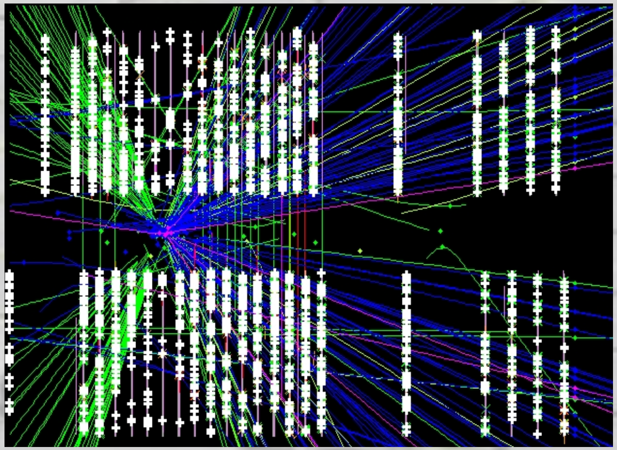
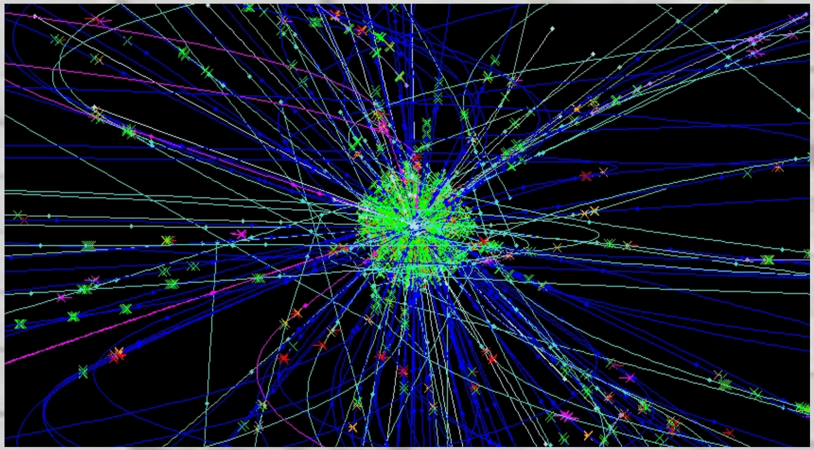
# Status report on LHCb

P. Campana (CERN/Frascati)
RRB meeting, 31.10.2012

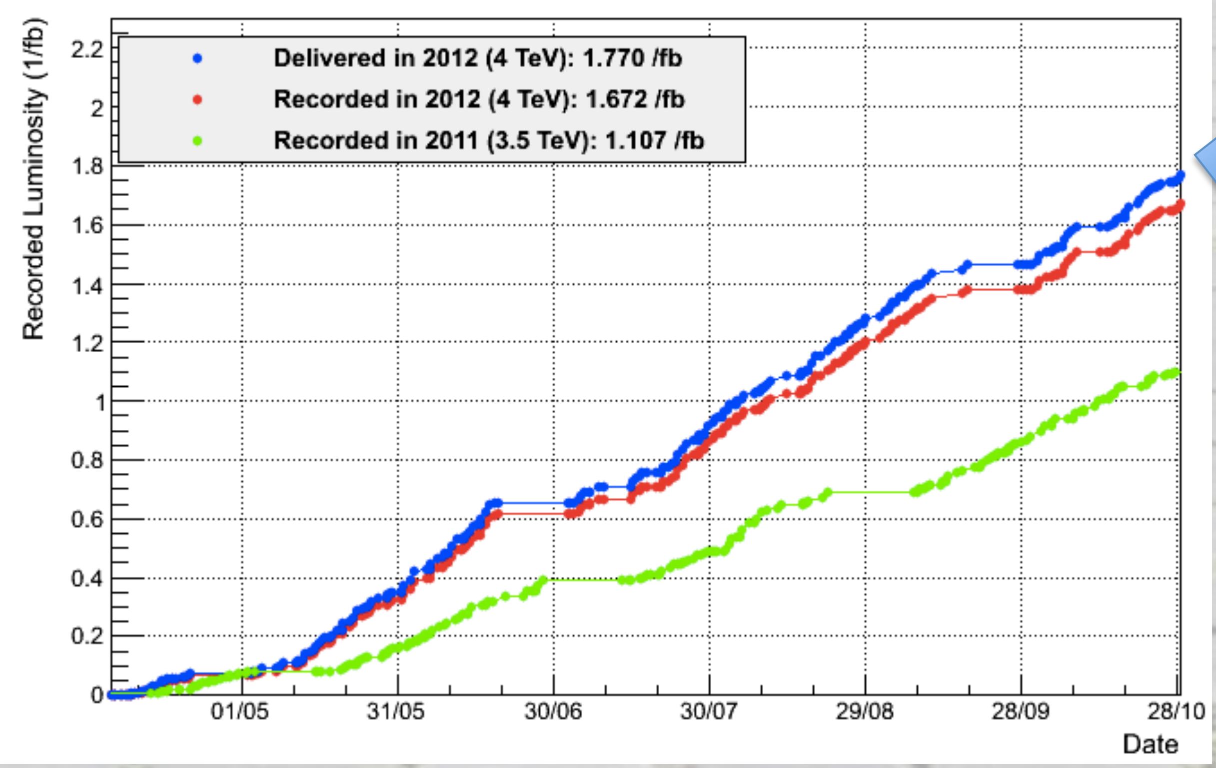




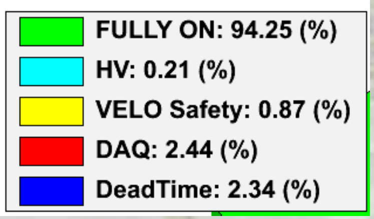
# LHCb running in 2012

Smooth and efficient running

- L ~ 4 $10^{32}$ $cm^{-2}s^{-1}$ – L0 trigger level at 1 MHz (max possible) - 5 kHz of data written on tape (was 3 kHz in 2011)
- Higher physics yields (due to energy and increased performance of HLT, especially for charm and events with $K_S$)
- Targeting to collect > 2.2/fb in 2012




>2.2 /fb



## Detector aging well under control

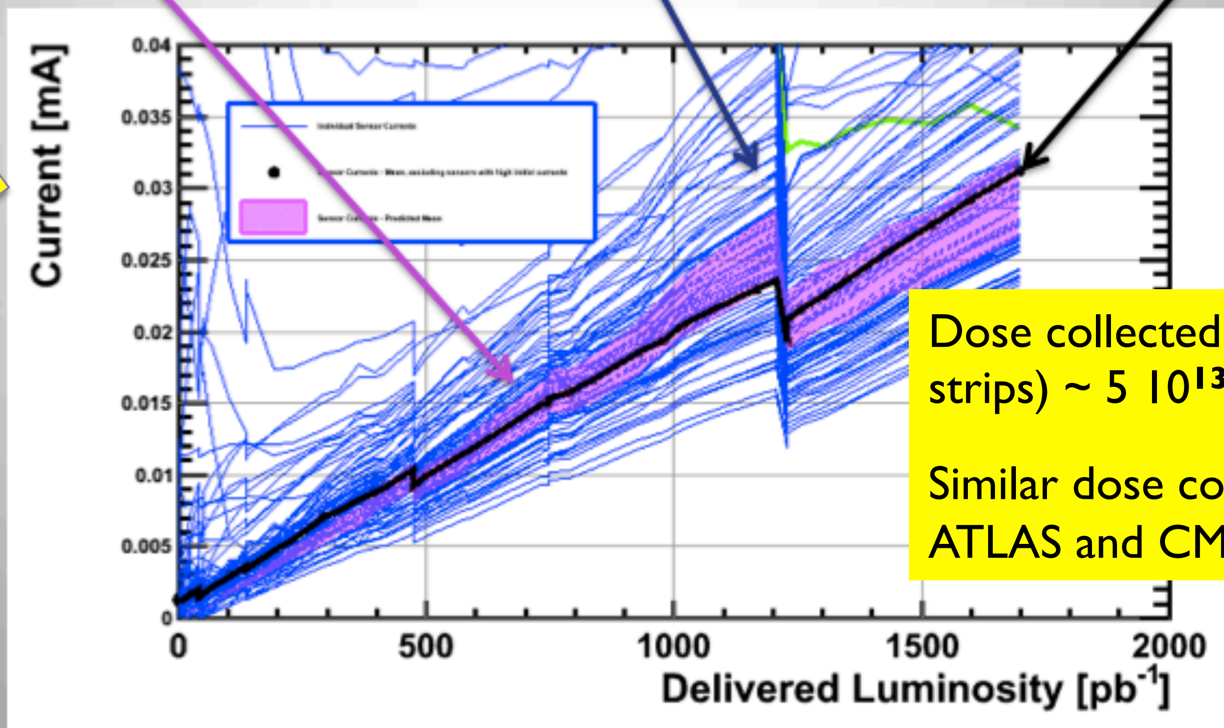
- Sensor leakage current monitored regularly
  - Simple and direct monitoring of the radiation damage

**Well described by predictions**

**Annealing clearly visible**

**Increase in multiplicity @ 8 TeV**

VELO
(ok up to 20/fb)



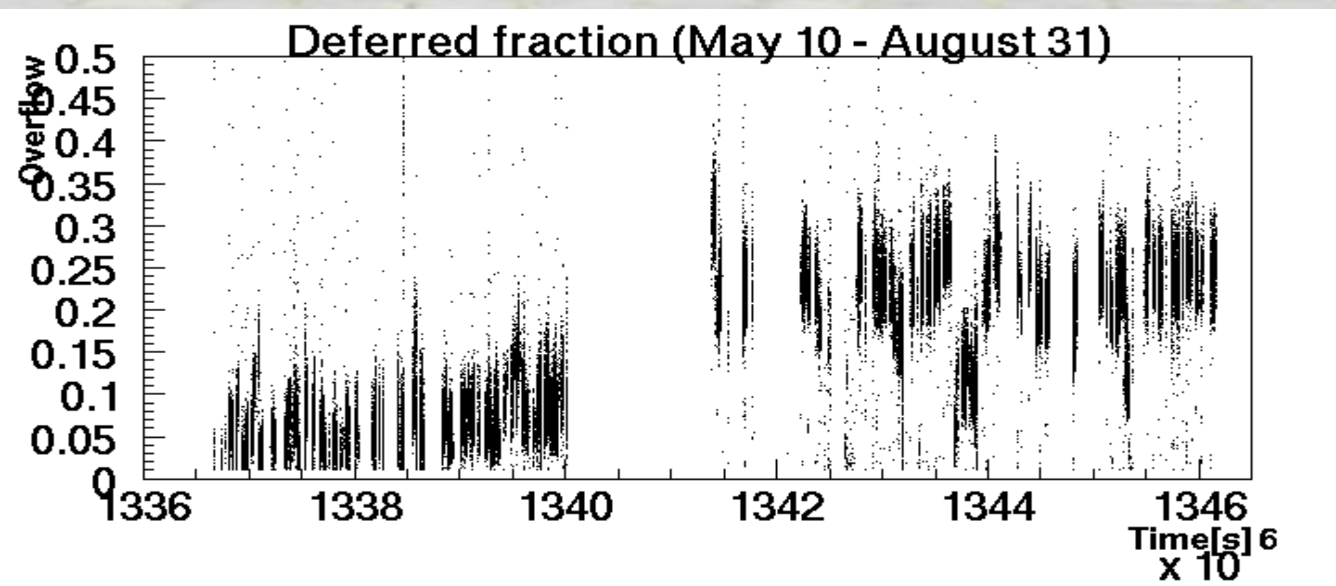

Dose collected (in innermost strips) ~ 5 $10^{13}$ neq/cm$^2$

Similar dose collected by ATLAS and CMS in ~20 /fb

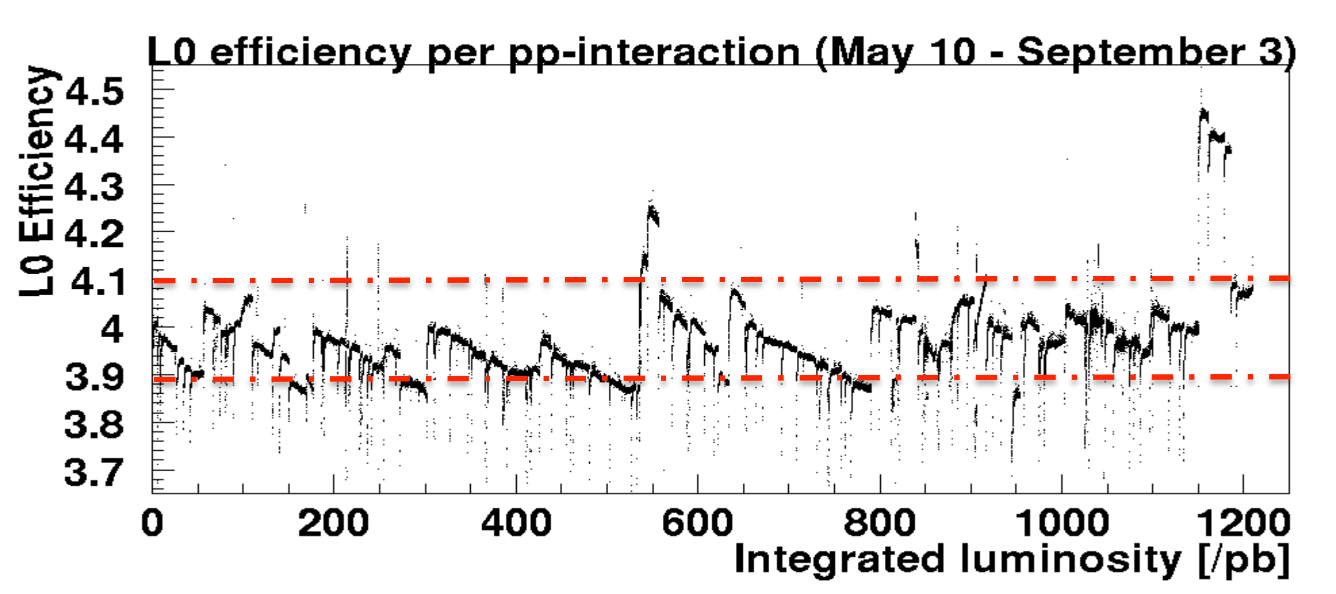


AGEING still OK also for other tracking systems and calorimeters

# Trigger and HLT




Deferred HLT trigger works very well up to ~ 30%




Intense efforts to keep L0 hadron trigger within 2.5% of allowed bandwidth

# Computing

- Processing of 2012 data (~ 1.4/fb) has been successful (thanks to several adaptations of LHCb computing model) despite:
  - reduced pledge relative to requests
  - +40% in RAW data arising from outstanding performance of LHC in 2012

All contingency used up !

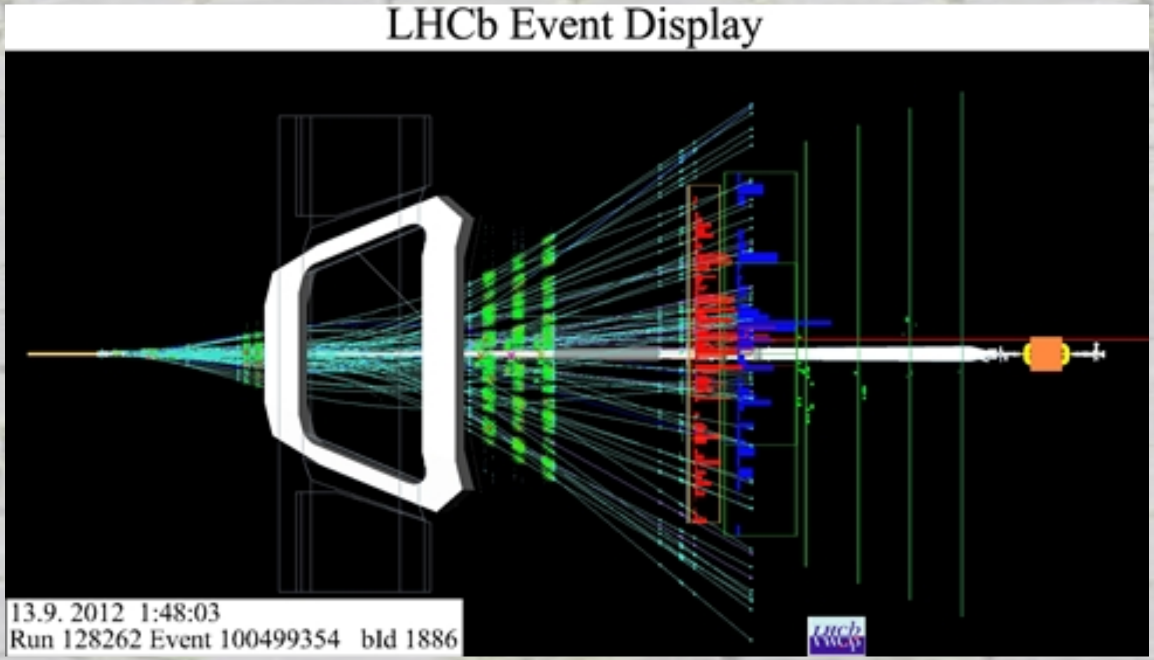
- Requests for 2013-2014 include:
  - CPU: + 20% increase at Tier1 in 2013
  - Disk: 20% increase per year at Tier1, 25% per year at CERN
  - Tape: 100% increase in 2013 at Tier1, 10% in 2014
  - Constant MC production

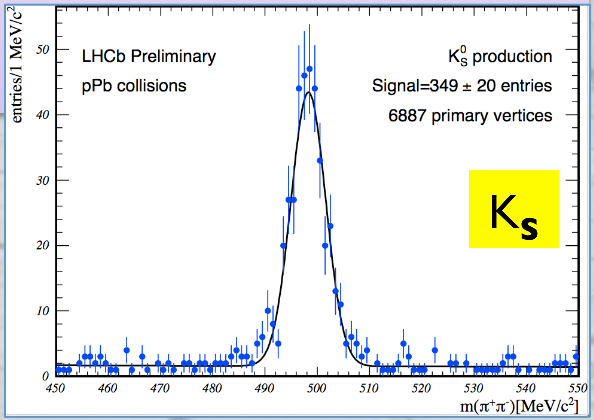
- Large step (factor x2) foreseen in needs after LS1
  - Launched a manpower intensive program of software optimisation
  - Significant increase of computing resources has to be foreseen, to match expansion of physics programme

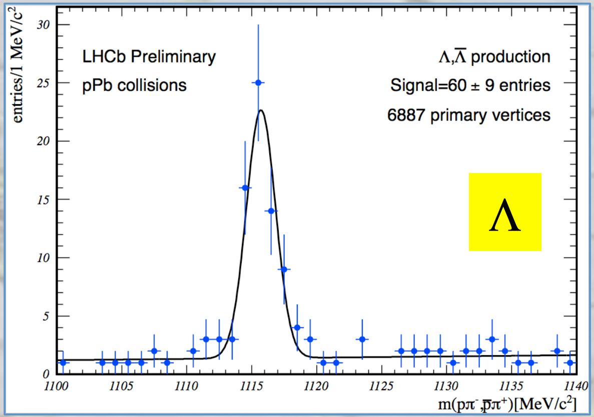
# pA collisions in LHCb

Sept 13 – *pA* run (also) in LHCb ~1 hour data taking at L ~ 5 $10^{25}$ $cm^{-2}s^{-1}$
Very good and stable conditions
No problem of multiplicities in the detector (very similar to *pp* collisions)

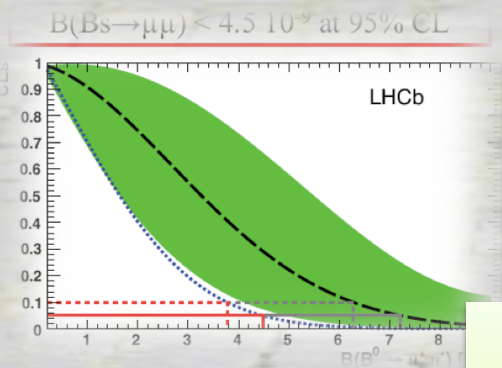
$K_s$ and $\Lambda$ peaks reconstructed offline
Good expectations for the January (*pA*, *Ap*) run

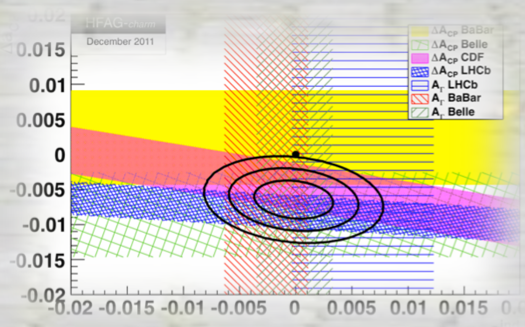


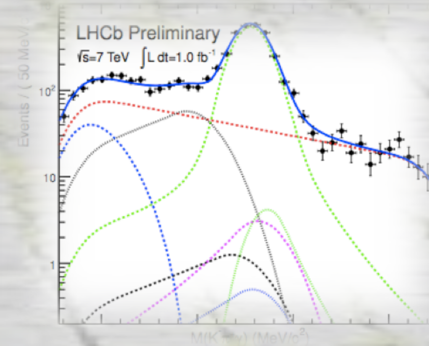



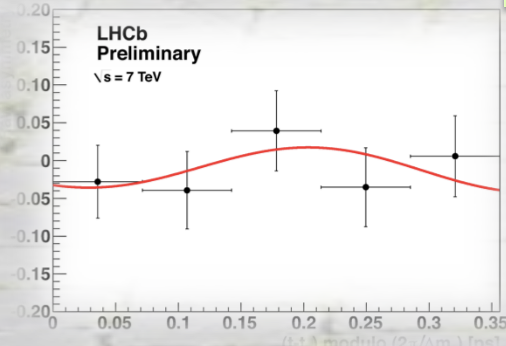



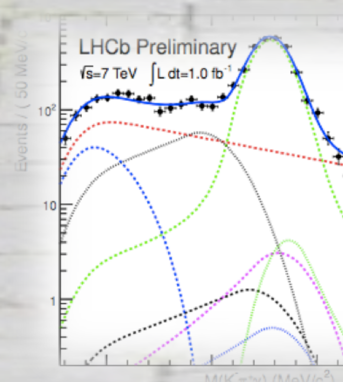
## Selected highlights of recent LHCb results (with 1/fb)



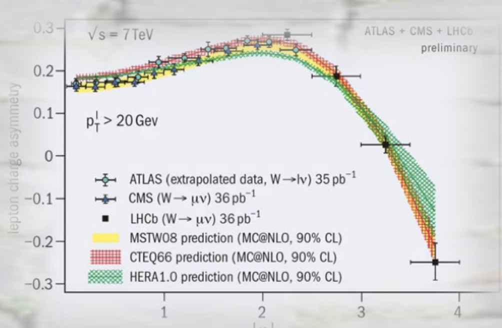



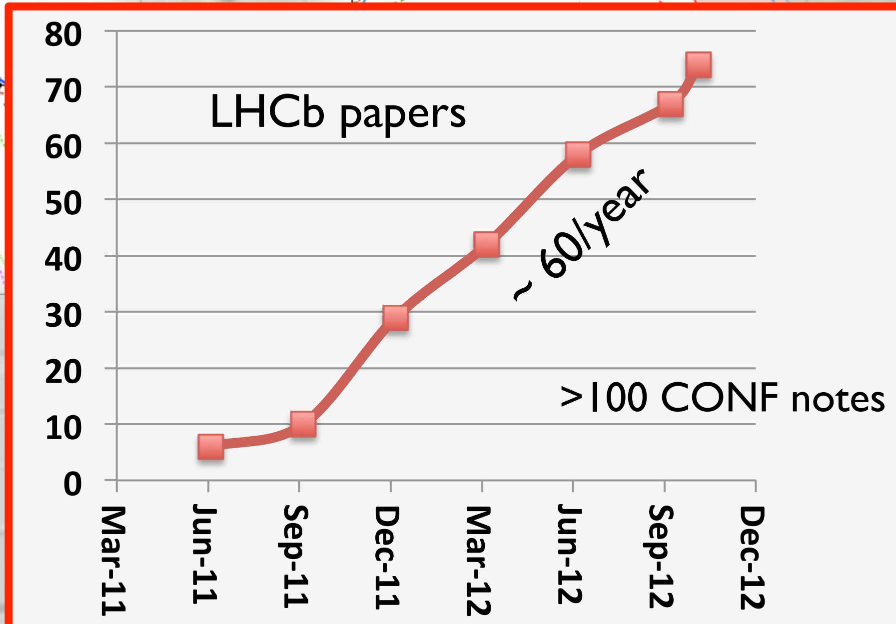







## Study of CPV in $B_s$ mixing

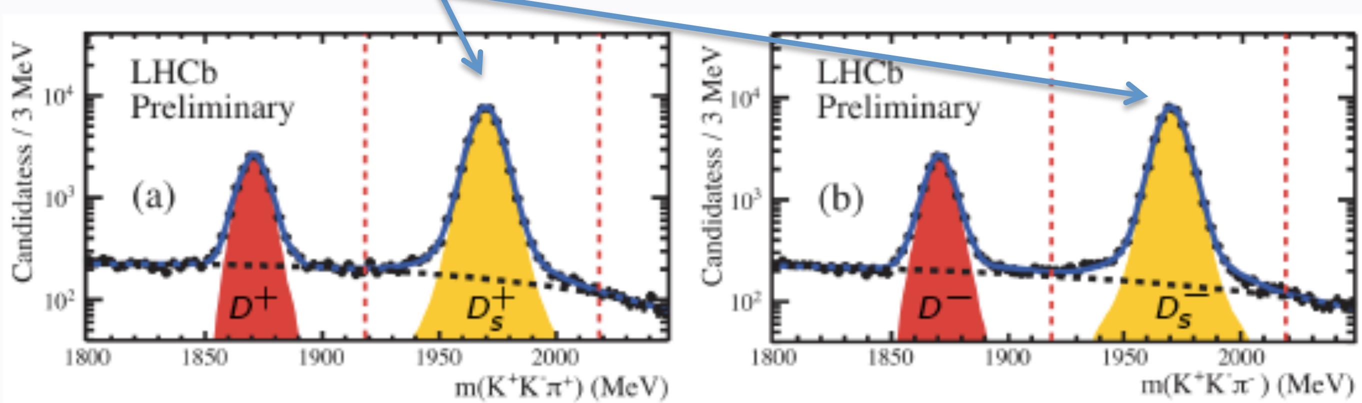
Time int. asymmetry in $B_s$ mixing tagged by specific flavor final state (e.g. muons)

$$a_{\rm sl}^{s} = \frac{\Gamma(\overline{B}{}_s^0(t) \to f) - \Gamma(B_s^0(t) \to \overline{f})}{\Gamma(\overline{B}{}_s^0(t) \to f) + \Gamma(B_s^0(t) \to \overline{f})}$$

Measured by D0 with semileptonic events ($\mu$ and di-$\mu$)

$A_{sl}^{\mu\mu} = ( -0.79 \pm 0.20 )\%$ (mix of $a_{sl}^{d}$ and $a_{sl}^{s}$)
~ 4 $\sigma$ tension with SM
Difficult to reconcile with $\phi_s$ LHCb data

- SM prediction: $a_{\rm sl}^{s} = (1.9 \pm 0.3) \times 10^{-5}$ *(arXiv: 1205.1444)*
- Use as final state $D_s^{\pm} X \mu^{\mp} \overset{(-)}{\nu}$, $D_s^{\pm} \to \varphi \pi^{\pm}$



- Time-integrated measurement:
  - Effect of small production asymmetry eliminated due to large $\Delta m_s$
- Detection asymmetries estimated from calibration samples
- Residual detector asymmetries averaged out using magnet-up and magnet-down data (roughly equal-sized datasets)

LHCb measurement:

$a^s_{sl} = (-0.24 \pm 0.54 \pm 0.33)\%$

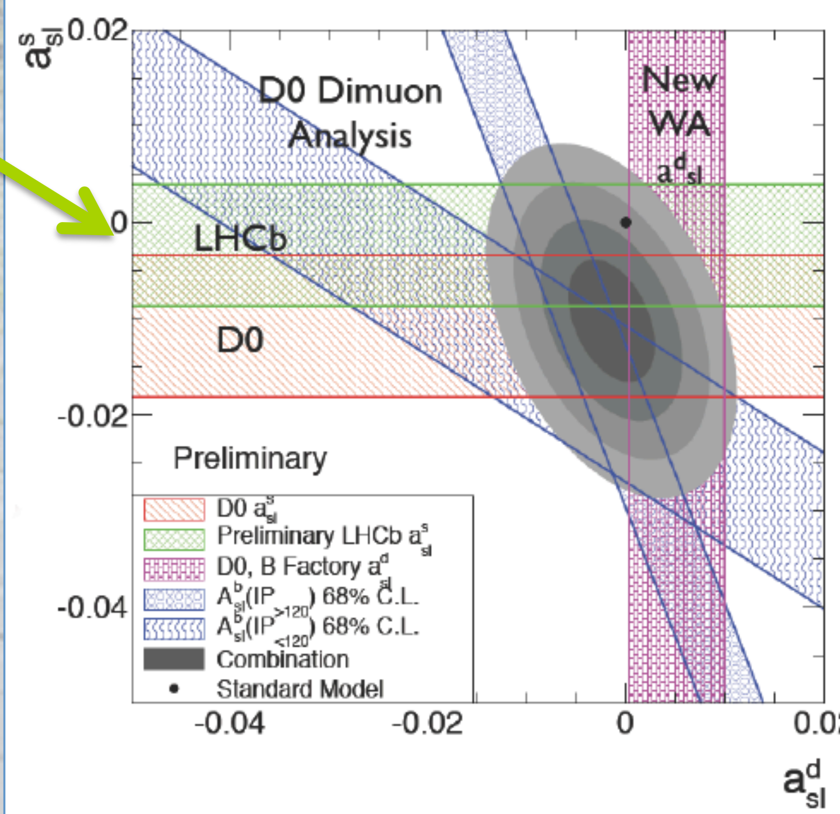
Combination (using also new WA from B-factories)

$a_{SL}(B_d)$ = (-0.15 ± 0.29) %

$a_{SL}(B_s)$ = (-1.02 ± 0.42) %

Fitted $a_{SL}(B_s)$: ~ 2.5 $\sigma$ from SM

More precision from LHCb needed to solve $a_{SL}$ D0 discrepancy (if any)



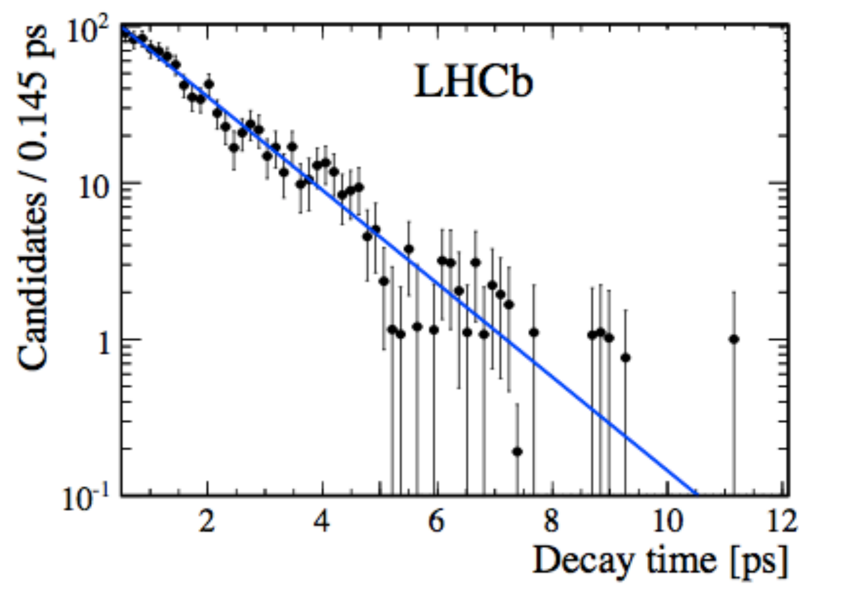
# Lifetime measurements as probe of NP

$B_s \to K^+ K^-$

- B charmless decays as probe of NP – dominated by penguin diagrams
- CP-even final state: decay dominated by $B_s$ light mass eigenstate

$\tau_{KK} \sim \Gamma_L^{-1} = 1.455 \pm 0.046 \pm 0.006$ ps

Further statistics available from other samples with different selections



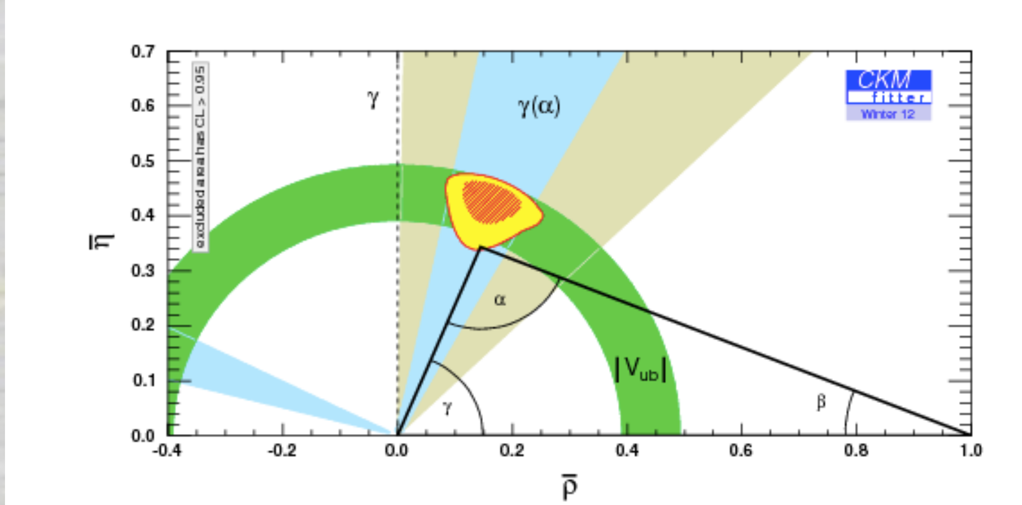

$B_s \to J/\psi\ f_0$

- Pure CP-odd final state: decay dominated by $B_s$ heavy mass eigenstate

  $\tau_{J/\psi\ f} \sim \tau(B_H) = \Gamma_H^{-1} = 1.700 \pm 0.040 \pm 0.026$ ps

Uncertainties on $\Gamma_s$ are comparable to those from angular analysis of $B_s \to J/\psi\ \phi$
Independent from the measurement of $\phi_s$ (can be used as input to the fit)

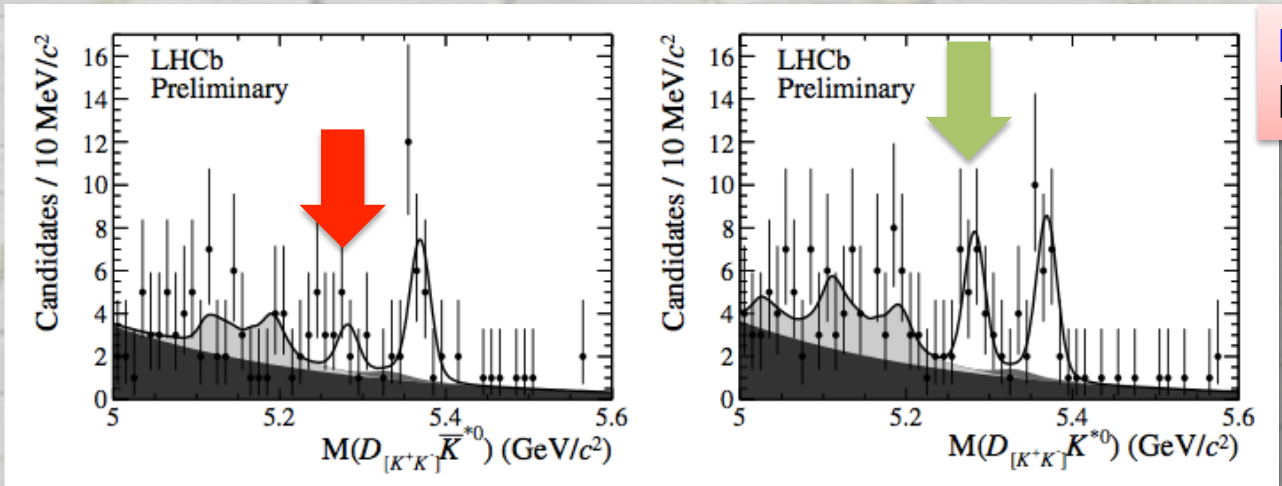
# The first LHCb measurement of CKM angle $\gamma$




The angle $\gamma$ is still the least known among CKM angles

B factories error: ±17°

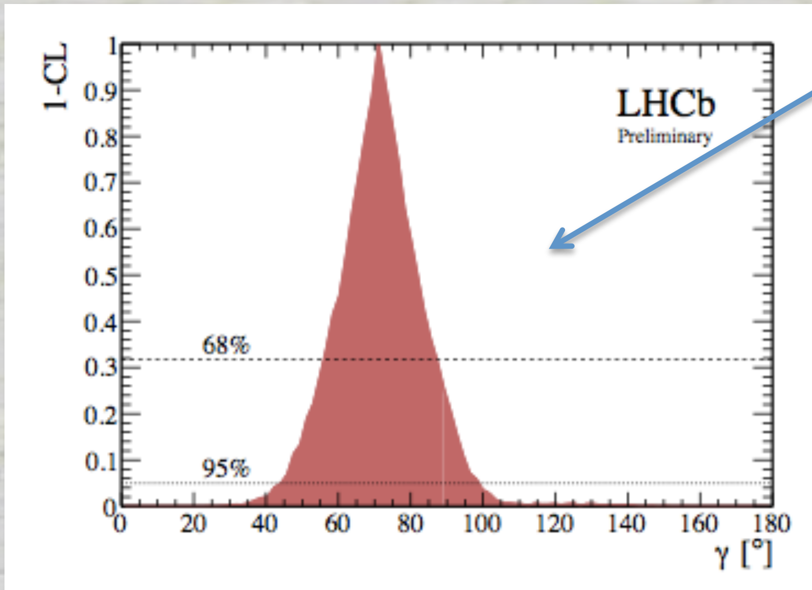
The increasing statistics of LHCb starts to populate the suppressed hadronic decays useful for the determination of $\gamma$




$B^0 \to DK^*$ (GLW) – $D \to KK$
$B^-$ 7 ev. – $B^+$ 20 ev.

First observation !

$B^0 \to DK^{0*},\ D \to hh$




Constraints on γ obtained from GGSZ and ADS/GLW analysis of $B^+ \to DK^+$

Combinations of $B^+ \to DK^+$ modes gives

$\gamma = 71^{+17}_{-16}$ deg

An error similar to the one obtained from full fits at B factories

Further info will come from the determination of γ from time dependent analysis and from B to charmless decays (NP could affect penguin diagrams)

LHCb-CONF-2012-32

LHCb will soon measure γ from the global combination of the following (tree) channels

- $B^+ \to DK^+$, *with* $D \to hh$ [GLW/ADS*] PLB 712 (2012) 203
- $B^+ \to D\pi^+$, *with* $D \to hh$ [GLW/ADS] PLB 712 (2012) 203
- $B^+ \to DK^+$, *with* $D \to K_s hh$ [GGSZ] arXiv 1209.5869
- $B^+ \to D\pi^+$, *with* $D \to K_s hh$ [GGSZ] arXiv 1209.5869
- $B^+ \to DK^+$, *with* $D \to \pi K\pi\pi$ [ADS*] LHCb-CONF-2012-30
- $B^+ \to D\pi^+$, *with* $D \to \pi K\pi\pi$ [ADS*] LHCb-CONF-2012-30
- $B^+ \to DK^+\pi\pi$, *with* $D \to hh$ [GLW*/ADS] LHCb-CONF-2012-21
- $B^0_{(s)} \to DK^{*0}$, *with* $D \to hh$ [GLW/ADS] LHCb-CONF-2012-24
- $B^0_{(s)} \to DKK$ *with* $D \to hh$ [GLW/ADS*] PRL 109 (2012) 131801

* First observations

# CPV in $B \to hhh$ charmless decays

Study of NP effects in the weak phase from interfering patterns of 2 body resonances in the Dalitz plot

Dominant diagrams: $b \to u$ tree and $b \to s$ (d) penguins

Measuring CPV in 3 body decays:

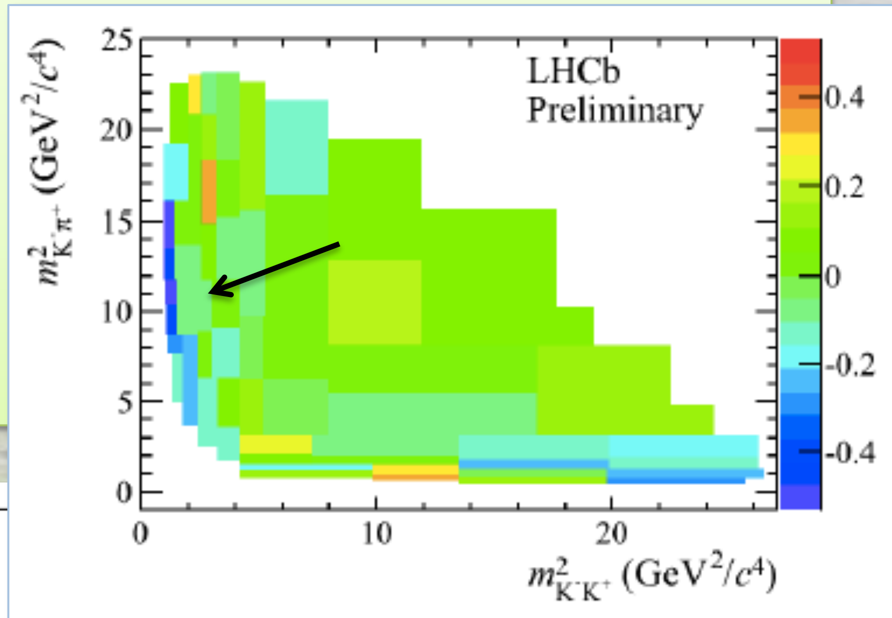
$B^+ \to K\pi\pi$ , $B^+ \to KKK$ , $B^+ \to \pi\pi\pi$ , $B^+ \to KK\pi$

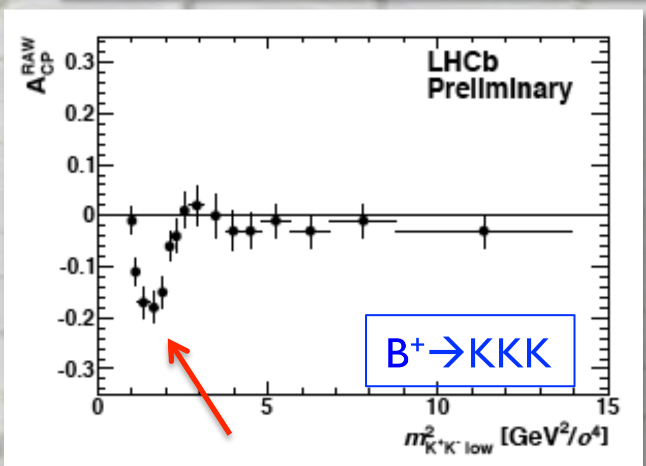
$A_{CP}(K\pi\pi) = 0.034 \pm 0.012$

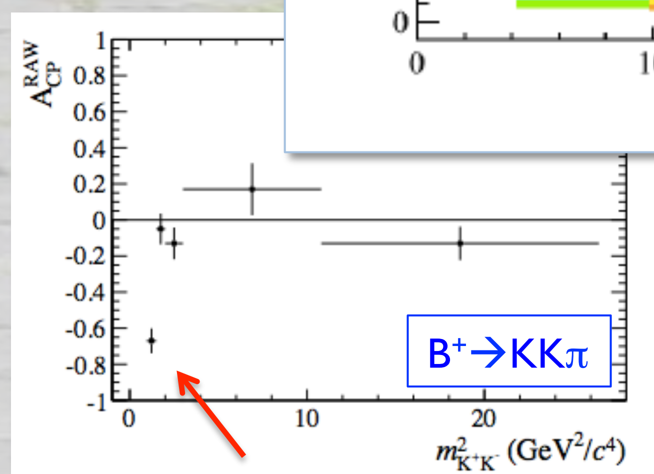
$A_{CP}(KKK) = - 0.046 \pm 0.012$

$A_{CP}(\pi\pi\pi) = 0.120 \pm 0.028$

$A_{CP}(KKK) = - 0.153 \pm 0.050$



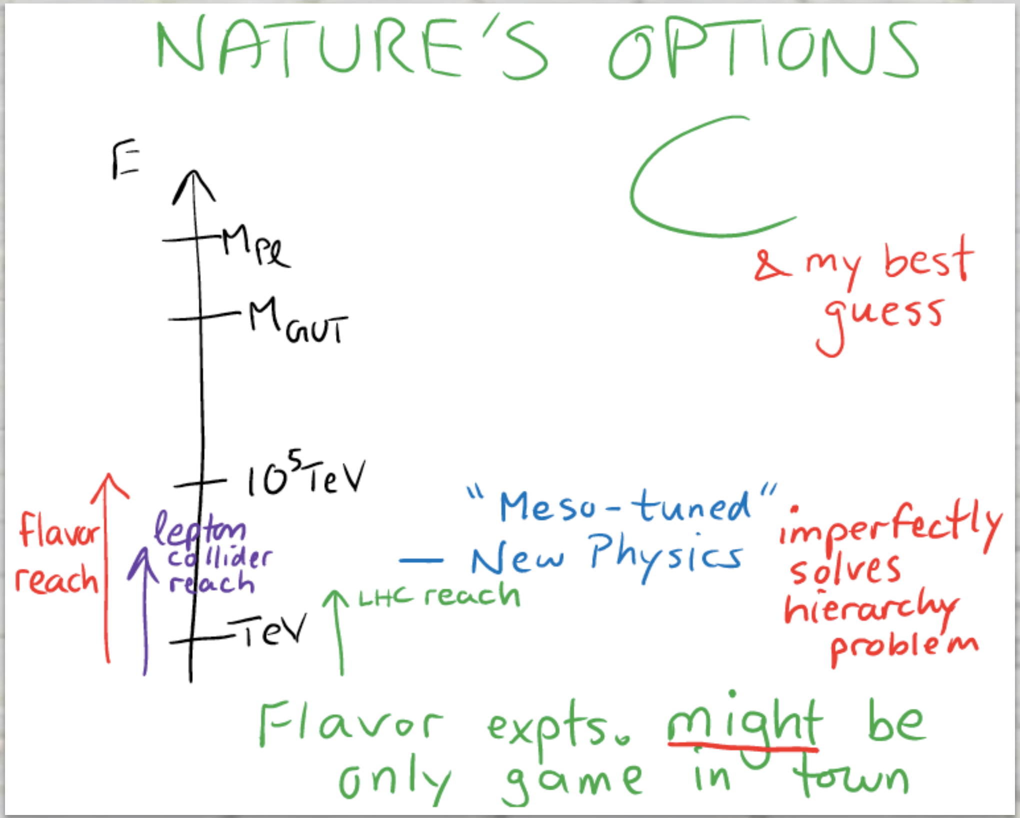

LHCb-CONF-2012-18
LHCb-CONF-2012-28

Study of CPV across Dalitz plot ($A_{CP}$ vs $m^2_{hh}$): large CPV in specific resonance areas
Typically at low $m^2$ . More experimental work needed as well as on theory side

# The LHCb upgrade

# In the search for NP

Higgs-like particle discovery was a great LHC success, but so far no significant sign of NP in direct searches
→ energy scale of NP mass scale pushed higher
→ fine tuning needed to protect Higgs mass ? "Naturalness" appears problematic




- Indirect searches have the potential to see NP in flavor phenomena. The LHCb Upgrade will push the experimental precision up to where NP may appear
- At the Krakow ESPP meeting, the LHCb Upgrade has been considered *"… an important part of the exploitation of LHC."*

R. Sundrum CKM2012

# Plans for the LHCb Upgrade

Based on running experience, LHCb will collect **~ 7/fb** by the end of 2017

Reaching ultimate theory precision in flavor variables will need more statistics. Current LHCb limitation is in L0 trigger rate capability (< 1 MHz) that does not allow to profit from an increase in luminosity

Upgrade plans:

- 1 MHz → 40 MHz readout
- Full software trigger (better yields for charm and hadronic triggers)
- Up to L ~ 2 $10^{33}$ $cm^{-2}s^{-1}$ to collect **50/fb**

Increase in yields (w.r.t. 2011): **x10** in muonic channels **x20** in hadronic channels

2013-14 Long Shutd. 1 / LHCb maintenance, first infrastructures for upgrade

2015-17 LHCb data taking (13-14 TeV) / 40 MHz protos in test

2018-19 Long Shutd. 2 / LHCb upgrade installation [ Atlas/CMS upgrades phase 1]

≥ 2019 Upgraded LHCb in data taking (14 TeV)

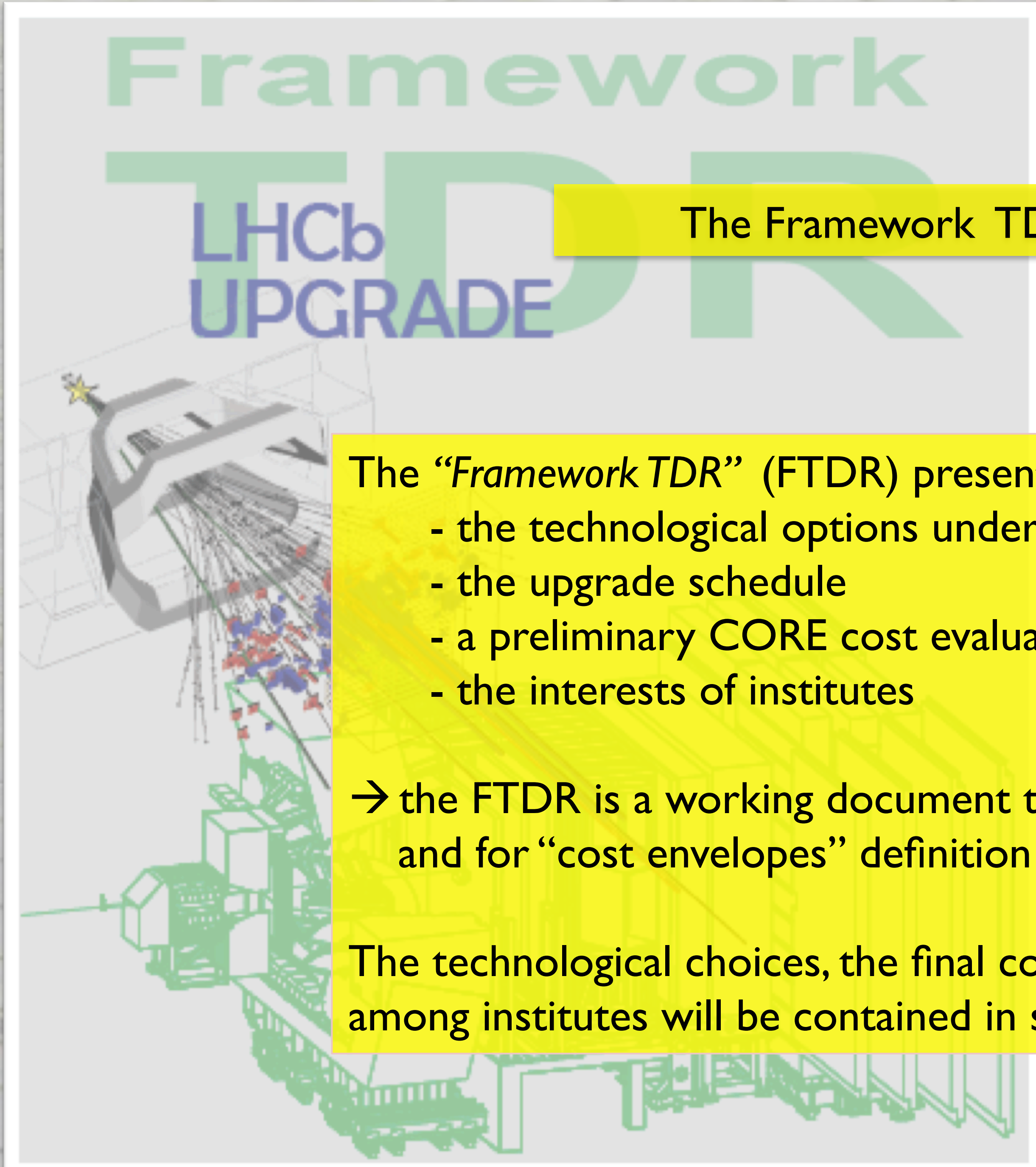
2012-13 R&D, technological choices, preparation of subsystems TDRs

2014 Funding/Procurements

2015-19 Construction & installation

# LHCb Upgrade: the formal steps

- *March 2011, "Letter of Intent for the LHCb Upgrade" submitted to LHCC* ✔
  *→ Endorsement of physics case. Review of proposed trigger concept (40 MHz)*
- *June 2011 → LHCC endorses the LOI, green light for TDR preparation* ✔
- *June 2012, Submission of "Framework TDR for the LHCb Upgrade" to LHCC* ✔
- *September 2012 → LHCC endorses the FTDR* ✔
- *October 2012, Presentation of "Framework TDR" and of "Addendum to MoU for the Common Items of the LHCb Upgrade" to RRB and to Funding Agencies* ✔
- *Fall 2013, Submission of LHCb subsystems TDRs to LHCC*




## The Framework TDR for the LHCb Upgrade

The *"Framework TDR"* (FTDR) presents:

- the technological options under study
- the upgrade schedule
- a preliminary CORE cost evaluation
- the interests of institutes

→ the FTDR is a working document to the FA for R&D funding and for "cost envelopes" definition

The technological choices, the final costs, and the sharing among institutes will be contained in subsystem TDRs

LHCb COLLABORATION CERN-RRB-2012-119A

Addendum

to the

Memorandum of Understanding

for Collaboration in the Construction of the

LHCb Detector

# The Addendum for the LHCb Upgrade Common Items

Scope of the Addendum to the MoU:

- present the first formal document to Funding Agencies to start discussions on resources needed for the upgrade
- get the approval specifically for the Common Projects (CP) and their planned share
- inform Funding Agencies on the "envelope" of CP costs
  - resources for Infrastructure & Common Electronics will be needed already during LS1)
  - final cost of Online part is deferred to the TDR in 2016

The Addendum approval process will run in parallel with TDR preparation

## Interactions with HL-LHC coordination group

No show-stoppers to operate LHCb at HL-LHC:

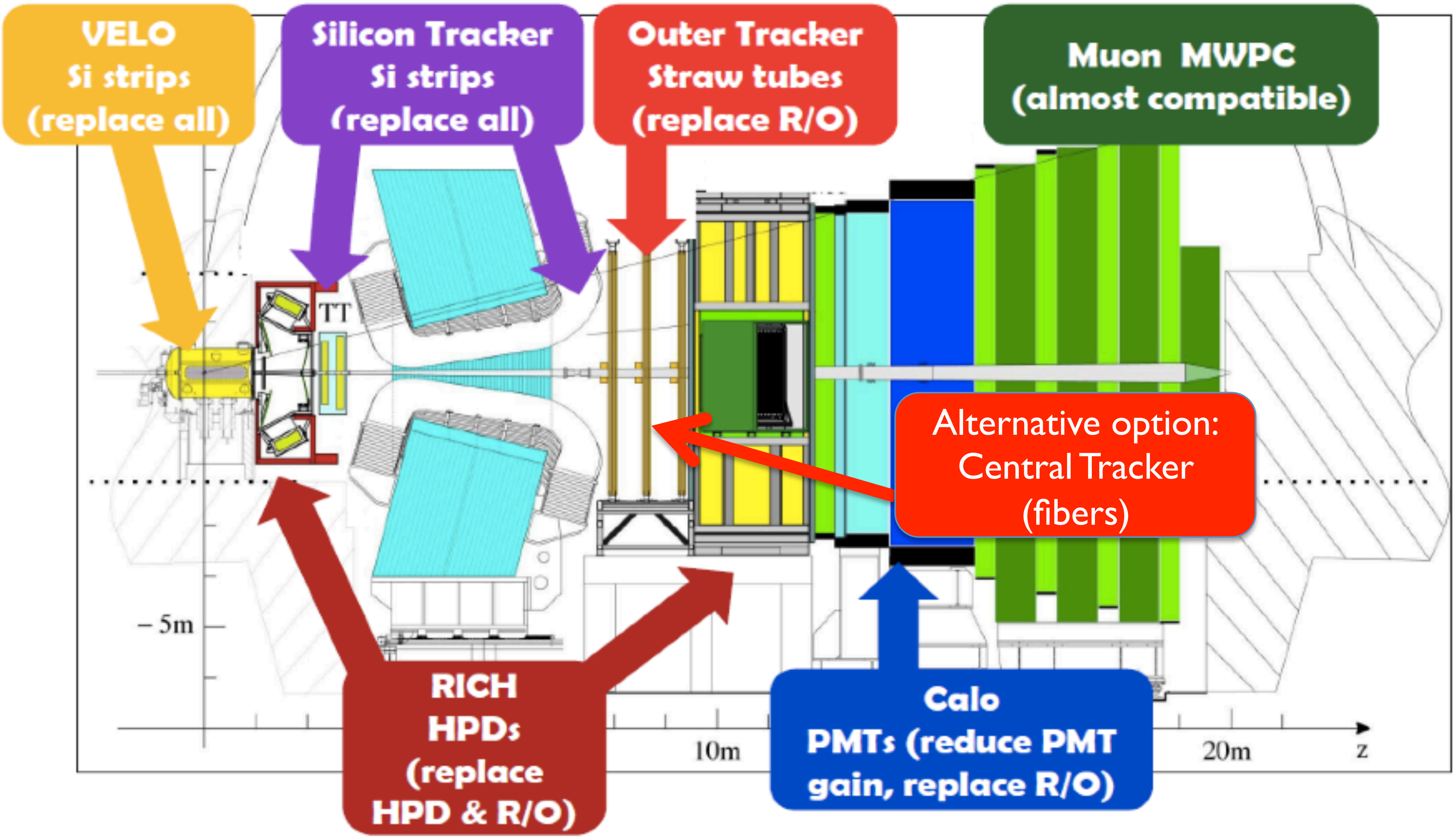
- Optics compatible with the requirements for ATLAS&CMS ($\beta^*$ 0.1m) and the LHCb upgrade ($\beta^*$ 3.5m) have been developed

- FLUKA simulations showed that for luminosities of $2 \times 10^{33}$ /cm$^2$/s no TAS (Target Absorber for Secondaries) is needed (safety-factor of ~ 3). Additional measurements to be done with 7+7 TeV in 2015

- Minimum required aperture in the LHCb VELO has been conservatively defined more than 10 years ago. To improve the physics performance, investigations are on-going to reduce it from 5.1mm to 3.5mm. First conclusions indicate feasibility

Decisions by the HL coord. group and LMC should be taken in November

# LHCb detector modifications for the upgrade



# VErtex LOcator

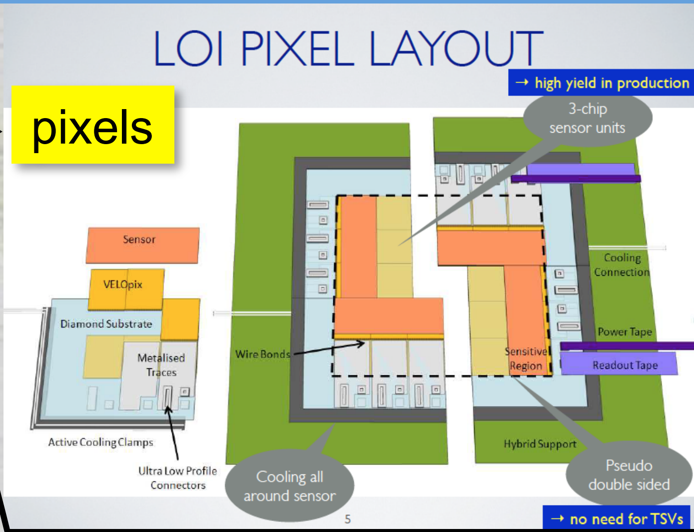
Completely new modules and FE electronics:

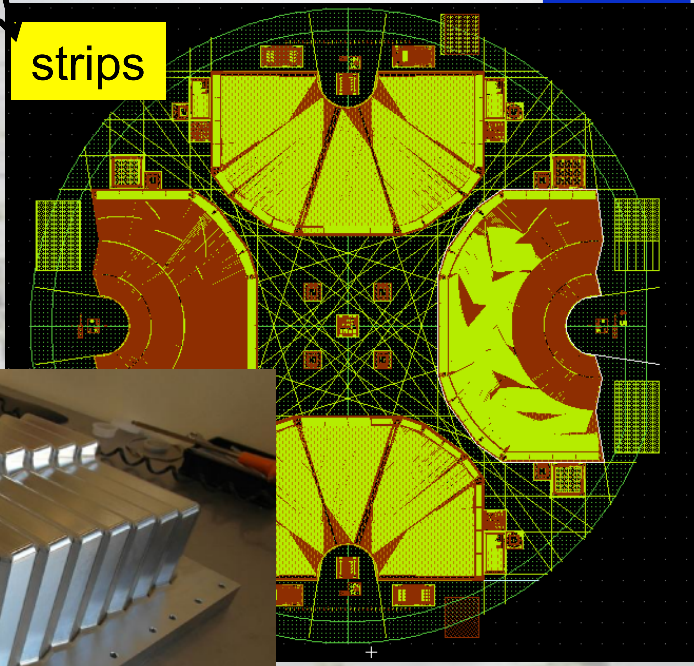
Two major options under consideration:

- STRIPS (40 MHz implementation pushes boundaries)
- PIXEL (based on Timepix R&D)

Challenges:

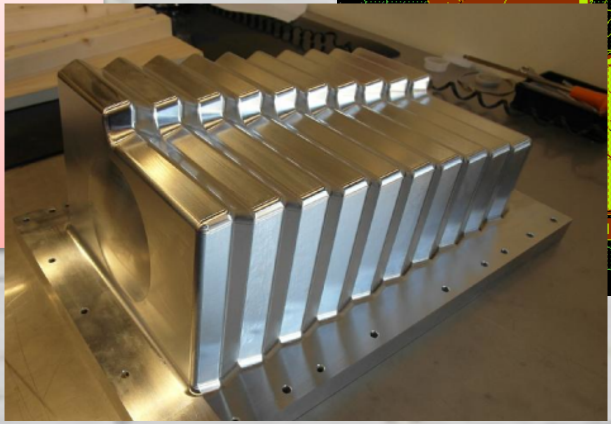
- Huge data rates (up to 12 Gbit/s)
- High radiation levels (~370 MRad or $8\ 10^{15}\ n_{eq}/cm^2$)
- Nearer to BEAM ?




Common developments:

- New module cooling interface
- New RF foil
- All without sacrifices in material budget



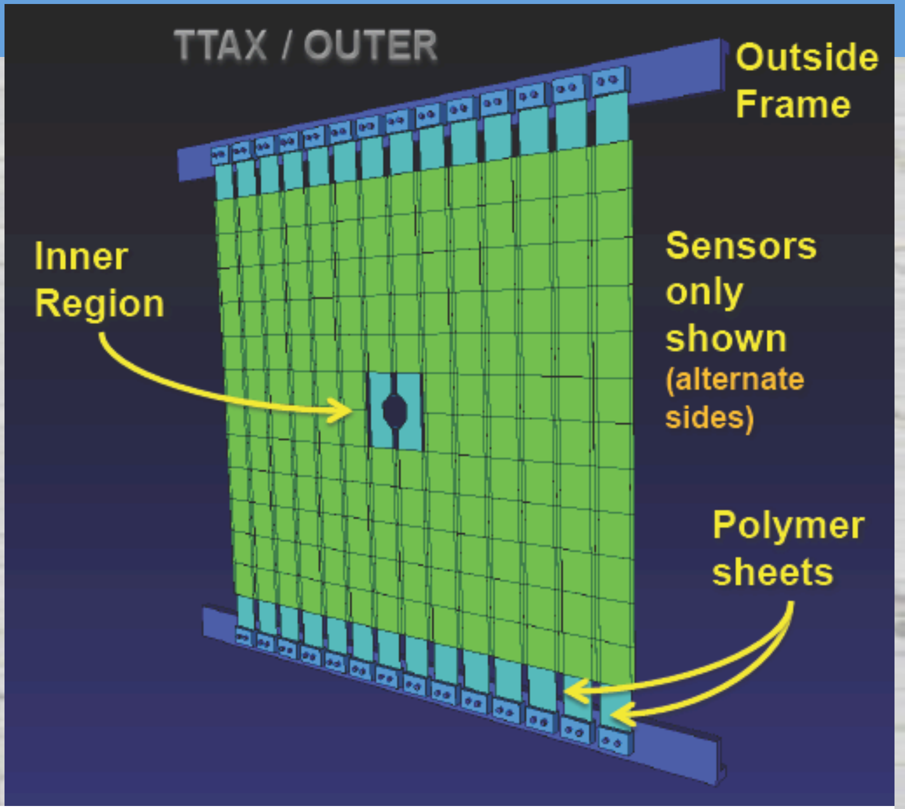
# Trigger Tracker

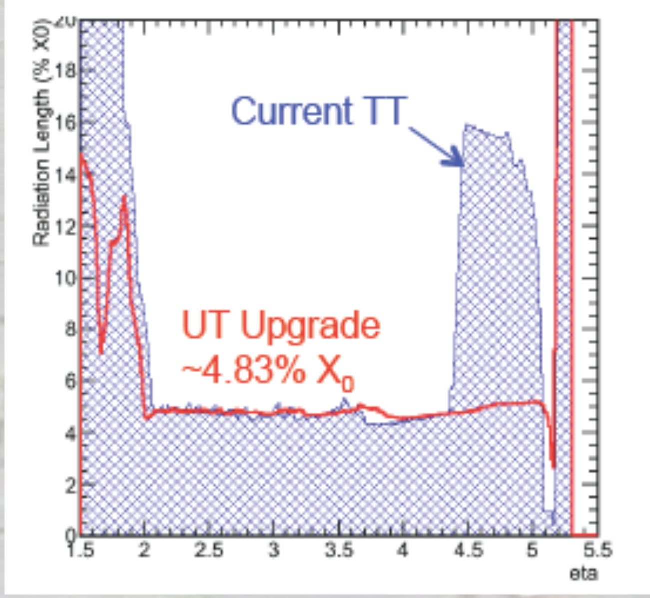
Trigger Tracker (silicon detector) of vital importance to:

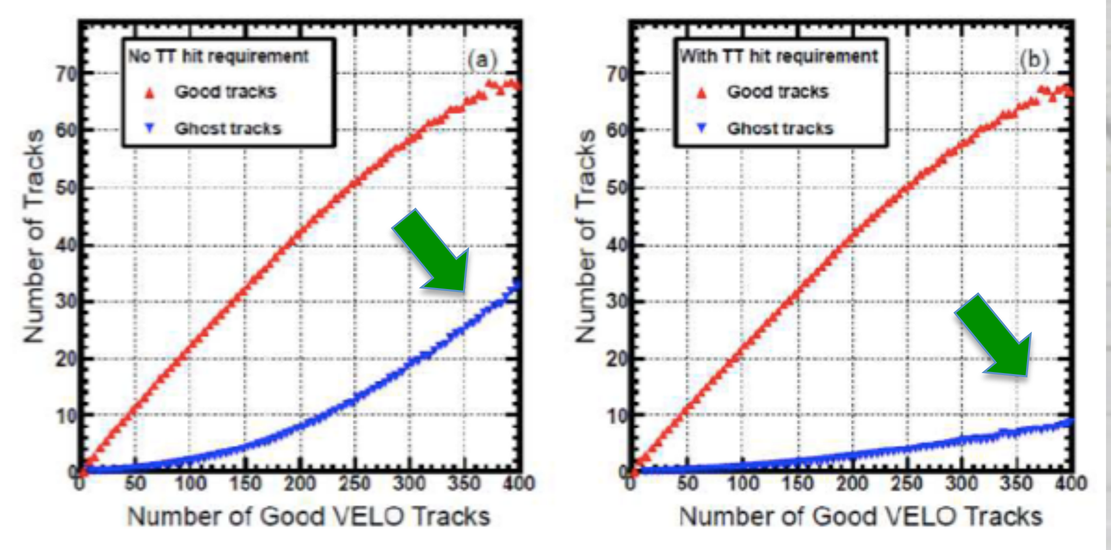
- give first measurement of p in HLT
- $K_s$ and $\Lambda$ reconstruction
- remove ghosts

Challenges:

- long ladders (cooling, mechanics)
- coverage at low $\eta$
- low material budget

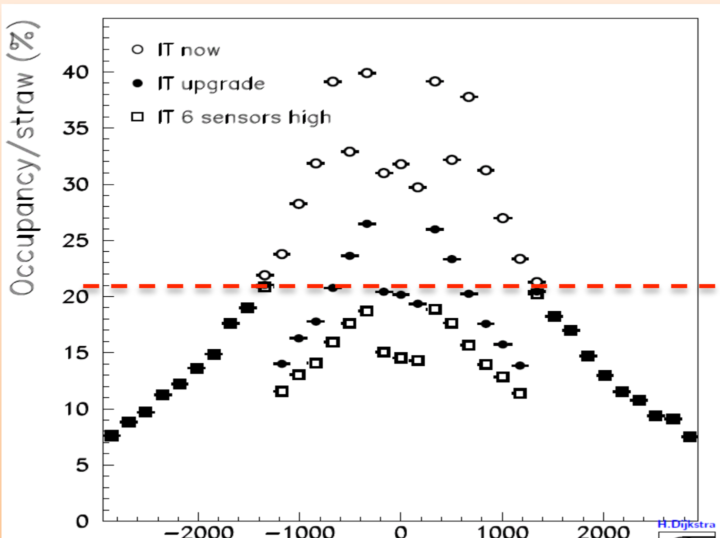


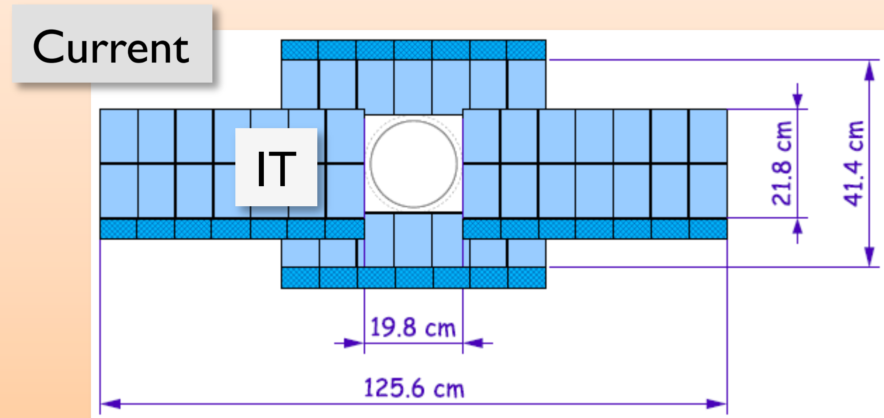



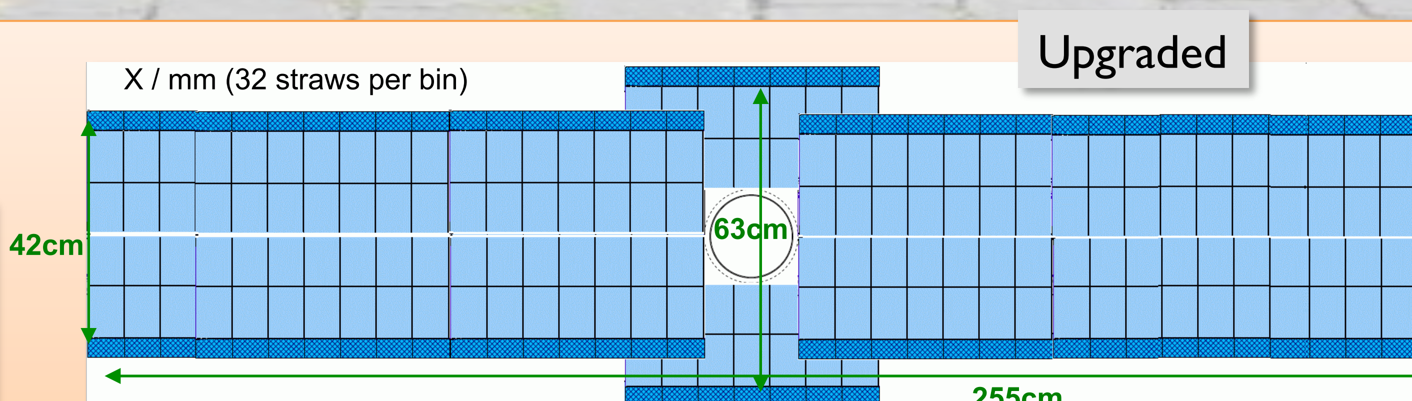



# TRACKER – Silicon Option

Increase size + decrease mass of IT to cure the OT occupancy problem




Challenges:
- Mass reduction
- Cooling
- Cost

- From 126x22(41) cm to 255x42(63) cm
- Increase number of sensors/layer by nearly factor 4, $\times 3.3$ for 10 layers.
- "$\eta$" coverage: IT/(IT+OT)= $33\% \rightarrow 54\%$

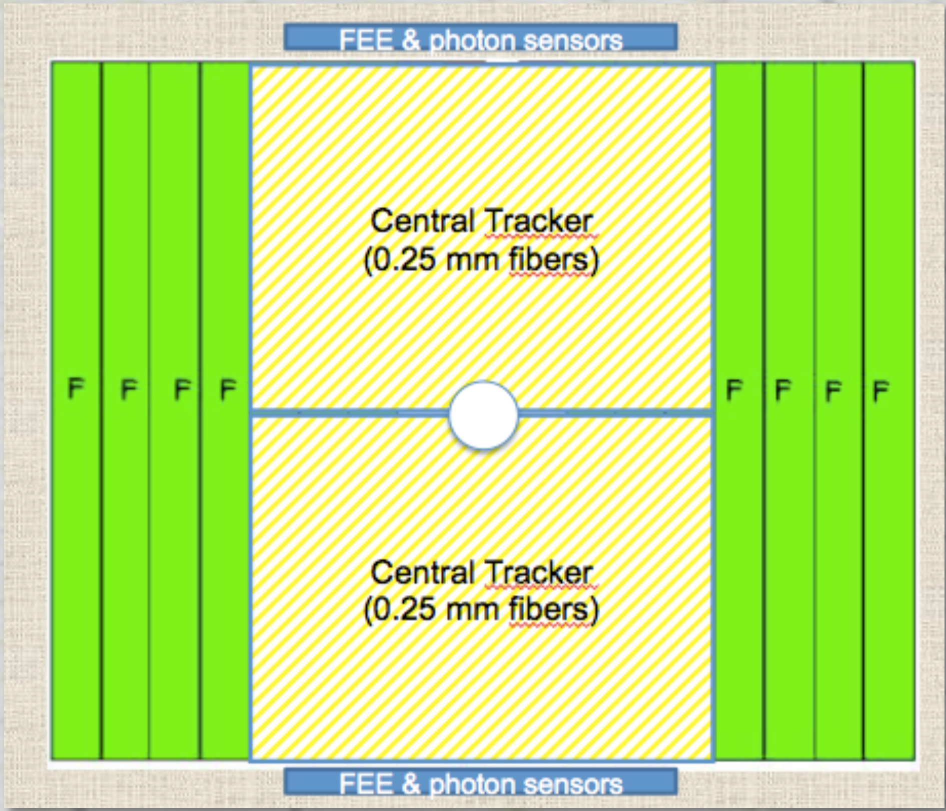
# TRACKER – Central Tracker Option

Inner part - w/ scintillating fibers modules (Sci.Fi.)
Outer part – w/ current straw tubes

Sci. Fi. central tracker:

- 5 layers of densely packed 250 μm diameter fibers, readout with 128-channel Silicon Photomultipliers (SiPM)
- 2.5m long fibers elements, readout on top and at bottom of stations
- Very light material budget

Challenge:
fibers and SiPM can sustain the occupancy and radiation (~ 1 Mrad) ?




# Particle ID: RICH, CALO, MUON

**RICH-1** and **RICH-2**

Aerogel removed (due to occupancy)
New photosensors needed to allow installation of readout at 40 MHz
Multi anode PMT as baseline solution. New readout chip needed

Exploring the possibility of combining RICH-1& -2 in a single mechanical envelope (under study)

**CALO**

SPD&PS probably removed (less material in front of ECAL)
Adaptation of ECAL and HCAL FEE electronics for 40 MHz operation
Study of radiation hardness of inner ECAL modules for operation at $2\ 10^{33} cm^{-2}s^{-1}$ :
possibility of their replacement

**MUON**

Removal of M1 (due to occupancy)
Adaptation of off-detector electronics for 40 MHz operation
High occupancy rates in inner regions of M2
Compatibility with operation at $L > 10^{33}\ cm^{-2}s^{-1}$ to be studied
Smaller size readout pads likely necessary (new detectors)

# Cost estimate (CORE)

| | Sub-Detector | Options | Cost (kCHF) |
|---|---|---|---|
| Tracking systems | | | |
| | VELO | Pixel Option | 5430 |
| | | Strip Option | 4530 |
| | Trigger Tracker | | 6215 |
| | T-stations with CT + OT option | | |
| | | CT | 7860 |
| | | OT | 2000 |
| | T-stations with IT + OT option | | |
| | | IT | 5350 |
| | | OT | 5915 |
| Particle Identification | | | |
| | RICH | | 9435 |
| | Calorimters | | 1905 |
| | Muon System | | 1805 |
| Trigger and Readout | | | 1840 |
| Common Projects | | | |
| | General Infrastructure | | 2500 |
| | Common Electronics | | 2500 |
| | Online System | | 10670 |

RICH-CALO-MUON (2 $10^{33}$) reserve 3500

TOTAL COST (depending on options) **55÷57 MSF** (15% contingency included)

# Group's interests

| Detector | Sub-system | Countries involved |
|---|---|---|
| VELO | modules & infrastructure | BR, CERN, ES, IE, NL, RU, UK, US |
| | electronics & readout | BR, ES, CERN, CN, NL, PL, UK, US |
| Tracker | modules & infrastructure | CERN, CH, DE, NL, RU, UK, US |
| | electronics & readout | BR, CERN, CH, CN, DE, ES, FR, NL, PL, US |
| RICH | mechanics & infrastructure | CERN, IT, UK |
| | electronics & readout | CERN, IT, RO, UK |
| Calo | electronics & readout | ES, FR, RU |
| Muon | chambers | IT, RU |
| | electronics & readout | IT |
| Trigger | electronics & readout | BR, CN, FR, IT |

All LHCb institutes have shown interest in joining the Upgrade

The present interests are subject to funding and will be defined in the TDR
The R&D activities have started in all countries

## Collaboration matters. New members

- Padova INFN & University (CDF - interests in flavor tagging, computing, also in view of the upgrade, and measurement of $\gamma$). Participation and funds approved by INFN in September.

- Pisa INFN, University & S. Normale (CDF - interests in tracking, trigger, also in view of the upgrade, and CPV in b). Participation and funds approved by INFN in September.

- University of Maryland (Babar/SuperB - interests in tracking, flavor tagging, also in view of the upgrade, and CPV in b). Request for grant to DOE submitted last September

Several new institutes lining up for membership or associateship (to be discussed at next Collaboration Board)

# Conclusions

Thanks to LHC performances and luminosity leveling technique, ***LHCb*** has collected over 1 $fb^{-1}$ in the 2011 run, 1.7 $fb^{-1}$ so far in 2012 - and is planning to more than triple the statistics

World best measurements on several channels:
$B_s \to J/\psi\ \phi$ , $B_s \to \mu\mu$ , $B_d \to K^* \mu\mu$, $B_s$ mixing and charm physics. Many new physics results under preparation (HCP 2012)
First ***LHCb*** measurement on CKM angle $\gamma$

***LHCb*** is complementing ATLAS & CMS searches for New Physics and the chance of having it at a high mass scale is relevant

The ***LHCb*** upgrade will contribute significantly to a full exploitation of LHC and to increase the opportunities of New Physics discovery in the next decades

First steps for the Upgrade successfully completed. TDRs planned for late 2013