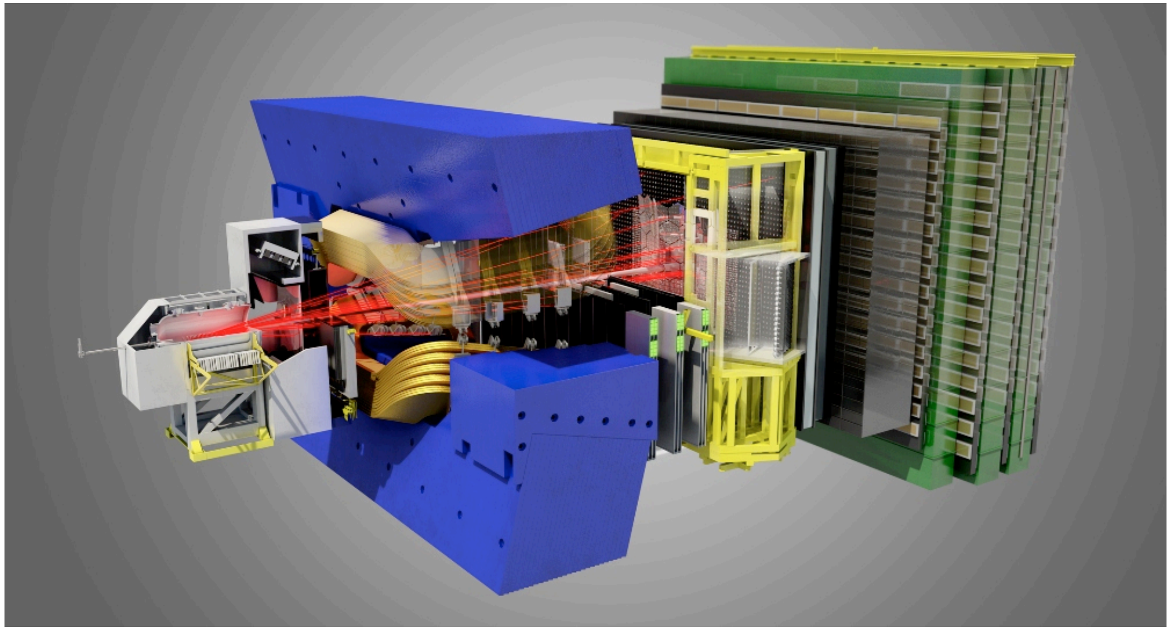
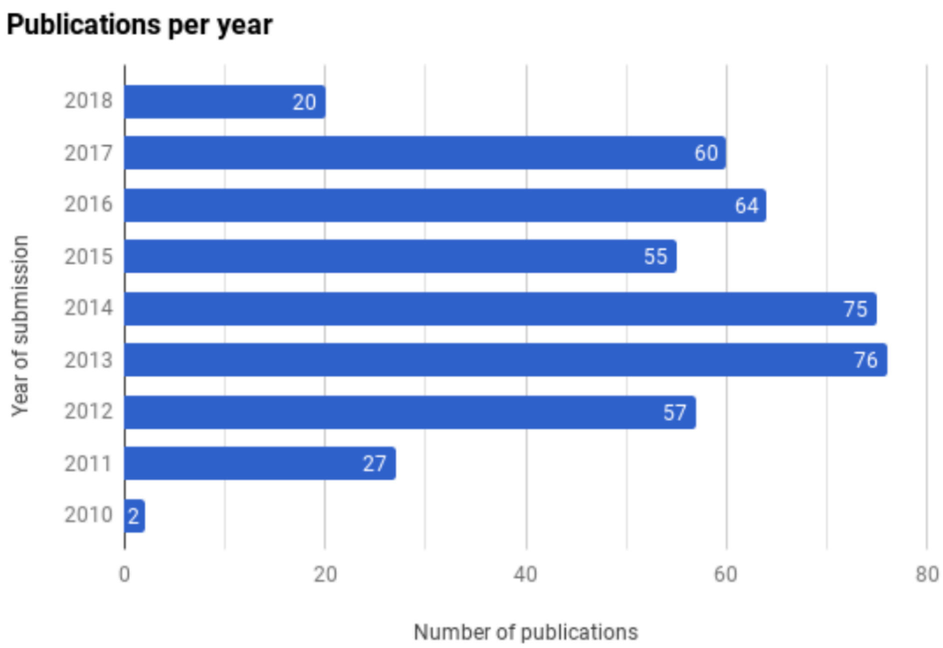
LHCb - Frascati

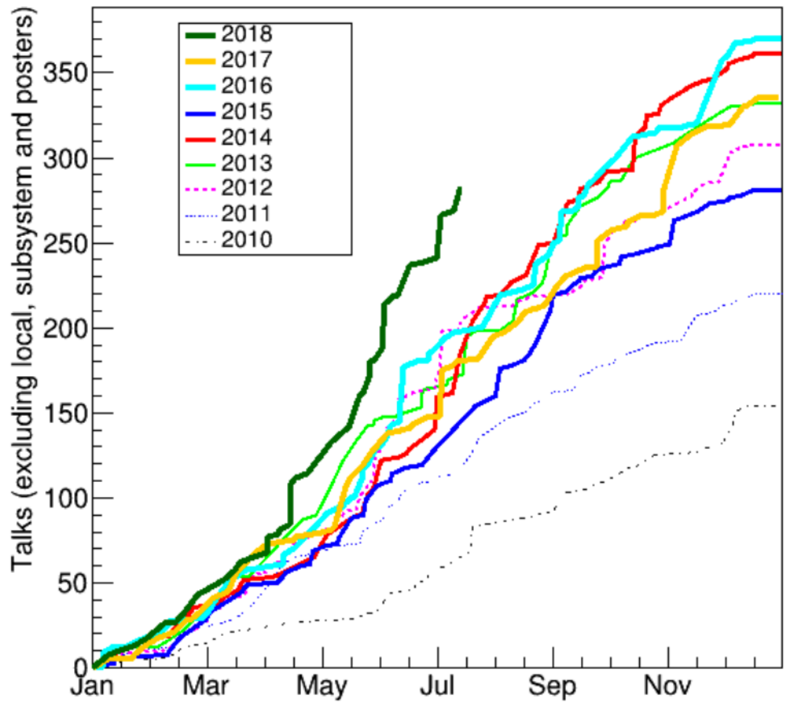
Pietro Albicocco, Gianni Bencivenni, Liliet Calero Diaz, Pierluigi Campana, Paolo Ciambrone, Patrizia de Simone, Pasquale di Nezza, Giulietto Felici, Nikita Kazeev, Suzanne Klaver, Gaia Lanfranchi, Simonetta Liuti, Gianfranco Morello, Matteo Palutan, Marco Poli Lener, Marcello Rotondo, Marco Santimaria, Alessio Sarti, and Barbara Sciascia



LHCb: broad physics program

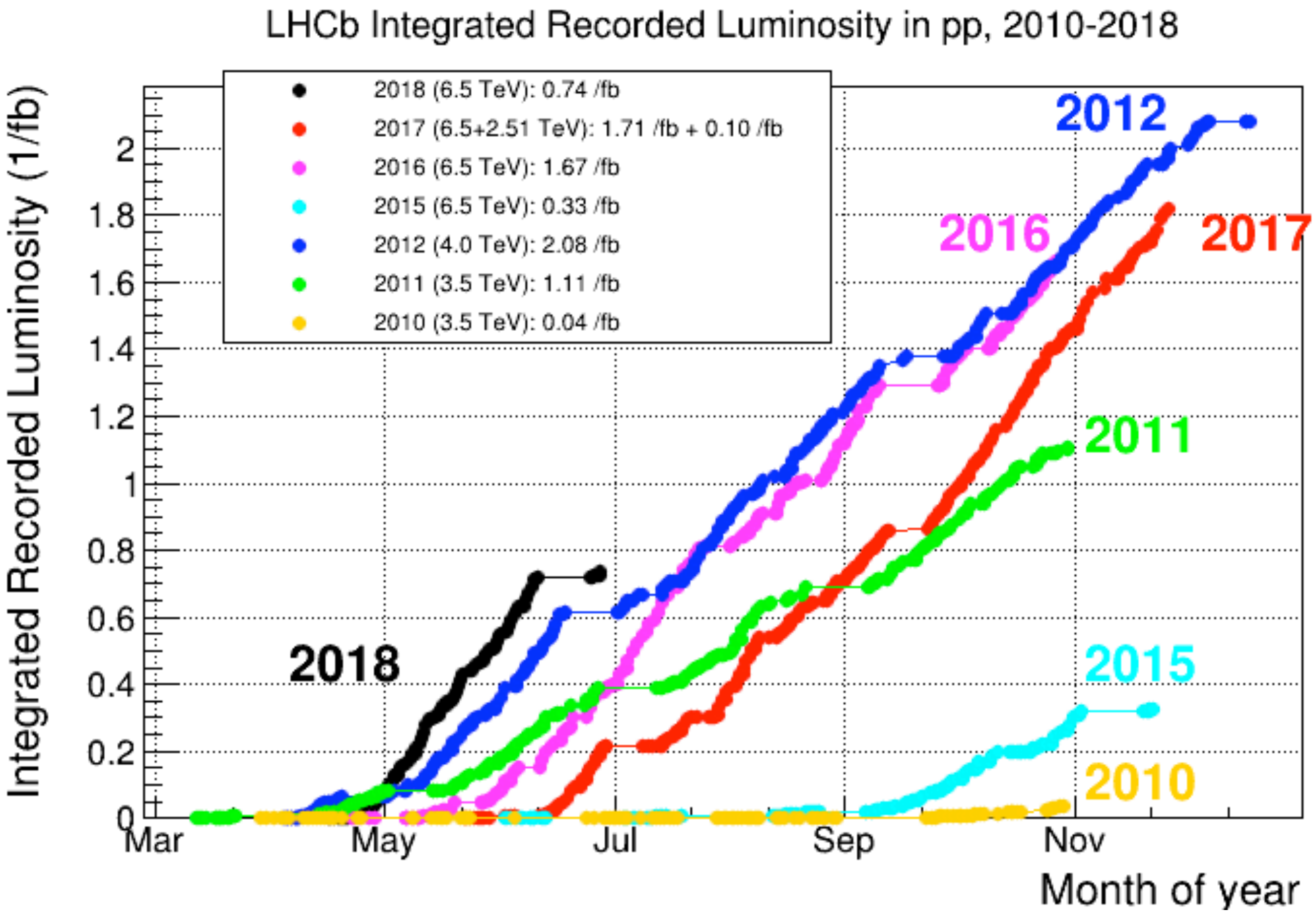
- CKM mechanism and CP Violation: γ, sin2β, φ_s, amplitude and mixing in B,D decays,…
- Rare decays: $B^0_{s,d} \rightarrow \mu\mu$, b→sll, …
- SL decays: B→Dτν/B→Dμν,
- Spectroscopy: Xi^{++}_{cc}, tetraquark, pentaquark,…
- EW, QCD, direct searches: Z^0, $W^{\pm}$, top, dark-photons, Long Lived Particles...
- Heavy ion, fixed target: production and nuclear effects in pA, AA





Most of the results from Run 1 data only. Full Run 1 + 2 data results coming soon

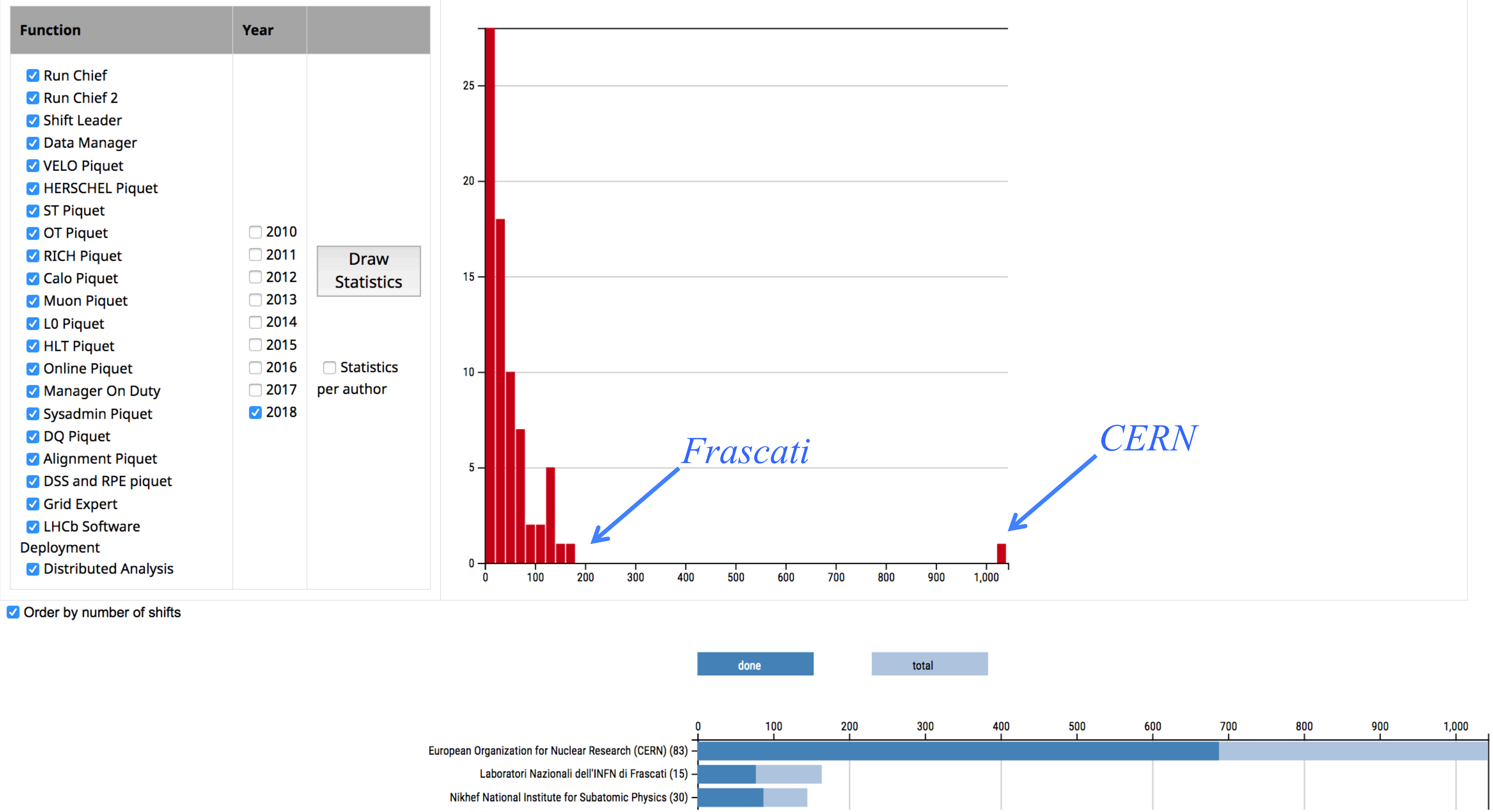
Ongoing data taking



Frascati direct contributions:

- **Large participation to shifts: control room, piquet, run chief**
- **Muon project leader**
- **(deputy) Operation Coordinator**
- **Online**
- **Data quality**

Data taking contribution



Data analyses

$B_{(s)}\mu\mu$ full Run 1 + Run 2:
[M. Palutan, M. Rotondo, M. Santimaria, A. Sarti, B. Sciascia]
- pubblicato [PRL 118, 191801 (2017)] con i dati di Run 1 + 1.6/fb di Run 2; prima osservazione (7.8 σ) di singolo exp. per il B_s. Ripetere per full Run 1 + Run 2

Misura del rapporto $R(D_s) = B_s \rightarrow D_s\mu\nu$ / $B_s \rightarrow D_s\tau\nu$; $B \rightarrow D$ form factors:
[P. de Simone, S. Klaver, M. Palutan, M. Rotondo, A. Sarti, B. Sciascia]
- importante perché gli analoghi R(D) e R(D*) mostrano deviazioni (~4 σ) dal MS (M. Rotondo convener del SL WG in HFLAV)

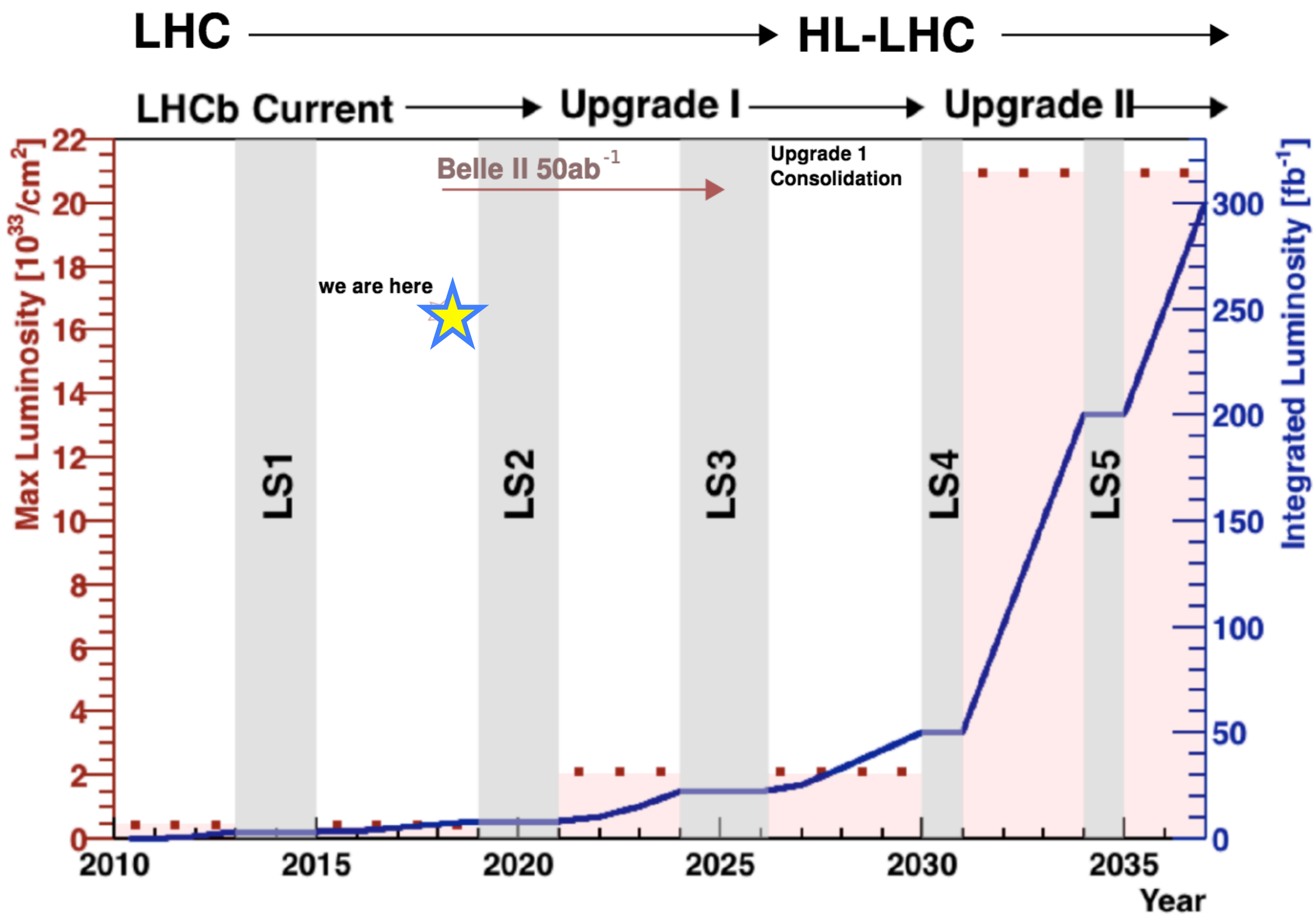
Measurement of the $D^{\pm}_s$ production asymmetry with $D^{\pm}_s \rightarrow K^+K^-\pi^{\pm}$ decays:
[S. Klaver]
- completa, articolo sottomesso

* only Frascati names are indicated

Misura della polarizzazione della Λ_0:
[L. Calero Diaz, P. di Nezza, S. Liuti]
- importante per determinare la struttura di spin dei nucleoni, iniziata

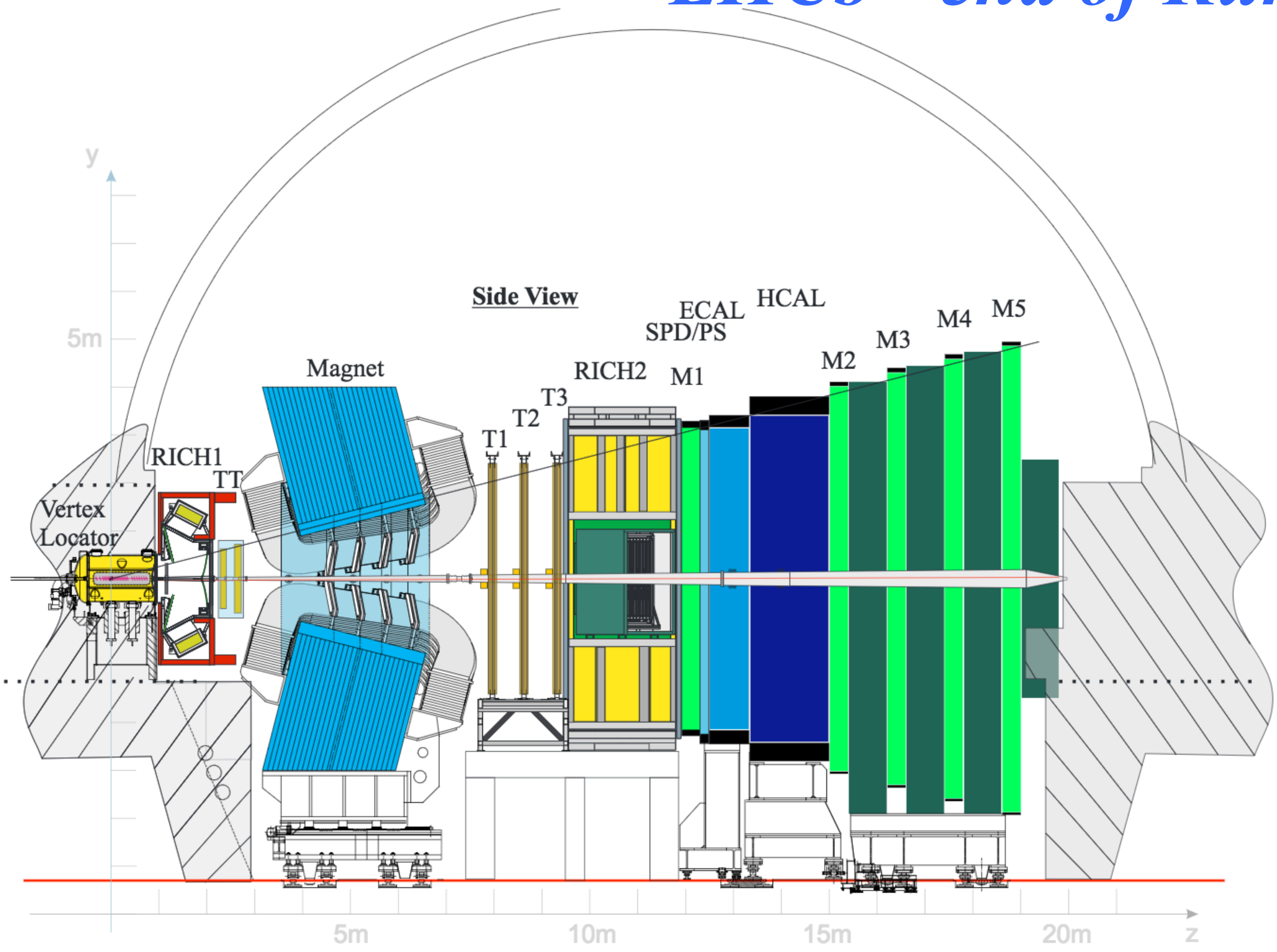
Misura del rapporto $\Lambda_b \rightarrow \Lambda_0 ee / \Lambda_b \rightarrow \Lambda_0 \mu\mu$ e ricerca del decadimento $\Lambda_b \rightarrow \Lambda_0 e\mu$:
[J. Cerasoli (laureando), M. Santimaria, B. Sciascia]
- LFU test

LHCb in coming years



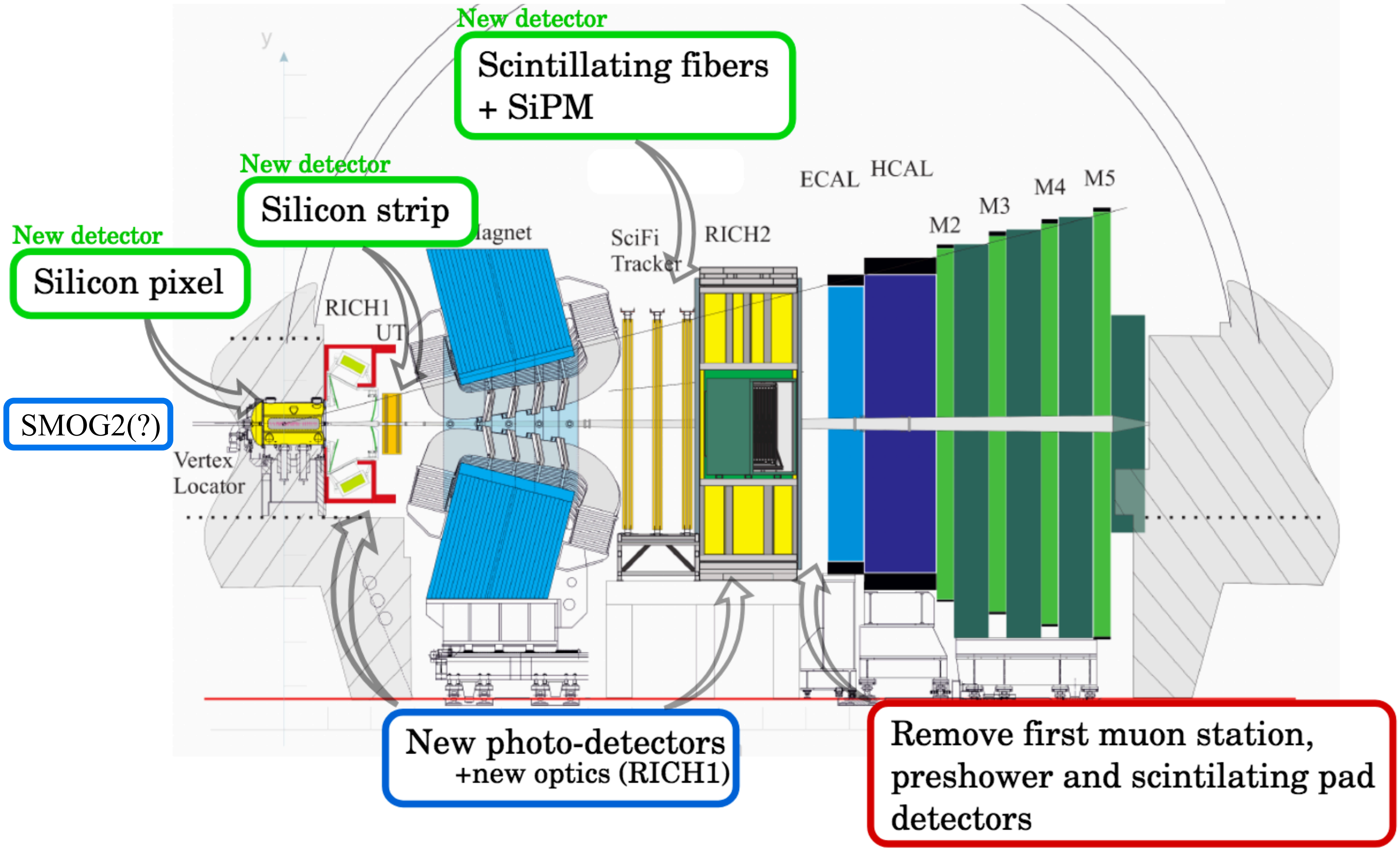
- During LHC era: $\mathcal{L} = 4 \times 10^{32} cm^{-2} s^{-1}$ to $2 \times 10^{33} cm^{-2} s^{-1}$.
- During HL-LHC era: $\mathcal{L} = 2 \times 10^{33} cm^{-2} s^{-1}$ to $2 \times 10^{34} cm^{-2} s^{-1}$.

LHCb - end of Run 2

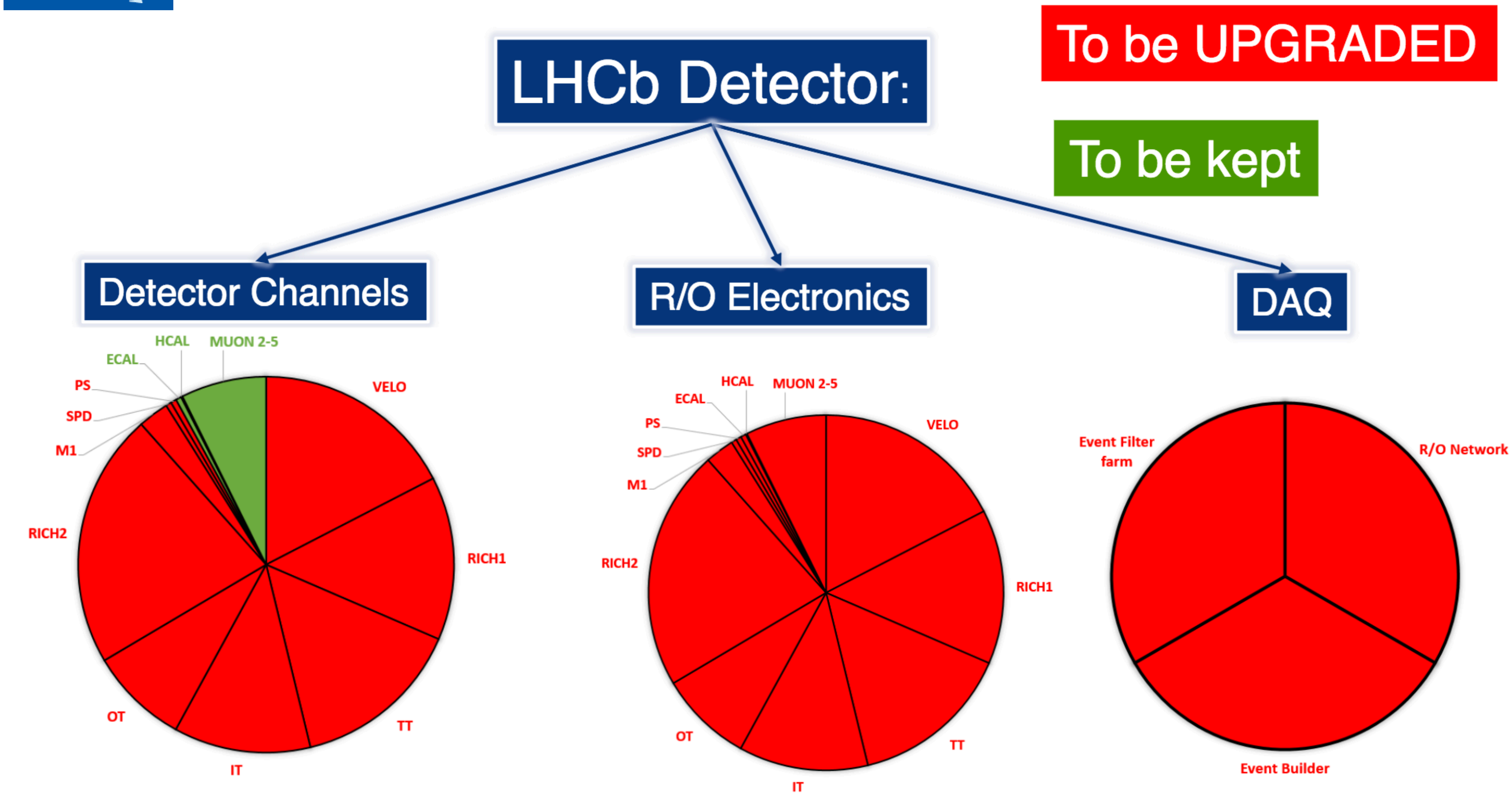


LHCb - Upgrade 1

+Upgraded electronics, trigger and data acquisition system



LHCb: what's new



- Less than 10% of LHCb detector channels will be kept
- 100% of R/O electronics will be replaced
- NEW DAQ system and DATA CENTER

Muon upgrade in a nutshell

1) New off-detector electronics

- **nODE** boards (with **nSYNC** ASIC) for an efficient 40 MHz readout
- **nPDM** and **nSB** boards for chamber pulsing an control using GBT
- **new firmware** for muon readout via **TELL40** boards
- **keep the same rack/crate infrastructure**, as well as cabling to the chambers

2) Additional shielding behind HCAL

- to mitigate the rates in the inner regions of M2

Frascati major contributions to each item

3) MWPC spares production

- to guarantee efficient operation for the next 10 years

4) Dismantling of M1 station

- no need for a standalone p_T measurement in the upgraded full software trigger

Muon activities since "preventivi 2018"

* only Frascati names are indicated

Production of 30 MWPC spare. At CERN since October 2017. Dressed and tested; 9 already installed in last EYETS	**M. Anelli, E. Paoletti, L. Pasquali, A. Zossi**

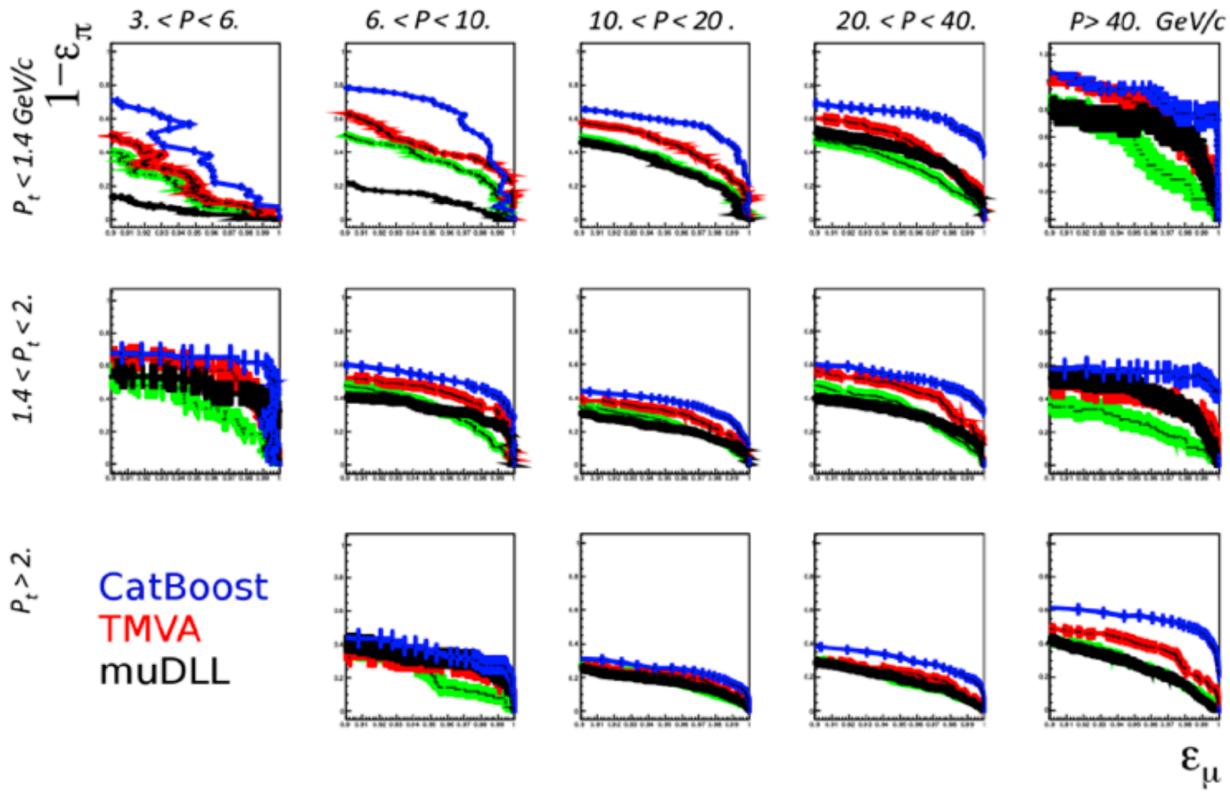
Software (PVSS) and firmware (ODE, FEE) maintenance and update for the LHCb ECS (Experimental Control System)	**M. Carletti**

M1R1: construction of 8 GEM detectors [= 4 LHCb chambers] as spares. At CERN since December 2017; 1 already installed in last EYETS.	**G. Bencivenni, E. Danè, G. Morello, E. Paoletti, L. Pasquali, M. Poli Lener,**

Muon identification

- Optimization of the muon ID algorithm for the upgrade.
- Development of new algorithms exploiting also state-of-the-art classifies.

P. de Simone, N. Kazeev, M. Palutan, M. Santimaria



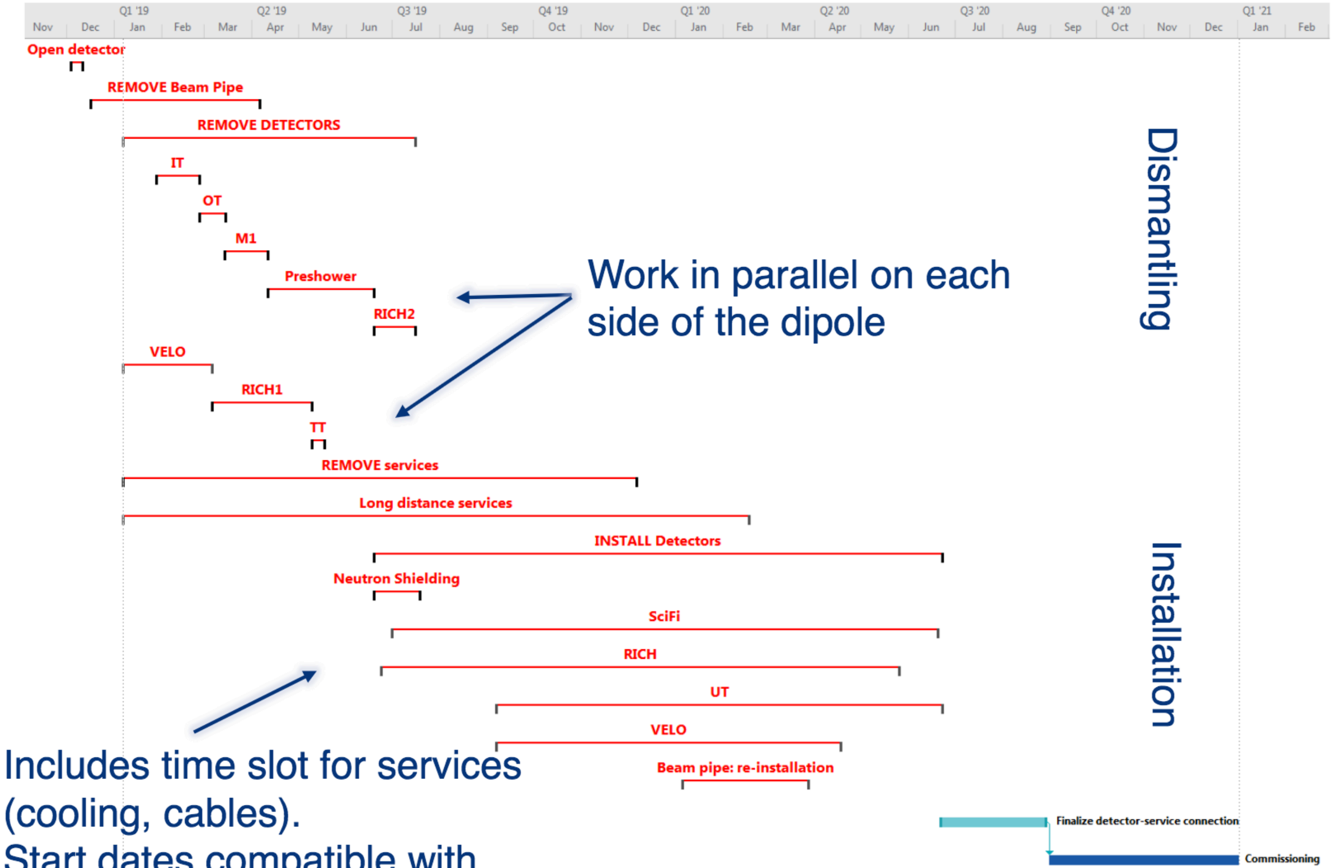
* only Frascati names are indicated

- Improved description of Muon system in Monte Carlo
- Low background simulation (crucial for study background rejection at the Upgrade)

M. Palutan, A. Sarti

LS2 planning

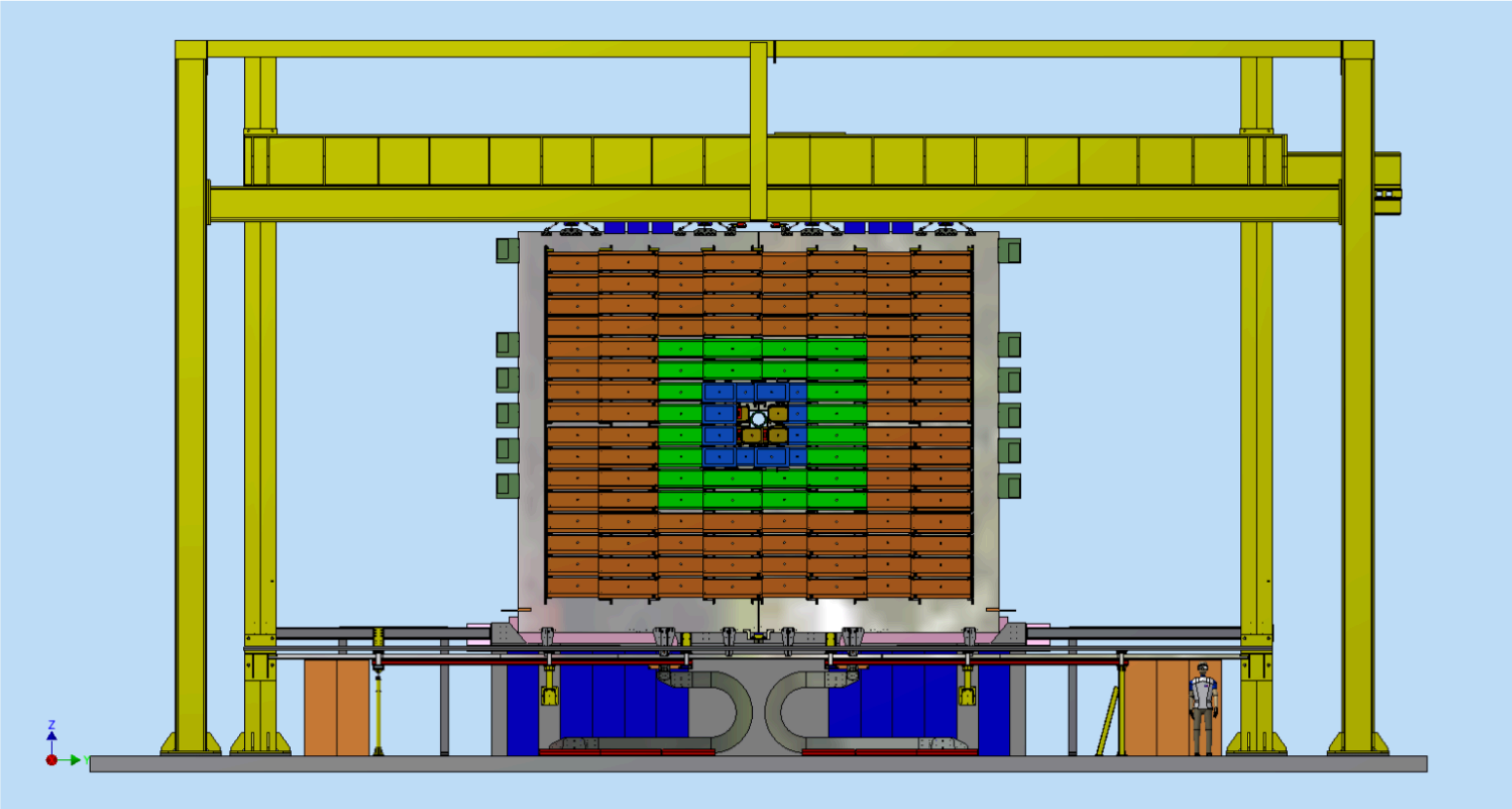
* only Frascati names are indicated



- Includes time slot for services (cooling, cables).
- Start dates compatible with milestones.

Dismounting of M1: work package leader A. Saputi
Beam plug under HCAL/M2: M. Palutan
M2-5 removing and installation readouts and control electronics: WPL P. Ciambrone
Neutron shielding installation: A. Saputi

M1 dismantling



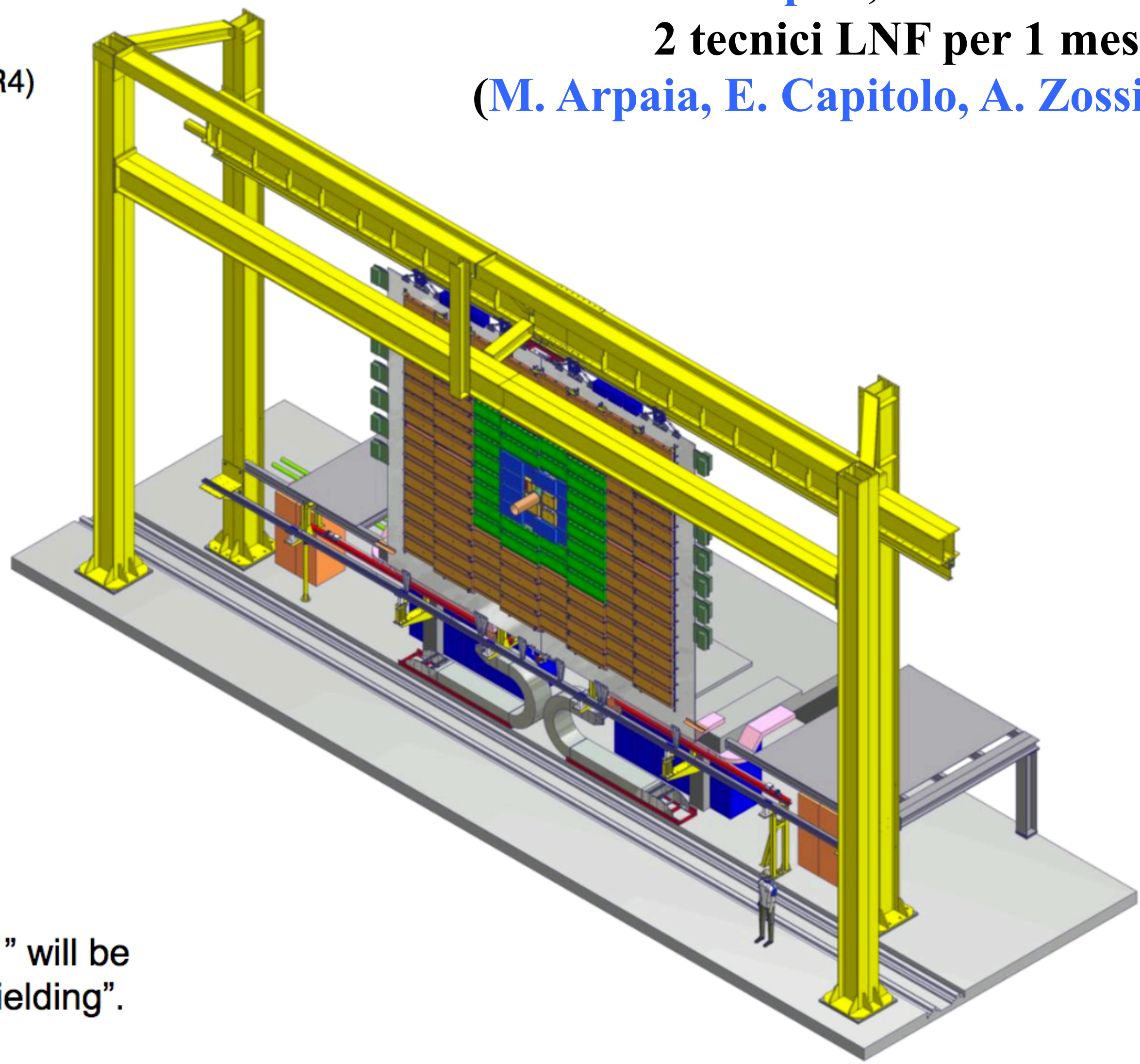
The total weight of the "Muon Station - 1" amounts to about **5 tons** per detector side.

The total volume of the "Muon Station - 1" is about **9 m x 8 m x 0,35 m**

M1 dismantling

A. Saputi, M. Palutan +
2 tecnici LNF per 1 mese
(M. Arpaia, E. Capitolo, A. Zossi)

Removal of:
1. Muon Chambers (M1R1, M1R2, M1R3 and M1R4)
2. Cable chains
3. Pipes
4. Cables
5. Fastening components
6. Racks (gas and electronics)



* only Frascati names are indicated

The support structure of “Muon Station 1” will be reused to install the “SciFi – Neutron Shielding”.

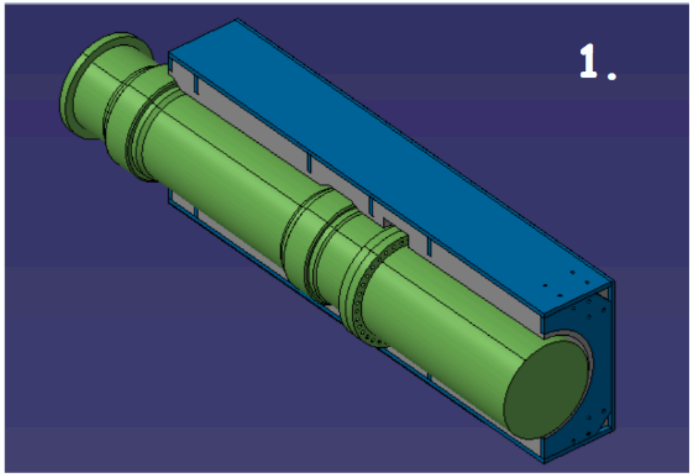
Additional shielding behind HCAL

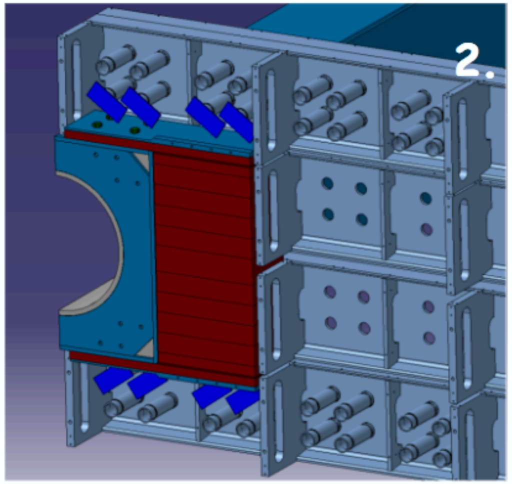
* only Frascati names are indicated

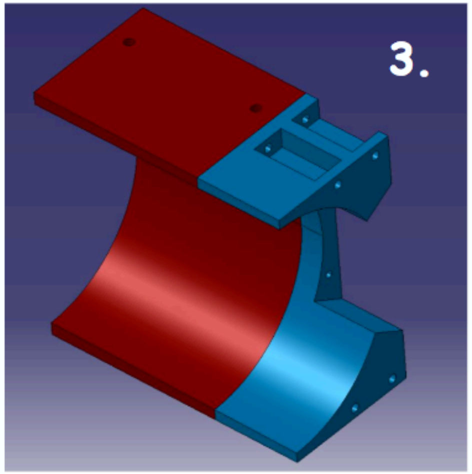
M. Palutan

We plan to install a significantly improved shielding in front of M2, which is expected to reduce the rate in the hottest M2 region by as much as 60%. This shielding consists of three parts:

1. A new HCAL beam-plug made of lead in a steal carcass; this plug will have a similar design with respect to the present one, but with a smaller clearance **(1cm)** to the beam pipe in the part facing M2: **reproducibility of HCAL position better than 1mm**
2. An additional shielding made of tungsten in the position of the PMTs of the innermost HCAL cells .
3. An improved M2 plug, of identical dimensions with respect to the present one, but partially made of tungsten.



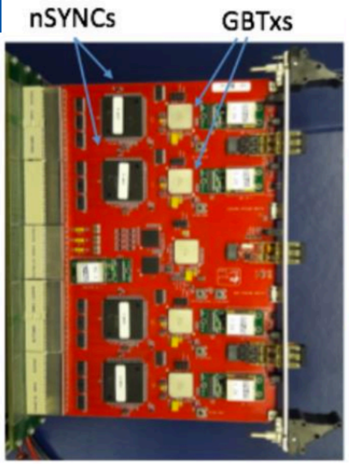


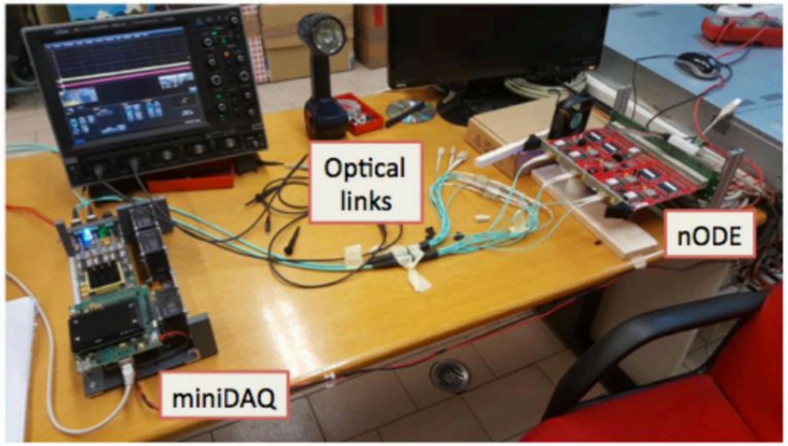


Status: - EDR passed jan 2017 , see https://indico.cern.ch/event/603210/, design of HCAL beam plug refined

- Discussion/preparation of installation well advanced, see https://indico.cern.ch/event/699600/

Muon readout and control electronics





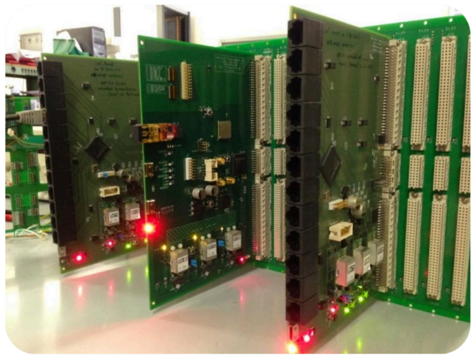
P. Albicocco, A. Balla,
P. Ciambrone, M. Gatta

* only Frascati names are indicated

New On Detector Electronics (nODE) boards + nSYNC chip:
- nODE prototype developed, equipped with nSYNC (Cagliari) and tested with miniDAQ.
- PRR successfully passed October 2017
- nSYNC tender approved by INFN; full production ready October 2018 (Cagliari)
- nODE (190 boards): preproduction January 2019; March-June 2019, about 50/month

New Control boards (12 nPDM and 140 nSB):
- under Roma 1 responsibility
- Frascati support to finalise work for PRR (successfully passed May 2018l)
- Tender ongoing (Roma 1)
- Full production ready and tested at CERN April 2019

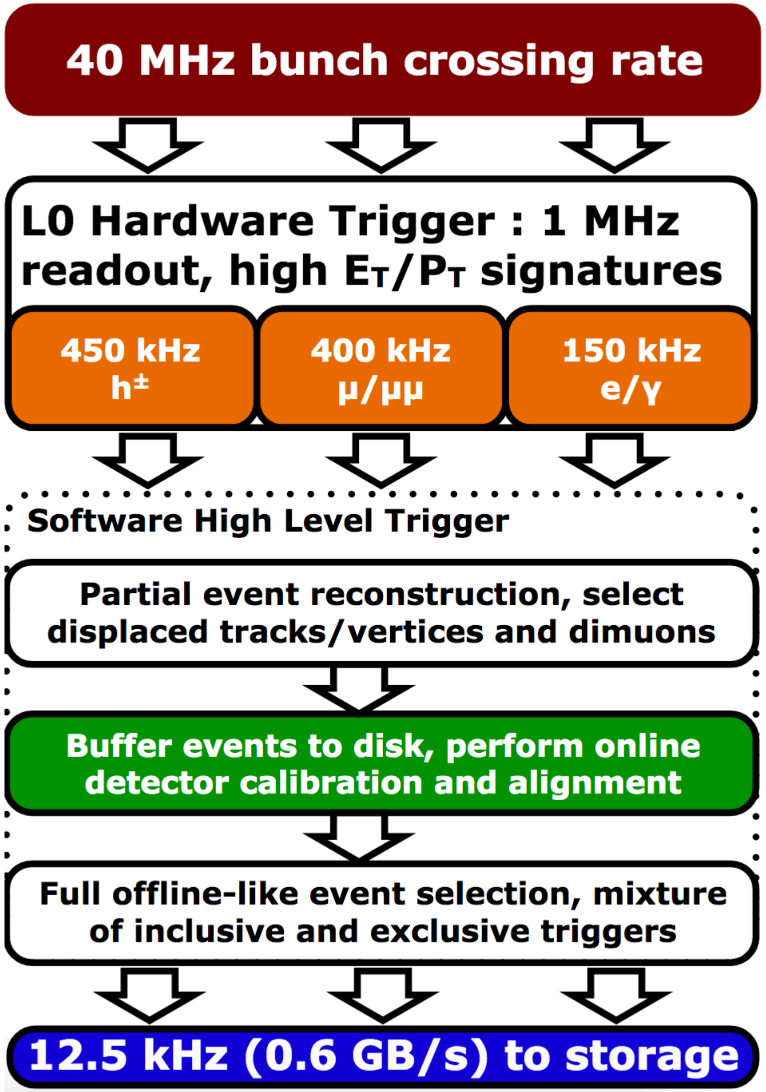
new Service Board System – FRONT-SIDE view



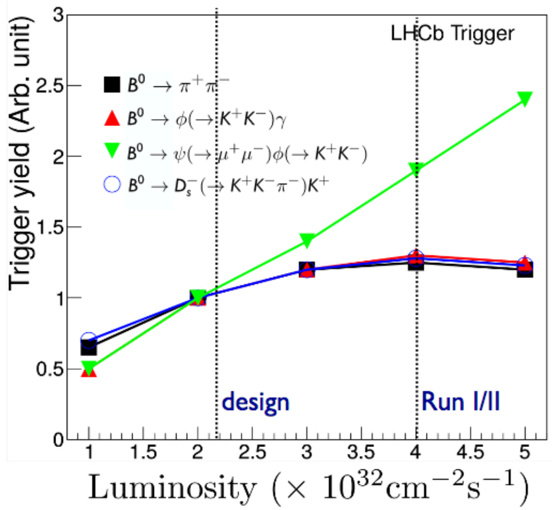
Installation and full commissioning at CERN; ~6 months over 2019-20 [1 people from LNF]

Data acquisition and trigger: Run 2

LHCb 2015 Trigger Diagram



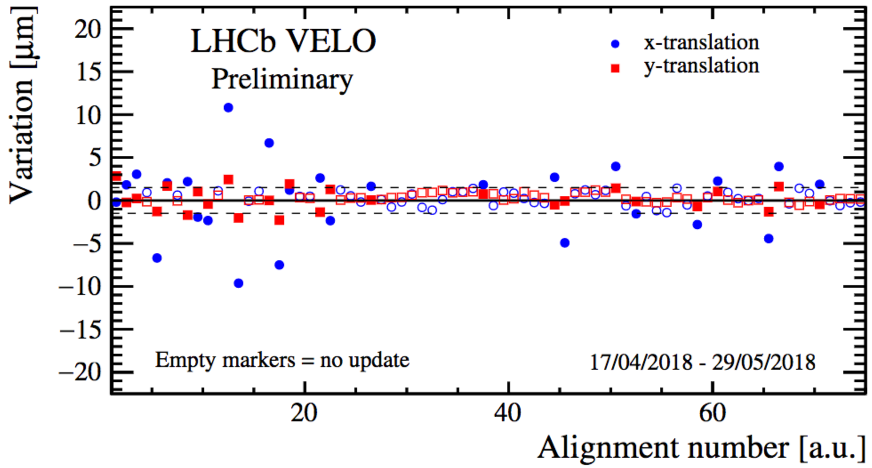
L0 hardware and readout limits hadronic modes



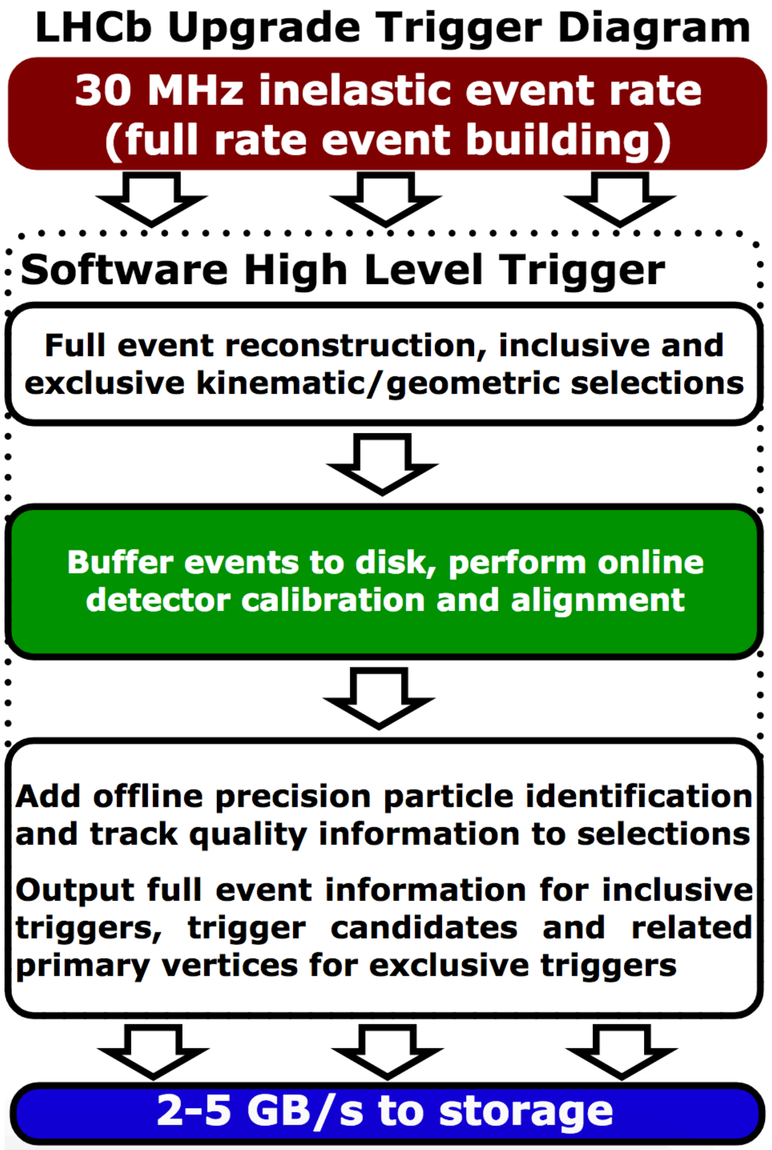
Scaling of trigger yields with current LHCb

[CERN-LHCC-2014-016]

Since 2015: online reconstruction with offline quality



Data acquisition and trigger: Run 3



	LHCb	LHCb Upgrade I
$\mathcal{L}_{Instantaneous}\,(cm^{-2}s^{-1})$	4×10^{32}	**2×10^{33}**
Pile-up	1.1	**6**
b-hadron per evt.	0.003	**0.02**
c-hadron per evt.	0.04	**0.22**
light,long-lived per evt.	0.51	**2.08**

[LHCb-PUB-2014-027]

40 MHz readout + fully process events at ~30 MHz

Event size reduced to write 2-10 GB/s to disk

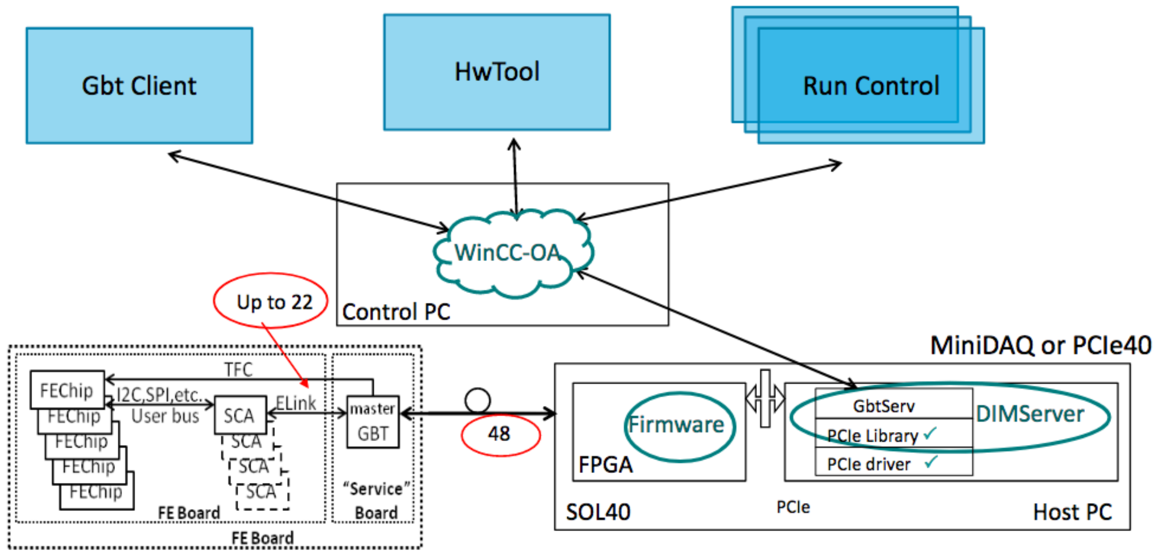
Flexible and efficient trigger for both S/B and S/S separation:
- Multithread framework is in place and works well.
- Algorithm optimization: a factor 2 speed-up in less than 6 months has been achieved. Work ongoing.
- In depth profiling of the algorithms shows that there are large margins to achieve additional speed-ups.

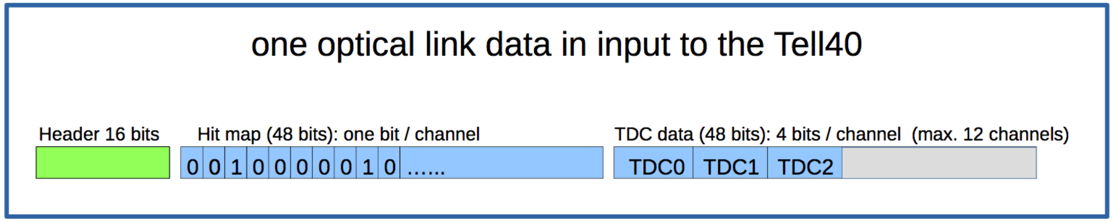
[Upgrade Software and Computing TDR CERN-LHCC-2018-007]

TELL40

Centralised tender at CERN;

- **Muon firmware under Roma 2 responsibility**
- zero-suppression algorithm implemented (large part of Muon detector has low occupancy).
- Number of Tell40 boards is fixed by the output bandwidth (<70 Gb/s)
- The FPGA resource usage is less than 70%





- Muon data preparation is presently too slow; discussion is ongoing if some of the work (crossing of vertical/horizontal strips) could be moved to TELL40
- Difficult without significant additional resources (+50%, very unlike)
- Confident we can cope by optimizing the muon reconstruction software: ongoing

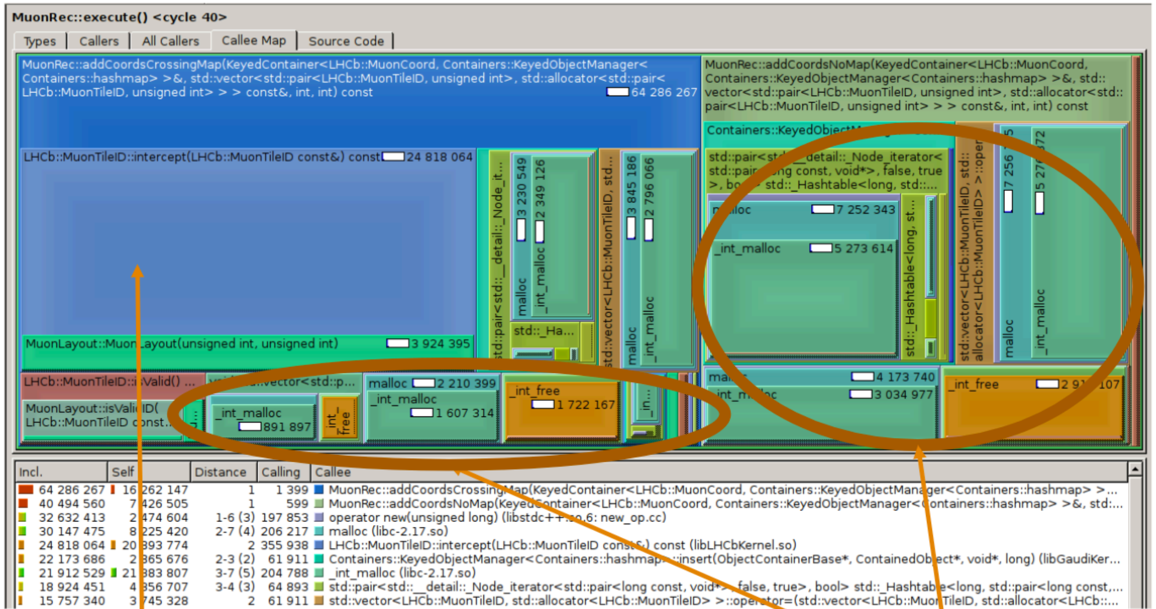
LHCb

Muon information reconstruction

S. Klaver

- Full restyling of beginning of Run 1 MuonRec
- Decoding of muon hits at upgrade needs to have "negligible" CPU time.

Callgrind CPU cycles map – **old algorithm**



Significant time spent computing intercept between MuonTileID's

Lots of time spent allocating memory

Callgrind runs of virtual CPU – much more reproducible results than Vtune Amplifier, especially on lxplus.

Callee map shows function calls inside other function calls with the size of the block indicating the number of CPU cycles spent on it.

Vtune gives absolute time measurement but is done via sampling whilst running on the real CPU. Highly variable on lxplus (cannot run locally as it requires a license) but could be tested on the online servers when all optimisations are done.

* only Frascati names are indicated

Muon information reconstruction

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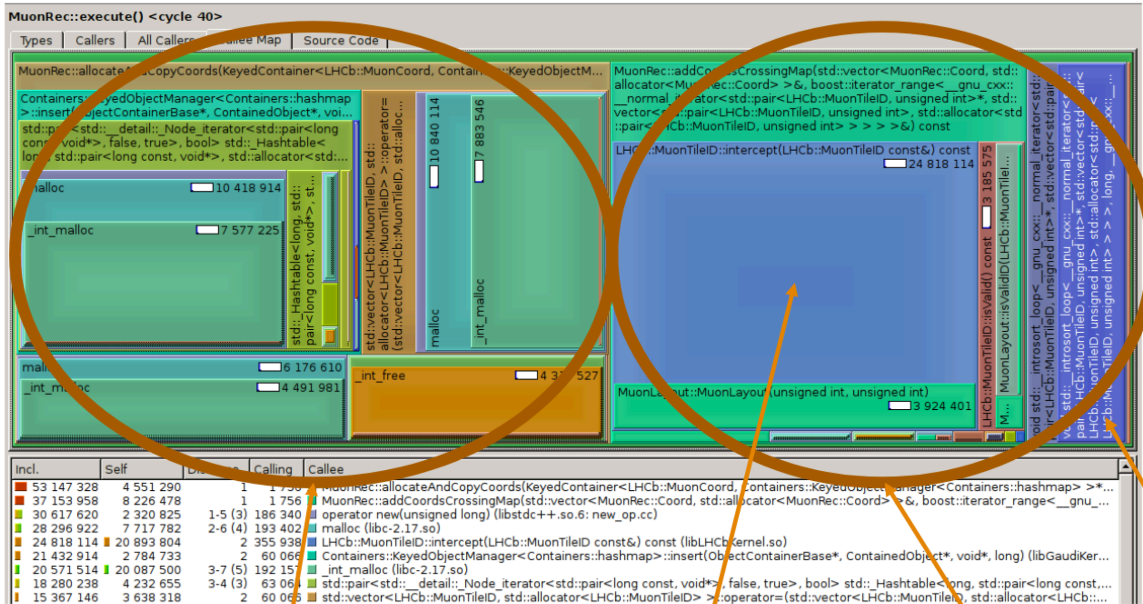
Callgrind CPU cycles map – **new algorithm**



Crossing algorithm takes now 37K CPU cycles for 100 events. Old algorithm was 104K. Additional 53K cycles still spent on memory allocation for the MuonCoords.

Cannot truly benefit from optimisation of MuonRec algorithm until MuonCoords container is re-written.

If digits are read out sequentially from TEL boards, we also save this block

All this is spent on saving the MuonCoords

If we can optimise **MuonTileID::intercept()** we will gain even more

Crossing algorithm

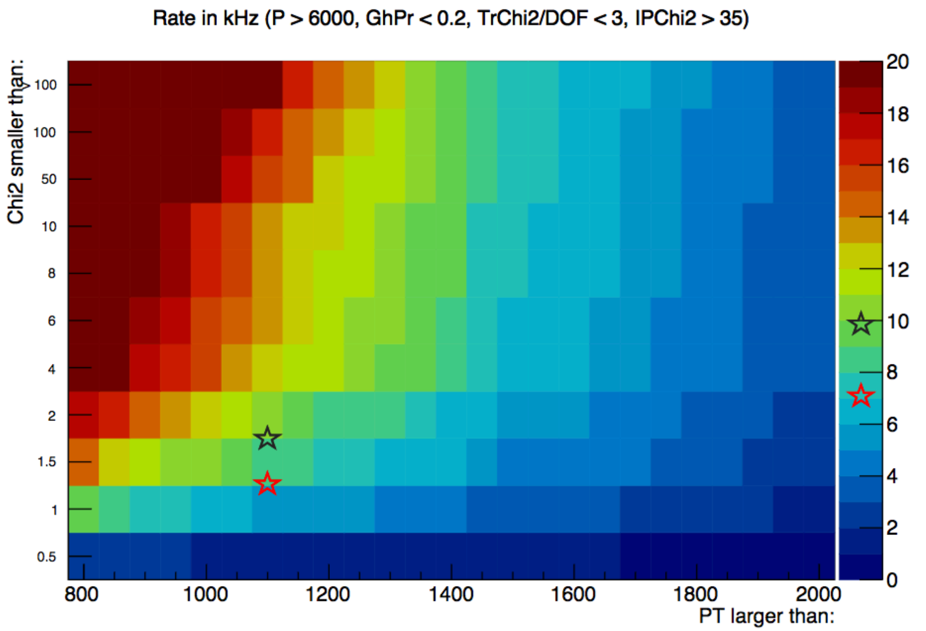
* only Frascati names are indicated

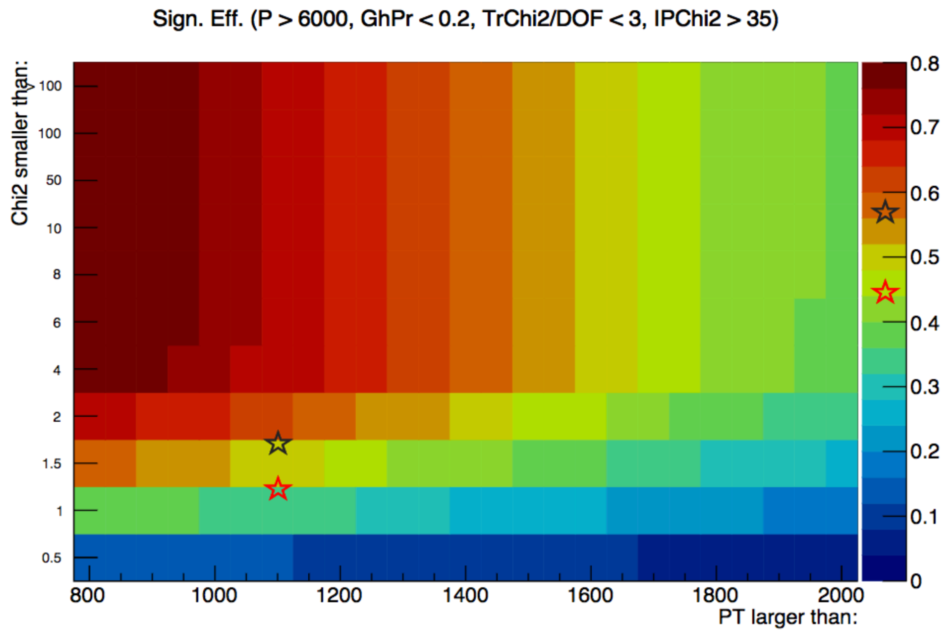
Muon selection in upgrade trigger

M. Palutan

- L0 hardware stage: deep use of Muon information
- After L0 removal in LS2, use minimum bias events to study "recovery strategies"

Current [L0Muon X HLT1TrackMuon]: 7.2 kHz, 46%
Current [L0Global X HLT1TrackMuon]: 9.7 kHz and 49%





PT > 1100 and Chi2Corr < 1.29: 7.2 kHz and 44% ☆

PT > 1100 and Chi2Corr < 1.75: 9.7 kHz and 57% ☆

* only Frascati names are indicated

SMOG2 and beyond

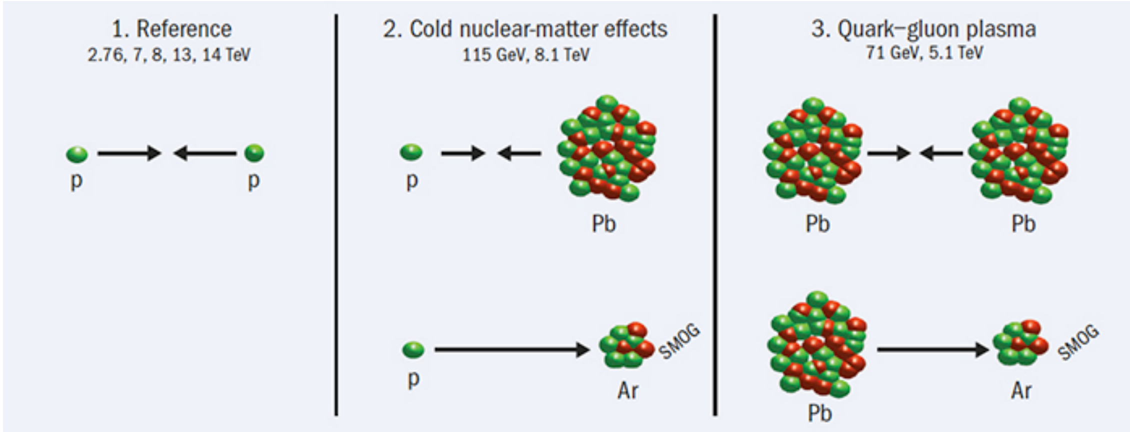
SMOG:
- Thanks to SMOG system, since 2013 LHCb can run in fixed-target mode.

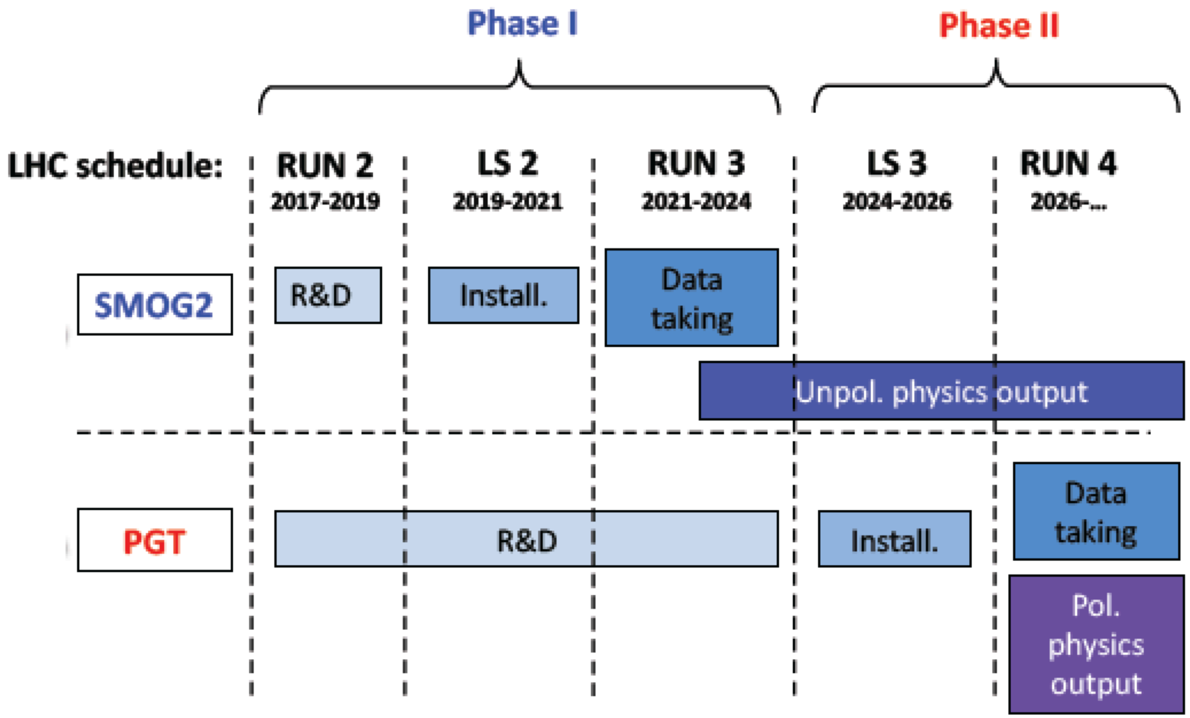
- pp and pA/Ap data collected <u>in parallel</u>: successfully tested and used since 2017

SMOG2:
- order 10-100 increase of the useful target density for the same gas flow to the LHC than SMOG

- Injection of H_2, D_2, He, … all noble gasses up to Xe

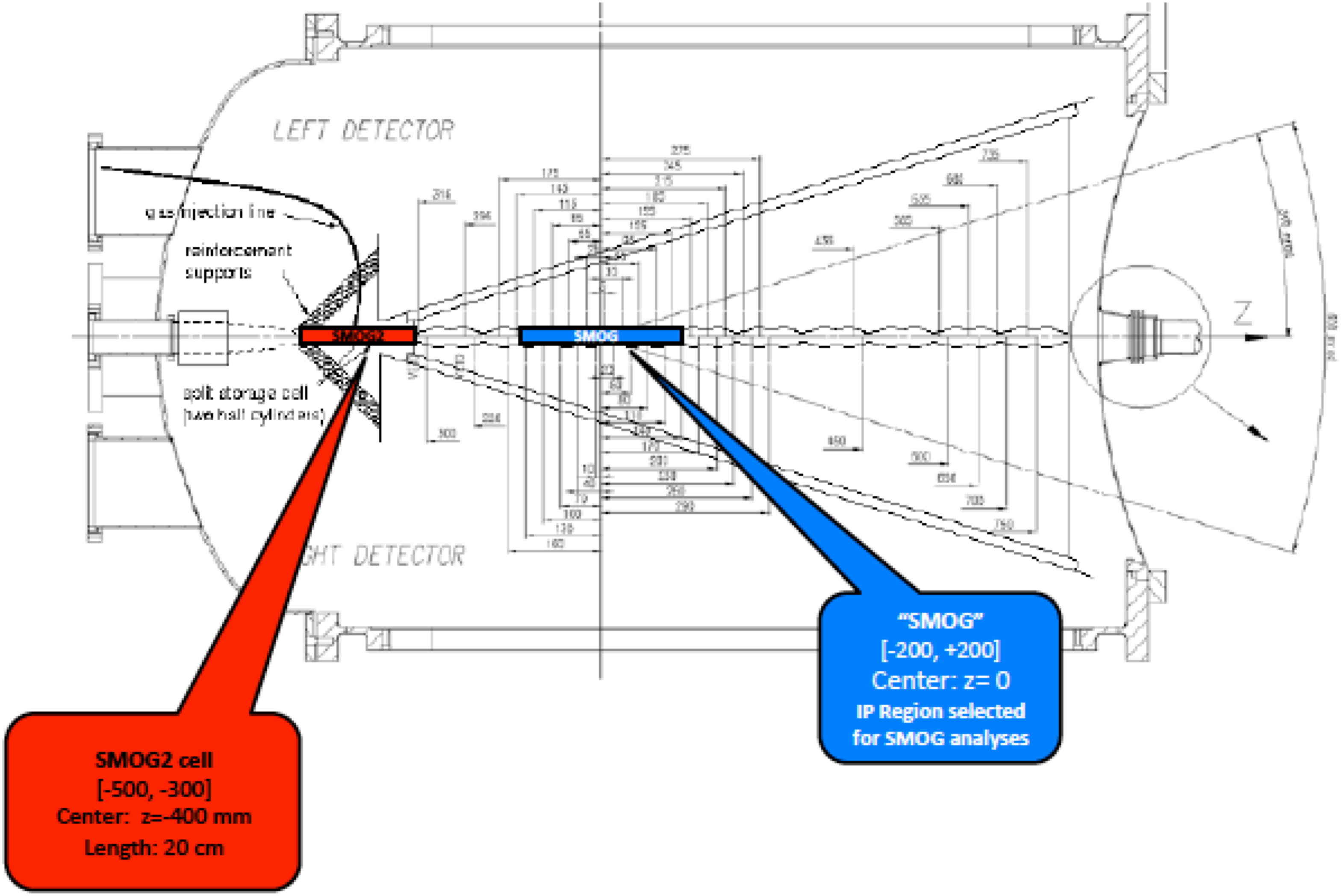
- More precise target density (major systematic error so far)





SMOG2 and beyond

P. Di Nezza



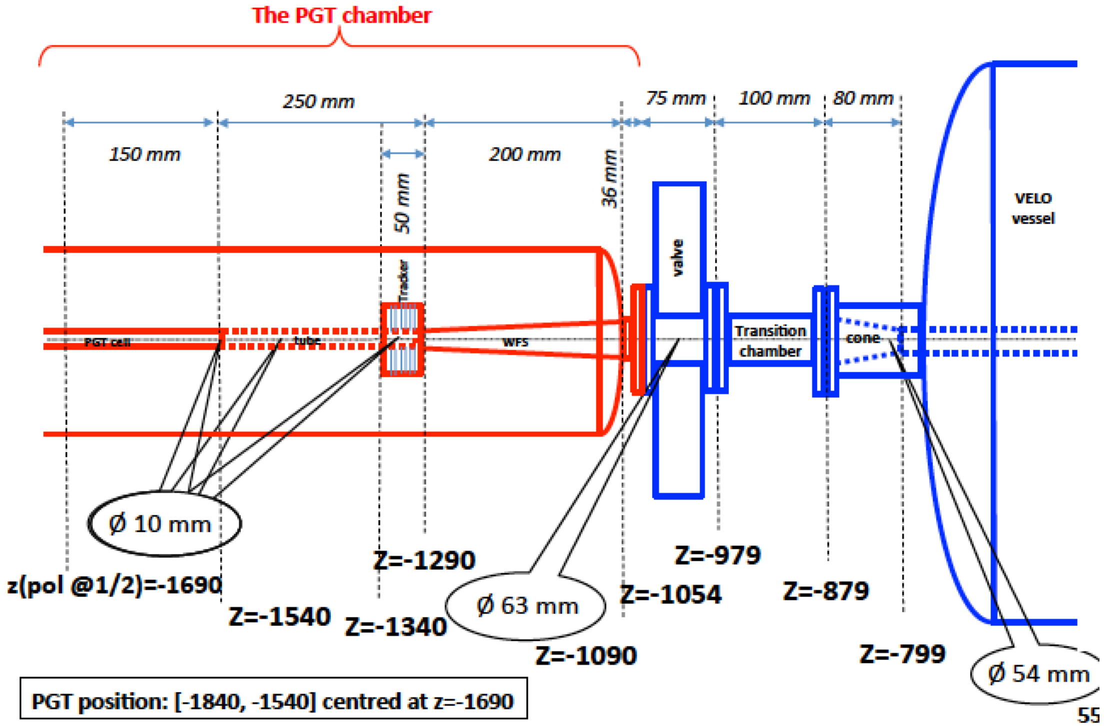
* only Frascati names are indicated

P. Di Nezza

Polarised Gas Target (PGT): use nucleons as QCD laboratory.
A three-dimensional description of the nucleon through measurable quantities
- Generalized Parton Distribution functions (GPDs)
- Transverse Momentum Distribution functions (TMDs)

Coating issue: fruitful collaboration with CERN vacuum group and WP4 (PI: R.Cimino) of the EU funded program EuroCirCol on: **"Cryogenic Beam Vacuum System Concept on:** vacuum stability at low temperature"

* only Frascati names are indicated



Conclusions and future plans

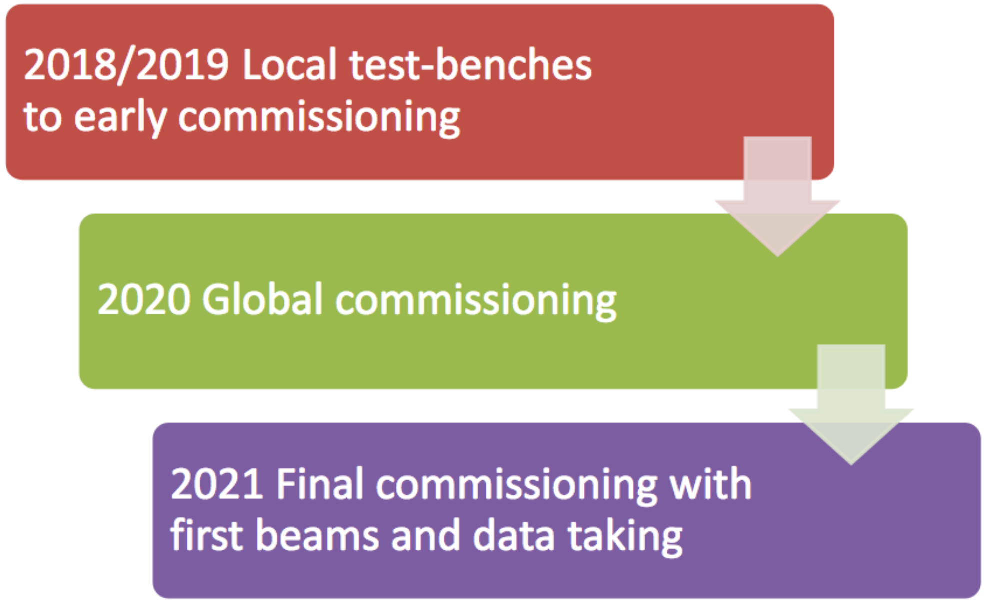
Involved in flagship analyses.

Frascati: important role on the ongoing data taking and LS2 activities
On track for a successful Upgrade 1.

Limited impact on LNF resources

Possible involvement in the monitoring at Upgrade 1. Key item given new detector, new DAQ, 2 shifters/shift.

Ongoing R&D for future upgrades: SMOG2 and mRwell (see G. Bencivenni contribution)



Ready for Upgrade 1 and beyond!

"All I'm saying is now is the time to develop the technology to deflect an asteroid."

Spares

Anagrafica 2019

Ricercatori [11.95 FTE, tbc]:
- Gianni Bencivenni: 40 % [*] 1 Ric
- Liliet Calero Diaz: 100 % PhD
- Pierluigi Campana: 50 % Dir. Ric.
- Patrizia de Simone: 90 % 1 Ric.
- Pasquale di Nezza: 95 % 1 Ric
- Nikita Kazeev: 100 % PhD
- Suzanne Klaver: 100 % PosDoc straniero
- Gaia Lanfranchi: 60 % 1 Ric.
- Simonetta Liuti: 50 % Ric. Straniero Associato
- Gianfranco Morello: 60% [*] Ric. TD
- Matteo Palutan: 100 % Ric.
- Marcello Rotondo: 80 % Ric.
- Marco Santimaria: 100 % AdR
- Alessio Sarti: 70 % Ric. Associato
- Barbara Sciascia: 90 % Ric

Tecnologi [2.2 FTE, tbc]:
- Pietro Albicocco: 70 % AdR
- Paolo Ciambrone: 70 % 1 Tecnologo
- Giulietto Felici: 20 % Dir Tecnologo
- Marco Poli Lener: 60 % [*] Tecnologo

[*]: da confermare

Coordinamento e turni

Ruoli di coordinamento:

- P. de Simone: Muon Software Coordinator [01/2017 - 01/2019]
- S. Klaver: convener of CPV, mixing and production SL subWG [01/2018 - 03/2020]
- M. Palutan: Muon Project Leader [01/2017 - 01/2019]
- M. Palutan: Responsabile nazionale [07/2018 - 06/2021]
- B. Sciascia: (deputy) Operation Coordinator [04/2017 - 03/2019]

Ampia partecipazione ai "turni centrali" (sala controllo, piquet, run chief)

CSN1 LNF: Richieste 2017, assegnato e SJ '18

Sigla	Ric	Tec	FTE	<FTE>	MISS			CON			APP(#)		ALTRO CAP(*)		
LHCb	13	3	11.7	0.73	161	90.0	-	21.5	14.5	-	255	255	85	73	-

\# **Apparati**: **255 kE**
- **125 kE**: 50% delle PCIe40 per il Muon System.
- **130 kE**: Produzione nODE e relativi spare

* **Altri servizi** (MOFb LHCb muon): **73 kE**
MOF-B Muon System: da CERN-RRB-2016-038, tabella 7, 120kCHF di cui l'Italia paga 70%, cioe' 84 kCHF = **72.58 kE** (for 0.864 eur/CHF)

Utilizzo servizi II sem. 2018 gruppo LHCb

Richieste II semestre 2018			
SEA	CAD	1.5 mu	13.0 mu
	Contingenza	2.0 mu	
	Staff	9.5 mu	
SPCM	Tecnici officina	0.25 mu	0.25 mu
SEM	Progettazione meccanica, Rivelatori	0.042 mu	0.042 mu
DR	Progettazione meccanica	1.2 mu	1.2 mu
DR	Informatico	3.0 mu	3.0 mu

Gruppo 1 LNF, LHCb, richieste nel 2019

Sigla	Ric	Tec	FTE	<FTE>	MISS	CON	APP	ALTRO CAP
LHCb	15	4	14.15	0.74	197	TBD	125	73

Missioni: tot 197.11 kE
  Estere: FTE*3M*3.7kE = 157.06 kE
  Interne: FTE*1kE = 14.15 kE
  Dismounting of M1 at CERN: 2 technicians * 1 MU * 3.7 kE = 7.4 kE
  Responsabilità: 3M*3.7kE [dOC]+1M*3.7kE [Muon soft]+1M*3.7kE[CPV, mixing and prod.] = 18.5 kE

Apparati: tot 125 kE
 55 kE per Tell40 [seconda tranche dopo l'assegnazione 2019]
 50 kE per fibre ottiche connessione nuova elettronica di readout muon [da pagare al CERN, gara in atto]
 20 kE per postproduzione meccanica ODE (frontalini)

Consumo:
  Metabolismo: FTE*1.5 kE = 21.225 kE
  15 kE setup test ODE [capitolo TBC]
  SMOG2: TBD

Altri servizi diversi: tot 77 kE
  MoF-B LHCb MUON

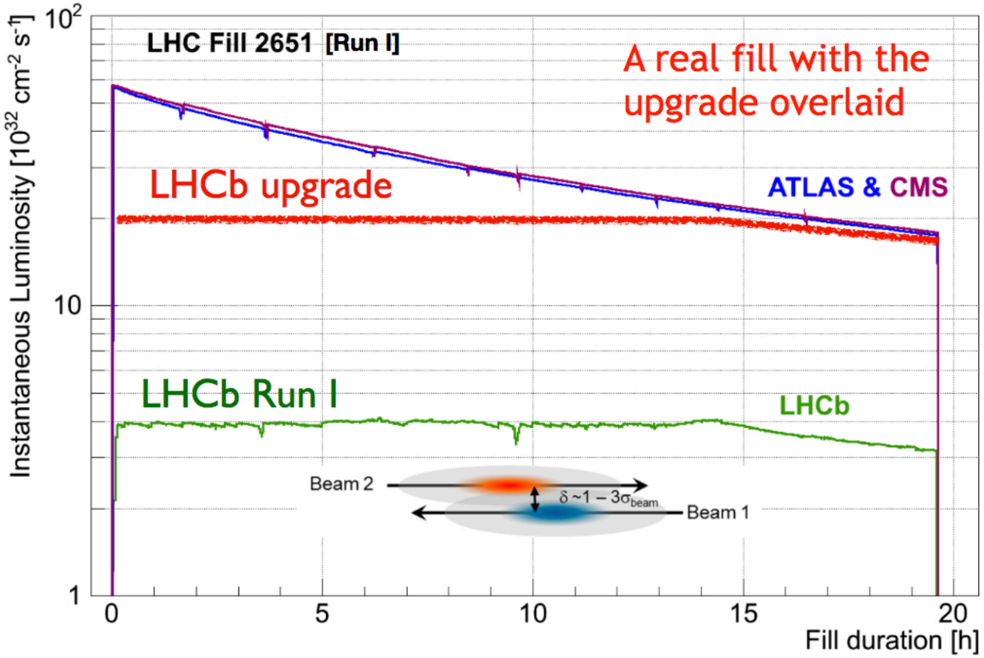
Richieste LHCb per il 2019

<table>
<tr><th colspan="4">Richieste I e II semestre 2019</th></tr>
<tr><td rowspan="3">SEA</td><td>Produzione e test ODE</td><td>TBD</td><td rowspan="3">TBD</td></tr>
<tr><td>Sviluppo firmware e software ECS</td><td>12 mu</td></tr>
<tr><td>Supporto esperimento</td><td>TBD</td></tr>
<tr><td>SPCM</td><td>Smontaggio stazione M1 (MUON system)</td><td>1 mu</td><td>1 mu</td></tr>
<tr><td>DR</td><td>Muon + SciFi</td><td>2.4 mu</td><td>2.4 mu</td></tr>
<tr><td>DR</td><td>Informatico</td><td>6 mu</td><td>6 mu</td></tr>
</table>

Upgrade for Run 3

- We currently level our luminosity at $\mathcal{L} \approx 4 \times 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
  - Huge gains available if we can run at higher luminosities
- Why do we run at lower luminosity?
  - Design choices for our physics programme
  - Detector and trigger limitations

Run I + II target : 8 fb^{-1}
Run III + IV target: 50 fb^{-1}



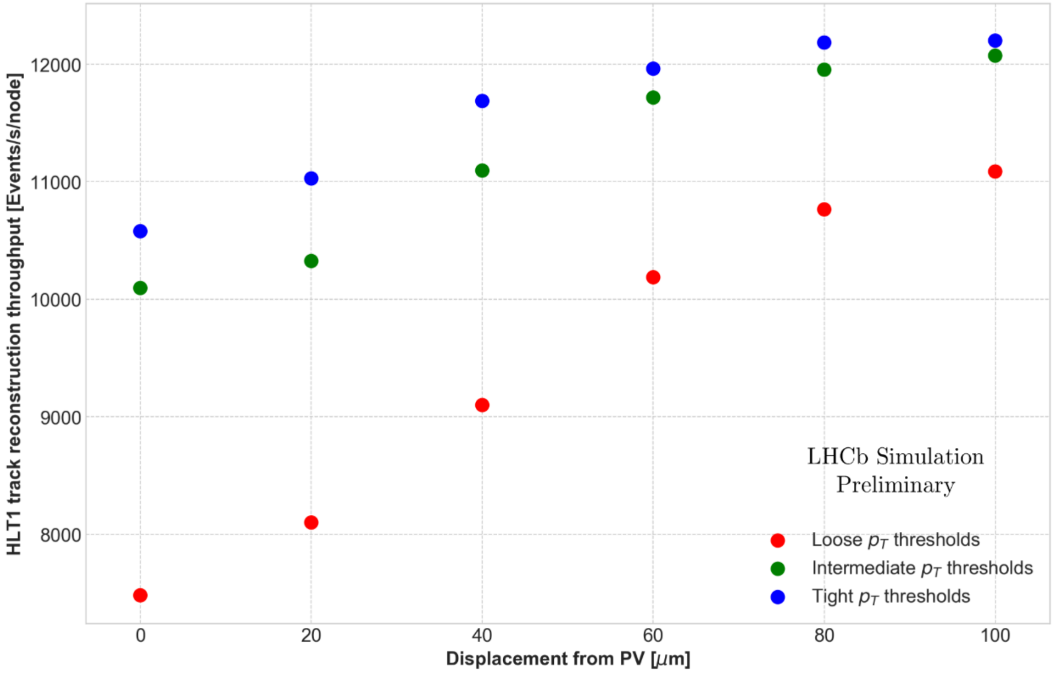
- Note that upgrading for Run 3 is before the HL-LHC era in Run 4 onwards

Physics prospects

Table from framework TDR, current estimates are better

Type	Observable	Current precision	LHCb 2018	**Upgrade** ($50\,\mathrm{fb}^{-1}$)	Theory uncertainty
B_s^0 mixing	$2\beta_s\ (B_s^0 \to J/\psi\ \phi)$	0.10 [9]	0.025	0.008	~ 0.003
	$2\beta_s\ (B_s^0 \to J/\psi\ f_0(980))$	0.17 [10]	0.045	0.014	~ 0.01
	$A_{\mathrm{fs}}(B_s^0)$	6.4×10^{-3} [18]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguin	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\mathrm{eff}}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\mathrm{eff}}(B^0 \to \phi K_S^0)$	0.17 [18]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{\mathrm{eff}}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
Electroweak penguin	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.08 [14]	0.025	0.008	0.02
	$s_0\ A_{\mathrm{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [14]	6 %	2 %	7 %
	$A_{\mathrm{I}}(K\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.25 [15]	0.08	0.025	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [16]	8 %	2.5 %	$\sim 10\,\%$
Higgs penguin	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [2]	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	–	$\sim 100\,\%$	$\sim 35\,\%$	$\sim 5\,\%$
Unitarity triangle angles	$\gamma\ (B \to D^{(*)}K^{(*)})$	~ 10–$12°$ [19, 20]	4°	0.9°	negligible
	$\gamma\ (B_s^0 \to D_s K)$	–	11°	2.0°	negligible
	$\beta\ (B^0 \to J/\psi\ K_S^0)$	0.8° [18]	0.6°	0.2°	negligible
Charm *CP* violation	A_Γ	2.3×10^{-3} [18]	0.40×10^{-3}	0.07×10^{-3}	–
	ΔA_{CP}	2.1×10^{-3} [5]	0.65×10^{-3}	0.12×10^{-3}	–

Data aquisition and trigger



[Upgrade Software and Computing TDR
CERN-LHCC-2018-007]