Trigger and Data Acquisition Strategy for the LHCb Upgrade

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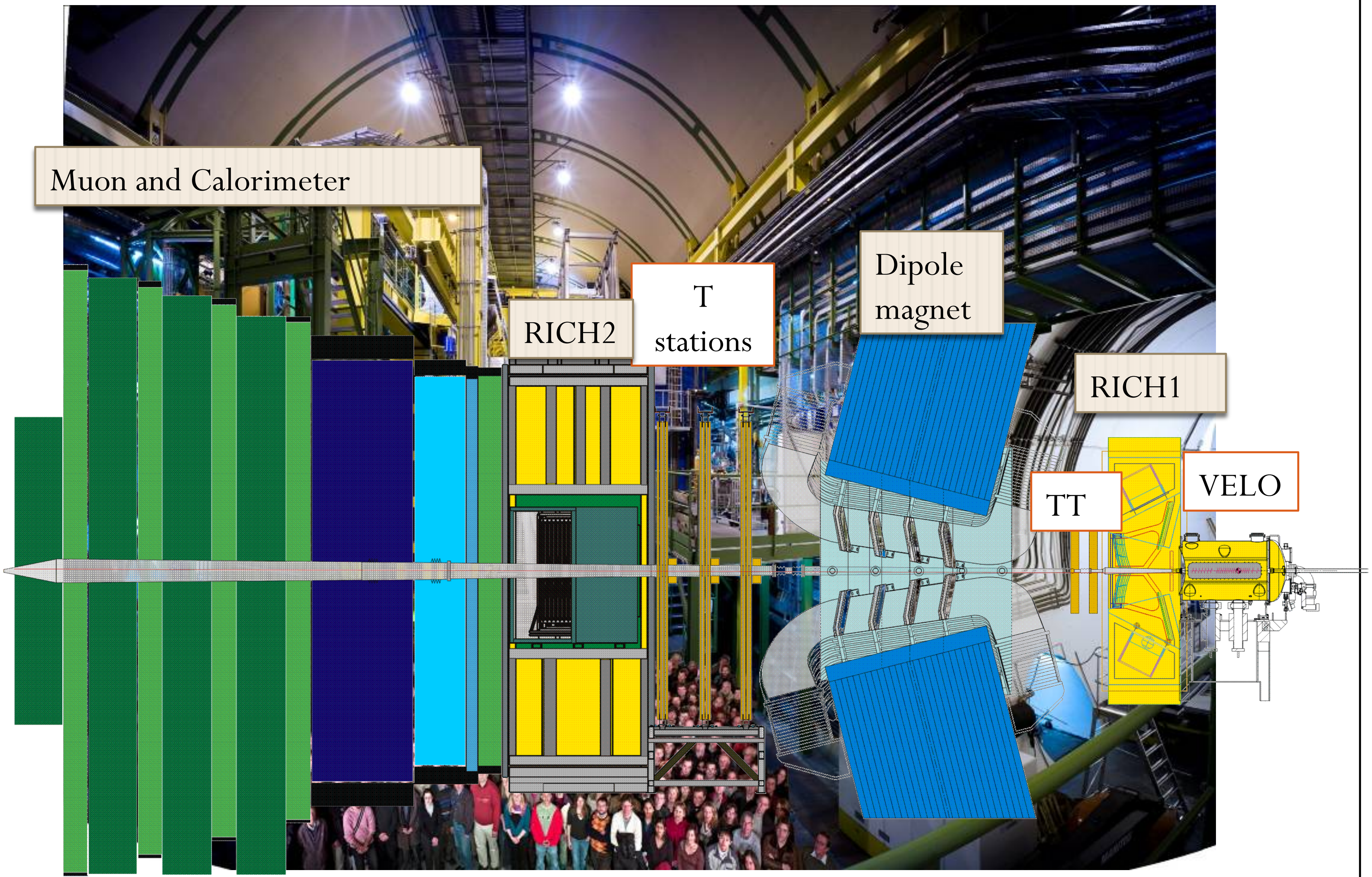
For the LHCb Collaboration

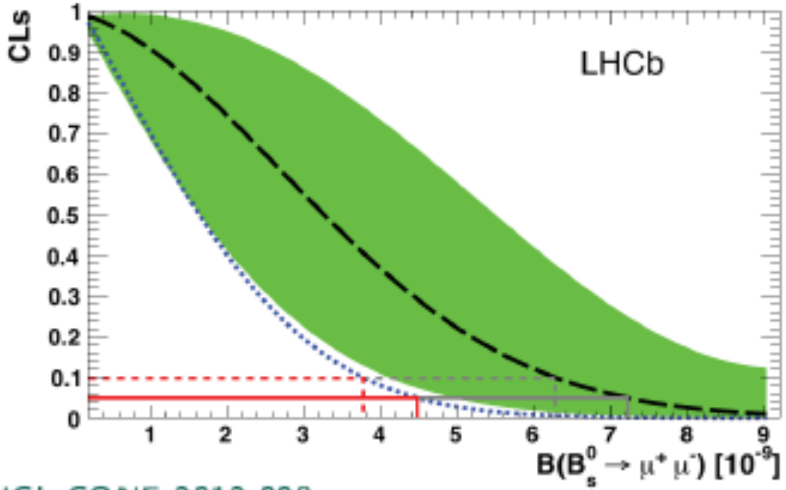
The LHCb experiment



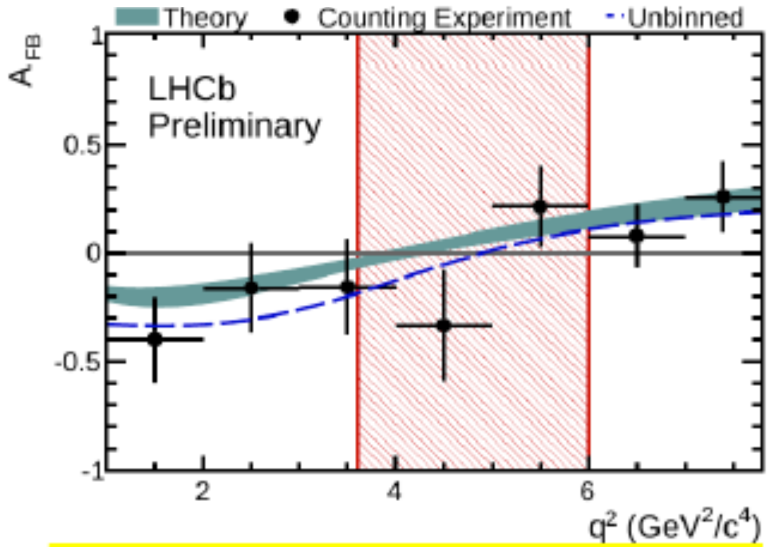
B Physics Highlights

LHCb-TALK-2012-028

$B(B_s \to \mu\mu) < 4.5\times10^{-9}$ at 95% CL



LHCb-CONF-2012-008

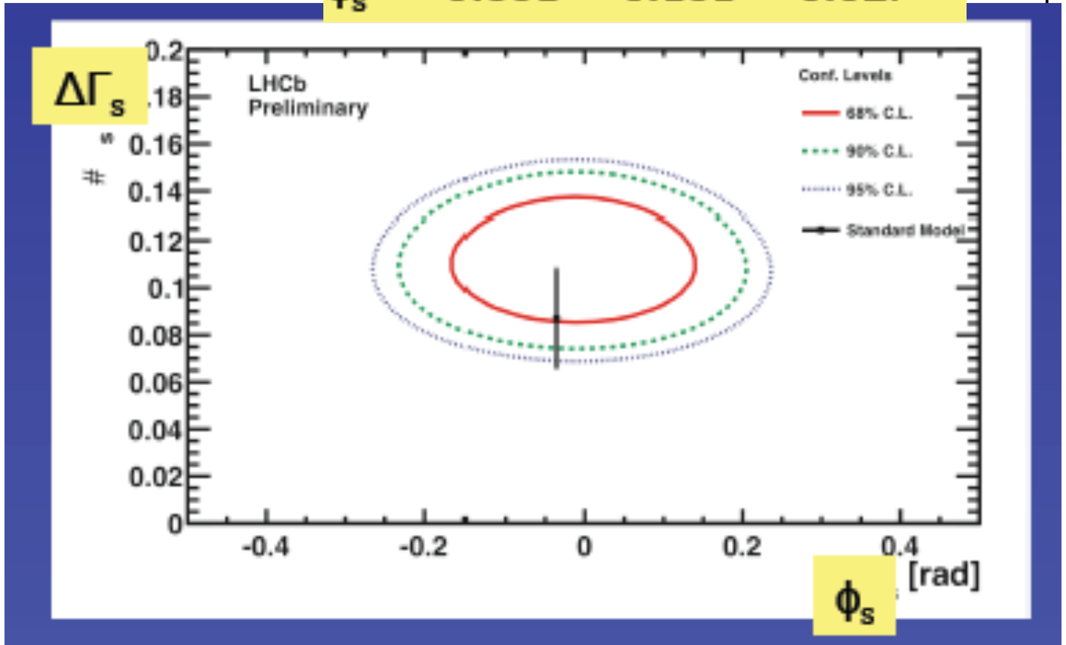


$q_0^2 = 4.9^{+1.1}_{-1.3}$ GeV$^2/c^4$ $[B^0 \to K^* \mu\mu]$

$$\phi_s^{SM} \cong -2\beta_s = -2\arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right) = -0.036 \pm 0.002$$

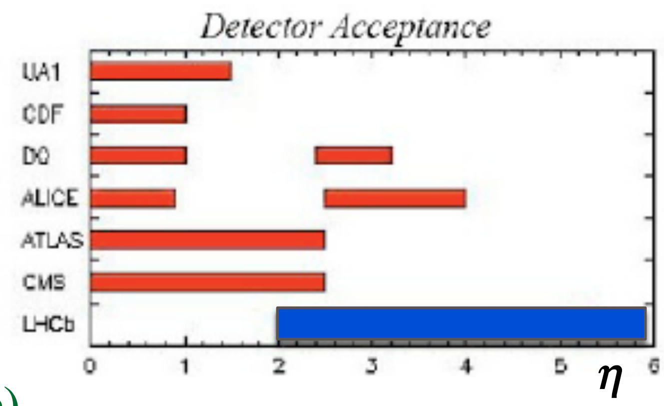
1 fb^{-1}, LHCb-CONF-2012-002

$\phi_s = -0.001 \pm 0.101 \pm 0.027$



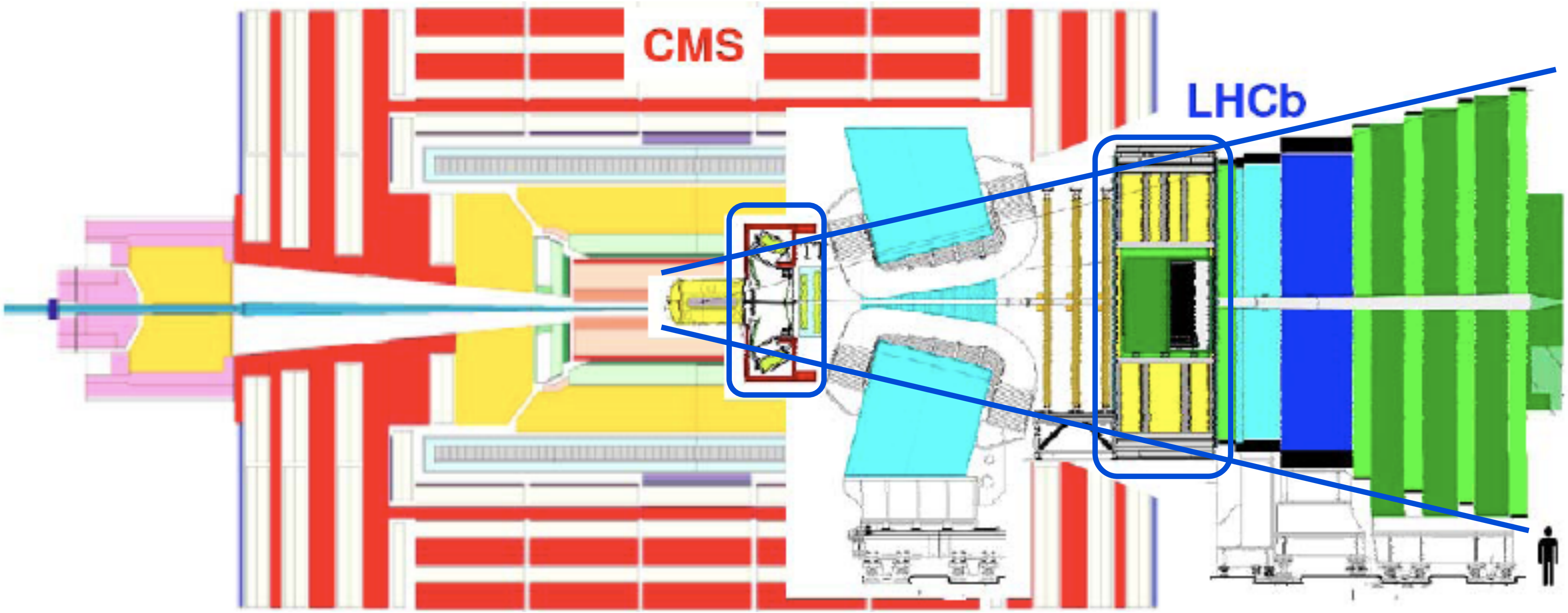
Study of flavor changing neutral currents and CPV in B_s decays so gives no indication of new physics, but new channels/increased sensitivity may open up new avenues

A new look at LHCb



Unique features of LHCb:

- ✓ particle detection in the forward region (down to beam-pipe)
- ✓ special particle identification capability in particular for hadrons due to RICH detector
- ✓ precise vertexing



The LHCb physics program

Comprehensive search for new physics signatures in *b* and *c* decays

- CP Violation
  - in B_s oscillations
  - in charmless hadronic decays
  - measurement of the angle γ
- Rare decays: $B_{s,d} \rightarrow \mu\mu$; $B \rightarrow K^{*0}\mu\mu$; $b \rightarrow s\gamma^{(*)}$

Charm Physics

- Mixing and CPV

Lepton Flavor Physics

- Searches for Majorana neutrinos
- Lepton Flavour Violating τ-decay

Physics Beyond Flavor

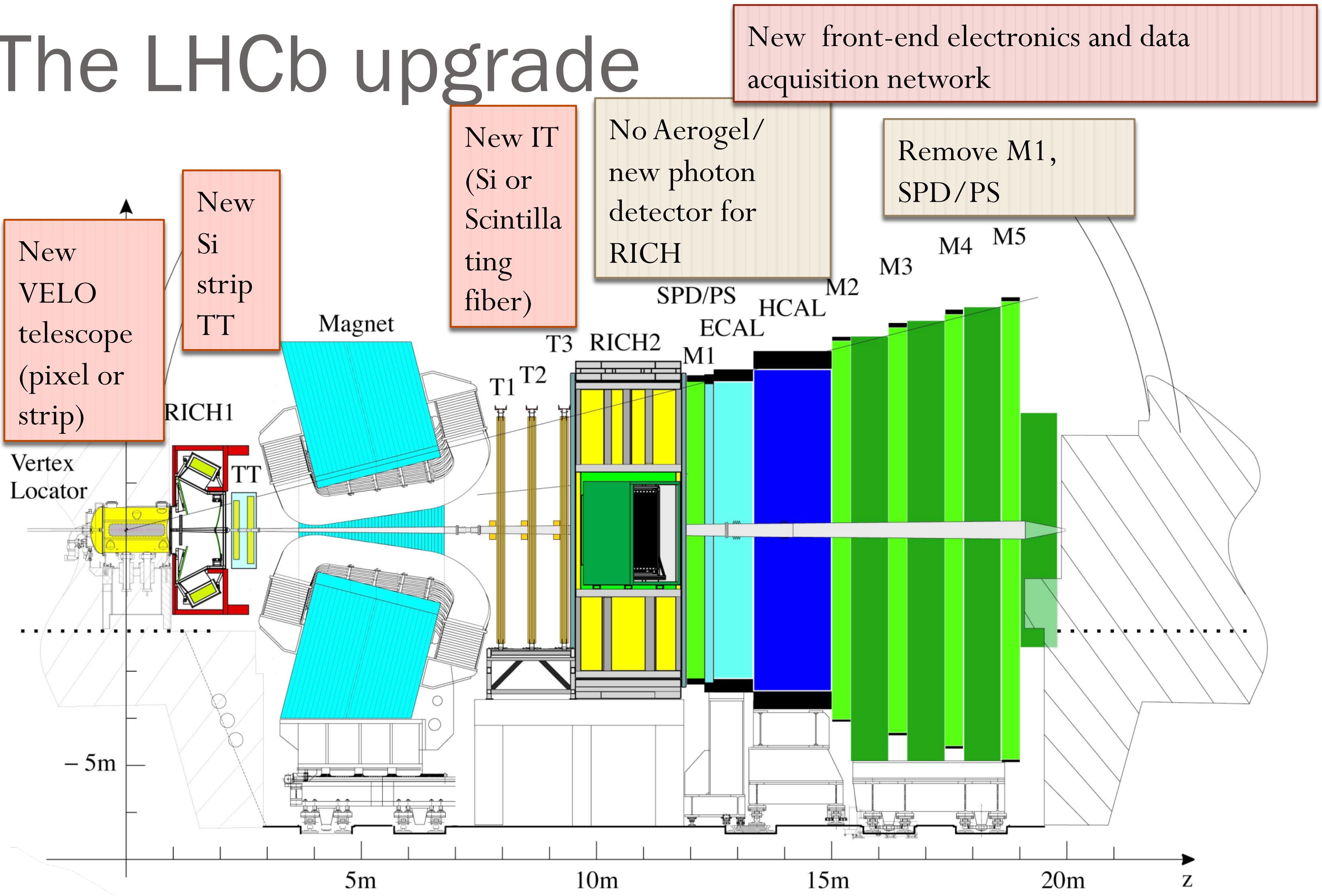
- Electroweak Physics
- Exotics (hidden valley particles…)

Upgrade goals

- In order to reach the required sensitivity for these measurements we want a ≥ 10 increase in our data sample through:
  - Increase nominal luminosity ($1\text{-}2 \times 10^{33}\ cm^{-2}s^{-1}$)
  - Increase efficiency on beauty and charm hadronic final states trigger (≥ 2)

- Schedule:
  - R&D phase in progress and should end in 2014
  - Installation during long shutdown ~2018.

The LHCb upgrade



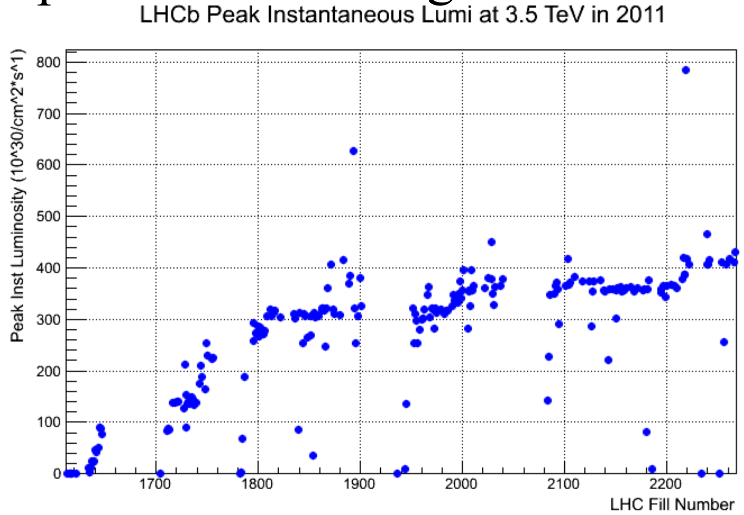
Sensitivities to key quark flavor

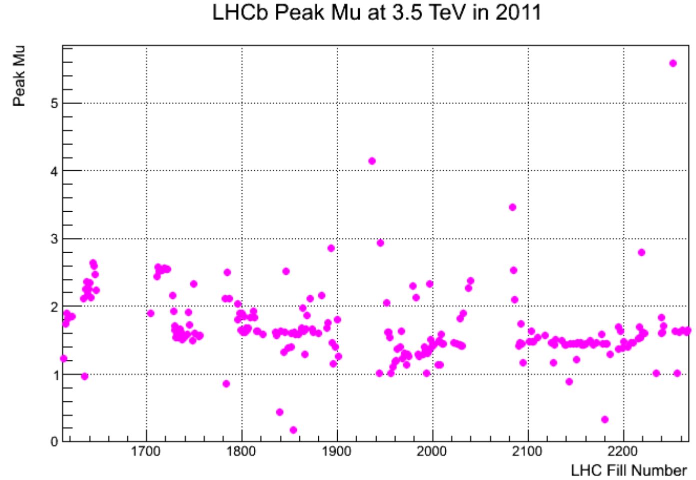
CERN-LHCC-2011-001

Type	Observable	LHCb (5 fb^{-1})	Upgrade (50 fb^{-1})	Theory uncertainty
Gluonic penguin	$S(B_s \to \phi\phi)$	0.08	0.02	0.02
	$S(B_s \to K^{*0}\bar{K}^{*0})$	0.07	0.02	< 0.02
	$S(B^0 \to \phi K^0_S)$	0.15	0.03	0.02
B_s mixing	$2\beta_s\ (B_s \to J/\psi\phi)$	0.019	0.006	~ 0.003
Right-handed currents	$S(B_s \to \phi\gamma)$	0.07	0.02	< 0.01
	$\mathcal{A}^{\Delta\Gamma_s}(B_s \to \phi\gamma)$	0.14	0.03	0.02
E/W penguin	$A_T^{(2)}(B^0 \to K^{*0}\mu^+\mu^-)$	0.14	0.04	0.05
	$s_0\,A_{\rm FB}(B^0 \to K^{*0}\mu^+\mu^-)$	4%	1%	7%
Higgs penguin	$\mathcal{B}(B_s \to \mu^+\mu^-)$	30%	8%	$< 10\%$
	$\frac{\mathcal{B}(B^0\to\mu^+\mu^-)}{\mathcal{B}(B_s\to\mu^+\mu^-)}$	-	$\sim 35\%$	$\sim 5\%$
Unitarity triangle angles	$\gamma\ (B \to D^{(*)}K^{(*)})$	$\sim 4°$	0.9°	negligible
	$\gamma\ (B_s \to D_s K)$	$\sim 7°$	1.5°	negligible
	$\beta\ (B^0 \to J/\psi\, K^0)$	0.5°	0.2°	negligible
Charm CPV	A_Γ	2×10^{-4}	4×10^{-5}	-
	$A^{dir}_{CP}(KK) - A^{dir}_{CP}(\pi\pi)$	4×10^{-4}	8×10^{-5}	-

Luminosity and pile-up

Pile-up: μ = number of visible pp collisions per bunch crossing





LHCb operation (design):

- $\mathcal{L} \sim 2\text{x}10^{32}$ cm^{-2} s^{-1} with 25 ns BX-ings
  - → ~10 MHz xings with ≥ 1 interaction
  - – $\mu \sim 0.45$

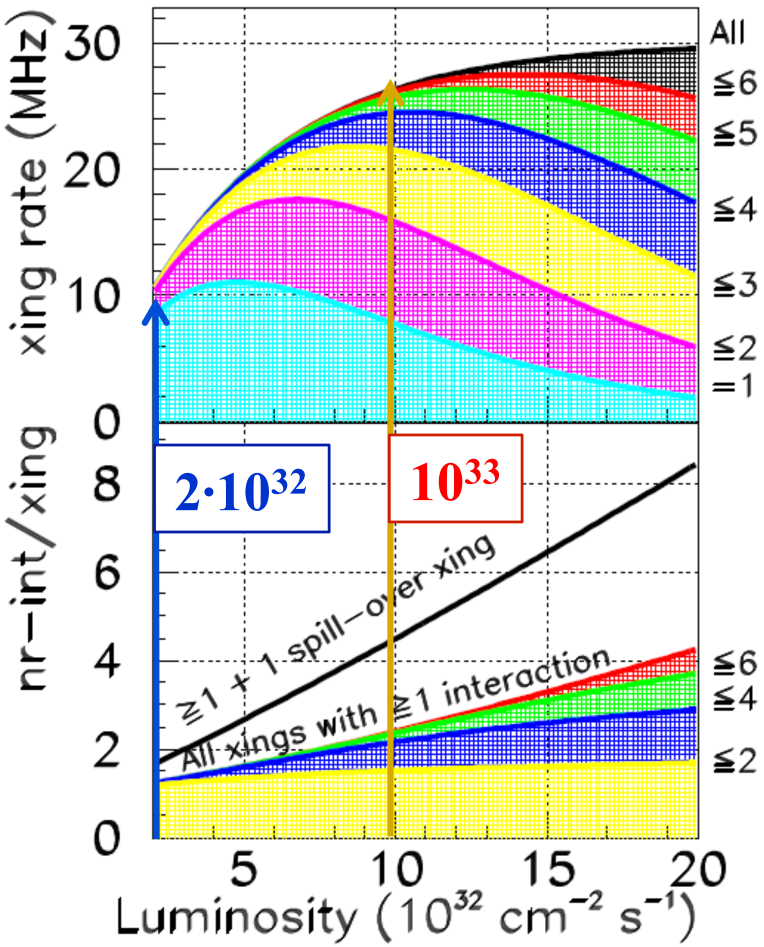
LHCb operation (2011):

- $\mathcal{L} \sim 3.5\text{x}10^{32}$ cm^{-2} s^{-1} with 50 ns BX-ings
  - – $\mu \sim 1.4$

Running at $\mathcal{L} \sim 1\cdot10^{33}$ cm^{-2} s^{-1}

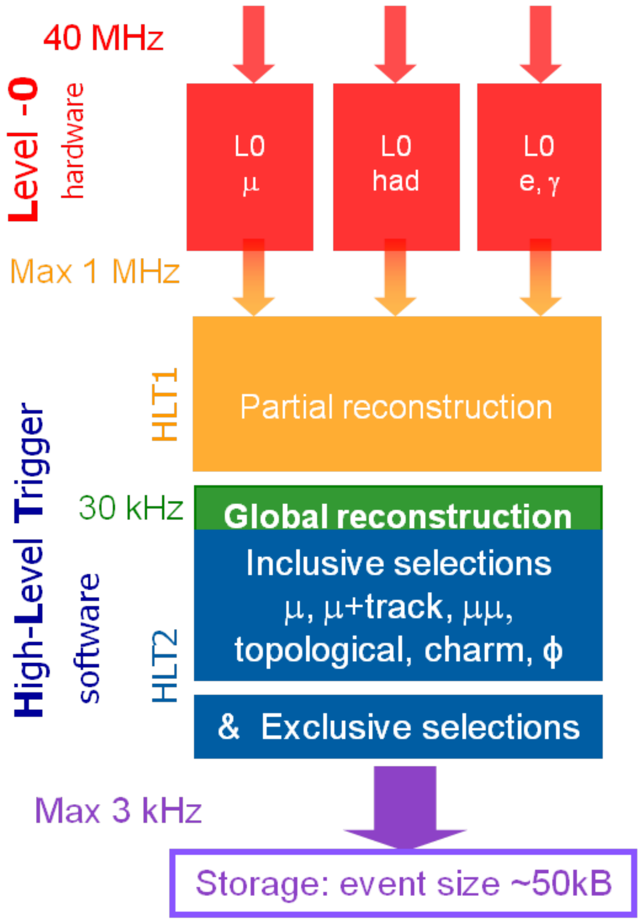
LHCb Upgrade Event Environment:

- L ~ 1x10^{33} cm^{-2} s^{-1} with 40 MHZ beam crossing frequency
  - → ~26 MHz rate for crossings with ≥ 1 interaction
  - → μ ~ 2.3

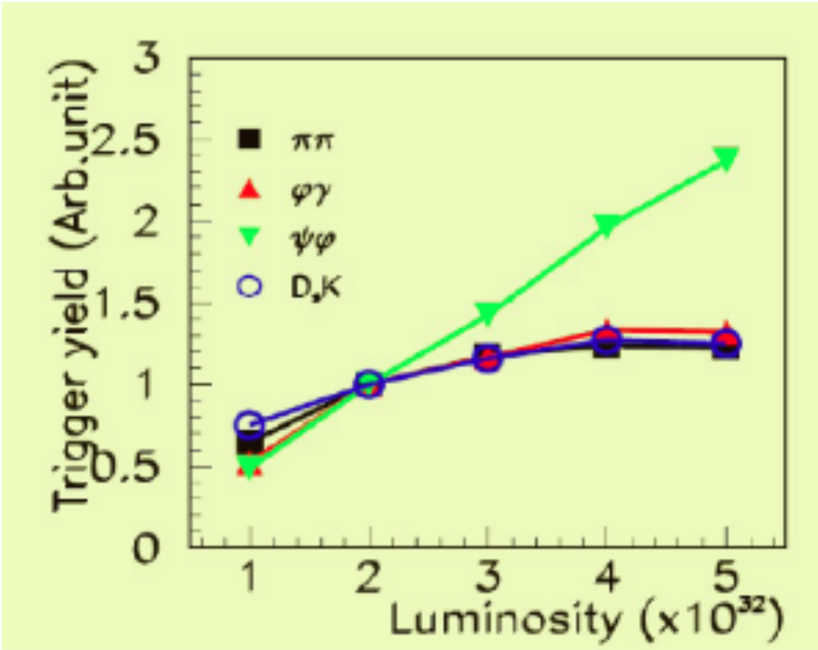


M. Artuso WIT2012, May 3 2012

LHCb current trigger strategy



2011 First Trigger Level:
Hardware Muon/ECAL/HCAL
1.1 MHz readout



The hadronic channel yields saturate at high luminosity

To exploit higher $\mathcal{L}$ for hadronic channels

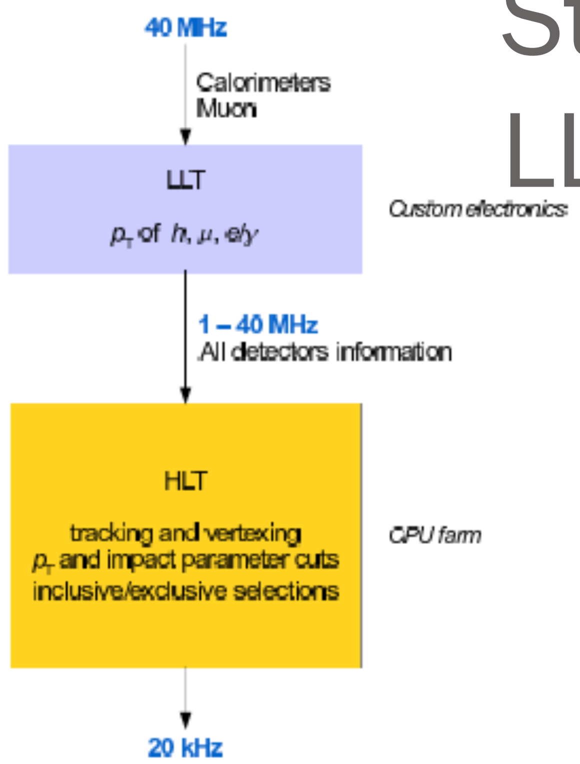
<u>A new trigger concept that is flexible and highly selective:</u>
software trigger exploiting detached vertex information early on and identifying interesting decays through their event topology.

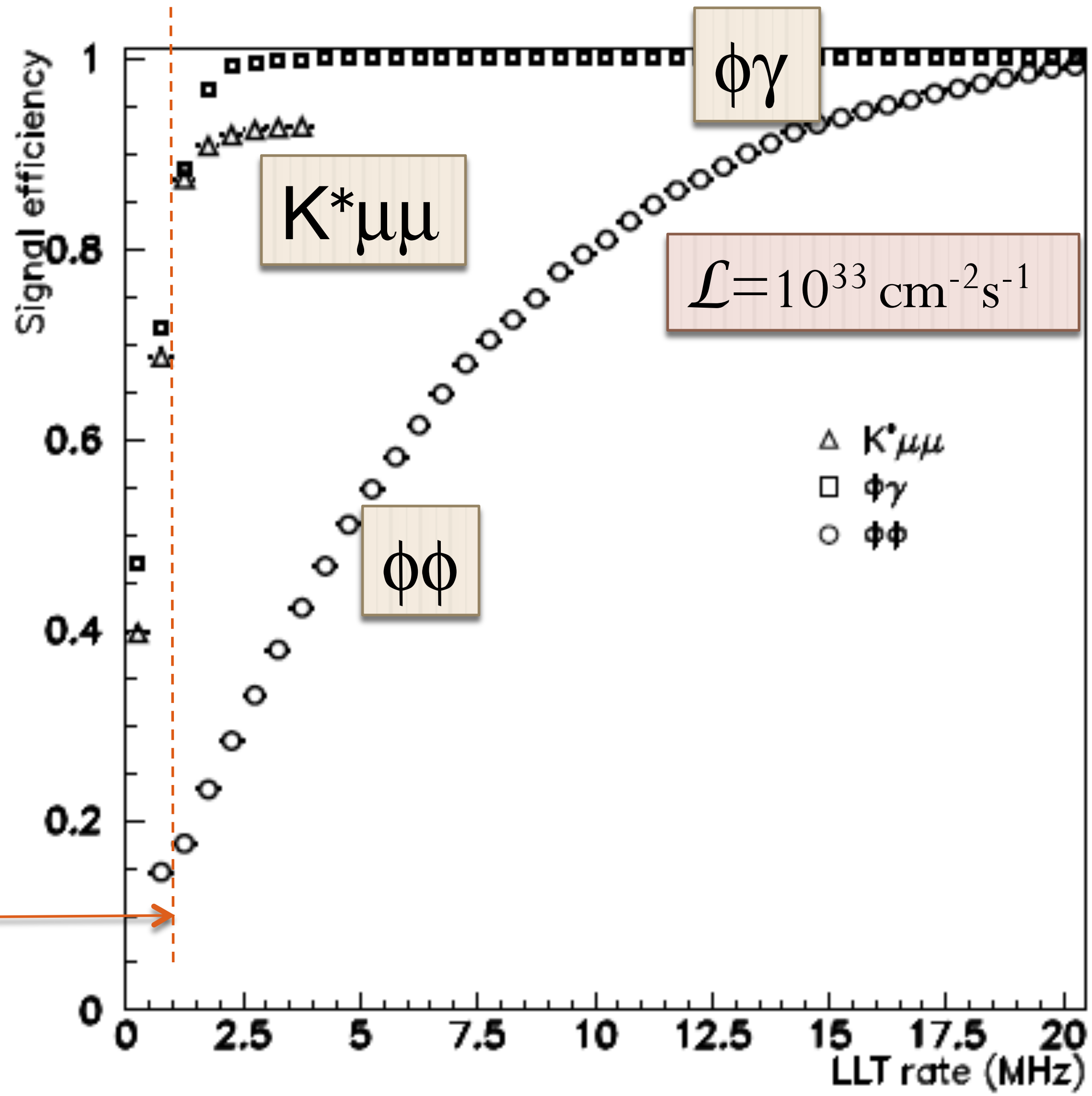
<u>Implementation:</u>
Read out the detectors at 40 MHz and use all the relevant information to suppress background (minimum bias, but also not so interesting beauty and charm signals)

<u>Goals:</u>

- ❑ 20 KHz on tape (in 2011 3 KHz)
- ❑ 10^5 reduction factor on minimum bias
- ❑ Trigger efficiency for interesting hadronic final states (B and D) $\geq$ 2x present one

Staging 40 MHz readout LLT as "throttle":





- Hadronic final states such as φφ benefit the most
- Can see the effect of current trigger at 1 MHz

HLT implementation and performance

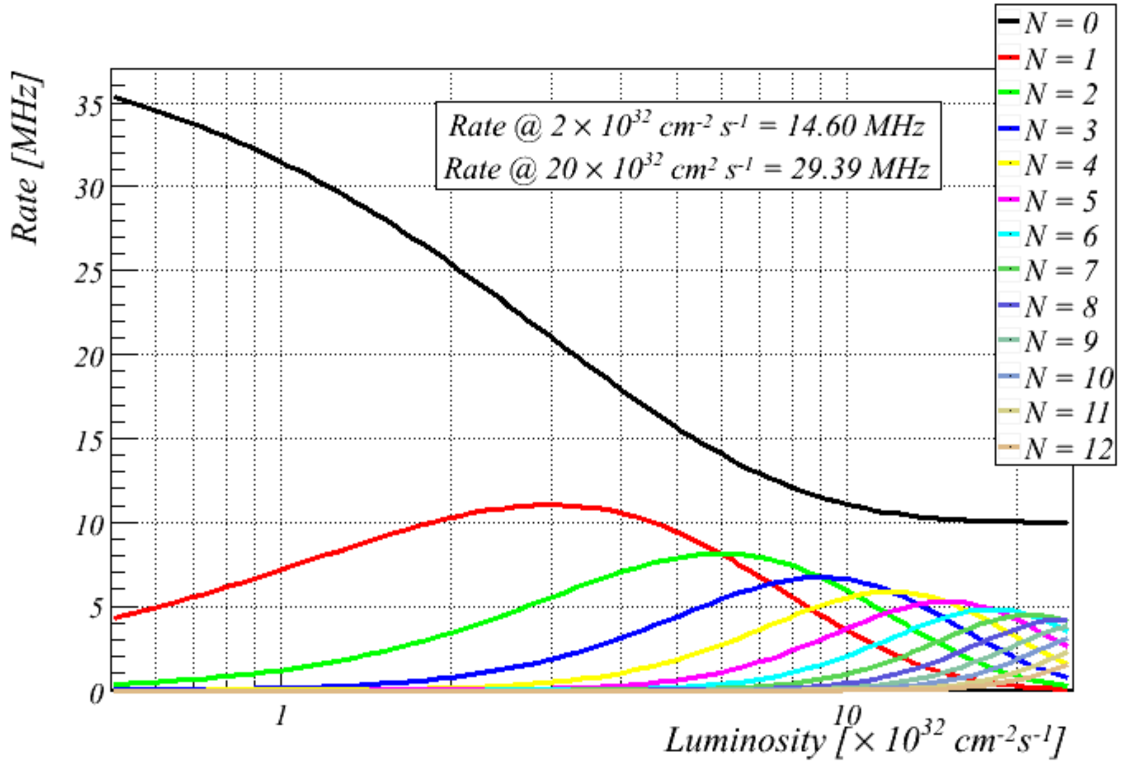
- HLT is a software application which runs on every CPU of an event filter farm:
  - Tracking and vertexing, p_T and impact parameter cuts are combined to derive inclusive event selection criteria largely based on the topology and kinematics of B decays, and additional selection of specific exclusive channels
  - increase to 20 kHz output rate

CERN-LHCC-2011-001

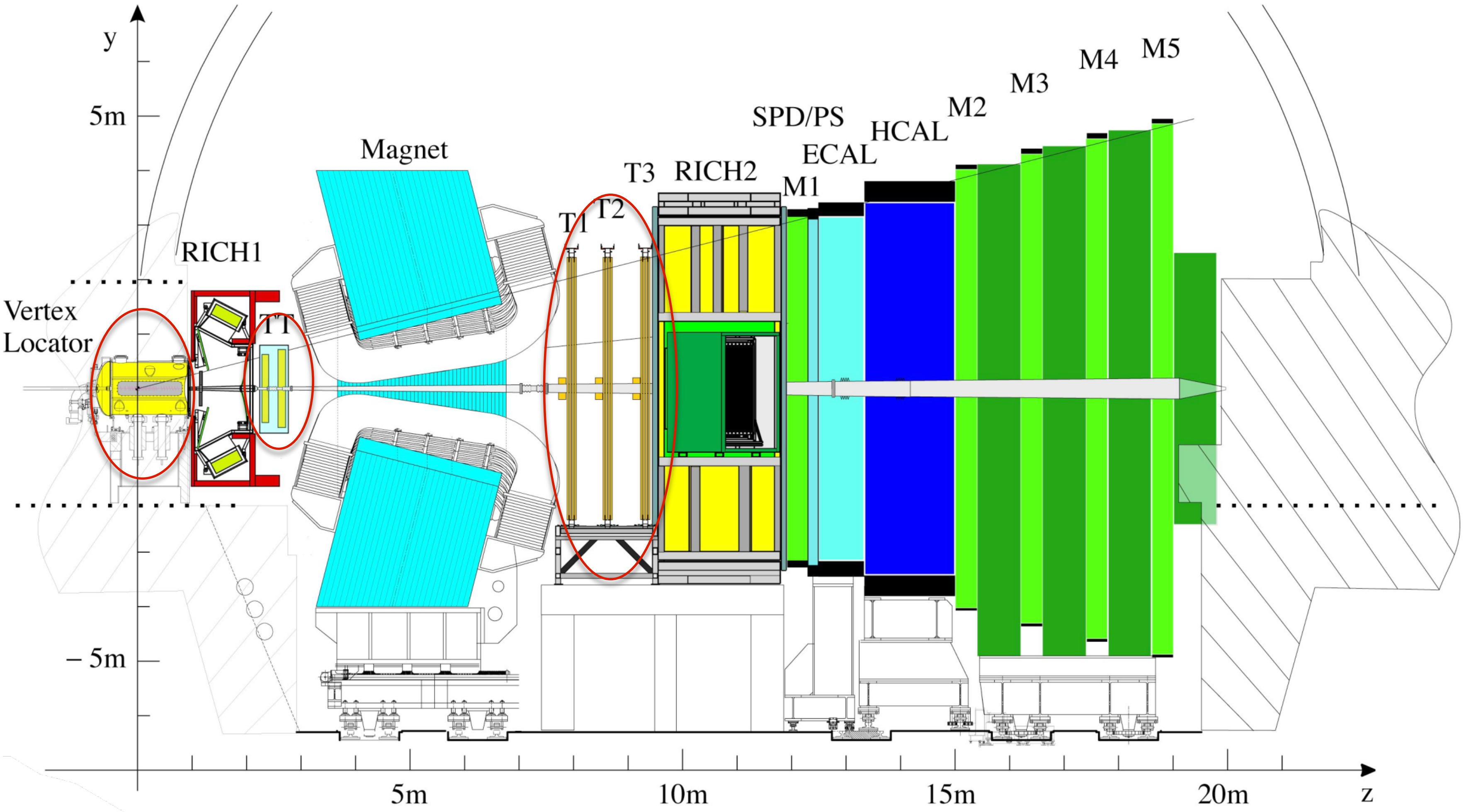
Efficiency (with respect to events selected with offline cuts)	Farm Size = 5 x 2011 (LLT 5.1 MHz)	Farm Size = 10 x 2011 (LLT 10.5 MHz)
$B_s \rightarrow \phi\phi$	29%	50%
$B^0 \rightarrow K^*\mu\mu$	75%	85%
$B_s \rightarrow \phi\gamma$	43%	53%

Tracking

- At $L=1x10^{33}$ $cm^{-2}s^{-1}$ the event topology is more complex:
  - More primary vertices
  - Increased track multiplicity
  - Bunch-to-bunch spillover
  - Detector occupancy
- The challenge:
  - Suppress ghost tracks (incorrect combination of track segments)
  - low processing time in HLT (~25 ms)
  - Maintain high track efficiency (~90% when p≥5GeV)
  - Excellent momentum, time, and vertex resolution

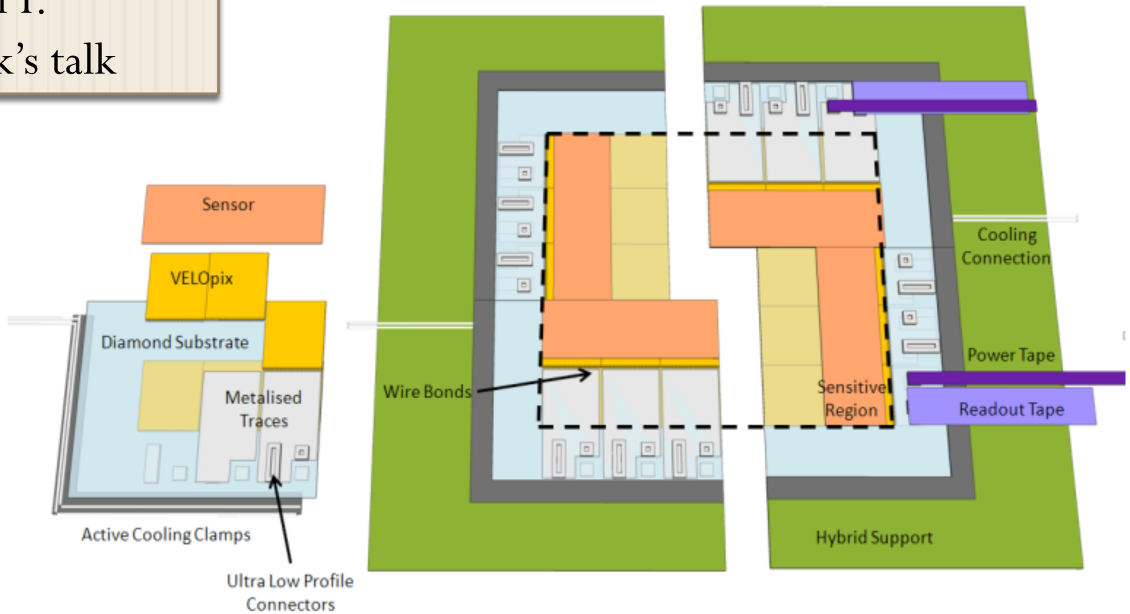


The LHCb upgrade tracking system



VELO upgrade

More in T. Szumlak's talk

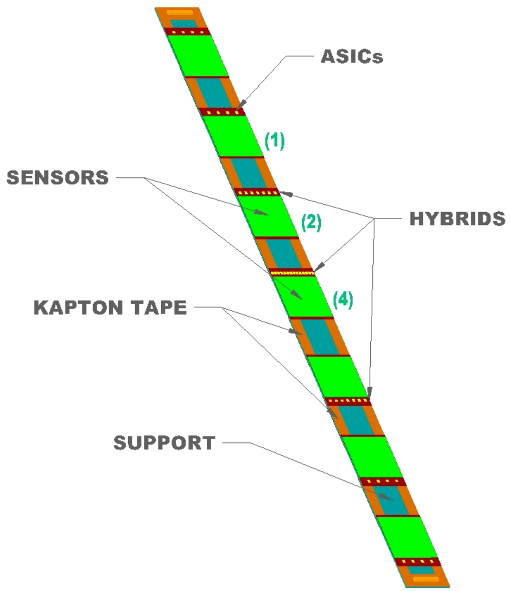


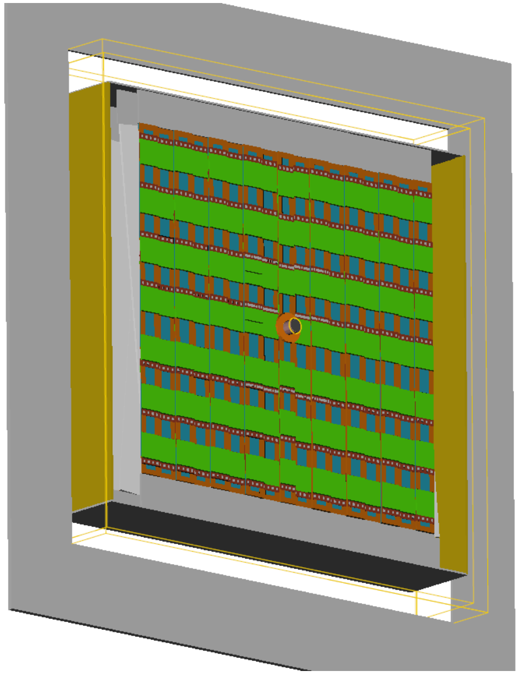
- Current VELO is built of (r,ϕ) strip Si detectors with a pitch 35-100 μm ⇒ one upgrade strategy built on pixel detector ⇒ very low occupancy, reduced combinatorial for tracking, very high data rate (≥ 12 Gbit/s for the hottest pixel ASIC)
- New front end ASIC (VeloPix based on TIMEPIX family) features 256x256 channels, square pixels 55x55 μm^2
- Alternative option based on strips being developed

The TT intermediate tracker

❑4-fold purpose:

- Selection of high momentum tracks in an early stage of the online track trigger.
- Reconstruct trajectories of long-lived tracks decaying outside the VELO
- Track segment to ease pattern recognition and ease matching between VELO and T station track segments
- Reconstruction of momentum of slow particles





To achieve this:
❑ use 4-6 planes of Si strip sensors with shorter strip lengths (2.5 to 10 cm)
❑Increase acceptance at high η

T Station Upgrade:

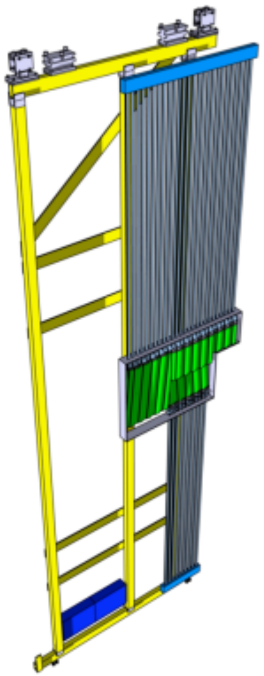
Present configuration: IT silicon strip and OT straw tubes

IT detectors must be replaced as 1 MHz electronics integrated.

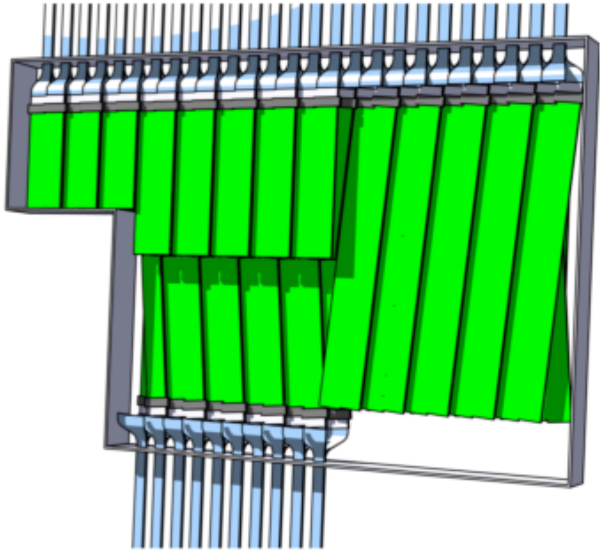
Two options for IT replacement:

- Silicon strips (current technology, but lower mass and larger coverage)
- 250 μm Scintillating Fiber Tracker read out by SiPM

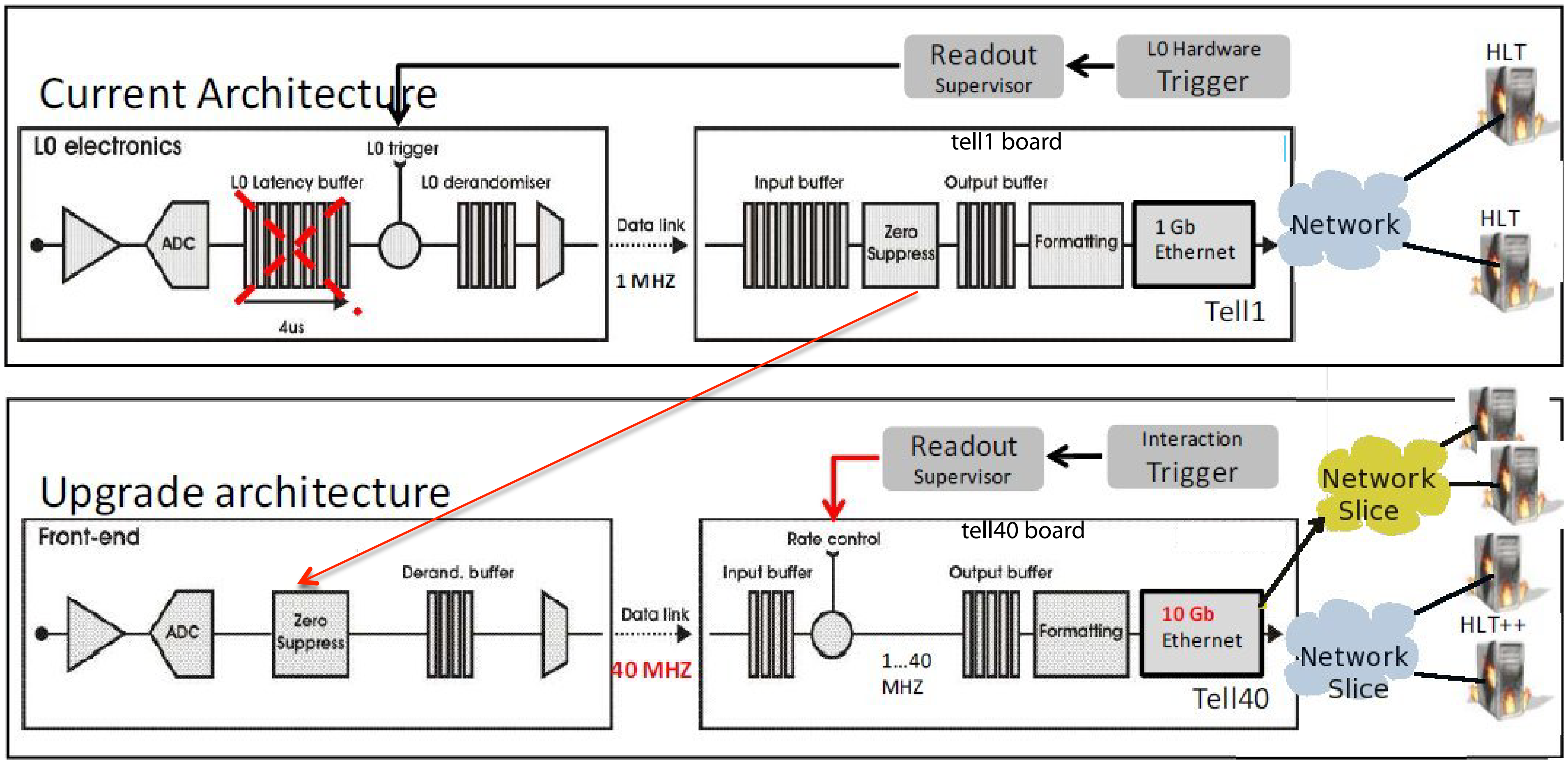
- A single Scintillating Fiber technology implementation for the the whole T station plane is being studied



IT-fiber detector layout:



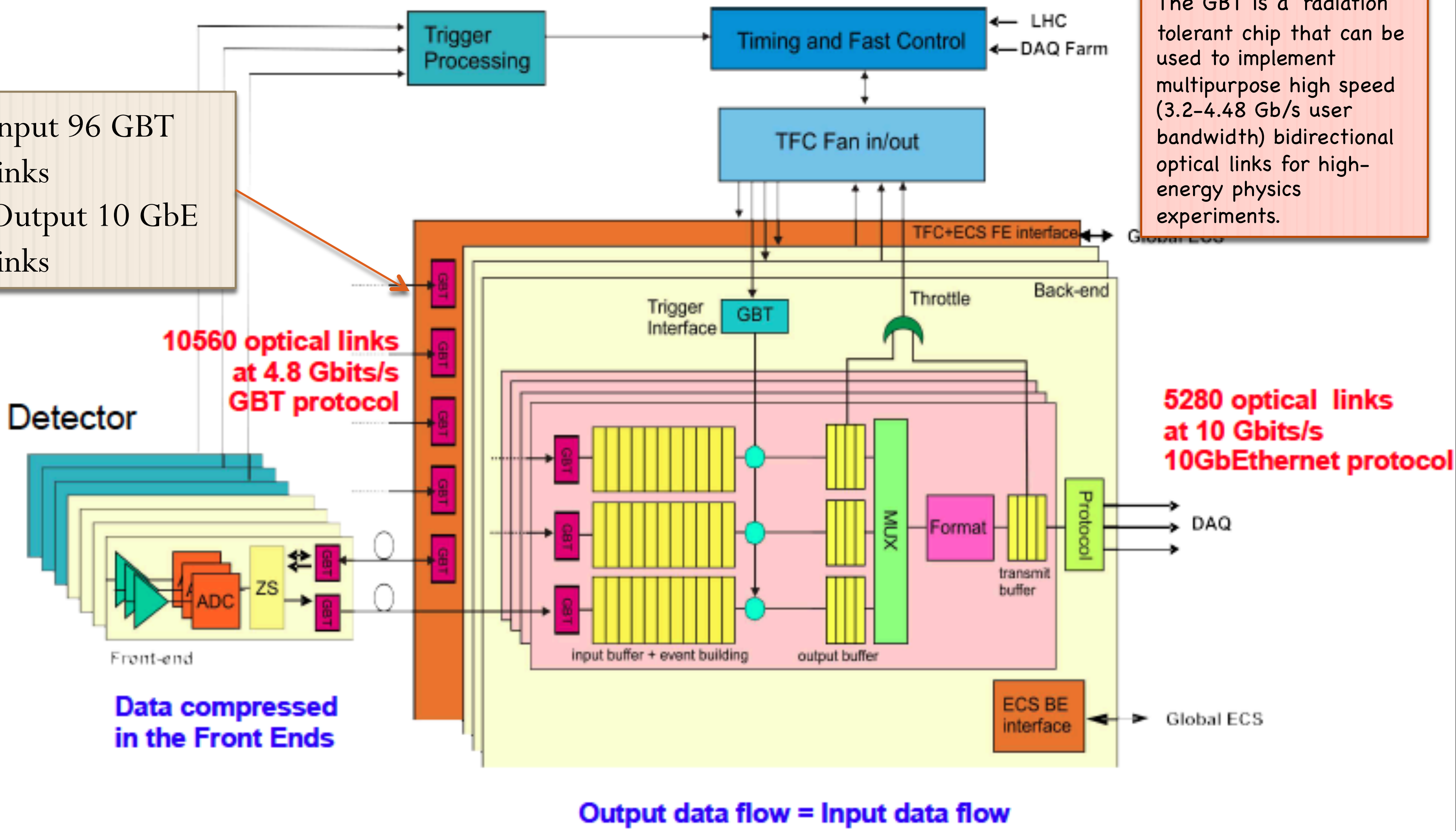
Data acquisition strategy



The Tell40 DAQ board

Input 96 GBT links
Output 10 GbE links

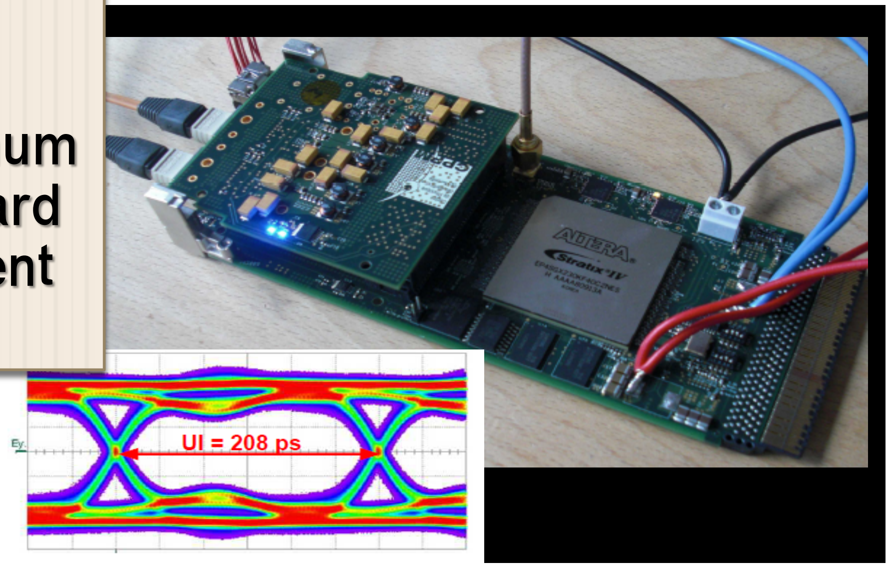
The GBT is a radiation tolerant chip that can be used to implement multipurpose high speed (3.2-4.48 Gb/s user bandwidth) bidirectional optical links for high-energy physics experiments.



The Acquisition board (AMC)

- Prototype board built
- Parallel optical I/Os (12 x > 4.8 Gb/s), GBT compatible

- Final aim: ATCA with different mezzanine recipe
- Powerful Stratix V GX FPGA: optimum use for tracking to be explored (1 board may combine information from different planes



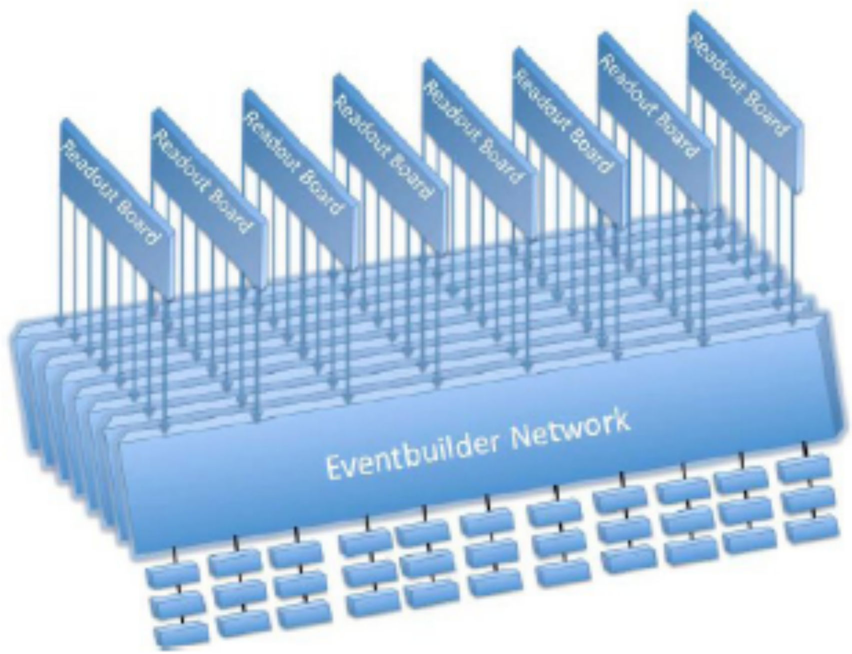
Serial link at 4.8 Gbits/s with GBT protocol

Data links based on GBT + Versatile link:

Good results from prototypes, on schedule for upgrade

Upgrade readout network and event builder farms

Single stage readout over a dedicated local area network.
Full connectivity between event builder farm nodes not required, so the network can be split in slices where each TELL40 is connected to all the slices.
Each output link (group of output links) is connected with an independent readout network with its own farm attached.

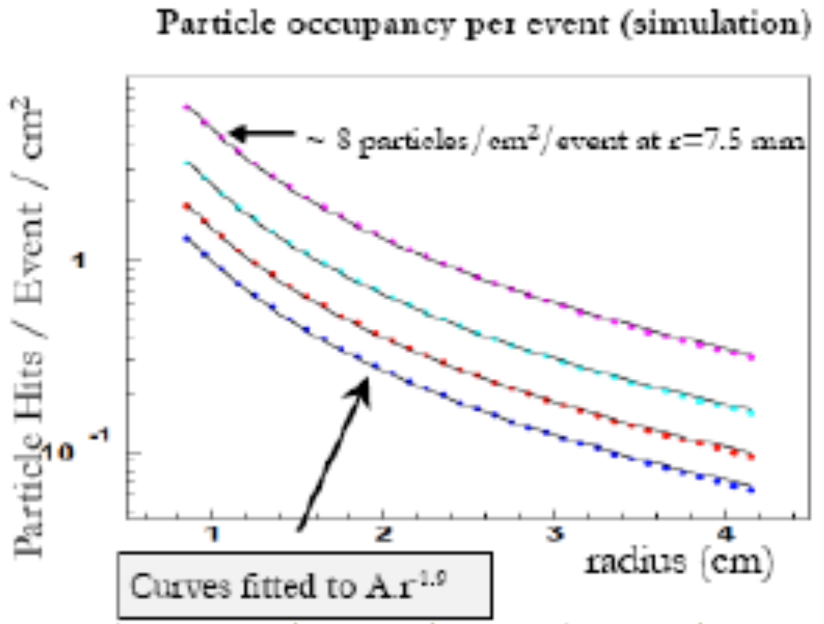


Conclusions

- The LHCb upgraded detector is poised to pursue a vast array of very exciting physics topics with great discovery potential.
- The trigger/data acquisition concept is based on shipping the zero suppressed data from the front end to an event builder farm where a complex and flexible HLT trigger exploiting the tracking information to reconstruct the event topology can be implemented.
- The performance of the current detector and the purity of the samples already accumulated gives confidence that this strategy will be successful.

The End

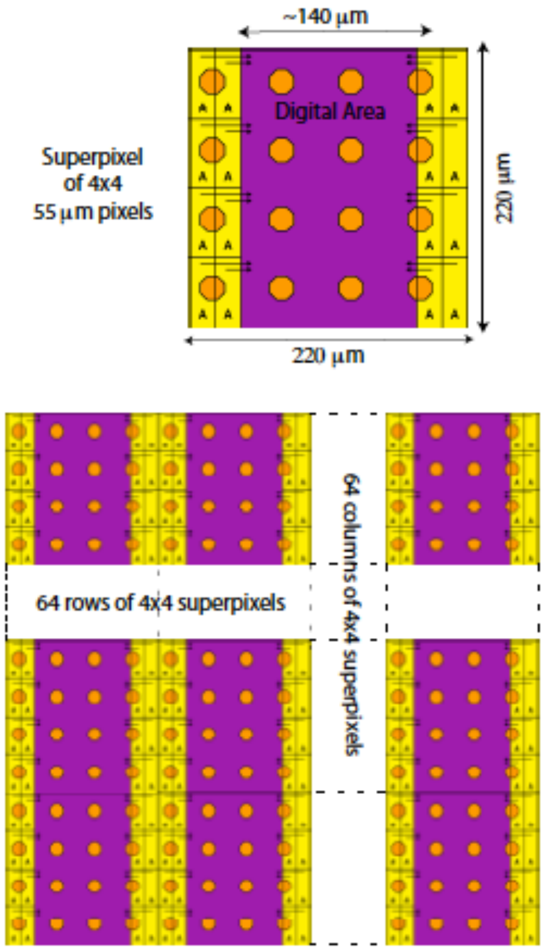
The occupancy challenge



Luminosity ($cm^{-2}s^{-1}$)	2.10^{32} Current	5.10^{32}	10.10^{32}	20.10^{32} Upgrade
A=	0.98	1.46	2.46	4.80

- Front end ASIC must digitize, zero suppress and transmit event data at 40 MHz
- Occupancy minuscule compared to other pixel devices, but huge data rates
- 1 ASIC has to transmit 10-20 Gbit/s

Super-pixel layout



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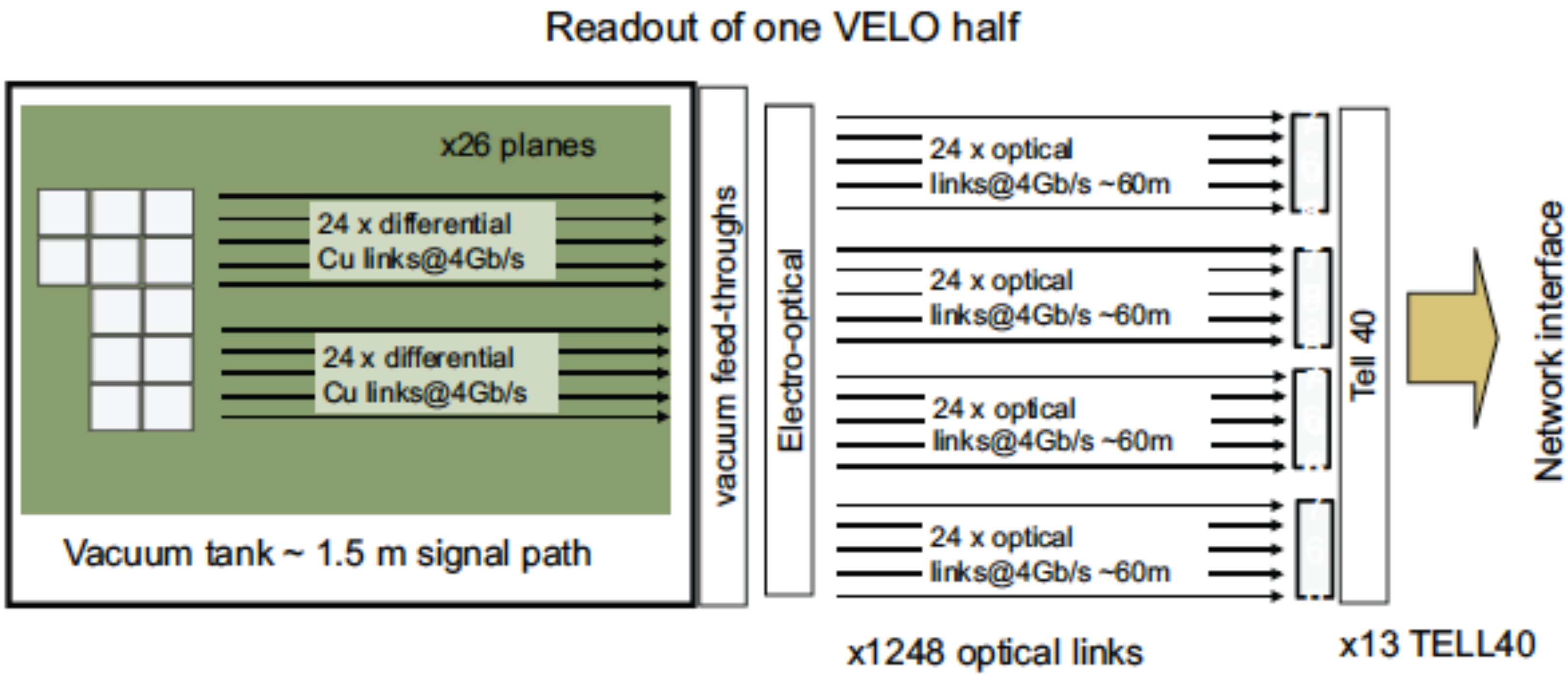
Readout Scheme



Generic sub-detector readout and control