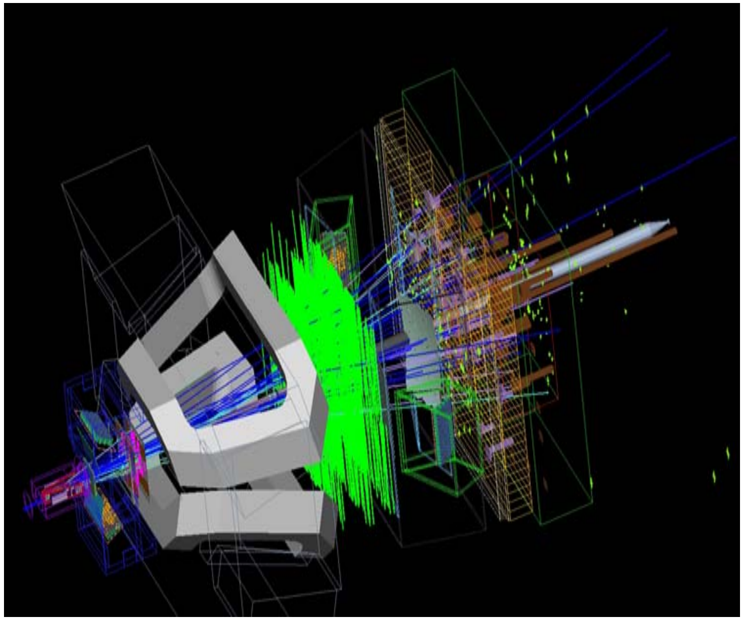
LHCb upgrade



Marcin Kucharczyk

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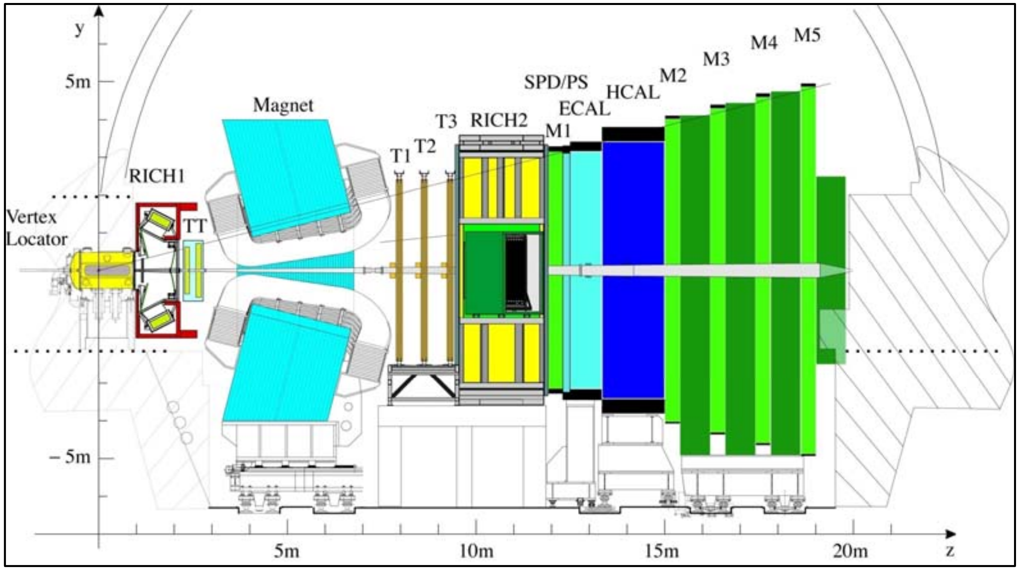
EPS 2009, Krakow

Detectors and accelerators
18.07.2009

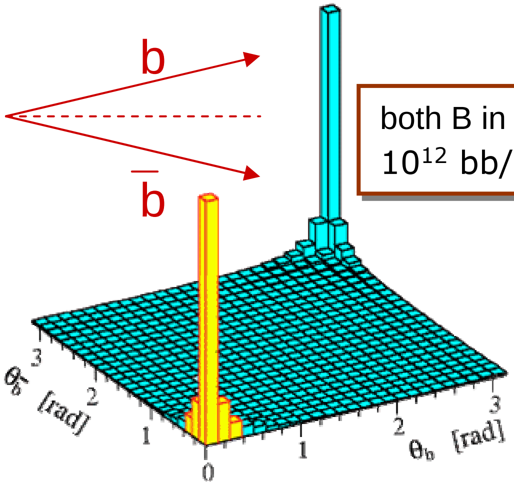
Present LHCb detector



Present LHCb detector conditions

- $\sqrt{s}$ = 10-14 TeV
- σ_{bb} = 350-500 μb
- σ_{inel} = 80 mb
- L = 2 × 10^{32} cm^{-2} s^{-1}

1 year at nominal lumi: ~2 fb^{-1}



Crucial for B physics

- optimised geometry and choice of luminosity
- trigger efficient in hadronic & leptonic modes
- excellent tracking and vertexing
- excellent particle ID - RICH *(2-100 GeV/c)*

TRIGGER: hardware - L0 & software - HLT

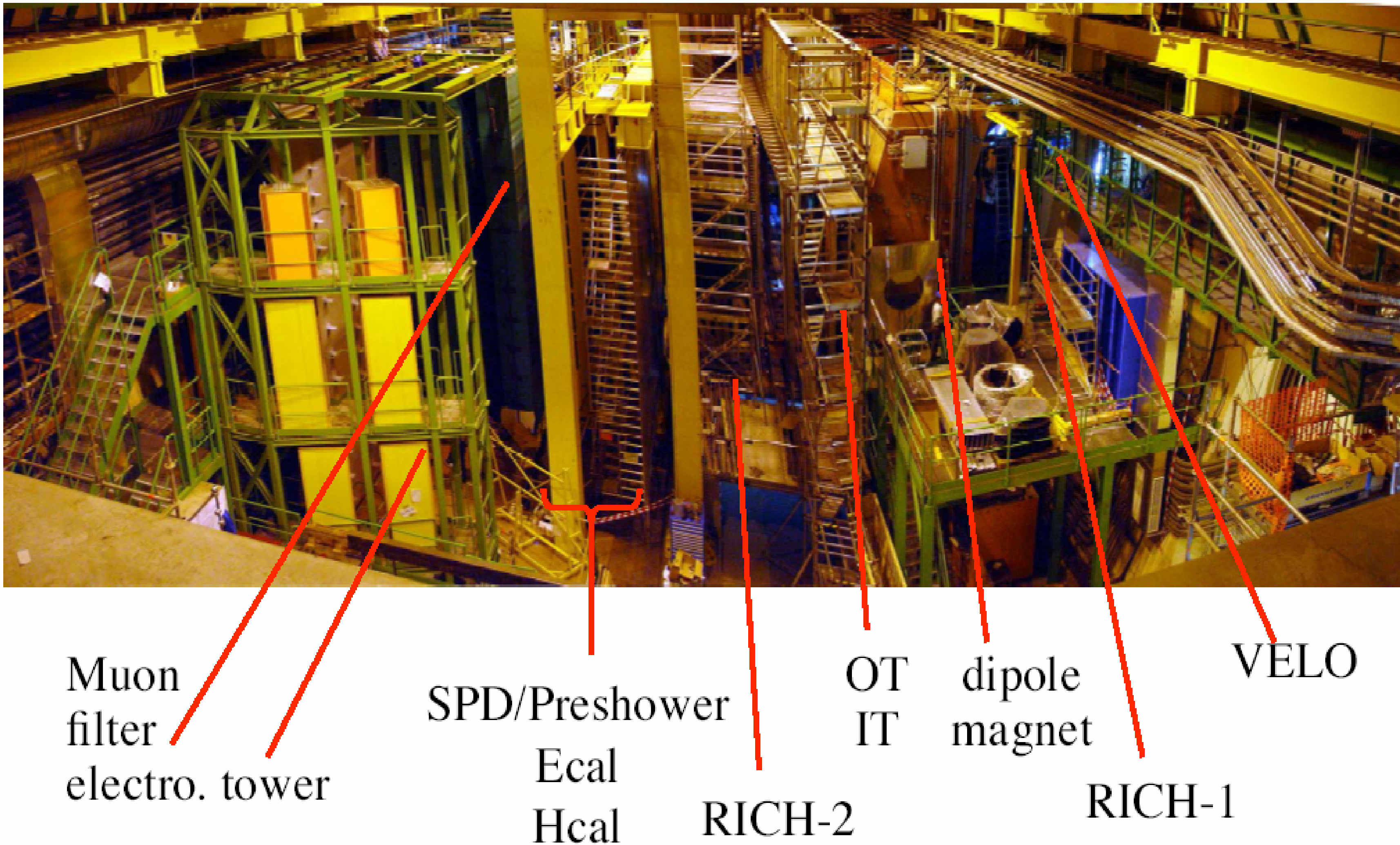
- **L0:** 40 MHz → 1 MHz *(high p_T μ,e,π^0,h,γ)*
- **HLT:** 1 MHz → 2 kHz *(farm of 1800 CPU)*

Performance

- mass resolution: 14 MeV *(B_s)*
- time resolution: 40 fs
- IP resolution: 30 μm
- PV resolution *(z)*: 47 μm

LHCb detector status

Installation of all subdetectors finished



LHCb physics program *(10 fb^{-1})* *wrt New Physics searches*

Precise measurement of mixing parameters B_s-$\bar{B}_s$: Δm, $\Delta\Gamma_s$
→ NP: mixing phase in $B_s \to J/\Psi\varphi$ (tree) & $B_s \to \varphi\varphi$ (loop)

$B_s \to D_s\pi$, $B_s \to J/\Psi\varphi$, $B_s \to J/\Psi\eta^{(\prime)}$, $B_s \to \varphi\varphi$,...

Precise measurement of γ angle *(tree & loop)*
→ NP: $B_s \to D_sK$ (tree) & $B_d \to \pi^+\pi^-$ (penguin)

$B_s \to D_sK$, $B_d \to DK^{*0}$, $B_d \to \pi^+\pi^-$, $B_s \to KK$,...

CP violation measurements
→ NP: compare CPV angle in φK_s & $J/\Psi K_s$

$B_d \to \varphi K_s$, $B_d \to J/\Psi K_s$, $B_s \to \varphi\varphi$,... $B_d \to \rho\pi$, $B_d \to \rho\rho$,...

Rare decays with BR down to 10^{-9}
→ NP: Asymmetry FB of $B_d \to K^*\mu\mu$
→ NP: $B_s \to \mu\mu$ at SM

$B_0 \to K^*\mu^+\mu^-$, $B_s \to \mu^+\mu^-$,...

Other New Physics searches

$B_d \to K^*\gamma$, $B_d \to K^{*0}l^+l^-$, $B_s \to \varphi\gamma$, $b \to sl^+l^-$,...

D meson physics

$\cancel{C}P$, D-$\bar{D}$ mixing

+ B_c physics, Lepton Flavour Violation, ...

Physics motivation for LHCb upgrade

LHCb upgrade: 100 fb^{-1} (5 years at $L=2\times10^{33}$cm^{-2}s^{-1}) 2015/2016

- **LHCb & ATLAS & CMS/ONLY ATLAS & CMS/ONLY LHCb/NO EXPERIMENT finds New Physics**
  - $\rightarrow$ *worthwhile to continue exploration of flavour structure of NP / analyze flavour structure of NP for (tiny) deviations*
- **For many observables 10 fb^{-1} will not make us reach theoretical limits**
  - $\rightarrow$ *theoretical progress in B physics + refined lattice calculations*
  - $\rightarrow$ *New Physics effect may be subtle and need higher statistics to be elucidated*

- ***(Precise)* angle measurements**
  - *- Φ_d, Φ_s, γ (knowledge of γ to a sub-degree level)*
  - *- study nature of New Physics (Φ_s, γ)*
- ***b* $\rightarrow$ *s* transitions**
  - *- sin(2β^{eff}) down to 0.04 ($B_d \rightarrow J/\Psi K_s$, $B_d \rightarrow \varphi K_s$)*
  - *- very sensitive to NP* — *extrap. from* LHCb-2007-130
- **$B_s \rightarrow \varphi\varphi$**
  - *- interesting b $\rightarrow$ s penguin mode for LHCb*
  - *- β_s^{eff} mixing phase in penguins $\sigma\approx0.015$ (SM=0)*
  - *- yield (100 fb^{-1}): 0.3M* — *extrap. from* LHCb-2007-047
- **$B \rightarrow K^*\mu\mu$**
  - *- zero for $A_{FB}(s)$ to ~2% (but theoretical error: 9%)*
  - *- yield (100 fb^{-1}): ~0.35M* — *extrap. from* LHCb-2008-041
- **New Physics with $B_s \rightarrow \mu\mu$**
- **Lepton Flavour Violation searches in $\tau \rightarrow \mu\mu\mu$ decays**

Expected sensitivity for LHCb upgrade *(100 fb^{-1})*
(LHCC-2008-007)

Observable	Sensitivity
$S(B_s \to \phi\phi)$	$0.01 - 0.02$
$S(B_d \to \phi K^0_S)$	$0.025 - 0.035$
$\phi_s\ (J/\psi\phi)$	0.003
$\sin(2\beta)\ (J/\psi K^0_S)$	$0.003 - 0.010$
$\gamma\ (B \to D^{(*)}K^{(*)})$	$< 1^\circ$
$\gamma\ (B_s \to D_s K)$	$1 - 2^\circ$
$\mathcal{B}(B_s \to \mu^+\mu^-)$	$5 - 10\%$
$\mathcal{B}(B_d \to \mu^+\mu^-)$	3σ
$A_T^{(2)}(B \to K^{*0}\mu^+\mu^-)$	$0.05 - 0.06$
$A_{\rm FB}(B \to K^{*0}\mu^+\mu^-)\ s_0$	0.07 GeV^2
$S(B_s \to \phi\gamma)$	$0.016 - 0.025$
$A^{\Delta\Gamma_s}(B_s \to \phi\gamma)$	$0.030 - 0.050$
charm x'^2	2×10^{-5}
mixing y'	2.8×10^{-4}
CP y_{CP}	1.5×10^{-4}

Examples of NP with 100 fb^{-1}

- ***Precise measurement of Φ_s***

$\Phi_s = -2\eta\lambda^2$ *(in SM)*

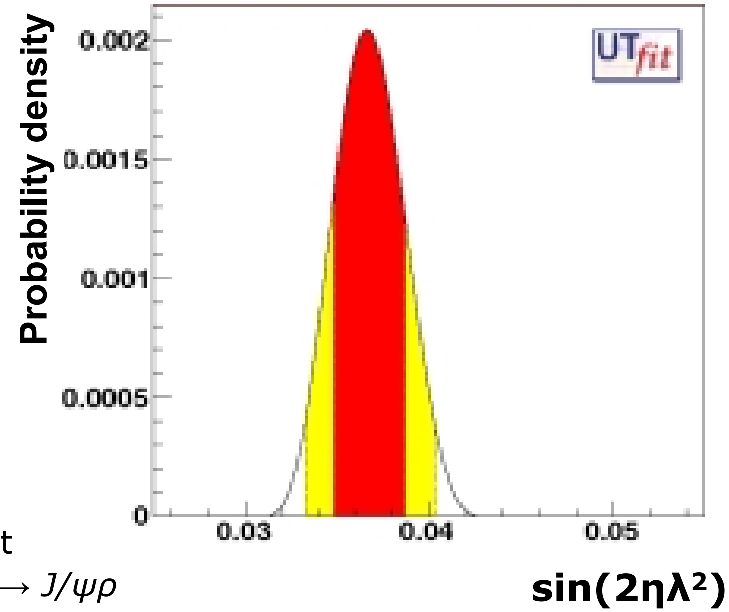
New Physics may manifest itself with e.g. $B_s \to J/\Psi\varphi$ through significantly larger value wrt very small SM expectation

Precise measurement with 100 fb^{-1}, noting that in SM Φ_s is very well constrained:

Φ_s (indirect) = -0.037 ± 0.002

(upgraded-) LHCb	2 fb^{-1}	10 fb^{-1}	100 fb^{-1}
statistical error	0.021	0.009	0.003

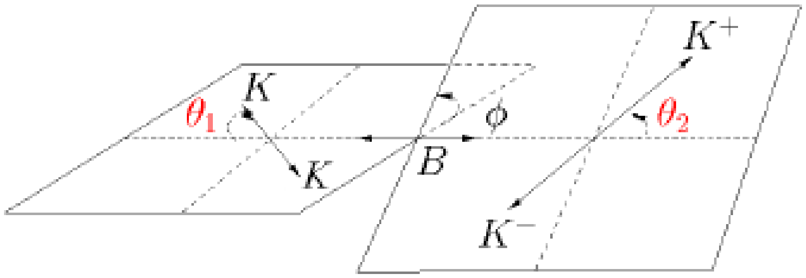
(extrapolation from LHCb-2003-119*)*



Here we must worry about penguins, and their relative effect could be large compared with this precision. Control with $B_d \to J/\psi\rho$ *(Fleischer, Phys.Rev. D60 (1999) 073008)*

- ***$B_s \to \varphi\varphi$***

Fully hadronic decay
Yield *(100 fb^{-1})*: 0.3M



Time dependent CPV
$\to$ *full angular fits needed* $\to$ *statistics*

β_s^{eff} mixing phase in penguins $\boxed{\sigma = 0.015}$ ***(SM=0)***

(extrapolation from LHCb-2007-047*)*

LHCb upgrade strategy

- **Goal: 5 years with L = 2 × 10^{33} $cm^{-2}s^{-1}$ *(100 fb^{-1})***

→ **30 MHz of crossing with ≥ 1 interaction**

(10 MHz for L=2 × 10^{32} cm^{-2} s^{-1})

→ **<number> of visible interactions / x-ing: ~5**

(~1.2 for L=2 × 10^{32} cm^{-2} s^{-1})

Upgrade strategy

- improve ×2 hadron trigger efficiencies

- move L0 to a fully software trigger

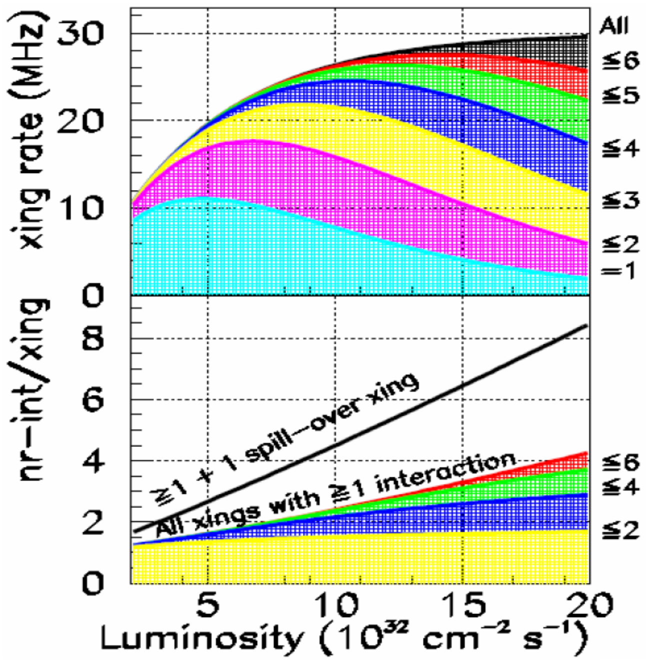
- improve resolutions *(photon detector, RICH)*

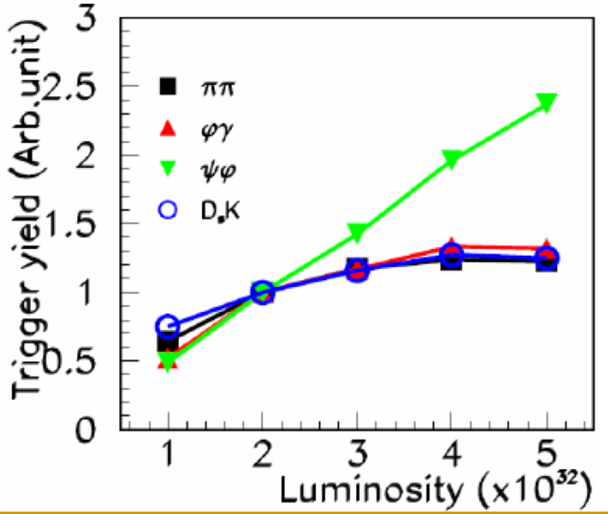
- all detector information to be used in trigger

- replace front-end electronics of most detectors

- replace all silicon detectors: VELO, TT, IT

- replace RICH photon detectors





Trigger & DAQ

Trigger needs for upgrade

- **reconstruct all primary vertices per bunch crossing**
- **measure track impact parameter (IP) to any PV**
- **measure track p_T with significant IP**

MC studies started

Proposal for „upgraded" trigger

Cut on p_T & *IP/track* simultaneously

$\rightarrow$ software trigger on large CPU farm to deal with input rate to 30 MHz

$\rightarrow$ **need to improve detector granularity** to deal with CPU time required for upgraded trigger

Example: $B_s \rightarrow \varphi\varphi$ *(after first step of current High Level Trigger)*

$L = 2 \times 10^{32}$ cm^{-2} s^{-1}

$E_T > 3.5$ GeV $\rightarrow$ efficiency = 22%

Minimum bias retention: 10 kHz

$L = 2 \times 10^{33}$ cm^{-2} s^{-1}

$E_T > 2$ GeV $\rightarrow$ efficiency = 45%

Minimum bias retention: 28 kHz

Vertex detector

Needs for upgrade

- **radiation hard solutions**
  flux (100 fb^{-1}) : 1.4 × 10^{16} n_{eq} cm^{-2}
- **lower occupancy**
- **improved pattern recognition**

Design optimum detector

→ **Pixel-based system**

Two geometris are studied:

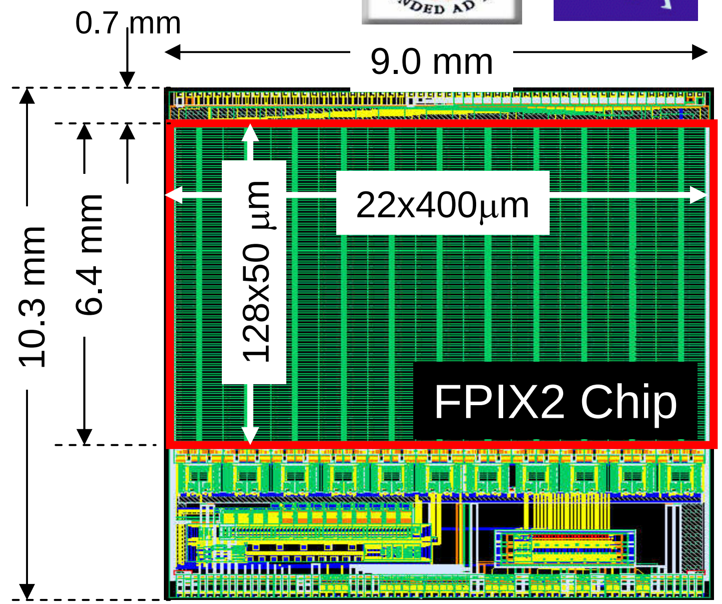
- rectangular pixel cells *(50×400 μm²)*, readout with ASIC based on FPIX2
- square pixel cells *(50×50 μm²)*, readout with ASIC based on TIMEPIX / MEDIPIX

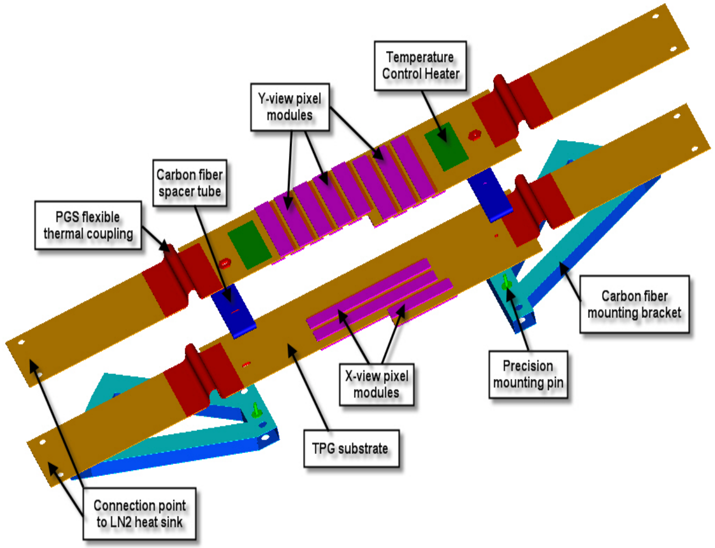
→ **Pixel system offers advantages**

- better resistance to radiation
- noise immunity
- better ghost reduction

Under study

- **radiation hardness**
- **sensor & electronic thinning**
- **cooling** *(CVD Diamond?)*
- **new geometry** *(smaller radius?)*
- **optimisation of RF foil design** *(towards minimization of the material in front of the first position measurement?)*





Tracking system

- **Higher luminosity has stronger effect on occupancy & ghosts in tracking system**
  - *especially in Outer Tracker (OT) → gas technique used*
- **Increase area covered by Inner Tracker *(silicon)***
- **Request for 40 MHz readout → change design of IT**
  - *new sensor, new FEE chip, …*
- **Material reduction *(if possible)***
  - *crucial for momentum resolution & occupancy*

- **NEW POSSIBILITY FOR TRACKING**

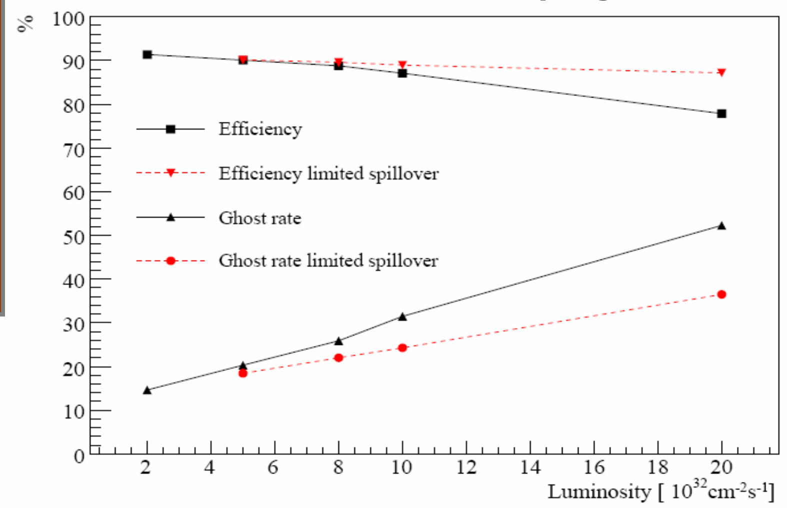
  FIBER TRACKER WITH MIXED FIBER DIMENSIONS
  - Inner Tracker: *250 μm*, Outer Tracker: *700-1000 μm*
  - readout with *SiPM* and/or conventional *MAPMT*

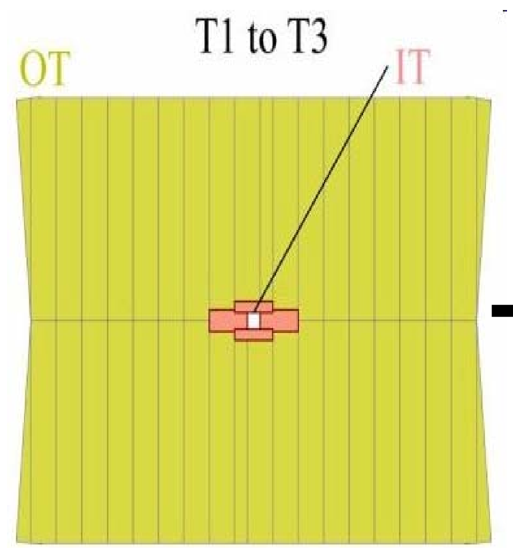
  ADVANTAGES
  - simplified services configuration: *no cables, no cooling, thinner frames, FEE outside → less material budget*
  - good timing performance
  - increase granularity in *x (good spatial resolution)*

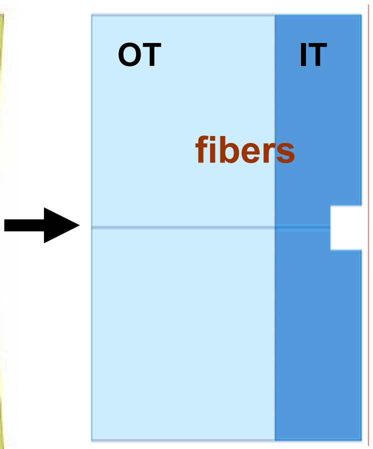
Possible problems *(fibers)*
- ***SiPM* readout and its optimisation**
- **radiation**
- **mechanics**

- **OTHER POSSIBILITY - *SILICON STRIPS***
  - enlarge IT - *remove inner section of OT & increase IT*
  - lower tracking system occupancy
  - lower material *(when possible)*

Track reconstruction efficiency & ghost rate







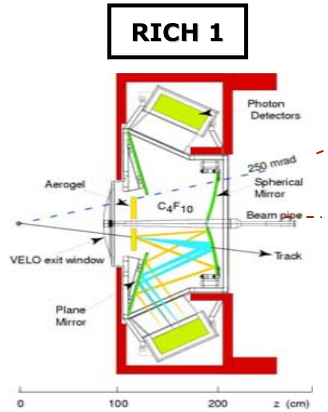
RICH / TORCH

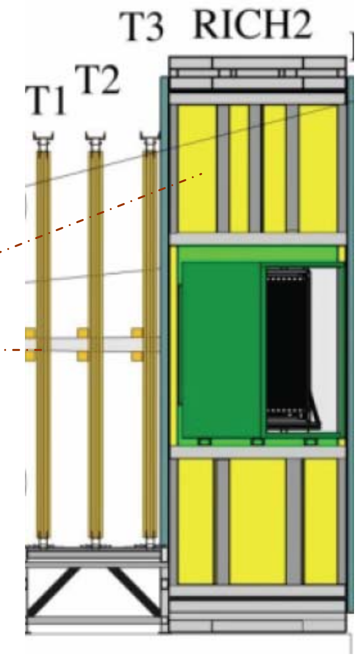
RICH wrt upgrade

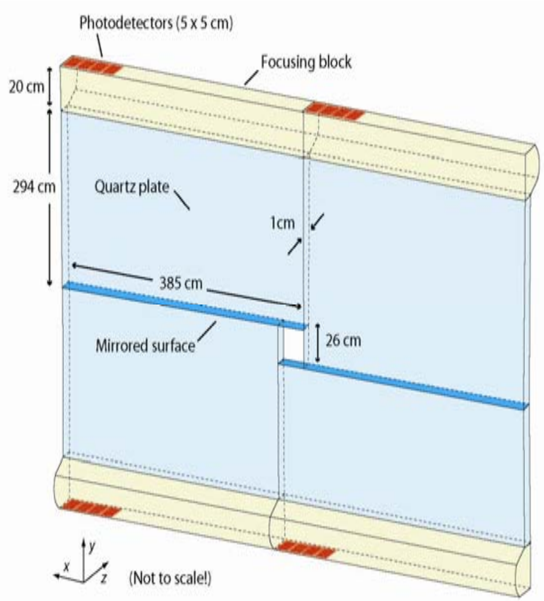
- **Maintain RICH 1 & 2**
- **New possibility replacing aerogel in RICH 1 with TORCH**

- **In any case NEW PHOTO SENSORS - two options:**
  - **new HPD** *(needs R&D to study ion feedback rate)*
  - **MAPMT** *(Multi-Anode Photomultiplier Tubes)*

both options with new independent chip readout

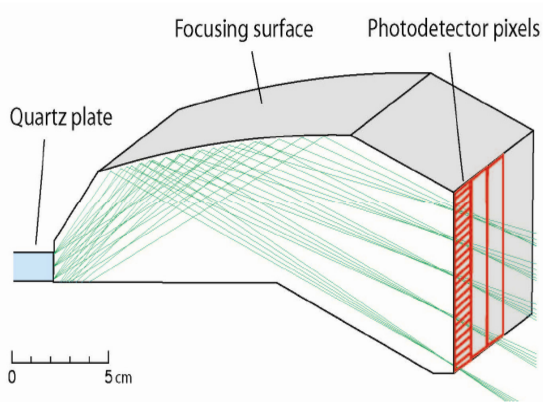






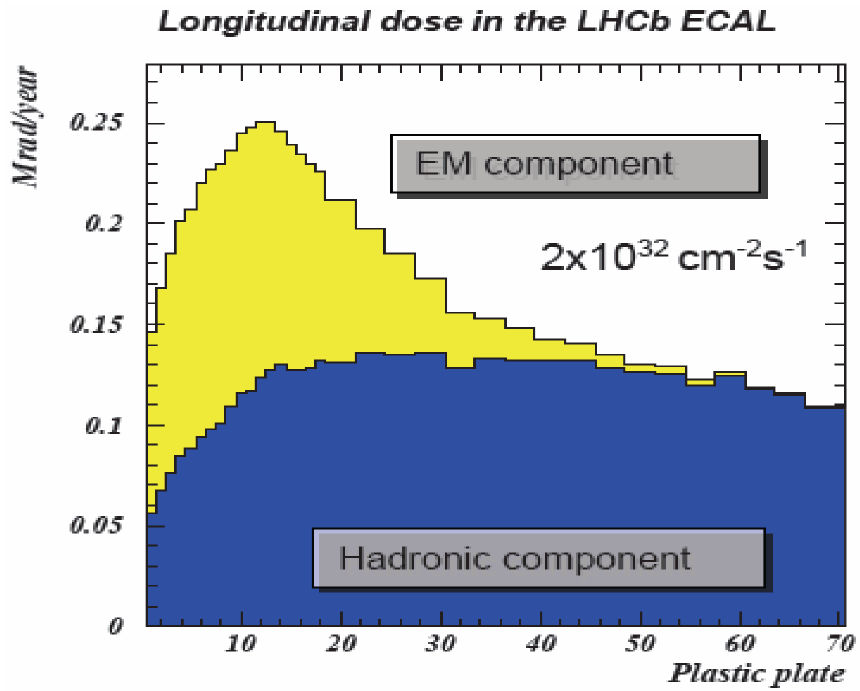
TORCH - combination of TO*f* & R*i*CH

- **quartz plane at the entrance of calorimeters**
  - TOF performance at 40ps level
  - MicroChannel Plate PM
  - multianode readout
- **idea is to measure time and position of Cherenkov γ's**
  - focusing system needed
- **A lot of R&D needed**
  (quartz plane mechanics, aging of MCP, electronics etc.)
- **project independent of RICH layout**



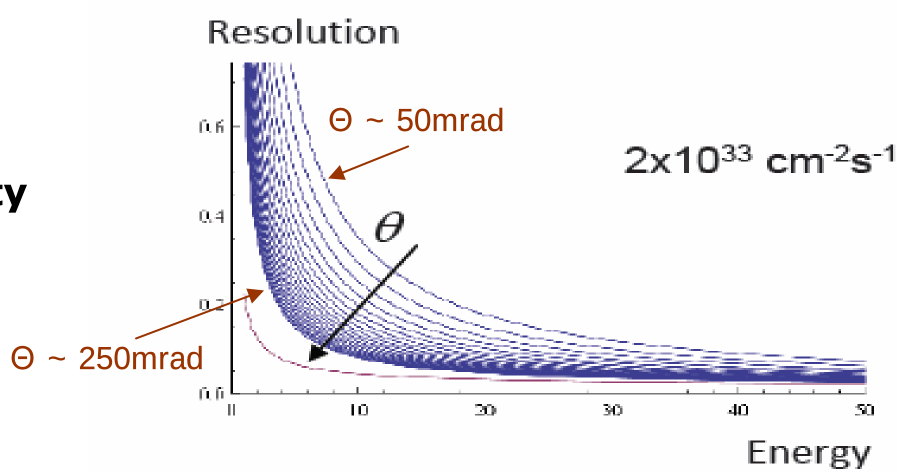
EM Calorimeter

- **At $2x10^{33}$ worst place has 2.5 Mrad/year**
  - → projected useful life is only 2 years
  - → no data for higher doses *(up to factor 5)*
- **Need replacement with radiation hard technology**
- **Useful would be increased segmentation in inner part**
  - → dense detection medium material: $PbWO_4$



ELECTRONICS

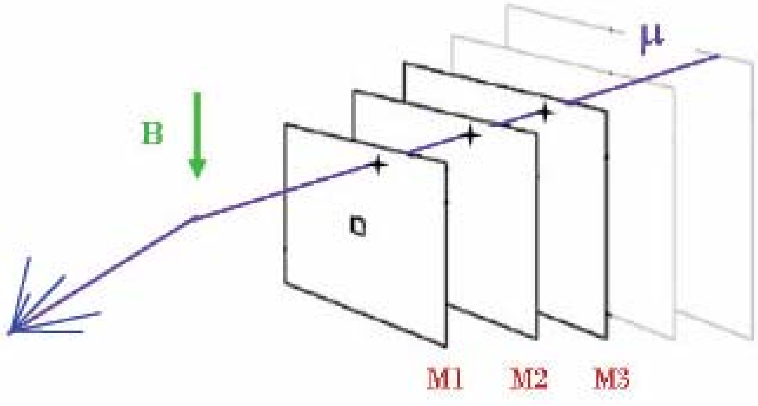
- **FEE readout already at 40MHz**
- **need to lower PM gain (×5)**
- **need to increase preamplifier sensitivity**
- **need to reduce noise**



Muon system

- **Major part of the muon detector can operate at 2×10^{33} for 5 years**
  - $\rightarrow$ **FE electronics is already at 40 MHz**

- **Upgrade of M1 station is not required**
  - $\rightarrow$ **it will likely be removed**
  - $\rightarrow$ **background / updated L0**



- **Ageing tolerable up to 100 fb^{-1}**
  - $\rightarrow$ **possible exception of region M2R1**
  - $\rightarrow$ **possibility of replacement of the inner parts with large area GEM *(70$\times$30 cm^2)* or with MWPC**

- **Transition to a fully 3D muon projective readout**
  - $\rightarrow$ **could reduce fake associations**

Limitations of present design at higher luminosities

- **dead time caused by high rate in inner regions**
- **aging due to radiation in inner regions**

Effects evaluated with first data

Conclusions

- LHCb installed and ready for data taking
  - initial plan: collect 10 fb^{-1} in first 5 years
- For upgrade leading to a factor of ≥10 improvement in sensitivity
  - broader scope of NP exploration
- LHCb upgrade foreseen for 2015/16
  - schedule coupled with LHC long shut-down planned for ~2014
  - luminosity increased to 2×10^{33} $cm^{-2}s^{-1}$
  - expected 100 fb^{-1} after 5 years of data taking
- Main challenges for higher luminosity have been identified
  - trigger & detector simulations have been started
  - R&D on subdetector projects is under way