LHCb : b Physics Prospects

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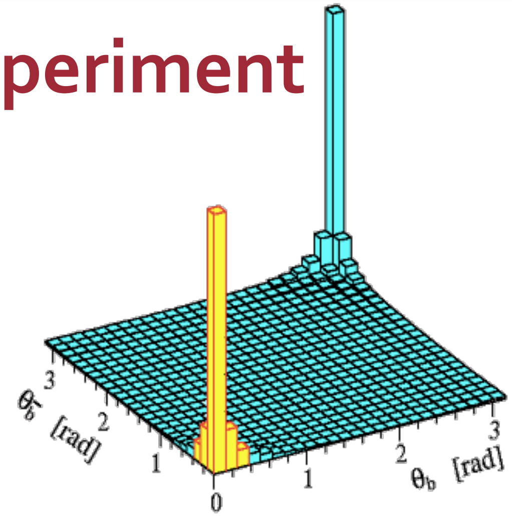
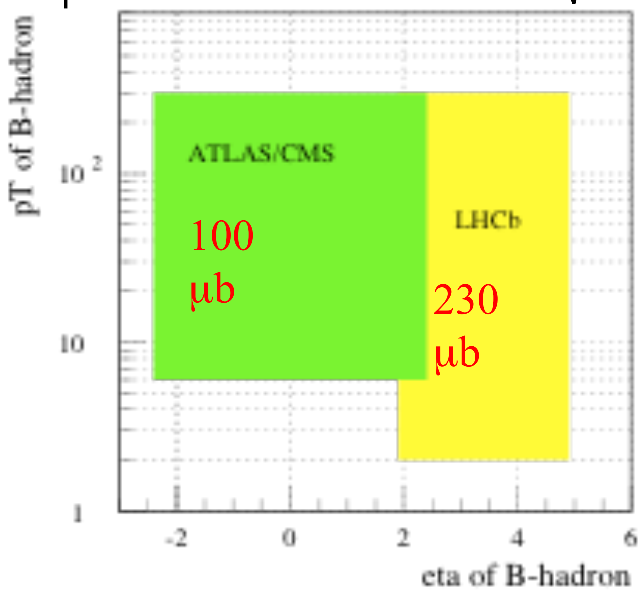
On behalf of the LHCb Collaboration
Aspen 2010

The LHCb Experiment

- **Dedicated precision heavy flavour experiment**
- **Why at a hadron collider like the LHC ?**
  - High beauty cross section TeV energies (σ_{bb}=500mb)
  - All b-hadrons are accessible (B^0,B_s^0,B_c,Λ_b)
- **Experimentally Challenging**
  - High track multiplicity (o(50) per event)
  - High background rate ($\sigma_{inelastic}$ ~ 80 mb)
- **Luminosity limited to ~ 2x10³² to limit multiple interactions per bunch crossing**
  - Expect to reach this in 2010
  - Expect ~ 2fb⁻¹ per nominal year @ 14 TeV (10⁷ secs)
  - In 2010 run. Also consider 200-500 pb⁻¹ @ 7 TeV
- **LHCb acceptance optimised for forward bb production**
  - b production at low angle and correlated to same hemisphere
  - Acceptance 1.9 < η < 4.9
  - Trigger optimised for b decays (e.g. low p_t, pure hadronic final states (compared to general purpose detectors).



$b\bar{b}$ production cross section at $\sqrt{s}$=14 TeV

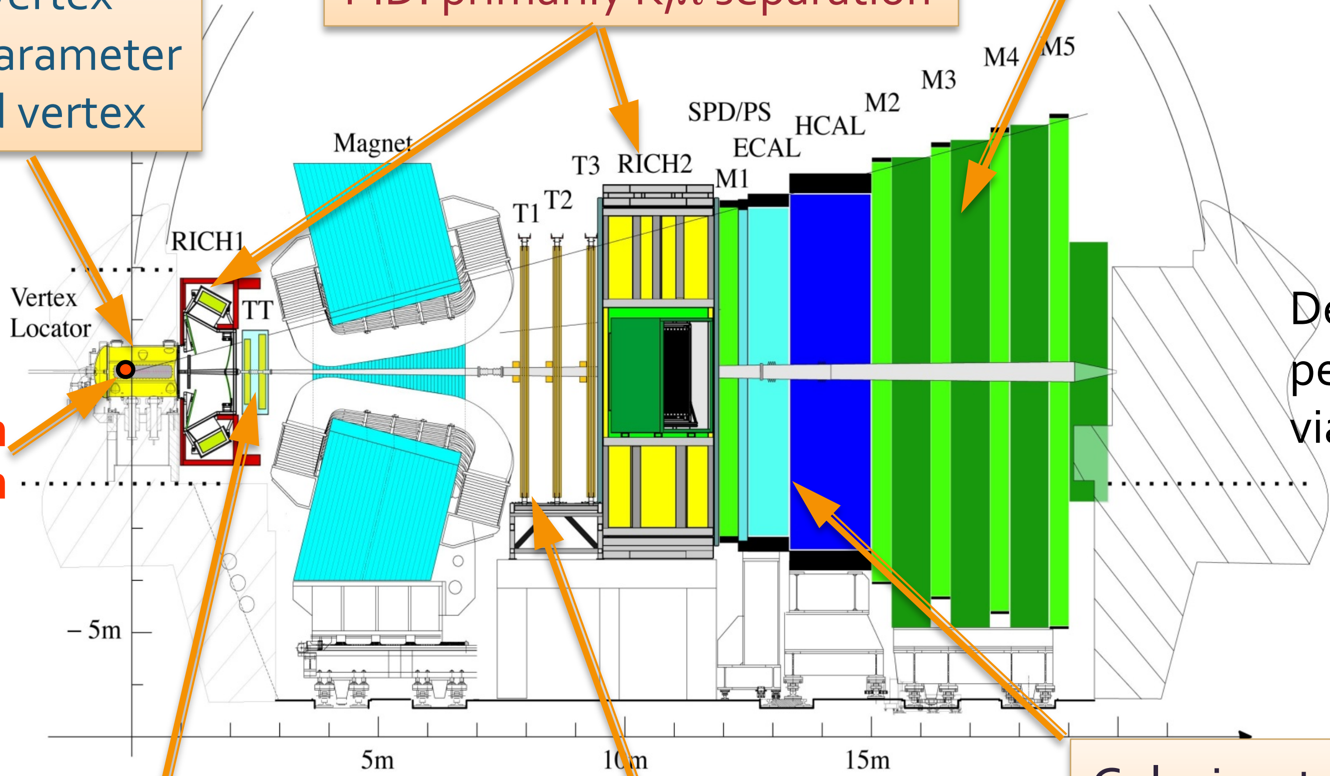


The LHCb Detector

VELO:
primary vertex
impact parameter
displaced vertex

RICH:
PID: primarily K,π separation

Muon System



Interaction region

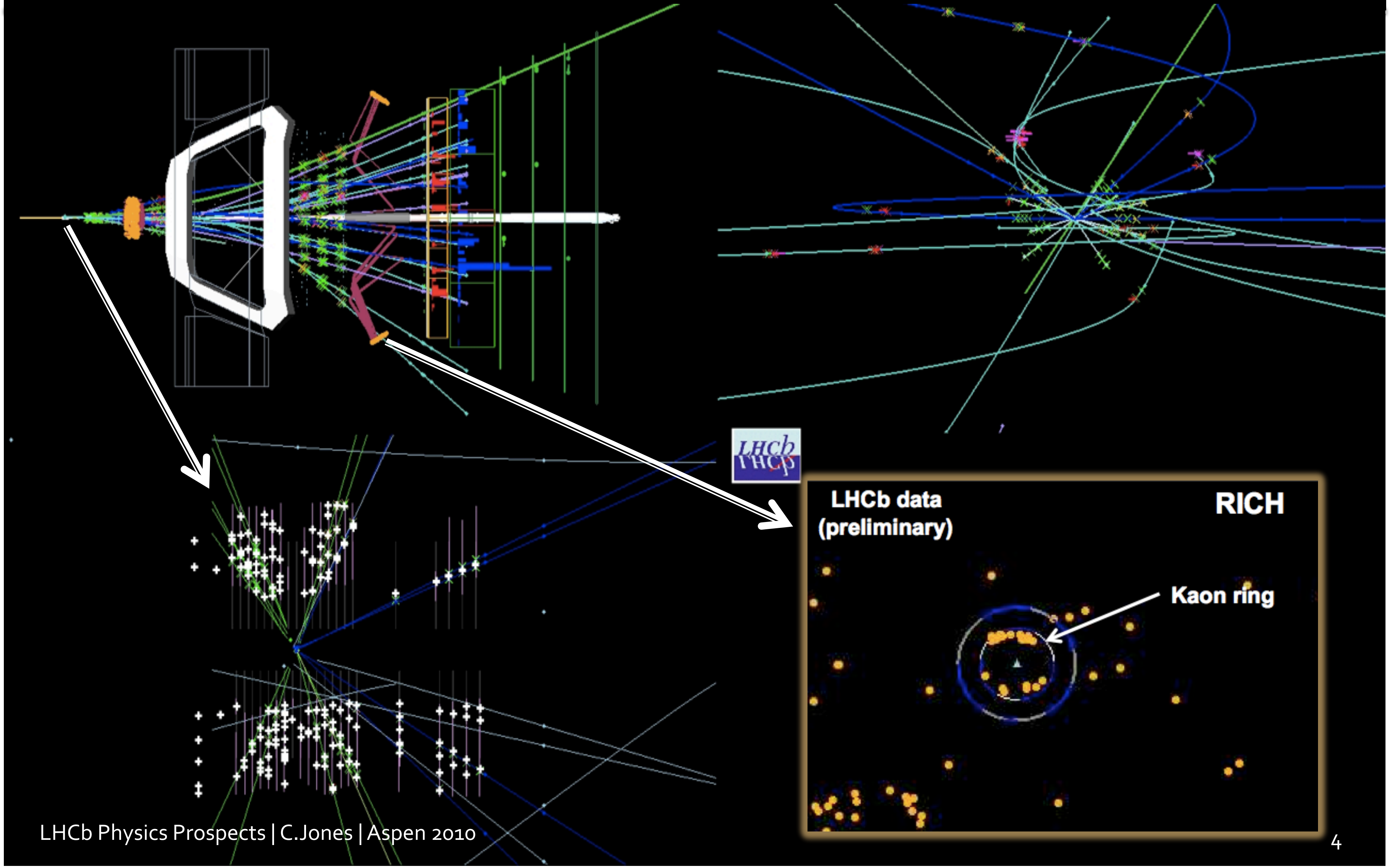
Demonstrate performance via examples

Tracking Station: p for lower energy tracks and long lived V° reconstruction

Tracking Stations:
p of charged particles that traverse the magnet

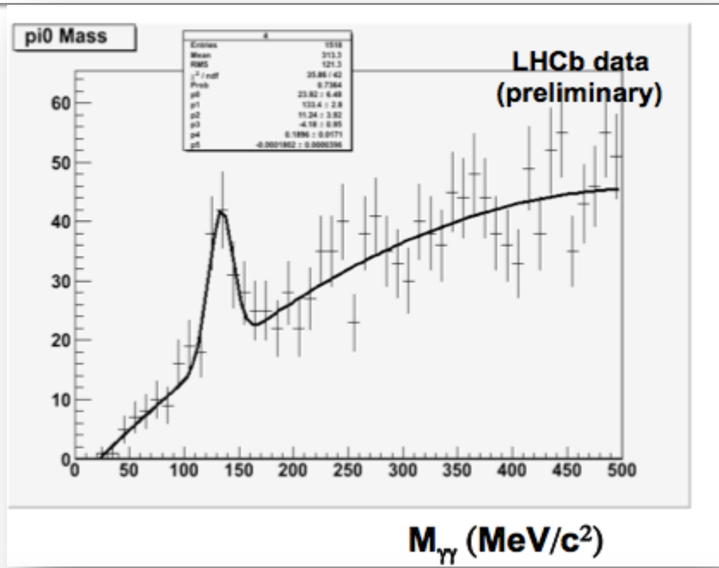
Calorimeters:
PID: h,e,γ, π°

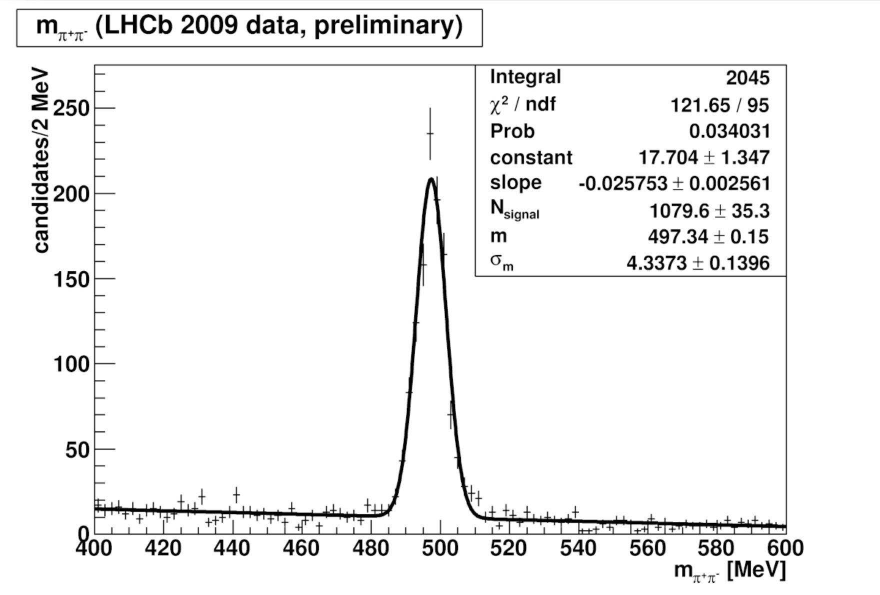
First pp Collisions in 2009 !

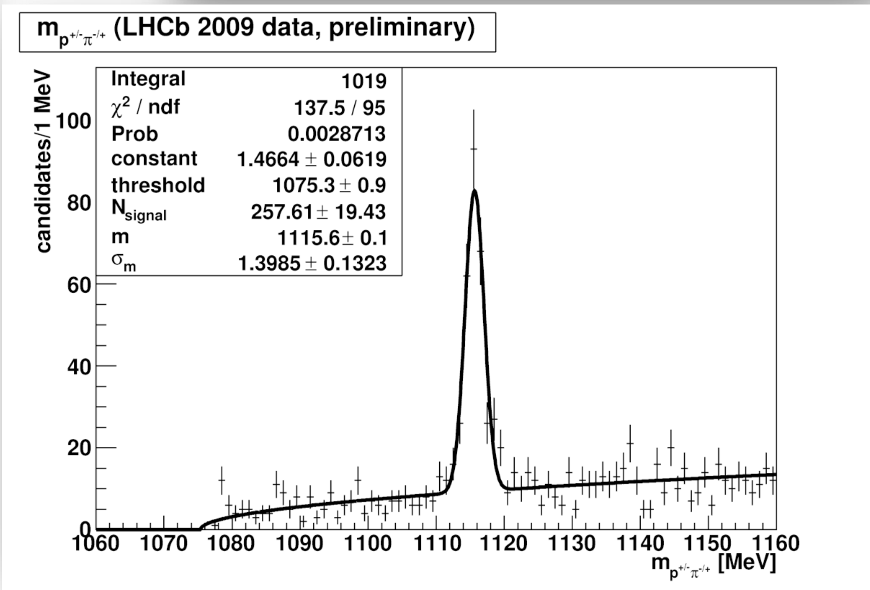


Rediscovering 'Old' Physics

- **Successful 2009 Run !**
  - Calibration and alignment data samples
    - LHCb geometry not optimal for using cosmic rays for calibration
  - e.g. Use π^0, K_s and Λ as known tools







LHCb Physics Program

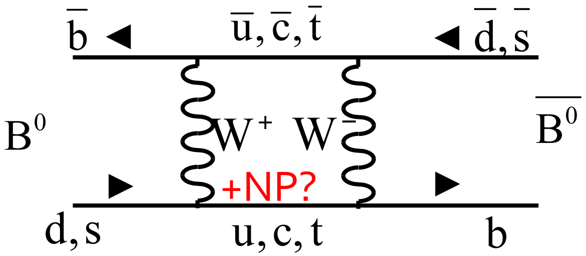
- **Great progress at B factories and Tevatron**
  - Standard Model cannot be the ultimate theory.
    - LHCb has expanded its focus to search for New Physics in the flavour sector
  - New physics models introduce new particles and/or symmetries at TeV energy scales.
    - Observed *directly* as real particles (Atlas, CMS)
    - Appear *indirectly* as virtual particles. E.g. loop processes.
      Produces deviations from SM expectation (e.g. CP observables, angular distributions and decay rates)
- **Focus on some key LHCb measurements**
  - CP Violation — B_s mixing phase Φ_s, $B \rightarrow DK$: γ from loops and trees, $B \rightarrow hh$
  - Rare Decays — $BR(B_s \rightarrow \mu^+\mu^-)$, forward-backward asymmetry in $B \rightarrow K^*\mu\mu$

For more details see the LHCb Roadmap document

http://arxiv.org/abs/0912.4179

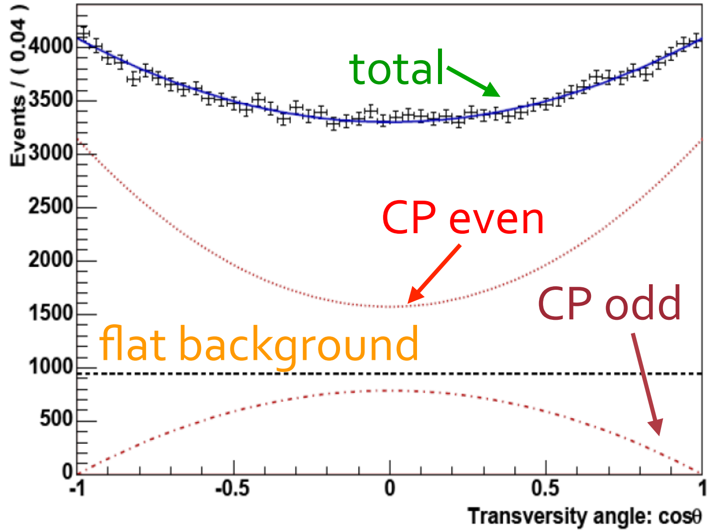
B_s-$\overline{B}_s$ Mixing Phase Φ_s in $B_s \to J/\psi(\mu\mu)\phi$

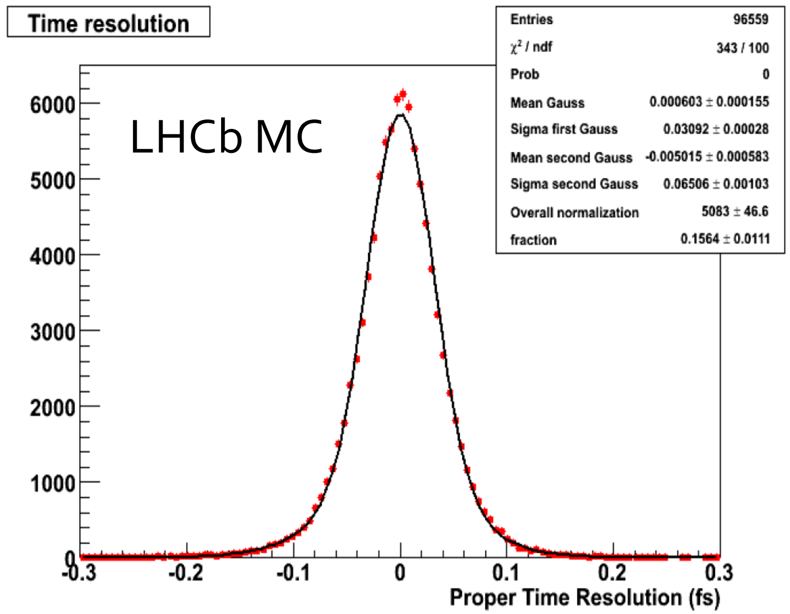
- **Counterpart to φ from $B^0 \to J/\psi K^0$ at B factories**
  - "Golden" mode for B_s mixing induced CP violation
  - Mixture of 2 even and 1 odd CP eigenstates
- **Mixing phase Φ_s sum of SM and NP contributions**
  - Precise SM prediction
  - Some NP models predict large phases still consistent with current constraints, e.g. Δm_s



➢ in SM: $\phi_s = -2\beta_s = -\arg(V_{ts}^2) = -0.036 \pm 0.002$

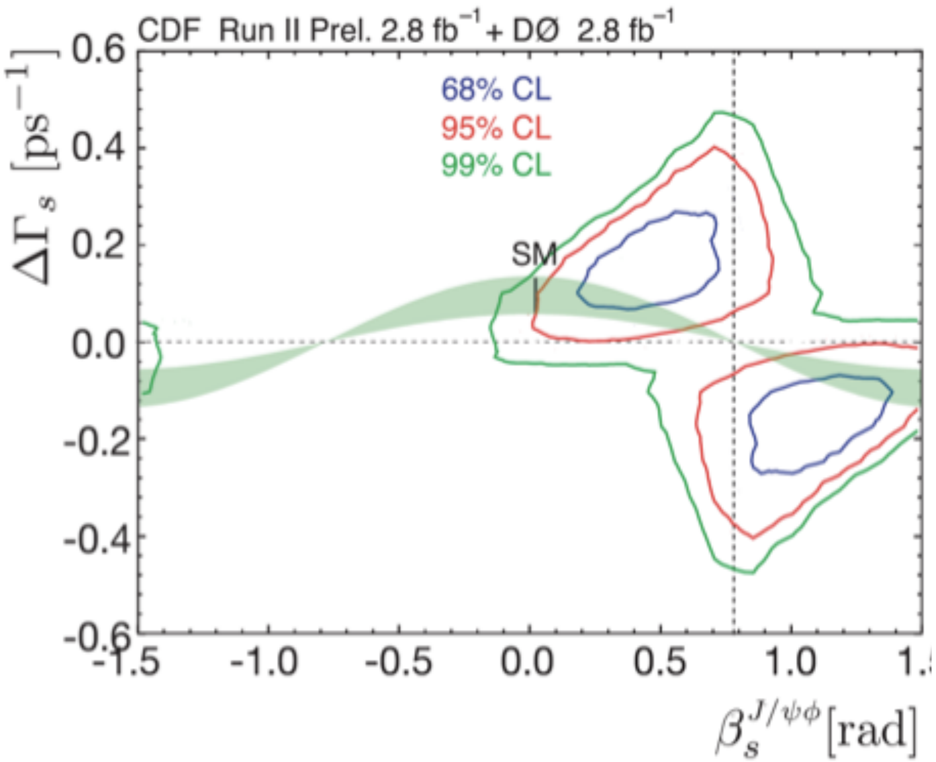
- **Detector Requirements**
  - Muon and Kaon ID
  - Proper time resolution (38 fs)
  - Flavour tagging

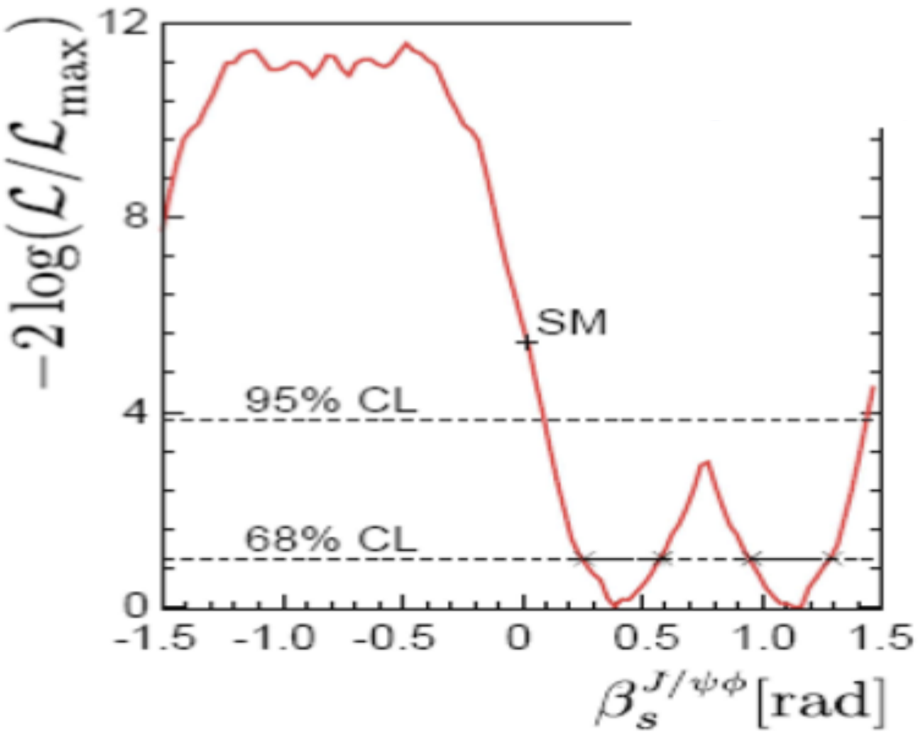




B_s-$\overline{B}_s$ Mixing Phase Φ_s in $B_s \rightarrow J/\psi(\mu\mu)\phi$

- **Current Tevatron result ~ 2.1 σ away from SM value**
  - … and where we might hope to see something

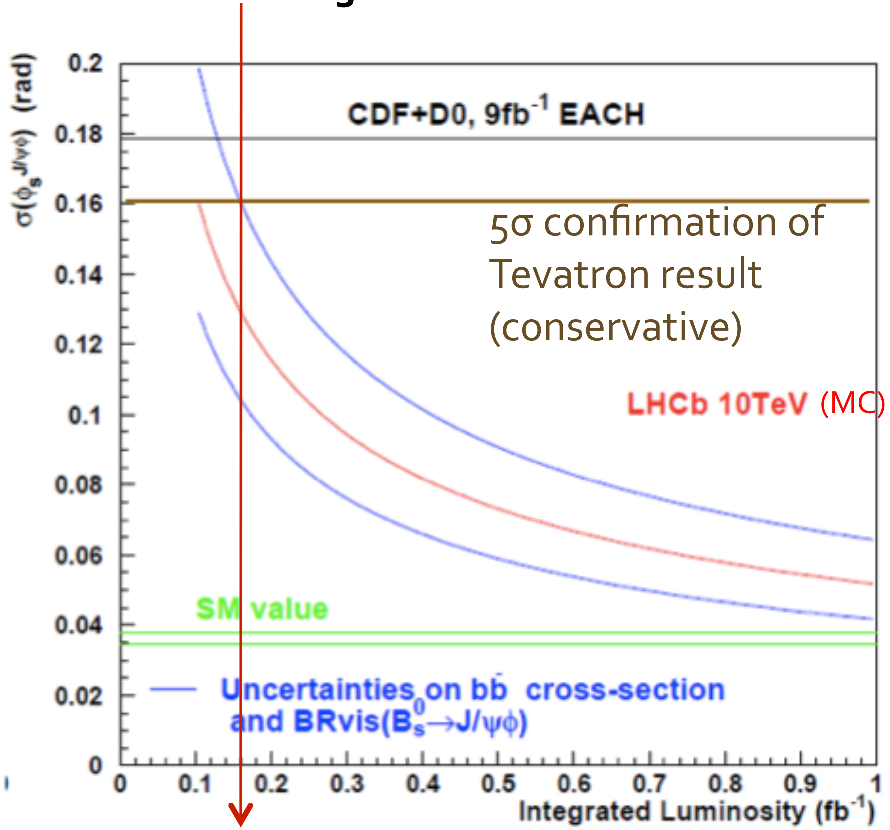


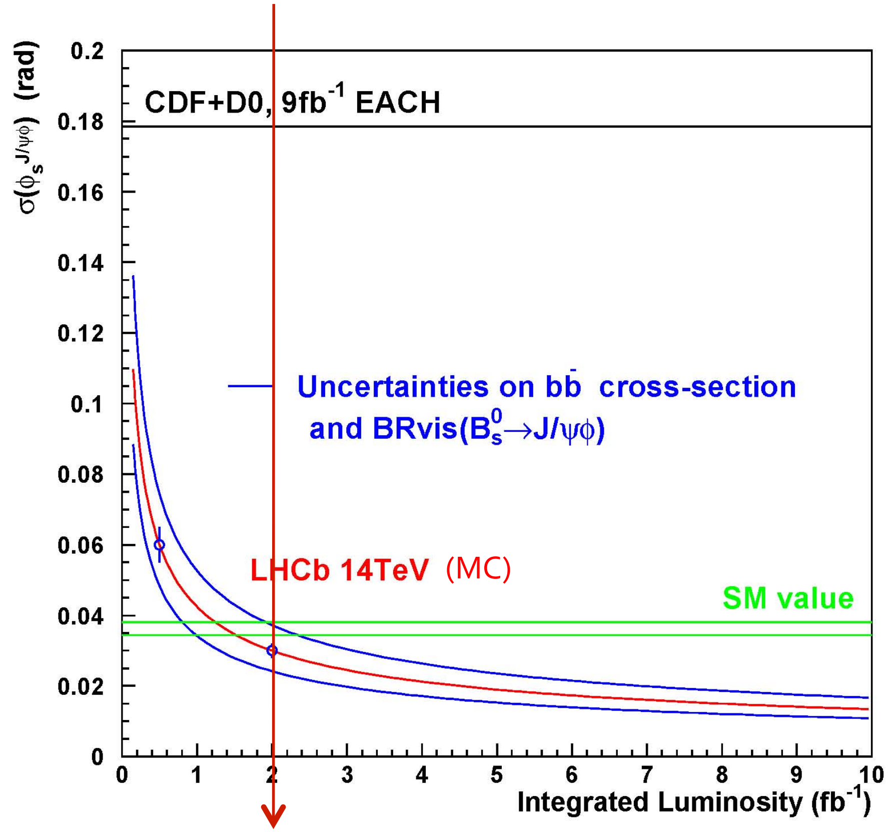


need to proceed with care though …

B_s-$\bar{B}_s$ Mixing Phase Φ_s in $B_s \to J/\psi(\mu\mu)\phi$

- **LHCb Φ_s reach as a function of integrated luminosity**



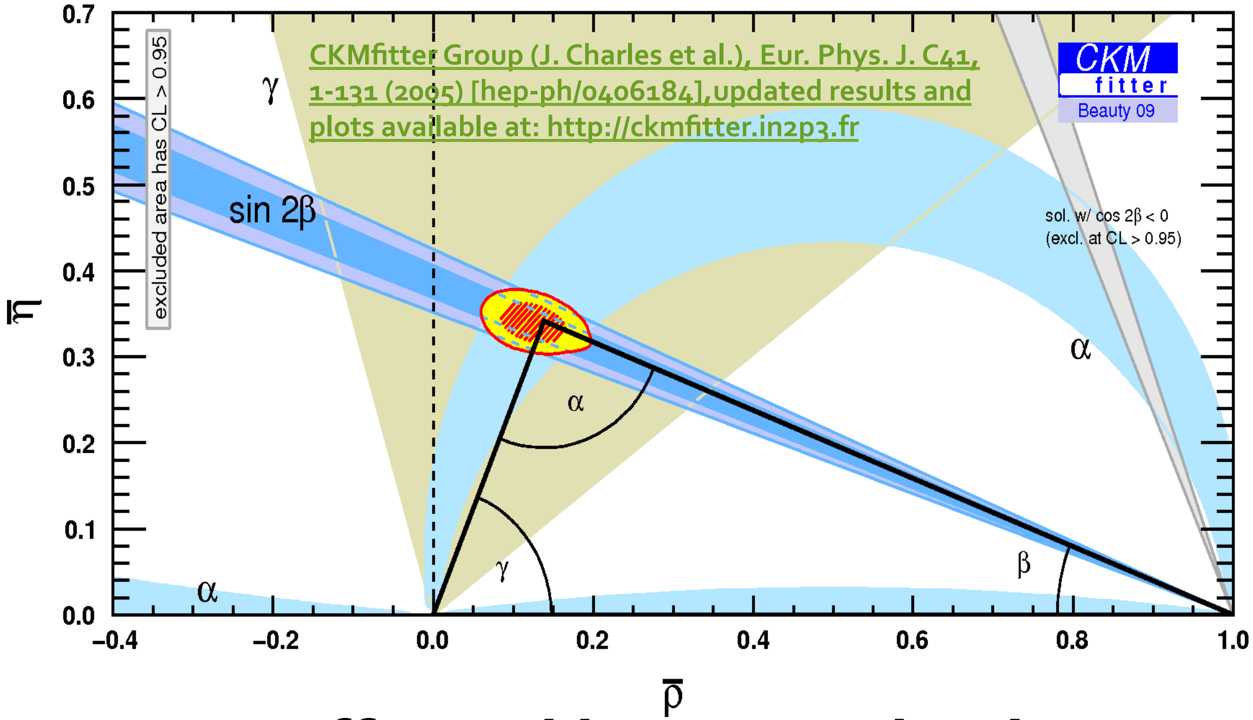


If true value is within 68% CL interval quoted by CDF and D0, LHCb can observe New Physics with early data (~0.15fb^{-1})

or … with ~2 fb^{-1} $\sigma(\phi_s)$ reaches SM value

2009 CKM γ Status

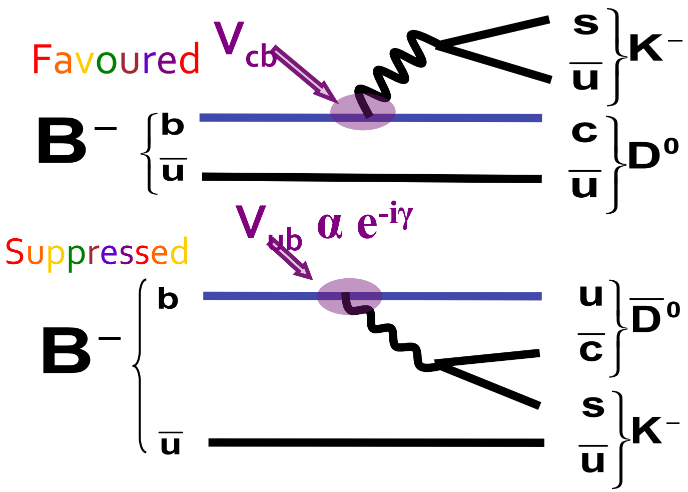
- γ is the least well known of the CKM angles
  - CKM Fitter
    $\beta = 21.2^{o} \pm 0.9^{o}$
    $\alpha = 89^{o} \pm 4^{o}$
    $\gamma = 70^{+22}_{-25}{}^{o}$
  - UT Fit
    $\gamma = 75^{o} \pm 12^{o}$

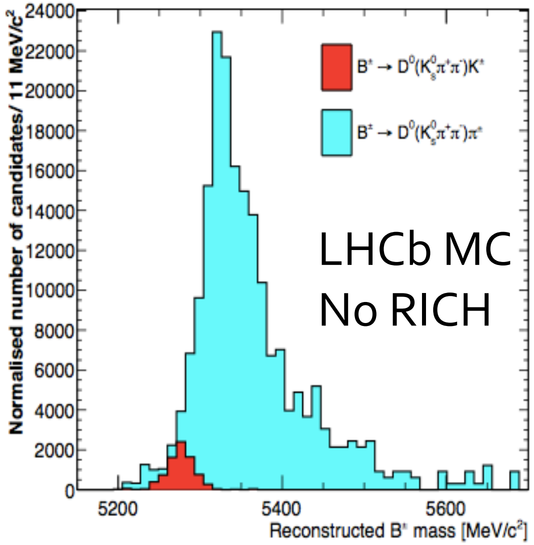


- Tree measurements unaffected by New Physics
  - Standard Model benchmark to be met by NP models
  - Precise measurement needed to probe NP from γ in loop measurements

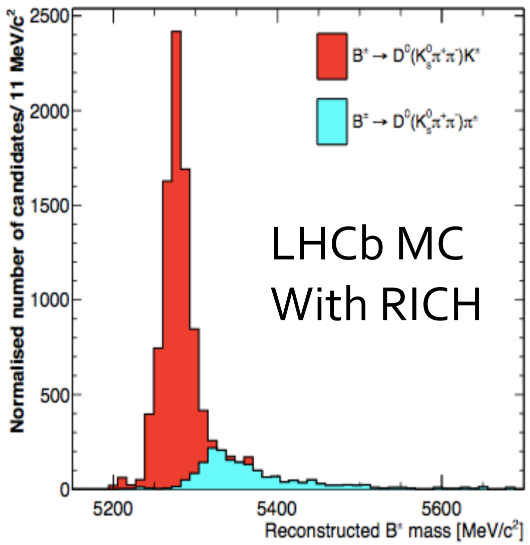
B → DK : γ from Trees

- **Various complementary methods :-**
  - Extract γ from interference of tree diagrams (Common $D^0/\bar{D}^0$ final states)
    - ***In sensitive to NP***
  - Hadron ID for kaon/pion separation





Kaon ID in B → DK



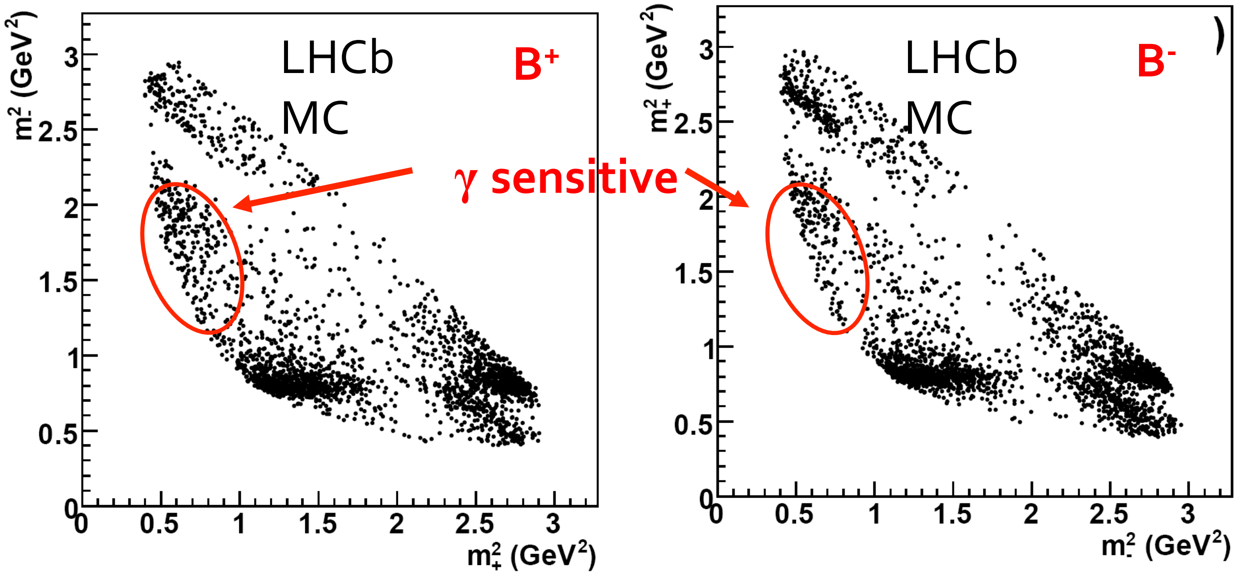
- **RICH PID performance:**
  - Kaon ID: ε >95% [2-100 GeV/c]
  - $\pi \rightarrow K$ misID < 4%

- Time independent methods :-
  - GLW : D → K^+K^-,$\pi^+\pi^-$ Phys. Lett. B 253, 483 (1991); Phys. Lett. B 265, 172 (1991).
  - ADS : D → $K^+\pi^-$,$K^-\pi^+$ Phys. Rev. Lett. 78, 3257 (1997); Phys. Rev. D 63, 036005 (2001).
    - 6 measured rates and 5 unknowns. Extrack γ from over-constrained fit
  - $B^\pm \rightarrow D^0(K_s\pi^+\pi^-)K^\pm$ Dalitz analyses

(… + others not discussed in detail)

Dalitz Extraction of γ

- **Sensitive through interference between B^+ and B^- in $B^\pm \to D^0(K_s\pi^+\pi^-)K^\pm$**
  - Large rate and rich resonant structure



- **Two approaches to extract γ**
  - Unbinned fit to using BaBar + Belle Isobar model, with systematic error from model dependence ~7°.
  - Binned method, bins of δ_D phase (using input from CLEO-c).
    - Strong phase uncertainty ~ 2°

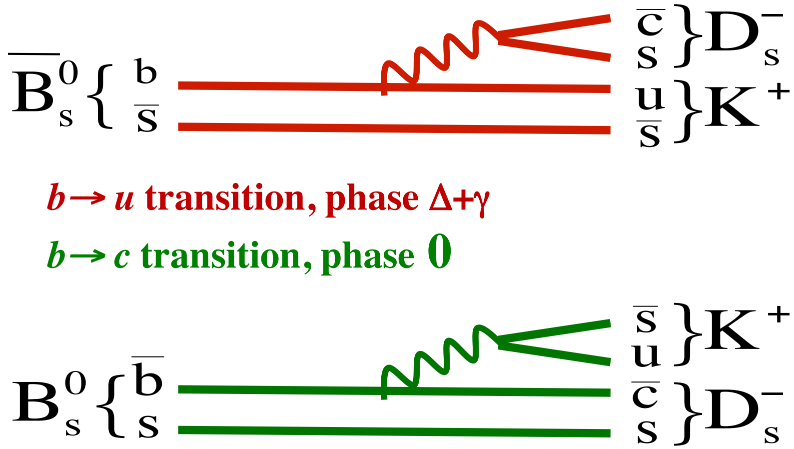
For 2fb^{-1}

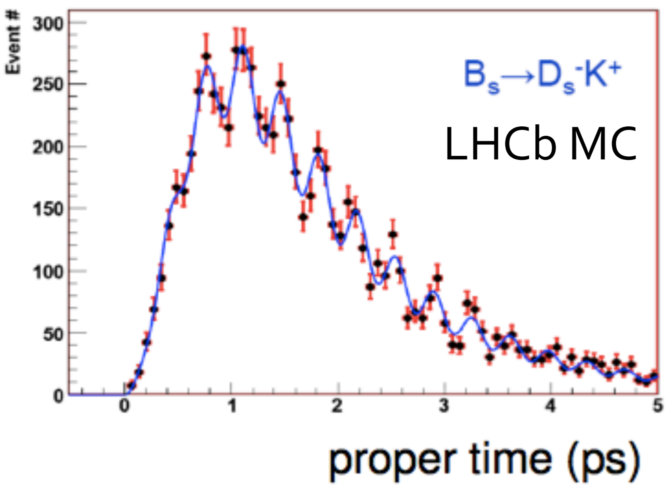
	Signal	B/S
$B^\pm \to D(K_s\pi\pi)K^\pm$	6.8 k	< 1.5 at 90% C.L.

Sensitivity $\sigma(\gamma)$ = 10-13°

$B_s \rightarrow D_s^- K^+$: Time Dependant Extraction

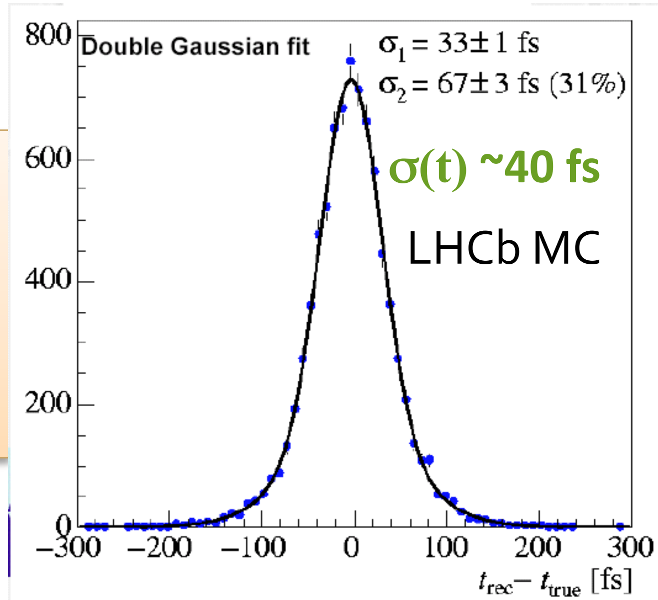
- **Time dependent analysis of $B_s \rightarrow D_s^- K^+$**
  - 2 tree decays *(b→c)* and *(b→u)* of same magnitude interfere via B_s mixing
    - Large interference effects
    - Insensitive to NP
  - Fit 4 flavour tagged time dependent rates
  - Proper time resolution crucial





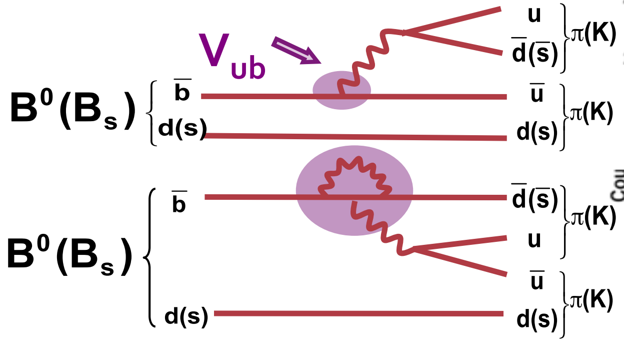
LHCb expects ~6200 events ($2fb^{-1}$) with B/S ~0.7

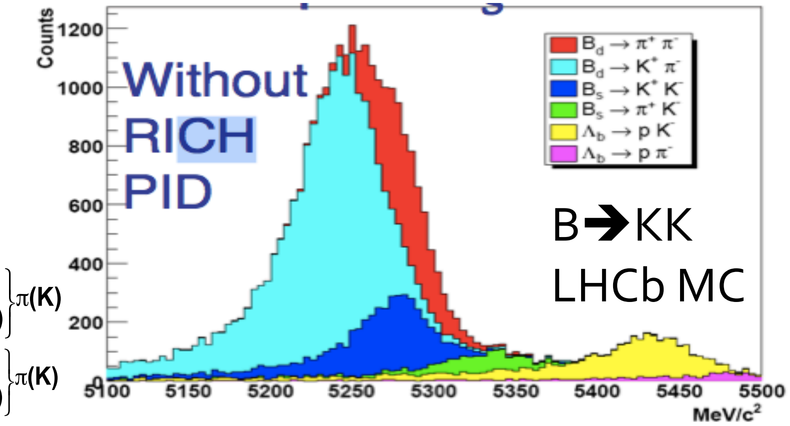
Sensitivity σ(γ) ~ 9-12°

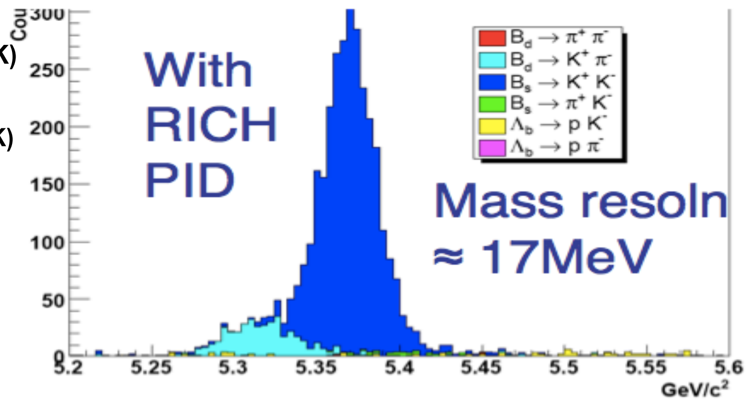


$B^o \rightarrow \pi\pi$ and $B_s \rightarrow KK$: γ in loops

- **Sensitivity to γ from interference**
  - Mixing
  - tree and penguin diagrams (Sensitive to NP)
- **Fit time dependent CP asymmetries**
- **Hadron ID Crucial**
- **$0.5\ fb^{-1}$ would give worlds largest B➔hh sample**
  - Early BR and asymmetry results
  - *First observation of B_s➔KK*
  - *First observation of time-dependant asymmetry.*





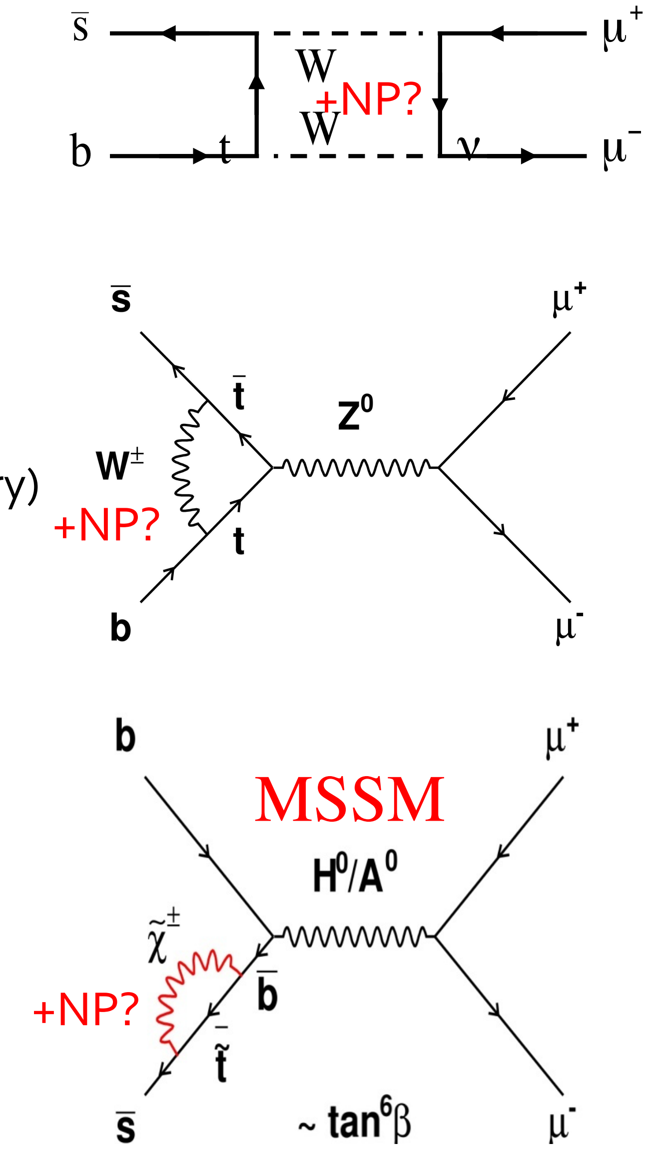


Mode	Sig. yield (untagged) ($/2fb^{-1}$)	B/S
$B^0 \rightarrow \pi\pi$	36k	0.5
$B_s \rightarrow KK$	36k	0.15
$B^0 \rightarrow K\pi$	140k	< 0.06
$B_s \rightarrow \pi K$	10k	1.9

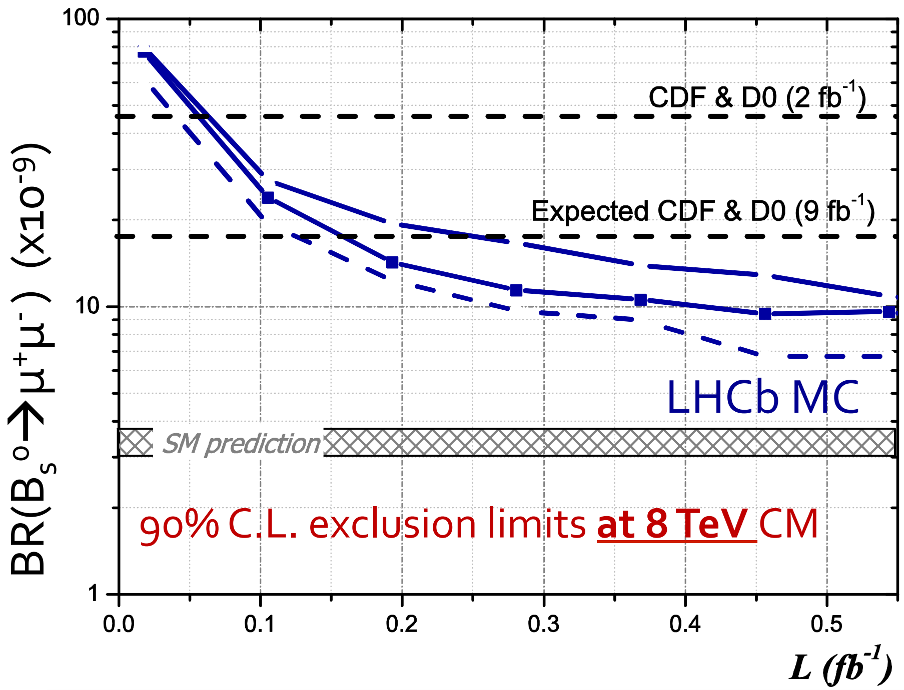
Sensitivity	$0.5\ fb^{-1}$	$2\ fb^{-1}$	$5 * 2\ fb^{-1}$
σ_γ B➔hh (°)		10	5
Compare to σ_γ from trees (°)	8-10	4-5	2-3

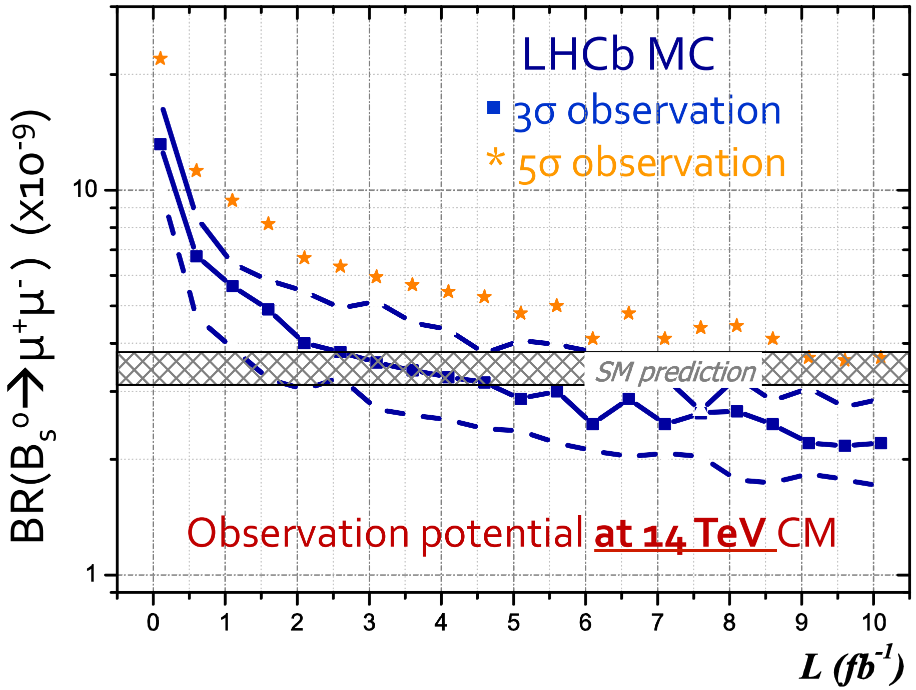
New Physics in $B_s \to \mu^+\mu^-$

- **Very rare decay (SM BR ~3.35x10^{-9})**
  - [hep-ph/0604057v5]
  - Sensitive to scalar sector of NP.
- **Statistics and background rejection is critical**
  - Efficient trigger
  - Loose event selection
  - Analysis in bins 3D space of (mass, Muon ID, geometry)
    - Backgrounds dominated by b➔μ
    - Other specific backgrounds include $B_c \to J/\psi(\mu\mu)\mu\nu$ and $B \to hh$
  - Good mass resolution (18 Mev/c²), vertexing and PID essential
- **Branching fraction normalisation through B → hh and B → J/Ψ K⁺ control channels.**



New Physics in $B_s \rightarrow \mu^+\mu^-$

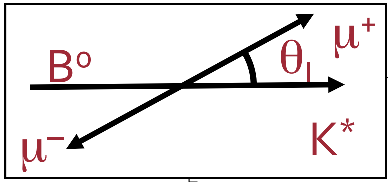


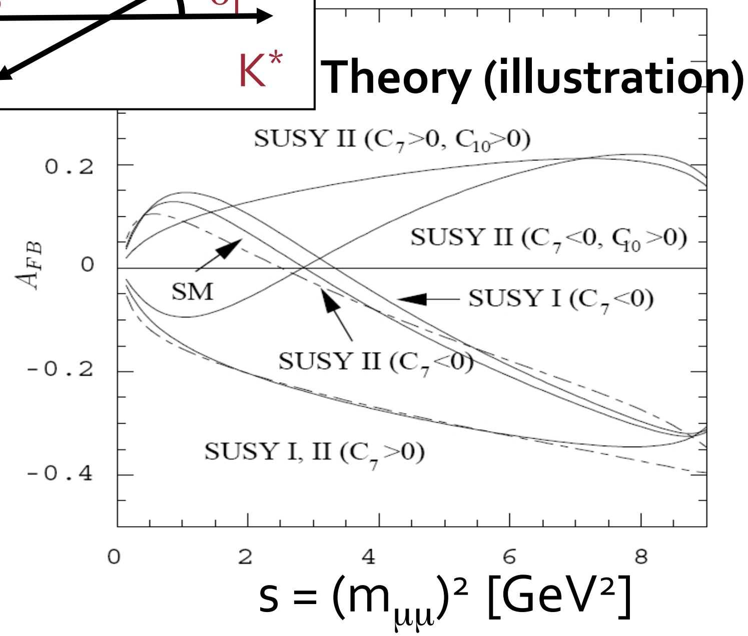


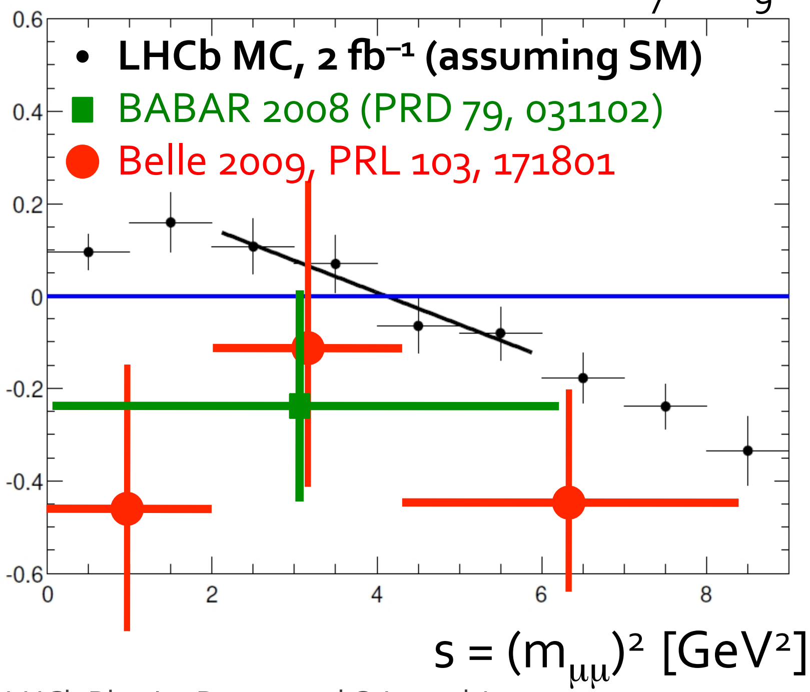
- **Require ~ 0.3 fb^{-1} at 8TeV to improve upon expected Tevatron limit with 9fb^{-1}**
- **Require ~ 3 fb^{-1} for 3σ evidence and ~ 10 fb-1 for 5σ observation of SM value**
- ***Potentially very exciting measurement for 2010***

New Physics in $B^o \rightarrow K^{*o}\mu^+\mu^-$

- **Suppressed loop decay**
- **Forward-backward asymmetry $A_{FB}(s)$ in μμ rest-frame**
  - Probe of new physics
  - zero of A_{FB} gives access to ratio of Wilson coefficients C_7^{eff}/C_9^{eff}







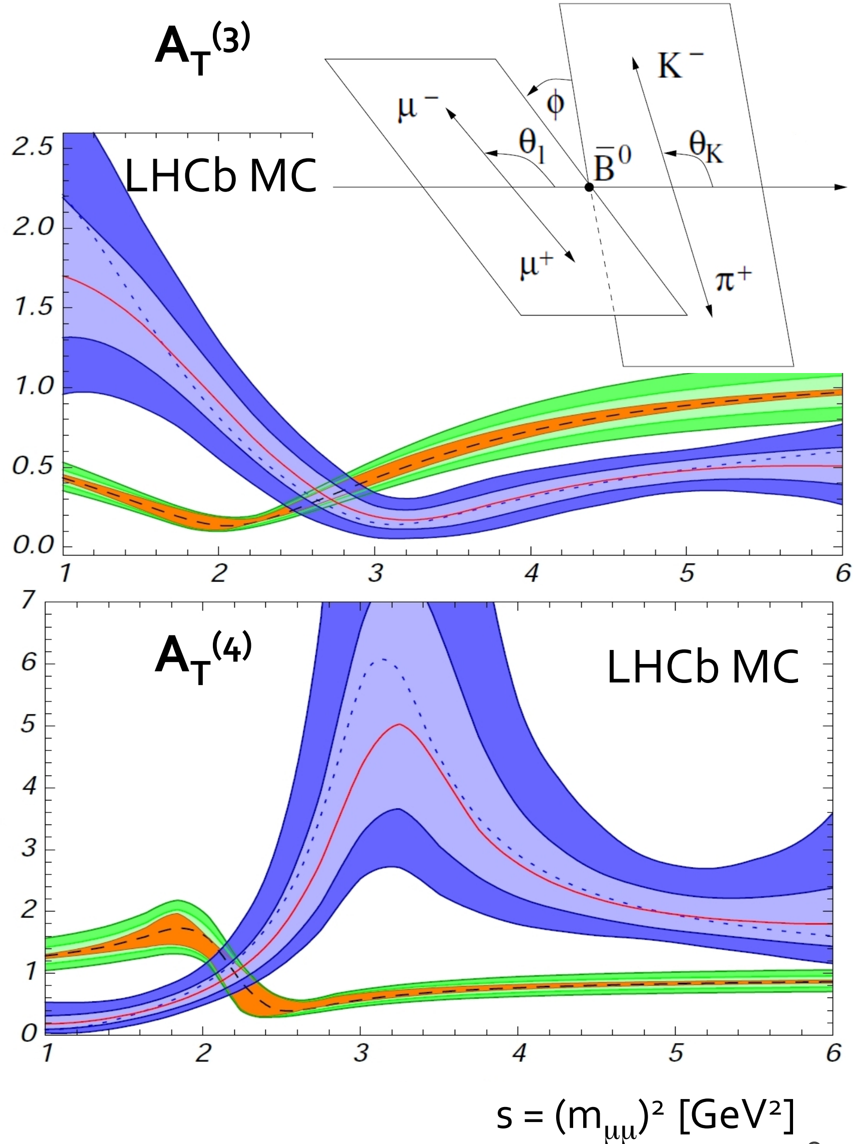
- **0.2fb⁻¹ provides LHCb with ~350 events**
  - **BABAR(~100) Belle(~250)**
  - **Match current knowledge on A_{FB}**
- **With 2fb⁻¹ $A_{FB}(s)$ can be measured to ±0.5 GeV²**

New Physics in $B^0 \rightarrow K^{*0}\mu^+\mu^-$

- **Increased statistics (>2fb^{-1})allows for a more sophisticated angular analysis**
  - Observables $A_T^{(2)}$, $A_T^{(3)}$, $A_T^{(4)}$ based on transversity amplitudes
    - Small theoretical errors in SM
    - Sensitive to right-handed FCNC
  - Acceptance and backgrounds need to be carefully understood.
    - E.g. Use of control channels like $B^0 \rightarrow J/\psi K^{*0}$
- **Example with 10fb^{-1}**

SM + theoretical errors

MSSM with right-handed currents + LHCb 1 and 2 σ error bands



Conclusions

- **LHCb is a heavy flavour precision experiment searching for New Physics at the LHC in CP violation and rare Decays**

- **B decays provide an excellent probe of NP via off-shell corrections**
  - Complementary to direct searches for new particles
  - Sensitive to higher scales and NP phases
  - 2010 run offers plenty of possibilities for significant measurements
    - … and perhaps new physics if nature is willing.

- **Many topics not covered here**
  - Radiative decays, Charm Physics, Flavour physics etc. etc.

- **Highly successful first run in 2009**
  - O(300k) events at 900GeV
  - Calibrate and commission the detector.

- ***LHCb ready and waiting for data in 2010 !***