Imperial College
London

LHCb results and outlook

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Durham 15-17 September 2010

Outline

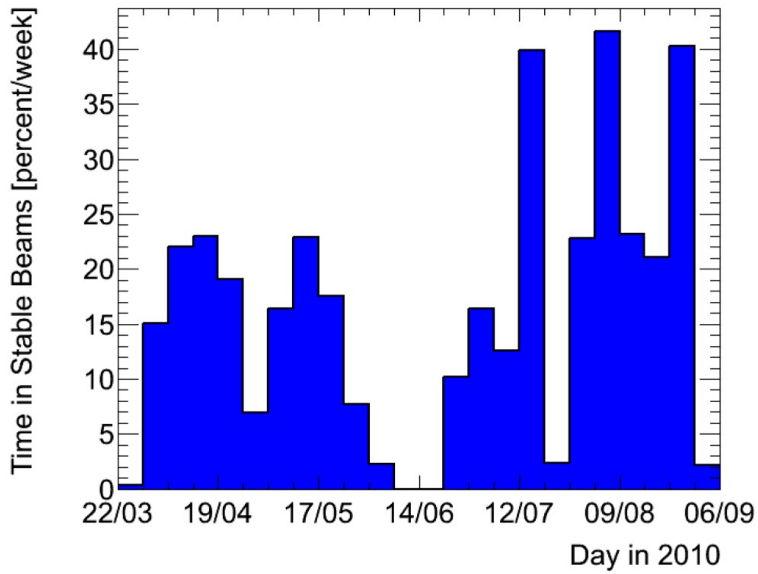
- Status of the the LHC and the LHCb experiment
- The b production cross section
- The core physics of LHCb
  - Validation of our analysis strategy
  - What to expect from first run
  - Where do we need lattice QCD input?
- Will focus on areas where we expect results from first run and where input from Lattice QCD is relevant
- Many areas where improved LHCb results and improved lattice results together will improve CKM fits
  - Not mentioned further here

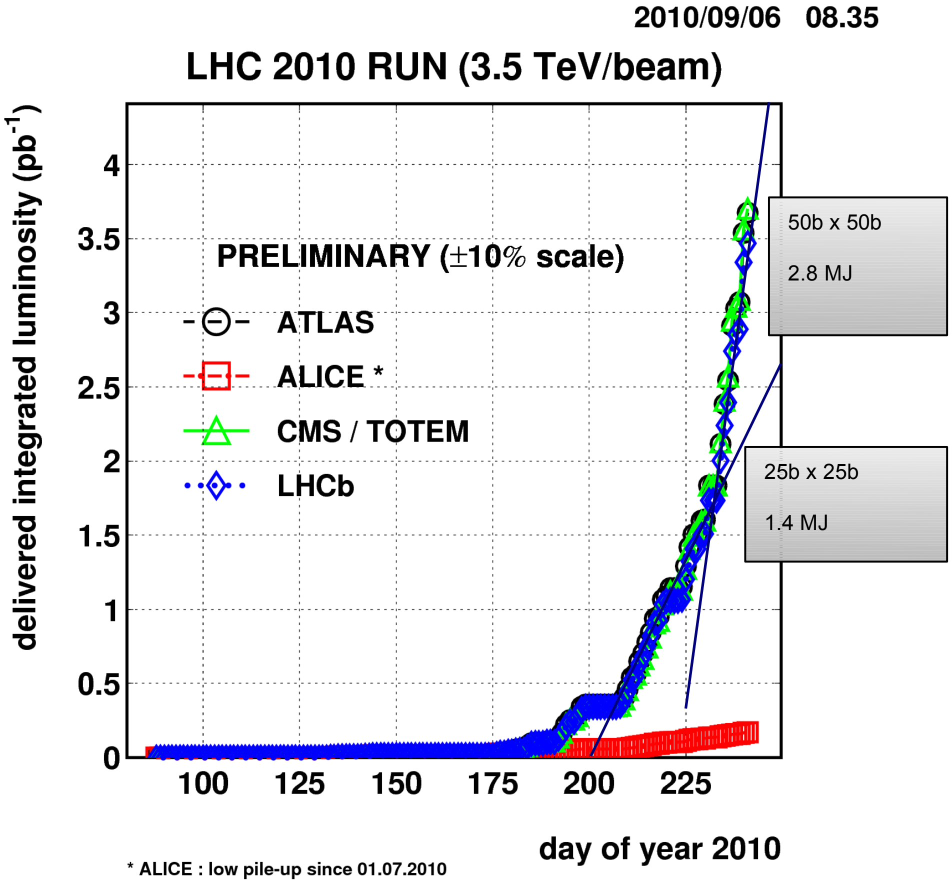
Status of the LHC

First collisions in 2009 at 900 GeV CoM energy

Since March 2010 collisions at 7 TeV CoM

Luminosity now is around 10^{31} cm^{-2}s^{-1}





Status of the LHC

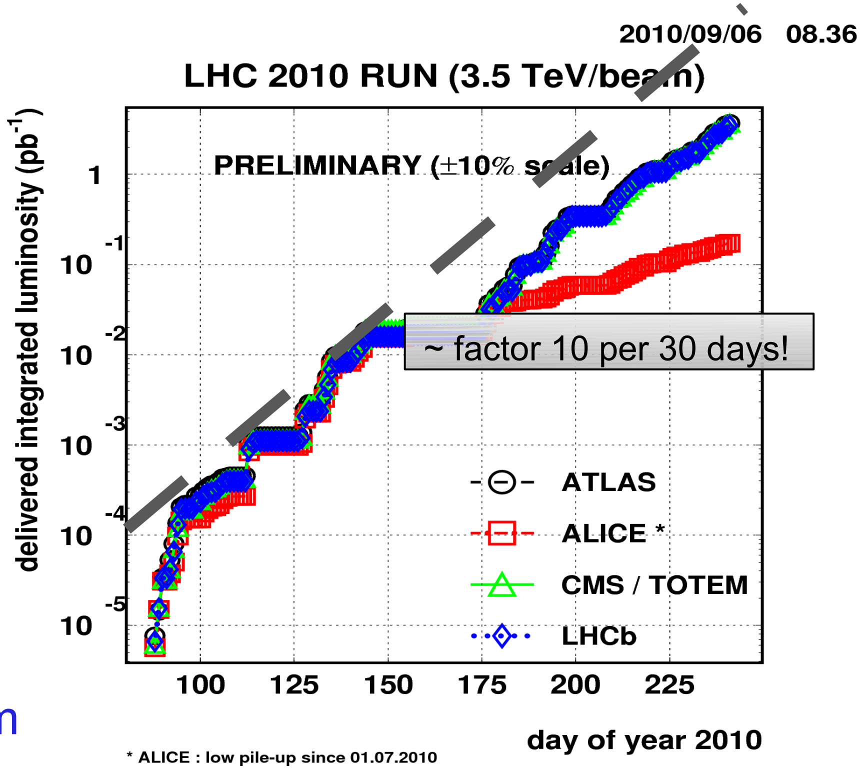
Goal for 2010 is to achieve 10^{32} $cm^{-2}s^{-1}$

- This is within a factor 2-5 of the nominal luminosity for LHCb

Steady running in 2011 will give around 1 fb^{-1}

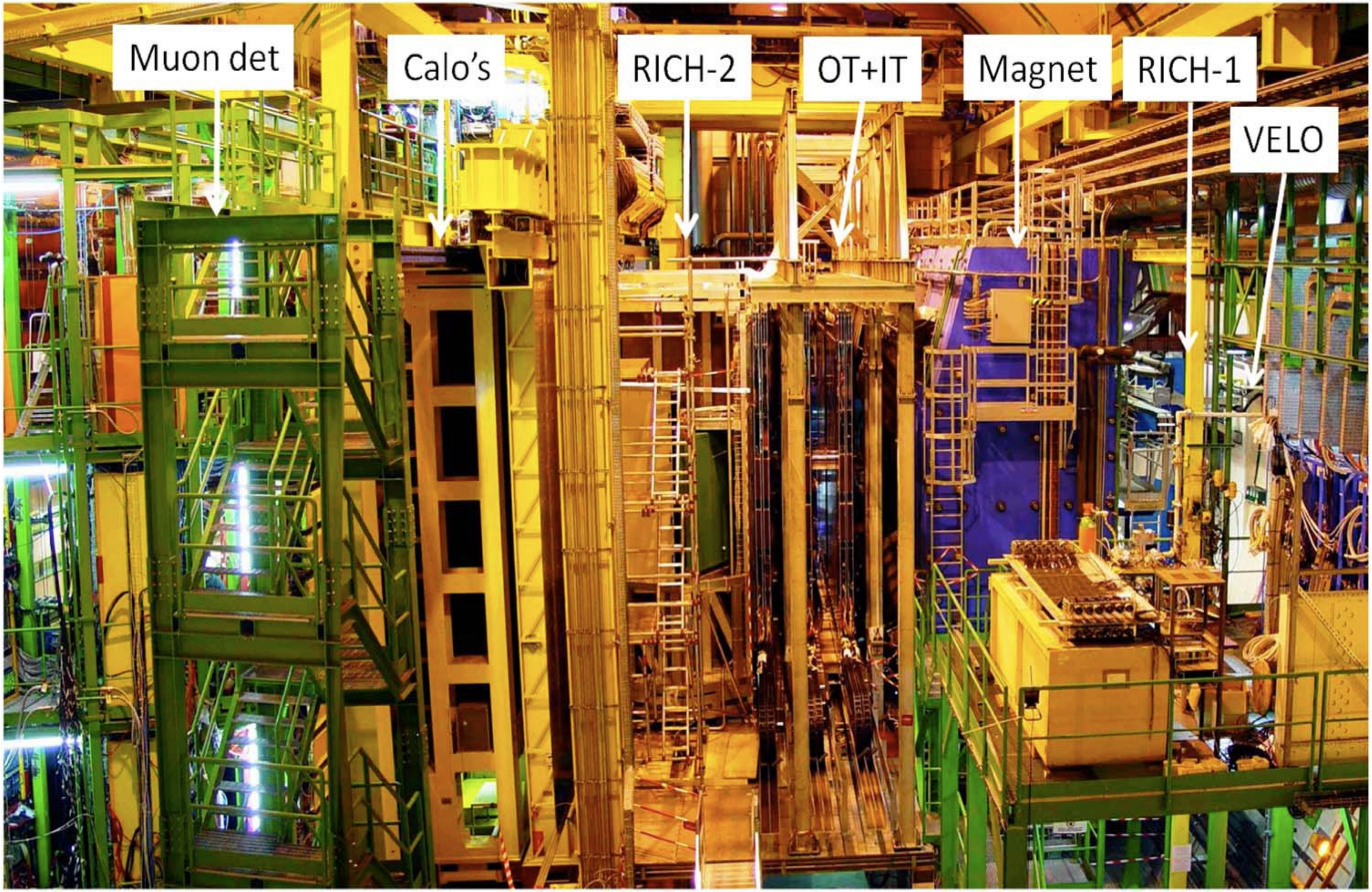
- This is O(10%) of integrated luminosity to achieve full LHCb physics programme

- ... well below 1% for ATLAS/CMS

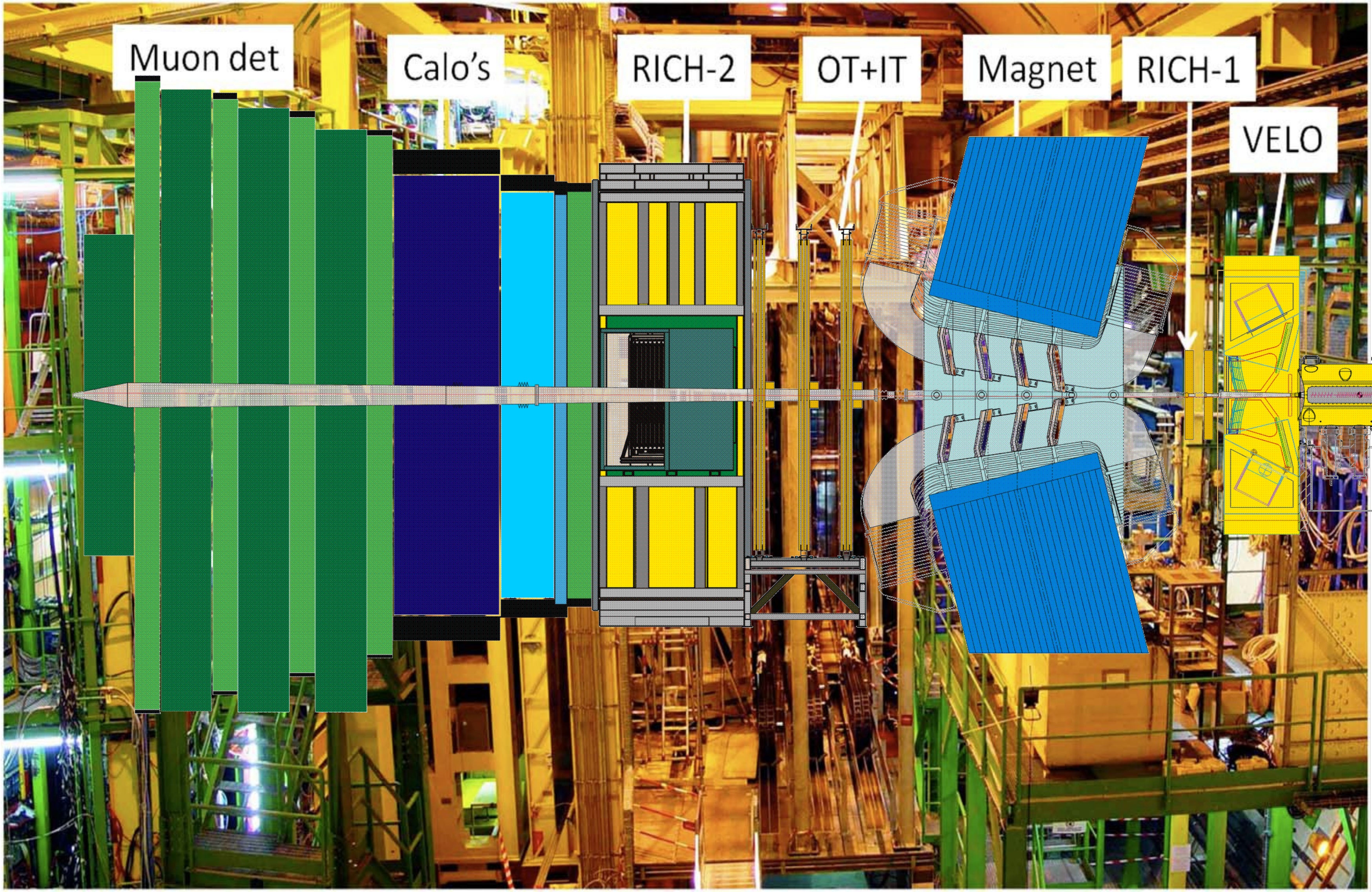


Figures from LHC commissioning team

LHCb layout



LHCb layout

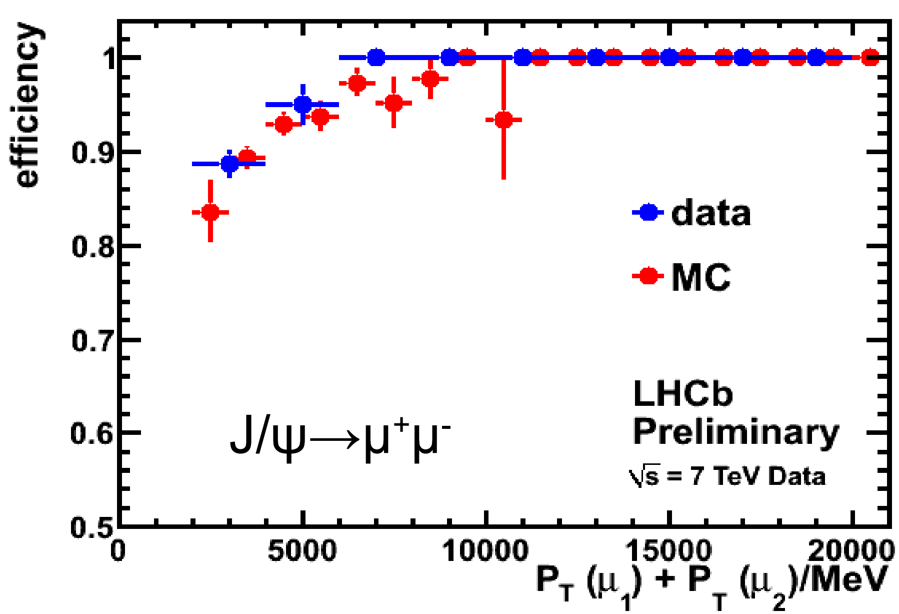


LHCb detector performance

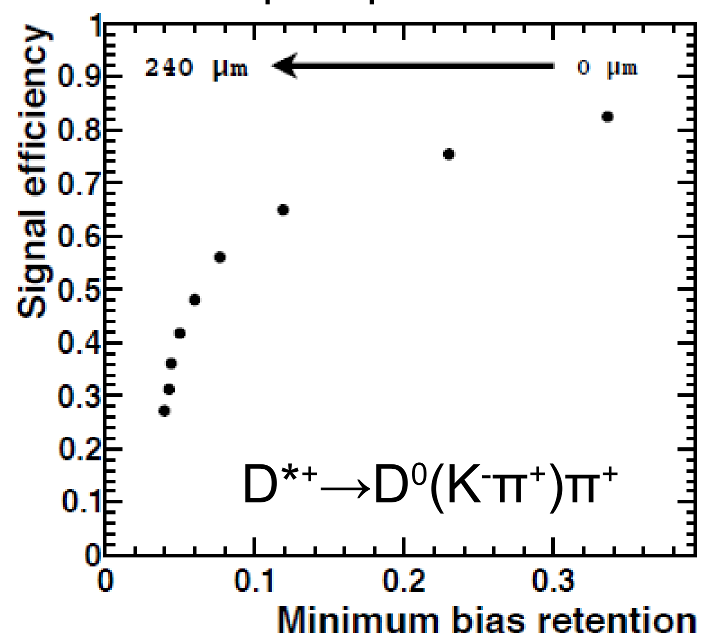
The key issues for achieving heavy flavour results at a hadron machine are excellent performance for:

- Trigger
  - To keep the correct events given huge minimum bias cross section
- Vertexing

L0 muon trigger



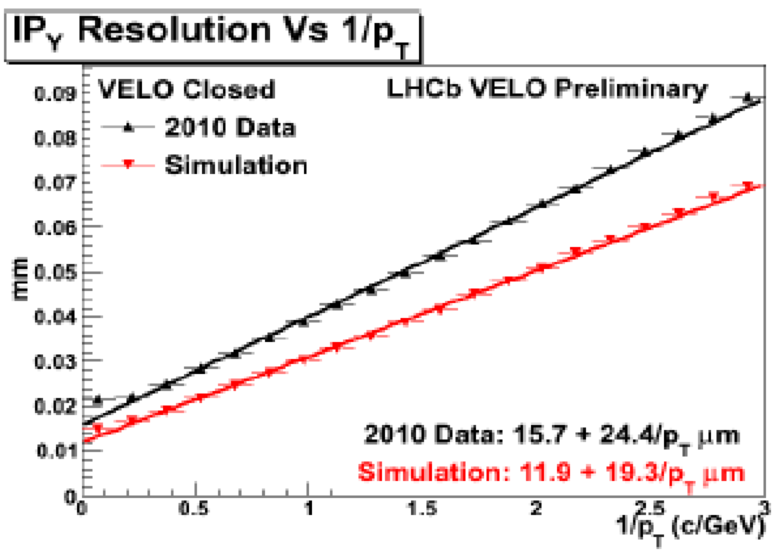
L0 hadron &
HLT Impact parameter

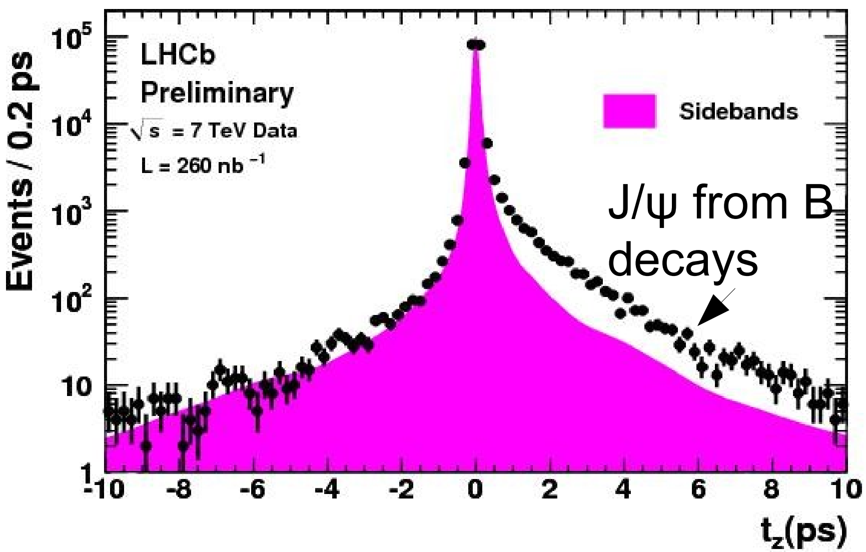


LHCb detector performance

The key issues for achieving heavy flavour results at a hadron machine are excellent performance for:

- Vertexing
  - To select final states cleanly and provide lifetime information
- Trigger



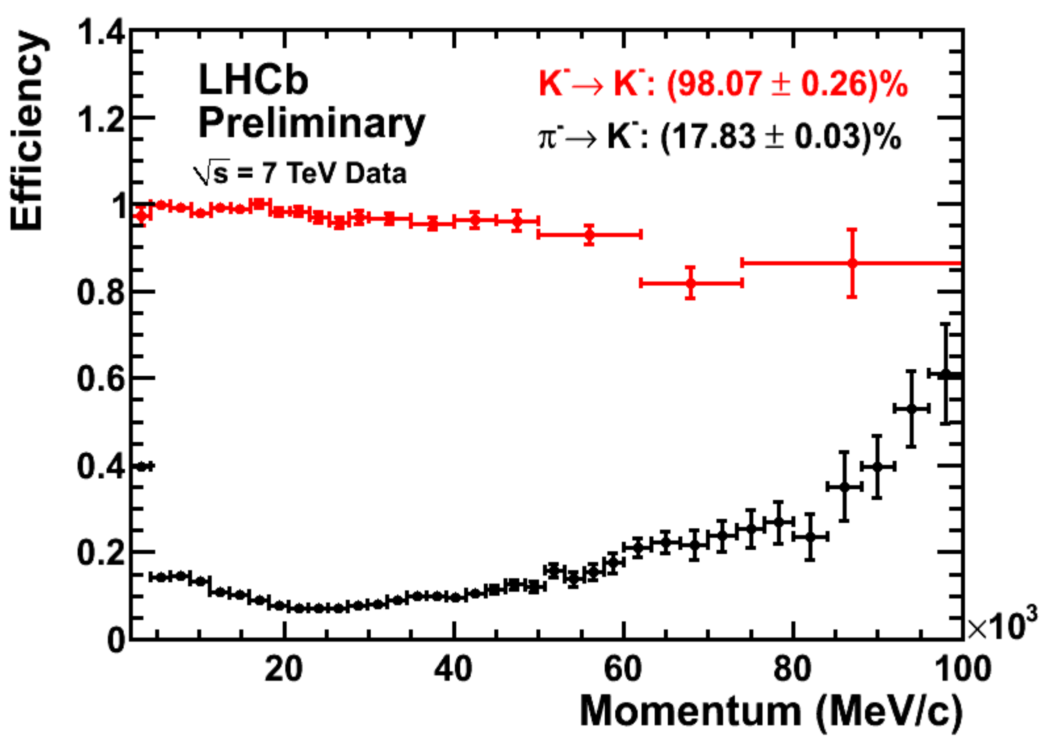


- Tracking
  - As background in most cases is proportional to mass resolution

LHCb detector performance

The key issues for achieving heavy flavour results at a hadron machine are excellent performance for:

- Hadron identification (K,π,p)
  - For separation of states such as Bs → D_sK and D_sπ



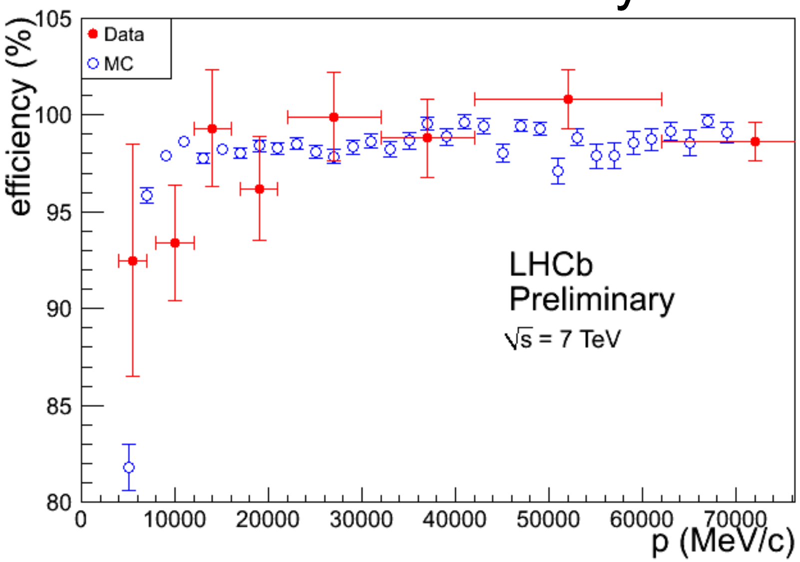
LHCb detector performance

The key issues for achieving heavy flavour results at a hadron machine are excellent performance for:

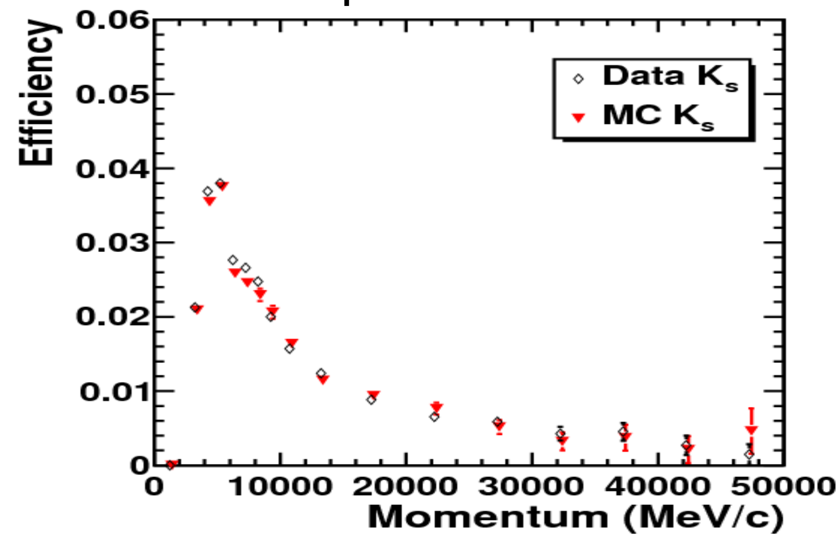
- Lepton identification (μ,(e))
  - For pure identification of states such as $B_s \rightarrow \mu\mu$

- Trigger

Muon efficiency



π to μ contamination

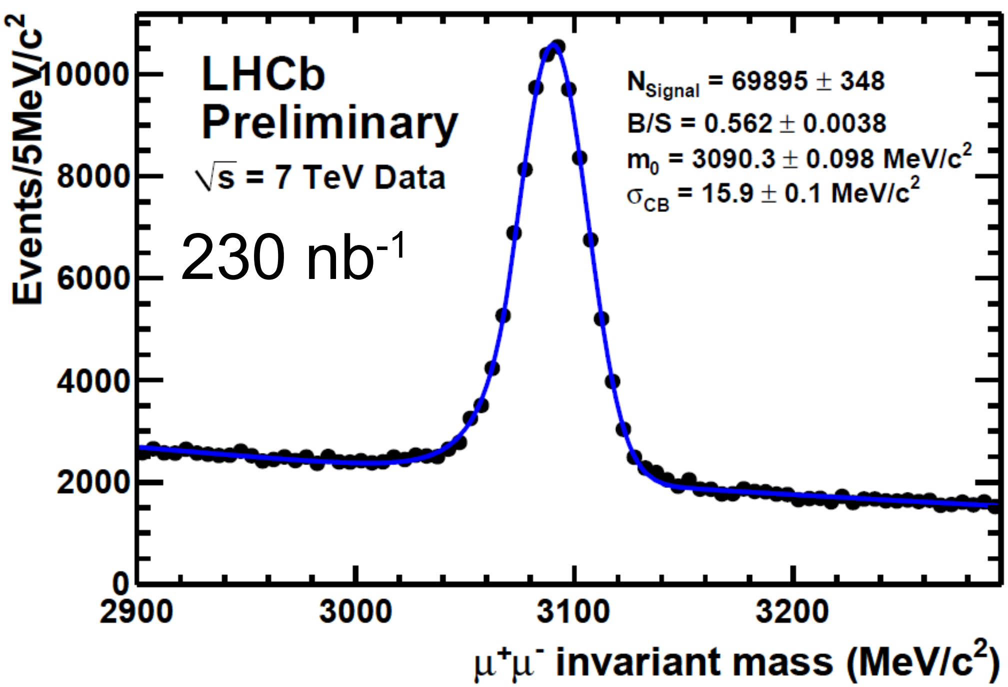


resolution

LHCb detector performance

The key issues for achieving heavy flavour results at a hadron machine are excellent performance for:

- Tracking
  - As background in most cases is proportional to mass resolution
- Trigger
  - To ke ... ias cross secti...
- Vertexi...
  - To se ... nformation
- Hadron
  - For s ... π
- Lepton
  - For p



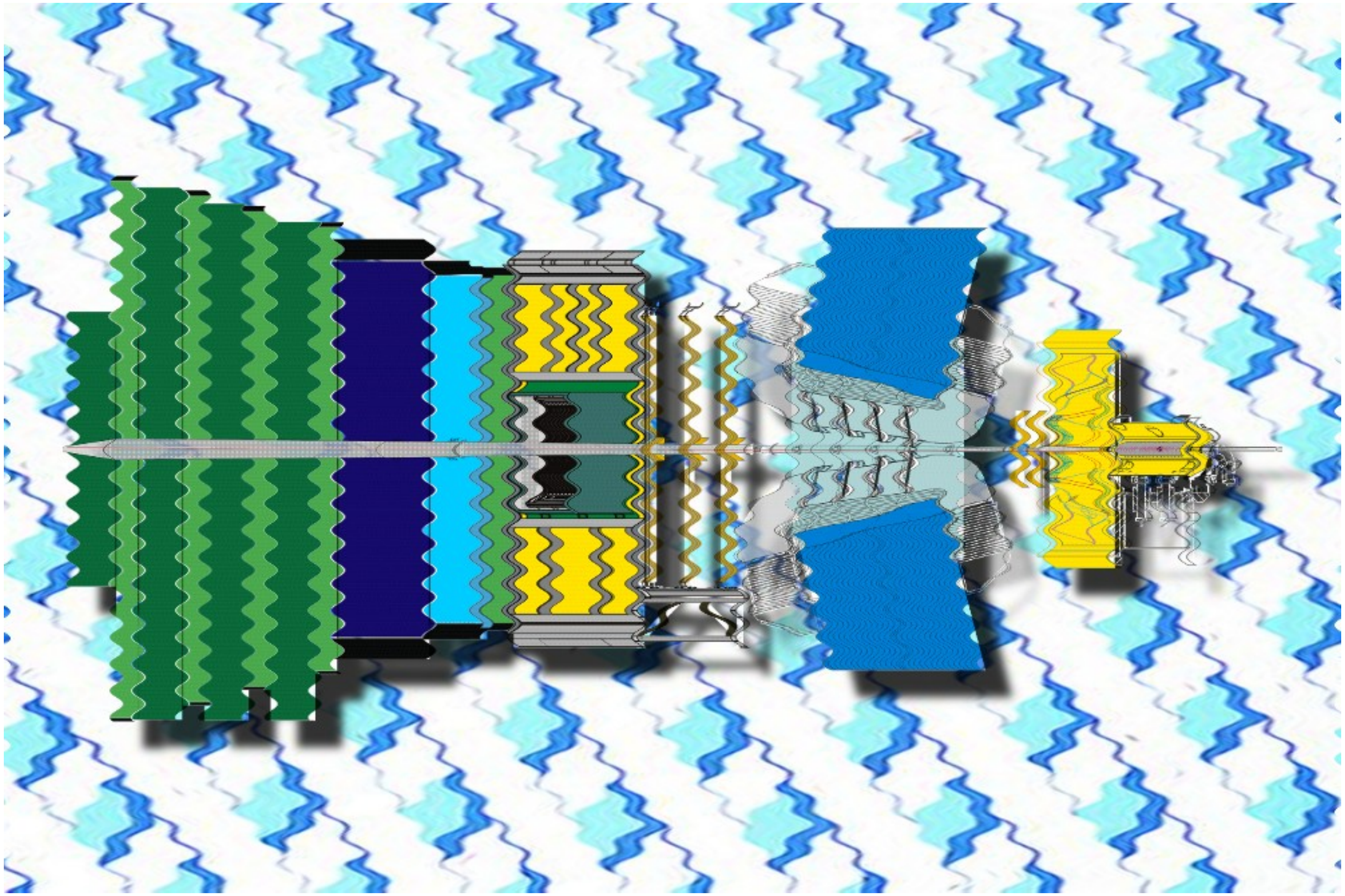
LHCb detector performance

The key issues for achieving heavy flavour results at a hadron machine are excellent performance for:

- Trigger
  - To keep the correct events given huge minimum bias cross section
- Vertexing
  - To select final states cleanly and provide lifetime information
- Hadron identification (K,π,p)
  - For separation of states such as $B_s \to D_s K$ and $D_s \pi$
- Lepton identification (μ,(e))
  - For pure identification of states such as $B_s \to \mu\mu$
- Tracking
  - As background in most cases is proportional to mass resolution

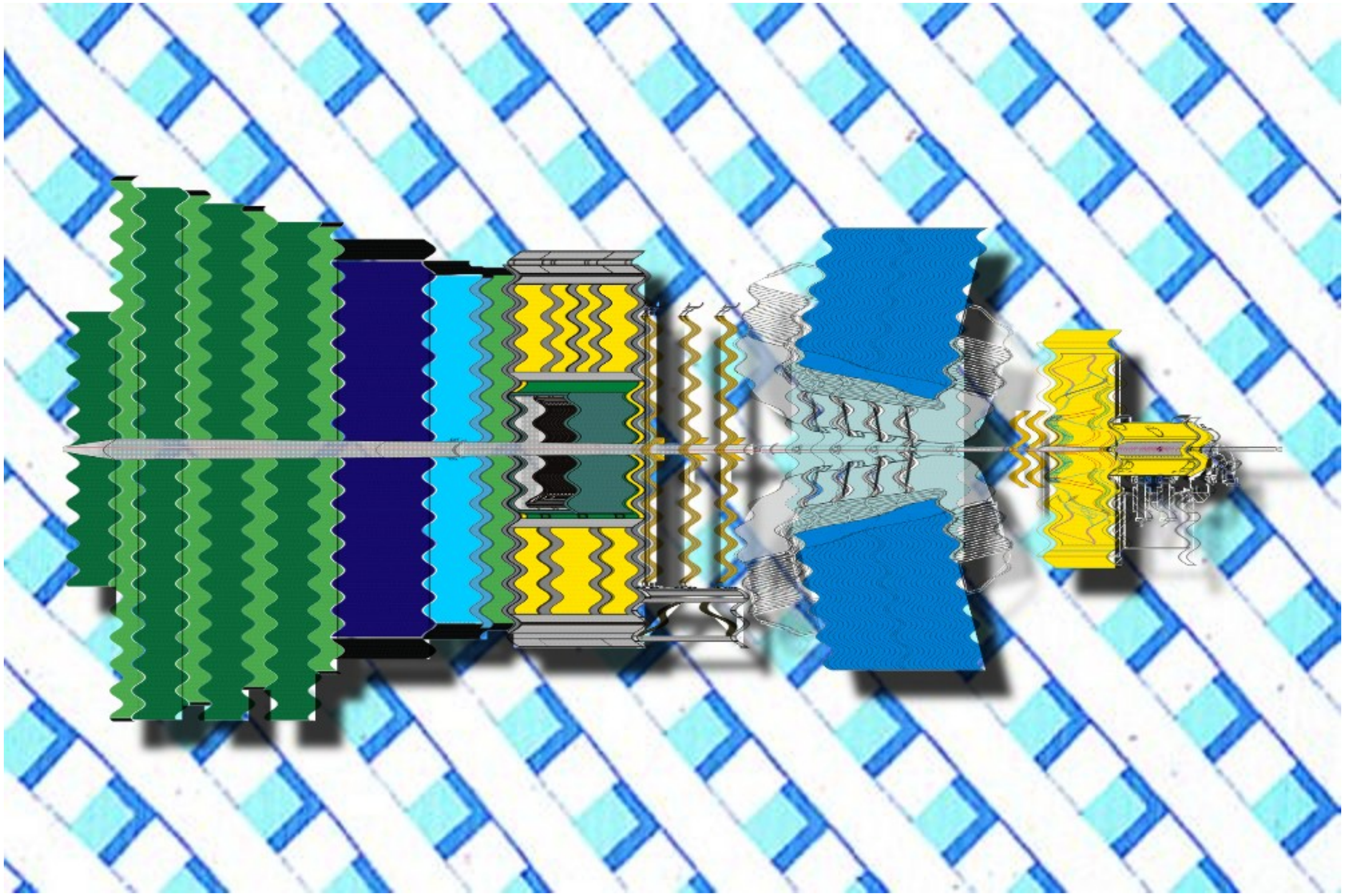
Synergy with lattice QCD

Limited precision lattice results give limited precision in LHCb results



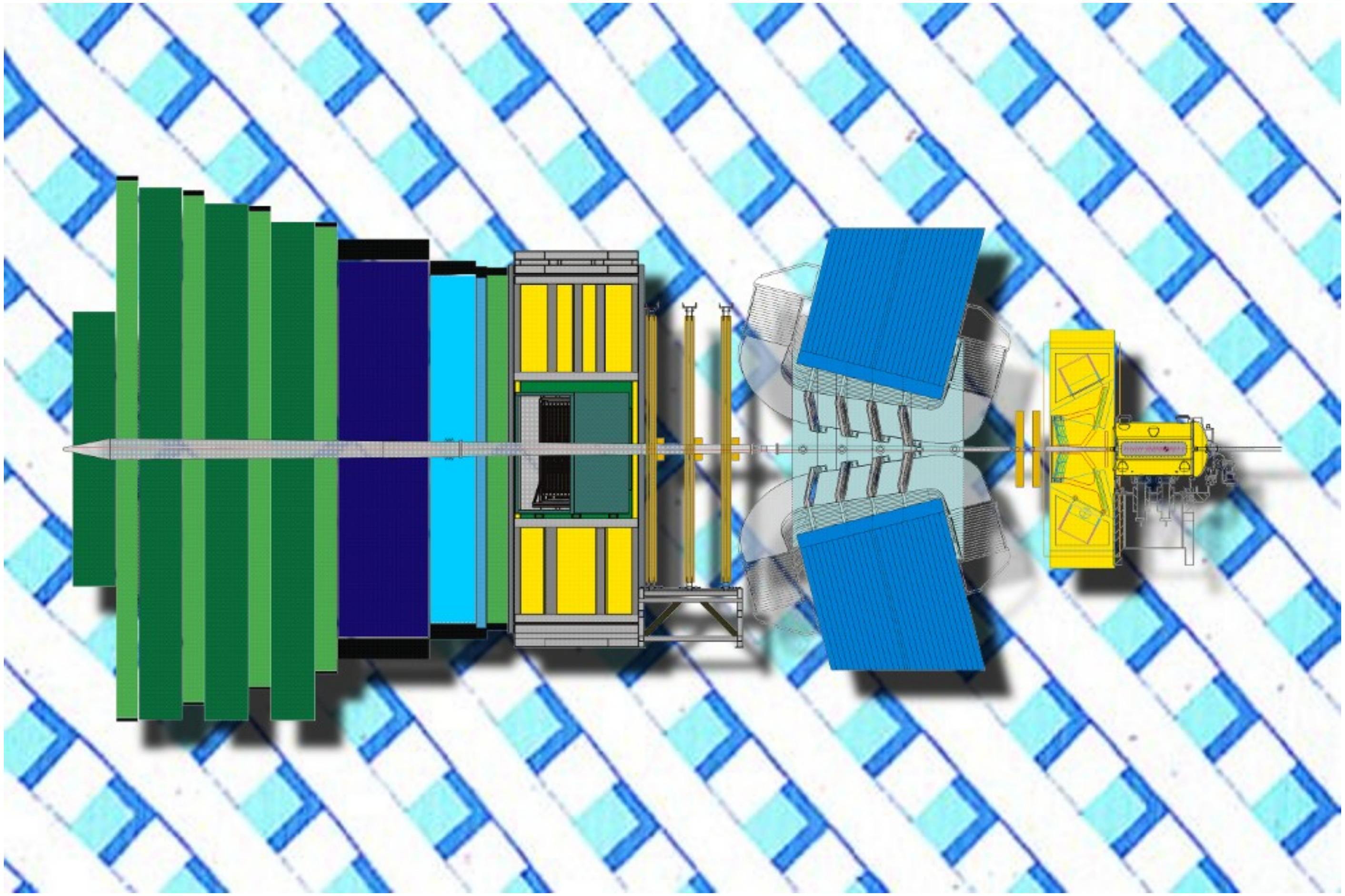
Synergy with lattice QCD

... improvements are taking place in Lattice QCD



Synergy with lattice QCD

... leading to improved results from LHCb!



The b production cross section

The production cross section at LHCb is interesting from a QCD point of view

- Also important for normalising our expectations for the future

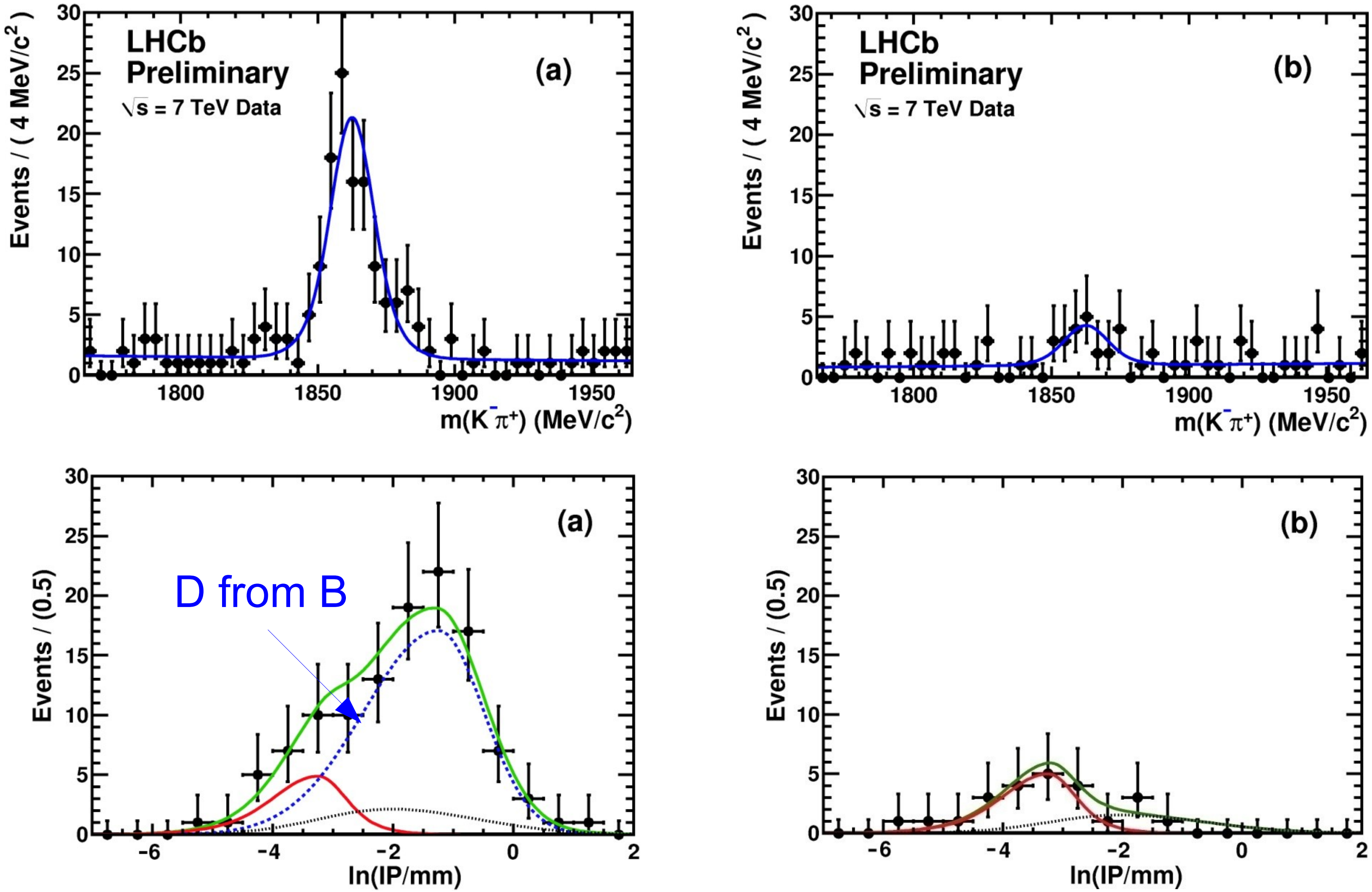
Find $D^0 \rightarrow K\pi$ decays and look for muon with right sign for semi-leptonic B decay.

- Use wrong sign decays to understand background

Independent analysis performed which uses lifetime to find J/ψ events from $B \rightarrow J/\psi\ X$ decays

Separation of prompt D and D from B decays

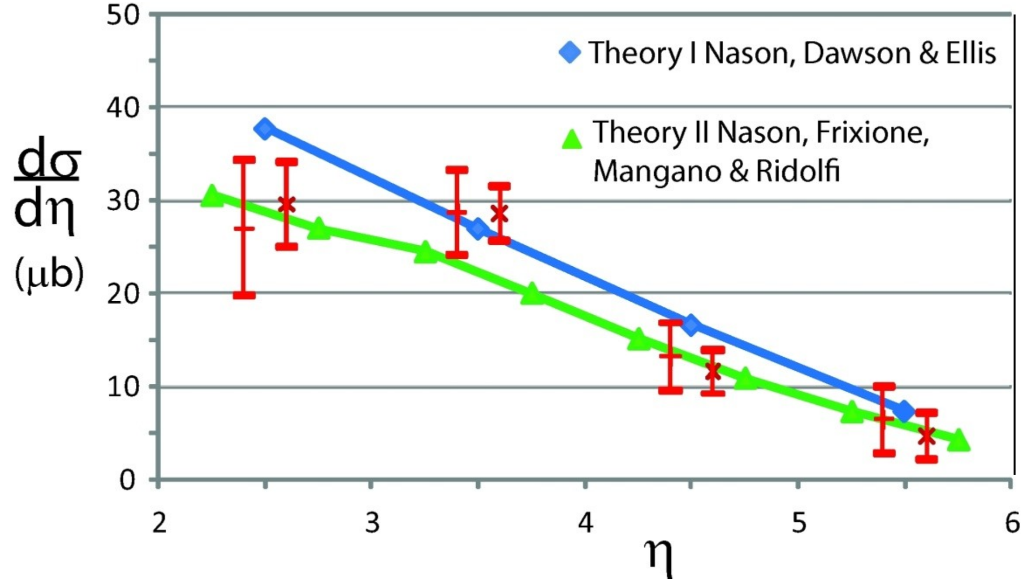
Right sign | Wrong sign



The result

ArXiV:1009.2731

The B production is measured in bins of pseudo rapidity



We get $\sigma(pp \rightarrow H_b\, X;\, 2<\eta<6) = 74.9 \pm 5.3 \pm 12.8\ \mu b$

LEP fragmentation functions used.

Pythia extrapolation to full phase space gives

$\sigma(pp \rightarrow b\ b\text{-bar}) = 292 \pm 15 \pm 43\ \mu b$ [LHCb preliminary]

No error from extrapolation taken into account

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

Decay a very sensitive probe for Higgs sector of any New Physics model

SM BR predicted to 10% precision at $3.6 \pm 0.3\ 10^{-9}$

Currently best result is from CDF 3.7 fb^{-1}

- BR < 4.3 10^{-8} 95%CL

LHC will quickly catch up.

We will very soon know if this is exciting.

On the other hand, if limit goes below ~5 10^{-9} it will be hard to identify New Physics.

Analysis validation

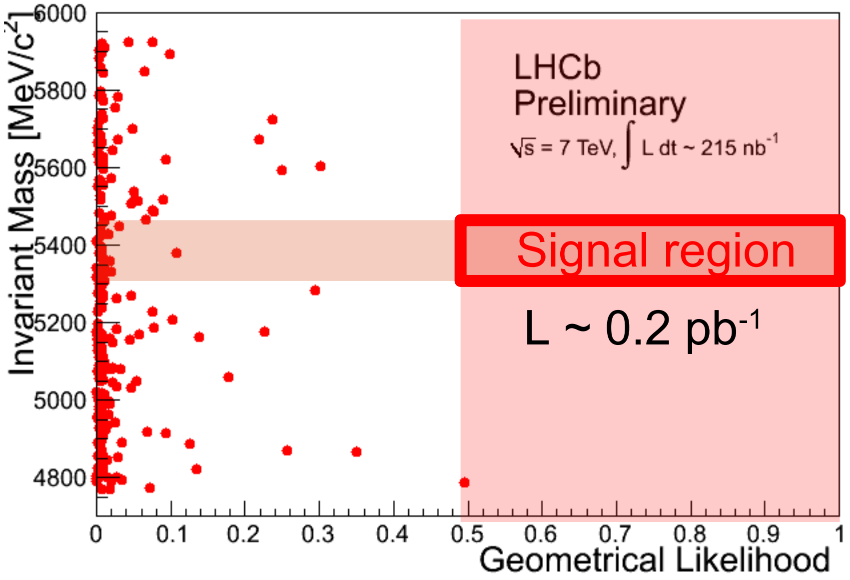
The search for $B_s \to \mu^+\mu^-$ is based on:

Counting in bins based on 3 independent variables

- Invariant mass of the muon pair
  - Power determined by the tracking system resolution and alignment
- Muon identification likelihood
  - Dominated by muon system but also use information from calorimeters and RICH detectors
- Geometrical likelihood
  - Quantities where the vertex detector provides the main discrimination: impact parameters, isolation, lifetime.

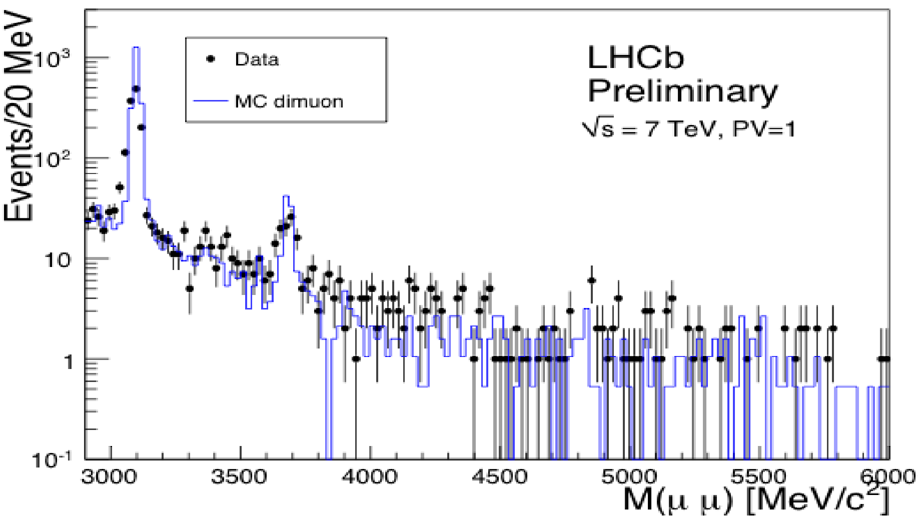
Normalisation

Analysis validation



Background events as distributed in invariant mass vs Geometrical likelihood.

In 1.2 GeV wide window around B_s mass, background is currently 50% above MC simulation estimate.



Getting to the branching ratio

At a hadron collider we measure branching ratios relative to a known BR

$$\mathrm{BR} = \mathrm{BR}_{\mathrm{cal}} \times \frac{\epsilon_{\mathrm{cal}}^{\mathrm{REC}} \epsilon_{\mathrm{cal}}^{\mathrm{SEL|REC}} \epsilon_{\mathrm{cal}}^{\mathrm{TRIG|SEL}}}{\epsilon_{\mathrm{sig}}^{\mathrm{REC}} \epsilon_{\mathrm{sig}}^{\mathrm{SEL|REC}} \epsilon_{\mathrm{sig}}^{\mathrm{TRIG|SEL}}} \times \frac{f_{\mathrm{cal}}}{f_{B_s^0}} \times \frac{N_{B_s^0 \to \mu^+\mu^-}}{N_{\mathrm{cal}}}$$

- Unfortunately no B_s branching ratios are well known
  - Either we need to know relative B^0/B_s (or B^+/B_s) production ratio
  - ... or get a B_s absolute BR with high precision from elsewhere.

Relative B^0/B_s production ratio

PRD.82.034038

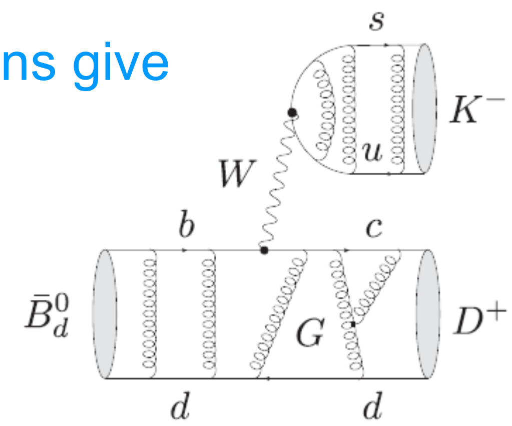
Measure $B_d \to D^+K^-$ and $B_s \to D_s^+\pi^-$ yields in LHCb

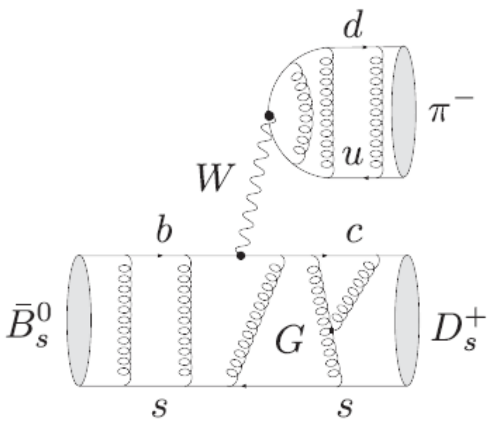
Then use theoretical prediction of BR's to extract the production ratio

- Only colour allowed tree diagrams involved
  - Factorisation works well.
- Dominating theoretical error from form factor ratio

$$\mathcal{N}_F \equiv \left[\frac{F_0^{(s)}(m_\pi^2)}{F_0^{(d)}(m_K^2)}\right]^2 = 1 + \delta$$

  - Can lattice calculations give us δ at 20% level?





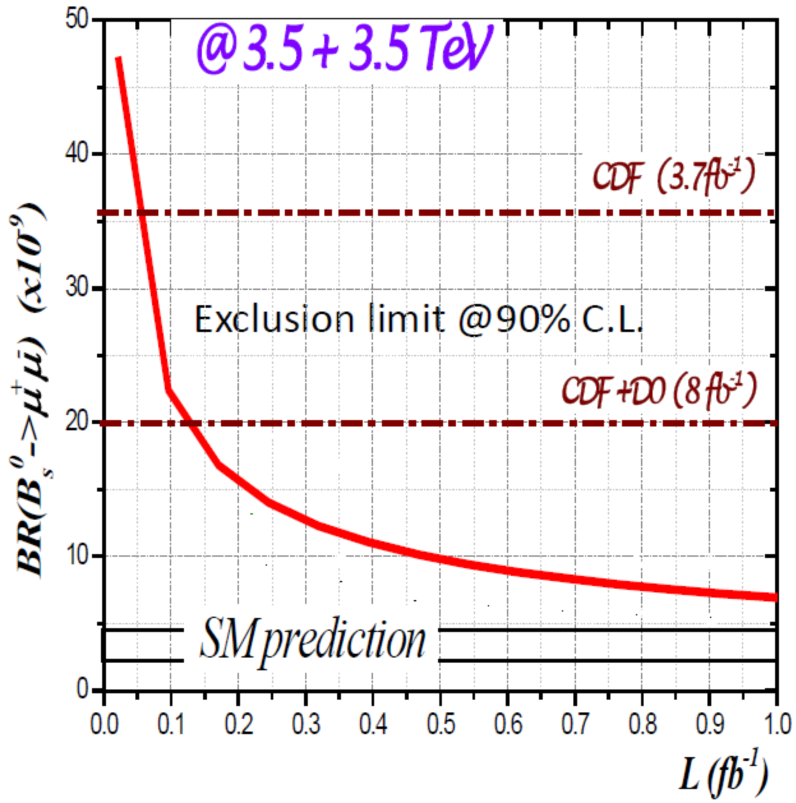
Absolute B_s branching ratio

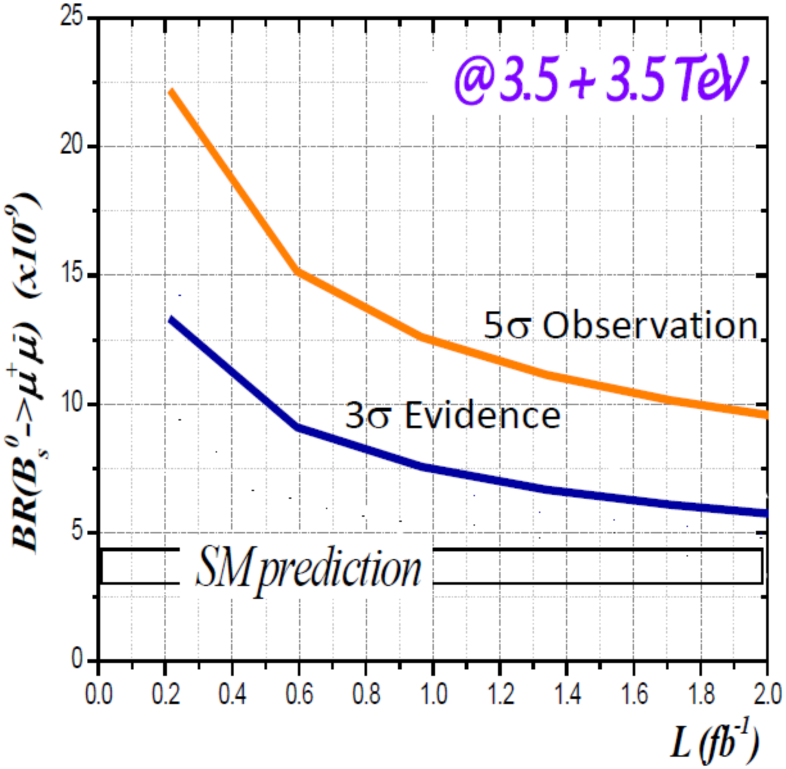
- We can normalise to BR($Bs \to J/\psi\ \varphi$) directly using a measurement from BELLE made at Υ(5S) resonance
  - Now fragmentation doesn't enter
- Measurement is difficult though. Current value
  - BR = $(1.18 \pm 0.25 + 0.22 - 0.25(\text{syst})) \times 10^{-3}$ (23.6fb^{-1})
- PRD 74, 031501 (06), id. PRD 80, 039901 (09) has idea to reduce fragmentation uncertainty at Υ(5S) by counting same sign leptons.
  - Prospect of reaching 10% statistical error in normalisation but a challenging measurement.
  - Systematics from theory are not relevant

Outlook

With main parts of analysis validated we estimate

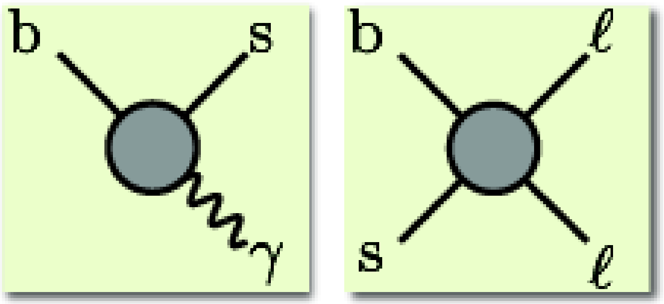
- 200 pb^{-1} (2010) of data to give us worlds best limit
- 5σ observation down to BR = 5 x SM with 1 fb^{-1} (2011)





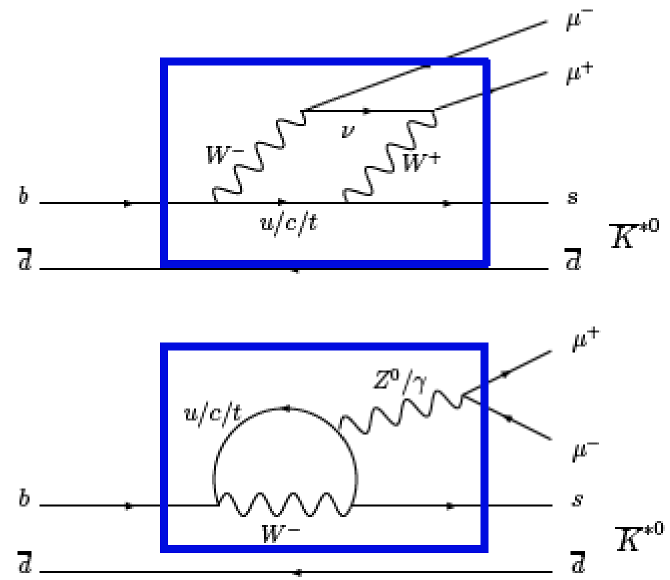
$B_d \to K^{*0}\mu^+\mu^-$ introduction

Interference between these



$O_{7\gamma}$ $O_{9,10}$

... and their primed counterparts



As an exclusive decay we need to find a way to cancel form factors to reduce theory uncertainty

A multitude of observables in the literature that have specific sensitivity to New Physics

What to measure?

JHEP 01 (2009) 019
JHEP 11 (2008) 032

Most well known observable is A_{FB}, the forward-backward asymmetry

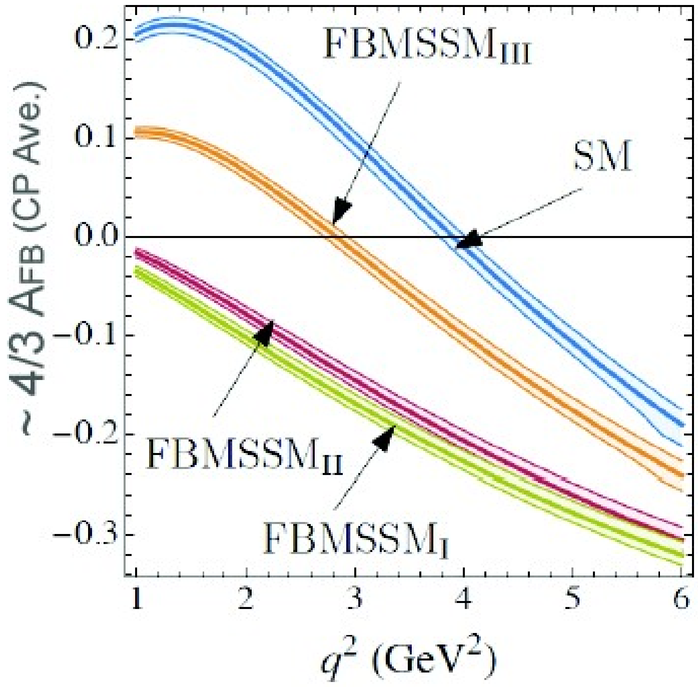
- FF cancellation only at zero crossing point

Sensitive to changes in C_7 and C_9

Other observables such as

$$A_T^{(4)} = \frac{|A_{0L}A^*_{\perp L} - A^*_{0R}A_{\perp R}|}{|A^*_{0L}A_{\parallel L} + A_{0R}A^*_{\parallel R}|}$$

constructed to have FF cancellation everywhere, but require more statistics



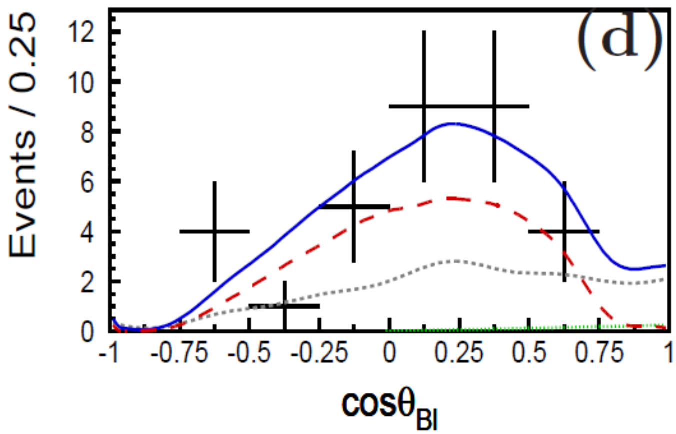
Current measurements of A_{FB}

Three results have arrived in the past 2 years

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

Example below of θ_l in $q^2 < 2\ \mathrm{GeV}^2$ from Belle

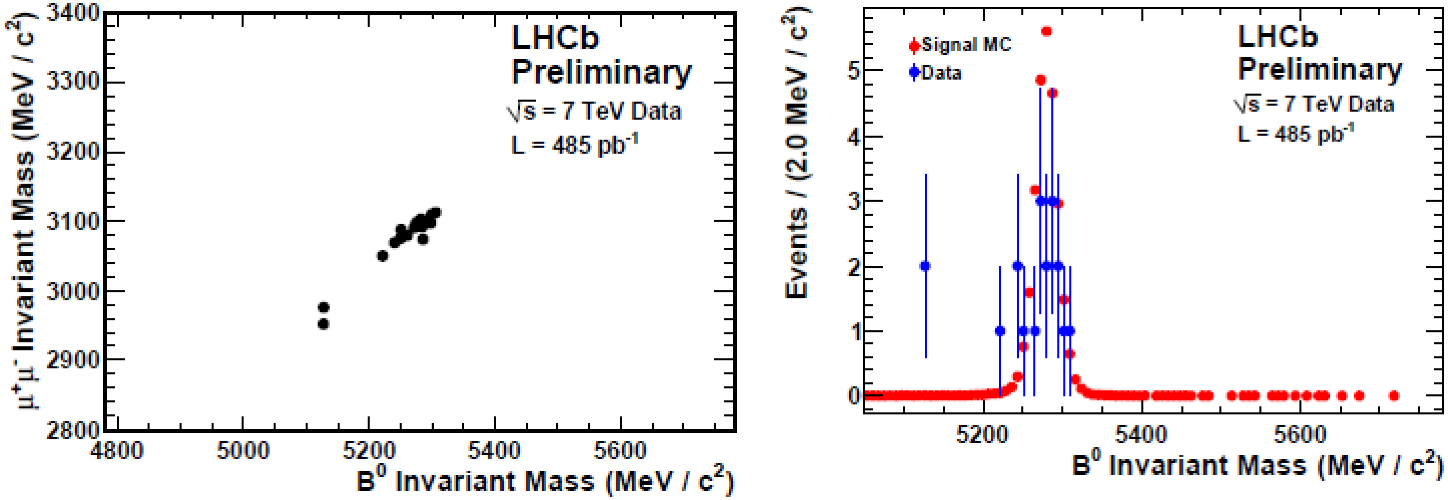
- Clearly statistics are still very limited for this type of measurement.



Validation

Insufficient data to see signal events. Instead use proxies:

- $B_d \to J/\psi K^{*0}$ for selection efficiency and background studies

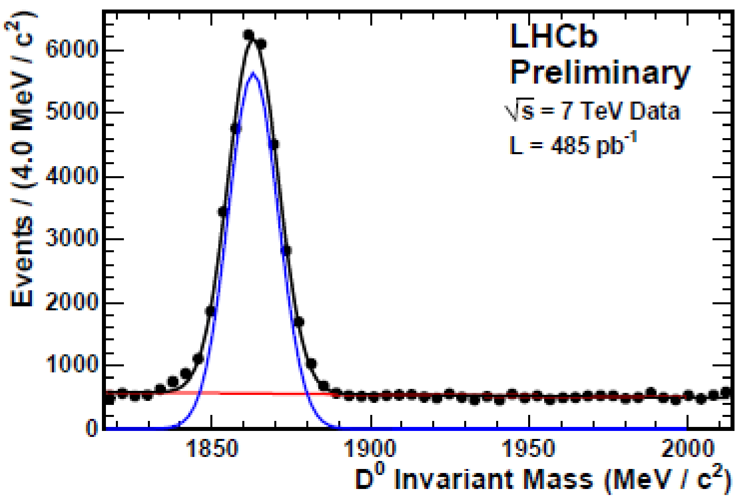


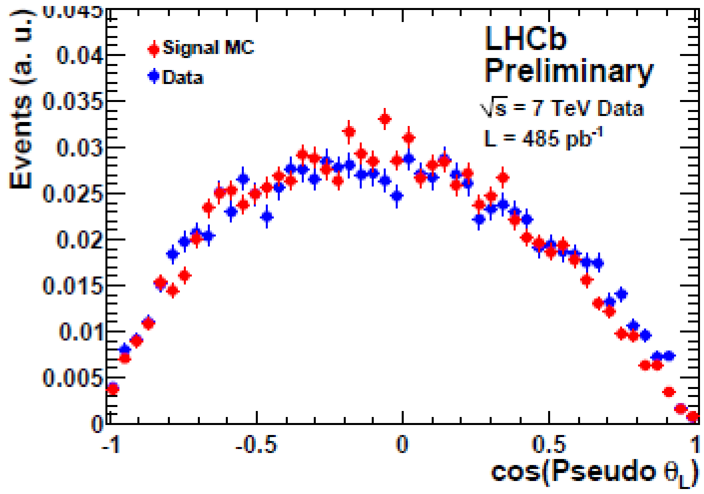
- When applying Bd→K*0μμ selection we see clear $B_d \to J/\psi K^{*0}$ peak
- Yield as expected when measured B production cross section used for normalisation

Validation

Insufficient data to see signal events. Instead use proxies:

- $D^0 \to K\pi\pi\pi$ for understanding angular analysis





- Use very clean D signal to form a "fake" lepton angle
- See very nice match to expectations from Monte Carlo
  - No nasty acceptance effects showing up.

Where can lattice calculations help

Form factors

- Starting to see first calculations of form factors.
- Only works at high dimuon masses (q^2)
- Can it be combined with LCSR calculations to improve FF at lower q^2?

Charm quark mass

- The charm quark mass enters into the SM value of A_{FB}
  - Actually it is m_c/m_b that matters so should already be insignificant?

Differential branching ratio

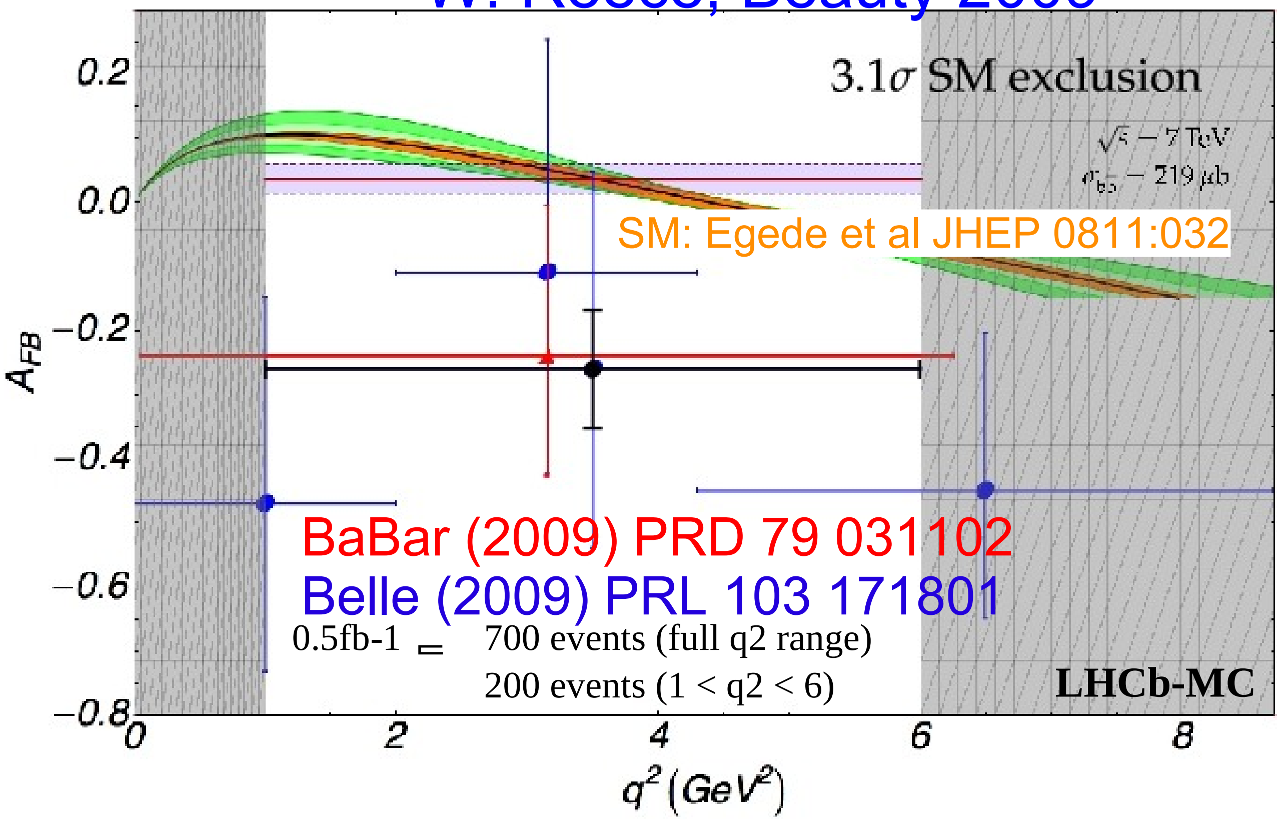
- Has so far received limited interest from LHCb. Can FF calculations be so accurate that we should reconsider?

Outlook

Just 0.1 fb^{-1} will give equivalent error to current B-factory measurements

0.5 fb^{-1} enough to exclude SM at 3.1σ level if Belle central value correct

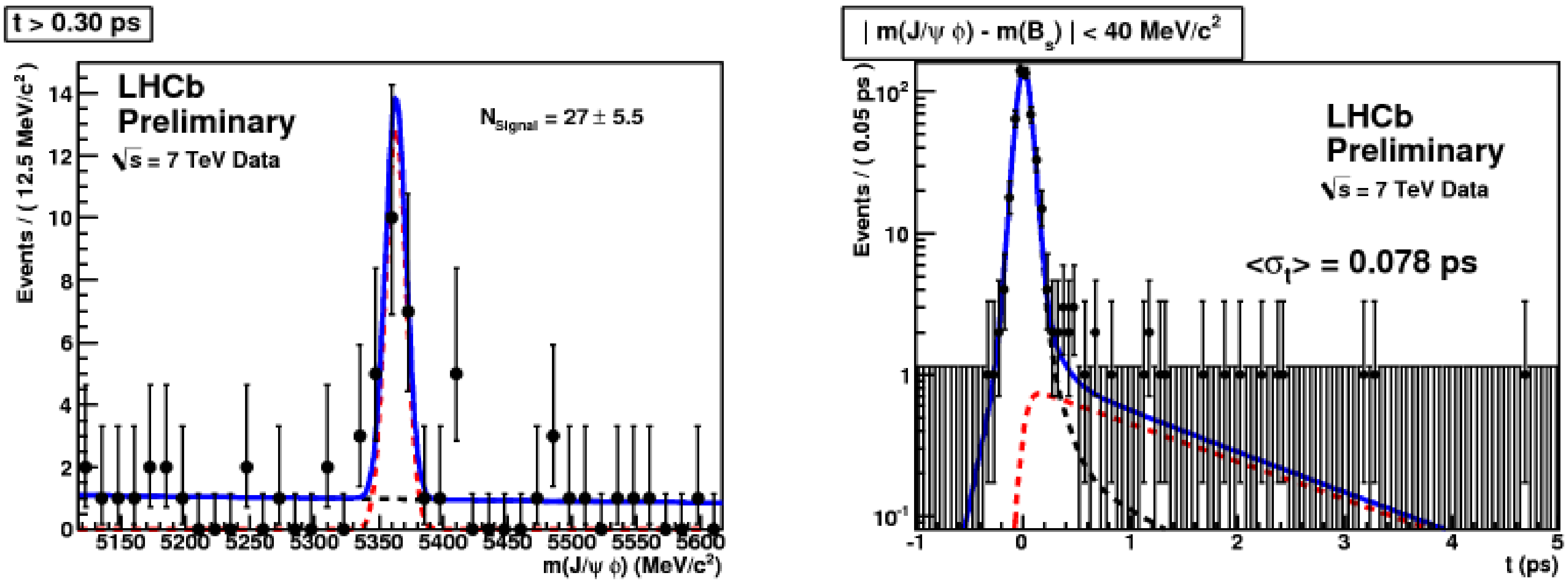
W. Reece, Beauty 2009



$B_s \to J/\psi\ \varphi$ for φ_s measurement

LHCb has the potential to quickly improve on the measurement from the Tevatron experiments.

- Already see a signal sample in ~600 nb^{-1}



Time resolution is 78 fs.

- About factor 2 above expectation
- Significant improvement seen with latest alignment

$B_s \to J/\psi\ \varphi$ for φ_s measurement

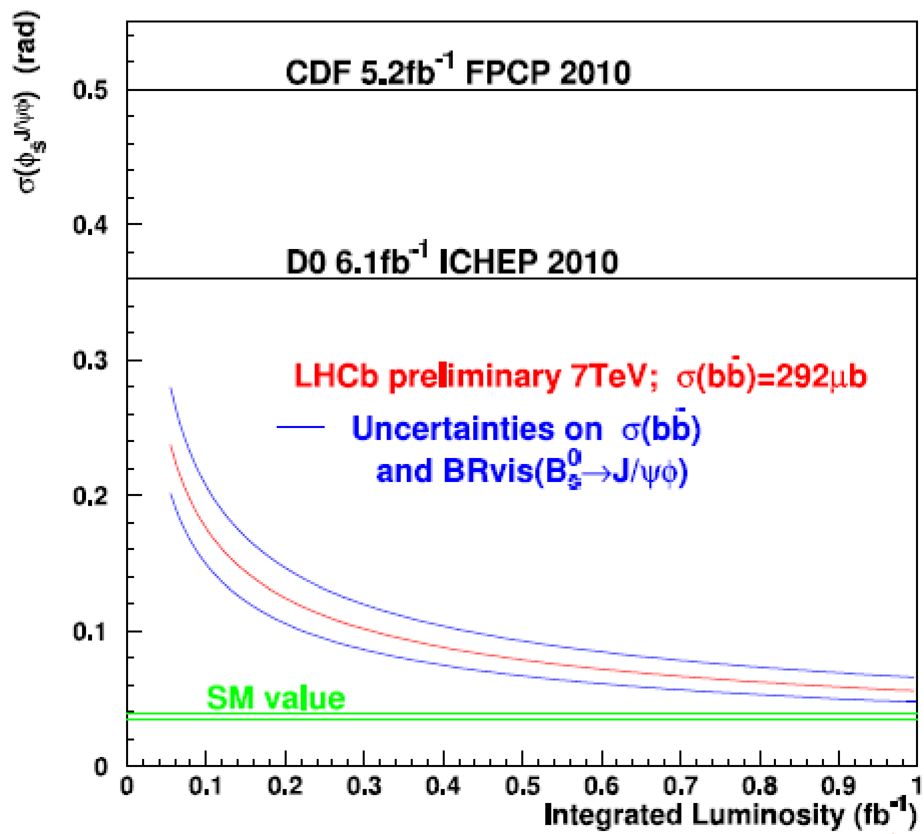
Assuming from MC simulations

- Background level
- Time resolution
- Flavour tagging efficiency

and from data

- B production cross section

We get sensitivity down to close to SM value with 1 fb^{-1}



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

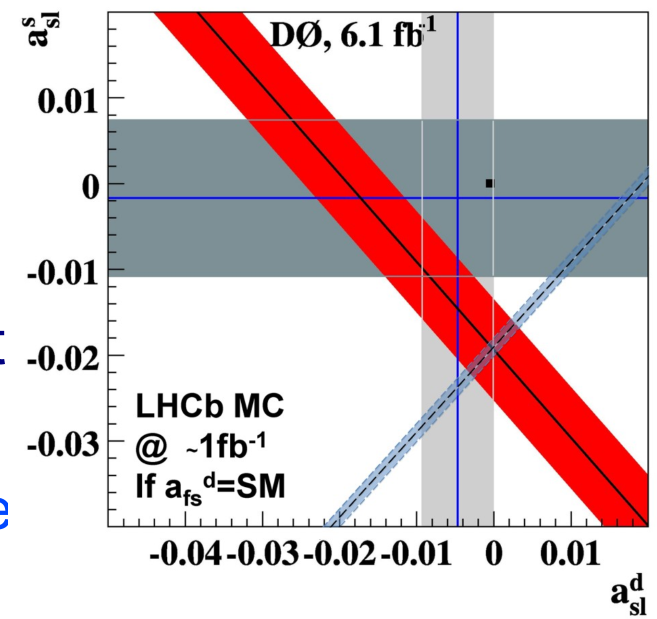
D0 measurement has increased interest in semi-leptonic asymmetry

$$a^b_{\rm sl} \equiv \frac{\Gamma(\bar{B} \to B \to \mu^+ X) - \Gamma(B \to \bar{B} \to \mu^- X)}{\Gamma(\bar{B} \to B \to \mu^+ X) + \Gamma(B \to \bar{B} \to \mu^- X)}$$

The p-p initial state of LHC gives production asymmetries making it impossible to replicate measurement from D0

- Instead look at difference in exclusive decays $B_d \to D^+(\to KK\pi)\mu^-\nu$ and $B_s \to D_s(\to KK\pi)\mu^-\nu$.
- Identical final state means detector bias heavily suppressed

Very interesting LHCb measurement



LHCb expectation with 1fb^{-1} (stat error only). Use D0 central value and no NP in a^d_{sl}

Conclusion

- The LHCb detector is fully functional
  - Validation of many aspects of detector done with control channels
  - Performance is very promising even if there is still work to do
- In both the coming year and in the long run we will see benefits from improved lattice calculations.
- Stay tuned ☺