# LHCb STATUS AND EARLY PHYSICS PROSPECTS

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on behalf of the LHCb Collaboration

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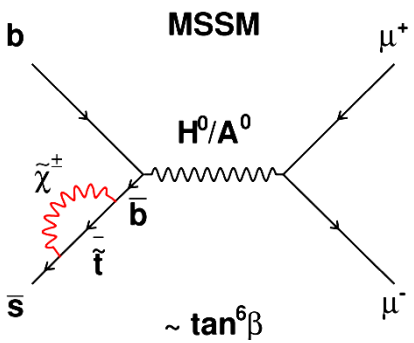
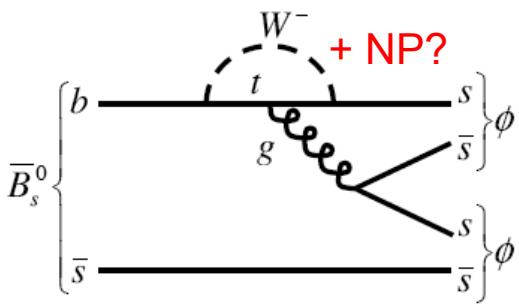
# Outline

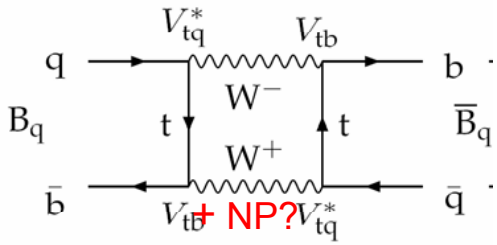
- Introduction to the LHCb Experiment
- Detector Overview and Performance
- Commissioning
- Early Physics at LHCb
- Conclusions

# The LHCb Experiment

- LHCb: dedicated B physics experiment at LHC
- Enormous progress in recent years from the B factories and Tevatron
  **What remains to be done at the LHC?**
- Focus has changed: no longer seeking to verify the CKM picture, instead searching for signs of New Physics beyond the Standard Model in the flavour sector
- $b \rightarrow s$ transitions: still limited knowledge, space for NP effects
- Flavour physics observables have sensitivity to new particles at high mass scales via their virtual effects in loop diagrams:



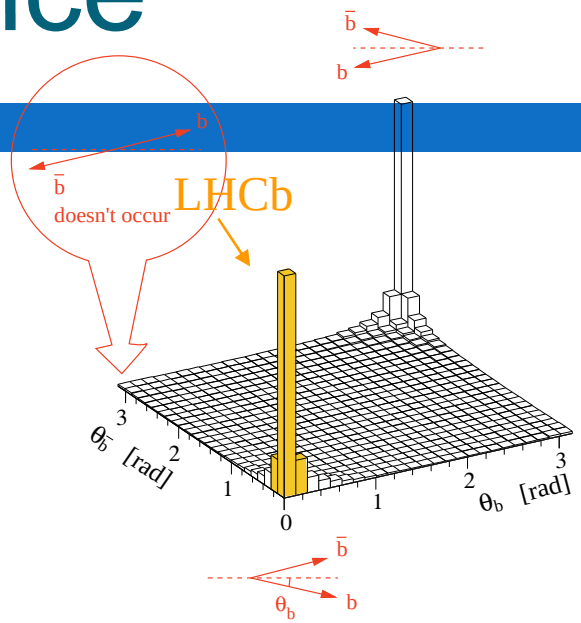



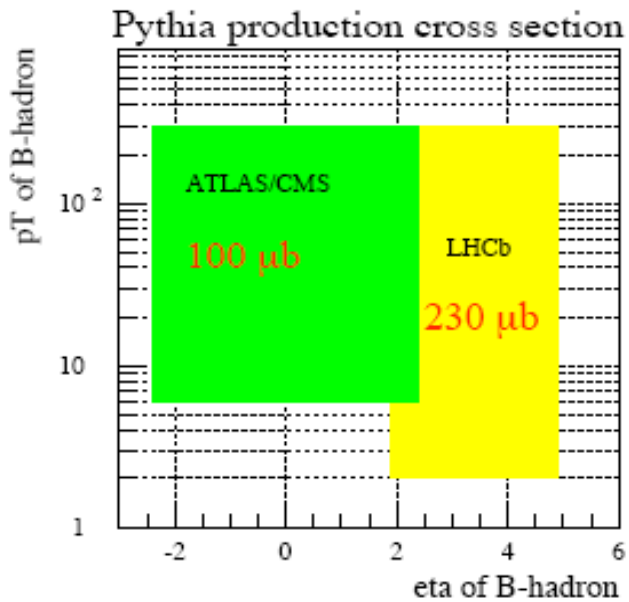
# The LHCb Experiment

- Advantages of beauty physics at hadron colliders:
  - High value of beauty cross section expected at 14 TeV:
    - $\sigma_{bb}$ ~ 500 μb (e+e- cross section at Y(4s) is 1 nb)
  - Access to all b-hadrons: $B^{\pm}$, $B^0$, $B_s$, $B_c$, b-baryons
- The challenges
  - Multiplicity of tracks (~30 tracks per rapidity unit)
  - Rate of background events: $\sigma_{inel}$~ 80 mb
- LHCb running conditions:
  - L limited to ~2 $10^{32}$ $cm^{-2}$ $s^{-1}$ by not focusing the beam as much as ATLAS and CMS
    - Maximize the probability of single interaction per bunch crossing
      - At LHC design luminosity pile-up of >20 pp interactions/bunch crossing
    - LHCb L reached soon after start-up
  - 2$fb^{-1}$ per nominal year ($10^7$s), ~ $10^{12}$ bb pairs produced per year

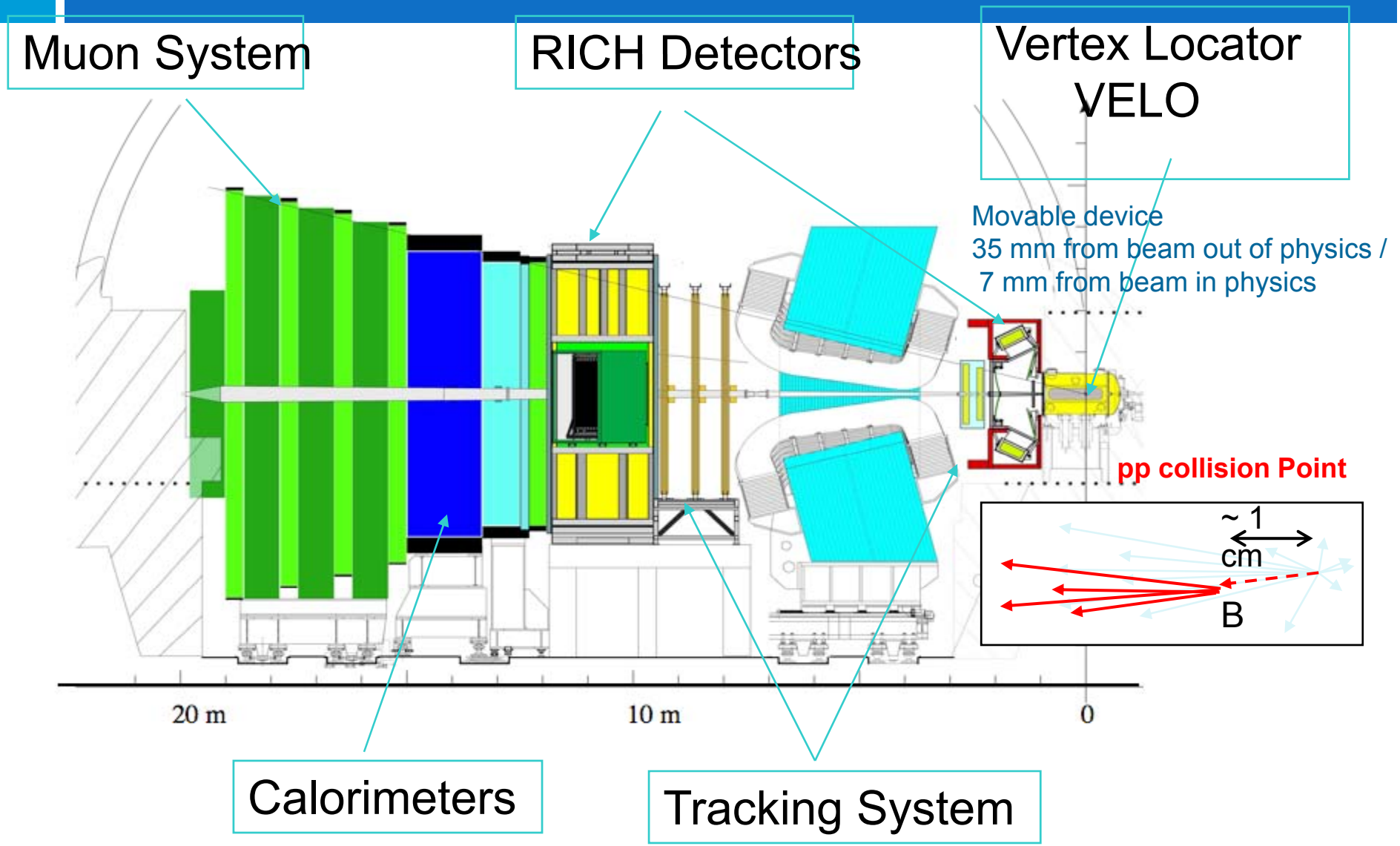
# The LHCb Acceptance

- Detector designed to maximize B acceptance (against cost)
- Forward spectrometer $1.9<\eta<4.9$
  - b-hadrons produced at low angle
  - Single arm OK as b quarks are produced in same fwd or backward cone
- Rely on much softer, lower $P_T$ triggers, efficient also for purely hadronic decays
- ATLAS/CMS: $|\eta|<2.5$
  - Will do B-physics using high $P_T$ $\mu$ triggers, mostly with modes involving di-$\mu$
  - Purely hadronic modes triggered by tagging $\mu$.



# The LHCb Detector

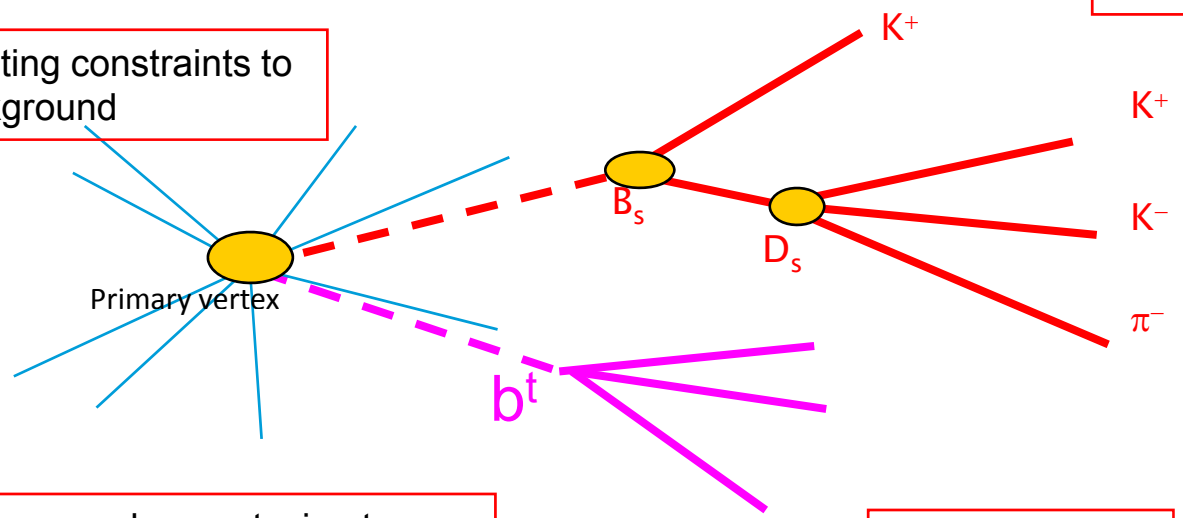


# Detector Performances

- Key features:
  - Highly efficient trigger for both hadronic and leptonic final states to enable high statistics data collection
  - Vertexing for secondary vertex identification
  - Mass resolution to reduce background
  - Particle identification

Example: $B_s \rightarrow D_s K$

Mass + pointing constraints to reduce background



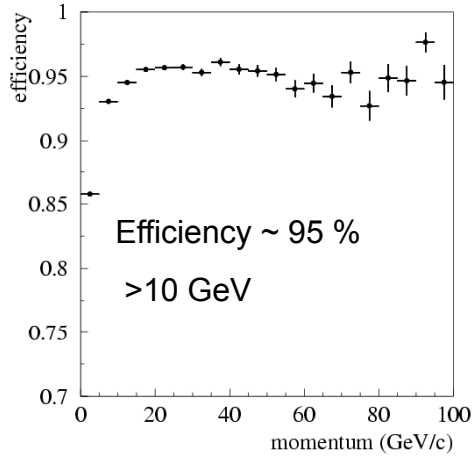

Good K/π separation

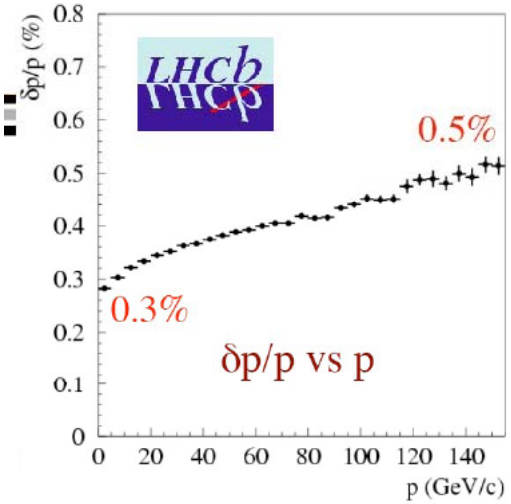
Good primary + secondary vertexing to measure proper time

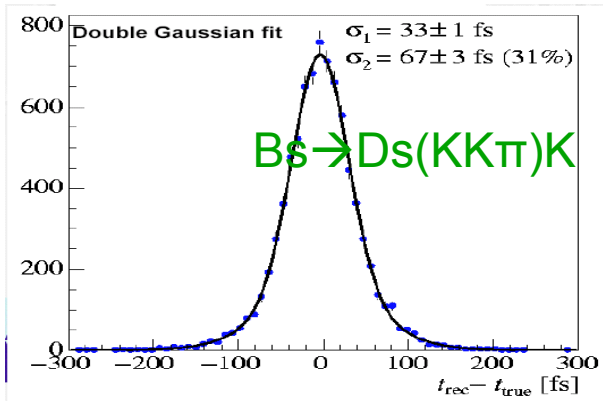
Flavour Tagging

# Detector Performances: Tracking

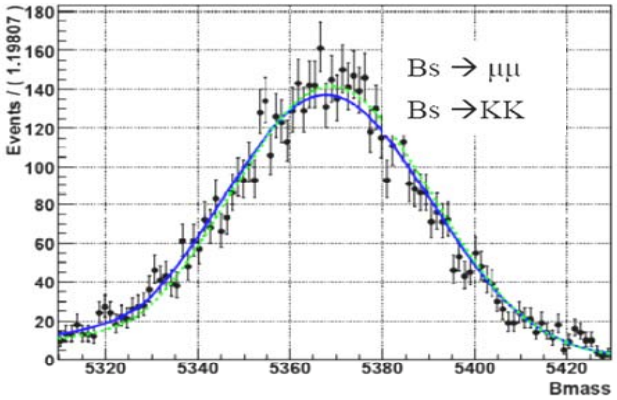
- Expected tracking performances:
  - Efficiency > 95% for tracks from B decays crossing whole detector
  - δp/p, depending on p: 0.3% ÷ 0.5%
  - Impact parameter resolution : $\sigma_{IP}$ ~ 30 μm
  - Proper time resolution: ~ 40 fs
  - B Mass resolution: 15÷20 MeV/c2




Proper time resolution ~ 40 fs




Mass resolution ~ 20 MeV

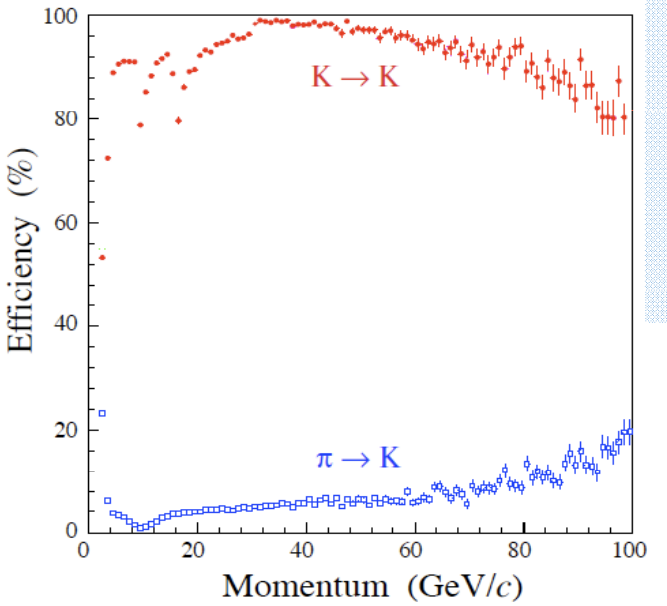
# Detector Performances: PID

Two RICH detectors with 3 radiators to cover range 2 < p <100 GeV :

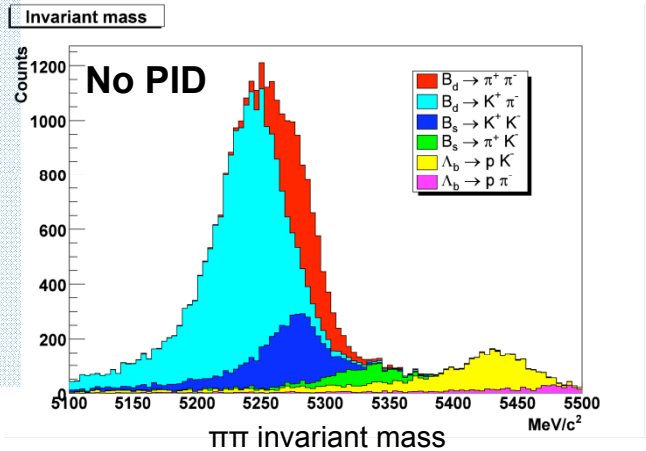
RICH1 Aerogel (2-10 GeV), C4F10 (10-60 GeV)

RICH2 CF4 (16-100 GeV)

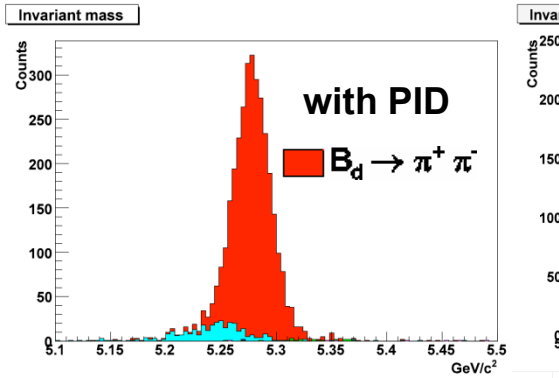
## π–K separation



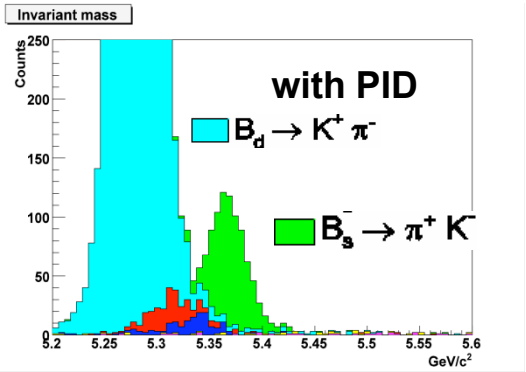

- Good π–K separation in 2-100 GeV/c range
  - Low momentum
    - Tagging kaons
  - High momentum
    - Clean separation of $B_{d,s}$ →hh modes




ππ invariant mass



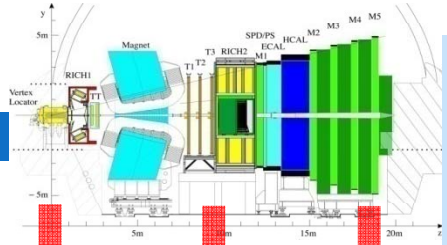

ππ invariant mass



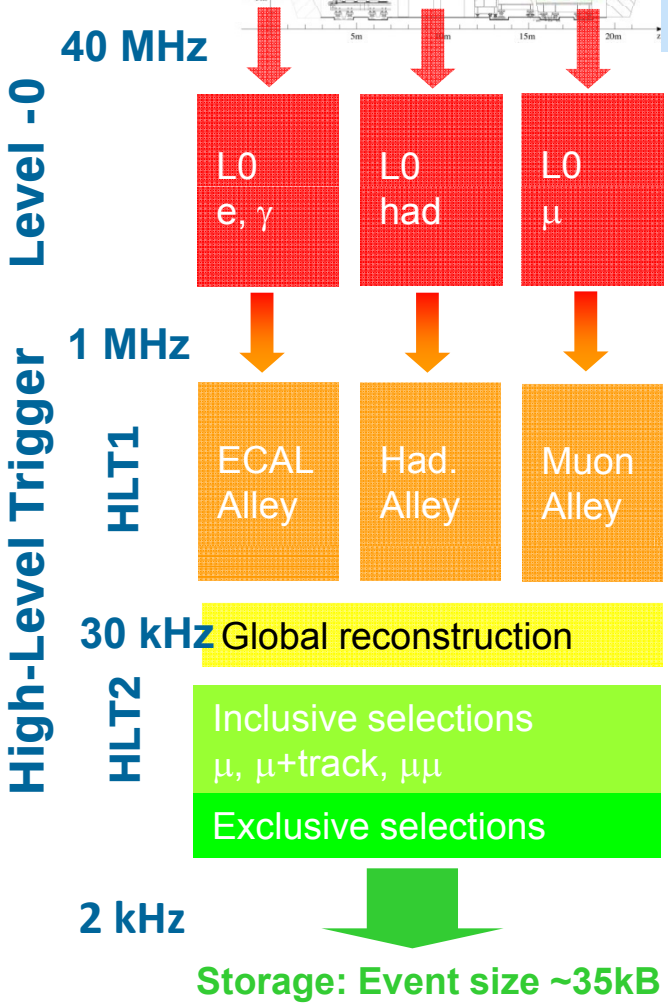

Kπ invariant mass

- Kaon ID ~ 88%
- Pion mis-ID ~ 3%

# LHCb Trigger



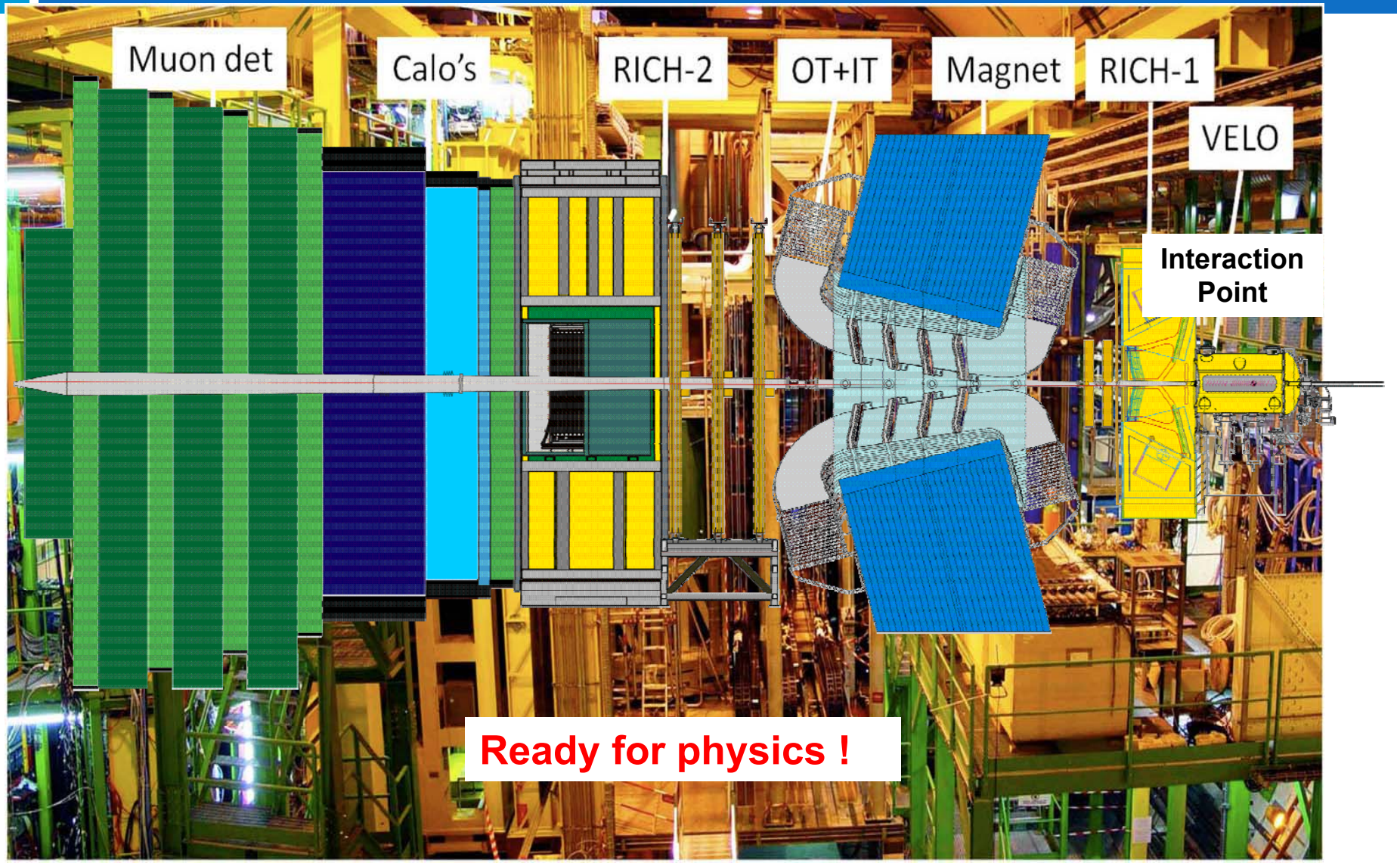
**Trigger is crucial as $\sigma_{bb}$ is less than 1% of total inelastic cross section and B decays of interest typically have BR < $10^{-5}$**




- Hardware level (L0)
  - Search for high-$p_T$ μ, e, γ, hadron candidates
- Software level (**H**igh **L**evel **T**rigger, HLT)
  - Farm with $\mathcal{O}$(2000) multi-processor boxes
  - HLT1: Confirm L0 candidate with more complete info, add impact parameter and lifetime cuts
  - HLT2: global event reconstruction + selections

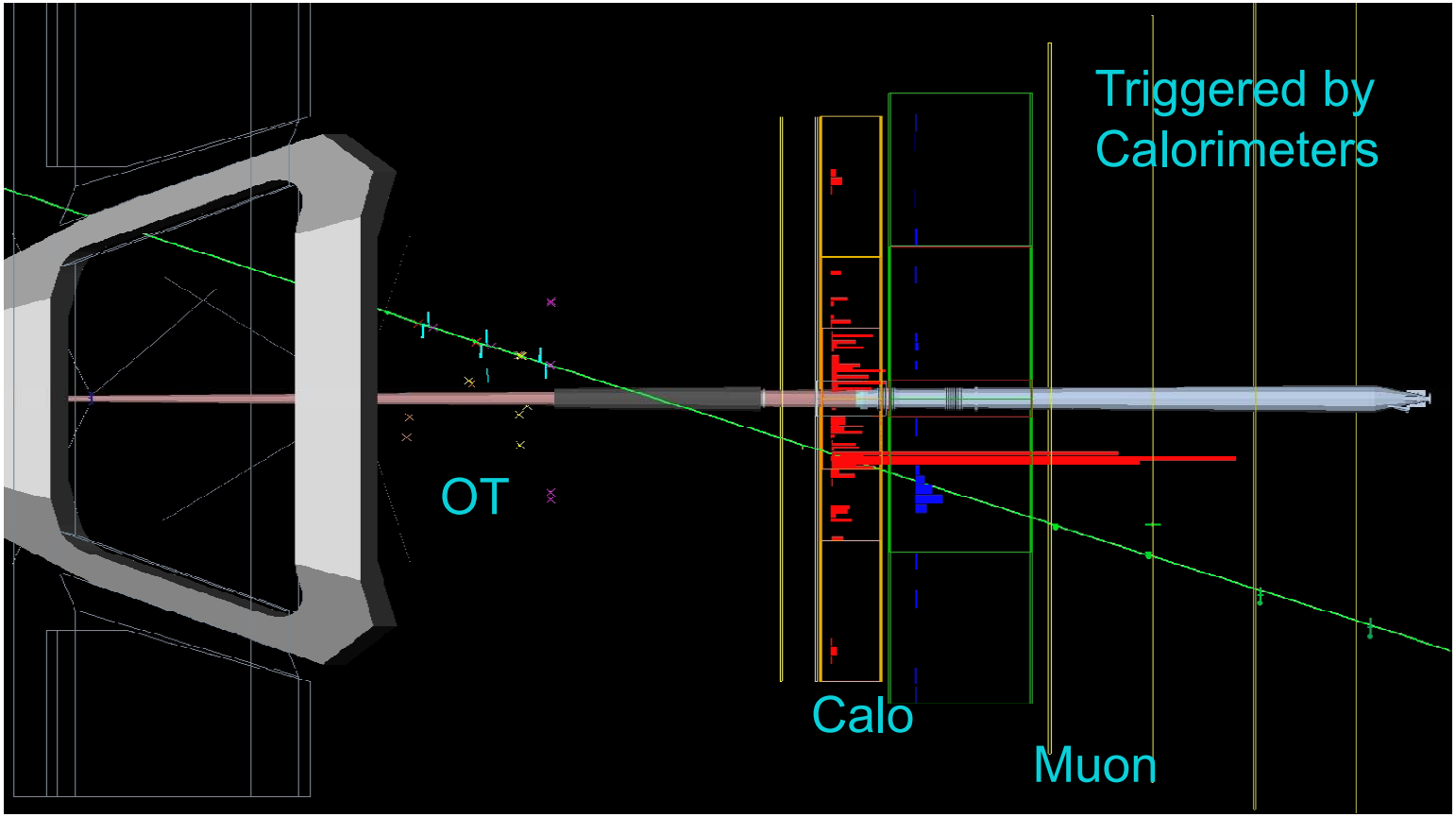
| | ε(L0) | ε(HLT1) | ε(HLT2) |
|---|---|---|---|
| Electromagnetic | 70 % | > ~80 % | > ~90 % |
| Hadronic | 50 % | | |
| Muon | 90 % | | |

# The LHCb Detector



# Commissioning: Cosmics

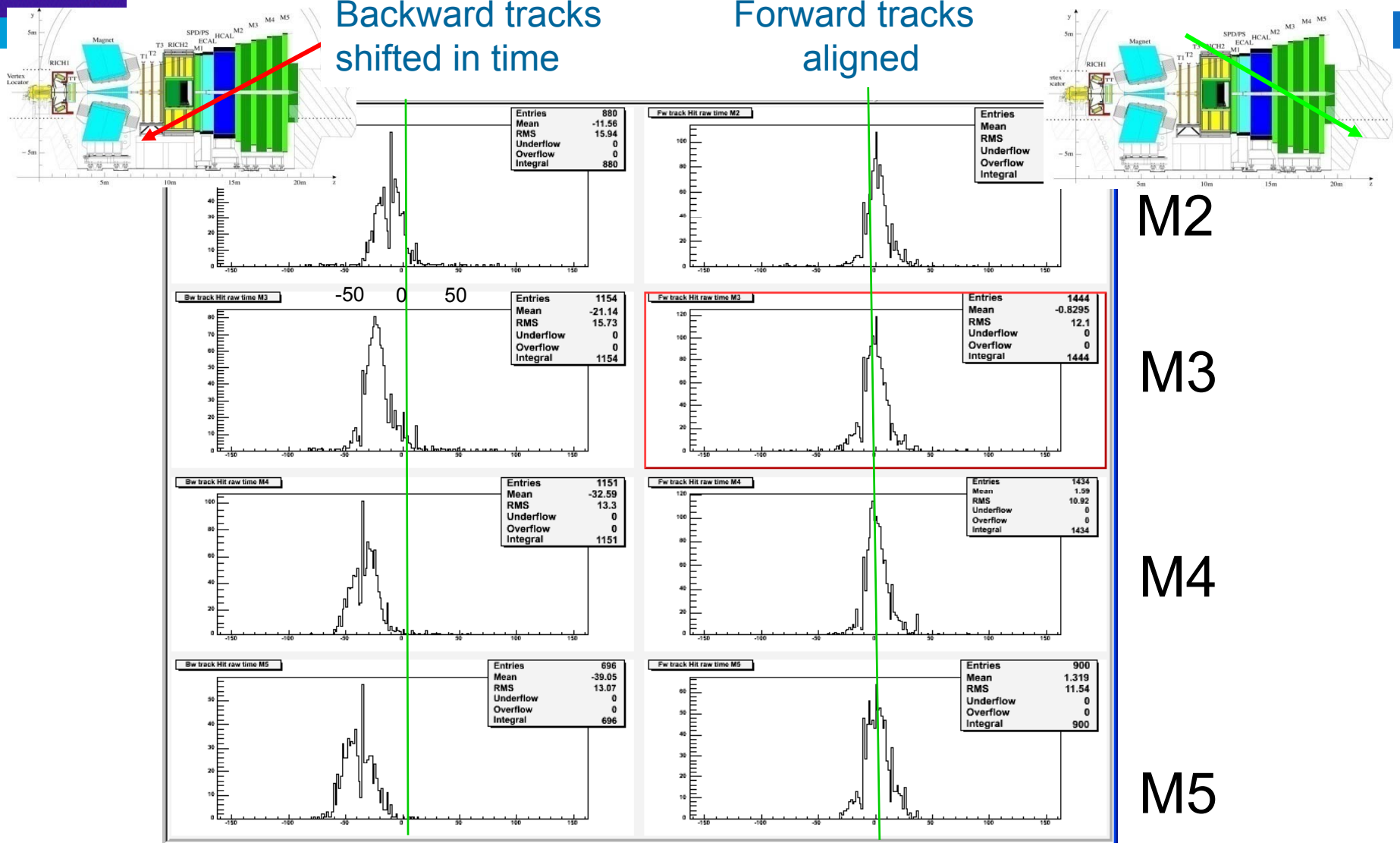
- LHCb geometry NOT well suited for cosmics… A challenge!
- Rate of ‘horizontal’ cosmics well below 1 Hz, still very useful
- Collected a total of ~ 1.1Million triggers



# Cosmic Alignment in Time of Muon Stations

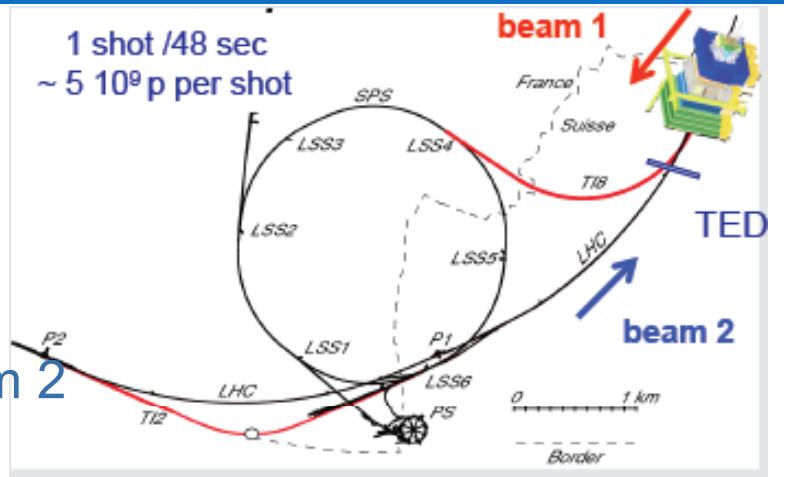
Backward tracks shifted in time

Forward tracks aligned



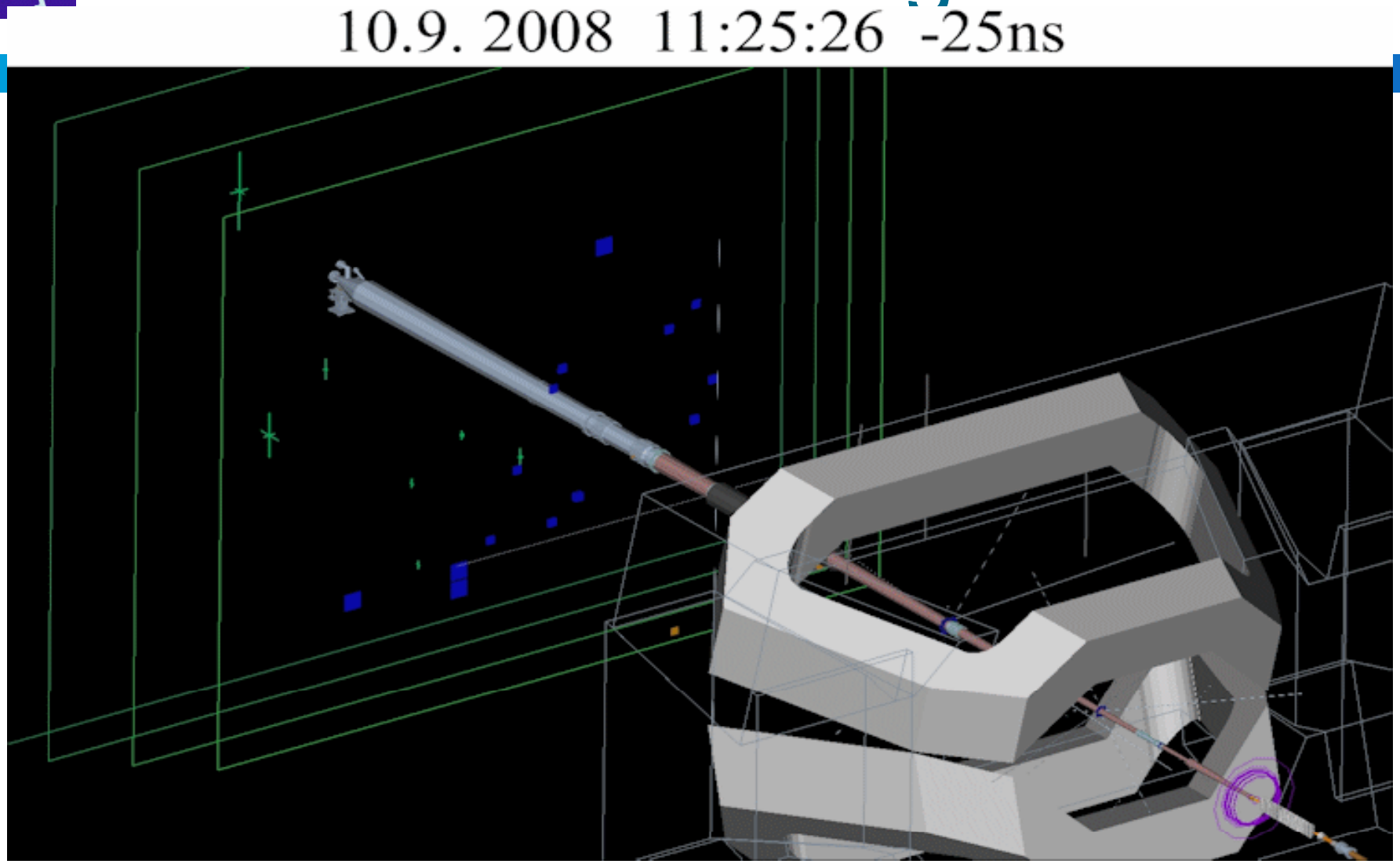

Expected arrival time wrt reference(ns)

# First Glimpse of LHC Protons




- Beam 2 dumped on injection line beam stopper (TED)
  - Located 340m before LHCb along beam 2
  - Wrong direction for LHCb
  - High flux, centre of shower O(10) particles/cm2
- Circulating beam 1
  - Right direction for LHCb
  - Events taken during beam1 circulation look either like low multiplicity events or splashes

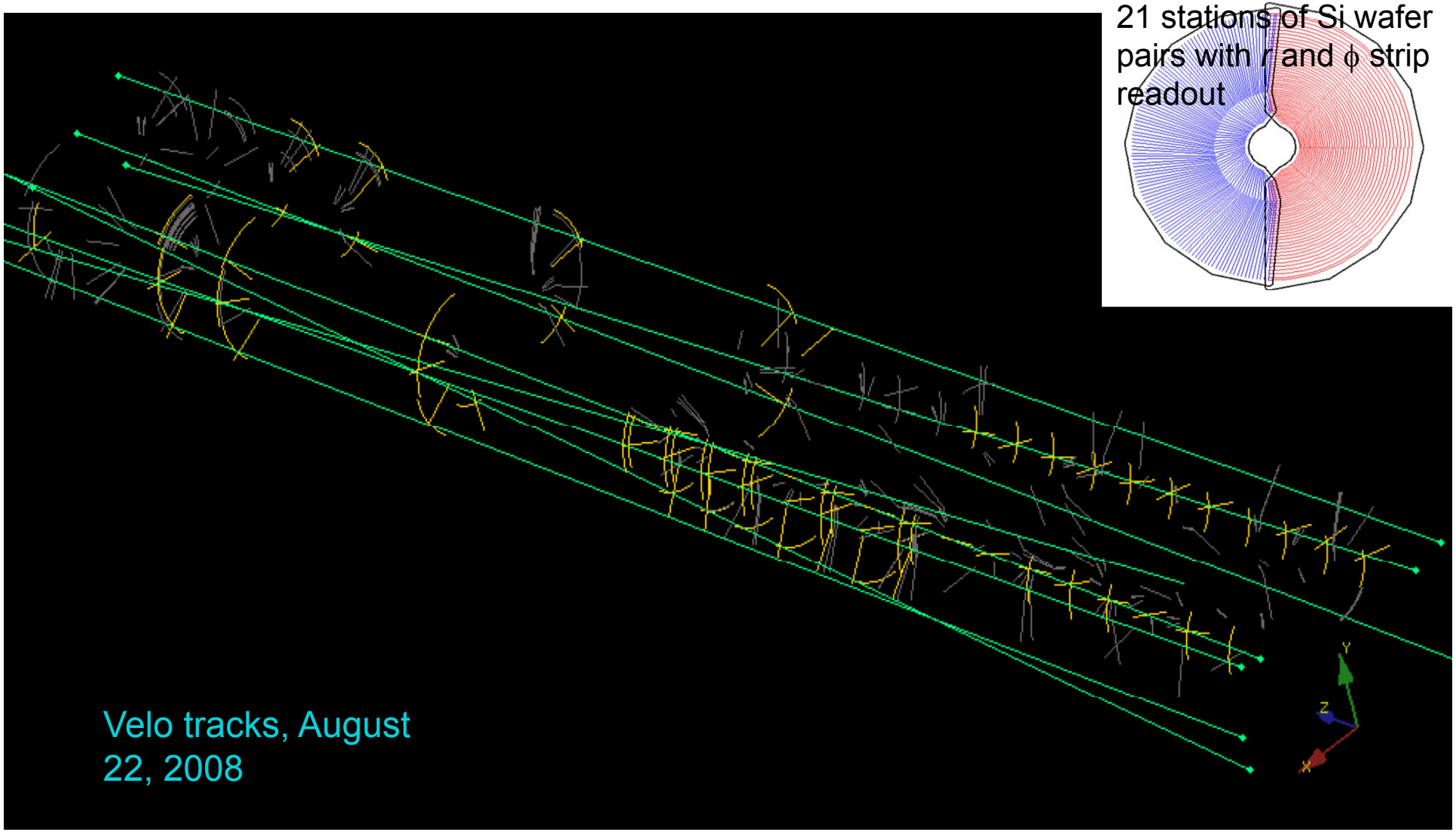
# LHCb commissioning




Readout of consecutive crossings for a single trigger

# Tracks in VELO



# VELO Space Alignment (with tracks from Beam 2 dumped on injection line beam stopper)

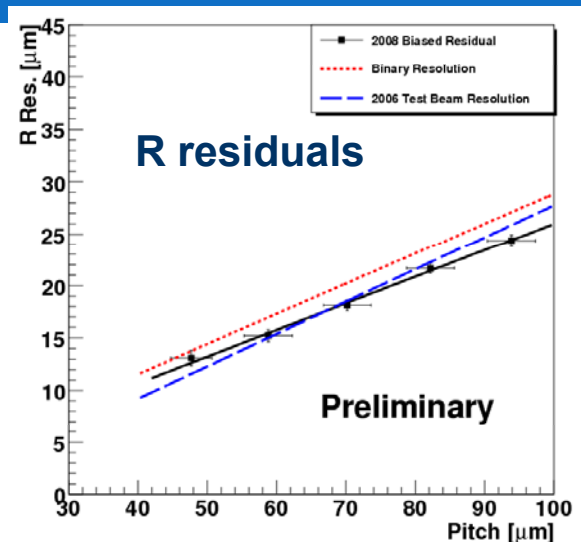
- **Alignment precision**

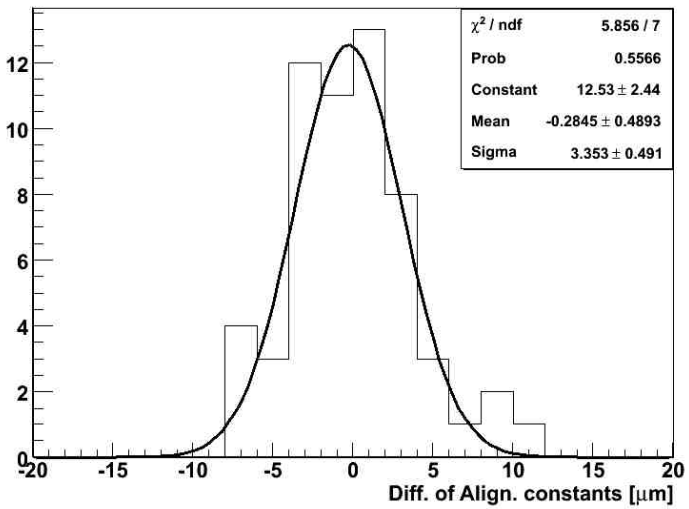
difference of two "alignment runs":

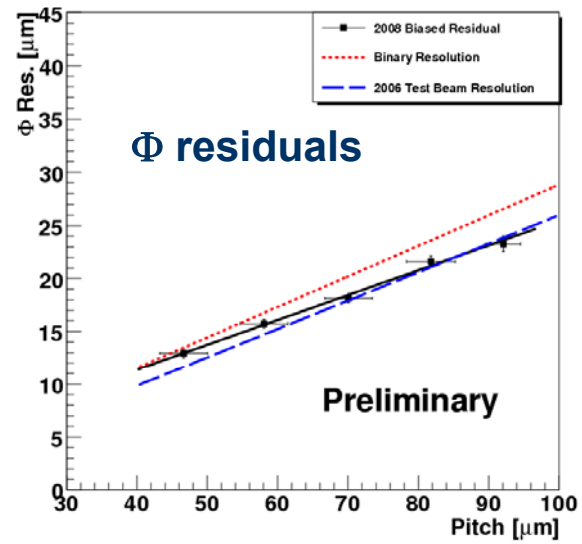
- 5 μm for X and Y translation
- 200 μrad for Z rotation

difference between survey and software alignment:

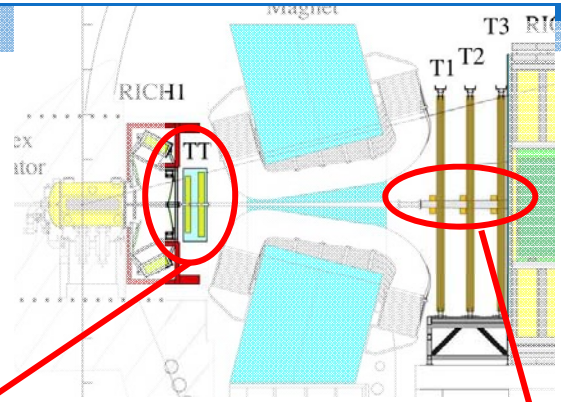
- 10 μm placement accuracy



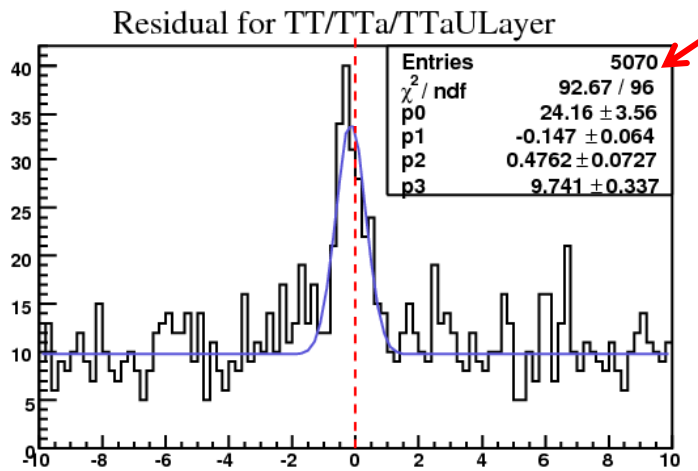



# TT and IT Space Alignment (with tracks from Beam 2 dumped on injection line beam stopper )

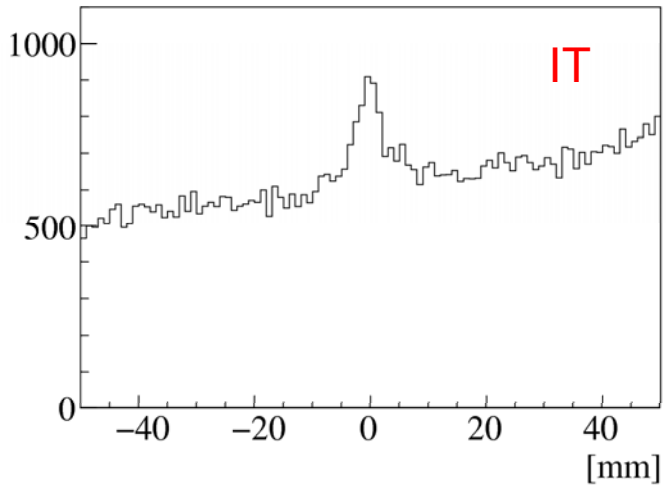



- Extrapolate VELO tracks
  - Distance to clusters in TT and IT
  - Large combinatorial due to huge occupancy in these events




Offset ~ 150-300μ

~7 m extrapolation



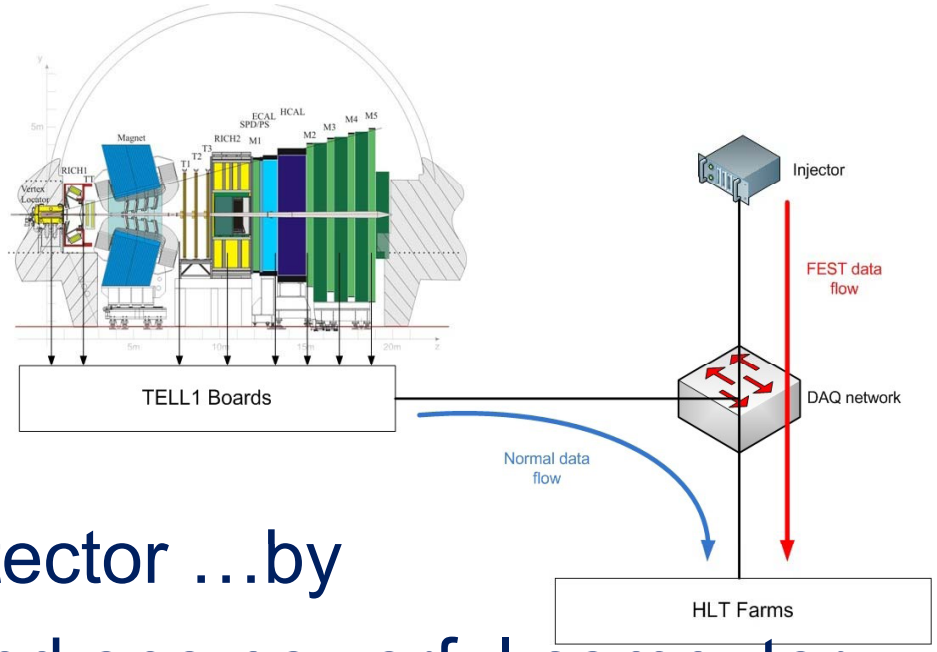
# While waiting for the LHC…

New LHC Restart Schedule (following Chamonix Workshop)

- **First beams in LHC at end of September, with collisions following in late October**
- **Beam physics running during winter 2009-2010**
- **Long running period of ~11 months is possible**
- **10TeV center of mass; ~ 300pb$^{-1}$**

- **LHCb:**
  - Detector consolidation
  - Adding 350 farm computing nodes to the current 200 in place
    - Farm nodes for computing power will be added as needed but infrastructure for up to 2000 in place
  - Installation of last Muon station in between RICH and the Calorimeters (M1)
  - Improving
    - HV control
    - Data Monitoring → Run detector with two shifters
    - Automating global control
  - **F**ull **E**xperiment **S**ystem **T**est (FEST09)

# FEST09




- Replacing a ~68M CHF detector …by a lot of simulated events and one powerful computer
  - HARDWARE+L0+READOUT BOARD → MonteCarlo & Event Injector
- Be ready to receive, process and analyze 7 million events in the first hour of collisions!
  - Exercise Online and Offline systems, Trigger, Monitoring, Data Quality checking and prompt (Online) reconstruction
  - Answer operational questions: e.g. “What is the best way to update alignment / calibration constants?”
  - FEST infrastructure can be used later for dry-run tests of various components of the system

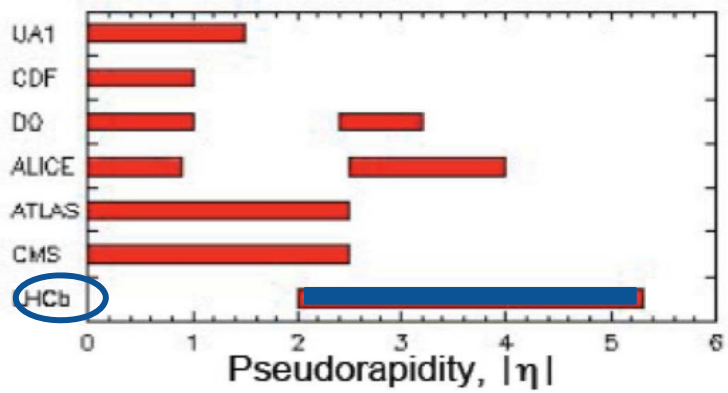
# LHCb Key Measurements

Potentially sensitive to NP discovery

- In CP violation:
  - **$B_s$-$B_s$ mixing phase**
  - weak phase $\gamma$ in trees
  - weak phase $\gamma$ in loops
- In rare decays:
  - **BR ($B_s \rightarrow \mu\mu$)**
  - forward-backward asymmetry in $B \rightarrow K^*\mu\mu$
  - polarization of photon in radiative penguin decays

# Very First Measurements
## (some examples)

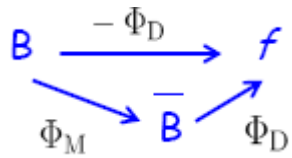
- Large Minimum Bias data samples collected as soon as the LHC delivers p-p collisions: $10^8$ O(day) @ 2kHZ
  - plenty of $K_s$ ,$\Lambda$ → measure differential production distributions ($\eta$,$p_T$) ….
  - Clean and unbiased samples for PID studies
- $p_T$ cut on single muon → expect ~$610^5$ $J/\psi \rightarrow \mu\mu$ with 1 $pb^{-1}$ (10 TeV)
  - Reconstruct $J/\psi \rightarrow \mu\mu$ , disentangle fraction of prompt and detached $J/\psi$s
  - Study proper time resolution with prompt component
  - Measure prompt $J/\psi$ and bb cross section in a region not accessible to other collider experiments
- With Full Trigger
  - Exclusive B and D decays

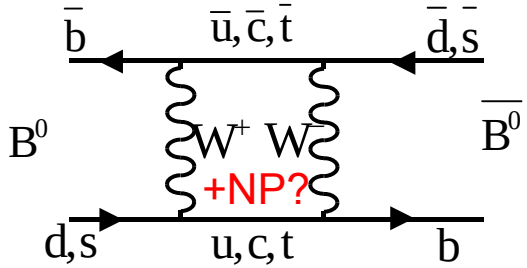


# $\phi_s$ measurements from $B_s \to J/\psi\ \phi$

- **The measure of $B_s$-$B_s$ mixing phase $\phi_s$ in $B_s \to J/\psi(\mu\mu)\phi$ is sensitive to NP effects in mixing**
  - **The phase arises from the interference between B decays with and without mixing**
  - $\phi_s = \phi_{s(SM)} + \phi_{s\ (NP)}$
  - $\phi_{s(SM)} = -2\beta_s = -2\lambda^2\eta \sim -0.04$
    - **Tevatron: ~2.2σ away from SM**

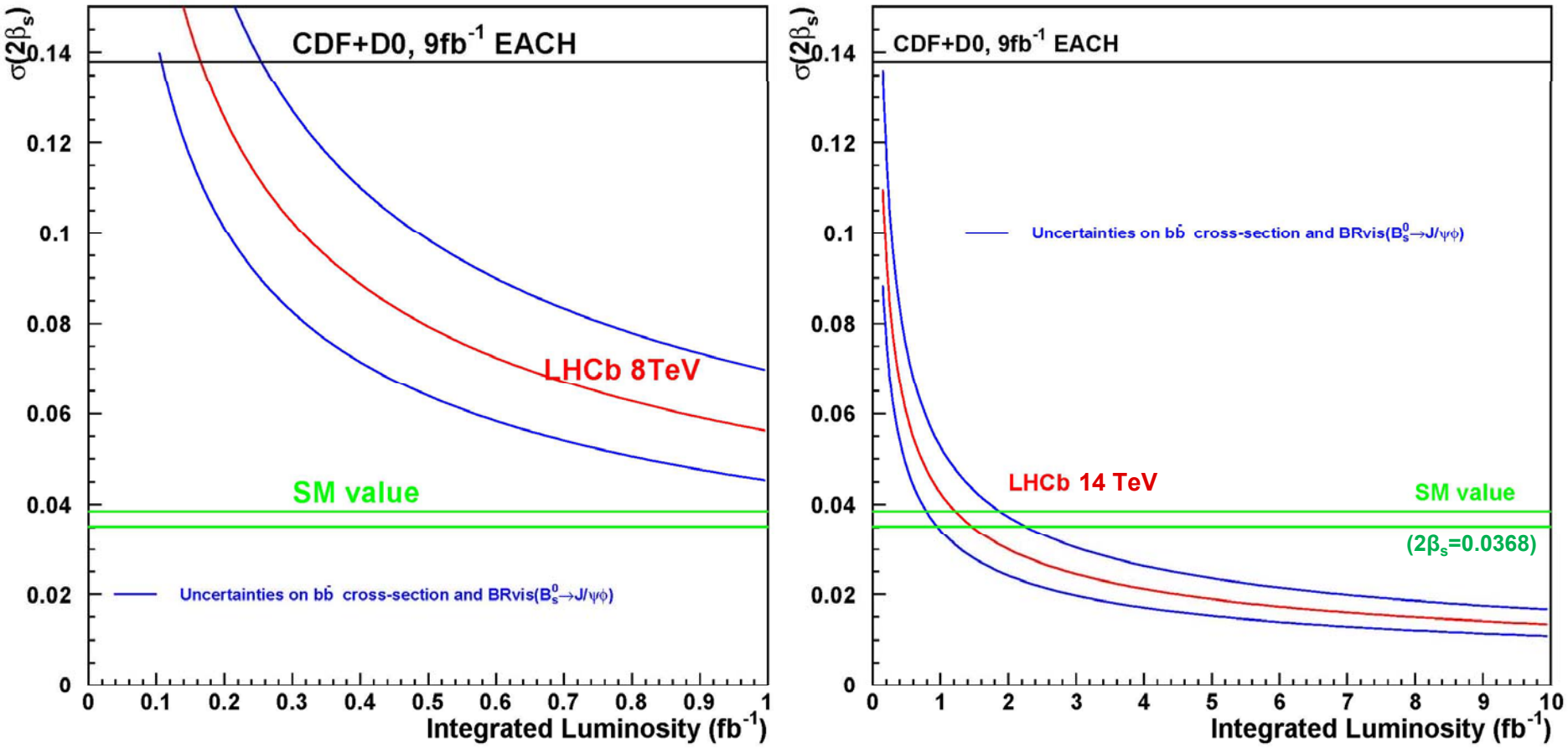
  (central experimental value -0.77)




- **Key ingredients for sensitivity:**
  - Large signal yield
  - Excellent proper time resolution to resolve fast $B_s$ oscillations: **~40 fs**
  - Good tagging of initial $B_s$ flavour : **~6%**
  - Good control of proper time and angular acceptances

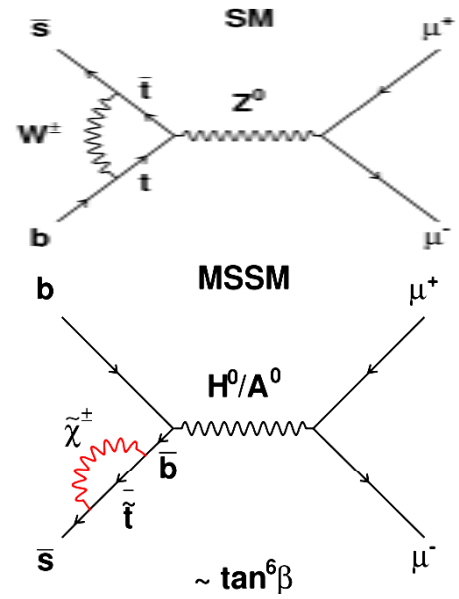
# Physics reach for $\phi_s$ measurement as function of integrated luminosity (and comparison with Tevatron)




→ With ~0.3 fb$^{-1}$ LHCb should improve on expected Tevatron limit

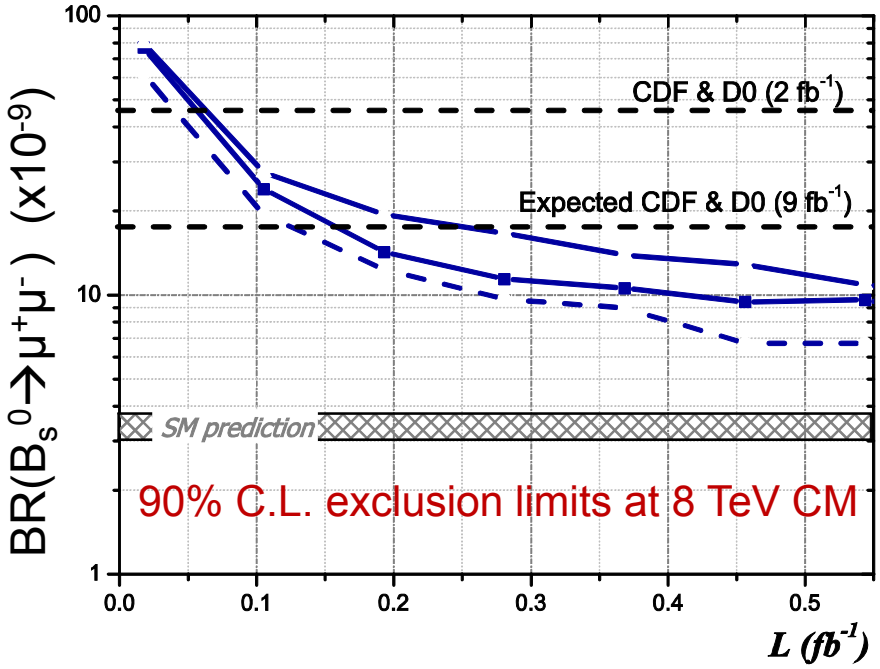
→ Collect ~2 fb$^{-1}$ for 3σ observation of SM value

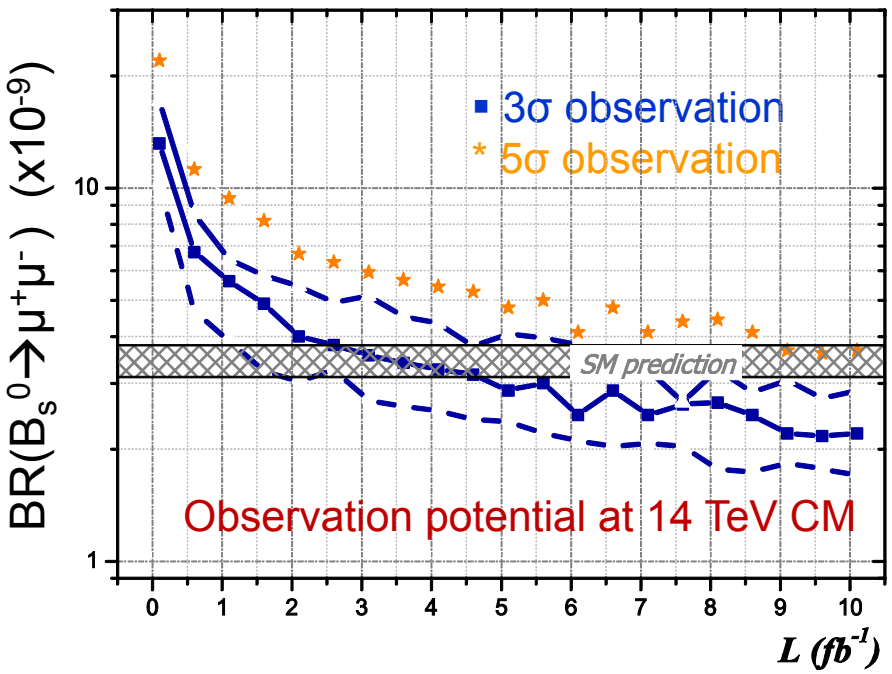
# New Physics in $B_s \to \mu^+\mu^-$




- Small BR in SM: $(3.35 \pm 0.32) \times 10^{-9}$
  - sensitive to NP
    - could be strongly enhanced in SUSY
      - In MSSM scales like ~$\tan^6\beta$
    - Current limit from CDF: < **47** $\times$**$10^{-9}$**
    - Expected with 9 $fb^{-1}$: **< 20**$\times$ **$10^{-9}$**
      - ~5 times higher than SM**!**
- LHCb:
  - high stat. & high trigger efficiency for signal
  - main issue is background rejection
  - dominated by $B \to \mu^+X$, $B \to \mu^-X$ decays
  - Exploits good mass resolution and vertexing, and good particle ID
  - Use of control channels to minimize dependence on MC simulation

# Physics reach for BR($B_s^0 \rightarrow \mu^+\mu^-$) as function of integrated luminosity (and comparison with Tevatron)




→ With ~0.3 $fb^{-1}$ LHCb should improve on expected Tevatron limit with 9 $fb^{-1}$

→ Collect ~3 $fb^{-1}$ for 3σ observation of SM value

# Conclusions

- LHCb is ready to take data
- Cosmics and first LHC-induced tracks were very useful to commission the detector
- Large Minimum Bias data samples, will be collected in the forward region at a rate of 2kHz, as soon as the LHC delivers pp collisions
- A few observables sensitive to NP should already be accessible at the end of the 1$^{st}$ year of data taking

# LHCb Upgrade

- Several measurements expected to remain statistically limited after $10fb^{-1}$
  - Increase Lumi by factor 10
    - 5 years at 2 $10^{33}$ $cm^{-2}$ $sec^{-1}$ → 100 $fb^{-1}$
  - Improve Trigger Efficiency
- Three main issues to be addressed:
  - Trigger bottleneck (1 MHz max. output rate of L0 hardware):
    - Need 40 MHz readout of all detector sub-systems + full trigger on CPU farm to get improved hadron trigger (×2) with yield proportional to luminosity
    - Event building & CPU power OK, but implies replacement of all FE electronics !
  - Radiation damage
    - Need to replace VELO, inner parts of Si tracker, inner part of calorimeter, …
  - Detector occupancy (increased due to pileup ~4 int./crossing + spillover)
    - Need replacement/solution for inner part of Outer Tracker (straws)
    - Need new reconstruction algorithms in high occupancy environment

# LHCb Upgrade

Sensitivities for 100 $fb^{-1}$

| Observable | Sensitivity |
|---|---|
| $S(B_s \to \phi\phi)$ | $0.01 - 0.02$ |
| $S(B_d \to \phi K_S^0)$ | $0.025 - 0.035$ |
| $\phi_s\ (J/\psi\phi)$ | $0.003$ |
| $\sin(2\beta)\ (J/\psi\, K_S^0)$ | $0.003 - 0.010$ |
| $\gamma\ (B \to D^{(*)}K^{(*)})$ | $< 1^\circ$ |
| $\gamma\ (B_s \to D_s K)$ | $1 - 2^\circ$ |
| $\mathcal{B}(B_s \to \mu^+\mu^-)$ | $5 - 10\%$ |
| $\mathcal{B}(B_d \to \mu^+\mu^-)$ | $3\sigma$ |
| $A_T^{(2)}(B \to K^{*0}\mu^+\mu^-)$ | $0.05 - 0.06$ |
| $A_{\rm FB}(B \to K^{*0}\mu^+\mu^-)\ s_0$ | $0.07\ \mathrm{GeV}^2$ |
| $S(B_s \to \phi\gamma)$ | $0.016 - 0.025$ |
| $A^{\Delta\Gamma_s}(B_s \to \phi\gamma)$ | $0.030 - 0.050$ |
| charm $x'^2$ | $2 \times 10^{-5}$ |
| mixing $y'$ | $2.8 \times 10^{-4}$ |
| CP $y_{CP}$ | $1.5 \times 10^{-4}$ |

Also studying Lepton Flavour Violation in $\tau \to \mu\mu\mu$