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 $M_{\text{Higgs}} \ll M_{\text{Planck}}$)
- 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 $\mathcal{L} \sim 2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$
- Accumulate $\sim100 \text{ fb}^{-1}$ 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 \(\Phi_s\) 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 \(\gamma\) 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, $\gamma$ & two highest $p_T \mu$
  • 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

Marina Artuso Vertex 2008
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 $\iff$ 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

Vertex detector requirements

- Radiation resistance ($\sim 10^{16} \text{ 1 MeV } n_{\text{eq}} / \text{cm}^2$)
- 40 MHz readout: time stamp and information transferred to buffers synchronized with BCO
- Fast and robust pattern recognition capabilities
  ⇒ 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

- $r\phi$ strip detector with variable pitch:
  - tradeoff between number of channels and resolution
  - Quick rz tracking for triggering purposes
- Radiation dose up to $1.3 \times 10^{14}$ 1 MeV n$_{eq}$/year (2 fb$^{-1}$)
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 $\mathcal{L}(100\text{fb}^{-1})$ ($\sim 10^{16}$ 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 capabilities:
  - Fast vertex reconstruction

- Optimal radiation resistance (inner detector in ATLAS & CMS):
  - Allows operation with smaller $r_{\text{min}}$ & higher luminosity without replacement for the duration of the experiment
  - Low noise ($\sim 200 \text{ e}^- @ 25 \text{ ns}$) 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 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

Double-sided 3D, 250 μm, simulated ! [1]
● n-in-p (FZ), 280 μm [2,3]
● n-in-p (MCZ), 300μm [4,5]
▲ p-in-n (MCZ), 300μm [6]
★ n-in-p (FZ), 140 μm, 500V [7]
● p-in-n (EPI), 150 μm [8,9]
▲ p-in-n (EPI), 75μm [10]

[1] 3D, double sided, 250μm columns, 300μm substrate [Pennicard 2007]
[p-EPI, 150μm, (-10°C, 25ns), pad [Kramberger 2006]
[n-EPI, 75μm, (-3°C, 25ns), pad [Kramberger 2006]

See also: [M. Bruzzi et al. NIM A 579 (2007) 754-761]
[H.Sadrozinski, IEEE NSS 2007, RD50 talk]
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

- 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

Pixel Unit Cell

- Analog front end
- Discriminator for 0 suppression
- Flash adc

Binary Encoder & Register

Command Interpreter
- 4 pairs of lines
- 4 commands each:
  - Latch Data
  - Output Data
  - Idle
  - Reset

Token & Bus Controller

Column logic – readout clock
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