LHCb Semileptonic Asymmetry

Mika Vesterinen, CERN
On behalf of the LHCb Collaboration

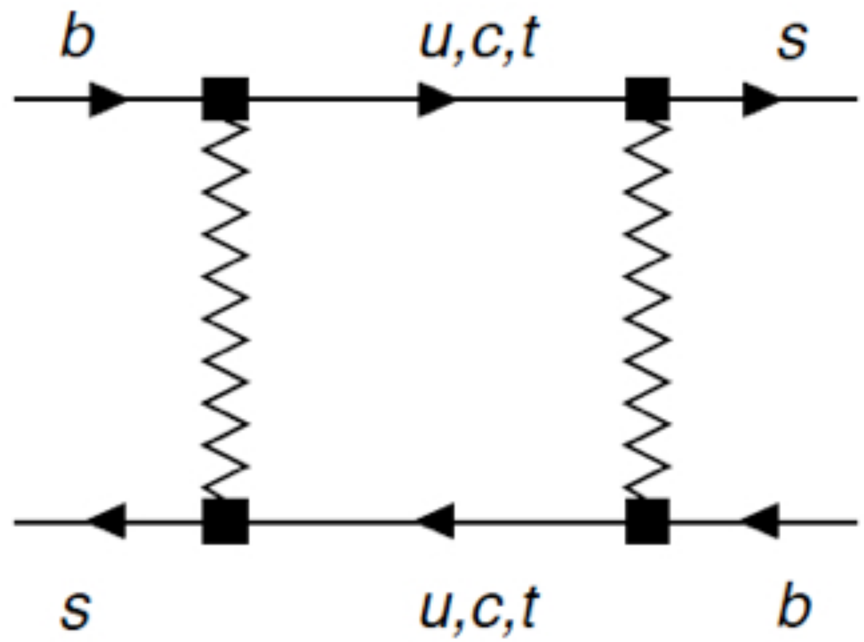
8th March 2013,
Beauty 2013, Bologna.

LHCb-CONF-2012-022

Outline

- Theoretical overview
- Experimental status
- The LHCb measurement
- Outlook

Neutral B mixing



- Time evolution:

$$i\frac{\partial}{\partial t}\begin{pmatrix}|B^0(t)\rangle\\|\overline{B}^0(t)\rangle\end{pmatrix}=\left[\begin{pmatrix}M_{11} & M_{12}\\M_{12}^* & M_{22}\end{pmatrix}-\frac{i}{2}\begin{pmatrix}\Gamma_{11} & \Gamma_{12}\\\Gamma_{12}^* & \Gamma_{22}\end{pmatrix}\right]\begin{pmatrix}|B^0(t)\rangle\\|\overline{B}^0(t)\rangle\end{pmatrix}$$

- Mass eigenstates

$$|B_{L,H}\rangle = p|B^0\rangle \pm q|\overline{B}^0\rangle \quad \text{where} \quad \frac{q}{p}=\sqrt{\frac{M_{12}^*-\frac{i}{2}\Gamma_{12}^*}{M_{12}-\frac{i}{2}\Gamma_{12}}}$$

$q \neq p$ implies CP violation in mixing

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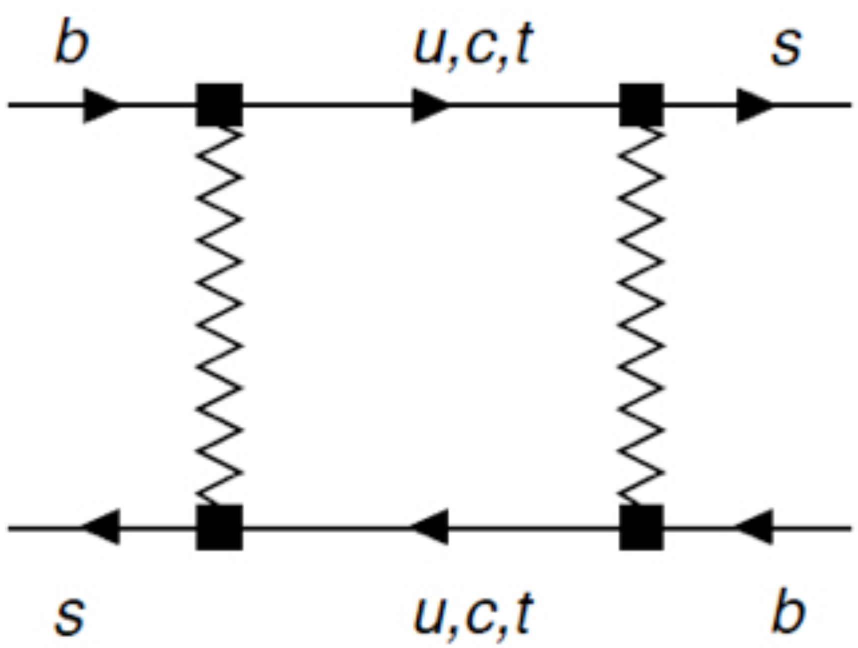
Neutral B mixing



- Can access q/p through asymmetries in flavour specific final states, e.g., semileptonic decays of B_s mesons.

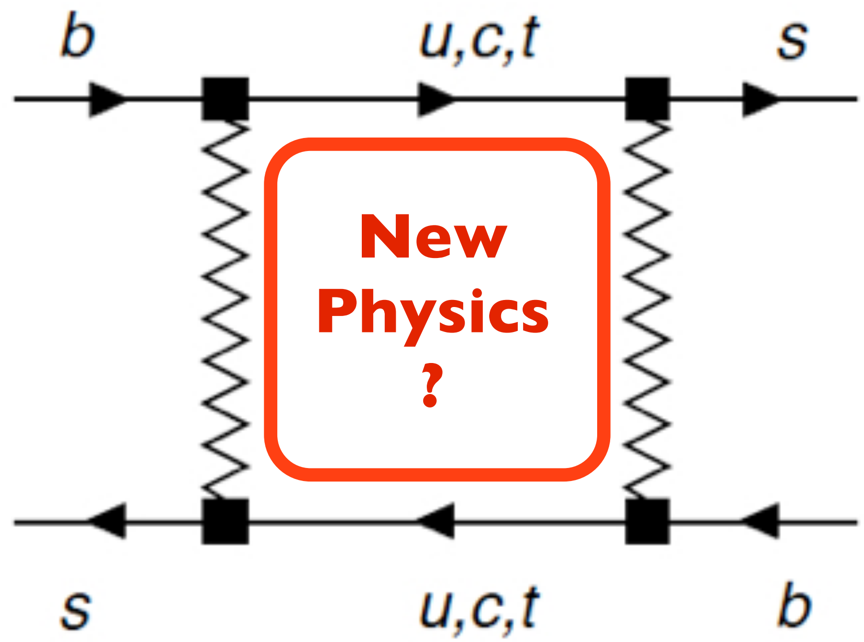
$$a^s_{\rm sl} \equiv \frac{\Gamma(\bar{B}^0_s \to \mu^+ D^-_s) - \Gamma(B^0_s \to \mu^- D^+_s)}{\Gamma(\bar{B}^0_s \to \mu^+ D^-_s) + \Gamma(B^0_s \to \mu^- D^+_s)} = \frac{1-|q/p|^2}{1+|q/p|^2}$$

- SM predictions are tiny compared to the experimental sensitivity.

$$a^s_{\rm sl} = (2.0 \pm 0.6) \times 10^{-5}$$
$$a^d_{\rm sl} = (-4.8 \pm 1.1) \times 10^{-4}$$

A. Lenz and U. Nierste, JHEP06(2007)072

Neutral B mixing



- Can access q/p through asymmetries in flavour specific final states, e.g., semileptonic decays of B_s mesons.

$$a_{\rm sl}^s \equiv \frac{\Gamma(\bar{B}_s^0 \to \mu^+ D_s^-) - \Gamma(B_s^0 \to \mu^- D_s^+)}{\Gamma(\bar{B}_s^0 \to \mu^+ D_s^-) + \Gamma(B_s^0 \to \mu^- D_s^+)} = \frac{1-|q/p|^2}{1+|q/p|^2}$$

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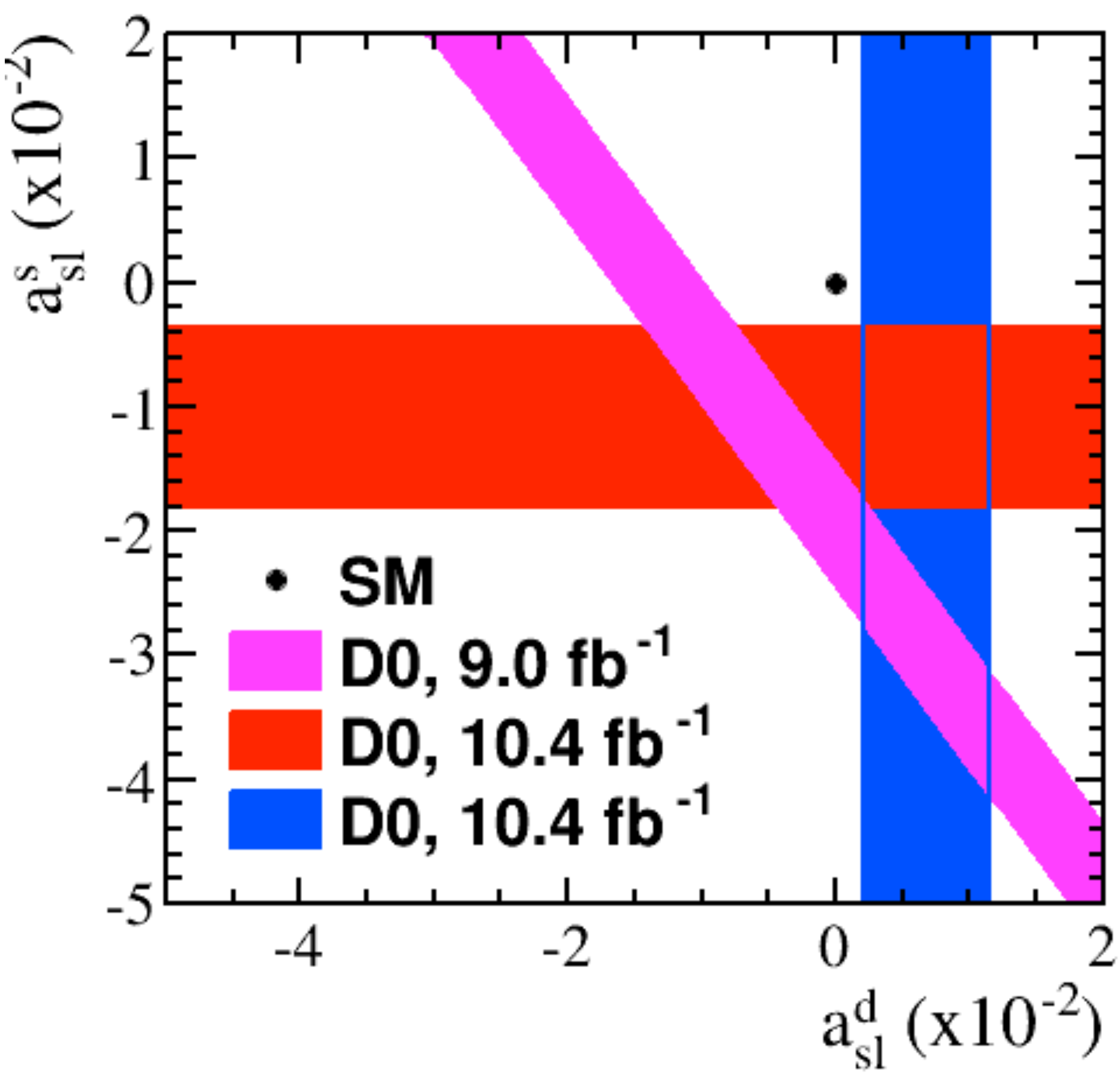
A. Lenz and U. Nierste, JHEP06(2007)072

Experimental status

- Dzero reported a 3.9σ discrepancy in the dimuon asymmetry.

  Phys. Rev. D **84**, 052007 (2011)

- More recent updates on a_{sl}^s and a_{sl}^d are compatible with the SM.



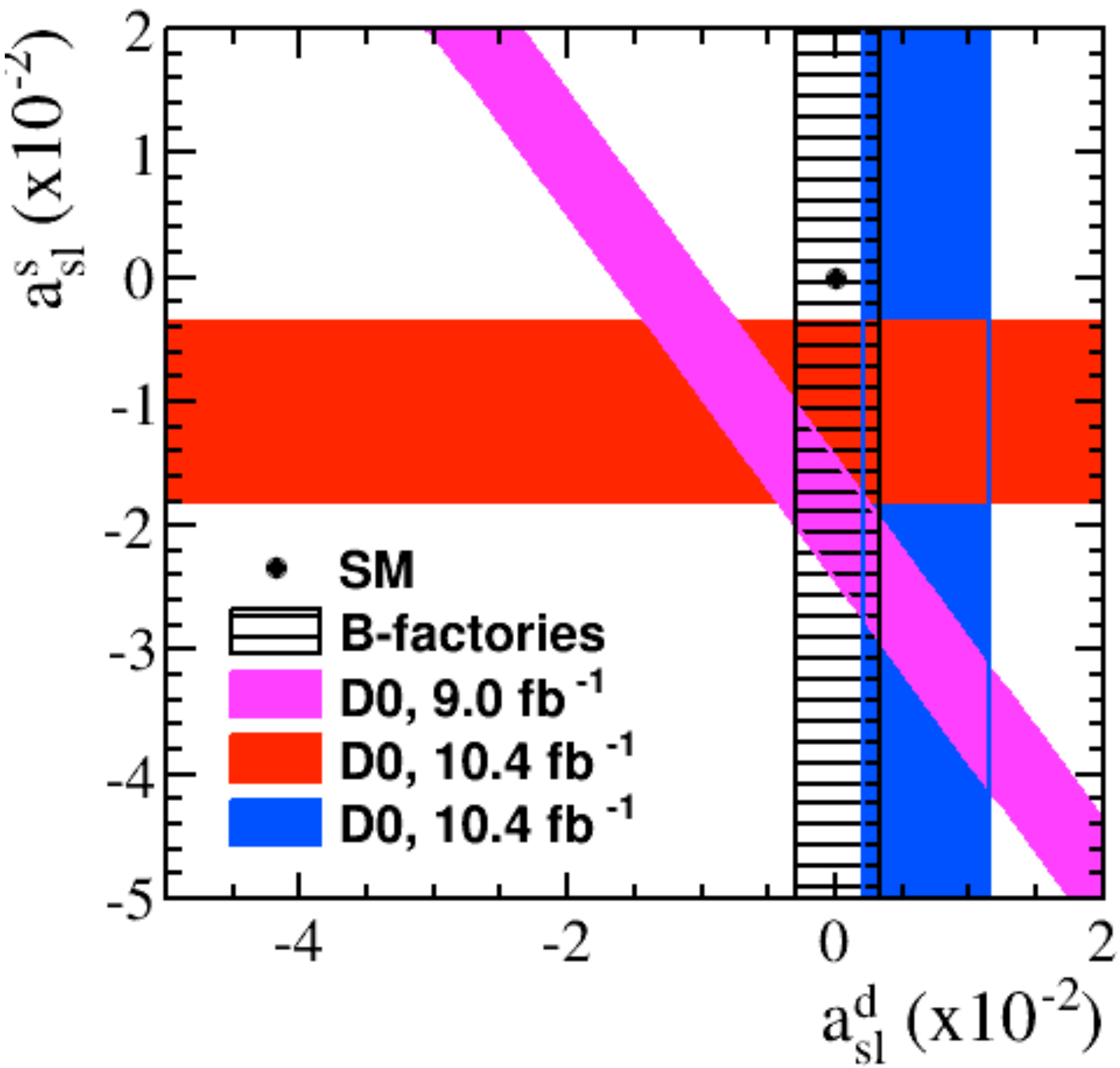
Phys. Rev. Lett., **110**, 011801 (2013)

Phys. Rev. D **86**, 072009 (2012)

See previous talk, by Iain Bertram

Experimental status

- B-factory average for a_{sl}^d is also consistent with the Standard Model.
  HFAG average from fall 2012
- Includes a recent update from BaBar
  M. Margoni for BaBar, Proceedings of CKM 2012.



See following talk,
by Concetta Cartaro

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What we actually measure

$$A_{\rm raw} \equiv \frac{N(D_s^-\mu^+) - N(D_s^+\mu^-)}{N(D_s^-\mu^+) + N(D_s^+\mu^-)} = \frac{a_{\rm sl}^s}{2} + \left[a_p - \frac{a_{\rm sl}^s}{2}\right] \frac{\int e^{-\Gamma_s t}\cos(\Delta M_s t)\epsilon(t)dt}{\int e^{-\Gamma_s t}\cosh(\Delta\Gamma_s t/2)\epsilon(t)dt}$$

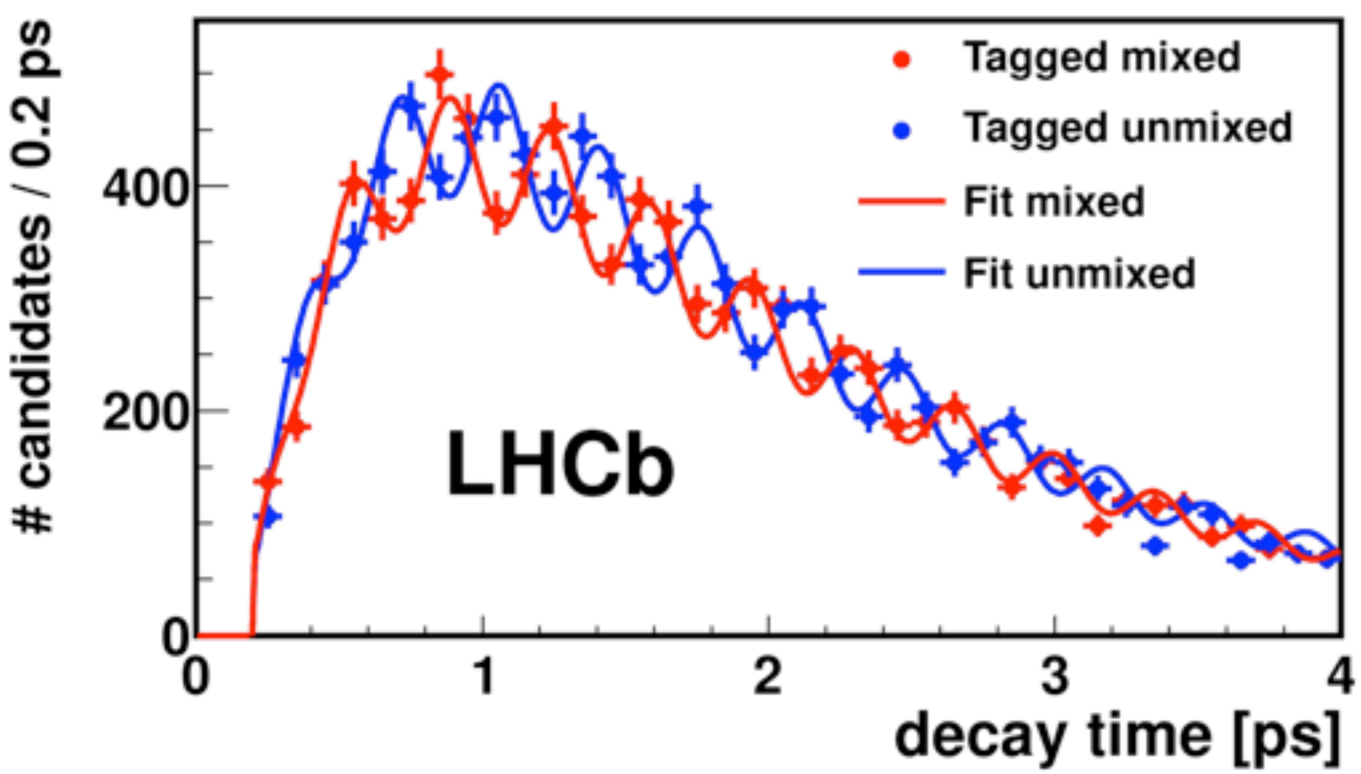
Untagged, time integrated, semileptonic asymmetry.

B_s production asymmetry (Roughly 1%).

LHCb, PRL 108 201601 (2012).

Thanks to the large ΔM_s, this acceptance integral is ≈0.2%.

The fast B_s oscillations wash out any B_s production asymmetry.

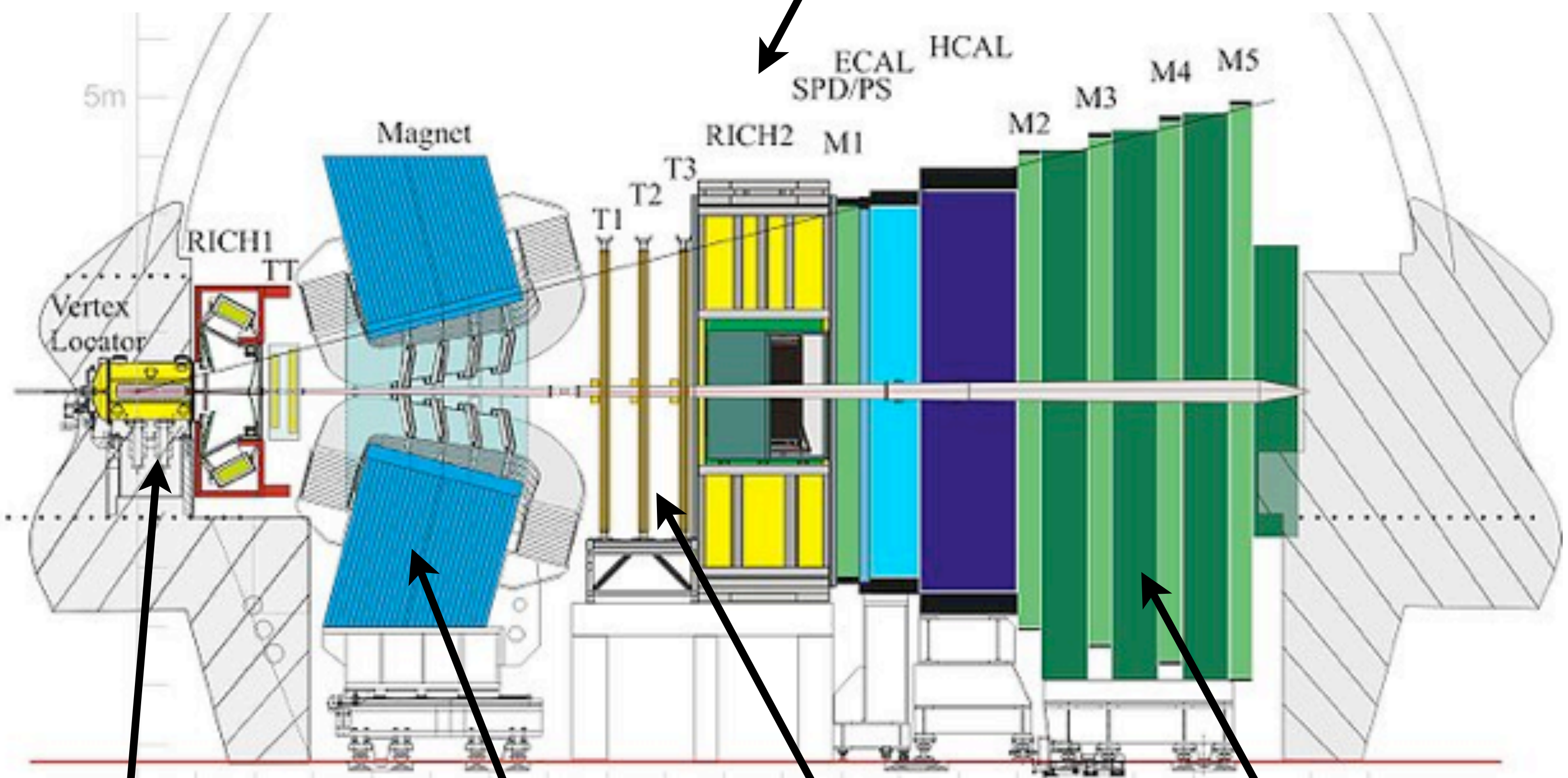


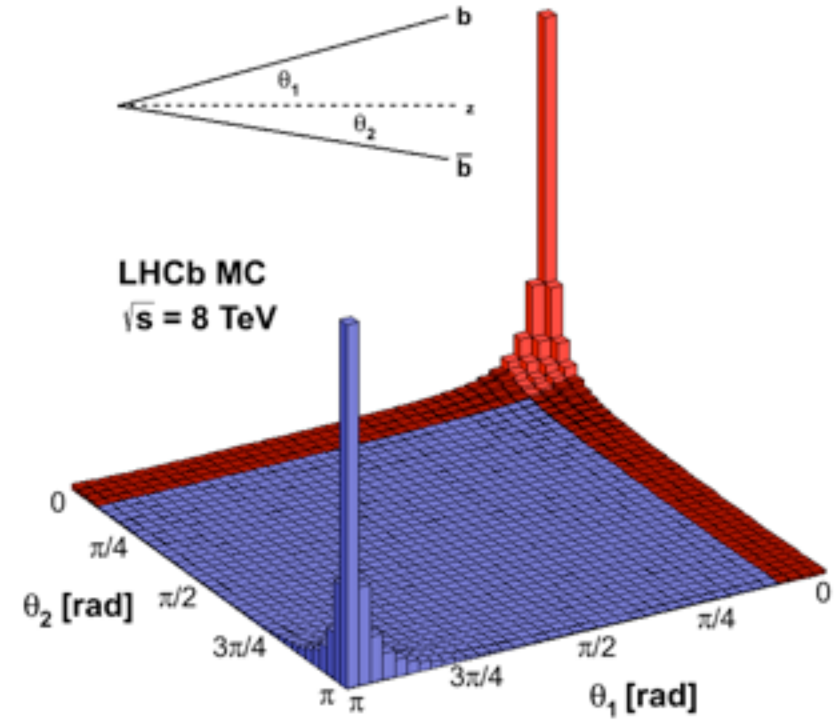
Recent measurement of the B_s mixing frequency from LHCb

See talk by Frederic Dupertuis on Friday morning.

LHCb detector

Excellent π, K, p separation





$\sigma(pp \to b\bar{b}X) \approx 80\ \mu b$
in the LHCb acceptance.

LHCb, PLB 694 (2010) 209

Precision vertexing.
IP resolution:
$12 \pm (24/\mathrm{GeV})/p_T\ \mu m$

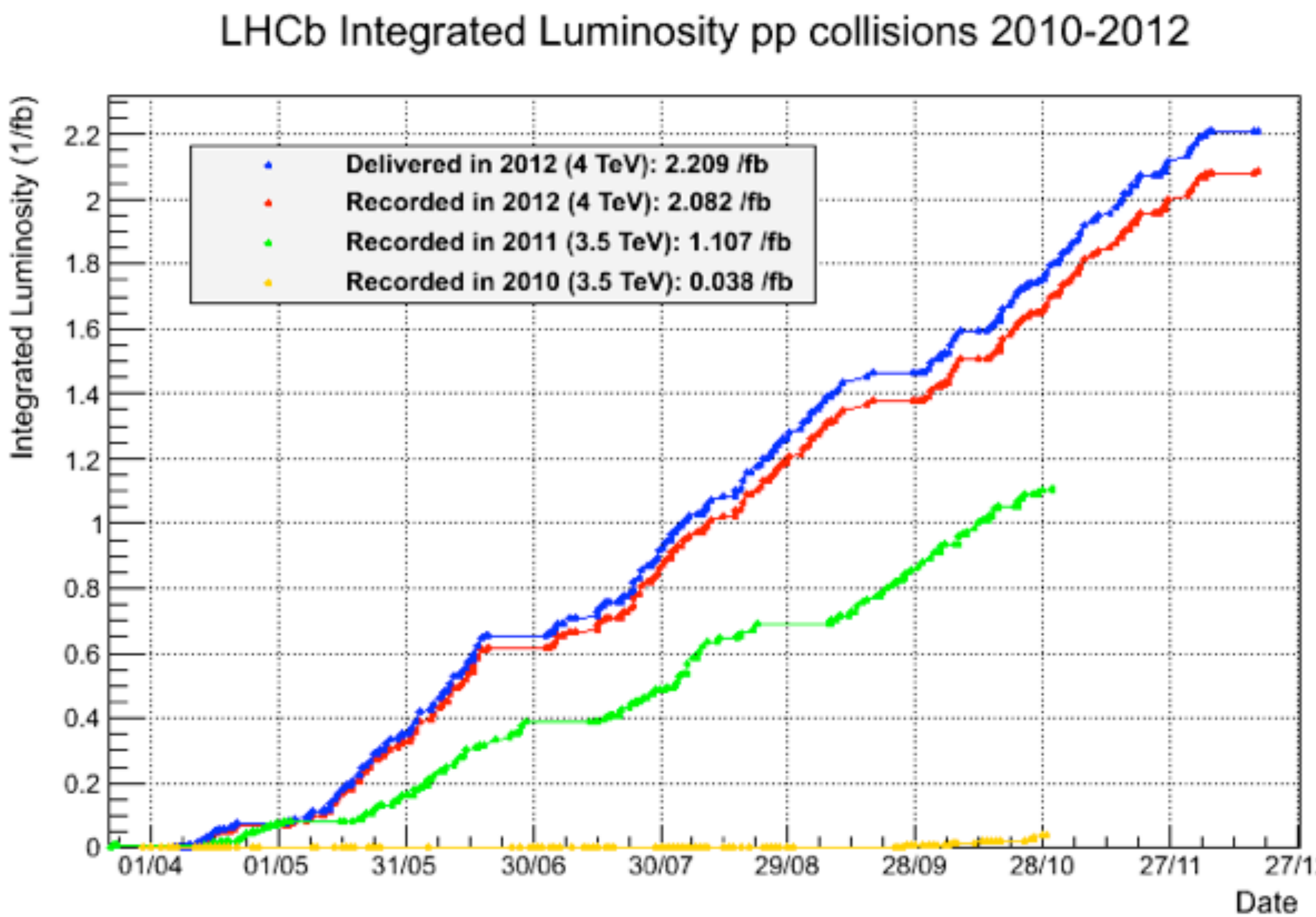
Regular reversal
of the magnet
polarity

Excellent
momentum and
mass resolution.
$\delta p/p \sim 0.5\%$

Muon identification

LHCb luminosity

- Excellent performance in 2011 and 2012.
- More than 3 fb^{-1} on tape gives us the largest b-hadron sample.



- This analysis is based on 1 fb^{-1} of data from the 2011 run.

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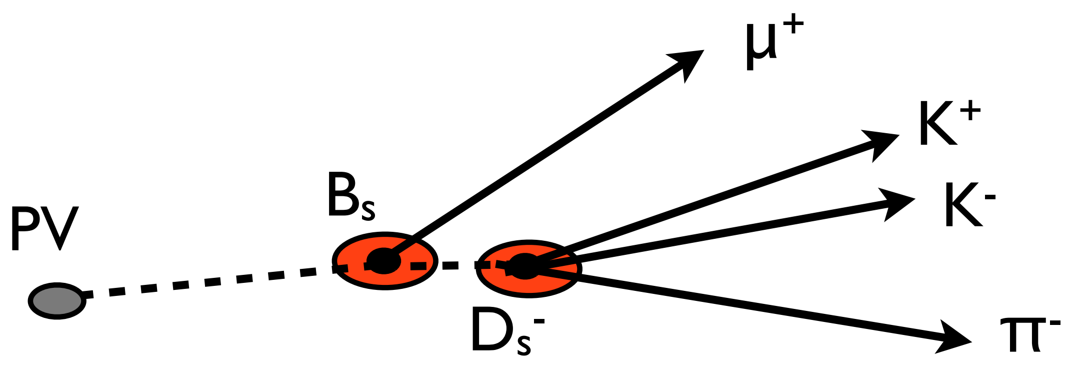
Analysis method

- Select a sample of $B_s^0 \rightarrow D_s^- \mu^+ + X$ candidates, with the decay $D_s^- \rightarrow \phi \pi^-$, and $\phi \rightarrow K^+K^-$.



- Measure the signal yields separately for $D_s^-\mu^+$ and $D_s^+\mu^-$, and in the two magnet polarity configurations.

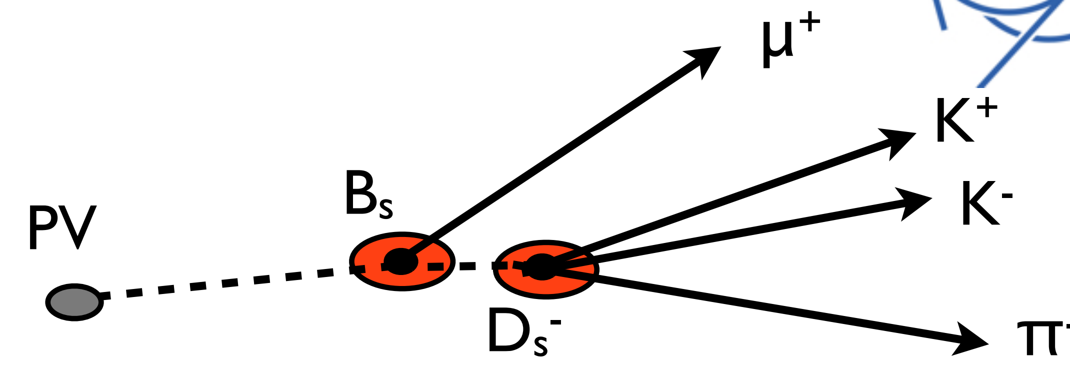
- Correct the signal yields for detection asymmetries using control channels.

$$A_{\rm meas} = \frac{N(D_s^-\mu^+) - N(D_s^+\mu^-) \times \frac{\epsilon(D_s^-\mu^+)}{\epsilon(D_s^+\mu^-)}}{N(D_s^-\mu^+) + N(D_s^+\mu^-) \times \frac{\epsilon(D_s^-\mu^+)}{\epsilon(D_s^+\mu^-)}}$$

- Detailed analysis of background sources.

Detection asymmetries

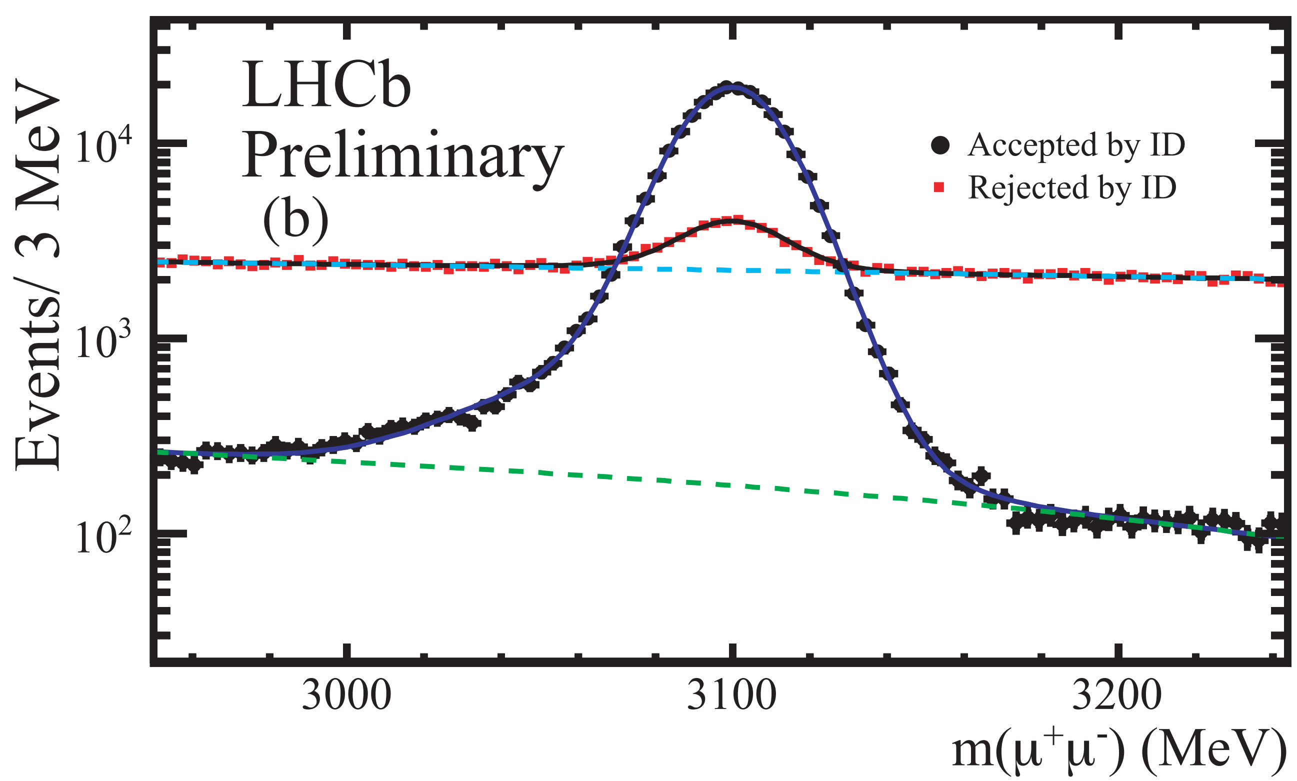
$$A_{\rm meas} = \frac{N(D_s^- \mu^+) - N(D_s^+ \mu^-) \times \frac{\epsilon(D_s^- \mu^+)}{\epsilon(D_s^+ \mu^-)}}{N(D_s^- \mu^+) + N(D_s^+ \mu^-) \times \frac{\epsilon(D_s^- \mu^+)}{\epsilon(D_s^+ \mu^-)}}$$

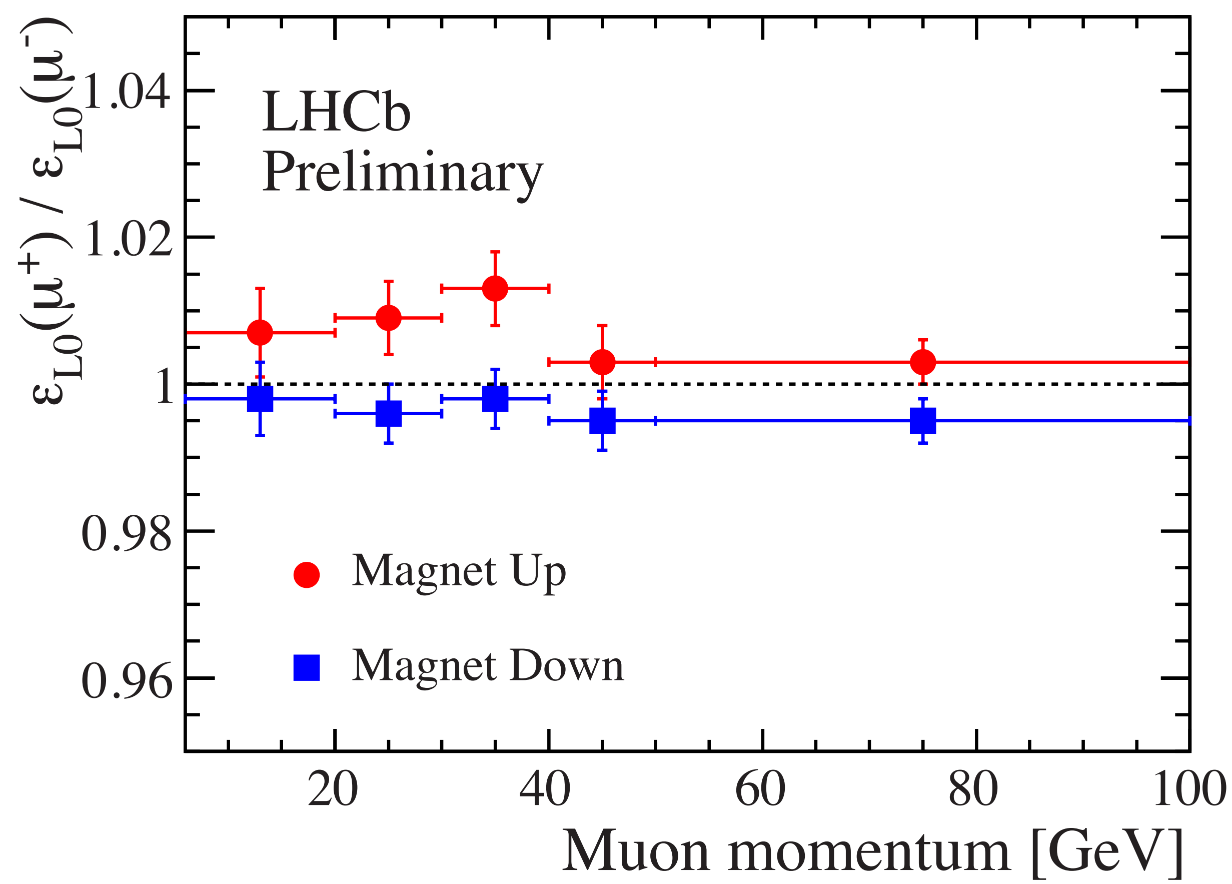


- Design analysis/selection to minimise asymmetries:
  - A tight cut of ±20 MeV around the ϕ resonance ensures almost equal momentum spectra for the kaons with equal/opposite charge to the Ds.
  - There are no PID requirements on the pion, and the tracking asymmetries mostly cancel between the muon and pion.
- Main sources of potential asymmetry:
  - Muon identification
  - The first two stages of the trigger (L0 and Hlt1) that require a muon with p_T > 1.4 GeV, and significant impact parameter w.r.t. the PV.
  - Residual tracking asymmetries.

Muon asymmetries

- A large sample of $J/\psi \to \mu^+\mu^-$ events is used to measure the muon ID, and trigger asymmetries.
- The largest source of asymmetry is in the first stage (L0) of the trigger.
- The signal yields in 50 bins of muon P, p_x and p_y.





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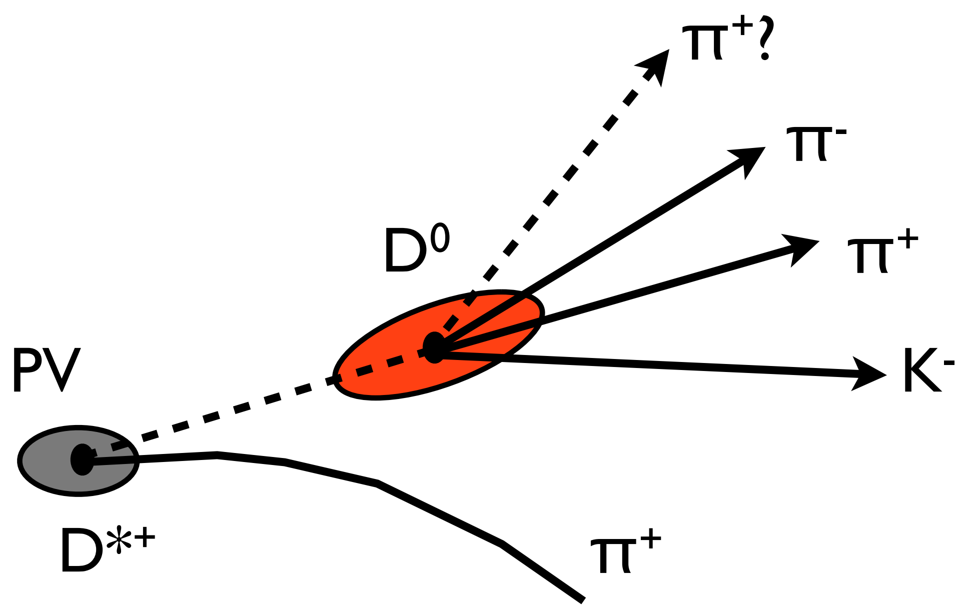
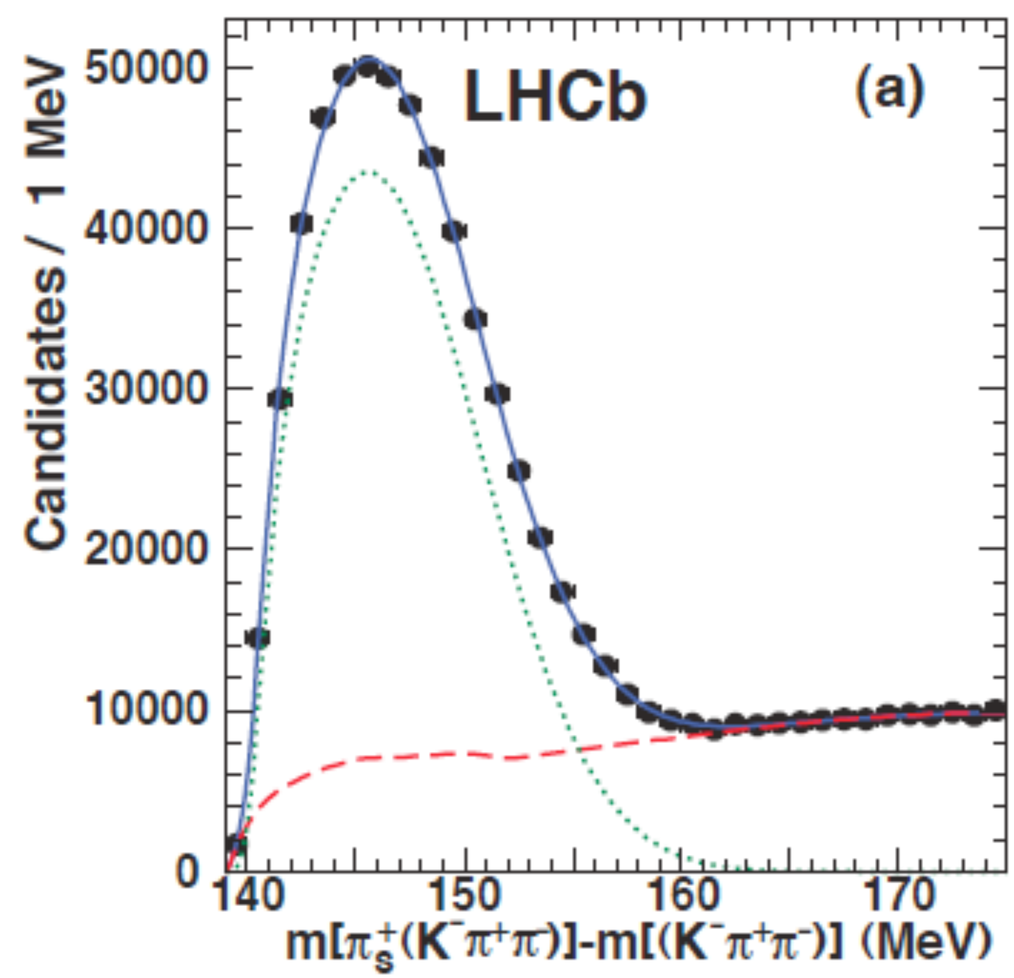
Tracking asymmetries

- The $\pi^{\pm}$ tracking efficiency/asymmetry is measured using a partially reconstructed sample of $D^{*+} \rightarrow D^0\pi^+$, with $D^0 \rightarrow K^- \pi^+\pi^-\pi^+$.
- This method was used in an earlier measurement of the D_s production asymmetry. LHCb, PLB 713 186-195 (2012)





- Vertex and kinematic constraints allow determination of the momentum of the missing particle.

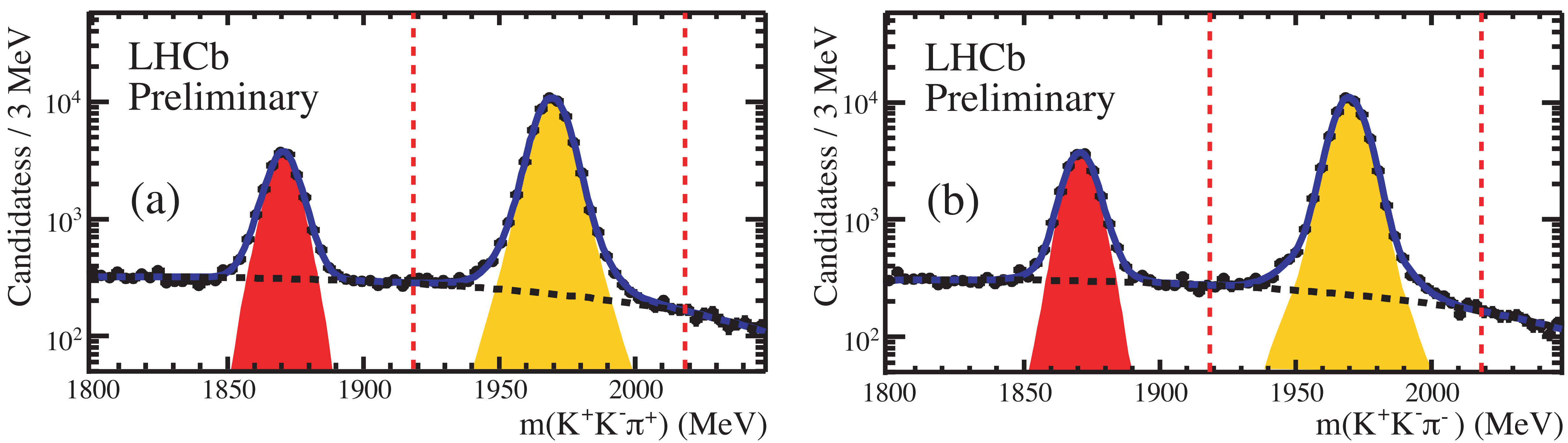
Signal yields

- Signal yields are extracted by fitting the KKπ invariant mass distributions.
  - PDF includes double Gaussians for the D_s and D^+ signals, plus 2nd order polynomial for the combinatorial background.
  - Various parameterisations are compared in the evaluation of systematic uncertainties.

Raw yields (not corrected for detection asymmetries).

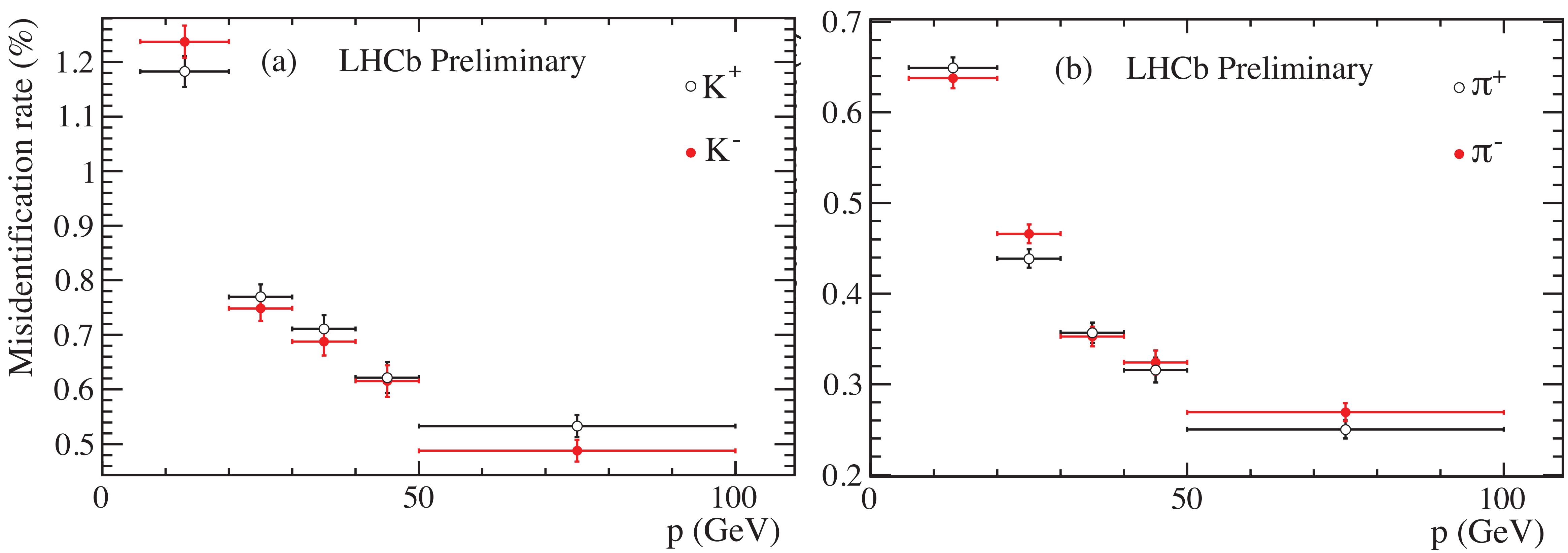
	Up	Down
$D_s^-\mu^+$	40945 ± 285	55755 ± 278
$D_s^+\mu^-$	39849 ± 239	56447 ± 294

Signal fits in the magnet down data



Backgrounds (misidentified muons)

- Estimated using $B \rightarrow D_s\pi X$ and D_sKX samples from real data,
- The probabilities for kaons and pions to be reconstructed as muons are measured with $D^{*+} \rightarrow D^0\pi^+$, $D^0 \rightarrow K^-\pi^+$ events.
- Found to have a negligible effect
  - Less than 1% contamination.
  - The asymmetry in the fake rates is also at the 1% level.



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Other backgrounds

- Prompt D_s production has a negligible effect
    - Its contribution is estimated to be ≈1.5%, in a 2D fit to the KKπ mass and the impact parameter of the D_s.
    - The D_s production asymmetry has been measured to be (-0.33 ± 0.22 ± 0.10)%

      LHCb, PLB 713 186-195 (2012)
- $B \rightarrow D_s X_c$, with $X_c \rightarrow \mu X$ is estimated at ≈3.5%, and inherits a ≈1% production asymmetry.
- However, $B \rightarrow D_s K \mu \nu X$ contributes at a similar level, but with an opposite sign. Accounted for in the systematic uncertainties.

Measured asymmetry

Preliminary

$A_{meas} = a_{sl}/2$

These are already corrected for the detection asymmetries.

Magnet Up

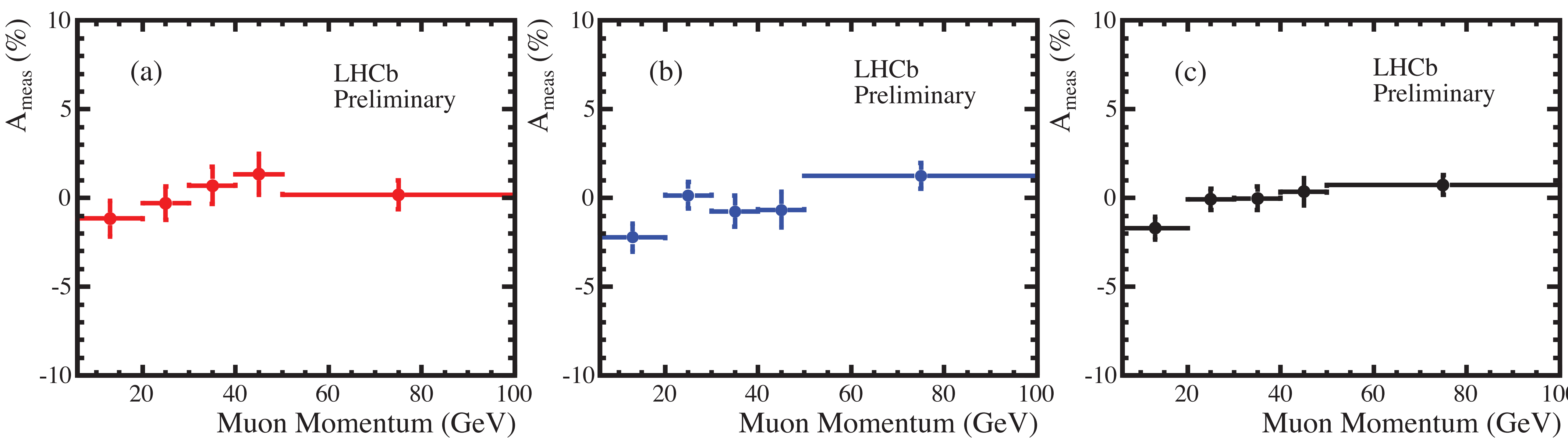
$A_{meas} = (0.10 \pm 0.41 \pm 0.15)\%$

Magnet Down

$A_{meas} = (-0.34 \pm 0.35 \pm 0.13)\%$

Average

$A_{meas} = (-0.12 \pm 0.27 \pm 0.10)\%$



Consistent results are obtained with the two magnet polarity configurations.

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Systematic uncertainties

Source	δa_{sl} (%)
Signal model in D_s mass fit	0.12
Background from other b hadrons	0.10
Kinematic difference between π and μ	0.12
Kaon asymmetries	0.04
Varying run conditions between field-up and field-down	0.02
Muon corrections	0.10
Muon related software trigger biases	0.10
Statistical uncertainty on efficiency ratios	0.20
Total	**0.33**

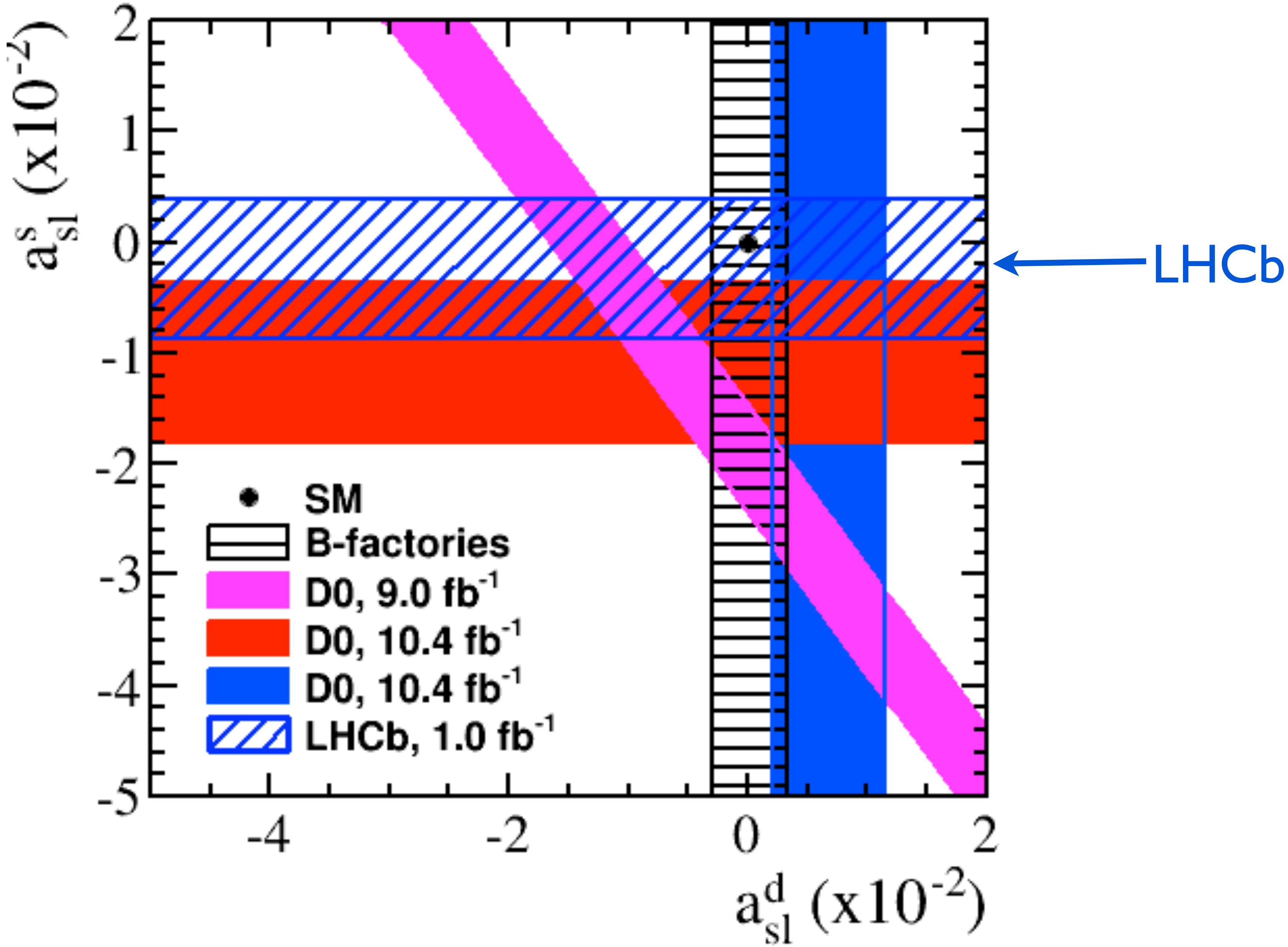
- The largest source is the statistical uncertainty on the muon ID and trigger asymmetries.

Our preliminary result

Preliminary

LHCb-CONF-2012-022

$$a_{sl}^{s} = (-0.24 \pm 0.54_{stat} \pm 0.33_{syst})\%$$



Conclusions

- LHCb reports the preliminary result

$$a_{sl}^{s} = (-0.24 \pm 0.54_{stat} \pm 0.33_{syst})\%$$

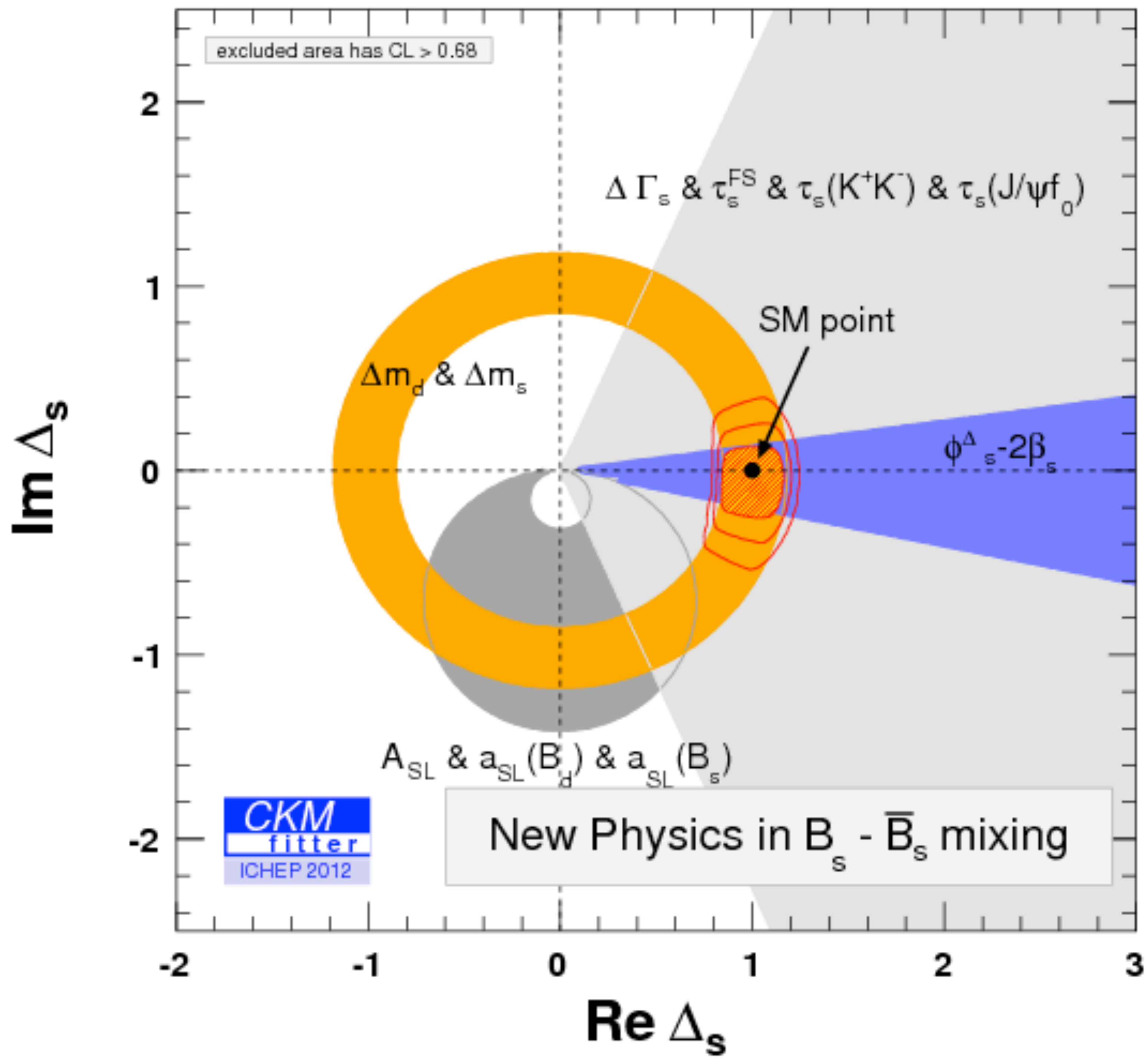
Preliminary
LHCb-CONF-2012-022

- Consistent with the Standard Model prediction.
- We already have three times the data on tape, and plan to include more decay modes.

Backup slides

New physics in B_s mixing

arXiv:1203.0238 [hep-ph]



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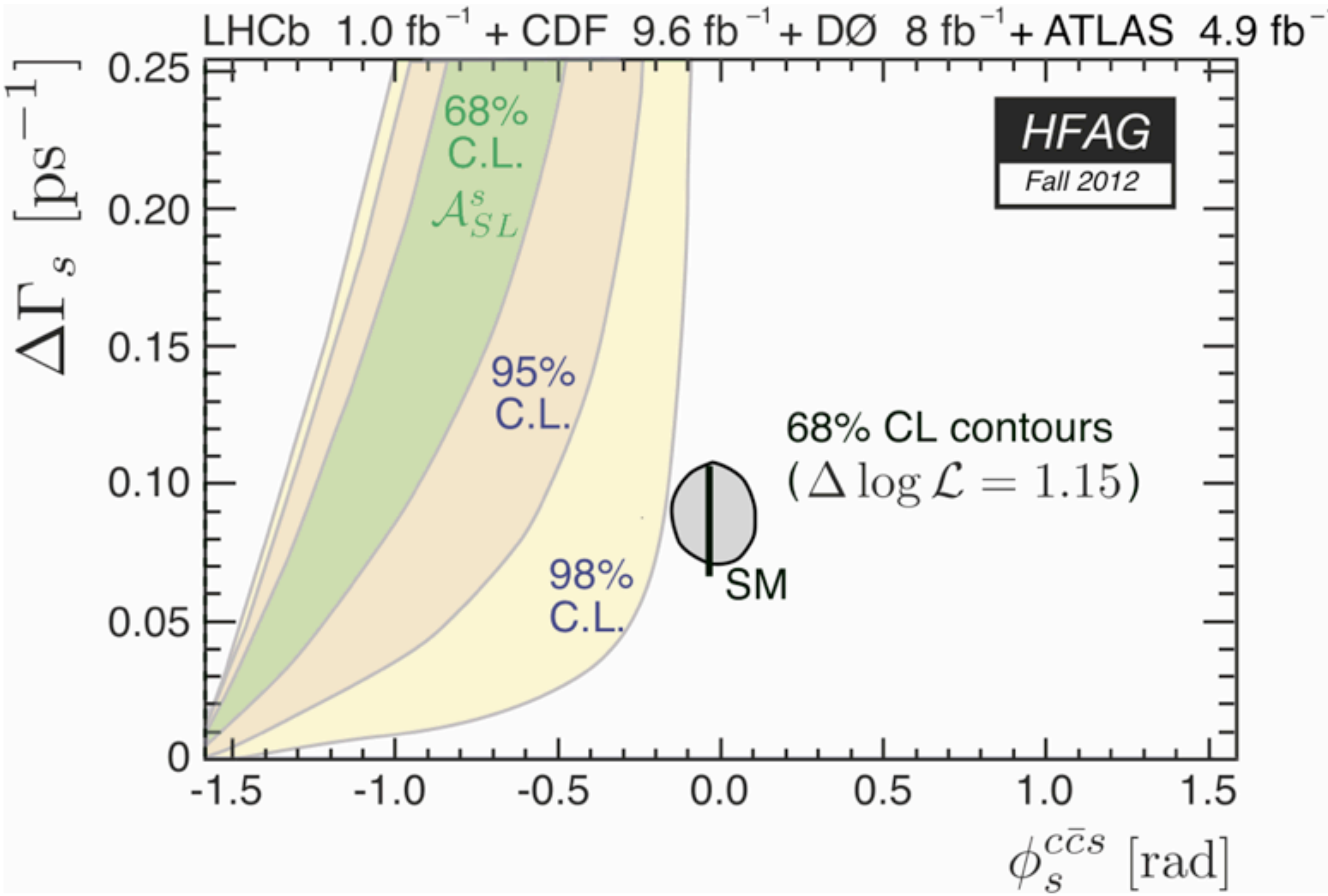
Interplay of ϕ_s and a_{sl}



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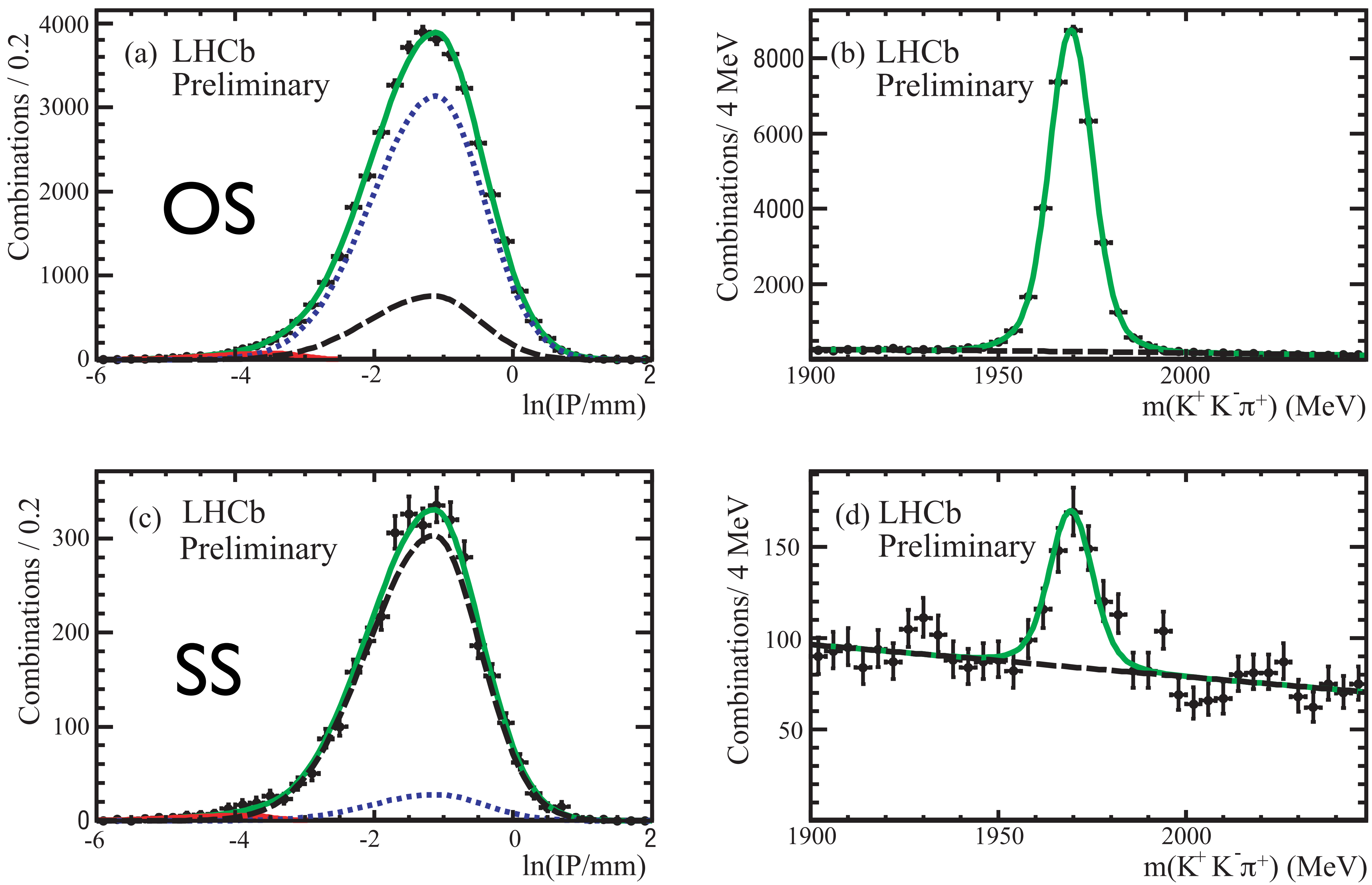
2D fits



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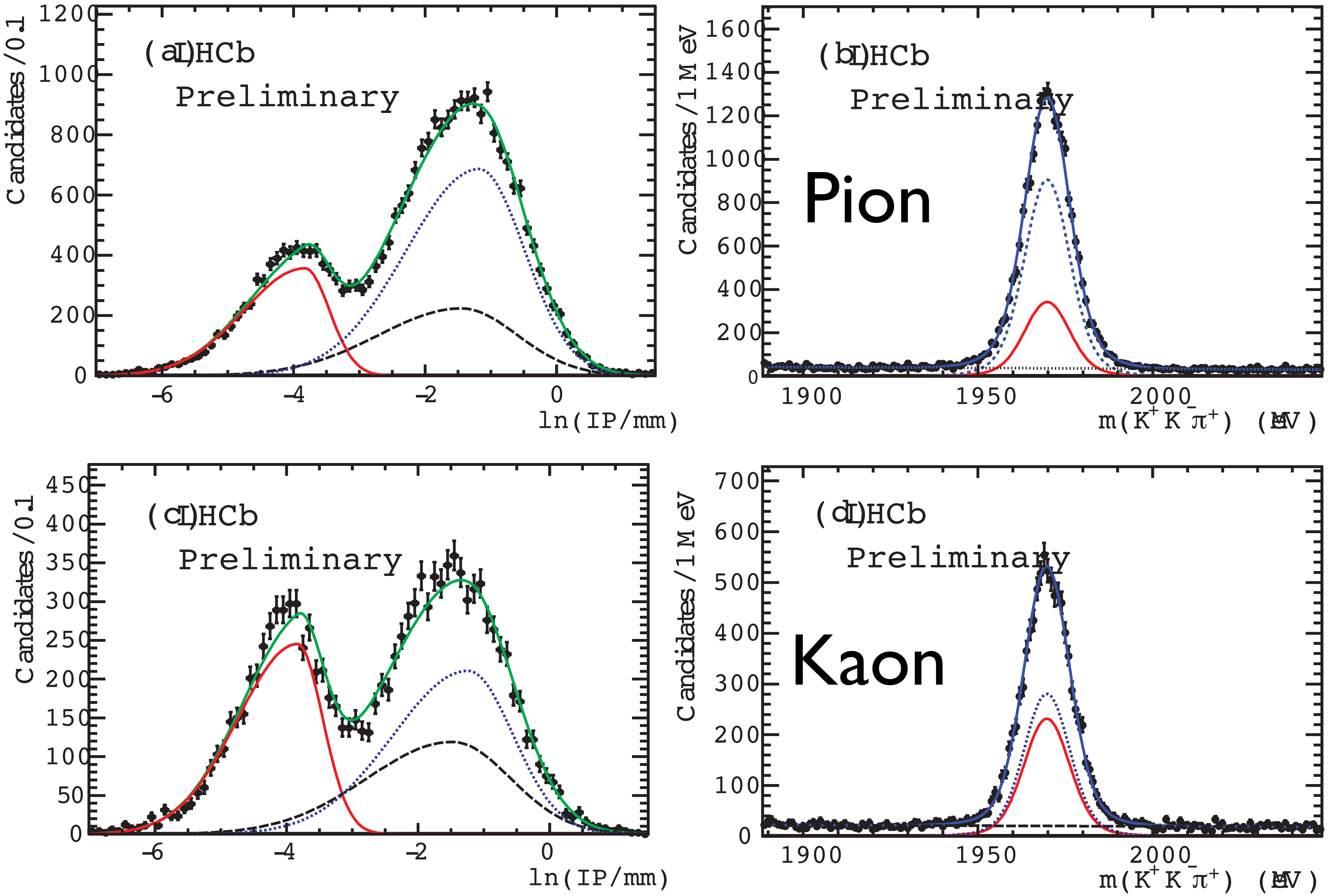
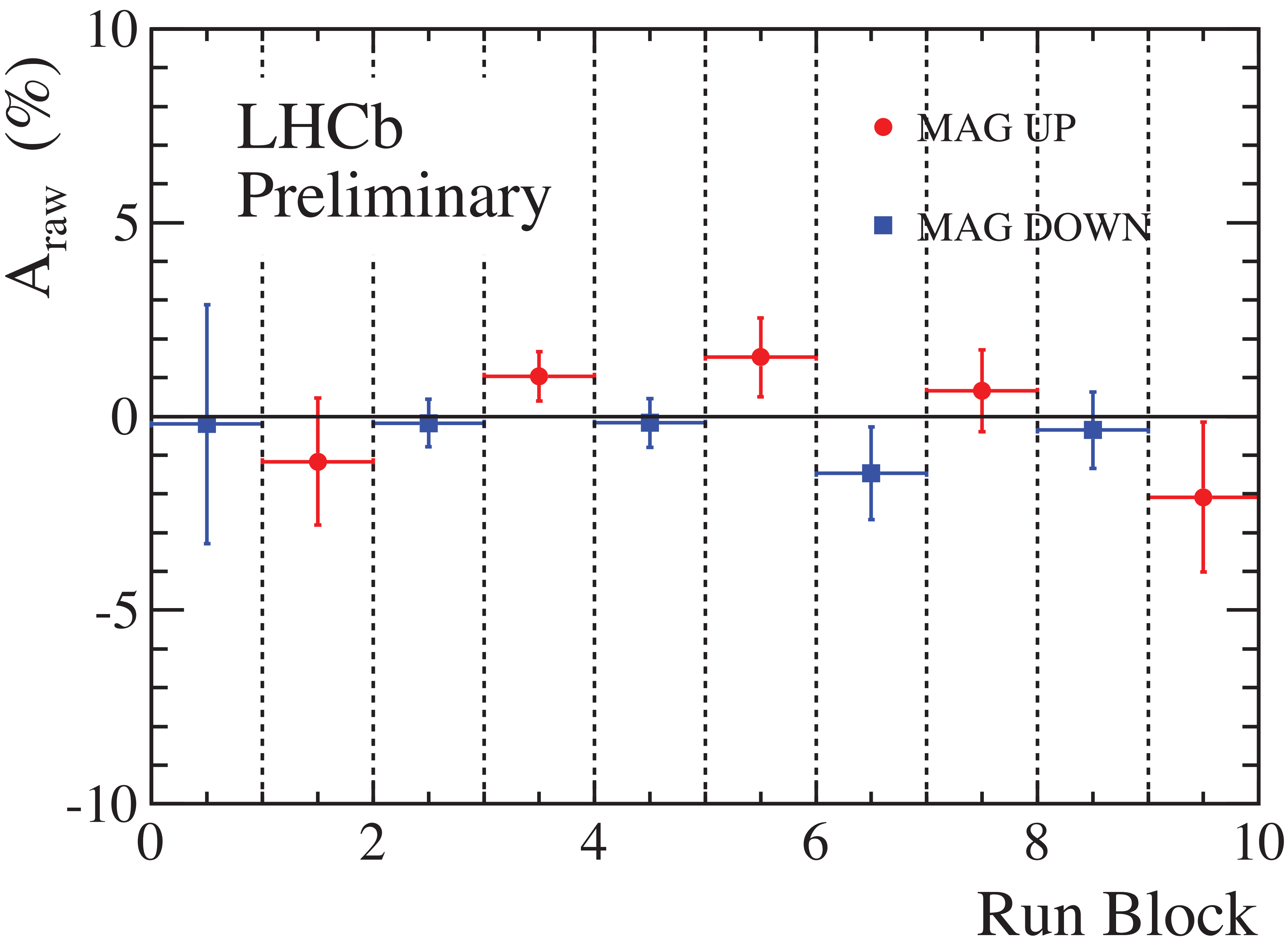
Fake muons

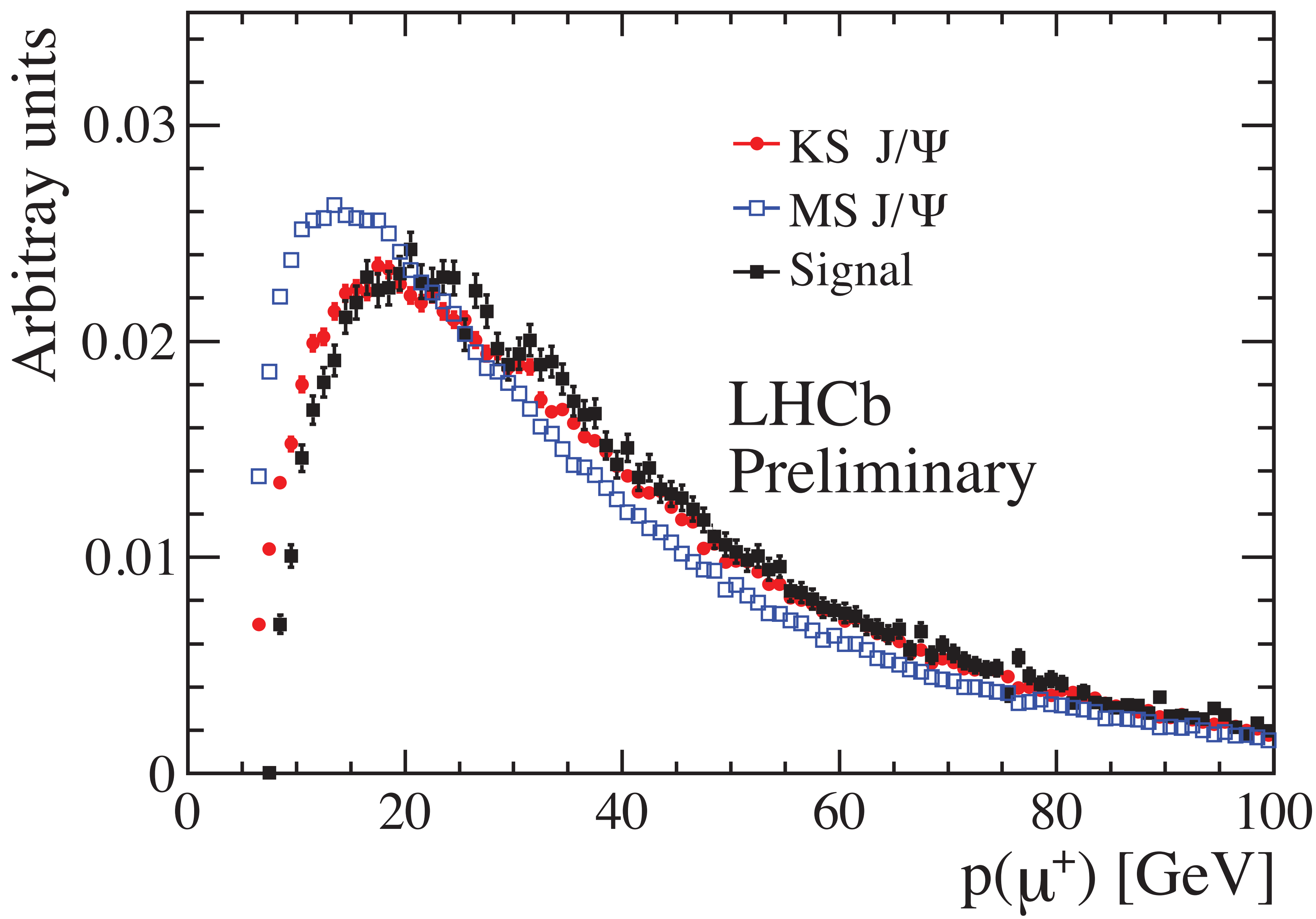


(a) LHCb
Preliminary
Candidates / 0.1
ln(IP/mm)
(b) LHCb
Preliminary
Pion
Candidates / 1 MeV
m(K+K−π+) (MeV)
(c) LHCb
Preliminary
Candidates / 0.1
ln(IP/mm)
(d) LHCb
Preliminary
Kaon
Candidates / 1 MeV
m(K+K−π+) (MeV)

Stability vs. time



Overlap of signal and calibration



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