Bilan et perspectives de LHCb-ions lourds

1. LHCb Heavy Ions
2. IN2P3 teams program and records
3. Perspectives

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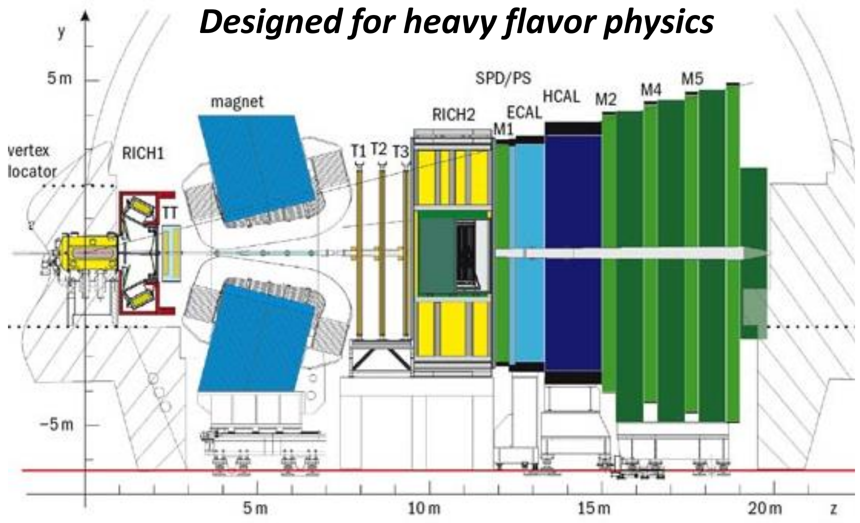
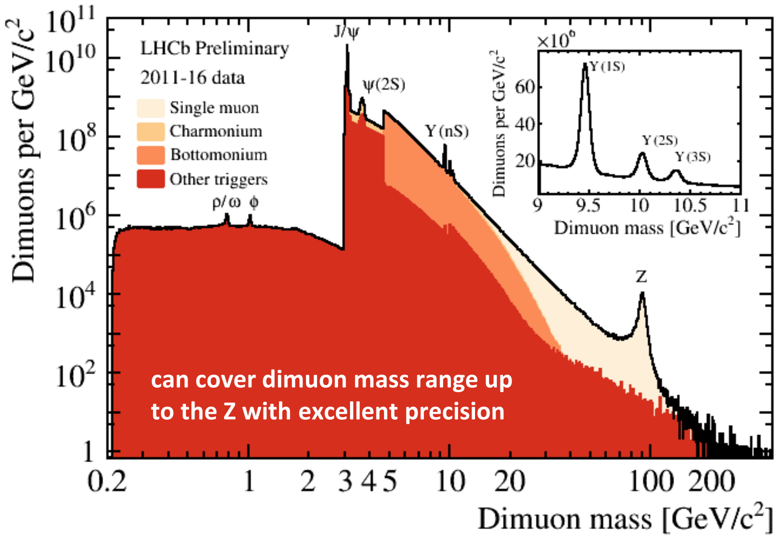
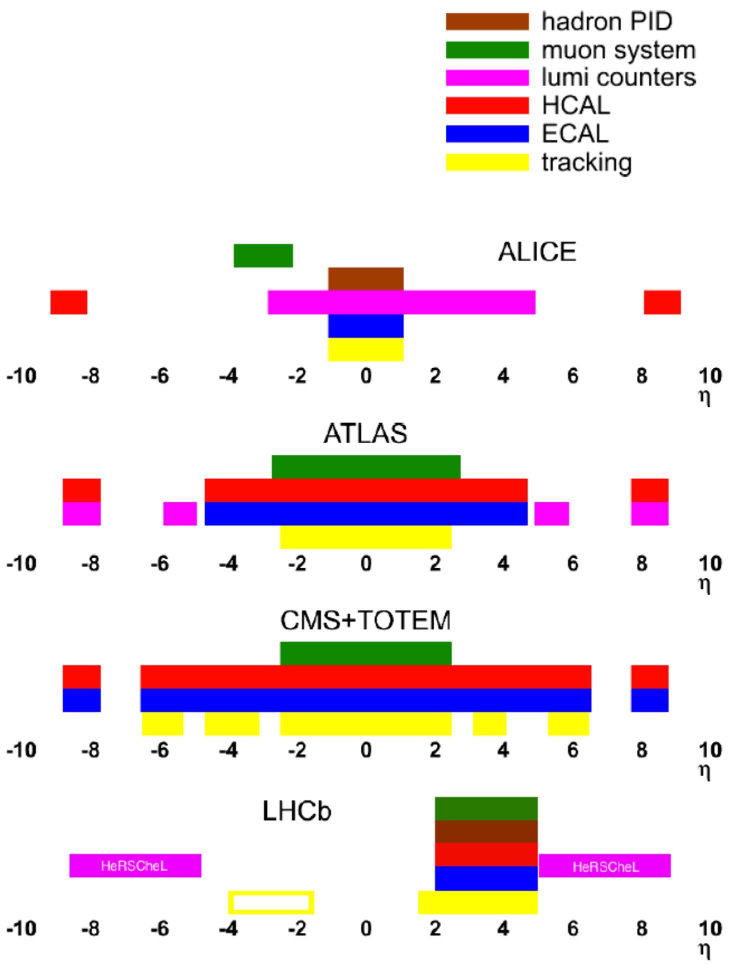
1. LHCb Heavy Ions: Detector setup

Single arm spectrometer, the only LHC experiment fully instrumented in 2 < η < 5

JINST 3 (2008) S08005
IJMPA 30 (2015) 1530022







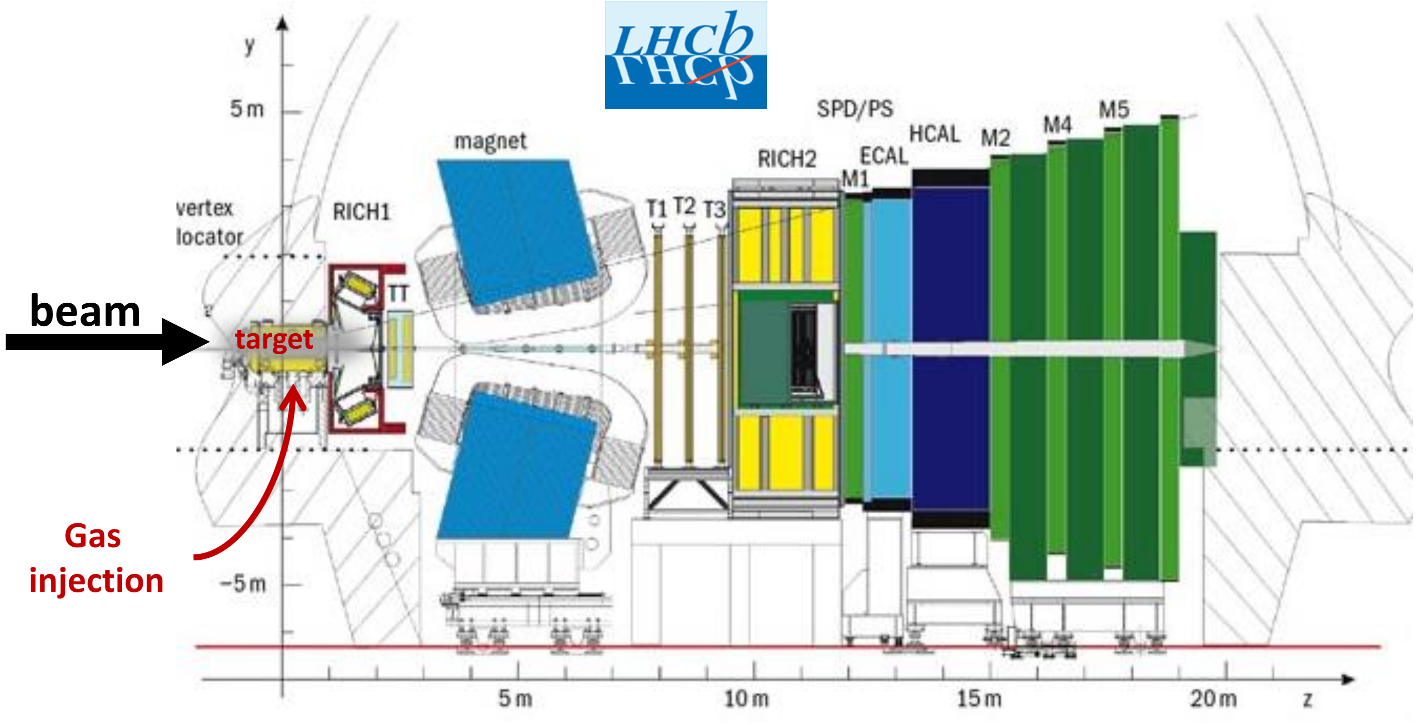
- **LHCb is specialised in heavy flavour precision physics, beauty and charm:**
  - Optimised for low pile-up collisions (*ie* low multiplicity):
    - Precise reconstruction of production and decay vertices
    - Correlations between particles: flavour tagging

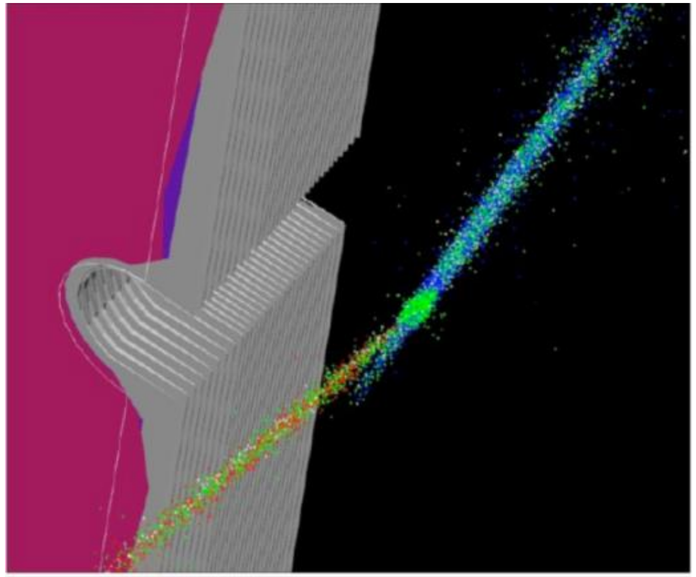
- **Main characteristics of the experiment make it attractive for Heavy ion physics :**
  - Instruments fully the forward region: 2<η<5
  - Precise vertexing: separation of prompt production from *B* decay products (IP resolut°: 20μm)
  - Precise tracking: reconstruction down to p_T=0
  - Particle identification: full reconstruction of hadronic decays of charm or beauty, such as $D^0 \rightarrow K\pi$

    (ε(K→K)~95%, mis-ID ε(π→K)~5%)

1. LHCb Heavy Ions: The fixed target mode

- **Can also operate in fixed-target mode: unique at LHC**
  - Injecting gas in the LHCb VErtex LOcator (VELO) tank, primarily done to perform luminosity measurement.
  - Can be used as an **internal gas target (SMOG)**
  - Allows measurement of *p*-gas and ion-gas interactions





Distribution of vertices overlaid on detector display. z-axis is scaled by 1:100 compared to transverse dimensions to see the beam angle.
Beam 1 - Beam 2, Beam 1 - Gas, Beam 2 - Gas.

Noble gas only :
(very low chemical reactivity)

He, Ne, Ar, Kr, Xe
A = 4, 20, 40, 84, 131

Gas pressure:
10^{-7} to 10^{-6} mbar

1. LHCb Heavy Ions: Operation modes

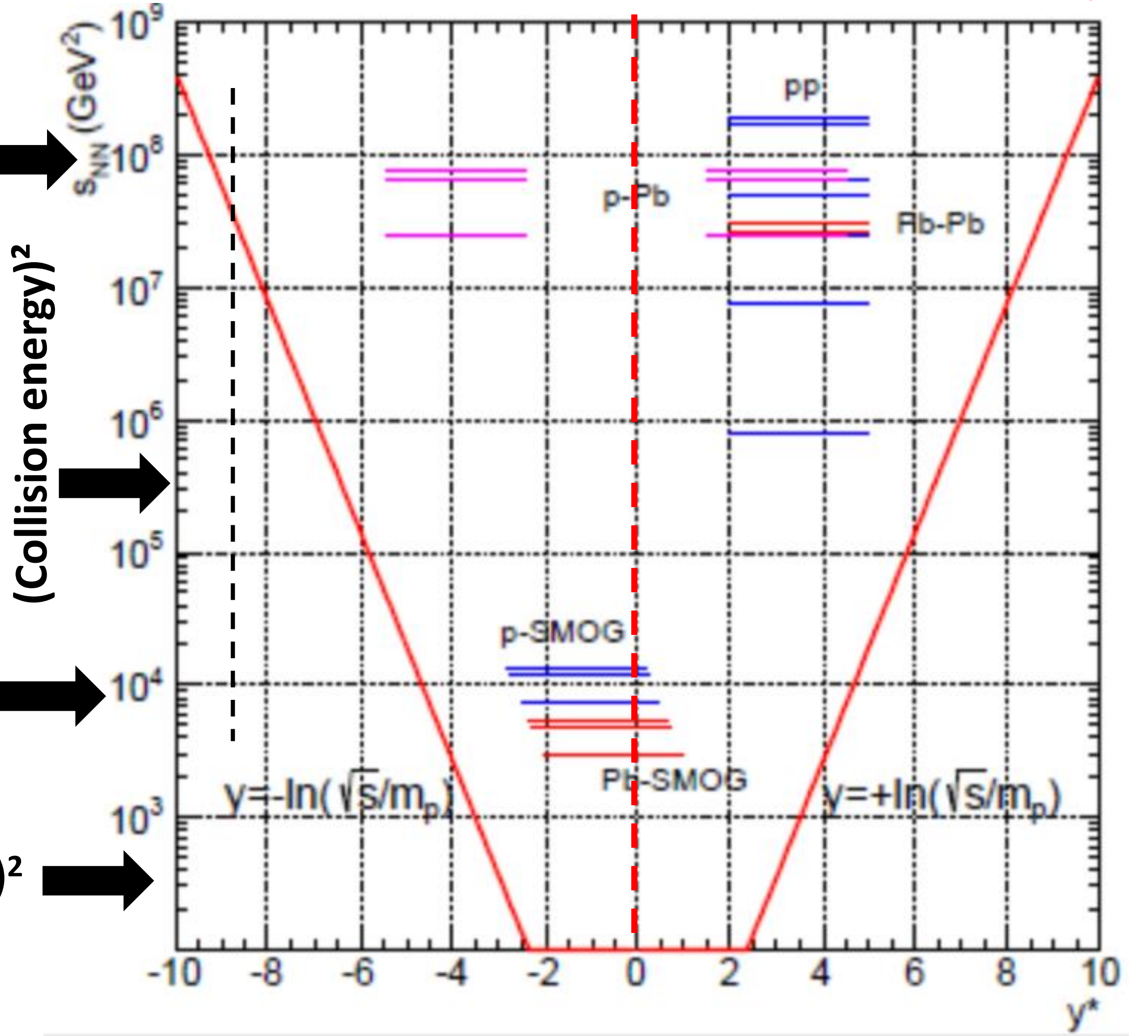
LHC-collider (10 TeV)^2

RHIC - (200 GeV)^2

LHC-FT (100 GeV)^2

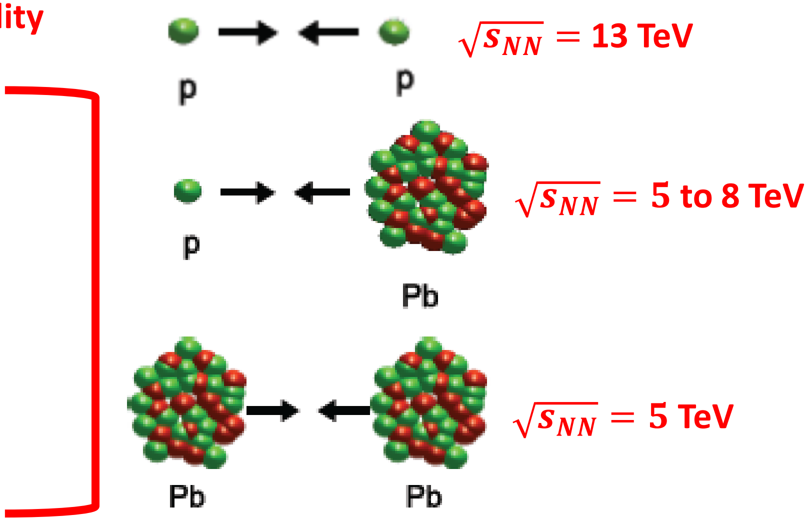
SPS - (20 GeV)^2

Backward rapidity ← Mid-rapidity → Forward rapidity

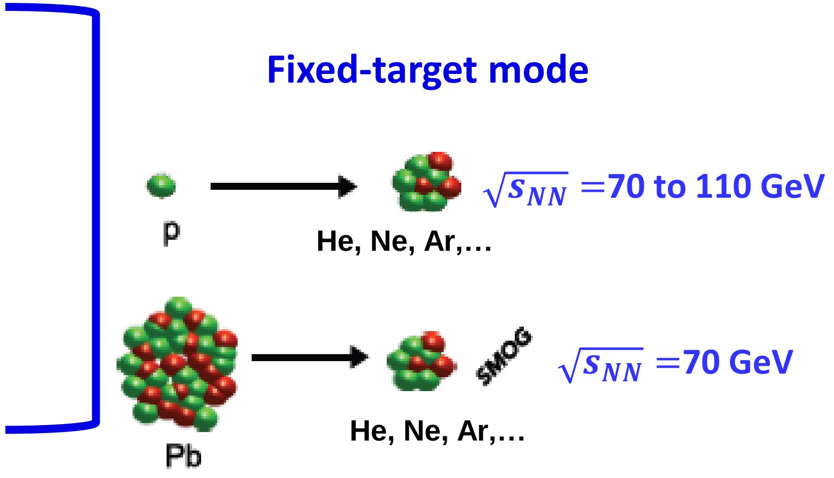


Rapidity in centre-of-mass

Collider mode



Fixed-target mode

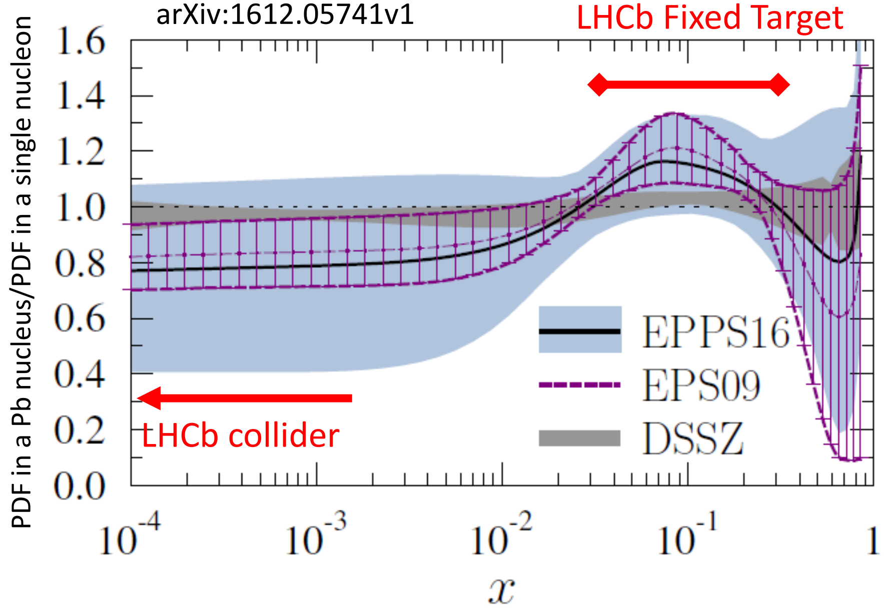


← At $\sqrt{s_{NN}}$ = 110 GeV, $y_{\text{centre-of-mass}} = y_{\text{lab}} - 4.77$

2. IN2P3 teams @ LHC Run 1 and 2: Heavy flavors in heavy ion collisions

- **LHC- Collider mode: focus on Proton-nucleus collisions**
  - Serve as a **baseline for nucleus-nucleus collisions**
  - Nuclear parton distribution function **(nPDF), energy loss, saturation**, …
  - **Unique capabilities with LHCb** in the heavy flavor sector to constraint nPDF at very small (pPb collisions – charm and beauty) and large (fixed target - charm) Bjorken-x

- **LHC-Fixed Target mode ($\sqrt{s_{NN}}$~70 GeV)**
  - Thanks to **unique capabilities**, LHCb offers **new opportunities** in the charm sector: J/ψ, ψ', χ_c, D^0, $D^{+/-}$, D^*, Λ_c… *(in the 90's the NA50/SPS experiment measured only J/ψ and ψ' in PbPb @ 17 GeV)*
  - **Proton-nucleus collisions**
    - Investigate nPDF, nuclear absorption, … at **large Bjorken-x (valence region)**
  - **Nucleus-nucleus collisions**
    - Fill the gap between SPS (~20 GeV) and RHIC (200 GeV)
    - Investigate **color screening mechanism** (Lattice QCD prediction)
    - NA50/SPS observed anomalous J/ψ suppression in $\sqrt{s_{NN}}$~ 20 GeV PbPb collisions ; **still not fully conclusive and no capability to measure χ_c and open charm (mandatory)**
    - **Accessing similar energy density regime at LHC-FT**: operate PbAr@70 GeV ; unique opportunity to conclude on color screening.



Bjorken-x = fraction of the nucleon momentum carried by a parton

SPS | ←LHC → |

System \ centrality	60 – 100%	40 – 50%	20 – 30%	0 – 10%
PbNe – 71 GeV	108.6	392.5	814.5	1494.9
PbAr – 71 GeV	**123.6**	**496.5**	**1228.3**	**2372.7**
PbKr – 71 GeV	196.9	919.1	2205.5	4084.3
PbPb – 17 GeV	**124.2**	**605.9**	**1338.7**	**2980.5**

(charged particle multiplicity, based on EPOS-LHC-v3400)

2. IN2P3 teams: A bit of history

- **The Ion and Fixed Target (IFT) working group**

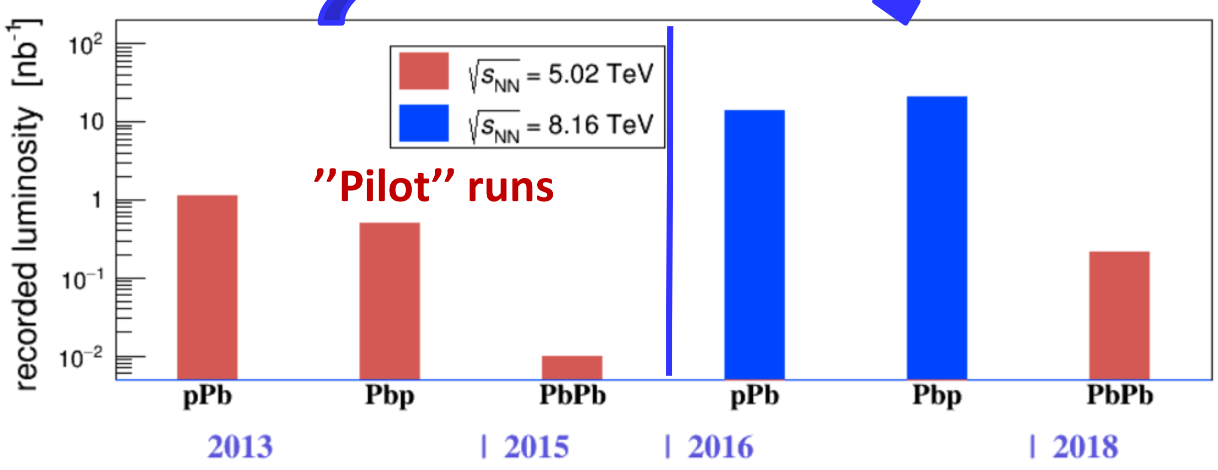
  - **July 2015** : proposal for LHCb participation to the Heavy Ion Runs
    - 10 people signing (**5 people from IJClab+LLR: 2 perm. + 3 postdocs**)

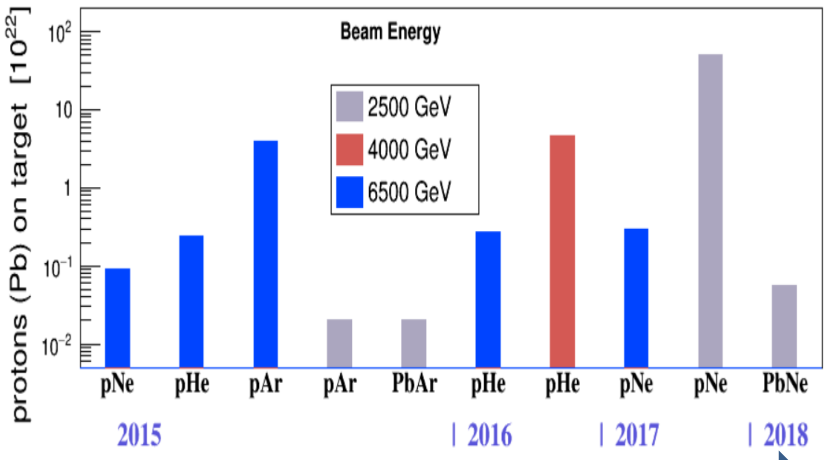
LHCb-INT-2015-019
July 29, 2015
version 0.5

  - Since then
    - **Strong synergies IJClab/LLR**: expertise sharing / IJClab mostly on collider data (*p*Pb) / LLR mostly on fixed-target data (*p*He, *p*Ne, *p*Ar, PbNe)
    - **Permanent physicists** : **P. Robbe** (CNRS/IJClab) – run coordinator (2015 – 2017), **F. Fleuret** (CNRS/LLR) – IFT convener (2018 - 2020)
    - **Postdocs** (lab/main financial support):
      - L. Massacrier (IJClab/P2IO) → now perm. @ IJClab (CNRS/ALICE) – IFT convener (2015 – 2016)
      - F. Bossu (IJClab /ERC) → now perm. @ Irfu (DPhN/Jlab) – IFT convener (2016 – 2018)
      - **E. Maurice** (LLR/P2IO+Polytechnique) → now perm. @ LLR (Polytechnique/LHCb) – lumi convener for SMOG (2017 – 2019)
      - M. Winn (IJClab /ERC) → now perm. @ Irfu (DPhN/Alice) – IFT convener (2018 – 2019)
      - Y. Zhang (IJClab /ERC) → now perm. @ Tsinghua (LHCb) – IFT convener (2019 – 2021)
      - B. Audurier (LLR/P2IO+Polytech.+CNRS) → now perm. @ Irfu (DPhN/LHCb) – IFT convener (2019 – 2021)
      - **M. Guittière** (IJClab/P2IO)
      - **O. Boente** (LLR/Polytechnique)
      - **K. Mattioli** (LLR/ANR)
    - **Thesis**
      - Elisabeth Niel (IJClab) → now postdoc @ EPFL (LHCb)
      - Felipe Garcia (LLR) → now in private company
  - **Nowadays**
    - Around 40 people working in IFT (**6 people from IJClab+LLR: 3 perm. + 3 postdocs**)

2. IN2P3 teams: Data taking for Heavy Ion physics

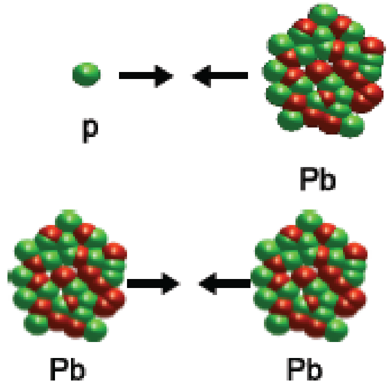
Lumi. × 20



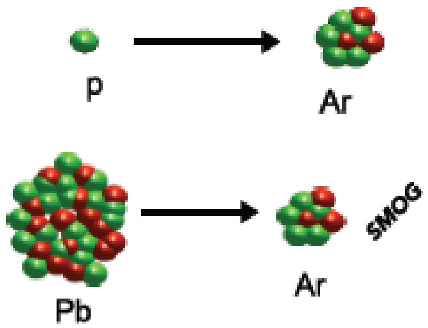


LHC RUN I LHC RUN II

Collider mode



Fixed-target mode



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2. IN2P3 teams: Summary of IFT published analysis

N°) Title	Journal (citation) – Submit. – authors (ana note)	Coll
1) J/ψ and D^0 production in PbNe collisions	arXiv:2211.11652/EPJC (0) – **Nov 2022** F. **Garcia**, E. **Maurice**, F. **Fleuret**, B. **Audurier**	Targ.
2) Charmonium production in *p*Ne collisions	arXiv:2211.11645/EPJC (0) – **Nov 2022** E. **Maurice**, F. **Fleuret**, F. **Garcia**, B. **Audurier**	Targ.
3) Open charm asymmetry in *p*Ne collisions	arXiv:2211.11633/EPJC (0) – **Nov 2022** E. **Maurice**, F. **Fleuret**, F. **Garcia**, B. **Audurier**	Targ.
4) Λ^+_c to D^0 ratio in peripheral PbPb collisions	arXiv:2210.06939/JHEP (1) – **Oct 2022** B. **Audurier**, S. Chen, F. **Garcia**, G. Manca	Coll.
5) coherent charmonium production in ultra-peripheral lead-lead collisions	arXiv:2206.08221/JHEP (5) – **Jun. 2022** B. **Audurier**, A. Bursche, V. Dobishuk, W. Duan, H. Li, Q. Lu, G. Manca, M. Rangel, B. Schmidt, X. Wang, Y. Zhang	Coll.
6) *Z* boson production cross-section in proton-lead collisions 8.16TeV	arXiv:2205.10213/JHEP (2) – **May 2022** H. Li, T. Li, G. Liu, R. Ma, J. Sun, S. Xian, Z. Yang, Q. Zhu, L. Zhang, Y. Zhang, X. Zhu	Coll.
7) antiproton production from antihyperon decays in pHe collisions	arXiv:2205.09009/EPJC (1) – **May 2022** L. Anderlini, A. Bizzeti, F. Davolio, G. Graziani, S. Mariani, V. Zhukov	Targ.
8) prompt D^0 nuclear modification factor in *p*Pb collisions at 8.16 TeV	arXiv:2205.03936/PRL (0) – **May 2022** S. Chen, Y. Gao, C. Gu, G. Manca, Y. Luo, B. Schmidt, J. Sun, J. Wang, D. Yang, Z. Yang, Y. Zhang, X. Zhu	Coll.
9) modification of *b* quark hadronization in high-multiplicity *pp* collisions at 13 TeV	arXiv:2204.13042/PRL (4) – **Apr. 2022** J. Durham, C. Dean, E. Epple, K. Smith, C. DaSilva, C. Wong	Coll.
10) R_{pA} of neutral pions in the forward and backward regions in *p*Pb collisions	arXiv:2204.10608/PRL (1) – **Apr. 2022** T. Boettcher, P. Ilten, M. Williams	Coll.
11) RpA of Prompt Charged Particle in *p*–*Pb* and *pp* Collisions at 5 TeV	PRL 128 (2022) 142004 (8) – **Aug. 2021** O. Boente, A. Gallas, C. Santamarina, R. Vazquez	Coll.
12) J/ψ photoproduction in Pb-Pb peripheral collisions at 5 TeV	PRC105 (2022) L032201 (11) – **Aug. 2021** S. Belin, B. **Audurier**, G. Manca, F. **Garcia**	Coll.
13) Study of coherent J/ψ production in lead-lead collisions at 5 TeV	arXiv:2107.03223/JHEP (14) – **Jul. 2021** B. Audurier, A. Bursche, V. Dobishuk, P. Gandini, D. Johnson, H. Li, G. Manca, V. Pugatch, L. Rangel, B. Schmidt, L. Silva, R. Kopecna, Q. Lu	Coll.
14) prompt-production cross-section ratio $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ in *p*Pb collisions at 8.16 TeV	PRC103 (2021) 064905 (5) – **Mar. 2021** J. Crkovska, C. DaSilva, M. Durham	Coll.
15) multiplicity-dependent prompt $\chi c1(3872)$ and $\psi(2S)$ production in *pp* collisions	PRL 126 (2021) 092001 (30) – **Sept. 2020** M. Durham, J. Crkovska, C. Dean, E. Epple, G. Kunde, C. DaSilva	Coll.

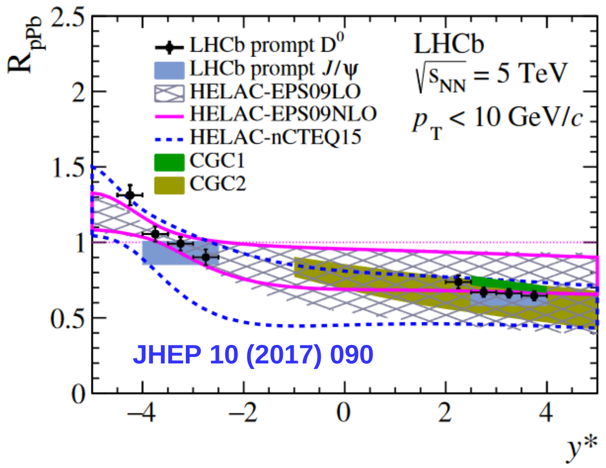
IN2P3 teams contributed to this analysis (Mostly heavy flavour production studies)

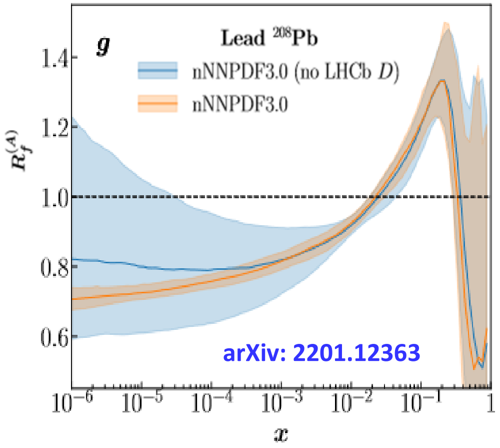
N°) Title	Journal (citation) – Submit. – authors (ana note)	Coll
16) Enhanced double parton scattering in proton-lead collisions at 8.16 TeV	PRL 125 (2020) 212001 (13) – **Jul. 2020** Y. Gao, P. **Robbe**, B. Schmidt, M. **Winn**, A. Xu, Y. Zhang	Coll.
17) Measurement of B^+, B^0 and Λ^0_b production in *p*Pb collisions at 8.16 TeV	Phys. Rev. D99 052011 (2019) (42) – **Feb. 2019** V. **Balagura**, F. **Fleuret**, E. **Maurice**, P. **Robbe**, M. **Winn**, Y. **Zhang**, B. Schmidt	Coll.
18) 1[st] Measurement of Charm Production in its Fixed-Target Configuration at the LHC	PRL 122 (2019) 132002 (74) – **Oct. 2018** E. **Maurice**, F. **Fleuret**, P. **Robbe**, M. **Winn**; Y. **Zhang**	Targ.
19) Υ production in *p*Pb collisions at 8.16 TeV	JHEP 11 (2018) 194 (54) – **Oct. 2018** S. Chen, G. Manca	Coll.
20) Prompt Λ^+_c production in *p*Pb collisions at 5.02 TeV	JHEP 02 (2019) 102 (51) – **Sept. 2018** Y. Gao, B. Schmidt, J. Sun, D. Yang, Z. Yang, Y. Zhang, X. Zhu	Coll.
21) Measurement of antiproton production in pHe collisions at 110 GeV	PRL 121 (2018) 222001 (72) – **Aug. 2018** L. Anderlini, G. Graziani, C. Lucarelli, S. Mariani, G. Passaleva, M. Ferro Luzzi, T. Verlage, V. Zhukov	Targ.
22) Study of prompt D^0 meson production in pPb collisions at 5 TeV	JHEP 10 (2017) 090 (116) – **Jul. 2017** E. **Maurice**, F. **Bossu**, F. **Fleuret**, Y. Gao, G. Manca, P. **Robbe**, M. **Winn**, Z. Yang, Y. **Zhang**, L. **Massacrier**	Coll.
23) Prompt and nonprompt J/ψ production in *p*Pb collisions at 8.16 TeV	Phys. Lett. B774 (2017) 159 (92) – **Jun. 2017** V. **Balagura**, F. **Bossu**, F. **Fleuret**, E. **Maurice**, P. **Robbe**, M. **Winn**, Y. **Zhang**	Coll.
24) $\psi(2S)$ production in *p*Pb collisions at 5 TeV	JHEP 03 (2016) 133 (66) – **Jan. 2016** Y. Gao, F. Jing, Y. Zhang, M. Zhao, M. Schmelling, B. Schmidt	Coll.
25) Long-range near-side angular correlations in 5TeV proton-lead collisions	Phys. Lett. B762 (2016) 473 (109) – **Dec. 2015** M. Meissner	Coll.
26) *Z* production in pPb collisions at LHCb	JHEP 09 (2014) 030 (72) – **Jun. 2014** C. Elsasser, K. Müller	Coll.
27) Υ production in pPb collisions at 5TeV	JHEP 07 (2014) 094 (95) – **May 2014** Y. Gao, J. He, F. Jing, Y. Li, M. Schmelling, B. Schmidt, Z. Yang, X. Yuan, L. Zhong	Coll.
28) J/ψ production in *p*Pb collisions at 5 TeV	JHEP 02 (2014) 72 (199) – **Aug. 2013** Y. Gao, J. He, F. Jing, Y. Li, B. Liu, M. Schmelling, B. Schmidt, Z. Yang, X. Yuan, L. Zhong	Coll.
29) centrality determination in PbPb and PbNe	JJINST 17 (2022) P05009 **F. Garcia, B. Audurier, E. Maurice, F. Fleuret**	All

2. IN2P3 teams: Some Flagship results

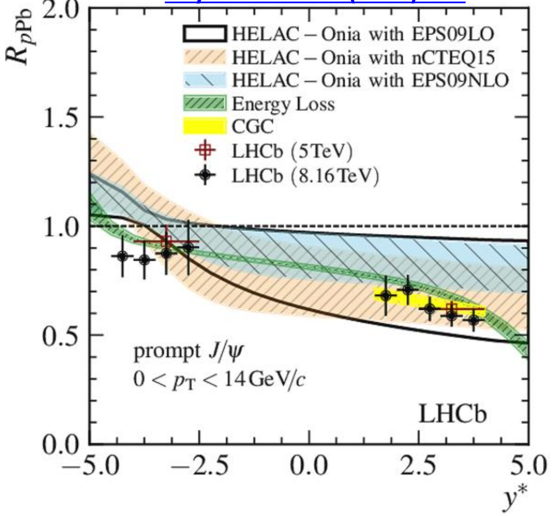
- **Proton-Pb collisions at 5 TeV and 8.16 TeV**

Modification of **D^0 production in *p*Pb** wrt *pp* → Effect on recent **nNNPDF3.0 fit**





Phys. Lett. B774 (2017) 159



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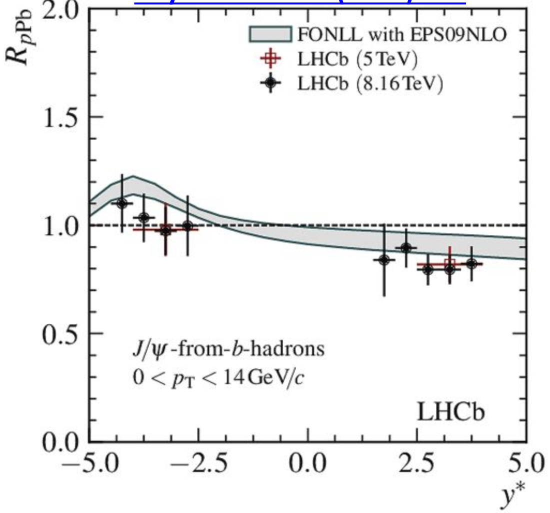


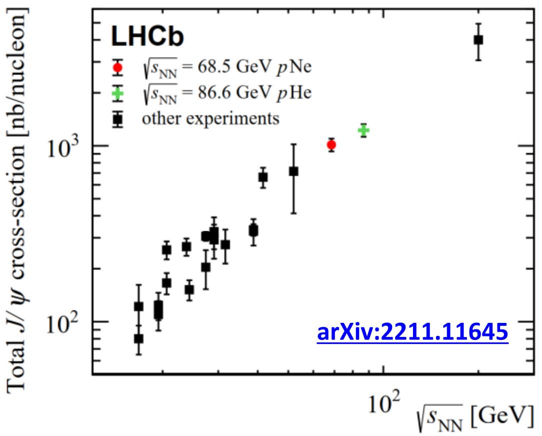
Prompt J/ψ production also modified

Non-Prompt J/ψ production less modified

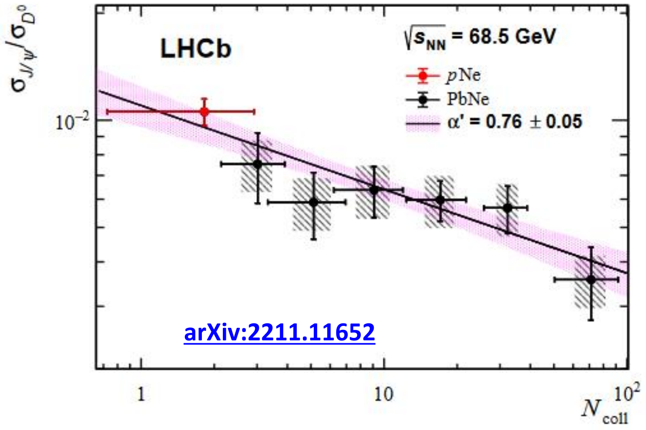
J/ψ in agreement with expectations from nPDF

- **Fixed-target collisions**

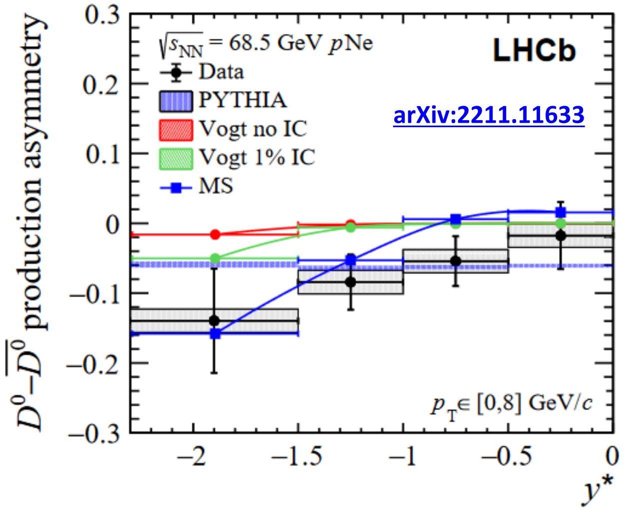
J/ψ production follows power law vs $\sqrt{s_{NN}}$



No evidence of anomalous **J/ψ suppression in PbNe** collisions (expected)



Hint of $D^0 - \overline{D^0}$ **production** asymmetry in Bjorken-x valence region



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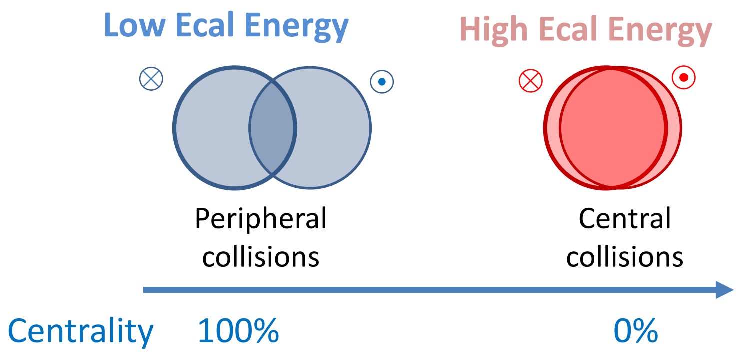
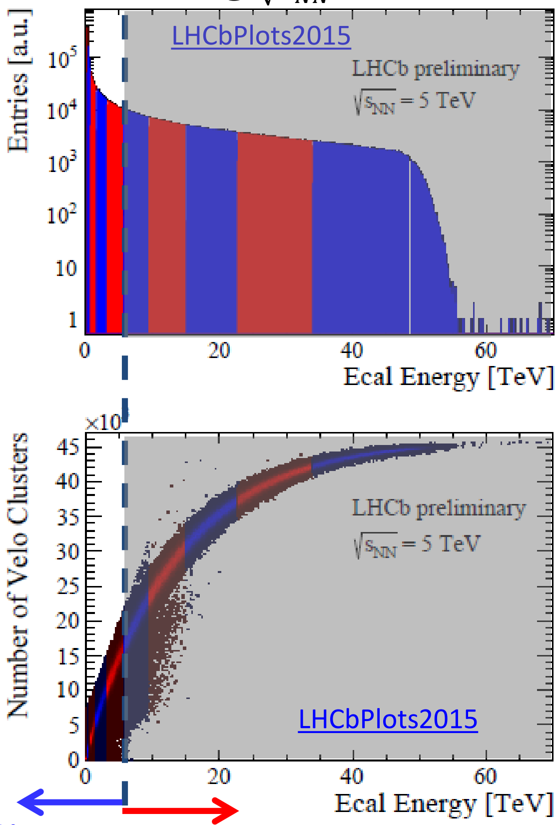


- **Limitation of LHCb detector at LHC Run 1 and Run 2**
  - LHCb centrality reach
    - **Detector limitation due to high occupancy in PbPb collisions**
    - No saturation of the calorimeter
    - But, saturation of the Vertex Locator (VELO)
  - LHCb current limitations
    - Current tracking algorithm efficient up to 50% most central collisions
    - **Physics studies limited to 50% less central PbPb events**
- **Perf. With SMOG (Fixed-target)**
  - No saturation up to PbNe
  - But **saturation expected in PbAr**

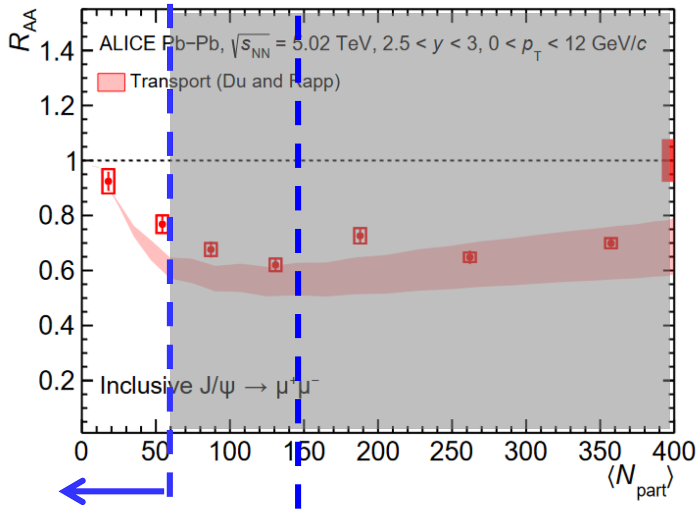
Pb-Pb collisions @ $\sqrt{s_{NN}}$ = 5 TeV – 2015 data



50% less central

50% most central

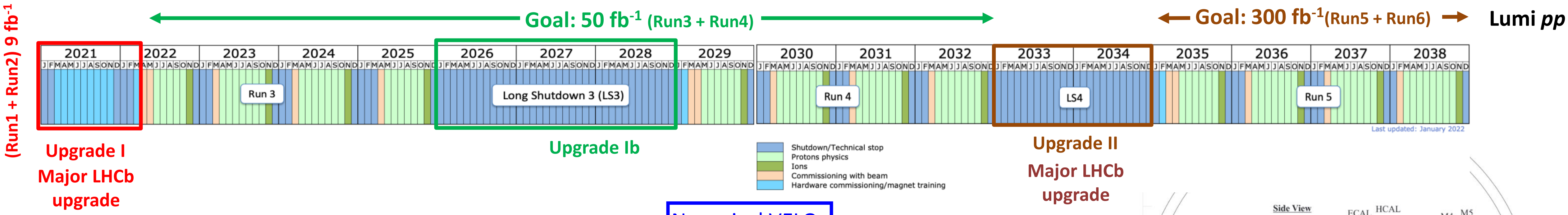
J/ψ production – PbPb – ALICE



Current LHCb limitation 50% less central

70% less central

30% more central

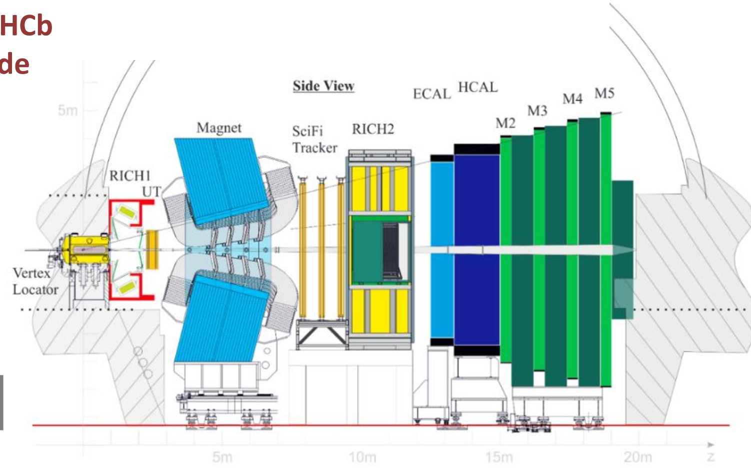


New pixel VELO

New Tracking system :
- Silicon upstream detector (UT)
- Scintillating Fiber Tracker (SciFi)

New RICH optics and photodetectors

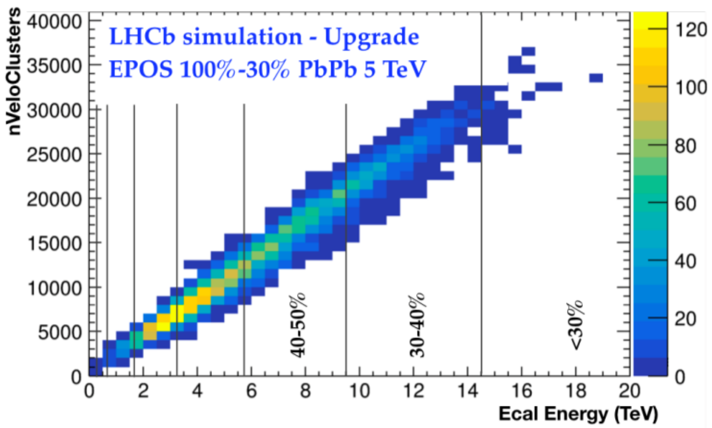
New electronics for muon and calorimeter systems



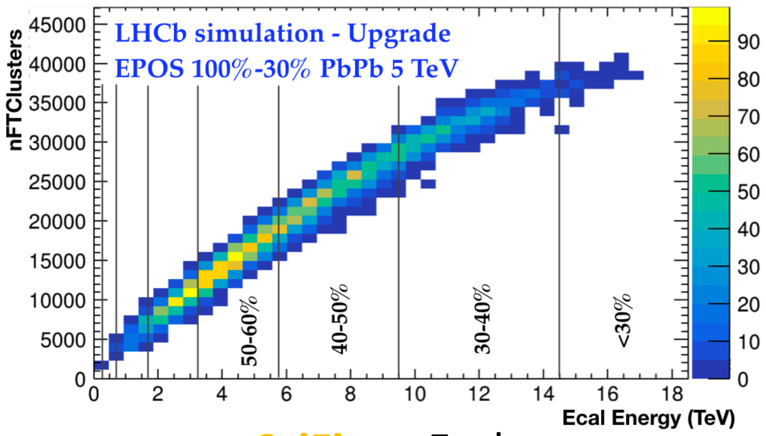
- **LHCb Upgrade I : based on pp collision requirements**
  - Collision rate at 40 MHz.
  - Pile-up factor $\mu \approx 5$ (instead of $\mu \approx 1$ up to LS2)
  - Remove L0 triggers (software trigger)
  - Read out the full detector at 40 MHz.
  - Replace the entire tracking system.

- **Benefit for heavy ion physics**
  - **Collider mode**
    - Up to **30% most central PbPb** collisions
  - **Fixed-target mode: SMOG2**
    - New system to inject gas: up to × 100 lumi
    - Possibility to inject non noble gases (H^2, D^2, O^2)
    - Full centrality range for **PbAr collisions**
  - **Limitation in centrality reach due to SciFi Tracker**

(B. Audurier LHCb-INT-2020-004)



Velo .vs. Ecal



SciFi .vs. Ecal

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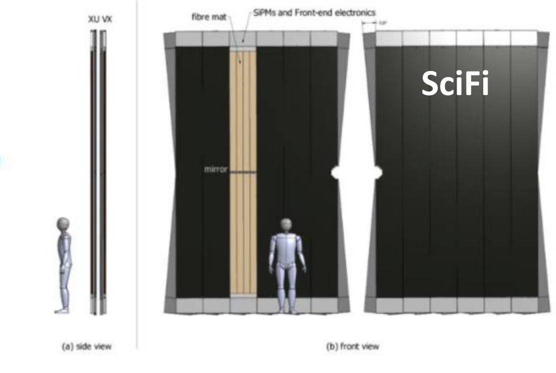
LHCb at Run 3 (2022): Upgrade I

- Inst. *pp* lumi = **2.10^{33} cm^{-2}s^{-1}** ➔ $\langle N_{pp}\rangle$ / BX ~ 5
- PbPb: should run **ok up to ~30-40% centrality**

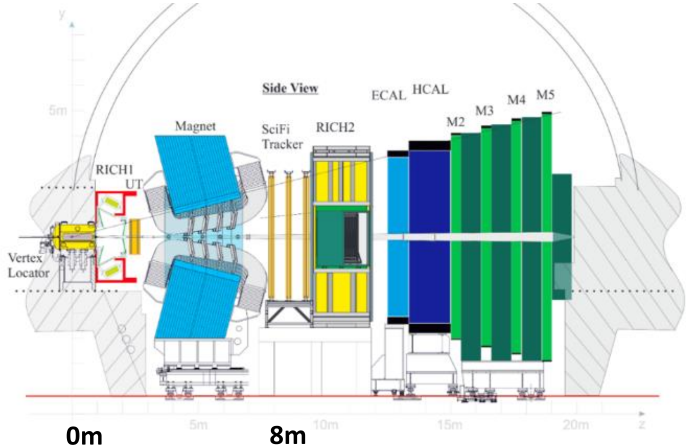
Fixed Target ok up to PbAr (A=40)

Centrality	<dNch/dη> (Δη=1)	<dNch/dη> * 3	Eq. pp@13TeV Coll.	Eq. <pp@13TeV> / 5	Eq. <pp@13TeV> / 40
0-5%	1940	5820	366	73	9
0-10%	1777	5331	335	67	8
10-20%	1180	3540	223	45	6
20-30%	786	2358	148	30	4
30-40%	512	1536	97	19	2

PbPb limit



Layout of one of three stations for the LHCb SciFi Tracker.



0m VELO

8m SciFi

3. Perspectives: Improving LHCb capabilities in PbPb collisions

LHCb at Run 3 (2022): Upgrade I

- Inst. *pp* lumi = **2.10^{33} cm^{-2}s^{-1}** ➔ <N_{pp}> / BX ~ 5
- PbPb: should run **ok up to ~30-40% centrality**

Fixed Target ok up to PbAr (A=40)

PbPb limit: 30-40%

Centrality	<dNch/dη> (Δη=1)	<dNch/dη> * 3	Eq. pp@13TeV Coll.	Eq. <pp@13TeV> / 5	Eq. <pp@13TeV> / 40
0-5%	1940	5820	366	73	9
0-10%	1777	5331	335	67	8
10-20%	1180	3540	223	45	6
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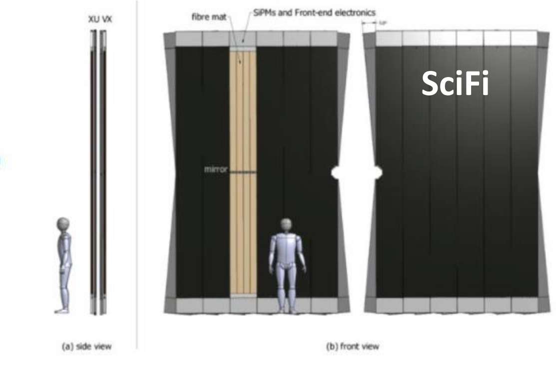
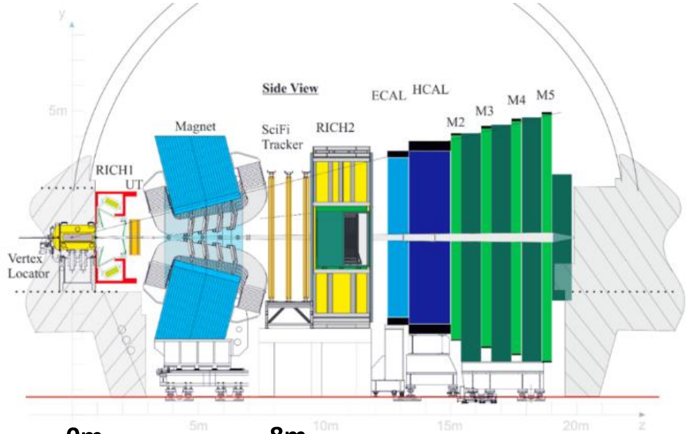
30-40%	512	1536	97	19	2



Layout of one of three stations for the LHCb SciFi Tracker.



0m VELO

8m SciFi **IT**

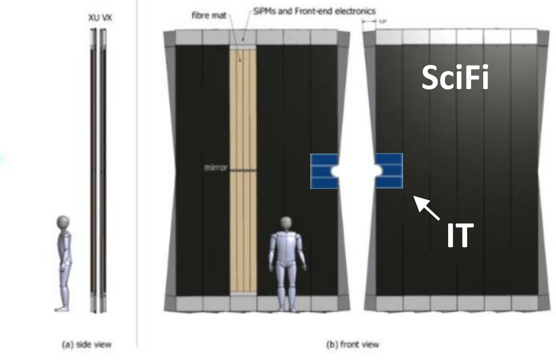
LHCb at Run 4 (2029): Upgrade Ib

- Inst. *pp* lumi = **4.10^{33} cm^{-2}s^{-1}** ➔ <N_{pp}> / BX ~ 10
- PbPb: should run **ok up to ~10-20% centrality** (thanks to **IT**)

Fixed Target ok up to PbKr (A=84)

PbPb limit: 10-20%

Centrality	<dNch/dη> (Δη=1)	<dNch/dη> * 3	Eq. pp@13TeV Coll.	Eq. <pp@13TeV> / 5	Eq. <pp@13TeV> / 40
0-5%	1940	5820	366	73	9
0-10%	1777	5331	335	67	8
10-20%	1180	3540	223	45	6
20-30%	786	2358	148	30	4
30-40%	512	1536	97	19	2



Layout of one of three stations for the LHCb SciFi Tracker.

IT = (silicon pixel) Inner Tracker (replace **small central part** of SciFi)

3. Perspectives: Improving LHCb capabilities in PbPb collisions

LHCb at Run 3 (2022): Upgrade I

- Inst. *pp* lumi = **2.10^{33} cm^{-2}s^{-1}** ➔ <N$_{pp}$> / BX ~ 5
- PbPb: should run **ok up to ~30-40% centrality**

Fixed Target ok up to PbAr (A=40)

PbPb limit (30-40%)

Centrality	<dNch/dη> (Δη=1)	<dNch/dη> * 3	Eq. pp@13TeV Coll.	Eq. <pp@13TeV> / 5	Eq. <pp@13TeV> / 40
0-5%	1940	5820	366	73	9
0-10%	1777	5331	335	67	8
10-20%	1180	3540	223	45	6
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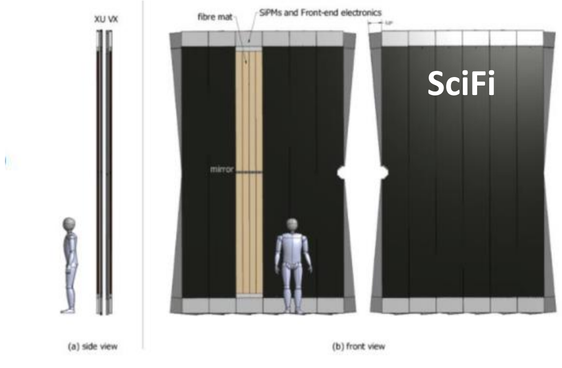
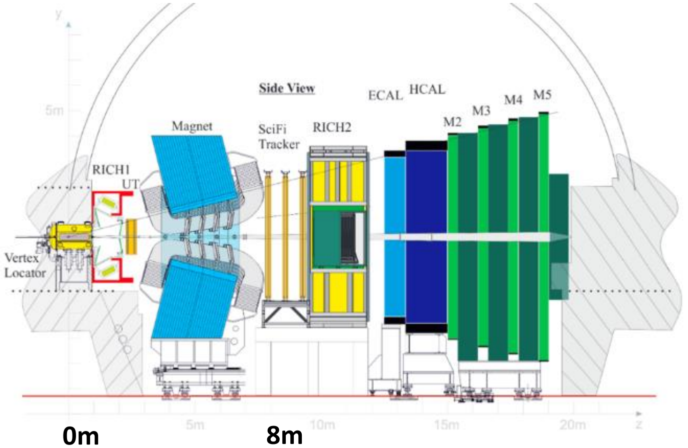
30-40%	512	1536	97	19	2



Layout of one of three stations for the LHCb SciFi Tracker.



0m VELO

8m SciFi **IT** **MT**

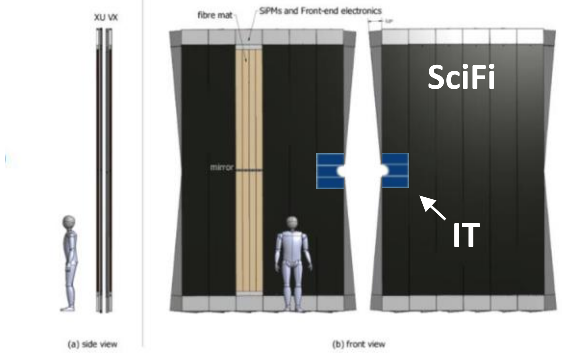
LHCb at Run 4 (2029): Upgrade Ib

- Inst. *pp* lumi = **4.10^{33} cm^{-2}s^{-1}** ➔ <N$_{pp}$> / BX ~ 10
- PbPb: should run **ok up to ~10-20% centrality** (thanks to **IT**)

Fixed Target ok up to PbKr (A=84)

PbPb limit (10-20%)

Centrality	<dNch/dη> (Δη=1)	<dNch/dη> * 3	Eq. pp@13TeV Coll.	Eq. <pp@13TeV> / 5	Eq. <pp@13TeV> / 40
0-5%	1940	5820	366	73	9
0-10%	1777	5331	335	67	8
10-20%	1180	3540	223	45	6
20-30%	786	2358	148	30	4
30-40%	512	1536	97	19	2



Layout of one of three stations for the LHCb SciFi Tracker.

IT = (silicon pixel) Inner Tracker (replace **small central part** of SciFi)

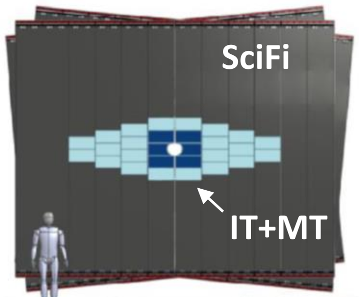
LHCb at Run 5 (2035): Upgrade II

- Inst. *pp* lumi = **$1.5.10^{34}$ cm^{-2}s^{-1}** ➔ <N$_{pp}$> / BX ~ 40
- PbPb: should run **ok up to ~0-5% centrality** (thanks to **IT+MT**)

PbPb limit (0-5%)

Fixed Target ok up to PbXe (A=131)

Centrality	<dNch/dη> (Δη=1)	<dNch/dη> * 3	Eq. pp@13TeV Coll.	Eq. <pp@13TeV> / 5	Eq. <pp@13TeV> / 40
0-5%	1940	5820	366	73	9
0-10%	1777	5331	335	67	8
10-20%	1180	3540	223	45	6
20-30%	786	2358	148	30	4
30-40%	512	1536	97	19	2



MT = (silicon pixel) Middle Tracker (replace **large central part** of SciFi)

With Mighty Tracker (IT+MT) Tracking stations can cope with PbPb high multiplicity and fixed-target up to PbXe

patrick.robbe@ijclab.in2p3.fr & frederic.fleuret@llr.in2p3.fr

3. Perspectives: Improving LHCb capabilities in PbPb collisions

LHCb at Run 3 (2022): Upgrade I

- Inst. *pp* lumi = 2.10^{33} cm^{-2}s^{-1} ➔ $\langle N_{pp} \rangle$ / BX ~ 5
- PbPb: should run **ok up to ~30-40% centrality**

Fixed Target ok up to PbAr (A=40)

PbPb limit

Centrality	<dNch/dη> (Δη=1)	<dNch/dη> * 3	Eq. pp@13TeV Coll.	Eq. <pp@13TeV> / 5	Eq. <pp@13TeV> / 40
0-5%	1940	5820	366	73	9
0-10%	1777	5331	335	67	8
10-20%	1180	3540	223	45	6
20-30%	786	2358	148	30	4
30-40%	512	1536	97	19	2

LHCb at Run 4 (2029): Upgrade Ib

- Inst. *pp* lumi = 4.10^{33} cm^{-2}s^{-1} ➔ $\langle N_{pp} \rangle$ / BX ~ 10
- PbPb: should run **ok up to ~10-20% centrality** (thanks to **IT**)

Fixed Target ok up to PbKr (A=84)

PbPb limit

Centrality	<dNch/dη> (Δη=1)	<dNch/dη> * 3	Eq. pp@13TeV Coll.	Eq. <pp@13TeV> / 5	Eq. <pp@13TeV> / 40
0-5%	1940	5820	366	73	9
0-10%	1777	5331	335	67	8
10-20%	1180	3540	223	45	6
20-30%	786	2358	148	30	4
30-40%	512	1536	97	19	2

LHCb at Run 5 (2035): Upgrade II

- Inst. *pp* lumi = $1.5.10^{34}$ cm^{-2}s^{-1} ➔ $\langle N_{pp} \rangle$ / BX ~ 40
- PbPb: should run **ok up to ~0-5% centrality** (thanks to **IT+MT**)

PbPb limit

Fixed Target ok up to PbXe (A=131)

Centrality	<dNch/dη> (Δη=1)	<dNch/dη> * 3	Eq. pp@13TeV Coll.	Eq. <pp@13TeV> / 5	Eq. <pp@13TeV> / 40
0-5%	1940	5820	366	73	9
0-10%	1777	5331	335	67	8
10-20%	1180	3540	223	45	6
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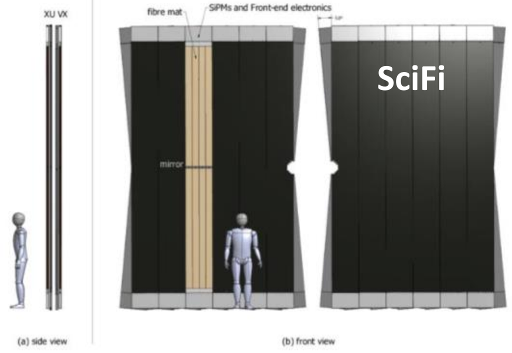
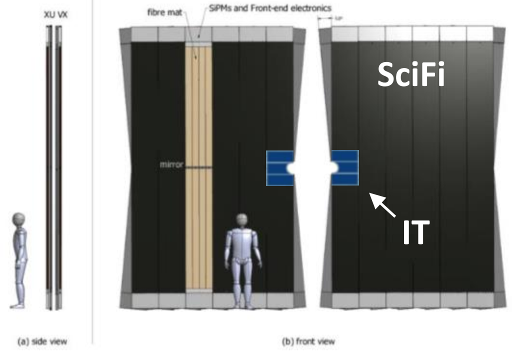
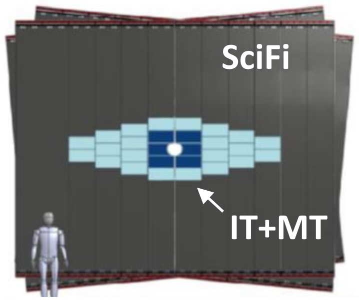
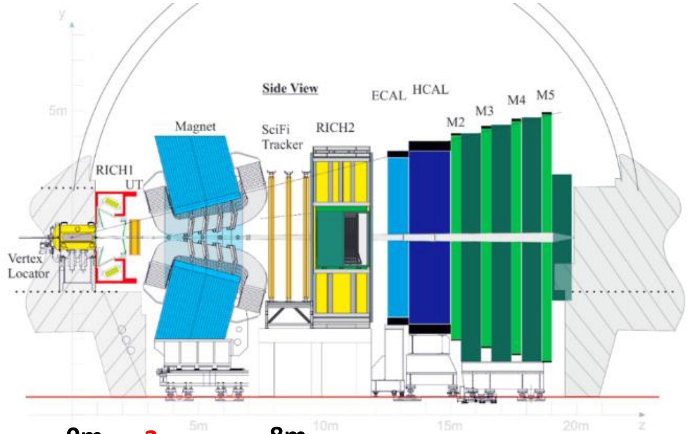


Layout of one of three stations for the LHCb SciFi Tracker.



Layout of one of three stations for the LHCb SciFi Tracker.





0m VELO — 3m UT — 8m SciFi, IT, MT

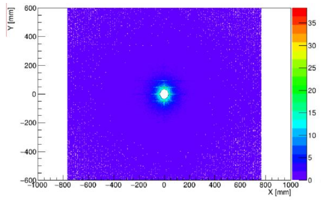
Upstream Tracker (UT)

Located **upstream** of the magnet

Needed for ghost (fake) tracks reduction and tracking efficiency improvement

Current UT must be replaced for LHC Run 5

Very high granularity needed especially for PbPb collisions



Up to 50 hits/cm² in central PbPb

Best (only) candidate: silicon pixel detector

Strong interest to contribute from France & China

With Mighty Tracker (IT+MT) Tracking stations can cope with PbPb high multiplicity and fixed-target up to PbXe

3. Perspectives: Improving LHCb capabilities in PbPb collisions

LHCb at Run 3 (2022): Upgrade I

- Inst. *pp* lumi = **2.10^{33} cm^{-2}s^{-1}** ➔ <N_{pp}> / BX ~ 5
- PbPb: should run **ok up to ~30-40% centrality**

Fixed Target ok up to PbAr (A=40)

PbPb limit (30-40%)

Centrality	<dNch/dη> (Δη=1)	<dNch/dη> * 3	Eq. pp@13TeV Coll.	Eq. <pp@13TeV> / 5	Eq. <pp@13TeV> / 40
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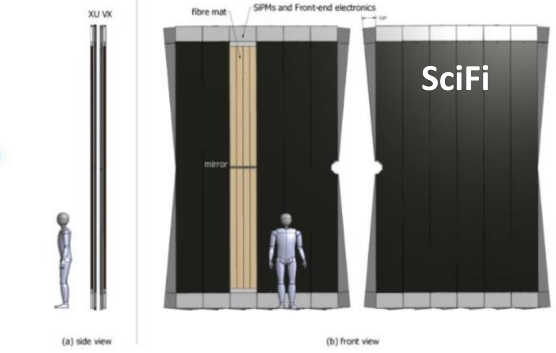

Layout of one of three stations for the LHCb SciFi Tracker.

LHCb at Run 4 (2029): Upgrade Ib

- Inst. *pp* lumi = **4.10^{33} cm^{-2}s^{-1}** ➔ <N_{pp}> / BX ~ 10
- PbPb: should run **ok up to ~10-20% centrality** (thanks to **IT**)

Fixed Target ok up to PbKr (A=84)

PbPb limit (10-20%)

Centrality	<dNch/dη> (Δη=1)	<dNch/dη> * 3	Eq. pp@13TeV Coll.	Eq. <pp@13TeV> / 5	Eq. <pp@13TeV> / 40
0-5%	1940	5820	366	73	9
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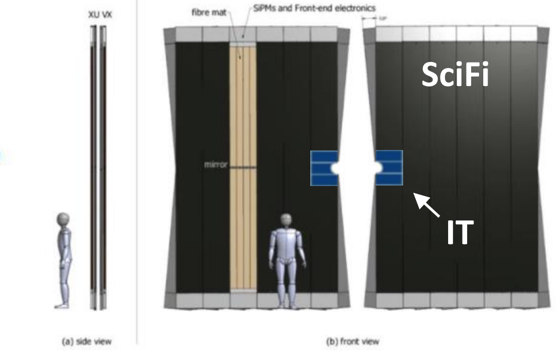

Layout of one of three stations for the LHCb SciFi Tracker.

LHCb at Run 5 (2035): Upgrade II

- Inst. *pp* lumi = **1.5.10^{34} cm^{-2}s^{-1}** ➔ <N_{pp}> / BX ~ 40
- PbPb: should run **ok up to ~0-5% centrality** (thanks to **IT+MT**)

PbPb limit (0-5%)

Fixed Target ok up to PbXe (A=131)

Centrality	<dNch/dη> (Δη=1)	<dNch/dη> * 3	Eq. pp@13TeV Coll.	Eq. <pp@13TeV> / 5	Eq. <pp@13TeV> / 40
0-5%	1940	5820	366	73	9
0-10%	1777	5331	335	67	8
10-20%	1180	3540	223	45	6
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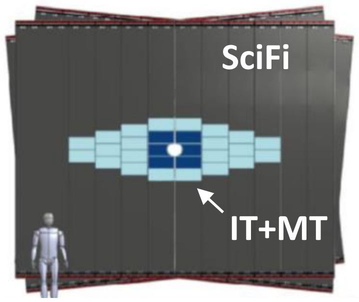
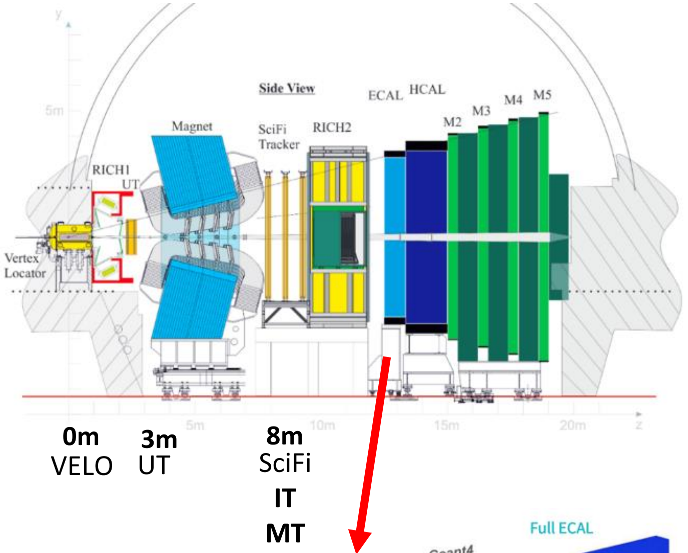
30-40%	512	1536	97	19	2



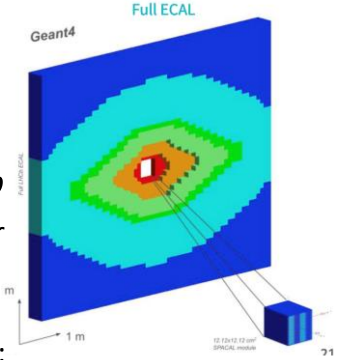
With Mighty Tracker (IT+MT) Tracking stations can cope with PbPb high multiplicity and fixed-target up to PbXe



Electromag. Calo. (Ecal)

Upgrade needed to Improve performances for high pile-up

Reorganize ECAL zones for better handling of occupancy shapes



Five areas of different cell areas:
1.5x1.5 cm^2, 3x3 cm^2, 4x4 cm^2, 6x6 cm^2, 12x12 cm^2

Add longitudinal segmentation at maximum of shower development for electron/hadron separation

Total of **30208 channels compared to 6000 now**

Improved granularity for Heavy Ion program

Strong interest to contribute from France, Spain, CERN, Italy, US, China, Australia, Hungary

patrick.robbe@ijclab.in2p3.fr & frederic.fleuret@llr.in2p3.fr

LHCb Heavy Ions: Conclusion

- **LHC Run 1 (2009 – 2012) and Run 2 (2015 – 2018): *pp*, *p*Pb, PbPb at TeV scale ($\sqrt{s_{NN}}$ x 20 larger than RHIC energies)**
  - **Main physics outcome**
    - QGP : confirmed and refined the picture of a **nearly-perfect fluid (sQGP)** first observed at RHIC/BNL
    - **Stricking new results** : collective-like effects observed also in high-multiplicity *pp* and *p*Pb collisions (smooth transition from small to big systems) → now *major focus of "heavy-ion" physics*
  - **LHCb collider** mode provided many new results in *p*Pb thanks to great performances of the LHCb detector
  - **LHCb Fixed Target** mode demonstrated the feasibility of the program in proton-nucleus and PbNe collisions

- **LHC RUN 3 (2022 – 2025) and Run 4 (2026 – 2029): high luminosity *pp*, *p*Pb, PbPb, and (maybe) *p*O and/or OO**
  - High luminosity (goal: 10 x more lumi than Run 1 and Run 2 in *p*Pb and PbPb): **towards accurate quantitative description**
  - **LHCb collider** mode **can reach more central PbPb collisions** (up to 30% most central)
  - **LHCb Fixed Target** mode (SMOG2) : **High-lumi measurements** in *p*A, up to PbAr (and maybe PbKr after Upgrade Ib)

- **LHC RUN 5+ (2035 – 2038)+…: lighter systems (O, Ar, Xe,…) and PbPb**
  - Characterize **collective like-effects** and physics continuum from *pp* to PbPb
  - **LHCb collider** mode **can reach full central PbPb**; very well placed to explore collective-like effects from small to large systems
  - **LHCb Fixed Target** mode : **no limitation in PbA** and very large versatility in colliding systems
  - **Contribution to LHCb upgrade II** envisioned: **Upstream Tracker II**, **Electromagnetic Calorimeter**, key detectors for heavy ion physics

- **IN2P3 teams (IJClab, LLR) involved in LHCb heavy-ion since the beginning**
  - Now joined by CEA/Saclay (technical associate)
  - Other (currently ALICE) IN2P3 teams interested in joining (LPC, Subatech)