Activities of the LNF LHCb group

54th LNF scientific committee meeting / November 13th-14th, 2017

Marco Santimaria
on behalf of the LNF LHCb group

OUTLINE

1. The group
   members and responsibilities
2. Physics analyses at LNF
   $B_{d,s} \rightarrow \mu^+\mu^-$, $R(D_s)$, Λ^+_c
3. Upgrade
   MWPC, nODEs, trigger software
4. Future projects
   μ-RWELL, fixed target @ LHCb
5. Conclusions

1. the group

The LNF LHCb group

Large group with many responsibilities in the LHCb collaboration

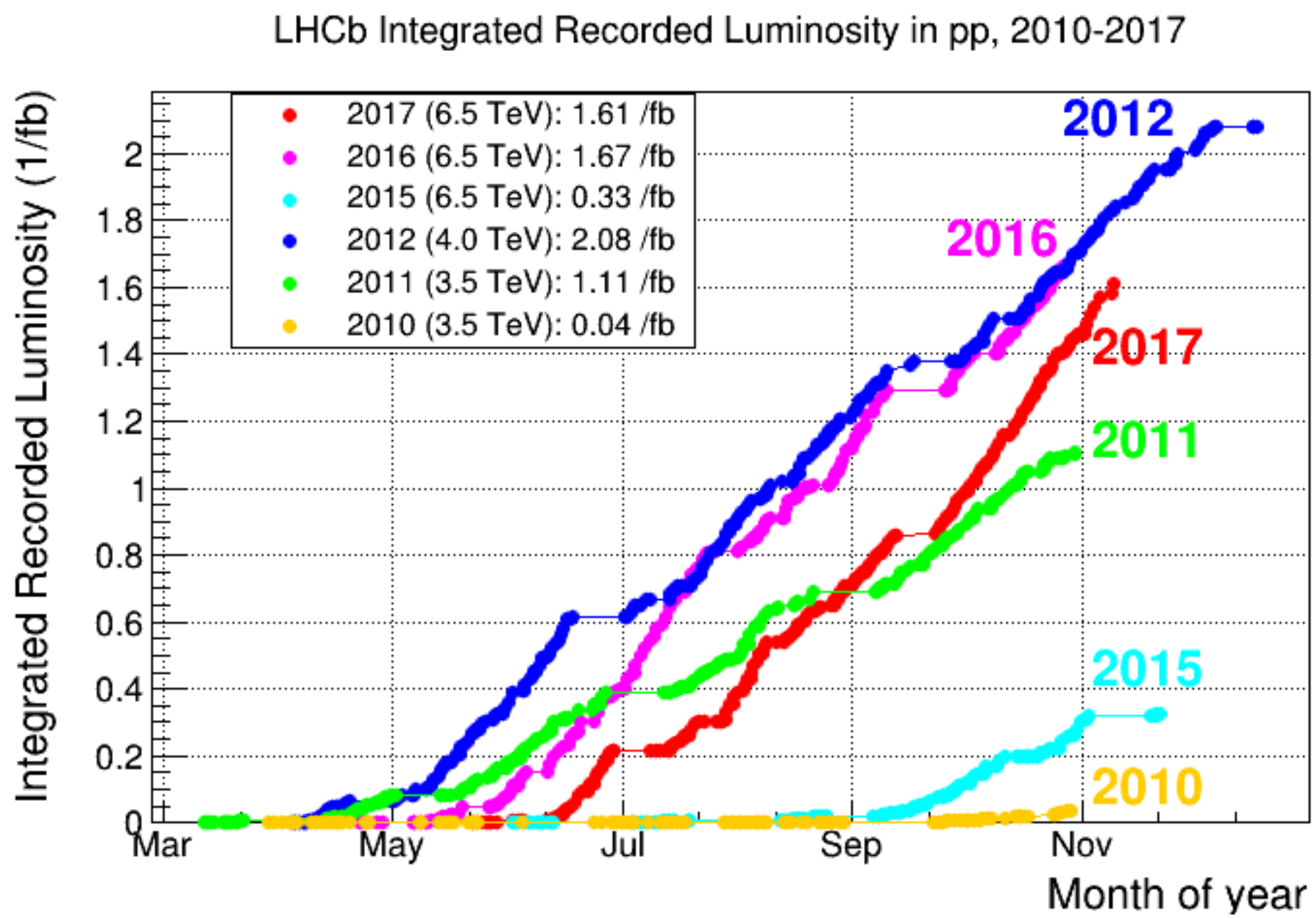
- Pietro Albicocco [POST-DOC]
- Giovanni Bencivenni [STAFF]
- Liliet Calero Diaz [PHD STUDENT]
- Pierluigi Campana [STAFF]
- Paolo Ciambrone [STAFF]
- Patrizia De Simone [STAFF] (Muon reconstruction coordinator)
- Pasquale Di Nezza [STAFF] (SMOG2 coordinator)
- Suzanne Klaver [POST-DOC]
- Gaia Lanfranchi [STAFF]
- Simonetta Liuti [ASSOCIATE RESEARCHER]
- Gianfranco Morello [POST-DOC]
- Matteo Palutan [STAFF] (Muon project leader)
- Marco Poli Lener [STAFF]
- Marcello Rotondo [STAFF]
- Marco Santimaria [POST-DOC]
- Alessio Sarti [ASSOCIATE RESEARCHER]
- Barbara Sciascia [STAFF] (LNF group coordinator, deputy operation coordinator)

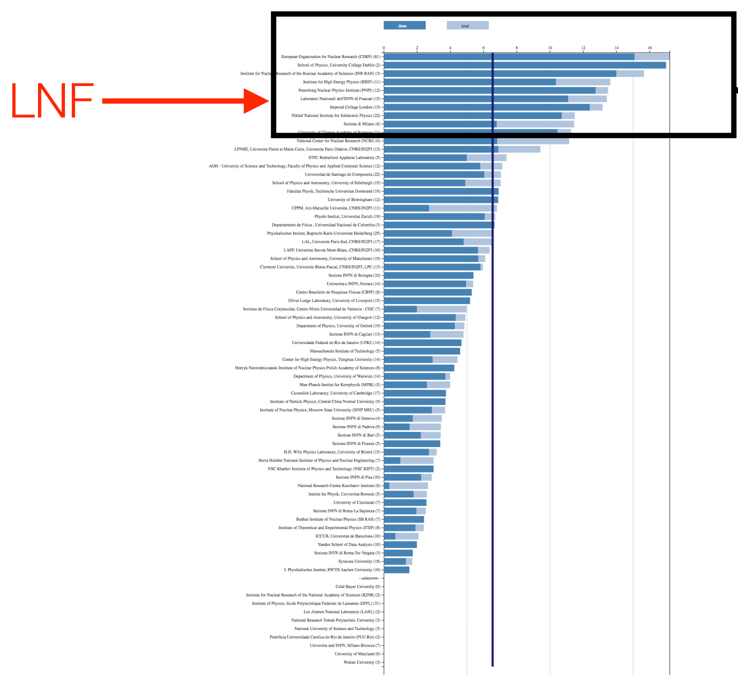
Run 2 data taking

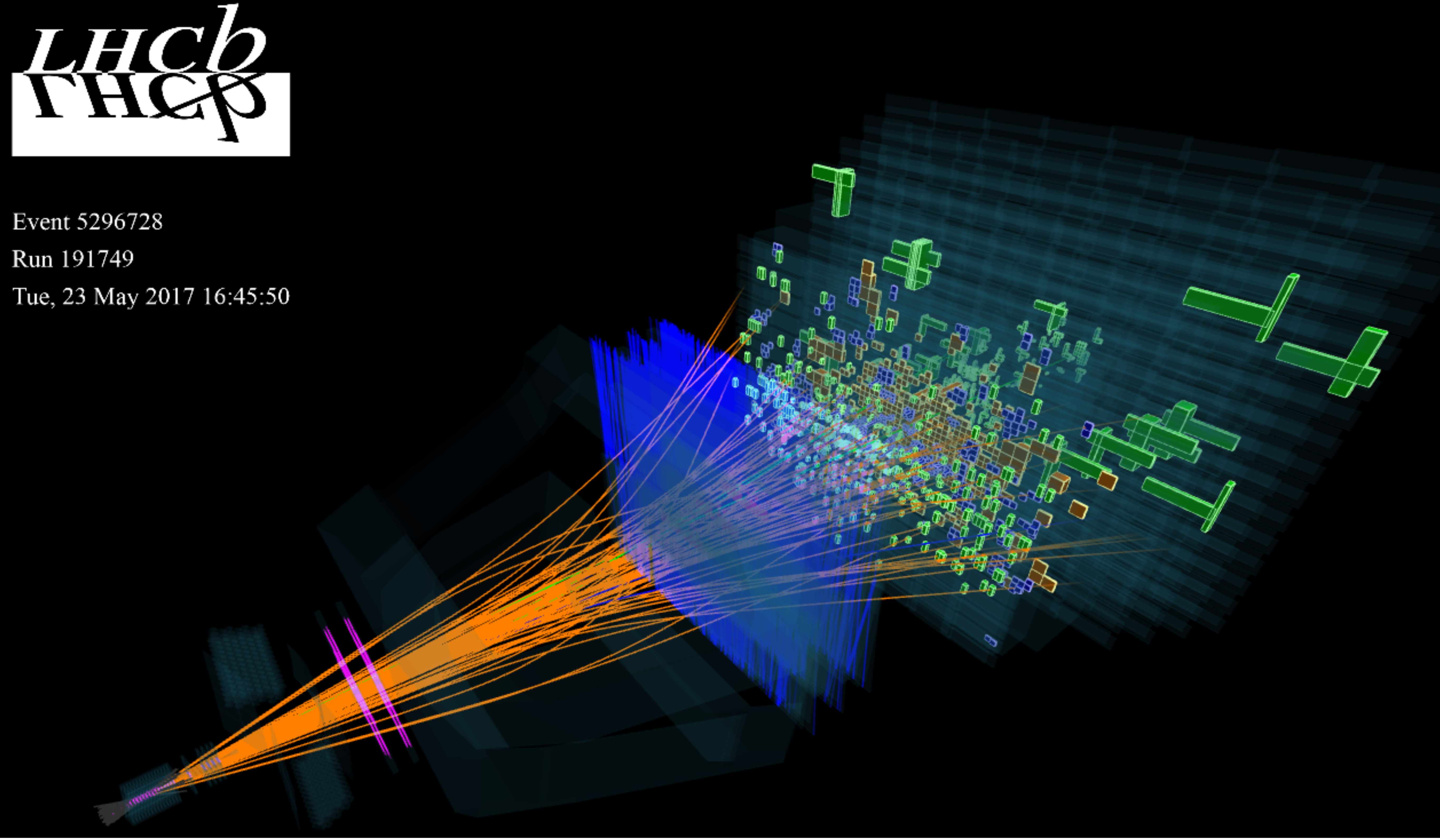
Very good LHC availability and very efficient LHCb data-taking (ε~91%)

Run 1 statistics has been surpassed in Run 2, whose data are also enriched in B-hadrons (a factor ~2)

The LNF group is one of the most active in taking shifts and on-call duties

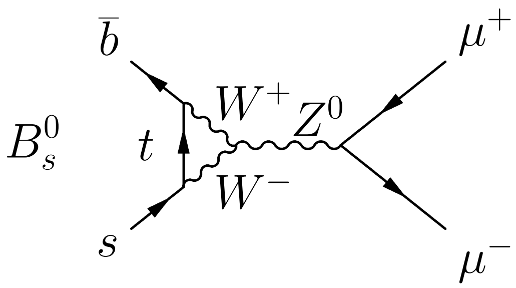


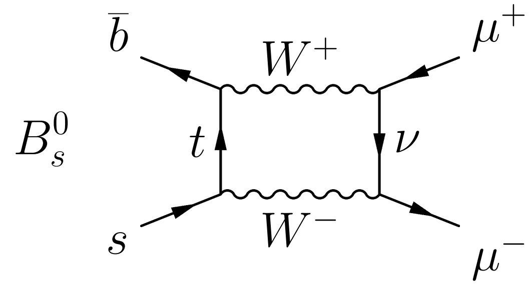




2. physics analyses at LNF

$B_{d,s} \to \mu^+\mu^-$





- In the SM, $B_{d,s} \to \mu^+\mu^-$ decays can only occur via higher order FCNC and helicity-suppressed processes
- New particles entering the loop can affect the BF

Very clean probe of possible scalar and pseudo-scalar contributions:

1. Single hadronic constant
2. Single Wilson coefficient

→ precise prediction

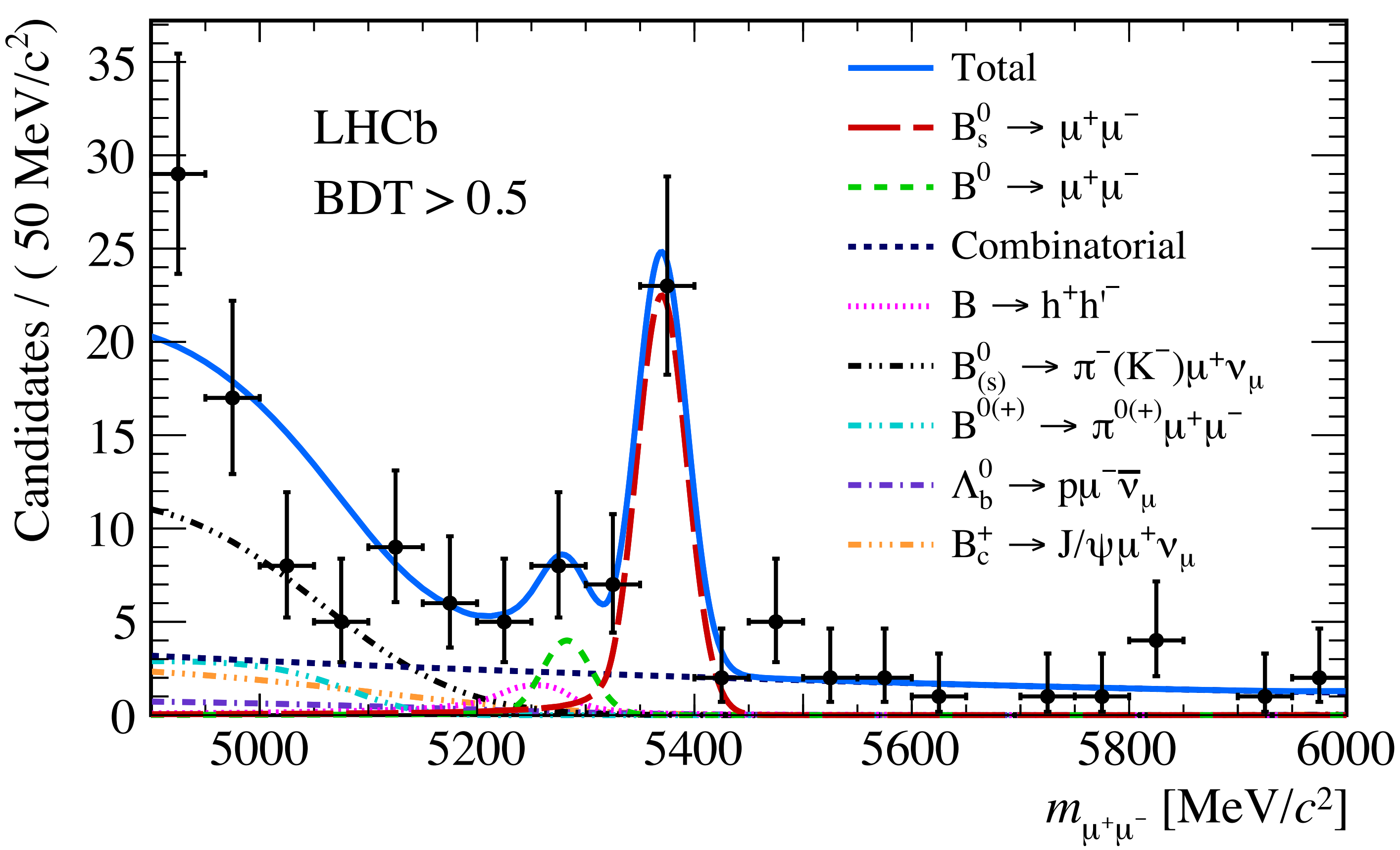
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.65 \pm 0.23) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.06 \pm 0.09) \times 10^{-10}$$

[Phys. Rev. Lett. 112 (2014) 101801]

1984: First limit to the $B_s \to \mu^+\mu^-$ BF [CLEO, Phys. Rev. D 30 (1984)11]

2014: First observation with LHCb+CMS combined analysis [Nature 522, 68-72 (2015)]

2016: Run 2 data, reoptimised analysis and improved background rejection



$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.0 \pm 0.6^{+0.3}_{-0.2}) \times 10^{-9}$$
$$\mathcal{B}(B_d^0 \to \mu^+\mu^-) < 3.4 \times 10^{-10} \quad @ \ 95\% \ \mathrm{CL}$$

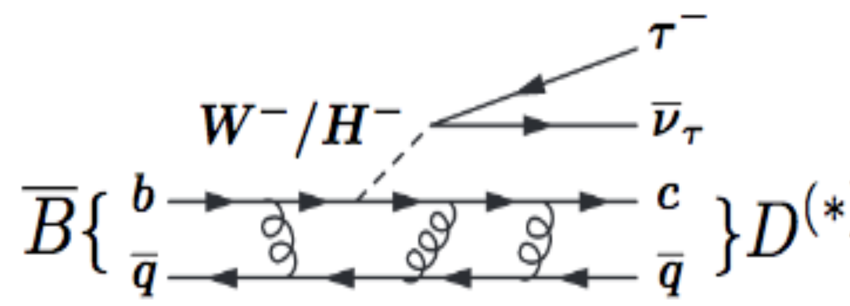
- First single-experiment observation of the $B_s \to \mu^+\mu^-$ decay
- World best measurement of the $B_s \to \mu^+\mu^-$ BF and first measurement of its effective lifetime
- $B_d \to \mu^+\mu^-$ limit approaching the SM prediction
- Published on [Phys. Rev. Lett. **118**, 191801]
- **My PhD thesis!**

LFU test with semileptonic decays

$$\mathcal{R}(D) = \frac{\mathcal{B}(\bar{B} \to D\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to Dl^-\bar{\nu}_l)}$$

$$\mathcal{R}(D^*) = \frac{\mathcal{B}(\bar{B} \to D^*\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^*l^-\bar{\nu}_l)}$$

- Solid SM prediction (V_{cb} and FF uncertainties largely cancel)
- Sensitive to LFV contributions from e.g. 2HDM



- R(D): FNAL/HPQCD + BaBar and Belle FF
  R(D*): Recent (consistent) calculations

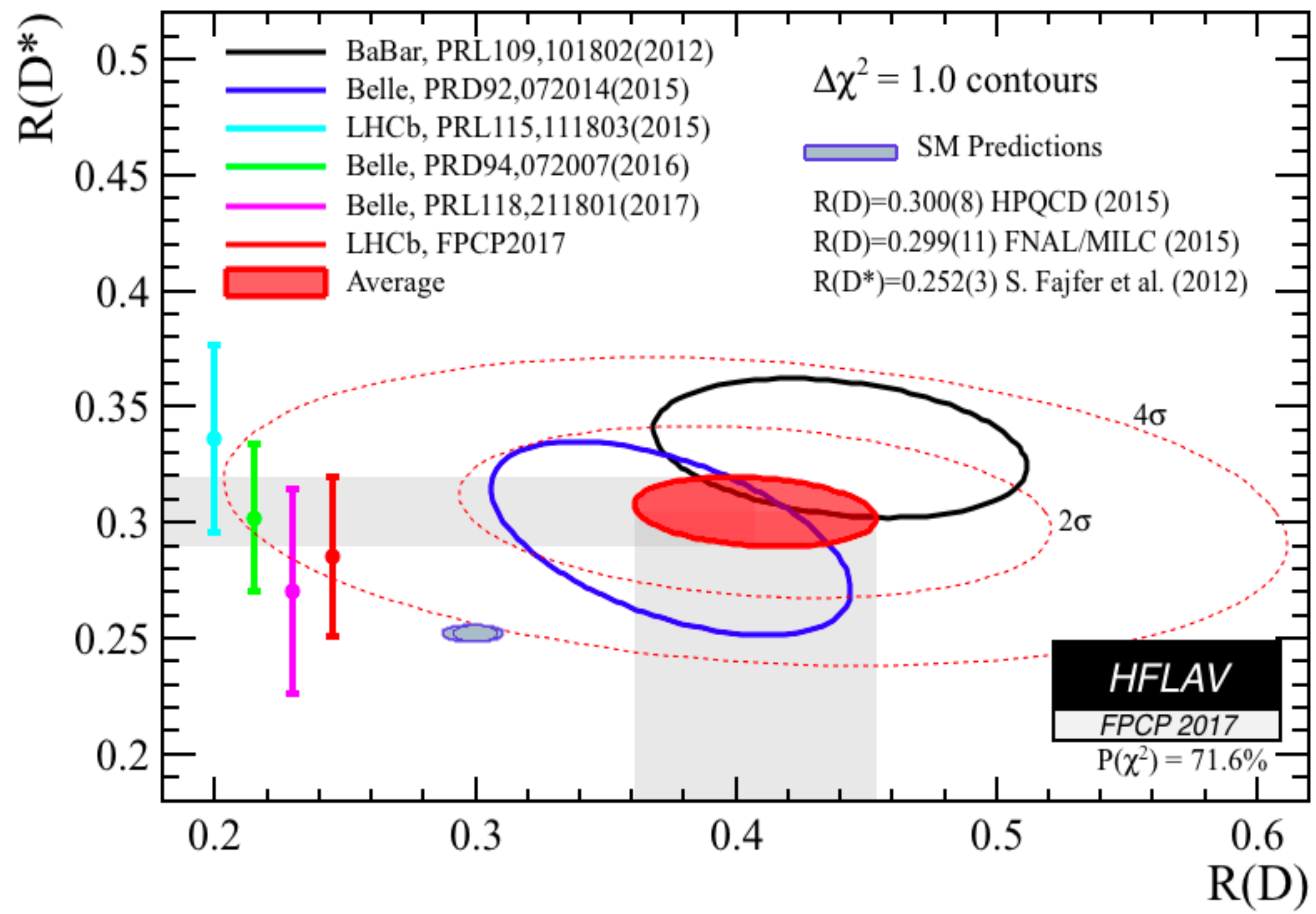
- LHCb contributes to R(D*) with leptonic (cyan) and 3-prong (red) tau decays.

  → 4 σ discrepancy wrt the SM

Many NP models to explain this difference point towards large LFU violation

2 σ deviation from SM recently observed in R(J/ψ) from B_c decays @ LHCb

[LHCb-PAPER-2017-035]



R(D$_s$)-R(D*$_s$)

$$\mathcal{R}(D_s) = \frac{\mathcal{B}(\bar{B} \to D_s \tau^- \bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D_s l^- \bar{\nu}_l)}$$

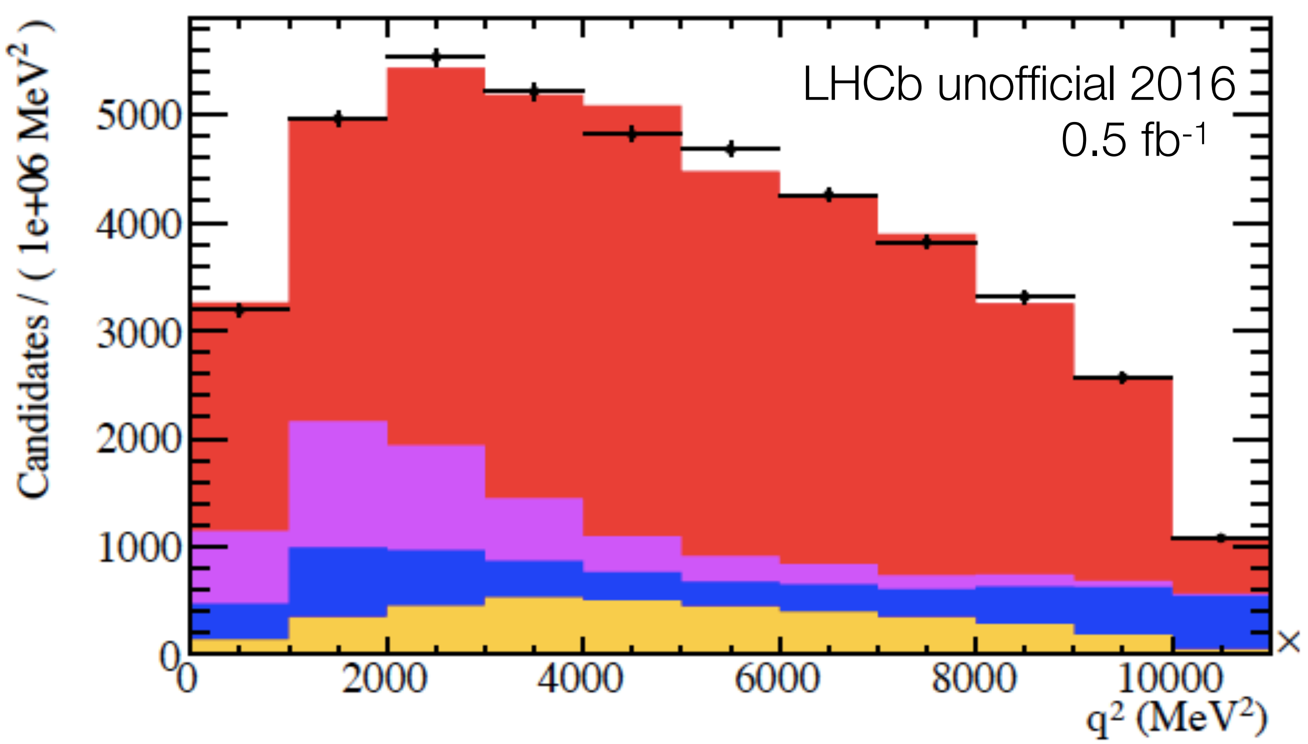
$$\mathcal{R}(D_s^*) = \frac{\mathcal{B}(\bar{B} \to D_s^* \tau^- \bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D_s^* l^- \bar{\nu}_l)}$$

LFU: Exploit the abundant B$_s$ production to study semitauonic B$_s$ decays.
Ongoing work on B$_s$→D$_s$τν and B$_s$→D*$_s$τν :

- PRO: Small feed-down from excited Ds** states in B$_s$→D$_s$**μν
- CON: D$_s$* hard to reconstruct in LHCb due to the photon

ANALYSIS ROADMAP:

1) Measurement of the B$_s$→D$_s$*μν form factor



B$_s$→D$_s$*μν (red), H$_b$→D$_s$*H (purple), combinatorial (blue), B$_s$→D$_s$*τν (yellow)

$$\frac{d\Gamma}{dq^2} = \frac{|V_{cb}|G_F^2}{48\pi^3} \cdot \mathcal{K}(q^2) \cdot \mathcal{F}^2(q^2)$$

- FF is fundamental to allow for a reliable SM prediction of R(D*$_s$). Inputs from LQCD at low recoil are ongoing
- Well advanced state of the measurement

2) Measurement of R(D*$_s$) and other observables e.g. q^2 , D*$_s$ polarisation

3) Combined R(D$_s$)-R(D*$_s$) measurement, as done for B decays

$\Lambda^+_c \to phh'$ branching fractions

Hadronic decays of charmed baryons are a useful environment to study the interplay between weak and strong interactions

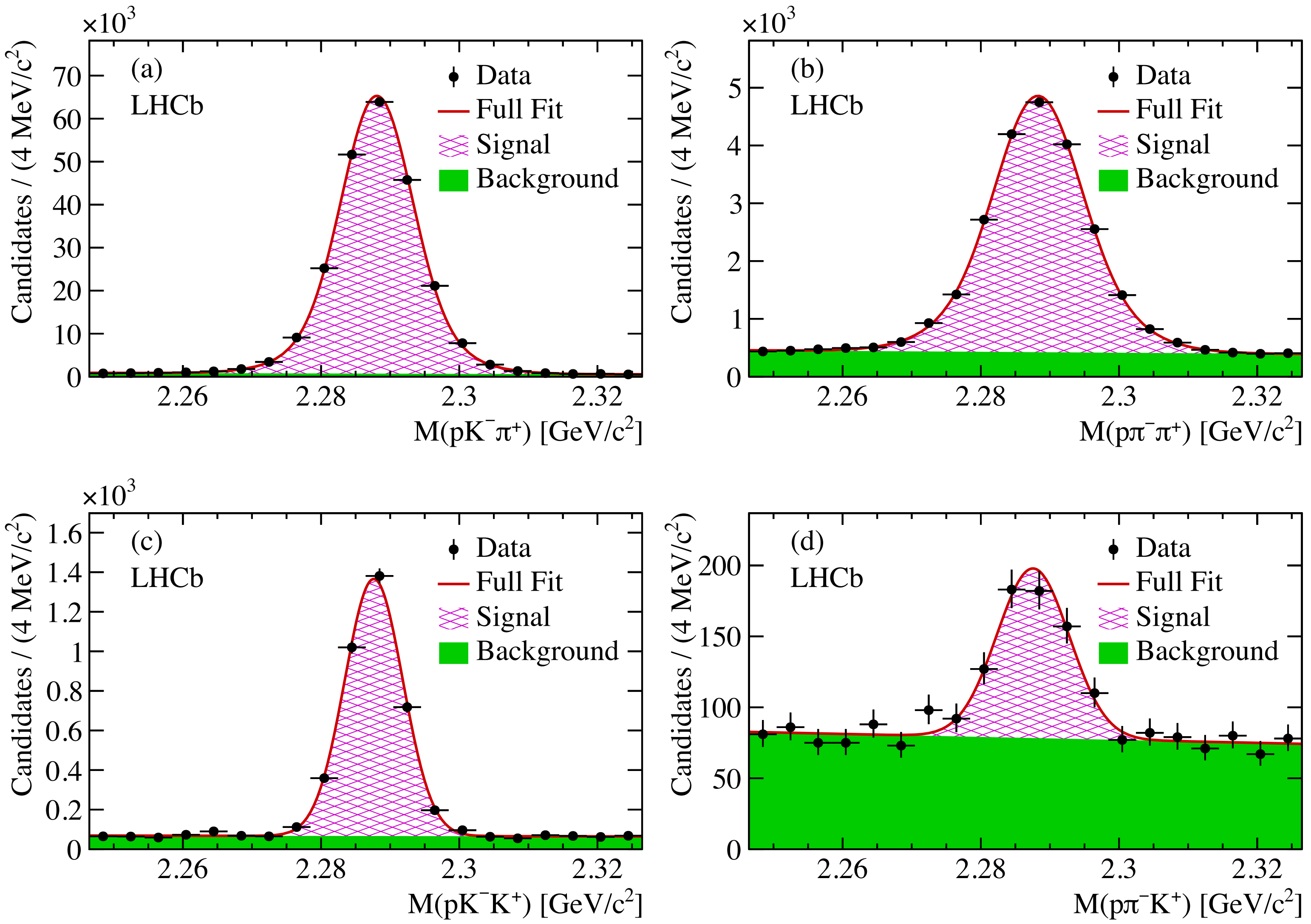
→ B(DCS)/B(CF) measurements are crucial for understanding the contributions from W-boson exchange diagrams (external emission, internal emission, exchange)

- Λ^+_c reconstructed in $\Lambda^0_b \to \Lambda^+_c \mu^- X$ (SL)
- Λ^+_c prompt sample as cross-check, separated via the impact parameter (IP)

Most precise measurement of the ratios:

$$\frac{\mathcal{B}(\Lambda_c^+ \to p\pi^-\pi^+)}{\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)} = (7.44 \pm 0.08 \pm 0.18)\,\%,$$
$$\frac{\mathcal{B}(\Lambda_c^+ \to pK^-K^+)}{\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)} = (1.70 \pm 0.03 \pm 0.03)\,\%,$$
$$\frac{\mathcal{B}(\Lambda_c^+ \to p\pi^-K^+)}{\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)} = (0.165 \pm 0.015 \pm 0.005)\,\%,$$

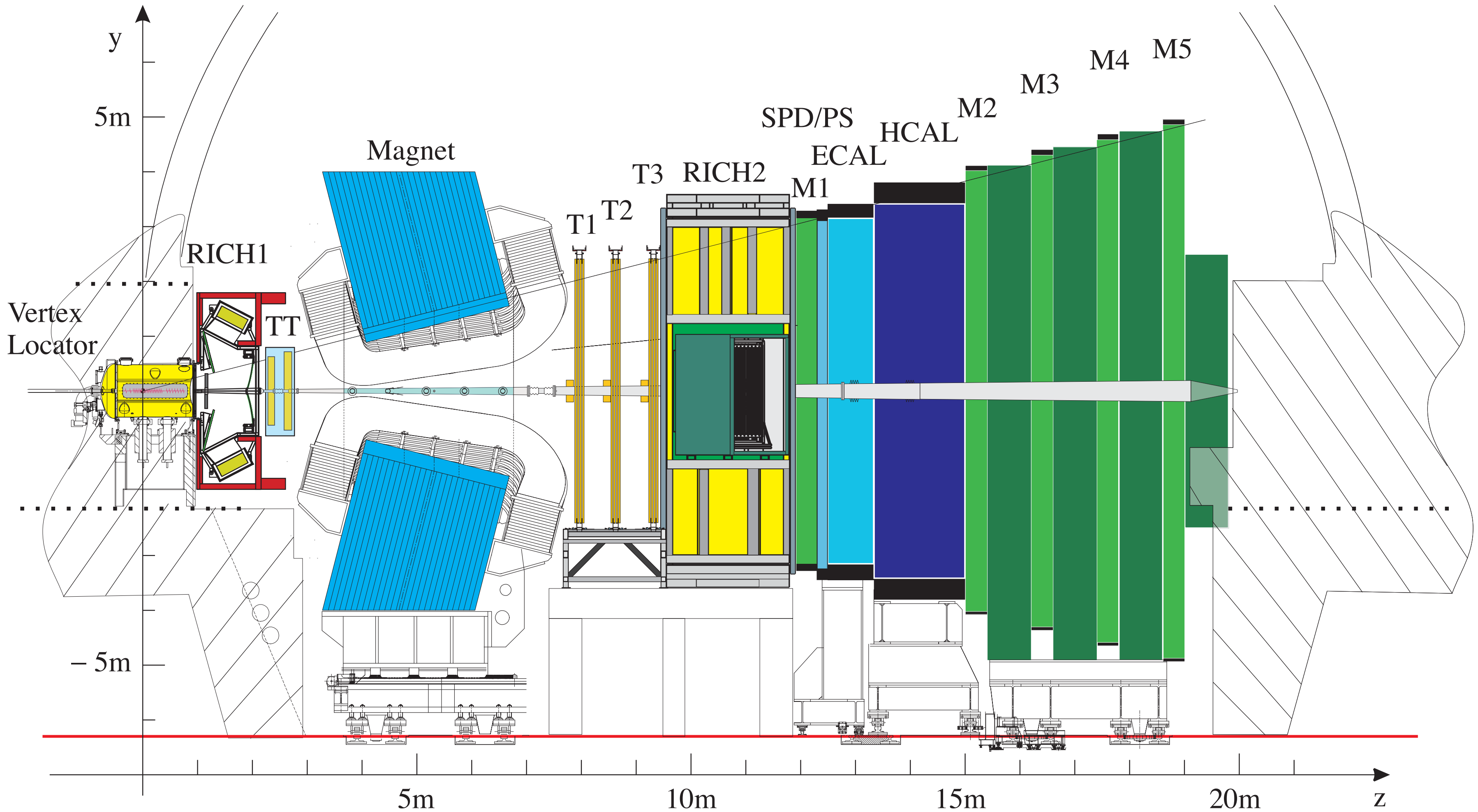
- [ArXiv:1711.01157], submitted to JHEP



3. upgrade

The muon detector upgrade

2019: LHCb luminosity increase $4x10^{32} \rightarrow 2x10^{33}$ $cm^{-2}s^{-1}$



- The first muon station (M1) will be removed
- A tungsten shield will be installed in front of the inner part of M2 to mitigate the particle flux
- Data readout at 40 MHz (now 1 MHz)
- The hardware trigger will be removed: development of a fully software trigger

LNF has a fundamental role in the upgrade:
MWPC spare production, production of the new muon readout boards, trigger software development

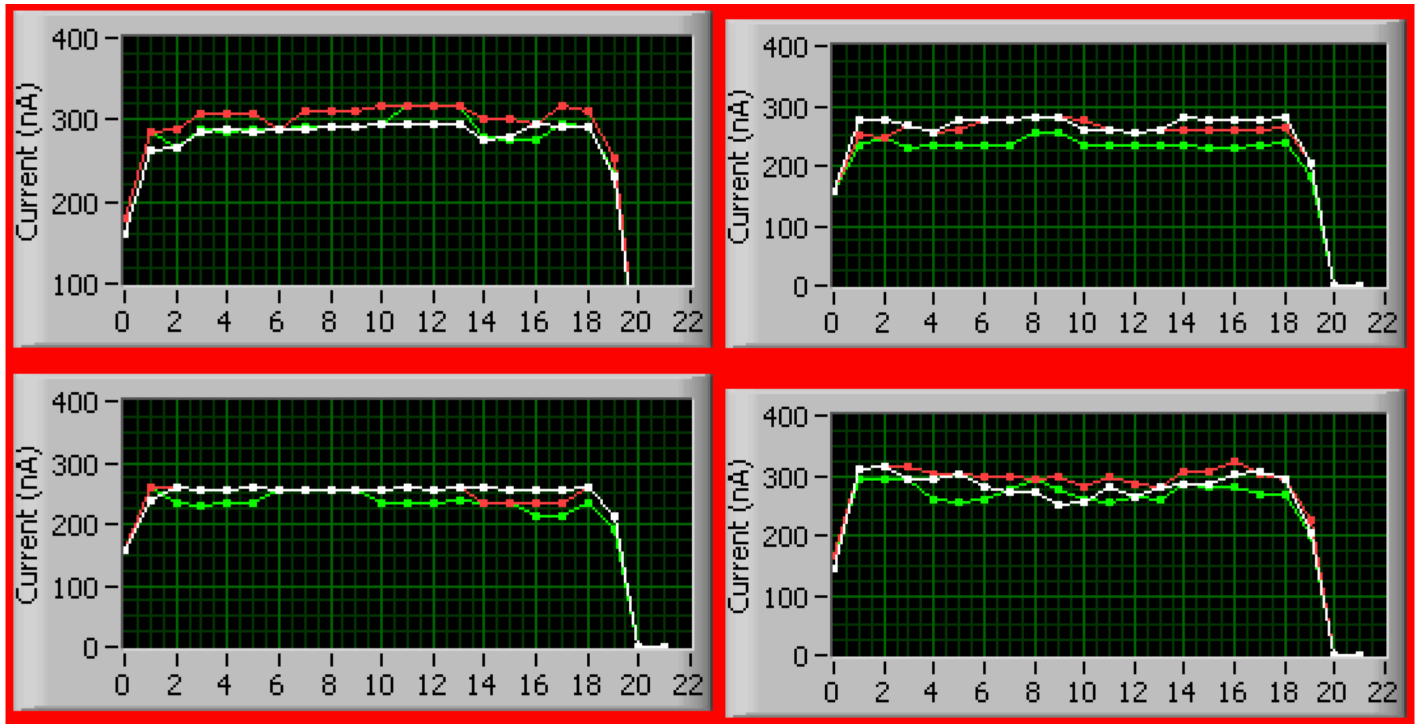
MWPC production

Mario Anelli, Emiliano Paoletti, Luigi Pasquali, Andrea Zossi

LNF produced ~50% of the MWPC of LHCb in 2004.

The production site at LNF has been setup again:

1. clean chamber:
   production of 30 spare chambers is finished
2. radiation facility:
   current profile measurement with Cs source



The chambers have been sent to CERN, where they are dressed with the electronics and finally tested (HV, gas, FEE)

The nODE

Pietro Albicocco, Alessandro Balla, Maurizio Carletti, Paolo Ciambrone, Maurizio Gatta

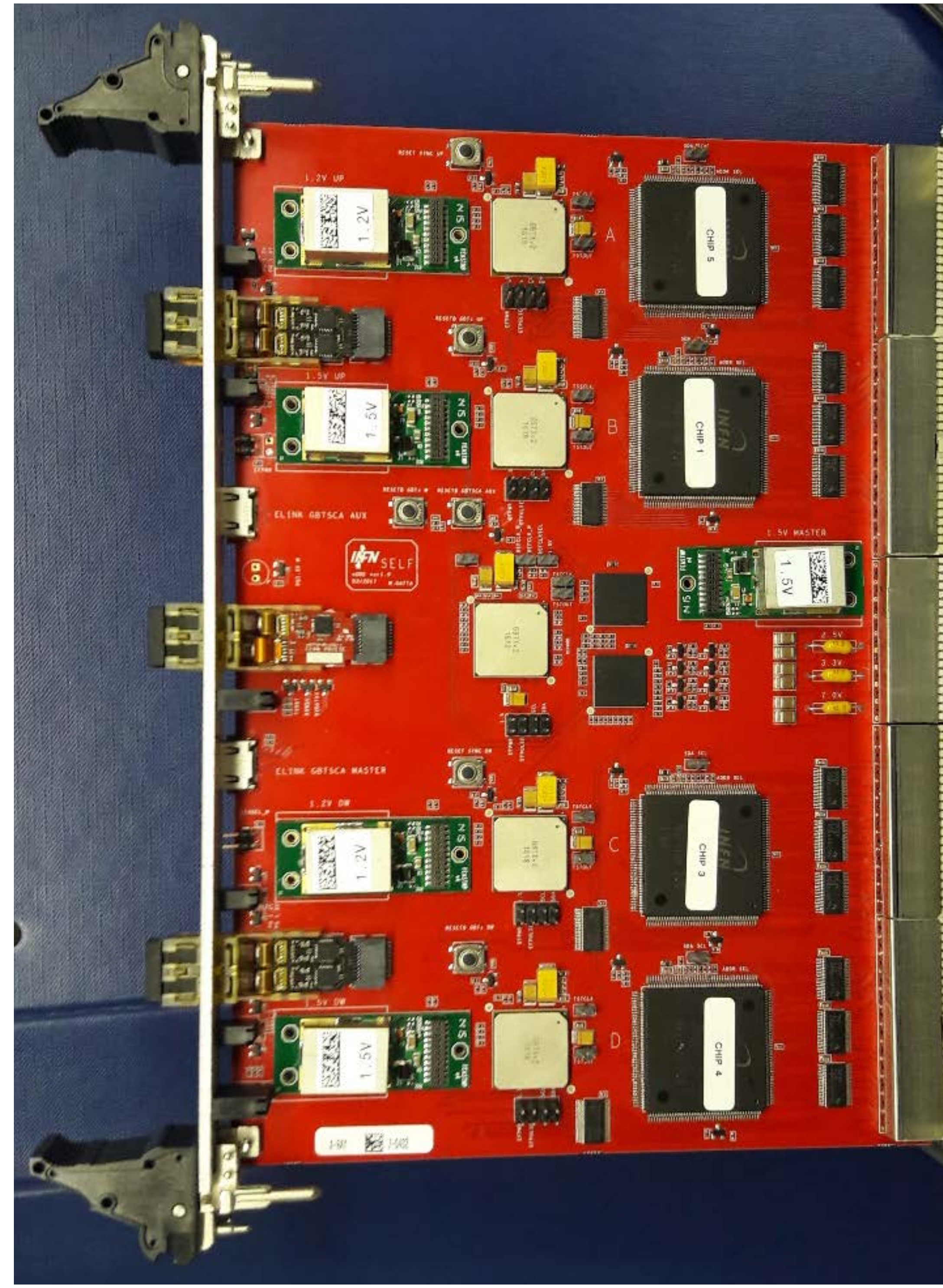
The **Off-detector readout electronics (ODE):**
receive the front-end signals of the muon chambers and provide:

- L0 pipeline (removed in the upgrade)
- signal synchronisation and bunch-cross identification
- interface to trigger and DAQ (hit map + time information)

At the upgrade, the ODE output rate will increase from the present **1 MHz to 40 MHz:**

❖ **The new ODE board (nODE) has been developed at LNF**
  - 1 GBTx chip + 2 GBT_SCA chips + 1 VTRx transceiver for TFC and ECS stage
  - 4 GBTx chips + 4 nSYNC chips for DATA stage
  - flexible to different granularities
  - backward compatible

❖ A new custom ASIC (nSYNC) has been developed in Cagliari
  - 4 chips x 48 channels

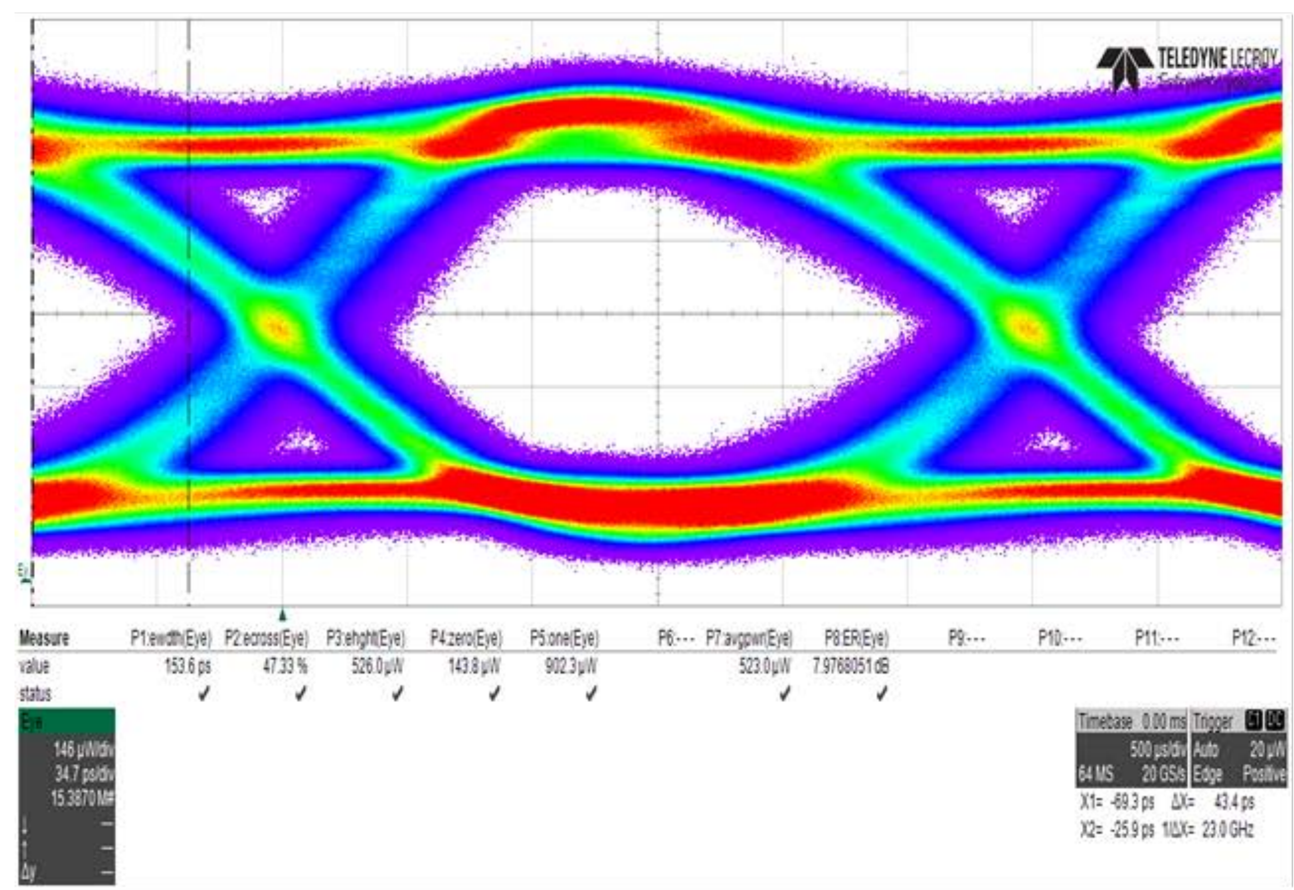


nODE production

June 2017: First prototype of the nODE

- nODE prototype fully tested and characterised:
  - Local configuration
  - GBTx master & slave optical links
  - TFC & ECS interfaces
  - E-fuse procedure
  - nSYNC data e-links

- Passed all tests without major issues
  - Good optical link quality, BER < 10^{-13} @ 99% CL
  - **PRR @ CERN passed**



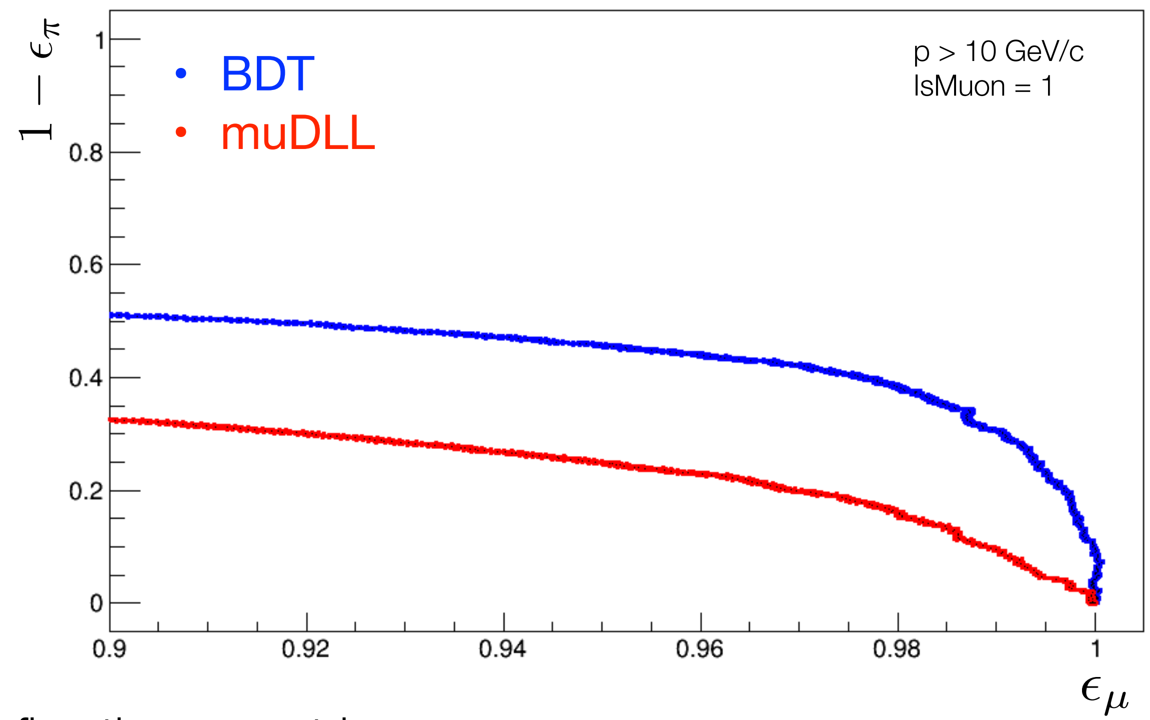
- **Ready for production**
  - nSYNC production will start next month
  - 190 nODEs (148 on detector + spares)
  - 20 nODE preproduction in spring 2018 followed by the full production after testing

MuonID software for the upgrade

At the upgrade luminosity, **a factor ~2 more background is foreseen** after HLT1 (IsMuon), i.e. the binary choice based on particle penetration through the iron absorbers.
→ **We want to ensure the proper background rejection at the upgrade.**

We developed a BDT which is able to restore the projected misidentification rate to the present level.
The BDT exploits many informations (and their correlations) wrt the simple scalar likelihood (muDLL).

The algorithm has been recently **implemented in HLT2 with negligible timing impact**



Development of many other algorithms is ongoing to redefine the muon trigger:

- χ^2 with multiple scattering information (already implemented), cluster size, isolation → low p_T MVC

PARADIGMS OF THE NEW TRIGGER CODE

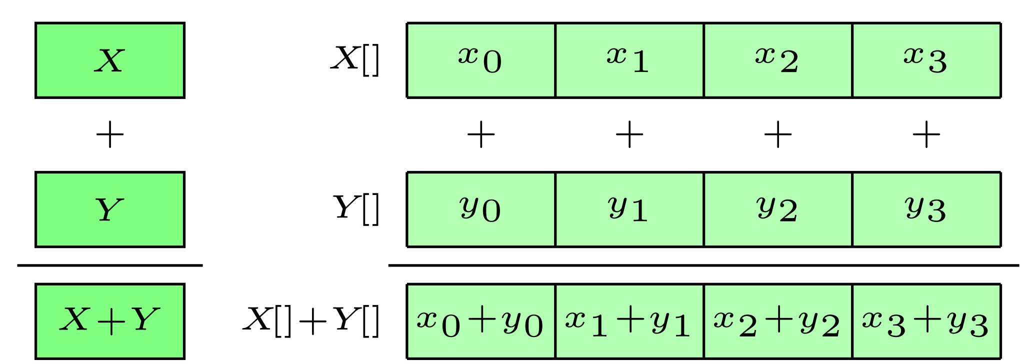
Embedded in the new functional framework (Gaudi-Hive)

Thread safety, Vectorisation, C++11 and C++14 standards

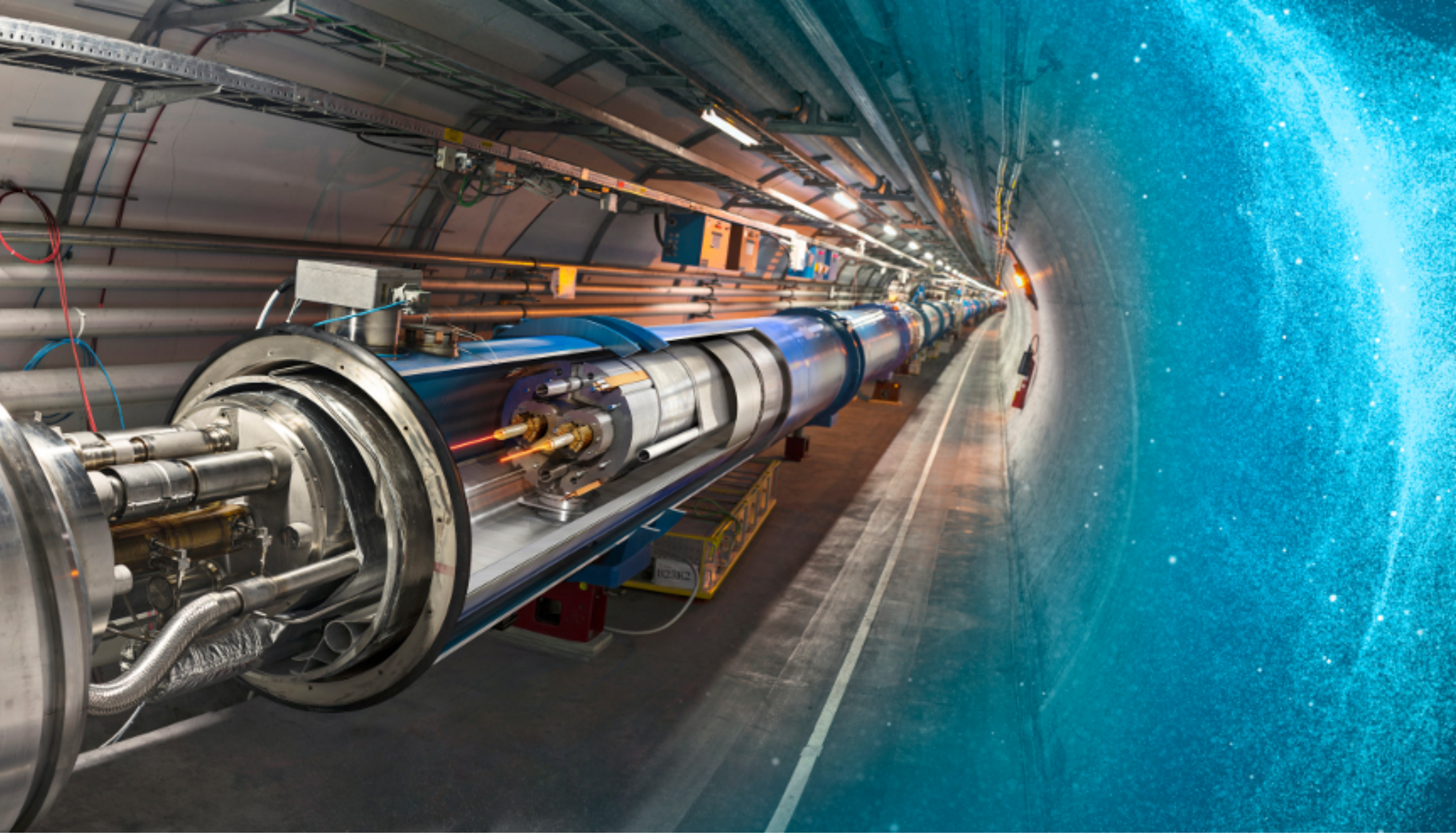
Performance evaluation (e.g. callgrind)

→ **Fast execution time** (~1 ms/event)

Single Instruction Multiple Data



Next: run the algorithms without L0 (upgrade scenario) on minimum bias events



4. future projects

The μ-RWELL detector

Giovanni Bencivenni, Gianfranco Morello, Marco Poli Lener

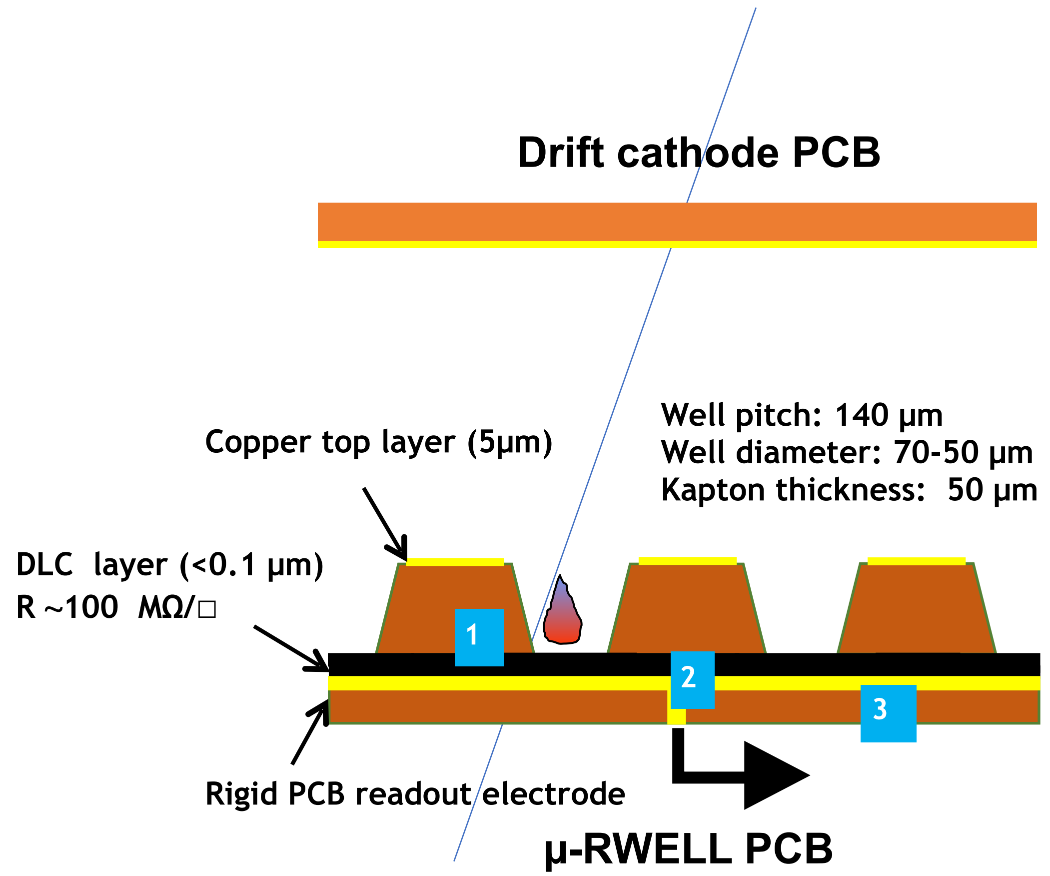
The **R&D on μ-RWELL** (supported by INFN group 1 and 5) is mainly motivated by the wish of

- improving the stability under heavy irradiation
- simplifying the construction/assembly procedures

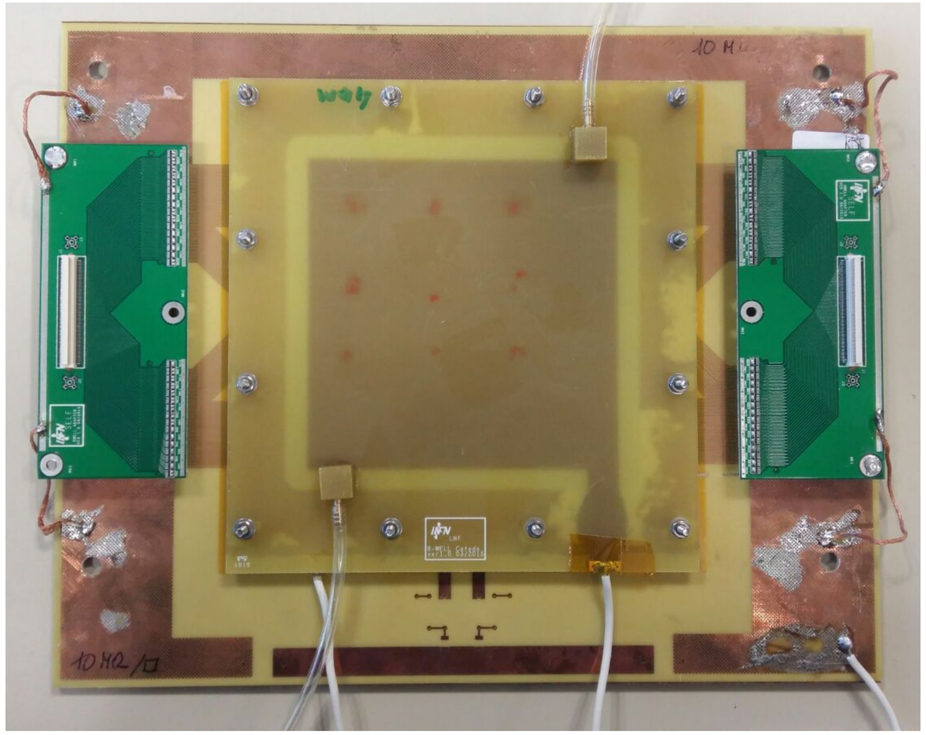
The μ-RWELL is composed by two elements: the **μ-RWELL PCB** and the **cathode.**

The μ-RWELL PCB is realised by coupling:

1. A "WELL patterned kapton foil" as **single amplification stage**
2. A **resistive stage** for the discharge suppression & current evacuation. **2 schemes:**
   1. "Low particle rate" (LR) << 100 kHz/cm²: single resistive layer with surface resistivity ~100 MΩ/□ (CMS-phase2 upgrade, SHIP)
   2. "High particle rate" (HR) > 1 MHz/cm²: more sophisticated resistive scheme is under study (**suitable for LHCb-Muon at L > 10^{34} cm^{-2}s^{-1}**)
3. A standard readout PCB

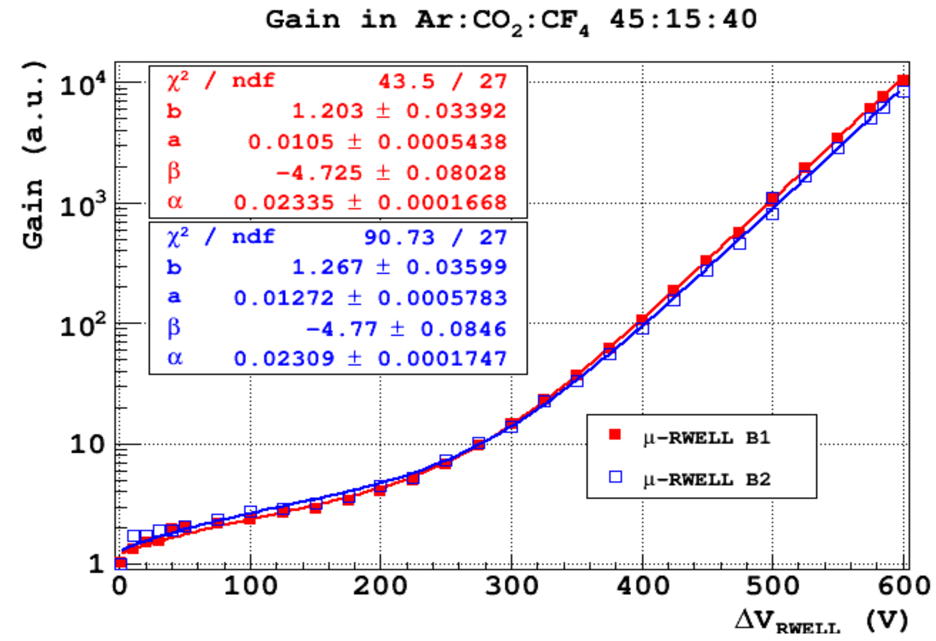


[G. Bencivenni et al., 2015 JINST 10 P02008]

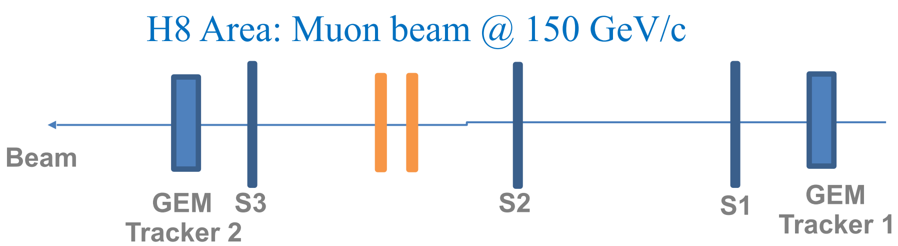


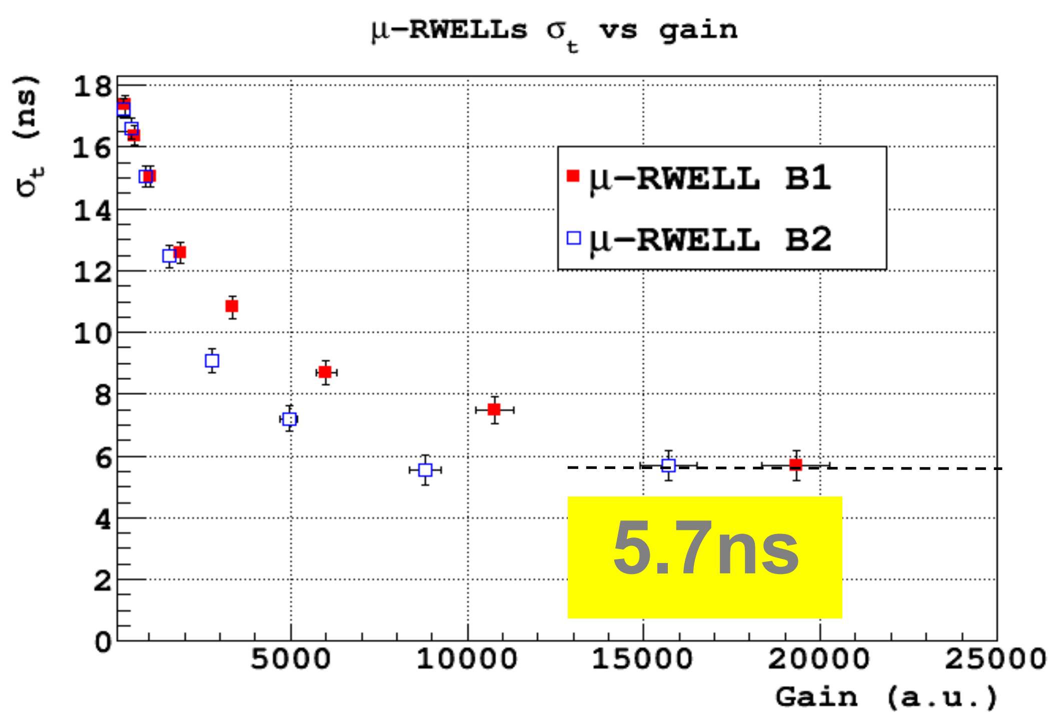
The μ-RWELL performances

2 prototypes tested:
- 10x10 cm^2
- 40 and 35 MΩ/□
- HR scheme
- 400 μm strip pitch
- Ar/CO_2/CF_4 45:14:40

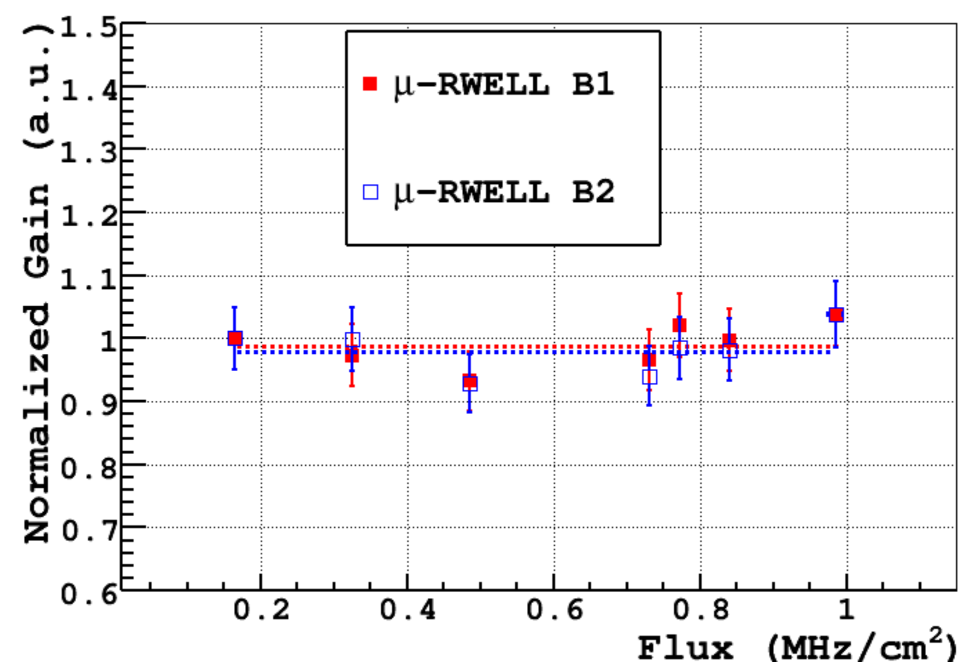


X-rays:
Gas gain > 10^4
with a single amplification stage





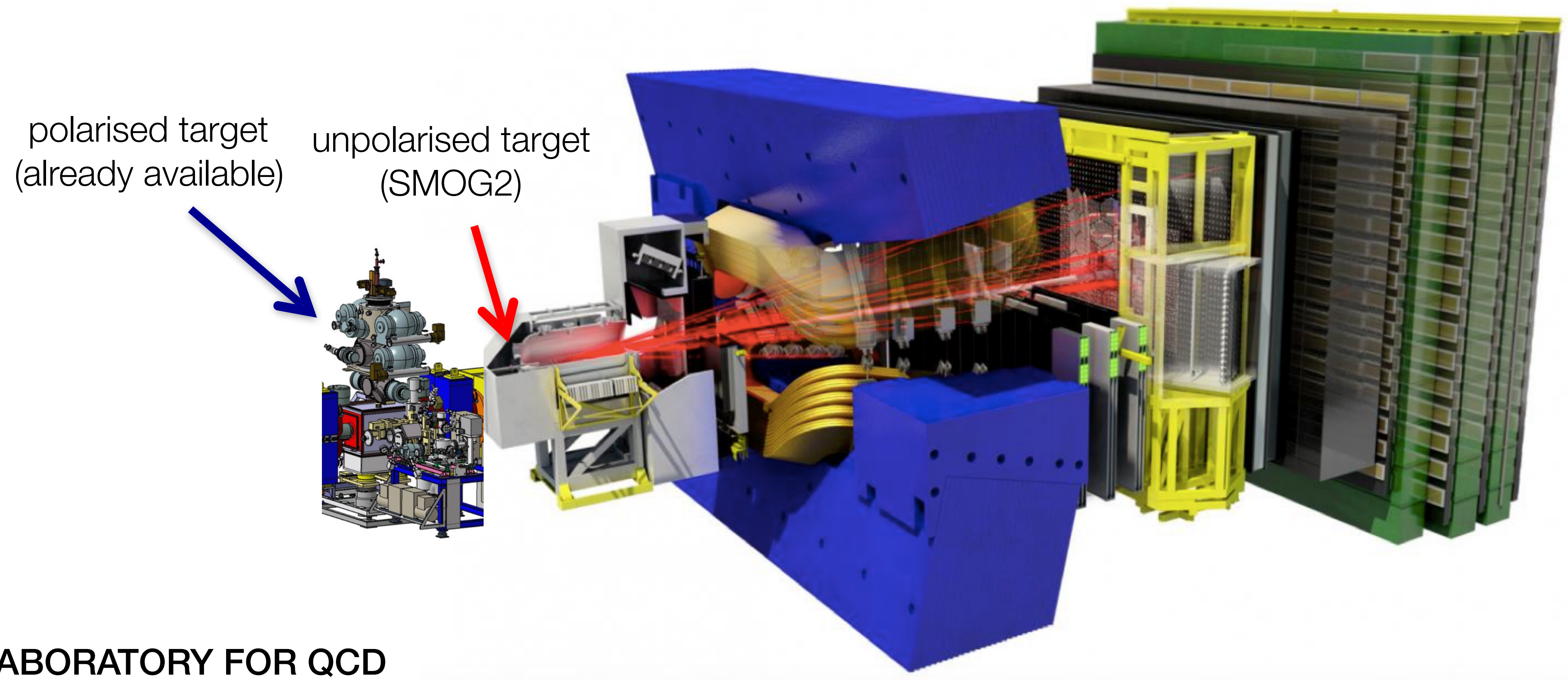
The saturation at 5.7 ns is dominated by the FEE (VFAT2)



Detectors rate capability up to 1 MHz/cm^2 @ gain=10^4

Fixed target at LHCb

LHC spin aims to bring unpolarised and polarised physics at the LHC, by LHCb, in parallel fixed-target and collider data taking (under test in the ongoing Run @ 5 TeV)



A LABORATORY FOR QCD

- Broad physics program for both unpolarised and polarised cases:
  3D (tomography) nucleon structure, quark and gluon orbital angular momenta, fundamental QCD tests, spin with quarkonia production, low-p_T Higgs sector
- Wide range of reactions: pp , pA, PbA (A=p, d, ^{3,4}He, … all noble gasses up to Xe)
- Synergic run p-target and pp-collider modes
- Negligible impact on the LHC beam (1/e beam life-time ~74 days)
- Target technology is well established for more than 10 years at DESY
- FITPAN: LHCb+LHC panel is giving positive feedback to the project

Leading role of LNF as responsible of the SMOG2 upgrade (LS2) and proponents of LHCSpin (LS3)

5. conclusions

Conclusions

- We are a large group with important responsibilities within the LHCb collaboration
- Involved in fundamental physics analyses
- We bring a large contribution for the hardware and software upgrade (2019)

  → 10th LHCb computing workshop for the upgrade will be held at LNF (20-24 November 2017)
- Very promising projects for the longer future (LS3)