Amplitude analysis in $B \to J/\psi X$ decays

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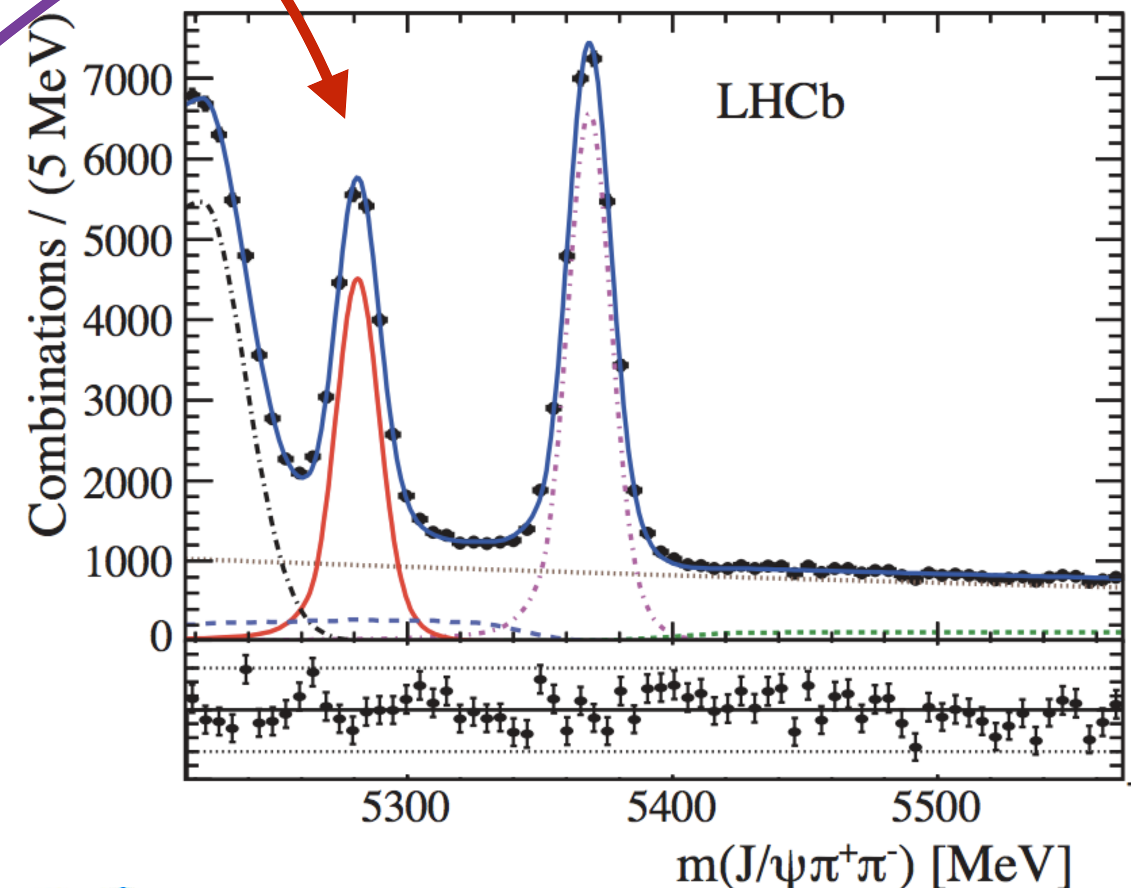
on behalf of the LHCb collaboration

#beauty2014, 14th July

Overview

- Amplitude analysis of $B^0 \to J/\psi\pi^+\pi^-$
  - [arXiv:1404.5673, PRD]
- Amplitude analysis of $B_s \to J/\psi\pi^+\pi^-$
  - [PRD 89, 092006 (2014)]



[arXiv:1404.5673, PRD]

- First observation of $B_c \to J/\psi\, p\bar{p}\pi^+$
  - [LHCb-PAPER-2014-039]

NEW!

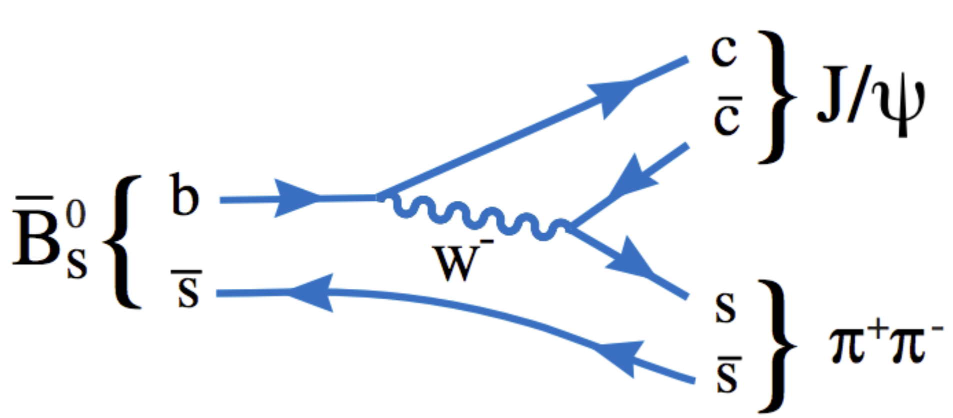
All results use 1fb^{-1} @ 7TeV and 2fb^{-1} @ 8TeV data

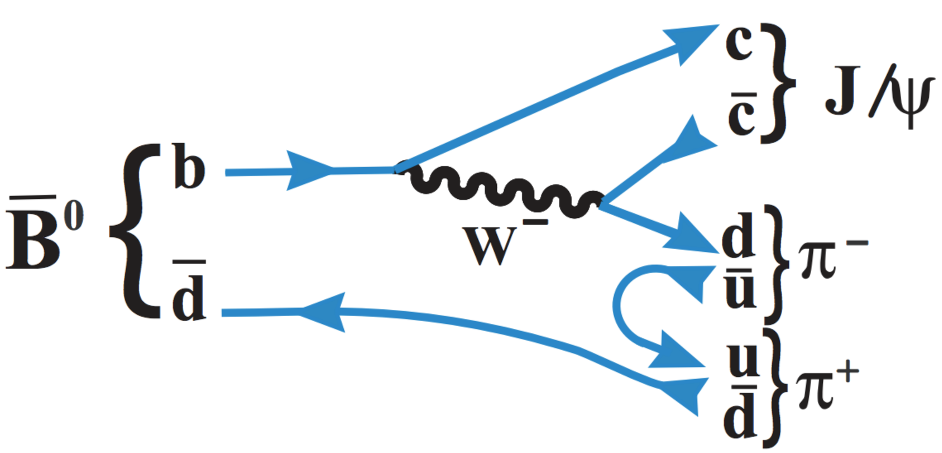
Motivation

- $B^0_{(s)} \to J/\psi\pi^+\pi^-$ decays very useful for CP violation measurements and new physics searches.
- Also excellent place to study substructure of light mesons that decay to $\pi^+\pi^-$.
    - Mass ordering is reversed between the scalar and vector mesons nonets below 2GeV not well understood.

Isospin	$I=0$	$I=1/2$	$I=0$	$I=1$
Scalar mesons	$f_0(500)$	$\kappa(800)$	$f_0(980)$	$a_0(980)$
Vector mesons	$\phi(1020)$	$K^*(892)^0$	$\omega(783)$	$\rho(776)$

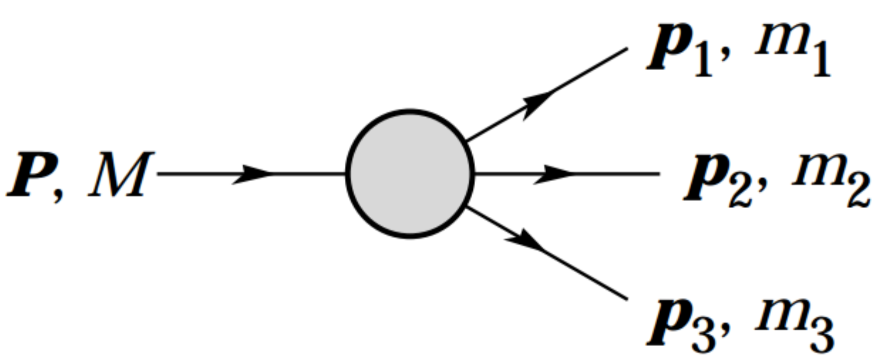
- Are the scalar mesons [$f_0(500)$, $f_0(980)$] $q\bar{q}$ or **tetraquarks** or a mixture?





Reminder about Dalitz plots - 3 body decay

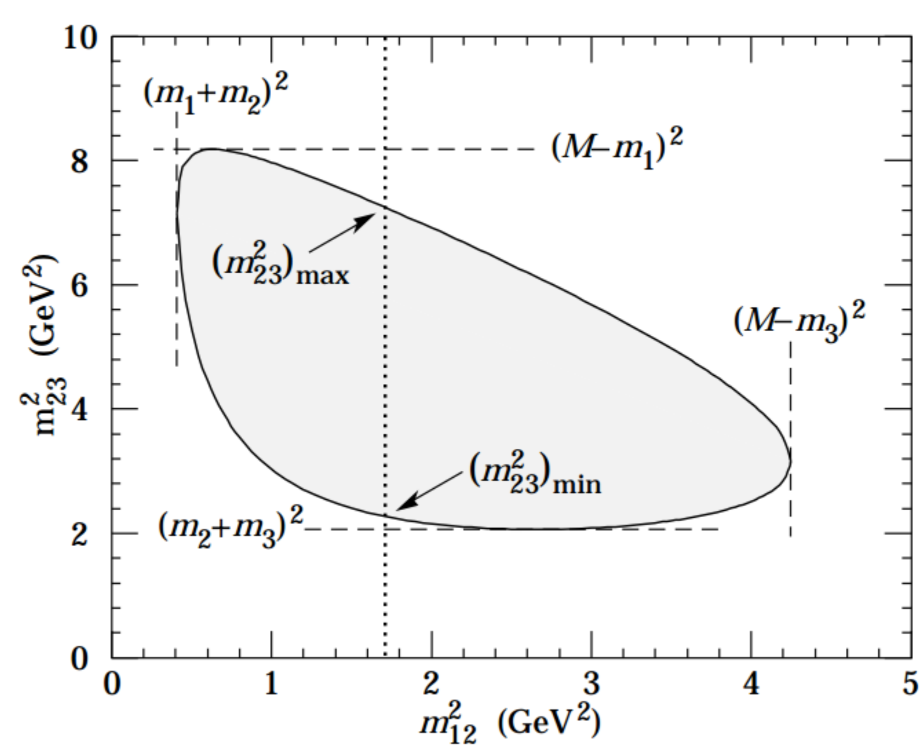
scalar ⟶ 3 scalars



$$d\Gamma = \frac{1}{(2\pi)^3}\frac{1}{32M^3}\overline{|\mathscr{M}|^2}\, dm_{12}^2\, dm_{23}^2$$

Constraints	Degrees of freedom
3 four-vectors	$+12$
All decay in same plane ($p_{i,z} = 0$)	-3
$E_i^2 = m_i^2 + p_i^2$	-3
Energy + momentum conservation	-3
Rotate system in plane	-1
Total	$+2$

- Configuration of decay depends on angular momentum of decay products.
- All dynamical information contained in $|\mathcal{M}|^2$.
- Density plot of m_{12}^2 vs. m_{23}^2 to infer information on $|\mathcal{M}|^2$.

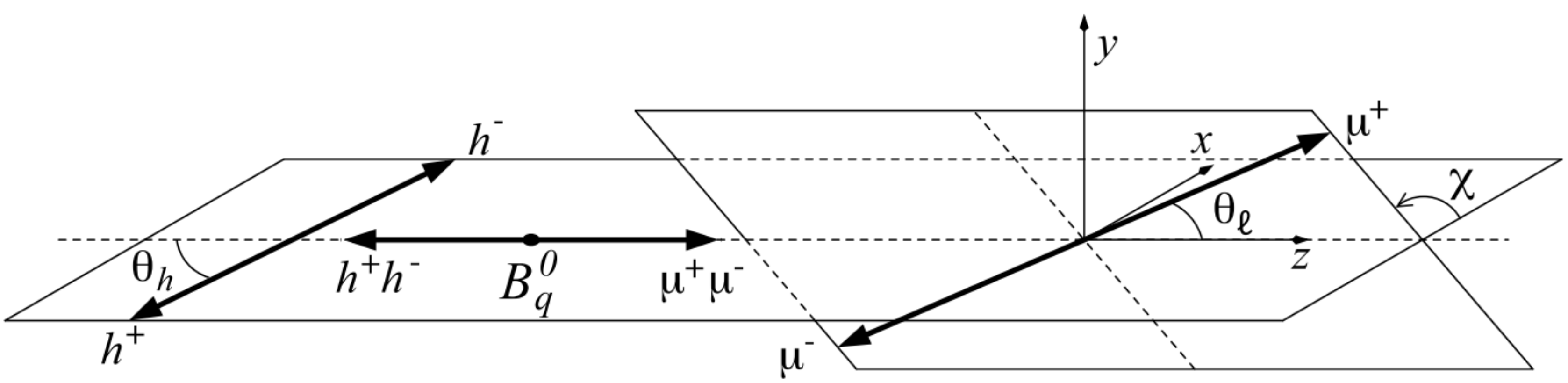


[PDG]

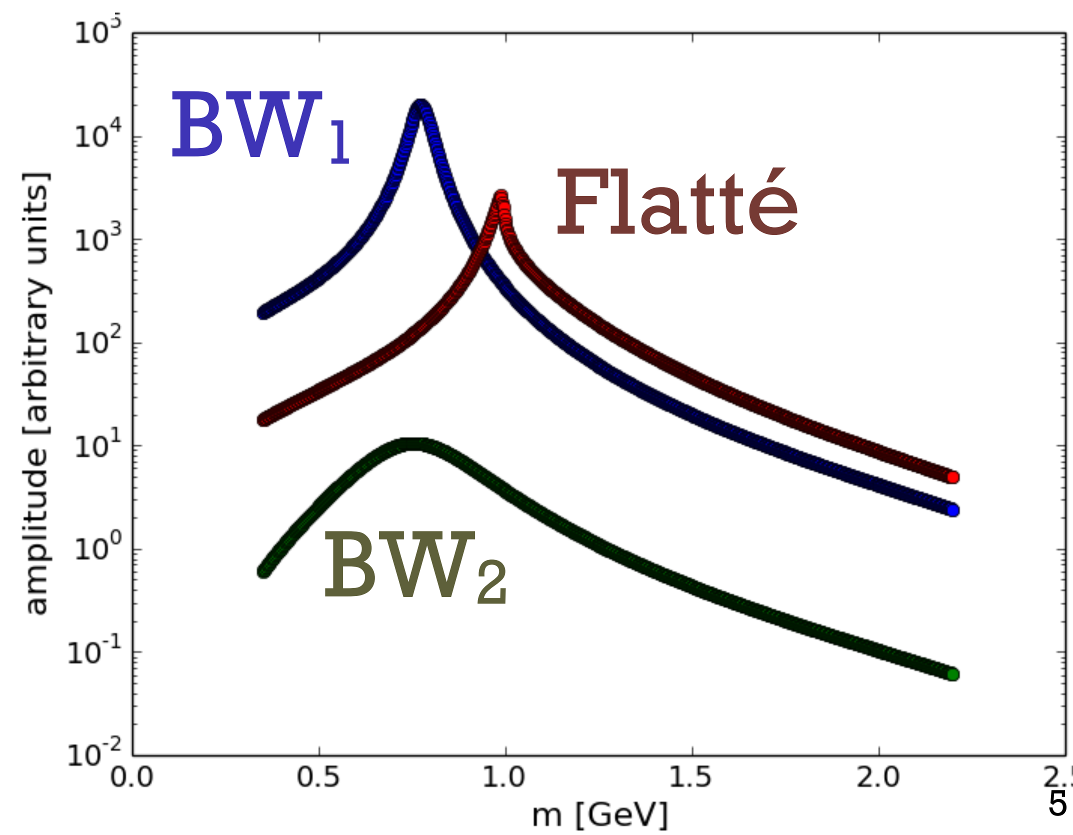
4D amplitude analysis (scalar ⟶ vector scalar scalar)

- $B^0_{(s)} \rightarrow J/\psi\pi^+\pi^-$, $J/\psi \rightarrow \mu^+\mu^-$ so need to consider 3-helicities in final state.
- Use 4 variables to describe the system: m_{hh} and 3 angles $\Omega = (\theta_{hh}, \theta_{J/\psi}, \chi)$.

Constraints	Degrees of freedom
3 four-vectors	+12
All decay in same plane ($p_{i,z} = 0$)	−3
$E_i^2 = m_i^2 + p_i^2$	−3
Energy + momentum conservation	−3
Rotate system in plane	−1
Vector helicity	+2
Total	+4



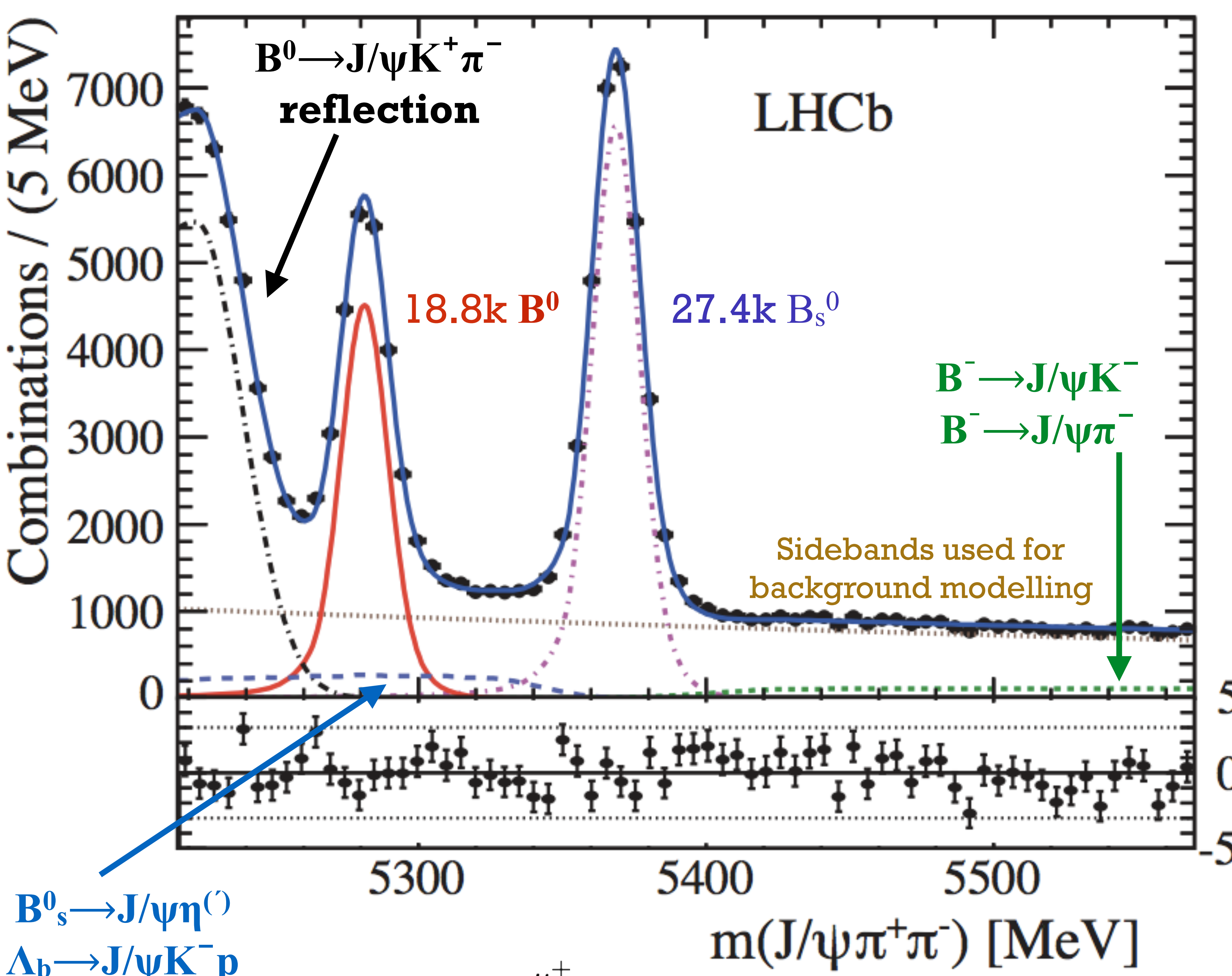
- Use the **Isobar** approach.
- Build amplitude from sum of two-body $\pi^-\pi^+$ resonances.
- Overlapping and interfering Breit-Wigner and Flatté resonances.
- Include efficiency and background.

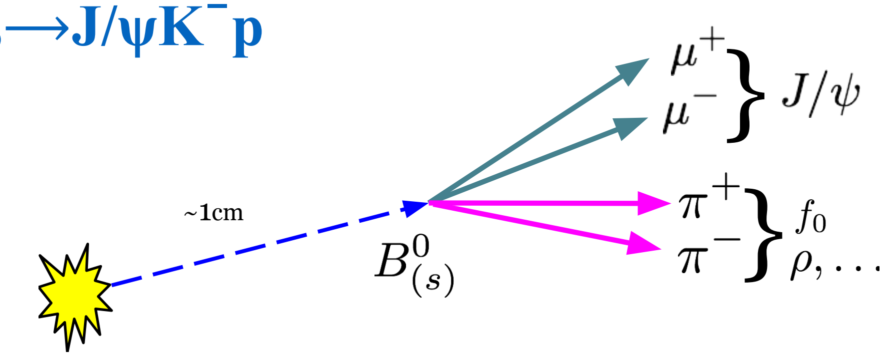


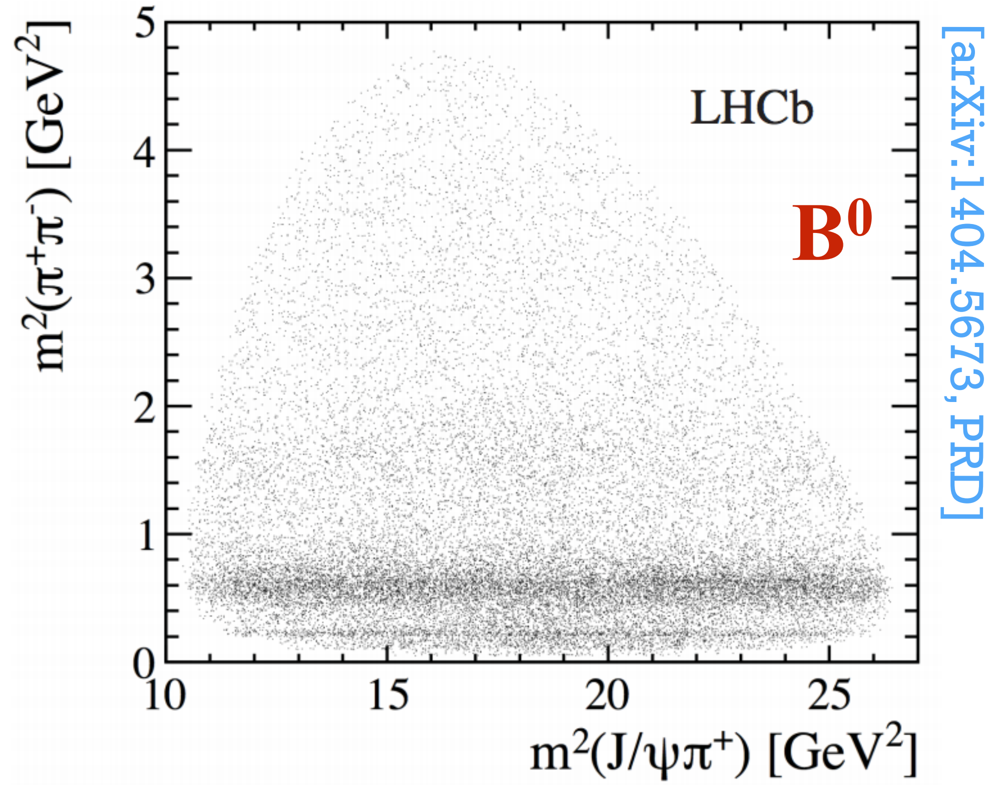
See talk from A. Alves on Z(4430)$^-$

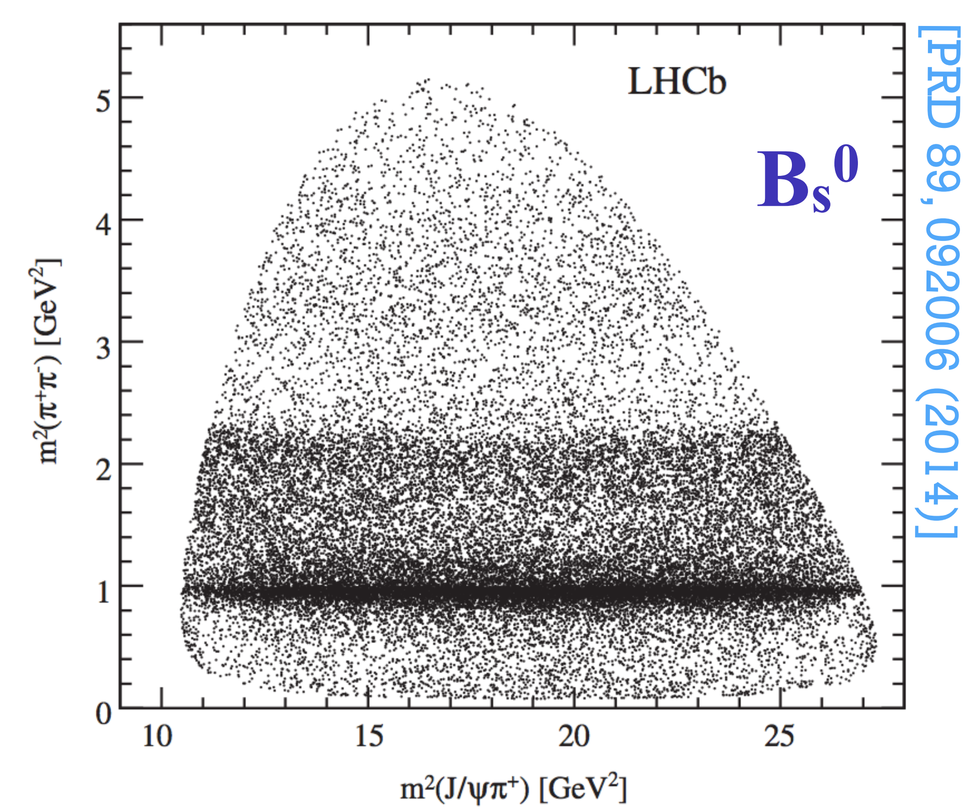
Data sample: $B^0_{(s)} \longrightarrow J/\psi\pi^+\pi^-$

No sign of exotic $J/\psi\pi^+$ resonances

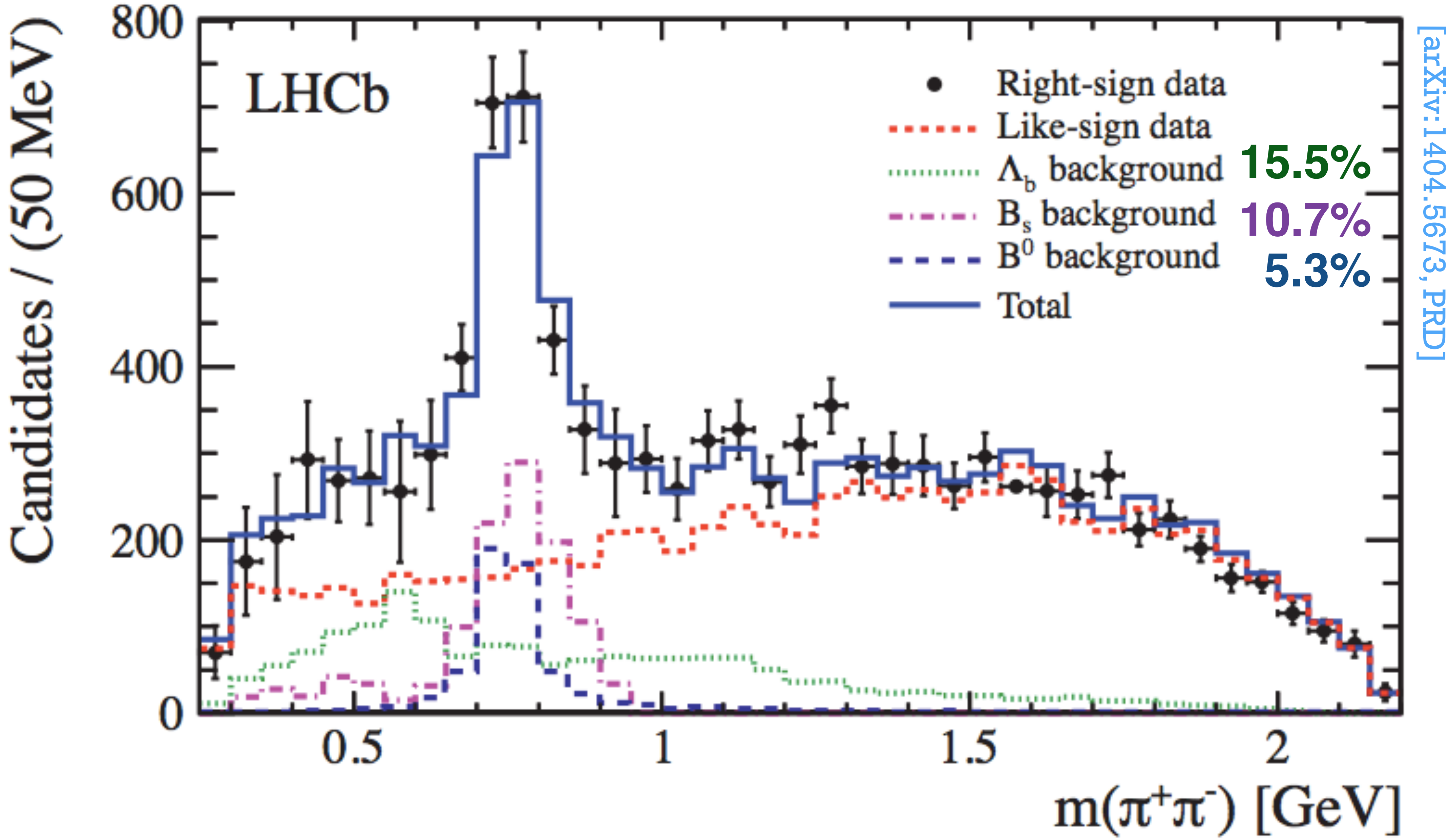








$B^0 \longrightarrow J/\psi\pi^+\pi^-$: background

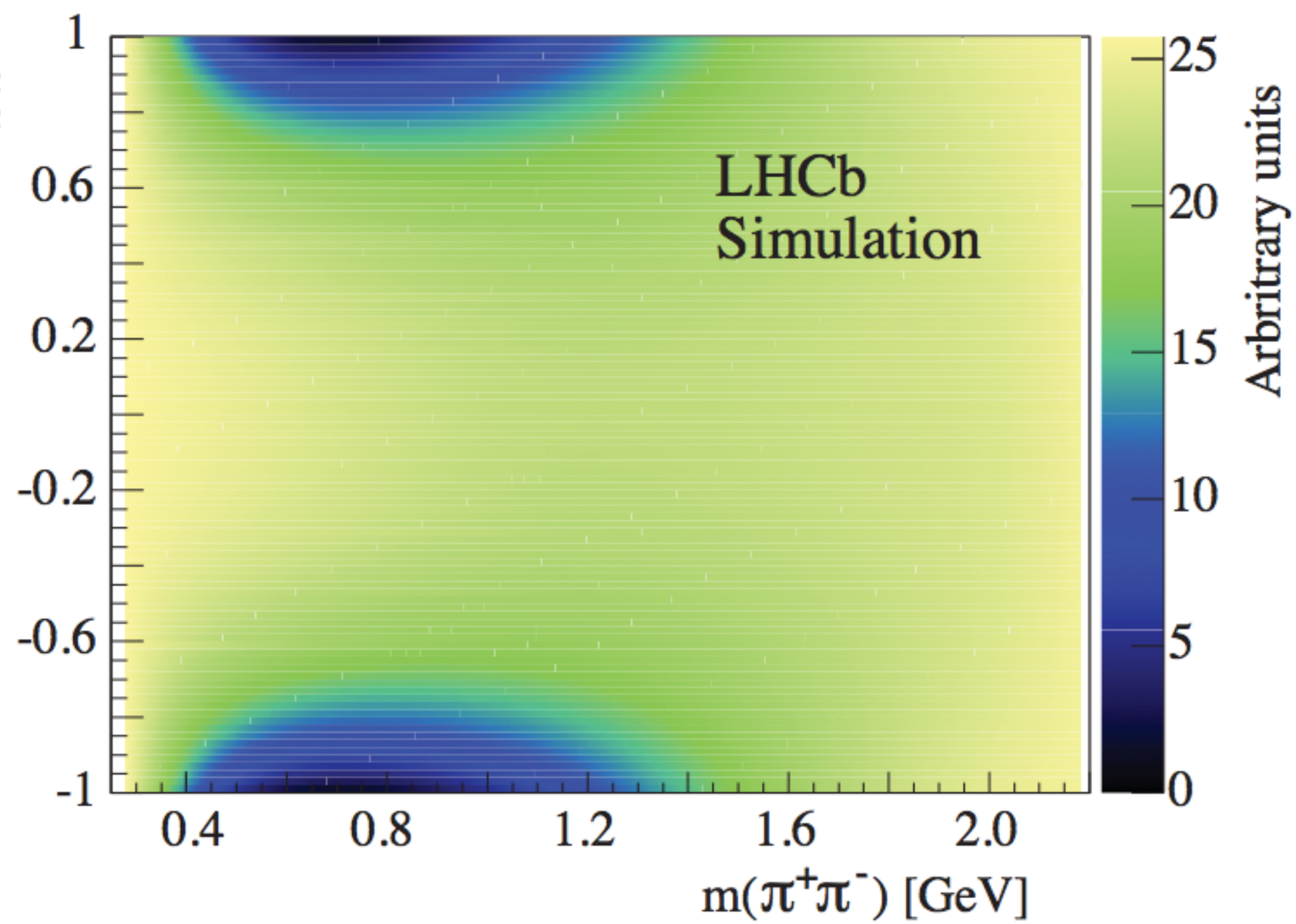


- Main background is combinatorial, taken from same-sign events.
- Use simulation to get shape of partially reconstructed $B^0{}_s$ decays and reflections from B^0 and $\Lambda_{b.}$
- Use mixed sample to get 4D background parameterisation.

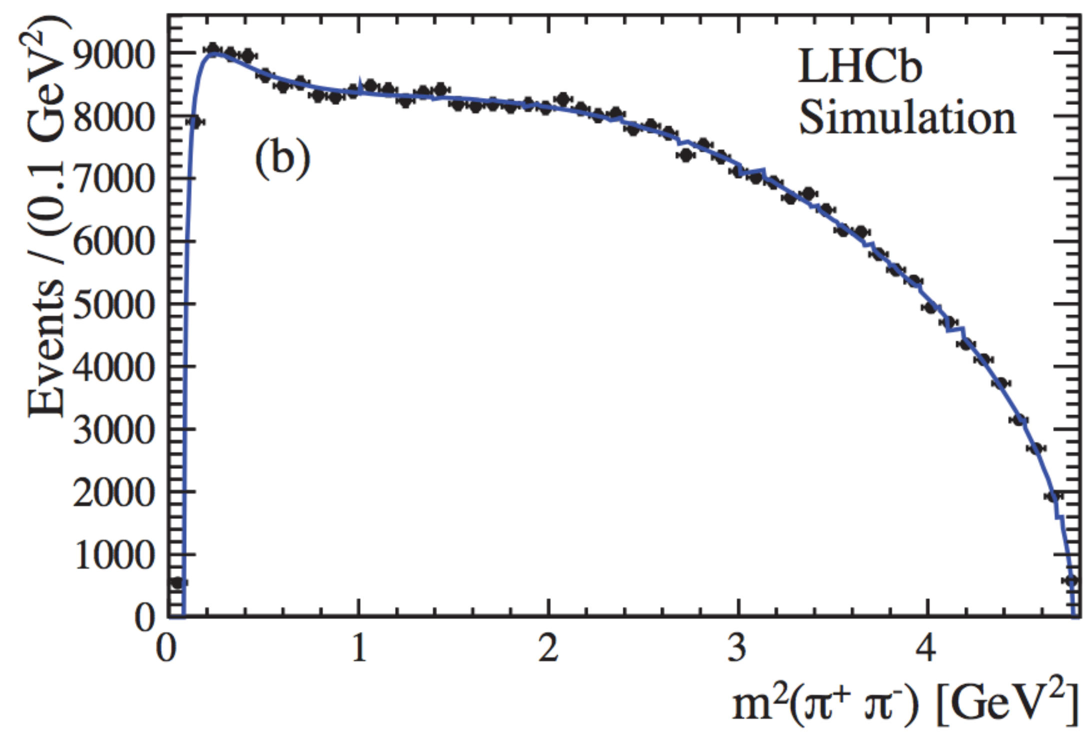
$B^0 \longrightarrow J/\psi\pi^+\pi^-$: efficiency

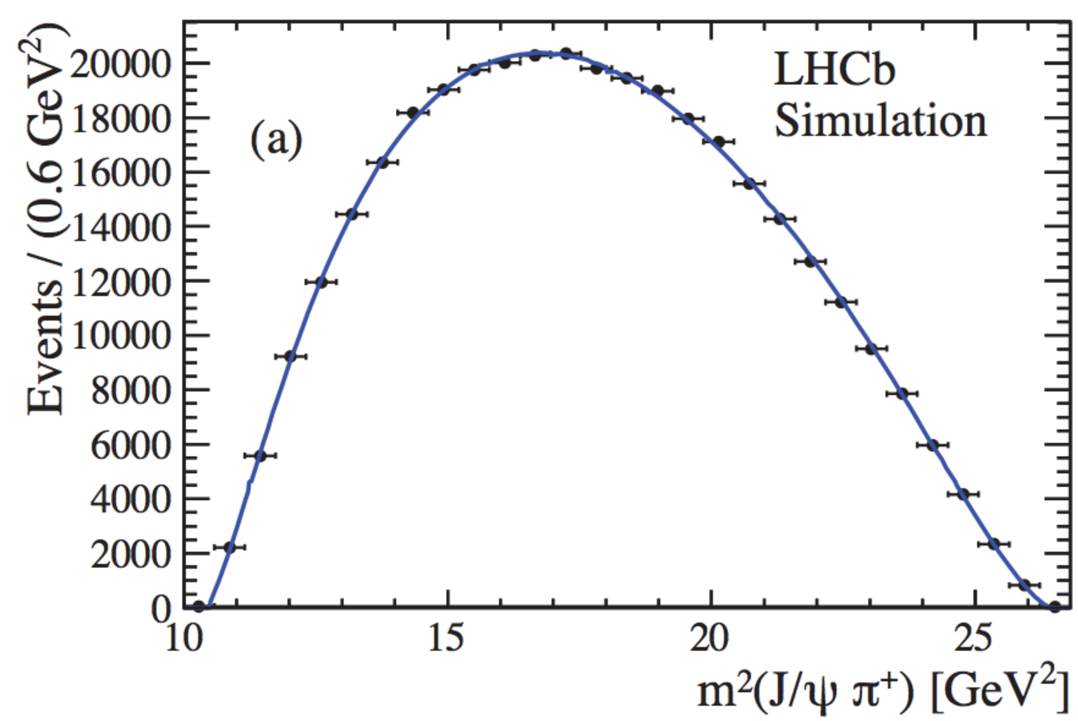
$$\varepsilon(m_{\pi\pi}, \theta_{\pi\pi}, \theta_{J/\psi}, \chi) = \varepsilon(m^2_{J/\psi\pi^+}, m^2_{J/\psi\pi^-}) \times \varepsilon(\theta_{J/\psi}, m_{\pi\pi}) \times \varepsilon(\chi, m_{\pi\pi})$$

- LHCb < 100% efficient at reconstructing the decay particles in 4D space.
- Large simulated signal sample used to model 4D efficiency.
- Use simulation to show that efficiency factorises.



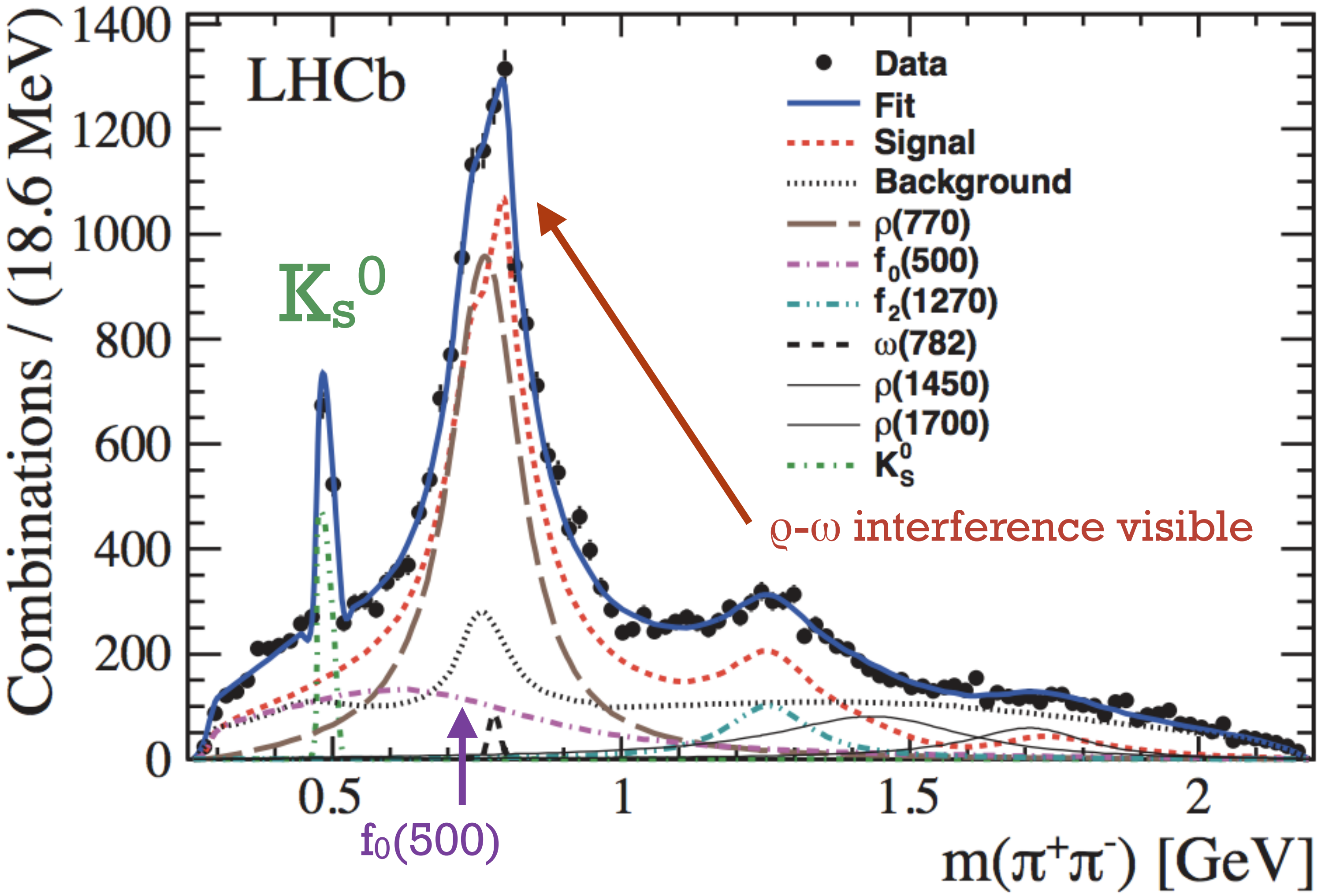
[arXiv:1404.5673, PRD]





$B^0 \to J/\psi \pi^+\pi^-$: amplitude model

[arXiv:1404.5673, PRD]



- Build amplitude from all possible resonances and a non-resonant (NR) component.
- Use Poissonian χ^2 to distinguish models.
- Systematics: alternative models (Bugg and G&S) used for $f_0(500)$ and ϱ resonances.
- Fix resonance mass and width to PDG values.

Baseline model

- 6 resonances
- No NR component
- No $f_0(980)$

Resonance	Spin	Helicity	Resonance formalism	Mass (MeV)	Width (MeV)	Source
$\rho(770)$	1	$0, \pm1$	BW	775.49 ± 0.34	149.1 ± 0.8	PDG [18]
$f_0(500)$	0	0	BW	513 ± 32	335 ± 67	CLEO [26]
$f_2(1270)$	2	$0, \pm1$	BW	1275.1 ± 1.2	$185.1^{+2.9}_{-2.4}$	PDG [18]
$\omega(782)$	1	$0, \pm1$	BW	782.65 ± 0.12	8.49 ± 0.08	PDG [18]
$f_0(980)$	0	0	Flatté	–	–	See text
$\rho(1450)$	1	$0, \pm1$	BW	1465 ± 25	400 ± 60	PDG [18]
$\rho(1700)$	1	$0, \pm1$	BW	1720 ± 20	250 ± 100	PDG [18]
$f_0(1500)$	0	0	BW	1461 ± 3	124 ± 7	LHCb [27]
$f_0(1710)$	0	0	BW	1720 ± 6	135 ± 8	PDG [18]

[Phys. Rev. D 89, 092006 (2014)]

$B^0 \longrightarrow J/\psi\pi^+\pi^-$: fit result

Component	Fit fraction (%)	Transversity fractions (%)		
		$\tau = 0$	$\tau = \parallel$	$\tau = \perp$
$\rho(770)$	$63.1 \pm 2.2^{+3.4}_{-2.2}$	$57.4 \pm 2.0^{+1.3}_{-3.1}$	$23.4 \pm 1.7^{+1.0}_{-1.3}$	$19.2 \pm 1.7^{+3.8}_{-1.2}$
$f_0(500)$	$22.2 \pm 1.2^{+2.6}_{-3.5}$	1	0	0
$f_2(1270)$	$7.5 \pm 0.6^{+0.4}_{-0.6}$	$62 \pm 4^{+2}_{-4}$	$11 \pm 5 \pm 2$	$26 \pm 5^{+4}_{-2}$
$\omega(782)$	$0.68^{+0.20+0.17}_{-0.14-0.13}$	39^{+15+4}_{-13-3}	60^{+12+3}_{-15-4}	$1^{+9}_{-1} \pm 1$
$\rho(1450)$	$11.6 \pm 2.8 \pm 4.7$	$58 \pm 10^{+14}_{-23}$	$27 \pm 13^{+7}_{-11}$	$15 \pm 7^{+28}_{-10}$
$\rho(1700)$	$5.1 \pm 1.2 \pm 3.0$	$40 \pm 11^{+13}_{-23}$	$24 \pm 14^{+7}_{-10}$	$36 \pm 14^{+28}_{-9}$

[arXiv:1404.5673, PRD]

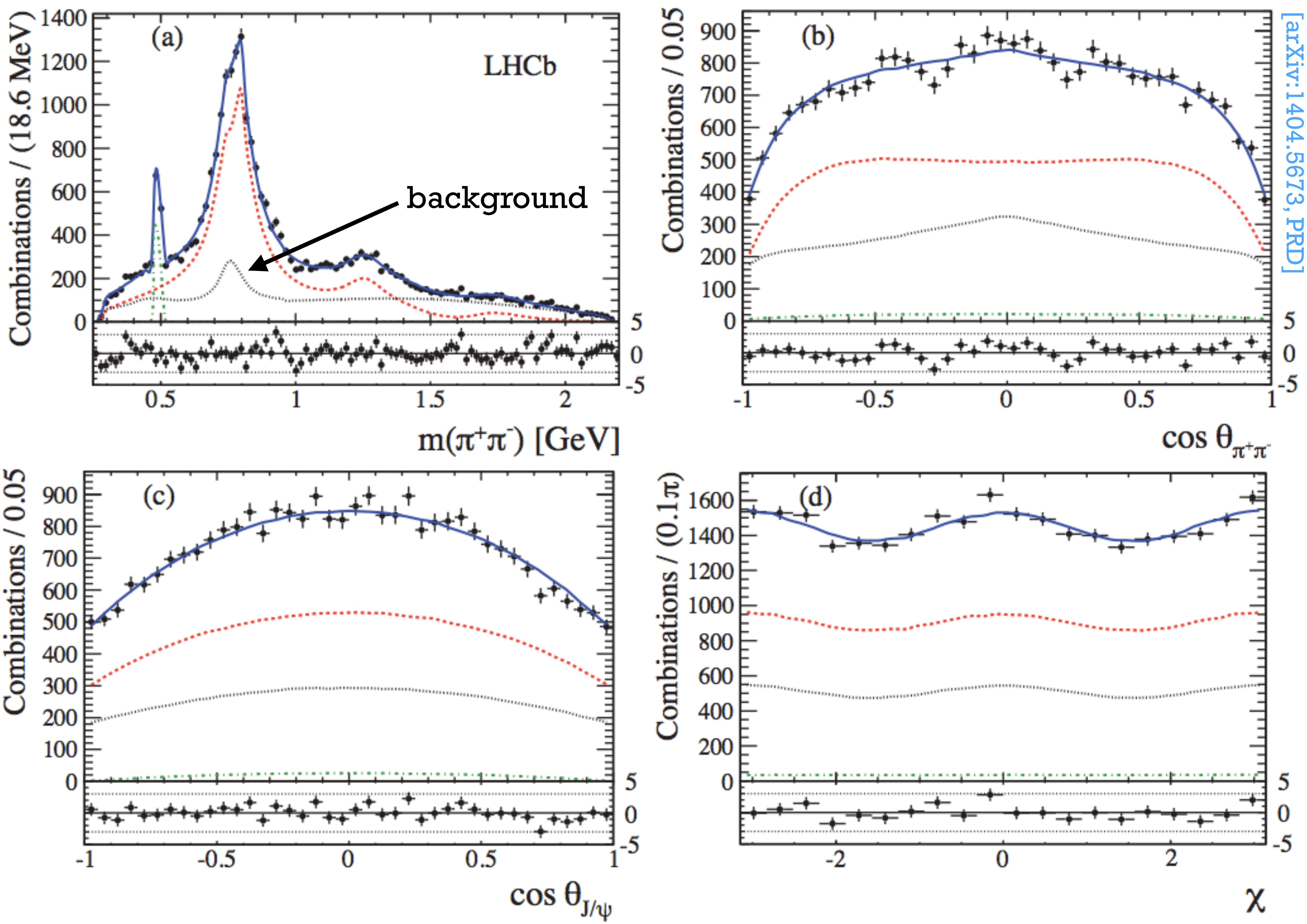
$$f_i = \frac{\int |A_i(m_{\pi\pi}, \Omega)|^2 dm_{\pi\pi} d\Omega}{\int |\sum_k A_k(m_{\pi\pi}, \Omega)|^2 dm_{\pi\pi} d\Omega}$$

- Baseline model keeps resonances with fit fractions >3σ.
- Main systematics come from model variation, efficiency parameterisation and PDG mass/width of resonances.
- **CP-even fraction is 56.0%.**
  - Future CP violation measurements possible.

Transversity basis describes angular momentum states in a basis of CP eigenstates

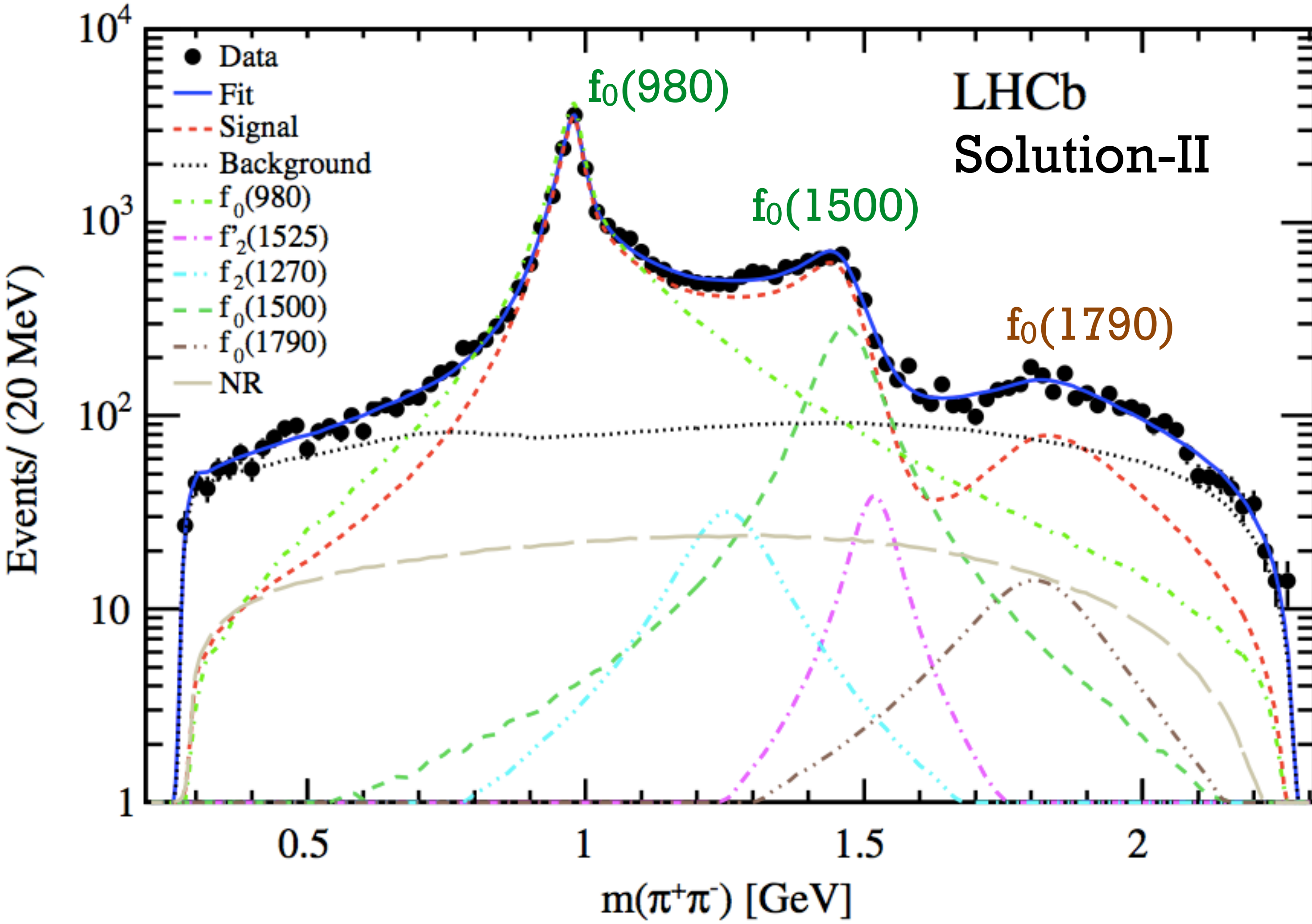
Spin	η_0	$\eta_\parallel$	$\eta_\perp$
0	-1		
1	1	1	-1
2	-1	-1	1

$B^0 \longrightarrow J/\psi\pi^+\pi^-$: fit projections



$B^0_s \to J/\psi\pi^+\pi^-$: amplitude model

[PRD 89, 092006 (2014)]



Component	Solution I	Solution II
$f_0(980)$	$70.3 \pm 1.5^{+0.4}_{-5.1}$	$92.4 \pm 2.0^{+0.8}_{-16.0}$
$f_0(1500)$	$10.1 \pm 0.8^{+1.1}_{-0.3}$	$9.1 \pm 0.9 \pm 0.3$
$f_0(1790)$	$2.4 \pm 0.4^{+5.0}_{-0.2}$	$0.9 \pm 0.3^{+2.5}_{-0.1}$
$f_2(1270)_0$	$0.36 \pm 0.07 \pm 0.03$	$0.42 \pm 0.07 \pm 0.04$
$f_2(1270)_\parallel$	$0.52 \pm 0.15^{+0.05}_{-0.02}$	$0.42 \pm 0.13^{+0.11}_{-0.02}$
$f_2(1270)_\perp$	$0.63 \pm 0.34^{+0.16}_{-0.08}$	$0.60 \pm 0.36^{+0.12}_{-0.09}$
$f'_2(1525)_0$	$0.51 \pm 0.09^{+0.05}_{-0.04}$	$0.52 \pm 0.09^{+0.05}_{-0.04}$
$f'_2(1525)_\parallel$	$0.06^{+0.13}_{-0.04} \pm 0.01$	$0.11^{+0.16+0.03}_{-0.07-0.04}$
$f'_2(1525)_\perp$	$0.26 \pm 0.18^{+0.06}_{-0.04}$	$0.26 \pm 0.22^{+0.06}_{-0.05}$
NR	$\cdots$	$5.9 \pm 1.4^{+0.7}_{-4.6}$
Sum	85.2	110.6
$-\ln \mathcal{L}$	−93738	−93739
χ^2/n.d.f.	2005/1822	2008/1820

CP-even

- D-wave [$f_2(1270)$, $f_2'(1525)$] fraction is 2.3% in both solutions.
- Systematics: alternative model including $\rho(770)$ resonance.

- **CP-even fraction < 2.3% @ 95% CL.**
  - CP violation measurement with $B^0_s \to J/\psi\pi^+\pi^-$
  - See talk by P. Clarke, [arXiv:1405.4140]

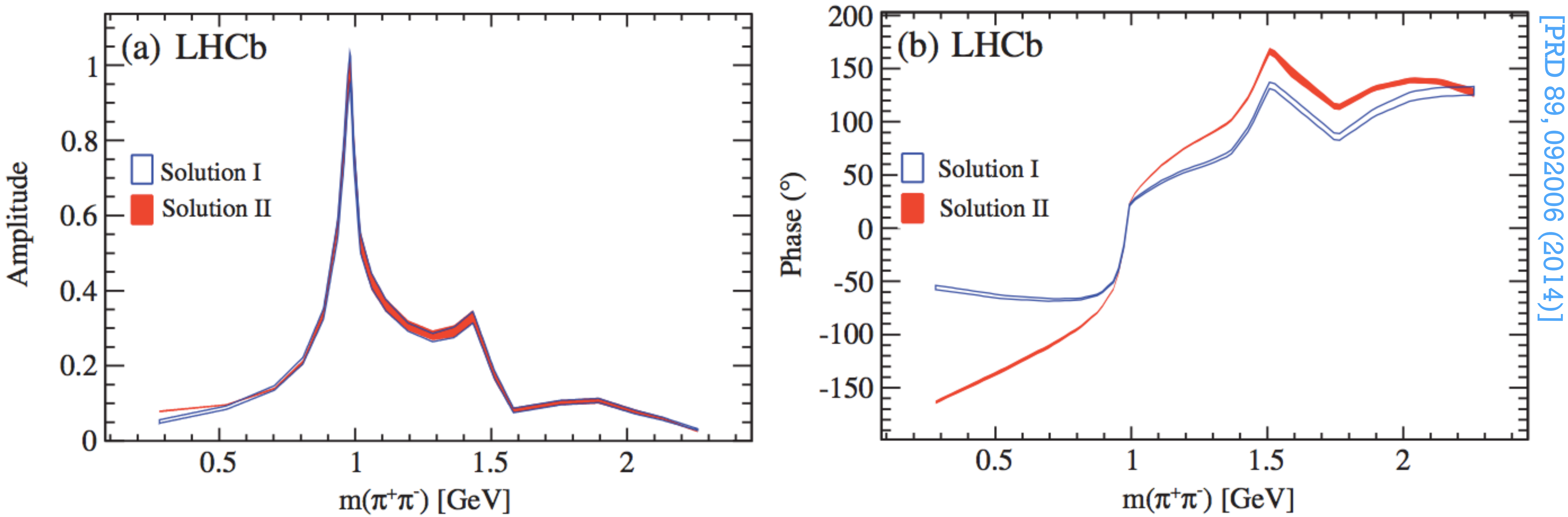
Two suitable models

- Sol-I without NR; Sol-II with NR
- 5 resonances
- No significant $f_0(500)$, $\rho(770)$

$B^0_s \to J/\psi\pi^+\pi^-$: S-wave dominates

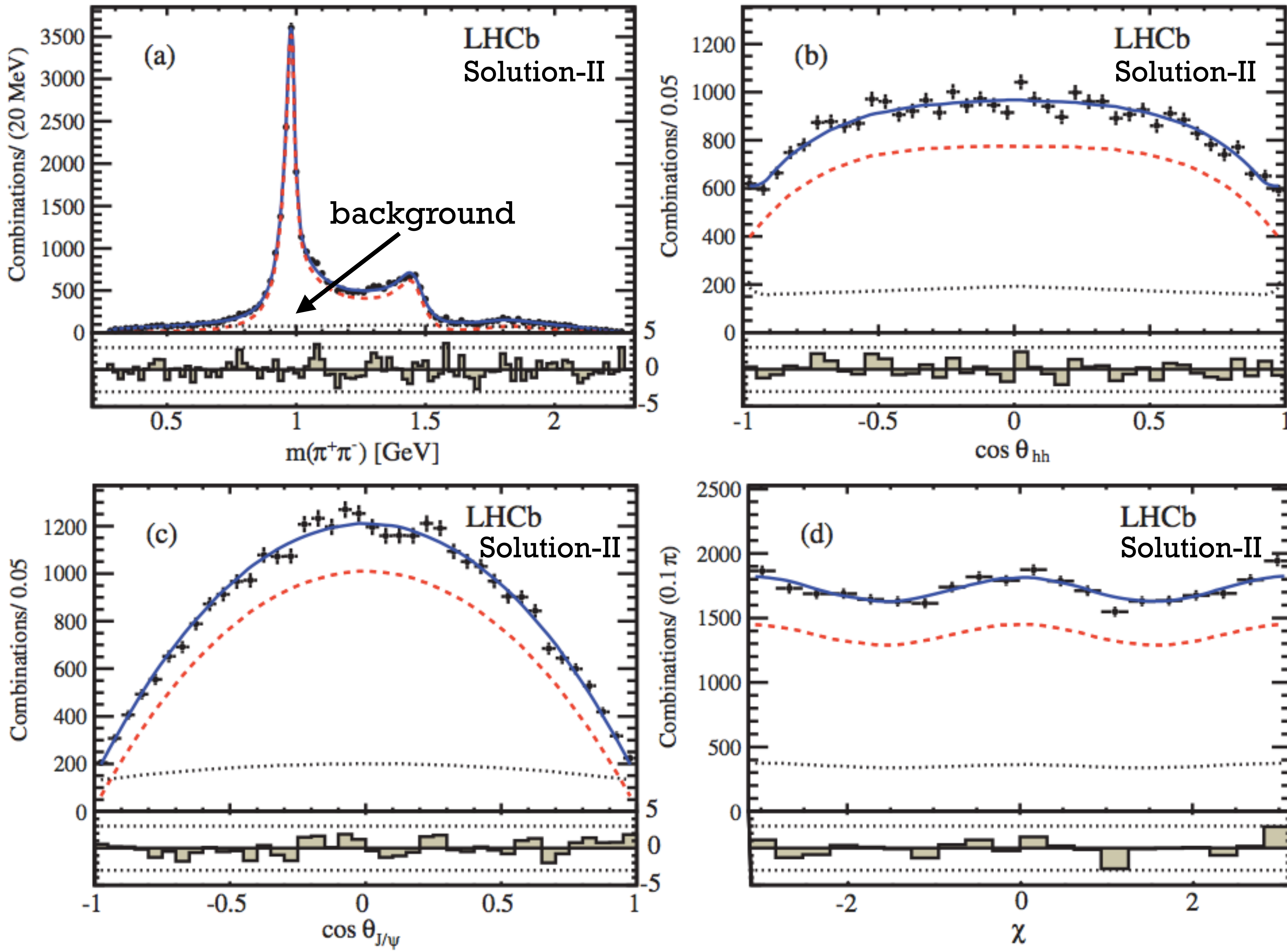
- Two S-wave solutions.
- Plot amplitude and phase in bins of $m(\pi^+\pi^-)$.
  - **Consistent** amplitude but **different** phase
- Phase cannot be well determined due to lack of P&D waves.

Component	Solution I	Solution II
$f_0(980)$	$70.3 \pm 1.5^{+0.4}_{-5.1}$	$92.4 \pm 2.0^{+0.8}_{-16.0}$
$f_0(1500)$	$10.1 \pm 0.8^{+1.1}_{-0.3}$	$9.1 \pm 0.9 \pm 0.3$
$f_0(1790)$	$2.4 \pm 0.4^{+5.0}_{-0.2}$	$0.9 \pm 0.3^{+2.5}_{-0.1}$



Width of curve represents statistical uncertainty

$B^0_s \longrightarrow J/\psi\pi^+\pi^-$: fit projections



[PRD 89, 092006 (2014)]

Light quark spectroscopy with $B^0_{(s)} \to J/\psi\pi^+\pi^-$

- Are the scalar mesons [$\sigma = f_0(500)$, $f_0 = f_0(980)$] **$q\bar{q}$** or **tetraquarks** or a mixture?

Scalar meson mixing

$$|f_0(980)\rangle = \cos\varphi_m|s\bar{s}\rangle + \sin\varphi_m|n\bar{n}\rangle$$
$$|f_0(500)\rangle = -\sin\varphi_m|s\bar{s}\rangle + \cos\varphi_m|n\bar{n}\rangle,$$
$$\text{where } |n\bar{n}\rangle \equiv \frac{1}{\sqrt{2}}\left(|u\bar{u}\rangle + |d\bar{d}\rangle\right).$$

$$|f_0(980)\rangle = \frac{1}{\sqrt{2}}\left(|[su][\bar{s}\,\bar{u}]\rangle + |[sd][\bar{s}\bar{d}]\rangle\right)$$
$$|f_0(500)\rangle = |[ud][\bar{u}\bar{d}]\rangle.$$

[Fleischer, Knegjens Eur.Phys.J. C71 (2011) 1832]

Light quark spectroscopy with $B^0_{(s)} \to J/\psi \pi^+ \pi^-$

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$$|f_0(980)\rangle = \frac{1}{\sqrt{2}}\left(|[su][\bar{s}\,\bar{u}]\rangle + |[sd][\bar{s}\bar{d}]\rangle\right)$$
$$|f_0(500)\rangle = |[ud][\bar{u}\bar{d}]\rangle.$$

[Fleischer, Knegjens Eur.Phys.J. C71 (2011) 1832]

B^0

$$\frac{\Gamma(\bar{B}^0 \to J/\psi\, f_0)}{\Gamma(\bar{B}^0 \to J/\psi\, \sigma)} = \frac{|F^{f_0}_{B^0}(m^2_{J/\psi})|^2}{|F^{\sigma}_{B^0}(m^2_{J/\psi})|^2} \frac{\Phi^{f_0}_{B^0}}{\Phi^{\sigma}_{B^0}} \times r_{B0}$$

B^0_s

$$\frac{\Gamma(\bar{B}^0_s \to J/\psi\, \sigma)}{\Gamma(\bar{B}^0_s \to J/\psi\, f_0)} = \frac{|F^{\sigma}_{B^0_s}(m^2_{J/\psi})|^2}{|F^{f_0}_{B^0_s}(m^2_{J/\psi})|^2} \frac{\Phi^{\sigma}_{B^0_s}}{\Phi^{f_0}_{B^0_s}} \times r_{Bs}$$

	$q\bar{q}$	tetraquark
$r_{B^0} =$	$\tan^2\varphi_m$	$1/2$
$r_{B^0_s} =$	$\tan^2\varphi_m$	0

[Stone, Zhang, PRL 111, 062001 (2013)]

ratio of form factors = 1
for the interpretation of results

phase space

PREDICTIONS

Light quark spectroscopy with $B^0_{(s)} \longrightarrow J/\psi\pi^+\pi^-$

1. Measure the ratio of branching fractions for B^0 and B^0_s.
2. Correct for $BR(f_0 \longrightarrow \pi^+\pi^-)$ and phase space ratio. ⟵ $\frac{\Phi(500)}{\Phi(980)} = 1.25$
3. Compute r_B.

$$\frac{\mathcal{B}\left(\overline{B}^0 \to J/\psi\, f_0(980),\ f_0(980) \to \pi^+\pi^-\right)}{\mathcal{B}\left(\overline{B}^0 \to J/\psi\, f_0(500),\ f_0(500) \to \pi^+\pi^-\right)} = (0.6^{+0.7+3.3}_{-0.4-2.6}) \times 10^{-2} \longrightarrow r_{B0} = \left(1.1^{+1.2+6.0}_{-0.7-0.7}\right) \times 10^{-2}$$

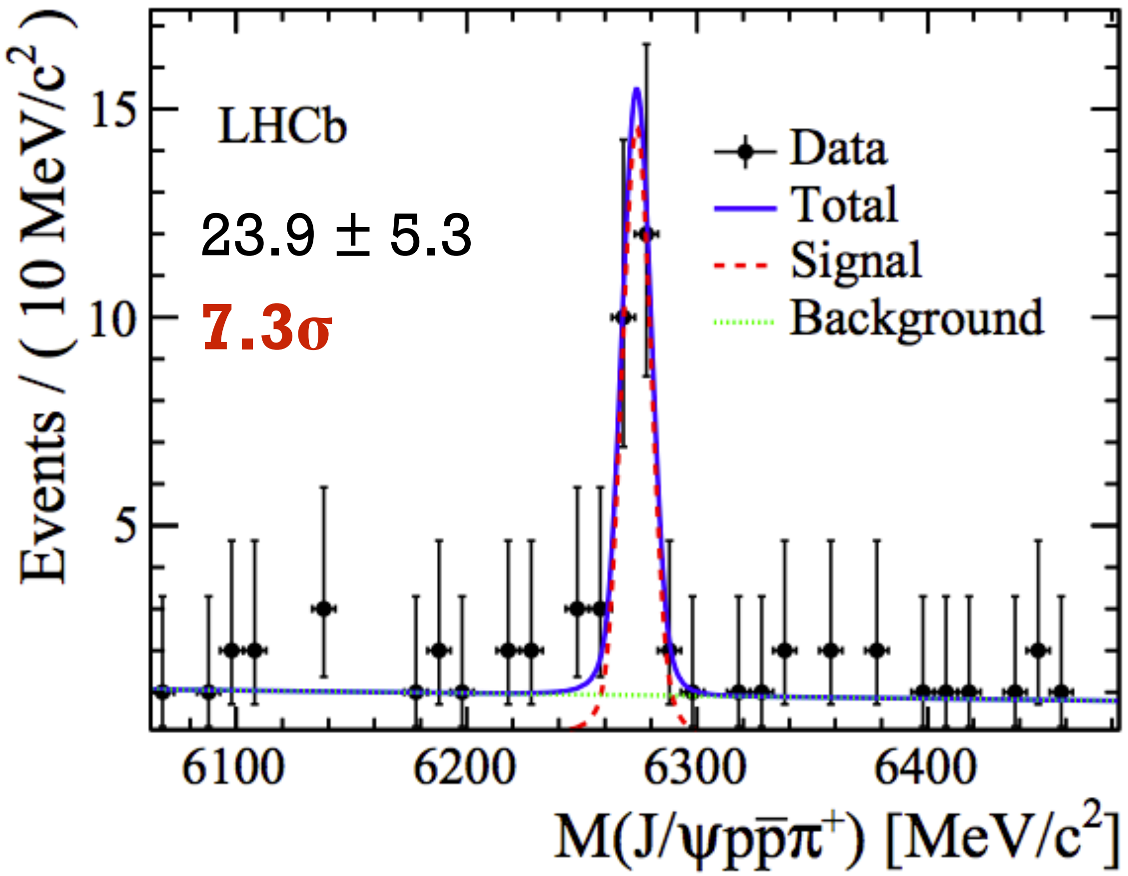
$$\frac{\mathcal{B}(\bar{B}^0_s \to J/\psi f_0(500), f_0(500) \to \pi^+\pi^-)}{\mathcal{B}(\bar{B}^0_s \to J/\psi f_0(980), f_0(980) \to \pi^+\pi^-)} < 3.4\% \longrightarrow r_{Bs} < 0.098 \text{ @ } 90\% \text{ CL}$$

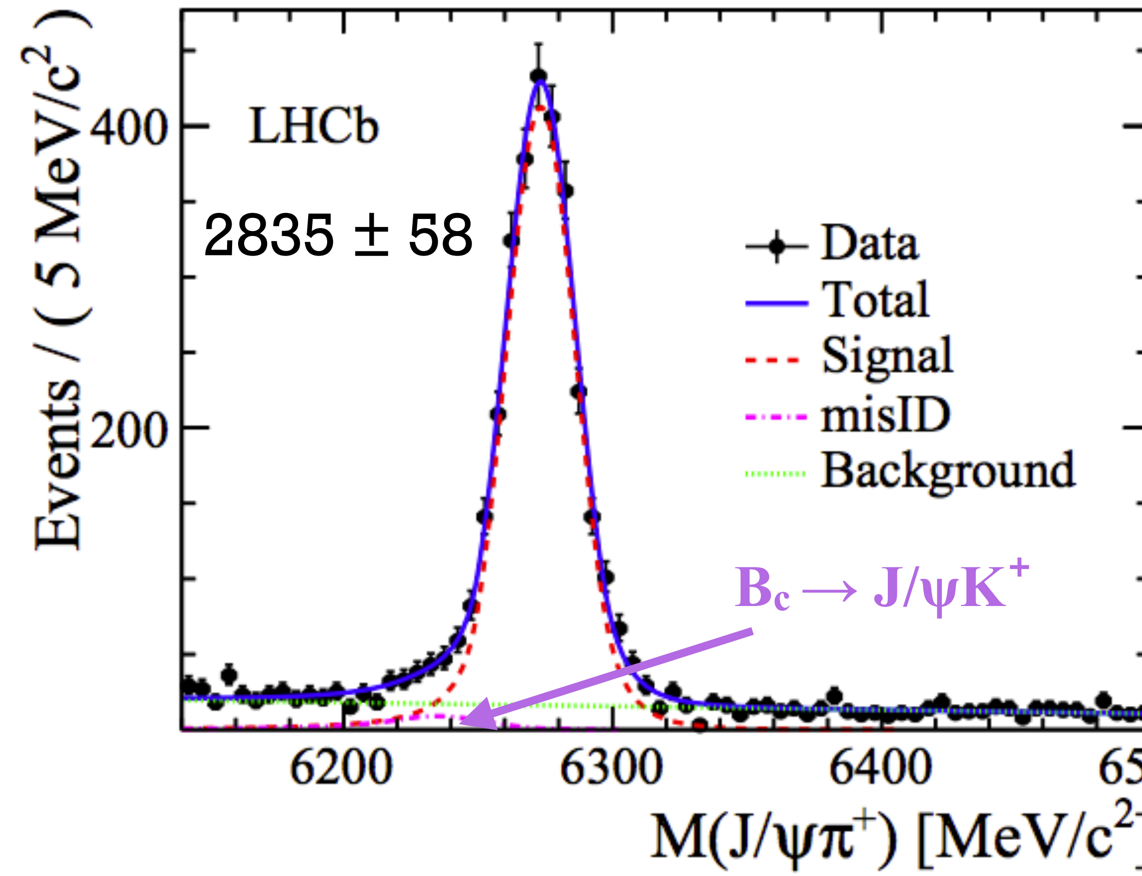
Inconsistent with tetraquark prediction for $f_0(500)$ and $f_0(980)$ of 1/2 by ~8σ

Both consistent with 0

First observation of $B_c \to J/\psi p\bar{p}\pi^+$

Gaussian with power-law tails + poly

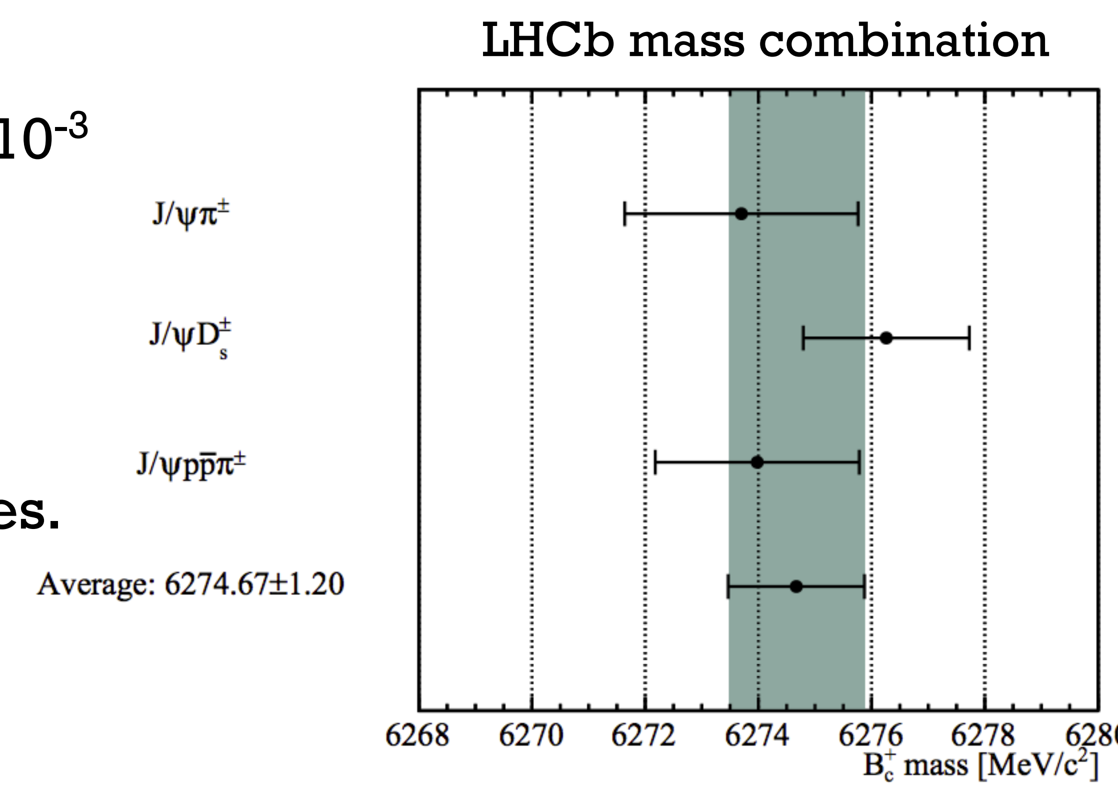




[LHCb-PAPER-2014-039]

- First observation of baryonic decay mode of B_c.
- Study mechanism of baryon production: $\sigma(B_c)/\sigma(B)$~10^{-3}
- BDT: signal from MC, bkg from sidebands.
- $B_c \to J/\psi p\bar{p}\pi^+$ mass resolution fixed to 6.4MeV, taken from ratio in MC and fit to $B_c \to J/\psi\pi^+$ in data.
- Best mass measurement, momentum scale dominates.

$m(B_c) = 6274.67 \pm 1.20$ MeV



First observation of $B_c \to J/\psi p\bar{p}\pi^+$

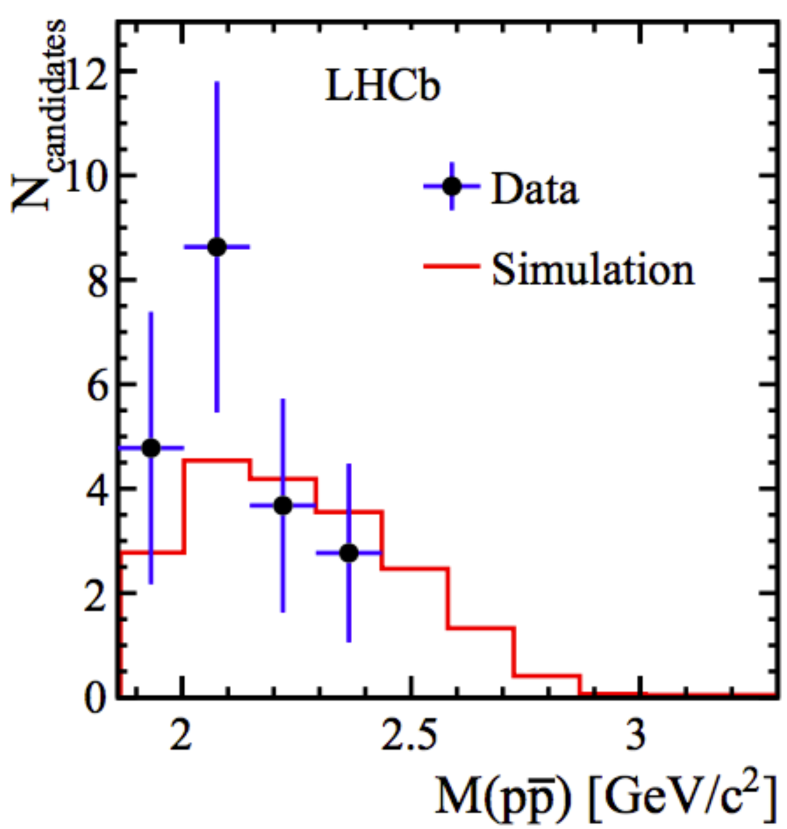
$$\frac{\mathcal{B}(B_c^+ \to J/\psi\, p\bar{p}\pi^+)}{\mathcal{B}(B_c^+ \to J/\psi\, \pi^+)} = 0.143^{+0.039}_{-0.034}\,(\text{stat}) \pm 0.013\,(\text{syst})$$

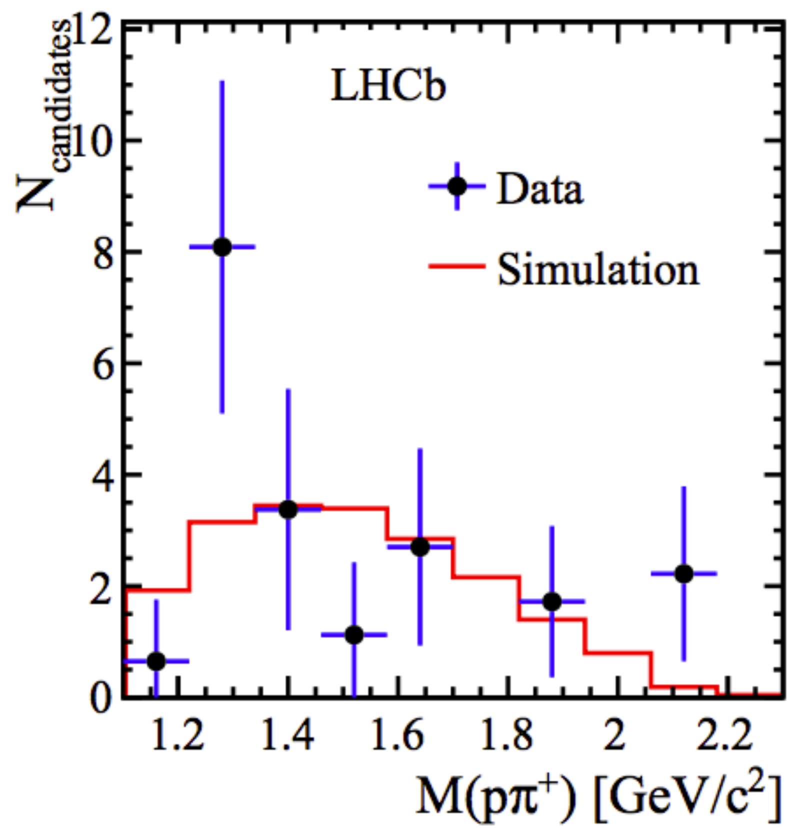
$$\frac{\mathcal{B}(B^0 \to D^{*-} p\bar{p}\pi^+)}{\mathcal{B}(B^0 \to D^{*-}\pi^+)} = 0.17 \pm 0.02$$

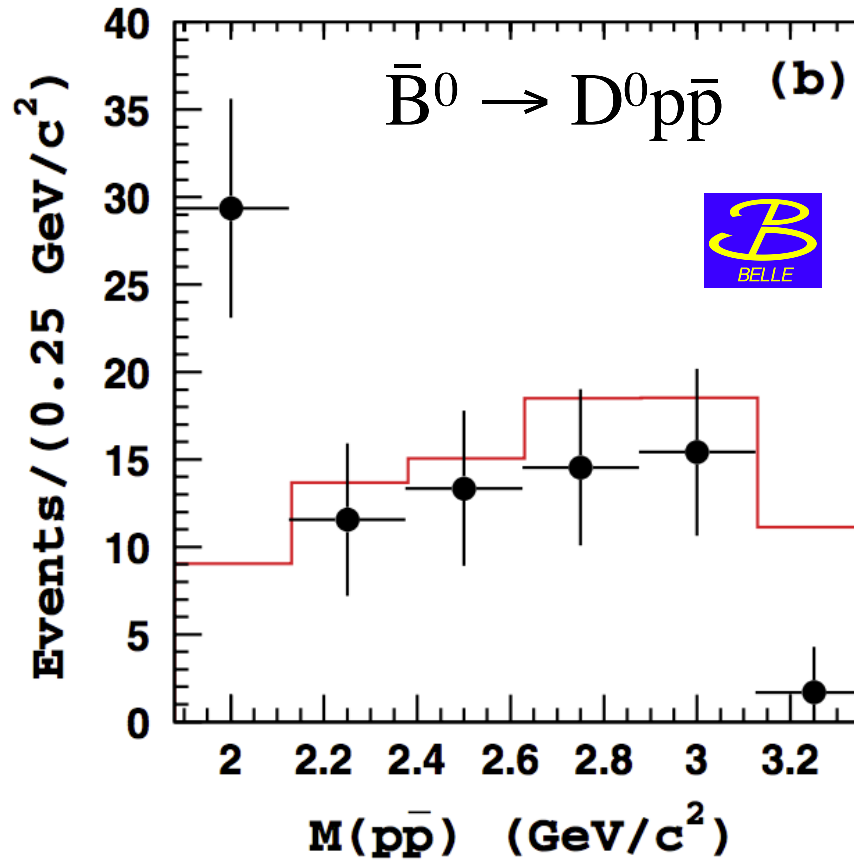
Consistent with factorisation

- Ratio of efficiencies = $(4.76 \pm 0.06)\%$ (mostly from simulation)
- Dominant systematics from B_c decay model in simulation and proton reconstruction (determined from sample of $\Lambda_c \to pK^-\pi^+$).
- Bkgd subtracted mass distributions consistent with **phase-space simulation**.
- Looking forward to more data that may allow **amplitude analysis** to be performed.

[LHCb-PAPER-2014-039]



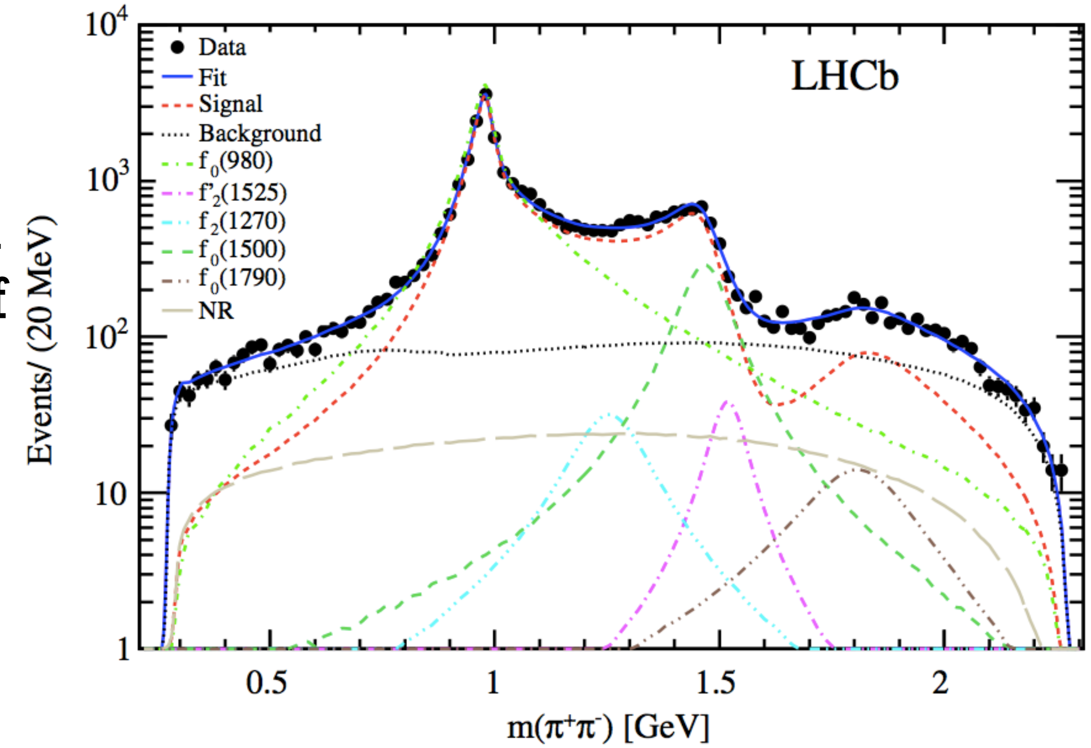




Belle [PRL 89, (2002) 151802]

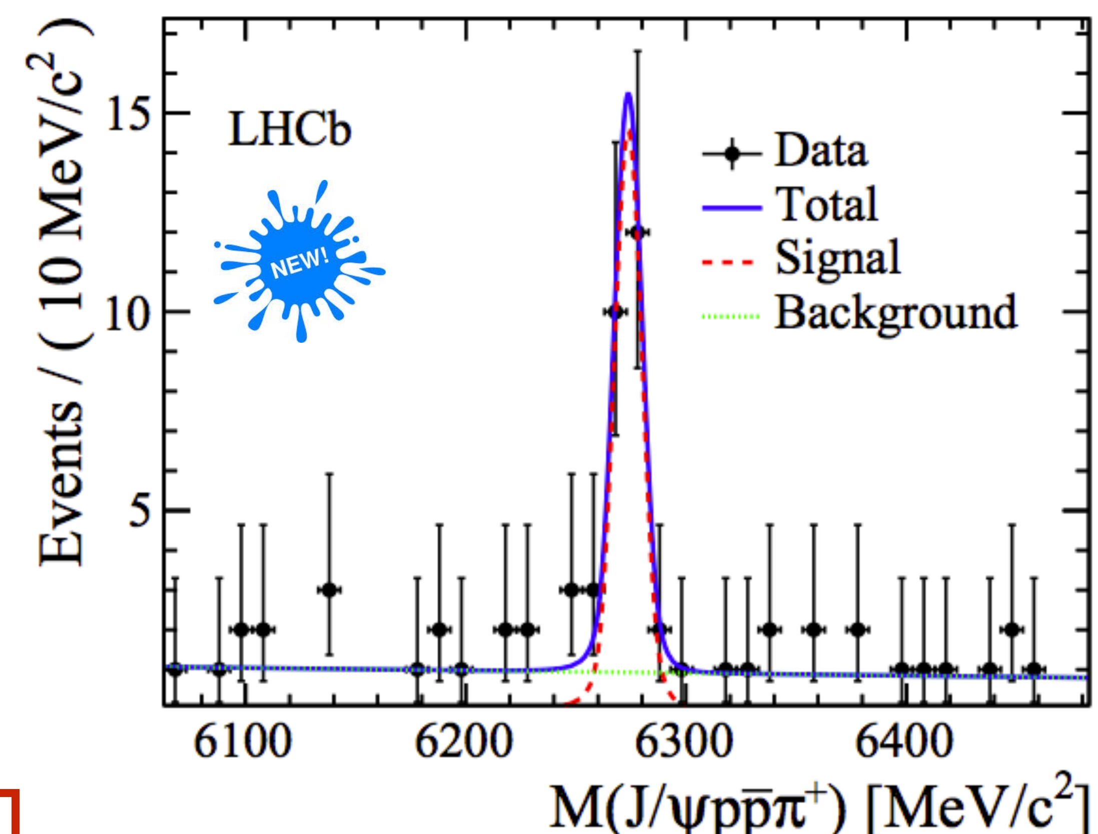
Summary

- LHCb has used $3fb^{-1}$ of data to study $B^0_{(s)} \to J/\psi\pi^+\pi^-$ decays.
  - Excellent environment to perform light hadron spectroscopy by studying resonant structure of $\pi^+\pi^-$ system.
  - Opened up **new possibilities** for performing CP violation measurements with these decays.
  - Rule out $f_0(980)$ as a pure tetraquark at 8σ.



[PRD 89, 092006 (2014)]

- LHCb is leading the way with B_c meson physics
  - Most precise mass measurement.
  - First observation of many new (baryonic) decay mode.
  - Opens up potential amplitude analyses in the future.



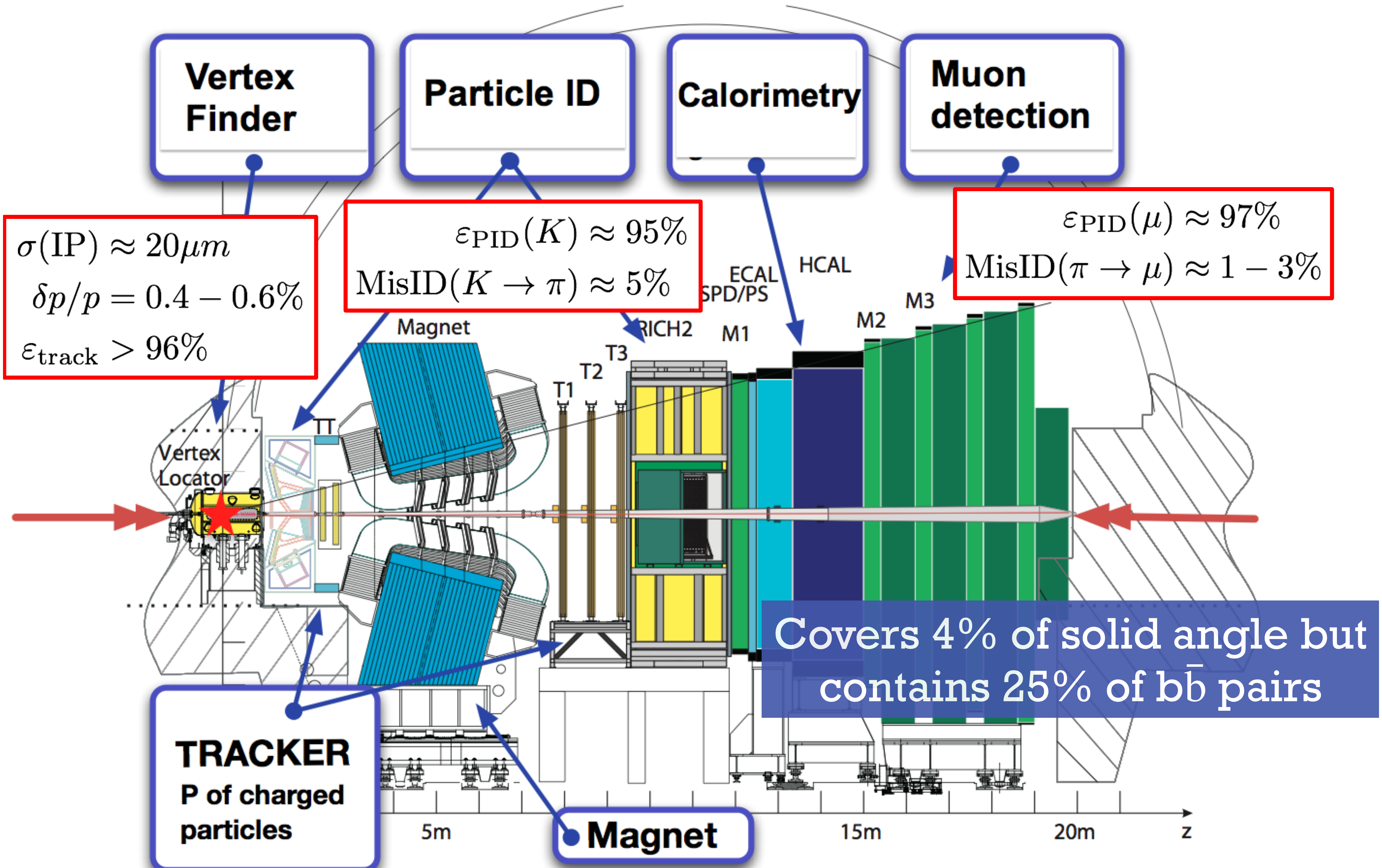
[LHCb-PAPER-2014-039]

Stay tuned for more results with Run-2

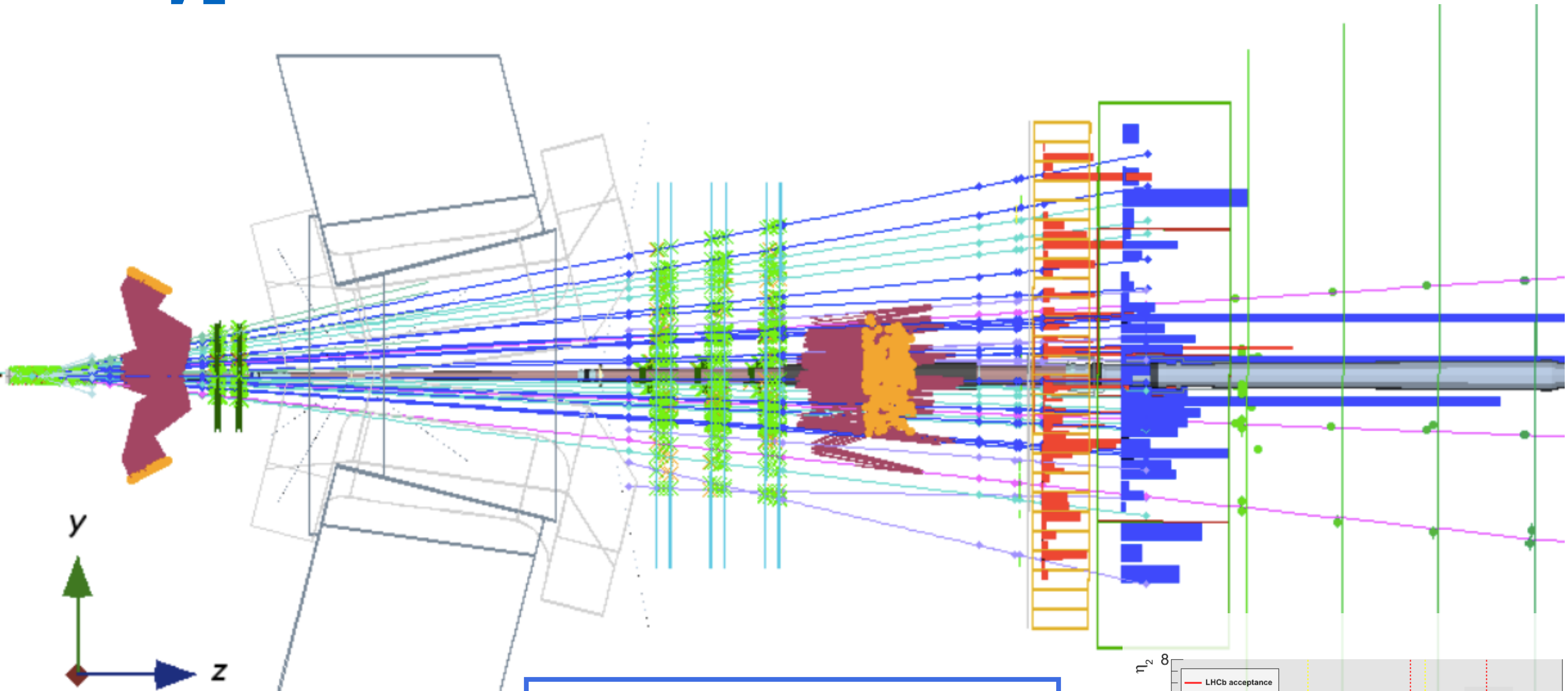
BACKUP

The LHCb detector

[2008 JINST 3 S08005]

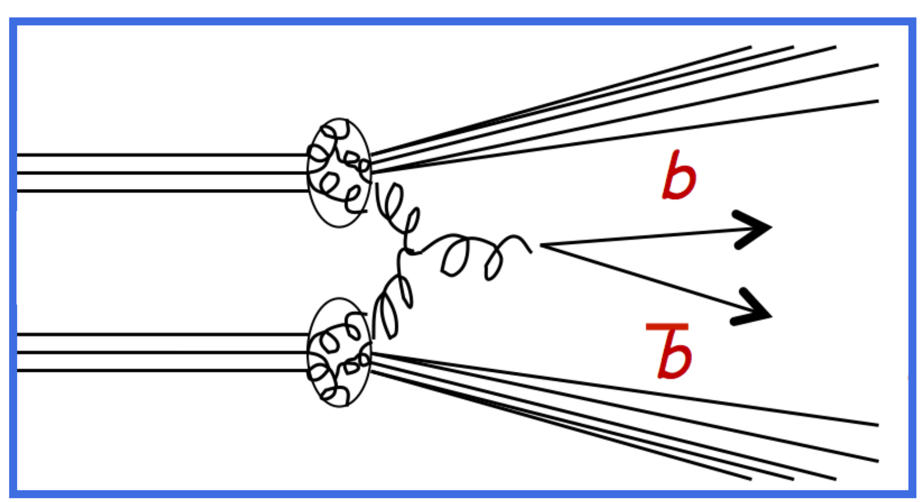


A typical LHCb event

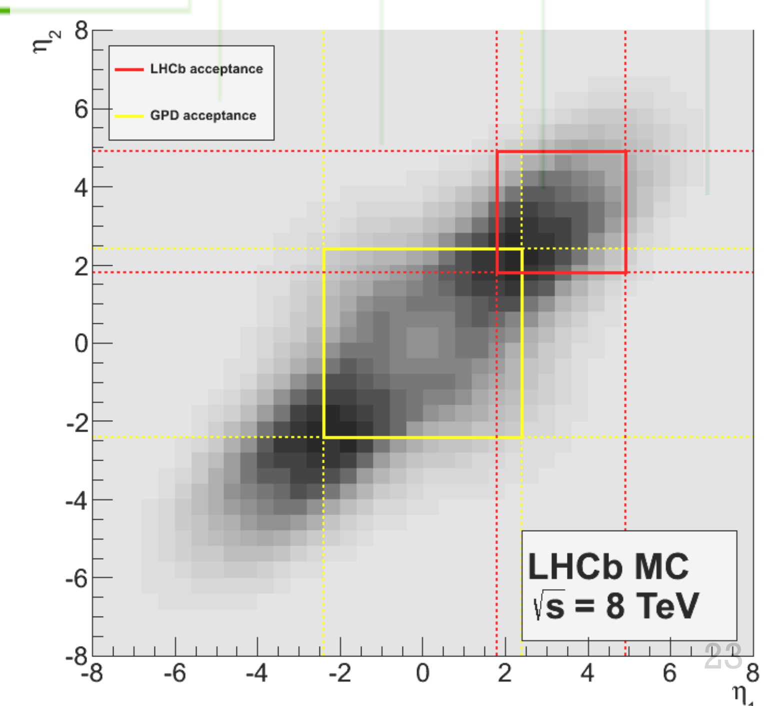


$$\langle nPVs \rangle \sim 2.0$$
$$\langle nTracks \rangle \sim 200$$

$$\sigma(p\bar{p} \to b\bar{b}X) \sim 80\mu b$$
$$\sigma(c\bar{c}) \quad \sim 1500\mu b$$

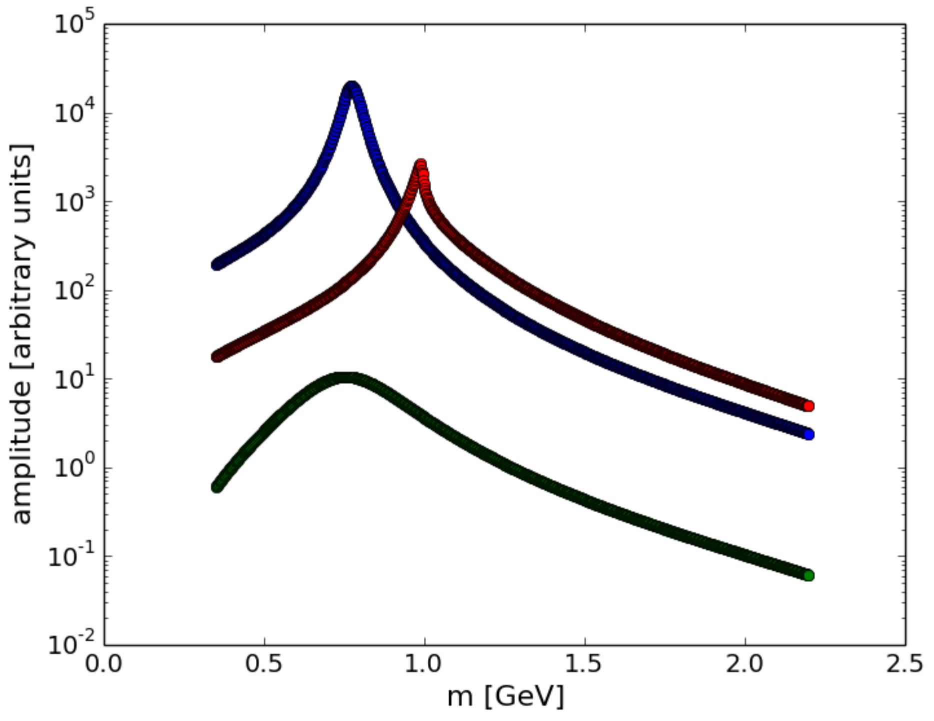


B hadrons fly ~1cm in the detector



Flatté amplitude

- Flatté provides better description of line shape when a second channel opens up near resonance mass.
- Constants $g_{\pi\pi}$ and g_{KK} are coupling constants.



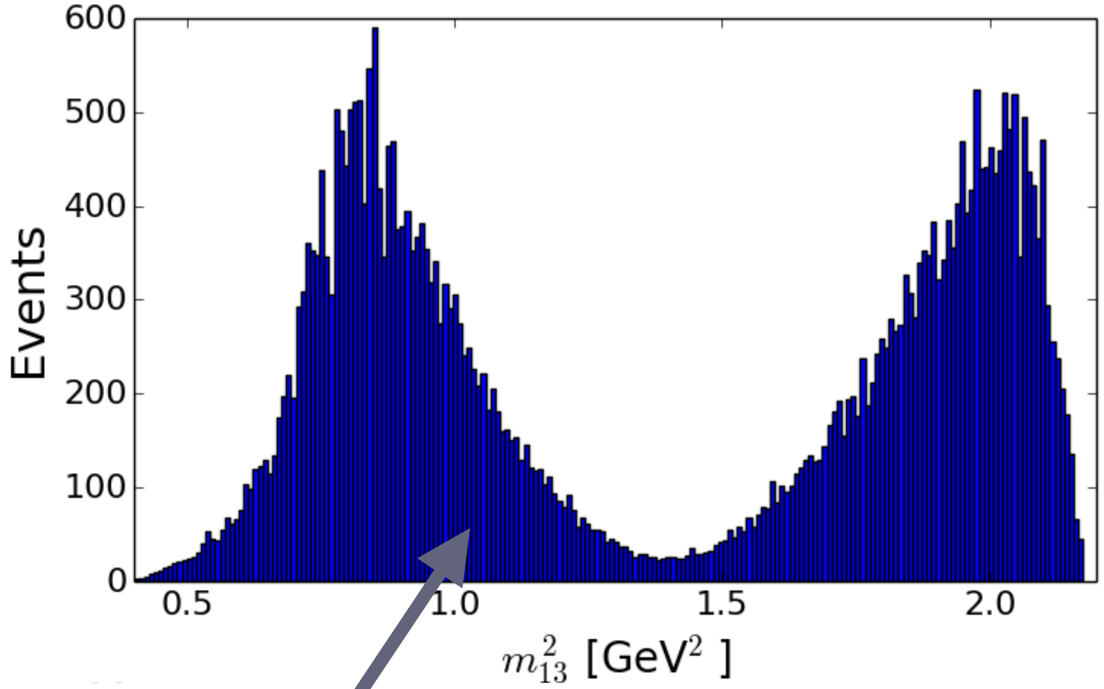
$$A_R(s_{23}) = \frac{1}{m_R^2 - s_{23} - i m_R (g_{\pi\pi}\rho_1 + g_{KK}\rho_2)}$$

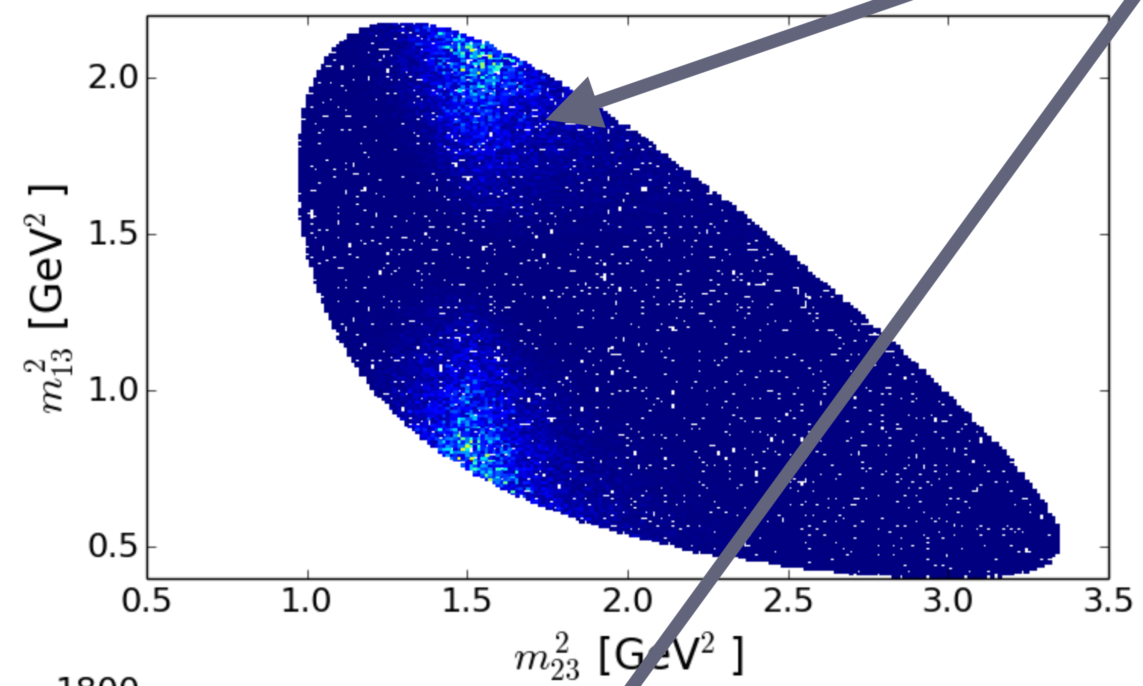
$$\begin{aligned}
\rho_{\pi\pi} &= \frac{2}{3}\sqrt{1 - \frac{4m_{\pi^\pm}^2}{m^2(\pi^+\pi^-)}} + \frac{1}{3}\sqrt{1 - \frac{4m_{\pi^0}^2}{m^2(\pi^+\pi^-)}}, \\
\rho_{KK} &= \frac{1}{2}\sqrt{1 - \frac{4m_{K^\pm}^2}{m^2(\pi^+\pi^-)}} + \frac{1}{2}\sqrt{1 - \frac{4m_{K^0}^2}{m^2(\pi^+\pi^-)}}.
\end{aligned}$$

Reminder about Dalitz plots

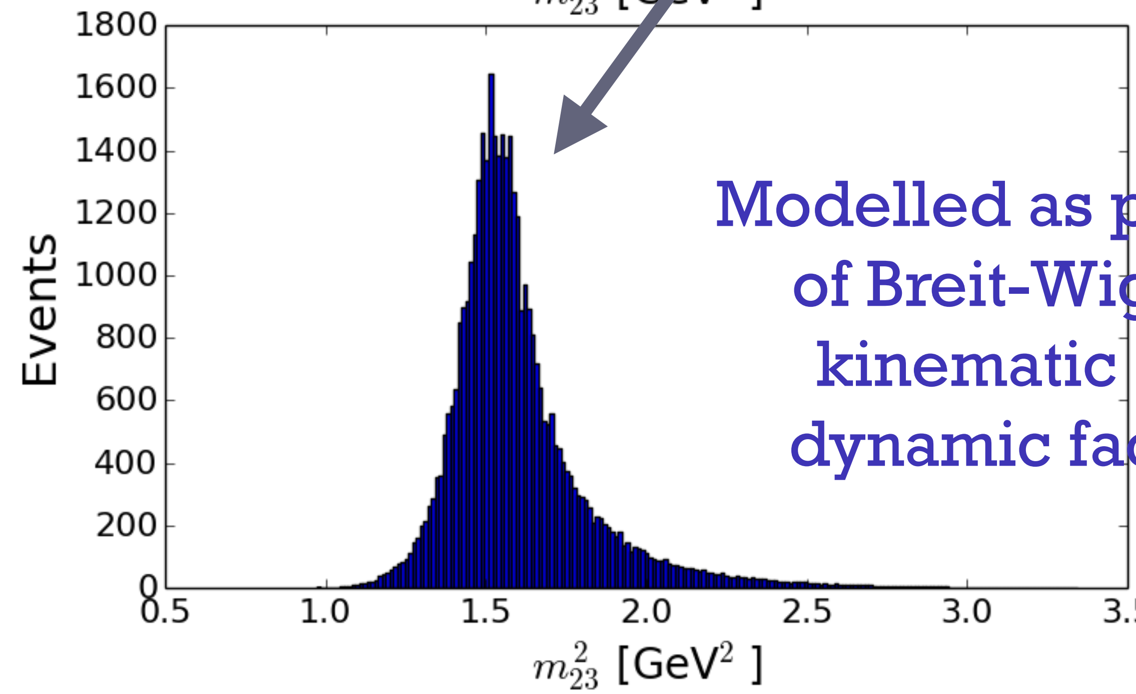
$$d\Gamma = \frac{1}{(2\pi)^3}\frac{1}{32M^3}\overline{|\mathscr{M}|^2}\,dm_{12}^2\,dm_{23}^2$$

Spin-1 resonance

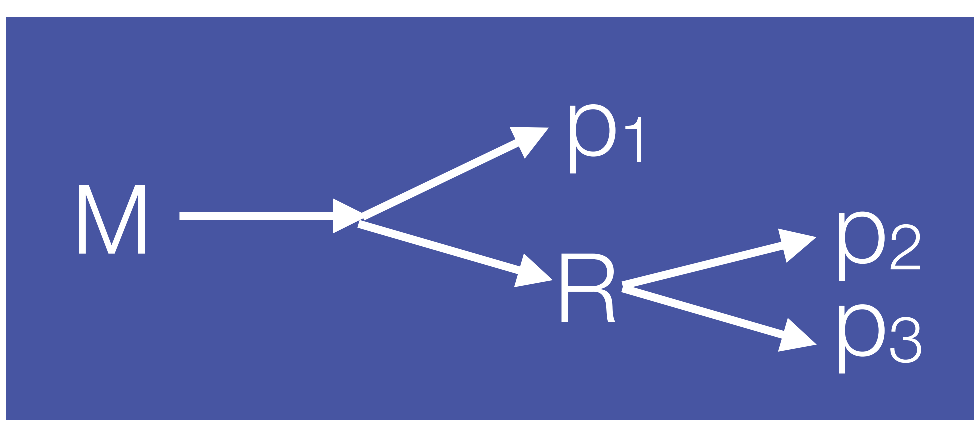




Peaks in distribution do not correspond to a real resonance - just a shadow/reflection

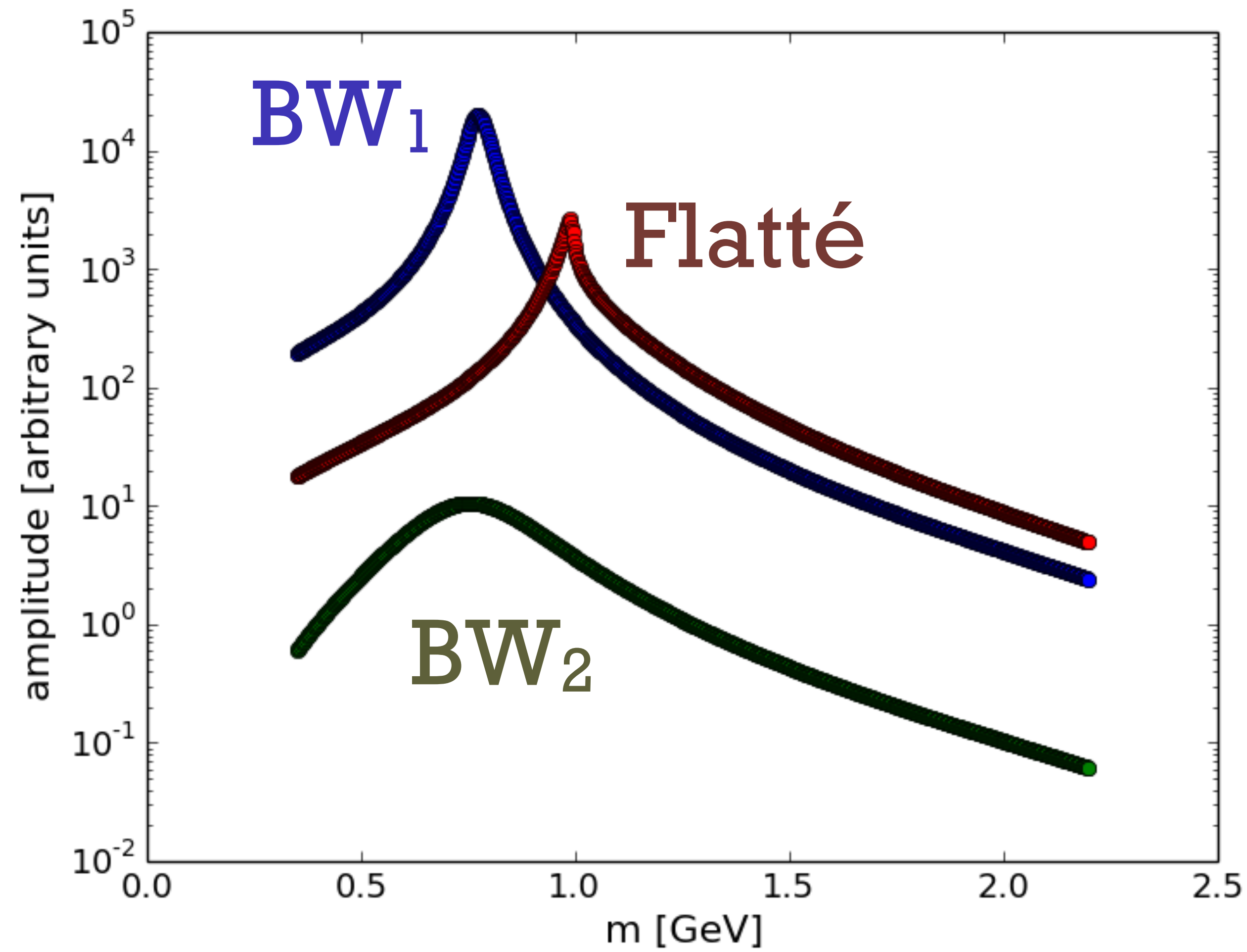


Modelled as product of Breit-Wigner, kinematic and dynamic factors



Amplitude model

- Use the **Isobar** approach.
- Build amplitude from sum of two-body $\pi^-\pi^+$ resonances.
- Overlapping and interfering Breit-Wigner and Flatté resonances.



Sum over the k resonances

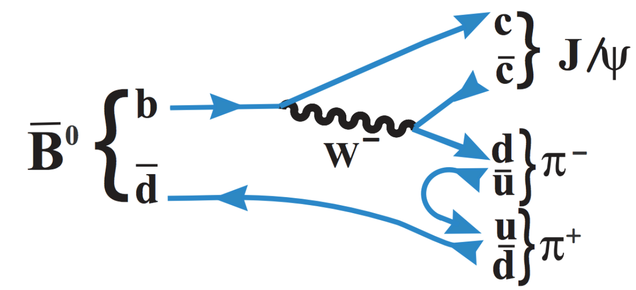
$$|\mathcal{M}|^2 = \sum_{\Delta\lambda_\mu=-1,1} \left| \sum_{\lambda_\psi=-1,0,1} \sum_k A_{k,\lambda_\psi}(m_{K\pi}, \Omega | m_{0\,k}, \Gamma_{0\,k}) \right|^2$$

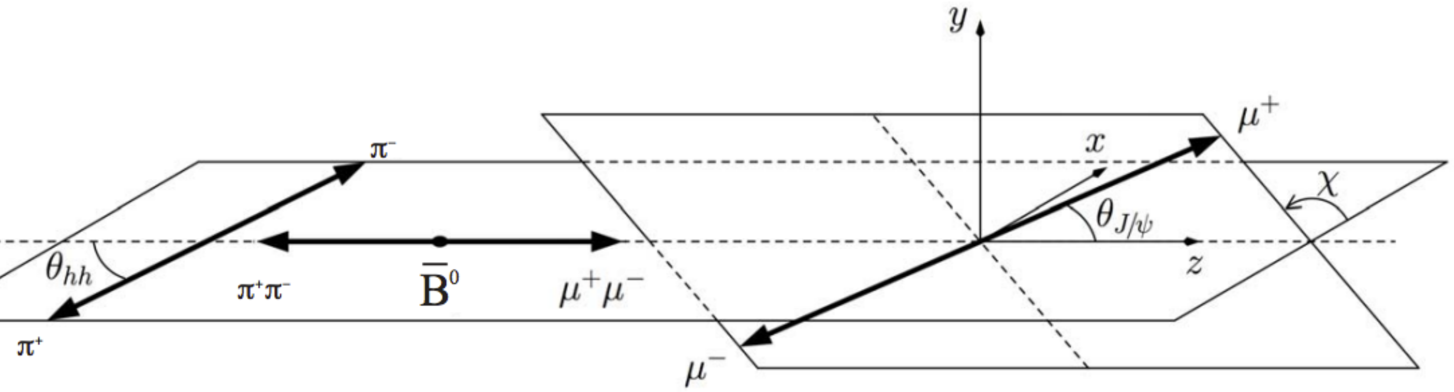
In 4D fit, $\mu^+\mu^-$ are final state particles so different dimuon helicity amplitudes are incoherent (cannot interfere)

Different J/ψ helicity amplitudes interfere

Complex amplitude that encodes the mass and angular dependence

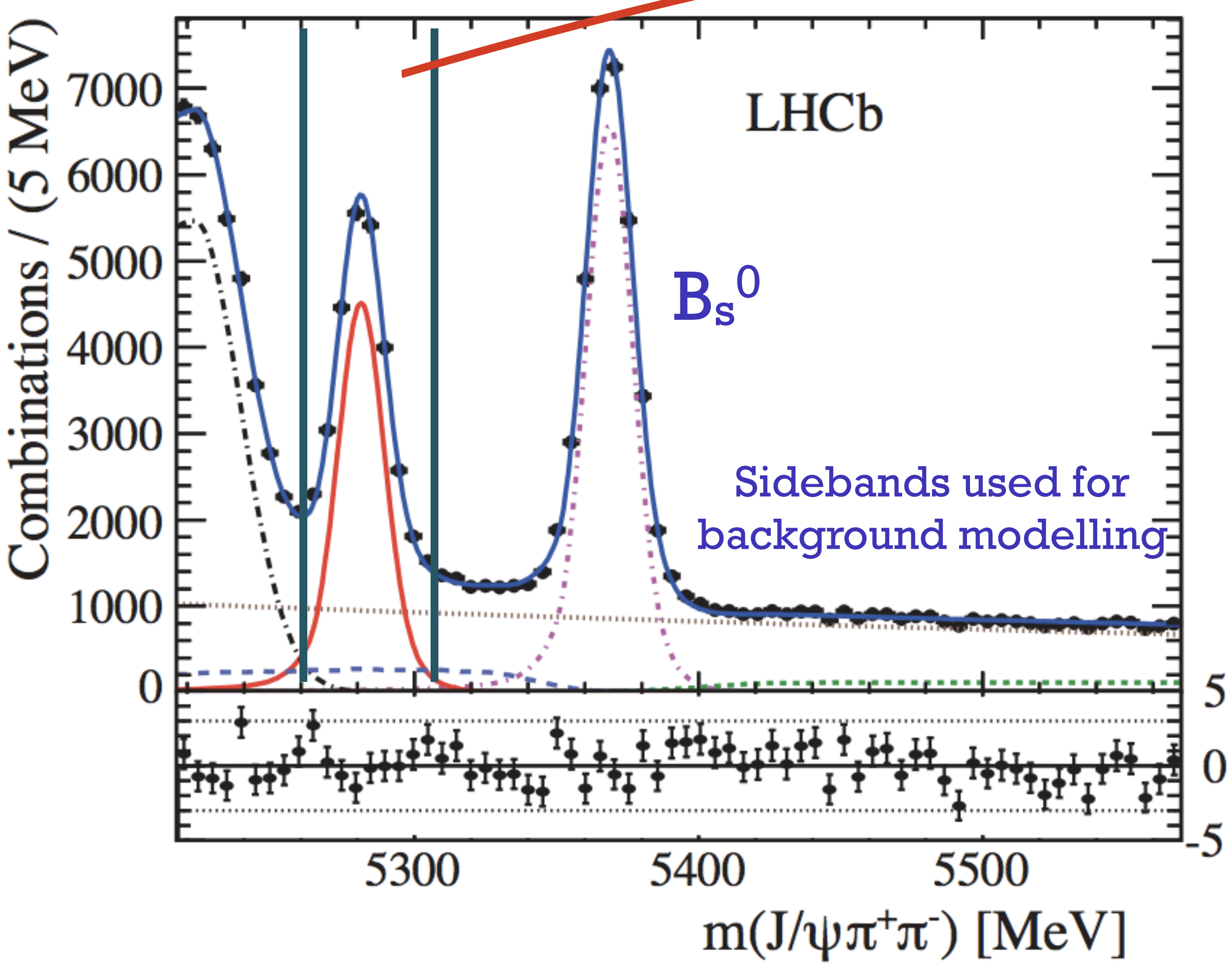
Amplitude analysis of $B^0 \to J/\psi\pi^+\pi^-$

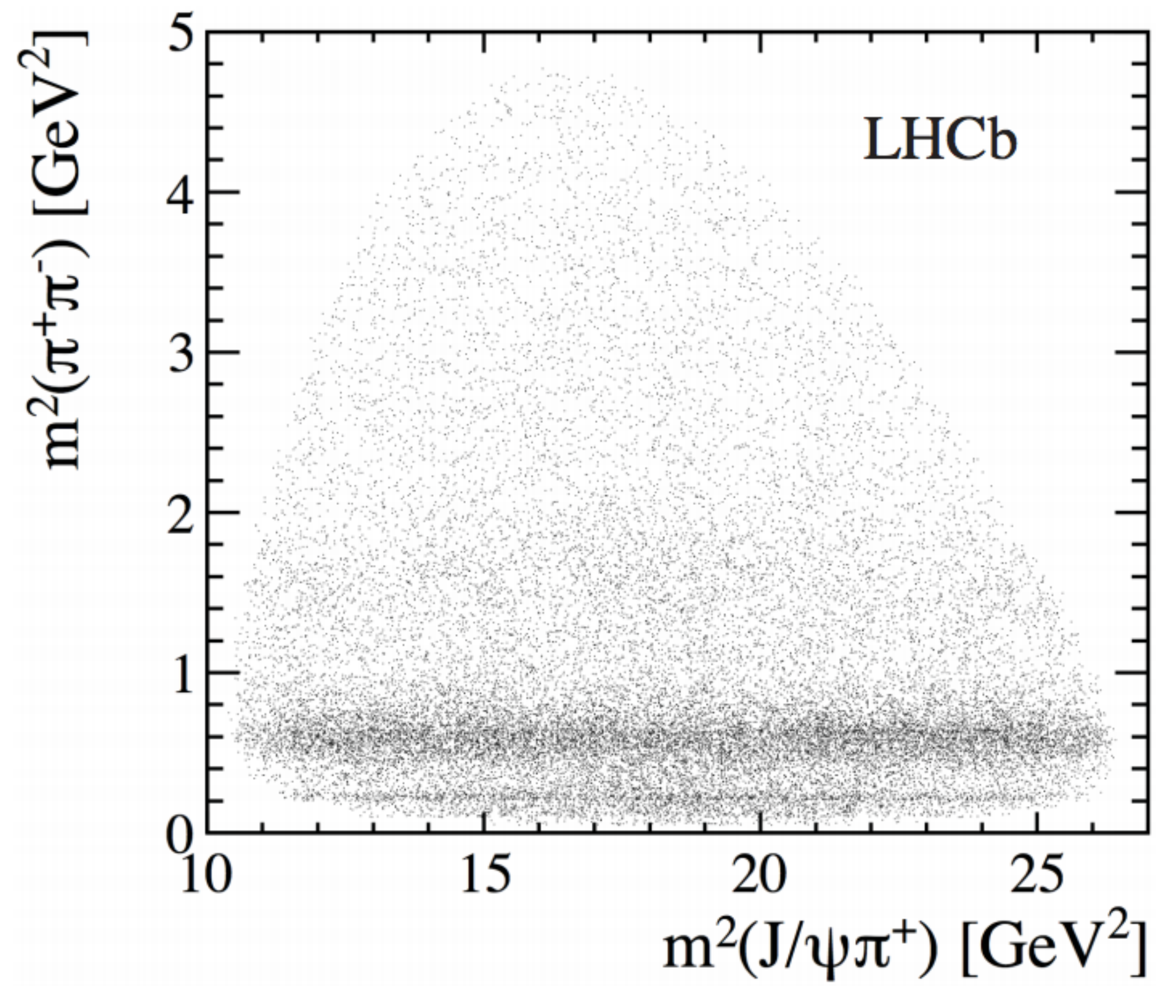




- Similar analysis to Z(4430)
  - Build 4D matrix element from overlapping $\pi^+\pi^-$ resonances.
  - Correct for efficiency.
- No sign of exotic $J/\psi\pi^+$ resonances…

19k **B⁰** signal

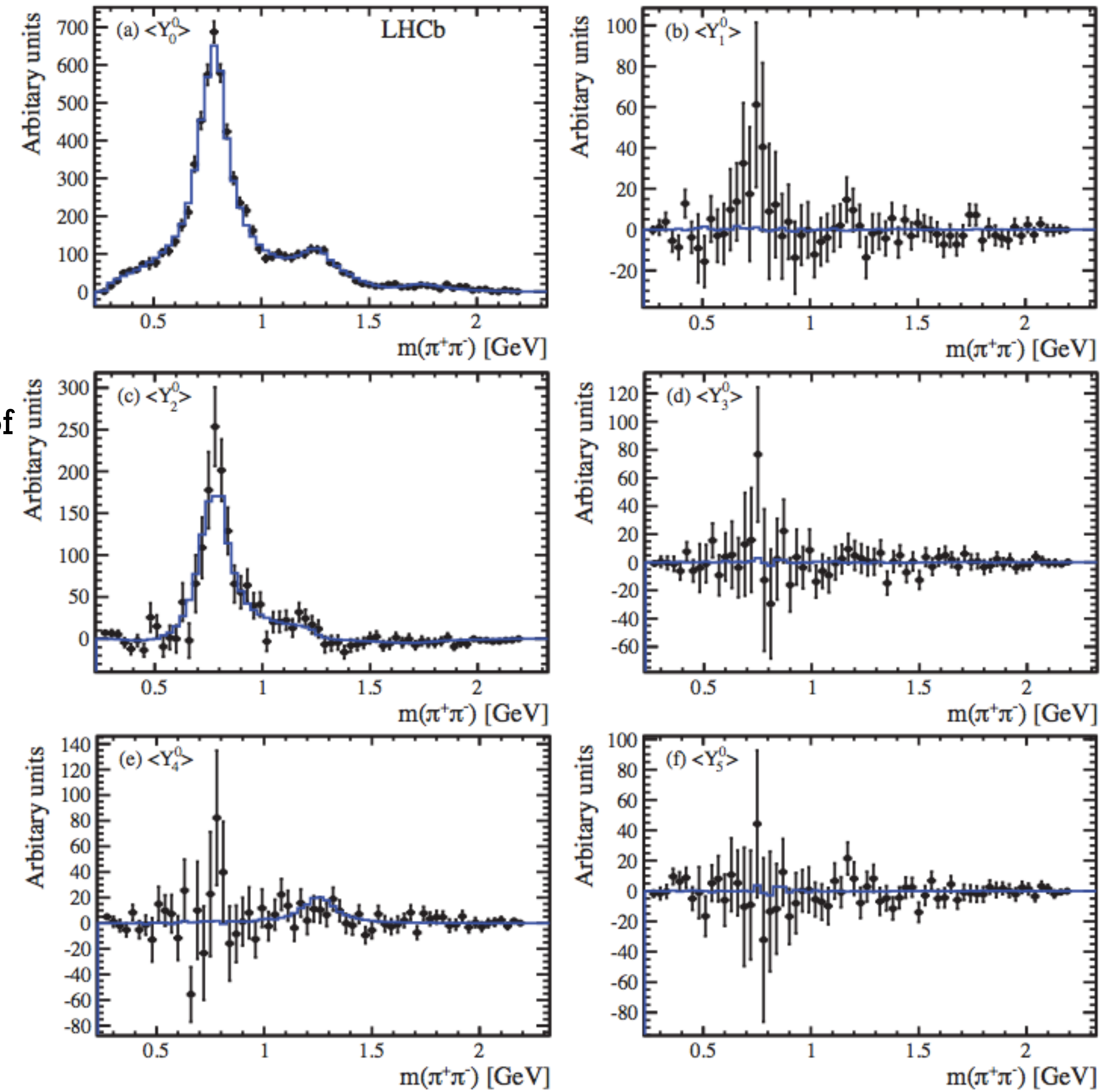




[arXiv:1404.5673, PRD]

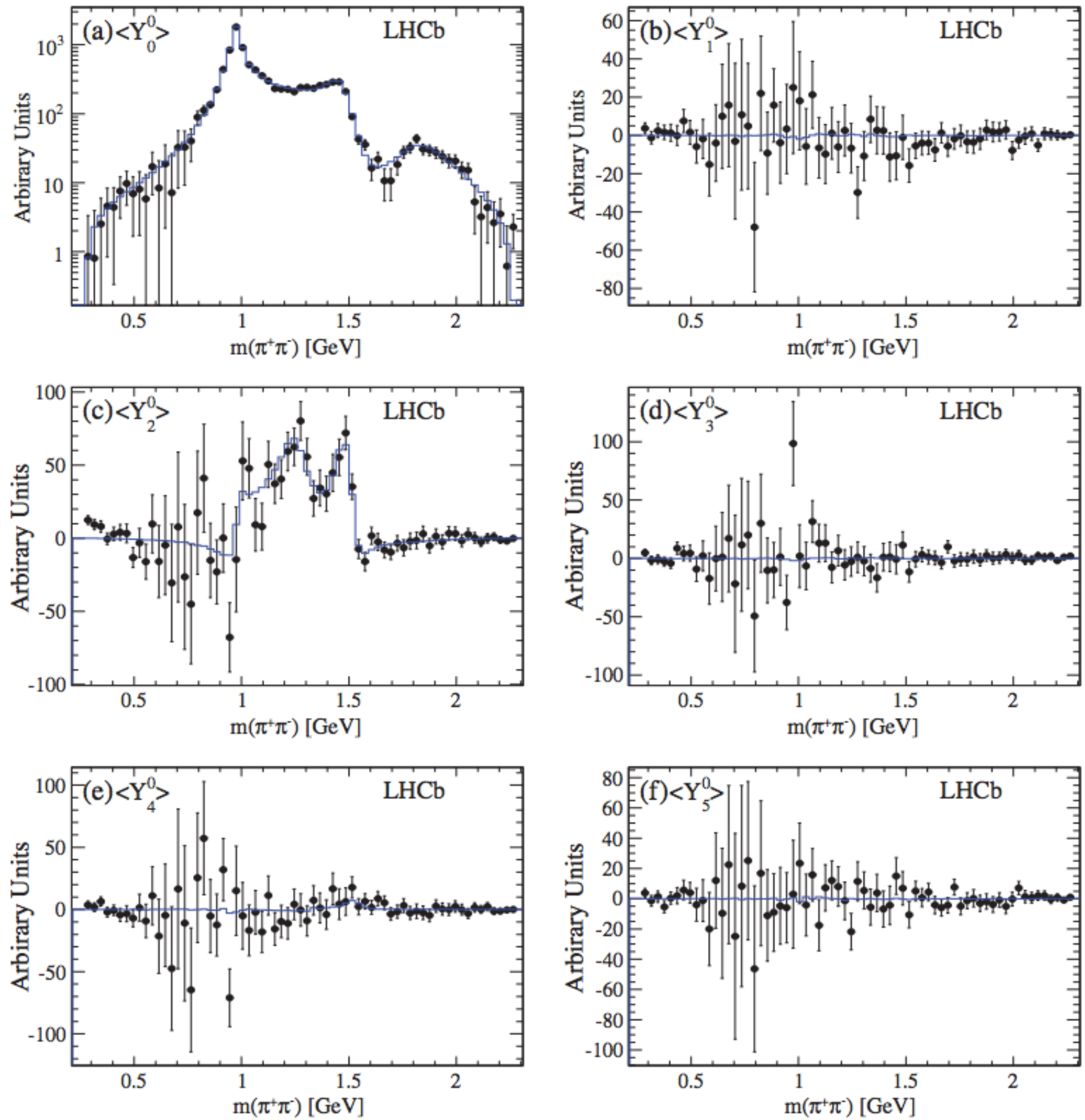
$B^0 \to J/\psi\pi^+\pi^-$: harmonic moments

- Efficiency corrected and background subtracted m(ππ) distribution, weighted with spherical harmonics, $Y_l^0(\cos\theta_{\pi\pi})$.
- Structure of each moment gives qualitative picture of spin contributions and their interference.



$B^0_s \to J/\psi\pi^+\pi^-$: harmonic moments

- Efficiency corrected and background subtracted m(ππ) distribution, weighted with spherical harmonics, $Y_l^0(\cos\theta_{\pi\pi})$.
- Structure of each moment gives qualitative picture of spin contributions and their interference.



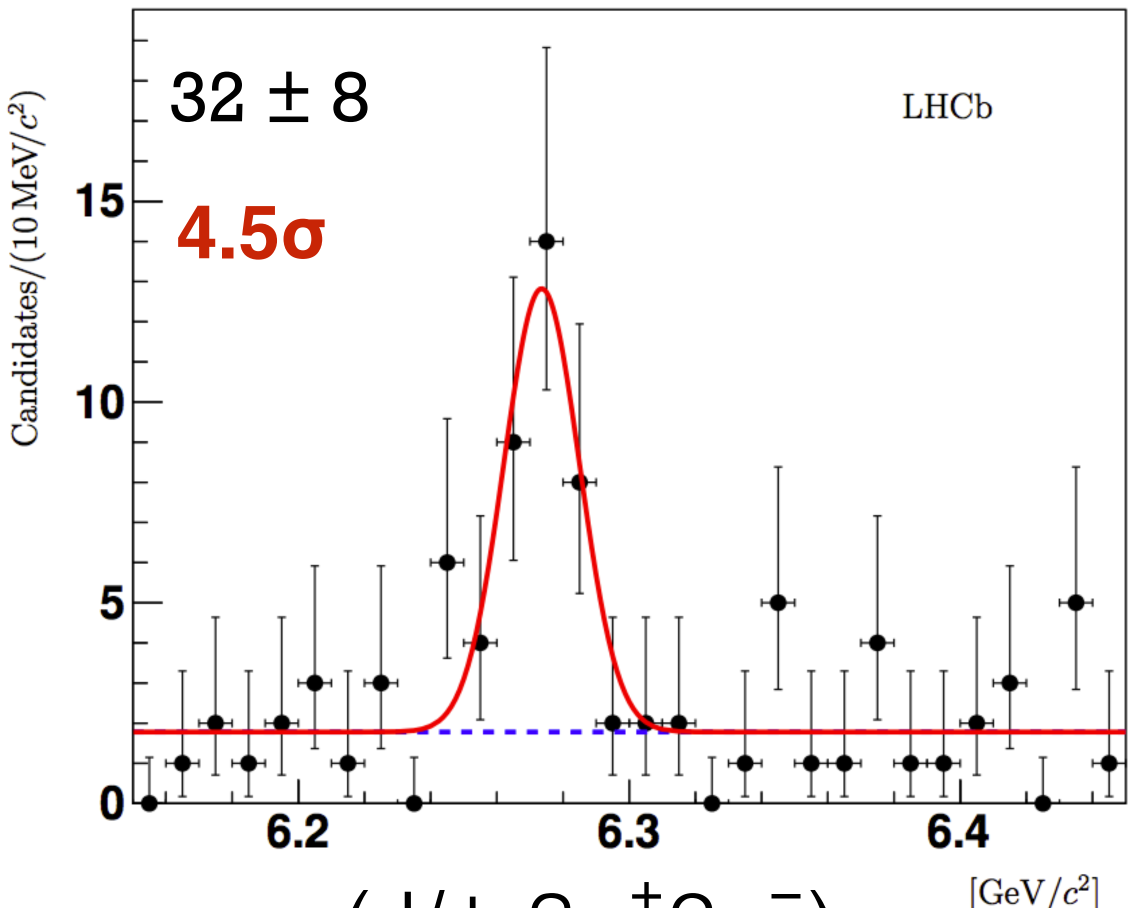
$B_c \to J/\psi$ X decays, $J/\psi \to \mu^+\mu^-$

- Interesting to study due to B_c being made of two heavy quarks ($\bar{b}c$).
- Only decays weakly, so has longer lifetime (~0.5ps) than quarkonia, but shorter lifetime than other B mesons (~1.5ps) due to c quark.
- Discovered by CDF, now observed in many different decay modes by LHCb.
- At LHCb, use clean signature of the $J/\psi \to \mu^+\mu^-$ to trigger these modes.
- Simulation needed to correct for efficiency of selection and detector acceptance.
  - Use BCVEGPY generator to simulate $gg \to B_c$

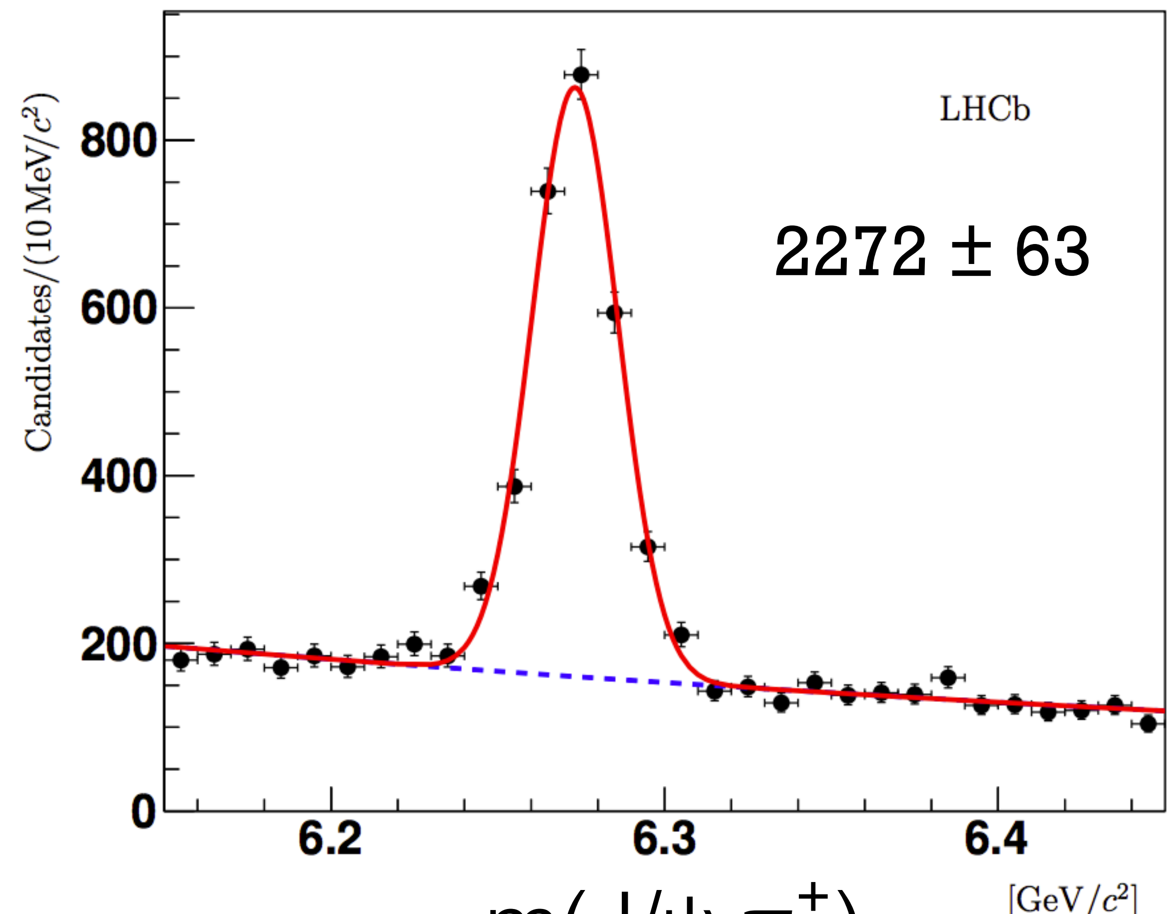
Evidence for $B_c \to J/\psi\, 3\pi^+ 2\pi^-$

Parameter		Value
$m_{B_c^+}$	$[\mathrm{MeV}/c^2]$	6273 ± 3
$\sigma_{B_c^+}$	$[\mathrm{MeV}/c^2]$	11.4 ± 3.4
$N_{B_c^+ \to J/\psi\, 3\pi^+ 2\pi^-}$		32 ± 8

Gaussian + constant



$m(J/\psi\, 3\pi^+ 2\pi^-)$



$m(J/\psi\, \pi^+)$

[JHEP 05 (2014) 148]

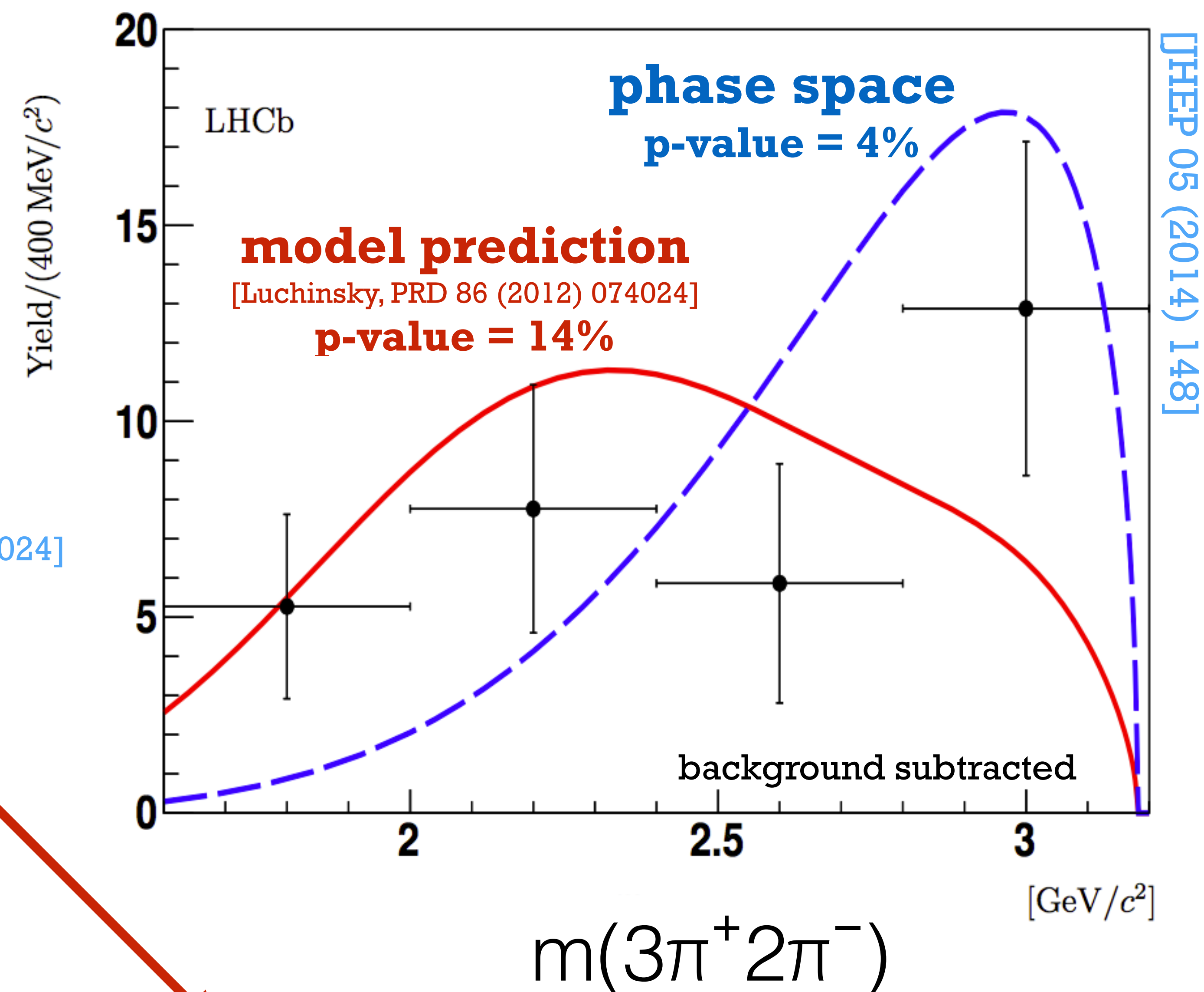
$$\frac{\varepsilon(B_c^+ \to J/\psi\, \pi^+)}{\varepsilon(B_c^+ \to J/\psi\, 3\pi^+ 2\pi^-)} = 123.8 \pm 5.6 \pm 15.1$$

- NN for muon and pion ID.
- $p_T(\pi^+) > 400$MeV and IP $\chi 2$ cuts.
- Suppress combinatorial bkg by requiring vertex χ^2 of all $J/\psi\, \pi^+$ combinations < 20.
- Measure BR relative to $B_c \to J/\psi\, \pi^+$ selected with similar selection.
  - From simulation, efficiency to reconstruct 4 extra pions leads to factor 100 lower efficiency.

100 from efficiency and acceptance?

Evidence for $B_c \rightarrow J/\psi\, 3\pi^+2\pi^-$, $J/\psi \rightarrow \mu^+\mu^-$

- No resonant structure seen in combination of final state particles.
- Dominant systematic from fit model and decay model in simulation.
  - Reweight MC with $m(3\pi^+2\pi^-)$ spectrum.
- Good agreement with theory predictions of **0.95 and 1.1** [PRD86 (2012) 074024]
- Consistent with measurements in B^+ and B^0 sectors, expected from **factorisation**.
  - $B_c \rightarrow J/\psi\, W^+$ form factors and experimental information from $\tau \rightarrow n\pi$



$$\frac{\mathcal{B}\left(B_c^+ \rightarrow J/\psi\, 3\pi^+2\pi^-\right)}{\mathcal{B}\left(B_c^+ \rightarrow J/\psi\, \pi^+\right)} = 1.74 \pm 0.44 \pm 0.24$$

$$\frac{\mathcal{B}\left(B^0 \rightarrow D^{*-} 3\pi^+2\pi^-\right)}{\mathcal{B}\left(B^0 \rightarrow D^{*-}\pi^+\right)} = 1.70 \pm 0.34$$

$$\frac{\mathcal{B}\left(B^+ \rightarrow \bar{D}^{*0} 3\pi^+2\pi^-\right)}{\mathcal{B}\left(B^+ \rightarrow \bar{D}^{*0}\pi^+\right)} = 1.10 \pm 0.24$$

Factorisation in B_c decays

- Factorise the decay amplitude into two independent parts
  - $B_c \to J/\psi\, W^+$
    - form factors
    - experimental information on W^+ from $\tau \longrightarrow n\pi$