NEXT Meeting on “B and Heavy Flavour Physics” Southampton, January 20th 2010

LHCb highlights and prospects for early physics

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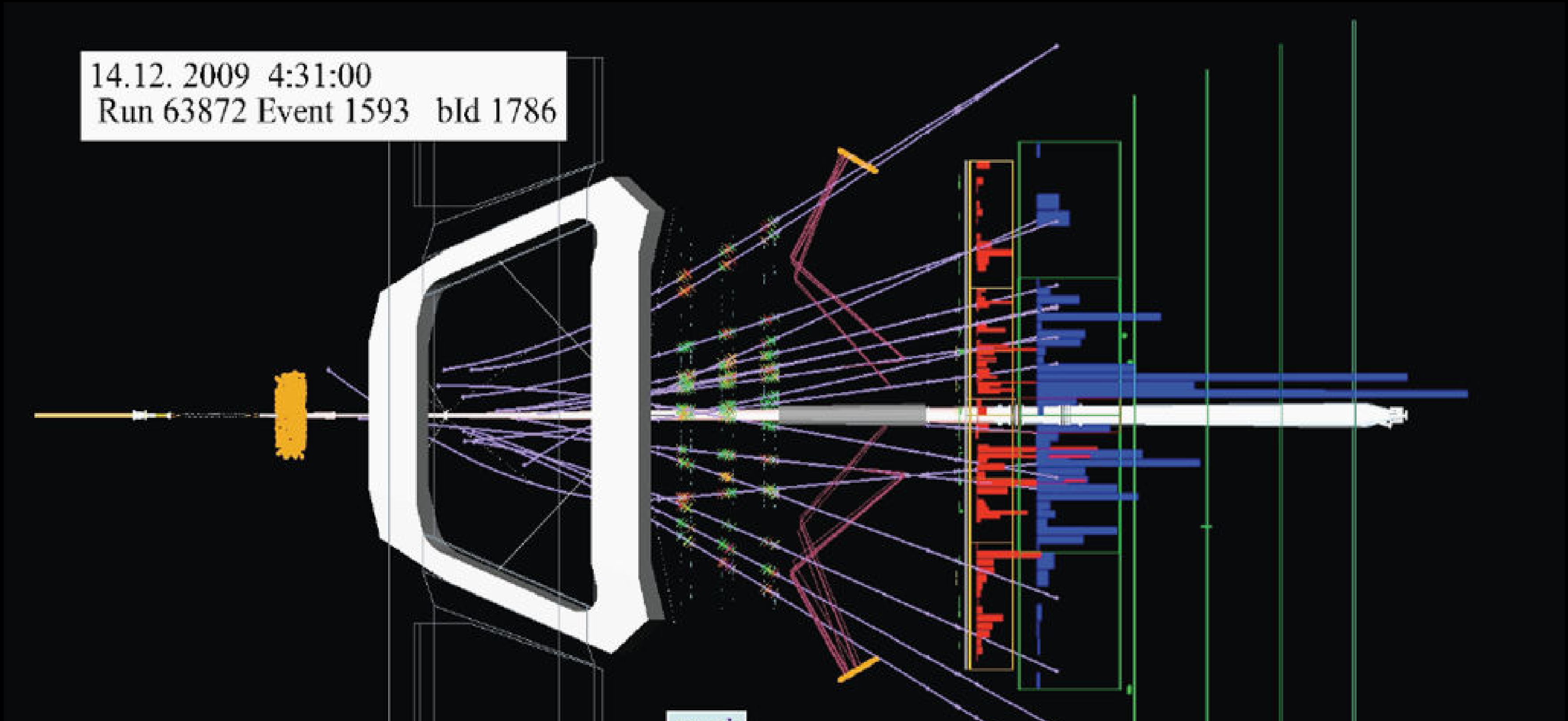
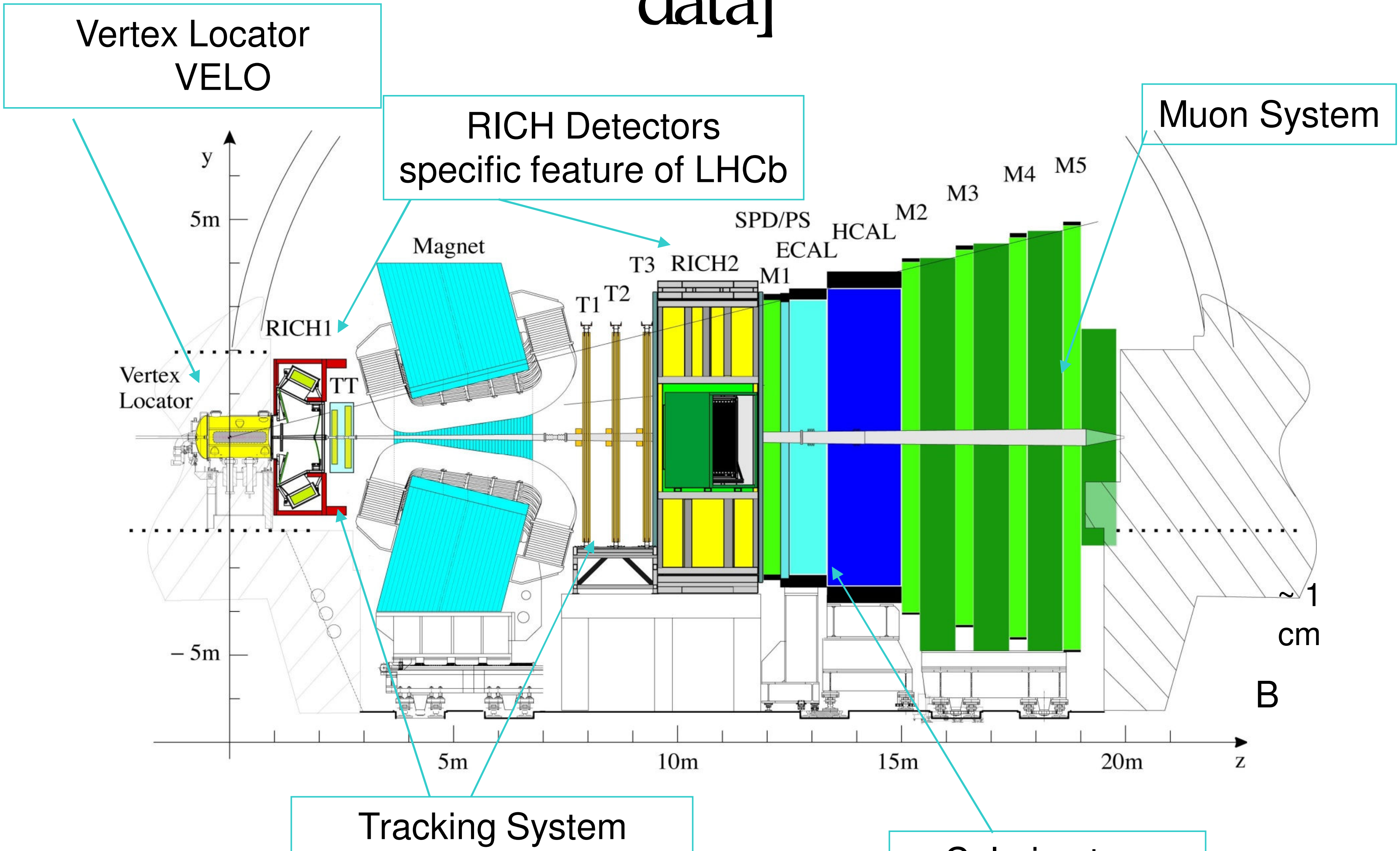
LHCb collision data!



Outline:

1. First data
2. Key measurements
3. Prospects for early physics

LHCb detector [walk through with 2009 data]



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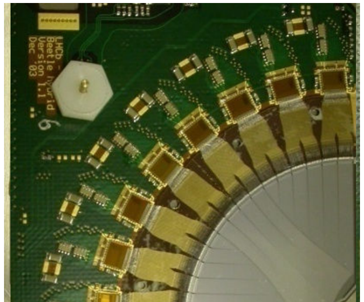
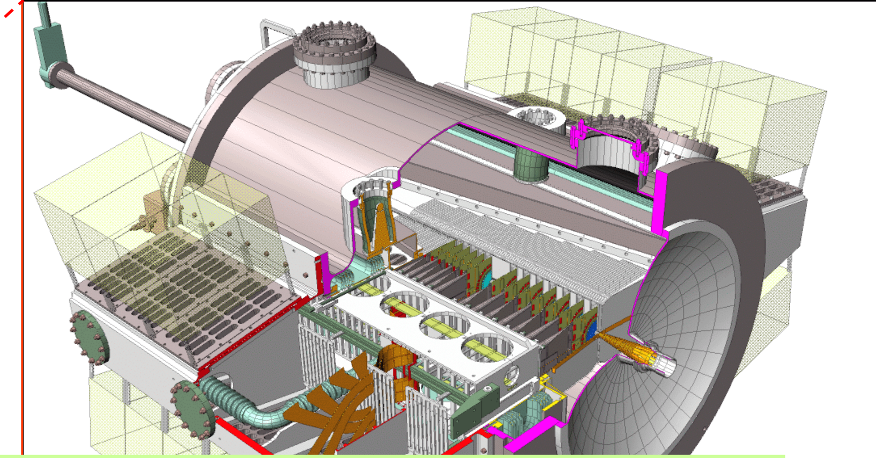
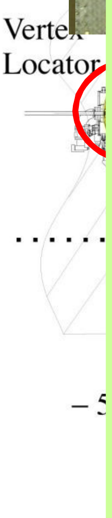
B-Vertex Measurement

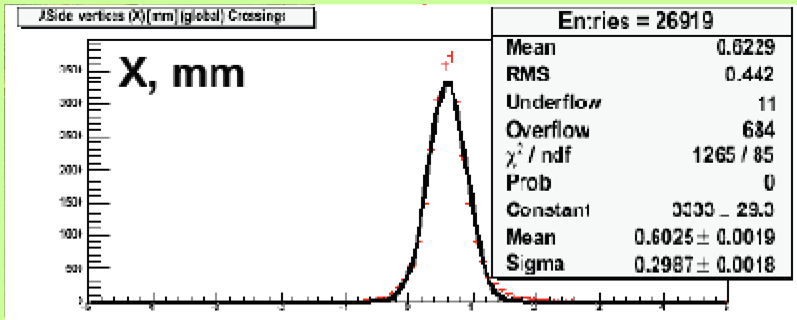


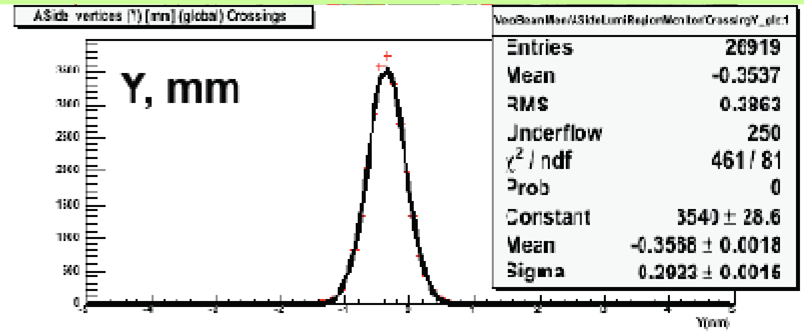
Movable device
35 mm from beam out of physics /
7 mm from beam in physics

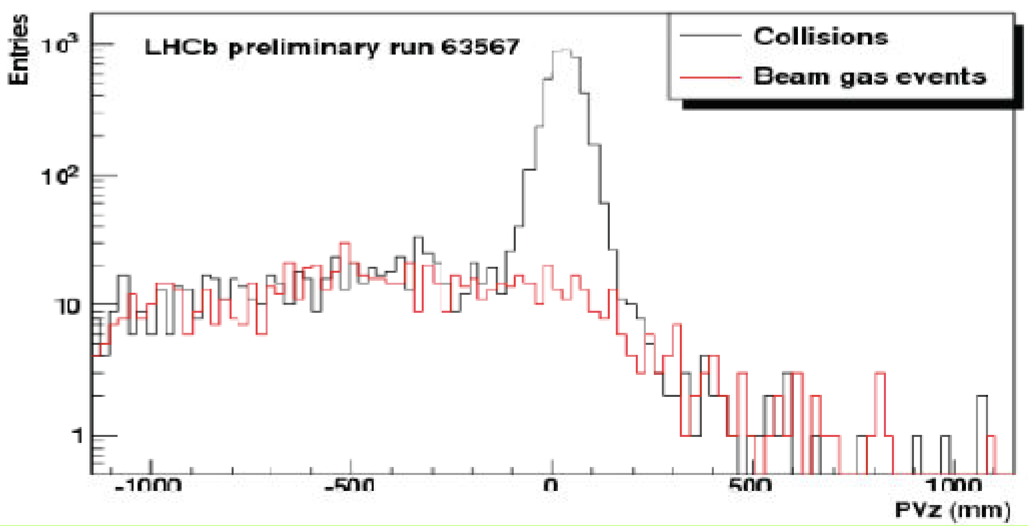
Was 15mm away from nominal in 2009







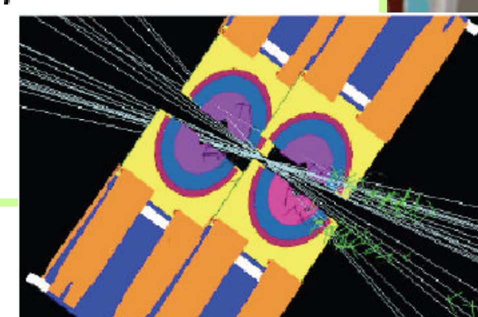




Measured dimensions of the luminous region:

$\sigma_X \approx \sigma_Y \approx 0.3$ mm

$\sigma_Z \approx 40$ mm



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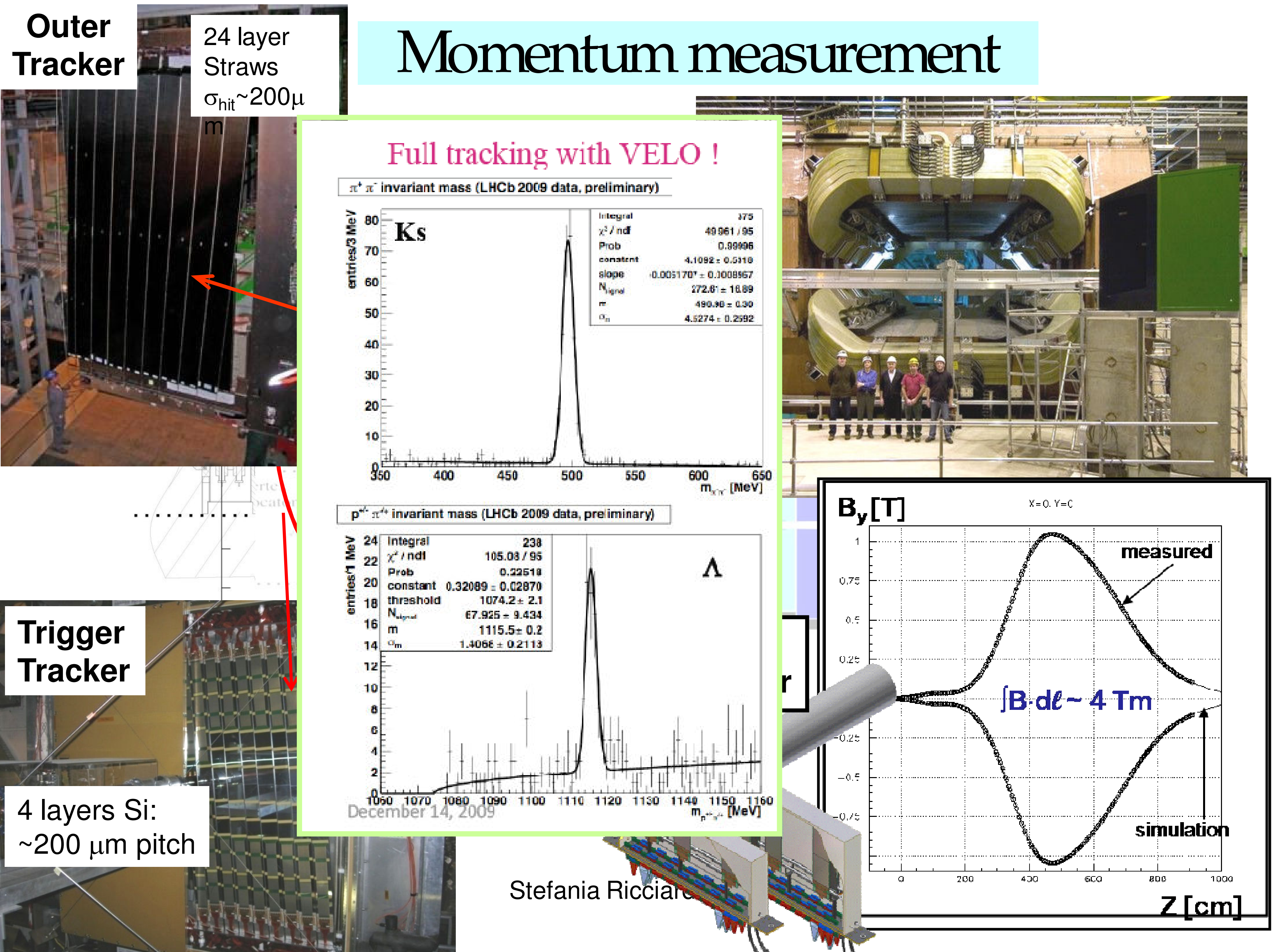
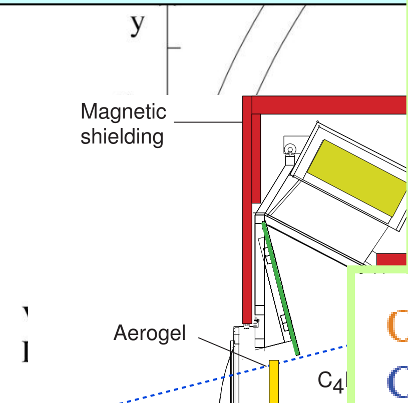
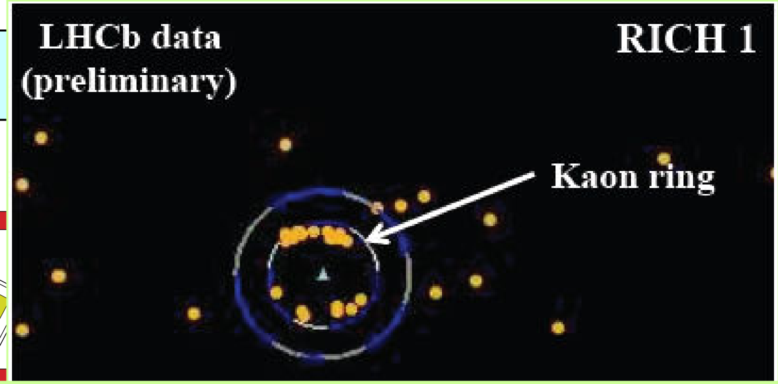
Momentum measurement



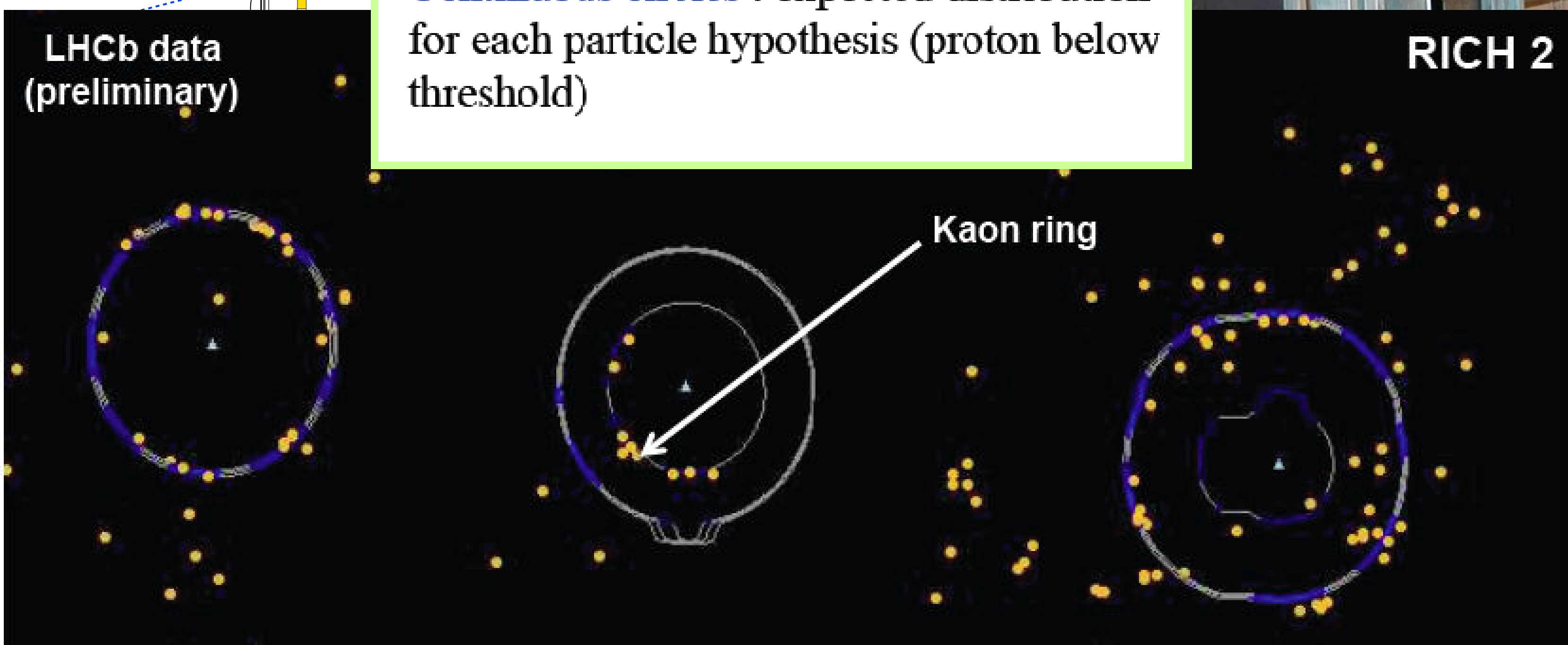
Particle Identification

RICH: K/π identification ...le



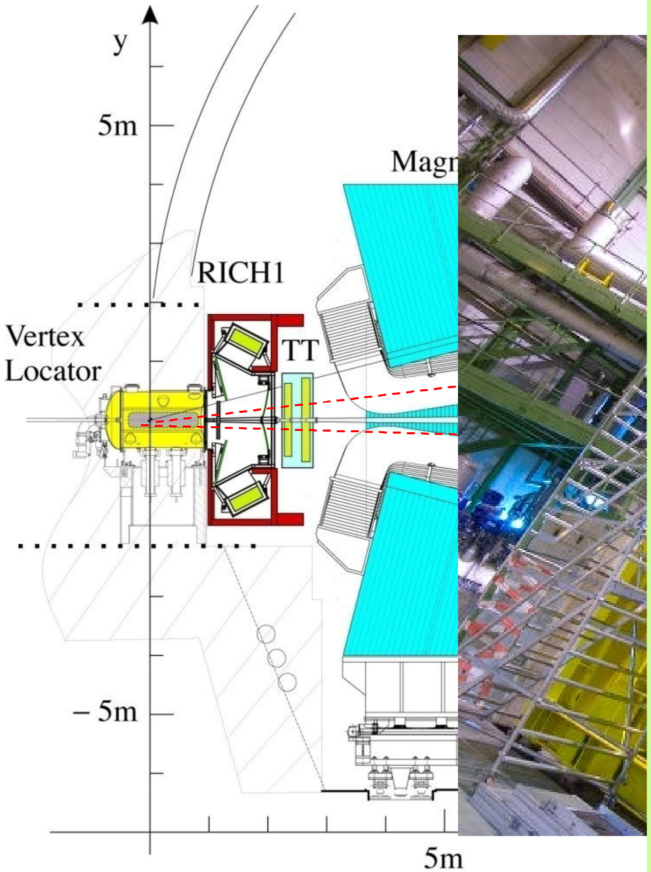


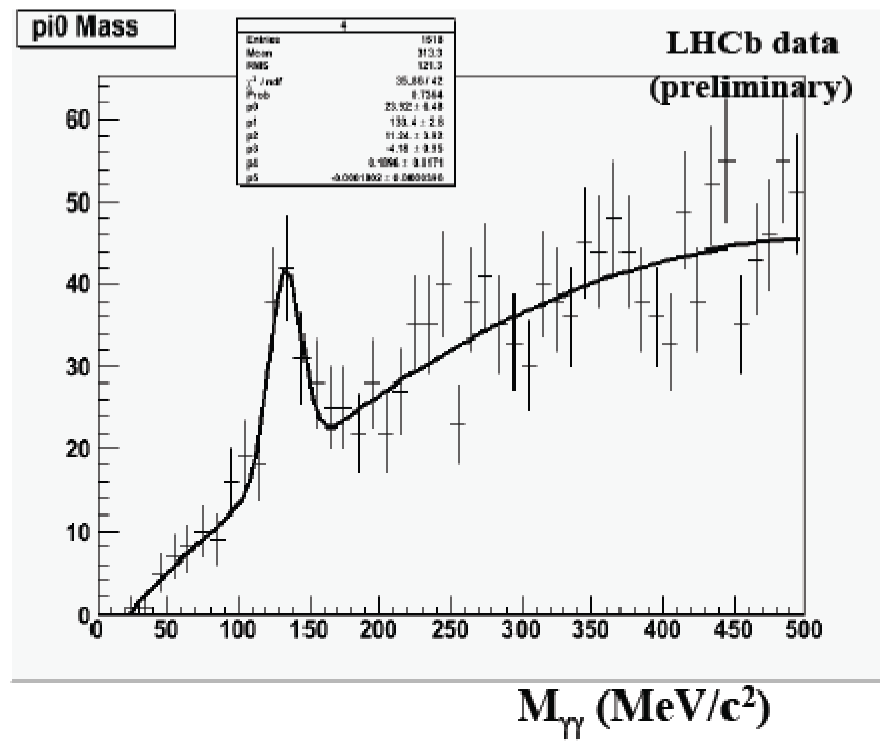
Orange points : photon hits
Continuous circles : expected distribution for each particle hypothesis (proton below threshold)



RIC

e/h/γ identification and L0 trigger



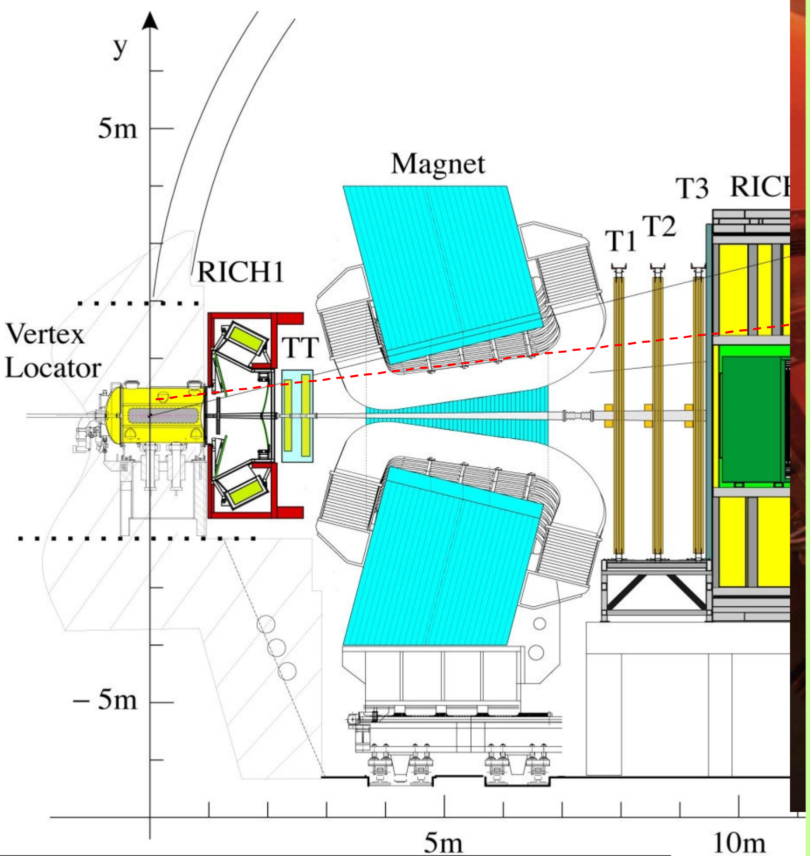


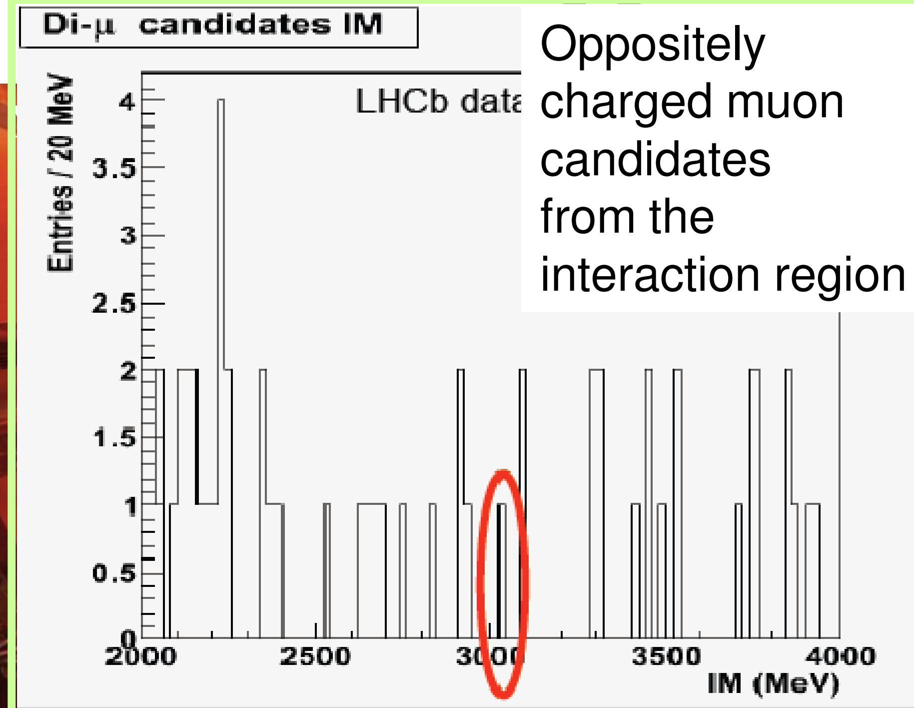
$\langle m \rangle = (133 \pm 3)$ MeV/c^2
$\sigma \quad = (11 \pm 4)$ MeV/c^2

Calorimeter system :

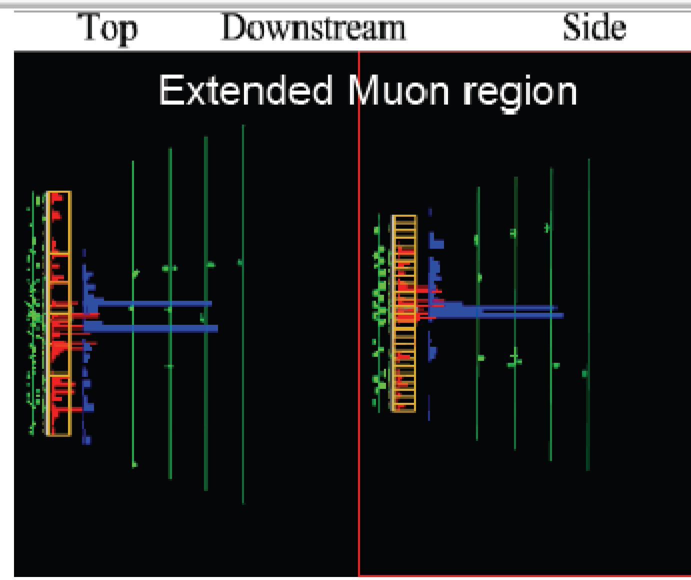
- Level 0 trigger: high E_T electron and hadron
- Identify electrons, hadrons, π^0 ,γ

Muon identification and L0 trigger





Oppositely charged muon candidates from the interaction region



Muon system:

- Level 0 trigger: High P_t muons
- Identify muon
  (also important for flavour tagging)

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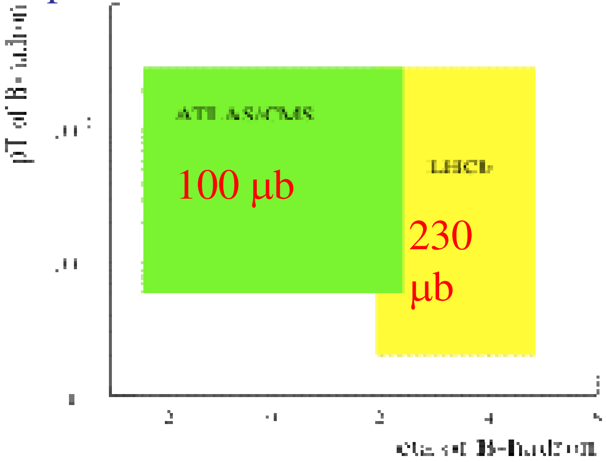
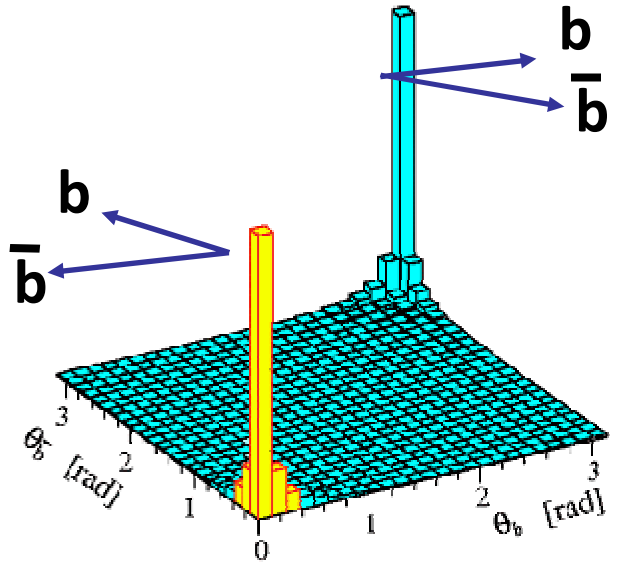
Why a forward spectrometer at LHC?

- Large $b\bar{b}$ cross section:
  - σ_{bb} ~ 250 - 500 μb at 7 - 14 TeV (total bb)
- Access to all b-flavoured hadrons
  - B^+ (40%), B^0 (40%), B_s (10%), b-baryons (10%), B_c (< 0.1%)
- Large acceptance
  - bb production at low angle and correlated in the same hemisphere

~ 40% in LHCb acceptance $1.9 < \eta < 4.9$

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



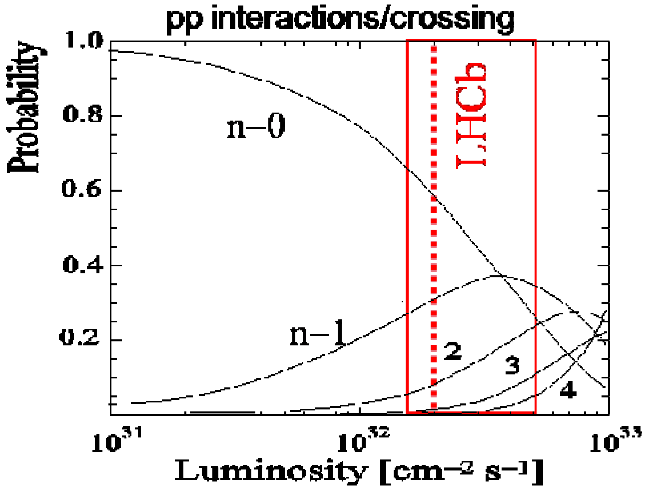


LHCb running conditions

- Experimental challenge:
  - high track multiplicity (~50/event) in the forward direction
  - high background rate [σ(inelastic)~80mb, i.e. ~160 x σ(bb)]

⇒ Nominal run: luminosity limited to **~2×10³² cm⁻² s⁻¹** by not focusing as much as ATLAS and CMS so to limit multiple interactions per bunch crossing

⇒ Start-up: LHCb can exploit all available luminosity in the start-up phase. Similar integrated *L* as ATLAS and CMS in 2010

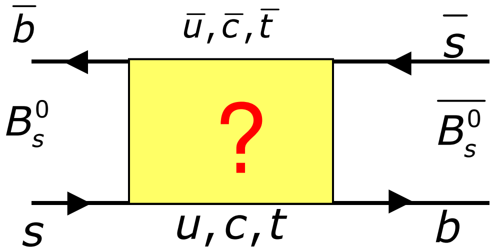


Nominal Year: 2 fb^{-1}
(10^{7}s, 14 TeV)
10^{12} bb pairs/year

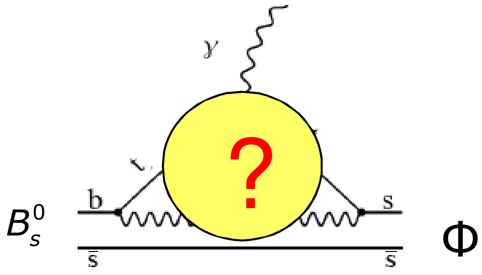
Startup phase: 0.2-0.5 fb^{-1}
(2010 run, 7-10 TeV)
0.5-2 x 10^{11} bb pairs

Why physics in the *b* sector?

- Privileged path towards **New Physics** discovery and characterisation
  - If new virtual particles contribute to loop processes ⇒ Observe:
    - **Changes in CP-asymmetries (new amplitude phases)**
    - **Changes in decay rates (new amplitude magnitude)**
    - **Changes in angular distributions (new Lorentz structure)**



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



- Complementary to direct search of new real particles, which may be produced and observed at ATLAS, CMS

- Still large discovery potential with B
- intriguing hints from B-factories and Tevatron measurements demand
  ⇒ larger B data samples, on the experimental side
  ⇒ precise predictions on the theoretical side

Joy of B physics: many clean observables sensitive to NP!

LHCb Physics Highlights

LHCb-PUB-2009-029
17 December 2009

Roadmap for selected key measurements of LHCb

The LHCb Collaboration[1]

Now on ArXiV:0912.4179
379 pp.

Search for new CPV phases

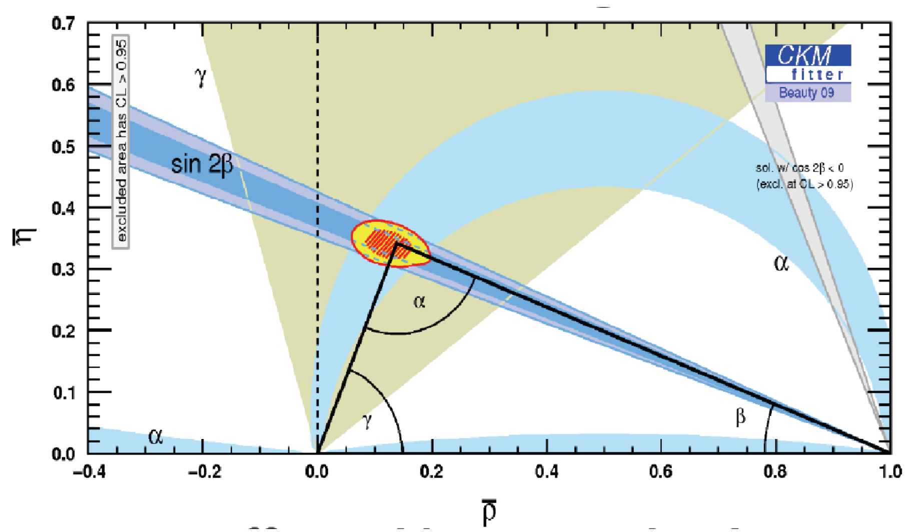
- CKM angle γ
- Φ_s from $B_s \rightarrow J/\psi\phi$

Search for New Physics in rare decays

- $B_s \rightarrow \mu\mu$
- $B_d \rightarrow K^*\mu\mu$
- $B_s \rightarrow \phi\gamma$

First key measurement: γ

- Flagship measurement for LHCb
- B-factories have set first important constraints much beyond design
    - thanks also to development of new measurement methods (good example of interplay of theory and experiment)
- Still, as of 2010, least constrained UT angle from direct measurements
- Tree-level determination: clean SM reference
    - required to unravel subtle NP effects and disentangle between different models

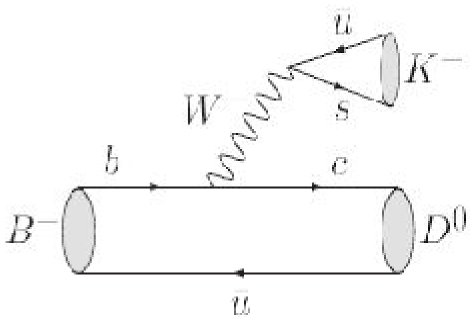


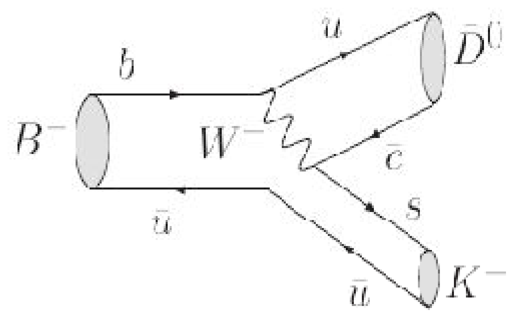
angle	Direct measurement	Fit (excl. dir. meas.)
α	89.0 [+4.4, -4.2]	92.2 [+6.4, -6.3]
β	21.15 [+0.90, -0.88]	26.5 [+1.3, -1.7]
γ	75 [+19, -25]	67.7 [+4.5, -3.7]

γ from trees and loops

Tree level: $B_d \to DK$, $B_s \to D_sK$

SM standard-candle



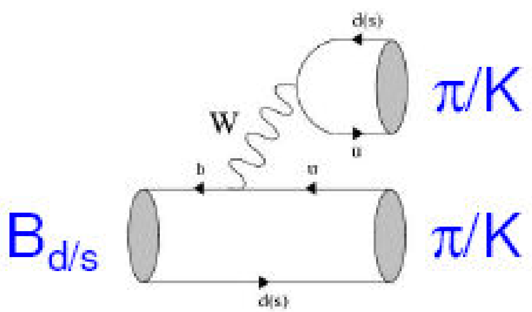


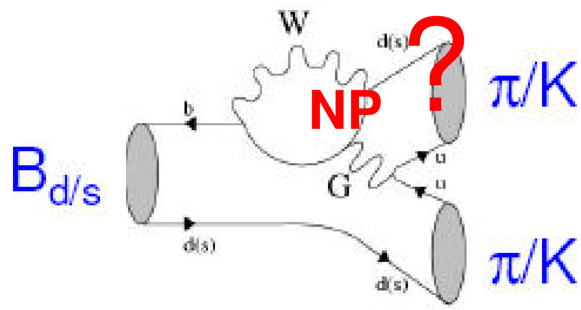
γ(loop-induced)

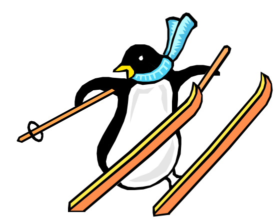
=

γ(tree-level) ?

Loop-induced: $B \to hh$

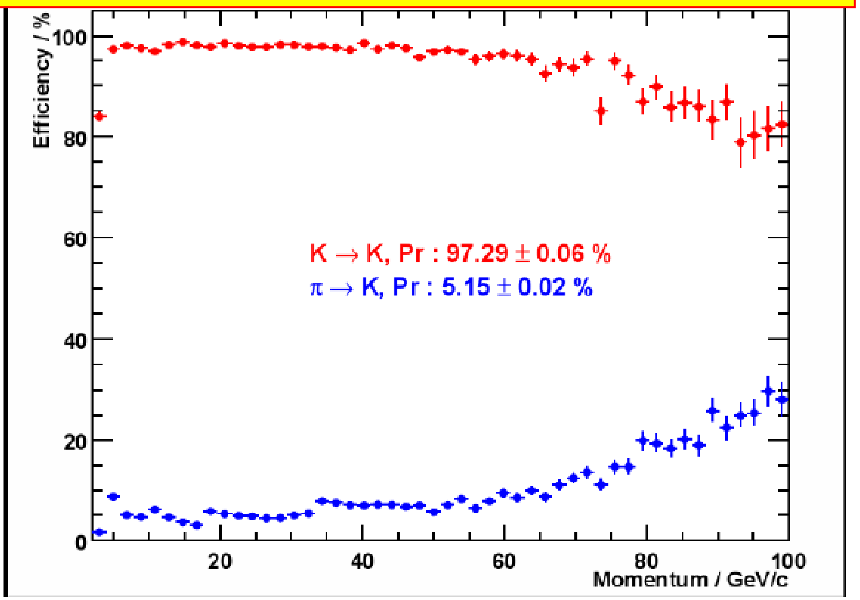


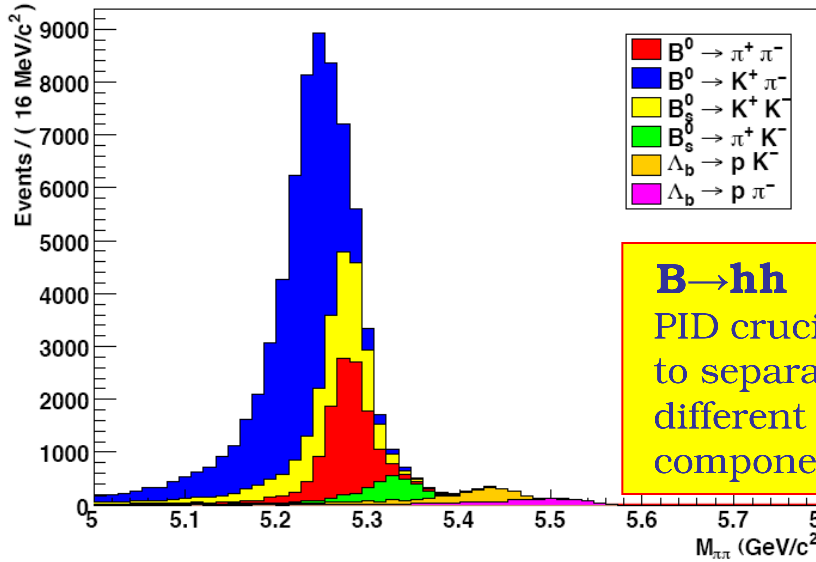




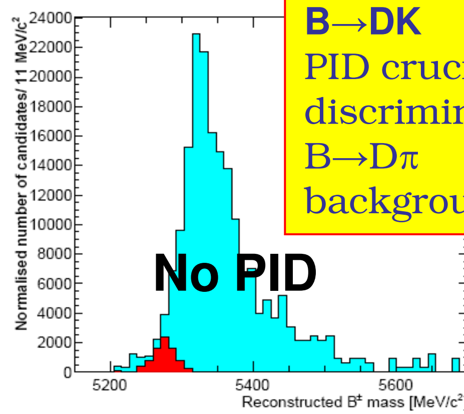
Particle identification crucial for γ measurements

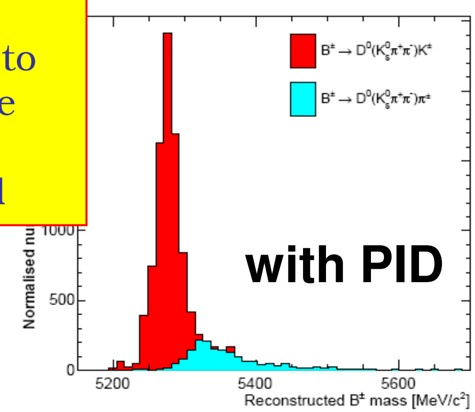
- **RICH Kaon ID performance**:
  - Kaon ID: ε >97% [2-100 GeV/c]
  - $\pi \to K$ misID < 5%





B→hh
PID crucial to separate different signal components

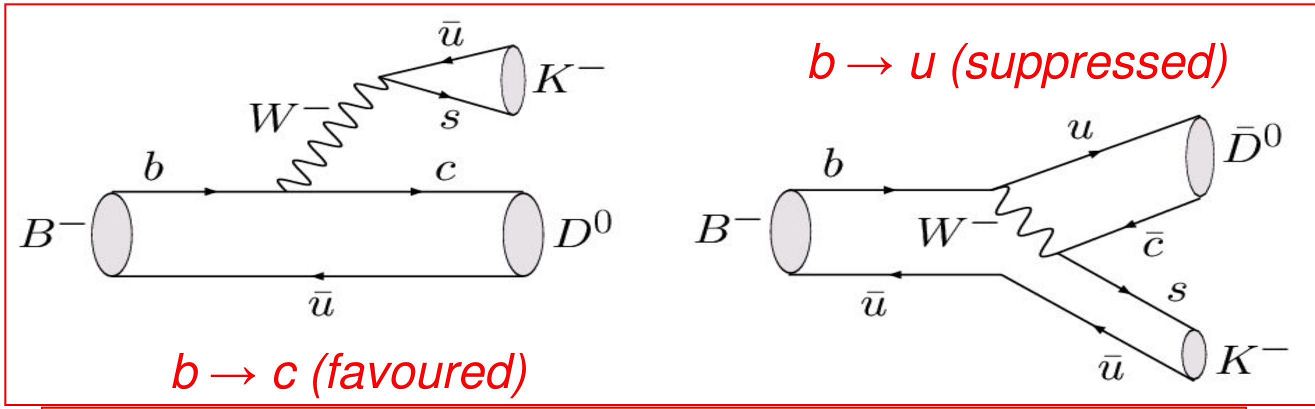




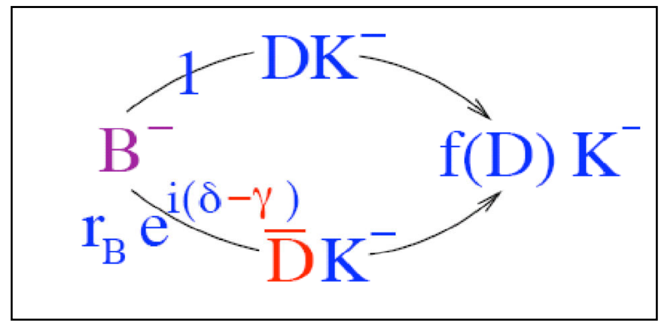
B→DK
PID crucial to discriminate B→Dπ background

Tree-level γ determination with B→ DK

B → DK rates sensitive to γ through interference of b → c and b → u transitions



Interference if D^0 and $\overline{D^0}$ decay to common final state ***f***



Several strategies to extract γ:

GLW : f =CP eigenstate

Gronau & London, PLB 253, 483 (1991);
Gronau & Wyler, PLB 265, 172 (1991)

ADS: f =Flavour state

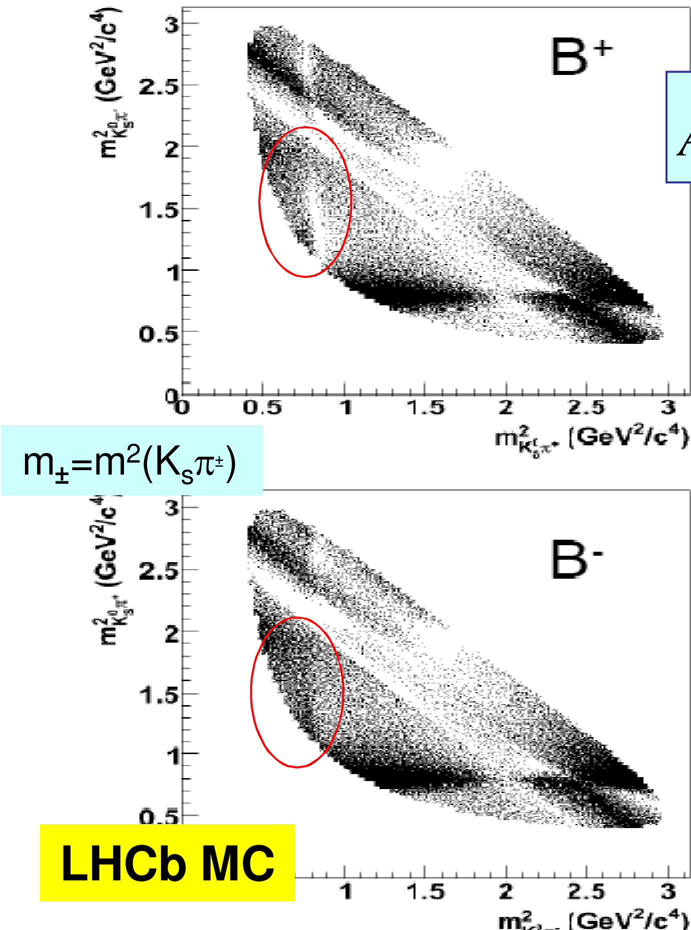
Atwood, Dunietz, & Soni, PRL 78, 3257 (1997),
Atwood, Dunietz, & Soni, PRD 63, 036005 (2001)

GGSZ: f =3-body decays

Giri, Grossman, Soffer, & Zupan, PRD 68, 054018 (2003),
Bondar, PRD 70, 072003 (2004)

$B^+ \to D(K_S\pi^+\pi^-)K^+$ measurement principle [GGSZ]

- Dalitz Measurement – current best constraint on γ from B-factories
- exploits different interference pattern in the two $D \to K_S\pi\pi$ Dalitz plots (from *B*+ and *B*- decays)



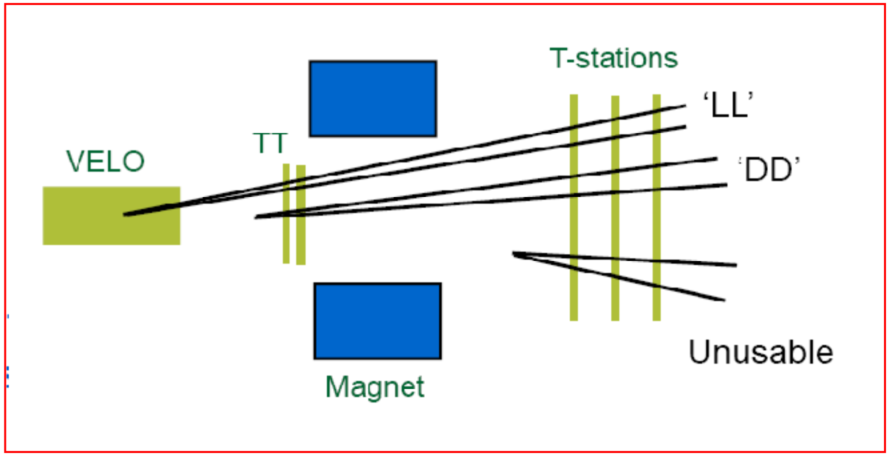
$$A(B^\pm \to D(K_S\pi\pi)K^\pm) \propto f(m_\mp, m_\pm) + r_B e^{i(\delta_B \pm \gamma)} f(m_\mp, m_\pm)$$

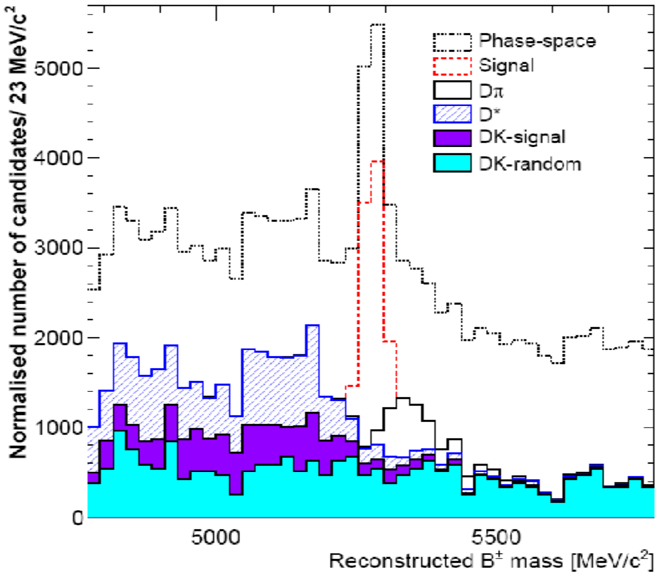
Two approaches to extract γ:

- Unbinned fit, using model for D decay amplitude;
  ⇒systematic error from model dependence **~7°**
- Binned method – bins of δ_D phase (using input from **CLEO-c**);
  ⇒induced systematic uncertainty **~2°** (due to CLEO-c statistics, no model dependence)

$B^+ \to D(K_S\pi^+\pi^-)K^+$ Selection and Yields

- **Specific for this decay: K_s challenge**
  - 2/3 decay downstream (DD) of vertex detector (but have hits in downstream tracker stations)
- Overall efficiency ~ 0.1 % including Level-0 trigger
- Signal Yields for 2 fb^{-1}
  - 7k with B/S < 1.5 @90%CL
- Compared with B-factories:
  - BaBar (351/fb) - 610 events
  - Belle (602/fb) - 756 events





γ (tree-level) sensitivity summary

Channel	Analysis method	$\sigma(\gamma)(°)$ (2/fb)
$B^{\pm} \to D^0(K\pi)K^{\pm}$ fav	2-body ADS	11
$B^{\pm} \to D^0(hh)K^{\pm}$	2-body GLW	
$B^{\pm} \to D^0(K3\pi)K^{\pm}$ fav	4-body ADS	Improves the above
$B^0 \to D^0(K\pi)K^{*0}$ fav	B0 ADS	15-25
$B^0 \to D^0(hh)K^{*0}$	B0 GLW	
$B^{\pm} \to D^0(K_S\pi\pi)K^{\pm}$	GGSZ	12.5
$B_s \to D_s^{\mp} K^{\pm}$	TD	9-12
$B_d \to D^{\mp} \pi^{\pm}$	TD	≥22

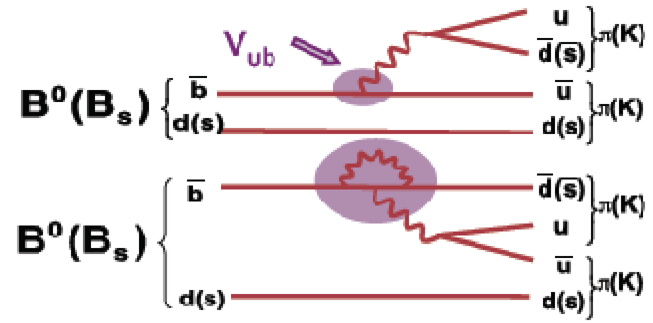
- No mode is dominant
- Optimal sensitivity via a global fit, where γ and other parameters common to several BDK modes are simultaneously extracted

Luminosity (fb^{-1})	$\sigma(\gamma)$ (°)
0.5	8-10
2	4-5
10	2-3

Time integrated
Time dependent

The B→hh measurement of γ

Time-dependant asymmetries for $B_d \to \pi\pi$ and $B_s \to KK$ to determine A_{dir} and A_{mix}



$$A_{CP}(t) = A_{dir} \cos(\Delta m\, t) + A_{mix} \sin(\Delta m\, t)$$

- A_{dir} and A_{mix} depend on:
  - γ
  - Mixing phases Φ_d or Φ_s
  - Penguin/Tree = $de^{i\theta}$

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

- Φ_d from $J/\psi K_S$
- U-spin simmetry: $d_{\pi\pi} = d_{KK}$, $\theta_{\pi\pi} = \theta_{KK}$
- 4 observables, 3 unknowns: solve for γ

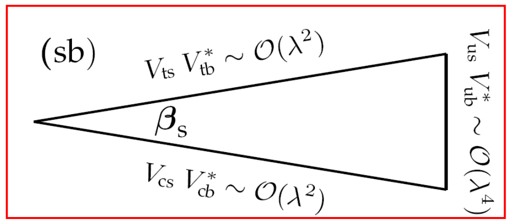
$\sigma(\gamma) = 7°$ with 2 fb^{-1}

Including U-spin symmetry breaking effects at 20% level on d, +/-20 degrees on θ

0.5 **fb^{-1}** gives world largest B→hh sample
- BF and charge asymmetry results
- First observation of time-dependent asymmetries in Bs→KK

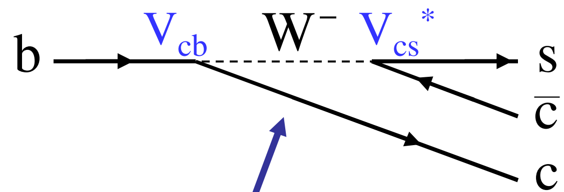
$B_s \rightarrow J/\psi\ \phi$

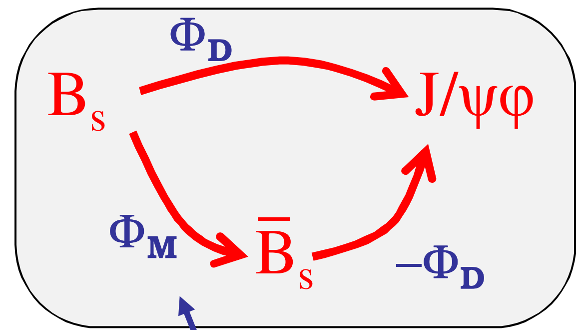
- **Time-dependent CPV measurement equivalent to $B_d \rightarrow J/\psi K^0_S$**
  - "golden" mode for B_s mixing-induced CP violation
  - Measures $\Phi_S = \Phi_M - 2\Phi_D$
  - $\Phi_S^{SM} = -2\,\beta_s = (0.037 \pm 0.002)$ rad (from CKM fits)
  - Precise SM prediction ⇒ a significant non-zero value of Φ_S is New Physics

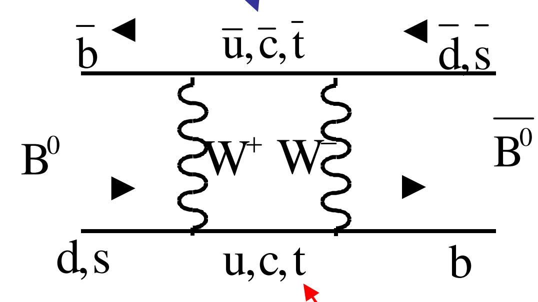


- **Specific challenges:**
  - Fast B_s oscillations ($\Delta m_s >> \Delta m_d$)
    - need excellent proper time resolution to avoid dilution
    - Can't be done at B-factories
  - Additional physics parameters
    - Non vanishing $\Delta\Gamma_s$ to fit for ($\Delta\Gamma_s >> \Delta\Gamma_d$);
    - Mixture of CP-even (S and D waves) and CP-odd (P wave) eigenstates

  ⇒need angular analysis to separate the two components







Sensitive to NP in ΔF=2 transitions

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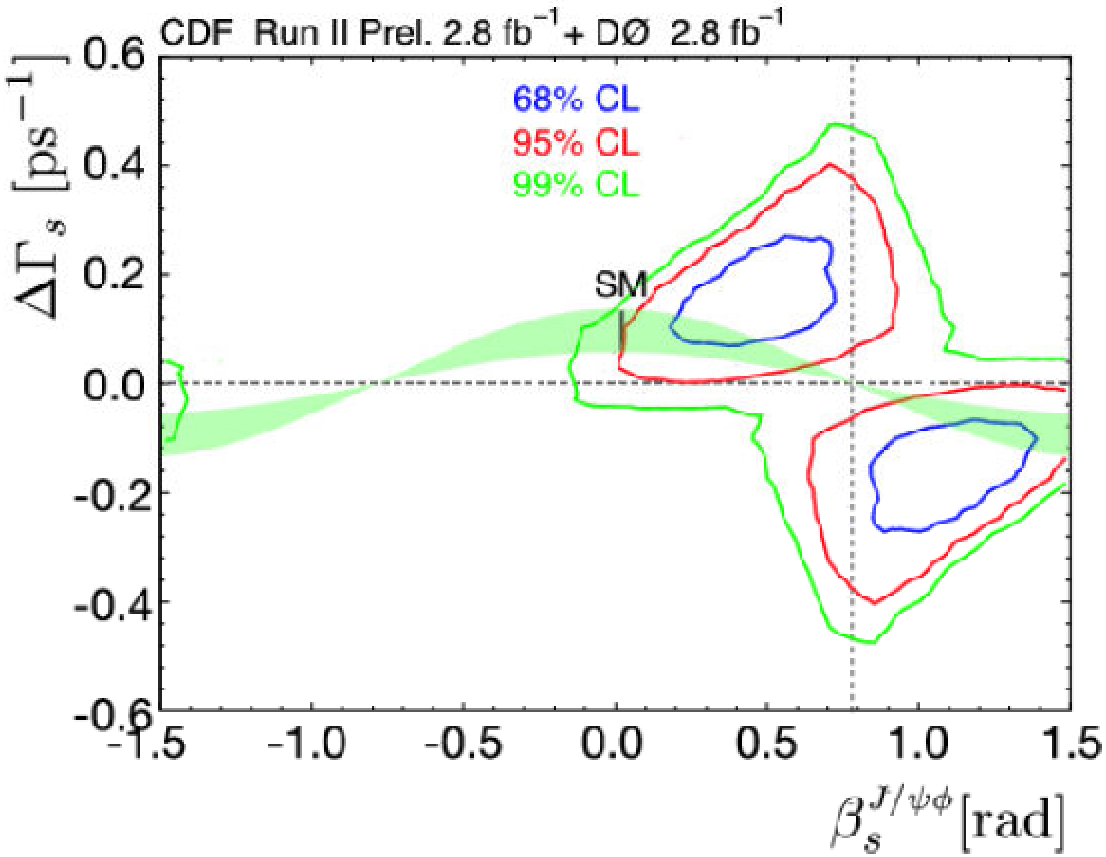
Combined CDF+D0 result



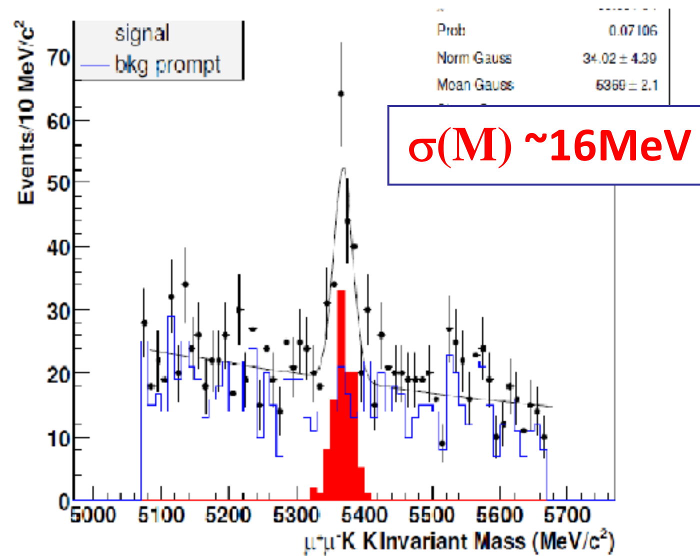
- Large central values measured by both CDF and D0
- Combined result on β_s is within [0.10,1.42] at 95% C.L., 2.3σ from SM
- Intriguing CDF and D0 deviations from SM in the same direction
- Eagerly awaiting for an update on larger data-samples

$B_s \to J/\psi\ \phi$: key ingredients

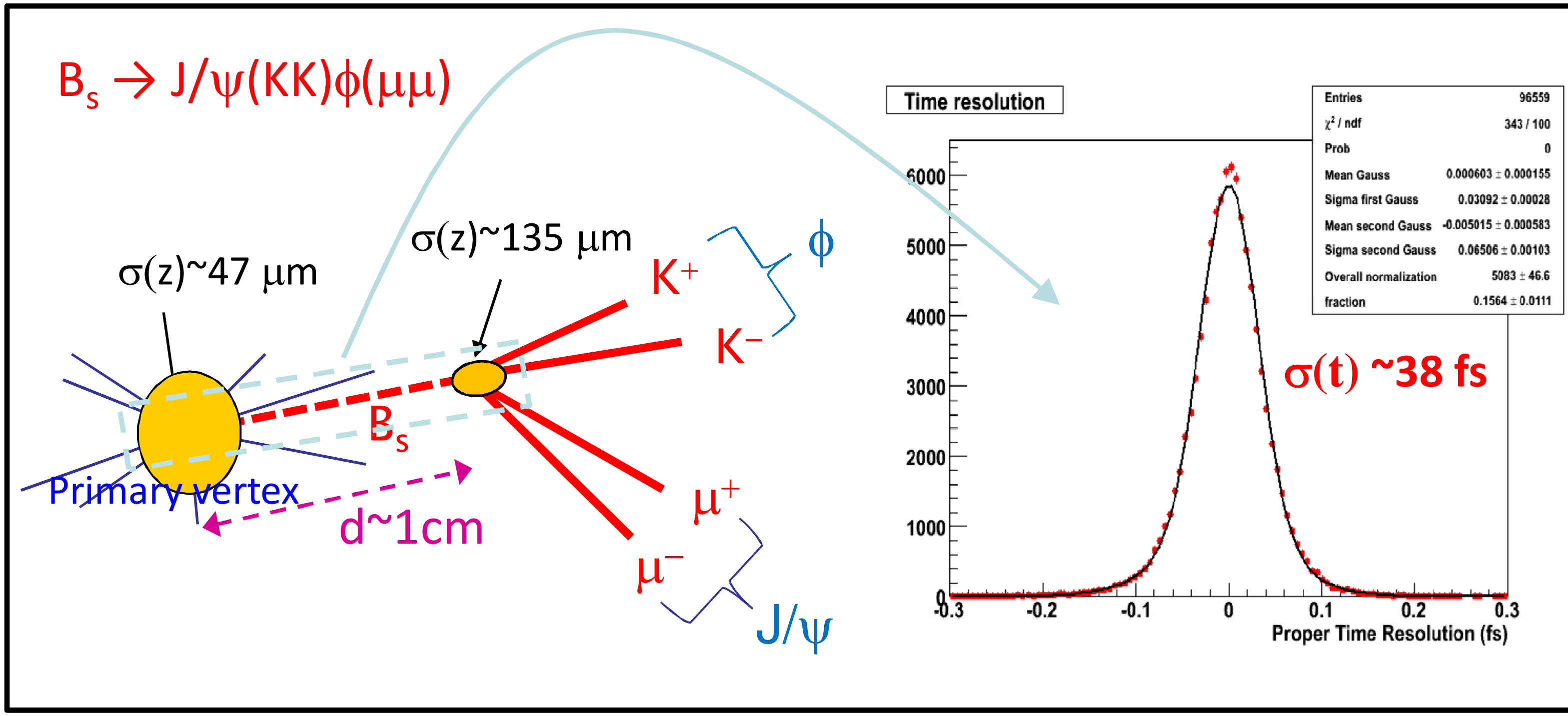
- Sensitivity depends on
  - signal yield and background level
    - Large signal yield with low background
    - Largest background from prompt J/ψ harmless in β_s fit
  - reconstruction quality of input variables, particularly proper time, angles, flavour tagging
- Calibration and validation on large control samples
  - $B_d \to J/\psi K^*$ to check angular acceptance
  - $B^+ \to J/\psi K^+$ to calibrate opposite side tagging
  - $B_s \to D_s \pi$ to validate proper time and same-side tagging

Signal yield (2 fb^{-1})	117 k
B(long-lived) /S	0.5
B(prompt J/ψ) /S	1.6

Full MC: inclusive $J/\psi(\mu\mu)$

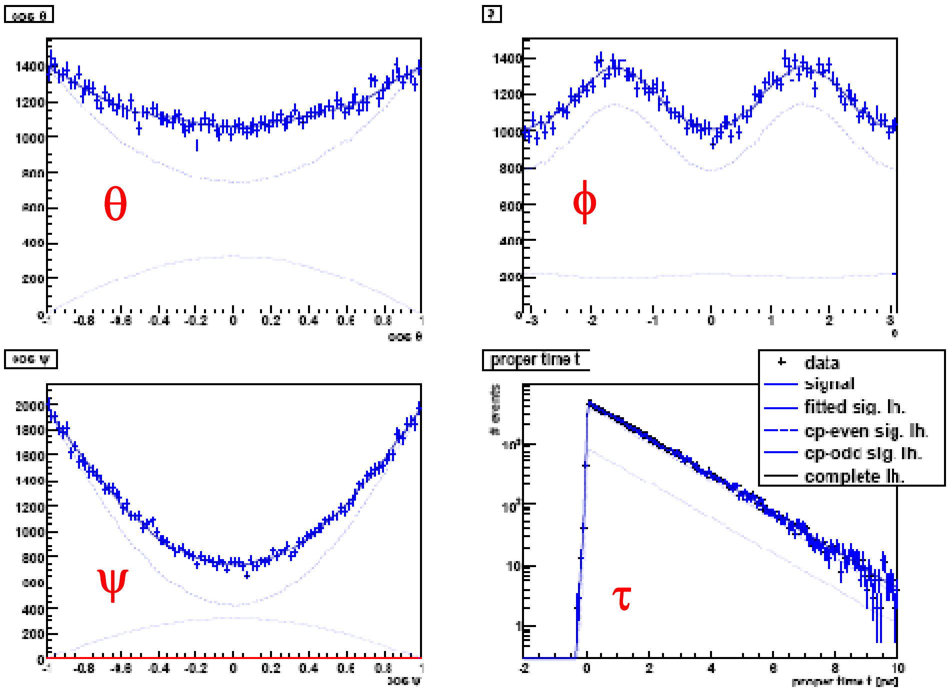


Most crucial: proper time resolution



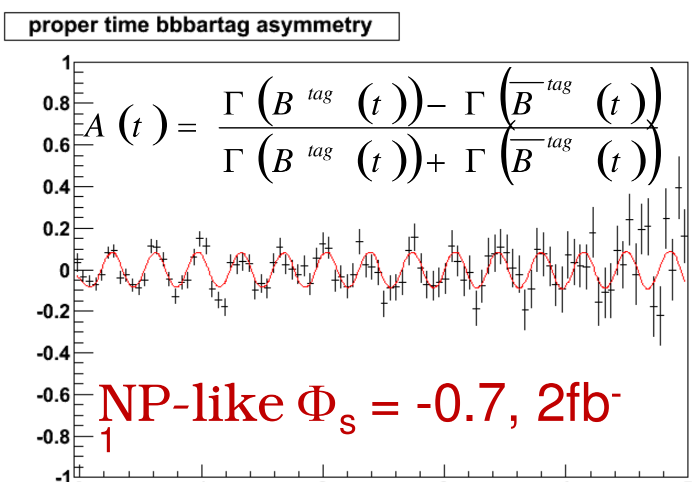
Average $\sigma(t) \approx 38$fs, compared with oscillation period $T = 2\pi/\Delta m_s \approx 314$fs for $\Delta m_s = 20\text{ps}^{-1}$

$B_s \to J/\psi\ \phi$: sensitivity

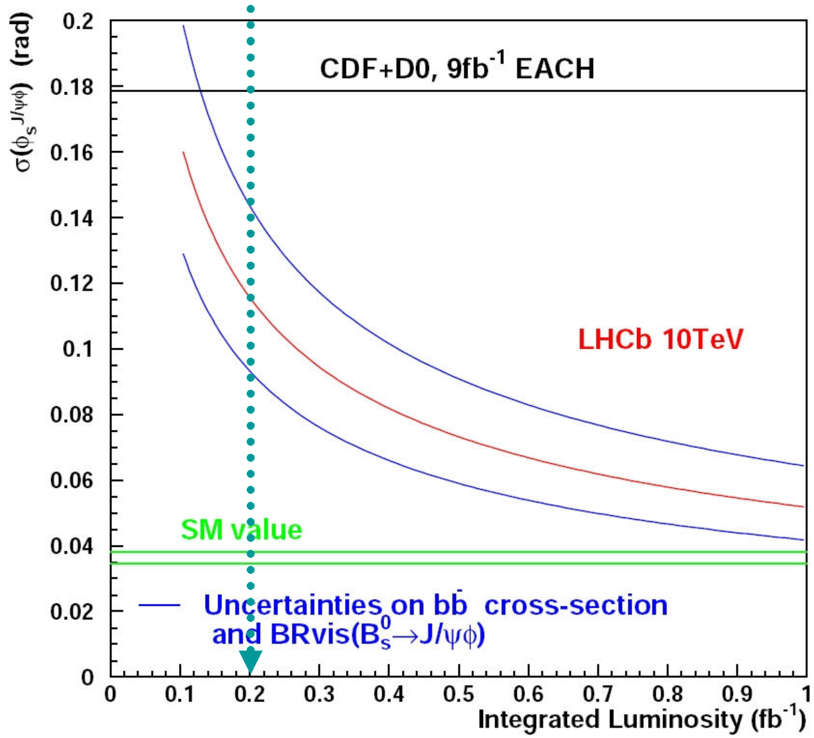


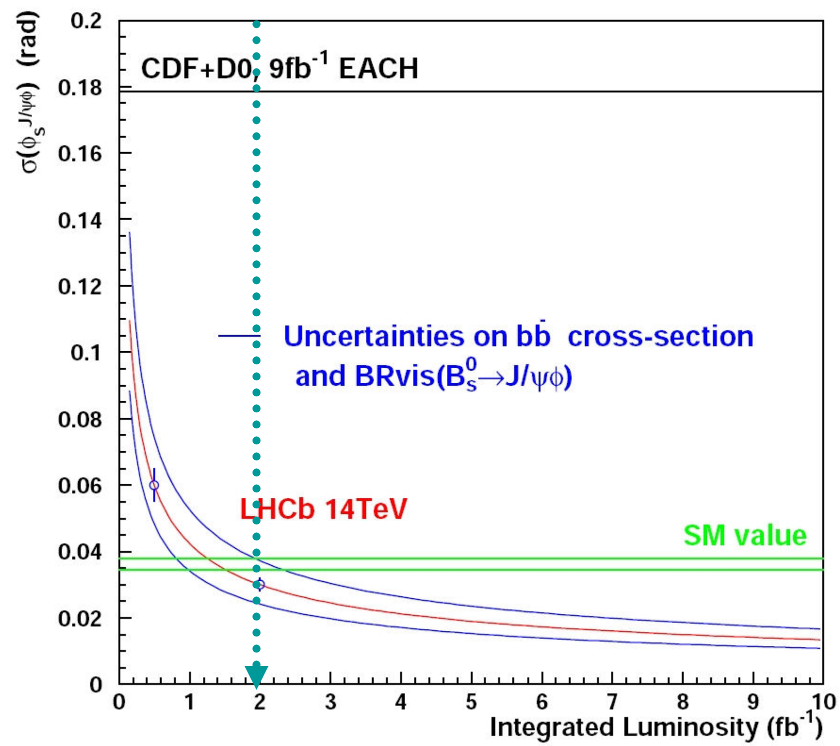
- Sensitivity studies with $2fb^{-1}$: **$\sigma(\Phi_s)$~0.03 for SM value**
- Good convergence for all physics parameters, all detector parameters can also be fitted

Parameter	Result	Units
m_{B_s}	5368.01 ± 0.05	MeV/c^2
$f^s_{m,1}$	0.47 ± 0.13	
$\sigma^s_{m,1}$	12.0 ± 0.7	MeV/c^2
$\sigma^s_{m,2}$	19.0 ± 1.3	MeV/c^2
$\lvert A_0(0)\rvert^2$	0.599 ± 0.002	
$\lvert A_\perp(0)\rvert^2$	0.162 ± 0.004	
$\delta_\parallel$	2.49 ± 0.02	rad
$\delta_\perp$	-0.28 ± 0.10	rad
$-2\beta_s$	-0.0399 ± 0.0272	rad
Γ_s	0.686 ± 0.004	ps^{-1}
$\Delta\Gamma_s$	0.061 ± 0.010	ps^{-1}
$f^s_{t,1}$	0.96 ± 0.01	
$\sigma^s_{t,1}$	0.032 ± 0.001	ps
$\sigma^s_{t,2}$	0.12 ± 0.01	ps
Δm_s	19.96 ± 0.04	ps



Sensitivity versus integrated luminosity





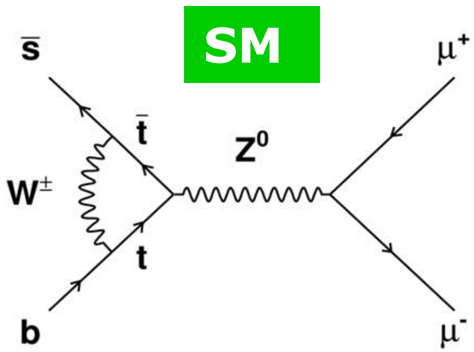
0.2 fb^{-1}:

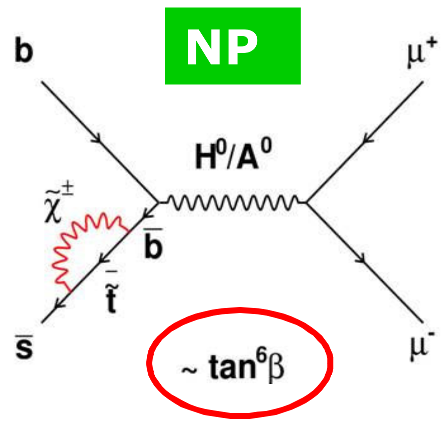
- LHCb overtakes expected final Tevatron sensitivity
- Can observe NP if true value of Φ_s is close to the Tevatron central value (~ -0.8)

2 fb^{-1}:

- $\sigma(\phi_s)$ reaches SM value

$B_s \rightarrow \mu\mu$





Branching fraction can be modified in a variety of NP models

Example: strongly enhanced in MSSM with scalar Higgs exchange for large $\tan\beta$

$BR^{SM} = (3.35 \pm 0.32).10^{-9}$

FCNC – Helicity suppressed

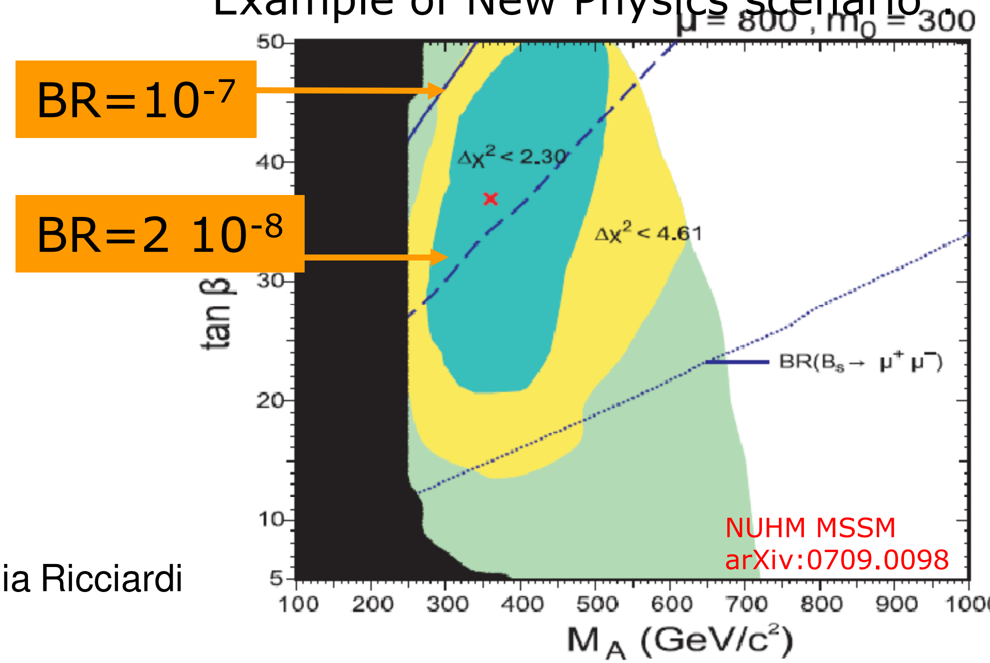
Precise SM prediction

CDF upper limit (2 fb^{-1}) :

CDF, Phys. Lett. 100(2008) 101802

BR < 47 10^{-9} @ 90% CL

Example of New Physics scenario :



Stefania Ricciardi

$B_s \to \mu\mu$ analysis

- Decay easy to trigger and reconstruct at LHC
- Main experimental challenge is background rejection
  - largest background is $b \to \mu$, $b \to \mu$
  - also specific backgrounds such as $B \to hh$
- Selection:
  - loose event selection
  - analysis in bins of 3D space (mass, muonID, geometry)
- Event yields per fb^{-1}:

	ATLAS	CMS	LHCb [2]
SM signal [1]	5.7	2.4	3.8
background	14^{+13}_{-10}	6.5 ±2.4	11^{+15}_{-7}

[1] Slightly different assumptions across experiments
[2] Most sensitive bin only

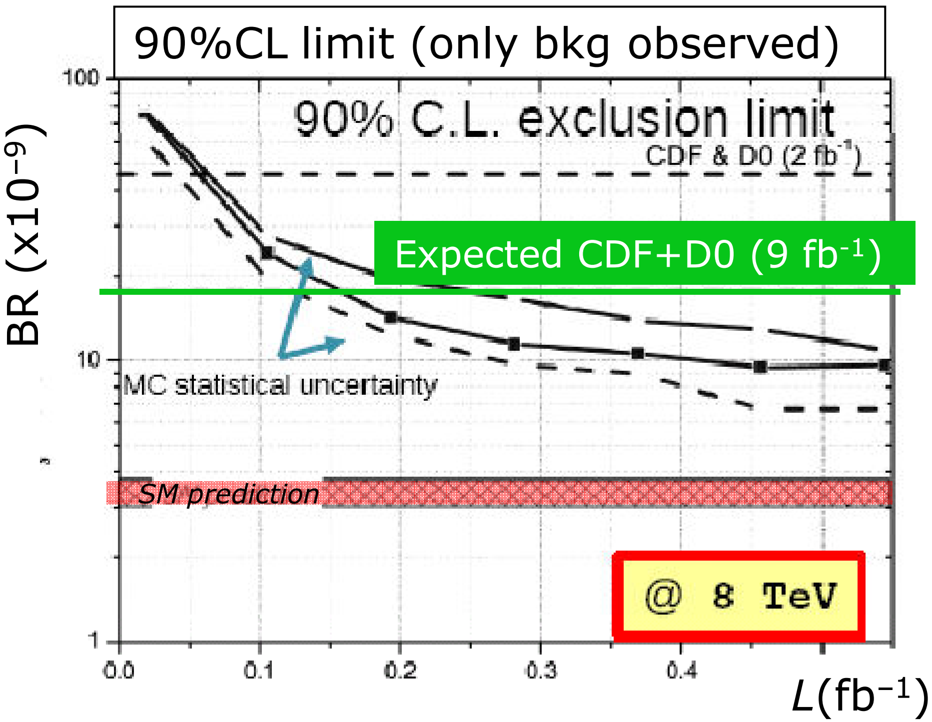
	ATLAS	CMS	LHCb
σ_{mass} [MeV/c^2]	90	53	22

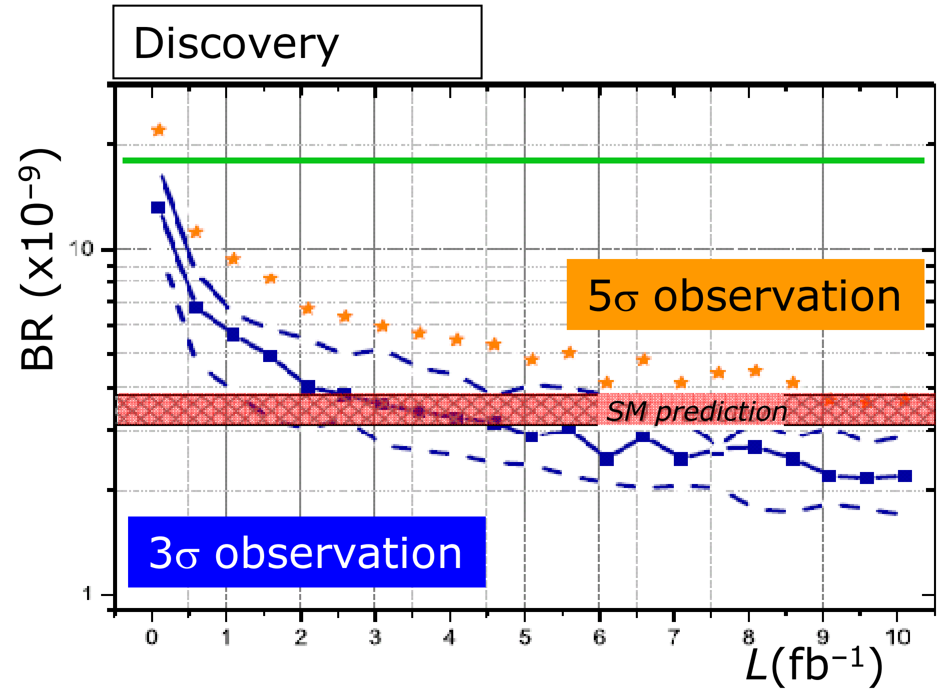
Excellent mass resolution at LHCb is the key for background rejection

- Branching fraction normalisation
  - through $B_d \to hh$ and $B^+ \to J/\psi K^+$
  - no need of absolute luminosity, cross-section, efficiencies
  - 14% systematic due to mainly $f(B_s)/f(B_d)$

$B_s \to \mu^+\mu^-$ reach

- First 5 years: statistics dominated
- Atlas and CMS: similar performance with 5 times more luminosity



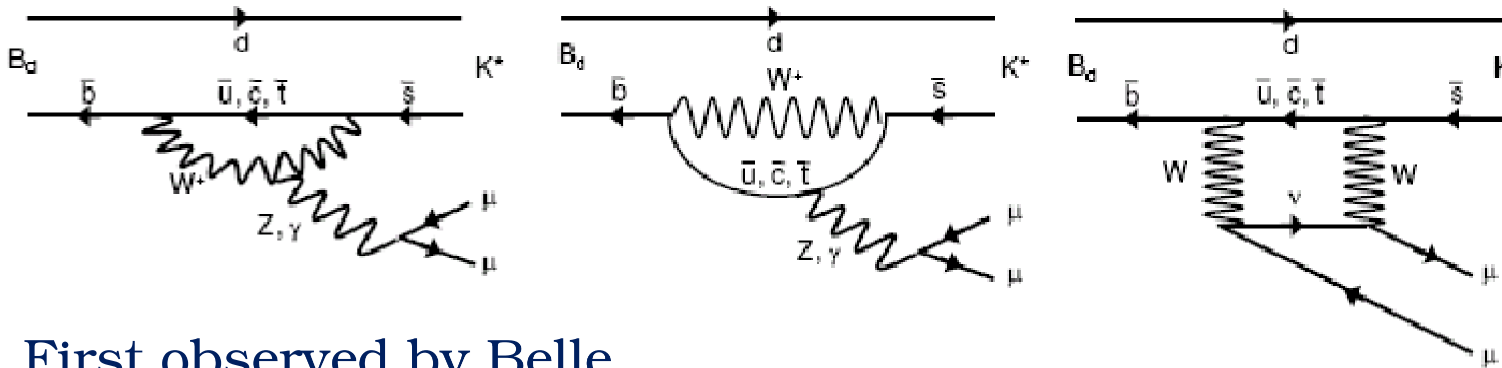


0.2 fb^{-1} : LHCb overtakes expected final Tevatron limit
0.5 fb^{-1} : BR < 10^{-8}

3 fb^{-1} : 3σ evidence
10 fb^{-1}: 5σ observation

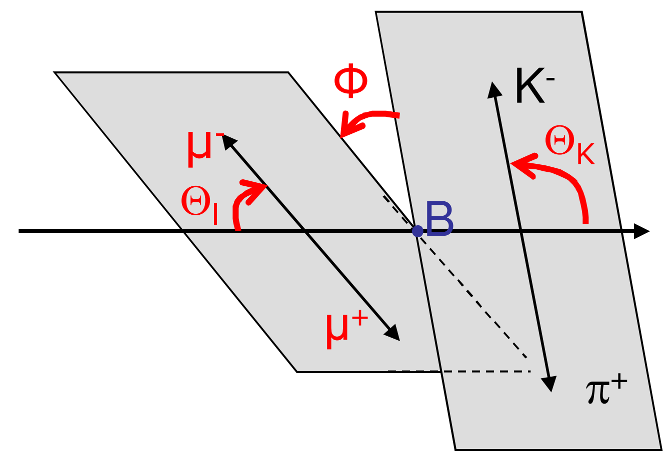
$B_d \to K^* \mu\mu$

- FCNC b→s transition



- First observed by Belle

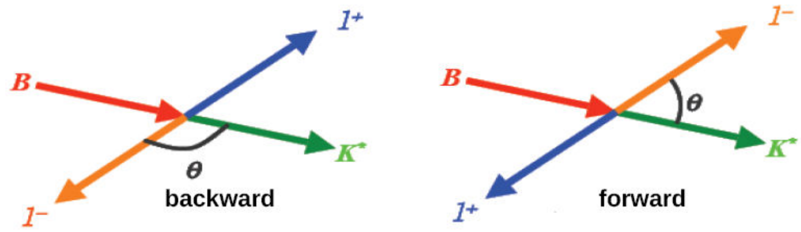
$$Br(B_d \to K^{*0}\mu^+\mu^-) = (1.22^{+0.38}_{-0.32}) \times 10^{-6}$$



- Decay described by Θ_l, Φ, Θ_K and $q^2 \equiv m_{\mu\mu}{}^2$
  ⇒Several angular observables can be built
- Crucial: identify observables with low theory errors [*See R.Zwicly talk*]
- Differential cross sections as a function of $m_{\mu\mu}{}^2$ *first one to be studied*

Forward-backward asymmetry: $A_{FB}(q^2)$

$$A_{FB}(q^2) = \frac{N_F - N_B}{N_F + N_B}$$

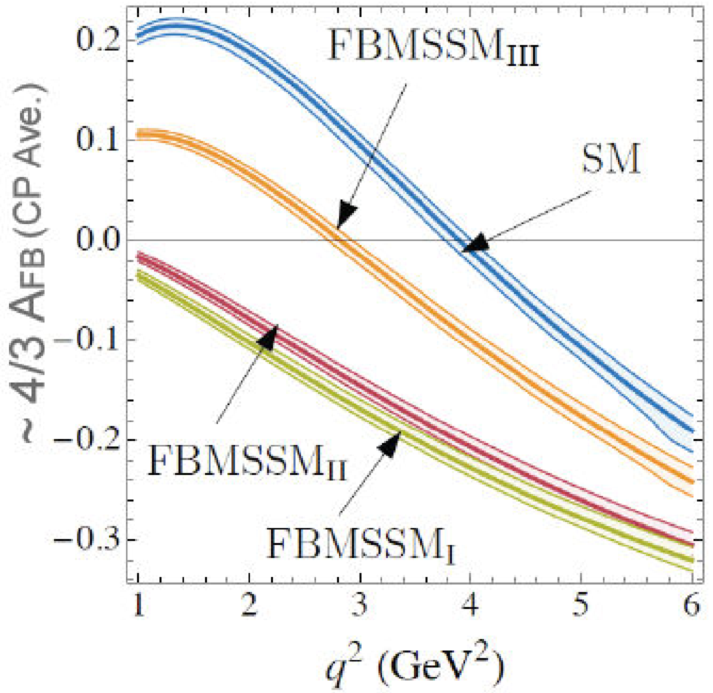


- Large deviations from SM with plausible New Physics
- zero-crossing point s_0 precisely predicted in the SM [$A_{FB}(s_0)=0$]:

$$s_0^{SM} = 4.36\ ^{+0.33}_{-0.31}\ \text{GeV}^2$$

- **Accessible with (0.5 fb^{-1})**

⇒ first goal for LHCb

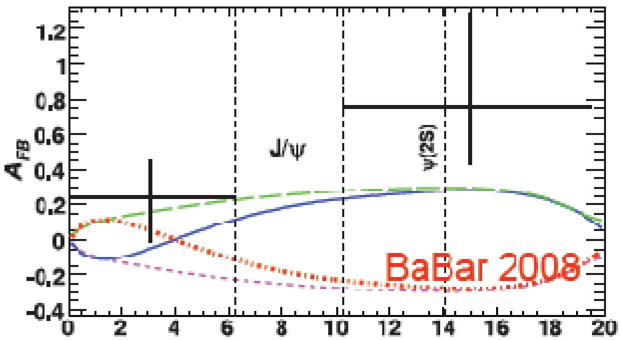


Altmannshofer *et al*, JHEP **0901**:019,2009

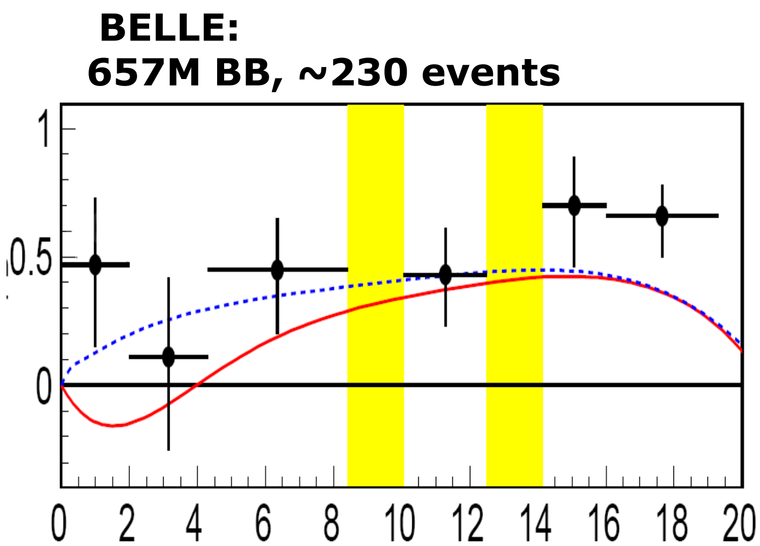
$A_{FB}(q^2)$ Current Status

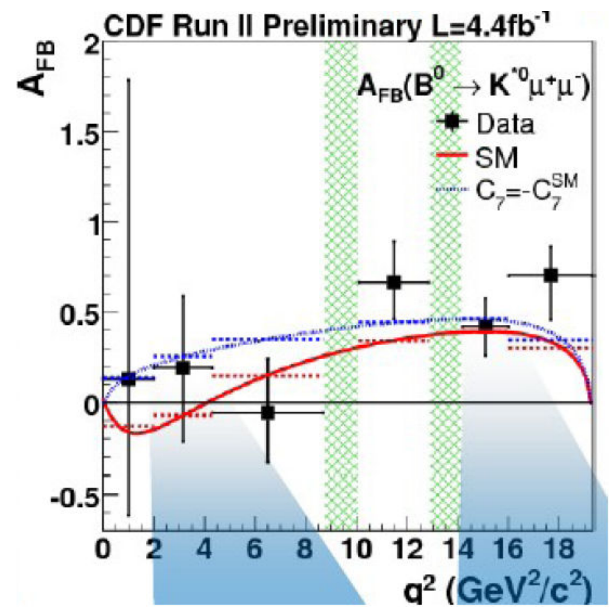
3 recent interesting results:

- Belle PRL 103:171801 (2009).
- BaBar PRD 79:031102 (2009)
- CDF preliminary (HCP 2009)



All 3 see sign of A_{FB} for low=q^2 opposite to SM





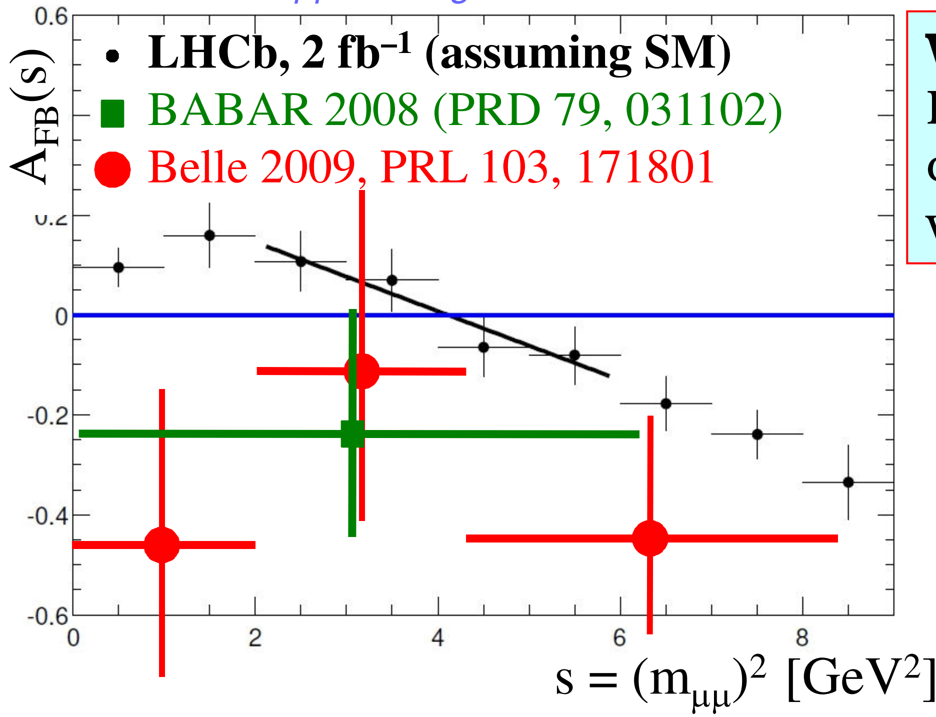
SM

NP $C_7=-C_7^{SM}$

$B_d \to K^* \mu\mu$: LHCb sensitivity to A_{FB}

- 6.2k signal events/$2fb^{-1}$, $B_{bb}/S \sim 0.25$

LHCb uses opposite sign convention



With ~200 pb^{-1} in 2010
LHCb will accumulate ~300 events could confirm tendency of A_{FB} with similar sensitivity to B-factories

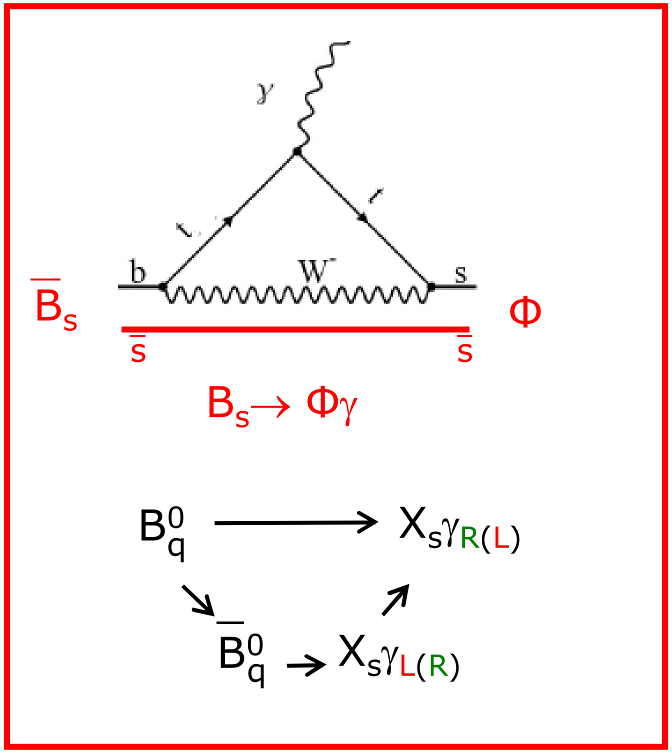
Crucial: understand angular acceptance (detector and reconstruction) and background

Extensive studies with suitable control samples: in particular, $B_d \to J/\psi\ K^{*0}$

- **With 2 fb^{-1}**, the zero of $A_{FB}(s)$ can be measured to ±0.5 GeV^2 (~11% of SM value)

$B_s \rightarrow \phi\gamma$

- Measurement of photon polarisation
- Photon polarisation is correlated with B-flavour ⇒ no interference and therefore no CP asymmetry within SM (suppressed by ~ms/mb)
- Non-zero asymmetry reveals presence of RH currents in penguin
- BaBar & Belle performed CPV analysis for $B_d \rightarrow K^*(K^0\pi^0)\gamma$ decay
  - $\sigma\,(A(B\rightarrow f^{CP}\gamma_R) / A(B\rightarrow f^{CP}\gamma_L)) \sim 0.16$



Essentially we study *CP*-violation in $B_s \rightarrow \phi\gamma$ as ***an instrument*** to probe Lorentz structure of $b \rightarrow s\gamma$ transitions

F.Muheim, Y.Xie & R.Zwicky, **Phys.Lett.B664:174-179,2008**

$B_s \to \phi\gamma$ Sensitivity

- CPV analysis in $B_s \to \phi\gamma$ can be performed without flavour tagging

Yield (2 fb^{-1})	B/S
11000	<0.6-0.9 @ 90 % CL

$$\Gamma(\mathrm{B}_q(\bar{\mathrm{B}}_q) \to f^{CP}\gamma) \propto e^{-\Gamma_q t}\left(\cosh\frac{\Delta\Gamma_q t}{2} - \mathcal{A}^{\Delta}\sinh\frac{\Delta\Gamma_q t}{2} \pm \right.$$

$$\left. \pm\mathcal{C}\cos\Delta m_q t \mp \mathcal{S}\sin\Delta m_q t\right).$$

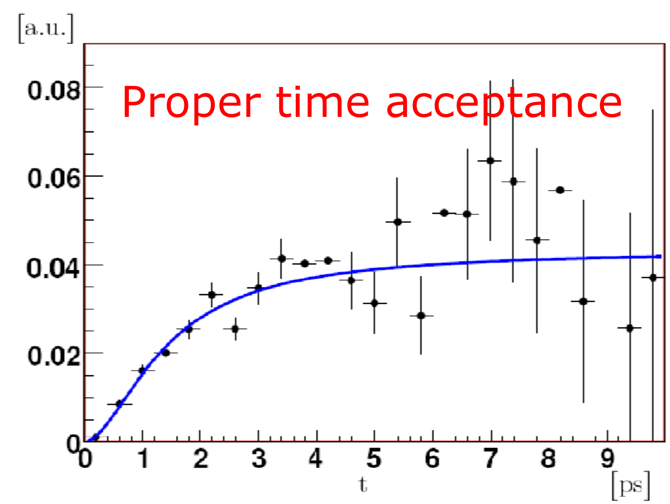
$$\tan\psi \equiv \left|\frac{A(\bar{\mathrm{B}}\to f^{CP}\gamma_R)}{A(\bar{\mathrm{B}}\to f^{CP}\gamma_L)}\right|$$

- SM:
  - $\mathcal{C}$ = 0 no direct CP-violation
  - $\mathcal{S}$ = sin2ψ sinϕ
  - $\mathcal{A}^{\Delta}$ = sin2ψ cosϕ

Crucial point :

- proper time acceptance (to be controlled on data)

2 fb^{-1} : $\sigma(A^{\Delta}) \sim 0.22 \Rightarrow \sigma\left(\frac{A_R^*}{A_L}\right) \sim 0.1$



Stefania Ricciardi, RAL

Prospects for early physics

Beyond the B

(some examples)

Day 1 Measurements: Minimum Bias

As soon as stable collision mode at √s>4TeV record:

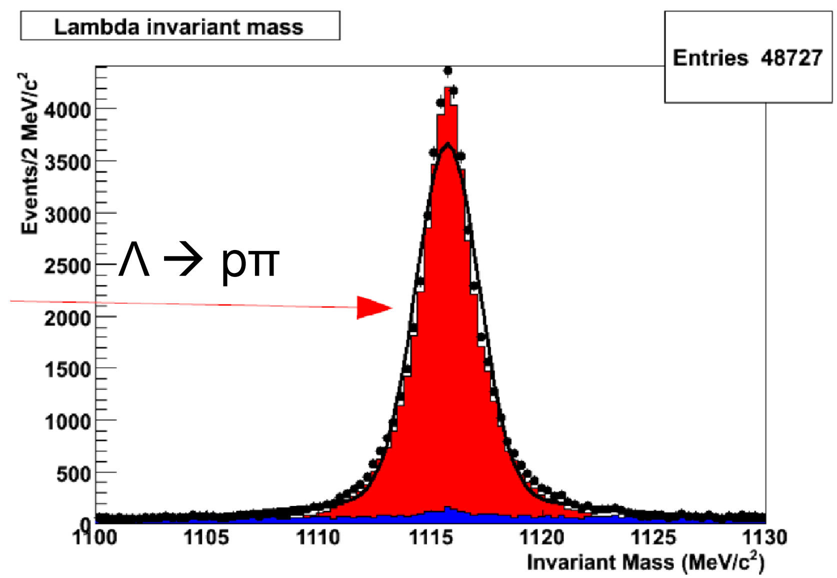
- 10^8 mbias events

O(day) @ 2kHZ

Large number of reconstructed K_s,Λ,φ for:

- Detector calibration
- Trigger studies
- Early physics, in particular QCD
    - inclusive studies of strangeness production

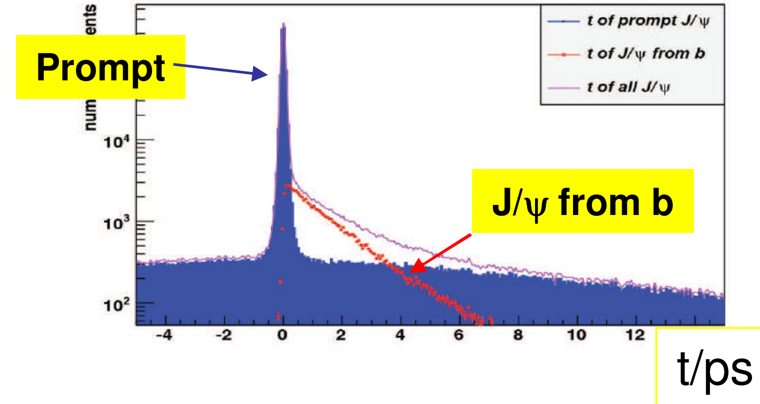
95% purities achievable using Kinematical cuts alone

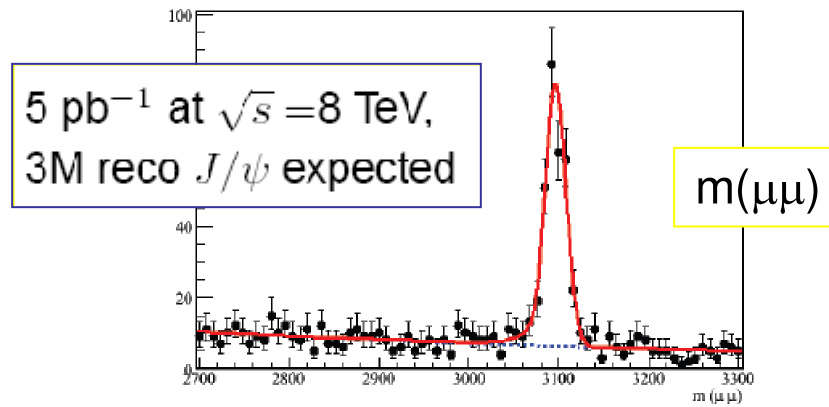


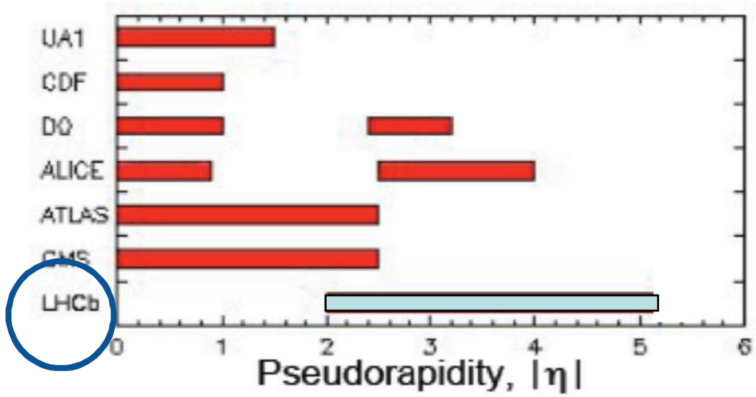
1-5 pb^{-1}: J/ψ production

$t = \frac{dz}{p_z^{J/\psi}} m^{J/\psi}$ separates:

- prompt J/ψ
  - Proper time calibration
  - cross-section/polarisation
- secondary J/ψ :
  - *$pp \to X + bb$ $(b/\bar{b} \to J/\psi + X)$*
  - bb cross-section







- Unique LHCb coverage in regions not accessible to other collider expts, where theoretical predictions are less accurate

20 pb^{-1} and upward : charm physics

- **Very high statistics** for charm physics at LHCb
  - $\sigma(cc) \sim 7x\ \sigma(bb)$
  - Example: D* tagged trigger provides 42k $D^0 \rightarrow KK$ events per pb^{-1} [$\Rightarrow$ 10 pb^{-1} LHCb data sample ≥ total B-factory]
- **Unprecedented sensitivity even with first data**
  - D^0 mixing and CPV (CPV observation would be clear NP!)
  - Two body lifetime ratio measurement

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

$$= y$$ (Assuming no CP violation)

$\sigma(y_{CP}) \sim 1.1 \times 10^{-3}$ with $100 pb^{-1}$ [$SM < 10^{-3}$]

Belle: $\sigma(y_{CP}) = 3 \times 10^{-3}$

  - Direct CP violation in singly Cabibbo-suppressed charm decays ($D^0 \rightarrow KK$, $D^+ \rightarrow KK\pi$)

Summary and conclusions

- **LHCb 2009 :** Highly successful first data-taking period
  - O(300k) events at 900 GeV
  - Used to commission and calibrate the detector
- **LHCb 2010:** expect first results for several key-measurements in the B sector. Mentioned here just a narrow selection of promising channels:
  - γ from $B \to DK$
  - γ from $B \to hh$
  - ϕ_s from $B_s \to J/\psi\phi$
  - $B_s \to \mu\mu$
  - $B_d \to K^*\mu\mu$
  - $B_s \to \phi\gamma$

NP discovery in 2010 if Φ_s @ Tevatron central value!

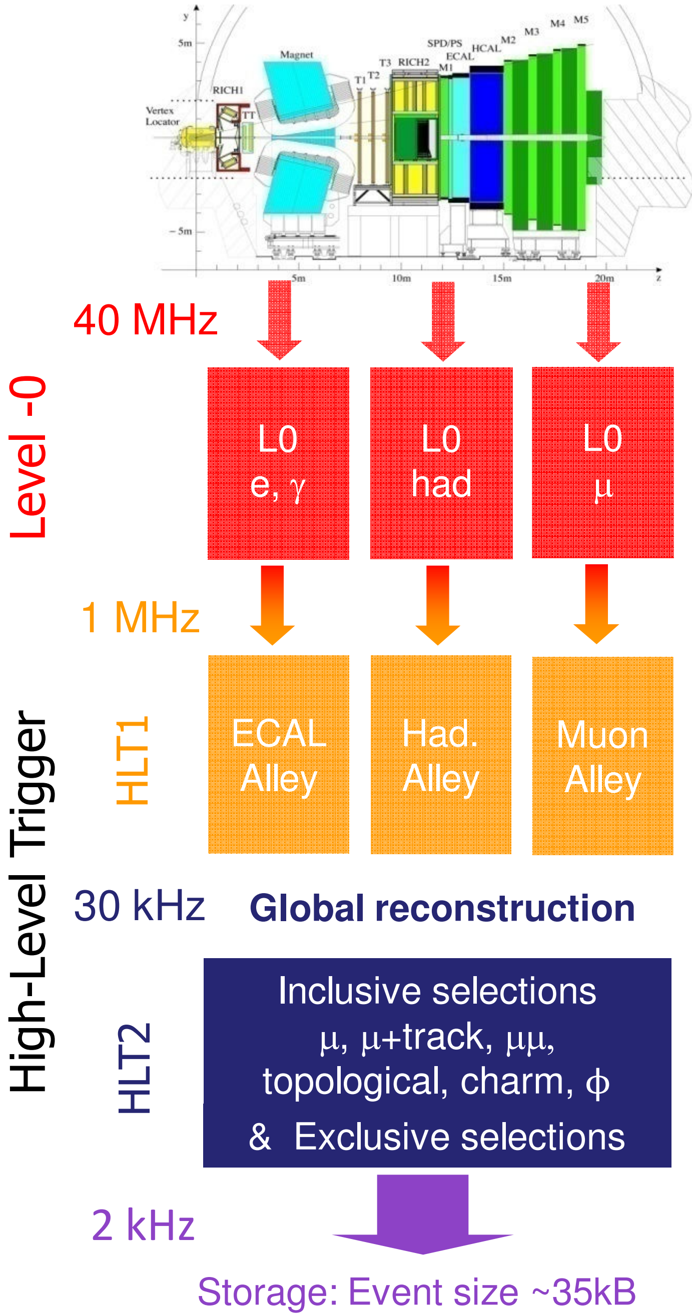
- In addition, rich program of physics Beyond the B with early data

Watch for beauty and charm results at next Summer Conferences!

Fetes de Geneve 2009

LHCb-upgrade physics reach

	Measurement	Current precision	LHCb ($10\ fb^{-1}$)	**LHCb upgrade ($100\ fb^{-1}$)**	Irreducible theory error	Competition
E/W Penguins	$s_0 A_{FB}$ ($K^*\mu\mu$)	Unmeasured	4%	1%	7%	None
	$A_T^{(2)}$ ($K^*\mu\mu$)	Unmeasured	0.10	**0.03**	0.05	None
Right-handed currents	S ($B_s \to \varphi\gamma$)	Unmeasured	0.05	**0.01**	<0.01	None
	$A^{\Delta\Gamma}$ ($B_s \to \varphi\gamma$)	Unmeasured	0.10	**0.02**	0.02	None
Higgs penguins	$\mathcal{B}(B_d \to \mu\mu) / \mathcal{B}(B_s \to \mu\mu)$	Unmeasured	Unmeasured	**~20%**	~5%	ATLAS, CMS
Gluonic penguins	$\beta_s^{NP}(B_s \to K^{0*}\bar{K}^{0*})$	Unmeasured	5°	**1°**	<1°	None
	β_s^{NP} ($B_s \to \phi\phi$)	Unmeasured	5°	**1°**	~1°	None
	β^{NP} ($B_d \to \phi K_S$)	8°	8°	**2°**	~1°	SFF
SM bench-marks	γ ($B \to DK$)	~25°	~2°	**<1°**	Negligible	None
	β ($B_d \to J/\psi K_S$)	1°	0.2°	**<0.1°**	~0.1°	None
	β ($B_d \to D\pi^+\pi^-$)	Unmeasured	1°	**0.2°**	Negligible	None
NP in Bs mixing	β_s ($B_s \to J/\psi\ \varphi$)	20°	0.3°	**≤0.1°**	~0.1°	None
CPV in charm	A_Γ ($D \to KK$)	25×10^{-4}	3×10^{-4}	**0.7×10^{-4}**	~10^{-4}	None



Trigger

Trigger is crucial:
- $\sigma_{b\bar{b}}$ is less than 1% of total inelastic cross section
- B decays of interest typically have BR < 10^{-5}

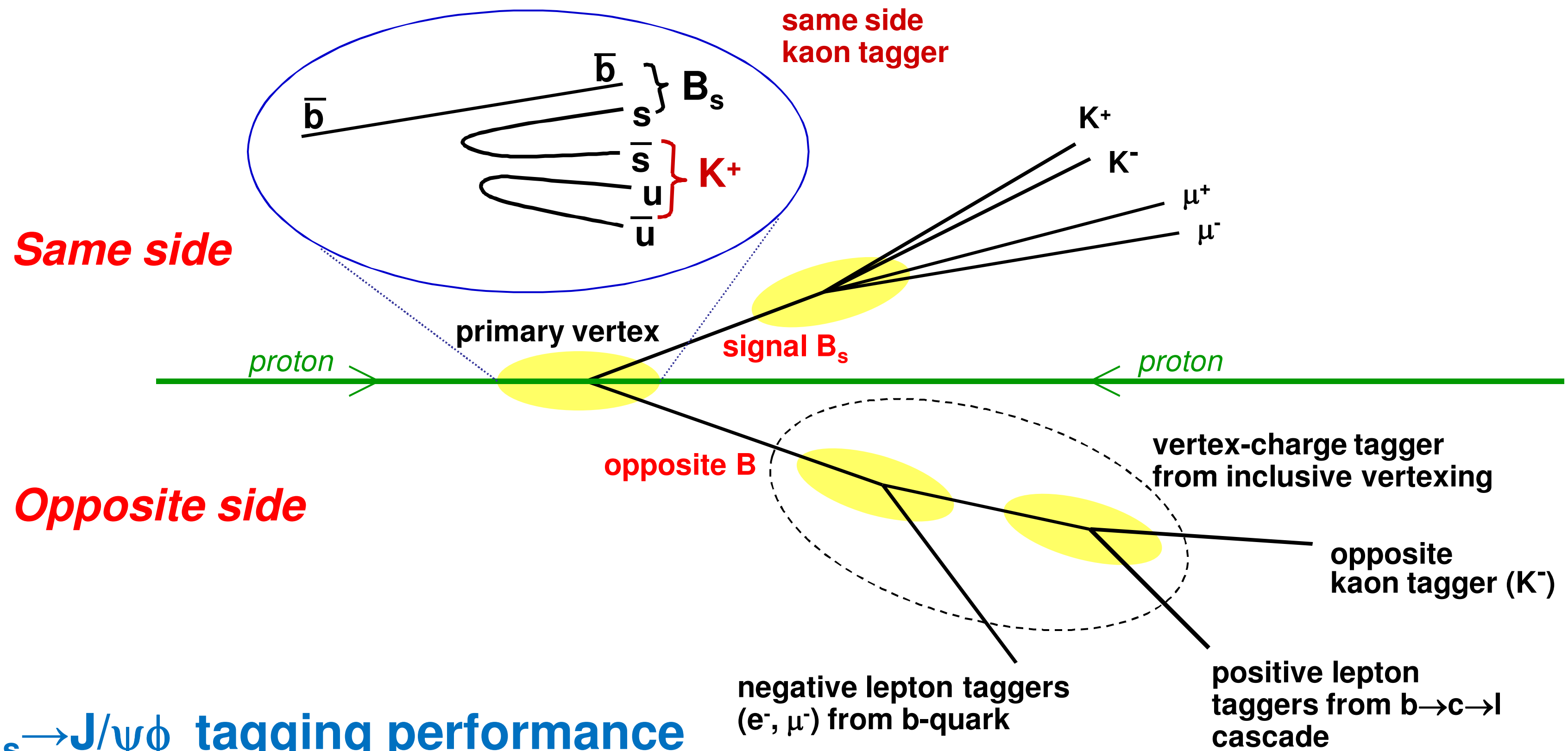
Hardware level (L0)
- Search for high-p_T μ, e, γ and hadron candidates

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

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

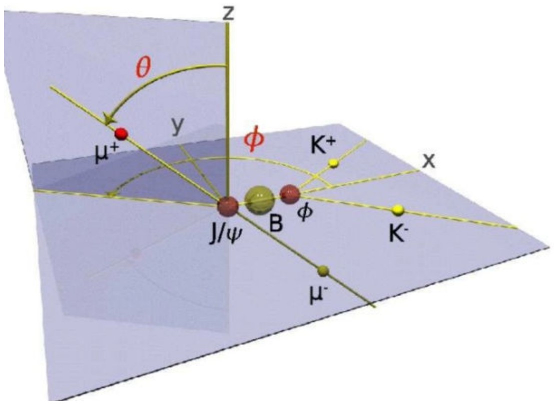
Flavour tagging performance

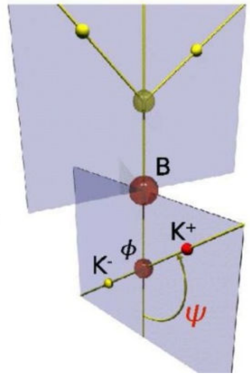


$B_s \to J/\psi\phi$ tagging performance

Tagger	Tag eff.	mistag	$\varepsilon(1-2\omega)^2$
Opposite side	45%	36.5%	3.3%
+ same side	56%	33.3%	6.2%

$B_s \to J/\psi\, \phi$ time-dependent angular fit





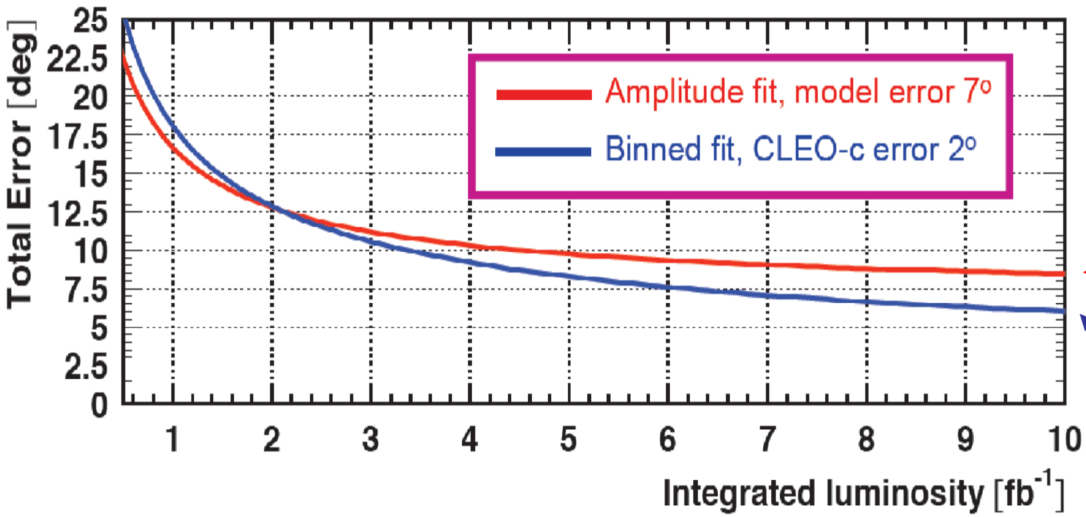
P→VV decay : mixture of CP-even (ℓ=0,2) and CP odd (ℓ=1) final states. An angular analysis allows to separate statistically the decay amplitudes.

3 angles $\Omega=(\theta, \phi, \psi)$ to describe the final decay products directions.

- Physics parameters extraction via unbinned maximum likelihood fit
- Input
  - **angles** $\Omega=(\theta, \phi, \psi)$: to separate different CP eigenstates
  - B_s **invariant mass**: to separate signal and background
  - B **flavour tag**: pin down initial state of the decay
  - **proper decay time**: to extract Φ_s from the time-dependent asymmetry
- Output
  - 8 physics parameters Φ_S, Γ_s, $\Delta\Gamma_s$, Δm_s, $R_\perp$, $R_\parallel$, $\delta_\perp$, $\delta_\parallel$
  - various detector parameters

$B^+ \to D(K_S\pi^+\pi^-)K^+$ sensitivity to γ

Extrapolated total error for $B^+ \to D(K_S\pi^+\pi^-)K^+$ vs luminosity



With 10 fb^{-1}, if r_B=0.1:

Unbinned fit with model assumptions: 8.5° (systematic dominated)

Binned fit with Cleo-c input: 6° (statistics dominated)

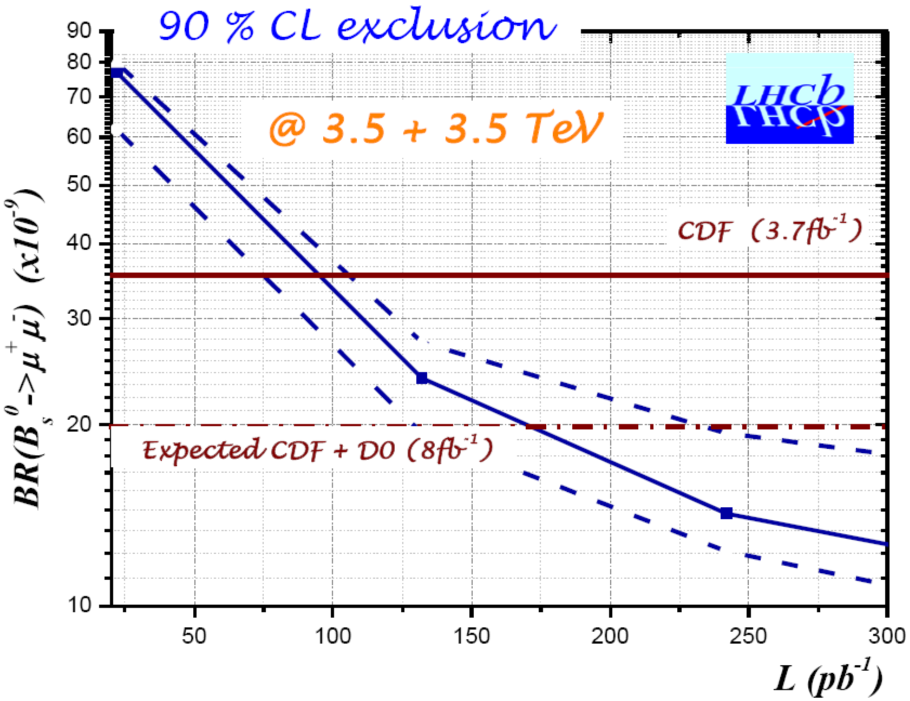
Two approaches pursued in parallel:

1. ***Unbinned*** approach will be limited by model error at LHCb
2. ***Binned*** approach
   - has no hard-to-quantify model systematic
   - small loss of statistical power in using discrete bins < 2 fb^{-1}
   - outperforms unbinned fit for luminosity > 2 fb^{-1}

$B_s \rightarrow \mu\mu$ in 2010

LHCb, Beauty 2009

- LHC first data:
  - Less energy (3.5 + 3.5 TeV)
  - Less instant luminosity
- Exclusion sensitivity for
  - 45% of σ_{bb} w.r.t. 14 TeV (Pythia ratio $\sigma_{bb\_7TeV}/\sigma_{bb\_14TeV}$), so 225 μb
  - First 10 months after LHC startup (assumed 300 pb^{-1})
- This data could allow LHCb to overtake Tevatron limits and impose new constraints on SUSY models



$B_s \to \mu^+\mu^-$ reach

- LHCb and CMS sensitivities:
  - same "Modified Frequentist Approach"
    shown at Beauty 2009 (D. Martinez Santos)

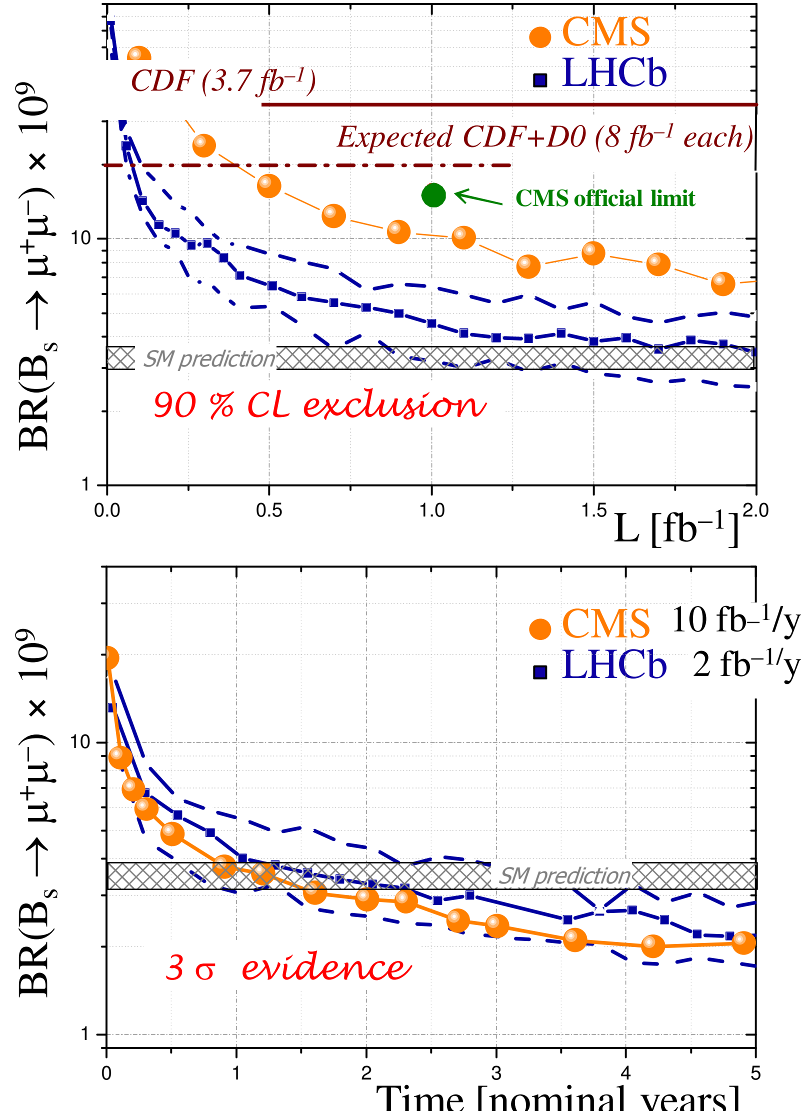
- LHCb performance (nominal conditions)

1 fb^{-1} $\Rightarrow$ exclude BR values down to 5×10^{-9}
3 fb^{-1} $\Rightarrow$ 3σ evidence of SM signal
10 fb^{-1} $\Rightarrow$ 5σ observation of SM signal

  - CMS/ATLAS performance similar with 5 times more L_{int} (collected in ~equal time)

- Startup conditions in 2010
  ($\sqrt{s}$ = 7 TeV)

LHCb can overtake Tevatron's final sensitivity with ~ 0.2 fb^{-1}



Normalization for $B_s \to \mu\mu$

- Normalization is needed to convert # events into a BR w/o relying on knowledge of σ_{bb}, integrated luminosity or absolute efficiencies

$$BR = BR_n \frac{\varepsilon_n}{\varepsilon} \cdot \frac{P(b \to B_n)}{P(b \to B_s)} \cdot \frac{N}{N_n}$$

Channel	Use	Yield (1 fb^{-1})
Inclusive $J/\psi(\mu\mu)$	μ-ID calibration	1.7G
Inclusive $\Lambda(\pi p)$	μ-ID calibration	740G
$B \to hh'$	Mass calibration GL calibration Normalization	220k
$B^+ \to J/\psi(\mu\mu)K^+$	Normalization	790k
$B^0 \to J/\psi(\mu\mu)K^{*0}(\pi K)$	Normalization	640k

LHCb can trigger on hadronic B decays:

Ultimate limitation:
Normalization *to known BR such as $B^+ \to J/\psi(\mu\mu)K^+$ with similar detector dependencies*
Limited due to uncertainty in B_s/B production ratio: about 13%.

Important when close to SM value!

Recent Belle measurement for $B_s \to D_s^- \pi^+$ (20% now) is promising if Belle continues to run further at $\Upsilon(5s)$