LHCb Upgrade

- Quick reminder of our strategy
- New developments
  - New simulation results on occupancies
  - Reduced material beampipe support
  - New progress in the VELO
  - Developments for RICH
  - Calorimeter irradiation tests
  - Readout architecture
- Conclusions

Paula Collins (CERN)
On behalf of the LHCb collaboration

Reminder of LHCb upgrade Strategy

The idea

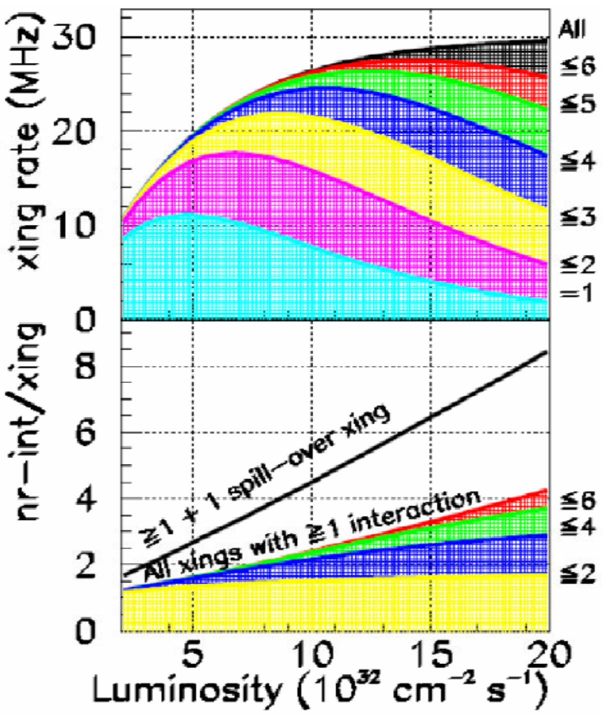
- Aim to operate at $\mathcal{L}$=2.10^{33}
- Perform entire trigger on CPU farm with input rate 30 MHz
- Goal is to double trigger efficiency for hadronic channels and make it scale with luminosity
- Trigger uses ALL event information, reconstructs all primary vertices, and can cut on p_T and i.p. simultaneously
- A very flexible solution to adapt to physics landscape in the next decade

The consequence

- All subsystems must be fully read out at 40 MHz
- Replace most FE electronics, silicon modules, RICH HPDs, FE boards of calorimeter and outer tracker

Why the choice of $2x10^{33}$?

- Up until this luminosity, our yield improves enormously, while the underlying event characteristics remain reasonable
  - Crossings with ≥ 1 interaction 10 MHz → 30 MHz
  - Average number of interactions per crossing 1.2 → 4
  - BUT: spillover increases linearly with $\mathcal{L}$
- We make the assumption that a luminosity range of 0.5-5 x 10^{33} is compatible with LHC and SLHC running scenarios, (and everything in between…)
  - May need dedicated study on machine side?



LHCb Upgrade TimeLine

- First upgrade workshop Jan '07 Edinburgh
- EOI submitted April '08
- Upgrade task force formed
  - Sheldon Stone, Hans Dijkstra
- TDR planned for 2010

Plan to:

- Accumulate $10 fb^{-1}$ @ LHCb in 5 years
- Install substantial upgrade in 2015-16 (in synch with machine shut downs and long GPD interventions)
- Accumulate 100 fb-1 in a further 5 years operation

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

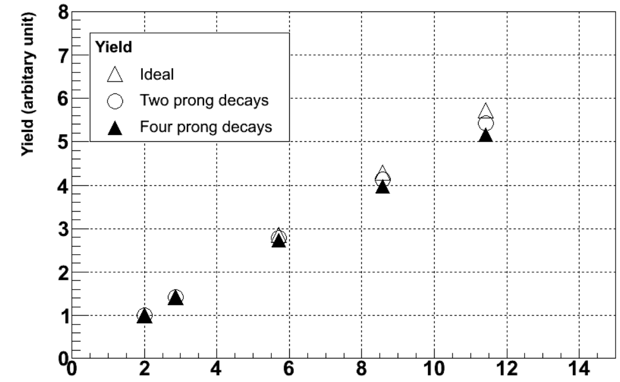
Observable	Sensitivity
$S(B_s \to \phi\phi)$	0.01 – 0.02
$S(B_d \to \phi K_S^0)$	0.025 – 0.035
ϕ_s $(J/\psi\phi)$	0.003
$\sin(2\beta)$ $(J/\psi K_S^0)$	0.003 – 0.010
γ $(B \to D^{(*)}K^{(*)})$	$< 1°$
γ $(B_s \to D_s K)$	$1 - 2°$
$\mathcal{B}(B_s \to \mu^+\mu^-)$	5 – 10%
$\mathcal{B}(B_d \to \mu^+\mu^-)$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

Extract from EOI CERN-LHCC-2008-007

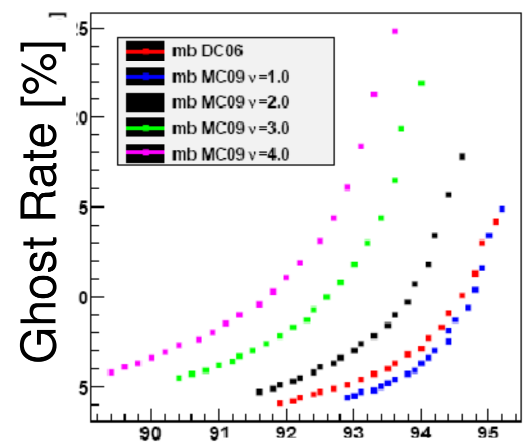
Detector Environment @ Upgrade

- Radiation:
  - Current detector designed to withstand only 20 fb^{-1}
  - Affects mainly large η (trackers, inner part of calorimeter)
  - Running experience needed
  - Note that VELO in any case will be replaced
- Tracking and Occupancy:
  - Silicon can be operated without spillover: giving occupancy increase of ~2
  - Outer tracker straws: occupancy too high:
    - Increase area coverage of IT and use faster gas
    - Or Move to scintillating fibres
- Material Budget an important issue (occupancy, momentum resolution)

HLT B yield from tracking efficiency and ghost rate (no spillover) with current detector



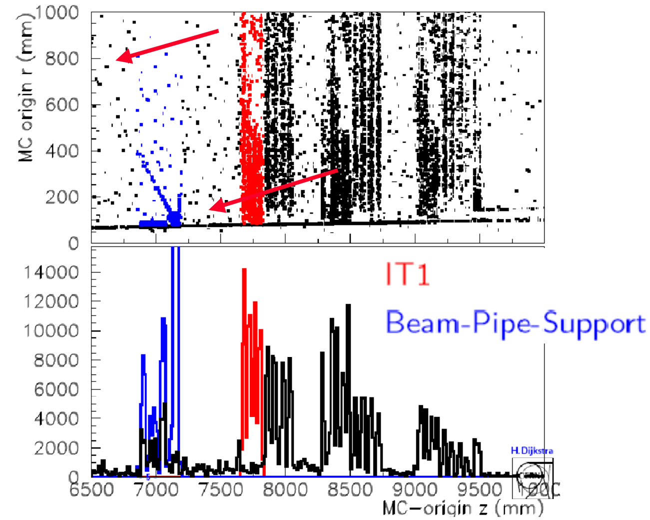
Luminosity (10^{32} $cm^{-2}s$-1)



Efficiency [%]

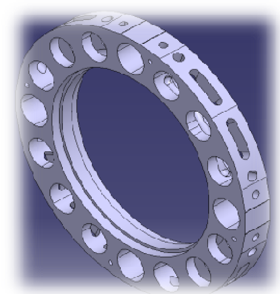
Controlling Occupancies (I)

- Within OT, 77% of occupancy does not come from primary interaction envelope
  - ➢ Move IT behind OT
  - ➢ Reduce beam pipe support material
  - ➢ Remove aerogel and improve foil
- Result: 11% improvement in average occupancy (but better in inner regions) for a factor 2 improvement in beam pipe support (T. Skwarnicki, Upgrade Meeting 9 September 2009)
- In fact, much better than this can be achieved (factor 3-4? see presentation of R. Veness)

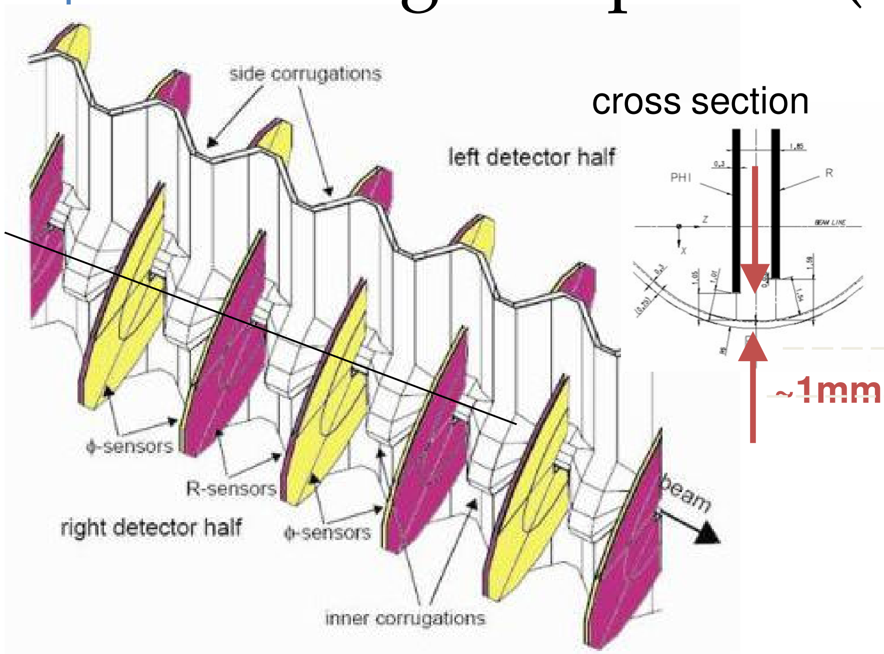


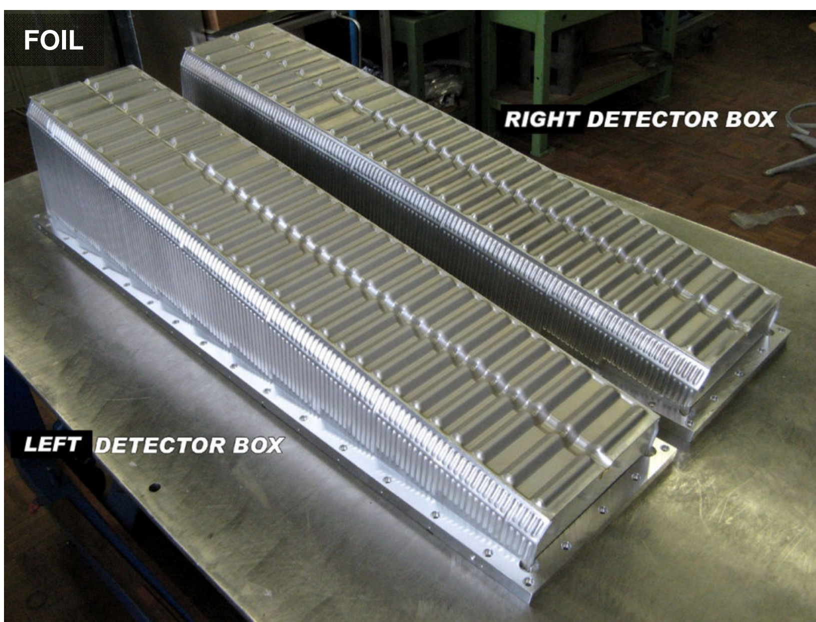
Hans Dijkstra, Upgrade Meeting 19 March 2009

New optimized beampipe support collar



Controlling Occupancies (II) RF FOIL & RF BOX





REQUIREMENTS

- Separates accelerator and detector vacua (must be ultra-high vacuum compatible)
- Should minimise material before first and second measured points
- Shield against RF EMI pick-up effects
- Carry beam image charge
- Accommodate sensor geometry
- Withstand heating, cooling, and radiation levels

CURRENT DESIGN

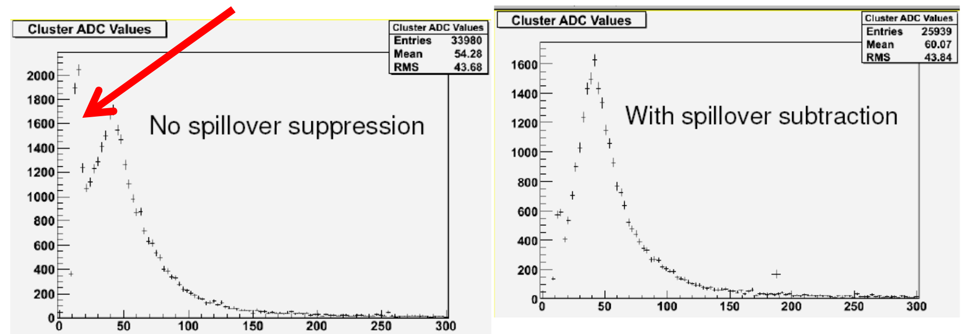
- Foil is 300 um AlMg3, coated with insulator and getter
- Foil shape set by overlapping sensors and beam clearance and beam effects
- Large area: 200 x 1000 mm^2
- Maximum allowed pressure differential: 5 mbar
- Contributes significant material to VELO
- Was a huge engineering effort (NIKHEF)

UPGRADE DESIGN

- Carbon Fiber composite
  - Large modulus fibers (stiff, low density)
  - Resin with high rad tolerance, low outgassing (space qualified), micro-crack and delamination resistant
- Produce foil+box+flange as single integrated unit
  - Avoids sealing problems
- Aim for ~50% of current mass thickness
- In development with industrial partner CMA (Composite Mirror Applications Inc.)
- Prototyping planned to start by end 2009, testing early 2010

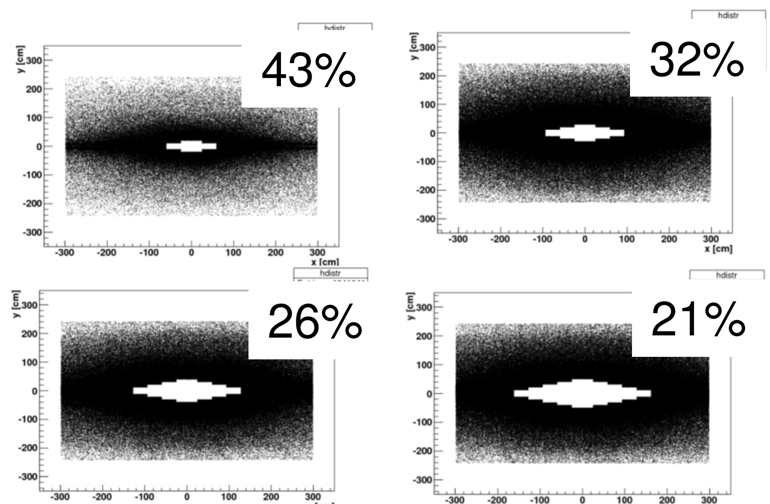
Controlling Occupancies (III)

- Spillover suppression for silicon detectors
  - Highly effective
  - Can be applied given knowledge of previous/next event
  - e.g. 31% reduction of TT clusters



- OT geometry modifications
  - Occupancy of worst region at $2x10^{33}$ can be brought down to 21%

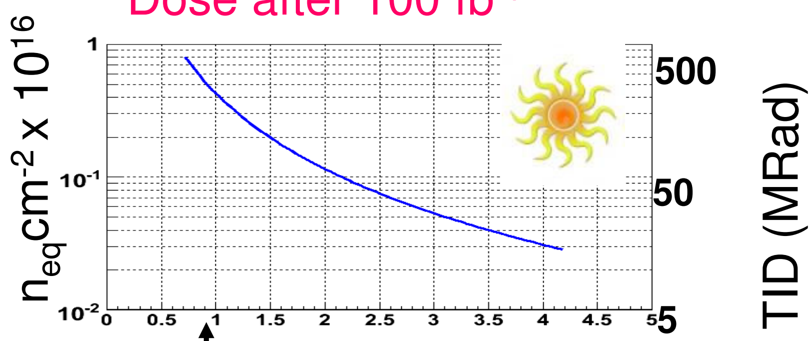
- Reducing the readout gate (75→50 ns) gives another factor ~1.6



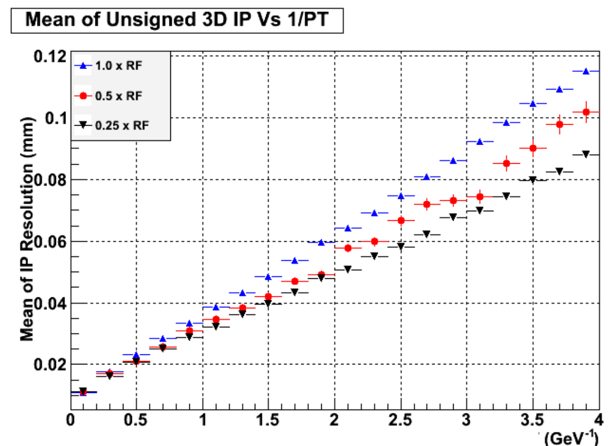
Vertexing @ LHCb Upgrade

- Upgrading the VELO to 40 MHz implies complete replacement of all modules and FE electronics.
- Two major challenges
  - Data rate of ~1300 GBit/s
  - Radiation levels and hence thermal management of modules
- Important to maintain current performance by keeping material low
  - Small modules with low power
  - Thinning of sensor and electronics
  - Use of CVD diamond planes for cooling and/or sensor
  - Removal/rework of RF foil

Dose after 100 fb^{-1}



tip of current VELO



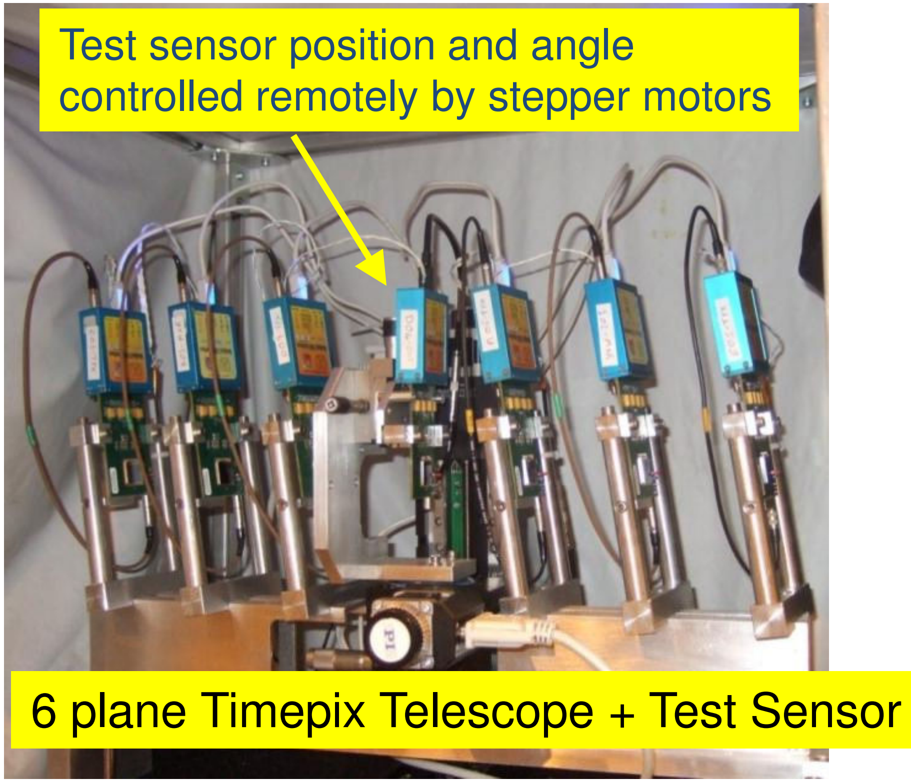
Impact parameter resolutions for varying foil thicknesses

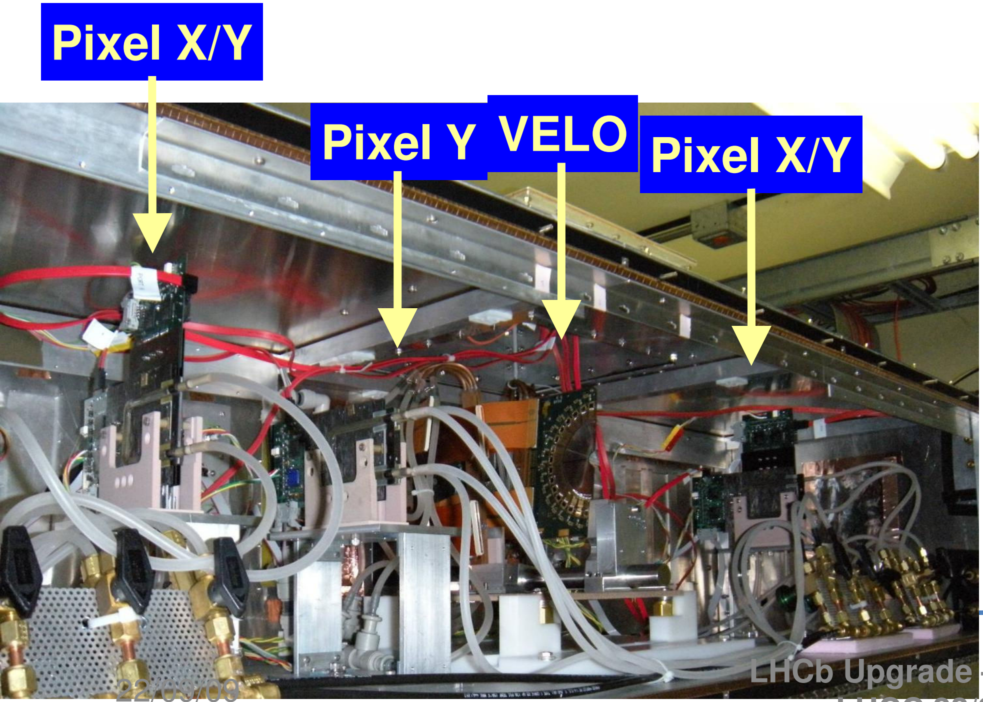
Lots of activity over the summer

Timepix (derivative of Medipix) is a contender for the VELO pixel electronics readout

- Square pixel and 3 side buttable design opens up possibility of single sided module

Testbeam carried out to investigate suitability of chip for charged particle tracking

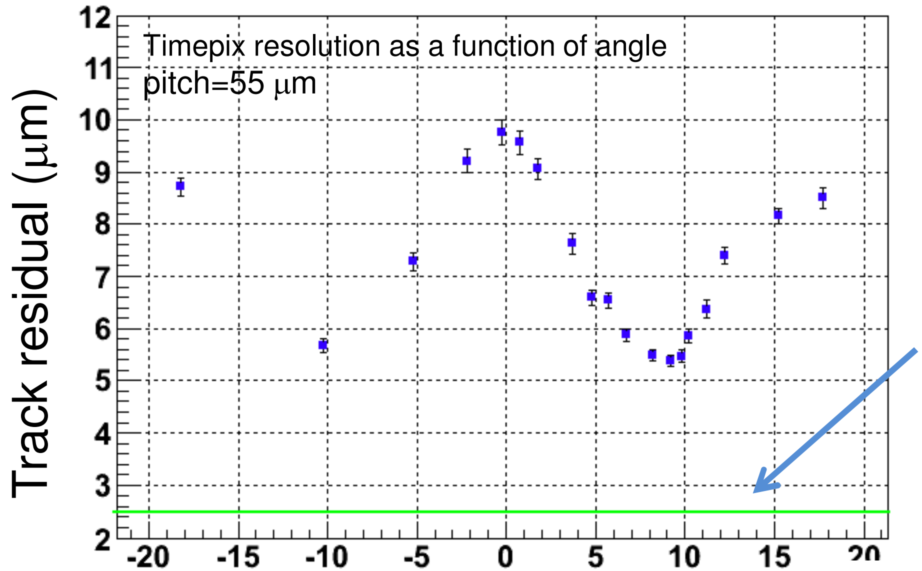




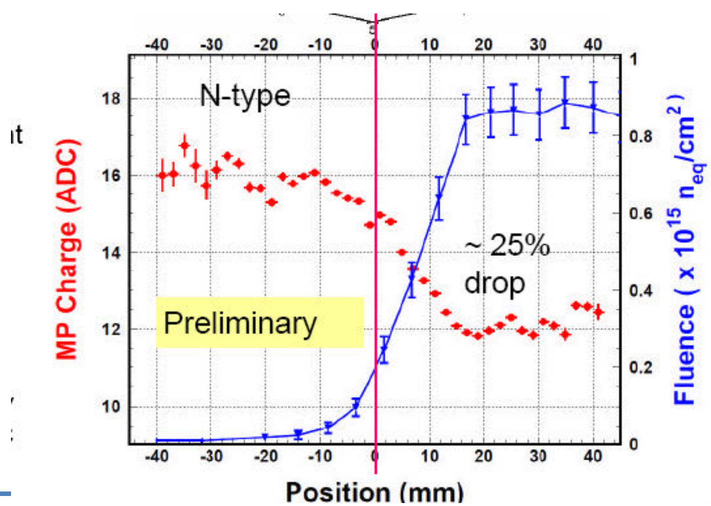
FPIX telescope also in action at Fermilab
Main purpose: to investigate VELO sensor performance (resolution, efficiency, radiation hardness)

Testbeam highlights

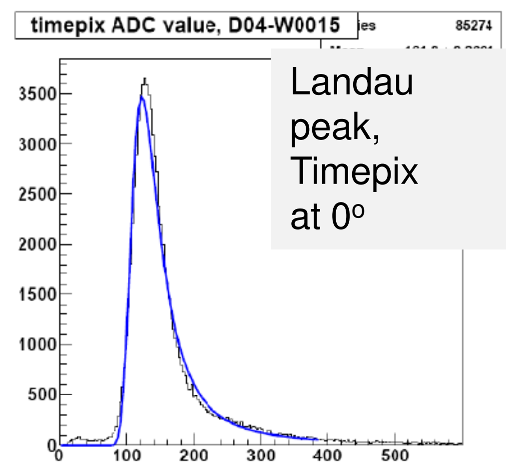
PRELIMINARY:
UNCALIBRATED
DATA!!



2.5μm Estimated track contribution to residual



First look at irradiated VELO strip sensors
Fermilab testbeam



Timepix shows clean landaus and excellent resolution

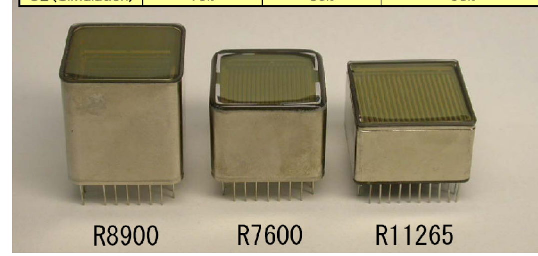
Future developments for VELO

- Group will concentrate pixel electronics efforts in Timepix, which looks promising
  - Many issues to be solved: architecture modifications, high speed links, on-chip processing, fast column readout, timewalk....
  - MPW runs planned for next year, followed by full chip submission
- Module and Sensor R&D is also going ahead
  - Rad hard n-in-p silicon
  - Diamond as a sensing element
  - 3D
  - Module thermal, mechanical and hybridisation issues
  - Upgraded strip design
  - Construction of LHCb telescope facility at CERN for R&D
- Institutes are moving fast to secure resources. Already some grants approved

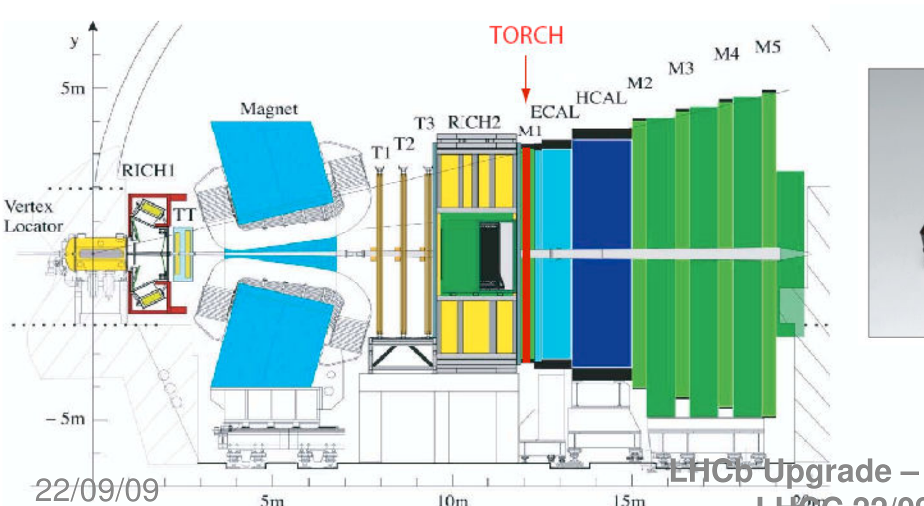
Particle ID in the RICH system

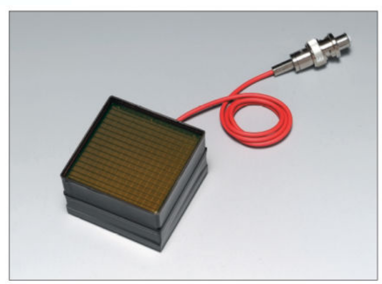
- Need to replace front end electronics AND photon detectors to cope with 40 MHz readout
- Baseline approach; keep current geometrical layout RICH1 (aerogel+C_4F_{10}) + RICH2 (CF_4)
- OR, replace aerogel with new TOF system (TORCH) located after RICH2
- Photon sensors together with their new (independent) chip are the critical item:
- Front runners are flat panel and MaPMTs
  - 0.3M channels
  - R&D needed (x talk, spillover, B field, lens...)
- or upgraded HPDs
  - study ion feedback rate
  - many new components: production time an issue
- Non-baseline idea: MCPs
  - B tolerance, timing, new idea...

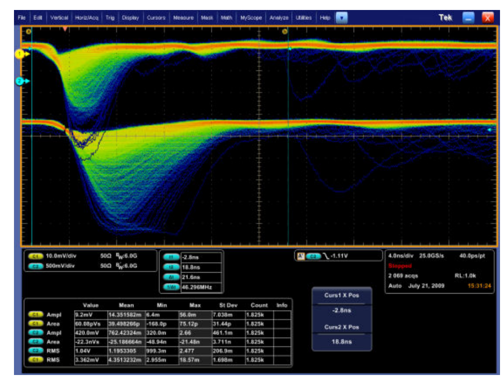
	R8900	R7600	R11265
Total length	34mm	27mm	23mm
Effective area	23.5mm	18mm	23mm
CE (Simulation)	75%	80%	90%



Next generation MaPMTs







HPDs under study by several RICH groups

New concept for RICH: the TORCH

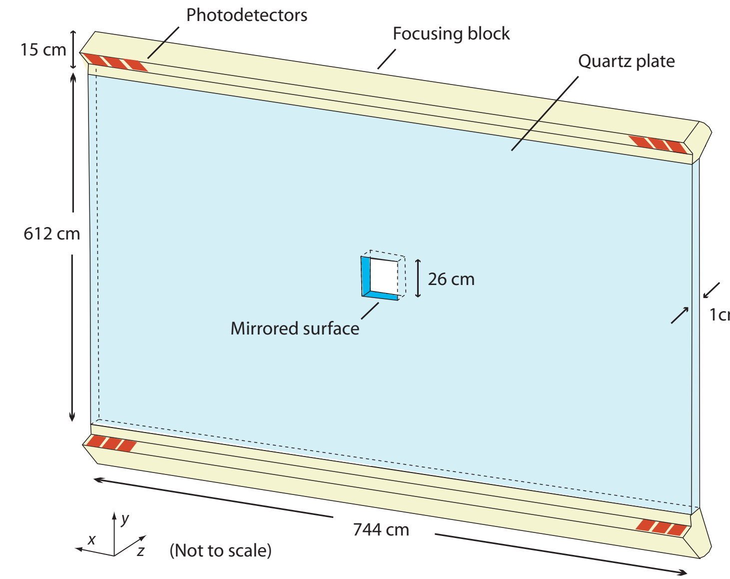
Time of flight detector based on a quartz plate, for the identification of p<10 GeV hadrons (replacing aerogel)

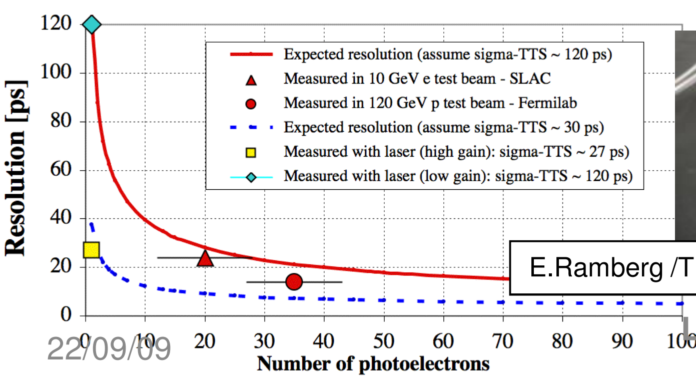
- reconstruct photon flight time and direction in specially designed standoff box
- Clock arrival time to ~20 ps
- Deduce photon emission time → track ToF

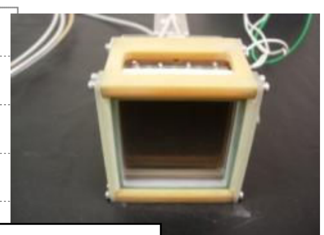
R&D on hardware needed:

Microchannel plate PM with multianode readout

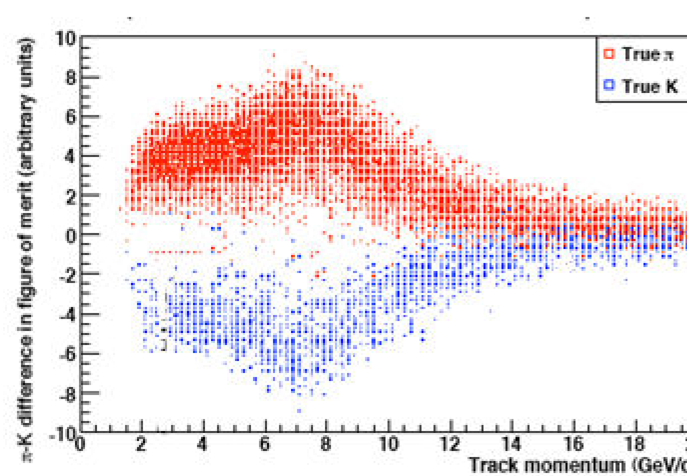
- MCP-PM achieved in testbeam 10-20 ps time resolution with 30-20 p.e.
- mechanics, electronics (Timepix?), aging etc.
- possible synergy with PANDA and VELO







E.Ramberg /TIPP09



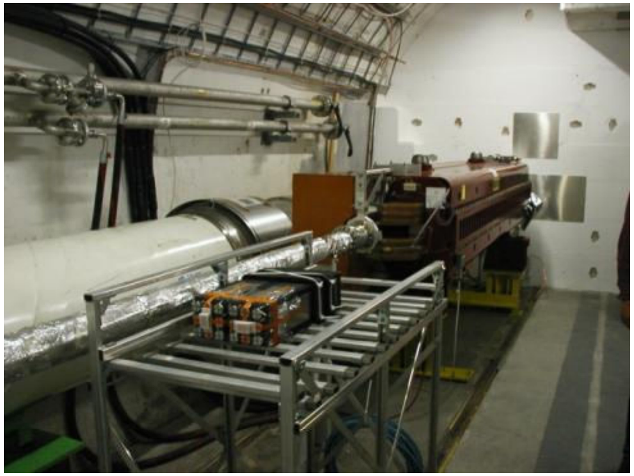
New simulation results for TORCH with full pattern recognition

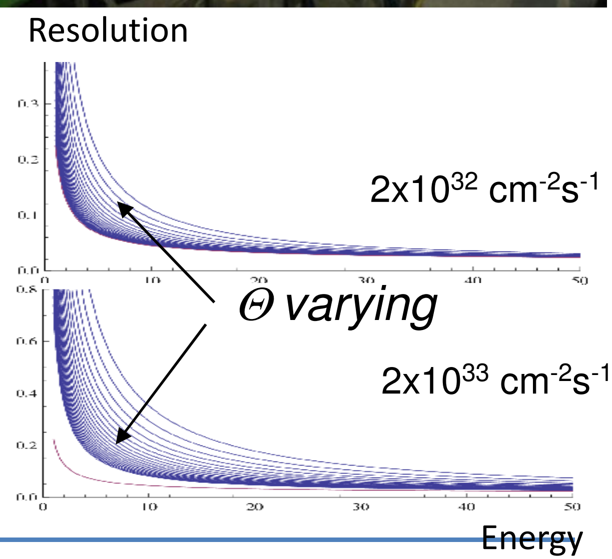
Calorimeters

- HLT seeds already provided at 40 MHz
- Modifications to electronics needed:
  - Upgraded FE boards
  - Lower PM gain (5) and increase preamp sensitivity and lower noise accordingly
  - No showstopper forseen
- Radiation tolerance currently an open issue
  - Affects inner part of ECAL (would need replacement)
  - Tested up to 2.5 Mrad (1 upgrade year)
  - R&D underway to collect more comprehensive data
- Pile-up (~4 at upgrade) will affect resolution: watch carefully for low p_T, γ physics

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

September 2009: calorimeter modules placed in LHC tunnel to accumulate dose





New results for RO architecture

- Full simulation framework has been built based on the new Readout/S-TFC architecture

  1. synthesizable "clock level-fidel" simulation of S-TFC component and links (Based on the proven GBT simulation)
  2. clock level emulation of FE+ROB model with variable parameters

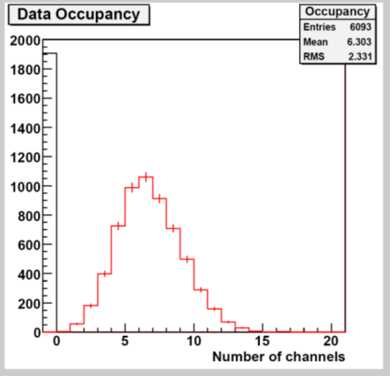
- In parallel, investigation planned of latency, phase control and stability of common Altera GX links

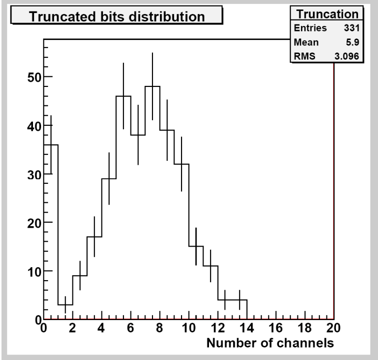
- Based on mature ideas on new S-TFC architecture presented at IEEE Real Time Conference 2009 in Beijing, China

http://lhcb-doc.web.cern.ch/lhcb-doc/presentations/conferencetalks/postscript/2009presentations/Alessio-IEEE-NPSS.ppt

Example test case:
<Detector occupancy> = 30%
#channels / GBT link = 21
→ ~ 6.3 channels / GBT after ZS
Derandomizer depth = 24
Channel size = 12
(e.g. ADDR = 5bits + ADC_DATA = 7bits)

→Size of truncated events follows occupancy PDF, no bias!

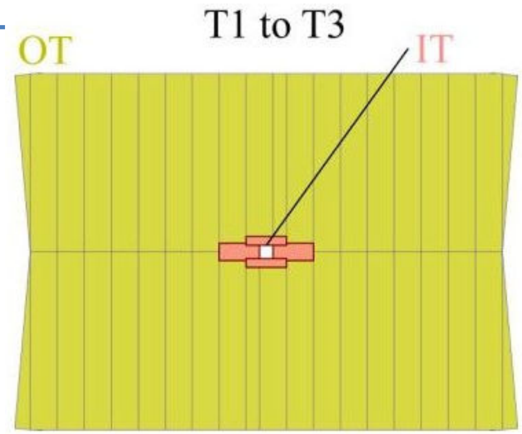


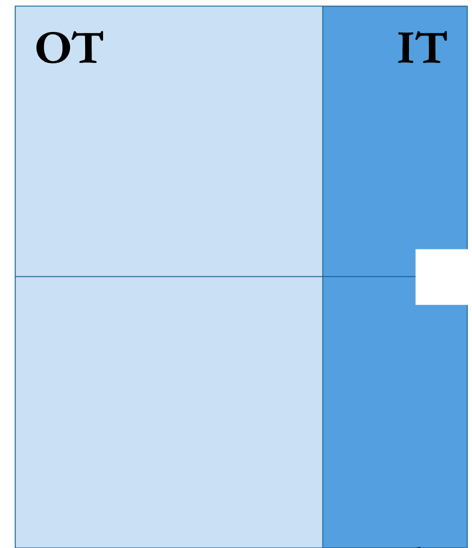


Outlook

- LHCb upgrade on track
- Upgrade strategy SLHC independent:
  - Goal: 100 fb^{-1} in 5 years at $\mathcal{L}$=2x10^{33}
  - x20 statistics in hadron channels
  - x10 statistics in leptonic channels
  - Maintain tracking and PID performance
- Much progress in hardware and software (simulation studies not shown today)
- Experience with LHC running CRITICAL for fixing design parameters. After first data, can aim for upgrade TDR (~2010)

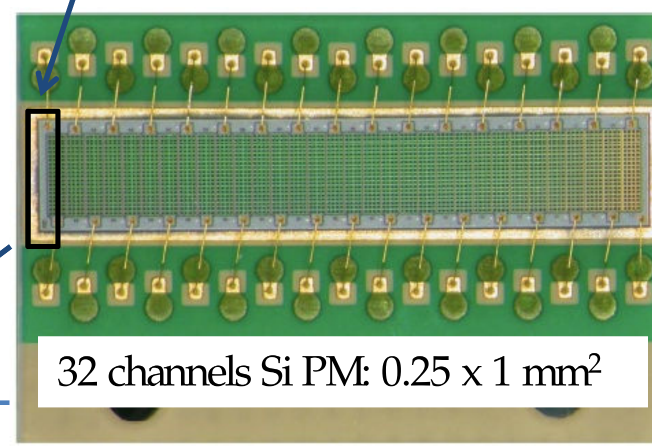
Alternative Solutions for Tracking



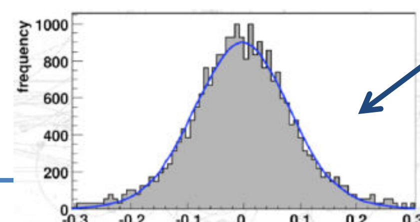


A fiber tracker with mixed fiber dimensions (250 mm for inner part, 700-1000 mm for outer) to be readout with SiPM and/or conventional MaPMT

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



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



Preliminary: 80 μm residuals