Precision in flavour (& beyond): LHCb status & prospects

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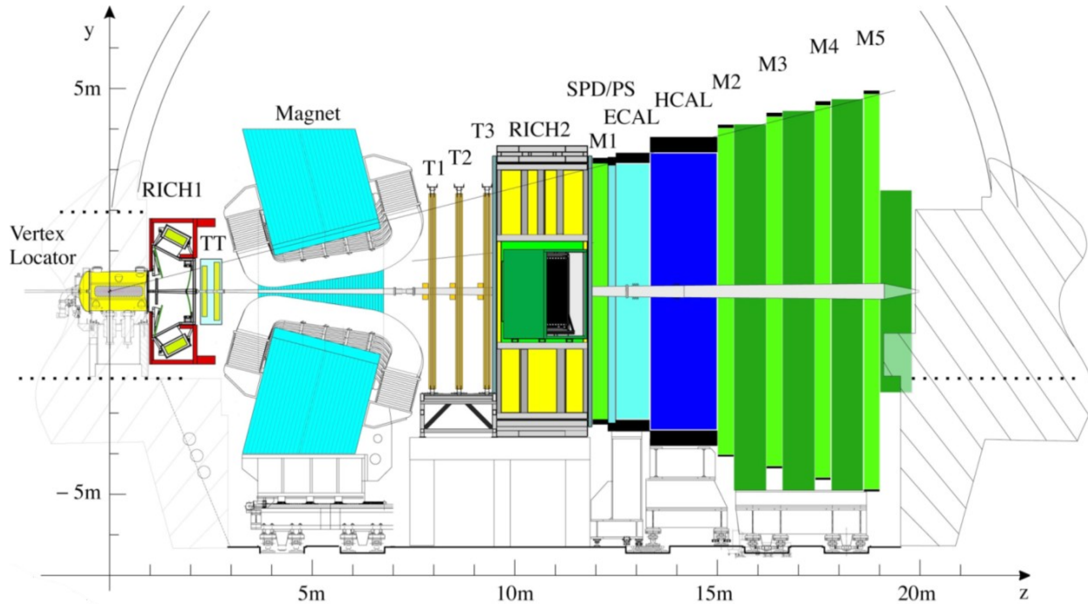
Paris, 15/12/10

Precision in flavour (& beyond): LHCb status & prospects

- Detector and 2010 operation
- Selected early results
- Goals of 2011, and beyond
- Beyond flavour
- Conclusions

Detector and 2010 operation

LHCb detector

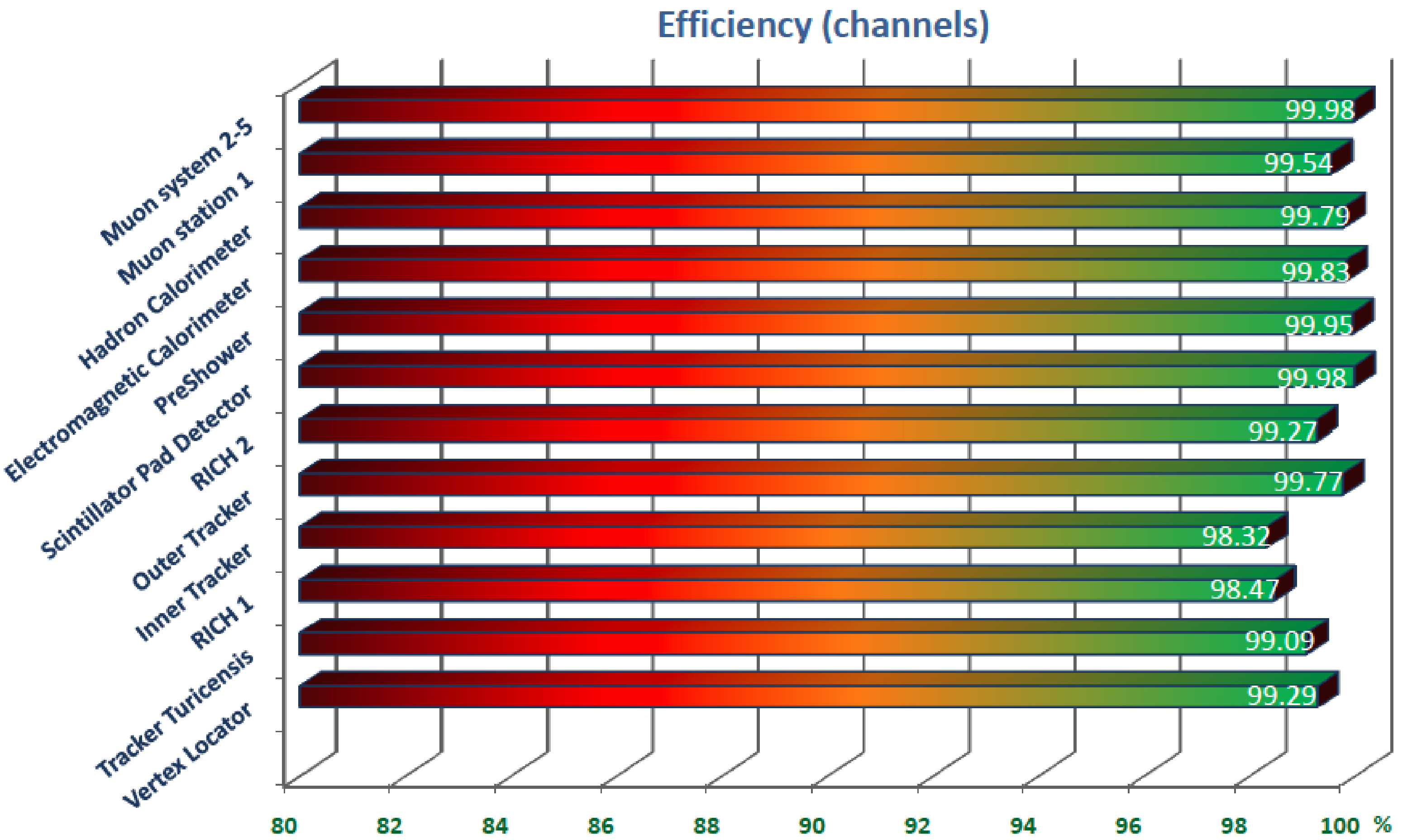


Optimised for flavour physics:

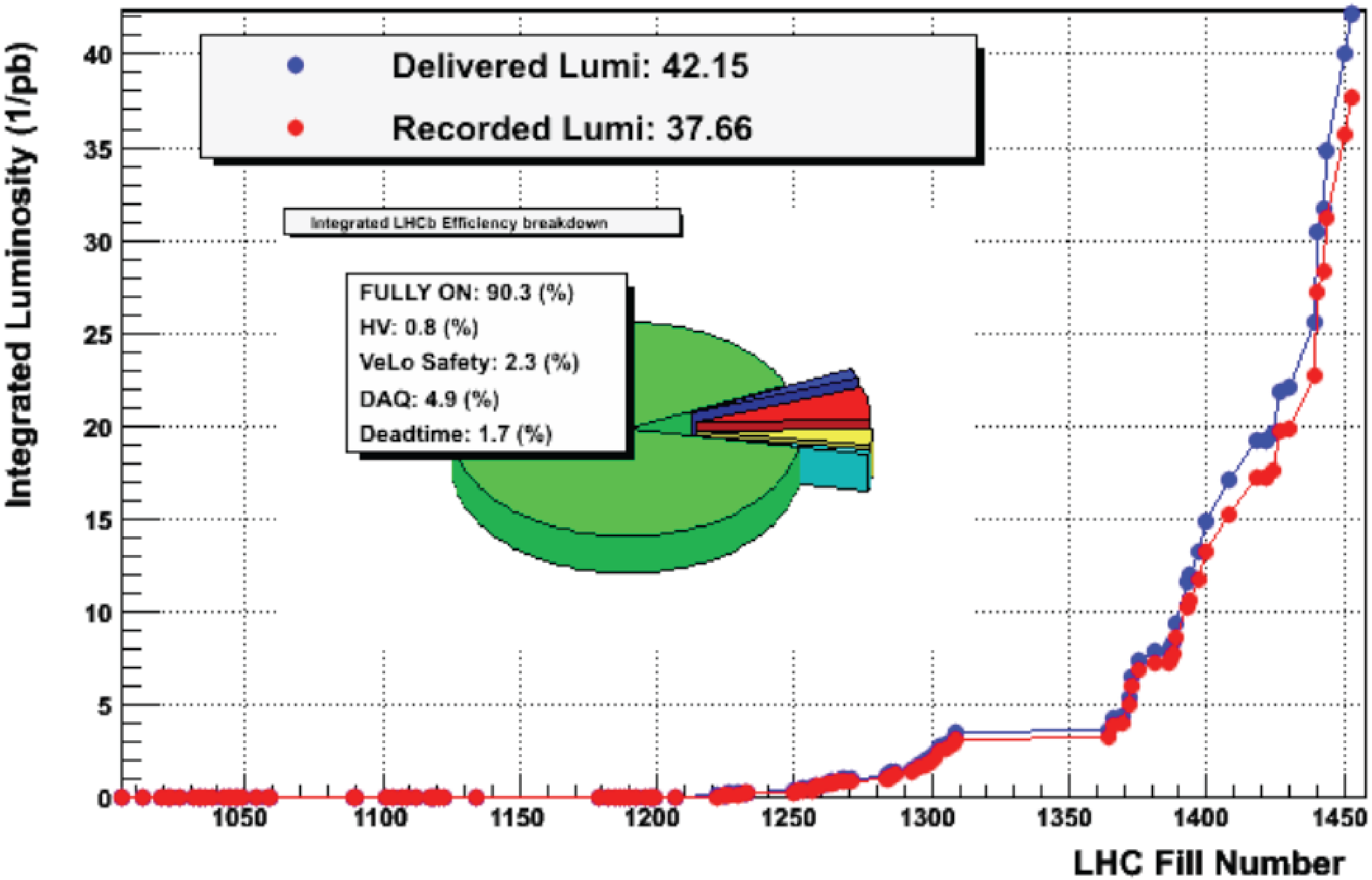
- forward acceptance ($2 < \eta < 5$)
- high bandwidth trigger
- acceptance down to low p_t
- precise vertexing (VELO)
- hadron identification (RICHes)

Unique acceptance and high quality instrumentation opens up possibilities in other physics areas!

Subdetector efficiency in 2010



Integrated luminosity in 2010

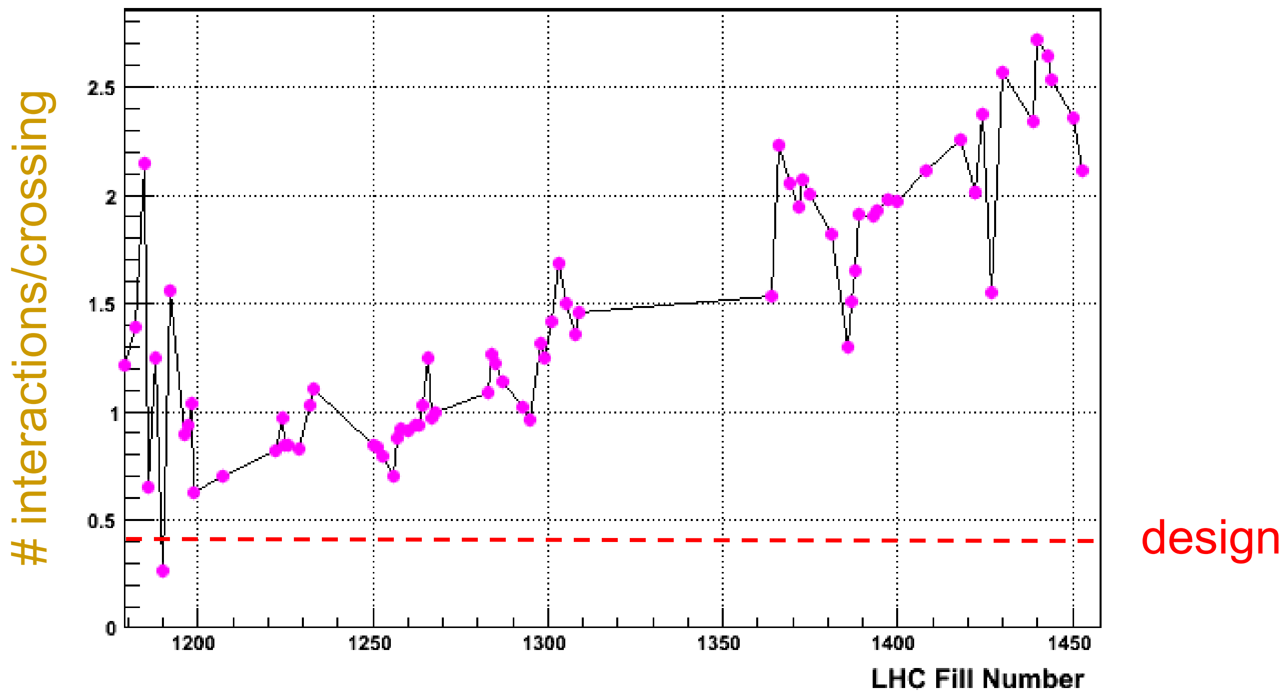


Design luminosity 'a few' (< 5) x 10^{32} cm^{-2} s^{-1}. Almost there at end of run!

2010 running conditions

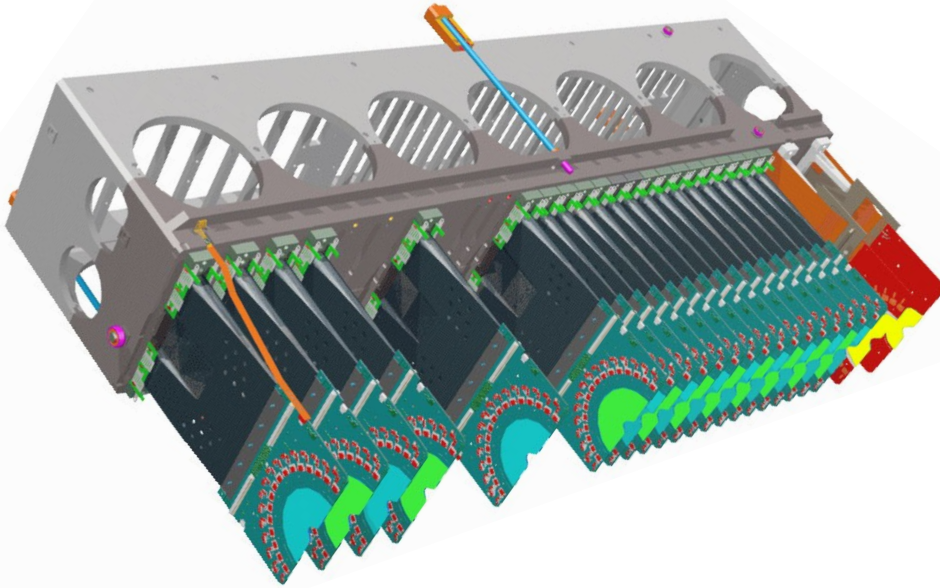
LHCb designed for luminosity of ~2 x 10^{32} cm^{-2} s^{-1} and ~0.4 interaction/crossing

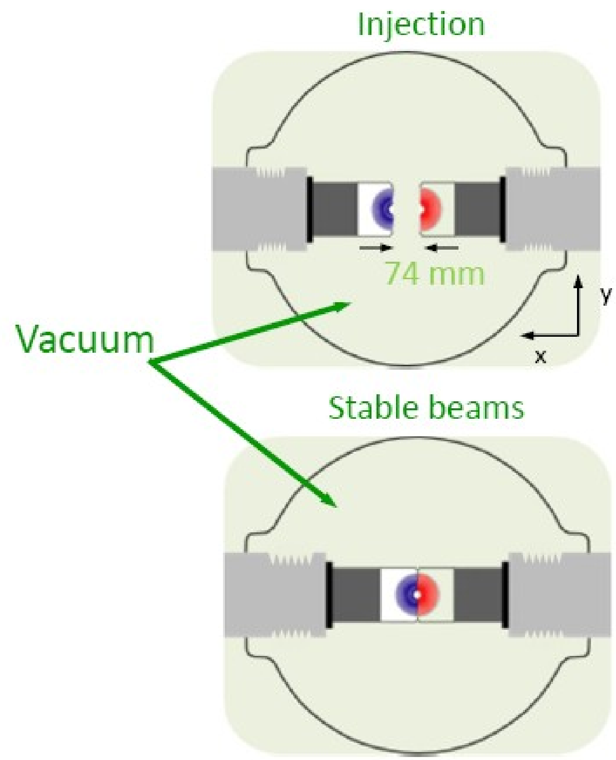
In 2010 machine quickly went to (above) nominal in emittance and bunch charge, whilst still having only a few hundred bunches. It was therefore necessary to run at > 2 interactions/crossing in order to obtain acceptable luminosity.

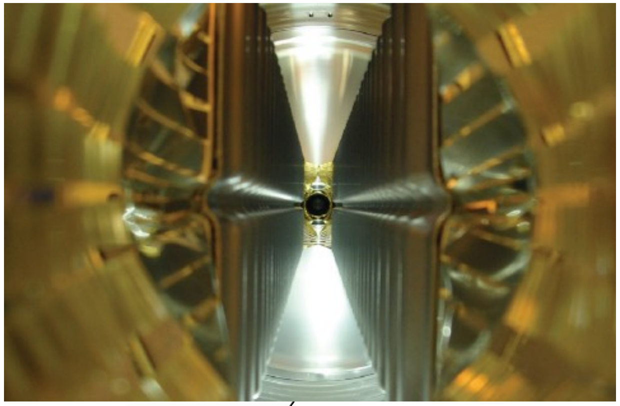


Very challenging for trigger, offline reconstruction and processing. But we did it !

LHCb Vertex Locator (VELO)

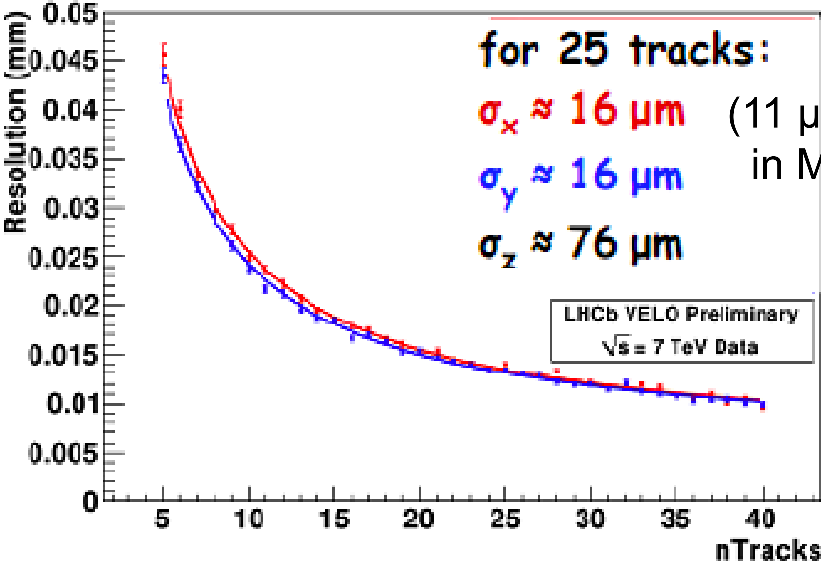






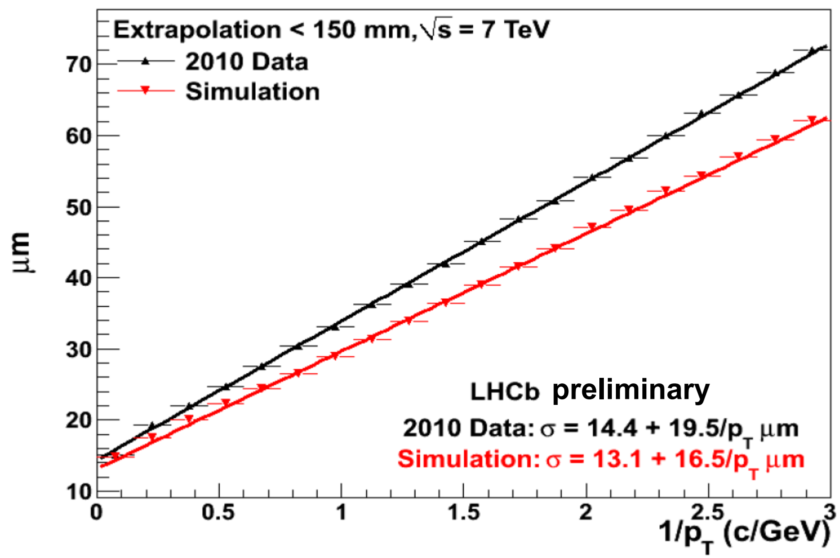
VELO performance

Primary vertex resolution



(11 μm in MC)

Impact Parameter (x-projection) vs $1/p_T$

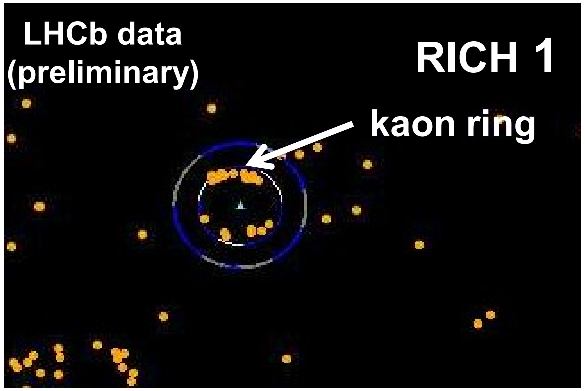


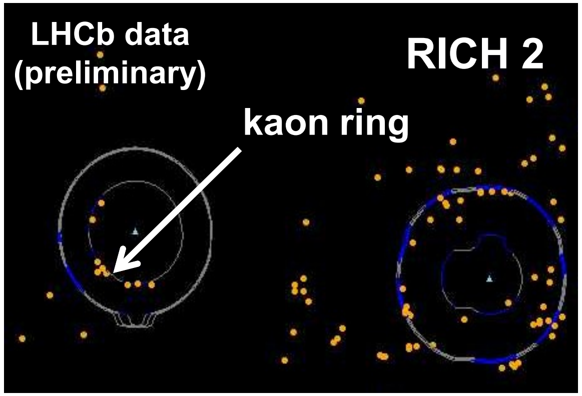
Data-MC agreement not yet perfect, but achieved precision already excellent !

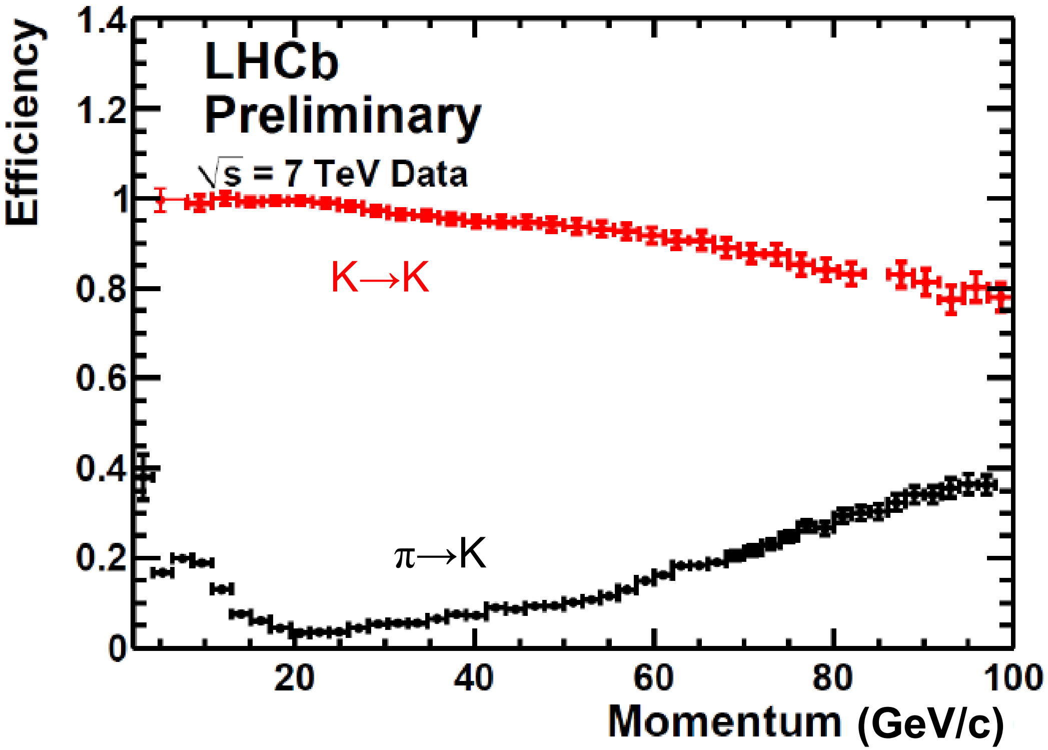
(Proper time resolution on B decays ~50 fs , << B_s oscillation period of ~350 fs)

RICH performance

PID provided by two RICH detectors. A pattern recognition using both track & RICH info gives a track-by-track log-likelihood difference (dLL) for each particle hypothesis.





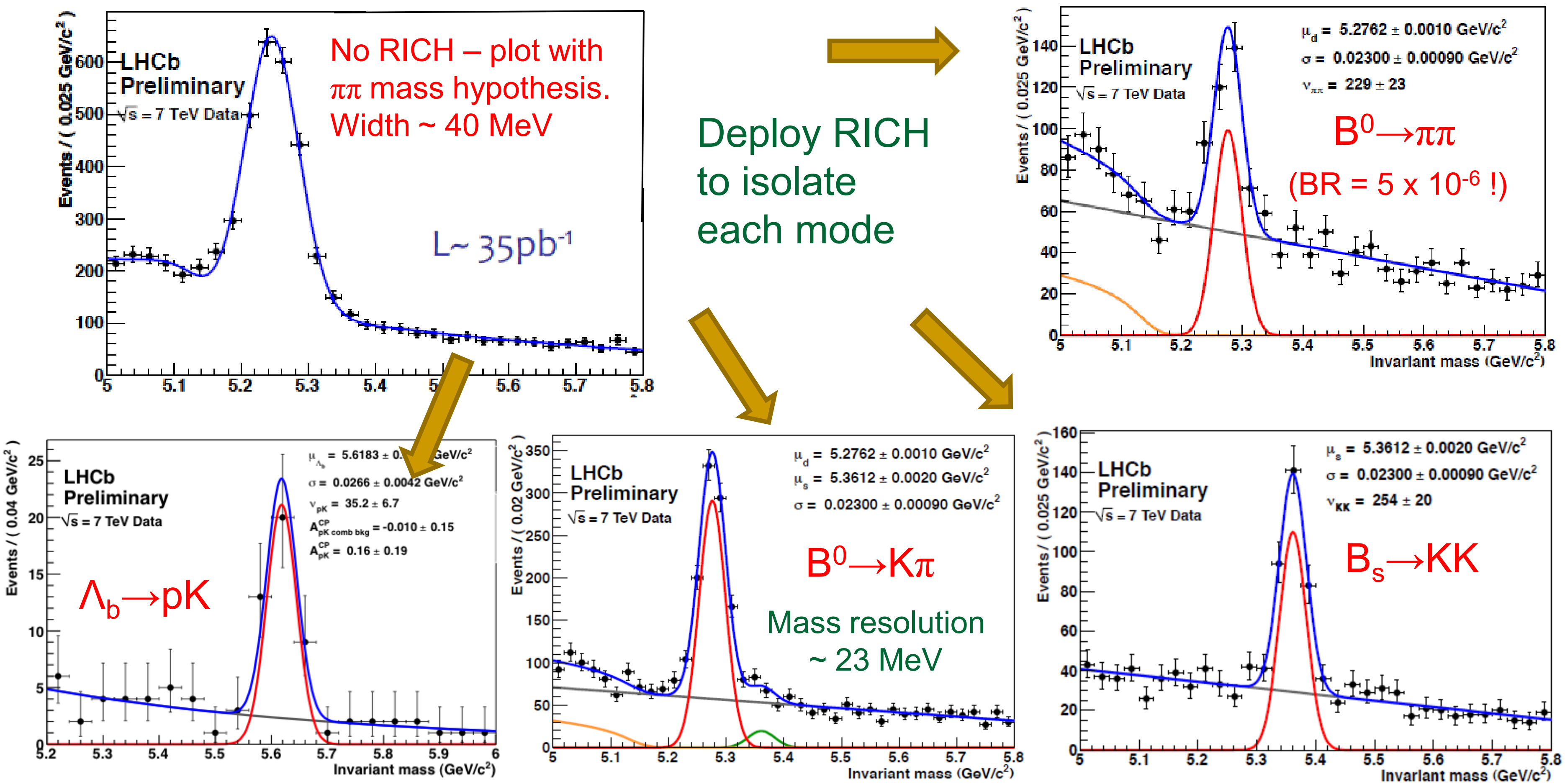


Efficiency / purity working point can be chosen by changing cut value on dLL

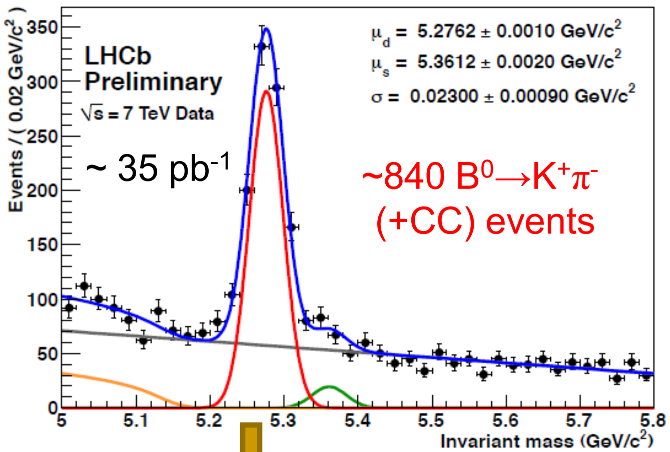
RICH in action: charmless B-decays

Two-body charmless B-decays central to LHCb physics. Significant contribution of Penguin diagrams provide entry points for new physics.

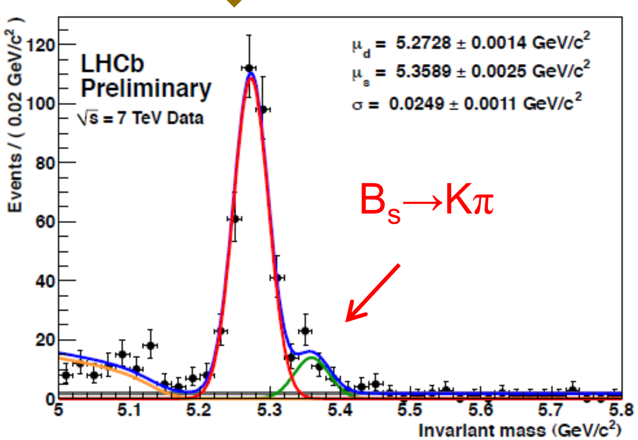
Experimentally, rely on good performance of hadron trigger and RICH system



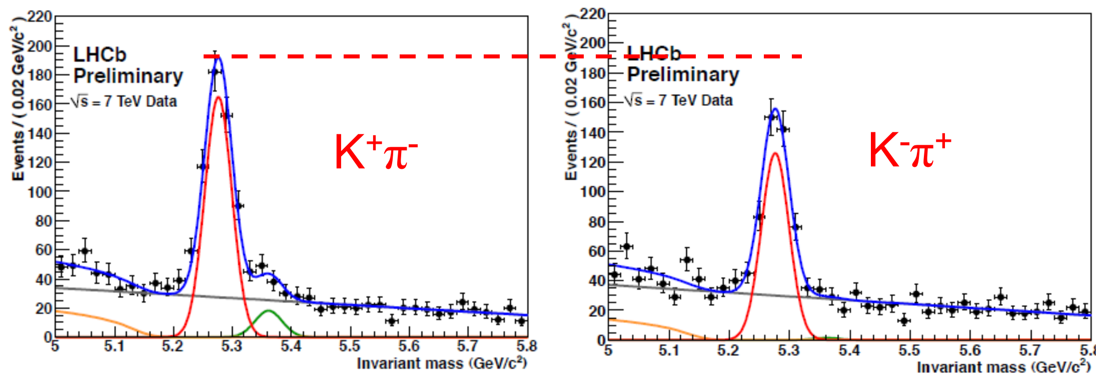
A closer look at B→Kπ



Tighter selection



Divide into B^0 and B^0-bar



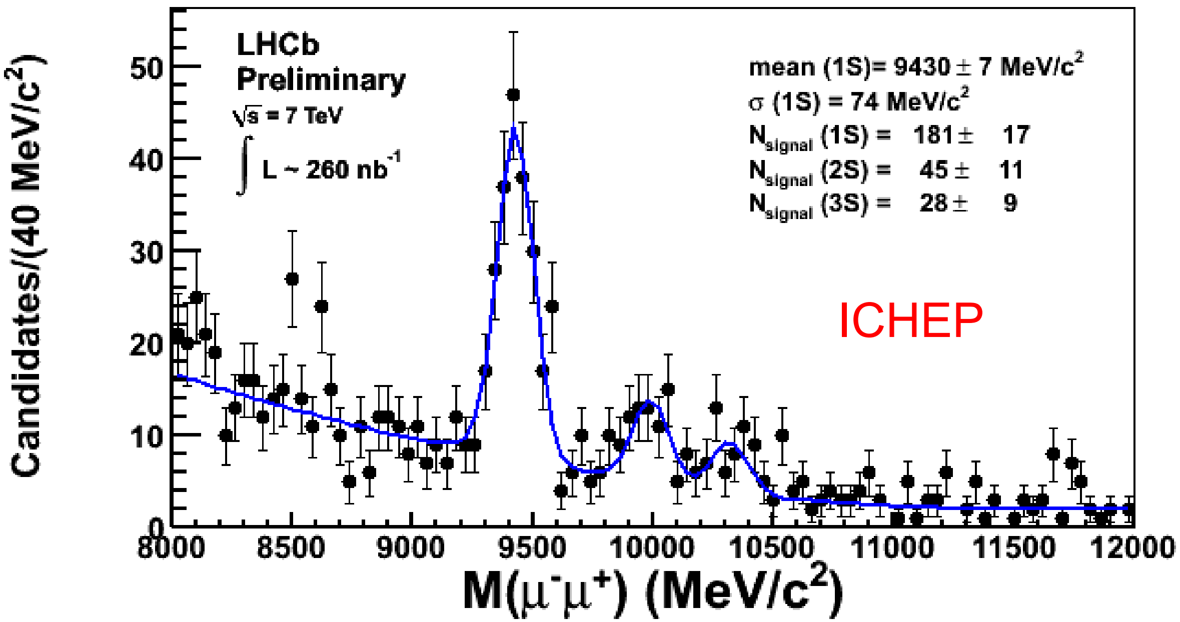
Raw result shows CP-violation at > 3 σ with central value consistent with world-average !

Analysis being optimised & account being taken of (small) production and detector asymmetries

Progress in alignment

Excellent mass resolution is critical tool in enhancing signal purity (e.g. for $B_s \to \mu\mu$).

This has improved throughout year as alignment has been better understood (recall LHCb could not really benefit from cosmic running prior to collisions)



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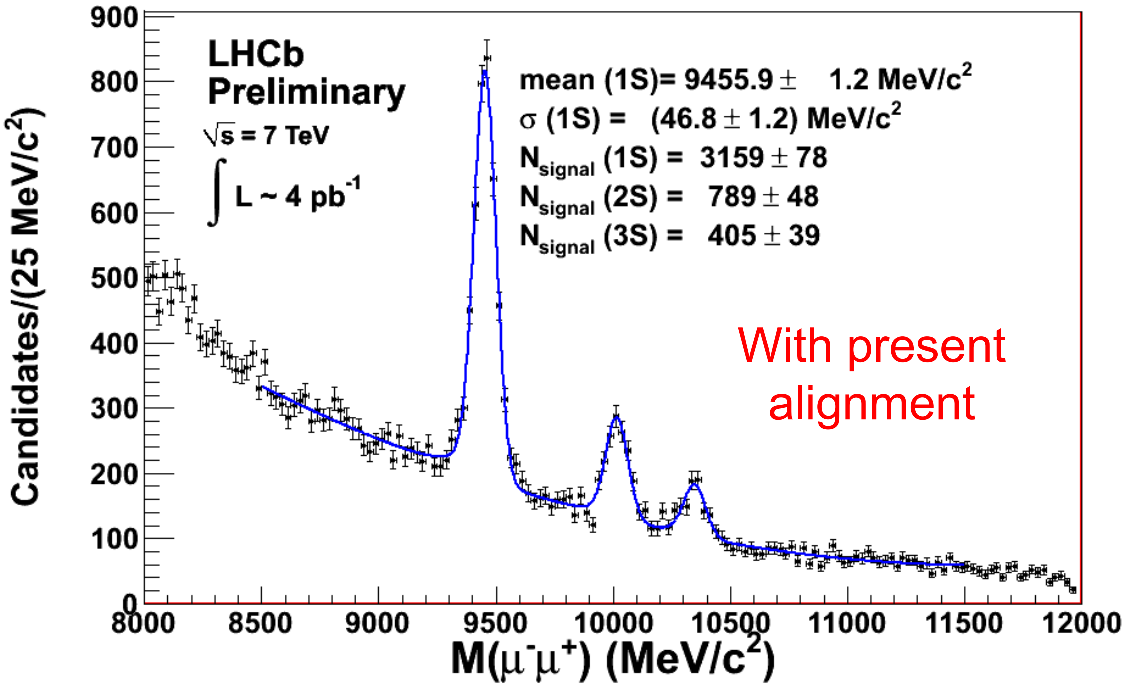


Resolution now very close to Monte Carlo expectation

Selected early results in flavour

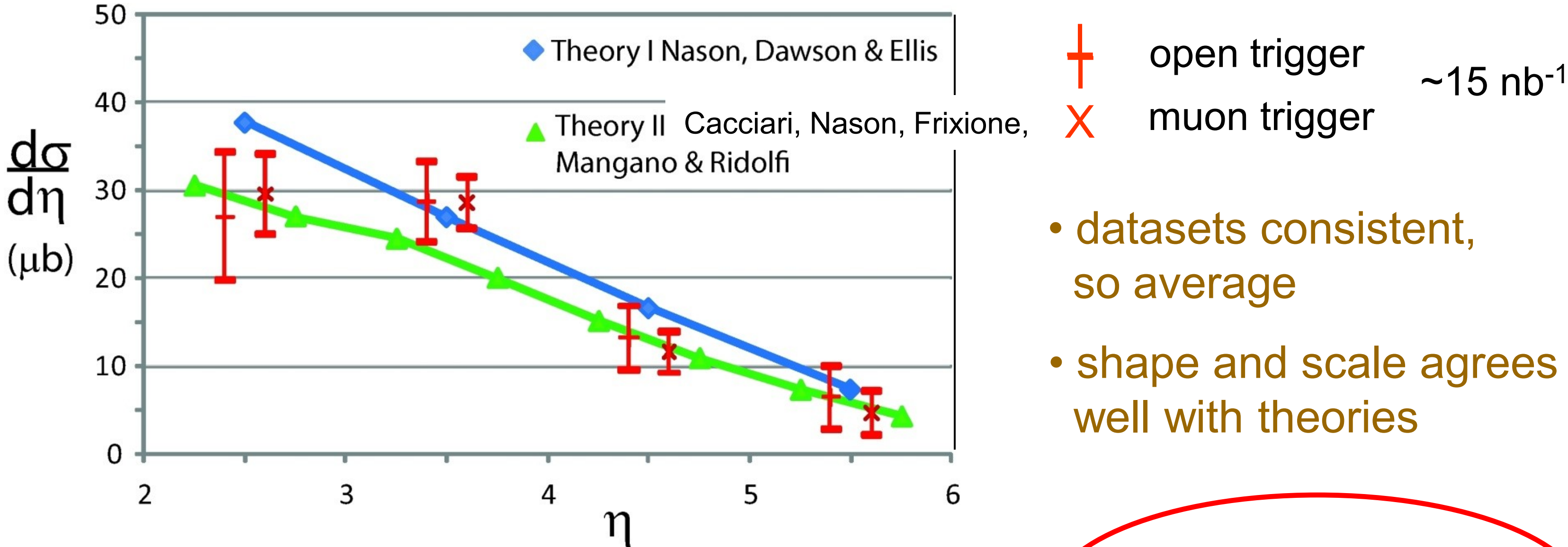
- Open beauty production
- Open charm production
- Onia (not covered here)

LHCb $B \to D^0 \mu X$ analysis

Phys Lett B 694 (2010) 209

LHCb has measured bb x-section at LHC, by looking for displaced D^0 which vertex with a muon of correct sign correlation to come from semileptonic B decay

Compare with theory predictions for $b\bar{b}$ production



- datasets consistent, so average
- shape and scale agrees well with theories

σ (pp$\to H_b X$; $2 < \eta < 6$) = $75.3 \pm 5.4 \pm 13.0$ μb

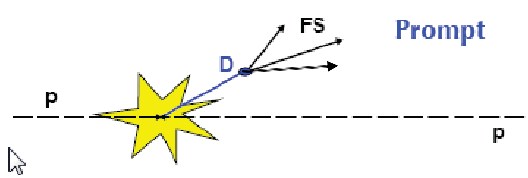
Extrapolates to $284 \pm 20 \pm 49$ μb over 4π

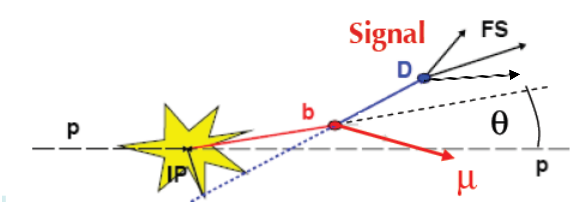
Almost identical to value assumed in all CP sensitivity studies – good news !

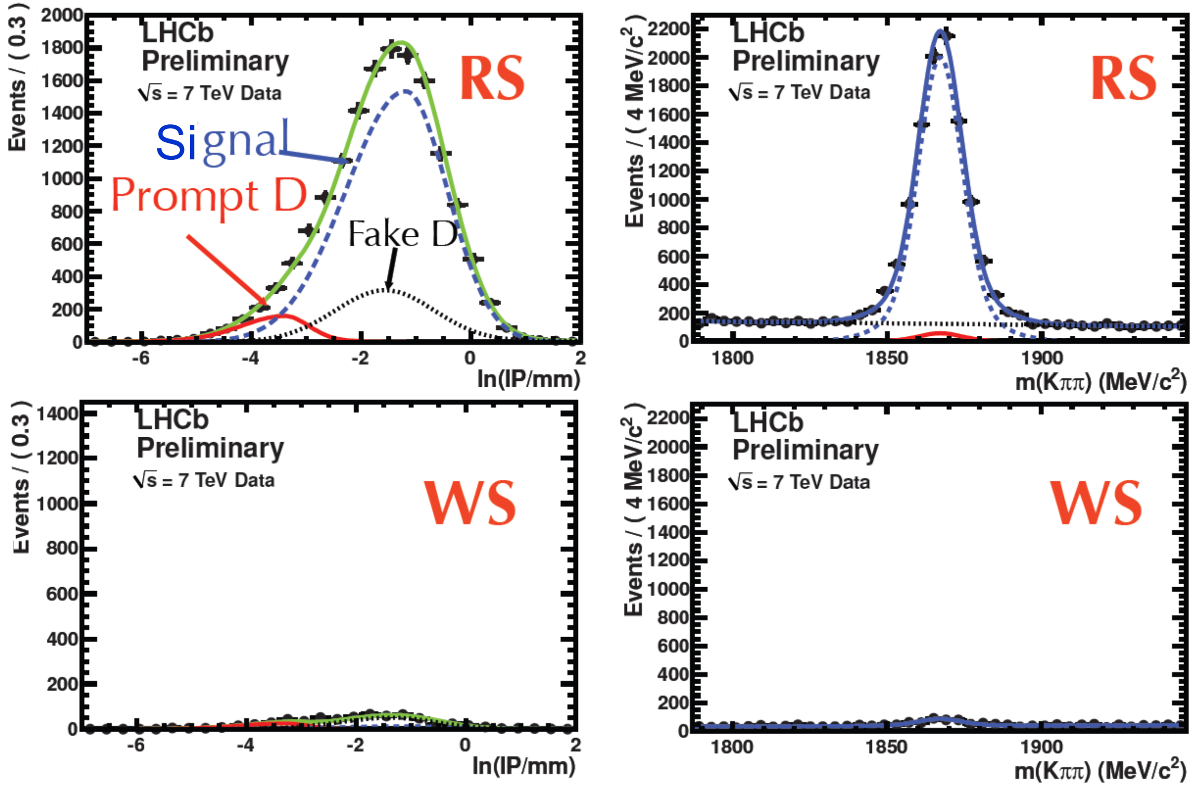
New results from semileptonics

Analysis has been extended with ~ 3 pb^{-1} to look for $D^0\mu$, $D^+\mu$, $D_s\mu$ and $\Lambda_c\mu$ events.
Goal is to determine relative rates of B^0, B^+, B_s & Λ_b. Needed for BR measurements.
e.g.: look for D^+ decays through displaced $D\mu$ vertices of right sign (RS) correlation

Fit log of impact parameter (IP) of D







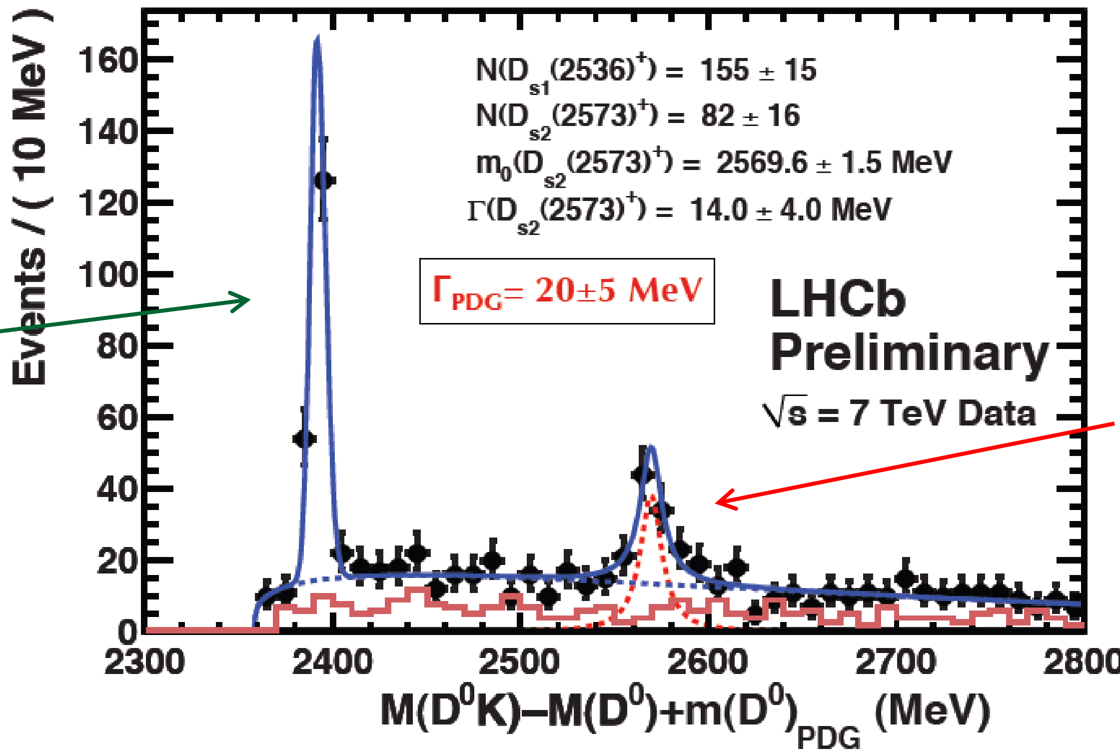
New understanding of B_s decays

Need to account for cross-feed, e.g. excited D_s states which decay into D + K

$B_s \to D^0K^+X\mu^-\nu$ 20 pb^{-1}

$D_{s1}(2536) \to D^*(2007)^0K^+$ with missed π^0 or γ

Decay seen by D0 [PRL102 051801]



$D_{s2}^*(2537) \to D^0K^+$

Never previously observed !

$$\frac{\mathcal{B}(\overline{B}^0_s \to D^+_{s1}X\mu^-\overline{\nu})}{\mathcal{B}(\overline{B}^0_s \to X\mu^-\overline{\nu})} = 6.5 \pm 1.5 \pm 0.5\%$$

LHCb preliminary

$$\frac{\mathcal{B}(\overline{B}^0_s \to D^{*+}_{s2}X\mu^-\overline{\nu})}{\mathcal{B}(\overline{B}^0_s \to X\mu^-\overline{\nu})} = 4.0 \pm 1.1 \pm 0.5\%$$

Semi-leptonic results

Preliminary result:

$$f_s/(f_u + f_d) = 0.130 \pm 0.004\ \text{(stat)} \pm 0.013\ \text{(sys)}$$

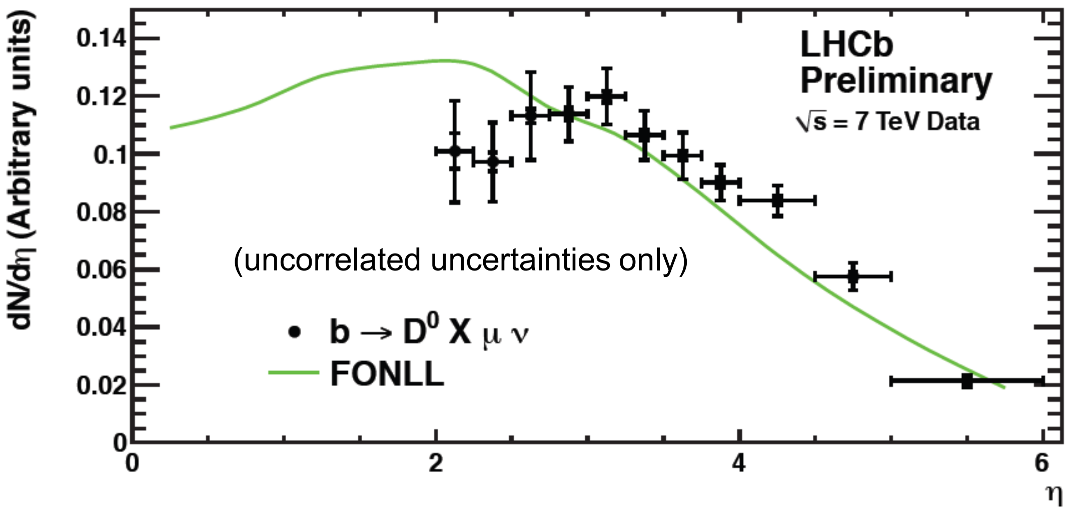
No reason for it to be same as at LEP or Tevatron, but more consistent with measurements of former

$$f_s/(f_u + f_d) = 0.129 \pm 0.012$$ LEP

$$f_s/(f_u + f_d) = 0.18 \pm 0.03$$ Tevatron

Systematic Sources	Relative Error [%]
Charm hadron BR	5.5
$B_s \to D^0 K X \mu\nu$ Yield	6.3
$B^{0/+}, \Lambda_b \to D_s K X \mu\nu$ Correction	2.0
Efficiencies, mainly Bs	3.0
Λ_c reflection	1.0
MC statistics	3.0
Background	2.0
Tracking	2.0
Lifetime ratio	1.8
PID	1.4
Trigger	1.4
Total	10

Increase in data has allowed for more detailed look at shape of x-section



Interesting hints of discrepancy at low η – but this is edge of acceptance, & warrants further study

Open charm cross-sections

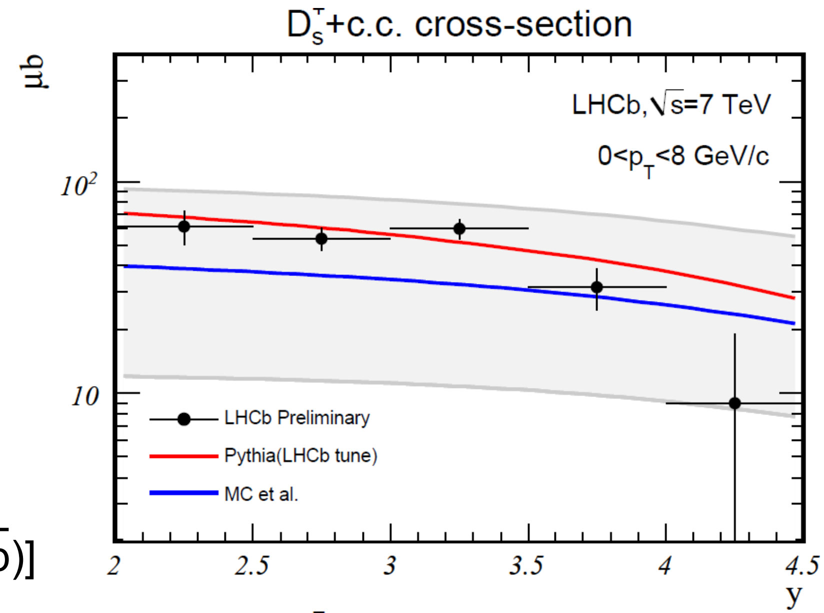
[LHCb-CONF-2010-013]

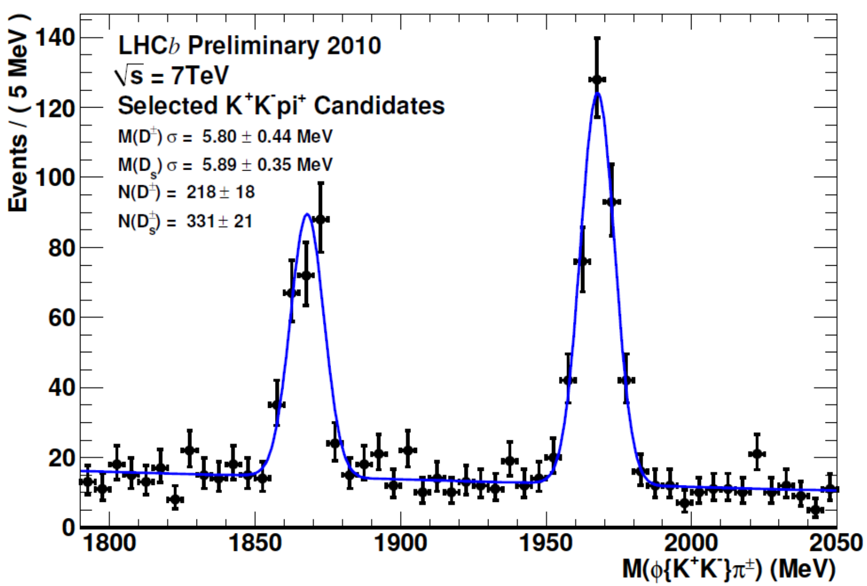
LHCb has also performed preliminary measurements of cross-section vs y, p_t for D^{*+}, D^0, D^+ and D_s (shown here)

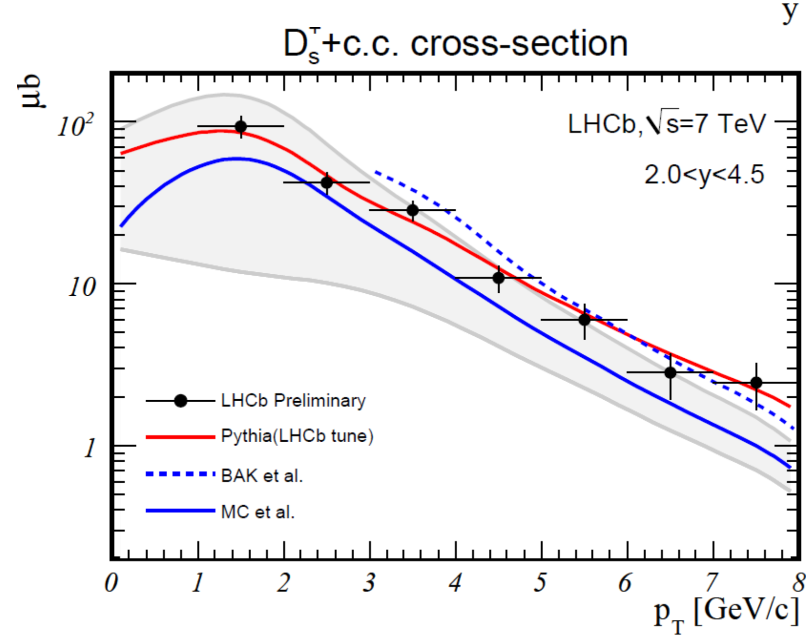
Performed with ~ 2 nb^{-1} using open trigger.
Being updated with more statistics and Λ_c

Good agreement with expectation – charm production is *huge* at $\sqrt{s}$ = 7 TeV !

$\sigma(c\bar{c}) = 6.10 \pm 0.93$ mb [~ 20 x $\sigma(b\bar{b})$]







Goals for 2011, and beyond

Levels of precision - some LHCb examples

Can distinguish three levels of desired precision (with some LHCb examples). Typically measurements appearing at level 1) will then proceed to level 2) and 3)

1) Exploration of promising new territory

Confirm theory to 1st order (e.g. B-factories and CKM-picture)

Look for big effects in promising places: $B_s \rightarrow \mu\mu$
CP-violation in B_s system

2) Down to the level of existing theory

Measurement of CKM-angle γ

3) As well as you possibly can

Null-test of SM, e.g. CP-violation in charm mixing

Out of scientific nobility (difficult argument for the funding agencies)

Hard to know when to stop but never assume 10% is ‘good enough’...

Unwise to assume ~10% (or even 0.1%) is 'good enough'

Courtesy Browder and Soni

"A special search at Dubna was carried out by E. Okonov and his group. They did not find a single $K_L \rightarrow \pi^+ \pi^-$ event among 600 decays into charged particles [12] (Anikira et al., JETP 1962). At that stage the search was terminated by the administration of the Lab. The group was unlucky."

-Lev Okun, "The Vacuum as Seen from Moscow"

BR $(K^0_L \rightarrow \pi\pi) \sim 2 \times 10^{-3}$ Cronin, Fitch et al. , 1964

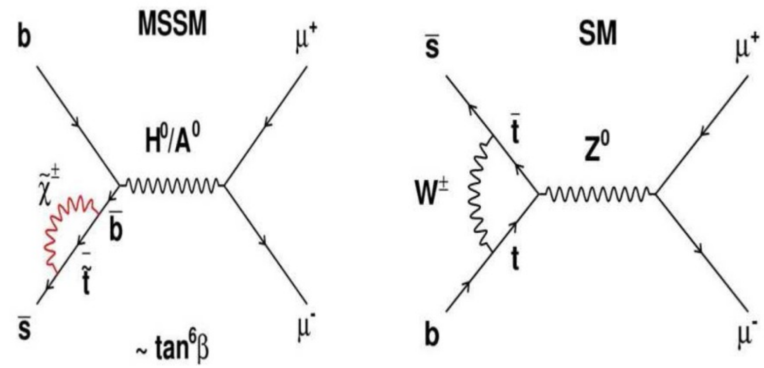
The golden mode: $B_s \to \mu\mu$

B physics rare decay par excellence:

$BR(B_s \to \mu\mu)_{SM} = (3.35 \pm 0.32) \times 10^{-9}$

(Blanke et al., JHEP 0610:003,2006)

Precise prediction (which will improve) !



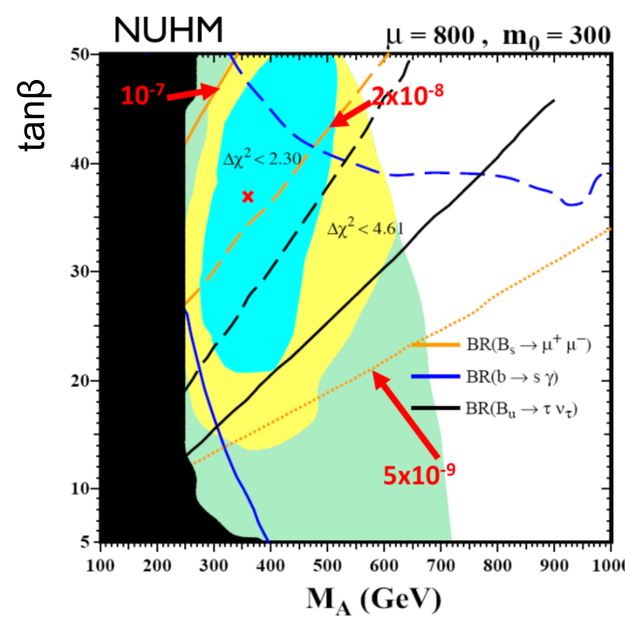
Very high sensitivity to NP, eg. MSSM:

$$Br^{MSSM}(Bq \to l^+l^-) \propto \frac{m_b^2 m_l^2 \tan^6\beta}{M_{A0}^4}$$

One example (Ellis et al., JHEP 0710:092,2007) with NUHM (= generalised version of CMSSM)

- $b \to s\gamma$ and Higgs > 114.4 GeV
  ⟹ M_A > ~ 300 GeV & tanβ < ~50
- (g_μ-2) is 3.4σ from SM
  ⟹ M_A < ~ 500 GeV & tanβ > ~20

} $BR(B_s \to \mu\mu) \approx 2 \times 10^{-8}$



$B_s \to \mu\mu$ at LHCb

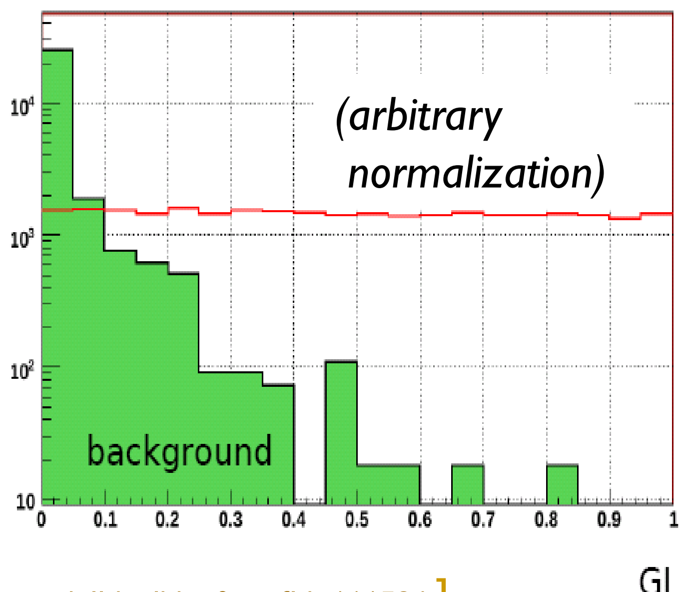
LHCb approach: loose preselection (which is optimised to have similar efficiency for signal and control channels $B_{(s)} \to h^+h^-$, $B^+ \to J/\psi K^+$, $B \to J/\psi K^*$), and then construction of global likelihood

Global likelihood built from:

- 'Geometrical likelihood' (topology & lifetime info)
- Invariant mass likelihood
- Particle id likelihood

Signal calibrated on control channels; background from sidebands. No MC input !

Observation then turned into limit or BR measurement after comparing with known control channel, e.g. $B^+ \to J/\psi K^+$



For this need to know B_s/B^+ production ratio at LHC. Already preliminary measurements of this important 'engineering number' :

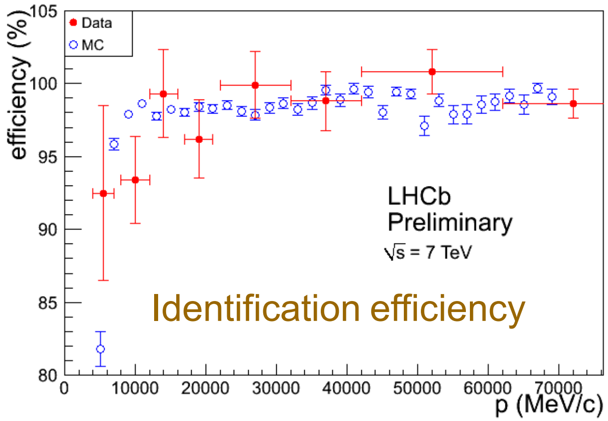
$$f_s/(f_u+f_d) = 0.130 \pm 0.004(\text{stat.}) \pm 0.013(\text{sys.})$$

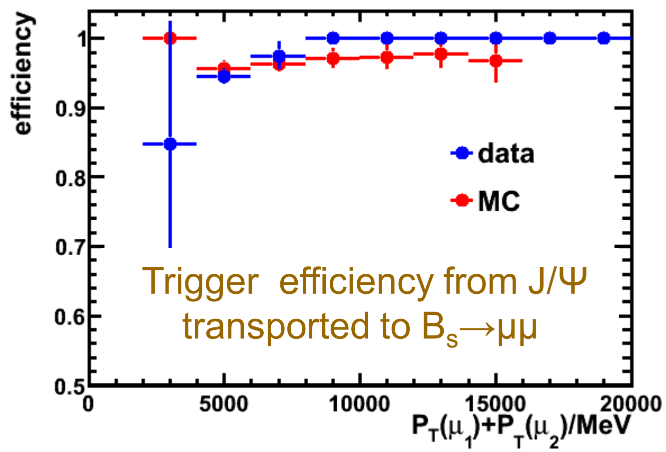
from LHCb semileptonic analysis.

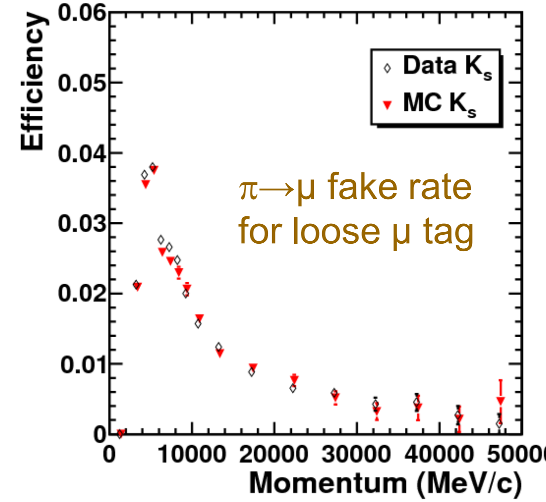
[http://indico.cern.ch/getFile.py/access?contribId=4&sessionId=0&resId=2&materialId=slides&confId=111524]

$B_s \to \mu\mu$ at LHCb: critical analysis inputs

Muon identification, trigger & misidentification performing as expected from MC:

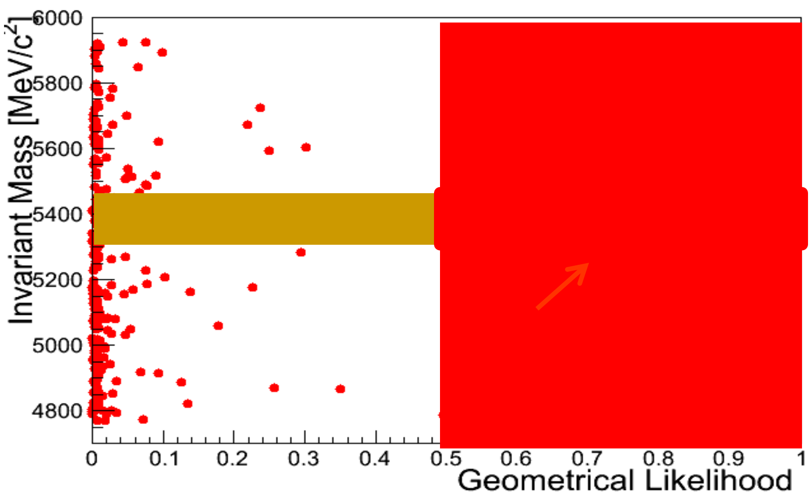


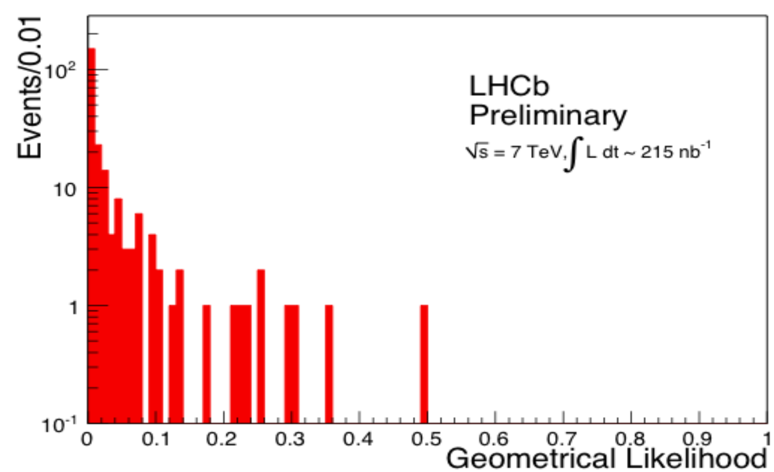




Geometrical likelihood vs invariant mass for 0.2 pb^{-1}:

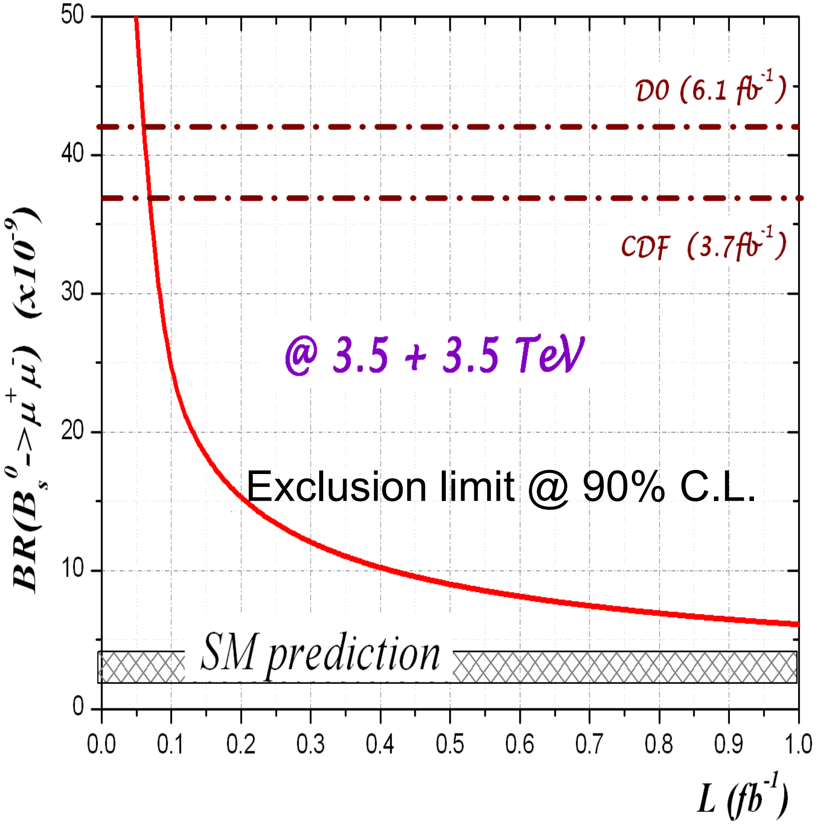
no events in sensitive region and general properties of background as expected

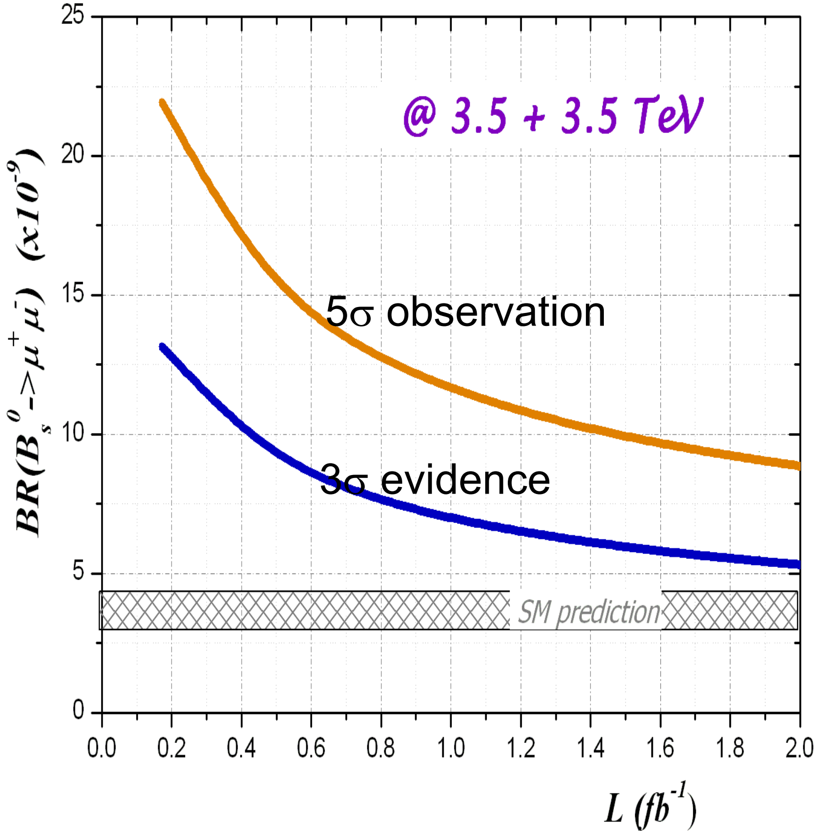




Prospects for $B_s \rightarrow \mu\mu$ at LHCb

Expected sensitivity at LHCb assuming measured $b\bar{b}$ cross-section (292 μb)





LHCb results from 2010 data will be presented in 2011 Spring conferences

Hints of anomalous CPV in B^0_s sector

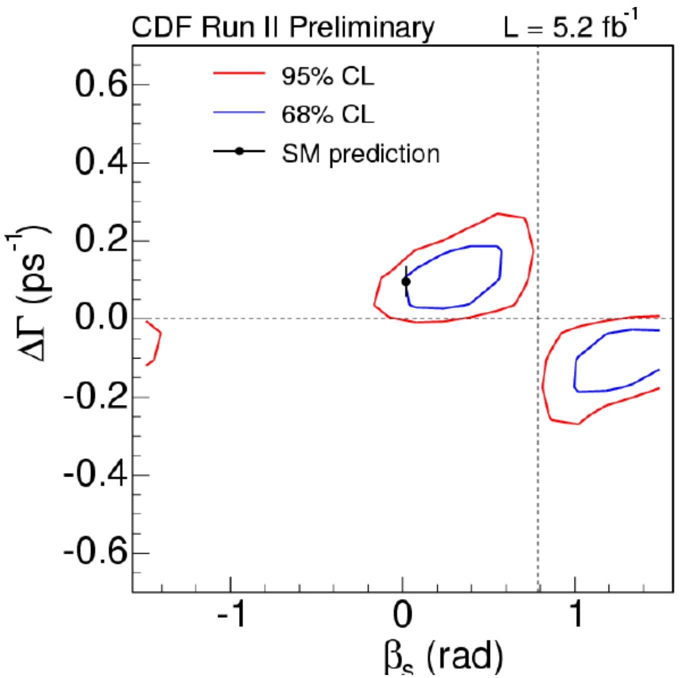
Tevatron has recently initiated CPV studies in B^0_s sector. Leading observables:

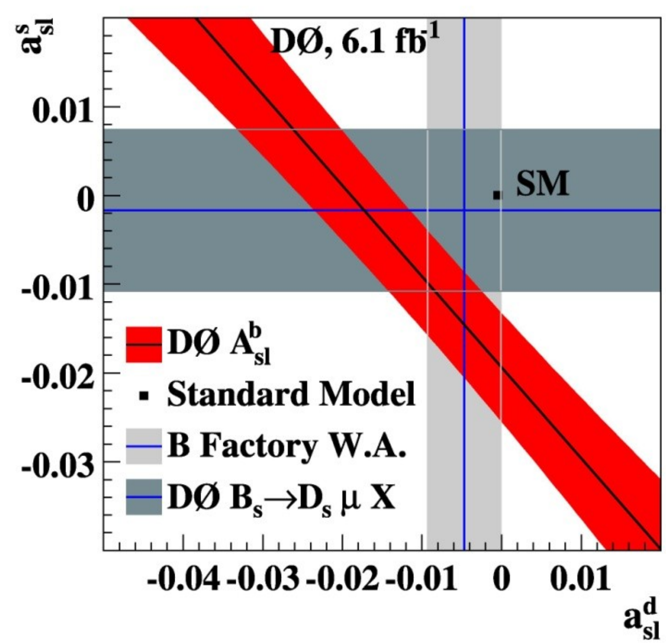
1) CPV in decay-mixing interference – probe with $B^0_s \to J/\Psi\Phi$
2) CPV in mixing – probe with e.g. semileptonic CP-asymmetry

Both very small in SM (especially 2). NP would enhance both simultaneously.

Hints of anomalously large effects in both !

CDF note 10206



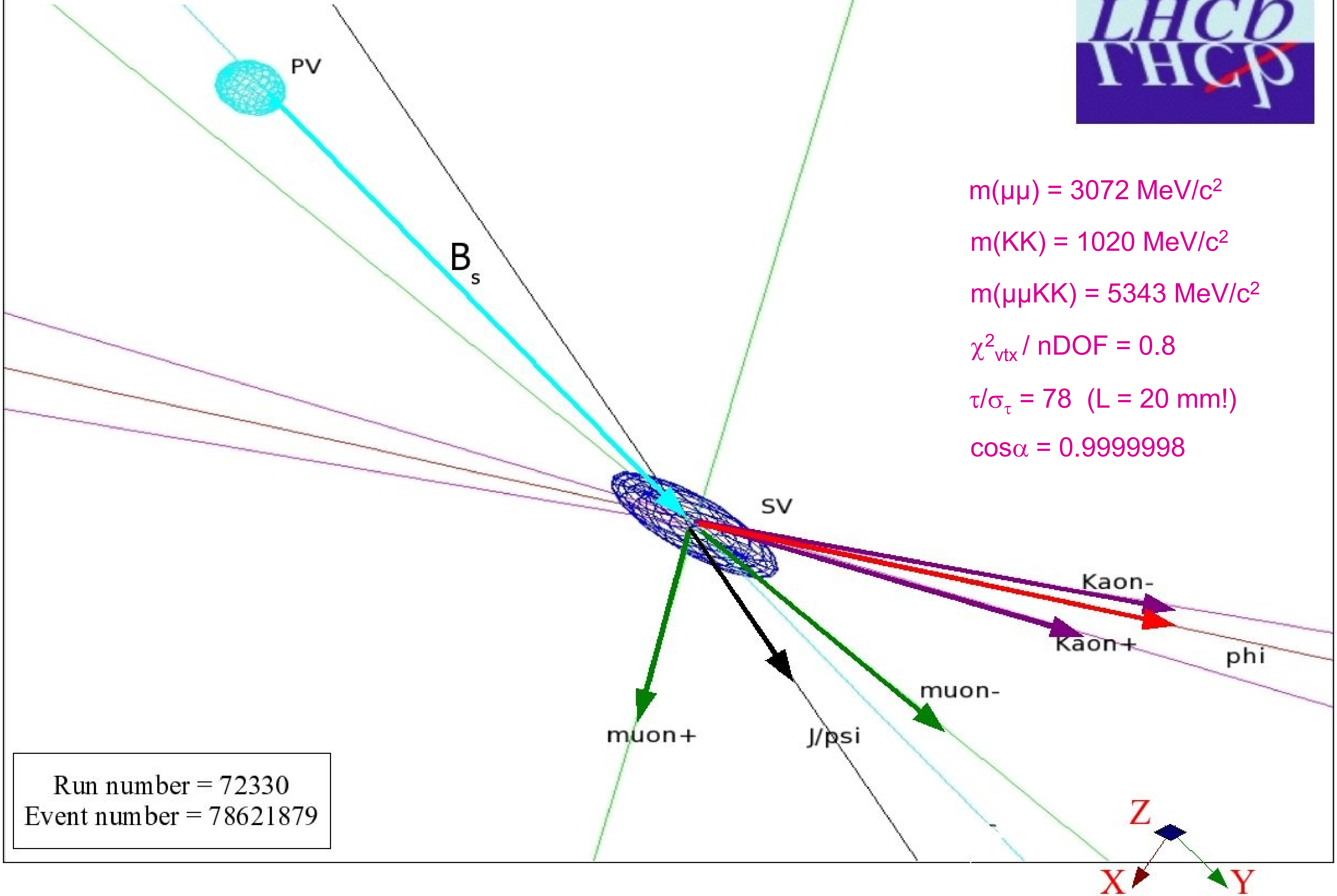


D0, arXiv:1005.2757 [hep-ex]

– One sigma tension (once was larger!), with same picture seen at D0 [D0-6098-CONF]

Three sigma away from SM –

An early LHCb $B^0_s \to J/\Psi\Phi$ event



$m(\mu\mu) = 3072$ MeV/c^2

$m(KK) = 1020$ MeV/c^2

$m(\mu\mu KK) = 5343$ MeV/c^2

χ^2_{vtx} / nDOF = 0.8

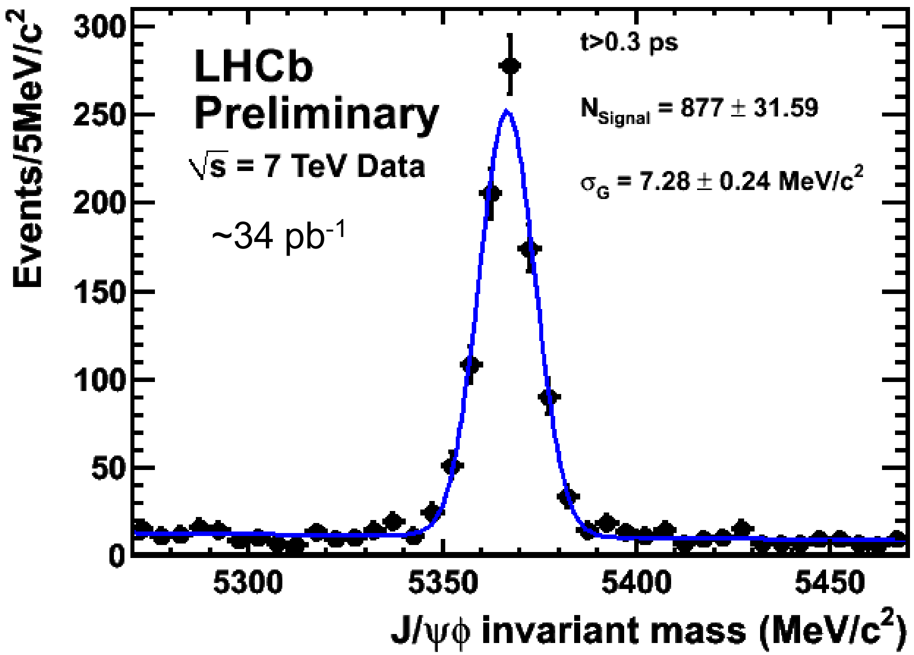
$\tau/\sigma_\tau = 78$ (L = 20 mm!)

$\cos\alpha = 0.9999998$

$B^0_s \to J/\Psi\Phi$ at LHCb

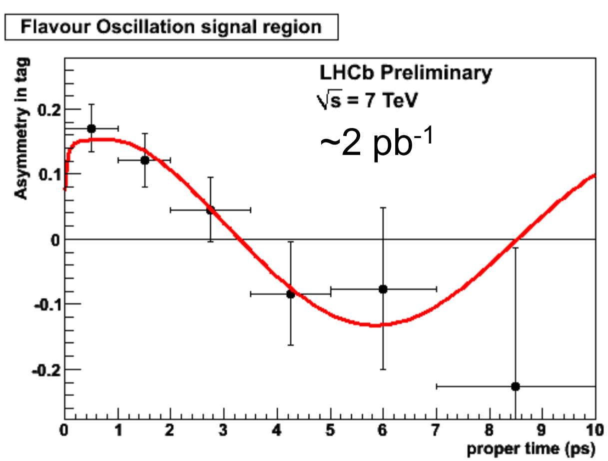
Φ_s, the CP violating phase in $B^0_s \to J/\Psi\Phi$, is the B^0_s analogue of 2β in $B^0_d \to J/\Psi K^0_s$

Events accumulated during the 2010 run at the expected rate



Analysis harder than $B^0_d \to J/\Psi K^0_s$:

- interference between mixing & decay in fast oscillating B^0_s system
- $P \to VV$ decay - need angular analysis to distinguish CP-odd and CP-even



B^0_d oscillations already seen early in run

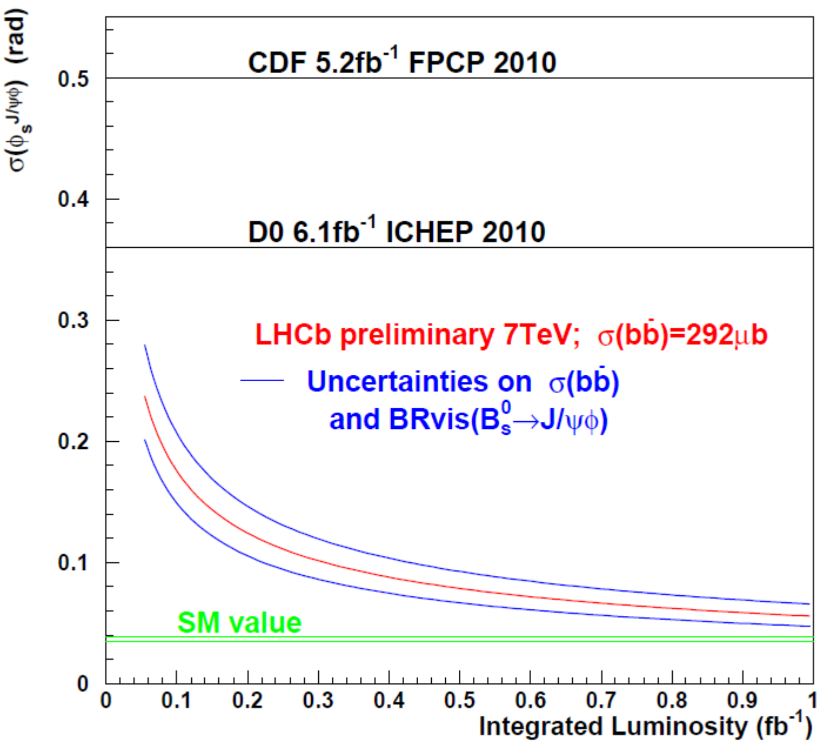
Φ_s prospects at LHCb in 2010

Sensitivity to Φ_s at LHCb vs. integrated luminosity using $B_s \rightarrow J/\Psi\Phi$ alone

Reality checklist

- Measured cross-section:
  consistent with expectations
- Rate of signal events:
  consistent with expectations
- Proper time resolution:
  ~50 fs, dilution 13% w.r.t. nominal
- Tagging performance:
  presently being optimised

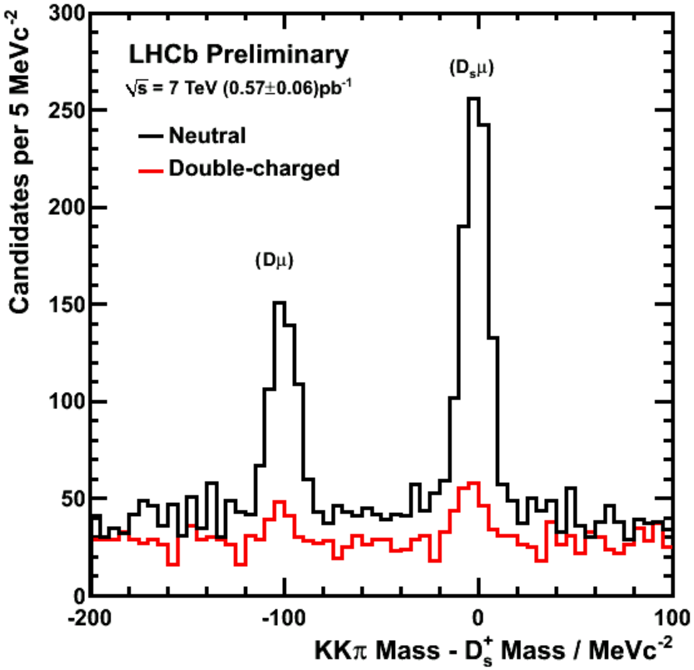
Promising, but lots of hard work ahead!
May already prove possible to say *something* interesting at Moriond 2011.

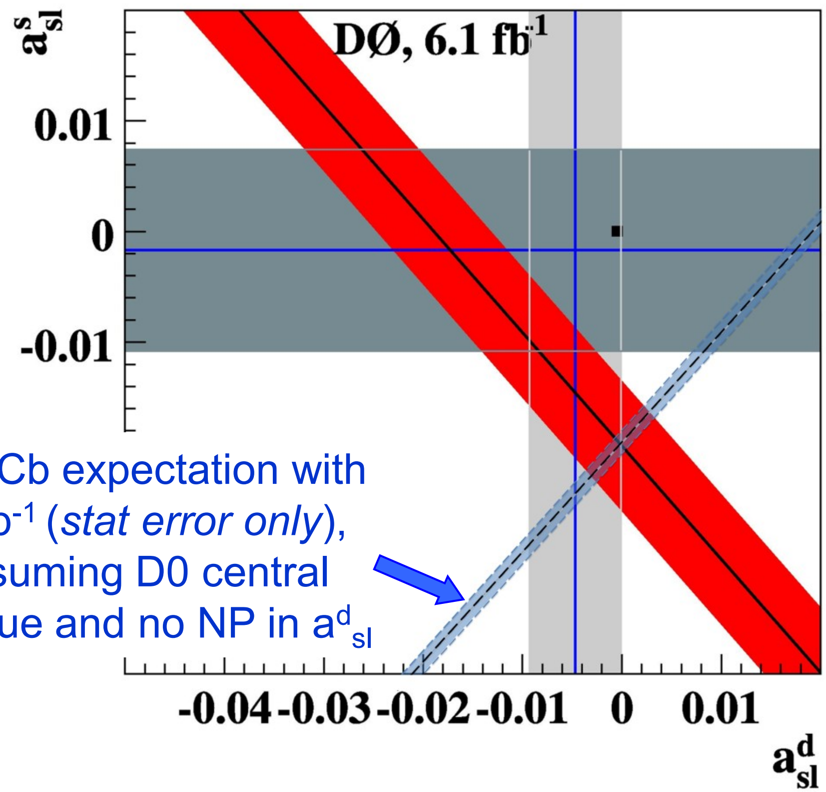


Performance will be augmented
using other modes, e.g. $B_s \rightarrow J/\Psi f_0(\pi\pi)$ – CP eigenstate, so simpler analysis

a^s_{sl} & a^d_{sl} at LHCb

LHCb proposes to measure a^s_{sl} - a^d_{sl}, by determining the difference in the asymmetry measured in $B_s \rightarrow D_s(KK\pi)\mu\nu$ & $B^0 \rightarrow D^+(KK\pi)\mu\nu$ - same final state suppresses detector biases. Provides orthogonal constraint to D0 dileptons.

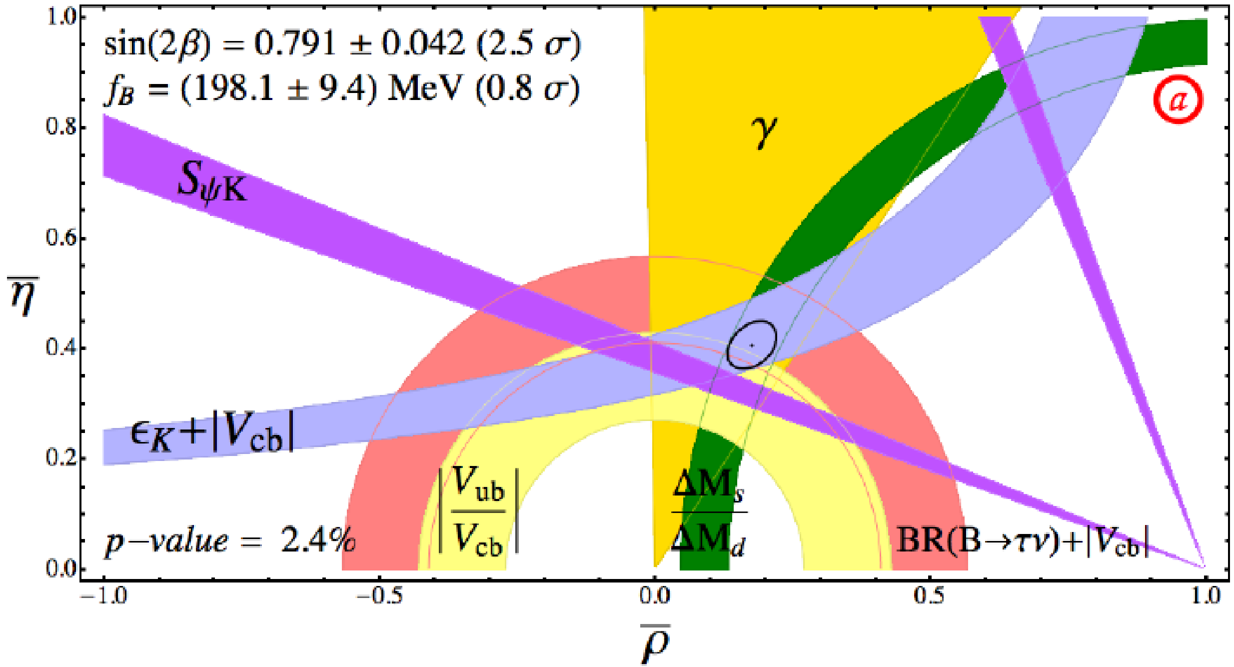




Events already being accumulated

Tension in CKM-fit

Achievement of B-factories has been to validate CKM-mechanism as dominant source of CP-violation in quark sector. But New Physics may still contribute to B^0 observables at 10-20%. Indeed unitarity triangle does display some tension...



Lunghi and Soni, arXiv:1010.6069 [hep-ph]

Higher precision needed in all these observables, especially angle γ

In this analysis $\gamma = (74 \pm 11^o)$. CKMfitter has $\gamma = (71^{+21}_{-25})^o$

Measuring γ at LHCb

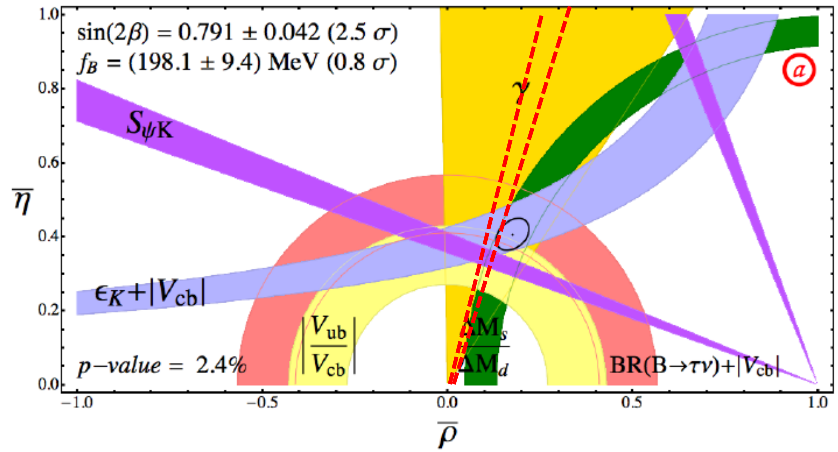
Important goal of LHCb: precision ($\sim$1-2°) measurement of tree level γ

Present precision on indirect prediction is ~ 4° – will improve as does lattice QCD

Advantages of LHCb vs e^+e^-:

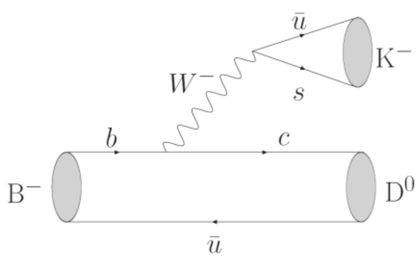
1. High statistics !

LHCb with 5-10 fb^{-1} ?

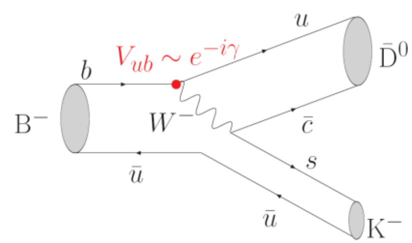


2. No need for flavour tagging with time integrated strategies, e.g. $B^+ \to DK^+$

$B^- \longrightarrow D^0 K^-$



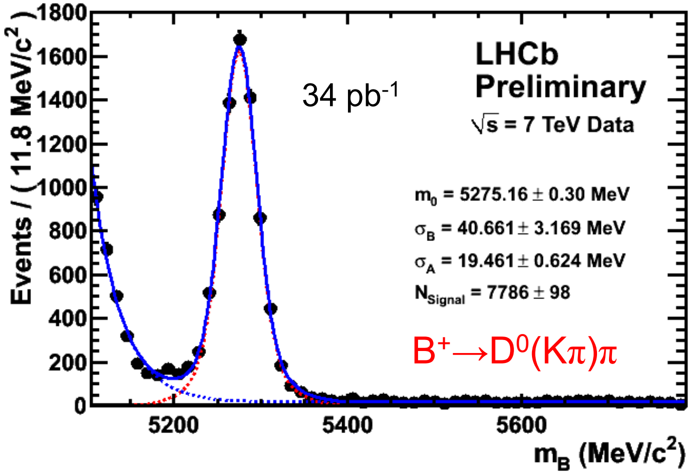
$B^- \longrightarrow \overline{D}^0 K^-$

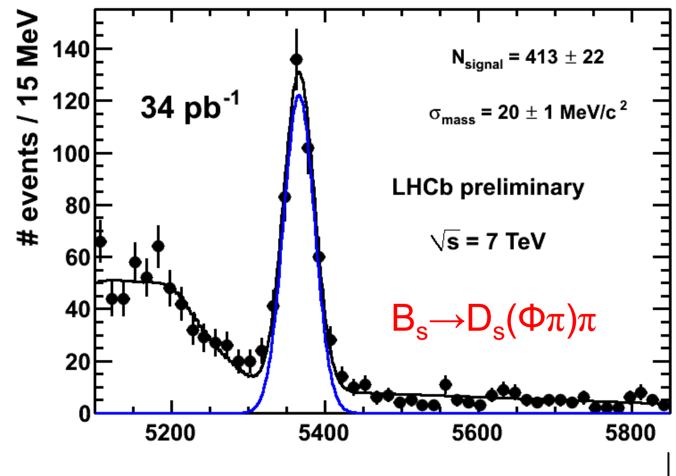


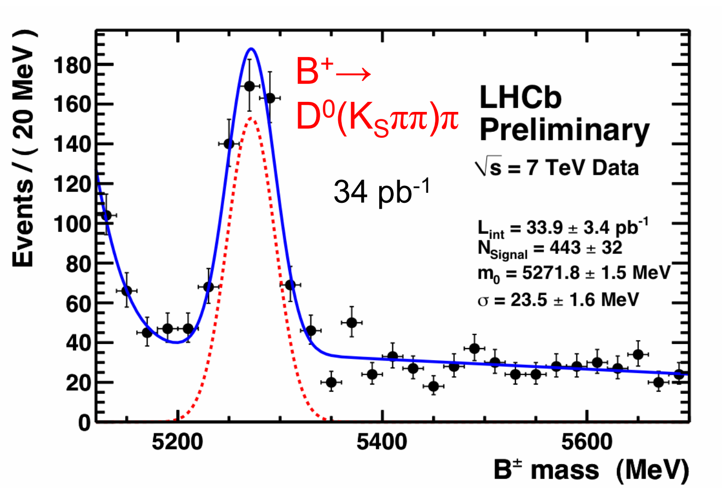
Reconstruct D^0,$\overline{D}^0$ in same final state, e.g. $K\pi$, KK, $K^0{}_S\pi\pi$

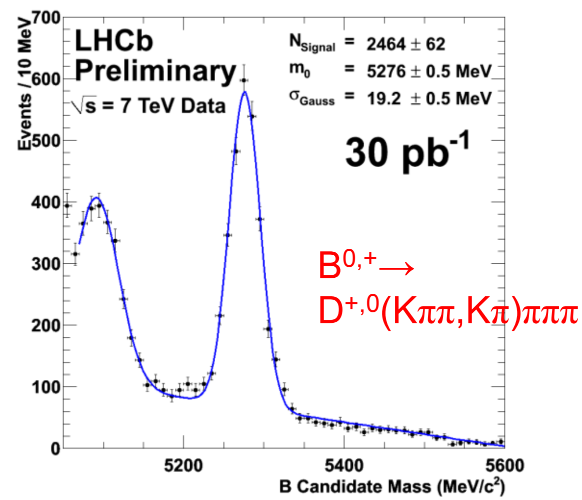
3. Time dependent measurements with B_s mesons, e.g. $B_s \to D_s K$

First ‘B→Dh’ signals at LHCb









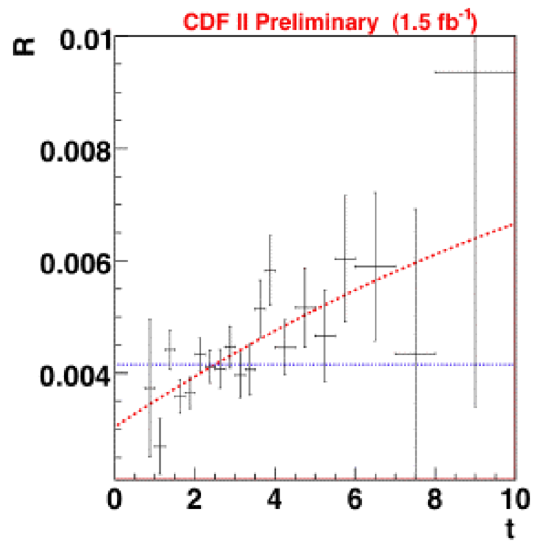
Very clean – 2011 data will allow for significant improvement on knowledge of γ

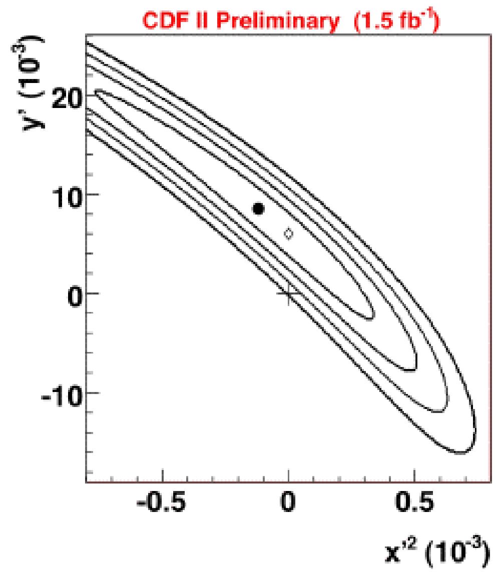
Charm – the new frontier

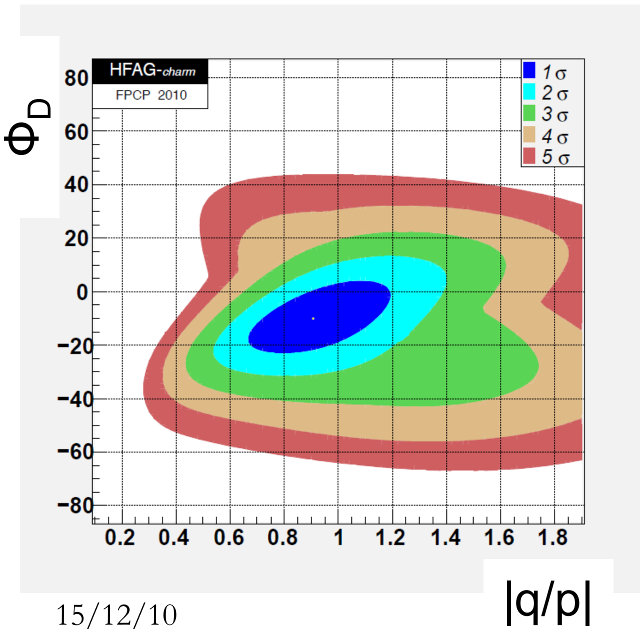
Discovery of charm mixing one of highlights of recent years.

Hadron colliders have played their part – CDF WS Kπ study [PRL 100 (2008) 121802]

Next, and most exciting goal, is to find CPV, both direct and in mixing related phenomena







Present constraints on φ_D & (|q/p|-1) are weak.

Significant progress requires order of magnitude improvement in sensitivity to mixing phenomena.

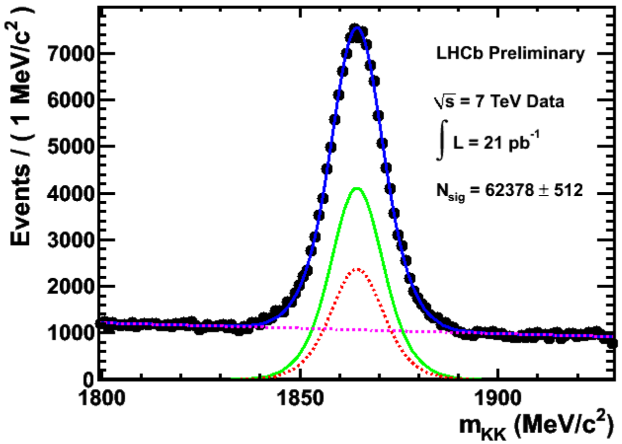
Feasible at LHCb in 2010-11 run !

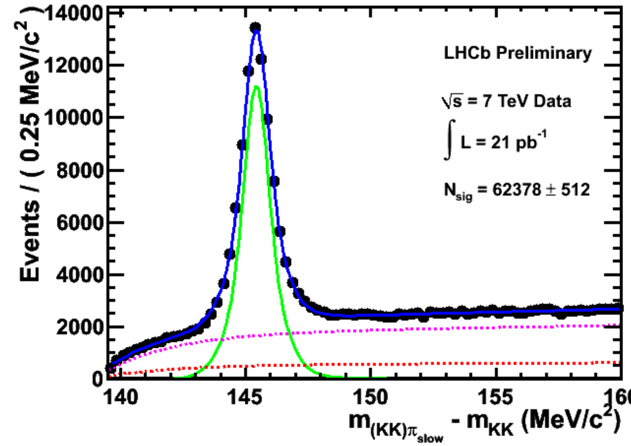
Charm at LHCb

LHCb yields in two-body D^0 decays already very similar to that of B-factories

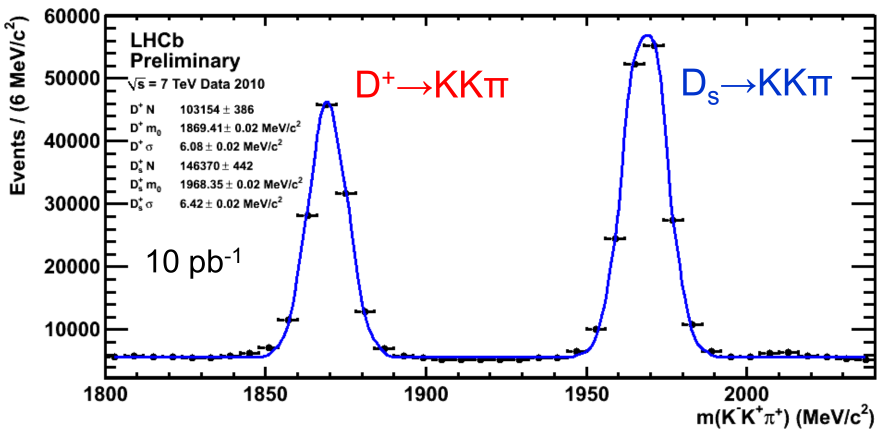
e.g. $D^* \to D^0\pi, D^0 \to KK$

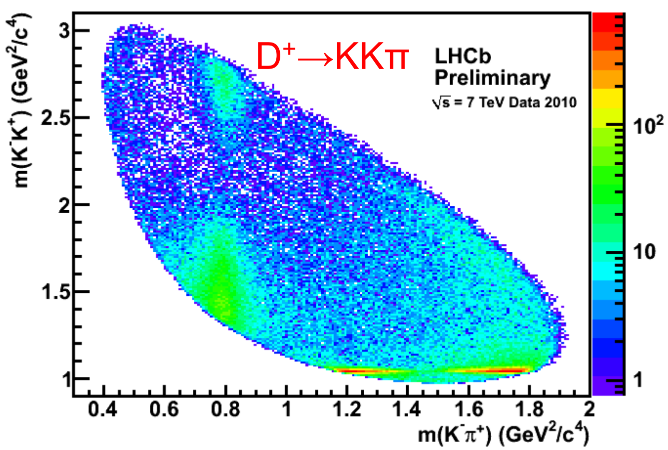
Use this sample to measure the time-dependent CP-observable 'A_Γ'





Also use large (& pure) yields in e.g. $D^+ \to KK\pi$ to look for direct CPV in Dalitz space





A taste beyond flavour

- PDF and EW studies at LHCb

For more information see Tara Shears talk on Friday morning

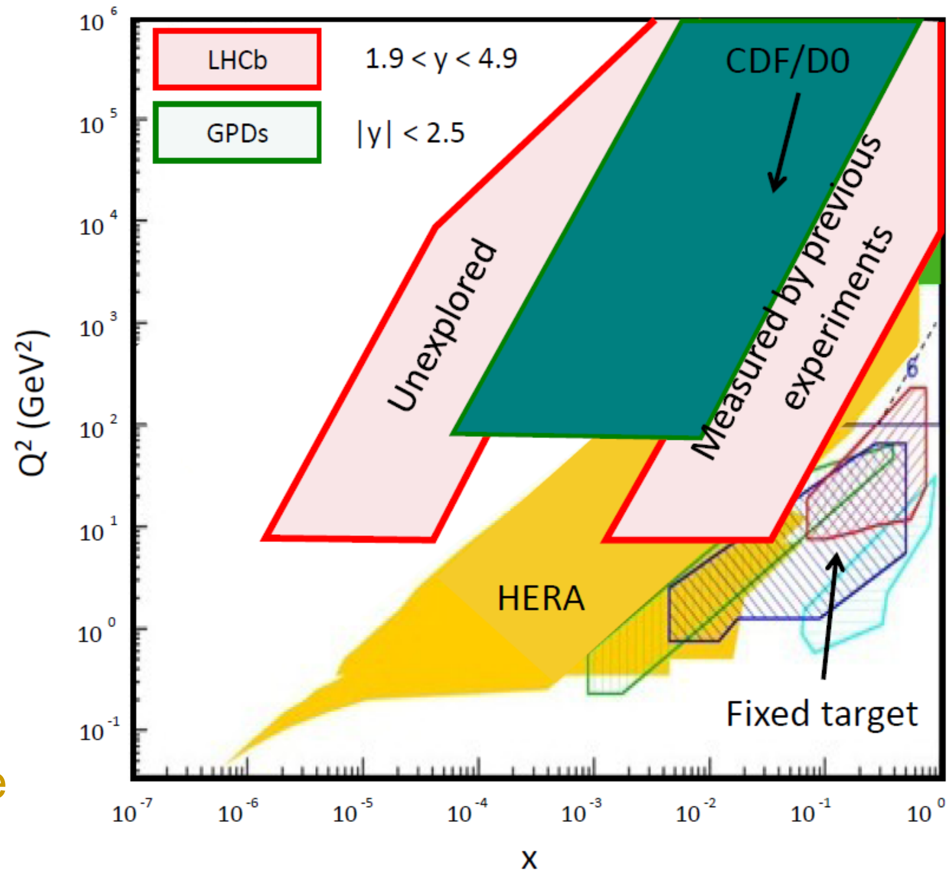
PDF studies at LHCb

LHCb's forward acceptance provides very interesting possibilities for PDF studies.

Take large x from one proton and a small x from the other

Can probe the low-x, high Q^2 region inaccessible to other experiments

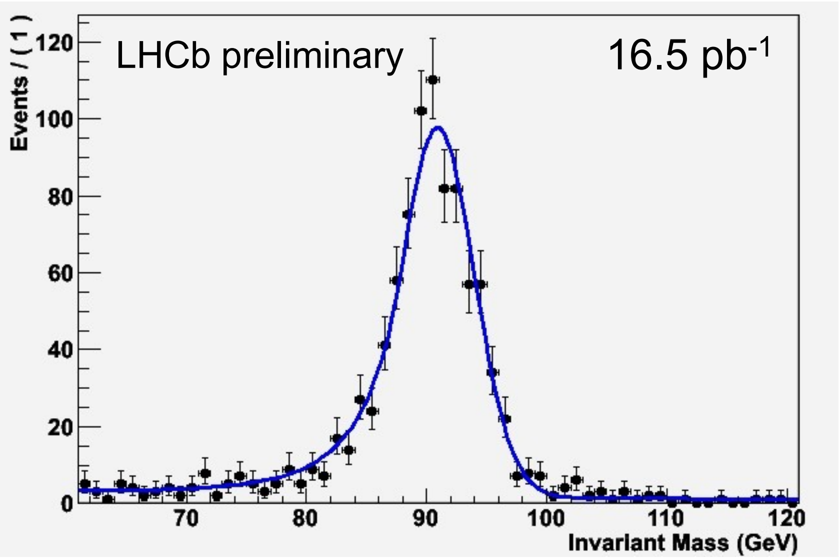
PDF predictions for this region are more sensitive to model changes than in central acceptance

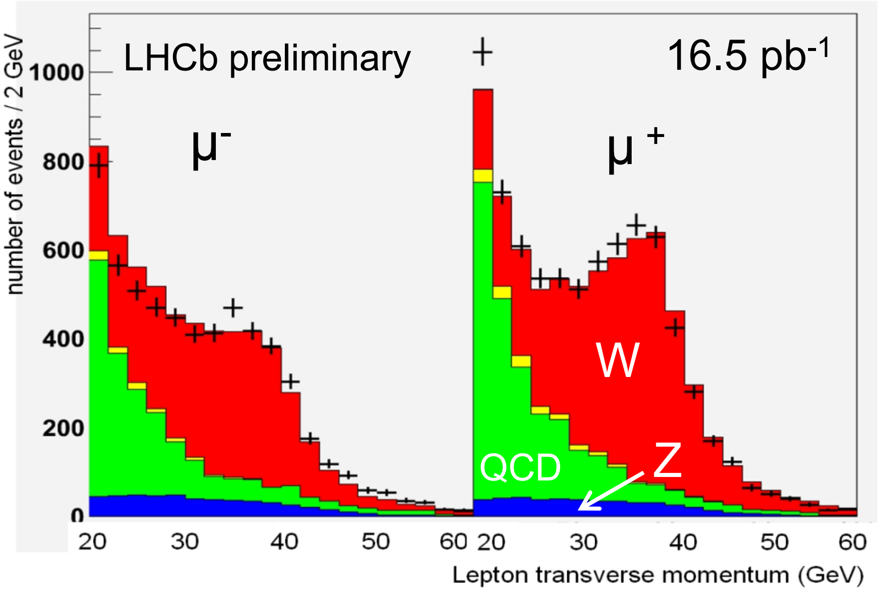


Explore with W,Z and low-mass Drell-Yan production

First W and Z studies at LHCb

First W/Z studies at LHCb: ~12,000 W events and ~ 800 Z events in 16.5 pb^{-1}

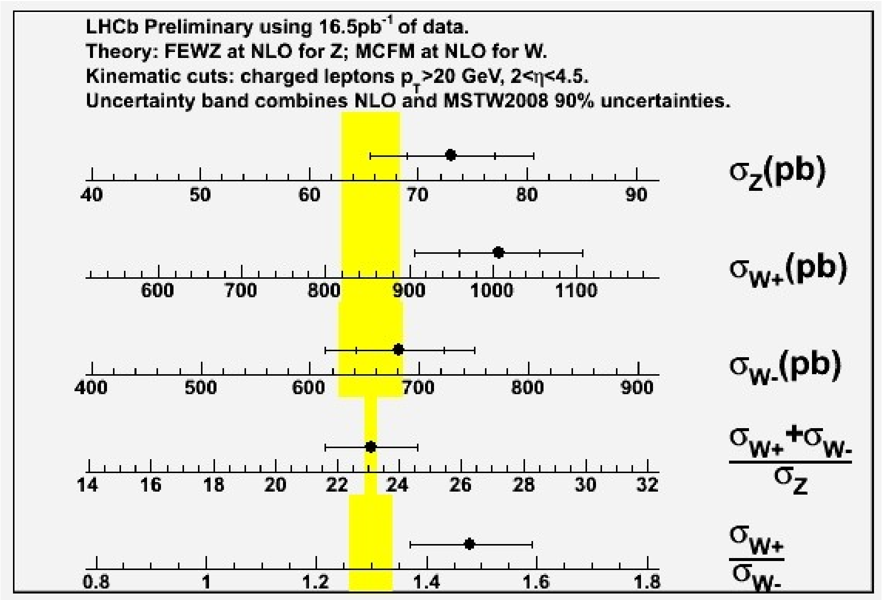




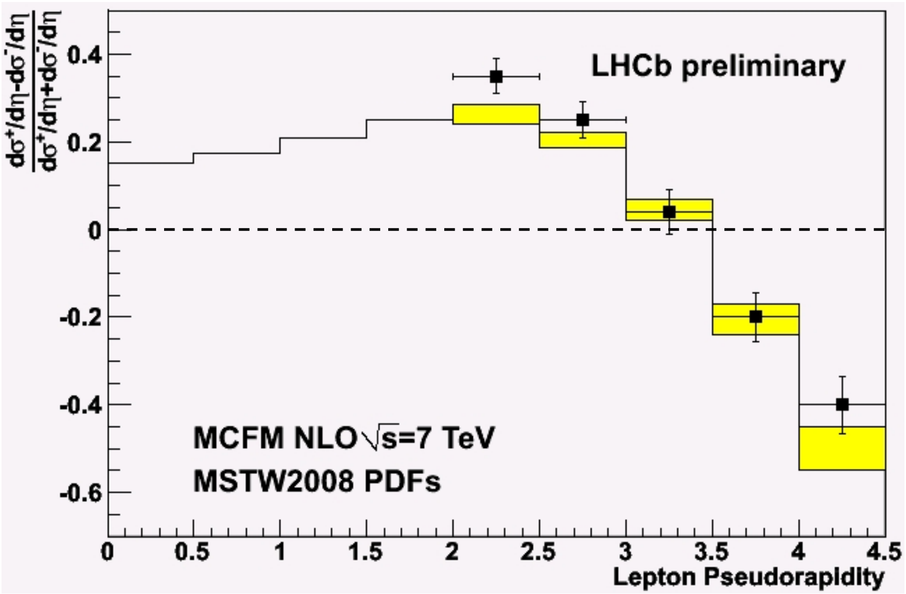
Perform preliminary measurement of x-sections, and W charge asymmetry vs η

Preliminary W and Z results

Cross-section results and ratios



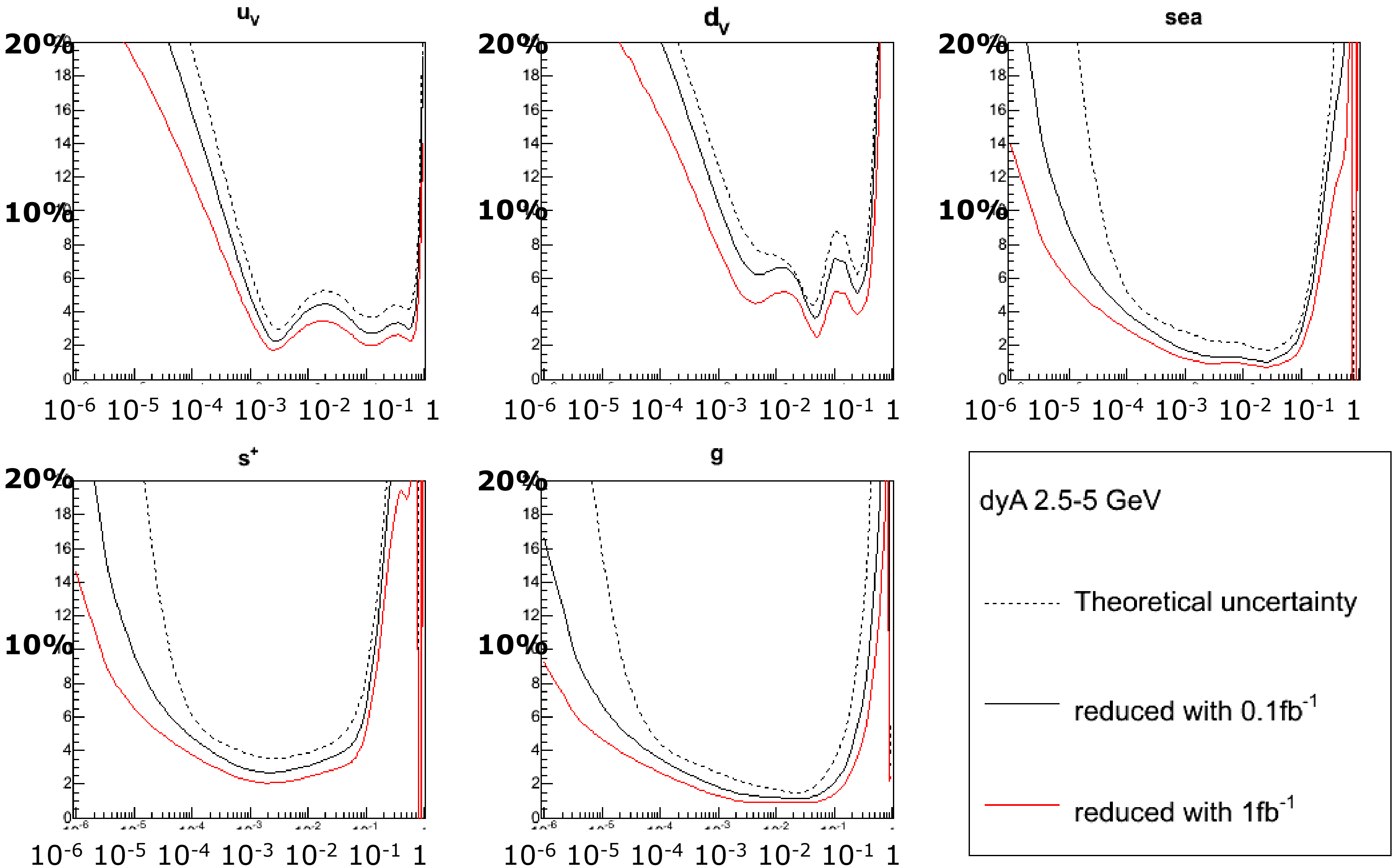
W charge asymmetry vs η



These W,Z data may be used both to test SM, and constrain PDFs.

Even more interesting input to PDF studies will come from low mass (< 10 GeV/c^2) Drell-Yan, where LHCb has good acceptance.

Current uncertainty on MSTW08 PDFs and projections with 0.1 fb^{-1}, 1 fb^{-1} of very low mass $\gamma^* \to \mu^+\mu^-$ at 7 TeV



Significant improvements possible with modest amount of data !

Conclusions and prospects

Operation

LHCb managed to take and process high quality data during 2010, despite extreme pileup conditions.

Early period of 2011 run may be similar, but situation will ameliorate as number of bunches rises. Note we will not follow the GPDs to high luminosity !

Physics

The 2010 integrated luminosity already gives LHCb the statistical precision to match B-factories and Tevatron in several key measurements.

2011 will allow for exciting prospects of finding New Physics in these and other areas. All anticipated discoveries rely on measurements!

Much can be done with existing experiment (~10 fb^{-1}), but an upgraded detector with fully software trigger and the ability to run at 10^{33} is needed in the long-term

Unique acceptance offers tantalising possibilities beyond flavour physics !