# The LHCb Upgrade: Progress & Plans

Sheldon Stone

# General Physics Justification

- Expect New Physics will be seen at LHC
  - Standard Model is violated by the Baryon Asymmetry of Universe & by Dark Matter
  - Hierarchy problem (why $M_W << M_{Planck}$)
- 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
- It is also possible that b or c decays will reveal physics beyond the SM on their own

# Hint of New Physics: $A_{sl}$

- New D0 measurement
- Idea here is to use dilepton asymmetry

$$A_{SL} \equiv \frac{\Gamma(b\bar{b} \rightarrow \mu^+\mu^+X) - \Gamma(b\bar{b} \rightarrow \mu^-\mu^-X)}{\Gamma(b\bar{b} \rightarrow \mu^+\mu^+X) + \Gamma(b\bar{b} \rightarrow \mu^-\mu^-X)}$$ Fermilab-Pub-10/114-E

Evidence for an anomalous like-sign dimuon charge asymmetry

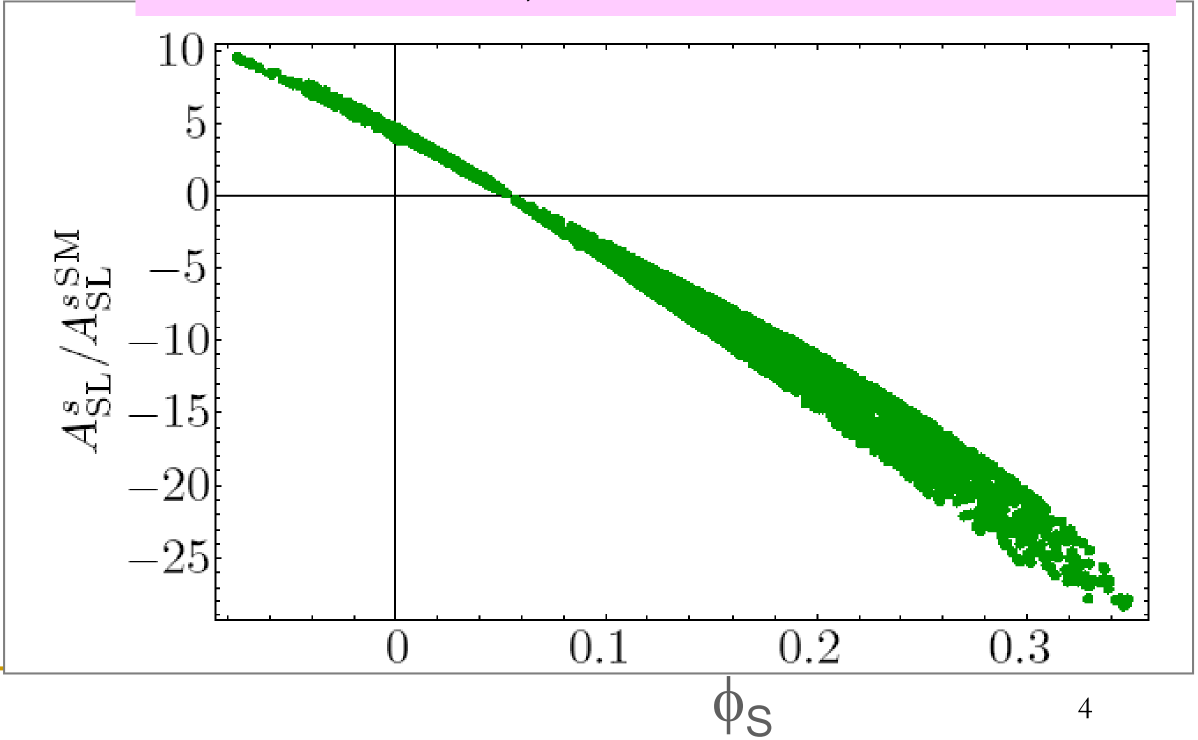
- D0 measures $A_{sl}$ = $(-9.57\pm2.51\pm1.46)\times10^{-3}$
- SM prediction is $(-2.3\pm0.6)\times10^{-4}$
- Only 3.2 $\sigma$, therefore a hint to be pursued by LHCb
- But how far down do we need to go & how far can we go?

# Little Higgs Model with T Parity

- There exist regions of parameter space consistent with measurement where large $\phi_S$ is predicted & $\Delta M_S$ is found somewhat smaller than in the SM.
- In particular, significant enhancement of $\phi_S$ & the semileptonic asymmetry $a_{SL}(S)$ relative to the SM are found

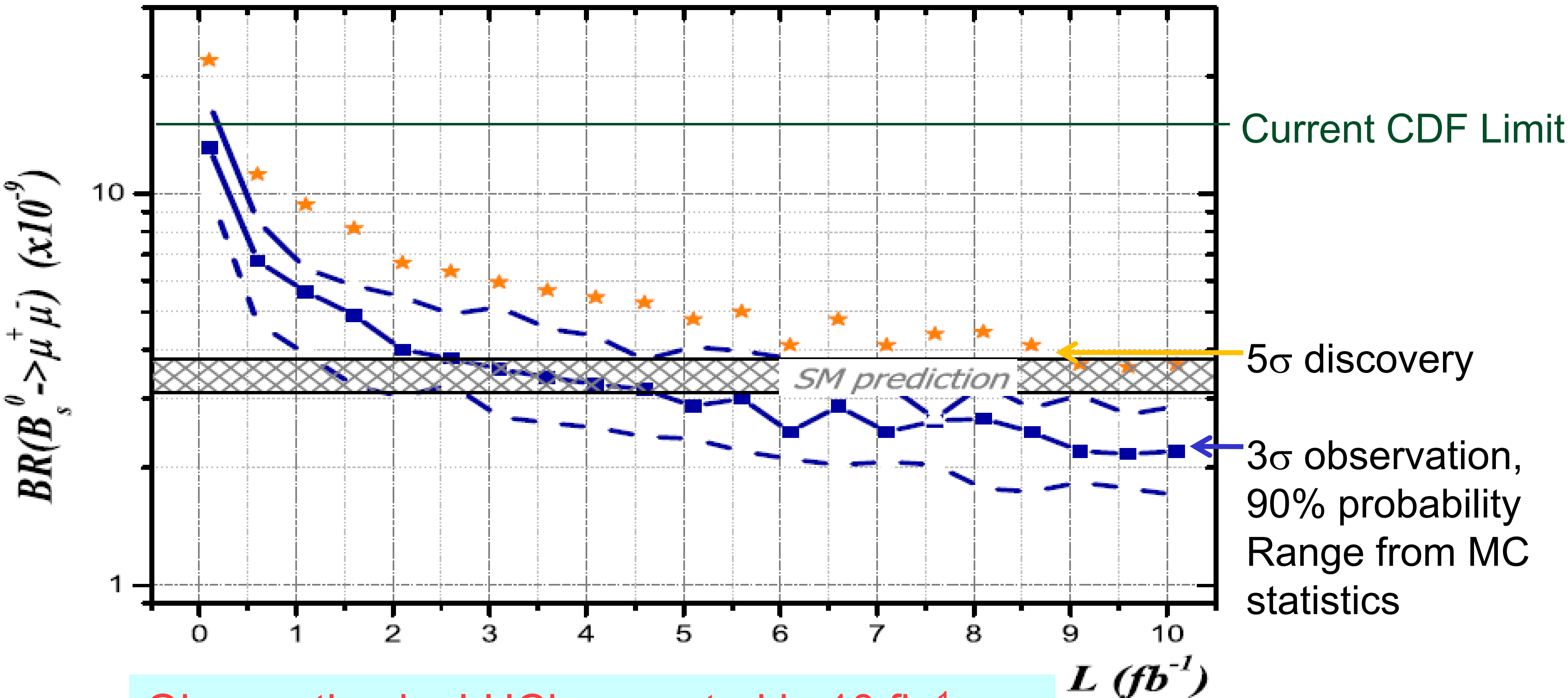
D0 result 42x SM, would rule out these models

•From Blanke & Buras, [hep-ph/0703117]




- Need precision measurements of CP asymmetry in $B_S \rightarrow J/\psi\phi$ & $\mathcal{B}(\bar{B}_S \rightarrow D_S^+ \ell^- \nu) - \mathcal{B}(B_S \rightarrow D_S^- \ell^+ \nu)$

# LHCb Reach for $\mathcal{B}(B_S \to \mu^+\mu^-)$

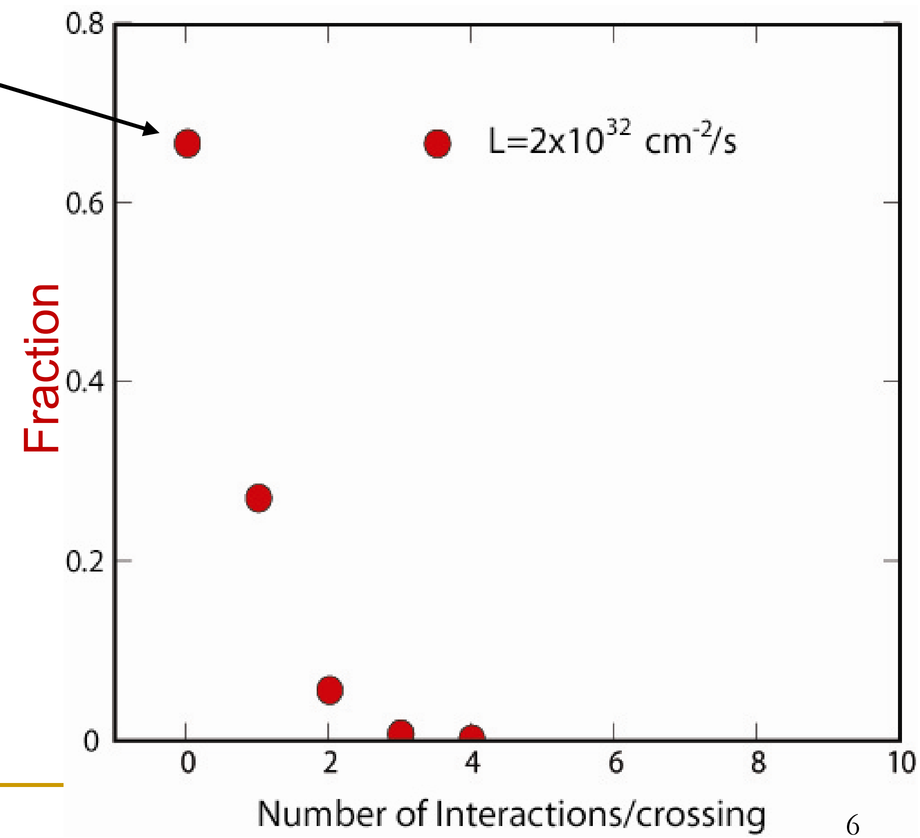



Observation by LHCb expected in 10 $fb^{-1}$, but 100 $fb^{-1}$ needed for precise measurement

***Background is dominated by combinations of $b \to \mu^- X$ $b \to \mu^+ X$ events.***

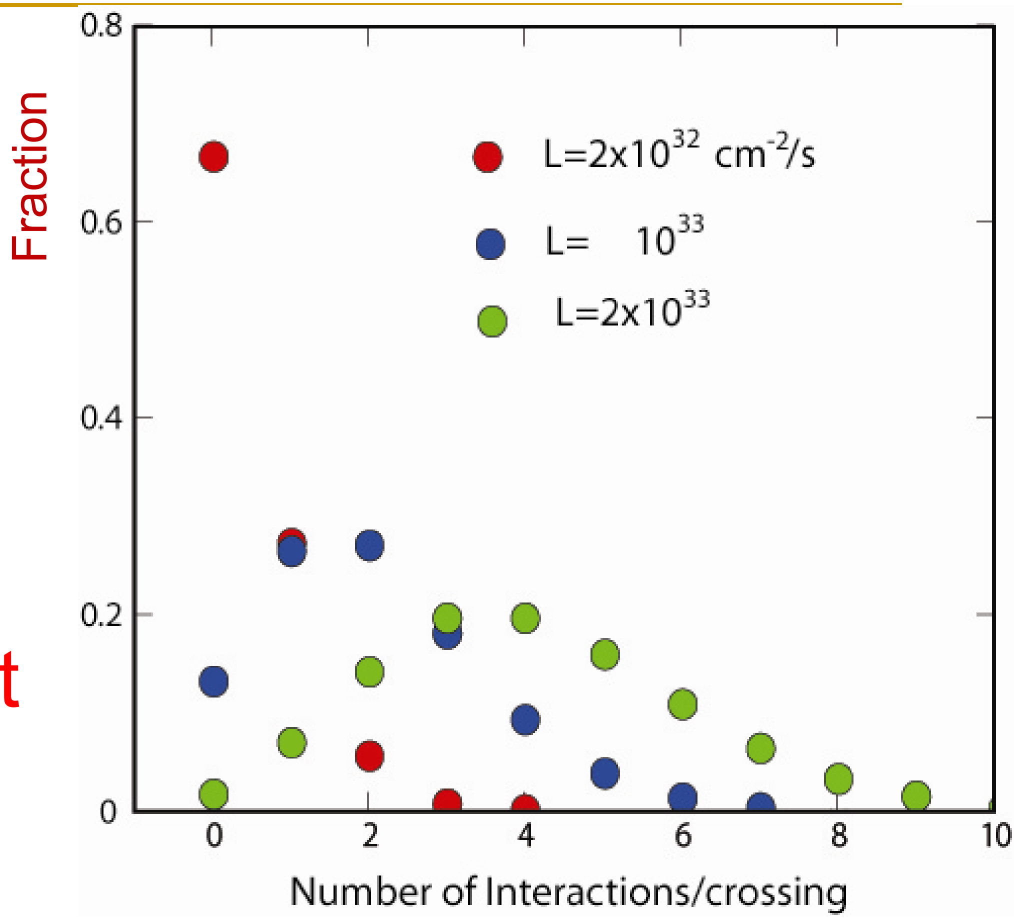
# ~~Current~~ Nominal Running Conditions

- Luminosity $2x10^{32}$ $cm^{-2}/s$ at beginning of run
- Take $\sigma$ = 60 mb, [$\sigma$(total) - $\sigma$(elastic) - $\sigma$(diffractive)]
- Account for only 29.5 MHz of two filled bunches
- Most xings don't have an interaction
- Need 1st level trigger "L0" to reduce data by factor~30 to 1 MHz
- Higher Level Triggers reduce output to 2 kHz



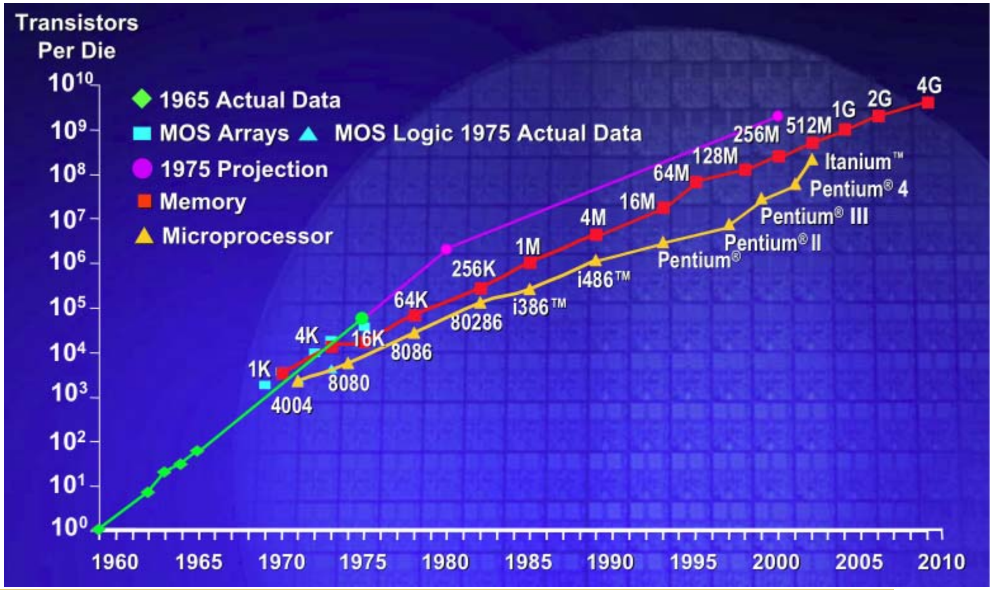
# Upgrade Running Conditions

- At $L=10^{33}$ increases average # of int/xcrossing to only ~2.3
- At $L=2x10^{33}$ increases to ~4.6
- We are learning a great deal from current running, since the L/bunch xing is high



# Upgrade Trigger & DAQ

- Readout entire detector at 40 MHz
- Have an software based trigger
- Use detached vertex information early on in Trigger
- Take advantage of Moore's law increases in CPU & storage
- Have "Interaction trigger" to be able to throttle rate



# Constraints

- Need to be ready for 2016 installation
- Super Belle is **approved** (see http://kek.jp/ intra-e/press/2010/KEKBupgrade.html) and plans to start taking data in 2014, with a final projected luminosity of $8 \times 10^{35}$ $cm^{-2}/s$, and a lower initial luminosity.
- Money
- Learning from current running

# Two Stage Plan

- First Upgrade step with a goal of $L=10^{33}$, followed by a second upgrade to higher L.
- First phase: After 6 $fb^{-1}$, collect ~50 $fb^{-1}$ more
- New VELO, Save Straws, but new electronics, RICH photon detectors, TT & IT replacement, Calorimeter & some muon electronics
- Costs: very rough estimate about ½ that of the current detector

# Phase II

- Detector Improvements independent of instantaneous Luminosity
  - Torch or Super-RICH (Maybe in Phase I ?)
  - Better Ecal segmentation
- Improvements necessary to run at higher L
  - Changes to tracking: IT & OT geometry

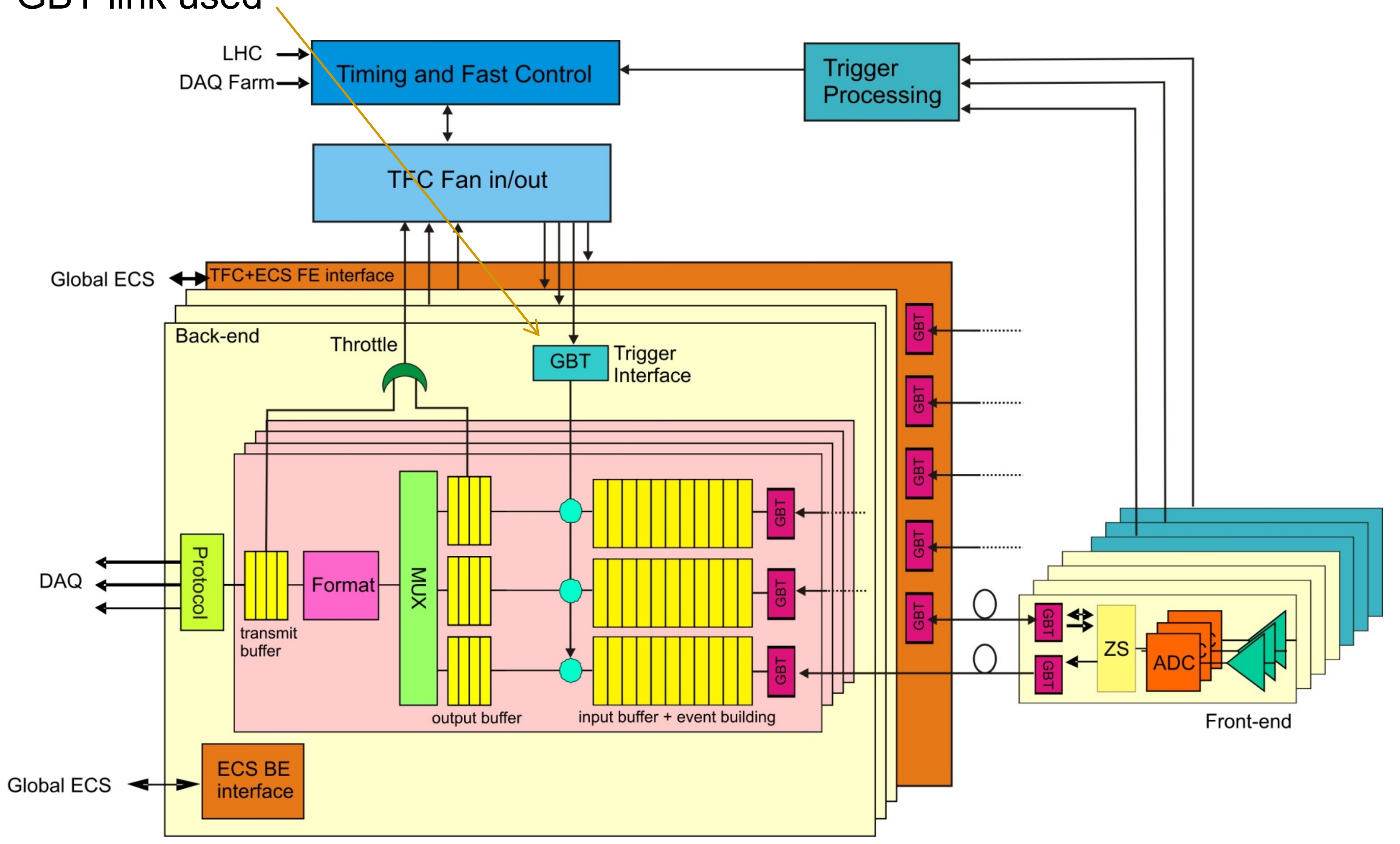
# Uprgrade Categories

- Introduction
- Physics goals
- VELOPiX
- Tracking (baseline Si & Straws)
- RICH –TORCH
- Calorimeters
- Muon
- Online
- Trigger
- Electronics
- Simulations & Software

# Progress

# Electronics/DAQ Architecture

- Zero-suppressed readout
- GBT link used



# Upgrade Electronics Specifications

Recent progress on:

- Modular architecture
- Interaction trigger
- DAQ interface
- Zero suppressed + Non-zero suppressed
- OK within a sub-detector
- Computing plan

Next steps: Organize simulations for defining buffering limits. We need each sub-detector to provide data

# Common projects

GBT + Versatile Link:

Good progress

Proto SERDES: initial tests look good

GBTIA successfully coupled to photodiode

Corrected version of GBLD under test

ACTEL FPGA irradiations postponed until August (Syracuse)

Infrastructure

Using existing fibres, transmission limited to < 6 Gbit/s

Info needed on Radtol Voltage Regulators……….

(OT, Calo replied)

New ‘CC-PC’ nearly ready (CBPF, Rio)

# TELL40

From Jean-Pierre Cachemiche

Mezzanine-based proposal

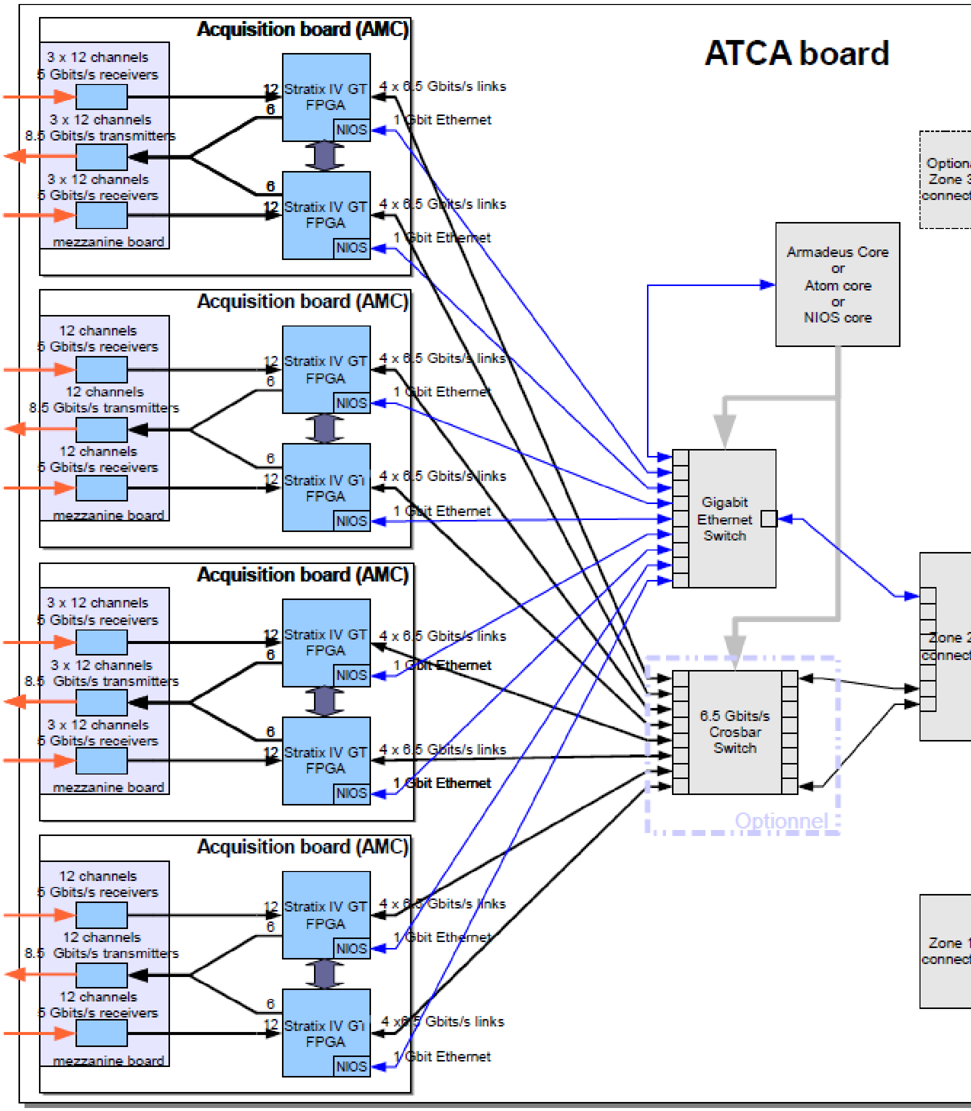
ATCA 'motherboard'

Multiple mezzanines required:
'GBT-DAQ', 'GBT-ECS/TFC', 'GOL'

For data:
~ 96 input links (4.8 Gbit/s)

Output interface to DAQ under study:
eg large buffers (don't rely on buffering in switch)

Starting to look at event building & data-packing

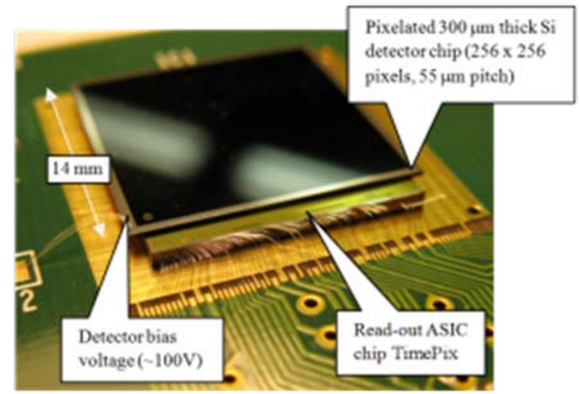


# Simulations

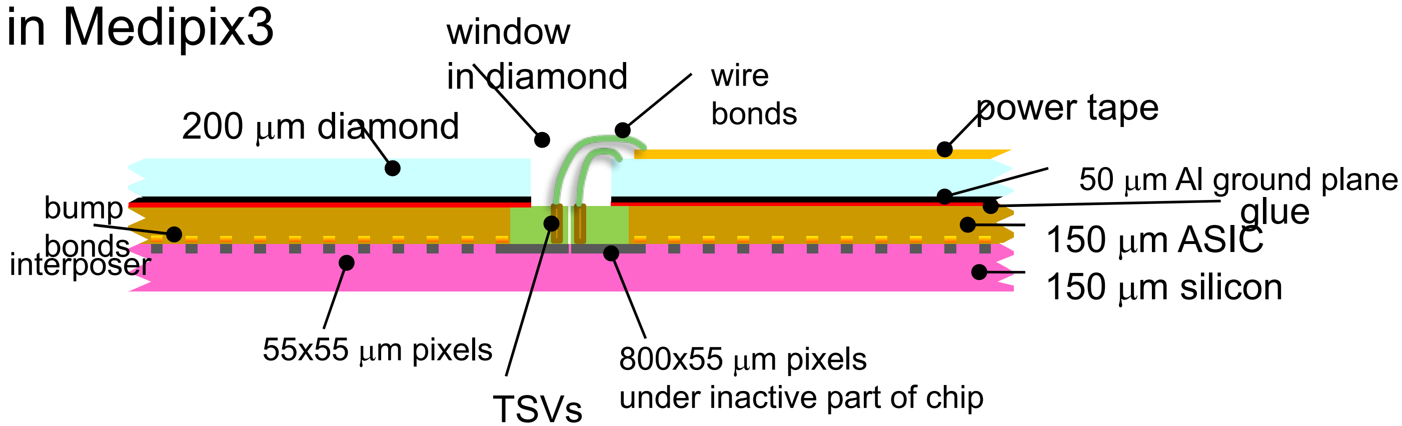
- Optimize new detector components.
- Substantiate physics reach of the proposed upgrade:
  - More hostile event composition can easily wash out gains from luminosity increase (we have seen plenty of examples of this already).
  - The toughest part of heavy flavor experiment at hadronic collider is triggering, especially of hadronic final states. Realistic trigger simulations (timing!) unfortunately require mature and sophisticated simulation code.
- All detectors are being worked on - substantial progress.

# VELO Upgrade

- Essential for establishing precision verticies
- Essential for trigger & tracking
- Upgrade baseline VELOPix is based on Medipix/Timepix Pixel readout chip




  - 256 x 256 pixels 55 μm square. Chip is 3 side buttable
  - By using TSV (Through Silicon Via) dead side can be reduced to 0.8 mm in Medipix3

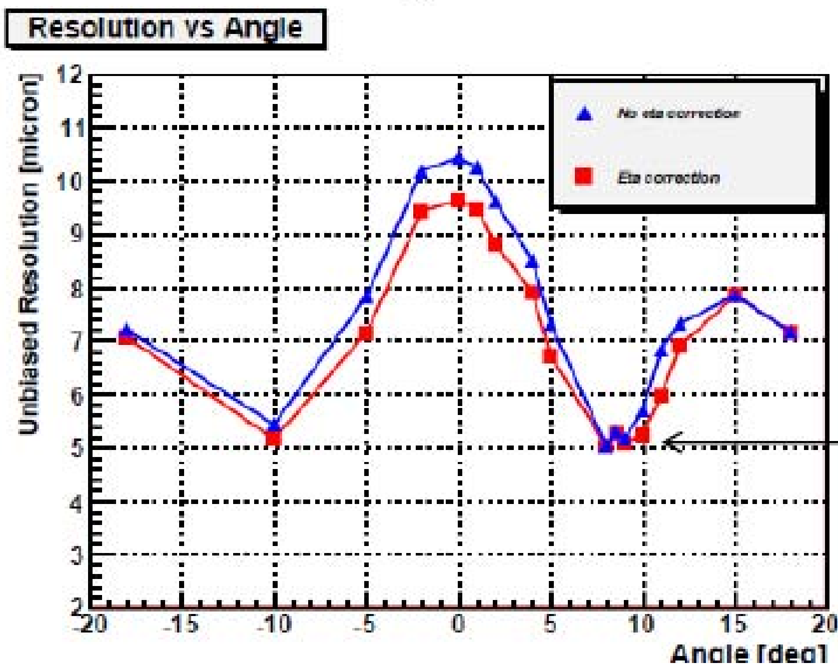


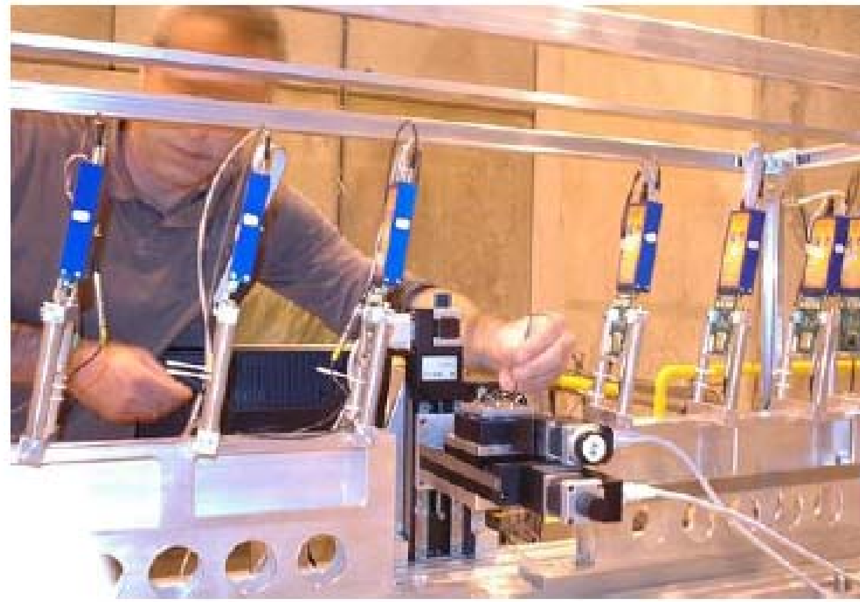
# Work Packages

- Strawman detector
- Cooling choice
- Module cooling structure and hybridisation
- Link technology
- Planar silicon sensor
- Diamond sensor
- 3d silicon sensor
- Simulation software
- Electronics
- Infrastructure
- R. F. foil

# VELOPix Test Beam

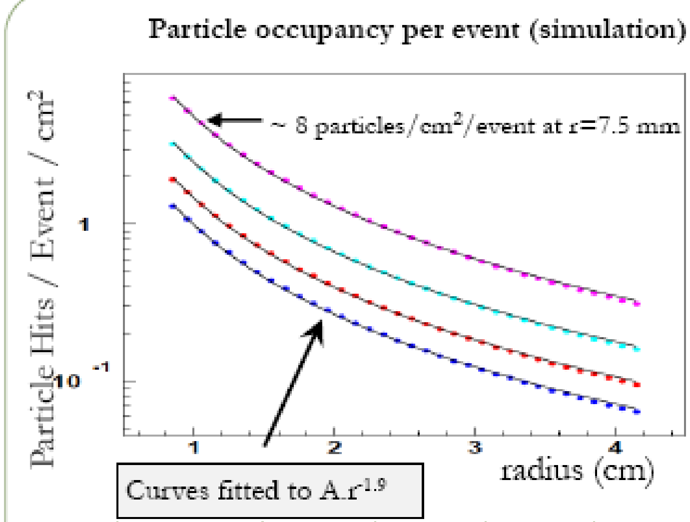
- Particle telescope →
  - obtained ~2 um track prediction error at the D.U.T.
  - High track rate: ~ 1000 tracks/s
  - 1 ns timestamp on tracks.



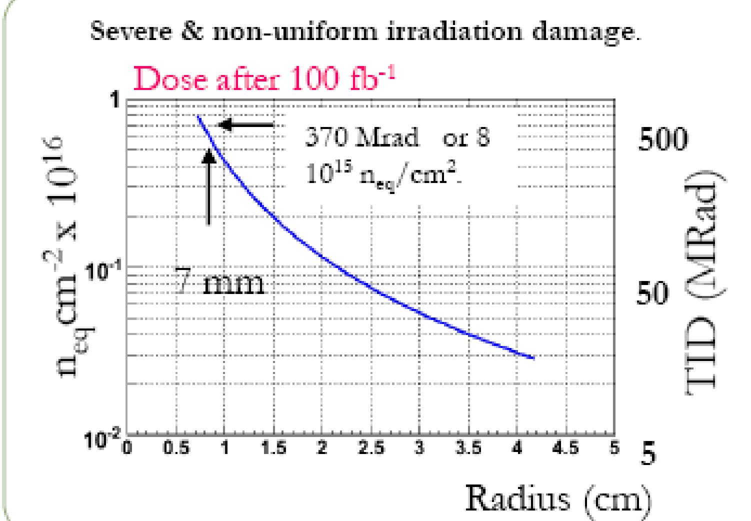



5 um at 8 degree,
still including 2.3um track prediction error.
Red curve is with eta correction.

# VELO Environment at High L



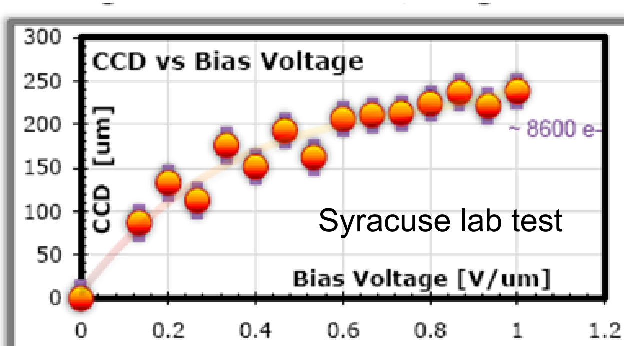

| Luminosity ($cm^{-2}s^{-1}$) | $2.10^{32}$ Current | $5.10^{32}$ | $10.10^{32}$ | $20.10^{32}$ Upgrade |
|---|---|---|---|---|
| A= | 0.98 | 1.46 | 2.46 | 4.80 |




=> Danger of thermal run away !

=> Silicon must be cooled to -10 $^0$C.

- Sensor choices
  - Thin planar Silicon: 100-150 μm p on n, or 3D
  - Diamond: solves thermal runaway, better radiation resistance

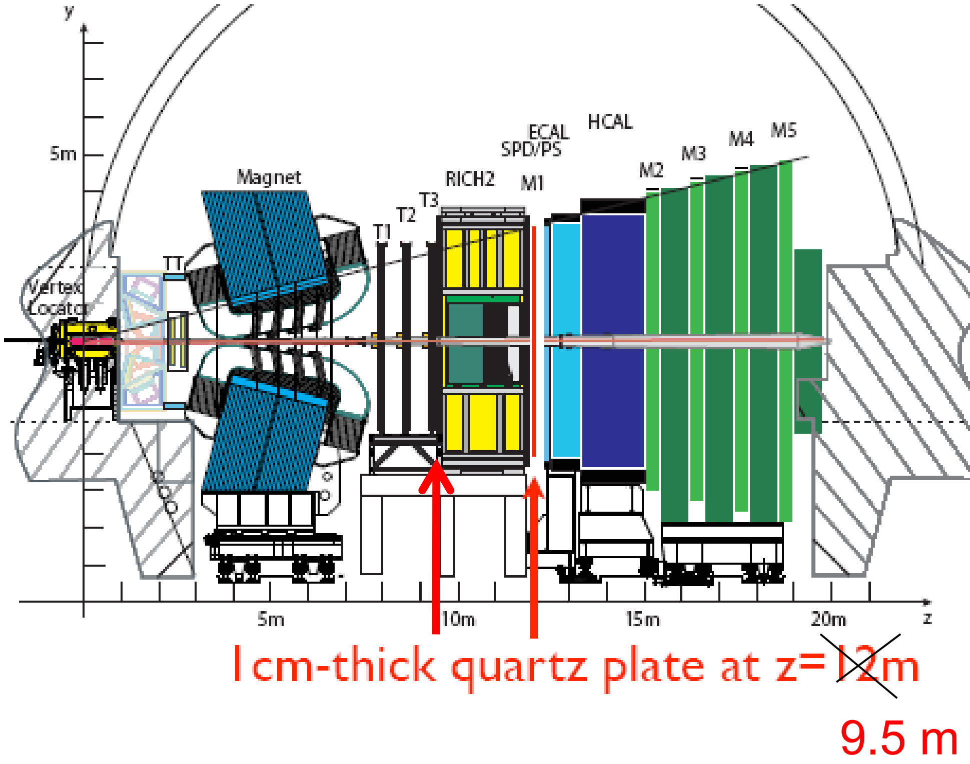


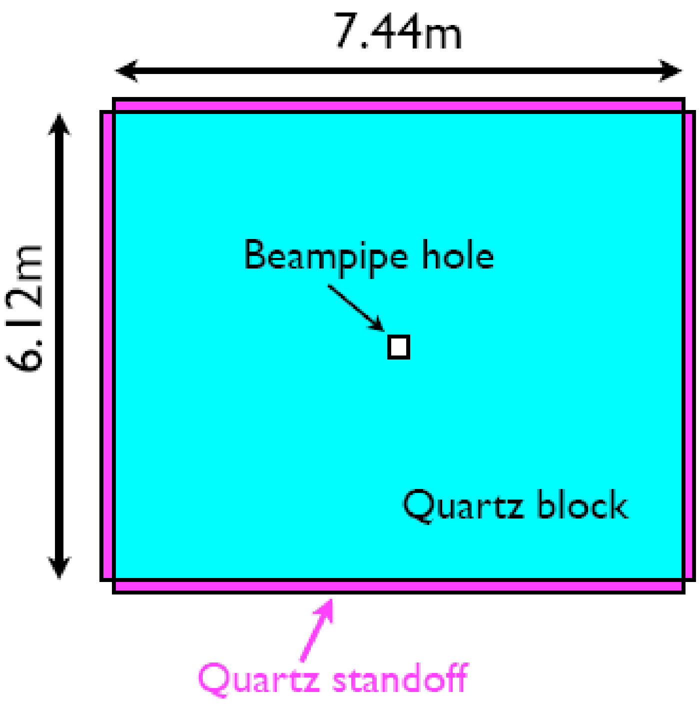
# RICH

- RICH simulation
- RICH photon detector evaluation (MAPMT R7600)
- RICH electronics
- RICH mechanics
- TORCH simulation
- TORCH R&D
- TORCH electronics

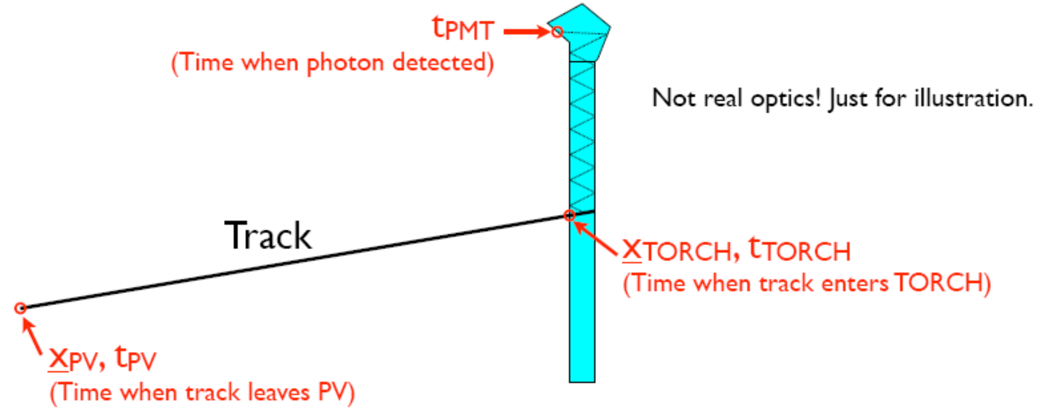
# The Torch

- Idea: Measure Time-of-Flight using Cherenkov radiation in a 1 cm thick quartz block



# Principle



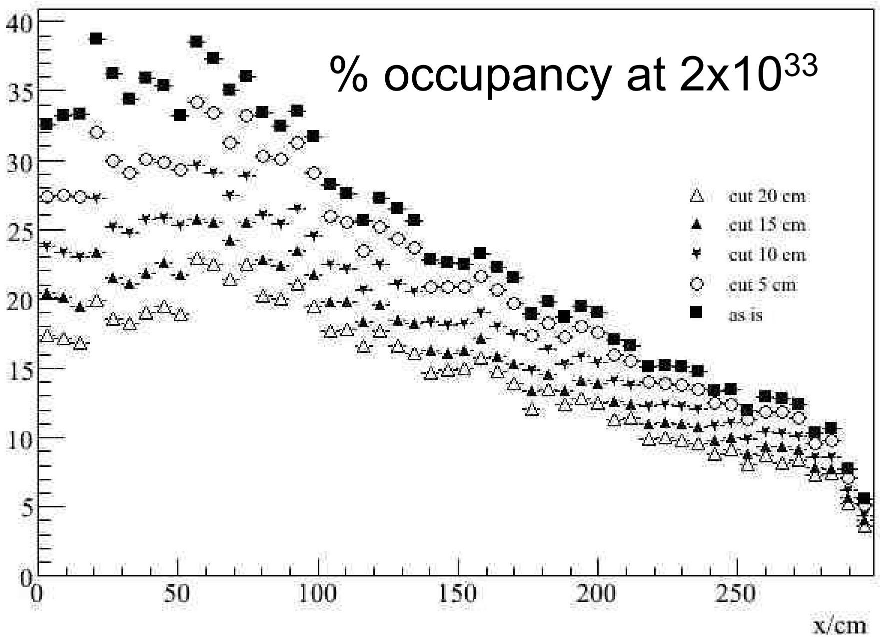

- Measure time it takes Cherenkov light to get to photodetectors, this takes into account different Cherenkov angles for the emitted light for different particle species but relies on different flight times over the ~10 m from production point to quartz
- Need photon detectors with good time resolution: Micro-Channel-Plates

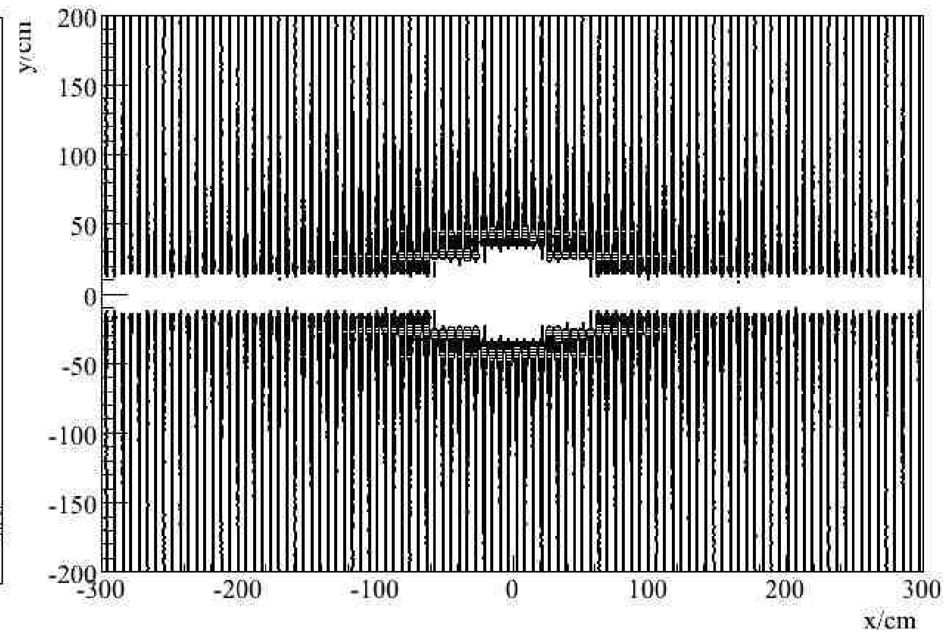
# Calorimeters & Muon

- These detectors currently are readout at 40 MHz
- Electronics plan is already worked out
- Some concerns especially about occupancies in inner part of EM calorimeter in Phase II
- Muon: One new board needed

# Tracking

- Outer Tracker occupancies will become unacceptably high in Phase II
- Solutions
  - Enlarge Inner tracker
  - Use faster gas to reduce spillover



# Tracking

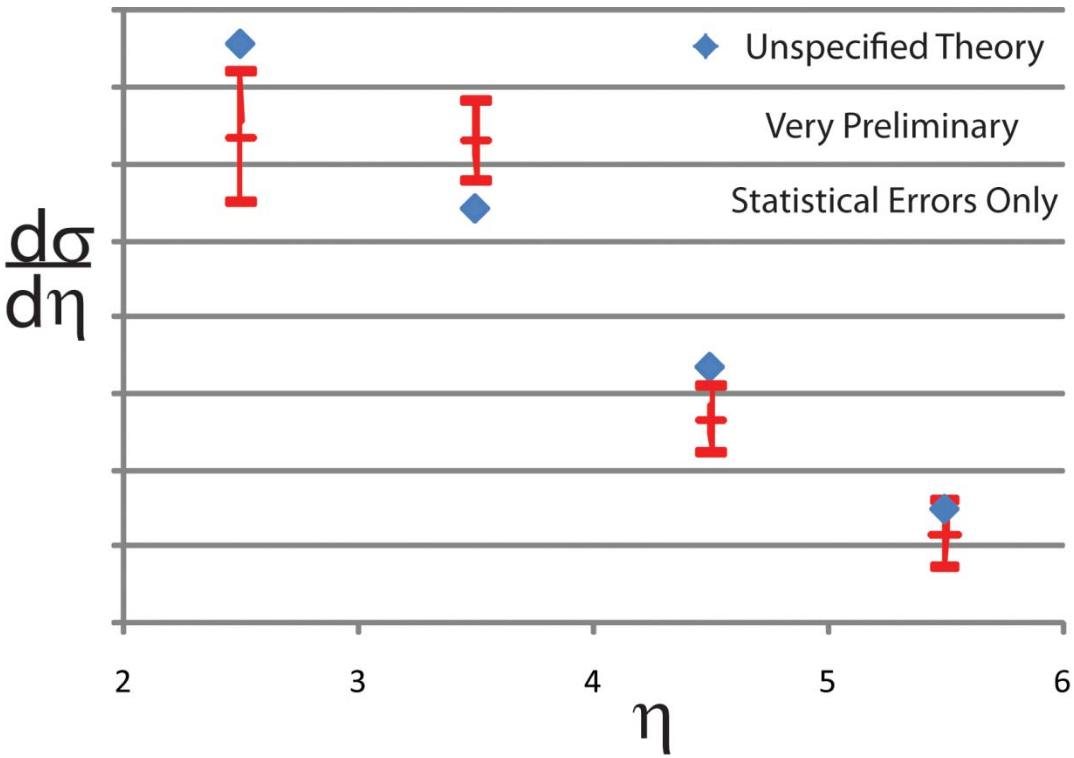
- OT electronics is proceeding nicely
- Groups working on Fibers for IT
- Rebuild of IT & TT needs to be guided by current experience in tracking & triggering. Intellectual effort needed here on implications for ghost rate reduction & trigger speed

# Trigger

- Many ideas on how to speed up
  - Use VELOPix TT match?
  - This would be helped by reducing material and/or increasing B field between VELO & TT
  - All schemes need detailed simulations

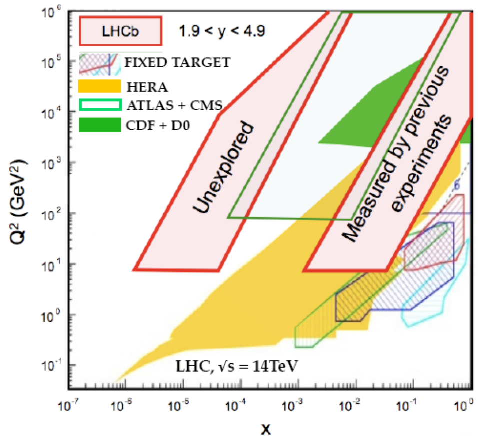
# LHCb High $P_t$ Physics

- Unique capabilities at high $\eta$
- Example: $\sigma(pp \rightarrow b\bar{b}X)$ at 7 TeV

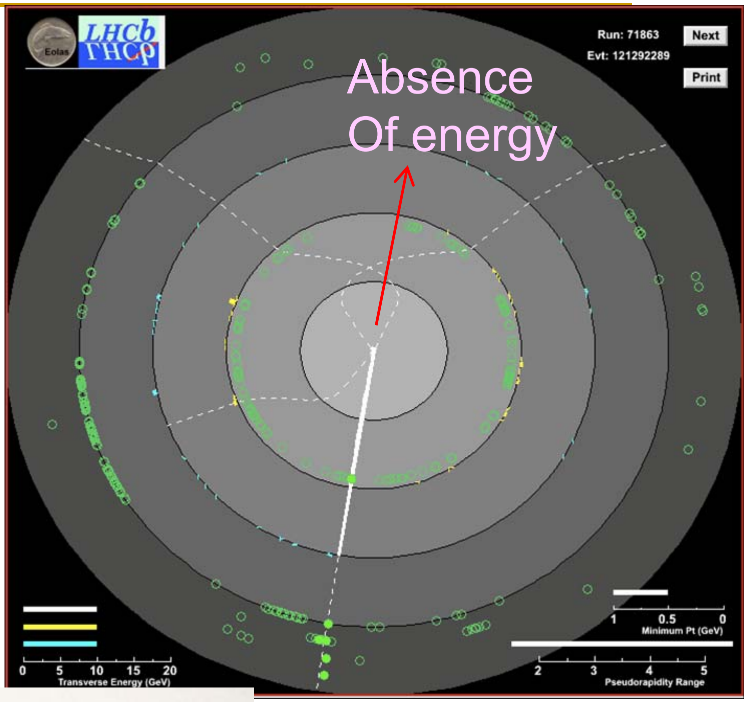


# W/Z cross-sections

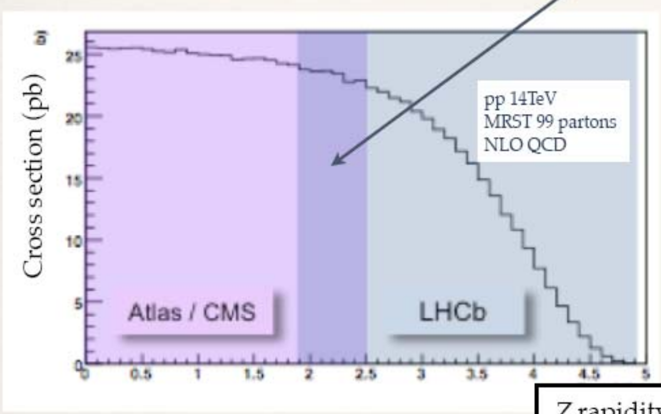
- Precision electoweak physics
- Expect $10^6$ W's in 1 $fb^{-1}$



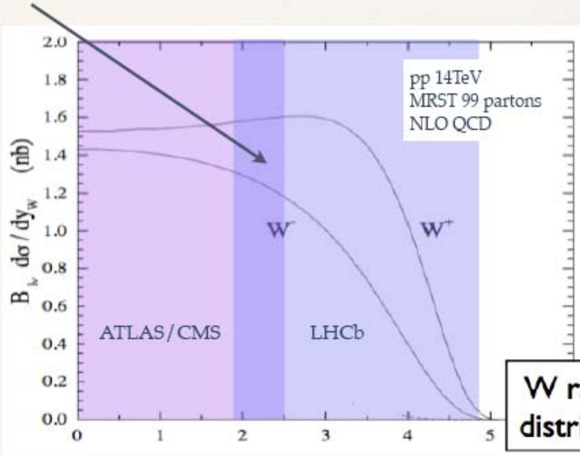

First event candidate




Overlap region



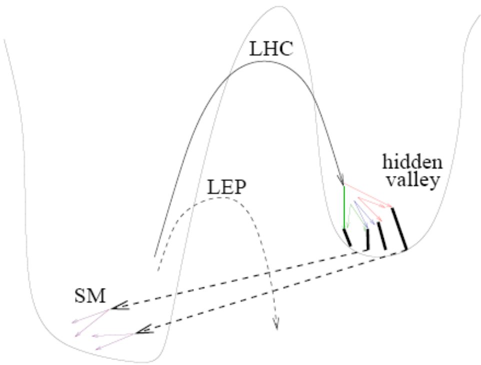

Z rapidity distribution



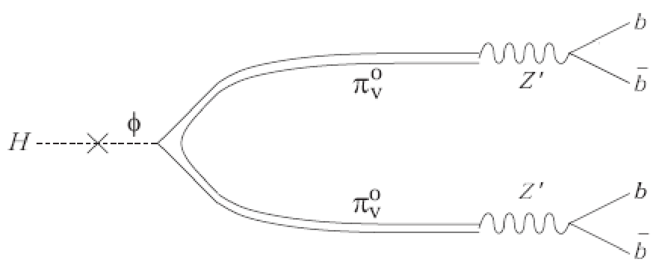

W rapidity distribution

# Hidden Valley Higgs decays

- New heavy Gauge sectors can augment the Standard Model (SM) as well SUSY etc..
- These sectors arise naturally in String theory
- It takes Energy to excite them
- They couple to SM via Z′ or
   heavy particle loops

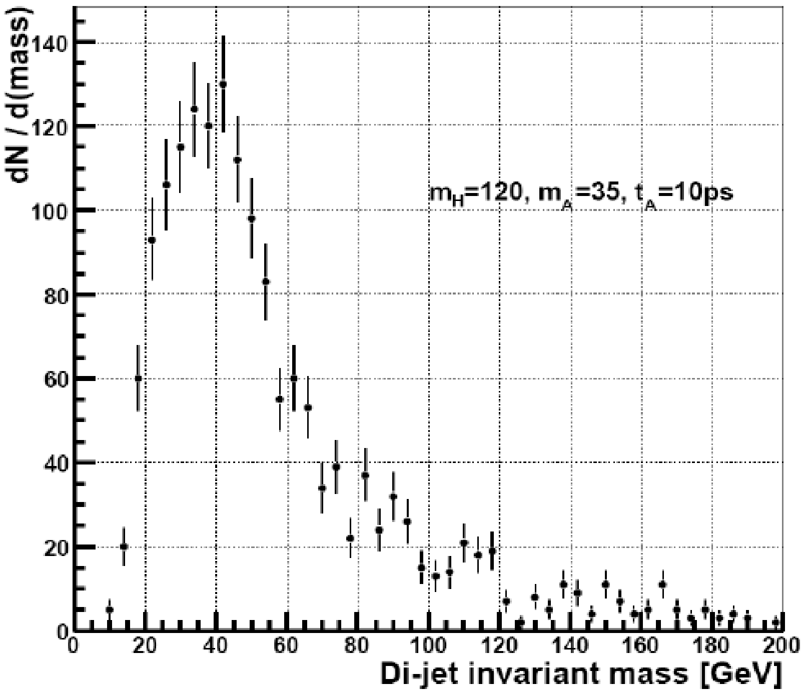


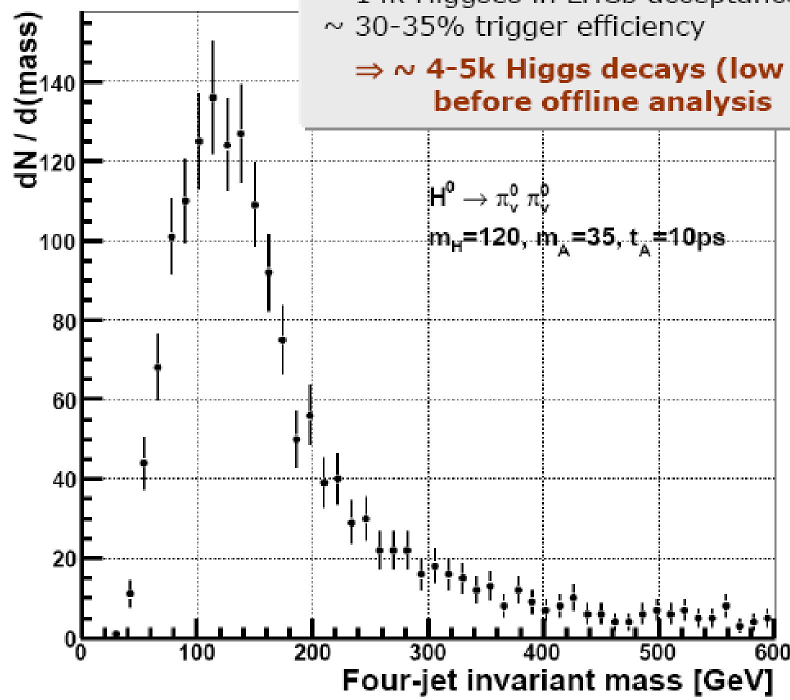

- Hidden Valley provides new scalars $\pi^o{}_v$, allowing $H^o \rightarrow \pi^o{}_v\, \pi^o{}_v \rightarrow bb$, with long lifetimes possible




- From Strassler & Zurek [hep-ph/604261]

# Mass Resolutions




~ 14k Higgses in LHCb acceptance for 2fb$^{-1}$
~ 30-35% trigger efficiency

**⇒ ~ 4-5k Higgs decays (low bckgrd) before offline analysis**

- Expect a few thousand reconstructed decays in 2 fb$^{-1}$

# Conclusions

- We hope to see effects of NP found by Atlas/CMS (CD's) in "flavor" studies in our 1st 6 $fb^{-1}$
- Upgrading will allow us to precisely measure these effects
- At low $\mathcal{L}$ flavor physics can be done at LHCb, ATLAS and CMS. At $\mathcal{L}$ >$10^{34}$ flavor physics will be only possible at the upgraded LHCb
- Complementary to SuperB:
  - LHCb – $B_S$, SuperB – τ's
  - Healthy overlap - $B^o$, $B^-$

| Upgraded Sensitivities (50 $fb^{-1}$) | |
|---|---|
| Observable | Sensitivity |
| CPV($B_s \to \phi\phi$) | 0.024 |
| CPV($B_d \to \phi K_s$) | 0.027-0.064 |
| CPV($B_s \to J/\psi\phi$) ($2\beta_s$) | 0.004 |
| CPV($B_d \to J/\psi K_s$) ($2\beta$) | 0.004-0.014 |
| CPV($B \to DK$) ($\gamma$) | <1.4° |
| CPV($B_s \to D_s K$) ($\gamma$) | 1.4-2.8° |
| $\mathcal{B}(B_s \to \mu^+\mu^-)$ | ~15% of SM |
| $A_{FB}(B \to K^* \mu^+\mu^-)$ | Zero to ±0.1 $GeV^2$ |
| $\sigma(\sin 2\psi)(B_s \to \phi\gamma)$ | 0.03 |
| Charm mixing $x'^2$ | $3x10^{-5}$ |
| Charm mixing $y'$ | $4x10^{-4}$ |
| Charm CP $y_{CP}$ | $2x10^{-4}$ |

# The End

# $a_{sl}$

- Note that $$2|M_{12}| = \Delta M = M_H - M_L$$
$$2|\Gamma_{12}|\cos\phi = \Delta\Gamma = \Gamma_L - \Gamma_H$$
- Another quantity of interest is
$$a_{sl} = \mathrm{Im}\frac{\Gamma_{12}}{M_{12}} = \frac{|\Gamma_{12}|}{|M_{12}|}\sin\phi = \frac{\Delta\Gamma}{\Delta M}\tan\phi$$
- Which characterizes CPV in flavor specific $B \rightarrow f$. Generally $B^o \rightarrow X\ell^- \nu$, $\bar{B}^o \rightarrow X\ell^+ \nu$
- Here $|A(B\rightarrow f)| = |\bar{A}(\bar{B}\rightarrow \bar{f})|$, which is not always true

# $a_{sl}$ II

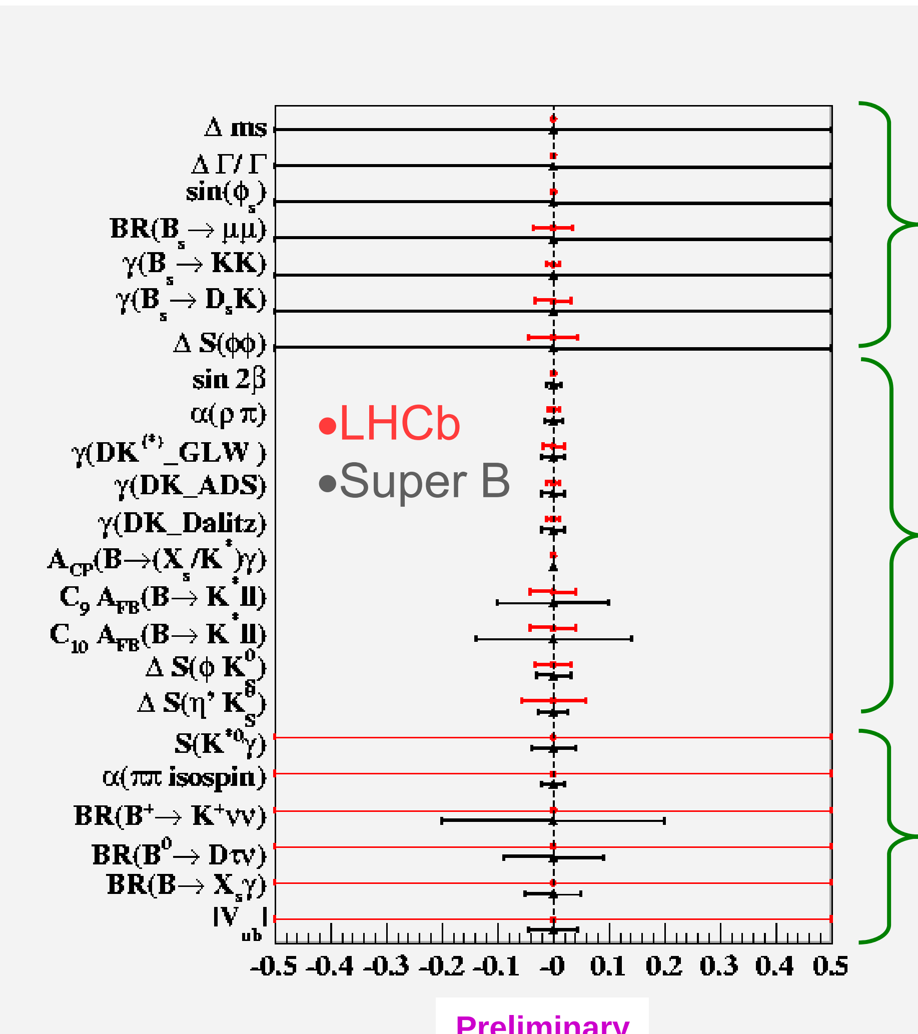
- Then $$a_{sl} = \frac{\Gamma\left(\bar{B} \to f\right) - \Gamma\left(B \to \bar{f}\right)}{\Gamma\left(\bar{B} \to f\right) + \Gamma\left(B \to \bar{f}\right)}$$
- Which is the asymmetry in wrong-sign decays & measures the CP violation in mixing
- As an example take f to be a semileptonic decay such as $B_s \to D_s^- \mu^+ \nu$. The measurement is to see an asymmetry between $D_s^+ \mu^- \nu$ and $D_s^- \mu^+ \nu$. Can use other decays.
- $$A_{SL} \equiv \frac{\Gamma(b\bar{b} \to \mu^+ \mu^+ X) - \Gamma(b\bar{b} \to \mu^- \mu^- X)}{\Gamma(b\bar{b} \to \mu^+ \mu^+ X) + \Gamma(b\bar{b} \to \mu^- \mu^- X)}$$

# Comparison with Super B factory

**Sensitivity Comparison ~2020**

LHCb 100 $fb^{-1}$ vs Super-B factory 50 $ab^{-1}$

SuperB numbers from M Hazumi - Flavour in LHC era workshop; LHCb numbers from Muheim



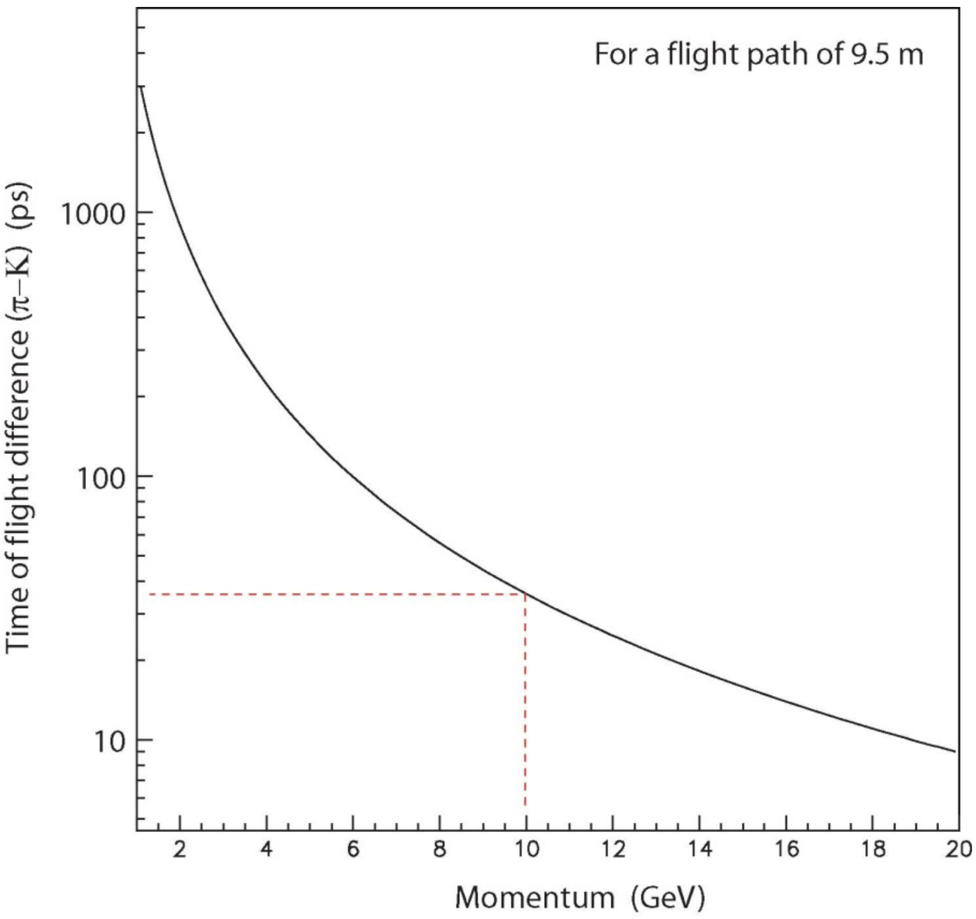

**$B_s$ highly favored at LHCb**

Common

No IP
Neutrals, ν

# Possible Separation

- ΔTOF (π–K) = 35 ps at 10 GeV → aim for 10 ps resolution per track
- With ~ 50 detected photons/track, this implies ~ 70 ps required per p.e.
- Simulation projects = 9 ps per track, as required

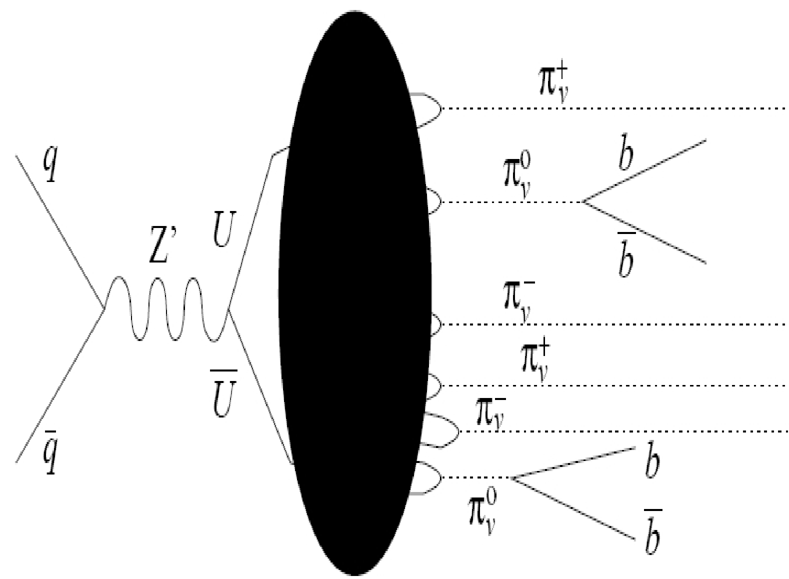



Needed: Hardware tests

# Other Possibilities: “Hidden” Gauge Sectors

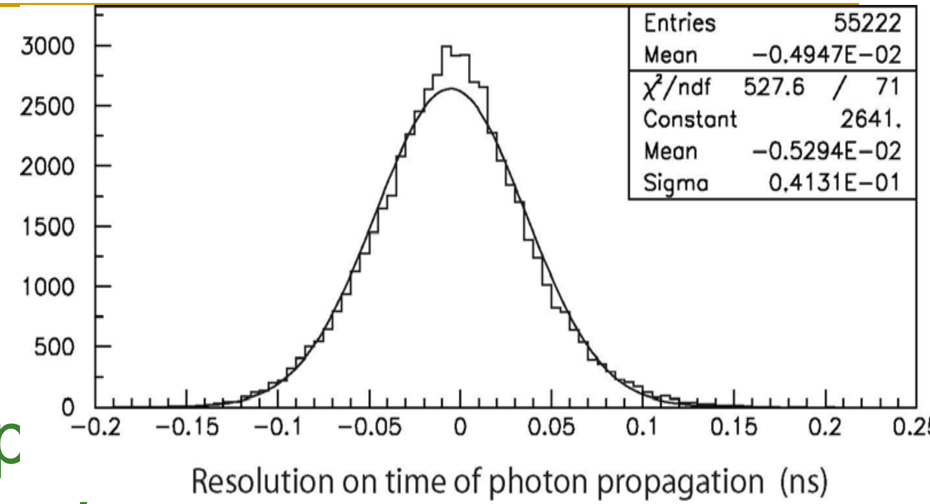
- Many possible extensions to SM, SUSY, ED, etc…
- Consider here adding a U(1)′ Gauge group with a color charge v, useful for generating Electroweak Baryogenisis
  - e. g. : Barger et al [hep-ph/0702001]. Carpenter et al [hep-ph/0607204], Strassler & Zurek [hep-ph/0604261, & 0605193] & many others
  - Produce new quark(s) $U_i$ via $Z' \to U\bar{U}$, fragmentation causes lots of particle production, with some particles containing new $U_1$ & $U_2$ with v=0. These scalar particles $\pi_v^0 \to b\bar{b}$ preferentially due to helicity conservation if $2m_B < m(\pi_v) < m_{WW}$

Strassler & Zurek



# Torch Simulations

- Smearing of photon propagation time due to the pixellization of photodetector ~ 40 ps




- Would increase to 130 p if the existing 32 × 32 pixel layout had to be used instead
- Assuming an intrinsic arrival time measurement resolution per p.e. of 50 ps the total resolution per detected p.e. is 40 ⊕ 50 = 64 ps

  With 50 p.e. / track this would give 64 /√50 = 9 ps per track, as required

# Interaction Trigger