LHCb Vertex Detector Upgrade Plans

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General Physics Justification for LHCb

- Expect New Physics will be seen at LHC
  - Standard Model is violated by the Baryon Asymmetry of Universe & by Dark Matter
  - Hierarchy problem (why $M_{Higgs} << M_{Planck}$)
- However, it will be difficult to characterize this physics
- How the new particles interfere virtually in the decays of b's (& c's) with W's & Z's can tell us a great deal about their nature, especially their phases

LHCb Upgrade Goals

- Upgrade LHCb detector such that it can operate at 10 times design luminosity of $\mathcal{L} \sim 2 \times 10^{33}$ cm^{-2}s^{-1}
- Accumulate ~100 fb^{-1} without detector replacement
- Maximize sensitivity to many interesting hadronic channels ⇒ fast, efficient, and selective vertex trigger
- Present design luminosity is about a factor of 25 reduced from maximum luminosity that could be delivered to it ⇒This upgrade does not need sLHC but is compatible with it

Why upgrade?

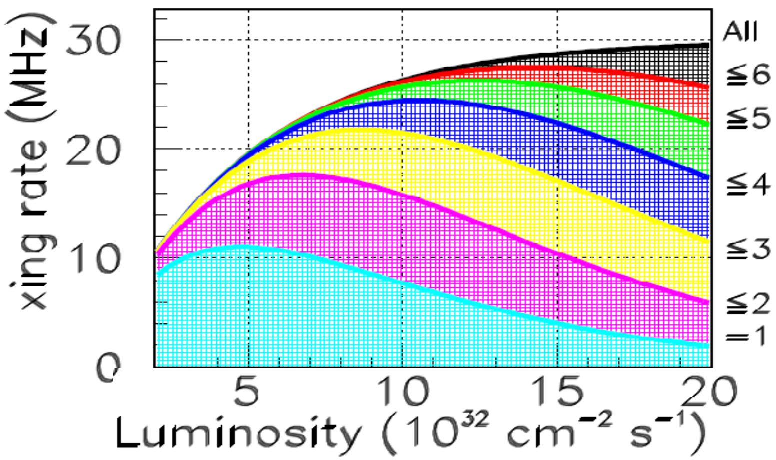
- Determination of new physics effects requires high statistics (~100 fb^{-1})
- For example:
  - Weak mixing phase Φ_s studied through the time dependent asymmetry of flavor tagged $B_s \rightarrow J/\Psi\Phi$ can be determined to an error of 0.003
  - CKM angle γ can be determined with an error of 1°-2° depending upon the channel used
  - Precision studies of rare decays such as $B \rightarrow K^*\mu\mu$
  - Precision studies of CP violation in charm decays

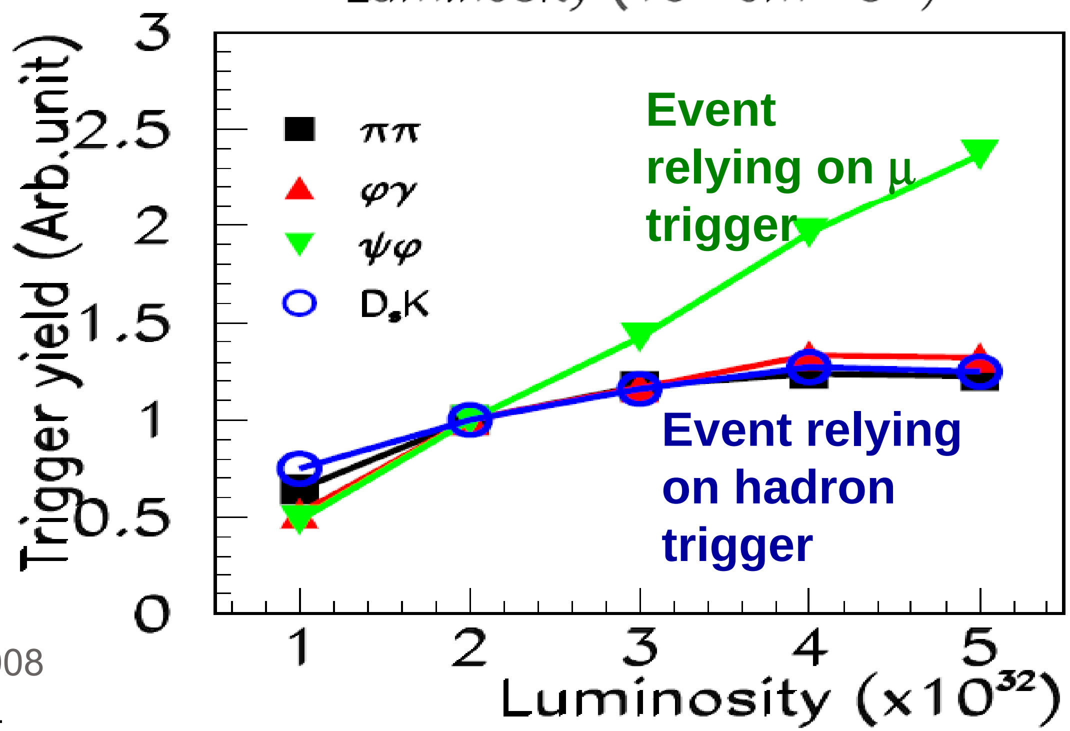
Trigger considerations

- Current L0 trigger:
  - Reconstructs highest E_t hadron, electron, γ & two highest p_t μ
  - Thresholds
    1. $E_T^{hadron} \geq 3.5$ GeV
    2. $E_T^{e,\gamma} \geq 2.5$ GeV
    3. $p_T^{\mu} \geq 1$ GeV
- Even at nominal luminosity #of interactions cut on (1) to stay below the 1MHz L0 rate

  More details in LHCC/2008-007

rate of pp interactions



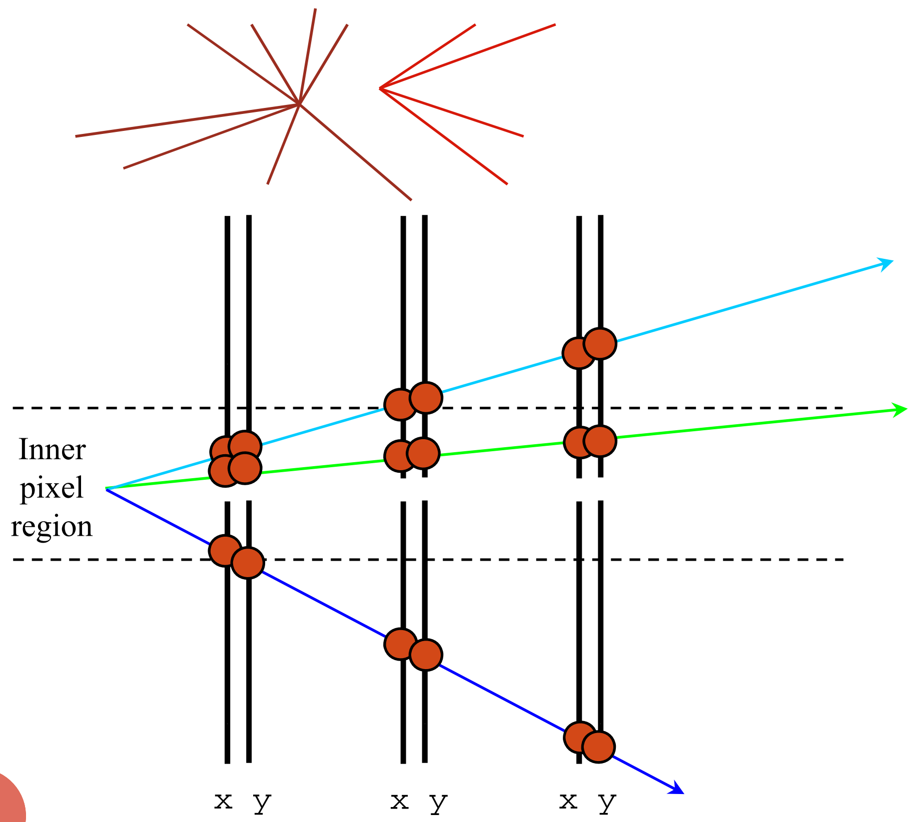


To improve trigger performance on hadronic channels

- Measurement of both momentum and impact parameter of the B decay products
  - → Data read out at 40 MHz ⇔ difficult to find algorithm that is sufficiently selective for hadronic B decays in "real time"
  - → Identify best solution for fast and efficient measurement of momentum and impact parameter of the B hadron
    - ? Modification of present higher level hadronic B selection algorithm
    - ? Vertex detector in B field

Possible Vertex Triggering

◆ Idea: find primary vertices & detached tracks from b or c decays



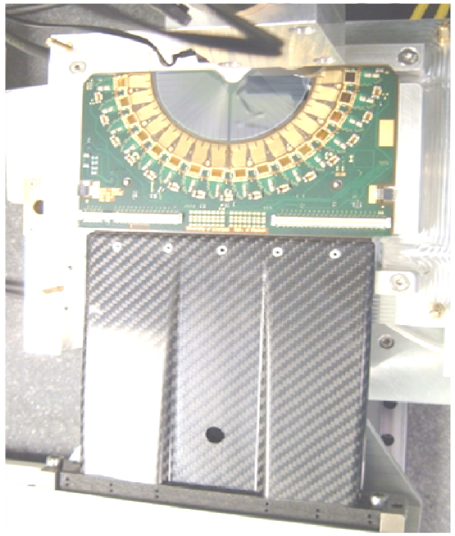
- Pixel hits from 3 stations are sent to a tracker that matches "interior" and "exterior track hits
- Interior and exterior triplets are sent to a CPU farm to complete the pattern recognition:
  - interior/exterior triplet matcher
  - fake-track removal
- *See E. Gottschalk, Nucl.Phys.Proc.Suppl. 156, 252 (2006).*

Vertex detector requirements

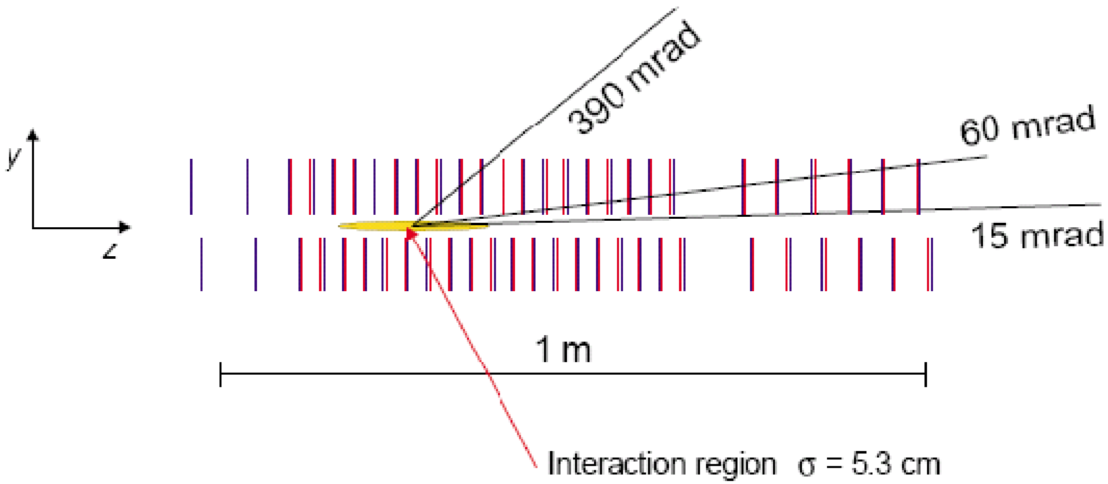
- Radiation resistance ($\sim 10^{16}$ 1 MeV n_{eq} /cm^2)
- 40 MHz readout: time stamp and information transferred to buffers synchronized with BCO
- Fast and robust pattern recognition capabilities $\Rightarrow$ detached vertex criteria almost "in real time"
- Optimization of impact parameter resolution
  - Reduce detector inner radius
  - RF foil modifications
- Material minimization for chosen solution

Velo now

- rφ strip detector with variable pitch:
  - tradeoff between number of channels and resolution
  - Quick rz tracking for triggering purposes
- Radiation dose up to 1.3×10^{14} 1 MeV n_{eq}/year ($2fb^{-1}$)



VELO Module



Length determined by goal of matching full LHCb η coverage

Velo after ~3 years of operation

- Looks the same!
- Replacement of modules with sensors built on p-type substrates: first full scale sLHC type silicon detectors!
- EVELO concept of upgraded detector based on this system:
  - Reoptimization with smaller strip length, smaller inner pitch, rad-hard bias…

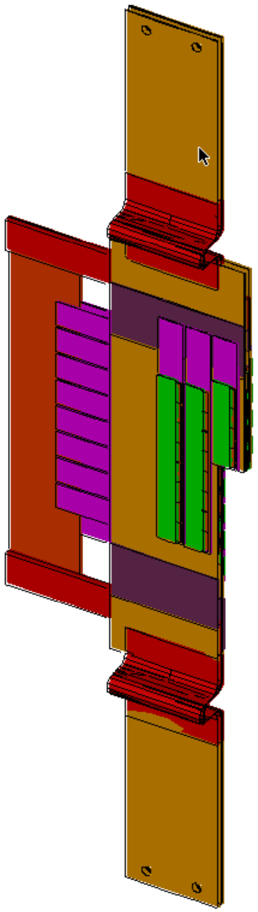
From VELO

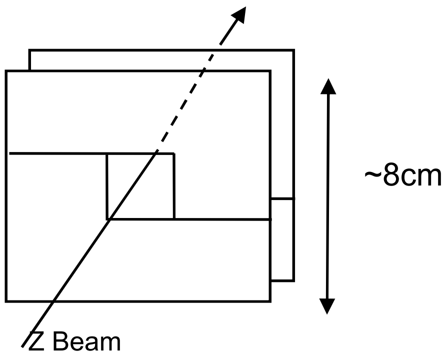
To VESPA

REQUIREMENTS

- radiation tolerance corresponding to an integrated luminosity of $\mathcal{O}(100 fb^{-1})$
  ($\sim 10^{16}$ 1 MeV n_{eq} /cm^2)
- Close coupling with trigger for optimal hadron trigger algorithm.
- Optimal spatial resolution
- Secure technology

A very promising option for VESPA: hybrid pixel devices





- Measurement of 3D space points, with very few additional noise hits, implies excellent pattern recognition capabilies:

  ⇒Fast vertex reconstruction

•Optimal radiation resistance (⇒inner detector in ATLAS & CMS):

•Allows operation with smaller r_{min} & higher luminosity without replacement for the duration of the experiment

•Low noise (~200 e^- @ 25 ns) allows more precise charge interpolation & (in principle) thinner detectors.

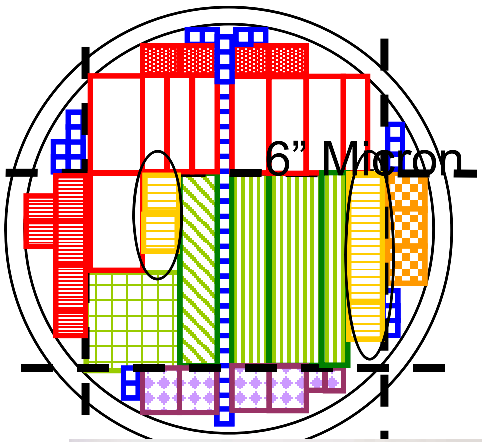
R&D activities - sensors

- Substrate material to ensure maximum radiation resistance (in collaboration with RD50):
  - p-type substrates
  - Magnetic Czochralski
- Alternative considered
  - 3D sensors

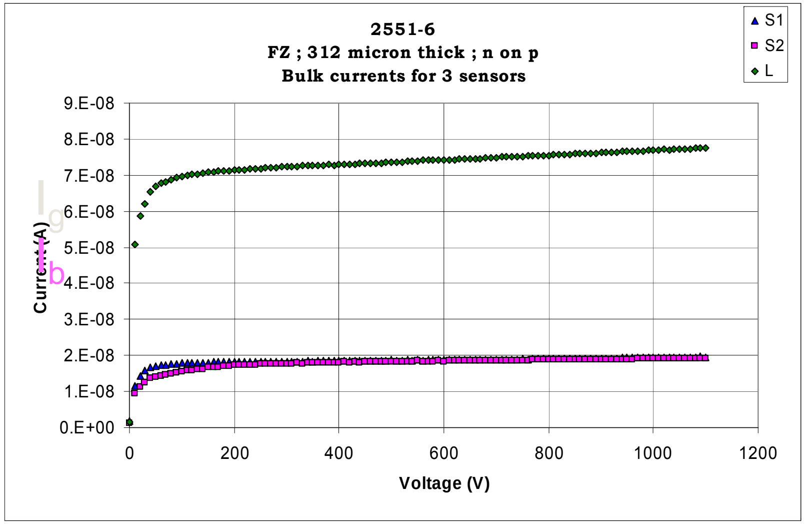
See also G. Casse & C. Parkes contributions

University of Glasgow, University of Liverpool, Syracuse University working in the RD50 framework

n-on-p pixels



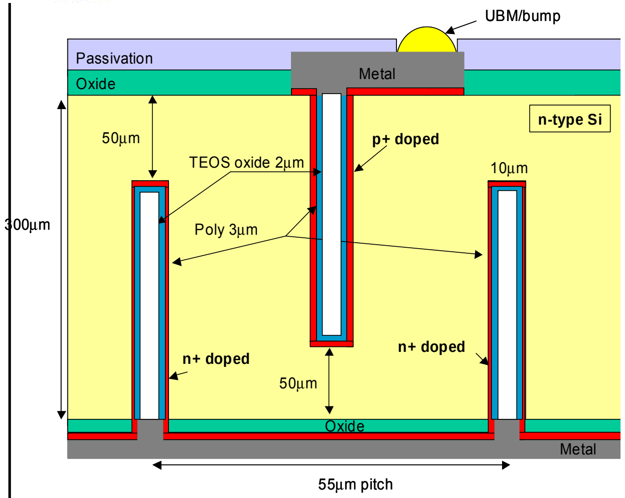
Syracuse/RD50 p-type "BTeV style" single chip pixel devices fabricated by Micron Semiconductor

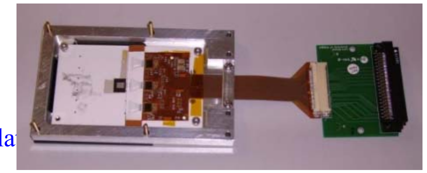


Depletion voltage 20-80 V unirradiated
Started examining performance of irradiated detectors

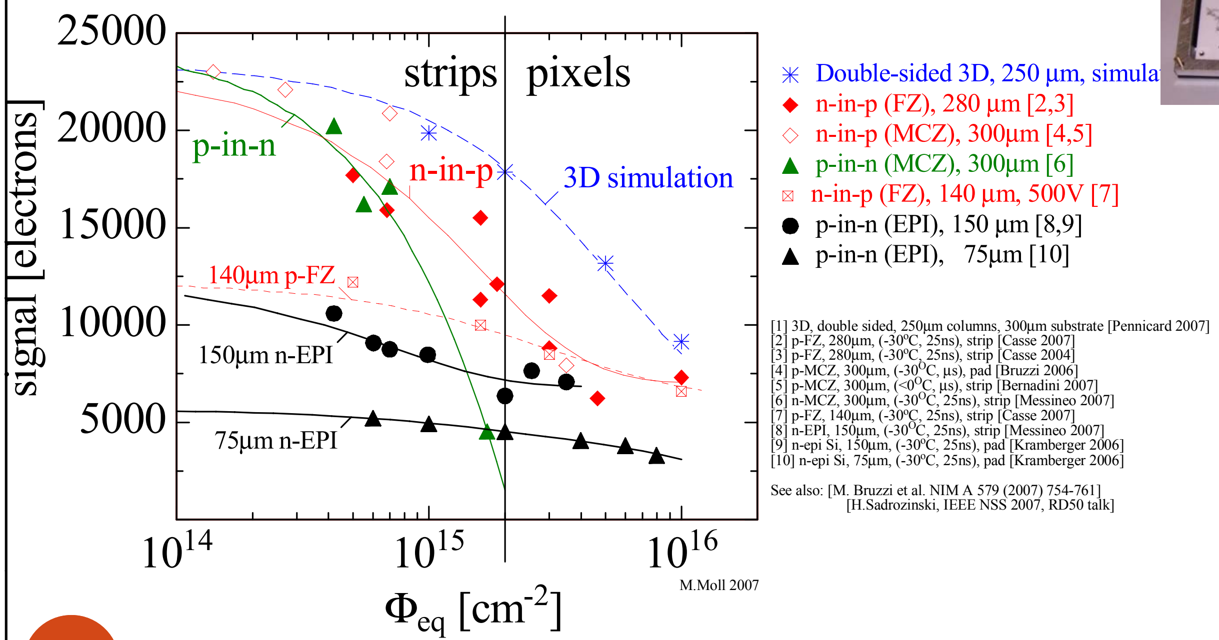
3D Detectors

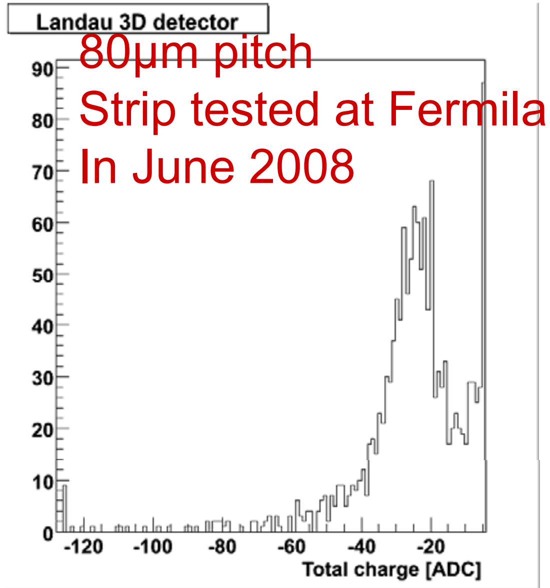
- 3D Detectors provide extreme rad hard solution
  - novel double sided processing
- Glasgow/CNM produced strip and pixel detectors
  - See talk from C.Parkes
  - Pixel devices with ATLAS/BTeV pixel chip geometry in production





Strip device readout with LHCb electronics software





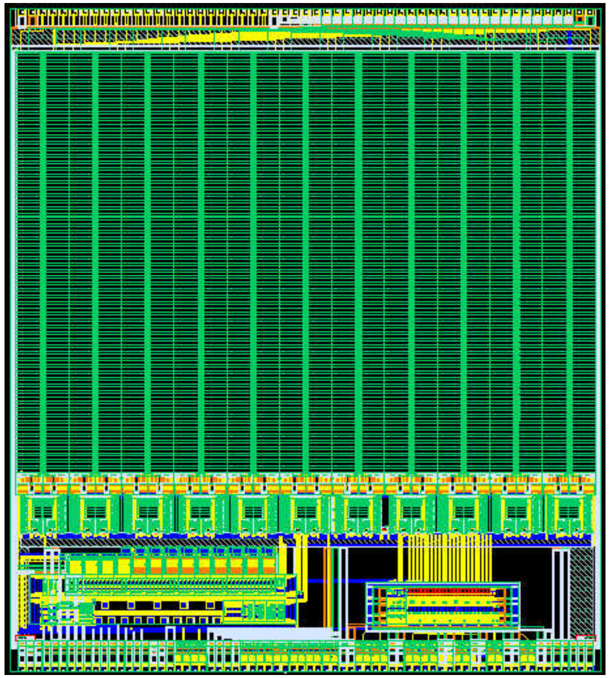
80µm pitch
Strip tested at Fermilab
In June 2008

Front-end electronics

- Must provide digitized data to trigger processor in real time:
  - On chip sparsification
  - On chip digitization
  - Push data to storage buffer within a beam crossing
- New smaller feature size technologies may allow smaller pixel size or higher spatial resolution

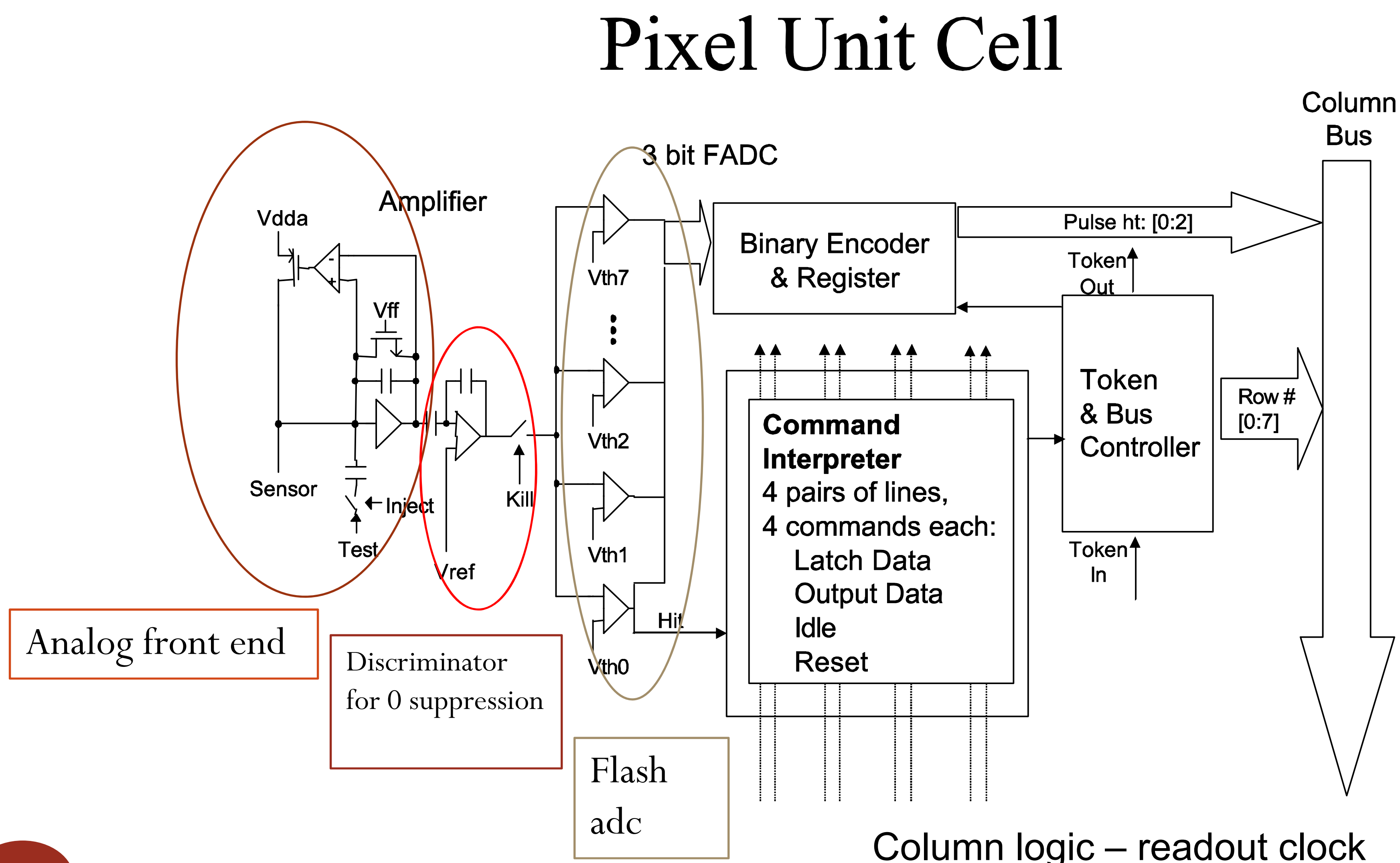
An interesting prototype

FPIX2



- 128X22 pixel electronics array with 1 flash ADC per cell providing sparsified hit information
- Tested with protons up to 87 Mrad with no degradation in analog performance and only minor changes required to bias conditions.
- Digital cells insensitive to total dose.
- No latch-up, no gate rupture.
- Single event upset cross sections measured, typically < 10^{-15} cm^{-2} per bit.
- R&D Issues:
  - Data push speed
  - Timing parameters of the analog front-end
  - Match to optimized VESPA sensor
  - Migration to rad hard technology of the next decade

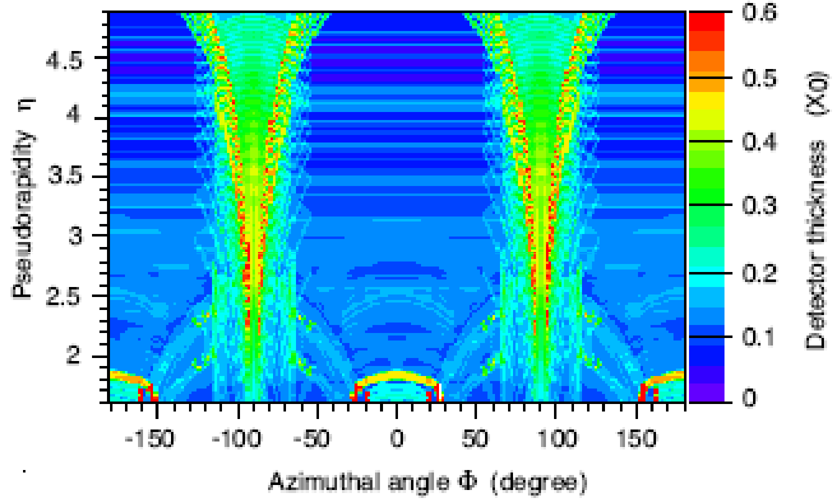
Single cell readout & relevant times

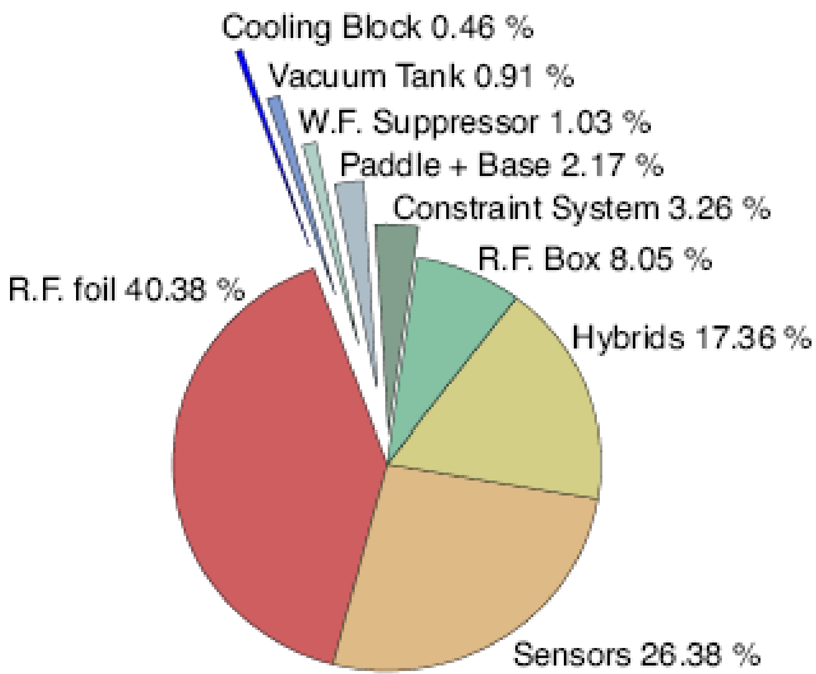


Material budget optimization

- Relative contribution of the main components of the VELO to the average X_0 of particles traversing the VELO in the range $2.0 < \eta < 4.2$ is dominated by RF foil.
  - NIKHEF R&D on alternative RF design with less material

VELO now (see M. Tobin's talk)



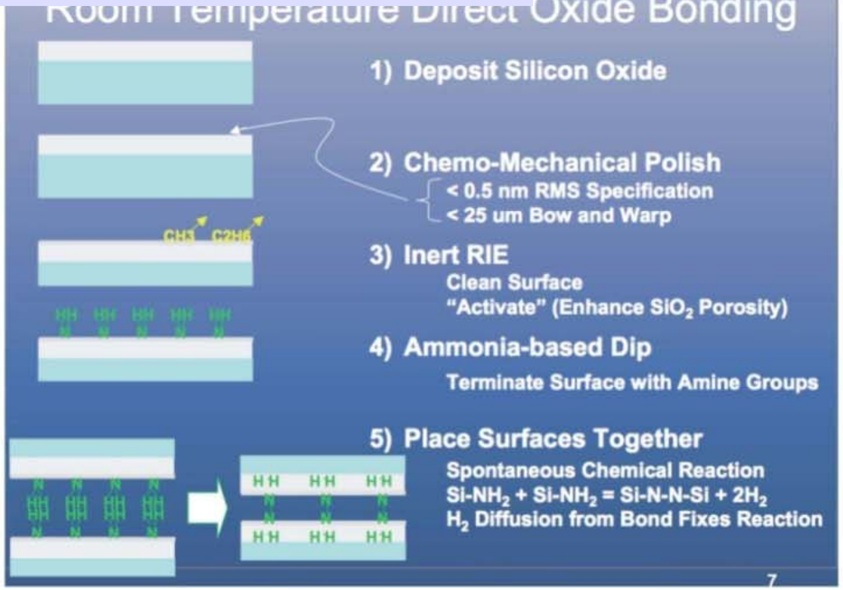


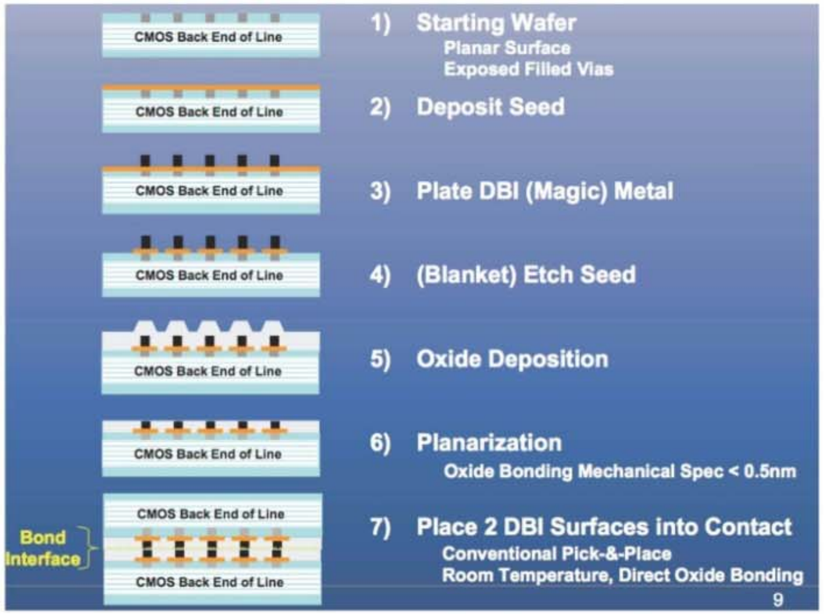
Thin modules

•VELO Silicon budget is purely sensor, pixel solution includes front end electronics comparable with new approaches of 3D integration of thinner sensor/electronics assemblies

- In collaboration with Fermilab 2 approaches with Ziptronics & Tezzaron (more from G. Deptuch)
- European efforts with IZM
- Prototype devices with 100 μm sensor/electronics

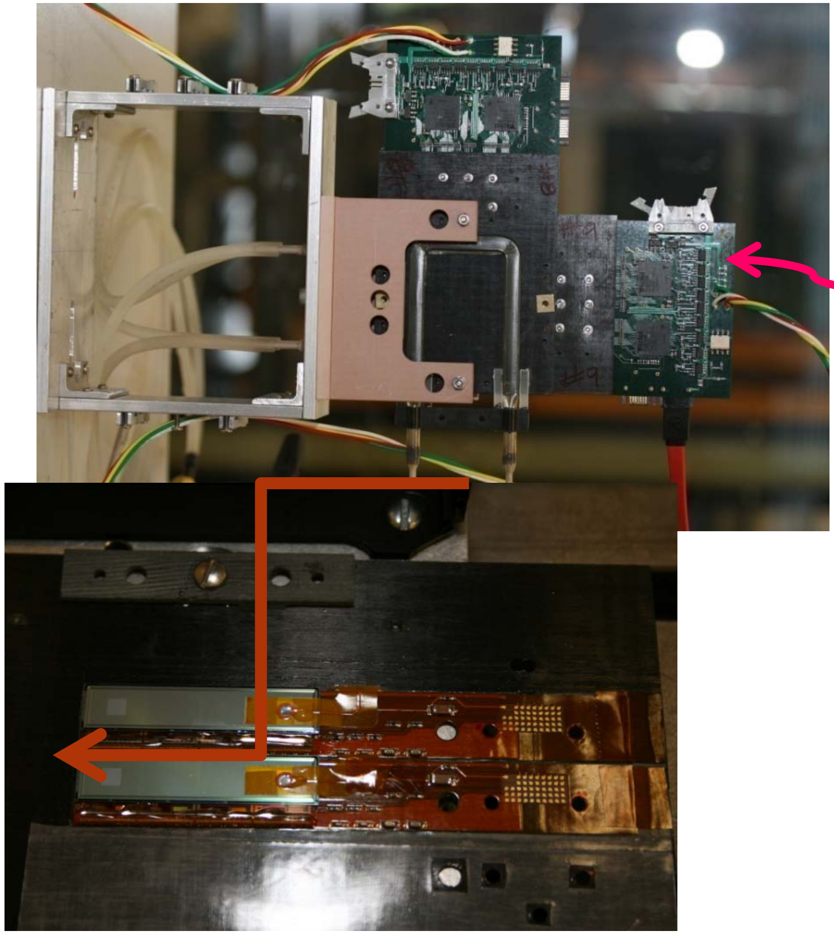
Ziptronix direct oxide bonding process





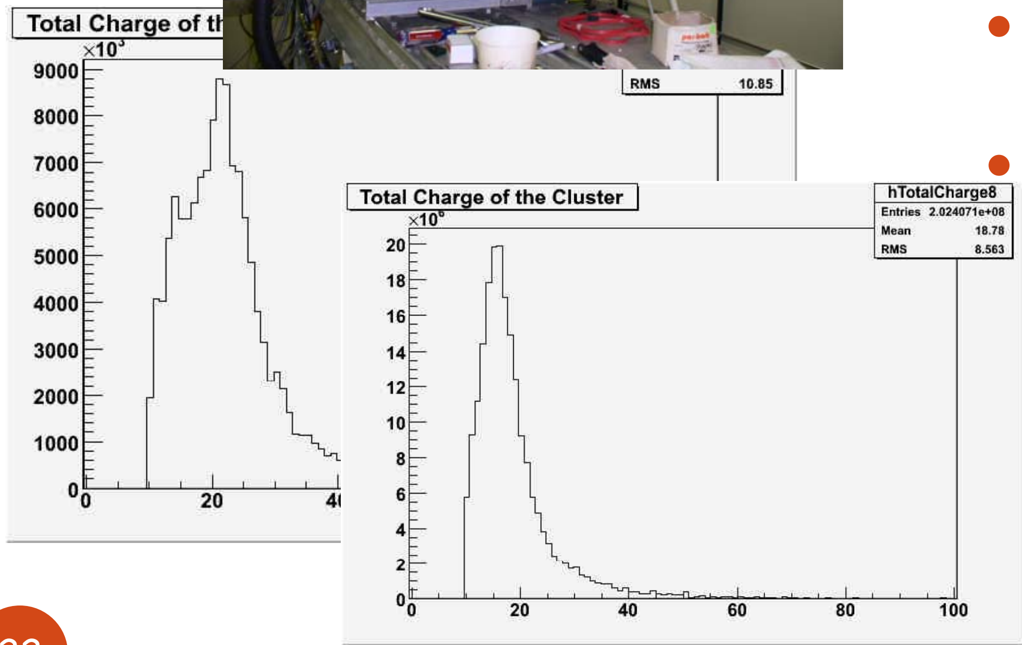
Next steps

Large acceptance pixel telescope [3.5 cm x 3.5 cm aperture (270k pixels)]



- Detailed simulation to optimize system geometry
- Choice of sensor technology
- Study to determine the front end specifications (filtering properties, sparsification, flash ADC resolution, preferred technology)
- Intense test beam program utilizing pixel telescope facility at Fermilab Mtest (starting with T-971 which took the first data set in June 2008, only 3 pixel planes operational, follow up run with full pixel telescope planned for later this year)
- RF shield design
- TDR planned for 2010

Sneak preview June FNAL test beam



- Tested 2 r sensitive VELO modules with non uniform level of irradiation, one fabricated with p-type technology & the other with n-type technology
- Some data with 3 pixel planes
- Soon: charge collection studies as a function of the radiation dose

Next run with 4 fully functional pixel planes.

Conclusions

- Quest for new physics discovery requires the ability to detect small deviations from the Standard Model predictions ⇒ VERY large samples of beauty and charm decays need to be collected.
- LHCb is poised to start soon the first phase of its program (integrated luminosity ~10 fb^{-1}) & is planning the next phase
- R&D items for the VERTEX detector:
  - Sensor optimization (segmentation & technology for optimum radiation hardness & fast and robust pattern recognition)
  - New front end electronics architecture and technology
  - New RF shield