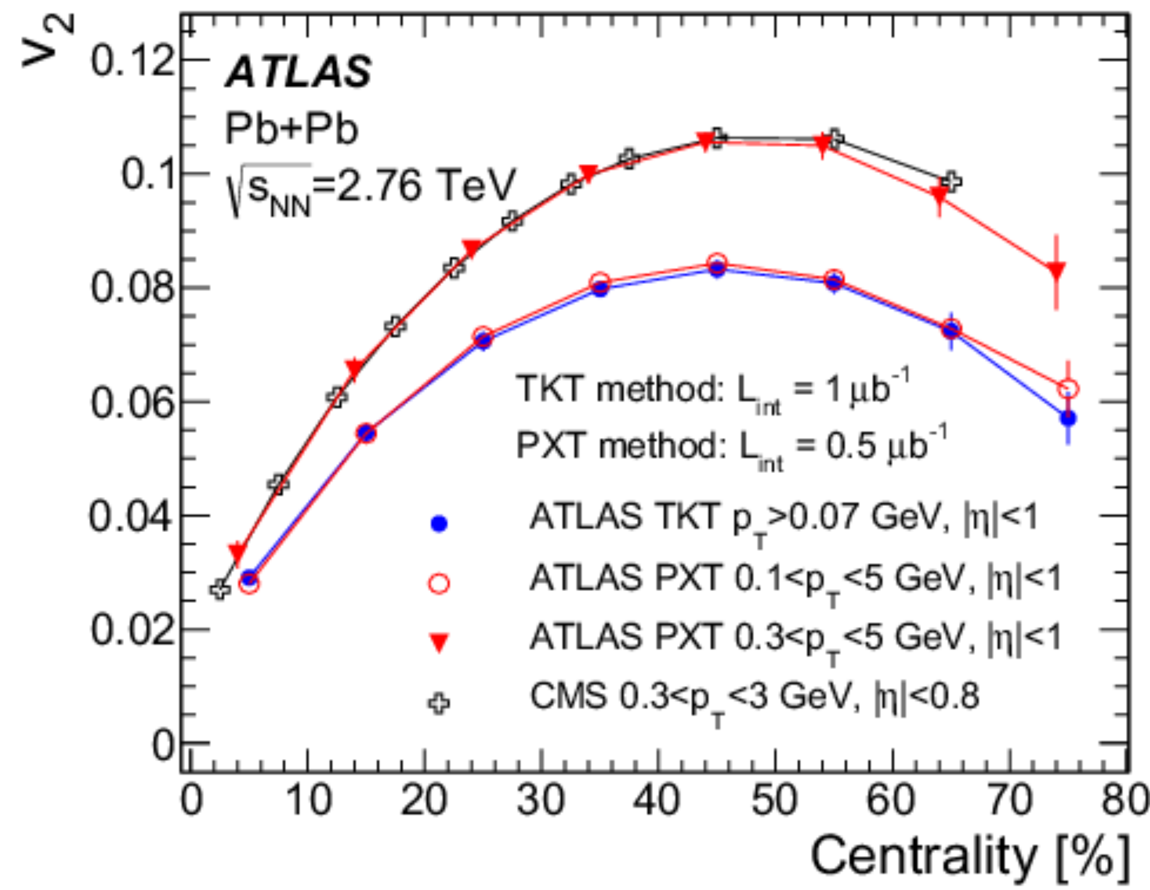
Flow measurements with the LHCb detector

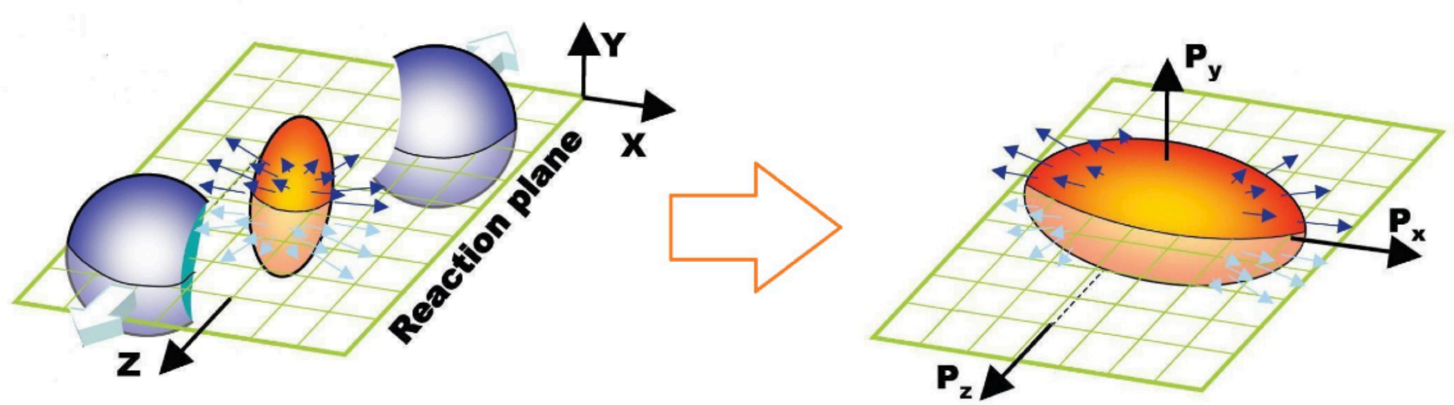
Samuel Belin on behalf of the LHCb collaboration

Samuel Belin
samuel.belin@cern.ch

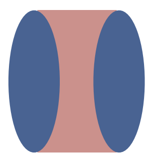
Flow in heavy-ion collisions

- Anisotropy in distributions of final-states particles described by Fourier transforms
- Those Fourier coefficient (v_n), with the initial geometry of the collision, can provide detailed information on the transport properties of the created medium (Quark Gluon Plasma)
- Well described by hydrodynamic model

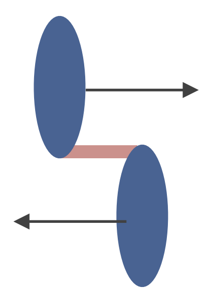




Pb



Pb

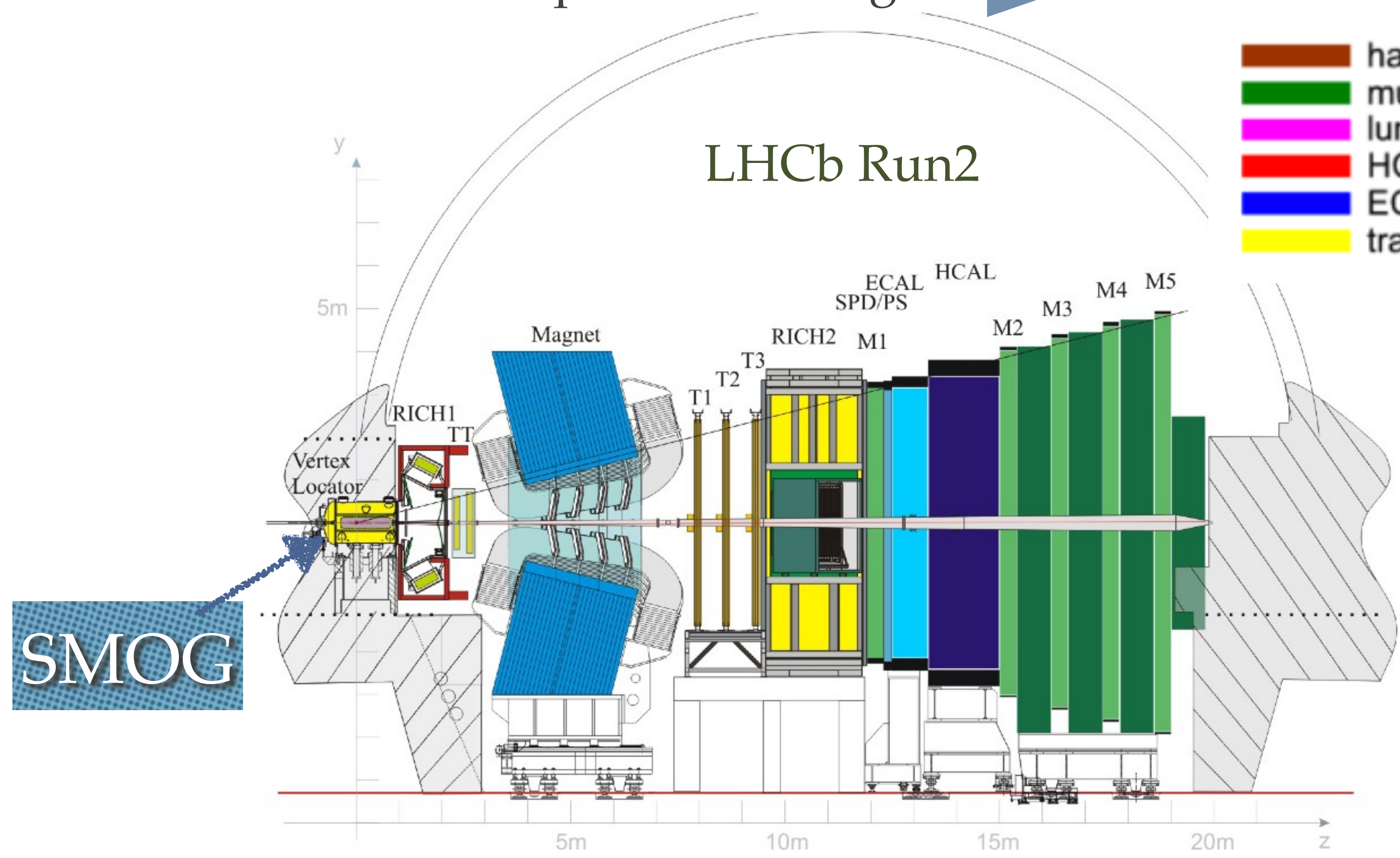


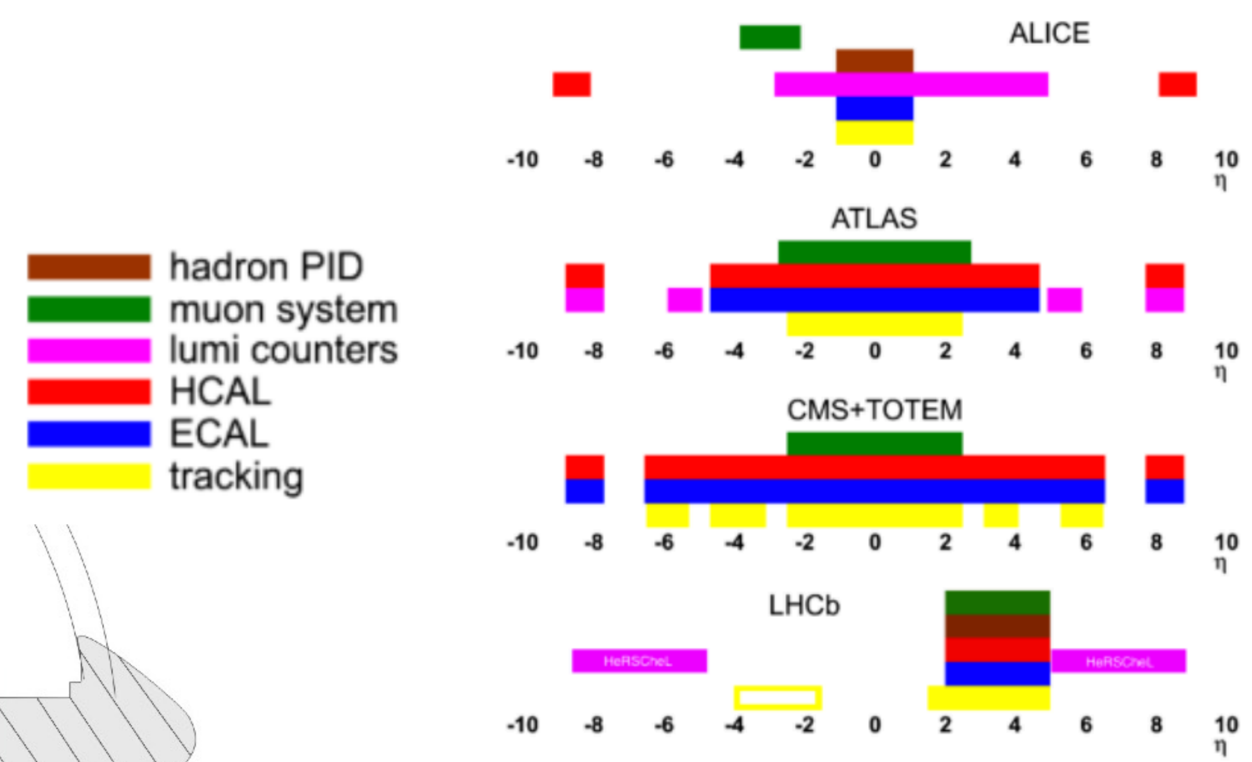
Elliptic flow in a non-central symmetric heavy-ion collisions

The LHCb detector

Single arm spectrometer fully instrumented in pseudorapidity range $2 < \eta < 5$

Unique in this range





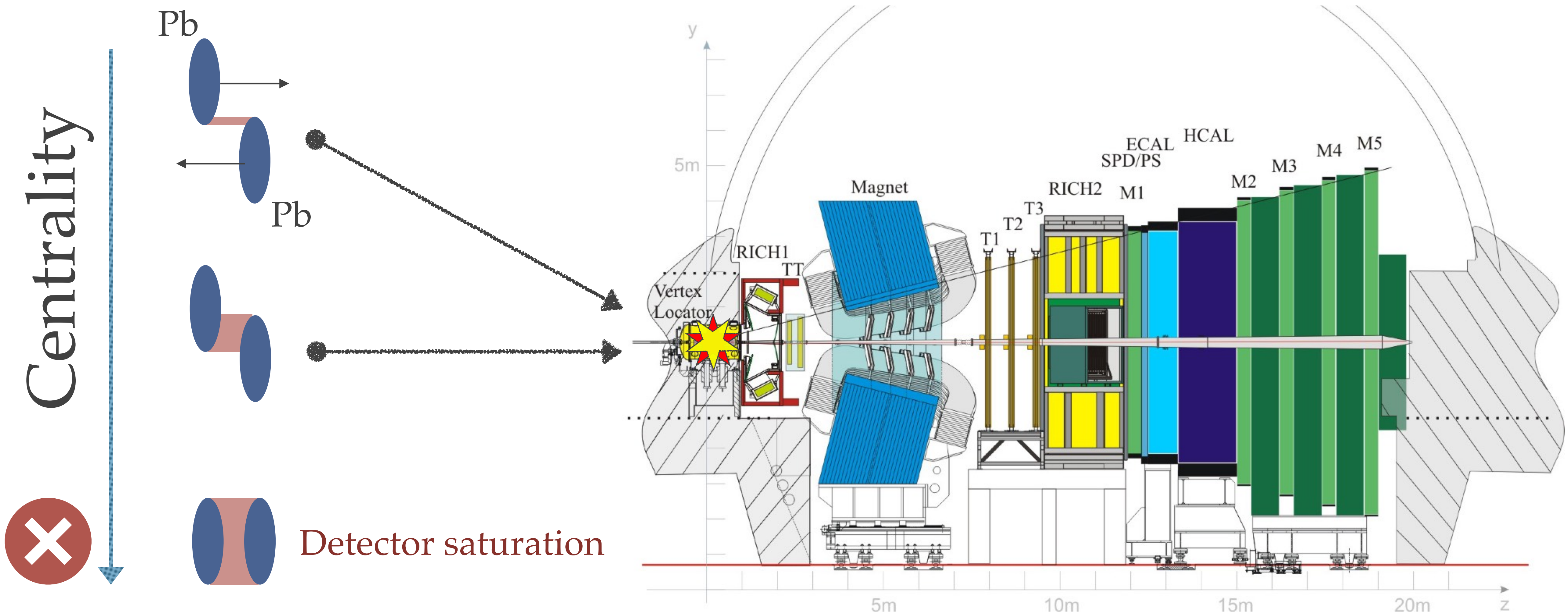
[JINST 3 (2008) S08005] [Int. J. Mod. Phys. 734 A30 (2015) 1530022]

- Excellent tracking
- Excellent particle identification.
- Excellent primary vertex determination.

Samuel Belin samuel.belin@cern.ch

The LHCb detector

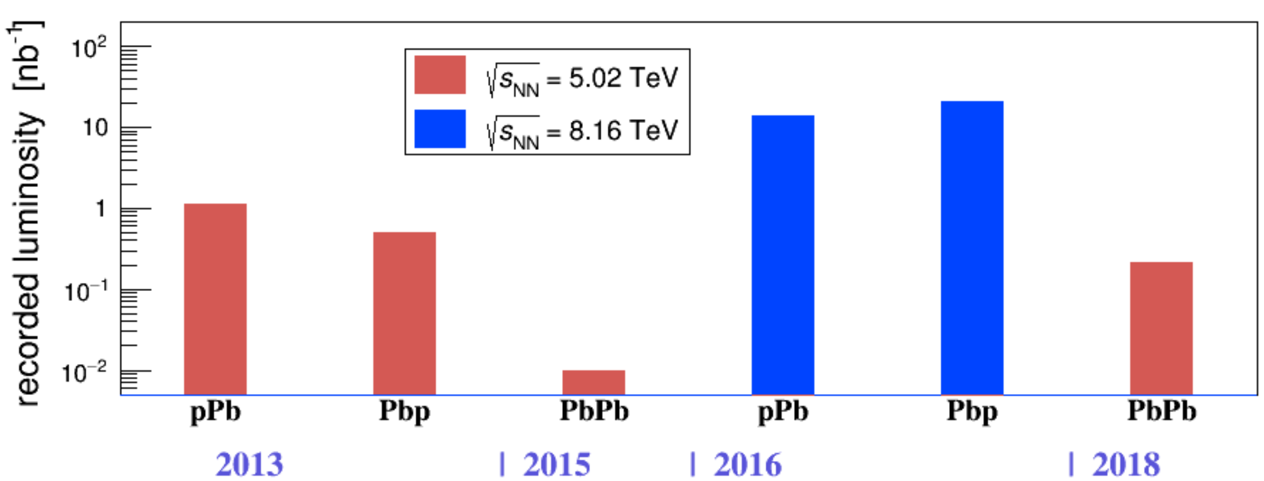
Excellent tracking and PID performance in *pp* and *p*Pb collisions



Samuel Belin samuel.belin@cern.ch

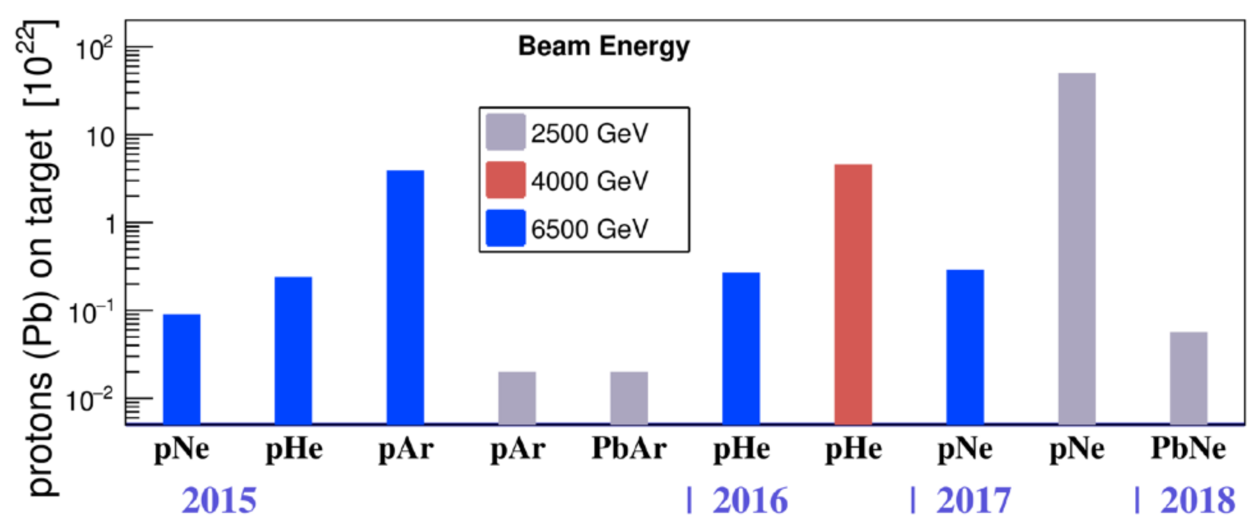
Available Datasets

Collider mode



Done or ongoing studies

Fixed Target mode

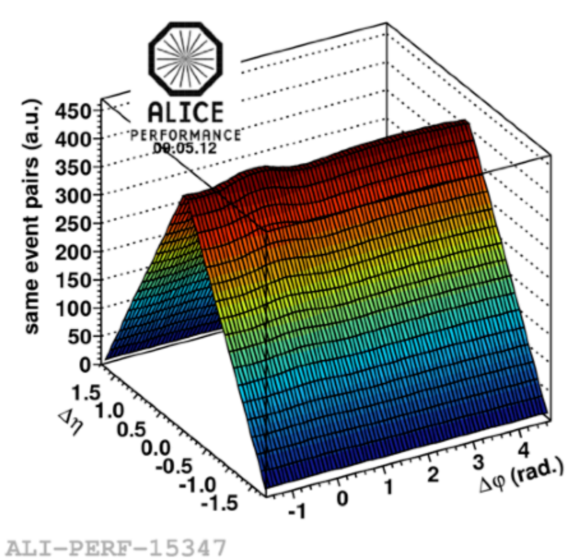


Still many possibilities with fixed target samples

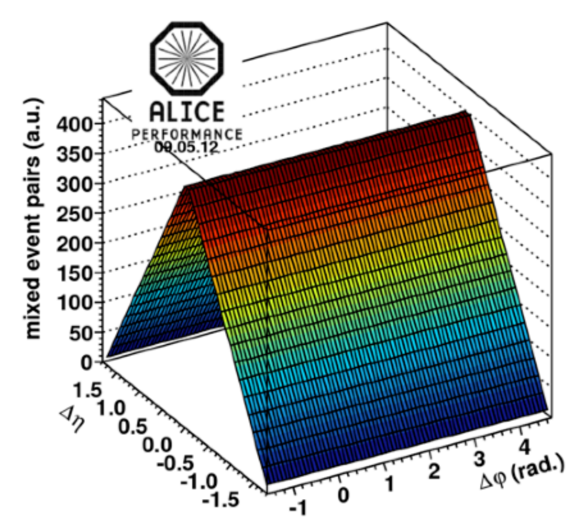
Samuel Belin samuel.belin@cern.ch

Correlation functions

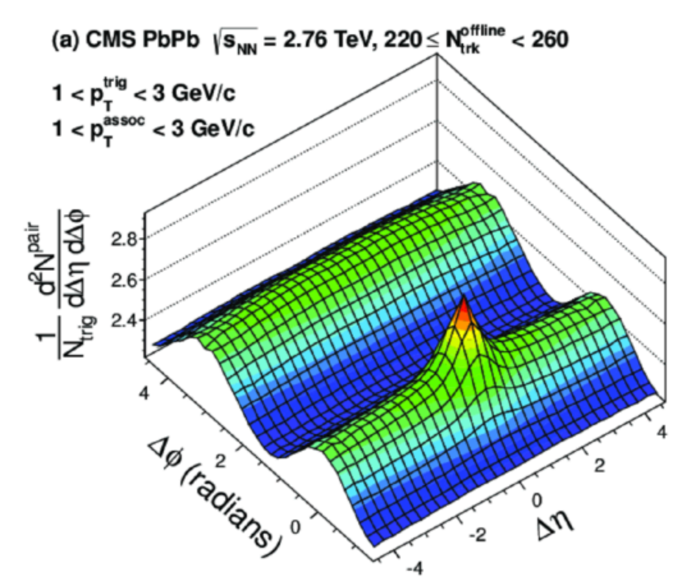
- Correlation function: $$\frac{1}{N_{trig}}\frac{d^2N_{pair}}{d\Delta\eta\, d\Delta\varphi} = \frac{S(\Delta\eta,\Delta\varphi)}{B(\Delta\eta,\Delta\varphi)} \times B(0,0)$$ ← Normalization factor
- Same-event h-h pairs: $$S(\Delta\eta,\Delta\varphi) = \frac{1}{N_{trig}}\frac{d^2N^{same}}{d\Delta\eta\, d\Delta\varphi}$$
  - all possible pairs within the same event
- Mixed-event h-h pairs: $$B(\Delta\eta,\Delta\varphi) = \frac{1}{N_{trig}}\frac{d^2N^{mix}}{d\Delta\eta\, d\Delta\varphi}$$
  - The two hadrons from two different events
  - Correlated through detector effects, no real physics correlation
  - Background



/



=



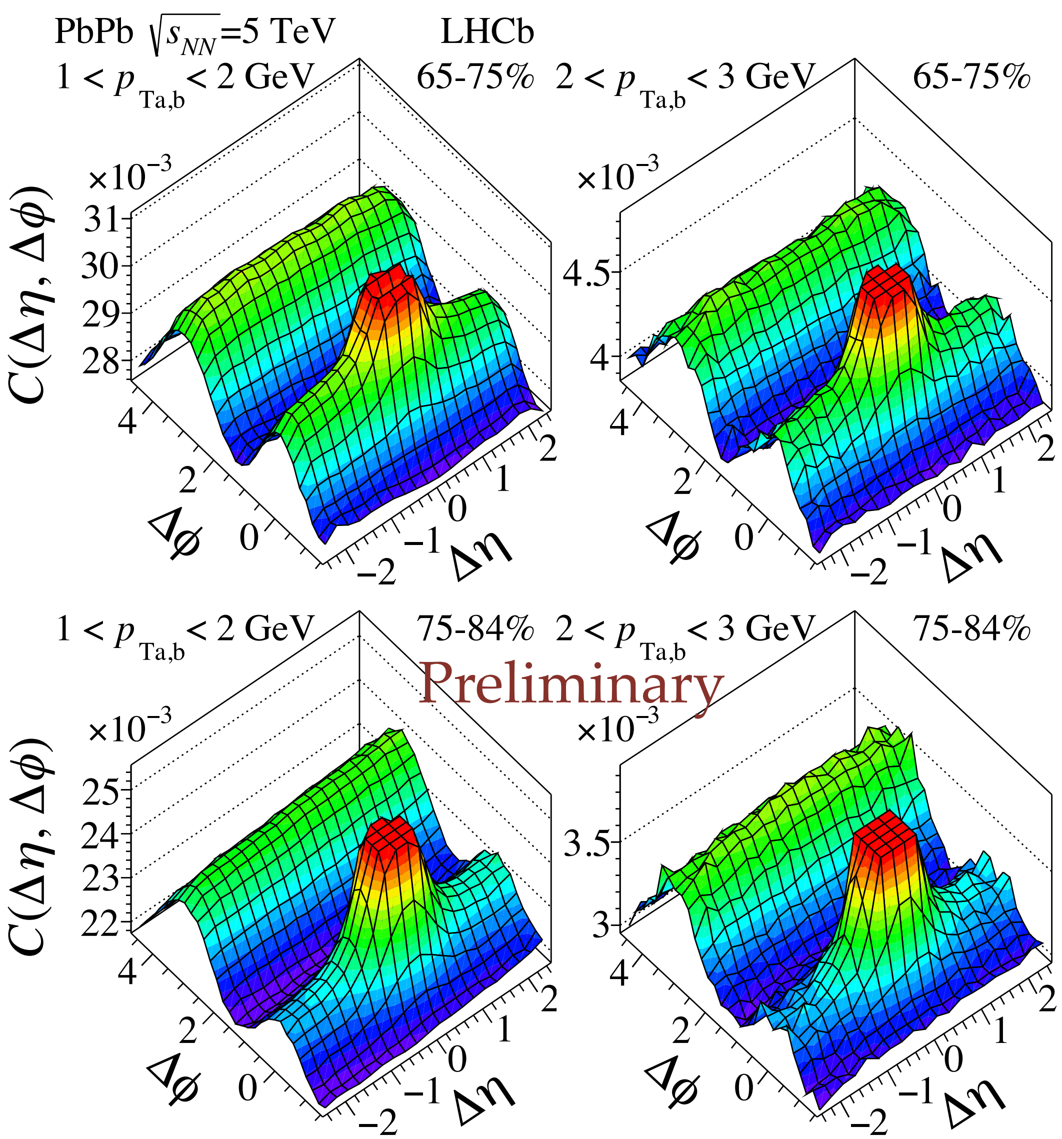
Samuel Belin samuel.belin@cern.ch

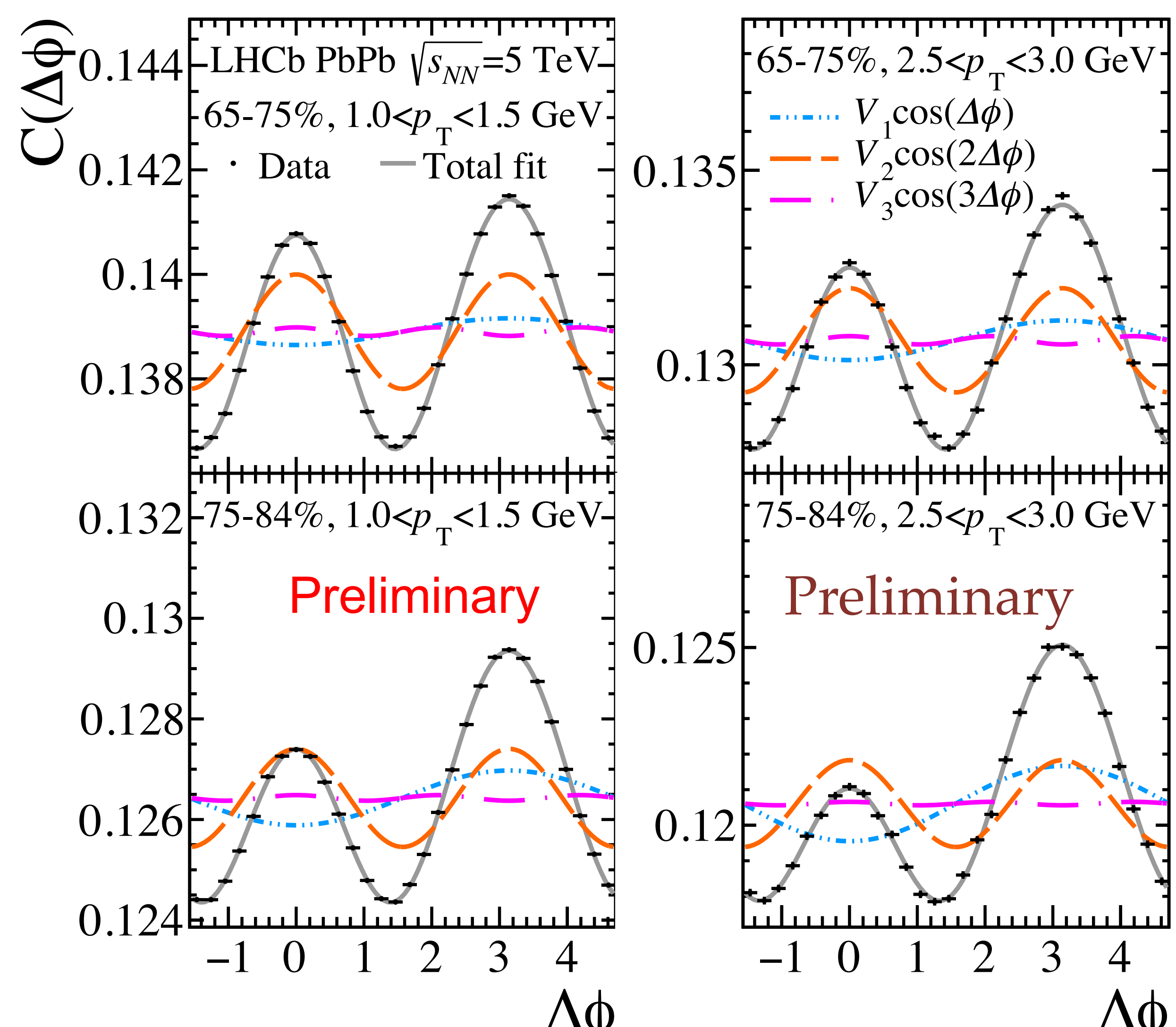
Flow in PbPb collisions at LHCb

Projection on $\Delta\phi$ excluding the jet region ($\Delta\eta < 1$)

Fourier fit

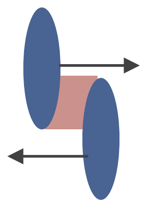
LHCB-PAPER-2023-031

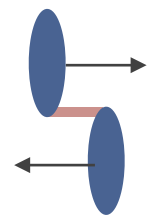




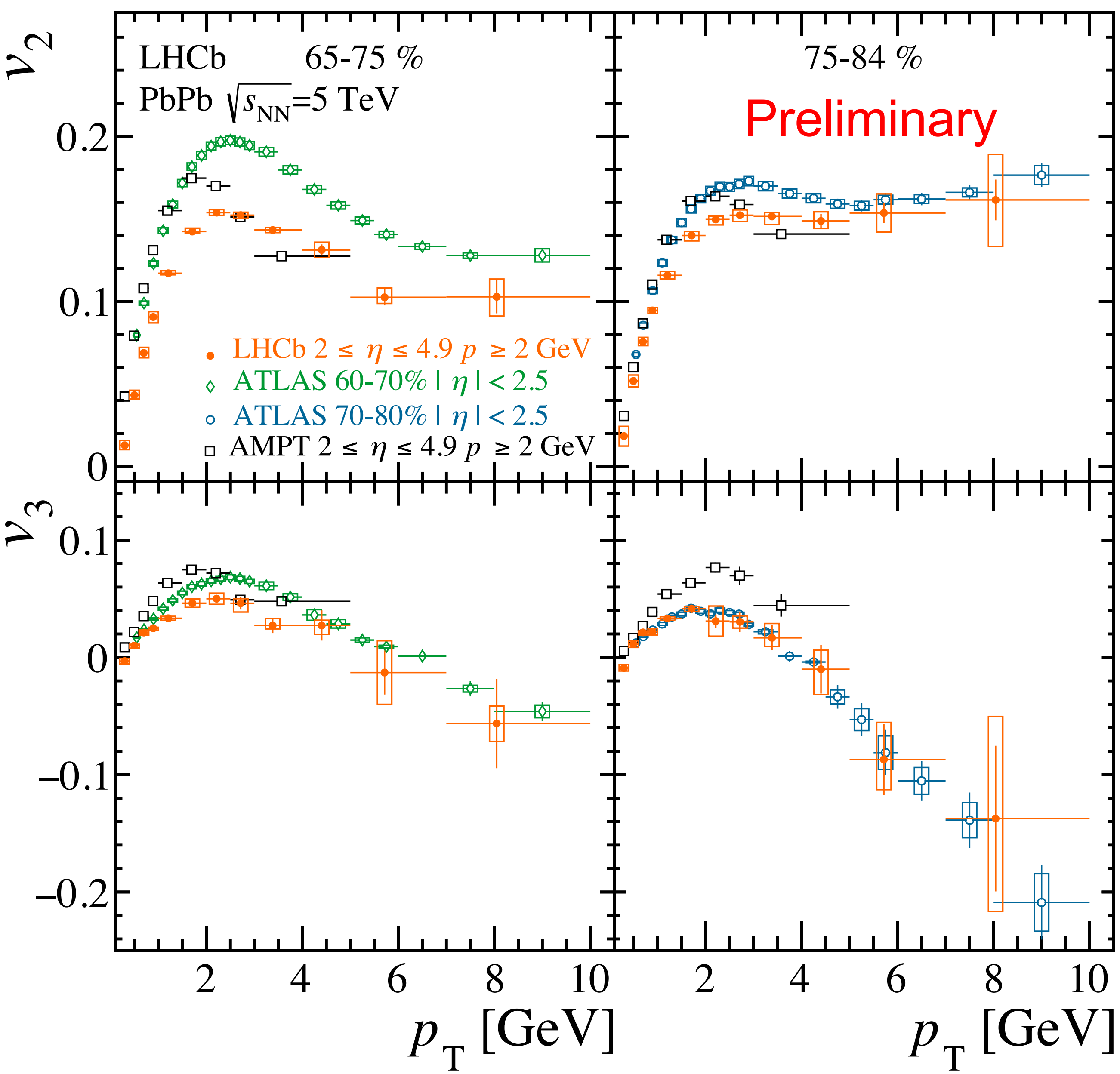
Samuel Belin samuel.belin@cern.ch

Flow in PbPb collisions at LHCb





LHCB-PAPER-2023-031



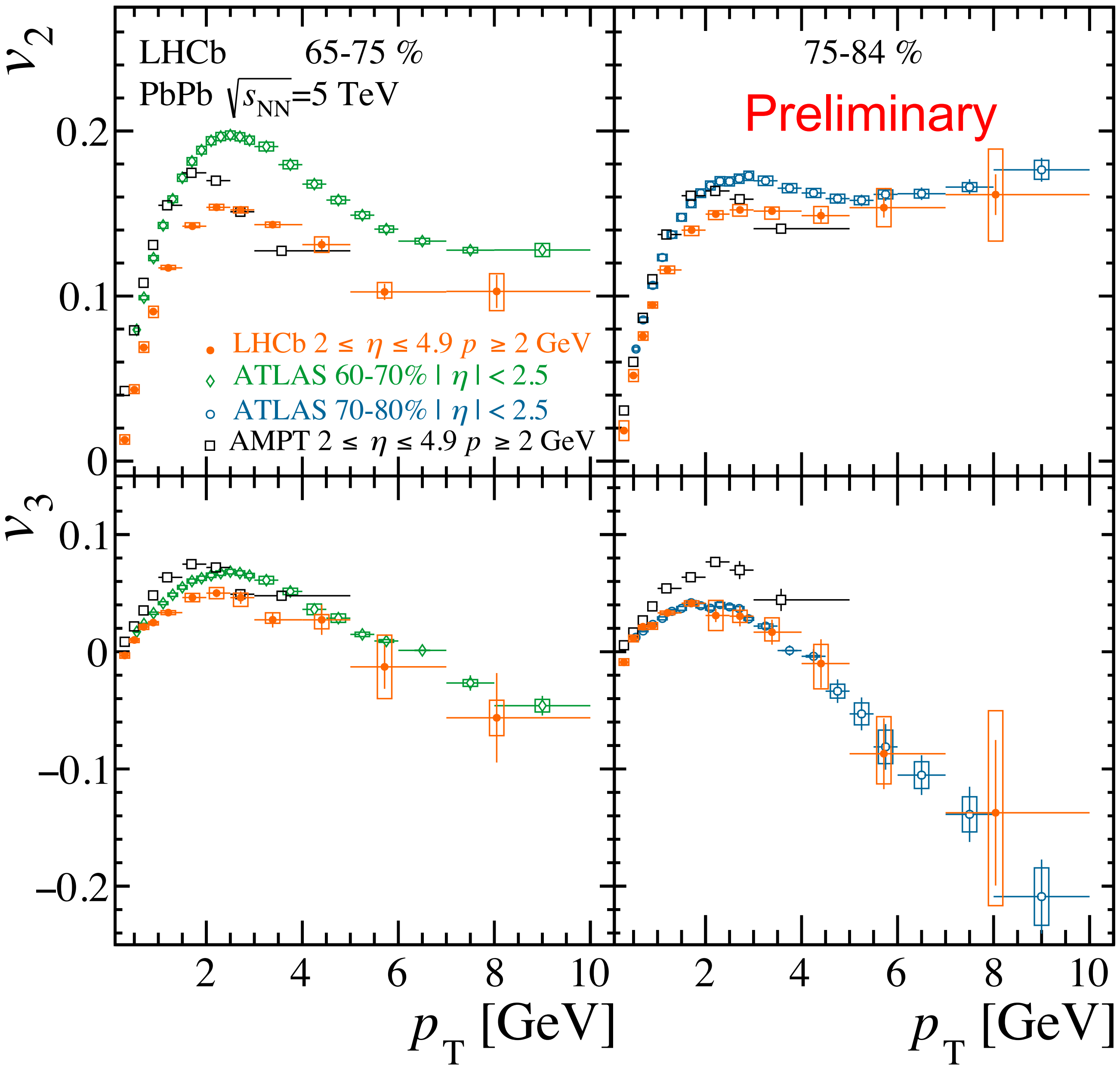
First measurement in the forward region at LHC!

	Centrality Class		Acceptance
LHCb	65-75%	75-84%	$2 \leq \eta \leq 4.9$
ATLAS	60-70%	70-80%	$\|\eta\| < 2.5$
AMPT	65-75%	75-84%	$2 \leq \eta \leq 4.9$

Samuel Belin samuel.belin@cern.ch

Flow in PbPb collisions at LHCb

LHCB-PAPER-2023-031



- Cleary lower v_2 for the forward region
- Plateau for the v_2 after 2 GeV / c
- No significative difference of v_2 for the two centrality bins
- V_3 compatible between ATLAS and LHCb and reach below zero value at high p_T

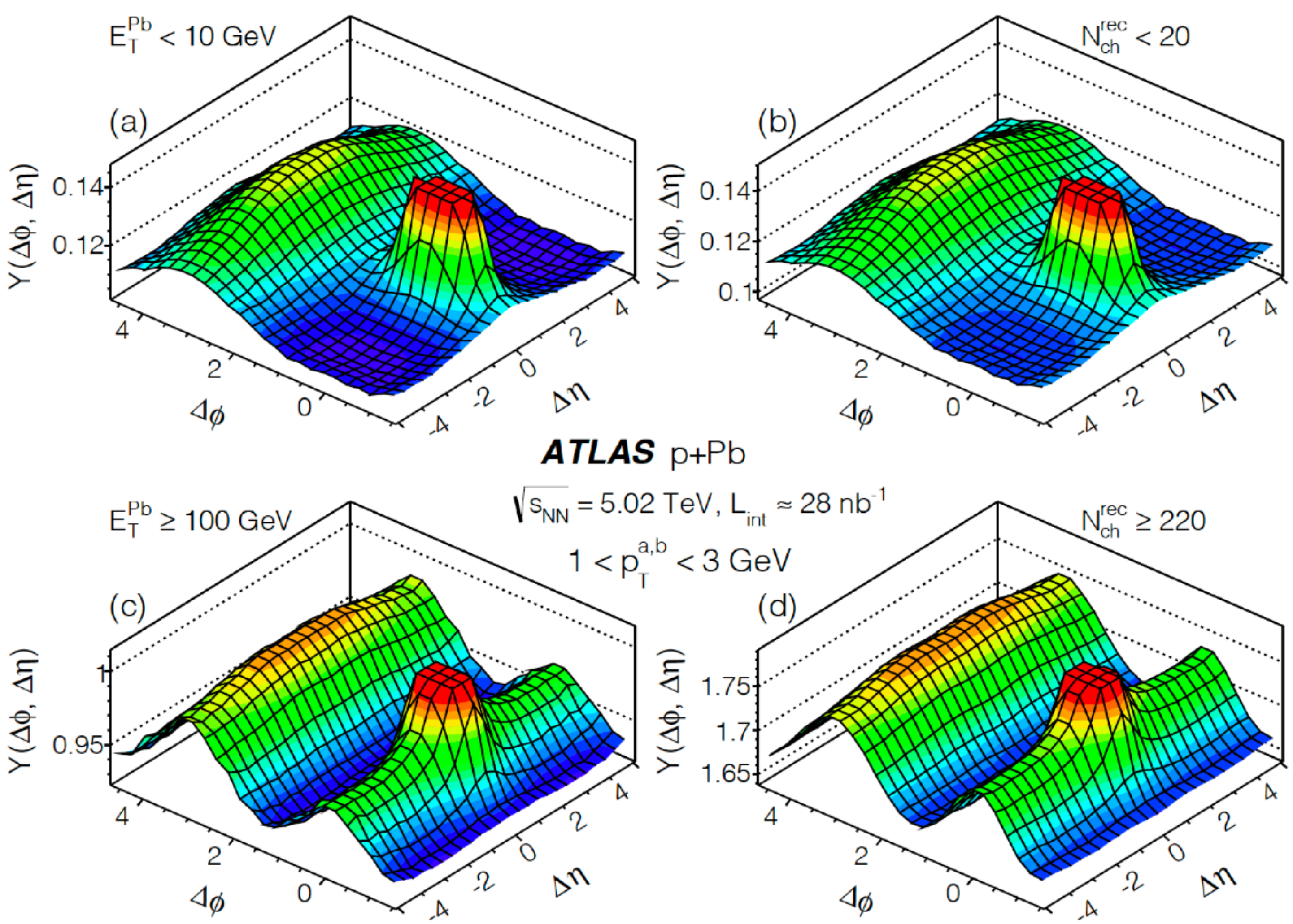
IMPORTANT INPUT FOR THE FORWARD REGION

Samuel Belin samuel.belin@cern.ch

Flow in small system

ATLAS, PRC 90,044906 (2014)

- v_2 thought to be present only in large system such as PbPb but seen in small system as well:



- Style a debate on the origin of this « ridge like » structure
- Original geometry gives flow in final stage?
- One fluid for all colliding system ? (Use of hydrodynamic to describe all system)
- Initial correlation
- Everything together ?

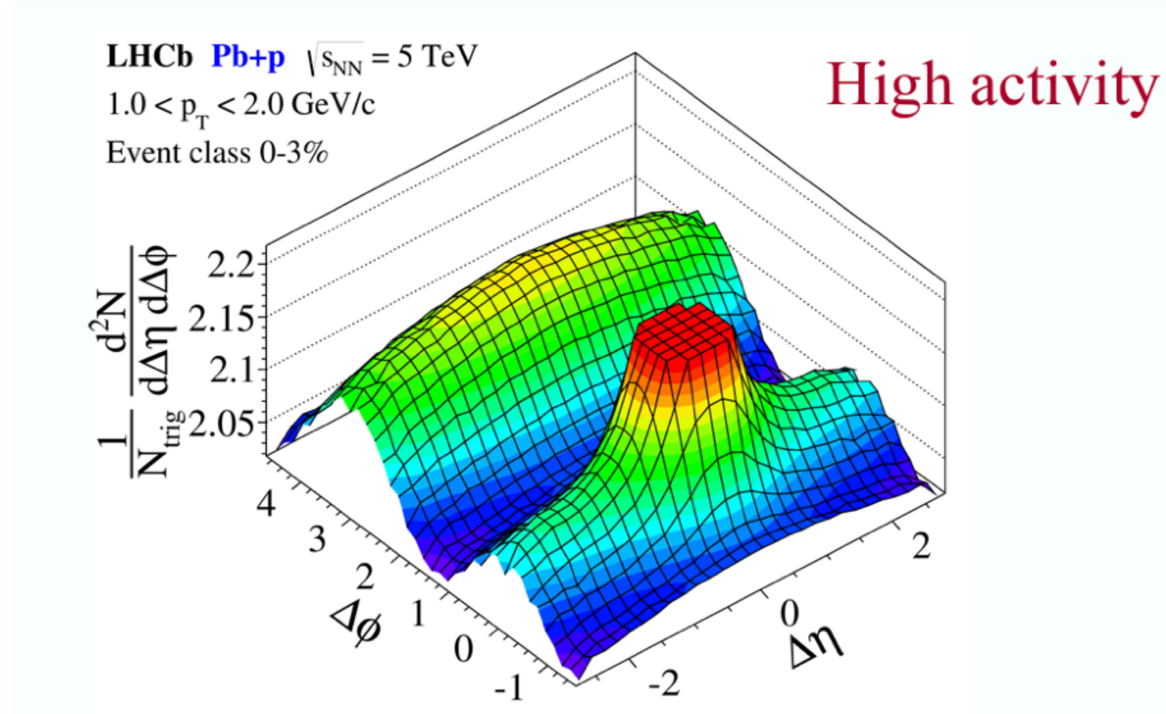
 Can we see it in *p*Pb collisions from LHCb

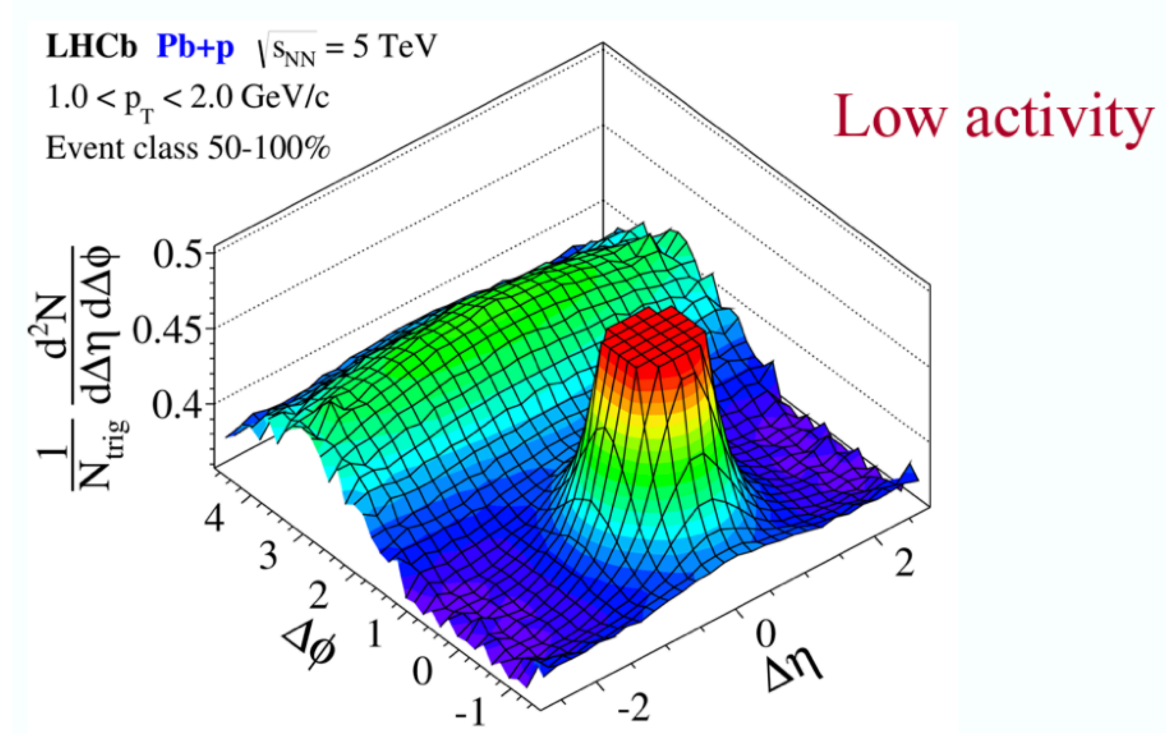
Samuel Belin samuel.belin@cern.ch

Flow in small system

Physics Letters B762 (2016) 473

- Evidence of a ridge-like structure as well in pPb/Pbp data from LHCb
- Visible only in collisions with high multiplicity
- Ongoing analysis for the charged hadrons flow in pPb and Pbp at 8 TeV





Samuel Belin samuel.belin@cern.ch

Prospect in LHCb

- LHCb has the power to investigate the flow in small system thanks to:
  - The Fixed Target system (SMOG2)
  - The geometry of the detector
  - Precision in measuring heavy flavors
- LHCb can further study flow in AA collisions thanks to the new freshly recorded PbPb data-sample

Samuel Belin samuel.belin@cern.ch

Prospect in LHCb

- LHCb has the power to investigate the flow in small system thanks to:
  - The Fixed Target system (SMOG2)
  - The geometry of the detector
  - Precision in measuring heavy flavors
- LHCb can further study flow in AA collisions thanks to the new freshly recorded PbPb data-sample

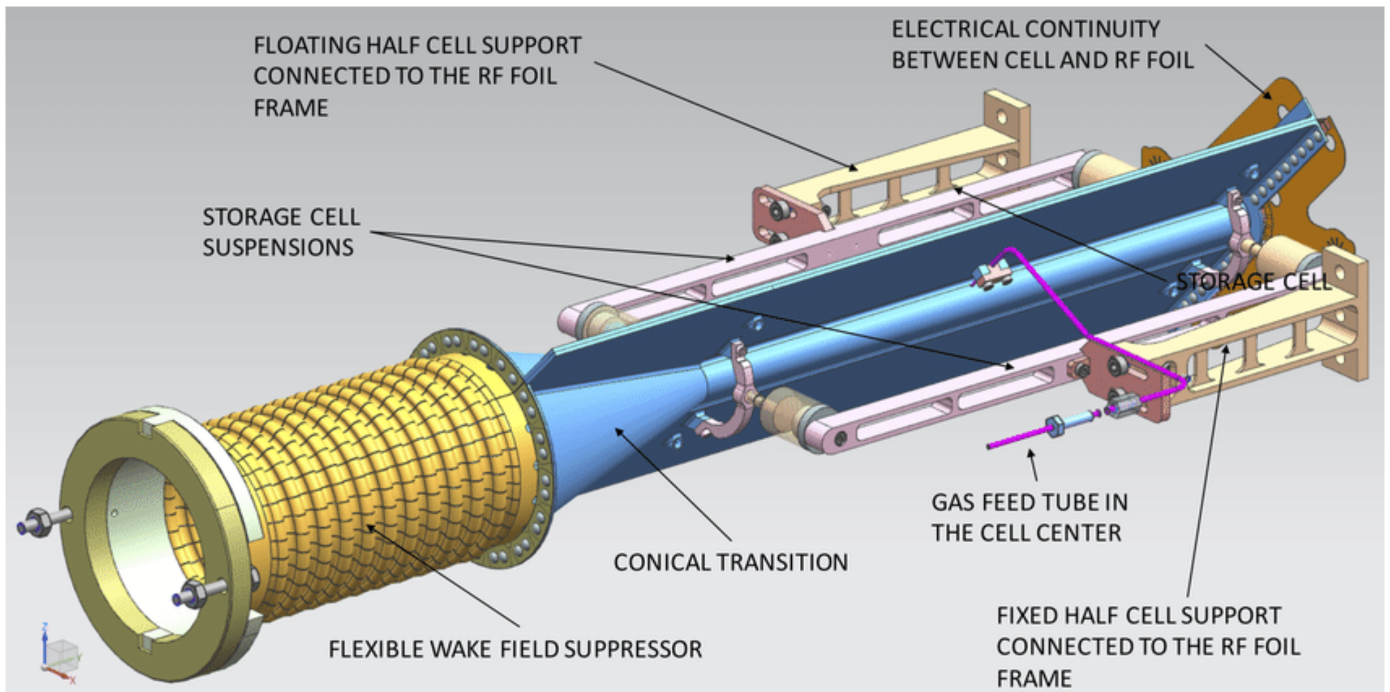
Samuel Belin samuel.belin@cern.ch

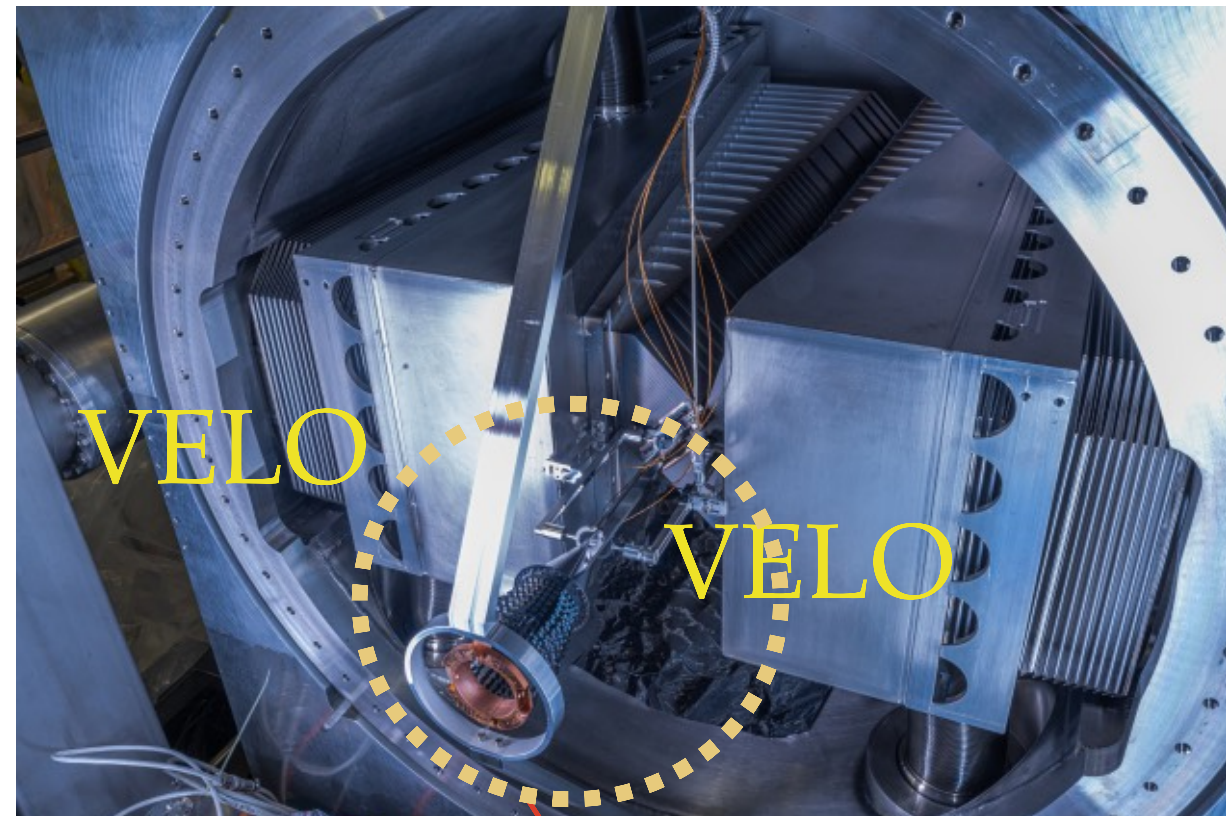
LHCb upgrade run 3

LHCb-TDR-020

SMOG2 : A dedicated fixed target system to run simultaneously with normal collisions

Length: 20 cm, placed in front of the VELO





SMOG2 system

- Higher density of the gas (100 times higher luminosity)
- Better control of the gas density (better luminosity determination)
- New gas H_2, D_2, O_2 in addition to all noble gases

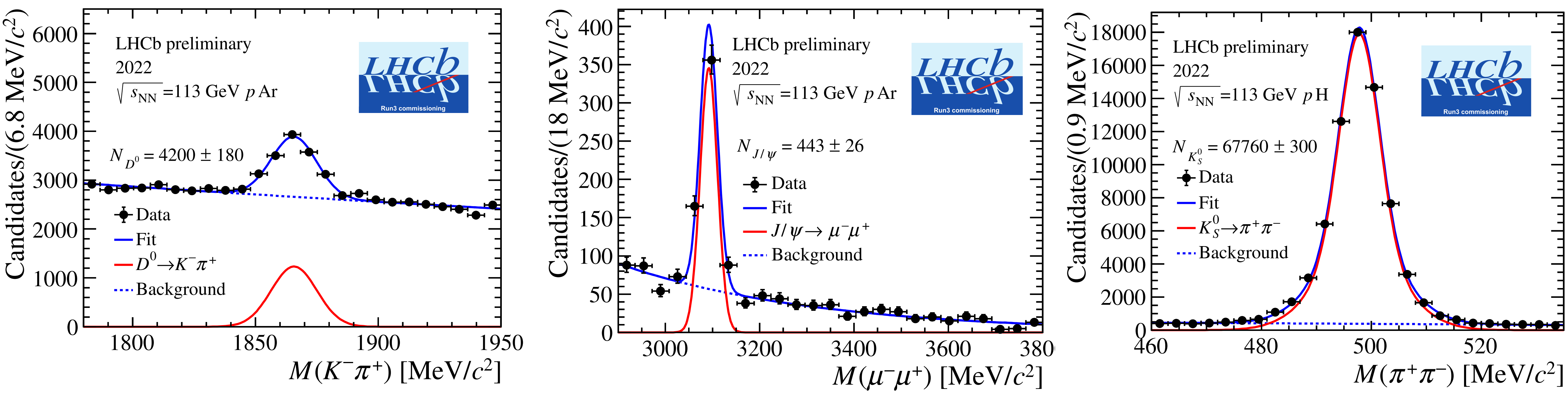
Samuel Belin samuel.belin@cern.ch

LHCb upgrade run 3

LHCb-FIGURE-2023-008

SMOG2 : A dedicated fixed target system to run simultaneously with normal collisions

Less than a hour of commissioning data-taking



VERY HIGH STATISTIC FOR FLOW IN SMALL SYSTEM

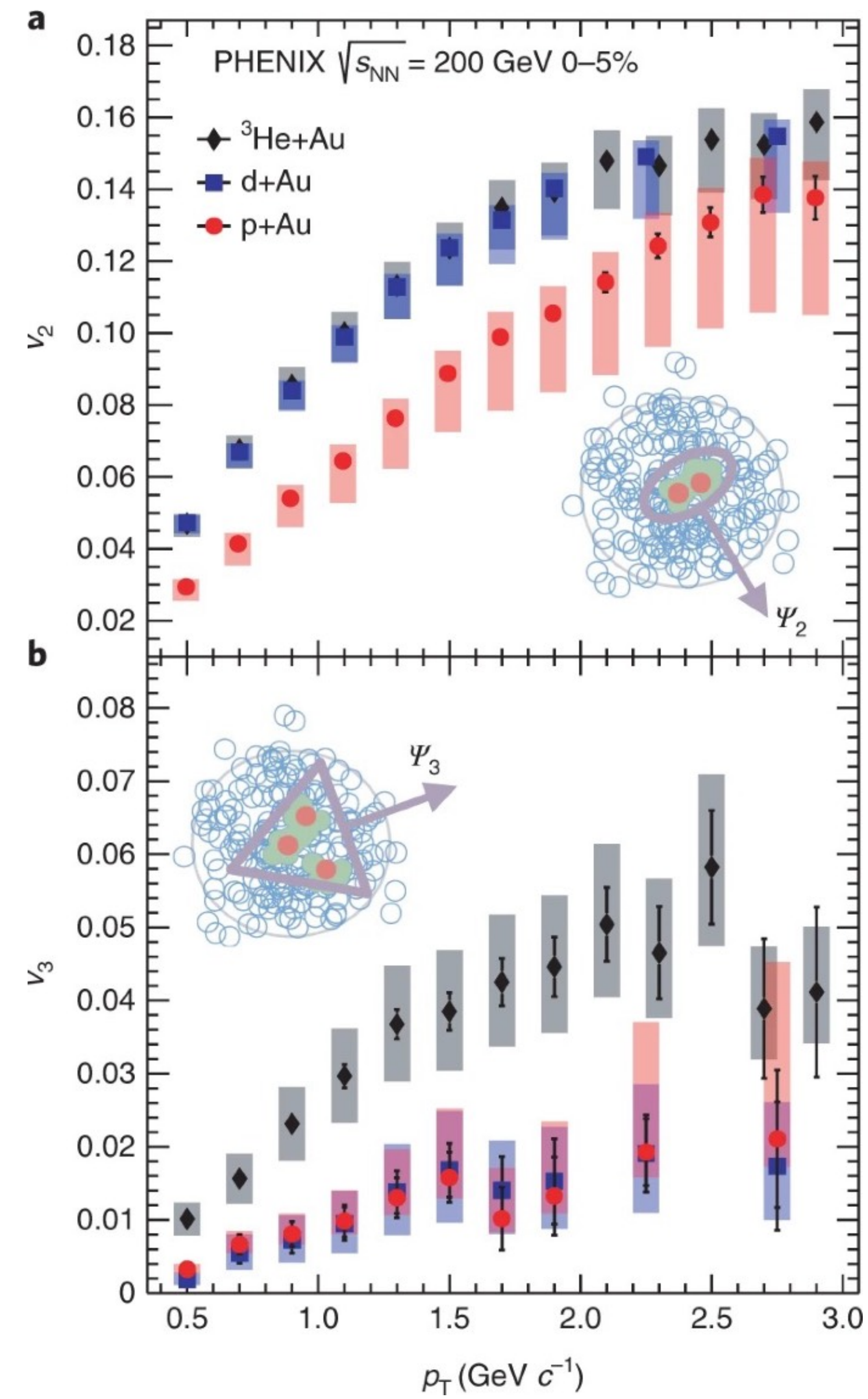
Samuel Belin samuel.belin@cern.ch

The Initial Geometry

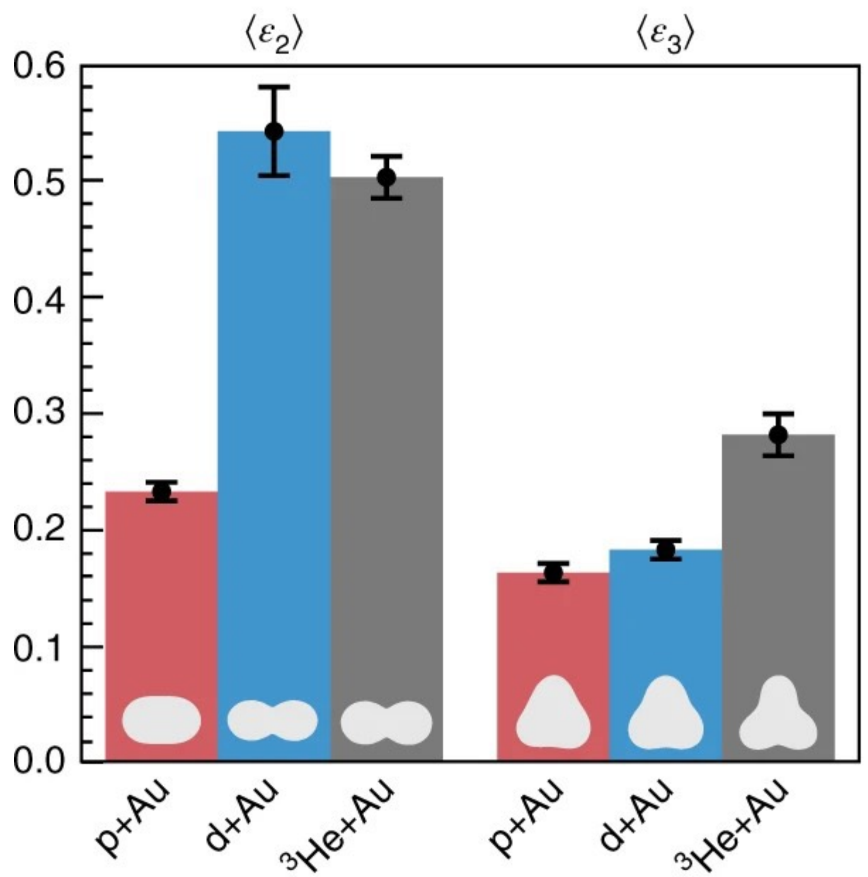
- In small systems, the initial geometry of the collision seems to have an impact on final state correlations
- The initial geometry can be characterize by the eccentricities variables:

$$\epsilon_n = \frac{\sqrt{< r^n cos(n\phi) >^2 + < r^n sin(n\phi) >^2}}{< r^n >}$$

Nat. Phys. 15, 214–220 (2019)



Computed with MC Glauber



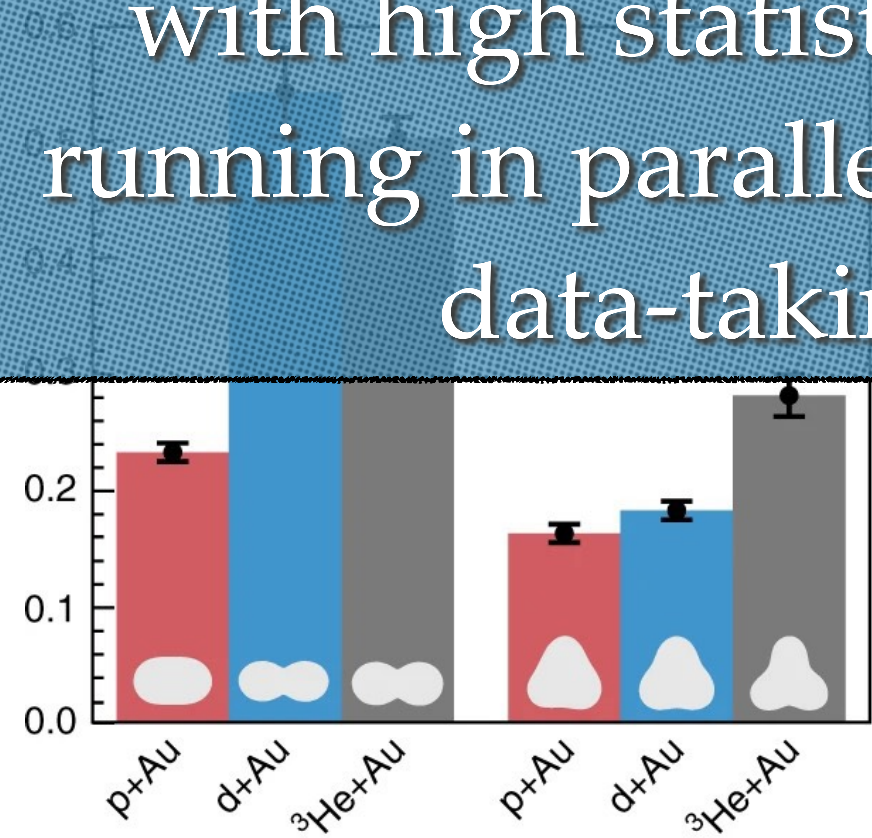
Samuel Belin samuel.belin@cern.ch

The Initial Geometry

- In small systems, the initial geometry of the collision seems to have an impact on final state correlations
- The initial geometry can be characterize by the eccentricities variables:

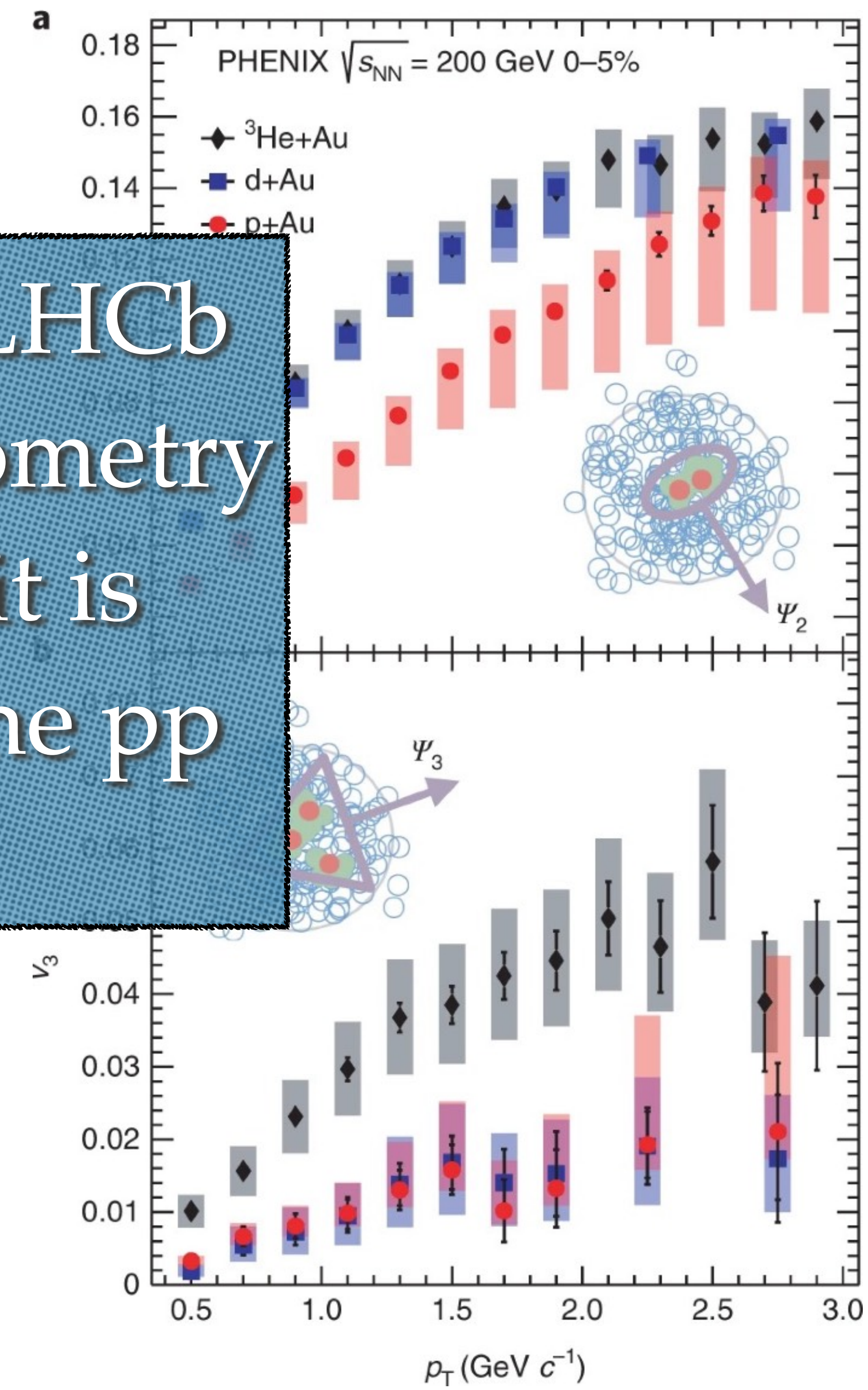
$$\epsilon_n = \frac{\sqrt{< r^n \ldots}}{\ldots}$$

Computed with MC Glauber



Fixed target system in LHCb can explore different geometry with high statistic as it is running in parallel to the pp data-taking

Nat. Phys. 15, 214–220 (2019)

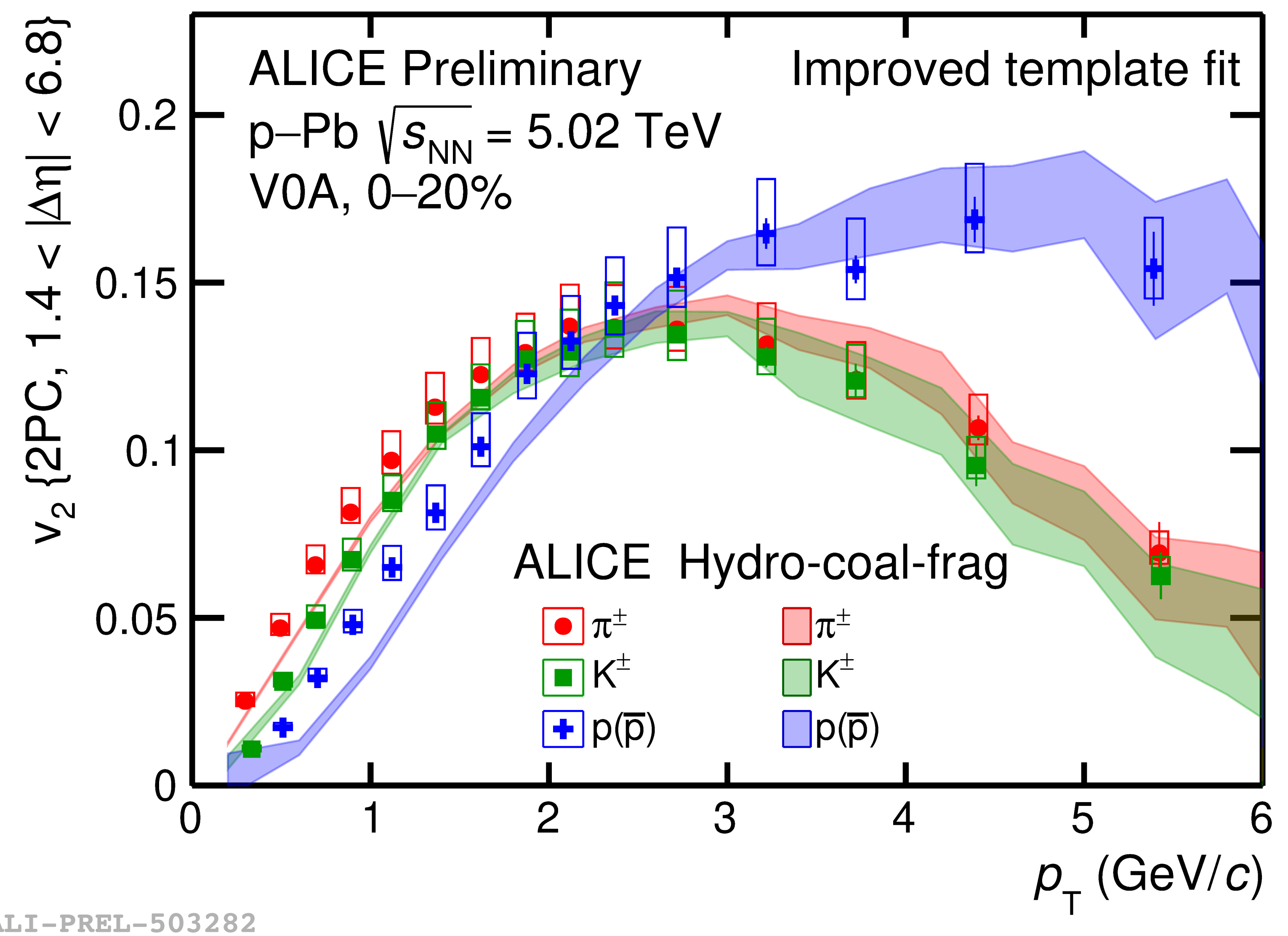


Samuel Belin samuel.belin@cern.ch

Identified Flow

ALI-PREL-503282

- Mass ordering at low-p_T
- Baryon-meson change of ordering at intermediate p_T
- Models must combine Hydrodynamics, quark coalescence and jet fragmentation to describe data



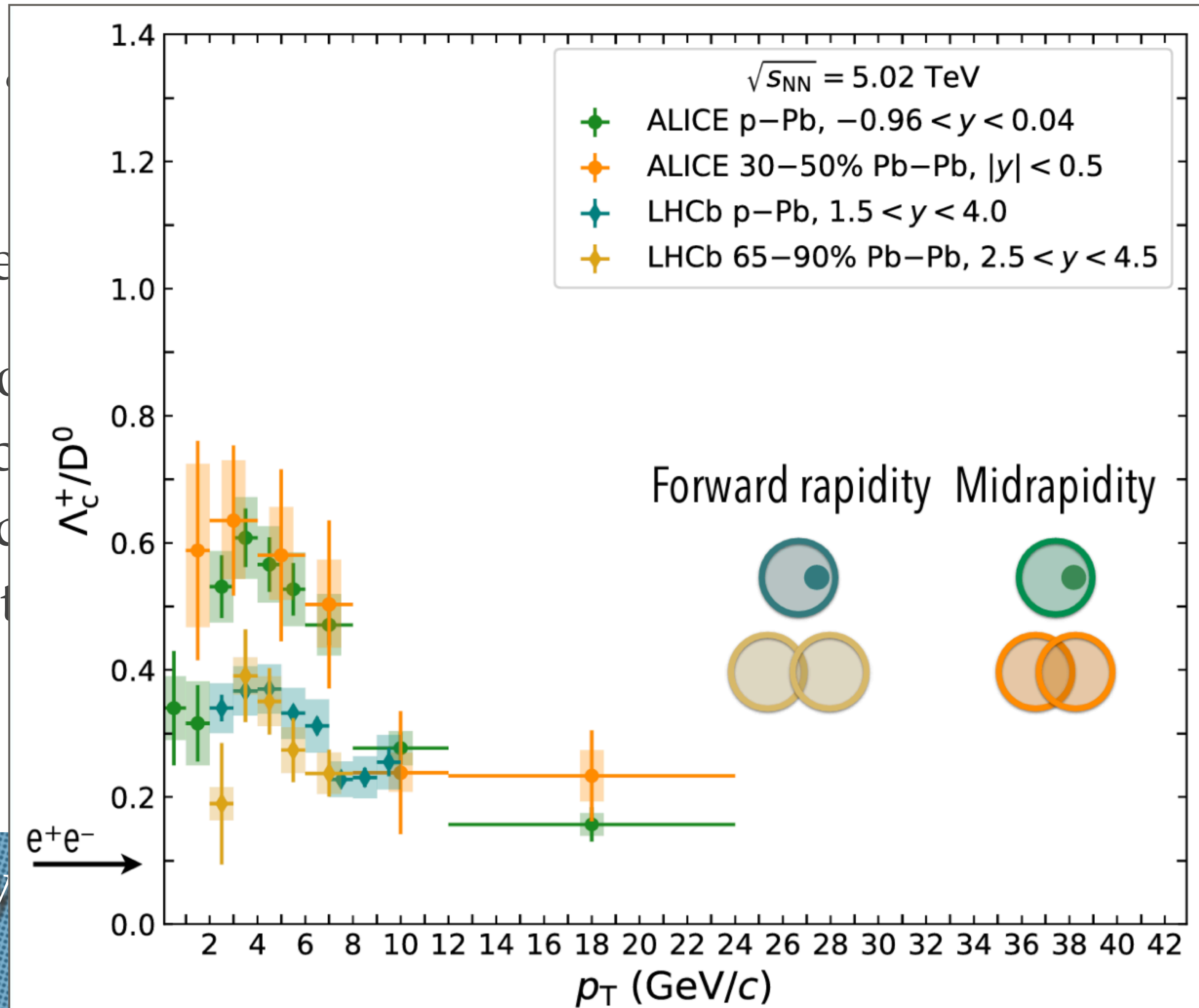
Complementary results could be provided by LHCb for the forward region!

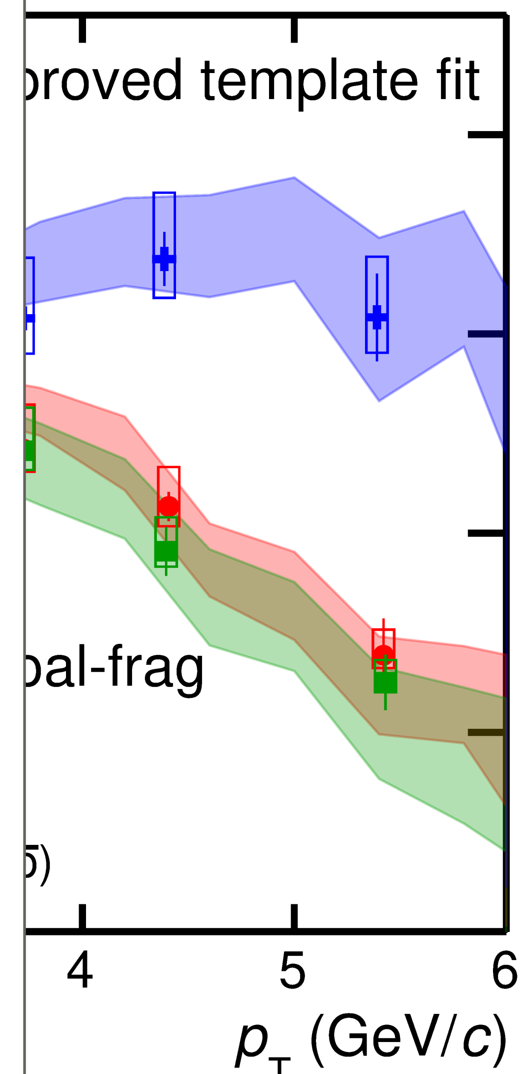
Identified Flow

PLOT FROM FABRIZIO GROSA STOLEN FROM QUARK MATTER 2023

ALI-PREL-503282

- Mass ordering
- Baryon-meson ordering at inte
- Models must c Hydrodynamic coalescence and fragmentation t data



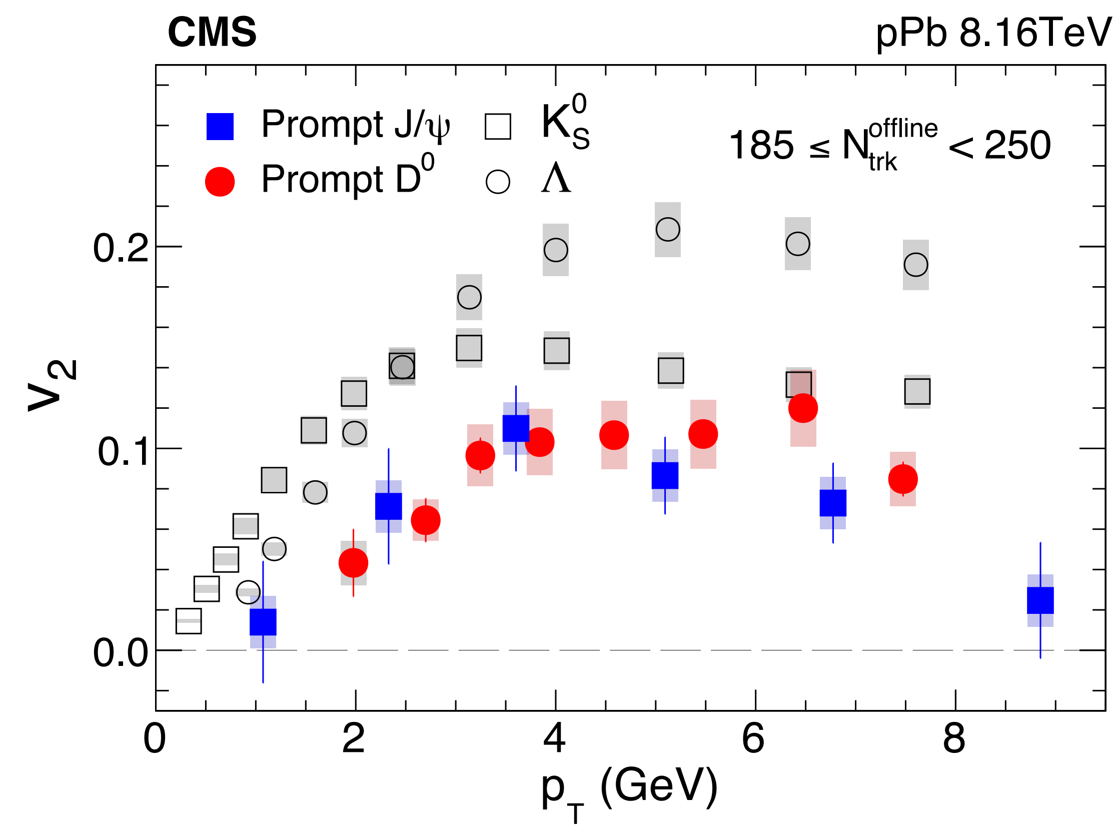


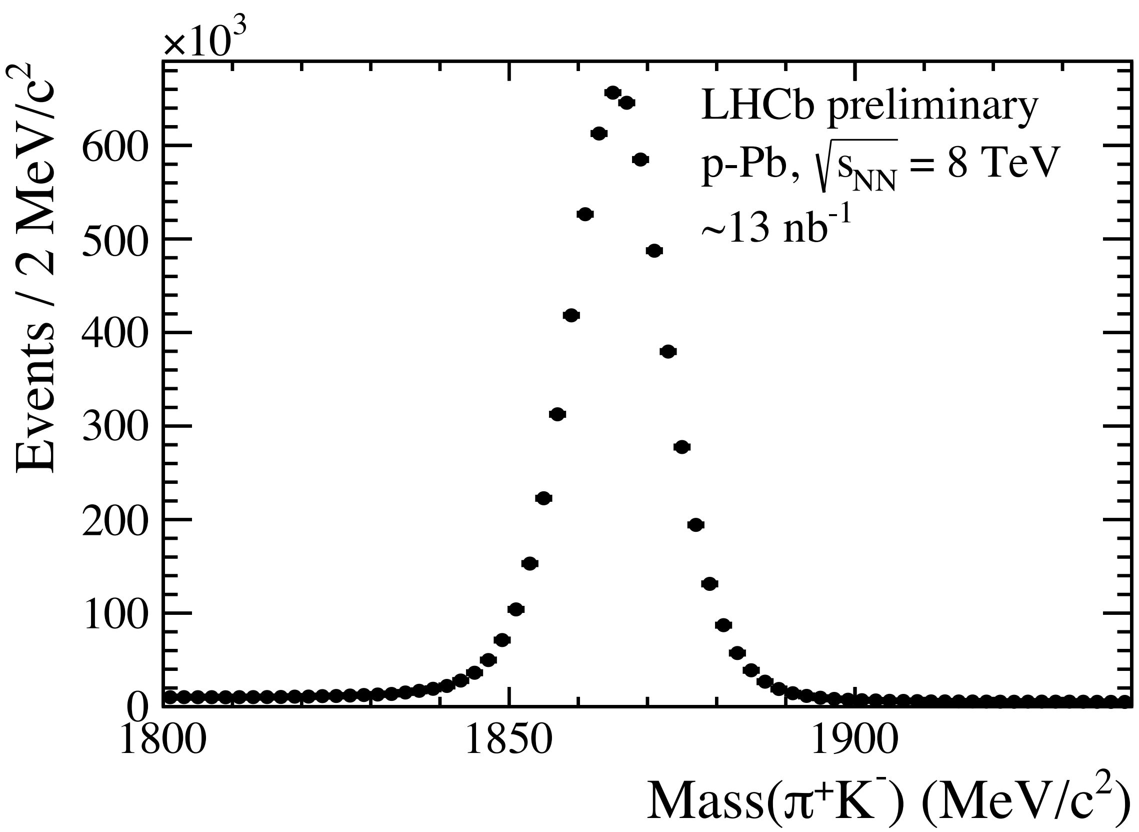
Complementary be provided by forward region!

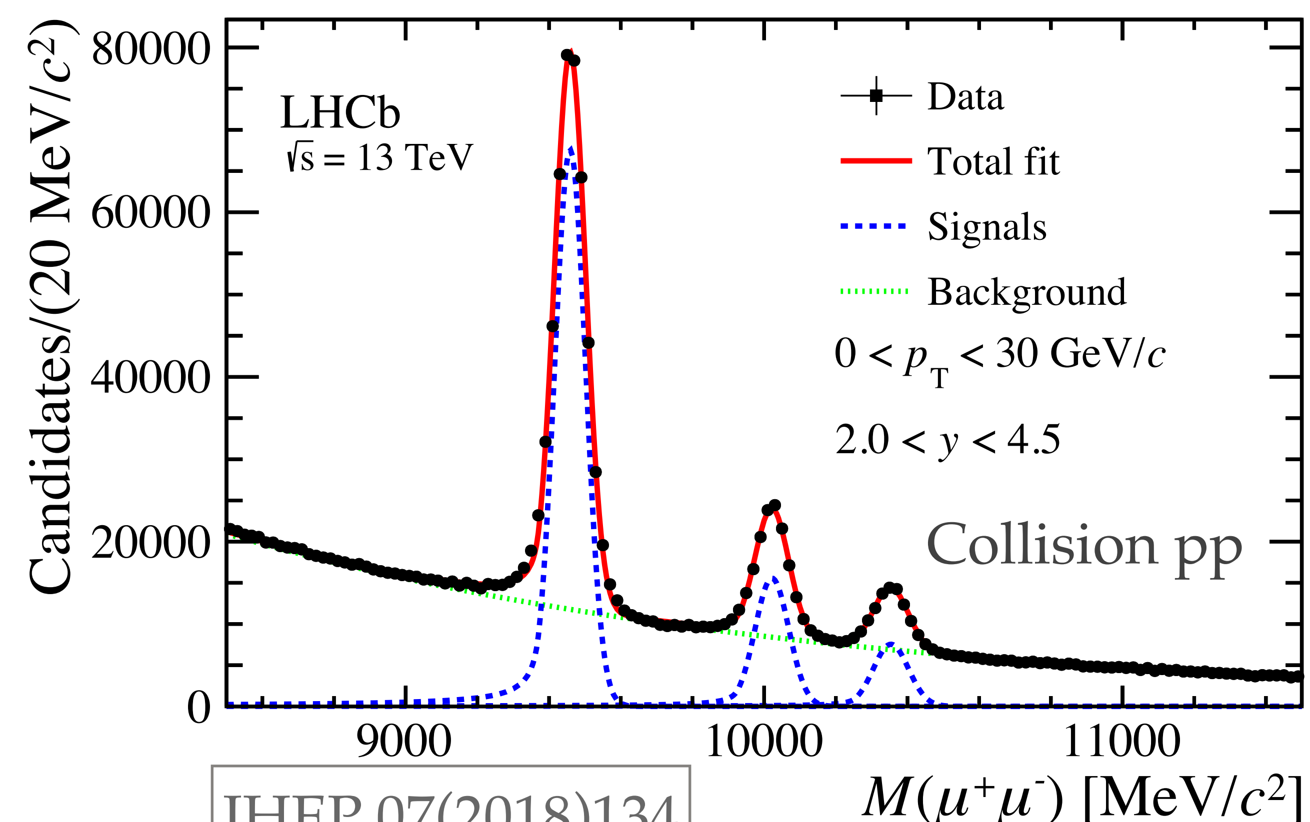
Heavy Flavor

Phys. Lett. B 791 (2019) 172

- Result from CMS shows a compatible flow for J/ψ and D^0. Cannot be explain by hydrodynamic.
- Heavy flavor hadrons may be more sensitive to possible initial-state gluon saturation effects
- LHCb is ideal to thanks to its geometry and precision







JHEP 07(2018)134

Conclusion

- First measurement of flow in the forward region at LHC in PbPb collisions
- Incoming measurement in *p*Pb / Pb*p* of:
  - Charged hadrons flow
  - Heavy flavor flow
- With the new Run3 data:
  - New PbPb sample with higher centrality reach
  - Many new fixed-target samples to come (geometry, heavy flavor…)

MANY POSSIBILITIES AT LHCb TO SHED LIGHT ON THE ORIGIN OF FLOW IN LARGE AND SMALL SYSTEM!

Elliptic flow

In equations Particle anisotropy in terms of a simple Fourier decomposition

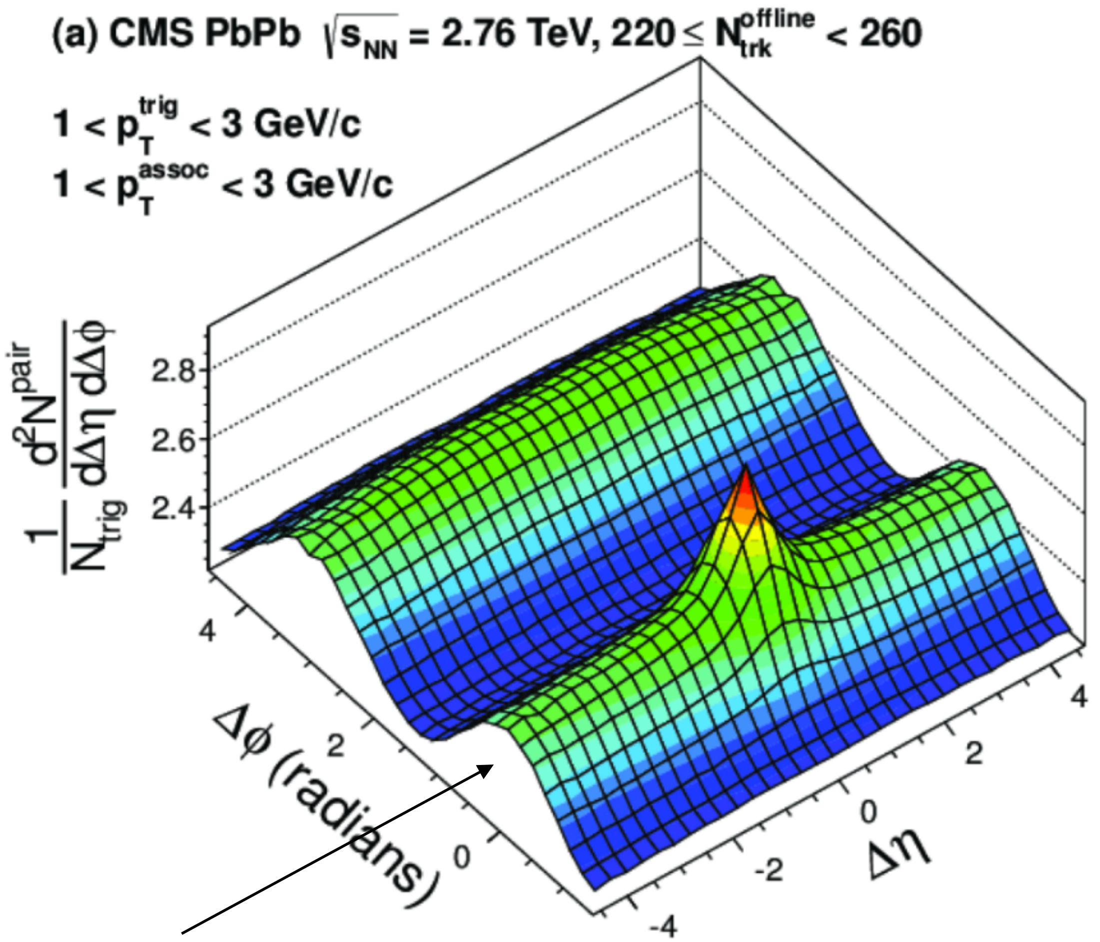
$$\rho(\phi_i|\Psi) = \overline{\rho}\left(1 + 2\sum_{n=1}^{inf} v_n cos(n(\phi_i - \Psi))\right)$$

Average particle density

Orientation angle of the reaction difficult to measure in LHCb

We consider then the 2 particle correlations

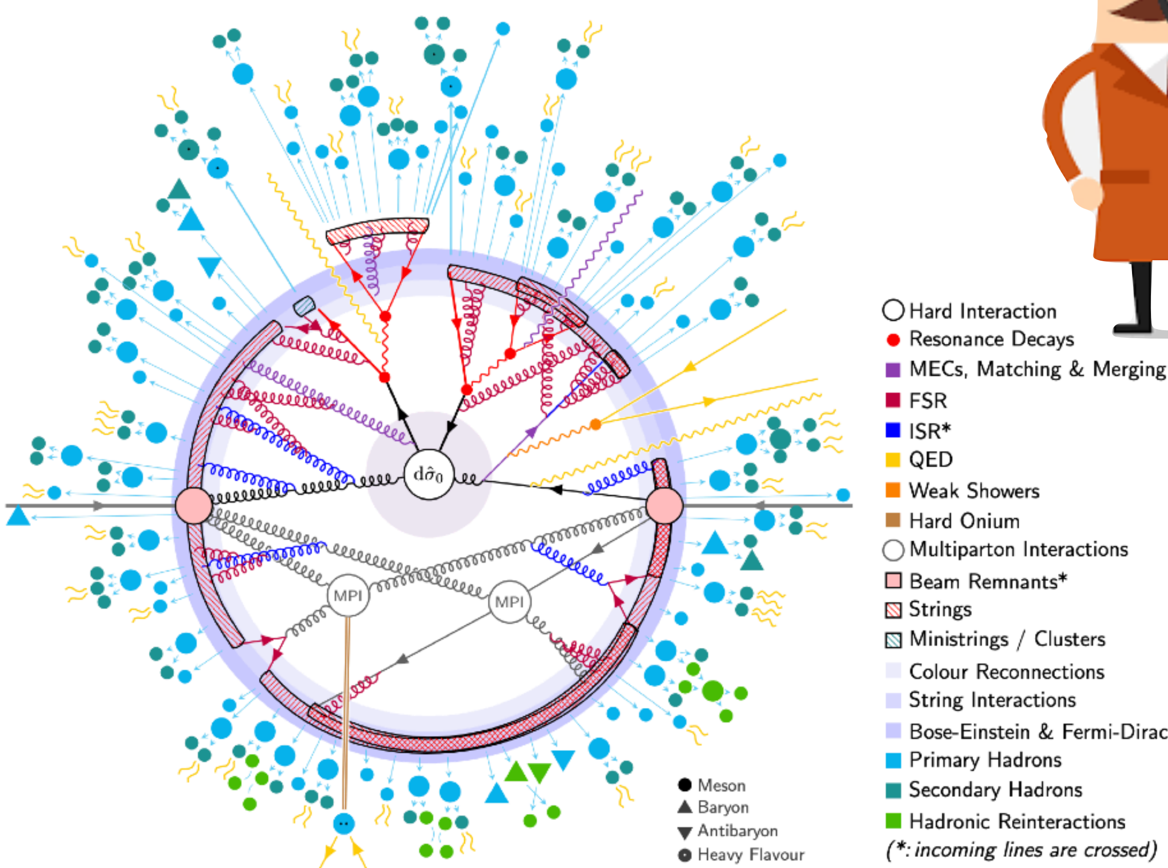
$$dN^{pair}/d\phi = A\left(1 + 2\sum_{n=1}^{inf} V_{n\Delta} cos(n(\Delta\phi))\right)$$



V2

Complexity of a hadronic collision

*Effects taken into account by the collision generator **PYTHIA***

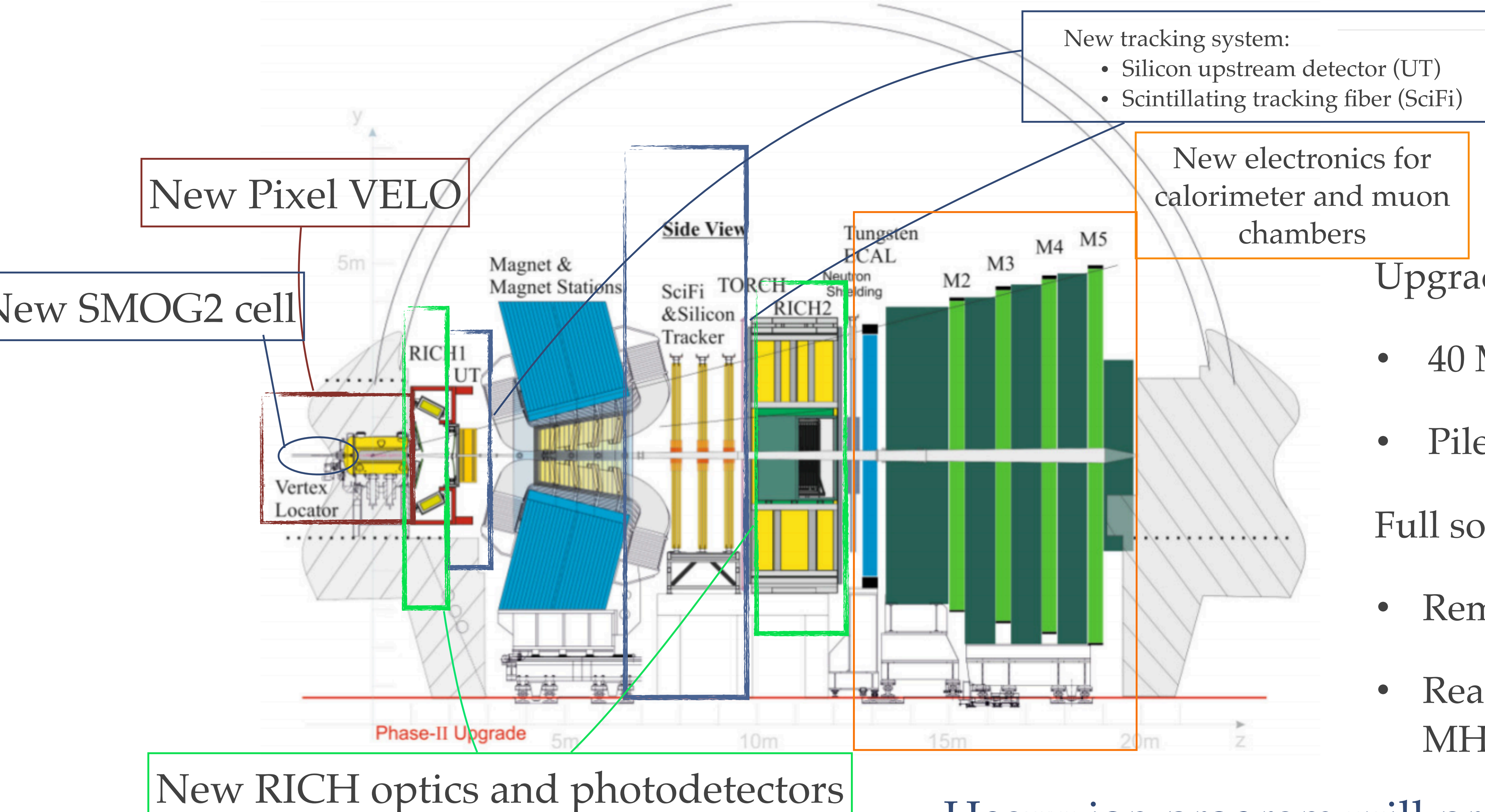


proton-proton collision

- Important to study QCD in confined and unconfined medium (QGP)
- *proton-proton* and *proton*-Plomb collisions → confined QCD
- Plomb-Plomb collisions → QGP

LHCb is the ideal detector for confined QCD

LHCb upgrade run 3



[CERN-LHCC-2012-

Upgrade for pp requirement

- 40 MHz collision rate
- Pile Up factor ~ 5

Full software trigger

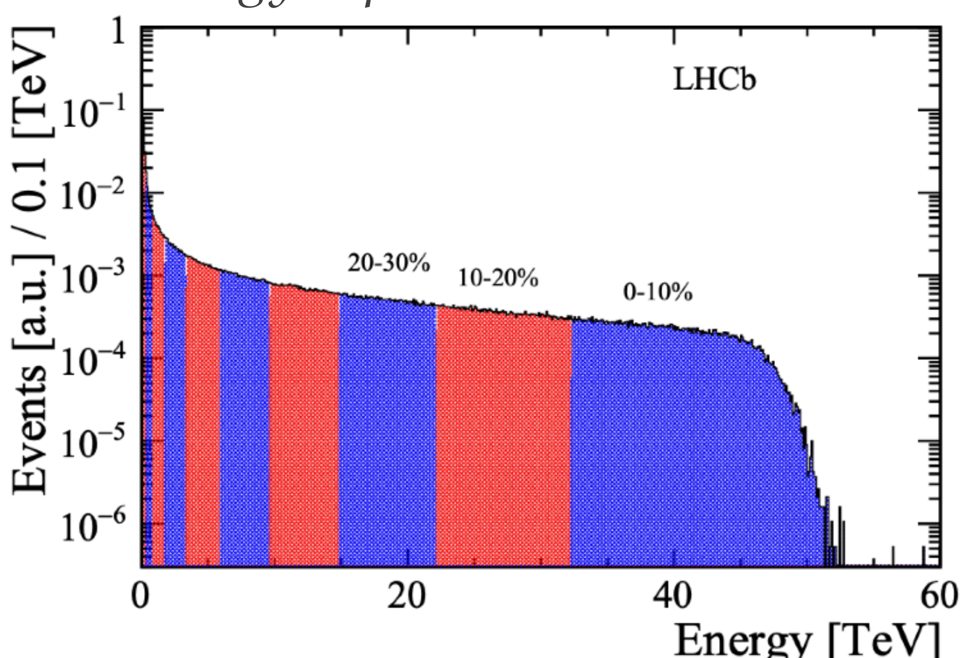
- Remove L0 triggers.
- Read out full detector at 40 MHz.

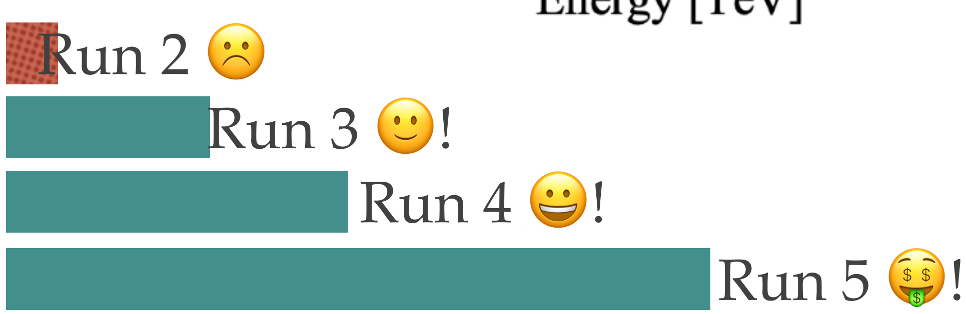
Heavy ion program will profit from this upgrade

LHCb upgrade run 3

Improved tracking system pushes further the limitation of the detector

Energy deposit in the calorimeter





- Access to more central collisions
- QGP study possible with run3 data!
- Many new study possible (quarkonia suppression, low-mass mesons, flow…)
- Expect higher reach in run 4 and no limitations for run 5
  - Note there is no limitation for the SMOG2 system

Centrality determination

arXiv:2111.0
1607

ntrality determination using MCGlauber model

Centrality %	$N_{\text{part}} \pm \sigma$	$N_{\text{coll}} \pm \sigma$	$b \pm \sigma$
100 − 90	2.91 ± 0.54	1.83 ± 0.34	15.41 ± 2.96
90 − 80	7.03 ± 0.78	5.77 ± 0.64	14.56 ± 1.80
80 − 70	15.92 ± 0.64	16.44 ± 0.69	13.59 ± 0.52
70 − 60	31.26 ± 0.67	41.28 ± 0.93	12.61 ± 0.28
60 − 50	54.65 ± 1.13	92.59 ± 2.01	11.59 ± 0.24
50 − 40	87.54 ± 1.01	187.54 ± 2.43	10.47 ± 0.14
40 − 30	131.24 ± 1.15	345.53 ± 3.89	9.23 ± 0.08
30 − 20	188.02 ± 1.49	593.92 ± 6.62	7.80 ± 0.06
20 − 10	261.84 ± 1.83	972.50 ± 10.37	6.02 ± 0.04
10 − 0	357.16 ± 1.70	1570.26 ± 15.56	3.31 ± 0.01