$a_{\rm sl}^s$ and the D_s^+ Production Asymmetry

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on behalf of the LHCb collaboration

IOP - Joint annual HEPP and APP conference
21 March 2016

MANCHESTER 1824
The University of Manchester

LHCb

Neutral Meson Mixing

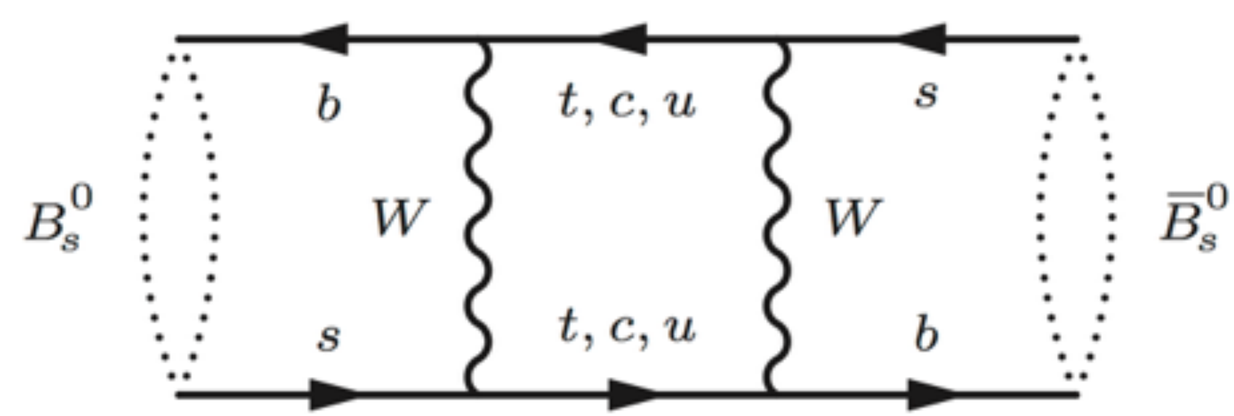
Neutral mesons oscillate into their own antiparticle:

$$i\frac{d}{dt}\begin{pmatrix}|B_q^0(t)\rangle\\|\bar{B}_q^0(t)\rangle\end{pmatrix} = (M - \frac{i}{2}\Gamma)\begin{pmatrix}|B_q^0(t)\rangle\\|\bar{B}_q^0(t)\rangle\end{pmatrix}$$

Heavy and light mass eigenstates:

$$|B_L^0\rangle = p|B_q^0\rangle + q|\bar{B}_q^0\rangle$$

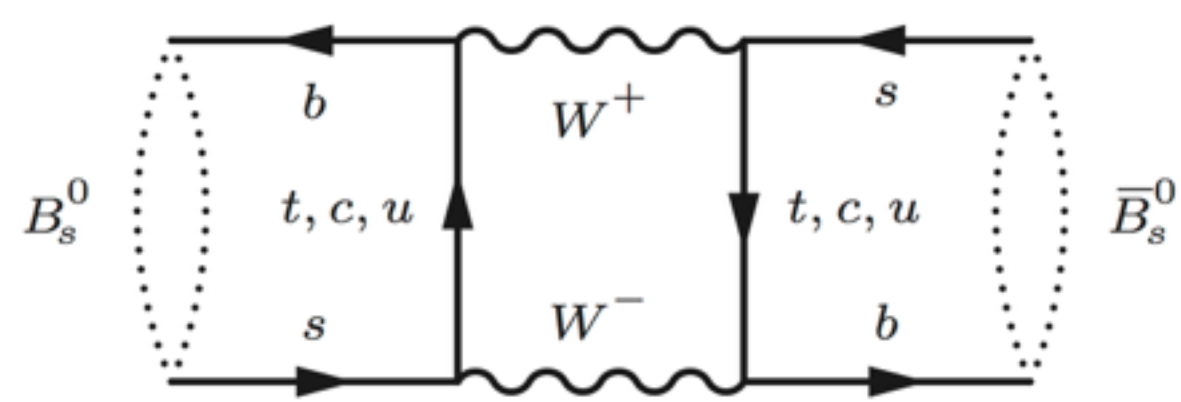
$$|B_H^0\rangle = p|B_q^0\rangle - q|\bar{B}_q^0\rangle$$



Different masses and decay widths:

$\Delta m = m_H - m_L$ → oscillations

$\Delta\Gamma = \Gamma_L - \Gamma_H$ → lifetime difference



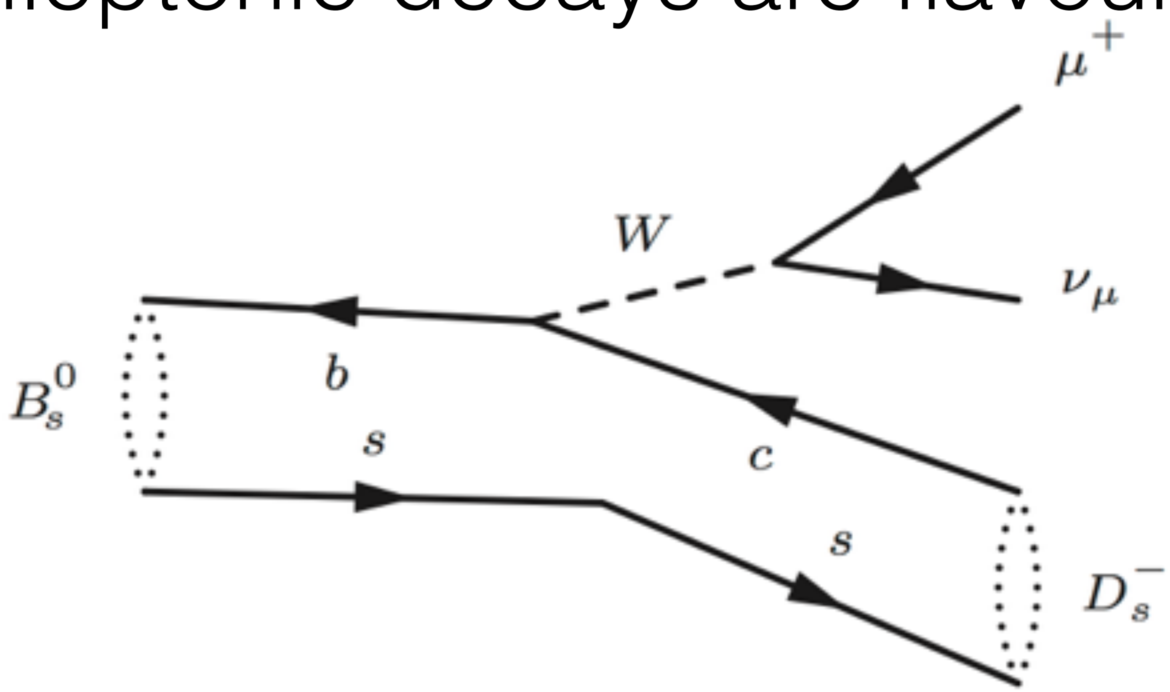
CP Violation in Mixing

$$\mathcal{P}(B_q \to \bar{B}_q) \neq \mathcal{P}(\bar{B}_q \to B_q)$$

Flavour specific asymmetry:

$$a_{\rm fs} = \frac{\Gamma(\bar{B}_q \to B_q \to f) - \Gamma(B_q \to \bar{B}_q \to \bar{f})}{\Gamma(\bar{B}_q \to B_q \to f) + \Gamma(B_q \to \bar{B}_q \to \bar{f})} = \frac{1 - |q/p|^4}{1 + |q/p|^4}$$

Semileptonic decays are flavour-specific:

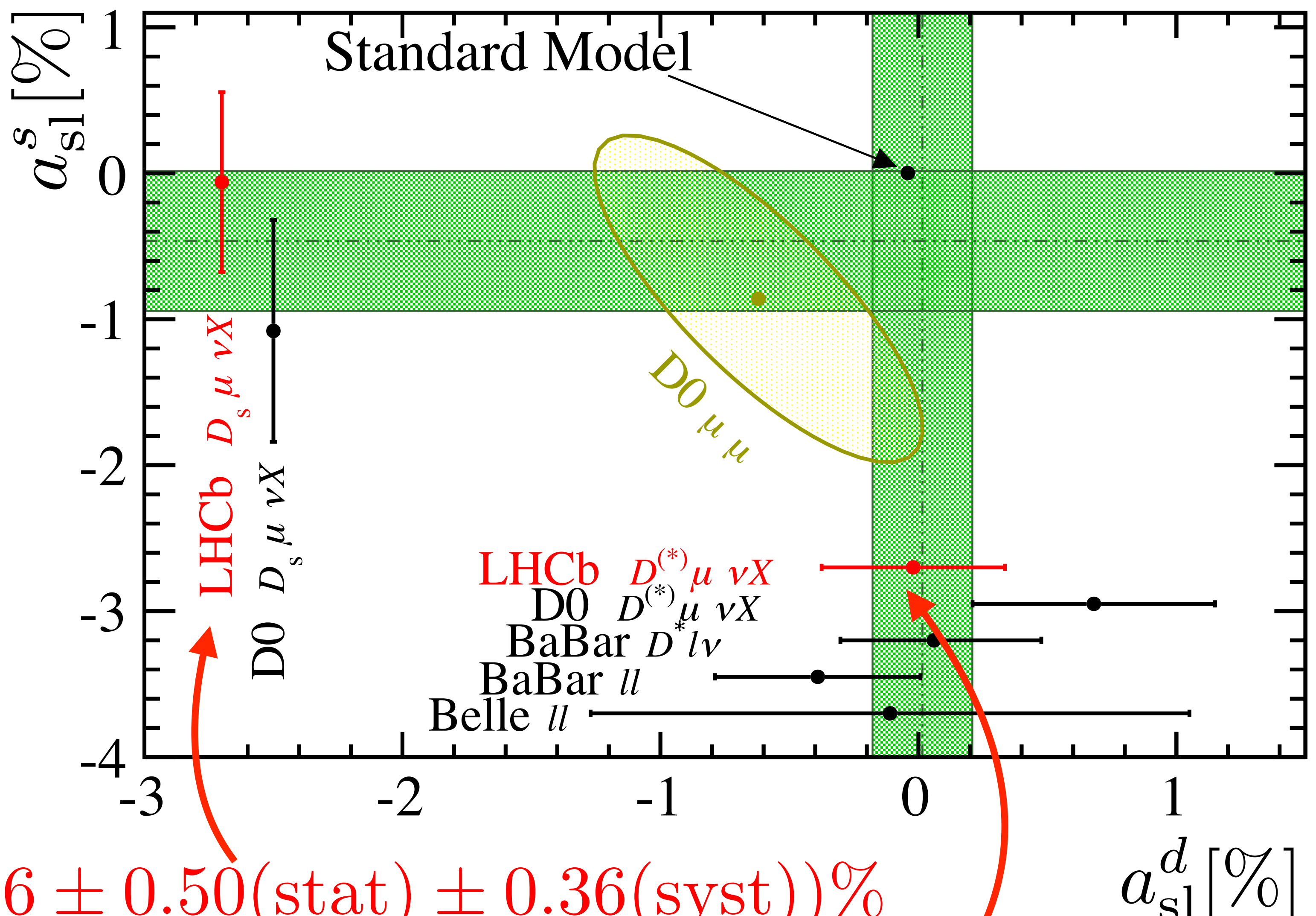


CP violation if |q/p|≠1

→a_{fs} is very small in SM

$B_s \to D_s (\to K K \pi) \mu \nu_\mu$

Experimental Overview



1 fb^{-1} $a^s_{\rm sl} = (-0.06 \pm 0.50(\text{stat}) \pm 0.36(\text{syst}))\%$

Phys. Lett. B 728 607-615 (2014)

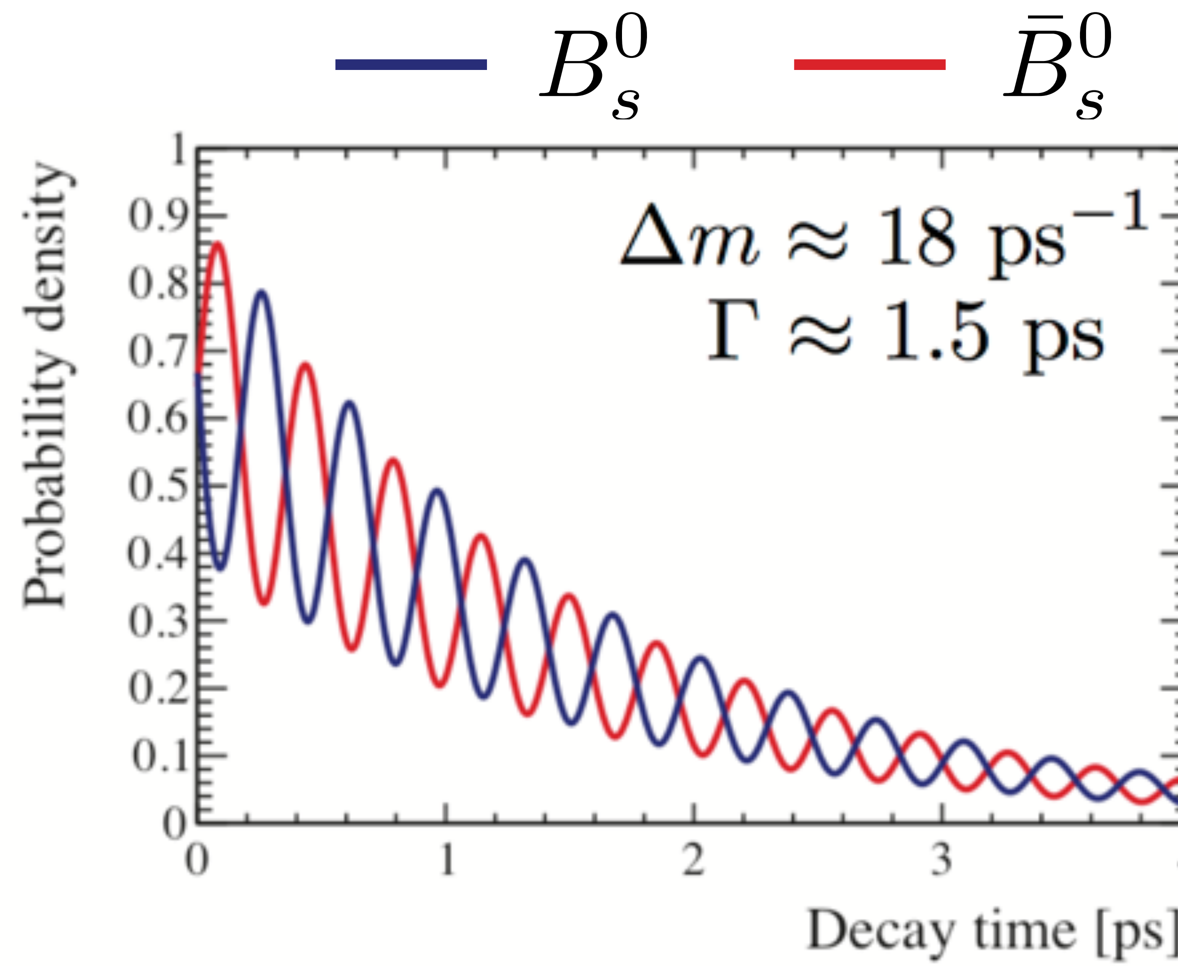
3 fb^{-1} $a^d_{\rm sl} = (-0.02 \pm 0.19(\text{stat}) \pm 0.30(\text{syst}))\%$

Phys. Rev. Lett. 114 041601 (2015)

Measuring $a_{\rm sl}^s$ in LHCb

We start with a different amount of B_s^0 and $\bar{B}_s^0$ mesons:

$$A_P = \frac{\sigma(pp \to B_s^0) - \sigma(pp \to \bar{B}_s^0)}{\sigma(pp \to B_s^0) + \sigma(pp \to \bar{B}_s^0)}$$



→ rapid oscillations dilute production asymmetry

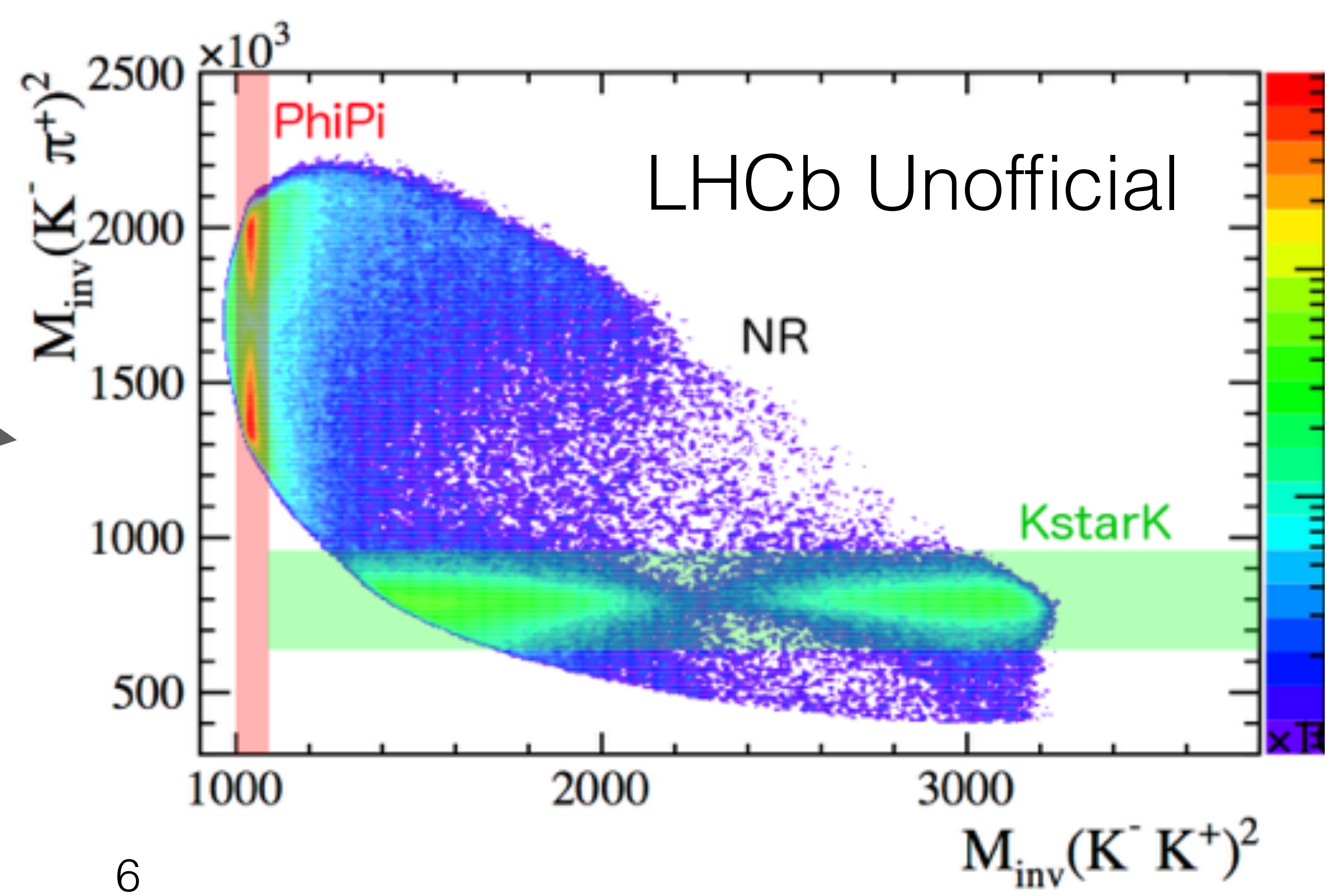
How to measure $a_{\rm sl}^{s}$

$$A_{\rm raw} = (1 - f_{\rm bkg})\frac{a_{\rm sl}^{s}}{2} + f_{\rm bkg}A_{\rm bkg} + A_D$$

$$\frac{a_{\rm sl}^{s}}{2} = \frac{1}{1 - f_{\rm bkg}}(A_{\rm raw} - A_{\rm det} - f_{\rm bkg}A_{\rm bkg})$$

$B_s \rightarrow (D_s \rightarrow K\,K\,\pi)\,\mu\,\nu_\mu$

Expanding phase space compared to previous measurement of $a_{\rm sl}^{s}$:



Cross-check and analysis on its own: $A_P(D_s^+)$

$$A_P = \frac{\sigma(pp \to D_s^+) - \sigma(pp \to D_s^-)}{\sigma(pp \to D_s^+) + \sigma(pp \to D_s^-)}$$

$D_s \to K K \pi$

- Divided in the same bins of phase space
- Same background cuts have been applied (when applicable)
- Similar methods to determine detection asymmetry
- Similar fit strategy
- Splitting in kinematic bins

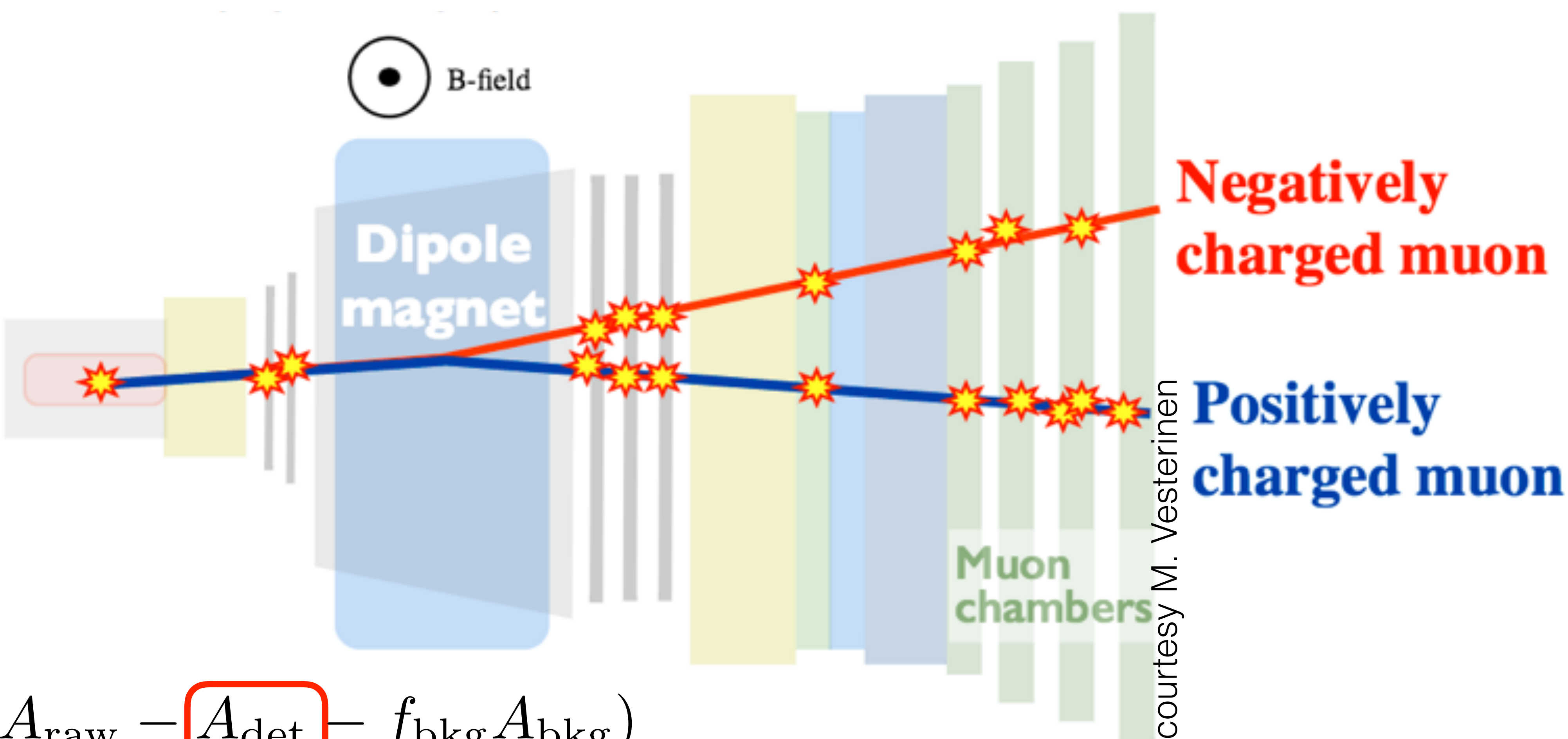
$$A_P(D_s^+) = \frac{1}{1 - f_{\text{bkg}}}(A_{\text{raw}} - A_D - f_{\text{bkg}} A_P(B))$$

Detection Asymmetries

$$A_{\rm det} = \frac{\varepsilon(f) - \varepsilon(\bar{f})}{\varepsilon(f) + \varepsilon(\bar{f})}$$

Due to:

- left-right asymmetric detector
- interaction asymmetries
- asymmetric pattern recognition

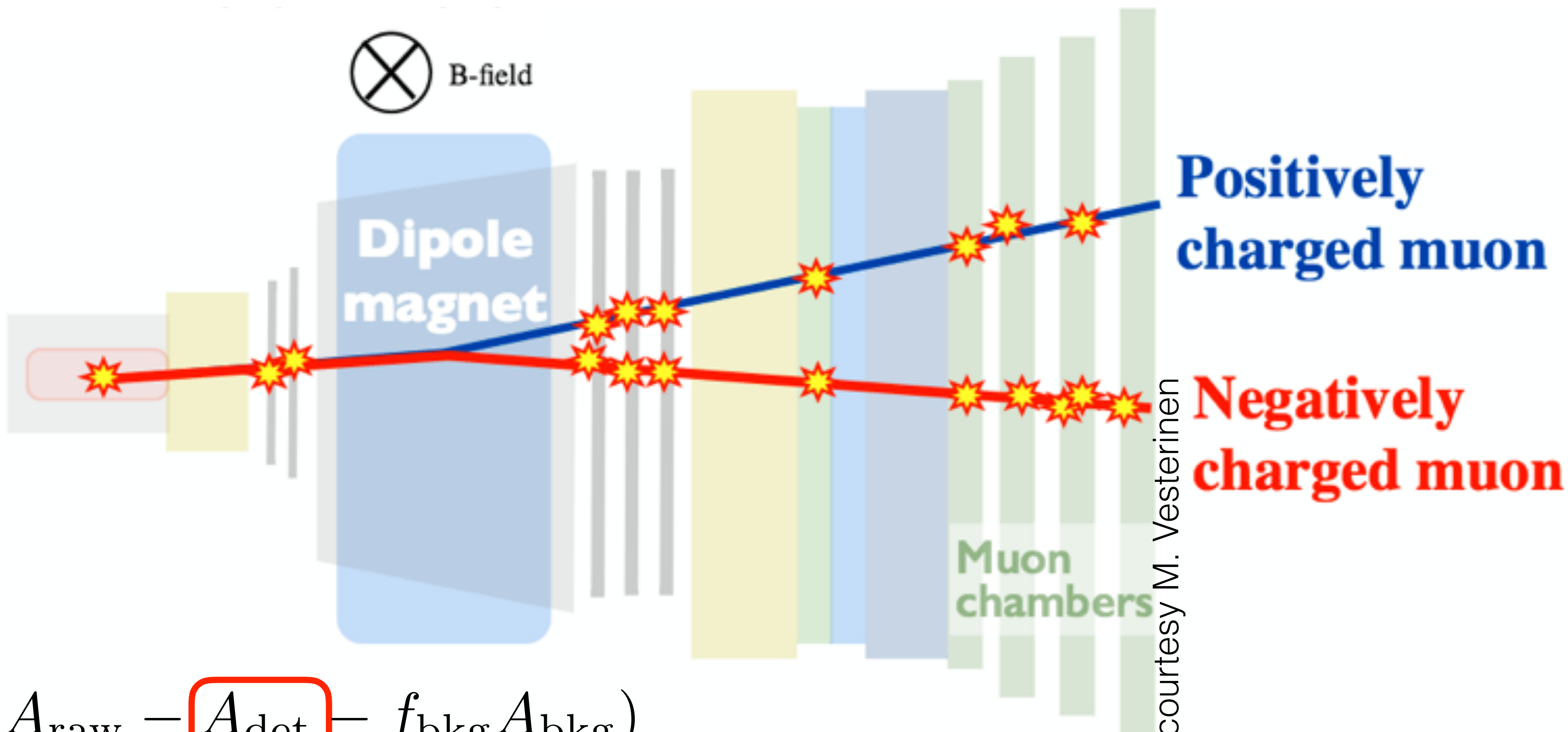


$$\frac{a_{\rm sl}^s}{2} = \frac{1}{1 - f_{\rm bkg}} (A_{\rm raw} - A_{\rm det} - f_{\rm bkg} A_{\rm bkg})$$

Detection Asymmetries

$$A_{\text{det}} = \frac{\varepsilon(f) - \varepsilon(\bar{f})}{\varepsilon(f) + \varepsilon(\bar{f})}$$

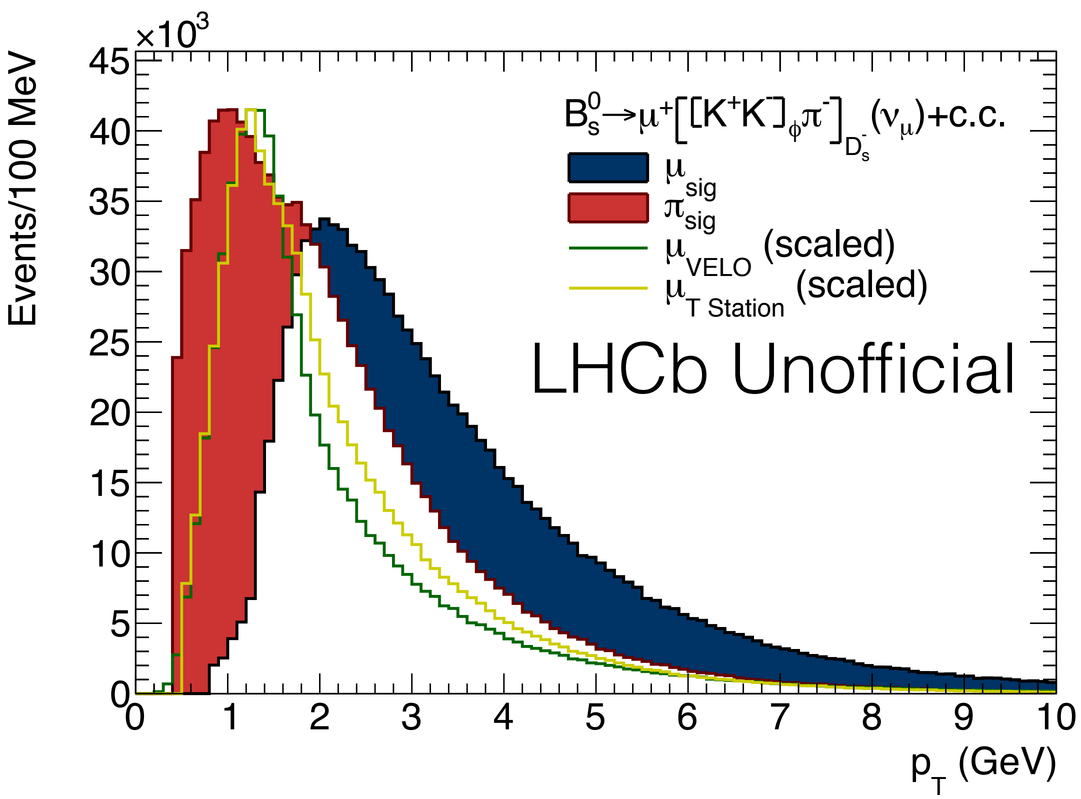
- largely measured by reversing magnet polarity
- measure the remaining asymmetry using data-driven methods

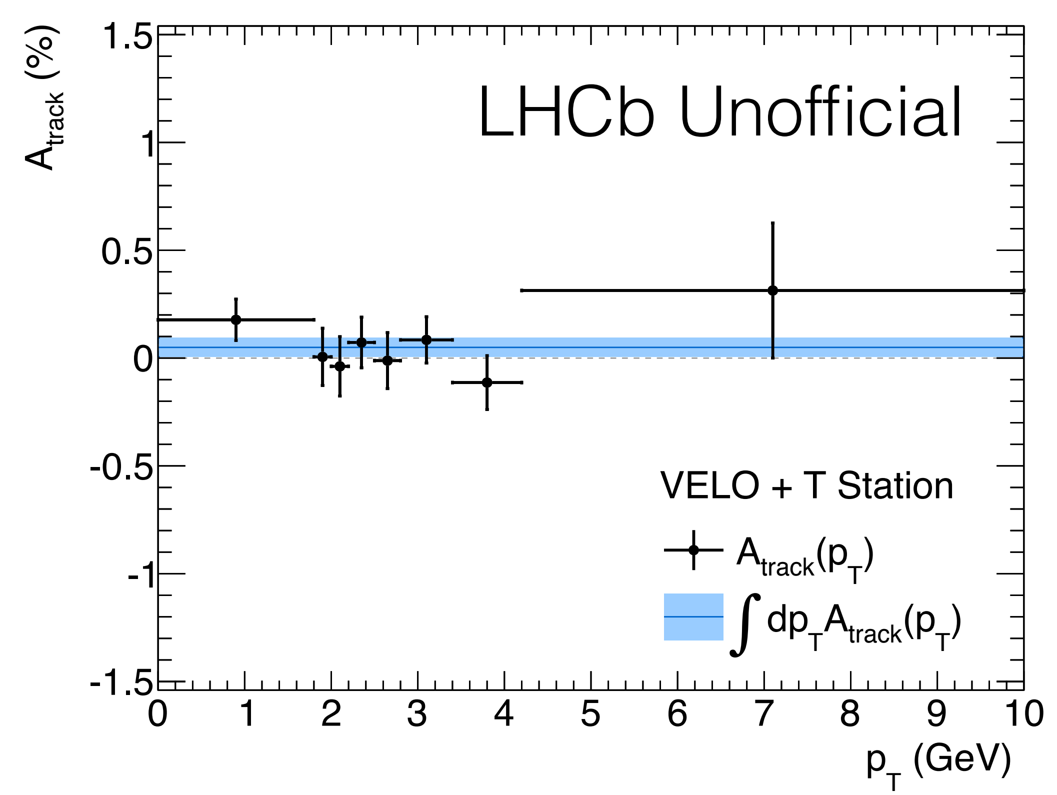


$$\frac{a_{\text{sl}}^s}{2} = \frac{1}{1 - f_{\text{bkg}}}(A_{\text{raw}} - A_{\text{det}} - f_{\text{bkg}} A_{\text{bkg}})$$

Example of Detection Asymmetry: $A_{\mu\pi}$ track using $J/\psi \rightarrow \mu^+\mu^-$

$$A^{\mu\pi}_{\text{track}} = \int d\Phi \, \left(\mathcal{P}^{\mu_{\text{sig}}}(\Phi) - (\mathcal{P}^{\pi_{\text{sig}}}(\Phi)\right) A_{\text{track}}(\Phi)$$



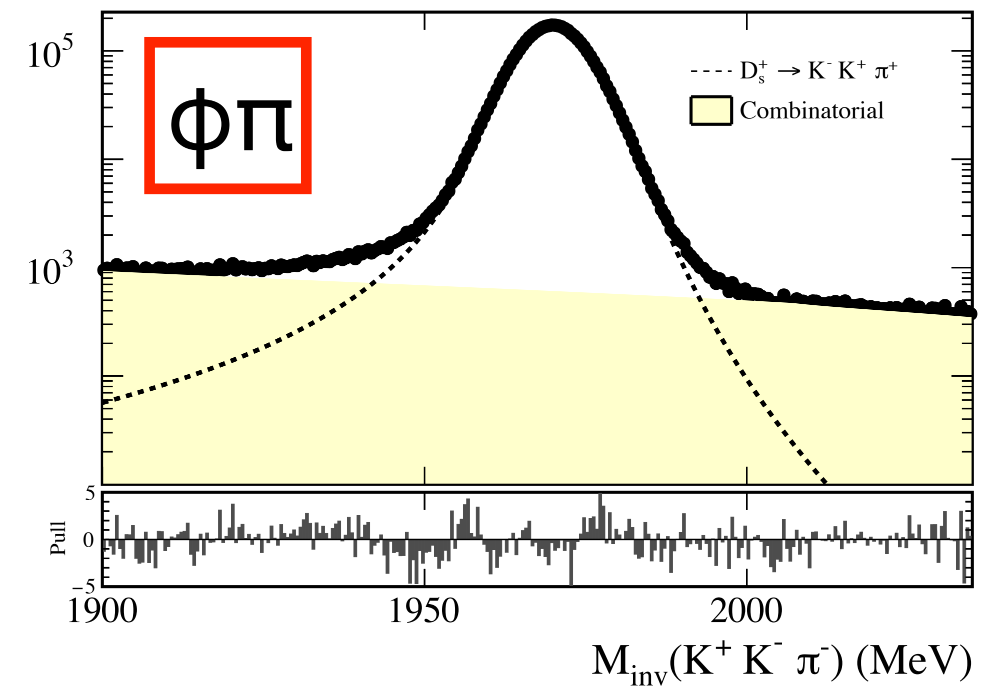


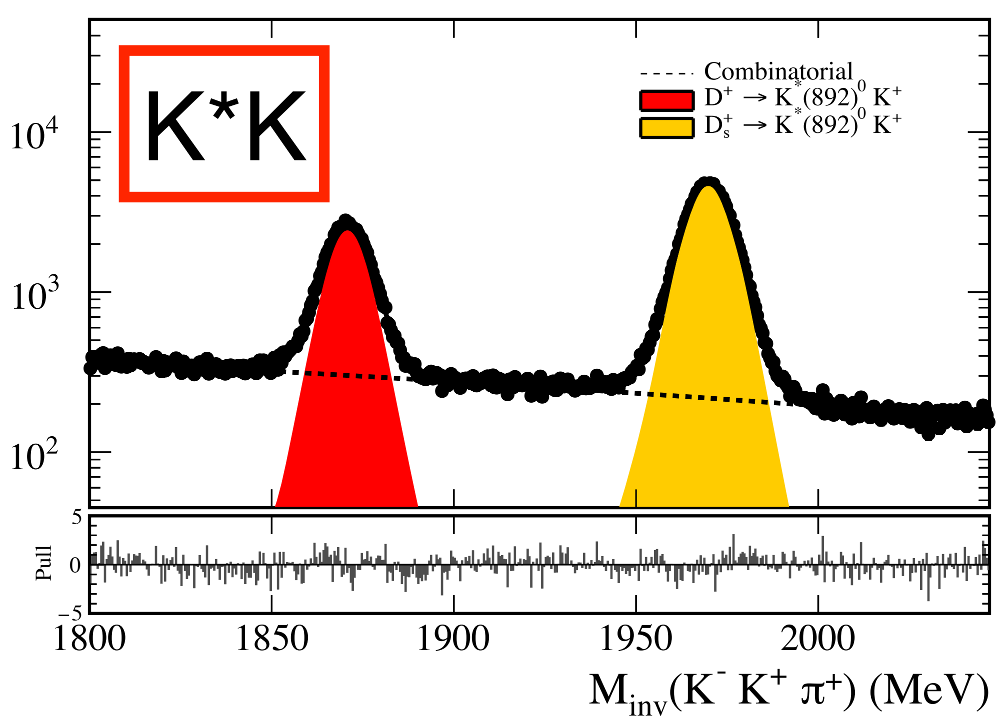
Similar for $A_P(Ds)$

Signal Extraction

Prompt:

$$A_P(D_s^+) = \frac{1}{1 - f_{\rm bkg}}\left(A_{\rm raw} - A_D - f_{\rm bkg} A_P(B)\right)$$





From Bs:

$$\frac{a_{\rm sl}^s}{2} = \frac{1}{1 - f_{\rm bkg}}\left(A_{\rm raw} - A_{\rm det} - f_{\rm bkg} A_{\rm bkg}\right)$$

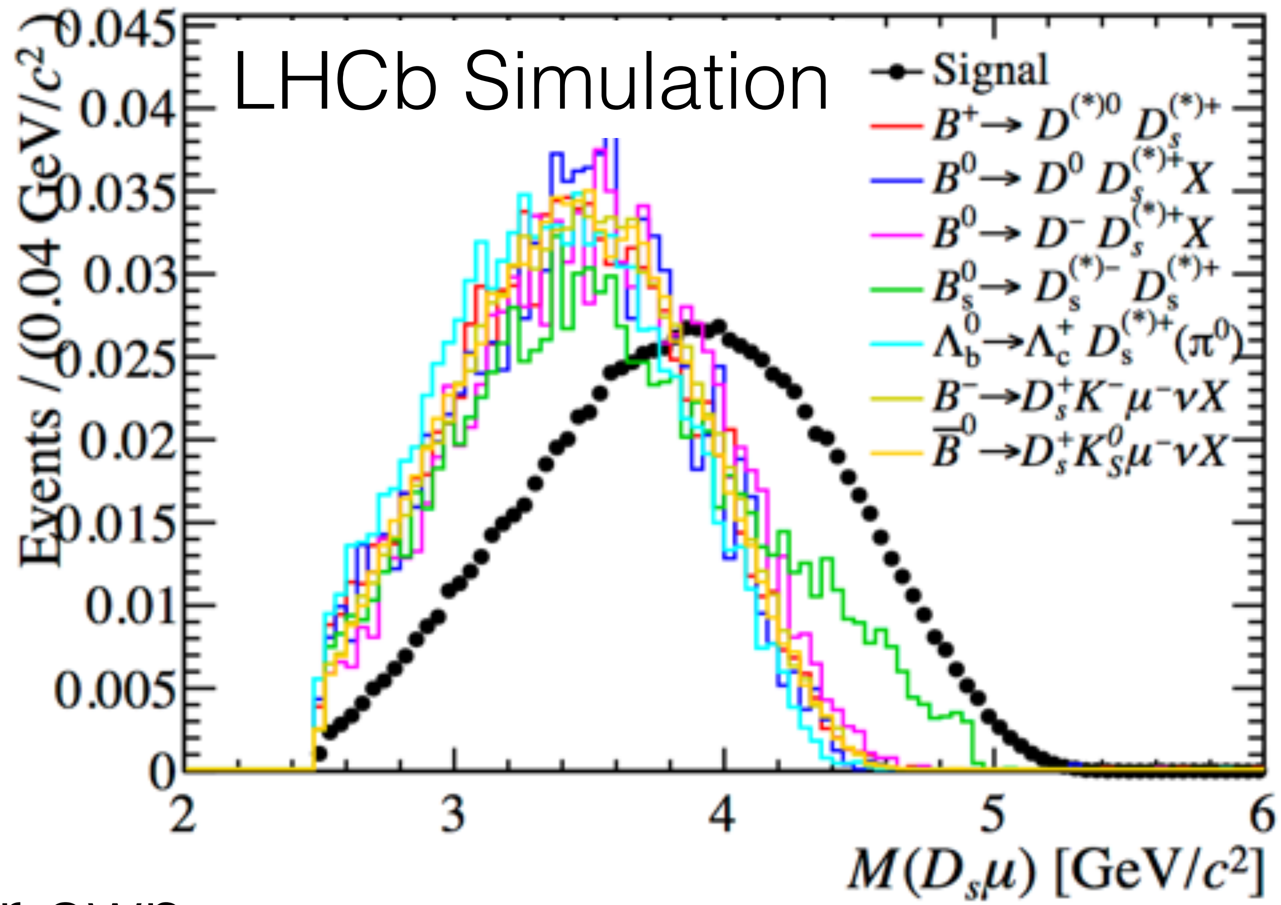
→ very clean signal

Background Contributions and Asymmetries for $a_{\rm sl}^s$

$B_s \to D_s (\to K K \pi) \mu \nu_\mu$

Backgrounds from:

- prompt D_s decays
- double D decays
- b-hadron decays



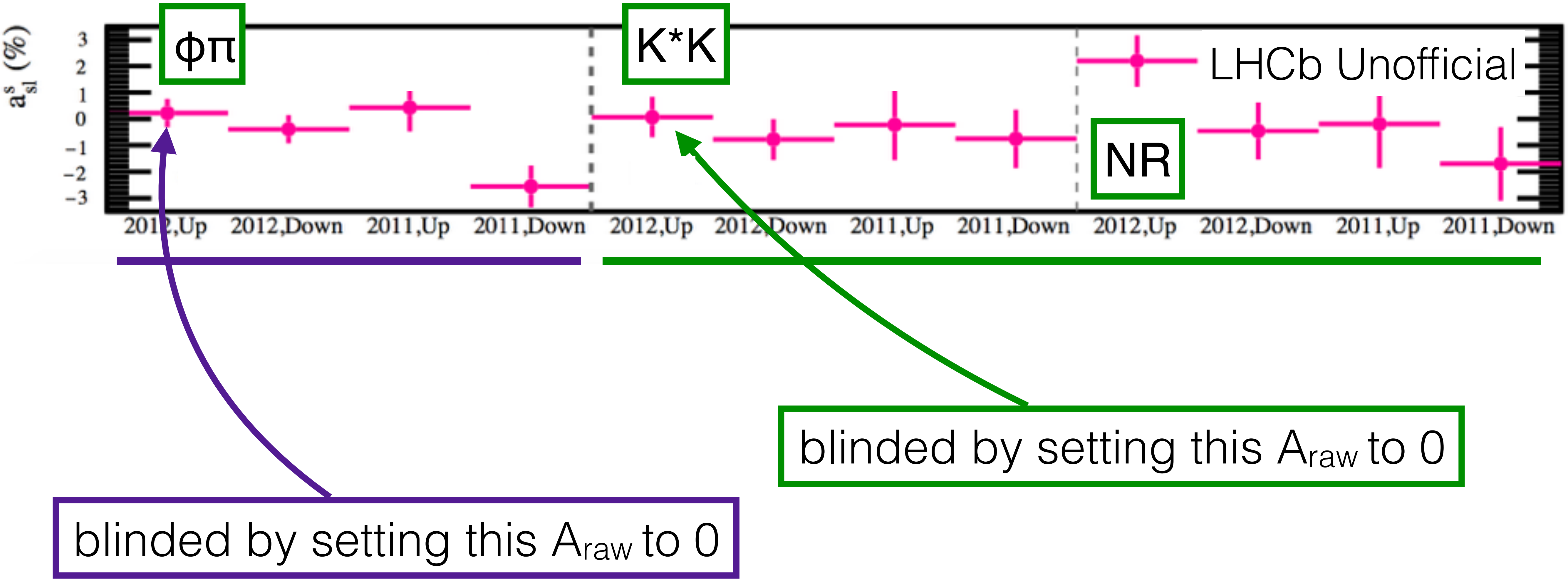
These backgrounds come with their own asymmetries, which need to be corrected

$$\frac{a_{\rm sl}^s}{2} = \frac{1}{1-f_{\rm bkg}}(A_{\rm raw} - A_{\rm det} - f_{\rm bkg}A_{\rm bkg})$$

$$f_{\rm bkg}A_{\rm bkg} = (-0.037 \pm 0.028)\%$$

$$\frac{1}{1-f_{\rm bkg}} = 1.23 \pm 0.09$$

Preliminary blinded results of $a_{\rm sl}^s$



$$a_{\rm sl}^s = (XX \pm 0.26({\rm stat}) \pm 0.18({\rm syst})\%$$

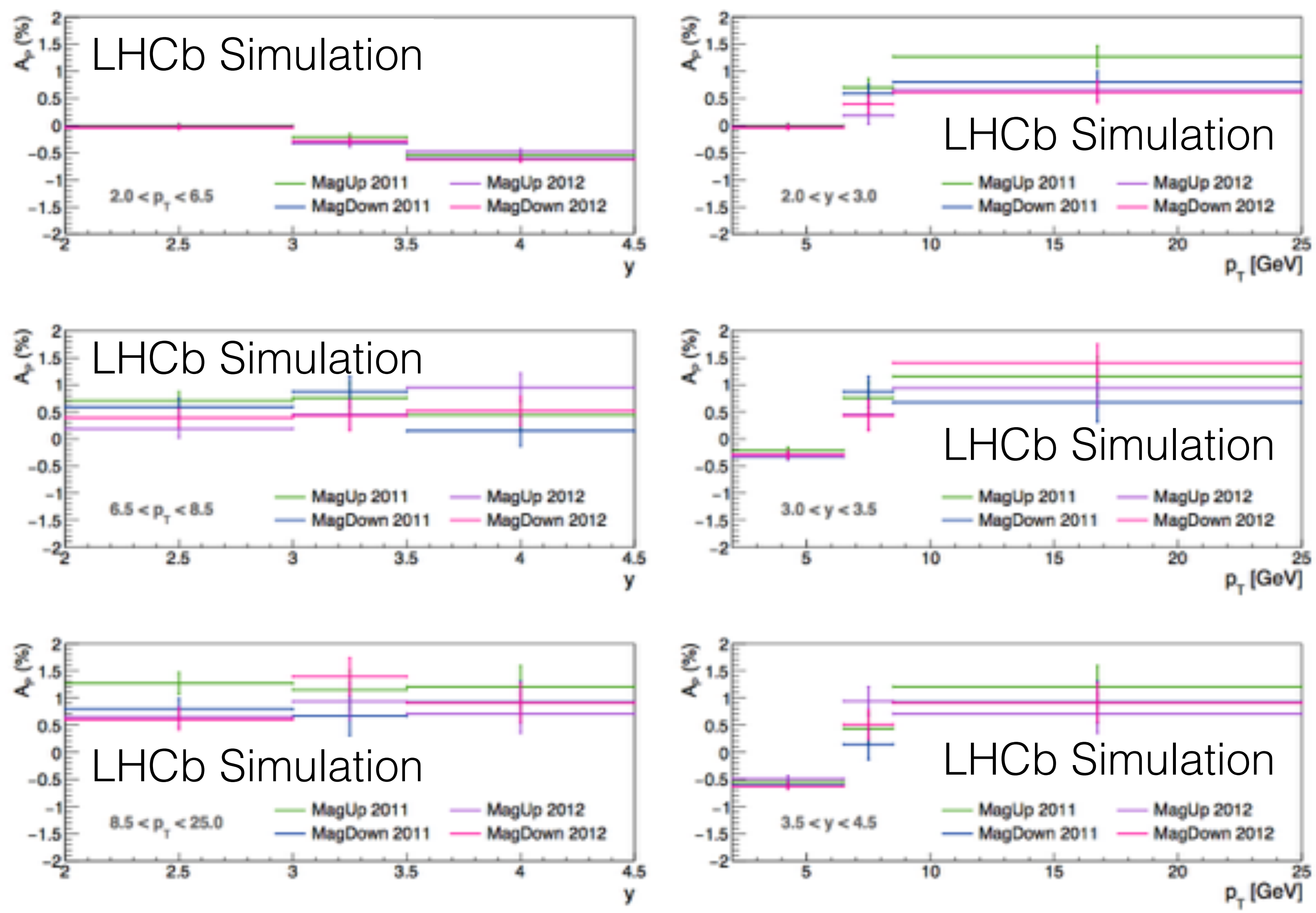
Background Contributions and Asymmetries for $A_P(D_s^+)$

	$f_{\rm bkg}$ [%]	$A_P(B)$ [%]	sign(A_P)	$f_{\rm bkg}A_P(B)$ [$\times 10^{-4}$]
B^+	0.63 ± 0.18	-0.3 ± 0.5	$-$	0.18 ± 0.30
B^-	0.09 ± 0.04	-0.3 ± 0.5	$+$	-0.03 ± 0.04
B^0	0.81 ± 0.26	-0.2 ± 0.1	$-$	0.16 ± 0.10
$\overline{B}^0$	0.20 ± 0.21	-0.2 ± 0.1	$+$	-0.04 ± 0.05
$\overline{B}^0_s$	2.01 ± 0.21	0.0 ± 0.0	$+$	0.00 ± 0.00
Λ_b^0	0.43 ± 0.11	-0.9 ± 1.5	$+$	-0.39 ± 0.72
Total	4.18 ± 1.42	-	-	-0.11 ± 0.72

→ Very small

Comparing to MC predictions

- Generator level MC also includes a non-zero production asymmetry
- Will compare this to our measurement

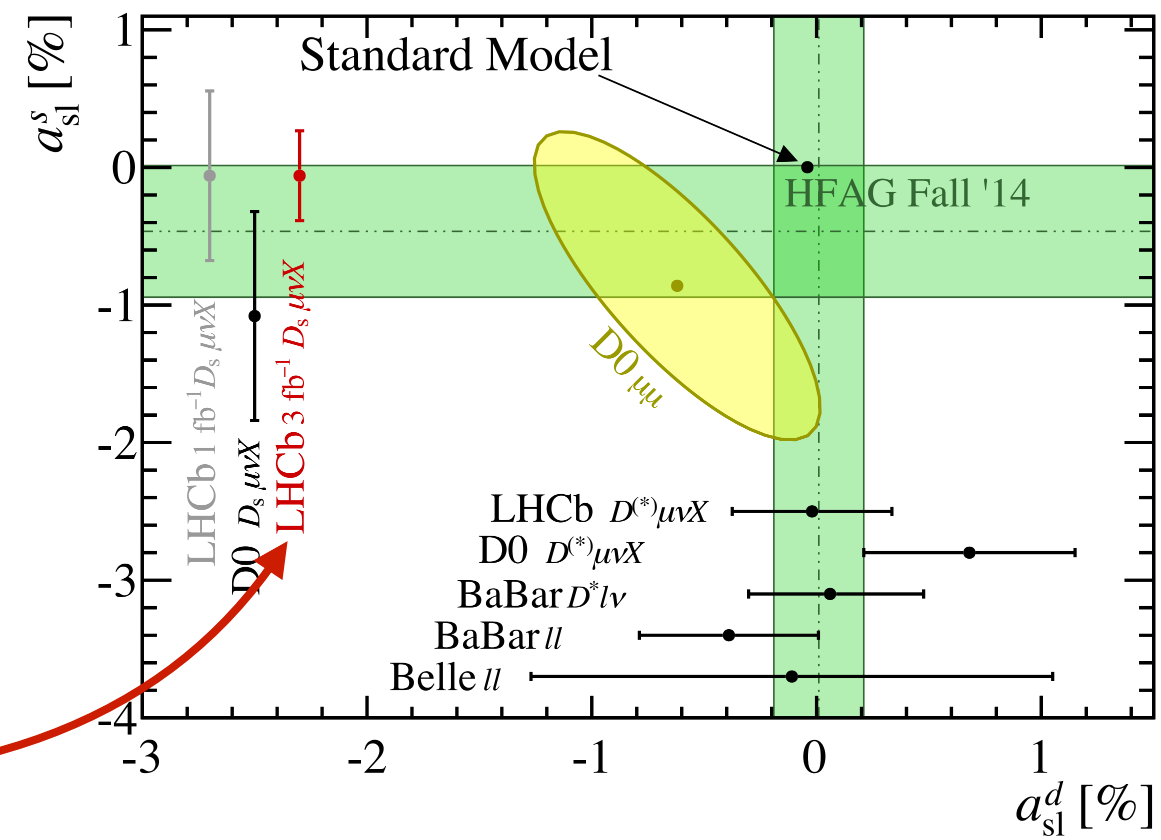


Conclusion and Outlook

- World's most precise measurement of $a_{\rm sl}^s$ is coming soon

- Measurement of $A_P(D_s^+)$ around the same time

- Expected 0.26% statistical and 0.18% systematic uncertainty for $a_{\rm sl}^s$



Projection of outcome with same asymmetry as before, but uncertainties of current analysis

Back-Up

Selection and Reflection Vetoes

Selection for $a_{\rm sl}^{s}$

Dalitz regions		
$\phi\pi$	$\lvert m(KK) - 1020\,\text{MeV}\rvert < 20\,\text{MeV}$	
$K^{*}K$	$\lvert m(KK) - 1020\,\text{MeV}\rvert > 20\,\text{MeV}$ and $\lvert m(K^{-}\pi^{+}) - 892\,\text{MeV}\rvert < 90\,\text{MeV}$	
NR	$\lvert m(KK) - 1020\,\text{MeV}\rvert > 20\,\text{MeV}$ and $\lvert m(K^{-}\pi^{+}) - 892\,\text{MeV}\rvert > 90\,\text{MeV}$	
Trigger and global		
runNumber	$!\in [110000, 114000]$	
L0 TOS	μ is L0Muon TOS	
Hlt1 TOS	μ is Hlt1TrackMuon TOS	
	OR B is Hlt1TrackAllL0 TOS	
Hlt2 TOS	B is B_Hlt2TopoMu(2|3|4)BodyBBDT TOS	
	OR μ is Hlt2SingleMuon TOS	
Candidate		
$z(D_s) - z(D_s\mu)$	> 0.0 mm	
D_s log(IP)	> -3.0	
B_s M_{corr}	$> 4200]$ MeV	
B_s Mass	$< 5200]$ MeV	
D_s Mass	$\in [1900, 2040]$ MeV	
Final state particles		
muon P_T	> 1.2 GeV	
muon P	> 6.0 GeV	
pion P_T	> 400 MeV	
pion P	> 5.0 GeV	
same-sign kaon $probNNk$	> 0.1	$\phi\pi$
same-sign kaon $probNNk$	> 0.15	$K^{*}K$, NR

Reflection Vetoes for a_{sl}^{s}

Vetoes	Veto if	Applied to
J/ψ veto	π^+ isMuon AND $3042 < m(\pi^+_\mu \mu^-) < 3147$ MeV	$\phi\pi$, K^*K, NR
J/ψ veto	K^+ isMuon AND $3042 < m(K^+_\mu \mu^-) < 3147$ MeV	K^*K, NR
Λ_c^+ veto	K^+ PIDp-PIDK > -0.0 AND $2261 < m(K^+_p K^- \pi^+) < 2315$ MeV	$\phi\pi$
Λ_c^+ veto	K^+ PIDp-PIDK > -15.0 AND $2261 < m(K^+_p K^- \pi^+) < 2315$ MeV	K^*K, NR
$K^*(892)^0$ veto	K^+ PIDK < 8 AND $\lvert m(K^+_\pi K^-) - 892\rvert < 25$ MeV	K^*K, NR
D^+ veto	K^+ PIDK < 30 AND $\lvert m(K^+_\pi K^- \pi^+) - 1870\rvert < 20$ MeV	K^*K, NR
Misid $K^+(D_s^+) \to \pi^+$ low mass	K^+ PIDK < 7 AND $m(K^+{}_\pi K^-) < 800$ MeV	K^*K, NR
$B \to D^*(\to D^0\pi)\mu\nu$ veto	$m(K^+_\pi K^- \pi^+) - m(K^- \pi^+) < 175$ MeV	$K^*(892)^0 K^\pm, (K^+K^-\pi^\pm)_{\mathrm{NR}}$
$B \to D^*(\to D^0\pi)\mu\nu$ veto	$m(K^+ K^-_\pi \pi^+) - m(K^+ \pi^+) < 175$ MeV	$K^*(892)^0 K^\pm, (K^+K^-\pi^\pm)_{\mathrm{NR}}$
$D^{*+} \to D^0(K^+K^-)\pi^+$	$135 < m(K^+K^-\pi^+) - m(K^+K^-) < 152$ MeV	NR

Reflection Vetoes Example

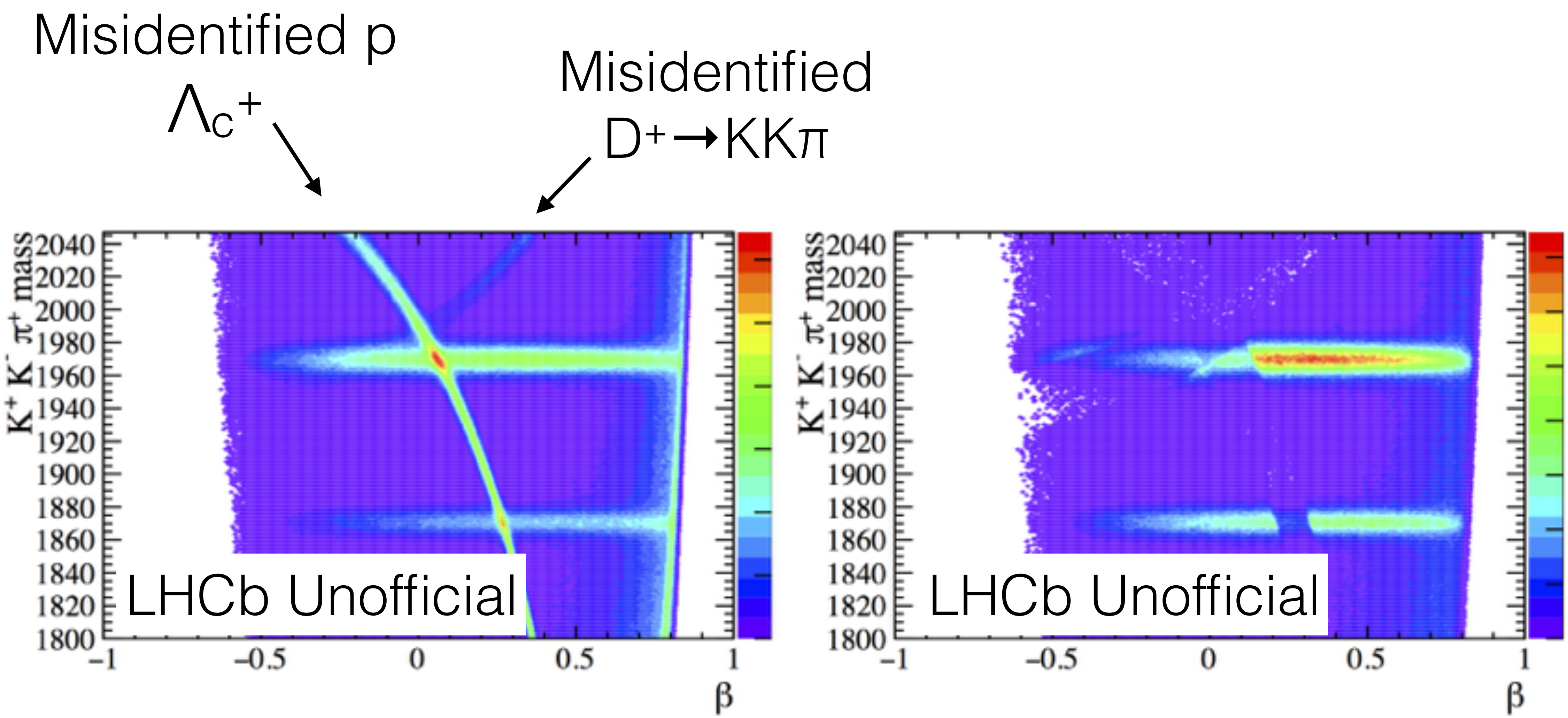


Figure 14: The $(M_{D_s^+}, \beta)$ spectrum for the 2012 + 2011 MagUp & MagDown dataset, selecting events for which the opposite-sign kaon and pion are candidates for the KstarK region, without (left) and with (right) reflection vetoes.

Selection for $A_P(D_s^+)$

- L0 Global_TIS
- HLT1 TrackAllL0_TOS
- HLT2 CharmHadD2HHH
- Stripping D2hhh_KKPLine

	Variable	Cut
Global	runNumber	$!\in [110000, 114000]$
Pions	p_T	> 400 MeV
	p	> 5.0 GeV
	Track GhostProb	< 0.5
Kaons	Track GhostProb	< 0.5
D_s	DOCA χ^2	< 30
	Vertex χ^2/DOF	< 8.0
	M	$\in [1900, 2035]$ MeV

Reflection Vetoes $A_P(D_s^+)$

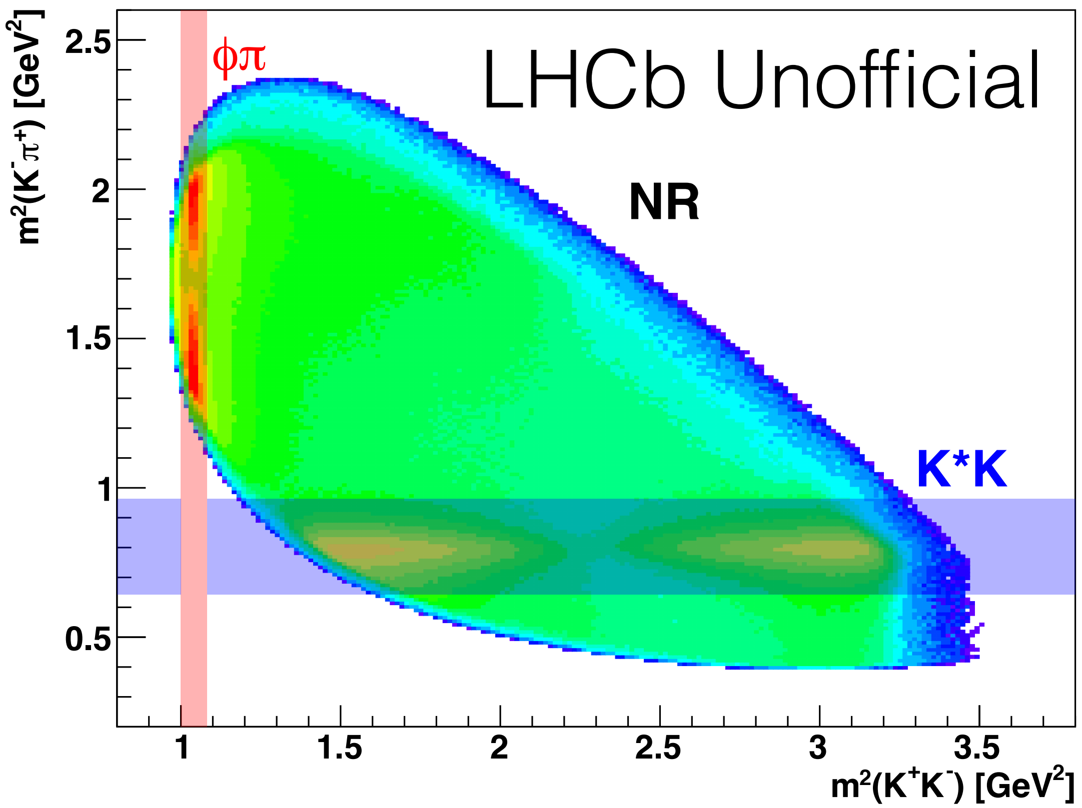
Table 49: Reflection vetoes applied to the prompt Ds sample.

Vetoes	**Veto if**	**Applied to**
ProbNNk	K^+ ProbNNk < 0.10	$\phi\pi$
Λ_c^+ veto	K^+ PIDp-PIDK > 0.0 AND $2261 < m(K_p^+ K^- \pi^+) < 2315\,\text{MeV}$	$\phi\pi$
D^+ veto	K^+ PIDK < 20 AND $\lvert m(K_\pi^+ K^- \pi^+) - 1870\rvert < 20$ MeV	$\phi\pi$
$D^{*+} \to D^0(K^+K^-)\pi^+$	$135 < m(K^+K^-\pi^+) - m(K^+K^-) < 152$ MeV	$\phi\pi$, K^*K, NR
ProbNNk	K^+ ProbNNk < 0.15	K^*K, NR
$D^* \to D^0\pi$	$m(K_\pi^+ K^- \pi^+) - m(K^-\pi^+) < 175\,\text{MeV}$	K^*K, NR
$D^* \to D^0\pi$	$m(K^+ K_\pi^- \pi^+) - m(K_\pi^-\pi^+) < 175\,\text{MeV}$	K^*K, NR
Λ_c^+ veto	K^+ PIDp-PIDK > -15.0	K^*K, NR
	AND $2261 < m(K_p^+ K^- \pi^+) < 2315\,\text{MeV}$	
$K^*(892)^0$ veto	K^+ PIDK < 8 AND $\lvert m(K_\pi^+ K^-) - 892\rvert < 25$ MeV	K^*K, NR
D^+ veto	K^+ PIDK < 30 AND $\lvert m(K_\pi^+ K^- \pi^+) - 1870\rvert < 20$ MeV	K^*K, NR

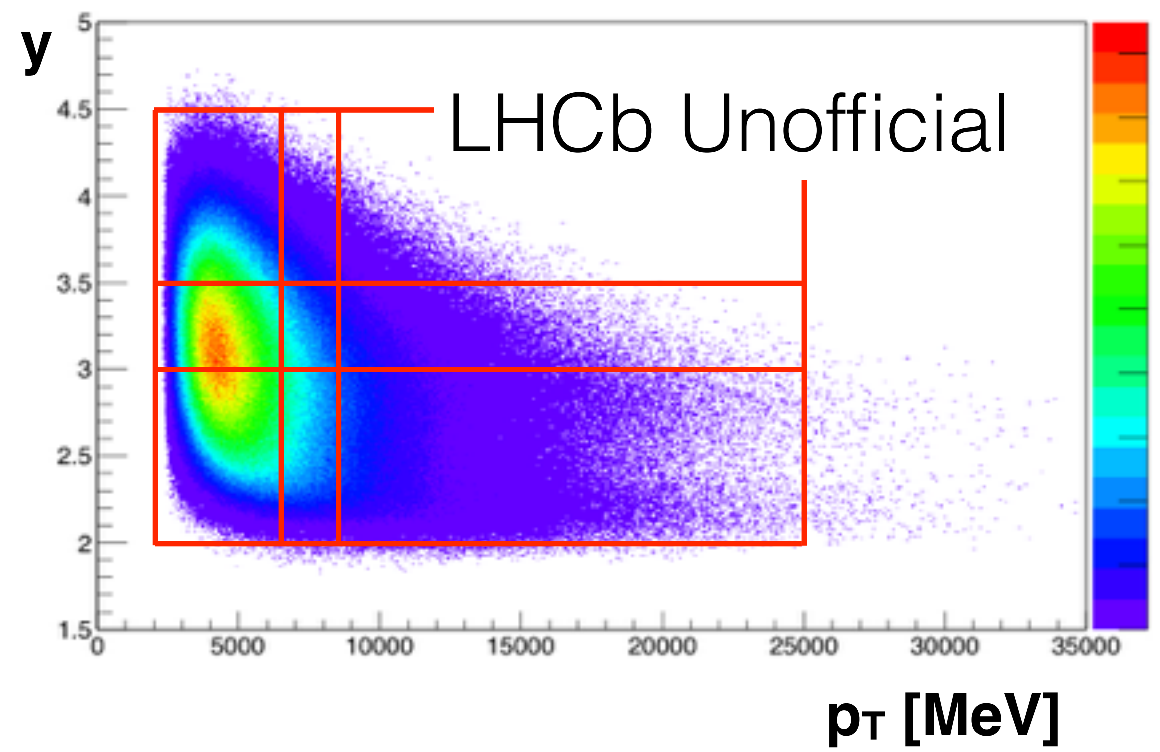
Signal Extraction

Splitting in bins of p_T and y

Same Dalitz regions:



Bins in p_T and y, same as for 2011 measurement:
Phys. Lett. B 713 (2012) 186-195



If the detection asymmetries and backgrounds are treated correctly: $A_P(D_s^+)$ is the same in each Dalitz region, within each (p_T,y) bin

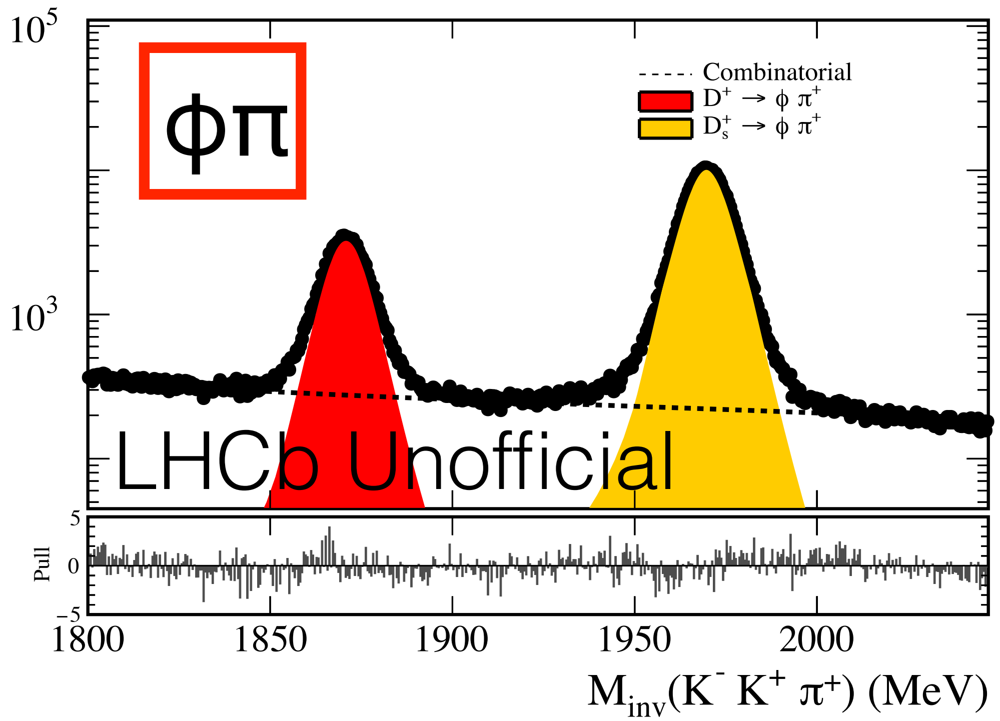
Measuring A_{raw} for a_{sl}^{s}

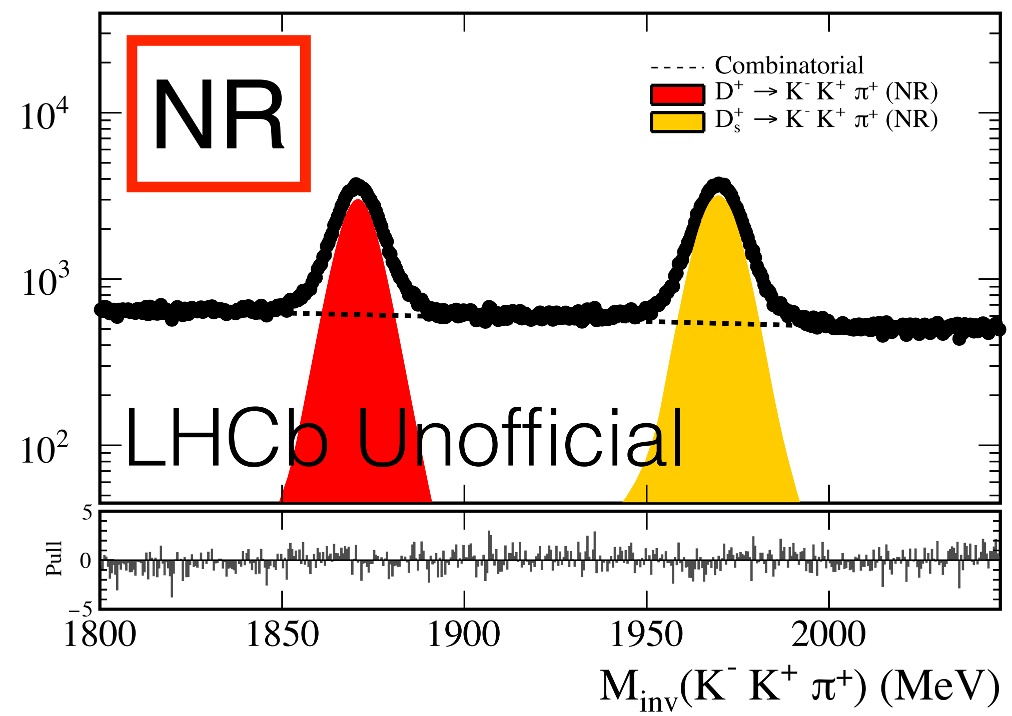
Two strategies:

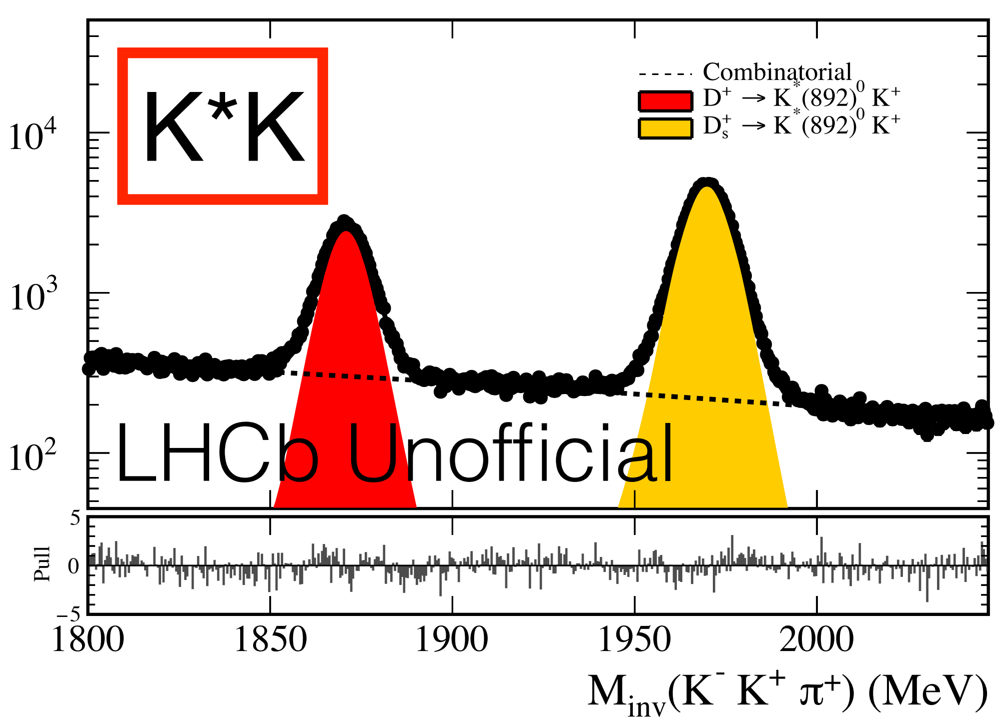
- $\phi\pi$ region: 2D fit in m($KK\pi$) and log(IP) in bins of p_{μ}
- $\phi\pi$, K^*K and NR: 1D fits in m($KK\pi$) + cut on log(IP)

  more signal, but in K^*K and NR regions also:
  → more combinatorial background
  → contributions from mis-ID Λ_C and D^+

Signal Extraction for $a_{\rm sl}^{s}$



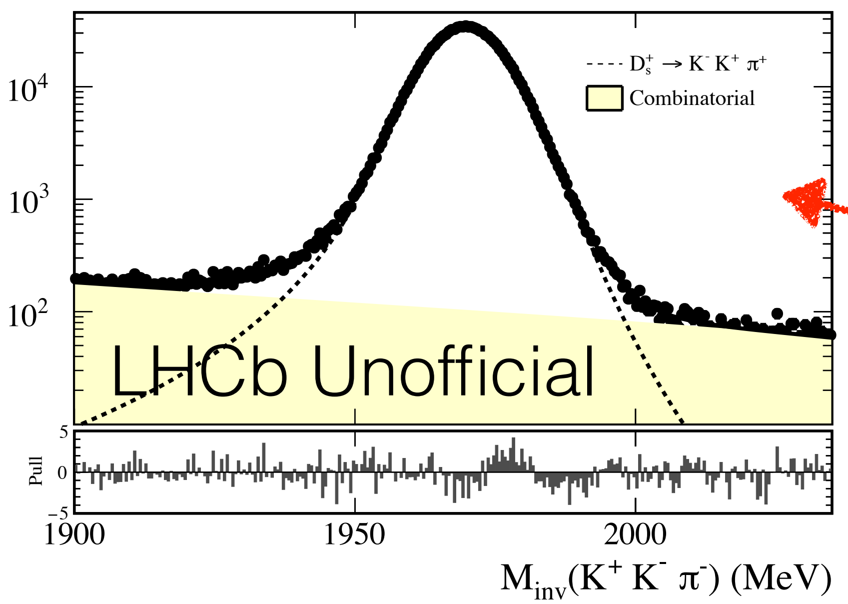


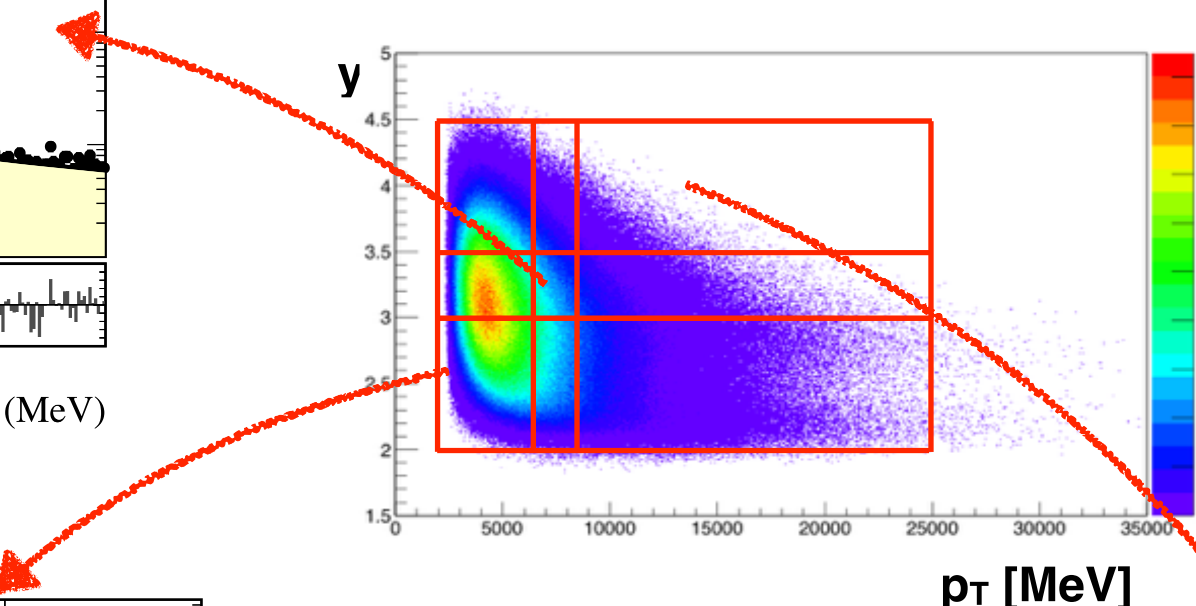


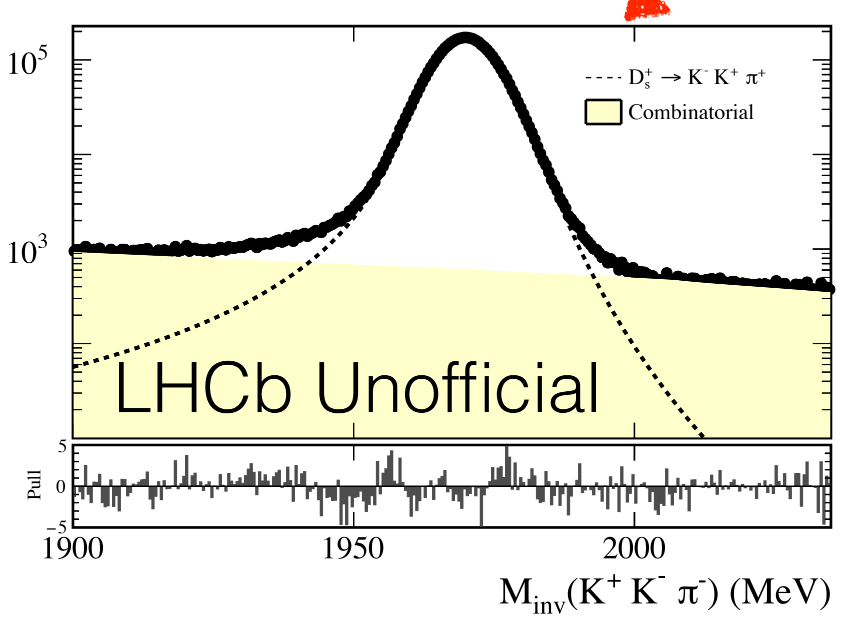
$$\frac{a_{\rm sl}^{s}}{2} = \frac{1}{1 - f_{\rm bkg}}\left(A_{\rm raw} - A_{\rm det} - f_{\rm bkg} A_{\rm bkg}\right)$$

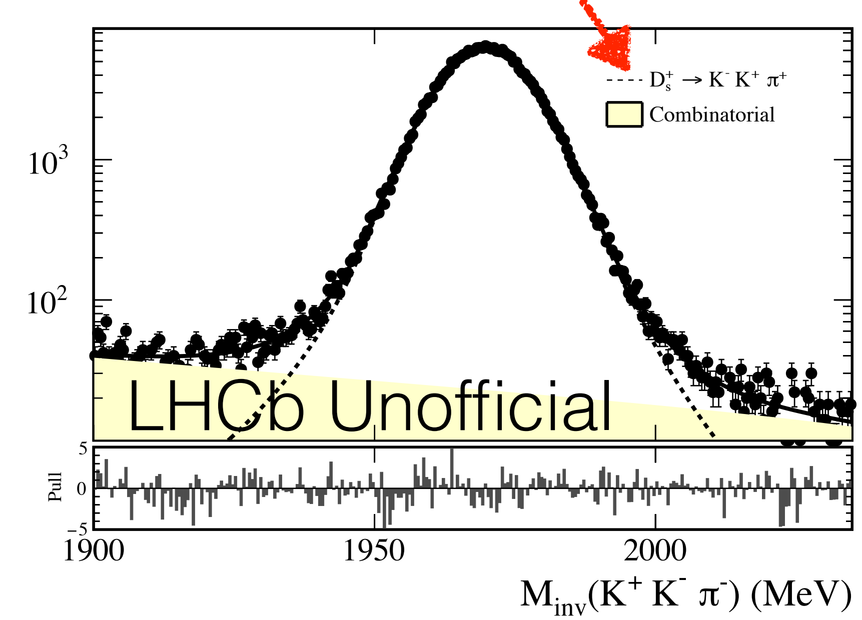
Signal Extraction for $A_P(D_s^+)$

$$A_P(D_s^+) = \frac{1}{1 - f_{\mathrm{bkg}}}\left(A_{\mathrm{raw}} - A_D - f_{\mathrm{bkg}} A_P(B)\right)$$





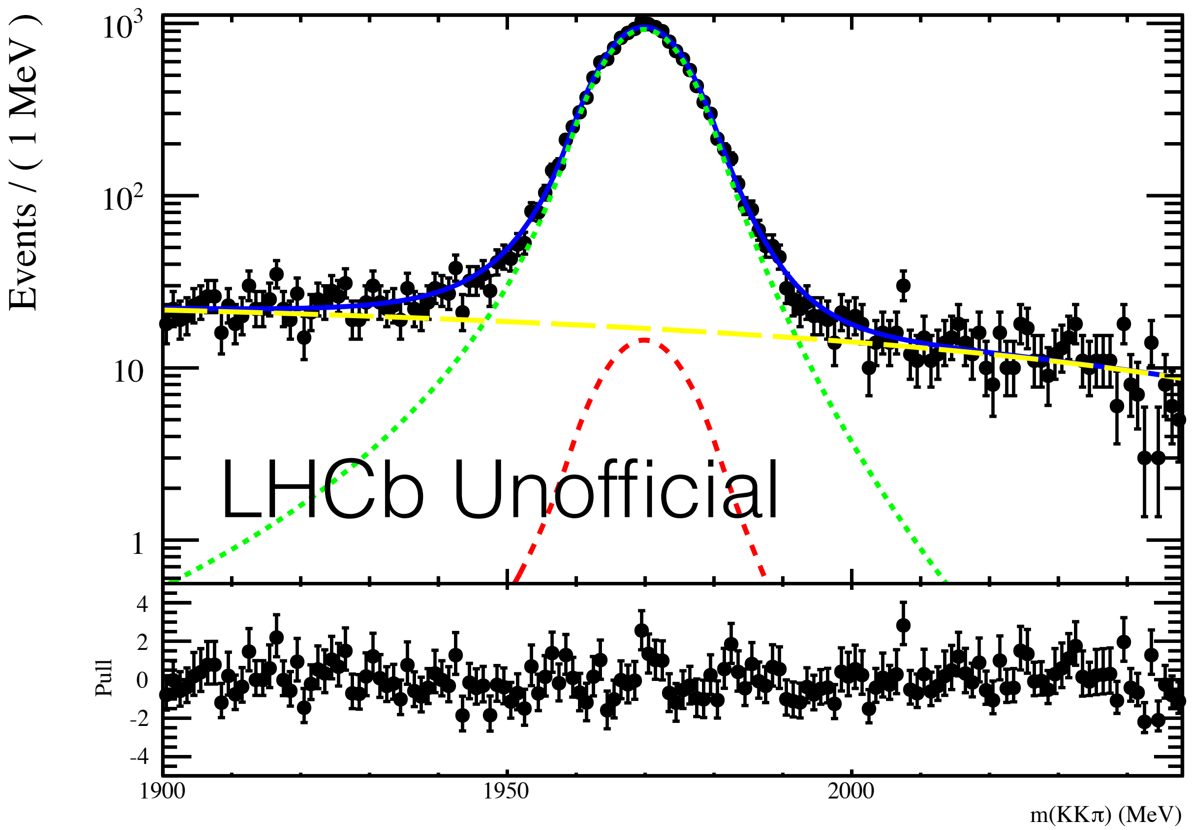




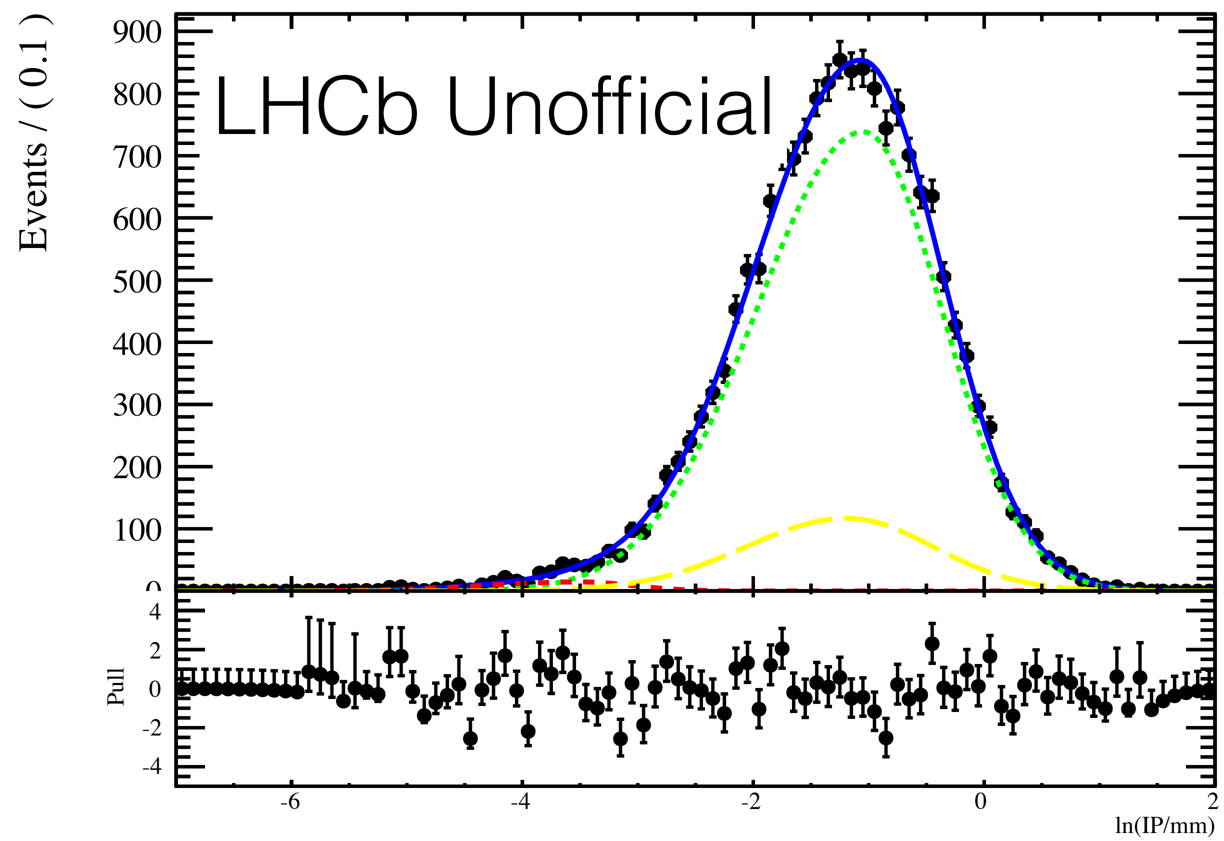
φπ 2D fit

fits in bins of muon momentum

m(KKπ)



log(IP)



Signal: DSCB
Secondaries: DSCB
Background: 2nd order Chebyshev

Signal: Bifurcated Gaussian
Secondaries: Bifurcated Gaussian
Background: Bifurcated Gaussian

Detection Asymmetries

Gathering all detection asymmetries

* Same for $A_P(D_s^+)$

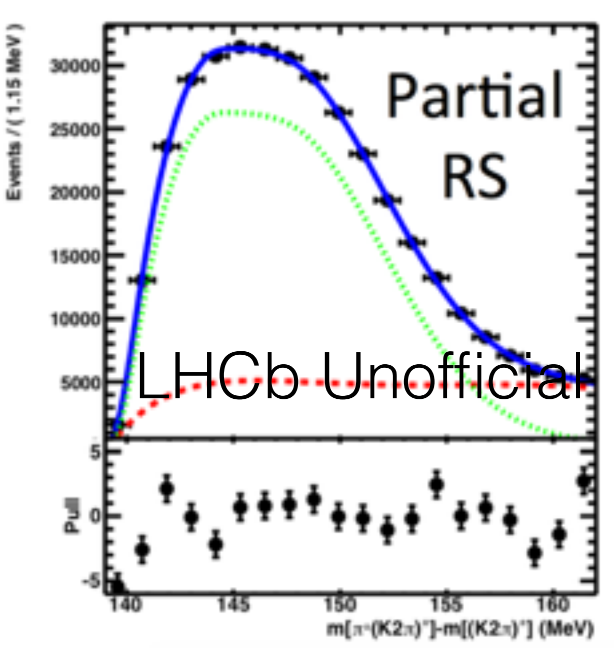
- A_{track} (μ and π): 3 methods
  - $J/\psi \rightarrow \mu\mu$
  - $D^* \rightarrow D^0 (\rightarrow K\pi\pi\pi)\ \pi_s$
  - $D^* \rightarrow D^0\pi$, ratio: $D^0 \rightarrow K\pi$ / $D^0 \rightarrow K\mu\nu$
- A_μ, using $J/\psi \rightarrow \mu\mu$
- A_{HLT1}, 2 trigger lines:
  - HLT1TrackMuon
  - HLT1TrackAllL0
- A_{KK}, using $A_{K\pi}$
- A_{PID}, using PIDcalib

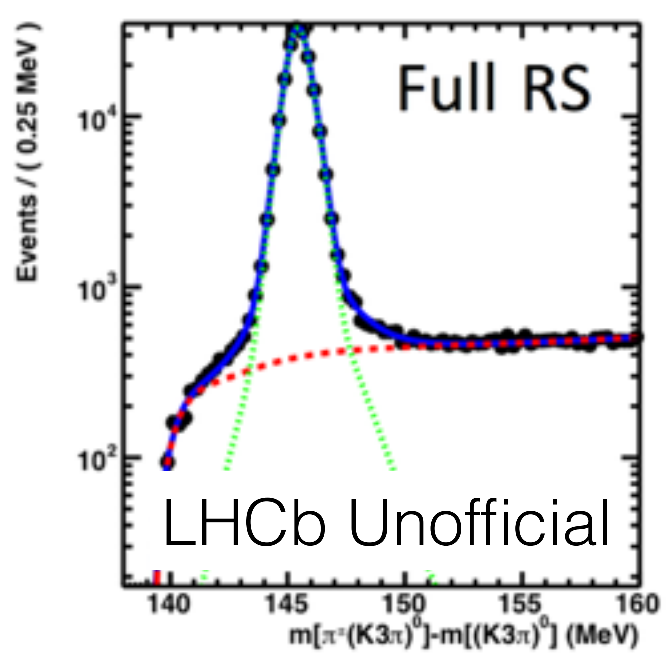
$A_{\mu\pi}$ track using $D^* \rightarrow D^0(\rightarrow K\pi\pi\pi)\pi_s$

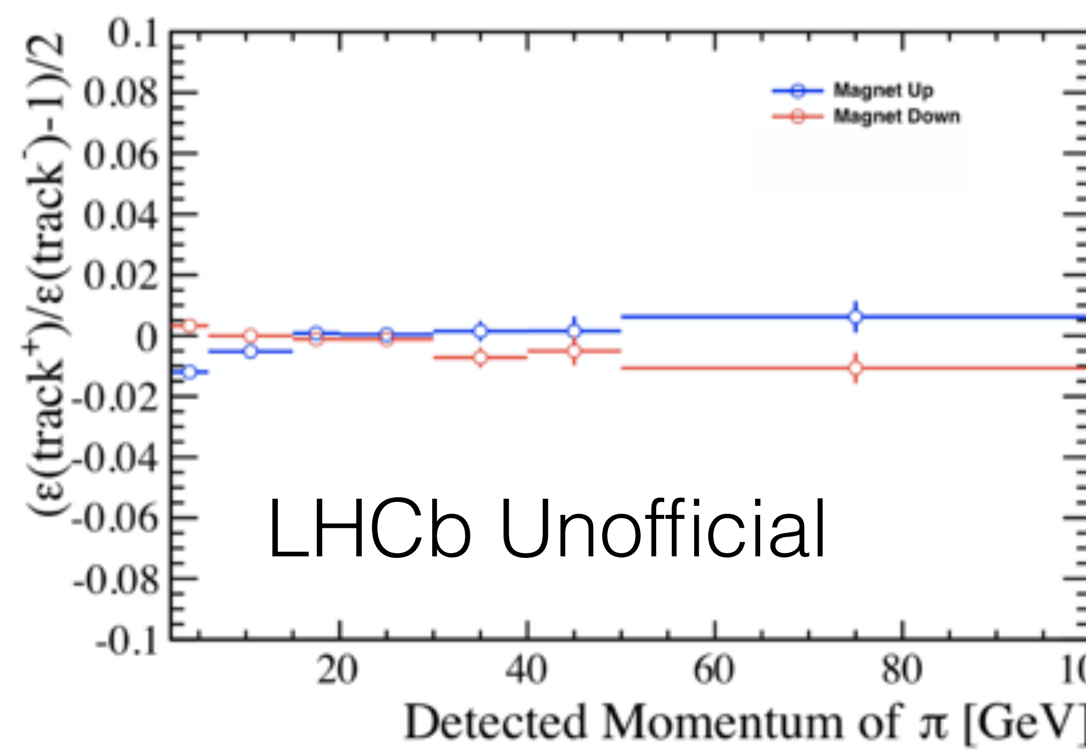
$$A^{\mu\pi}_{\text{track}} = \int d\Phi\ (\mathcal{P}^{\mu_{\text{sig}}}(\Phi) - (\mathcal{P}^{\pi_{\text{sig}}}(\Phi))\ A_{\text{track}}(\Phi)$$

Using: $D^* \rightarrow D^0(\rightarrow K\pi\pi\pi)\pi_s$

compare partially (missing π) and fully reconstructed decays



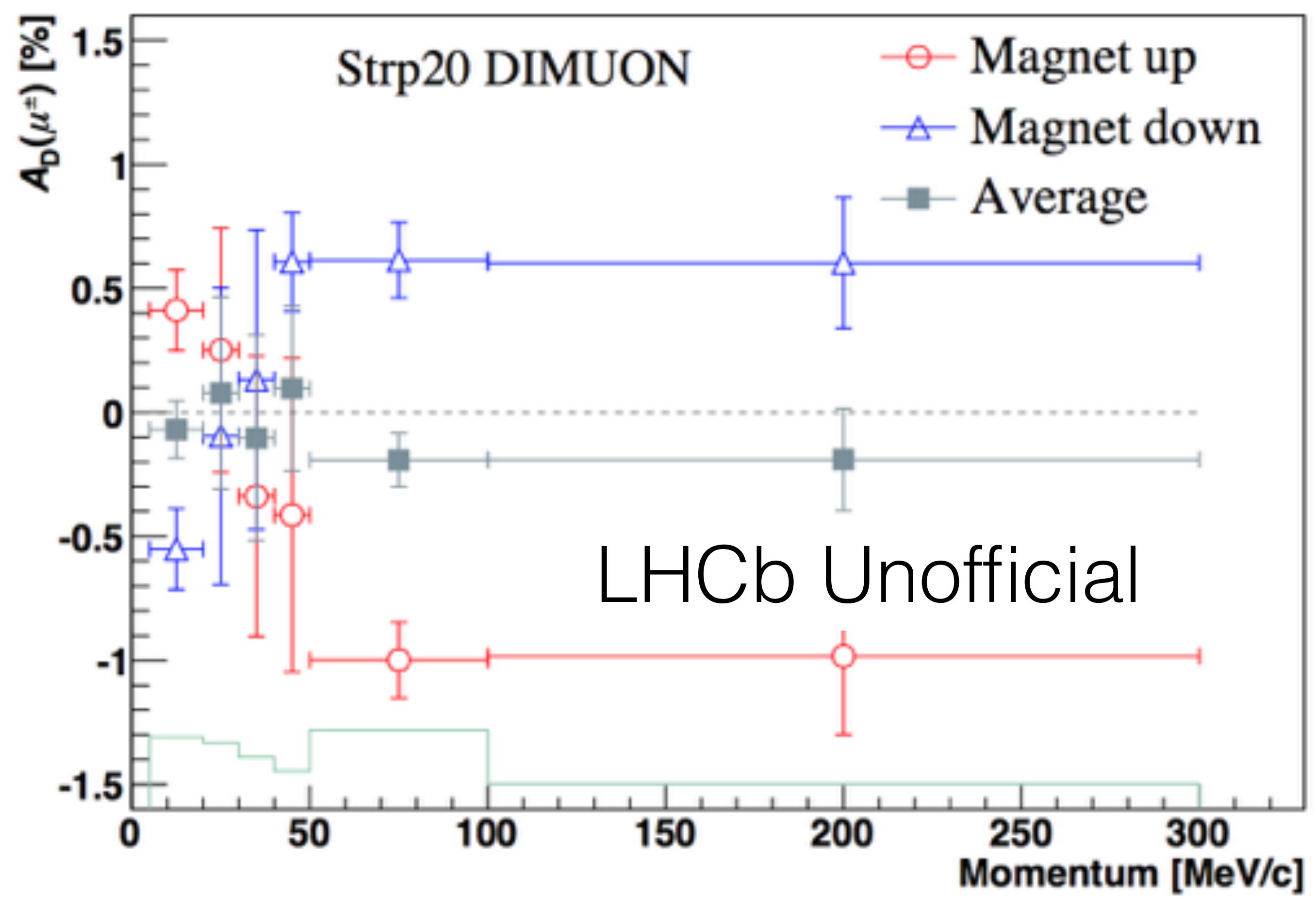




A_μ using $J/\psi \to \mu^+\mu^-$

tag-and-probe method using $J/\psi \to \mu^+\mu^-$ decays

Measures the μ ID, L0 and HLT1 asymmetry as a function of p and p_T



$$\boxed{A_{\mu\pi}} = A_{\mu\pi}^{\text{track}} + A_{\pi}^{\text{interaction}} + A_{\pi}^{\text{ID}} + A_{D^*}^{\text{L0Global\_TIS}} + A_{\mu}^{\text{ID}} + A_{\mu}^{\text{L0Muon\_TOS}} + A_{\mu}^{\text{Hlt1Muon\_TOS}}$$

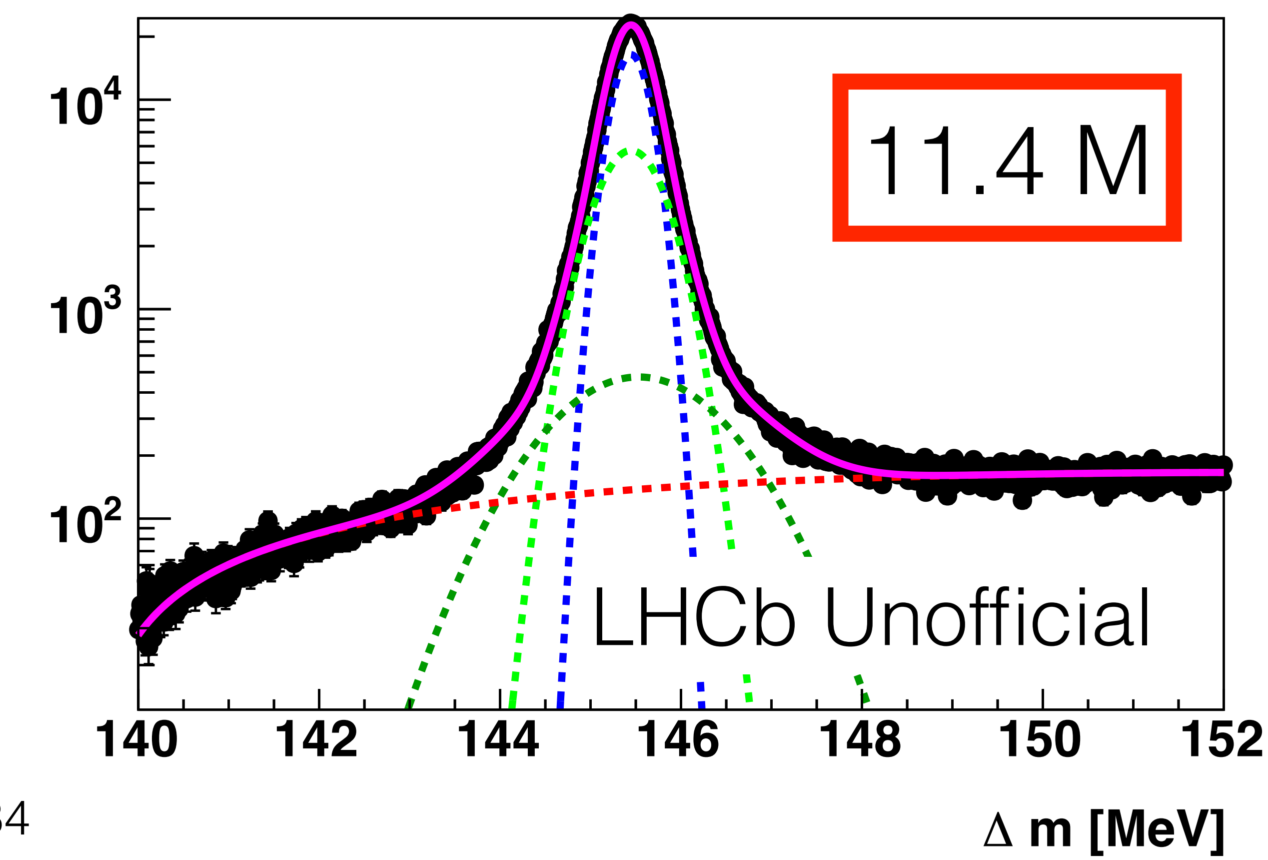
μπ Detection Asymmetries

- Efficiency ratios:

$$\frac{\varepsilon(\mu^+\pi^-)}{\varepsilon(\mu^-\pi^+)} = \frac{N(D^0 \to K^-\mu^+\nu_\mu)}{N(\overline{D}^0 \to K^+\mu^-\overline{\nu}_\mu)} \times \frac{N(\overline{D}^0 \to K^+\pi^-)}{N(D^0 \to K^-\pi^+)}$$

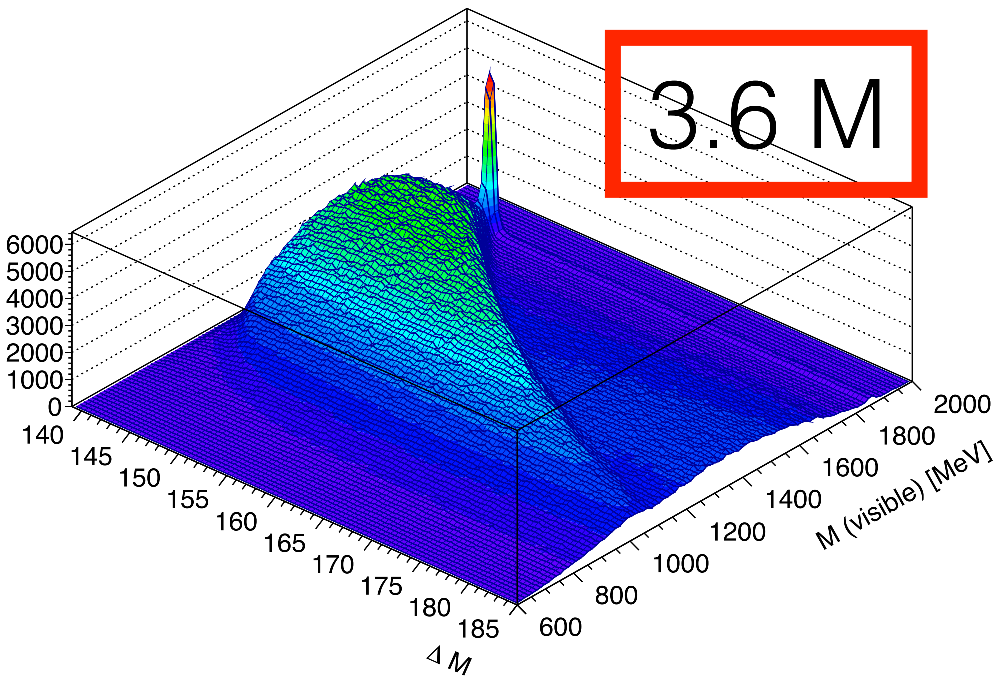
- Use ratio to cancel A_P (D*) and A_D (K)

Large samples for $D^* \to D^0 (\to K\pi)\pi_s$:

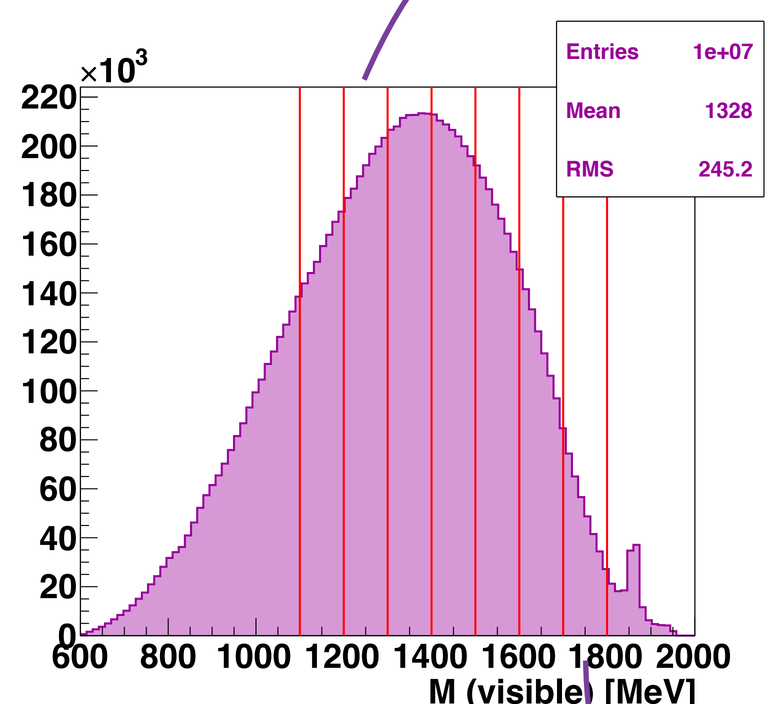


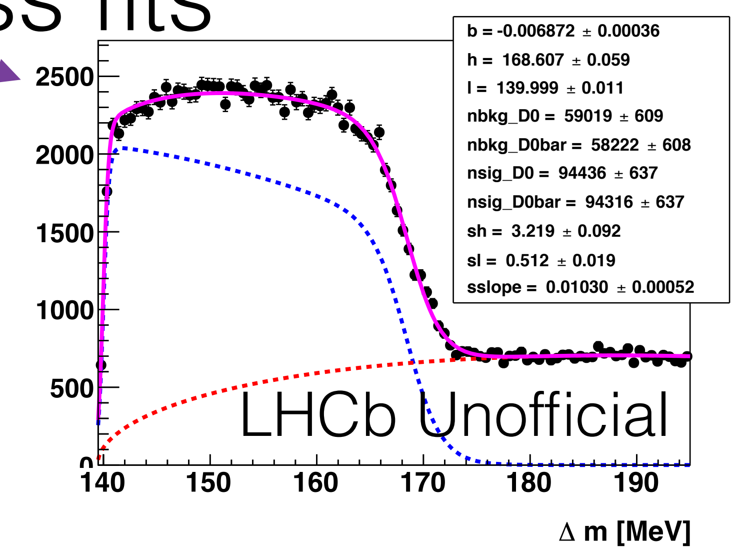
$$\boxed{A_{\mu\pi}} = A_{\mu\pi}^{\mathrm{track}} + A_{\pi}^{\mathrm{interaction}} + A_{\pi}^{\mathrm{ID}} + A_{D^*}^{\mathrm{L0Global\_TIS}} + A_{\mu}^{\mathrm{ID}} + A_{\mu}^{\mathrm{L0Muon\_TOS}} + A_{\mu}^{\mathrm{Hlt1Muon\_TOS}}$$

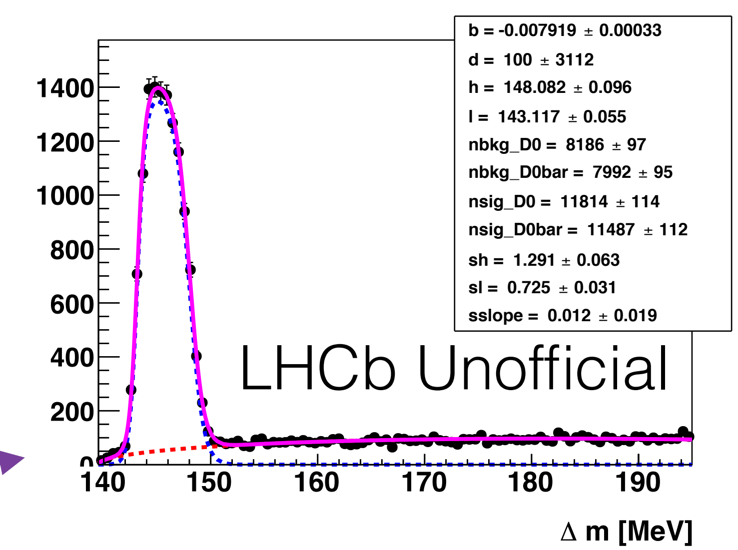
μπ Detection Asymmetries



Split in bins of visible mass to make mass fits



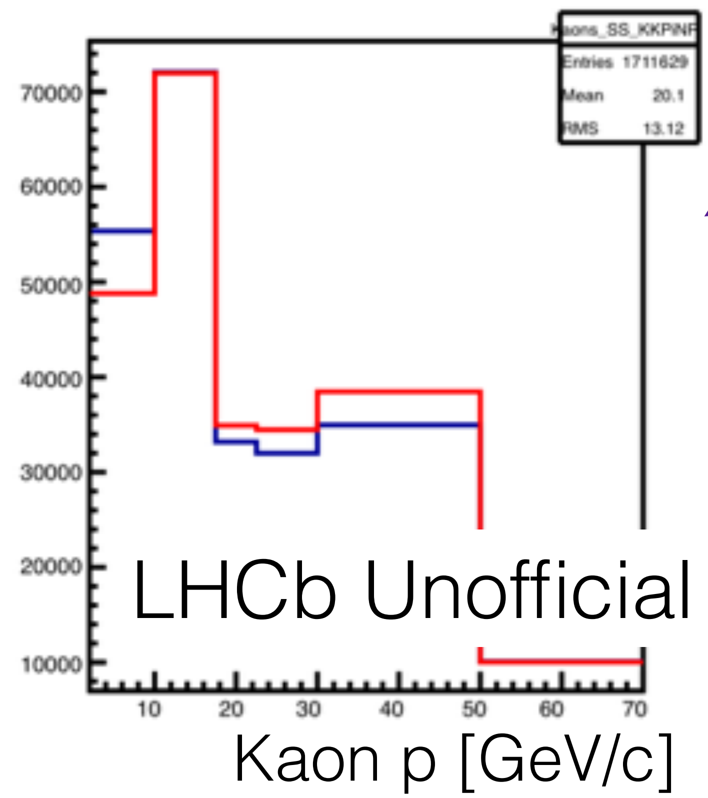


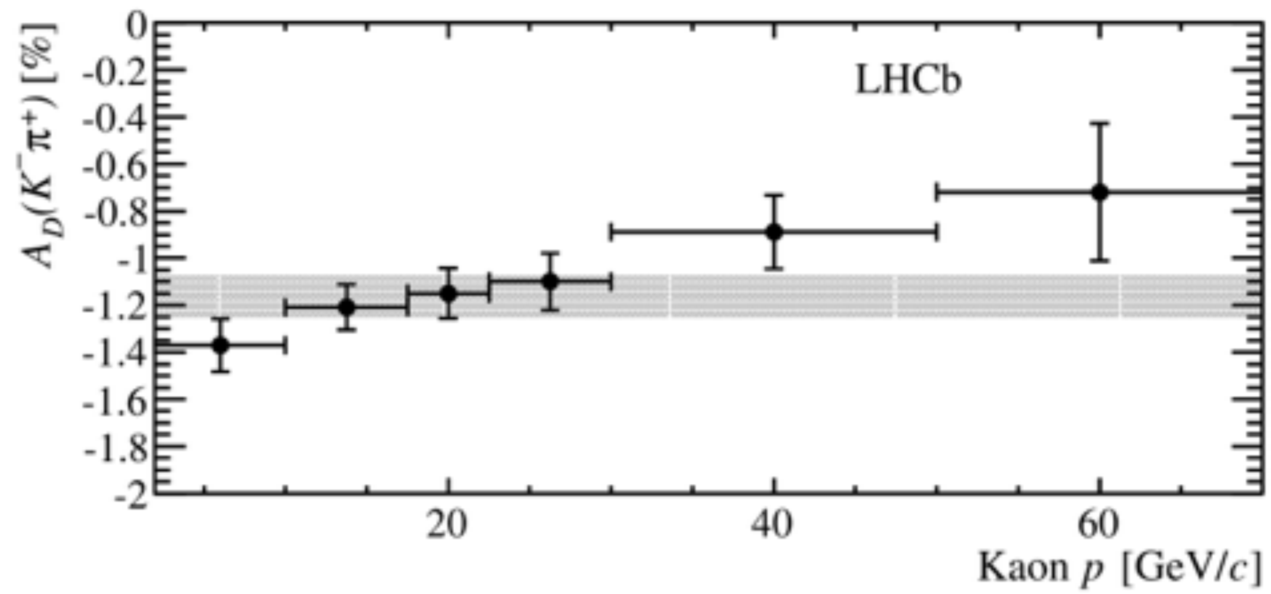


Large samples also for $D^* \to D^0 (\to K \mu \nu_\mu) \pi_s$

A_{KK}

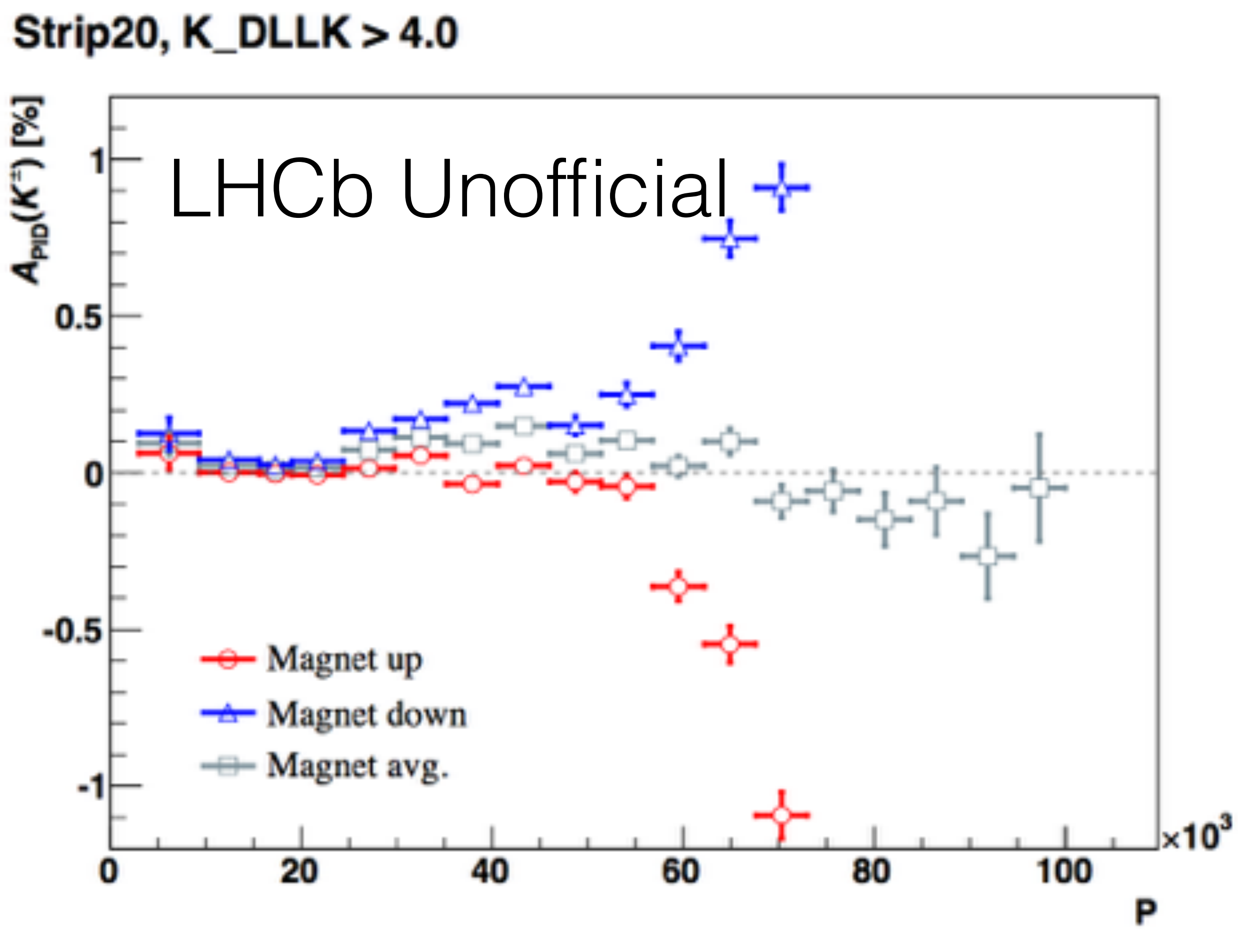
$$A_{KK} = \int \mathrm{d}\Phi \left\{ P_{OS}(\Phi) - P_{SS}(\Phi) \right\} A_K(\Phi)$$





looks at the global difference in momentum spectra for the same-sign and opposite-sign kaons.

APID



Large PID asymmetries, that are dependent on the background vetoes

- Using PIDcalib; D* tagged $D^0 \to K\pi$ for K and π
  $J/\psi \to \mu\mu$ for μ
- Currently evaluating the effect of sWeights in PIDcalib on the raw asymmetry