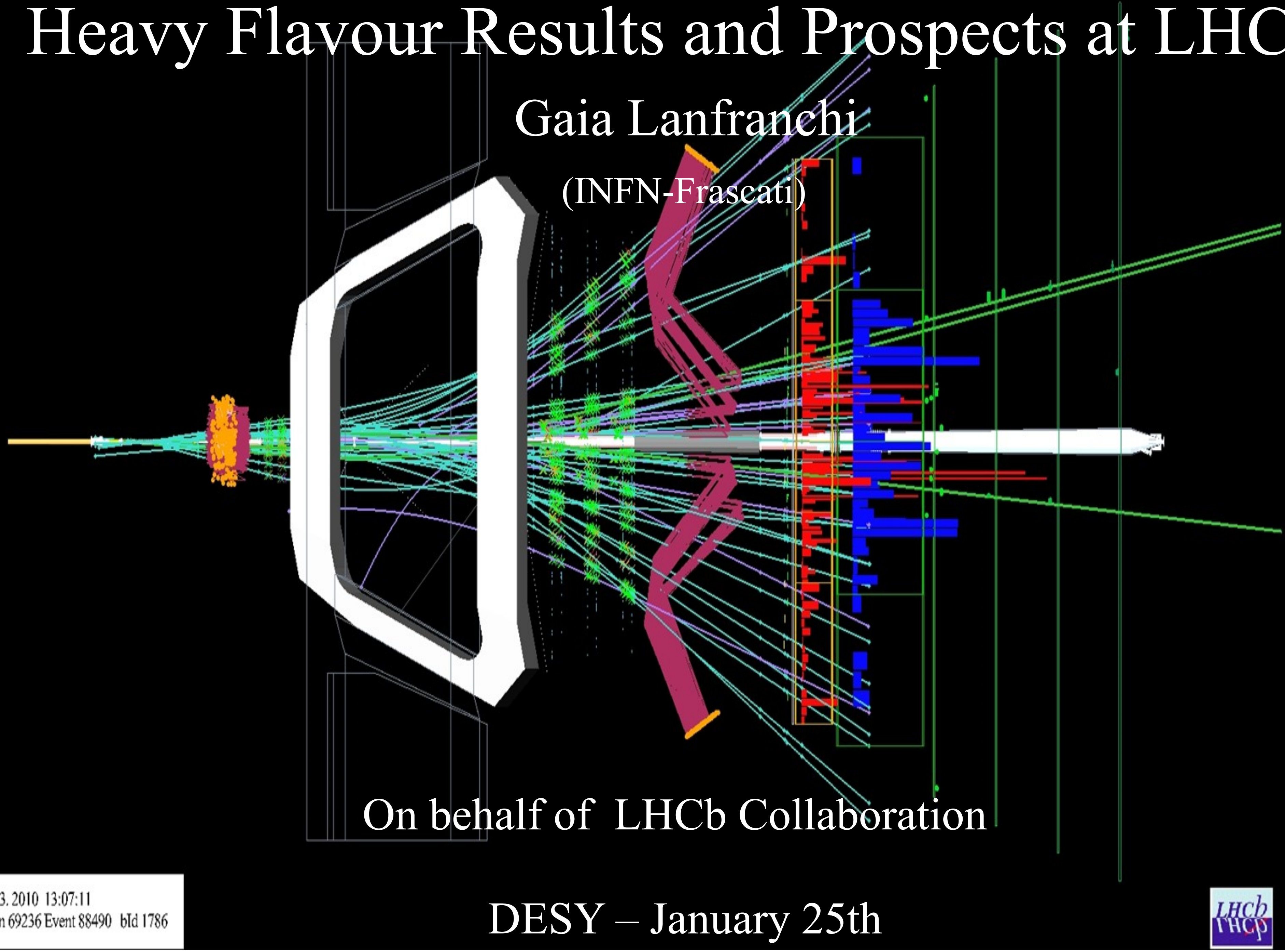
Heavy Flavour Results and Prospects at LHCb

Gaia Lanfranchi

(INFN-Frascati)



On behalf of LHCb Collaboration

DESY – January 25th

http://www.fnal.gov/pub/today/Tevatron-brinkman-to-shochet.pdf

Department of Energy
Office of Science
Washington, DC 20585

Office of the Director

JAN 6 2011

From Tevatron…..

Professor Melvyn Shochet
Chairman, High Energy Physics Advisory Panel
Department of Physics
University of Chicago
5630 S. Ellis Ave
Chicago, IL 60637

Dear Professor Shochet:

I am writing to convey the Office of Science's response to the recent High Energy Physics Advisory Panel (HEPAP) report on extending the operation of the Tevatron at Fermi National Accelerator Laboratory. As you know the Office of Science received in the summer of 2010 a widely supported proposal to extend operation of the Tevatron through FY 2014. At our request, HEPAP and its subpanel, Particle Physics Project Prioritization Panel (P5), responded quickly and analyzed both the physics merits of the proposal and the potential impacts on the rest of the field. HEPAP and P5 provided valuable and timely advice to the Office of Science that informed our FY 2012 budget request. I thank HEPAP and P5 for these efforts.

In summary, P5 found the proposed physics program had significant scientific value and would complement what can be accomplished at the Large Hadron Collider (LHC) in the same time period, but recognized that without additional funding the extension of Tevatron operations would delay progress on the development of the Intensity Frontier program by HEP. P5 therefore recommended that extension of the operation of the Tevatron be approved only if additional funds were available to HEP, and encouraged the funding agencies to find the necessary resources. Unfortunately, the current budgetary climate is very challenging and additional funding has not been identified. Therefore, based in part on the P5 recommendation, operation of the Tevatron will end in FY 2011, as originally scheduled.

The strategic plan for the U.S. particle physics program, developed by P5, attacks the

….to LHC!

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
- Status of the LHCb experiment:

  key experimental ingredients for heavy flavour physics measurements: status of the art

- First results in flavour physics @ LHCb 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?

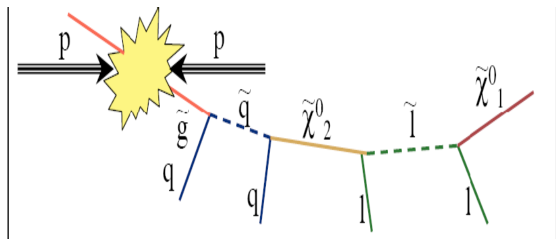
  2) which is the symmetry structure of the new degrees of freedom?

Flavour Physics in LHC era

Two complementary ways to answer these two questions:

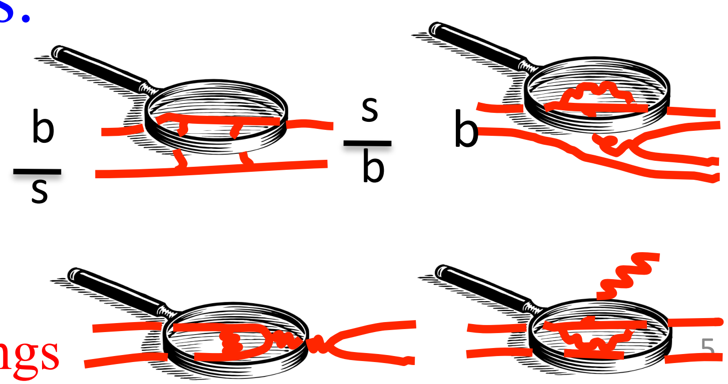
1) Direct searches in high-p_T physics:

→ 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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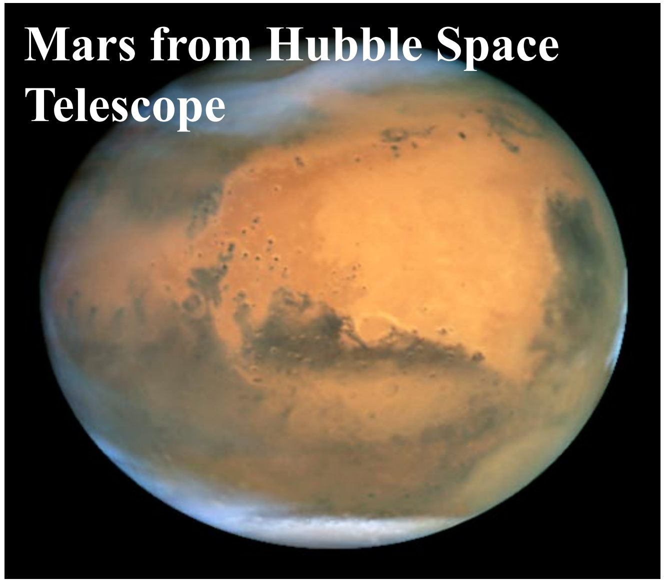


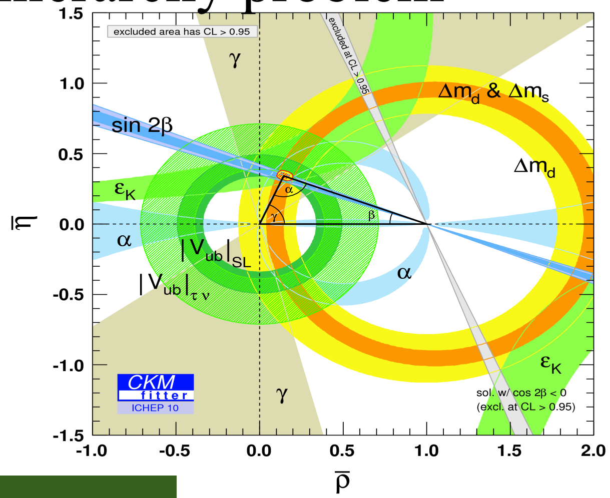
Flavour physics as a window for New Physics

- 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

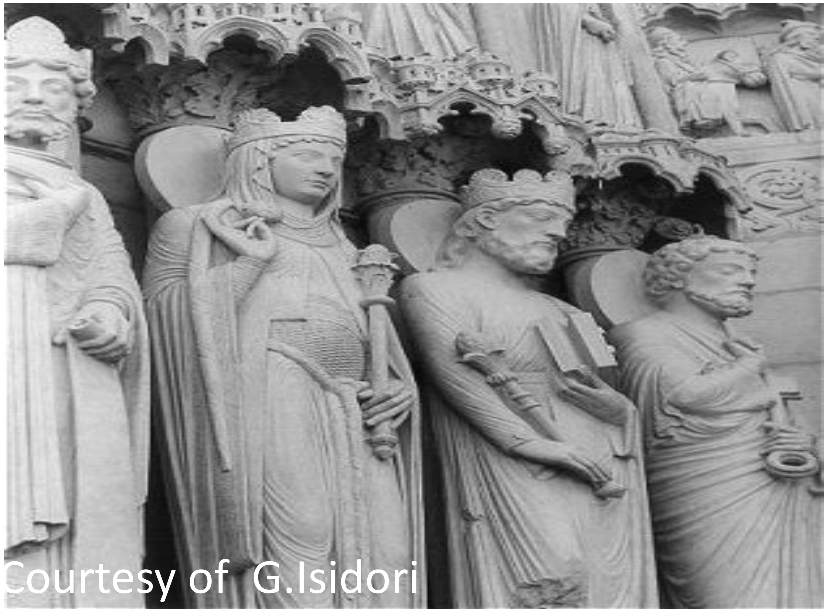
  - eg reachable by ATLAS/CMS -

  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

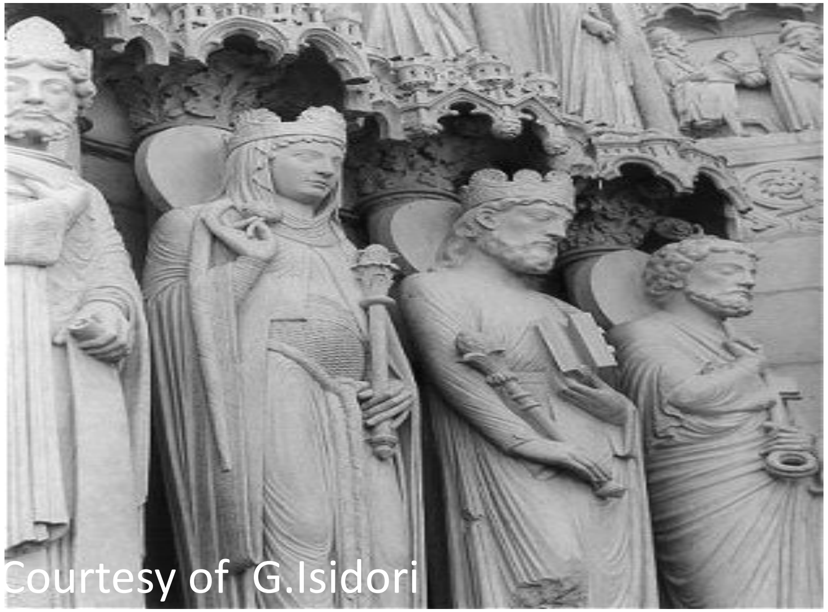
"Anomalies" in the Standard Model picture



Despite the overall success of the "Standard picture"…

6

"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.

6

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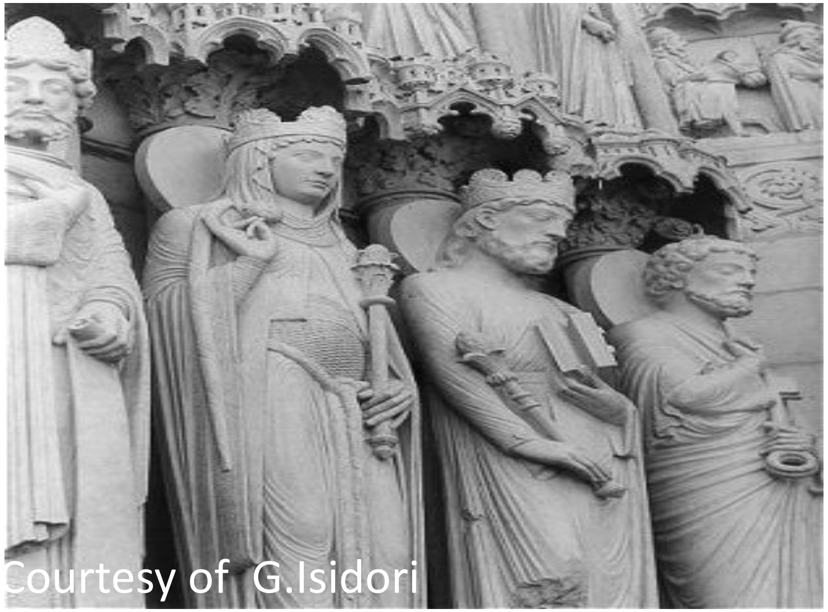

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“Anomalies” in CKM fits:

1) A(ψK)= sin(2β) 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 → τν):
→ exp = (1.68 ± 0.31) 10^{-4} [Babar + Belle ‘10]
→ SM = (0.79 ± 0.07) 10^{-4} [UTFit ’10]

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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

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

- Calibrating the sources [**σ(bb) , σ(cc),..]:**
  - measure σ(bb) at √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 transitions where NP may show up as a relatively large contribution:
  - B_s mixing phase: β_s **and a_{sl}**
  - $b \to s\gamma$, **$b \to sl^+l^-$, $B_{(s)} \to \mu\mu$**
  - Also: **CP phase in D^0 mixing**

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Preliminary result based on L ~5 pb^{-1}

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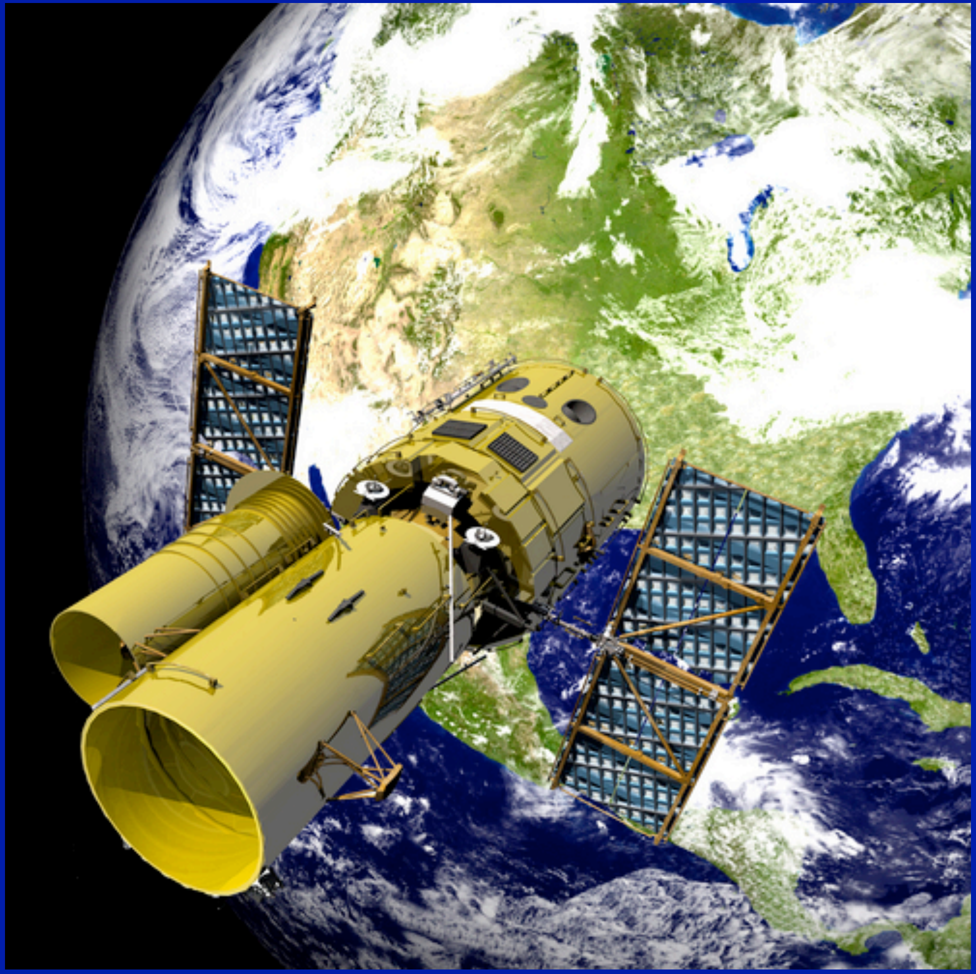
  - Also: **CP phase in D^0 mixing**

Here LHCb expects to have competitive results with data collected in 2010+2011 runs

2. LHC: machine status and detector performance



The Hubble space telescope

2010, March 30th: the adventure begins………..

…..and since then…..

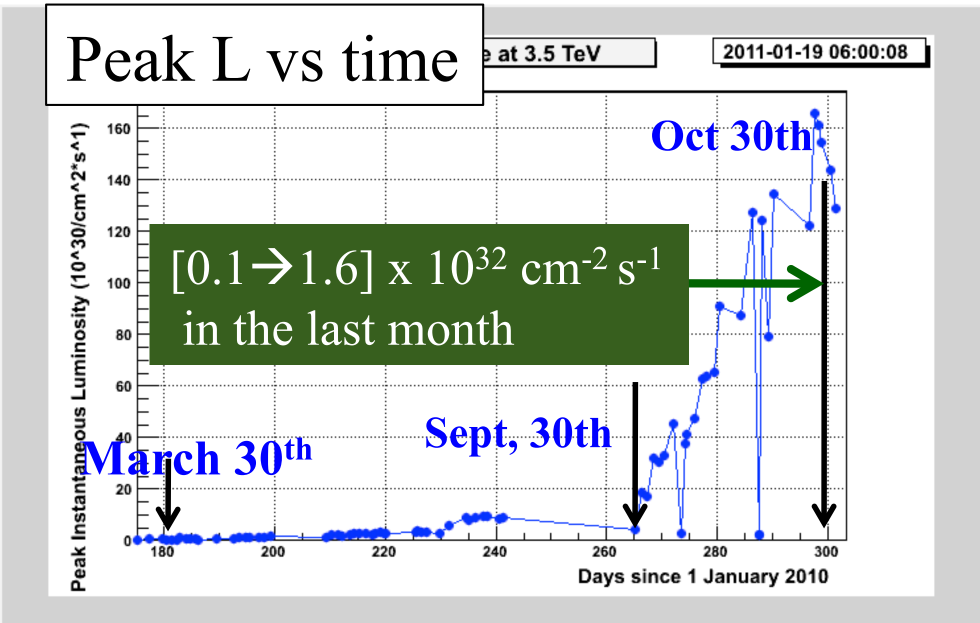
LHC: status of 2010 run and perspectives for 2011

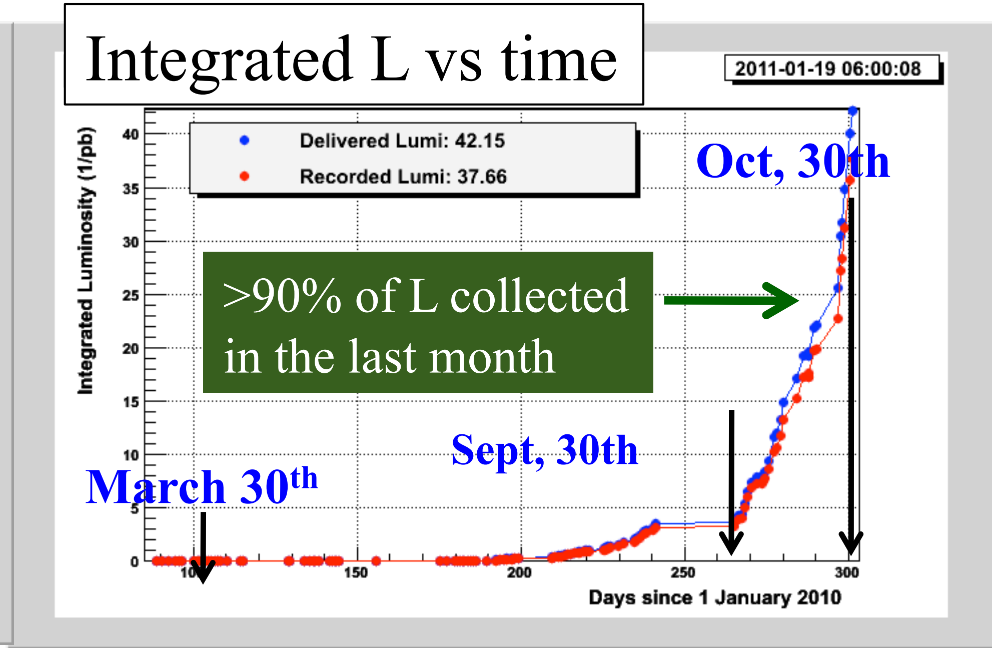
❑ Excellent machine performance:

- 2010 run @ $\sqrt{s}$ = 7 TeV - a "glorious" run:

L_{peak} increased ~1 order of magnitude per month, x15 last month (October)

L_{int} ~ 42/38 pb^{-1} (delivered/recorded) with $L_{peak,max}$ ~ 1.6 x 10^{32} cm^{-2} s^{-1}





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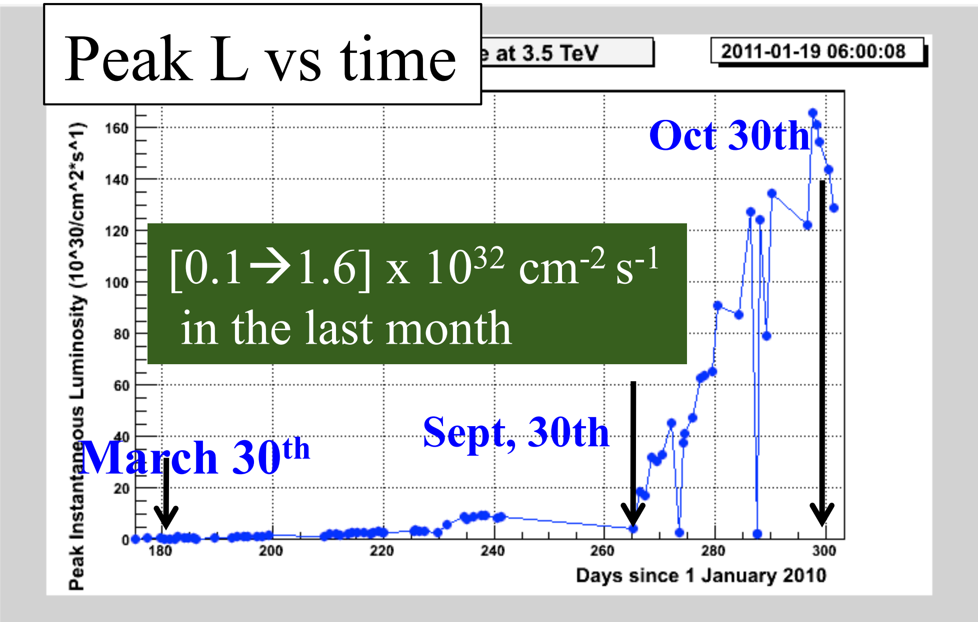

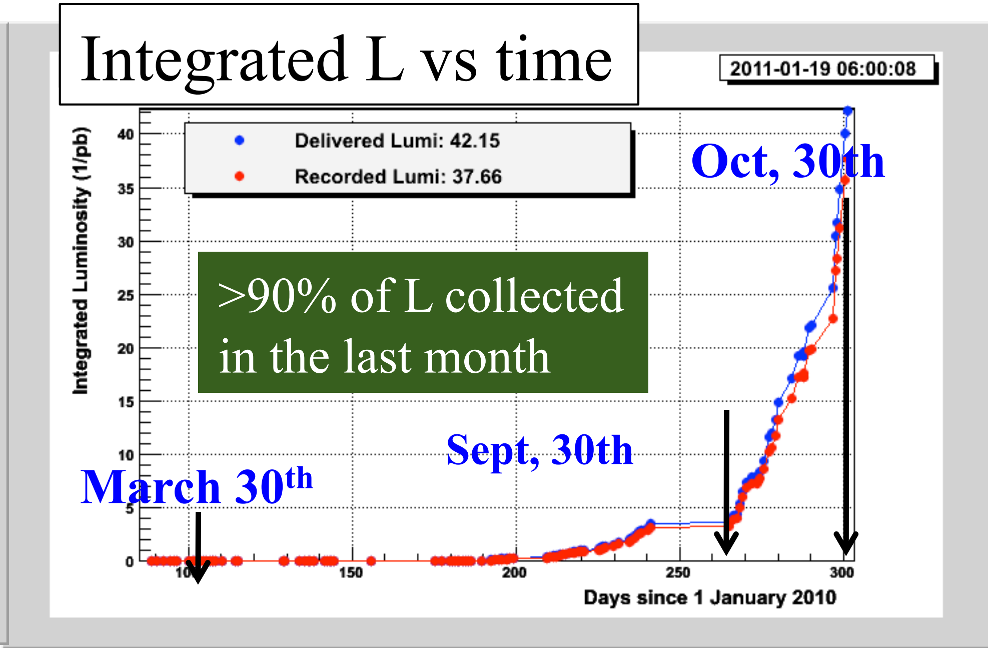

- 2011 run @ √s = 8 TeV
LHCb expects to collect ~ 2 fb^{-1}, L_{peak}(@ IP8) ~ 3 x 10^{32} cm^{-2} s^{-1}

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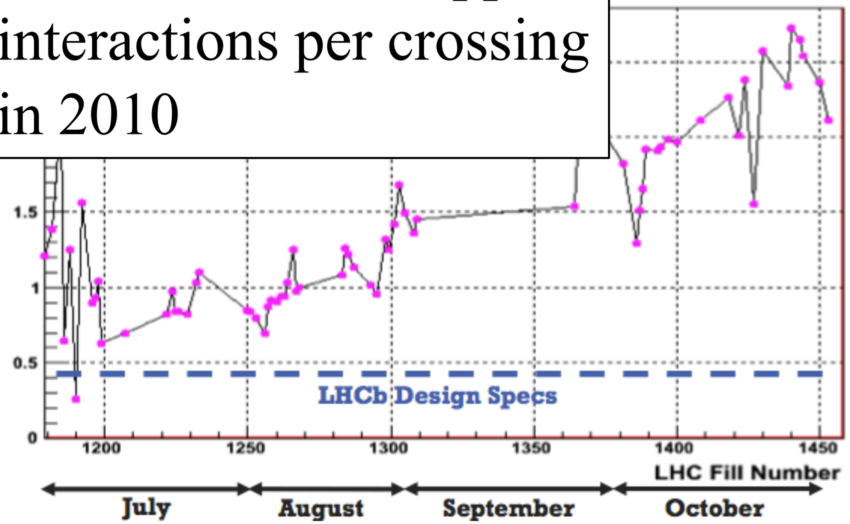
80% of L reached with 344 bunches
(2622 nominal) and β^*~3.5 m
(β^* ~ 10 m nominal) thus:

more vertices per collision!
- more tracks and event complexity!
- increase the readout rate per bx !
- increase event size and processing time

Number of visible pp interactions per crossing in 2010



…AND very tough from a detector/trigger/DAQ/reconstruction point of view!

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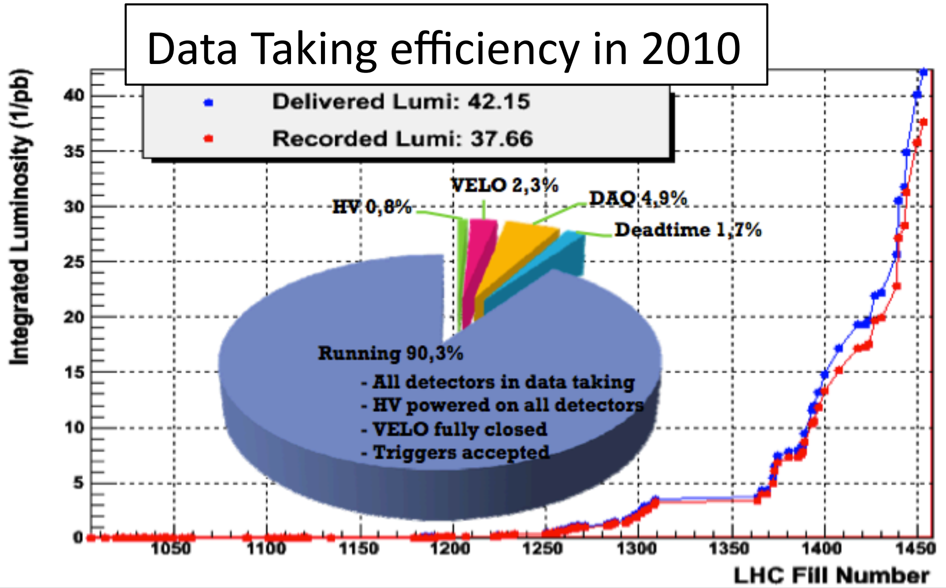

…AND very tough from a detector/trigger/DAQ/reconstruction point of view!
BUT we managed: overall data taking efficiency over the year > 90%!

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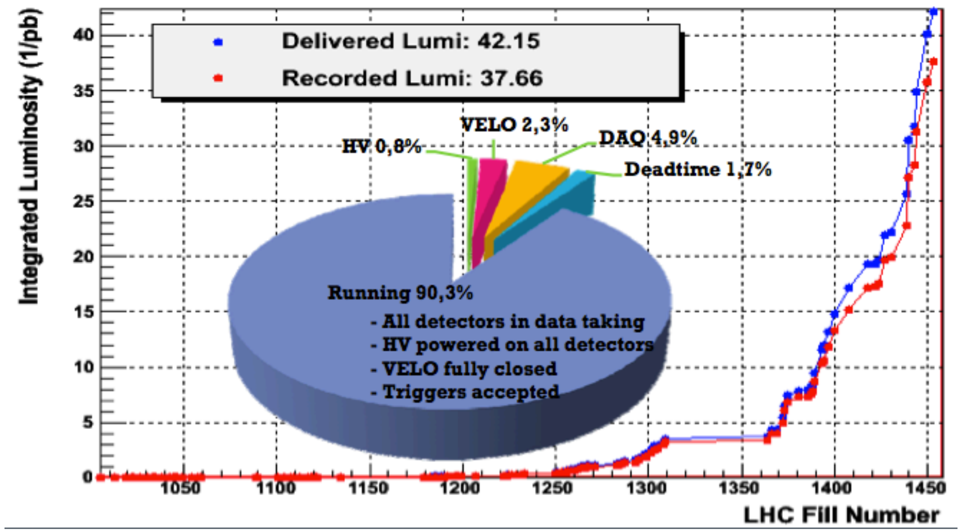
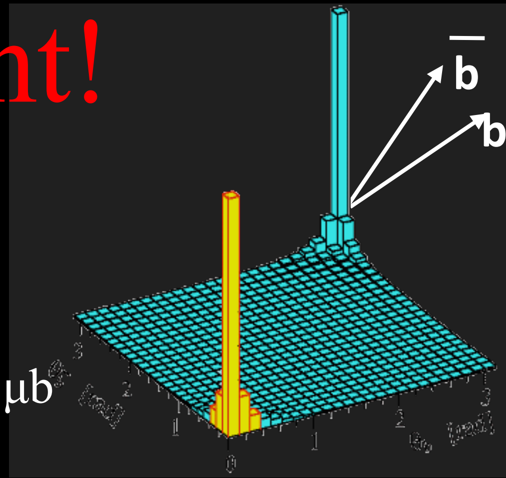
NB: L ~ 38 pb^{-1} corresponds to ~ 10^{10} of bb-pairs produced:
(only some % of what expected by the end of 2011);

Babar+Belle @ ϒ(4S),
L ~ 1.5 ab^{-1}, 1.5 10^{9} bb pairs produced



…HUGE STATISTICS ………

…. in a harsh environment!

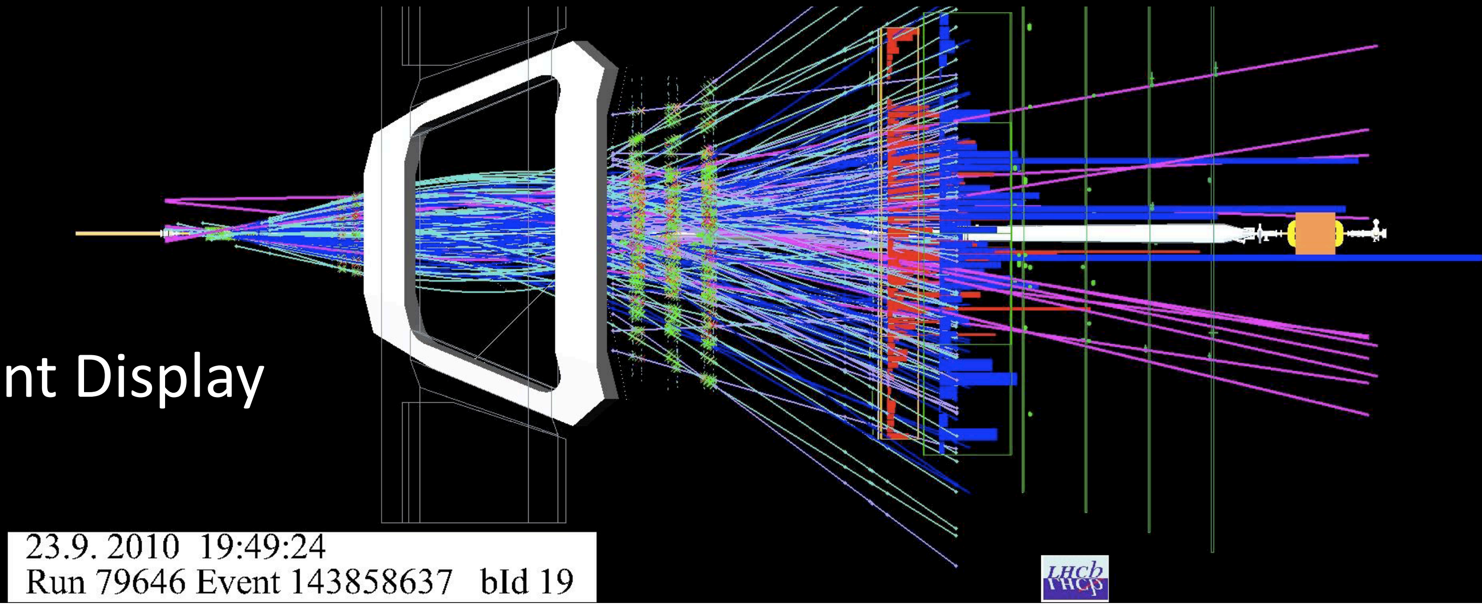


-LHCb is a FORWARD spectrometer :

- it maximizes acceptance for b- and c- decays….
  - 40% of the b decays in LHCb acceptance, σ(bb) @ √s=7 TeV ~ 300 μb

…and has to deal with a HUGE background:

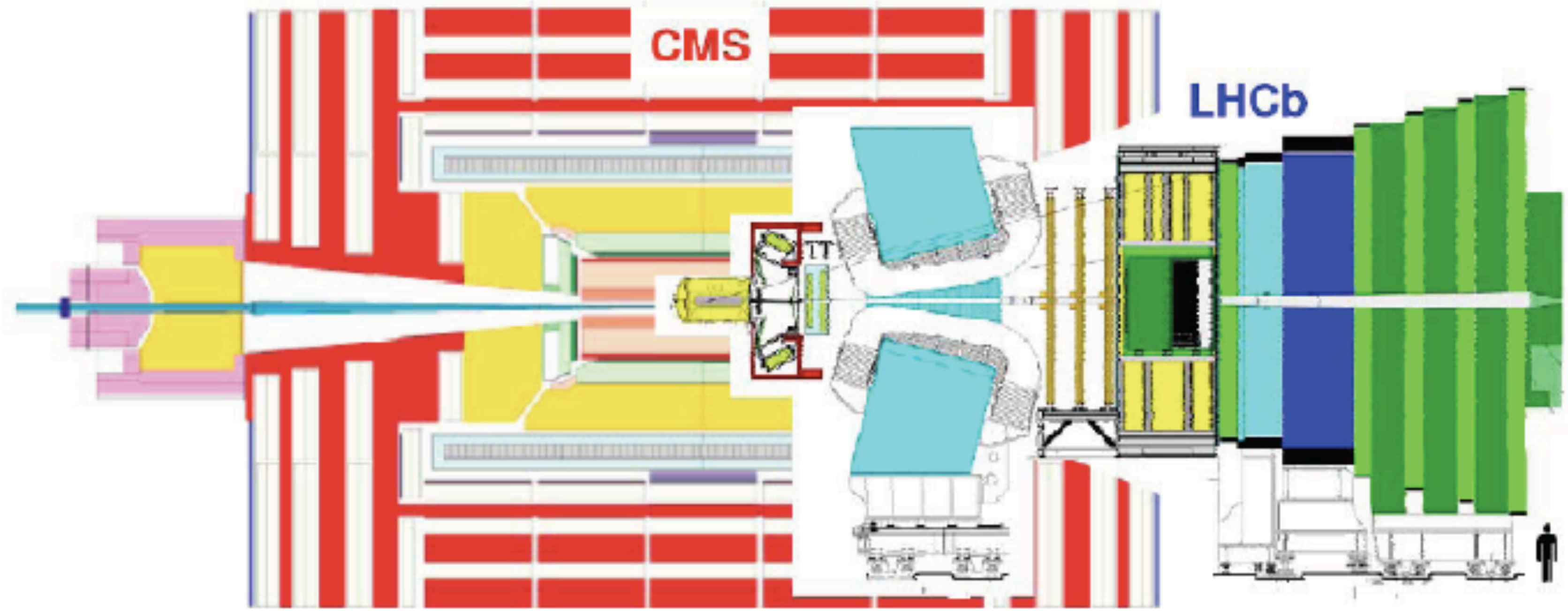
- σ(pp) @ √s=7 TeV ~ 90 mb
- 30 tracks per event per pseudorapidity unit in low-pileup conditions
  → now this number must be multiplied by a factor 3-4.
- 1/200 event contains a b quark , typical interesting BR < 10^{-3}



LHCb Event Display

LHCb: a forward detector

LHCb: $2 < \eta < 6$
ATLAS, CMS: $|\eta|<2.5$



Not only LHCb maximizes the acceptance for b-decays…
..but also allows to study the eta,pT dependence of the cross sections in a region not covered by the GPD (see after): fully complementary to ATLAS/CMS!

Key ingredients for LHCb:
[where we cannot fail]

1) Efficient trigger:

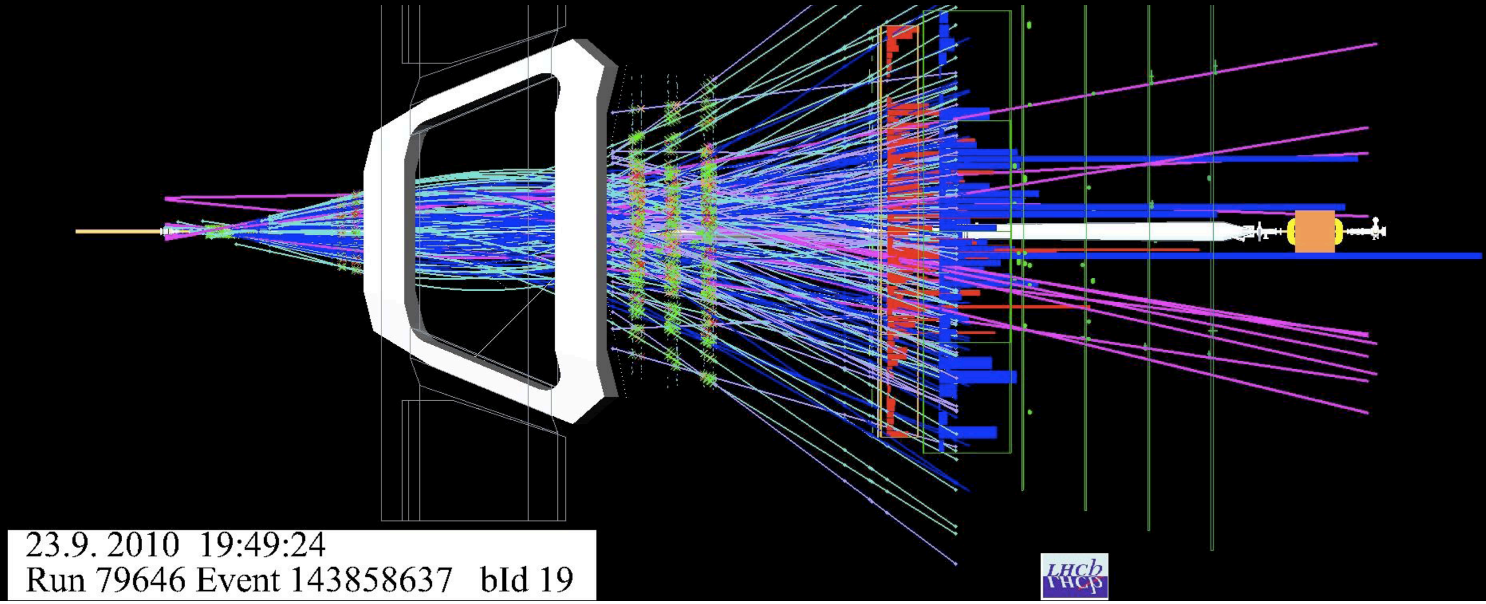
- to separate hadronic and leptonic final states from the HUGE background

2) Background reduction:

- Very good mass resolution
- Particle identification

3) Excellent vertex resolution:

- to resolve fast Bs oscillations and separate signals from background



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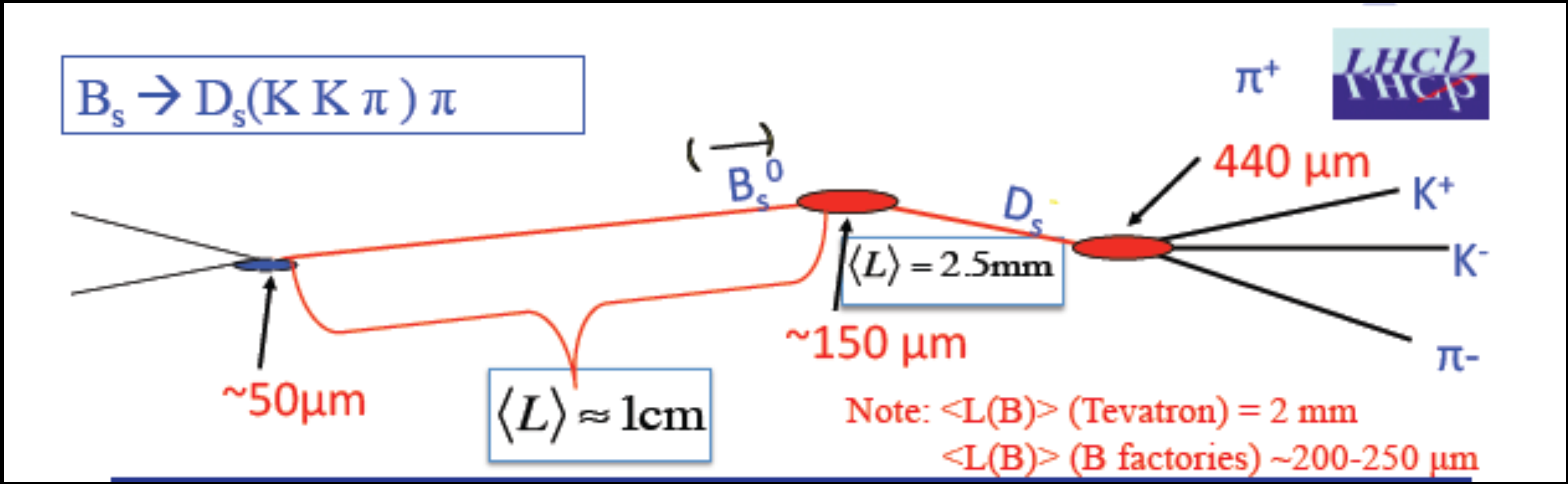
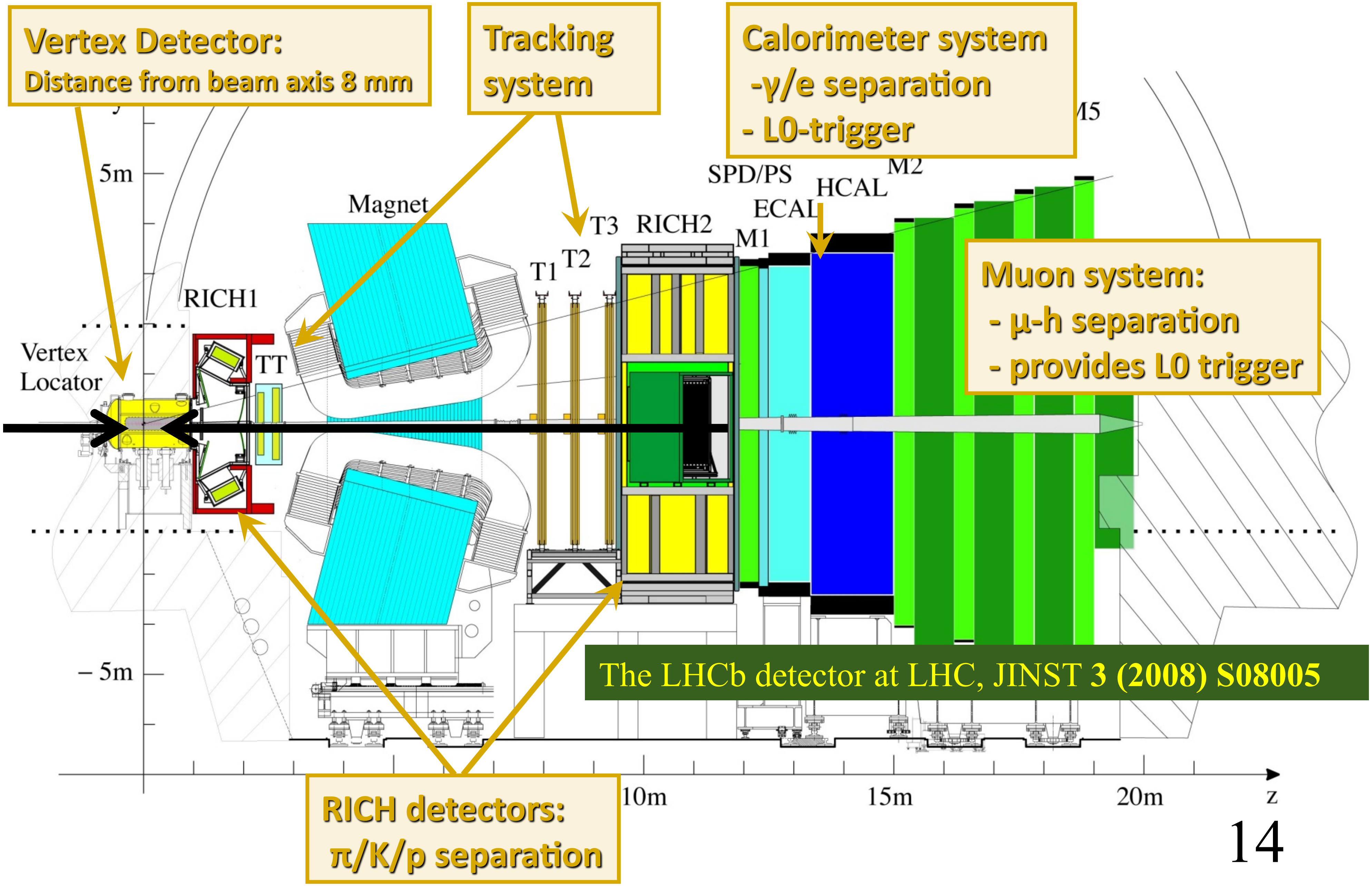
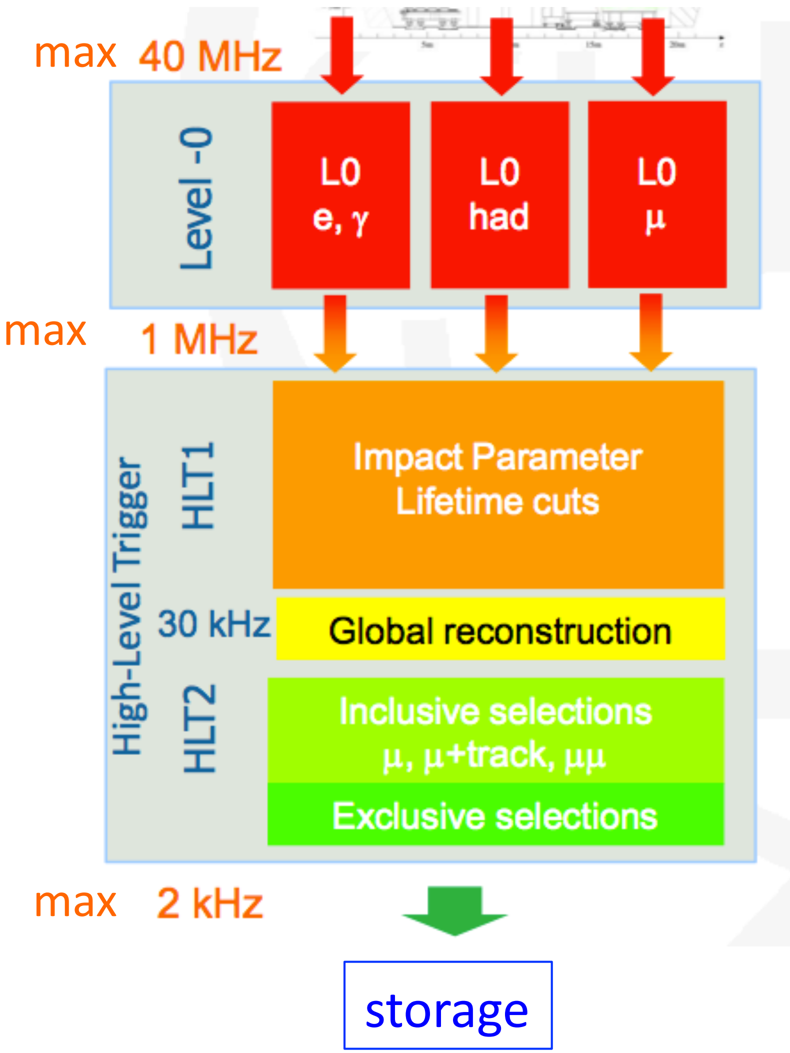


LHCb detector: scheme



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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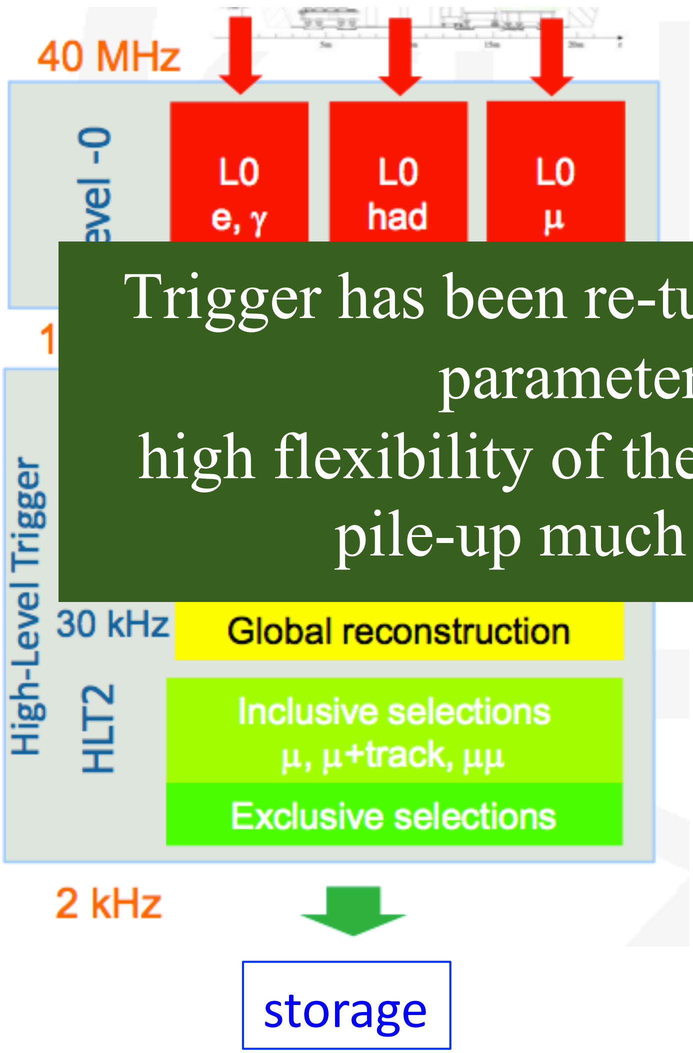


Level-0 [hardware]

'High-pt' signals in calorimeter & muon systems

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

ially

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

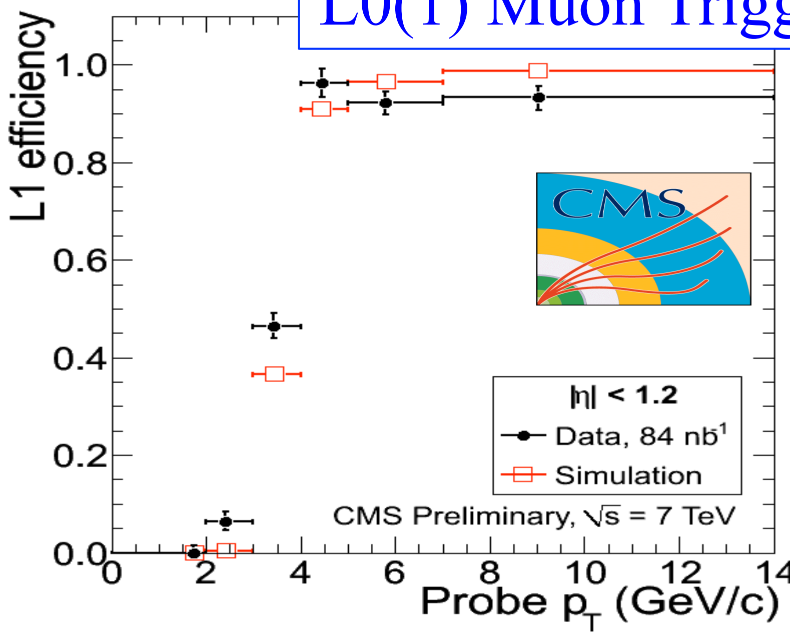
Key channels as $B_s \rightarrow \mu\mu$, $B_d \rightarrow K^*\mu\mu$, $B_s \rightarrow J/\psi\varphi$ contain muons in the final state

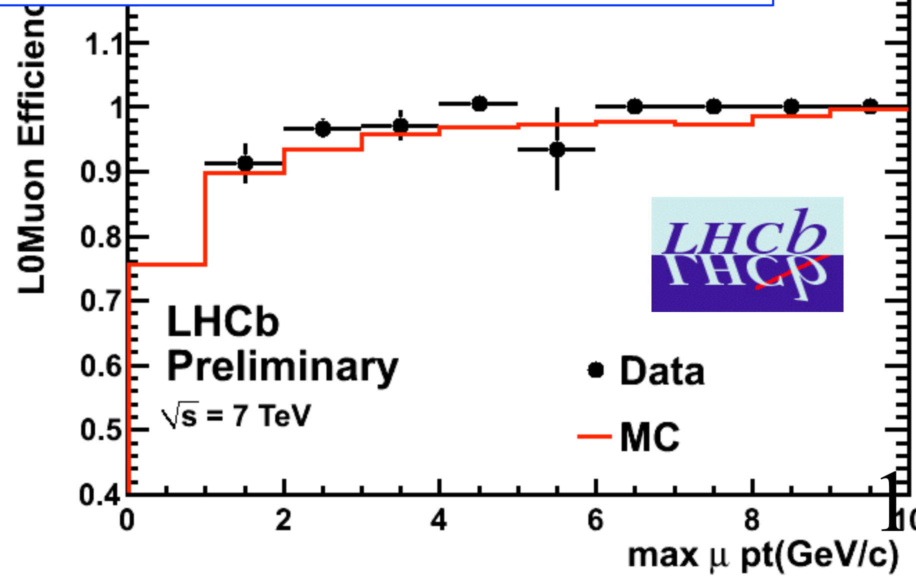
	L0(1) pt cut	HLT pt-cut	Rates
LHCb	p_T (1μ)> 1.4 GeV p_{T1}>0.6 +p_{T2}>0.5 GeV	p_T(1μ) > 1.8 GeV + IP 2μ: M>2.5 GeV	~ 1000 Hz

ATLAS/CMS:

intrinsic threshold at pT=3-4 GeV/c, further increased to maintain the muon trigger rate < 50 Hz.

L0(1) Muon Trigger efficiency vs pT for $J/\psi \rightarrow \mu\mu$



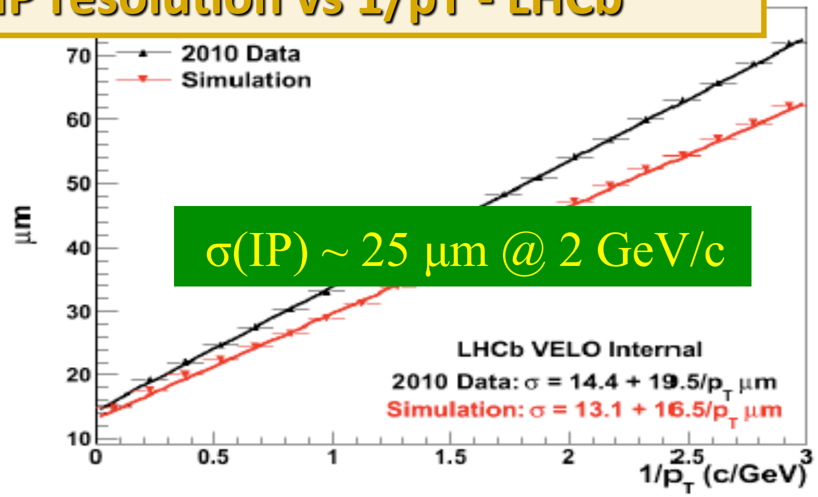


key ingredients for b- [c-]physics: Vertex & IP resolutions

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

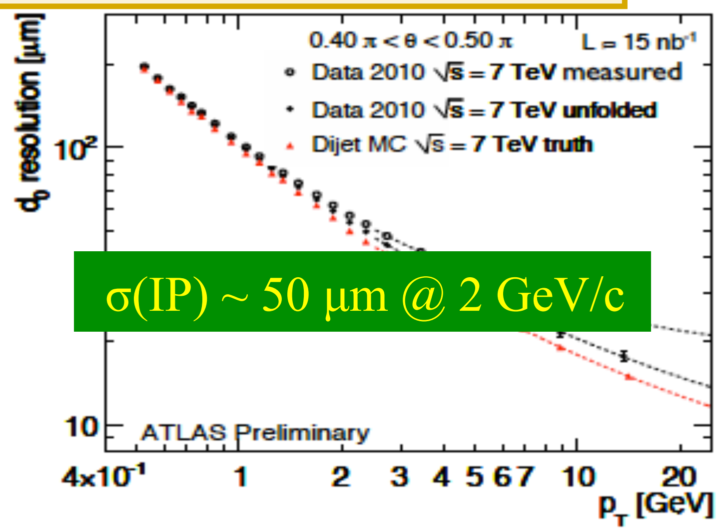
Primary vertex resolutions (25 tracks):	LHCb [μm]	ATLAS [μm]	CMS [μm]
σ(x)	15.8	60	20-40
σ(y)	15.2	60	20-40
σ(z)	91.0	100	40-60

IP resolution vs 1/pT - LHCb



σ(IP) ~ 25 μm @ 2 GeV/c

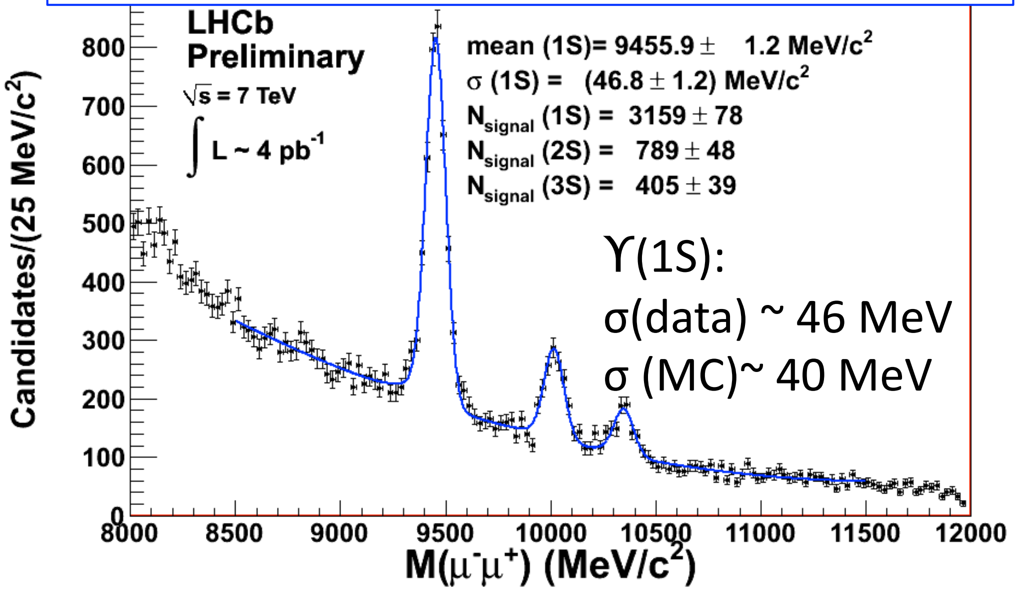
IP resolution vs pT - ATLAS



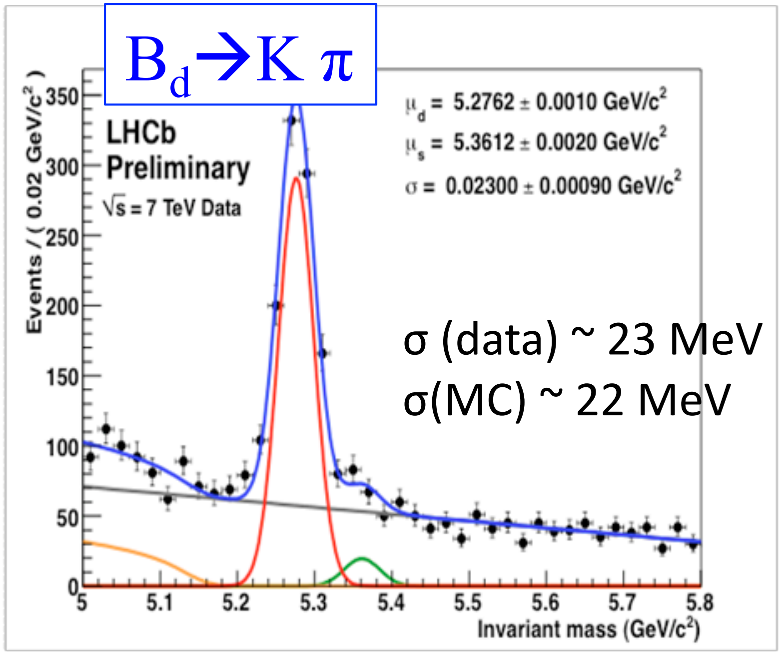
σ(IP) ~ 50 μm @ 2 GeV/c

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

The ϒ family: ϒ(1S), ϒ(2S), ϒ(3S)



$B_d \rightarrow K\,\pi$

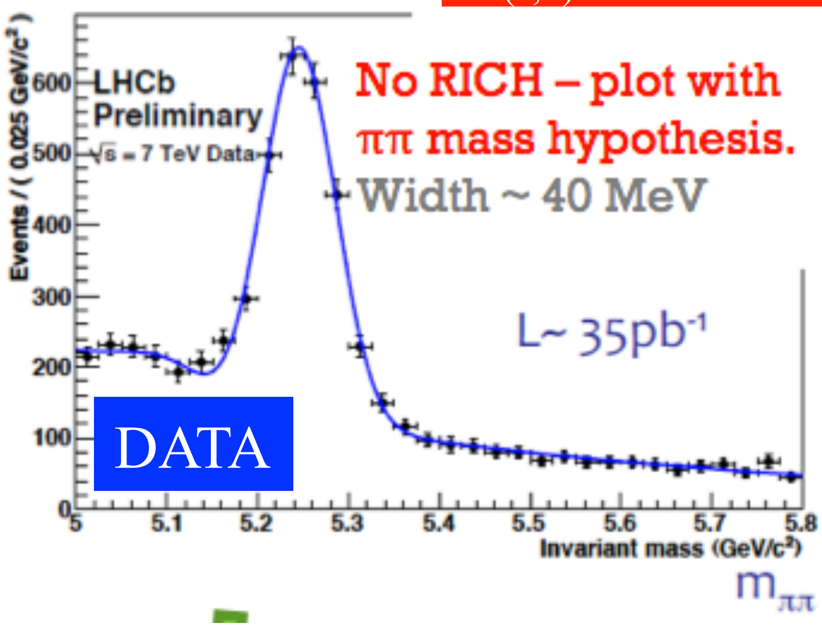


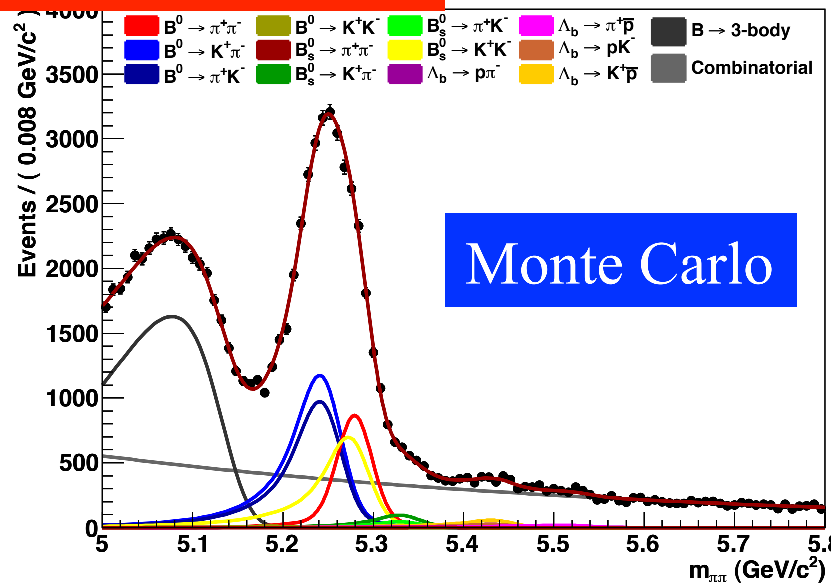
	p-resolution	Mass resolution $J/\psi \rightarrow \mu\mu$
LHCb	$\delta p/p$ = 0.4-06 %	13 MeV
CMS	$\delta pt/pt$ = 1-3 %	40 MeV
ATLAS	$\delta pt/pt$ = 5-6 %	71 MeV

key ingredients for b- [c-]physics: RICH PID

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

$B_{(s,d)}$→ hh' peak WITHOUT RICH





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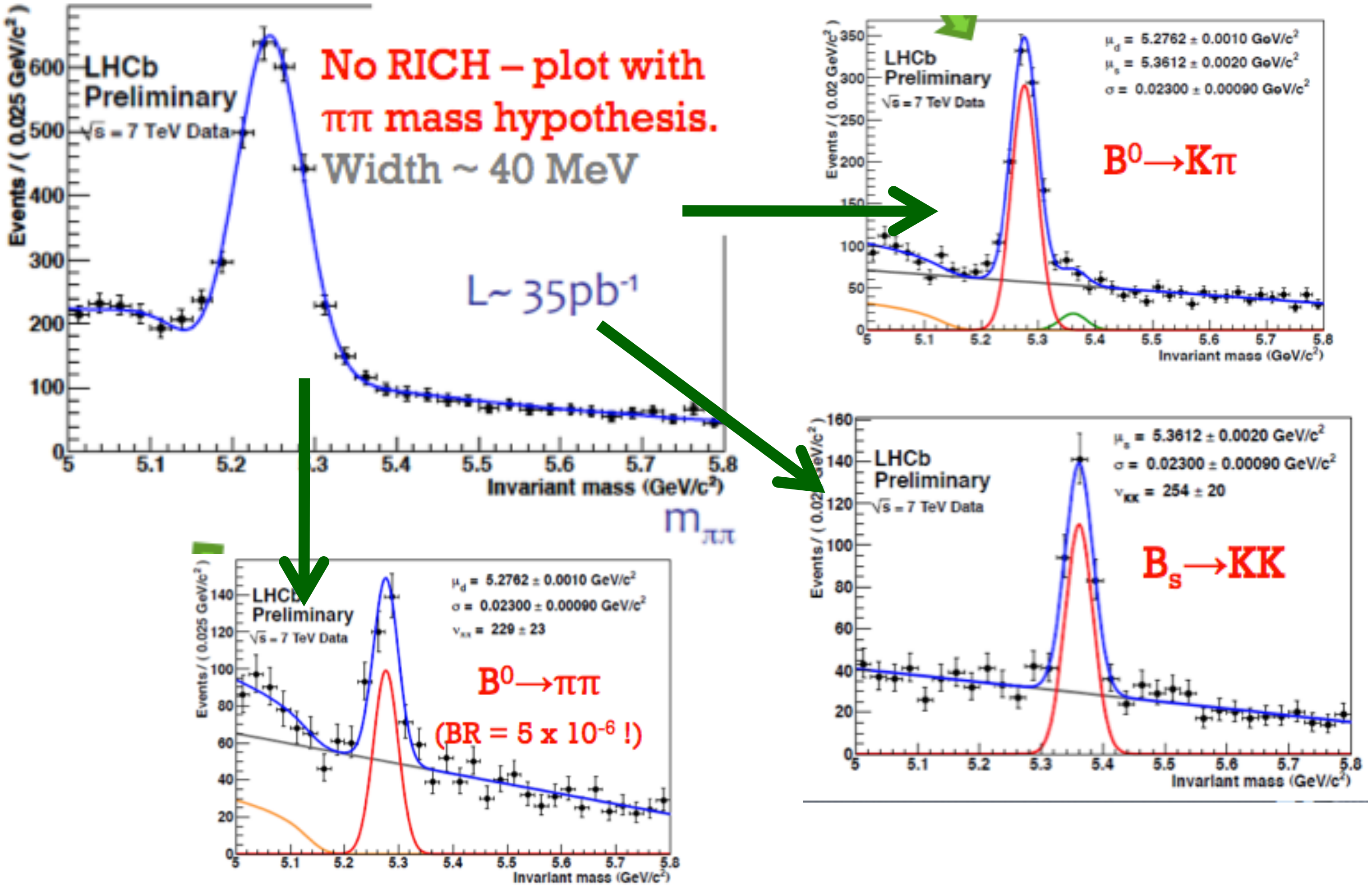
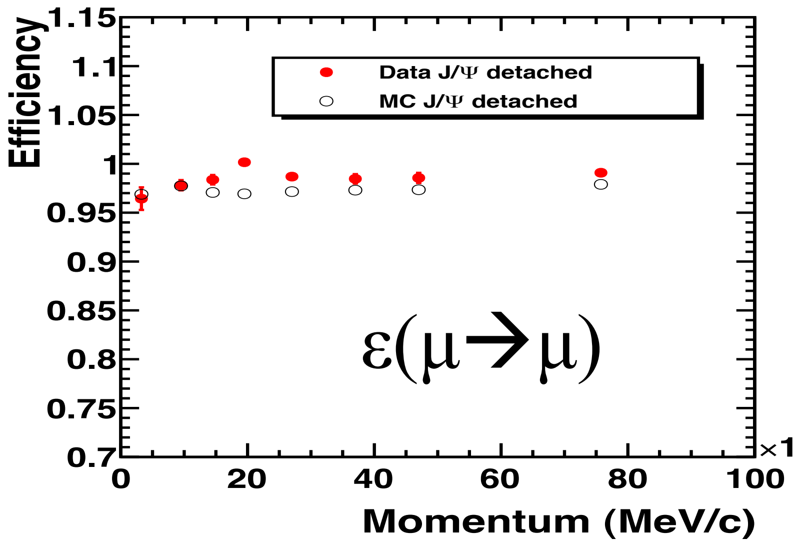
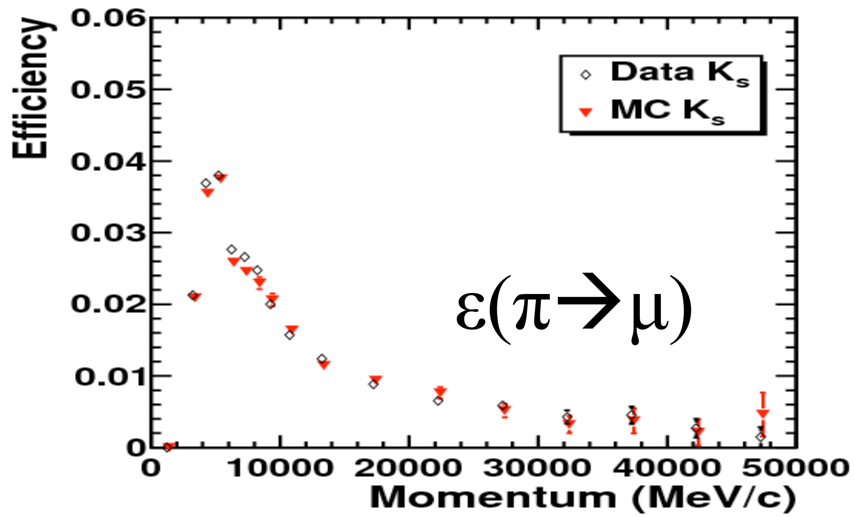


key ingredients for b- [c-]physics: MUON PID

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





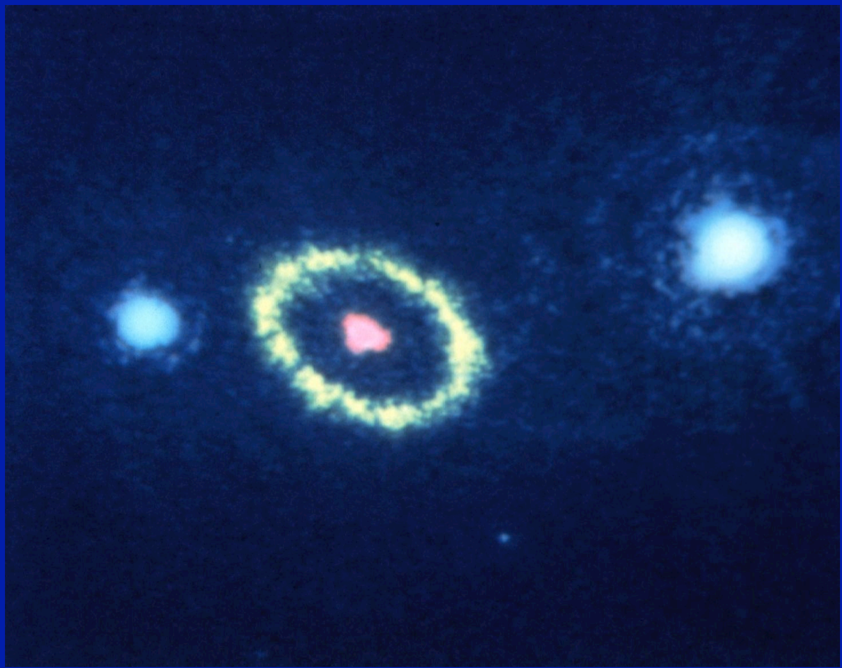
All experiments use data-driven methods to measure muonid efficiency [J/ψ with 1 μ identified] and misidentification rates [π→μ, K→ μ, proton→μ by using pure samples of Ks(ππ), φ(KK) and Λ(pπ)

LHCb: MuonID eff > 95% for misID < 1% p> 10 GeV/c

All results are in good agreement with Monte Carlo expectations

We have all the arms to attack our core physics program:

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(b)

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

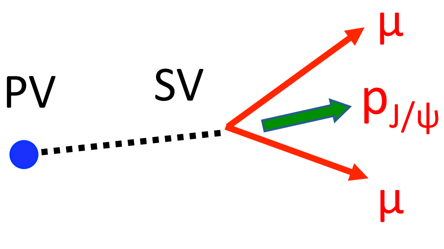
  (first two: Prompt J/ψ; last: J/ψ from b)
- Prompt J/ψ very interesting in its own right:

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

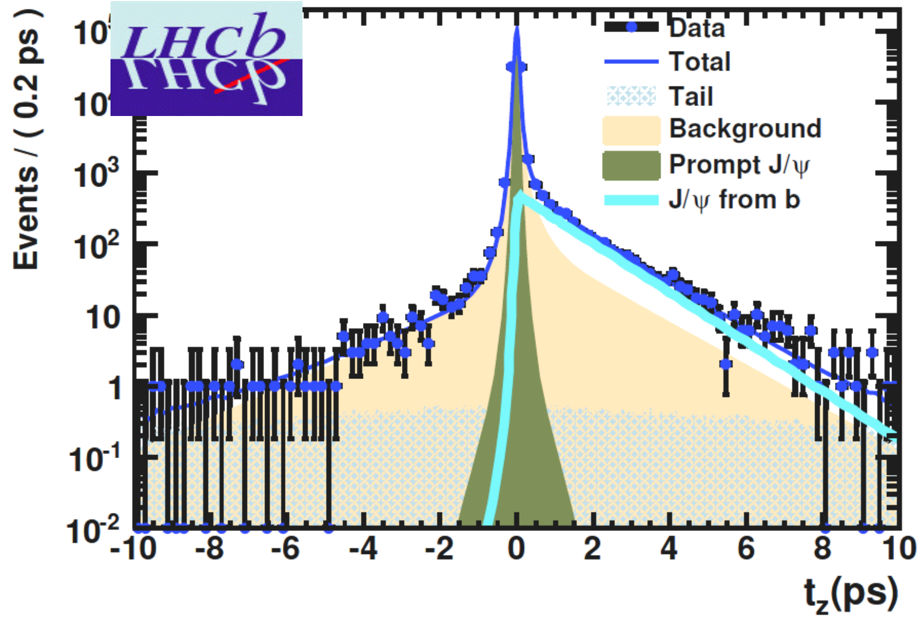
2] σ (pp→bbX) from b→ D(Kπ) μ ν X (LHCb)

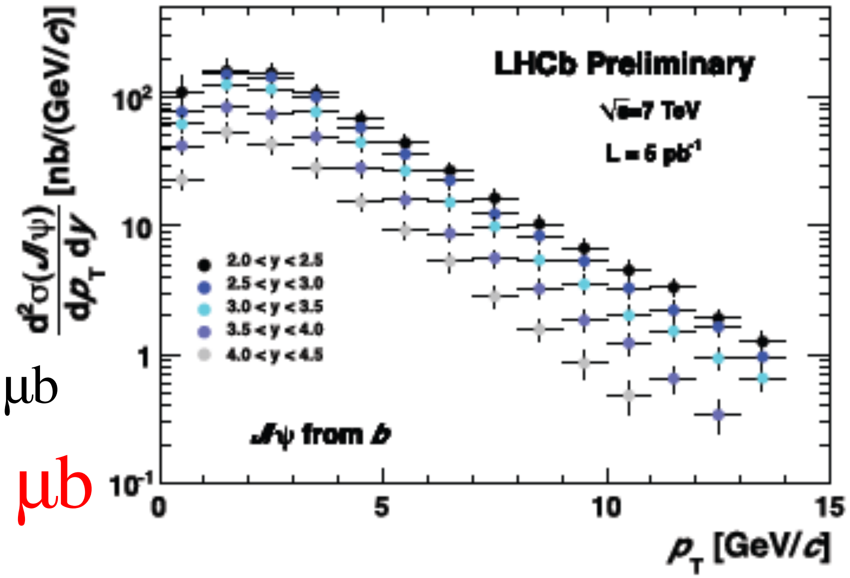
σ (pp→bbX) from b→J/ψ X

- ❑ 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



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



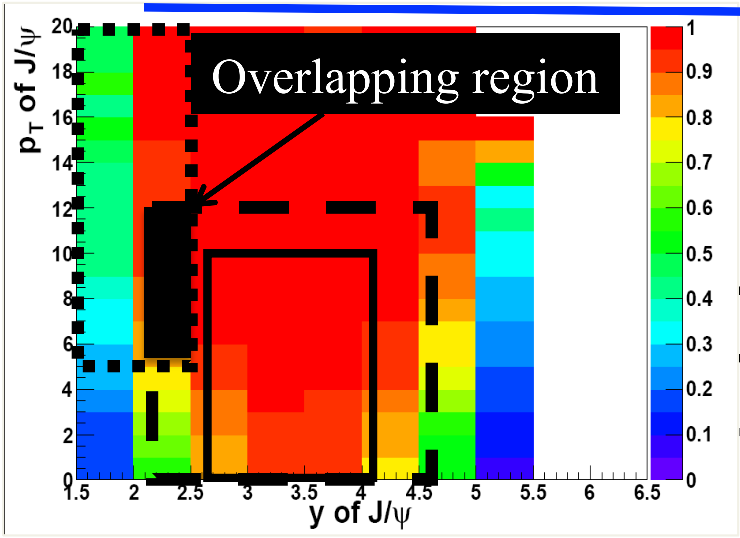


- ❑ σ(b→J/ψX) from detached component:

σ(b→J/ψX, 2<y<4.5) =1.16±0.01±0.17 μb

➔ σ(pp→bbX) = 295±4±48 μb

Prompt and detached J/ψ production: comparison LHCb-CMS



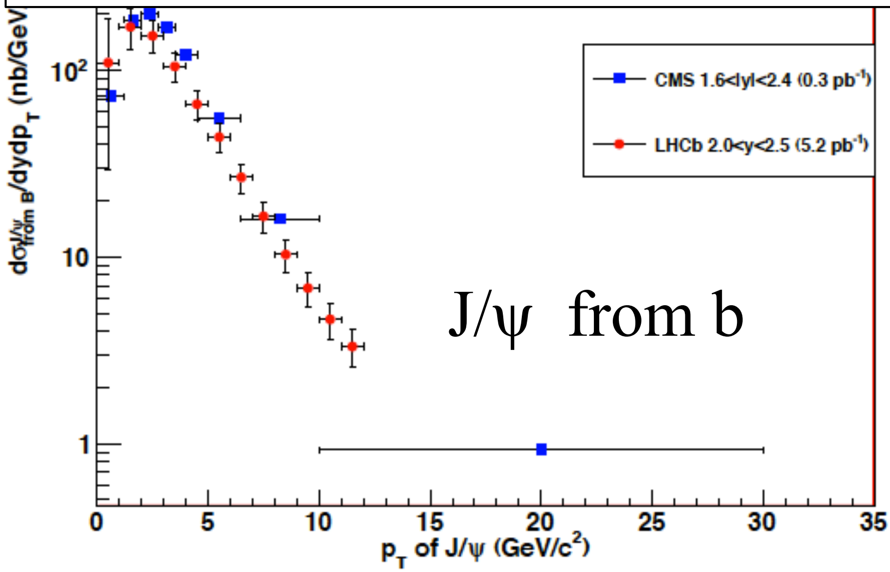
Acceptances for LHCb and ATLAS/CMS:

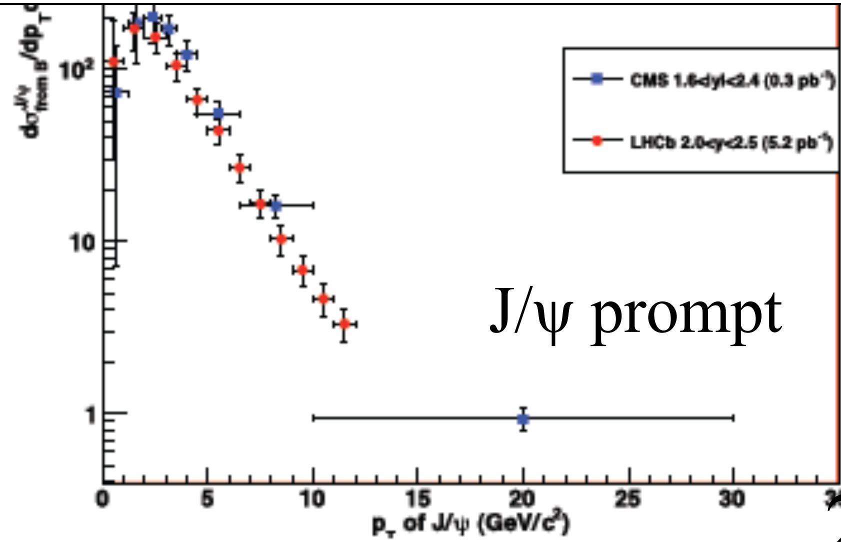
LHCb 14 nb^{-1} (ICHEP10)

LHCb 5 pb^{-1} (today), 35 pb^{-1} analysis ongoing

ATLAS/CMS

$d^2\sigma/dyd(p_T)$ vs p_T: Comparison LHCb-CMS in the overlapping region

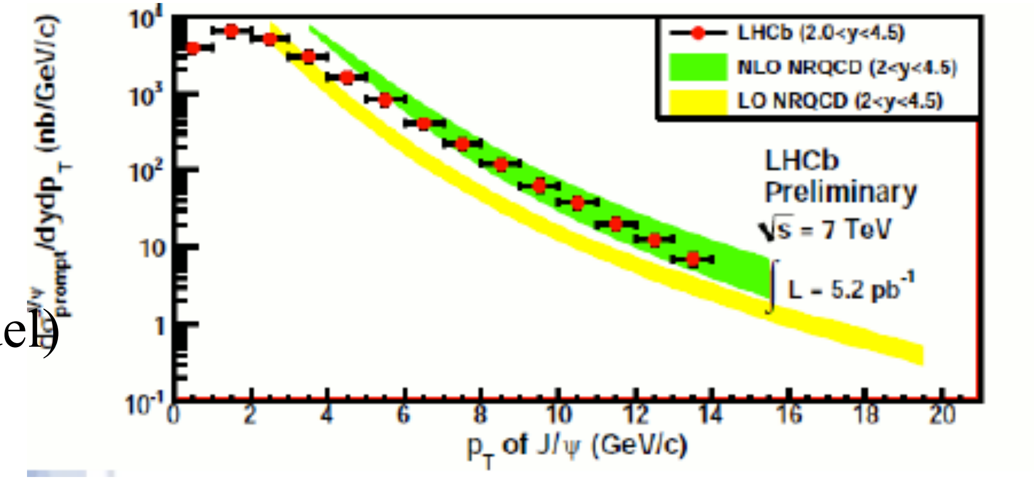




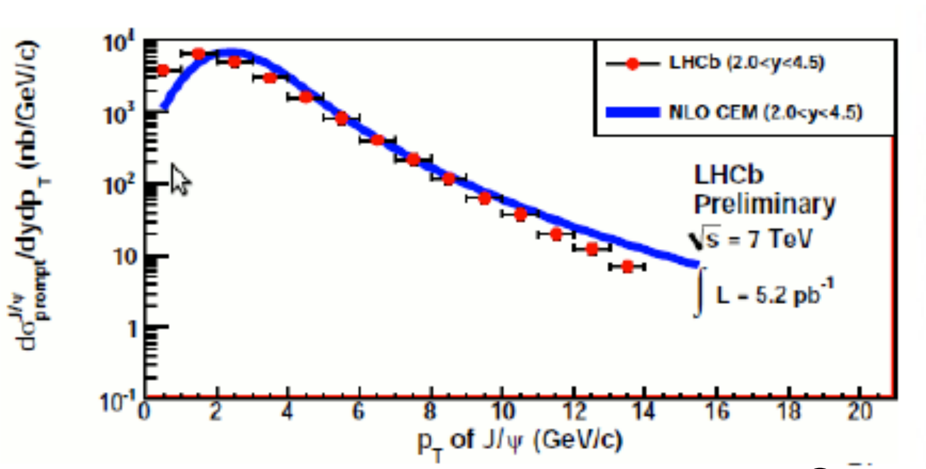
Prompt J/ψ production: comparison with the theory

Comparison with three models:

1) LO and NLO NRQCD
(Non Relativistic QCD summing color Singlet and color Octet)
2) NLO CEM (Color Evaporation Model)



The NLO NRQCD model seems to fit data reasonably well in the high p_T region, though the uncertainty is much larger and there is a clear problem at low p_T



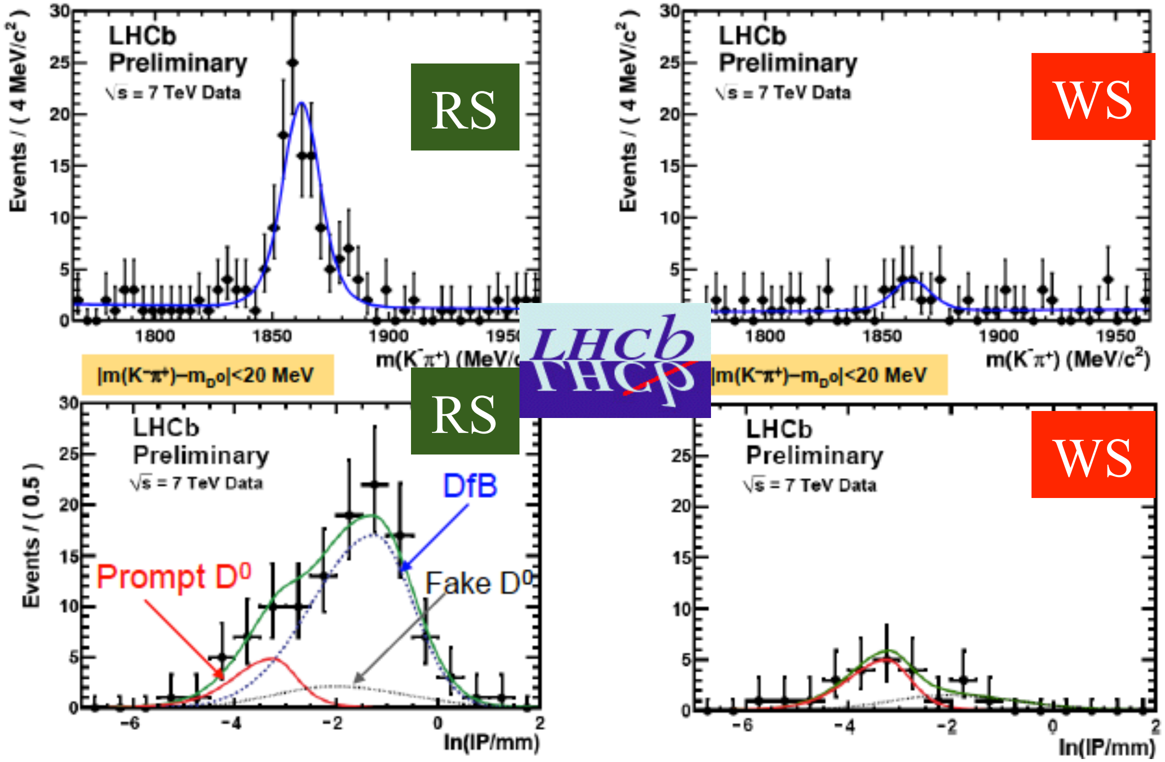
σ (pp→bbX) from b→D(Kπ)μ ν X

Use b→D^0(Kπ) μν X decay (BR=6.82 ± 0.35 %)

Signal: measure right-sign D^0μ 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:



Pro: high statistics

Cons: dependence on the value of the fragmentation fractions.

σ (pp→bbX) from b→D(Kπ)μX

Use b→D^0(Kπ) μν X decay (BR=6.82 ± 0.35 %)

Signal: measure right-sign D^0μ combinations, where D^0→ K π uses tracks forming a displaced vertex with respect to the primary one

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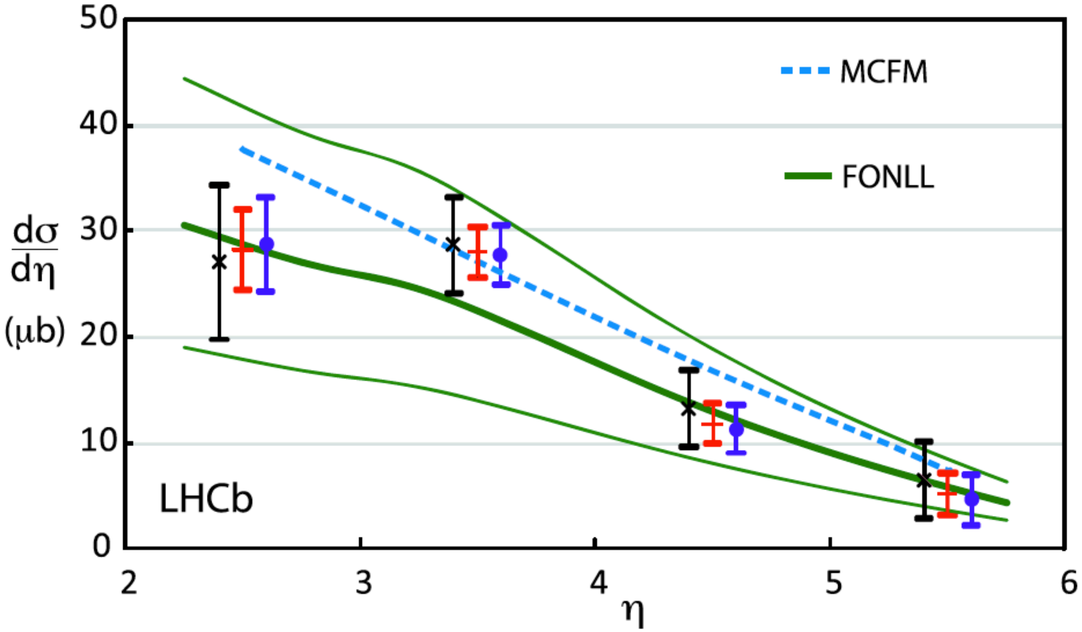


Results:

σ(pp→bbX in 2<η<6) = 75.3±5.4±13.0 μb

In 4π:

σ(pp→bbX) = 284±20±49 μb

Physics Letters B 694 (2010) 209.
(Based on 15 nb^{-1} of data; updated measurement with 35 pb^{-1} ongoing)

Theory I (MCFM): Nason, Dawson, Ellis
Theory II (FONLL): Nason, Frixion, Mangano, Ridolfi

averaging $\sigma(pp \rightarrow bbX)$ 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

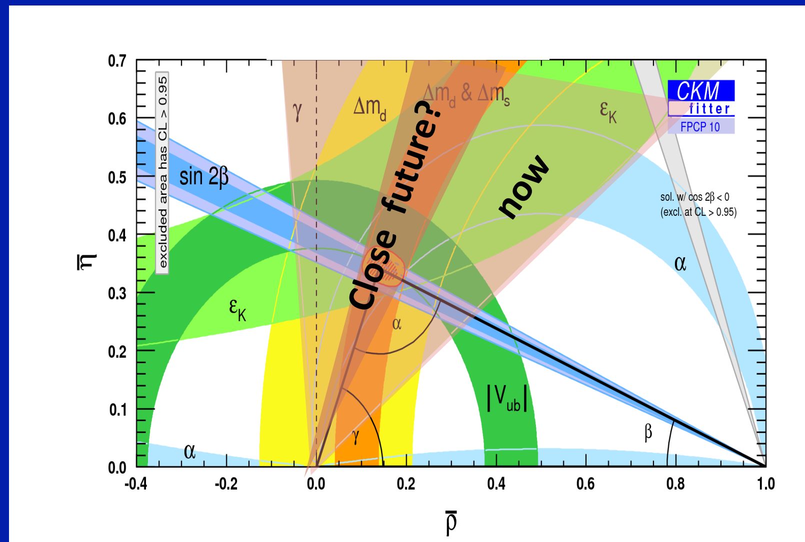
Theory I: Nason, Dawson, Ellis

Theory II: Nason, Frixion, Mangano, Ridolfi

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

4. Prospects in flavour physics @ LHC

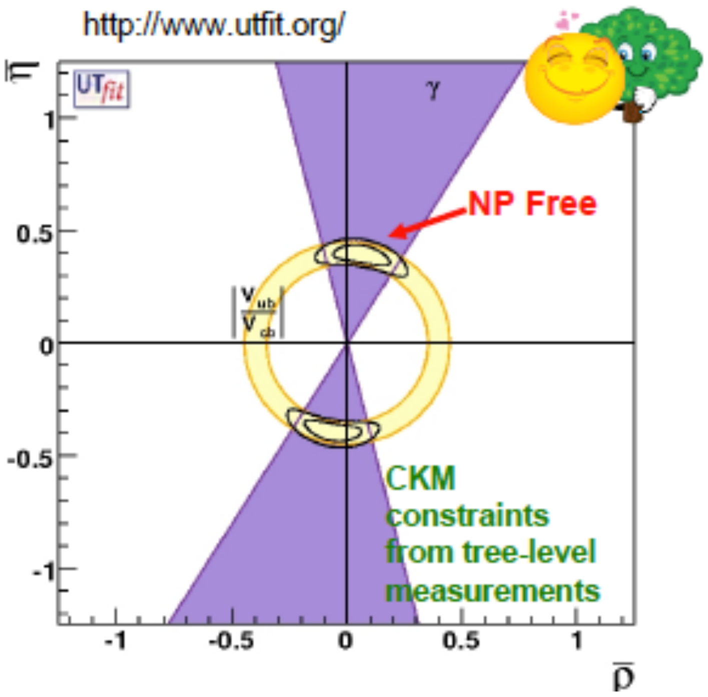
Unitarity Triangle from tree-level processes



… 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.

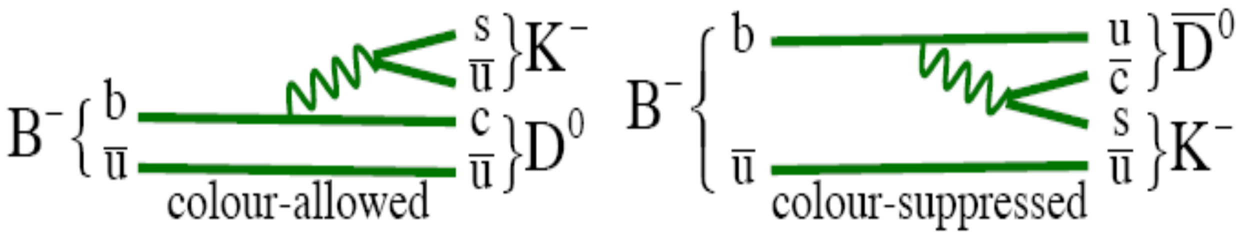
Present accuracy by direct measurement of γ from tree process B→D K is still poor:

$\gamma\,(WA) = (70^{+21}_{-25})^\circ$

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 eigenstates
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!

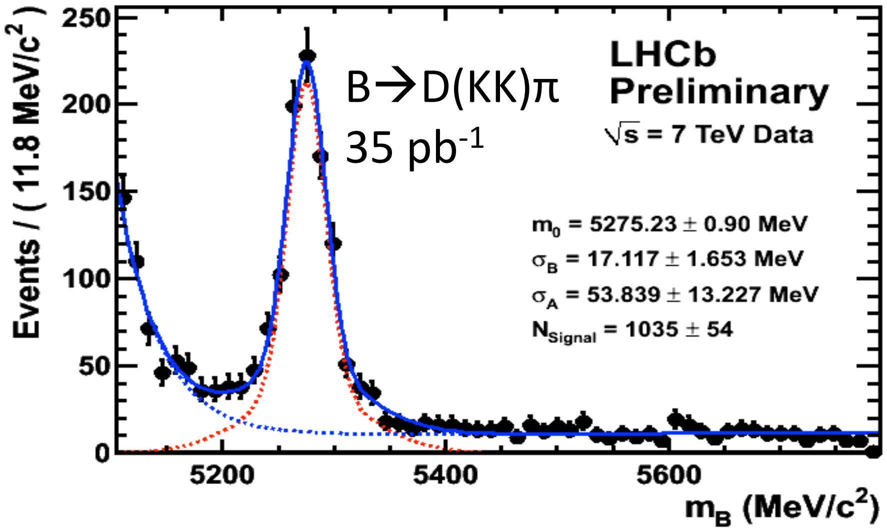
Crucial role of hadronic trigger and π/K separation in this analysis

Measuring γ @ LHCb

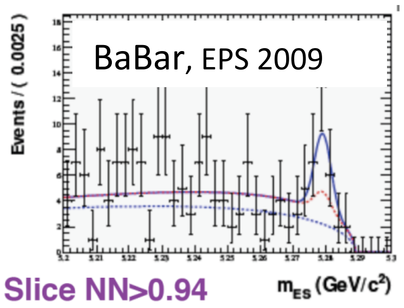
~ 1 fb^{-1} already offers possibilities to improve on knowledge from B factories

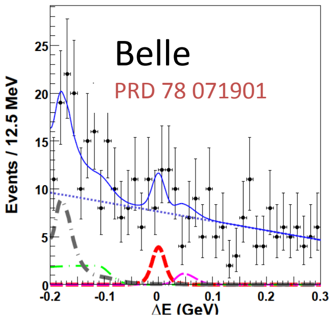
LHCb expected yields at 7 TeV, 1 fb^{-1}
Assuming r_B~0.1 (0.4) for $B^{\pm}$ (B^0)

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
$\sigma\gamma^{LHCb}$ ~ 10 ° with 1 fb^{-1} [end 2011]

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

- The observable weak phase is: $\Phi = \Phi^{SM} + \Phi^{NP}$

- In the Standard Model is small…..

$$\Phi^{SM}(B_s \to J/\psi\, \phi) = 2\arg(V_{ts}^* V_{tb}) - 2\arg(V_{cs}^* V_{cb}) = -2\beta_s \cong o(\lambda^2)$$

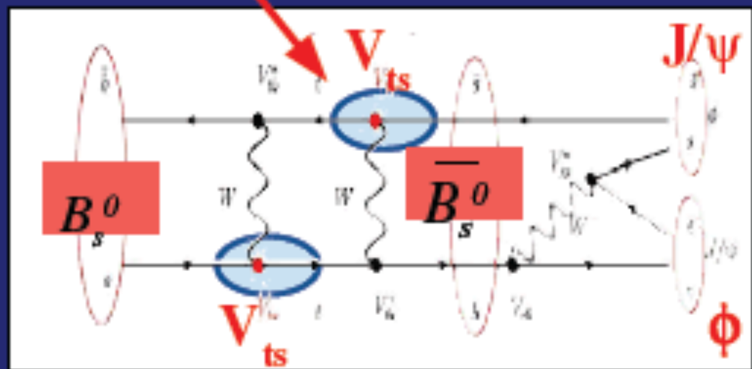
$$V_{CKM} = \begin{pmatrix} 1 - \frac{1}{2}\lambda^2 - \frac{1}{8}\lambda^4 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda + \frac{1}{2}A^2\lambda^5[1-2(\rho+i\eta)] & 1 - \frac{1}{2}\lambda^2 - \frac{1}{8}\lambda^4(1+4A^2) & A\lambda^2 \\ A\lambda^3[1-(1-\frac{1}{2}\lambda^2)(\rho+i\eta)] & -A\lambda^2 + \frac{1}{2}A\lambda^4[1-2(\rho+i\eta)] & 1 - \frac{1}{2}A^2\lambda^4 \end{pmatrix}$$

…. and well known:

$$\Phi^{SM}(B_s \to J/\psi\, \phi) = -2\beta_s = -0.0368 \pm 0.0017 \text{ (CKMFitter, summer07)}$$

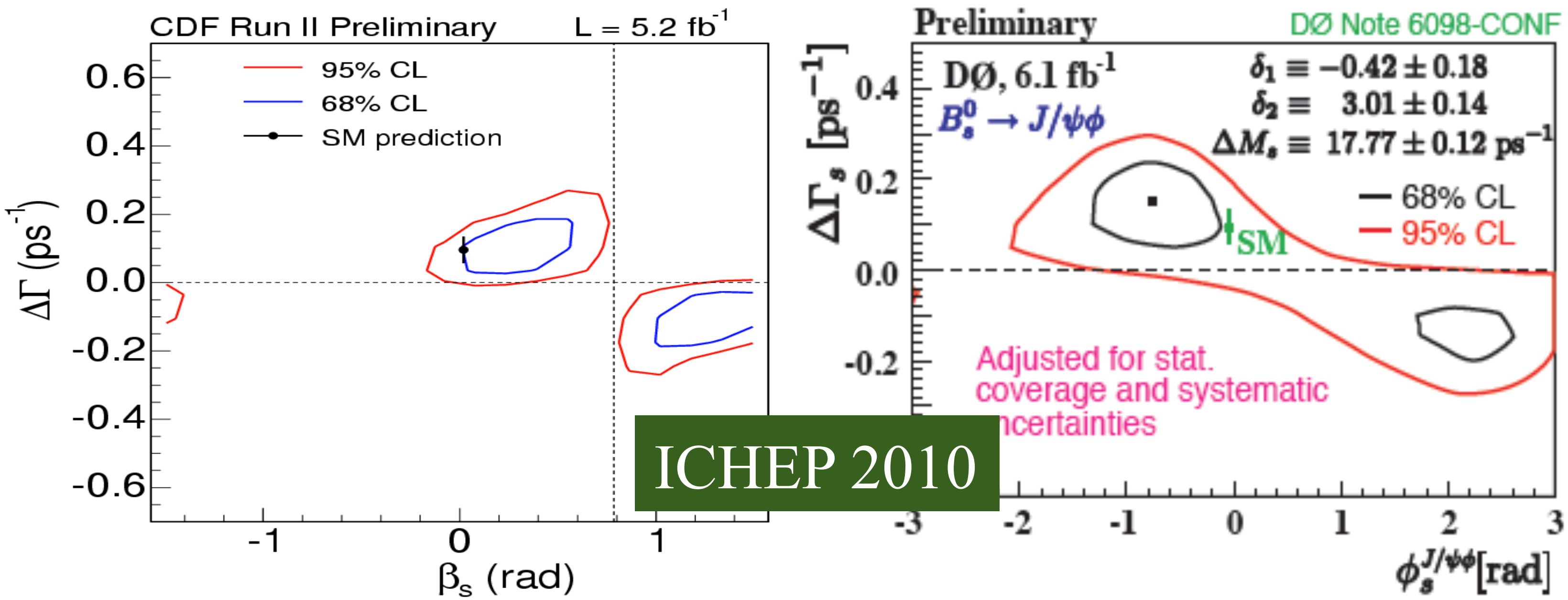
- In presence of New Physics:

$$\Phi(B_s \to J/\psi\, \phi) = -2\beta_s + \Phi^{NP}_M$$

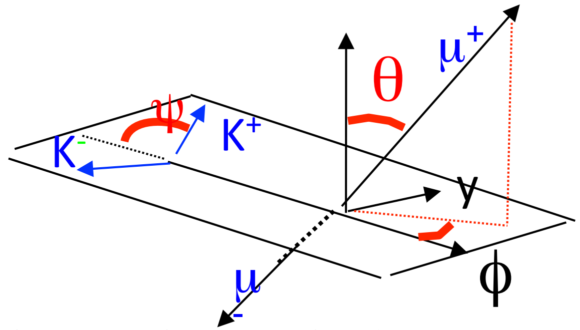


CPV in B_s mixing:
…the (still) unresolved saga…

- 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]



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



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

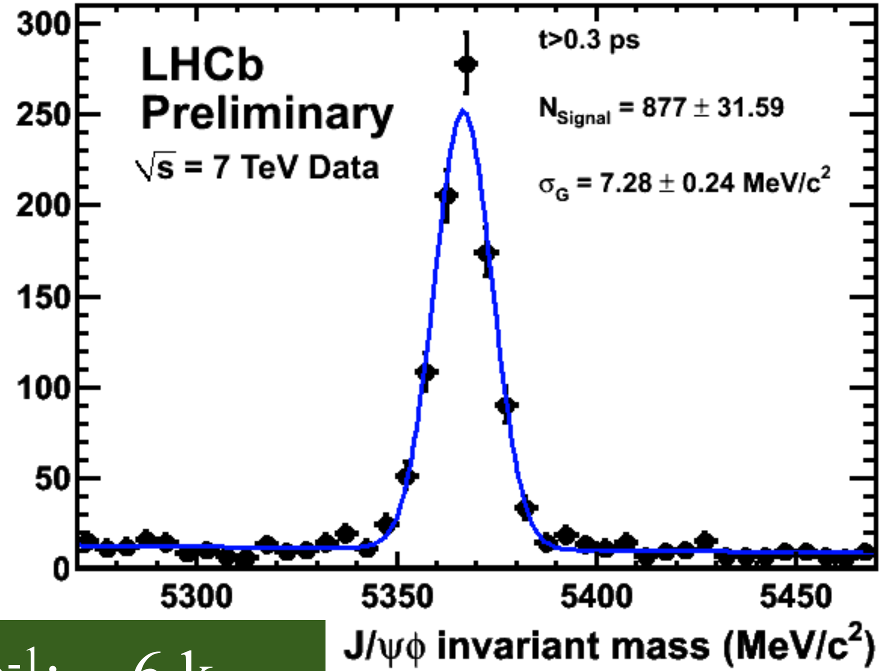
… and the extraction of the phase experimentally very challenging:

Most critical parameters are mistag and proper time resolution

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

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

- Selection is cut based, optimized for $S/\sqrt{S+B}$
- Unbiased selection
  - No cuts on IP, decay length, etc
  - Significant prompt background $B/S \sim 3$
  - Yield $\sim$ 30 k event per fb^{-1}
- Rely on kinematics & PIDs



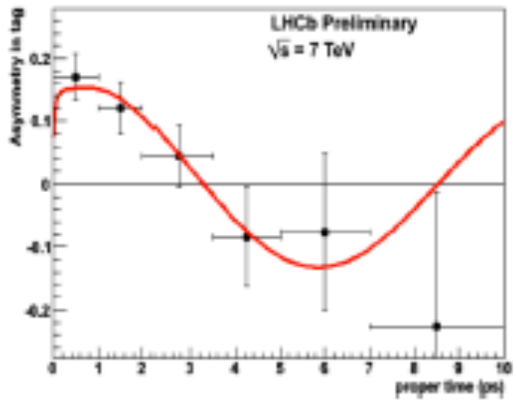
LHCb: yield for 200 pb^{-1}: ~ 6 k
[comparable to CDF @ 5.2 fb^{-1}]

LHCb vs CDF: x30 in statistics:
x3 for the bb cross section
x10 for trigger-acceptance.

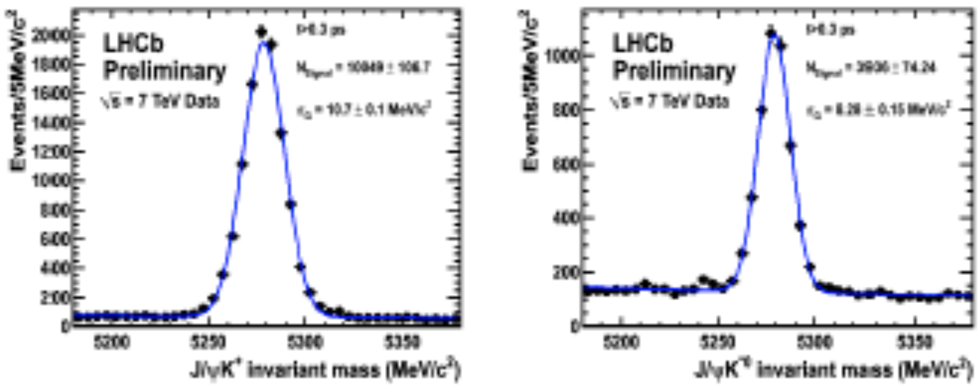
B_s mixing phase in $B_s \rightarrow J/\psi\ \varphi$: tagging

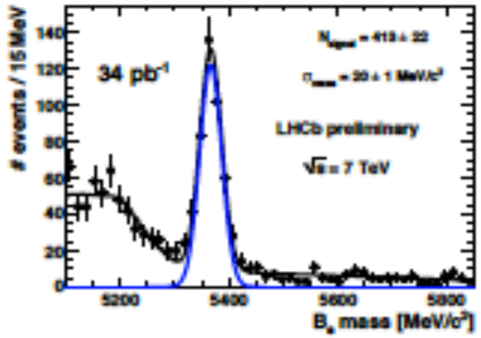
- Tagging optimization in $B^0 \rightarrow D^{*-}\mu^+\nu_\mu$
    - Fit for time evolution
      $\rightarrow$ extract mistag rate from oscillation ($\varepsilon_{tag}(1-2\omega)^2 \sim 60\%$ of MC expectations)
- Opposite side tagging's calibration:
    - Count the right/wrong tagged events in $B^+ \rightarrow J/\psi K^+$
    - Fit for time evolution in $B^0 \rightarrow J/\psi K^{*0}$
      $\rightarrow$ extract mistag rate from oscillation
- Same side tagging's calibration:
    - Fit for time evolution in $B_s^0 \rightarrow D_s^- \pi^+$
      $\rightarrow$ extract mistag rate from oscillation

$\mathcal{L}_{int} \sim 2\,pb^{-1}$



$\mathcal{L}_{int} \sim 33\,pb^{-1}$

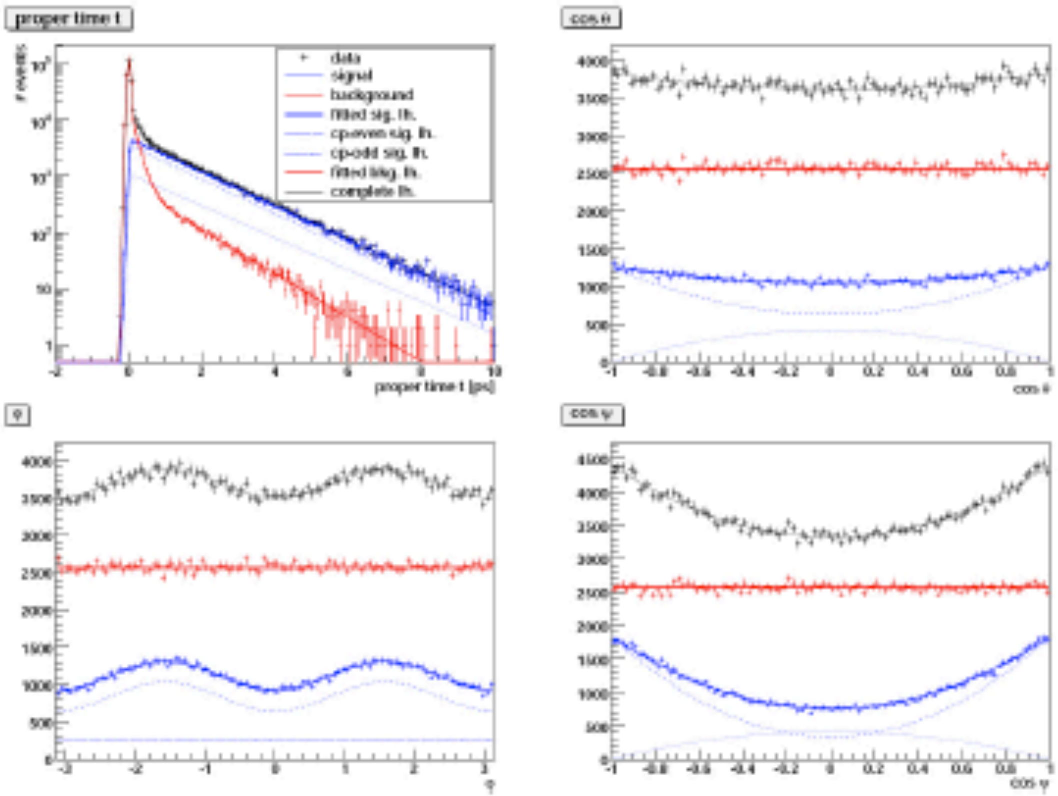




B_s mixing phase in $B_s \rightarrow J/\psi\ \varphi$: fit

- Unbinned likelihood :
  $\mathcal{L} = \prod_e^N \mathcal{P}(X_e, \lambda_{phys}, \lambda_{det})$
  - X_e : proper time t, decay angles Ω, B_s^0 mass and initial B_s^0 flavor
  - $\lambda_{phys} = \{\phi_s^{J/\psi\phi}, \Gamma_s, \Delta\Gamma_s, R_\perp, R_0, \delta_\perp, \delta_\parallel, \Delta m_s\}$
  - λ_{det} mass resolution σ_m, proper time resolution σ_t, mistag rate ω, background properties
  - Angular distortion corrections

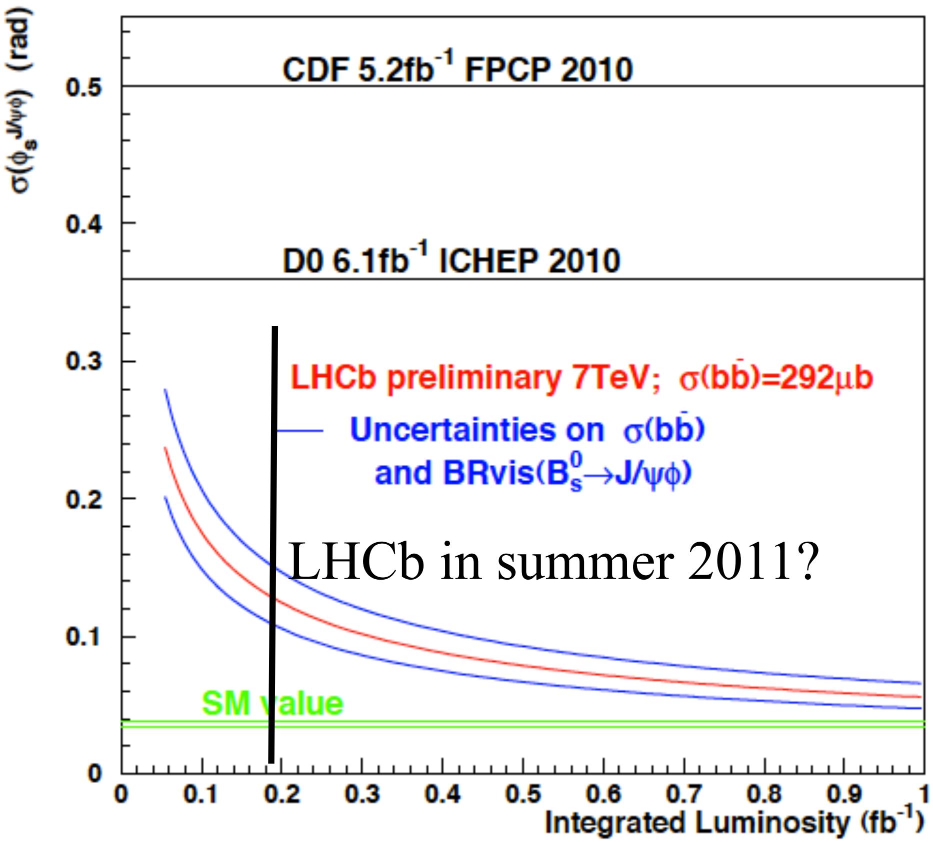
All details in arXiv: 0912.4175



LHCb toy MC, LHCb-PUB-2009-028

$$\sigma_{stat}(\phi_s^{J/\psi\phi}) \sim 0.07 \text{ rad for } 1\ \text{fb}^{-1}$$

LHCb: β_s sensitivity



<u>Reality check-list:</u>

- 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:
  under calibration

All looks very promising

Expect world best result in 2011 from LHCb in 2011

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

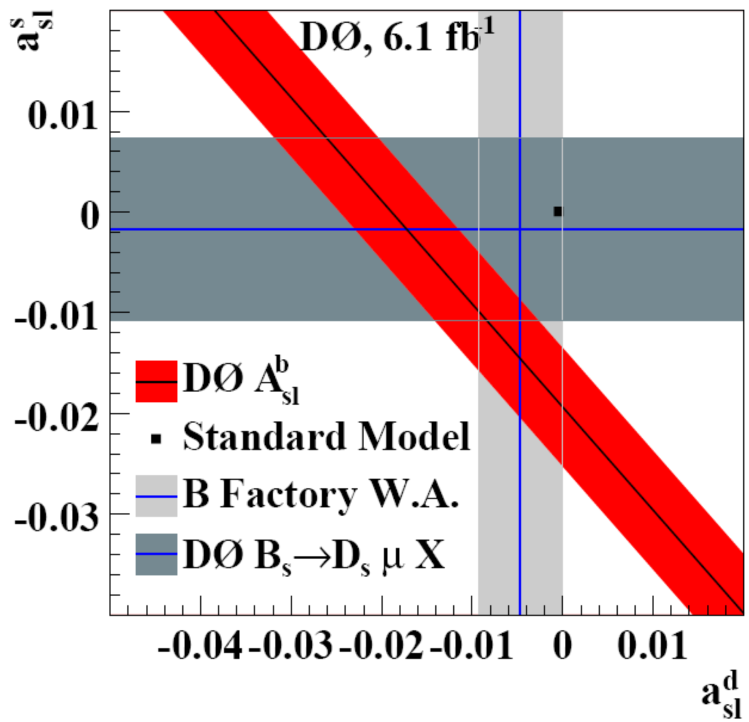
If New Physics enhances CP-violation in $B^0_S \to J/\psi\Phi$, it will likely also dominate over the (negligible) SM CP-violation predicted in the semi-leptonic asymmetry.

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} :

$$A_b = (0.493 \pm 0.043)\, a^s_{fs} + (0.506 \pm 0.043)\, a^d_{fs}$$

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



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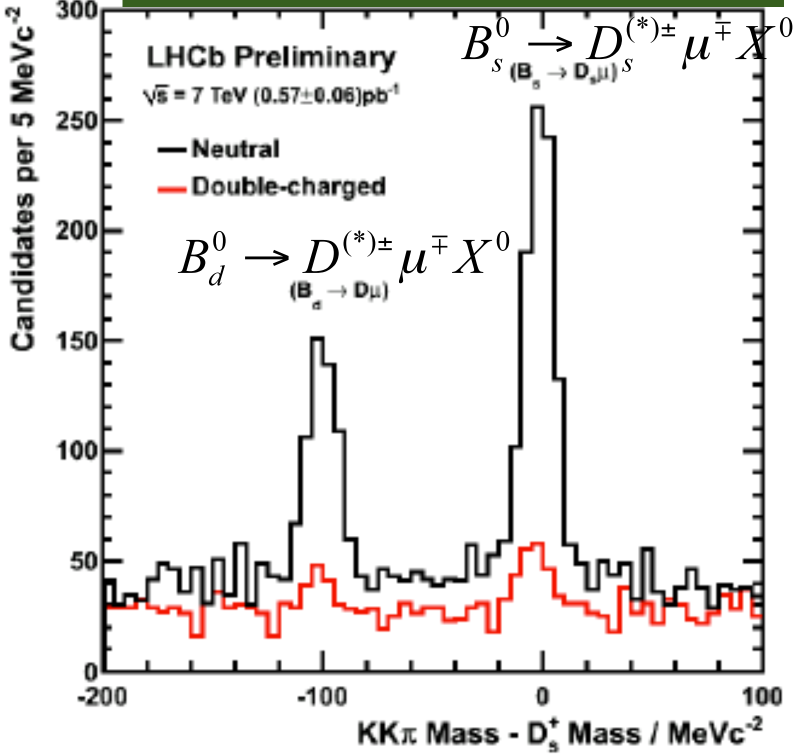
Inclusive method at LHCb is difficult due to the $\sim 10^{-2}$ production asymmetry in pp collisions and control of detector asymmetry.

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.

First signals from 570 nb^{-1}



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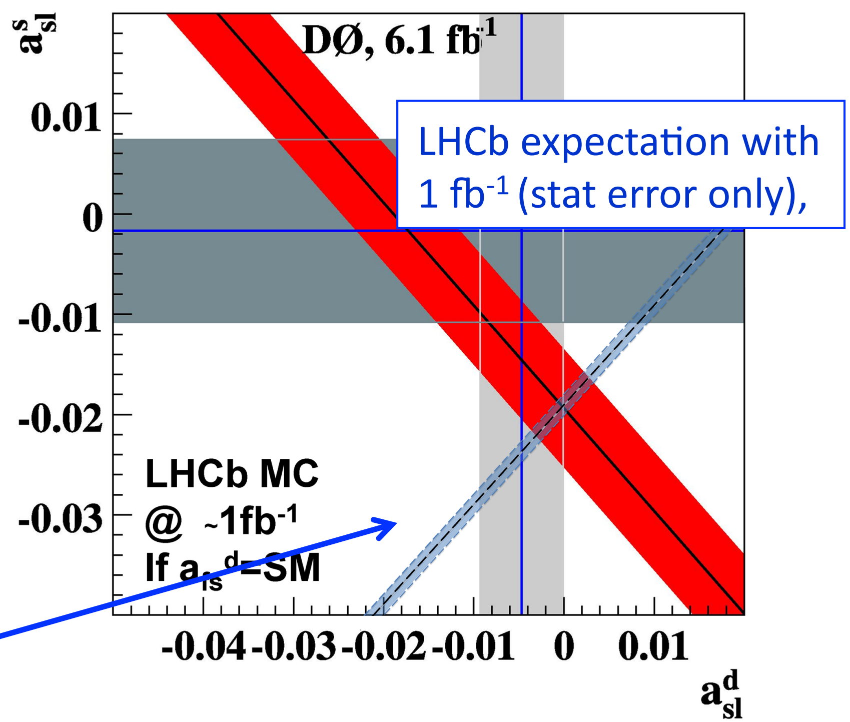
→ difference suppresses production asymmetry

→ same final state suppresses detector biases.

This method provides orthogonal constraint to D0 di-leptons.

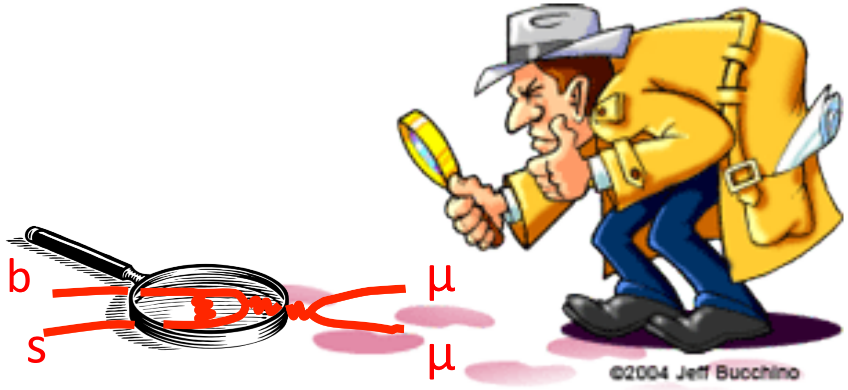


Rare Decays @ LHC

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

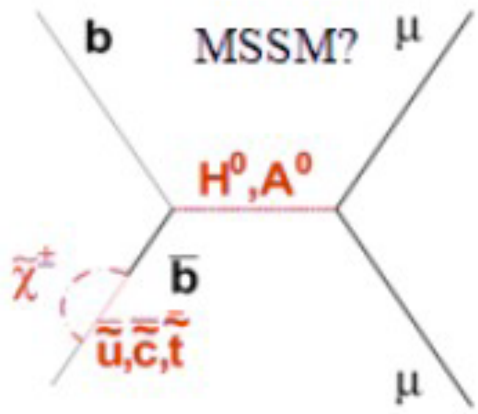
New physics modifies the Wilson coefficients affecting observable quantities as BRs [ex:B_s→μμ] (C_s, C_p), Angular distributions [B_d→K*μμ] (C_9,C_{10}, C_7) and Polarization [B_s→φγ] (C_7).

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

- Highly suppressed in SM:

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

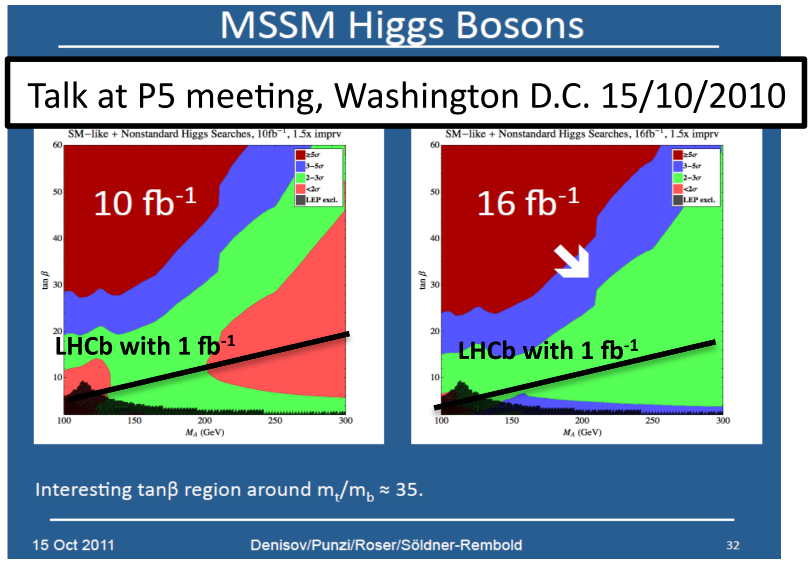
BR =[3.6 ± 0.2] 10^{-9} [Buras et al., arXiv: 0904.4917v1

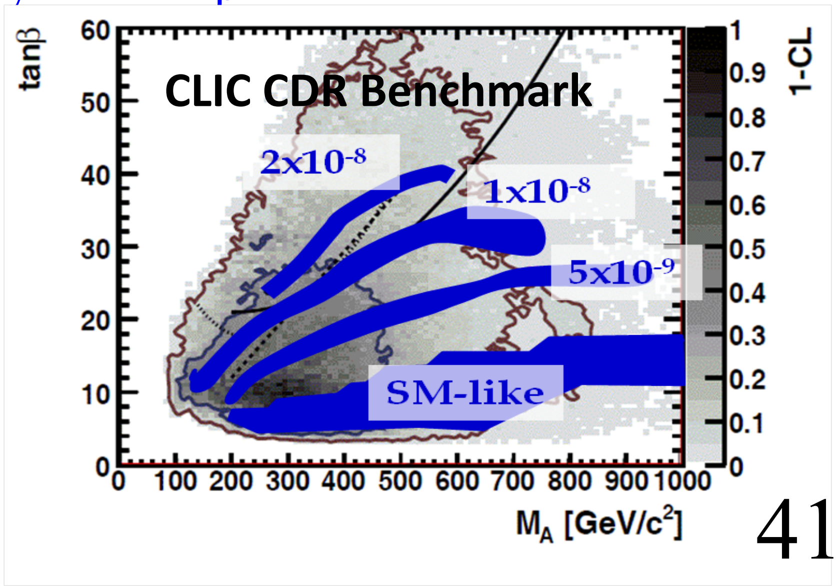


- Test the (pseudo-) scalar penguins:

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

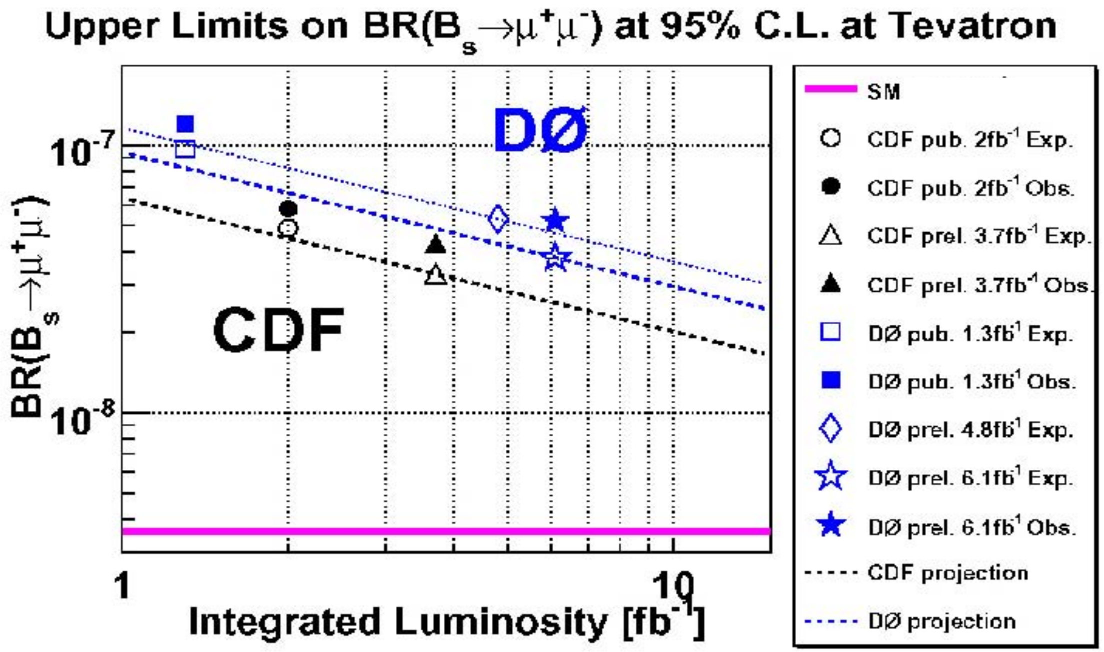
-eg: in 2HDM-II BR~$\tan^4\beta$, is MSSM with R-parity BR~$\tan^6\beta$





$B_s \rightarrow \mu\mu$: current results from Tevatron

- Limit from Tevatron at 90% CL:
  - CDF (~3.7 fb^{-1}) < **36×10^{-9} (@90% CL)** ~ 11 times higher than SM!
  - D0 (~6.1 fb^{-1}) < **42×10^{-9} (@90% CL)**



  - Observed limit at Tevatron, worse than expected… however it has always been like this!

$B_s \to \mu\mu$ @ LHCb

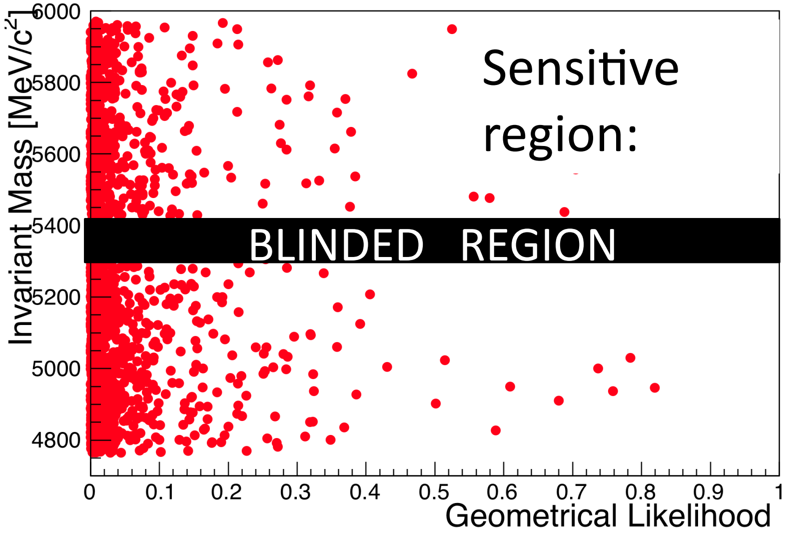
LHCb approach is philosophically similar to Tevatron's: loose selection and then construction of global likelihood, which is built from:

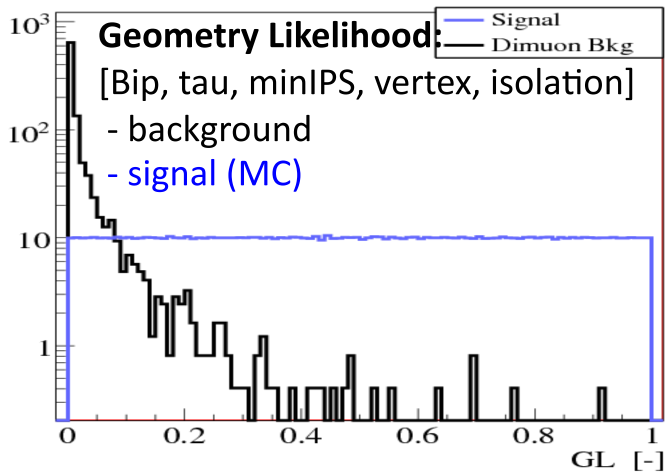
Mass:

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





$B_s \rightarrow \mu\mu$ @ 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:

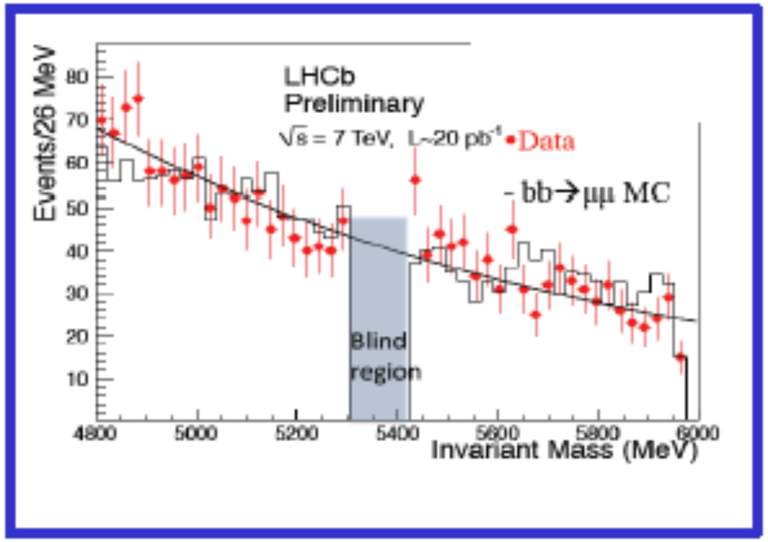
Geometrical Likelihood

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

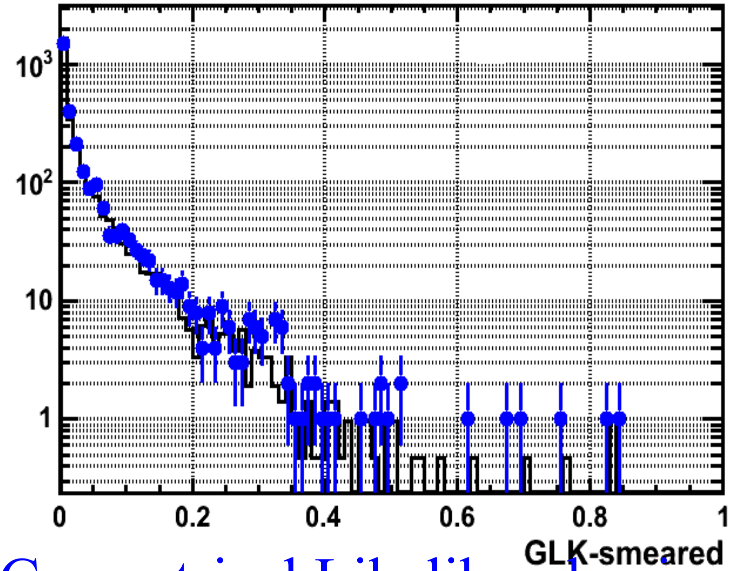
Observation then turned into limit or BR measurement after comparing with known control channel, eg. $B^+ \rightarrow J/\psi K^+$ [knowledge of f_d/f_s required, LHCb method in arXiv: 1004.3982v2] or $B_s \rightarrow J/\psi\phi$ [no problem with fragmentation fractions but larger error in the BR, expected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

$B_s \rightarrow \mu\mu$ @ LHCb: calibration of Likelihoods

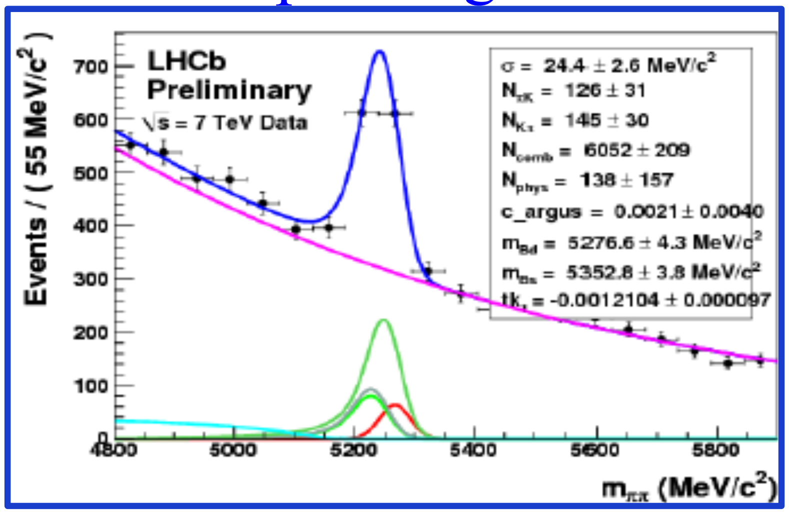
Mass pdf - background



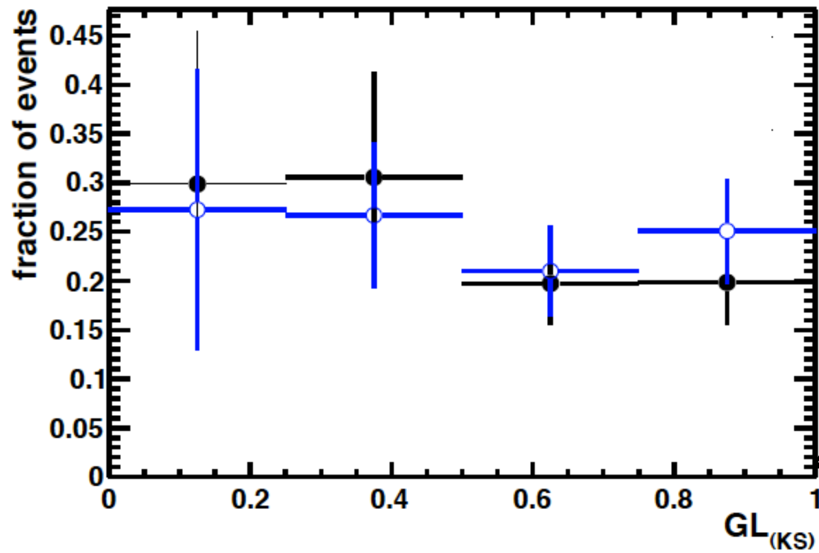
Geometrical Likelihood - background



Mass pdf - signal



Geometrical Likelihood - signal



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

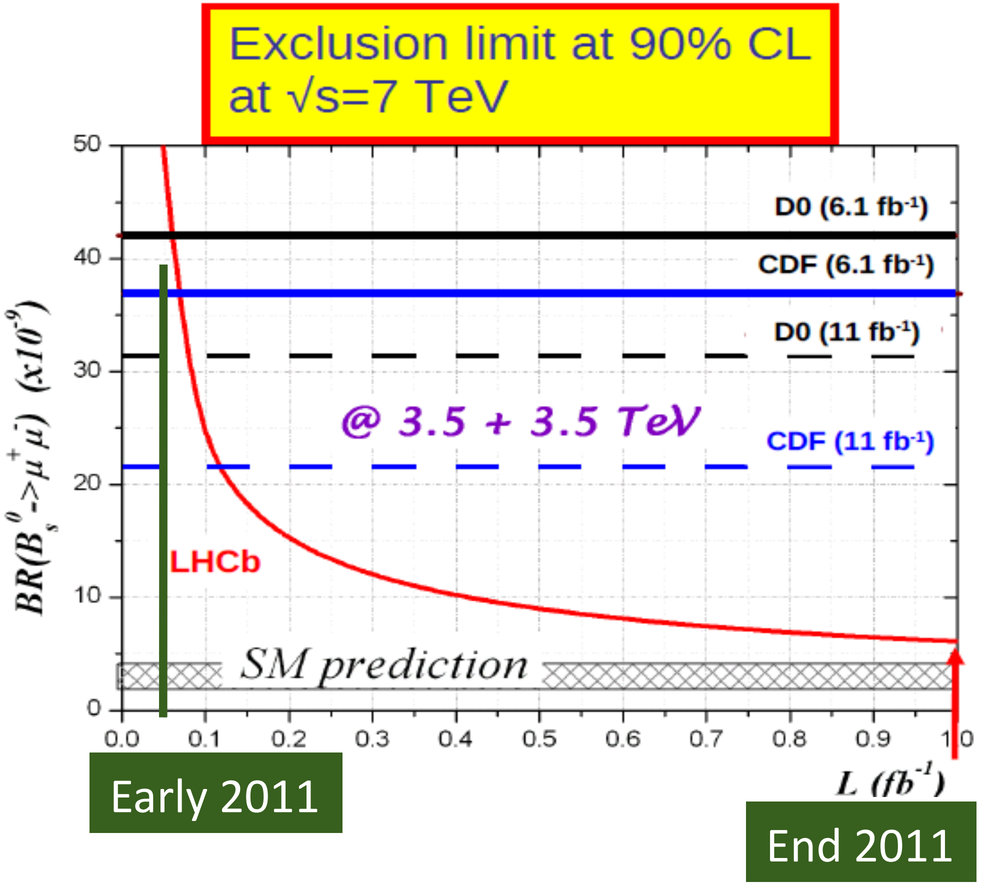
In absence of signal, 90% C.L. limits:

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]

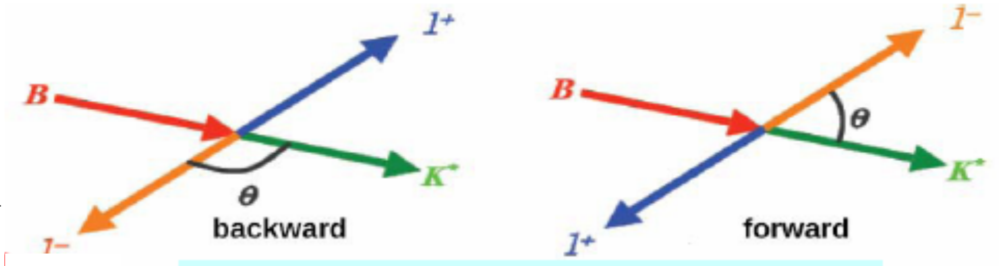
BR<1.6 x 10^{-8} @ 1 fb^{-1}, 14 TeV
[CMS-PAS-BPH-07-001 (2009)]



First LHCb result will be presented in La Thuile in ~ 1 month time

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

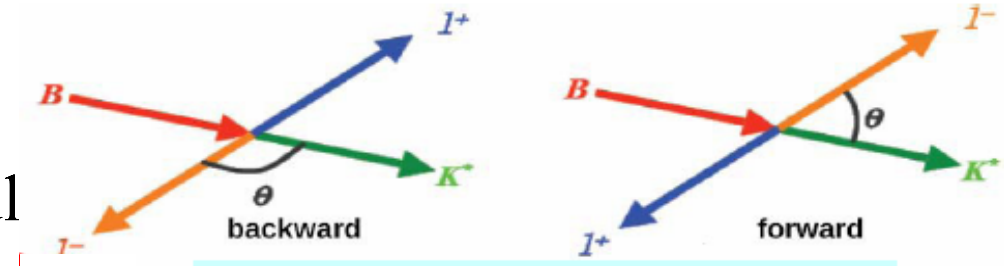
q^2 = dilepton invariant mass

- C_7: γ penguin [dipole] ⇔ b→sγ
- 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 $B \rightarrow K^{(*)} l^+ l^-$

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



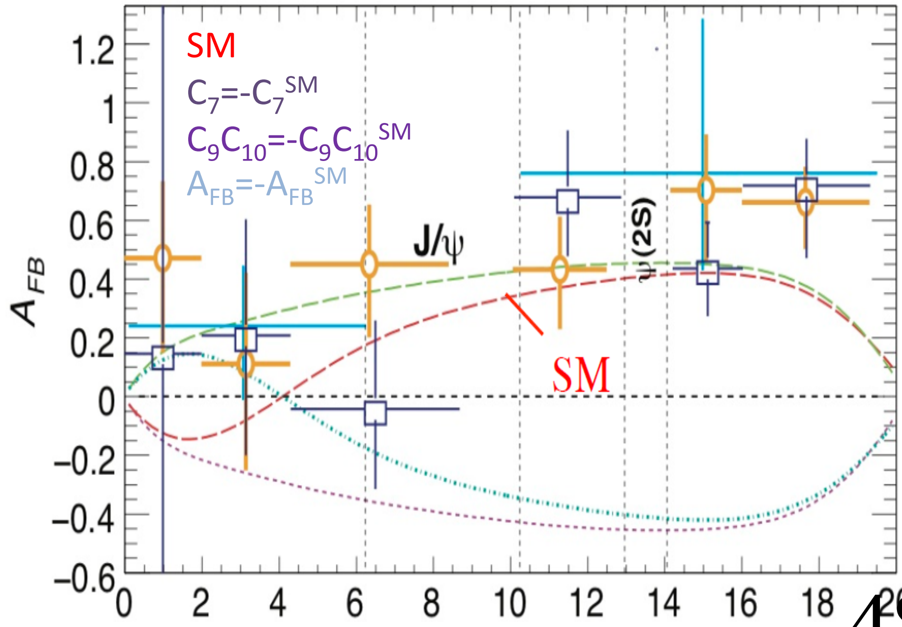
$$A_{FB}\left(s = m^2_{\mu^+\mu^-}\right) = \frac{N_F - N_B}{N_F + N_B}$$

Early results are showing intriguing hints….

250 K* ll
[80% of data]

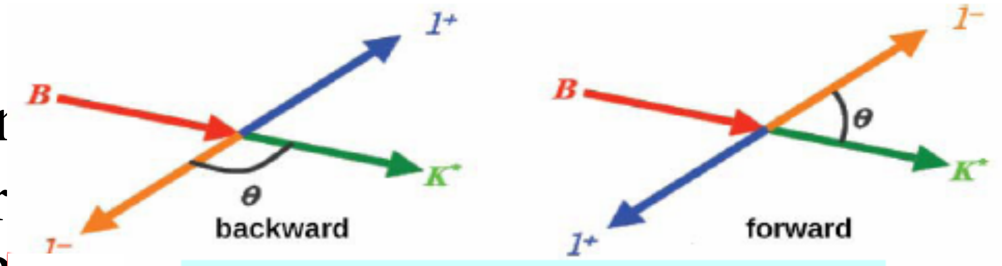
100 K* ll
[75% of data

100 K*ll
[4.4 fb-1]



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

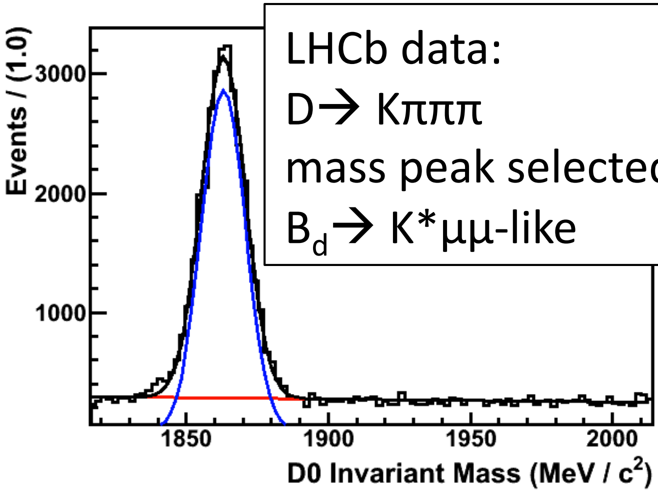
Forward backward asymmetry in
$B^0 \to K^* l^+ l^-$ is a extremely power
observable for testing SM vs NP



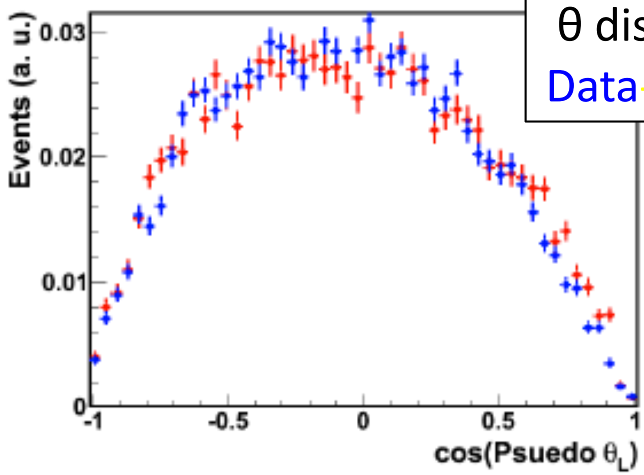
$$A_{FB}\left(s = m^2_{\mu^+\mu^-}\right) = \frac{N_F - N_B}{N_F + N_B}$$

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

→ use topologically similar and abundant control channels as $D \to K\pi\pi\pi$:



LHCb data:
$D \to K\pi\pi\pi$
mass peak selected
$B_d \to K^*\mu\mu$-like

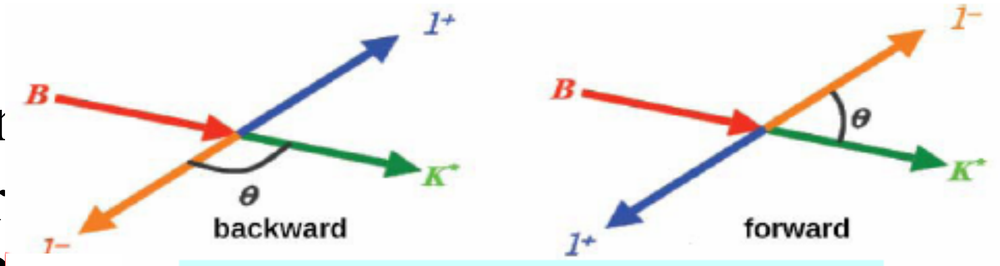


θ distribution:
Data-MC comparison

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

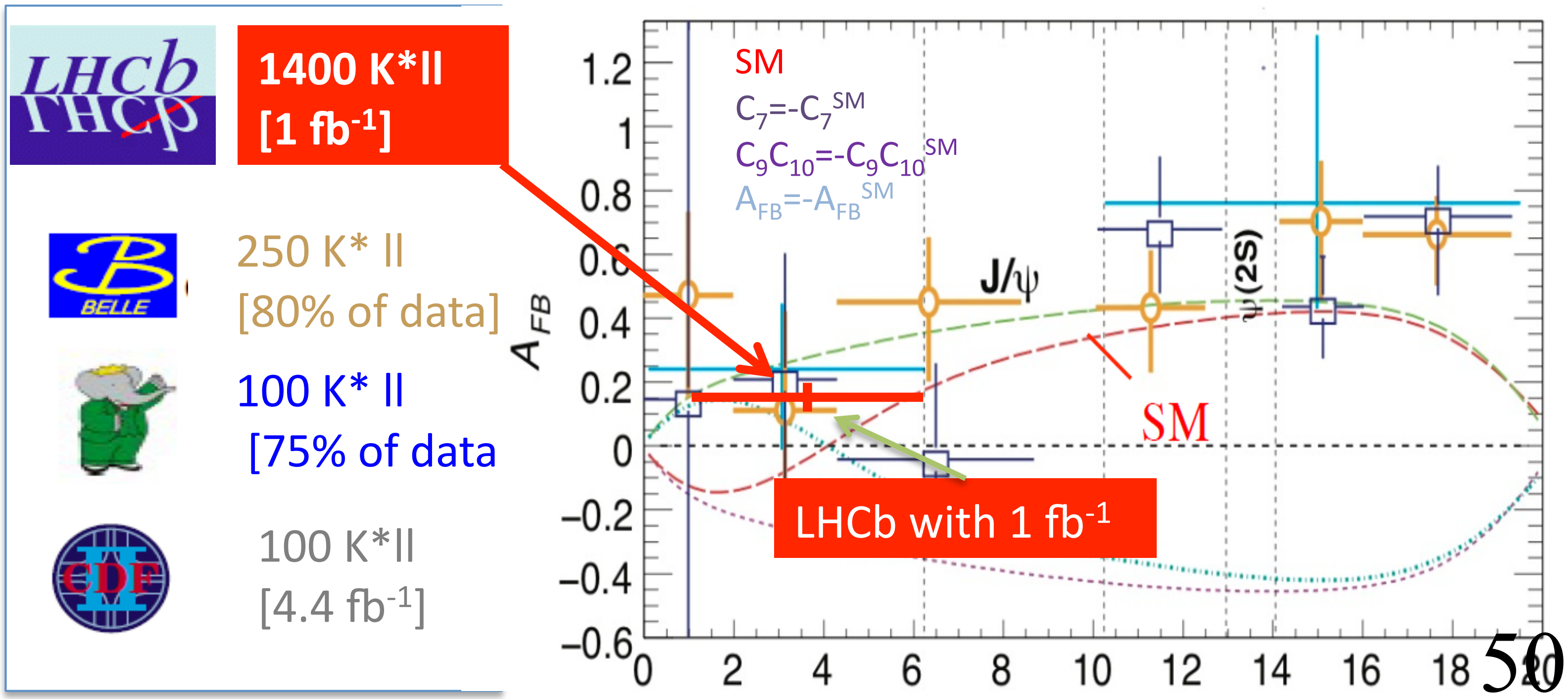
Intriguing hints from $B \to K^{(*)} l^+ l^-$

Forward backward asymmetry in $B^0 \to K^* l^+ l^-$ is a extremely power 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!



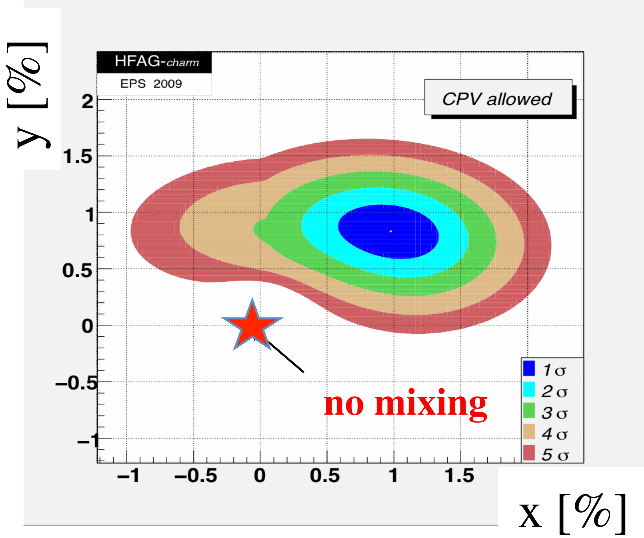
Prospects in the Charm sector

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

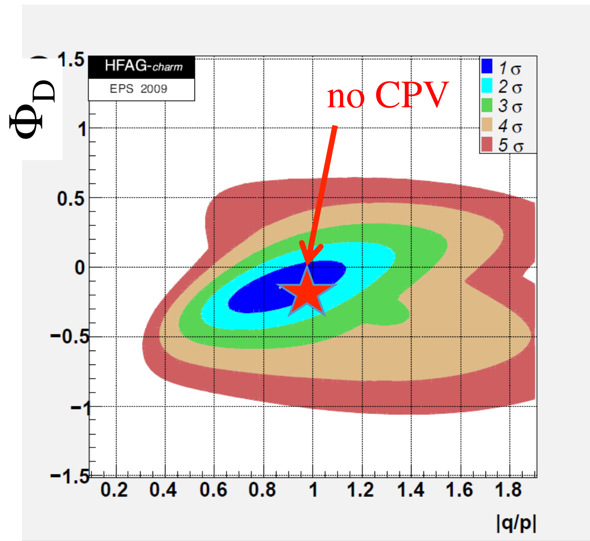
- the GIM mechanism is very effective in suppressing the FCNC transitions;
- long distance contributions prevent the evaluation of the ΔM_D;
- insensitivity to top physics in the loops.

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!

Open Charm cross section

Statistics at the LHC is not a problem….

Putting together:

$D^0 \rightarrow K\pi$,

$D^+ \rightarrow K\pi\pi$

$D^* \rightarrow D^0(K\pi)\pi$

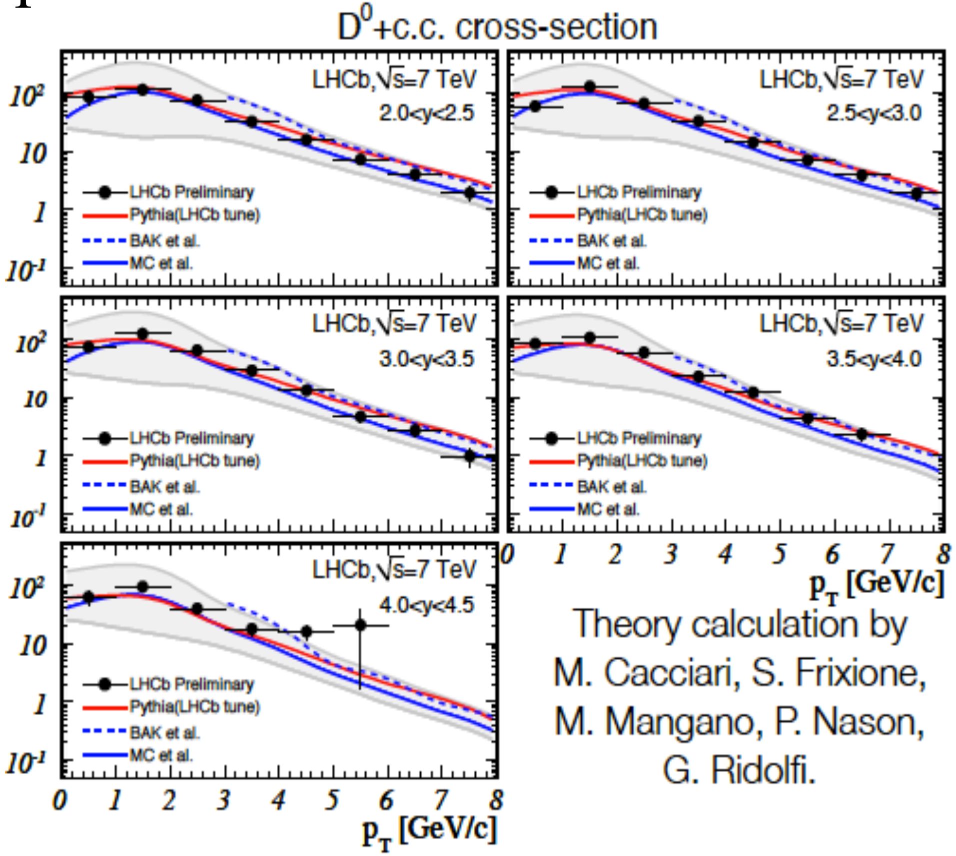
$D^+ \rightarrow \phi\pi$

and extrapolating to 4π

we get:

$\sigma(pp \rightarrow cc) = (6.10 \pm 0.93)$ mb

x 20 $\sigma(pp \rightarrow bb)$!



$\sigma(c\bar{c}, D^0) = 1280 \pm 36 \pm 151 \pm 150\,\mu\text{b} = 1280 \pm 216\,\mu\text{b}$

Charm mixing studies at LHCb

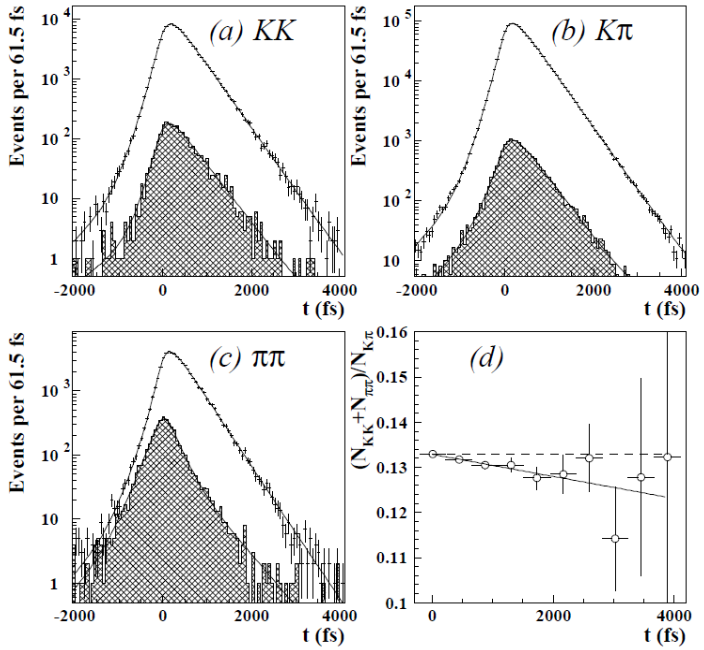
Example mixing analysis is measurement of "y_{CP}", which is D^0 width splitting parameter modified by CP-violating effects. Comparison to pure "y" measurements probes for CP-violation, as does measurement of pure CP-violating observable A_Γ

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]

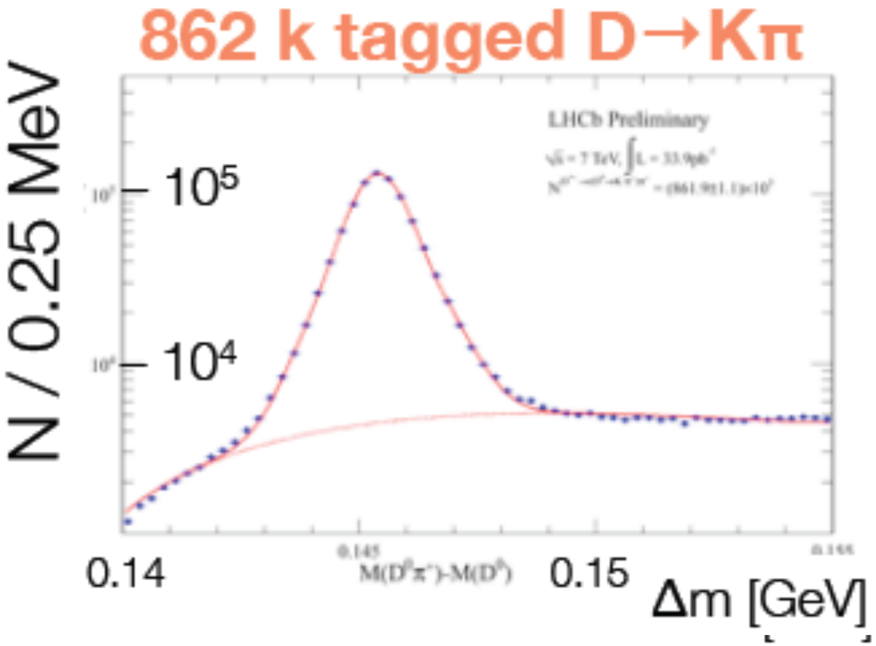
$$A_\Gamma = \frac{\tau(\overline{D}^0 \to K^-K^+) - \tau(D^0 \to K^+K^-)}{\tau(\overline{D}^0 \to K^-K^+) + \tau(D^0 \to K^+K^-)}$$

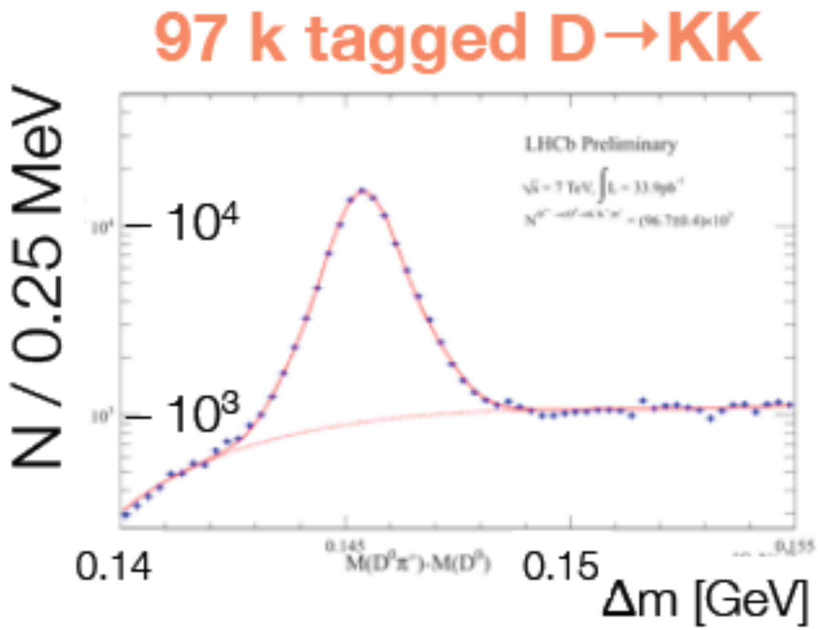


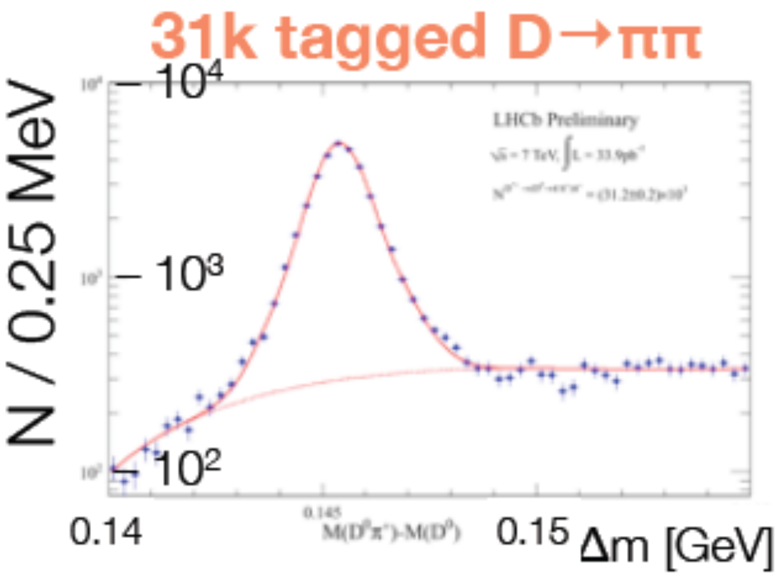
Belle, PRL 98 (2007) 211803

y_{CP}: current world best by Babar (2.6 M Kπ and 260k KK in 0.38/ab
→Statistical precision 0.22% (PRD80:071103 (2009))
A_Γ: current world best from Babar+Belle (180k tagged KK)
--> Statistical precision 0.25%

Charm mixing studies at LHCb







Enough events for competitive y_{CP}, A_Γ measurements in 2010 data - 2011 data will increase this again by more than an order of magnitude

Conclusions

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

•LHC and LHCb 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 LHCb 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 ….

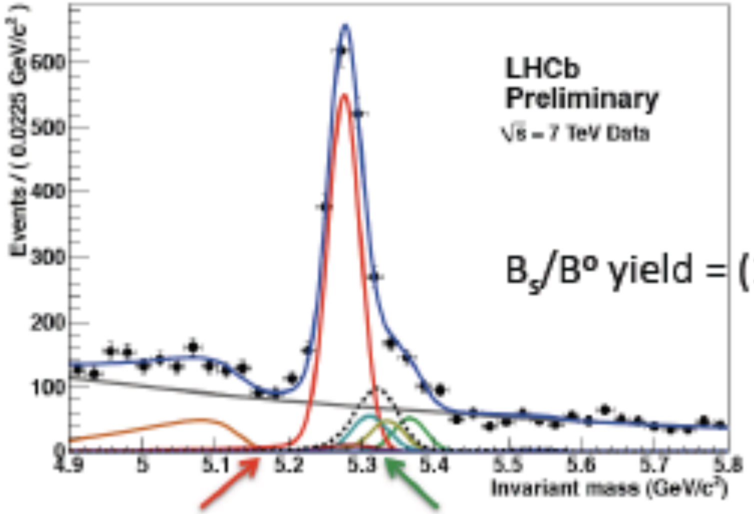
Remember that also the Hubble Space Telescope had a problem at the beginning ….

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

Thank You!

STOP

$B \to K\pi$



B_s/B^o yield = (10.7±2.0)%

Tail due to FSR

Cross feed backgrounds

μ_d = 5.27570 ± 0.00082 GeV/c²

μ_s = 5.3651 ± 0.0015 GeV/c²

σ = 0.02201 ± 0.00062 GeV/c²

$A^{CP}_{K\pi}$ = -0.0862 ± 0.033

$A^{CP}_{comb\ bkg}$ = 0.028 ± 0.030

$A^{CP}_{phys\ bkg}$ = -0.005 ± 0.13

$\nu_{K\pi}$ = **1436 ± 49**

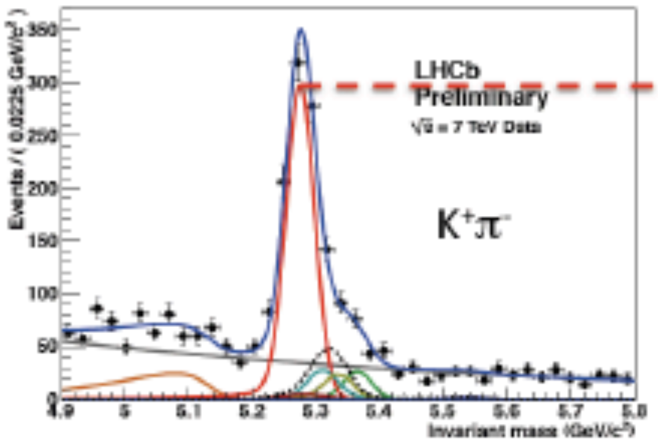
Cross-feed backgrounds at the same level of combinatorial with PID cuts in use

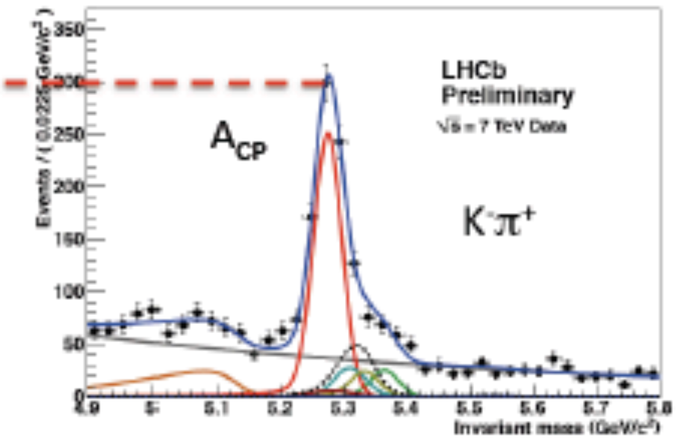
Direct CP violation

$$(A_{CP})_{RAW} = \frac{N\left(\overline{B}^0_d \to K^-\pi^+\right) - N\left(B^0_d \to K^+\pi^-\right)}{N\left(B^0_d \to K^+\pi^-\right) + N\left(\overline{B}^0_d \to K^-\pi^+\right)}$$

LHCb: -0.0862±0.033

HFAG: -0.098±0.012





$(A_{CP})_{raw}$ to A_{CP}

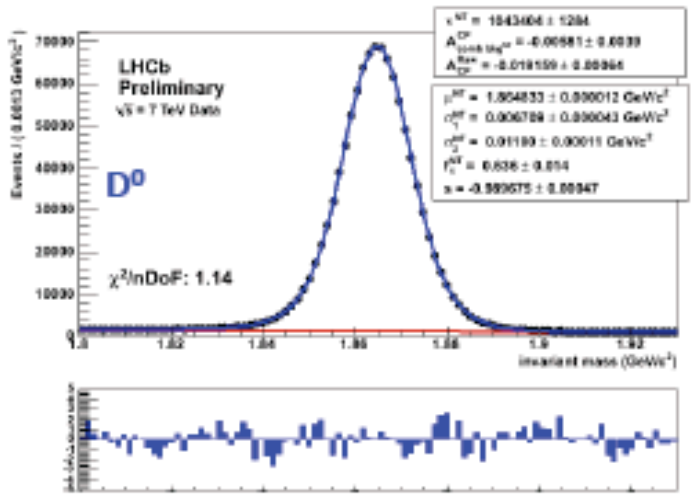
- $(A_{CP})_{RAW} = A_{CP} + A_{prod} + A_{det}$
- A_{prod} from $B^+ \to J/\psi K^+$
- A_{det} from D decays

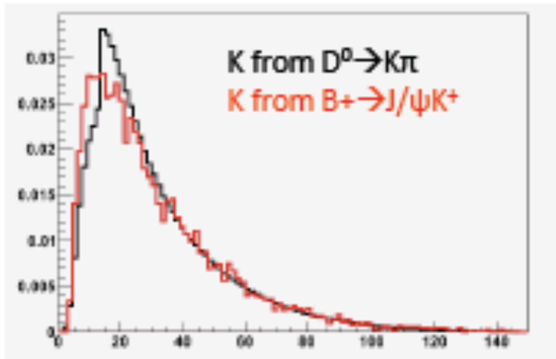
Channel	Magnet UP	Magnet Down
$D^{*+} \to D^0(K\pi)\pi^+$	5.26×10^5	4.53×10^5
$D^{*+} \to D^0(KK)\pi^+$	6.2×10^4	5.1×10^4
$D^{*+} \to D^0(\pi\pi)\pi^+$	2.1×10^3	1.7×10^3
$D^0 \to K\pi$	3.1×10^6	2.5×10^6

$\delta(D^0)=(-0.0108\pm0.0034)$

$\delta A(K\pi)=(-0.0054\pm0.0034) \to A_{det}$

$\delta(B^+)= -0.015\pm0.010 \to A_{prod}$

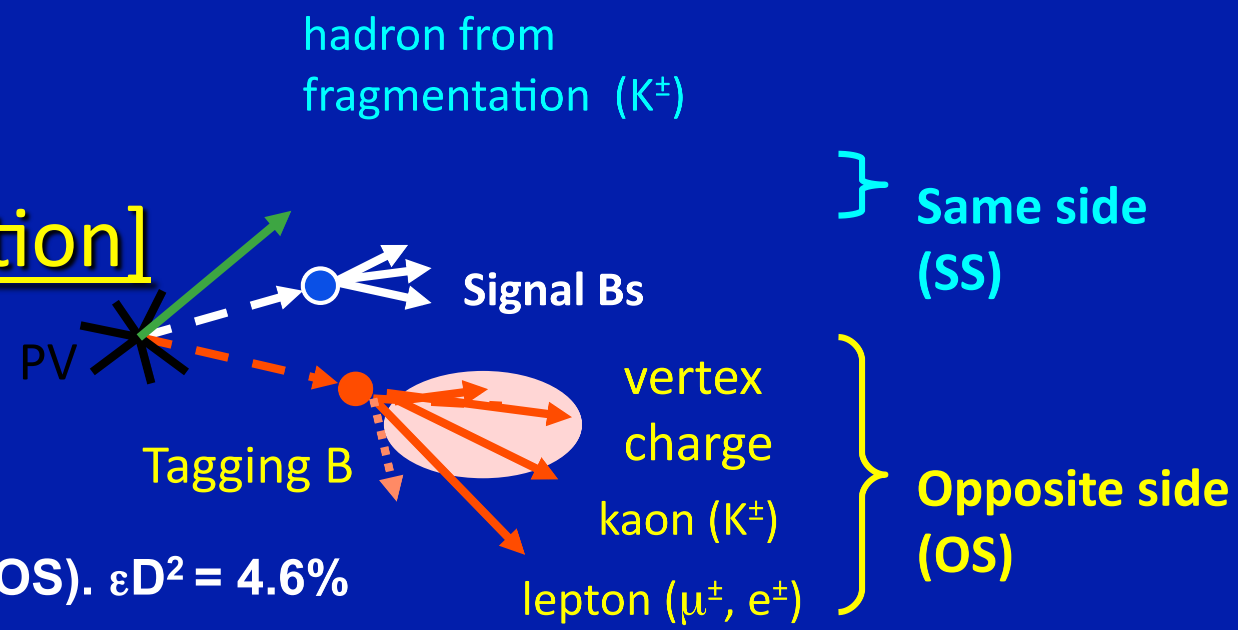




$A_{CP}(KK)-A_{CP}(\pi\pi)=(0.0009\pm0.0063)$ LHCb

$A_{CP}(KK)-A_{CP}(\pi\pi)=(-0.0038\pm0.0043)$ HFAG average

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:

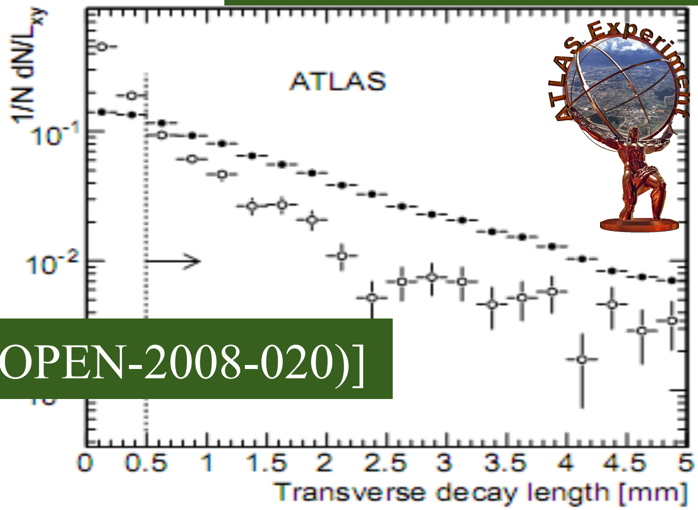
B species	Z0 fractions [%]	Tevatron fractions [%]
$B^{\pm}$	40.3±0.9	33.3 ± 3.0
B^0	40.3±0.9	33.3 ± 3.0
B_s	10.4±0.9	12.1 ± 1.5
Λ_b	9.1±1.5	21.4 ± 6.8

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.

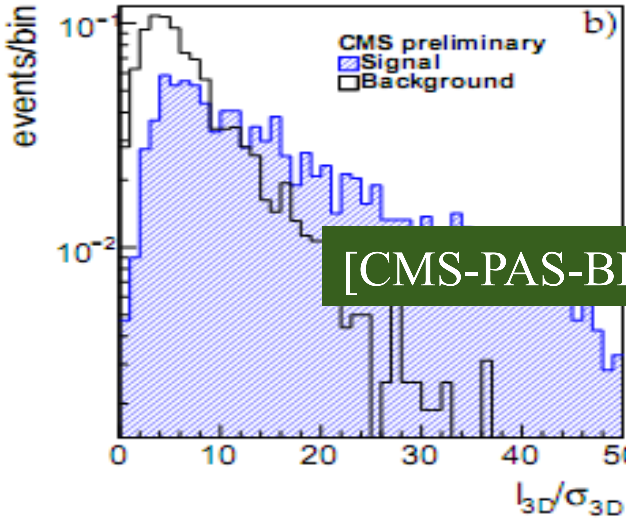
$B_s \to \mu\mu$ @ ATLAS/CMS

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)]

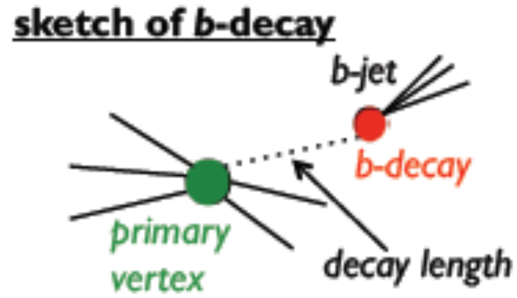


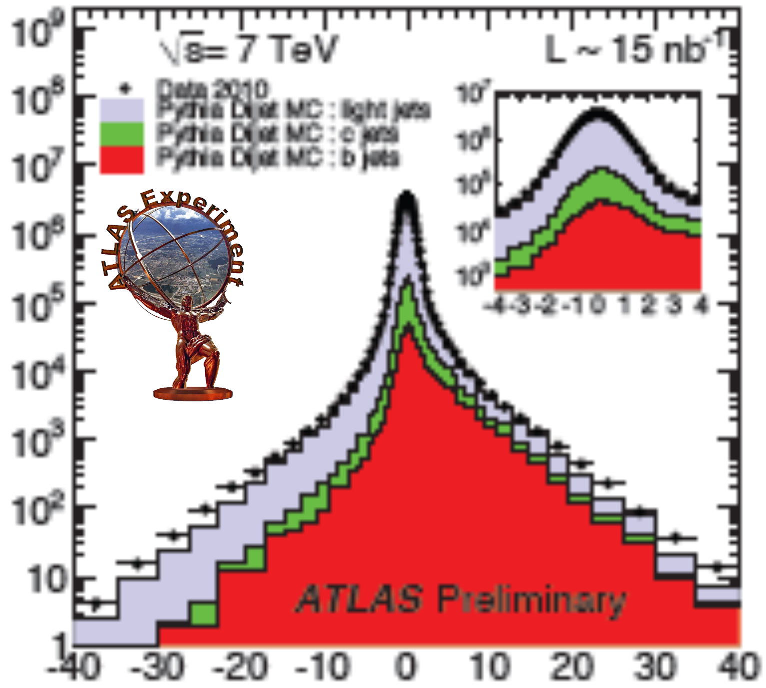
[CMS-PAS-BPH-07-001 (2009)]

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 x 10^{-8}

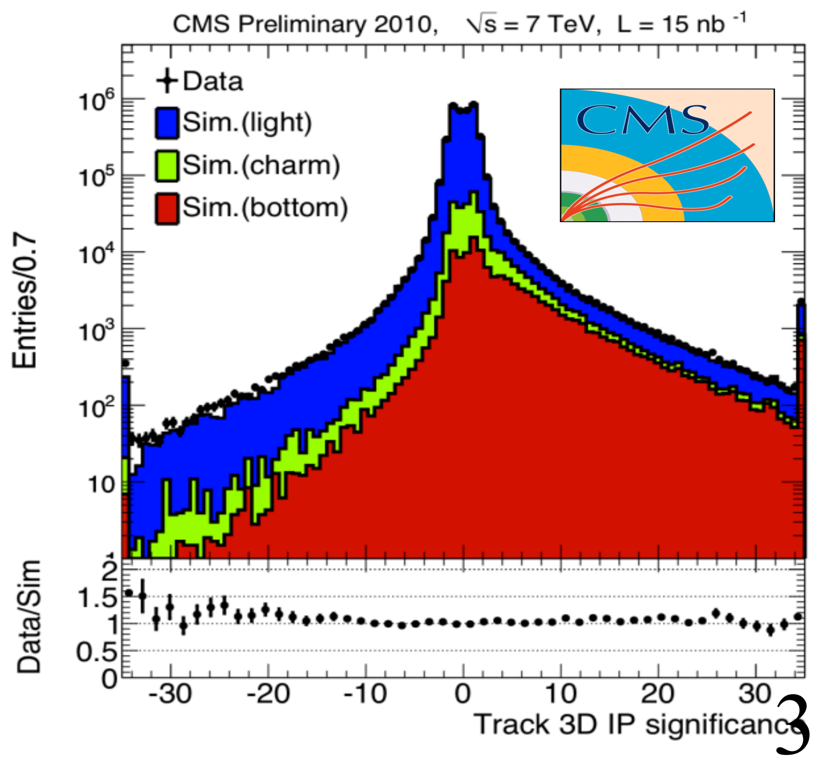
Tagging calibration [ATLAS/CMS]

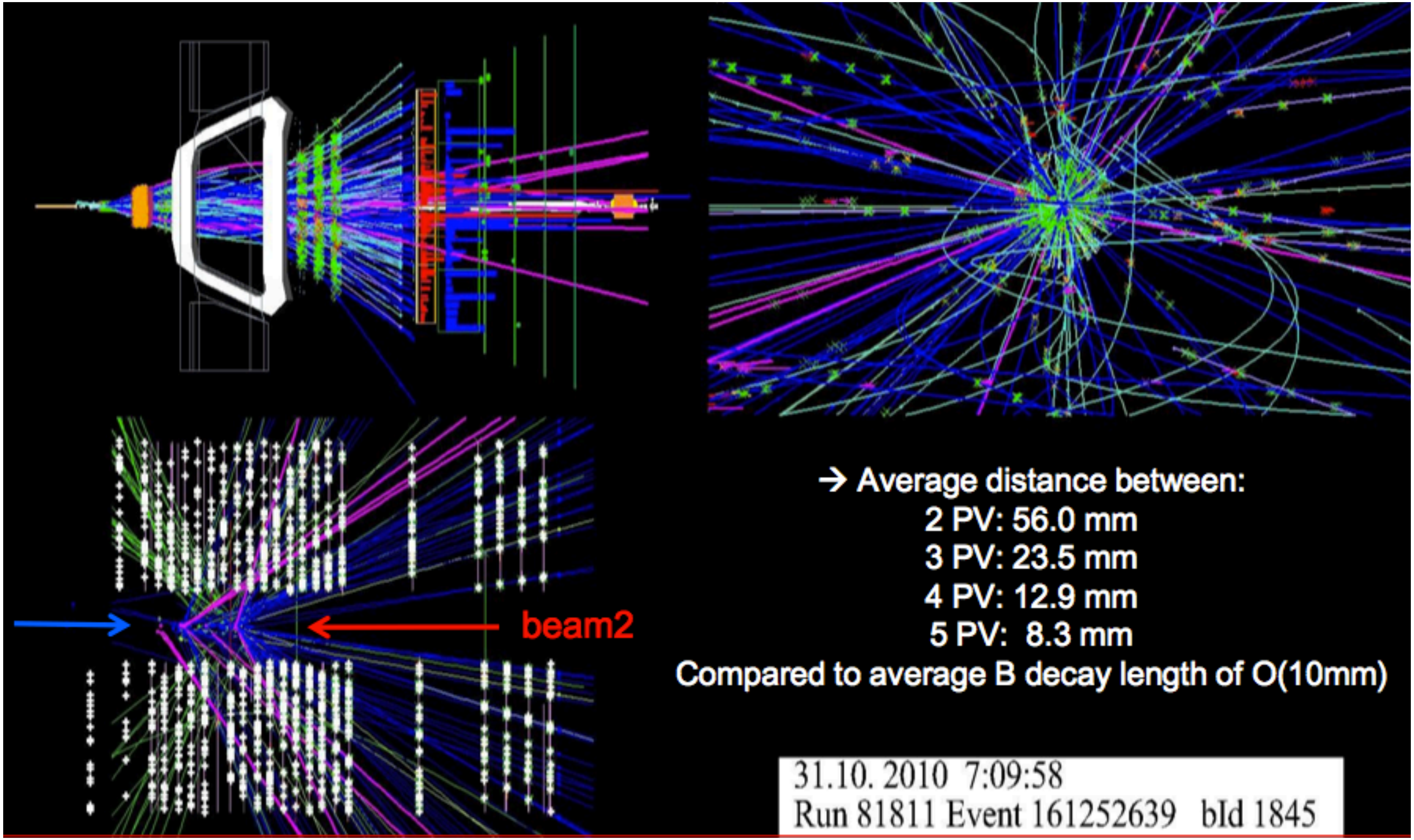
- Explicit reconstruction of the b-hadron secondary vertex via a b-jet.
- Decay length significance is the discriminant variable.





Decay length significance



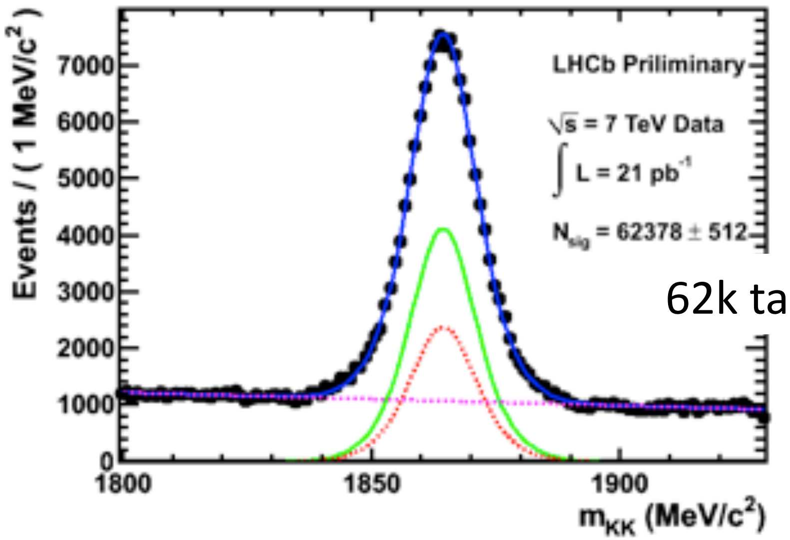

beam2
→ Average distance between:
2 PV: 56.0 mm
3 PV: 23.5 mm
4 PV: 12.9 mm
5 PV: 8.3 mm
Compared to average B decay length of O(10mm)
31.10. 2010 7:09:58
Run 81811 Event 161252639 bId 1845

Charm mixing studies at LHCb

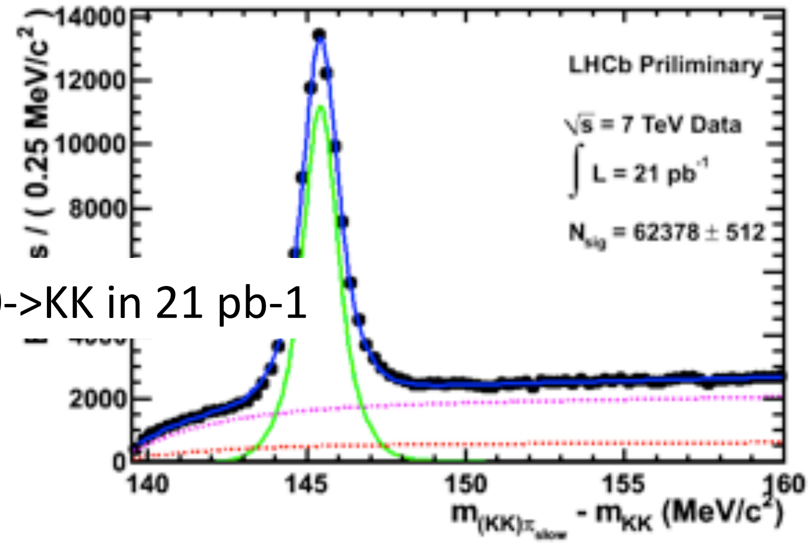
Example mixing analysis is measurement of "y_{CP}", which is D^0 width splitting parameter modified by CP-violating effects. Comparison to pure "y" measurements probes for CP-violation, as does measurement of pure CP-violating observable A_Γ

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

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



62k tagged D0->KK in 21 pb-1



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