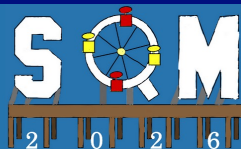



# Open heavy flavor and strangeness at LHCb

The 22<sup>nd</sup> International Conference on  
**Strangeness in Quark Matter**  
22-27 March, 2026, Los Angeles, CA



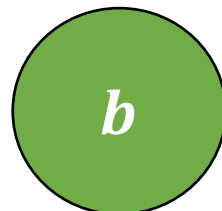
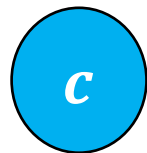
Matt Durham, standing in for Oleksander Kot  
for the LHCb collaboration  
*durham@lanl.gov*

# Strange and heavy quarks in medium

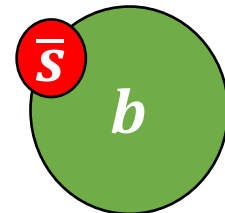
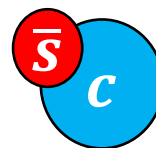
  $m_s \sim 90 \text{ MeV}$

- $m_s < T_c$
- Strangeness production enhanced in hot QGP
- Requires understanding of strangeness production where QGP is not dominant effect

Use *perturbatively* produced heavy quarks to study *non-perturbative QCD* phenomena like strangeness enhancement, hadronization

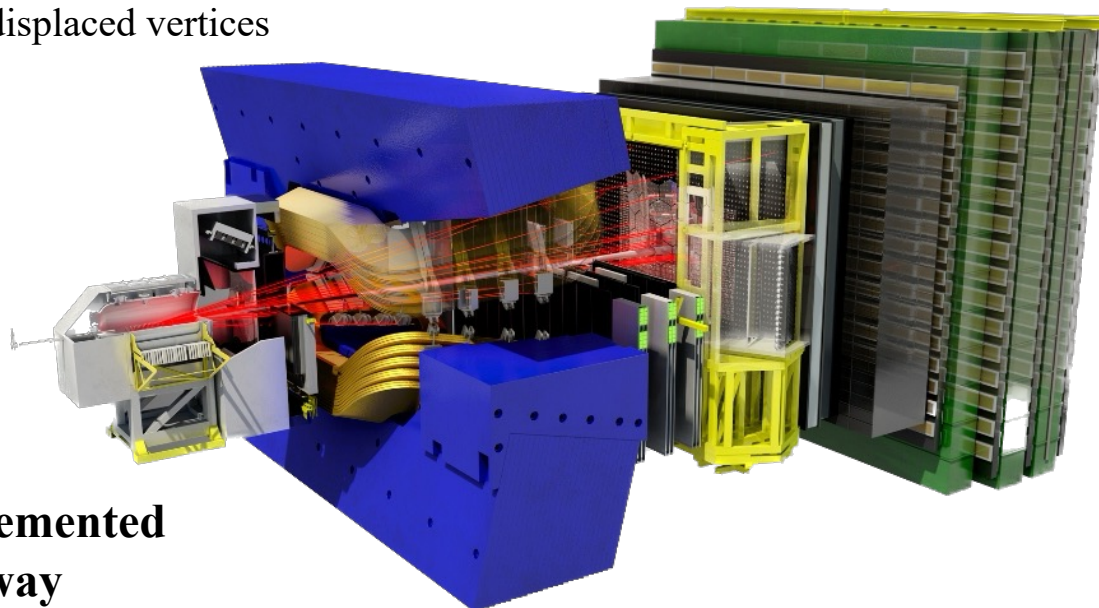
 $m_c \sim 1.3 \text{ GeV},$   
 $m_b \sim 4.5 \text{ GeV}$

- $m_{c,b} \gg T_c$
- Thermal production of heavy quarks suppressed by large mass
- pQCD techniques describe charm and bottom total cross sections well

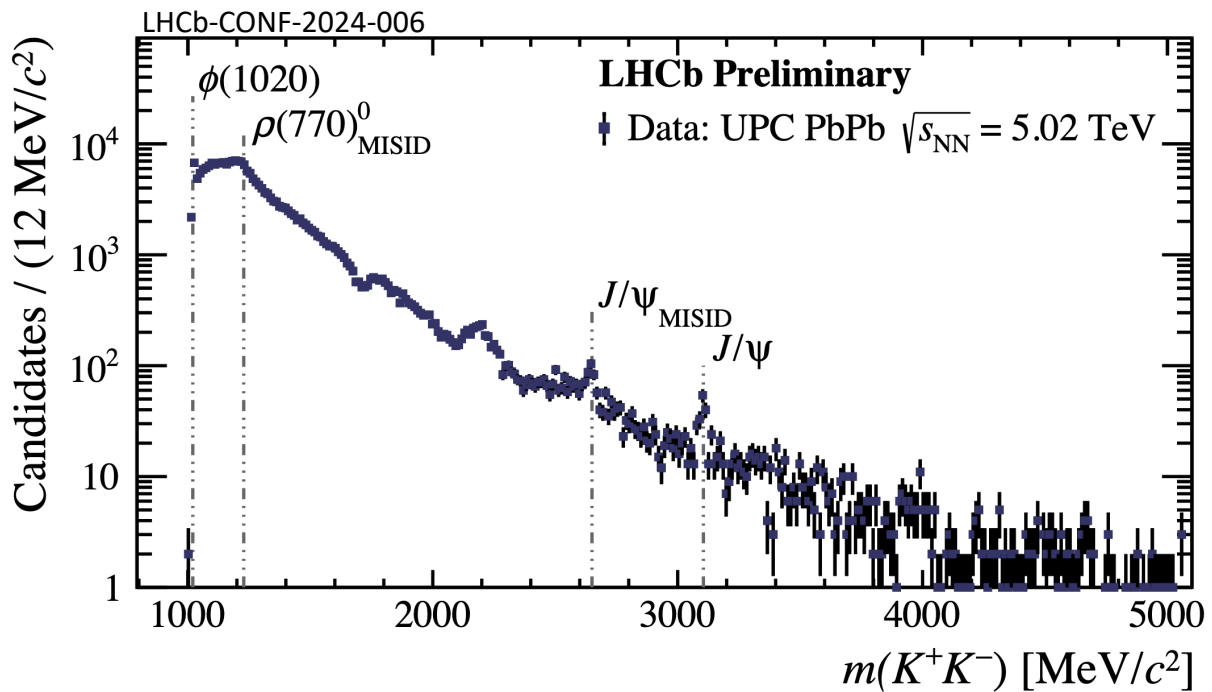
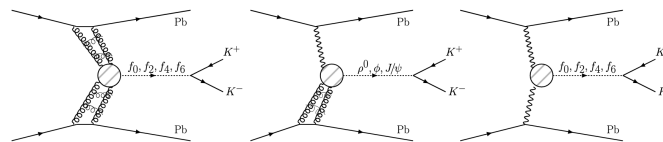


# LHCb – a unique detector for heavy ion physics

- **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
  - $b$ , higher charmonia, exotics
- **Unique fixed-target system**
  - Explore p+gas and Pb+gas collisions
  - Hugely versatile physics program
- **Successful detector upgrades implemented**
  - **Ambitious Upgrade II underway**

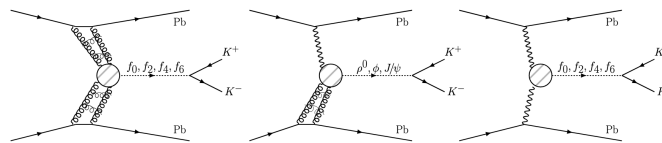


# Strangeness in UPCs

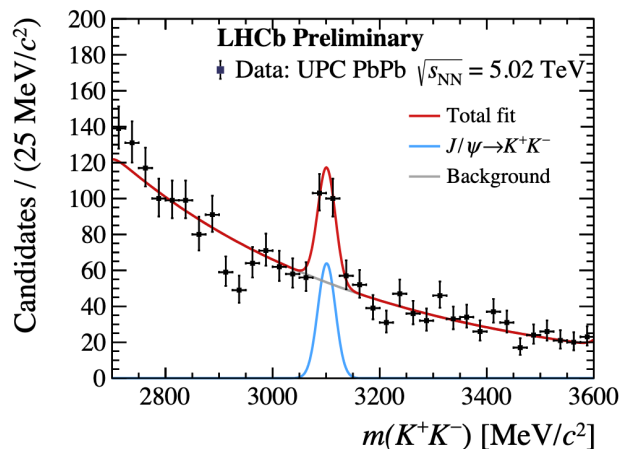
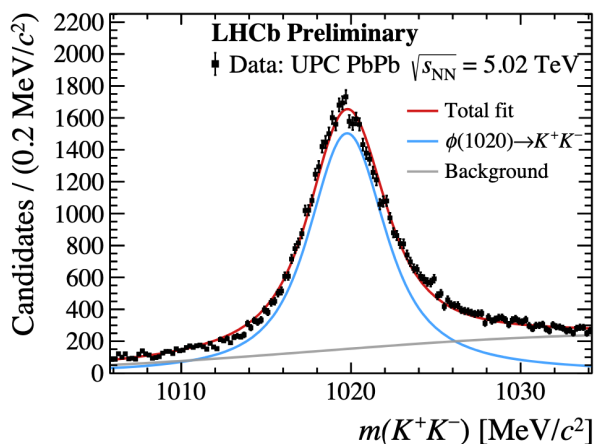


- Select events where both Pb nuclei remain intact
- Exactly 2 long tracks in spectrometer which satisfy nominal kaon ID
- Observe rich structure: resonances + NR + mis ID

# Strangeness in UPCs



LHCb-CONF-2024-006

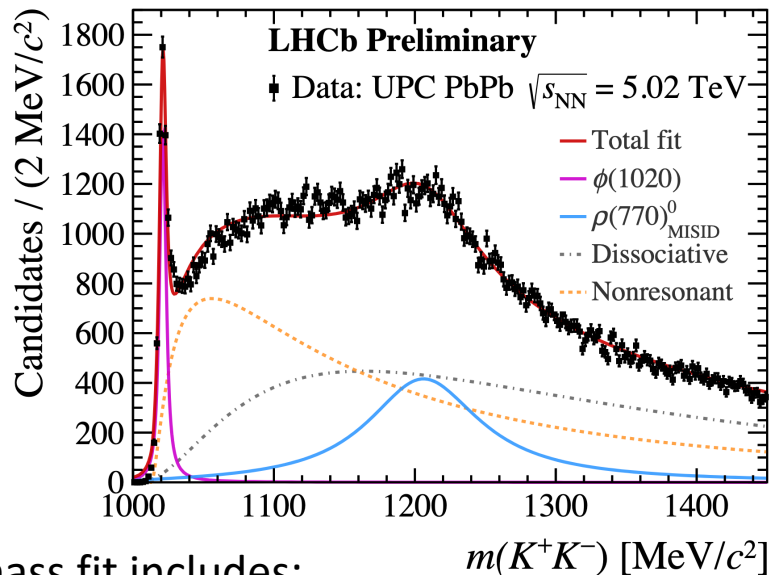
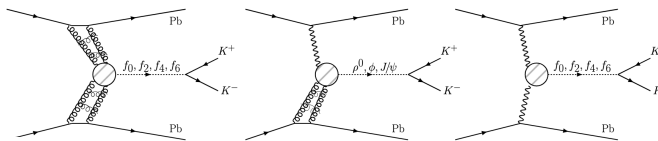


Clear signals of  $\phi$  and  $J/\psi$  decays to  $K^+K^-$

- Select events where both Pb nuclei remain intact
- Exactly 2 long tracks in spectrometer which satisfy nominal kaon ID
- Observe rich structure: resonances + NR + mis ID

# Strangeness in UPCs

LHCb-CONF-2024-006

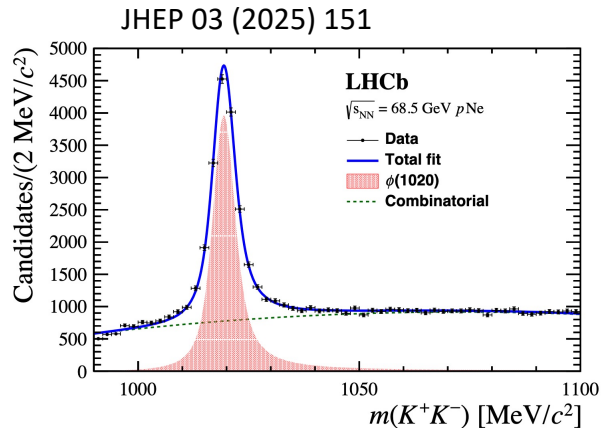
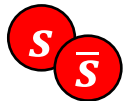


Low mass fit includes:

- $\phi$  and mis ID  $\rho \rightarrow \pi^+\pi^-$
- non-resonant  $K^+K^-$  production
- contamination from events when Pb nucleus dissociates

- Select events where both Pb nuclei remain intact
- Exactly 2 long tracks in spectrometer which satisfy nominal kaon ID
- Observe rich structure: resonances + NR + mis ID

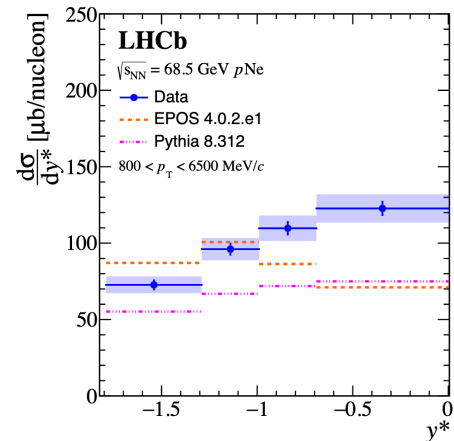
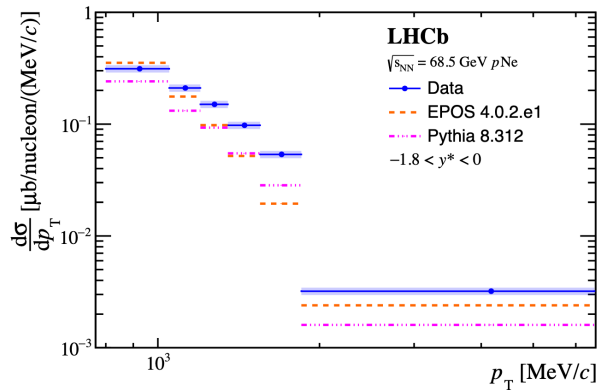
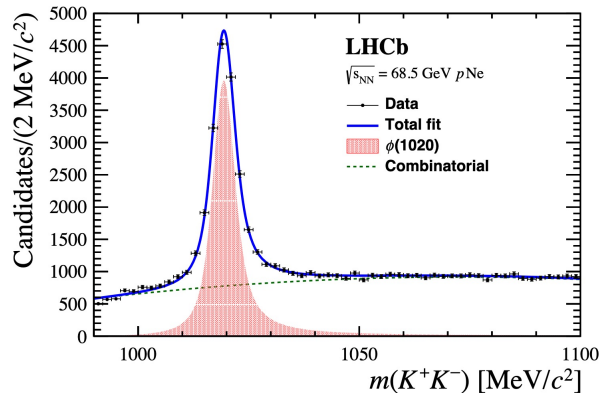
# $\phi(1020)$ production in fixed-target $p$ Ne $\sqrt{s_{NN}} = 68.5$ GeV



- Fixed target  $p$ Ne collisions enabled by SMOG system
- Relatively low  $\sqrt{s_{NN}}$ 
  - plasma effects not dominant
- Relatively small nucleus
  - CNM effects should be small

# $\phi(1020)$ production in fixed-target $p$ Ne $\sqrt{s_{NN}} = 68.5$ GeV

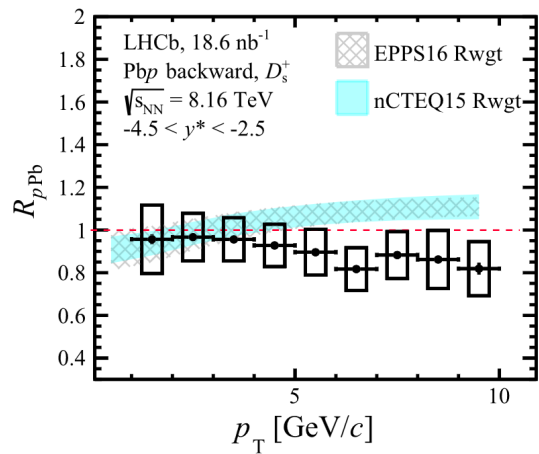
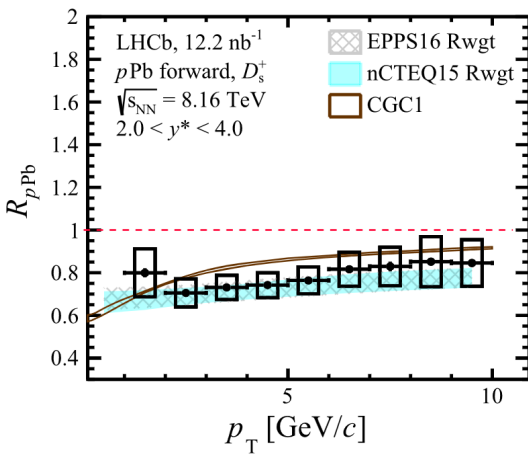
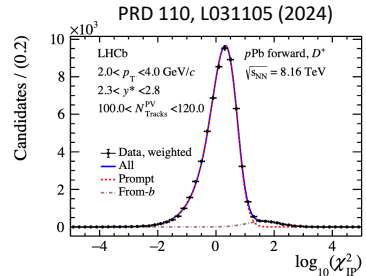
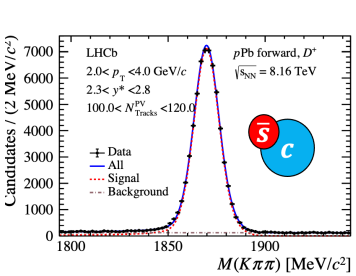
JHEP 03 (2025) 151



- Fixed target  $p$ Ne collisions enabled by SMOG system, covers  $-1.8 < y^* < 0$
- Relatively low  $\sqrt{s_{NN}}$ 
  - plasma effects not expected to dominate
- Relatively small nucleus
  - CNM effects expected to be small
- **PYTHIA and EPOS generator both underpredict cross sections**

# Strangeness enhancement with charm - $p\text{Pb}$

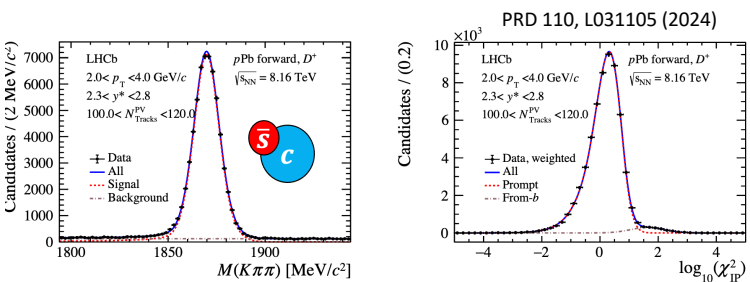
$$D_s^+ \rightarrow K^+ K^- \pi^+$$



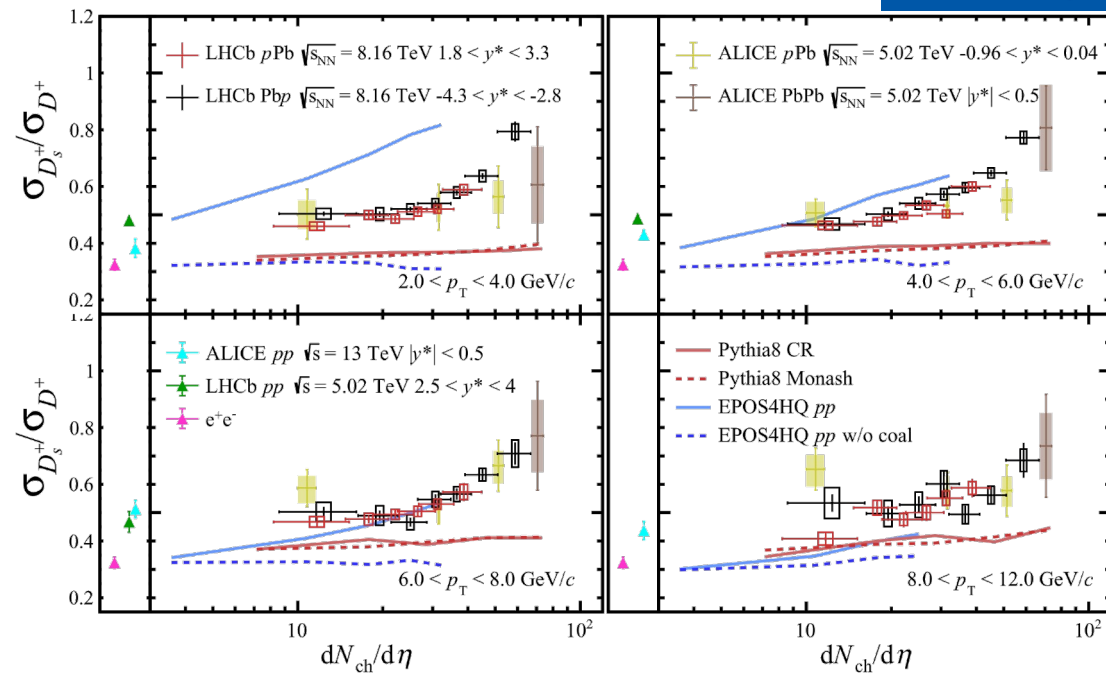
- Prompt  $D_s^+$  data consistent with updated nPDF calculation
- Tension at backwards rapidity
  - Additional effects beyond nPDF becoming important?

# Strangeness enhancement with charm - $p\text{Pb}$

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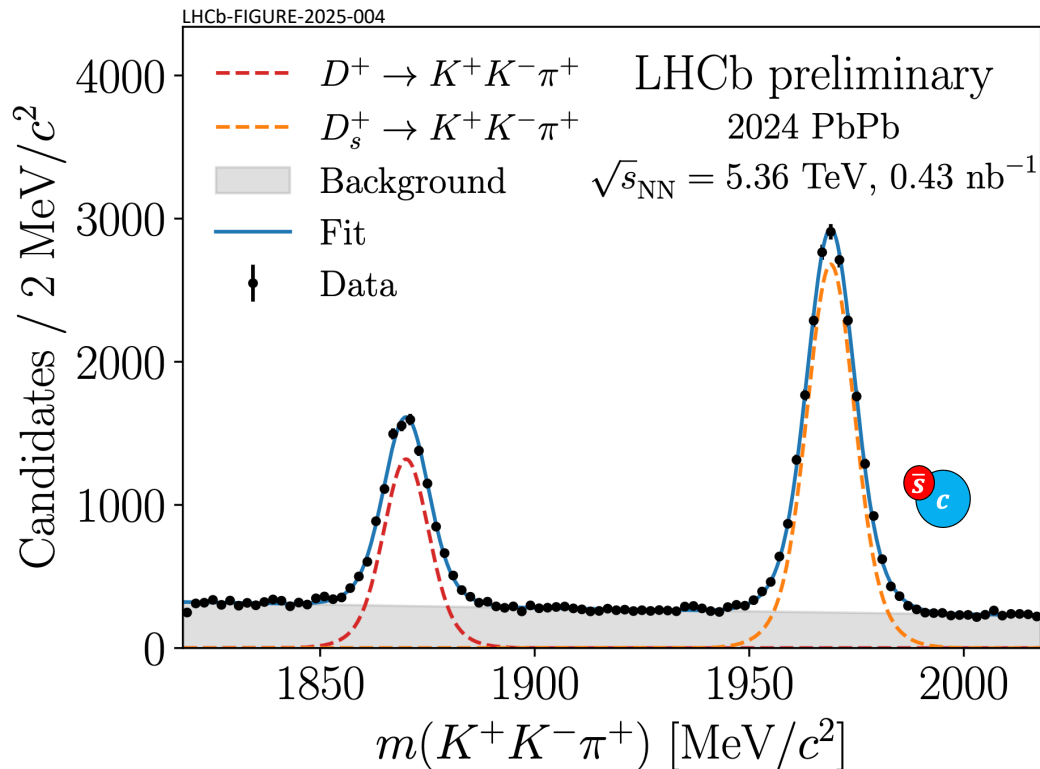


- Prompt  $D_s^+$  data consistent with updated nPDF calculation
- Tension at backwards rapidity
  - Additional effects beyond nPDF becoming important?



- **Clear onset of strangeness enhancement with multiplicity**
- **Rapidity dependence in  $p\text{Pb}$  removed when controlling for multiplicity**

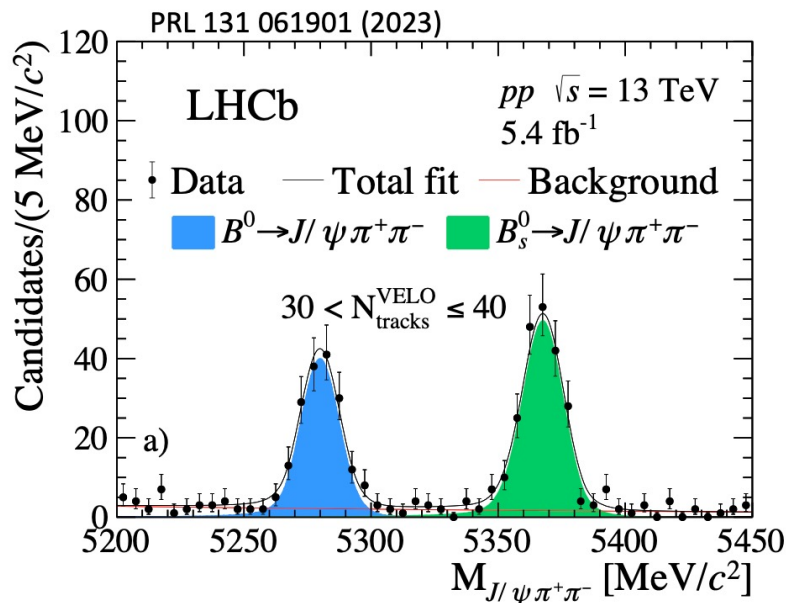
# Extending strangeness studies to PbPb



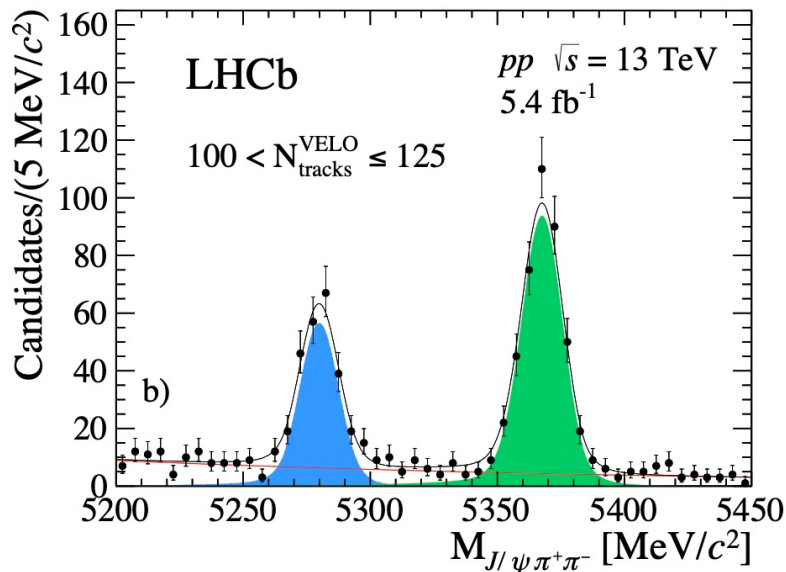
- Upgraded LHCb detector allows PbPb collisions to be reconstructed up to  $\sim 30\%$  most central
- Tagging displaced vertices from forward boosted charm hadrons greatly reduces combinatorial background
- Clear signals in 2024 PbPb data under analysis

# Modification of $b$ hadronization – strange B mesons

- Large mass of  $b$  quarks  $\rightarrow$  low  $b$  velocity; potential for substantial overlap with other quarks
- Strangeness enhancement plus coalescence should lead to enhanced  $B_s^0$  yields



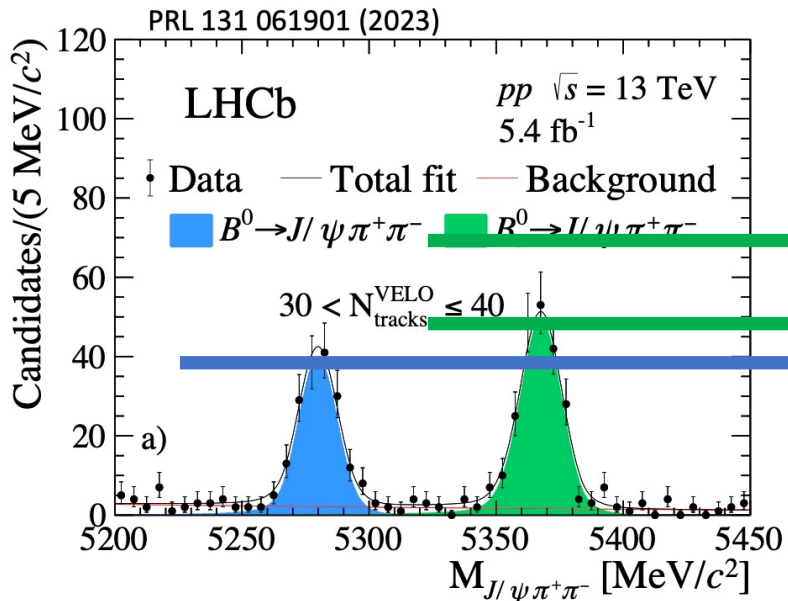
Low multiplicity



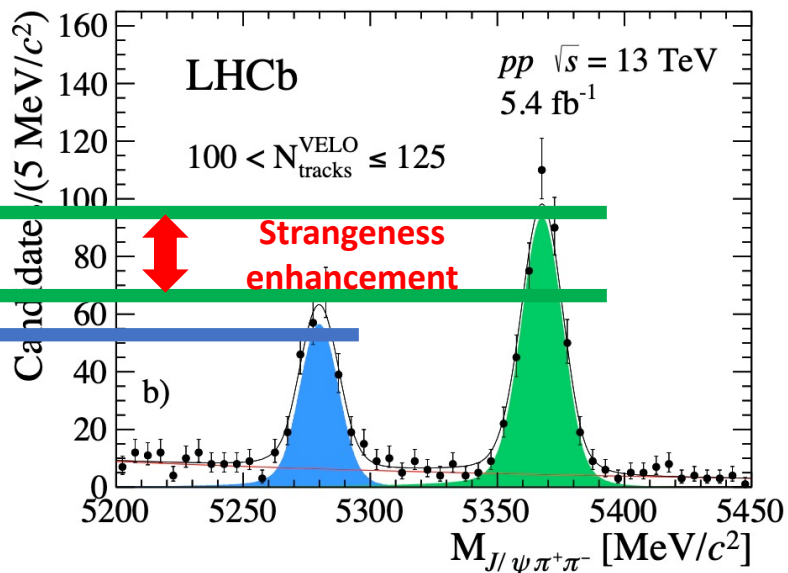
High multiplicity

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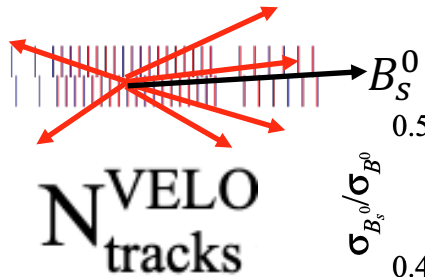


Low multiplicity



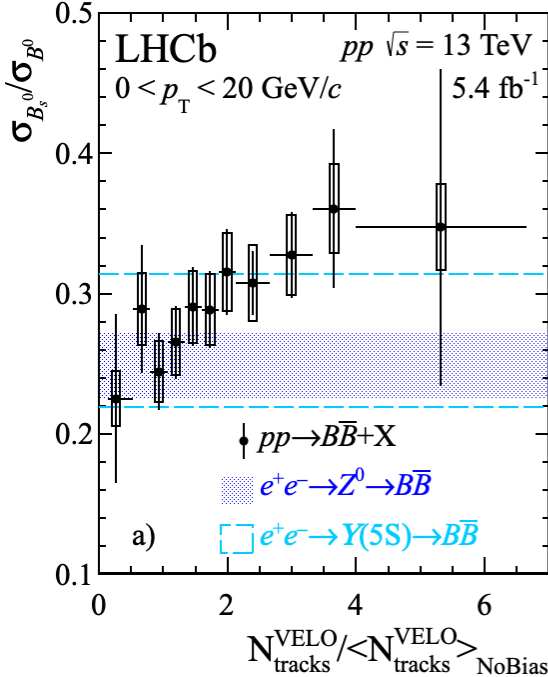
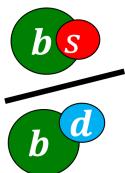
High multiplicity

# Modification of $b$ hadronization – strange B mesons

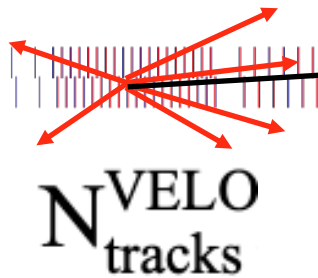


PRL 131 061901 (2023)

Total VELO multiplicity, dominated by forward tracks

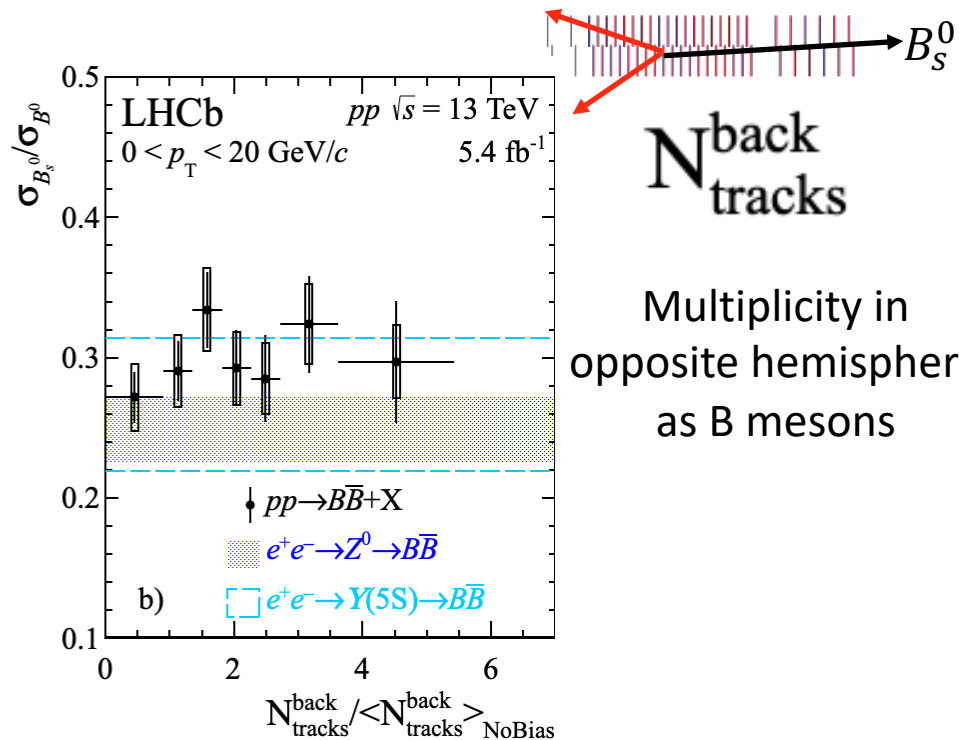
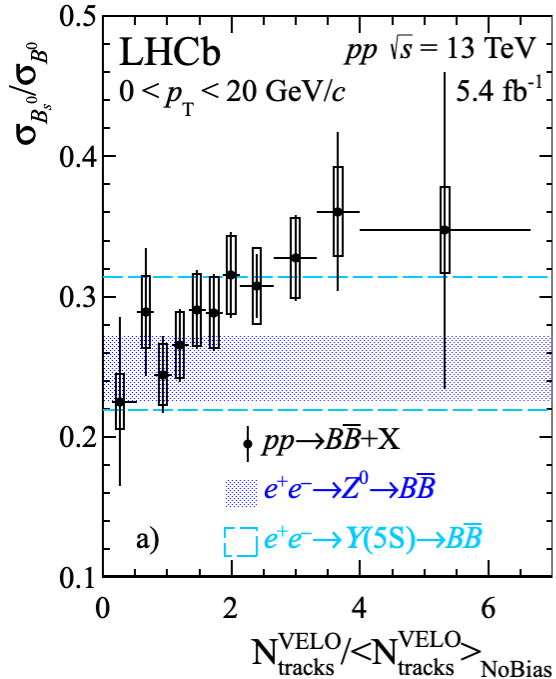
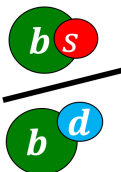


# Modification of $b$ hadronization – strange B mesons



PRL 131 061901 (2023)

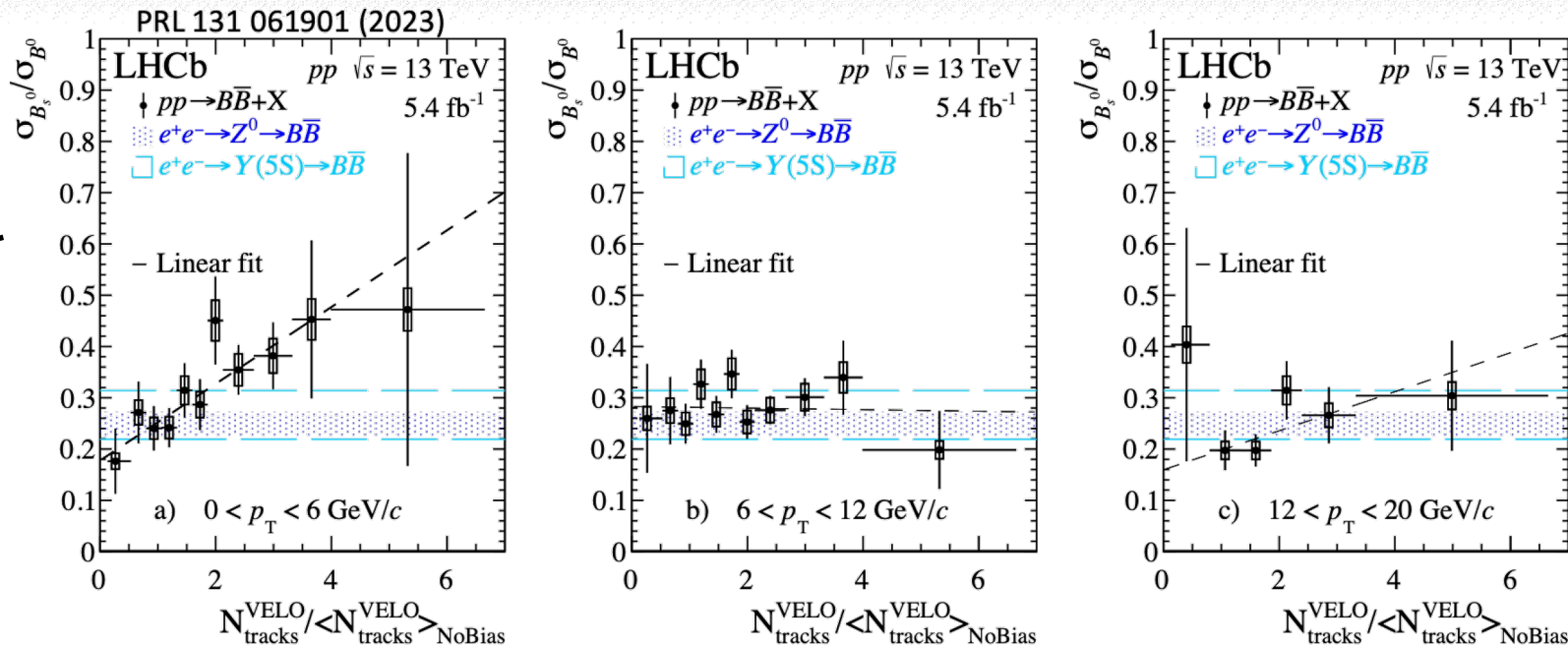
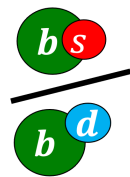
Total VELO multiplicity, dominated by forward tracks



Multiplicity in opposite hemisphere as B mesons

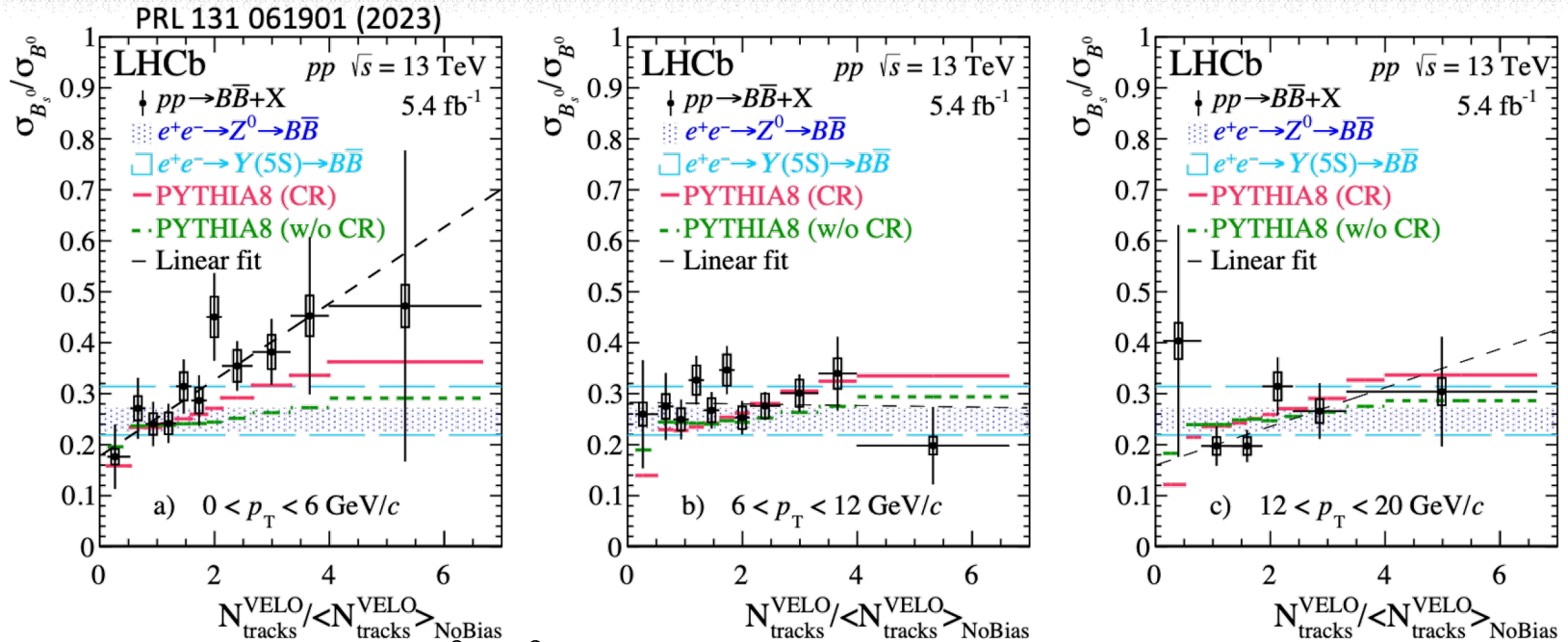
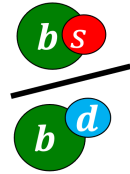
- Enhancement depends on *local* particle density around B mesons

# Modification of $b$ hadronization



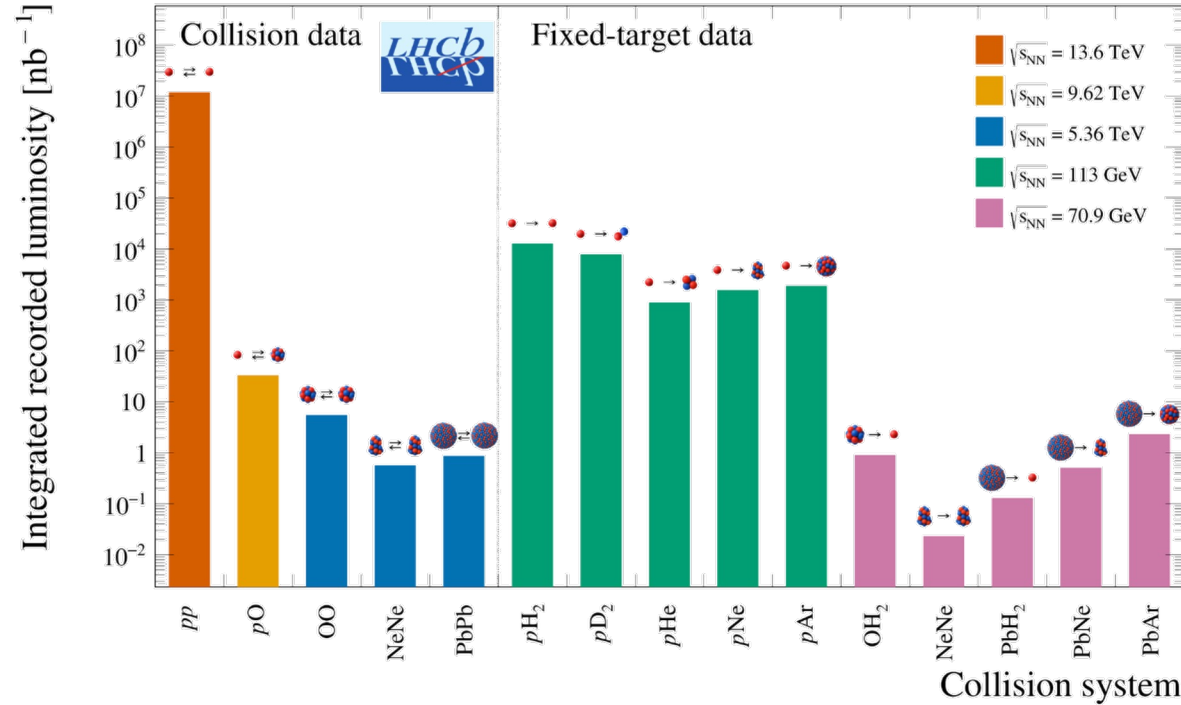
- Evidence for an increase of  $B_s^0/B^0$  at low  $p_T$
- Low multiplicity data consistent with fragmentation in vacuum measured in  $e^+e^-$  collisions
- Higher  $p_T$  B mesons show no enhancement

# Modification of $b$ hadronization – PYTHIA8



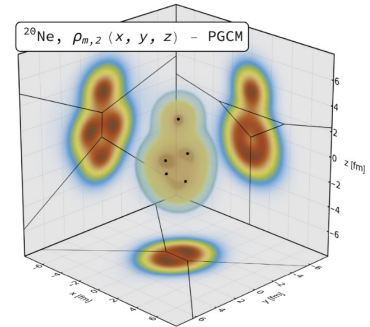
- Evidence for an increase of  $B_s^0/B^0$  at low  $p_T$
- Low multiplicity data consistent with fragmentation in vacuum measured in  $e^+e^-$  collisions
- Higher  $p_T$  B mesons show no enhancement
- PYTHIA8 w/color reconnection enabled describes high  $p_T$  data, undershoots low  $p_T$

# Outlook: 15 new data sets recorded by LHCb in 2025



New data sets all LHCb to probe:

- QCD at highest energies
- CNM and QGP at high temperatures
- (De)confinement at small energy densities
- Totally unique geometries



**LHCb is the most versatile heavy ion experiment ever fielded**

# Summary

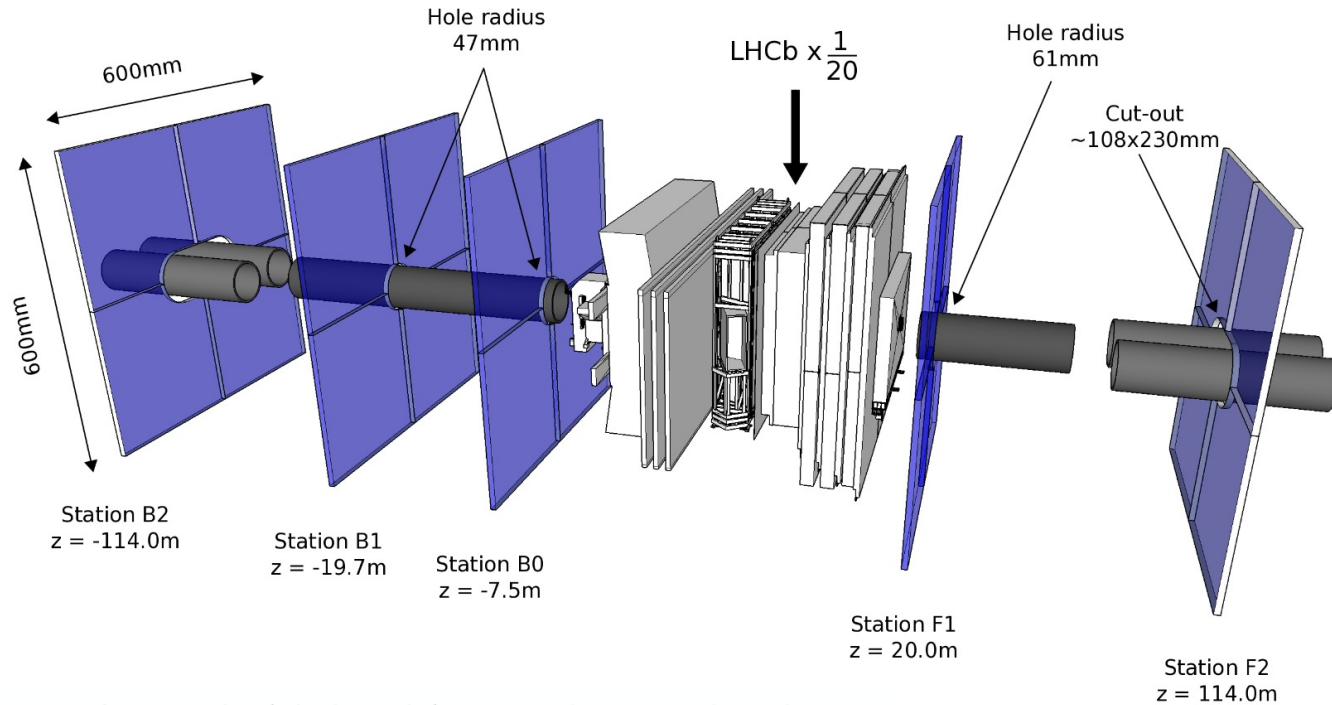
- LHCb has the most versatility of any heavy ion experiment that has ever existed:
  - Probes the widest range of  $x$  of any experiment
  - Largest lever arm in  $\sqrt{s_{NN}}$  of any experiment
  - More collision species than any experiment
- Strangeness is studied in UPCs, fixed target,  $pp$ ,  $pA$ , and AA collisions
  - Multiple production mechanisms across dramatically varying nuclear environments
- Results from amazing data sets recorded in 2025 under preparation
  - LHCb remains highly under-leveraged for heavy ion physics



**Los Alamos is supported by the US Dept. of Energy  
Office of Science/Nuclear Physics**

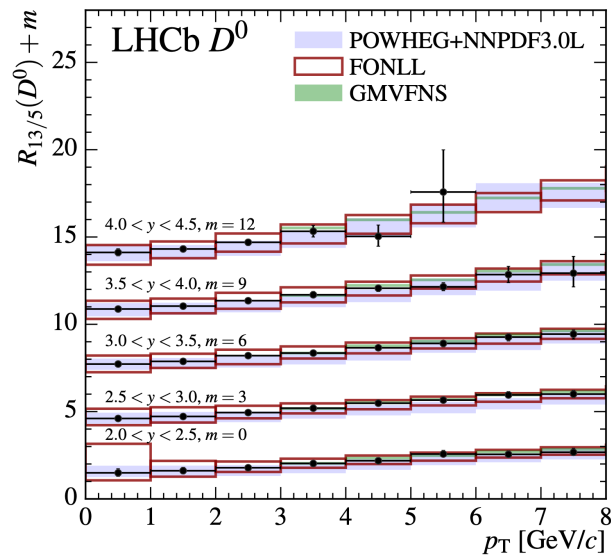
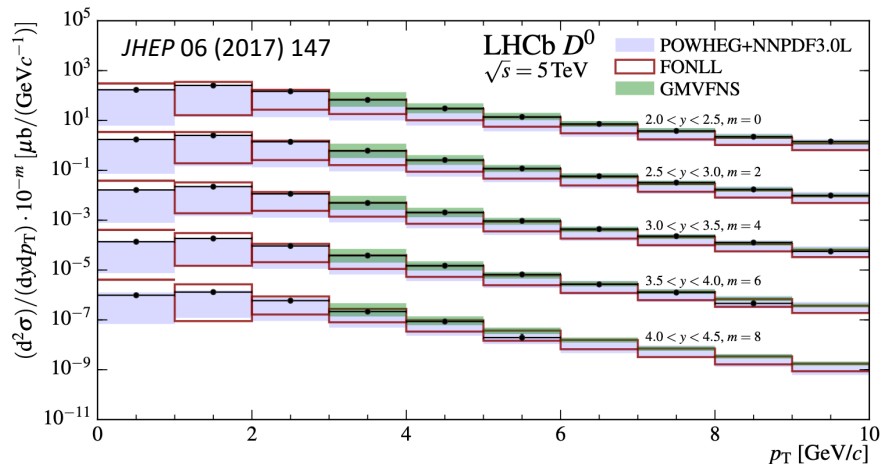
# BACKUPS

# HERSCHEL



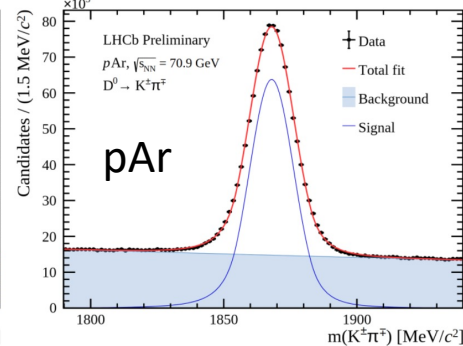
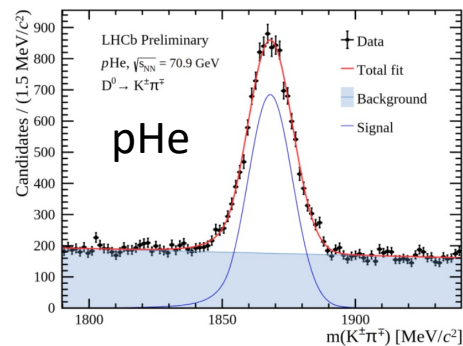
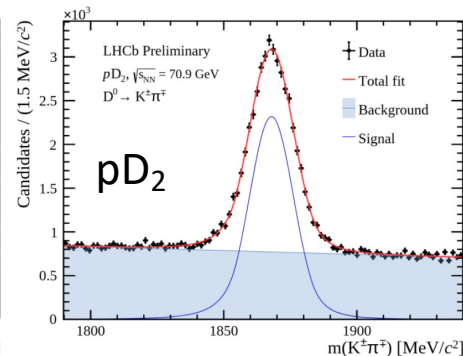
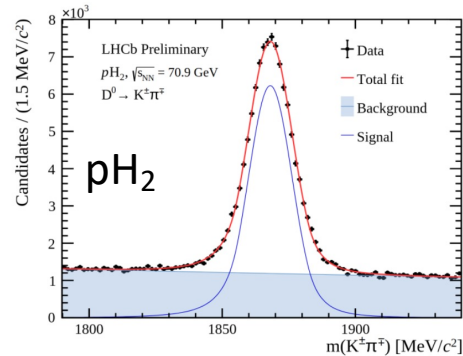
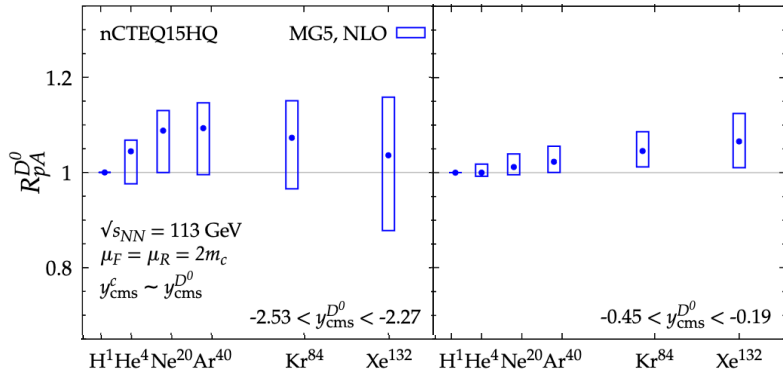
JINST 13 (2018) no.04, P04017

# Cross sections in $pp$



- LHCb has the largest sample of charm decays of any experiment
- Enables precise measurements of cross section to test pQCD
- Ratios at different collision energies cancel many theoretical uncertainties

# Fixed target: charm with SMOG



Ann.Rev.Nucl.Part.Sci. 74 (2024)

