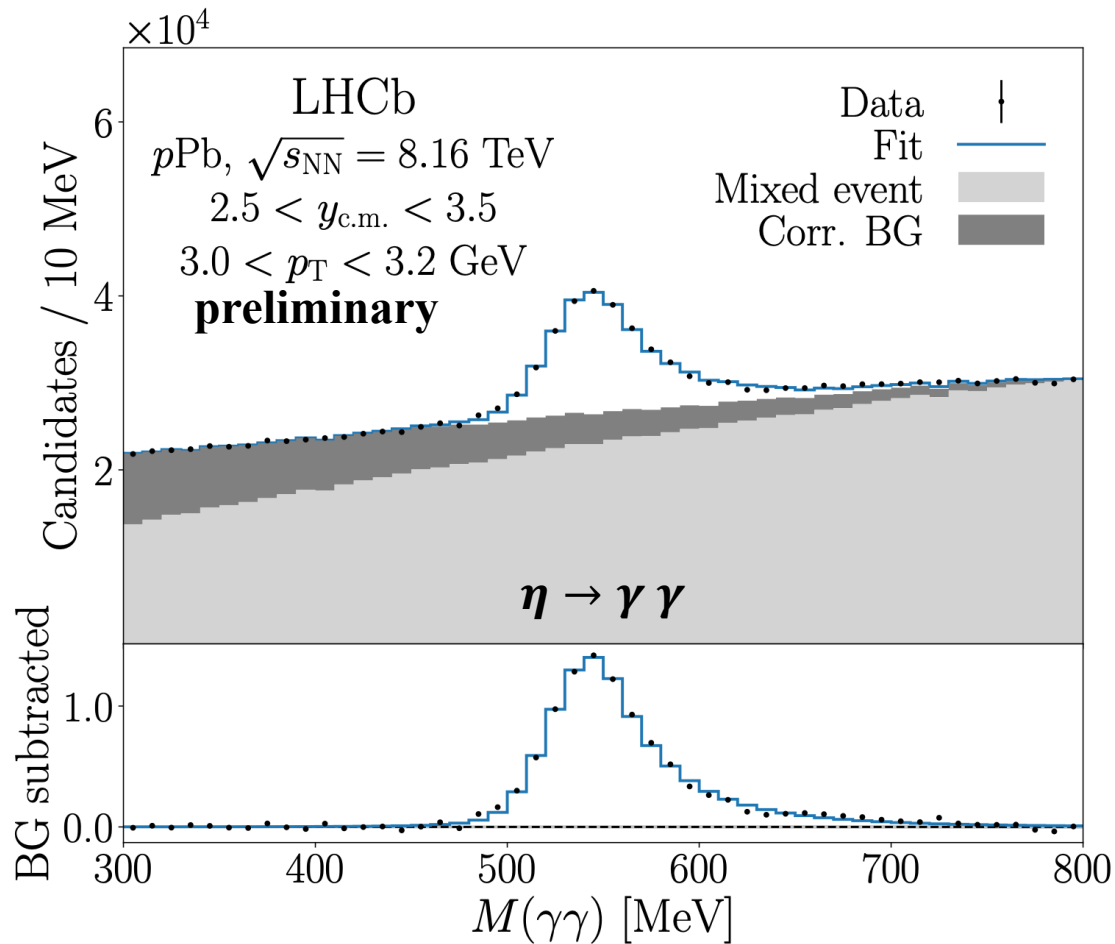
LHCb-PAPER-2023-030
in preparation



Tom Boettcher

Tues 16:30

- Nuclear modification of identified particles allows us to probe mass-dependent effects
- The η' is especially interesting: a meson with nearly the same mass as a proton



NEW! Identified particles at low-x

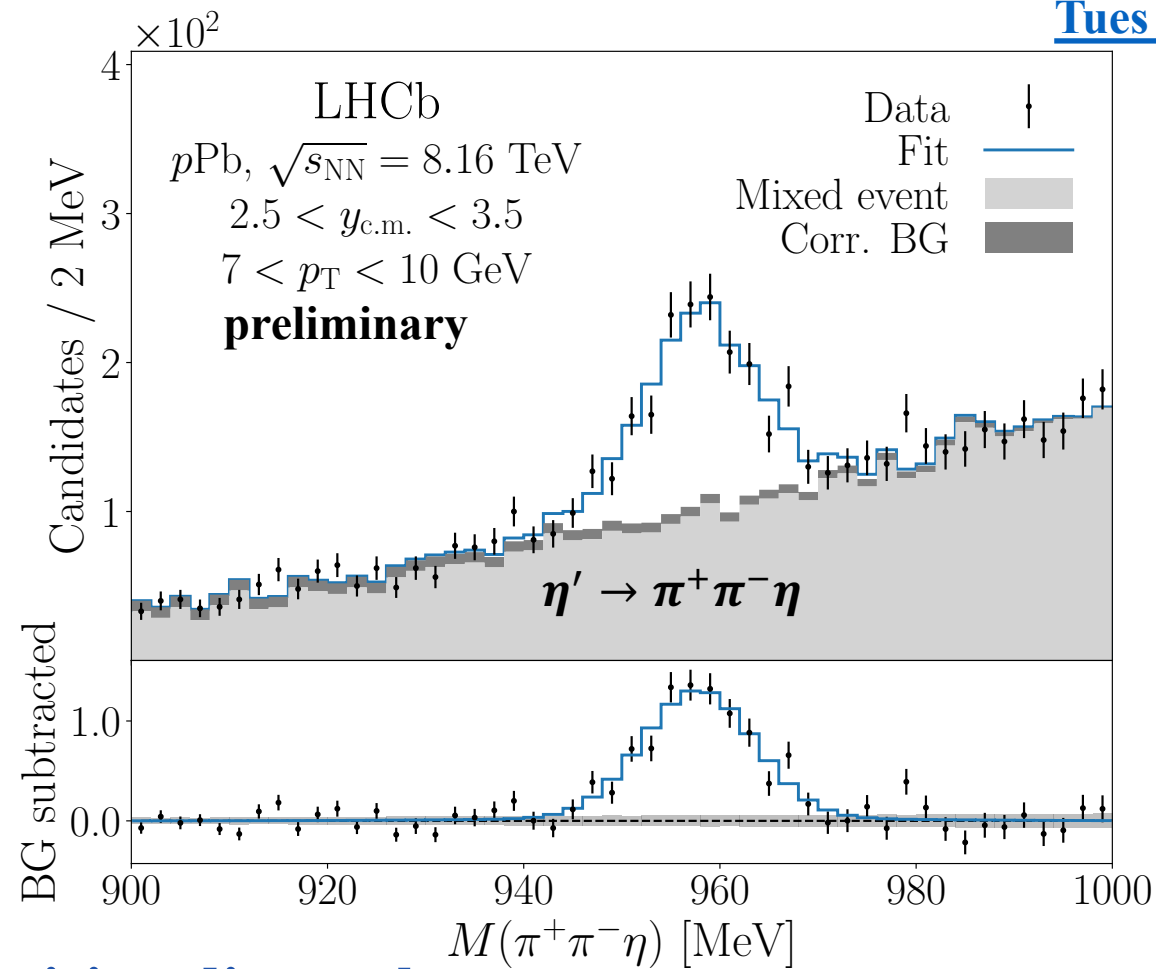
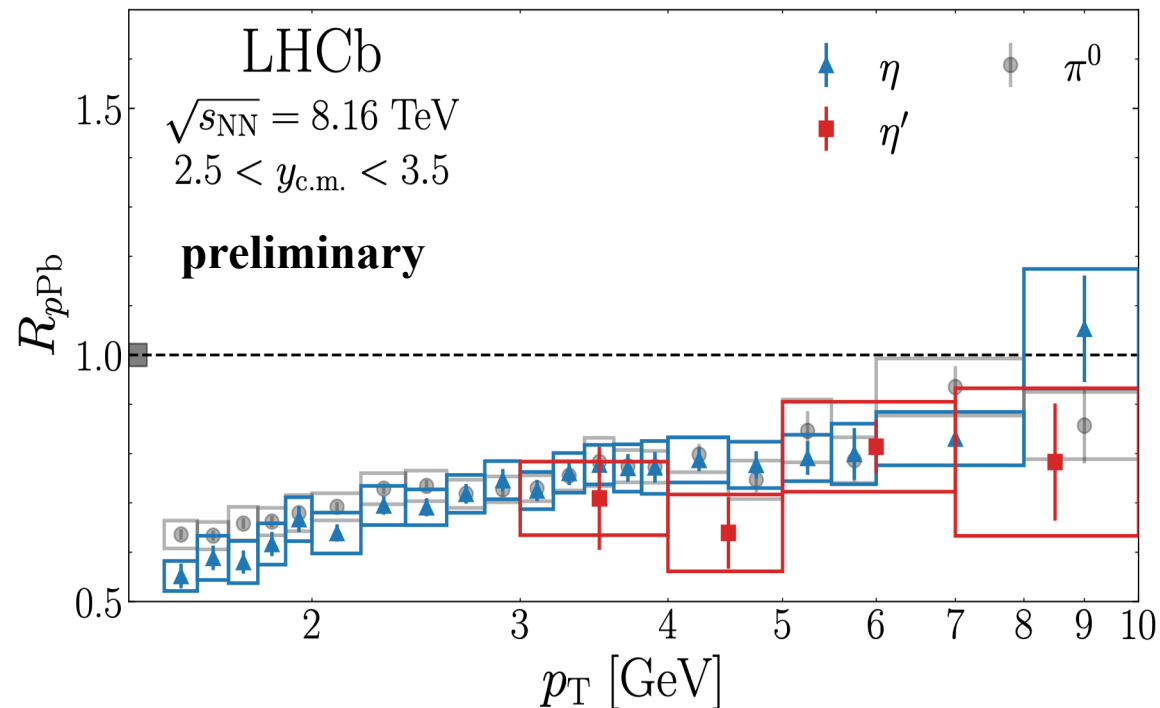
LHCb-PAPER-2023-030
in preparation



Tom Boettcher

Tues 16:30

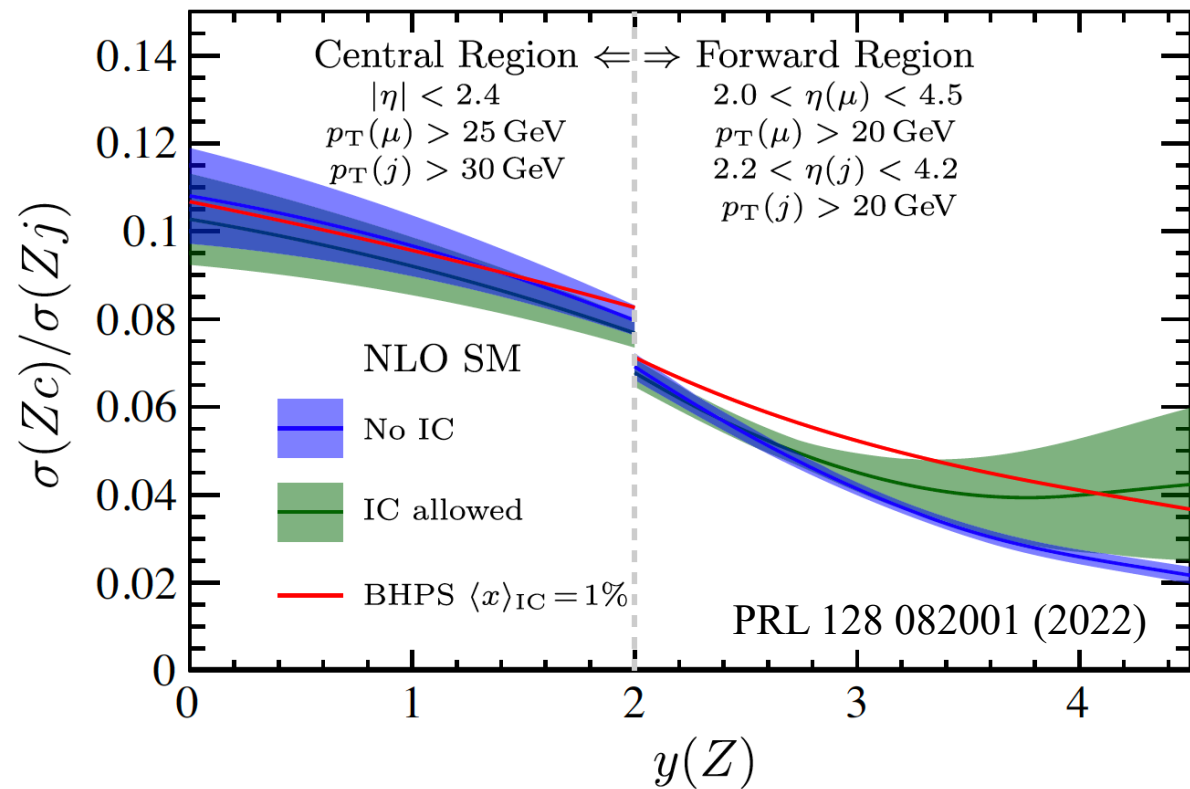
- Nuclear modification of identified particles allows us to probe mass-dependent effects
- The η' is especially interesting: a meson with nearly the same mass as a proton
- No evidence for mass-dependent R_{pPb}
- Potential baryon vs meson effects?



Important input towards a precision direct photon measurement



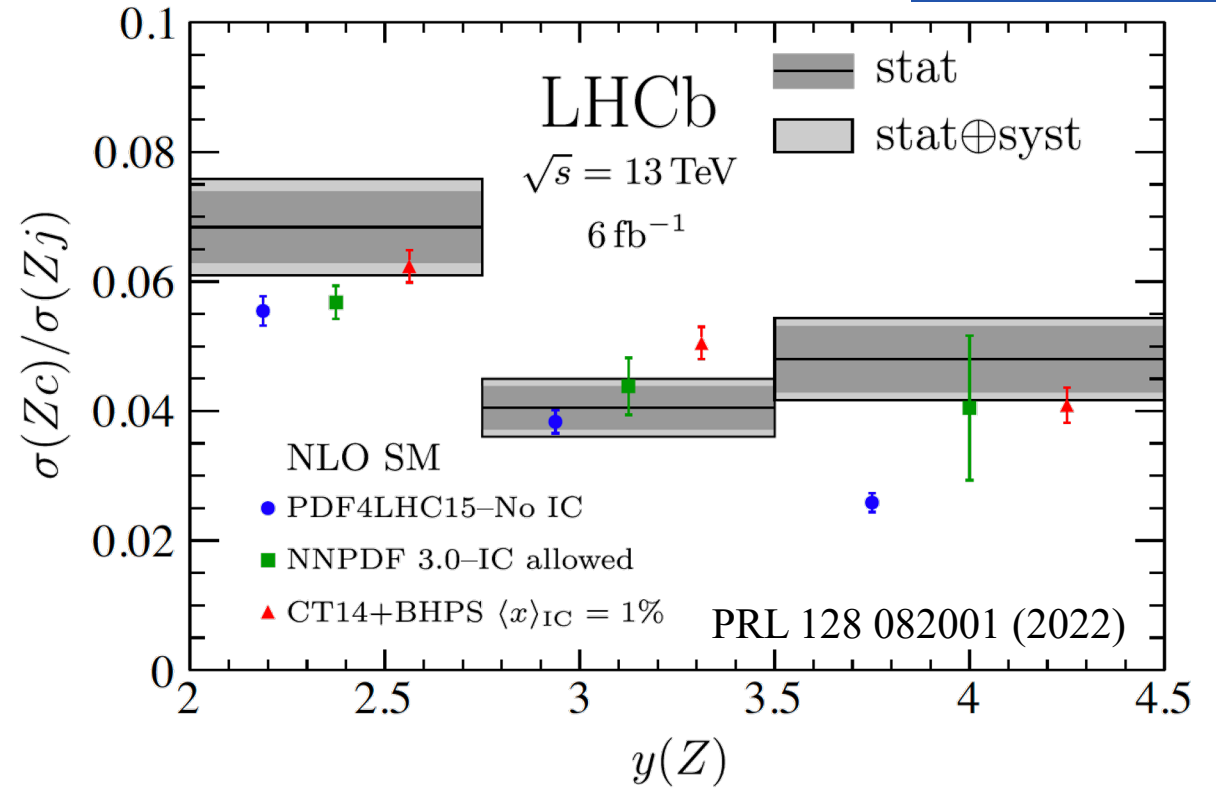
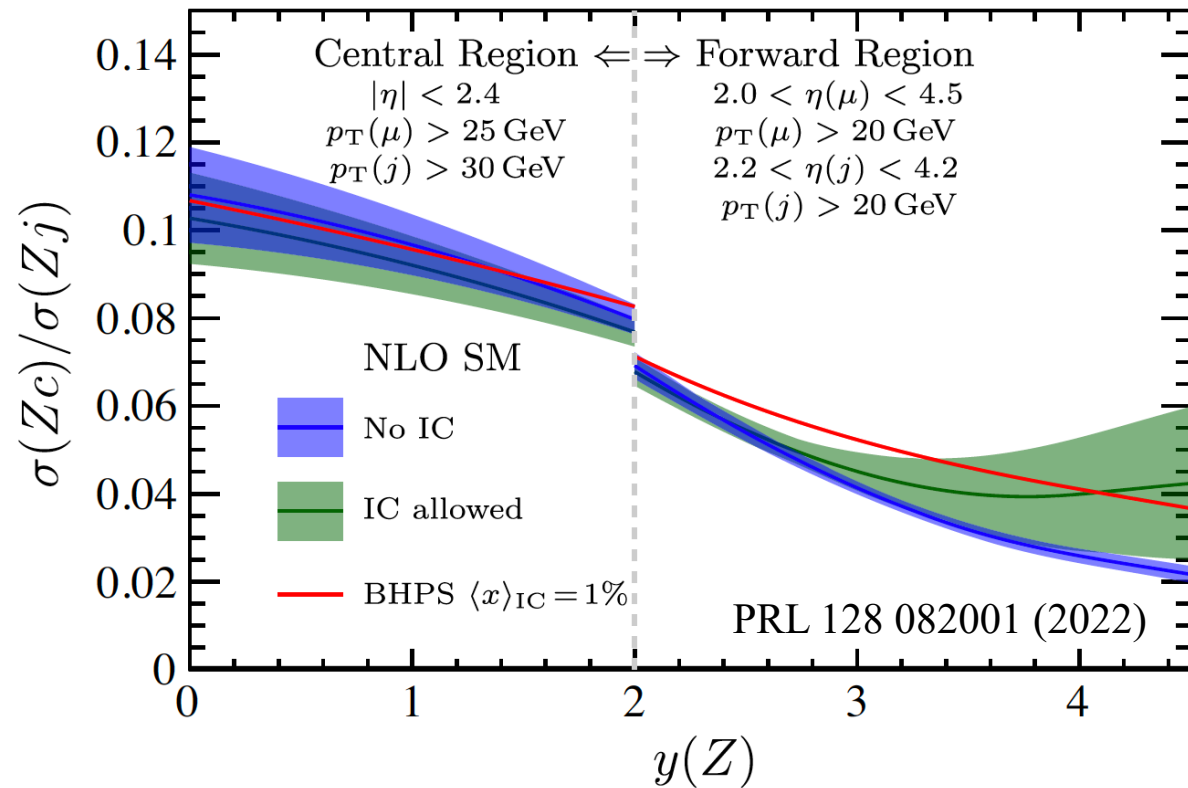
Intrinsic charm



- $Z + \text{jet}$ production at forward rapidity probes high x region – sensitive to intrinsic charm



Intrinsic charm



- $Z + \text{jet}$ production at forward rapidity probes high x region – sensitive to intrinsic charm

- LHCb data favors calculations allowing IC at most forward rapidity

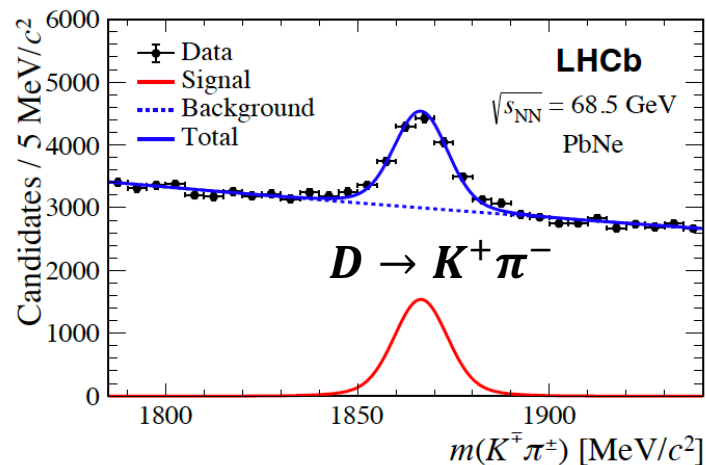
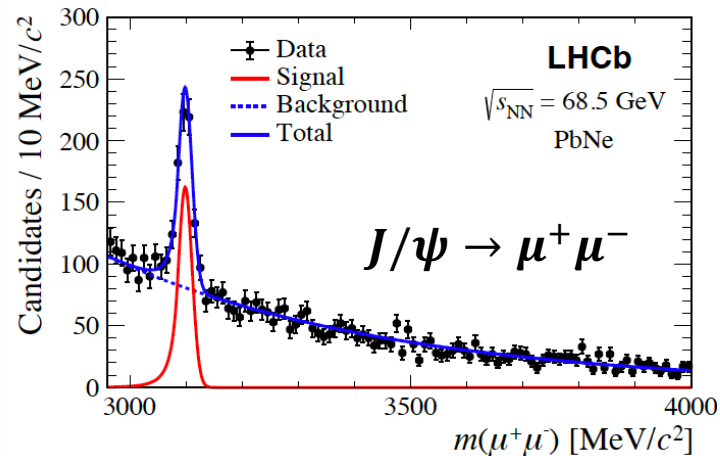
Recent global PDF analysis finds **3σ evidence** for IC in proton: NNPDF collab, *Nature* 608 (2022)

- Data currently statistics limited, Run 3+ fertile soil for future exploration



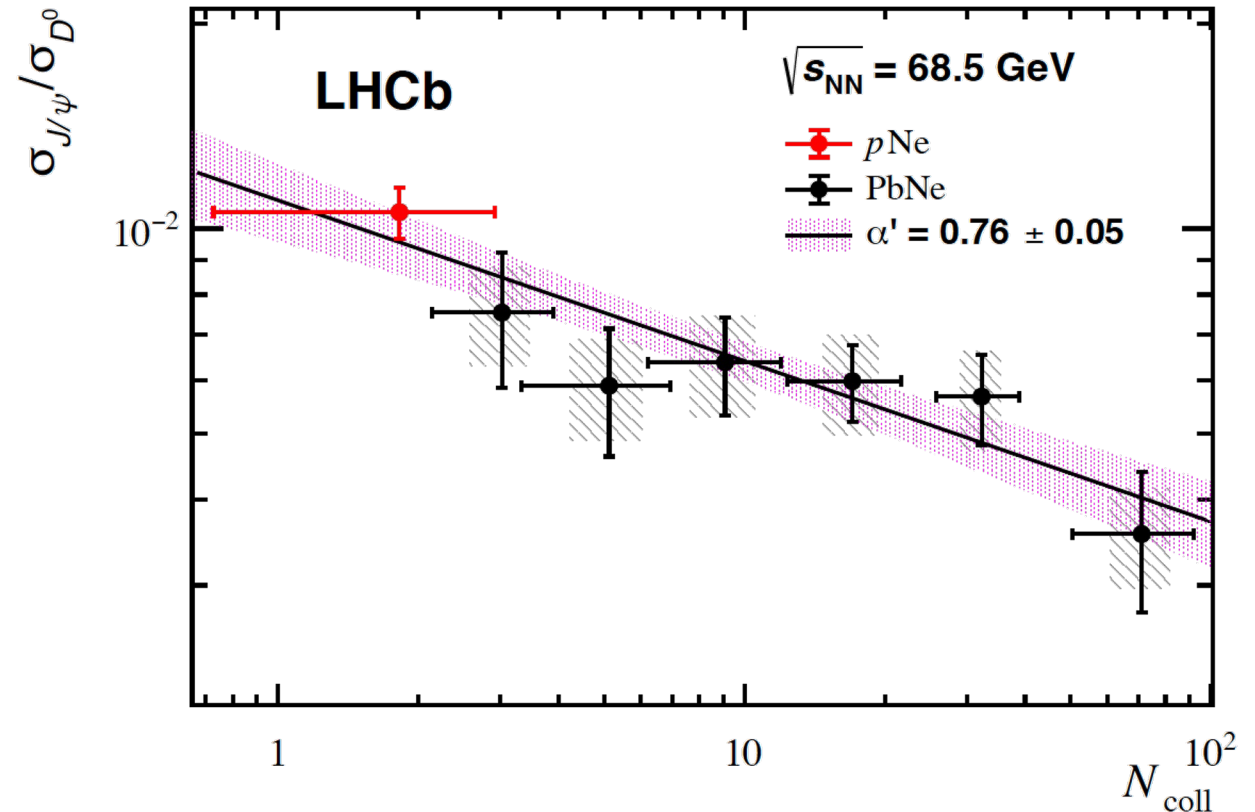
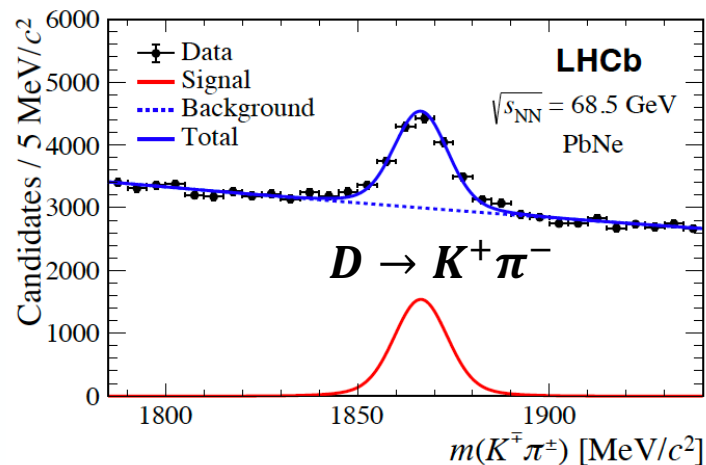
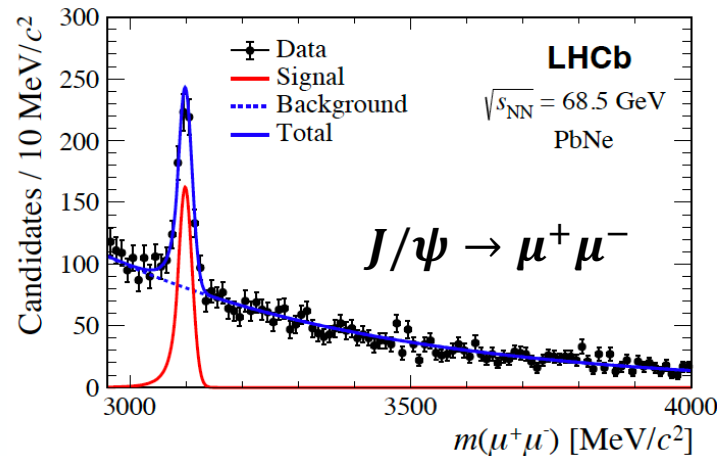
Charm in fixed-target collisions

- Multiple charm(onium) results now available from pHe, pNe, pAr, PbNe collisions
- Allows us to study onset of nuclear effects and transition to QGP as a function of system size



Charm in fixed-target collisions

- Multiple charm(onium) results now available from pHe, pNe, pAr, PbNe collisions
- Allows us to study onset of nuclear effects and transition to QGP as a function of system size
- One example: use open charm as baseline to study charmonium suppression



No evidence for “anomalous suppression” in PbNe
Coming soon: PbAr data



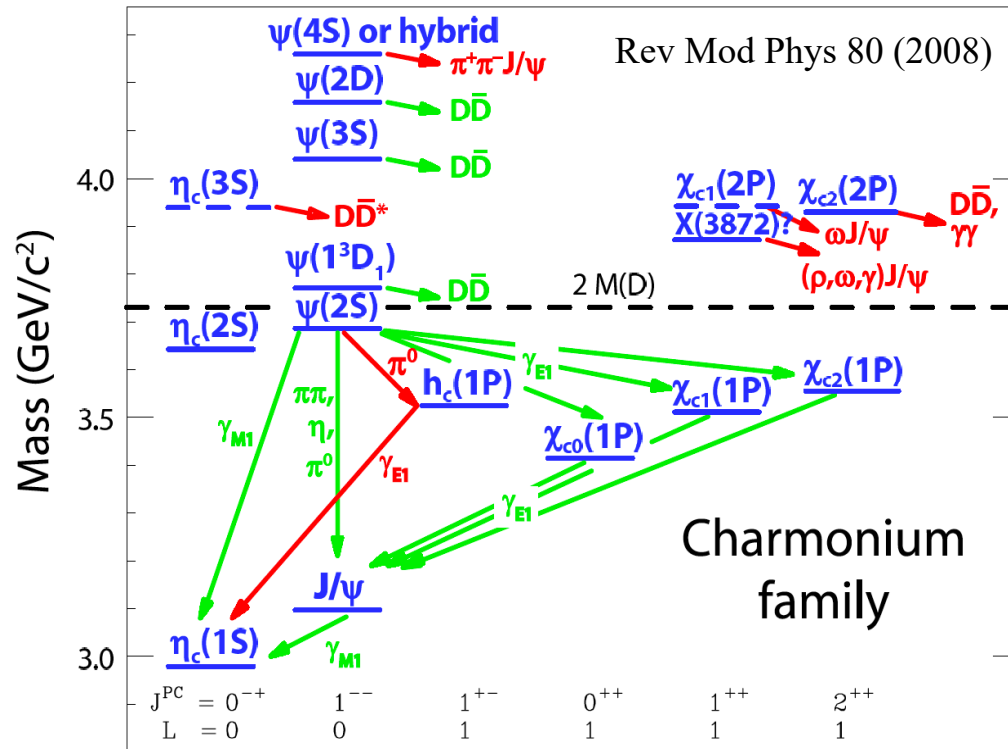
Higher charmonia in $p\text{Pb}$

LHCb-PAPER-2023-024, 028
in preparation



Cesar da Silva
Tues 12:40

- A significant fraction of J/ψ production comes from feeddown: decays of higher charmonia states
- Higher charmonia with weaker binding energies may also be more sensitive to final-state effects

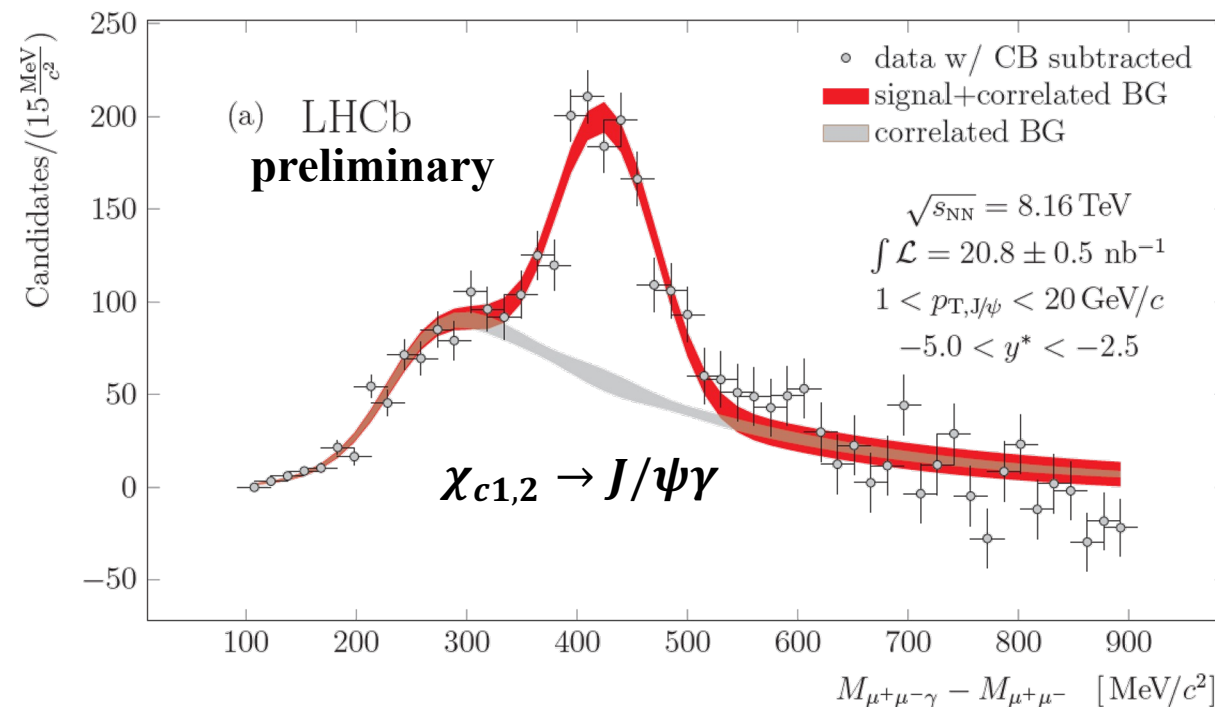
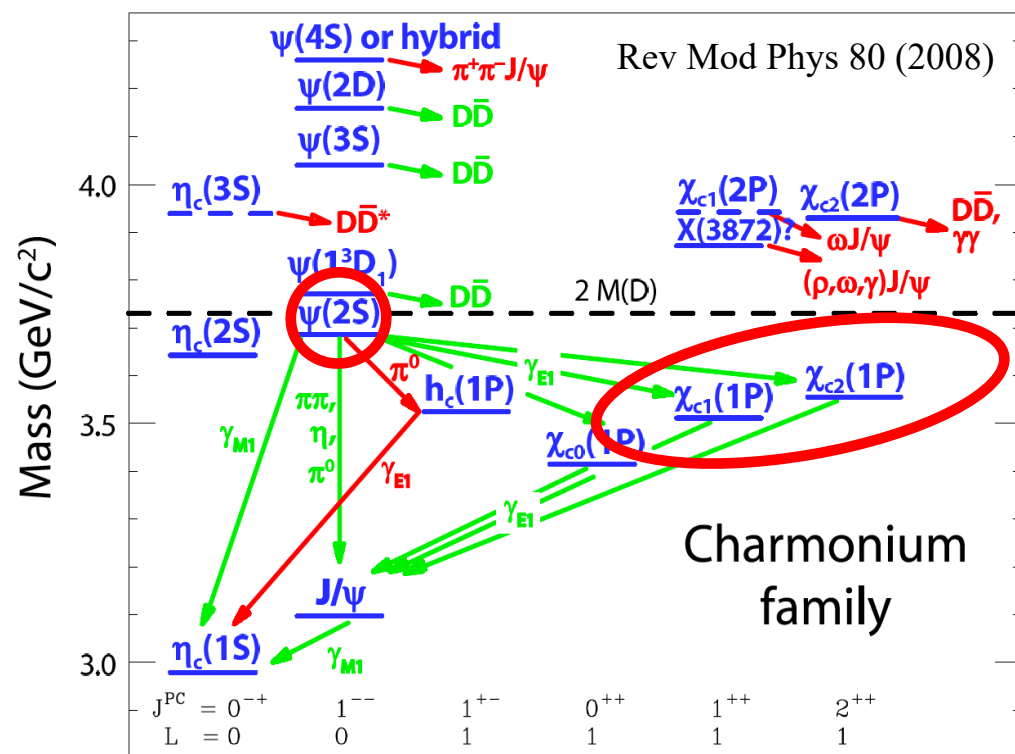


Higher charmonia in $p\text{Pb}$



Tues 12:40

- A significant fraction of J/ψ production comes from feeddown: decays of higher charmonia states
- Higher charmonia with weaker binding energies may also be more sensitive to final-state effects



NEW!

Higher charmonia in $p\text{Pb}$

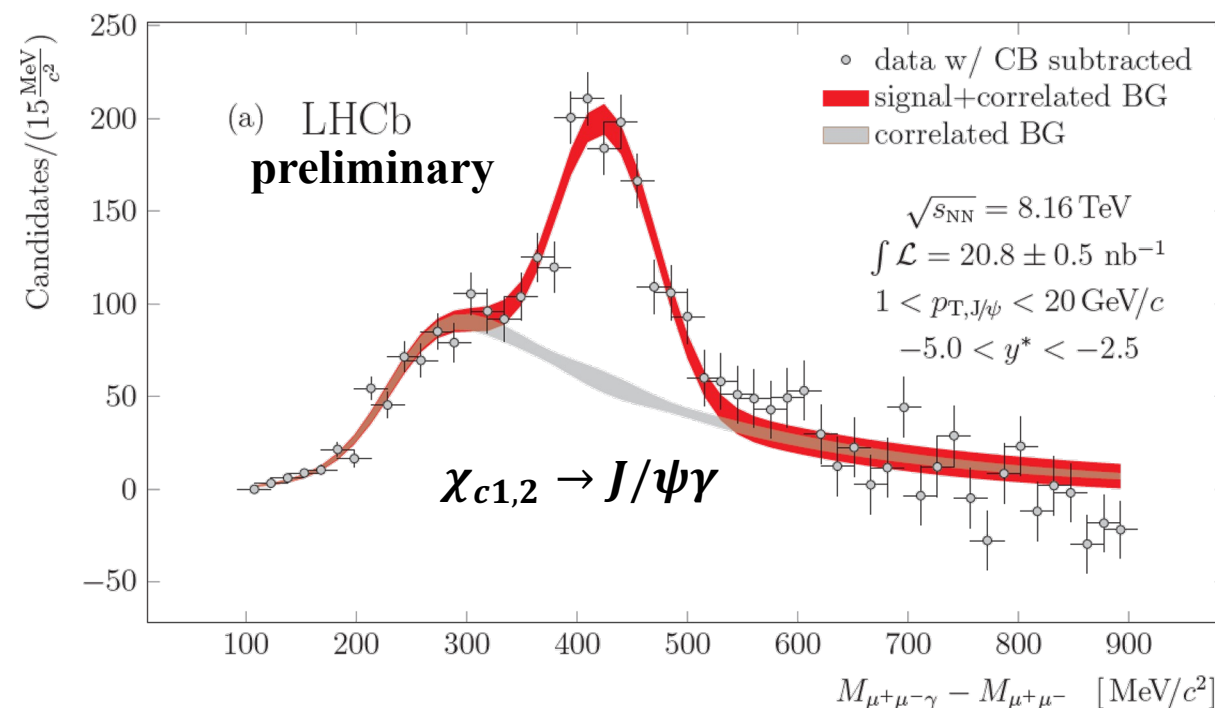
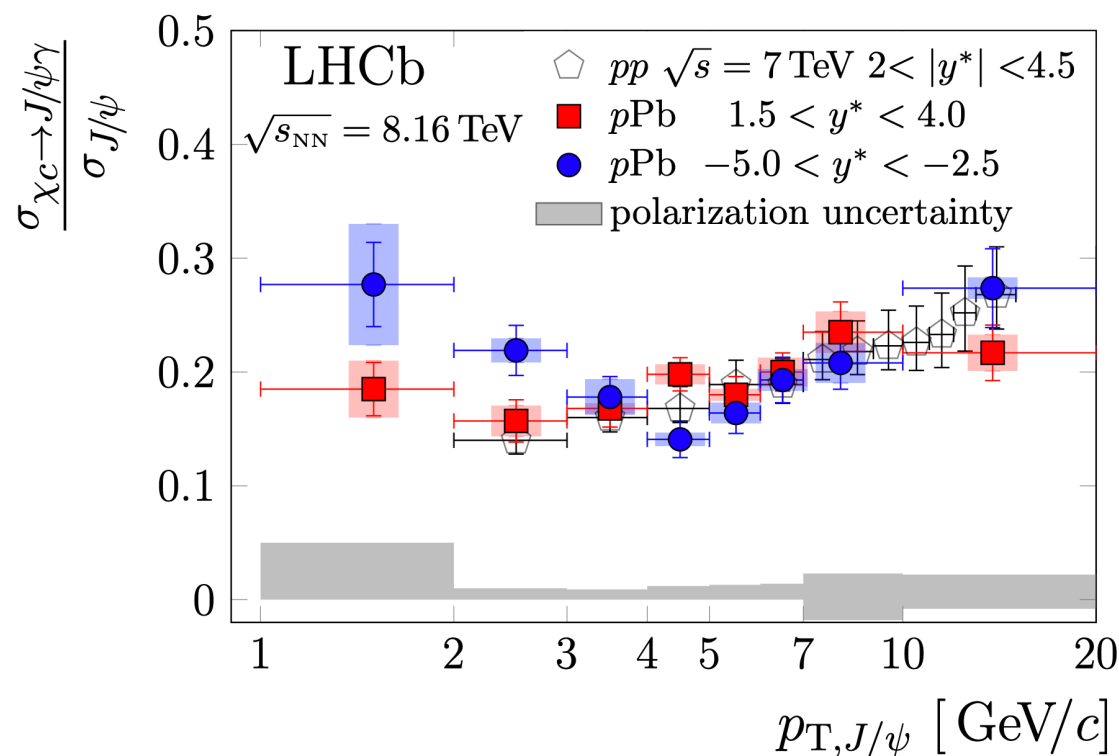
LHCb-PAPER-2023-024, 028
in preparation



Cesar da Silva

Tues 12:40

- A significant fraction of J/ψ production comes from feeddown: decays of higher charmonia states
- Higher charmonia with weaker binding energies may also be more sensitive to final-state effects



- Unique low- p_{T} access to $\chi_{c1,2}$ a significant source of feeddown, measured with precision
- Detailed new study of prompt and non-prompt $\psi(2S)$ suppression in $p\text{Pb}$
- Provides new constraints on the potential impact of QGP color screening in small systems



NEW!

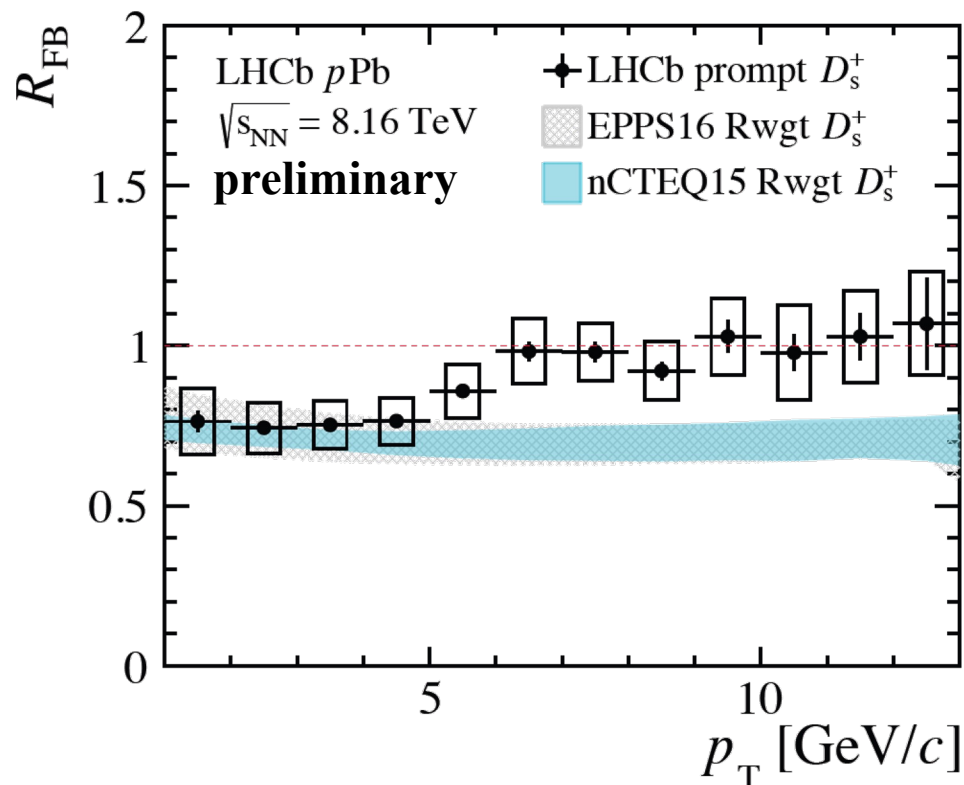
Strangeness enhancement in charm

- How does the underlying event affect the hadronization process?
- LHCb's access to heavy quark states gives powerful probes of confinement mechanisms

LHCb-PAPER-2023-021
in preparation



Chenxi Gu
Tues 12:20



- nPDF calculations cannot describe forward/backward ratio for D_s^+
 - Final state effects? Hadronization modified?
 - A precision regime where nPDFs assumptions no longer apply?



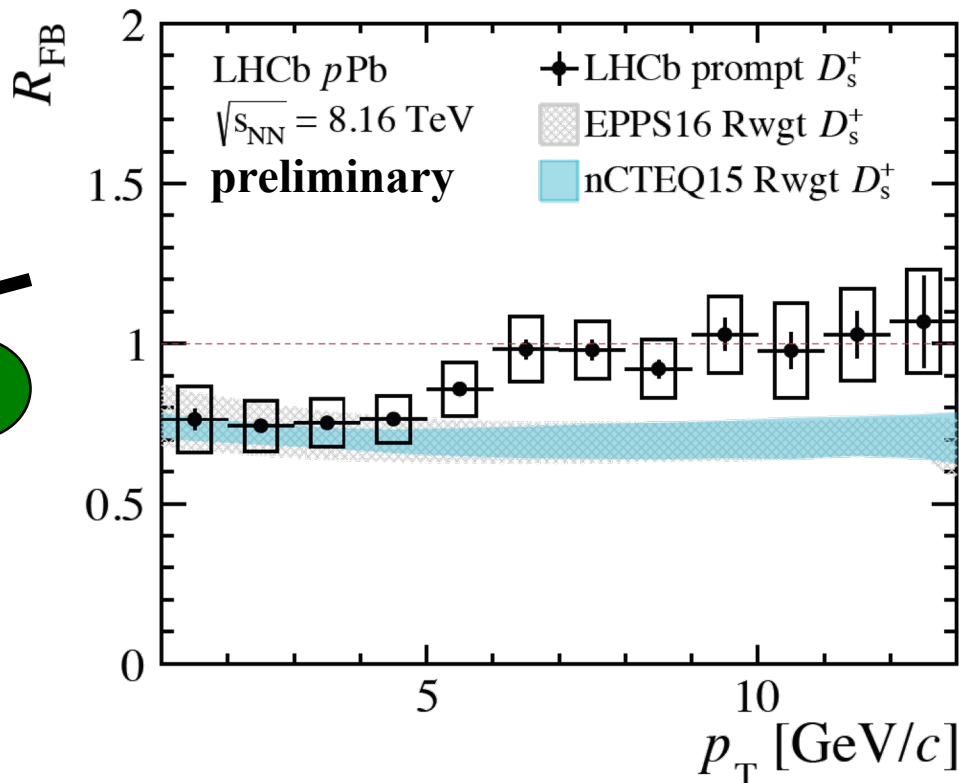
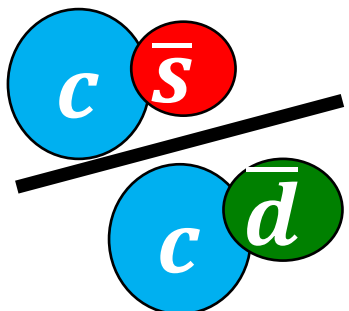
NEW!

Strangeness enhancement in charm

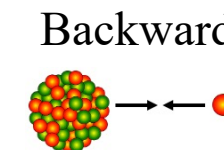
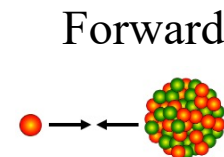
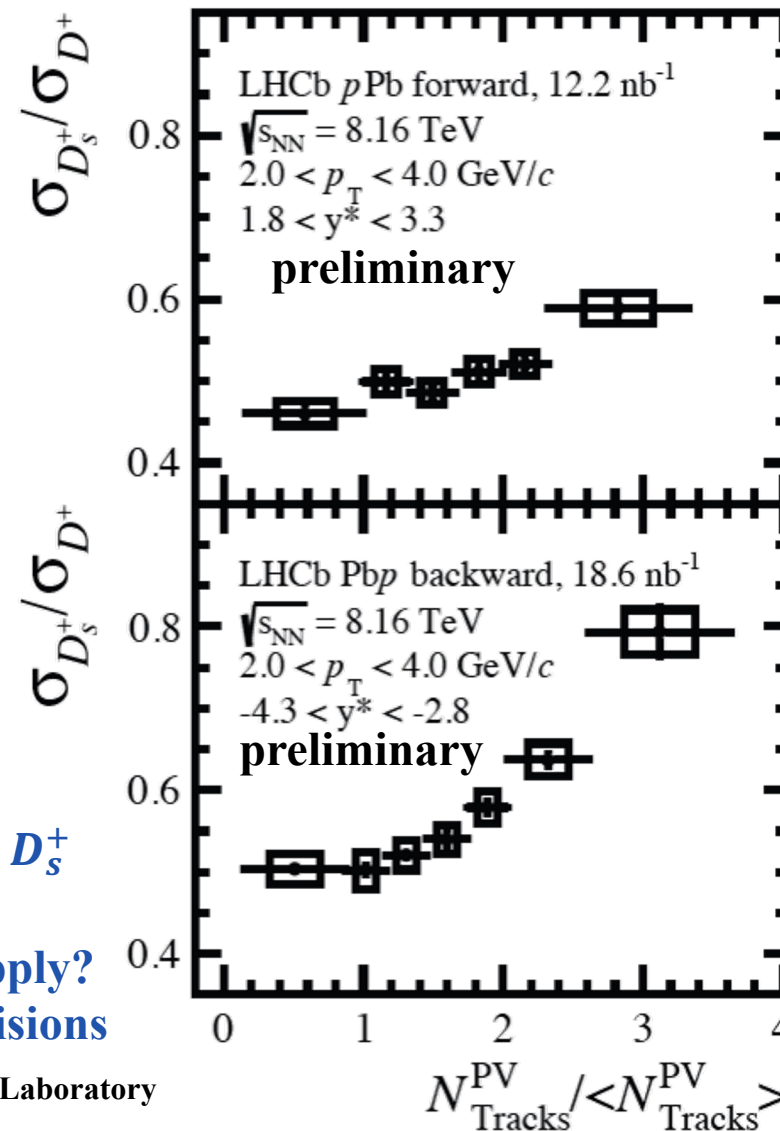
- How does the underlying event affect the hadronization process?
- LHCb's access to heavy quark states gives powerful probes of confinement mechanisms

LHCb-PAPER-2023-021
 in preparation

Chenxi Gu
Tues 12:20



- nPDF calculations cannot describe forward/backward ratio for D_s^+
 - Final state effects? Hadronization modified?
 - A precision regime where nPDFs assumptions no longer apply?
- Strangeness enhancement in charm sector observed in p Pb collisions



NEW!

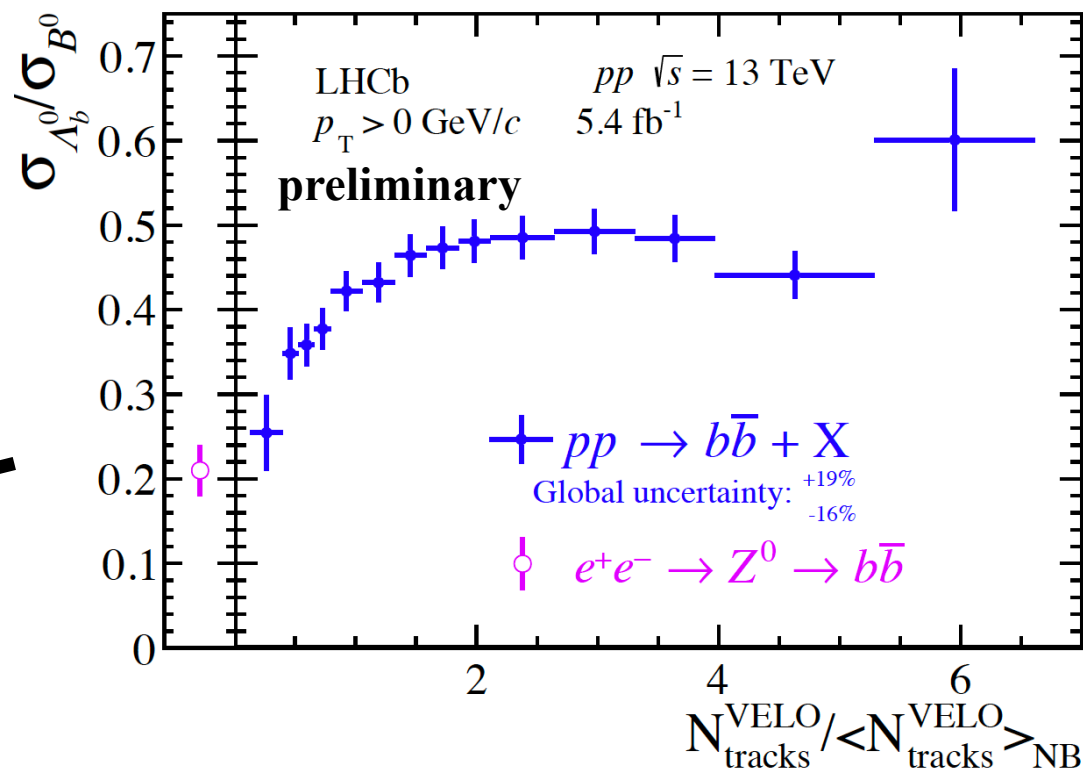
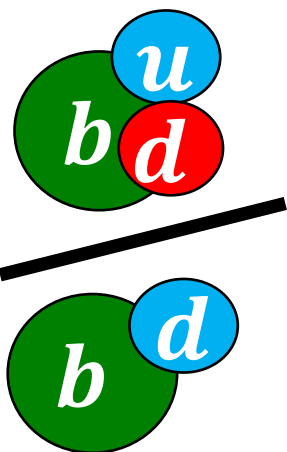
Bottom baryon enhancement in pp

- LHCb has unique access to large sets of b baryons and mesons at low p_T
- Heavy b quarks have relatively long wavelengths – large overlap with bulk particles

LHCb-PAPER-2023-027
in preparation



Chenxi Gu
Tues 12:20



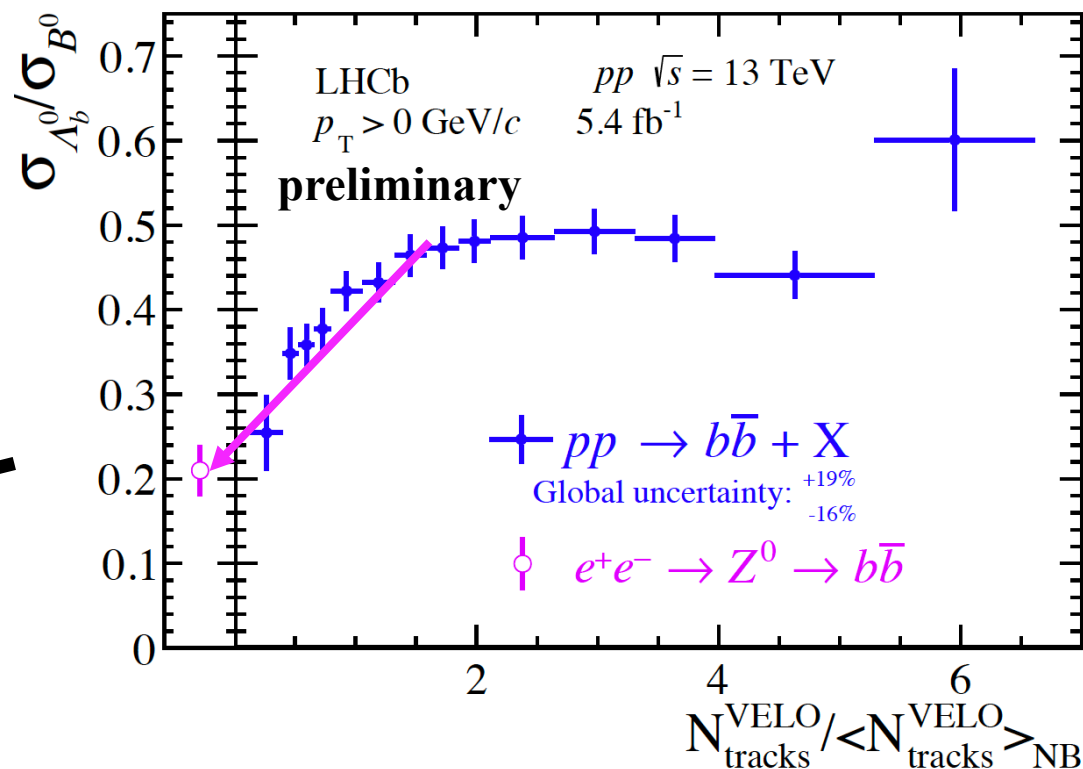
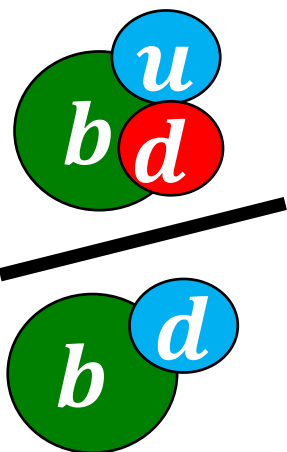
NEW!

Bottom baryon enhancement in pp

- LHCb has unique access to large sets of b baryons and mesons at low p_T
- Heavy b quarks have relatively long wavelengths – large overlap with bulk particles

LHCb-PAPER-2023-027
in preparation

Chenxi Gu
Tues 12:20



- Compare to baryon/meson ratio from e^+e^- collisions



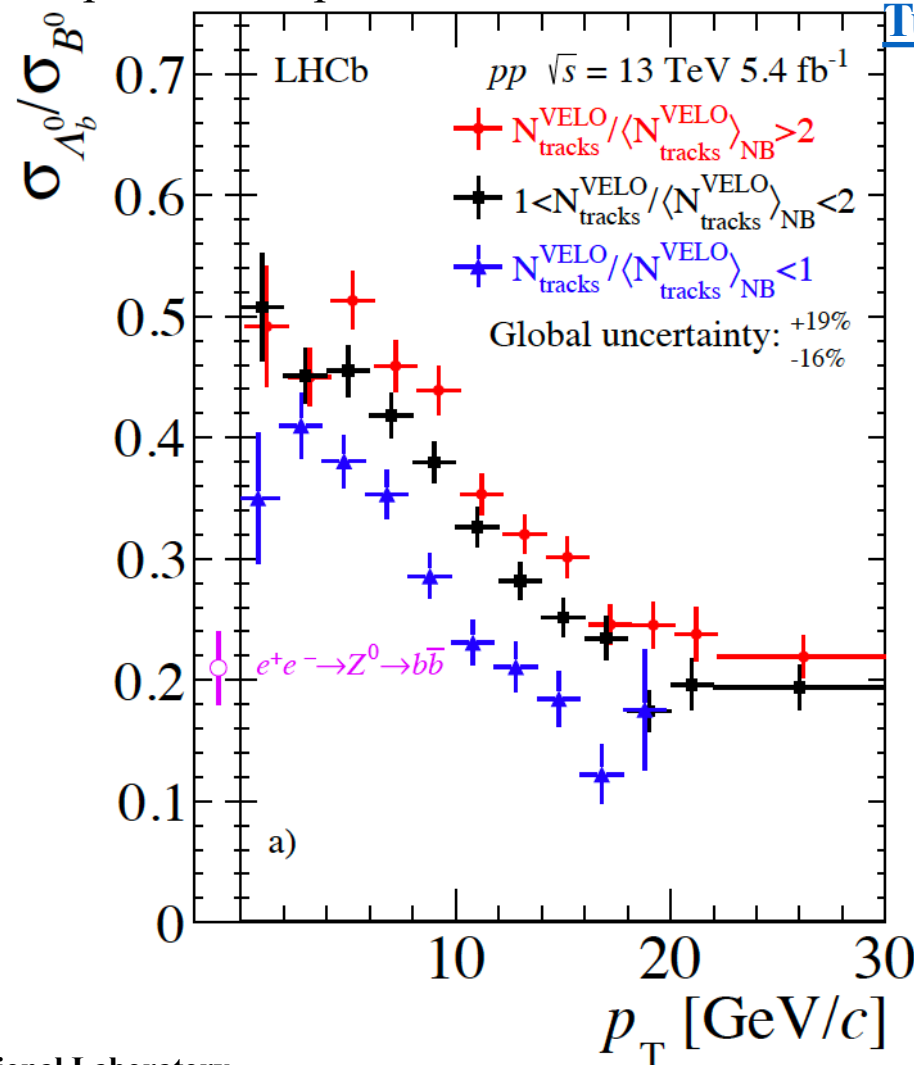
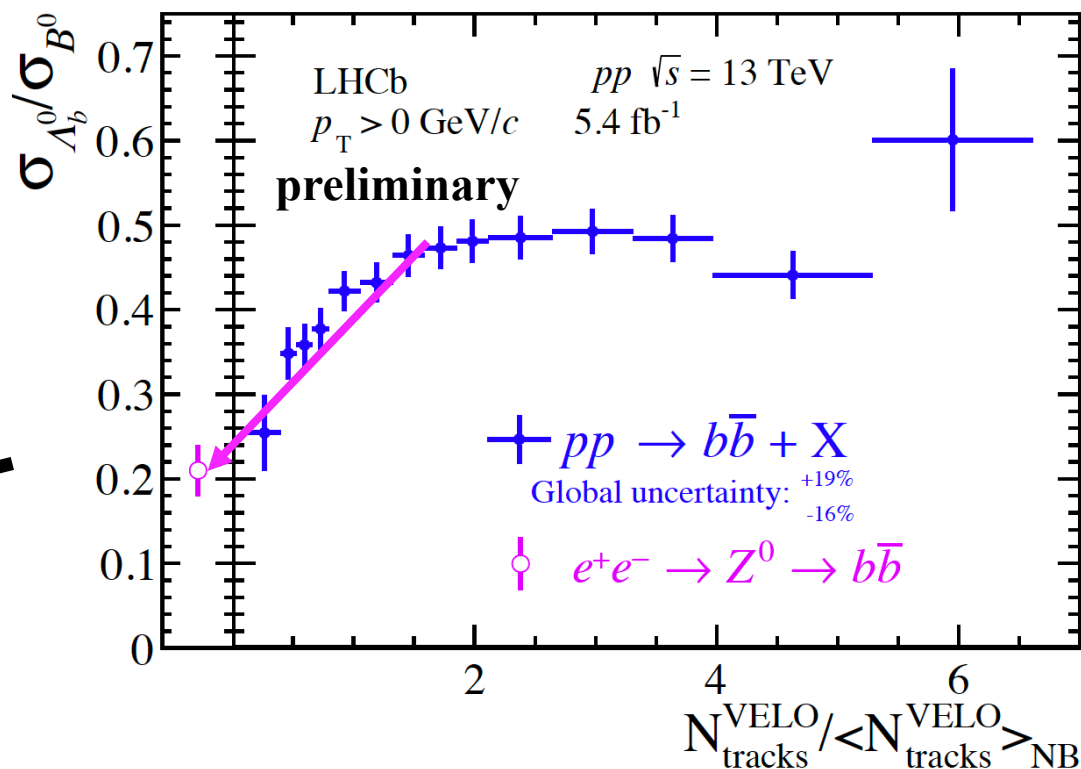
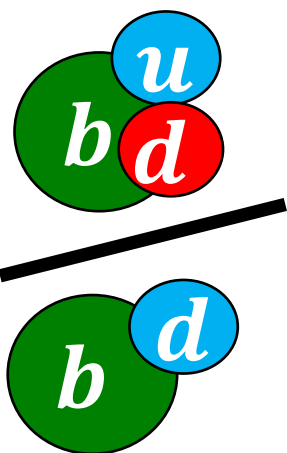
NEW!

Bottom baryon enhancement in pp

- LHCb has unique access to large sets of b baryons and mesons at low p_T
- Heavy b quarks have relatively long wavelengths – large overlap with bulk particles

LHCb-PAPER-2023-027
in preparation

Chenxi Gu
Tues 12:20



- Compare to baryon/meson ratio from e^+e^- collisions
 - Reproduced at low multiplicity



NEW!

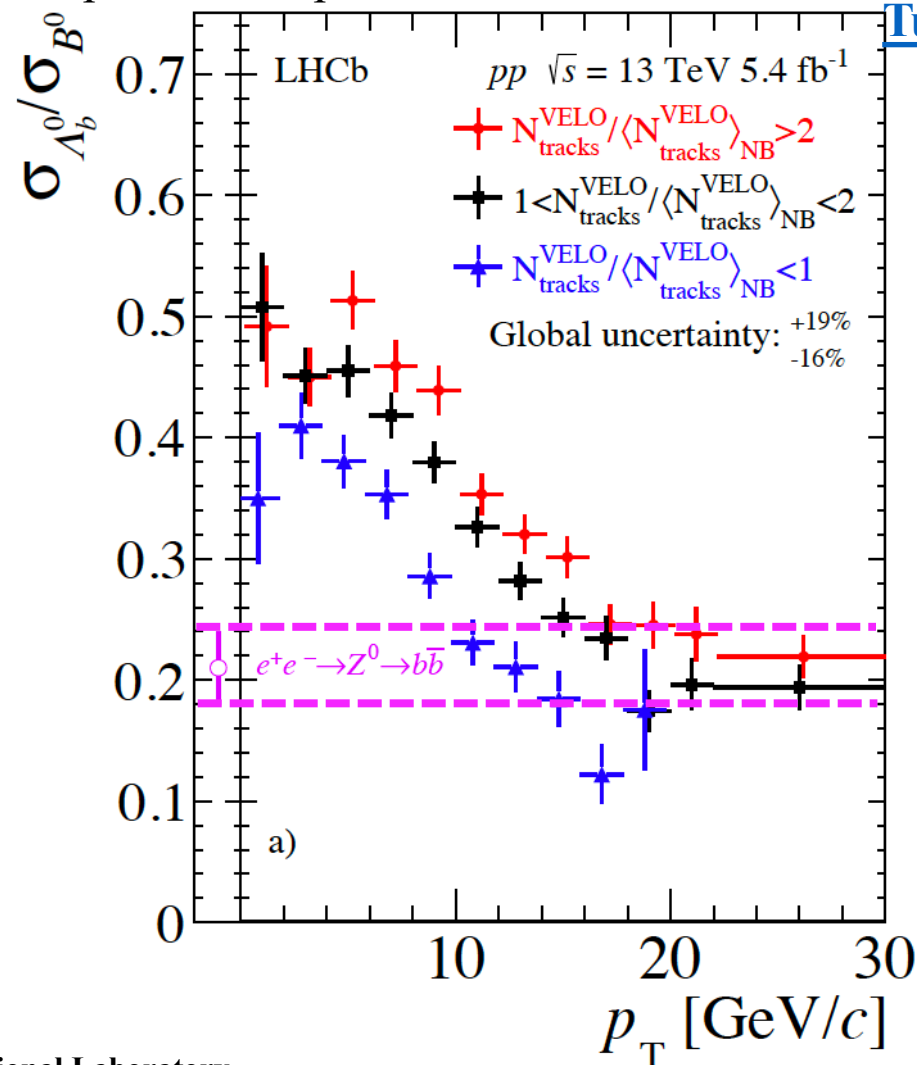
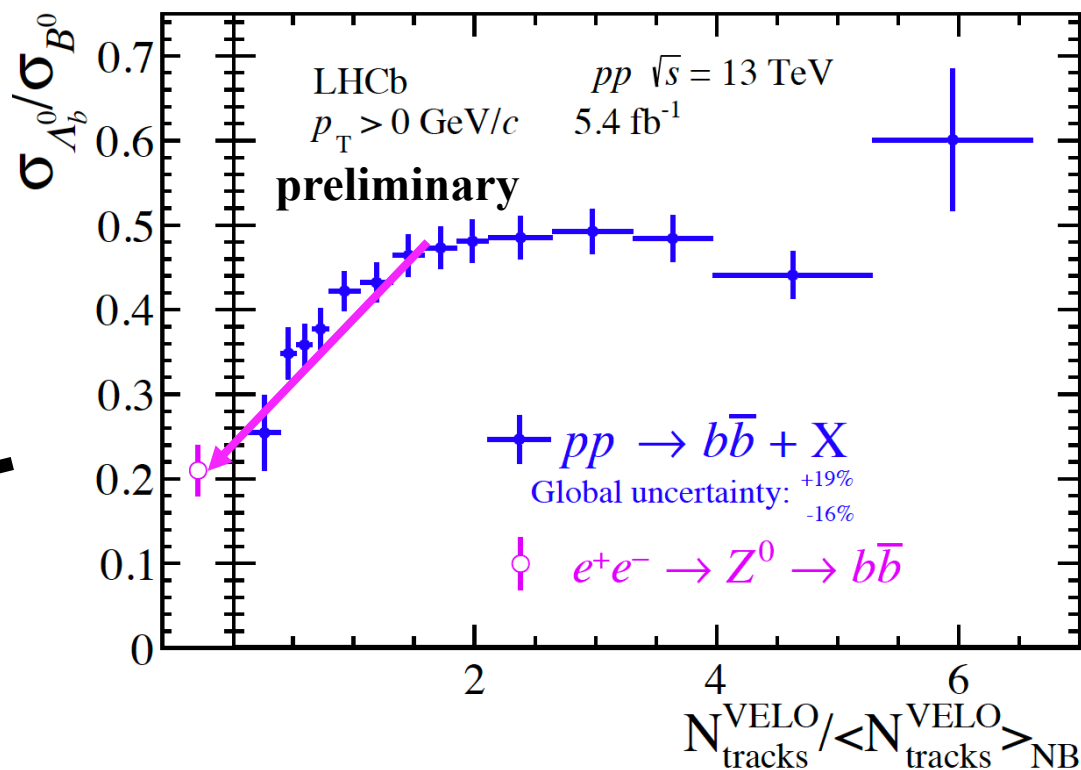
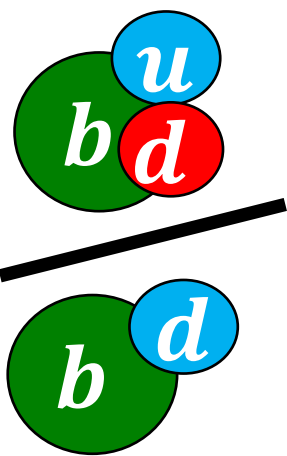
Bottom baryon enhancement in pp



LHCb-PAPER-2023-027
in preparation

Chenxi Gu
Tues 12:20

- LHCb has unique access to large sets of b baryons and mesons at low p_T
- Heavy b quarks have relatively long wavelengths – large overlap with bulk particles



- Compare to baryon/meson ratio from e^+e^- collisions
 - Reproduced at low multiplicity and high p_T :
 - Pure fragmentation limit achieved in pp

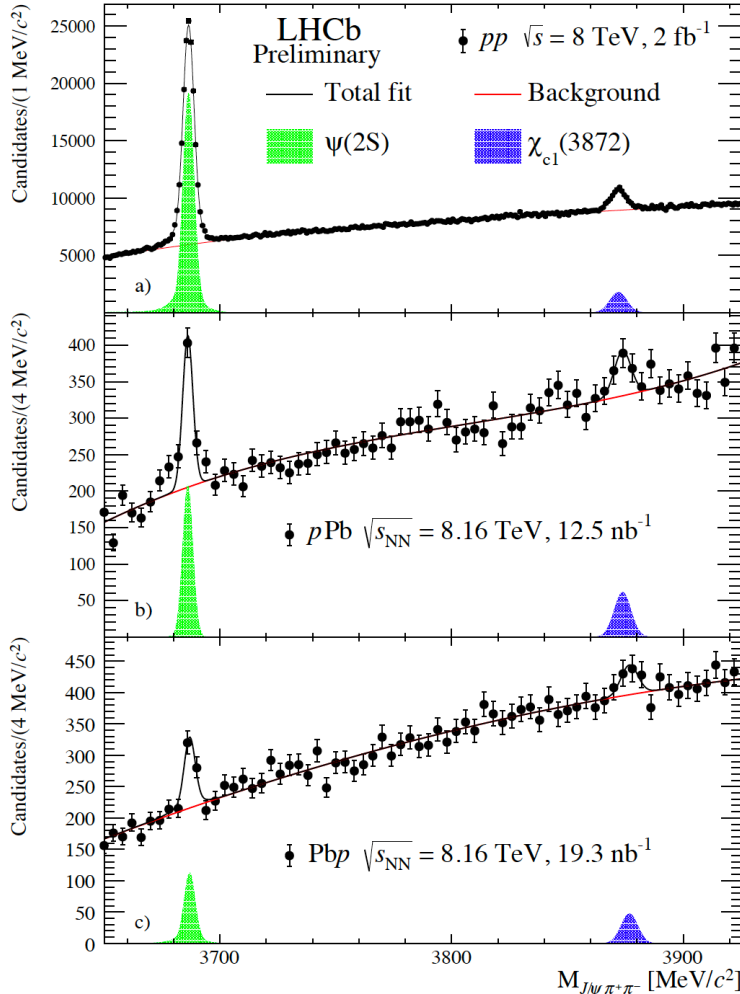
Modification of X(3872) in $p\text{Pb}$

LHCb-PAPER-2023-026
in preparation

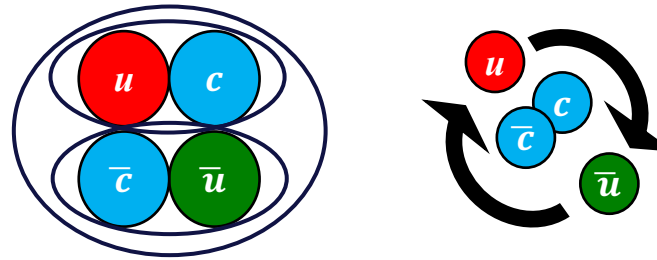


Cesar da Silva
Tues 12:40

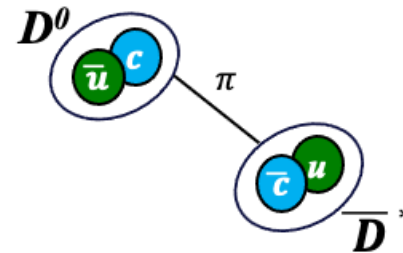
- LHCb can uniquely reconstruct exotic hadrons at low p_T
- Exotic multiquark states can give new constraints on hadronization models at unprecedented NCQ



X(3872) structure:
Compact? Hadrocharmonium?



Hadronic molecule?



Modification of X(3872) in $p\text{Pb}$

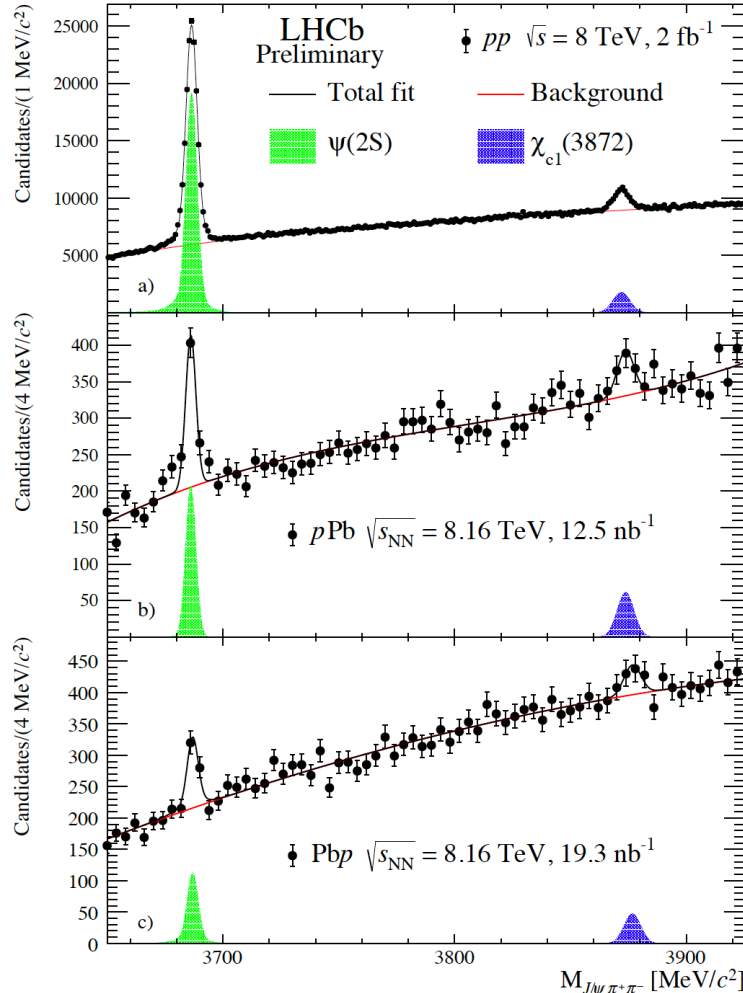
LHCb-CONF-2022-001



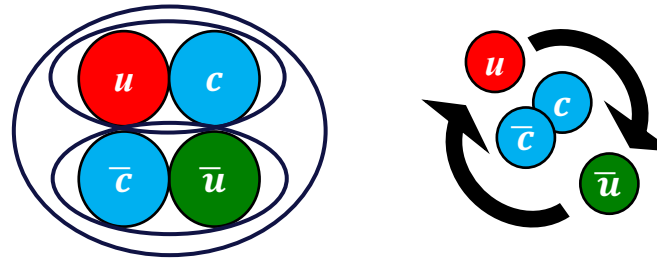
Cesar da Silva

Tues 12:40

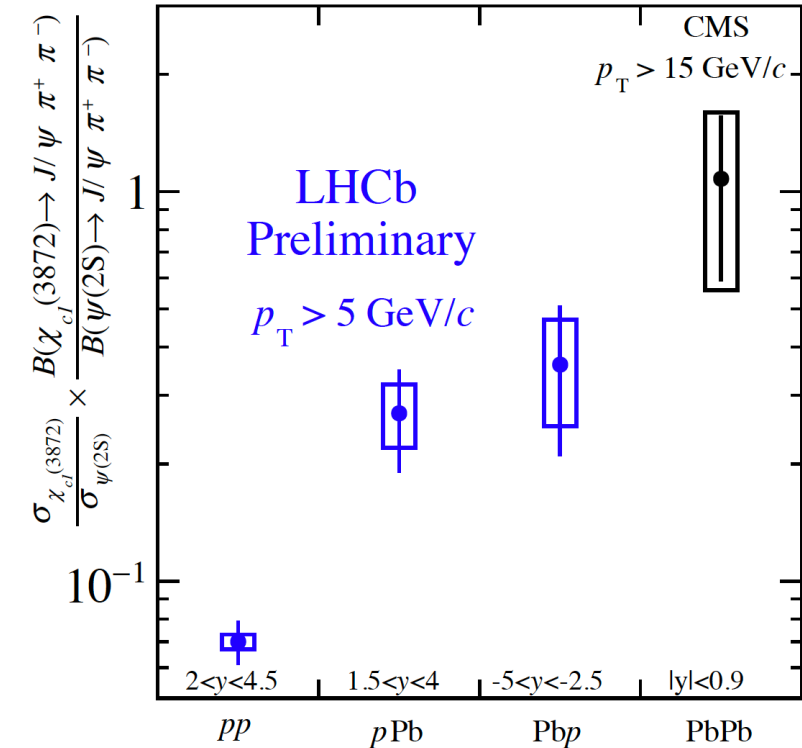
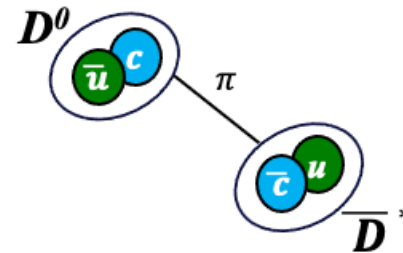
- LHCb can uniquely reconstruct exotic hadrons at low p_T
- Exotic multiquark states can give new constraints on hadronization models at unprecedented NCQ



X(3872) structure:
Compact? Hadrocharmonium?



Hadronic molecule?



Something different between exotic state and conventional charmonia

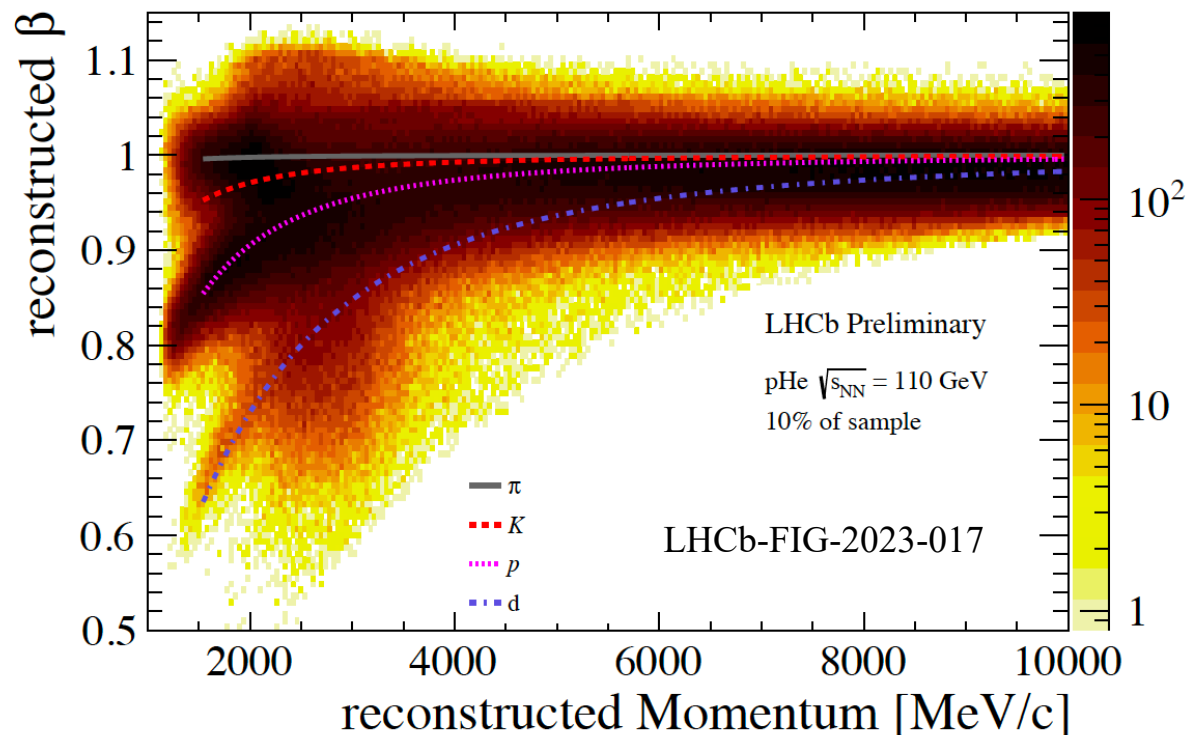
NEW!

Nuclei production



Chiara Lucarelli
poster

- New methods are being developed to positively identify d and ${}^3\text{He}$ produced at LHCb



Deuteron production with SMOG data –
particle ID accomplished by TOF with Outer Tracker



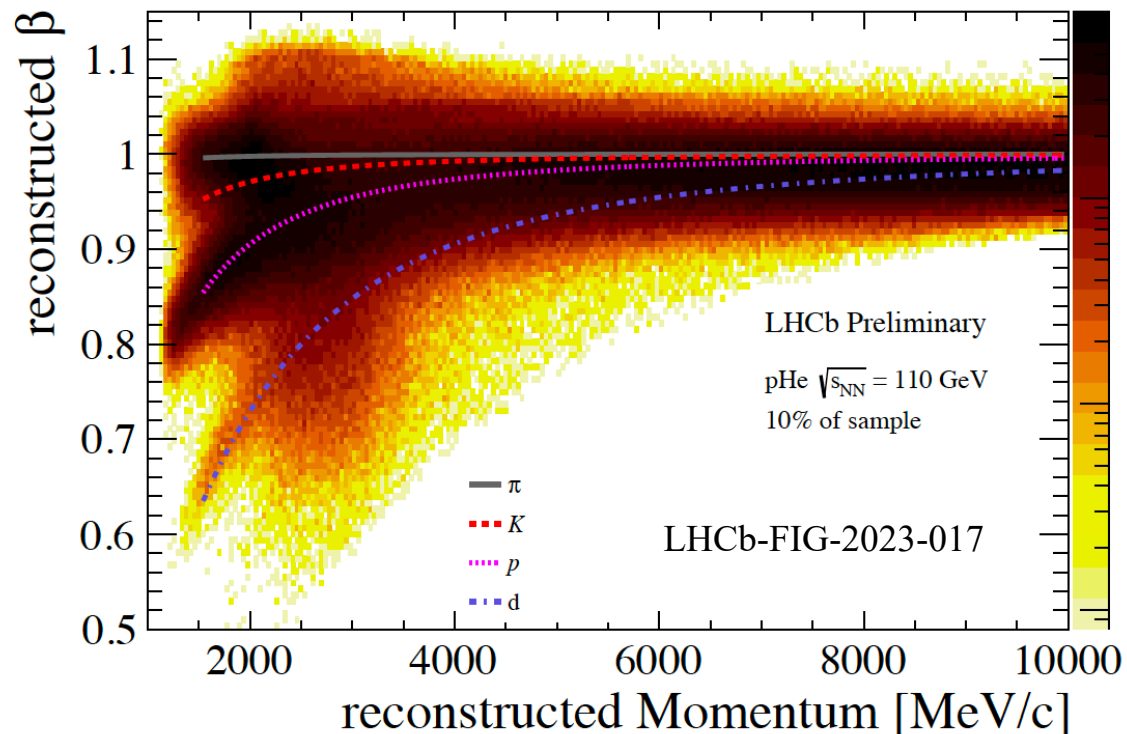
NEW!

Nuclei production

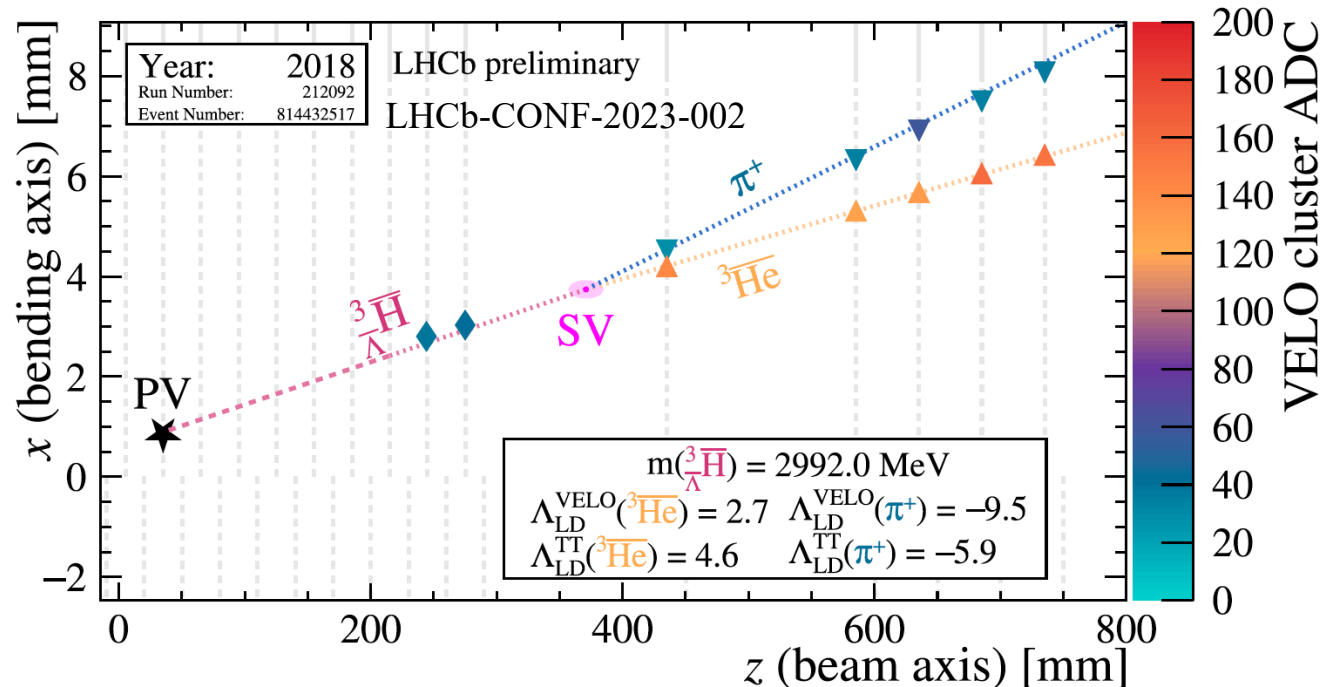


Chiara Lucarelli
poster

- New methods are being developed to positively identify d and ${}^3\text{He}$ produced at LHCb



Deuteron production with SMOG data –
particle ID accomplished by TOF with Outer Tracker



Event display of hypertriton decay candidate –
 ${}^3\text{He}$ identified by dE/dx in silicon layers



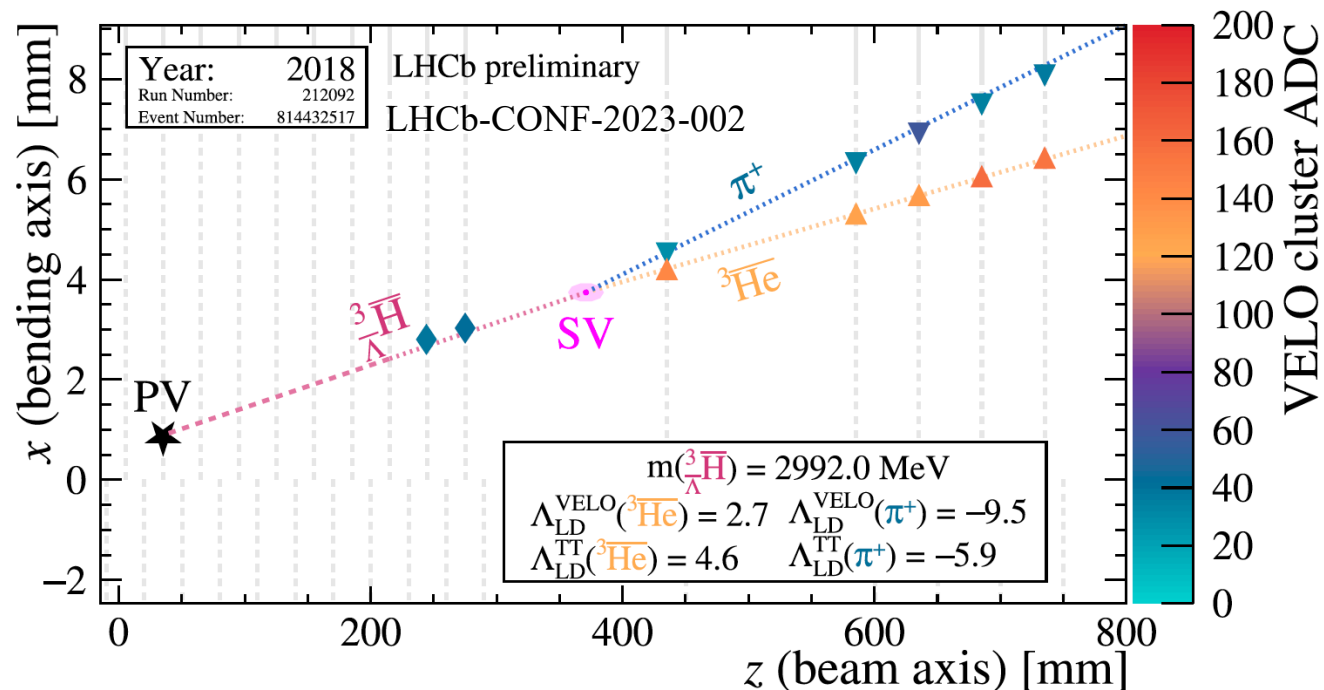
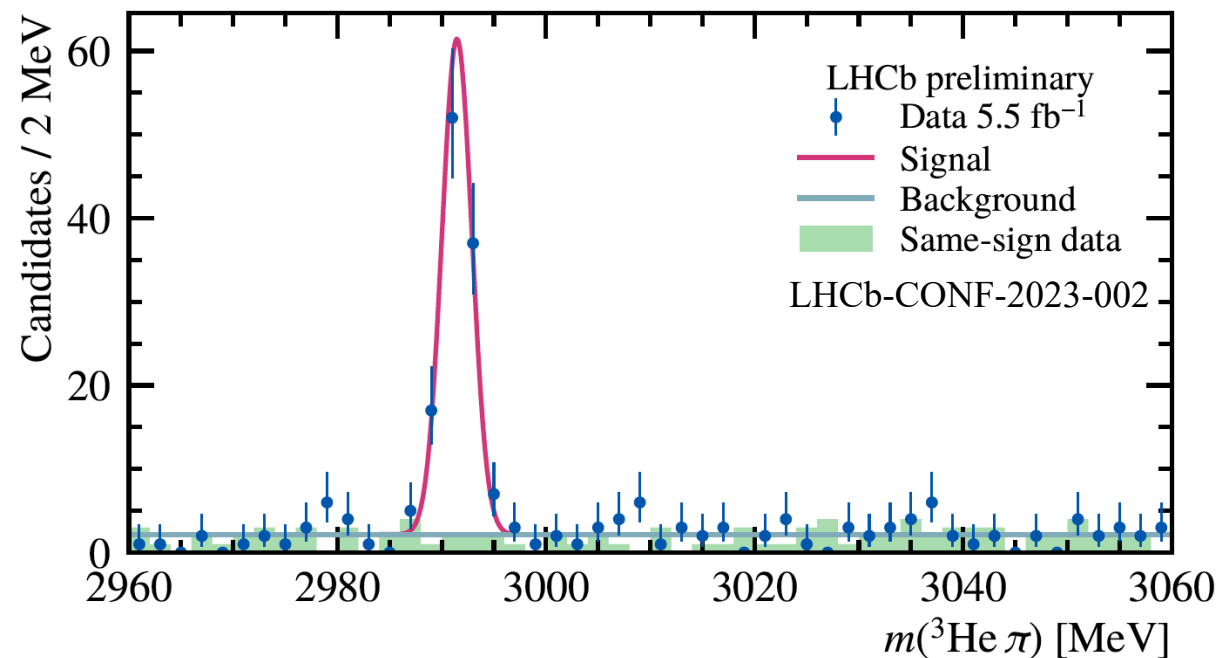
NEW!

Nuclei production



Chiara Lucarelli
poster

- New methods are being developed to positively identify d and ^3He produced at LHCb



Extremely clean sample of hypertritons –
Method gives access to exotic nuclei in pp, pA, AA collider data
and will also be applied to fixed-target collisions

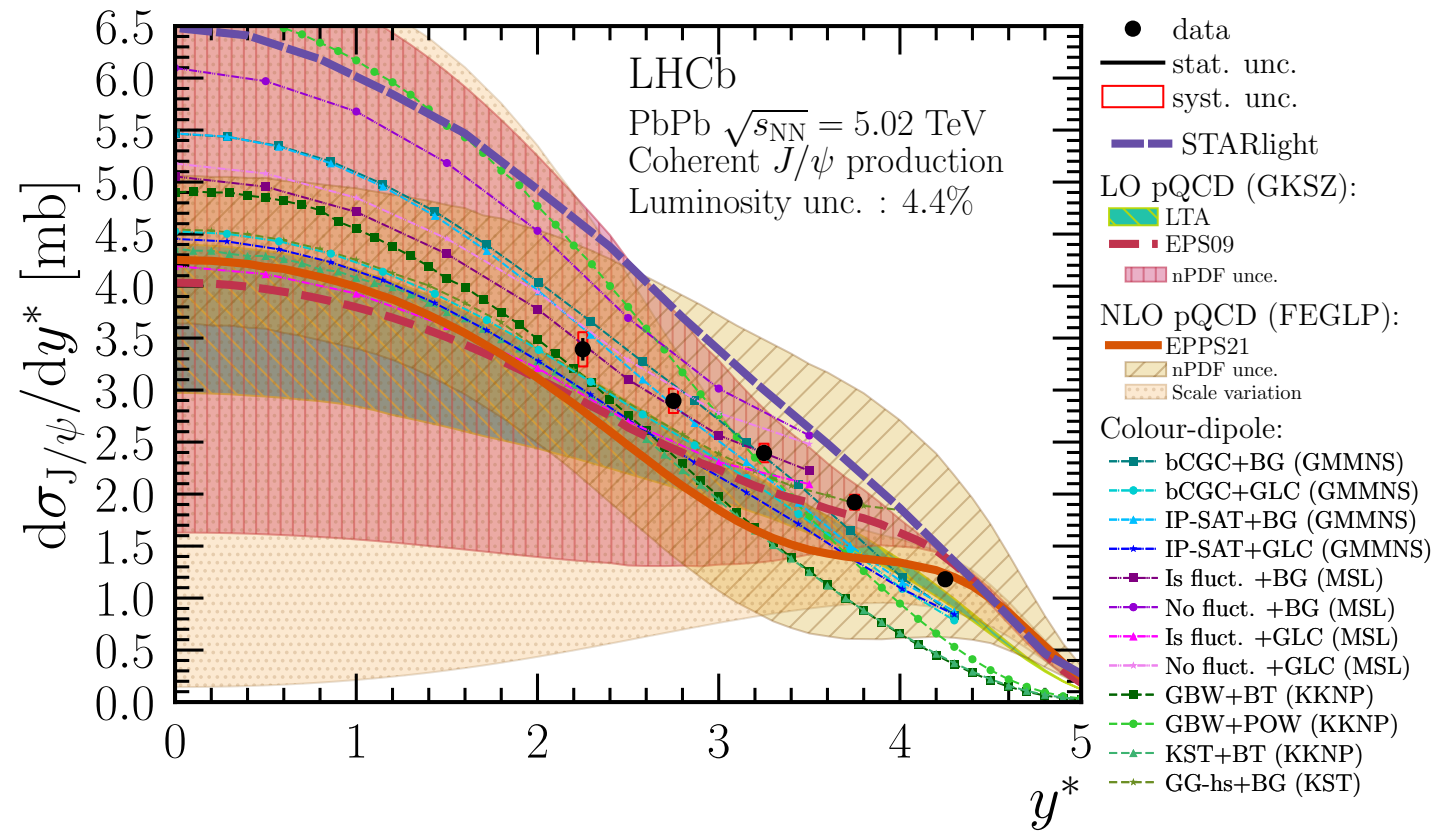
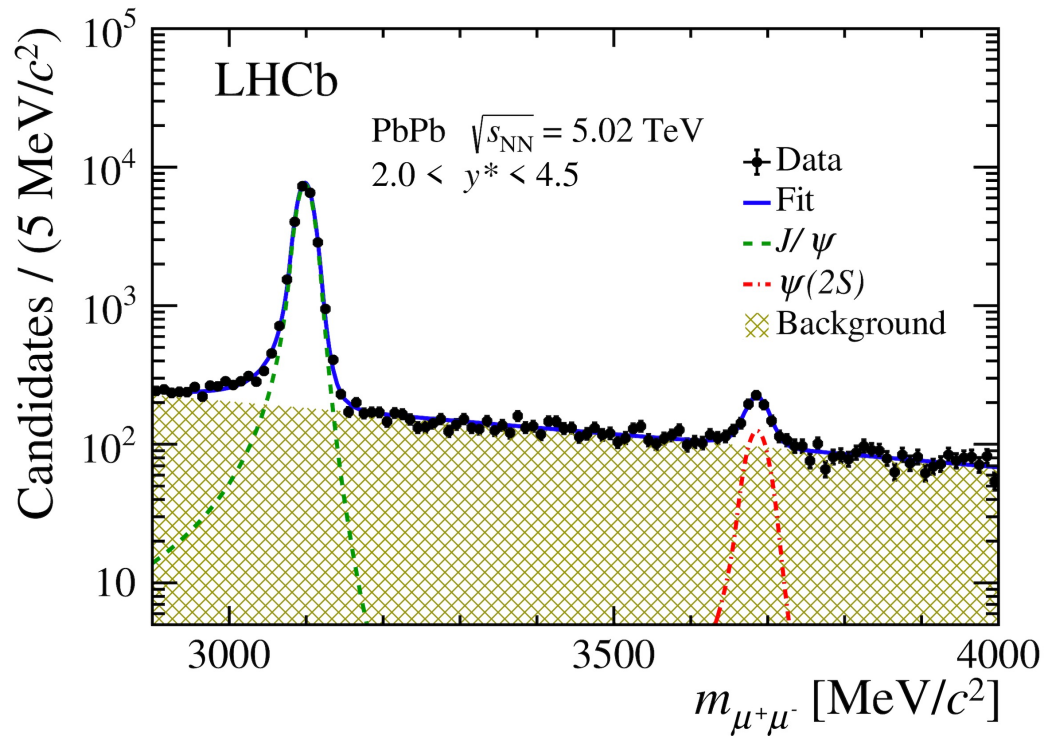
Event display of hypertriton decay candidate –
 ^3He identified by dE/dx in silicon layers



Charmonium in UPC PbPb collisions

- LHCb has full particle ID and collects large samples of UPC events
- Soft particles (which can be produced through coherent processes) can be measured
- Forward reach and high statistics provides new constraints on saturation models

JHEP 06 (2023) 146



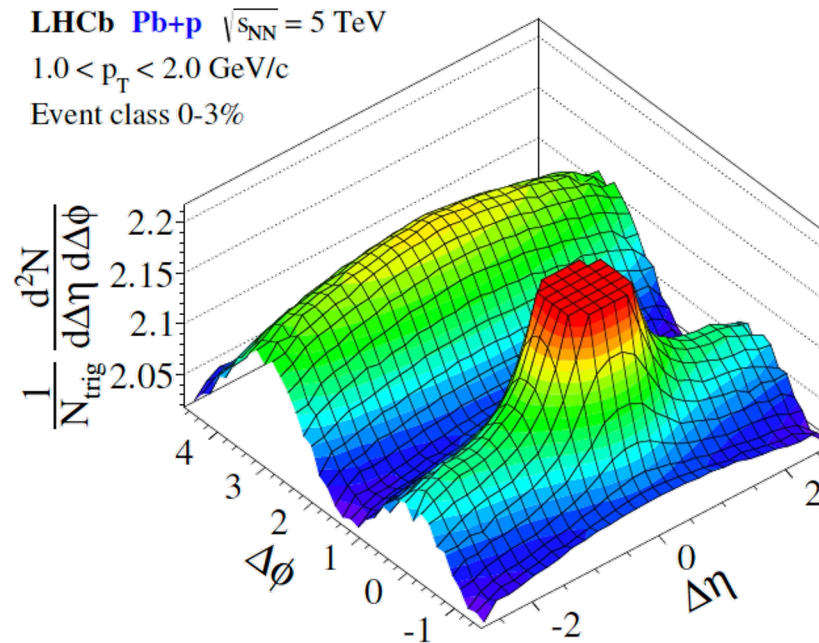
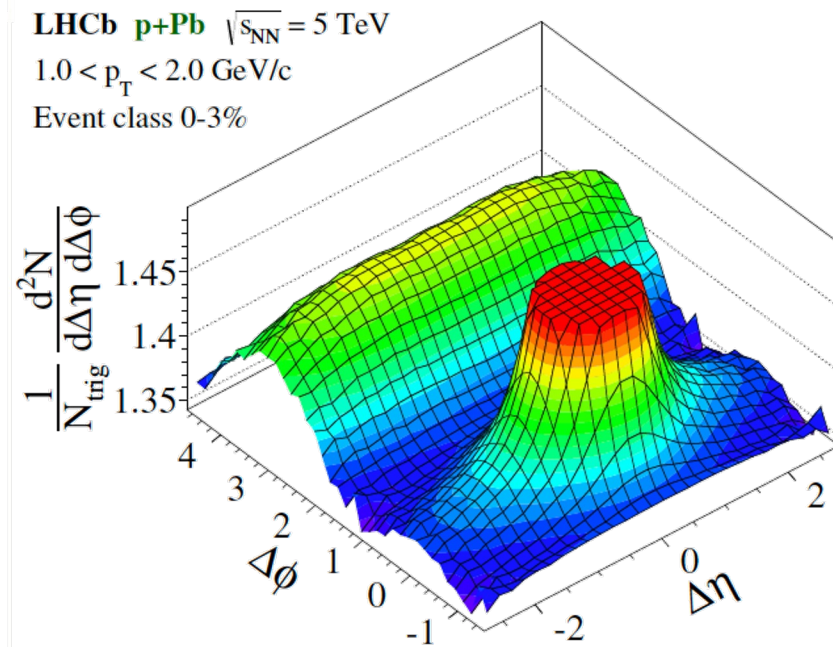
Collectivity in PbPb

LHCb-PAPER-2023-031
in preparation



Ping Wong
Tues 13:00

- Previous LHCb measurements confirmed presence of the ridge at forward rapidity in p Pb collisions



NEW!

Collectivity in PbPb

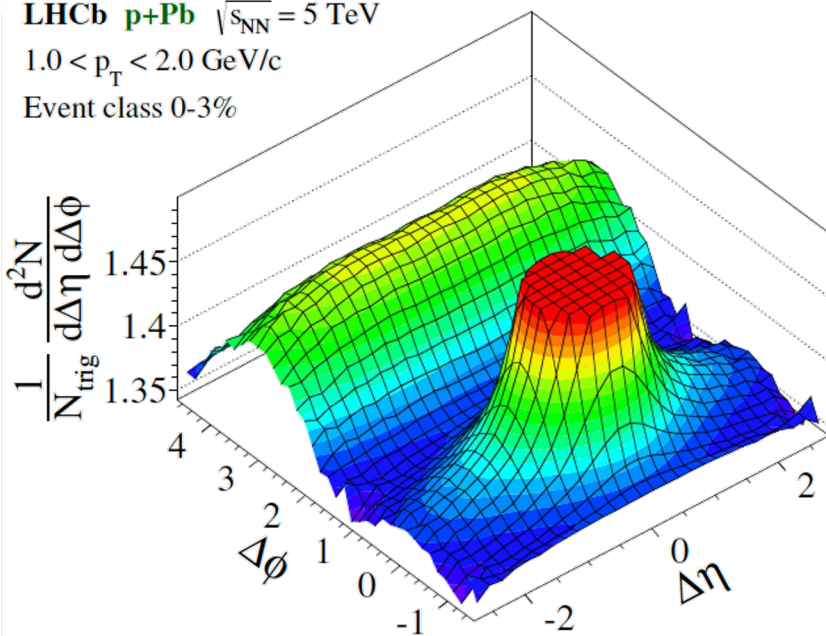
LHCb-PAPER-2023-031
in preparation



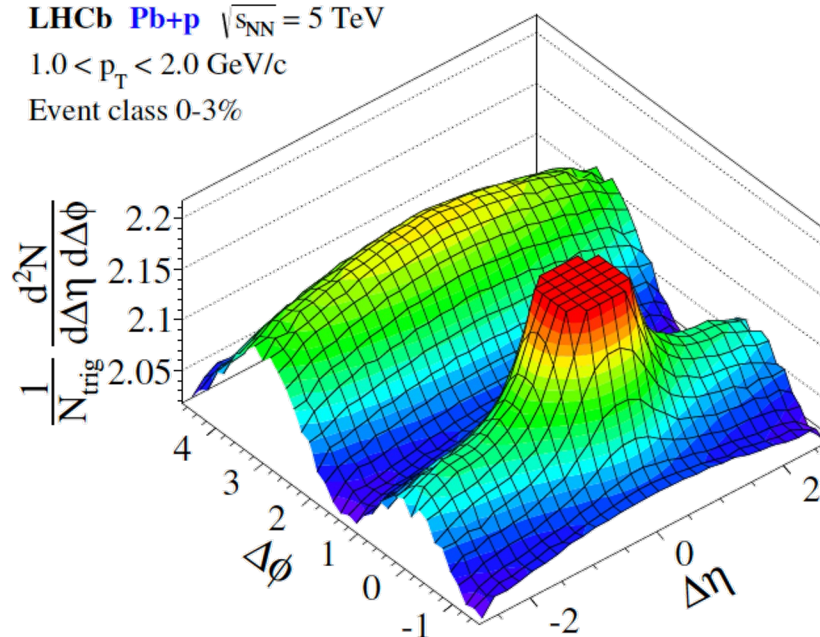
Ping Wong
Tues 13:00

- Previous LHCb measurements confirmed presence of the ridge at forward rapidity in p Pb collisions
- New results show stronger ridge in PbPb

LHCb **p+Pb** $\sqrt{s_{NN}} = 5$ TeV
 $1.0 < p_T < 2.0$ GeV/c
Event class 0-3%

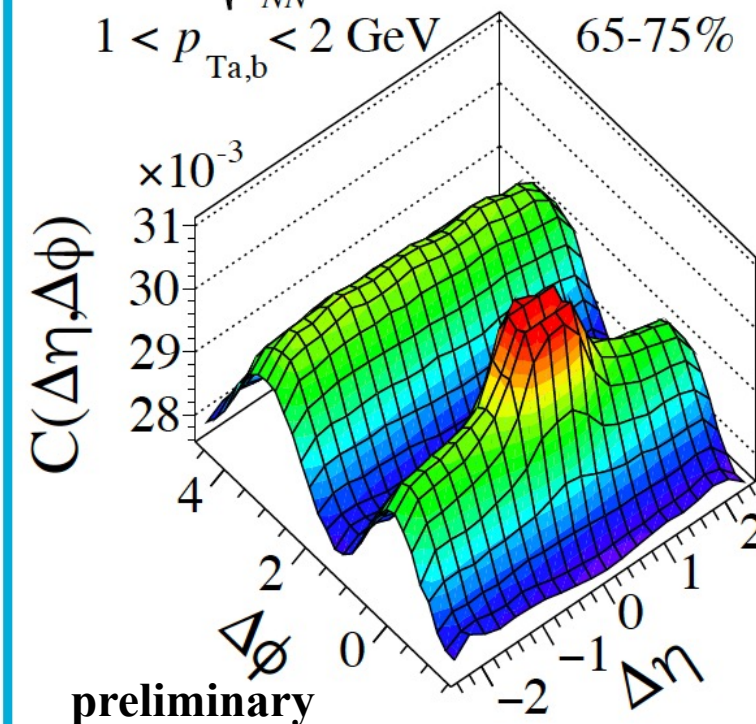


LHCb **Pb+p** $\sqrt{s_{NN}} = 5$ TeV
 $1.0 < p_T < 2.0$ GeV/c
Event class 0-3%



New

PbPb $\sqrt{s_{NN}} = 5$ TeV
 $1 < p_{Ta,b} < 2$ GeV
LHCb
65-75%



NEW!

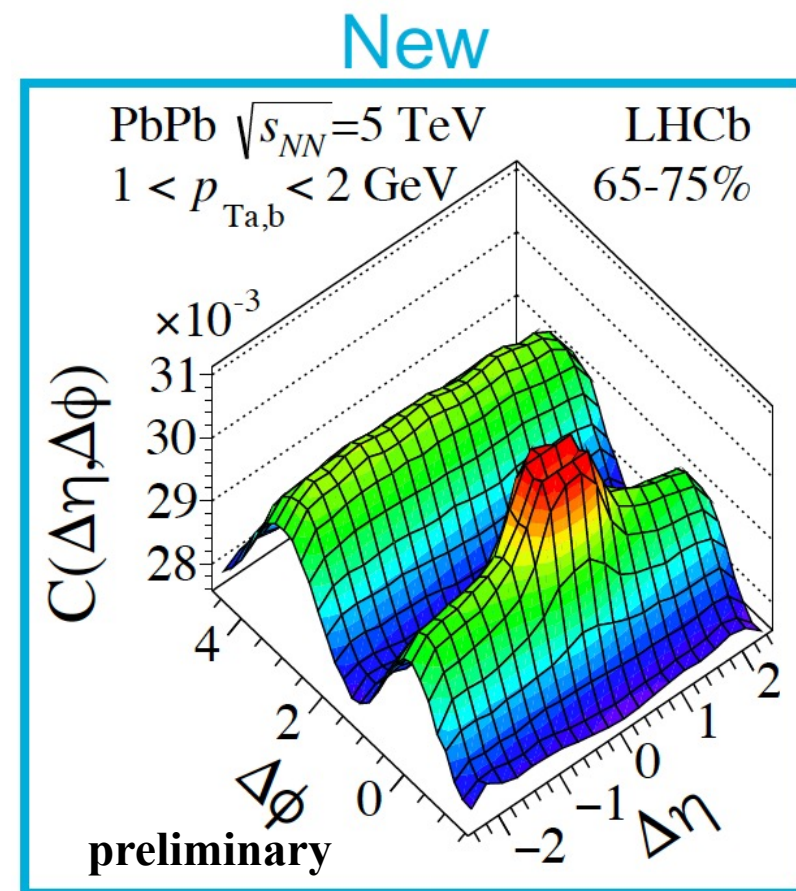
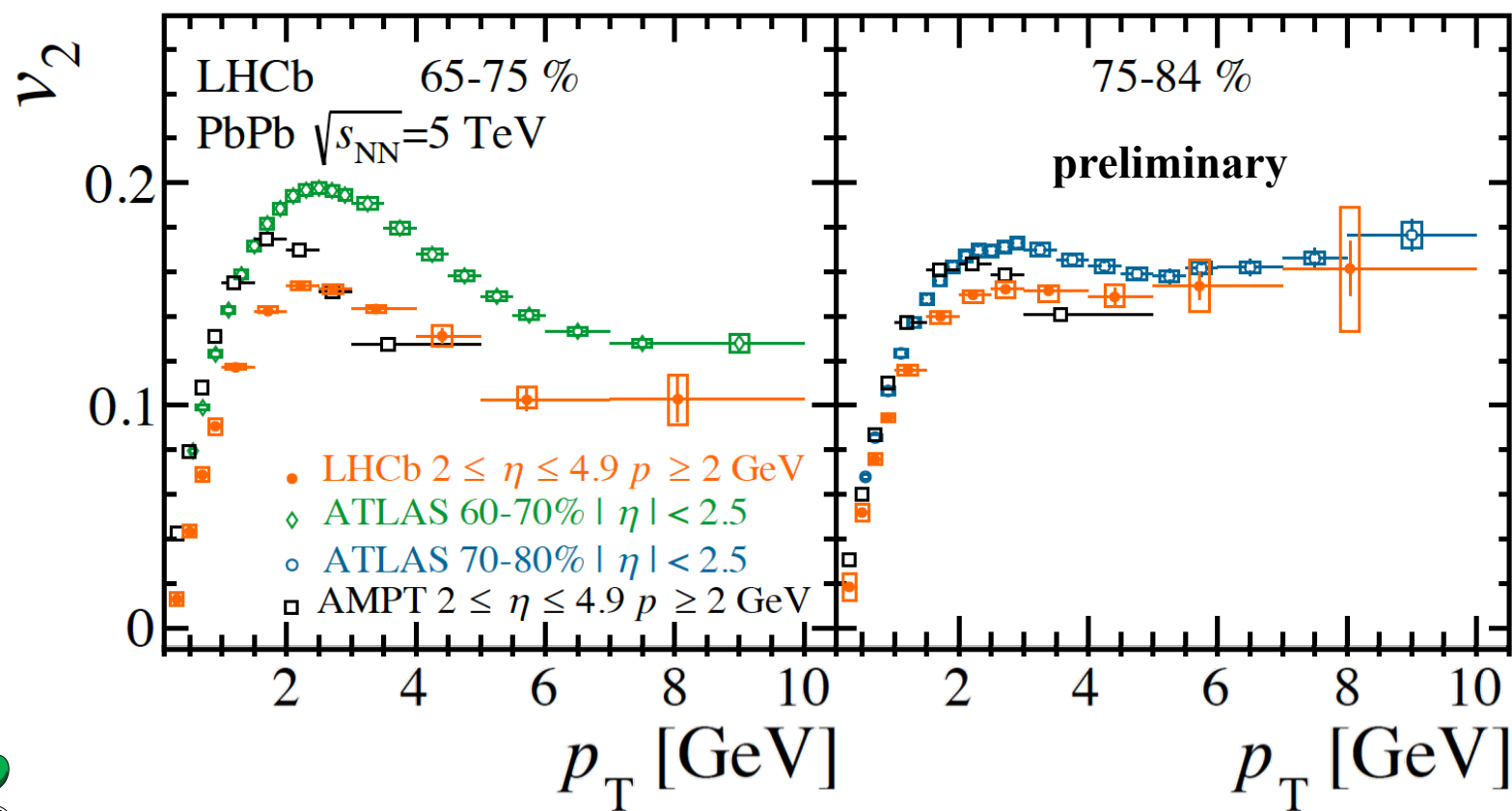
Collectivity in PbPb

LHCb-PAPER-2023-031
in preparation



Ping Wong
Tues 13:00

- Previous LHCb measurements confirmed presence of the ridge at forward rapidity in p Pb collisions
- New results show stronger ridge in PbPb
- First LHCb measurements of $v_{2,3}$ flow coefficient measurements
- A new thrust for LHCb, with unique reach into far forward angles

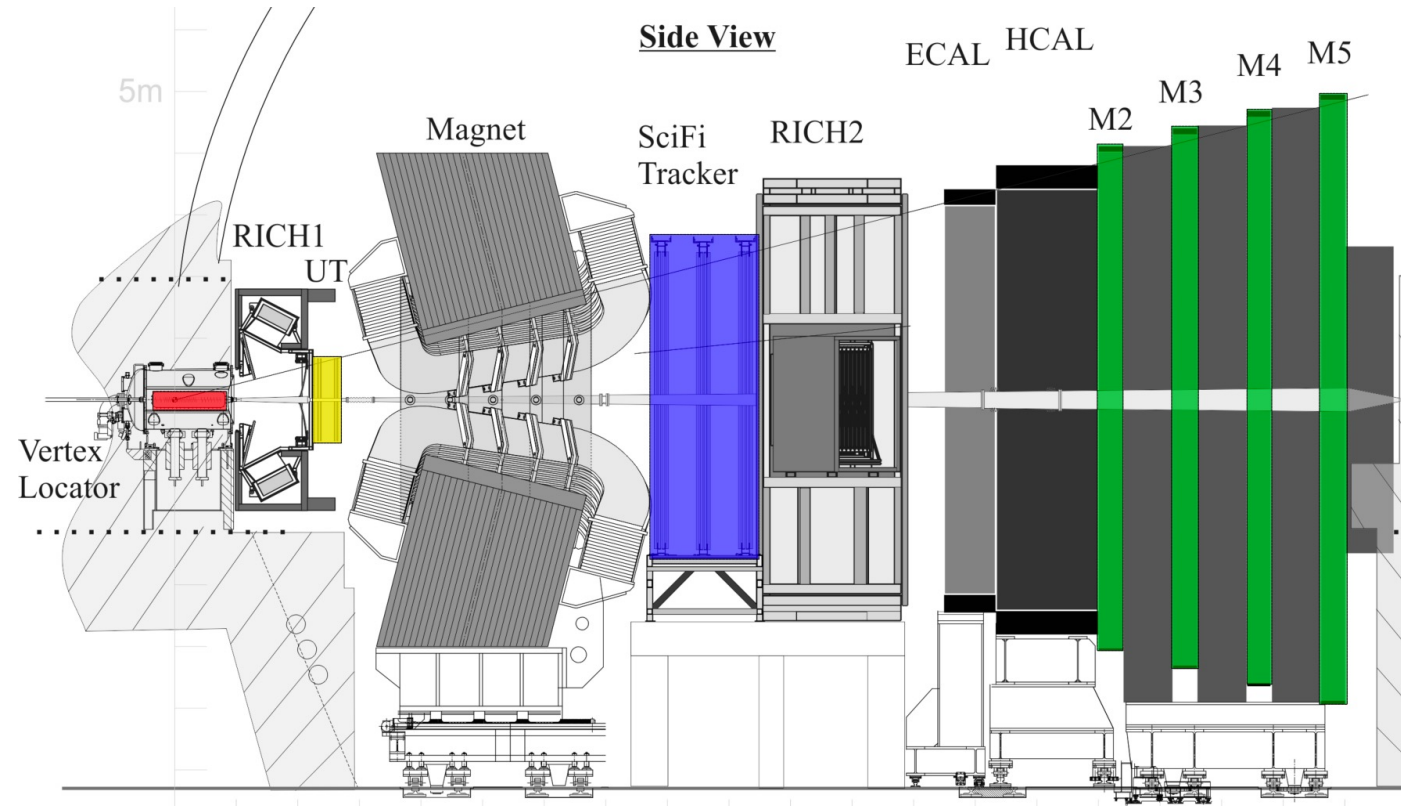
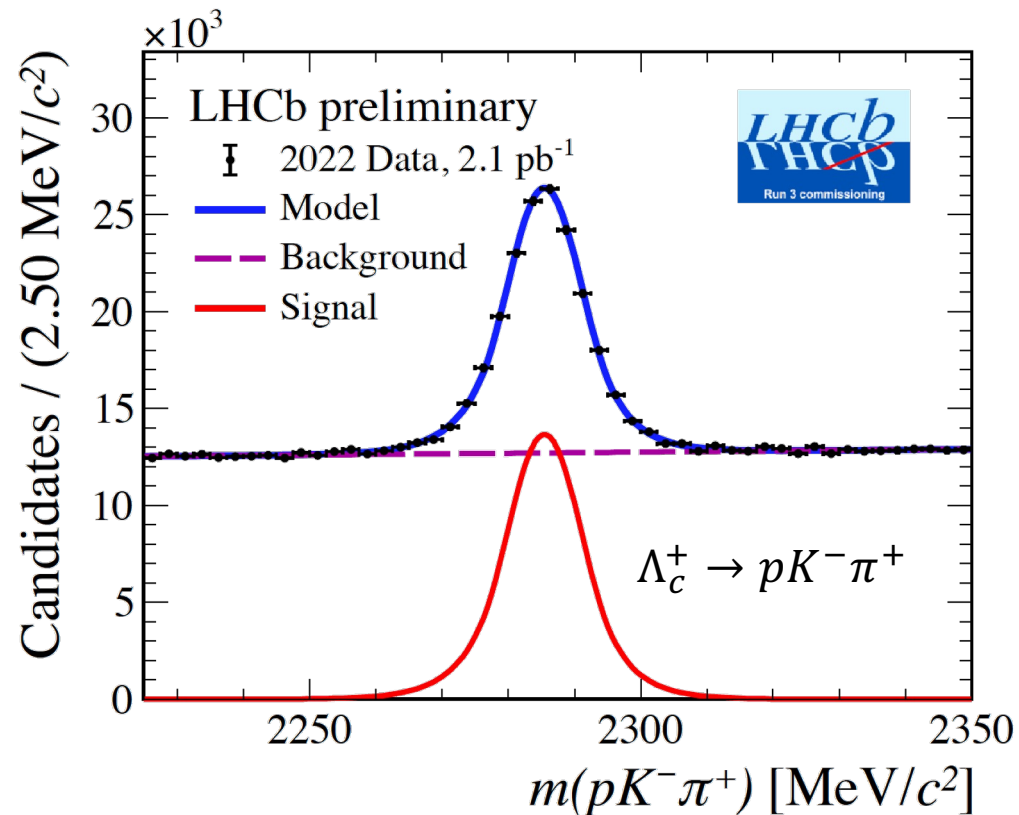


Upgrade 1(a) – Installed



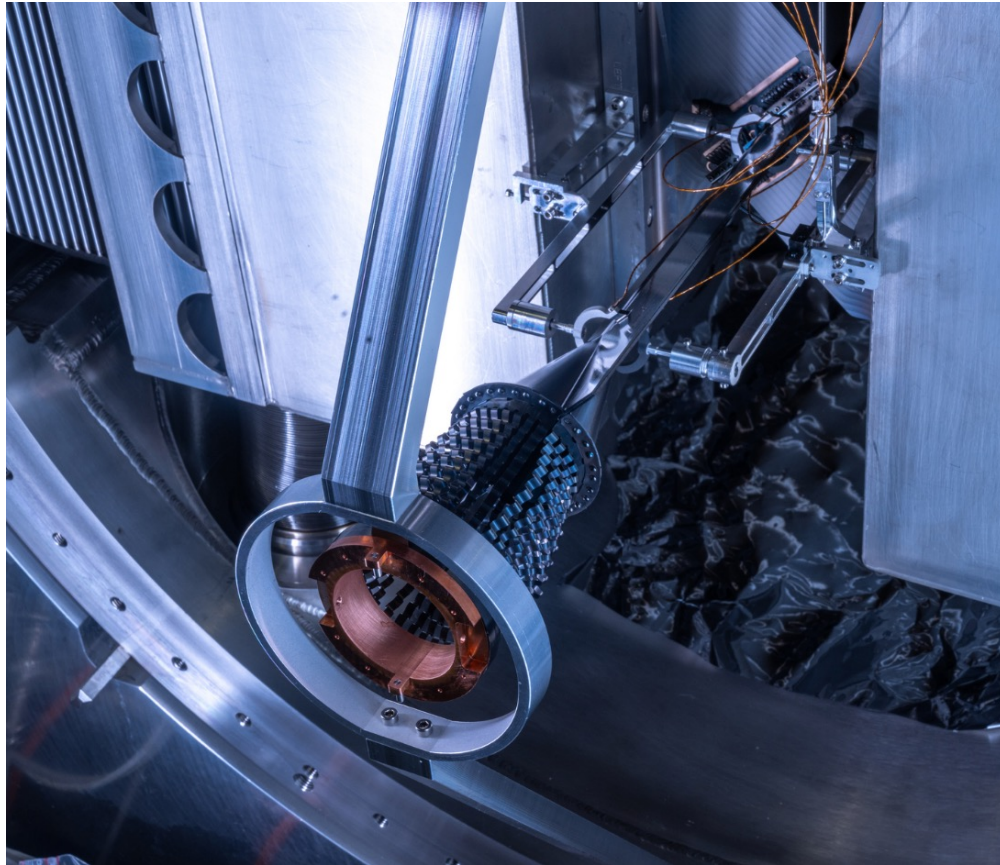
- LHCb has **advanced the state of the art** with full streaming readout in pp at 40MHz
- All new tracking system allows reconstruction up to $\sim 30\%$ most central PbPb collisions

[Imanol Corredoira poster](#)

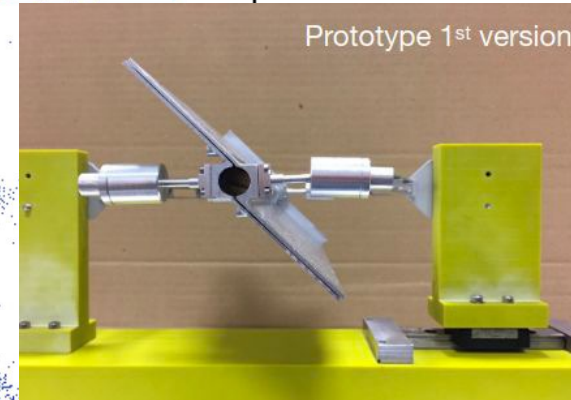
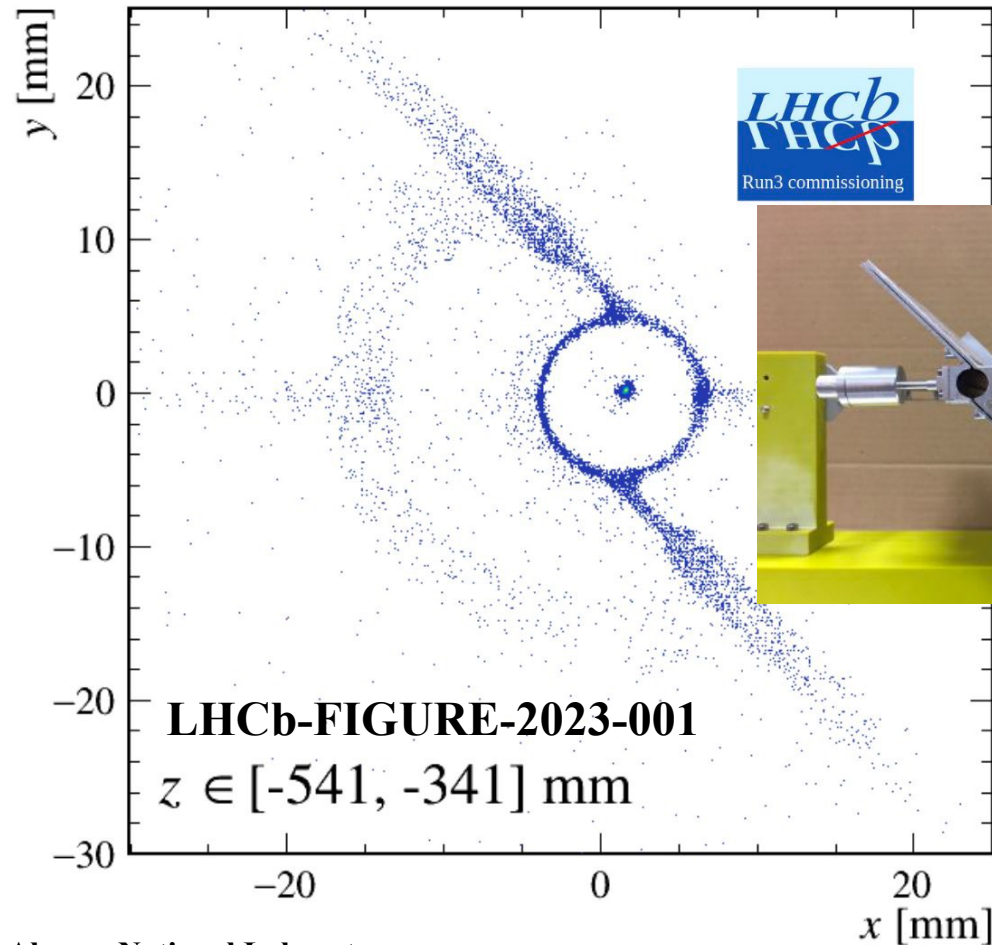


Fixed target upgrade – SMOG2

- Dedicated gas storage cell has been installed in front of LHCb VELO
- Allows greatly increased rates of beam+gas collisions

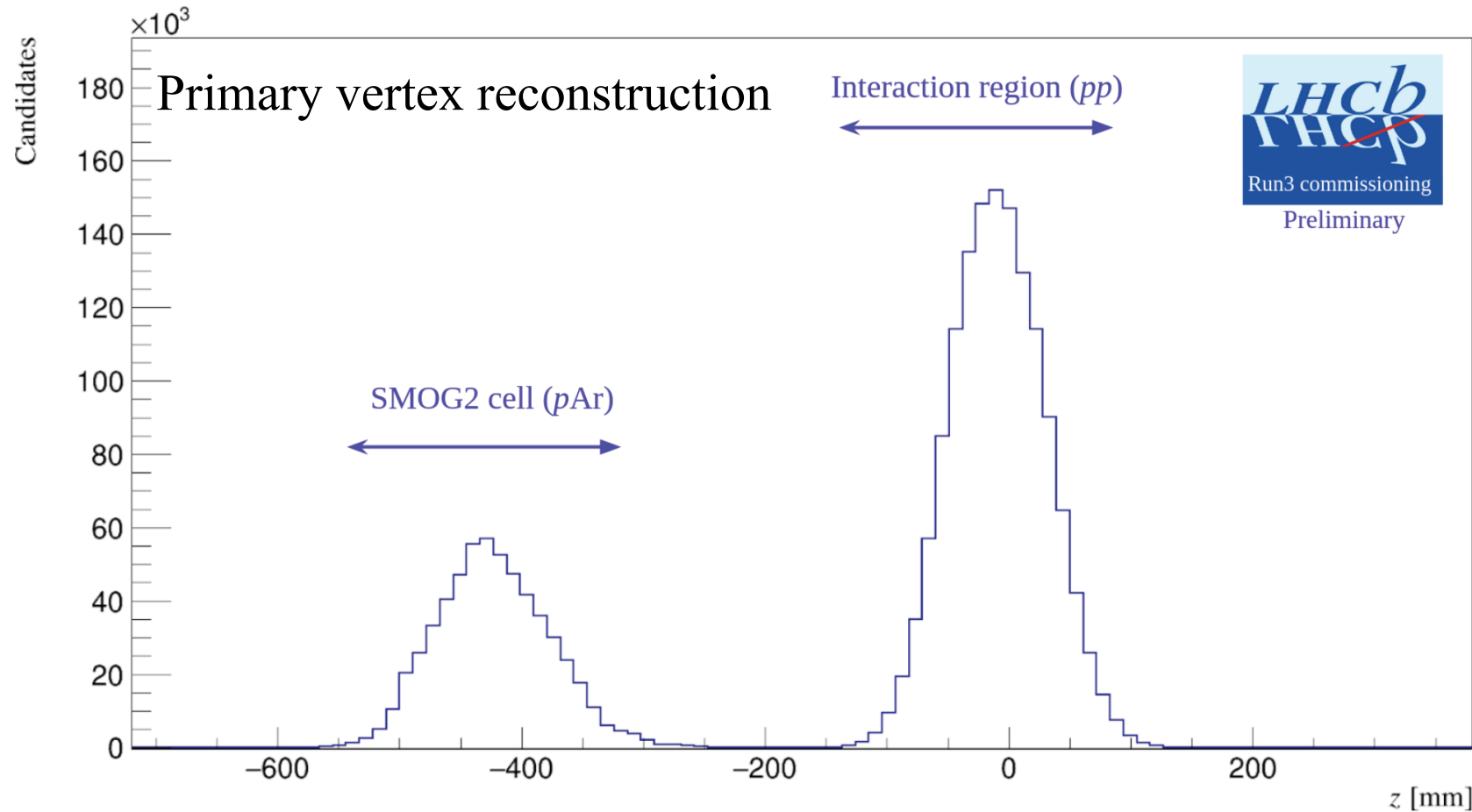


Reconstructed material interaction vertices



Fixed target upgrade – SMOG2

- Concurrent running with pp data will provide HUGE data samples



SMOG2 can provide any gas as target: run O+O at two collision energies simultaneously

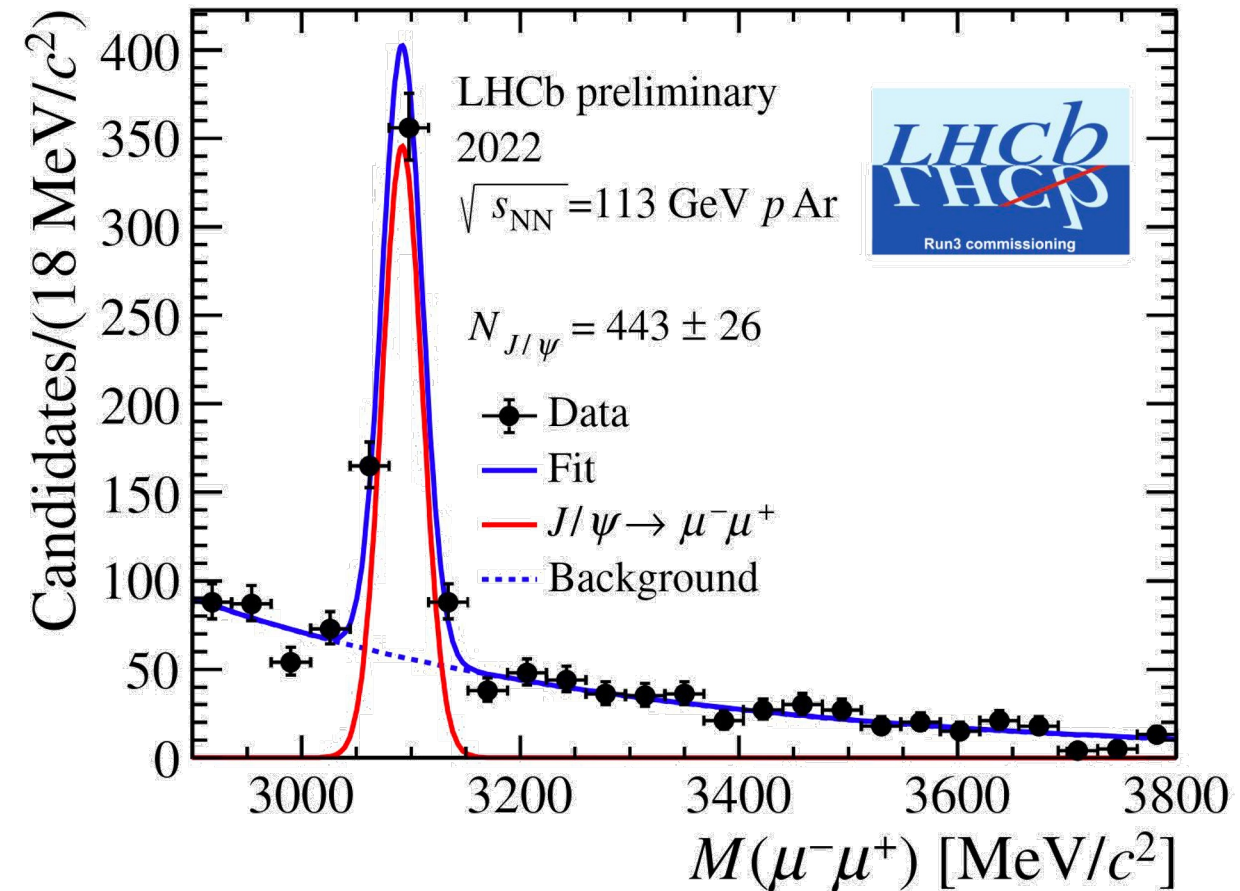
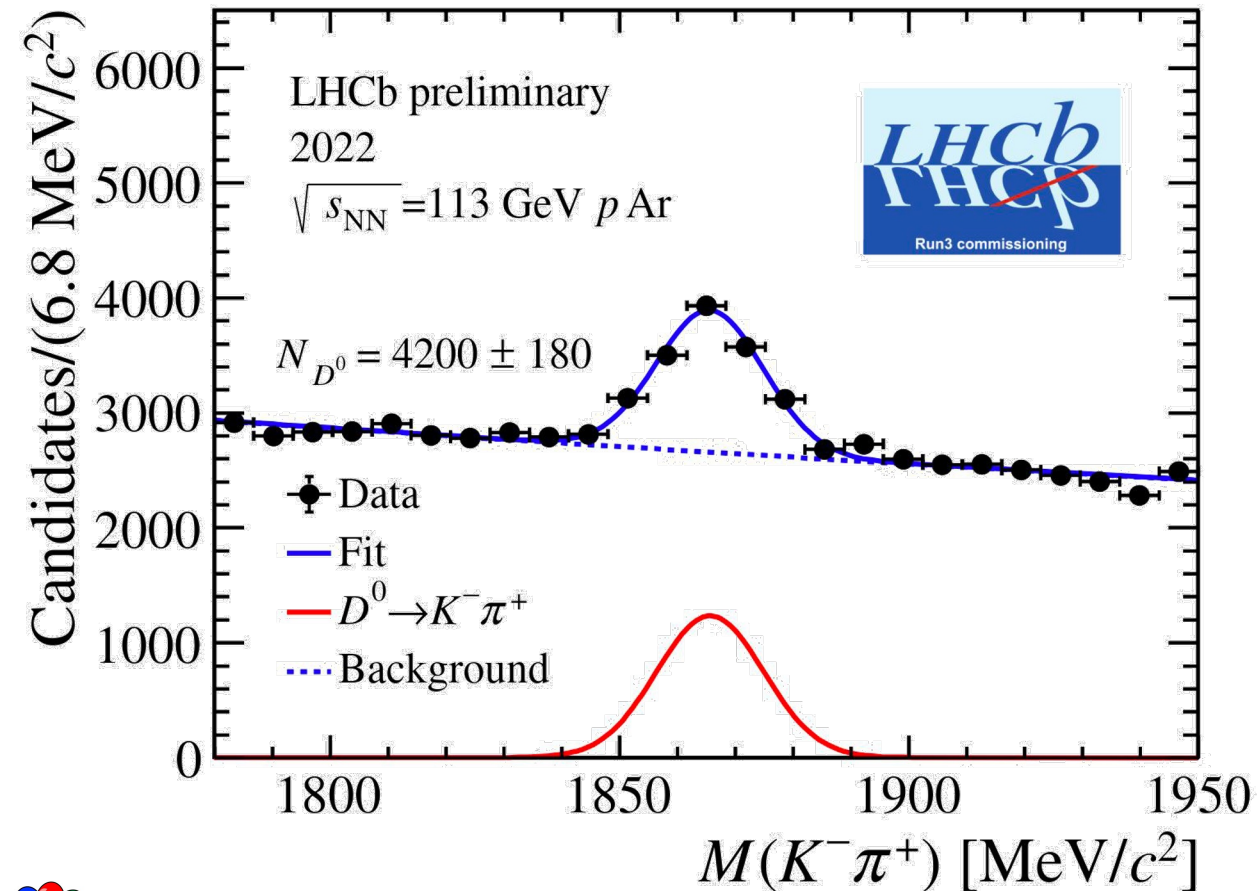


Fixed target upgrade – SMOG2



Saverio Mariani
Weds. 12:20

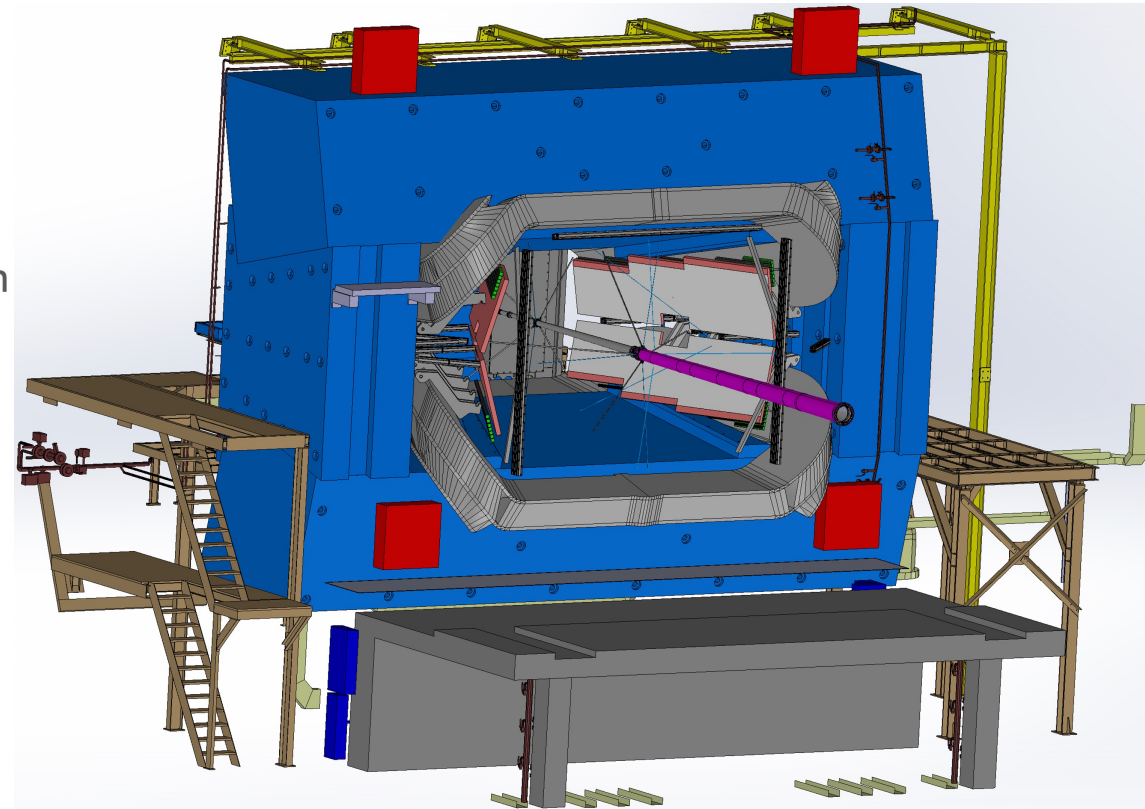
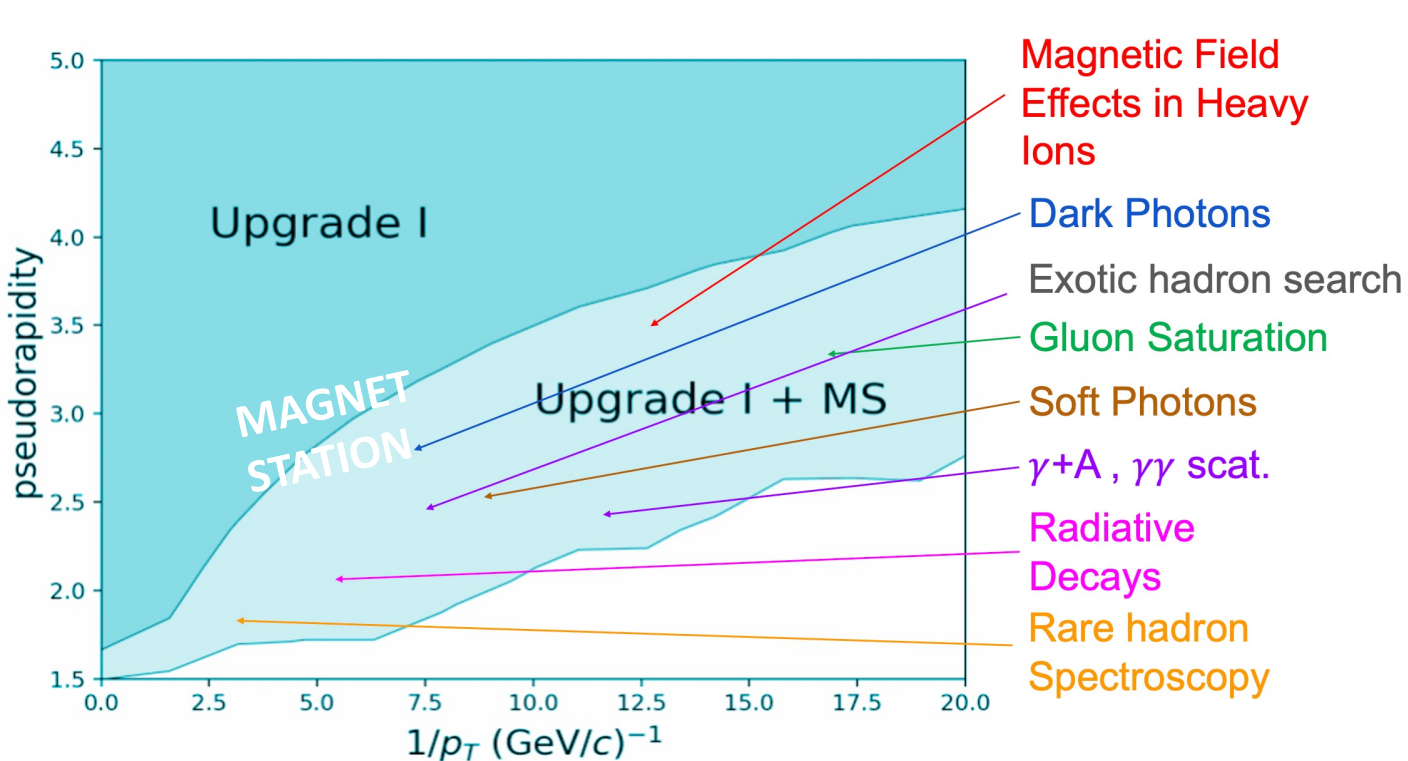
- Concurrent running with pp data will provide HUGE data samples
- Reconstructions from **18 minutes** of early 2022 data



Tracking upgrade – Magnet Station (LS3)



- Scintillating bar tracker for very soft particles at LHCb, start installation LS3
- Expands soft physics channels previously unreachable at the LHC.
- Allows access to very low x , Q^2 region where gluon saturation may exist in nuclei.



LHCb Upgrade II (Run 5+)

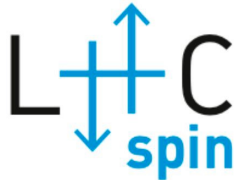


Imanol Corredoira
poster

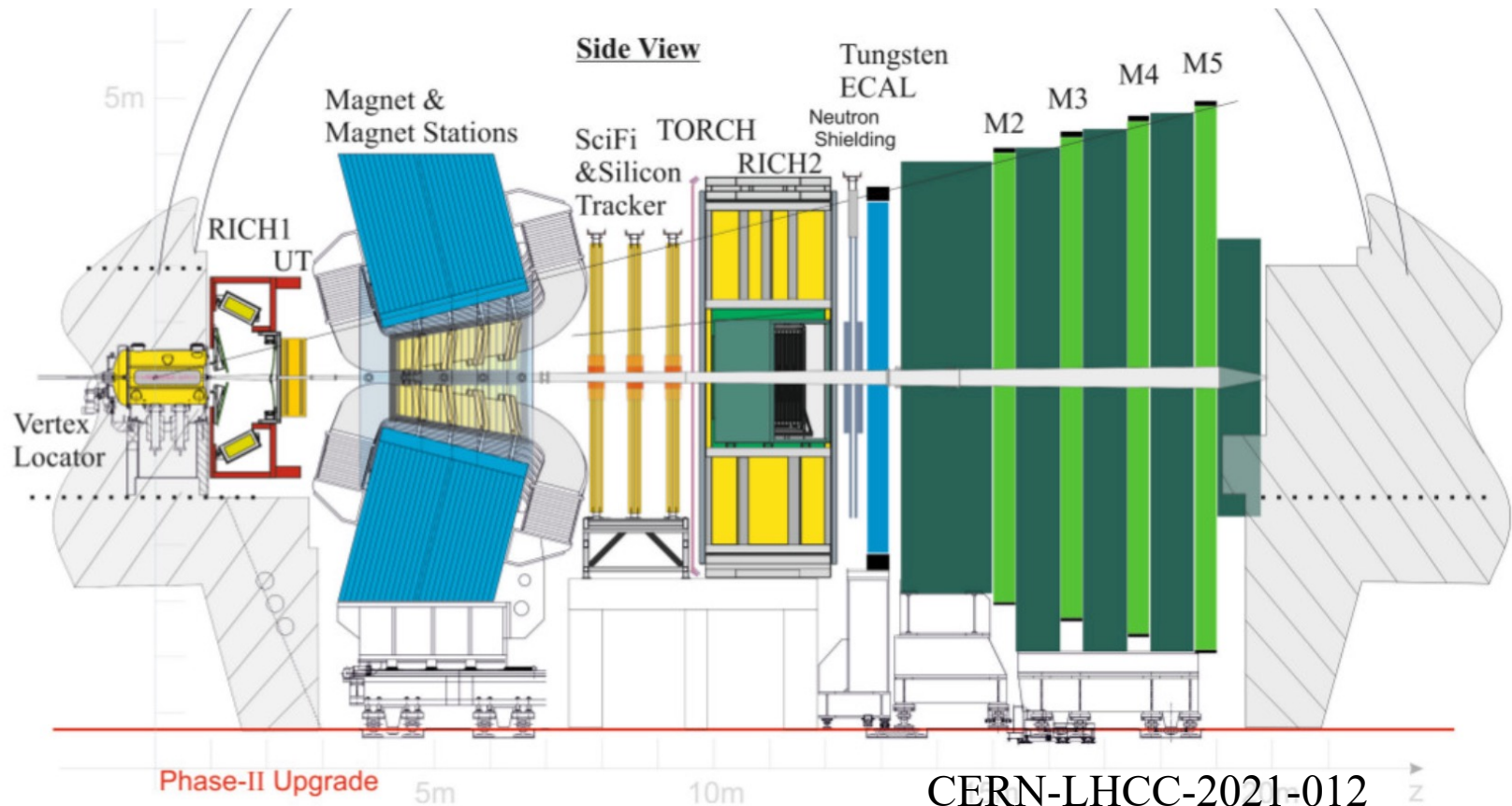
Further upgraded tracking to deal with high pp pileup and heavy ion collisions

- Access the full PbPb centrality range
- Precise measurements of B hadrons, exotic states, and more at low p_T in central collisions
- R&D well underway

Discussions beginning for a new era of fixed target physics:
Spin polarized target?



[arXiv:1901.08002](https://arxiv.org/abs/1901.08002)



Summary



- **The LHCb collaboration has a full, diverse heavy ion physics program**
 - pp to pA to AA with an unmatched variety of beam and target configurations
 - pp , pHe , pNe , pAr , pPb , $PbNe$, $XeXe$, $PbPb$ on tape, with much more to come
- **LHCb detector capabilities provide unique access to rare probes of nuclear matter**
 - Unprecedented access to low- x region of nuclei with identified particles
 - Precise open and hidden charm and bottom measurements in small systems
 - Unique access to higher charmonia and exotics at low p_T
- **LHCb program is rapidly expanding with new capabilities**
 - Vigorous upgrade program that directly impact LHCb heavy ion physics is underway



**Los Alamos National Laboratory is supported by the
DOE/Office of Science/Nuclear Physics and DOE Early Career Awards**

