LHCb – 2 upgrades & LLR

Contributions possibles du LLR à l'**upgrade II** de **LHCb**

(towards LHC Run 5 + Run 6)

LHCb Upgrade II **F**ramework **T**echnical **D**esign **R**eport : février **2022**

R&D phase

Technical **D**esign **R**eport : ~2025 – 2026

construction

Installation (LS4): ~2033 – **2034**

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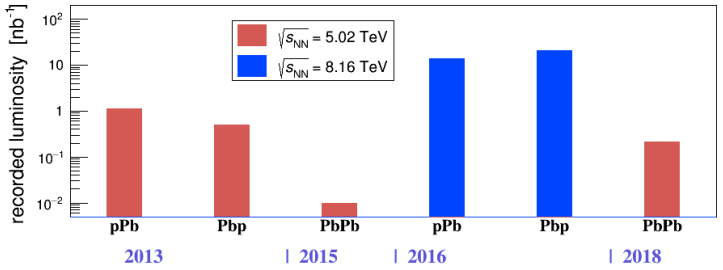
LHCb – status run 1 & run 2

- **LHCb = single arm forward spectrometer,**
  the only experiment fully instrumented in $2 < \eta < 5$
  Designed for heavy flavour physics

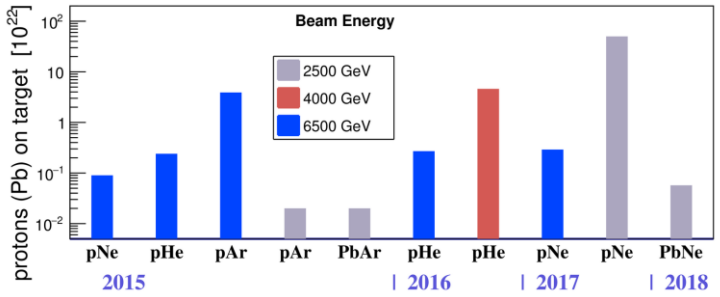
Lumi *pp*

9 fb^{-1}								
Run 1			LS1		Run 2			
2010	2011	2012	2013	2014	2015	2016	2017	2018

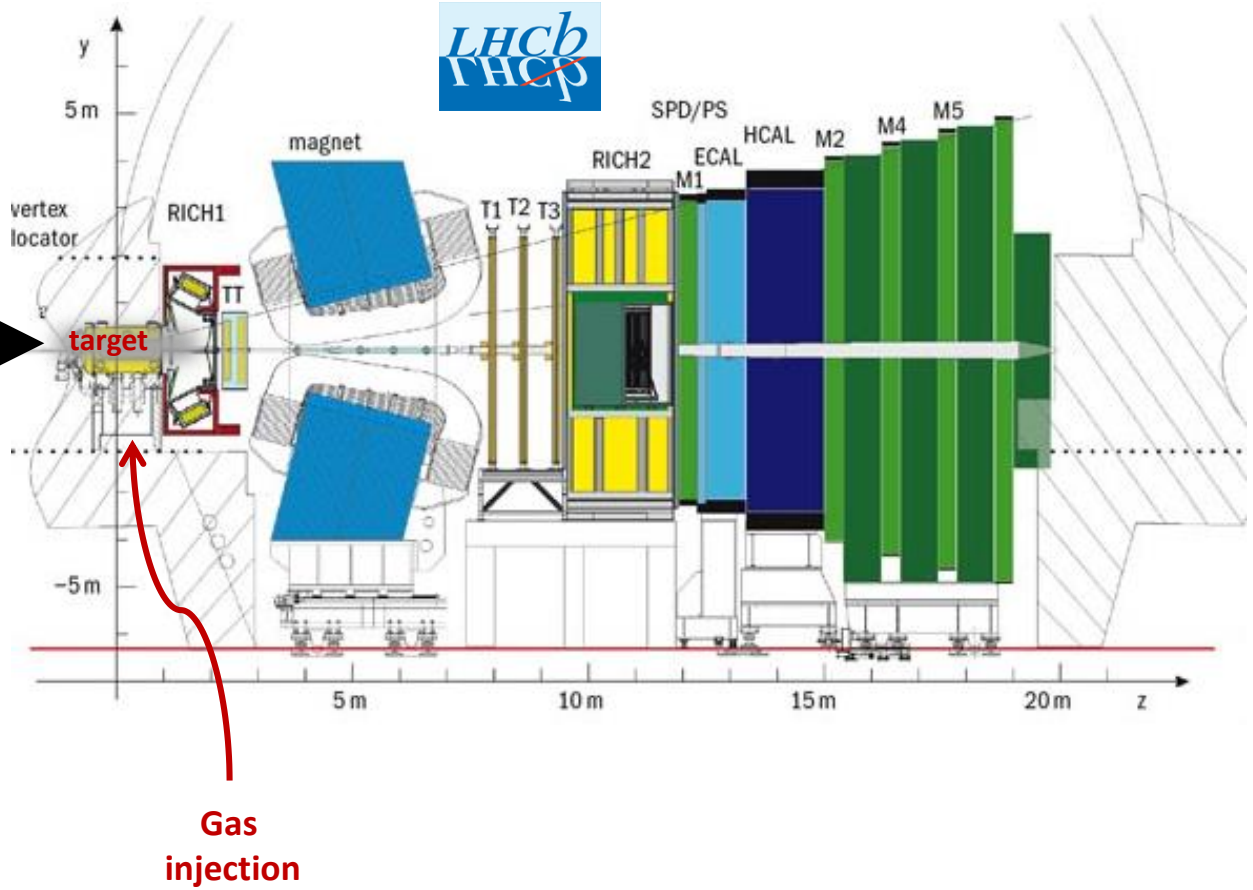
- **LHCb can operate p-Pb and Pb-Pb collisions**



- **LHCb can operate in Fixed-Target mode (unique at LHC)**
  - Allows measurement of p-gas and ion-gas interactions
  - Noble gas only : He(4), Ne(20), Ar(40), Kr(84), Xe(131)



beam



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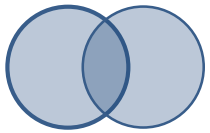
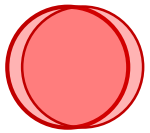
Current tracking limitation in Heavy Ion collisions

Low Ecal Energy



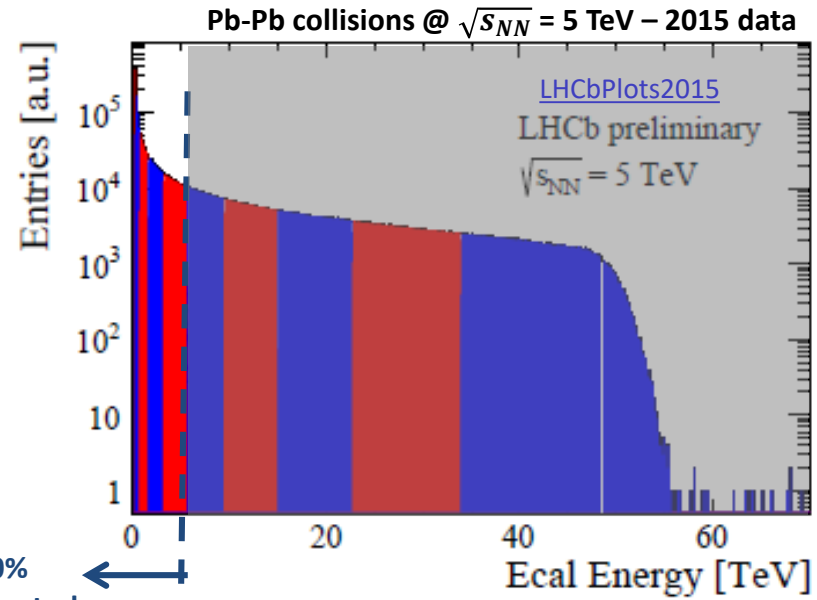
peripheral

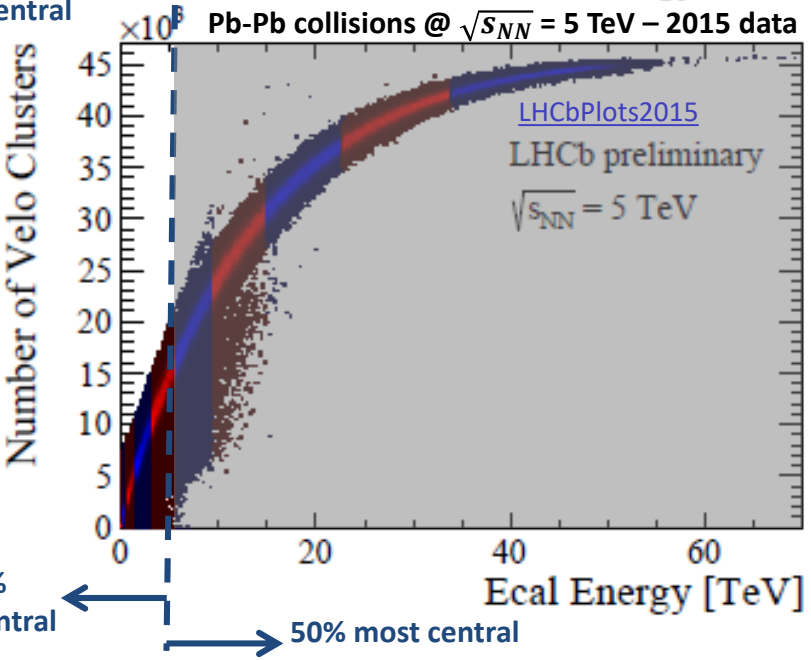
High Ecal Energy

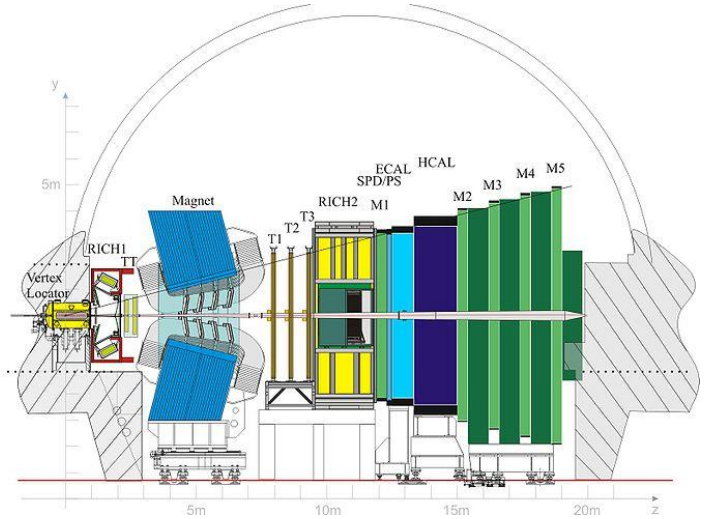


central

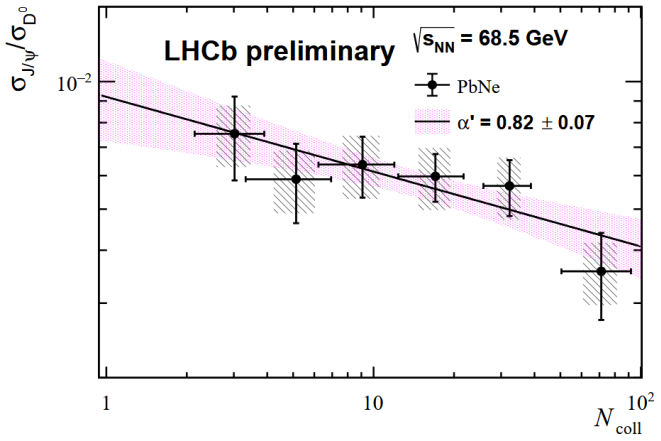
- **LHCb centrality reach**
  - Detector limitation due to high occupancy in Pb-Pb collisions
  - No saturation of the calorimeter
  - But, saturation of the Vertex Locator (VELO)
- **LHCb current limitations**
  - Current tracking algorithm efficient up to 50% most central
  - **Physics studies limited to 50% less central events**







- **Perf. with SMOG (Fixed-Target)**
  - No saturation up to PbNe
  - But **saturation expected in PbAr**



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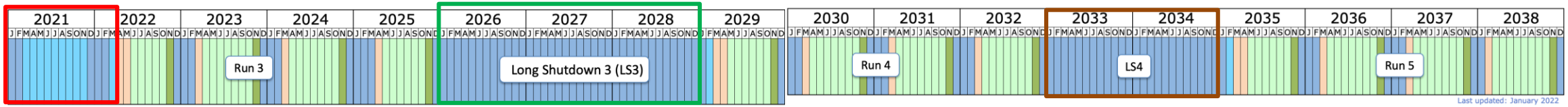
LHCb upgrade – phase I

(Run1 + Run2) 9 fb^{-1}

Goal: 50 fb^{-1} (Run3 + Run4)

Goal: 300 fb^{-1}(Run5 + Run6)

Lumi *pp*



Upgrade I
Major LHCb upgrade

Upgrade Ib

Upgrade II
Major LHCb upgrade

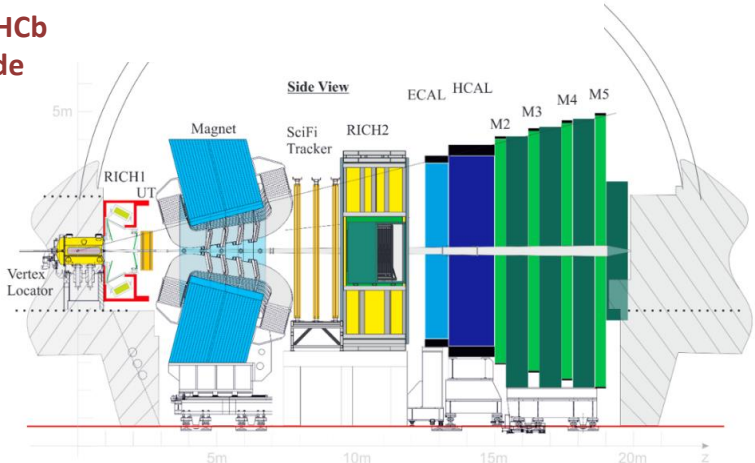
Shutdown/Technical stop
Protons physics
Ions
Commissioning with beam
Hardware commissioning/magnet training

New pixel VELO

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

New RICH optics and photodetectors

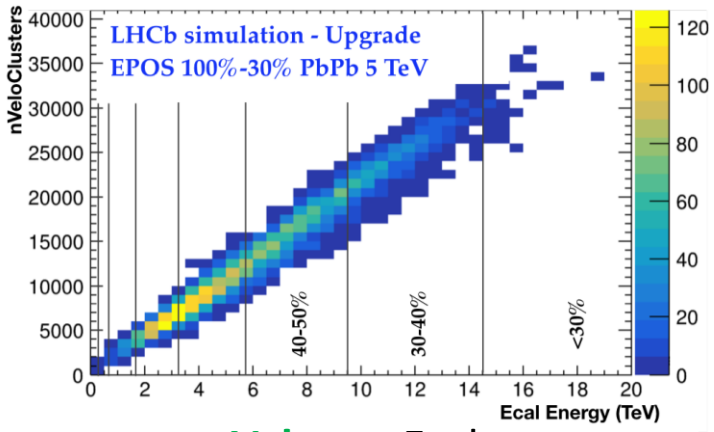
New electronics for muon and calorimeter systems



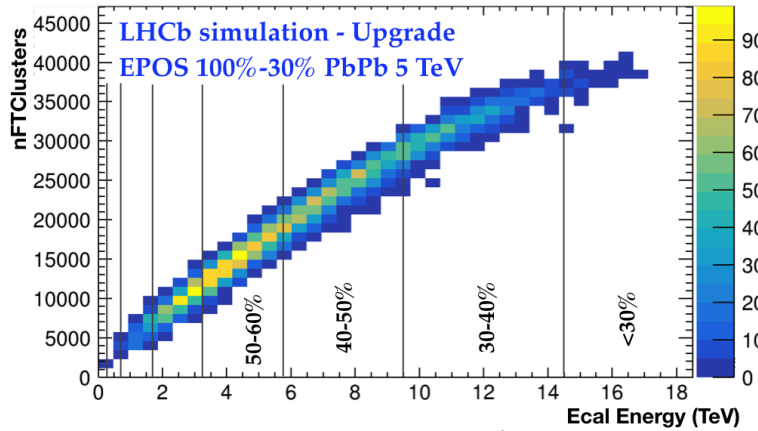
- **LHCb Upgrade I : based on pp collision requirements**
  - Collision rate at 40 MHz.
  - Pile-up factor μ ≈ 5 (instead of μ ≈ 1 up to LS2)
  - Remove L0 triggers (software trigger)
  - Read out the full detector at 40 MHz.
  - Replace the entire tracking system.

- **Benefit for heavy ion physics**
  - **Collider mode**
    - Up to **30% most central PbPb** collisions
  - **Fixed-target mode**
    - New system to inject gas (SMOG2) : × 100 lumi
    - 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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Improving LHCb capabilities in PbPb collisions

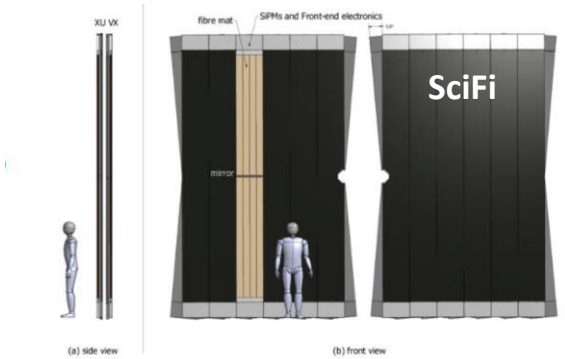
LHCb at Run 3:

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

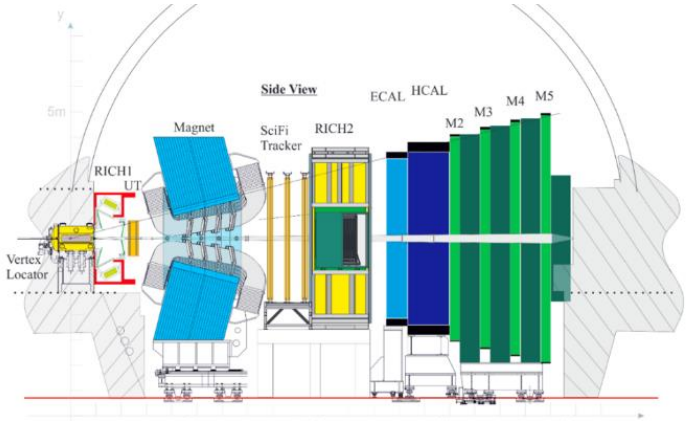
Fixed Target ok up to PbAr (A=40)

PbPb limit

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.



0m VELO

8m SciFi

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20-30%	786	2358	148	30	4
30-40%	512	1536	97	19	2

PbPb limit

LHCb at Run 4:

- 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)

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
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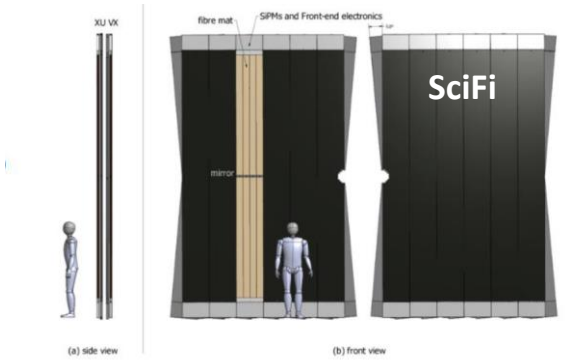
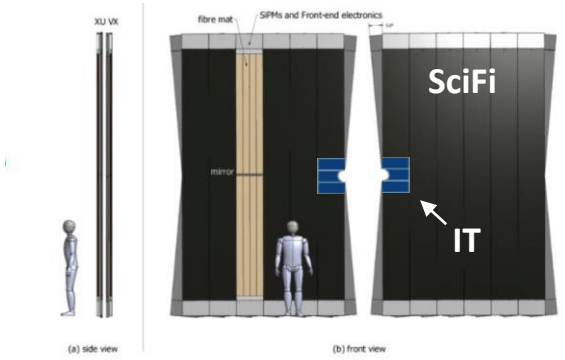
PbPb limit



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



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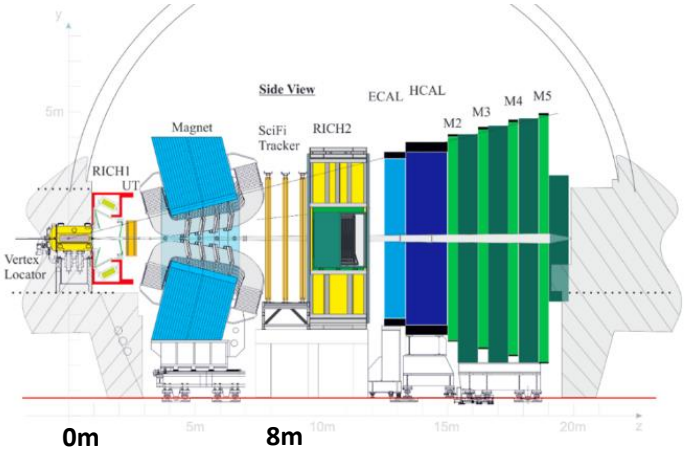

0m VELO

8m SciFi

IT

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

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Improving LHCb capabilities in PbPb collisions

LHCb at Run 3:

- 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)

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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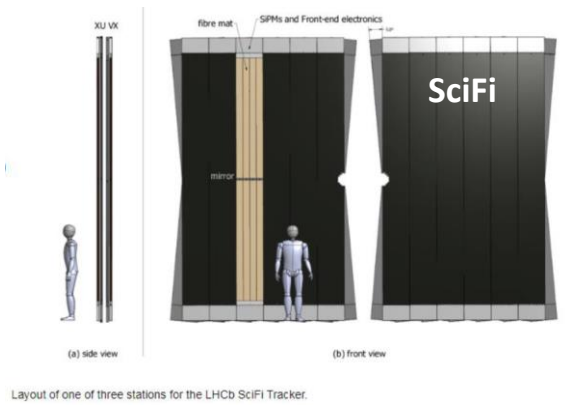
PbPb limit



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

0m VELO

8m SciFi

IT

MT

LHCb at Run 4:

- 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)

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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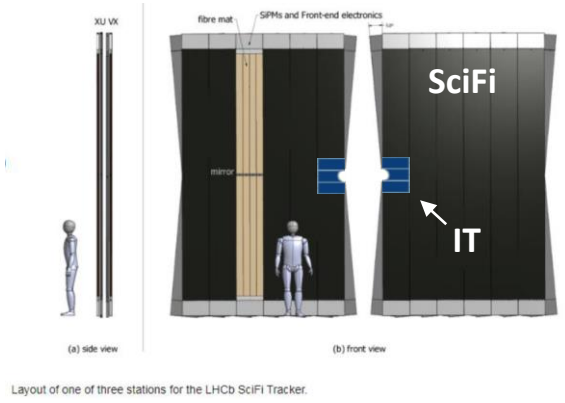
PbPb limit



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

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

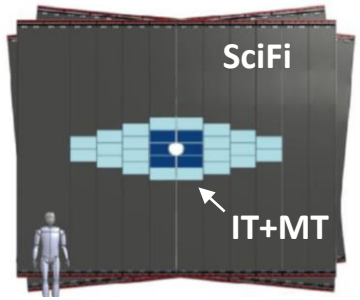
LHCb at Run 5:

- 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

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

Fixed Target ok up to PbXe (A=131)



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

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

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Improving LHCb capabilities in PbPb collisions

LHCb at Run 3:

- 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)

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
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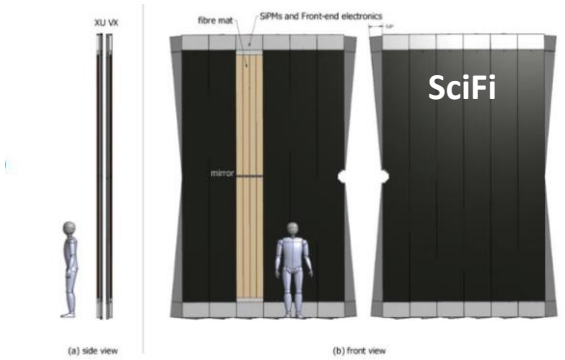
30-40%	512	1536	97	19	2

PbPb limit



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

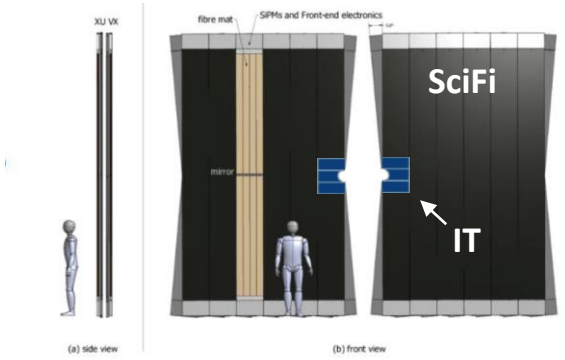
LHCb at Run 4:

- 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)

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.

LHCb at Run 5:

- 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

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
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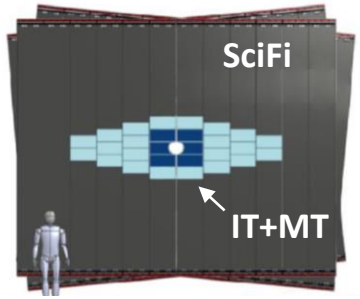
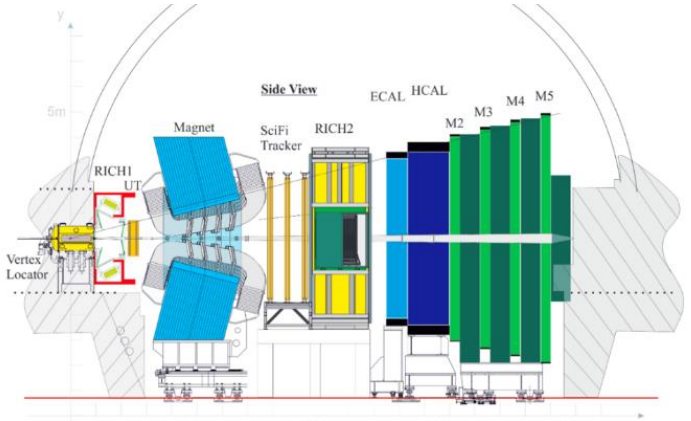
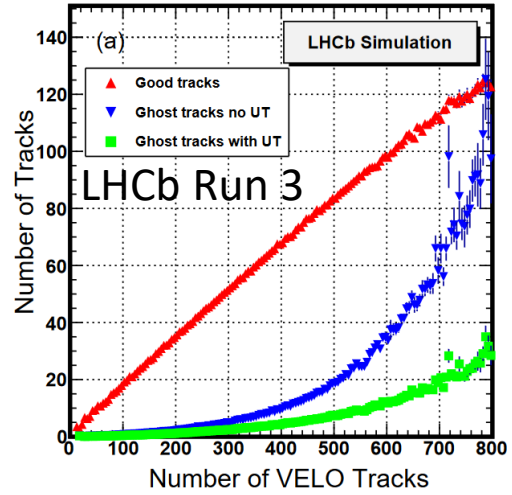




Upstream Tracker (UT)

Located upstream of the magnet



UT needed to deal with ghost (fake) tracks

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

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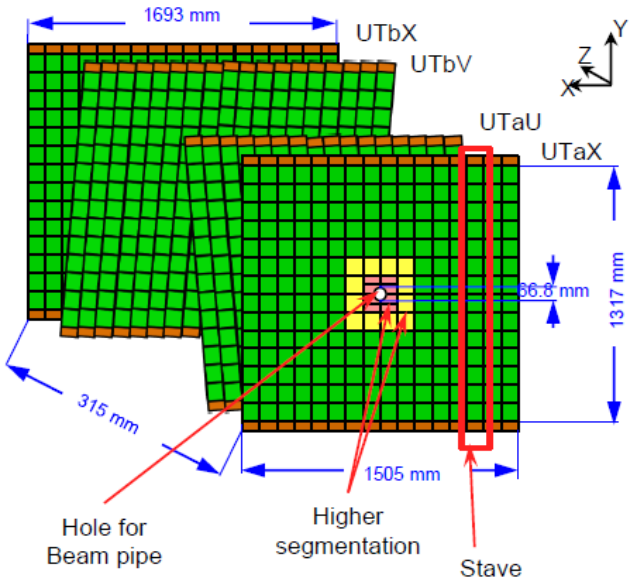
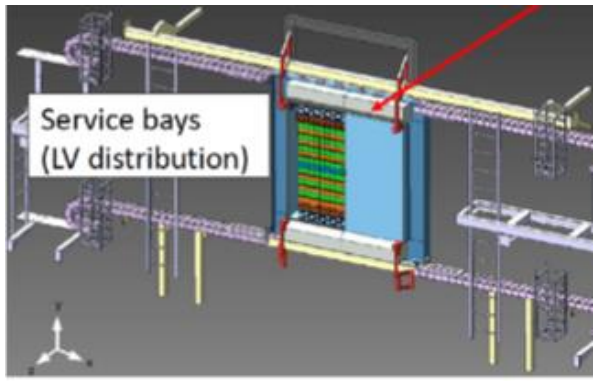
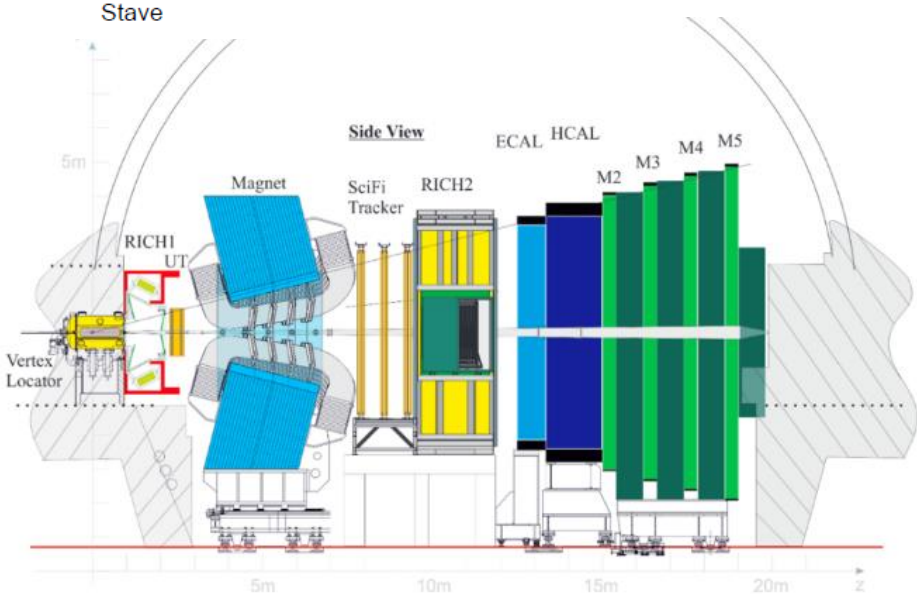
Current UT detector must be replaced

- **Current UT**
  - Silicon strips, oriented vertically
  - from 100µm×50mm to 187.5µm×100mm

Sensor	A	B	C	D
Pitch (µm)	187.5	93.5	93.5	93.5
Length (mm)	~100	~100	~50	~50
Strips/sensor	512	1024	1024	1024
Numbers	888	48	16	16







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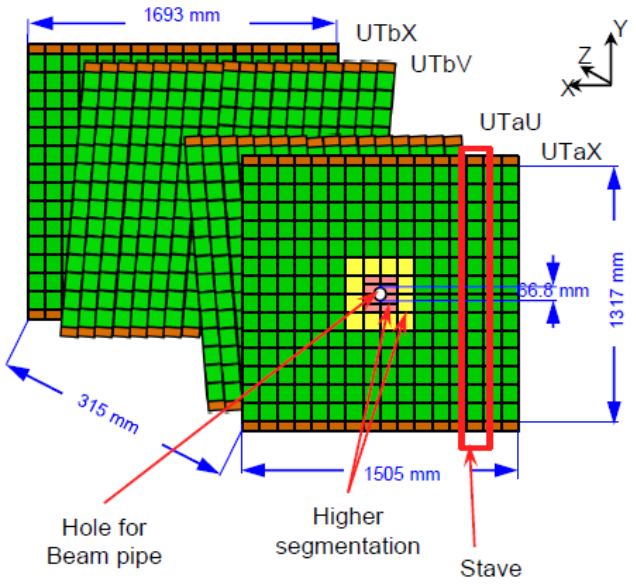
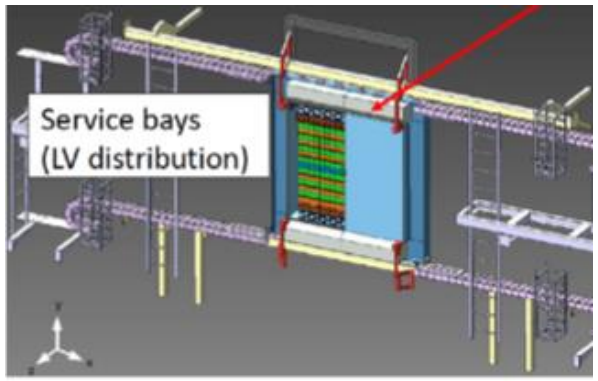
Current UT detector must be replaced for phase II

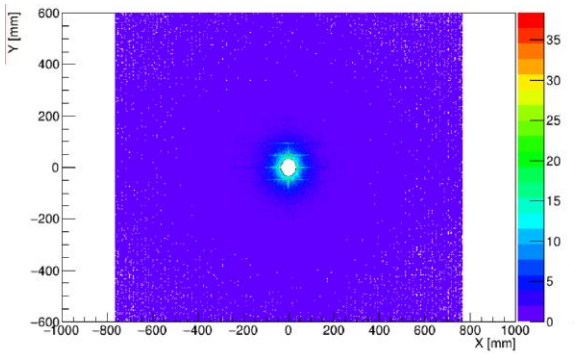
- **Current UT**
  - Silicon strips, oriented vertically
  - from 100µm×50mm to 187.5µm×100mm

Sensor	A	B	C	D
Pitch (µm)	187.5	93.5	93.5	93.5
Length (mm)	~100	~100	~50	~50
Strips/sensor	512	1024	1024	1024
Numbers	888	48	16	16

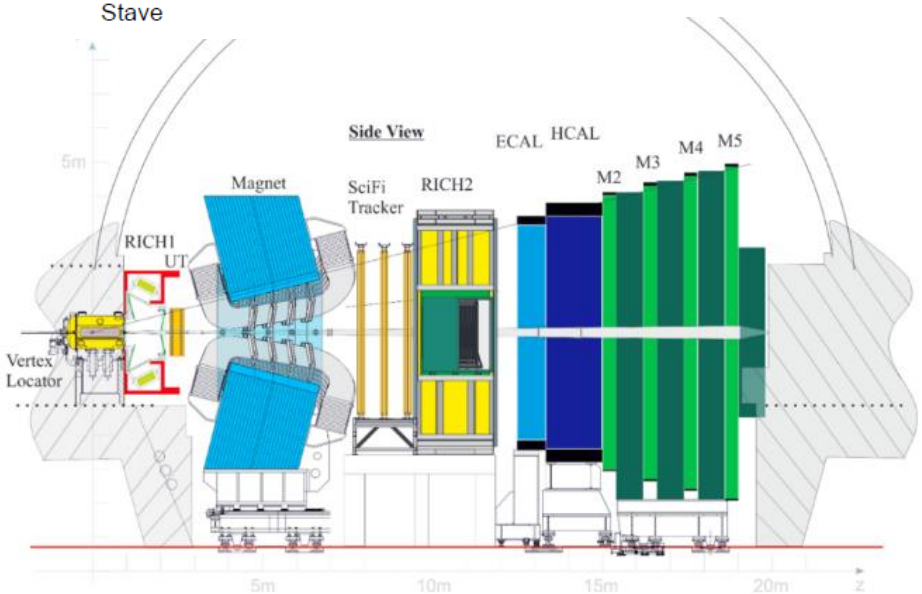




- **UT upgrade needed for LHC Run 5+:**
  - **High data rate** in *pp* high luminosity
  - **High hit density** in central PbPb collisions
    - ***Up to ~50 hits/cm² in central PbPb***



Occupancy [hit/cm² event] for PbPb in UT 1st plane



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Possible french contribution to UT upgrade II

- **Several groups in France are interested in contributing to UT2**
  - ***LHCb members***
    - **LLR** – Palaiseau
    - **LPNHE** - Paris
  - ***Currently in ALICE***, willing to join LHCb for Run 5
    - **Irfu** - Saclay
    - **Subatech** - Nantes
  - Irfu/Subatech = leaders of ALICE Muon Forward Tracker
    - CMOS MAPS detector installed early 2021 based on ALPIDE towerJazz techno

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Possible French contribution to UT upgrade II

- **Several groups in France are interested in contributing to UT2**
  - ***LHCb members***
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- **6 groups in China are also interested in contributing to UT2**
  - Institute of Particle Physics (CCNU) *Wuhan*
  - Physics and micro electronic college (HNU) *associated to Wuhan*
  - Institute of High Energy Physics (IHEP) *Beijing*
  - University of Chinese Academy of Science (UCAS), *Beijing*
  - Laboratory of Nuclear Science (SCNU), Guangzhou, *associated to Tsinghua*
  - School of Physics and technology (WHU), Wuhan, *associated to Tsinghua*

- Other groups (China, US) may join …

Possible french contribution to UT upgrade II

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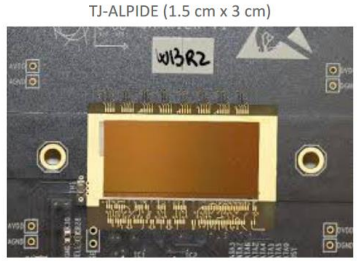
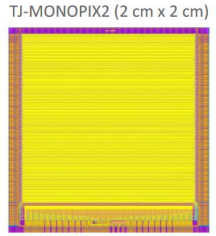
- Other groups (China, US) may join …

- **Technology currently envisioned to cope with *high data rate + high hit density***
  - *CMOS pixels*
  - *Specifications to be finalized*

LV-CMOS Example: TowerJazz chip (ALPIDE, MONOPIX)

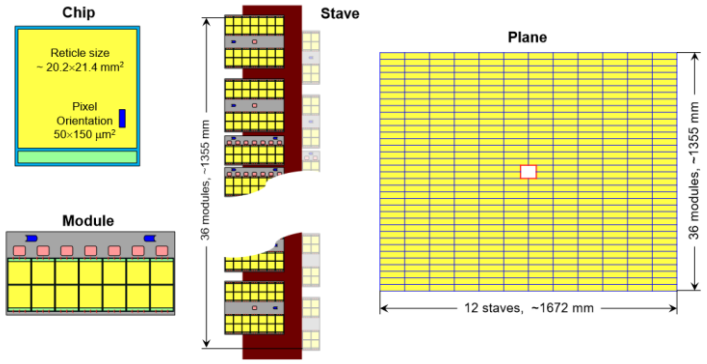
Process	TJ 180 nm CMOS
Pixel size	33 µm x 33 µm
Time precision	25 ns
TID	100 MRad
Power	~150 mW/cm²
Hit rate	100 – 200 Mhit/s/cm²
Involved labs	Bonn Univ., CERN, CPPM, Irfu





- **First tentative design**

LHCB-TDR-023



First cost estimate (4 planes, 9.4 m²)

LHCB-TDR-023

Components	Cost [kCHF]
Silicon sensor	1,250
Module and stave	2,490
DAQ boards and special components	1,520
HV and LV power supplies	570
Cooling, mechanics, UT box	1,540
Electronics: PCB, cable, etc	1,480
Total	8,850

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Upstream Tracker – Upgrade II – CMOS option

- **French team interests for the R&D phase (~4 years), towards TDR**

List of participants (LHCB-TDR-023)

LPNHE – Paris: (full member)

C. Agapopoulou, E. Ben-Haim, P. Billoir, M. Charles, L. Del Buono, S. Esen, M. Fontana, V.V. Gligorov, T. Grammatico, F. Polci, A. Scarabotto, D.Y. Tou, P. Vincent, S.G. Weber
[13] *LPNHE, Sorbonne Université, Paris Diderot Sorbonne Paris Cité, CNRS/IN2P3, Paris, France*

LLR – Palaiseau: (full member)

B. Audurier, V. Balagura, F. Fleuret, F.A. Garcia Rosales, E. Maurice
[12] *Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau, France*

Irfu – Saclay: (technical associate)

A. Baldisseri, H. Borel, J. Castillo, Y. Degerli, A. Ferrero, F. Guilloux, S. Panebianco, A Rakotozafindrabe, C. Riccio, C. Vuillemin, M. Winn
[88] *Université Paris-Saclay, Centre d'Etudes de Saclay (CEA), IRFU, Saclay, France, associated to* [12]

Subatech – Nantes: (not a member)

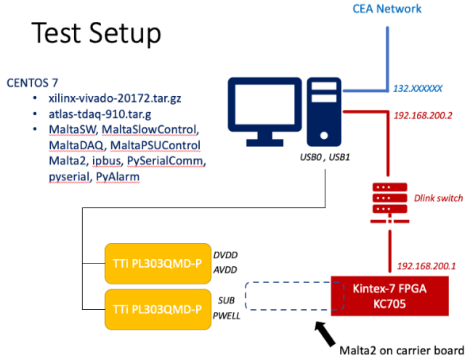
- G. Batigne,
- M. Germain,
- M. Guilbaud

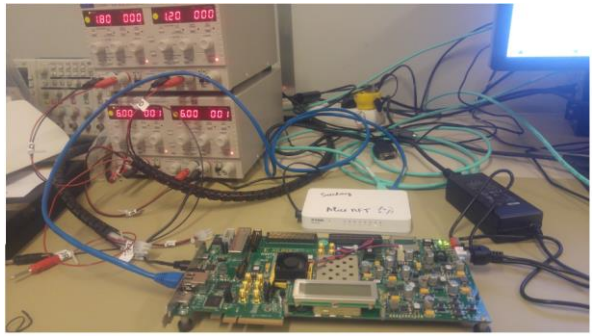
Work package	tasks	French teams Interests (estimated FTE)
WP0 – coordination		
WP1 – simulations and performances pp and PbPb	• Physics performances • Occupancy, Tracking and reconstruction • Geometry and material budget	**LLR** LPNHE Irfu Subatech (~2 – 2.5 FTE/y)
WP2 – chip design and characterization	• Pixel design and optimization • Chip design and simulation • Demonstrator and prototype production • **Test bench design and building** • **Characterization of prototypes**	**LLR** Irfu (~1.5 – 2 FTE/y)
WP3 – module stave and mechanical structure	• Flex (FPC) design and pototype production • Structure design and prototype production • Cooling studies	~~LLR~~ Irfu Subatech (~1.5 – 2 FTE/y)
WP4 – overal mechanics, integration and services	• Global mechanics design • Integration in LHCb • Power, cooling and readout services design	Subatech (~0.5 – 1 FTE/y)
WP5 – readout	• Data throughput studies • Architecture design • Data links optimization • Frontend/backend card design and prototypes • Integration into LHCb DAQ	LPNHE Subatech (~1 – 1.5 FTE/y)

LHCb Upstream Tracker – Upgrade II

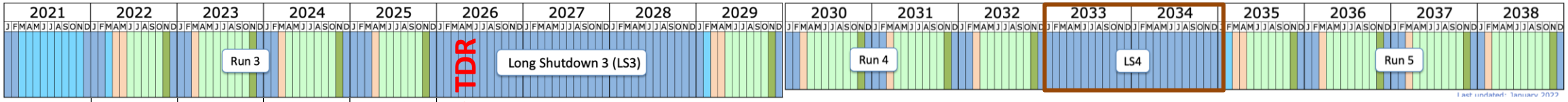
- **Contributions LLR envisagées:**
  - **Électronique**: banc test de caractérisation des matrices de pixel (chips) en collaboration avec nos collègues de l'Irfu :

    1 banc à l'Irfu (actuellement en cours de mise en place) + 1 banc au LLR
    - Tests fonctionnels → Irfu
    - Caractérisation → LLR





- Calendrier prévisionnel **phase de R&D (contrib. LLR)**



ETP (électron. + phys.) **0.1 +0.1** **0.4 +0.2** **0.5 +0.5** **0.5 +0.5**

R&D → **Construction** → **Installation** →

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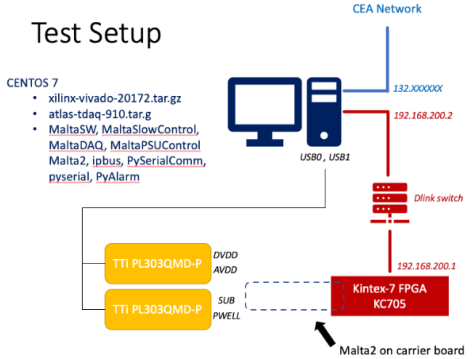

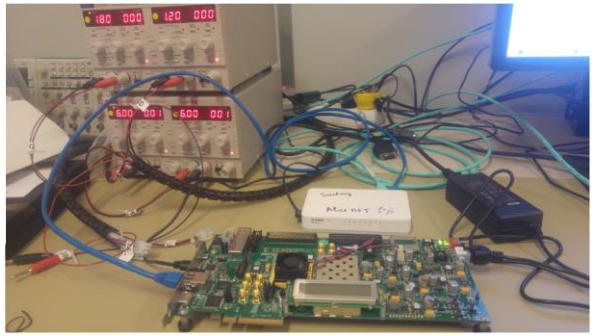

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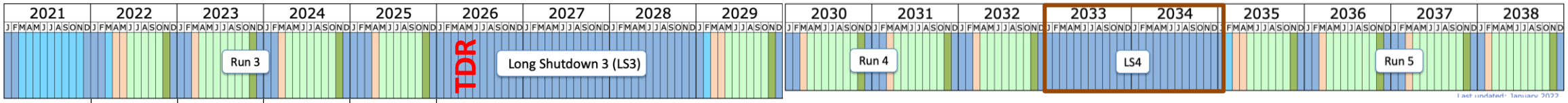

- **EAOM 2022 (demandes groupe LHCb)**
  - Financement de **thèse** :

    Les premières activités sur l'***Upstream Tracker – Upgrade II (UT2)*** et les prises de données ***SMOG2*** commencent en 2022. La période est optimale pour accueillir un doctorant qui participerait à la fois au design et à la caractérisation du futur UT2 ainsi qu'à l'analyse des premières données SMOG2.
  - **CDD IT** électronique :

    Les activités de R&D sur les CMOS pour l'*Upstream Tracker – Upgrade II (UT2)* ont commencé et une forte montée en charge est prévue en 2023. Le recrutement d'un CDD électronique (typiquement IE) pour la caractérisation sur ***banc test des CMOS de l'UT2***, en complément de l'implication des physiciens (perm./postdoc/thèse), offrirait au laboratoire un rôle central dans ces développements. Le CDD, possèdera des compétences dans la conception de systèmes électroniques embarqués (cible FPGA) et aura en charge la mise en oeuvre du cahier des charges définis avec les physiciens en vue d'instrumenter une chaîne de mesure d'un asic de front-end.
  - **CRCN** :

    Depuis 2015, le groupe du **LLR** a acquis une visibilité importante au sein de la collaboration LHCb (luminosité, mise en œuvre du programme SMOG, prospectives Run3+, upgrade Run5). Afin de consolider notre participation aux futures activités du groupe : ***luminosité***, ***SMOG2***, ***Upgrade II*****,** un renforcement RH est nécessaire.

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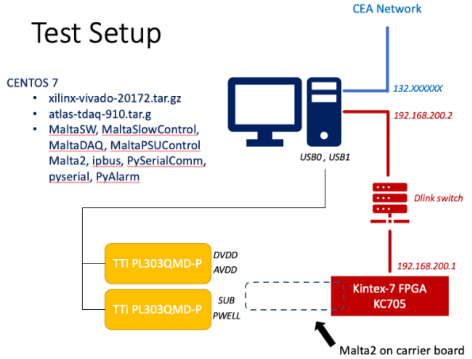

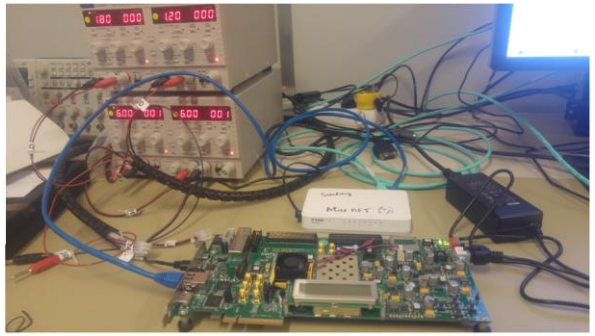

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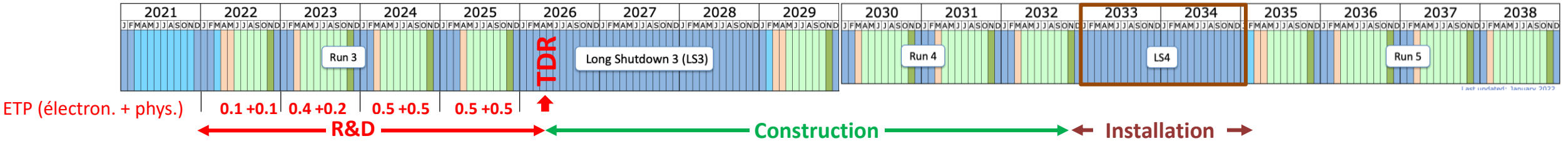

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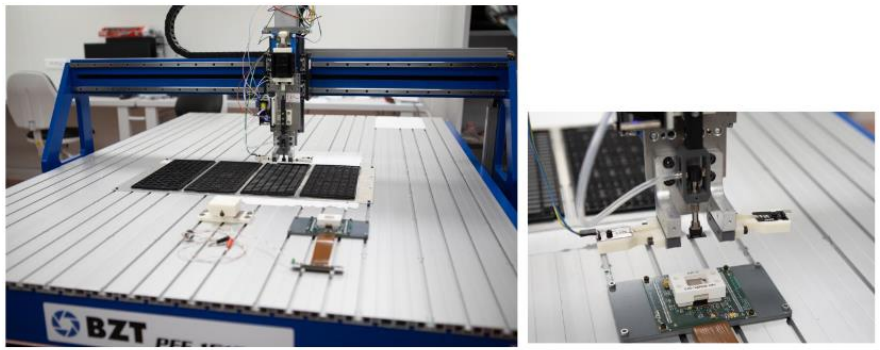
- **Possible contribution à la phase de construction (2026+)**
  - Test de validation des chips issus de la production de masse



Mass production test bench for CMS HGCroc ***ASIC (120k chips)***

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