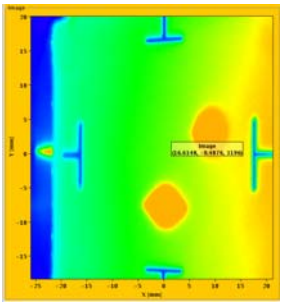
Status of the LHC*b* Experiment

Steven Blusk

Syracuse University

(*for the LHCb Collaboration*)



M. Kobayashi T. Maskawa Y. Nambu

- Introduction
- Detector
- Status of the Experiment
- Expected Physics reach
- Conclusion

Introduction

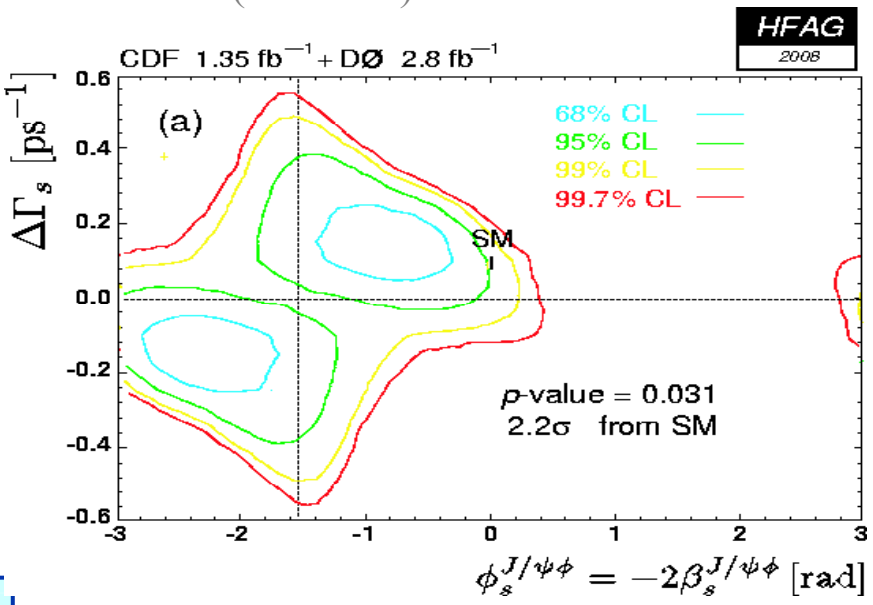
- **Flavor physics** continues to play a prominent role in probing the SM and **searches for NP**.

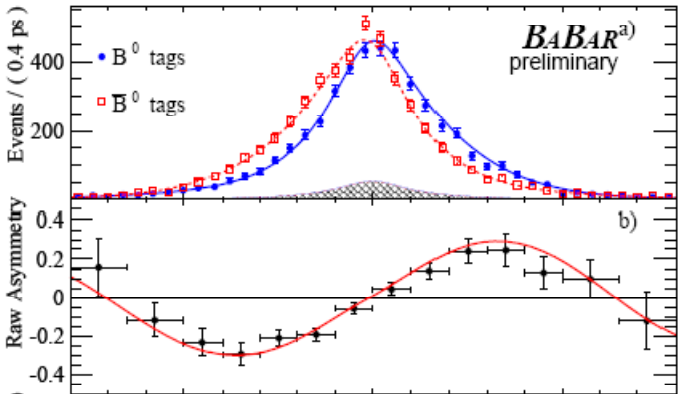
- **CKM matrix a central battleground**
  - Origin in different Yukawa couplings of 'up-type' and 'down-type' quark sector

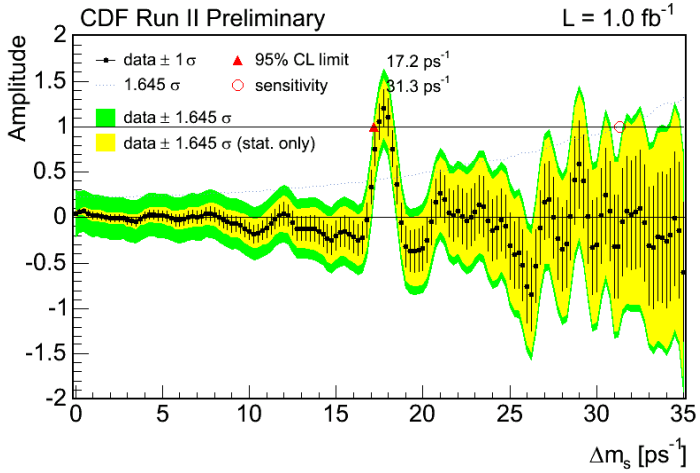
- **New physics around the corner** → New particles/fields
  - Direct detection (Central detectors, CDF, D0…and soon CMS, ATLAS)
  - Influence in loops and rare decays (K, D, B, τ decays, g-2, etc)
    - $A_{tot} = A_{SM}(1+r_{NP}e^{i\phi NP})$
    - Amplitudes & phases described by CKM matrix, but phases may not be SM values
    - If NP, should contribute to loops & rare decays: $r_{NP} \neq 0$
    - Cannot rule out NP with |A| alone: *e.g.* $r_{NP} = 2$, $\phi_{NP}=180^o$ → $|A| = |A_{SM}|$

An Explosion of B Physics

- In the last few years alone:
  - $\sigma(\sin(2\beta)) \sim 3.5\%$ (B-factories)
  - $\sigma(\Delta m_s) \sim 0.5\%$ (TeVatron)
- No smoking gun yet, but **there is tension**
  - $\sin(2\beta)$ **~1.5-2σ** (Soni, arXiv:0803.4340)
  - $|A_{CP}(B^0 \to K^+\pi^-) - A_{CP}(B^+ \to K^+\pi^0)| =$ **4.4 σ**
    (Belle, Nature 452, 332 (2008))
  - $\sin(2\beta_s)$ **~2.2σ** tension with SM
    (Tevatron)







Other tantalizing hints in flavor
- $A_{CP}(b \to sss)$ vs $A_{CP}(b \to ccs)$
- FBA in $B \to K^* \ell\ell$
- $D_s \to \mu\nu$ (~3.2σ from LQCD)
- Muon g-2
- …

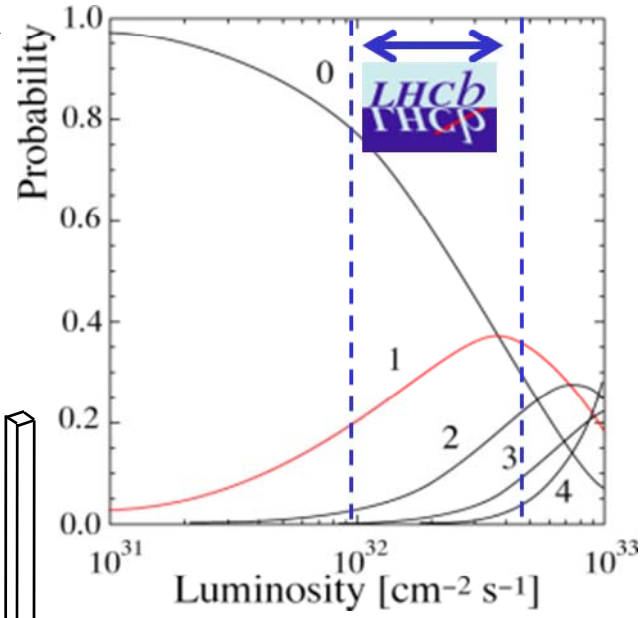
Enter… LHC*b*

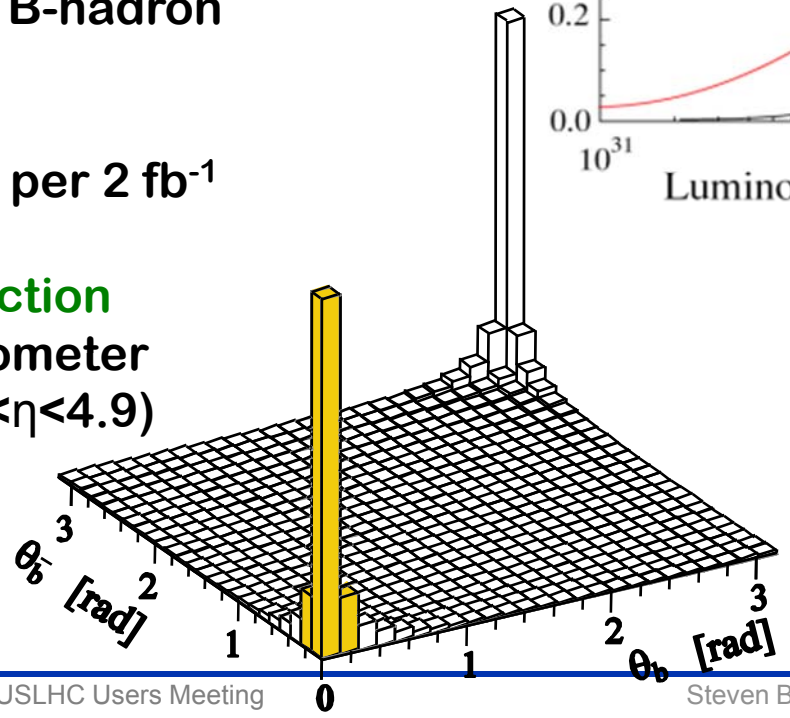
- **LHC*b*** is a first dedicated precision heavy flavour experiment searching for **new physics** in **CP-Violation** and **Rare Decays** at a hadron machine

  - **Beams are (intentionally) less focused**
    $\mathcal{L}_{int}$ ~ 2 x 10^{32}cm^{-2}s^{-1} at the start
    → mostly single interaction.

  - **100K bb/sec expected and all B-hadron species produced:**
    - B^0, B^+, B_s, B_c, b-baryons.
    - Yields ~10^2 - 10^6 / channel per 2 fb^{-1}

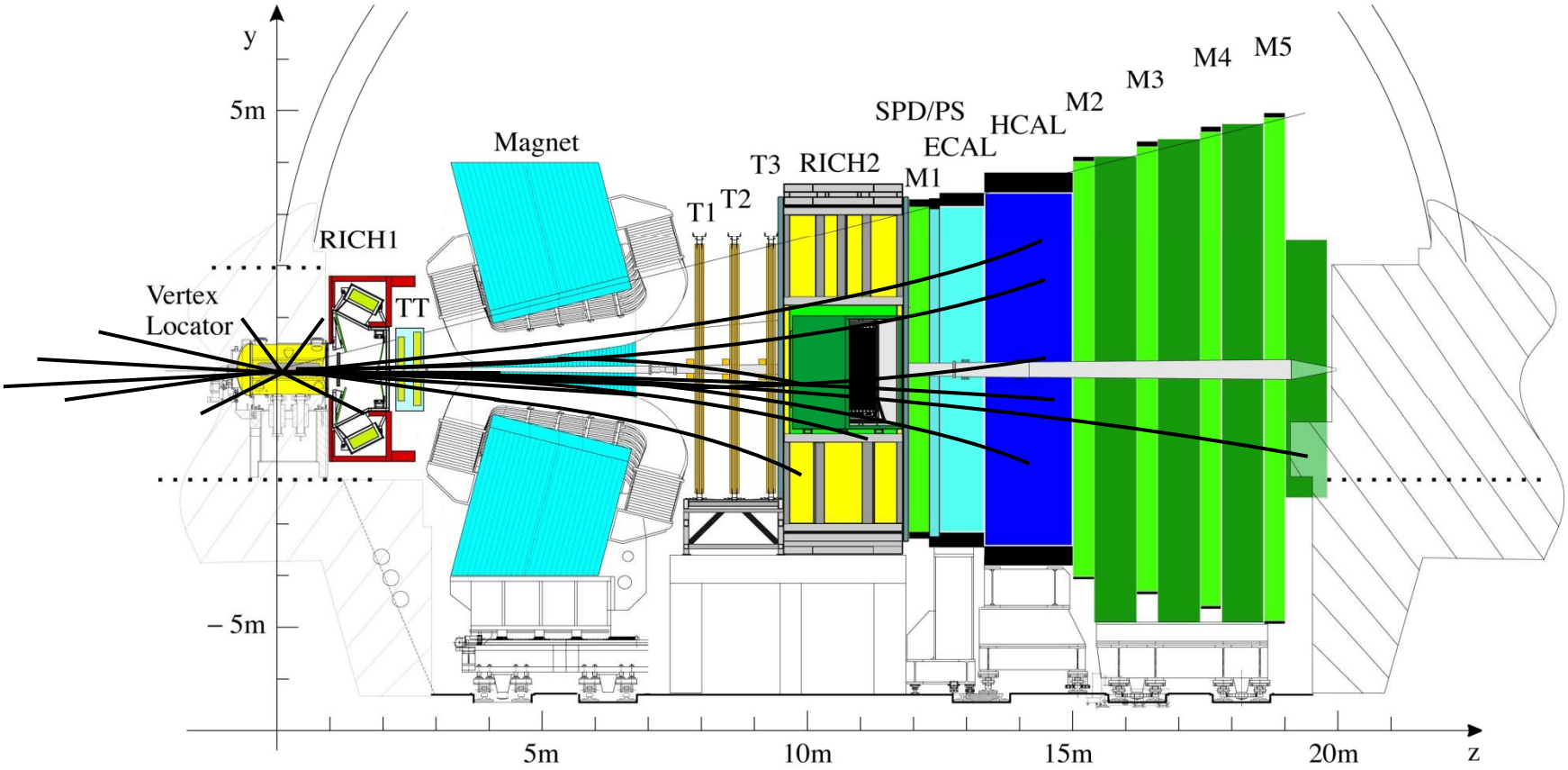
  - **Forward, correlated bb production**
    Single arm forward spectrometer
    12 mrad<θ< 300 mrad (1.9<η<4.9)



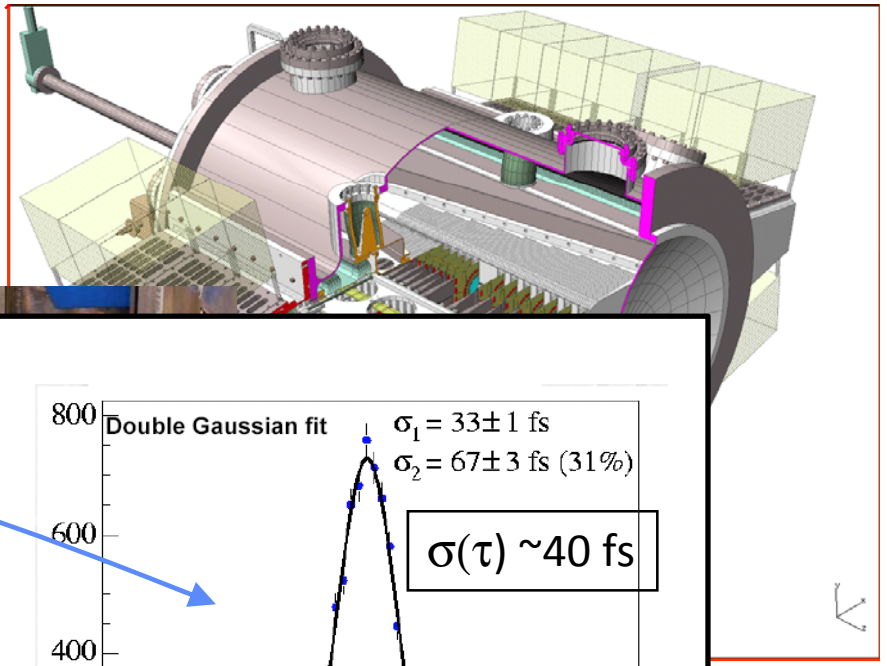


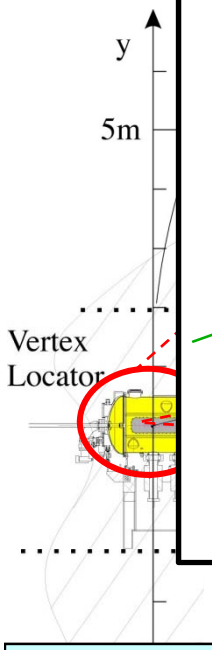
Detector overview and expected performance

walk through the detector
with the example of a $B_s \rightarrow D_s K$ decay

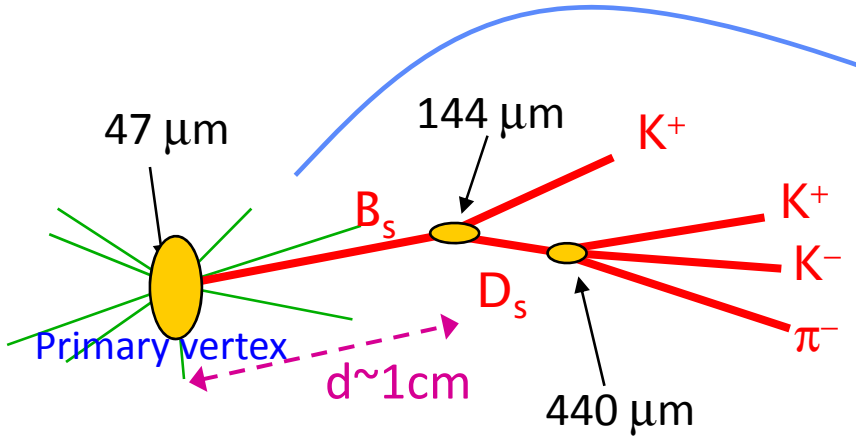


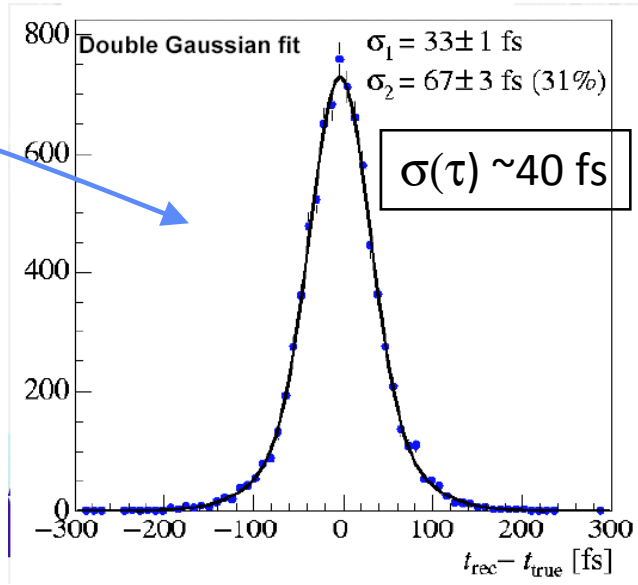
B-Vertex Measurement



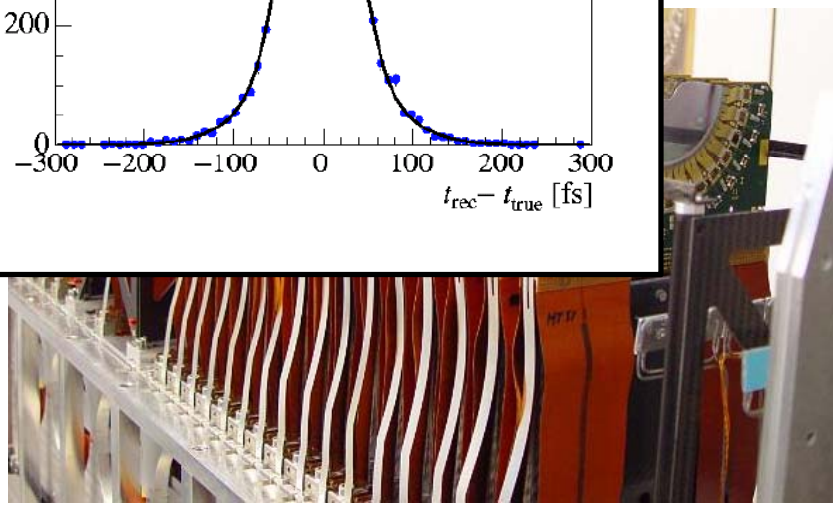


Example: $B_s \rightarrow D_s K$





Decay time resolution = 40 fs



Vertex Locator (Velo)

21 stations of silicon strip detectors (r-ϕ)

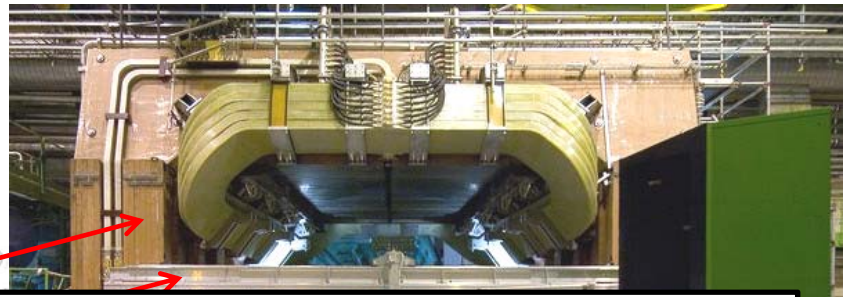
~ 8 µm hit resolution

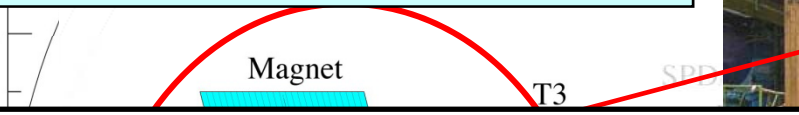
~25 µm IP resolution

- Trigger on large IP tracks
- Measurement of decay distance (time)

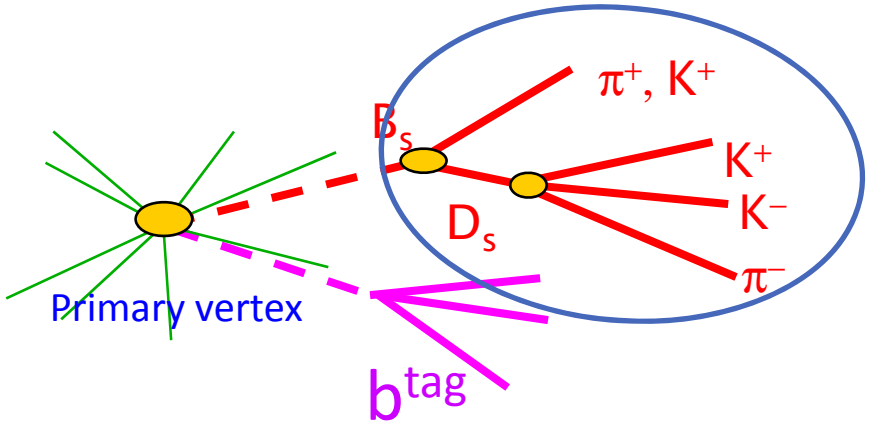
Momentum and Mass measurement

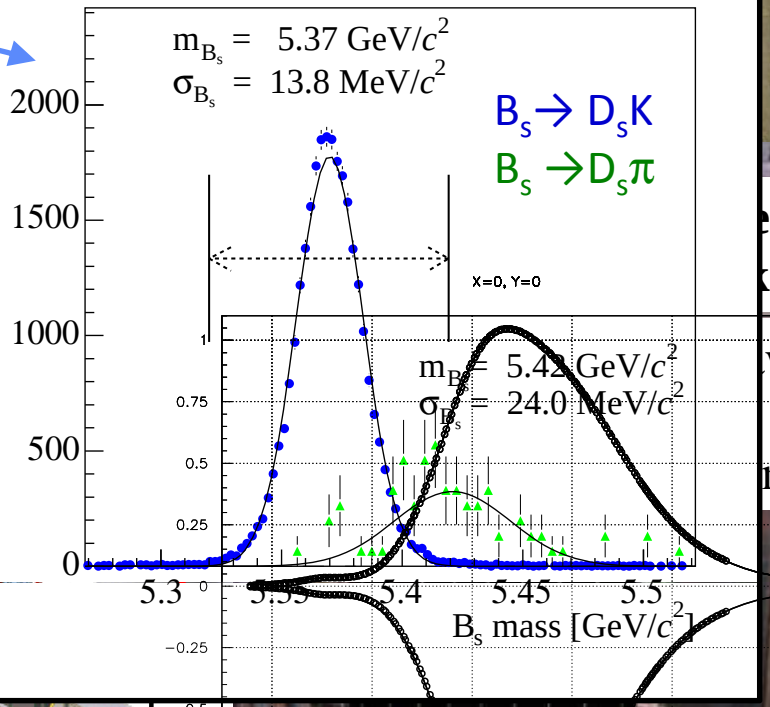
Momentum meas. + direction (VELO):
Mass resolution for background suppression



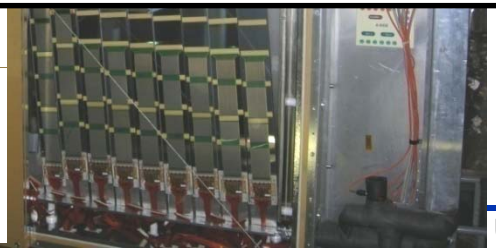


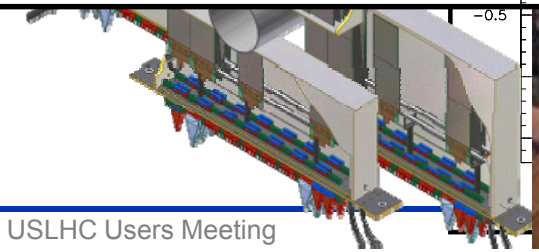
Mass resolution
σ ~14 MeV





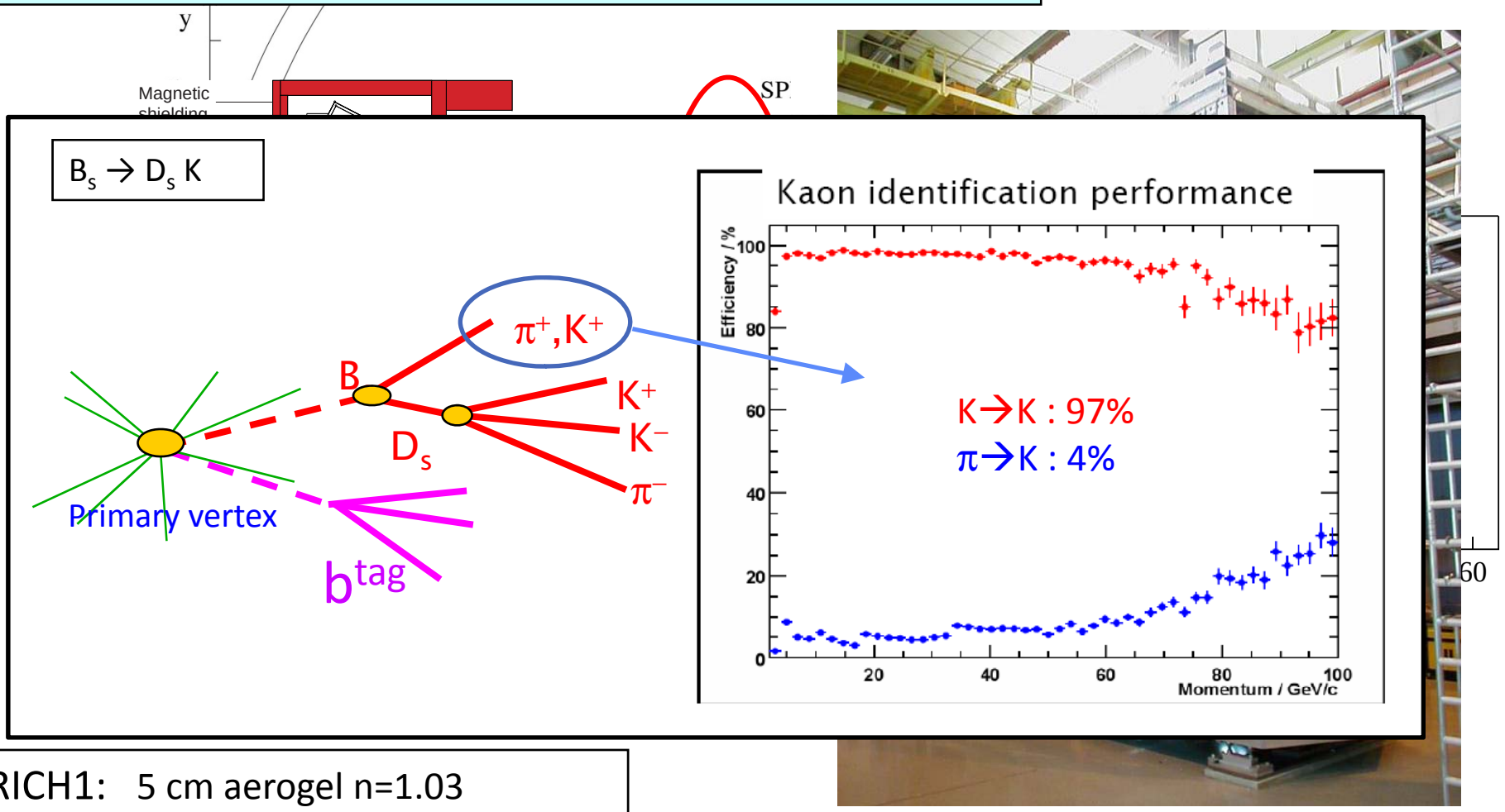
4 lay
(0°,+5°,-5°, 0°)
~200 µm pitch
143K chnls
σ_{hit} 50µm





Particle Identification

RICH: p/K/π identification using Cherenkov angle (rings)

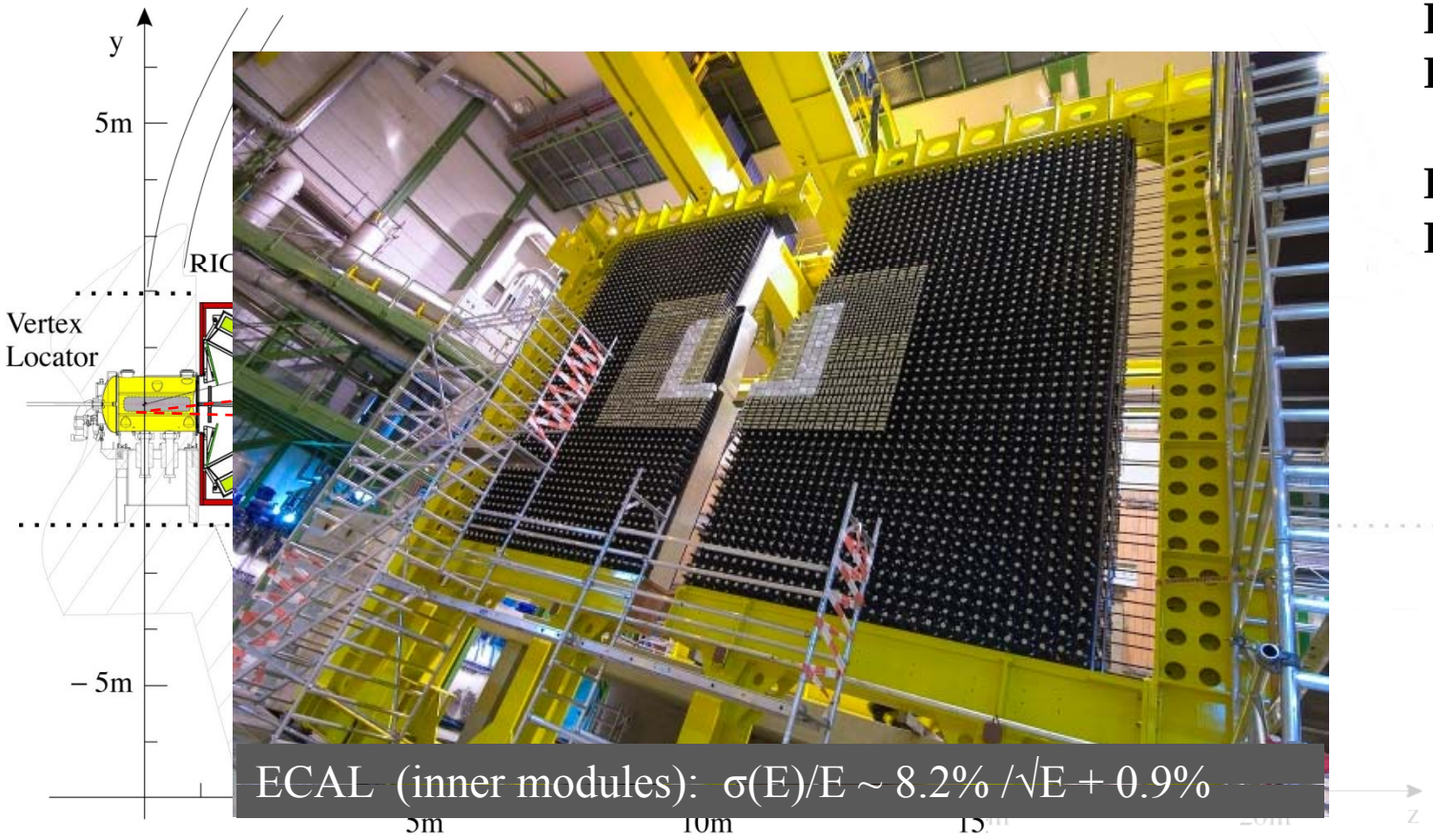


RICH1: 5 cm aerogel n=1.03

4 m^3 C_4F_{10} n=1.0014

RICH2: 100 m^3 CF_4 n=1.0005

ECAL & HCAL: L0 trigger & Particle identification



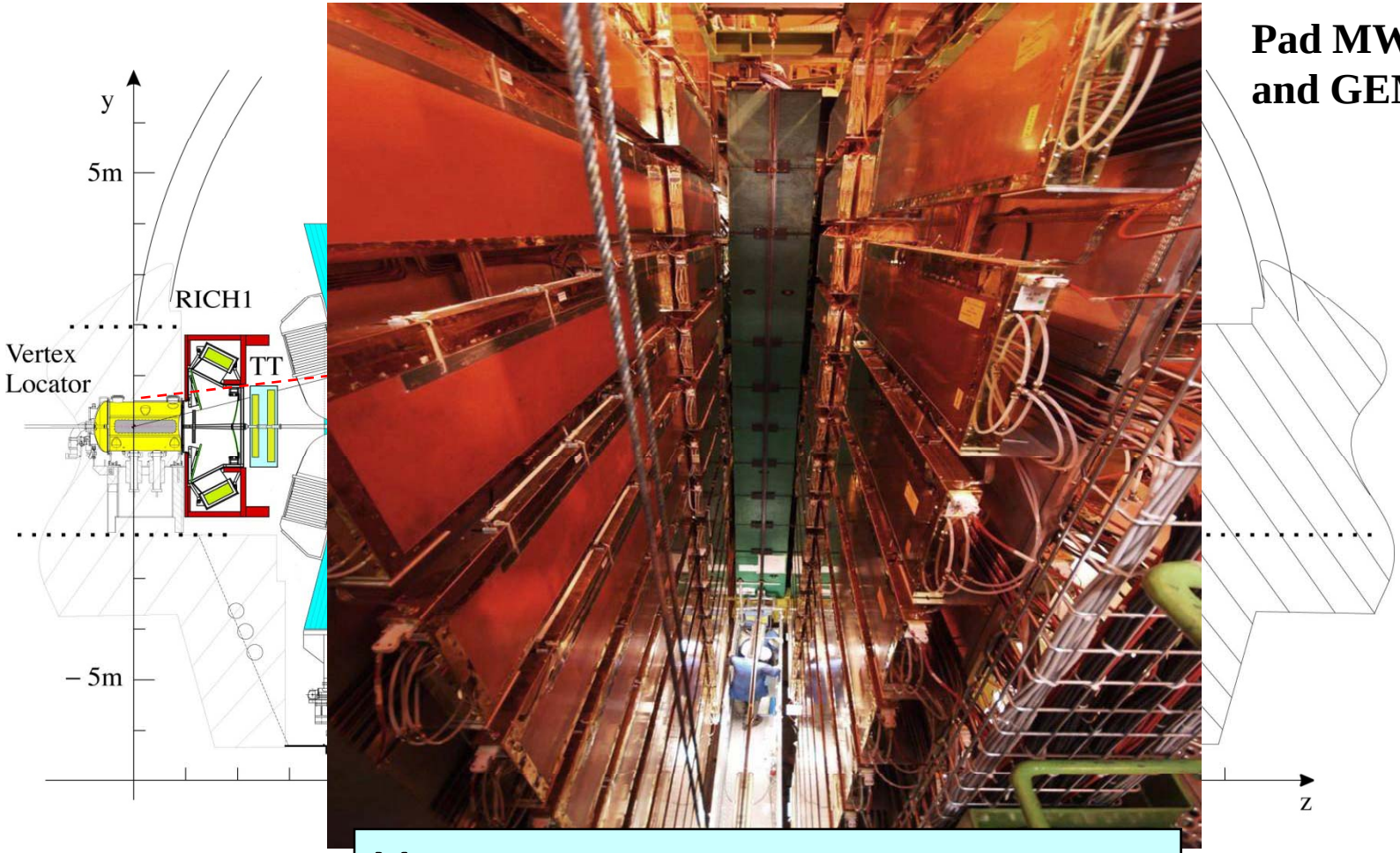
ECAL (inner modules): $\sigma(E)/E \sim 8.2\% /\sqrt{E} + 0.9\%$

ECAL:
Pb-Scint.

HCAL
Fe-Scint.

- Level 0 trigger: high E_T electron and hadron
- Identify electrons, hadrons, π^0, γ

Muon System: L0 trigger & Particle identification



Pad MWPCs and GEMs

Muon system:

- Level 0 trigger: High P_t muons
- contributes to flavour tagging:
  Total $\varepsilon D^2 = \varepsilon (1-2w)^2 \approx 6\%$

LHCb trigger

40 MHz

Detector

L0: high p_T (μ, e, γ, *h*) [hardware, 4 μs]

1 MHz

Software (~16K cores)

HLT1: Confirm L0 w/ tracking in ROI; pT, IP cuts

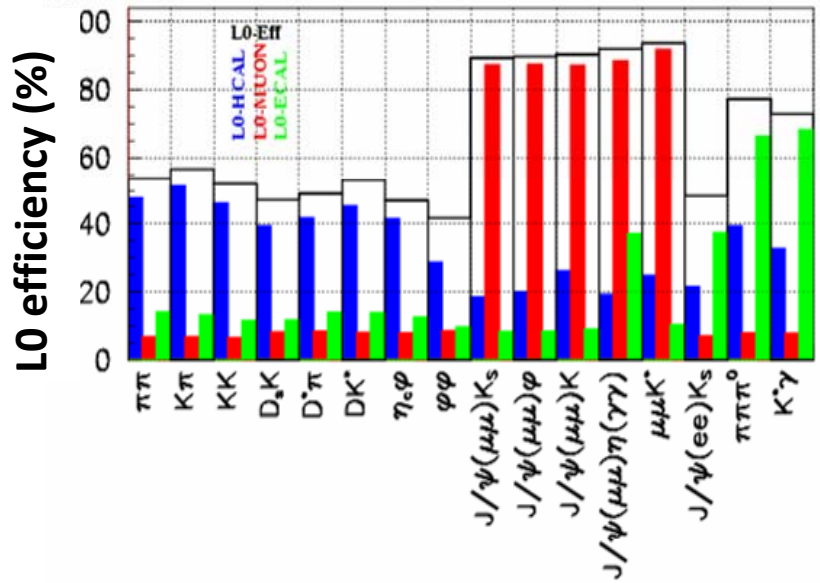
~30kHz

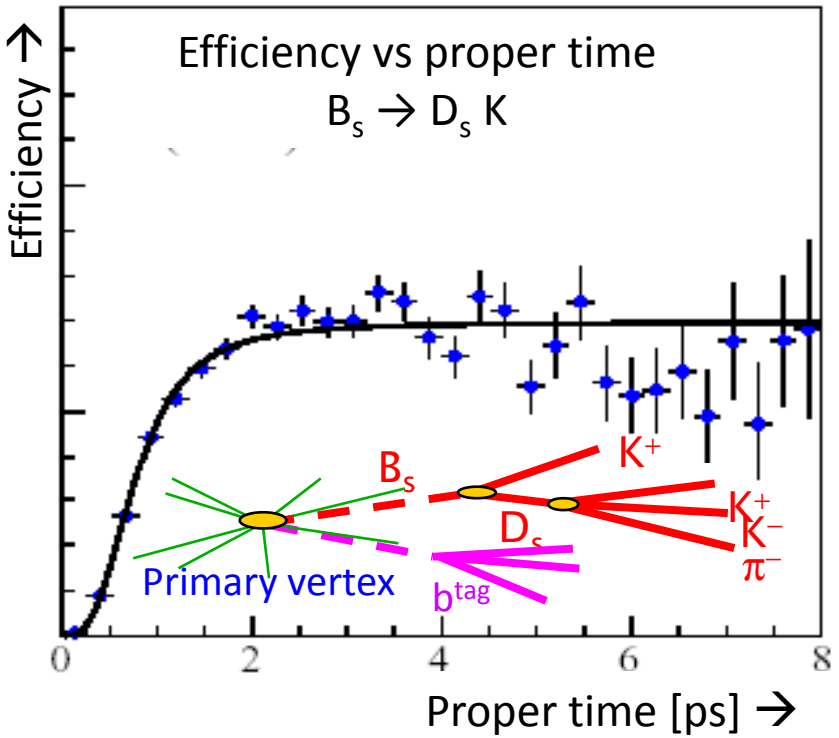
HLT2: full reconstruction of event

2 kHz

(~35 kB/event)

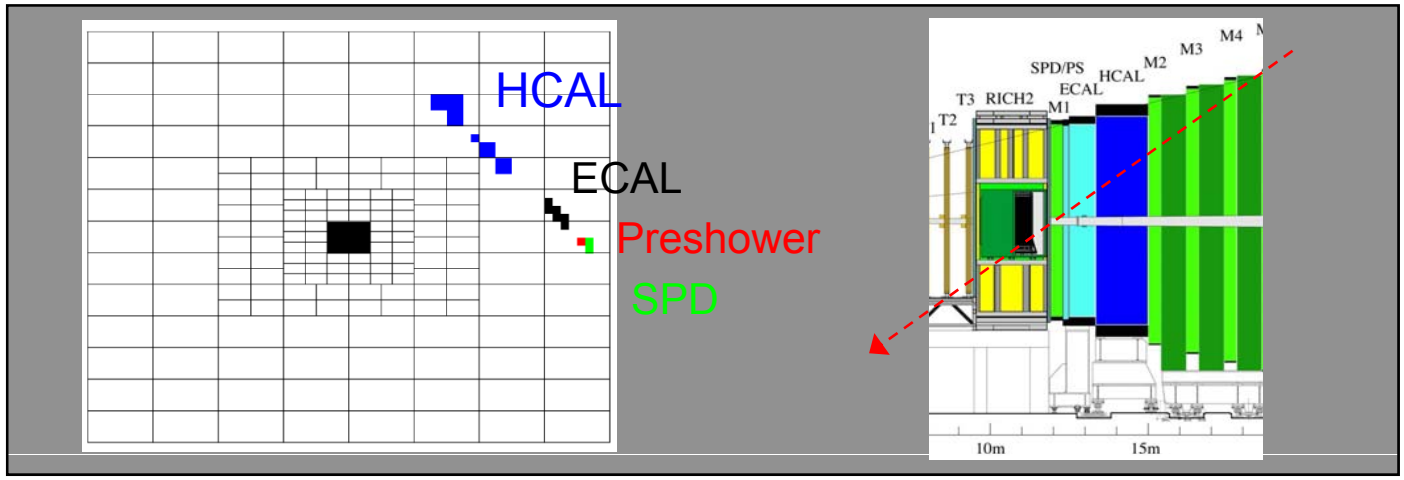
HLT rate	Event type	Physics
200 Hz	Exclusive B candidates	B (core program)
600 Hz	High mass di-muons	J/ψ, b→J/ψX (unbiased)
300 Hz	D* candidates	Charm (mixing & CPV)
900 Hz	Inclusive b (*e.g.* b→μ)	B (data mining)





Status/Commissioning of LHCb

- LHCb detector fully installed and commissioned (except M1), including L0 trigger
- All sub-detectors have undergone first time and space alignment
- Some particle data available
  - Cosmics:
    - mostly close-to vertical (~10 hz ECAL/HCAL coincidence);
    - ~mHz to get tracks in tracker (with SPD trigger)
  - Some TED events
  - And Media Day, of course!



Cosmic Event Display

- LHCb detector fully installed and commissioned (except M1), including L0 trigger
- All su
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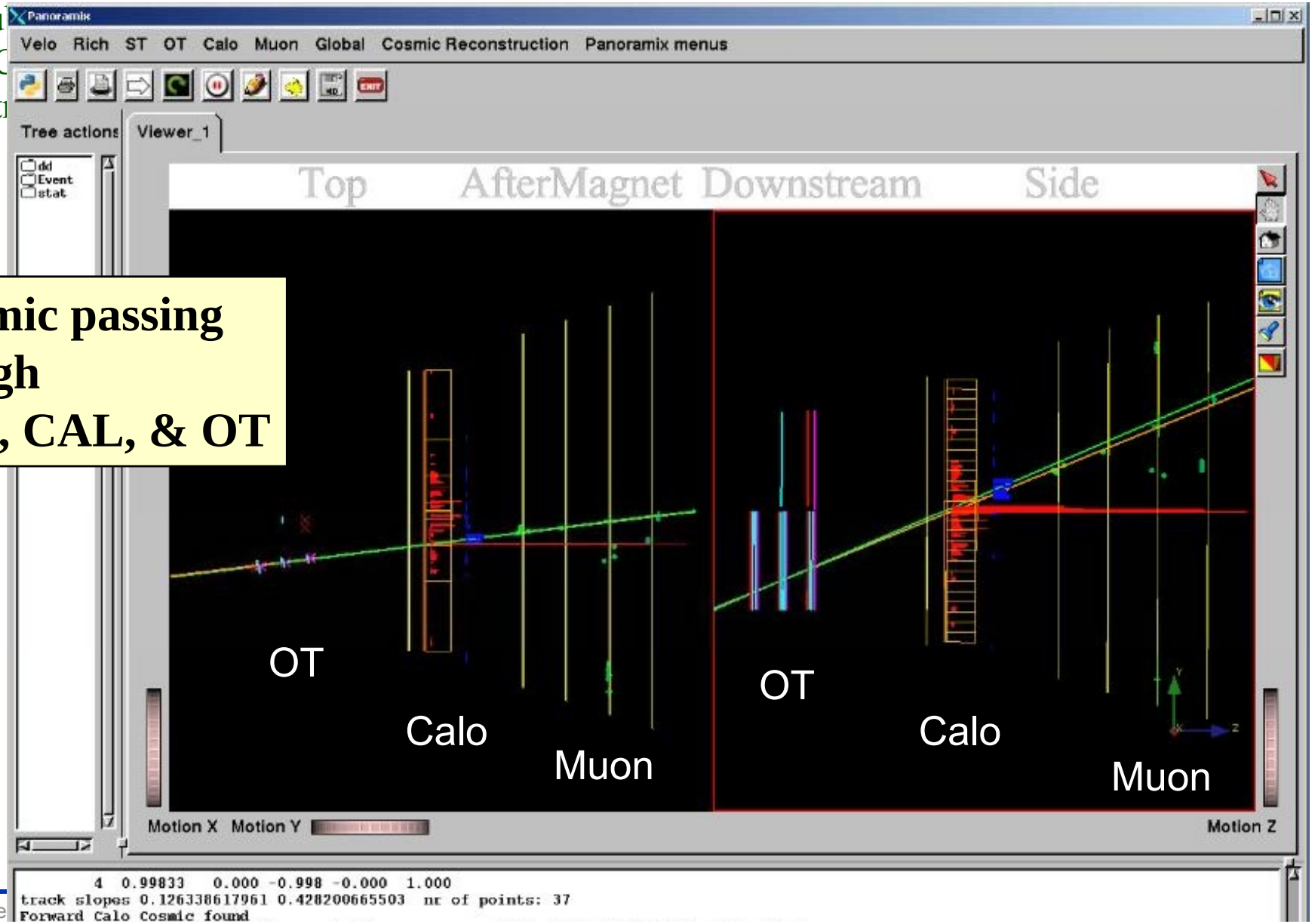
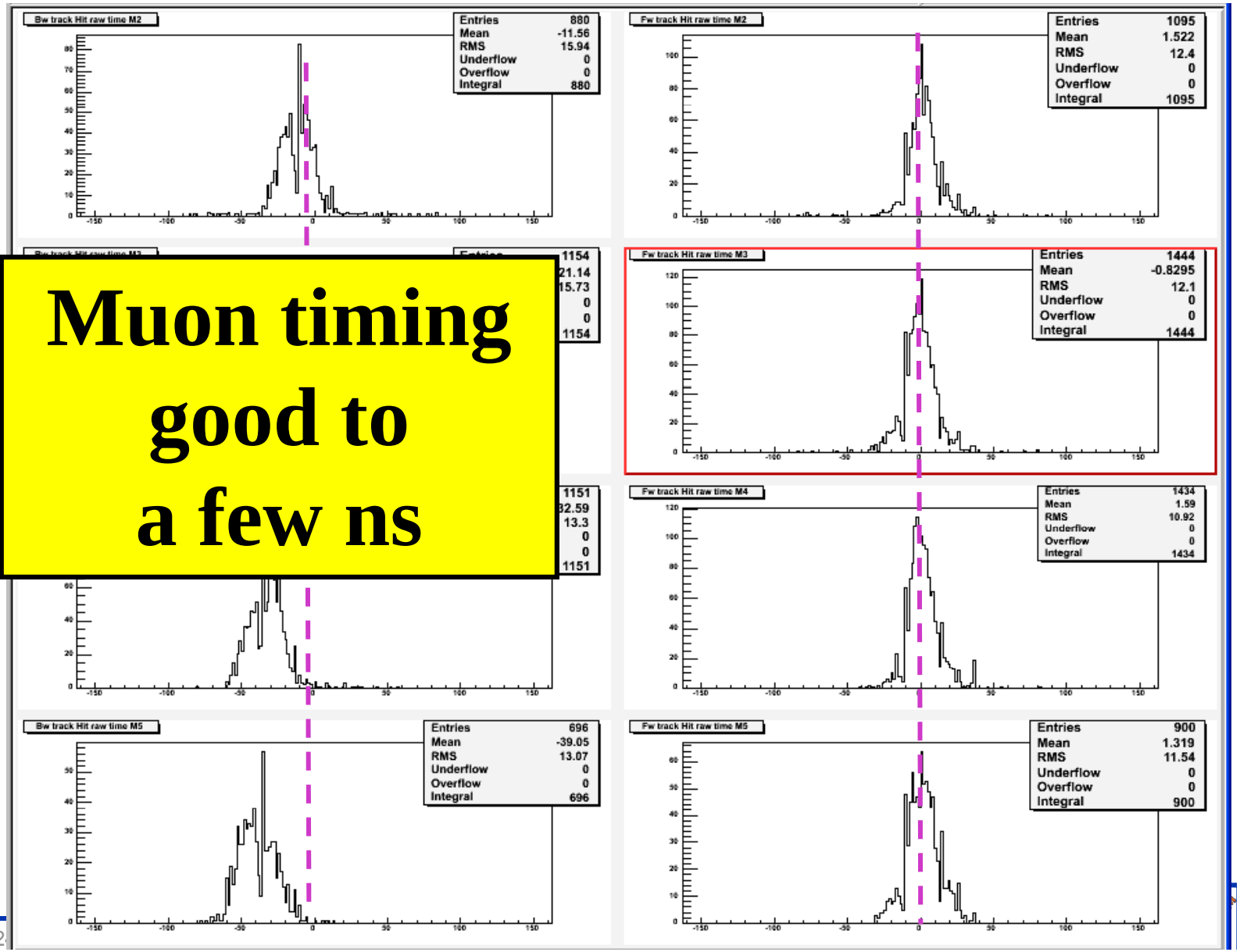
A cosmic passing through Muon, CAL, & OT



Muon System Timing using cosmics

Backward tracks - shifted in time

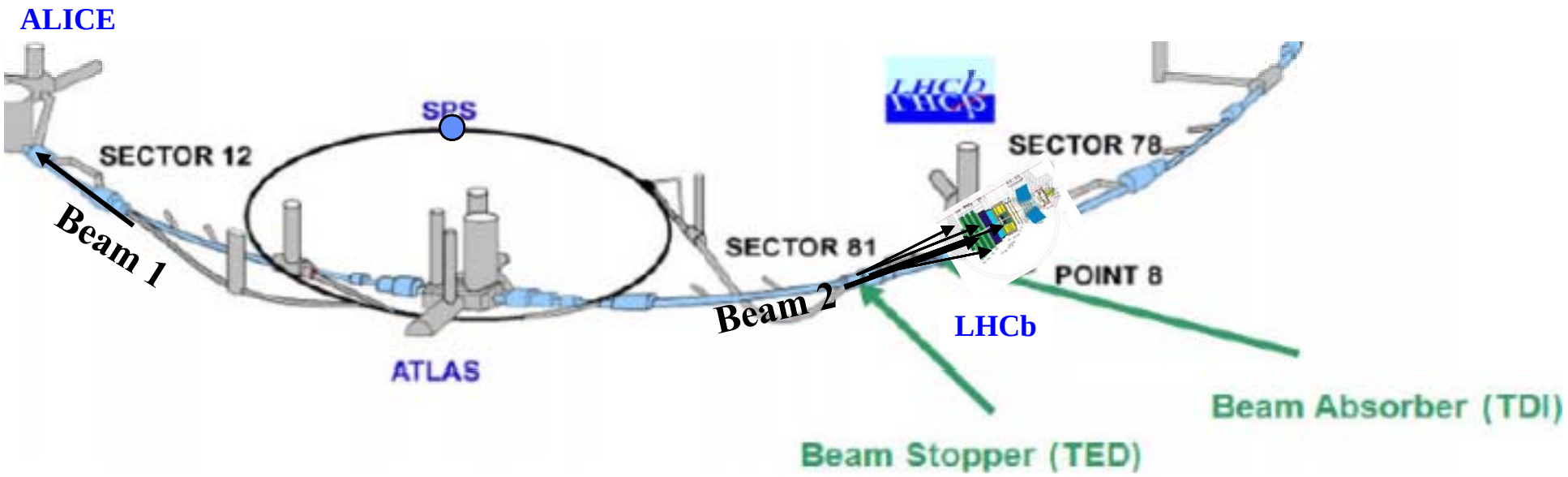
Forward tracks – time aligned



Muon timing good to a few ns

TED Data (Injection tests)

- **LHC*b* is near the Beam 2 injection line**
  - **TED beam stopper ~350 m behind LHCb**
    - Particles traverse detector from Muon → VELO ('reverse' direction)
    - ~10^9 p/bunch on TED ➔ **~10 particles ($\mu^{\pm}$) per cm^2 at LHC*b***

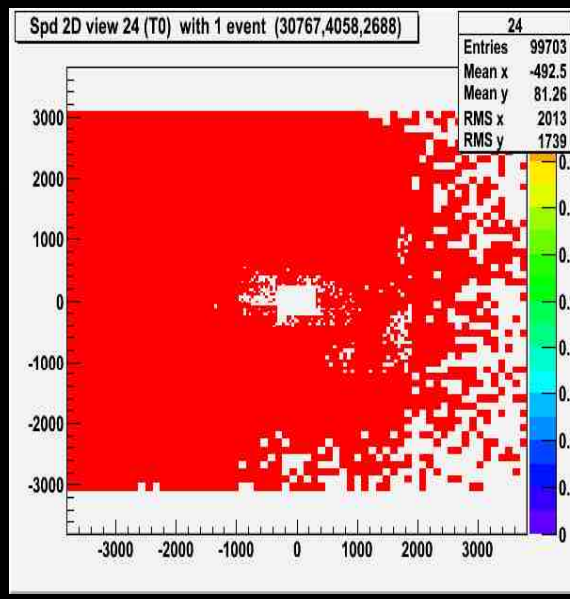


Stopped Beam 2 - “TED” Events

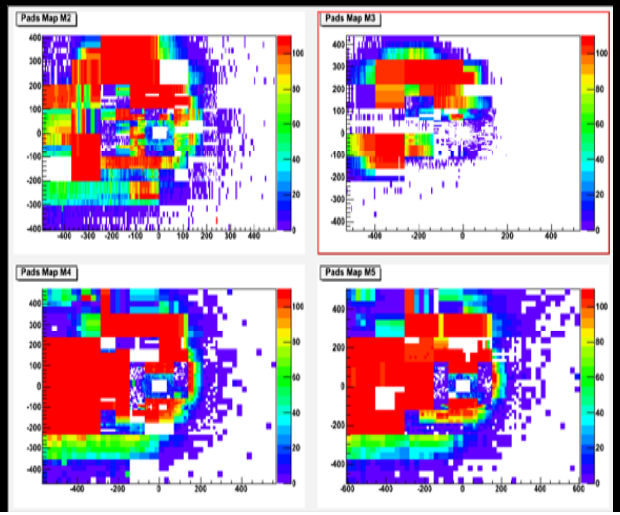
Muon tracks cross LHCb in the “wrong” direction

LHCb sees tracks from the LHC injection tests on August 22

SPD (provided trigger)



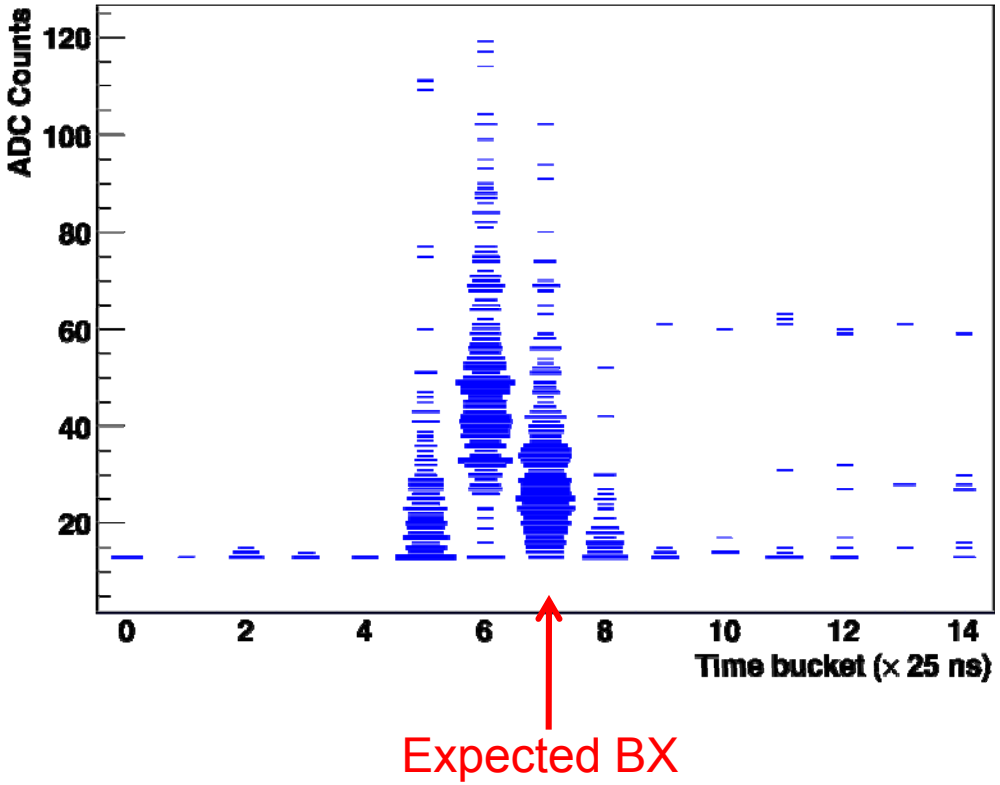
Muon chambers

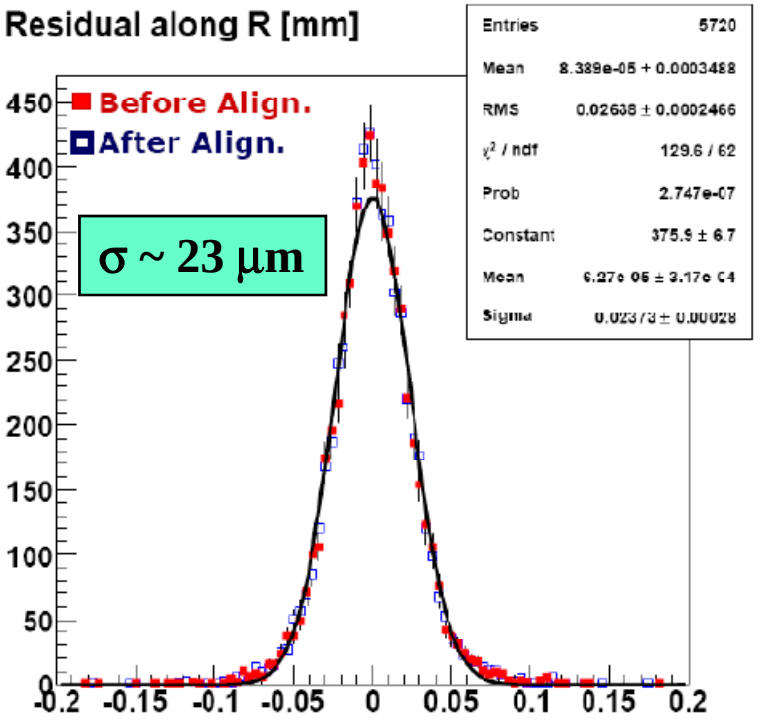


VELO
(Run 30933, Event 14)

VELO: Time & Space Alignment with TED events

- LHC*b* can read out 15 consecutive bunch crossings
- VELO retracted 30 mm from beamline



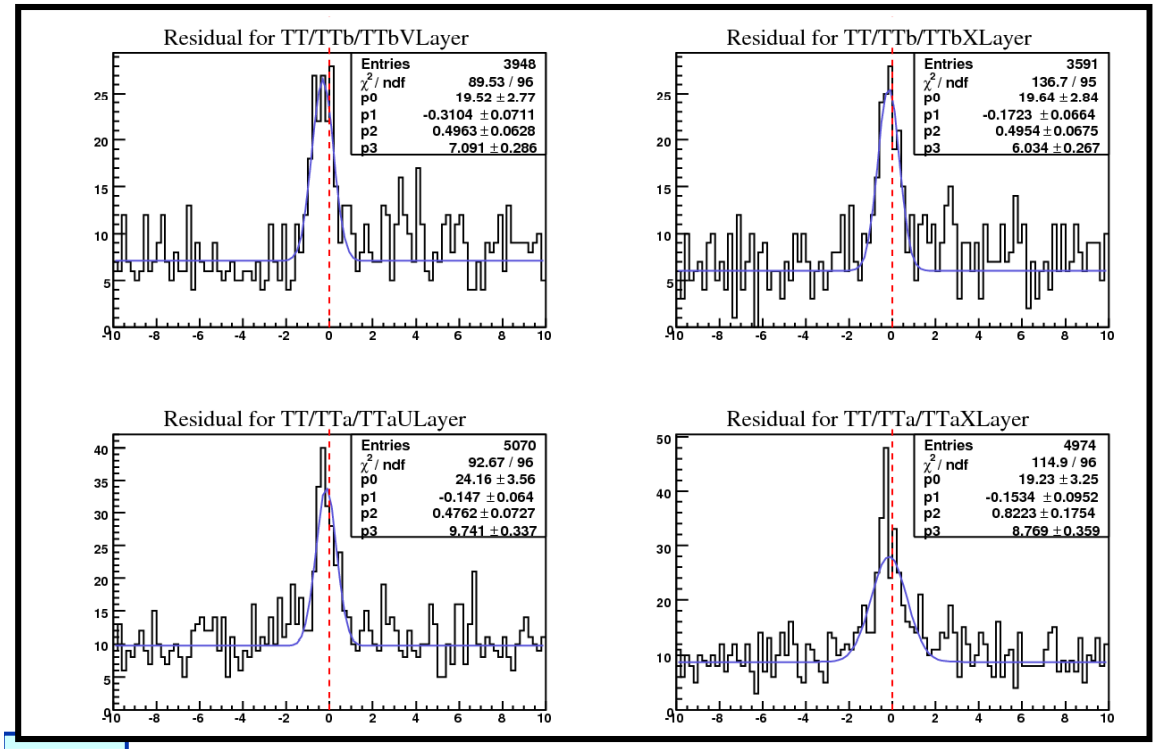


After: VELO sensors time aligned to ~ 5 ns, and space aligned to ~10 μm.

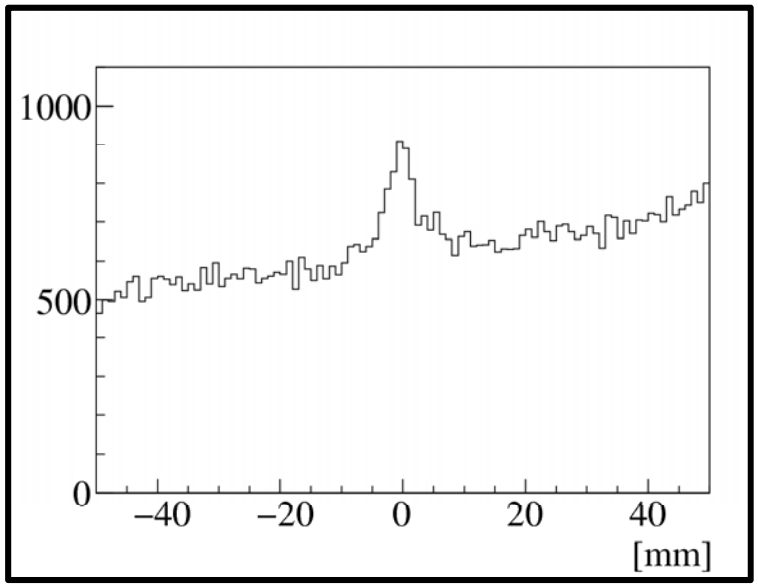
Space Alignment of TT and IT with TED events

- **Extrapolate Velo tracks**
  - **Distance to clusters in TT and IT**
  - **Large combinatorics due to <u>huge occupancy</u>**
    - 10 tracks/cm^2, normal value is 20 tracks in the whole detector

TT at ~ 2 m



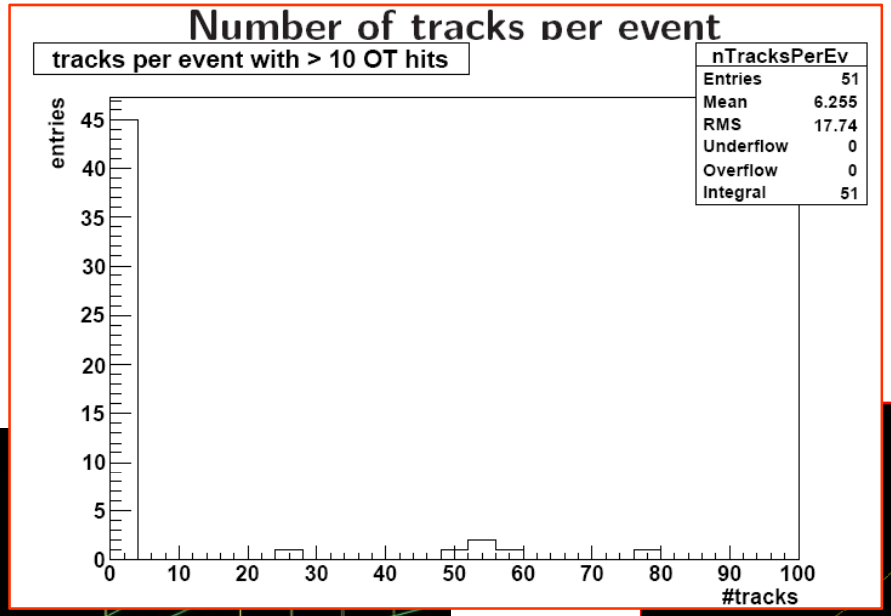
IT at ~ 7 m

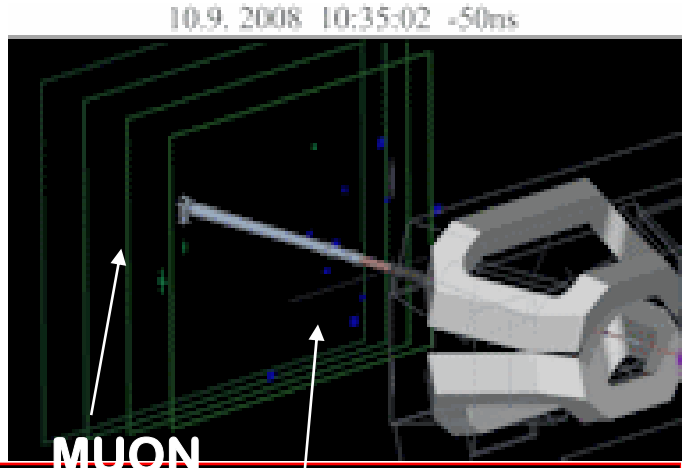


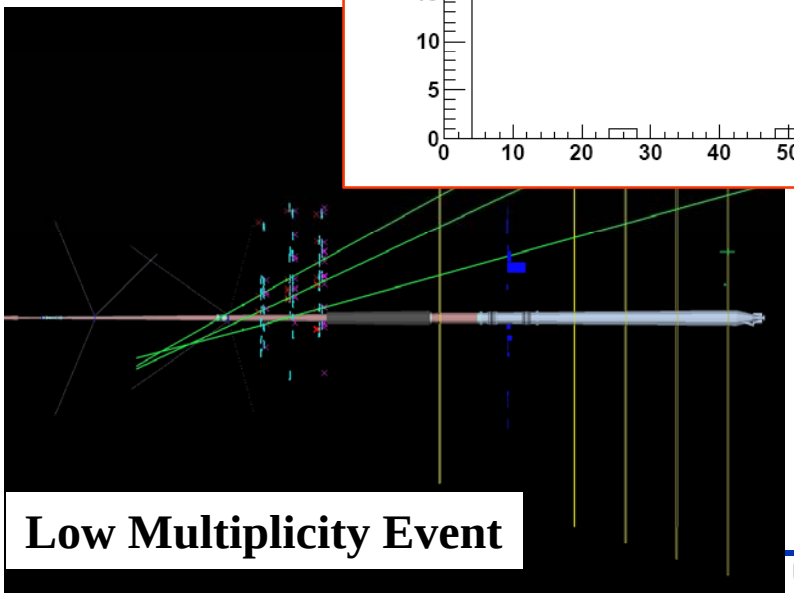
Beam 1 on “Media Day”

Beam 1: - 1 shot every 48 sec.
- 5×10^9 protons per shot

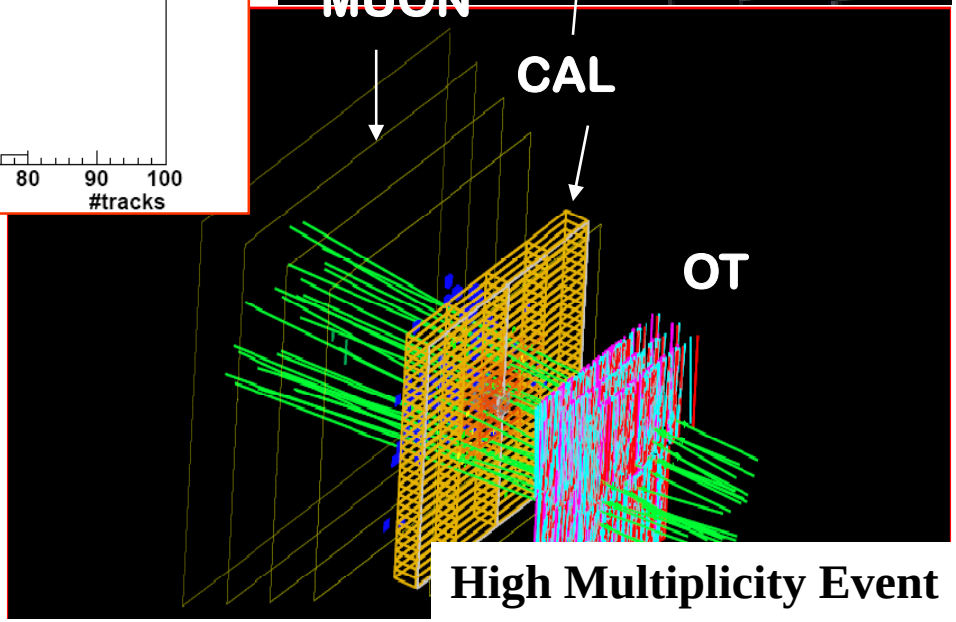
Observed events were either low multiplicity ***or high multiplicty***







Low Multiplicity Event



High Multiplicity Event

Major Shutdown Goals

- **Muon Station 1 installation/commissioning**
- **Modifications to ECAL bases to reduce noise**
- **Improve constraints on TT and RICH1**
  (1 mm movement when magnet ramped from 0 to full field)
- **Improve IT closing system**
- **+ other smaller issues**

- **Learn as much as possible from cosmic data**

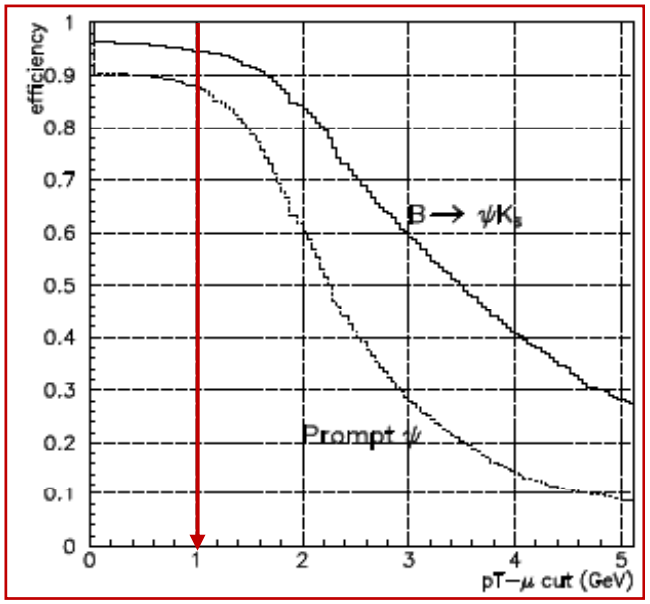
- **Full Scale Test (FST-09)**
  - **Generate 100M L0-accepted MinBias events, no MC truth**
  - **'Inject' into HLT farm – process like real data (2 kHz output)**
    - Full online monitoring
    - Alignment & calibration cycle, updated constants, update Conditions Database → give Green light to Offline processing
    - Offline Reconstruction at Tier 1s
    - Updating of Bookkeeping DBs

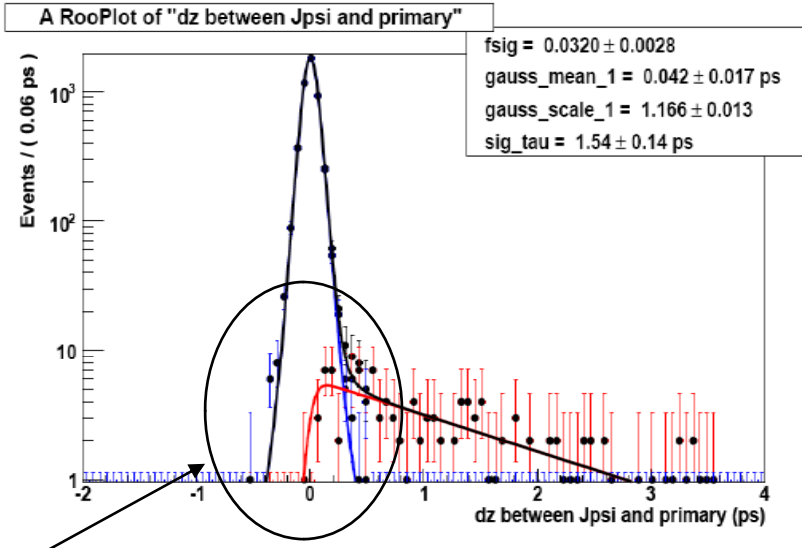
Exploiting 1 pb^{-1} – inclusive muon trigger

few hours at 2×10^{32} cm^{-2} s^{-1}

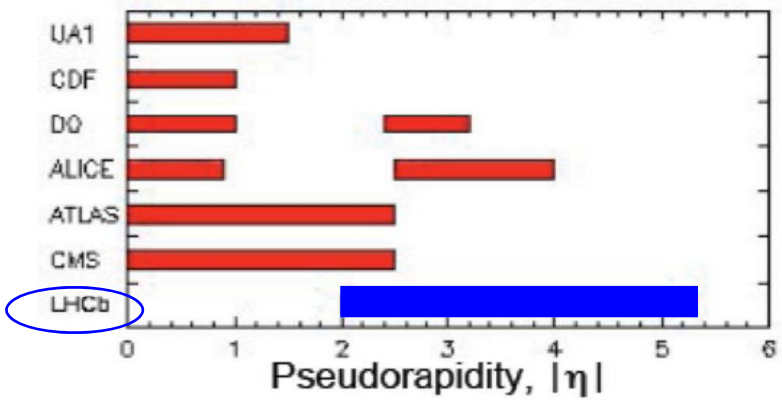
J/ψ trigger with p_t-cut on single muon
→ expect **~10^6 J/ψ→μμ** with **1 pb^{-1}**

- Measure prompt J/ψ vs B→J/ψ in a region not accessible to other collider experiments





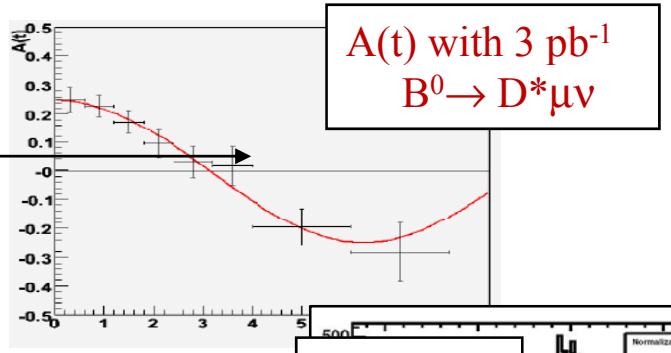
study proper time resolution with prompt component



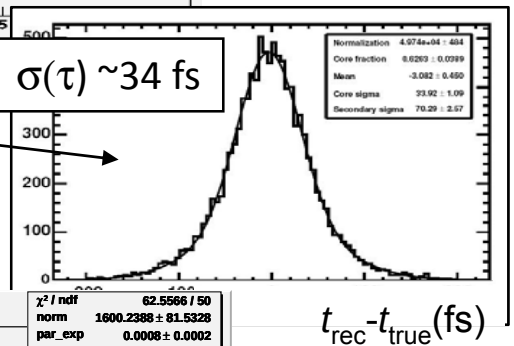
Exploiting ~5 pb^{-1} - full trigger (just a few examples)

(~days of data taking)

- ✓ 23k $B^0 \rightarrow D^*\mu\nu$
  - ➢ tagging studies with flavour specific modes

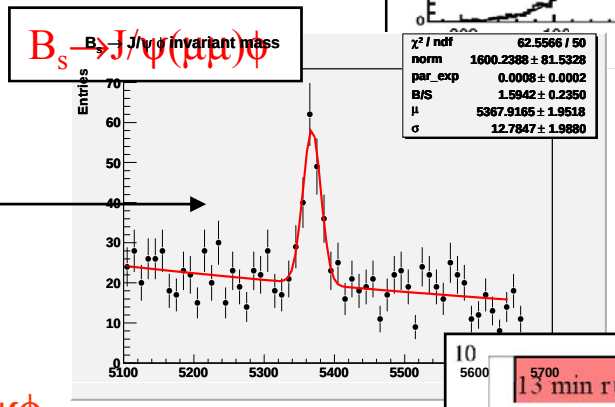


- ✓ 4.3k $B^0 \rightarrow D^-(K^-\pi^+\pi^-)\,\pi^+$
  - ➢ measure B^0 lifetime



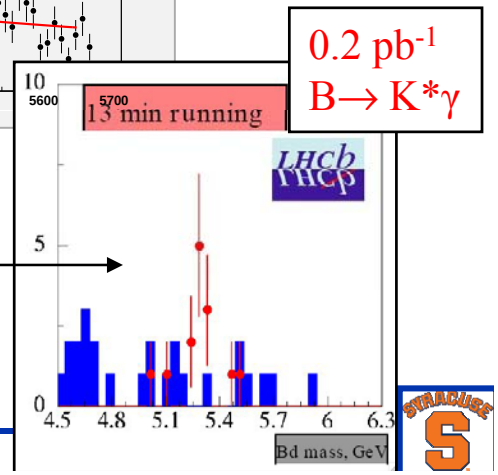
- ✓ 3.2k $B^+ \rightarrow J/\psi K^+$
  - ➢ unbiased lifetime distribution to determine resolution

- ✓ Select first 285 $B_s \rightarrow J/\psi\phi$



- ✓ 2.3k $B \rightarrow J/\psi K^*$
  - ➢ exercise fit machinery for analysis of $B_s \rightarrow J/\psi\phi$

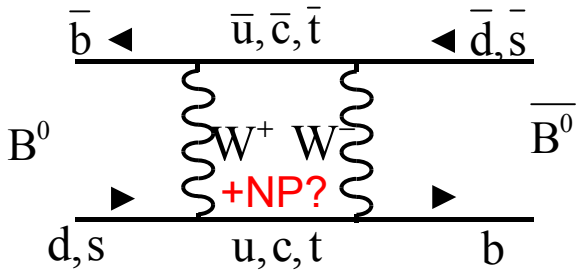
- ✓ 3.7k $B \rightarrow K^*\gamma$
  - ➢ reference channel for all radiative loop decays



Exploiting 0.5 fb^{-1} (two of the key measurements)

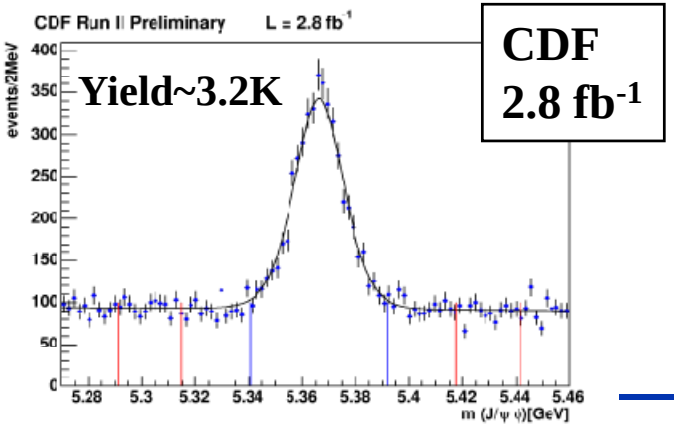
(1/4 of a nominal year)

➢ B_s-$\bar{B}_s$ mixing phase ϕ_s in $B_s \to J/\psi(\mu\mu)\phi$



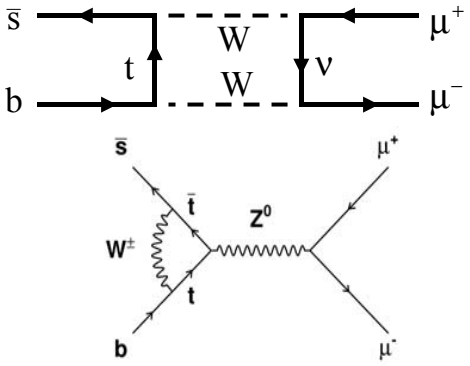
✓ **29K** reconstructed $B_s \to J/\psi(\mu\mu)\phi$ signal events (before tagging)

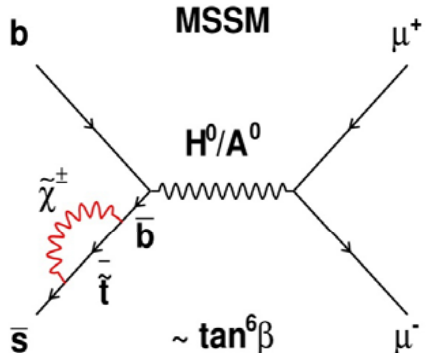
→ $\sigma_{stat}(\phi_s) \sim 0.06$ with 0.5 fb^{-1}



CDF 2.8 fb^{-1}

➢ measure BR of rare decay $B_s \to \mu^+\mu^-$





✓ $BF_{SM} \sim 3.5 \times 10^{-9}$

✓ may be strongly enhanced in SUSY

Exclude BR down to SM value for 0.5 fb^{-1}

→ with 2 fb^{-1} : 3σ evidence of SM signal

→ with 10 fb^{-1}: > 5σ observation of SM signal

Current combined limit from CDF/D0

$BF(B_s \to \mu^+\mu^-)/BF_{SM}$ 13

Sensitivities on a few key measurements

Measurement	Channel	Yield ($10\ fb^{-1}$)	Sensitivity ($10\ fb^{-1}$)
$2\beta_s$			
in Trees	$B_s \rightarrow J/\psi\phi$	650 K	0.01
in Penguins	$B_s \rightarrow J/\psi\phi$	~15 K	0.05
2β			
in Trees	$B \rightarrow J/\psi K_s$	200 K	0.6^o
in Penguins	$B \rightarrow \phi K_s$	~15 K	0.05
γ			
in Trees	$B^+ \rightarrow D^0 K^+$	~100 K	$\sim 3^o$
in Box	$B_s \rightarrow D_s K^{(*)+}$	~50 K	$\sim 5^o$
in Penguins	$B_{(s)} \rightarrow hh$	~10 M	$\sim 5^o$
Rare			
Branching fraction	$B_s \rightarrow \mu^+\mu^-$	~350	5σ observation
FBA zero cross (s_0)	$B \rightarrow K^*\mu^+\mu^-$	~30K	$\sigma(s_0) \sim 0.3\ GeV^2$

- If NP is large-ish, will see it early($<10\ fb^{-1}$); **higher precision** important to distinguish various models/elucidate the NP.
- If NP not-so-large, will need higher stats on many of these (& other) key observables

→ **SuperLHCb**

Conclusion

Thank You

Backups

'Super-LHCb'

- At $\mathcal{L}$~2x10^{32} cm^{-2}/s^{-1}, will collect ~8 fb^{-1} by ~2013
- Strong physics case for upgrade to collect 100 fb^{-1}

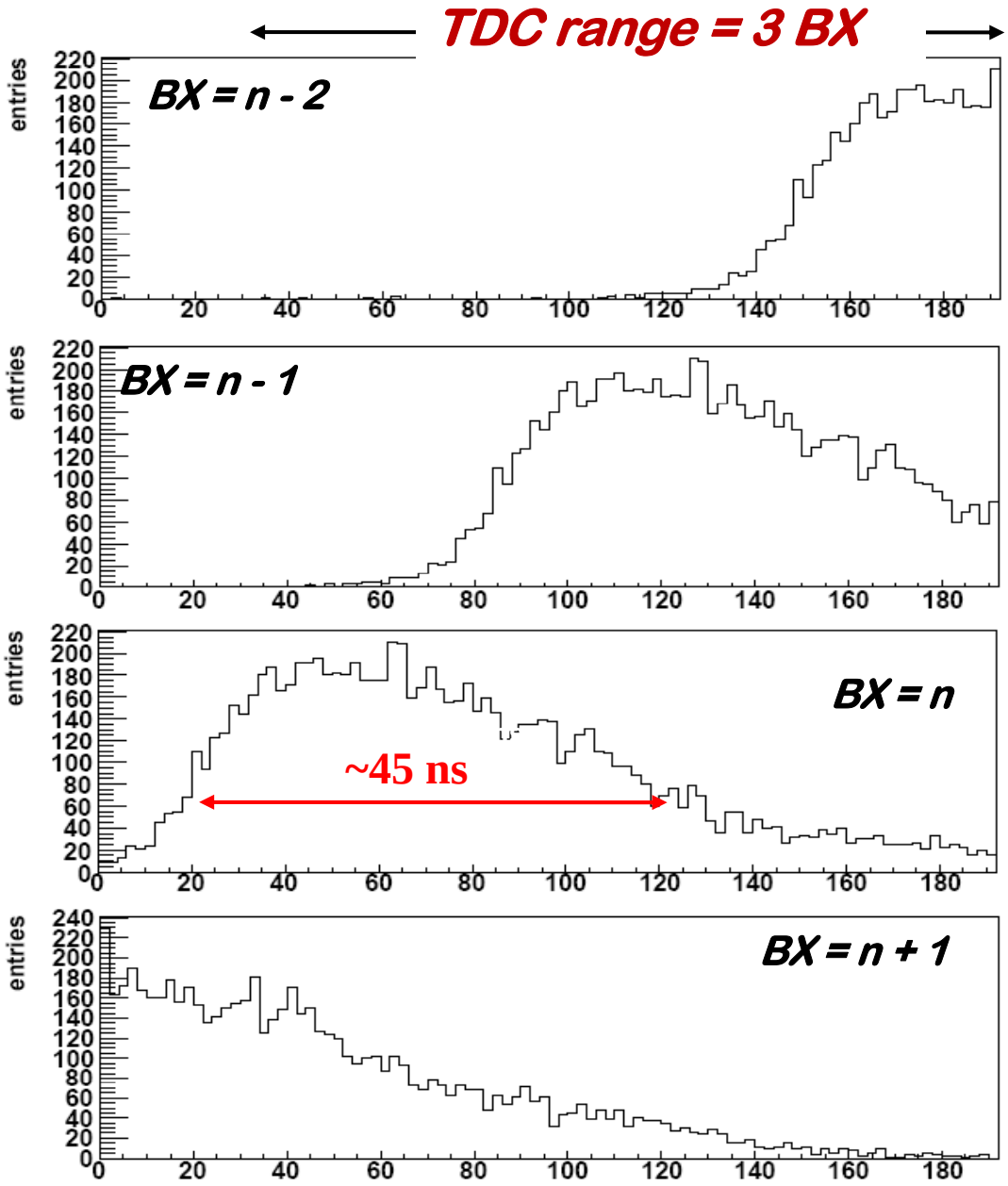
(see talk by A. Golutvin at "Physics at the LHC", Split, Croatia)

- Upgrade for 2013: 10^{33} cm^{-2}/s^{-1} → 20 fb^{-1}
  - Readout entire detector at 40 MHz
    → Trigger handled in software based on p_T & IP
    - Replace all FE's, except MUON & CAL
    - Replace all Silicon detectors
    - Replace RICH photon detectors – various options being explored
    - Reuse existing infrastructure, mechanics as much as possible.
- Upgrade for 2017: 2x10^{33} cm^{-2}/s^{-1} → 100 fb^{-1}
    - VELO → VESPA (pixels, 3D detectors); add B field around it?
    - Extend IT into higher occupancy region of OT
    - Reduce OT timing window; faster gas
    - Inner CAL region replacement (perhaps $PbWO_4$)

Outer Tracker Timing

Using 6 Beam1 'splash' events, with ~ 50 tracks/event

TDC spectra of all OT chambers



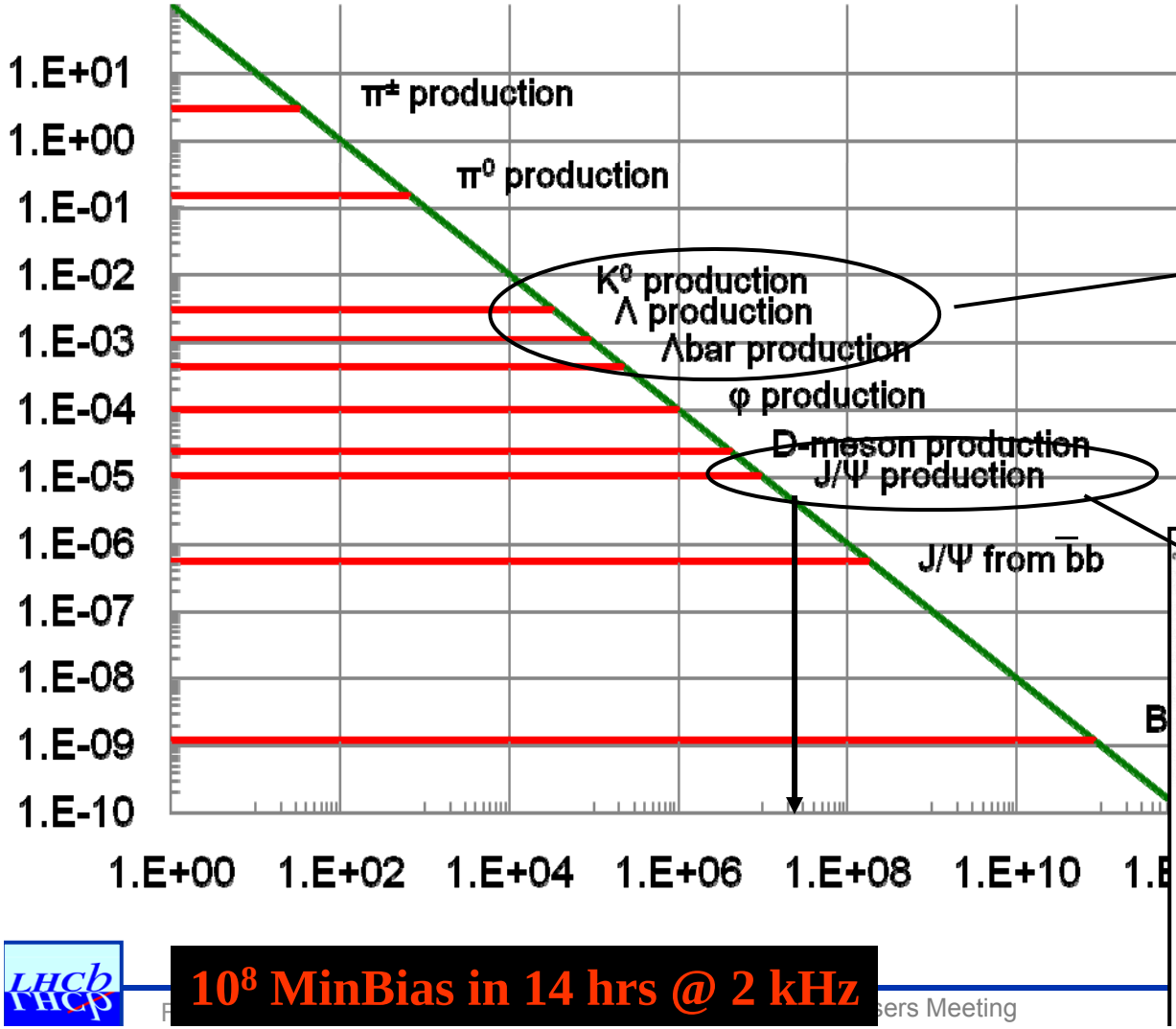
Extracting physics from (very) first data

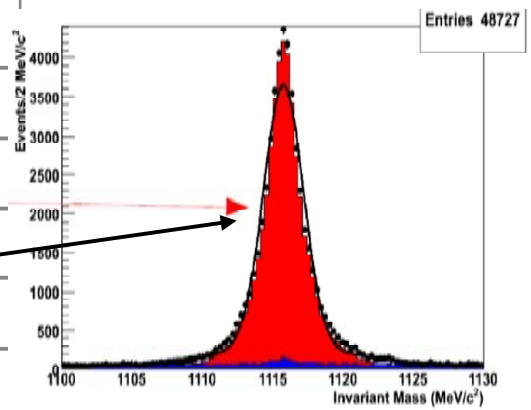
Exploiting minimum bias data

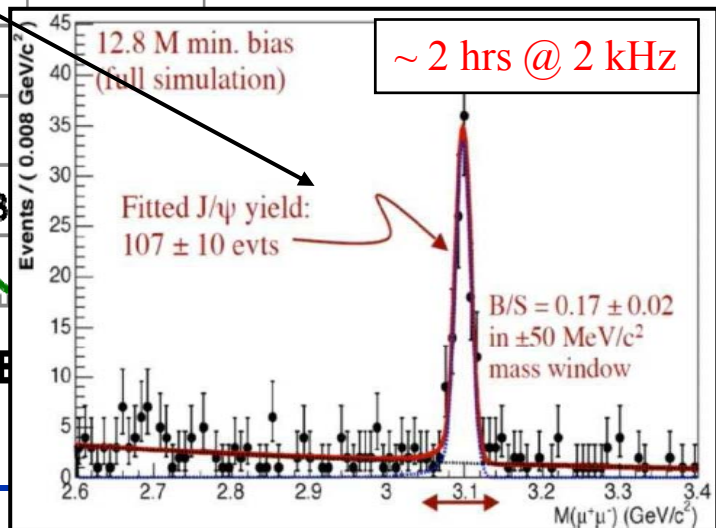
$\sigma\cdot\varepsilon/\sigma_{mb}$

Number of selected signal events: $S = \frac{\sigma\cdot\varepsilon}{\sigma_{mb}}\cdot N_{mb}$

~ 40 mins @ 2 kHz
→ ~50k $\Lambda\rightarrow p\pi$ events







10^8 MinBias in 14 hrs @ 2 kHz