FPCP 2013
May 19 – 24, 2013
Buzio – Brazil

The LHCb upgrade

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on behalf of the LHCb collaboration

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Outline

- Motivation
- Overview of the LHCb upgrade
- Tracking, particle identification, data processing challenges
- Conclusions

Motivation

Heavy flavor physics

- The LHCb experiment is devoted to the study of the CP violation and the rare decays in the b and c-quark sectors:
  - The origin of the observed pattern of masses and mixing angles for quark and leptons ?
  - Reveal new sources of flavor symmetry breaking ?

Isidori '12

- The method is based on:
  - theoretically clean observables
  - measured with a high precision

  and on the comparison between measurements and predictions looking for deviations.

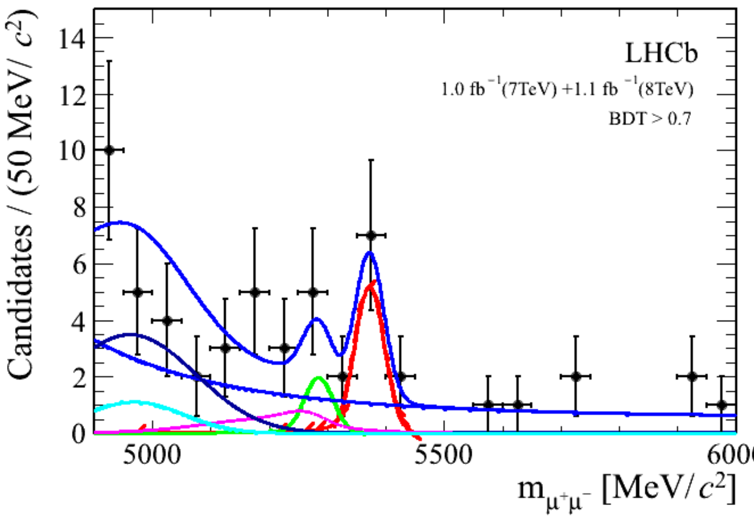
Top 10 theoretically clean observables

γ from tree ($B \rightarrow DK$, ...)	**LHCb**	SuperKeKB
$\|V_{ub}\|$ from exclusive semi-leptonic B decays		SuperKeKB
$B_{s,\,d} \rightarrow l^+ l^-$	**LHCb**	Atals, CMS
CP violation in B_s mixing	**LHCb**	Atlas, CMS
$B \rightarrow K^{(*)} l^+ l^-, \nu\nu$	**LHCb**	SuperKeKB
$B \rightarrow \tau\nu, \mu\nu$		SuperKeKB
$K \rightarrow \pi\nu\nu$		NA62, KOTO, ORKA
CP violation in charm	**LHCb**	SuperKeKB
Lepton flavor violation		MEG

Isidori '12

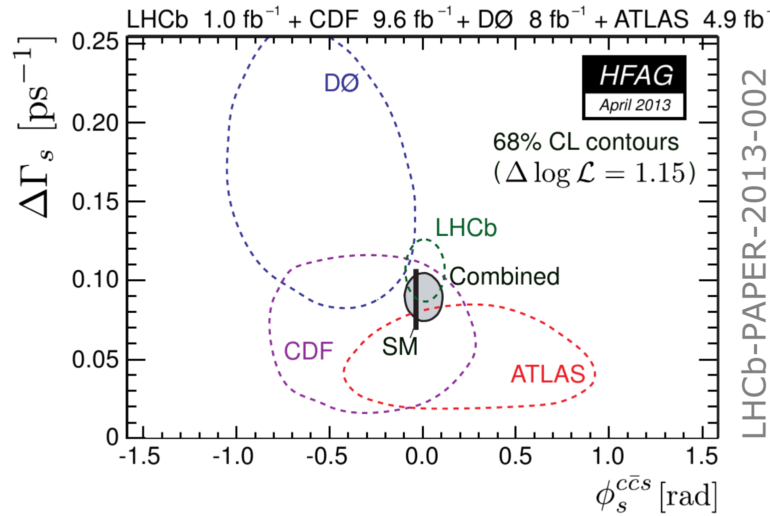
LHCb takes over B-factories and Tevatron exp.

$$\mathrm{B}(B_s \to \mu\mu) = (3.2^{+1.5}_{-1.2}) \times 10^{-9}$$

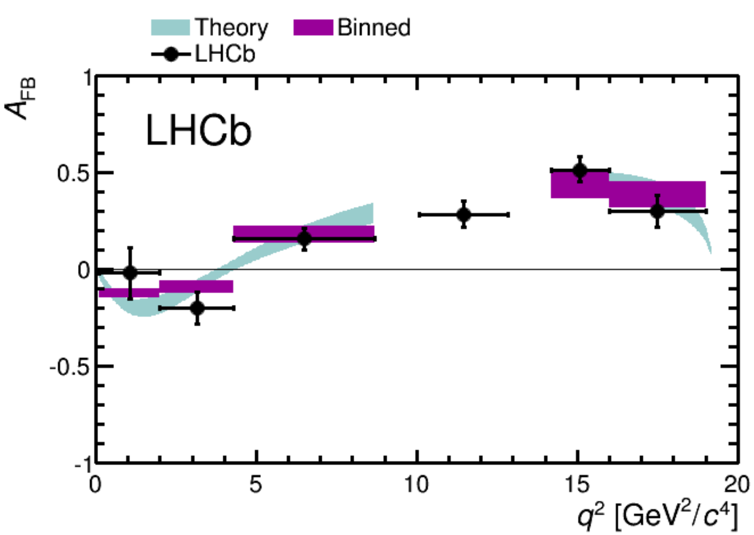


LHCb-PAPER-2012-043

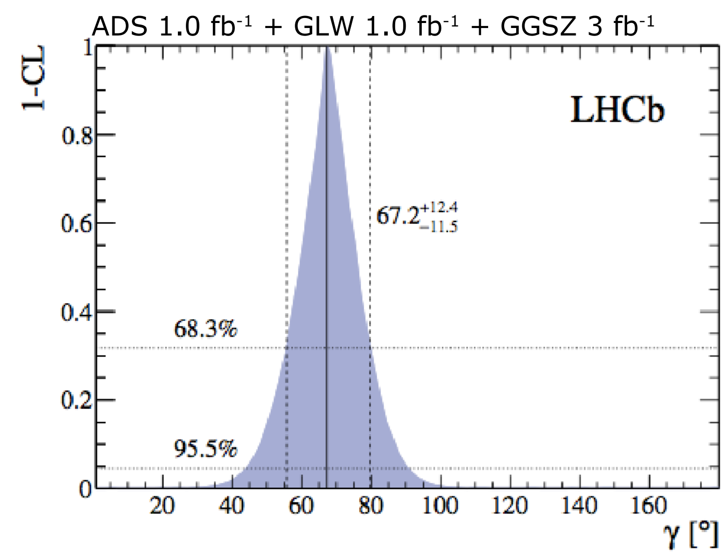
$$\phi_s = (0.01 \pm 0.07\,(\mathrm{stat.}) \pm 0.01\,(\mathrm{syst.}))$$



LHCb-PAPER-2013-002



LHCb-PAPER-2013-019



LHCb-CONF-2013-006

$$q_0^2 = 4.9 \pm 0.9 \;\; \mathrm{GeV}^2/c^4 \quad [B^0 \to K^* \mu\mu]$$

$$\gamma = (67.2 \pm 12.0)° \qquad [B \to DK]$$

What do we learn so far

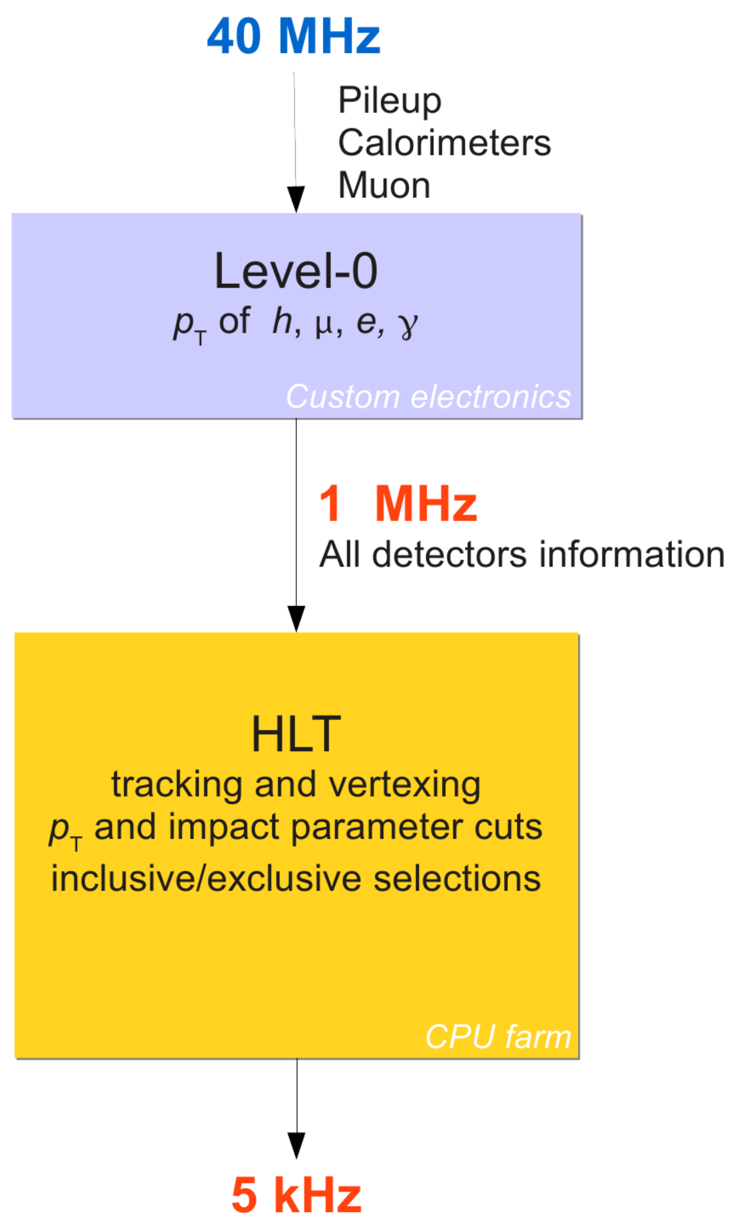
- Past and running experiments have shown that:
  - Flavor changing processes are consistent with the CKM mechanism.
  - Large source of flavor symmetry breaking are excluded at the TeV scale.
  - The flavor structure of the new physics, if it exists, is very peculiar at the TeV scale (MFV).
- Measurable deviations from the standard model are still expected but should be small.
- The main road is to go to very high precision measurements for the most clean observable.

  This is the main motivation for the LHCb upgrade

From G.Isidori – ESPP Open Symposium – Kracow Sept. 2012

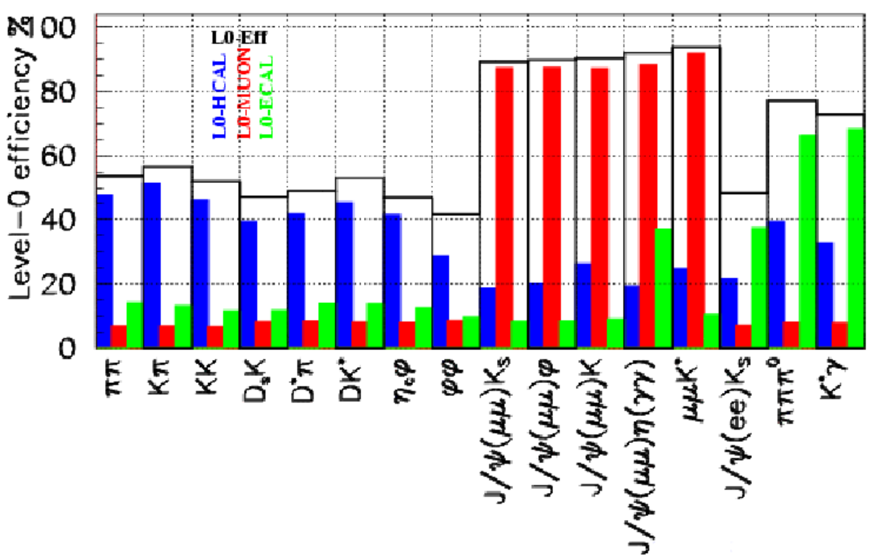
Overview of the LHCb upgrade

The current trigger



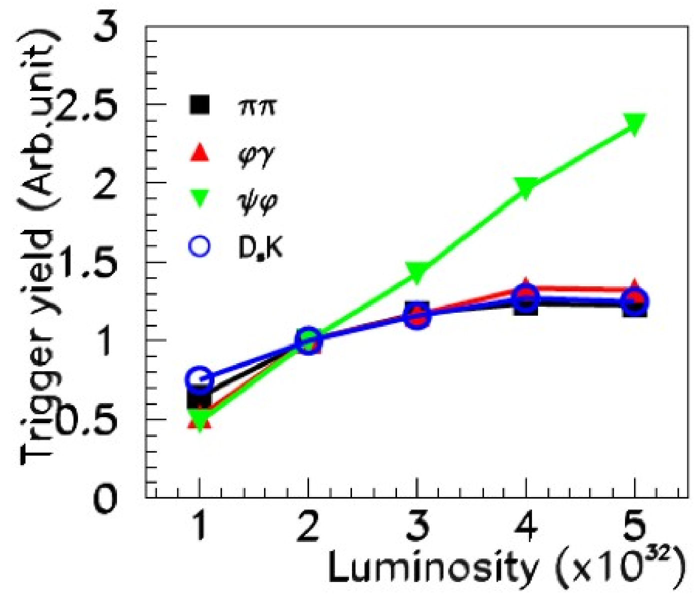
The trigger limitations

- L0 efficiencies:



  - ε (hadron) ~ 0.5 × ε (muon)
  - p_T (hadron) ≫ p_T (muon)

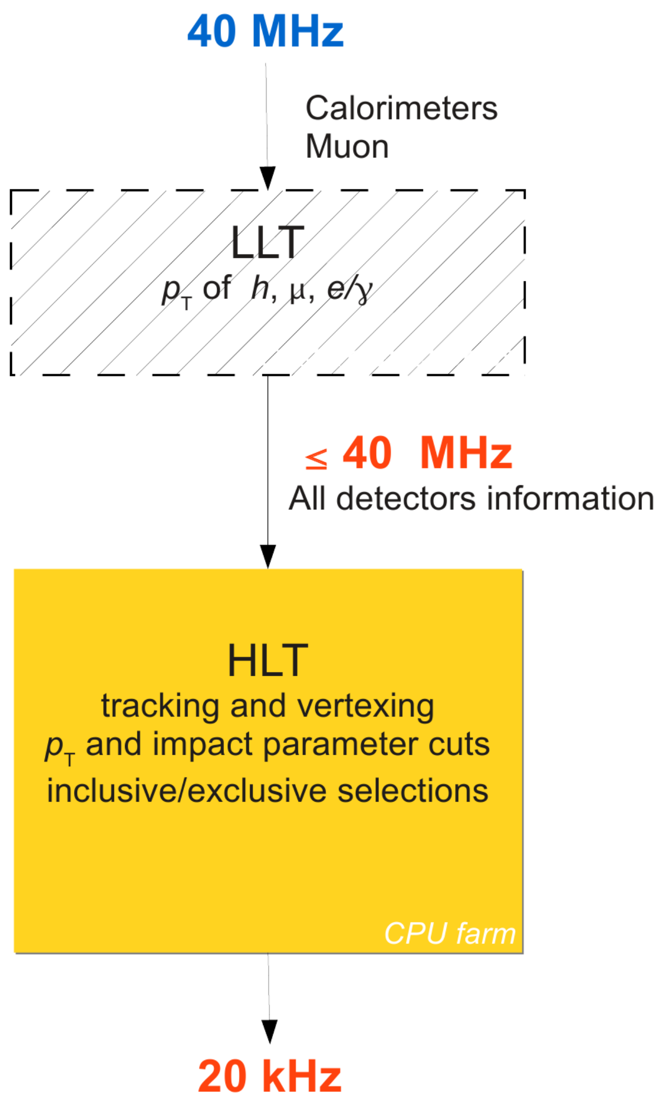
- Saturation of the yields:



  - p_T cuts must be raised to stay within the 1 MHz readout rate

The Upgrade Trigger

- Increase the L0 output rate would considerably improve efficiency and yields for hadronic channels:
  - Remove the L0 (almost)
  - Readout the detector at 40 MHz
  - Full software trigger



Running conditions

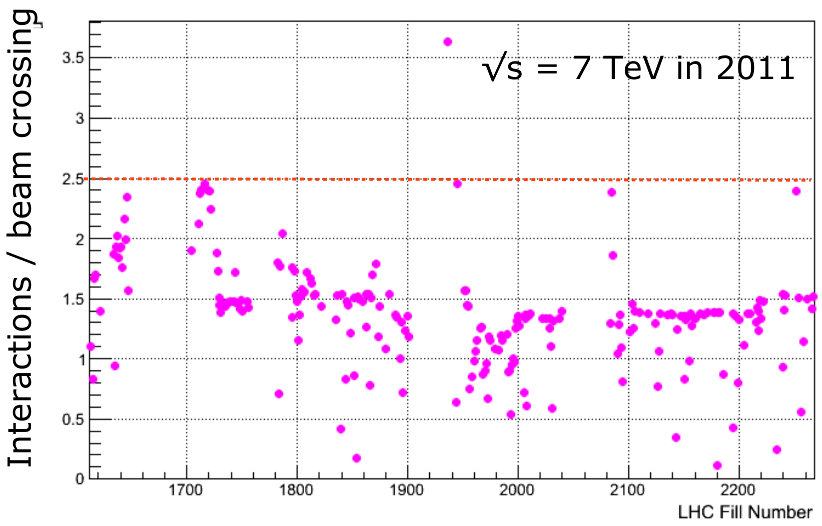
- 25 ns bunch spacing
- 2400 colliding bunches at $\sqrt{s}$ = **14 TeV**
- Luminosity leveling at $\mathscr{L}$ **= 1×10^{33} cm^{-2}s^{-1}**
- Pileup = interactions / beam crossing ~ 2.7

2012

50 ns
8 TeV
4×10^{32}
1.7

  – design upgraded sub-system to sustain a peak luminosity of $\mathscr{L}$ = 2×10^{33} cm^{-2}s^{-1}

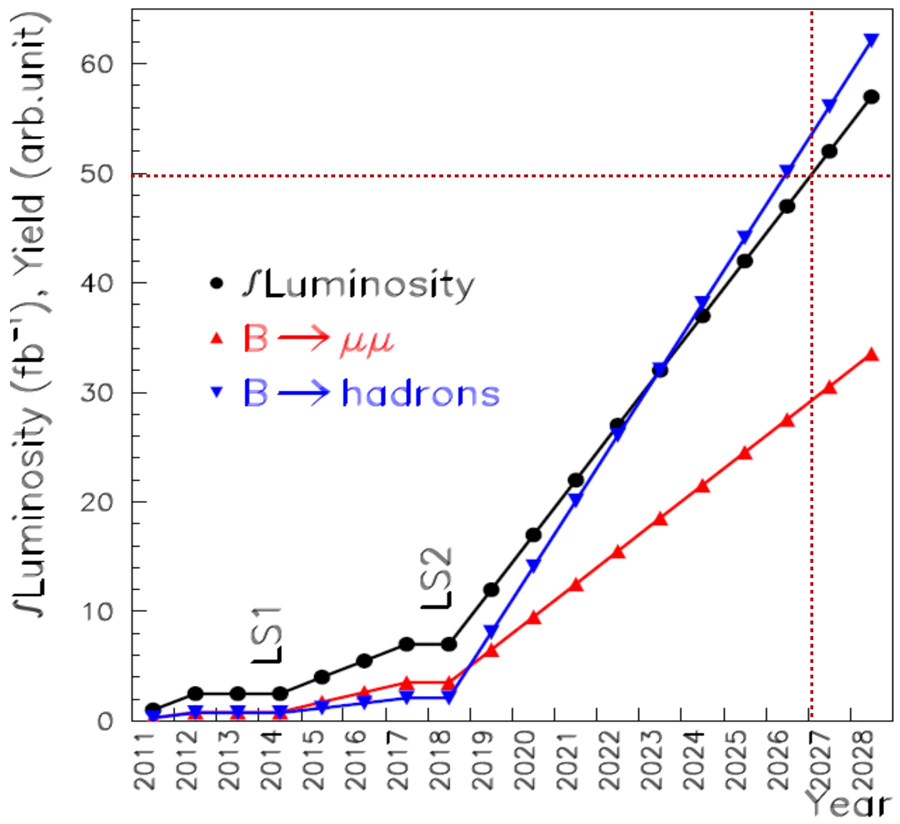
  – Already gained expertise running LHCb in such conditions



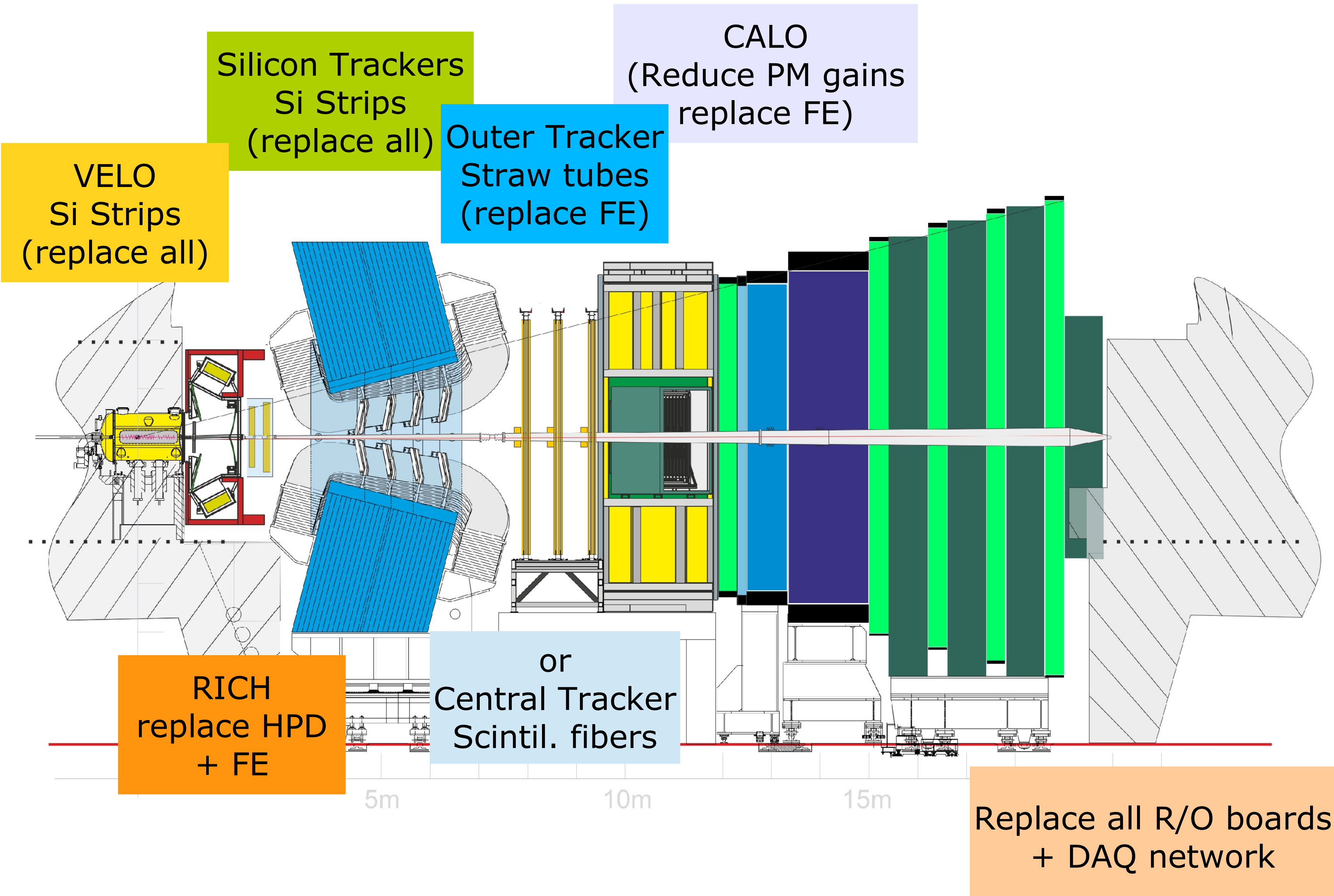
LHC upgrade features

- Readout rate at **40 MHz** instead of 1 MHz
- Full software trigger
- Collect **50 fb^{-1}** over 10 years

With the improved trigger and luminosity, the annual yields increase by a factor 20 (10) for hadronic (leptonic) channels w.r.t 2011



40 MHz Detector Upgrade



LHC 10 years plan

2013	LS1
2014	
2015	Physics at 6.5 / 7 TeV (phase 1)
2016	
2017	
2018	LS2 – Injector upgrade
2019	Physics at $2.4\times10^{34} cm^{-2} s^{-1}$ (phase 2)
2020	
2021	
2022	LS3 – HL-LHC upgrade

From L. Ponce – LHC France 2013 - Annecy

The LHCb detector will be upgraded **in one go** during LS2
It will take data during the phase 2 and the phase 3 (>2022)

Roadmap of the LHCb Upgrade

- Letter of Intent submitted in March 2011

  Framework TDR submitted in June 2012
  It defines cost, milestones and institutes scientific interest:

  - The LHCC endorses the upgrade plans of the Collaboration
  - the CERN Research Board approved the upgrade of LHCb to be part of the long-term exploitation of the LHC

- Decide on technical options by mid 2013
  All detector TDRs by end 2013

- 40 MHz detector ready for installation in 2018 during LS2

Statistical sensitivities to key observables

- Comparable to or better than the theoretical uncertainties:

Observable	**Upgrade** [50 fb^{-1}] σ_{stat} / expected	Theory uncertainty σ_{theo} / expected
$\phi_s(B_s \to J/\psi\phi)$	**22%**	~1%
$s_0 A_{FB}(B^0 \to K^{*0}\mu\mu)$	**2%**	7%
$B(B_s^0 \to \mu^+\mu^-)$	**5%**	9%
$B(B^0 \to \mu^+\mu^-)/B(B_s^0 \to \mu^+\mu^-)$	**~35%**	~5%
$\gamma(B \to D^{(*)}K^{(*)})$	**1%**	negligible

+ more observables in LHCC 2012-007

Enlarge the core physics program

Lepton flavor physics	Majorana neutrino Lepton Flavor Violation in $\tau^{\pm}$ decays
Electroweak physics	$\sin 2\,\theta_{eff}^{lept}$ M_W
Exotic search	Hidden valley ...
QCD	Central Exclusive Production

Tracking Challenges

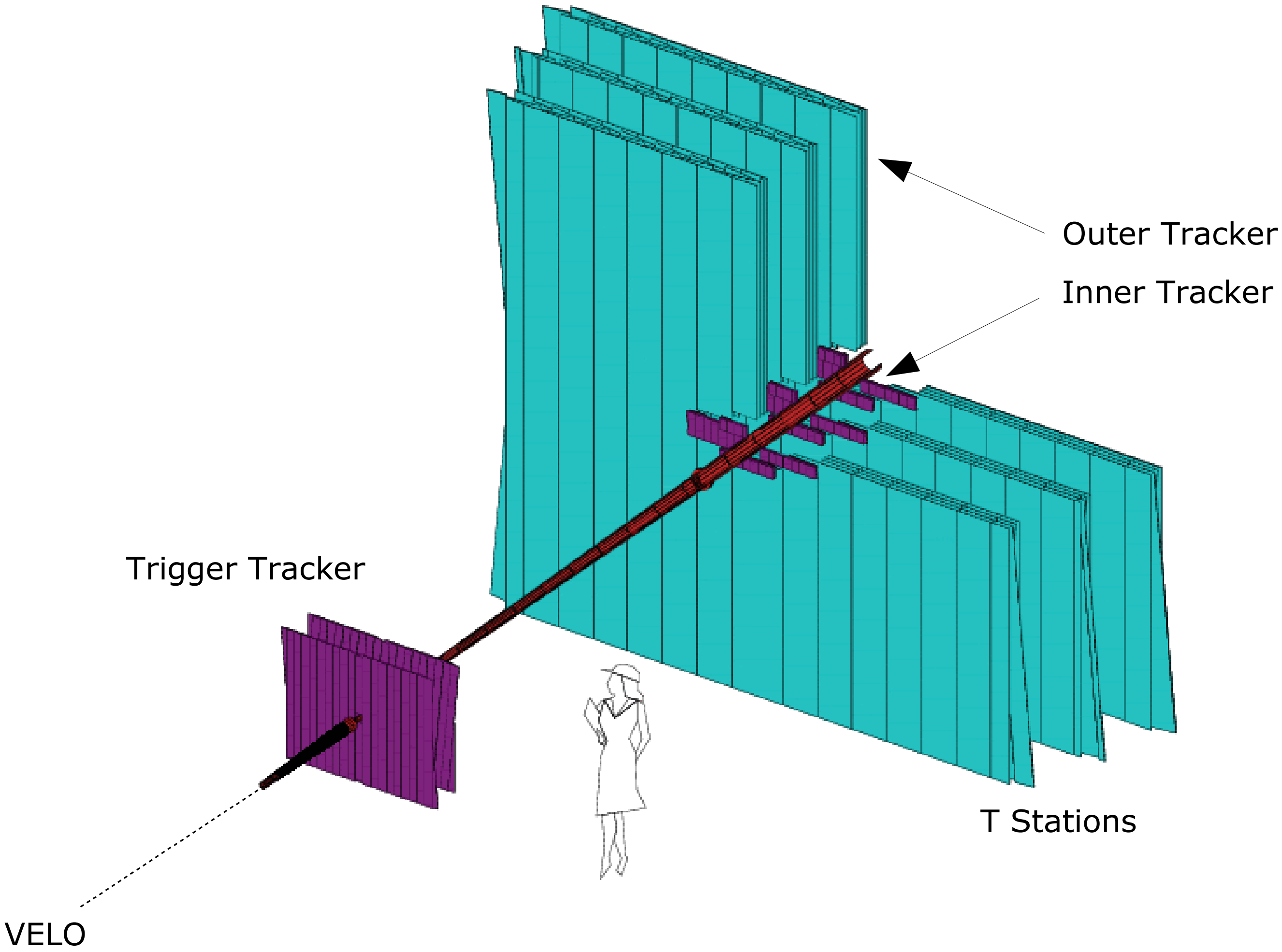
Tracking Challenges

- When the luminosity and the pile-up increase,
  it is challenging to keep or even improve:

  - High momentum resolution [$\sigma(p)/p = 4\times10^{-3}$ at 5 GeV/c]
  - High IP resolution [20 μm at hight p_T]
  - High Track efficiency [96% for long tracks]
  - Low Ghost rate [~10%]
  - Fast pattern recognition

Fast pattern recognition is a key issue for the upgrade
since it has to run in the software trigger.

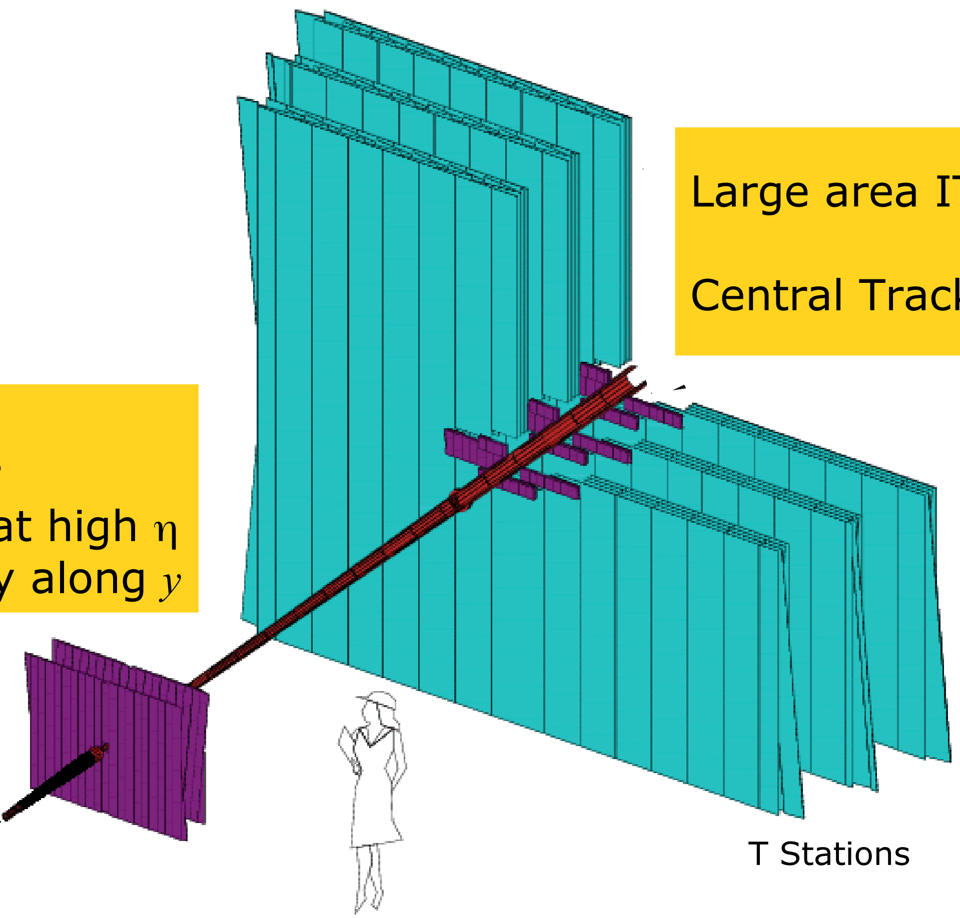
The Current Tracking System



The Upgrade Tracking System

Large area IT (Si strip)
or
Central Tracker (Sci. Fiber)

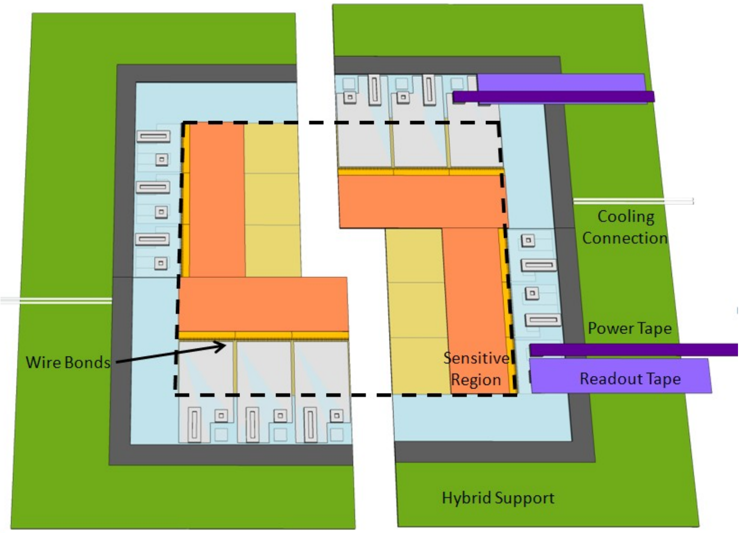
New UT
Silicon strip detector
Enlarge acceptance at high η
Improved granularity along y



New VELO
Pixel or Strip

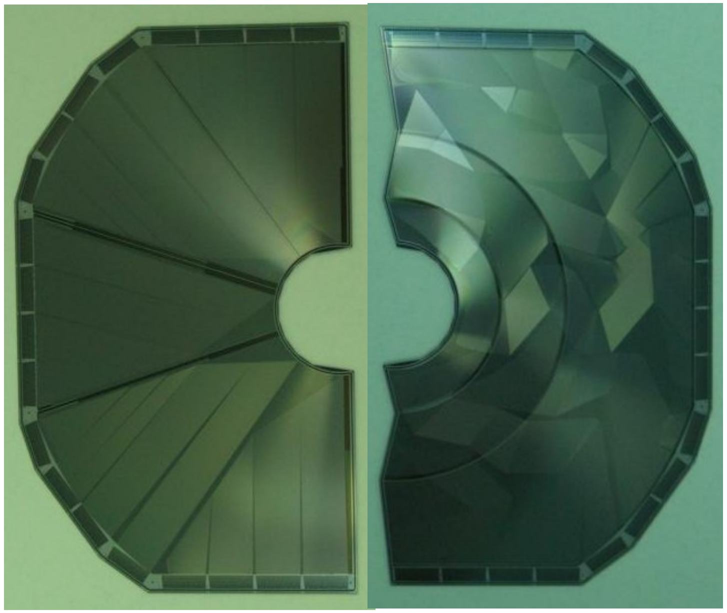
VELO Options

- Pixel



  - Square pixel 55×55 μm²
  - VELOPix chip
  - Channels 41×10^6

- Strip with (r, φ) sensors



  - Inner pitch 30 μm
  - SALT chip
  - Channels 215×10^3

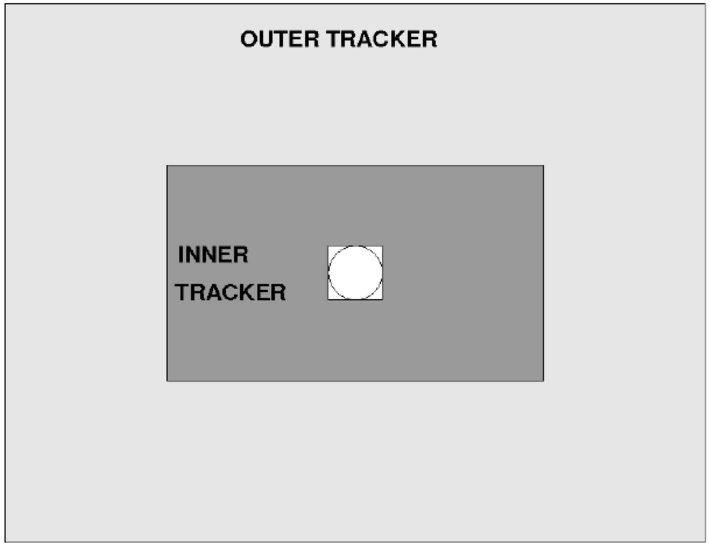
VELO Challenges at 40 MHz and 2×10^{33} $cm^{-2}s^{-1}$

Enlarge acceptance at high η	Move closer to the beam Inner aperture reduce from 5 to 3.5 mm
Irradiation dose	370 Mrad or 8×10^{15} n_{eq}/cm^2
Low material budget	Sensor thickness 200 μm Thickness of the RF foil 300 → 150 μm CO_2 cooling using micro channels
High output data rate	2.8 Tbit/s (pixel) 2.4 Tbit/s (strip)

- Decision on the VELO technology → June 2013.

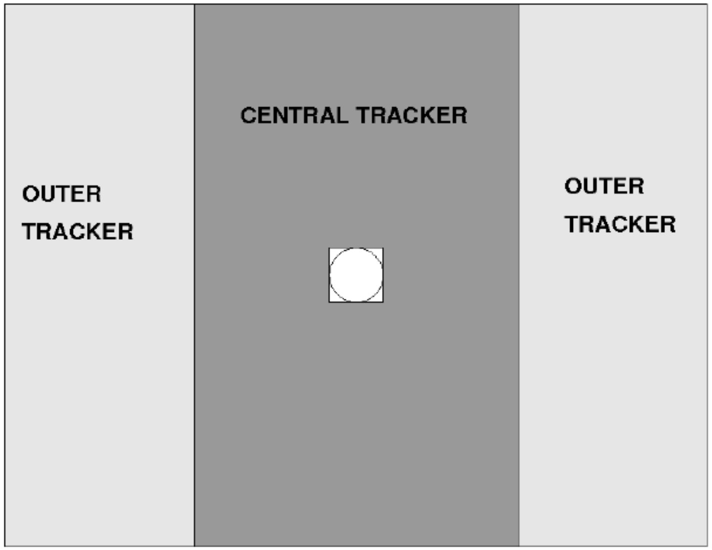
T Stations Options

- Large IT area



  - Si strips + straw tubes
  - Increase the IT acceptance in order to reduce the OT occupancy below 20%
  - Air cooling to reduce X/X_0

- Central Tracker



  - 250 µm diameter scint. fibers
  - 5 layers of fibers / module
  - 2.5 meter long modules
  - Readout by multi-channel SiPM, outside the acceptance

CT Challenges at 40 MHz and 2×10^{33} $cm^{-2}s^{-1}$

- Scintillating fiber detector never used with the conditions expected for the LHCb upgrade

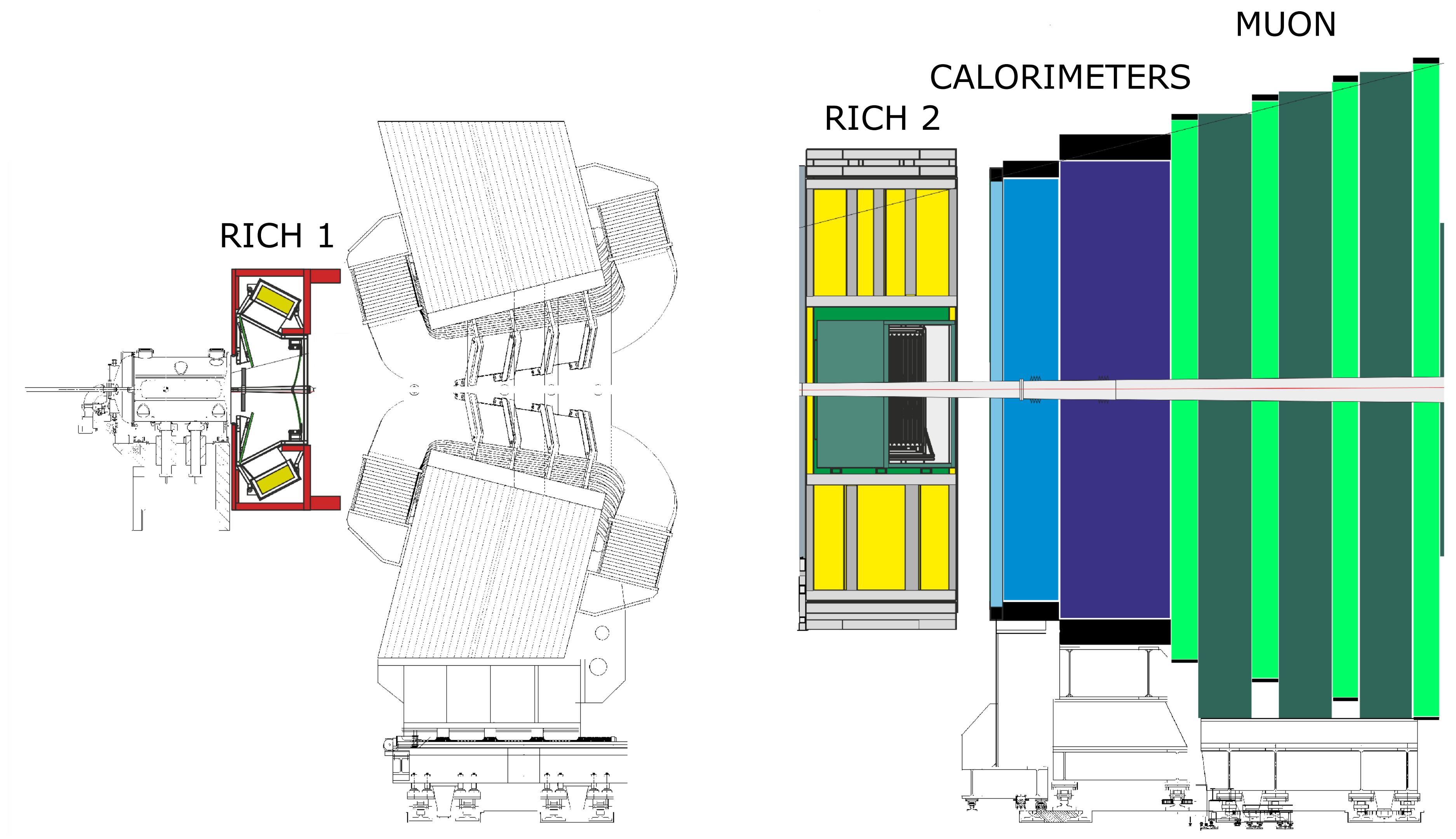
SiPM are sensitive to neutron fluence	6×10^{11} n_{eq}/cm^2	Neutron shielding Cooling at -40°
Fiber transmission degrades with irradiation dose	26 kGy at 9 cm	Mirror on one side
Fiber position in x	50 µm	
Module flatness	≤ 300 µm over 2.5 meters	

- The viability of the technology has been demonstrated from the point of view of the neutron fluence and the irradiation dose.

- Decision on the Tracker technologies → September 2013

Particle Identification Challenges

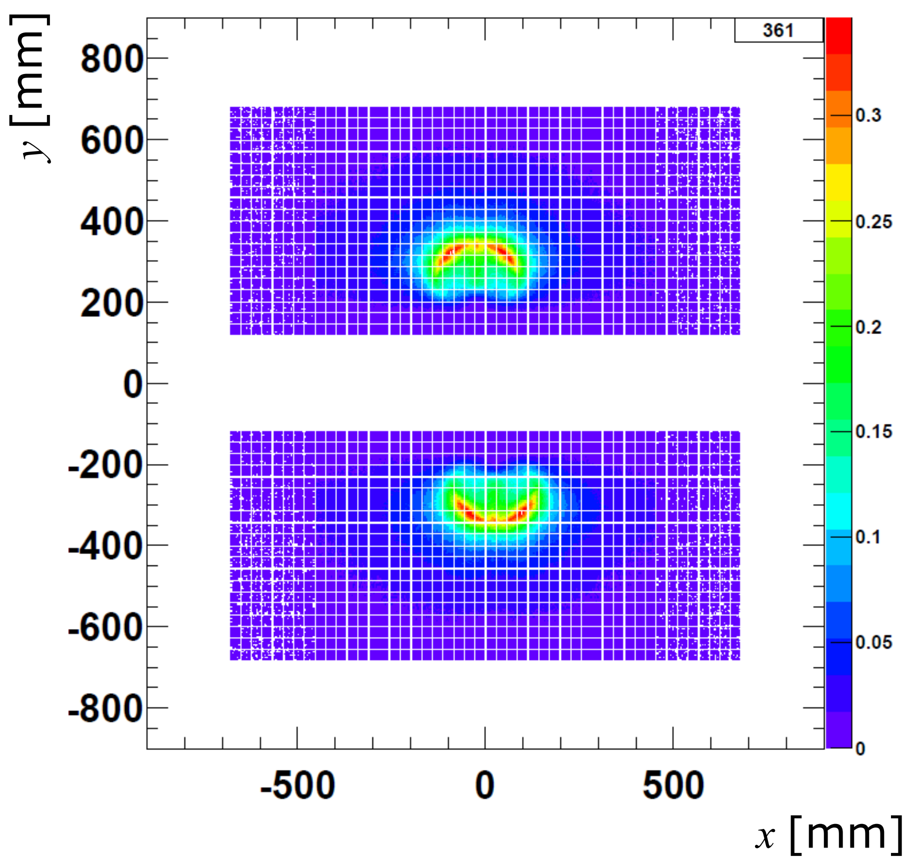
The PID System



RICH Challenges at 40 MHz and 2×10^{33} $cm^{-2}s^{-1}$

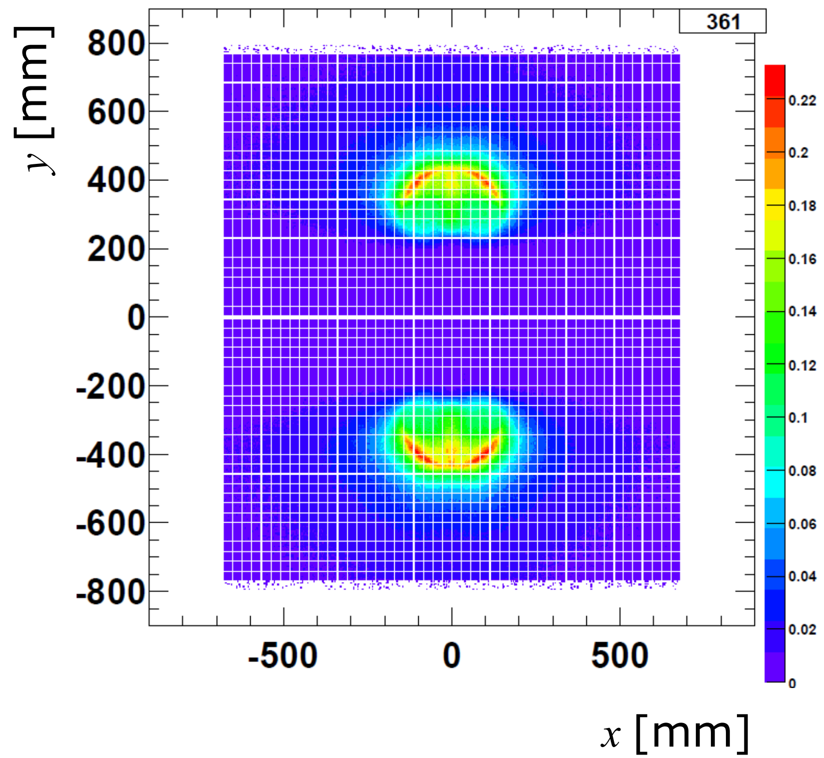
40 MHz readout	MaPMT + ASIC (MAROC3 or CLARO)
RICH1 occupancy	

RICH 1 occupancy in the focal plan at 2×10^{33} – current optics:



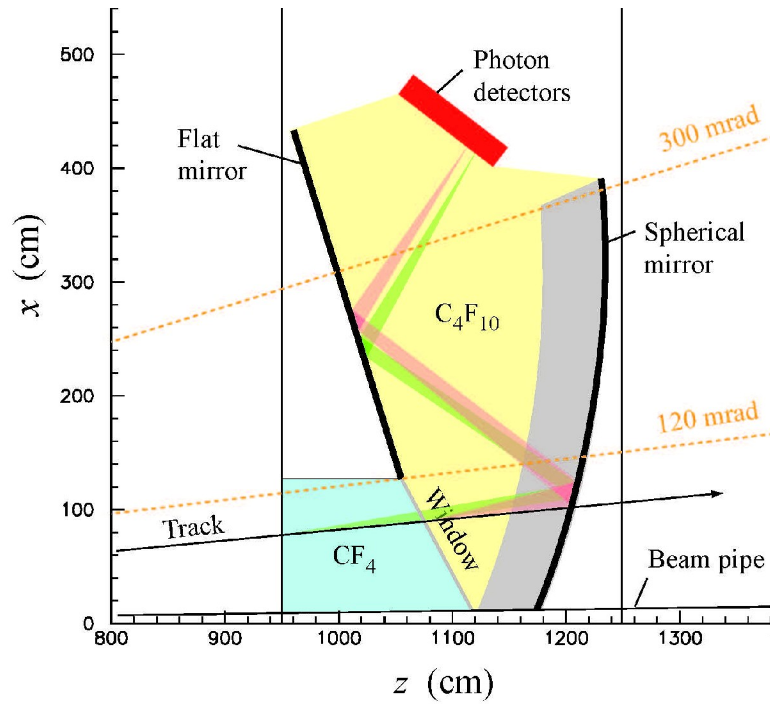
RICH Options

- RICH 1 with new geometry



  - Spherical mirror with larger r
  - Occupancy reduced 0.3 → 0.2

- TRIDENT



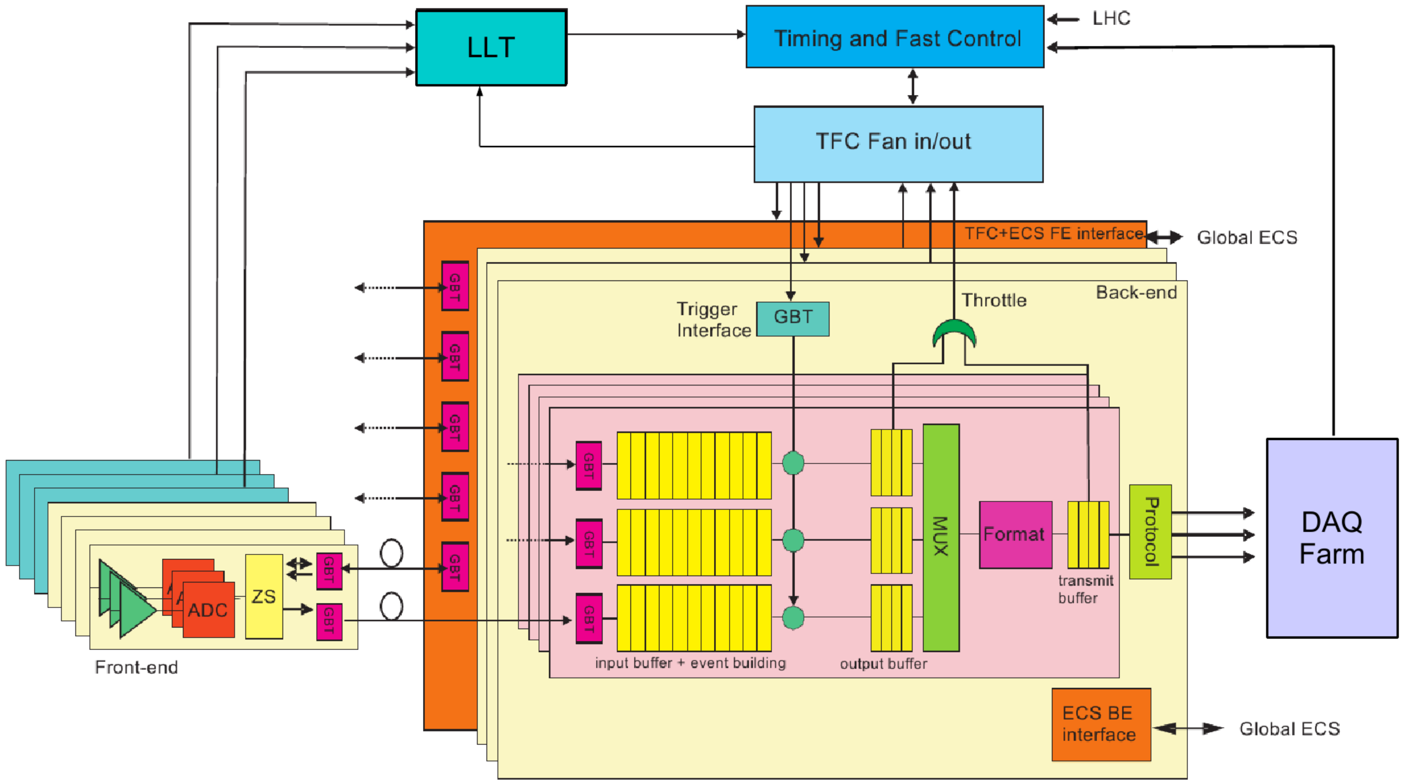
  - RICH1+2 gas radiator in a single vessel
  - Gas radiators are separated by a quartz glass

- Decision → June 2013

Data Processing Challenges

Data acquisition

40 MHz



20 kHz

- Common readout board with different firmwares for timing and fast command distribution, slow control and data concentration.

Event building at 40 MHz

- Future DAQs

	Event-size [kB]	Rate [kHz]	Bandwidth [Gb/s]	Year
ALICE	20 000	50	8 000	2019
ATLAS	4 000	200	6 400	2022
CMS	2 000	200	3 200	2022
LHCb	100	40 000	32 000	2019

Neufeld -- DAQ@LHC '13

- The main challenge is to build a cost-effective architecture for the event building (mixture of network and CPU)

- Exploring:
  - Merging readout unit and event builder in a single entity
  - Ethernet / Infiniband / PCI express technologies
  - Use of co-processors like GPGPUs or FPGA

HLT Challenges at 40 MHz and 2×10^{33} $cm^{-2}s^{-1}$

- The limitation of the output rate at 20 kHz is strong requirement:
  - $b\bar{b}$ and $c\bar{c}$ cross-sections increase with $\sqrt{s}$
  - Output rate increases with $\mathscr{L}$ and pileup
  - Good trigger efficiency for b and c-hadron decays

- Exploring:
  - Split the two stages of HLT in order to run them independently. This enables the deferral to disk of the HLT1 output, and delaying the HLT2 processing until after relevant calibrations become available.
  - Optimize the code through improved vectorization where possible
  - Perform some analyses on trigger information only
  - Use of co-processors like GPGPUs to reduce the CPU load.

Conclusions

- High precision measurements are the main road to better understand the flavor structure of the SM and to reveal NP.
- The performance of the current detector and the purity of the samples already accumulated gives confidence that measurements of very high sensitivity can be achieved.
- Challenging upgrade is in preparation.
  It is a good opportunity to join the LHCb collaboration.