Status of the LHCb Experiment

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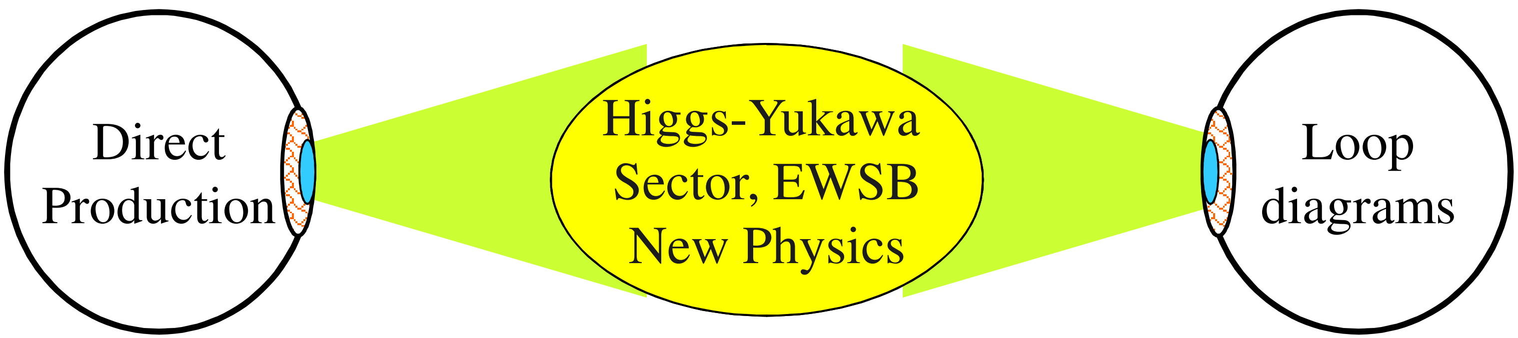
(on behalf of the LHCb Collaboration)

- 701 members
- 15 countries
- 52 institutes

- Introduction
- The LHC*b* Experiment
- Expected Performance from simulation
- Performance with 'data'
- Looking ahead to 09-10 Run
- Conclusions

Introduction

- Standard Model cannot be the final word
  - Hierarchy problem? Dark Matter? BAU? Why 3 generations? Patterns of masses & couplings? …
- New physics at the TeV energy scale (LHC)
  - **Direct production** of new HEAVY particles.
  - **NP in Loops**: $A^2 = |A_{SM}+A_{NP}|^2 = |A_{SM}|^2 + |A_{NP}|^2 + 2\,|A_{SM}||A_{NP}|\cos\phi$
    - *Heavy particles dominate in loops*
  - *Complementary approaches to uncovering and/or constraining New Physics*



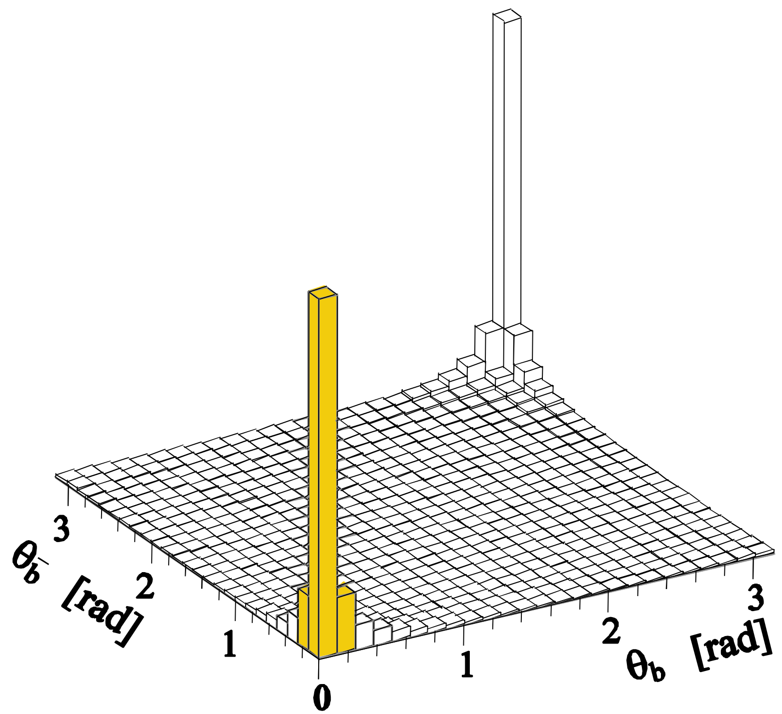
The LHCb Experiment

LHC*b* is a first dedicated precision heavy flavor experiment searching for **New physics** in **CP-Violation** and **Rare Decays** at a hadron collider

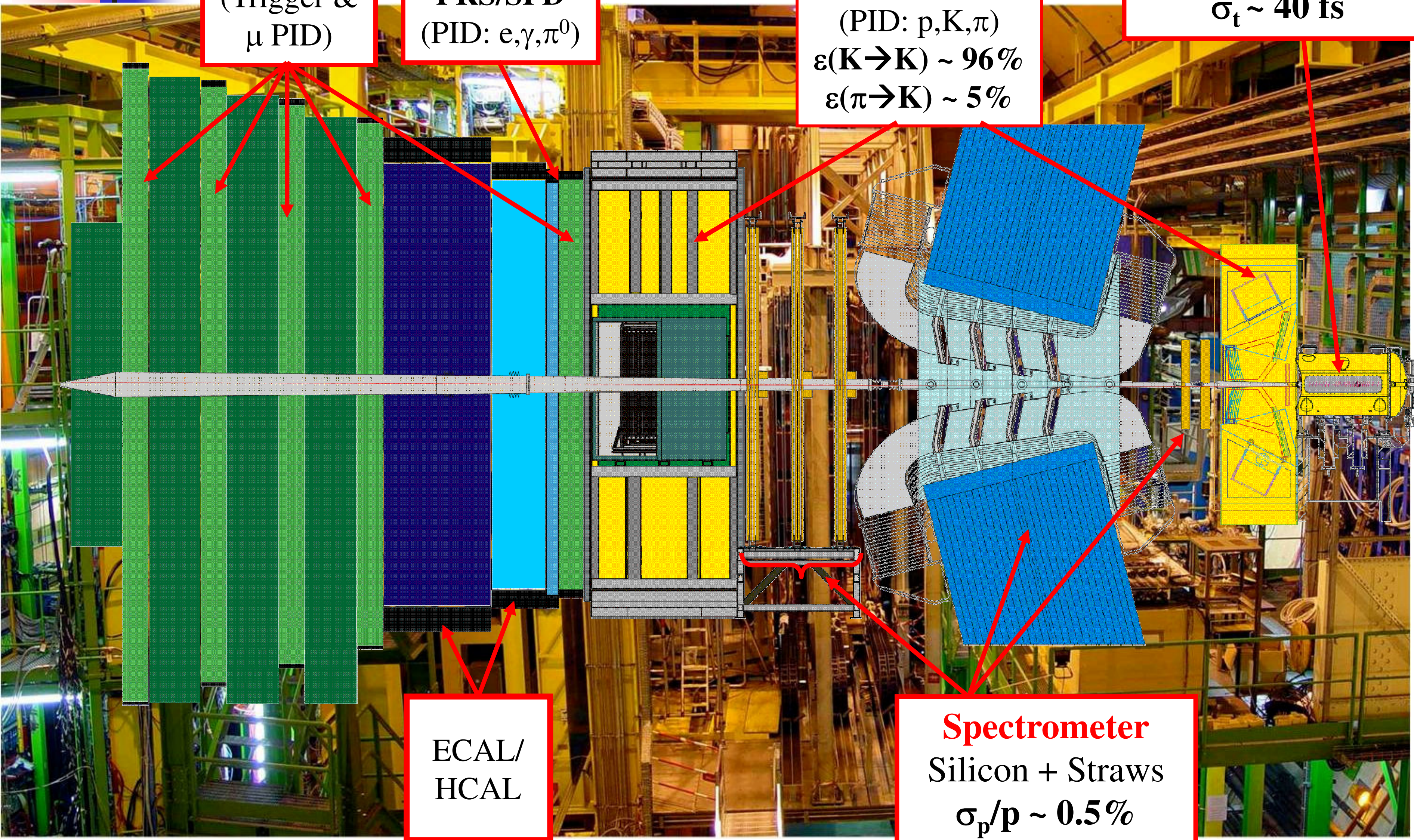
- **Beams (intentionally) less focused**
  $\mathcal{L}_{inst} \sim 2 \times 10^{32} cm^{-2}s^{-1}$
  → mostly single interaction.

- **100K $b\bar{b}$/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 $b\bar{b}$ production**
  Single arm forward spectrometer
  13 mrad<θ< 300 mrad (1.9<η<4.9)



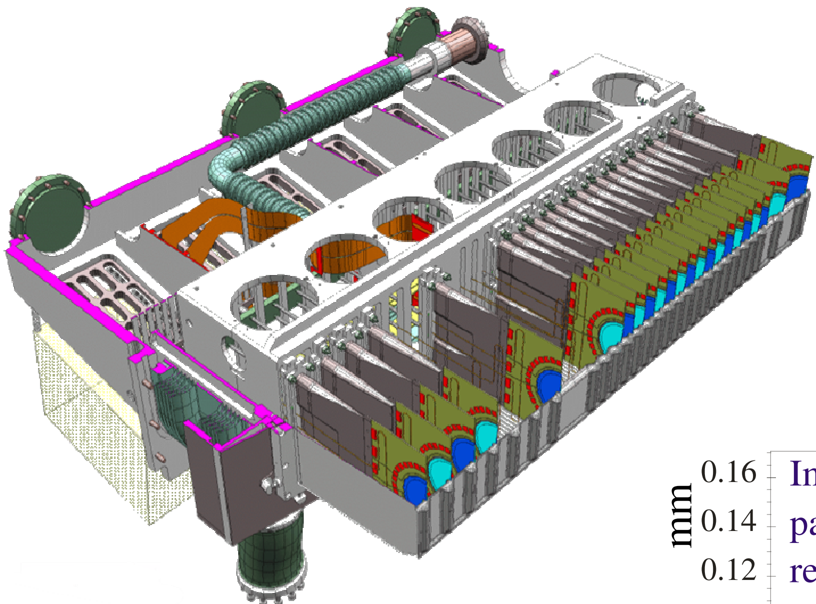
The LHCb detector



LHCb is ready for collisions !

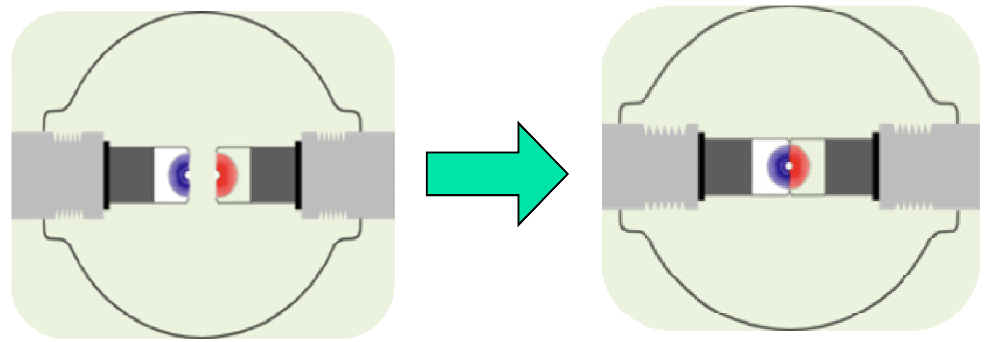
Expected Detector Performance

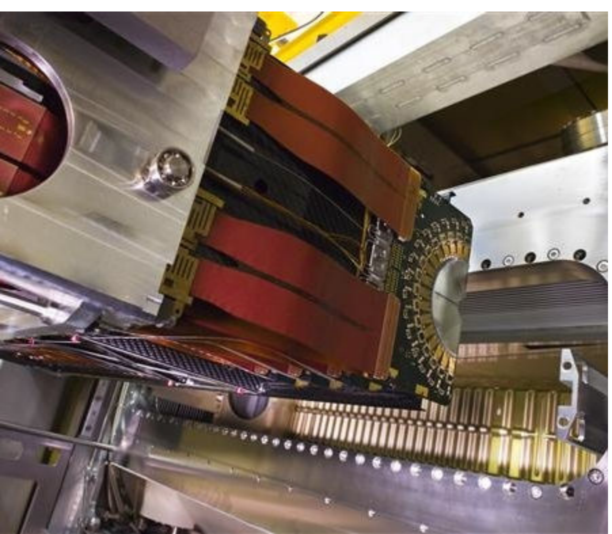
VELO

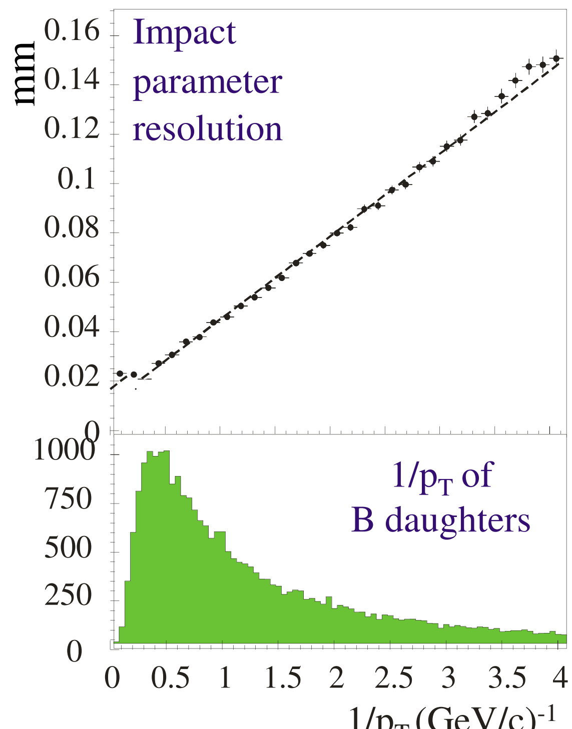


Retracted 30 mm during injection

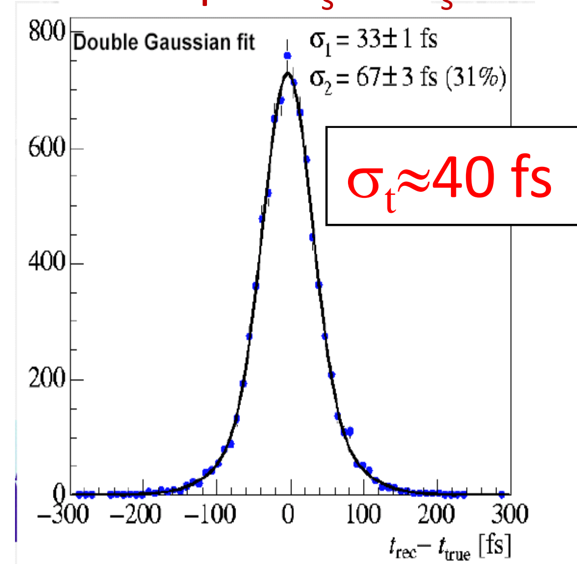
Stable Beams Inner strip at 8 mm





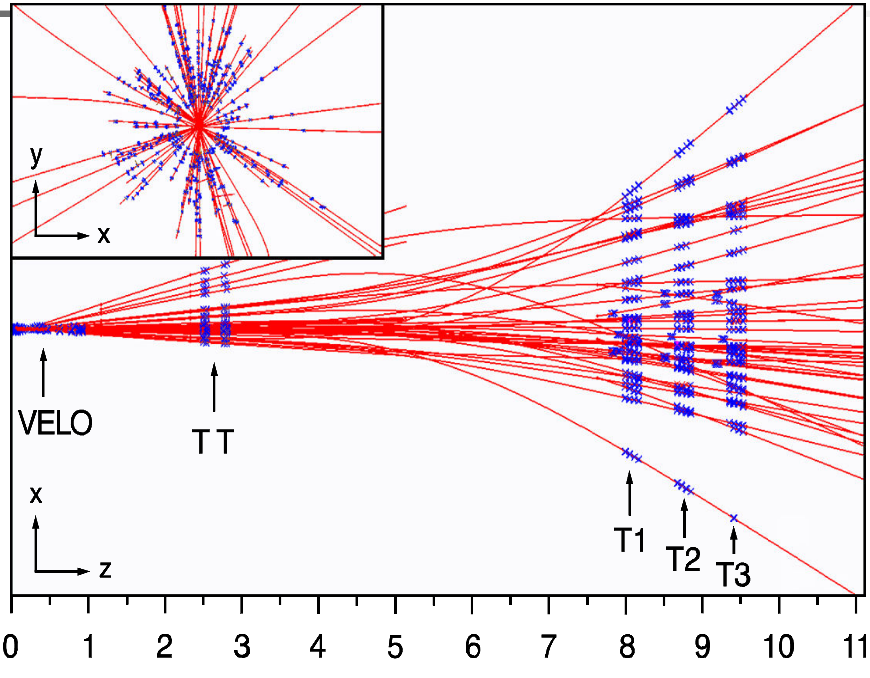


Example: $B_s \rightarrow D_s K$



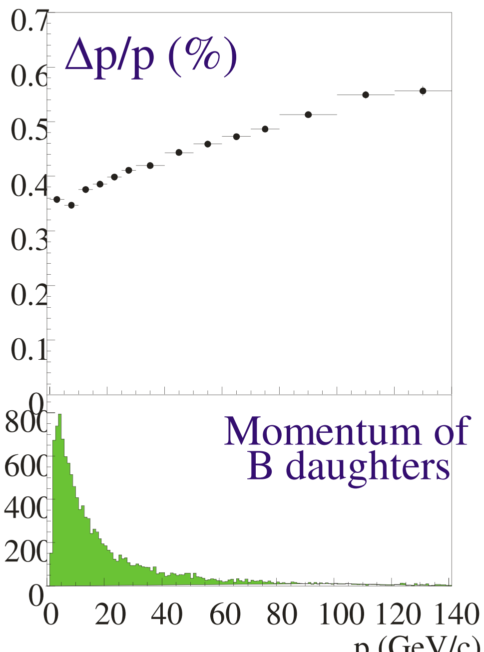
B_s oscillations: $\Delta m_s^{-1} = 56$ fs

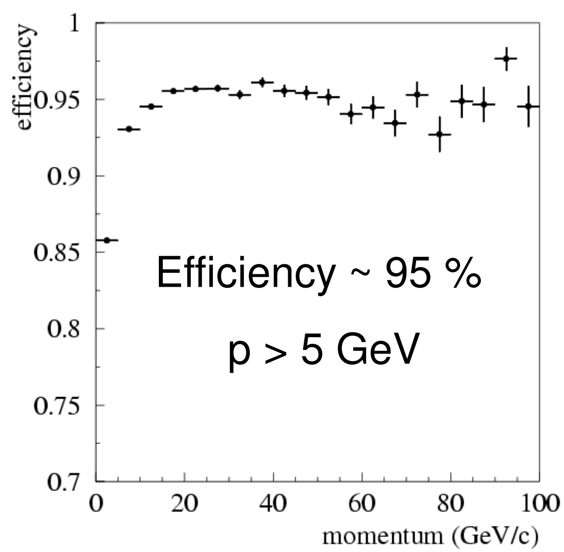
Charged Particle Tracking

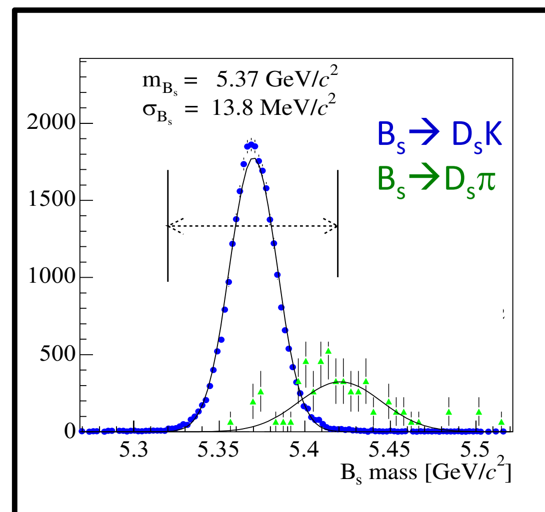


Mass resolution (MeV)

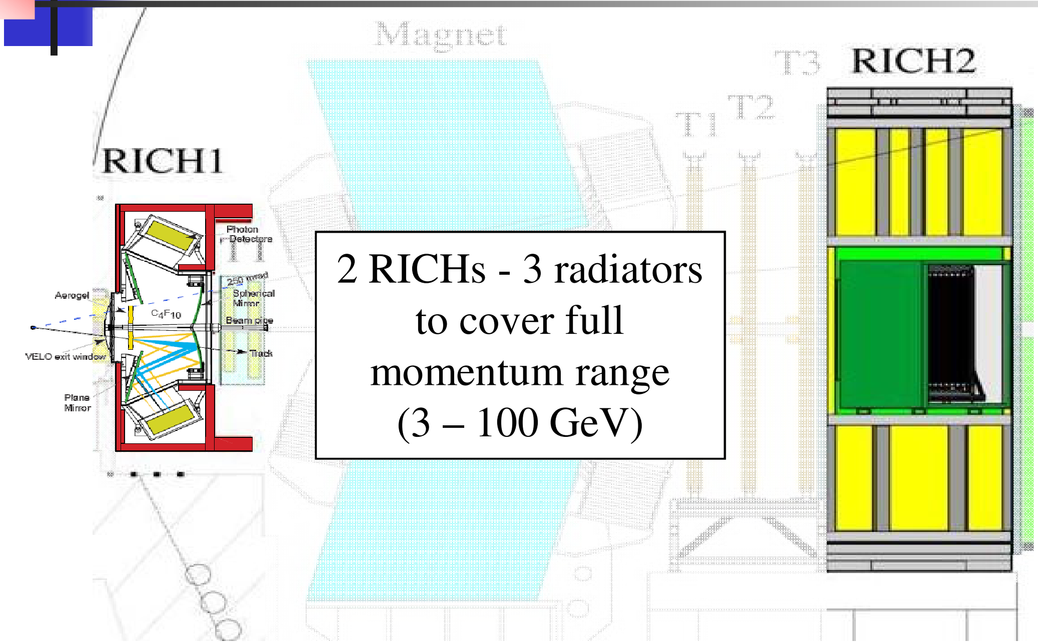
$B_s \rightarrow \mu\mu$	20
$B_s \rightarrow D_s\,\pi$	14
$B_s \rightarrow J/\psi\ \phi$	16





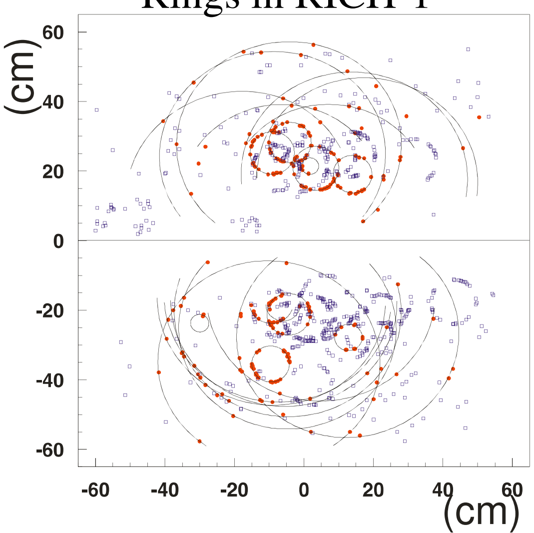


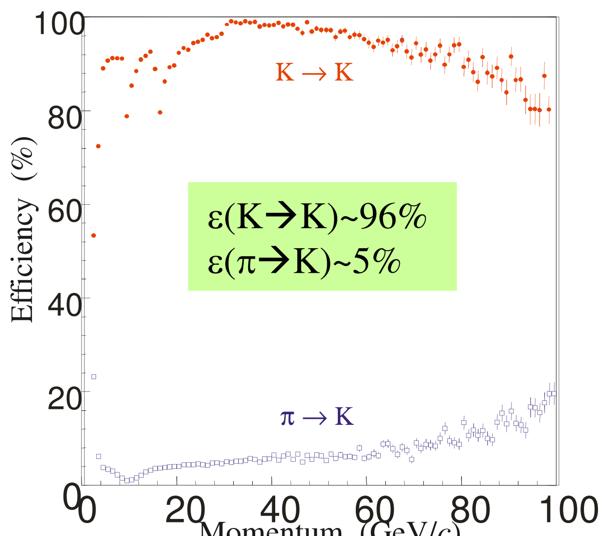
Particle Identification - RICH

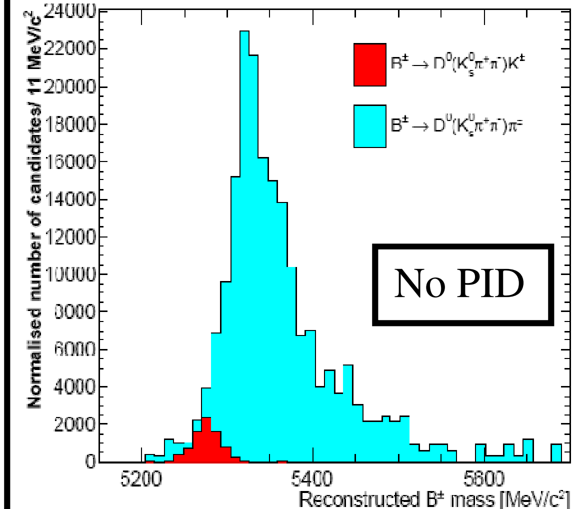


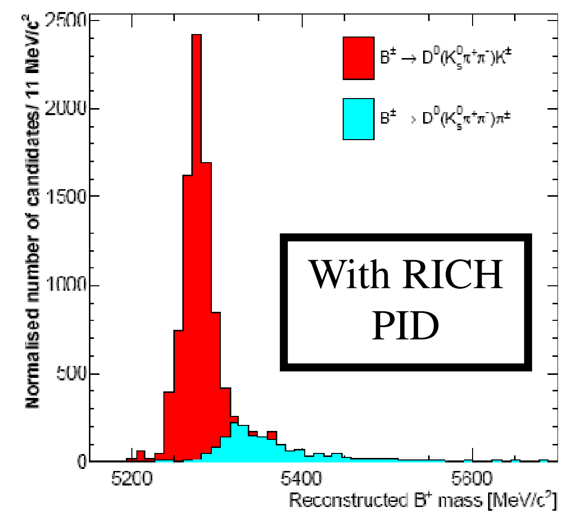
2 RICHs - 3 radiators to cover full momentum range (3 – 100 GeV)

Rings in RICH-1







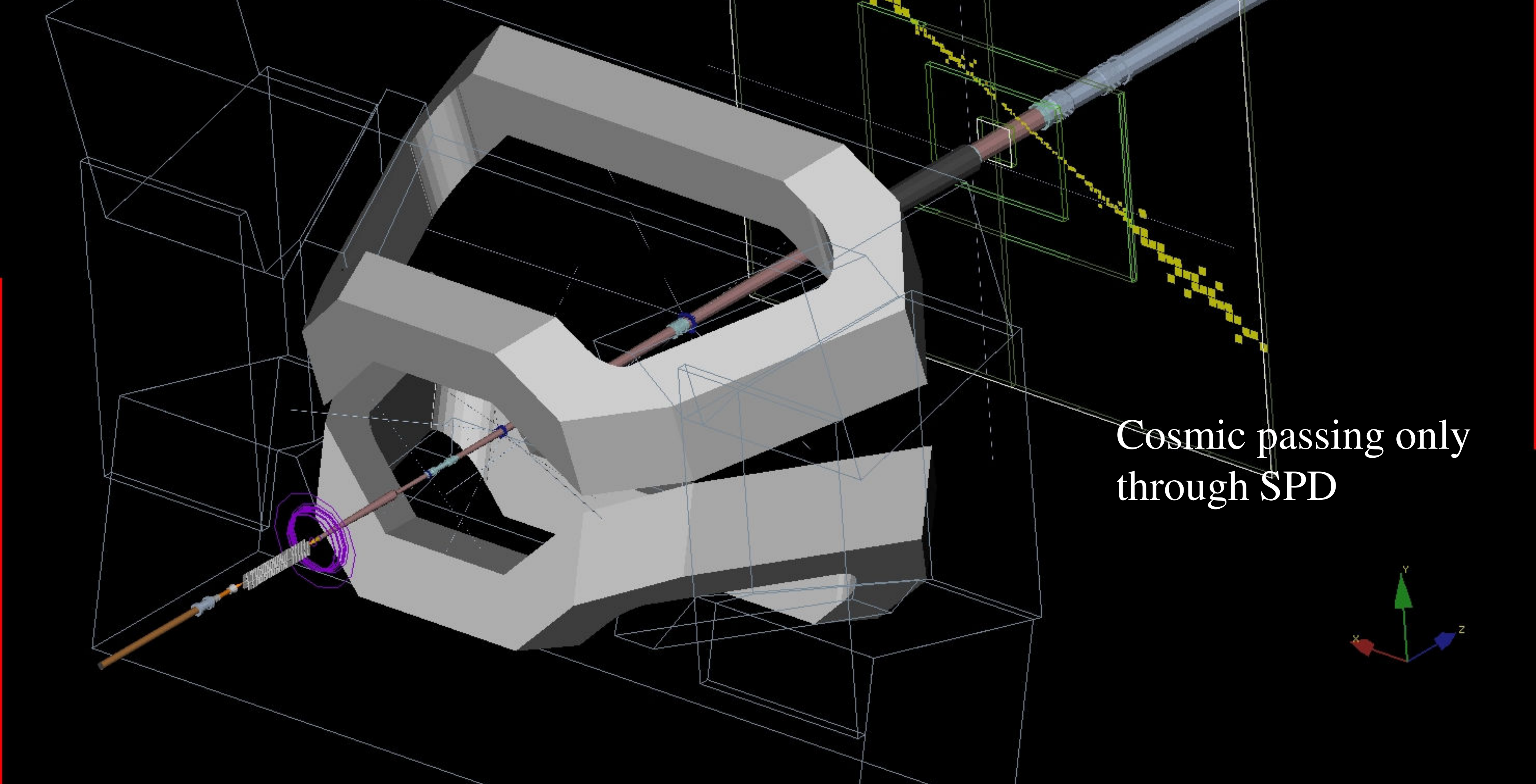


Experience with Data

Cosmics
TED runs

Cosmics

- Low rate due to horizontal acceptance, ~ 1 hz → 2M events to tape.
- Both forward & backward-going
- Hard for "small" detectors (VELO & IT) to take advantage due to large vertical angle



Cosmic passing only through SPD

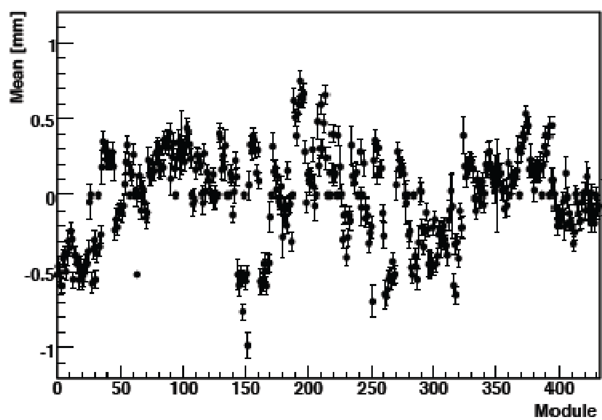
Outer Tracker Alignment with Cosmics

Mean of Residual Distribution versus OT Module Number: DOF: ΔX, ΔZ, Δγ

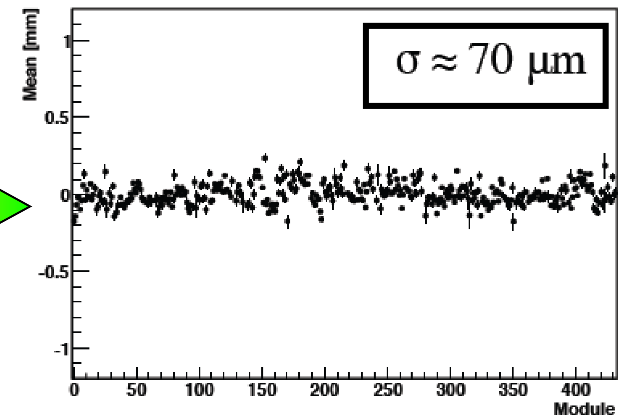
Drift Time not used (here)

~20K Cosmics

Survey alignment, no software



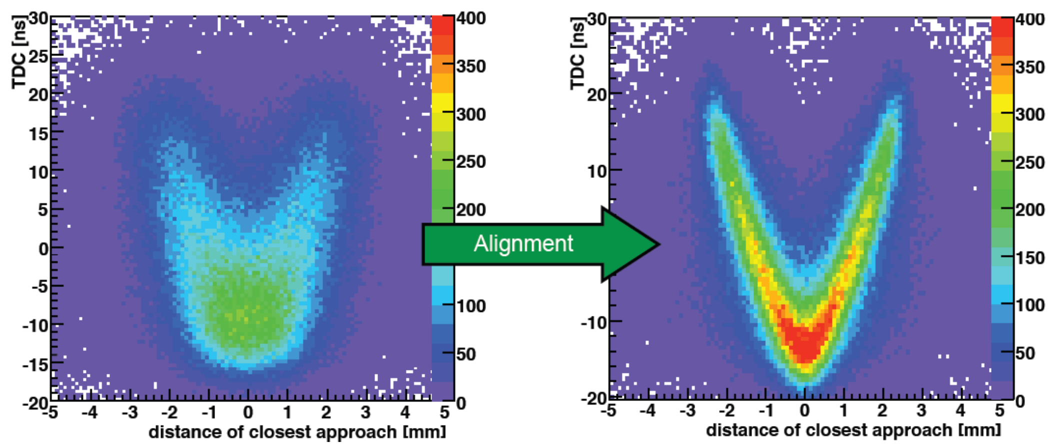
Software alignment
at the module level (64 tubes)



Compare TDC time versus distance of closest approach before & after alignment.

Large improvement

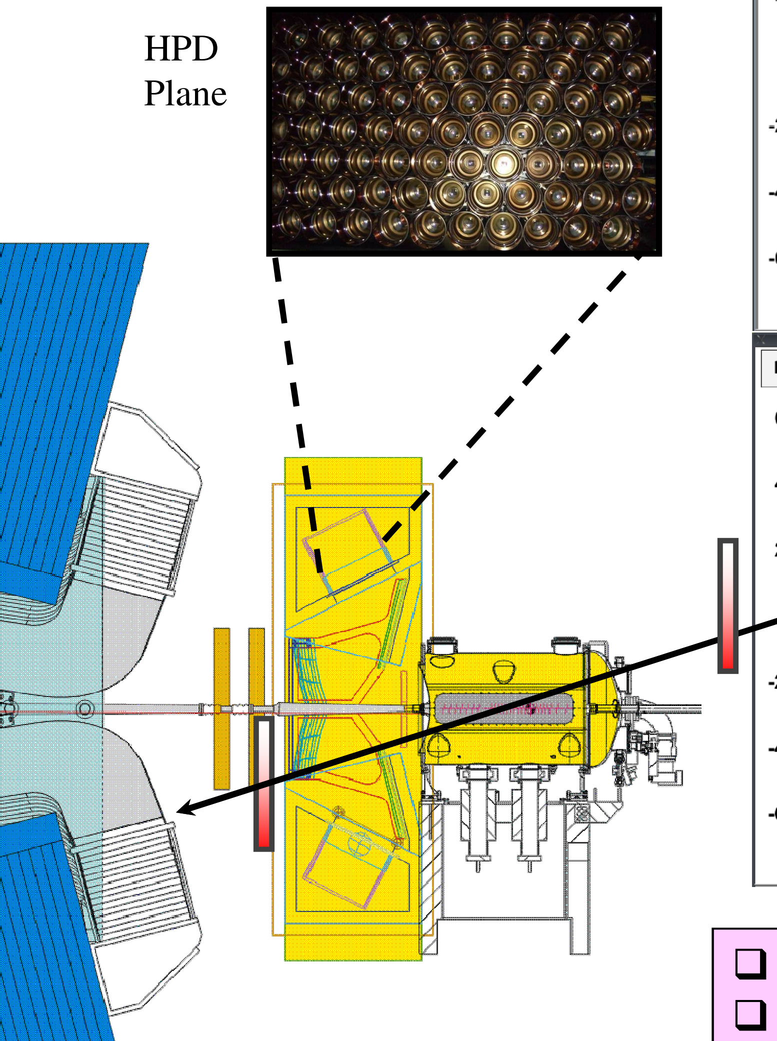
Very good starting point once we have collision data.

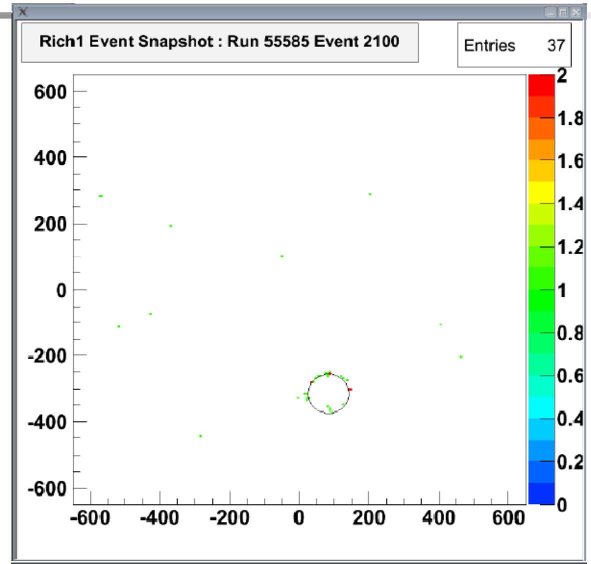


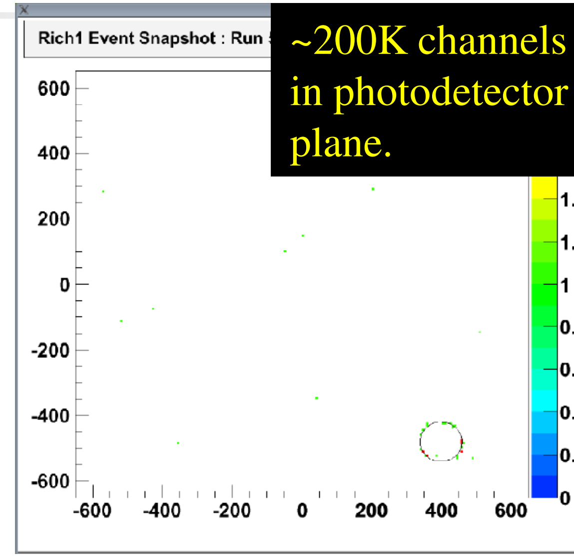
Hit resolution within ~25% of nominal!

Cosmics in RICH1

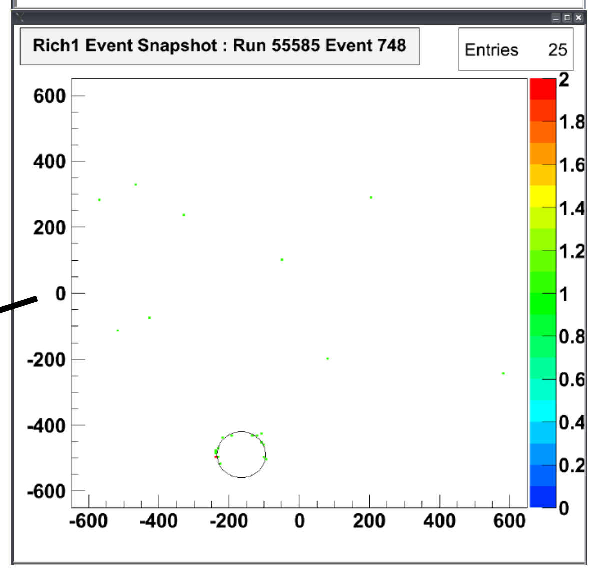
Scintillators placed to mimic tracks from the IR
(~1 cosmic trigger per hour !)

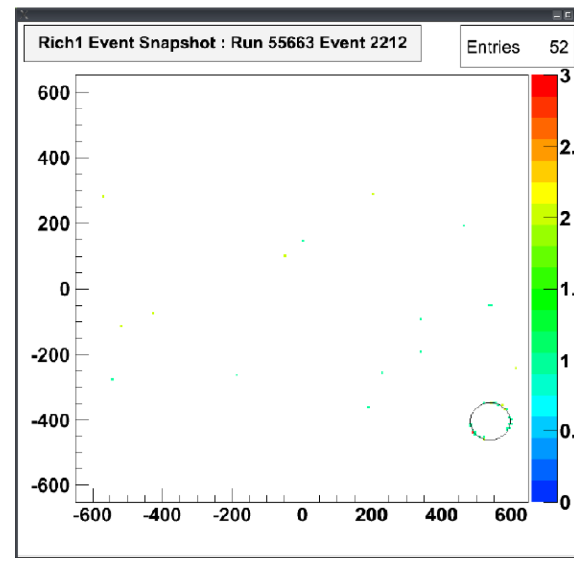






~200K channels in photodetector plane.





- ❑ “Trackless” ring finding -- Work/analysis ongoing, use TT tracks
- ❑ Low noise (as expected)

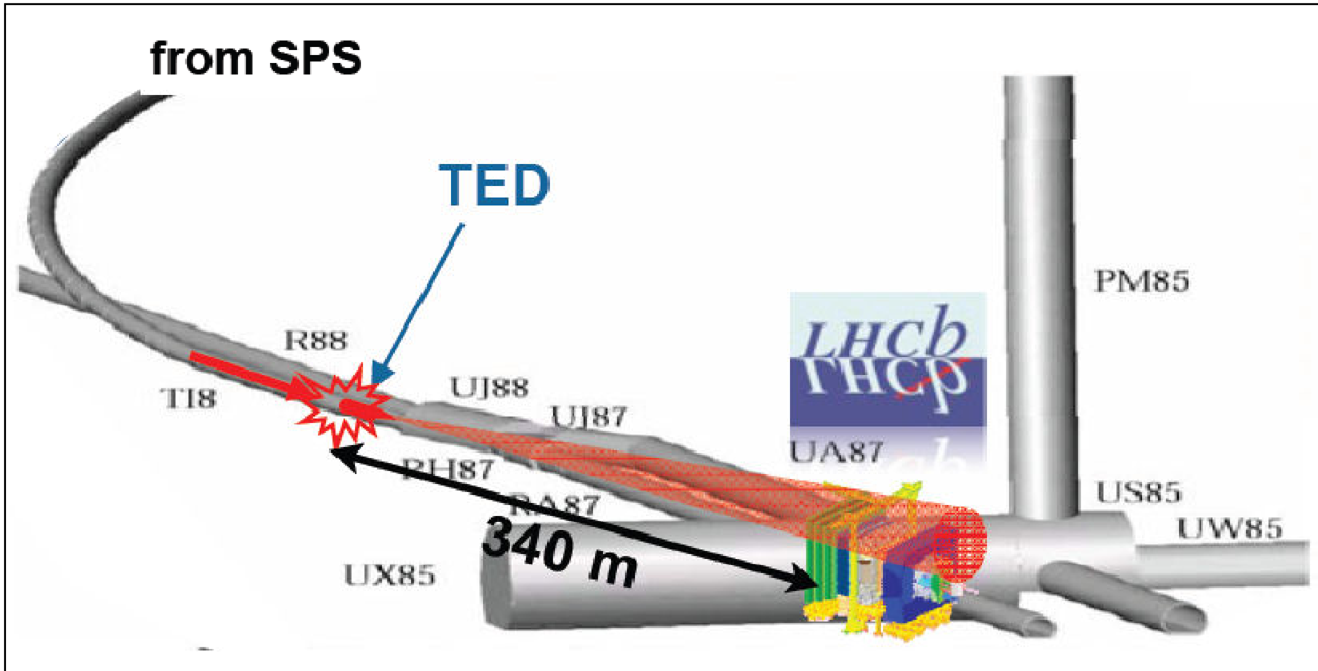
TED runs

- ❑ Injection tests in August and Sept, 2008, and again in June 2009
  - ❑ Another one coming up in October

- ❑ SPS beam (450 GeV) dumped on beam stopper (TED)

- ❑ 1 shot/48 sec, 12 consecutive bunches of ~10^{10} protons/bunch
  → **10 particles/cm² at LHCb** (flux >> normal running conditions)

- ❑ Particles coming *backwards* through spectrometer



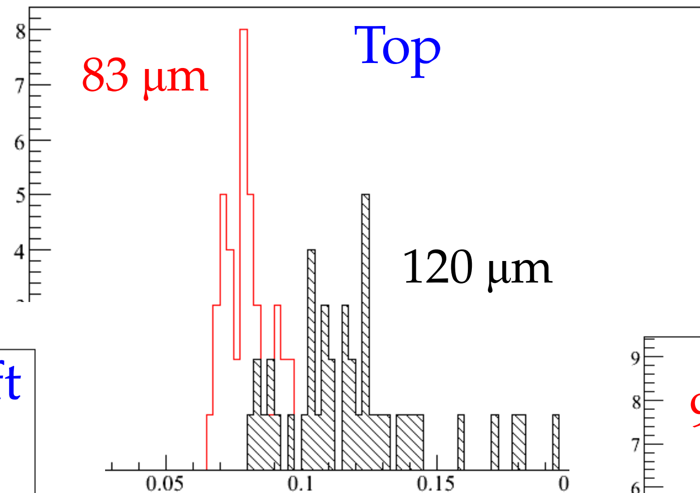
TED events in Inner Tracker (IT)

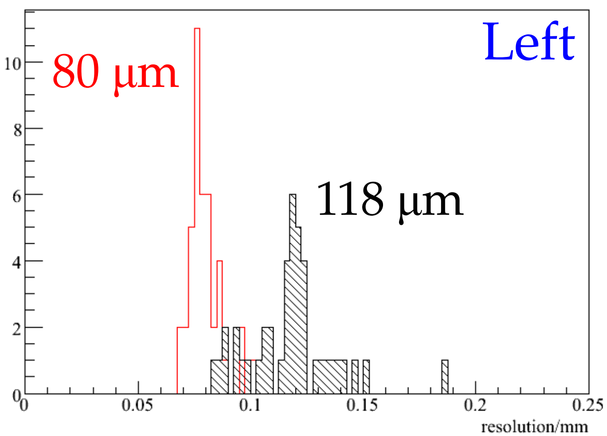
- ❑ 200 μm pitch
- ❑ Ladder residuals after alignment

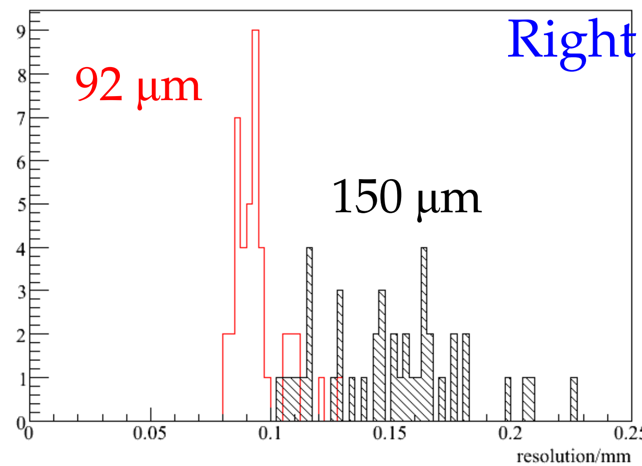
X layers (red outline)

±5° stereo layers (hatched)

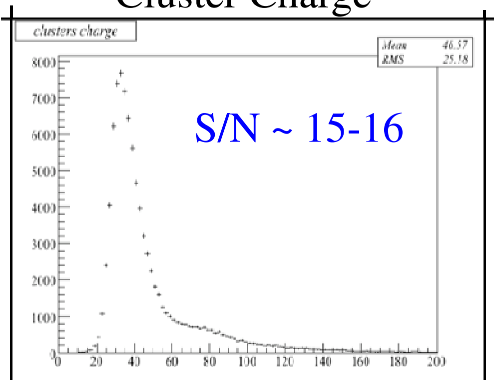
Box	# tracks
Top	3170
Bottom	1604
Left	3443
Right	7302

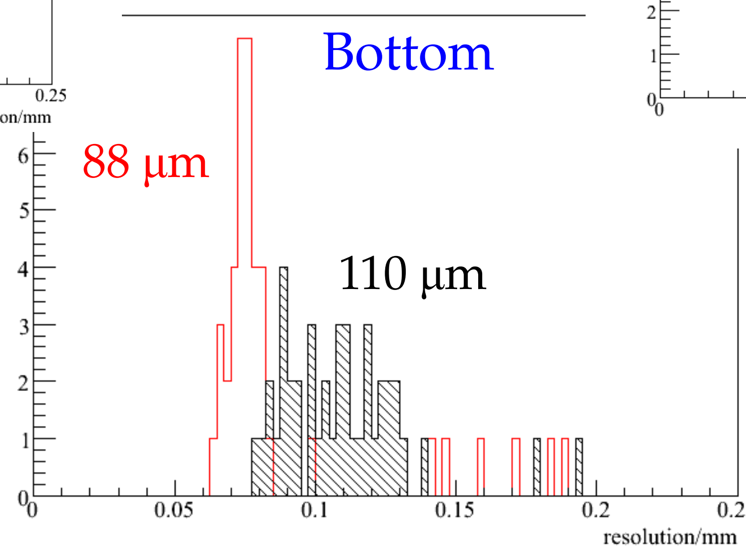






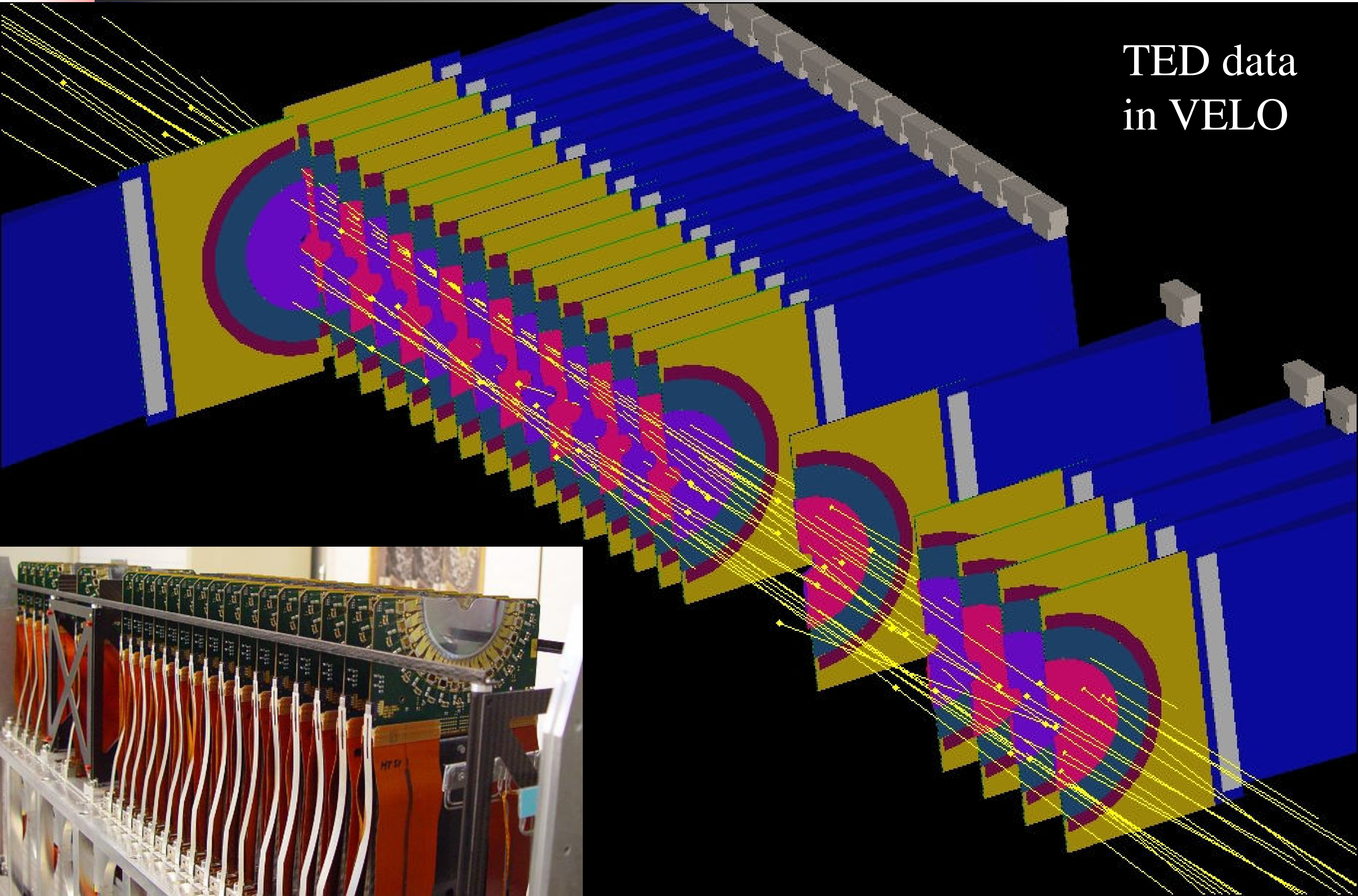
Cluster Charge





- ❑ IT aligned to ~15 μm
- ❑ Widths consistent with expectations for ~10 GeV muons
- ❑ < ε_{hit} > ~ 98%

VELO

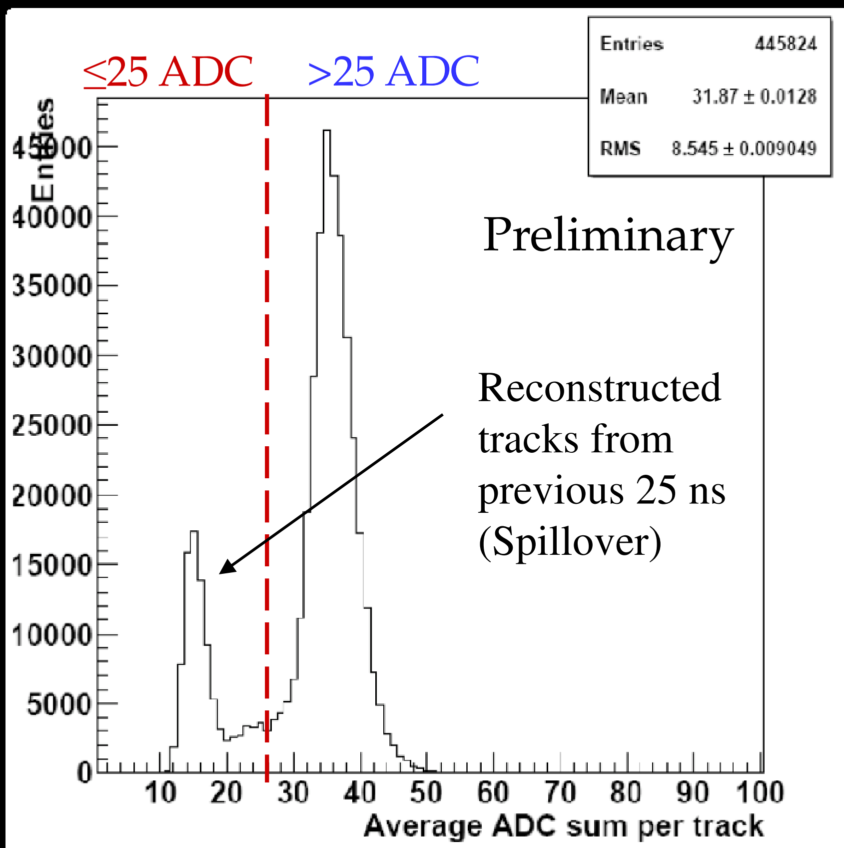


TED Data, 12-bunch train

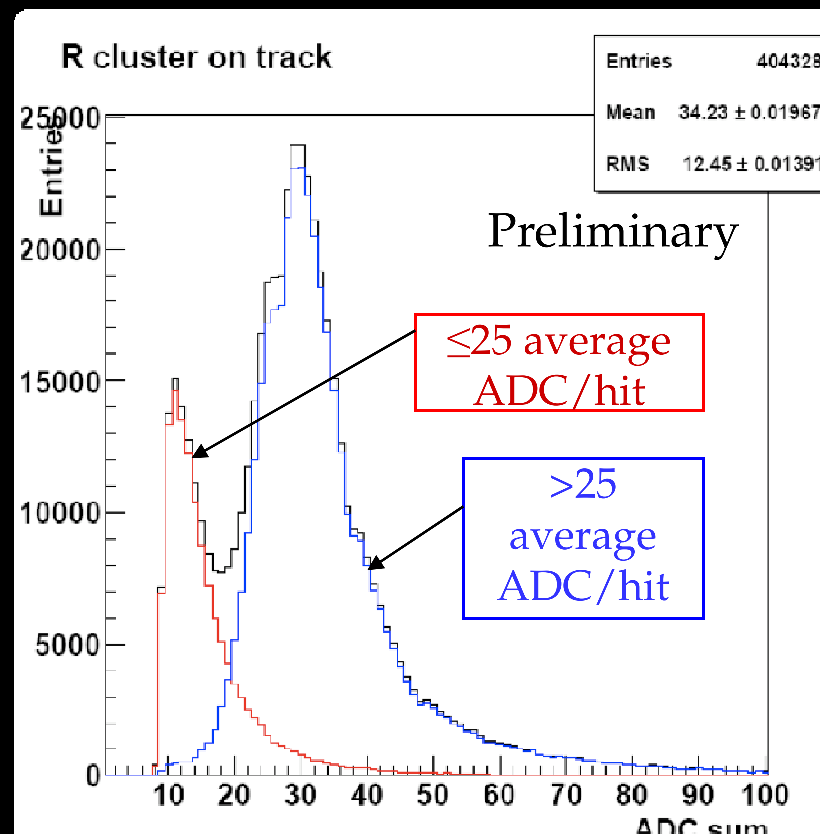
Landau distributions from VELO

S/N ~ 20

Average cluster ADC counts/track



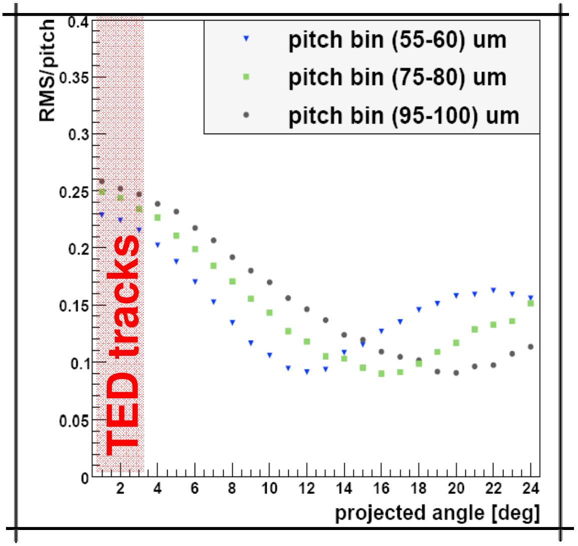
Cluster ADC counts

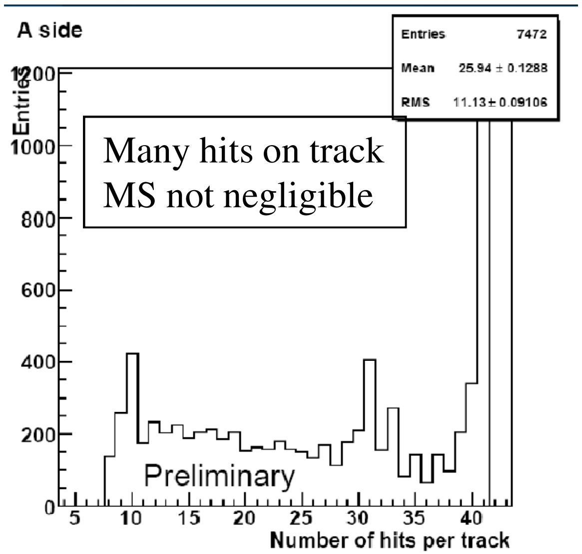


VELO Resolution from TED data

(Preliminary)

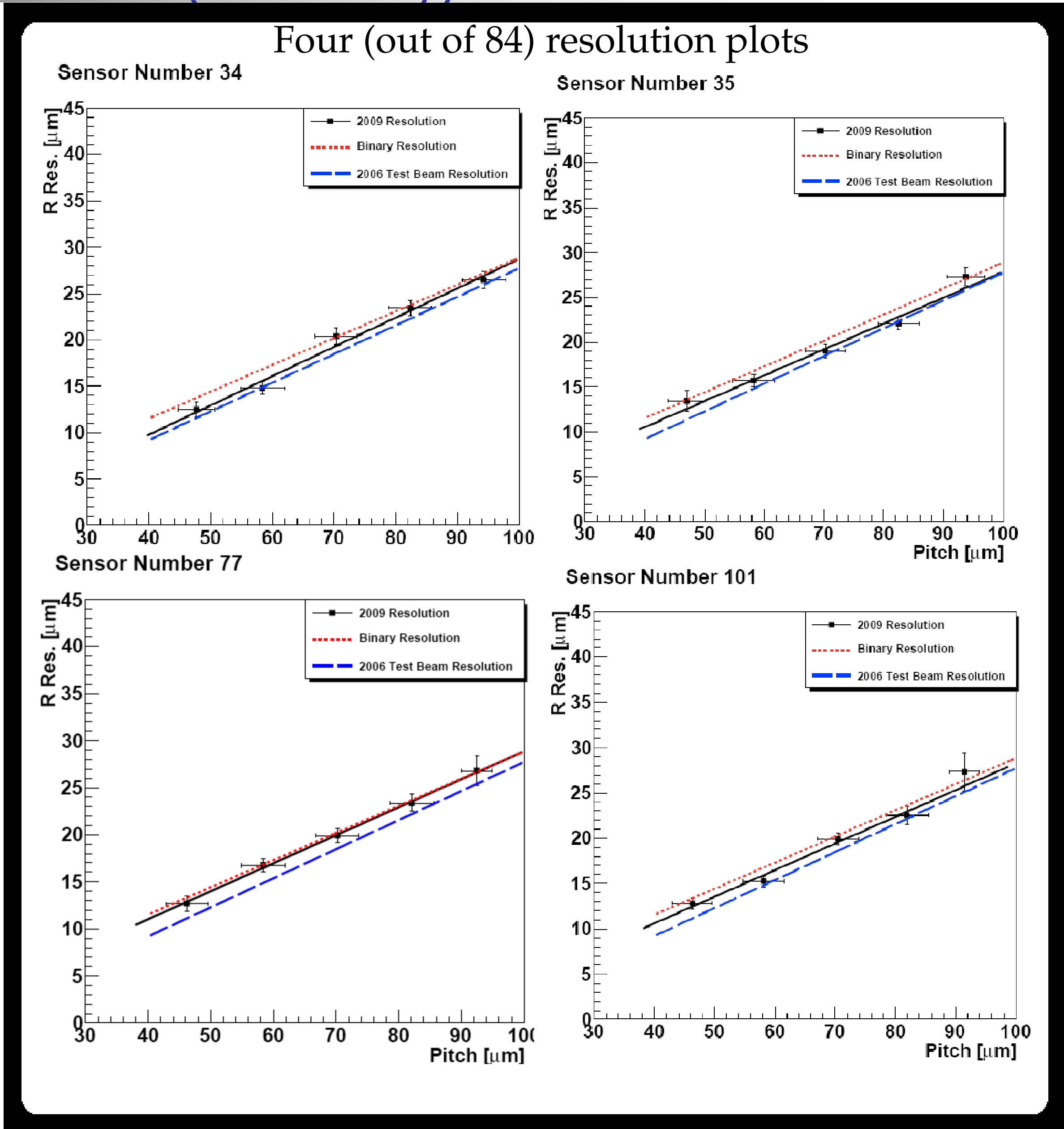
Expected resolution vs. track angle





R sensors

Phi sensors



By the numbers

CALORIMETERS

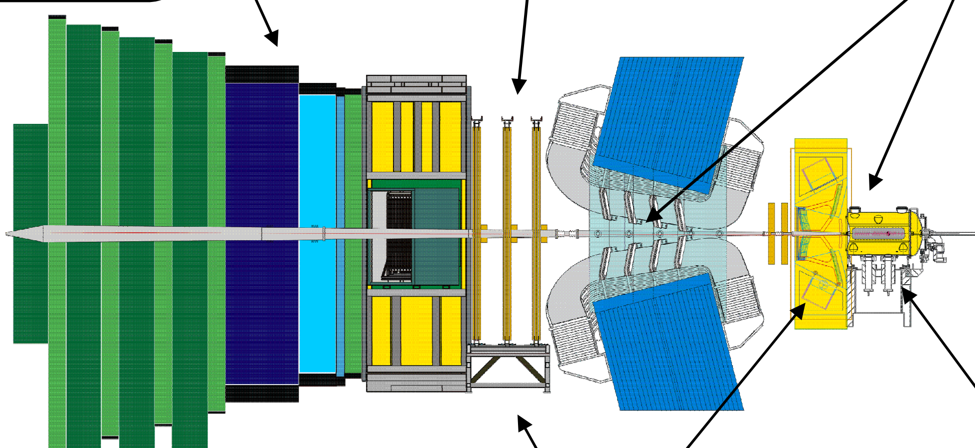
99.9% fully commissioned
~0.1% problematic ECAL channels and 2-3 HCAL channels

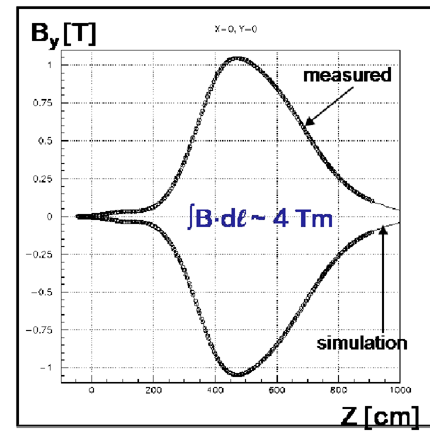
STRAW-TUBE TRACKER

>98.5% of 56,000 channels fully operational

SILICON TRACKER

99.7% of 300,000 channels working





Precise field maps in both polarities (σ□0.4%)

MUON CHAMBERS

100% fully commissioned (M1 needs to be timed in)

RICHs

>99.1% of phototubes functioning perfectly (4 to be replaced soon)
<20 dead/noisy pixels per tube (8192 pixels)

VERTEX DETECTOR

>99.0% [of 180,000] channels fully functional

In the coming weeks

- Remove beam pipe protection in the region of OT/IT and Magnet
  - 28 September

- Closing OT and IT - 29 September

- Pumping down of the beampipe at LHCb
  - Starting 30 September

- TED run ~ October 12,

- Replace a few HPDs in RICH2

- Ramp up of LHCb dipole with compensator magnets (Week of 12-19 Oct)

- All equipment and material not needed for operation or data taking out of cavern by 16 October

- Oh, and of course, the cavern floor will get a final painting.

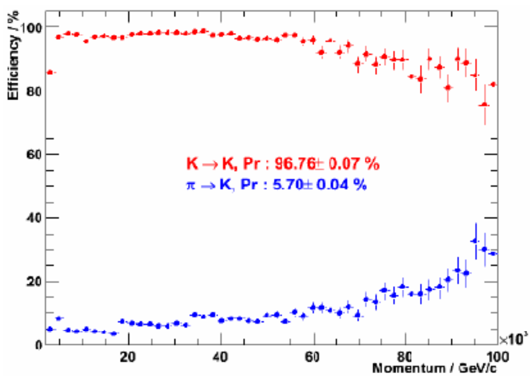
Looking ahead to 09-10 data

- @3.5 TeV → only lose ~factor of 2 in bb cross-section…
- Initial **"low luminosity"** (min bias trigger, L0 (hardware) only)
  - **Record ~7 Million events/hr** (at 2 kHz)
  - Fine calibrations, precise timing, alignment, B field, mis-ID rates,… using large samples of J/ψ, D, K_s, Λ, etc
    - E.g ~3.2M J/ψ with 5 pb^{-1}
  - Understand performance of HLT1, HLT2 on data → tuning of HLT selections, etc for higher lumi. running.
  - First look at backgrounds, etc with data, as opposed to MC !
- **Higher luminosity**, toward $\mathcal{L}_{int}$ ~ 100-300 pb^{-1}
  - Will need HLT1 (online software, L0 conf., IP & p_T, DOCA cuts, etc) to reduce rate; HLT2 possibly needed
  - Collect large charm samples, mixing, CPV, rare decays
    - 100 pb^{-1}: O(10M) $D^0 \to K\pi$, O(1M) $D^0 \to K^+K^-$, $D^0 \to \mu^+\mu^-$ (O(25) if BF~10^{-7}),…
    - B samples, $B \to J/\psi X$ modes,
    - Start cracking into key measurements

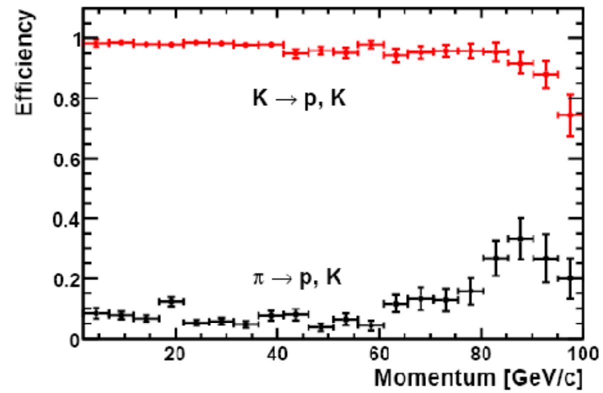
Example of Calibrations with first data

Particle ID

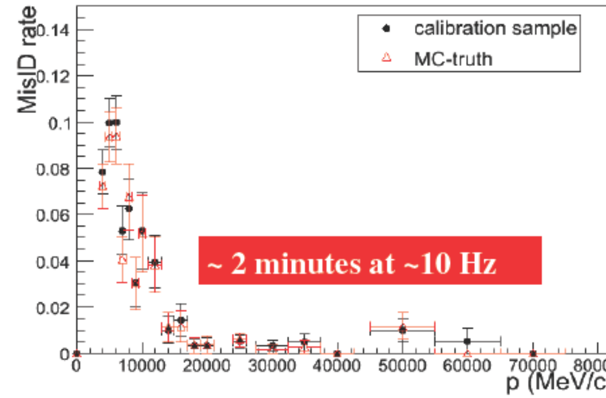
MC Truth



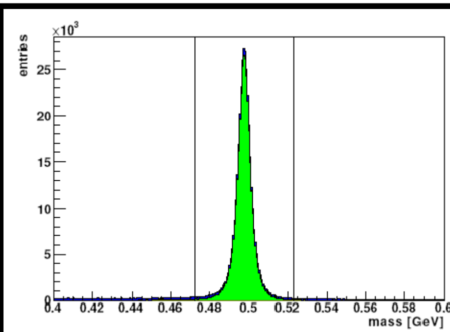
$D^{*+} \rightarrow D^0(K\pi)\ \pi_s$



Calibration Stream:
Muon misID rates using $\Lambda \rightarrow p\pi$

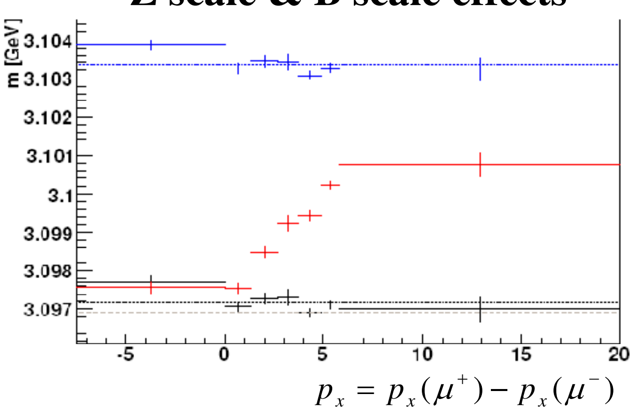


B Field



~370K $K_s \rightarrow \pi^+\pi^-$ in first 1.5 hrs

B Field calibration using J/ψ mass
Z scale & B scale effects



B scaled by 0.2%

T Station z-scale increased by ~0.1%

Nominal detector

Can also begin to measure tracking efficiencies from each sub-detector, **time resolution** using prompt J/ψ's, momentum resolution, L0 and HLT trigger efficiencies, …

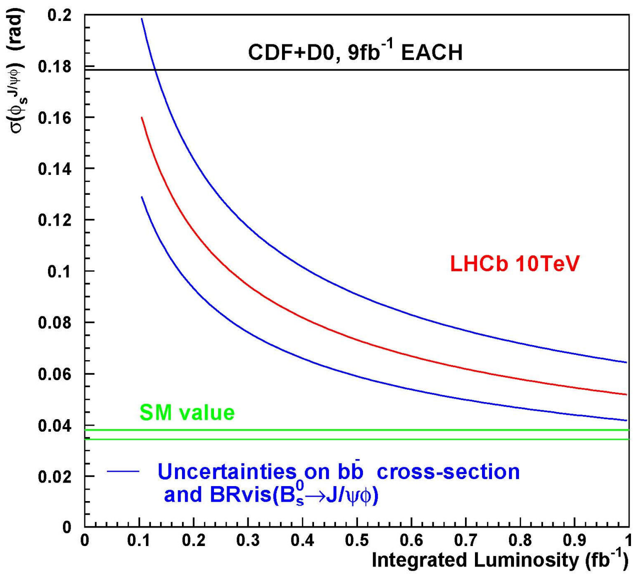
Flavor Physics in 2010

- K_s, Λ production cross-section
- Various J/ψ analyses
  - B vs prompt cross-sections
  - J/ψ, $\psi(2S)$, $\chi_{c1,2}$ cross-sections, J/ψ polarization
  - XYZ states, confirmations, properties, direct vs in B decay.
- Charm production cross-sections, Λ_c, doubly-charmed baryons
- $Y(1S) \rightarrow \mu\mu$, $\sim 10^5$ expected in 100 pb^{-1}
- Λ_b , B_c (~250 ev. Exp/100 pb^{-1})
- Di-muon production, Drell-Yan → significant imprvements on gluon PDF, particularly at small and large x.
- D^0 mixing & CPV, rare decays

Two key early measurements with O(150-300 pb^{-1})

ϕ_s in $B_s \to J/\psi\phi$

Including other modes, *e.g. $J/\psi f_0$*, should push these limits down..



Competitive Results in 2010 [$\sqrt{s}$=7 TeV, σ_{bb}~ 220 μb]

increasing complexity, increasing luminosity

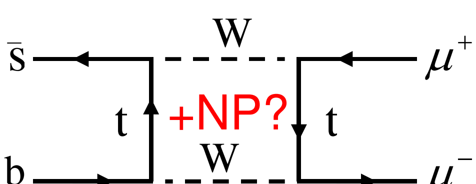
1) Masses and mass differences of B-hadrons: B_d, B_s, B^+, Λb... ~10-20 pb^{-1}

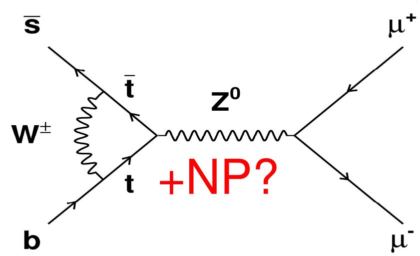
2) Lifetimes and lifetime ratios ~30-40 pb^{-1}
[B_d, B_s, B^+, Λb], ΔΓs ~ 60 pb^{-1}
polarization amplitudes in $B_d \to J/\psi K^*$ ~ 100 pb^{-1}

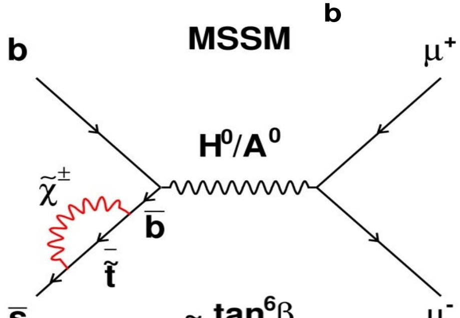
3) Bd-Bd mixing in Bd→J/ψ K*:
[Bs-Bs mixing in Dsπ] ~ 100 pb^{-1}

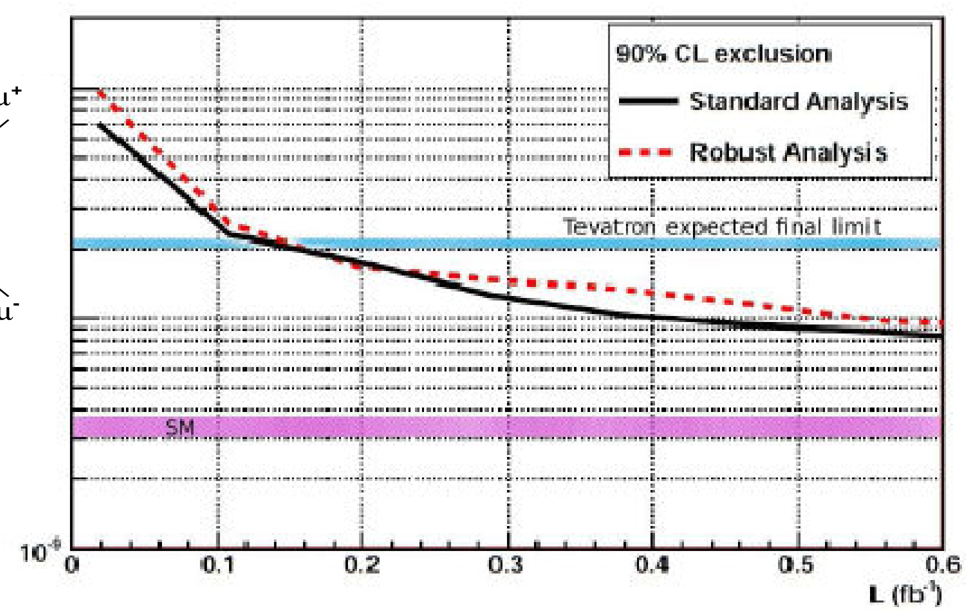
4) CP asymmetries:
- sin(2β)
- βs with tagged analysis ~ 200 pb^{-1}

$B_s \to \mu\mu$







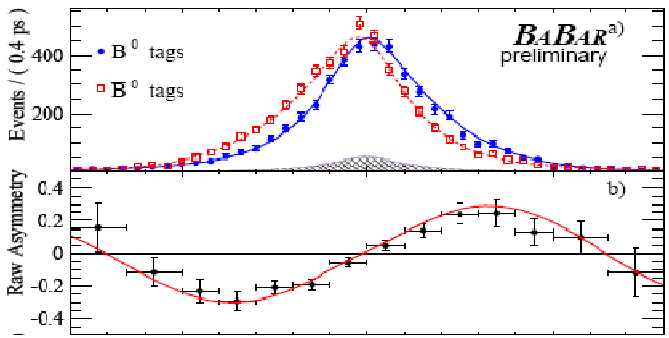


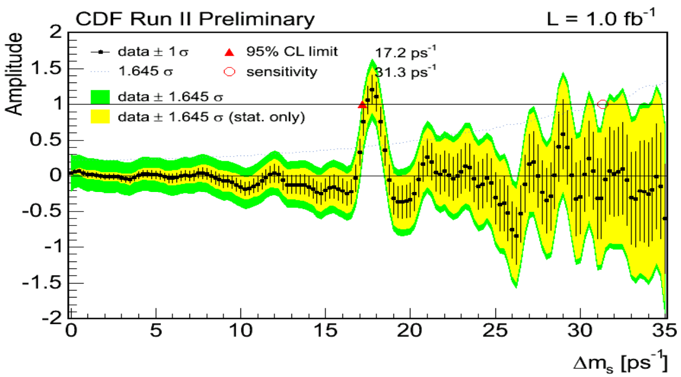
Summary

- **LHCb is ready** for collision data
- 1 MHz L0 readout, 2 kHz to tape, ready
- Detector calibrations in good shape using cosmic & TED data
- Continued work on monitoring, automation of various tasks
- **With 100 – 300 pb^{-1}**
  - Fine calibrations of sub-detectors, trigger, etc
  - bb & cc rates only down by ~2 at 3.5 TeV
    → some results competitive (or better) than TeV/ b-factories. $B_s \rightarrow \mu\mu$, ϕ_s, A_{fb} in $B \rightarrow K^*\mu\mu$, D mixing pars, some direct γ meas.
- **s-LHCb**
  - Several important measurements still stat. limited with 10 fb^{-1}.
  - From 10→100 fb^{-1}
    - 2×10^{32} cm^{-2} s^{-1} → 2×10^{33} cm^{-2} s^{-1}
    - 40 MHz readout of full detector → new FEs for most sub-detectors
    - Detector upgrades

Backups

Great progress, but much room for NP



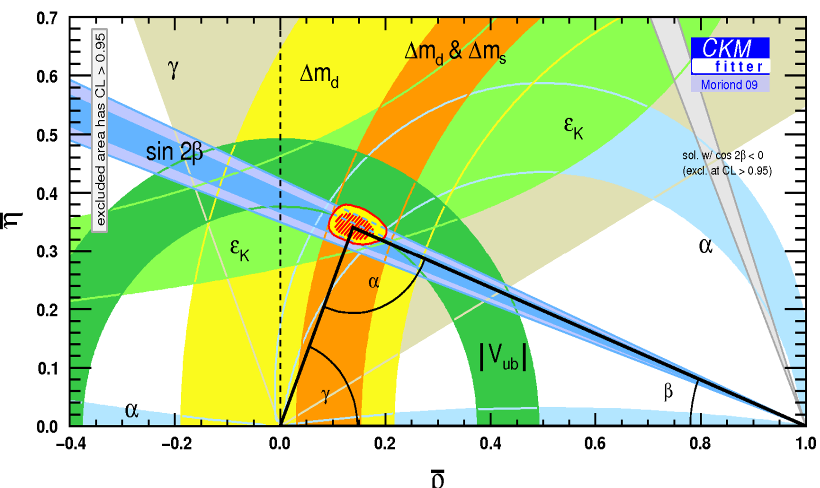


- Need more precise m'ment of B_s mixing phase
- CKM Angle γ
  - Only CKM angle that can be measured from <u>purely trees</u>
  - Indirect $\gamma = (67.8^{+4.2}_{-3.9})^o$ → possible NP contribution
  - Direct $\gamma = (70^{+27}_{-20})^o$: from Trees, but large uncertainty.
- With precise Δm_d, Δm_s, $\sin(2\beta)$ in hand, and first meas. of $\sin(2\beta_s)$, we may be seeing hints of NP.

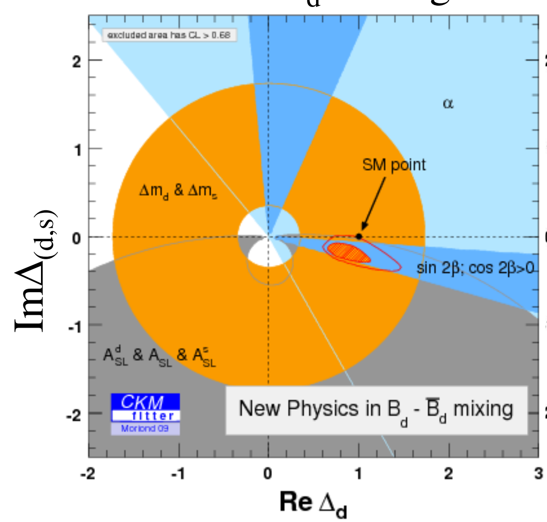
$$\frac{\left\langle B^0_{s,d} \left| M^{SM+NP}_{eff} \right| \overline{B^0_{s,d}} \right\rangle}{\left\langle B^0_{s,d} \left| M^{SM}_{eff} \right| \overline{B^0_{s,d}} \right\rangle} = |\Delta_{s,d}^{NP}| e^{i\phi^{NP}_{s,d}}$$

Lenz,
Nierste, arXiv.0612.167

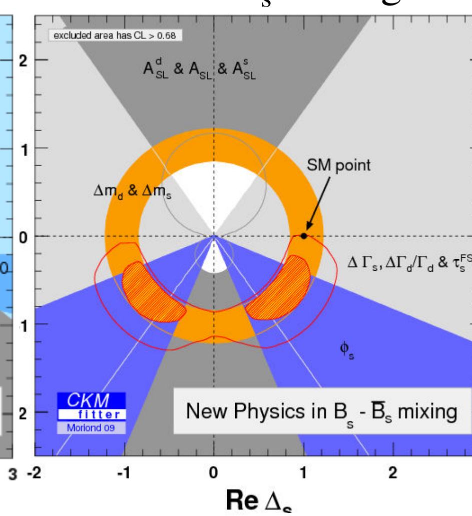
Much learned from B-factories and Tevatron.



NP in B_d mixing



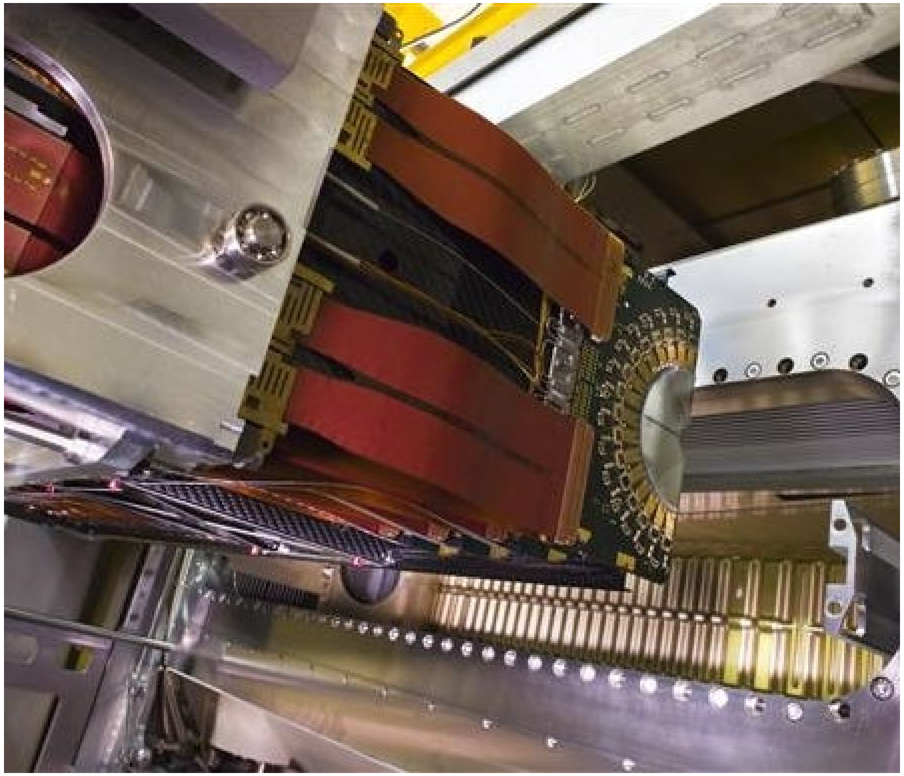
NP in B_s mixing



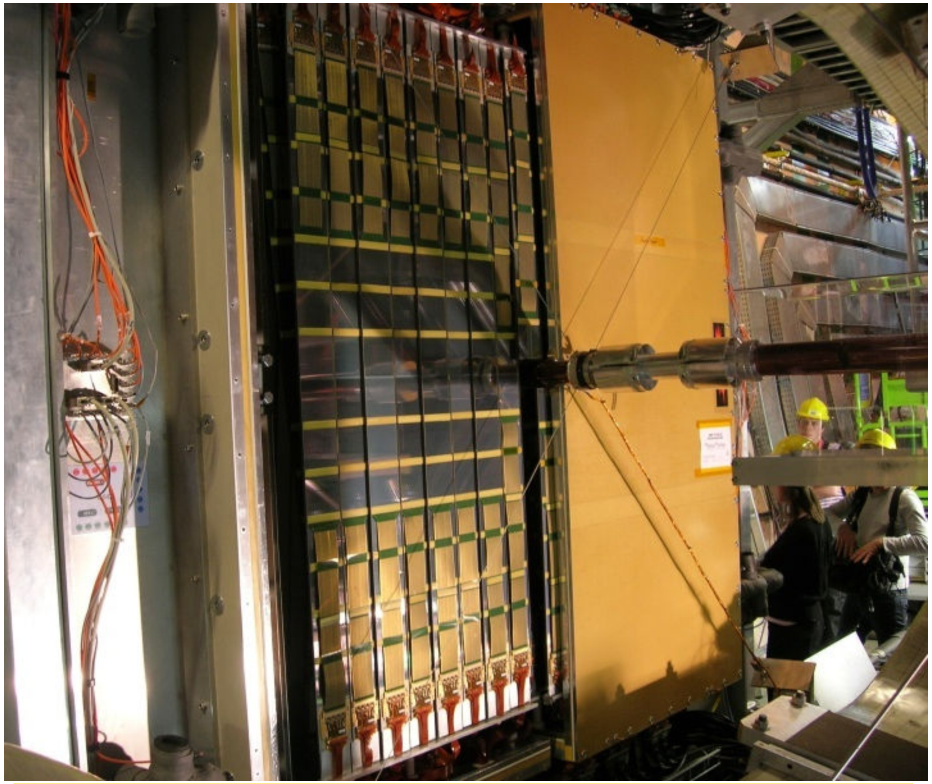
~2σ from SM in both!

CKMFitter,
arXiv.0810.3139

Tracking Detectors Upstream of Magnet

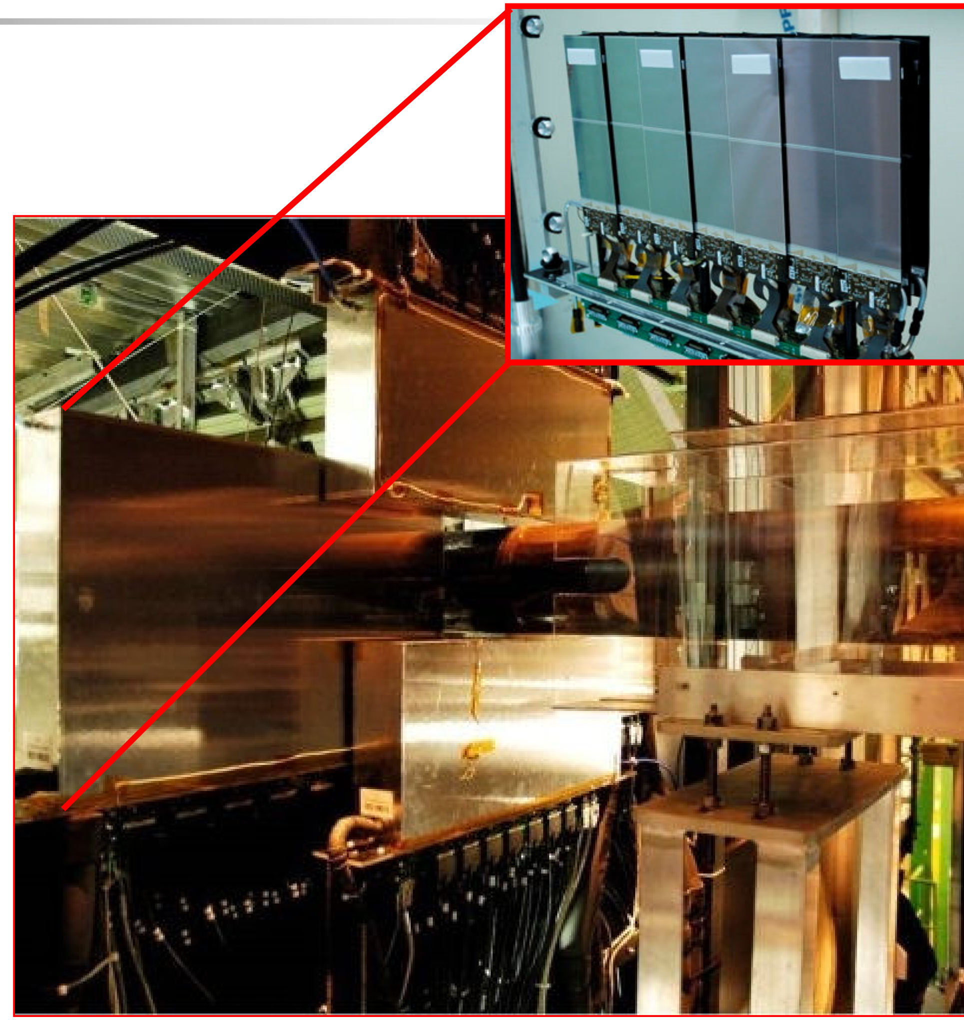


VELO
- 21 r-ϕ silicon sensor pairs
- 8 < r < 42 mm (40<Pitch<100 mm)
- σ_{hit} ~ 10 μm
- Retracted from beam during injection.



Trigger Tracker (TT)
- 4 layers of Si strips
- 1.5 m x 1.3 m
- ~200 mm pitch, shit ~50-70 mm

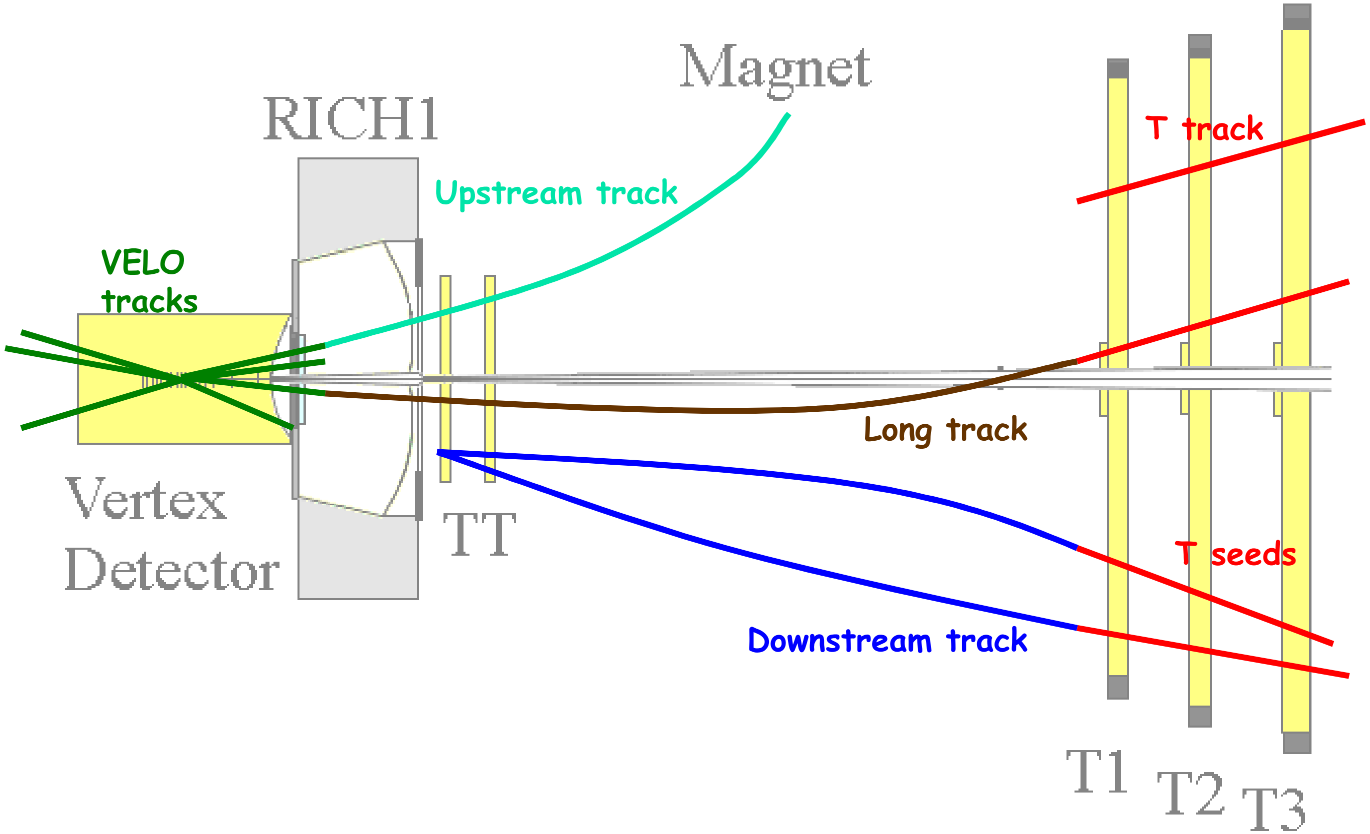
Tracking Detectors Downstream of Magnet



Outer Tracker
- 3 stations (±3 m in X , ±2.4 m in Y)
- 24 m'ments
- 5 mm straws, σ_{hit} ~200 μm

Inner Tracker silicon strip detectors
- 3 stations (120x40 cm cross around beam pipe)
- 4 layers/station
- ~200 μm pitch, σ_{hit} ~50-70 mm

Tracking in LHCb



Long tracks ⇒ highest quality for physics (good IP & p resolution), p □ 3 GeV

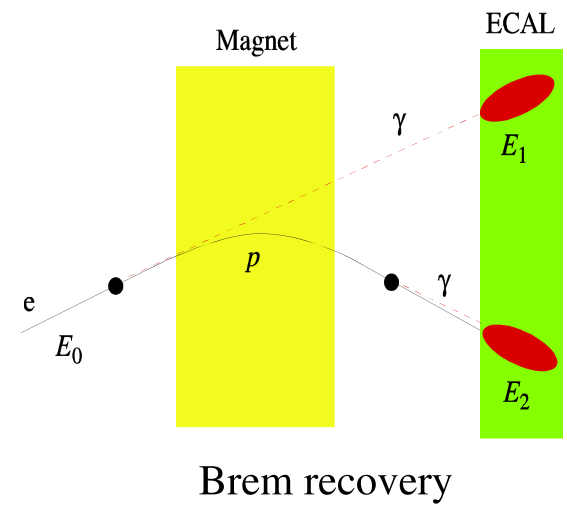
Downstream tracks ⇒ hits in TT and T, for long-lived particles, K_S (good p resolution)

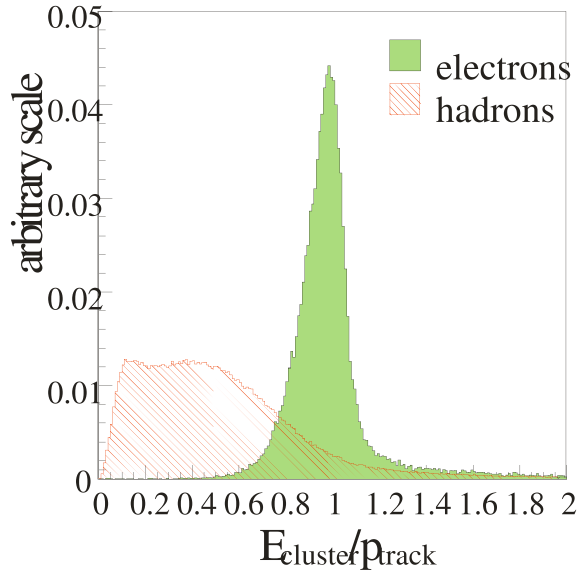
Upstream tracks ⇒ lower p, worse p resolution, but useful for RICH1 pattern recognition

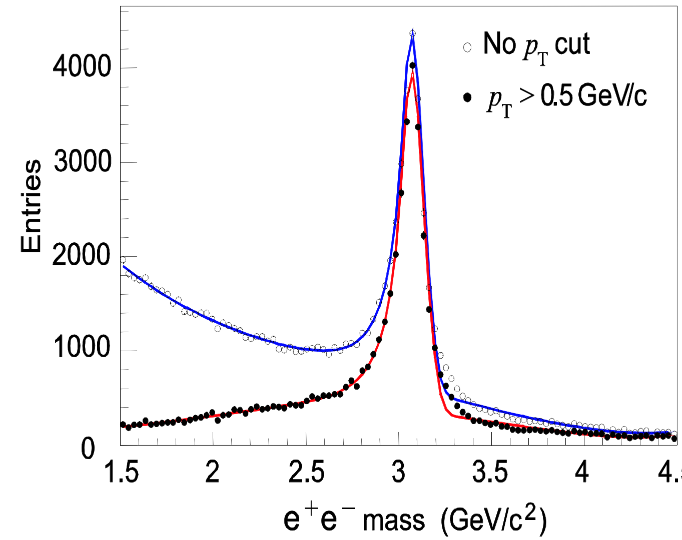
VELO tracks ⇒ useful for primary vertex reconstruction (good IP resolution)

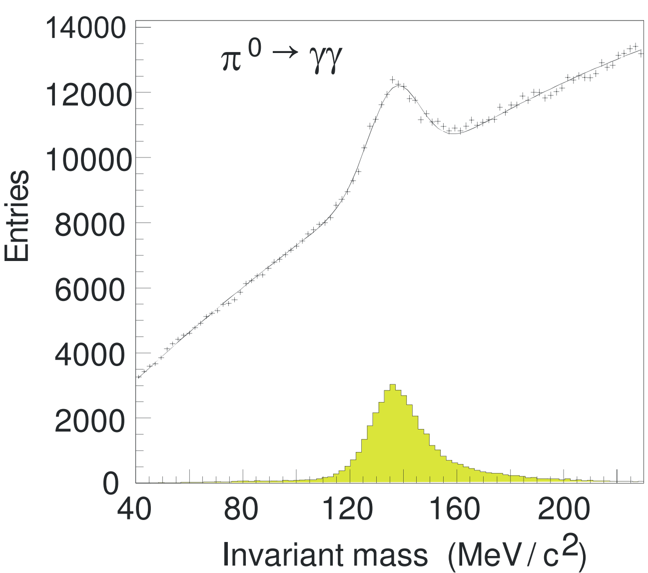
T tracks ⇒ useful for RICH2 pattern recognition

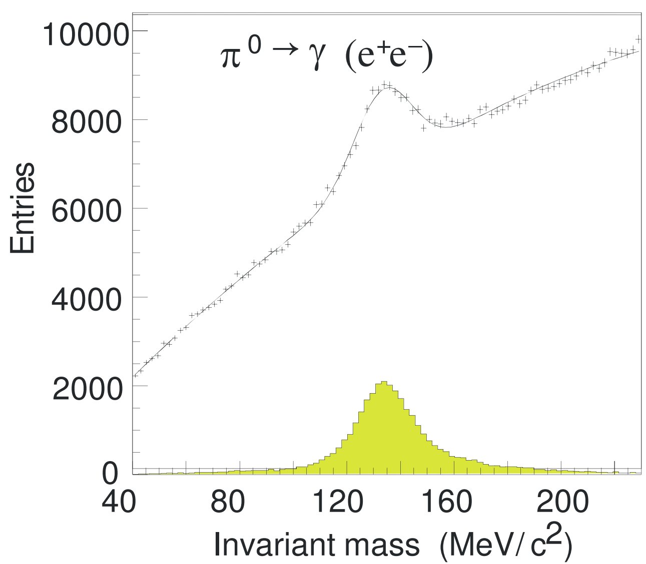
ECAL – Neutrals & Electrons

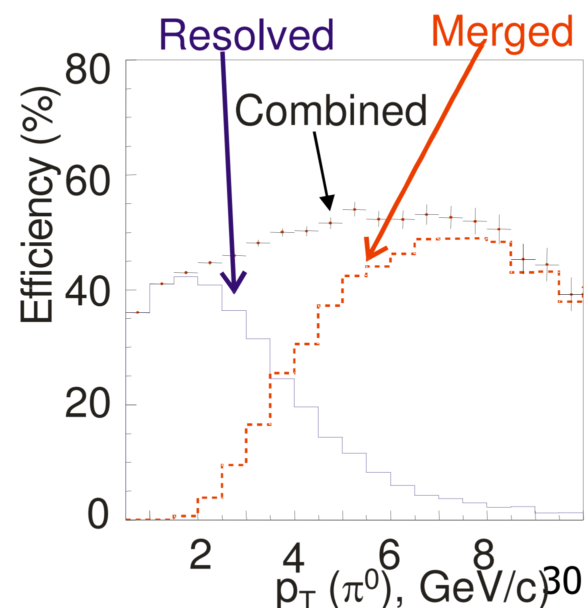




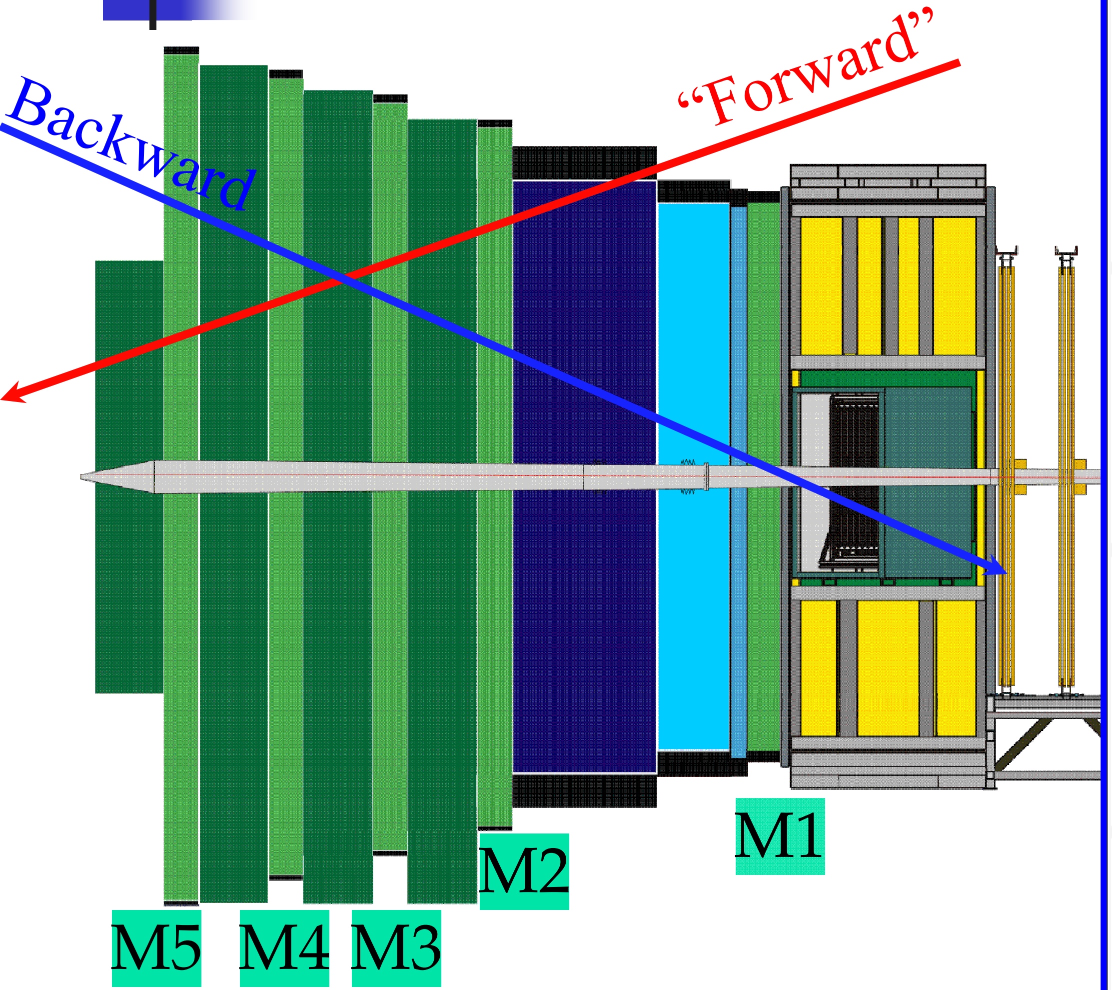


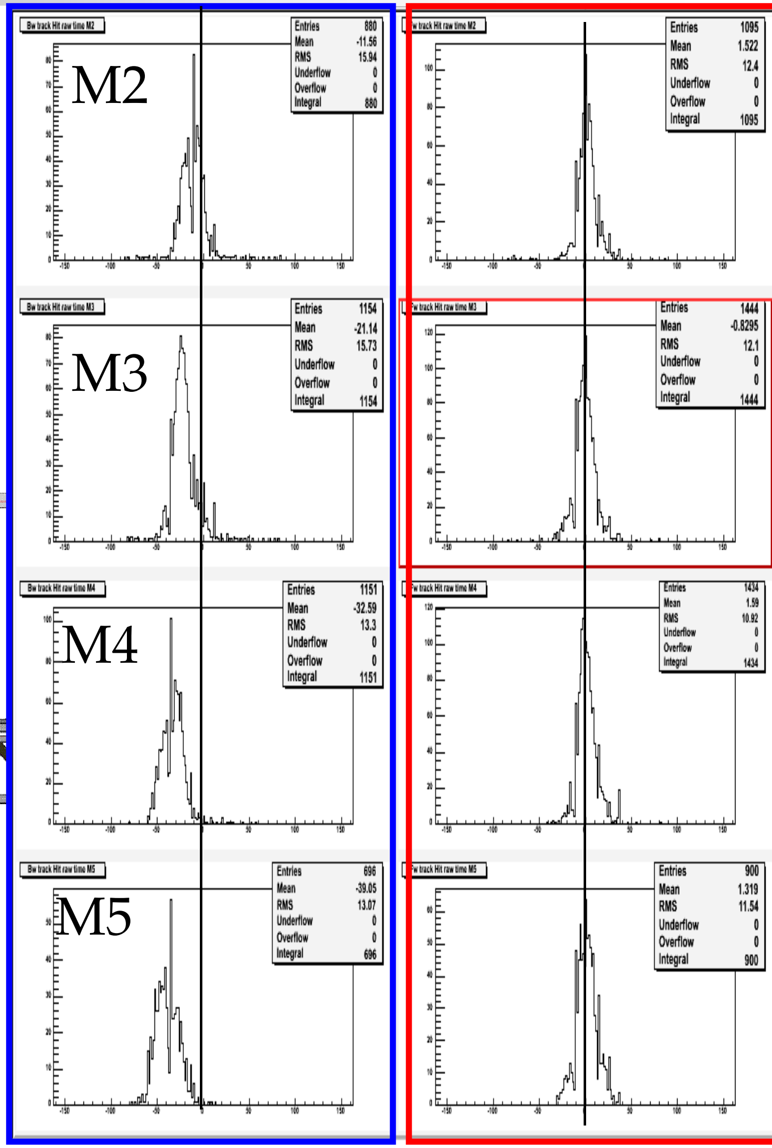






Cosmics in Muon System

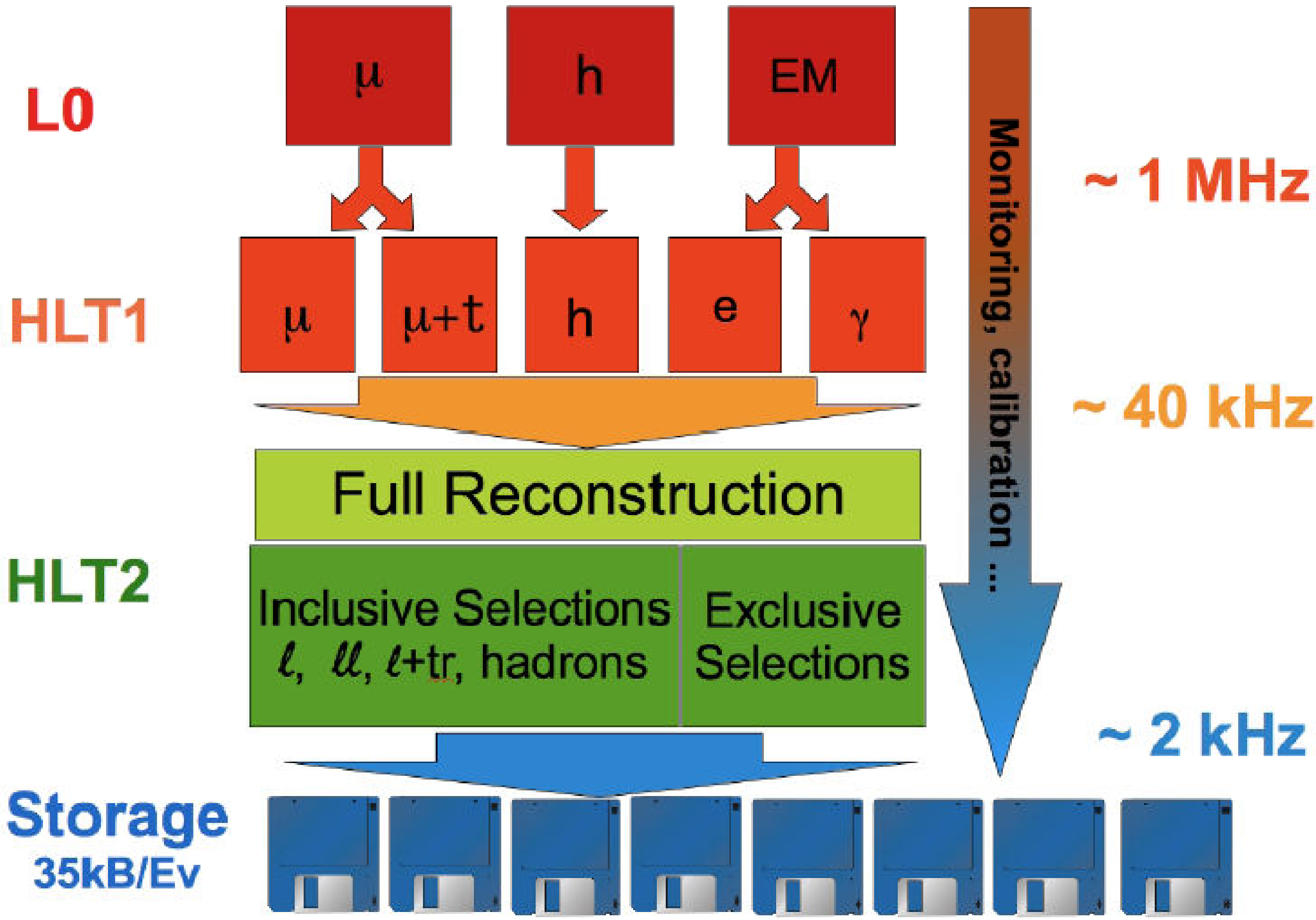




Similar relative timing for Calorimeters

Muon system time-aligned to < 2ns

Trigger


L0
μ
h
EM
HLT1
μ
μ+t
h
e
γ
Full Reconstruction
HLT2
Inclusive Selections
ℓ, ℓℓ, ℓ+tr, hadrons
Exclusive Selections
Storage
35kB/Ev
Monitoring, calibration ...
~ 1 MHz
~ 40 kHz
~ 2 kHz

FEST

Full Experimental System Test 09
Part of STEP 09

- Replace detector with 10^8 min bias events injected into online system at 2 kHz
  - 4 TeV beam, Velo closed, no spillover, $1x10^{32}$ cm^{-2} s^{-1}, 50 ns bunch spacing & crossing angle
- Test flow of data after the HLT
  - Data monitoring, histogramming..
  - HLT configuration
  - Alignment
  - Propagation of conditions and alignment constants
  - Express stream
  - Data transfer
  - Run database
  - Bookkeeping
  - Reconstruction at Tier 1
  - Data quality checking & procedures
  - Conditions database updates
  - …

What LHCb is hoping for

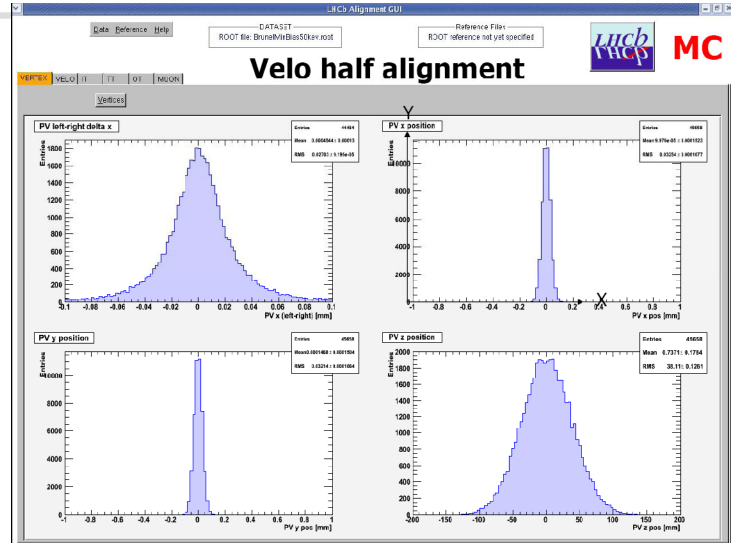
Month	Comment	Turn around time	Availability	Max number bunches	Protons/Bunch	% nom. intensity	Min beta*	Peak Luminosity $cm^{-2}s^{-1}$	Integrated Luminosity	events/X
1	Beam commissioning								First collisions	
2	Pilot physics, partial squeeze, gentle increase in bunch intensity, 40%	Long	Low	43	3×10^{10}		4 m	8.6×10^{29}	100 - 200 nb^{-1}	
3		5	40%	43	5×10^{10}		4 m	2.4×10^{30}	~ 1 pb^{-1}	
4		5	40%	156	5×10^{10}	2.5	2 m	1.7×10^{31}	~9 pb^{-1}	
5a	No crossing angle - could at this stage push intensity see 5b	5	40%	156	7×10^{10}	3.3	2 m	3.4×10^{31}	~18 pb^{-1}	0.8
5b	No crossing angle - squeezing to beta* = 1m at this stage would double these lumi numbers (and the pile-up)	5	40%	156	10×10^{10}	3.3	2 m	6.9×10^{31}	~36 pb^{-1}	1.6
6	50 ns - nominal crossing angle - aperture restricts squeezing further	5	40%	144	7×10^{10}	6.7	2-3 m	3.1×10^{31}	~16 pb^{-1}	
7	50 ns	5	40%	288	7×10^{10}	4.5	2-3 m	8.6×10^{31}	~32 pb^{-1}	
8	50 ns*	5	40%	432	7×10^{10}	9.3	2-3 m	9.2×10^{31}	~48 pb^{-1}	
9	50 ns*	5	40%	432	9×10^{10}	11.5*	2-3 m	1.5×10^{32}	~80 pb^{-1}	
10		5	40%	432	9×10^{10}	11.5*	2-3 m	1.5×10^{32}	~80 pb^{-1}	
								TOTAL	**~ 300 pb^{-1}**	

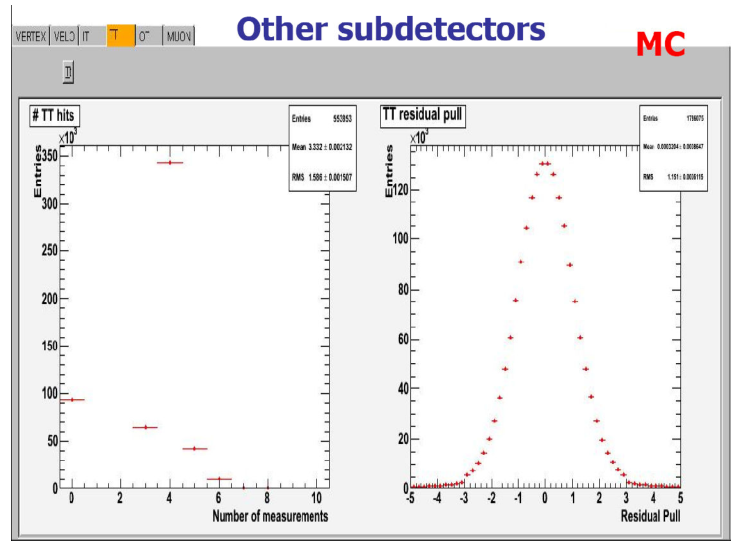
Other Areas of Progress

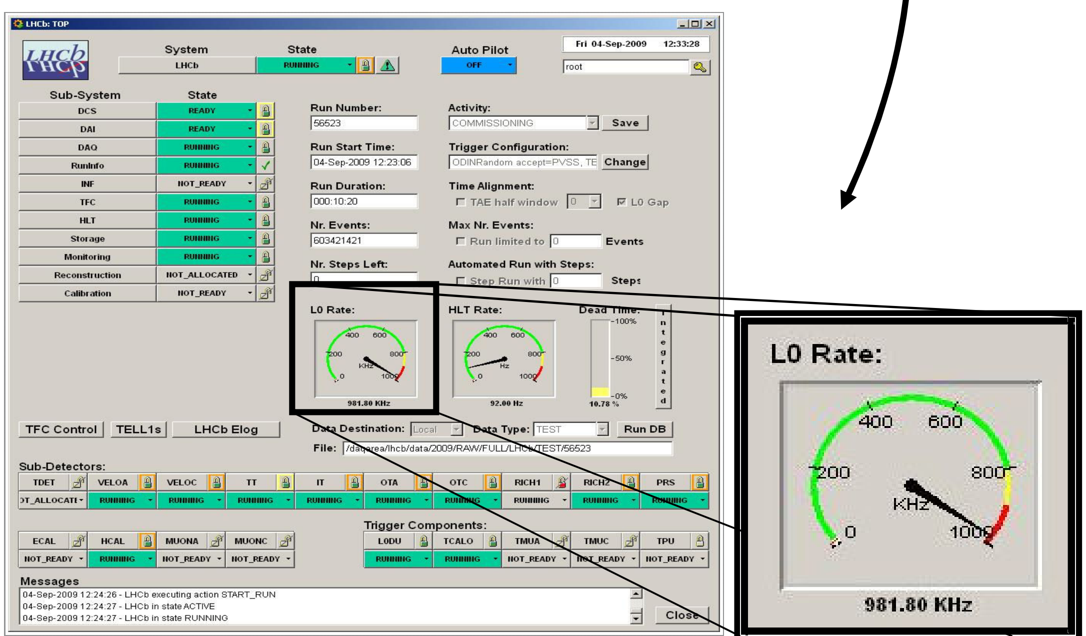
- Muon Station 1 installation complete
- Alignments & calibrations in good shape for startup
- Recently, big efforts on monitoring
- 1 MHz Readout commissioned
- FEST09 (part of STEP09)
  –readiness to handle ~7M events in the 1st hour?

example

example







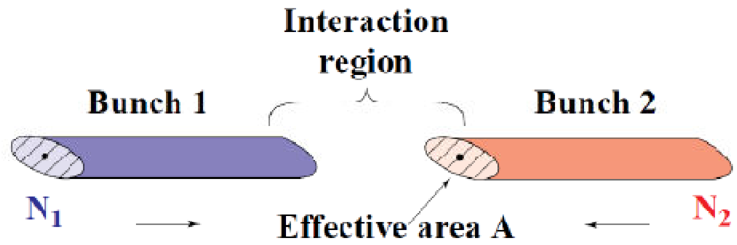
Mike Lamont's most recent report to LHCb

Month	OP scenario	Max number bunch	Protons per bunch	Min beta*	Peak Lumi	Integrated	% nominal
1	Beam commissioning						
2	Pilot physics	19	3×10^{10}	4	2.5×10^{29}	~100 nb^{-1}	
3		19	5×10^{10}	4	1.4×10^{30}	~0.7 pb^{-1}	
4		72	5×10^{10}	3	5.3×10^{30}	~2.5 pb^{-1}	2.5
5a	No crossing angle	72	7×10^{10}	3	1×10^{31}	~5 pb^{-1}	3.4
5b	No crossing angle – pushing bunch intensity	72	1×10^{11}	3	2.1×10^{31}	~10 pb^{-1}	4.8
6	Shift to higher energy: approx 4 weeks	Would aim for physics without crossing angle in the first instance with a gentle ramp back up in intensity					
7	4 – 5 TeV (5 TeV luminosity numbers quoted)	72	7×10^{10}	4	1.1×10^{31}	~6 pb^{-1}	3.4
8	50 ns – nominal Xing angle	138	7×10^{10}	4	2.2×10^{31}	~10 pb^{-1}	3.1
9	50 ns	276	7×10^{10}	4	4.2×10^{31}	~20 pb^{-1}	6.2
10	50 ns	414	7×10^{10}	4	6.5×10^{31}	~31 pb^{-1}	9.4
11	50 ns	414	9×10^{10}	4	1×10^{32}	~50 pb^{-1}	12

→ Closer to 100 pb^{-1} … but "big error bars on these numbers"

Luminosity

$$\mathcal{L} = \frac{N_1 N_2 f}{A_{\text{eff}}}$$



$$\frac{1}{A_{\text{eff}}} = \int g_1(x,y)\, g_2(x,y)\, dx\, dy$$

1) **Van der Meer scan** – take one beam and give it an artificial offset in *x* and then in *y*. Should allow one to de-convolute to get $g_1(x,y)$ & $g_2(x,y)$
2) **Beam gas method** – inject small amount of gas (if needed), and reconstruct interaction vertices → Long VELO allows one to reconstruct Beam1-BeamGas & Beam2-BeamGas interactions → determine beam angles, profiles and relative positions → get overlap integral

3) **Reference cross section** – use a well-predicted cross-section for "X", $\mathcal{L}=N_X/\varepsilon_X*\sigma_X$ e.g. W,Z production, pp→pp$\mu^+\mu^-$ elastic di-m prod.

4) **Look at rates in detectors**, e.g. in SPD, … also #vertices, #chg tracks need to keep track of bb, be, eb, ee crossings.. Also systematics, *e.g.* efficiency vs mult….