Perspectives on Flavour Physics at Hadron Machines

- **LHC experiments**
  - **LHCb, mainly**
  - → **Status**
  - → **Physics reach**
  - → **Upgrade plans**
- **Future Kaon experiments**

09/09/08, CKM Workshop, Roma

On behalf of the LHCb collaboration

Patrick Koppenburg

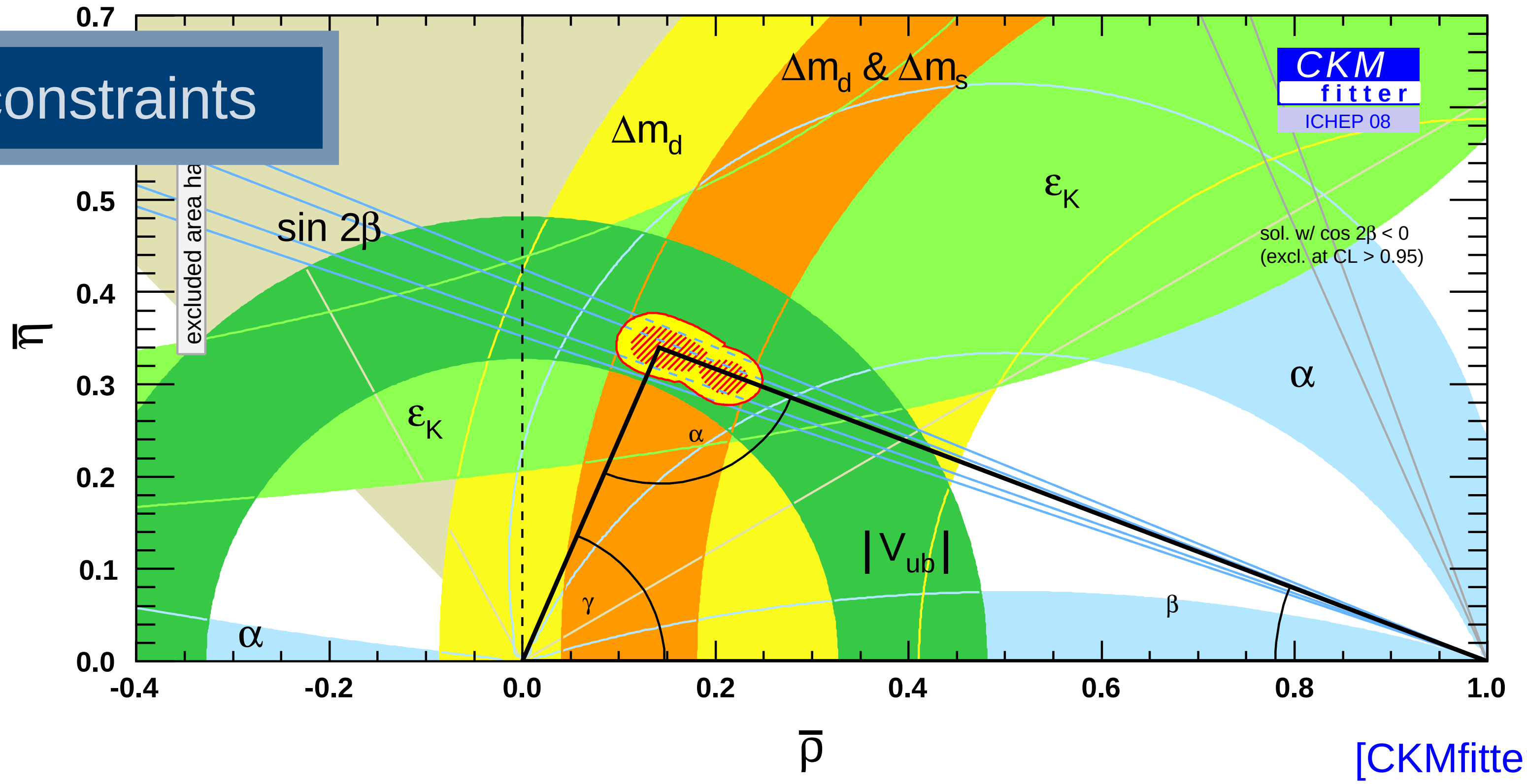
Imperial College

London

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 08/08]

Unitarity Triangle

- Changed focus: No longer seeking to verify the CKM picture
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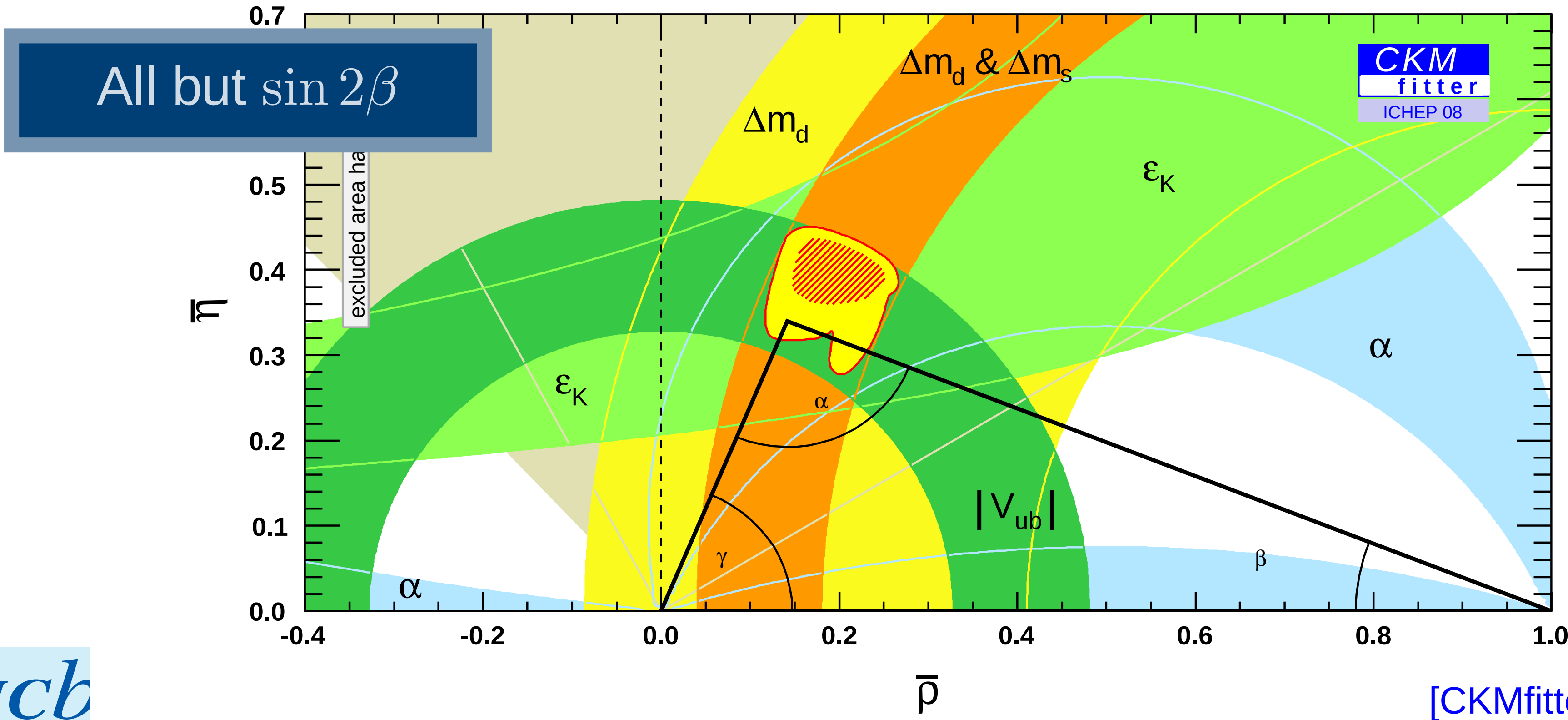
  - ➜ Discrepancies in measurements or unitarity triangle
- $(\bar{\rho}, \bar{\eta})$ fit is dominated by $\sin 2\beta$

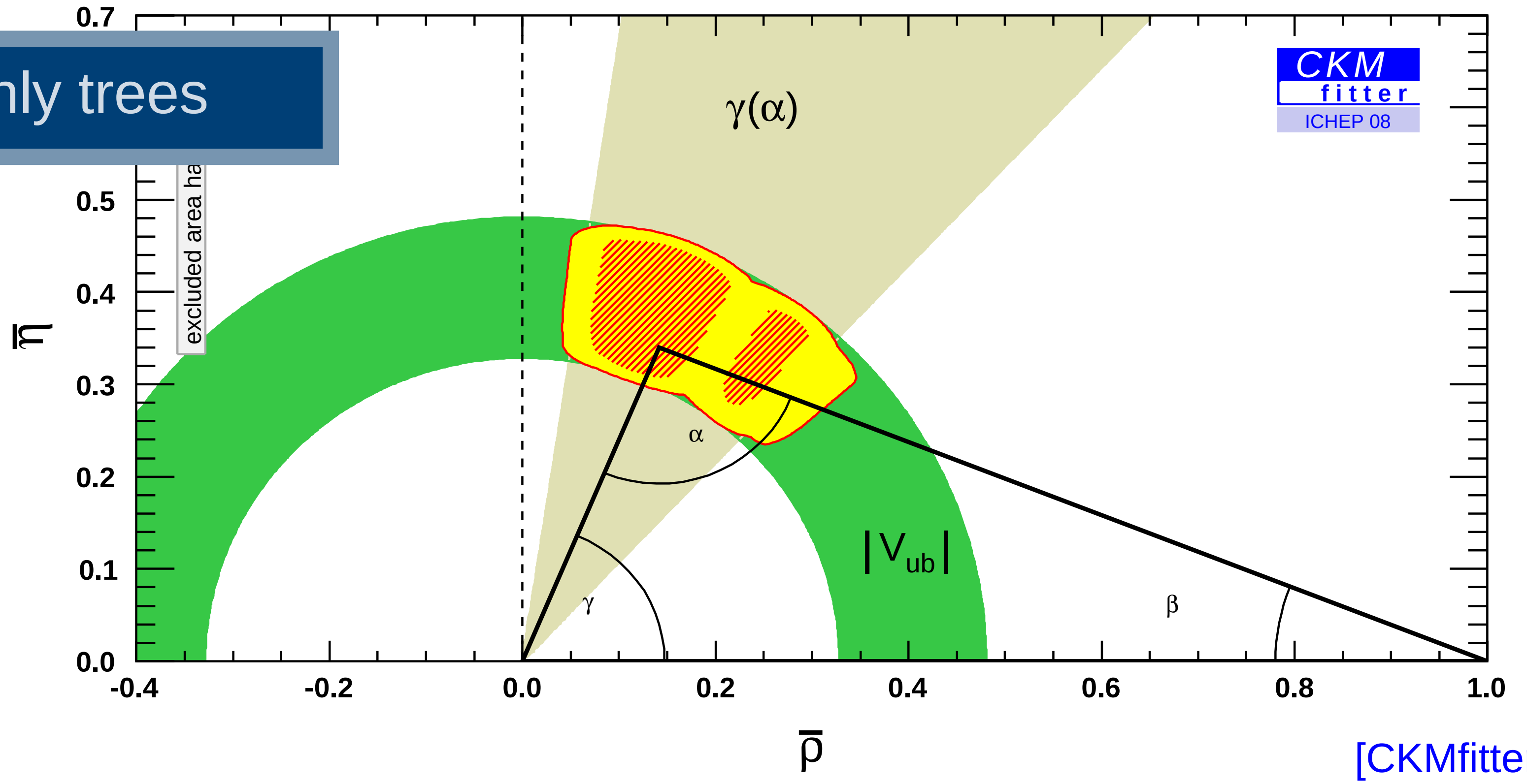


[CKMfitter 08/08]

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
- We don't know much about constraints from trees

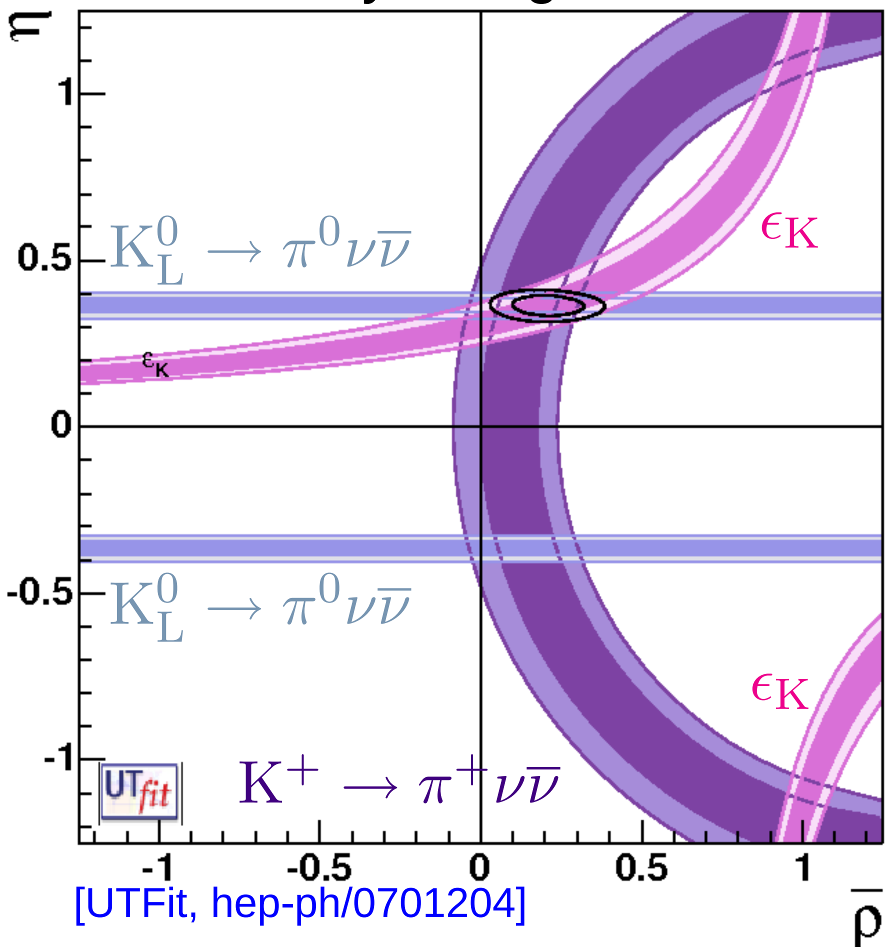
Only trees



[CKMfitter 08/08]

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
- We could learn a lot more from rare kaon decays
  - In particular $\mathrm{K} \to \pi\nu\overline{\nu}$



[UTFit, hep-ph/0701204]

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
- ✔ Need very good precision on all angles and sides.
  - ✔ Precise measurement of γ
- ✔ Need $\mathrm{B_s}$ as well ➜ β_s and more
- ✔ Look for rare decays in K and B

➜ **Need a lot of data and a good precision**

Hadron Machines provide a high cross-section

⬇

Loads of statistics

LHC

LHC Environment

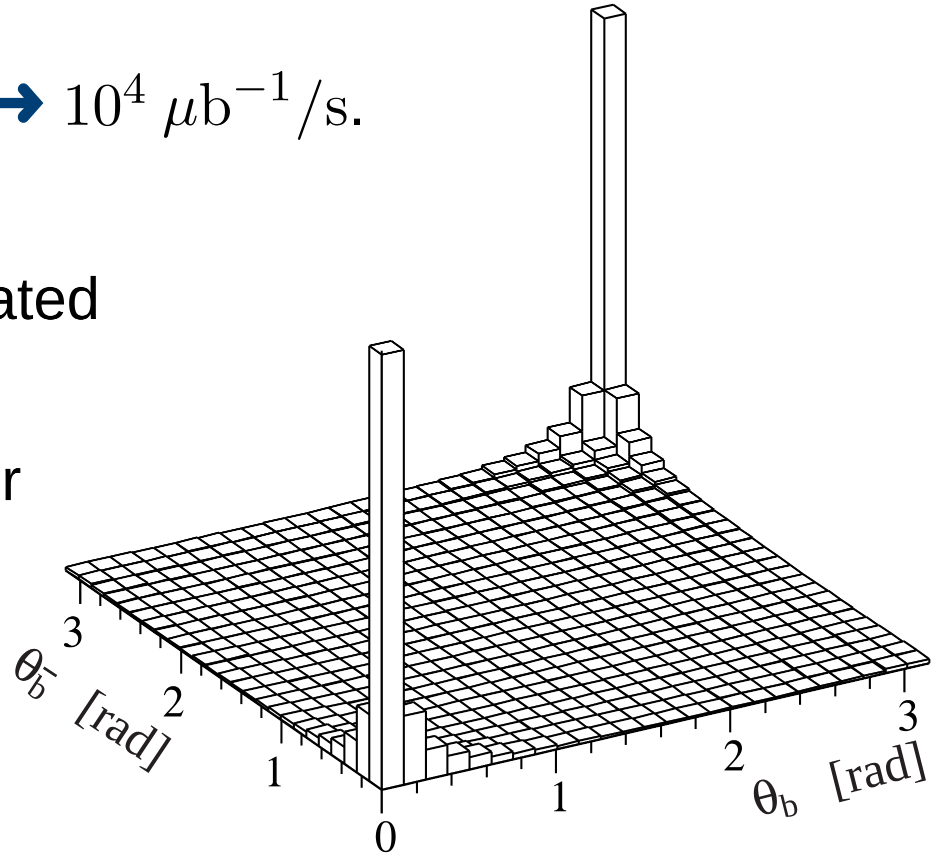
- pp collider at 14 TeV
  - Inelastic cross-section about $60\ \mathrm{mb}$
  - $\mathrm{b\bar{b}}$ cross-section about $500\ \mu\mathrm{b}$ (one every 120)
- Bunch crossings at 40 MHz
- Luminosity up to $10^{34}\ \mathrm{cm^{-2}s^{-1}}$ ➜ $10^{4}\ \mu\mathrm{b}^{-1}/\mathrm{s}$.

  ➜ $5 \cdot 10^{6}\ \mathrm{b\bar{b}}$ pairs per second
- Direction of b and $\mathrm{\bar{b}}$ very correlated

  ➜ A 4π coverage not optimal

  ➜ Build a forward spectrometer

The choice of the LHCb collaboration



b physics at Hadron Colliders

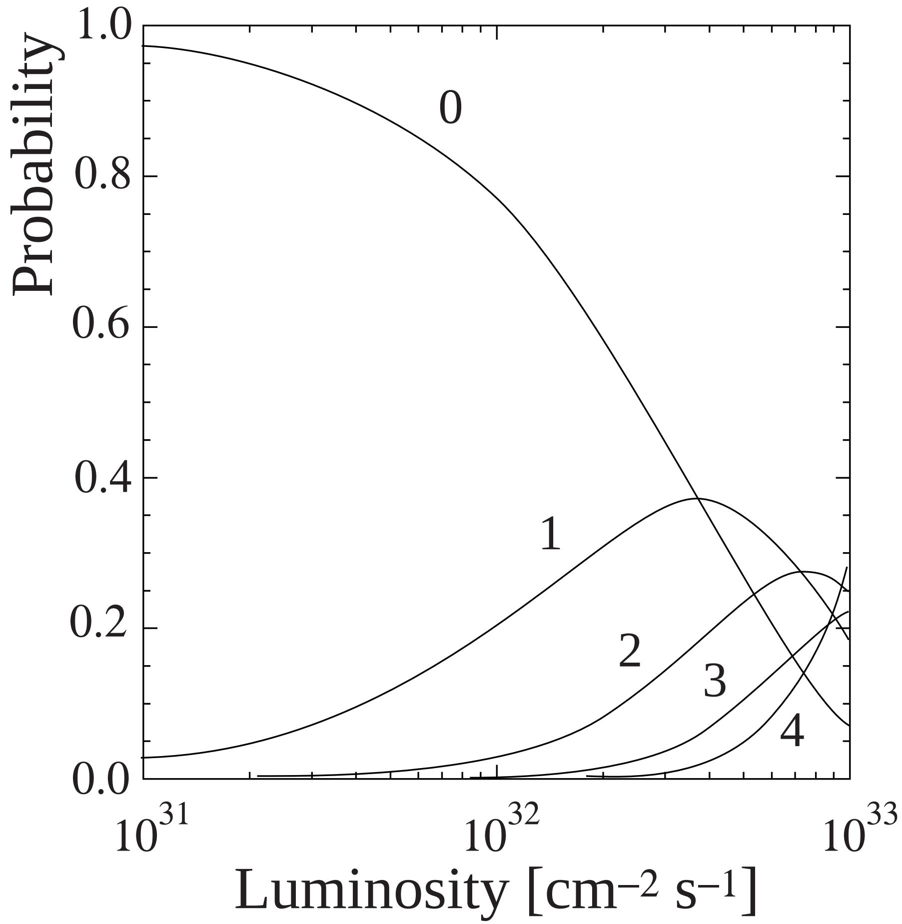
- B mesons have a long lifetime $c\tau = 0.5\ \mathrm{mm}$ with $\gamma = \mathcal{O}(10\text{–}100)$
  - You want to make lifetime-dependent measurements
  - ➜ **Good vertex resolution**

✗ Not too many pp interactions per bunch crossing

➜ Start at $2\text{–}5 \times 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

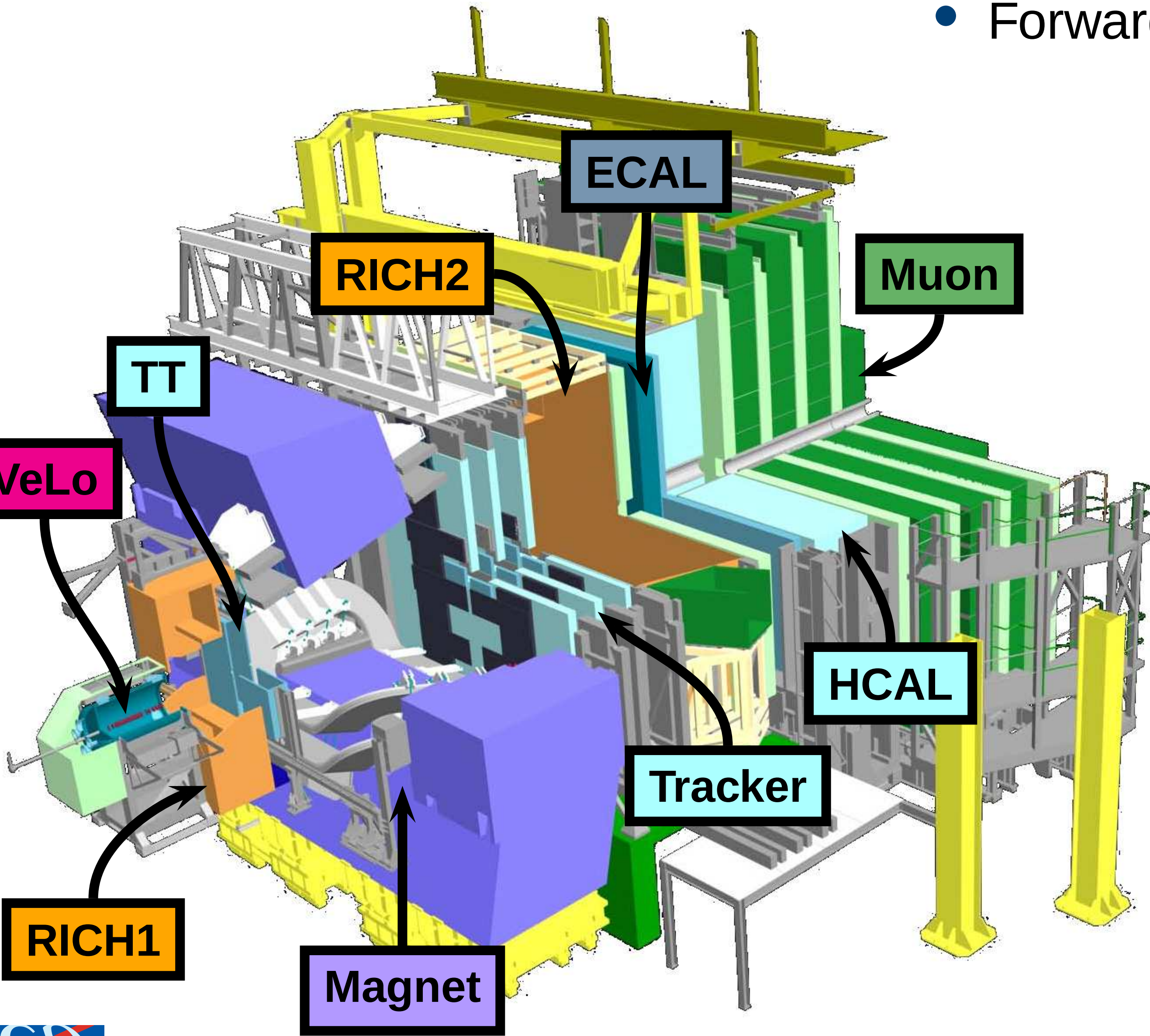
- Still $> 10^5$ b per second
- We will reach baseline luminosity very early

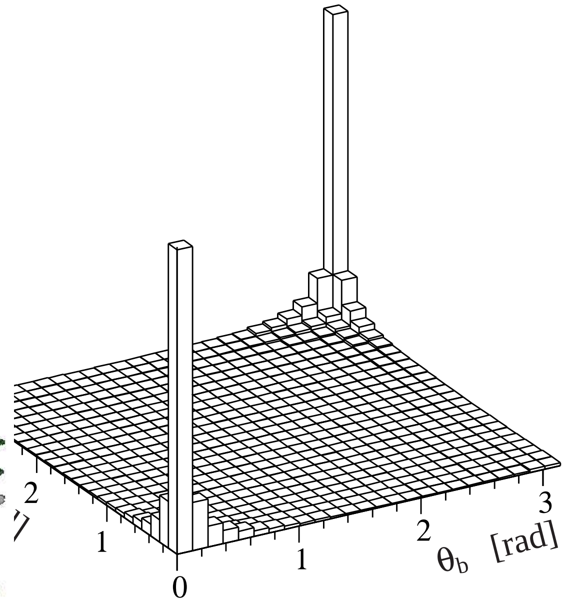
- Good particle ID to fight large background



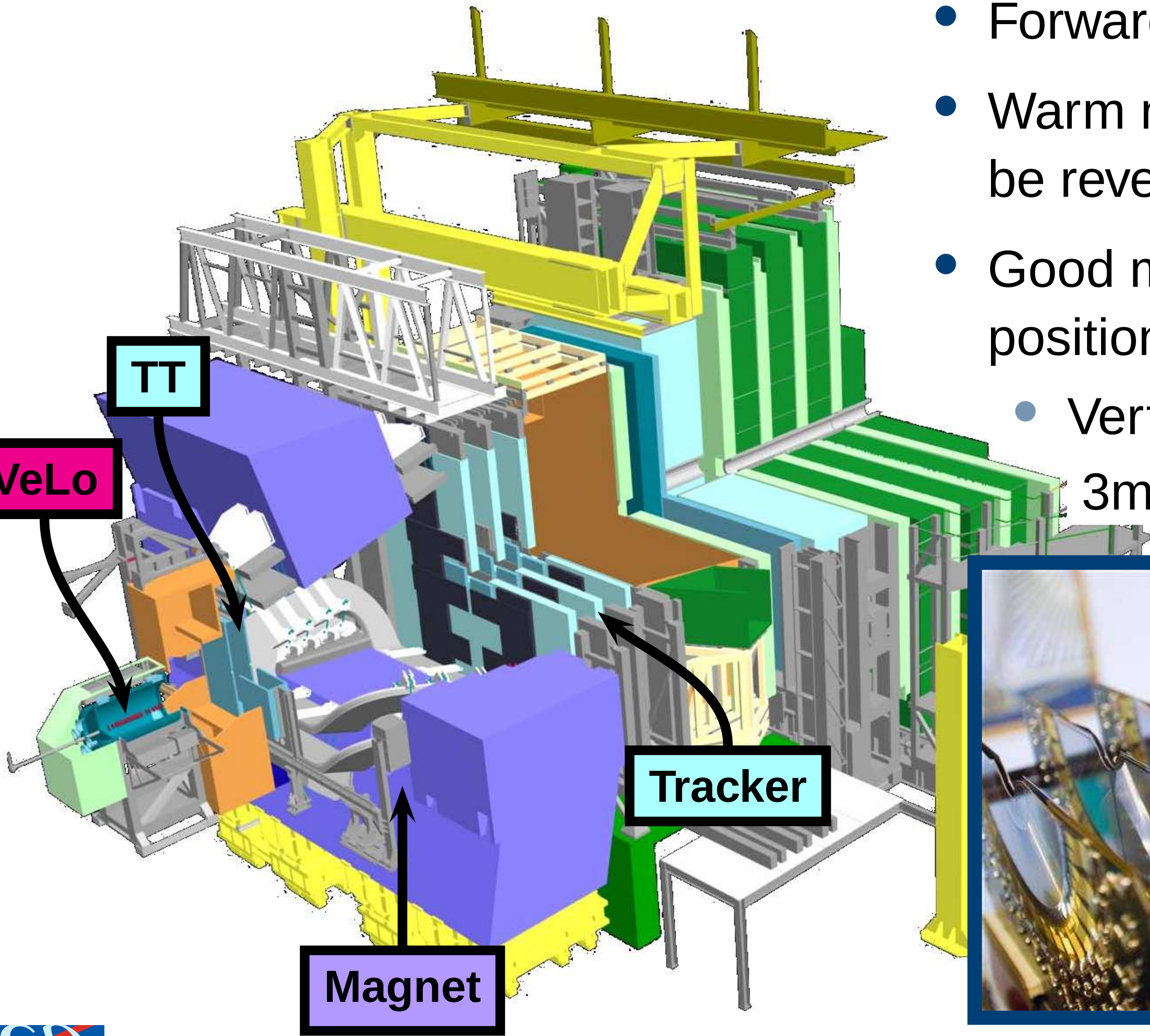
LHCb

- Forward detector





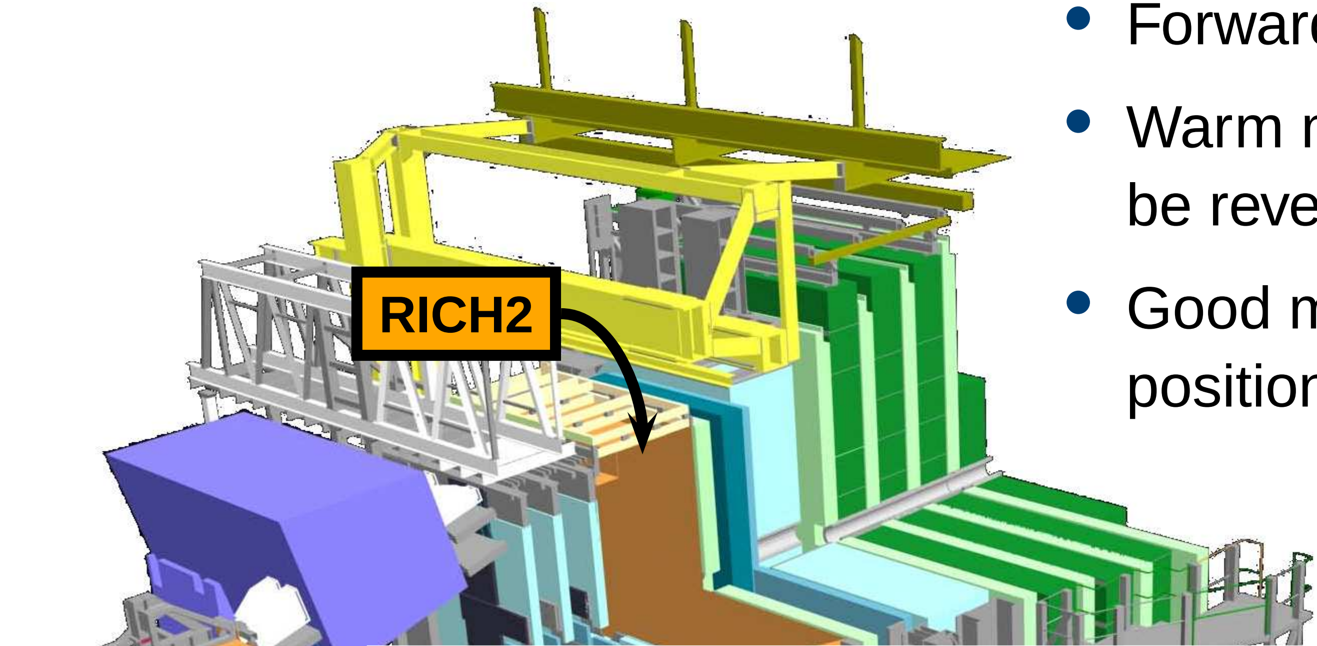
LHCb

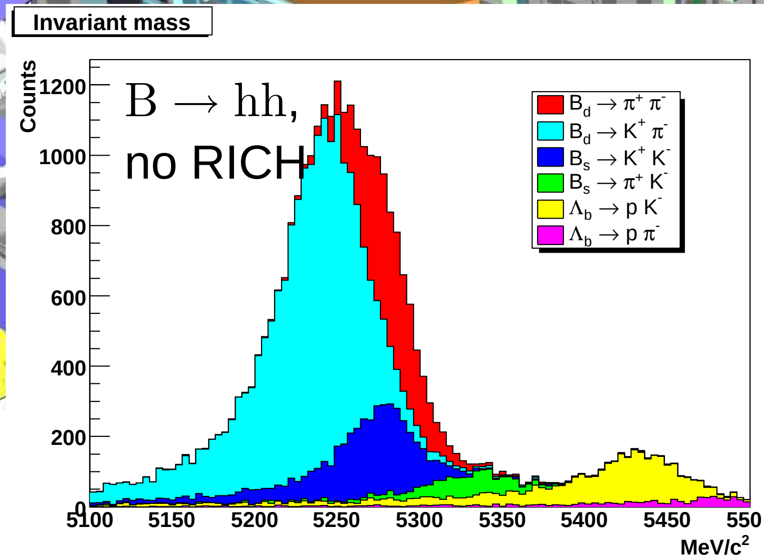


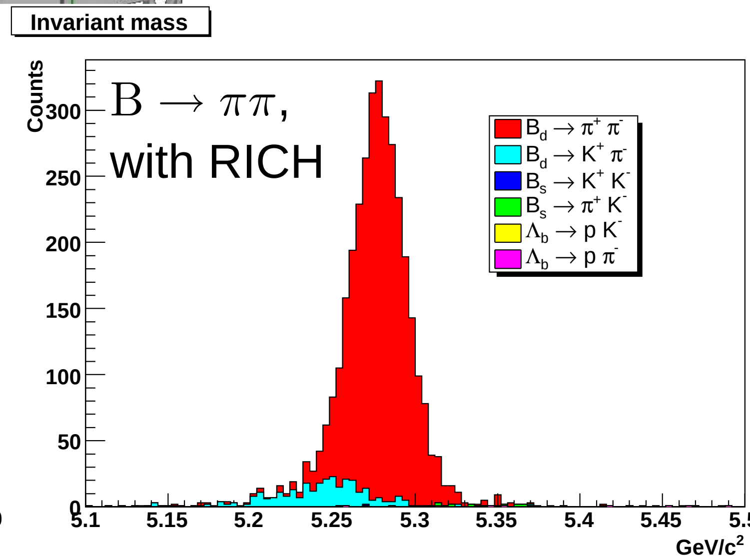
- Forward detector
- Warm magnet. Polarity can be reversed
- Good momentum and position resolution
  - Vertex detector gets 3mm to the beam

LHCb

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

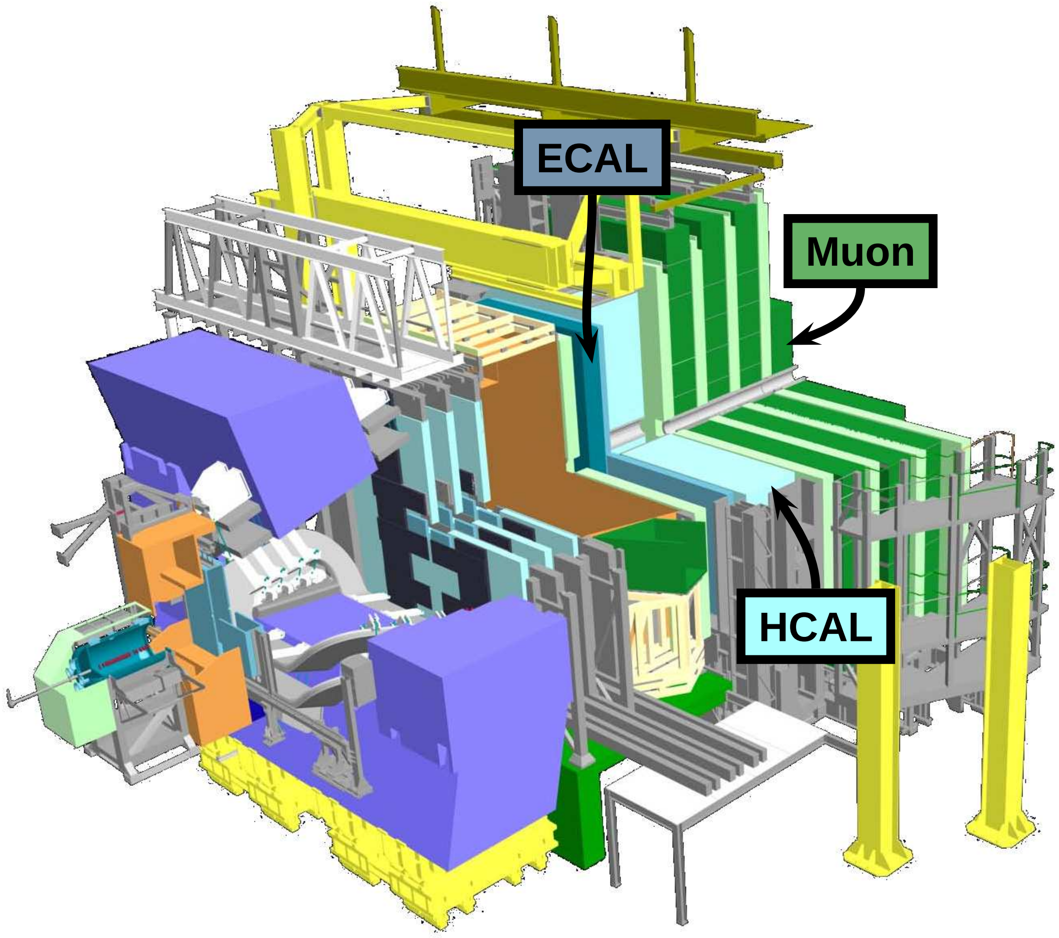






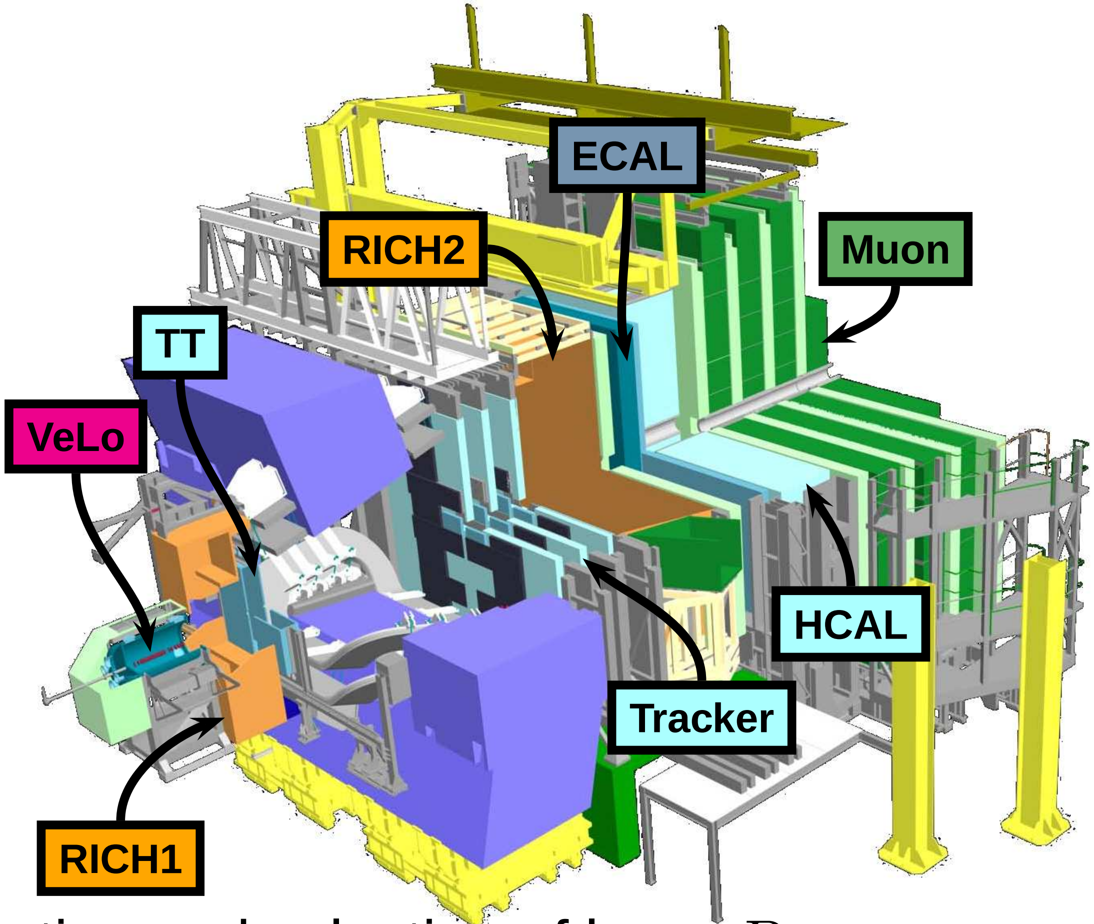
LHCb Trigger

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



LHCb Trigger

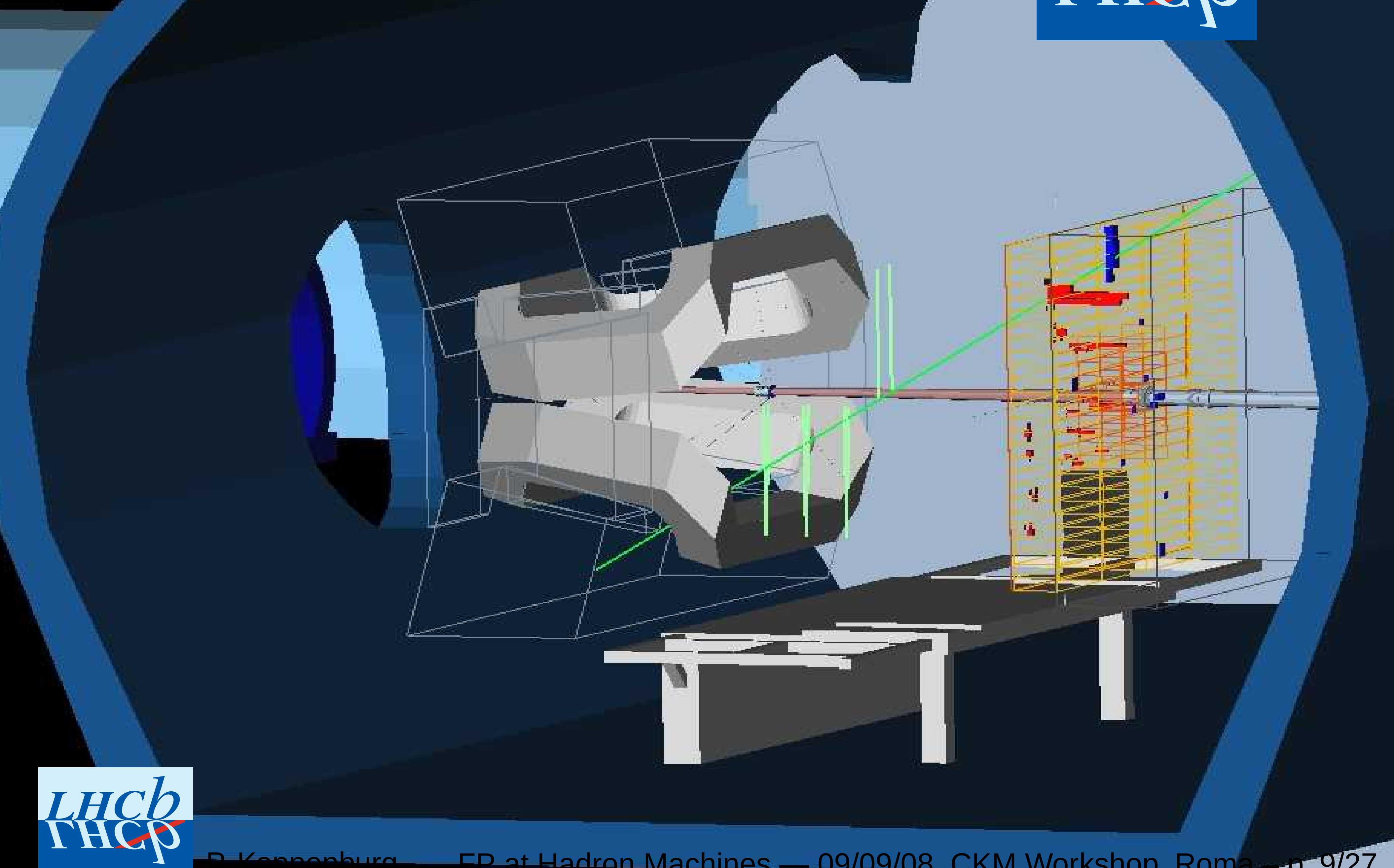
- Hardware-based L0 trigger: moderate p_T cuts 40 MHz ➜ 1 MHz
- The whole data is then sent at 1 MHz to a farm of $\mathcal{O}(2000)$ CPUs
- HLT1 tries to confirm a L0 decision by matching the L0 candidates to tracks. ➜ $\sim$ 30 kHz



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

LHCb Cavern

Real Events

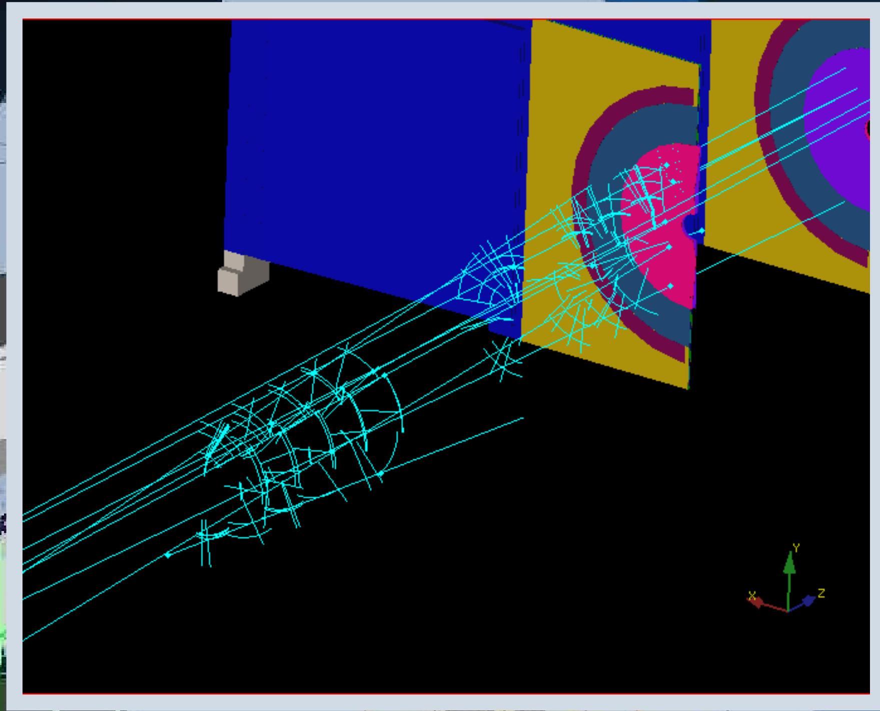


Real Events

Commissioning

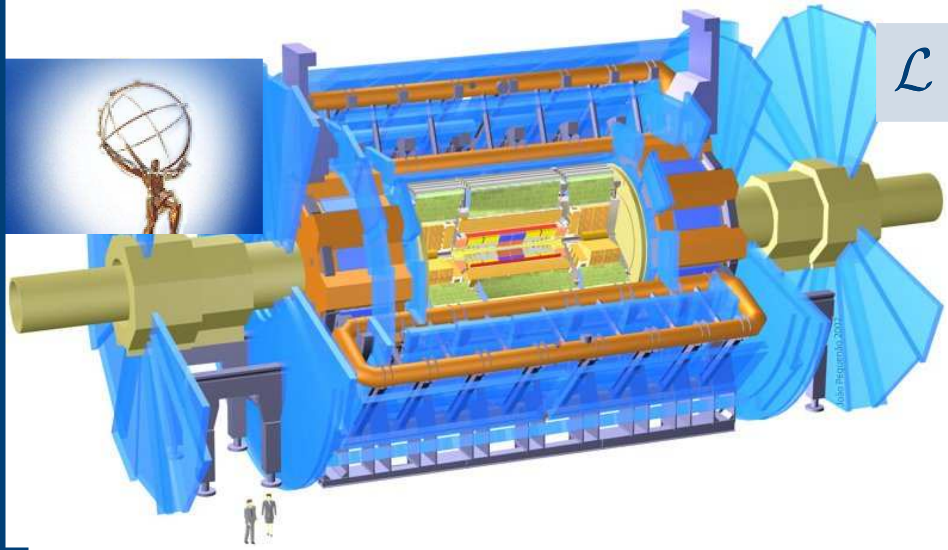
- All pieces are there
- We start to read out the whole detector
- We see some cosmic events
- And secondaries

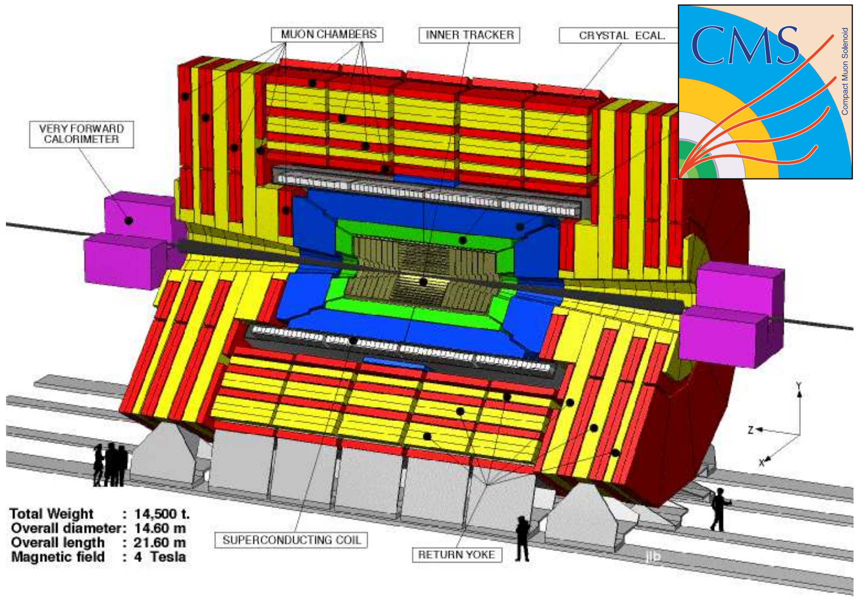
➜ Waiting for collisions!

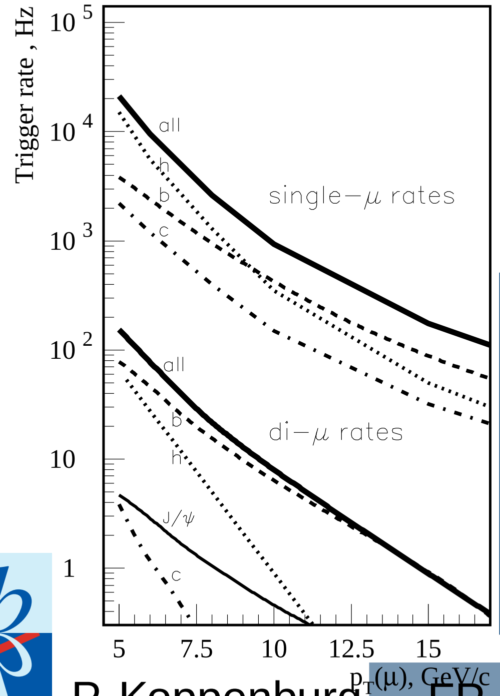


Atlas and CMS

$\mathcal{L} = 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1} \rightarrow 5 \cdot 10^{12}\ \mathrm{b}\bar{\mathrm{b}}/$year



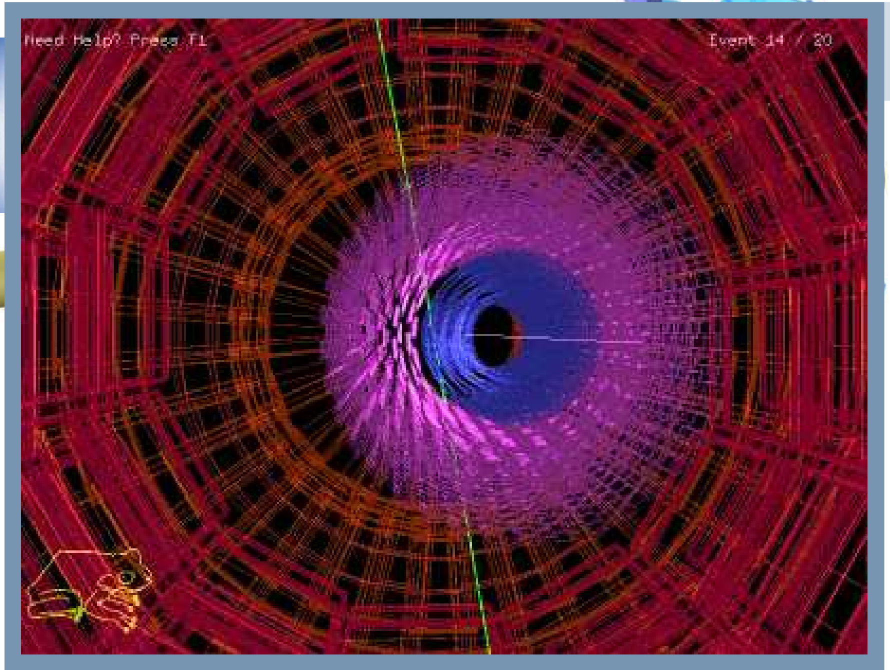


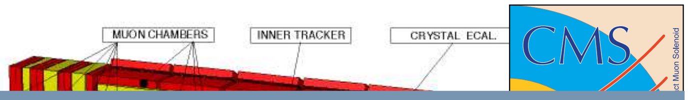


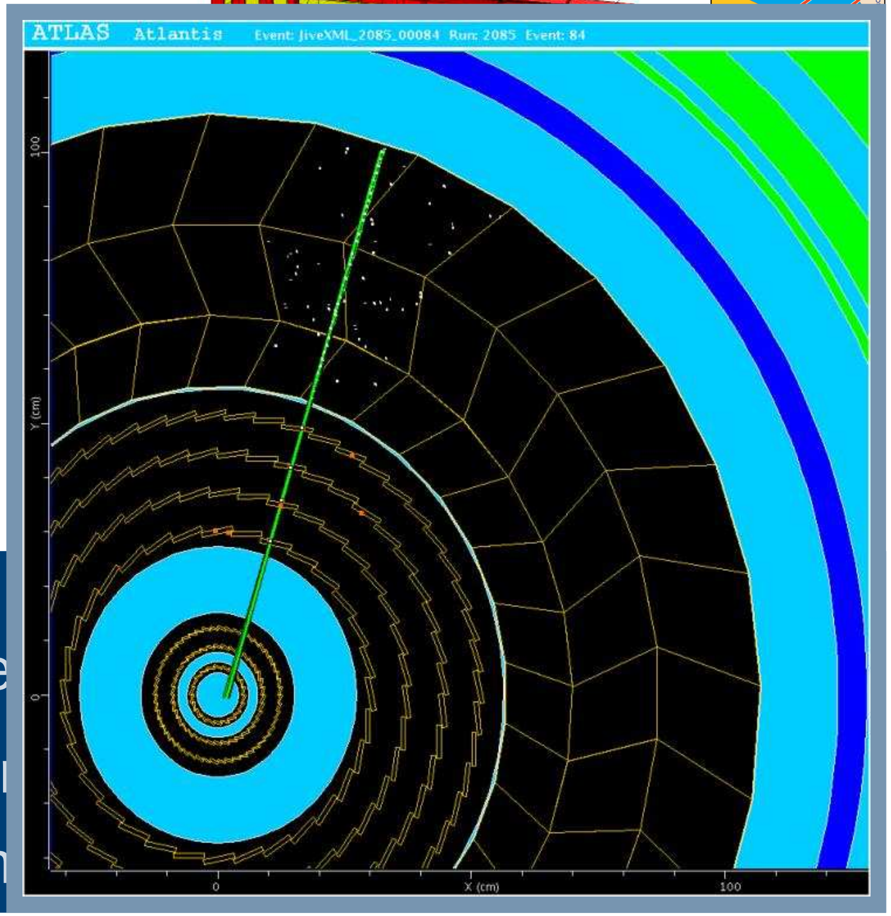
- General purpose detectors with a b physics programme (at the beginning)
- High trigger efficiency on muon channels
  - But with high p_T cut

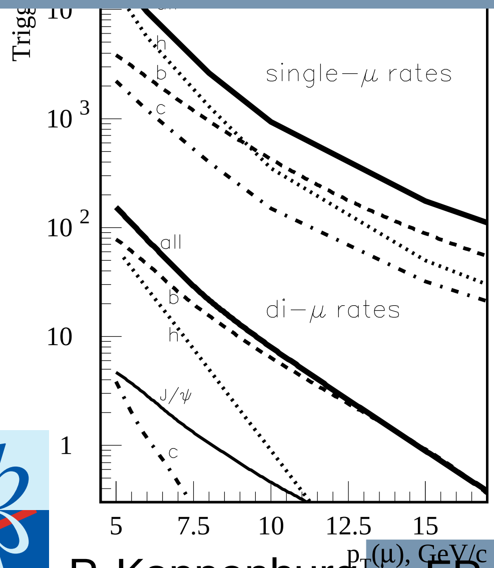
Atlas and CMS

$= 10^{33}\ \mathrm{cm^{-2}s^{-1}} \rightarrow 5\cdot 10^{12}\ b\bar{b}$/year





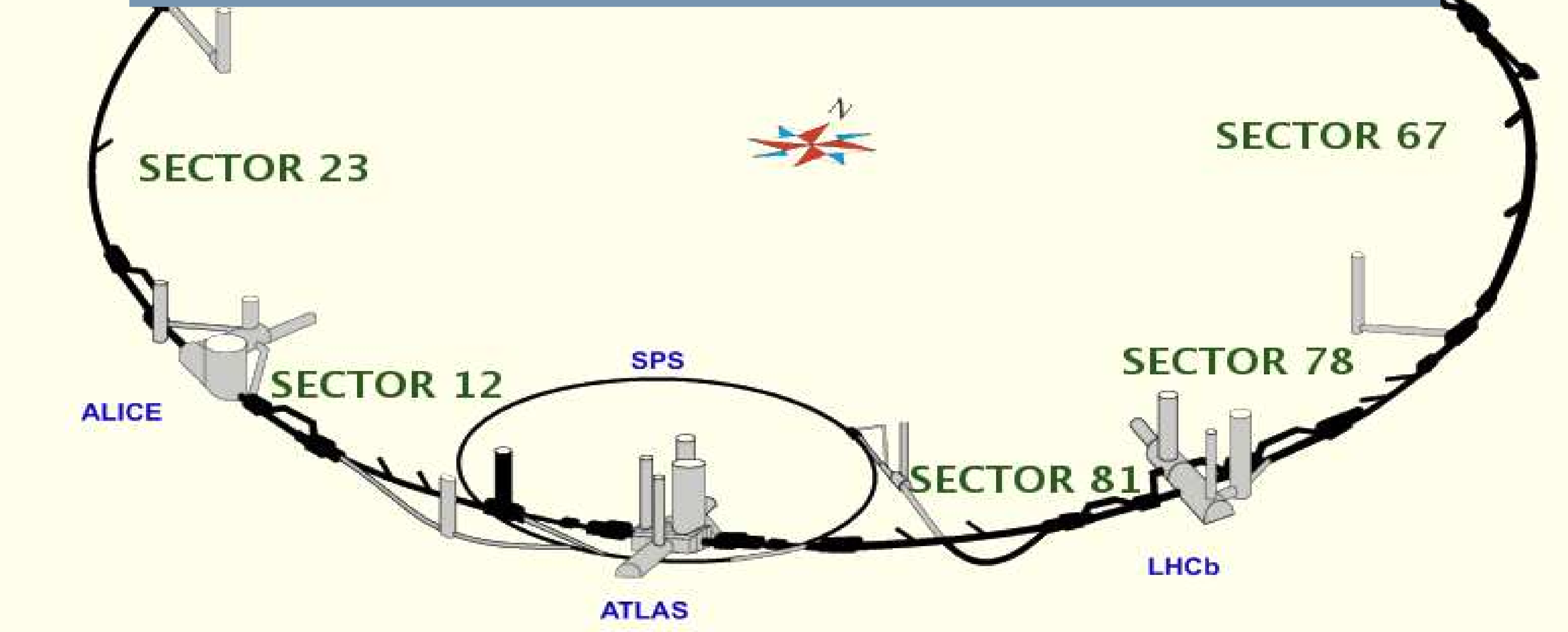




- General pu
  programme
- High trigger
  - But with

Status and Plans of LHC

08–10 Aug	Synchronisation tests, Sectors 12, 23
22–24 Aug	Synchronisation tests, Sectors 81, 78, 12
10 Sep	First circulating beam



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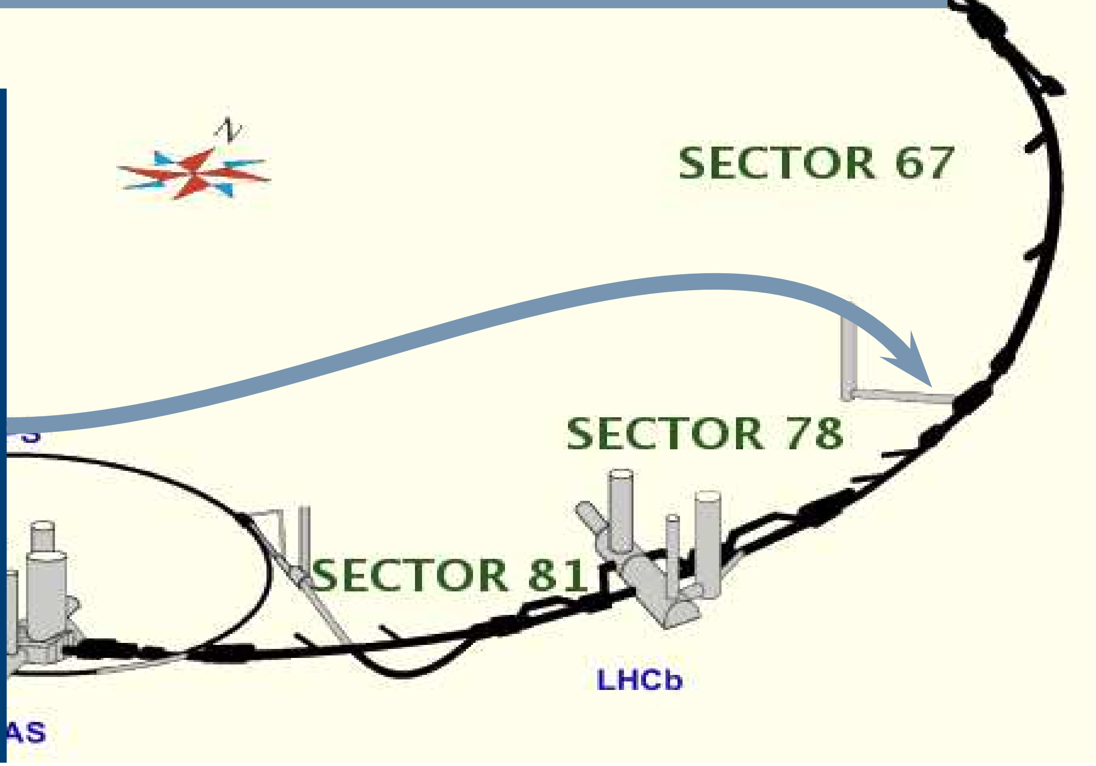
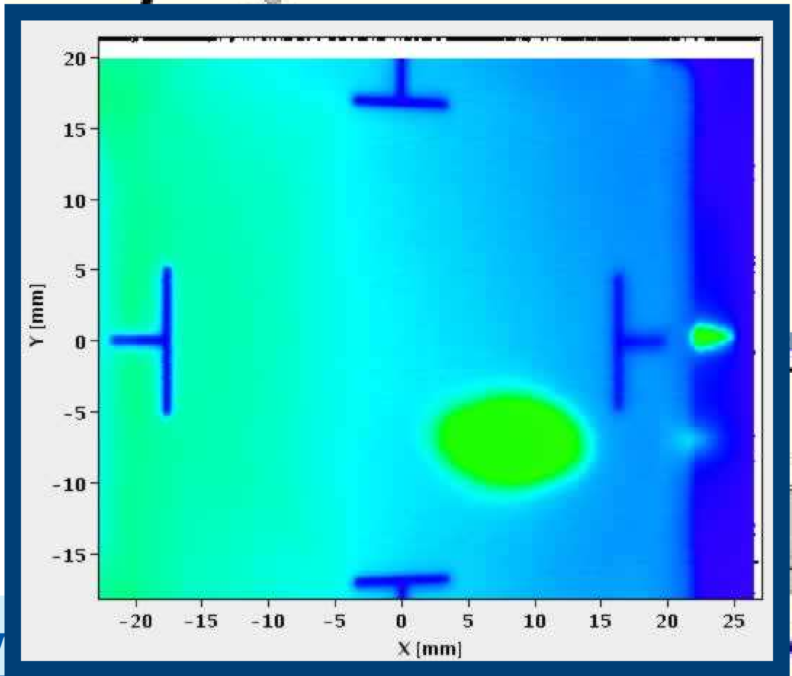


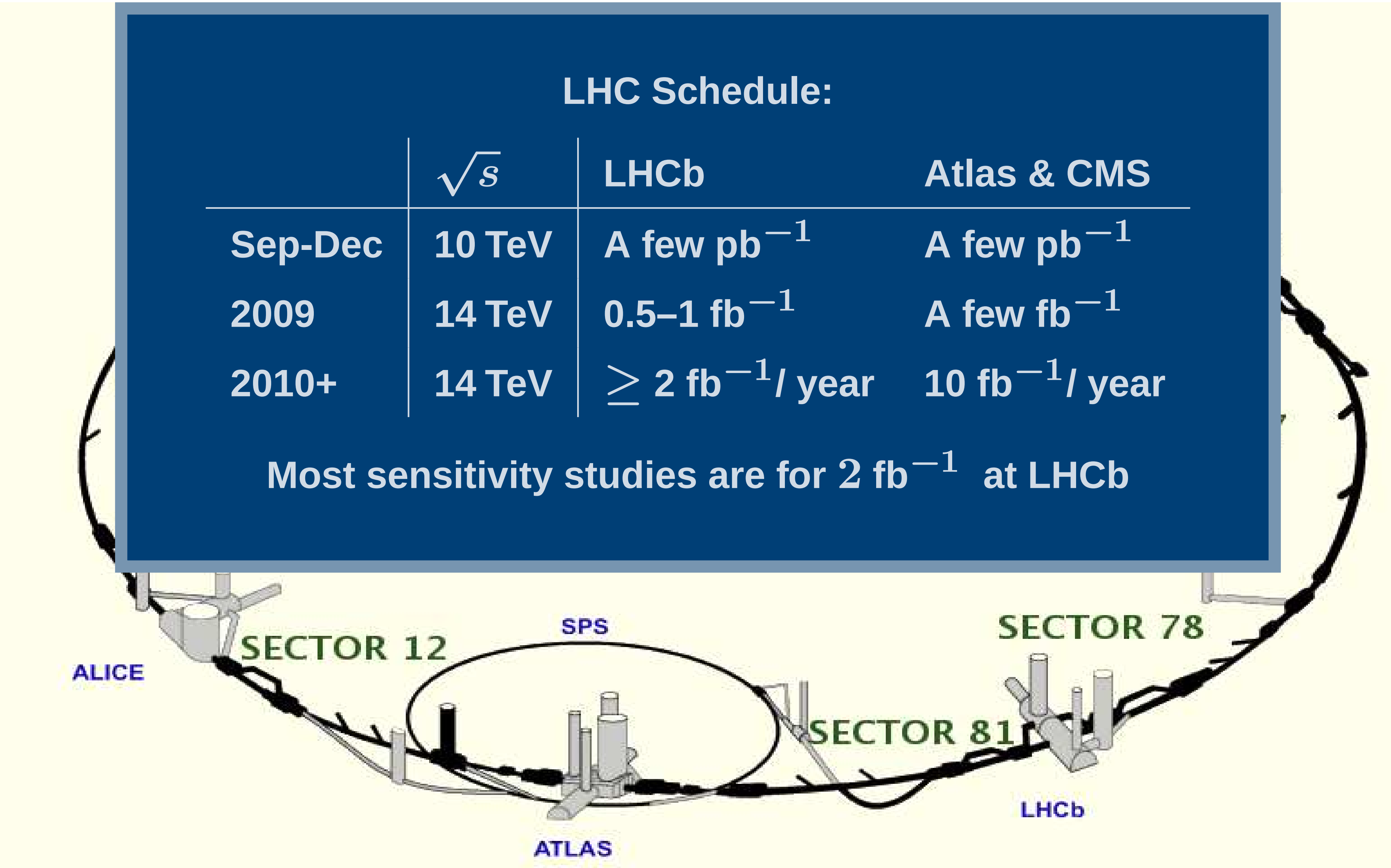


Status and Plans of LHC

LHC Schedule:

	$\sqrt{s}$	LHCb	Atlas & CMS
Sep-Dec	10 TeV	A few pb^{-1}	A few pb^{-1}
2009	14 TeV	0.5–1 fb^{-1}	A few fb^{-1}
2010+	14 TeV	$\geq$ 2 fb^{-1}/ year	10 fb^{-1}/ year

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

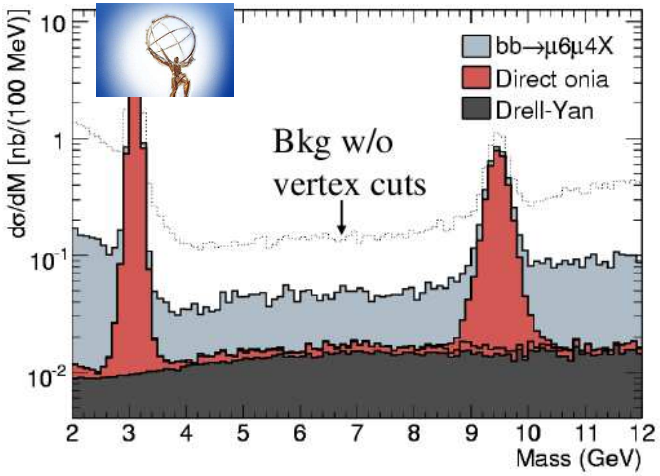


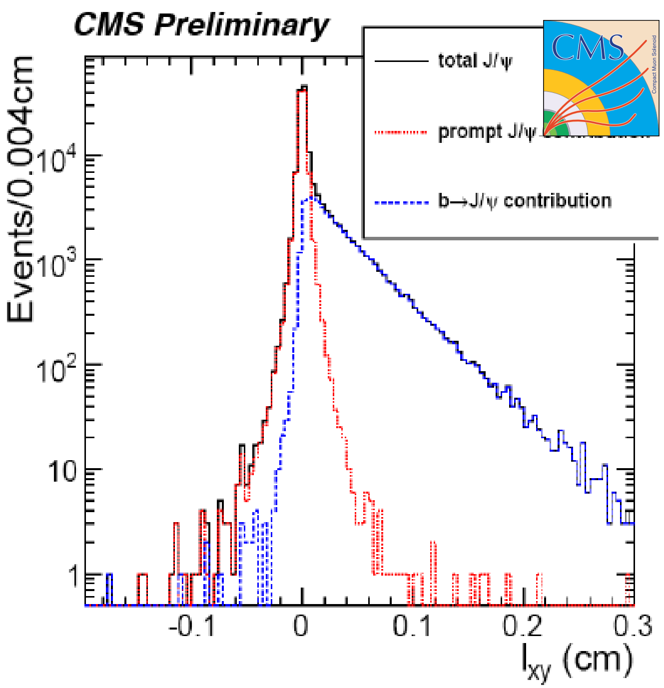
2008 data

- In 2008 expect a few pb^{-1} at 10 TeV
- Data will mostly be used to calibrate detector, exercise trigger . . .
  - ➜ Do not expect too much
- But still some first measurements can be made with little data
  - Multiplicities
  - Cross sections (K^0_S, Λ, J/ψ, B)

➜ 10 and 14 TeV is new territory

➜ These measurements will allow to understand our detectors





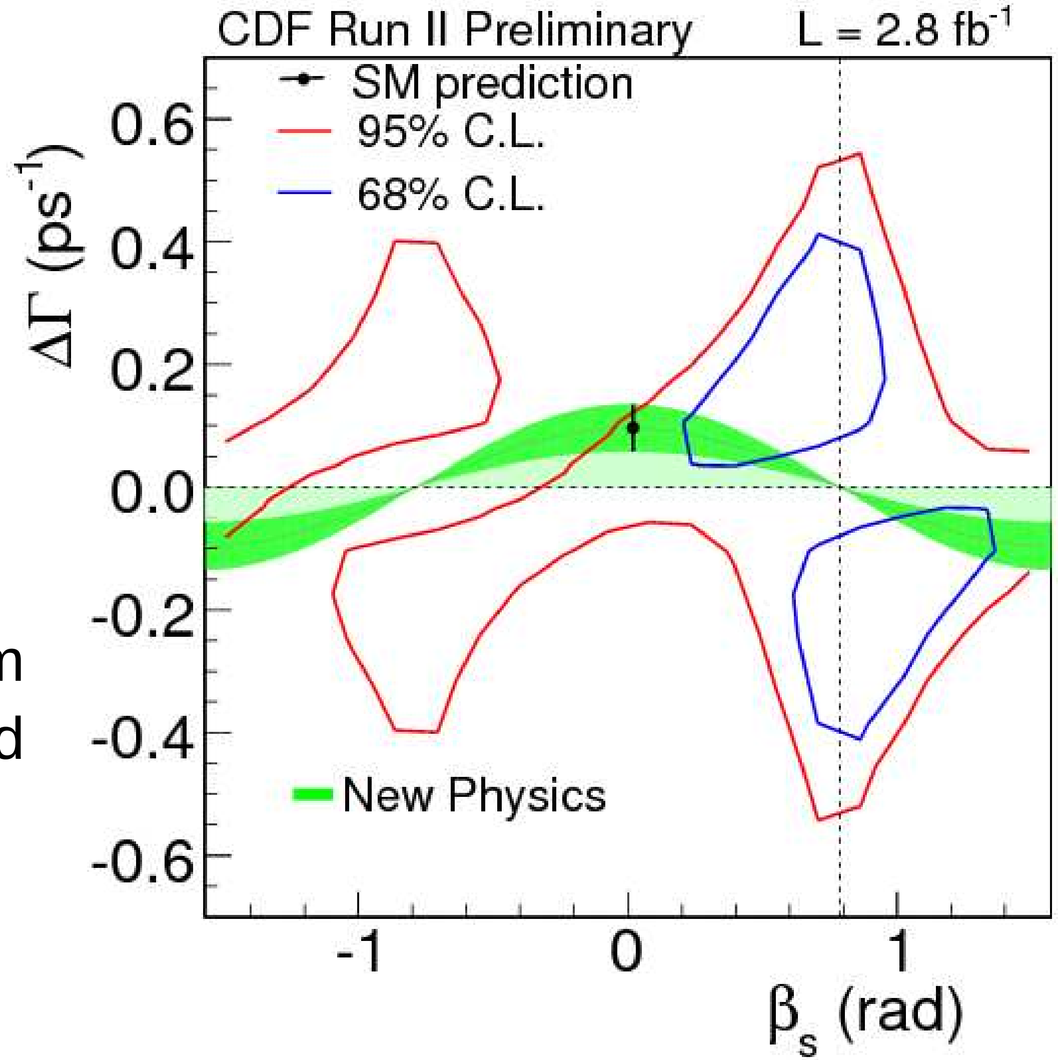
Some sensitivities

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

$\mathrm{B_s} \to \mathrm{J}/\psi\phi$ at LHCb

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

- $\mathrm{B_s}$ counterpart to β in $\mathrm{B_d} \to \mathrm{J}/\psi \mathrm{K}^0$
- Tiny in the SM: $\beta_\mathrm{s} \sim 0.04$
- But $P \to VV$
  - ➜ need angular analysis to disentangle CP-even and CP-odd
- Very interesting results from CDF and D0. The standard model is at 7% C.L.



$\mathrm{B_s} \to \mathrm{J}/\psi\phi$ at LHCb

Gaia Lanfranchi
Search for New Physics
in $\mathrm{B_s} \to \mathrm{J}/\psi\phi$ at LHC
11-Sep 09:30

$\phi^{\mathrm{SM}} = -2\beta_s$: Time-dependent CP asymmetry

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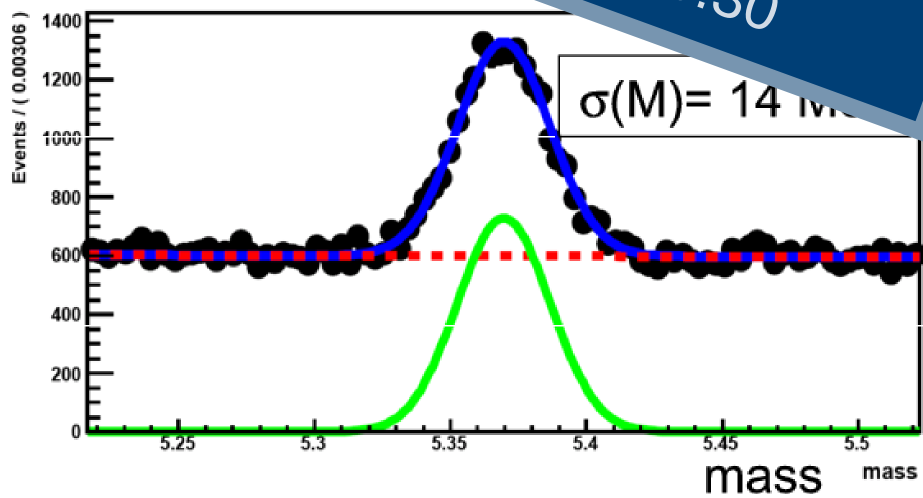
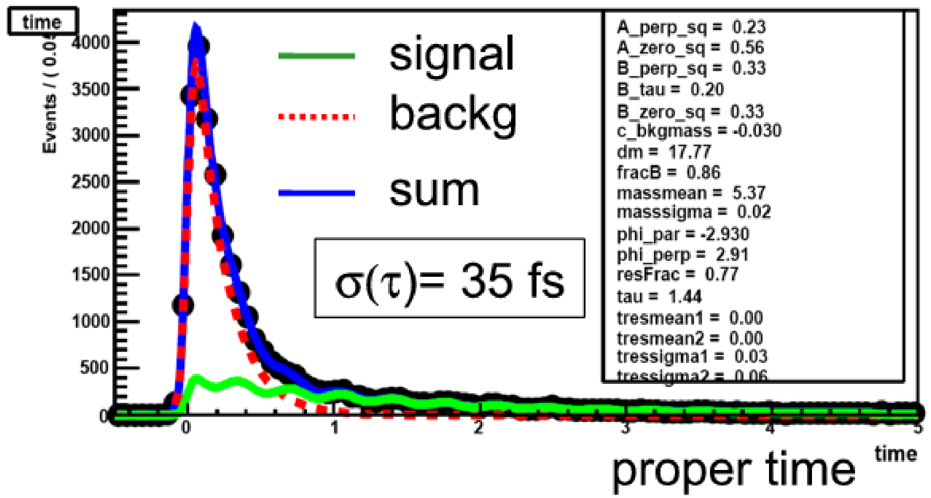
- Tiny in the SM: $\beta_s \sim 0.04$
- But $P \to VV$
  - ➜ need angular analysis to disentangle CP-even and CP-odd
- Time-dependent fit with resolution 40 fs
- Expect 100k events / 2 fb^{-1}
  - ➜ 0.03 precision on β_s





$B_s \to J/\psi\phi$ in 2009

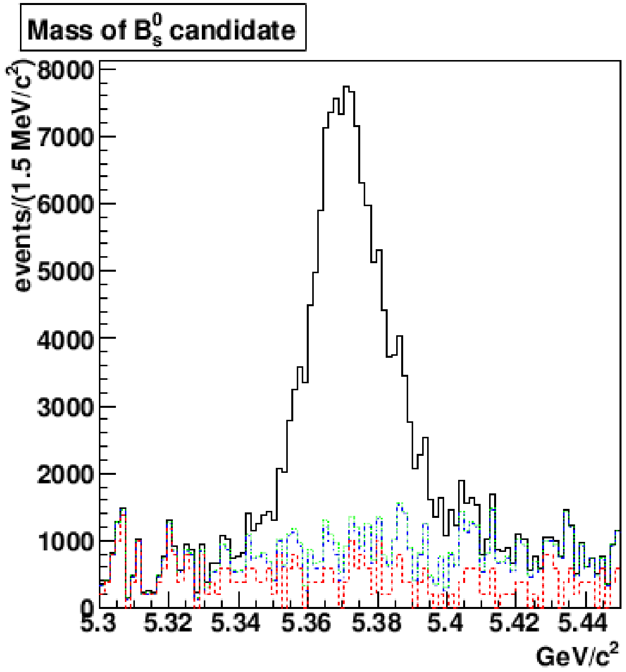
Scaling to 2009 expected luminosities

	Atlas	CMS	LHCb
$\int \mathcal{L}dt$ (fb^{-1})	2.5	2.5	0.5
Events	$23\,000$	$27\,000$	$25\,000$
B/S	0.30	0.33	2^*
M resol. (MeV)	17^{**}	14^{**}	17
τ resolution (fs)	83	77	40
Tagging ϵD^2 (%)	4.6	N/A	5.8
β_s resolution	**0.16**	N/A	**0.06**

* 90% is prompt background

** with J/ψ mass constraint

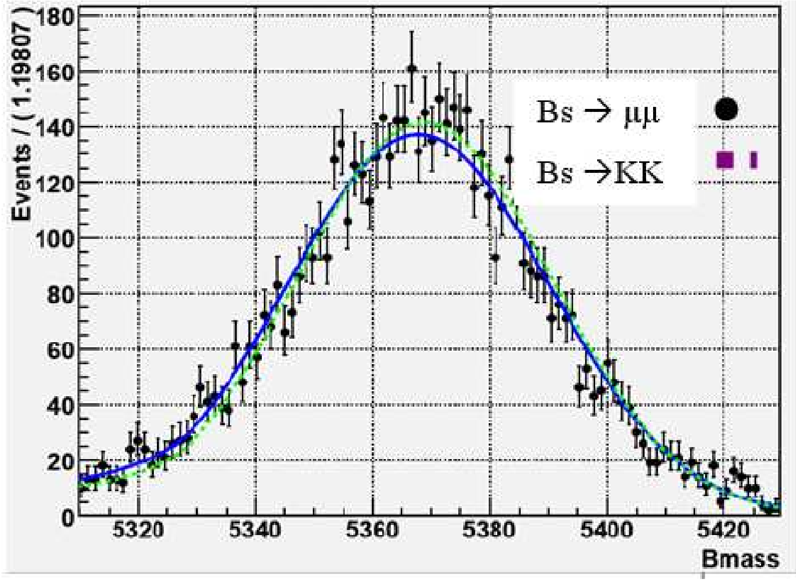
B_s mass at CMS:

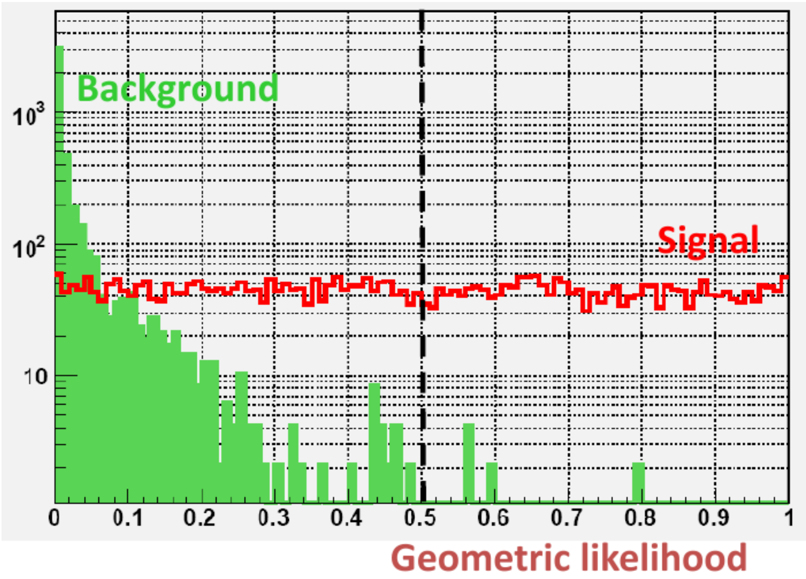


SM expectation is 0.04 ± 0.01

$\mathrm{B_s} \to \mu\mu$

- Very rare but SM BF well predicted $\mathcal{B} = (3.55 \pm 0.33) \cdot 10^{-9}$
- Sensitive to (pseudo)scalar operators
  - MSSM: $\mathcal{B} \propto \frac{\tan^6 \beta}{M_A^4}$
- Present limit from CDF $\mathcal{B} < 4.7 \cdot 10^{-8}$ (90% 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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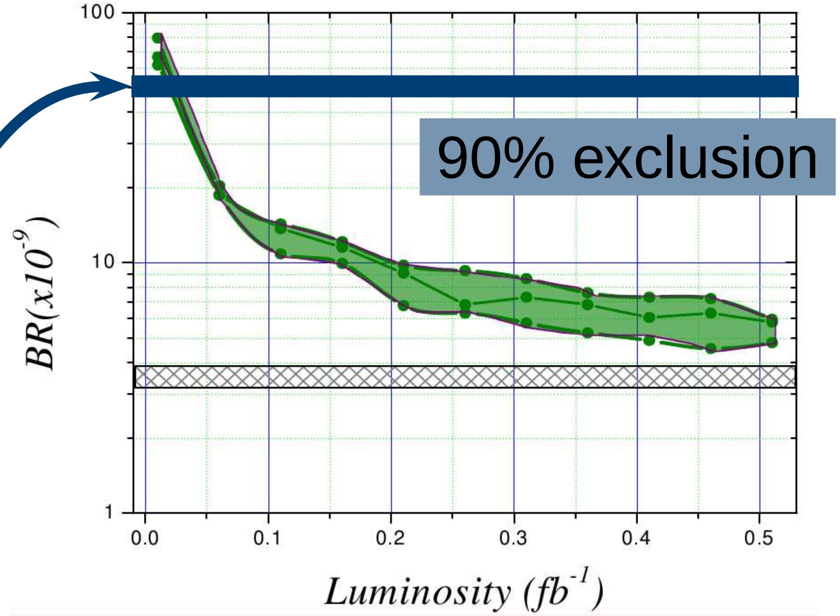
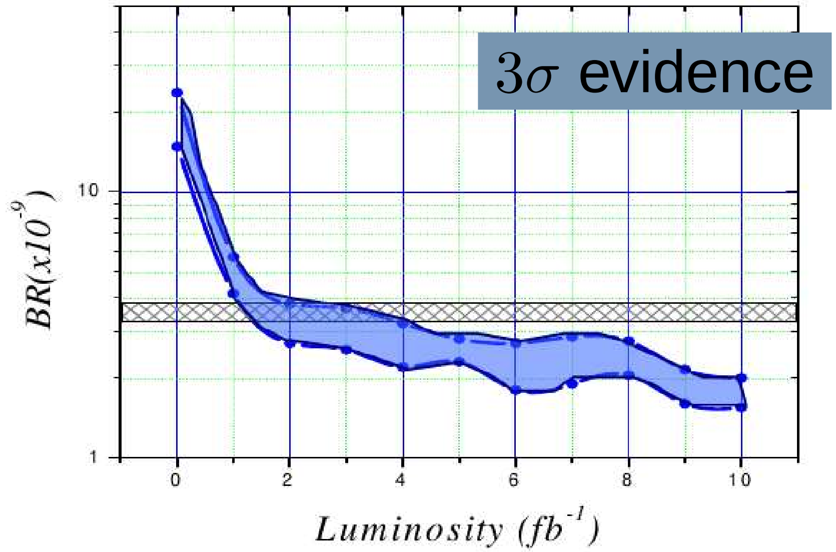
- With SM BF, expect 8 signal and 12 background events in most sensitive bin in 2 fb^{-1}

➜ 3σ evidence with 2 fb^{-1}

➜ 5σ observation with 6 fb^{-1}





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- … calar

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Serguey Sivoklokov
$B_s \to \mu\mu$ at LHC
12-Sep 15:10

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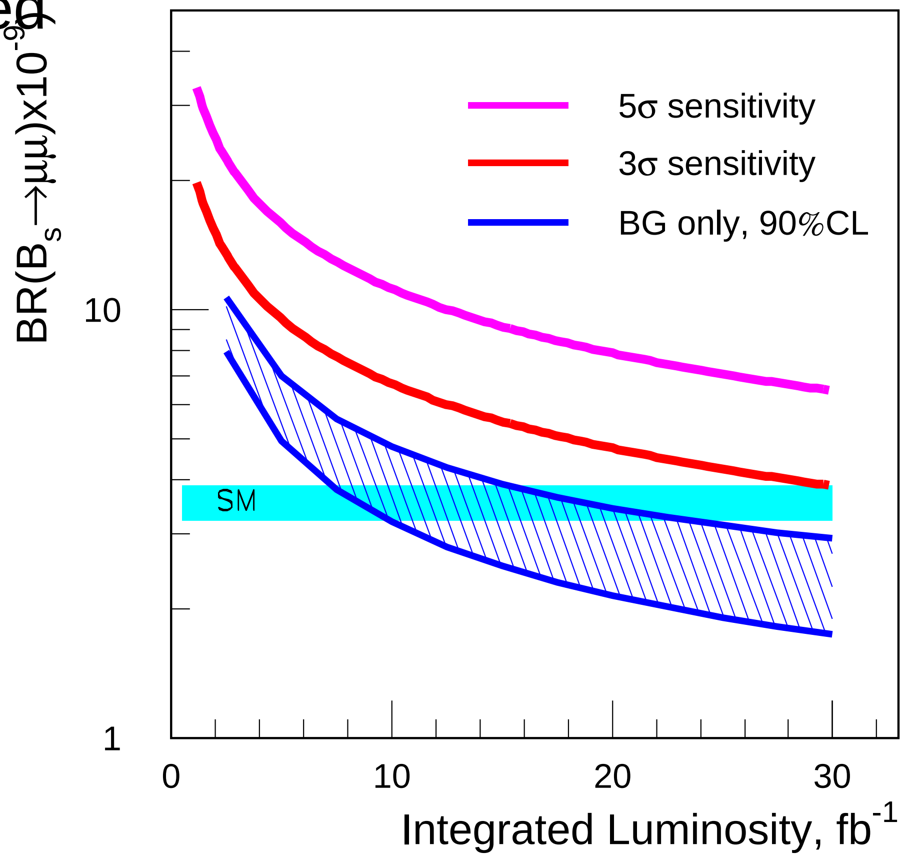
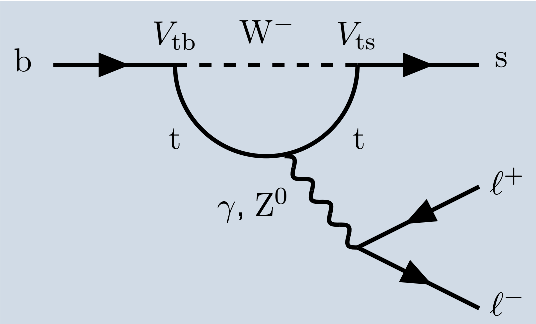
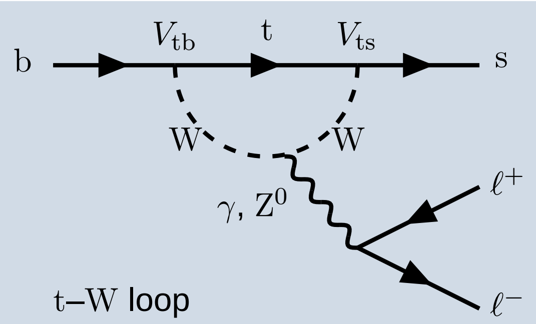


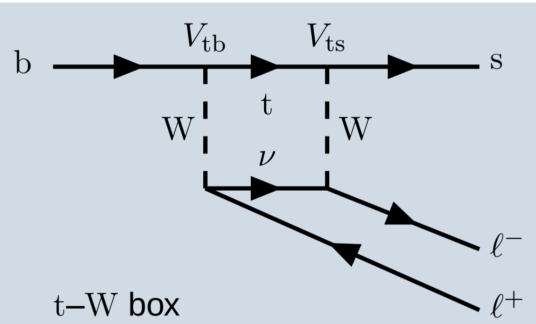
Atlas and CMS also contribute:

➜ 3σ evidence with 30 fb^{-1}

Penguins rule!





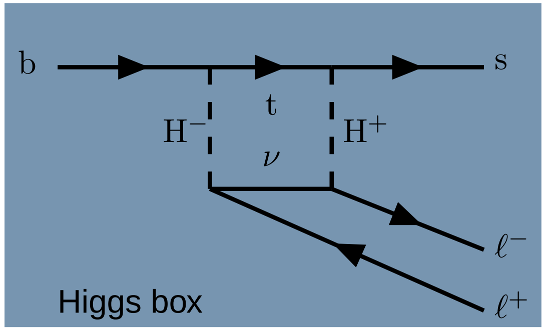


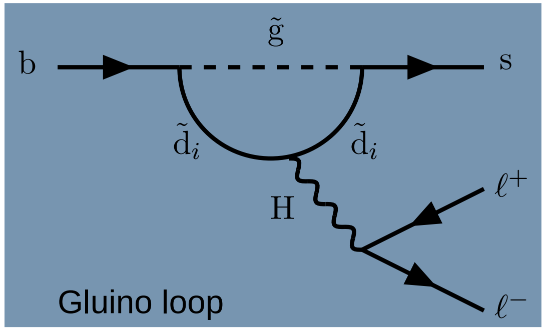
- $B \to \mu\mu K^*$ very rare in the SM
  $\mathcal{B}\left(B \to \ell\ell K^*\right) = (1.2 \pm 1.0) \cdot 10^{-6}$
  $\mathcal{B}\left(B \to \ell\ell K\right) = (0.5 \pm 0.1) \cdot 10^{-6}$

Military penguin becomes a 'Sir'

[Watch movie]

Penguins rule!





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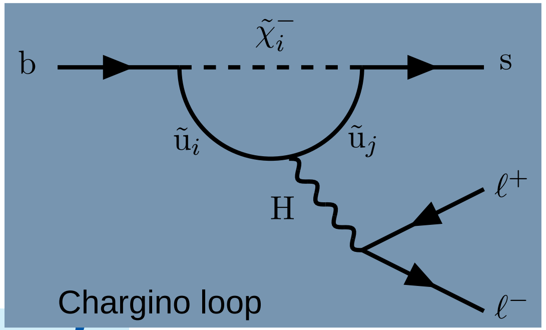
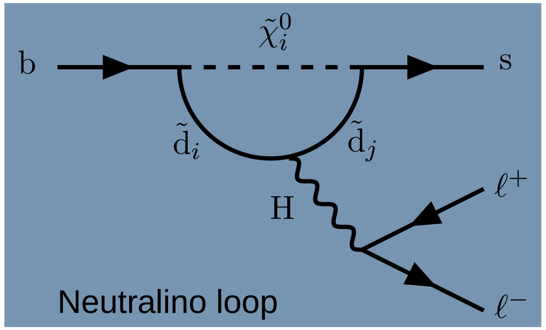
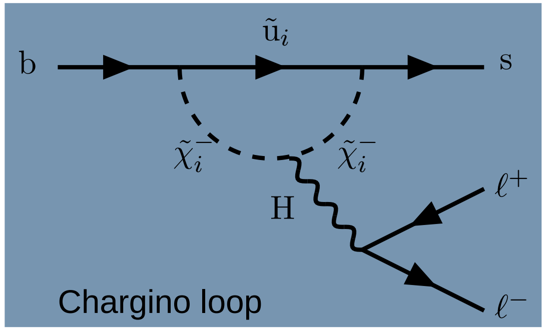
  $\mathcal{B}(B \to \ell\ell K) = (0.5 \pm 0.1) \cdot 10^{-6}$
- Sensitive to
  - Supersymmetry,
  - Graviton exchanges,
  - Extra dimensions

➜ Ideal place to look for new physics







Messages from the B factories

Belle: 170+230 $\mathrm{B}\to\ell\ell\mathrm{K}^{(*)}$ events in $657 \cdot 10^6$ $\mathrm{B\overline{B}}$

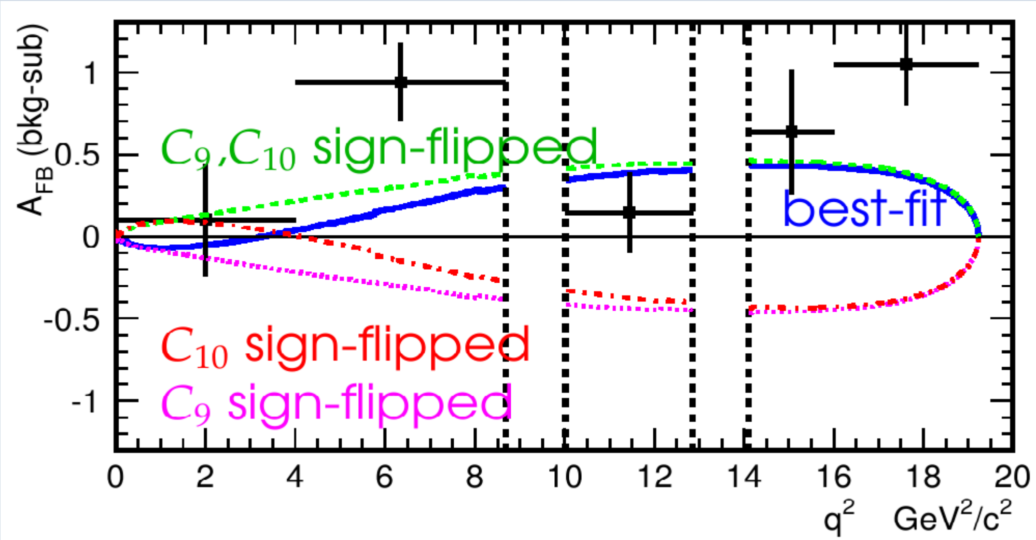
[Jui-Te Wei, ICHEP 2008]

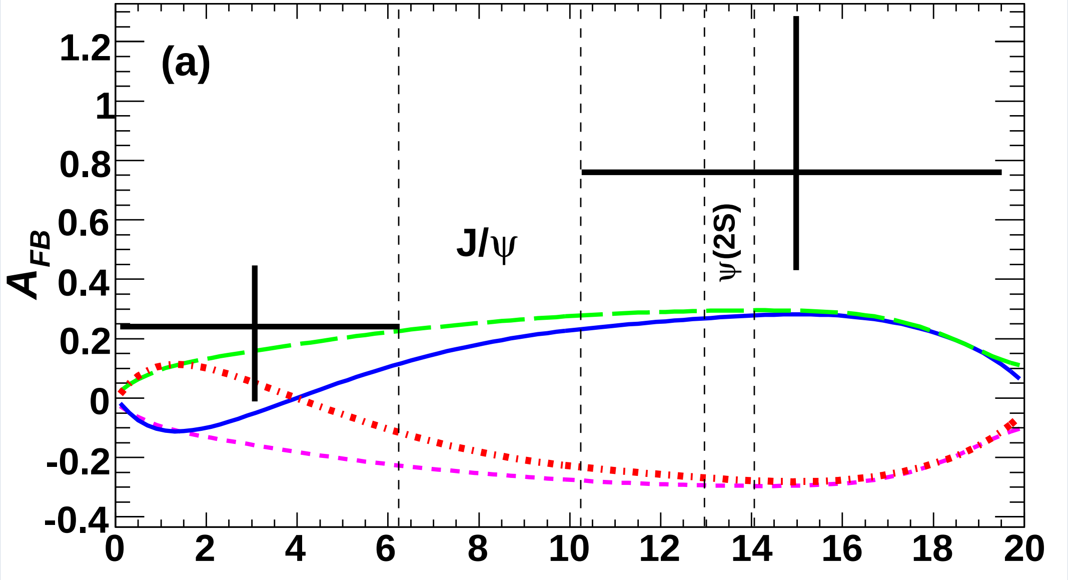
Babar: 50+60 $\mathrm{B}\to\ell\ell\mathrm{K}^{(*)}$ events in $384 \cdot 10^6$ $\mathrm{B\overline{B}}$

[Aubert et al., hep-ex/0804.4412]

[Aubert et al., hep-ex/0807.4119]

FB asymmetry: Not conclusive yet. . .





Messages from the B factories

Belle: 170+230 $B \to \ell\ell K^{(*)}$ events in $657 \cdot 10^6$ $B\overline{B}$

[Jui-Te Wei, ICHEP 2008]

Babar: 50+60 $B \to \ell\ell K^{(*)}$ events in $384 \cdot 10^6$ $B\overline{B}$

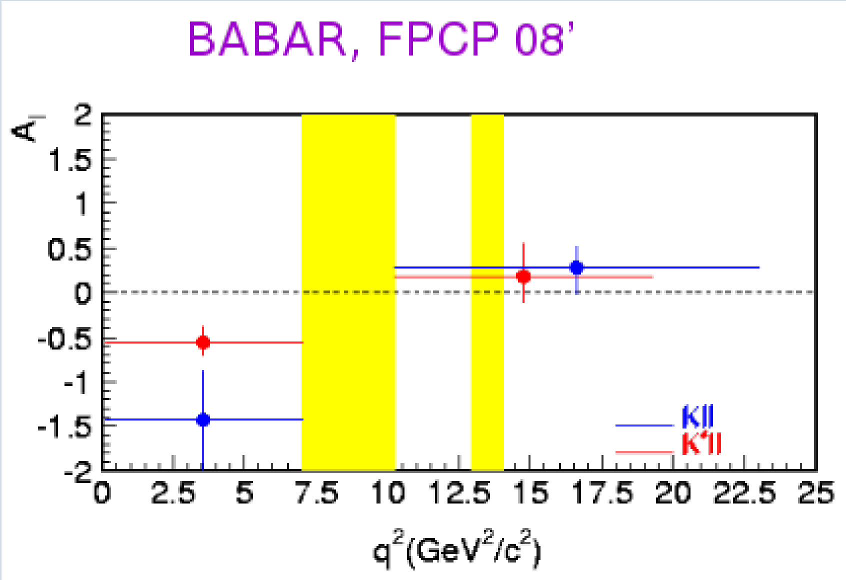
[Aubert et al., hep-ex/0804.4412]

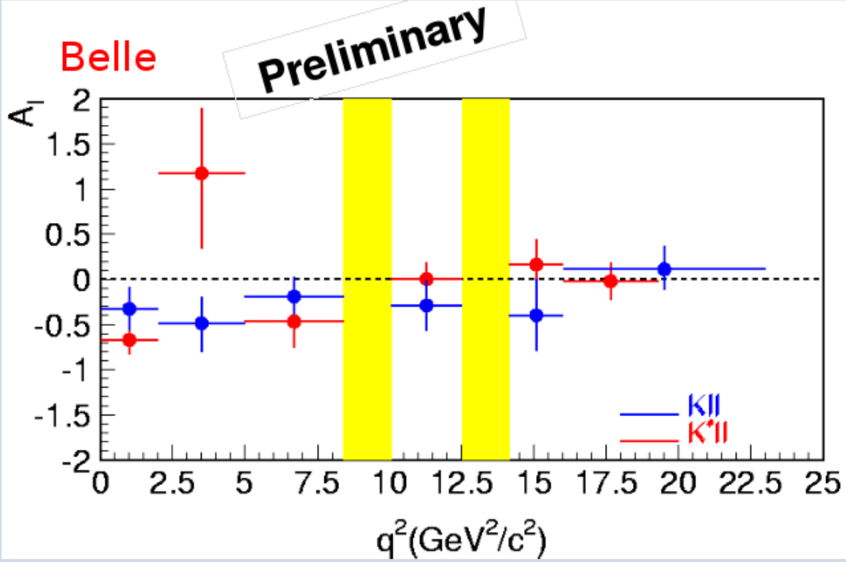
[Aubert et al., hep-ex/0807.4119]

FB asymmetry: Not conclusive yet. . .

Isospin: Belle and Babar disagree.

➜ Need much more statistics

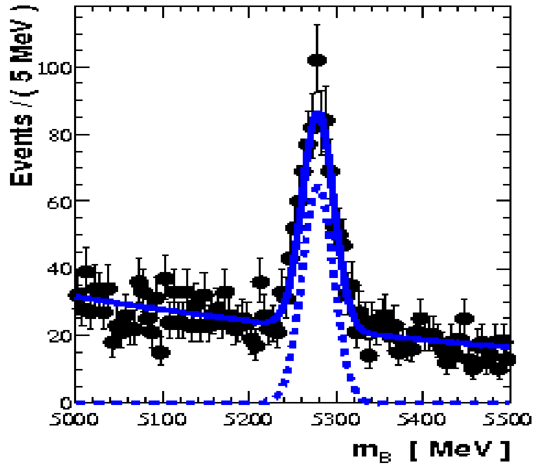


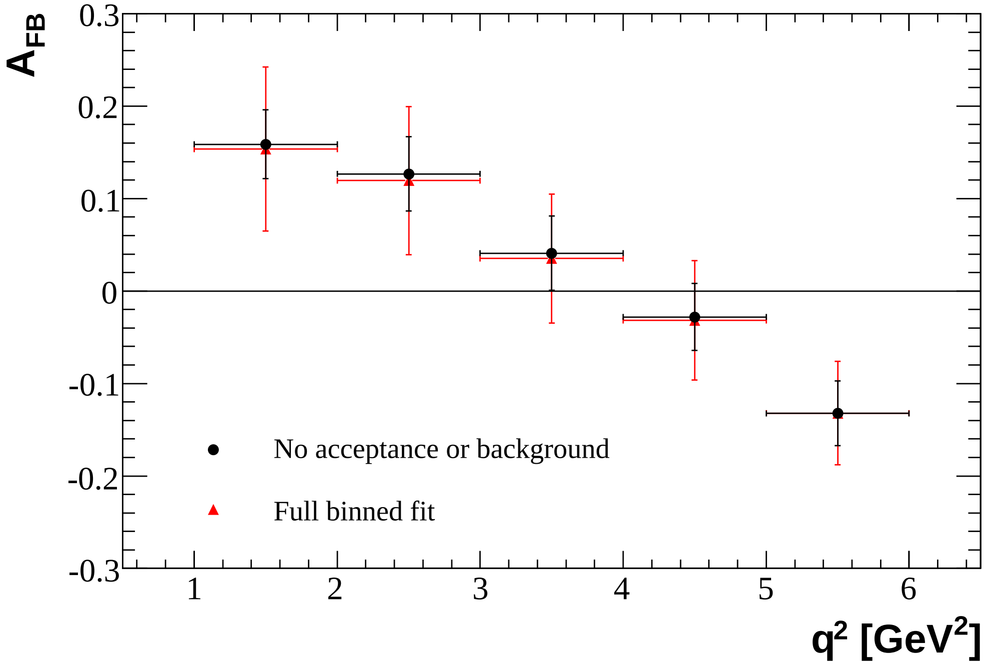


$B_d \to \mu\mu K^*$ yields with $2\ \mathrm{fb}^{-1}$

Expected signal and background yields in $2\ \mathrm{fb}^{-1}$ 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
$\boldsymbol{B/S}$	$\mathbf{0.5 \pm 0.2}$





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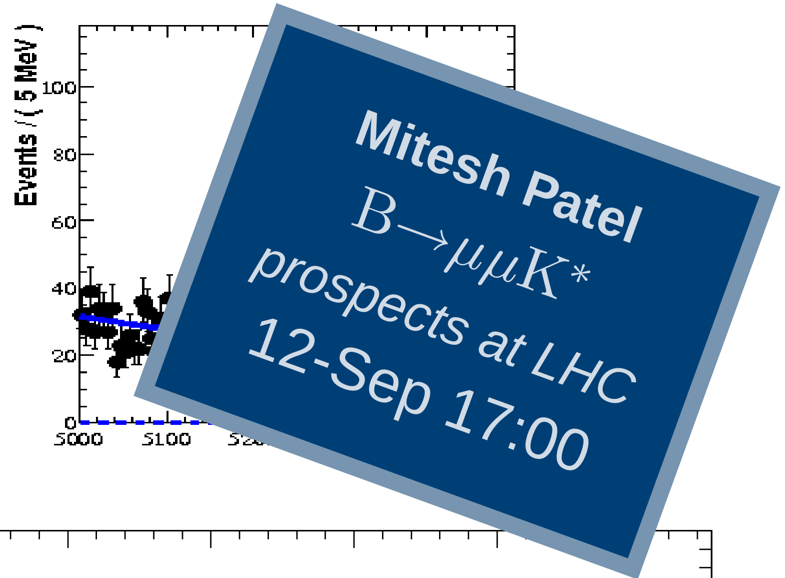
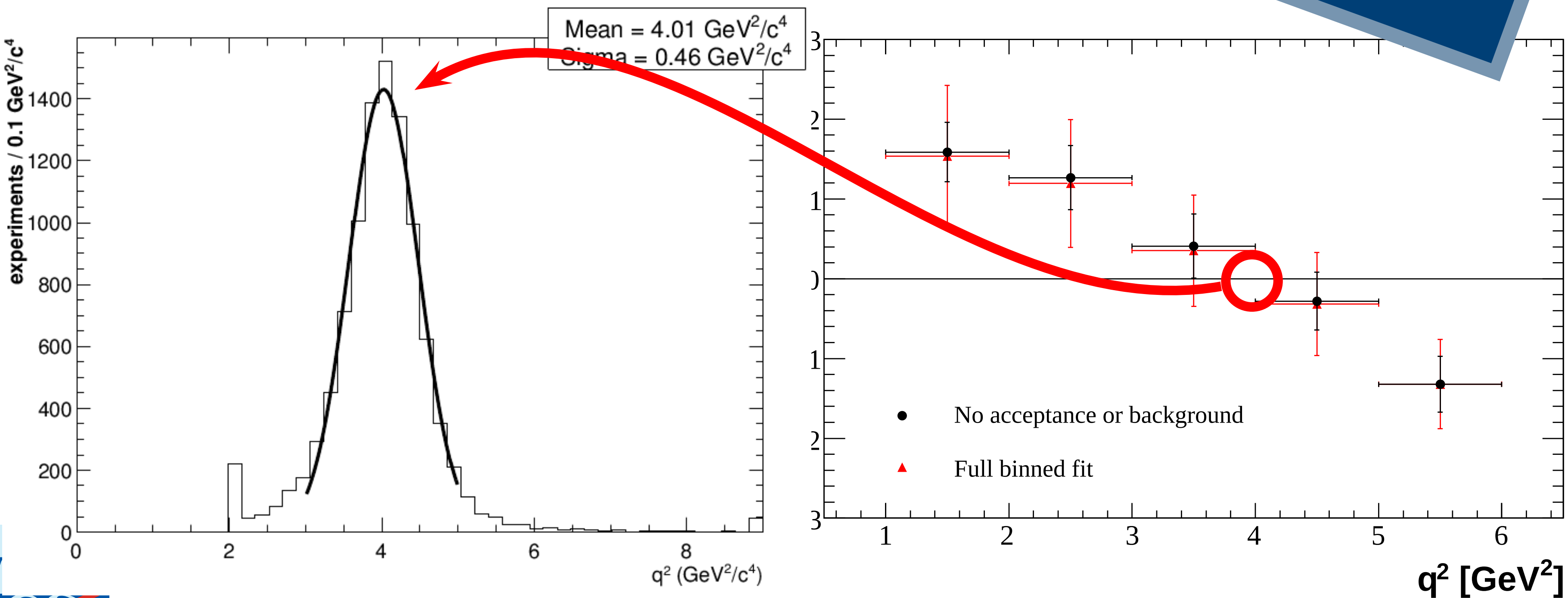
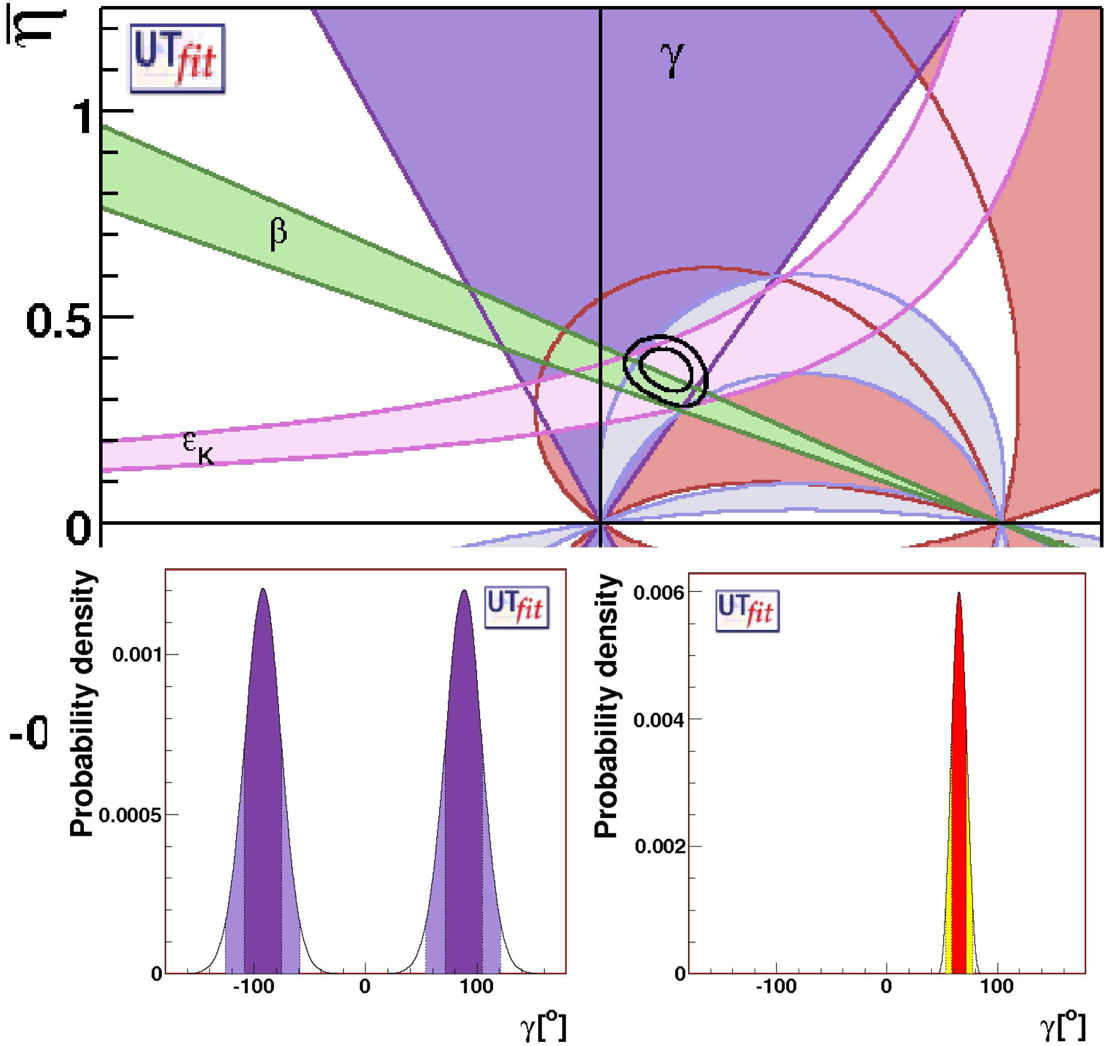


→ Resolution on A_{FB} zero : $\pm 0.46\,\mathrm{GeV}^2$ (12%) in $2\ \mathrm{fb}^{-1}$



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



Direct and indirect determinations 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}

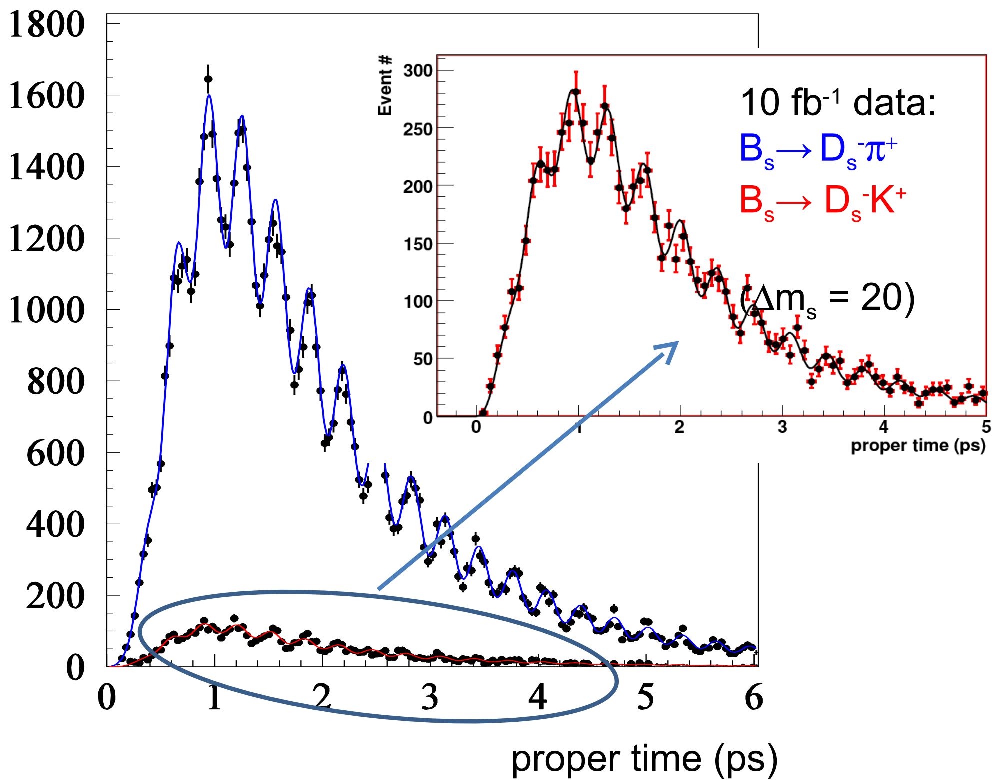
$B \to DK$: Combined $\sim 5°$

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 $\gamma + \beta_s$

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



$B_s \to D_s K$: 9°–12°

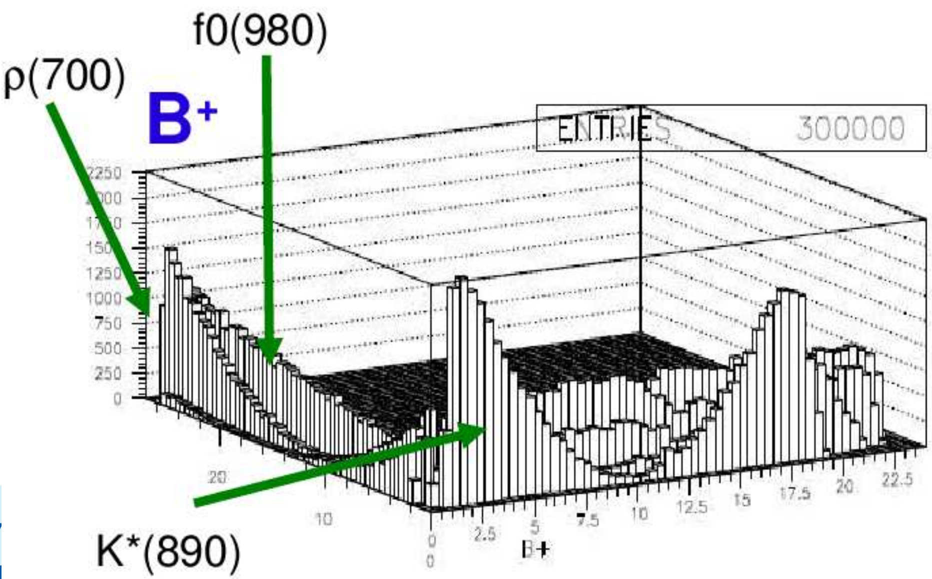
$B \to DK$: Combined $\sim 5^\circ$

γ in Loops

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

$\mathbf{B} \longrightarrow \mathbf{hh}$: Lifetime-dependent CP in $\mathrm{B_d} \to \pi\pi$ and $\mathrm{B_s} \to \mathrm{KK}$ and direct CP in $\mathrm{B} \to \mathrm{K}\pi$

Dalitz: analysis of $\mathrm{B_d} \to \mathrm{K^0_S}\pi\pi$ and $\mathrm{B_d} \to \mathrm{K}\pi\pi$



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

$\mathbf{B \longrightarrow hh}$ 7–10°

$\mathbf{B \longrightarrow K\pi\pi}$ $\sim 5°$

$\mathbf{B_s \to D_s K}$: 9°–12°

$\mathbf{B \to DK}$: Combined $\sim 5°$

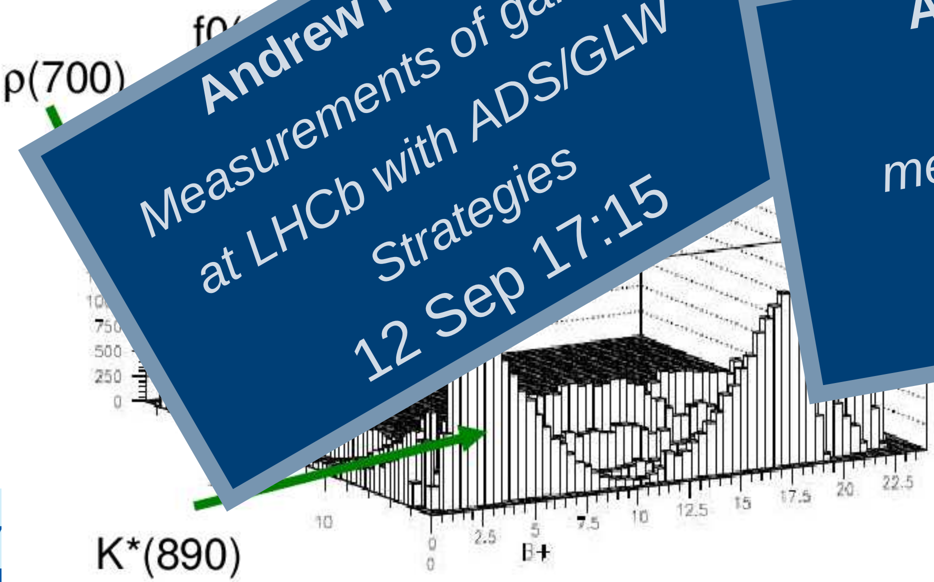
γ in Loops

Inte... of tree and penguin di-
ag...

B ... $\to$ K ... $K\pi$

Dalitz: analysis ... and

$B_d \to K\pi$ ...



Guy Wilkinson
γ at LHCb: Dalitz fits in $B\to DK$ decays
12 Sep 17:30

Eduardo Rodrigues
Prospects for $B\to hh$ at LHCb
10 Sep 16:20

Gabriel Guerrer
γ from $B\to hhh$ at LHCb
09 Sep 18:45

Andrew Powell
Measurements of gamma at LHCb with ADS/GLW Strategies
12 Sep 17:15

Angelo Carbone
Time dependent measurements of γ at LHCb
12 Sep 17:00

...-1	...Sig	B/S
...$\pi\pi$ ... KK ... $K\pi$ ... $B_s\to\pi K$		...5
B ... K...	...0 k	
	...0 k	TBD

...0°

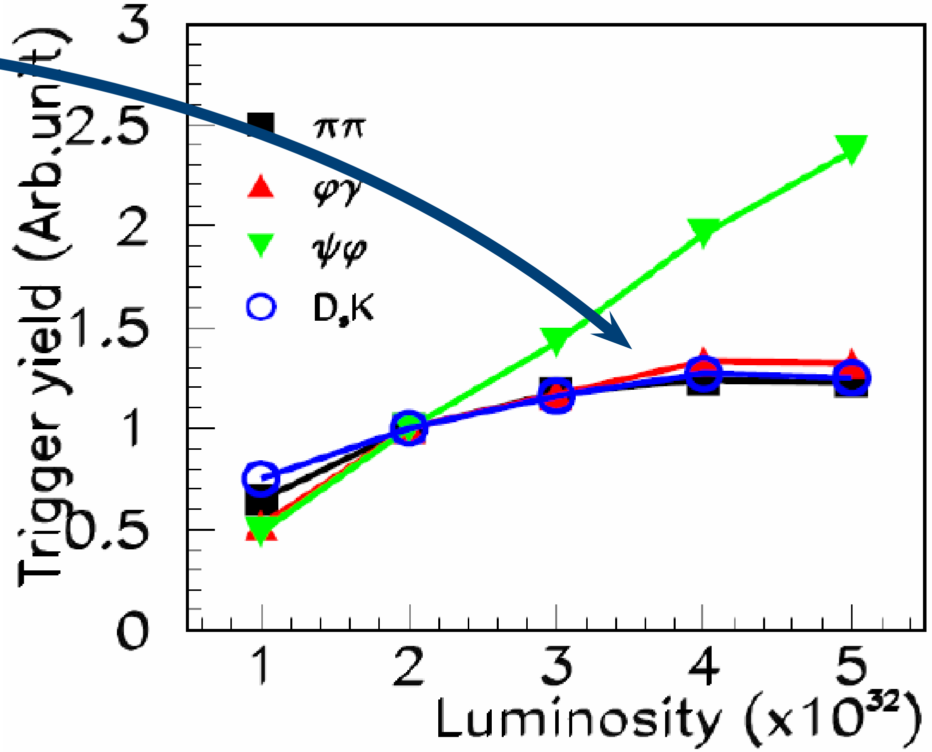
$B\to K\pi\pi$ $\sim 5°$

$B_s\to D_sK$: 9°–12°

$B\to DK$: Combined $\sim 5°$

LHCb Upgrade plans

- Expect that integrated luminosity increases linearly with time. After 10 fb^{-1} , would take $>$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

	$10\ \text{fb}^{-1}$	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 when LHC installs triplets to reach 10^{34}, scheduled in 2013

➜ Fits well with LHC plans

Some Upgraded Physics

	$10\ \text{fb}^{-1}$	With upgrade
β_s	Known to 0.01 rad	Level of CKM fits
$B_s \to \phi\phi$		
γ		
$B_s \to \mu\mu$		$\to \mu\mu$
$B \to \mu\mu K^*$		ular fit
D		

This programme is complementary to B factories programme.

We will not compete for

- **Inclusive measurements**
- **Neutrals**
- **Lepton flavour measurements**
- **. . .**

- No detai
- R&D has
- Aim to upgrade when LHC installs triplets to reach 10^{34}, scheduled in 2013

➜ Fits well with LHC plans

Rare Kaon Decays

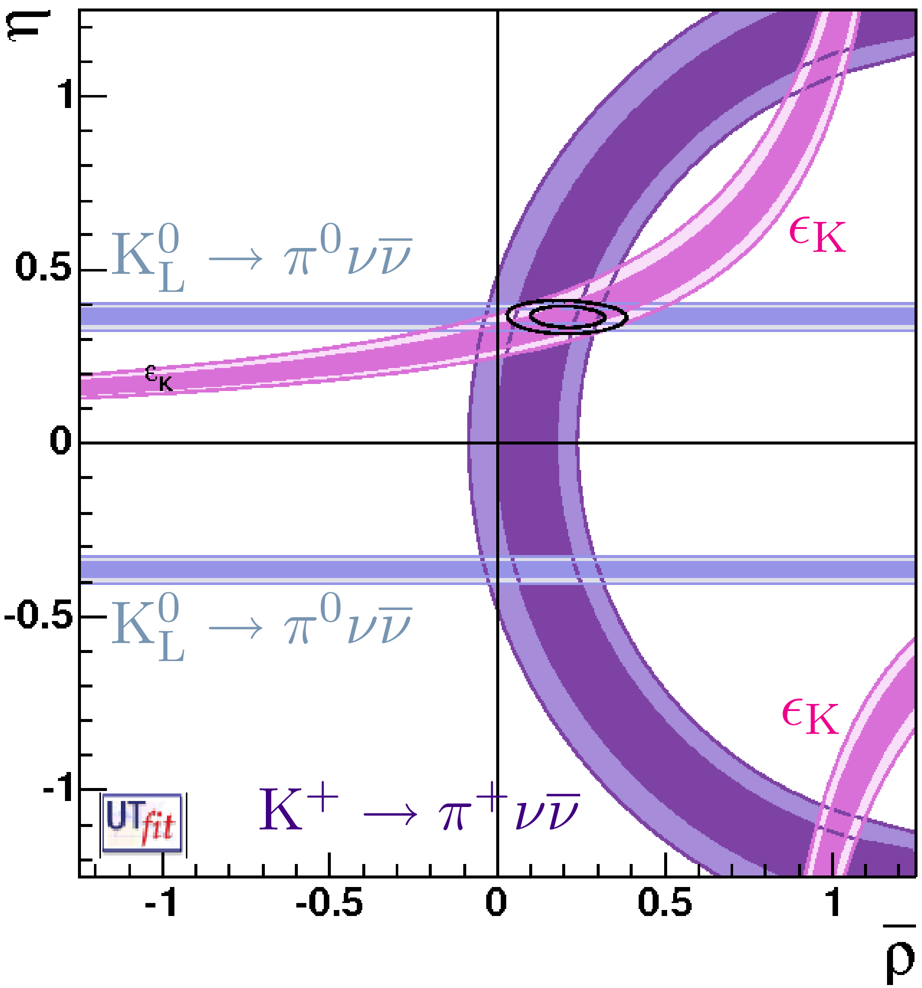
$K^+ \to \pi^+ \nu\overline{\nu}$ is 90% unaffected from long-distance contributions.

- SM $\mathcal{B} = 8 \cdot 10^{-11}$
- 5% irreducible error
- $\mathcal{B} = 1.47^{+1.30}_{-0.89} \cdot 10^{-10}$ (E949/E787)

$K^0_L \to \pi^0 \nu\overline{\nu}$ is 99% unaffected from long-distance contributions.

- SM $\mathcal{B} = 3 \cdot 10^{-11}$
- 2% irreducible error
- $\mathcal{B} < 6.7 \cdot 10^{-8}$ (E391a)

➜ Aim at $\mathcal{O}(100)$ events



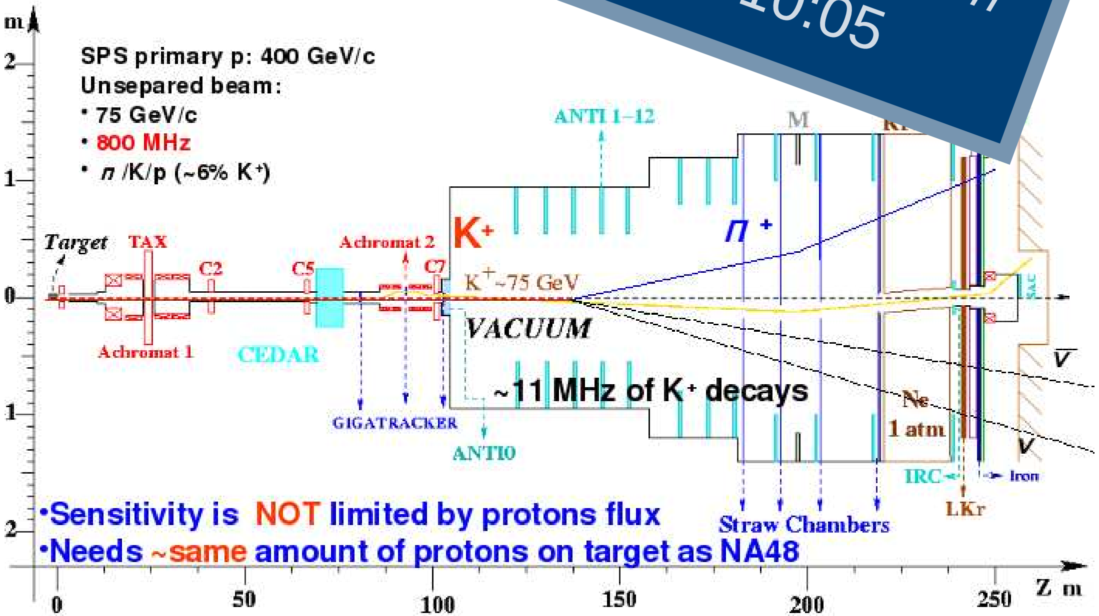
Future impact of kaon physics on unitarity triangle

[UTFit]

Future Kaon Experiments

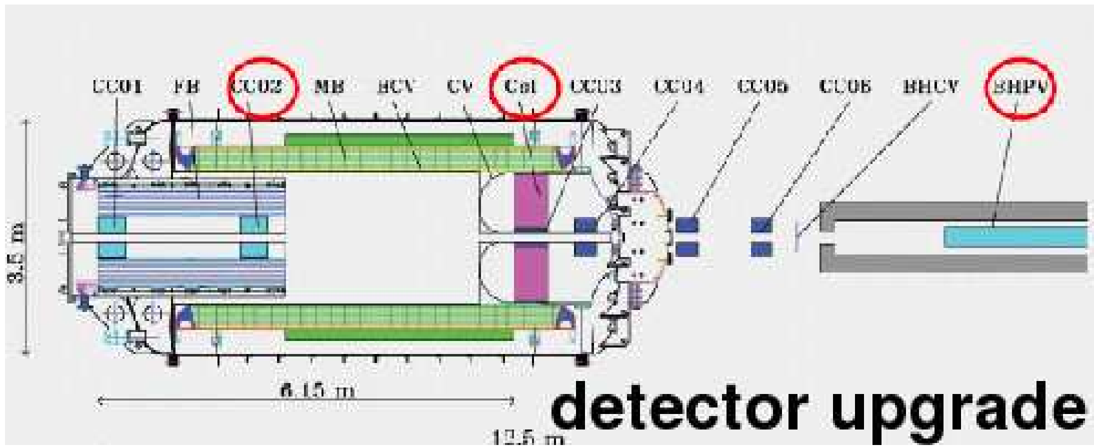
$\mathrm{K}^+ \to \pi^+ \nu\overline{\nu}$: **NA 62 at CERN**

- Being reviewed. Aim to start in 2012.
- Expect 80 events with $S/B \sim 10$.



$\mathrm{K}^0_\mathrm{L} \to \pi^0 \nu\overline{\nu}$: **E14 at J-PARC**

- Now upgrading detector. Start in 2011.
- Expect 100 events with $S/B \sim 1.5$.



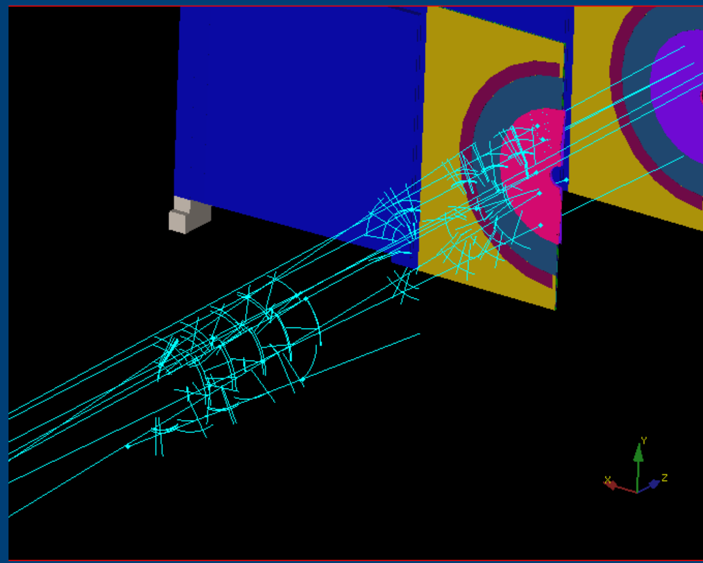
Conclusion

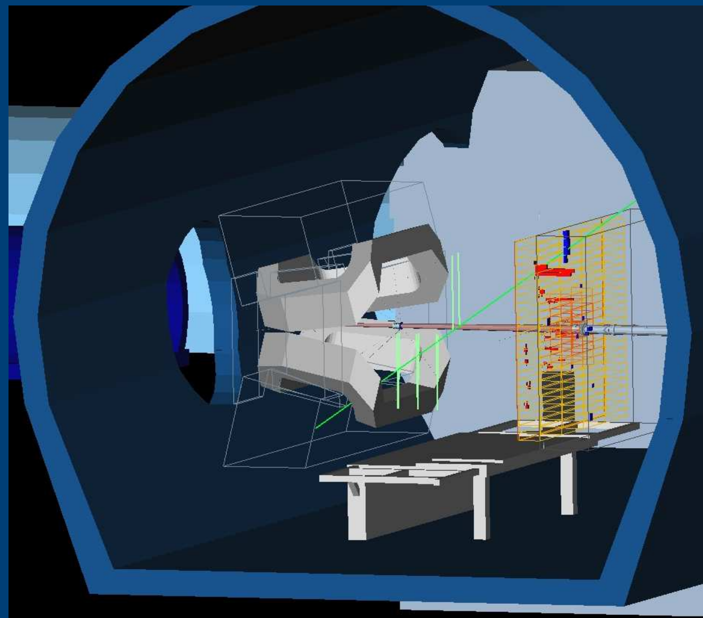
- Thanks to the B factories and the Tevatron for their wonderful work
- LHCb, Atlas and CMS ready to collect data

→ Expect first results at next workshop

- LHCb upgrade and kaon experiments expected for 2011–2013

A new era in flavour physics starts tomorrow!





Further Perspectives at Hadron Colliders

Gabriel Guerrer : γ *from* $\mathrm{B} \to \mathrm{hhh}$ *at LHCb*, 09 Sep 18:45

Marco Sozzi: *"The well tempered Kaon"*, 10 Sep 10:05

Vanya Belyaev : $\mathrm{B_s} \to \phi\gamma$ *prospects*, 10 Sep 11:50

Yuehong Xie : $\mathrm{B_s} \to \phi\phi$ *&* $\mathrm{B_s} \to \mathrm{K}^*\overline{\mathrm{K}}^*$, 10 Sep 16:00

Eduardo Rodrigues : *Prospects for* $\mathrm{B} \to \mathrm{hh}$ *at LHCb*, 10 Sep 16:20

Patrick Robbe : *LHC Perspectives for* b *lifetimes,* Δm*,* $\Delta\Gamma$, 10 Sep 18:45

Gaia Lanfranchi : *Search for New Physics in* $\mathrm{B_s} \to \mathrm{J}/\psi\phi$ *at LHC*, 11 Sep 09:30

Patrick Spradlin : D–$\overline{\mathrm{D}}$ *mixing & CP violation at LHC*, 12 Sep 12:40

Serguey Sivoklokov : $\mathrm{B_s}{\to}\mu\mu$ *at LHC*, 12 Sep 15:10

Mitesh Patel : $\mathrm{B}{\to}\mu\mu\mathrm{K}^*$ *prospects at LHC*, 12 Sep 17:00

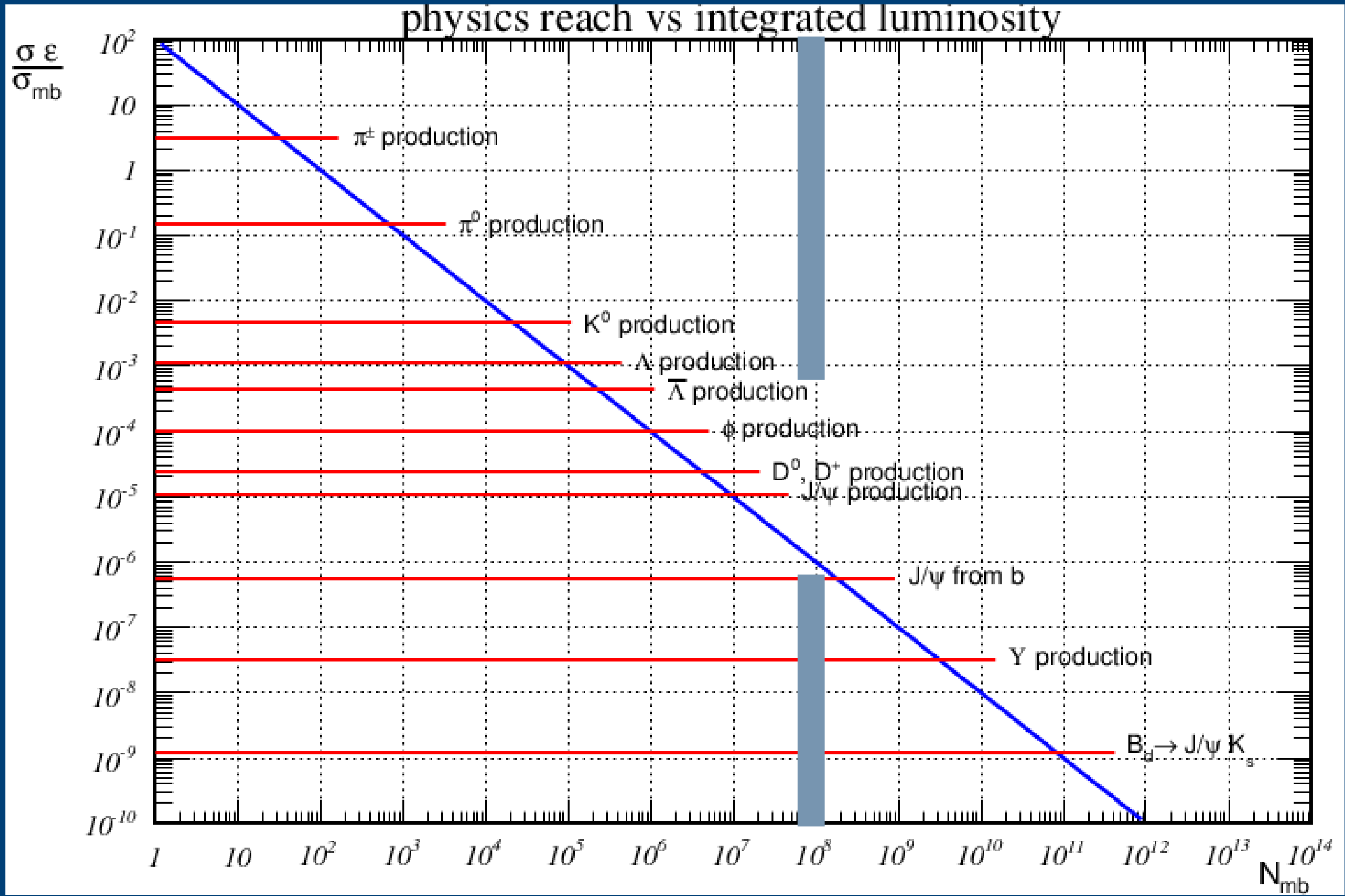
Angelo Carbone: *Time dependent measurements of* γ *at LHCb*, 12 Sep 17:00

Andrew Powell : *Measurements of* γ *at LHCb with ADS/GLW Strategies*, 12 Sep 17:15

Guy Wilkinson : *Gamma at LHCb: Dalitz fits in* $\mathrm{B} \to \mathrm{DK}$ *decays*, 12 Sep 17:30

Backup Slides

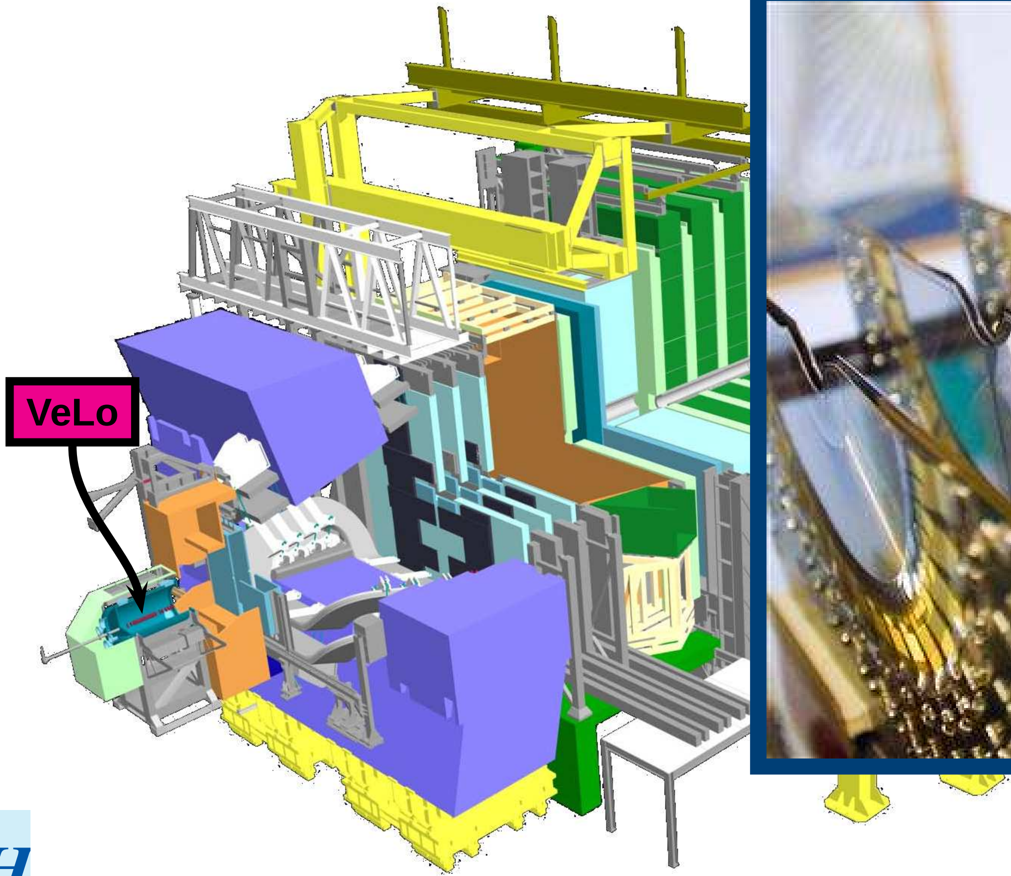
2008 data



LHCb anticipate 10^8 Minimum Bias events this year.

LHCb Vertex Locator

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



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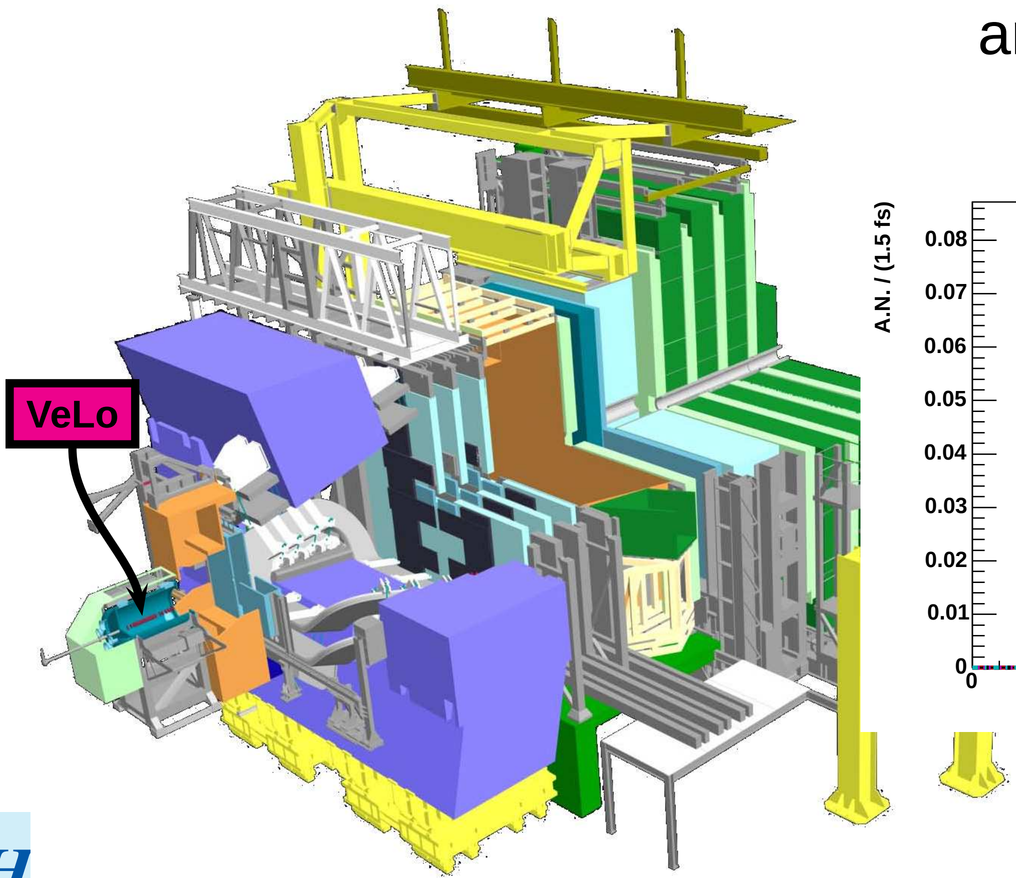
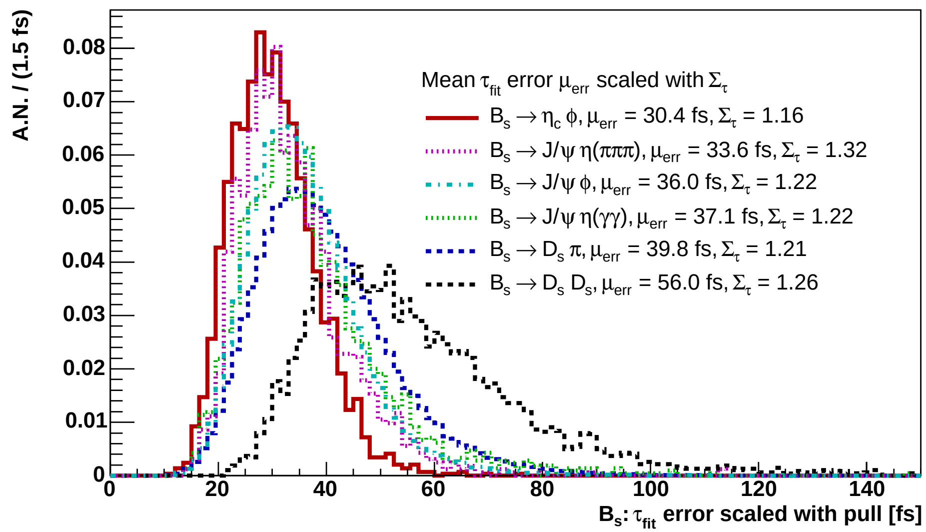
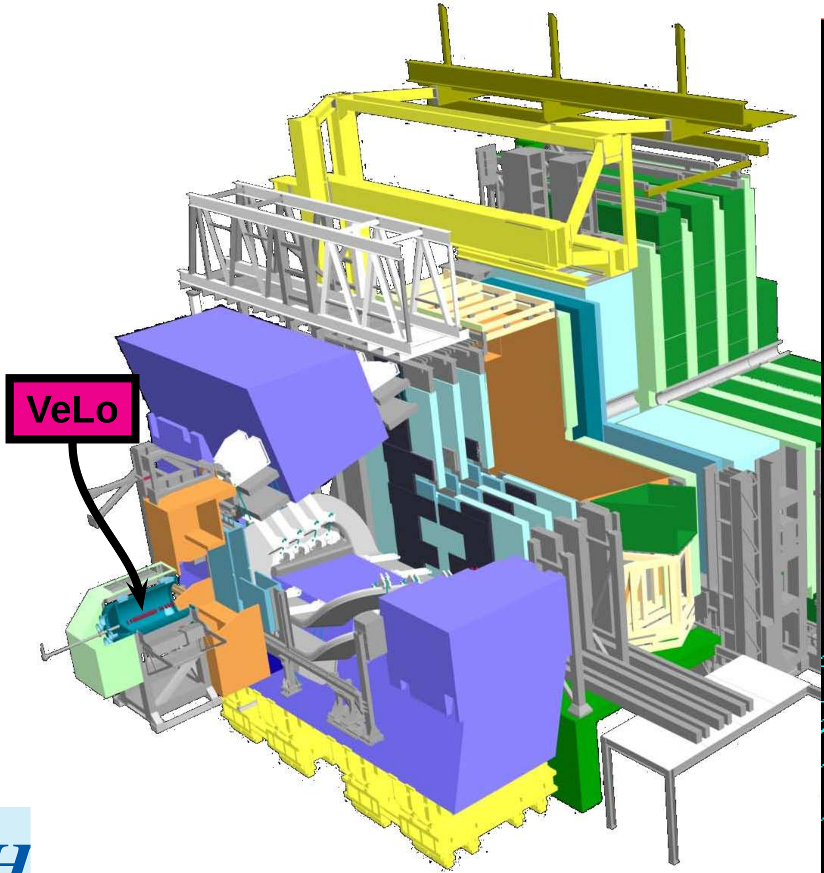


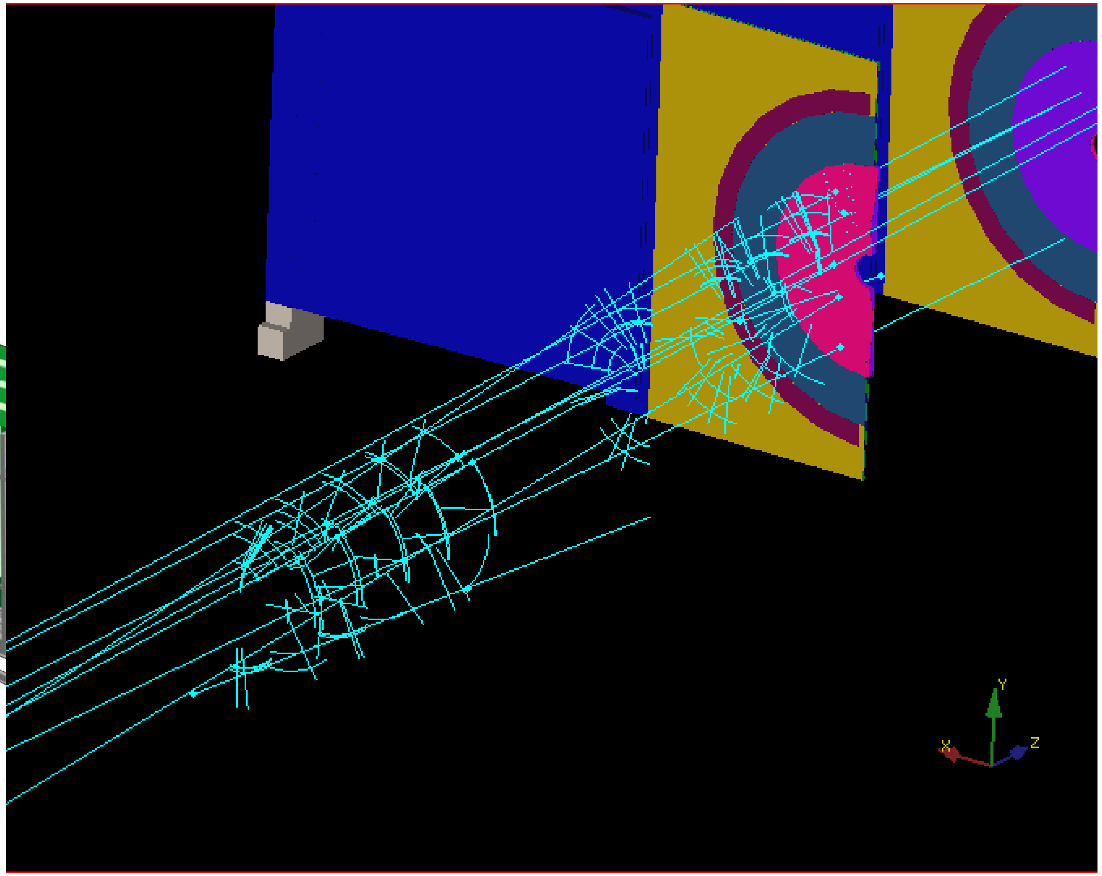
- Proper time resolution between 30 and 50 fs, depending on channel



LHCb Vertex Locator

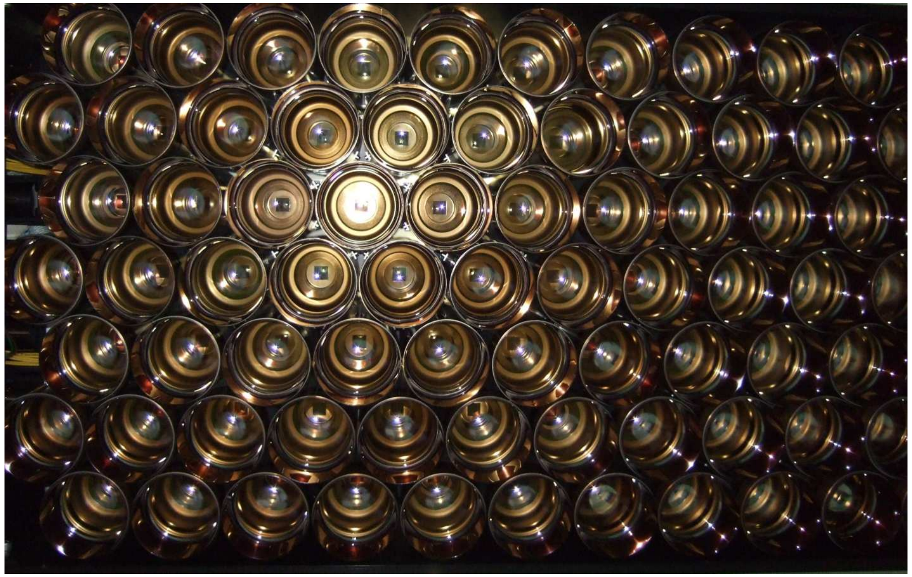
- 21 stations with r and ϕ strips
- In secondary vacuum and retracted during injection
- First tracks reconstructed during final LHC synchronisation tests

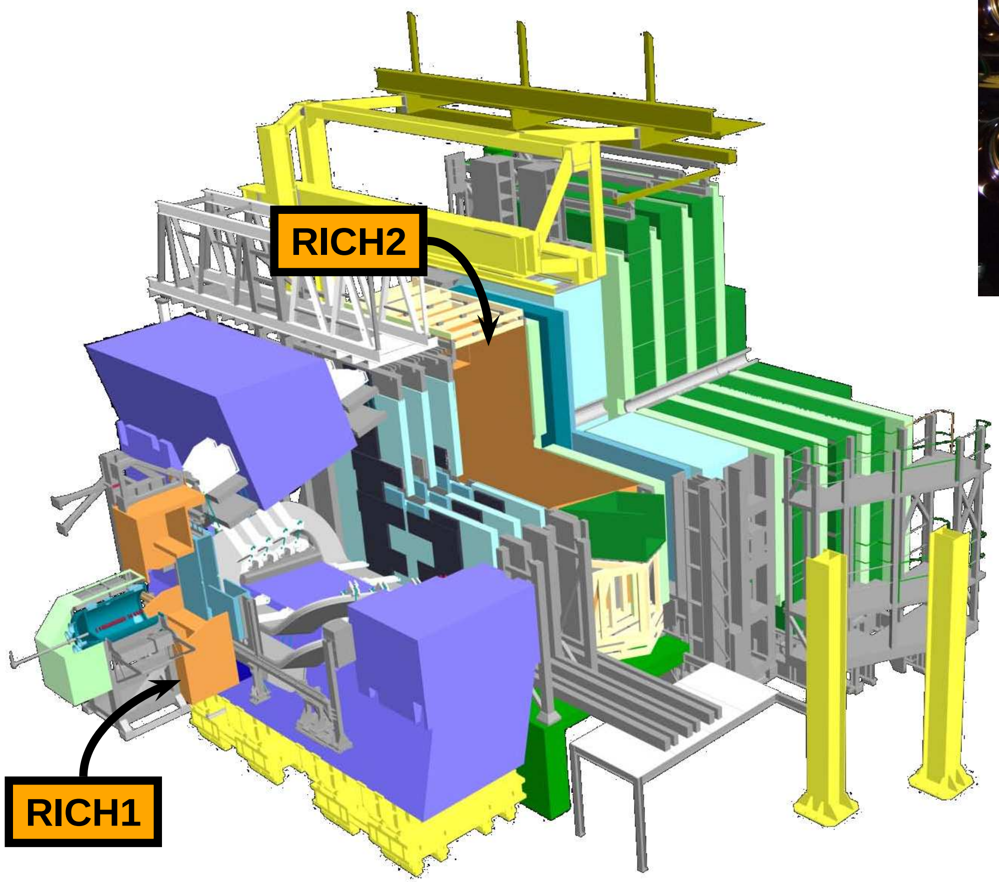




LHCb RICH

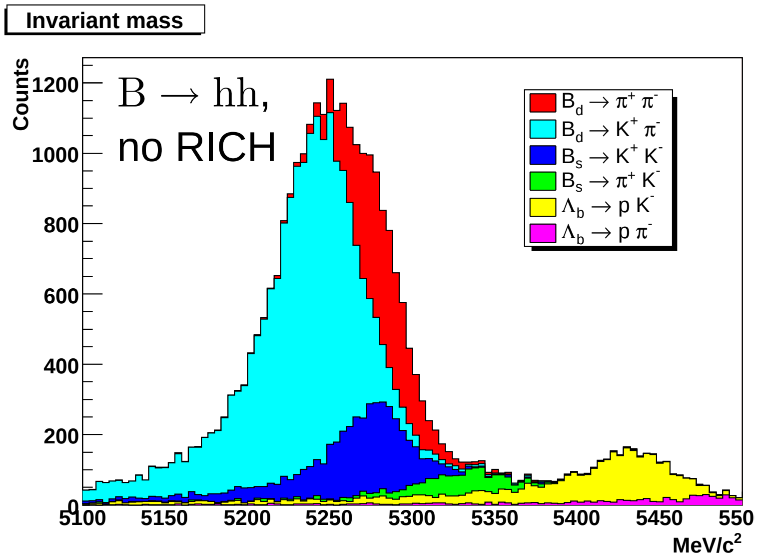
- RICH provides K/π separation using Cherenkov radiation

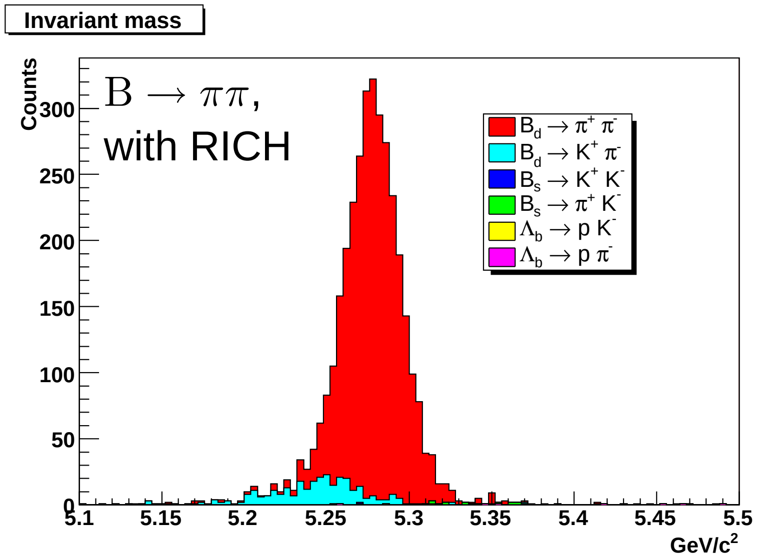


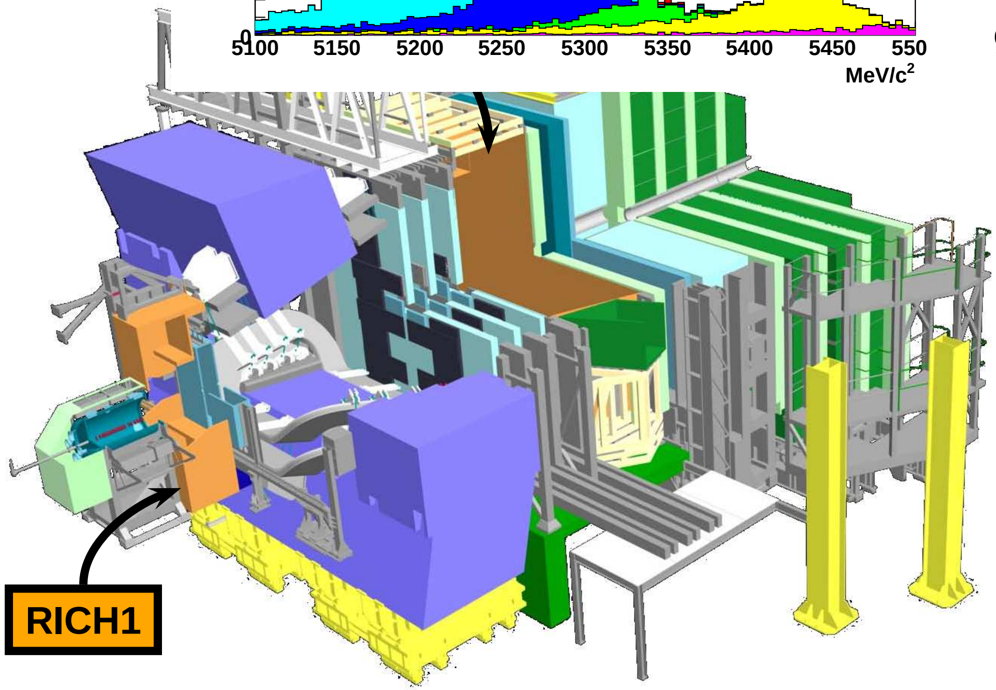


- Use gas and aerogel radiators
- Two detectors for different momentum ranges

LHCb RICH





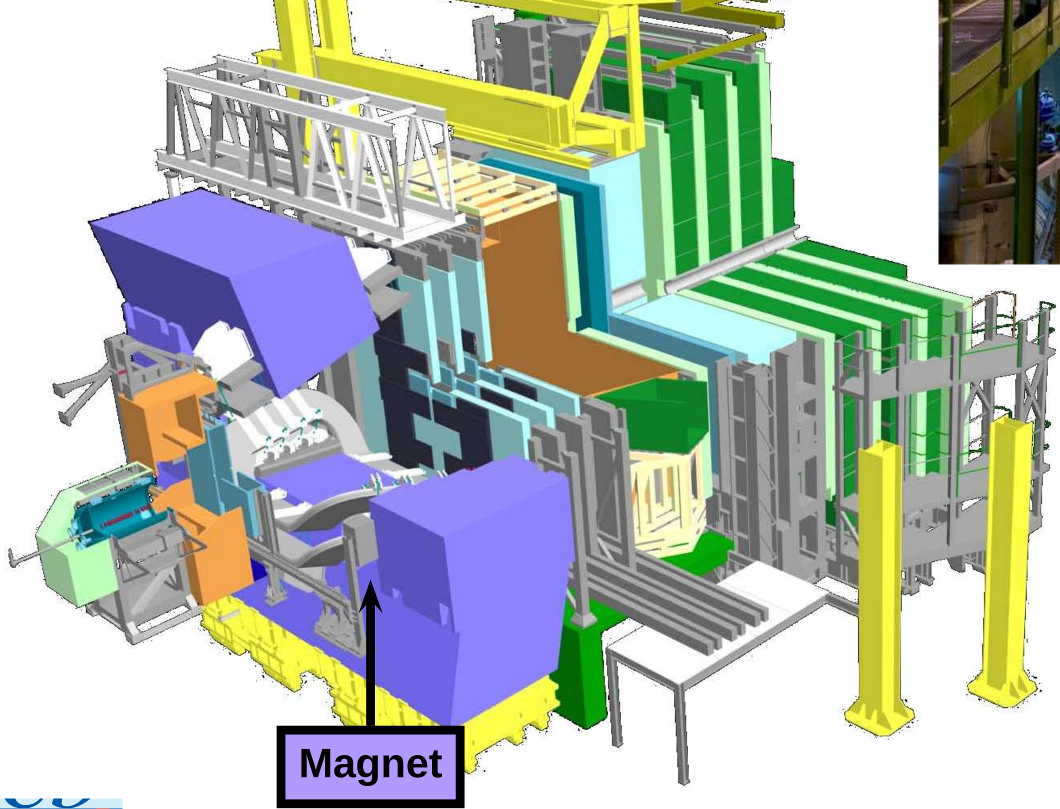


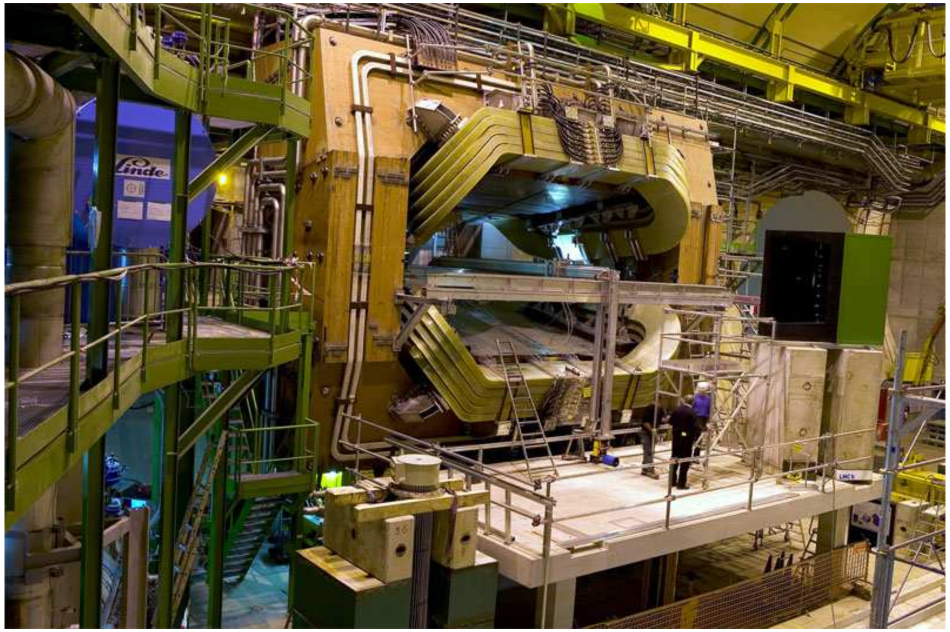
- Use gas and aerogel radiators
- Two detectors for different momentum ranges

➜ Important for $\mathrm{B} \to \mathrm{hh}$ and $\mathrm{B_s} \to \mathrm{D_s}\pi$

LHCb Magnet

- Warm solenoid magnet
- $3\,\mathrm{Tm}$ integrated field
- Can swap polarity
  - ➜ needed for CP studies



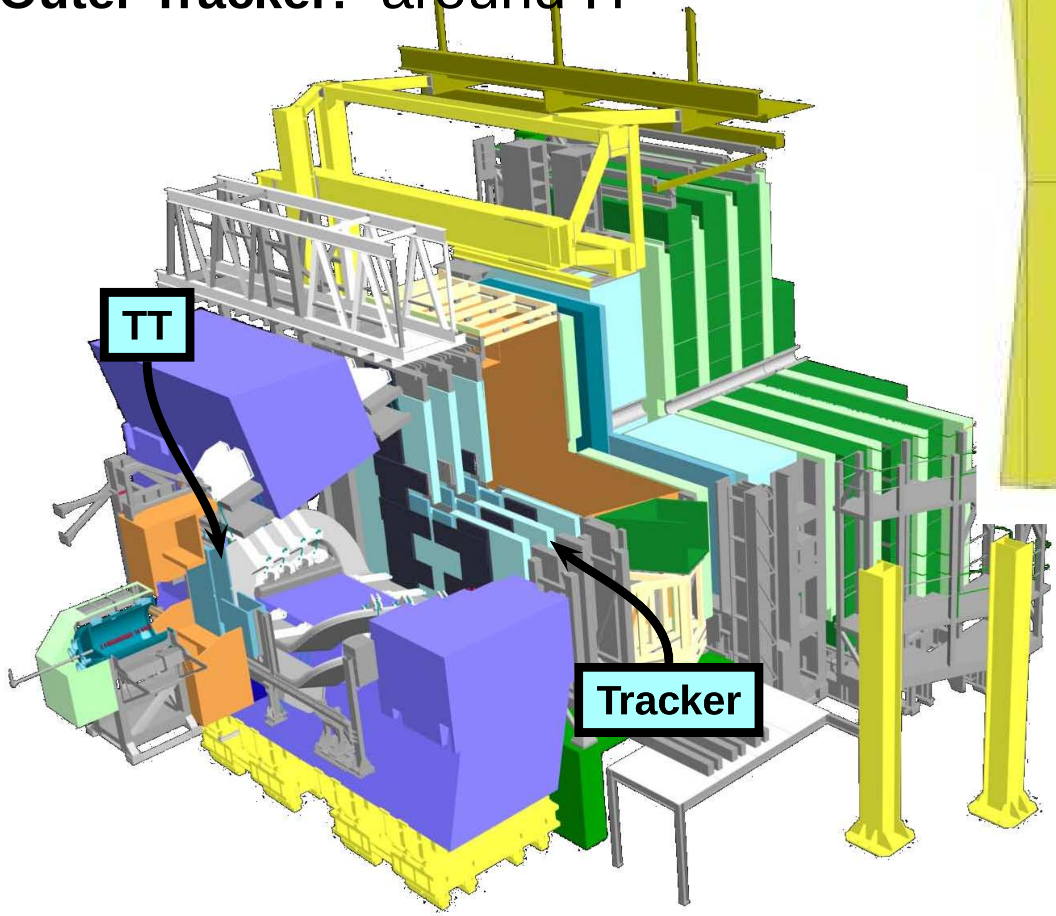


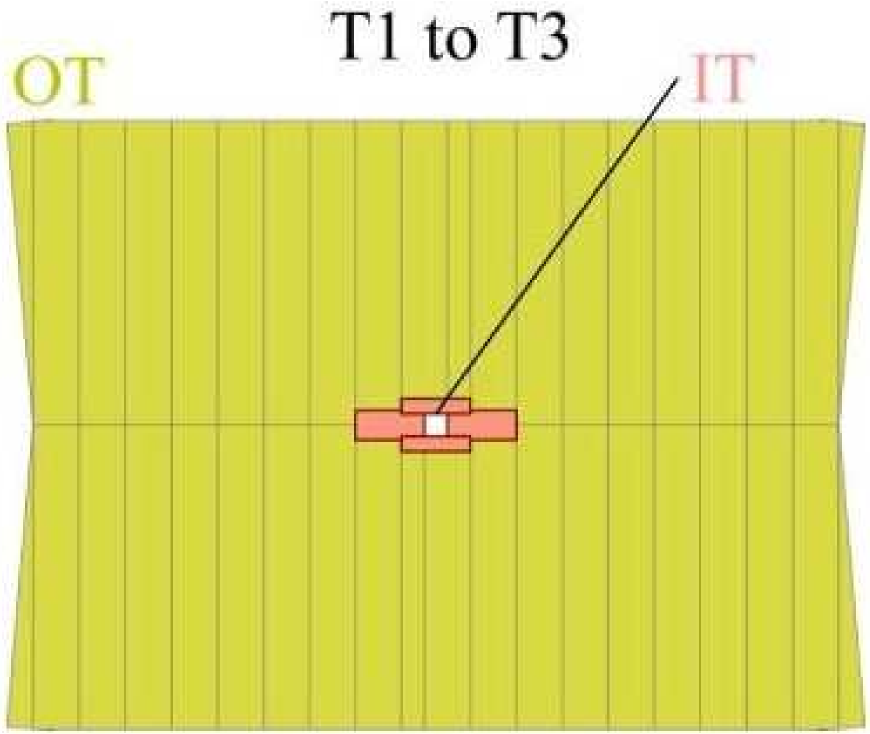
LHCb Trackers

Trigger Tracker: before the magnet

Inner Tracker: around the beam pipe

Outer Tracker: around IT





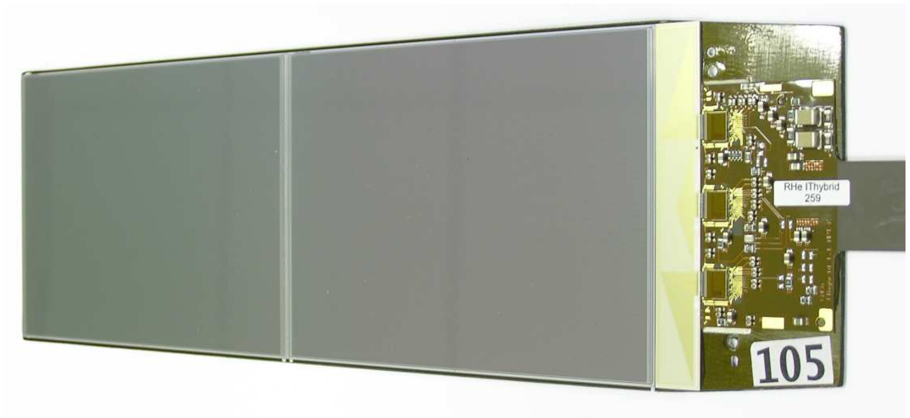
LHCb Trackers

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

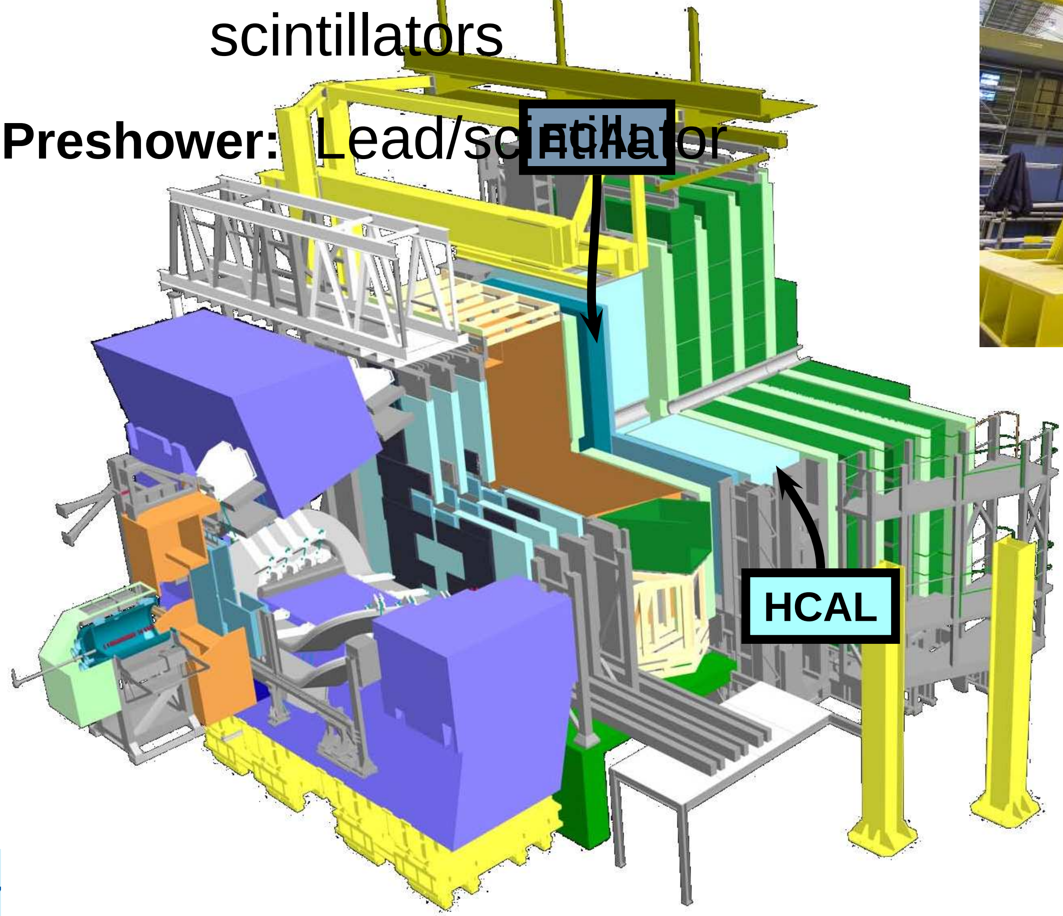


Calorimetry

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

- Layers of lead and plastic scintillators

Preshower: Lead/scintillator



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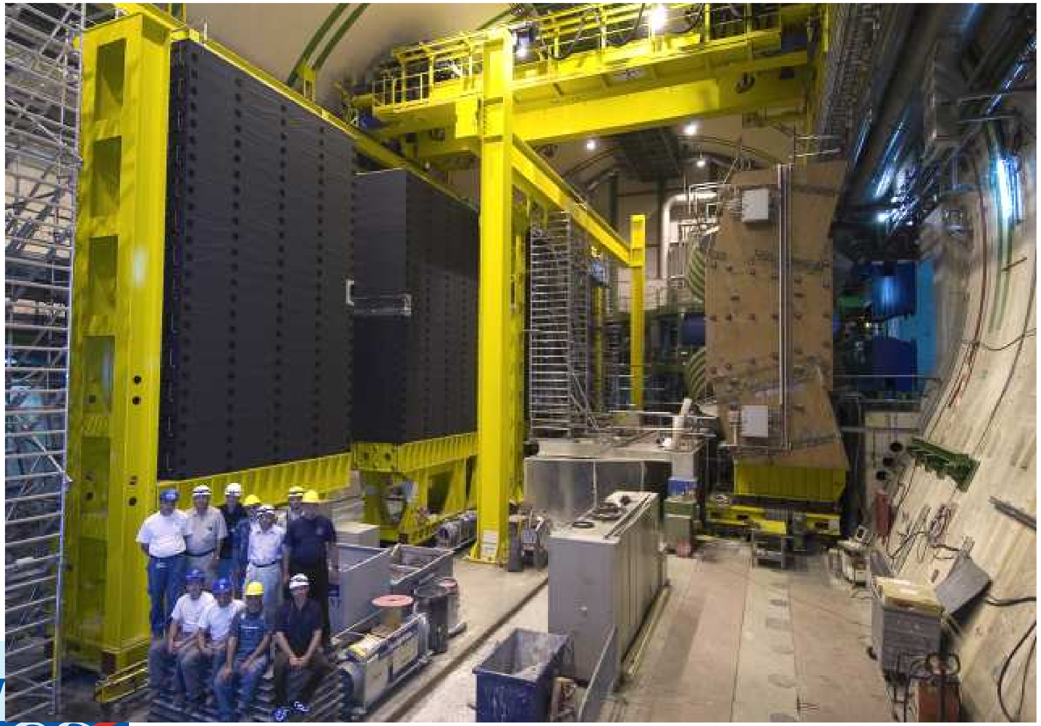
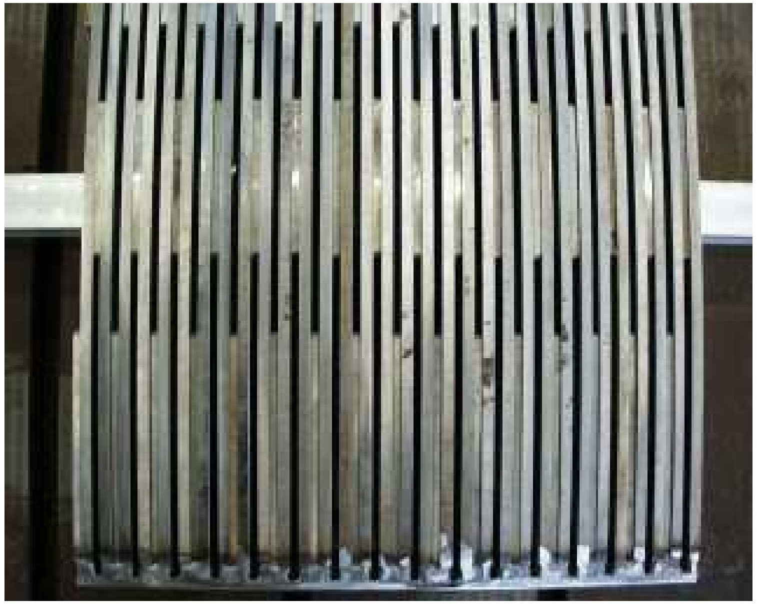
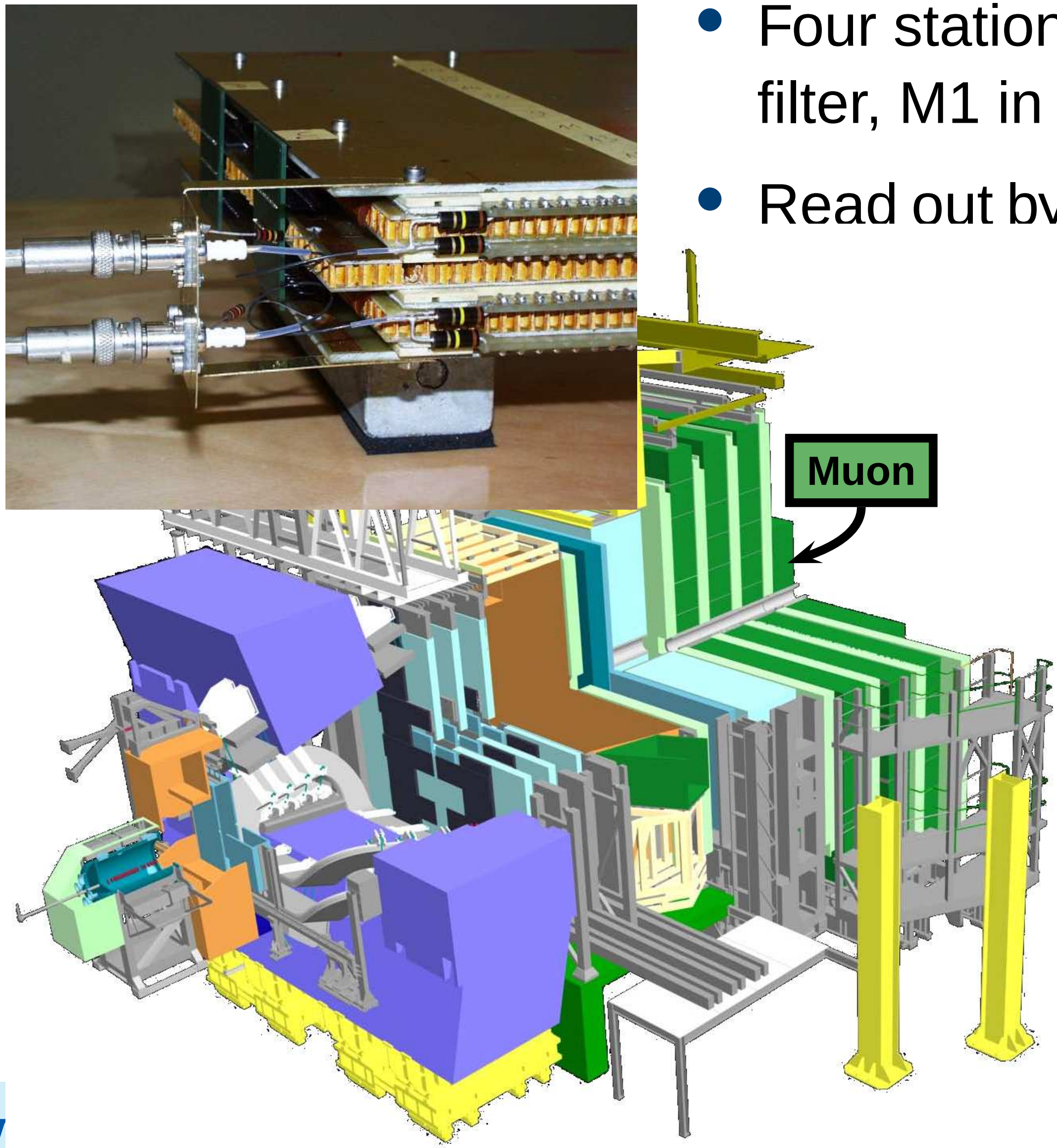




HCAL: For any hadron

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

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