Searches for New Physics in heavy flavour decays: LHC prospects for 0.1 & 1.0 fb^{-1}

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LHCC 5/6/10

Contents

- The importance of flavour physics
- To what degree is LHCb physics reach degraded by descoped 2010-11 machine parameters?
- Production studies with a few pb^{-1}
- Opportunities with charm (and trigger considerations)
- Core B-physics with 100 pb^{-1} and more
- Flavour physics opportunities at ATLAS, CMS and ALICE
- Conclusions

Bulk of talk – discussion will be LHCb specific

Flavour Physics is Important

Many of open questions in Standard Model (SM) found in flavour sector:

- Why are there 3 generations?
- What determines the extreme hierarchy of fermion masses?
- What determines the elements of the CKM matrix?
- What is the origin of CP violation (CPV)?

Progress in flavour physics may help understand open questions in cosmology - SM CPV insufficient to explain matter/antimatter asymmetry

Flavour physics is a proven tool of discovery:

- BR($K^0_L \to \mu\mu$) & GIM → prediction of charm
- CP violation → need for a third generation
- B mixing → mass of top is very heavy

Lesson from history: precise measurements of processes suppressed in existing theories have high sensitivity to New Physics (NP) contributions. An excellent way to look for the NP expected at the TeV scale!

Reality check: $\sqrt{s}$ and $\int L dt$ in 2010-11

All LHCb simulation studies until recently assumed E_{cm}=14 TeV & annual event yields of 2 fb^{-1}. How do parameter values of 2010-11 run affect the physics reach?

Beam Energy

Compare expected cross-section at design energy with 3.5 TeV

LHCb physics reach is not seriously compromised by de-scoped parameters of 2010-11 run

Small penalty in statistical precision (but all MC predictions shown today assume, for historical reasons, $b\bar{b}$ cross-section of 500 μb at 14 TeV – conservative ?)

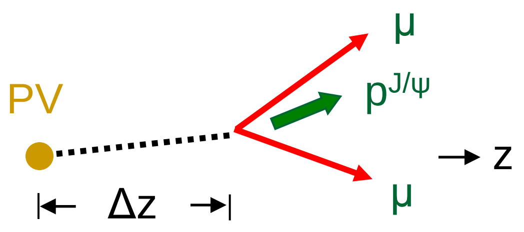
Luminosity

LHCb design luminosity is 2 x 10^{32} cm^{-2}s^{-1} – will be in this regime in 2011 !
Lower luminosities of 2010 allows for lower trigger thresholds – see later

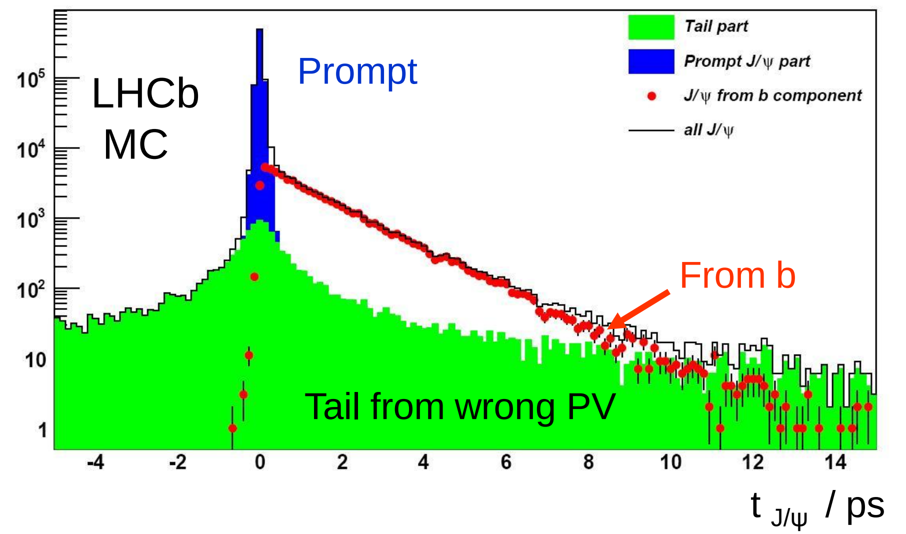
Calibrating the signal source

Heavy flavour studies at LHCb will begin with a measurement of the $b\bar{b}$ cross-section, as determined from production rate of displaced J/ψ mesons

Form pseudo proper-time, $t_{J/\psi}$:



$$t_{J/\psi} = \frac{\Delta z}{p_z^{J/\psi}} m_{J/\psi}$$

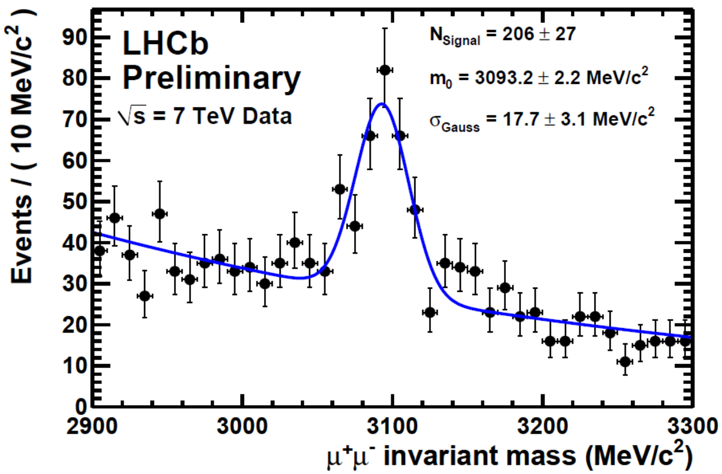


Combined fit to invariant mass and pseudo proper-time allows for both prompt J/ψ and $b\bar{b}$ production in bins of p_t and pseudo-rapidity.

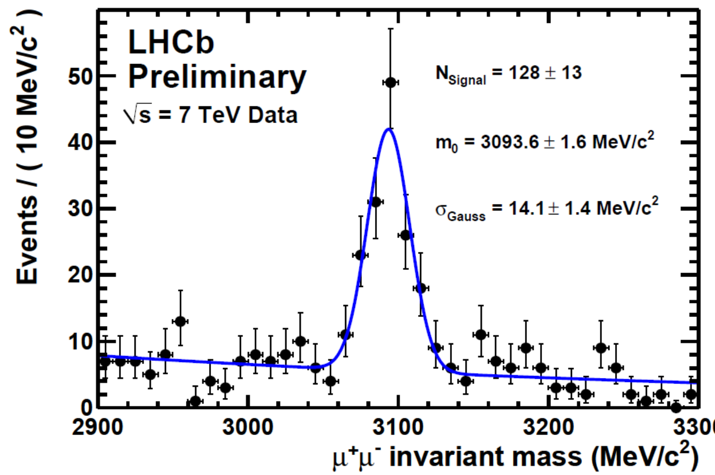
Prompt J/ψ production a very interesting topic in its own right: Colour Octet Model (COM) predicts well cross-sections seen at Tevatron, but not polarisation

First J/ψ data results

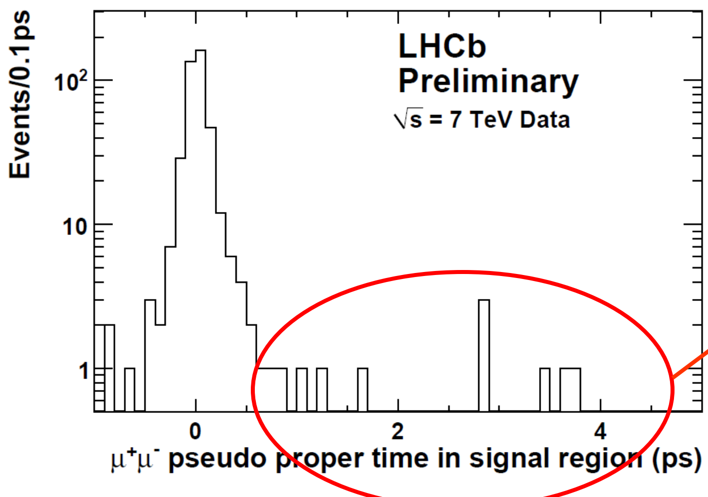
Loose selection



Tight selection



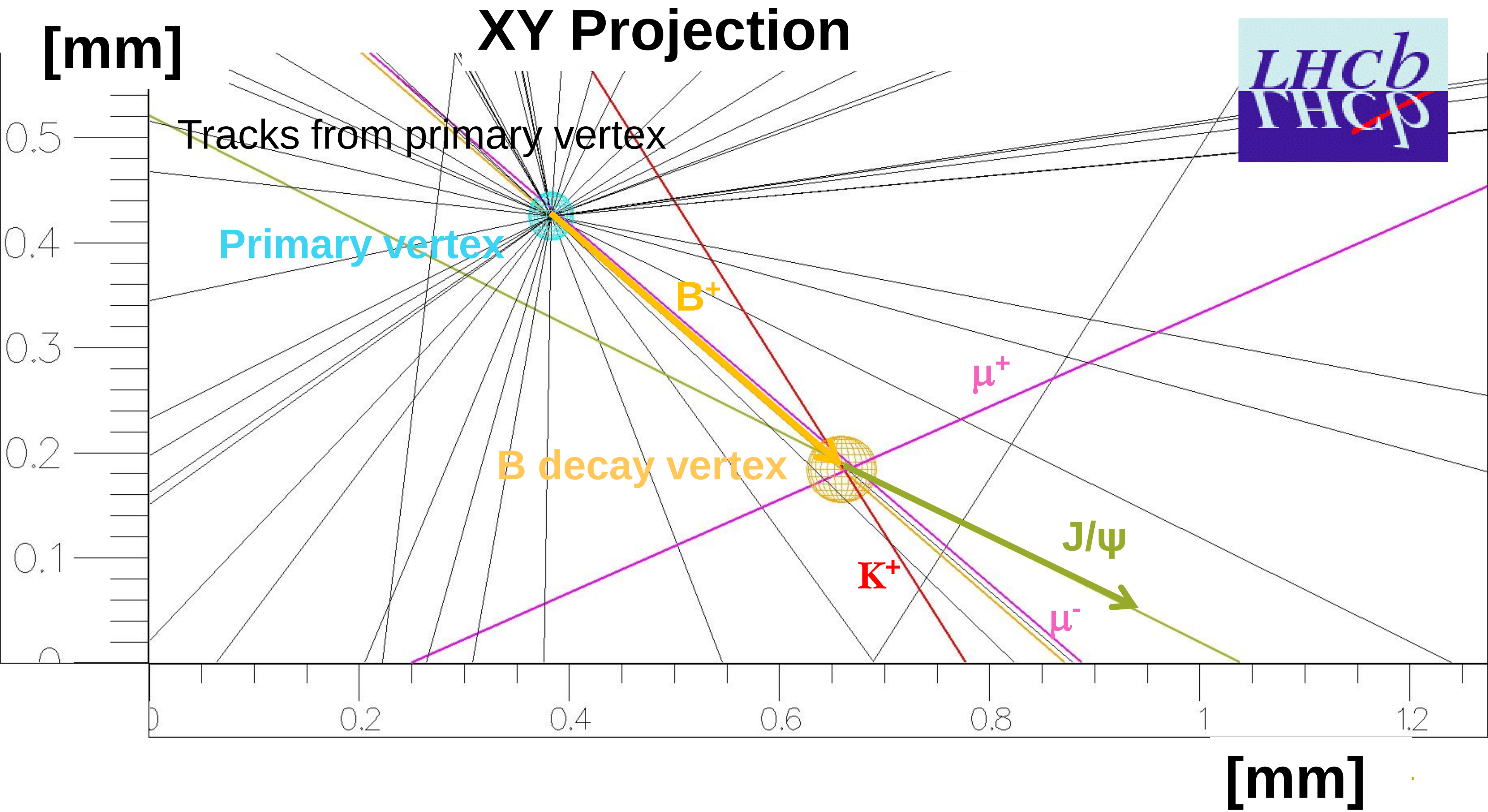
Pseudo-proper time in signal peak



These are B→J/ψX candidates !
Can any be fully reconstructed?

$B^+ \to J/\psi K^+$ candidate

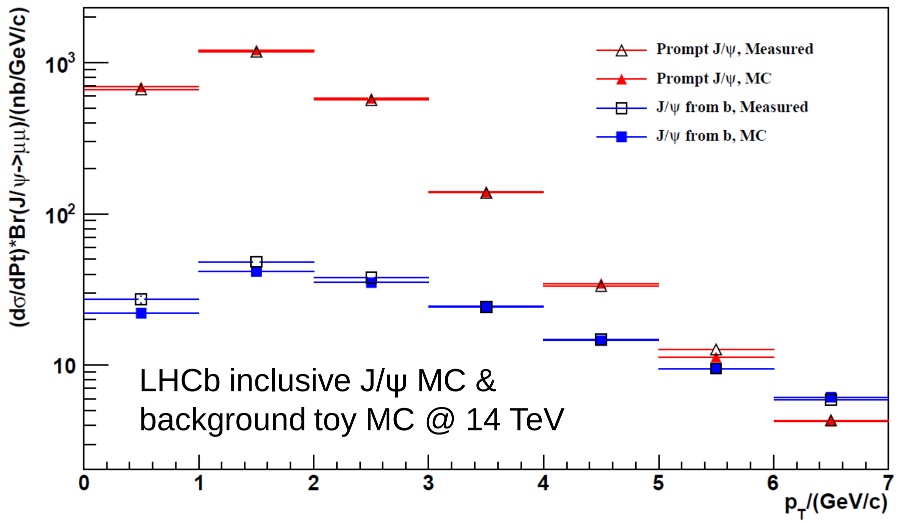
Comfortably passes selection cuts devised prior to data taking



LHCb J/ψ production studies

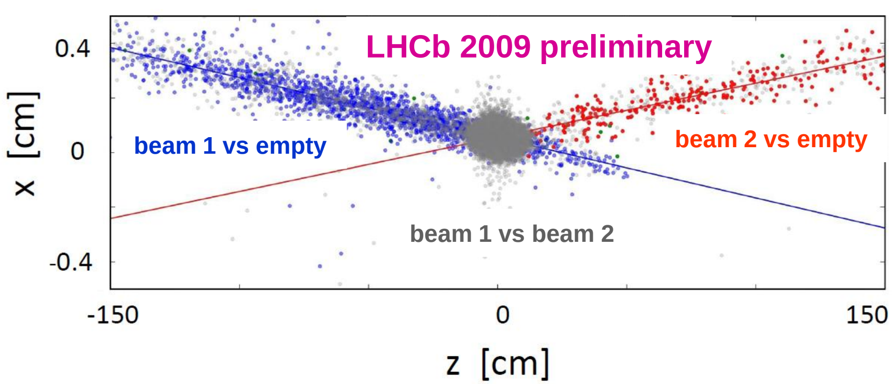
Plan is to make study in:

- 4 pseudo-rapidity bins, with $3 < \eta < 5$
- 7 transverse momentum bins up between $p_t=0$ and $p_t = 7$ GeV/c



With 5 pb^{-1} all bins will have statistical uncertainty < 10%

Largest systematic will come from unknown polarisation – varies bin to bin up to maximum of 25%. Polarisation will be measured in 2nd pass analysis.



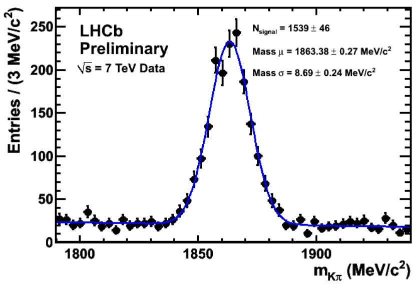
Expected integrated luminosity uncertainty ~5% through measurements of beam profile in beam-gas and beam-beam collisions.

(Already determined to 15% in 2009, with uncertainty limited by knowledge of beam intensities)

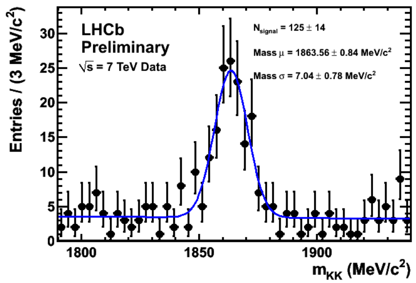
LHCb Open Charm – the story so far

Many 'old friends' rediscovered. These are important detector calibration signals…

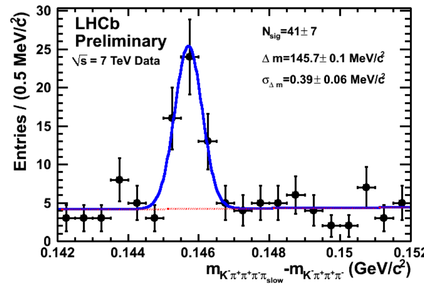
$D^0 \to K\pi$



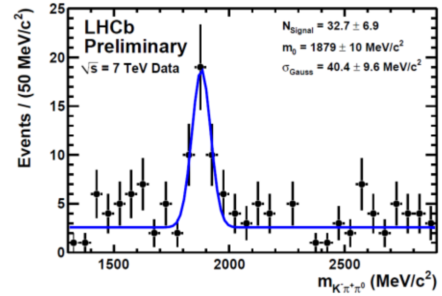
$D^0 \to KK$



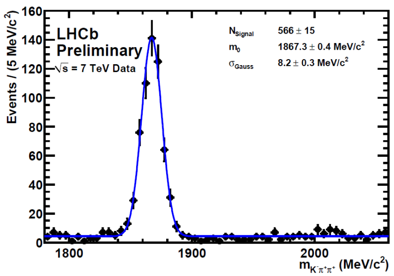
$D^* \to D^0\pi,\ D^0 \to K\pi\pi\pi$



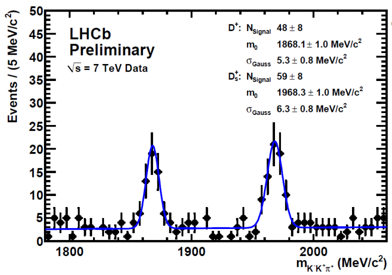
$D^0 \to K\pi\pi^0$



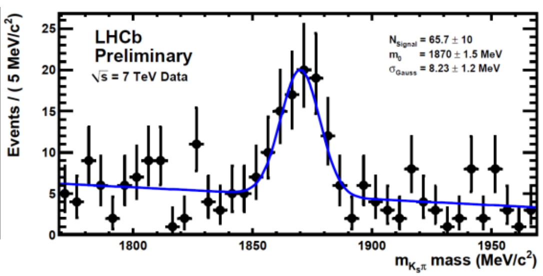
$D^+ \to K\pi\pi$



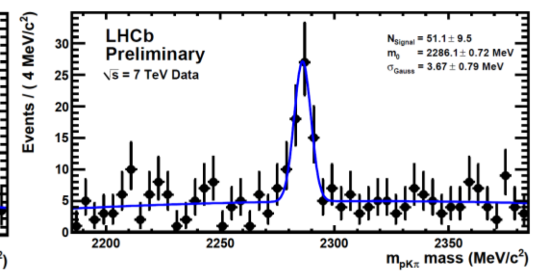
$D^+, D_S \to KK\pi$



$D^+ \to K_S\pi$



$\Lambda_c \to pK\pi$



…but even more so, many are signal modes for indirect New Physics searches. But all above collected with open trigger. What happens when we start to veto ?

Reminder of LHCb trigger scheme

40 MHz

Level-0

At LHCb design luminosity (2 x 10^{32} cm^{-2} s^{-1}) all thresholds must be optimised for B-physics, and consequently trigger efficiency for D decays from prompt-production is low

Eff-trig $_{L0*HLT1*HLT2}$ for prompt D decays typically ~ 10%

Still adequate for accumulating very large samples, but corresponding efficiencies for hadronic B-decays ~4x higher

HLT2

Inclusive selections: topological, μ, μ+track, μμ, D→X, Φ

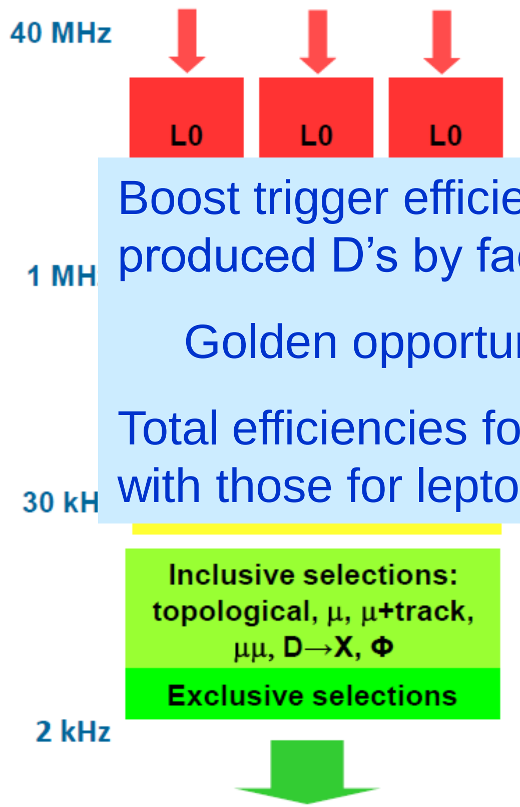
Exclusive selections

2 kHz

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

LHCb trigger – opportunities in 2010

For bulk of running foreseen this year, with luminosities up to a few 10^{31} cm^{-2} s^{-1} , we can afford to relax many of our trigger cuts, with large benefits for efficiencies



2010 approach

Level-0

Apply very low pt cuts – main purpose of

interest

act

HLT2

Not needed at all initially, then introduce with rather loose suppression requirements

Boost trigger efficiencies for hadronic decays of promptly produced D's by factor 4-5 w.r.t. nominal settings

Golden opportunity for charm physics studies !

Total efficiencies for hadronic B decays now 75-80%, with those for leptonic decay modes >90%.

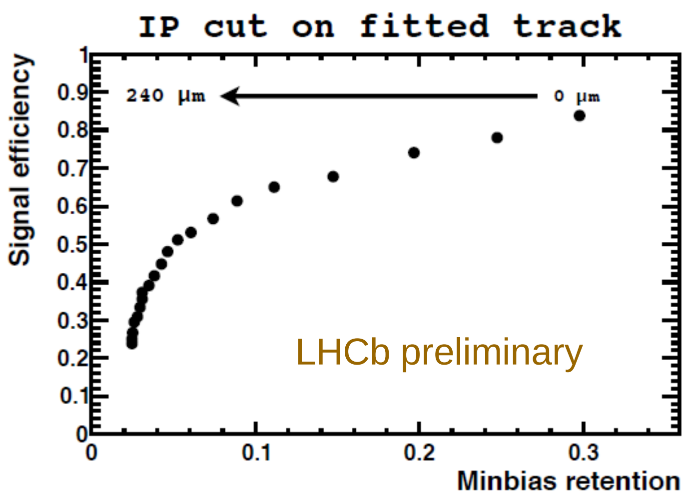
Trigger in data – a first look

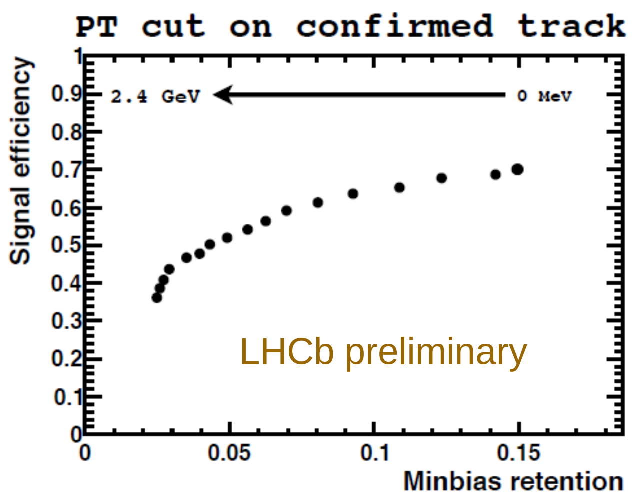
Take D*, $D^0 \to K\pi$ signal collected in minimum bias events & evaluate preliminary L0*HLT1 performance with 2010 low luminosity trigger settings

$$\text{Eff-trig}_{L0*HLT1}(\text{data}) = 60 \pm 4\ \%$$

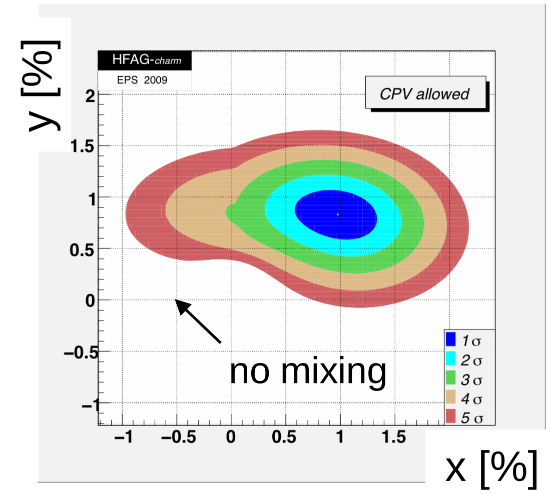
$$\text{MC expectation} = 66\ \%$$

Performance curves of single-hadron HLT1 line on data





Charm – the new frontier



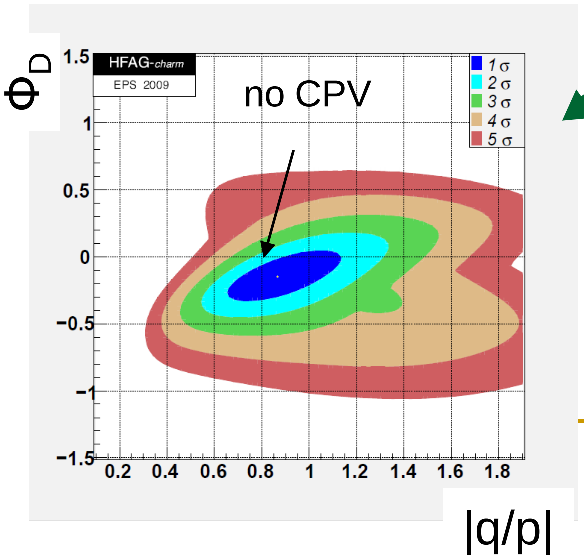
D^0 mixing discovery a recent highlight of flavour physics:

$$x_D = 0.98 \pm 0.25\ \%$$
$$y_D = 0.83 \pm 0.16\ \%$$

Improved sensitivity to x_D, y_D will (probably) not lead to New Physics discovery *in itself* (SM predictions too imprecise), but necessary for CP violation (CPV) studies

Mixing related charm CPV utterly negligible in SM. Not so in many NP models. Moreover important correlations between flavour observables in K, B & D systems.

➡ Precision D-physics programme critical front in the flavour physics campaign !



Present CPV constraints are weak – this because:

CP-asymmetry ~ $x_D \sin 2\Phi_D^*$ and x_D ~ 1%

Need sub 0.1% precision for useful CPV sensitivity

Feasible at LHCb with first ~100 pb^{-1} !!!

* example expression when |q/p|=1

Charm mixing studies at LHCb

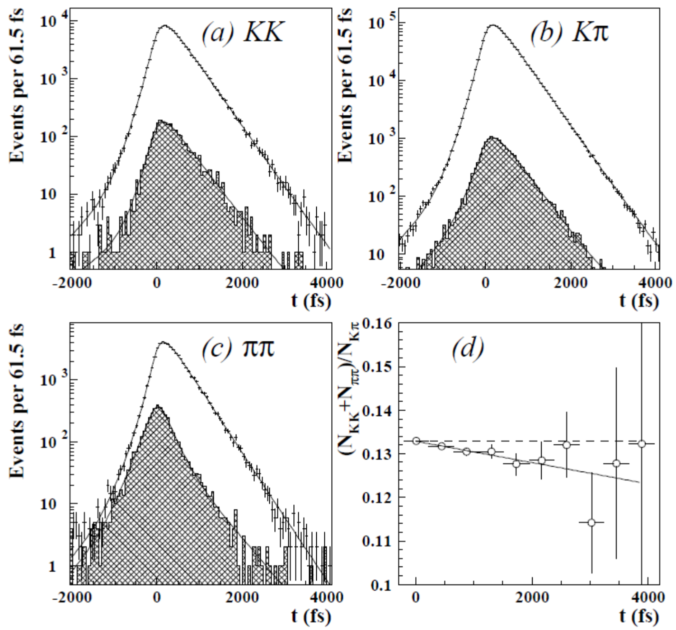
Example mixing analysis is measurement of "y_{CP}", which is D^0 width splitting parameter modified by CP-violating effects. Comparison to pure "y" measurements probes for CP-violation, as does measurement of pure CP-violating observable A_Γ

y_{CP}: compare lifetime of $D^0 \to$CP-eigenstate, eg. KK or $\pi\pi$, to $D^0 \to$non-eigenstate eg. $K\pi$

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

A_Γ: compare D^0 and $\bar{D}^0 \to$KK lifetimes

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



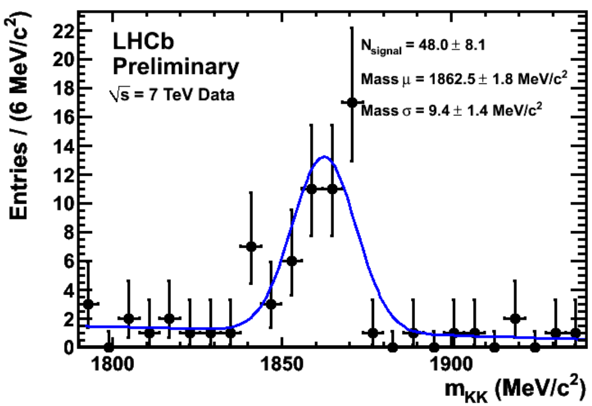
Belle, PRL 98 (2007) 211803

Belle 540 fb^{-1} analysis uses 1.1 x 10^5 flavour tagged $D^0 \to$KK events
$\to$ stat precision on y_{CP} = 0.32 % and on A_Γ = 0.30 %

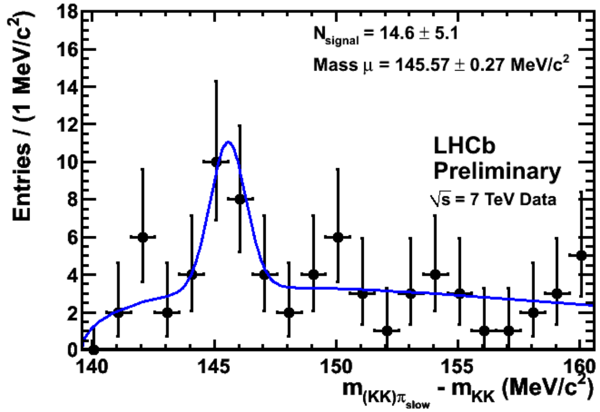
$D^0 \to hh$ at LHCb and mixing prospects

Signals already emerging for $D^0 \to K\pi$, KK in both untagged & tagged (ie. $D^{*+} \to D^0 \pi^+$) modes with ~0.8 nb^{-1} demonstrate potential for precise measurement of y_{CP}

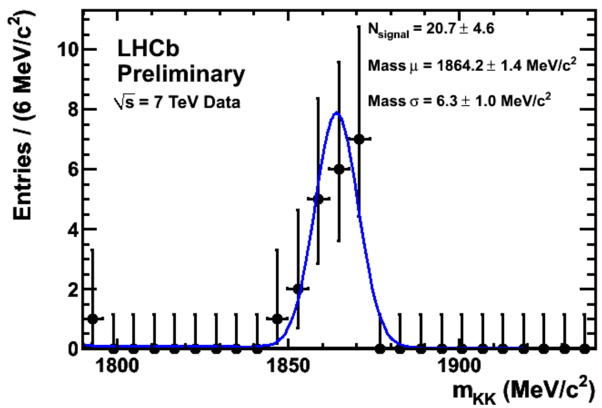
Tagged $D^0 \to KK$



m_D



Δm

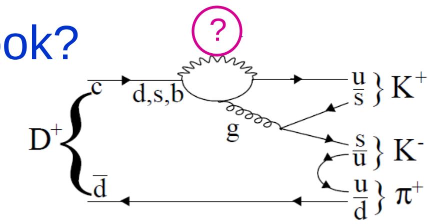


m_D with 2σ cut on Δm

Efficiency will remain good when trigger veto mode enabled, especially in 'low luminosity' conditions of 2010 → expect several million tagged $D^0 \to KK$ in 100 pb^{-1}

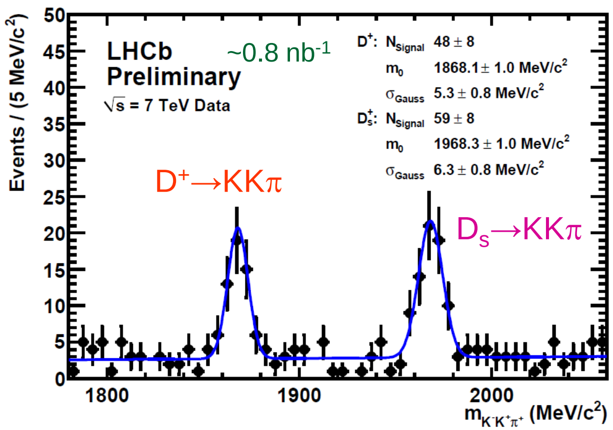
Search for direct CPV in charm

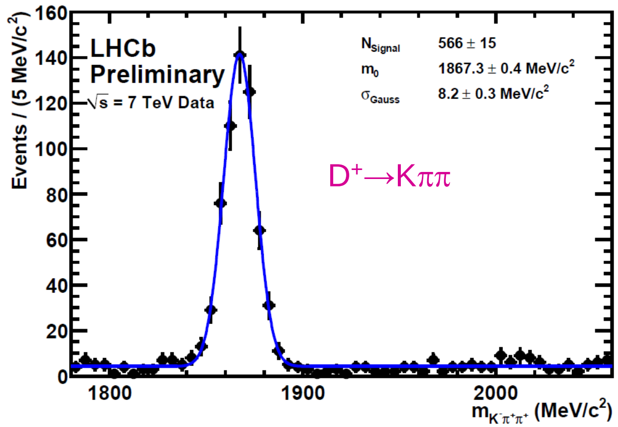
Of equal interest is search for direct CPV in charm. Where to look?

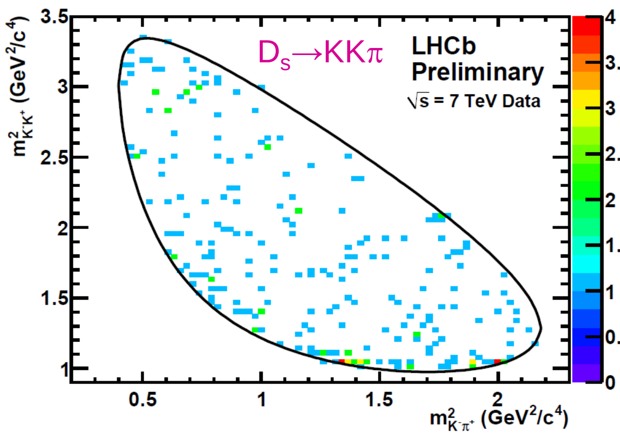


- Singly Cabibbo Suppressed decays – significant contribution of gluonic Penguins gives clear 'entry point' for New Physics
- 3-body decays: analysis of Dalitz plane allows for many interference effects to be probed & is more robust against systematics than two-body rate analysis

Excellent candidate: $D^+ \to K^+K^-\pi^+$ with $D_s^+ \to K^+K^-\pi^+$ & $D^+ \to K^-\pi^+\pi^+$ as control channels





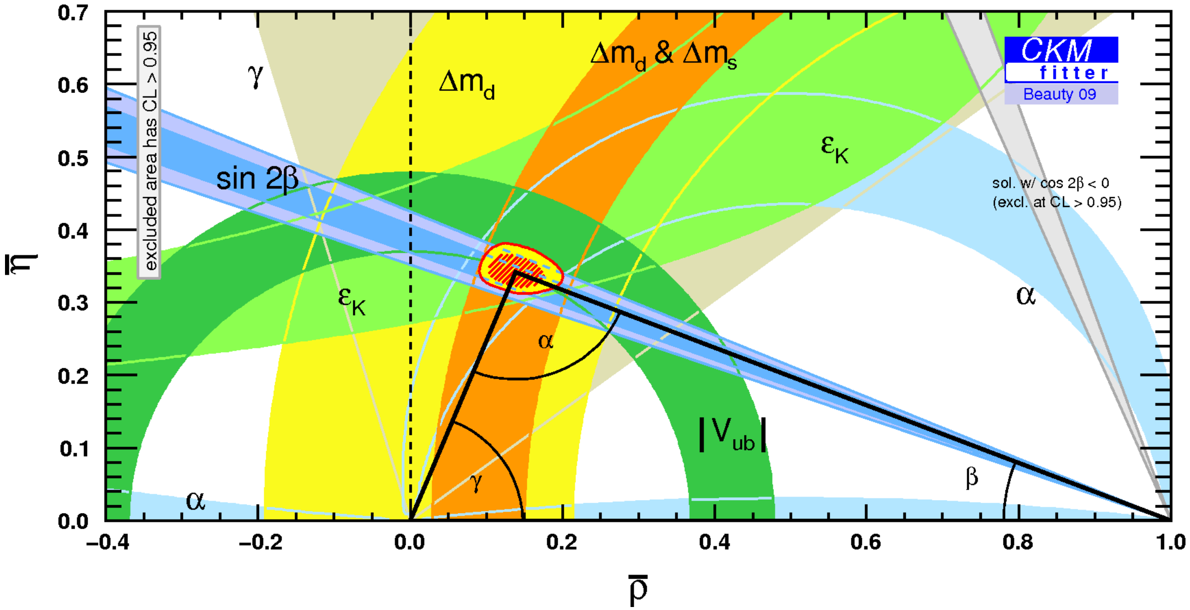


Can be confident of acquiring signal sample of several million events in 100 pb^{-1}
Again, order of magnitude increase on B-factories samples.

Similar opportunities in many other D physics topics, eg. search for $D^0 \to \mu\mu$

Precision CKM metrology

B-factories' big achievement: careful survey of B^0_d system.
Conclusion: CKM mechanism is principal driver of CP-violating effects…



…but tensions exists, & 10-20% corrections from NP are far from excluded

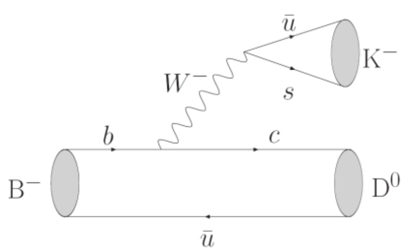
A main responsibility of LHC flavour programme is to sharpen picture still further:

- several parameters badly known eg. γ uncertainty > 20º [CKMfitter]
- big improvements in lattice QCD will need to be matched by experiment

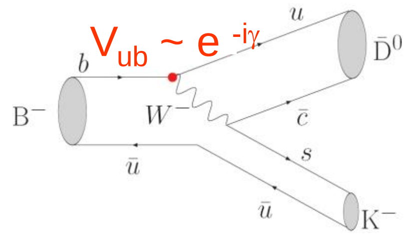
γ measurement at LHCb

All D^0 decay modes already observed (and others) will be used in measurement of ‘$B \to DK$’ direct CP-asymmetries which are sensitive to the unitarity angle γ

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



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



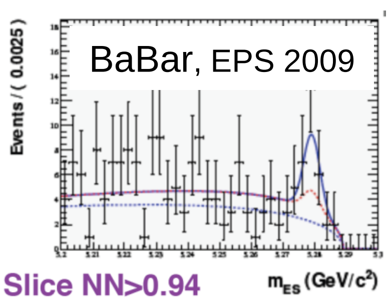
Final state common to D^0 & $\overline{D}^0$

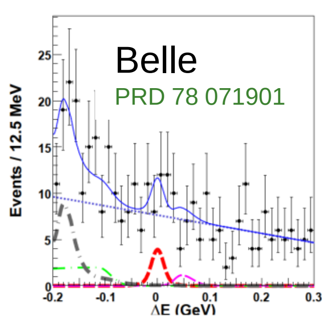
$K\pi$, KK, $\pi\pi$, $K\pi\pi\pi$,
$K\pi\pi^0$, $K^0{}_S\pi\pi$, $K^0{}_S KK$, …

allows for interference $\to \gamma$

~100 pb^{-1} already offers possibilities to improve on knowledge from B factories

eg. ‘ADS’ suppressed $B \to D(K\pi)K$ mode just beyond reach of B-factories ➡ LHCb expects ~70 of these events with 100 pb^{-1}





Combine all considered $B \to DK$ measurements and time dependent approaches from B_s system

$\sigma_\gamma^{LHCb} \approx 7^{o}$ with 1 fb^{-1}

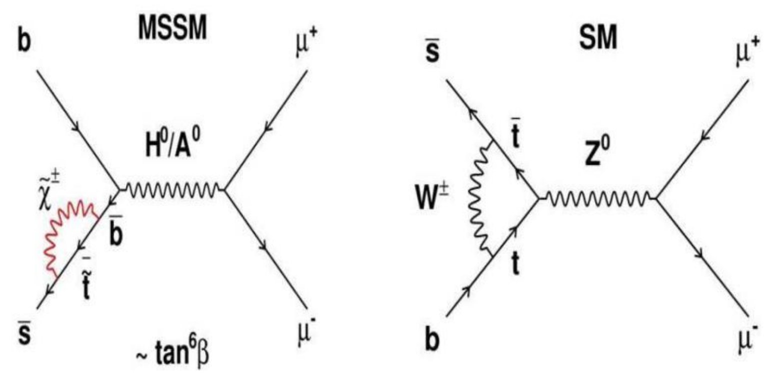
The golden mode: $B_s \rightarrow \mu\mu$

B physics rare decay par excellence:

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

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

Precise prediction (which will improve) !



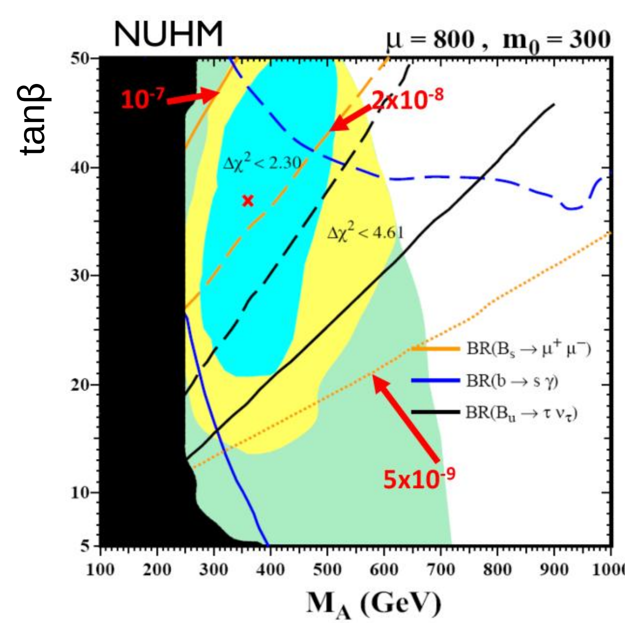
Very high sensitivity to NP, eg. MSSM:

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

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

- $b \rightarrow s\gamma$ and Higgs > 114.4 GeV
  - ⟹ M_A > ~ 300 GeV & $\tan\beta$ < ~50
- $(g_\mu$-2) is 3.4σ from SM
  - ⟹ M_A < ~ 500 GeV & $\tan\beta$ > ~20

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



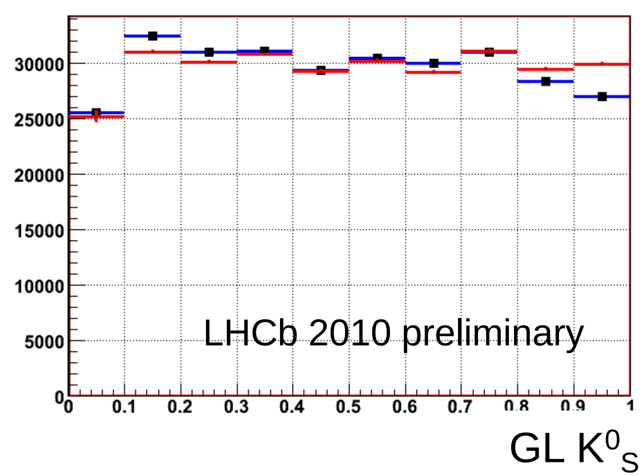
$B_s \to \mu\mu$ at LHCb – testing the input variables

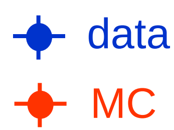
LHCb approach will be philosophically similar to Tevatron's: loose preselection and then construction of global likelihood, which is built from:

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

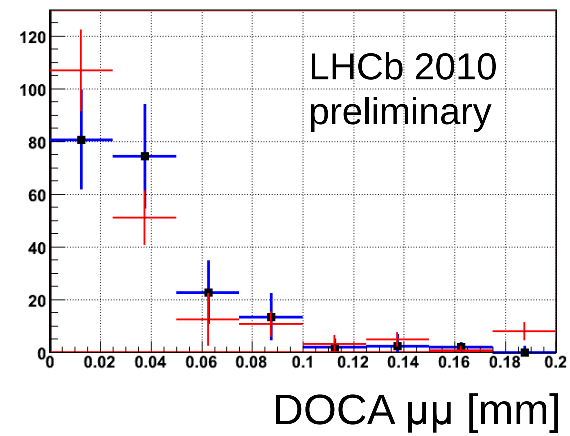
Observation then turned into limit or BR measurement after comparing with known control channel, eg. $B^+ \to J/\psi K^+$

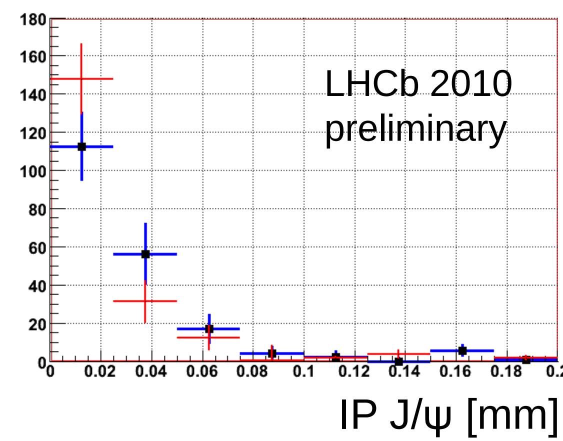
Behaviour of Geometrical Likelihood for signal can already be studied on data by looking at same topology short lived $K^0_S \to \pi\pi$ decays:





Checks of input variables also beginning using J/ψ sample

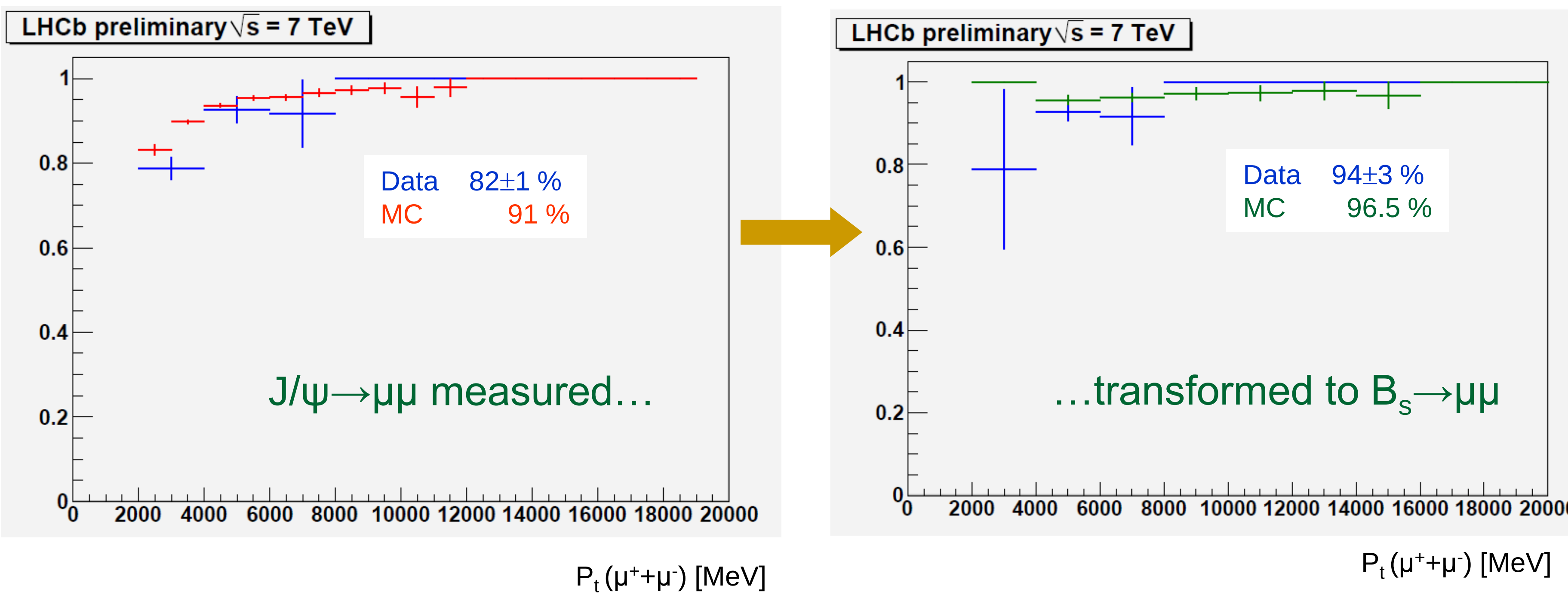




Muon trigger studies

Measure performance of L0*HLT1 (using lifetime unbiased HLT1 lines) for $J/\psi \to \mu\mu$

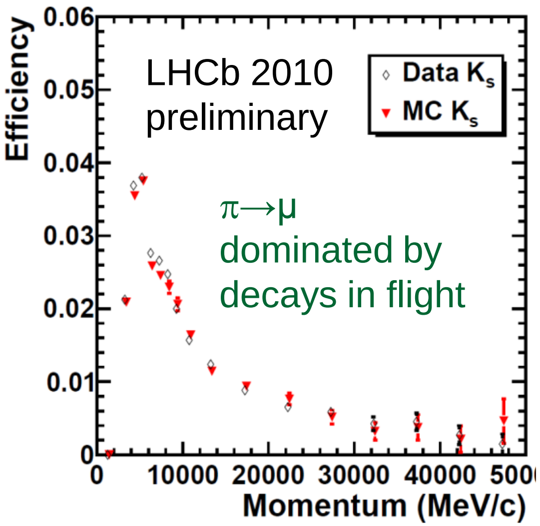
Transport results to harder p_t spectrum of $B_s \to \mu\mu$

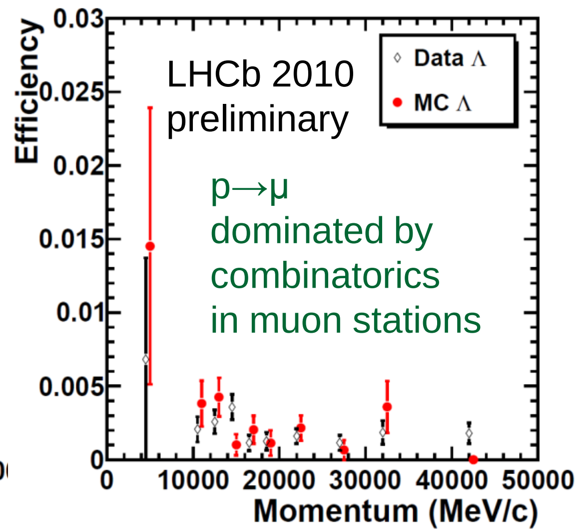


Muon identification studies

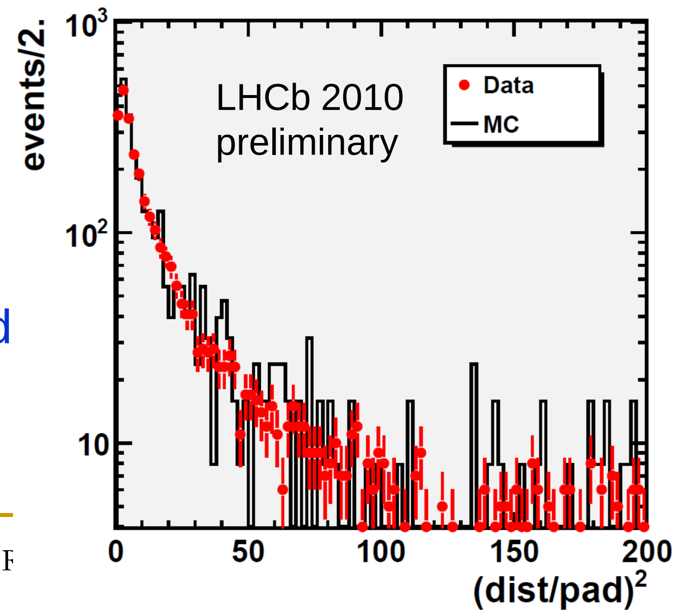
$B_s \to \mu\mu$ sensitivity relies on good performance of muon-identification. Misid performance is already under study. (Muon efficiency will be measured with J/ψ's)

Fake rate data and simulation for *first* stage of algorithm





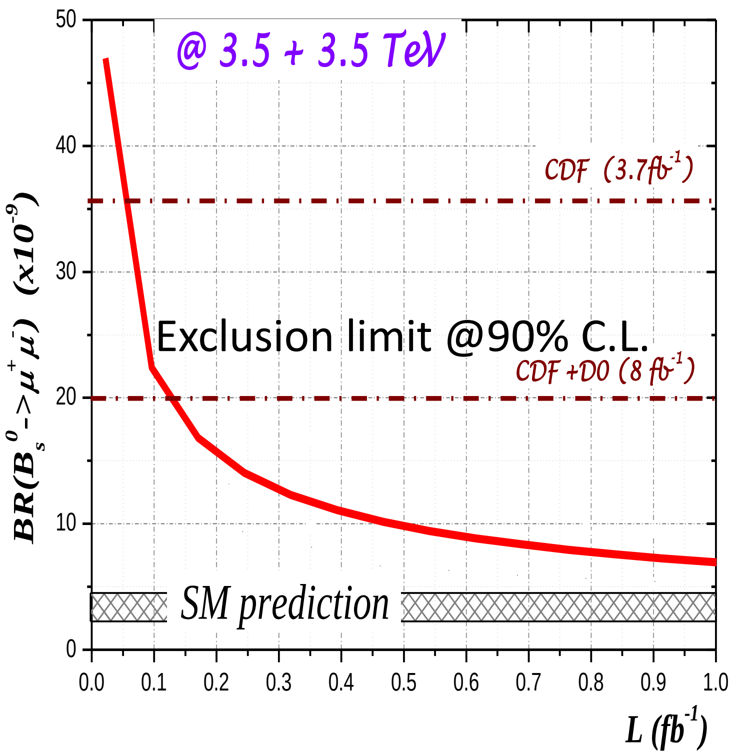
Squared distance between background hits in muon system & extrapolated tracks

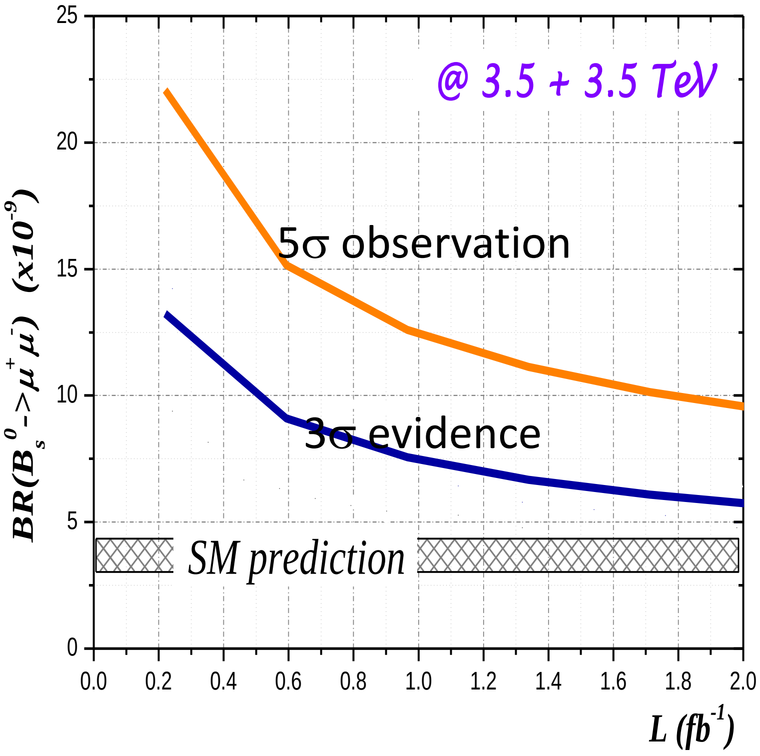


Next step will be to calibrate likelihood which is used to achieve higher suppression. First look at key ingredients shows promising data/MC agreement

LHCb prospects for $B_s \rightarrow \mu\mu$

All studies with existing data indicate that $B_s \rightarrow \mu\mu$ sensitivity as determined from simulation is realistic. The simulation studies give the following expectations:





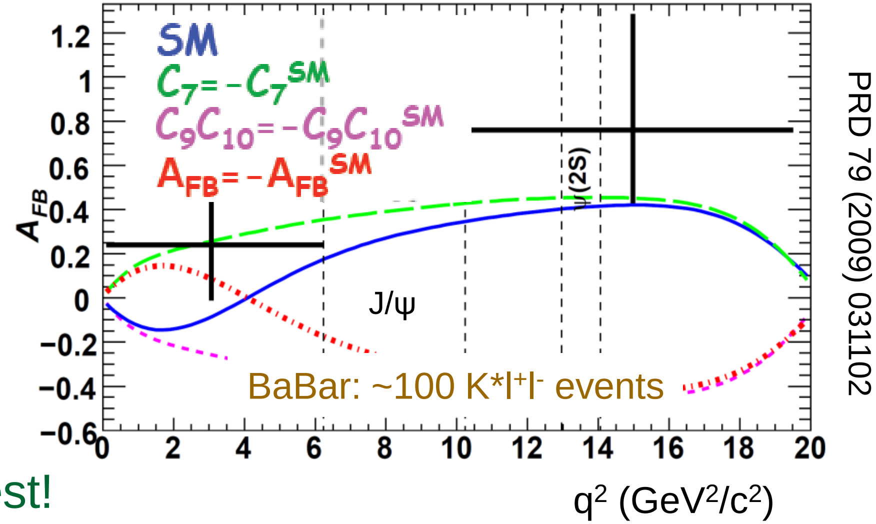
Already much is possible with 0.1 fb^{-1}; possibilities with 1 fb^{-1} are very exciting

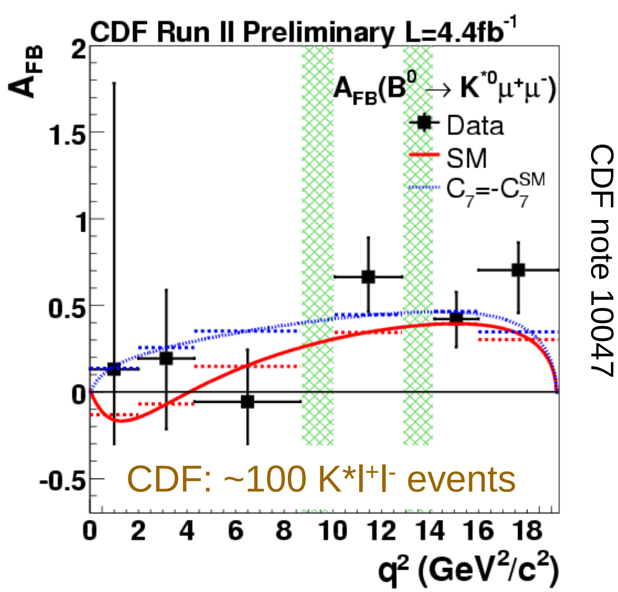
Intriguing hints from B→K(*)l+l-

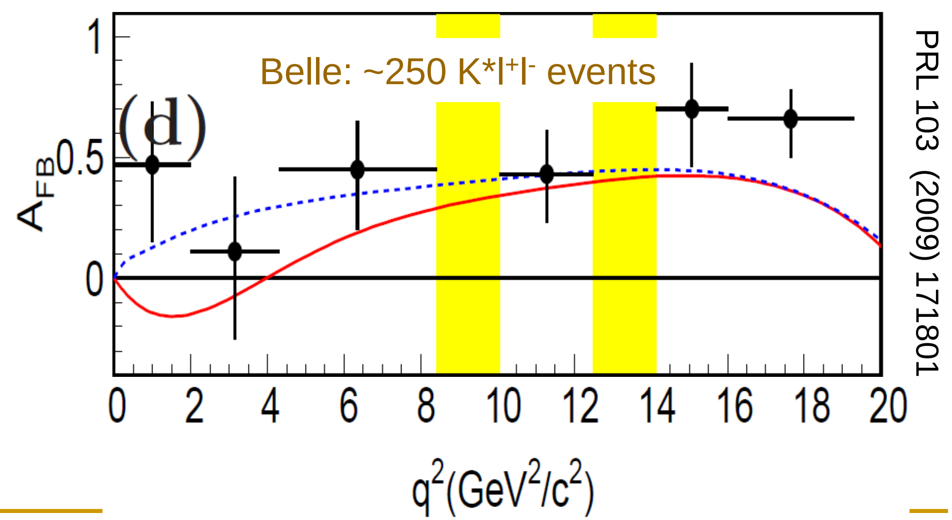
Forward backward asymmetry in $B^0 \to K^* l^+ l^-$ is a extremely powerful observable for testing SM vs NP

Most reliable predictions are at low q^2 - below & up to crossing-point

Early results are showing intriguing hints. Not yet an 'anomaly', but any deviation where one is hoped for has special interest!

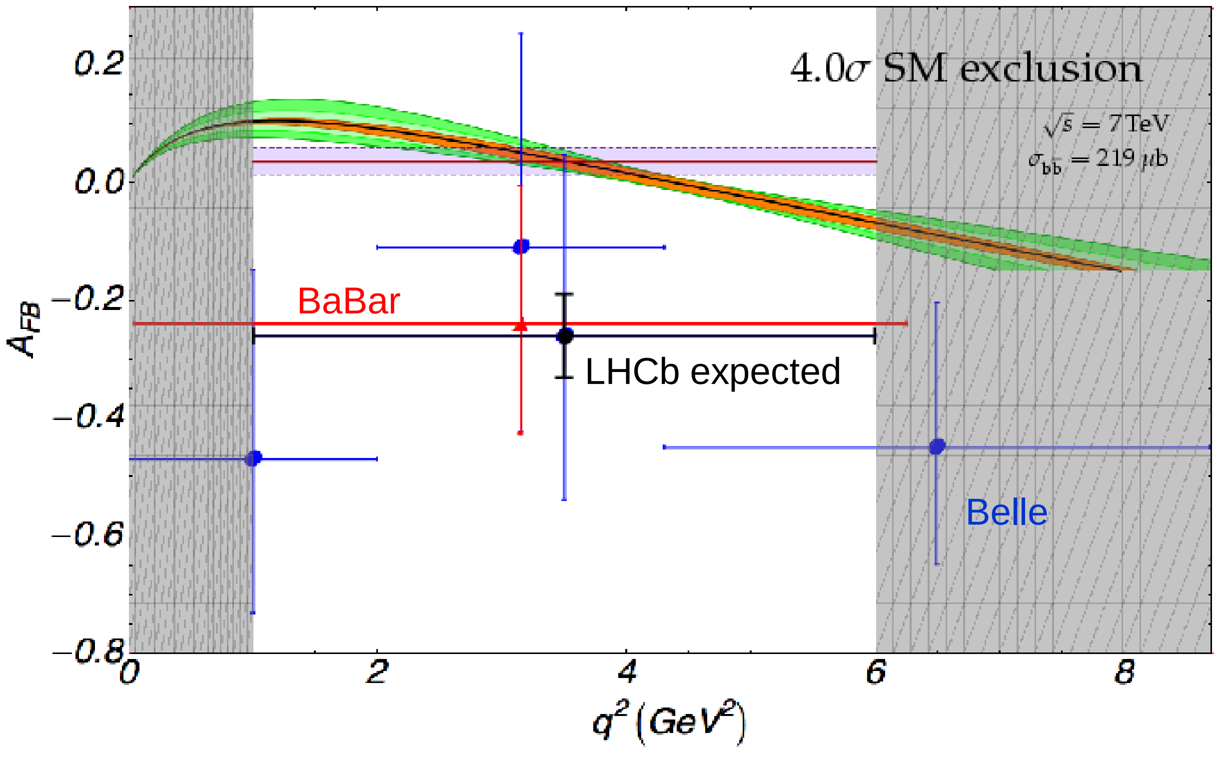






B→K$^{(*)}$l$^+$l$^-$ prospects

With 1 fb^{-1} LHCb expects 1200 events, and should clarify existing situation



Flipped sign in asymmetry definition compared with slide on existing results

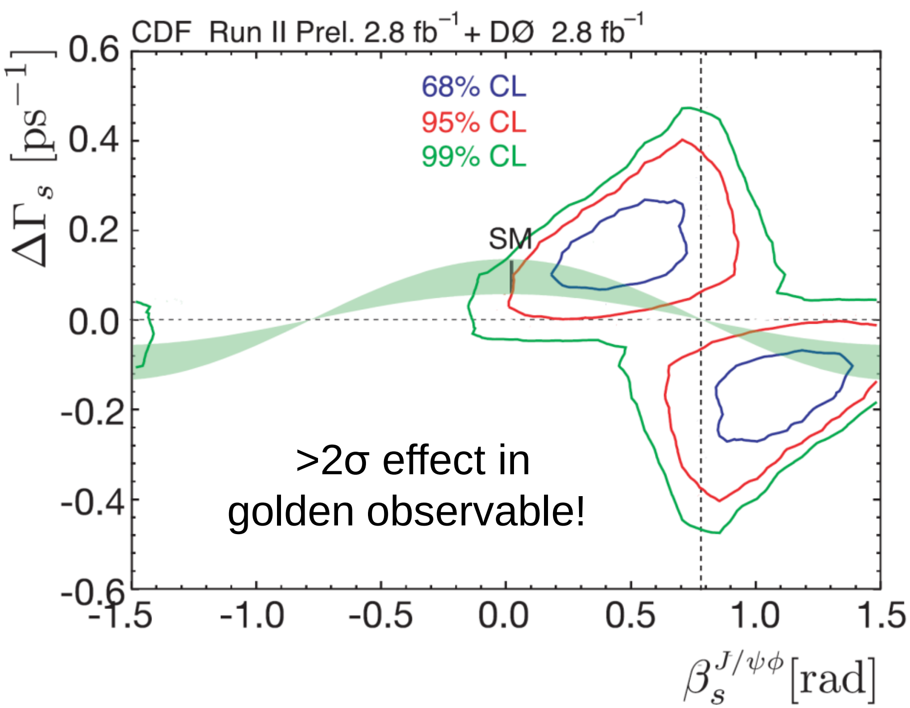
If picture becomes more SM-like then next task will be to pin down position of A_{FB}=0 which is cleanly predicted. Precision of 0.8 GeV^2 in 1 fb^{-1}

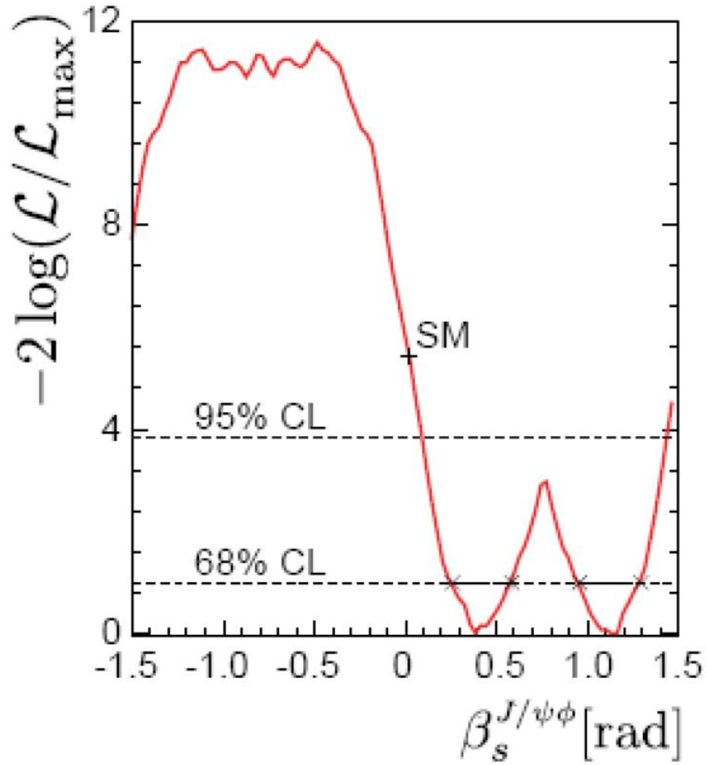
Search for CPV in $B_s \rightarrow J/\psi\Phi$

Mixing induced CPV in $B_s \rightarrow J/\psi\Phi$ is golden mode at hadron machines:

- precisely predicted in SM
- very small in SM – any signal at present sensitivity is very exciting
- a priori sensitive to NP (box diagram) in ways not explored at B-factories

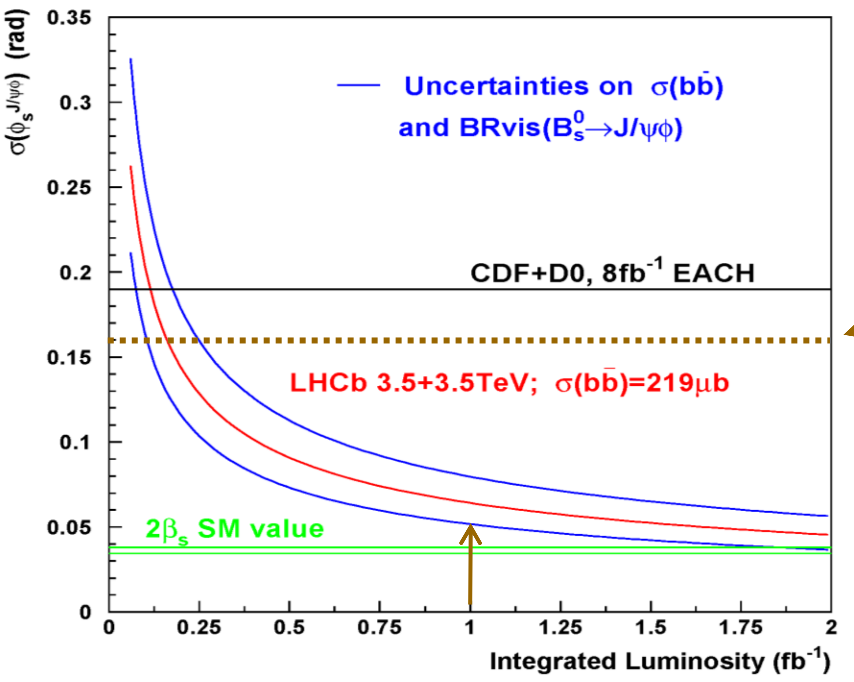
Hence first results from Tevatron have understandably caused a stir





LHCb prospects in $B_s \to J/\psi\Phi$

If nature agrees with Tevatron central value then LHCb can make 5σ discovery in coming run. Statistical precision on measured CPV phase of ~0.07 with 1 fb^{-1}



Approximate sensitivity needed to establish non-zero CPV phase if Tevatron central value is true

This result will be complemented by equivalent measurement in CP-eigenstate $B_s \to J/\psi f^0(980)$, $f^0(980) \to \pi^+\pi^-$. Φ_s sensitivity could be similar, depending on BR.

Other LHCb Opportunities

- Charmless B-decays

  Including time dependent B^0, $B_s \to hh$ studies
  Dalitz studies of 3-body decays

- Radiative Penguins

  3k $Bs \to \Phi\gamma$ events in 1 fb^{-1}

- CP-asymmetries involving $b \to s$ Penguins, eg. $B_s \to \Phi\Phi$, K^*K^*

- More CKM metrology

  $\sin 2\beta$, α from $B \to \rho\pi$, $\rho\rho$ etc

- Exotic charmonium spectroscopy

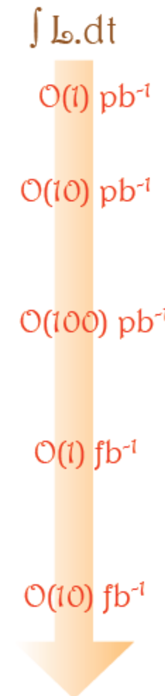
  Determining the quantum numbers of the X(3872)
  Searching for the Z(4430)

ATLAS and CMS Heavy Flavour Prospects in 2010-11 Run

Many studies possible – scope broadens as integrated luminosity increases

analysis examples and luminosity range

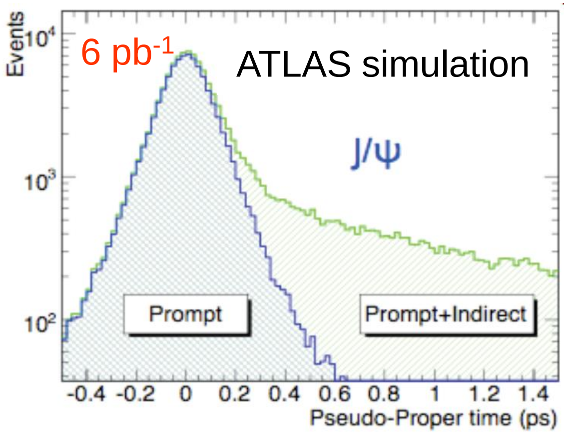
- cross section for bottom, charm and quarkonia
- inclusive J/ψ, exclusive *B* decays containing J/ψ
- quarkonia studies: polarization, production mechanisms
- *bb* production, and correlations: $J/\psi+\mu$, μ+jet, jet+jet
- lifetime and properties of *b* hadrons: B_u, B_d, B_s, B_c, Λ_b
- B_s oscillations, CP violation
- FCNC rare decays, eg $B\rightarrow\mu\mu$, $\mu\mu K^{(*)}$, $\mu\mu\Phi$, $\mu\mu\gamma$
- LFV eg $\tau\rightarrow3\mu$

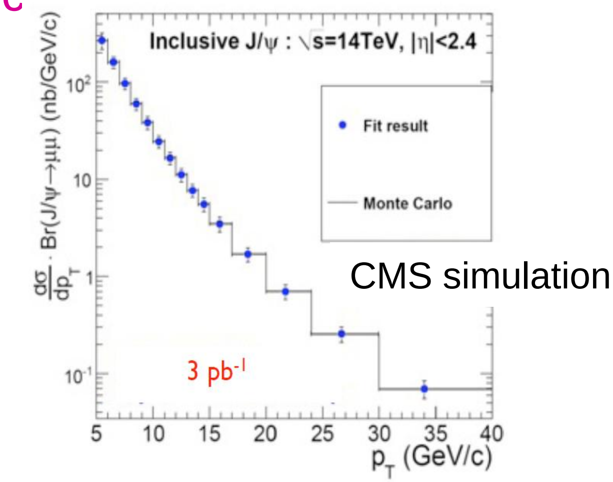


Courtesy, Nuno Leandro

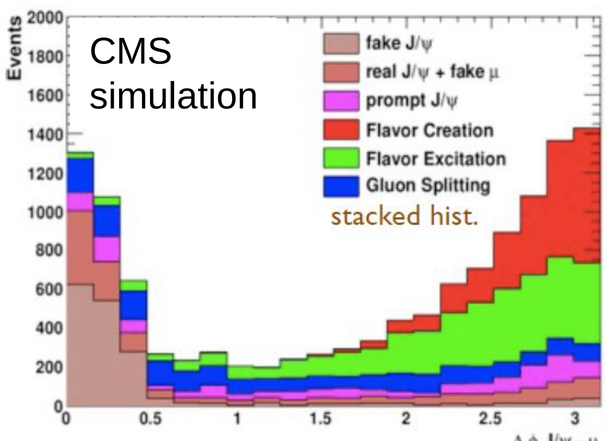
ATLAS & CMS Production Studies

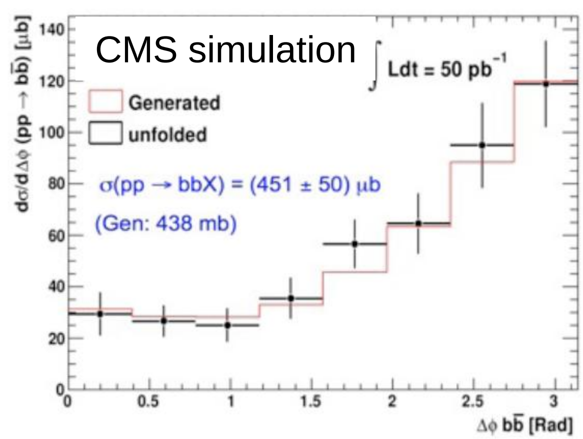
With a few pb^{-1} detailed studies of prompt and B-produced J/ψ are possible, with p_t reach beyond 20 GeV/c





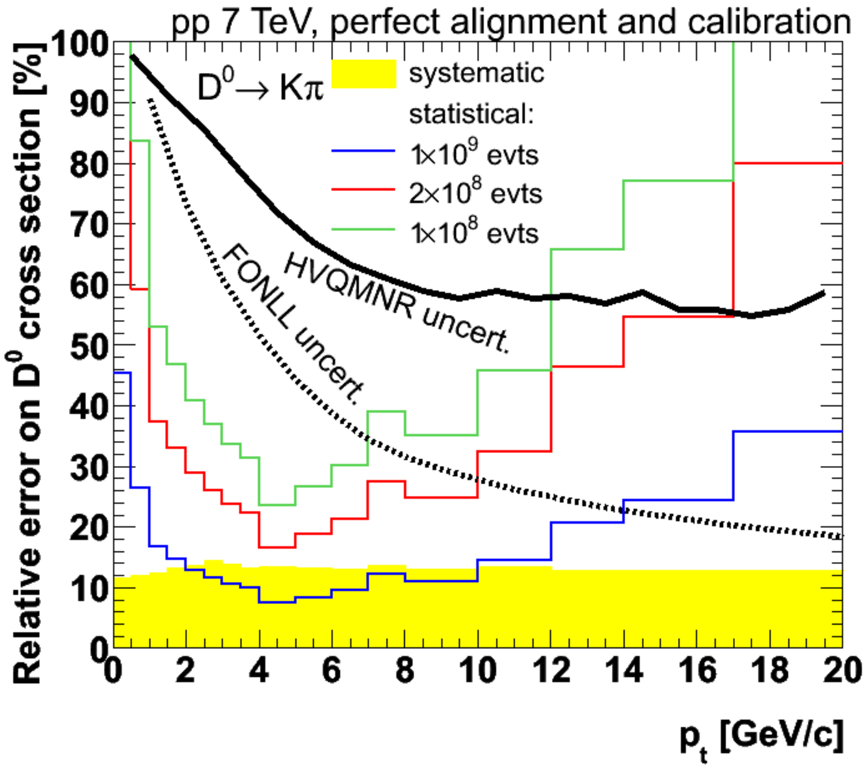
Larger datasets allow, through J/ψ–lepton correlations, different processes of heavy flavour production to be distinguished





ALICE Production Studies

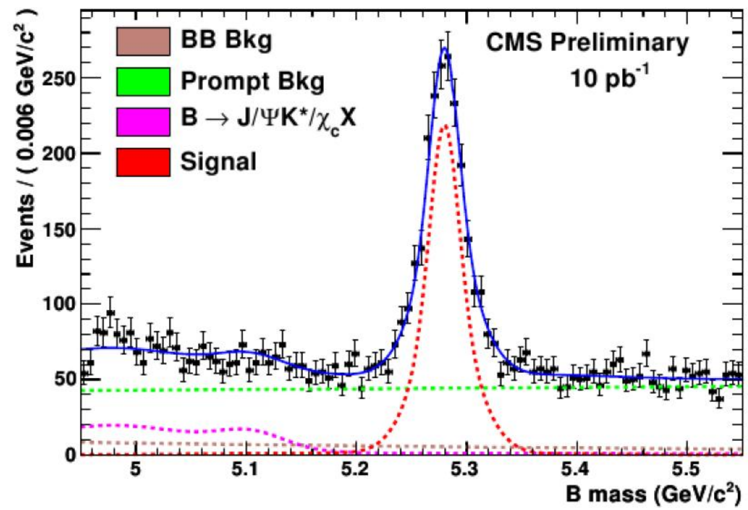
ALICE intend to measure cross-section for production of charm and beauty hadrons (D^0,D^+,D_s,D^*,Λ_c,$B \to J/\psi X$, $B \to eX$…). Expectations for $D^0 \to K\pi$ vs p_t:



With 10^9 min bias events measurement uncertainty < theory up to p_t of 14 GeV/c

ATLAS & CMS exclusive B-decays

~10 pb^{-1} already sufficient to reconstruct large samples of exclusive decay modes, suitable for eg. lifetime studies



Both ATLAS & CMS expect ~1000 $B_s \rightarrow J/\psi\Phi$ events in 100 pb^{-1}

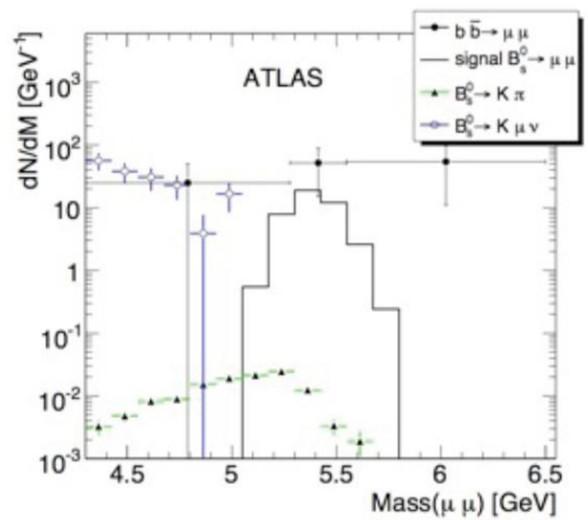
→ time-dependent B_s CP studies

Both experiments well suited to $B_s \rightarrow \mu\mu$ search.

	signal	bg	σ_m/MeV
ATLAS, 10 fb^{-1}	5.7	14	90 (70-120)
CMS, 1 fb^{-1}	2.4	6.53	53

CMS expected upper limit with 1fb^{-1}
$B(B_s \rightarrow \mu\mu) \leq 1.9 \cdot 10^{-8}$ at 95% CL

(evaluated at $\sqrt{s}$=14 TeV)



Conclusions

Flavour sector an excellent place to search for New Physics effects

Despite 'de-scoping' of present run, LHCb 2010-11 physics potential remains excellent. In almost all LHCb physics topics opportunity exists to improve significantly on present knowledge.

Areas with highest a priori discovery potential:

- charm CPV
- $B_s \to \mu\mu$
- $B_s \to J/\psi\Phi$
- $B \to K^*\mu\mu$

LHCb welcomes the highest possible integrated luminosity to realise these goals!

Very interesting production measurements will soon be achievable at ALICE, ATLAS and CMS

ATLAS and CMS have high sensitivity in B final states with di-muons, most notably $B_s \to \mu\mu$

Backups

Semi-leptonic flavour asymmetries

Any New Physics phase contributing to $B_s \rightarrow J/\psi\Phi$ will also be seen in semi-leptonic flavour asymmetry measured in eg. $B_s \rightarrow D_s \mu\nu$

These events are beginning to accumulate !