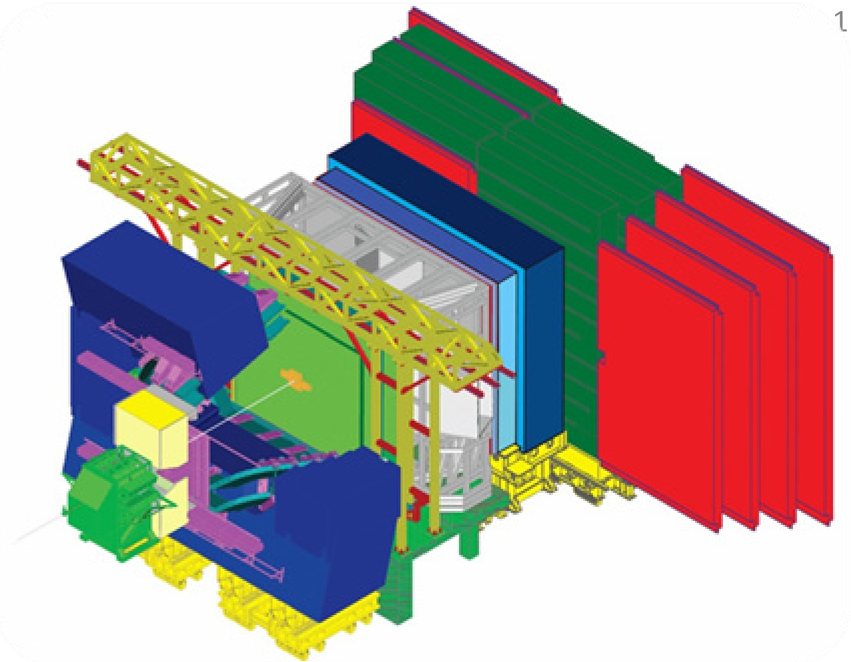


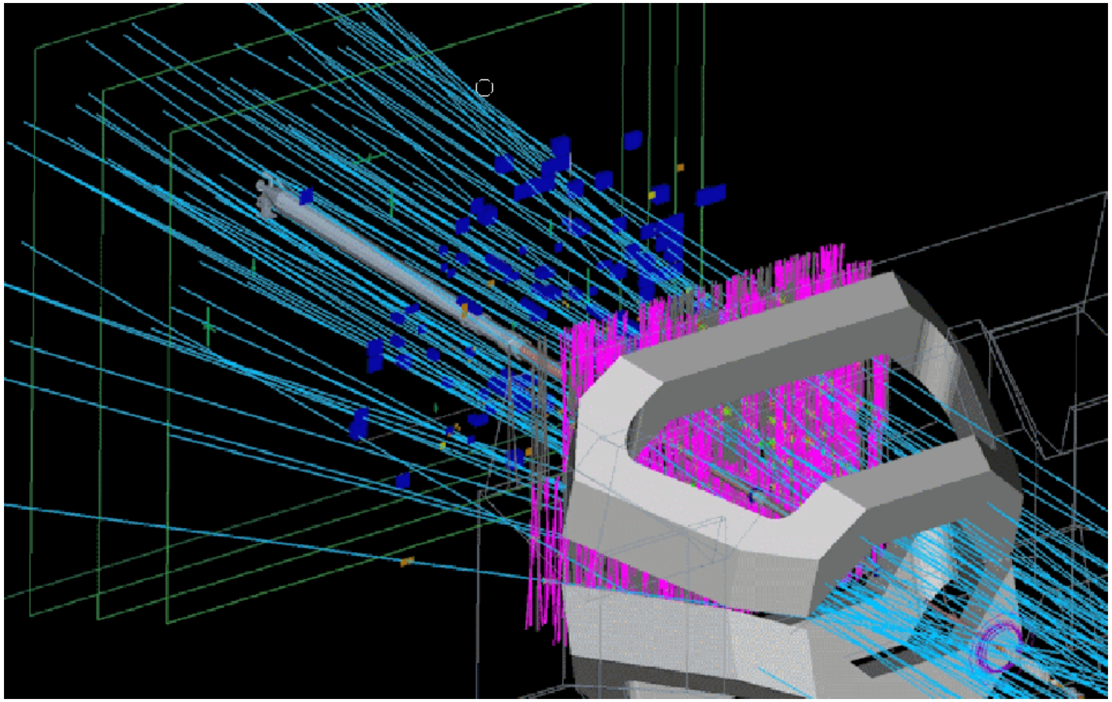
The LHCb Upgrade

Physics prospects and experimental challenges

P. Campana - Laboratori Nazionali di Frascati – INFN
on behalf of LHCb collaboration
FPCP – Lake Placid – May 29, 2009

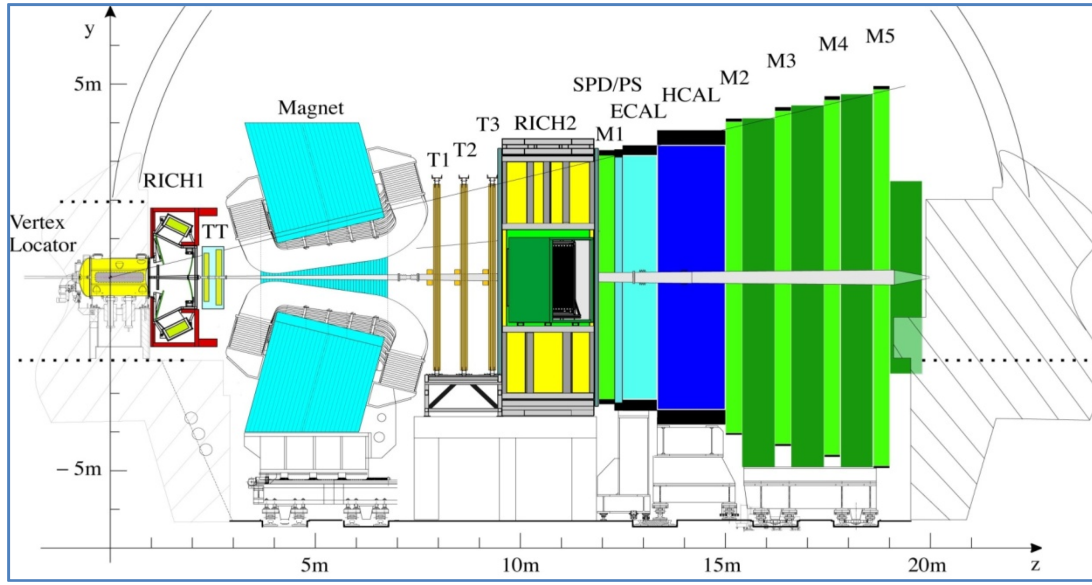
Outline of the talk

- LHCb in its present state
- Physics programme within 10/fb
- The quest for an upgraded LHCb
- NP reach opportunities with 100/fb
- The experimental challenges of the upgrade
    - Vertexing
    - Tracking
    - Kaon PID
    - Calorimetry
    - Muon PID
    - Trigger and DAQ
- Conclusions



Tracks in LHCb from the LHC beam on collimator (TED runs)

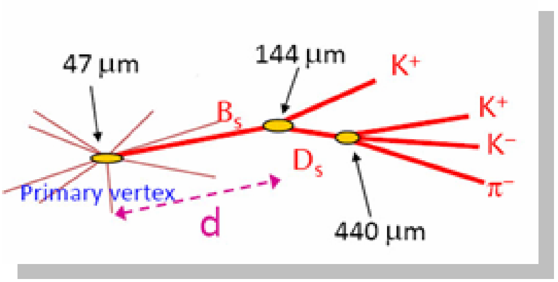
LHCb in brief



Forward geometry:
- one arm spectrometer
- both B in acceptance (tagging)

Tough experimental conditions:
σ_{bb} = 500 μb (σ_{inel} / σ_{bb} = 160)

- 30 μm imp. param. resolution
- 40 fs proper time resolution
- 14 MeV B_s mass resolution



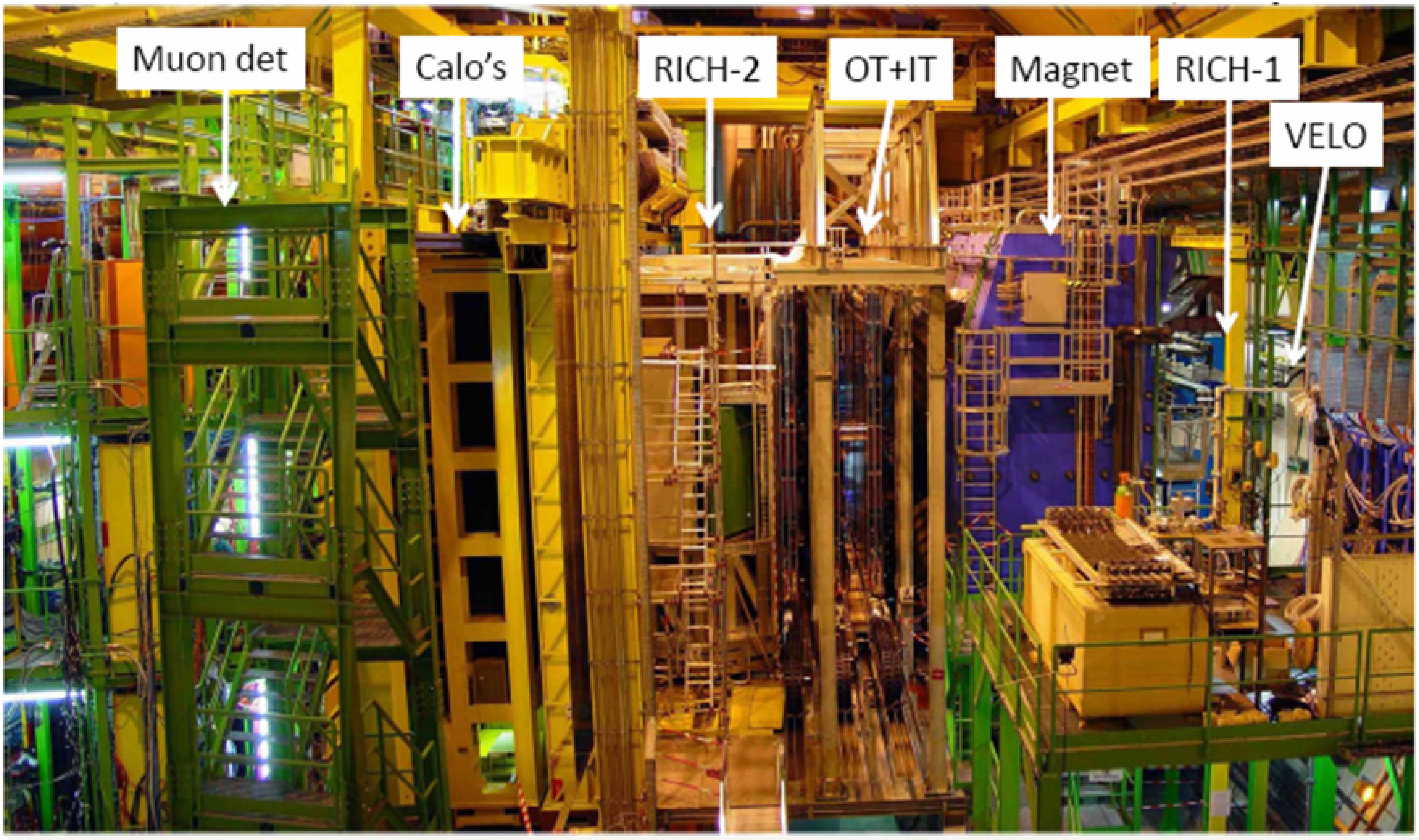
Operated at $\mathcal{L}$ = 2-5 10^{32} $cm^{-2}s^{-1}$ (50-20 below Atlas & Cms)
1 year @ nominal luminosity = 2/fb

- K PID with RICH (2-100 GeV/c)

- L0 hardware trigger on Calorimeters and Muon System: high p_T μ, e, π°, h and γ (40 MHz→ 1 MHz)
- HLT software trigger, 2000 CPU boxes (1 MHz → 2 kHz)

See talk by O. Dechamps

The LHCb detector



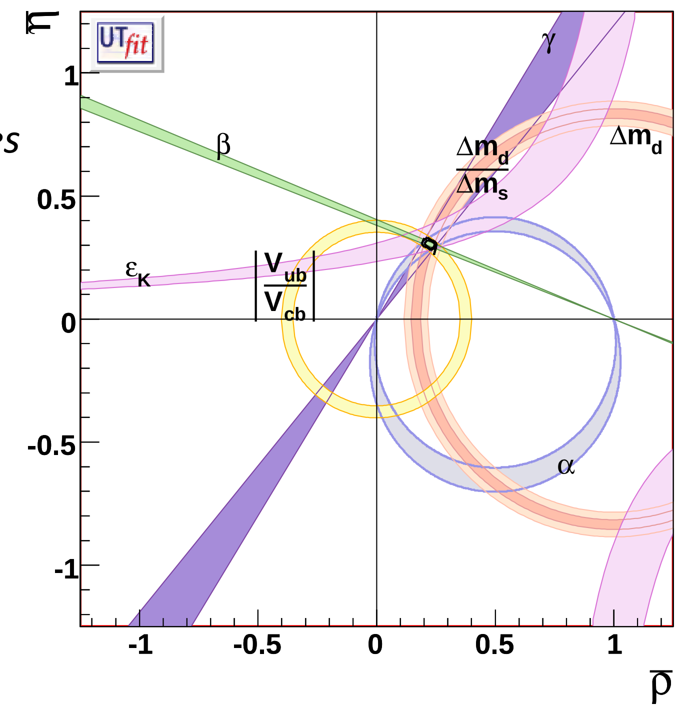
Installed and ready to start data taking

The LHCb Physics Programme @ 10/fb

Some highlights (NP searches):

- *$B_s \rightarrow \mu\mu$ at SM (15% uncertainty on BR)*
- *Mixing phase in $B_s \rightarrow \psi\phi$ (tree) at 0.01 (3σ from SM) and in $B_s \rightarrow \phi\phi$ (penguin) at 0.05*
- *Determination of CKM angle γ (tree and loops) to ~ 2° degrees*
- *Asymmetry FB of $B_d \rightarrow K^* \mu\mu$ (zero of $A_{FB}(s)$ to 7%)*
- *CPV in penguins $B_d \rightarrow \phi K_s$: β vs β^{eff} comparable to B factories*
- *Search for RH currents in radiative decays ($B_s \rightarrow \phi\gamma$, ...)*

LHCb 10/fb + lattice



LHCb competitive with Tevatron already with O(2-300/pb)

See details on the analysis in LHCb poster presentations:
M.O. Bettler, P. Bogdan, G. Conti, F. Soomro

Current LHCb Trigger flow

L0 bandwith sharing and p_T thresholds are set to minimize min. bias and maximize physics output

- *700 kHz* for the hadronic events (E_T > 3.5 GeV)
- *150 kHz* for e/γ/$\pi°$ (p_T >2.5 GeV)
- *150 kHz* for μ/2μ (p_T >1 GeV)

HLT1 confirms L0 (using partial tracking and optionally the IP) → 40 kHz
HLT2 performs exclusive/inclusive refined selections → 2 kHz on tape

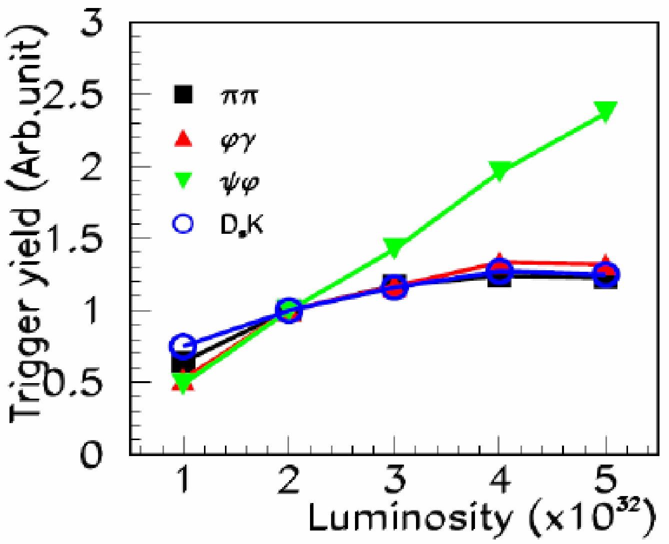
L0 trigger has an efficiency of 40% on hadronic channels and 90% on muon channels

An upgrade in luminosity ($2x10^{32}$ $cm^{-2}s^{-1}$ → $2x10^{33}$ $cm^{-2}s^{-1}$)
does not increase the statistics of hadronic channels

Two main reasons:

- to mantain the 1 MHz limit, the increase in thresholds for the hadronic trigger rate reduces the efficiency
- the events are more complex, many are superimposed, and tracking is difficult due to ghosts

Muon yield would increase linearly with $\mathcal{L}$



See talk by B. Jost

Running at "high" luminosities

Baseline luminosity for upgrade is still a factor 5 below nominal one of LHC (10^{34} cm^{-2}s^{-1})

Consequences on data taking:
- ✓ 30 MHz of crossing with ≥ 1 interaction (was 10 MHz)
- ✓ Average no. of visible interactions/x-ing ~ 5
- ✓ Spillover increases linearly with $\mathcal{L}$

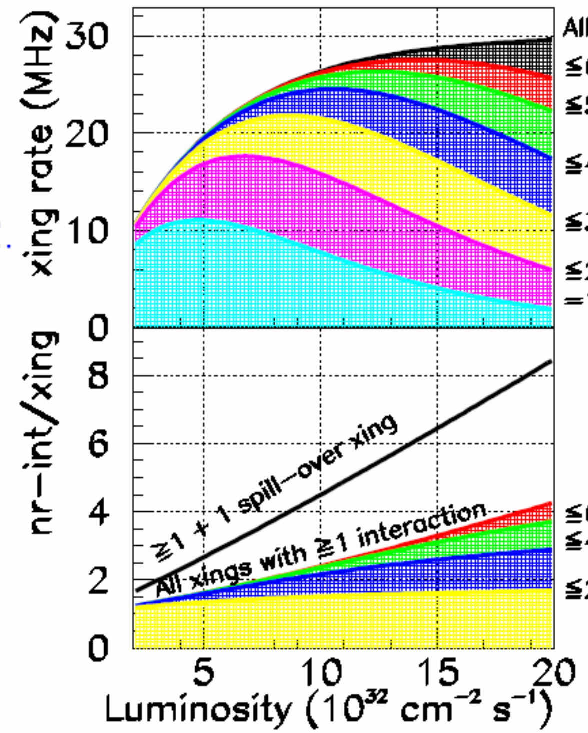
LHCb upgrade strategy:
- move the L0 to a fully software trigger, with all detectors readout at 40 MHz (use of IP and tracking)
- increase x2 the current hadronic efficiencies
- improve in some areas, profiting of lessons from first data

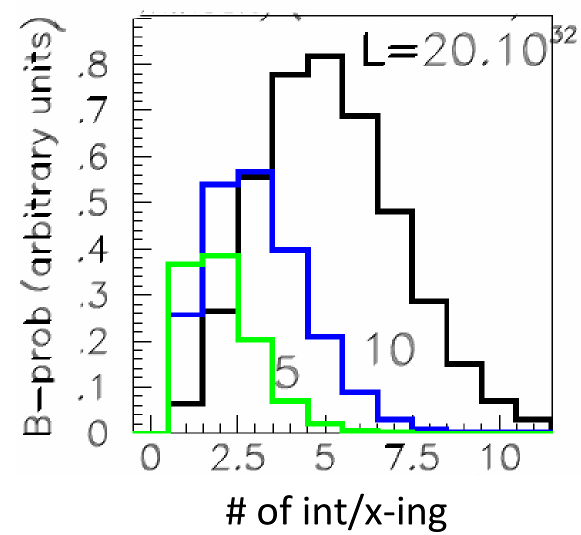
Goal: 5 years @ 2 10^{33} cm^{-2}s^{-1} ≈ 100/fb

These requests have non trivial implications on the detector

An upgraded LHCb does not need SLHC (8 10^{34} cm^{-2}s^{-1})

Operation of SLHC can be made compatible with LHCb





The future and the quest for more data

Case 1 - LHCb finds NP in the forecoming years → worthwhile to continue to explore the flavor structure of the NP

Case 2 – Atlas & Cms find NP (and LHCb not) in the forecoming years → worthwhile to elucidate the flavor structure of the NP for (tiny) deviations (e.g. predicted by MFV)

Case 3 – Nobody finds NP → worthwhile to insist in collecting data in the flavor sector, *although not easy to justify with funding agencies*...

Theoretical progresses in B physics, as well as refined lattice calculations, will ask for new and more precise measurements

Time scale: initial LHCb data taking is 10/fb (5 years at 2/fb/y) → 2015-16
Upgrade time plan should also match the modifications in LHC machine

Upgrade scale: depends on physics goals, but also on the available time, on manpower, on budget, etc...

Two examples of NP search at 100/fb

- $B_d \rightarrow K^*\mu\mu$

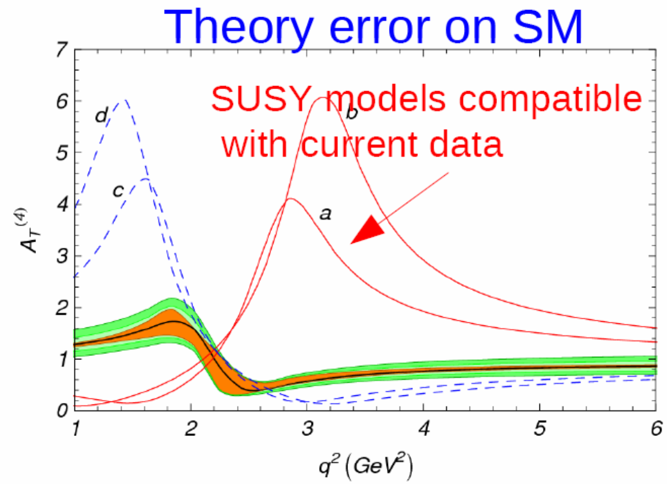
Yield (100/fb): 0.35 M
Zero of $A_{FB}(s)$ to 2% (but theoretical error: 9%)

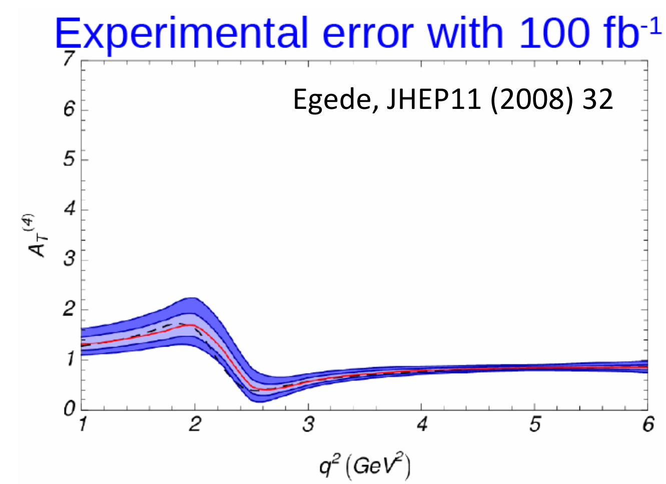
With a larger statistics, study of further observables (transverse asymmetries: $A_T^{(2)}$, $A_T^{(3)}$, $A_T^{(4)}$) sensitive to NP (especially C_7), and free of hadronic errors in the region $1 < q^2 < 6\ GeV^2$

$$A_T^{(2)} = \frac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2 + |A_\parallel|^2},$$

$$A_T^{(3)} = \frac{|A_{0L}A_{\parallel L}^* - A_{0R}^*A_{\parallel R}|}{\sqrt{|A_0|^2|A_\perp|^2}},$$

$$A_T^{(4)} = \frac{|A_{0L}A_{\perp L}^* - A_{0R}^*A_{\perp R}|}{|A_{0L}^*A_{\parallel L} + A_{0R}A_{\parallel R}^*|},$$

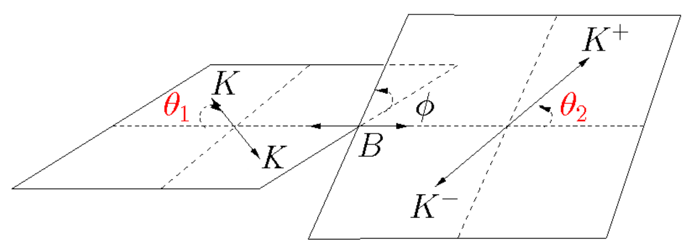




- $B_s \rightarrow \phi\phi$

Fully hadronic decay. Yield (100/fb): 0.3 M
Time dependent CPV: full angular fits needed (statistics)

Knowledge of β_s^{eff} mixing phase in penguins $\sigma \approx 0.015$ (SM=0)



Other NP search opportunities at 100/fb

- *Knowledge of γ to a sub-degree level*
- *Observation Br($B_s \to \mu\mu$) up to O(10^{-9})*
- *Search for RH currents with TDCPV in $B_s \to \phi\gamma$*
- *β vs β^{eff} down to 0.03° ($B_d \to \psi K_s$, $B_d \to \phi K_s$)*
- *Charm mixing and CPV searches*
- *NP in $B_s \to \phi\mu\mu$, $B_d \to \rho(\pi)\mu\mu$*
- *R_K in Br($B \to Kee$)/Br($B \to K\mu\mu$)*
- *Observation of very rare decays ($B_d \to \mu\mu$, $\tau \to 3\mu$)*

CERN/LHCC/2008-007

Table 1: Expected sensitivity for the LHCb upgrade with an integrated luminosity of 100 fb^{-1}. A factor two of improvement for the Level-0 hadron trigger and systematic error estimates are shown as a range.

Observable	Sensitivity
$S(B_s \to \phi\phi)$	0.01 – 0.02
$S(B_d \to \phi K_S^0)$	0.025 – 0.035
ϕ_s $(J/\psi\phi)$	0.003
$\sin(2\beta)$ $(J/\psi K_S^0)$	0.003 – 0.010
γ $(B \to D^{(*)}K^{(*)})$	$< 1°$
γ $(B_s \to D_s K)$	$1 - 2°$
$\mathcal{B}(B_s \to \mu^+\mu^-)$	5 – 10%
$\mathcal{B}(B_d \to \mu^+\mu^-)$	3σ
$A_T^{(2)}(B \to K^{*0}\mu^+\mu^-)$	0.05 – 0.06
$A_{FB}(B \to K^{*0}\mu^+\mu^-)$ 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}

LHCb - Expression of Intent in 2008 and presented to LHCC

TDR Upgrade to be prepared in 2010

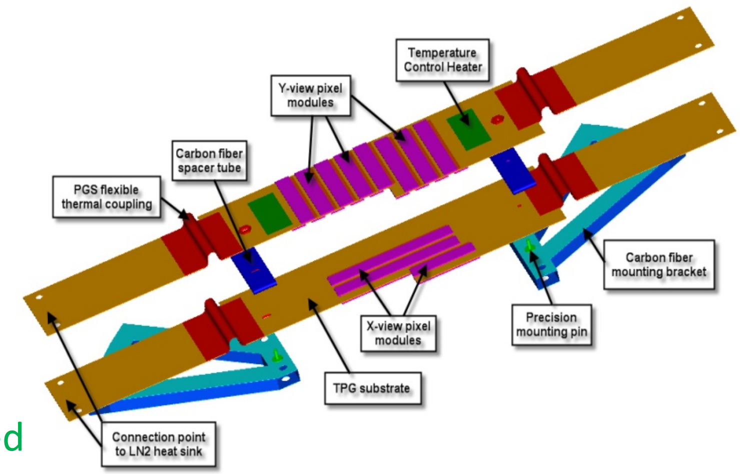
Vertexing

New running conditions of LHCb will require (more) rad hard solutions and improved pattern recognition.
Currently three options on the table:

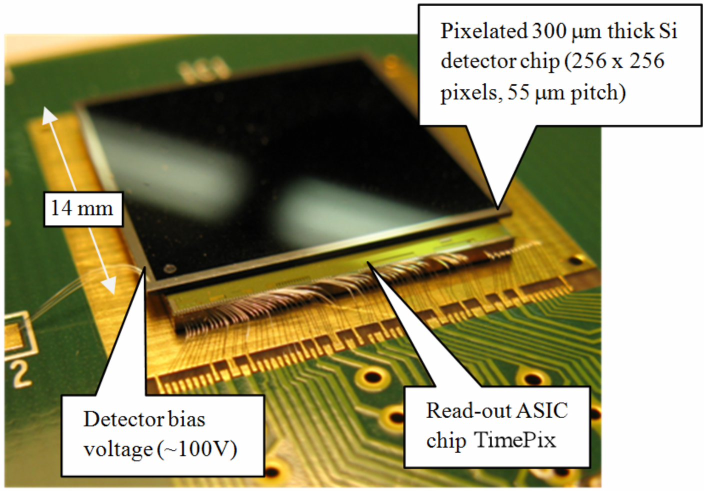
1. μ-**VELO** configuration with shorter strips and thin sensors

2a. **FPIX** pixels, 50 x 400 μm^2, each station with a double sided pixel, to guarantee full active area.
Based on BTeV experience. More material budget

2b. **TIMEPIX** pixels, 55 x 55 μm^2, to have single sided planes and save on material budget



Problems to be addressed:
- radiation hardness [Flux: 1.4×10^{16} $n_{eq} cm^{-2}$ (100/fb)]
- sensor and electronic thinning
- cooling solutions (CVD Diamond spine ?)
- new geometry (smaller radius) ?
- removal of RF foil (50% of present X_0) ?



Tracking

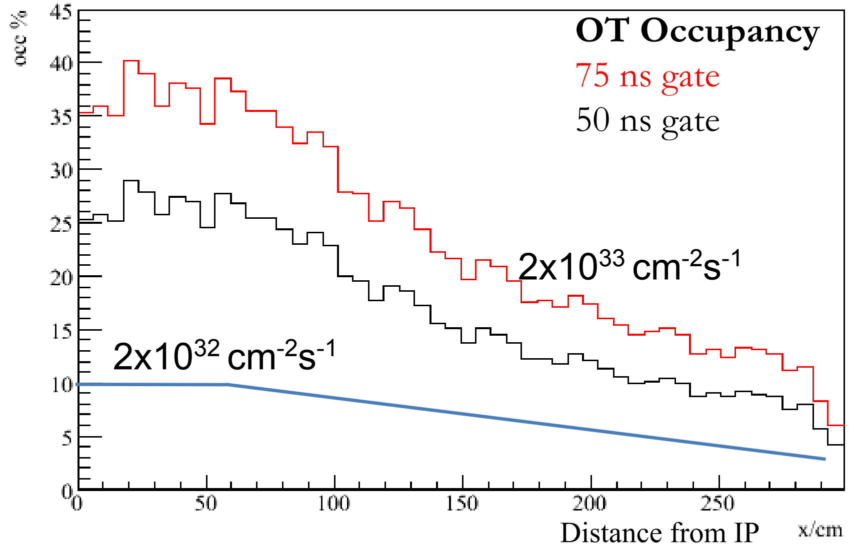
The increase in luminosity has strong effects on occupancy and ghosts in the tracking system (particularly in the Outer Tracker) where a gas technique is used (drift time in straw tubes) and signal is collected in 50-75 ns

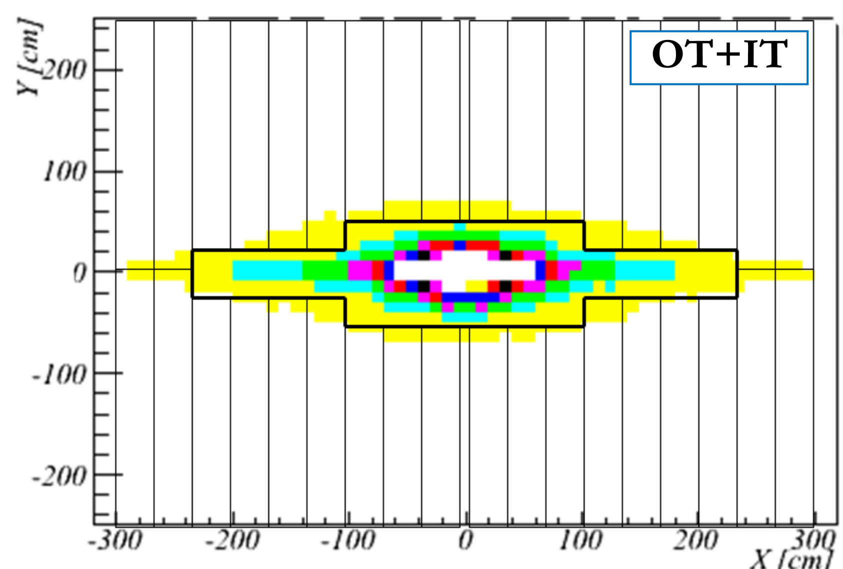
This forces to a relevant increase of the area covered by the Inner Tracker (Silicon)

The request for 40 MHz readout obliges to change the design of IT (new sensors, new FEE chip, etc...)

Material budget is an important issue

Momentum resolution depends heavily on this and an upgrade should aim to minimize material (especially at low η, also to reduce occupancy)

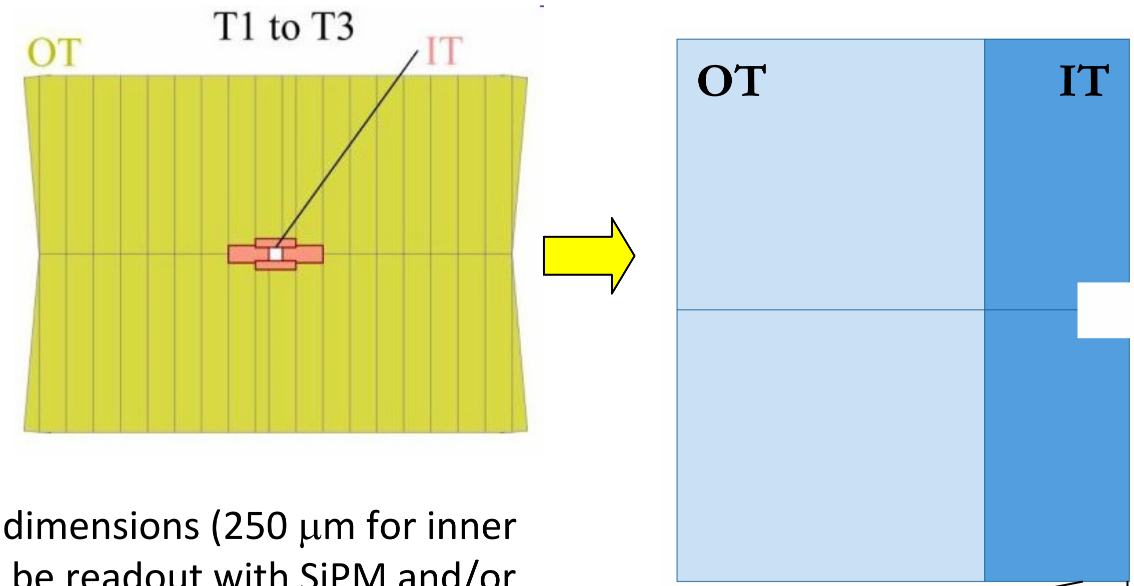




Boundaries of 10% occupancy

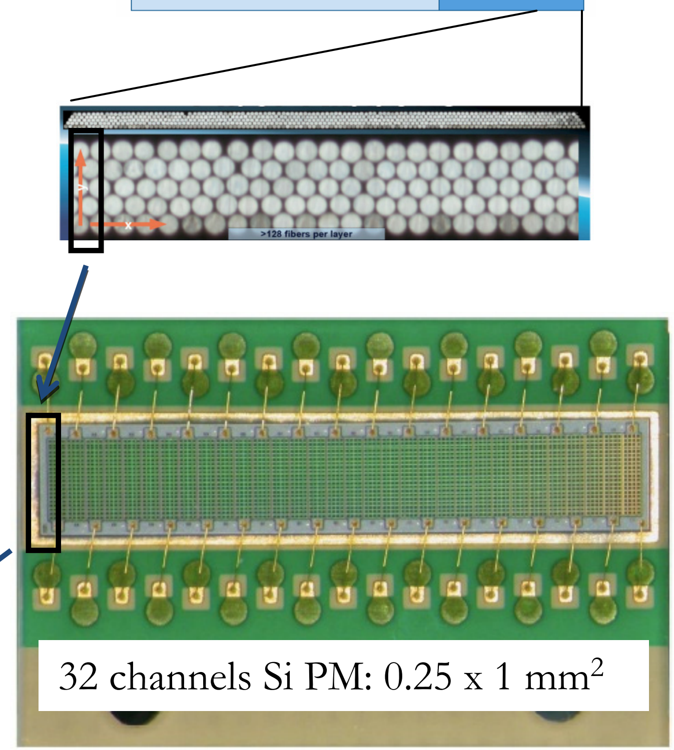
($2x10^{33}$ cm^{-2}s^{-1})

New ideas in Tracking



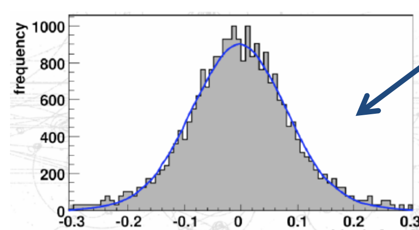
A fiber tracker with mixed fiber dimensions (250 μm for inner part, 700-1000 μm for outer) to be readout with SiPM and/or conventional MAPMT

- Simplified services configuration: no cables, no cooling, frames thinning, FEE outside → in theory less X_0
- Good timing performances
- Increased granularity in x – spatial resolution enough



Lausanne

Problems to be addressed:
- SiPM readout and its optimisation
- radiation hardness
- mechanics



Preliminary: 80 μm residuals

Particle ID: Kaons in RICH

The need for a 40 MHz readout has the consequence of changing the photon readout in the RICH system

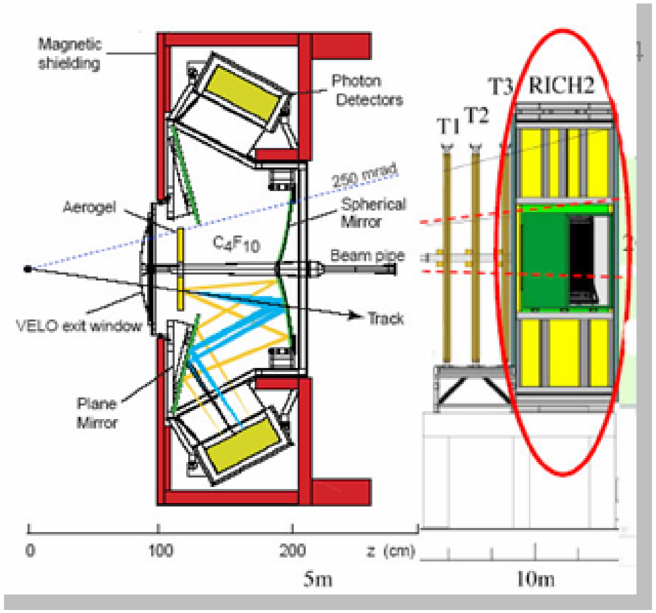
Baseline approach : keep the present geometrical layout (Rich1 + Rich2)

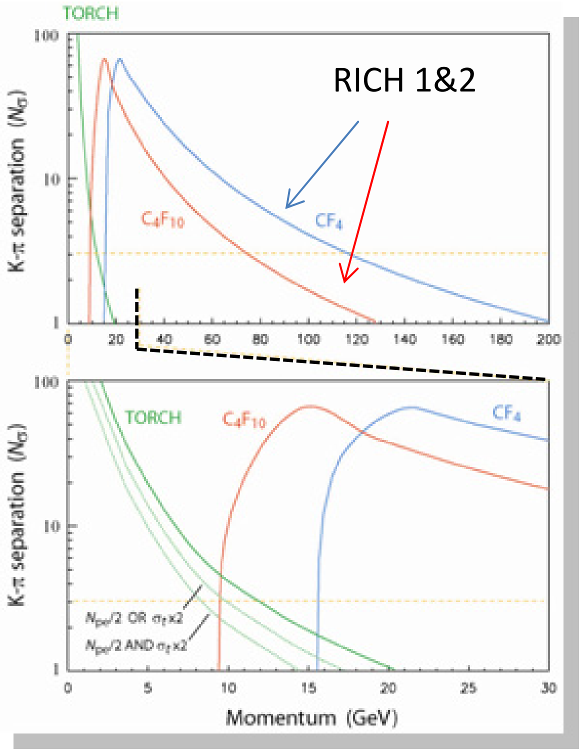
Two options for the Photo sensors: new HPD or MAPMT, both with independent chip (new) readout.

HPD option need R&D to study ion feedback rate.
Possibly a 3rd option (MCP for timing purposes)

Required granularity ca 1x1 mm^2
New chip readout configuration needed (to decouple it from the sensor – now FEE is bump bonded)

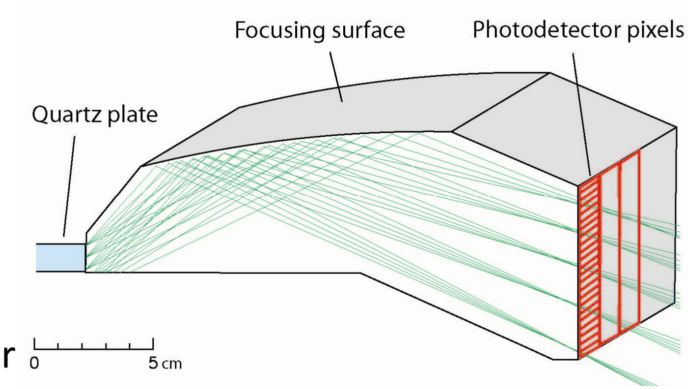
Possibility of replacing Aerogel with a new TOF system, located after the Rich2 (and save some X_0 in the tracking upstream) for p<10 GeV hadrons





New ideas in K- PID

A quartz plane (TORCH), at the entrance of calorimeters to perform *TOF at 40 ps* level with MicroChannel Plate PM with multianode readout

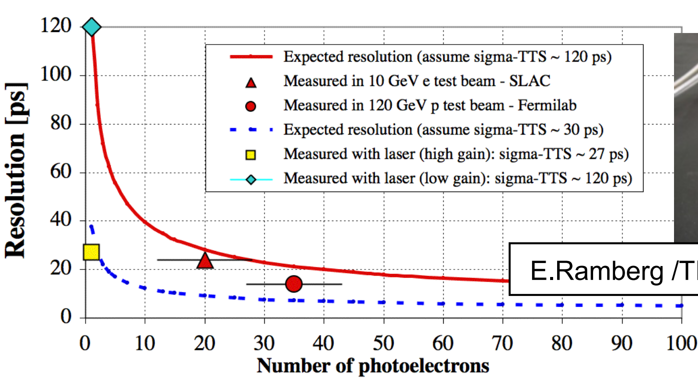


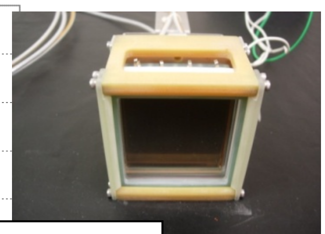
A focusing system is needed to measure $\theta_{Cherenkov}$ to correct for the chromatic dispersion of the media (and get the right T)

MCP-PM achieved in test beam 10-20 ps time resolution with 30-20 p.e.

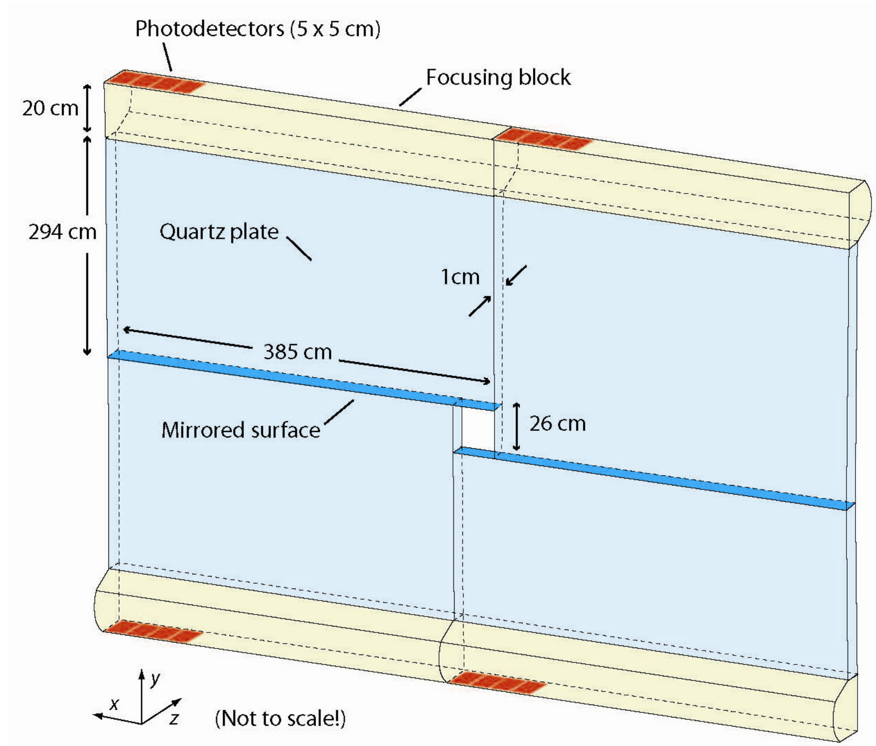
A lot of R&D is needed (quartz plane mechanical feasibility, aging of MCP, electronics, etc...).

Project independent of Rich layout





E.Ramberg /TIPP09



Calorimetry

FEE readout already at 40 MHz
One major issue: dose on calorimeter (inner regions)
Tested up to 2.5 Mrad
No reliable data for higher doses (up to a factor 5)

Currently considering replacement with PbWO (also here R&D needed on rad. hardness)

Electronics: need to lower PM gain (÷ 5) and to increase preamp. sensitivity and reduce noise

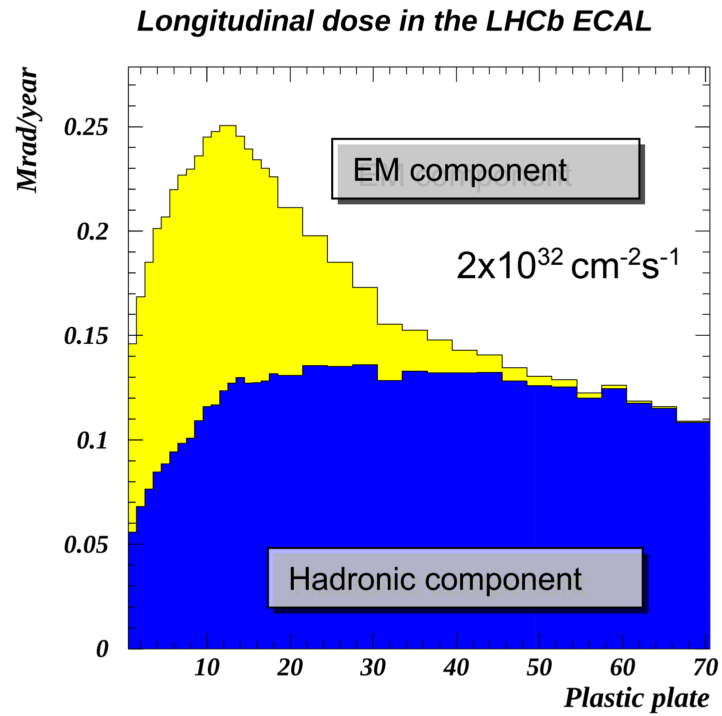
Pile up studies: present resolution

$$\frac{\sigma(E)}{E} = \frac{0.1}{\sqrt{E}} \oplus 0.015 \oplus \frac{0.050}{E\theta}(Pileup) \oplus \frac{0.010}{E\theta}(Electronics)$$

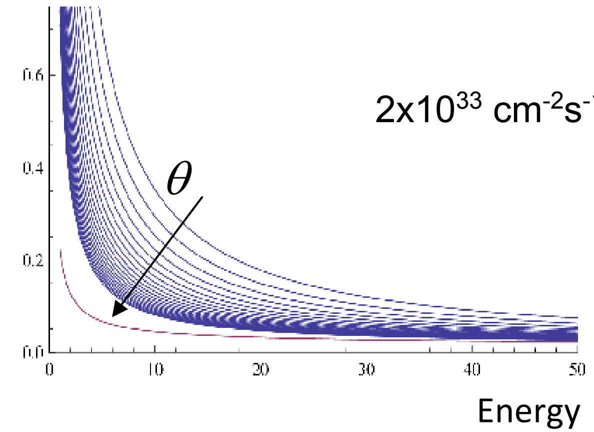
At 2×10^{33} $cm^{-2}s^{-1}$ could become

$$\frac{\sigma(E)}{E} = \frac{0.1}{\sqrt{E}} \oplus 0.015 \oplus \frac{0.175}{E\theta}(Pileup) \oplus \frac{0.010}{E\theta}(Electronics)$$

preventing from doing low p_T γ physics



Resolution



Particle ID: Muons

FEE readout already at 40 MHz

Two main concerns:

✓ dead time due to high rate in inner regions

✓ aging due to radiation in inner regions

An evaluation of these effects will come from first data

Table 3: Maximum rates per channel of FEE at $L = 2 \times 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$.

	R1	R2	R3	R4
M1	1.2 MHz [a]	1.2 MHz	1.8 MHz	3 MHz
M2	1.6 MHz	1.1 MHz	200 kHz	200 kHz
M3	500 kHz	70 kHz	14 kHz	15 kHz
M4	50 kHz	35 kHz	25 kHz	17 kHz
M5	20 kHz	33 kHz	25 kHz	18 kHz

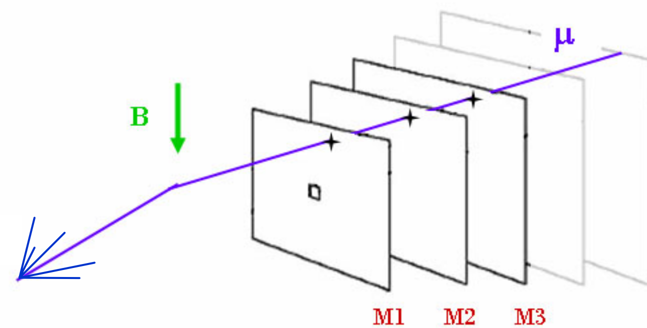
Table 2: Accumulated charge (C/cm) on wires for $100\,\mathrm{fb}^{-1}$

	R1	R2	R3	R4
M1	NA [1]	3.3	1.4	0.44
M2	1.32	0.95	0.45	0.1
M3	0.35	0.1	0.07	0.03
M4	0.45	0.15	0.05	0.02
M5	0.3	0.12	0.05	0.015

Possibility of replacement of the inner parts with large area GEM ($70 \times 30\,\mathrm{cm}^2$) or with MWPC, in any case with new, smaller pad readout

M1, due to background and to upgraded L0, will be removed

A transition to a *fully 3D muon projective readout* (and not based on strips crossing) could reduce the fake associations (detailed studies to be performed)



Trigger and DAQ

Several (MC) studies done, conclusions:

- Need to reconstruct all primary vertexes (PV) per bunch crossing
- Need to measure impact parameter (IP) of tracks to any PV
- Need to measure p_T of tracks with significant IP

A proposal for the First Level trigger: cut on p_T .AND. IP/track simultaneously.
To achieve the above: perform trigger in software on a large CPU farm capable of coping with an input rate up to 30 MHz
This gives the additional flexibility to adapt to the physics landscape in the next decade

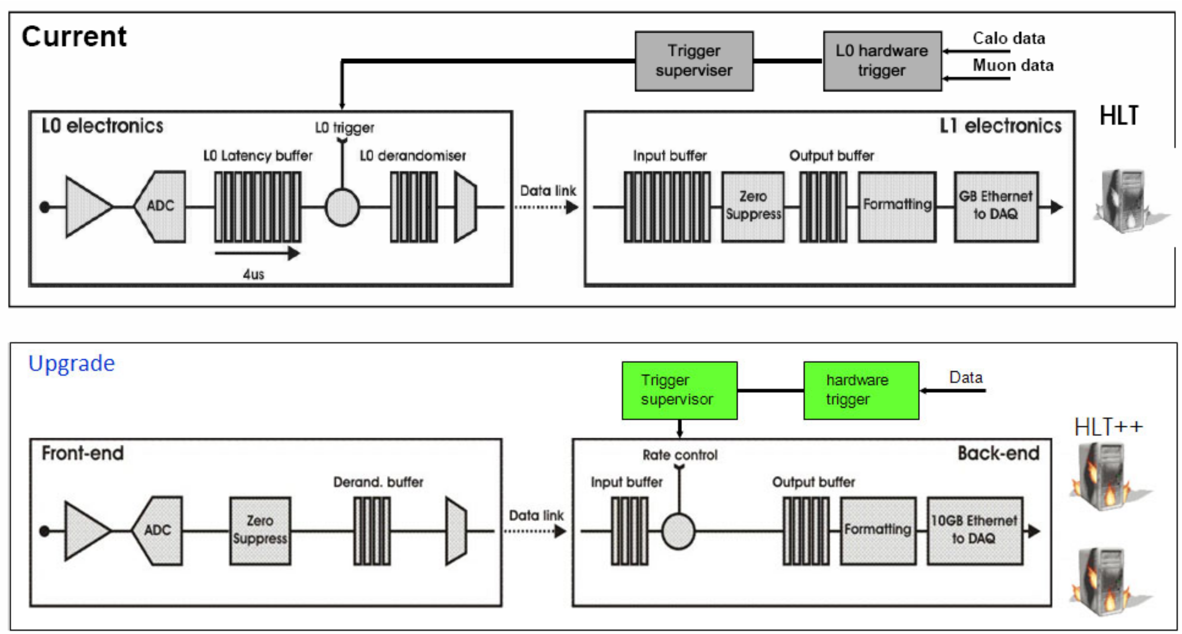
Case study: $B_s \rightarrow \phi\phi$ (after HTL1)

- $\mathcal{L} = 2\times10^{32}$ cm^{-2}s^{-1}

$E_T > 3.5$ GeV $\rightarrow \varepsilon \approx 22\%$
Min.Bias retention 10 kHz

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

$E_T > 2$ GeV $\rightarrow \varepsilon \approx 45\%$
Min.Bias retention 28 kHz



Read out data from every bunch crossing

Conclusions

✓ LHCb is installed in Pit 8 and ready for data taking

✓ Initial plan of detector operation is to collect 10/fb in 5 years

✓ Depending on hints on New Physics coming from LHC experiments (or elsewhere), a substantial upgrade in 2015-16 could be envisaged, to run LHCb at *x10* in luminosity and to get *x20* in statistics in hadronic channels (100/fb) by 2020(?)

✓ This statistics, supported by a substantial decrease of theoretical uncertainties and a deeper understanding of the systematics, can bring the flavor sector to an unprecedented degree of precision
This approach will be largely complementary to the physics program at a SFF

✓ The modifications of the LHCb detectors are relevant in some areas (vertexing, tracking, Rich, new TOF), less demanding in some others (calorimetry, muon system). The manpower and the economic effort is non negligible, but affordable from a well motivated crew

let us see....let us do....