Studying Lepton Flavour Universality and the Nuclear Structure with the Upgraded LHCb Experiment

PID2019-110378GB-I00

Instituto Galego de Física de Altas Enerxías (IGFAE)
Universidade de Santiago de Compostela (USC)

Abraham Gallas

UNIÓN EUROPEA
FONDO EUROPEO DE DESENVOLVEMENTO REXIONAL
"Unha maneira de facer Europa"

20 members

4 Permanent staff:
A. Gallas, J. Saborido, C. Santamarina, P. Vázquez.

2 Non-permanent researchers:
A. Romero, R. Vázquez.

4 Engineers/Technicians:
A. Fernández, E. Lemos, E. Pérez, M. Seco, A. Pazos.

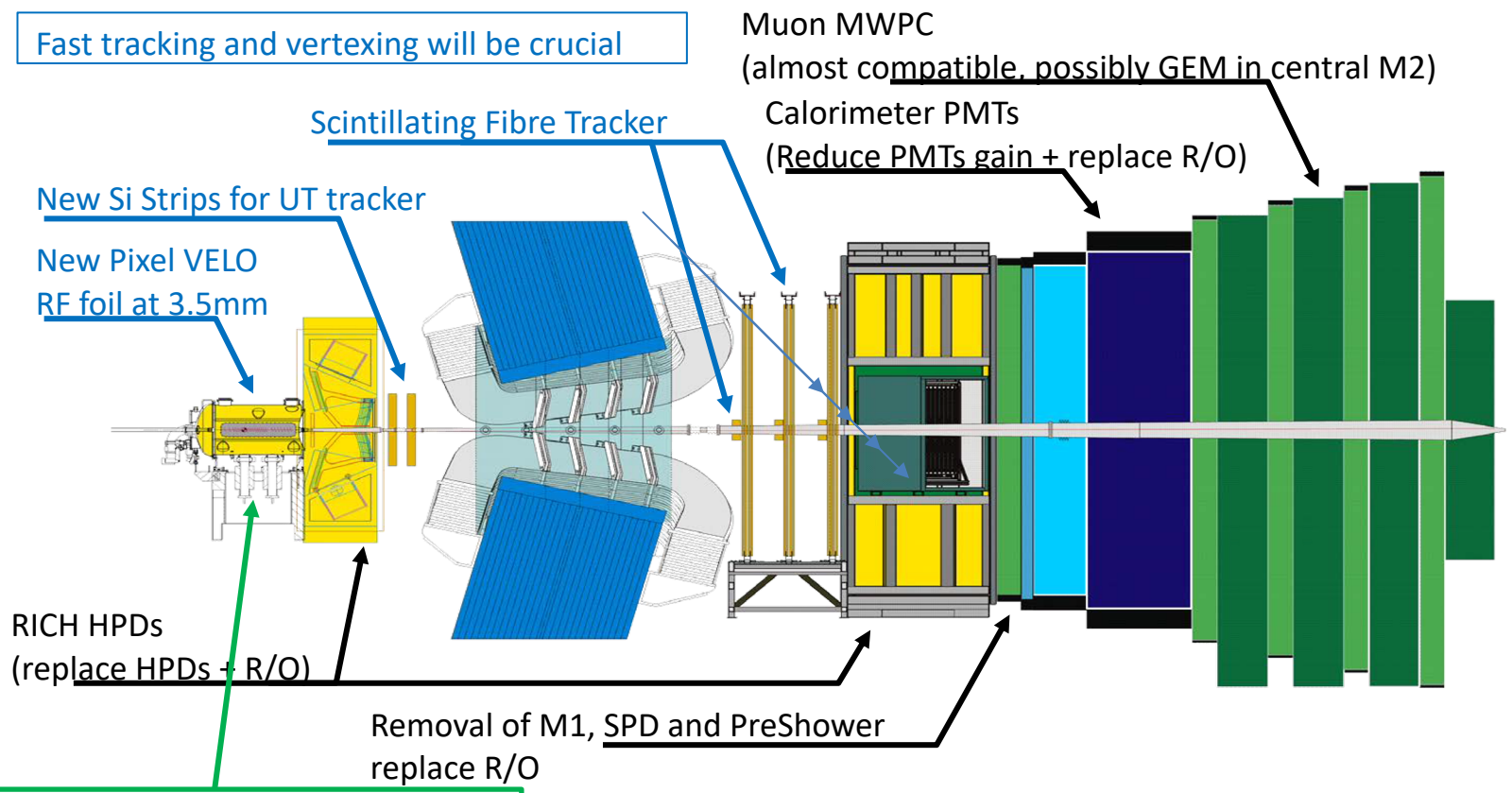
7 PhD students:
O. Boente, I. Corredoira, B. García, A. Gioventù, J. Lomba, E. Rodríguez, S. Sellam.

3 Master students:
C. Landesa, J. Novoa , C. Eirea.

LHCb Upgrade I

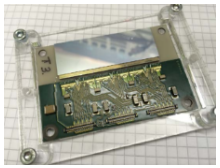
40 MHz readout software trigger only. New DAQ & Data Center.
Basically a new detector (less than 10% of original channels were kept)

LHCb upgrade ongoing



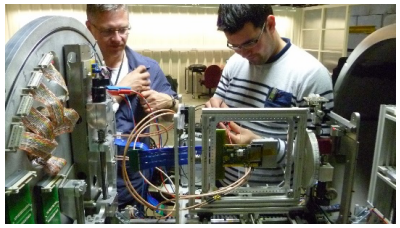
IGFAE/USC Contribution to the Vertex Detector: VELO

LHCb VELO Upgrade I @ IGFAE/USC



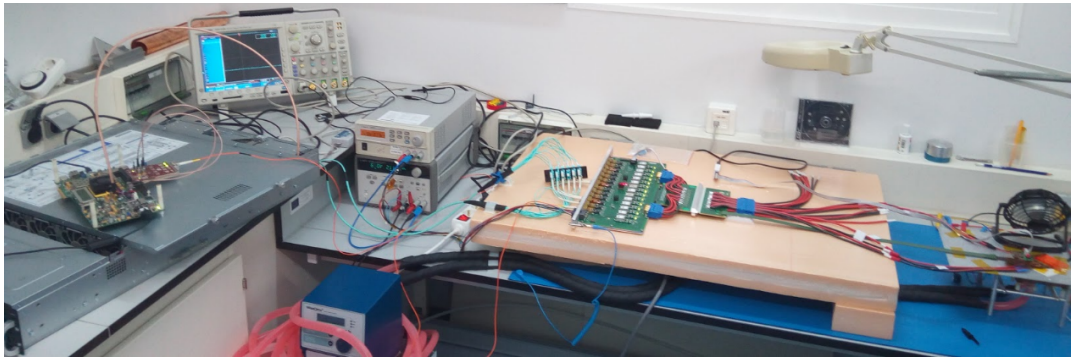
IGFAE/USC contributions to the VELO:

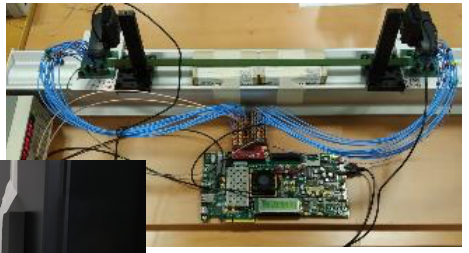
- **Sensors:**
  - Technology choice (strips vs pixels)
  - R&D, sensor design, prototype construction
  - Radiation resistance certification (n-irradiations)

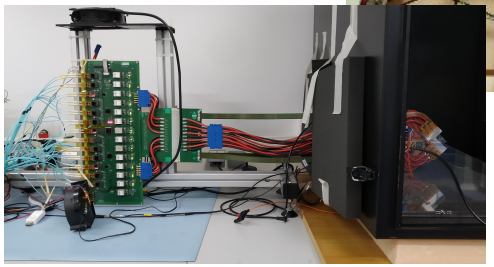


- **Front-end electronics:**
  - Full Qualification of VeloPix FEE ASIC
  - VeloPix Radiation hardness (SEE, TID)
  - Construction HV, High Speed Data Tapes and Vacuum Feed Through testing PCBs
  - Electronic Design Review (https://indico.cern.ch/event/725985/)
  - Testing and quality assurance

- **Back-end electronics development:**
  - VELO Readout Firmware and Control Software (Wincc)
  - 3 RO setups versions, based on Intel and Xilinx FPGAs
  - Workshop for the integration of VELO detector in the LHCb framework

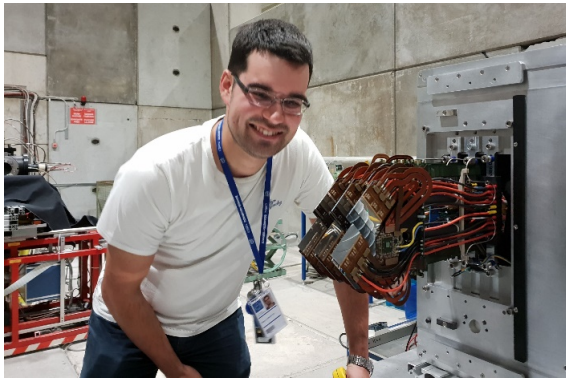




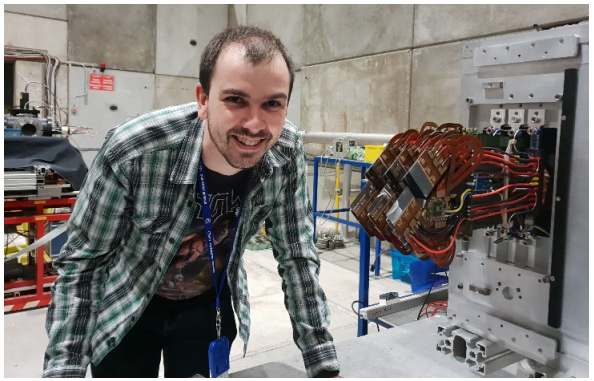


LHCb VELO Upgrade I @ IGFAE/USC

IGFAE Main contributor to the CERN test-beam: 1st full readout chain



Front-end electronics expert (IGFAE/USC)
VELO *DAQ and firmware coordinator*

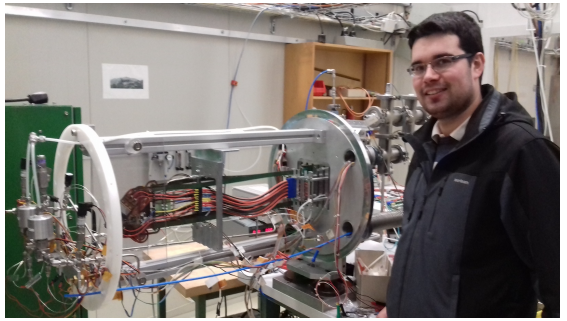


Back-end electronics expert (IGFAE/USC)
Main firmware developer

- **GBTx hybrid testing @ -38 ºC prior to final assembly**

- **Assembly of VFB (Vacuum Feedthrough Boards**

- **Optical Power Board DC assembly and testing**



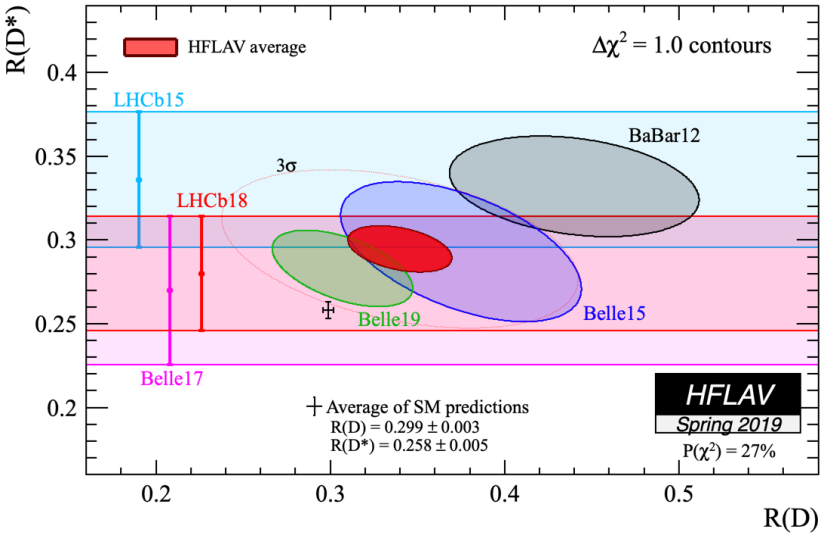
- **Slice test of full system**
  - **Final RO, cooling, monitoring, LV, HV…**
  - **2/52 Modules**

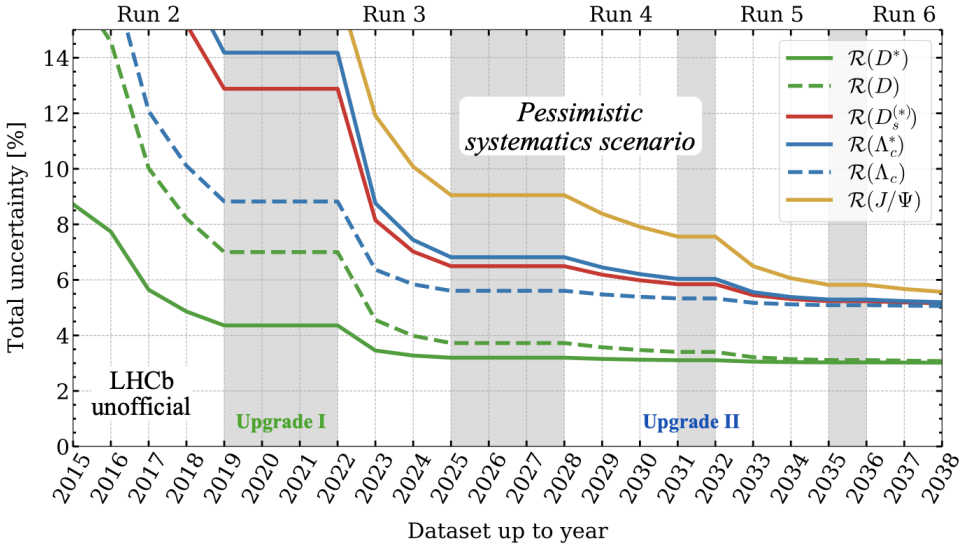
Lepton Flavour Universality (LFU) in semileptonic decays

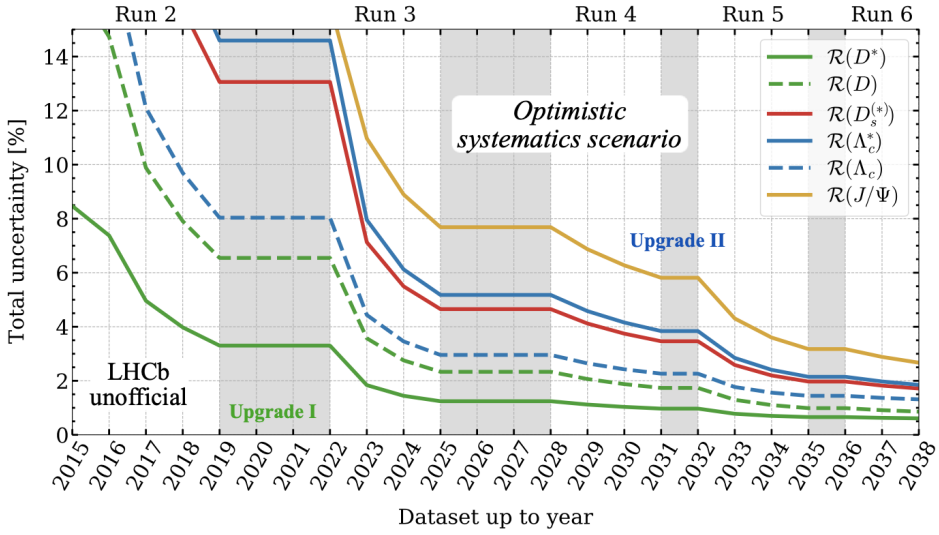
Test of LFU at tree level. Sensitive to charged Higgs bosons and leptoquarks

$$R\left(D^{(*)}\right) = \frac{\mathcal{B}\left(\bar{B}^0 \to D^{(*)+}\, \tau^-\, \bar{\nu}_\tau\right)}{\mathcal{B}\left(\bar{B}^0 \to D^{(*)+}\, \mu^-\, \bar{\nu}_\mu\right)}$$

- *Measurement of the ratio of the $B^0 \to D^{*-}\tau^+\nu_\tau$ and $B^0 \to D^{*-}\mu^+\nu_\mu$ branching fractions using three-prong tau-lepton decays,* ***Phys. Rev. Lett. 120, 17802 (2018).***
- *Test of lepton flavour universality by the measurement of the $B^0 \to D^{*-}\tau^+\nu_\tau$ branching fraction using three-prong decays,* ***Phys. Rev. D 97, 072013 (2018).***
- Review of Lepton Universality tests in B decays. ***J.Phys. G46 (2019) no.2, 023001.***

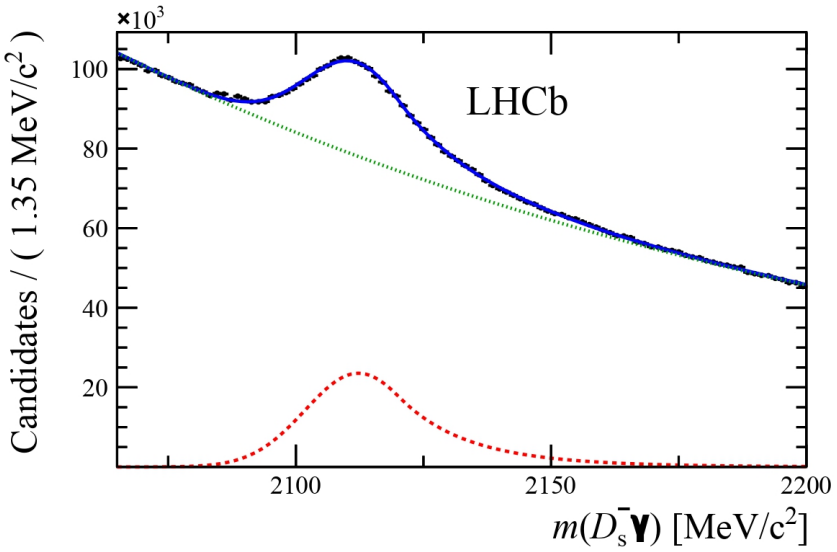






Lepton Flavour Universality (LFU) in semileptonic B_s decays

Test of LFU at tree level. Sensitive to charged Higgs bosons and leptoquarks.
LHCb has the unique ability to search for B_s decays.

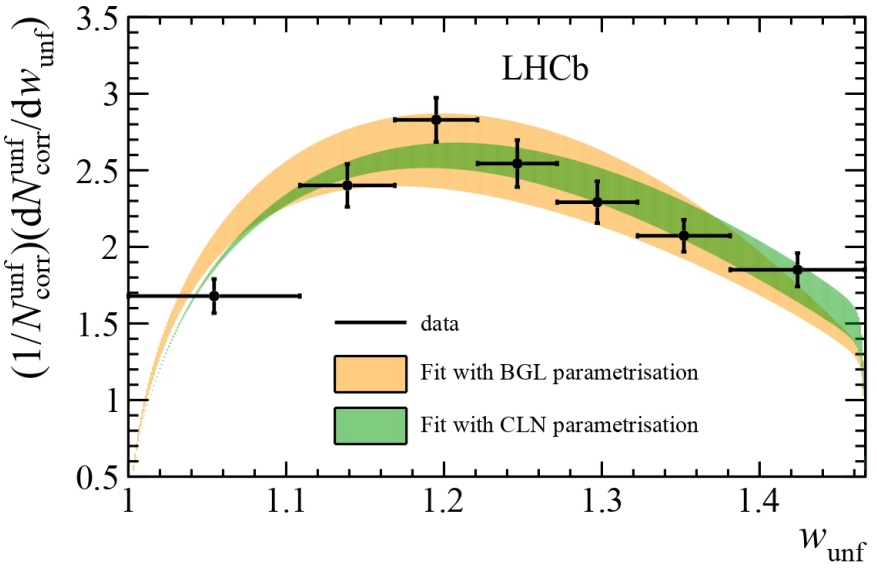


Semileptonic B_s decays are poorly studied. A first measurement of $R(D_s^*)$ would lack precision due to theory uncertainties i.e: hadronic form factors (FF).

- Measure the **hadronic FF** of B_s to D_s^* transitions.
- Fully reconstruct the D_s^* meson with soft photons.
- Heavy reduction of feed-down background.

[arXiv:2003.08453, already accepted by JHEP]

- First measurement of the differential decay BR and extraction of hadronic FF.
- Used two most common parametrisations: **CLN** and **BGL**.
- Proof of concept that full reconstruction with soft neutrals is possible.
- Extension to measure **$R(D_s^*)$** already ongoing.



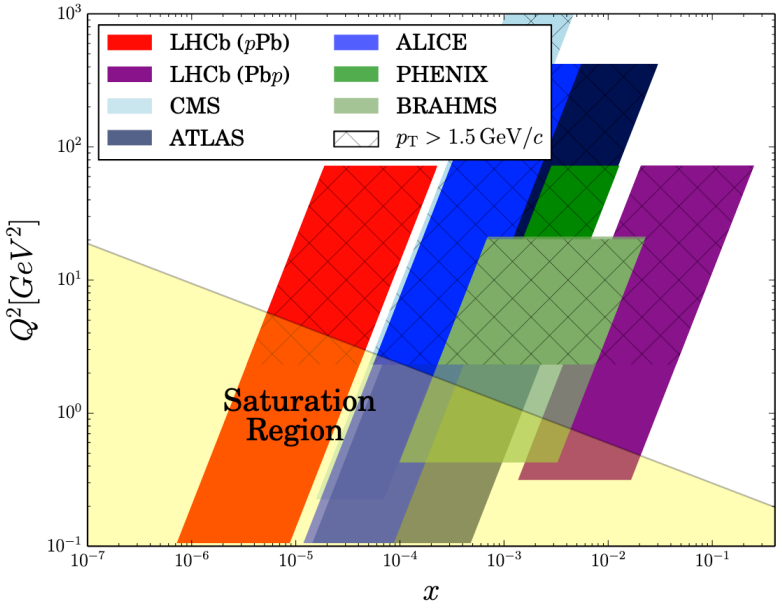
Proton-Lead collisions

Nuclear Modification Factor R_{pPb}

- R_{pPb}=1 in an incoherent superposition of nucleon-nucleon collisions.
- Deviations from unity reveal collective Cold Nuclear Matter effects (**CNM**): modifications of nuclear PDFs, Saturation, etc.

Measure R_{pPb} in **prompt charged** particle production

- LHCb can access uncovered phase space regions.
- This program is expanding to consider Particle Identification (pions, protons and kaons R_{pPb})
- Ongoing measurement of other observables $\langle p_T \rangle$

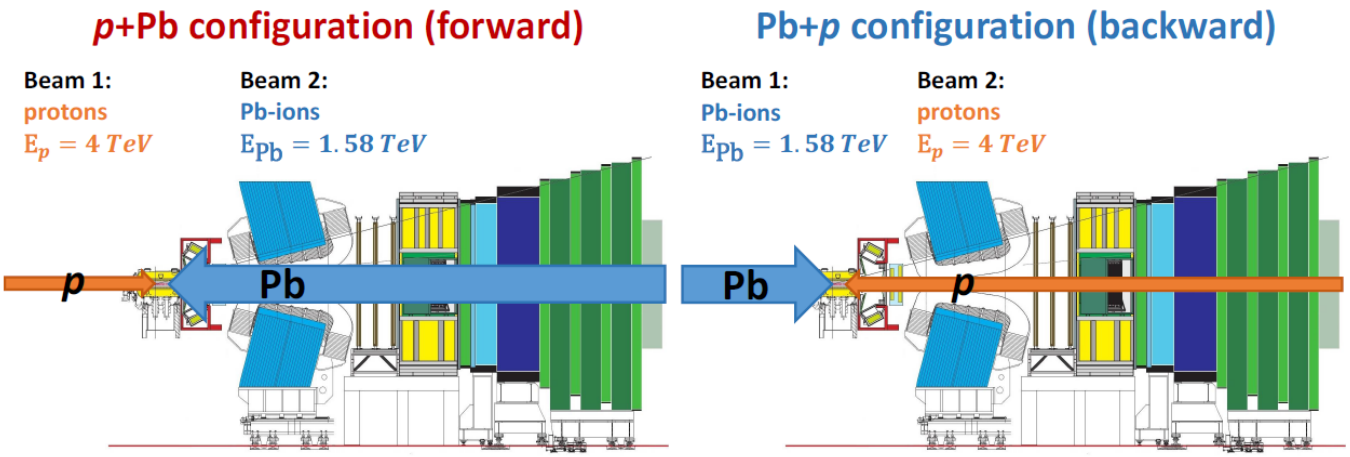


Joint effort with the IGFAE Phenomenology group: E. G Ferreiro and N. Armesto within STRONG 2020 action. First publication and Ph.D. thesis in spring 2021 (O. Boente). Two more Ph.D. theses ongoing (I. Corredoira and S. Sellam).

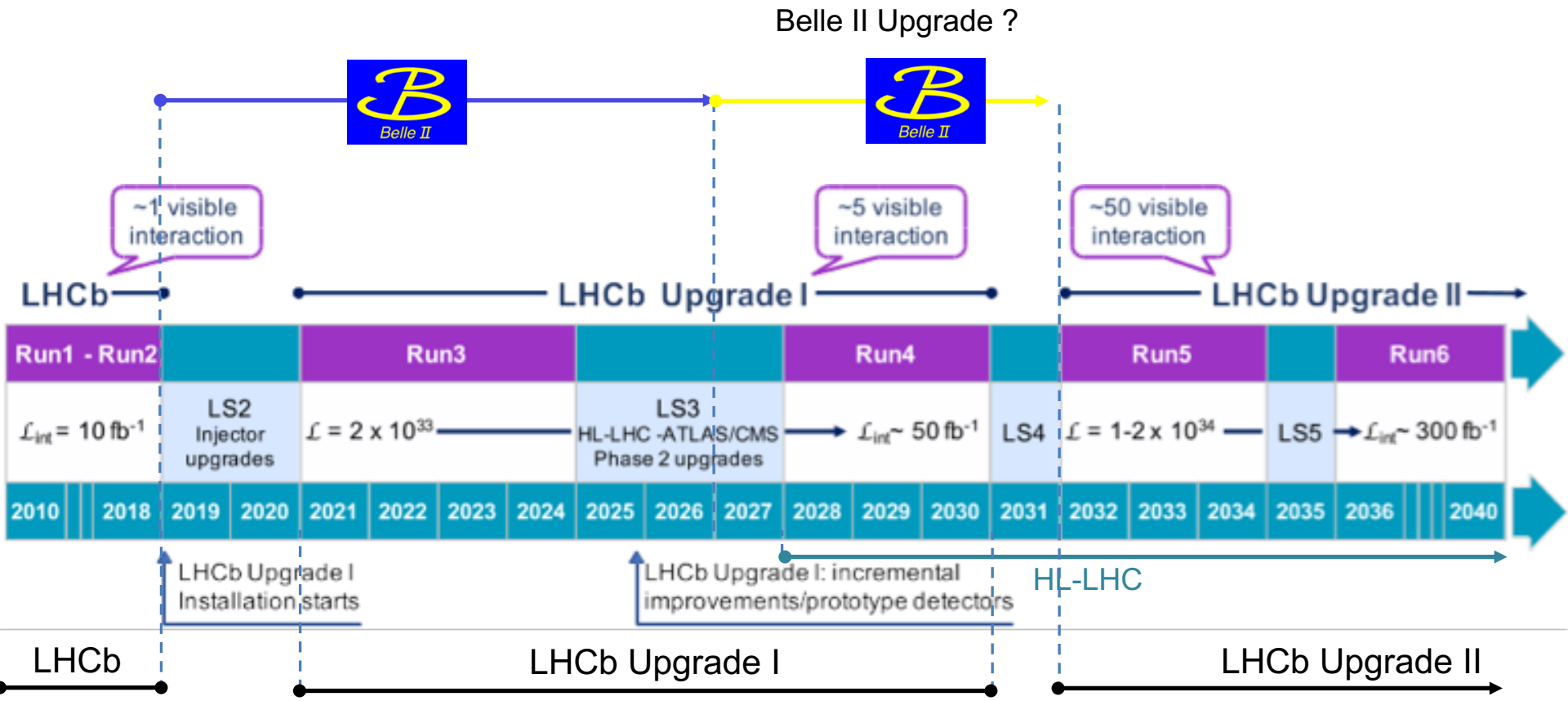
$$\mathrm{R}_{p\mathrm{Pb}}, \quad 1.5 < \eta < 4.5$$

$$\mathrm{R}_{\mathrm{Pb}p}, \quad 2.5 < \eta < 5.5$$

$$\mathrm{R}_{\mathrm{FB}} = \frac{\mathrm{R}_{p\mathrm{Pb}}}{\mathrm{R}_{\mathrm{Pb}p}}, \quad 2.5 < \eta < 4.5$$

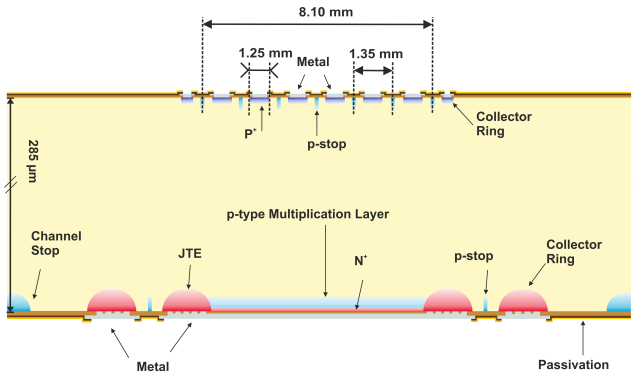


LHCb Timeline (before COVID-19)



LHCb Upgrade II at IGFAE/USC

- High temporal resolution and high granularity at high rates Vertexing for Upgrade II:
  - Sensors (pixelated iLGAD, 3D, thin planar…)
  - Front-end and DAQ (TimePix4,…)



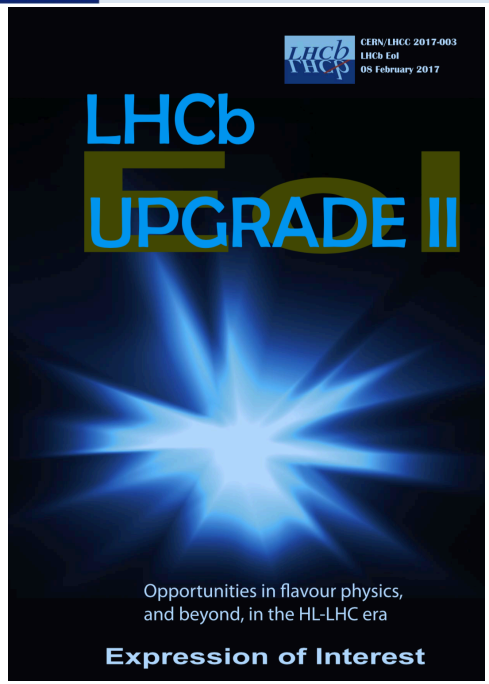
Thick I-LGAD cross-section

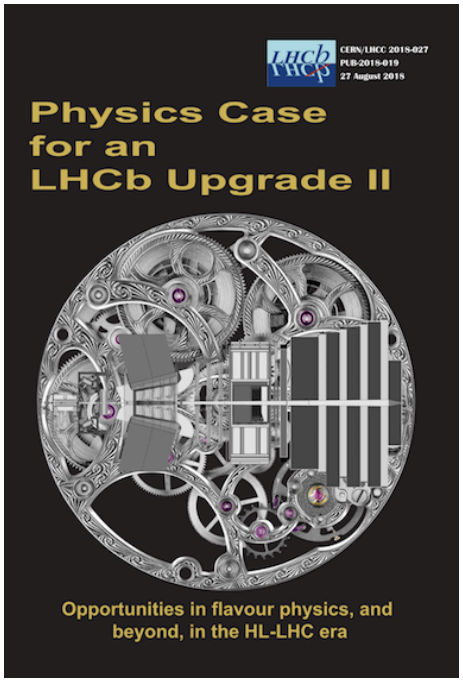
- R&D in collaboration with different partners from RD50, **AIDAinnova**

- Participation in the design group of the VELO Upgrade II FTDR
  - See Edgar´s talk at **LHCb upgrade 1b/2 electronics kick-off workshop**

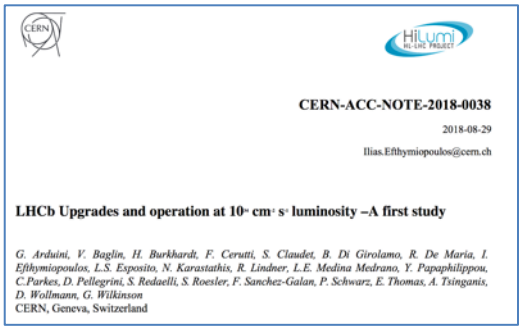
    https://indico.cern.ch/event/960837/

LHCb Upgrade II





1. CERN-LHCC-2017-003
2. CERN-LHCC-2018-027



CERN-ACC-NOTE-2018-0038

2018-08-29

Ilias.Efthymiopoulos@cern.ch

LHCb Upgrades and operation at 10^{34} cm^{-2} s^{-1} luminosity –A first study

G. Arduini, V. Baglin, H. Burkhardt, F. Cerutti, S. Claudet, B. Di Girolamo, R. De Maria, I. Efthymiopoulos, L.S. Esposito, N. Karastathis, R. Lindner, L.E. Medina Medrano, Y. Papaphilippou, C.Parkes, D. Pellegrini, S. Redaelli, S. Roesler, F. Sanchez-Galan, P. Schwarz, E. Thomas, A. Tsinganis, D. Wollmann, G. Wilkinson

CERN, Geneva, Switzerland

Framework TDR expected in 2021 !

Conditions:

- Luminosity: 1.5×10^{34} cm^{-2}s^{-1} (inst.), 300 fb^{-1} (int.)
- 50 visible interactions / crossing.

Challenge:

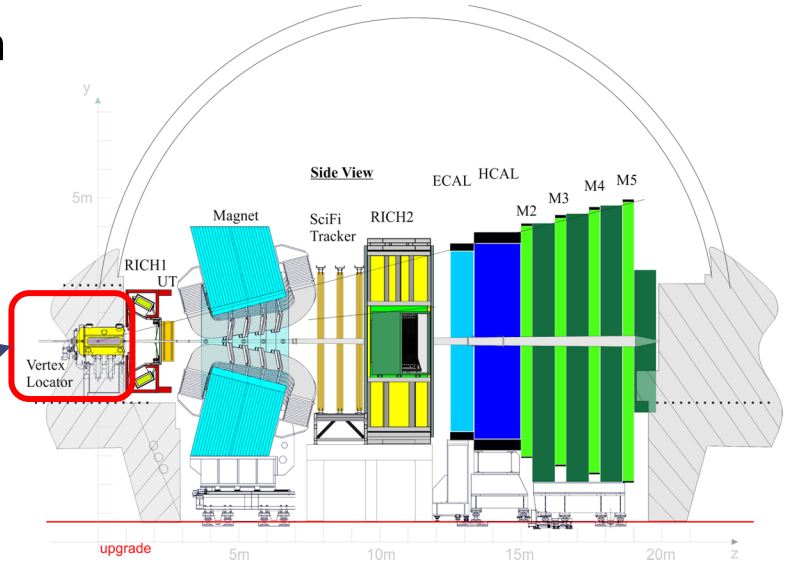
- Maintain current reconstruction performance in much, much harsher environment.
- Develop detectors with timing information for tracking & Particle ID.

Backup Slides

LHCb Upgrade phase-I

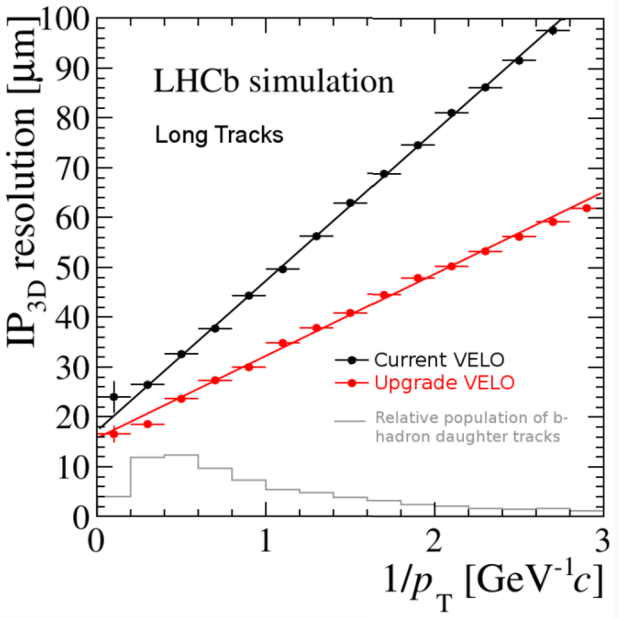
- Goal: 5x current luminosity 2×10^{33} cm^{-2} s^{-1}
- Double the present yield: collect 5 fb^{-1}/y in Run 3 and Run 4
- Improve trigger efficiency on hadronic channels and on rare decays
- Expand the scope to the lepton flavor sector, electroweak physics, QCD and exotics searches
- Actions:
  - Remove the current hardware trigger of 1MHz
  - New front-end and back-end electronics in most of the sub-detectors
  - New tracking system

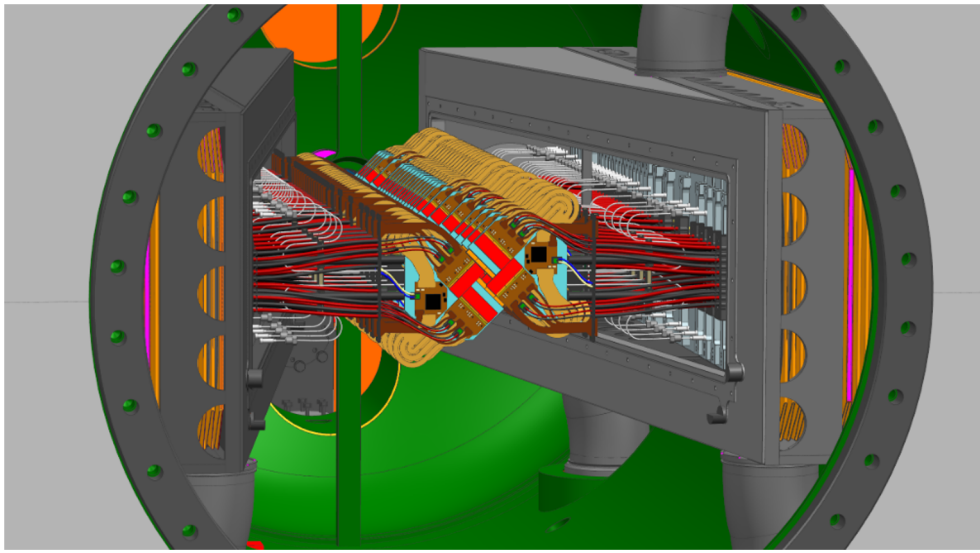
IGFAE/USC contribution to the vertex detector



LHCb VELO upgrade

- **Primary tracking and vertexing detector** surrounding the collision region
  - In high vacuum (separated from the LHC vacuum by a RF foil)
- **Pixel** technology (before r/ϕ microstrip)
  - **More robust track reconstruction performance**
  - Better resolution
  - Closer to beam (8.1mm to 5.1mm). **Retractable halves**.
- **Faster readout (1MHz to 40MHz)**
- New ASIC VeloPix, based on TimePix family
- New microchannel evaporative CO_2 cooling
- Some figures:
  - 52 modules, 624 VeloPix ASICs
  - Detector active area 0.12 m²
  - **~41 M pixels** (**55x55 µm²**)
  - HV tolerance of 1000V
  - **Trigger-less readout ~2.9 Tbit/s**
  - Highly non-uniform radiation. Up to 4MGy





CP-violating observables

Mixing-induced CP-violating parameters

$B_s^0 \longrightarrow f_{CP}$

$B_s^0 \rightarrow \bar{B}_s^0 \rightarrow f_{CP}$

Interfering amplitudes in decays to CP eigenstates

$B_s^0 \rightarrow J/\psi\, K^- K^-$

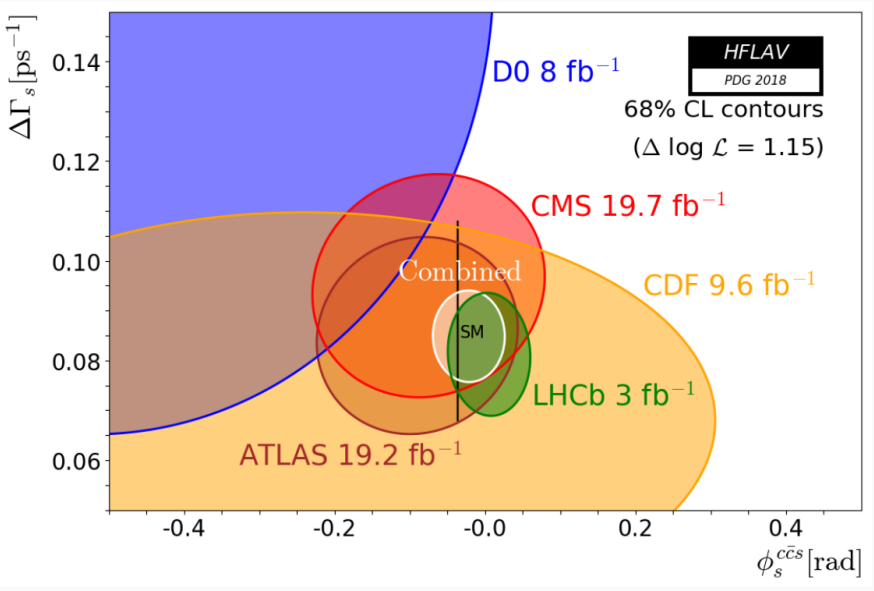
$\phi_s^{c\bar{c}}(\mathrm{SM}) = -2\beta_s$

$\beta_s = \arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right)$

$B_s^0 \rightarrow (K^+\pi^-)(K^-\pi^+)$

$\phi_s^{d\bar{d}}(\mathrm{SM}) \approx 0$

JHEP03 (2018) 140, JHEP11 (2015) 082, Phys. Rev. Lett. 114 (041801) 2015, Phys. Rev. D 86 (071102) 2012.



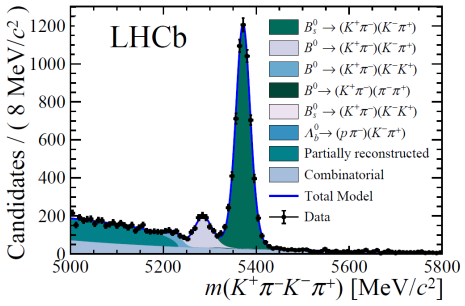
$B \rightarrow V_1 V_2$ Charmless decays to vector mesons

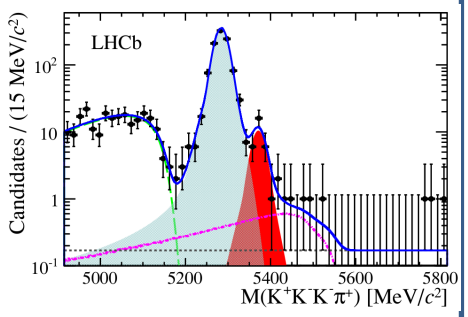
Measurement of polarization amplitudes, branching fractions, CP asymmetries in various decays of B mesons to charmless vector mesons.

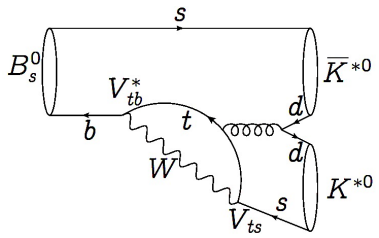
$B_s^0 \longrightarrow K^{*0}\bar{K}^{*0}, \quad \rho^0\rho^0, \quad \phi\bar{K}^{*0}$

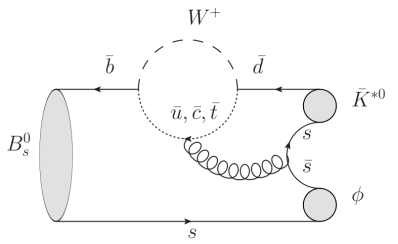
$B^0 \longrightarrow K^{*0}\bar{K}^{*0}, \quad \rho^0 K^{*0}, \quad \phi K^{*0}$

arXiv:1812.07008, JHEP03 (2018) 140, Phys. Lett. B 747 (2015) 468, JHEP07 (2015) 166, JHEP05 (2014) 069, JHEP11 (2013) 092, Phys. Lett. B 709 (2012) 50.



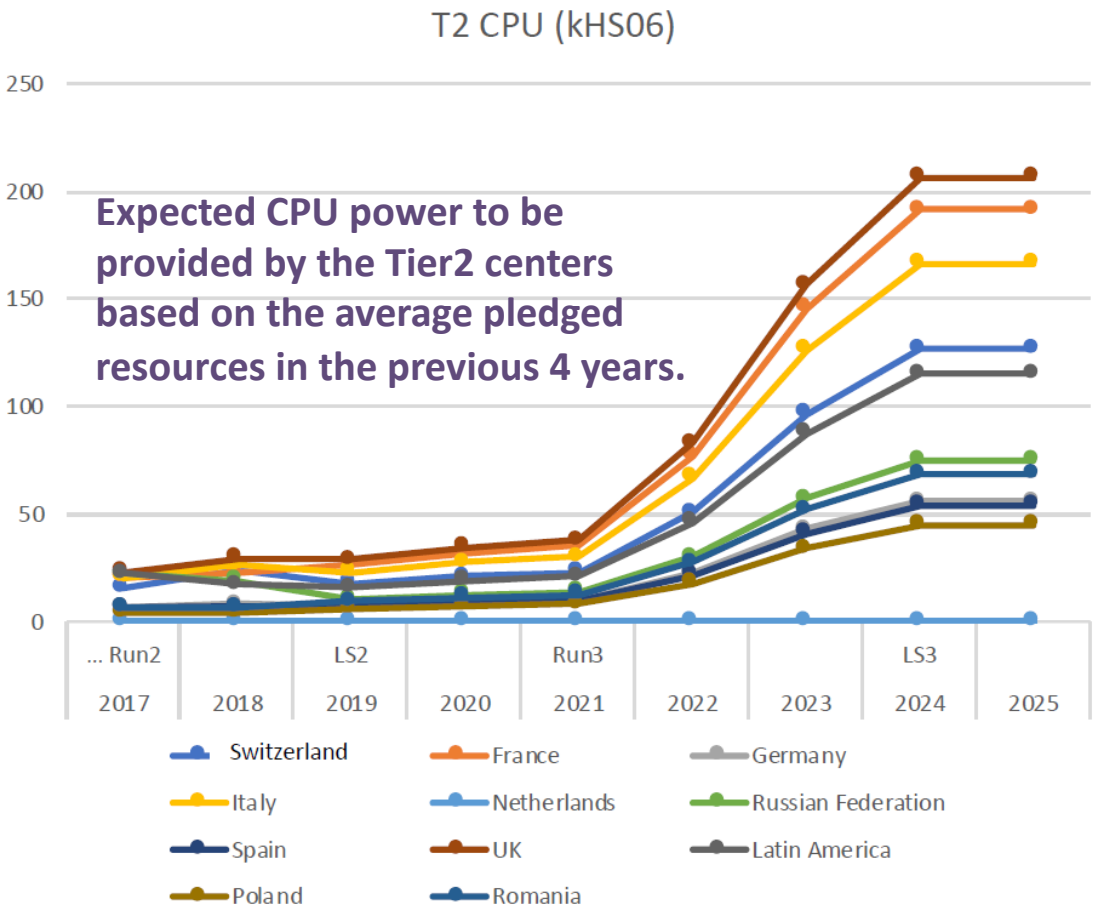






Tier2 GRID computing

- The Spanish LHCb Tier2 center runs now only at IGFAE. It has produced over the years about the 5% of the LHCb-Tier2 integrated resources.
- Exploring possibilities at BSC and CESGA supercomputing centers
- At present we have 74 working nodes: 148 physical (1016 logical) cores delivering 10 kHS06



(1 HS06 = 10 €)

Core Cost

50 kHS06 = 500 k€

Spain

This is what ES-LHCb-T2 would need to have installed by the end of 2023