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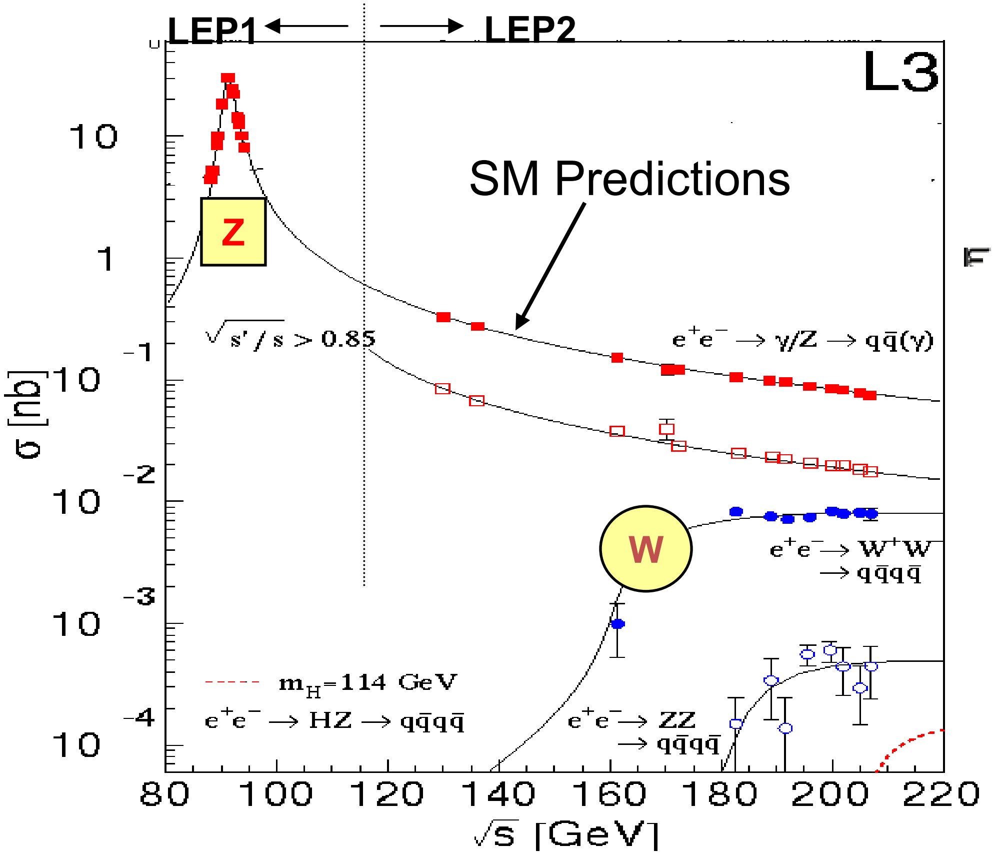
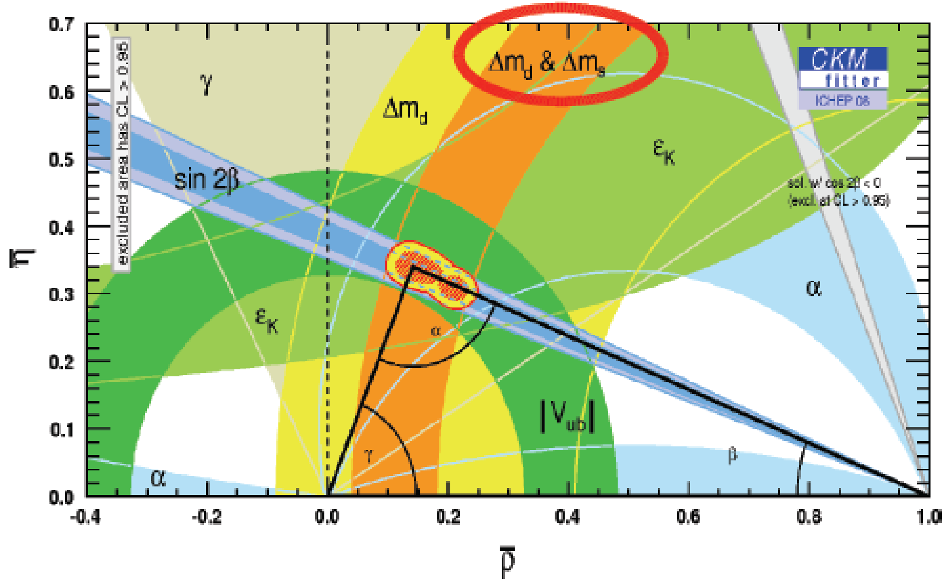
Status of the LHCb experiment

Successes of the Standard Model

LEP, SLC, Tevatron and B-factories established that Standard Model really describes the physics at energies up to √s ~ 200 GeV





The quark sector is well described by the CKM mechanism

Missing ingredient, Higgs particle, has been searched for decades but not yet found

- ***Standard Model is a precisely tested theory however does not provide the whole picture…***

LHC Physics Goals

Main Goals:

- Search for the SM Higgs boson in mass range ~ 115 < m_H < 1000 GeV
- Search for New Physics beyond the SM

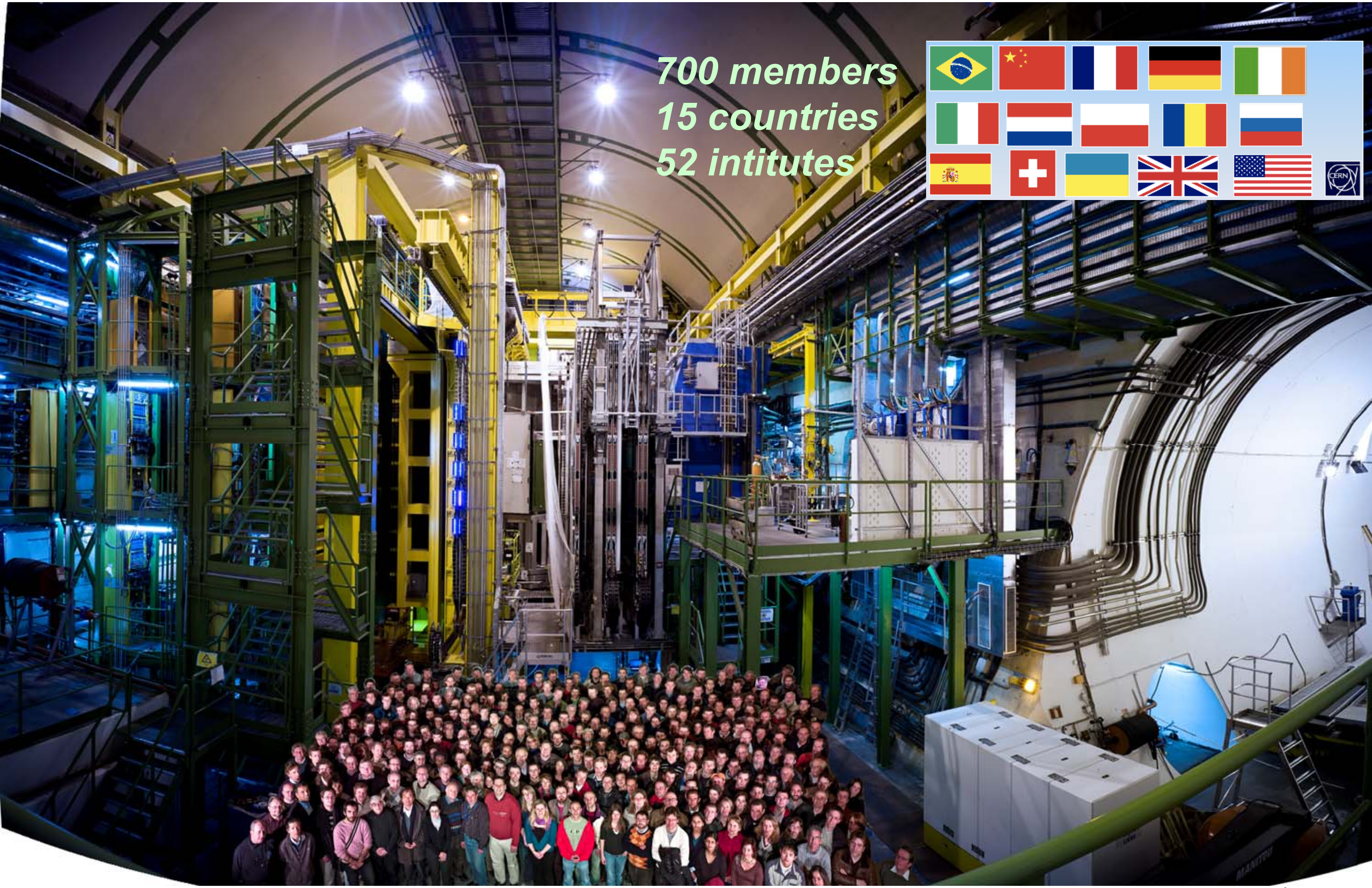
- Explore TeV-scale directly (ATLAS & CMS) and indirectly (LHCb)

No space left for the 4th possibility

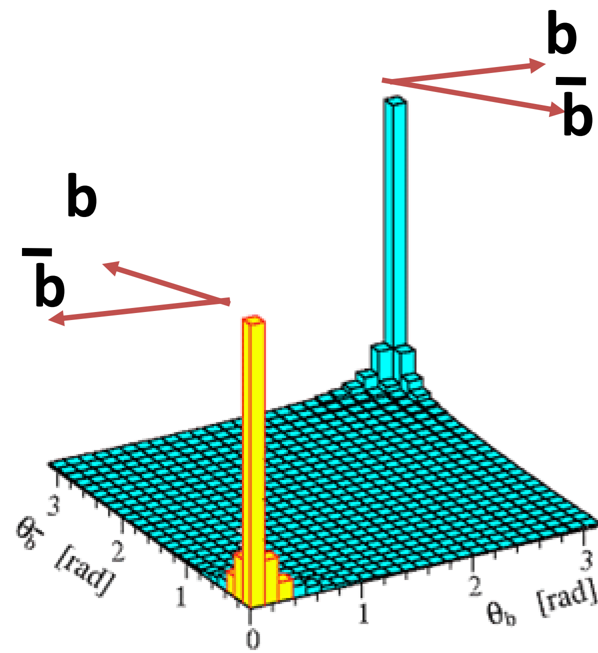
ATLAS CMS high p_T physics	BSM	Only SM	BSM	
LHCb flavour physics	Only SM	BSM	BSM	
Particle Physics	☺	☺	☺	

Even if 4th possibility → Measurements of virtual effects will set the scale of New Physics

LHCb Collaboration



The LHCb Experiment



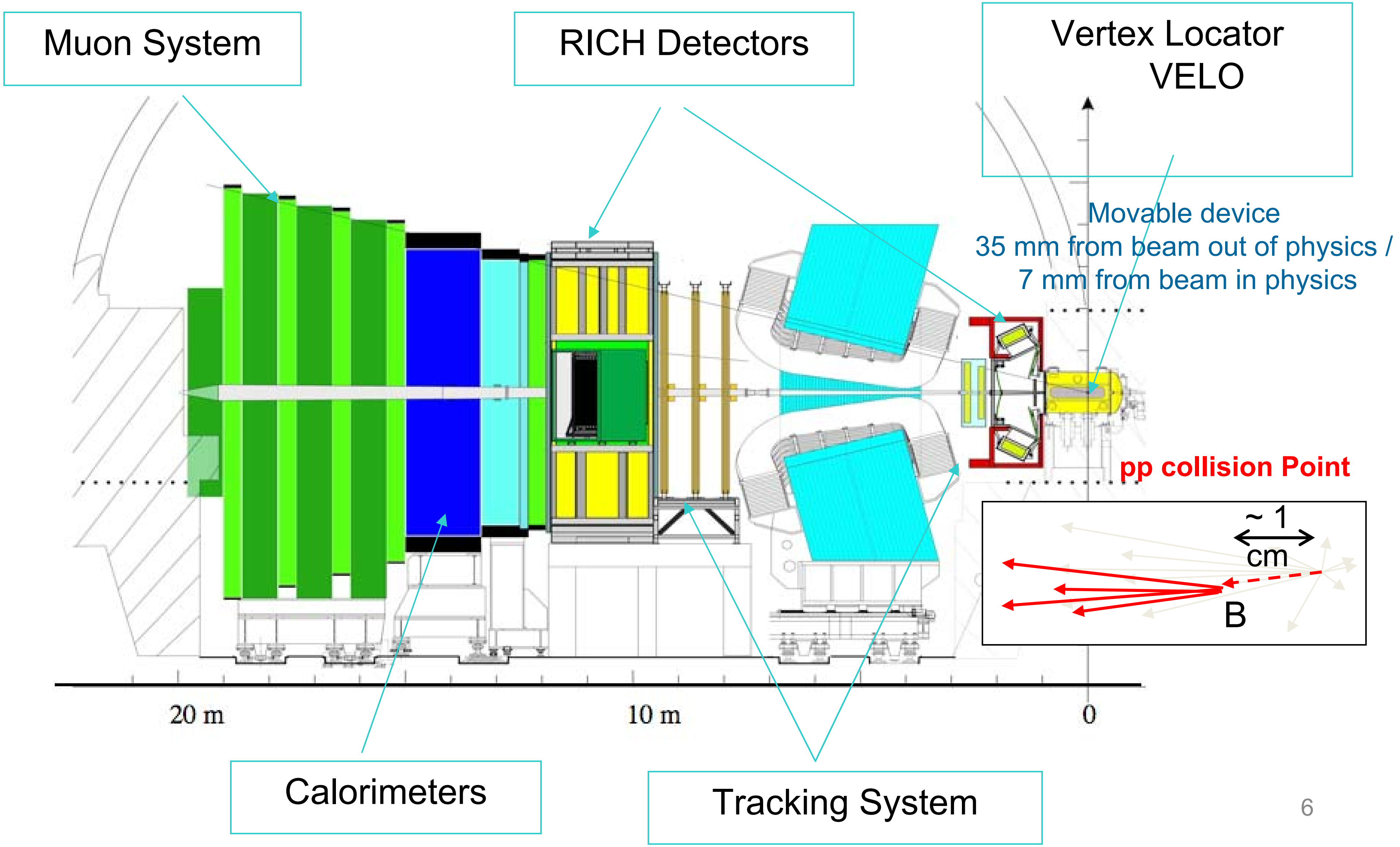
- *Advantages of beauty physics at hadron colliders:*
  - *High value of bb cross section at LHC:*

    σ_{bb} ~ 300 - 500 μb at 10 - 14 TeV

    (e+e- cross section at Υ(4s) is 1 nb)
  - *Access to all quasi-stable b-flavoured hadrons*
- *The challenge*
  - *Multiplicity of tracks (~30 tracks per rapidity unit)*
  - *Rate of background events: σ_{inel}~ 80 mb*
- *LHCb running conditions:*
  - *Luminosity limited to ~2×10^{32} cm^{-2} s^{-1} by not focusing the beam as much as ATLAS and CMS*
    - *Maximize the probability of single interaction per bunch crossing*

      At LHC design luminosity pile-up of >20 pp interactions/bunch crossing while at LHCb ~ 0.7 pp interaction/bunch
    - *LHCb will reach nominal luminosity soon after start-up*
  - ***$2fb^{-1}$ per nominal year (10^7s), ~ 10^{12} bb pairs produced per year***

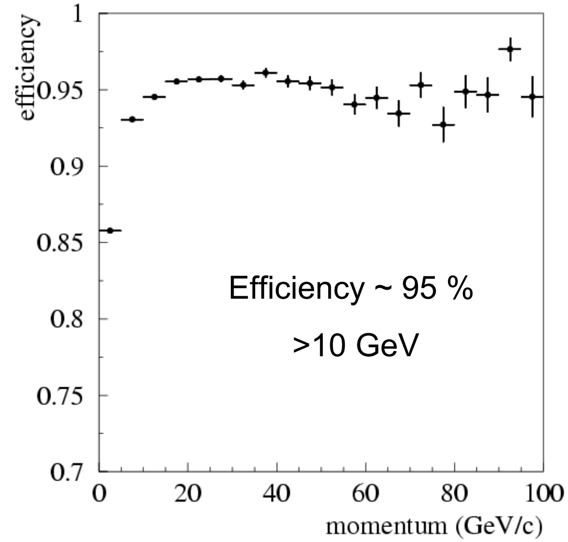
The LHCb Detector

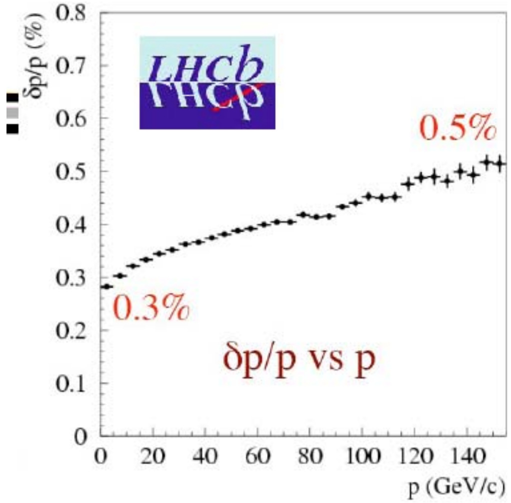


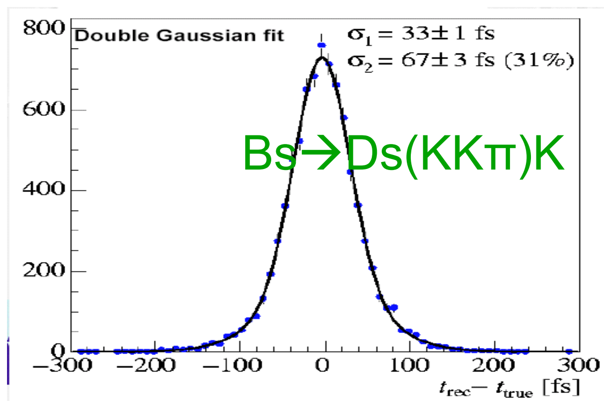
Detector Performances: Tracking

Expected tracking performance:

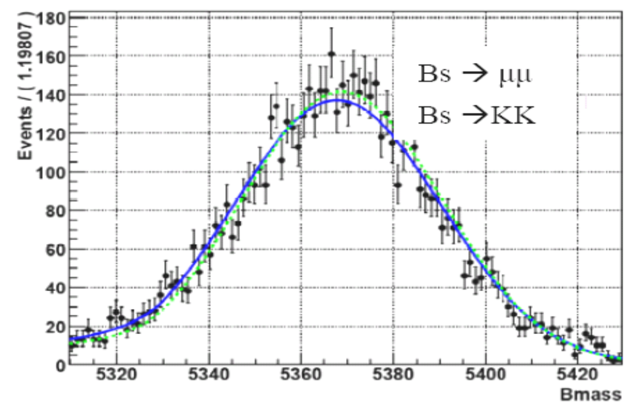
- *Efficiency > 95% for tracks from B decays crossing entire detector*
- *δp/p: 0.3% - 0.5% (depending on p)*
- *Proper time resolution: ~ 40 fs*
- *B Mass resolution: 15-20 MeV/c^2*







Proper time resolution ~ 40 fs



Mass resolution ~ 20 MeV

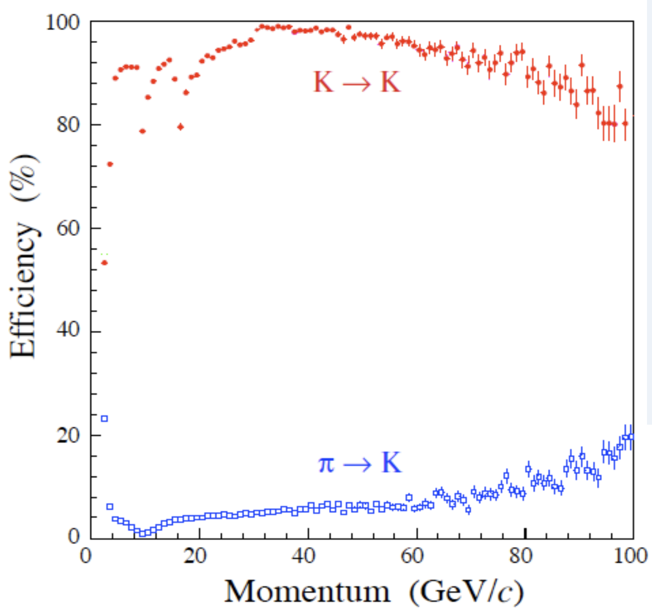
Detector Performances: PID

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

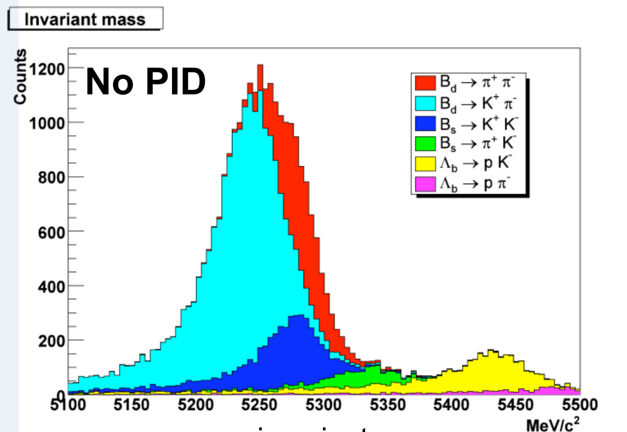
RICH1 Aerogel (2-10 GeV), C_4F_{10} (10-60 GeV)

RICH2 CF_4 (16-100 GeV)

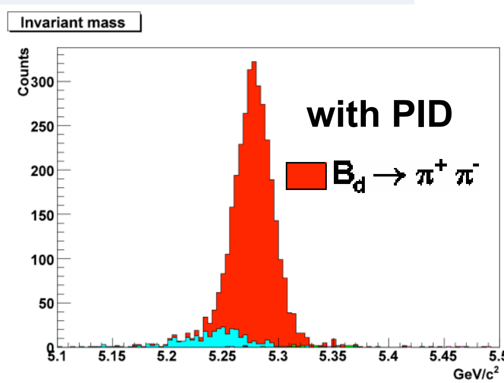
π–K separation



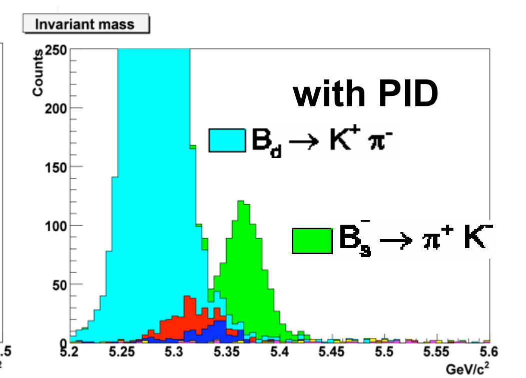
- *Good π–K separation in 2-100 GeV/c range*
  - *Low momentum*
    - *Tagging kaons*
  - *High momentum*
    - *Clean separation of $B_{d,s} \to hh$ modes*



ππ invariant mass



ππ invariant mass

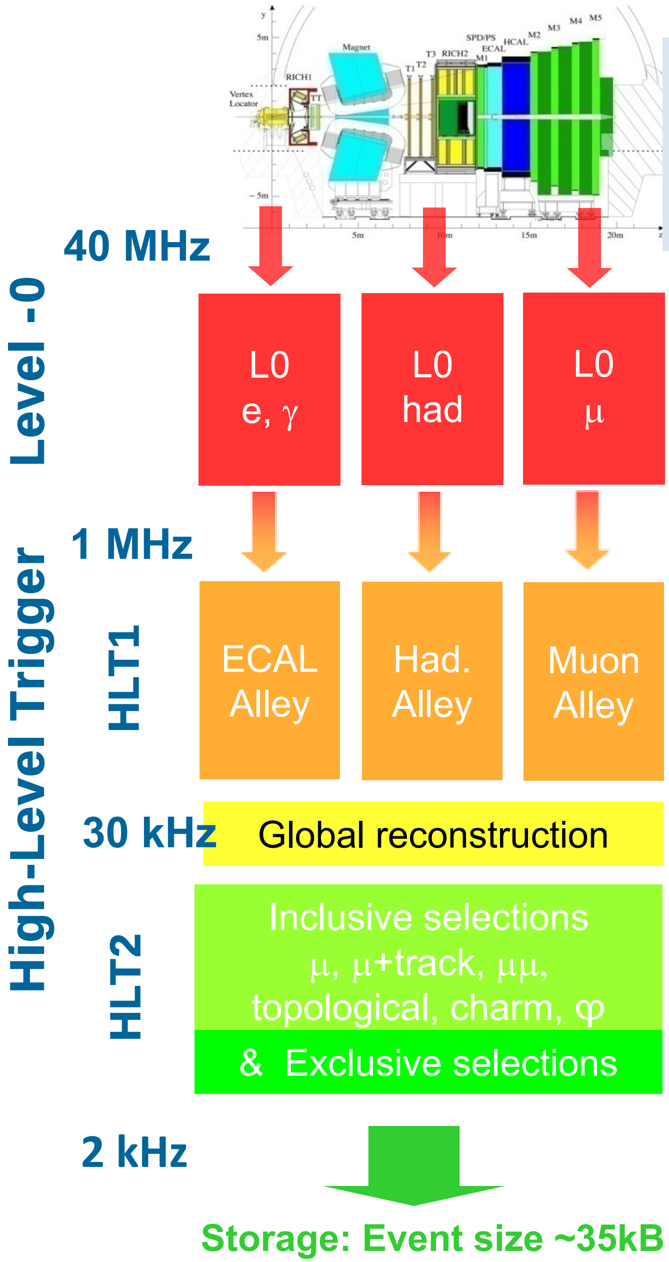


Kπ invariant mass

Kaon ID ~ 90%

Pion mis-ID ~ 3%

LHCb Trigger



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

- ***Hardware level (L0)***

  Search for high-p_T μ, e, γ and hadron candidates

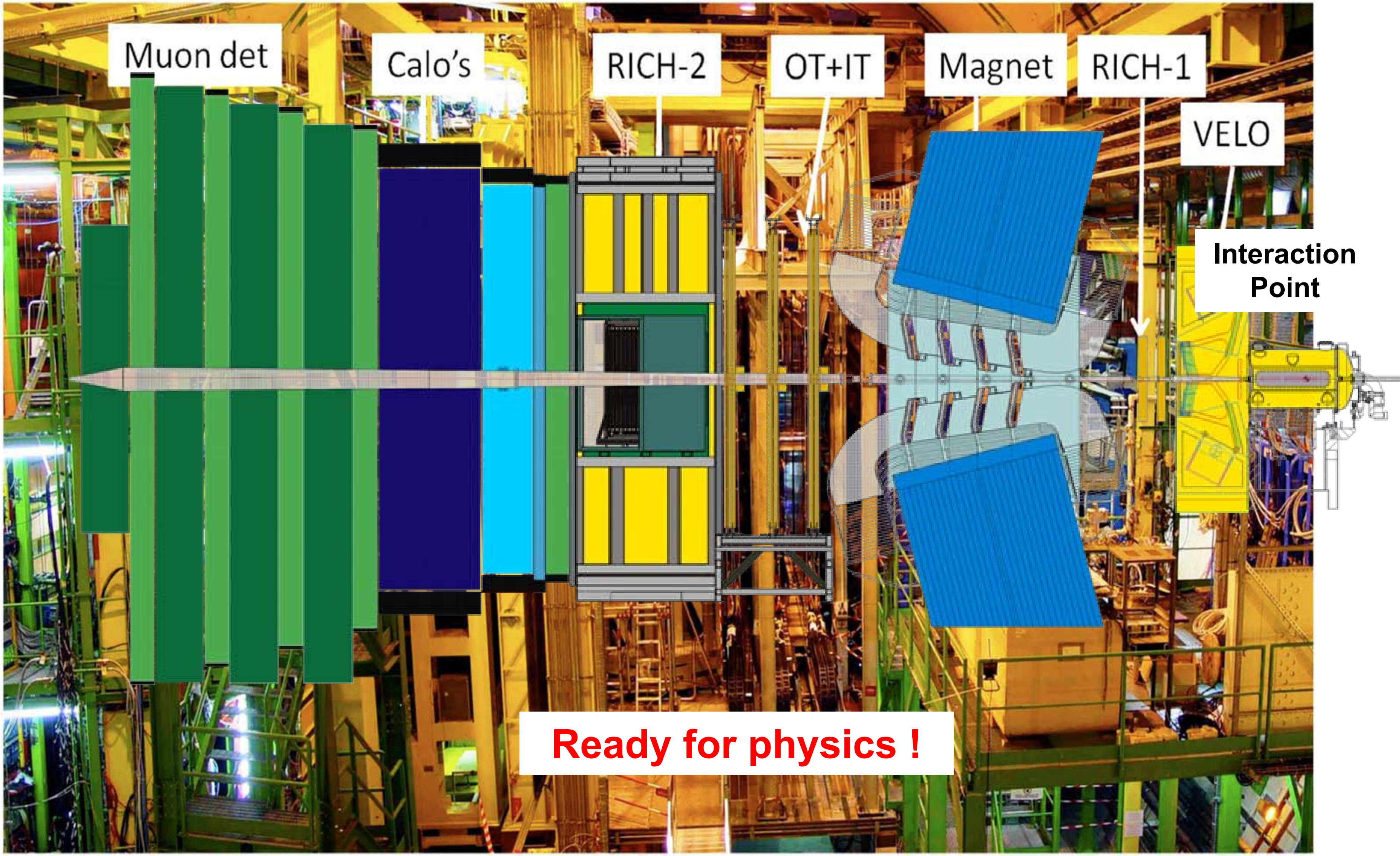
- ***Software level (High Level Trigger, HLT)***

  *Farm with **O**(2000) multi-core processors*

  HLT1: Confirm L0 candidate with more complete info, add impact parameter and lifetime cuts

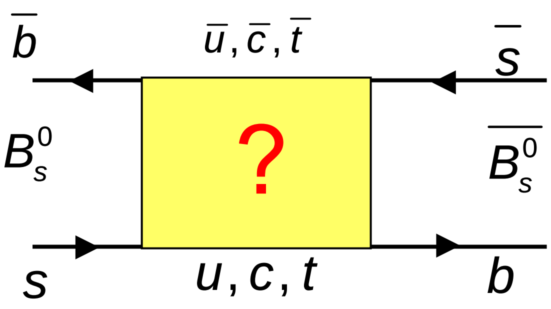
  HLT2: B reconstruction + selections

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

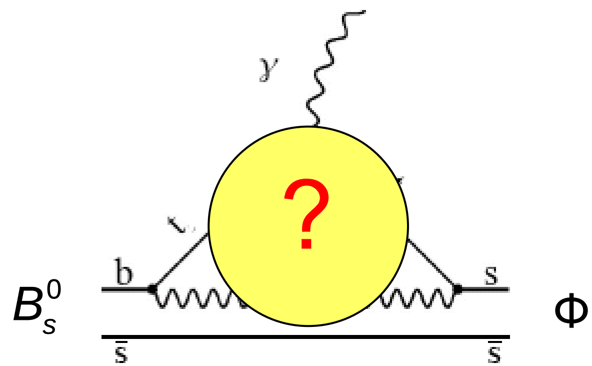

Muon det
Calo's
RICH-2
OT+IT
Magnet
RICH-1
VELO
Interaction Point
Ready for physics !

LHCb Physics Programme

Main LHCb objective is to search for the effects induced by New Physics in CP violation (see talk by M.Calvi) and Rare decays (see talk by M.-H. Schune) using the FCNC processes mediated by loop (box and penguin) diagrams



$\Phi_s \neq \Phi_s^{SM}$



Sensitivity to masses, couplings, spins and phases of New Particles

New Physics Search Strategy

- ***Phases***

  CPV processes are the only measurements sensitive to the phases of New Physics e.g. measurements of ***β , β_s & γ***

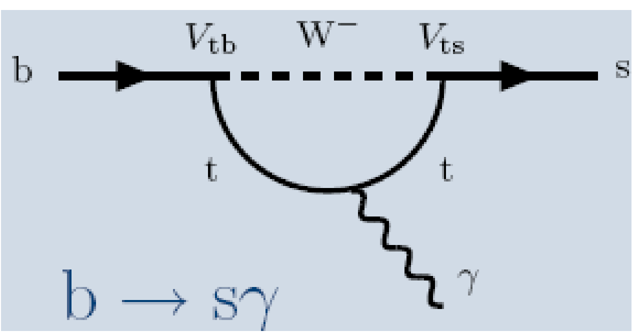
- ***Masses and magnitude of the couplings of new particles***

  Inclusive BR(b → sγ) indirectly constrains the scale of NP masses Λ > 10^3 TeV for generic coupling (flavour problem)

  Look at specific cases with enhanced sensitivity e.g. helicity suppression in ***Bs→μμ*** *decay gives increased sensitivity to SUSY with extended Higgs sector*

- ***Helicity structure of the couplings***

  Use the correlation between photon polarization and b flavour in ***b→sγ***



b → γ (L) + (m_s/m_b) × γ(R)

φγ produced in B_s and $\overline{B}_s$ decays do not interfere

→ corresponding CP asymmetry vanishes

Significantly non-zero A_{CP} indicates a presence of right-handed current in the penguin loop

Similar study using ***B→K*$\mu^+\mu^-$ & K*e^+e^-***

CPV measurements: UT angles

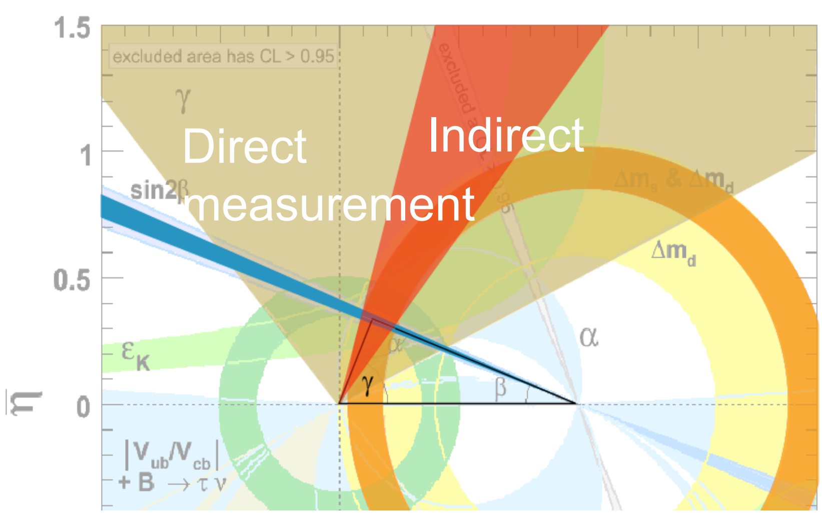
❑ Box diagrams (I)

Note: *UT geometry is such that the main constraint on NP comes from the comparison of the opposite elements i.e. angles vs sides*

β **vs $|V_{ub} / V_{cb}|$** *is largely limited by theory (~10% precision in $|V_{ub}|$)*

Note a discrepancy in $|V_{ub}|$ determined in inclusive and exclusive measurements : $|V_{ub}|$ incl ~ (4.0-4.9)$\times 10^{-3}$ and $|V_{ub}|$ excl ~ (3.3-3.6)$\times 10^{-3}$

γ **vs $\Delta m_d / \Delta m_s$** *is limited by experiment: γ is poorly measured (± 20°)*



Indirectly γ is determined to be $\gamma = (68 \pm 5)^{o}$ from processes involving boxes

LHCb will measure γ directly in tree decays using the global fit to the rates of $B \rightarrow D^0K, D^0K^*$ decays and time-dependent measurements with $B_s \rightarrow D_sK$ and $B^0 \rightarrow D\pi$ decays

Expected $\sigma(\gamma_{trees}) \approx 4°$ with 2 fb^{-1}

(See poster of M.Gersabeck)

CPV measurements: B_s mixing

- ***Box diagrams (II)***

*$\Phi(J/\psi\varphi)$ = **$-2\beta_s$** is the B_s meson counterpart of 2β*

penguin contribution ≤ 10^{-3}

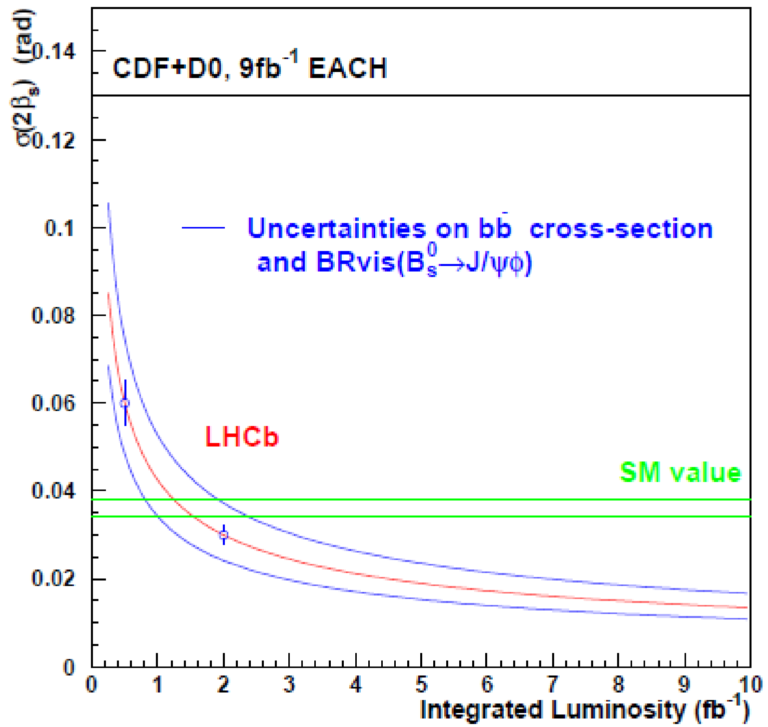
β_s not measured accurately (indication of large value from CDF/D0)
Theoretical uncertainty is very small
$-2\beta_s$ = - 0.0368±0.0017 (CKMfitter 2007)

LHCb prospects (2 fb^{-1} sample)

Expected yield 117k $B_s \rightarrow J/\psi\phi$ events

$\sigma(2\beta_s)$ ~ 0.03

Other channels are under study e.g.
$B_s \rightarrow J/\psi f^0$, $f^0 \rightarrow \pi^+\pi^-$. Looks promising
if this CP-eigenstate mode has sufficiently
large BR as indicated by CLEO (see talk
by T.Skwarnicki)

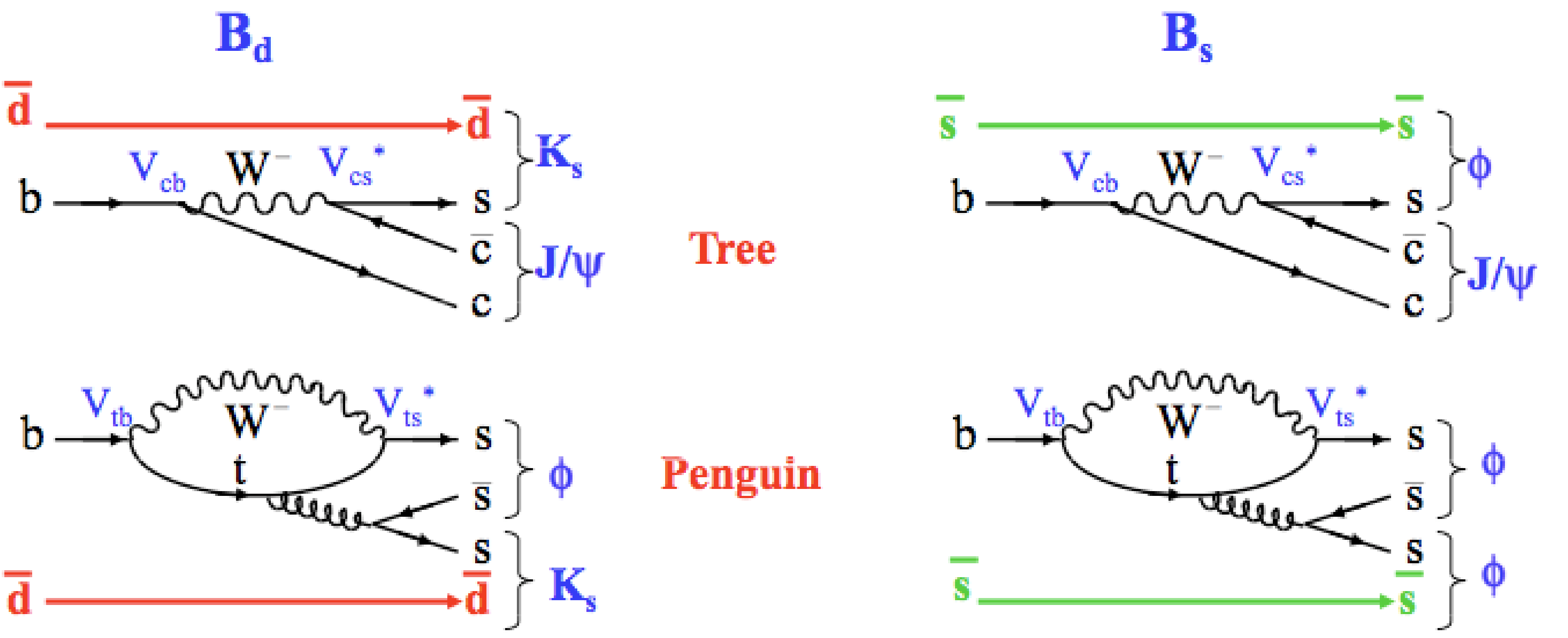


CPV measurements: Penguin vs Tree

- ***Penguin diagrams:***

$\delta 2\beta(NP) = 2\beta(B \rightarrow \phi Ks) - 2\beta(B \rightarrow J/\psi Ks) \neq 0$

$\delta 2\beta_s(NP) \approx 2\beta_s(B_s \rightarrow \phi\phi) - 2\beta_s(B_s \rightarrow J/\psi\phi)$



Thanks to B-factories
$\delta 2\beta(NP)) \sim -0.23 \pm 0.18$ rad

$\sigma(\delta 2\beta_s(NP))$ not measured
LHCb sensitivity with 2 fb^{-1} ~ 0.11 rad
(stat. limited)

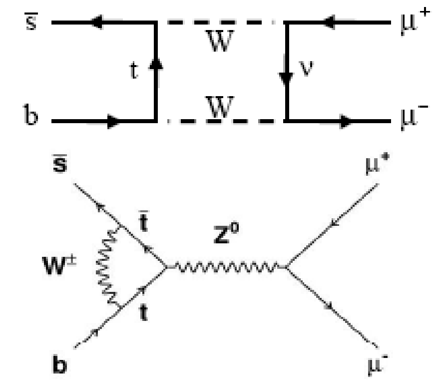
Rare Decays

Current experiments are only now approaching an Interesting level of sensitivity in exclusive decays:

- *BR ($B_s \rightarrow \mu\mu$) (CDF /D0)*
  BR ($B_d \rightarrow \mu\mu$)
- *Photon polarization in $B \rightarrow K^*\gamma$ (BELLE/BaBar)*
- *A_{FB} in $B \rightarrow K^*\mu\mu$ (BELLE/BaBar)*
- *BR ($D^0 \rightarrow \mu\mu$) (CDF)*

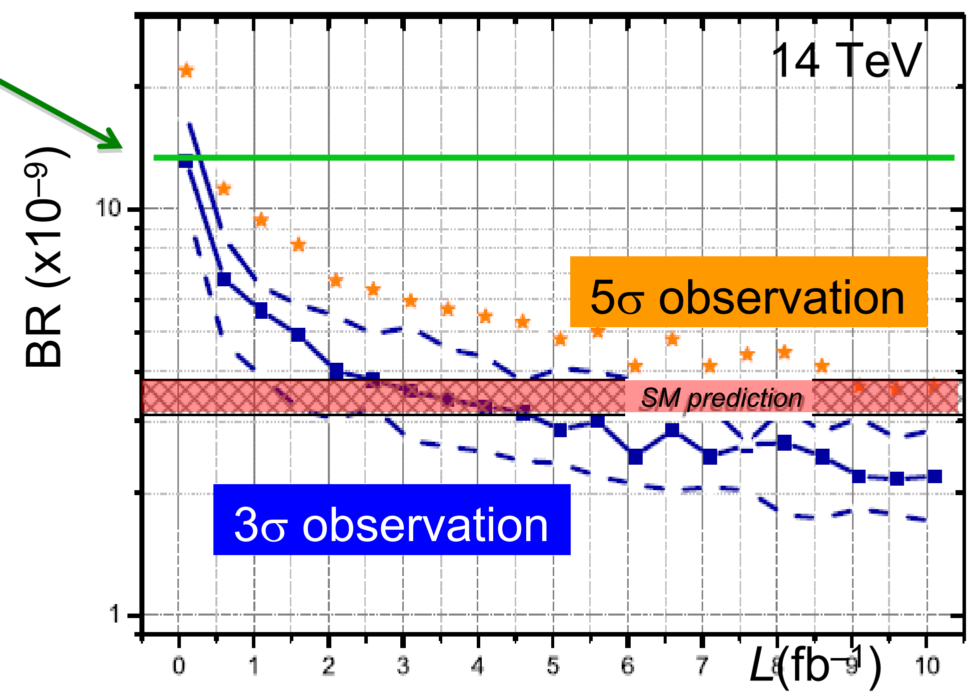
LHCb will study rare decays in depth !!!

$B_s \rightarrow \mu\mu$



- Super rare decay in SM with well predicted $BR(B_s \rightarrow \mu\mu) = (3.55\pm0.33)\times10^{-9}$
- Sensitive to NP, in particular new scalars
  In MSSM: $BR \propto \tan^6\beta / M^4_A$
- Best present limit is from CDF:
  $BR(B_s \rightarrow \mu\mu) < 4.7\times10^{-8}$ @ 90% CL
- For the SM prediction
  LHCb expects 21 signal and 180 background events with 2 fb^{-1}.
  Background is dominated by muons from two different semileptonic b-decays
- LHCb sensitivity for the SM BR:
  3σ evidence with 3 fb^{-1}
  5σ observation with 10 fb^{-1}

Discovery



Measurement of the photon polarization in $B_s \rightarrow \phi\gamma$ decay

- BaBar & BELLE used CPV analysis in $B \rightarrow K^*(K^0\pi^0)\gamma$ decay
  σ (A (B→f^{CP} γ_R) / A (B→f^{CP} γ_L)) ~ 0.16 (HFAG)
  (~0.04 within SM due to m_s/m_b and gluon effects)

- CPV analysis in the $B_s \rightarrow \varphi\gamma$ decay can be performed without flavour tagging

$$\Gamma(B_q(\bar{B}_q) \rightarrow f^{CP}\gamma) \propto e^{-\Gamma_q t}\left(\cosh\frac{\Delta\Gamma_q t}{2} - \mathcal{A}^{\Delta}\sinh\frac{\Delta\Gamma_q t}{2} \pm \pm\mathcal{C}\cos\Delta m_q t \mp \mathcal{S}\sin\Delta m_q t\right)$$

SM:

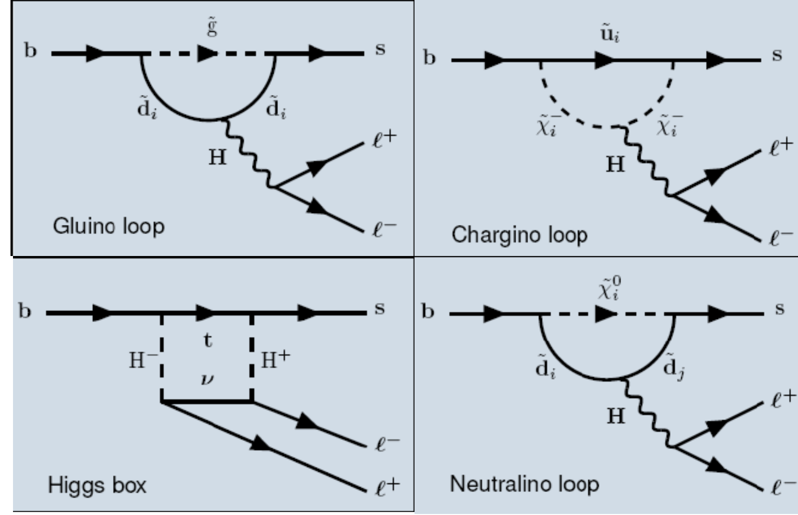
- C = 0 direct CP-violation
- S = **sin2ψ** sinϕ_s
- A^{Δ} = **sin2ψ** cosϕ_s

$$\tan\psi \equiv \left|\frac{A(\bar{B}\rightarrow f^{CP}\gamma_R)}{A(\bar{B}\rightarrow f^{CP}\gamma_L)}\right|$$

❑ Expected signal yield at LHCb is 11k for 2 fb^{-1}

Sensitivity: σ (A (B→f^{CP} γ_R) / A (B→f^{CP} γ_L) = 0.11 for 2fb^{-1}

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

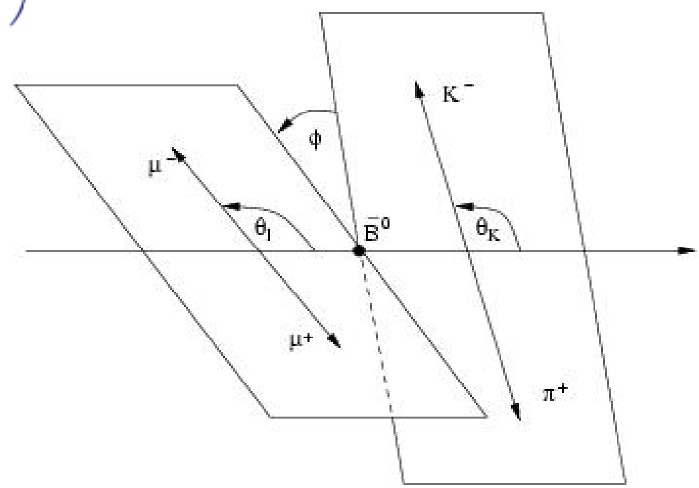


In SM this b→s penguin decay contains well calculable right-handed contribution but this could be added to by NP resulting in modified angular distributions

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

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

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



- *Described by three angles (θ_l, ϕ, θ_K) and di-μ invariant mass q^2*

- *Forward-backward asymmetry A_{FB} of θ_l distribution of particular interest:*
  - *Varies between different NP models →*
  - *At zero-point, dominant theor. uncert. from hadronic form-factors cancels at LO*

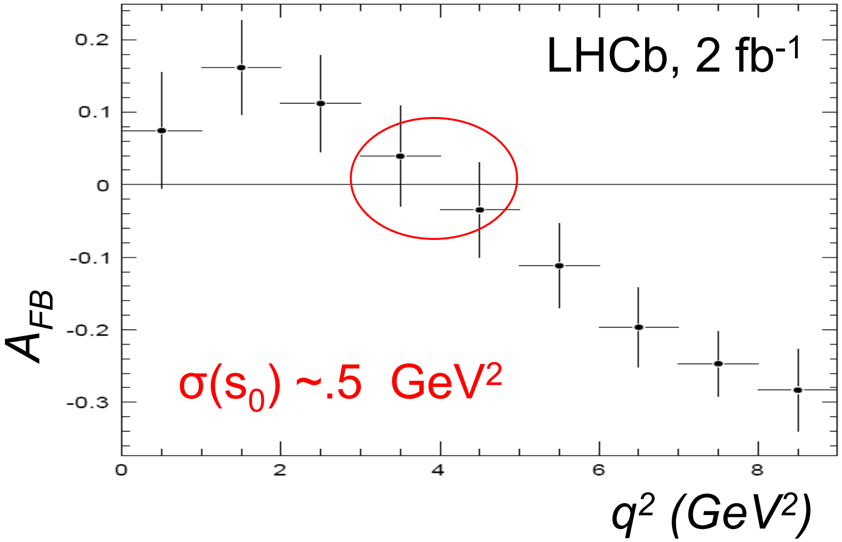
$$A_{FB}\left(s = m^2_{\mu^+\mu^-}\right) = \frac{N_F - N_B}{N_F + N_B}$$

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

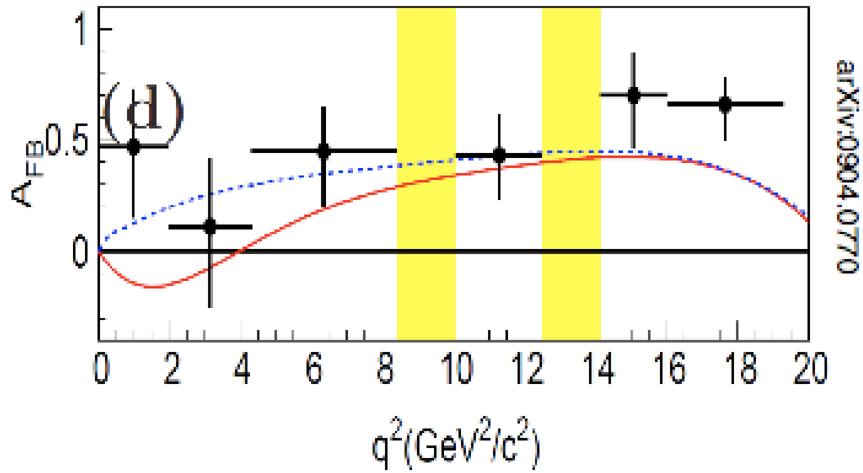
A_{FB} at B-factories defined with opposite sign to LHCb

- *Forward-backward asymmetry A_{FB} (s) in $\mu\mu$-rest frame is a sensitive NP probe*
- *Predicted zero of A_{FB} (s) depends on Wilson coefficients C_7^{eff} / C_9^{eff}*

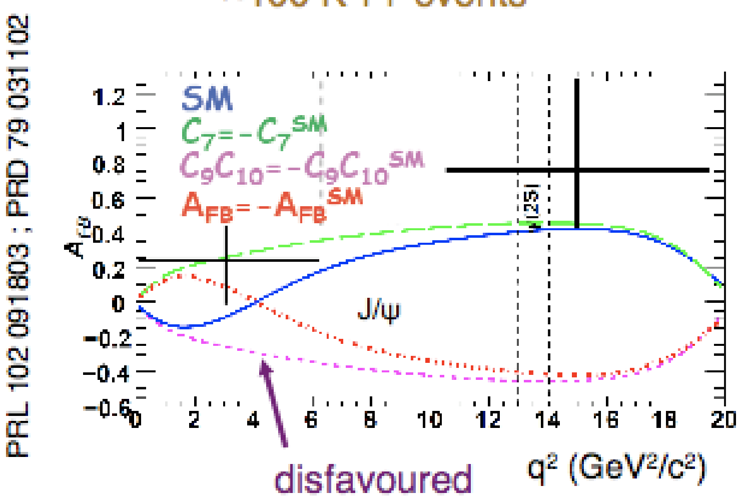
simple binned, counting analysis



Belle: 657million BBbars analysed
~250 K*l+l- events



BaBar: 384 million BBbars analysed
~100 K*l+l- events



LHCb expects ~7k events / $2fb^{-1}$ with B/S ~ 0.2 After 2 fb^{-1} zero of A_{FB} located to ±0.5 GeV^2. Full angular analysis gives better discrimination between models.

Photon polarization from $B_d \to K^{*0}e^+e^-$

Contribution not coming from virtual photons can be neglected at low $q^2 < (1\ \text{GeV})^2$

$\to$ *use of final state with electrons is more advantageous wrt muons*

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

- *In SM at $q^2 \to 0$ limit $A_T^{(2)} \approx -2Re\,|H_{+1}/H_{-1}|$*
  $\to$ *the fraction of right-handed photons in the amplitude*

- *$A_T^{(2)}$ can be extracted from the fit to the distribution of φ – angle between di-lepton and K* planes*

- *LHCb yield with 2 fb^{-1}: ~ 200 – 250 events with B/S ~ 1*

Expected sensitivity ***$\sigma(A(B\to f^{CP}\gamma_R)/A(B\to f^{CP}\gamma_L)) \approx 0.1$***
is limited by statistics and comparable to $B_s\to\varphi\gamma$ accuracy

LHCb key measurements

(to search for NP in CP violation and Rare Decays)

Key Measurements	**Accuracy in 1 nominal year ($2\ fb^{-1}$)**
❑ *In CP – violation*	
✓ β_s	**0.03**
✓ γ in trees	4.5^{o}
✓ γ in loops	$<10^{o}$
❑ *In Rare Decays*	
✓ $B_s \rightarrow \mu\mu$	**3σ measurement down to SM prediction**
✓ $B \rightarrow K^{*}\mu\mu$	$\sigma(s0) = 0.5\ GeV^2$
✓ Polarization of photon in radiative penguin decays	$\sigma(H_R/H_L) = 0.1$ (in $B_s \rightarrow \phi\gamma$) $\sigma(H_R/H_L) = 0.1$ (in $B_d \rightarrow K^{*}e^{+}e^{-}$)

Measurements highlighted in red will become competitive first

Commissioning of LHCb

First attempt to perform time synchronization and space alignment using cosmics and LHC beam induced events

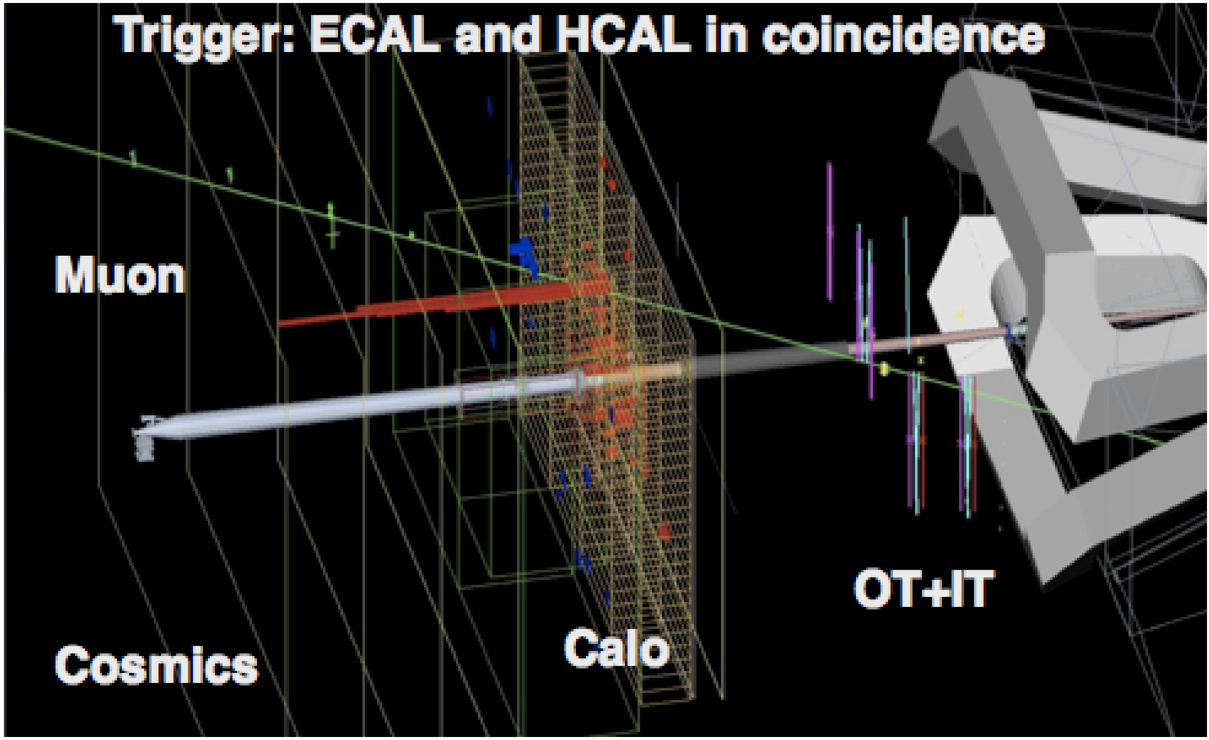
- Use of cosmics non-trivial since LHCb is horizontal and located deep underground → effectively works only for big sub-systems located downward the magnet: Outer Tracker (OT), Calorimeter and Muon

Few Hz Trigger on "horizontal" cosmic tracks

- Muon & CALO synchronized to a few ns

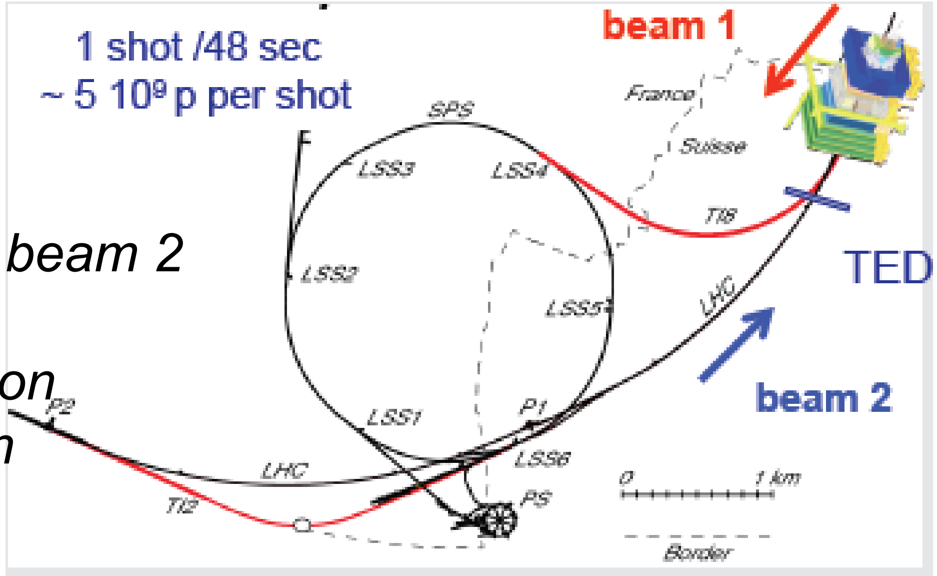
-OT aligned to ~ 1 mm

- L0 trigger commissioned

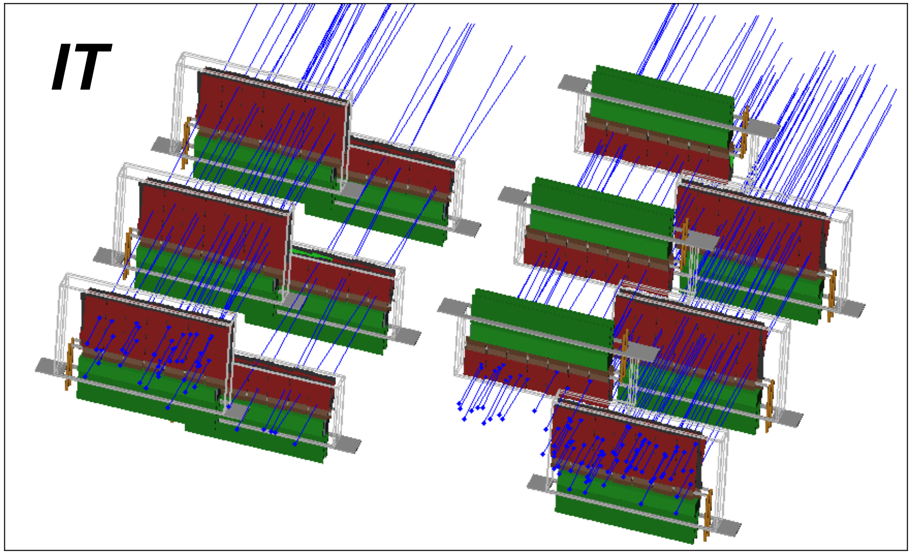


Commissioning of LHCb

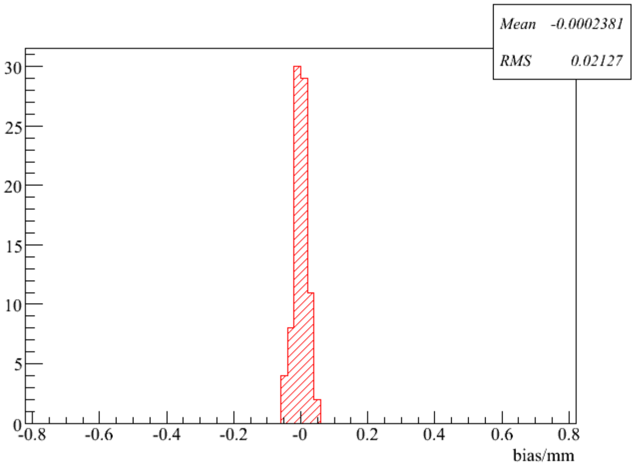
Beam 2 dumped on injection line beam stopper (TED)



- Located 340 m away from LHCb along beam 2
- High flux O(10) particles / cm^2
- Particles cross LHCb in a wrong direction
- ~40 k tracks collected and used to align high granular Vertex (VELO) and Inner Tracker (IT) detectors

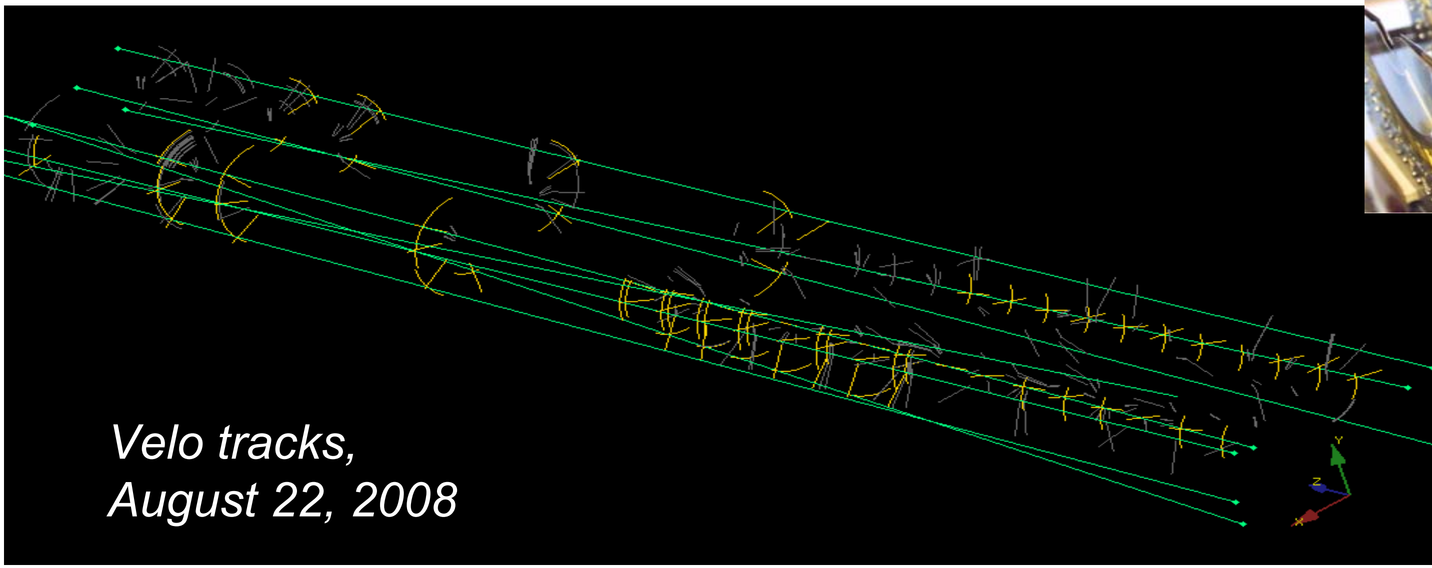


Ladder position in the Inner Tracker is known to 20μ precision

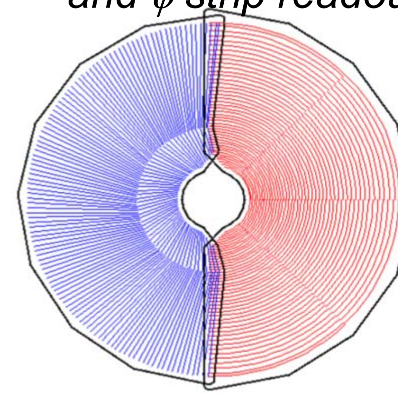


VELO alignment

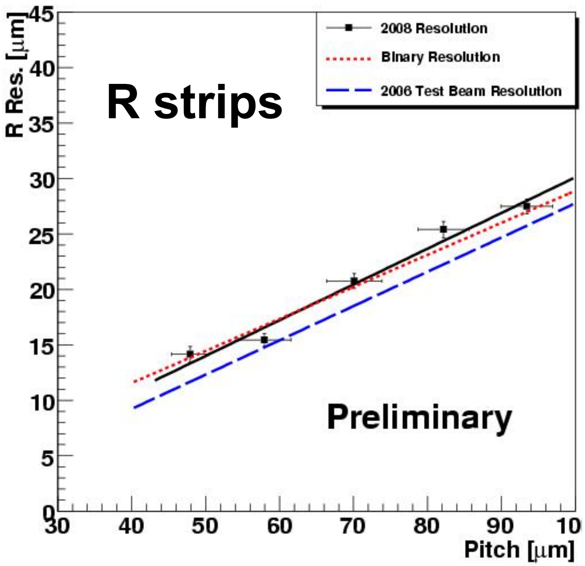
TED tracks perfect for VELO alignment: cross detector almost parallel to z-axis

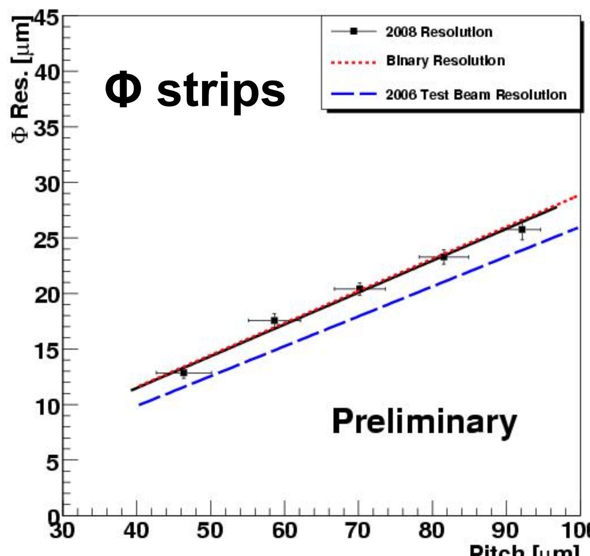


21 stations of Si wafer pairs with r and ϕ strip readout



resolution in μ



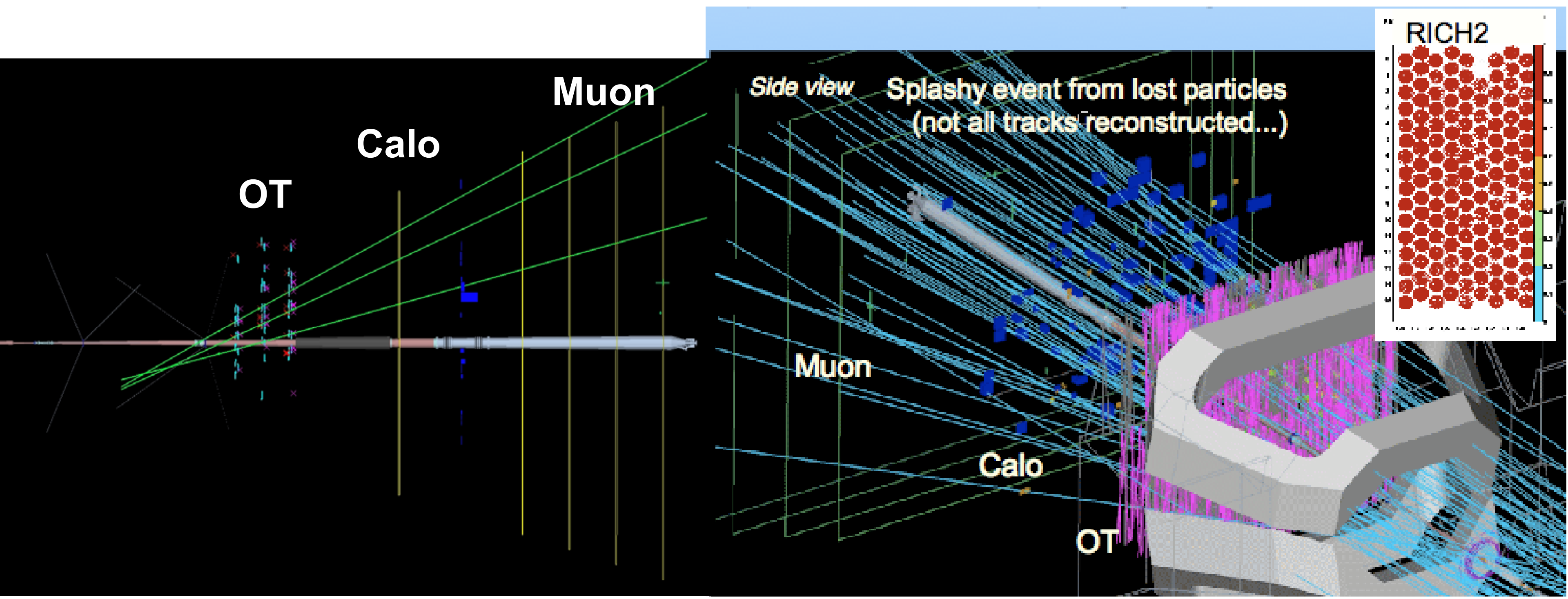


Resolution estimated from VELO hit residuals agrees well with expectations

Further improvement possible

Events registered on September 10, 2008 for a LHC operation (media day)

- *Beam 1 was circulated during few hours (correct direction for LHCb)*
- *Readout of consecutive triggers, 8 events every 25 ns*
- *Two types of events have been observed: a'la beam gas events and splashy events hitting on collimator*
- ***LHCb made very successful start !!!***



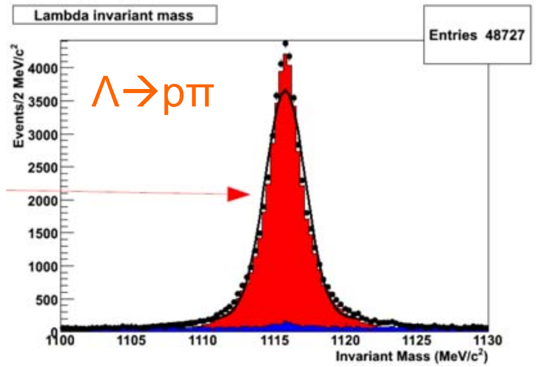
Physics goals of 2010

Early measurements

- Calibration signals and minimum bias physics: 10^8 events

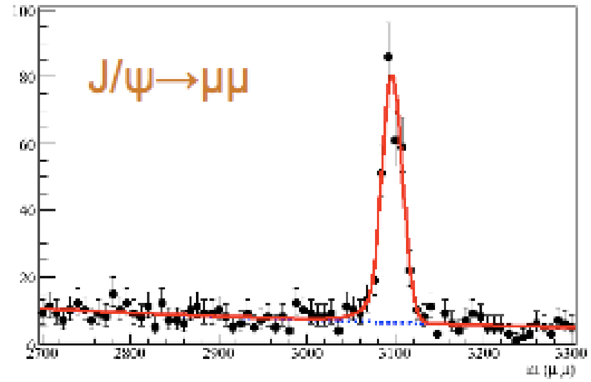
Key channels available in min bias data with simple trigger:

- $K_s \rightarrow \pi\pi$
- $\Lambda \rightarrow p\pi$



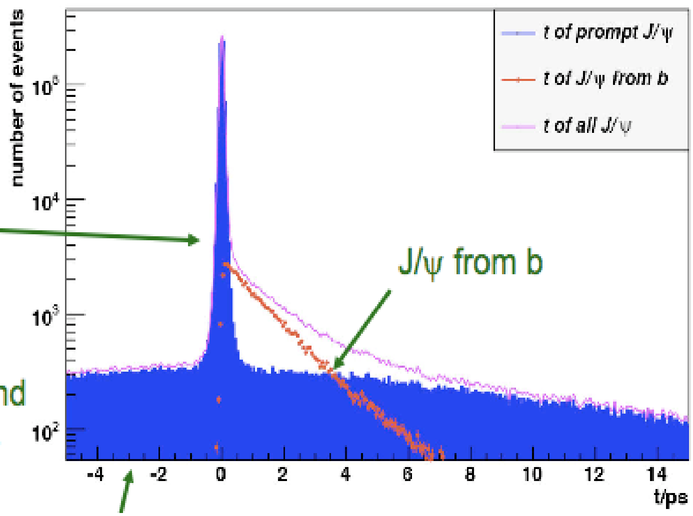
95% purities achievable using kinematical & vertex cuts alone

~ 40 mins @ 10^{31}
With 2 kHz random trigger



- *J/ψ trigger on single muon with p_t cut (600k ev./pb^{-1})*
  → one muon unbiased for PID studies and momentum calibration

- J/ψ physics & production cross-sections: ~ 1-5 pb^{-1}



Measure diff. cross-section for prompt J/ψ and bb production cross-section (from secondary J/ψ) in region inaccessible to other experiments

Physics goals of 2010

❑ Analysis commissioning in hadronic modes

Channel	Yield / 10 pb^{-1}
$B^0 \to K\pi$	340
$B \to D(K\pi)X$	31k
$B^+ \to D(K\pi)\pi^+$	1900
$B^+ \to D(K\pi)K^+$	160
$B_s \to D_s\pi^+$	320

Detailed studies of $D \to hh$ (rehearsal for $B \to hh$)

- *Separate $K\pi$, KK, $\pi\pi$ and DCS $K\pi$*
- *Vertex and mass resolutions*
- *Lifetimes*

Accumulate samples of $B \to D(K\pi)\pi$ ("ADS" control mode)

- *Study background environment*
- *Look for any evidence of B^+ / B^- asymmetries*

❑ Charm physics: 20 pb^{-1} and upward

(Exciting possibilities even with low luminosity)

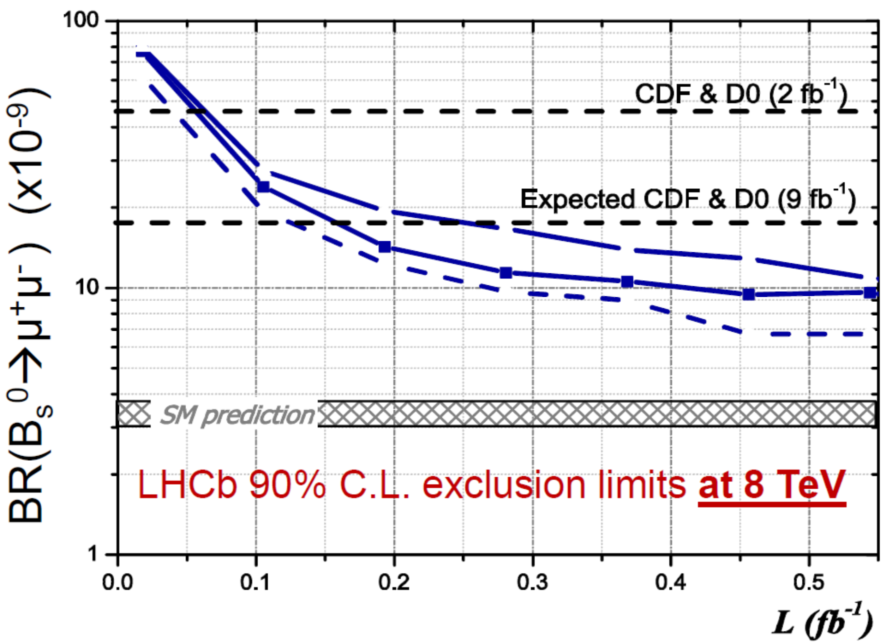
An example: flavour tagged $D^0 \to KK$ events for measuring y_{CP}

$$y = \tau(D^0 \to K\pi) / \tau(D^0 \to KK) - 1$$

and corresponding CP asymmetry

LHCb can collect ~ 10^5 flavour tagged KK events with 20 pb^{-1} (same statistics as BELLE with 540 fb^{-1}). Similar data sets for many related channels: $D^0 \to \pi\pi$, $KK\pi\pi$, $K_S\pi\pi$, K_SKK, $D^+ \to KK\pi$ …

Prospects for most competitive measurements in 2010

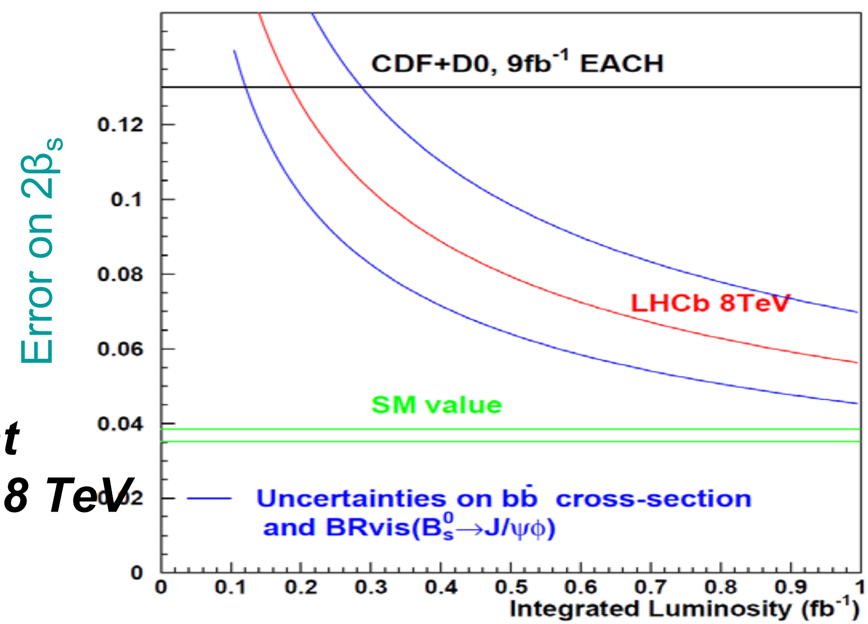


LHCb can exclude ***$BR(B_s \to \mu\mu)$*** *at 2×10^{-8} with about 100 – 150 pb^{-1}*

Similar limit is expected from Tevatron on this timescale

→ Sensitive test of SUSY should be possible in a year !!!

For β_s from $B_s \to J/\psi\varphi$ LHCb assumes data sets of a few 100 pb^{-1}, but method shown to extrapolate down to smaller event samples (works at Tevatron as well)



Present 'central value' would be confirmed at 5σ level with ~150-200 pb^{-1} collected at E_{cm}= 8 TeV
Similar sensitivity from Tevatron with 9 fb^{-1}

Conclusions

- *LHCb is ready for data taking*
- *First data will be used for calibration of the detector and trigger in particular. First exploration of low Pt physics at LHC energies. Some high class measurements in the charm sector may be possible*
- *With 150 – 200 pb^{-1} data sample LHCb will reach Tevatron sensitivity in a few golden channels in the beauty sector*
- *LHCb has plenty of room for discoveries of New Physics with a ~ 10 fb^{-1} data sample needed to complete LHCb physics programme*
- *Study of possible LHCb upgrade, in order to collect ~100 fb^{-1} data sample, is underway*