An improved measurement of direct CP violation parameters in $B^{\pm} \rightarrow J/\psi\, K^{\pm}$ and $B^{\pm} \rightarrow J/\psi\, \pi^{\pm}$ Decays

Beauty 2013

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SM expectations

$$A^{J/\psi h} = \frac{\Gamma\left(B^- \to J/\psi h^-\right) - \Gamma\left(B^- \to J/\psi h^+\right)}{\Gamma\left(B^- \to J/\psi h^-\right) + \Gamma\left(B^- \to J/\psi h^+\right)}$$

- Require new sources of CP-violation.
- $B^\pm \to J/\psi h^\pm$ decays provide a clean test for direct CP-violation.
- In $B^\pm \to J/\psi K^\pm$ the SM predicts that the tree and penguin contributions have the same weak phase and thus no direct CP violation is expected (a maximum asymmetry of 0.3%).
- $B^\pm \to J/\psi \pi^\pm$ decays could have CP violating effects of a few percent.

Current Best Measurements

$$\mathrm{Belle(2010)} : A^{J/\psi K} = [-0.76 \pm 0.55]\,\%$$

$$\mathrm{D0(2008)} : A^{J/\psi K} = [0.75 \pm 0.68]\,\%$$

$$\mathrm{LHCb(2012)} : A^{J/\psi \pi} = [-0.5 \pm 2.9]\,\%$$

Method

- Use the same methods as being used in the a_{sl} and anomalous dimuon analyses (see Monday) . Data Selection to optimise significance
- Re-weight data to based on magnet polarity
- Simultaneous sum and difference fit to extract asymmetry

$$A_{\rm raw}^{J/\psi K} = \frac{N_{J/\psi K^-} - N_{J/\psi K^+}}{N_{J/\psi K^-} + N_{J/\psi K^+}},$$

$$A_{\rm raw}^{J/\psi \pi} = \frac{N_{J/\psi \pi^-} - N_{J/\psi \pi^+}}{N_{J/\psi \pi^-} + N_{J/\psi \pi^+}},$$

- Correct for kaon asymmetry (in J/ψK channel)

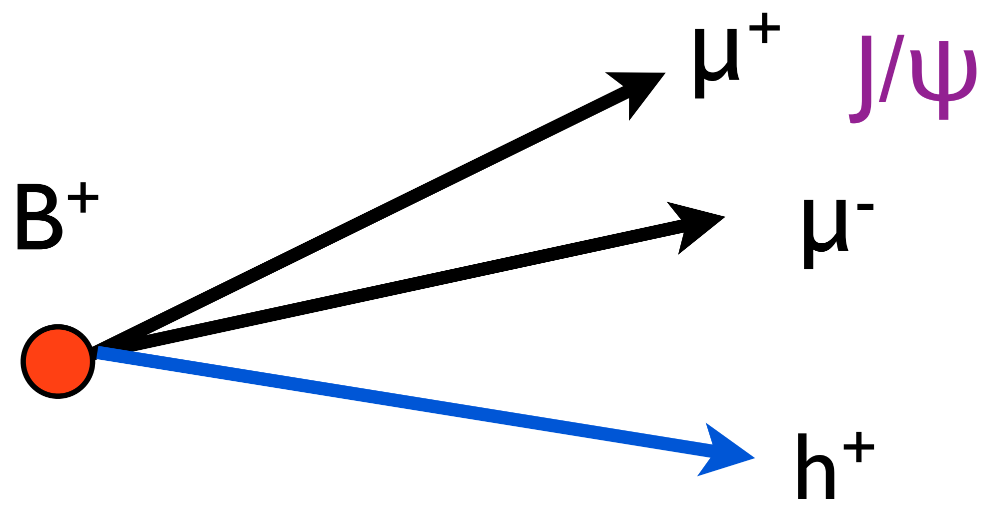
$$A^{J/\psi K} = A_{\rm raw}^{J/\psi K} + A_K,$$

$$A^{J/\psi \pi} = A_{\rm raw}^{J/\psi \pi} + A_\pi,$$

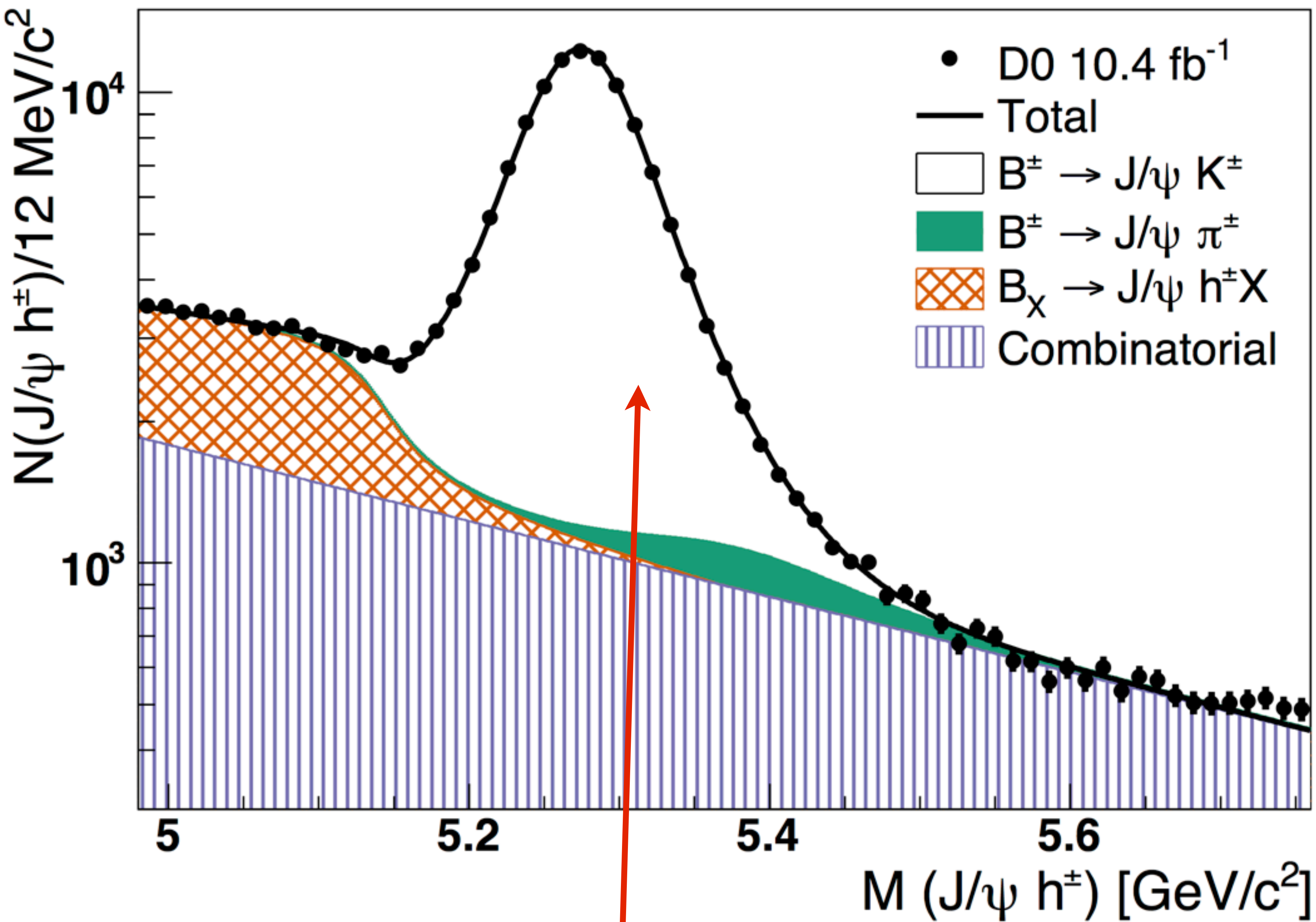
$$A_K = \frac{\epsilon(K^+) - \epsilon(K^-)}{\epsilon(K^+) + \epsilon(K^-)}.$$

Event Reconstruction

- Trigger off single/di-muons.
- Combine two muons to form J/ψ and constrain to PDG mass.
- Combine with charged hadron track to form vertex.
- No kaon/pion separation. Assign hadron the mass of the kaon (dominant decay).
- Apply multivariate likelihood ratio to reduce background.
- Fit invariant mass distribution.



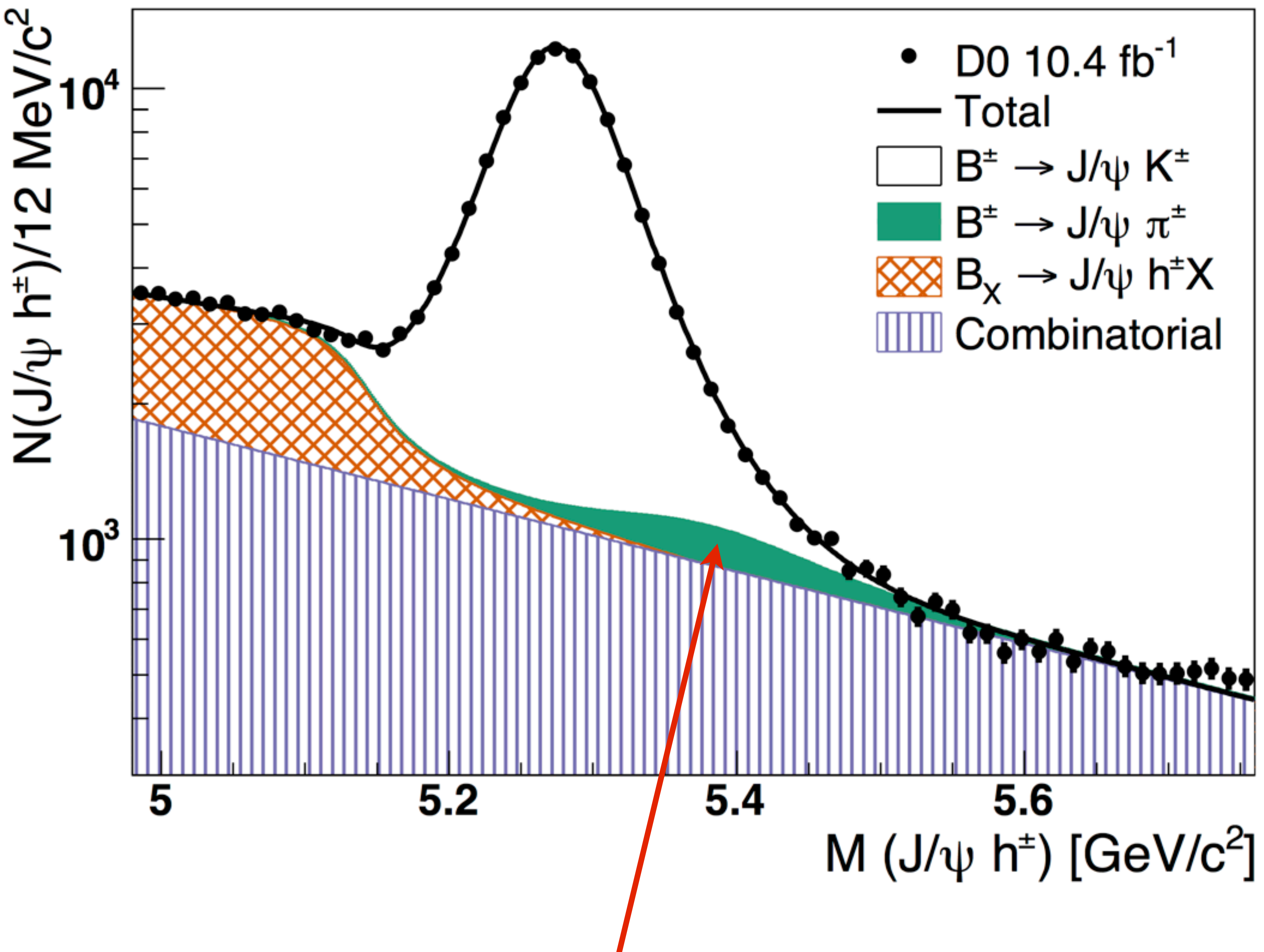
Fit to Sum



Unbinned maximum likelihood fit

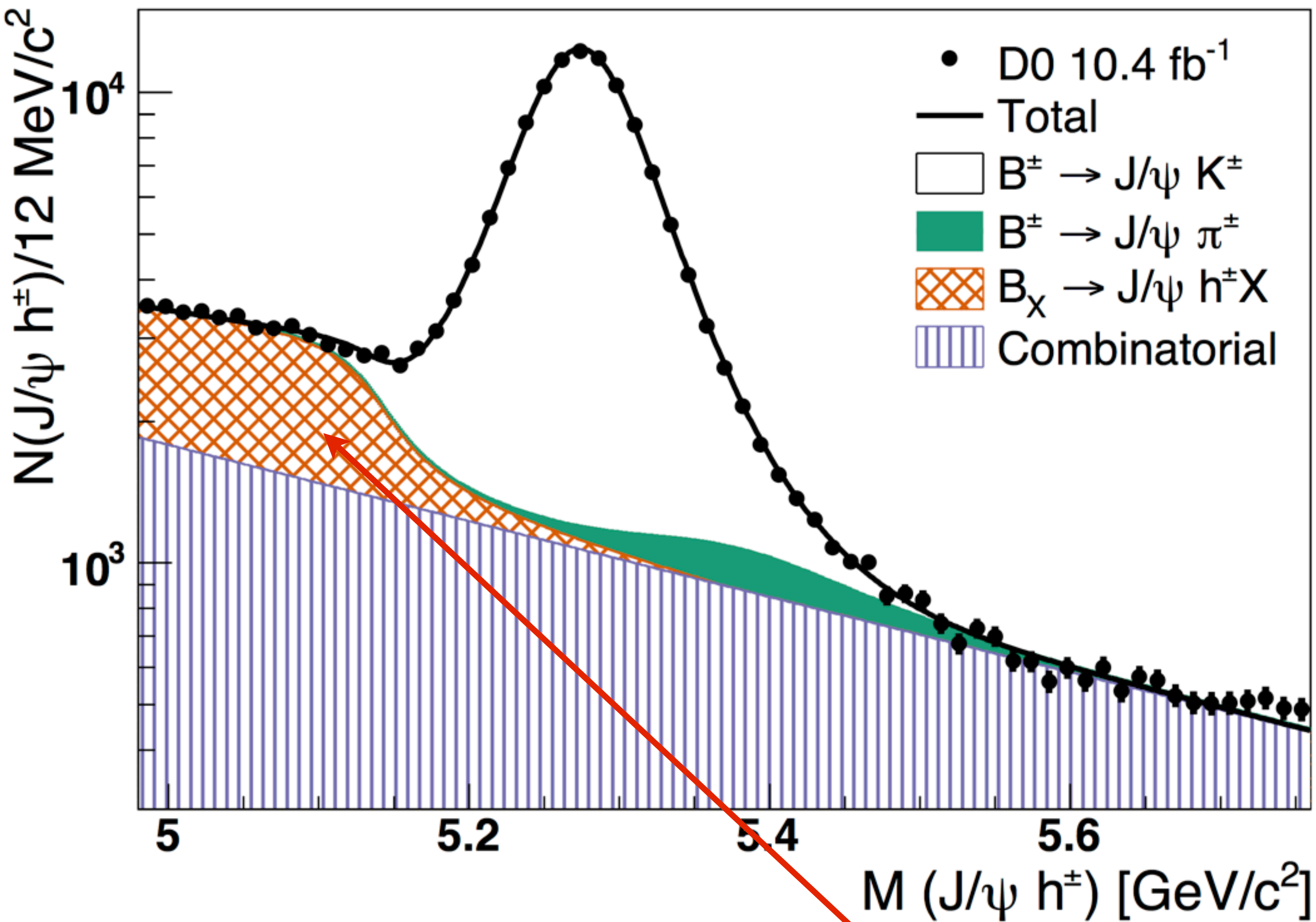
$G_K(m)$: J/ψK - Double Gaussian with width and normalisation depending on kaon energy

Fit to Sum



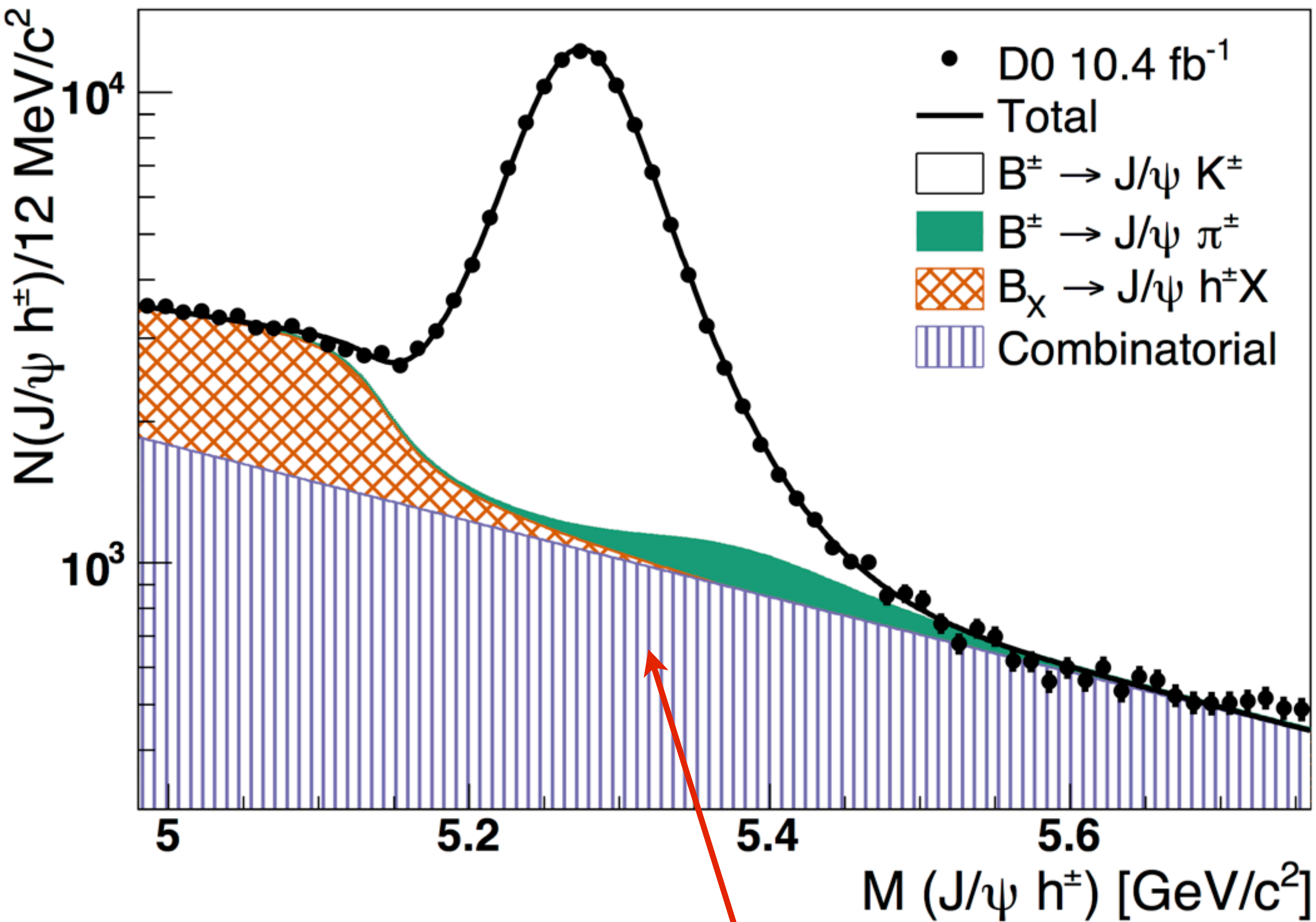
$G_{\pi}(m)$: $J/\psi\pi$ - Double Gaussian with width and normalisation depending on kaon energy

Fit to Sum



T(m): J/ψh - Threshold Function representing partially reconstructed B-hadrons

Fit to Sum

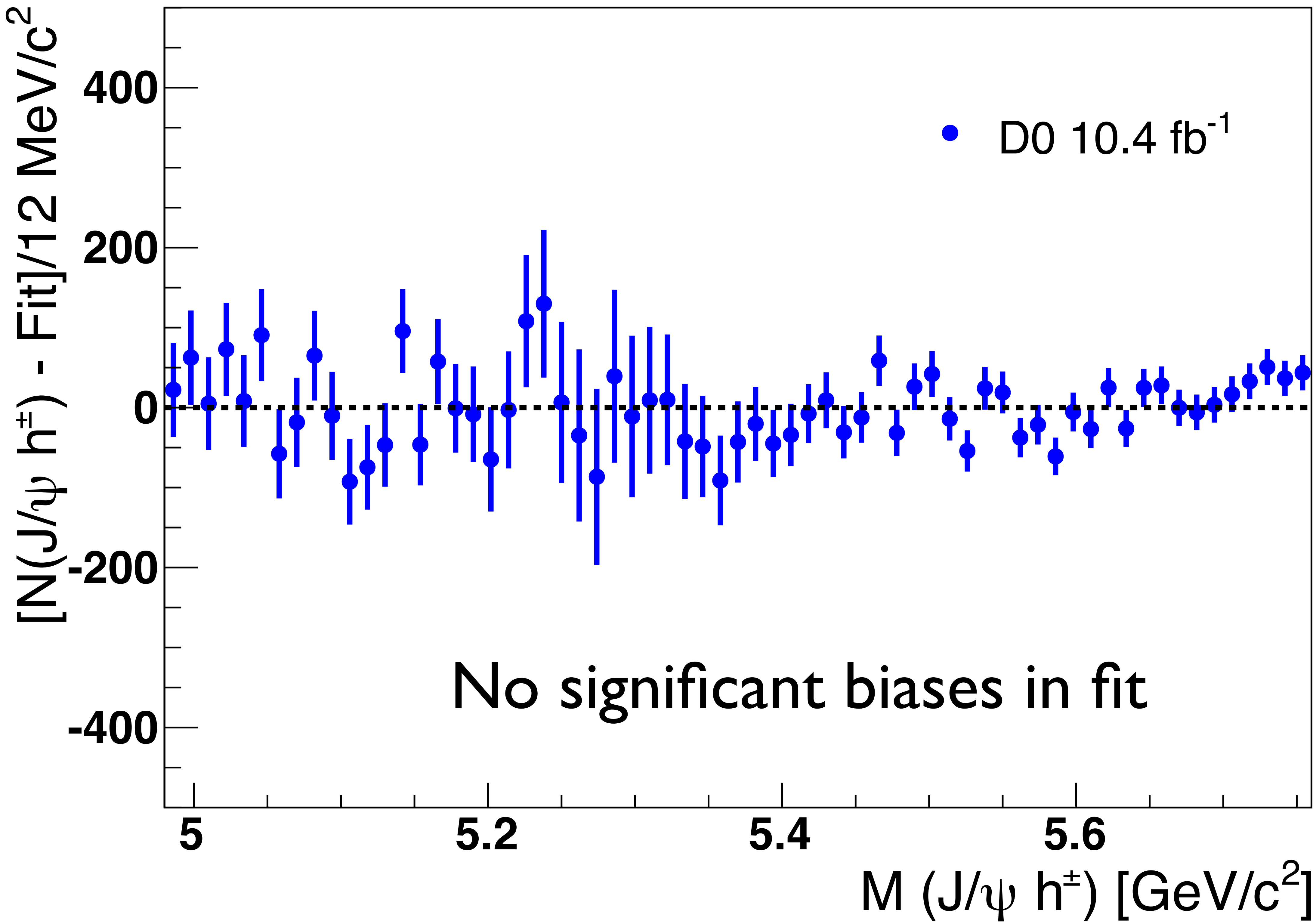


$\chi 2$ = 76.2 for 47 d.o.f.
$N(J/\psi K)$ = 105, 562 ± 370

$N(J/\psi\pi)$ = 3,110 ± 174

E(m): Combinatorics
exponential background function

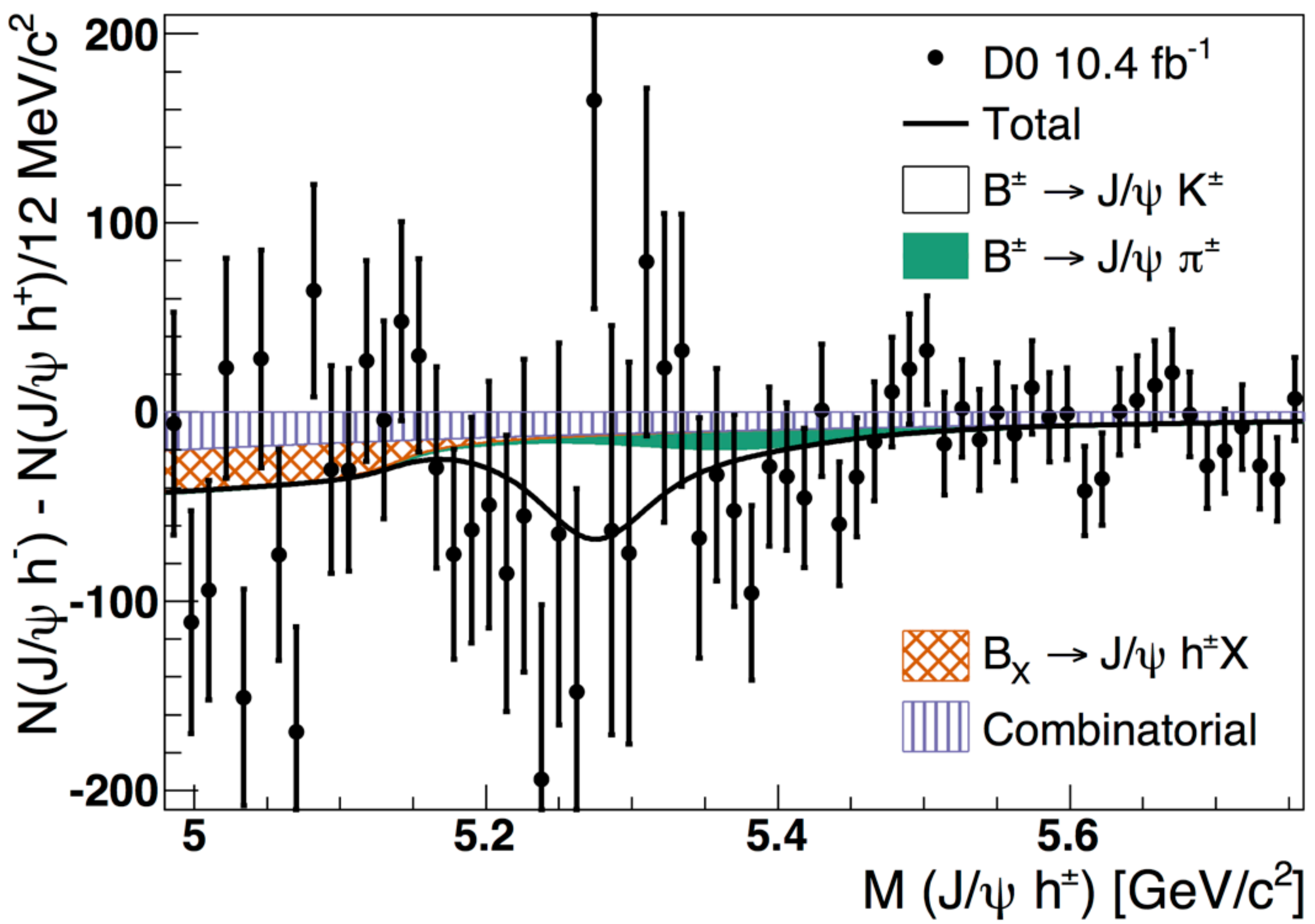
Data - Fit



[N(J/ψ h±) - Fit]/12 MeV/c²
400
200
0
-200
-400
D0 10.4 fb⁻¹
No significant biases in fit
5
5.2
5.4
5.6
M (J/ψ h±) [GeV/c²]

Difference

$$\mathcal{L} = \left(1 - q_h A_{\text{raw}}^{J/\psi K}\right) G_K(m) + \left(1 - q_h A_{\text{raw}}^{J/\psi \pi}\right) G_\pi(m)$$
$$+ (1 - q_h A_T)\, T(m) + (1 - q_h A_E)\, E(m),$$



Unbinned maximum Likelihood fit of sum and difference.

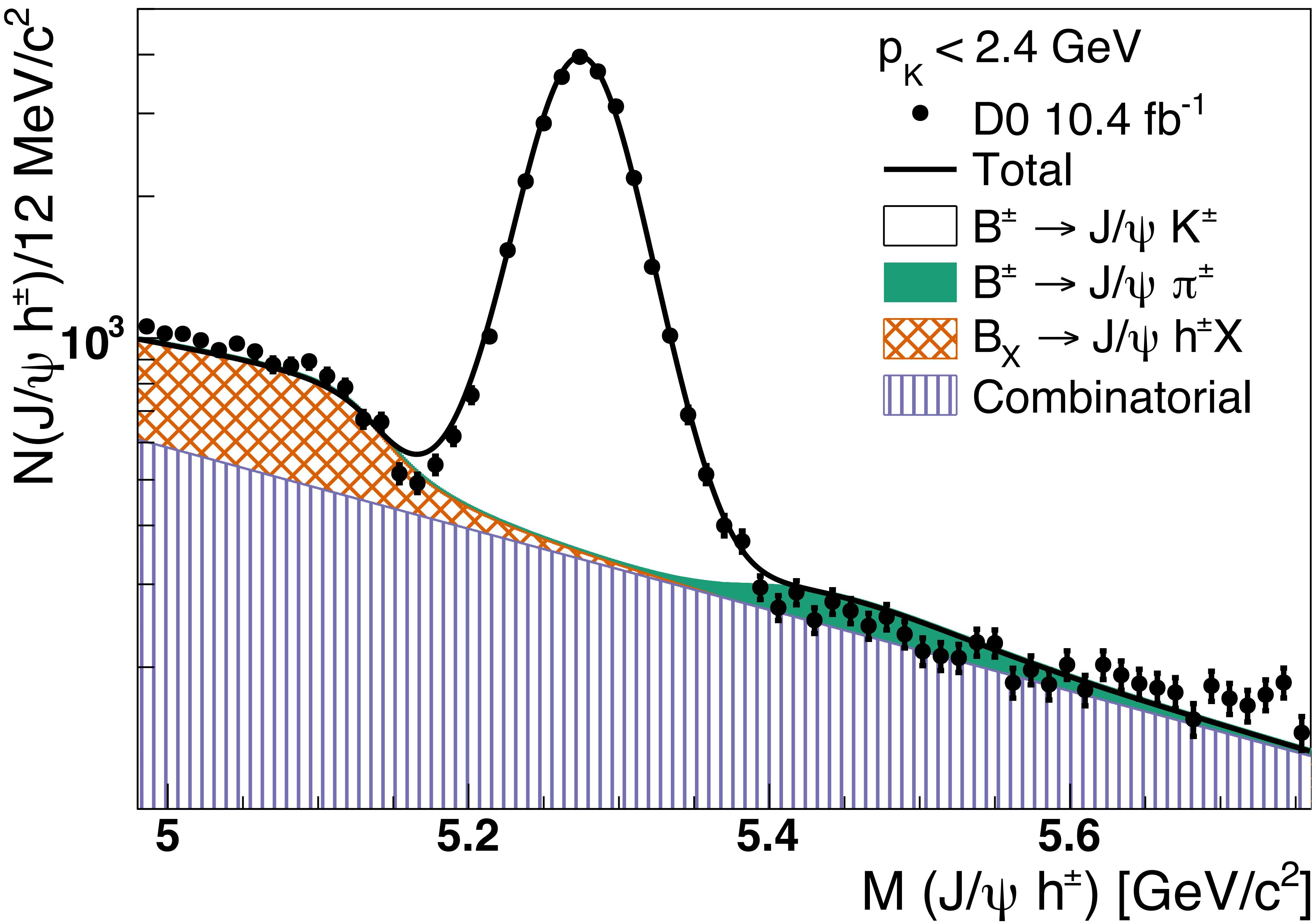
χ^2 = 58.5 for 61 d.o.f.

$$A_{\text{raw}}^{J/\psi K} = [-0.46 \pm 0.36\,(\text{stat})]\,\%,$$
$$A_{\text{raw}}^{J/\psi \pi} = [-4.2 \pm 4.4\,(\text{stat})]\,\%.$$

$$A_T = [-1.3 \pm 1.0\,(\text{stat.})]\,\%,$$
$$A_E = [-1.1 \pm 0.6\,(\text{stat.})]\,\%.$$

Do we need this Fit

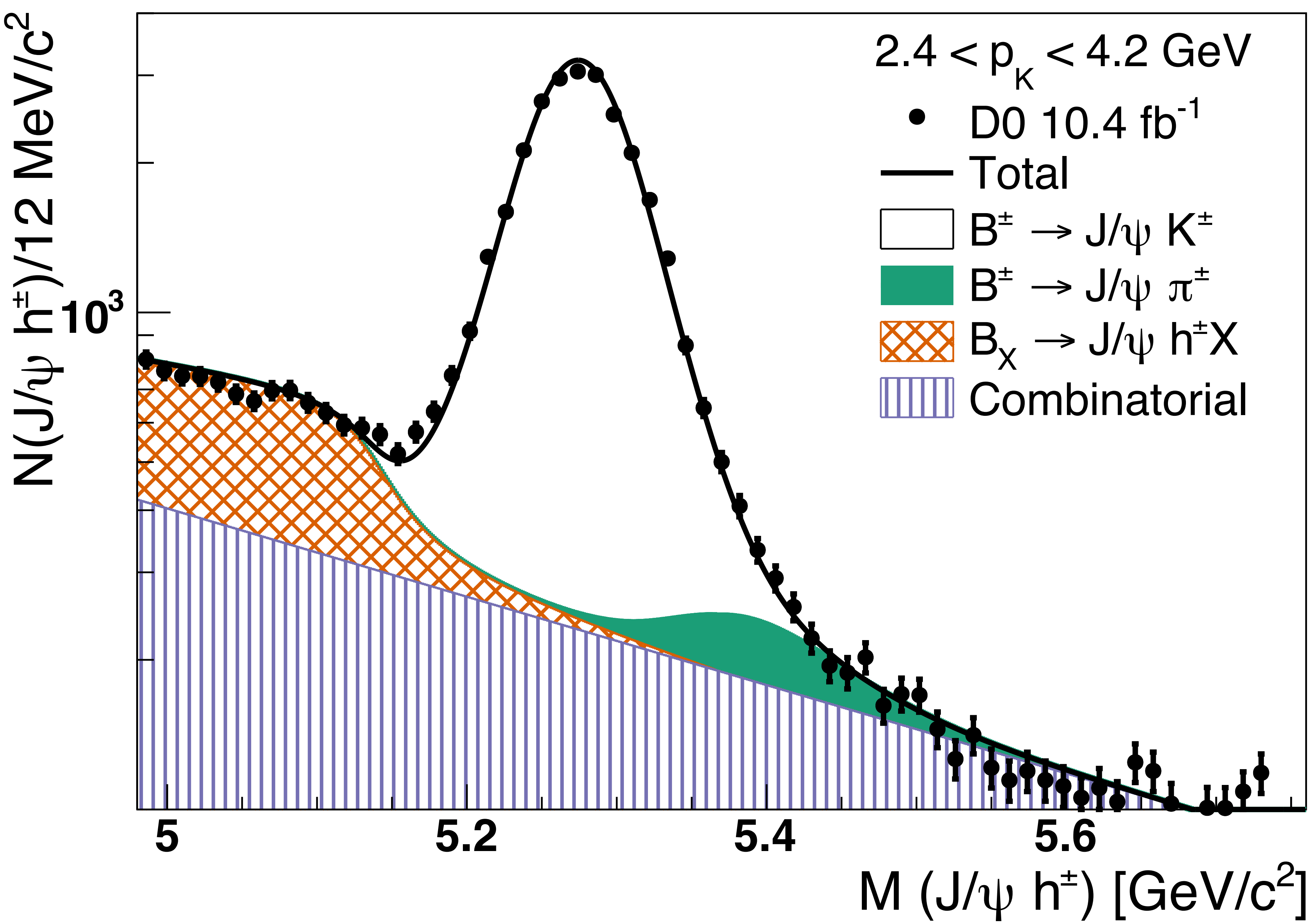
Projection of fit in momentum bins



Width of Signal depends on hadron momentum

Do we need this Fit

Projection of fit in momentum bins



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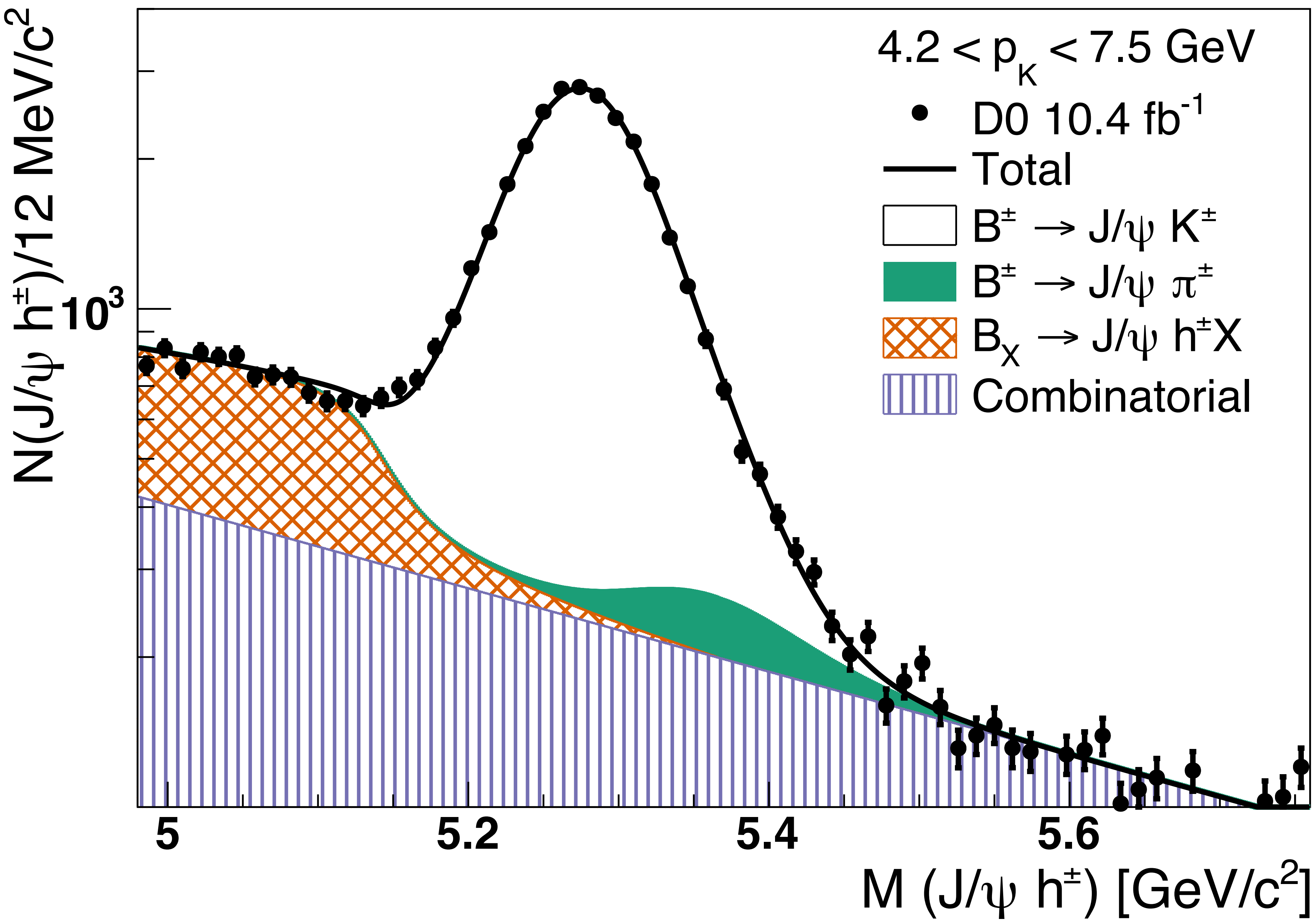

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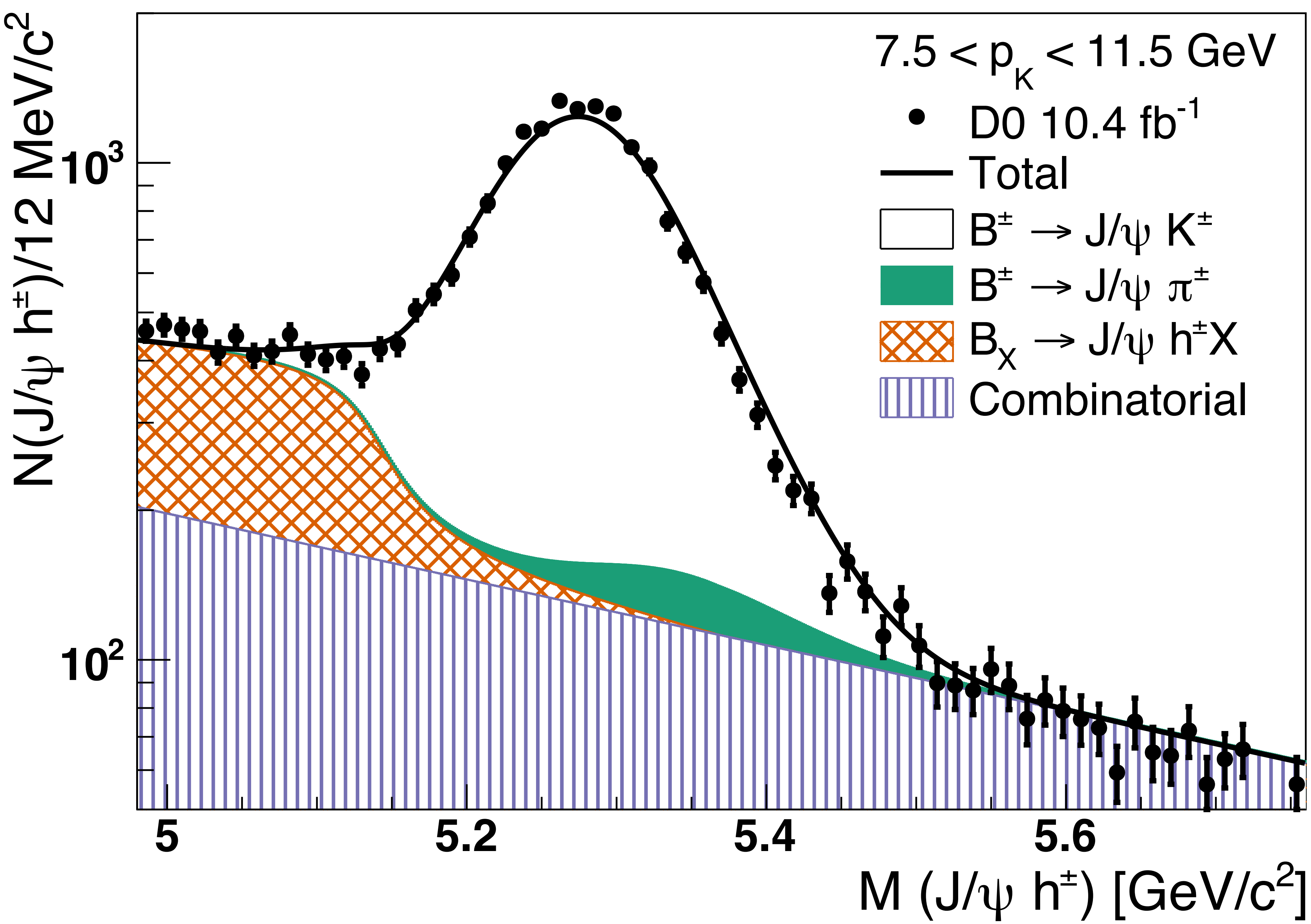
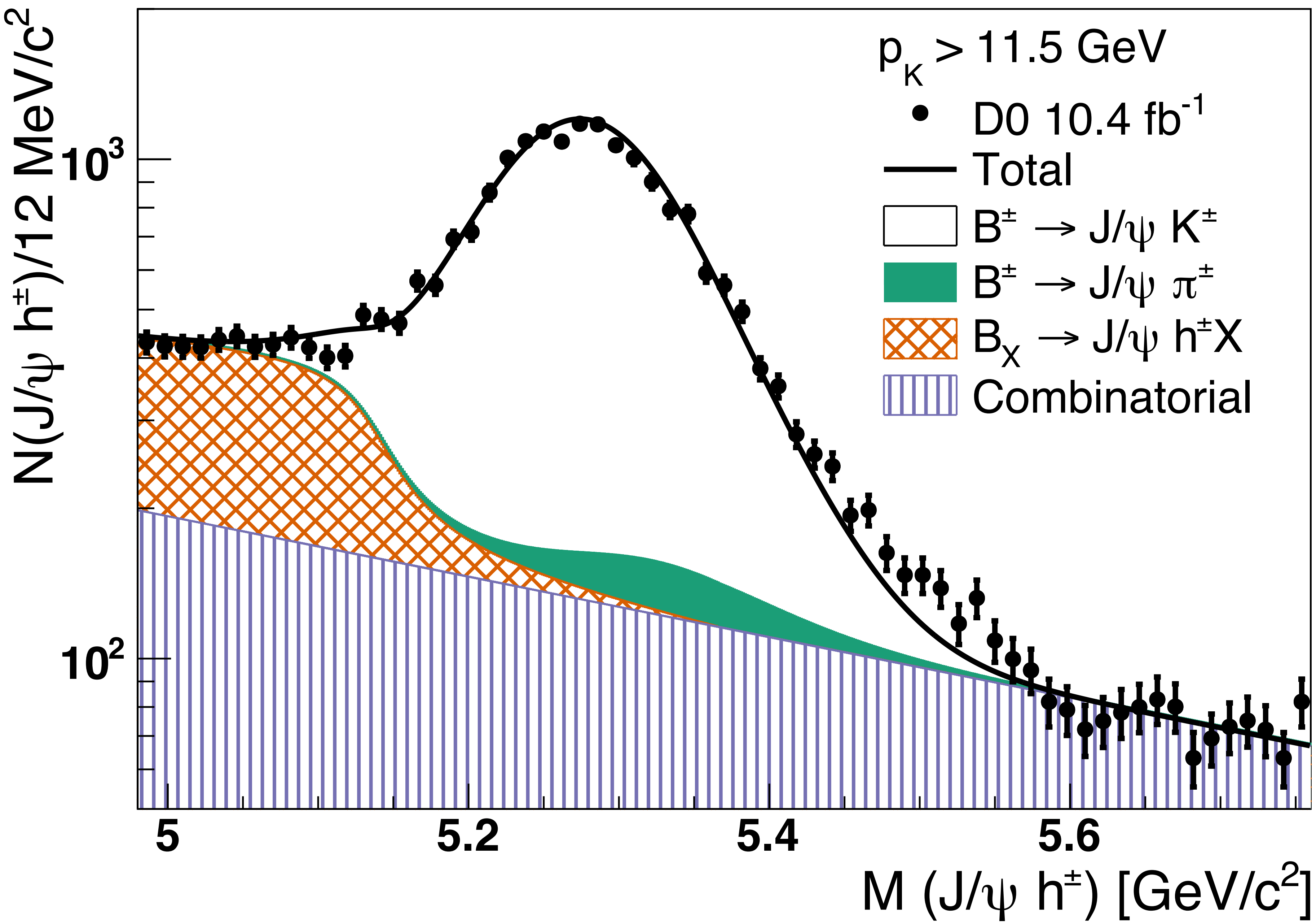


Width of Signal depends on hadron momentum

Do we need this Fit

Projection of fit in momentum bins



Width of Signal depends on hadron momentum

Fit Systematics

- Mass Range: the lower edge is varied from 4.95 to 5.01 GeV, and the upper edge from 5.73 to 5.79 GeV.
  $\Delta A^{J/\psi K}$ of 0.022% and in $\Delta A^{J/\psi\pi}$ of 0.55%.

- Fit Function:
  Vary Parameters of fit functions.
  $\Delta A^{J/\psi K}$ of 0.011% and in $\Delta A^{J/\psi\pi}$ of 0.69%.

- Asymmetry Modelling:
  A_E is set equal to A_T, $A_E=0$, $A_T=0$, $A_E=A_T=0$
  When extracting $A^{J/\psi K}$, $A^{J/\psi\pi}=0$, When extracting $A^{J/\psi\pi}$, $A^{J/\psi K}=0$
  $\Delta A^{J/\psi K}$ of 0.038% and in $\Delta A^{J/\psi\pi}$ of 1.6%.

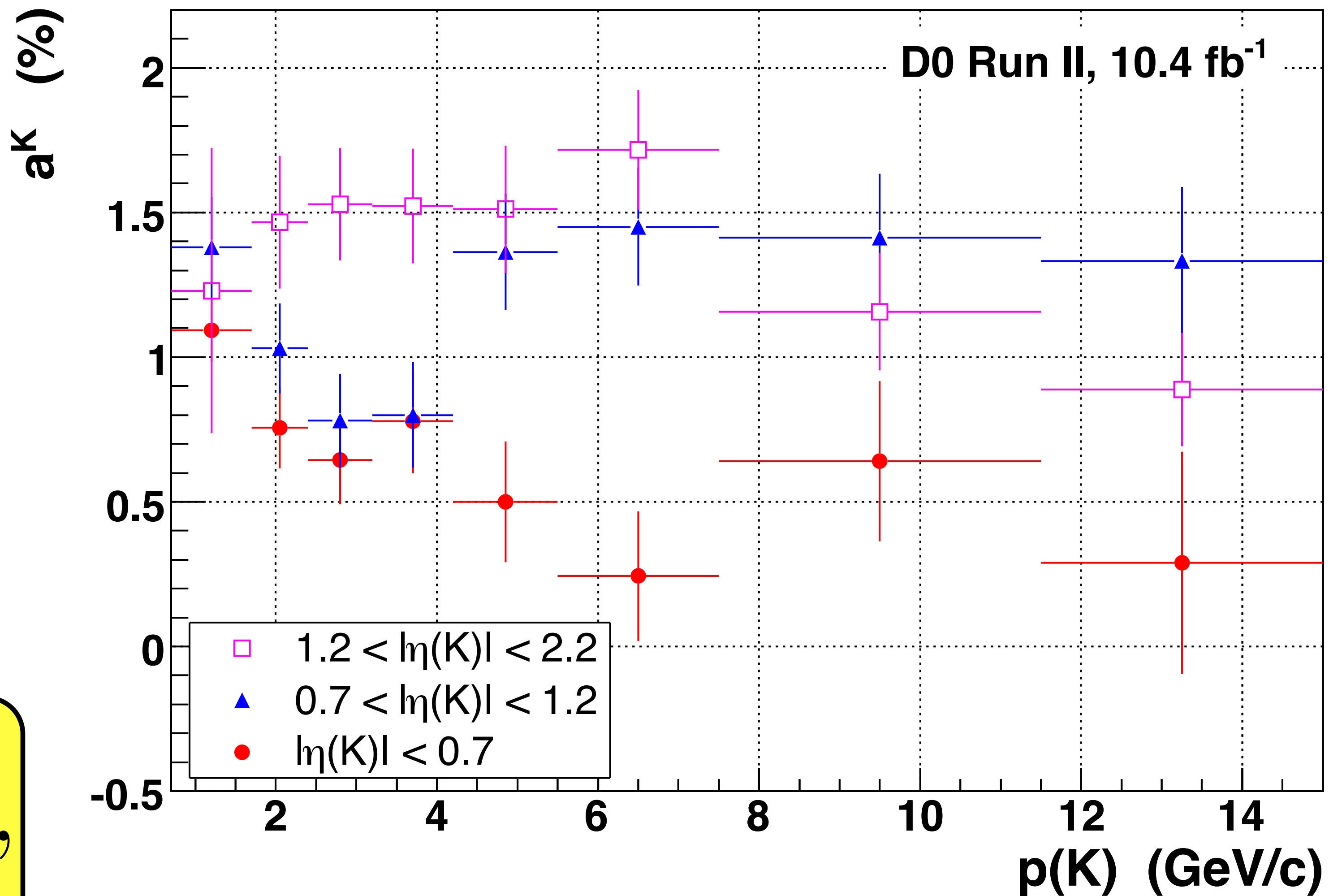
$$A^{J/\psi K}_{\rm raw} = [-0.46 \pm 0.36\,({\rm stat}) \pm 0.046\,({\rm syst})]\,\%,$$
$$A^{J/\psi \pi}_{\rm raw} = [-4.2 \pm 4.4\,({\rm stat}) \pm 1.82\,({\rm syst})]\,\%.$$

Kaon Correction

- Taken directly from Bd asymmetry analysis (see Mondays talk)
- Fit used to get number of $B^{\pm}$ events in momentum and pseudo rapidity bins
- Extract A_K (for K^+ - K^-)

$$A^{J/\psi K} = A_{\rm raw}^{J/\psi K} + A_K,$$
$$A^{J/\psi \pi} = A_{\rm raw}^{J/\psi \pi} + A_\pi,$$

$$A_K = \frac{\epsilon(K^+) - \epsilon(K^-)}{\epsilon(K^+) + \epsilon(K^-)}.$$



$$A_K = [1.05 \pm 0.04\,({\rm syst.})]\,\%.$$

Final Result

$$A^{J/\psi K} = [0.59 \pm 0.36\,(\text{stat}) \pm 0.08\,(\text{syst})]\,\%,$$
$$A^{J/\psi \pi} = [-4.2 \pm 4.4\,(\text{stat}) \pm 1.8\,(\text{syst})]\,\%.$$

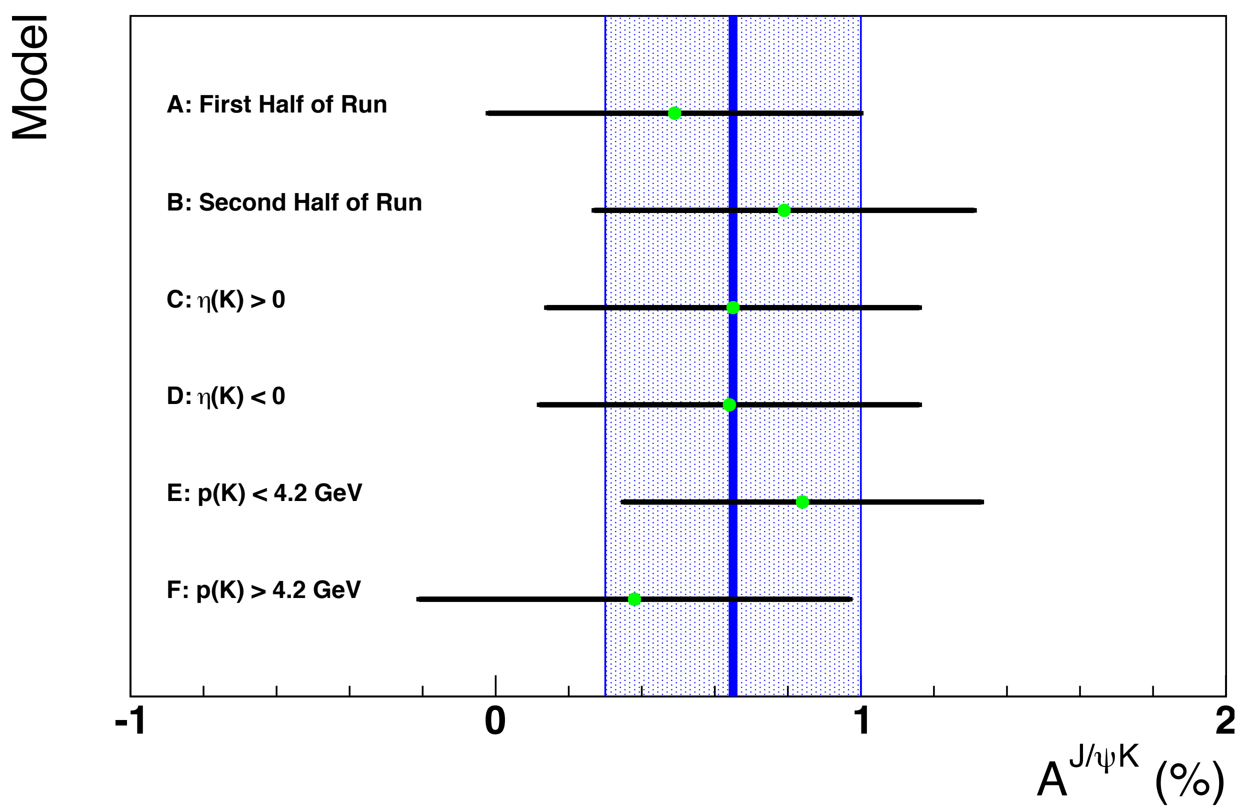
Type of uncertainty	$A^{J/\psi K}$ (%)	$A^{J/\psi\pi}$ (%)
Statistical	0.36	4.4
Mass range	0.022	0.55
Fit function	0.011	0.69
Asymmetry modeling	0.038	1.59
$\Delta A_{\text{tracking}}$	0.05	0.05
ΔA_K	0.043	n/a
Total systematic uncertainty	0.08	1.8
Total uncertainty	0.37	4.8

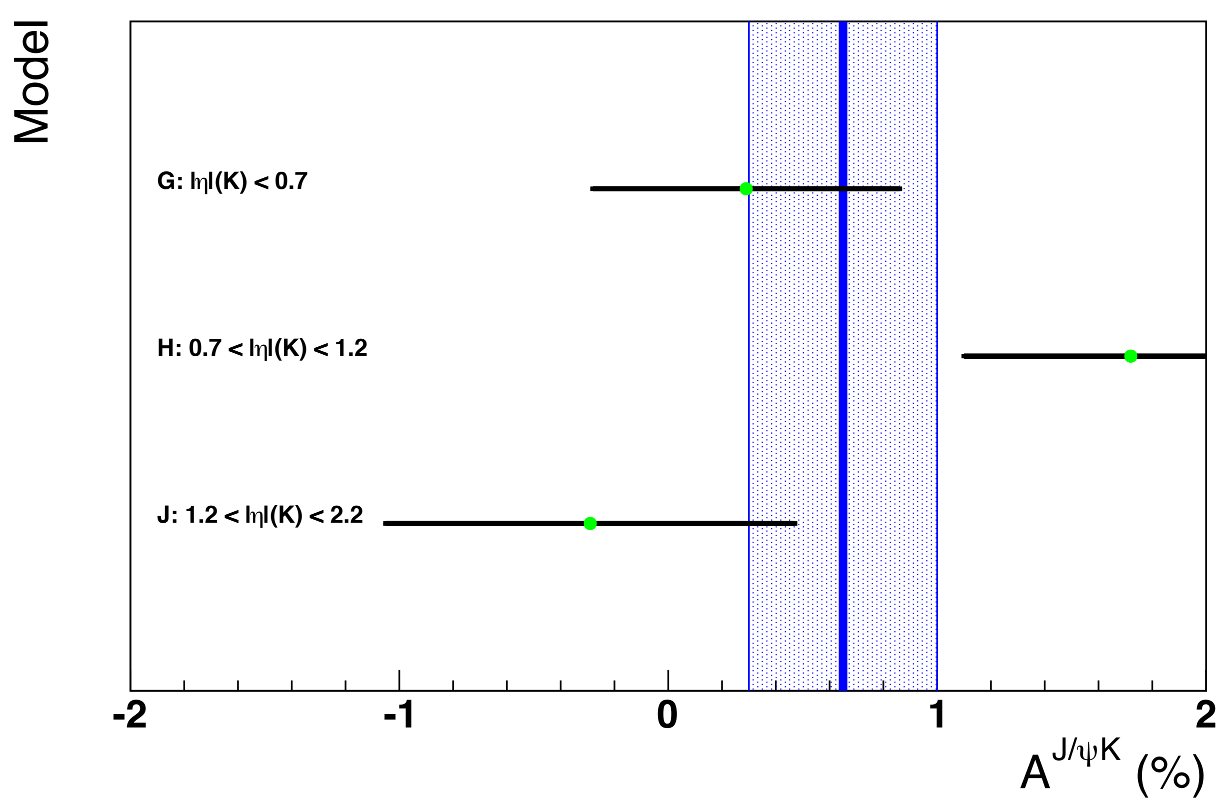
Stability Tests

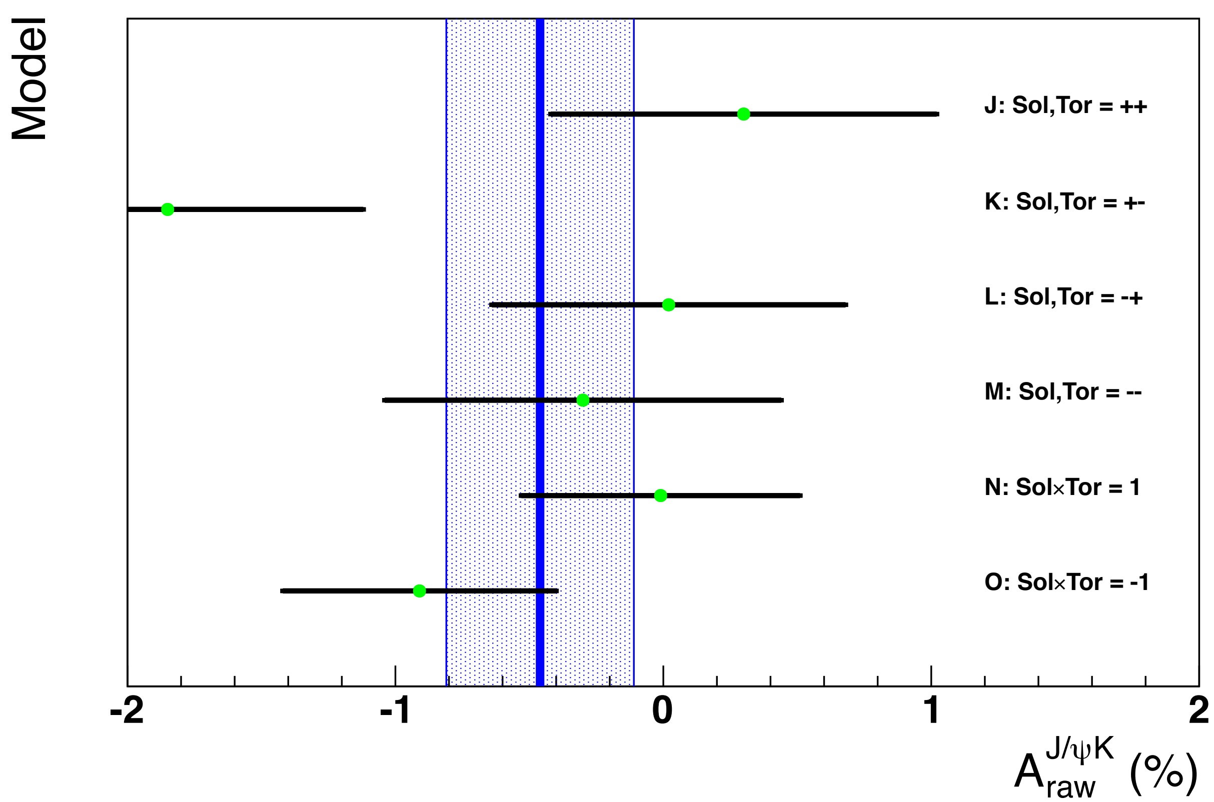
Repeat analysis using pairs of orthogonal sub-sets of the data to check stability

- Forward/Backward
- Forward/Central
- Low/High Momentum
- Early/Late Running

All measurements are consistent





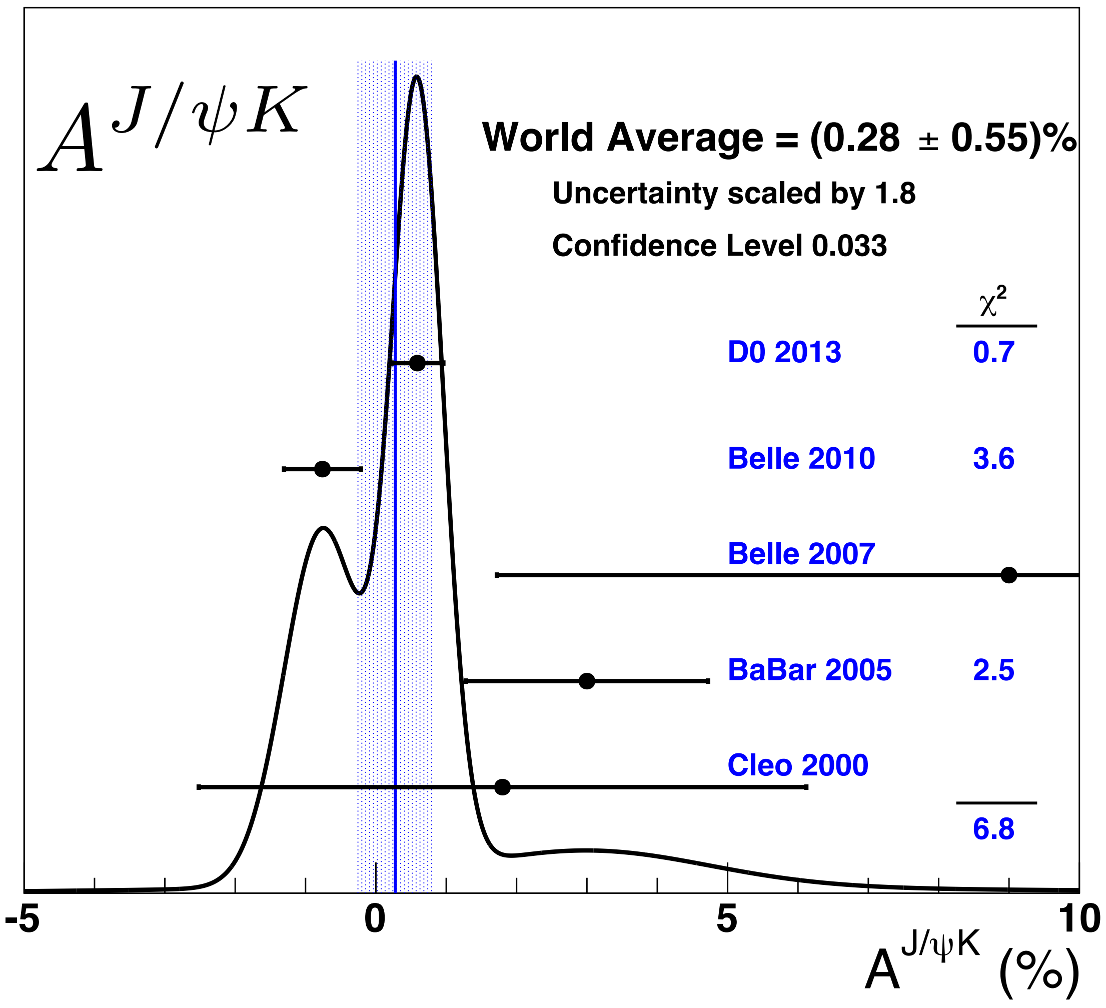


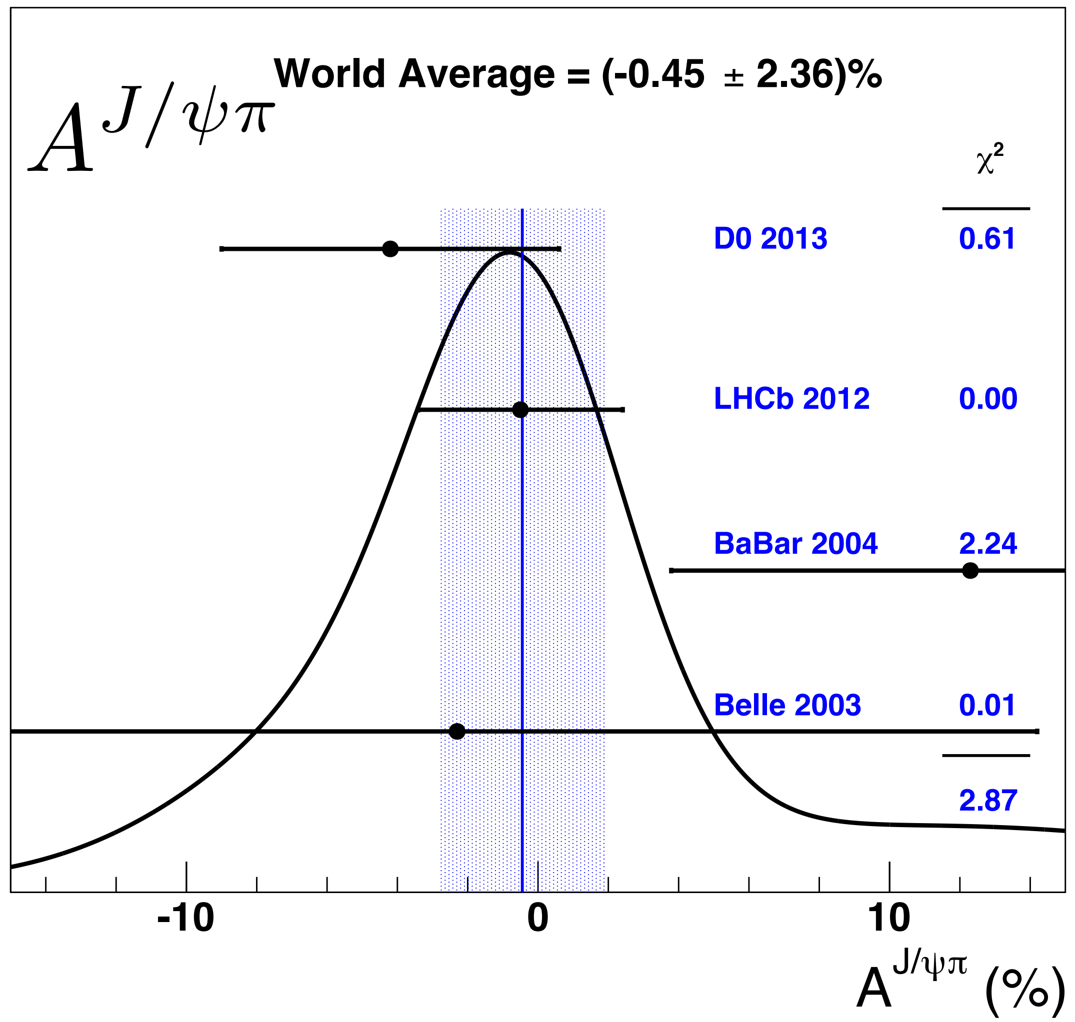
Closure

- To test the sensitivity of the fitting procedure, the charge of the charged hadron in the data is randomised to produce samples with no asymmetry, -1%, -0.5% and 1%.
- 1000 trials are performed for each asymmetry.
- The central value of the asymmetry distribution is consistent with the input asymmetry and for zero asymmetry we find
  - $A^{J/\psi K}$ width of 0.37% and a mean of +0.008 ± 0.011%
  - $A^{J/\psi \pi}$ width of 4.8% and a mean of +0.08 ± 0.17%
- This is consistent with the statistical uncertainty found in data.

New World Averages

World Averages
calculated using PDG procedure.





Summary

$$A^{J/\psi K} = [0.59 \pm 0.37]\,\%$$
$$A^{J/\psi\pi} = [-4.2 \pm 4.8]\,\%$$

- New measurements of $A^{J/\psi K}$ and $A^{J/\psi\pi}$ submitted to PRL hep-ex/1304.1655.
- $A^{J/\psi K}$ total uncertainty of 0.37% significantly improves on the previous best measurement 0.55%.
- Both measurements consistent with standard model predictions.
- $A^{J/\psi\pi}$ has been significantly improved over the previous measurement.