

# Can We Resolve the Nature of $\chi_{c1}(3872)$ with PANDA?

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*QWG Workshop 2021*

*The 14th International Workshop on Heavy Quarkonium*

*Mar. 19, 2021*



[Phys.Rev.D 102 (2020) 9, 092005]  
[https://arxiv.org/abs/2005.13419]

CERN-EP-2020-086  
LHCb-PAPER-2020-008  
May 27, 2020

## Study of the lineshape of the $\chi_{c1}(3872)$ state

### Abstract

A study of the lineshape of the  $\chi_{c1}(3872)$  state is made using a data sample corresponding to an integrated luminosity of  $3\text{fb}^{-1}$  collected in  $pp$  collisions at centre-of-mass energies of 7 and 8 TeV with the LHCb detector. Candidate  $\chi_{c1}(3872)$  mesons from  $b$ -hadron decays are selected in the  $J/\psi\pi^+\pi^-$  decay mode. Describing the lineshape with a Breit–Wigner function, the mass splitting between the  $\chi_{c1}(3872)$  and  $\psi(2S)$  states,  $\Delta m$ , and the width of the  $\chi_{c1}(3872)$  state,  $\Gamma_{\text{BW}}$ , are determined to be

$$\begin{aligned}\Delta m &= 185.588 \pm 0.067 \pm 0.068 \text{ MeV}, \\ \Gamma_{\text{BW}} &= 1.39 \pm 0.24 \pm 0.10 \text{ MeV},\end{aligned}$$

where the first uncertainty is statistical and the second systematic. Using a Flatté-inspired lineshape, two poles for the  $\chi_{c1}(3872)$  state in the complex energy plane are found. The dominant pole is compatible with a quasi-bound  $D^0\bar{D}^{*0}$  state but a quasi-virtual state is still allowed at the level of 2 standard deviations.

# LHCb Findings

- Breit Wigner fit

$$m_{\chi_{c1}(3872)} = 3871.695 \pm 0.067 \pm 0.068 \pm 0.010 \text{ MeV}$$

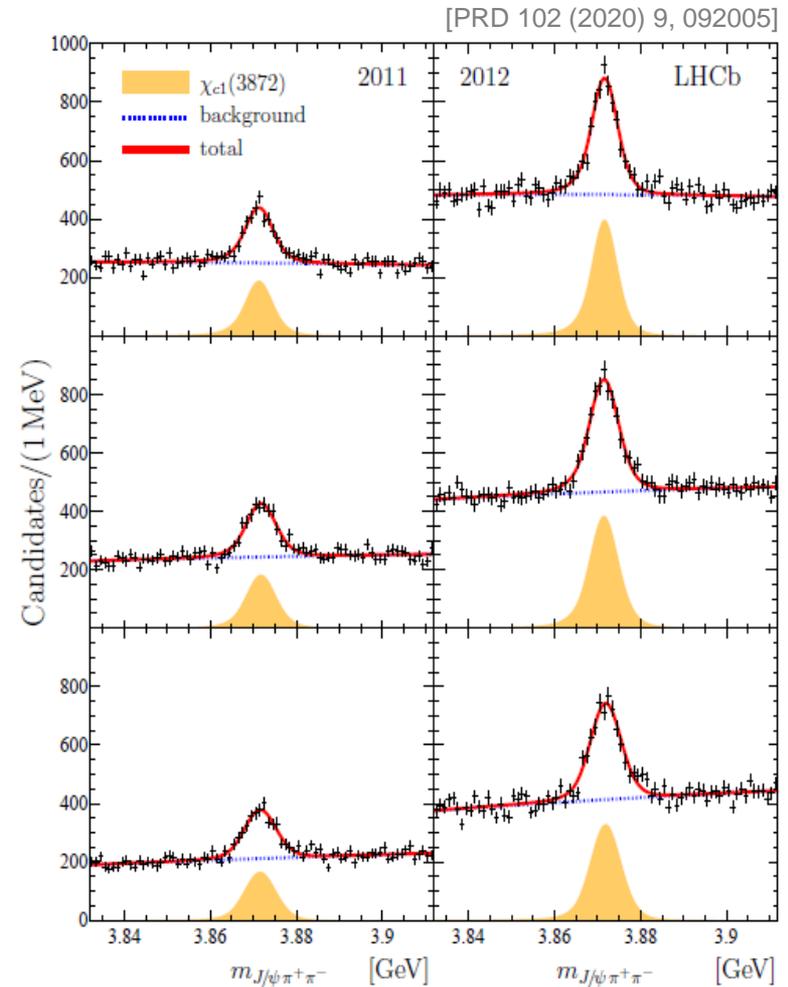
$$\Gamma_{\text{BW}} = 1.39 \pm 0.24 \pm 0.10 \text{ MeV}$$

[previous Belle result:  $\Gamma < 1.2 \text{ MeV (CL90)}$ ]

- Flatté model fit

Mode [MeV]		Mean [MeV]	FWHM [MeV]
$3871.69^{+0.00+0.05}_{-0.04-0.13}$		$3871.66^{+0.07+0.11}_{-0.06-0.13}$	$0.22^{+0.06+0.25}_{-0.08-0.17}$
$g$	$f_\rho \times 10^3$	$\Gamma_0$ [MeV]	$m_0$ [MeV]
$0.108 \pm 0.003$	$1.8 \pm 0.6$	$1.4 \pm 0.4$	3864.5 (fixed)

(Flatté energy  $E_f = -7.2 \text{ MeV}$ )



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Factor 6.3, analysis dependent

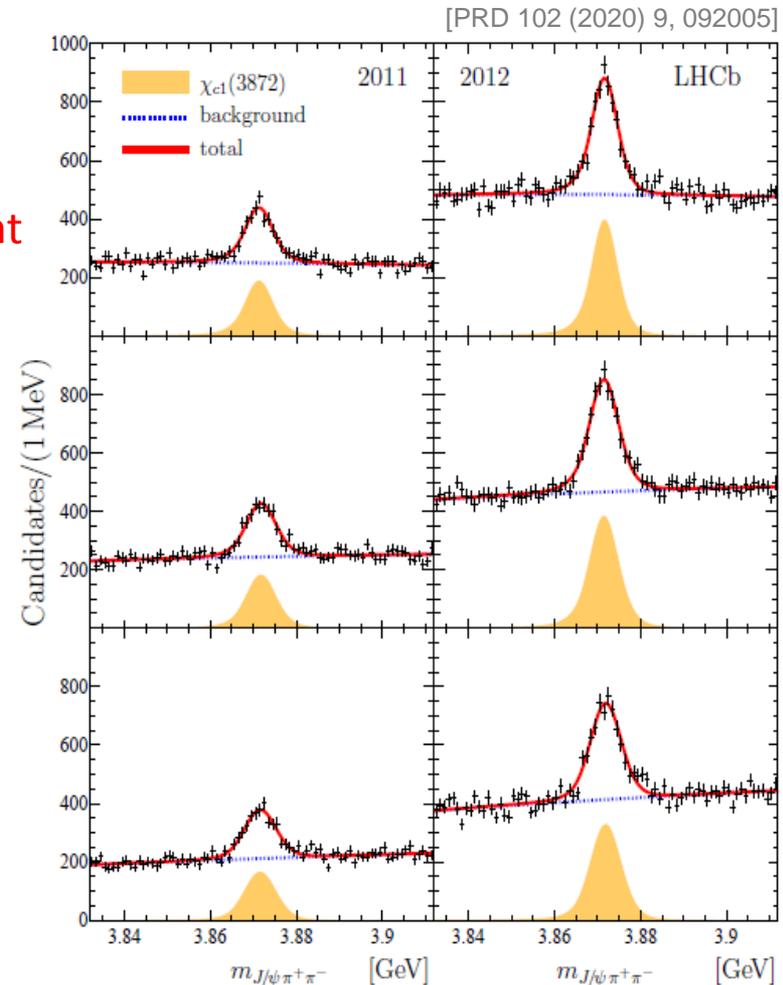
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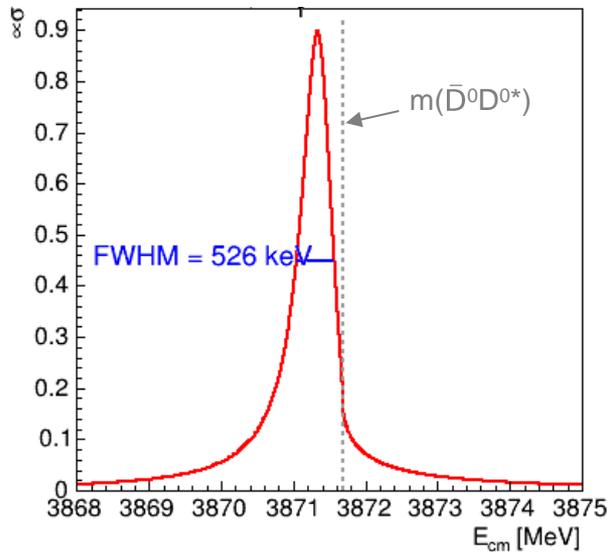
→ Need to fix the model!



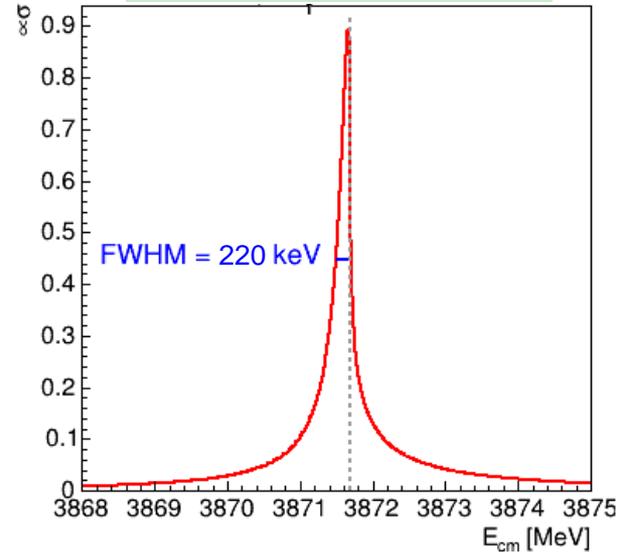
# J/ $\psi\pi^+\pi^-$ Lineshapes

- Flatté Model by Hanhart et al. [PRD 76 (2007) 034007]
- Lineshape for various Flatté energies  $E_f$  (*other parms. const*)

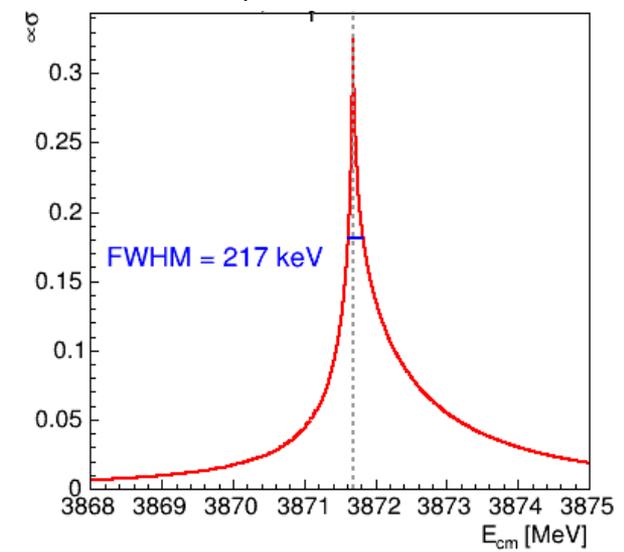
$E_f = -8.7$  MeV



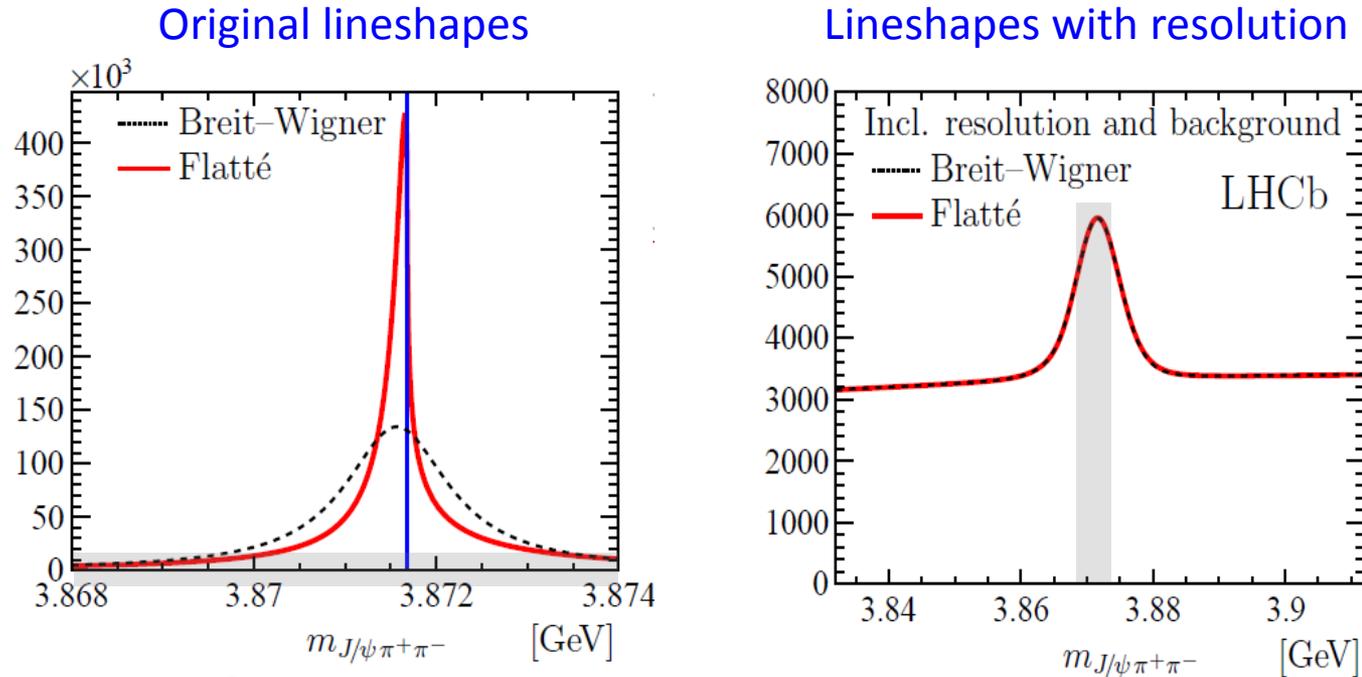
fixed by LHCb  
 $E_f = -7.2$  MeV



$E_f = -5.7$  MeV



# LHCb Lineshapes (incl Resolution)



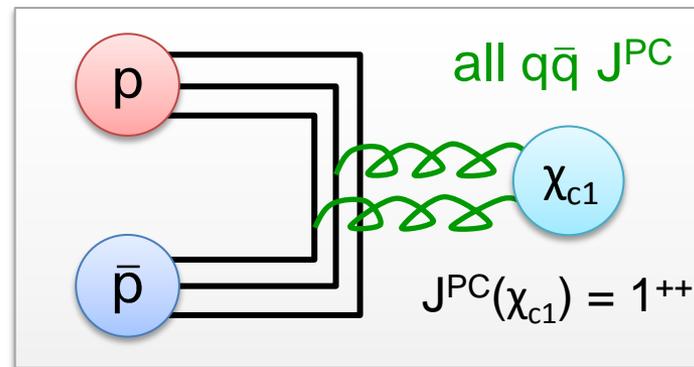
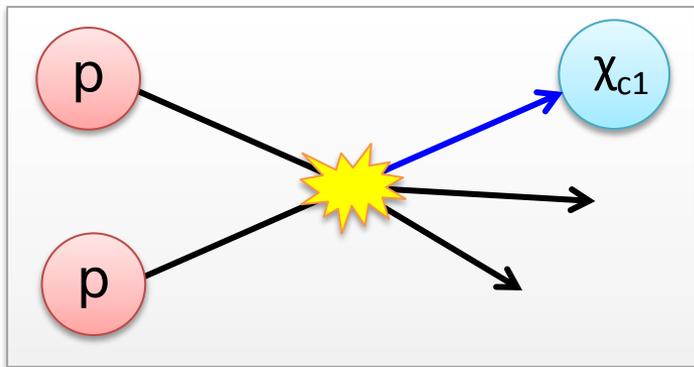
- Quote LHCb:

### 7.3 Comparison between Breit-Wigner and Flatté lineshapes

Figure 4 shows the comparison between the Breit-Wigner and the Flatté lineshapes. While in both cases the signal peaks at the same mass, the Flatté model results in a significantly narrower lineshape. However, after folding with the resolution function and adding the background, the observable distributions are indistinguishable.

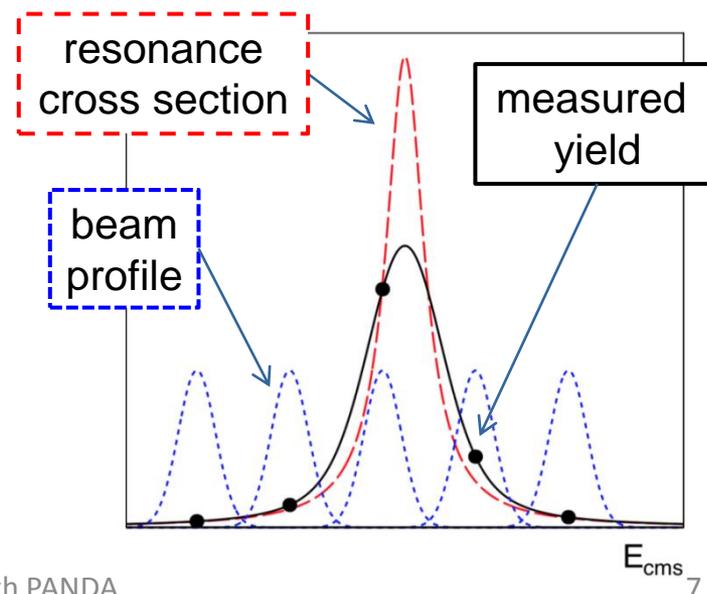
# Overcome Detector Resolution with Formation

- Production with recoils dominated by detector resolution ( $\sim$  MeV)
- Formation reaction  $\rightarrow$  produce  $\chi_{c1}(3872)$  [ $J^{PC} = 1^{++}$ ] w/o recoils



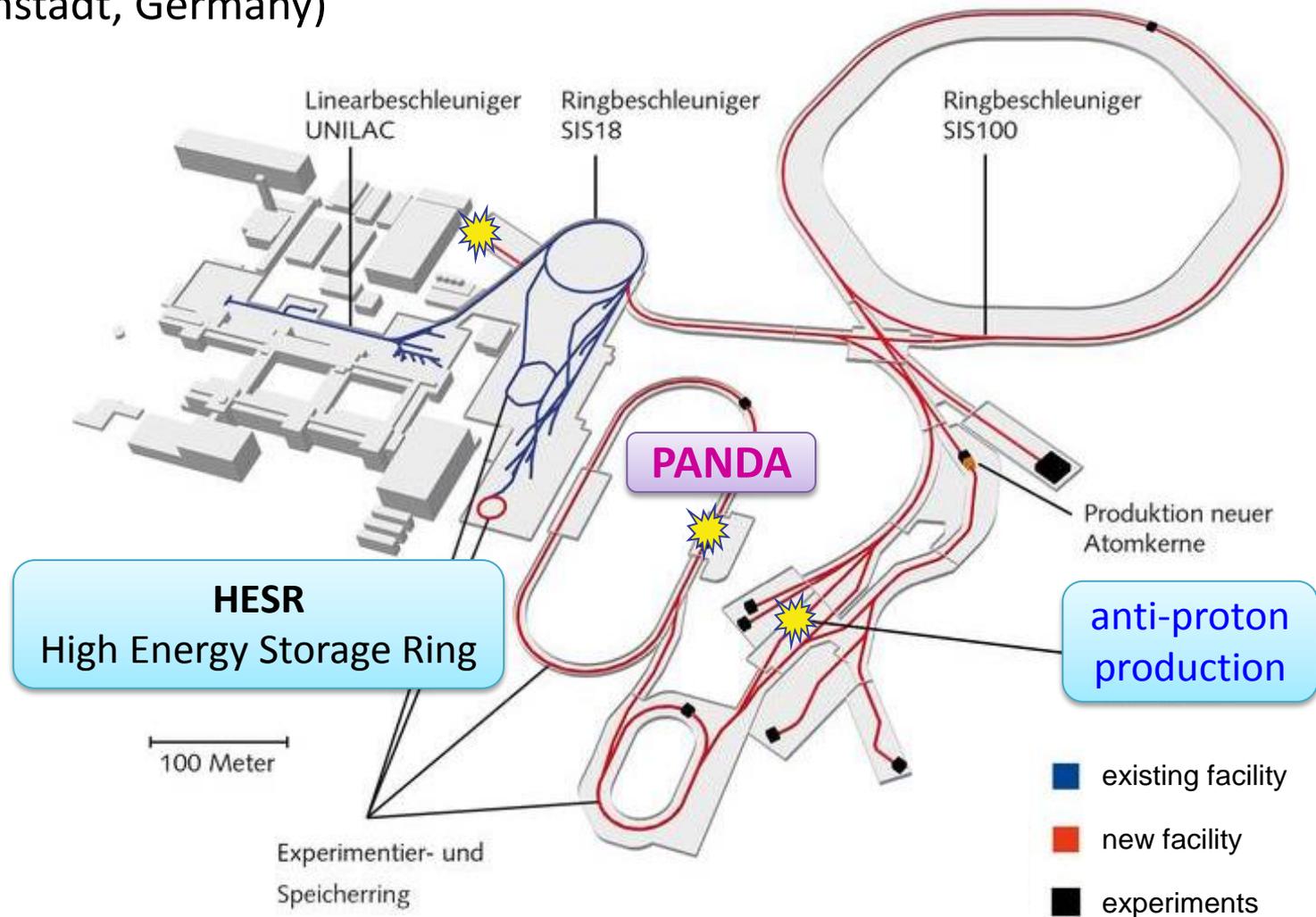
- Beam energy spread  $\rightarrow$  resolution
- Measure yield at different  $E_{\text{cms}}$

LHCb Detector Resolution  $\approx$  2.6 MeV  
PANDA Beam Resolution  $\approx$  0.05 MeV



# PANDA at FAIR

Facility for **A**ntiproton and **I**on **R**esearch  
(GSI, Darmstadt, Germany)



# FAIR Construction Site

- Good progress despite pandemic

SIS100 Tunnel with  
Transformer Building and  
Supply Building  
(Feb 2021)



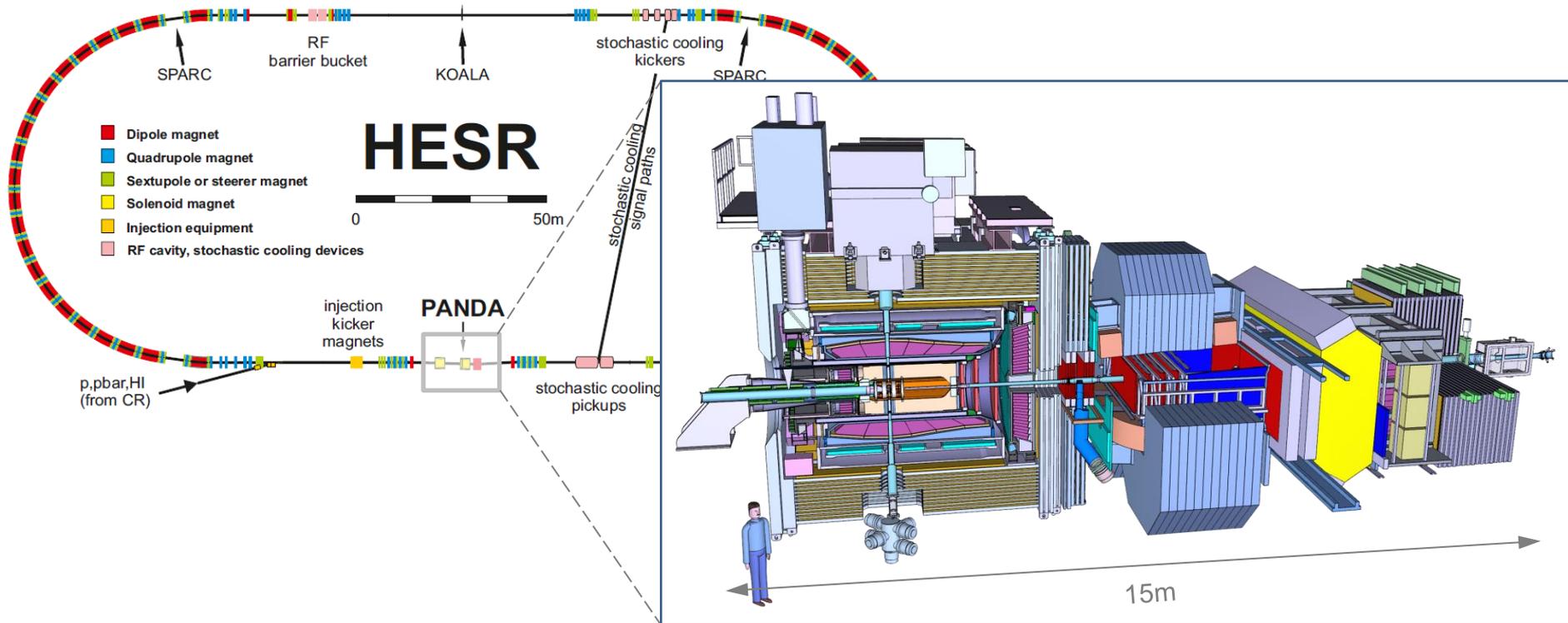
# FAIR Construction Site

- Good progress despite pandemic

Transfer Building, CBM Cave  
and Supply Building  
(Feb 2021)



# PANDA and HESR



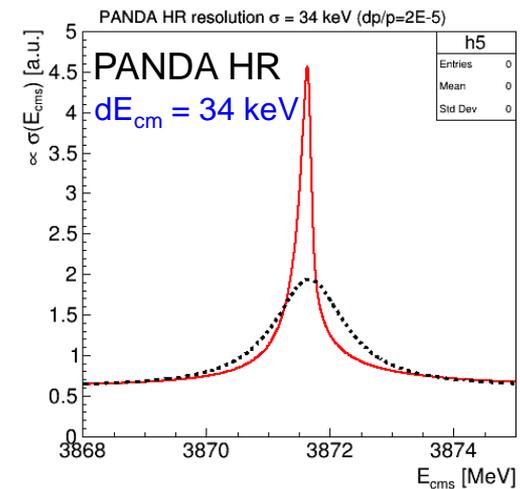
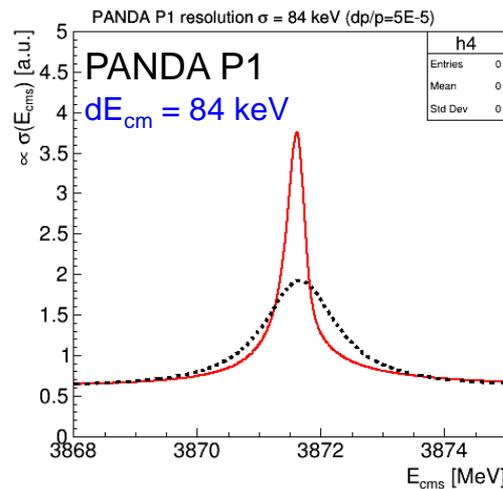
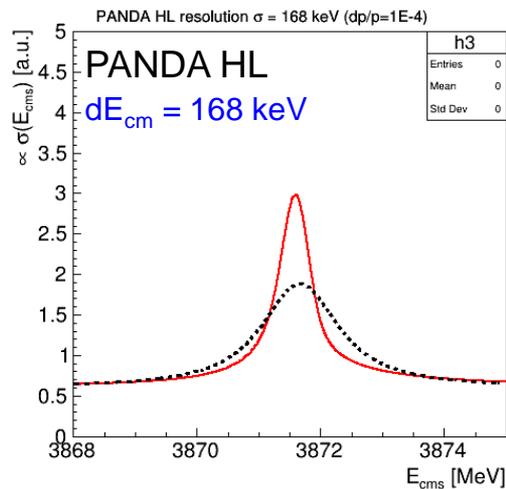
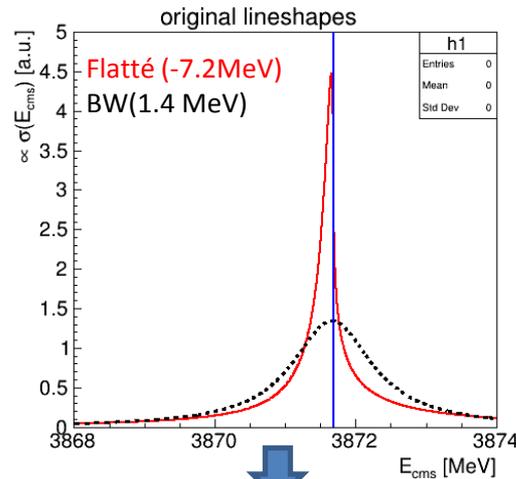
HESR mode	$dp/p$	$L_{\max}$ [1/cm <sup>2</sup> ·s]	$dE_{\text{cm}}$ [keV]
High Luminosity (HL)	$1 \cdot 10^{-4}$	$2.0 \cdot 10^{32}$	168
High Resolution (HR)	$2 \cdot 10^{-5}$	$2.0 \cdot 10^{31}$	34
Phase 1 Mode (P1)	$5 \cdot 10^{-5}$	$2.0 \cdot 10^{31}$	84

@  $E_{\text{cm}} = 3872$  MeV

# What can PANDA do?

Due to precise beam resolution

→ Breit-Wigner and Flatté-model are distinguishable



Strategy

# Ingredients from our Simulation Study

Eur. Phys. J. A (2019) 55: 42  
DOI 10.1140/epja/i2019-12718-2

[<https://arxiv.org/abs/1812.05132>]

THE EUROPEAN  
PHYSICAL JOURNAL A

Regular Article – Experimental Physics

## Precision resonance energy scans with the PANDA experiment at FAIR

Sensitivity study for width and line shape measurements of the  $\chi(3872)$

- Reaction:  $\bar{p}p \rightarrow \chi_{c1}(3872) \rightarrow J/\psi (\rightarrow e^+e^- / \mu^+\mu^-) \rho^0 (\rightarrow \pi^+\pi^-)$
- Take parameters ( $\sigma$ ,  $L$ ,  $\mathcal{B}$ ,  $\varepsilon_{reco}$ , ...) from study to estimate expected yields

$$N_{\text{exp}}(E_{\text{cms}}) = \sigma(E_{\text{cms}}) \cdot L \cdot t \cdot \prod \mathcal{B}_i \cdot \varepsilon_{\text{reco}}$$

- Investigate separation power between Flatté & BW lineshapes

Total beam time:  $T = 40 \times 2d = 80 d$

Cross section assumption:  $\sigma_{\text{peak}}(\bar{p}p \rightarrow \chi_{c1}) = 50 \text{ nb}$

Flatté energy:  $E_f = [-8.7, -8.2, -7.7, -7.2, -6.7, -6.2, -5.7, -5.2] \text{ MeV}$

BW Width:  $\Gamma = [100, 150, 200, 250, 300, \dots, 550] \text{ keV}$

# Procedure

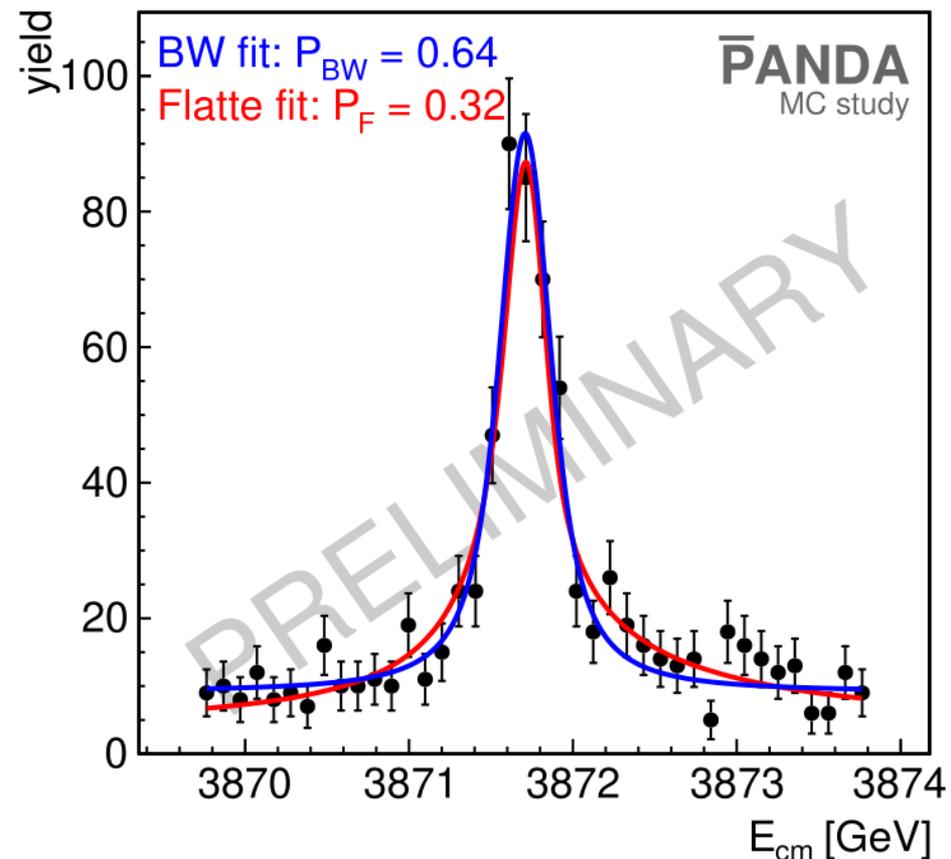
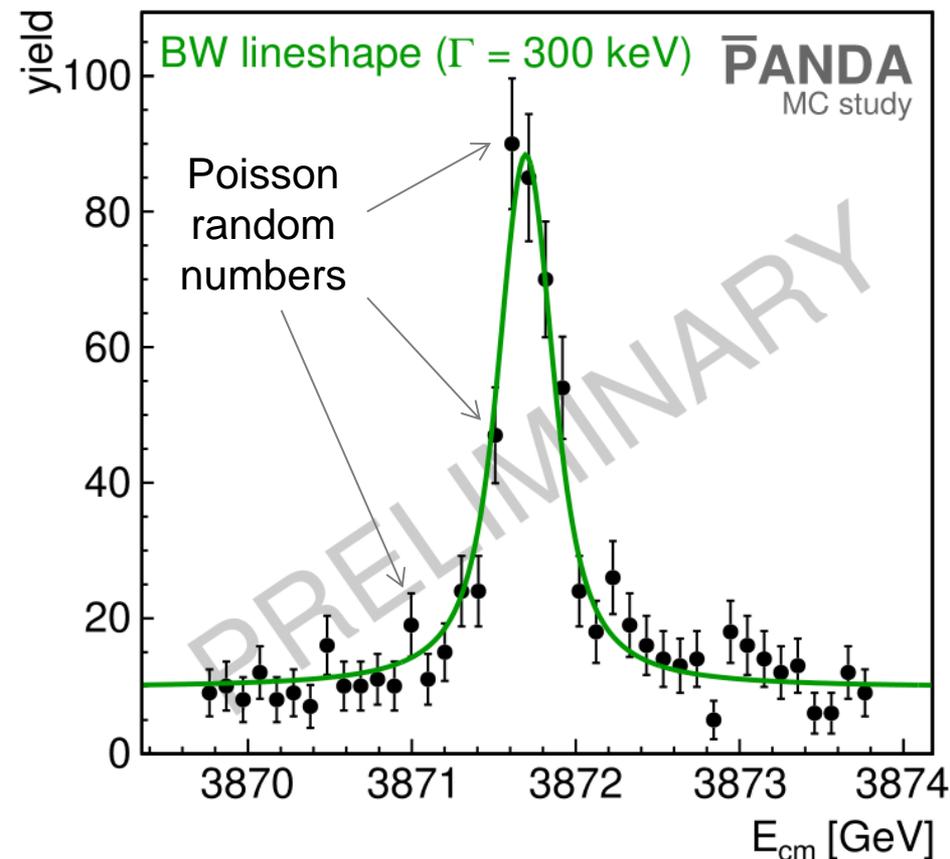
We use the following approach:

1. Use **key parameters** from EPJ A 55 (2019) 42
2. **Generate** many (toy) **spectra** for Flatté (**BW**) model
3. **Fit both BW and Flatté** to each generated distribution and determine **fit probabilities**  $P_{BW}$  and  $P_F$
4. Identification considered **correct**, if  $P_F > P_{BW}$  ( $P_{BW} > P_F$ )
5. **Count fraction** of incorrect assignments  $\rightarrow P_{mis}$
6.  $P_{mis}$  measure for **separation power**
7.  $P_{mis} = 50\%$  means: models **indistinguishable**

# Scan Procedure Principle (Example)

Example: Breit-Wigner,  $\Gamma = 300$  keV (P1 mode)

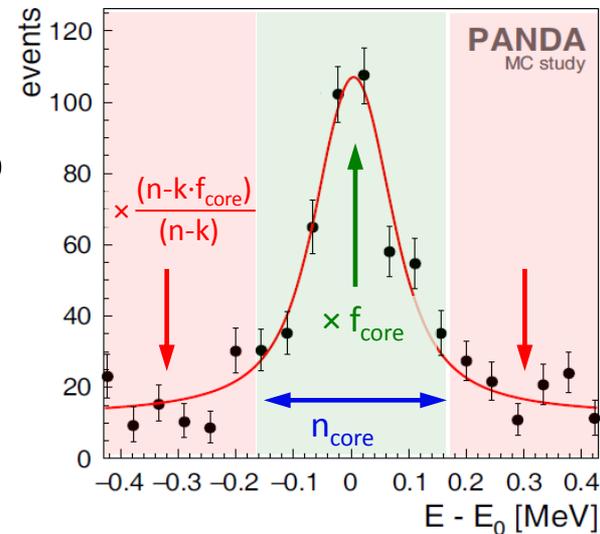
1. Compute true lineshape reflecting the expected yields
2. Generate poisson random number  $N_{\text{poisson}}$  for each  $E_{\text{cm}}$  and fill into graph
3. Fit lineshapes to extract fit probabilities  $P_{\text{BW}}$  and  $P_{\text{F}}$



# Scan Time Optimization

# Scan Time Optimisation

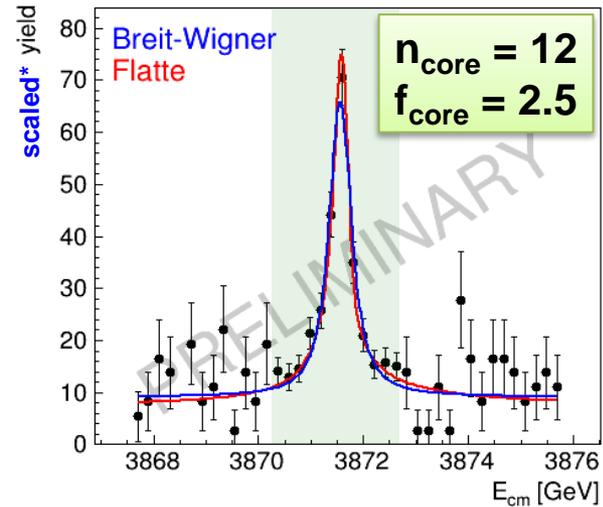
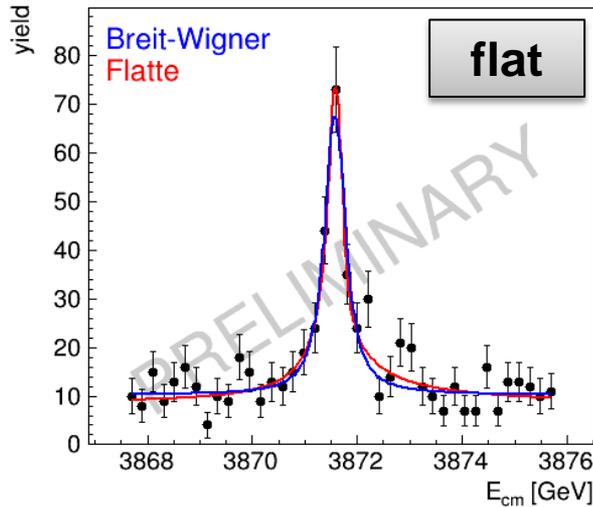
- Idea: Find better scan time distribution than constant time per energy
- Simple idea for optimisation approach:
  - Keep 40 equidistant energies in fixed energy range
  - Enhance the scan precision in center
- For that purpose:
  - Choose number  $n_{\text{core}}$  of central energy points
  - Take factor  $f_{\text{core}}$  more data at expense of tails to
  - Keep total beam time constant ( $T = 80\text{d}$ )
- Perform 2-dimensional grid search to identify optimum combination of  $(n_{\text{core}}, f_{\text{core}})$



# Scan Optimisation Example (P1)

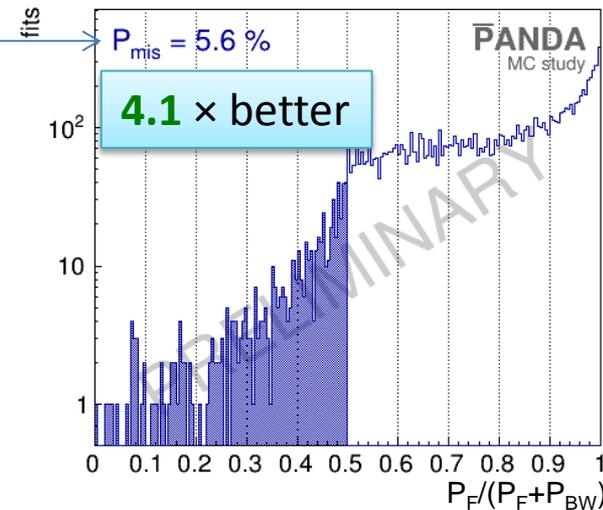
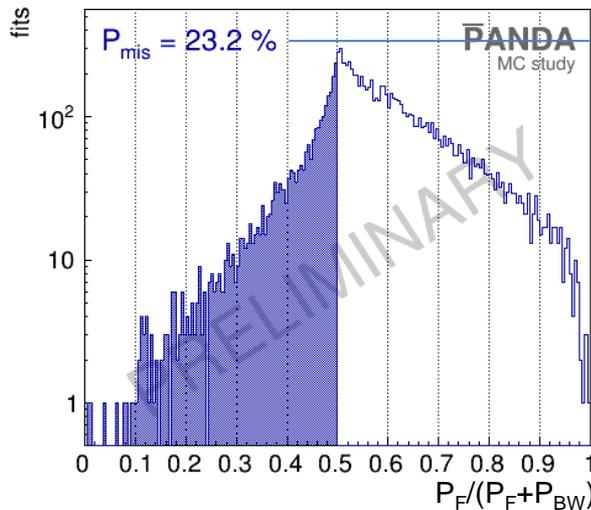
- P1 Mode:** Generated with **Flatté model** ( $E_f = -7.2\text{MeV}$ )

Fit Example



\* yields scaled, errors adapted

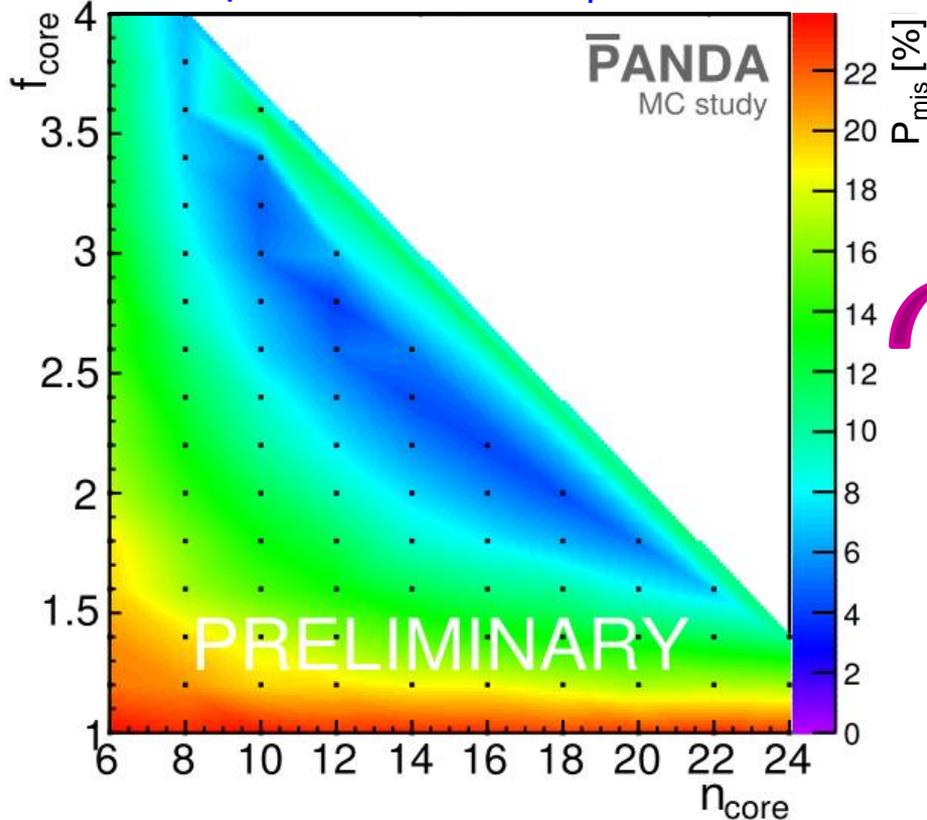
mis-ID from 10000 fits



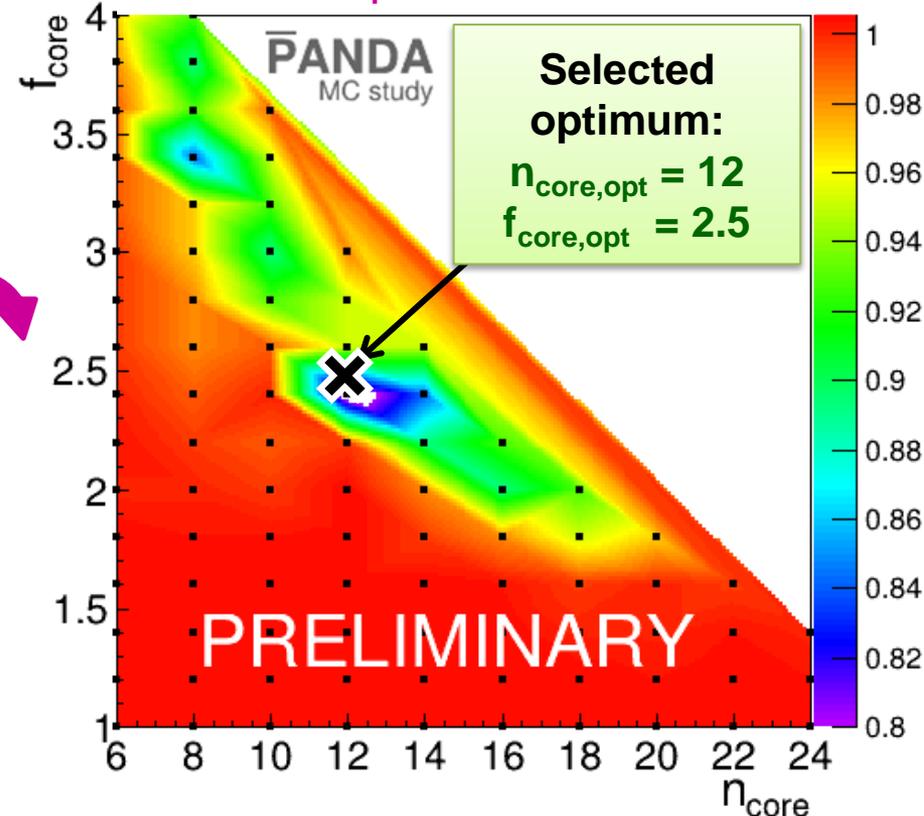
# Overall Optimisation

- Compute  $P_{\text{mis}}$  for 15 different scenarios with 91  $(f, n)_{\text{core}}$  combi's each  
(HL, P1, HR)  $\otimes$  ( $E_f = [-6.2, -7.2, -8.2]$  MeV &  $\Gamma = [0.3, 0.5]$  MeV)
- Combine plots of 15 scenarios

Example scenario: P1,  $E_f = -7.2$  MeV



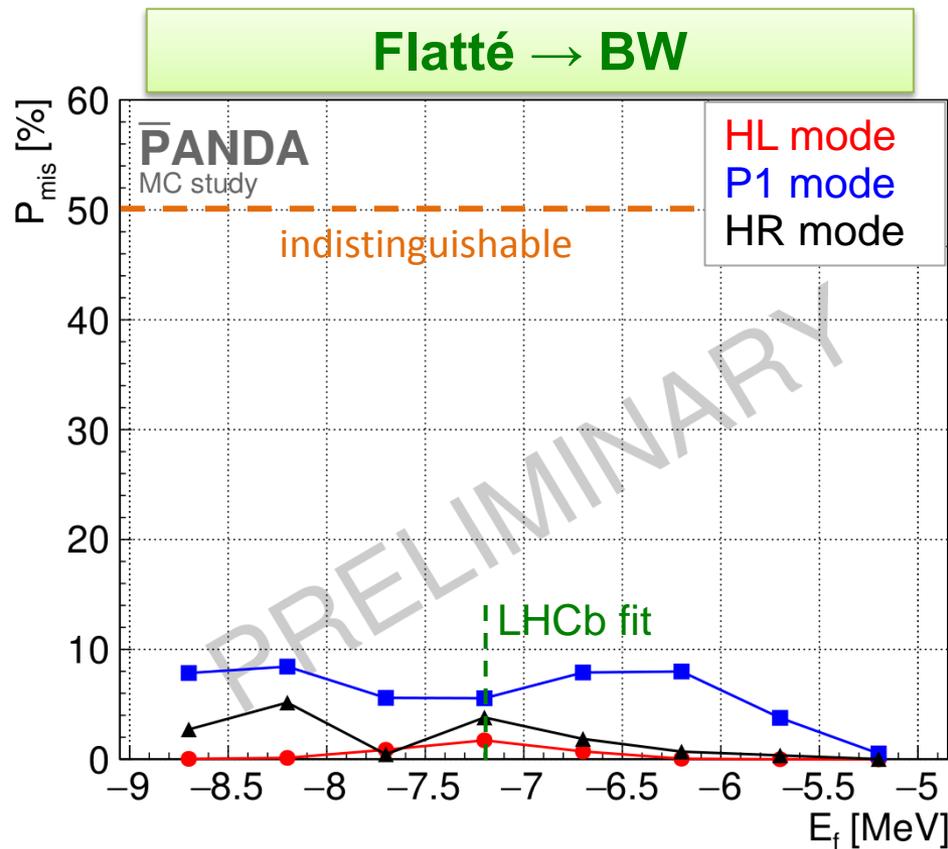
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# RESULTS

# Parameter Dependent Performance

- Performance across Flatté energy  $E_f$  range

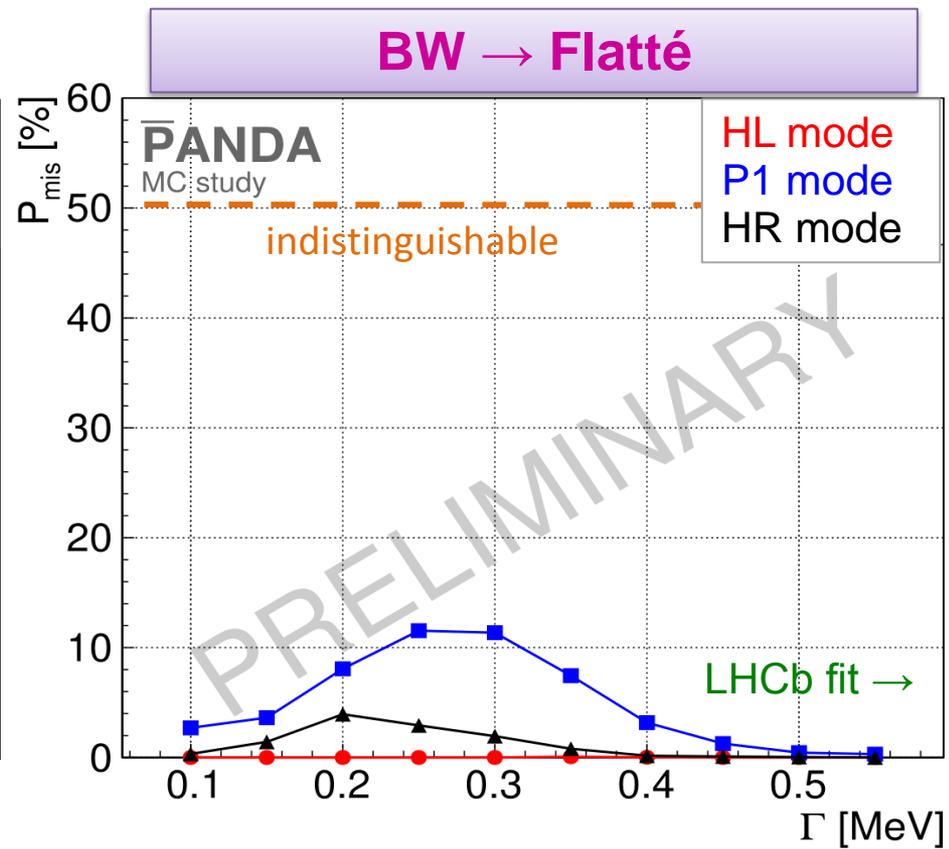
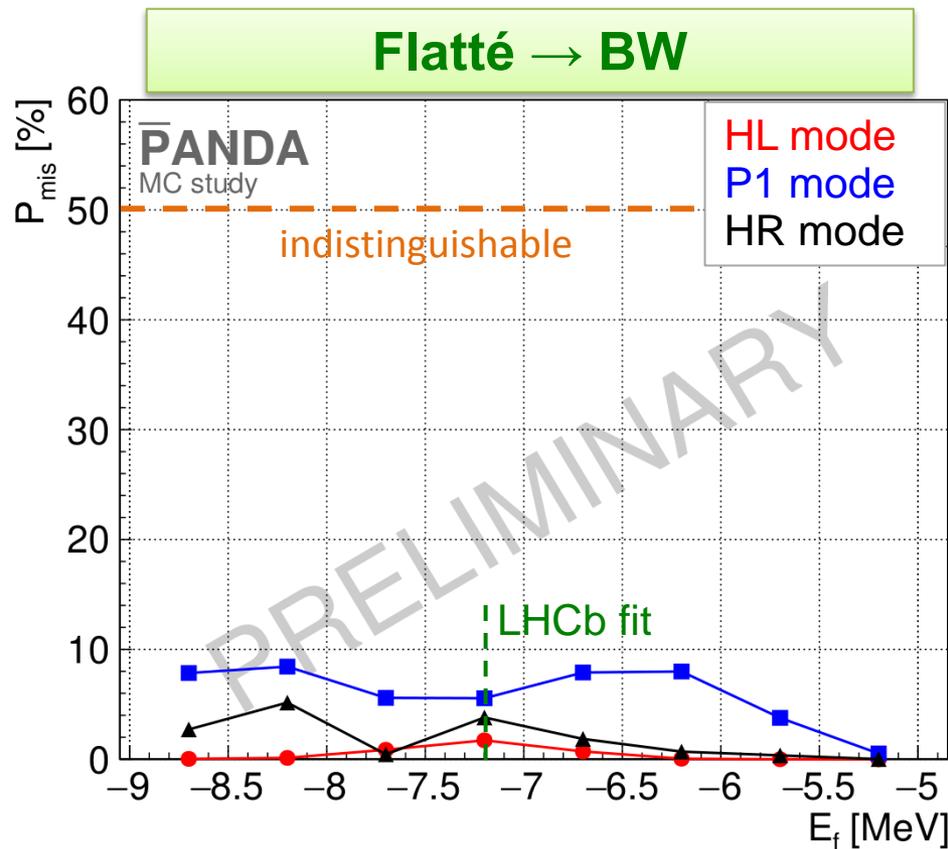


For Mis-match of Flatté as BW we see

- for the three beam modes **HL**, **HR**, **P1**
- the mis-identification probability  $P_{\text{mis}}$
- across range of input parameters  $E_f$
- with **LHCb** best fit  $E_f = -7.2$  MeV
- and  $P_{\text{mis}} = 50\%$  for "indistinguishable"

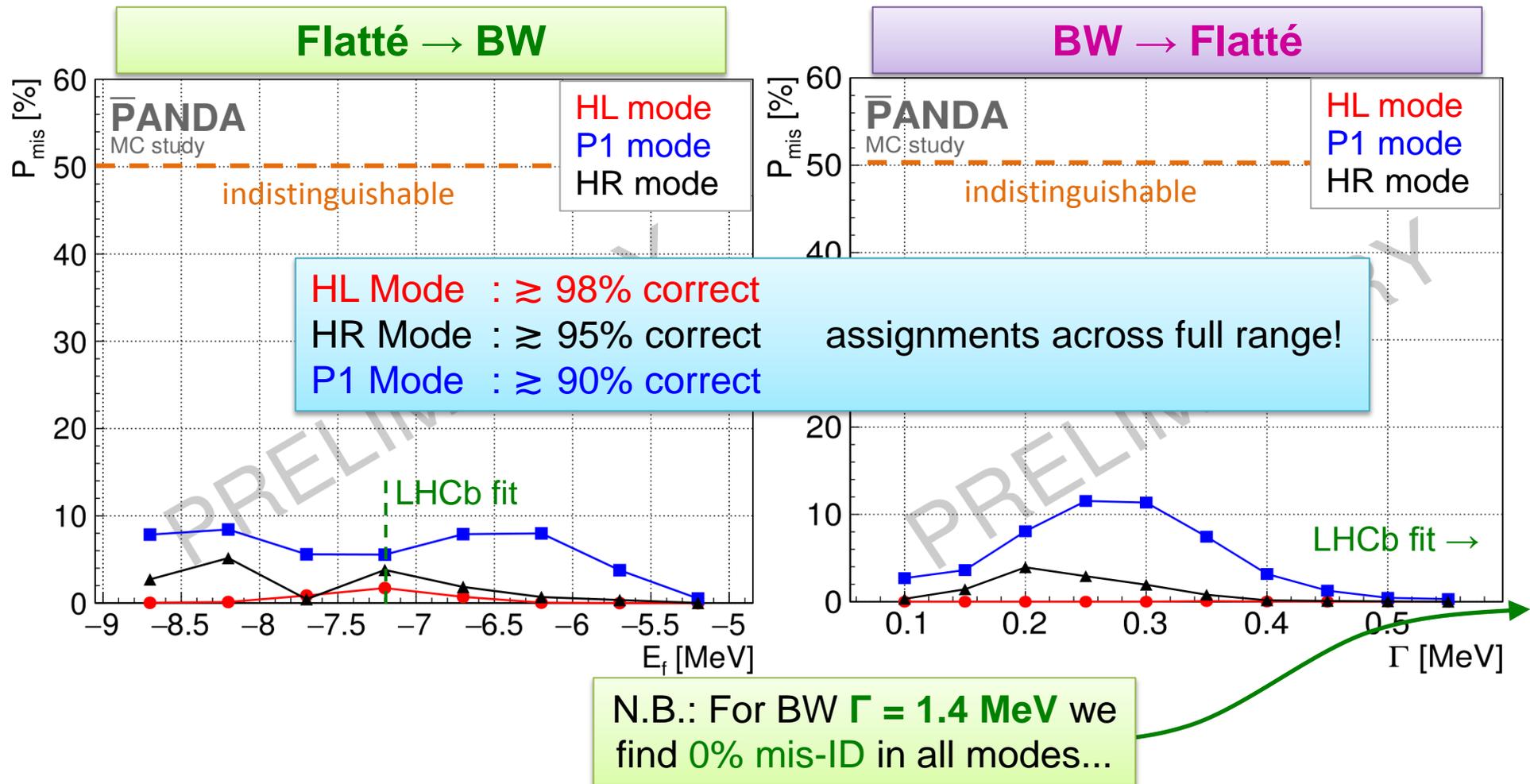
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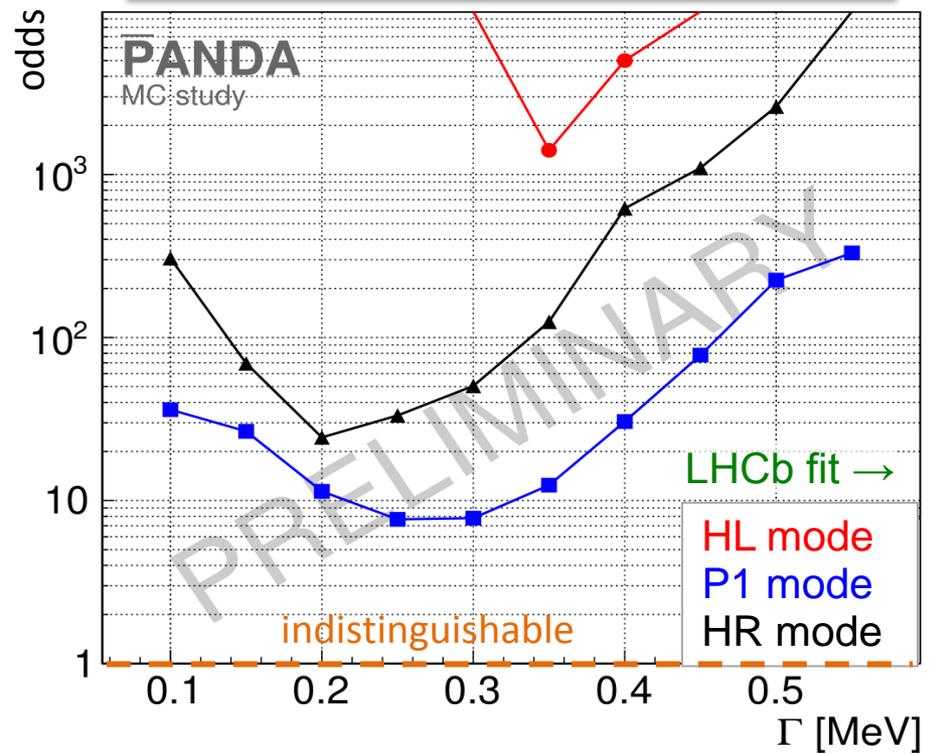
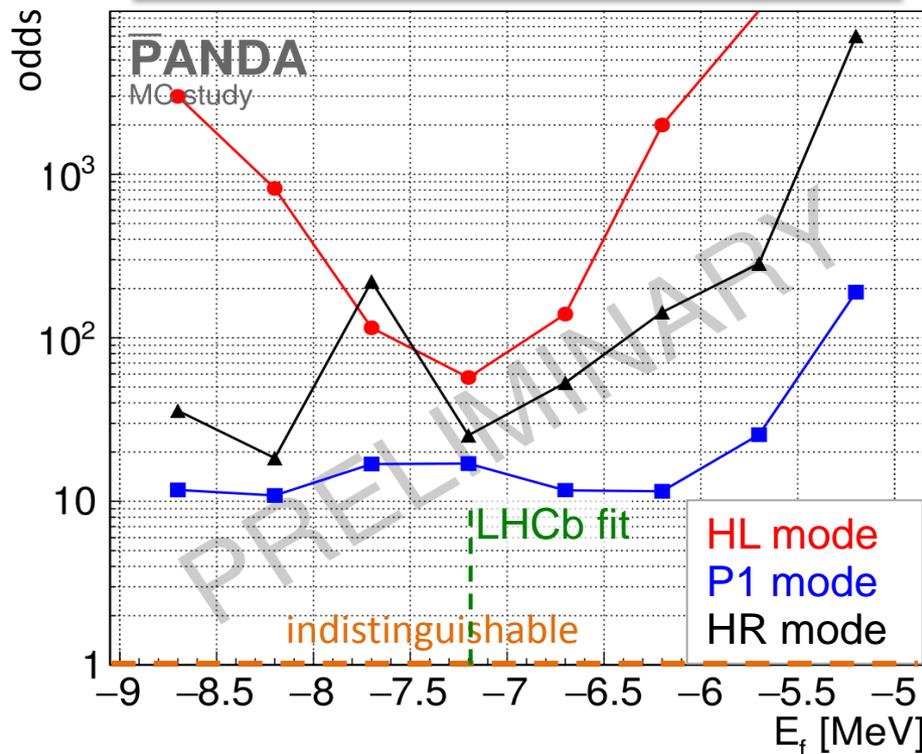
# Performance - Alternative Representation

- How much better than "indistinguishable" is it?
- Idea: Consider so-called **odds** = correct identifications per wrong one

$$\text{odds} = (1 - P_{\text{mis}}) / P_{\text{mis}}$$

Flatté → BW

BW → Flatté



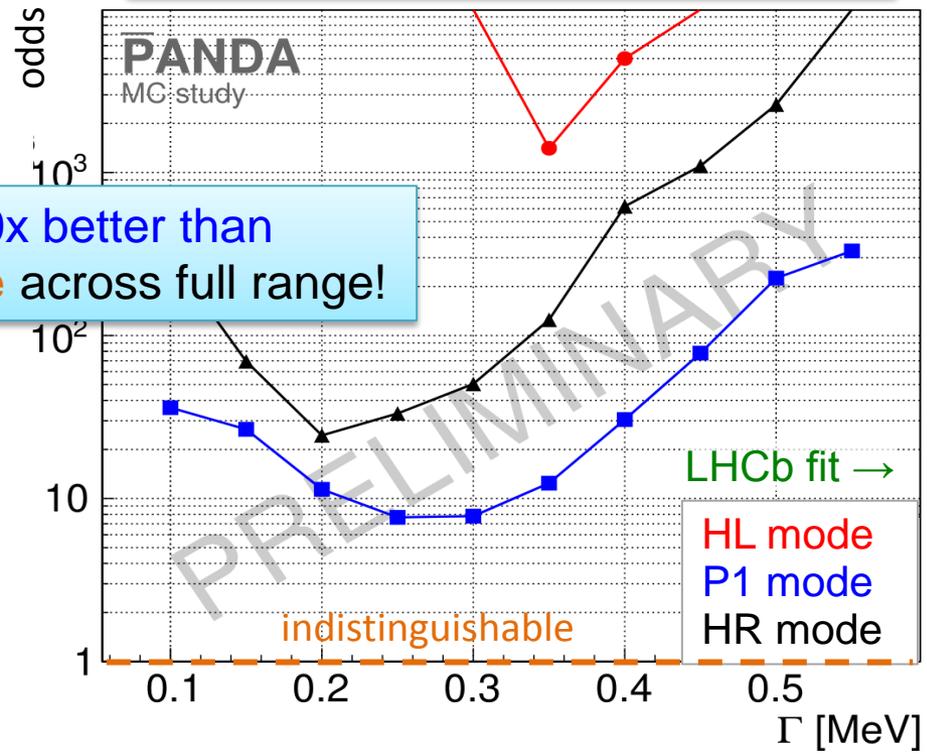
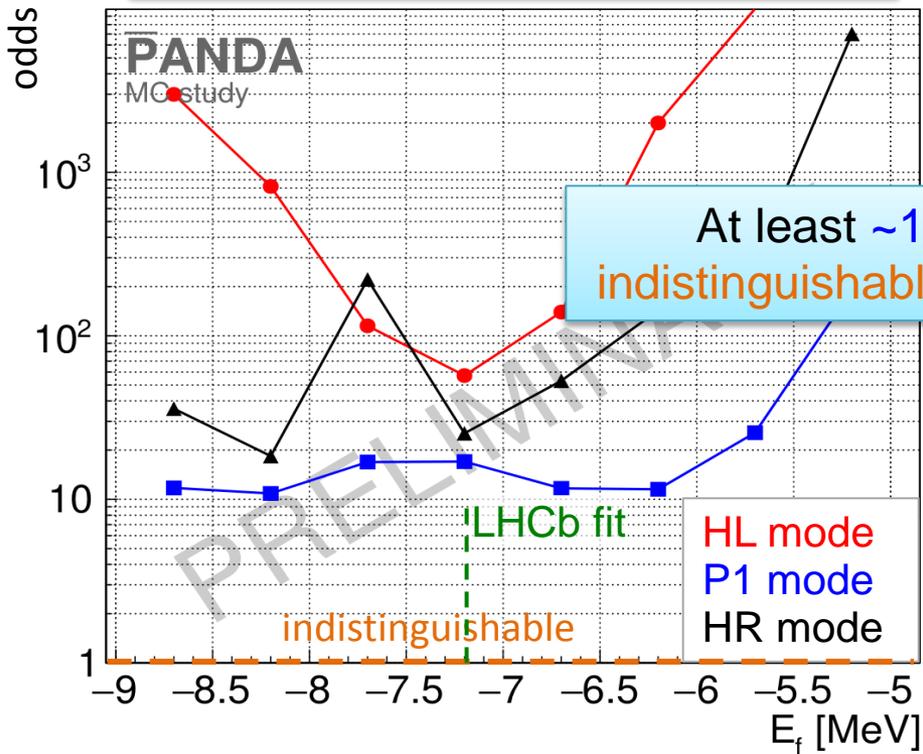
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- Simulation of line shape measurement of  $\chi_{c1}(3872)$  at **PANDA**  
⇒ Different models can be well distinguished
- Correct assignment of fit model over full range between  $\gtrsim 90\%$  (**P1**) and  $\gtrsim 98\%$  (**HL**) depending on beam mode
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**Thank you very much  
for your attention!**