Femtoscopy at LHCb

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Informal discussion notes

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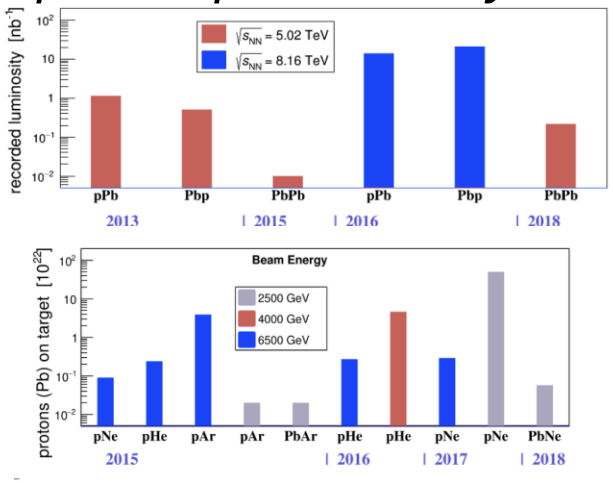
Why femtoscopy at LHCb?

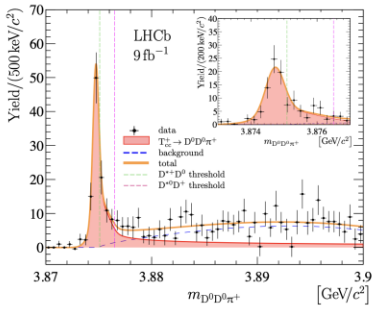
- Variety of different collision systems and energies
  → *probe source in different collisions*

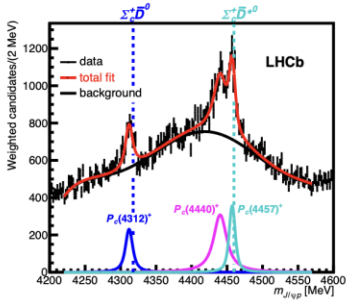
- Forward-rapidity coverage
  → *probe source in different kinematical region*

- Huge expertise in heavy-flavor physics and search for exotic hadrons
  → *femtoscopy as a complementary tool for further studies to well-developed amplitude analysis technique*

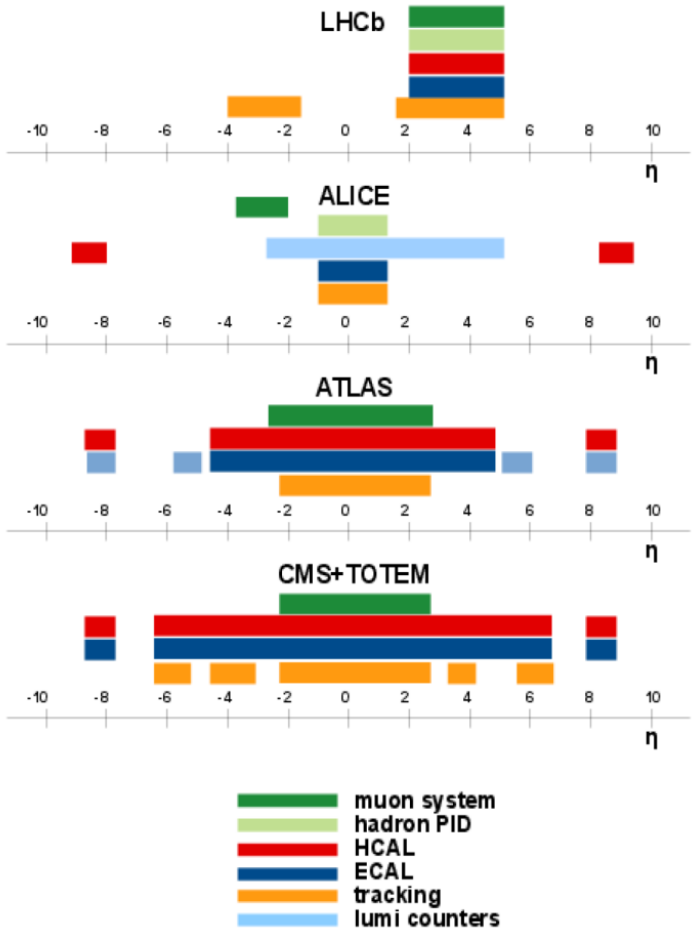


LHCb Run2 ion datasets



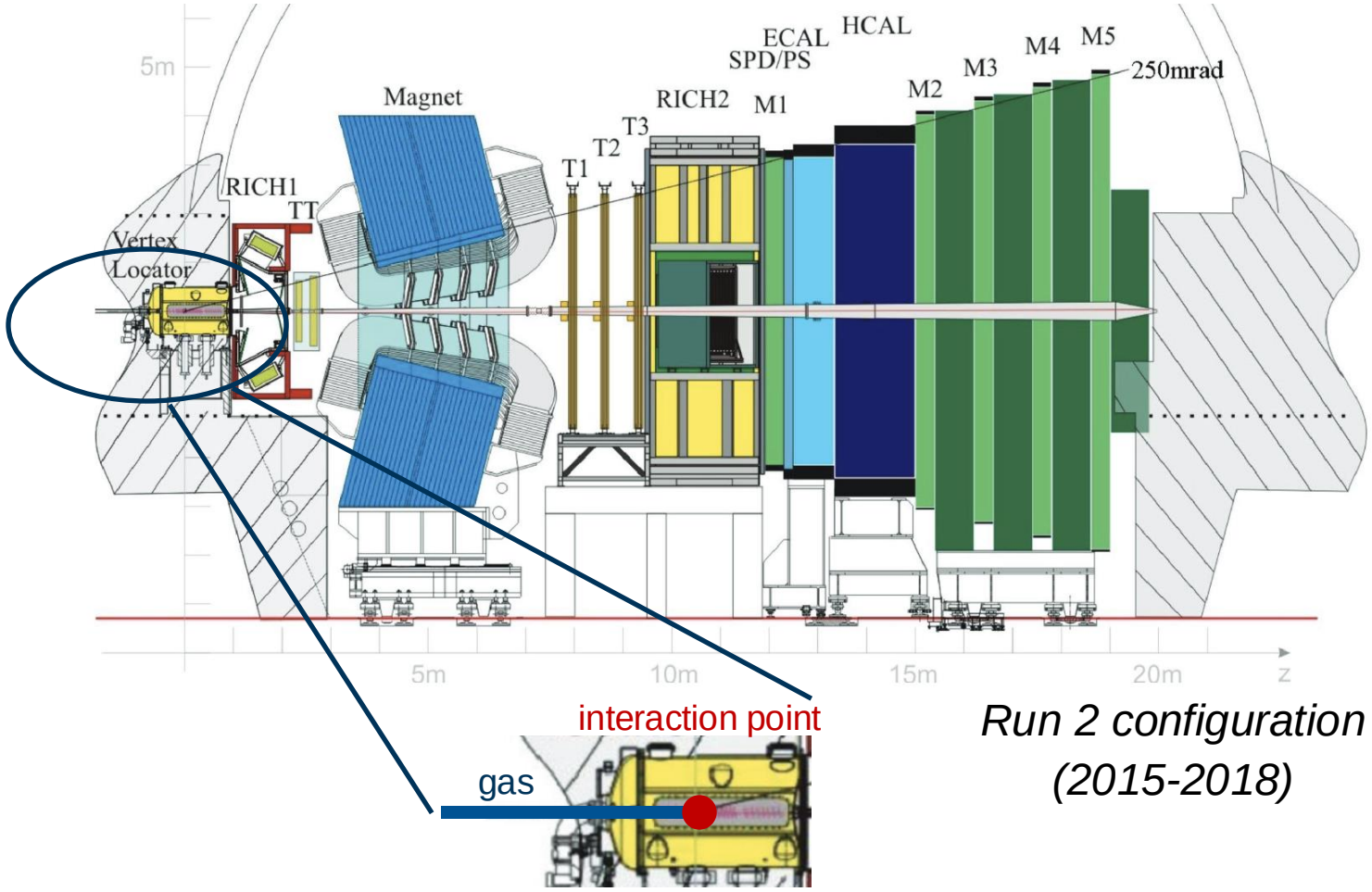


[Review on Exotic Hadrons at LHCb (Annu. Rev. Nucl. Part. Sci. 2024. 74:583–612)]



In more detail: The LHCb detector (Run1+2)

IJMPA 30 (2015) 1530022

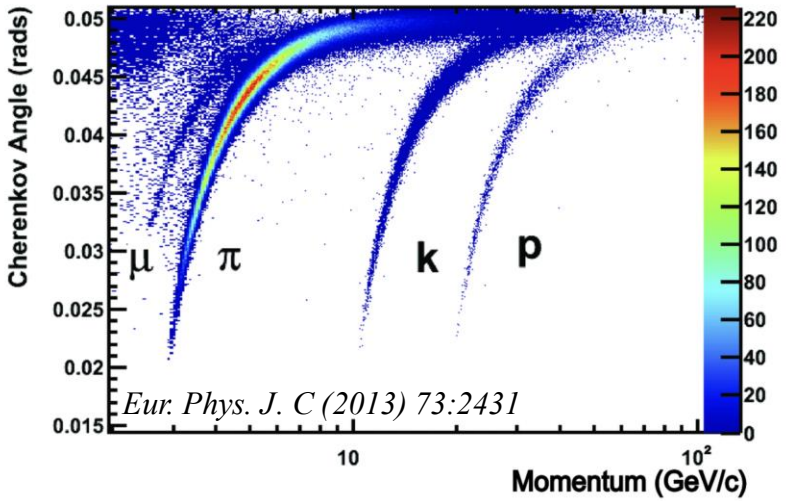


SMOG system

Run 2 configuration (2015-2018)

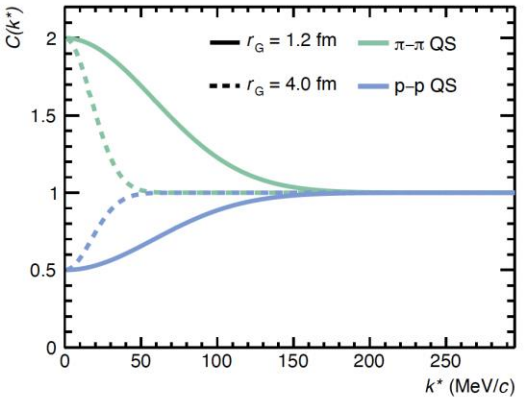
Forward spectrometer at the LHC $(2 < \eta < 5)$ with

- excellent PID with 2 RICH detectors + Calorimetry + Muon ID
- very good vertex and momentum resolution due to Vertex Locator (VELO)
- Fixed target system (SMOG) allows for different gaseous targets in addition to beam-beam collisions



Femtoscopic studies performed at LHCb so far: Bose-Einstein Correlation Studies in pp and pPb

Fig. from B. Hohlweger Diss. (TUM,2020)

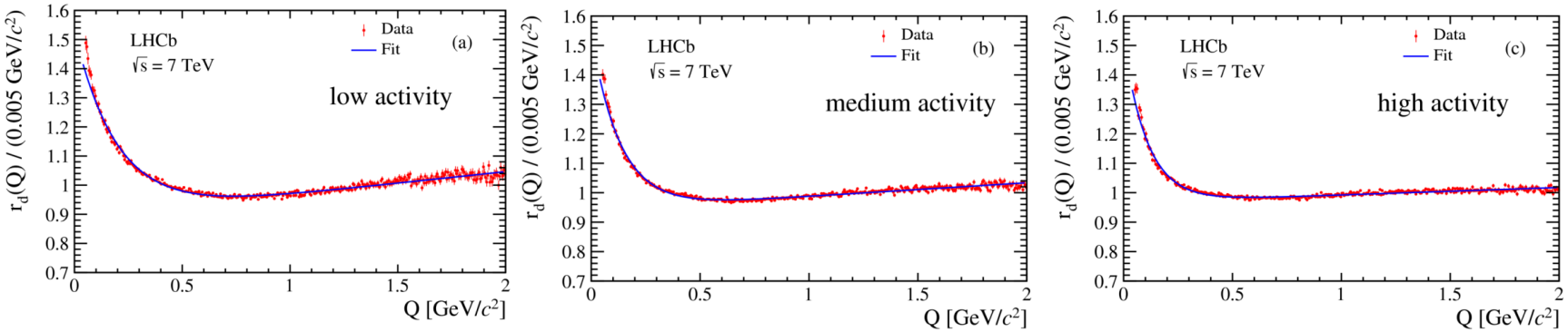


correlation function for indistinguishable particles
($k^* \approx 2Q$)

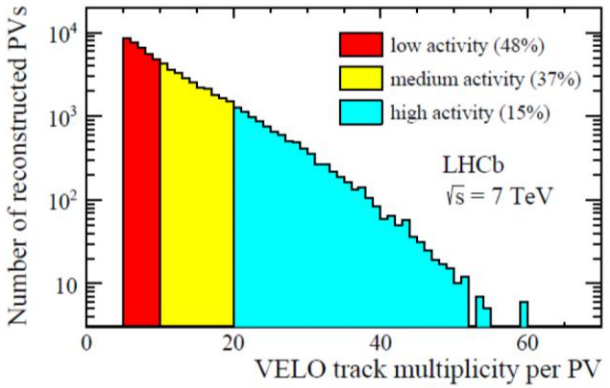
Studies on BEC with same-sign pions in pp (2017) and pPb/Pbp (2023)

pp: JHEP 12 (2017) 025, Nucl. Phys. A982 (2019) 347–350
pPb: JHEP 09 (2023) 172

- $\pi^{\pm} - \pi^{\pm}$ correlation to extract source size in pp@7TeV and pPb/Pbp@5TeV
- Fit to correlation function with Levy parameterization in range 0.05 GeV < Q < 2.0 GeV (with $\alpha = 1$) $C_2(Q) = N(1 + \lambda e^{-|RQ|^{\alpha}}) \times (1 + \delta \cdot Q)$
- extraction of source size in bins of activity (Velo track multiplicity per PV)



measured correlation functions in pp and fits with Levy paramterization in different activity bins



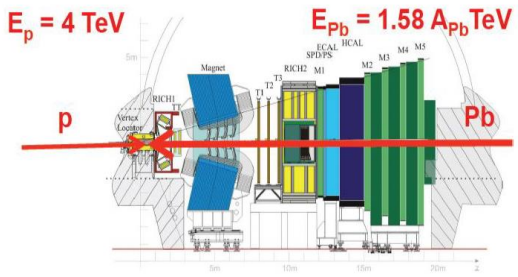
different activity regions in pp

Femtoscopic studies performed at LHCb so far: Bose-Einstein Correlation Studies in pp and pPb

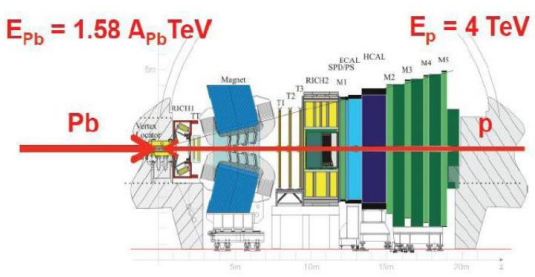
Studies on BEC with same-sign pions in pp (2017) and pPb/Pbp (2023)

pp: JHEP 12 (2017) 025, Nucl. Phys. A982 (2019) 347–350
pPb: JHEP 09 (2023) 172

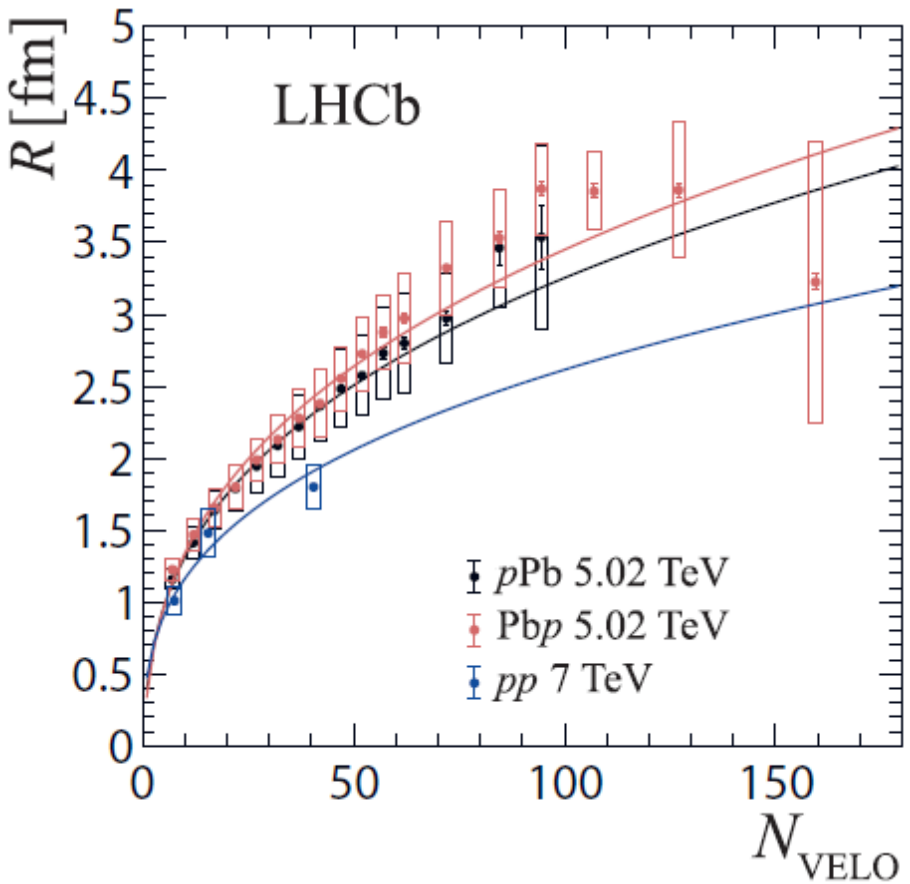
- first measurements of source size in forward/backward rapidity
- increase of source size with activity as expected from hydrodynamic models
- slightly higher activity in Pbp w.r.t. pPb could hint to rapidity dependence



pPb: $1.5 < y_{CMS} < 4.5$

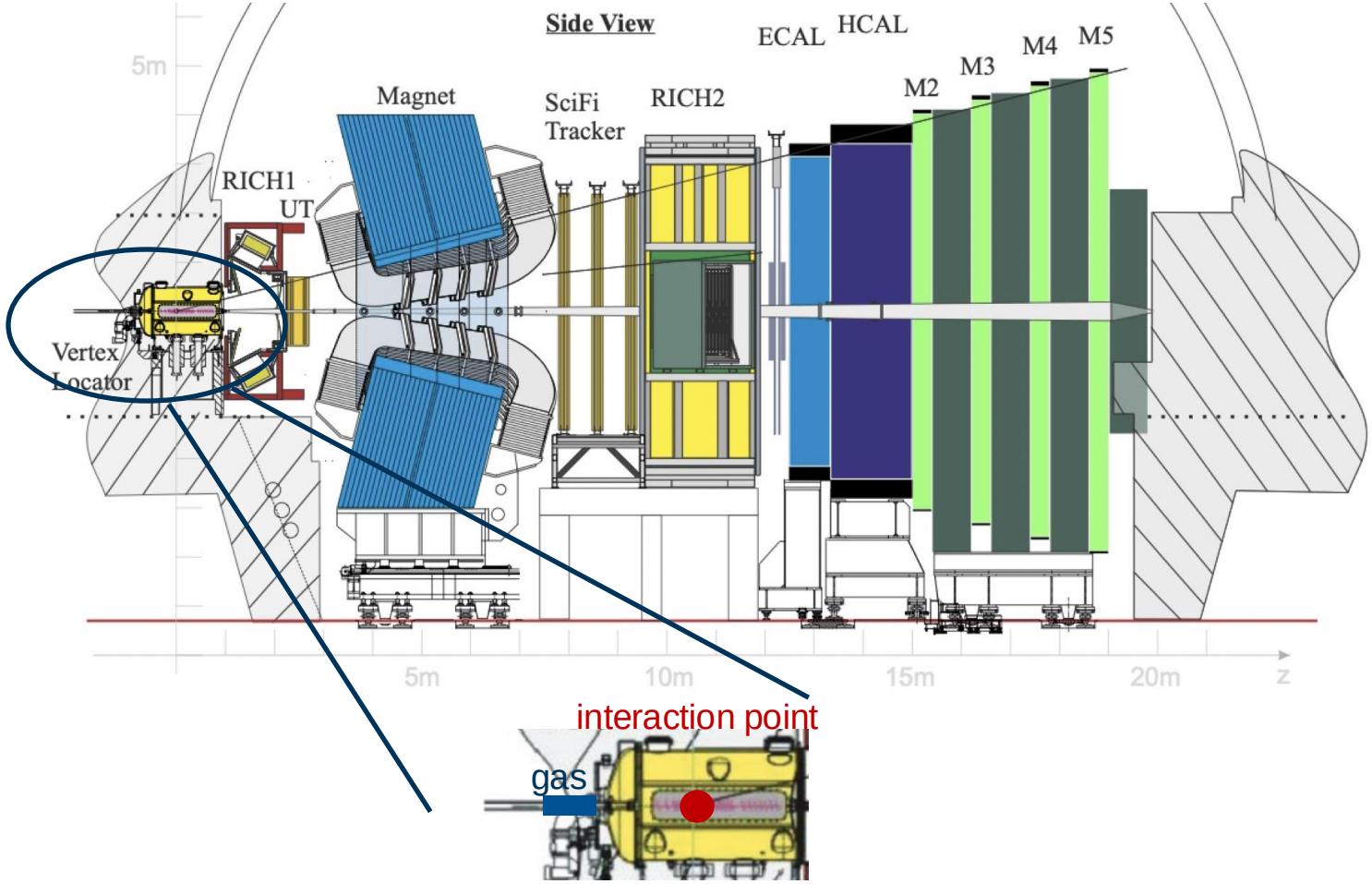


Pbp: $-5.5 < y_{CMS} < -2.5$



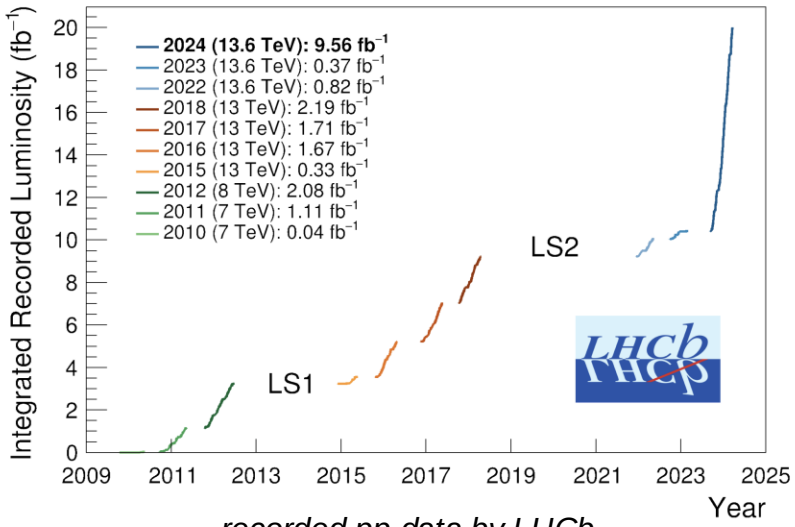
first interesting results and proof of potential of LHCb for femtoscopy!
More studies using Run2 data are on its way…

The next step: The upgraded LHCb detector (Run3)



SMOG2 system

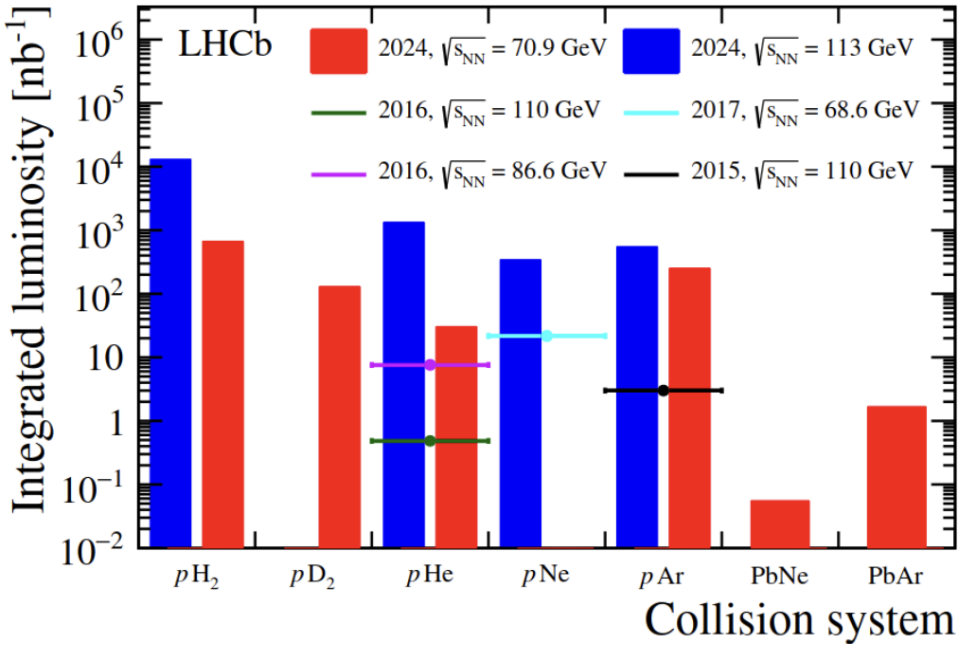
- almost completely renewed spectrometer to cope with 5x higher luminosity
- new DAQ scheme without hardware-trigger stage (Level-0)
- increase of yields up to order-of-magnitude
- plan to record around 50 fb^{-1} in Run 3+4

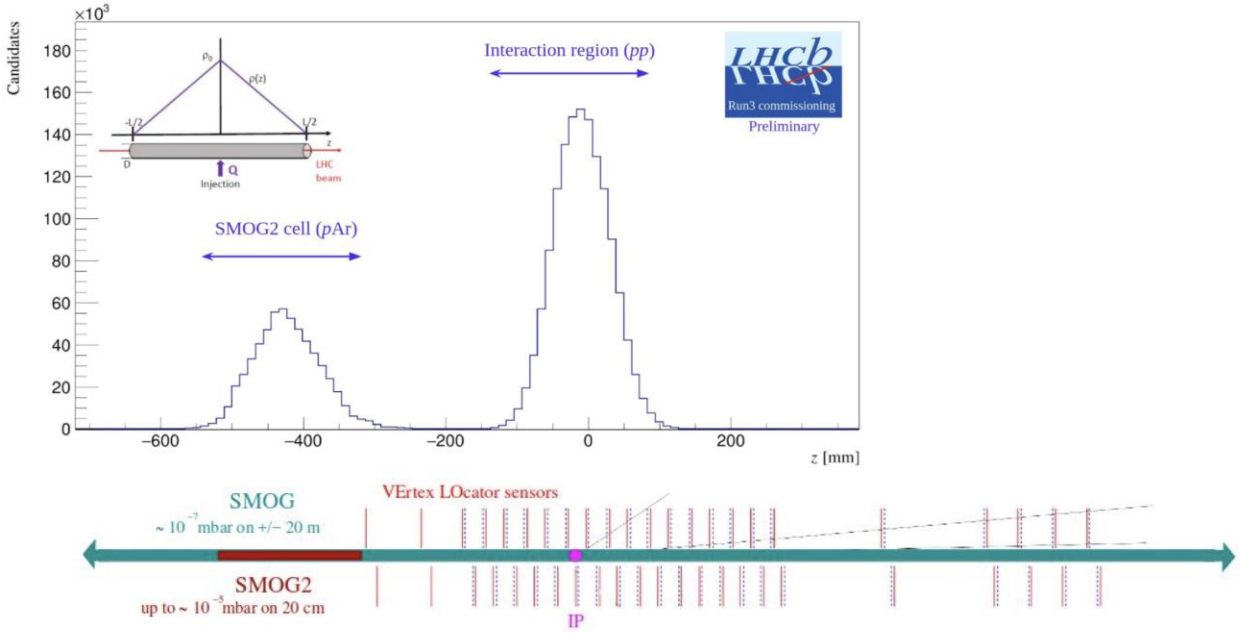


recorded pp data by LHCb

The fixed target program with SMOG2

- up to x100 increase of the local areal density in a storage cell upstream of the IP
- simultaneous data taking with pp/PbPb
- allows also non-nobel-gas targets (H,D, …)

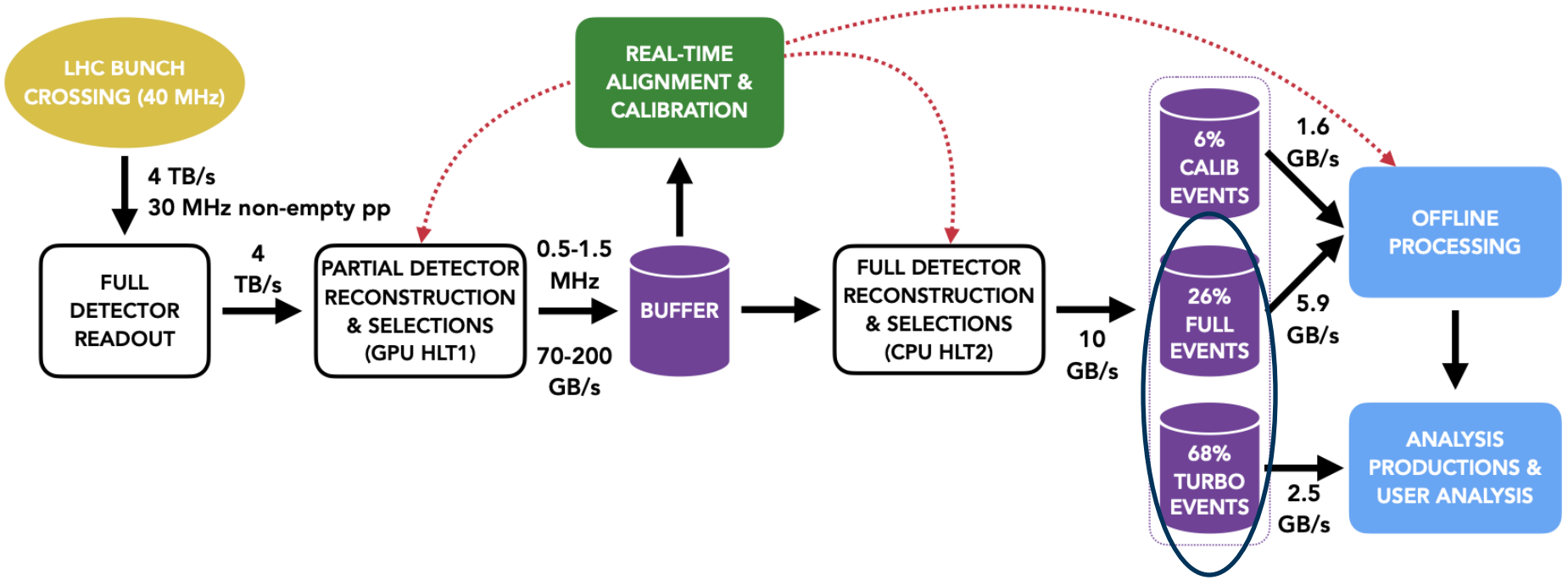




ideal datasets for source-size measurements at intermediate collision energies (~100 GeV) with various targets

Data Flow for Femtoscopic Measurements in Run 3

JINST 19 (2024) P05065



- *Turbo* approach: Save only candidates passing the trigger lines
- additional flexibility to add persistence (e.g. full persistence for b-hadron events, double charm events, …)

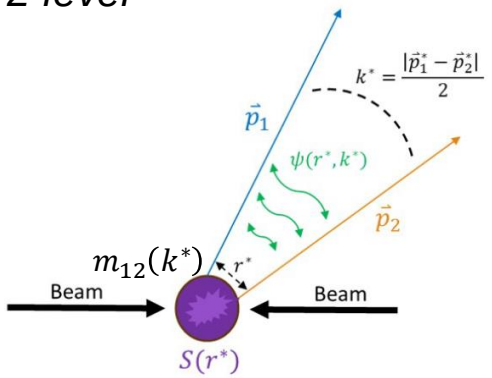
→ *dedicated trigger lines for many femtoscopy studies needed*

HLT2 algorithm concept for 2-particle femtoscopy lines

filter relevant particle pairs with small k → requires k* reconstruction + PID on HLT2 level*

use constraint on the invariant mass of the particle pair $m_{12}(k^*)$:

$$m_{12}(k^*) = \sqrt{m_1^2 + m_1^2 + 2k^* + 2\sqrt{((k^*)^2 + m_1^2)((k^*)^2 + m_2^2)}}.$$

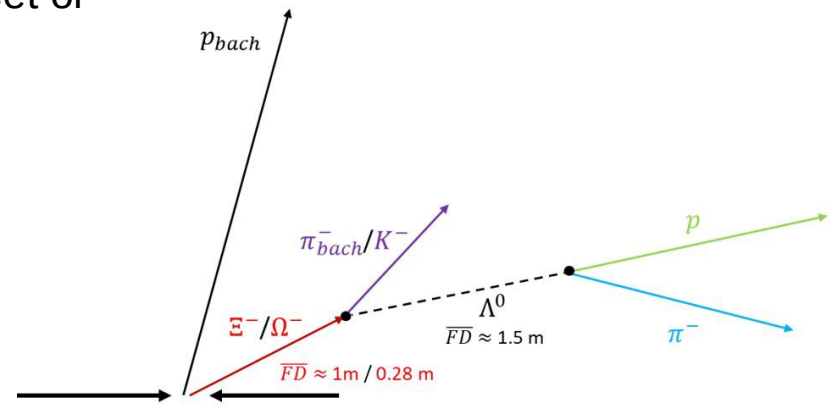


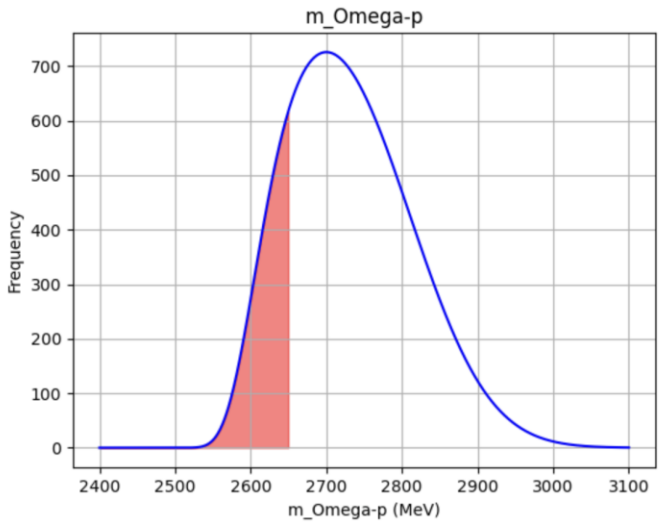
example: $p - \Omega$ correlation

- $m_{p\Omega}(k^* = 300\,MeV) - m_{p\Omega}(k^* = 0\,MeV) \approx 73\,MeV$

- region of interest is small region around on-set of invariant mass spectrum

- allows to enhance signal of small k*:
  different prescaling for different k* ranges
  (important for light, abundant hadrons)





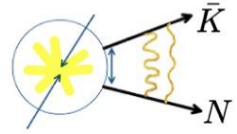
HLT2 trigger lines for strange-hadron femtoscopy – status 2024

pp/PbPb collider mode

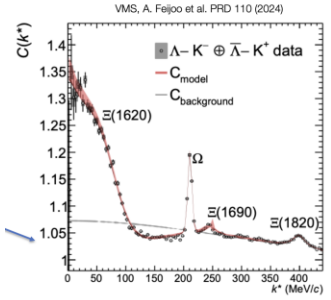
- currently everything from min. bias data (no dedicated lines)
  → *sufficiency to be checked!*

SMOG2 FT lines

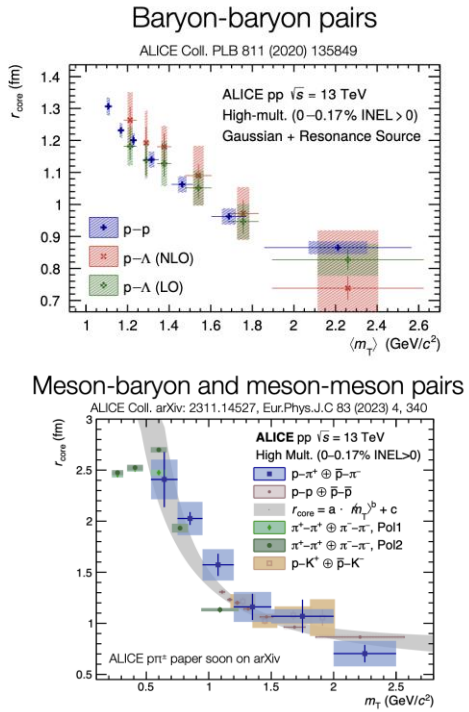
- $p - \Lambda$ (2 lines, k* < 100 unprescaled)
- $\Lambda - \Lambda$ (2 lines, k* < 100 unprescaled)
- $p - \Xi$ (2 lines, k* < 100 unprescaled)
- $\Lambda - \Xi$ (2 lines, k* < 100 unprescaled)
- $\Xi - \Xi$ (unprescaled)
- $p - \Omega$ (2 lines, k* < 100 unprescaled)
- $\Lambda - \Omega$ (2 lines, k* < 100 unprescaled)
- $\Omega - \Omega$ (unprescaled)
- $\Omega - \Xi$ (unprescaled)



Sasa Prelovsek

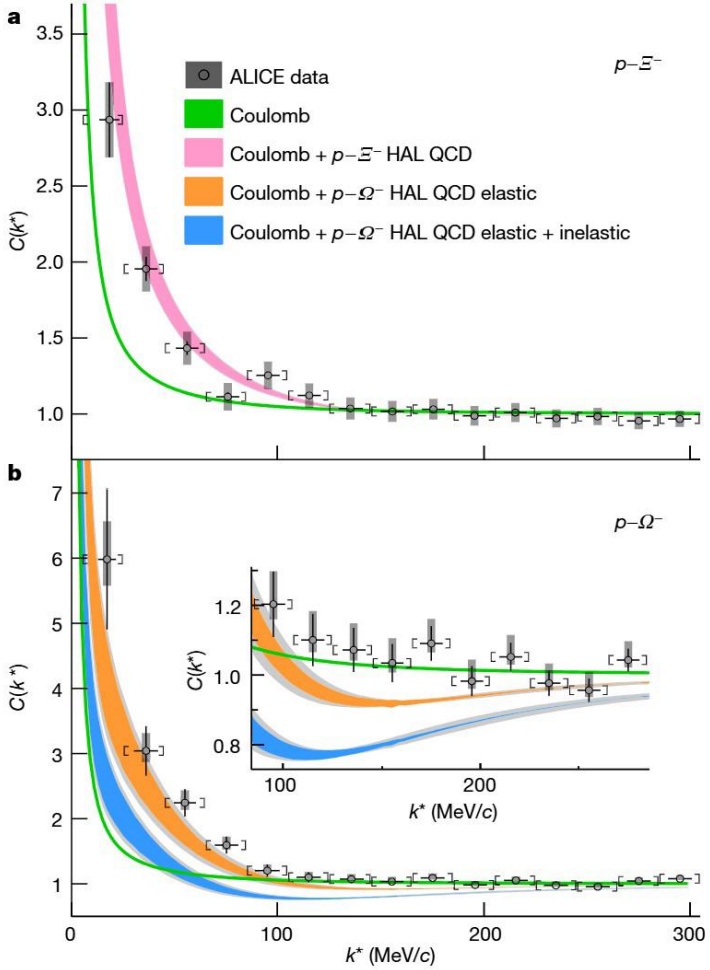


V. Mantovani Sarti



V. Mantovani Sarti

[Nature](#) ***volume 588***, *pages 232–238 (2020)*



HLT2 trigger lines for charmed-hadron femtoscopy – status 2024

pp/PbPb collider mode

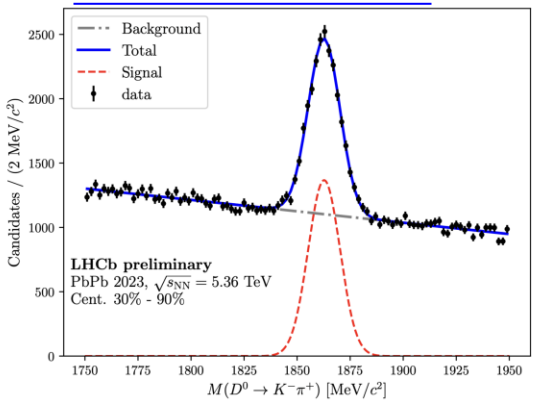
- $p - \Lambda_c$
- $\Lambda - \Lambda_c$
- $\Xi - \Lambda_c$
- $\Omega - \Lambda_c$
- $p - \Xi_c$
- $\Lambda - \Xi_c$
- $\Xi - \Xi_c$
- $p - D^0$
- $\Lambda - D^0$
- $\Xi - D^0$
- $\Omega - D^0$
- $p - D^+$
- $\Lambda - D^+$
- $\Xi - D^+$
- $\Omega - D^+$
- double charmed from persistent reco lines

D-meson lines?

SMOG2 FT lines

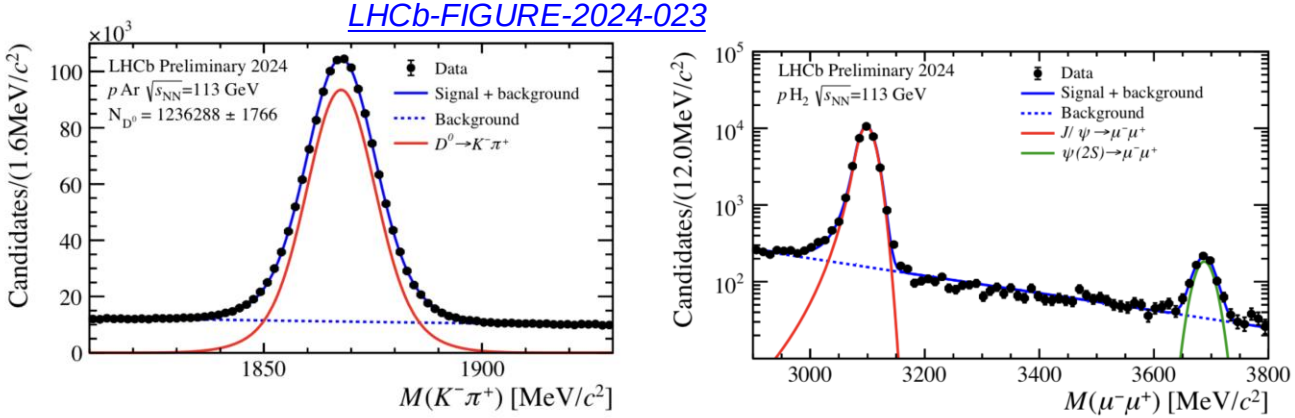
- no dedicated lines but persistent reco lines

LHCb-FIGURE-2024-004



D0 production in PbPb collisions (PbPb2023)

LHCb-FIGURE-2024-023



charm-hadron production in SMOG2 collisions (2024)

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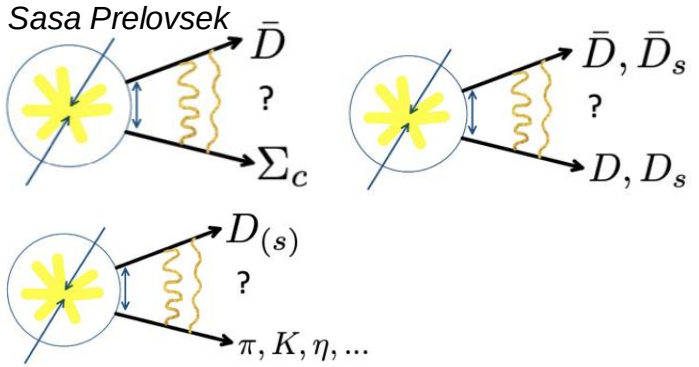
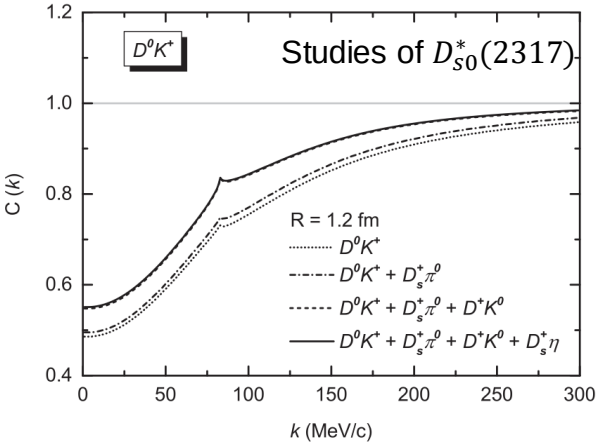


Further interesting lines?



*Phys. Rev. D **107**, 074019*

What about beauty-hadron femtoscopy?

To-be discussed: Importance of b-hadron femtoscopy

- same source as for light-quark hadrons?
- exotics search in beauty sector

To-be shown: Experimental feasibility

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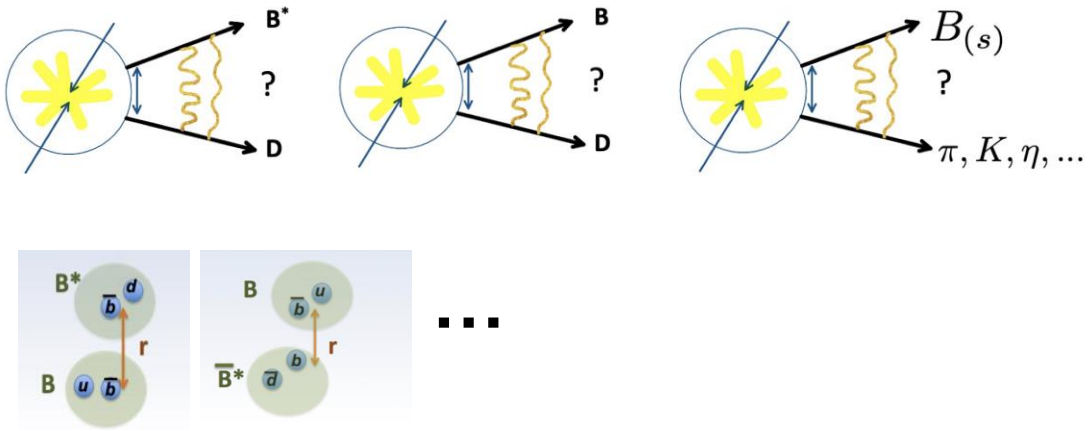
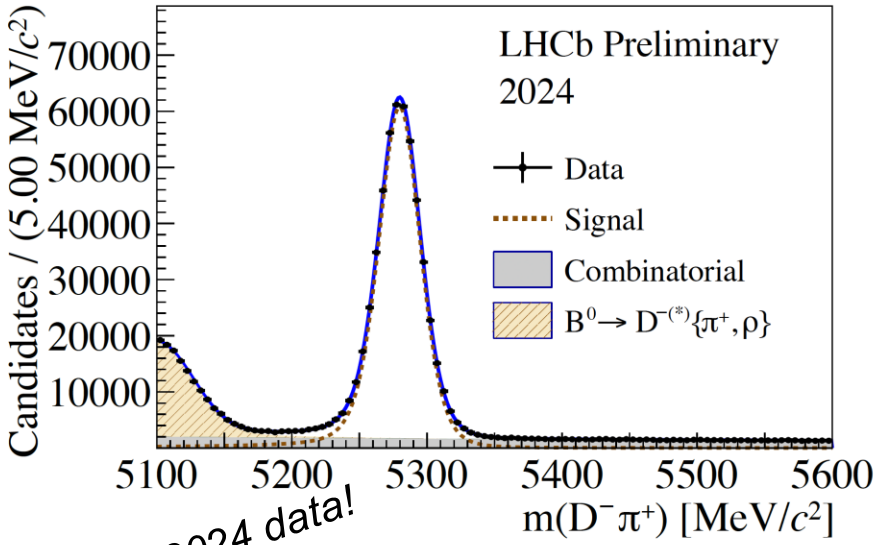
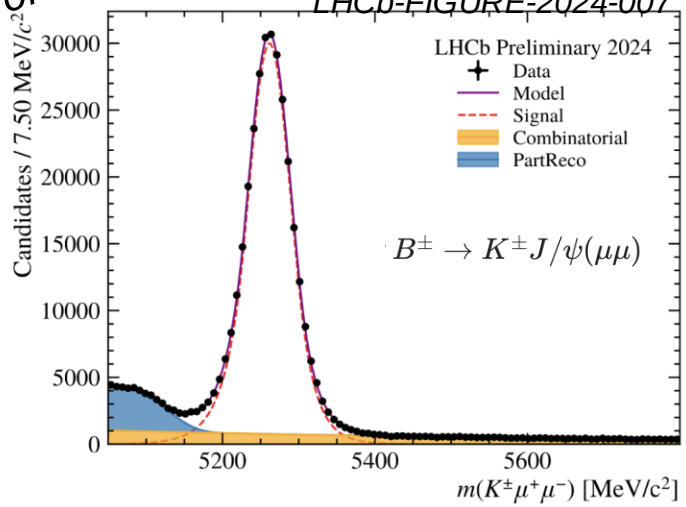


LHCb-FIGURE-2024-007



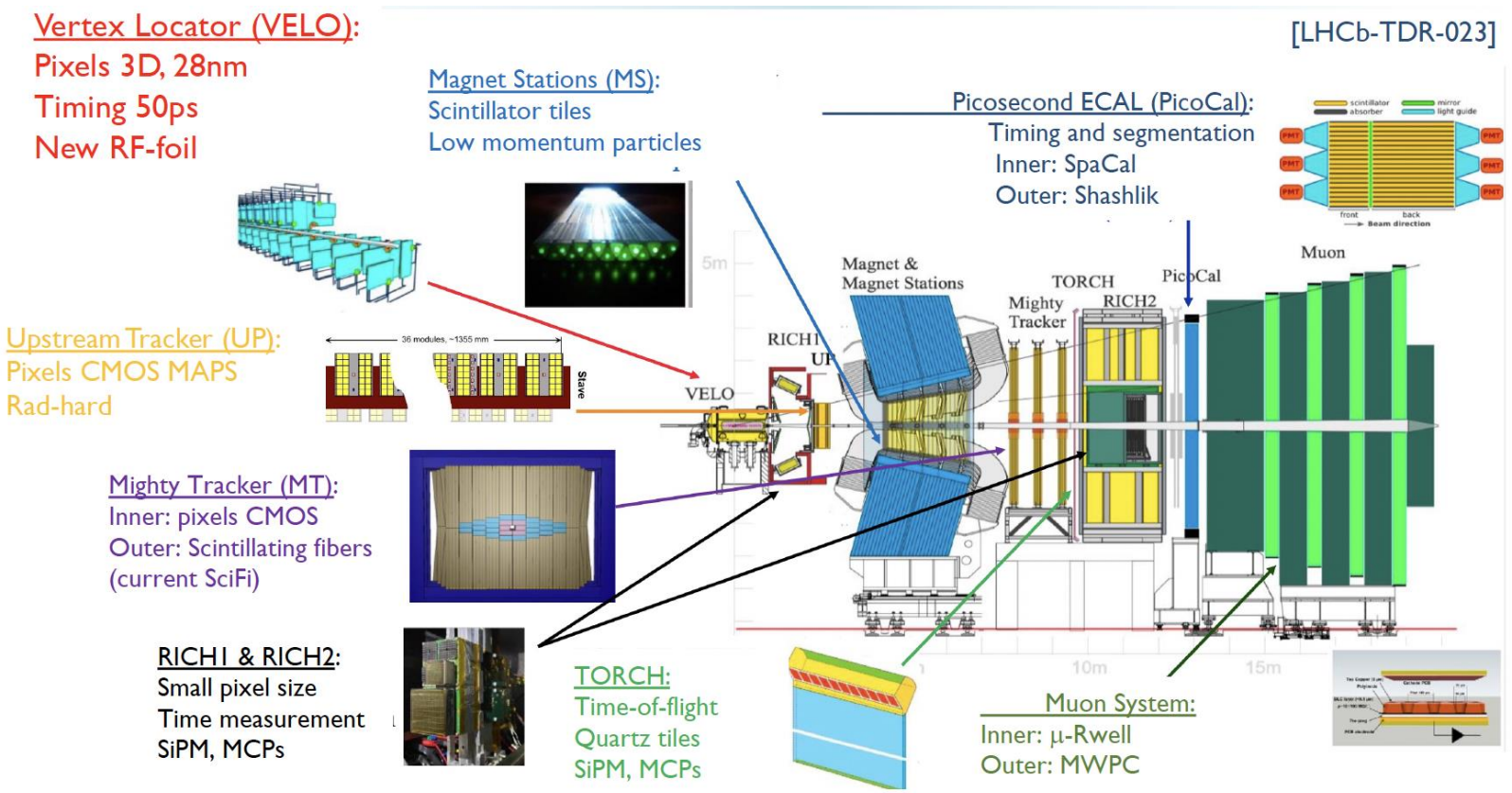
only a fraction of 2024 data!

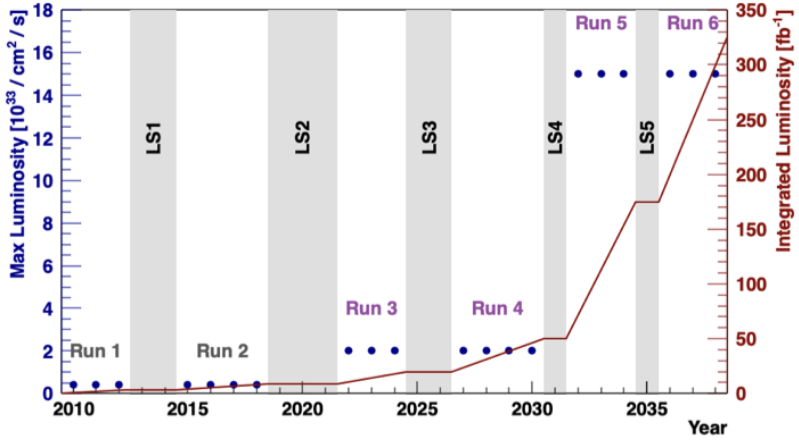
LHCb-FIGURE-2024-007

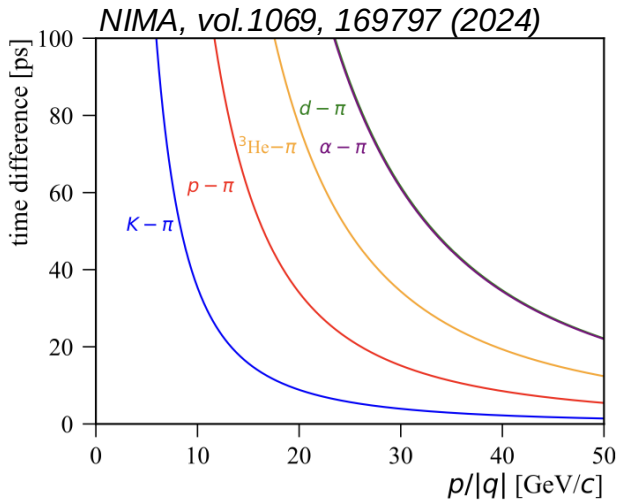


Femtoscopy with Upgrade II

https://doi.org/10.1016/j.nima.2024.169797







*beside **improved luminosity**, **extension of PID to lower momenta + nuclei PID** could expand the femtoscopy studies (e.g. nuclei femtoscopy)*

Conclusion and Discussion

- LHCb suitable for femtoscopy, proven by studies of BEC measurements with same-sign pions to extract source sizes in pp@7TeV and pPb@5TeV

- variety of different collision systems in collider and fixed-target mode for systematic studies of evolution of the particle source

- online HLT system allows efficient filtering of interesting particle-tuples/triplets/… by online reconstruction of k*

→ work ongoing: finalization / optimization of trigger lines after successful 2024 data taking for rest of Run 3 (2025+2026)

Most important question: Are we missing something important to record?

Explicit questions for the workshop:

- *What to focus on first?*
- *What missing lines to be added?*

Backup