Heavy Flavour Results and Prospects at LHC

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On behalf of LHCb Collaboration
including ATLAS/CMS results

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Outline

- Introduction:

  - Flavour physics in the LHC era as a window for new physics
  - Intriguing anomalies in the SM picture
- LHC: a heavy quarks factory
- The status LHC experiments (mostly LHCb):

  key experimental ingredients for heavy flavour physics measurements: status of the art
- First results in flavour physics @ LHC and prospects.

Flavour Physics in LHC era

- Flavour physics has been so far a powerful probe to test the Standard Model structure.

- However the Standard Model cannot be the ultimate theory:

  - it does not explain the hierarchy problem, the dark matter problem, the baryon asymmetry, the mass pattern and mixing angles of quarks and leptons and it does not account for gravitational interactions.

- The SM is likely the low-energy ($\sim M_W$) limit of a more fundamental theory that involves new particles, symmetries and degrees of freedom at higher energy scale.

- Therefore the two key questions of particle physics today are:

  1) which is the energy scale of new physics?

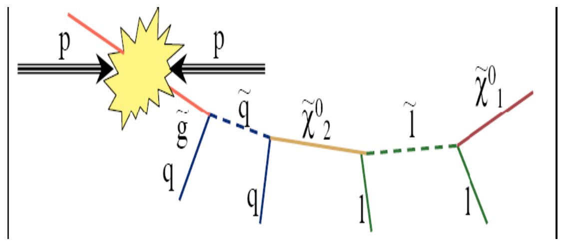
  2) which is the symmetry structure of the new degrees of freedom?

Flavour Physics in LHC era

Two complementary ways to answer these two questions:

1) Direct searches in high-pT physics:

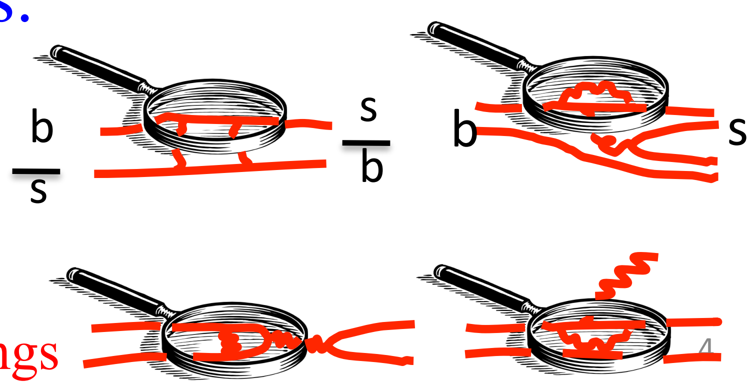
→ look for real particles with specific signatures (mostly ATLAS/CMS domain)



2) Indirect searches in flavour physics:

→ look for virtual particles in loop processes leading to observable deviations from SM

- can access higher energy scale
  [see the effect earlier]
- can study the flavour structure of new couplings
  [phases & amplitudes]



Flavour Physics in LHC era

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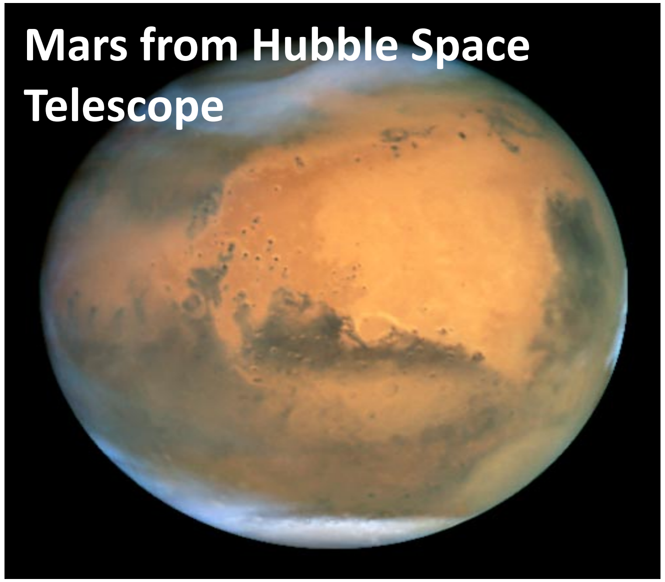
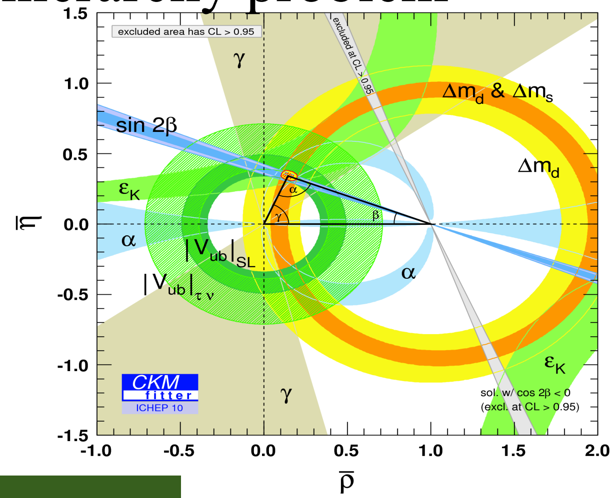


Flavour physics as a window for New Physics

- Flavour physics is expected to play a key role in constraining the parameters of any NP model emerging [or not emerging] from direct searches.

- However if NP is at the TeV scale to solve the hierarchy problem
 - eg reachable by ATLAS/CMS -
 it must have a rather sophisticated
 flavour structure to account
 for absence of unambiguous NP signal in
 FCNC transitions.



→NP [if any] will appear as small anomalies to the leading order CKM picture

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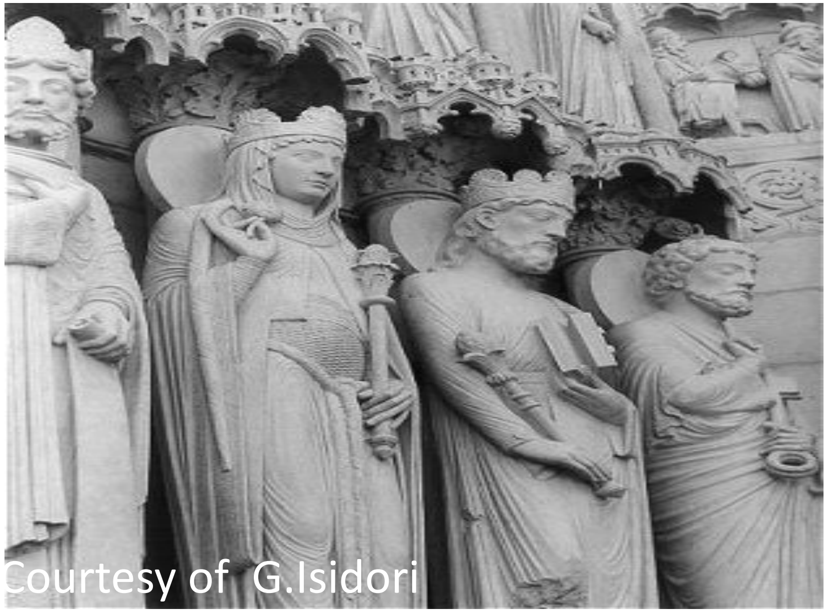
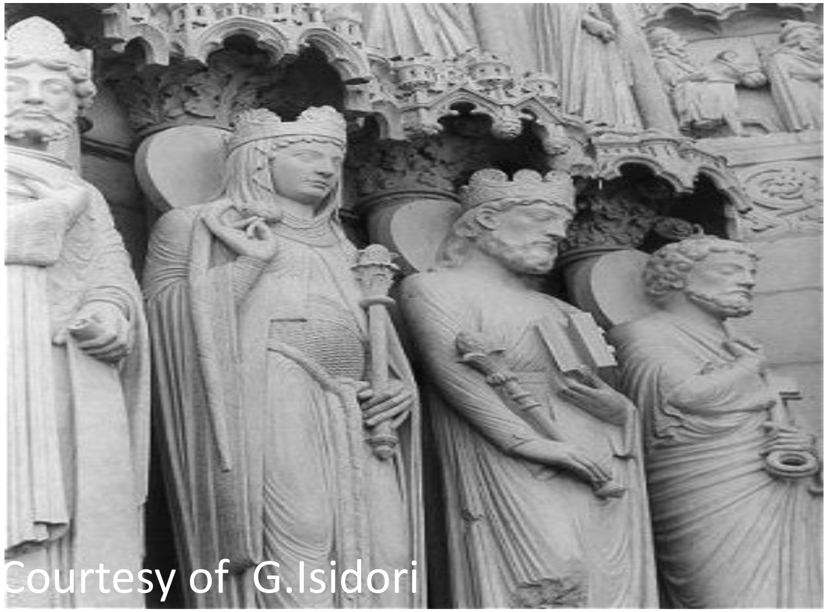
“Anomalies” in the Standard Model picture



Despite the overall success of the “Standard picture”…

6

“Anomalies” in the Standard Model picture



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. looking more closely there are some “anomalies” that disturb the overall consistency.

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“Anomalies” in CKM fits:

1) $A(\psi K) = \sin(2\beta)$ tension [2.6 σ] between direct measurement and its predictions [ε_K]

2) CPV in Bs mixing:

→ mainly driven by same-charge dimuon asymmetry measured by D0 [3.2 σ discrepancy with SM]

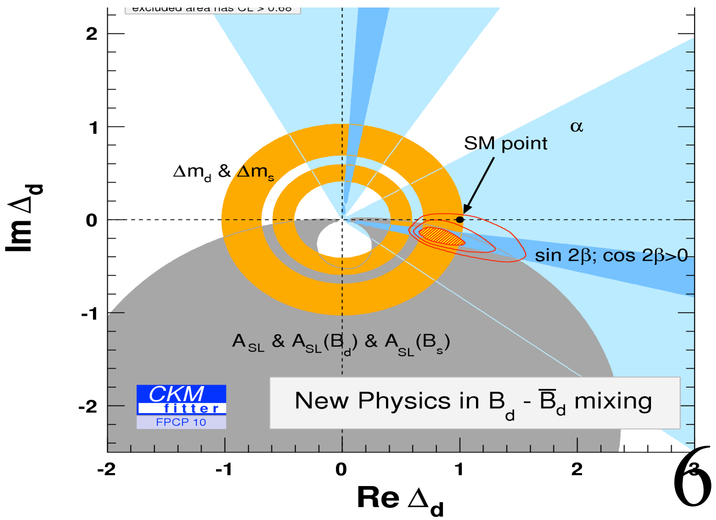
3) BR($B \to \tau\nu$):

→ exp = $(1.68 \pm 0.31)\ 10^{-4}$ [Babar + Belle ‘10]

→ SM = $(0.79 \pm 0.07)\ 10^{-4}$ [UTFit ’10]

New Physics in B_d-B_d mixing?

→ SM compatibility is at ~2σ level



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"Anomalies" in the Standard Model picture

Despite the overall success of the "Standard picture"…

.. looking more closely there are some "anomalies" that disturb the overall consistency.

Understanding these [and other] anomalies is the role of the flavour physics @ LHC in the coming years.

6

LHC b- and c-physics program

[not exhaustive list]

- Calibrating the sources [**$\sigma(bb)$, $\sigma(cc)$,..]:**
  - measure $\sigma(bb)$ at $\sqrt{s}$ =7 TeV via abundant processes as $b \to J/\psi X$ and $b \to D^0(K\pi)\ \mu\ \nu\ X$.

- Improve measurement precision of CKM elements:
  - Compare two measurements of the same quantity, one which is insensitive and another one which is sensitive to NP **(tree vs loop)**
    - $\sin(2\beta)$ from $B^0 \to J/\psi K_S$ and $\sin(2\beta)$ from $B^0 \to \phi K_S$
    - **γ from $B_{(s)} \to D_{(s)}K$** and γ from $B^0 \to \pi^+\pi^-$ and $B_s \to K^+K^-$
  - Measure all angles and sides in many different ways
    - any inconsistency will be a sign of new physics

- Measure FCNC and ΔF=2 transitions where NP may show up as a relatively large contribution:
  - B_s mixing phase: β_s **and a_{sl}**
  - $b \to s\gamma$, **$b \to s l^+ l^-$, $B_{(s)} \to \mu\mu$**
  - Also: **CP phase in D^0 mixing**

LHC b- and c-physics program
[not exhaustive list]

Preliminary result based on $L \sim 10 - 20\ nb^{-1}$

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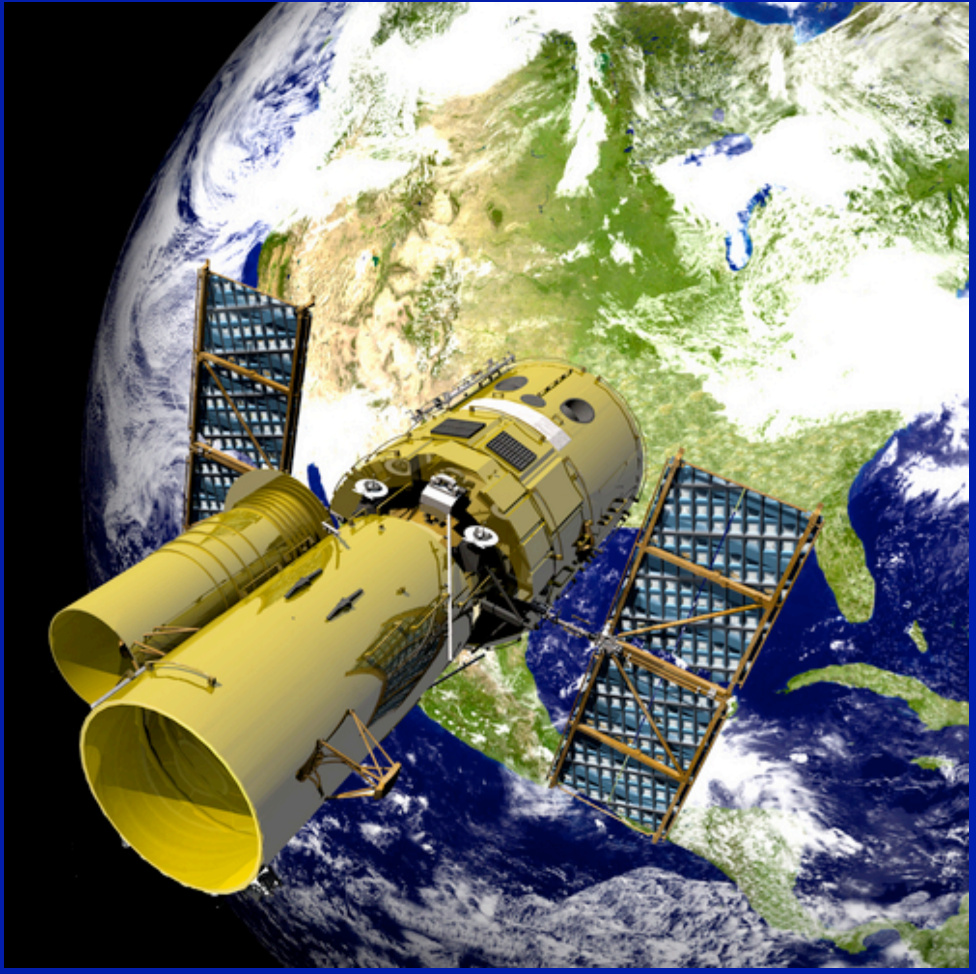
Here LHC experiments expect to have competitive results with data collected in 2010-2011 run

2. LHC: machine status and detectors performance



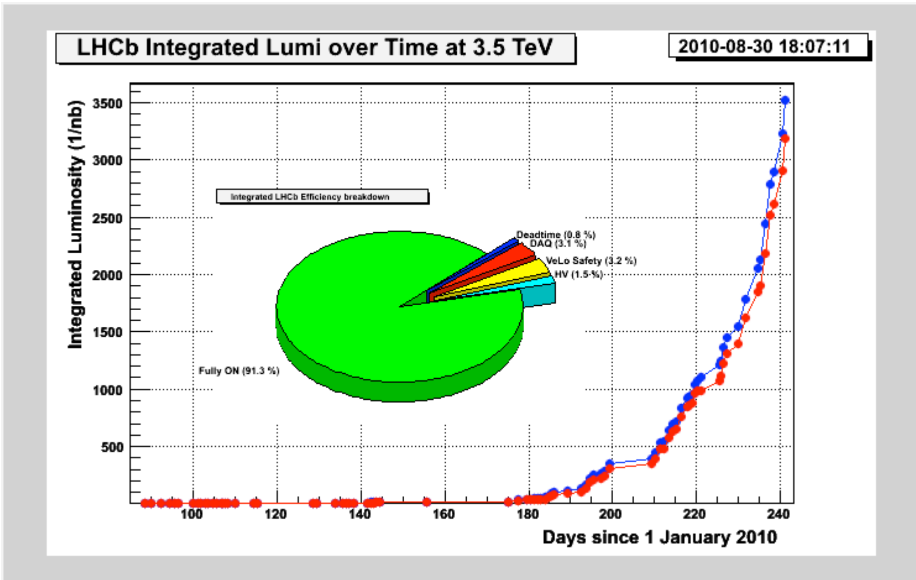
The Hubble space telescope

LHC: status and perspectives for 2010-2011 run

❑ Excellent machine performance:

- $\sqrt{s} = 7$ TeV , L_{peak} increased ~1 order of magnitude per month
  - now: ~3.5 pb^{-1} delivered, $L_{peak} \sim 10^{31}\ cm^{-2}\ s^{-1}$
  - end 2010: ~50 pb^{-1} with $L_{peak} < 10^{32}\ cm^{-2}\ s^{-1}$
  - end 2011: ~ 1 fb^{-1}, $L_{peak} \sim 10^{32}\ cm^{-2}\ s^{-1}$

→3.5 pb^{-1} correspond to ~ 1000 M of bb pairs:
→ only few% of what expected by the end of this year!

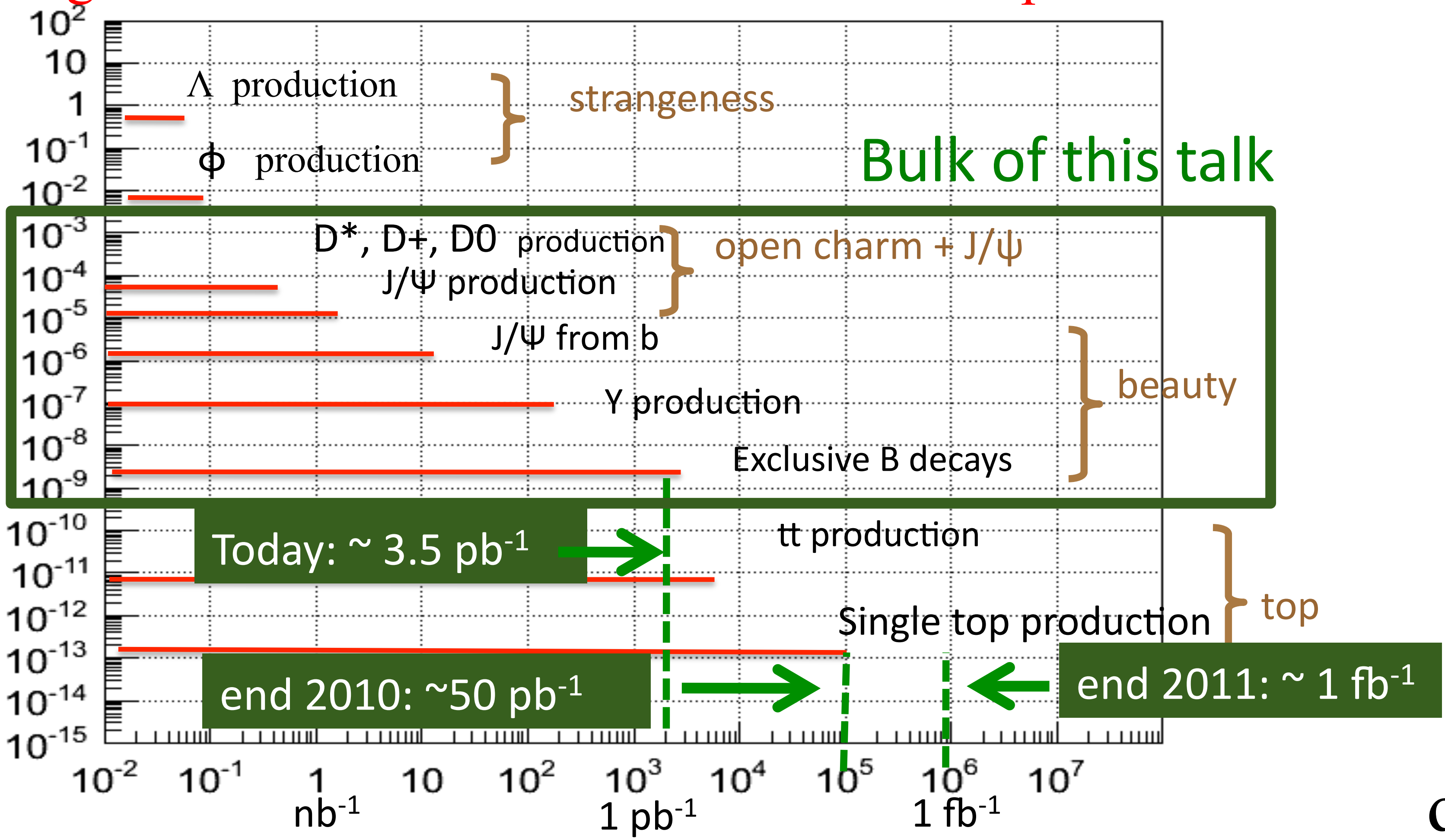


❑Excellent detectors start-up:

detectors ~95 % operational
L(recorded) ~ 95% L (delivered)

Heavy Flavour @ LHC: high statistics

Integrated L needed to observe 100 events of process X



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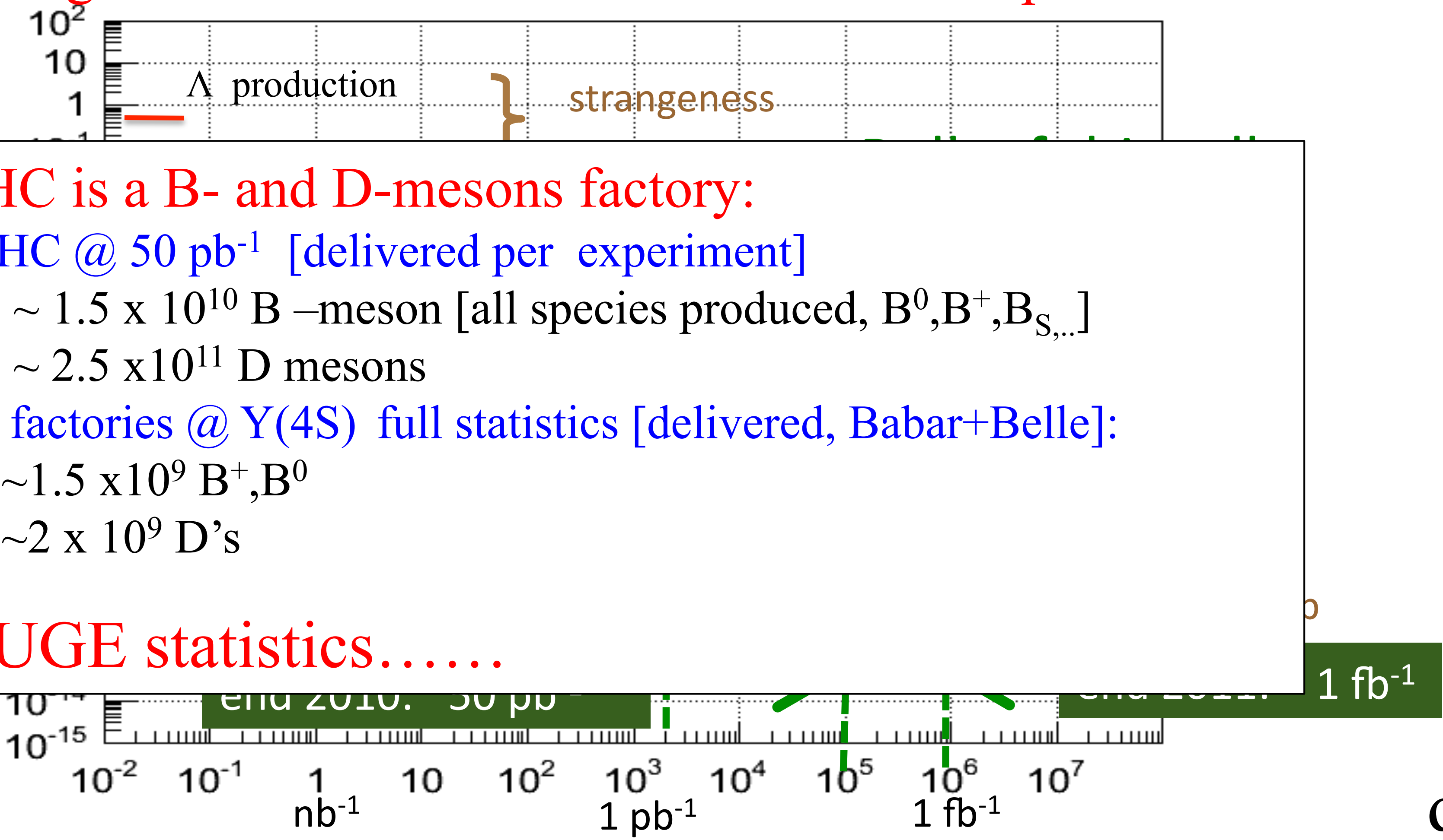


LHC is a B- and D-mesons factory:

LHC @ 50 pb^{-1} [delivered per experiment]

~ 1.5 x 10^{10} B –meson [all species produced, B^0,B^+,$B_{S,..}$]

~ 2.5 x10^{11} D mesons

B factories @ Υ(4S) full statistics [delivered, Babar+Belle]:

~1.5 x10^9 B^+,B^0

~2 x 10^9 D's

HUGE statistics……

…in a harsh environment

$b\bar{b}$ produced mostly forward/backward:

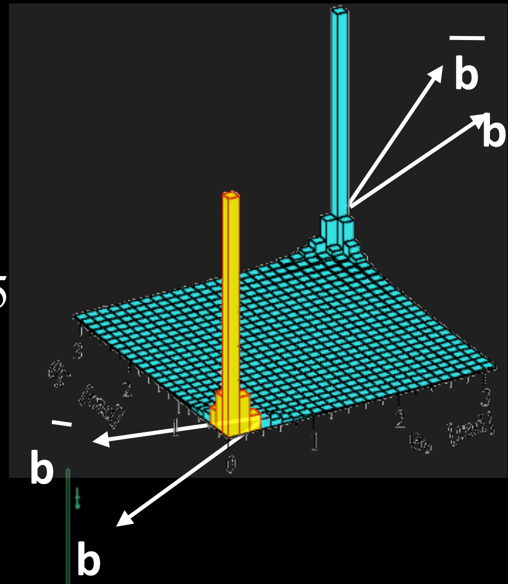
- LHCb forward spectrometer covering η=[2,6], ATLAS/CMS $|\eta|<2.5$

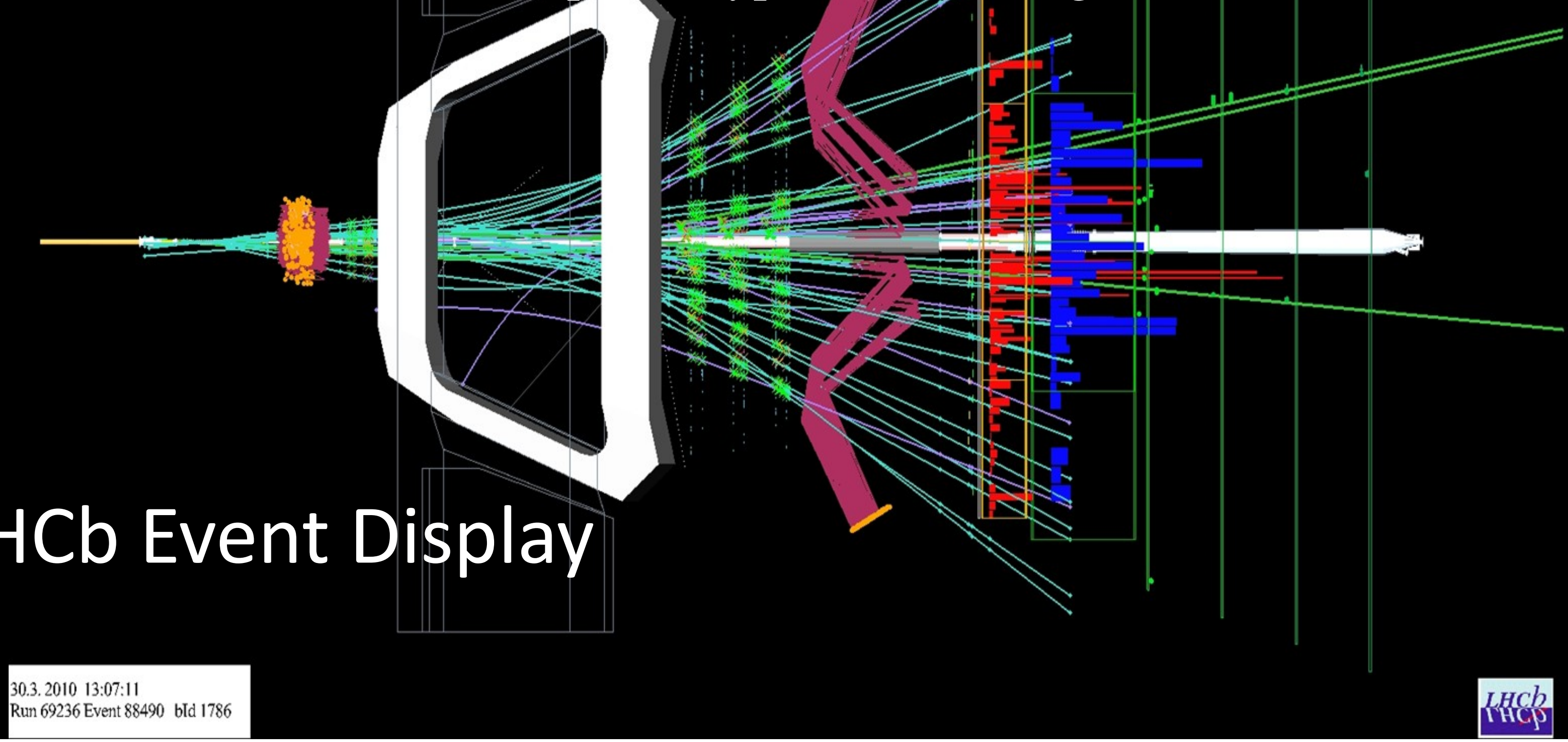
Large bb cross section [~300 ub @ $\sqrt{s}$=7 TeV]:

- ~30% in LHCb acceptance

But huge background: σ(pp) @ $\sqrt{s}$=7 TeV ~ 90 mb

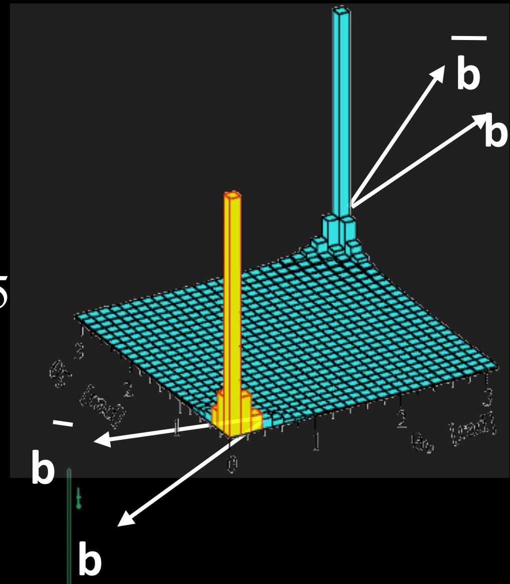
- 30 tracks per event per pseudorapidity unit
- 1/200 event contains a b quark , typical interesting BR < 10^{-3}





LHCb Event Display

…in a harsh environment



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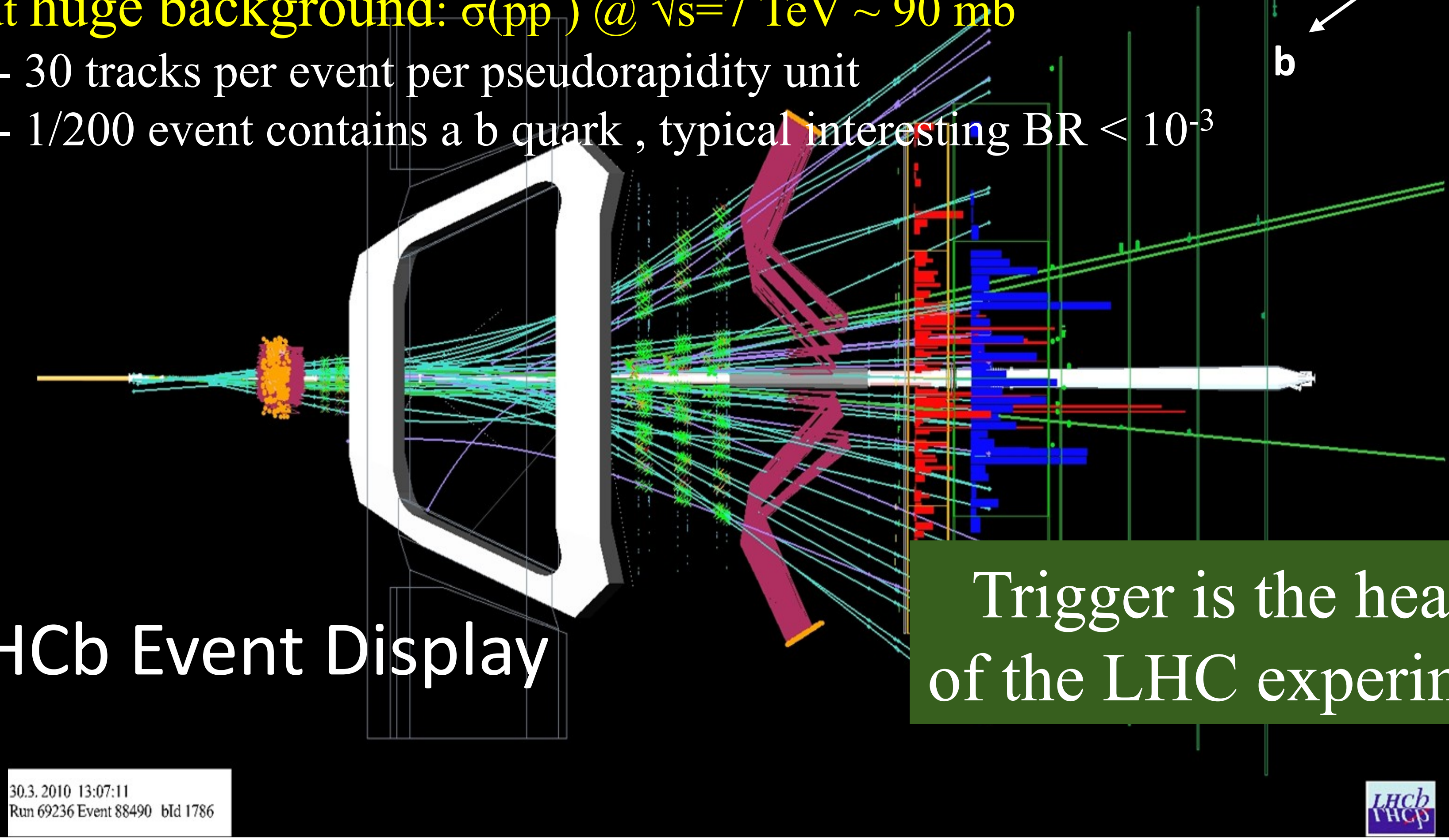
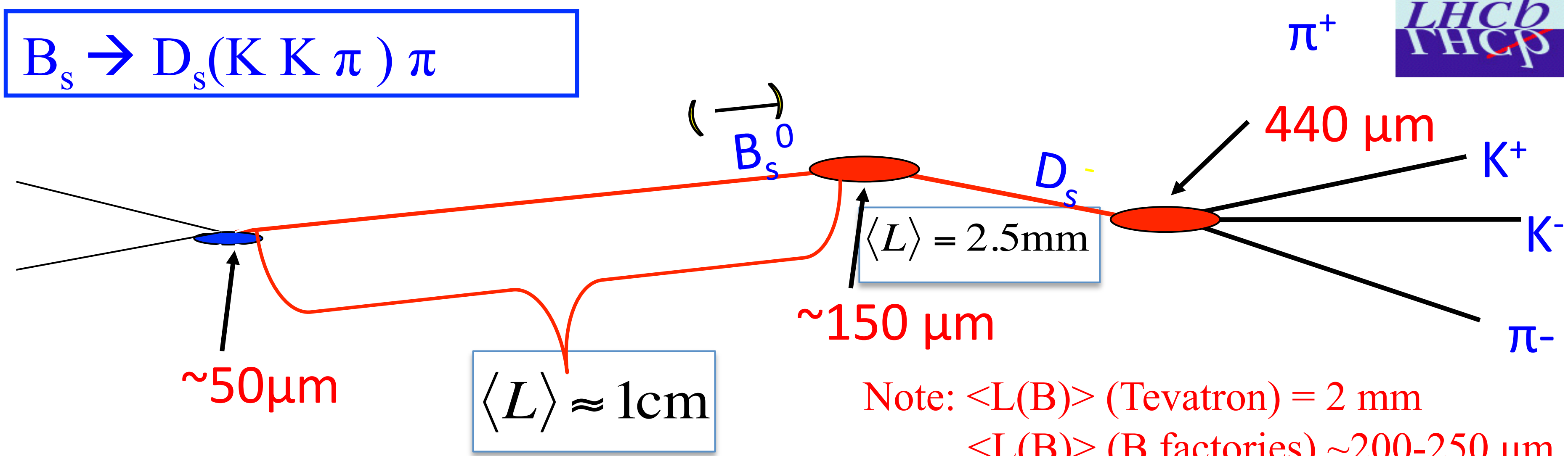


LHCb Event Display

Trigger is the heart of the LHC experiments !

Key ingredients for beauty (and charm) experiments

$B_s \rightarrow D_s(K\,K\,\pi\,)\,\pi$



Note: <L(B)> (Tevatron) = 2 mm
<L(B)> (B factories) ~200-250 μm

1) High statistics:

- Efficient trigger for hadronic and leptonic final states

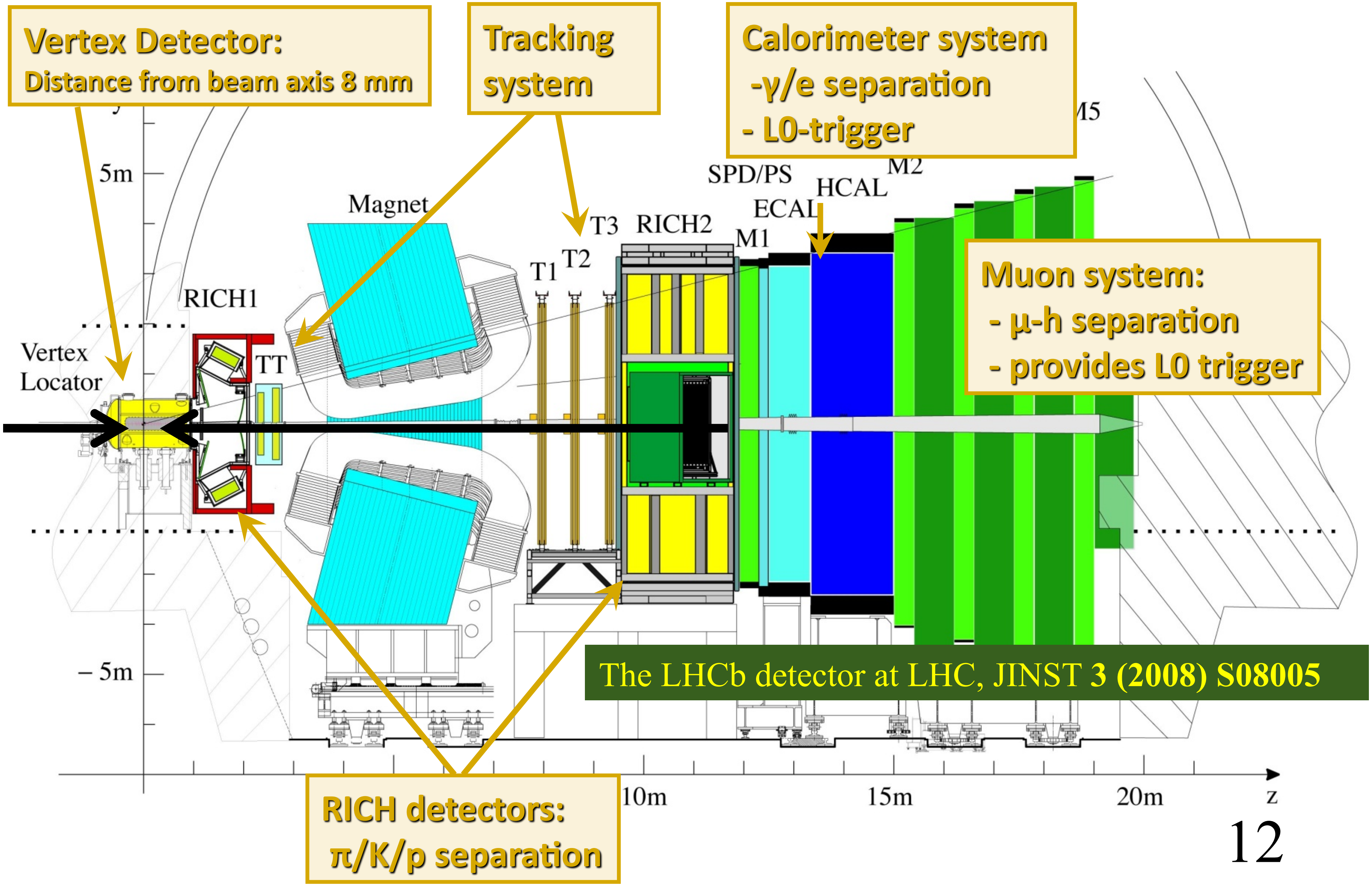
2) Background reduction:

- Very good mass resolution
- Particle identification

3) Excellent vertex resolution:

- to resolve fast Bs oscillations and separate signals from background

LHCb detector: scheme

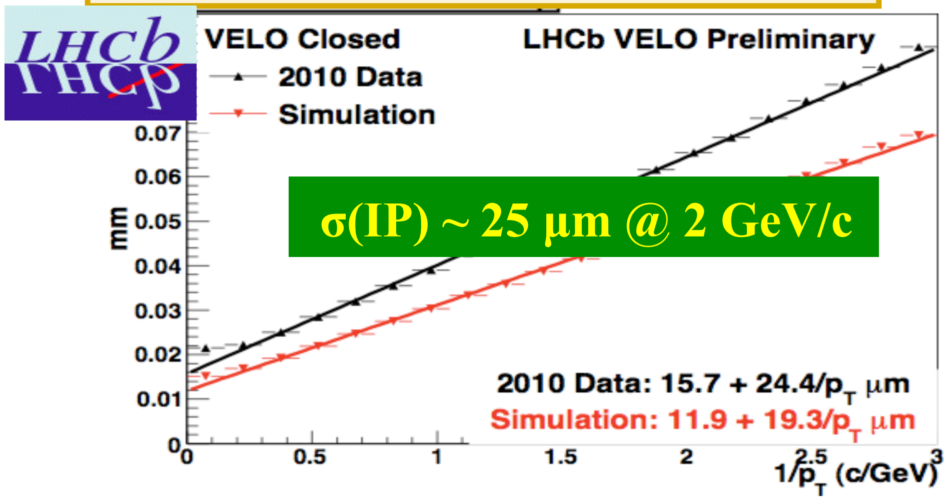


key ingredients for b- [c-]physics: Vertex & IP resolutions

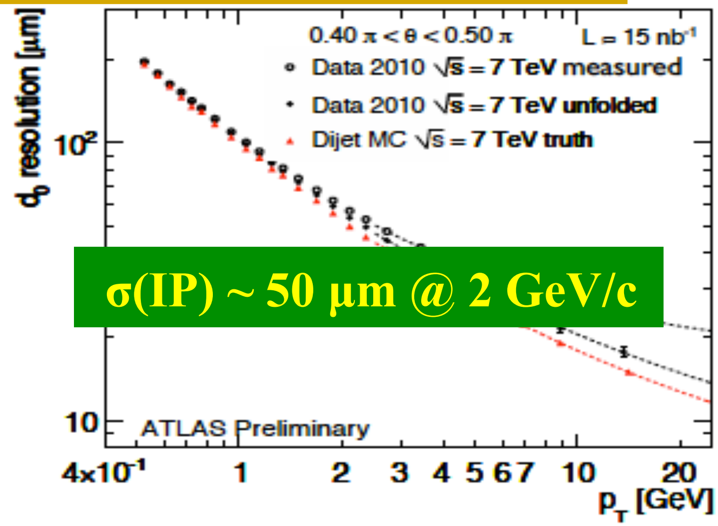
Crucial for time-dependent CP asymmetries: βs, γ, charm, …
Crucial for tagging and background rejection.

Primary vertex resolutions (25 tracks):	LHCb [μm]	ATLAS [μm]	CMS [μm]
σ(x)	15.8	60	20-40
σ(y)	15.2	60	20-40
σ(z)	91.0	100	40-60

IP resolution vs 1/pT - LHCb



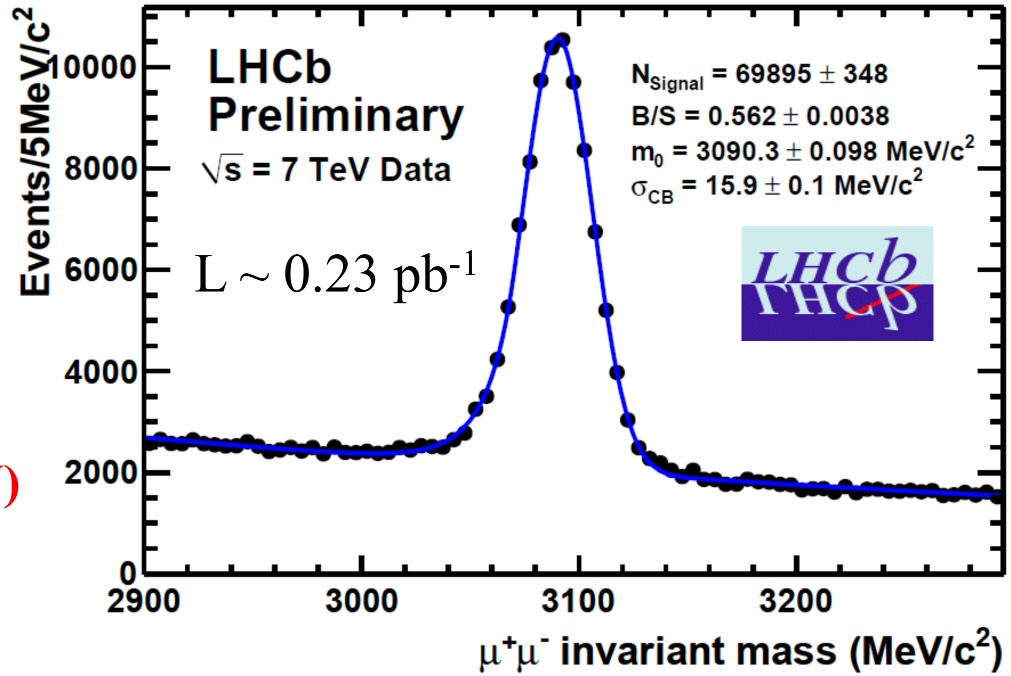
IP resolution vs pT - ATLAS



key ingredients for b- [c-]physics: mass resolutions

precise momentum and mass resolutions:

- $\delta p/p$ [LHCb] ~ 0.4-0.6 %
- $\delta pt/pt$ [ATLAS] ~ 5-6%
- $\delta pt/pt$ [CMS] ~ 1-3 %



Eg: M(J/ψ →μμ)

LHCb: **σ ~ 16 MeV [LHCb]**

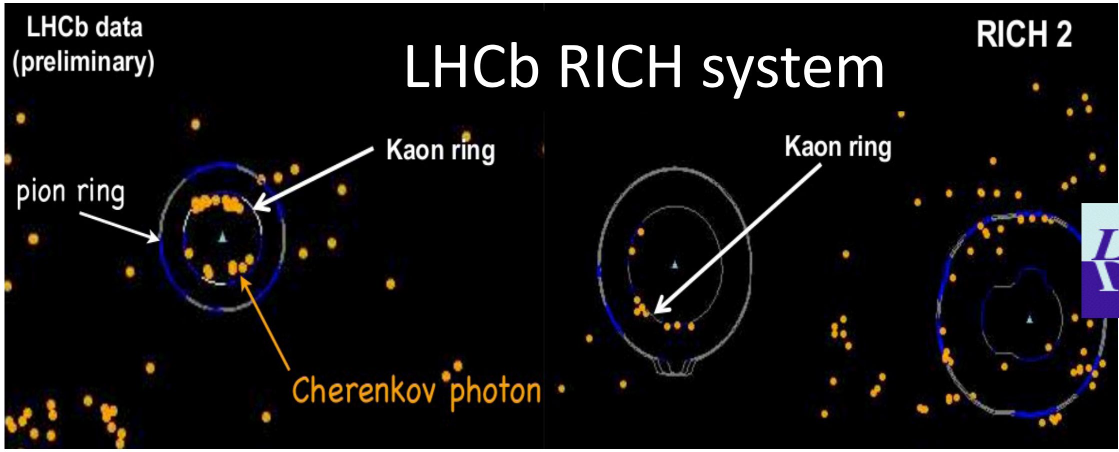
CMS: σ ~ 43 MeV (Barrel: 20 MeV)

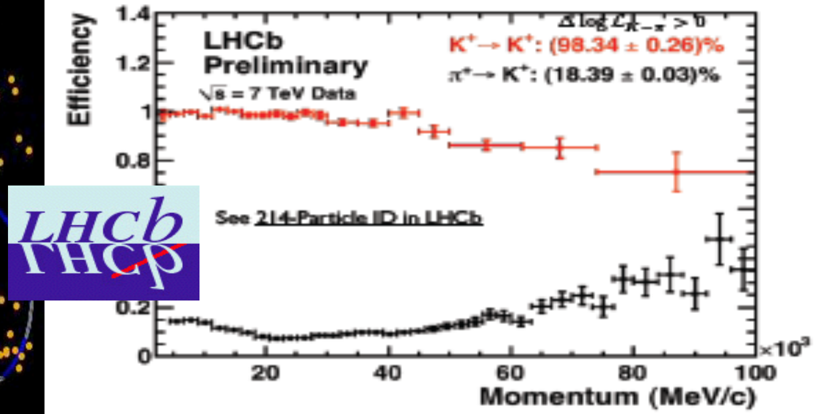
ATLAS: σ ~ 71 MeV (Barrel: 34 MeV)

LHCb has a very good resolution : however still 30-50% worse than expected
→ Better alignment will further improve the performance

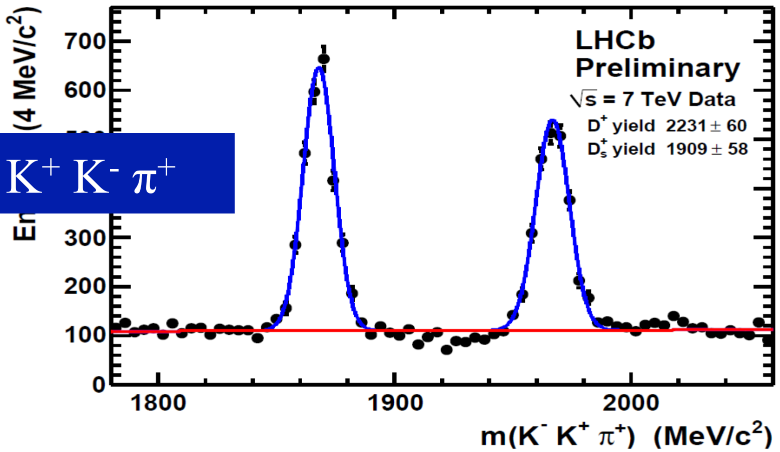
key ingredients for b- [c-]physics: mass resolutions

Crucial for γ from trees [B→D K], charm physics and b-tagging:

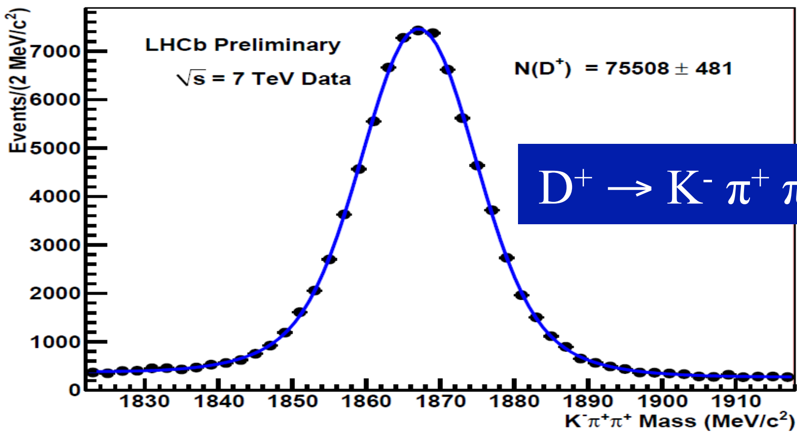




Eg: Separation of topologically identical final states:



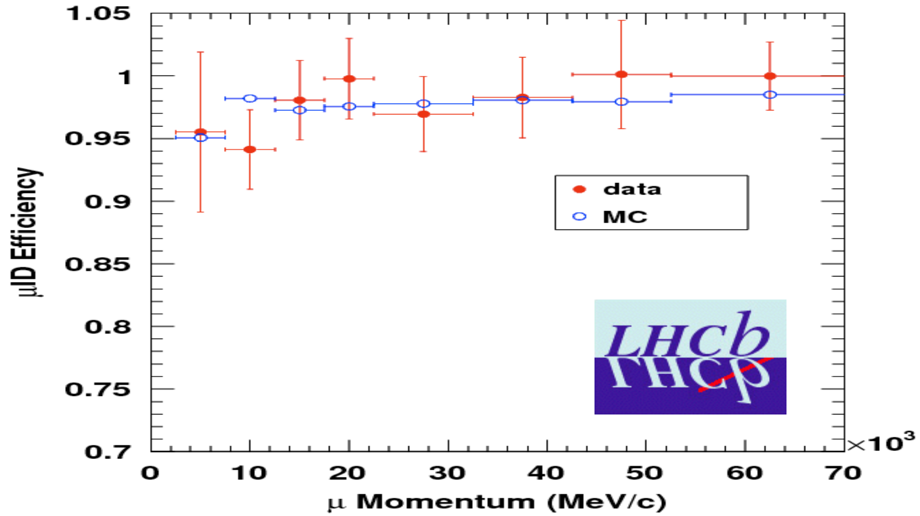
$D^+ \to K^+ K^- \pi^+$

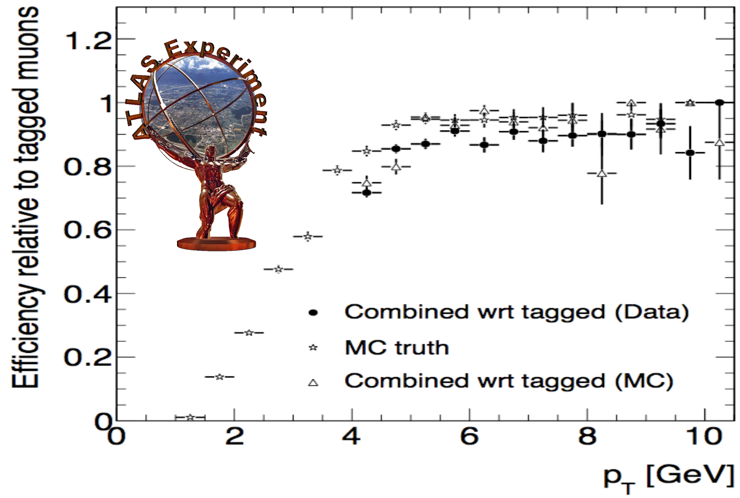


$D^+ \to K^- \pi^+ \pi^+$

Muon ID performance

Crucial for rare decays with muons in the final state [$B_{s,d} \rightarrow \mu\mu$, $D^0 \rightarrow \mu\mu$]





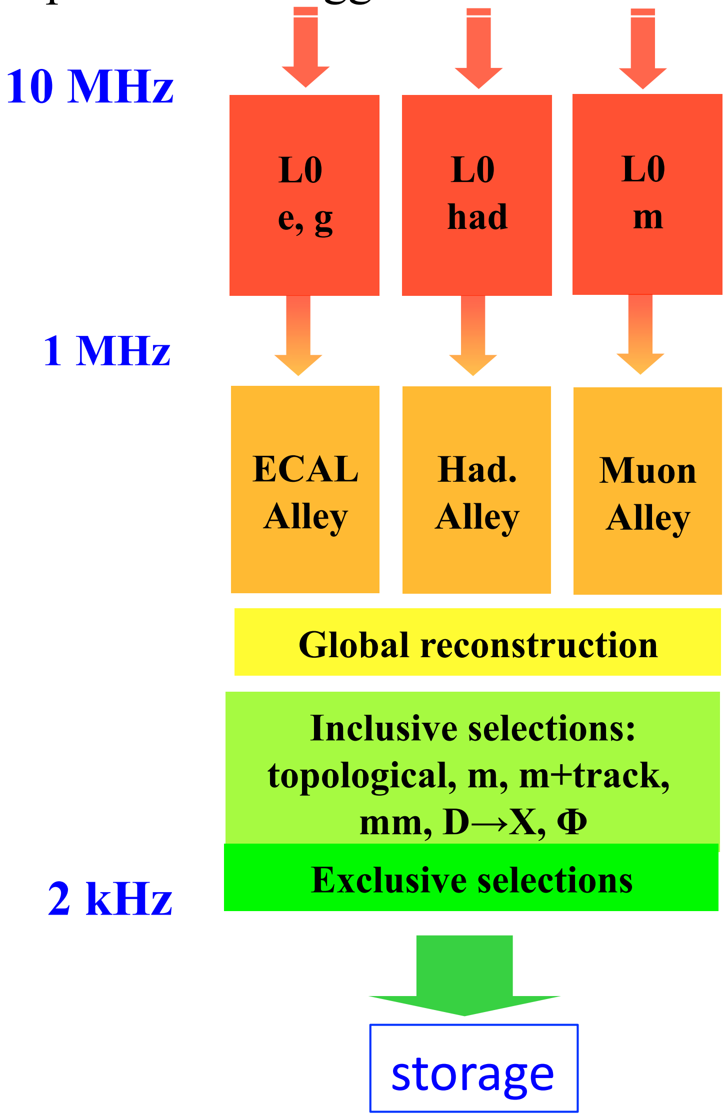
All experiments use data-driven methods to measure muonid efficiency [J/ψ with 1 μ identified] and misidentification rates [$\pi \rightarrow \mu$, $K \rightarrow \mu$, proton$\rightarrow \mu$ by using pure samples of Ks(ππ), φ(KK) and Λ(pπ)

LHCb: MuonID eff ~ 93% for misID ~ 1% p_T>0.5 GeV/c
CMS/ATLAS: MuonID eff ~ 90-95% for misID ~ 0.1-0.4% p_T>4 GeV/c

All results are in good agreement with Monte Carlo expectations

Trigger in LHCb - nominal

LHCb is optimized to work at moderate luminosity (L ~2 10^{32} cm^2 s^{-1}) thus avoiding overlapping collisions in the same bunch crossing (0.4 *pp* interactions/bunch x-ing): Input rate for trigger in nominal conditions is ~10 MHz.



Level-0 [hardware]

'High-pt' signals in calorimeter & muon systems

HLT1 - software

Associate L0 signals with tracks, especially those in VELO displaced from PV

HLT2 - software

Full detector information available. Continue to look for inclusive signatures, augmented by exclusive selections in key channels.

	charm	hadr. B	lept. B
nominal L	~ 10%	~ 40%	~ 90%

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10 MHz

L0 e, g	**L0 had**	**L0 m**

Level-0 [hardware]

'High-pt' signals in calorimeter & muon systems

1 M

ially

Trigger presently being re-tuned to cope with the machine parameters of the 2010 run: high flexibility of the trigger allows us to manage pile-up much higher than nominal !

Inclusive selections: topological, m, m+track, mm, D→X, Φ

Exclusive selections

2 kHz

storage

Full detector information available. Continue to look for inclusive signatures, augmented by exclusive selections in key channels.

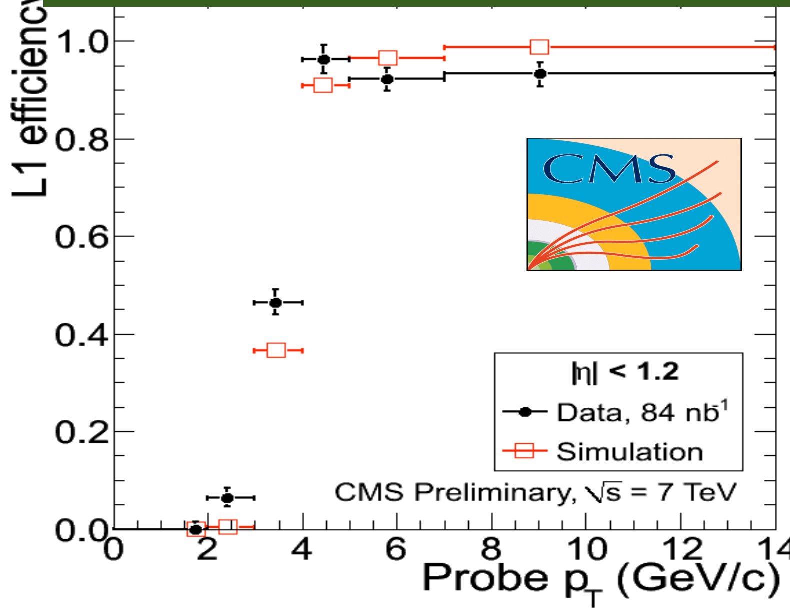
	charm	hadr. B	lept. B
nominal L	~ 10%	~ 40%	~ 90%

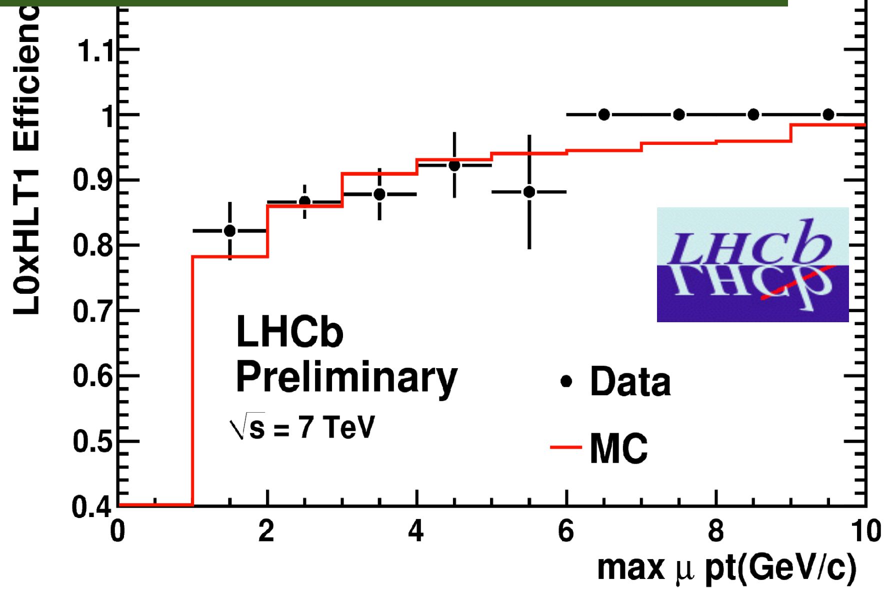
Muon Triggers: comparison among LHC experiments

Key channels as $B_s \rightarrow \mu\mu$, $B_d \rightarrow K^*\mu\mu$, $B_s \rightarrow J/\psi\varphi$ contain muons in the final state

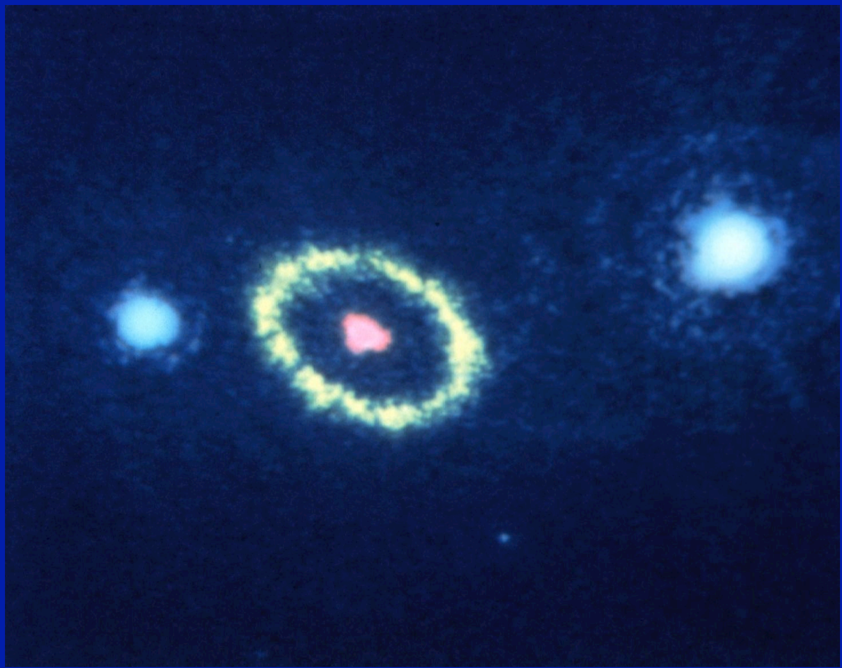
	L0(1) pt cut	HLT pt-cut	Rate
ATLAS	$p_T(1\mu) > 4$ GeV/c	$p_T(1\mu) > 6$ GeV/c	~10-20 Hz
CMS	$p_T(1\mu) > 3 \rightarrow 7$ GeV/c 2μ: no p_T cut	$p_T(1\mu) > 3$ GeV/c + $\mu 2$ 2μ: no p_T cut	"onia" line~25 Hz
LHCb	$p_T(1\mu) > 1$ GeV/c $p_T(1) + p_T(2)\| > 1$ GeV/c	$p_T(1\mu) > 0.8$ GeV/c + IP 2μ: no p_T cut	~ 100-200 Hz

Trigger efficiencies agree with MC expectations within few%





3. First flavour physics results



First images from the space:

“August 29, 1990: The Hubble Space Telescope has resolved, to an unprecedented detail of 0.1 arcsecond, a mysterious elliptical ring of material around the remnants of Supernova 1987A. “

σ (pp→bbX) measurement @ LHC

Heavy flavour studies at LHC begin with a measurement of the bb cross-section, as determined from production rate of displaced J/ψ or D^0

1] σ (pp→bbX) from b→ J/ψ X (LHCb,CMS,ATLAS)

- Three main sources of J/ψ:
  - direct production in pp collisions
  - feed down from heavier charmonium states (ψ(2S), χc, …)
  - J/ψ from b hadrons decays

} Prompt J/ψ

} J/ψ from b

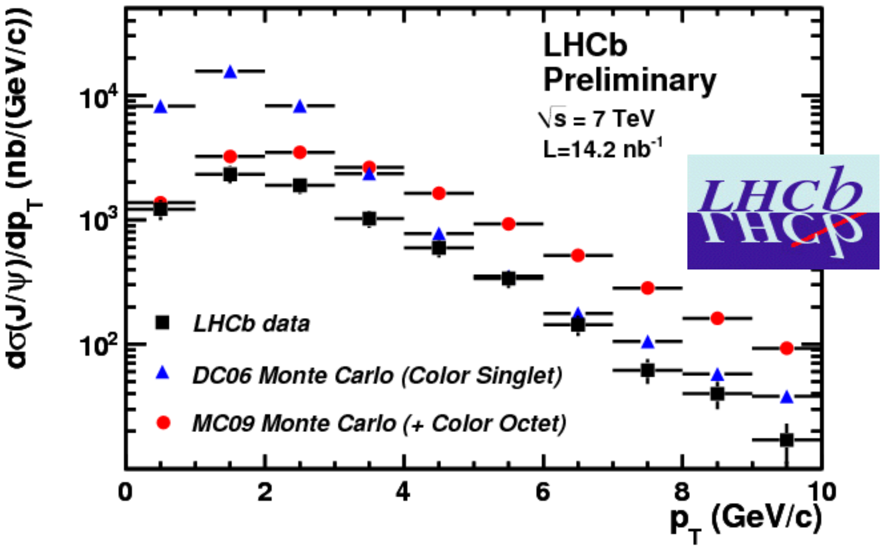
- Prompt J/ψ very interesting in its own right:

  colour octed model predicts well cross sections seen at Tevatron but not polarization

2] σ (pp→bbX) from b→ D(Kπ) μ ν X and b→ D* μ ν X (LHCb)

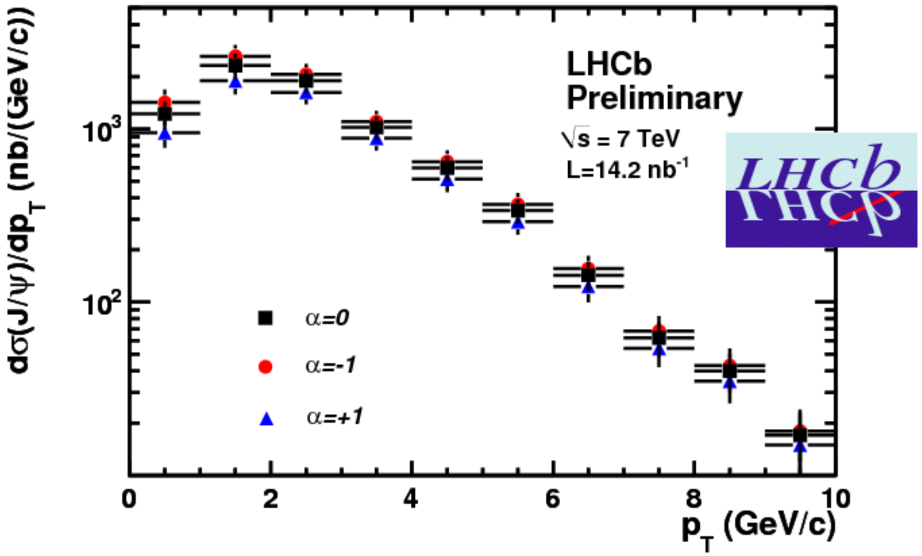
σ (pp→J/ψ X, inclusive) @ LHCb: preliminary result based on 14 nb^{-1}

$d\sigma/dp_T$(incl. J/ψ, 2.5 < $y^{J/\psi}$ < 4):



Scale and shapes not well described by either colour singlet or colour octet models as implemented in LHCb Pythia

Different polarization hypotheses:



Polarisation will eventually be measured !

$$\sigma(\text{ incl. } J/\psi,\ p_T^{J/\psi} < 10\ \text{GeV/c},\ 2.5 < y^{J/\psi} < 4) = (7.65 \pm 0.19 \pm 1.10^{+0.87}_{-1.27})\ \mu b$$

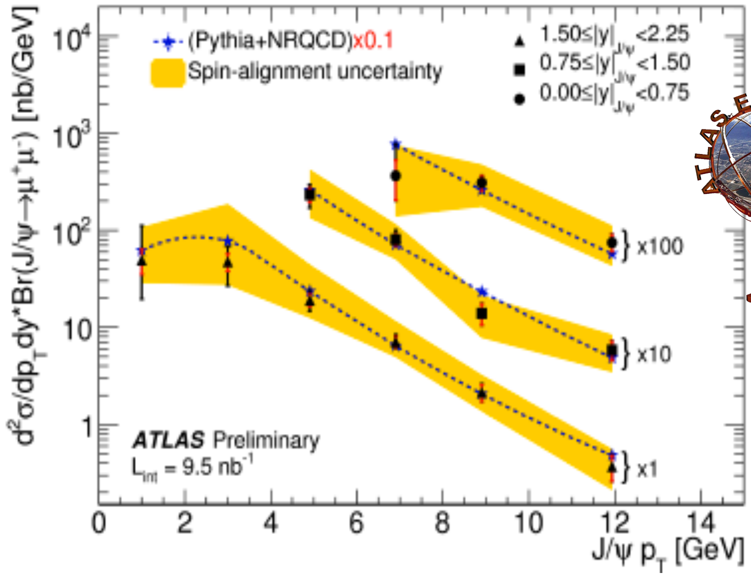
uncertainty from polarisation

σ (pp→J/ψ X, inclusive) @ ATLAS: preliminary result based on 9.5 nb^{-1}

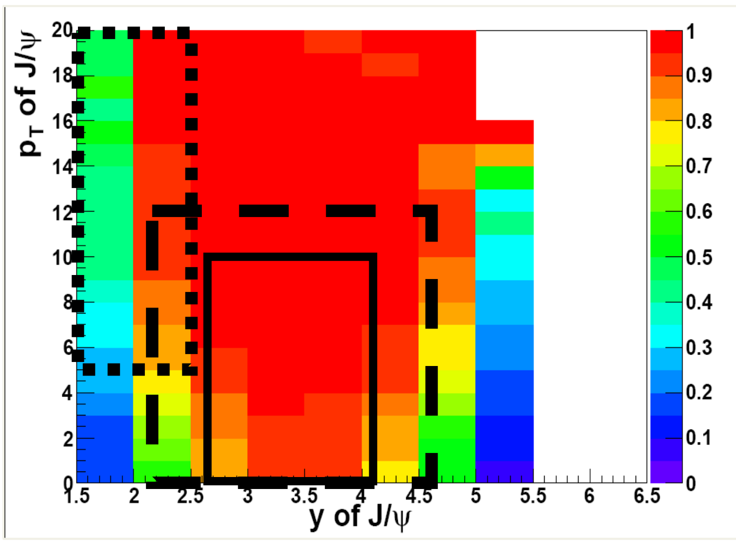
Differential J/ψ cross section vs pT and y:

- Shape agrees with Pythia MC expectations;
- Absolute value shows a significant deviation.

Polarization is the most significant systematic.



Acceptances for LHCb and ATLAS/CMS:



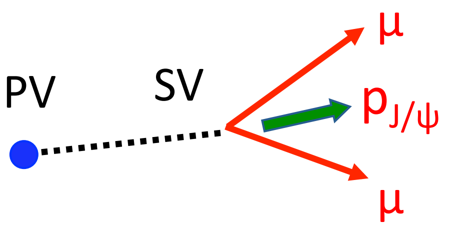
LHCb 14 nb^{-1}

LHCb 50 pb^{-1}

ATLAS/CMS

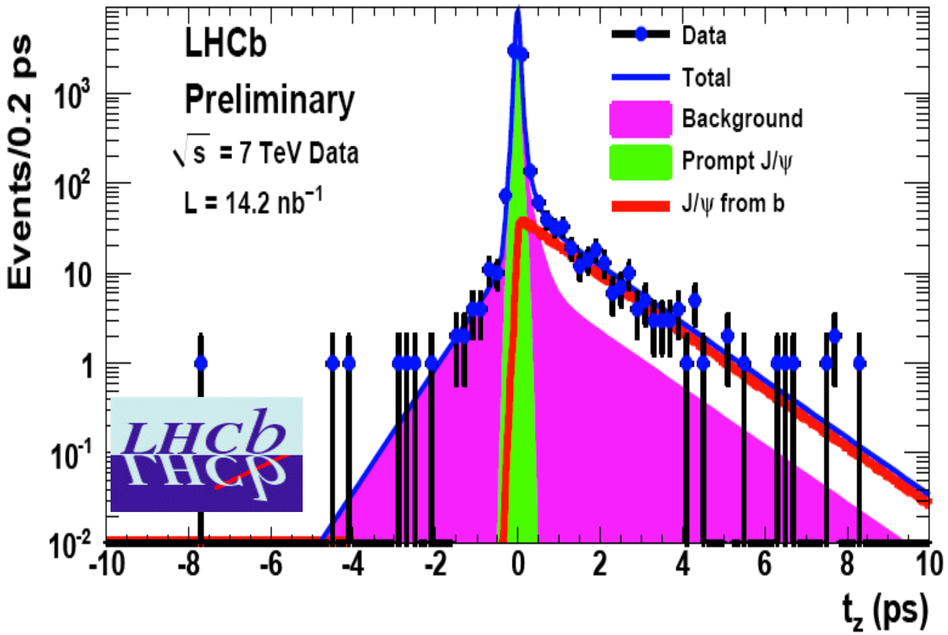
σ (pp→bbX) from b→J/ψ X

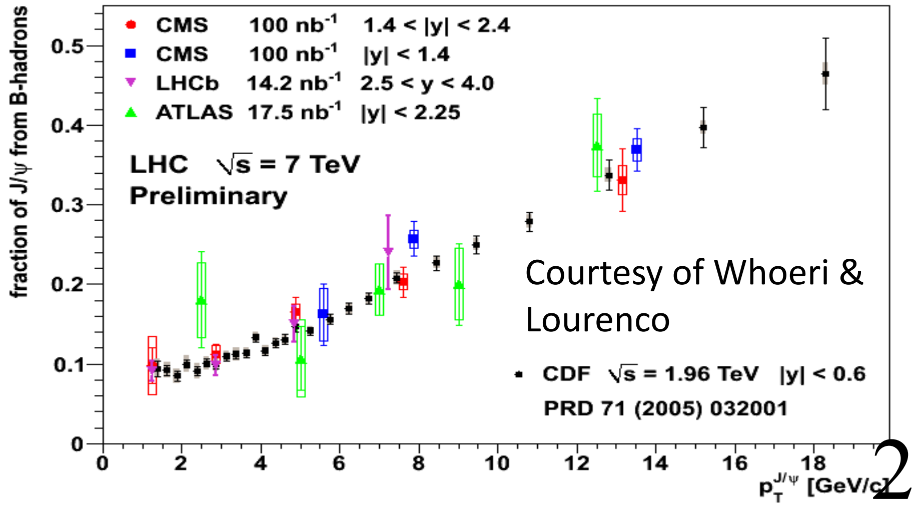
- Separation between prompt and detached component:
  - Via a combined fit to mass and pseudo proper-time
  - t_z [LHCb] or txy [CMS] in pt, y bins



$$t_z = \left(z_{J/\psi} - z_{PV}\right)\frac{m_{J/\psi}}{p_{z,J/\psi}}$$

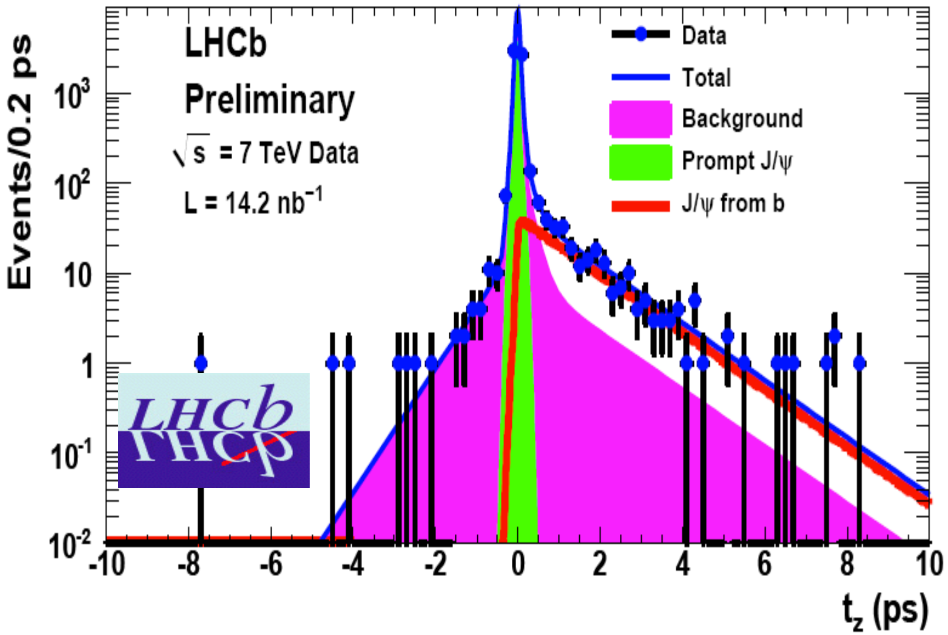
- Fraction of the detached component vs p_T:
  - → Nice agreement among
  - → CMS/ATLAS/LHCb and CDF





σ (pp→bbX) from b→J/ψ X

- Separation between prompt and detached component:
  - Via a combined fit to mass and pseudo proper-time
  - t_z [LHCb] or t_{xy} [CMS] in pt, y bins



Assuming BR(b→J/ψ X) = (1.16± 0.10)%:

σ(J/ψ from b, pT(J/ψ)<10 GeV/c, 2.5 < y (J/ψ)<4) = 0.81± 0.06 ± 0.13 μb

Use MC and Pythia to extrapolate from 2.5 < y(J/ψ) < 4 to 2 < η_b < 6:

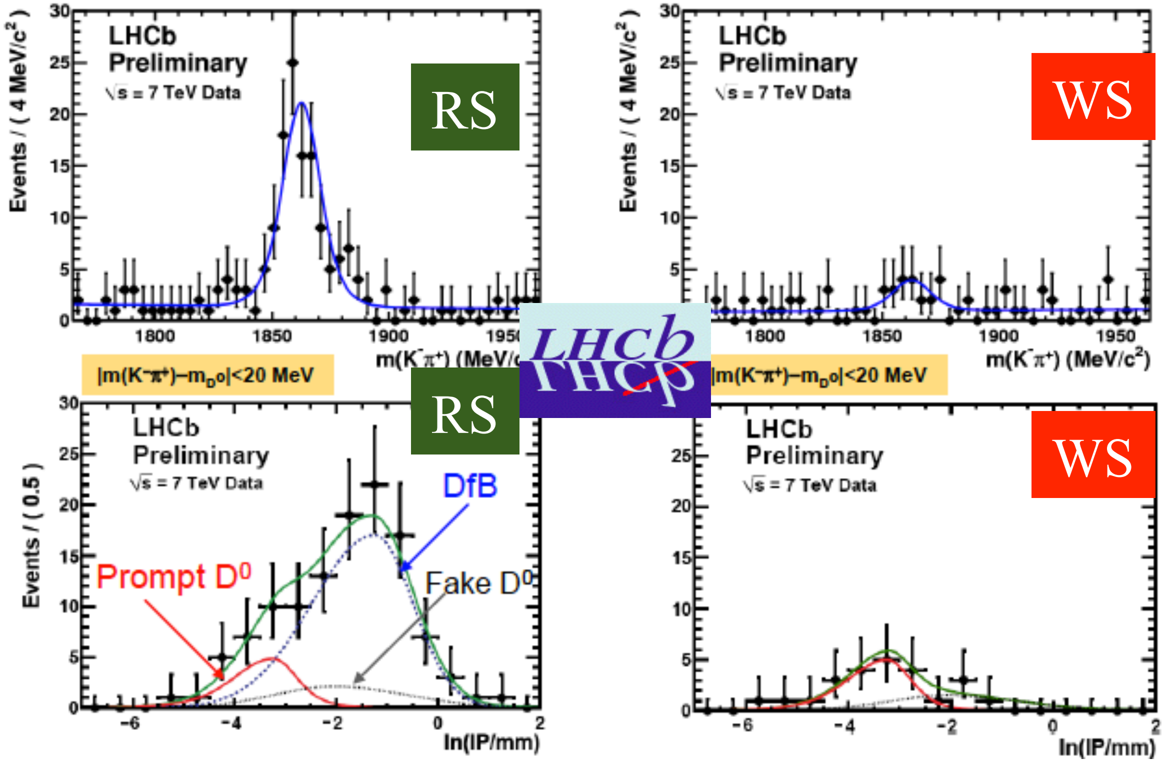
σ (pp → H_b X, 2 < η_b < 6) = (84.5 ± 6.3 ± 15) μb

For CMS result see N. Pastrone's talk yesterday

σ (pp→bbX) from b→D(Kπ)μ ν X - LHCb

Use b→D^0(Kπ) μν X decay (BR=6.82 ± 0.35 %)
Signal: measure right-sign $D^0\mu$ combinations, where D^0→ K π
uses tracks forming a displaced vertex with respect to the primary one

The two types of D^0 produced are prompt and from B's:
→ can be separated statistically by examining the impact parameter with respect to the primary vertex:



Pros & Cons of the method:
Pro: high statistics
Cons: dependence on the value of the fragmentation fractions.

LHCb: averaging preliminary b-production results:

All measurements of $\sigma(pp \rightarrow H_b X; 2<\eta_b<6)$ are compatible:

→ determine weighted average of J/ψ and $D^0\mu\nu X$ results

→ use MC and Pythia to extrapolate to 4π:

η	LHCb preliminary [μb]	Theory I [μb]	Theory II [μb]
2-6	77.4 ± 4.0 ± 11.4	89	70
all	292±15±43	332	254

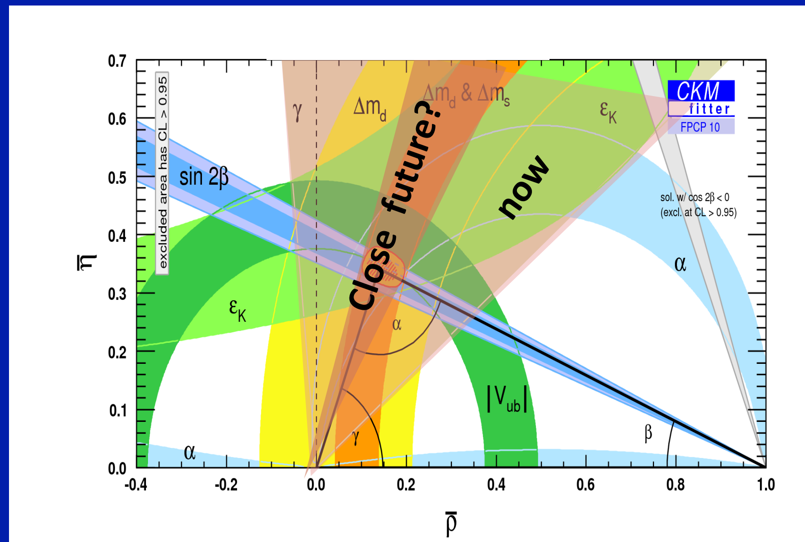
Theory I: Nason, Dawson, Ellis

Theory II: Nason, Frixion, Mangano, Ridolfi

All the LHCb sensitivity studies at $\sqrt{s}$=7 TeV assumed σ(bb) = 250 μb so all the yields quoted are in the right ballpark!

4. Prospects in flavour physics @ LHC

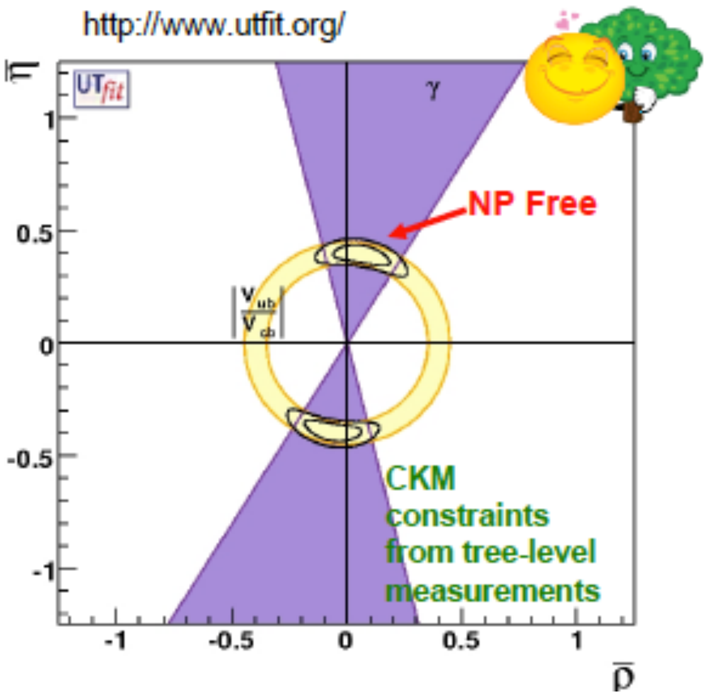
Unitarity Triangle from tree-level processes



… sharpening the picture….

Setting the CKM scale: γ from trees

Assume NP negligible in tree decays and fix Unitarity Triangle parameters from tree-level processes:



Tree decays w/o NP can determine: $|V_{ud}|$, $|V_{us}|$, $|V_{ub}|$, $|V_{cb}|$, and γ

γ [together with $|V_{ub}/V_{cb}|$] provides the SM signpost to be met by any NP model.

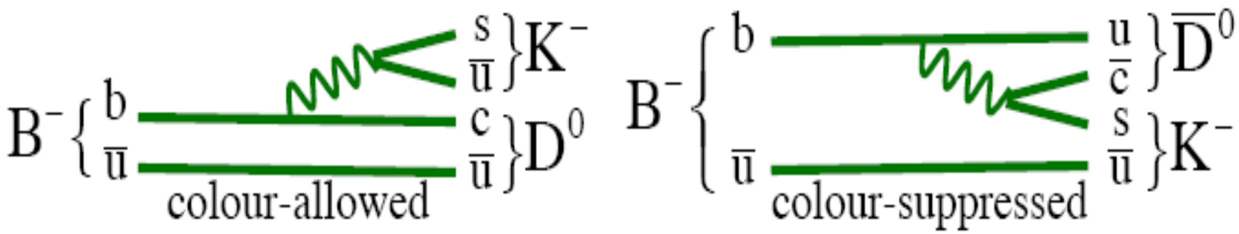
Present accuracy by direct measurement of γ from tree process B→D K is still poor:

$\gamma\ (WA) = (70\ ^{+21}_{-25})°$

Current tension (sin(2β) & ε_k) calls for precise γ determination
→ Milestone of the LHCb program

Measuring γ @ LHCb

Milestone of the LHCb physics program is the measurement of 'B→ DK' direct asymmetries which are sensitives to the unitarity angle γ



Weak phase difference = γ
Magnitude ratio = $r_B \sim 0.15$

Final state common to D^0 & D^0bar :
Kπ, KK, ππ, Kπππ, Ksππ, KsKK…
allows for interference → γ

GLW : D^0 decays into CP eigenstate
ADS : D^0 decays to $K^-\pi^+$ (fav.) and K+π-(sup.)
GGSZ : $D^0 \rightarrow K_S\pi\pi$ (interference in Dalitz plot)

These decays are self-tagging:
→ no need to do a time-dependent analysis
→ only need the ratio of the different decay modes
Extract γ, r_B,$\delta_B$simultaneously!

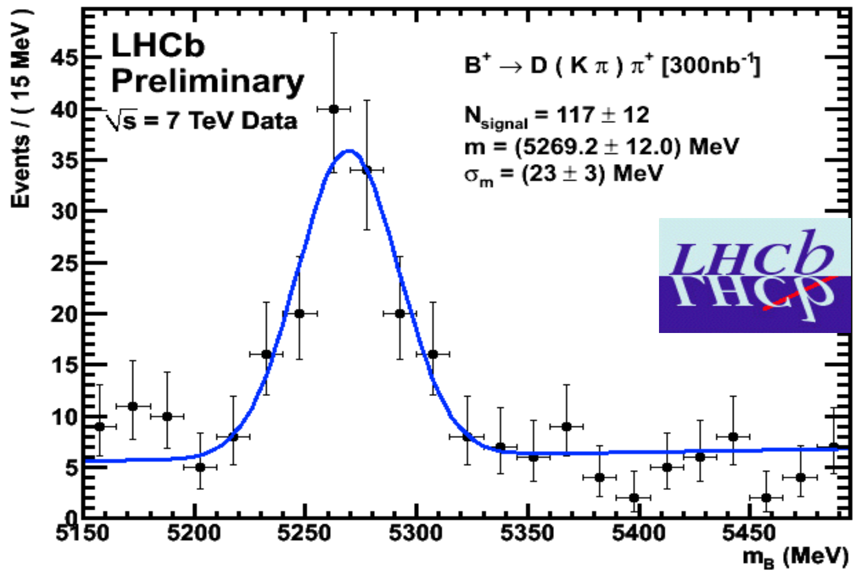
Crucial role of hadronic trigger and π/K separation in this analysis

Measuring γ @ LHCb

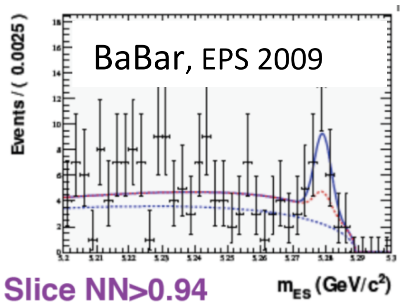
< 1 fb^{-1} already offers possibilities to improve on knowledge from B factories

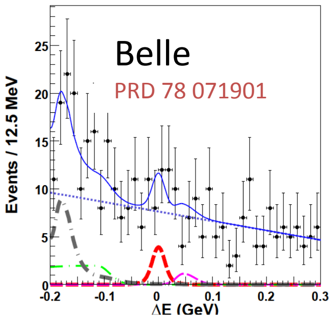
LHCb expected yields at 7 TeV, 1 fb^{-1}
Assuming r_B~0.1 (0.4) for $B^{\pm}$ (B^0)

Channel	Expected event yield
$B^- \to D(KK)K^-$	2000
$B^- \to D(\pi\pi)K^-$	750
$B^- \to D(K\pi)K^-$ favoured	20000
$B^- \to D(K\pi)K^-$ suppressed	400



eg. 'ADS' suppressed B→D(Kπ)K mode just beyond reach of B-factories → LHCb expects ~80 of these events with 200 pb^{-1}

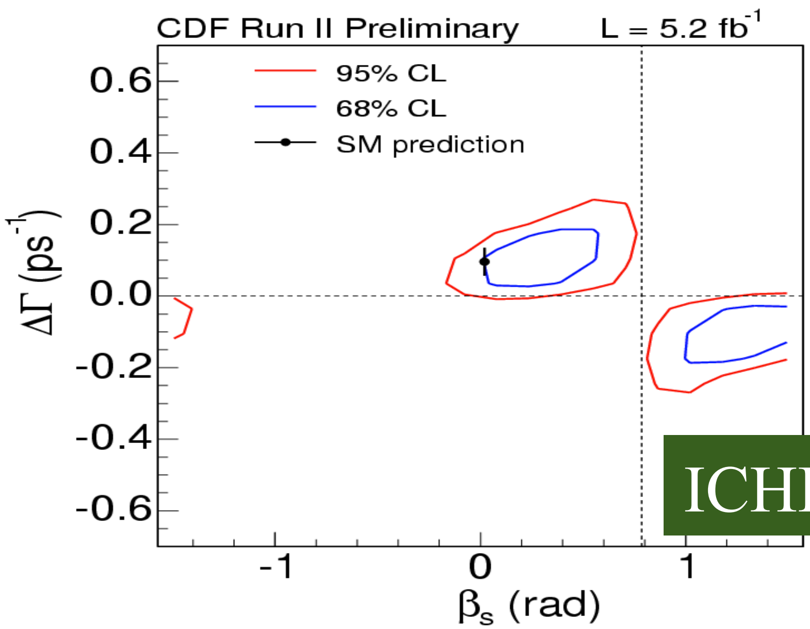


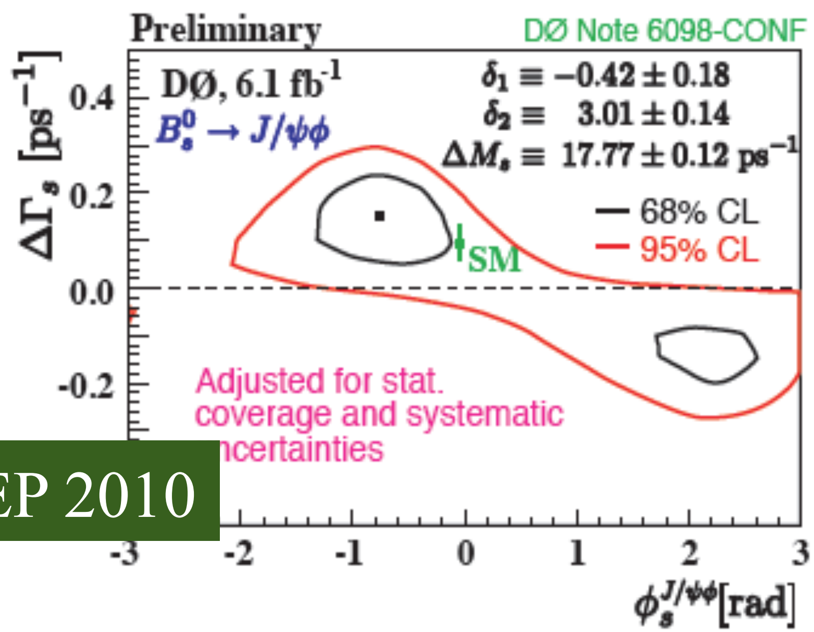


Combine all considered B→DK measurements and time dependent approaches from B_s system
$\sigma\gamma^{LHCb}$ ~ 8 ° with 1 fb^{-1} [end 2011]

CPV in B_s mixing:
…the (still) unresolved saga…

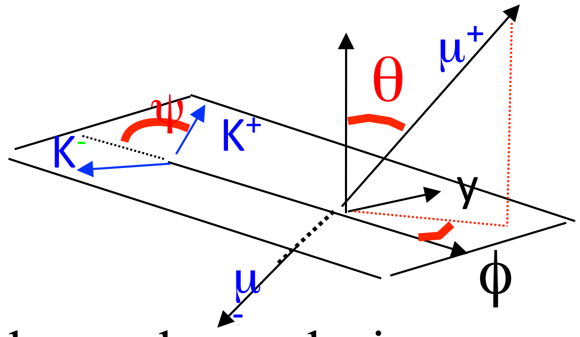
- The weak phase of B_s mixing is presently under investigation at Tevatron via the time-dependent study of the $B_s \rightarrow J/\psi\varphi$ decay [$A_{\psi\varphi}$] & via the semileptonic charge asymmetry [a_{sl}] (same-sign muons).
- Several new results in 2010: a_{sl} by D0 [~3σ deviation from SM] + update $A_{\psi\varphi}$ by both CDF and D0 [agreement with SM at ~1σ]





ICHEP 2010

B_s mixing phase in $B_s \rightarrow J/\psi\ \varphi$



The channel is complex….

two particles [B_s,$B_s$bar] decaying in 3 final states [2 CP-even, 1 CP-odd]:

→ initial states must be tagged

→ final states need to be statistically separated through angular analysis

… and the extraction of the phase experimentally very challenging:

Most critical parameters are mistag and proper time resolution

$\Rightarrow$ sensitivity on $2\beta_s$ goes as $\sim (1-2\omega)^2 \exp(-\Delta m_s^2 \sigma^2(\tau)/2)$

B_s mixing phase in $B_s \rightarrow J/\psi\ \varphi$

ATLAS/CMS will use B_s lifetime cuts: [CMS note 2006-12]:

→ main background is long-lived [mainly $b \rightarrow J/\psi X$]

→ main systematics : control of acceptances

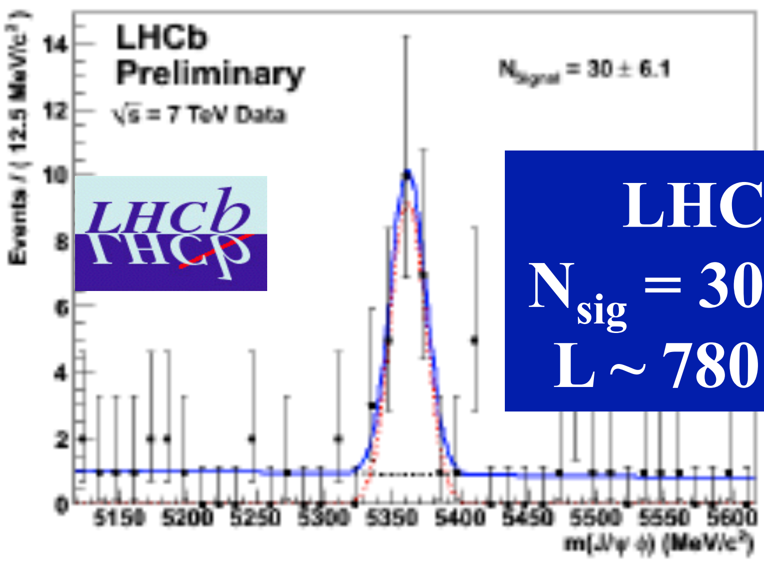
LHCb does not use B_s lifetime cuts [arXiv:0912.4179v1]

→ main background is prompt

→ Main systematics is mistag and proper-time resolution:

Signal starts to show up….

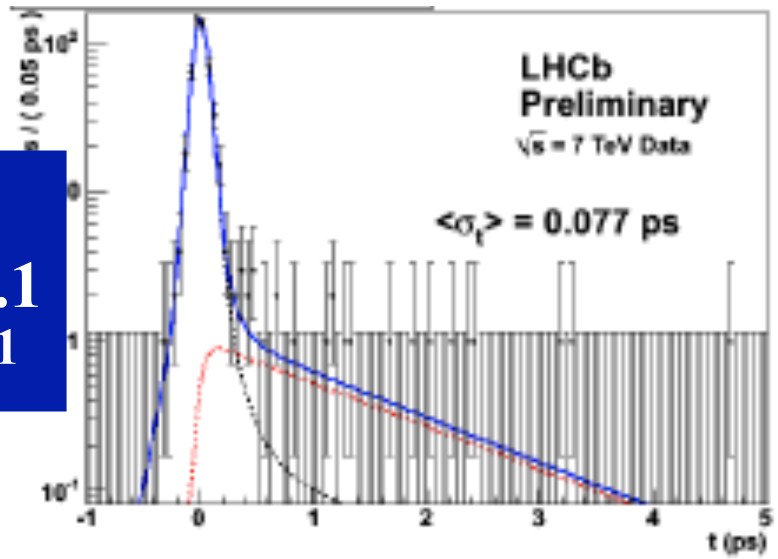
….with a proper time resolution of ~78 fs



LHCb:

$N_{sig} = 30 \pm 4.1$

$L \sim 780\ nb^{-1}$



B_s mixing phase in $B_s \rightarrow J/\psi\ \varphi$

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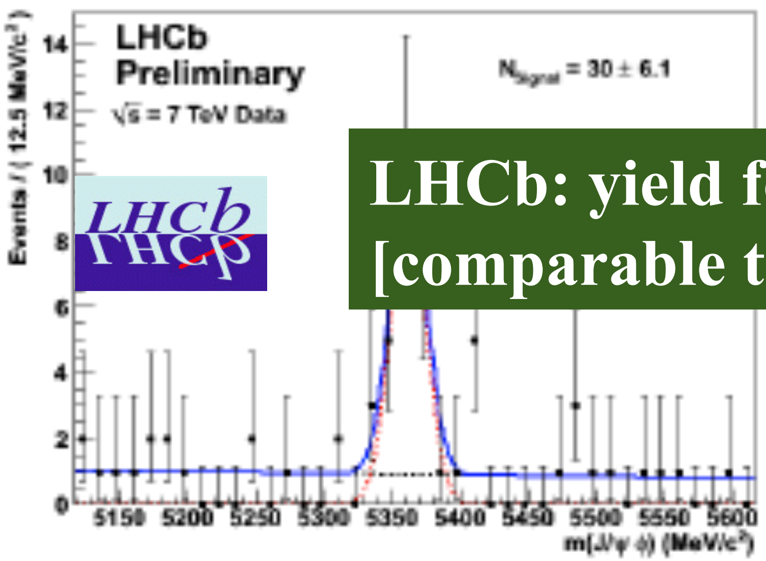

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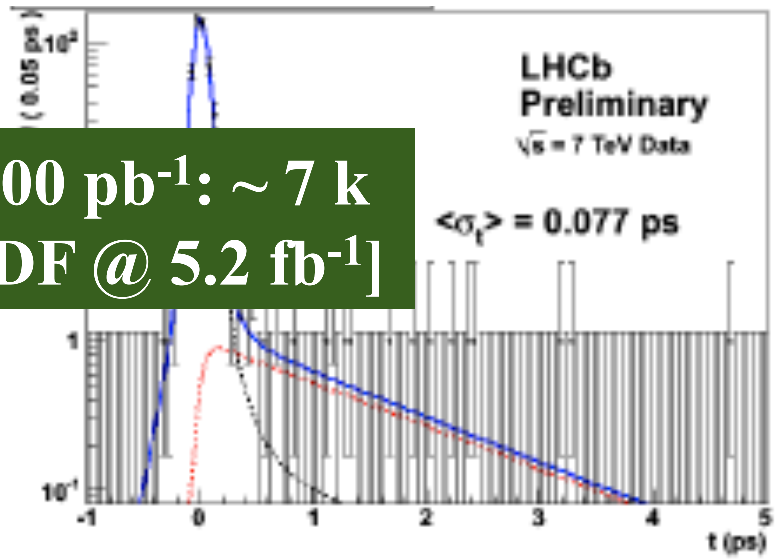


LHCb: yield for 200 pb^{-1}: ~ 7 k
[comparable to CDF @ 5.2 fb^{-1}]

B_s mixing phase in $B_s \rightarrow J/\psi\ \varphi$

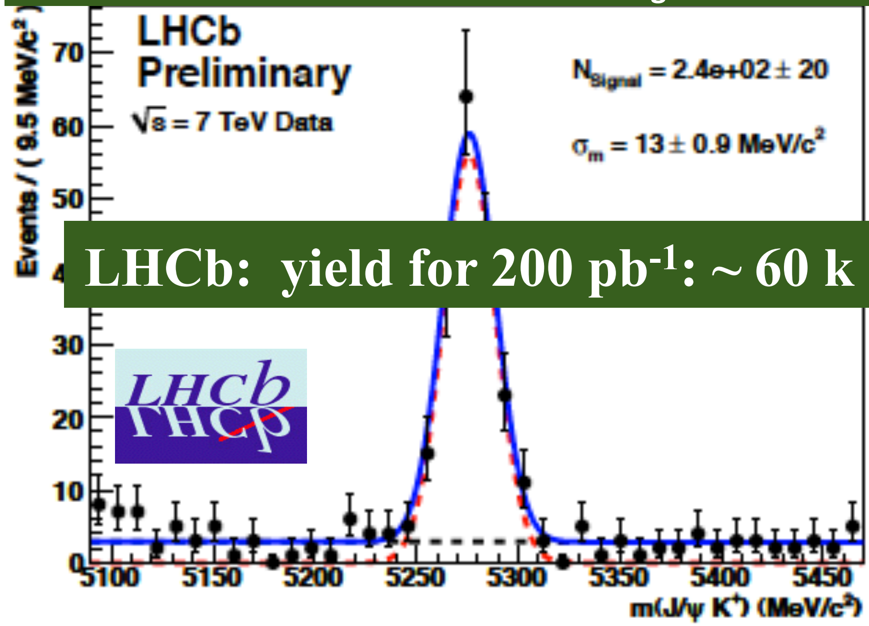
LHCb does not use B_s lifetime cuts [arXiv:0912.4179v1]

→ main background is prompt

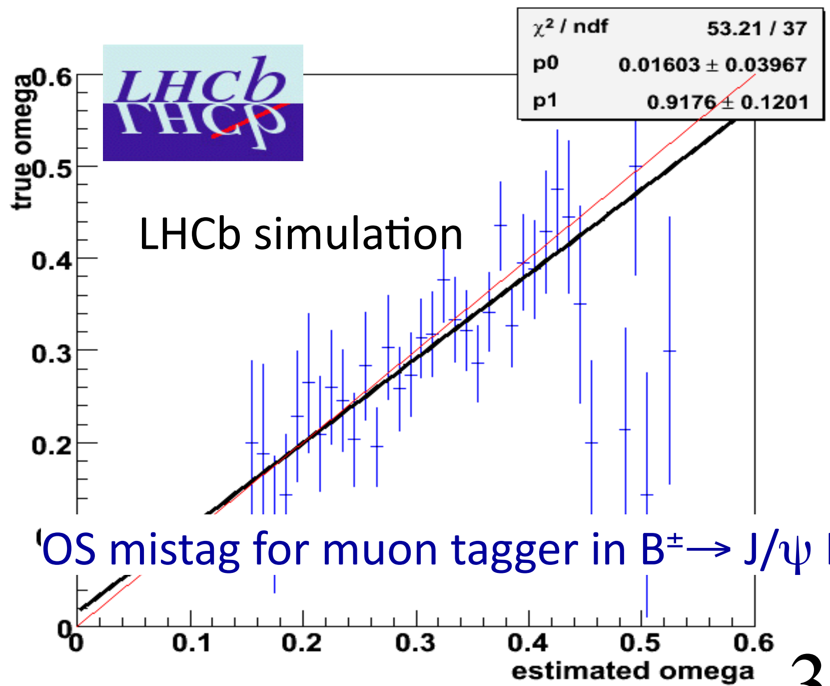
→ main systematics is mistag and proper time resolution:

LHCb calibrates OS mistag using flavour specific channel $B^{\pm} \rightarrow J/\psi\ K^{\pm}$

$B^{\pm} \rightarrow J/\psi\ K^{\pm}$, L ~ 780 nb^{-1}, N_{sig} = 240 ± 20



LHCb: yield for 200 pb^{-1}: ~ 60 k



OS mistag for muon tagger in $B^{\pm} \rightarrow J/\psi\ K^{\pm}$

B_s mixing phase in $B_s \rightarrow J/\psi\ \varphi$

LHCb does not use B_s lifetime cuts [arXiv:0912.4179v1]

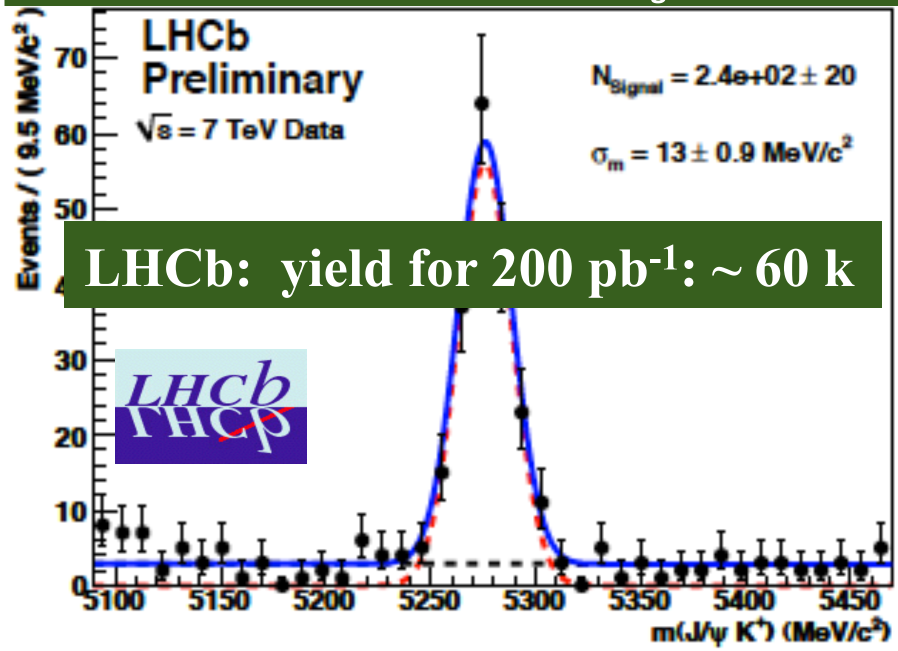
→ main background is prompt

→ main systematics is **mistag** and proper time resolution:

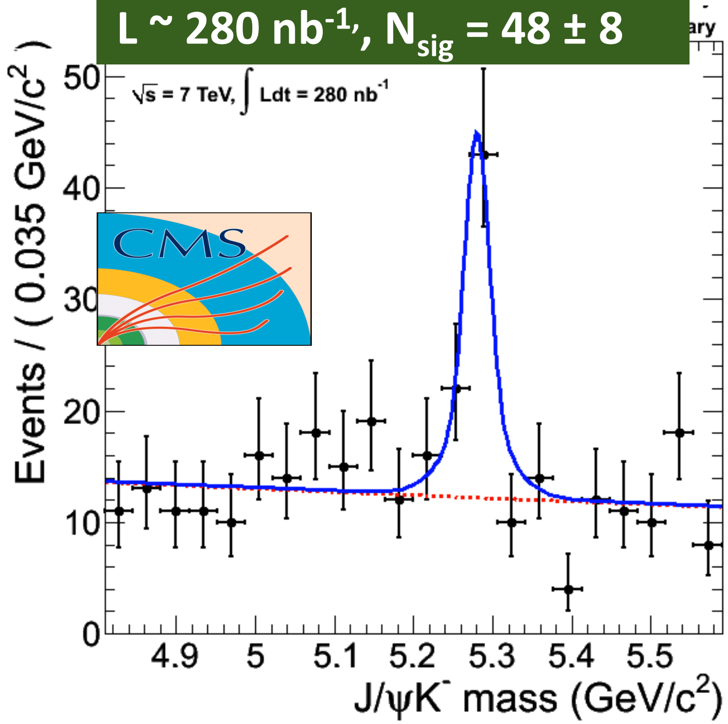
And also CMS is starting to see the peak: $B^{\pm} \rightarrow J/\psi\ K^{\pm}$

$B^{\pm} \rightarrow J/\psi\ K^{\pm}$, L ~ 780 nb^{-1}, N_{sig} = 240 ± 20

L ~ 280 nb^{-1}, N_{sig} = 48 ± 8



LHCb: yield for 200 pb^{-1}: ~ 60 k



Bs mixing phase in $B_s \rightarrow J/\psi\ \varphi$

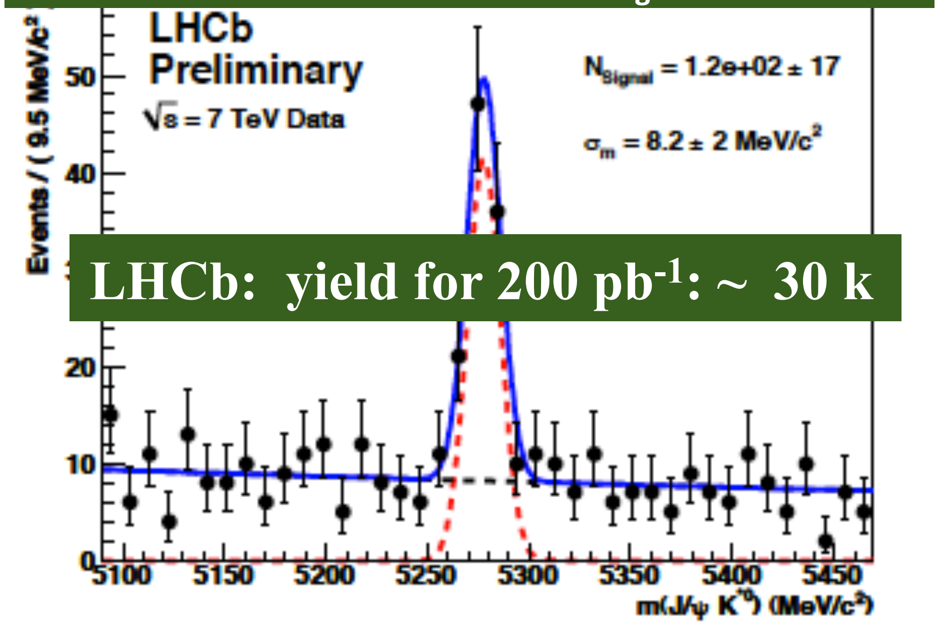
LHCb does not use Bs lifetime cuts [arXiv:0912.4179v1]

→ main background is prompt

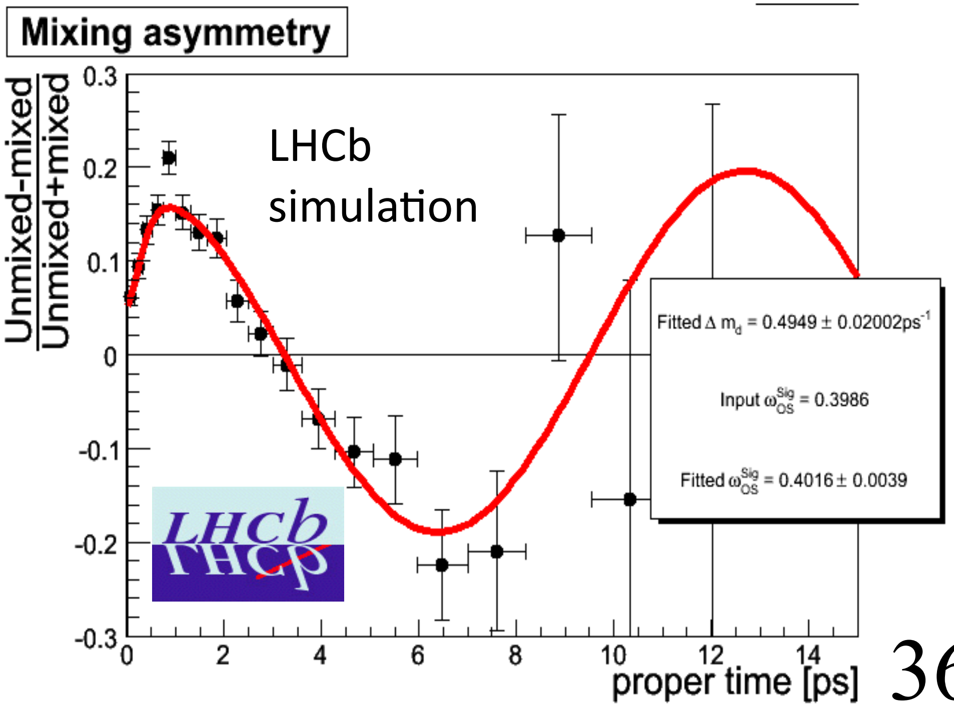
→ Main systematics is mistag and proper time evaluation

LHCb is going to calibrate OS mistag fitting the B0 → J/ψ K* asymmetry:

$B^0 \rightarrow J/\psi K^*$, L ~ 780 nb^{-1}, N_{sig} =120 ± 17



LHCb: yield for 200 pb^{-1}: ~ 30 k



B_s mixing phase in $B_s \to J/\psi\ \varphi$

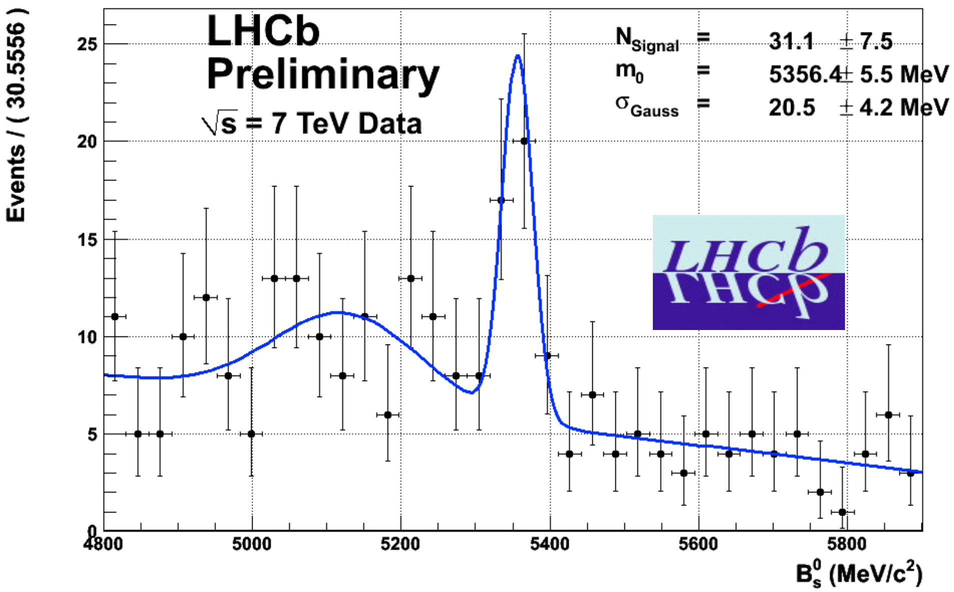
LHCb does not use Bs lifetime cuts [arXiv:0912.4179v1]

→ main background is prompt

→ Main systematics is mistag and proper time evaluation

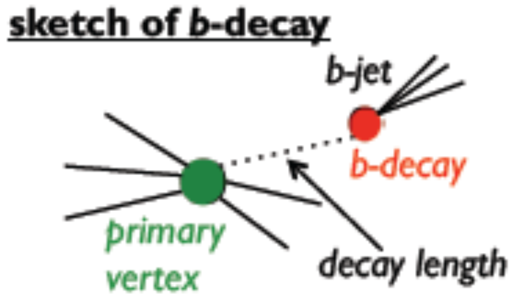
LHCb is going to calibrate OS mistag fitting the B0 → J/ψ K* asymmetry….
and the SS mistag [30% of the tagging power] fitting the $B_s \to D_s\pi$ oscillations

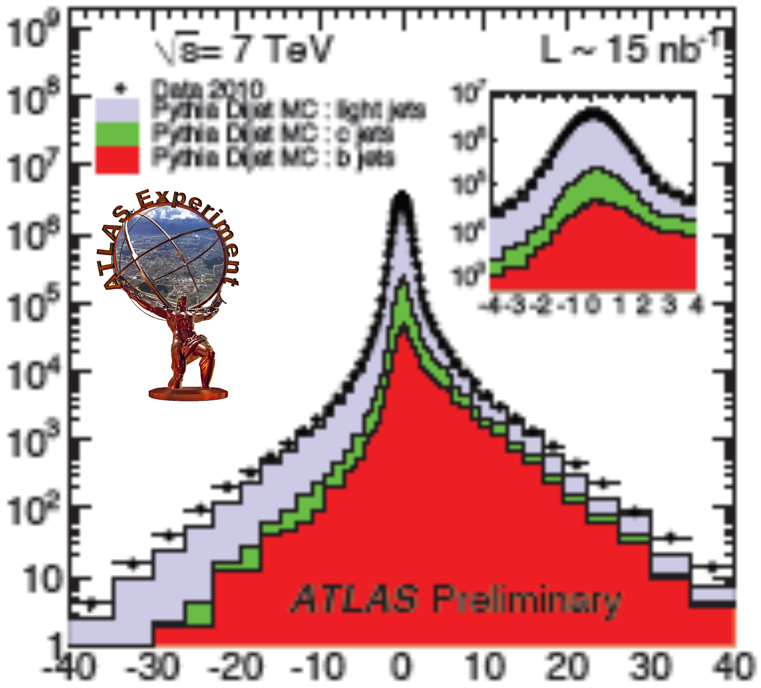
$B_S \to D_S\ \pi$, L < 500 nb^{-1}



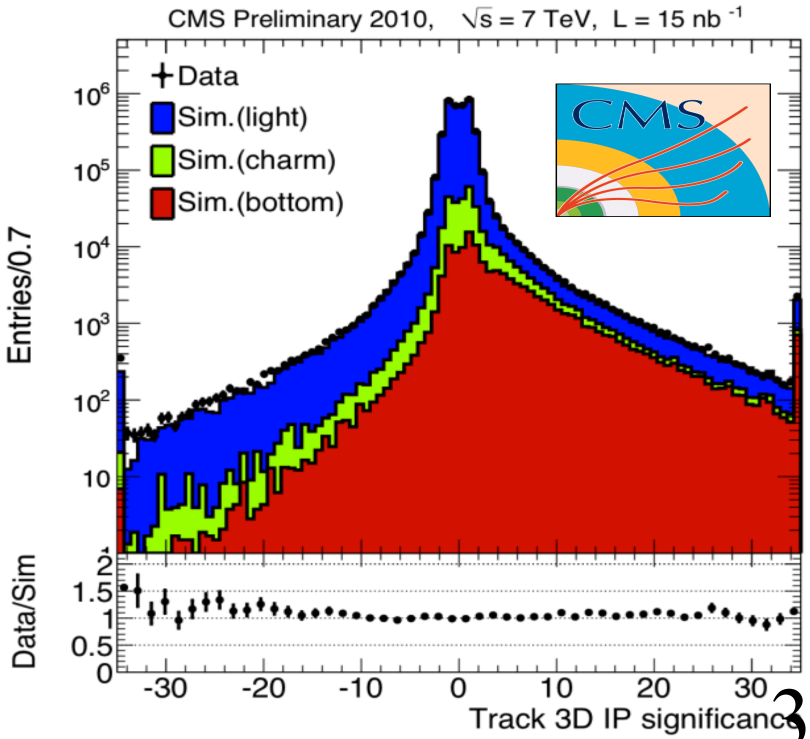
Tagging calibration [ATLAS/CMS]

- Explicit reconstruction of the b-hadron secondary vertex via a b-jet.
- Decay length significance is the discriminant variable.

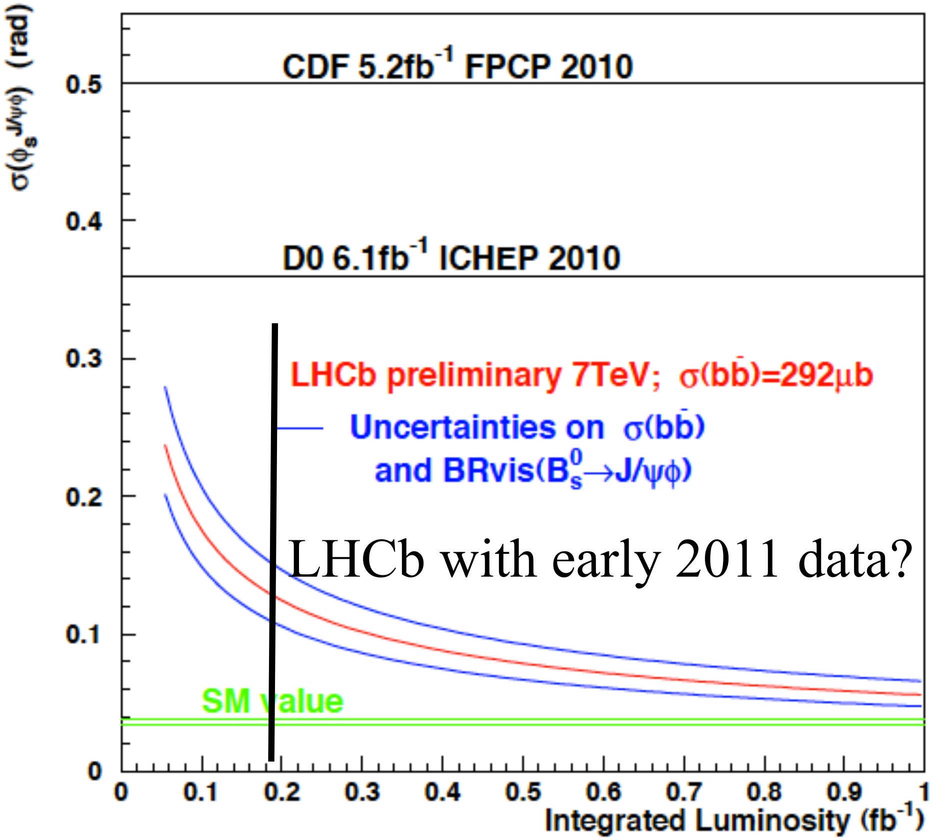




Decay length significance



LHCb: β_s sensitivity



Reality checklist:

- Measured bb cross section:
  → consistent with expectations

- Rate of signal events:
  → Consistent with expectations

- Proper time resolution:
  At present 60% worse than MC:
  if no improvement→ 30% dilution

- Tagging performance:
  We will know about this soon

All is looking very promising

New physics in a^s_{sl} (&/or a^d_{sl}) ?

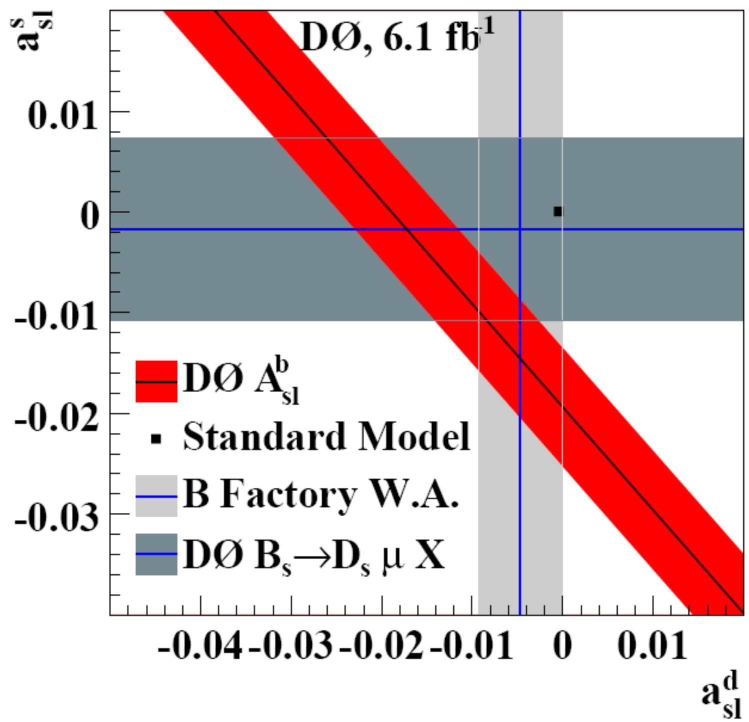
If New Physics enhances CP-violation in $B^0_S \rightarrow J/\psi\Phi$, it will likely also dominate over the (negligible) SM CP-violation predicted in the semi-leptonic asymmetry.

Recent D0 result shows 3σ discrepancy with SM (arXiv:1005.2757v1) using inclusive measurement of same-sign muon asymmetry A_b.

A_b is related to a^d_{fs} and a^s_{fs} :

$$A_b = (0.493\pm0.043)\, a^s_{fs} + (0.506\pm0.043)\, a^d_{fs}$$

where the coefficients are calculated using the production fractions measured at Tevatron [PLB 667,1 (2008)].



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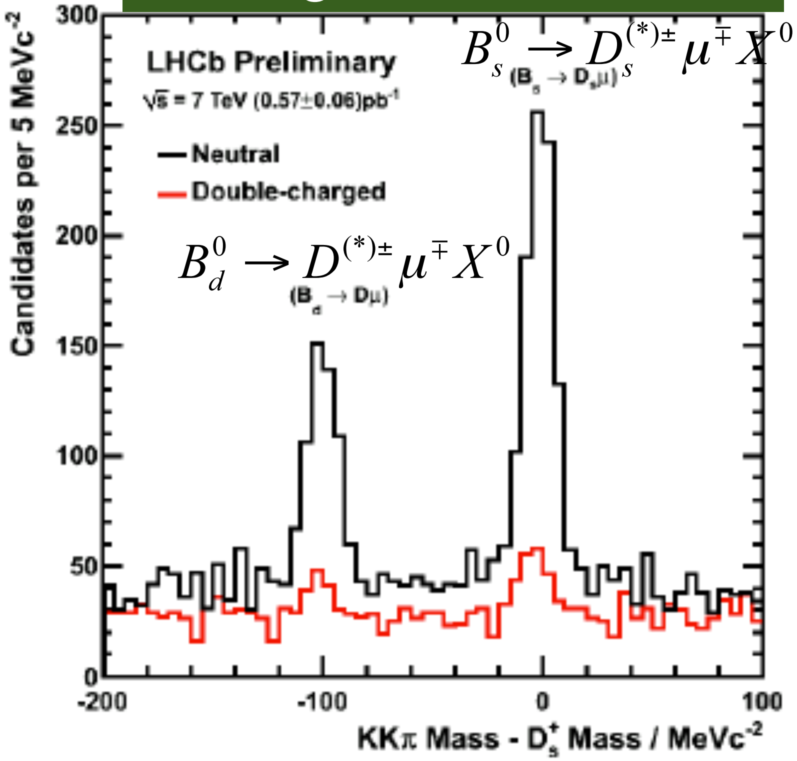
First signals from 570 nb^{-1}

Inclusive method at LHCb is difficult due to the $\sim 10^{-2}$ production asymmetry in pp collisions and control of detector asymmetry.



LHCb proposes to measure $a^s_{sl} - a^d_{sl}$, by determining the difference in the asymmetry measured in $B_s \rightarrow D_s(KK\pi)\mu\nu$ and $B^0 \rightarrow D^+(KK\pi)\mu\nu$:

- → **difference suppresses production asymmetry**
- → **same final state suppresses detector biases.**

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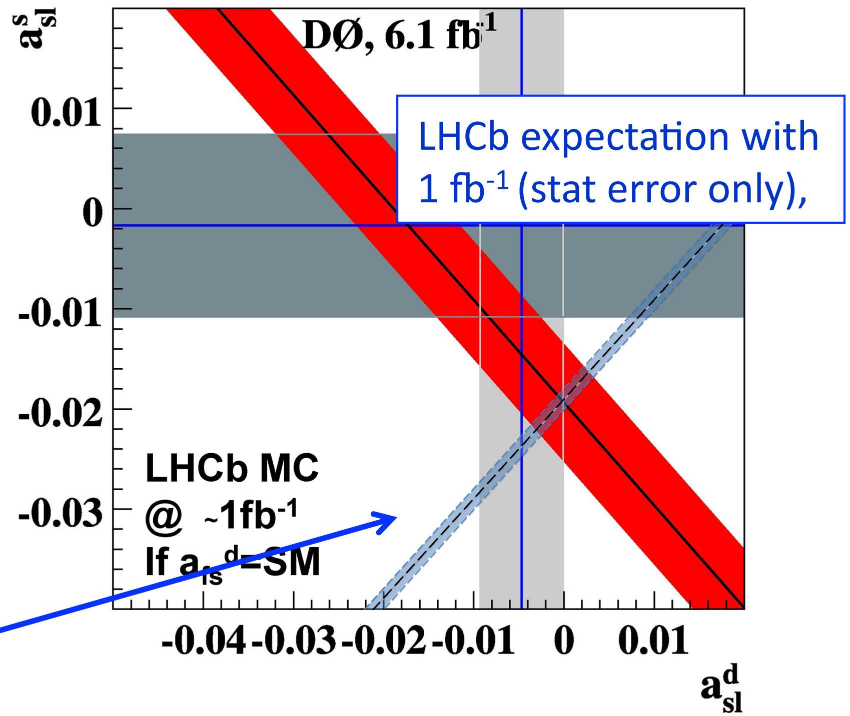
- **→ same final state suppresses detector biases.**

This method provides orthogonal constraint to D0 dileptons.

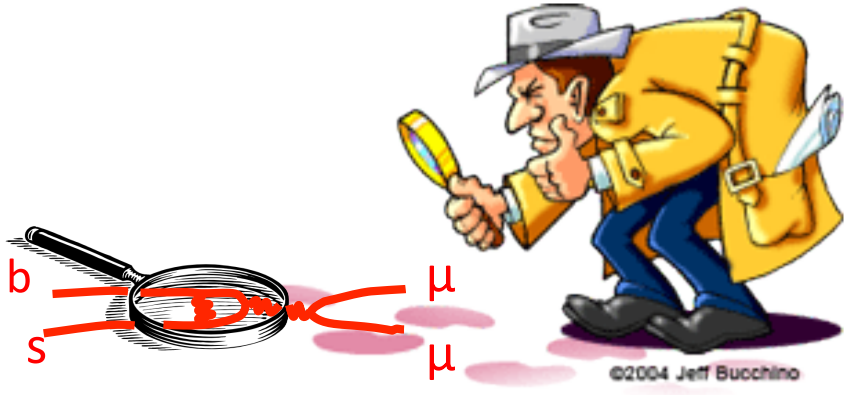


Rare Decays @ LHC

Back to FCNC processes….

→In SM only allowed at loop level

→ powerful probe for possible NP.



The FCNC processes can be described by an effective Hamiltonian, in the form of an Operator Product Expansion:

$$H_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^{*} \sum_i \Big[\underbrace{C_i(\mu) O_i(\mu)}_{\text{left-handed part}} + \underbrace{C_i'(\mu) O_i'(\mu)}_{\text{right-handed part}} \Big]$$

$i = 1,2$	Tree
$i = 3-6,8$	Gluon penguin
$i = 7$	Photon penguin
$i = 9,10$	Electroweak penguin
$i = S$	Higgs (scalar) penguin
$i = P$	Pseudoscalar penguin

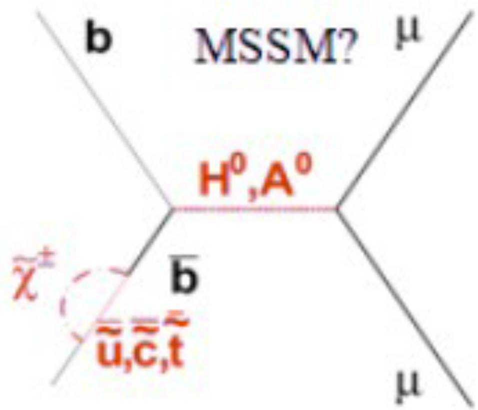
New physics modifies the Wilson coefficients affecting observable quantities as BRs [ex:B_s→μμ] (C_s, C_p), Angular distributions [B_d→K*μμ] (C_9,C_{10}, C_7) and Polarization [B_s→φγ] (C_7).

$B_s \to \mu\mu$: test the (pseudo-)scalar sector

•Highly suppressed in SM:

FCNC + helicity suppression (C_{10} dominates, Cp, Cs negligible):

BR =[3.6 ± 0.3] 10^{-9} [Buras et al., arXiv: 0904.4917v1



•Test the (pseudo-) scalar penguins:

→Can be strongly enhanced from contributions from Higgs sector in New Physics models [in particular for large tanβ]:

-eg: in 2HDM-II BR~$\tan^4\beta$, is MSSM with R-parity BR~$\tan^6\beta$

•Present best upper limit from CDF (3.7 fb^{-1}):

BR< 3.6 x 10^{-8} @ 90% CL [CDF note 9892]

•Similar result from D0 [6.1 fb^{-1}]:

BR< 4.2 x 10^{-8} @ 90% CL [arXiv:1006.3469v1]

$B_s \rightarrow \mu\mu$ @ LHCb

LHCb approach is philosophically similar to Tevatron's: loose selection and then construction of global likelihood, which is built from:

Mass:

Power determined by the tracking system resolution/alignment:

Geometrical Likelihood

Quantities where the vertex detector provides the main discrimination: impact parameters, isolation, B lifetime, vertex χ^2

Muon Likelihood

Dominated by muon system but uses also information from calorimeters and RICH detectors

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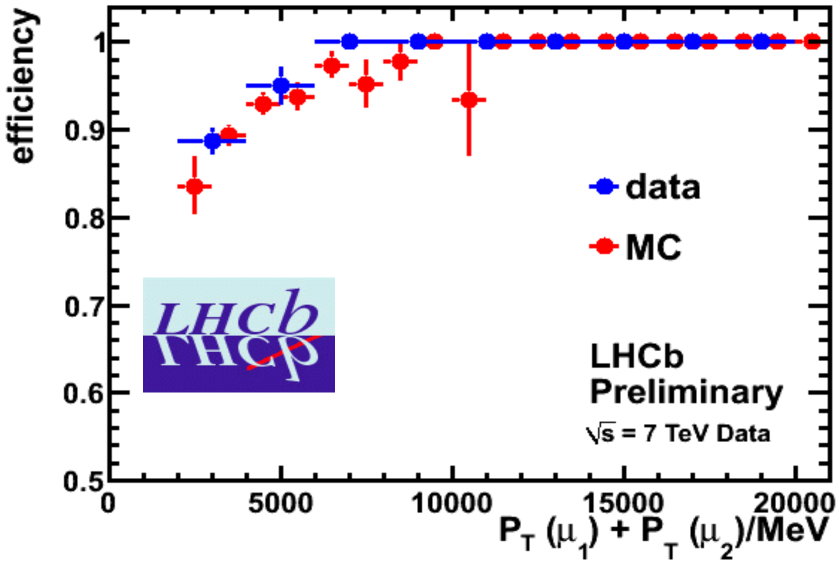
Dominated by muon system but uses also information from calorimeters and RICH detectors

Observation then turned into limit or BR measurement after comparing with known control channel, eg. $B^+ \rightarrow J/\psi K^+$ [knowledge of f_d/f_s required, LHCb method in arXiv: 1004.3982v2] or $B_s \rightarrow J/\psi\phi$ [no problem with fragmentation fractions but larger error in the BR, expected 10% statistical error from Belle @ Υ(5S)]

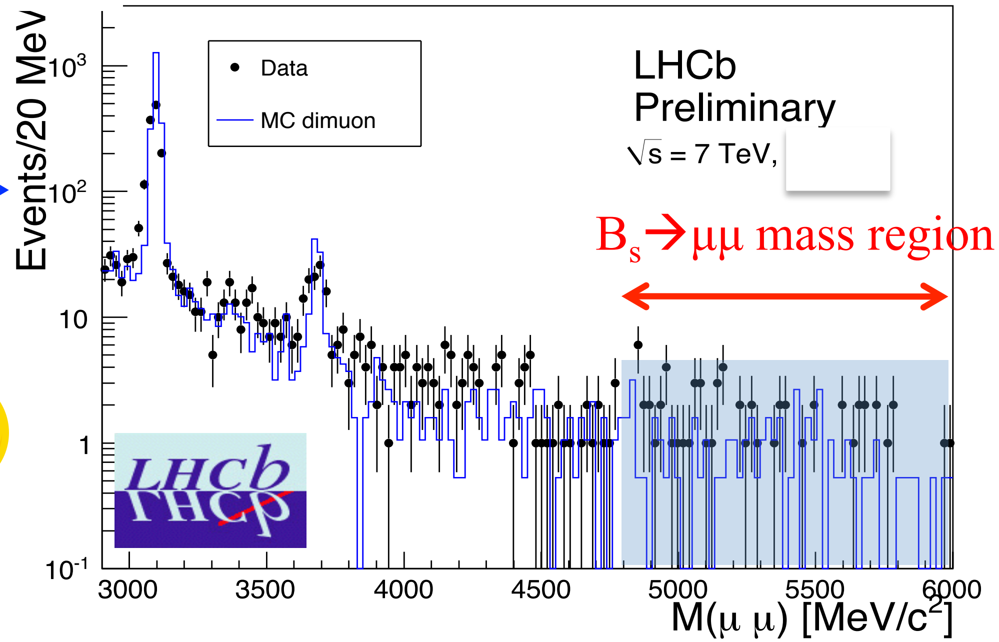
$B_s \to \mu\mu$ @ LHCb: validation with data



Trigger efficiency:

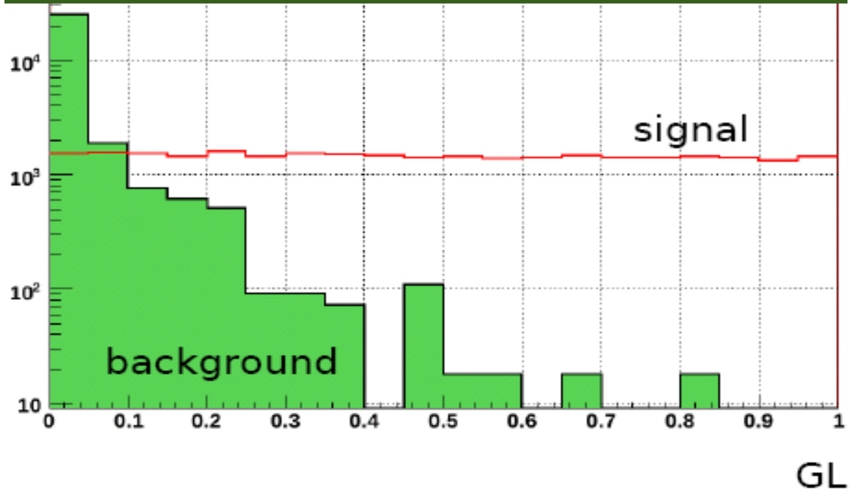
Measured on J/ψ(μμ):
High efficienct (> 95%)
Excellent Data/MC agreement!

Di-μ mass spectrum:
[after $B_s \to$ μμ loose selection]:
→ background in Bs mass region:
→ DATA/MC = 1.5 ± 0.4

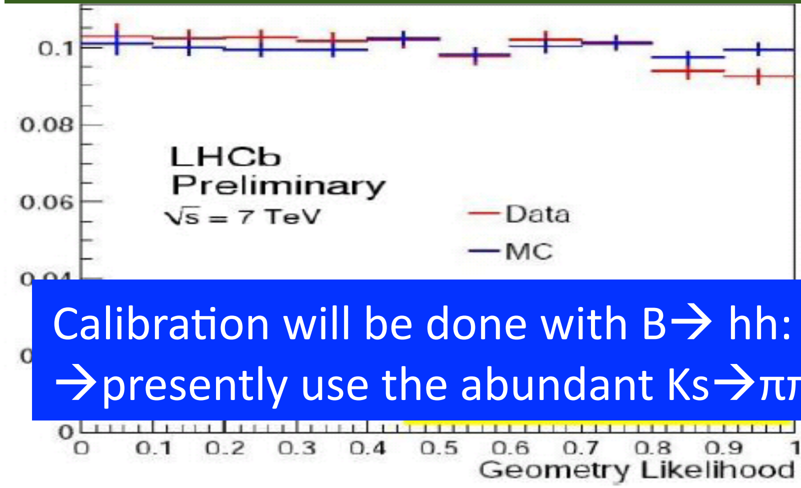


$B_s \rightarrow \mu\mu$ @ LHCb: validation with data

Geometrical Likelihood from simulation

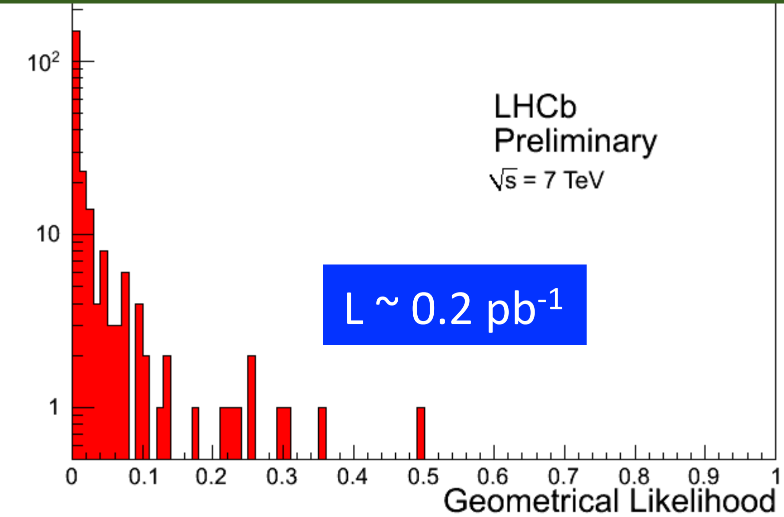


Geometrical Likelihood from data: signal



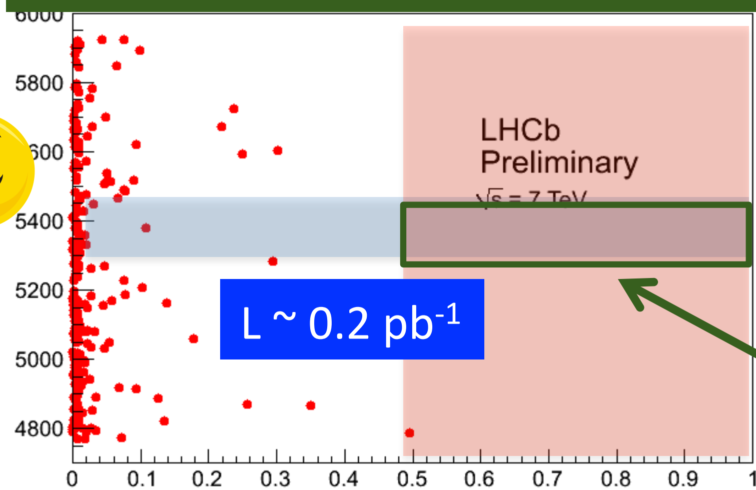
Calibration will be done with B→ hh:
→presently use the abundant Ks→ππ

Geometrical Likelihood from data: background



L ~ 0.2 pb^{-1}

Background: mass vs Geometrical Likelihood



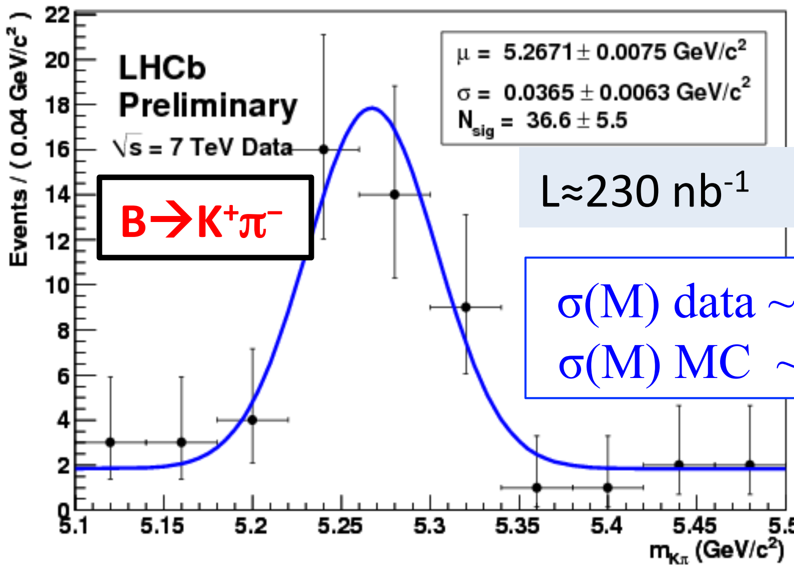
L ~ 0.2 pb^{-1}

Sensitive region: ± 60 MeV/c² & GL>0.5

$B_s \rightarrow \mu\mu$ @ LHCb: validation with data

Overall the agreement with the Monte Carlo expectations is remarkable..
However few issues require still some work to match with the design values:

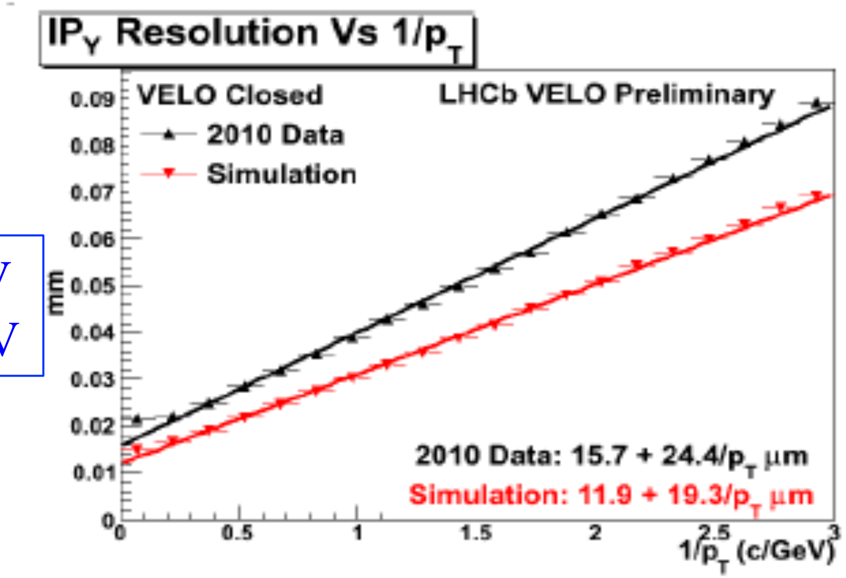
Mass resolution [main control channel $B \rightarrow K\,\pi$]



$L \approx 230\ nb^{-1}$

$\sigma(M)$ data ~ 36 MeV
$\sigma(M)$ MC ~ 22 MeV

IP resolution [main ingredient of the GL]



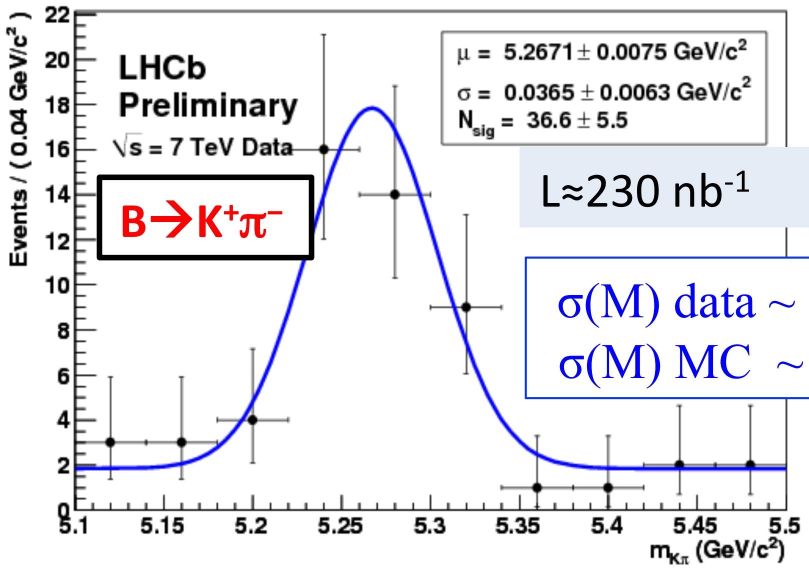
Mass and IP resolutions are the best among the LHC experiments.
However they are 30-50% off from the design value:
Expected to improve with better alignment…….

$B_s \to \mu\mu$ @ LHCb: validation with data

Overall the agreement with the Monte Carlo expectations is remarkable..
However few issues require still some work to match with the design values:

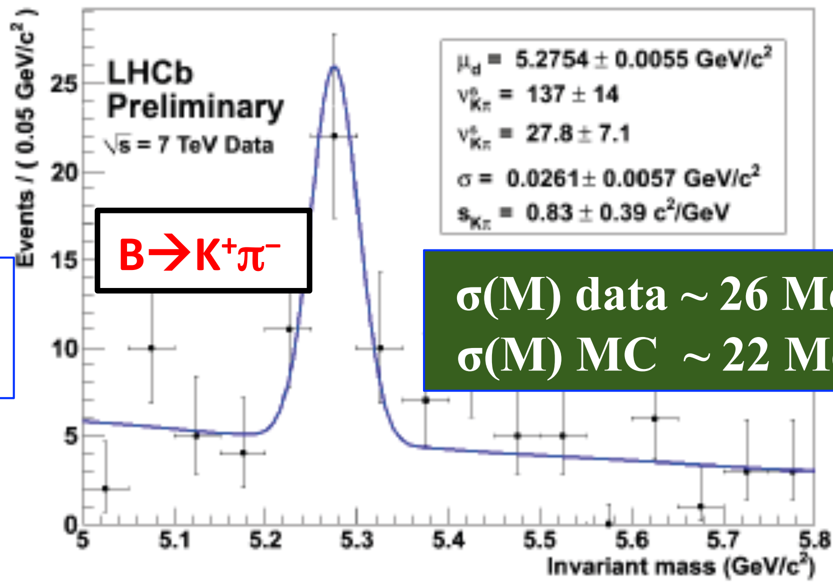
Mass resolution [main control channel B→K π]

L≈230 nb^{-1}



σ(M) data ~ 36 MeV
σ(M) MC ~ 22 MeV

L≈900 nb^{-1}



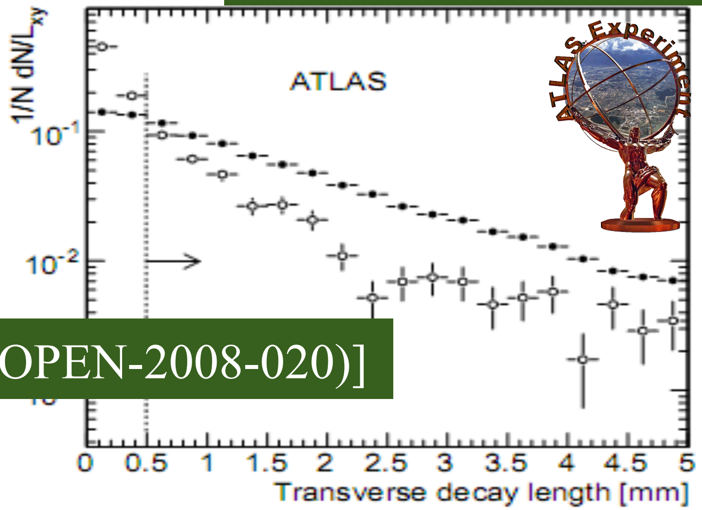
σ(M) data ~ 26 MeV
σ(M) MC ~ 22 MeV

…and in fact brand new (this week!) alignment parameters improve A LOT the resolution!

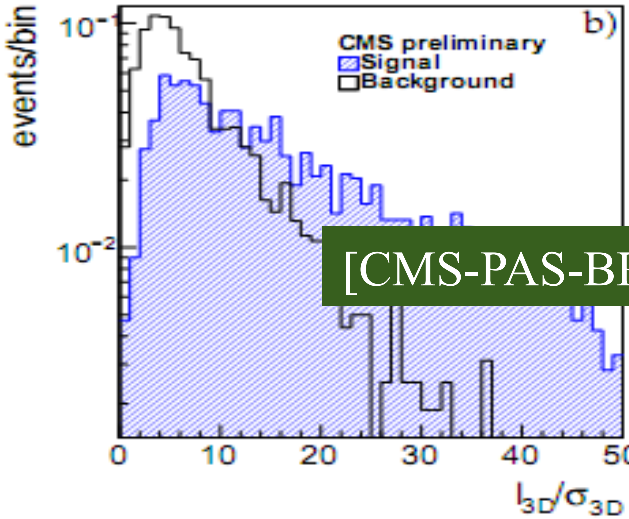
$B_s \to \mu\mu$ @ ATLAS/CMS

Cut based analysis: separate signal from background by using high discriminant variables such as pointing , isolation and secondary vertex displacement:

Eg: Distance of flight and distance of flight significance:



[CERN-OPEN-2008-020)]



[CMS-PAS-BPH-07-001 (2009)]

Experiment	N sig	N bkg	90% CL limit in absence of signal
ATLAS (10 fb^{-1}) $\sigma(bb)$=500 ub	5.6 events	14^{+13}_{-10} events (only $bb \to \mu\mu$)	-------
CMS (1 fb^{-1}) $\sigma(bb)$=500 ub	2.36 events	6.53 events (2.5 $bb \to \mu\mu$)	$< 1.6 \times 10^{-8}$

$B_s \rightarrow \mu\mu$ @ LHC: perspectives

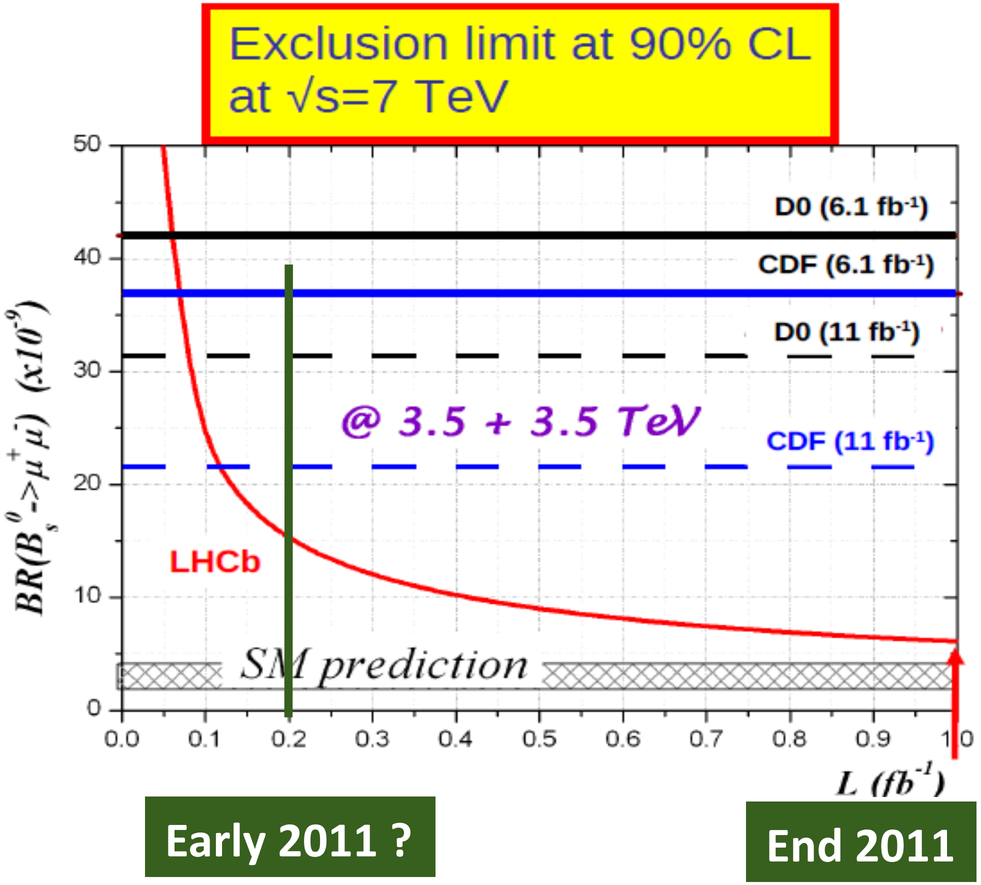
In absence of signal, 90% C.L. limits:

LHCb expectations [σ_{bb}~290μb]

- Current limit improved with ~0.1 fb^{-1}
- Expected Tevatron limit (~$2x10^{-8}$) reached with <0.2 fb^{-1} (early 2011)
- Exclusion of significant enhancement from the SM ($7x10^{-9}$) with < 1 fb^{-1} (end 2011)

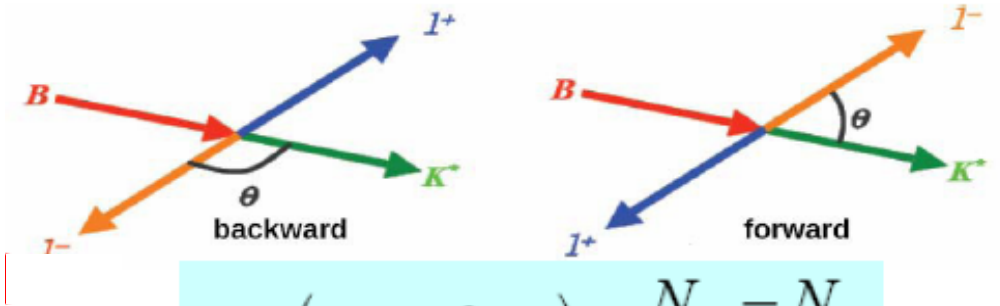
CMS expectations [σ_{bb}~500 μb]

BR<1.6 x 10^{-8} @ 1 fb^{-1}, 14 TeV
[CMS-PAS-BPH-07-001 (2009)]



Intriguing hints from $B \to K^{(*)} l^+ l^-$

Forward backward asymmetry in $B^0 \to K^* l^+ l^-$ is a extremely powerful observable for testing SM vs NP



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

$$A_{FB} = \int \frac{d^2 B(B \to K^* \mu^+ \mu^-)}{d\cos\theta} sgn(\cos\theta) \propto \mathrm{Re}\{C_{10}^*[q^2 C_9^{eff}(q^2) + r(q^2) C_7]\}$$

θ = angle between μ^+ & B in the dilepton rest frame

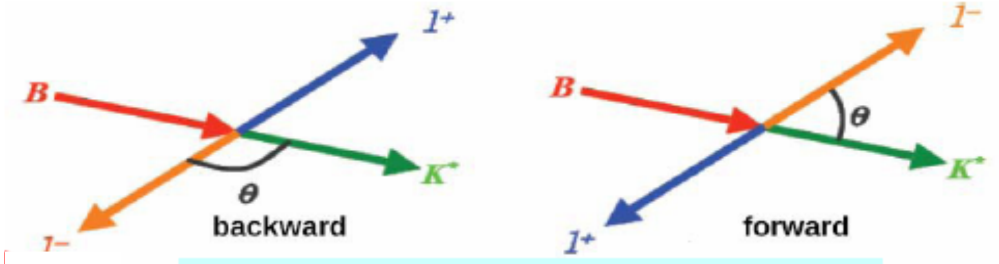
q^2 = dilepton invariant mass

- C_7: γ penguin [dipole] ⇔ $b \to s\gamma$
- C_9: γ peng. [vector] + (Z & box)
- C_{10}: Z peng. + box [axial]

- Interference of axial & vector currents ➔ direct access to relative phases of the Wilson coefficients.
- Uncertainties of hadronic form factors under control in the low-q^2 region.

Intriguing hints from $B \to K^{(*)} l^+ l^-$

Forward backward asymmetry in $B^0 \to K^* l^+ l^-$ is a extremely powerful observable for testing SM vs NP



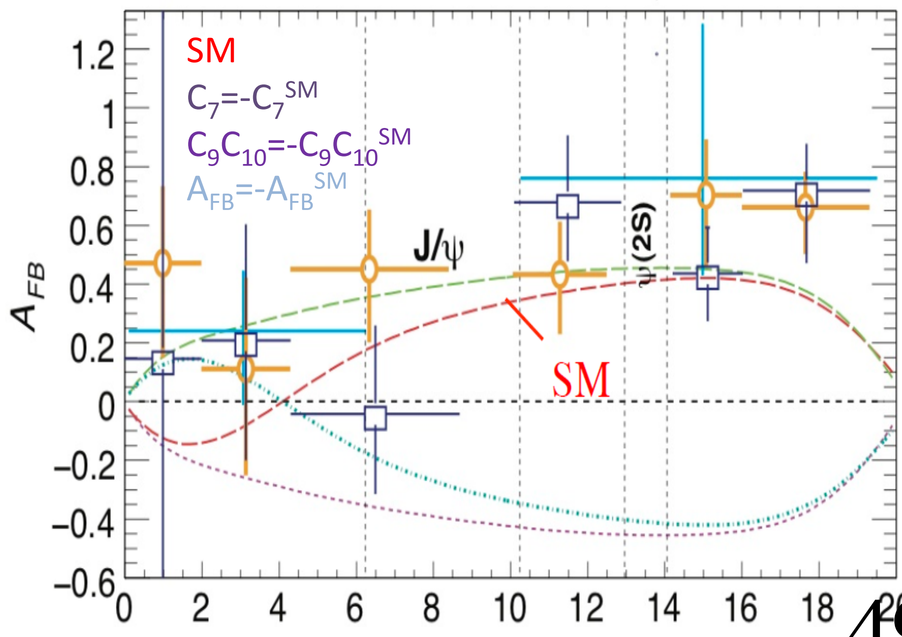
$$A_{FB}\left(s = m^2_{\mu^+\mu^-}\right) = \frac{N_F - N_B}{N_F + N_B}$$

Early results are showing intriguing hints….

250 K* ll [80% of data]

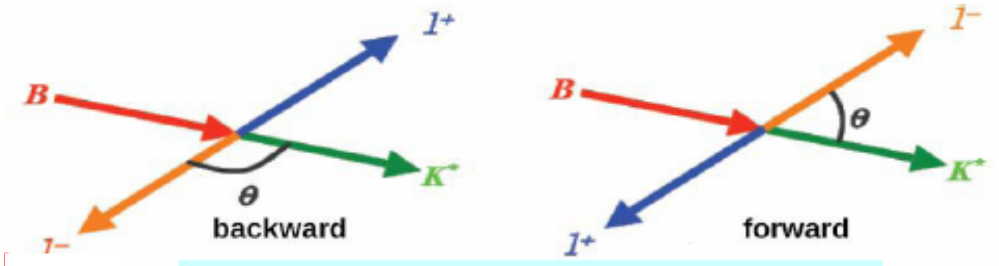
100 K* ll [75% of data

100 K*ll [4.4 fb^{-1}]



$B_d \to K^* \mu^+ \mu^-$ @ LHCb

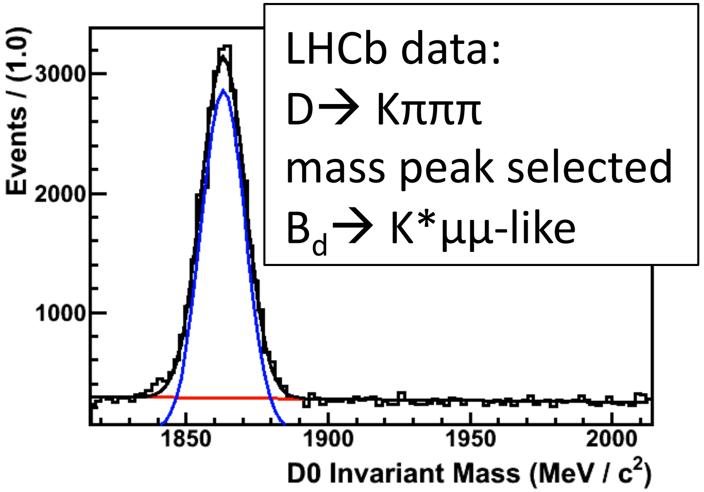
Forward backward asymmetry in $B^0 \to K^* l^+ l^-$ is a extremely powerful observable for testing SM vs NP

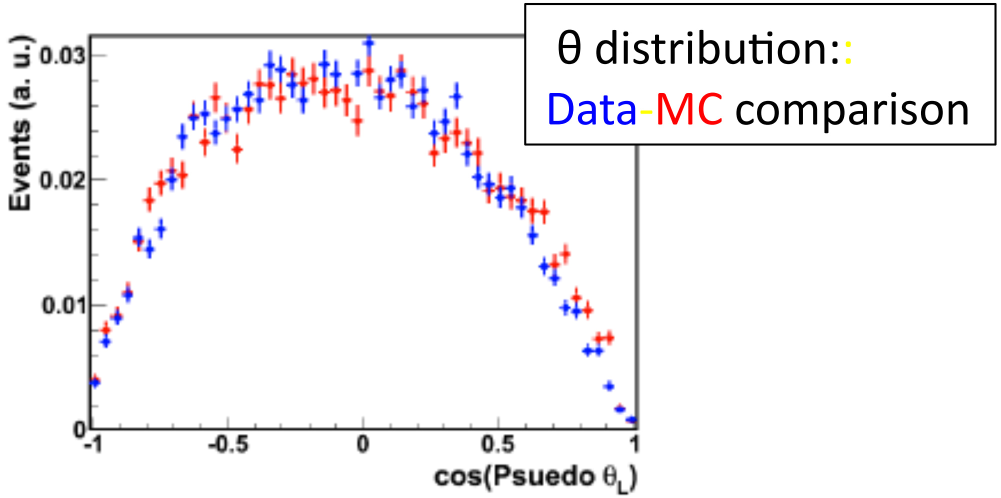


$$A_{FB}\left(s = m^2_{\mu^+\mu^-}\right) = \frac{N_F - N_B}{N_F + N_B}$$

Main experimental problem: control of acceptance biases introduced by detector acceptance, trigger and selection:

→ use topologically similar and abundant control channels as D→ K πππ:

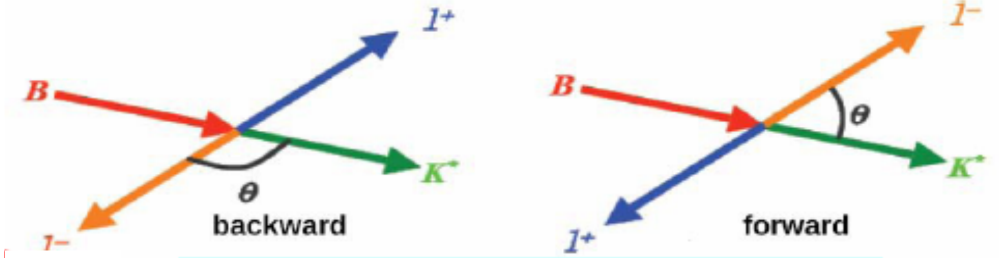




Good agreement data and Monte Carlo:
→ The angular biases predicted from MC are reliable

Intriguing hints from $B \rightarrow K^{(*)} l^+ l^-$

Forward backward asymmetry in $B^0 \rightarrow K^* l^+ l^-$ is a extremely powerful observable for testing SM vs NP



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

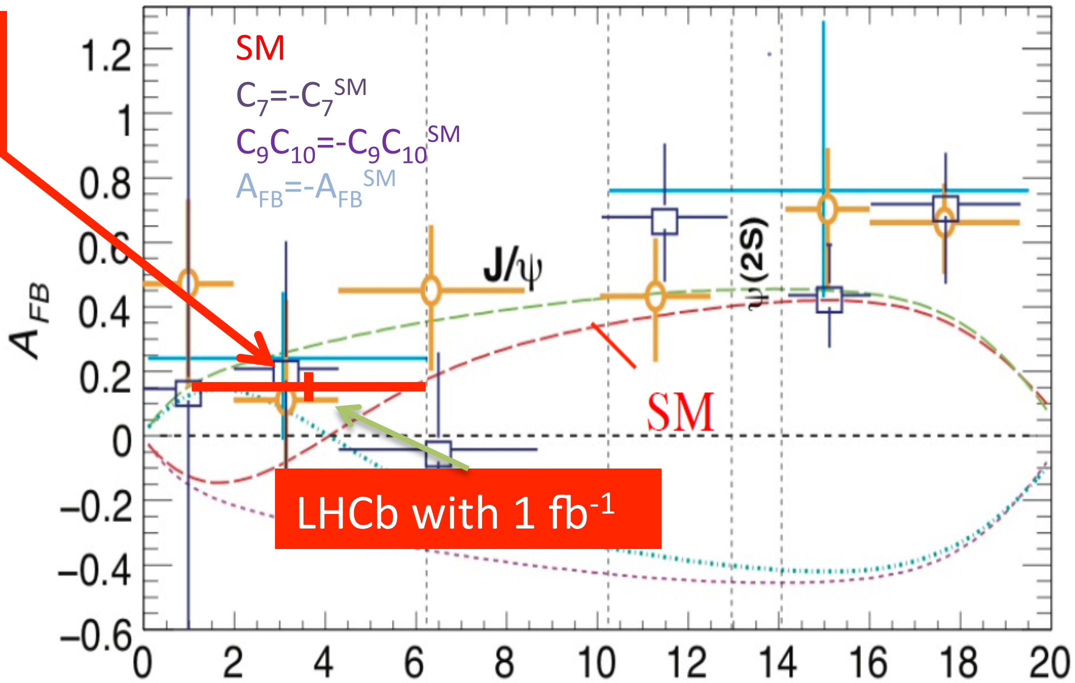
… and LHCb can help in understanding further the situation!

1400 K*ll [1 fb^{-1}]

250 K* ll [80% of data]

100 K* ll [75% of data

100 K*ll [4.4 fb^{-1}]



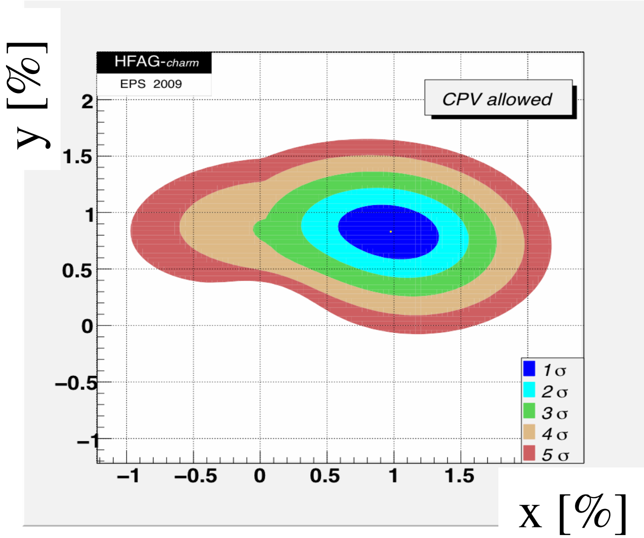
Prospects in the Charm sector - LHcb

Charm physics has been for many years shadowed by the successes of K decays and B decays, due to the fact that:

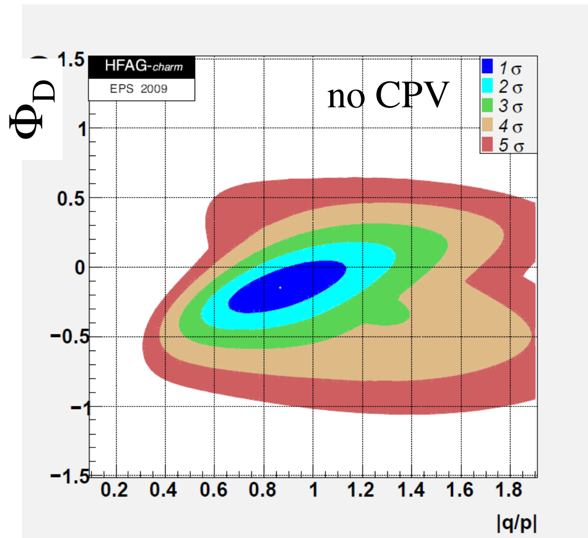
- the GIM mechanism is very effective in suppressing the FCNC transitions;
- long distance contributions prevent the evaluation of the ΔM_D;
- insensitivity to top physics in the loops.

However, large $D^0 - D^0$ mixing discovered in 2007 and good prospects for the study of CP violation in charm gave new impetus to this field.

"No-mixing" excluded at 10.2 σ:



All measurements consistent with no CPV:



Present constraints on CPV weak because CPV ~ $x_D \sin(2\varphi_D)$ and x_D~1%

→required sub-0.1% precision for CPV sensitivity!

Charm mixing studies at LHCb

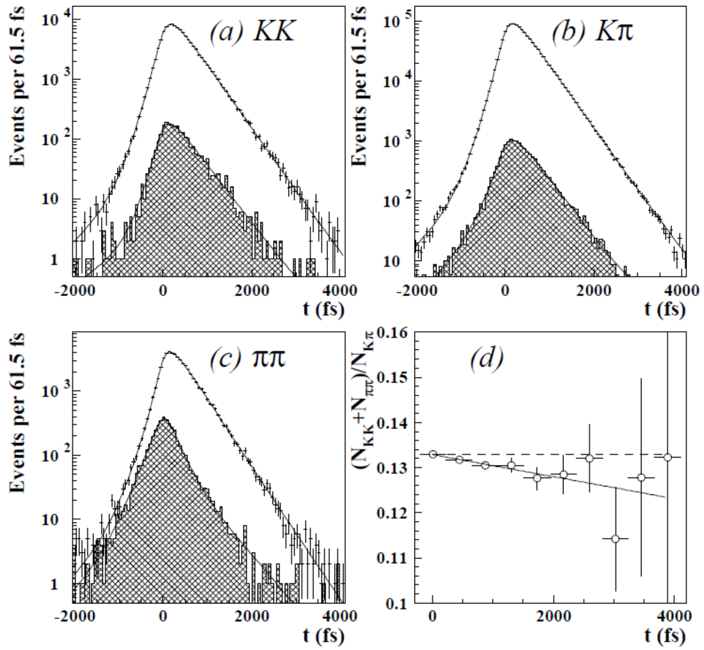
Example mixing analysis is measurement of "y_{CP}", which is D^0 width splitting parameter modified by CP-violating effects. Comparison to pure "y" measurements probes for CP-violation, as does measurement of pure CP-violating observable A_Γ

y_{CP}: compare lifetime of $D^0 \to$ CP-eigenstate, eg. KK or ππ, to $D^0 \to$ non-eigenstate eg. Kπ [untagged samples]

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

A_Γ: compare D^0 and $\overline{D}^0 \to$ KK lifetimes [tagged samples]

$$A_\Gamma = \frac{\tau(\overline{D}^0 \to K^-K^+) - \tau(D^0 \to K^+K^-)}{\tau(\overline{D}^0 \to K^-K^+) + \tau(D^0 \to K^+K^-)}$$



Belle, PRL 98 (2007) 211803

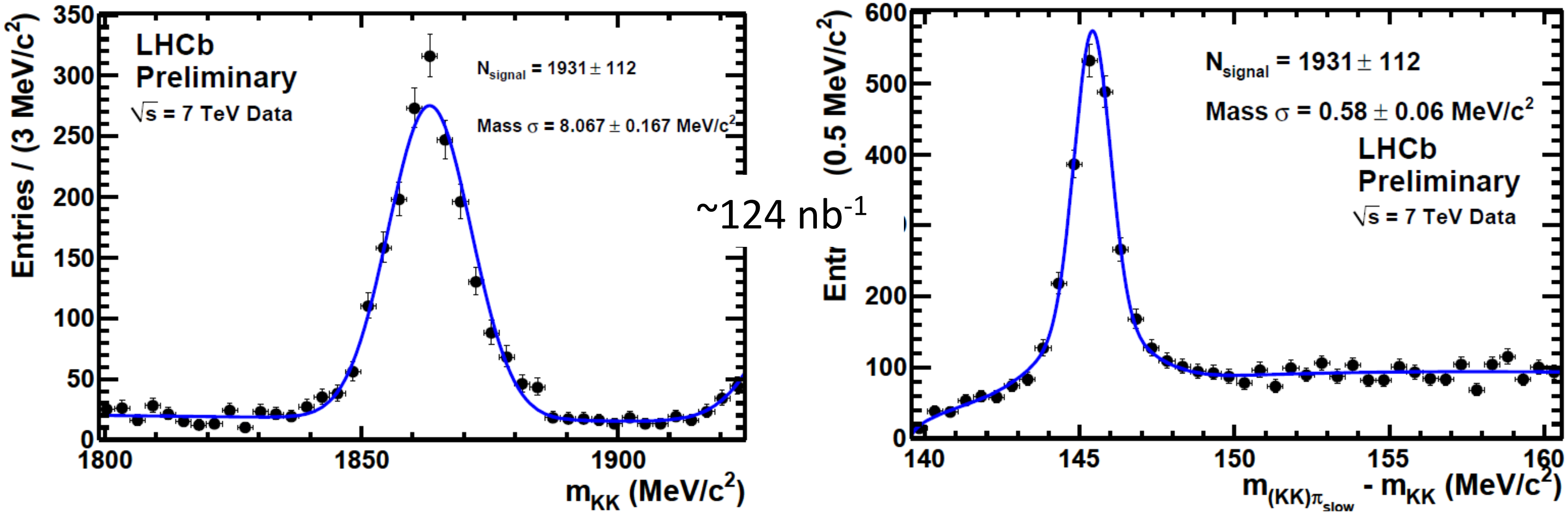
Belle 540 fb^{-1} analysis uses 1.1 x 10^5 flavour tagged $D^0 \to$ KK events
→ stat precision on y_{CP} = 0.32 % and on A_Γ = 0.3 %

Charm mixing studies at LHCb

Example mixing analysis is measurement of "y_{CP}", which is D^0 width splitting parameter modified by CP-violating effects. Comparison to pure "y" measurements probes for CP-violation, as does measurement of pure CP-violating observable A_Γ

A_Γ: compare D^0 and $D^0 \rightarrow KK$ lifetimes
[tagged samples]

$$A_\Gamma = \frac{\tau(\overline{D}^0 \to K^-K^+) - \tau(D^0 \to K^+K^-)}{\tau(\overline{D}^0 \to K^-K^+) + \tau(D^0 \to K^+K^-)}$$



LHCb @ 100 pb^{-1} competitive with Belle:
$D^0 \rightarrow KK$: [1.5-6] x 10^5 tagged, for ε(trg)=[10%-40%]
Belle @ 540 fb^{-1}: 1.1x10^5 [PRL98:211803,2007]

Conclusions

•Flavour physics in the LHC era is an excellent window for new physics searches fully complementary to the direct searches approach.

•LHC and LHC experiments are performing amazingly well.
→ First results show the excellent quality of the data collected so far.

•With the data collected in the 2010-2011 run the LHC experiments will have competitive results in the measurement of γ, $B_s \to \mu\mu$, $B_d \to K^*\mu\mu$, CPV violating phase in B_s mixing, CPV in charm which will allow to clarify better the already observed anomalies in the Standard Model picture.

Remember that also the Hubble Space Telescope had a problem at the beginning ….

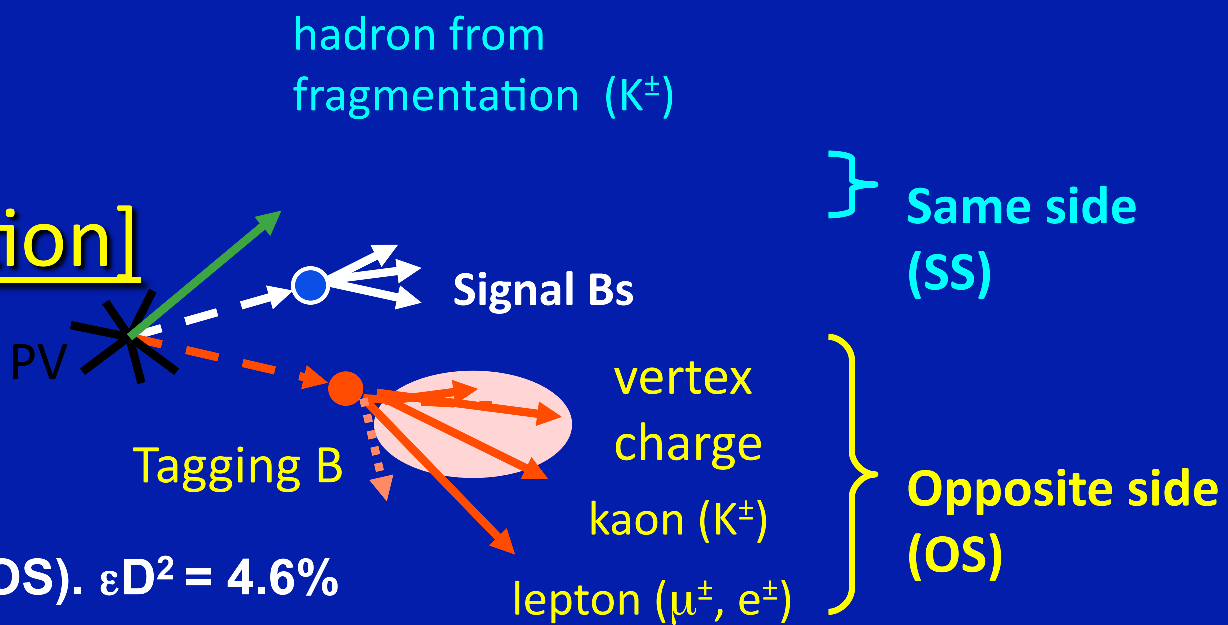
Remember that also the Hubble Space Telescope had a problem at the beginning ….

… but after the fixing it produced images of unprecedented clarity and sensitivity!

Thank You!

STOP

Tagging
[from simulation]



ATLAS: e, μ, Qjet (OS). $\varepsilon D^2 = 4.6\%$

CMS: ongoing

LHCb: e, μ, K, vertex charge (OS) + kaon (B_s) (SS). $\varepsilon D^2 = 6.2$ %

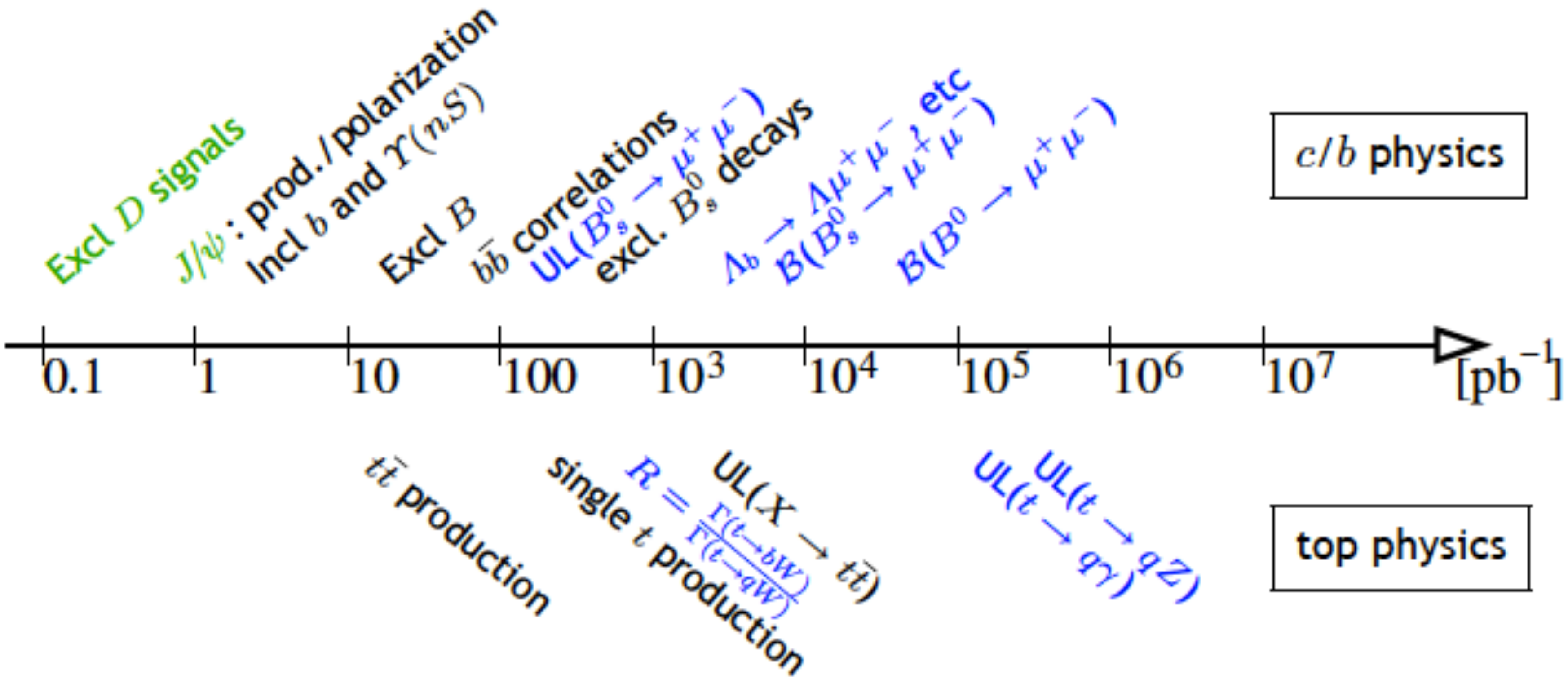
	$\varepsilon_{eff} = \varepsilon_{tag} (1-2\omega)^2$ [%]	ε_{tag}[%]	w [%]
Muon	0.75 ± 0.05	6.2	32.6
Electron	0.45 ± 0.04	2.8	29.9
Kaon opp. side	1.49 ± 0.07	15.3	34.4
Kaon same side	2.13 ± 0.09	25.5	35.6
Q vertex	1.14 ± 0.07	43.3	41.9
Combined	6.18 ± 0.14	56.6	33.3

Fragmentation fractions:

B species	Z0 fractions [%]	Tevatron fractions [%]
$B^{\pm}$	40.3±0.9	33.3 ± 3.0
B^0	40.3±0.9	33.3 ± 3.0
B_s	10.4±0.9	12.1 ± 1.5
Λ_b	9.1±1.5	21.4 ± 6.8

At LHCb/ATLAS/CMS these numbers can be different [different energy, different pseudorapidity region].
The production fractions can be different between LHCb and ATLAS/CMS.

Continuous Evolving Program



with many intermediate and/or improved results

Courtesy of U. Langenegger