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

Iain Bertram

9 April 2013

SM expectations

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

- 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

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

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

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

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)

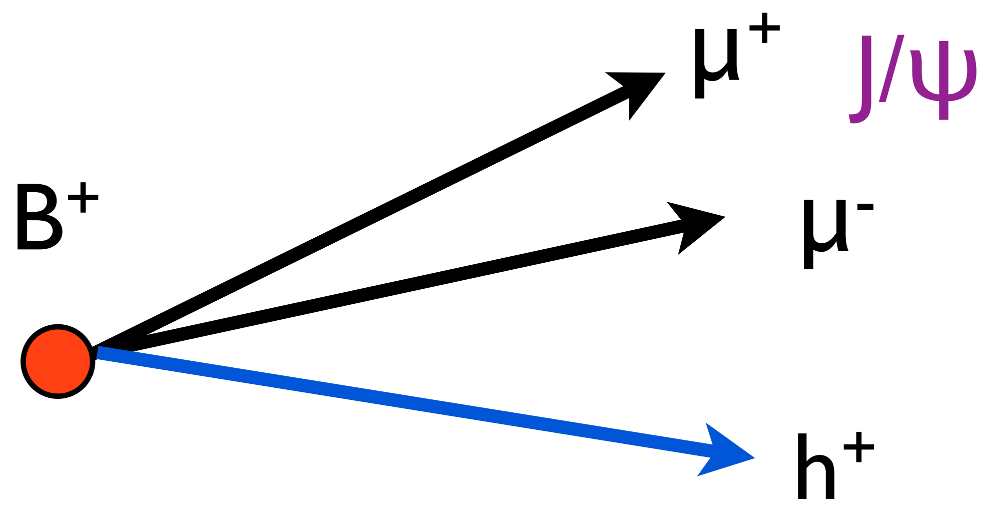
$$A^{J/\psi K} = A_{\rm raw}^{J/\psi K} + A_K,$$

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

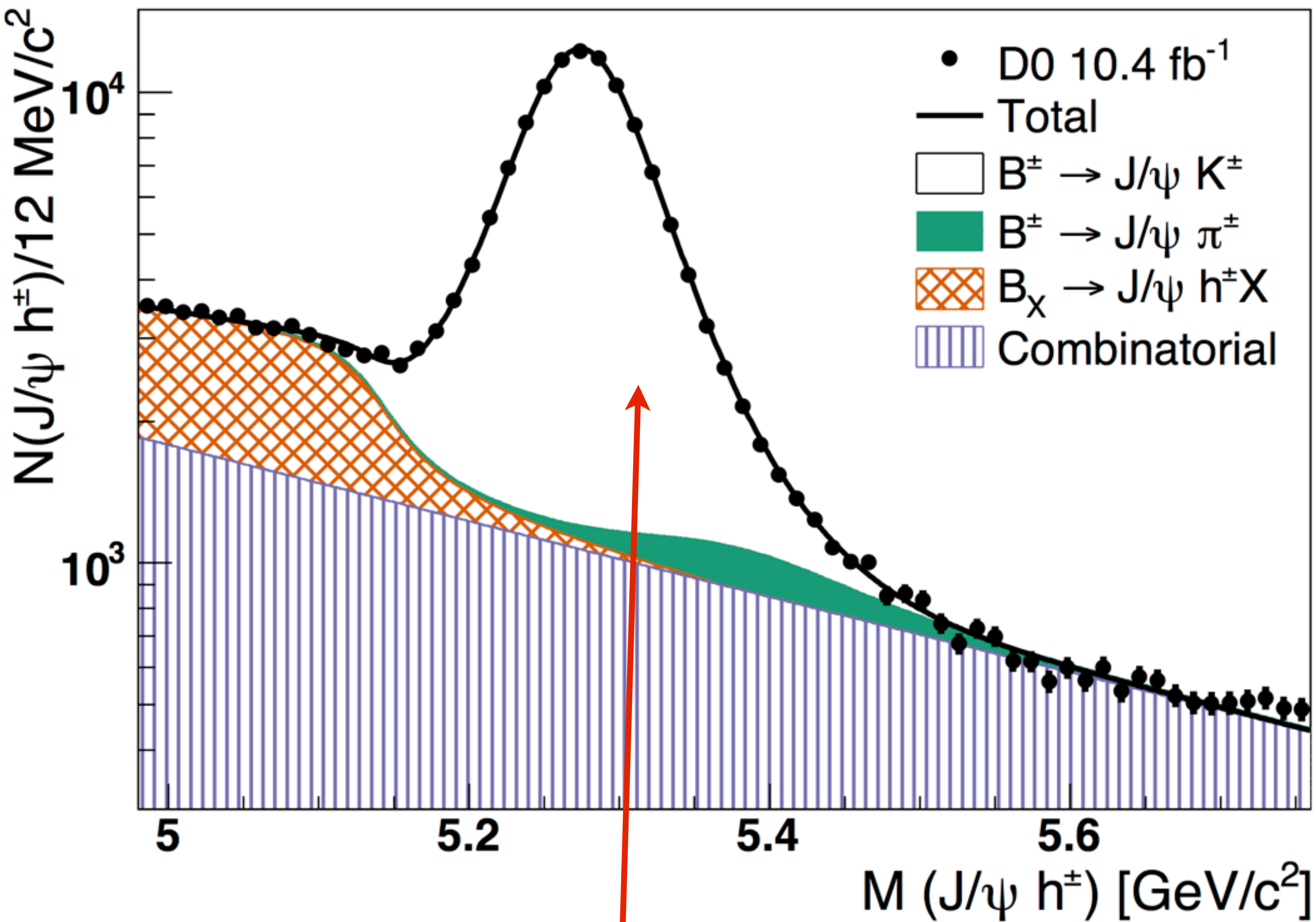
$$A_K = \frac{\epsilon(K^+) - \epsilon(K^-)}{\epsilon(K^+) + \epsilon(K^-)}.$$

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.



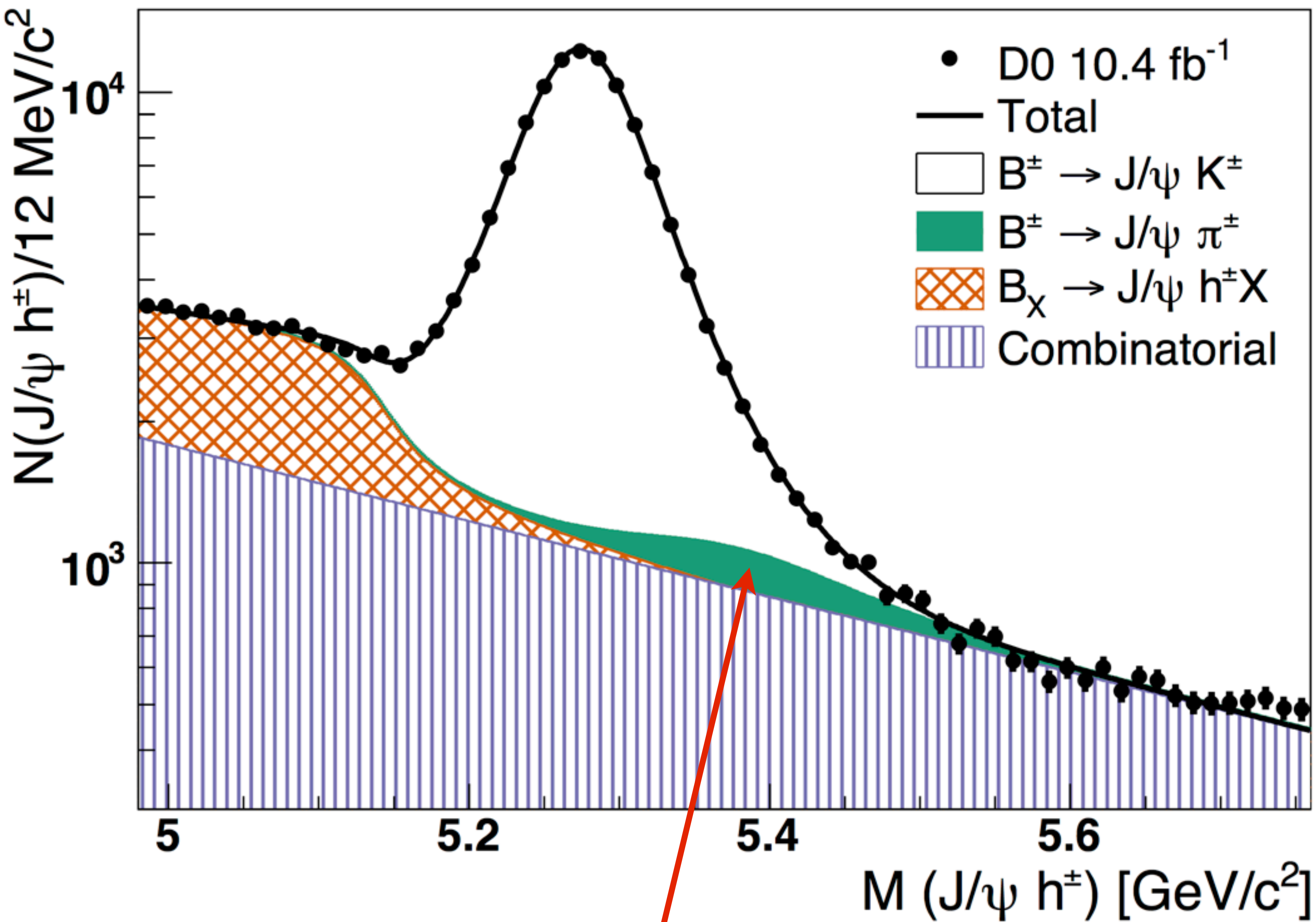
Fit to Sum



Unbinned maximum likelihood fit

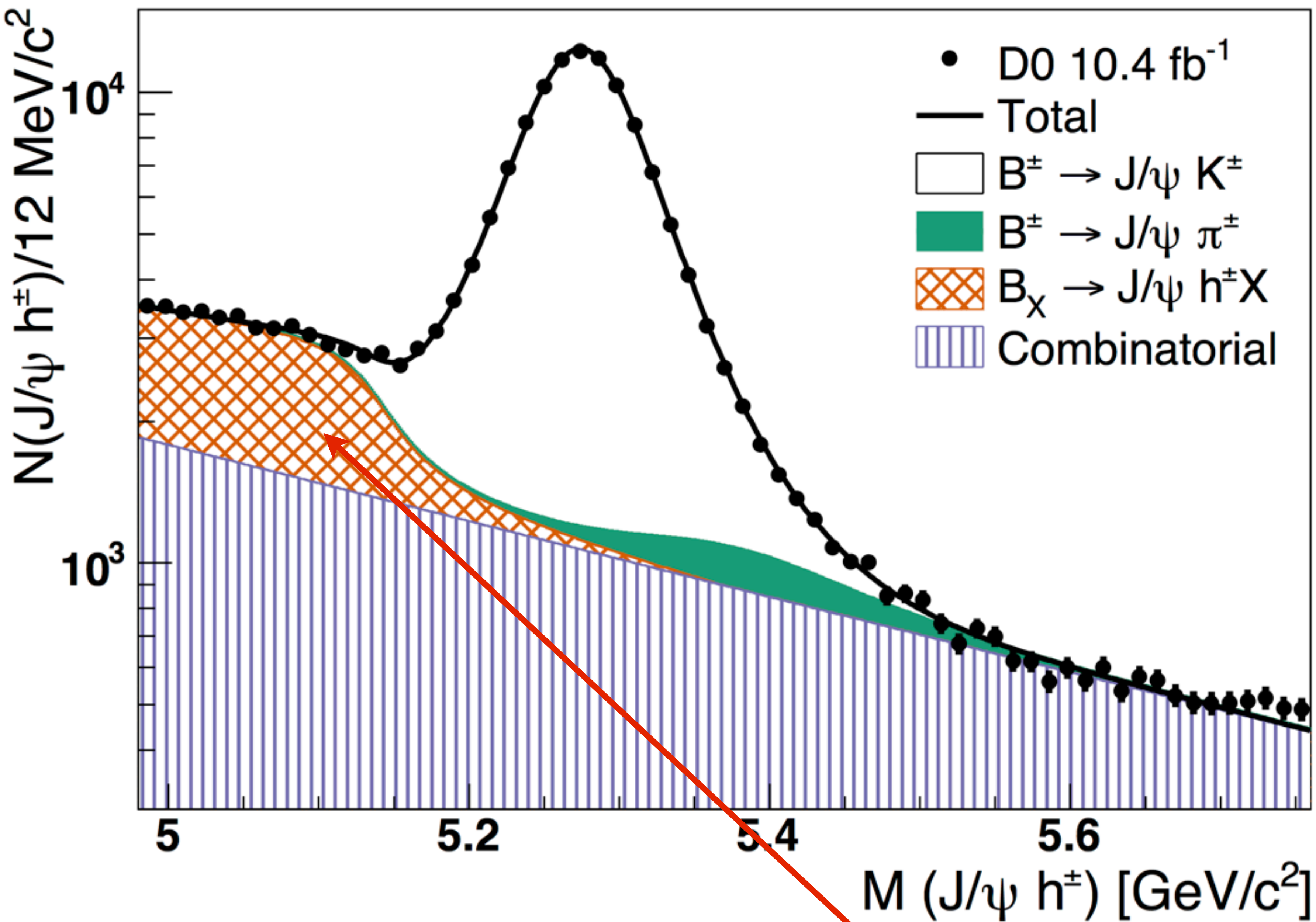
$G_K(m)$: J/ψK - Double Gaussian with width and normalisation depending on kaon energy

Fit to Sum



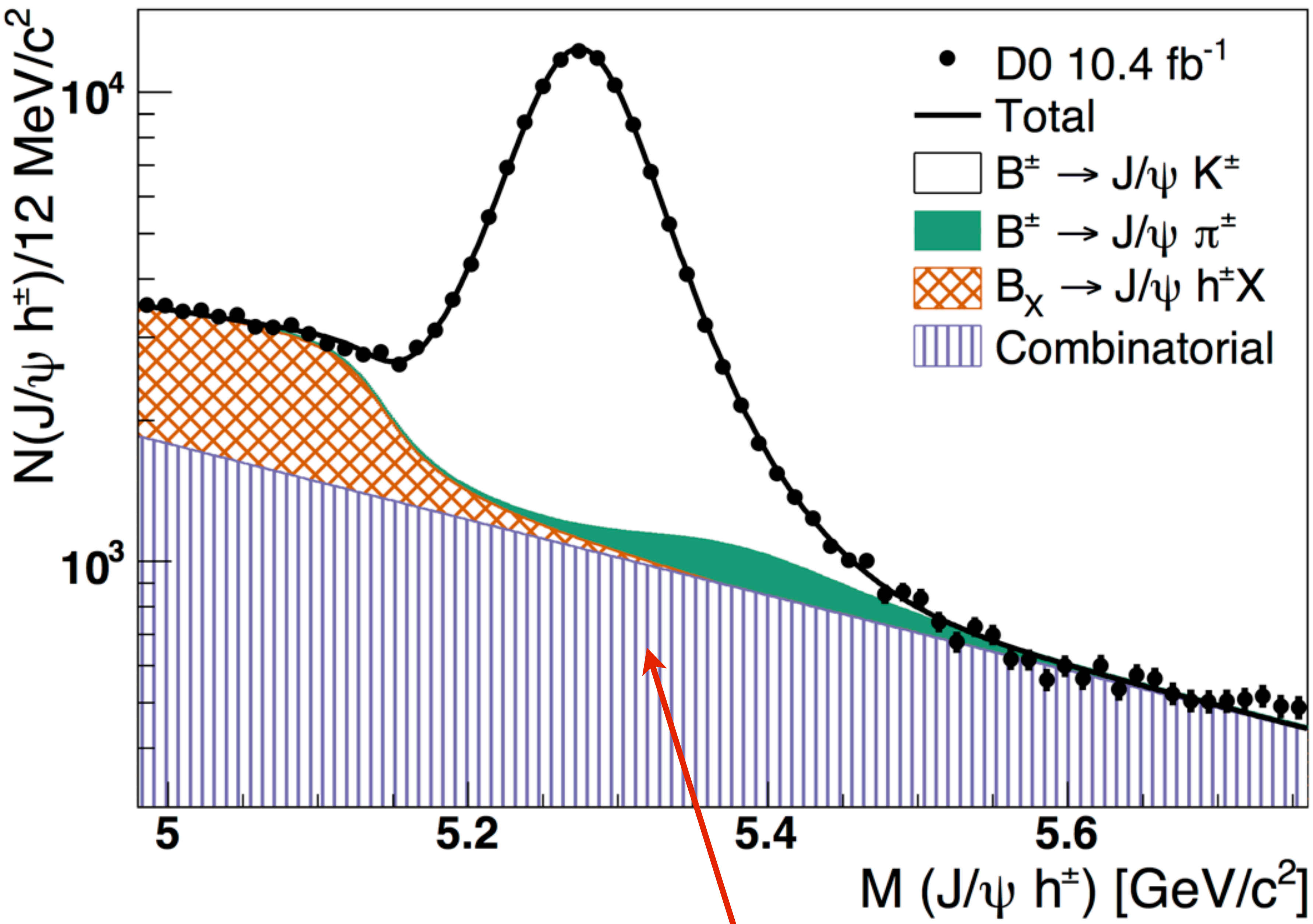
$G_\pi(m)$: $J/\psi\pi$ - Double Gaussian with width and normalisation depending on kaon energy

Fit to Sum



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

Fit to Sum

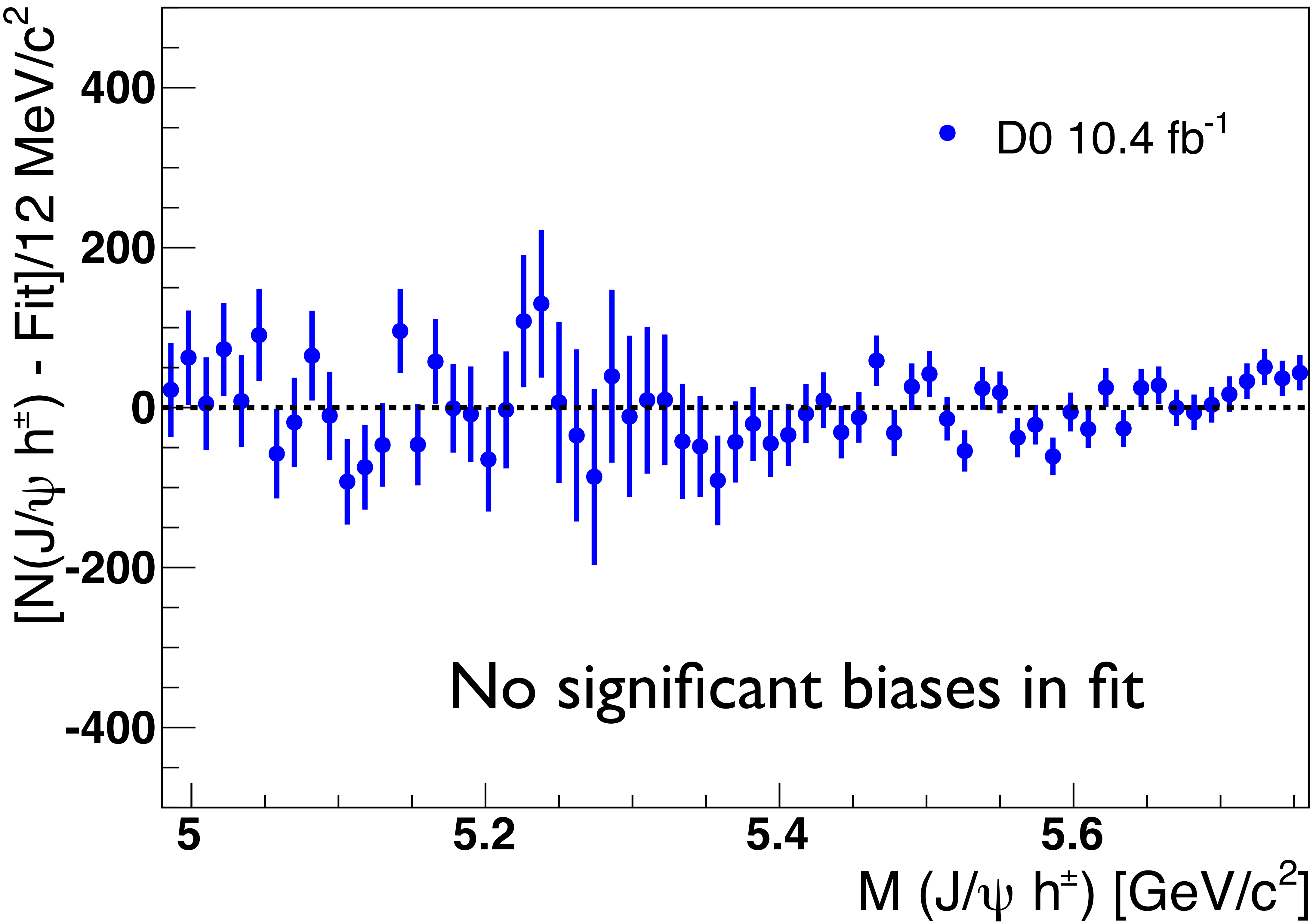


$\chi 2$ = 76.2 for 47 d.o.f.
N(J/ψK) = 105, 562 ± 370

N(J/ψπ) = 3,110 ± 174

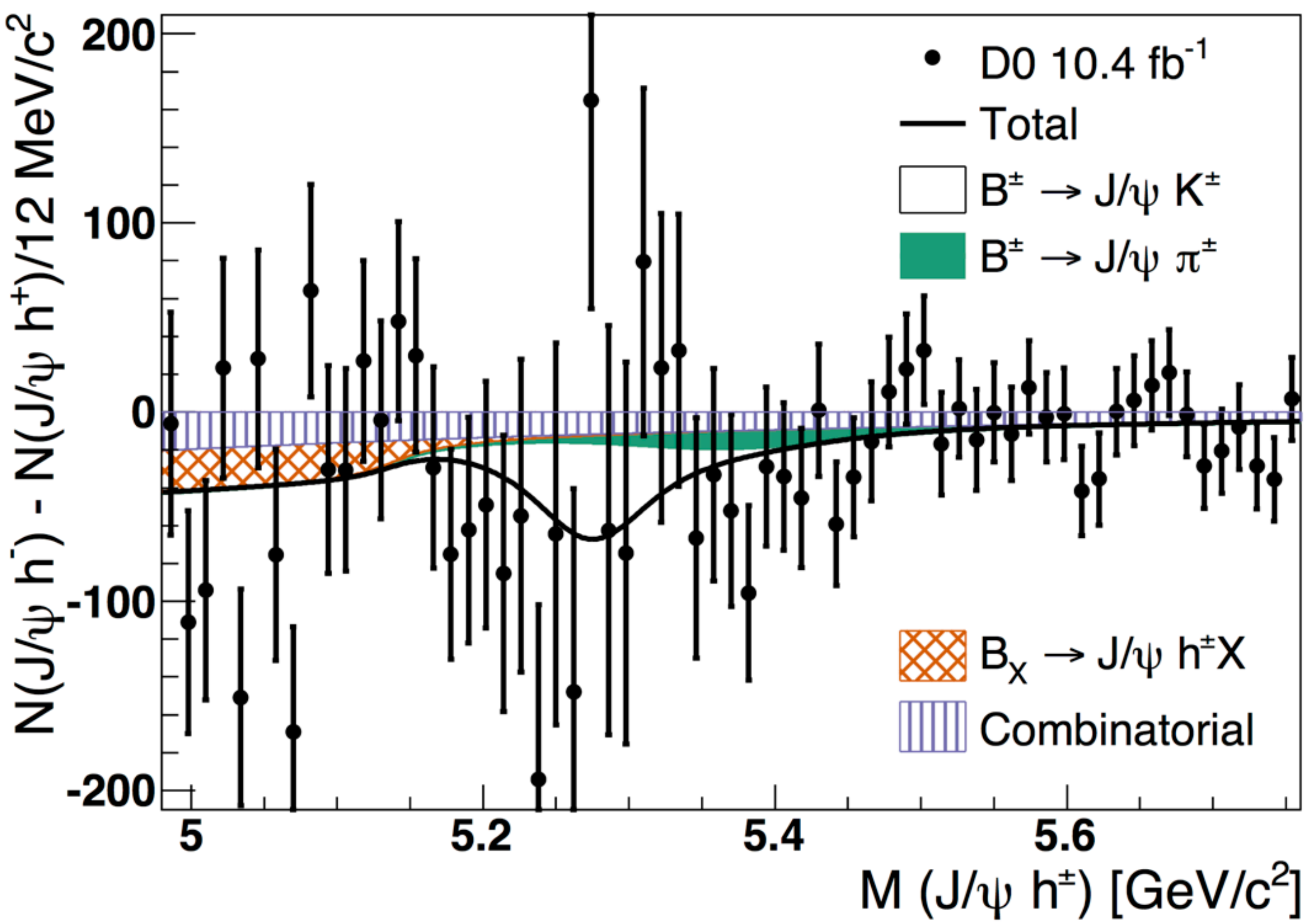
E(m): Combinatorics
exponential background function

Data - Fit


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

Difference

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



Unbinned maximum Likelihood fit of sum and difference.

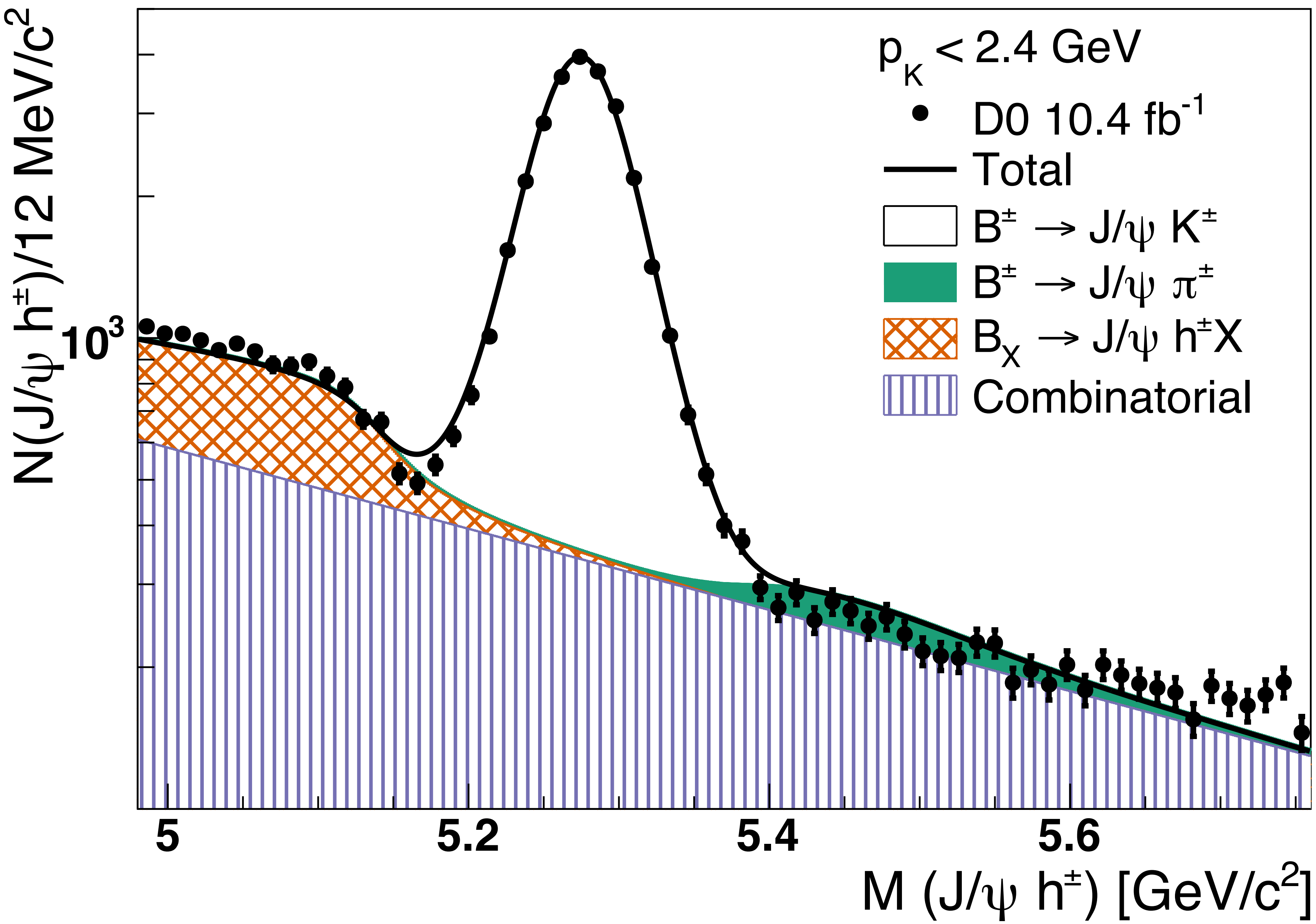
χ^2 = 58.5 for 61 d.o.f.

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

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

Do we need this Fit

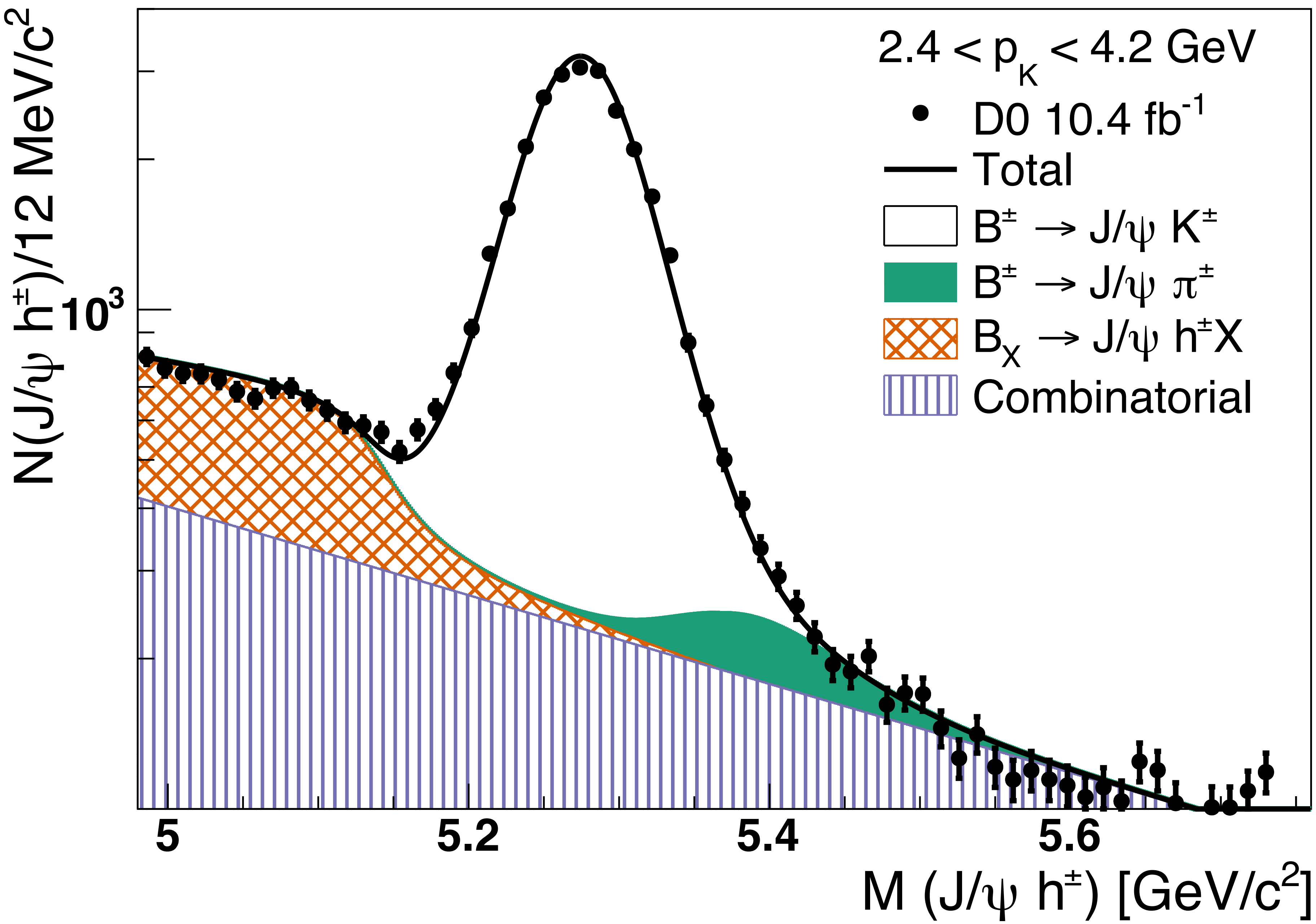
Projection of fit in momentum bins



Width of Signal depends on hadron momentum

Do we need this Fit

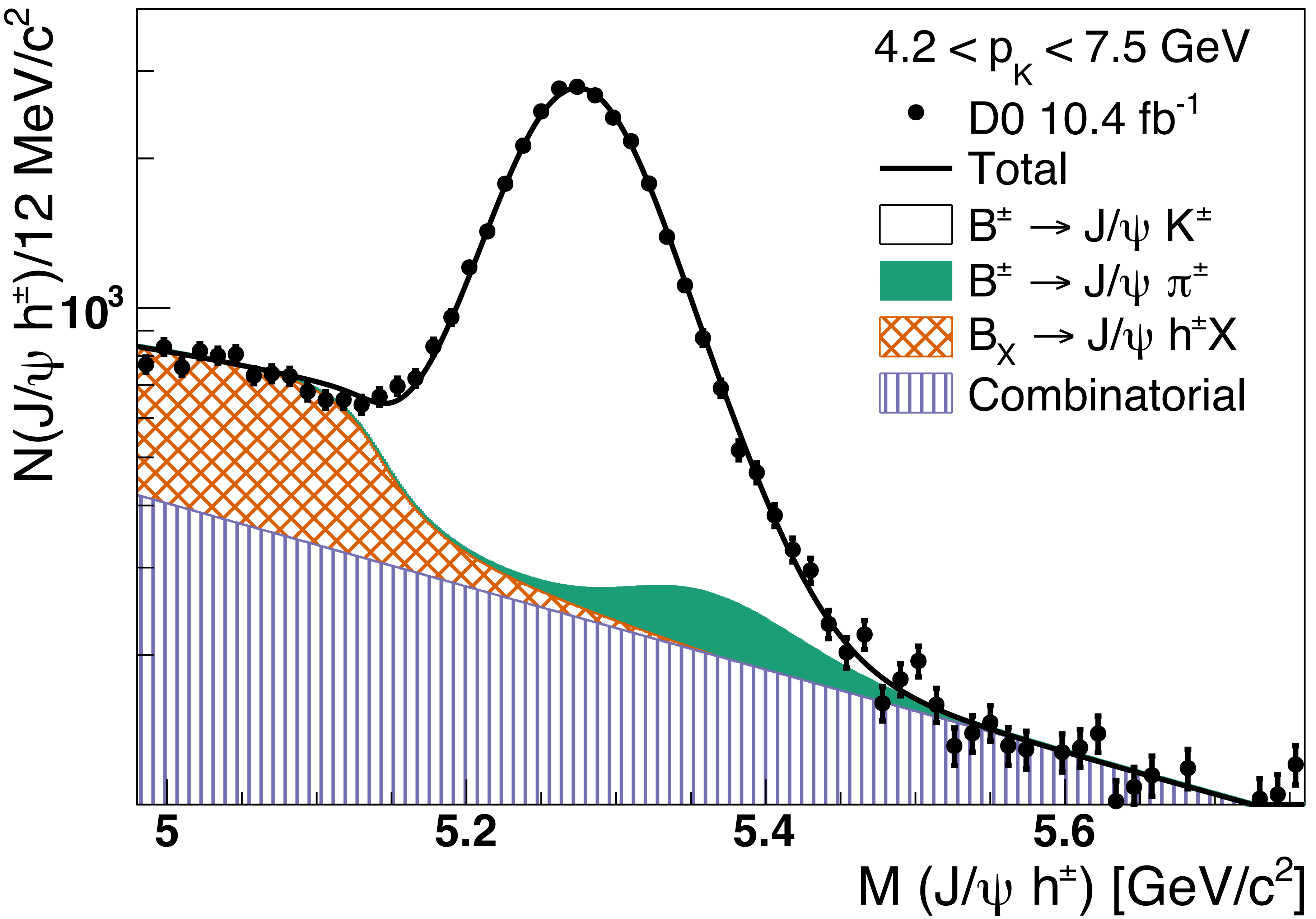
Projection of fit in momentum bins



Width of Signal depends on hadron momentum

Do we need this Fit

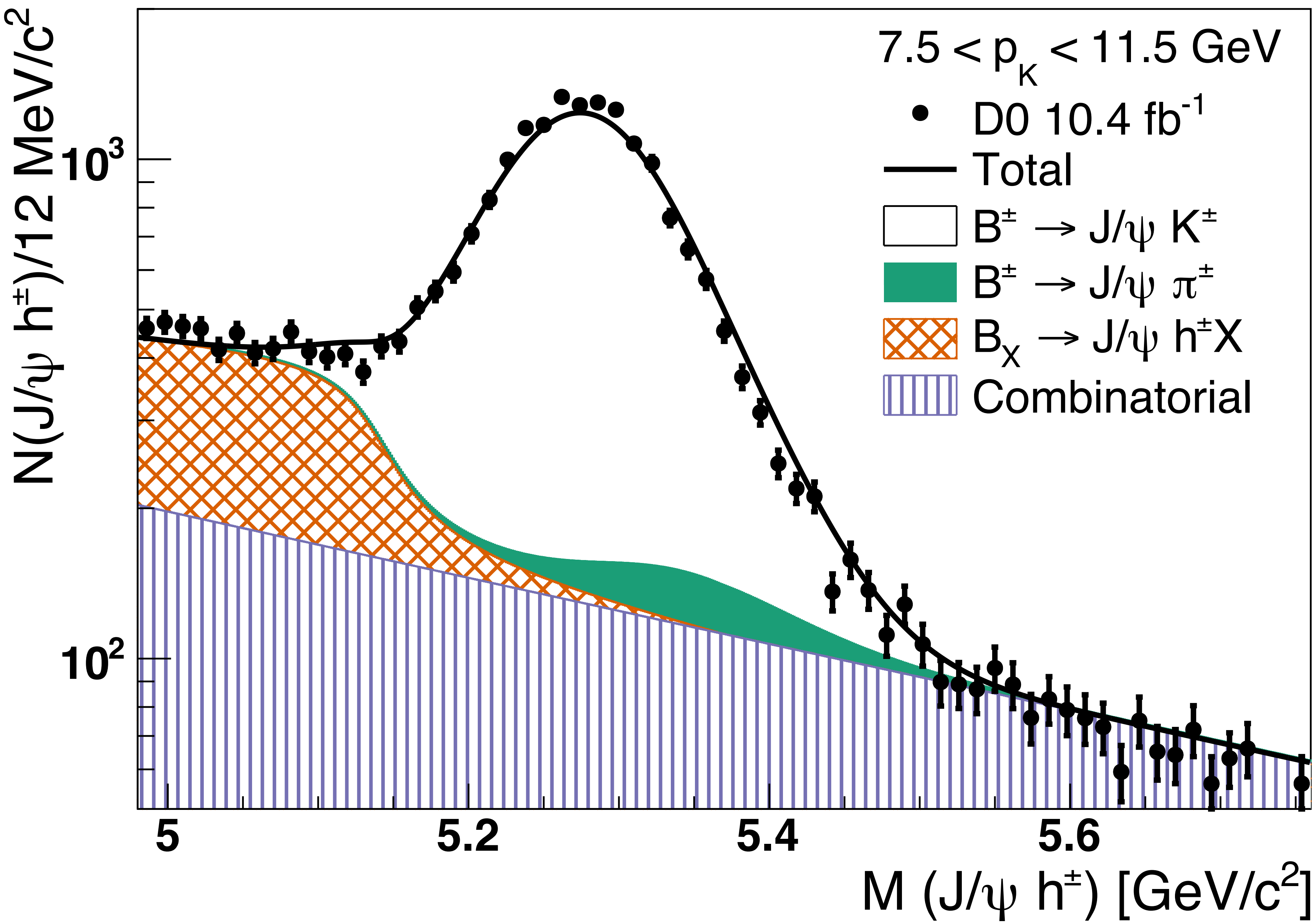
Projection of fit in momentum bins



Width of Signal depends on hadron momentum

Do we need this Fit

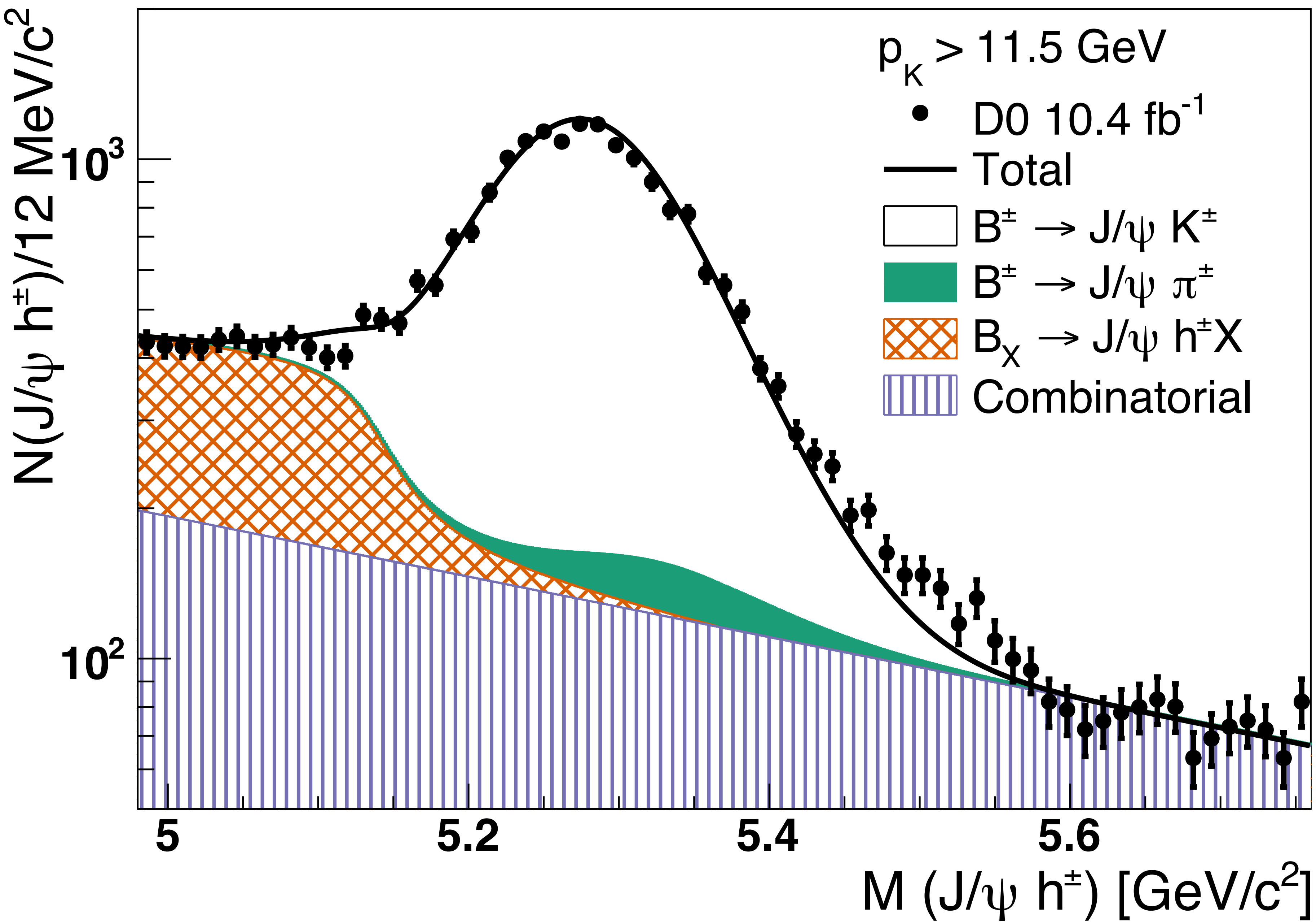
Projection of fit in momentum bins



Width of Signal depends on hadron momentum

Do we need this Fit

Projection of fit in momentum bins



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%.

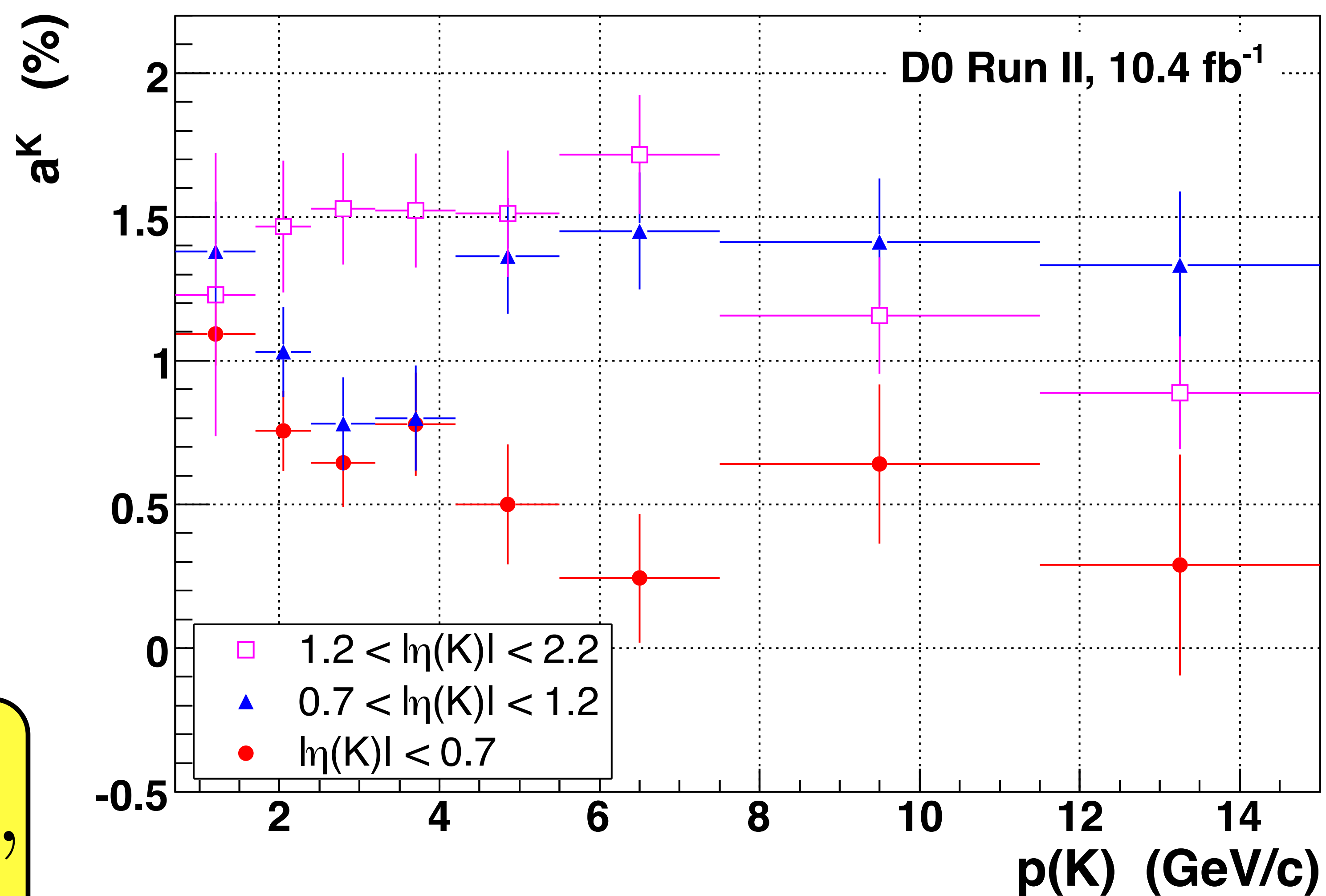
$$A^{J/\psi K}_{\rm raw} = [-0.46 \pm 0.36\,({\rm stat}) \pm 0.046\,({\rm syst})]\,\%,$$
$$A^{J/\psi \pi}_{\rm raw} = [-4.2 \pm 4.4\,({\rm stat}) \pm 1.82\,({\rm syst})]\,\%.$$

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^-)

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

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



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

Final Result

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

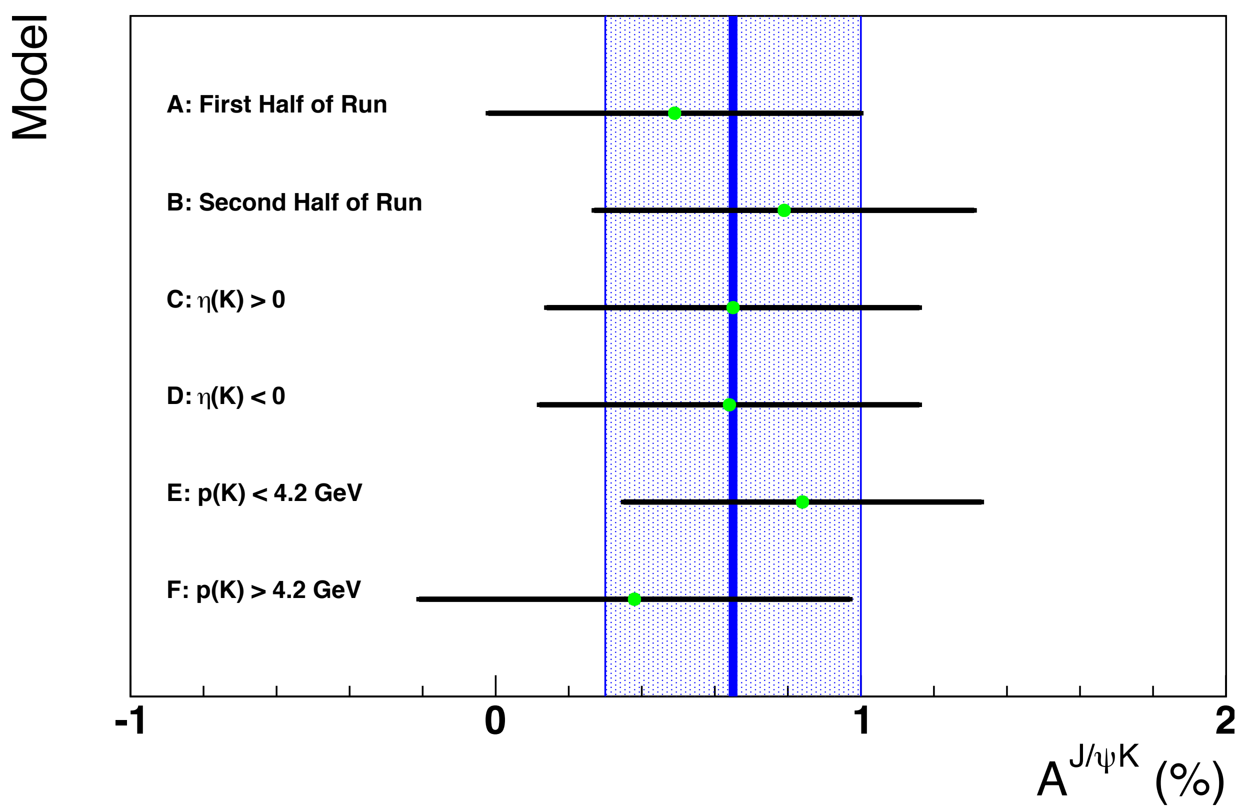
Type of uncertainty	$A^{J/\psi K}$ (%)	$A^{J/\psi \pi}$ (%)
Statistical	0.36	4.4
Mass range	0.022	0.55
Fit function	0.011	0.69
Asymmetry modeling	0.038	1.59
$\Delta A_{\text{tracking}}$	0.05	0.05
ΔA_K	0.043	n/a
Total systematic uncertainty	0.08	1.8
Total uncertainty	0.37	4.8

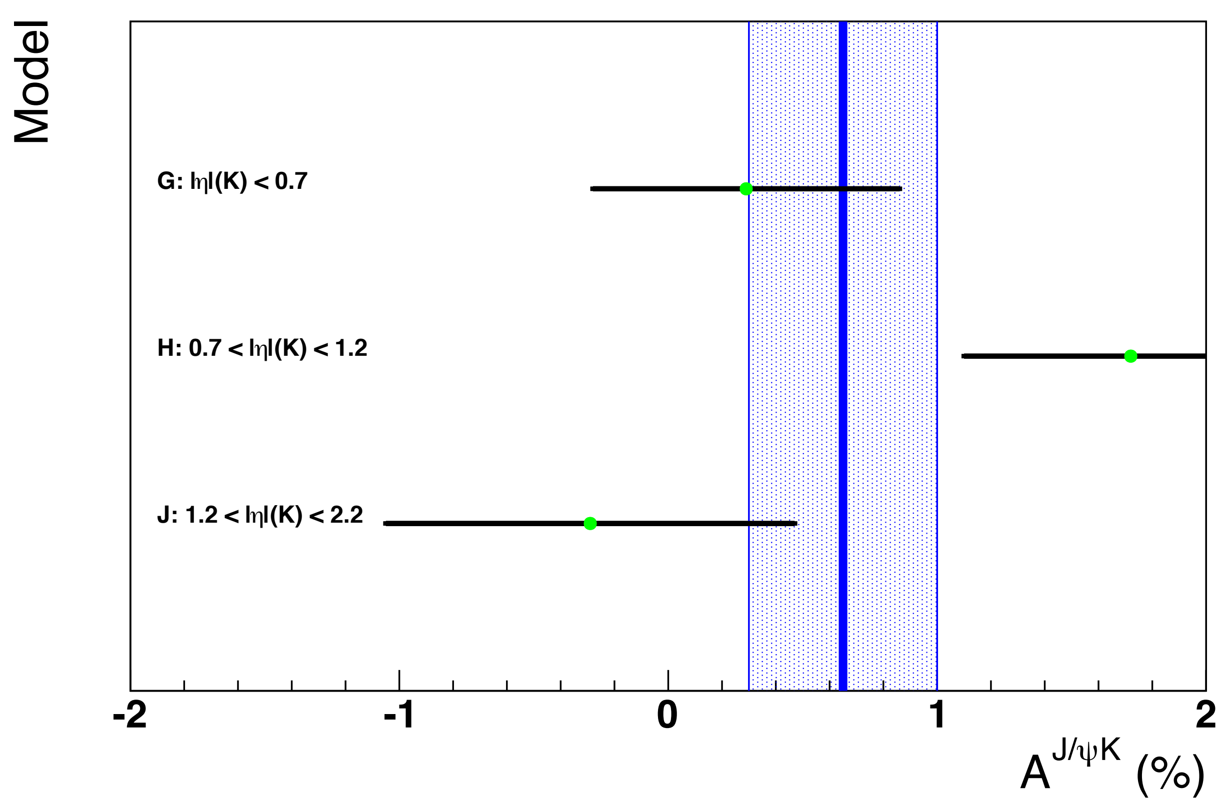
Stability Tests

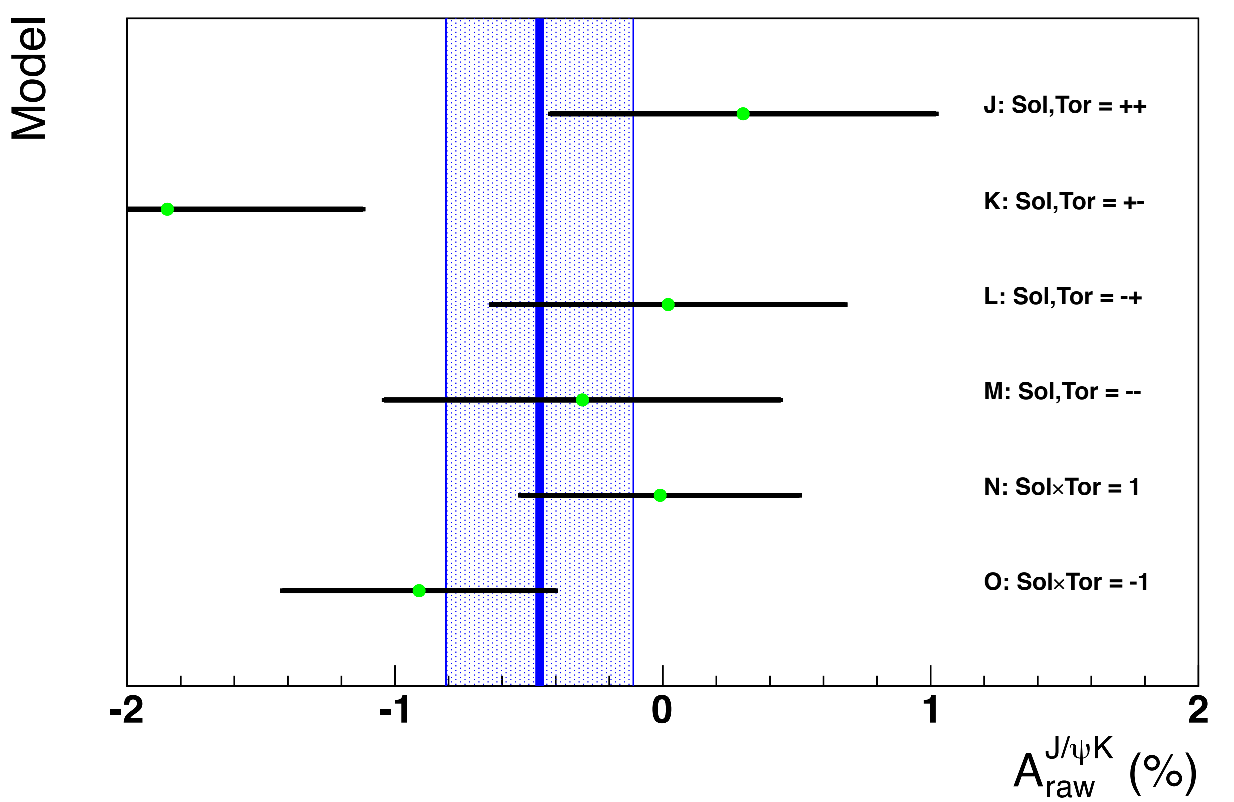
Repeat analysis using pairs of orthogonal sub-sets of the data to check stability

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

All measurements are consistent





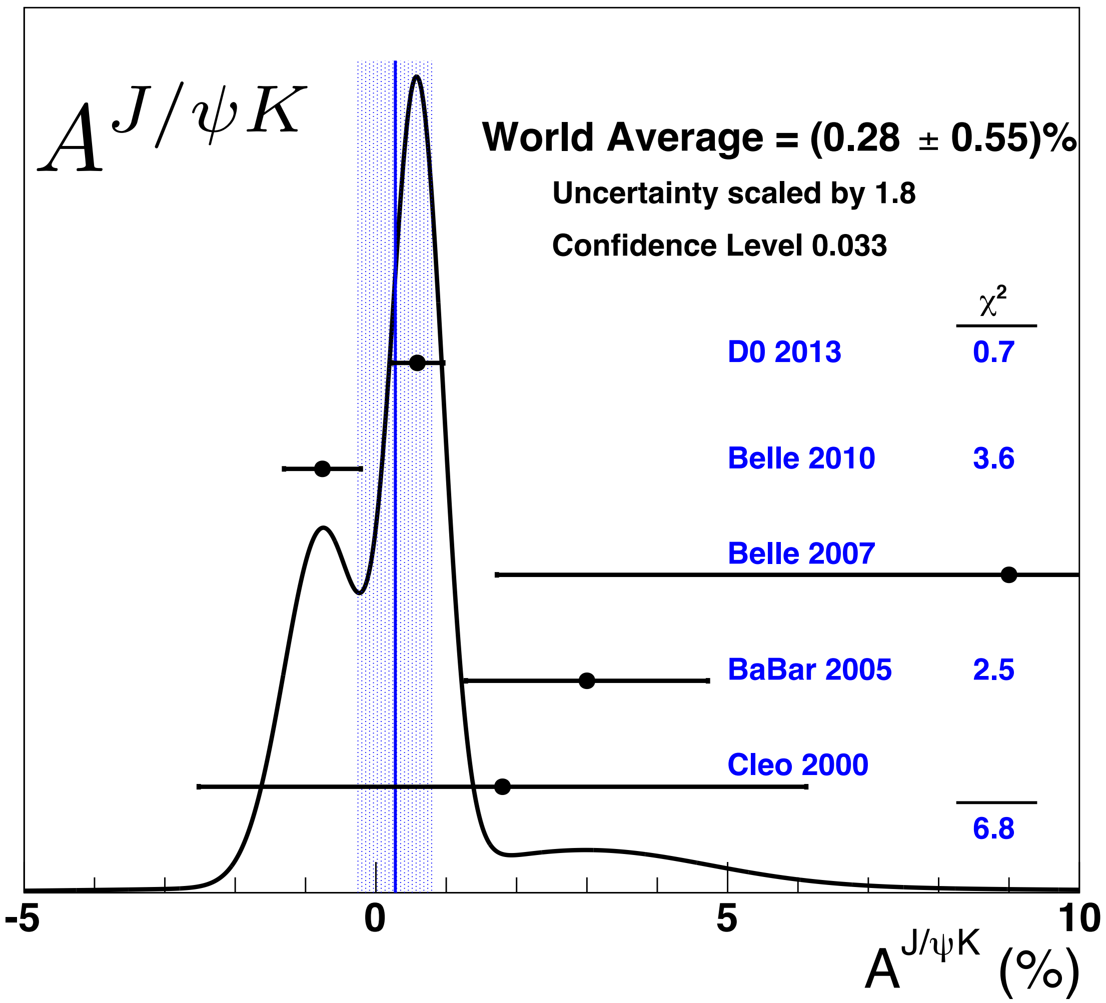


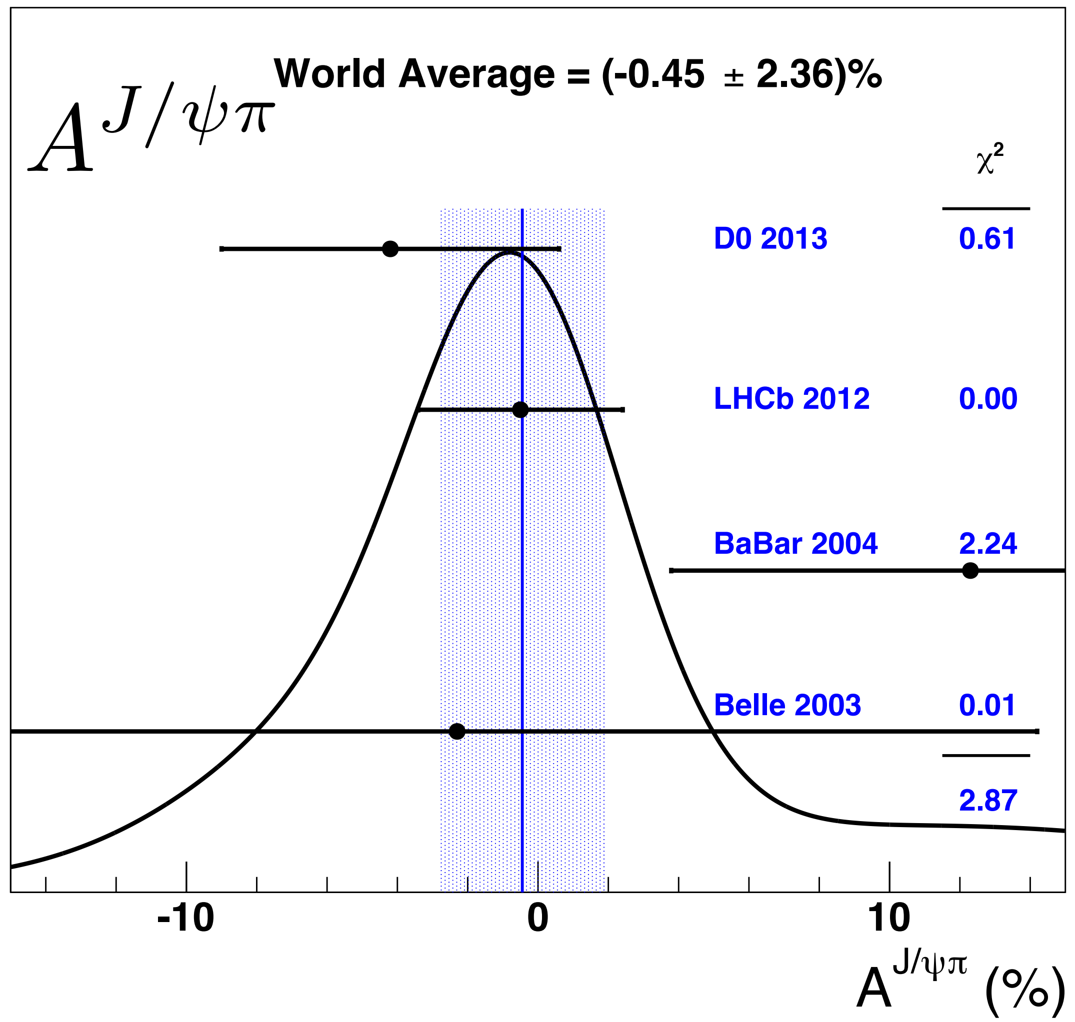
Closure

- 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.