LHCb Status and Prospects

- Introduction
- LHCb design, environment, detector
- Early data
- Promising analyses for the near future
- LHCb Upgrade

22 March 2010

Indirect Searches for New Physics at the time of LHC

Galileo Galilei Institute, Florence

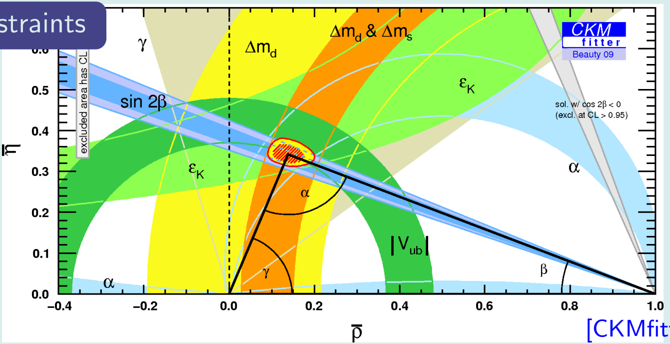
Patrick Koppenburg

On behalf of the LHCb Collaboration

Unitarity Triangle

- Changed focus: No longer seeking to verify the CKM picture
- Instead look for signs of New Physics
  - ➜ Discrepancies in measurements or unitarity triangle

All constraints

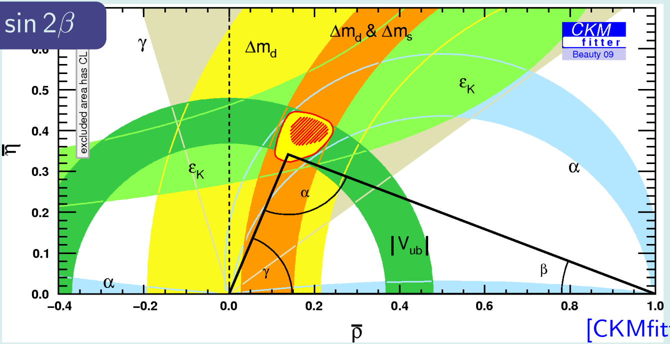


[CKMfitter 09/09]

Unitarity Triangle

- Changed focus: No longer seeking to verify the CKM picture
- Instead look for signs of New Physics
  - ➜ Discrepancies in measurements or unitarity triangle
- $(\bar\rho, \bar\eta)$ fit is dominated by $\sin 2\beta$

All but $\sin 2\beta$



[CKMfitter 09/09]

Unitarity Triangle

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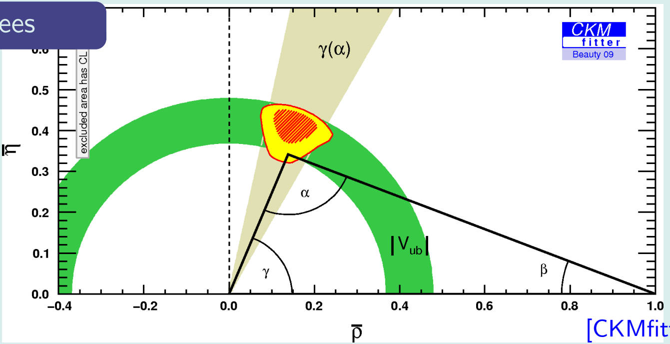
- Instead look for signs of New Physics
  - ➜ Discrepancies in measurements or unitarity triangle
- We don't know much about constraints from trees

Only trees



[CKMfitter 09/09]

Unitarity Triangle

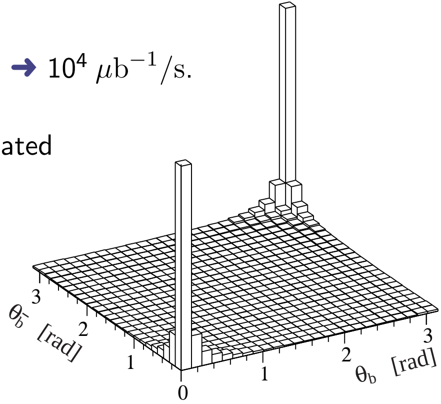
- Changed focus: No longer seeking to verify the CKM picture
- Instead look for signs of New Physics
  - ➜ Discrepancies in measurements or unitarity triangle
- ✔ Look for rare B & D decays (and K as well)
  - ➜ **Need a lot of data and a good precision**
- ✔ Need very good precision on all angles and sides.
  - ✔ Precise measurement of γ
- ✔ Need B_s as well ➜ β_s and more

The Large Hadron Collider beauty experiment for precise measurements of CP violation and rare decays

LHC

Nominal LHC Environment

- *pp* collider at 14 TeV (7 TeV in 2010–12)
  - Inelastic cross-section about 60 mb
  - Assumed $b\bar{b}$ cross-section about 500 μb (one every 120)
  - Our `Pythia` tuning predits more than 1 mb at 14 TeV
- Bunch crossings at 40 MHz
- Luminosity up to $10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ ➜ $10^4\,\mu\mathrm{b}^{-1}/\mathrm{s}$.
  - ➜ $5 \cdot 10^6$ $b\bar{b}$ pairs per second
- Direction of b and $\bar{b}$ very correlated
  - ➜ A 4π coverage not optimal
  - ➜ Build a forward spectrometer
- The choice of the LHCb collaboration

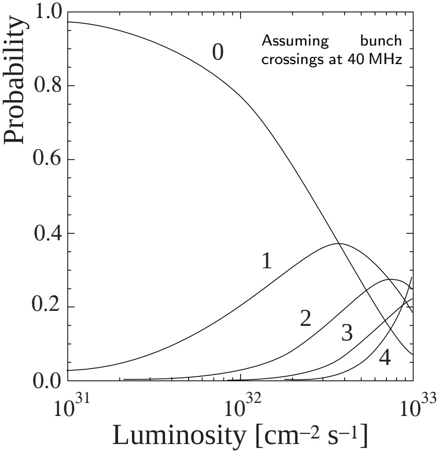


b Physics at Hadron Colliders

- B mesons have a long lifetime $c\tau = 0.5\,\mathrm{mm}$ with $\gamma = \mathcal{O}(10\text{–}100)$
  - You want to make lifetime-dependent measurements
    - ✔ Good vertex resolution

✗ Not too many pp interactions per bunch crossing
➜ Control luminosity to avoid multiple pp collision events

- We will reach baseline luminosity very early



b Physics at Hadron Colliders

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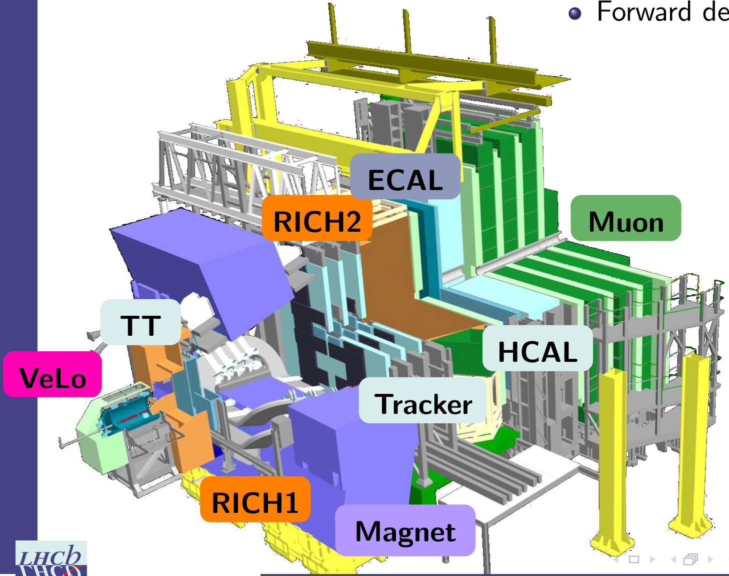
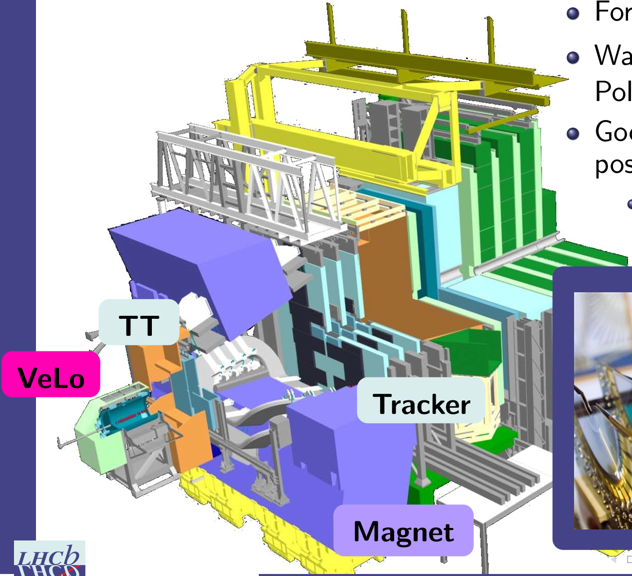
  - You want to make lifetime-dependent measurements
    - ✔ Good vertex resolution
- They have a large mass ~ 5 GeV, but not very large.
  - Look for particles with a transverse momentum $p_T = \mathcal{O}(1)$ GeV
- $b \to c$ and $c \to s$. 20% B decay to leptons.
  - ✔ Use Kaon, muon and electron-ID
- ✔ Good particle ID to fight large background
- There will still be a lot of background
  - ✔ Good mass, i.e. momentum resolution

LHCb

- Forward detector



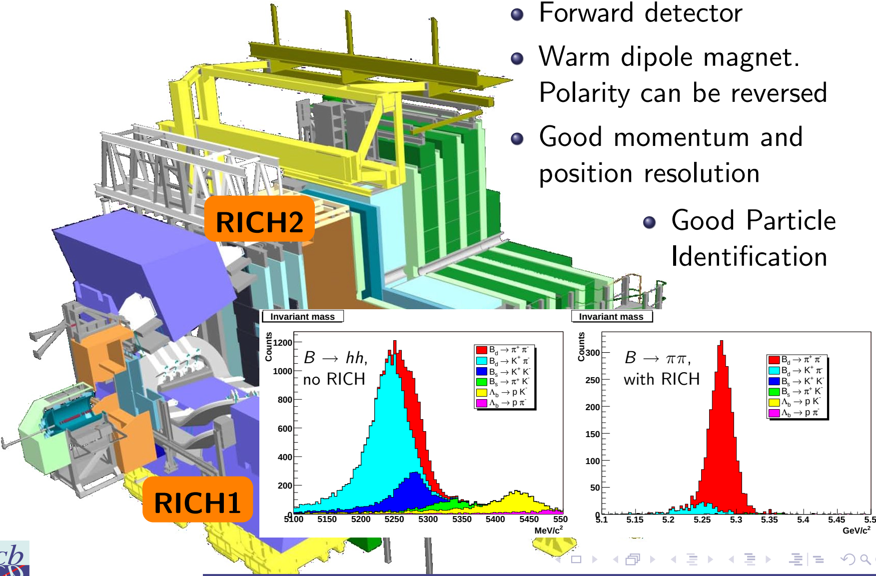
LHCb



- Forward detector
- Warm dipole magnet. Polarity can be reversed
- Good momentum and position resolution
  - Vertex detector gets 8mm to the beam

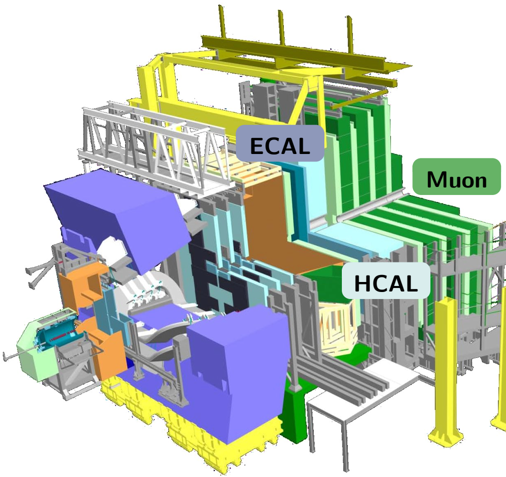
LHCb

- Forward detector
- Warm dipole magnet. Polarity can be reversed
- Good momentum and position resolution
- Good Particle Identification



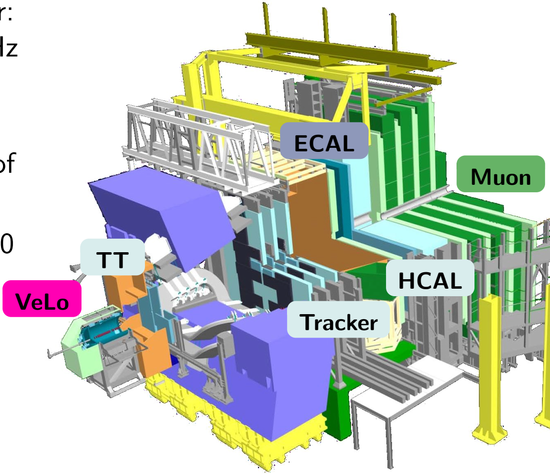
LHCb Trigger

- Hardware-based L0 trigger: moderate p_T cuts: 40 MHz ➜ 1 MHz



LHCb Trigger

- Hardware-based L0 trigger: moderate p_T cuts: 40 MHz → 1 MHz
- The whole data is then sent at 1 MHz to a farm of $\mathcal{O}(2000)$ CPUs
- HLT1 tries to confirm a L0 decision by matching the L0 candidates to tracks. → $\sim$ 30 kHz



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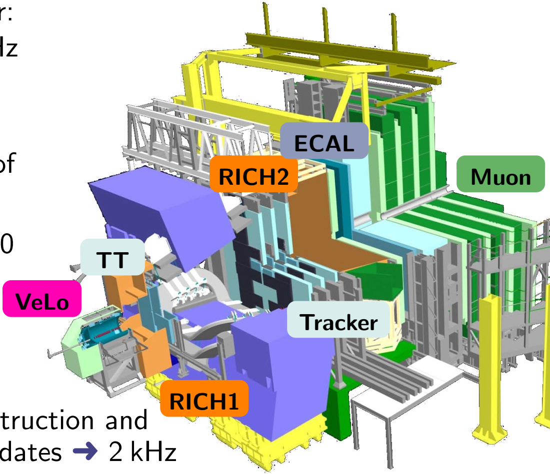
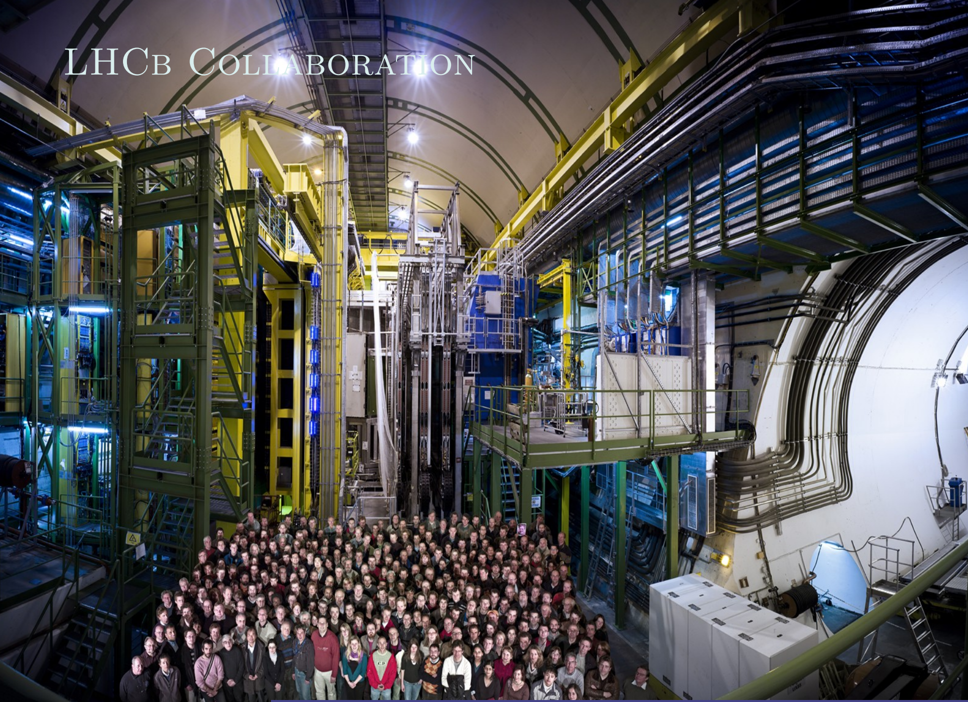


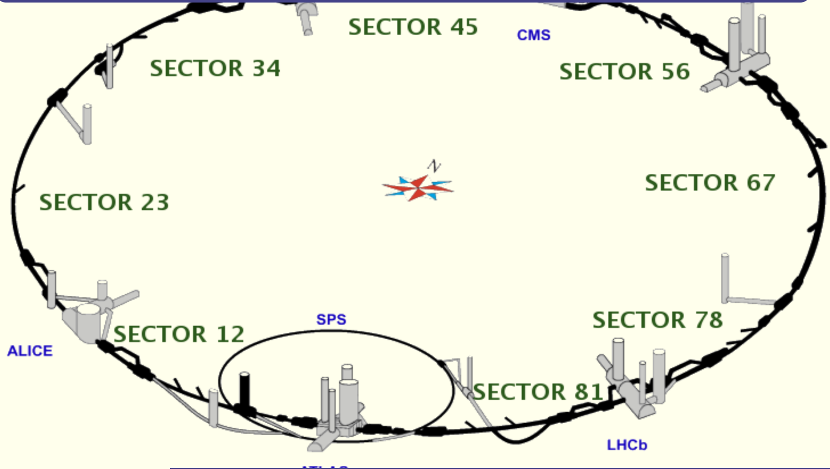
- HLT2 does the full reconstruction and loose selection of B candidates ➜ 2 kHz
  - This is much less than the 10^5 b events per second

LHCb Collaboration

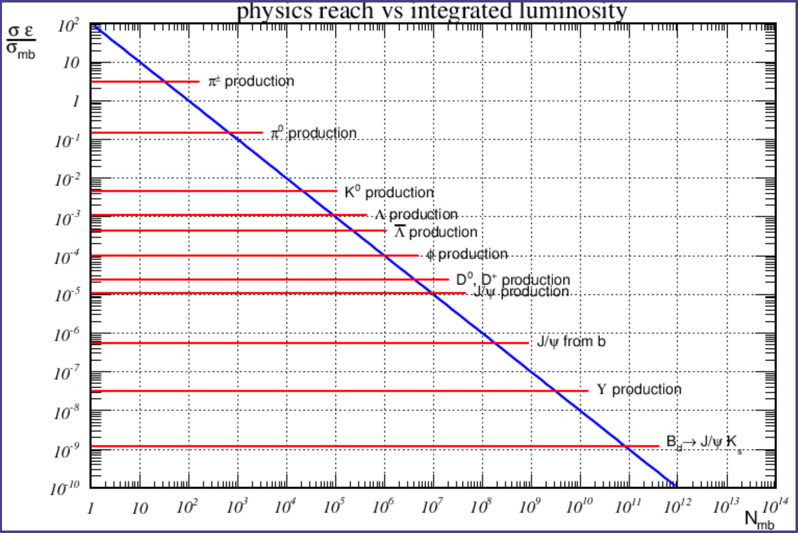


Status and Plans of LHC

Dec'09	A few days of collisions at $\sqrt{s} = 900$ GeV
Dec'09	Some collisions at $\sqrt{s} = 2.4$ TeV

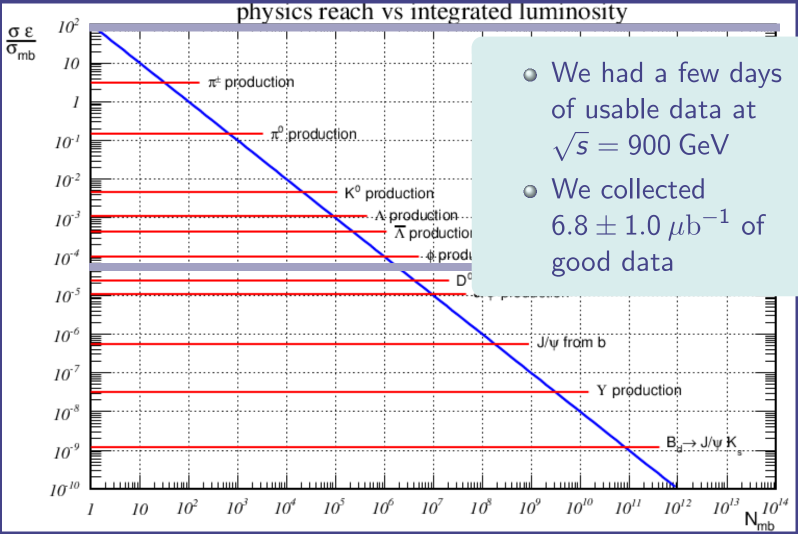


Early Data



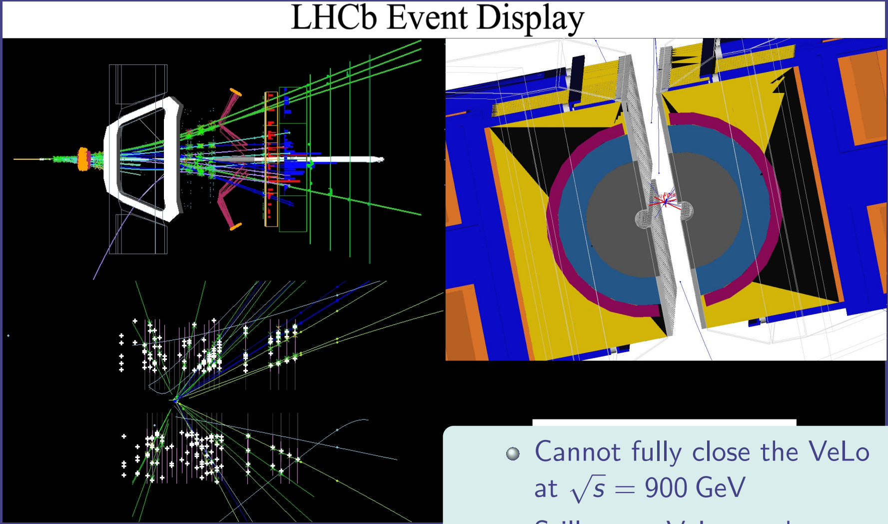
physics reach vs integrated luminosity
σ ε / σmb
π± production
π0 production
K0 production
Λ production
Λ̄ production
φ production
D0, D+ production
J/ψ production
J/ψ from b
Υ production
Bd → J/ψ Ks
Nmb
1
10
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^10
10^11
10^12
10^13
10^14
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10

Early Data



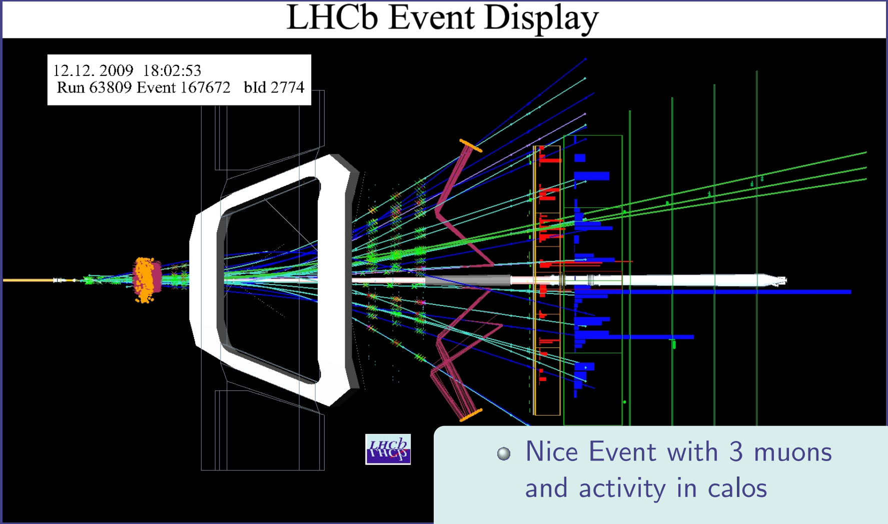
- We had a few days of usable data at $\sqrt{s} = 900$ GeV
- We collected $6.8 \pm 1.0\ \mu\mathrm{b}^{-1}$ of good data

December 2009 Run



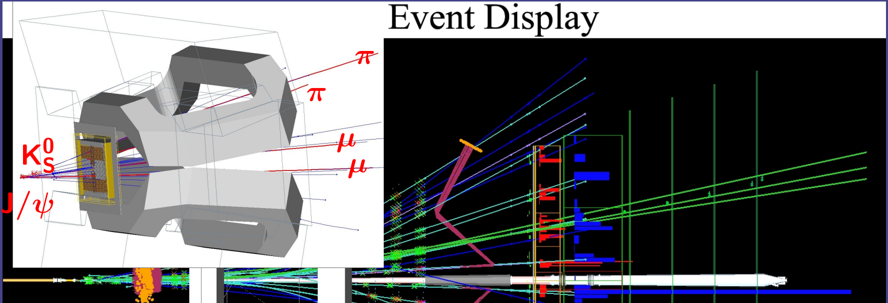
- Cannot fully close the VeLo at $\sqrt{s} = 900$ GeV
- Still many VeLo tracks seen

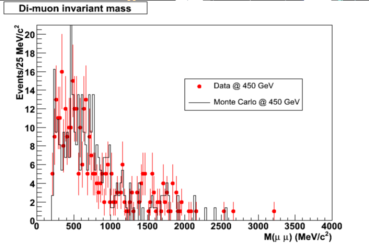
December 2009 Run



- Nice Event with 3 muons and activity in calos

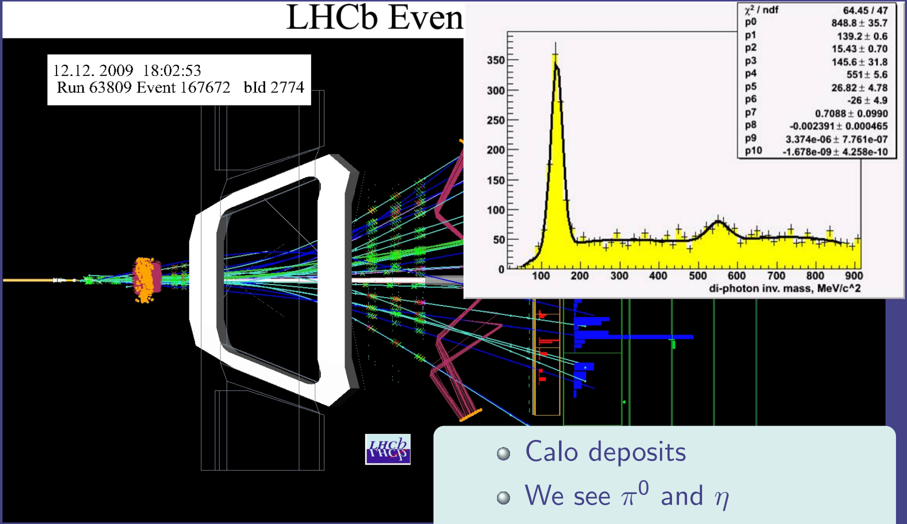
DECEMBER 2009 RUN





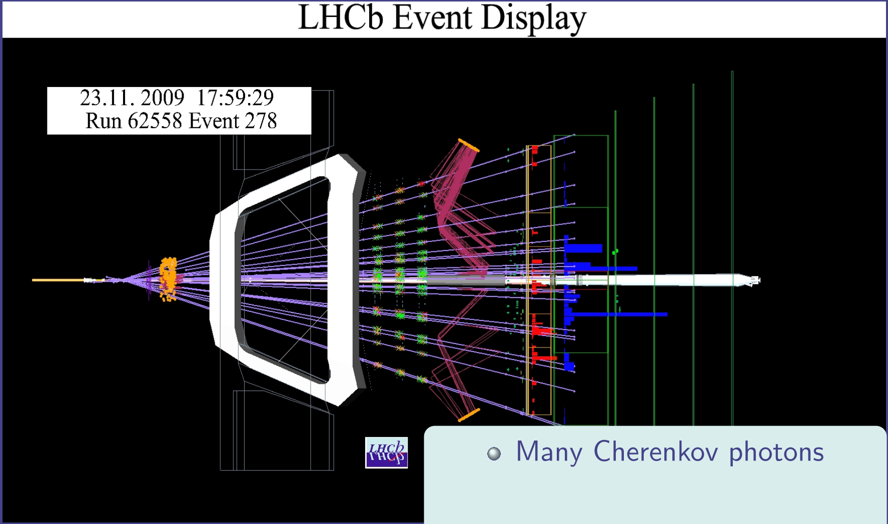
- One event passes the $B_d \to J/\psi\ K^0_S$ preselection

December 2009 Run



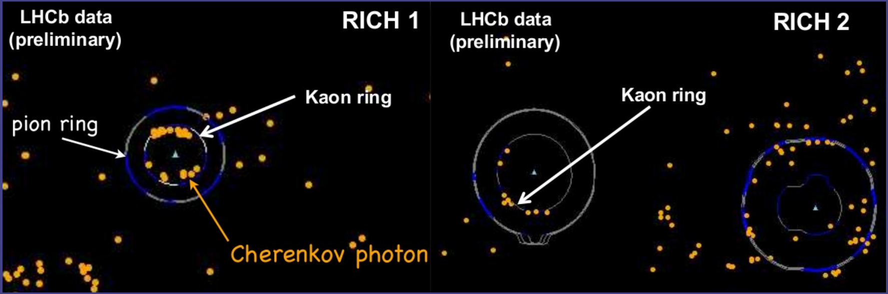
- Calo deposits
- We see π^0 and η

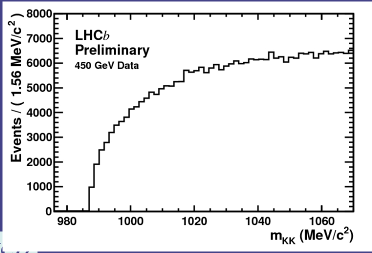
December 2009 Run



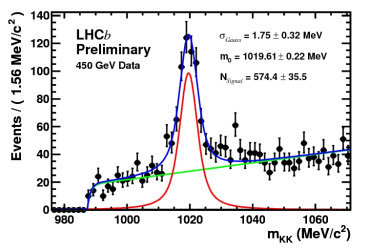
- Many Cherenkov photons

Real Events in the RICH

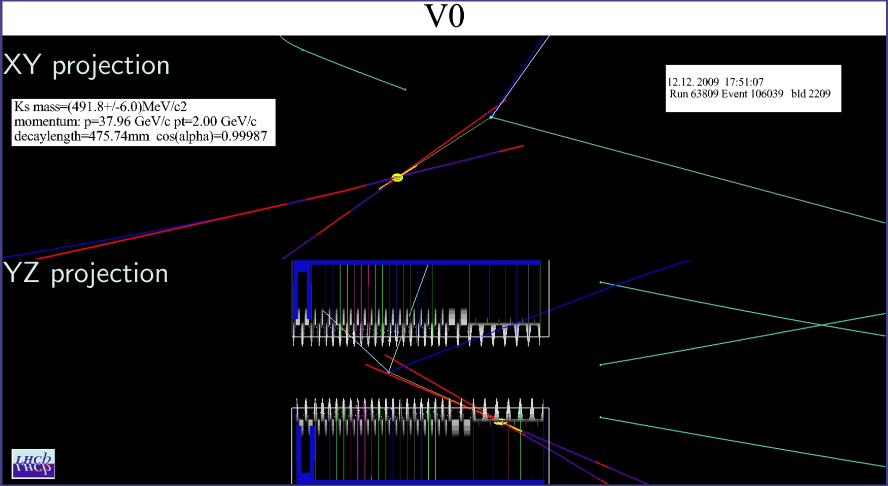




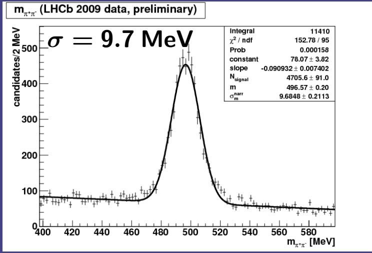
Add Rich

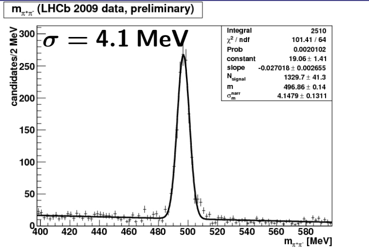


K_S^0 CANDIDATE

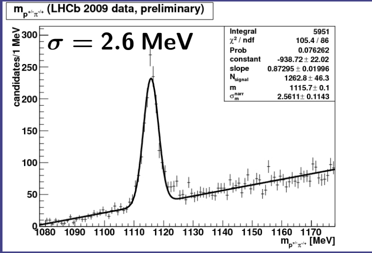


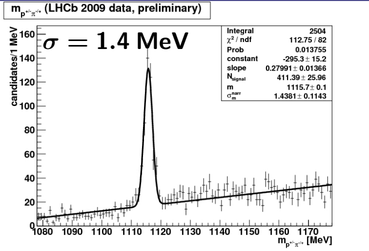
K_S^0 and Λ





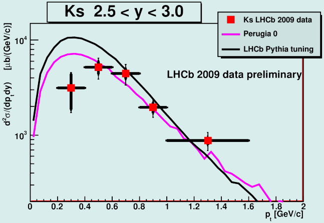
Add VeLo

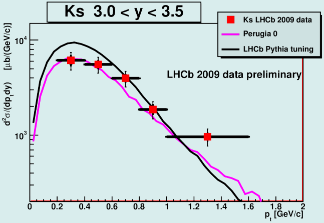


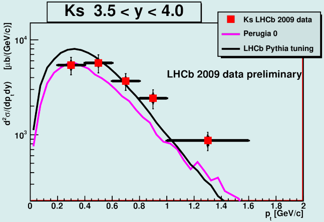


K_S^0 Production at $\sqrt{s} = 900$ MeV

First Public LHCb Result



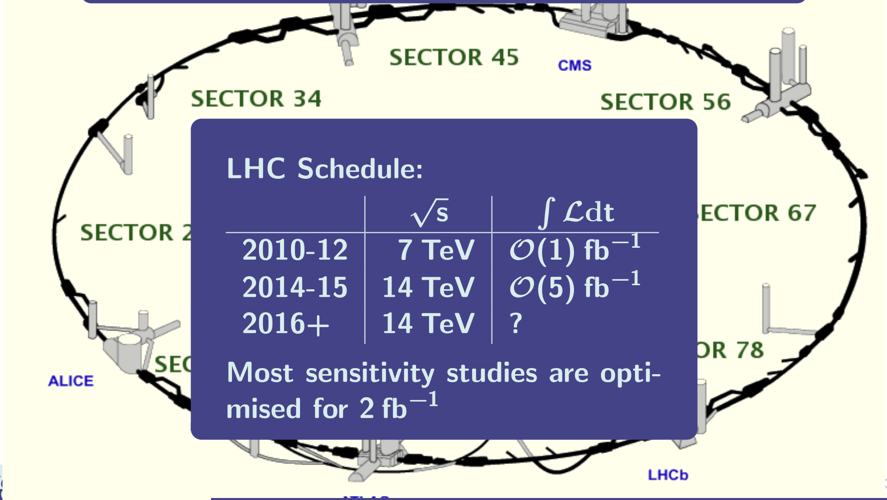




- Measure K_S^0 without using VeLo
  → K_S^0 p_T distributions in 3 rapidity bins
- Compare to `Pythia 6.2` with `Perugia0` tuning
- Luminosity measured by counting *pp* interaction vertices using VeLo
  → Main systematic error (15%)

Status and Plans of LHC

This week | **Commissioning of 3.5 TeV beams**



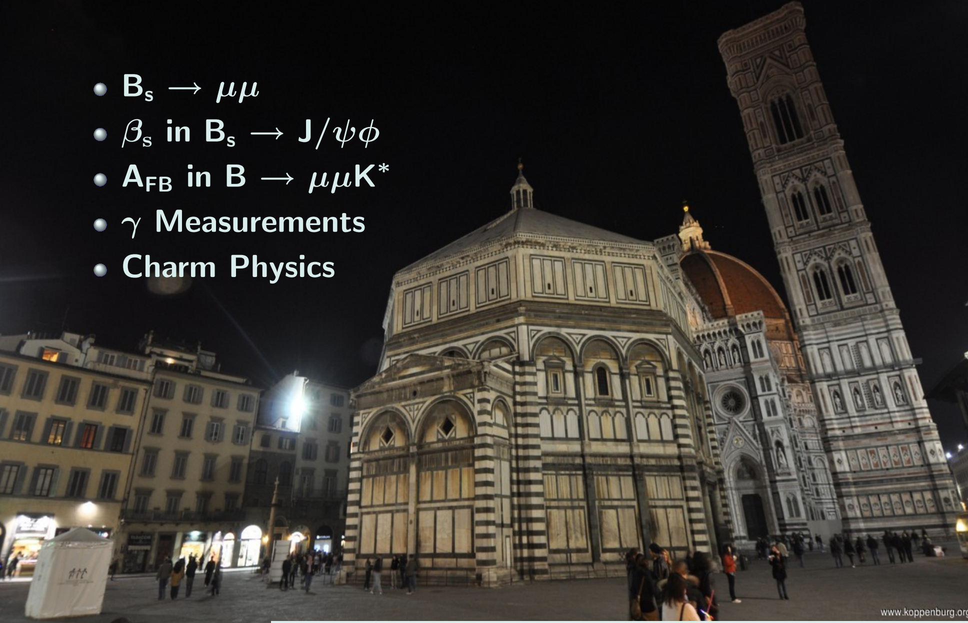
LHC Schedule:

	$\sqrt{s}$	$\int \mathcal{L}dt$
2010-12	7 TeV	$\mathcal{O}(1)\ \text{fb}^{-1}$
2014-15	14 TeV	$\mathcal{O}(5)\ \text{fb}^{-1}$
2016+	14 TeV	?

Most sensitivity studies are optimised for 2 fb^{-1}

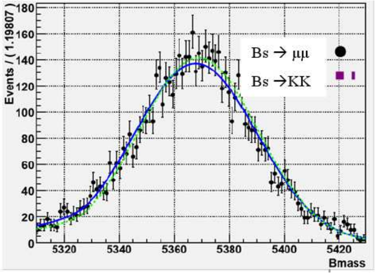
Some Sensitivities

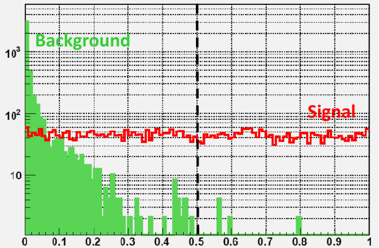
- $B_s \to \mu\mu$
- β_s in $B_s \to J/\psi\phi$
- A_{FB} in $B \to \mu\mu K^*$
- γ Measurements
- Charm Physics



$B_s \to \mu\mu$

- Very rare but SM BF well predicted $\mathcal{B} = (3.35 \pm 0.32) \cdot 10^{-9}$ [Blanke et al., JHEP0610:003,2006]
- Sensitive to (pseudo)scalar operators
  - MSSM: $\mathcal{B} \propto \frac{\tan^6 \beta}{M_A^4}$
- Present limit from CDF $\mathcal{B} < 4.3 \cdot 10^{-8}$ (95% CL)
- Select signal in a 3D-box of mass, geometrical likelihood, PID likelihood
  - Uncorrelated variables with different control samples
  - B mass resolution ~ 20 MeV





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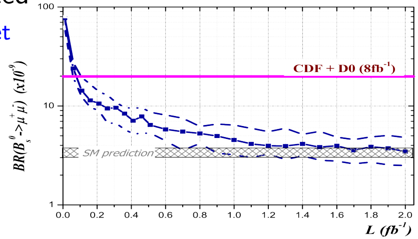
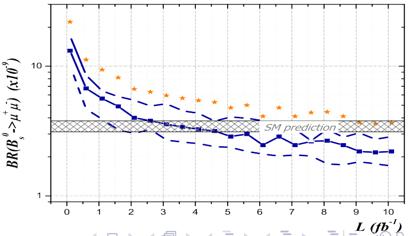
  - MSSM: $\mathcal{B} \propto \frac{\tan^6 \beta}{M_A^4}$
- Present limit from CDF $\mathcal{B} < 4.3 \cdot 10^{-8}$ (95% CL)
- With SM BF, expect 8 signal and 12 background events in most sensitive bin in 2 fb^{-1}
  - ➜ 3σ evidence with 2 fb^{-1}
  - ➜ 5σ observation with 6–10 fb^{-1}

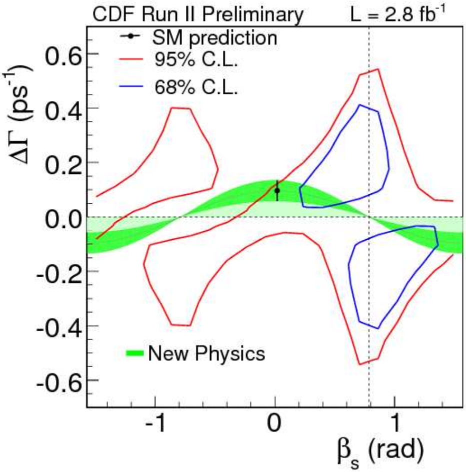




$B_s \to J/\psi\phi$

$\phi^{\mathrm{SM}} = -2\beta_{\mathrm{s}}$: Time-dependent CP asymmetry in $B_s \to J/\psi\phi$

- B_s counterpart to β in $B_d \to J/\psi K^0$
- Tiny in the SM: $\beta_{\mathrm{s}} \sim 0.04$
- Very interesting results from CDF and D0. The standard model is at 7% C.L.



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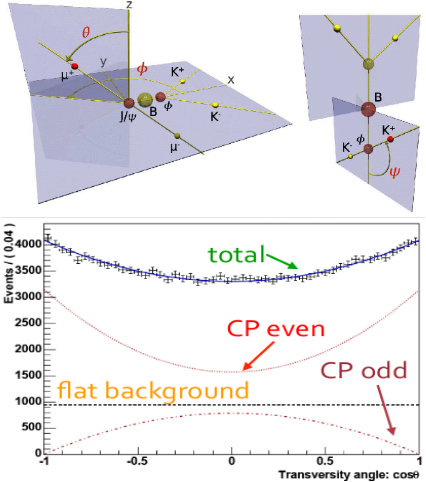
  - ➜ need angular analysis to disentangle CP-even and CP-odd



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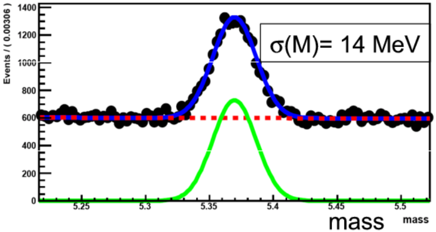
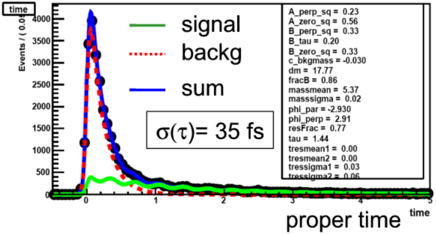
- But $P \to VV$
  - ➜ need angular analysis to disentangle CP-even and CP-odd
- Time-dependent fit with resolution 40 fs
- Expect 100k events / $2\ \mathrm{fb}^{-1}$ at $\sqrt{s} = 14$ TeV
  - ➜ 0.03 precision on β_{s}





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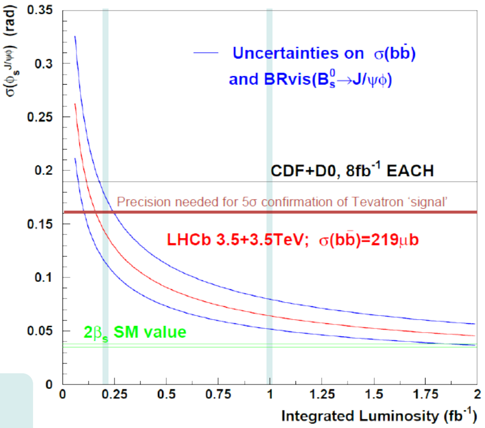
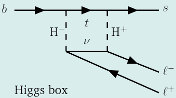


0.07 for 1 fb^{-1} at $\sqrt{s} = 7$ TeV

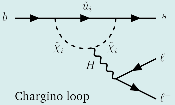
$B \to \mu\mu K^*$

- $B \to \mu\mu K^*$ very rare in the SM
  $\mathcal{B}\,(B{\to}\ell\ell K^*) = (1.2 \pm 1.0) \cdot 10^{-6}$
- Sensitive to
  - Supersymmetry,
  - Graviton exchanges,
  - Extra dimensions

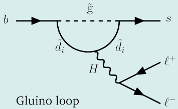
➜ Ideal place to look for new physics



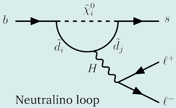
Higgs box



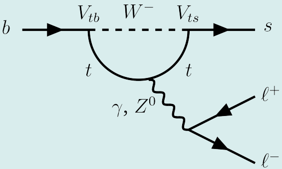
Chargino loop

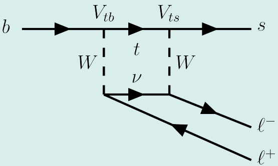


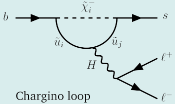
Gluino loop



Neutralino loop







Chargino loop

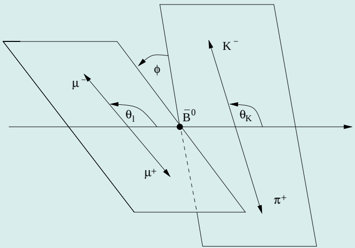
Angular Distributions

A lot of information in the full θ_ℓ, θ_K and ϕ distributions

$$\frac{\mathrm{d}\Gamma'}{\mathrm{d}\theta_l} = \Gamma'\left(\frac{3}{4}F_L\sin^2\theta_l + A_{\mathrm{FB}}\cos\theta_l + \frac{3}{8}(1-F_L)(1+\cos^2\theta_l)\right)$$

$$\frac{\mathrm{d}\Gamma'}{\mathrm{d}\phi} = \frac{\Gamma'}{2\pi}\left(\frac{1}{2}(1-F_L)A_T^{(2)}\cos 2\phi + A_{\mathrm{Im}}\sin 2\phi + 1\right)$$

$$\frac{\mathrm{d}\Gamma'}{\mathrm{d}\theta_K} = \frac{3\Gamma'}{4}\sin\theta_K\left(2F_L\cos^2\theta_K + (1-F_L)\sin^2\theta_K\right)$$



➜ **Many observables**

[Krüger & Matias]
[Egede, et. al.]

Angular Distributions

A lot of information in the full θ_ℓ, θ_K and ϕ distributions

$$\frac{\mathrm{d}\Gamma'}{\mathrm{d}\theta_l} = \Gamma'\left(\frac{3}{4}F_L\sin^2\theta_l + A_{\mathrm{FB}}\cos\theta_l + \frac{3}{8}(1-F_L)(1+\cos^2\theta_l)\right)$$

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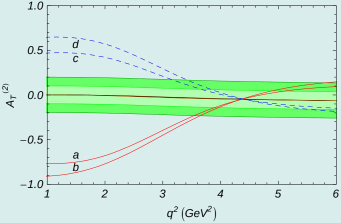


→ Transverse asymmetry $A_T^{(2)}$ (RH)

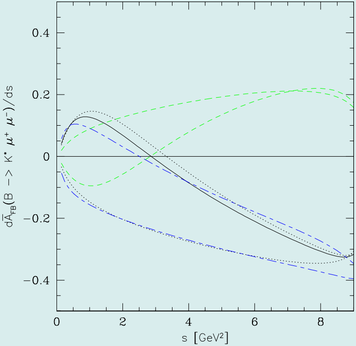
[Krüger & Matias]
[Egede, et. al.]

Angular Distributions

A lot of information in the full θ_ℓ, θ_K and ϕ distributions

$$\frac{\mathrm{d}\Gamma'}{\mathrm{d}\theta_l} = \Gamma'\left(\frac{3}{4}F_L\sin^2\theta_l + A_{\mathrm{FB}}\cos\theta_l + \frac{3}{8}(1-F_L)(1+\cos^2\theta_l)\right)$$

$$A_{\mathrm{FB}} = \frac{\left(\int_0^1 - \int_{-1}^0\right)\mathrm{d}\cos\theta_l\frac{\mathrm{d}^2\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta_l}}{\int_{-1}^1\mathrm{d}\cos\theta_l\frac{\mathrm{d}^2\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta_l}}$$



➜ Zero point measures ratio of Wilson coeffs C_9/C_7.

➜ Forward-backward asymmetry A_{FB}

[Krüger & Matias]
[Egede, et. al.]

Messages from Other Experiments

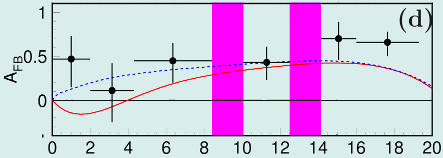
Belle: 230 $B \to \ell\ell K^*$ events in $657 \cdot 10^6$ $B\overline{B}$ [PRL103:171801,2009]

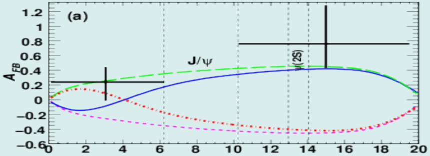
Babar: 60 $B \to \ell\ell K^*$ events in $384 \cdot 10^6$ $B\overline{B}$ [PRD79:031102,2009]

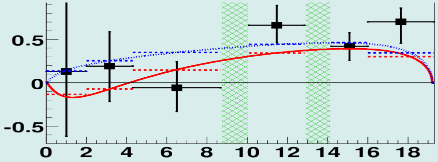
CDF: 100 $B \to \ell\ell K^*$ events in 4.4 fb^{-1} [PRD79:031102,2009]

FB asymmetry: All seem to favour $C_7 = -C_7^{\text{SM}}$ case. Not conclusive yet...

➜ Need much more statistics



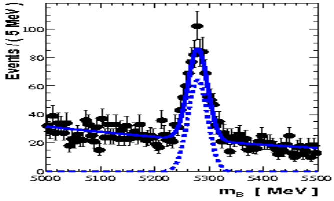


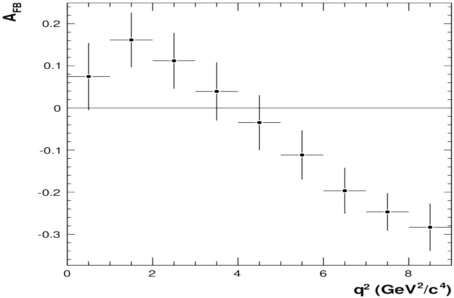


$B_d \to \mu\mu K^*$ yields with 2 fb^{-1}

Expected signal and background yields in 2 fb^{-1} of data (Assuming the SM BR of $\mathbf{12 \cdot 10^{-7}}$):

Sample	Yield
$\mathbf{B_d \to \mu\mu K^*}$	$\mathbf{7200 \pm 2100}$
$b \to \mu\mu s$	2000 ± 100
$2(b \to \mu)$	1050 ± 250
$b \to \mu c(\mu q)$	600 ± 200
Background	3700 ± 300
B/S	$\mathbf{0.5 \pm 0.2}$

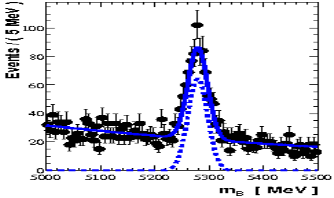


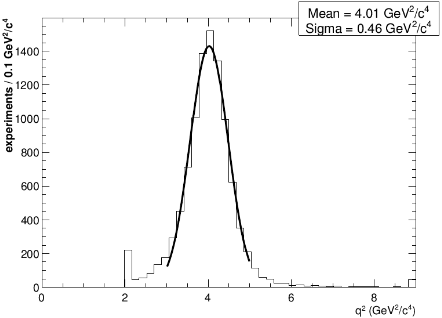


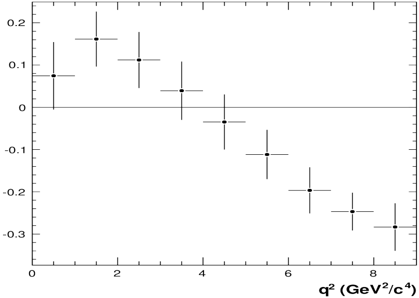
$B_d \to \mu\mu K^*$ yields with 2 fb^{-1}

Expected signal and background yields in 2 fb^{-1} of data (Assuming the SM BR of $\mathbf{12 \cdot 10^{-7}}$):

➜ Resolution on A_{FB} zero : $\pm 0.46\,\mathrm{GeV}^2$ (12%) in 2 fb^{-1}





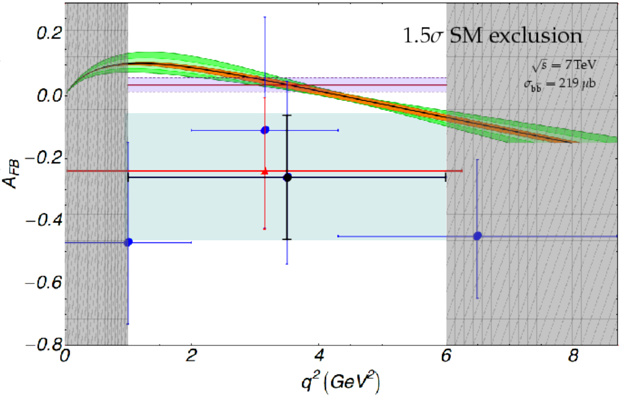


Scaling to Lower Luminosities

Assume Belle is right.

If we measure the mean A_{FB} in a bin 1–6 GeV^2. How well can we exclude the SM?

100 pb^{-1}: 1.5σ



SM prediction — Babar — Belle
LHCb at 100 pb^{-1}

Scaling to Lower Luminosities

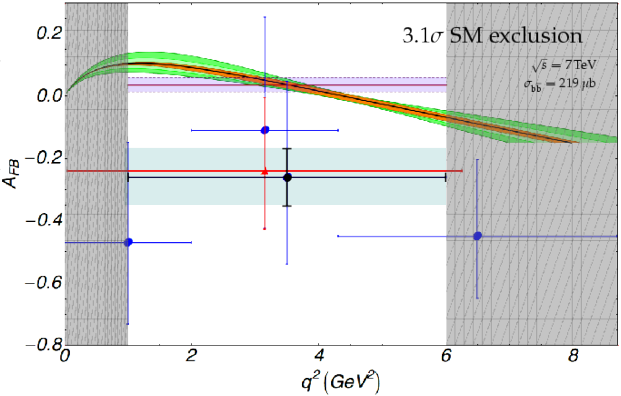
Assume Belle is right.

If we measure the mean A_{FB} in a bin 1–6 GeV^2. How well can we exclude the SM?

100 pb^{-1}: 1.5σ

300 pb^{-1}: 2.4σ

500 pb^{-1}: 3.1σ



SM prediction — Babar — Belle

LHCb at 500 pb^{-1}

Scaling to Lower Luminosities

Assume Belle is right.

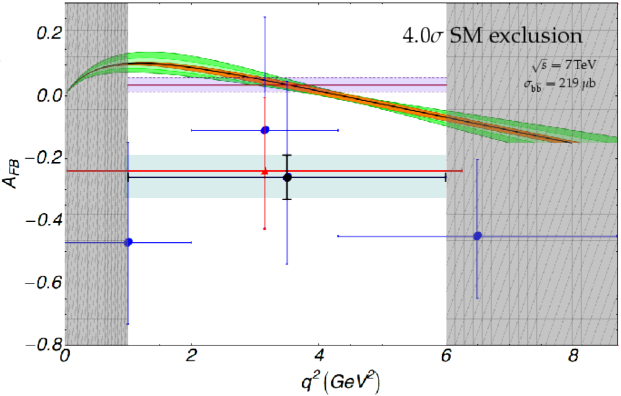
If we measure the mean A_{FB} in a bin 1–6 GeV^2. How well can we exclude the SM?

100 pb^{-1}: 1.5σ

300 pb^{-1}: 2.4σ

500 pb^{-1}: 3.1σ

1 fb^{-1}: 4.0σ

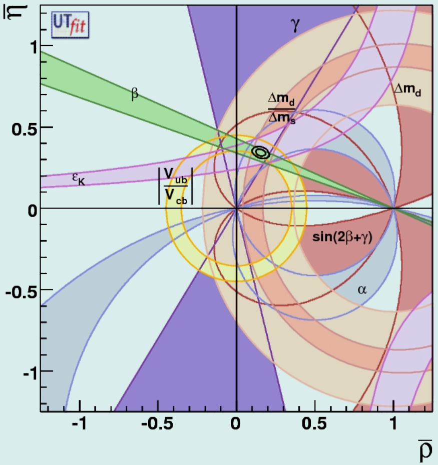


SM prediction — Babar — Belle

LHCb at 1 fb^{-1}

CKM ANGLE γ

- Is hardly measured
- Main constraints from $\sin 2\beta$ and Δm_s
- Can be measured in tree decays
  - ➜ The "real" γ (no NP expected)
- Can be measured in loops



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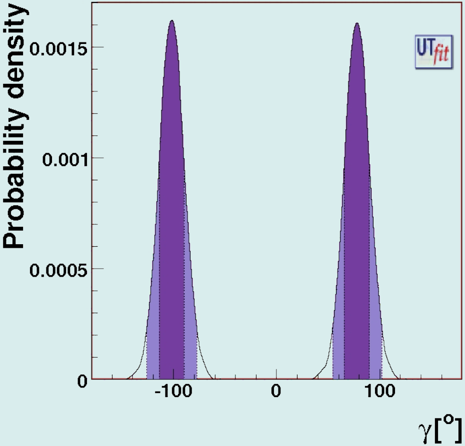
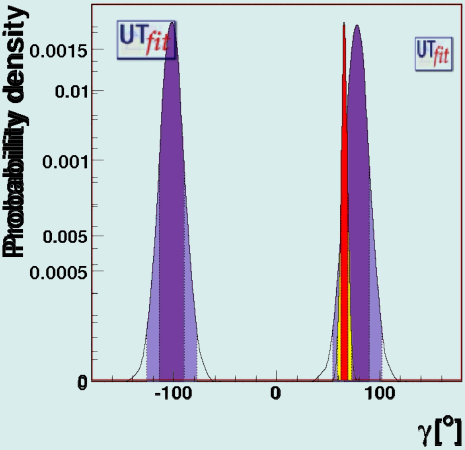


Direct determination of γ

CKM ANGLE γ

- Is hardly measured
- Main constraints from $\sin 2\beta$ and Δm_s
- Can be measured in tree decays
  - ➜ The "real" γ (no NP expected)
- Can be measured in loops
- Want to reach same precision in direct measurements



Direct and indirect determination of γ

γ in Trees

Favoured $B^- \to K^- D^0$ and colour-suppressed $B^- \to K^- \overline{D}^0$

ADS method: $D^0 \to K^- \pi^+$ and doubly-Cabibbo-suppressed $D^0 \to K^+ \pi^-$

- ✗ Low rate
- ✔ Large interference

GLW method: $D^0 \to$ CP eigenstate

- ✔ Large rate
- ✗ Low interference

Dalitz analysis in $D \to K^0_S \pi\pi$

➜ All analyses time independent

Method	$\sigma(\gamma)$
$B_u \to D(hh)K$	11–13°
$B_d \to D(hh)K^*$	6–13°
$B_u \to D(3K\pi)K$	5–10°
$B_u \to D(K^0_S\pi\pi)K$	6–9°

➜ Error on γ between 5° and 13° with 2 fb^{-1}

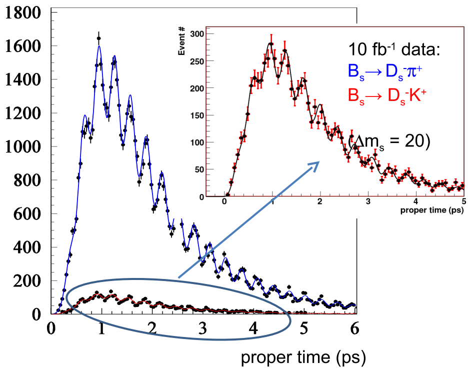
$B \to DK$: Combined $\sim 5°$

γ in Trees

Time dependent CP asymmetry in $B_s \to D_s^+ K^-$ and $B_s \to D_s^- K^+$

➜ Fit $B_s \to D_s K$ and $B_s \to D_s \pi$ for Δm_s, $\Delta\Gamma$, mis-tag and $\gamma + \beta_s$

2 fb^{-1}	Sig	B/S
$B_s \to D_s K$	6.2 k	< 0.4
$B_s \to D_s \pi$	140 k	< 0.4



$B_s \to D_s K$: 9°–12°

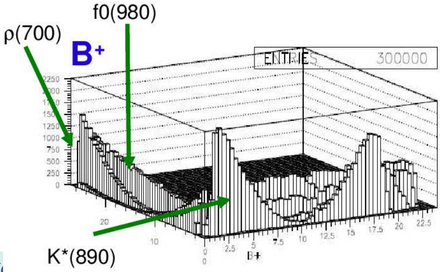
$B \to DK$: Combined $\sim$ 5°

γ in Loops

Interference of tree and penguin diagrams in $b \to u$ and $b \to d$ (s)

- $B \to hh$: Lifetime-dependent CP in $B_d \to \pi\pi$ and $B_s \to KK$ and direct CP in $B \to K\pi$
- Dalitz: analysis of $B_d \to K^0_S\pi\pi$ and $B_d \to K\pi\pi$

$2\ \mathrm{fb}^{-1}$	Sig	B/S
$B_d{\to}\pi\pi$	36 k	0.5
$B_s{\to}KK$	36 k	0.15
$B_d{\to}K\pi$	140 k	<0.06
$B_s{\to}\pi K$	10 k	1.9
$B_u{\to}K\pi\pi$	500 k	1
$B_d{\to}K^0_S\pi\pi$	40 k	TBD



$B \to hh$ 7–10°

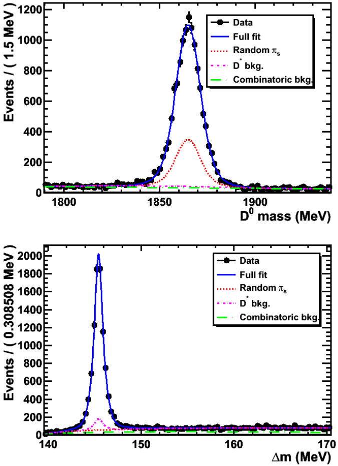
$B \to K\pi\pi$ $\sim 5°$

$B_s{\to}D_sK$: 9°–12°

$B{\to}DK$: Combined $\sim 5°$

Charm Physics

- Charm physics offers a unique potential to discover New Physics
  - $\sigma_{c\bar{c}} \sim 7\sigma_{b\bar{b}}$
  - ➜ $4 \cdot 10^6$ $D^* \to D^0(KK)\pi$ in 100 pb^{-1} (BaBar has $2.6 \cdot 10^5$ [PRD.80.071103])
- Re-tuned the trigger for low luminosities ($\mathcal{L} < 10^{31}\ \text{s}^{-2}\text{cm}^{-1}$)
  - Lower p_T, impact parameter thresholds
  - ➜ Improves prompt charm yields by a factor 4 compared to trigger setting optimised for B physics

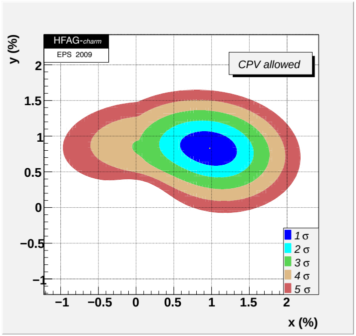


$D \to K\pi$ and $D^* \to D\pi$ with 0.2 pb^{-1}

Charm Physics

- Charm physics offers a unique potential to discover New Physics
- Re-tuned the trigger for low luminosities ($\mathcal{L} < 10^{31}\ \mathrm{s}^{-2}\mathrm{cm}^{-1}$)
- Extensive Charm physics programme
  - Rare Decays : $D^0 \to \mu\mu$, $D \to h\mu\mu$
  - CP violation: $D^0 \to KK$, $D^0 \to \pi\pi$
- Mixing:
  - Significant evidence for D mixing
  - But no single 5σ measurement yet
  - Many measurements being prepared, for instance

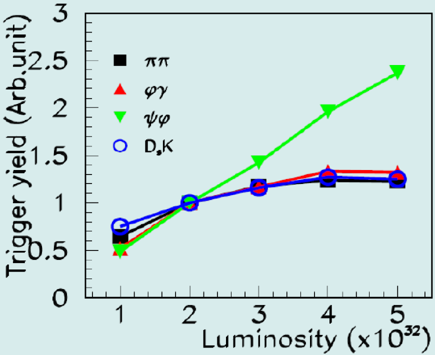
$$y_{\mathrm{cp}} = \frac{\tau(D^0 \to K^+\pi)}{\tau(D^0 \to K^+K^-, \pi\pi)} - 1$$



We'll soon have the largest D sample in the world!

LHCb Upgrade plans

- Expect that integrated luminosity increases linearly with time. After 6 fb^{-1}, would take $\sim$3 years to double statistics
  - Need a factor 10 increase in luminosity ➜ $\sim 10^{33}$
  - ✔ Most of the detector can cope, efficiencies don't degrade
- ✗ L0 saturates for hadronic channels
  - p_T is not a discriminating variable anymore
  - ➜ Cut on impact parameter
- ➜ Read all out at 40 MHz
  - Most of the electronics to be replaced



Some Upgraded Physics

	$6\ \mathrm{fb}^{-1}$	With upgrade
β_s	Known to 0.01 rad	Level of CKM fits
$B_s \to \phi\phi$	Search for CPV	NP reach?
γ	Measured to 2°	Below 1°
$B_s \to \mu\mu$	Observed	Measure $B_d \to \mu\mu / B_s \to \mu\mu$
$B \to \mu\mu K^*$	Measure A_{FB} to 7%	High precision on angular fit
D	Charm CPV to 10^{-3}	Observe CPV

- No detailed sensitivities yet
- R&D has started ➜ pixel vertex detector
- Aim to upgrade during one of the long shutdowns (2016?)
  - ➜ Decorrelated from SLHC

Conclusion

- Thanks to the B factories and the Tevatron for their wonderful work
- LHCb is starting up. First results coming out already

➜ Expect first c and b physics results soon

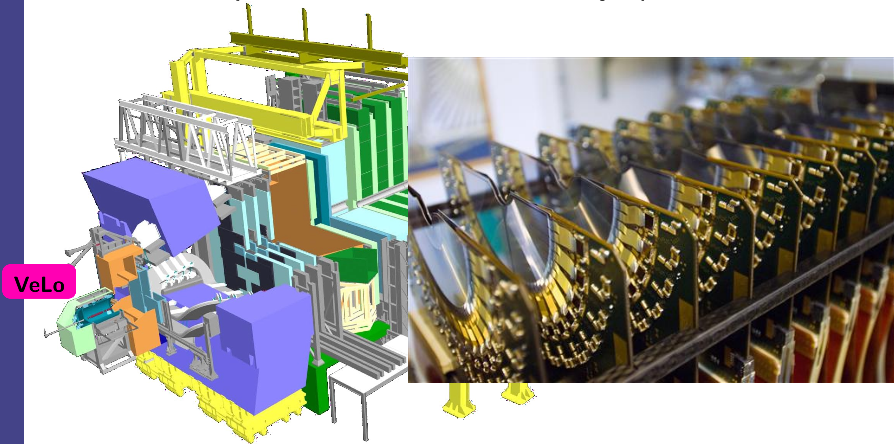
- LHCb upgrade expected for 2016

A new era in flavour physics is starting

Backup

LHCb Vertex Locator

- 21 stations with r and ϕ strips
- In secondary vacuum and retracted during injection



LHCb Vertex Locator

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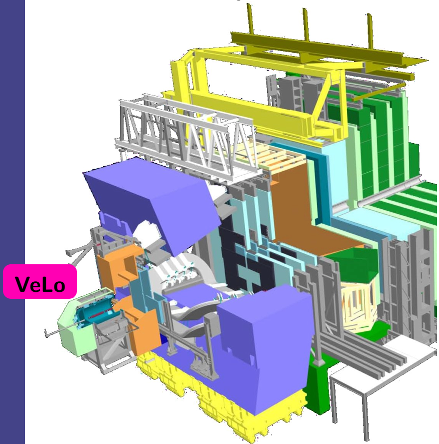
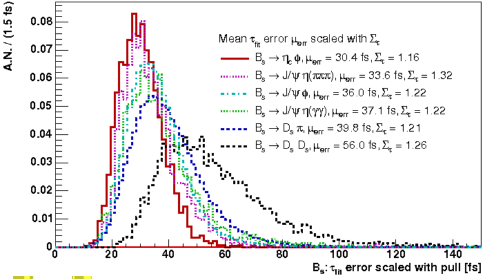


- Proper time resolution between 30 and 50 fs, depending on channel



LHCb Vertex Locator

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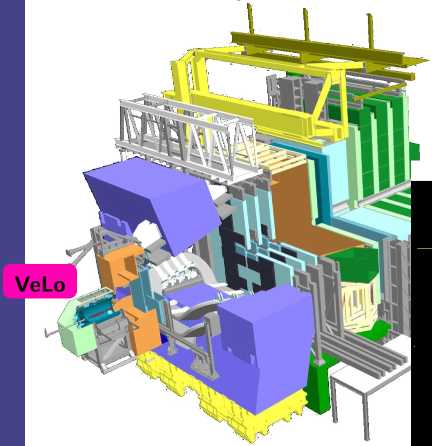
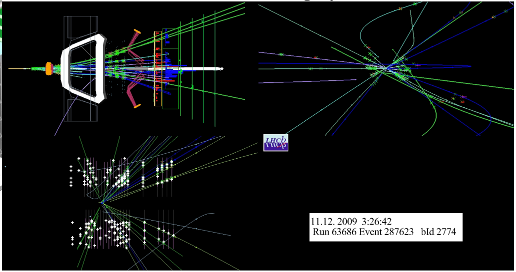
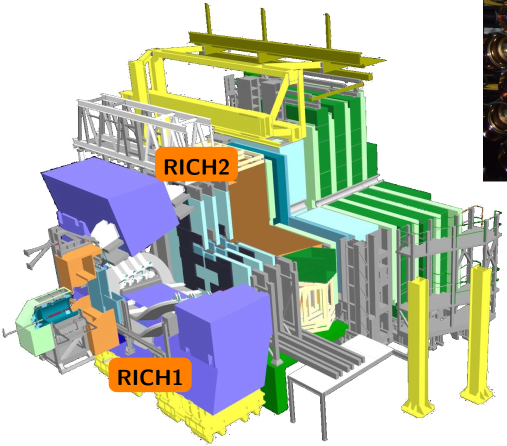


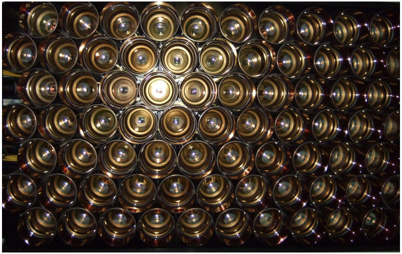
LHCb Event Display



LHCb RICH

- RICH provides K/π separation using Cherenkov radiation

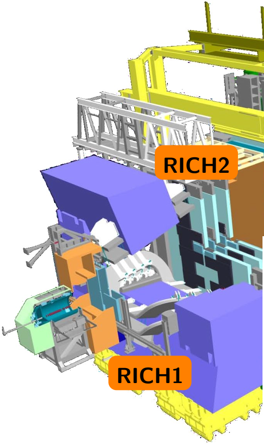




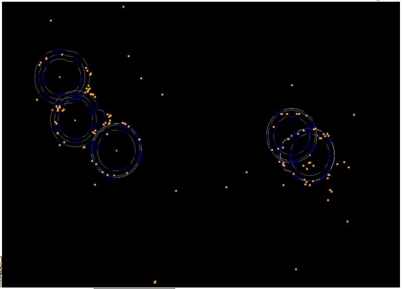
- Use gas and aerogel radiators
- Two detectors for different momentum ranges

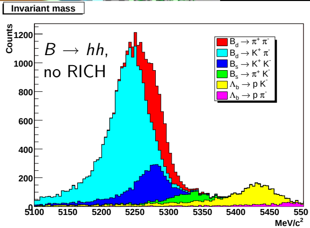
LHCb RICH

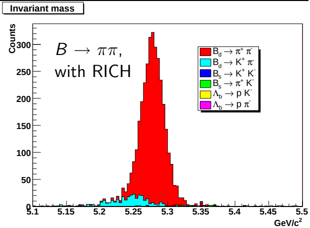
- RICH provides K/π separation using Cherenkov radiation



RICH2 HPD Panels with Pixels and CK Rings







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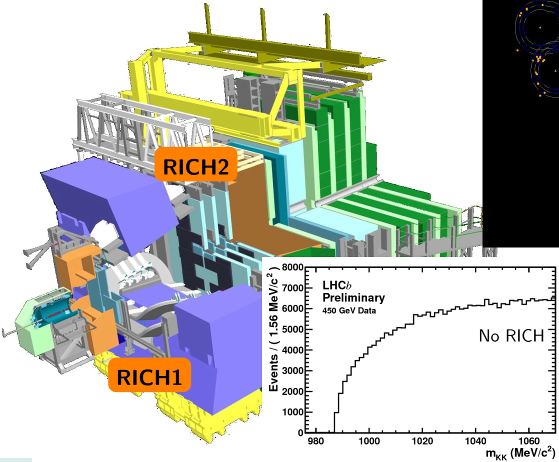
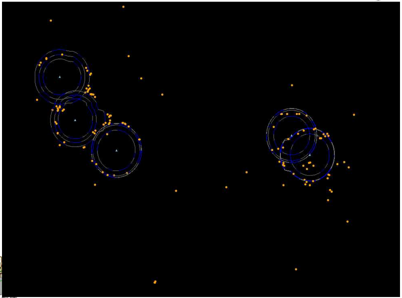
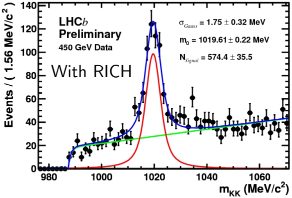
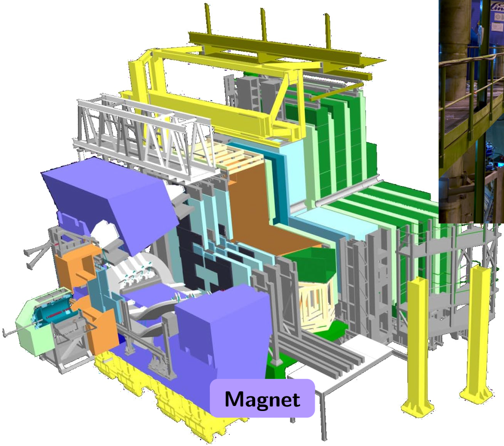


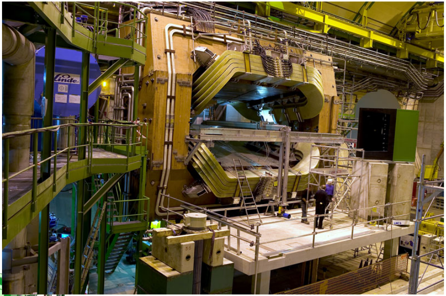
RICH2 HPD Panels with Pixels and CK Rings





LHCb Magnet





- Warm solenoid magnet
- 3 Tm integrated field
- Can swap polarity

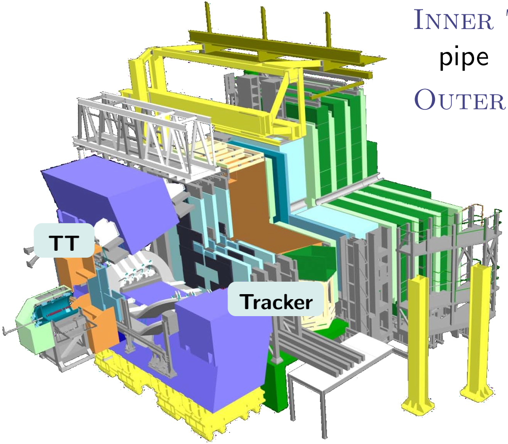
  ➜ needed for CP studies

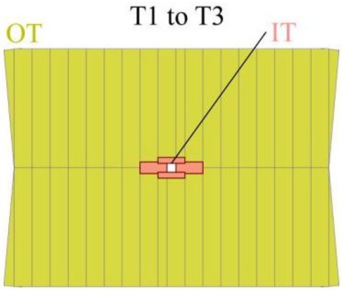
LHCb Trackers

Trigger Tracker: before the magnet

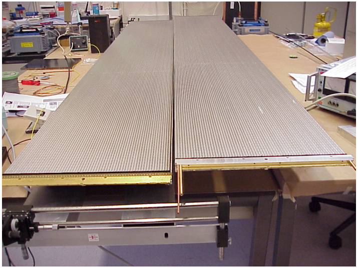
Inner Tracker: around the beam pipe

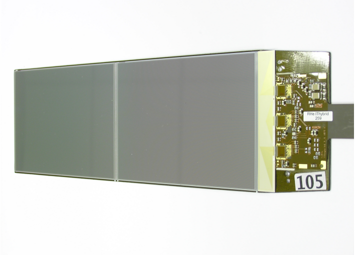
Outer Tracker: around IT





LHCb Trackers





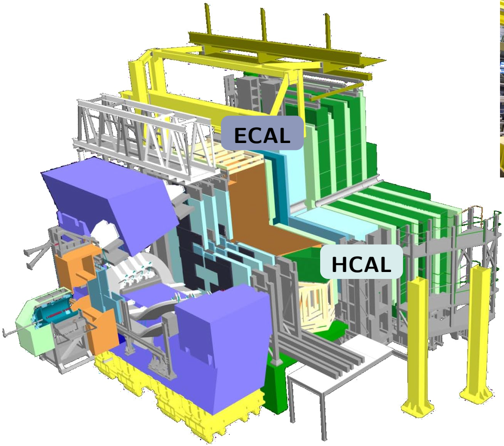
Trigger Tracker: before the magnet

Inner Tracker: around the beam pipe

Outer Tracker: around IT

- OT are straw tubes.
  - Close to the beam pipe the occupancy is too high
- TT and IT are silicon strip detectors

Calorimetry

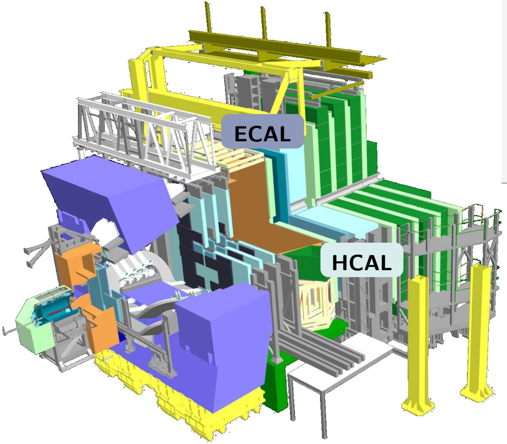


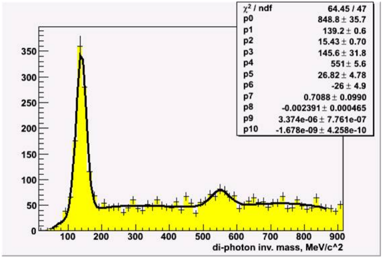
ECAL: For γ and π^0 detection, and e identification

- Layers of lead and plastic scintillators

PRESHOWER: Lead/scintillator

Calorimetry





ECAL: For γ and π^0 detection, and e identification

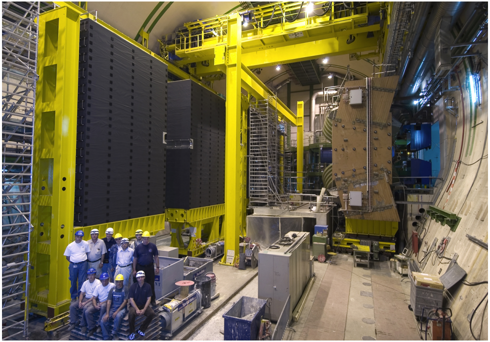
- Layers of lead and plastic scintillators

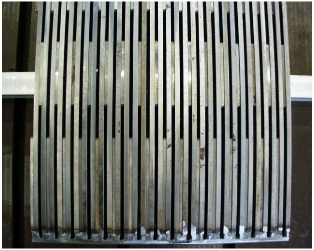
Preshower: Lead/scintillator

Calorimetry

HCAL: For any hadron

- Scintillator tiles embedded in an iron structure
- The HCAL is actually only used in the trigger





ECAL: For γ and π^0 detection, and *e* identification

- Layers of lead and plastic scintillators

Preshower: Lead/scintillator

LHCb Muon Detector

- Four stations M2–M5 embedded in an ion filter, M1 in front of ECAL
- Read out by gas detectors (triple GEM and MWPCs)