LHCb Upgrade: Flavour Physics at High Luminosity

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- **LHCb -** Aims for first phase (~10 fb^{-1}, ~ 5 years)
- **SuperLHCb physics –** Probing New Physics
- **SLHCb Detector** and the **VESPA**
- **Conclusion-** Forward Plan

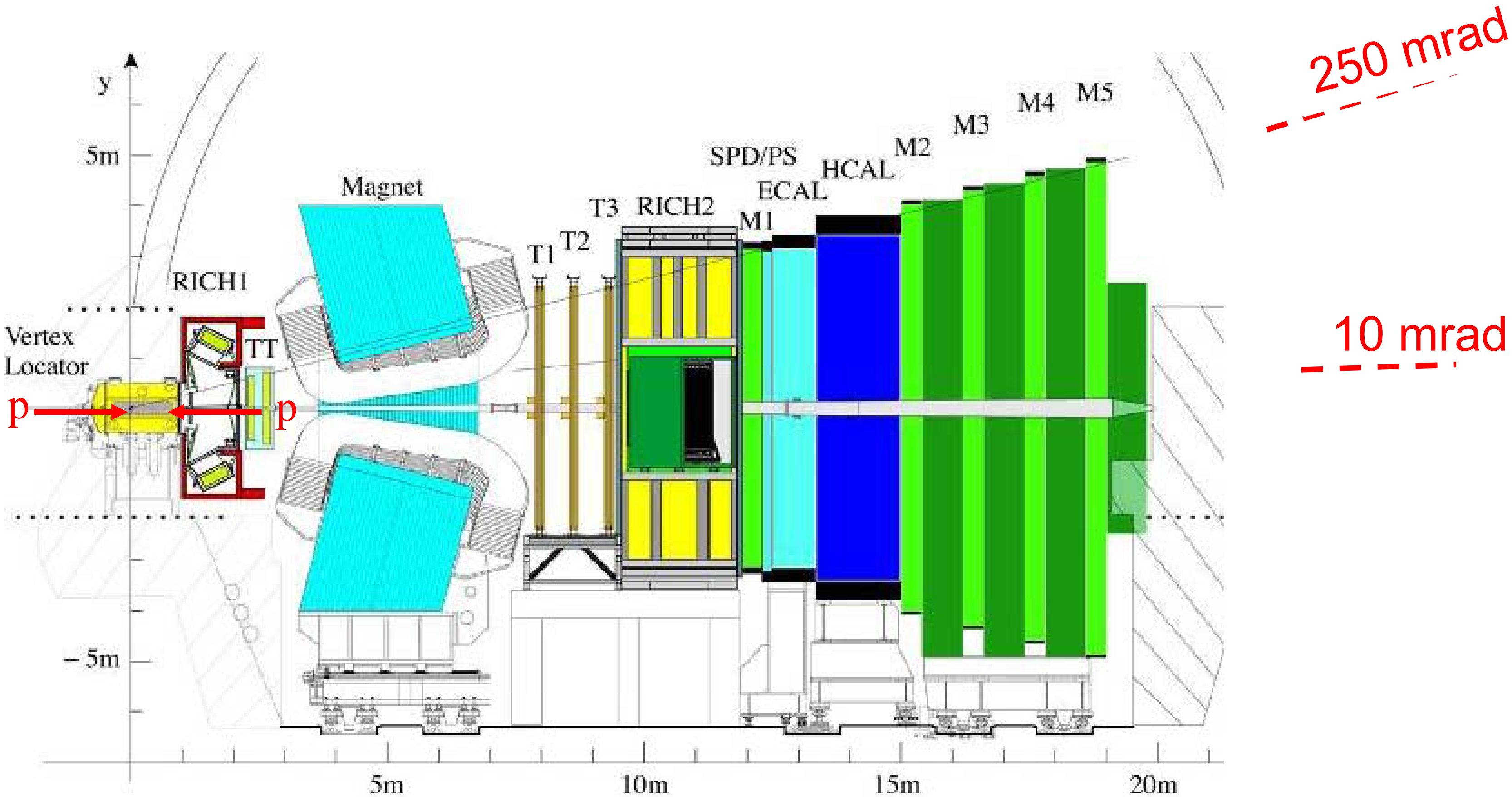
VElo Superior Performance Apparatus

CERN, Glasgow, Lausanne, Liverpool, NIKHEF, Syracuse

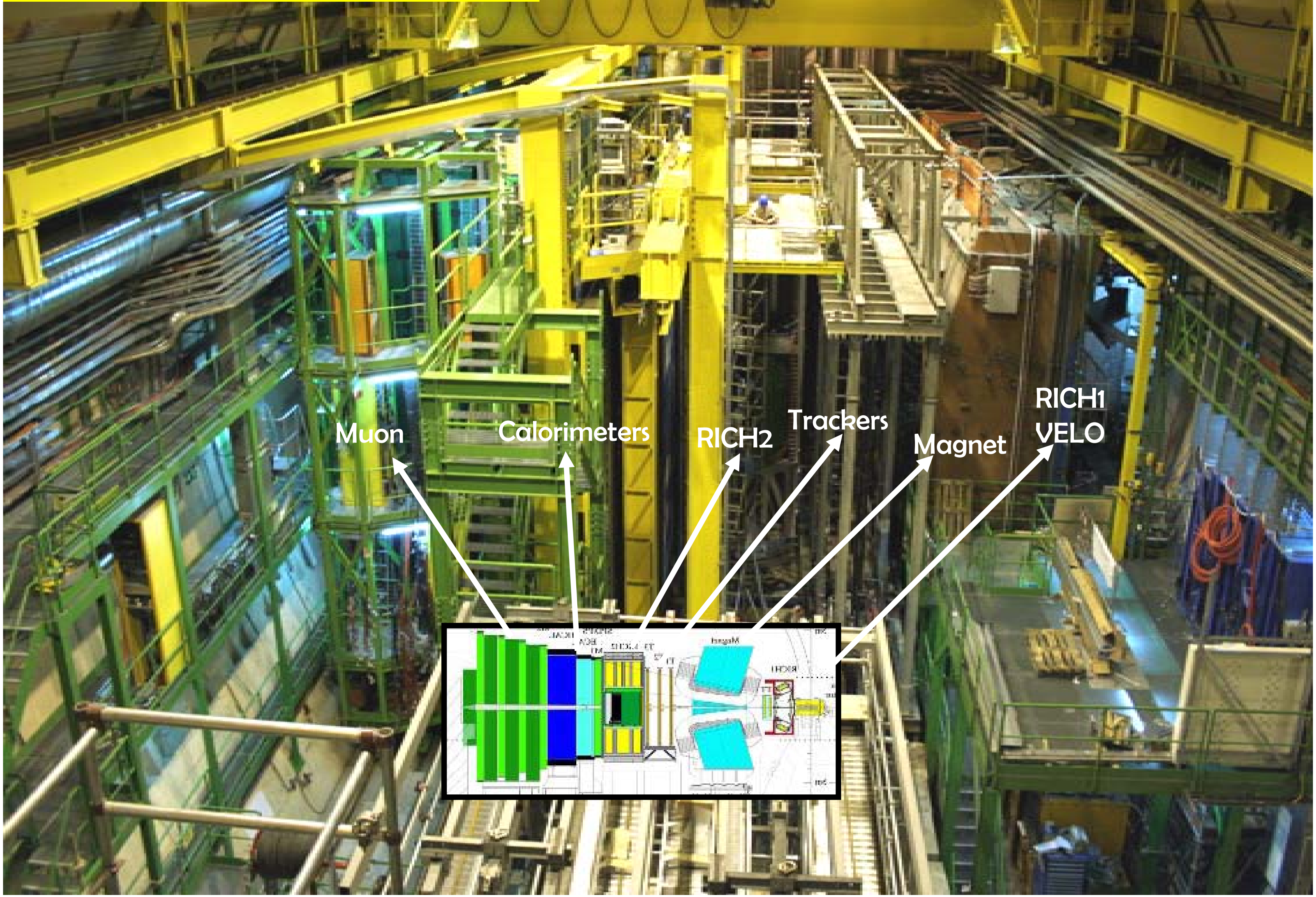
RD50 Meeting, CERN, November 12th 2007

Dedicated Experiment for study of CP Violation & Rare Decays in the B System

- Full spectrum of B hadrons: $B^{\pm}_{u,c}, B^{0}_{d,s}$, baryons
- B_s system, All angles and sides of both CKM triangles
- Lots of events ! $\sigma_{b\bar{b}} \approx 500\,\mu b,\ \mathcal{O}(10^{12})\ b\bar{b}$ pairs per year

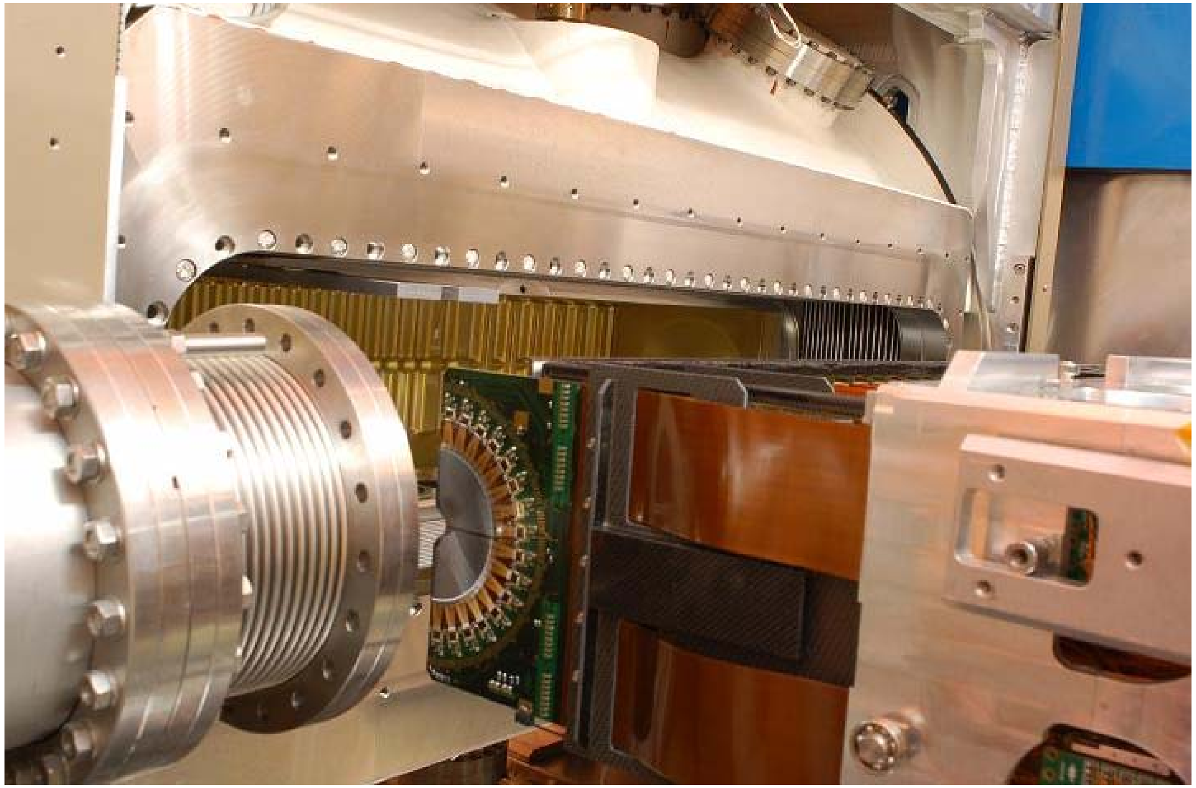


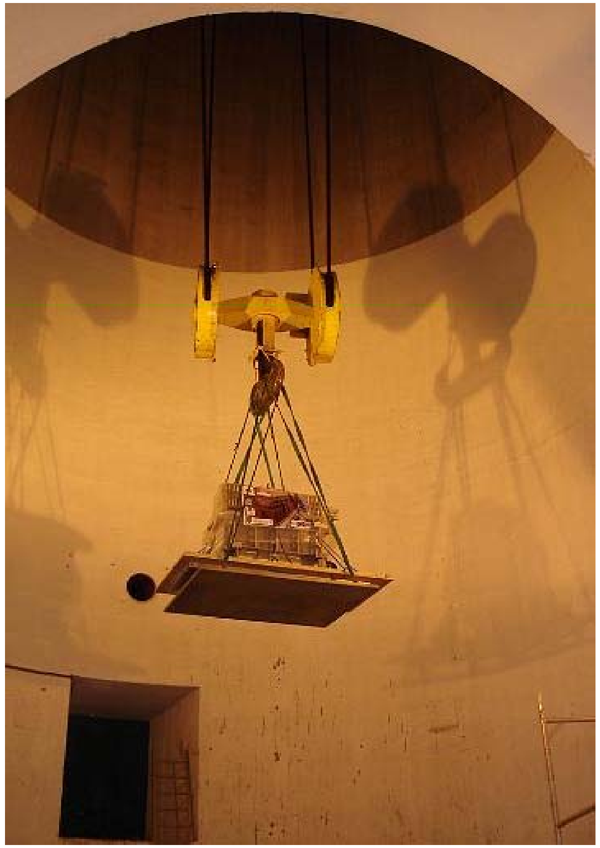
LHCb Construction on Schedule



VELO

- Installed in pit 31st October 2007

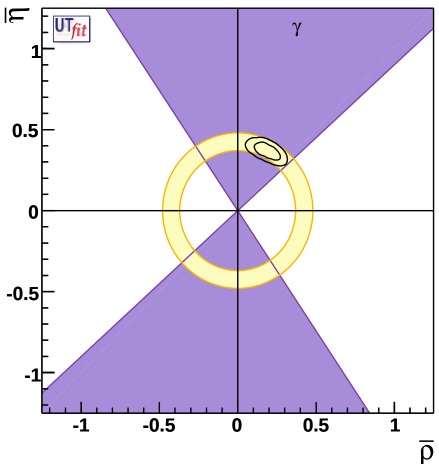




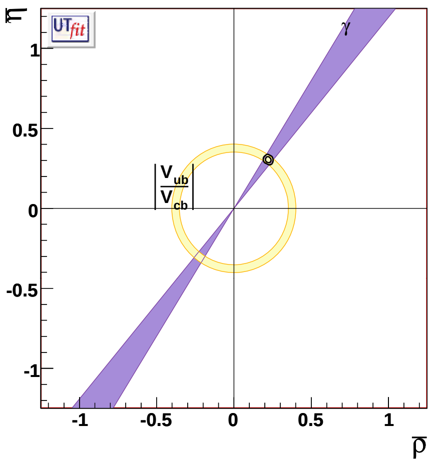
Flavour Physics Progress

- Spectacular progress in heavy flavour physics in recent years:
  - Baseline measurement angle β (J/ψ K_S)
  - B_s Oscillations Measurement, Charm mixing results (D_0-$\overline{D}_0$)
- Impressive range of additional measurements

Today



10 fb^{-1}
LHCb
+ lattice



LHCb Goals - First Phase 10 fb^{-1}

- First observation of very rare decay

$$B_s \rightarrow \mu^+ \mu^-$$

- B_s mixing phase

ϕ_s at 0.01 rad

- Unitarity Triangle

γ at few degrees

B→DK

Bs→DsK

B(s)→h+h− exploiting U-spin

VELO n-on-p Replacement

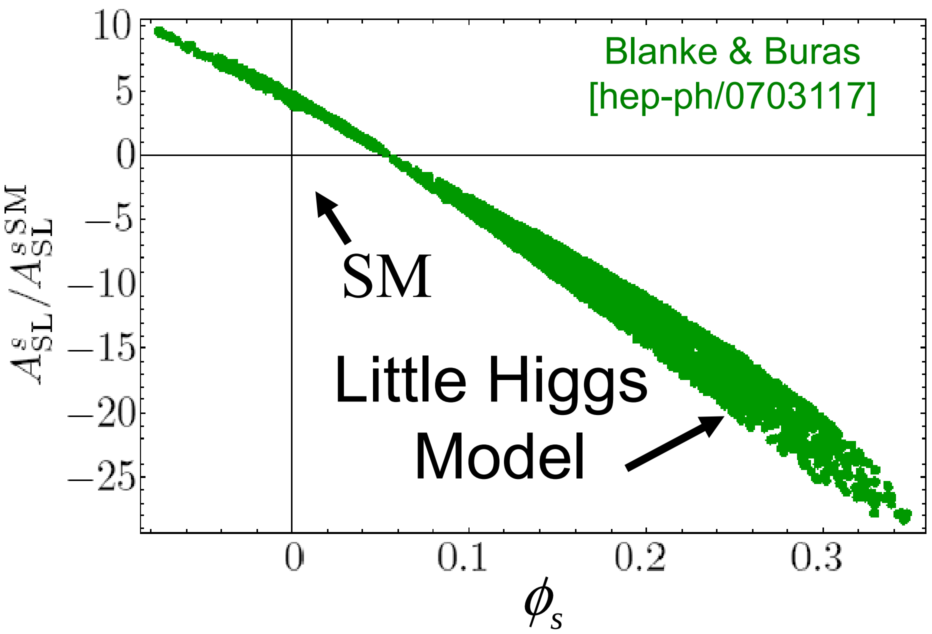
- 1st generation VELO n-on-n strip detectors
  - Will survive ~ 5×10^{14} 1 MeV n_{eq}/cm^2
- 2nd generation VELO replacement n-on-p detectors needed for initial programme
  - Minor design changes only
  - One prototype module installed in 1st VELO
  - Approved project
  - Construction in Liverpool will start summer 2008
- Here we discuss the longer term upgrade (VELO→VESPA)
  - Major design changes

Upgrade Physics Programme

Complementary to ATLAS / CMS direct searches

- New particles are discovered
  - LHCb measure flavour couplings through loop diagrams
- No new particles are found
  - LHCb probe NP at multi-TeV energy scale

Study new physics through loop effects



One example: LHCb upgrade can separate SM predictions from Little Higgs model predictions

LHCb Physics Programme

Limited by Detector

But **NOT** Limited by LHC

- Upgrade to extend Physics reach
  - Exploit advances in detector technology
    - Radiation Hard Vertex Detector
    - Displaced Vertex Trigger
  - Better utilise LHC capabilities
- Timescale, 2015
- Collect ~100 fb^{-1} data
- Modest cost compared with existing accelerator infrastructure

Independent of LHC upgrade

- SLHC not needed
- But compatible with SLHC phase

Initial Phase of LHCb Operations

- Displaced Vertex trigger
  - 2nd level of triggering
- Veto multiple Interactions
  - On first level trigger

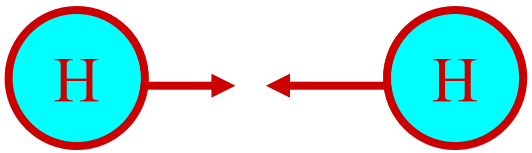
Data taking starts 2008

Defocus LHC beams

- LHCb L= 2×10^{32} cm^{-2}s^{-1}
- Factor 50 below ATLAS/CMS design luminosity
- Most events have single interaction

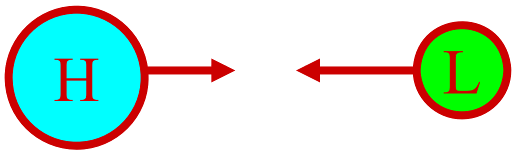
- **LHCb Upgrade** L= 2×10^{33} cm^{-2}s^{-1}
  - Cope with > 4 int./x-ing
- **SLHC peak** L= 8×10^{34} cm^{-2}s^{-1}
- Baseline - 40MHz, alternate High, Low I

GPDs



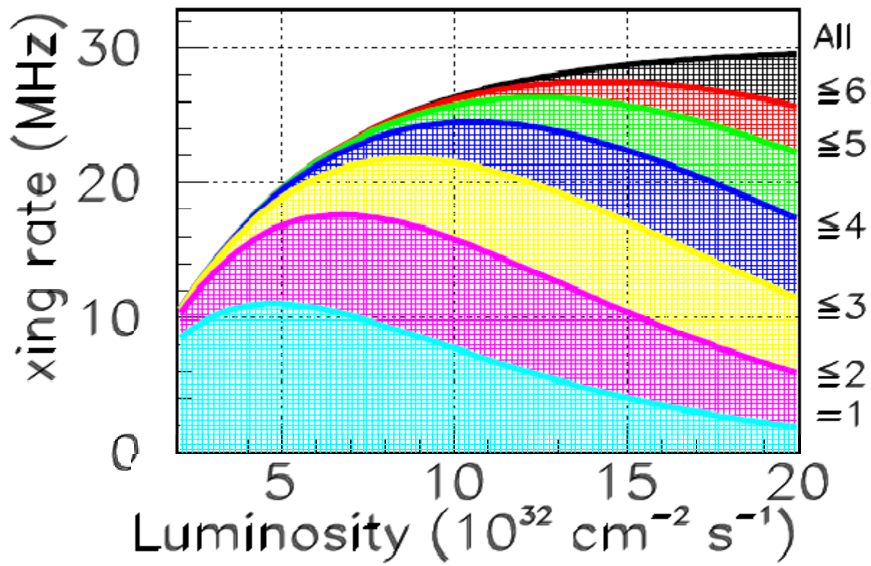
Effective 20MHz Crossing rate

LHCb



Select Low I for desired luminosity

rate of pp interactions



LHCb Trigger System

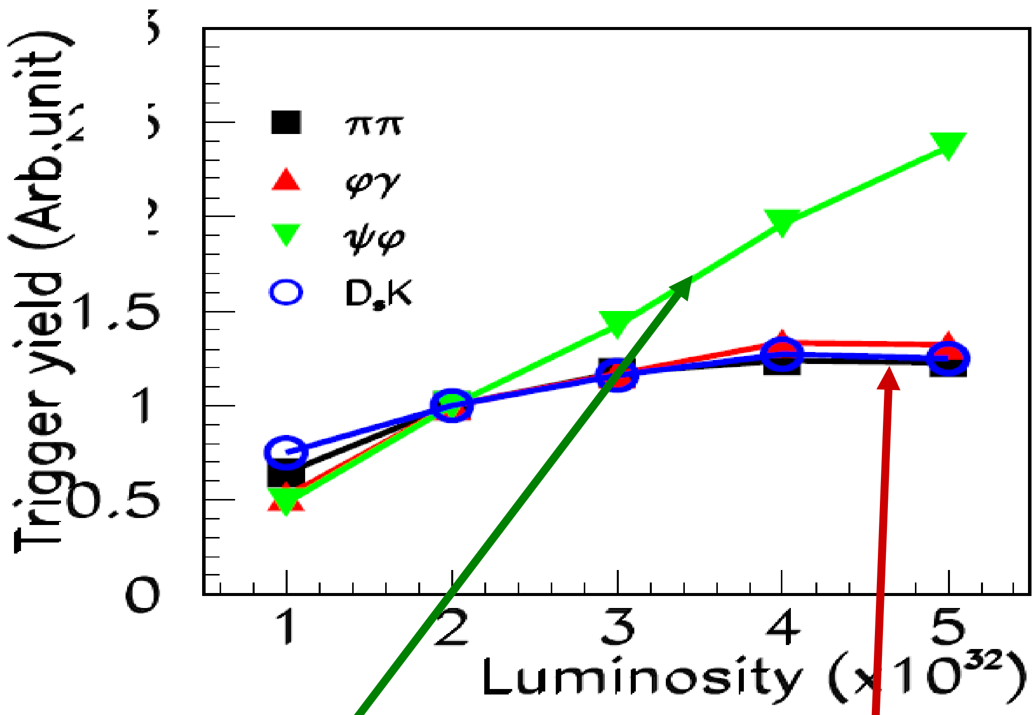
Will have to cope with 4 interactions / beam crossing

Current 1st Level Trigger Performance

Existing 1st Level Trigger 1MHz readout

- Veto on multiple interactions

- Existing Trigger based on:
  - High p_T Muons
  - Calorimeter Clusters



Require Displaced Vertex Trigger At 1st level

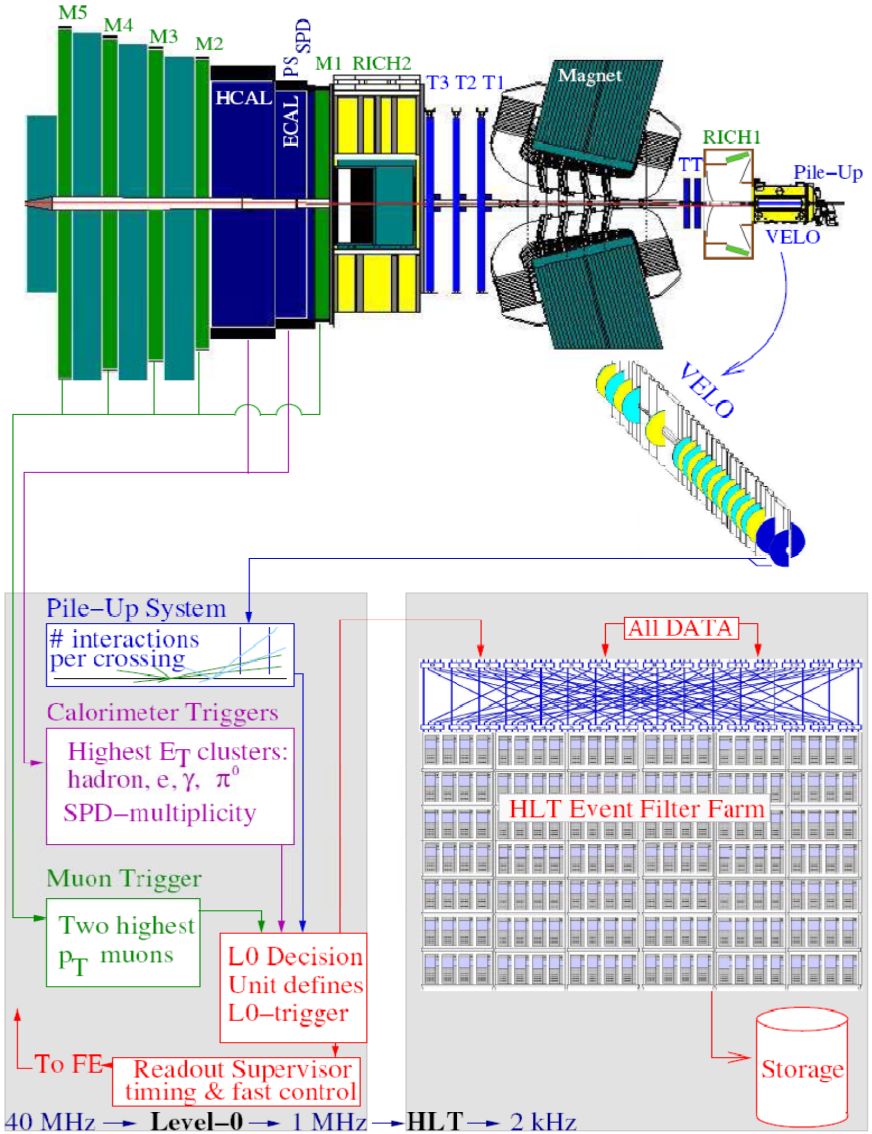
Events with muons – trigger efficient

Events with hadrons – need improved trigger

Trigger Gains – 40 MHz readout

- Improve efficiency for hadrons and photons.
- Current efficiencies:
  - $\varepsilon_{Trig}(B\rightarrow hadronic) \sim 25\text{-}35\%$
  - $\varepsilon_{Trig}(B\rightarrow \gamma X) \sim 30\text{-}40\%$
  - $\varepsilon_{Trig}(B\rightarrow \mu\mu X) \sim 60\text{-}70\%$

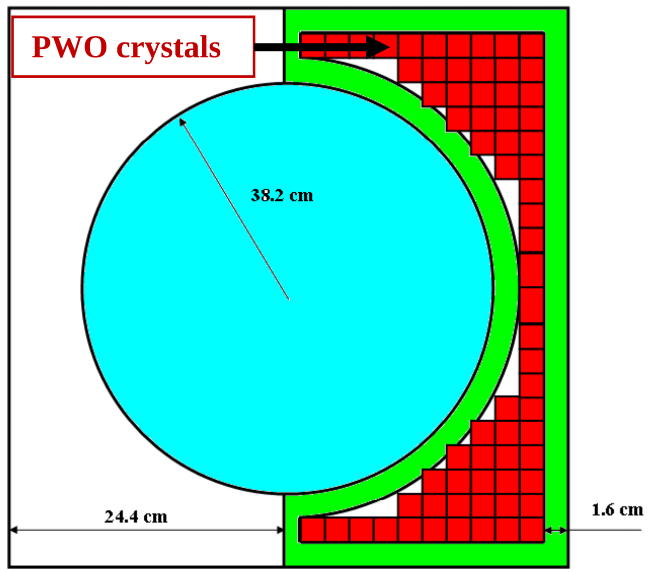
- Higher Level Trigger
  - Only limitations
    - CPU
    - Algorithmic Ingenuity
  - (Former) improves with Moore's Law



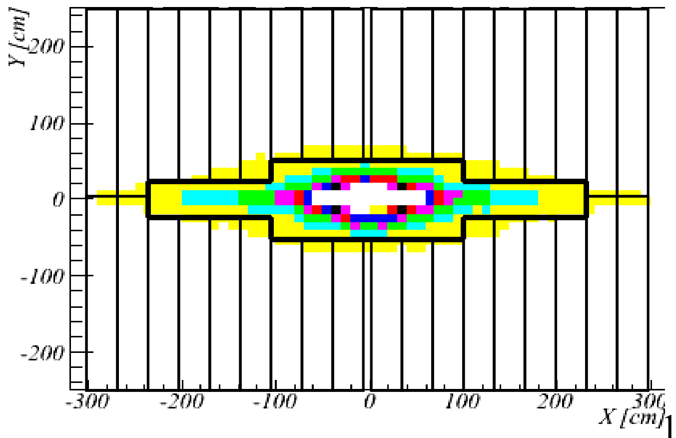
LHCb Upgrade Baseline & Issues

- Trigger in CPU Farm
  - Event building at 40 MHZ, CPU power OK
  - Hadron efficiency ~ factor two improvement
- Read-out all detector 40MHz
  - Replace all FE Electronics
    - Vertex locator, Silicon Tracker, RICH HPD,
    - Outer Tracker FE, Calorimeter FE boards
- Radiation Damage
  - Need to replace Velo anyway
  - Inner part of Shashlik Calorimeter
  - Inner part of silicon tracker
  - Remove muon chamber before Calorimeter
- Occupancy
  - Inner part of outer tracker, 6%→25%
    - Increase silicon coverage (faster gas, scintillating fibres)
  - Tracking algorithms for higher occupancy

ECAL

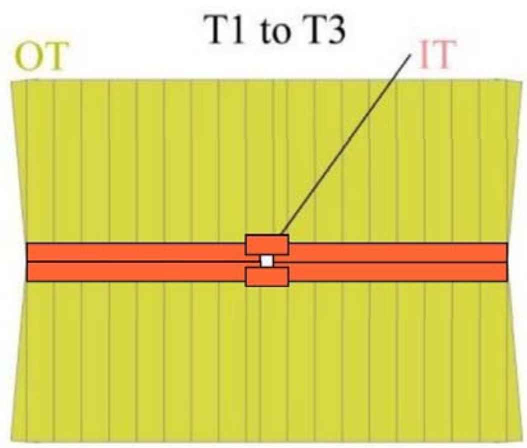


Inner / Outer Tracker

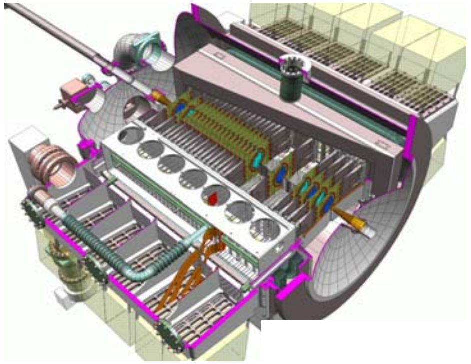


Silicon Trackers in LHCb

- Trigger Tracker – 8 m^2 silicon strips
  - Remains, modest pitch improvement in central region (200 → 100 μm)
- Inner Tracker
  - Complete replacement of outer tracker with Si not possible – 300 m^2 – or necessary.
  - Possible design, 10 m^2 device with 100 μm & 200 μm pitch sensor
  - NIEL Radiation level modest 1×10^{13} 1 MeV n_{eq}/cm^2/year at upgrade



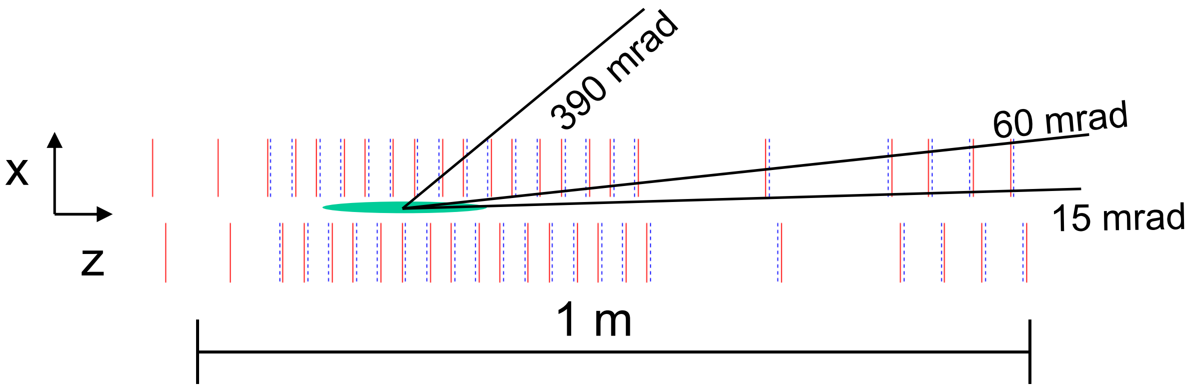
Radiation Hard Vertex Locator

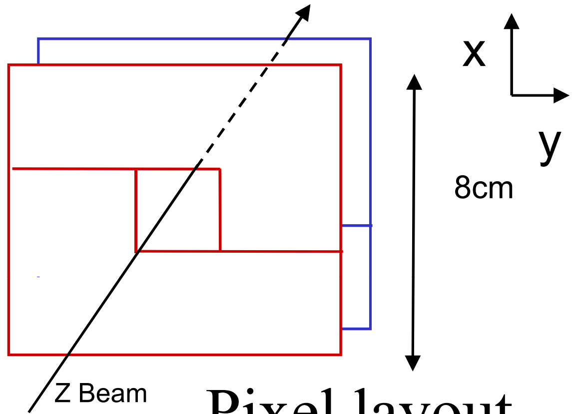


Active Silicon only
8mm from LHC beam

- Upgrade Requires high radiation tolerance device

- Strixels / Pixel layout
  - All leading RD50 technologies considered
  - n-on-p, MCz, 3D

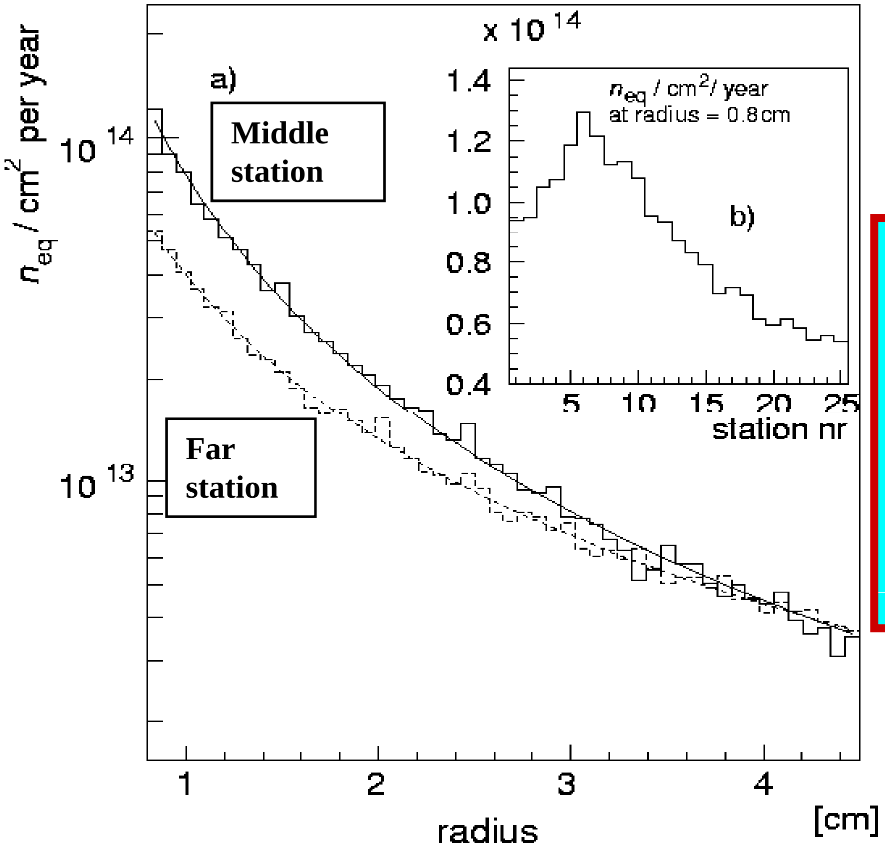




Pixel layout

Harsh Radiation Environment

- LHCb VELO will be ***HOT!***



- Maximum Fluence of current detector
  - NIEL 1.4 * 10^{14} MeV n_{eq}/cm^2/year
- Strongly non-uniform
  - dependence on $1/r^2$ and station (z)

VESPA requirements:
- ~ 10 times luminosity
- ~ 10 times the dose
- ~ 10^{16} n_{eq}/cm^2 charged particle tolerance

Approach 1 – Enhanced VELO

- Reduce inner active radius to approx 5.5 mm (from 8.2 mm)
  - 35 % improvement in impact parameter performance

- Reduced inner pitch of 20-30 microns (giving a resolution ~5-7 microns with analogue readout and 9° incidence).

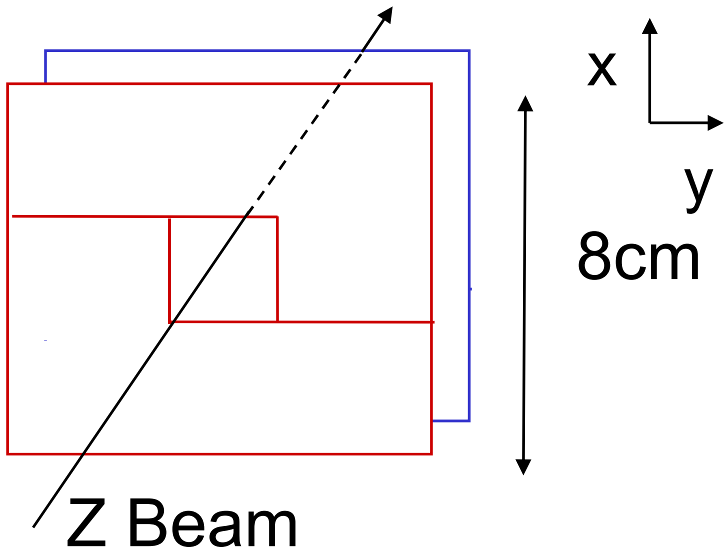
- Reduced strip lengths (4096 strips per sensor), giving an increased S/N of approximately 20% due to the reduction in capacitance (note that the routing lines still provide substantial capacitance)
  - double metal, use MCMD technology ?

- Improved radiation tolerance with the use of shorter strips and a bias chain with greater HV capacity.

- Need new 40MHz read-out front-end chip

- 40MHz readout means processing board can remove FE chip signal spill-over from previous beam crossing

Approach 2 - Pixel layout



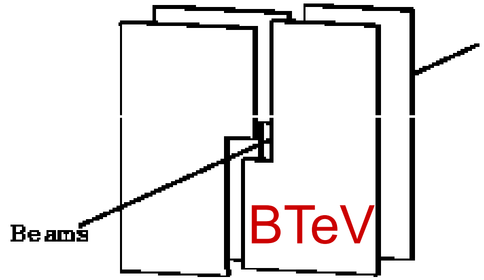
Make use of BTeV design and expertise,
FPix chip designed for 132ns operation at TeVatron

Small pixel size
50 x 400 →50 x 200μm? (follow ATLAS?)
Need two layers per module or one?

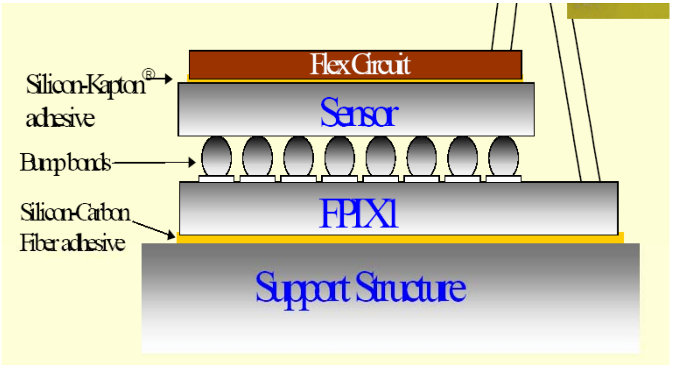
Material – sensor + chip (back thinned) + bumps + cooling

Could have significant advantages for pattern recognition
- Especially if add magnetic field in VELO region

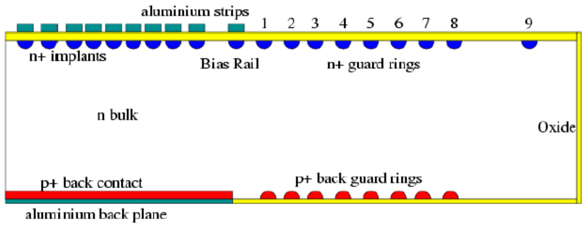
Strips or Pixels?



- Both potentially radiation hard
- Pixels better pattern recognition properties
  - Not major problem (Velo trk eff 97.3%, ghosts 2.3%)
  - But could be major trigger advantage
- Require approx. 50 μm^2 pixels
  - Achieve same resolution as Velo



- Strip geometry more `natural'
  - Tesselate, strixels
  - Smaller number of read-out channels
  - But if you can read-out the pixels who cares ?
- Material
  - Less pixel layers (not R/Phi)
  - Detector, Chip and services (cooling)
    - X_0 per layer 1.2% (BTeV), 1.7% (CMS), 1.8% (ATLAS)
    - Thin electronics, typically 500μm, achieve <200μm

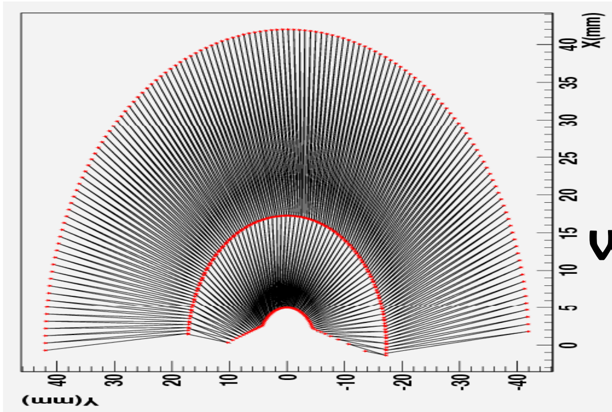


Move closer

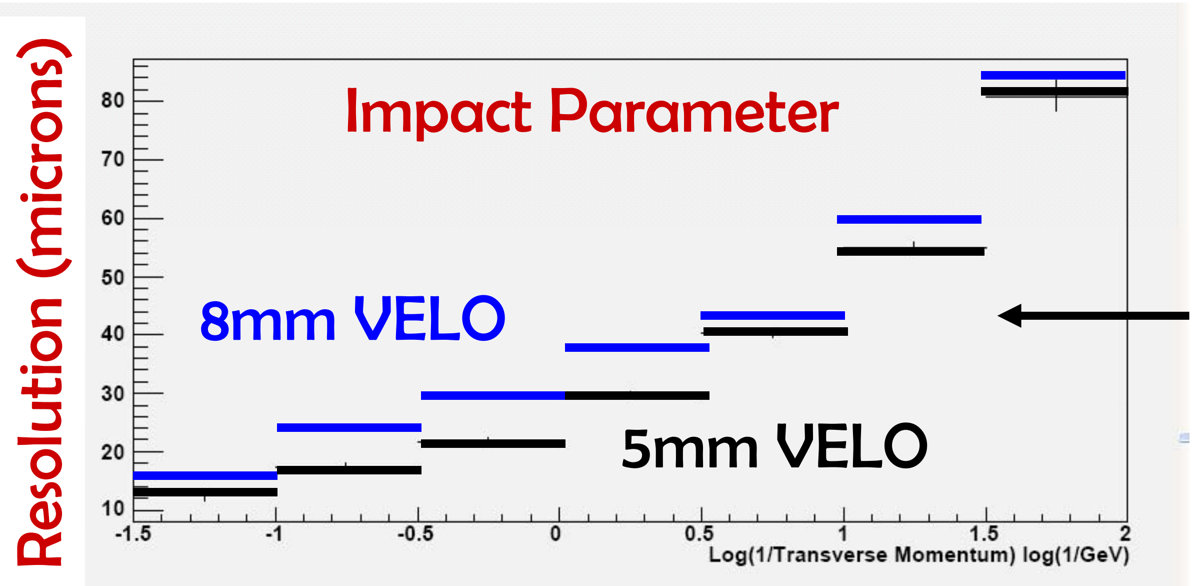
5mm limit from Accelerator

- Current safe guard ring design 1mm
- Use Edgeless technology?
  - Dope edges
  - etch, laser cut

Baseline first strip 8mm
7.1mm 10% improvement in IP

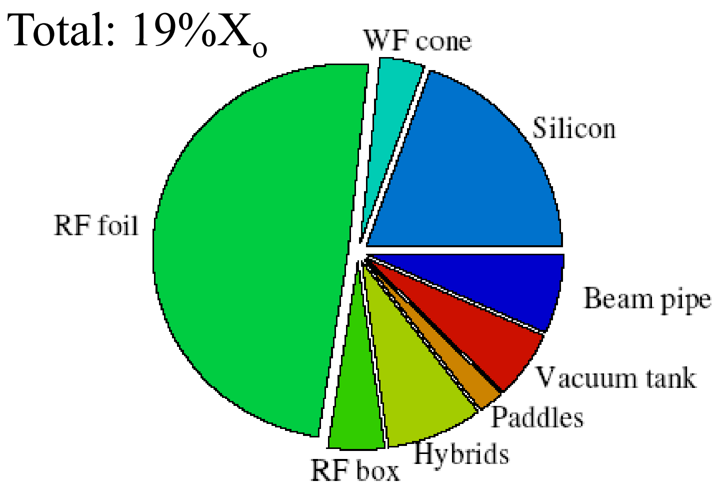


E-VELO
Sensor Design
with 5mm active
radius

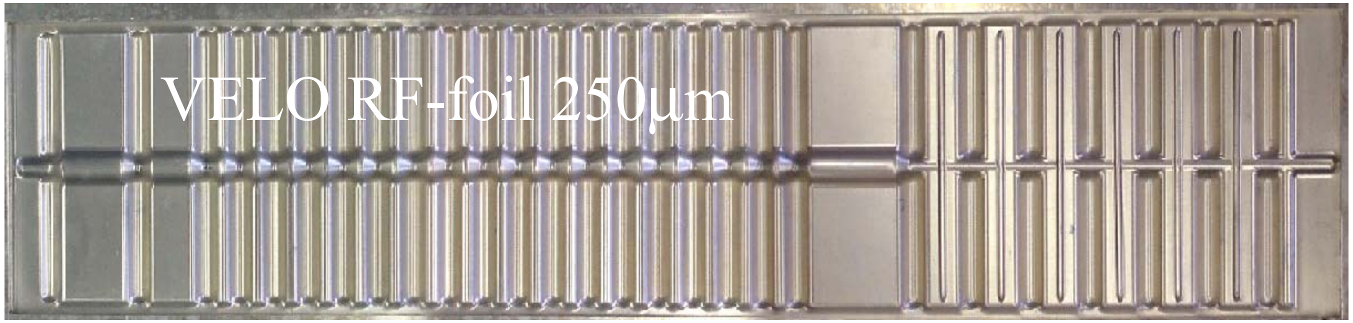


Simulation
- RF foil removed
- VELO Inner radius 5 mm
- 36% improvement.

Material Budget: RF-foil



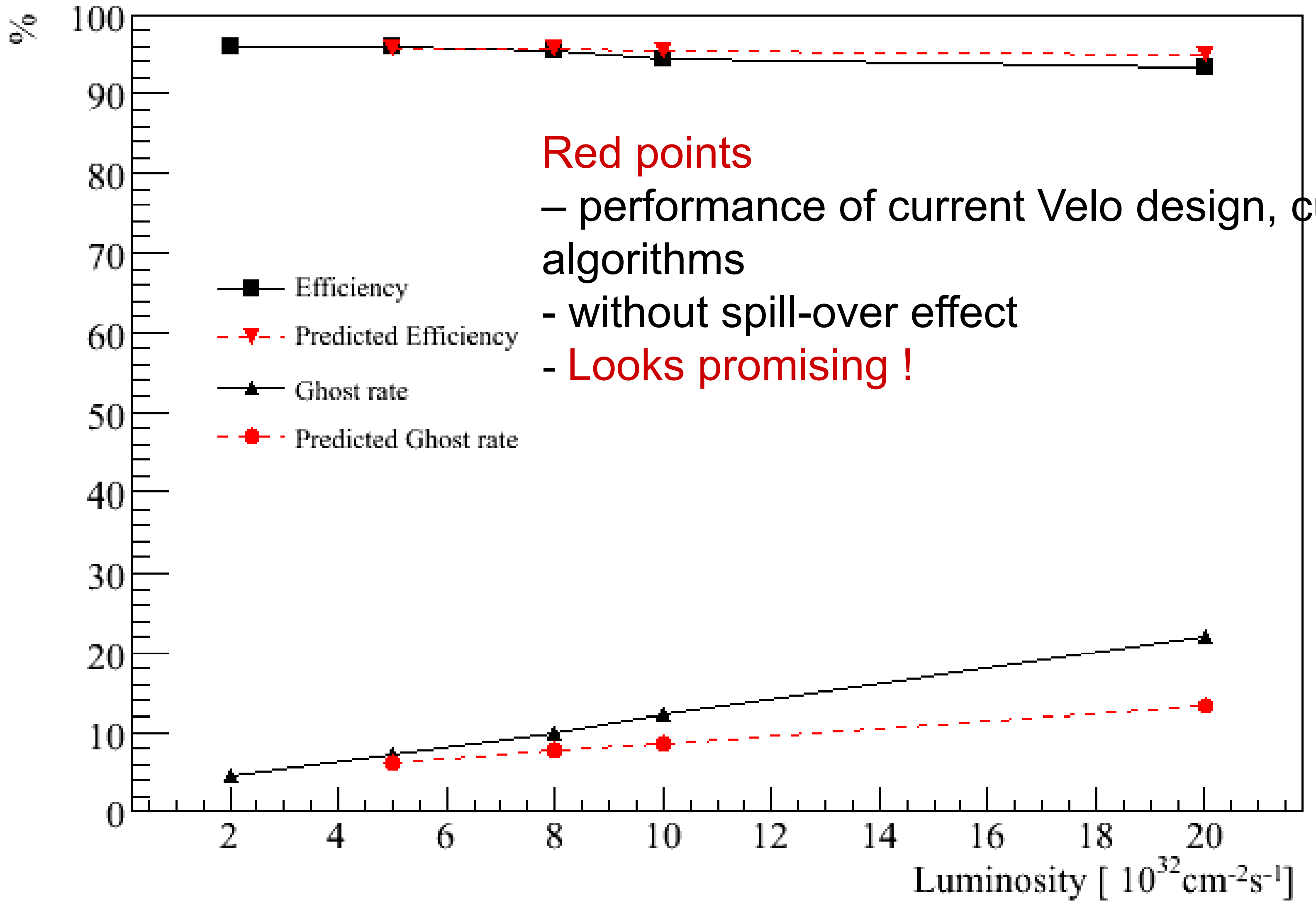
- Velo design has the services mostly outside the acceptance
- Still Silicon is not the main contributor – RF foil
- Could be different for pixels – VELO layers < 30% ATLAS pixel layers



- BTev - 150µm thick wires/foil, 6mm from beam
- In primary vacuum
- Cryo panels for absorb outgassing

- TOTEM
- 1mm from beam (v. diff optics)
- 150µm foil

Velo Tracking Efficiency vs Luminosity



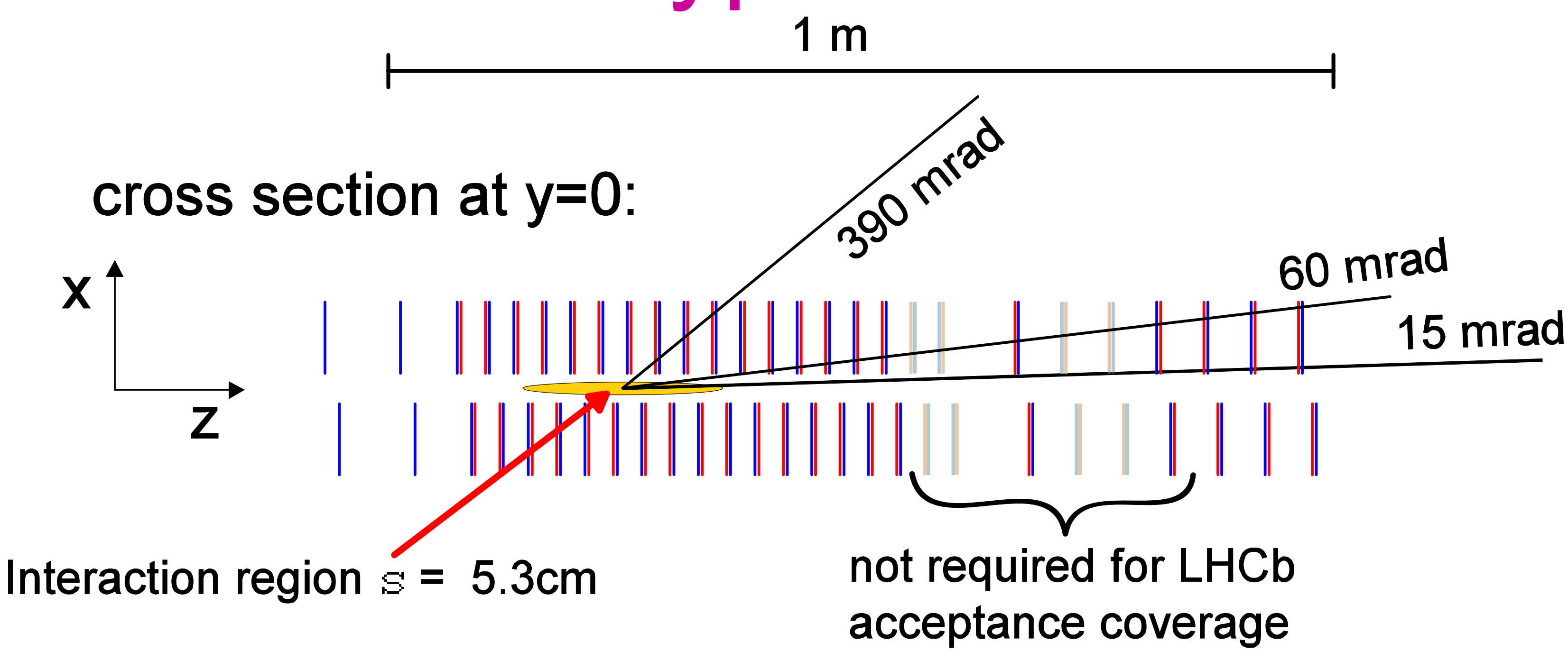
Red points

– performance of current Velo design, current algorithms

- without spill-over effect

- Looks promising !

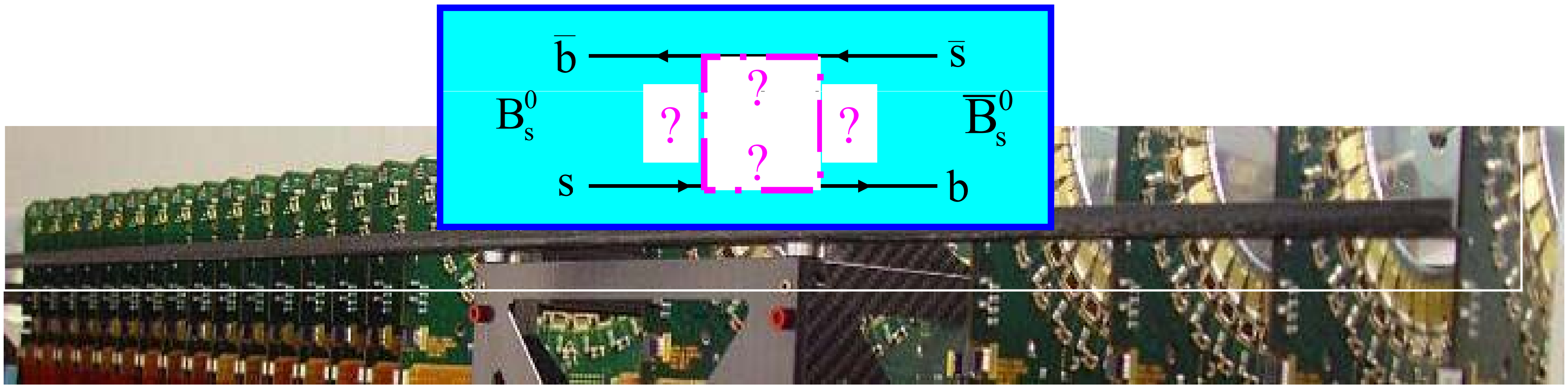
Prototype in LHC !



- Free station slots available
  - Removed during reoptimisation
- Pile-up sensor positions

Upgrade Summary

- Flavour Sector of New Physics
  - Major Physics Programme at modest cost
- Critical Technology
  - Radiation Hard Vertex Detector
    - RD50 Technologies
  - With Displaced Vertex Trigger
- Compatible with but independent of SLHC

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