LHCb Upgrade Plans

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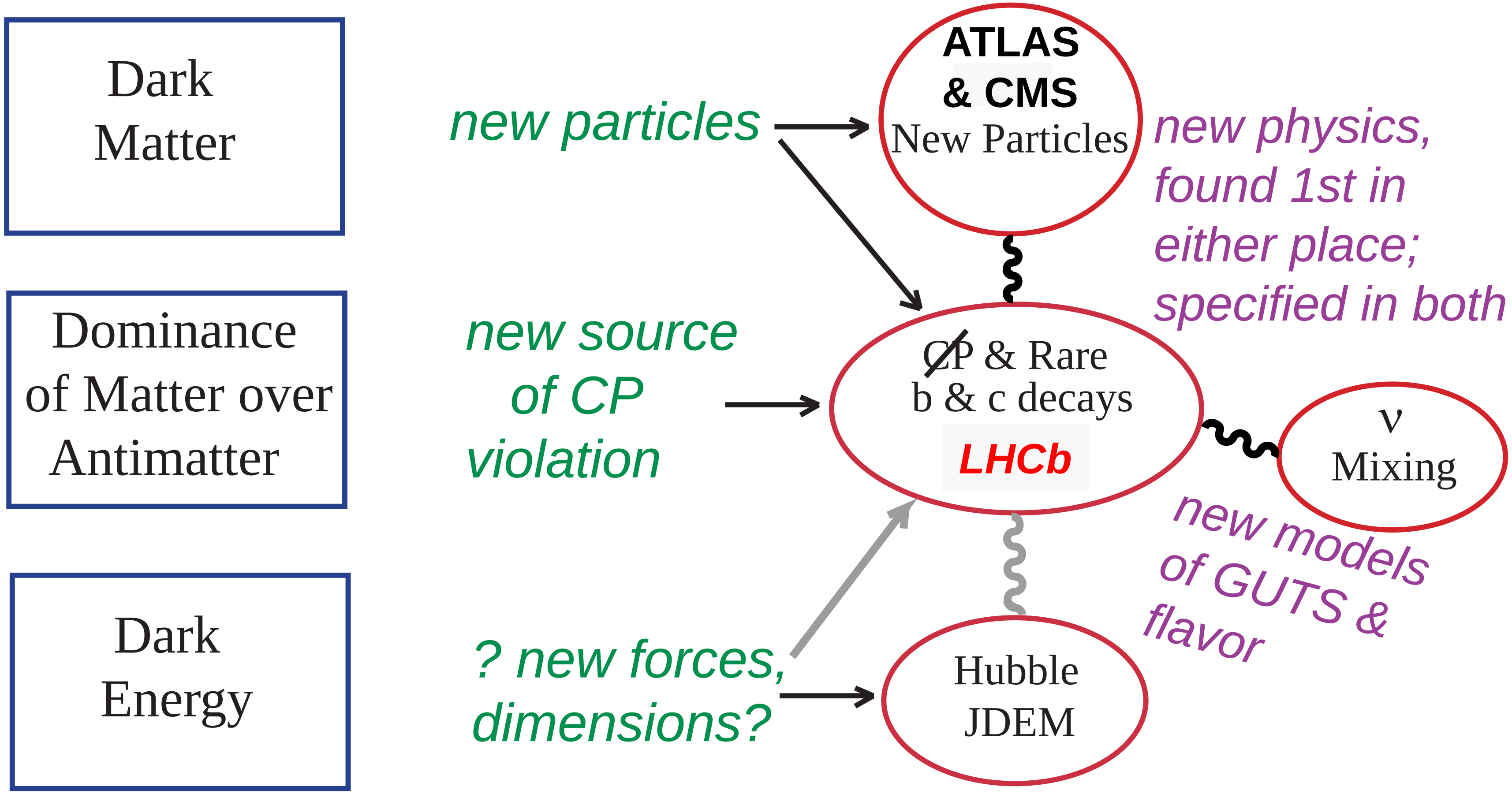
For the LHCb VELO Group

The Physics Landscape at the dawn of LHC

Mysteries

Solutions:
New Physics



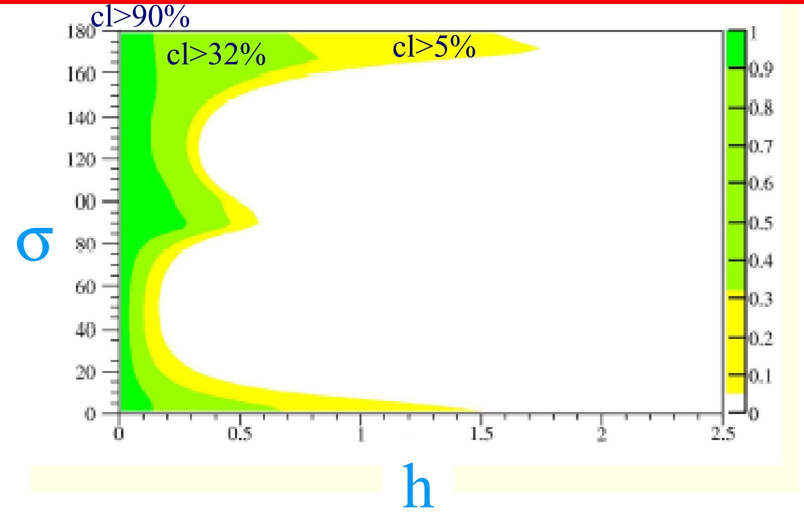
General Physics Justification for LHCb

- Expect New Physics will be seen at LHC
  - Standard Model is violated by the Baryon Asymmetry of Universe & by Dark Matter
  - Hierarchy problem (why $M_{Higgs} \ll M_{Planck}$)
- 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

Limits on New Physics From B^o

"Next to minimum flavor violation"

- Is there NP in B^o-$\bar{B}^o$ mixing?
- Assume NP in tree decays is negligible
- $$1+he^{i\sigma}=\frac{\langle B^o|H^{full}|\bar{B}^o\rangle}{\langle B^o|H^{SM}|\bar{B}^o\rangle}$$
- Use V_{ub}, A_{DK}, $S_{\psi K}$, $S_{\rho\rho}$, Δm_d, A_{SL}
- Fit to η, ρ, h, σ

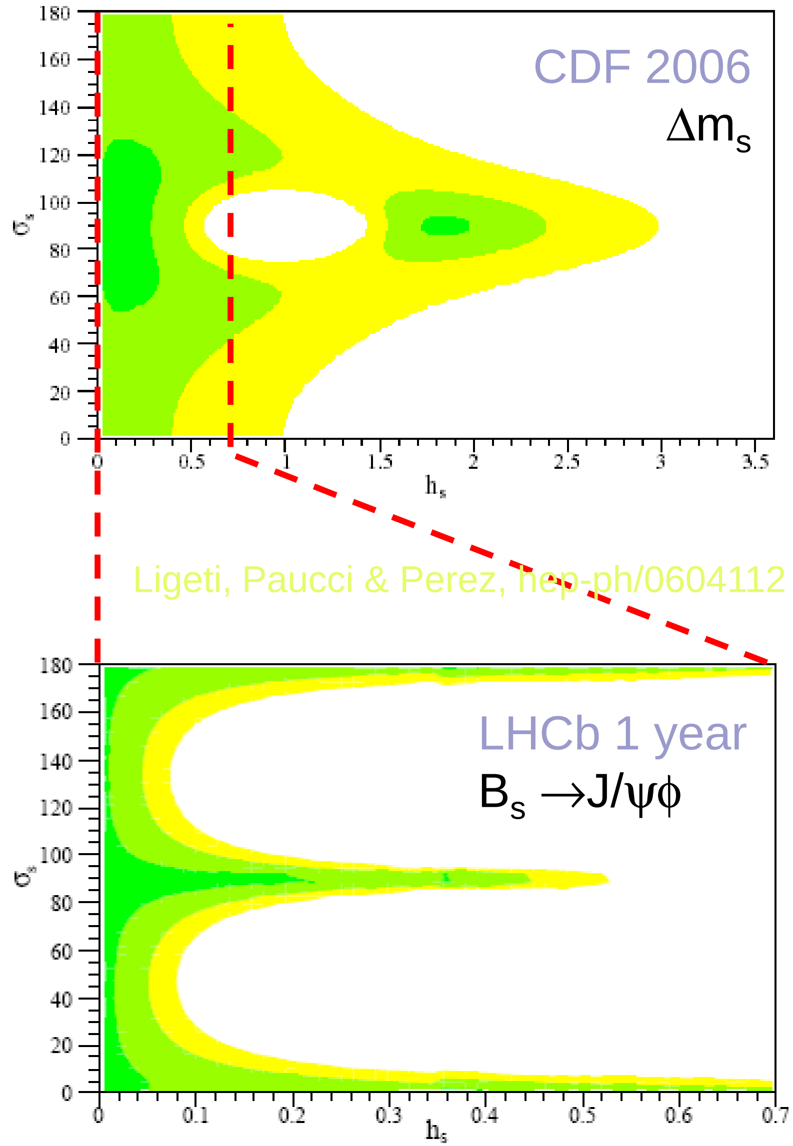


Agashe, Papucci, Perzez, Pirjol hep-ph/0509117

- For New Physics via B_d^o mixing, h is limited to ~<0.3 of SM except when σ_{Bd} is ~0° or ~180° of SM decays

Limits on New Physics From B_S

- Similar study for B_S decays including ΔM_S measurement from CDF
- Limits much weaker since phase in B_S mixing (ϕ_S) is yet to be measured



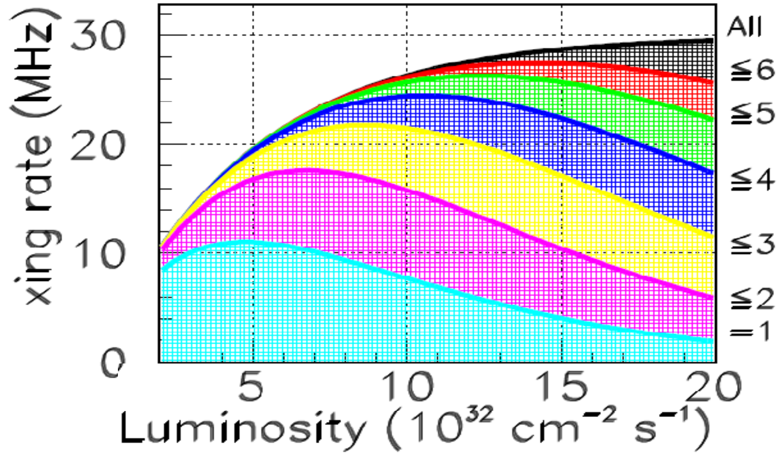
LHCb Upgrade Goals

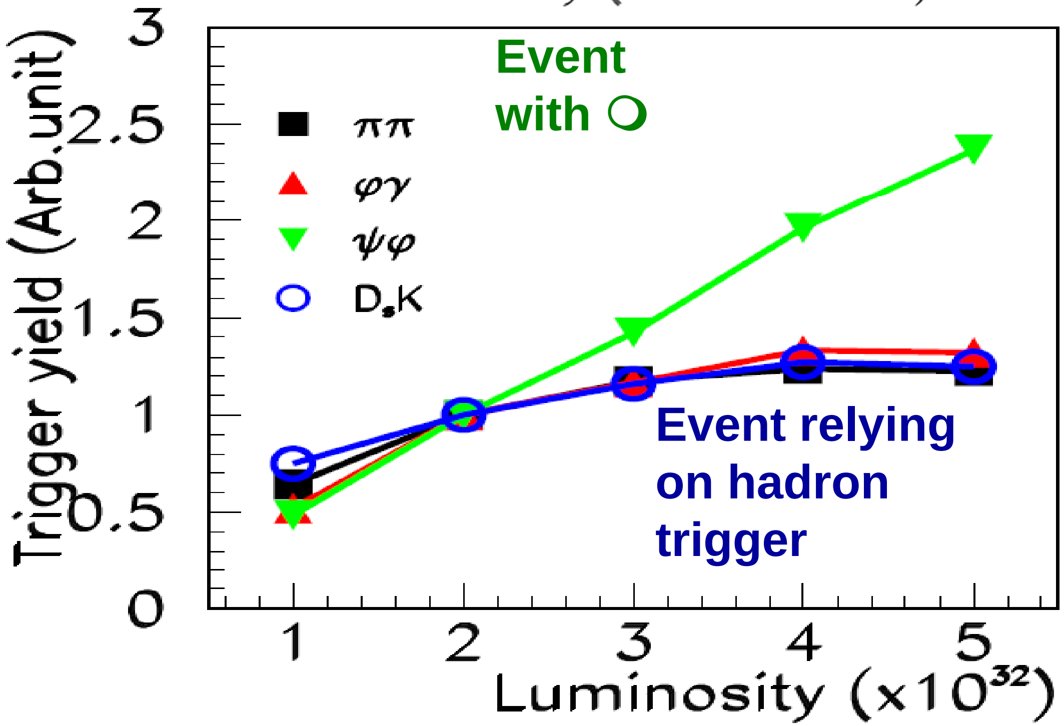
- Upgrade LHCb detector such that it can operate at 10 times design luminosity of $\mathcal{L} \sim 2 \times 10^{33}\ cm^{-2}s^{-1}$
- Accumulate ~100 fb^{-1} without detector replacement
- Maximize sensitivity to many interesting hadronic channels ⇒ vertex trigger at L0
- This upgrade does not need sLHC but is compatible with it

Trigger considerations

- Current hadron trigger yield saturates at a luminosity of ~ $2x10^{32}cm^{-2}s^{-1}$
  - →Perform trigger processing in CPU farm (possibly with intermediate levels of sophistication)
  - →Use displaced vertex information in the first trigger decision
- Develop tracking algorithms suitable for higher occupancy environments especially at high η

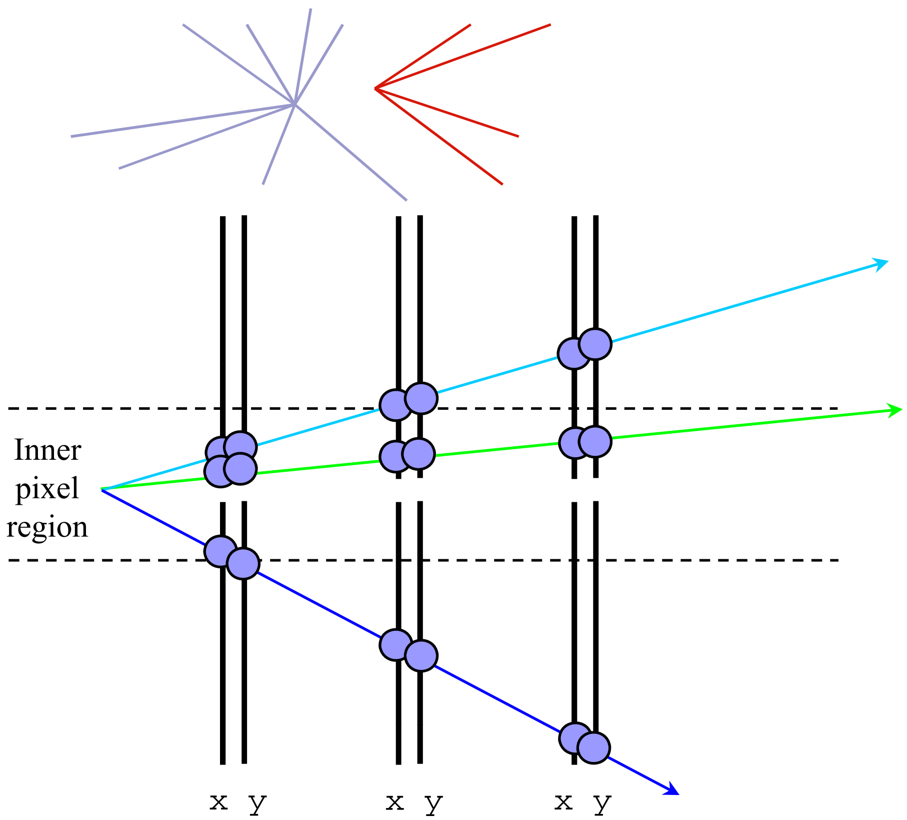
rate of pp interactions





Possible Vertex Triggering

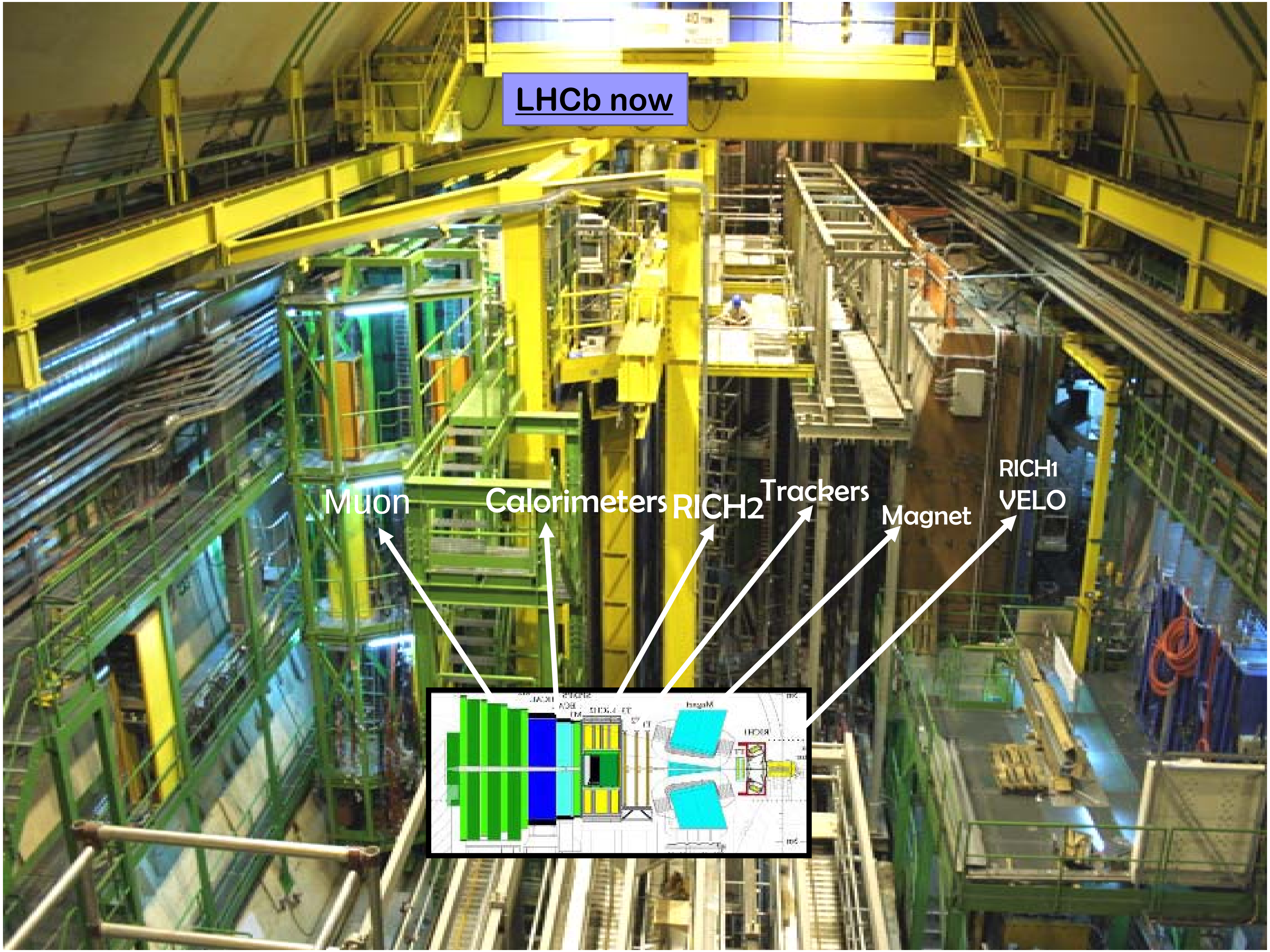
◆ Idea: find primary vertices & detached tracks from b or c decays



- Pixel hits from 3 stations are sent to an FPGA 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).*

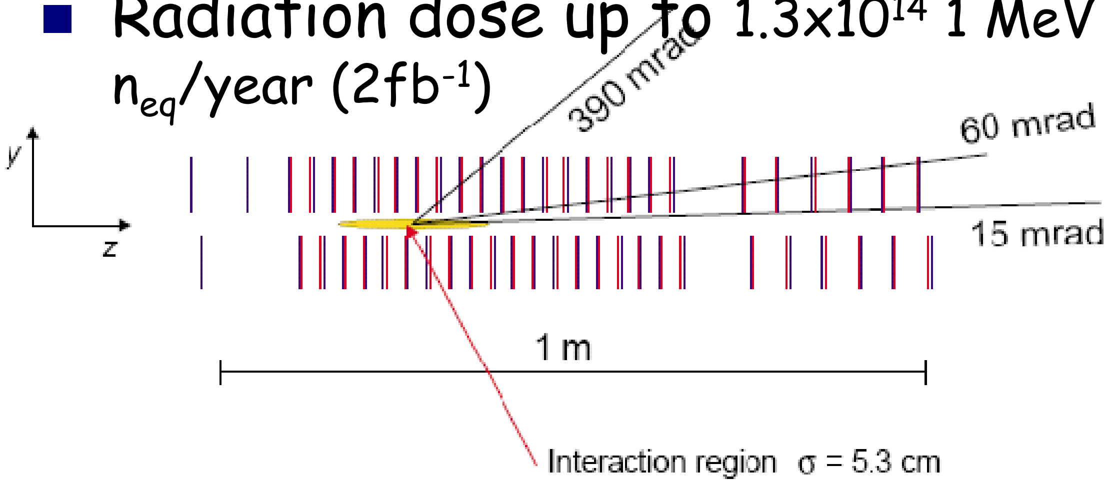
Impact on vertex detector requirements

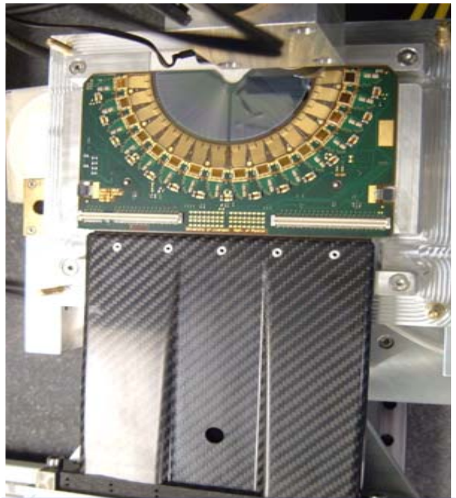
- Radiation resistance (~ 10^{16} 1 MeV n_{eq} /cm^2)
- Fast and robust pattern recognition capabilities ⇒ detached vertex criteria at the lowest trigger level
- Optimization of impact parameter resolution
  - Reduce detector inner radius
  - RF foil modifications
- Material minimization for chosen solution


LHCb now
Muon
Calorimeters
RICH2
Trackers
Magnet
RICH1
VELO

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 ($2fb^{-1}$)

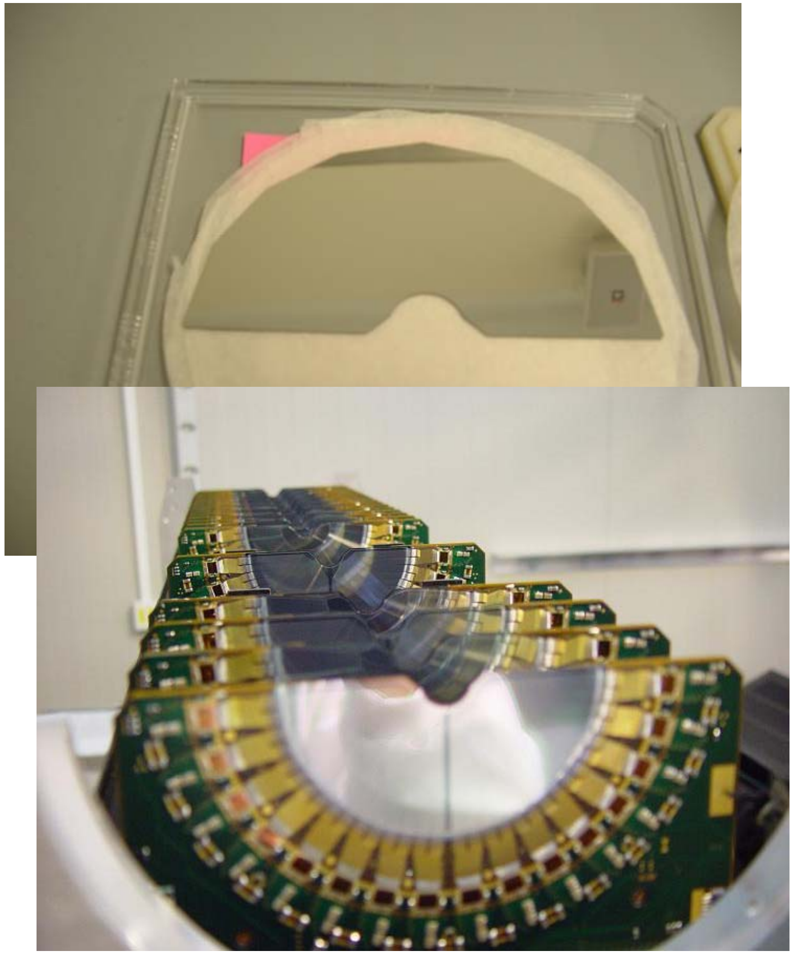




VELO Module

Length determined by goal of matching full LHCb η coverage

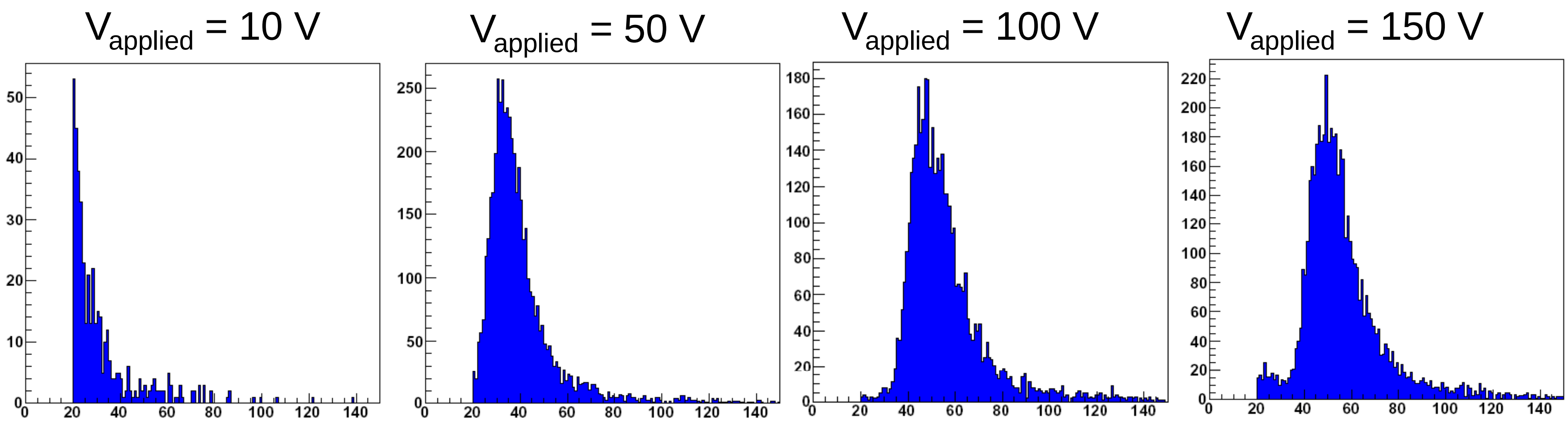
Velo after ~3 years of operation



- 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

p-Type Sensor HV scan (test beam Nov. 2006)

M26ϕ (TELL1 30), $V_{depletion} \approx 90$ V



Charge of Cluster (ADC Counts)

- Incoherent noise ~1.8 ADC counts (same as baseline sensors)
- When $V_{applied} < V_{depletion}$, partial charge is collected corresponding to effective depletion depth

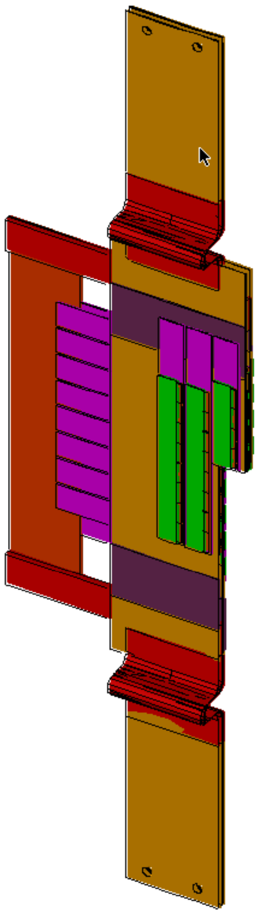
From VELO

To VESPA

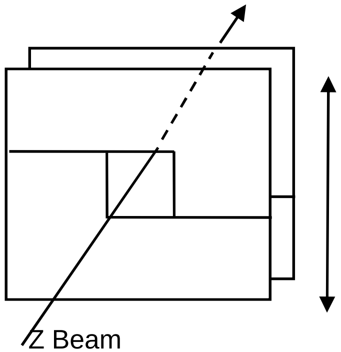
REQUIREMENTS

- radiation tolerance corresponding to an integrated luminosity of $\mathcal{O}(100fb^{-1})$
  ($\sim 10^{16}$ 1 MeV n_{eq} /cm^2)
- Close coupling with trigger for "intelligent" Level-0 decisions.
- Maximum 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

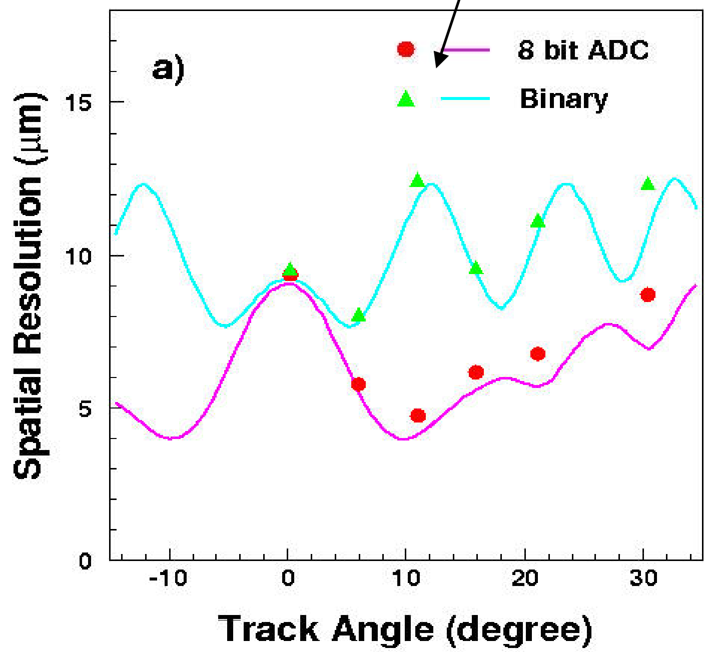


•Optimal radiation resistance (⇒inner detector in all LHC devices):
•Allows operation with smaller r_{min} & higher luminosity without replacement for the duration of the experiment
•Low noise (~200 e^- @ 25 ns) allows more precise charge interpolation & (in principle) thinner detectors.

Well understood technology

- Predictions from Monte Carlo simulation validated in extensive test beam studies
- Sensor design well established (Atlas, BTeV)
- Lots of experience in system issues during CMS/ATLAS commissioning
- Proven front end electronics design

MC
simulation

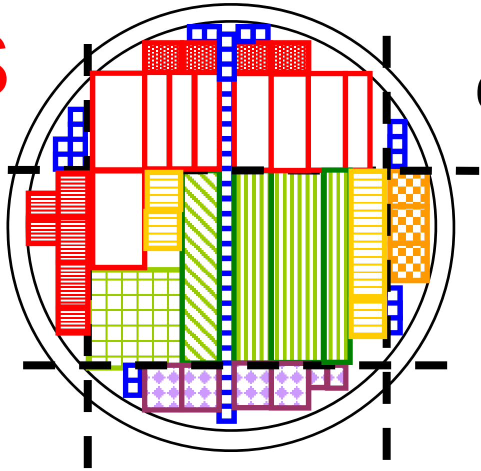


BTeV pixel
TB 1999

R&D activities - sensors

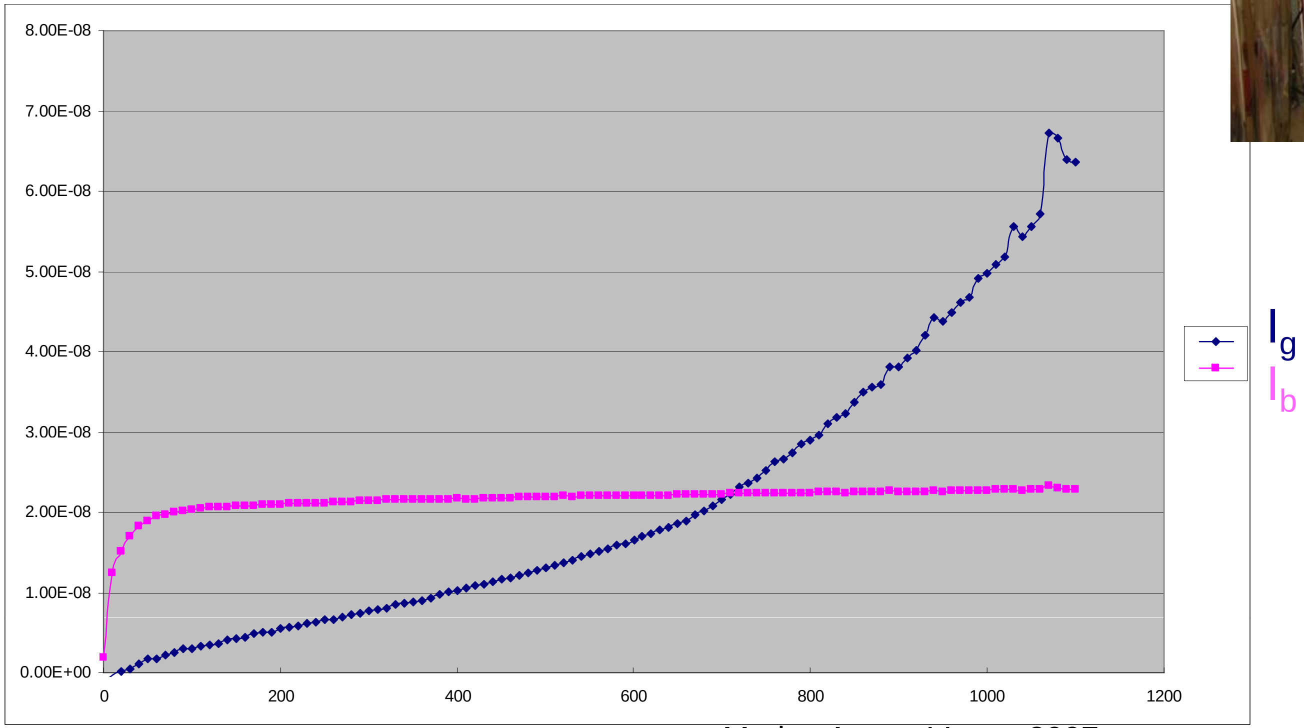
- Substrate material to ensure maximum radiation resistance (in collaboration with RD50):
  - p-type substrates
  - Magnetic Czochralski
- Alternative considered
  - 3D sensors

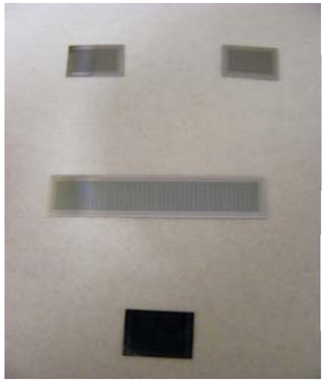
n-on-p pixels



6" Micron

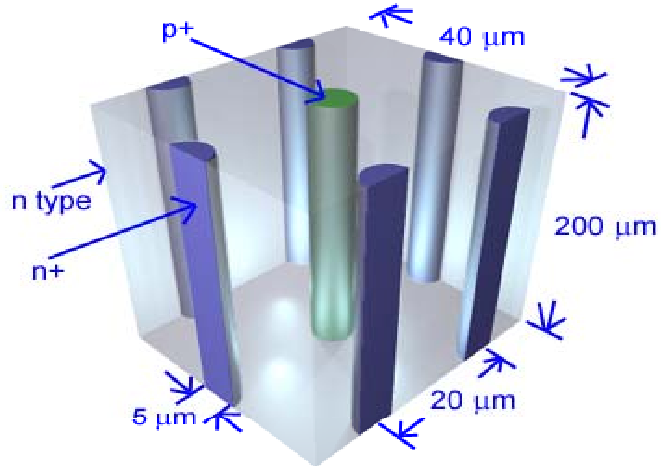
RD50 p-type "BTeV style" single chip pixel devices Micron

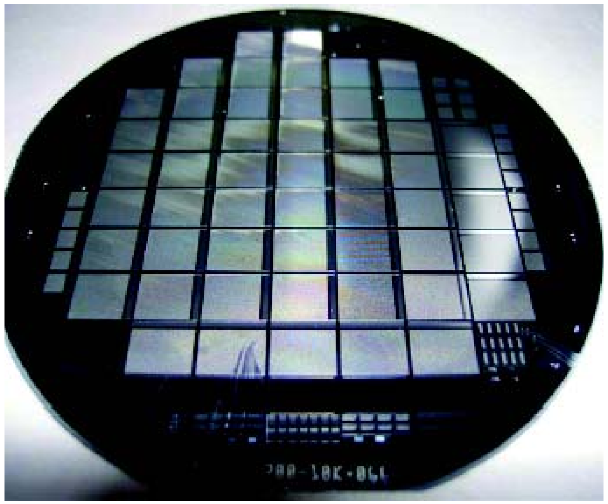




3d silicon sensors

- Combine VLSI processing and MEMs (Micro Electro Mechanical System) technology
- Variant of the sensor implementation in hybrid pixel systems
- Advantages:
  - Very low depletion voltage
  - Very low capacitance
  - The edge is an electrode: dead volume near the edge < 5μm
- Disadvantages: complicated manufacturing technology, not industrially produced (seem to be changing now).
- Active R&D towards large scale production in many sites (Glasgow…)



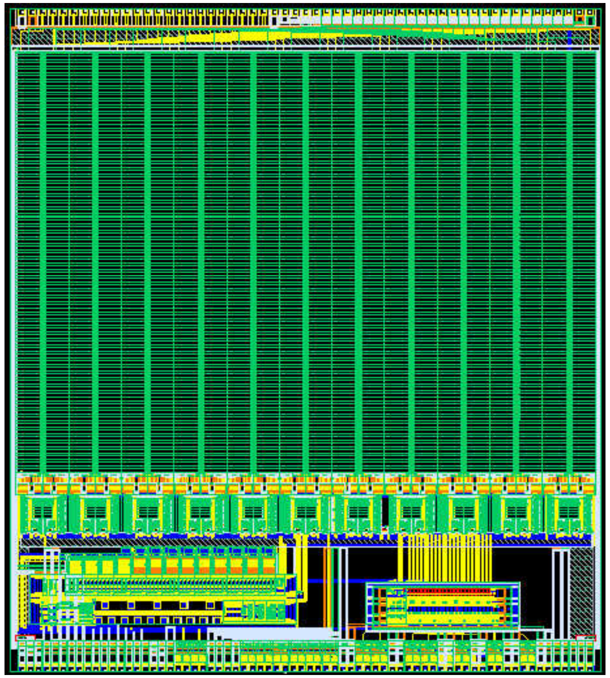


Front-end electronics

- Must provide digitized data to trigger processor in real time:
  - Time stamping ad LHC frequency
  - On chip sparsification
  - On chip digitization
  - Data push architecture
- New smaller feature size technologies may allow smaller "long pixel dimension"

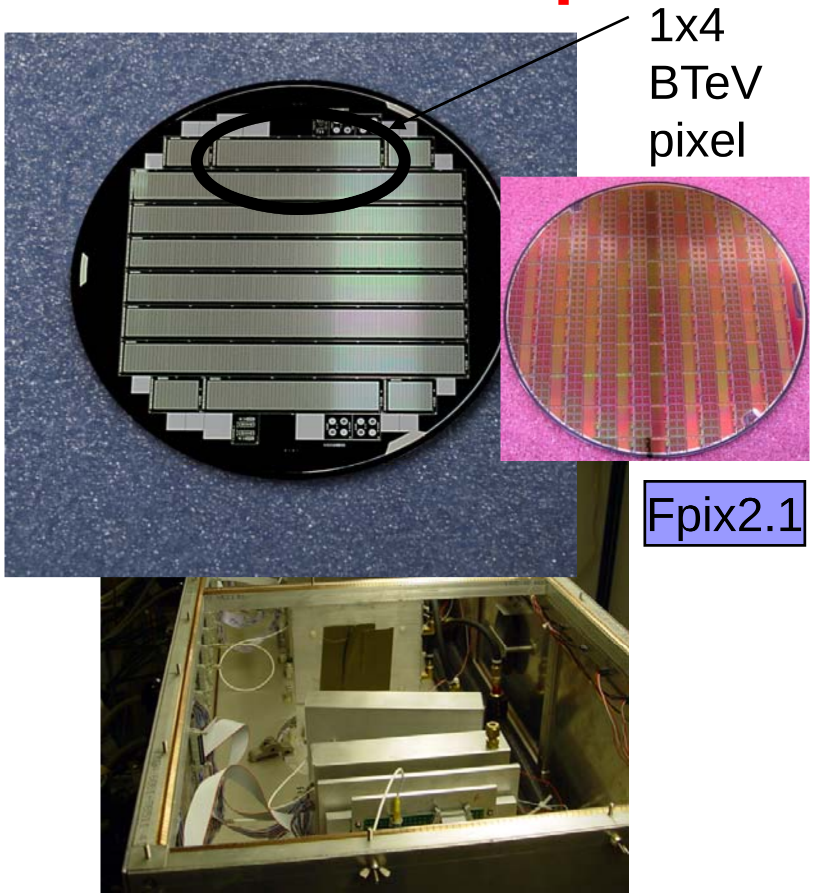
An interesting prototype

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

Next steps



Large acceptance pixel telescope [3.5 cm x 3.5 cm aperture (270k pixels)] under construction (D. Christian)

- Detailed simulation to optimize system geometry
- Intense test beam program utilizing pixel telescope facility at Fermilab Mtest (starting in 2008 with T-971)
- TDR planned for 2010

Conclusions

- There are several outcomes possible from the first data taking phase at LHC, for example
  - ATLAS/CMS see Higgs & NP & LHCb sees some NP effects that constrain NP models – *more sensitivity required to further elucidate NP*
  - ATLAS/CMS see Higgs but no NP & LHCb sees some NP effects that constrain NP models – *more sensitivity required to further elucidate NP*
  - ATLAS/CMS see Higgs but no NP & LHCb sees nothing beyond SM – *more sensitivity required to further elucidate NP & to try and estimate mass scale for NP*
- In all cases it is likely that *more LHCb sensitivity required to further elucidate NP*
- *the proposed upgrade is critical to make it possible*