First results from LHCb (an 'ICHEP snapshot') and prospects for the present run

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6/8/10

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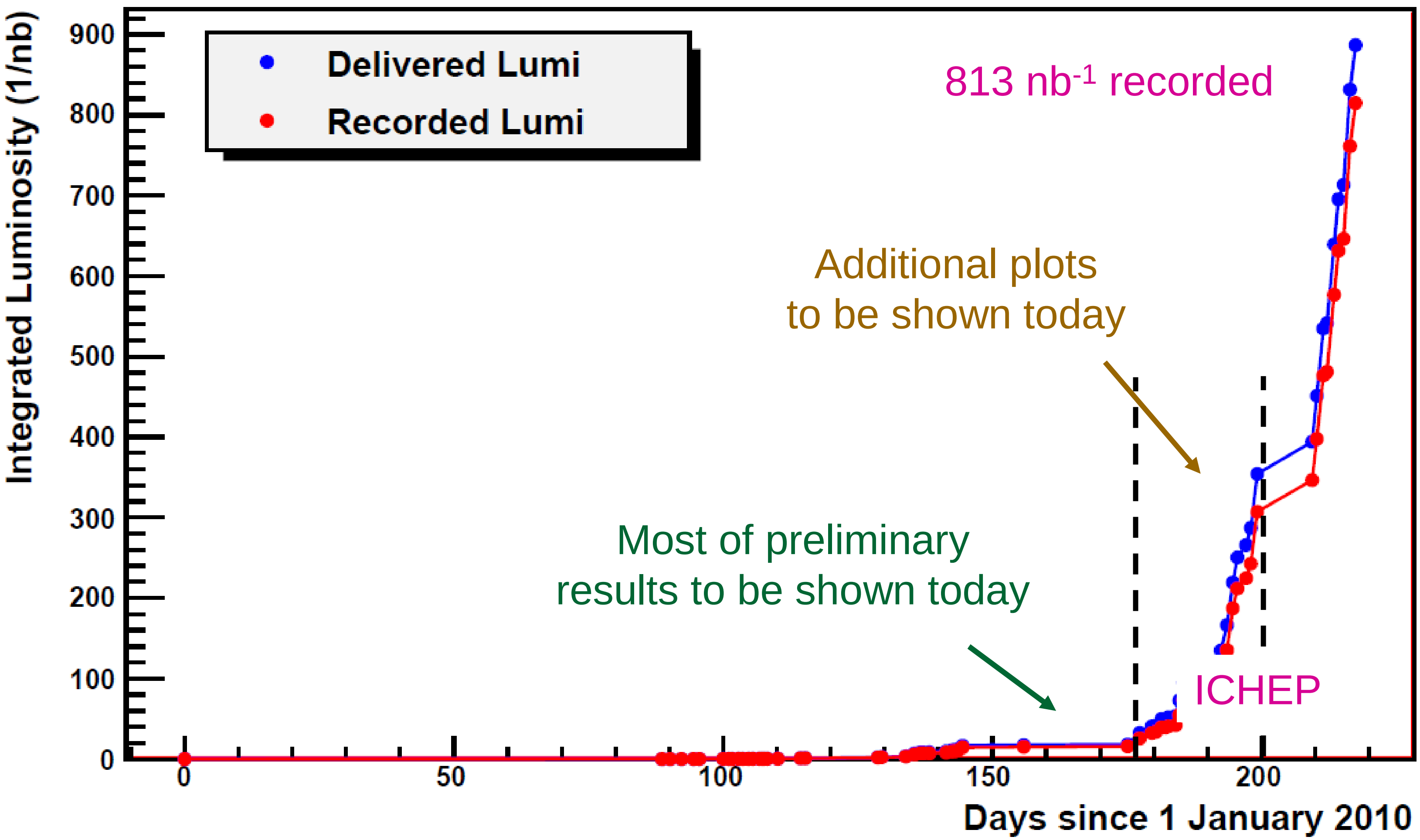
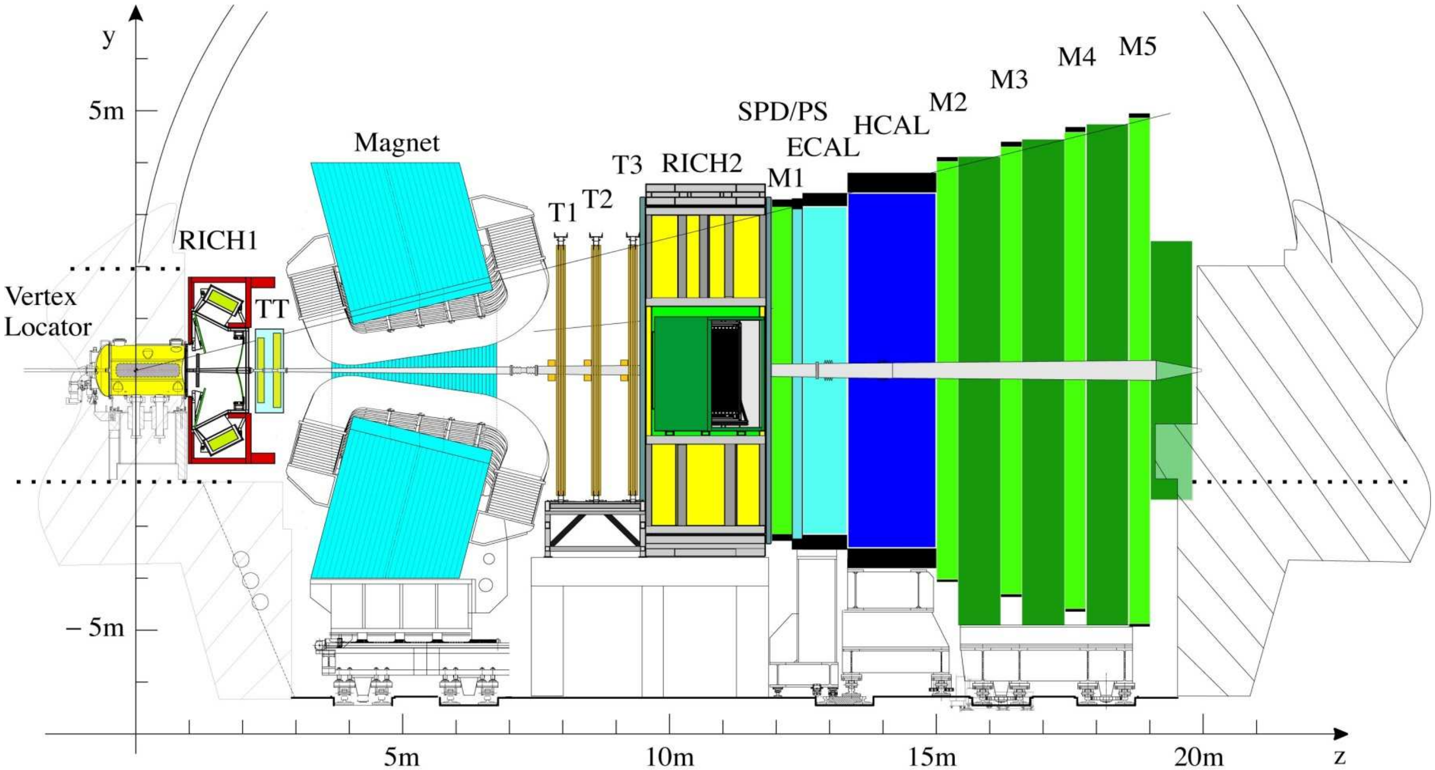
- Results from non-flavour physics
- J/ψ and beauty production
- Exclusive final states and discovery prospects for remainder of run

Integrated Luminosity at noon today





Most relevant attributes for results to be shown today

- Forward acceptance ($2 < \eta < 5$) and down to very low p_T
- Precise vertexing (VELO) – hit resolution of down to 4 μm achieved; measurements 8mm from beam-line
- RICH system providing hadron id between 2 and 100 GeV/c
- High performance muon system

Non-flavour physics at LHCb

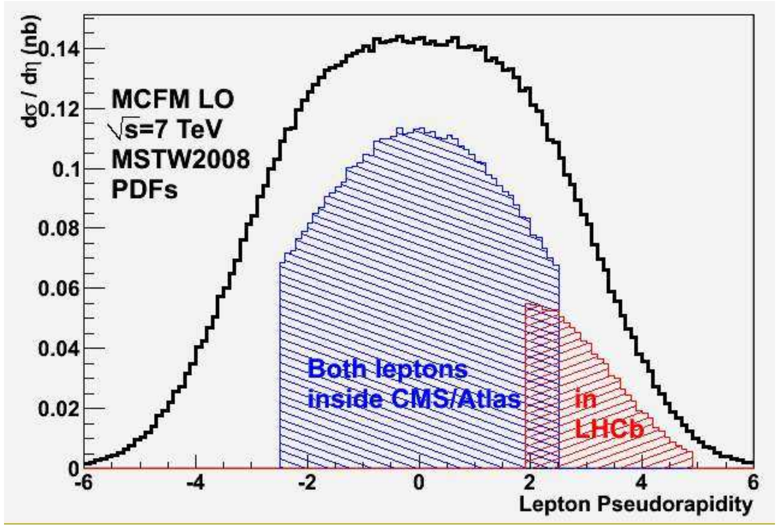
• W production

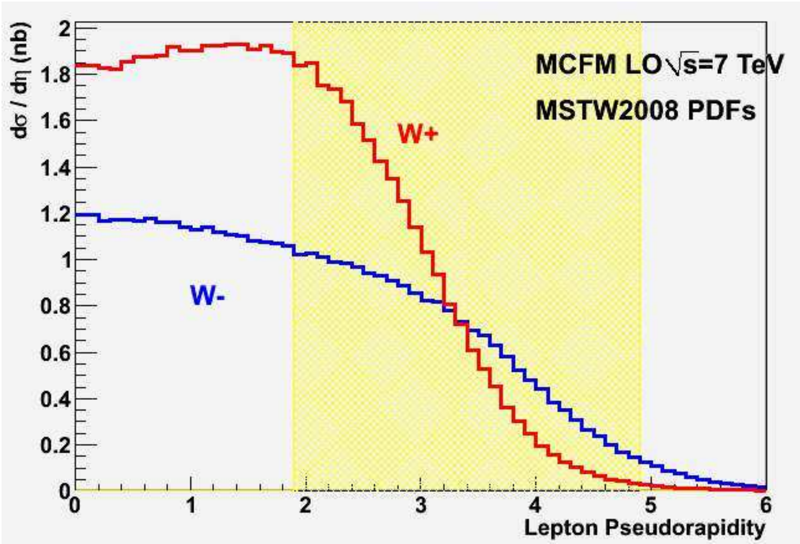
• Low mass Drell-Yan

• Minimum bias studies
  - baryon transport
  - baryon suppression

W physics at LHCb

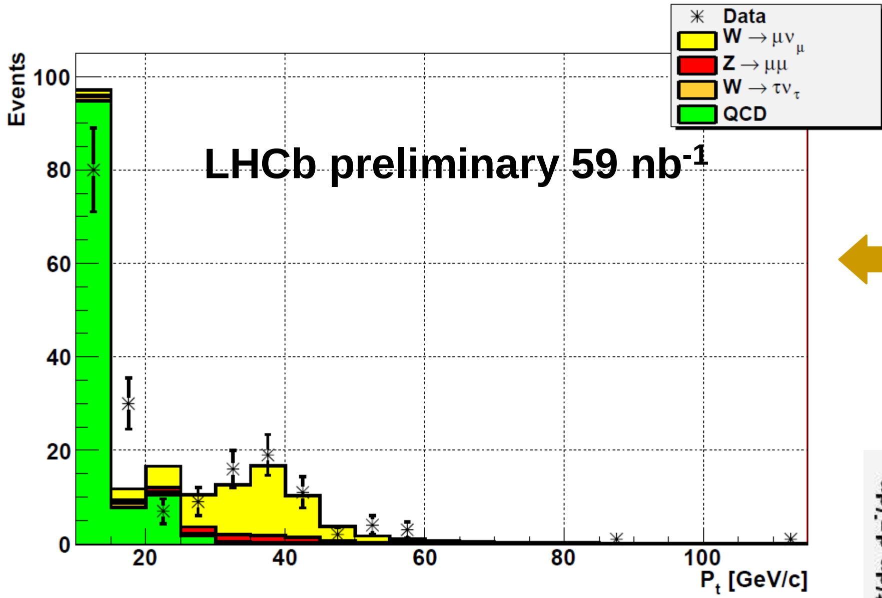
Unique η coverage of LHCb allows for very interesting W,Z production studies





For example switch-over in W^+ / W^- ratio in acceptance

W bosons in LHCb – first results

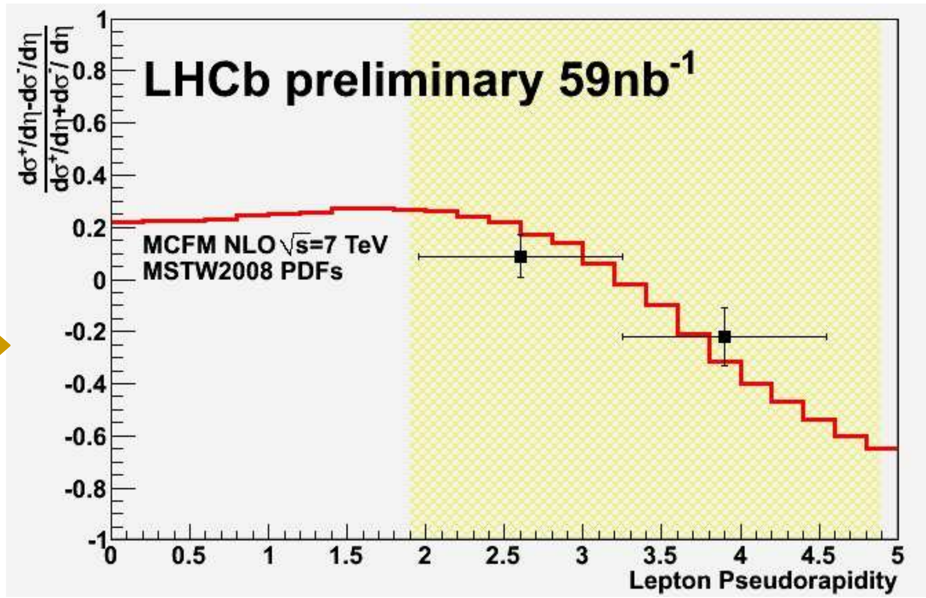


W events being accumulated

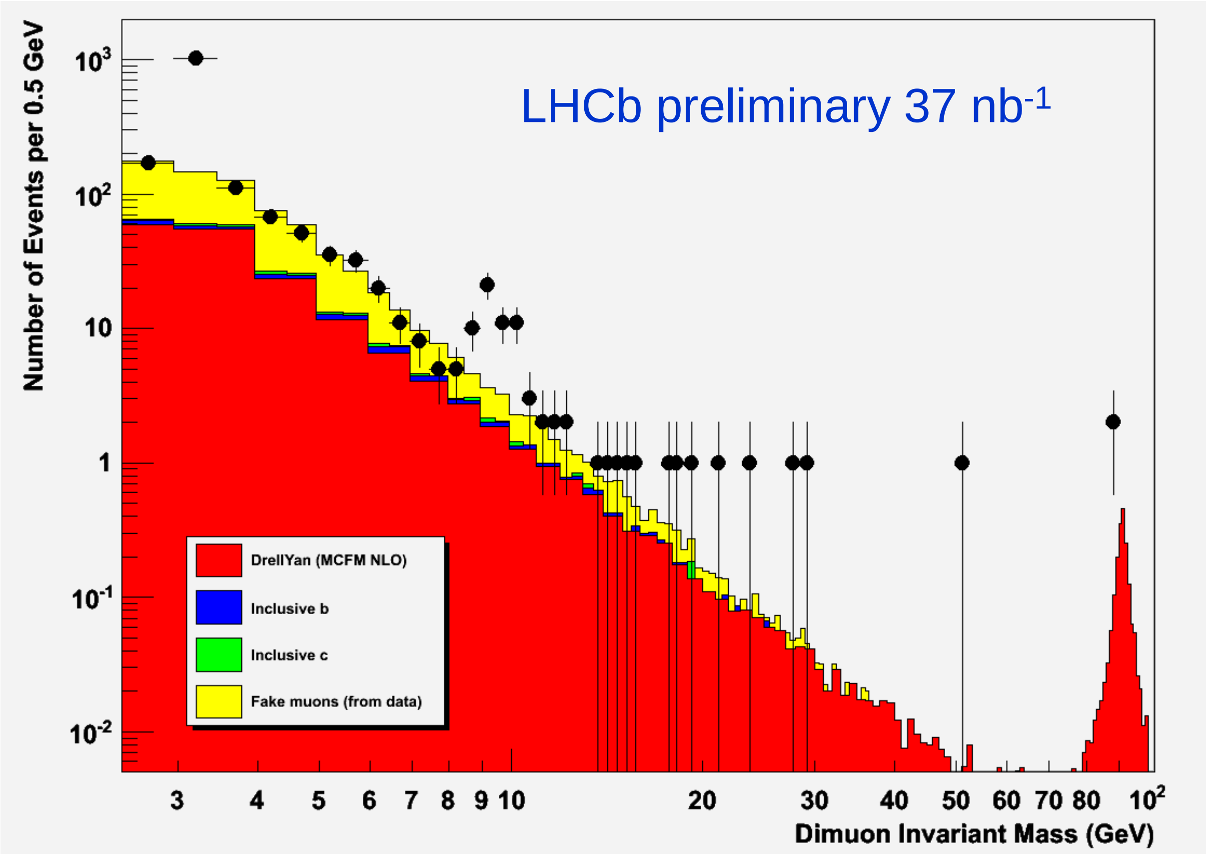
μ p_t spectrum after pre-selection

Already able to probe asymmetry between W^+ and W^- productions

(Stat errors only)

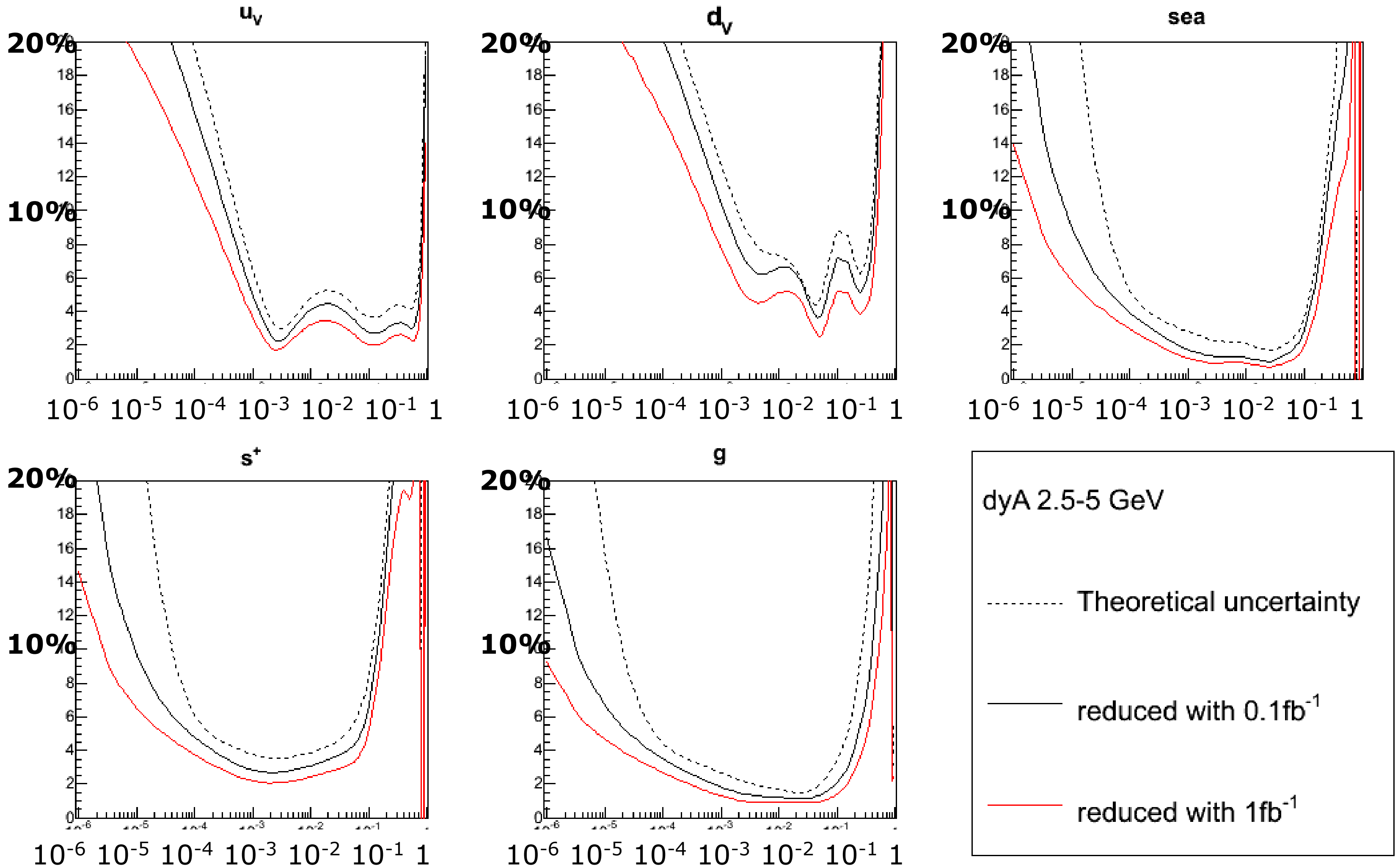


Dimuons in LHCb – low mass Drell-Yan



A possibly unique possibility at LHCb is opportunity to probe down to very low masses in Drell-Yan production → very helpful for constraining PDFs.

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



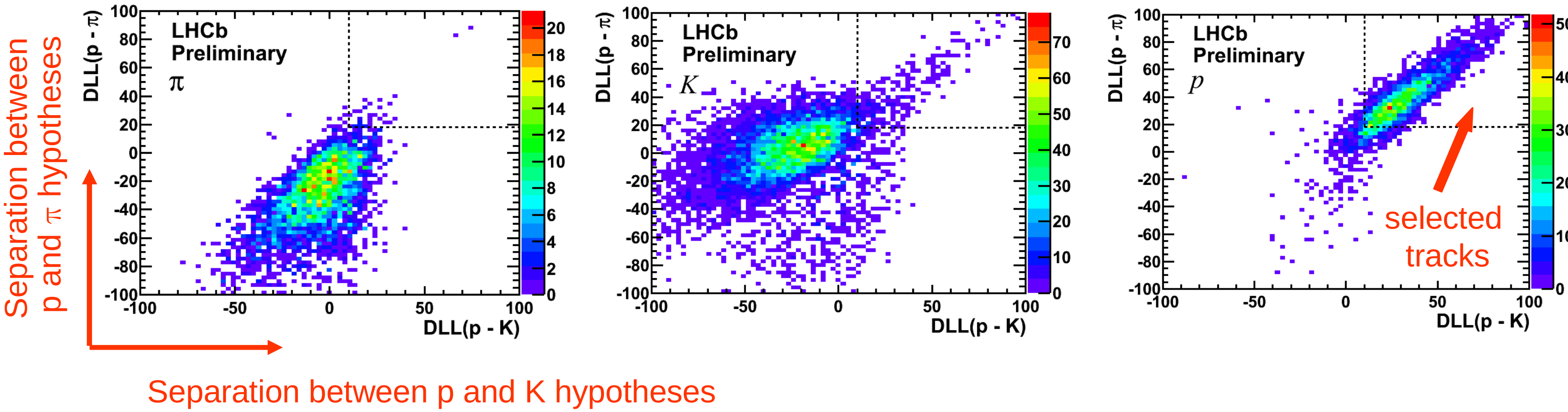
Significant improvements possible with modest amount of data !

Baryon number transport with $\bar{p}/p$

Baryon number conservation requires the destroyed beam particles in inelastic non-diffractive collisions must be balanced by creation of baryons elsewhere

Probe this baryon-number transport by measurements of antiproton/proton ratio as function of (pseudo)rapidity and p_t. Isolate pure samples with RICH likelihood ('DLL')

Performance calibrated in data using kinematically isolated samples of π, K and p

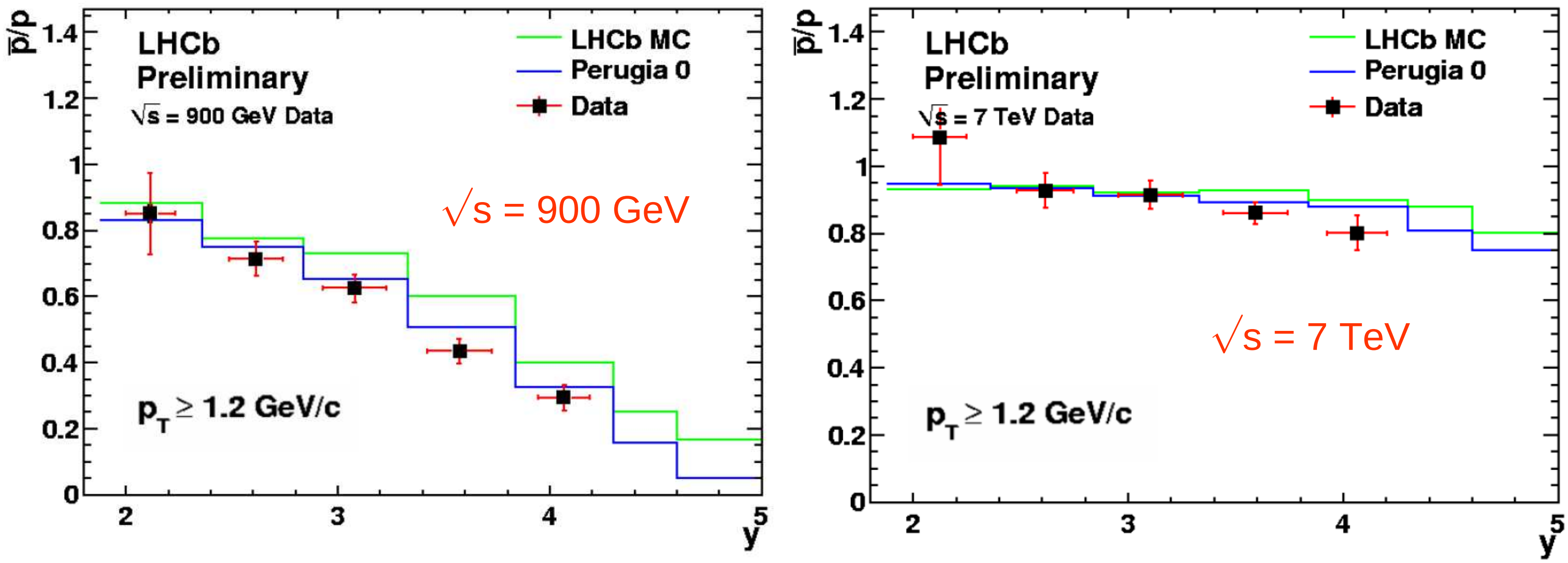


High purity (anti)proton samples of 90-95% obtained over full LHCb acceptance

$\bar{p}/p$ ratio vs y and p_t

Uncertainty dominated by finite statistics of calibration sample. Systematic effects eg. from difference in p-, p-nuclear cross-sections , from 'ghost' tracks etc small

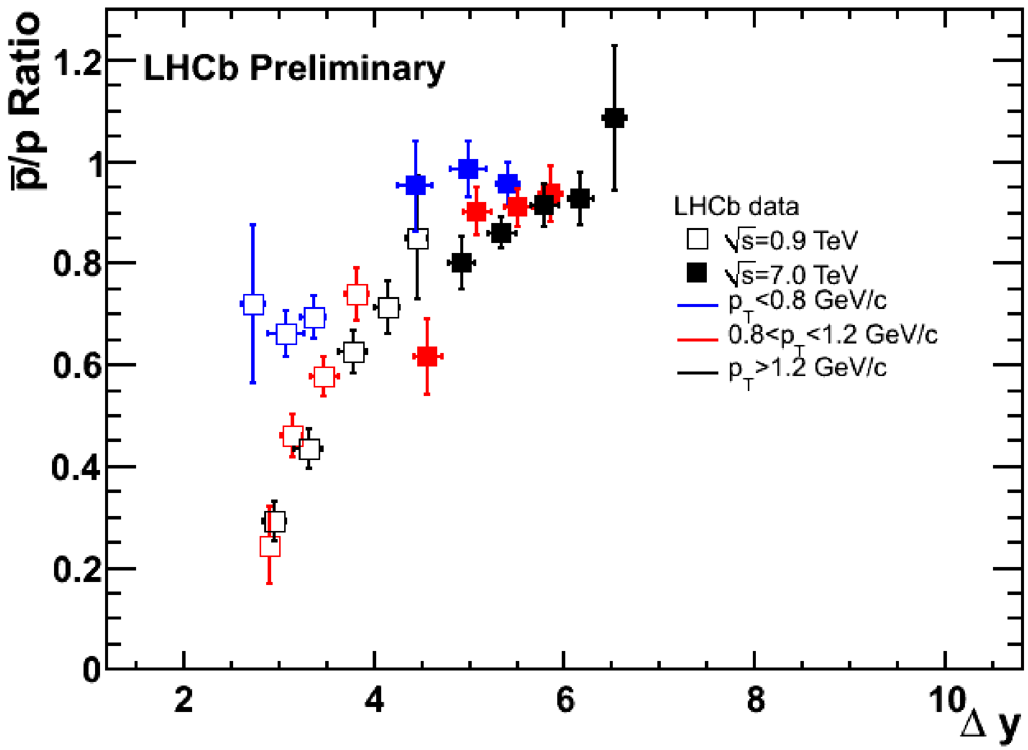
Example results for $p_T > 1.2$ GeV/c (also measured at lower values):



Big deviation in ratio from unity at low energy. Much less so at 7 TeV.
Reasonable agreement observed with Perugia 0 (some deviations at lower p_T)

$\bar{p}/p$ ratio vs Δy ($\equiv y_{beam} - y_{proton}$)

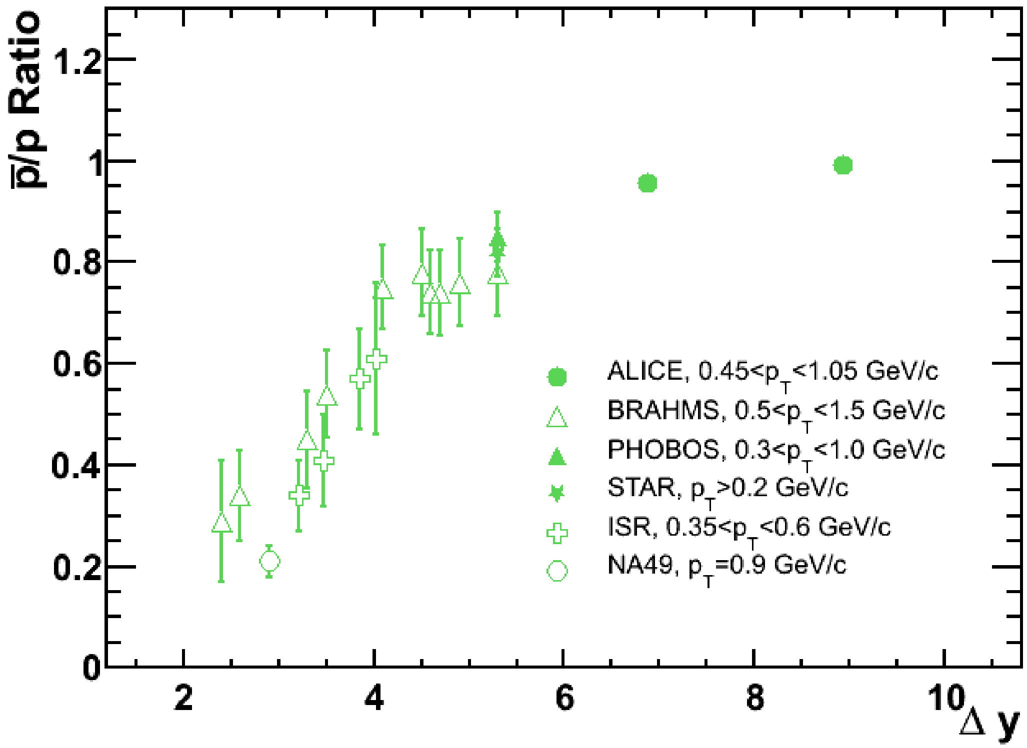
View results in energy independent manner by plotting ratio vs rapidity loss, Δy



- Big span in Δy – around 4 units.
- Some indication of p_T dependence

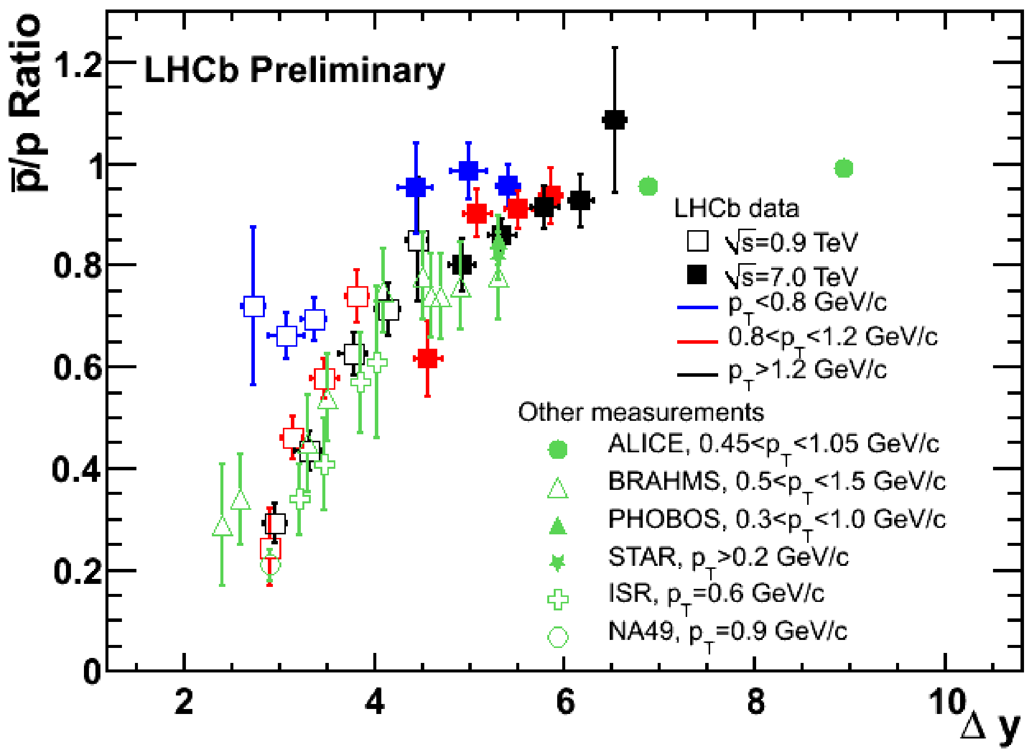
$\bar{p}/p$ ratio vs Δy ($\equiv y_{beam} - y_{proton}$)

Can assemble results of previous measurements



$\bar{p}/p$ ratio vs Δy ($\equiv y_{beam} - y_{proton}$)

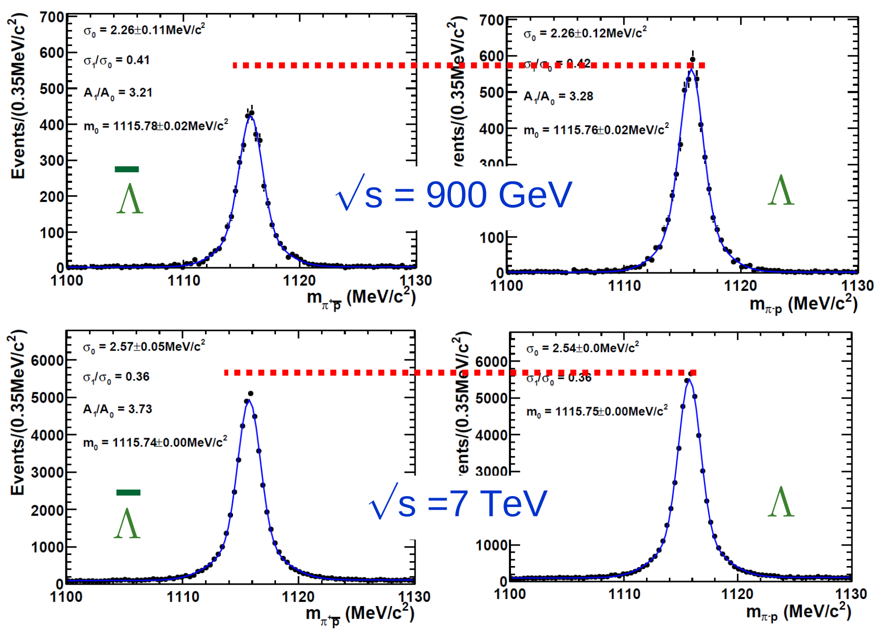
Can assemble results of previous measurements, and then compare with LHCb

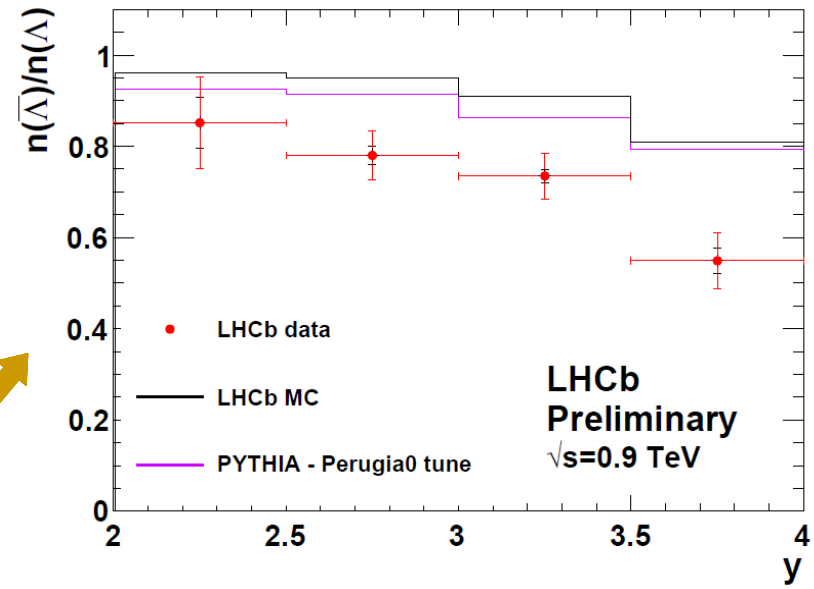


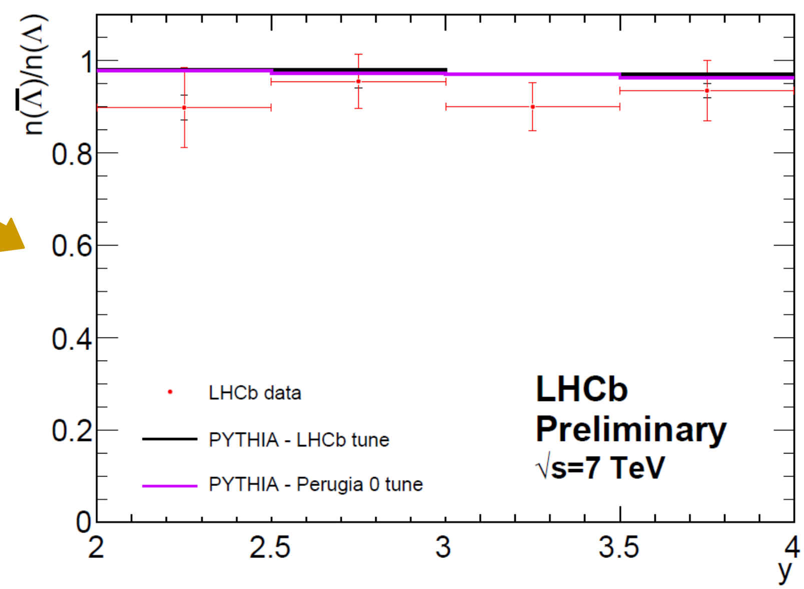
Reasonable consistency exists.
For final results extend calibration dataset to achieve higher precision.

Baryon number transport with $\bar{\Lambda}/\Lambda$

Raw yields (LHCb preliminary)

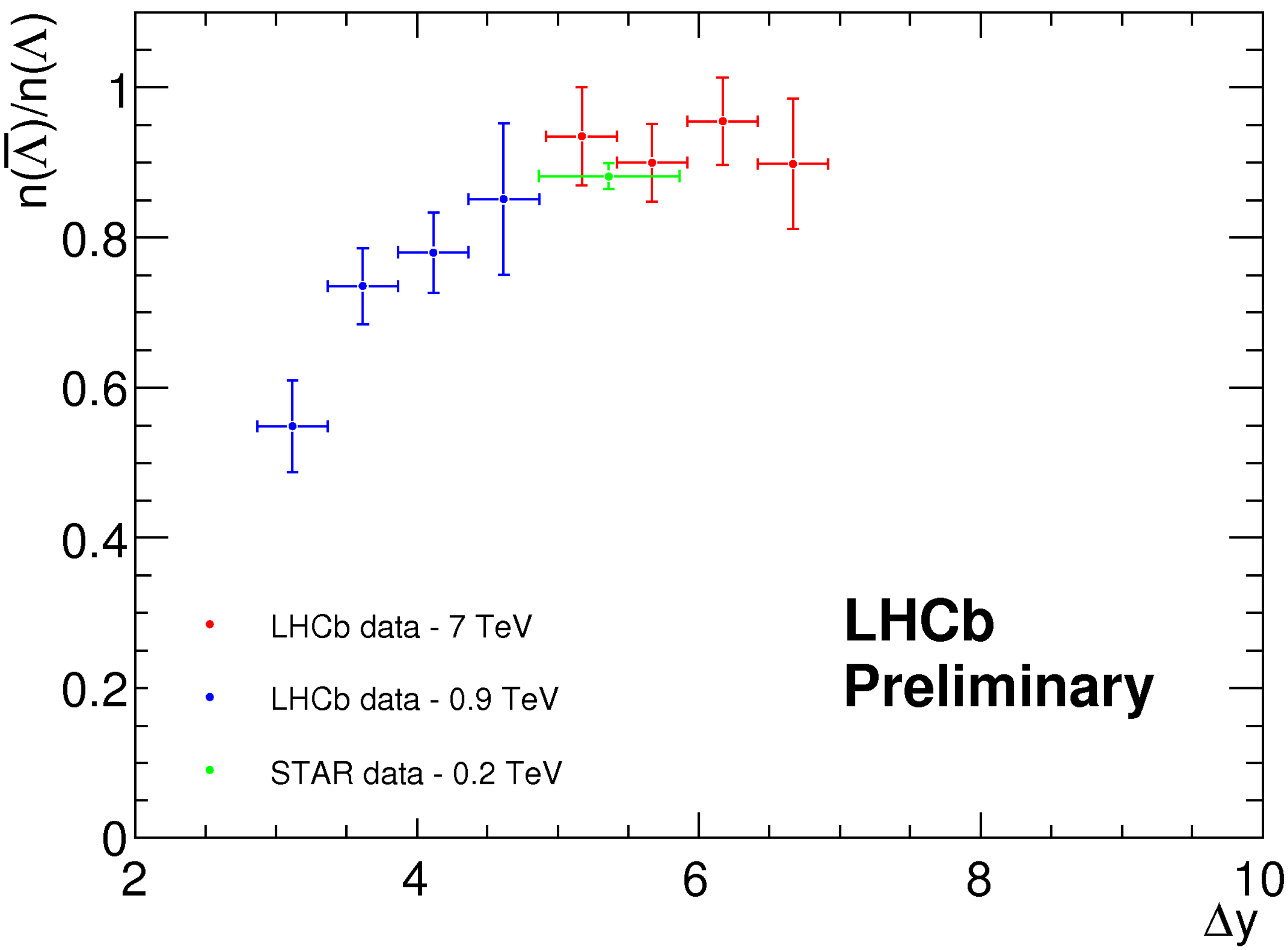






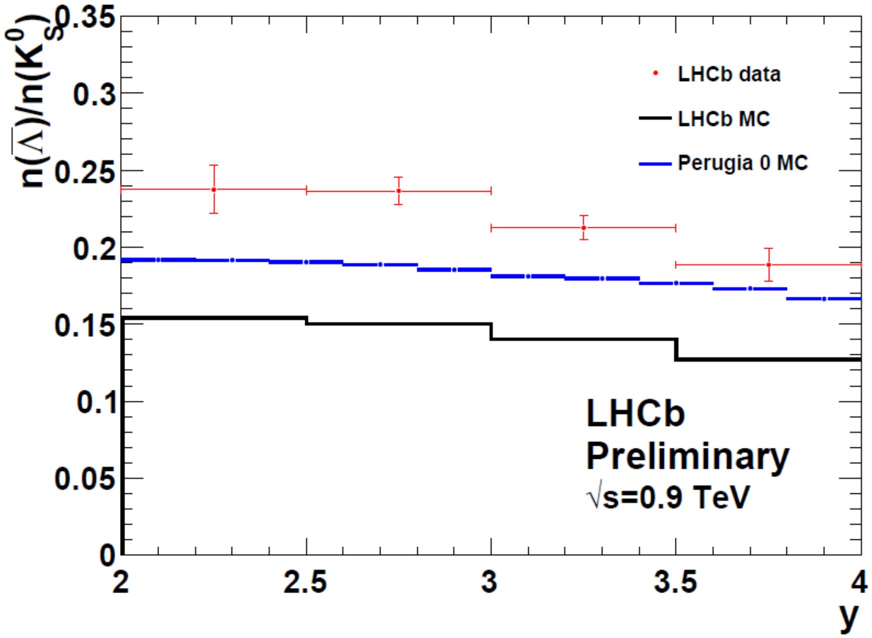
Measurements lie significantly below Perugia 0 expectation at 900 GeV

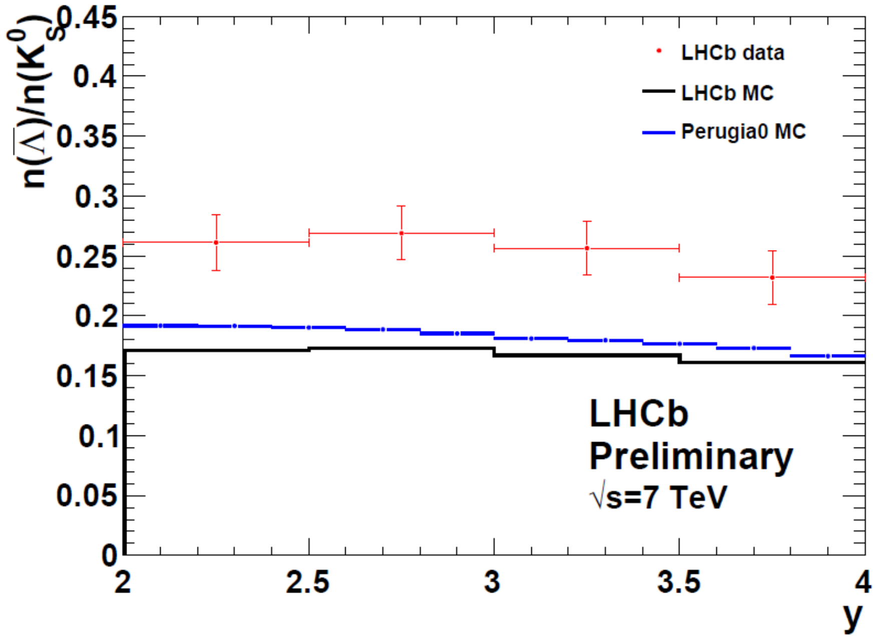
Baryon number transport with $\bar{\Lambda}/\Lambda$



Baryon suppression with $\bar{\Lambda}/K^0_S$

Ratio of $\bar{\Lambda}/K^0_S$ significantly higher than expectation at both energies





Perugia 0 summary:

- Performs adequately in describing $\bar{p}/p$ transport
- Performs poorly in describing $\bar{\Lambda}/\Lambda$ at low energy, and also does not reproduce $\bar{\Lambda}/K^0_S$ data

Heavy flavour production measurements at $\sqrt{s} = 7$ TeV

First, preliminary results on:

- J/ψ production
- Beauty production

All cross-sections normalised using luminosity determination coming from:

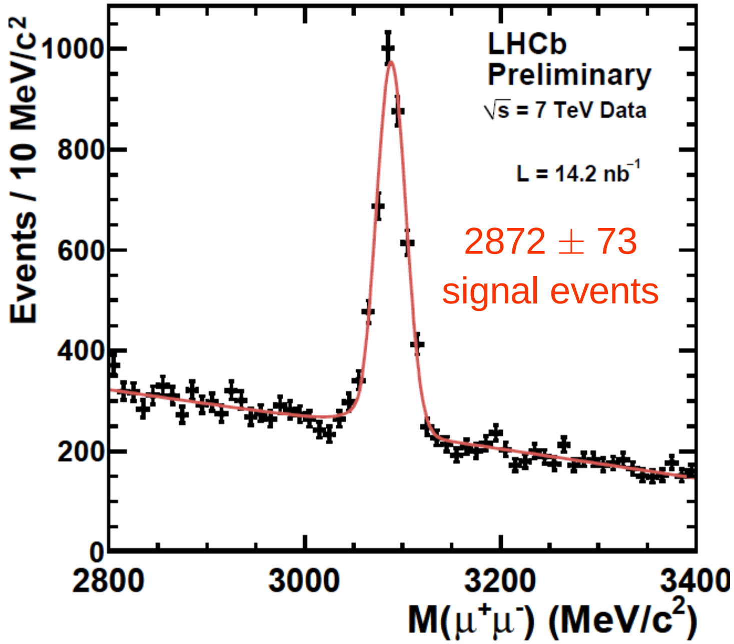
- van der Meer scan
- measurement of beam-profiles with LHCb VELO using beam-gas and beam-beam events

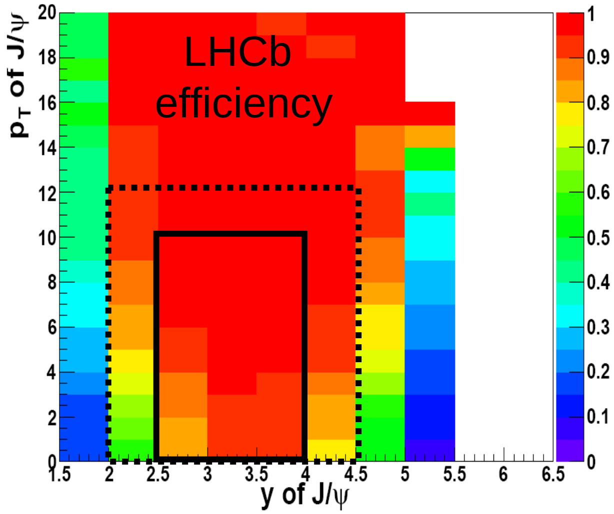
Consistent results with uncertainty of $\pm$10% (knowledge of beam currents)

J/ψ production studies with 14 nb^{-1}

J/ψ measurements of interest because:

- Prompt production mechanism not well understood
- Secondary J/ψ provide convenient b-tag
- di-muons central to many of core LHCb flavour studies





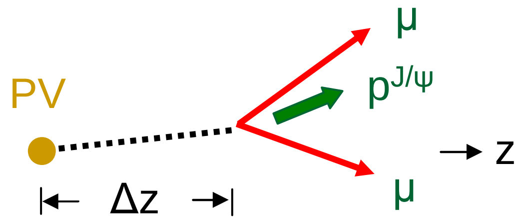
This analysis:

- $2.5 < y < 4$
- $0 < p_T < 10$ GeV/c

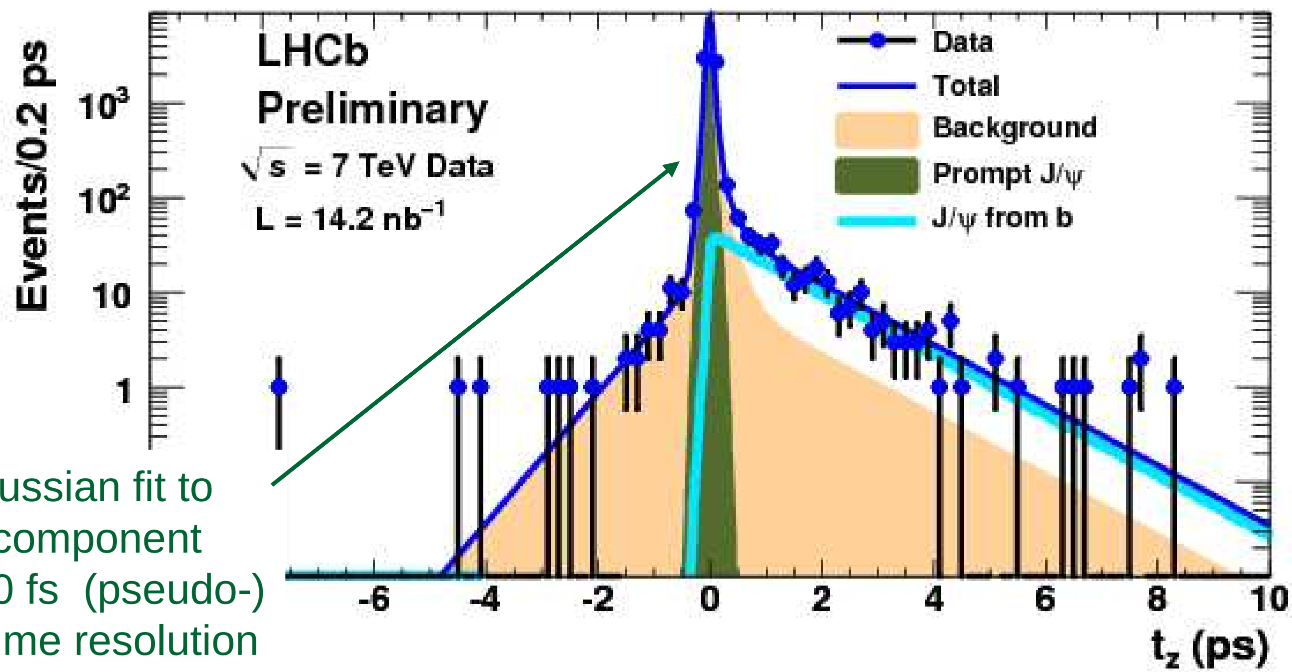
Region accessible with ~50 pb^{-1} (will allow overlap with GPDs)

Secondary J/ψ from B

Fit pseudo-propertime, t_z, of sample in four p_T bins (here shown integrated)



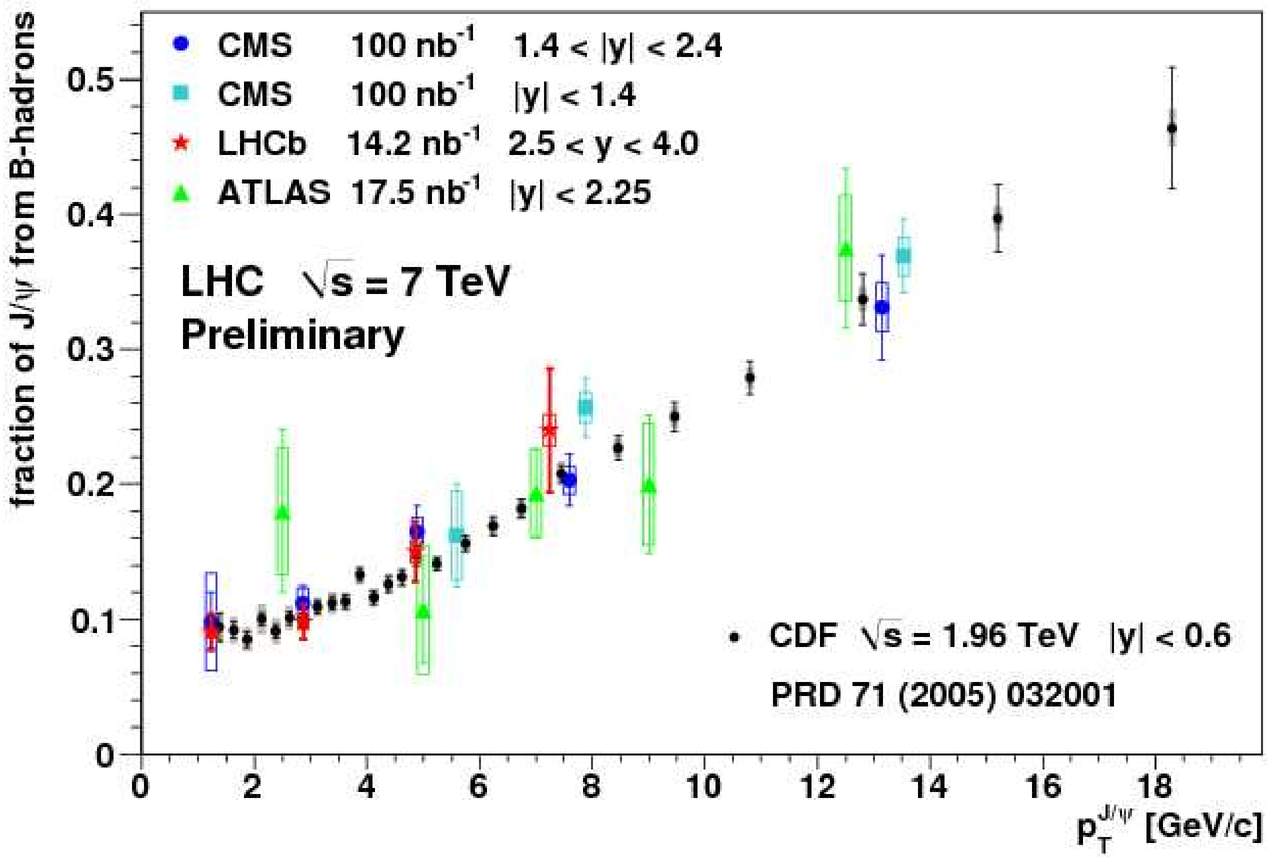
$$t_z = \frac{\Delta z}{p_z^{J/\psi}} m_{J/\psi}$$



Core gaussian fit to prompt component yields 40 fs (pseudo-) proper time resolution

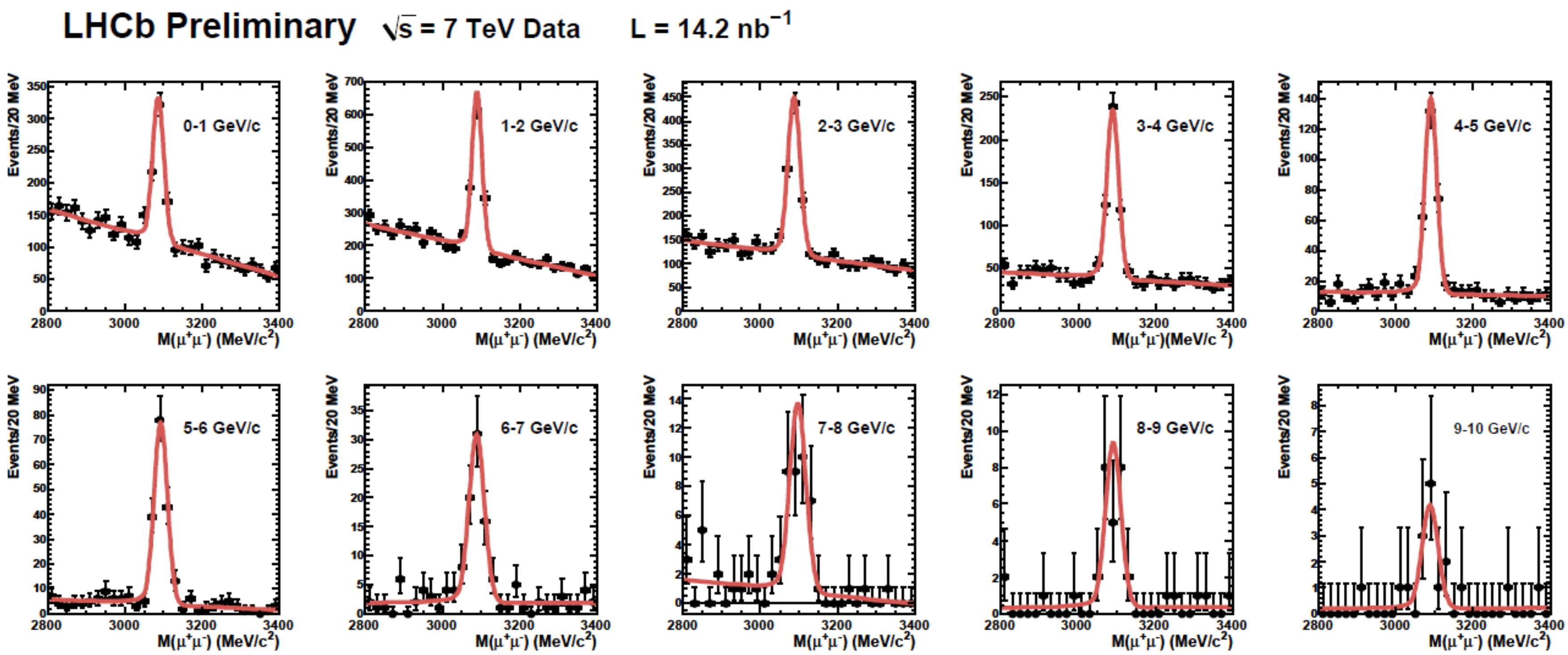
f_b = (11.1 ± 0.8) %

Compilation of preliminary LHC J/ψ results



Thanks to Woehri & Lourenco for plot !

Cross-section measured in bins of p_T



Efficiencies taken from Monte Carlo, with extensive cross-checks on data

Systematic Uncertainties

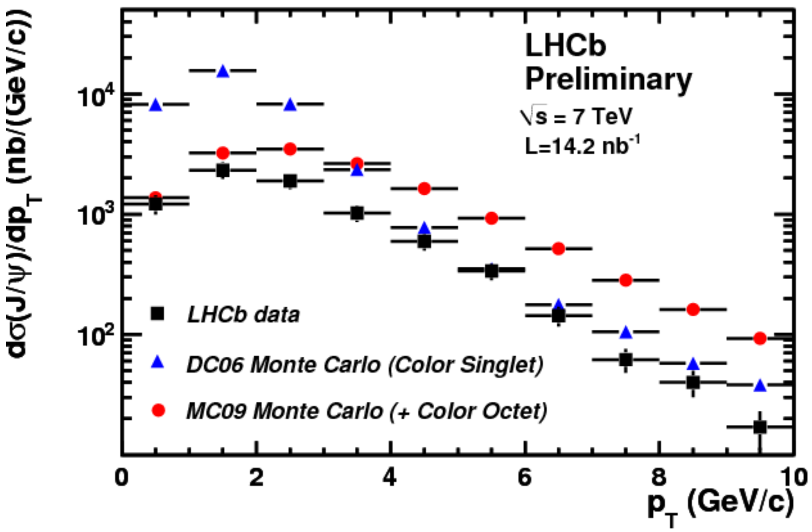
Quantity	Systematic error	Comment
Trigger	2.8 % to 9.4 %	Correlated between bins
Muon identification	2.5%	Correlated between bins
Tracking efficiency	8%	Correlated between bins
Track χ^2	2%	Correlated between bins
Vertexing	1%	Correlated between bins
Bin size	1.3% to 3.9%	Bin dependent
Inter-bin cross-feed	0.5%	Correlated between bins (not applied to the total cross section)
Radiative tail	1%	Correlated between bins
$\mathcal{B}(J/\psi \rightarrow \mu^+\mu^-)$	1%	Correlated between bins
Luminosity	10%	Correlated between bins
b momentum spectrum	4 %	Applies only to J/ψ from b cross section
b hadronization fractions	2%	Applies only to extrapolations of $b\bar{b}$ cross sections
$\mathcal{B}(b \rightarrow J/\psi X)$	9%	Applies only to extrapolations of $b\bar{b}$ cross sections

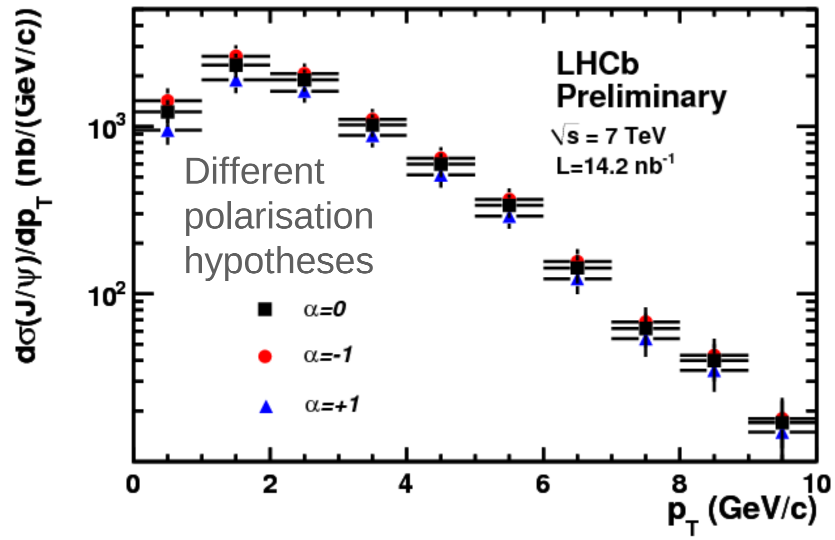
Preliminary Results

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

uncertainty from polarisation

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





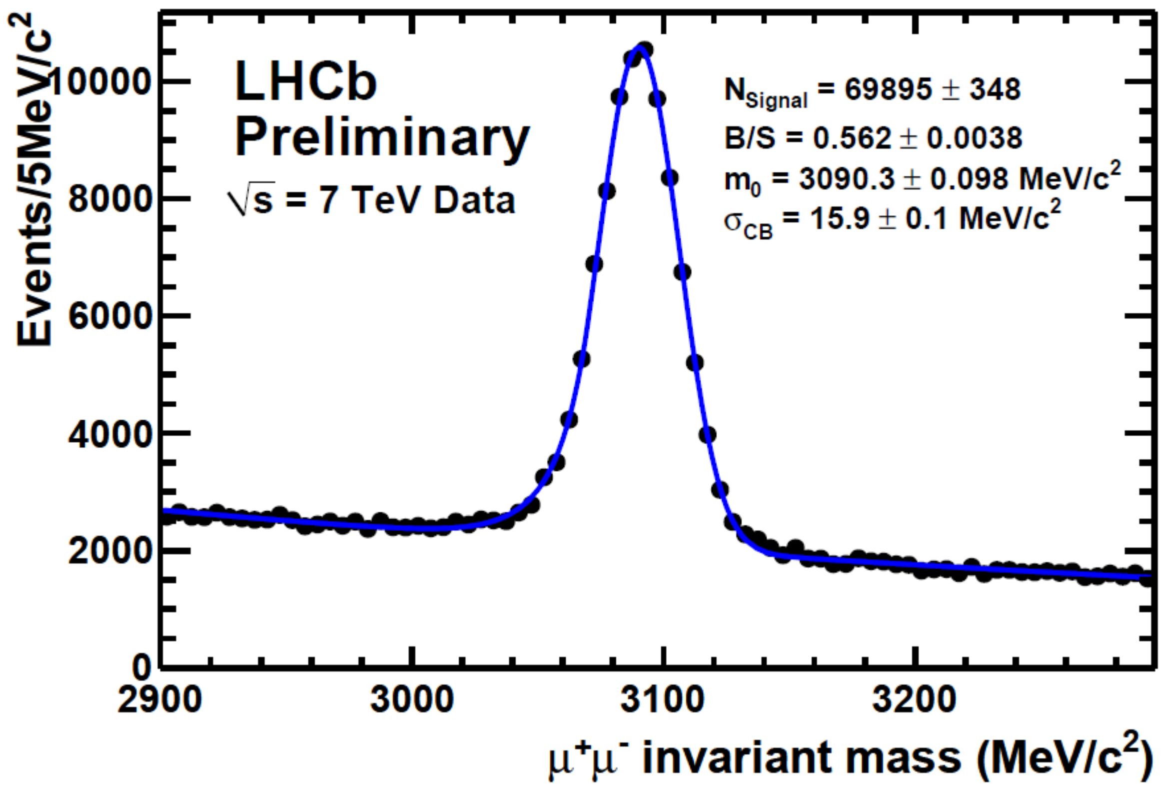
Scale and shapes not well described by either colour singlet or colour octet models as implemented in LHCb Pythia

Polarisation will eventually be measured !

σ(J/ψ from b, $p_T^{J/\psi}$ <10 GeV/c, 2.5<$y^{J/\psi}$ <4) = $(0.81 \pm 0.06 \pm 0.13)$ μb

J/ψ update with ~230 nb^{-1}

(Selection not identical to ICHEP analysis)



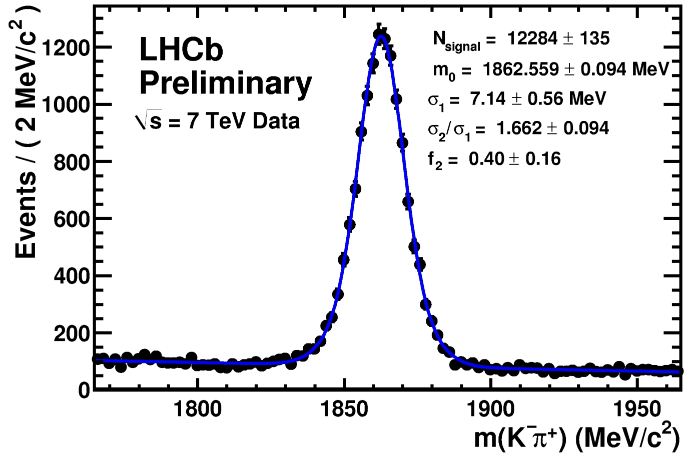
several 100k events / pb^{-1}

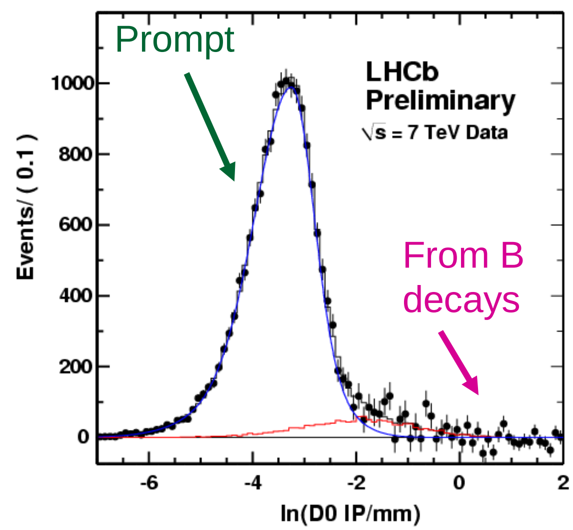
Measurement of b production cross-section with $D^0\mu X$ events

- Take clean $D^0 \rightarrow K\pi$ sample
- Impact parameter of D^0 direction w.r.t. primary vertex (or ln[D^0 IP]) used to separate prompt and secondary component
- Looking for μ in event with correct charge correlation allows background to be suppressed and a decay mode with known BR to be isolated

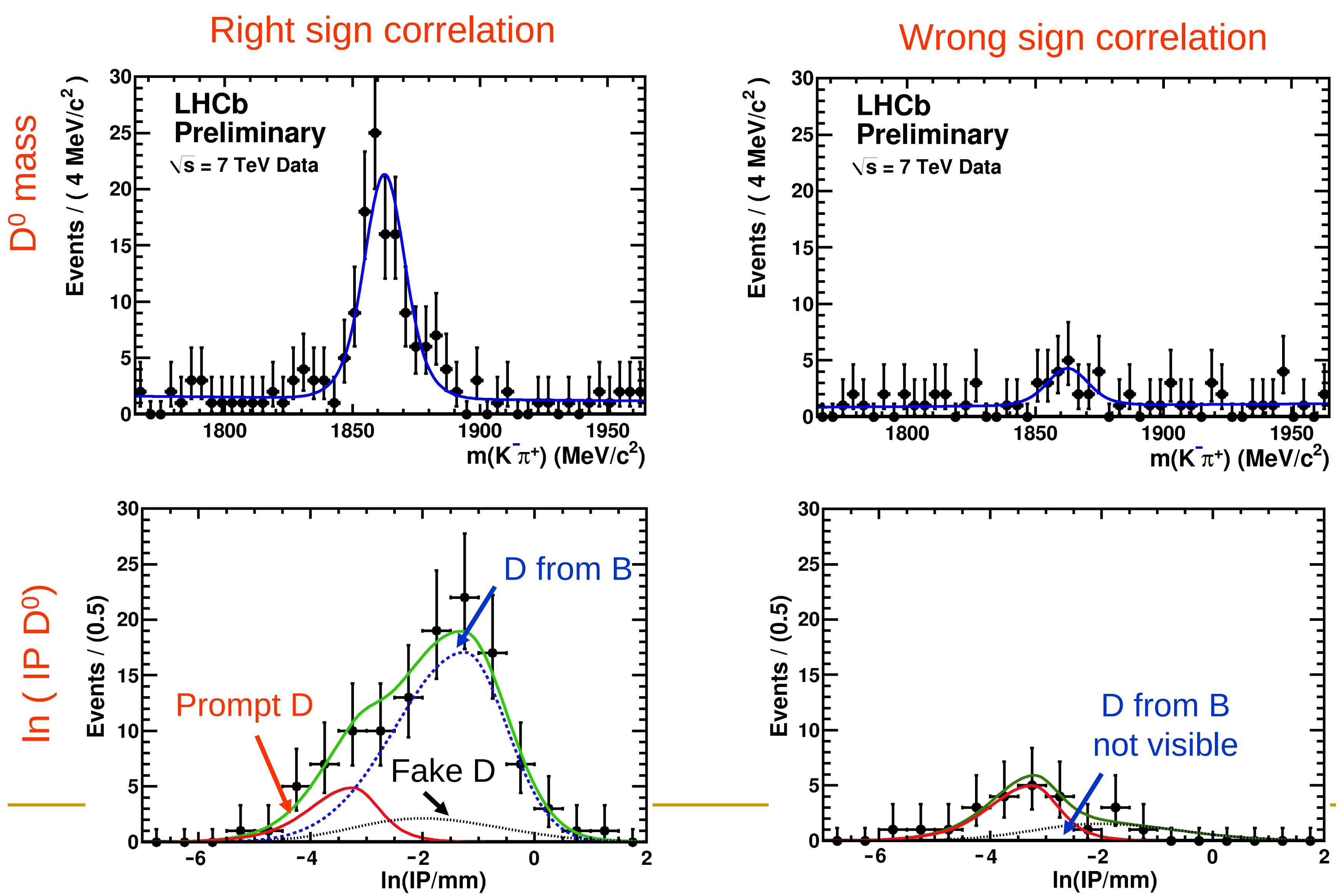
  $BR(b \rightarrow D^0\mu^-\bar{\nu}X) = 6.82 \pm 0.35\ \%$

- Perform analysis both on open triggered sample (~ 3 nb^{-1}) and on sample collected with p_T > 1.3 GeV/c muon trigger (~12 nb^{-1})
- Measure / cross-check efficiencies on data





$D^0\mu X$ events – open trigger



$D^0\mu X$ Systematics

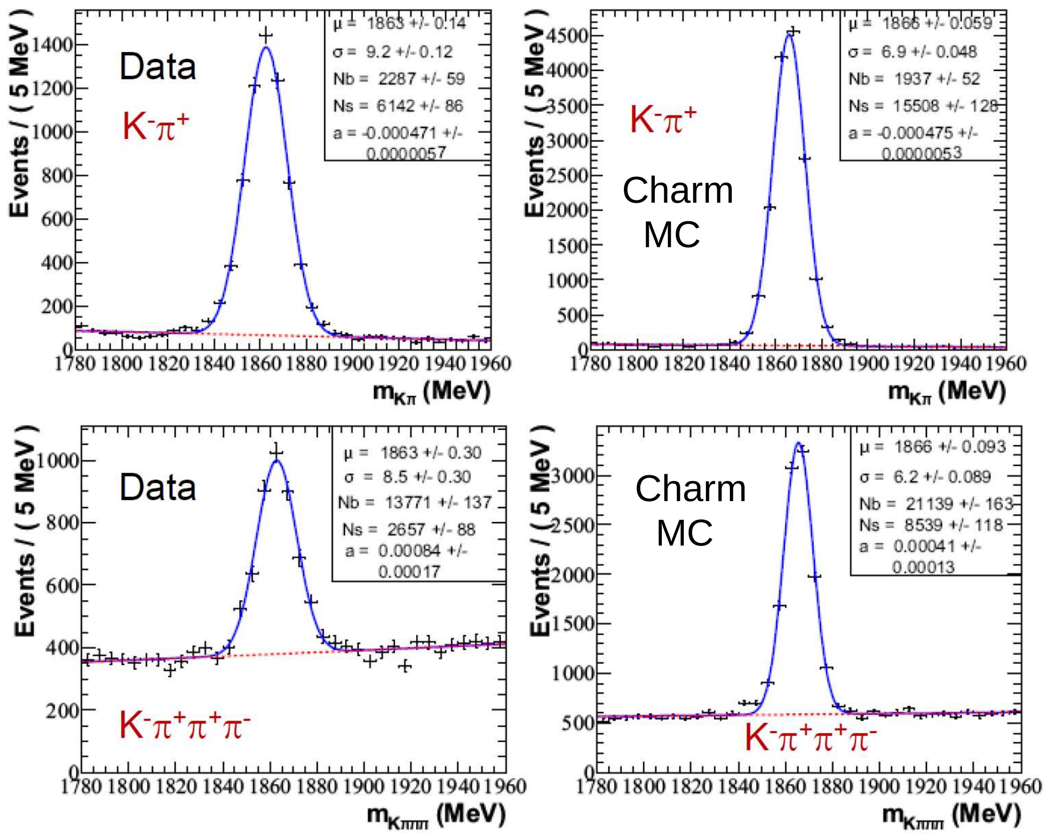
Source	Error (%)	Source	Error (%)
Luminosity	10.0	Prompt & DfB shapes	1.4
Tracking efficiency	10.0	$D^0\mu^-$ vertex χ^2	1.2
$\mathcal{B}(b \to D^0 X \mu^- \overline{\nu})$	5.1	Kaon identification	1.2
Efficiency assumed branching ratios	4.4	Muon fakes	1.0
Fragmentation fractions	4.2	D^0 mass cut	1.0
Efficiency assumed p_t distribution	3.0	D^0 vertex χ^2	0.6
Muon identification	2.5	D^0 flight distance	0.4
χ^2_{IP}	2.5	Pion identification	0.3
Efficiency MC statistics	1.5	Total	17.2

Determined from data whenever possible

Tracking efficiency in data vs MC

Use variety of methods:

- tag and probe
- relative rates of $D \to K\pi$ vs $D \to K\pi\pi\pi$ (below)



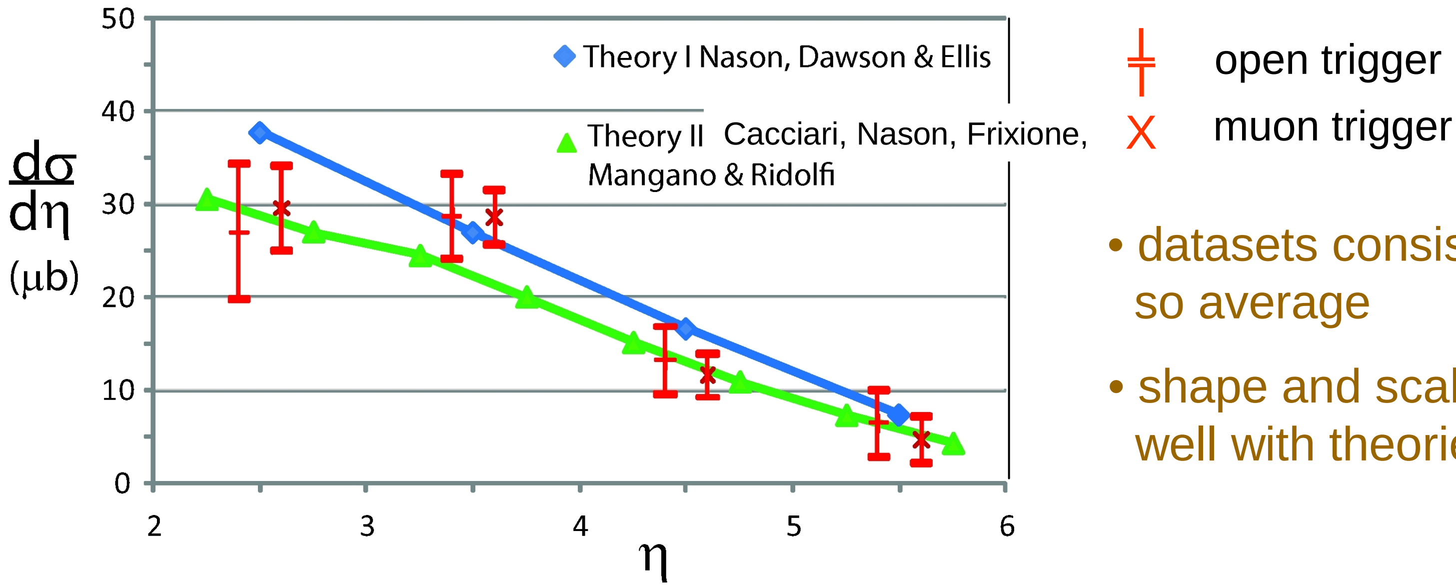
This study gives data / MC = 1.00± 0.03 per track

$D^0\mu X$ Preliminary Results

Measure cross-section
in four bins of η

$$\sigma(pp \to H_b X) = \frac{\#\text{ of detected } D^0\mu^- \text{ and } \overline{D}^0\mu^+ \text{ events}}{\mathcal{L} \times \text{efficiency} \times 2}.$$

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



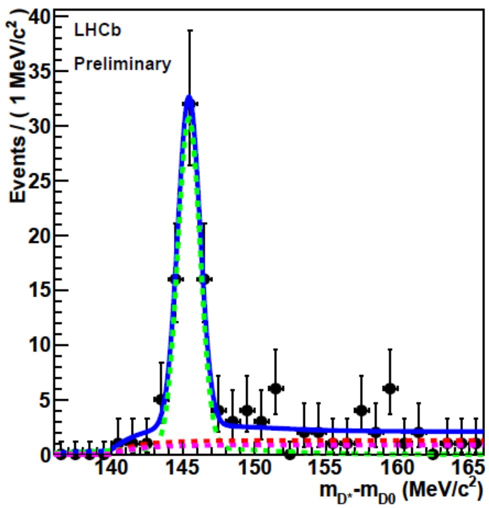
- datasets consistent, so average
- shape and scale agrees well with theories

σ $(pp \to H_b X;\ 2 < \eta < 6) =$ $74.9 \pm 5.3 \pm 12.8$ μb

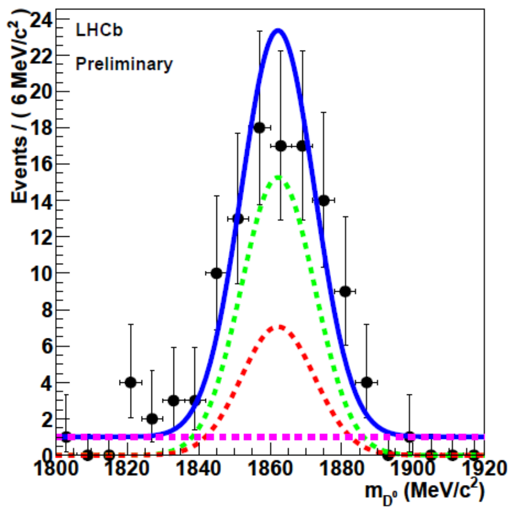
Measuring b-production in $D^{*}\mu\nu$ events

Production cross-section has also been measured in $D^{*}\mu\nu$ events with 14 nb^{-1}

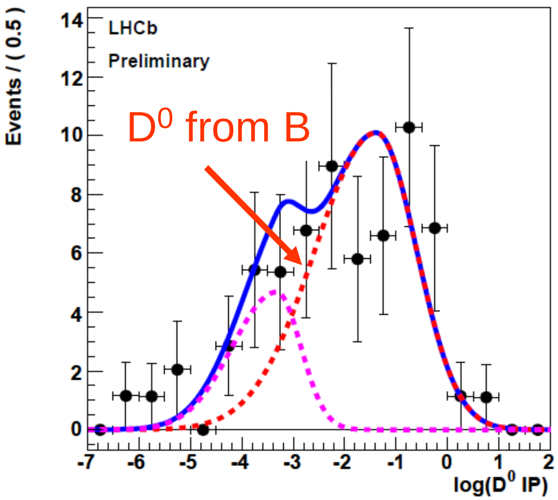
m_{D*} - m_{D}



m_{D}



ln (IP D^0)



σ ($pp \rightarrow H_b X$; $2 < \eta < 6$) = $73 \pm 12 \pm 17$ μb   LHCb preliminary

In agreement with other LHCb measurements !

NB: experimental numbers assume $B^+/B^0/B_s/\Lambda_b$ ratios measured at LEP.

Averaging preliminary b-production results

All three measurements of σ ($pp \rightarrow H_b X$; $2 < \eta < 6$) compatible

Determine weighted average of J/ψ and $D^0 \mu X$ results
($D^* \mu \nu$ result less precise and strongly correlated with $D^0 \mu X$)

σ ($pp \rightarrow H_b X$; $2 < \eta < 6$) = $77.4 \pm 4.0 \pm 11.4$ μb LHCb preliminary

Consistent with central values for bb cross-section in theory

I: Nason, Dawson, Ellis 89 μb

II: Nason, Frixione, Mangano and Ridolfi 70 μb

Using Pythia to extrapolate to full phase space

$\sigma(pp \rightarrow b\bar{b}X) = 292 \pm 15 \pm 43$ μb LHCb preliminary

Compare with expectation - theory I: 332 μb ; theory II: 254 μb

Note that all $\sqrt{s}$ = 7 TeV LHCb sensitivity studies until now assumed ~ 250 μb

NB: experimental numbers assume $B^+/B^0/B_s/\Lambda_b$ ratios measured at LEP.

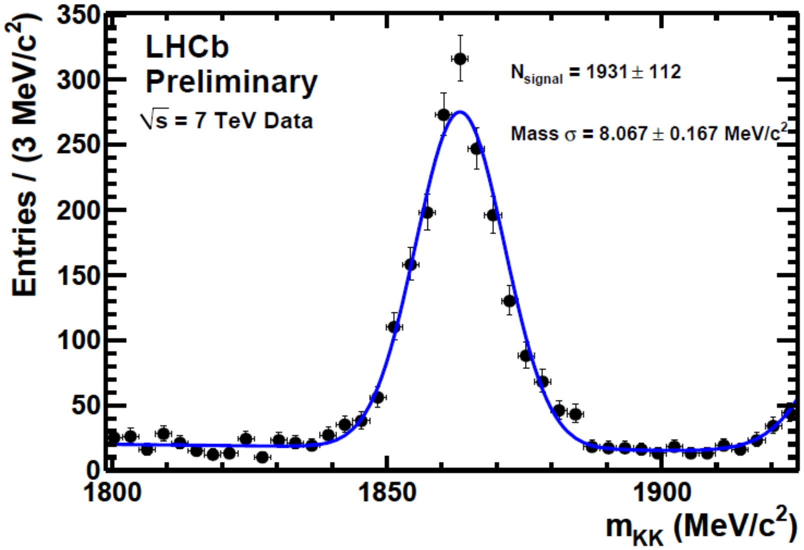
Exclusive final states with ~120-230 nb^{-1} and discovery prospects for remainder of run

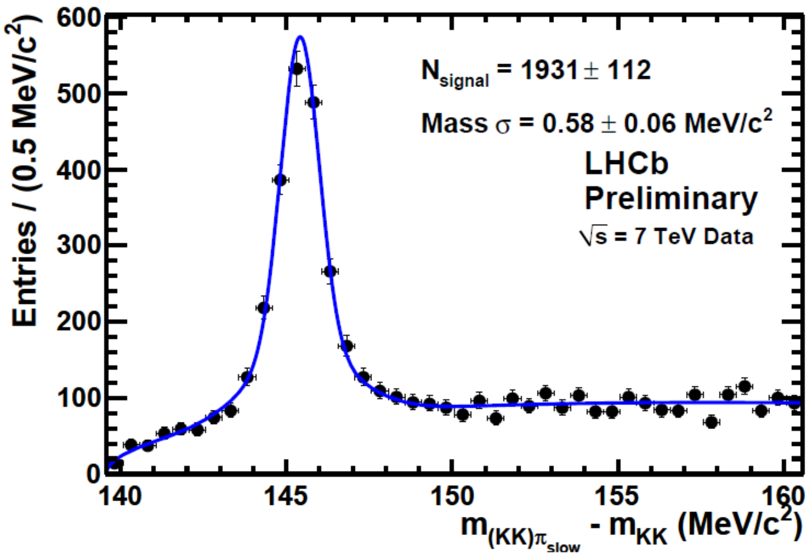
- CP-violation in charm
- $B \rightarrow hh$
- $B \rightarrow J/\psi X$
- CP-violation in $B_s \rightarrow J/\psi \Phi$
- a^s_{sl} (and a^d_{sl})
- $B_s \rightarrow \mu\mu$

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

~124 nb^{-1}

Main purpose – search for CP-violation in mixing (negligible in SM, not in many New Physics theories) through comparison of lifetime in D^0 and $\bar{D}^0$



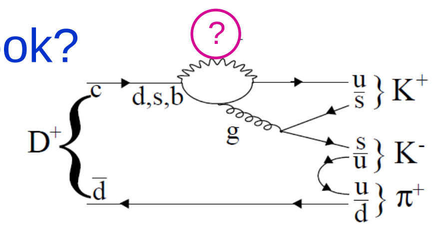


Immediate goal – to achieve order of magnitude increase in B-factory statistics
Already possible with ~100 pb^{-1}

Search for direct CPV in charm

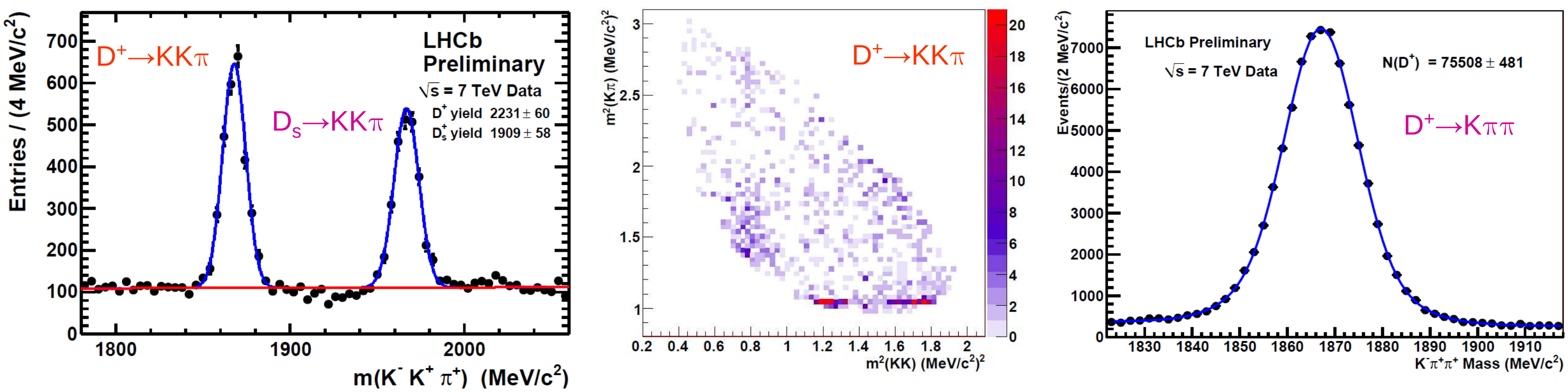
~124 nb^{-1}

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



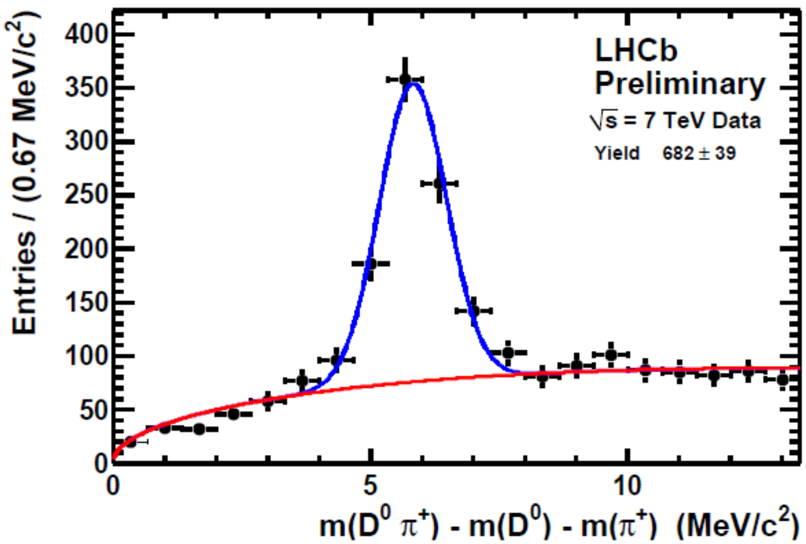
Can be confident of acquiring signal sample of several million events in 100 pb^{-1}
Again, order of magnitude increase on B-factories samples.

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

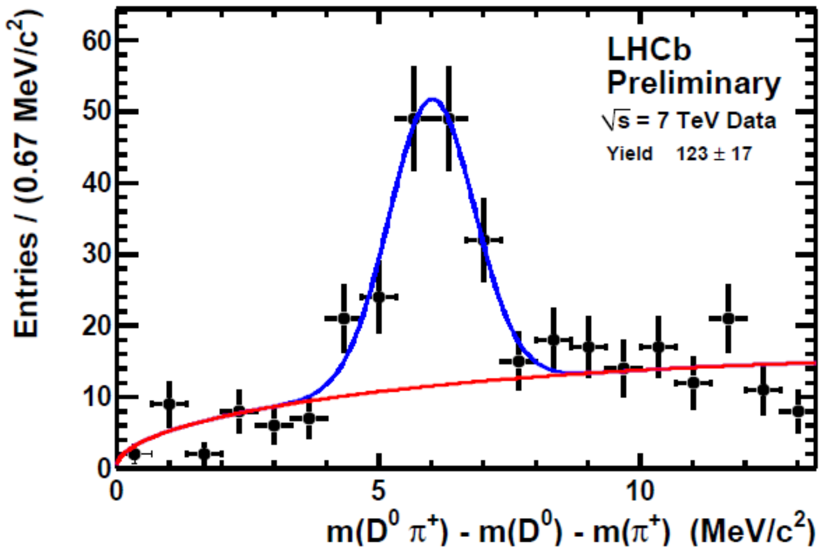
D decays with K^0_S

~124 nb^{-1}

$D^0 \to K_S \pi\pi$



$D^0 \to K_S KK$



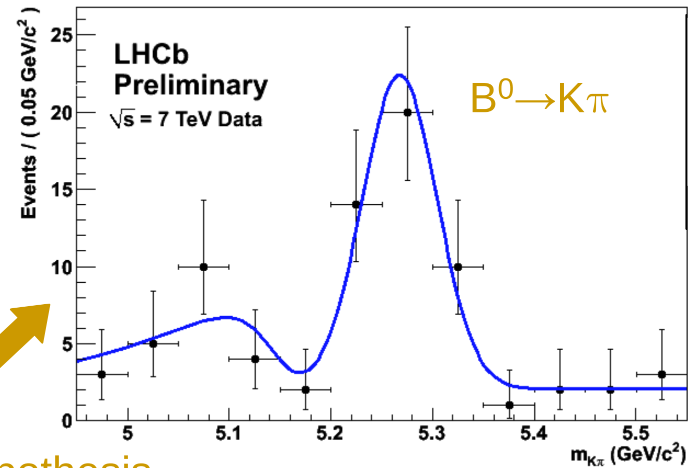
Valuable in charm mixing measurements and CP-violation searches

Important final state in $B \to DX$ for measurement of γ

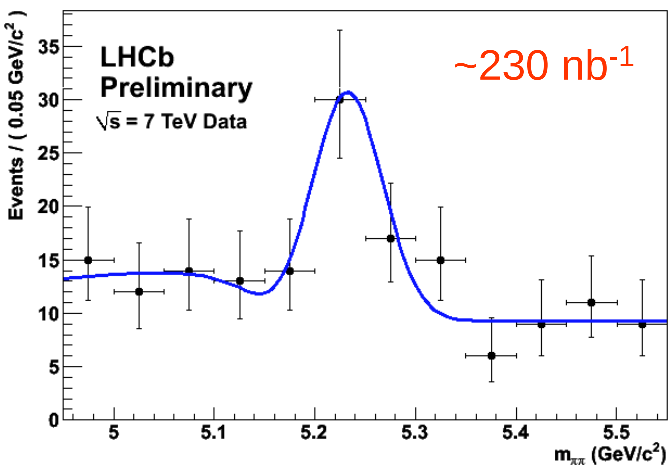
$B \to hh'$ ($h,h'=\pi,K,p$) at LHCb

Study of two body charmless B decays (BR ~ 10^{-5}) are core to LHCb programme: γ measurement, study of loop effects etc.

Mass peak already emerging. RICH system vital in disentangling contributing modes.

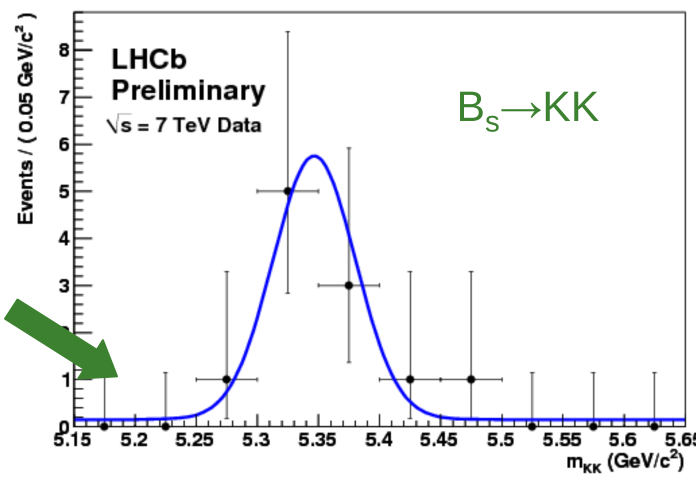


with RICH,
Kπ mass hypothesis

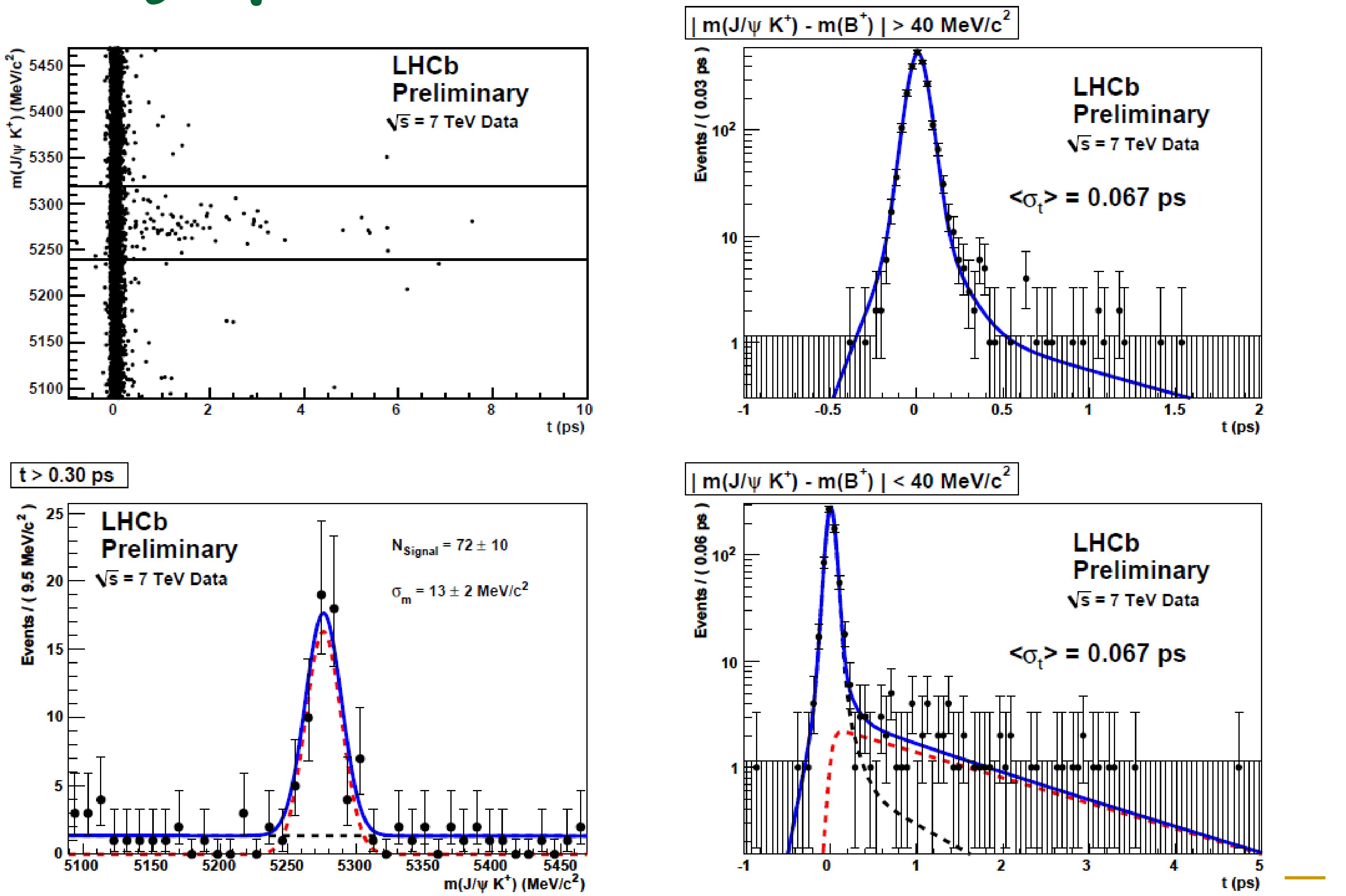


No PID, ππ mass hypothesis

with RICH,
KK mass hypothesis



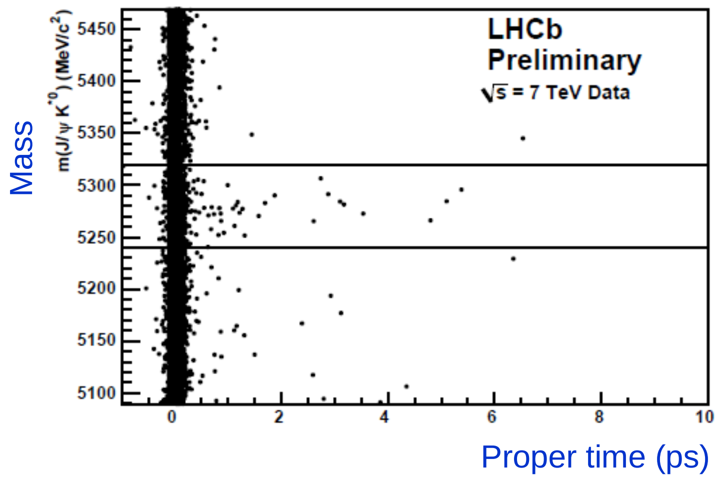
$B^+ \to J/\psi K^+$ with ~230 nb^{-1}

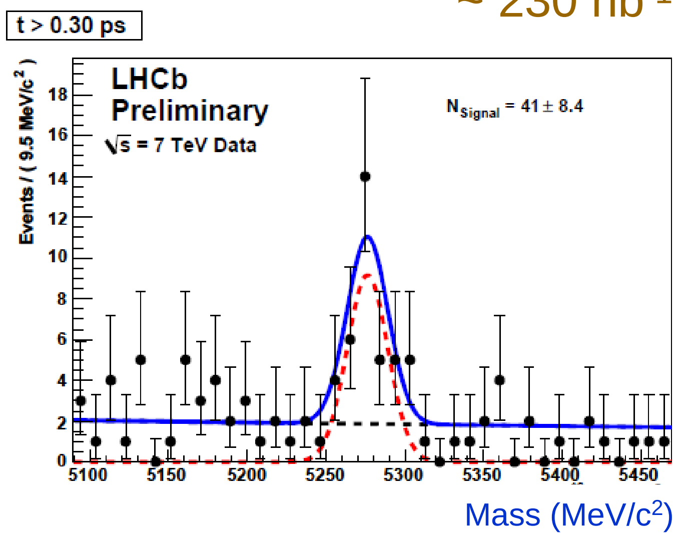


More J/ψX signals – rate as expected

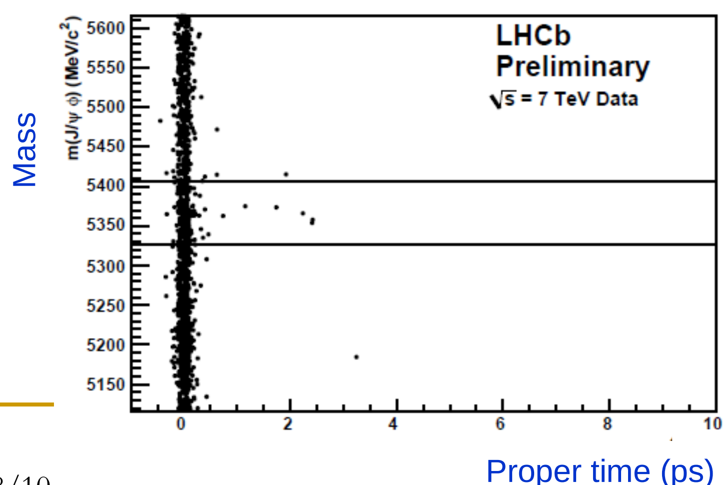
Clear $B^0 \rightarrow J/\psi K^*$ signal…

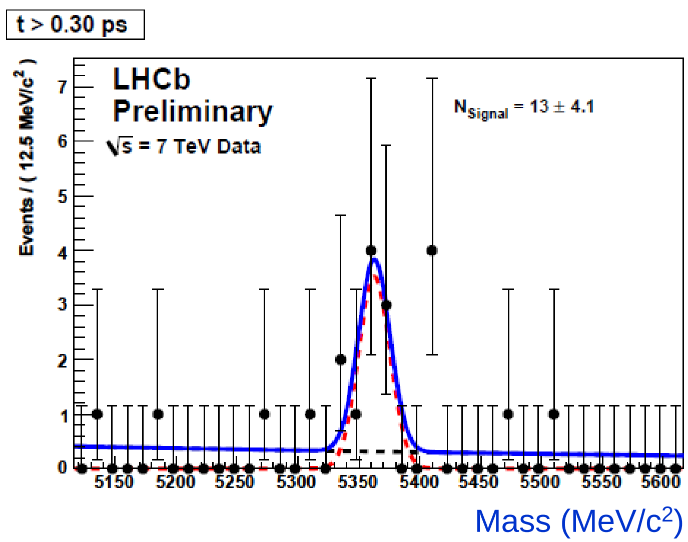
~ 230 nb^{-1}

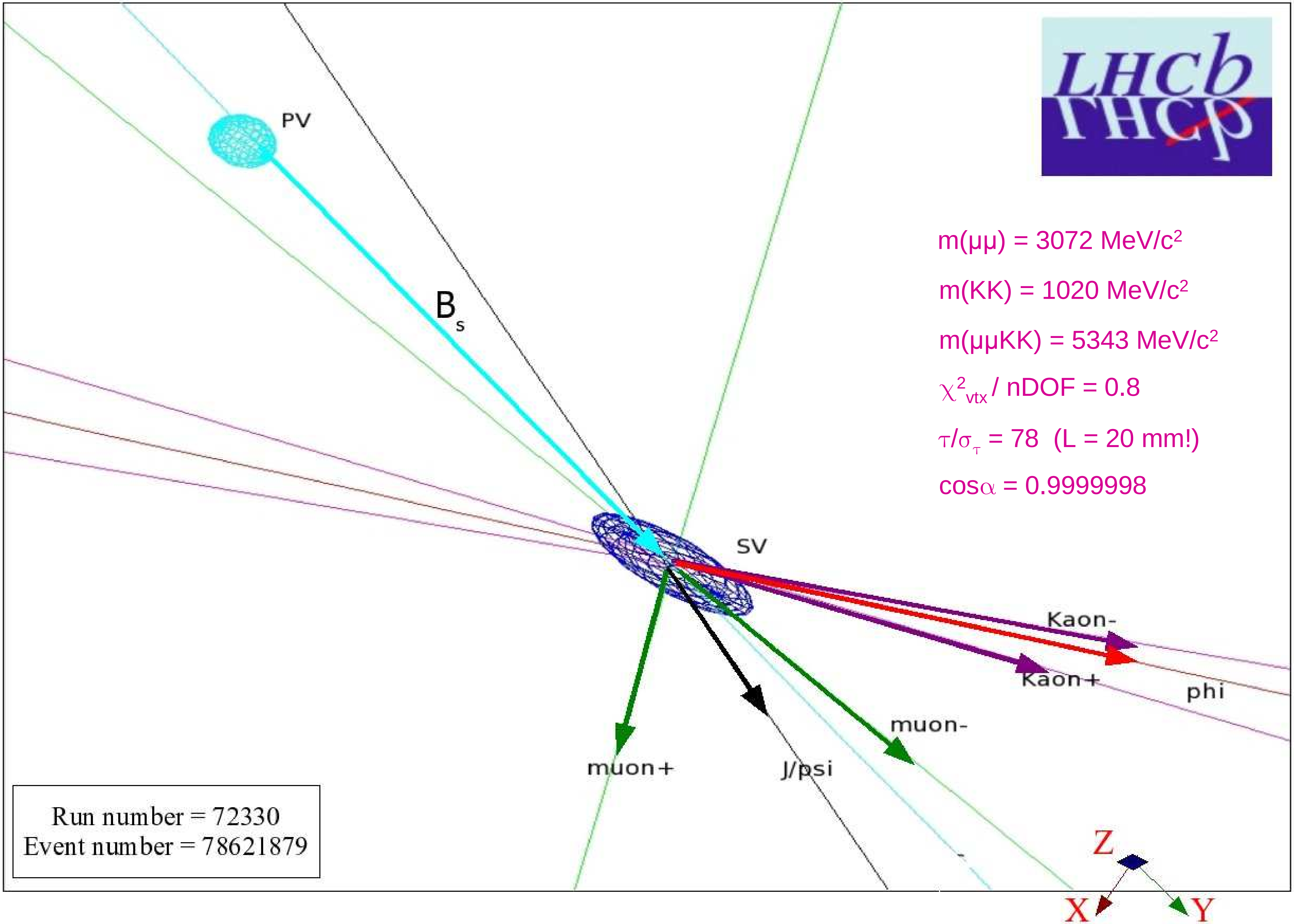




…and $B_s^0 \rightarrow J/\psi \Phi$ beginning to show itself.






PV
B_s
SV
Kaon-
Kaon+
phi
muon-
muon+
J/psi
m(μμ) = 3072 MeV/c²
m(KK) = 1020 MeV/c²
m(μμKK) = 5343 MeV/c²
χ²_vtx / nDOF = 0.8
τ/σ_τ = 78 (L = 20 mm!)
cosα = 0.9999998
Run number = 72330
Event number = 78621879
Z
X
Y

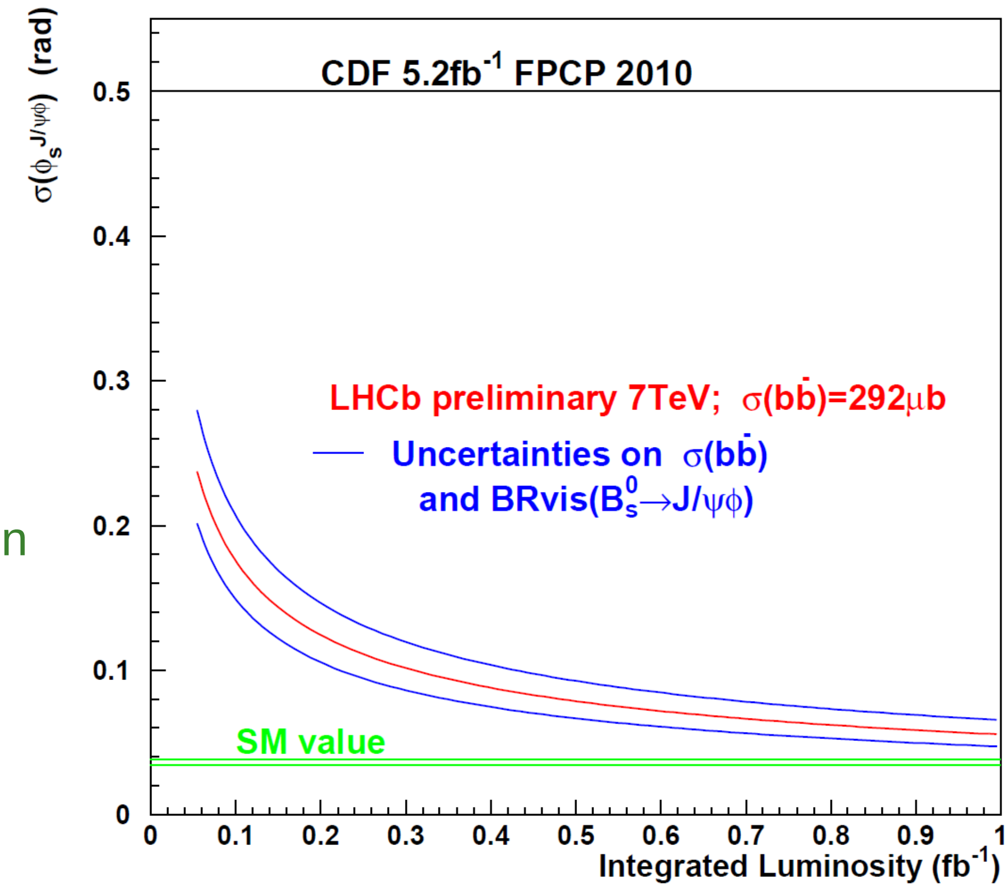
Φ_s prospects at LHCb in 2010

A major responsibility of LHC programme – to look for signs of New Physics from CP-violation in $B^0_s \to J/\psi\Phi$ (+ related modes) down to very low level predicted in SM

Reality checklist

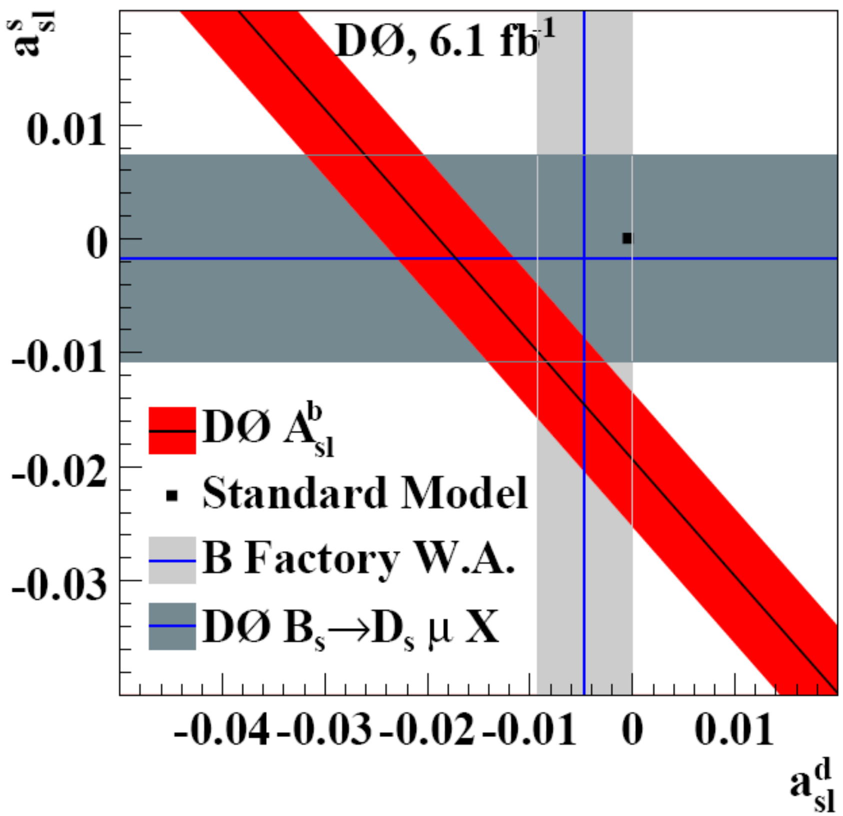
- Measured cross-section: consistent with expectations
- Rate of signal events: consistent with expectations
- Proper time resolution: at present 60% worse than MC; if no improvement → 30% dilution
- Tagging performance: we will know about this soon

All is looking very promising!



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

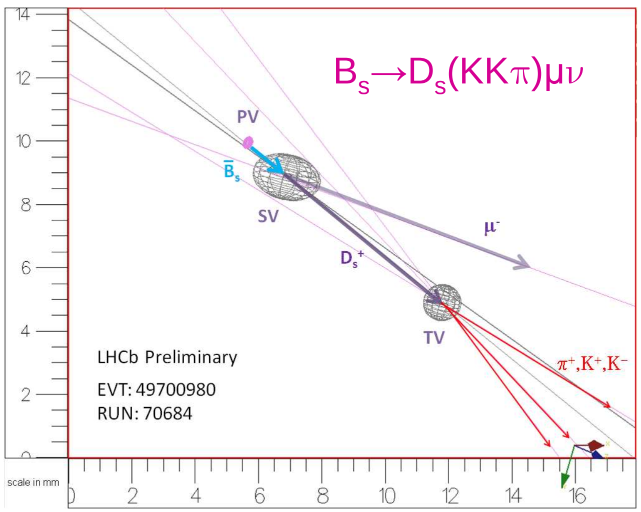
If New Physics enhances CP-violation in $B^0_s \rightarrow J/\psi\Phi$, it will likely also dominate over the (negligible) SM CP-violation predicted in the semi-leptonic asymmetry.

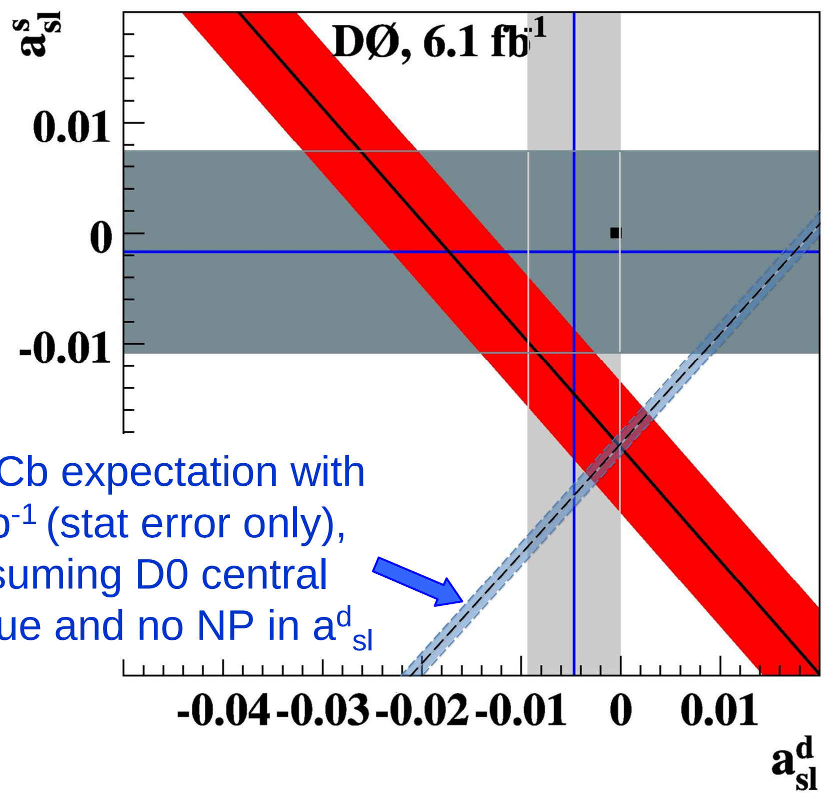


Recall interest in recent D0 result (arXiv:1007.0395) - 3σ tension with SM

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.





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

Excellent prospects to confirm or refute D0 result.

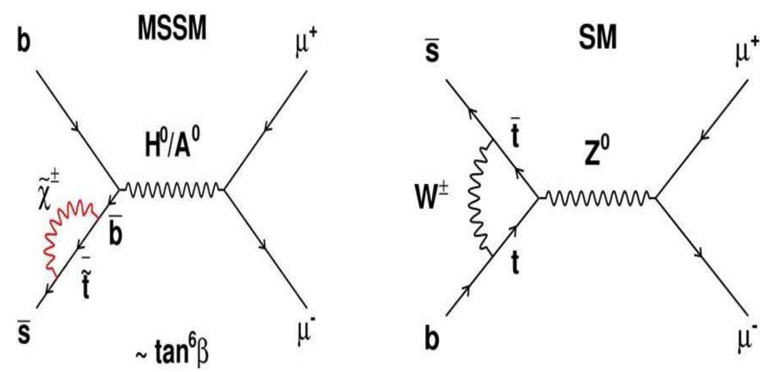
The golden mode: $B_s \to \mu\mu$

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) !



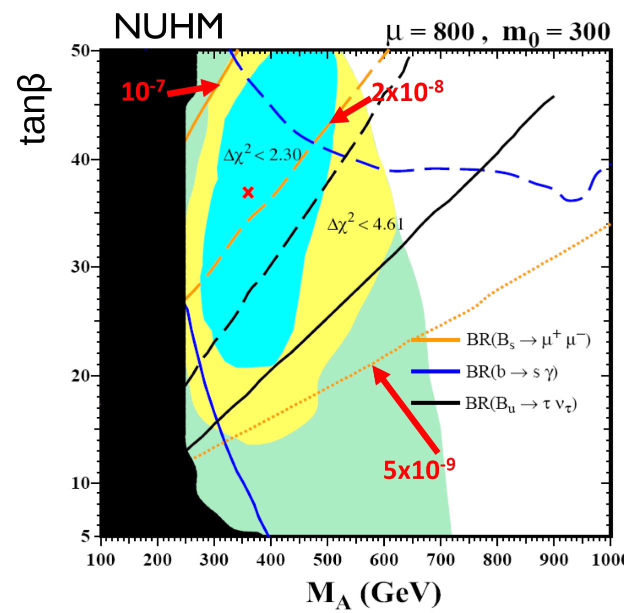
Very high sensitivity to NP, eg. MSSM:

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

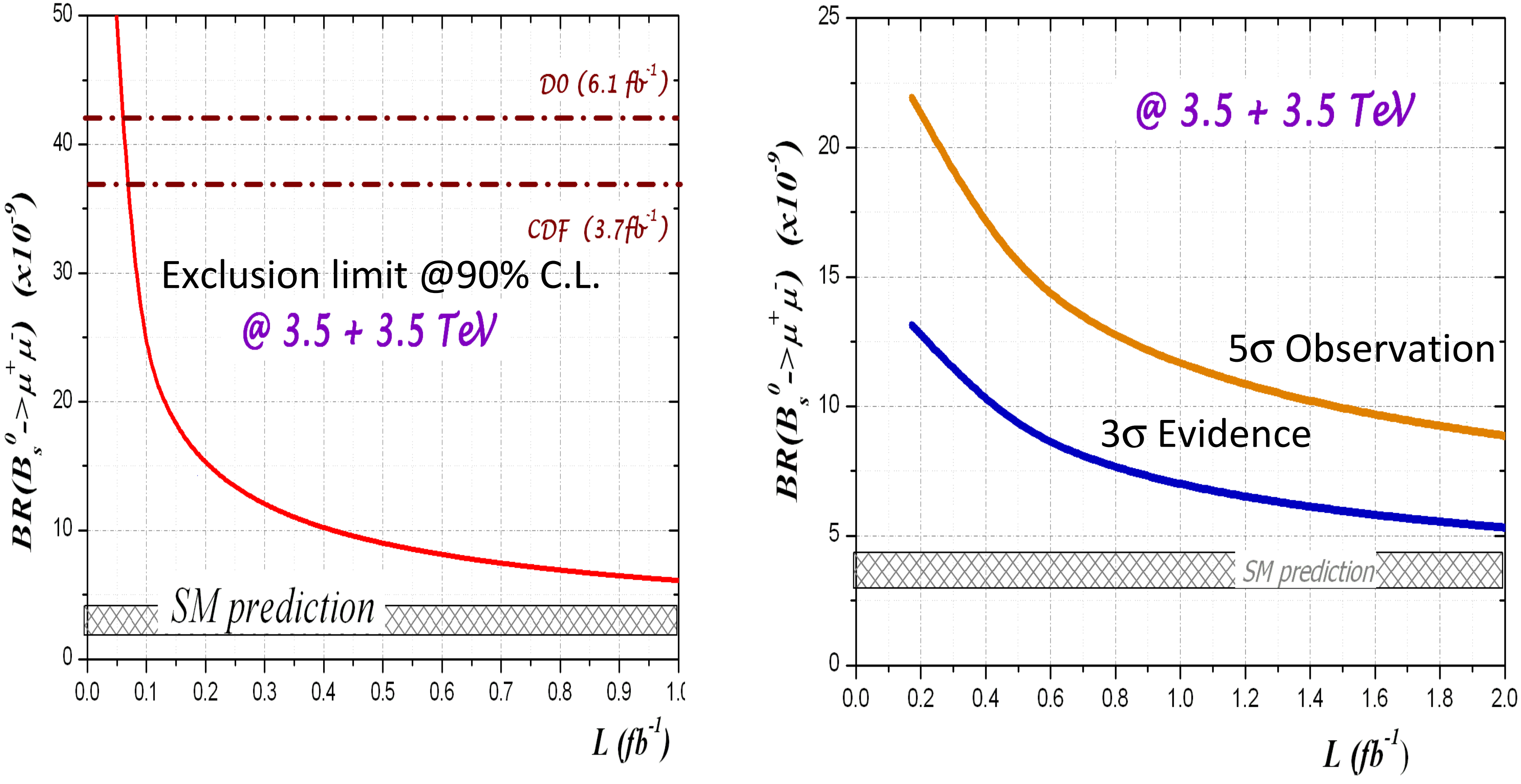
One example (Ellis et al., JHEP 0710:092,2007) with NUHM (= generalised version of CMSSM)

- $b \to s\gamma$ and Higgs > 114.4 GeV
  ⇨ M_A > ~ 300 GeV & tanβ < ~50
- $(g_\mu\text{-}2)$ is 3.4σ from SM
  ⇨ M_A < ~ 500 GeV & tanβ > ~20

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



$B_s \to \mu\mu$ prospects at LHCb in 2010



Conclusions

LHCb is not only a flavour physics experiment:

- LHCb is producing interesting first results in minimum bias physics which exploit the unique η and p_T acceptance of the experiment.
- Very interesting measurements are possible in W/Z physics and for telling us more about PDFs, again exploiting special acceptance

but flavour physics is our priority:

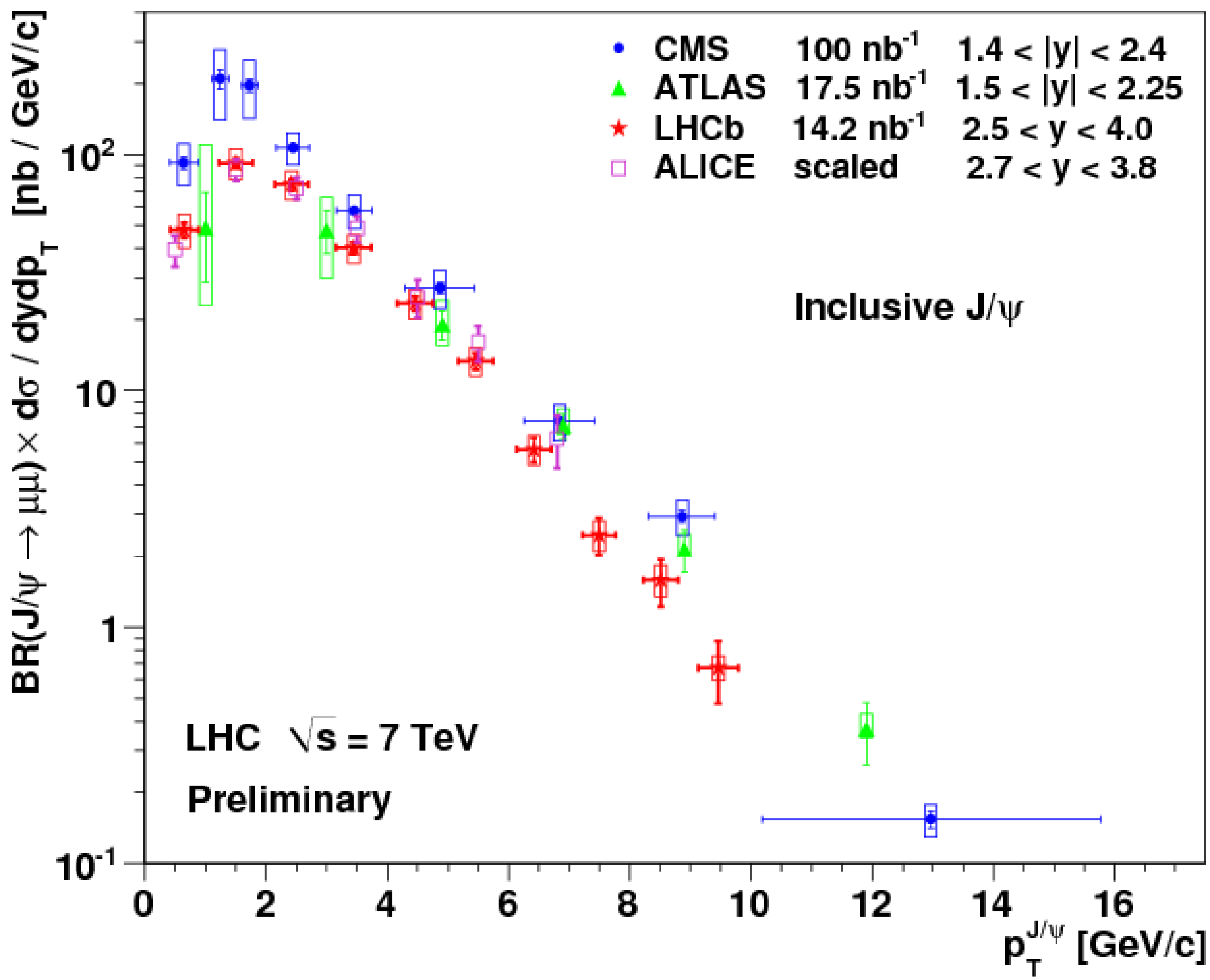
- First measurements of J/ψ production – very interesting results with which to confront production models
- $b\bar{b}$ cross-section measurements yield result consistent with expectations – good news for the B-physics programme

Detector working well, very clean charm signals seen, and already many B-peaks

→ well equipped for discovery physics in the coming 1 fb^{-1} !

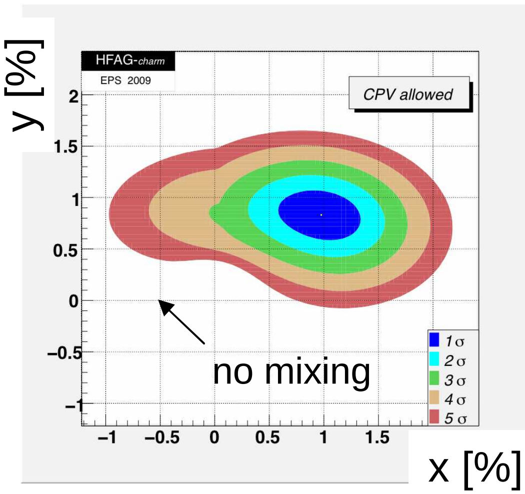
Backup

Compilation of preliminary LHC J/ψ results



Thanks to Woehri & Lourenco for plot !

Charm – the new frontier



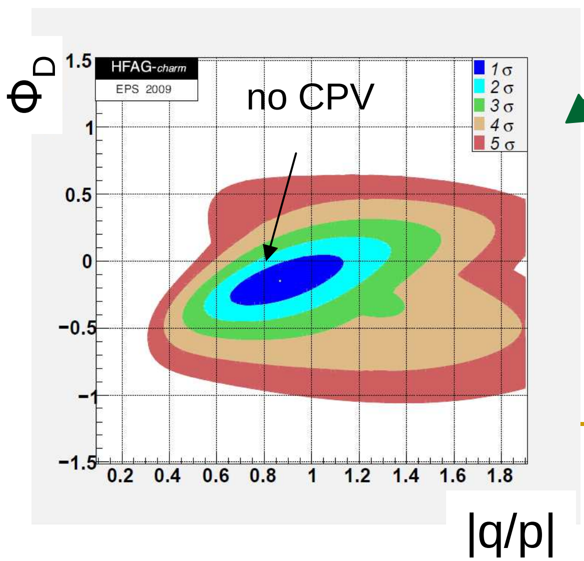
D^0 mixing discovery a recent highlight of flavour physics:

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

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

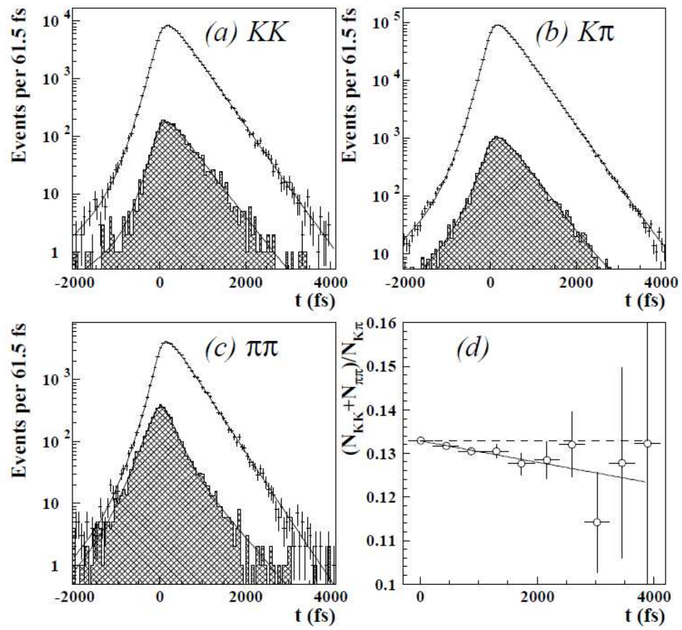
Example mixing analysis is measurement of "y_{CP}", which is D^0 width splitting parameter modified by CP-violating effects. Comparison to pure "y" measurements probes for CP-violation, as does measurement of pure CP-violating observable A_Γ

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

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

A_Γ: compare D^0 and $\overline{D}^0 \rightarrow$KK lifetimes

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



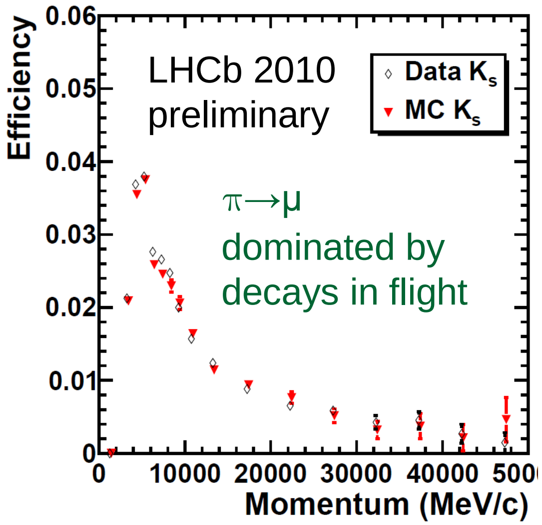
Belle, PRL 98 (2007) 211803

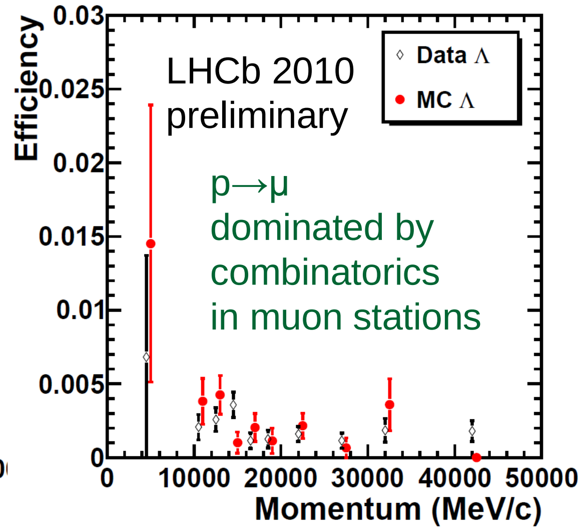
Belle 540 fb^{-1} analysis uses 1.1 x 10^5 flavour tagged $D^0 \rightarrow$KK events
$\rightarrow$ stat precision on y_{CP} = 0.32 % and on A_Γ = 0.30 %

Muon identification studies

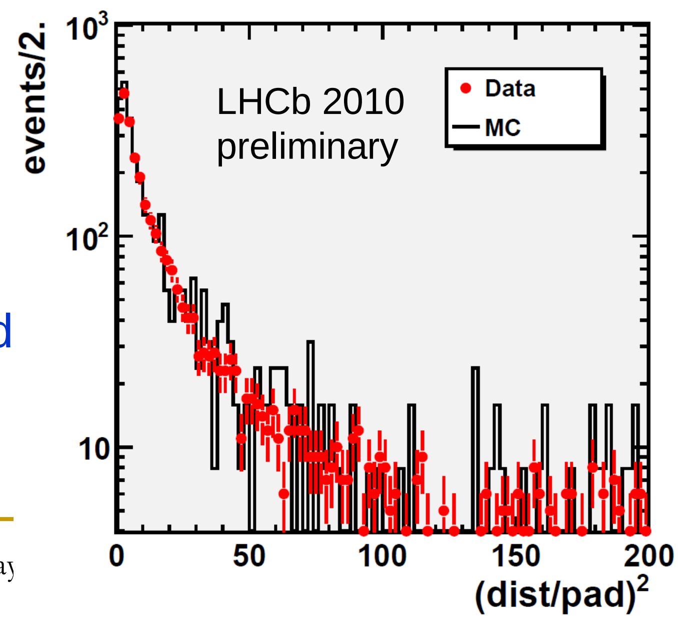
$B_s \rightarrow \mu\mu$ sensitivity relies on good performance of muon-identification. Misid performance is already under study. (Muon efficiency will be measured with J/ψ's)

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





Squared distance between background hits in muon system & extrapolated tracks



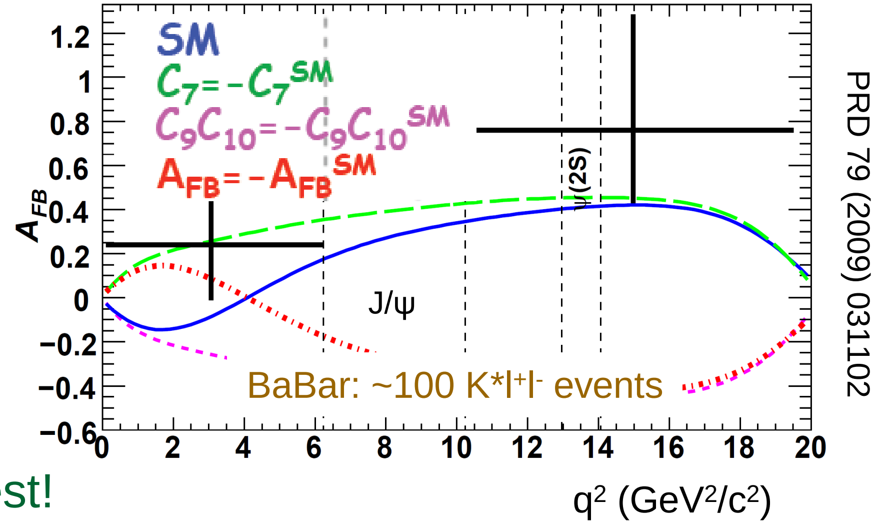
Next step will be to calibrate likelihood which is used to achieve higher suppression. First look at key ingredients shows promising data/MC agreement

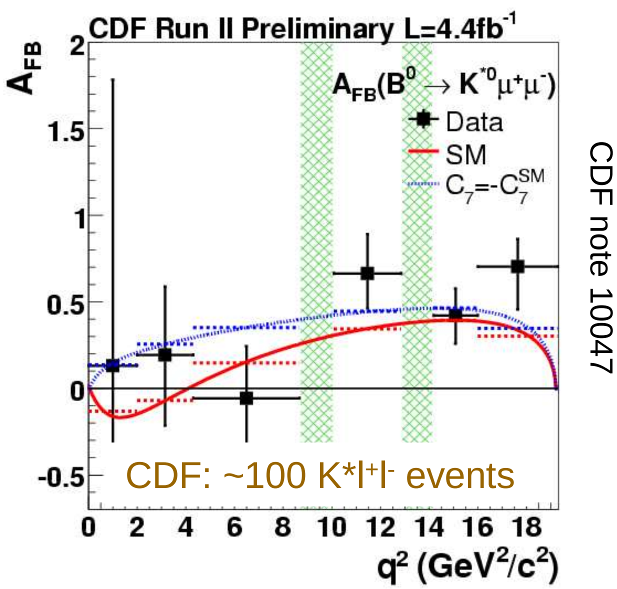
Intriguing hints from $B \to K^{(*)} l^+ l^-$

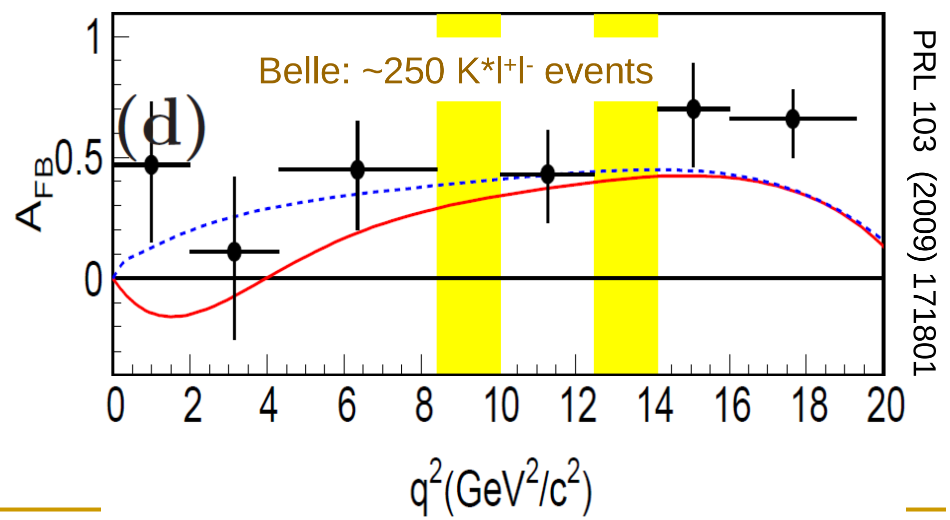
Forward backward asymmetry in $B^0 \to K^* l^+ l^-$ is a extremely powerful observable for testing SM vs NP

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!

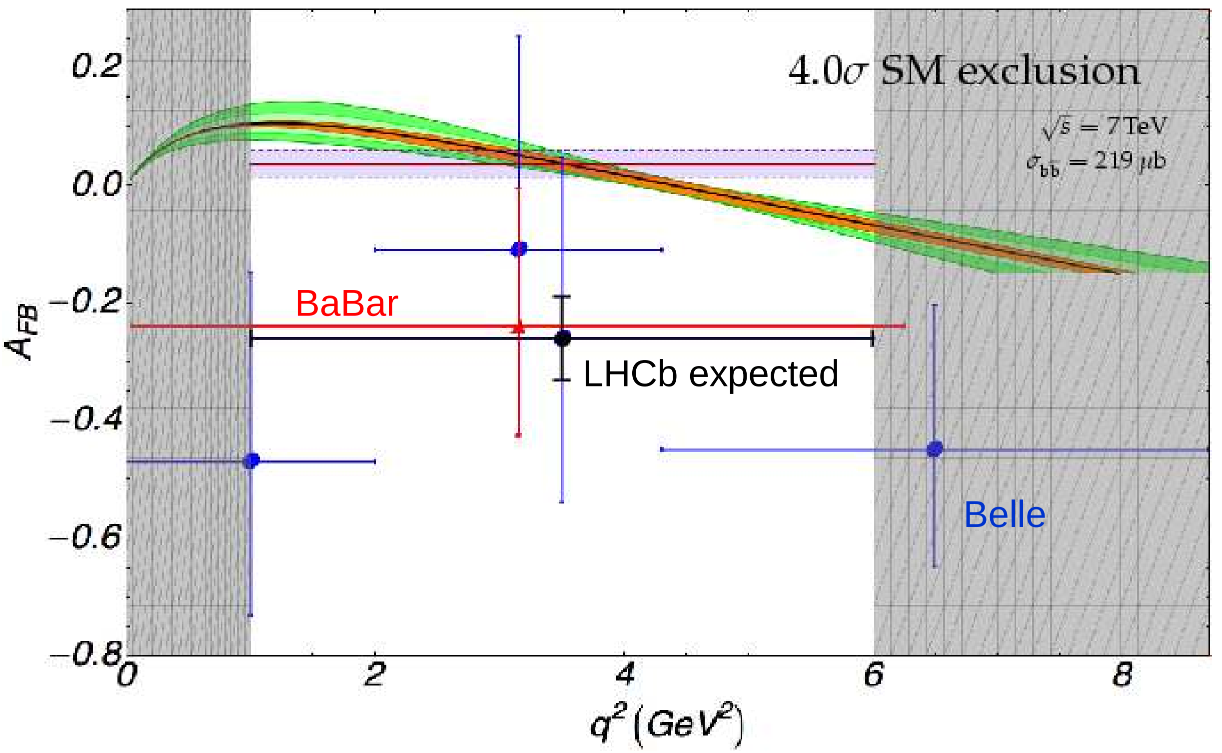






B→K(*)l+l- prospects

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}