X(3872) Lineshape Study and the new LHCb Measurement

PANDA CM Mainz

Charmonium Exotics Session

14. Sep. 16

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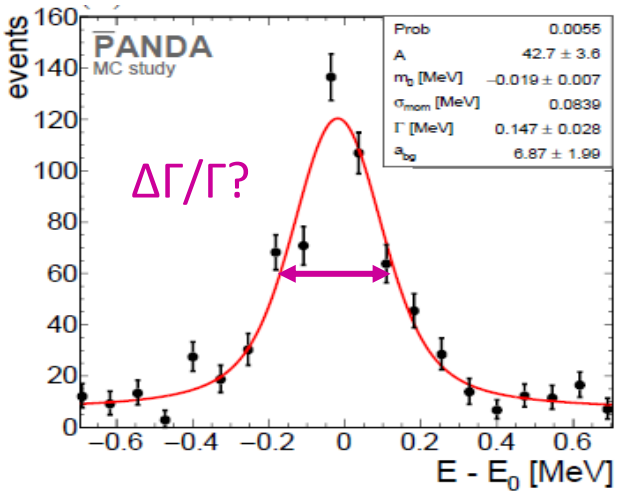
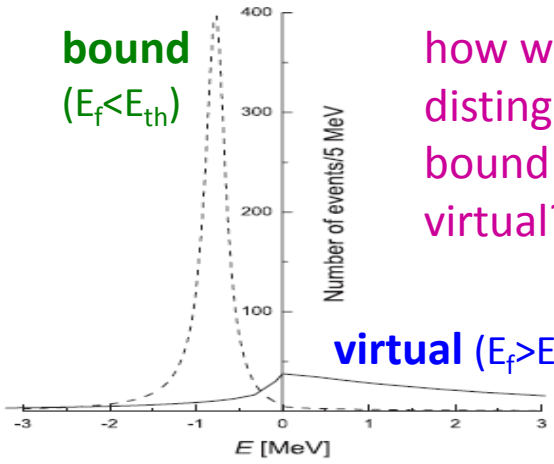
Reminder

- Nature of X(3872)
  - Need lineshape and width to understand nature
- Approach at PANDA
  - Fine scan around nominal mass
    → energy dependent cross section
- Analysis goals
  a) Sensitivity of Γ measurement (conventional BW)
  b) Sensitivity for virtual/bound state (molecular picture)

a)



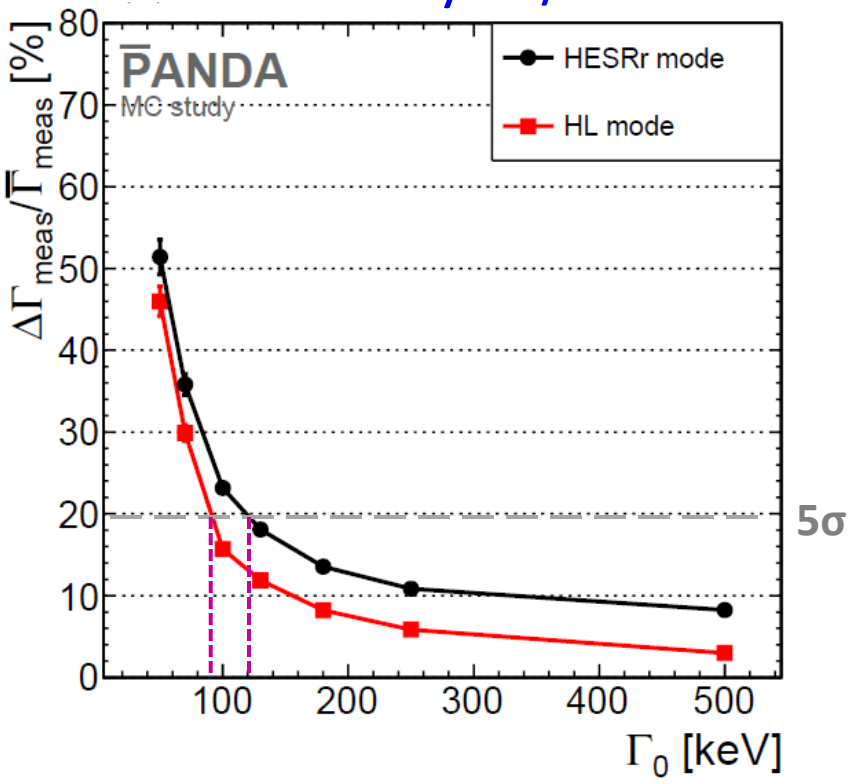
b)



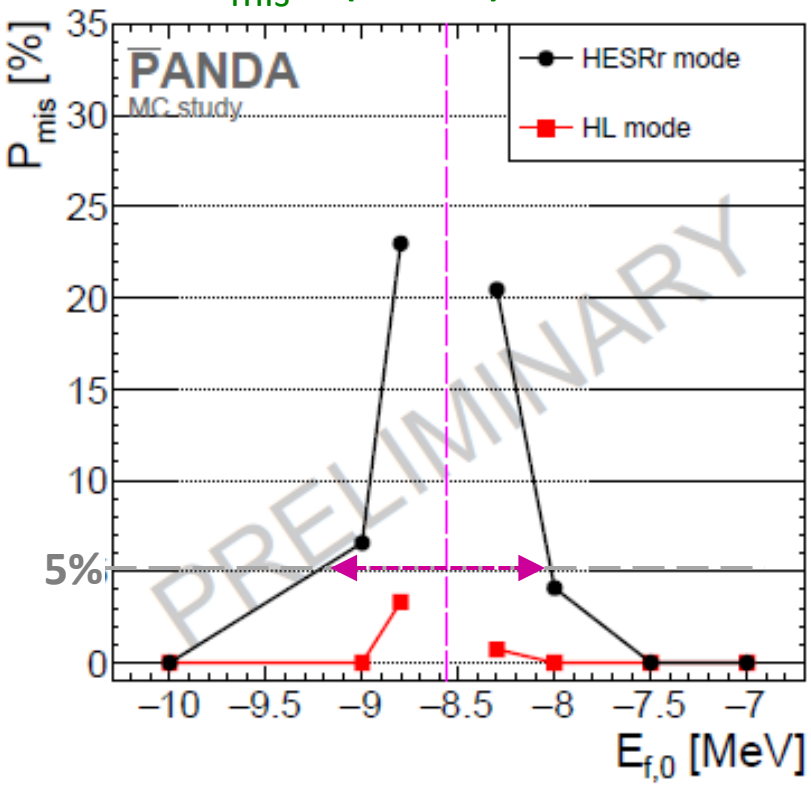
Main Results

- Precision of measured BW width Γ
- Distinguishability of nature (virtual/bound state) by lineshape

Sensitivity ΔΓ/Γ



P_{mis} X(3872) nature



ΔΓ/Γ =20% : Γ= 90 ... 120 keV

HL HESRr

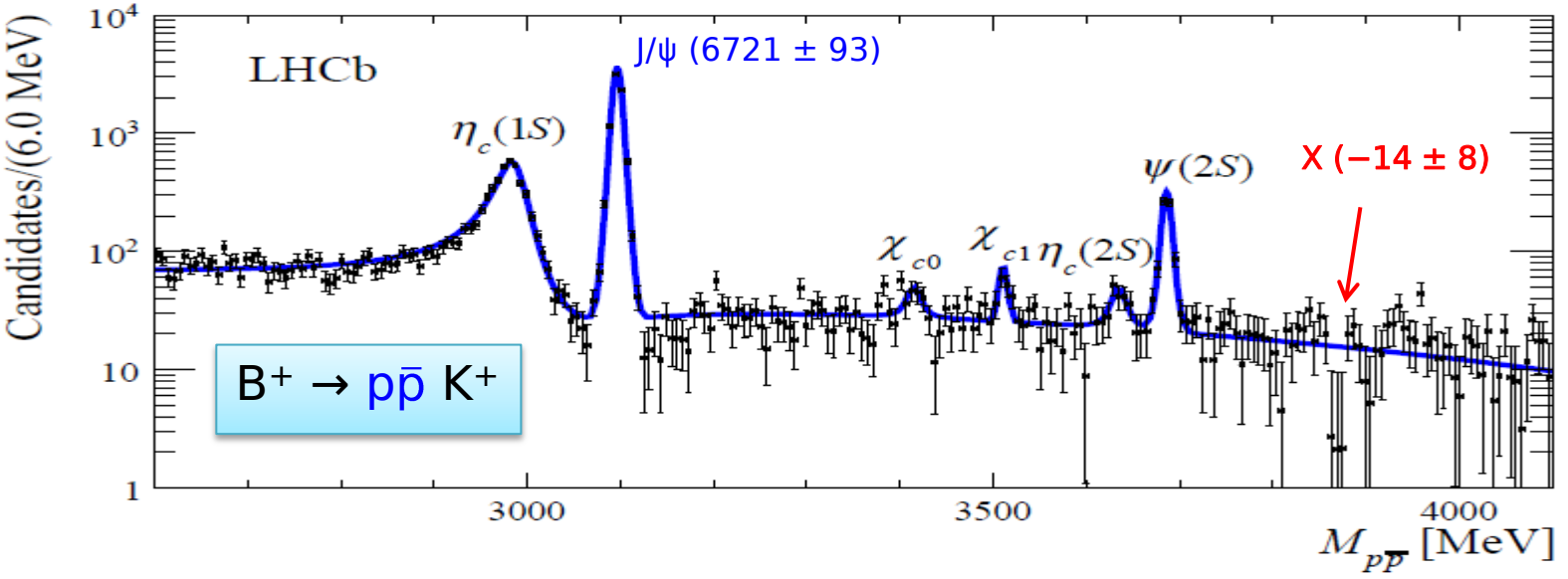
P_{HL} > 95%

P_{HESRr} > 95% for $|E_f - E_{f,th}| \gtrsim 0.75$MeV

Updated Result from LHCb

- Following inputs about the X(3872) needed:
  1. Assumption about production cross section $p\bar{p} \rightarrow X(3872)$
  2. Assumption about decay BR($X \rightarrow J/\psi\, \pi^+ \pi^-$)
- Since our study, (1.) changed due to a newer number from an updated LHCb measurement *(3x more data)* of

$$\frac{\mathcal{B}(B^+ \to X(3872)K^+) \times \mathcal{B}(X(3872) \to p\bar{p})}{\mathcal{B}(B^+ \to J/\psi K^+) \times \mathcal{B}(J/\psi \to p\bar{p})} < 0.20\,(0.25) \times 10^{-2}.$$



New LHCb Measurements

- New LHCb paper arXiv:1607.06446v1

$$\mathcal{R} = \frac{\mathcal{B}(B^+ \to X(3872)K^+) \times \mathcal{B}(X(3872) \to p\bar{p})}{\mathcal{B}(B^+ \to J/\psi\, K^+) \times \mathcal{B}(J/\psi \to p\bar{p})}$$

CL90 (CL95)

$$< 0.20\,(0.25) \times 10^{-2}$$

3.2x smaller

- Compare with old value: EPJ C73 (2013) 2462

$B^+ \to$ (mode) $\to p\bar{p}K^+$	Yield ± stat ± syst	$\epsilon_{\rm mode}/\epsilon_{J/\psi}$ ± syst	$\mathcal{R}$(mode) ± stat ± syst	Upper Limit 95% CL
$J/\psi\, K^+$	$1458 \pm 42 \pm 24$	–	1	–
total	$6951 \pm 176 \pm 171$	0.970 ± 0.002	$4.91 \pm 0.19 \pm 0.14$	–
$M_{p\bar{p}} < 2.85\,\mathrm{GeV}/c^2$	$3238 \pm 122 \pm 121$	1.097 ± 0.006	$2.02 \pm 0.10 \pm 0.08$	–
$\eta_c(1S)K^+$	$856 \pm 46 \pm 19$	1.016 ± 0.034	$0.578 \pm 0.035 \pm 0.026$	–
$\psi(2S)K^+$	$107 \pm 16 \pm 13$	0.921 ± 0.044	$0.080 \pm 0.012 \pm 0.009$	–
$\eta_c(2S)K^+$	$39 \pm 15 \pm 5$	0.927 ± 0.041	$0.029 \pm 0.011 \pm 0.004$	< 0.048
$\chi_{c0}(1P)K^+$	$15 \pm 13 \pm 4$	0.957 ± 0.024	$0.011 \pm 0.009 \pm 0.003$	< 0.028
$h_c(1P)K^+$	$21 \pm 11 \pm 5$	0.943 ± 0.032	$0.015 \pm 0.008 \pm 0.004$	< 0.029
$X(3872)K^+$	$-9 \pm 8 \pm 2$	0.896 ± 0.058	$-0.007 \pm 0.006 \pm 0.002$	< 0.008
$X(3915)K^+$	$13 \pm 17 \pm 5$	0.890 ± 0.062	$0.010 \pm 0.013 \pm 0.002$	< 0.032

Old Parameters

	Parameter	Value
Branching Fractions	$BR(J/\psi \rightarrow e^+ e^-)$	5.97 %
	$BR(J/\psi \rightarrow \mu^+ \mu^-)$	5.96 %
	$BR(\rho^0 \rightarrow \pi^+ \pi^-)$	100%
	$BR(X \rightarrow J/\psi \rho^0)$	5 % (UL: 6.6%)
Cross sections	$\sigma_{peak}(\bar{p}p \rightarrow X)$	**100 nb** (UL: 169nb)
	$\sigma(\bar{p}p \rightarrow J/\psi \pi^+\pi^-$ non-res)	1.2 nb* (theory)
	$\sigma(\bar{p}p \rightarrow$ inelastic) @ 3.872 GeV	46 mb
Luminosities	L_{HL} (3.872 GeV)	13683 $(nb \cdot d)^{-1}$ **
	L_{HESRr} (3.872 GeV)	1170 $(nb \cdot d)^{-1}$ **
Resolutions	ΔE_{abs} *(energy prec. w/ calibration)*	168 keV ($dp/p = 10^{-4}$)
	ΔE_{rel} *(relative energy positioning)*	1.7 keV ($dp/p = 10^{-6}$)
	ΔE_{mom} (HL)	168 keV ($dp/p = 10^{-4}$)
	ΔE_{mom} (HESRr)	84 keV ($dp/p = 5 \cdot 10^{-5}$)

* [PRD 77 (2008) 097501]
** [IN-IDE-2015-002 (2015)]

Production Signal Cross Section

- Input 1: **2.6%** < B(X→J/ψ π⁺π⁻) < **6.6%** (CL90)
- Input 2: B(X→p̄p) < **0.002**· B(X→J/ψ π⁺π⁻) (CL95)
  now ***0.00063***

[arXiv:0910.3138v2]
[Eur. Phys. J. C73 (2013) 2462]
[arXiv:1607.06446v1]

- Crossing symmetry (or detailed balance) gives at peak

$$\sigma_{\mathrm{peak},\bar{p}p\to X} = \frac{12\pi}{M_X^2 - 4m^2} \cdot B(X \to \bar{p}p)$$

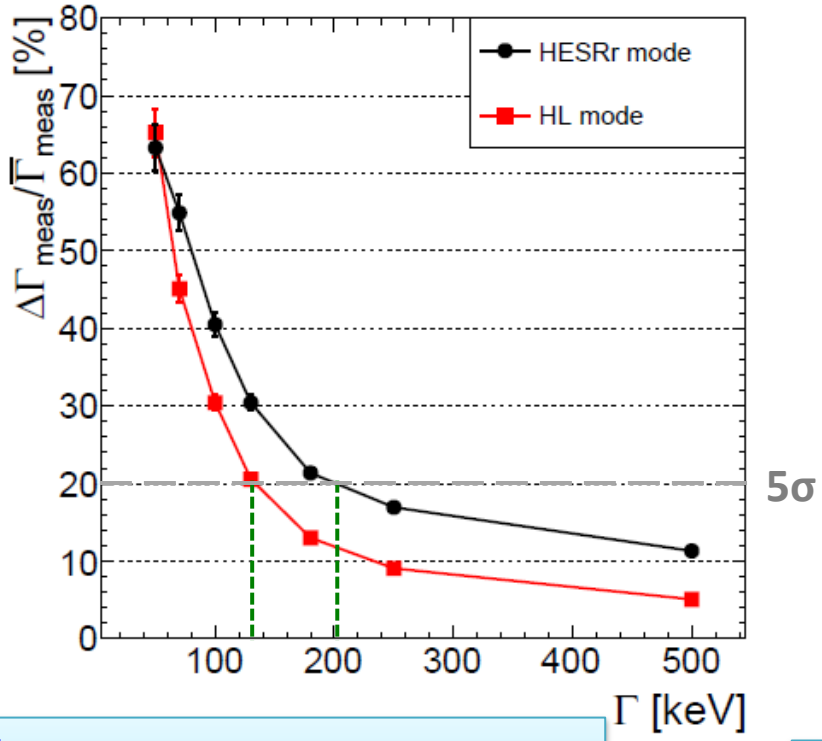
	2.6%	5%	6.6%	
old ⇒ $\sigma_{\mathrm{peak},\,p\bar{p}\to X}$ <	67 nb	... 128 nb	... **169 nb**	*@ CL95 · CL90*
new ⇒ $\sigma_{\mathrm{peak},\,p\bar{p}\to X}$ <	21 nb	... 40 nb	... **53 nb**	*@ CL95 · CL90*

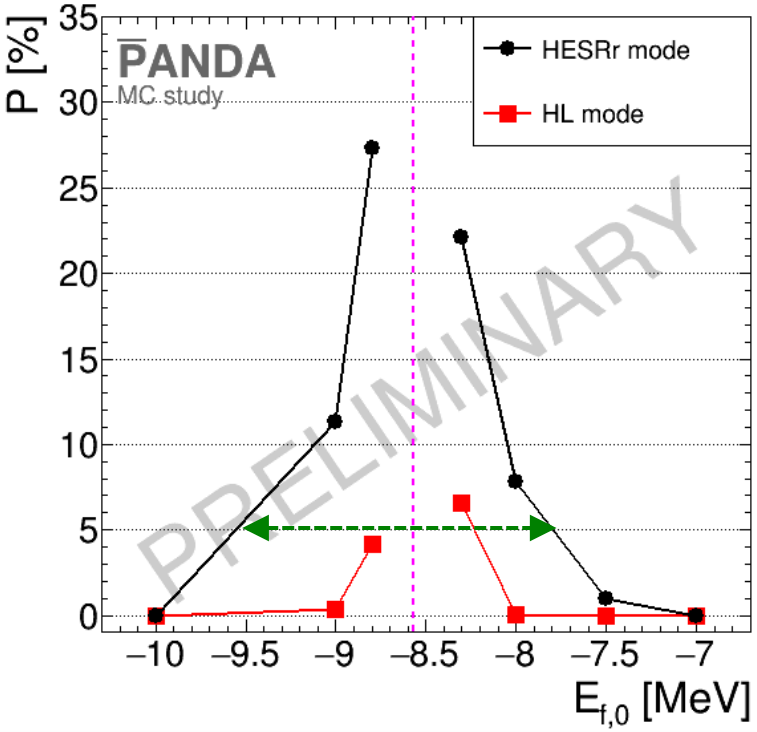
- Good news: study of **σ = 50 nb** already carried out in release note

Parameter Variation (d) in Note

- RN-QCD-2016-002: App. B, Fig 19/20d (BW performance)

(d) **Maximum peak cross section $\sigma_X(E_R)$**: The maximum signal cross section is set to the same value $\sigma_X(E_R) = 50$ nb as in the previous study [6]. This leads in combination with the lower branching fraction assumption $B(X(3872) \to J/\psi\pi^+\pi^-) = 5\%$ considered here to an effective reduction to 50% of the nominal signal strength as compared to the reference.





ΔΓ/Γ = 20% : Γ= 90 ... 120 keV
new: Γ= 130 ... 200 keV
HL HESRr

P_{HL} > 95% → 93%
P_{HESRr} > 95% for $\Delta E_f \gtrsim 0.75$ MeV → 1MeV

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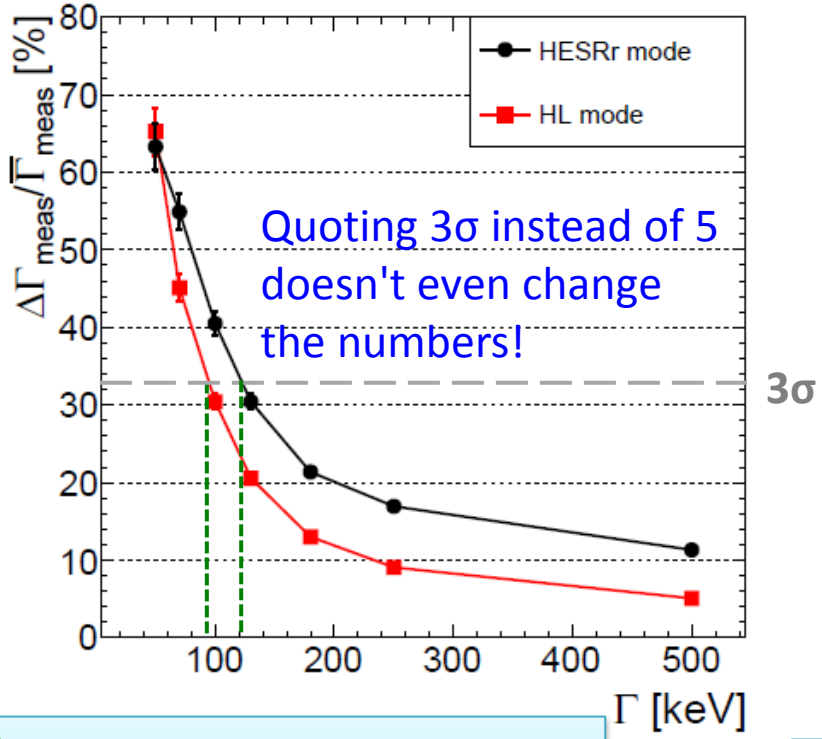
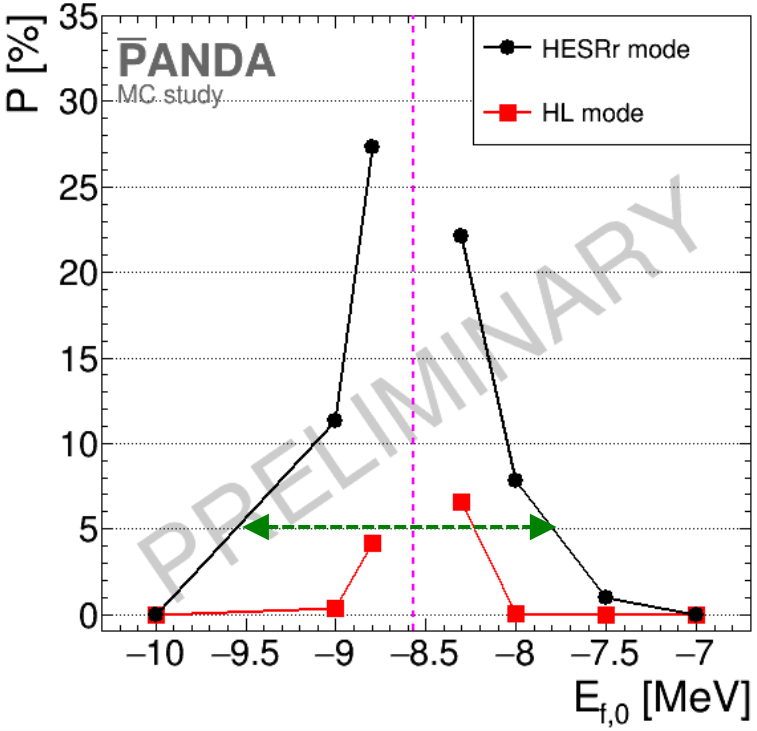




ΔΓ/Γ = **33%** : Γ= 90 ... 120 keV
HL HESRr

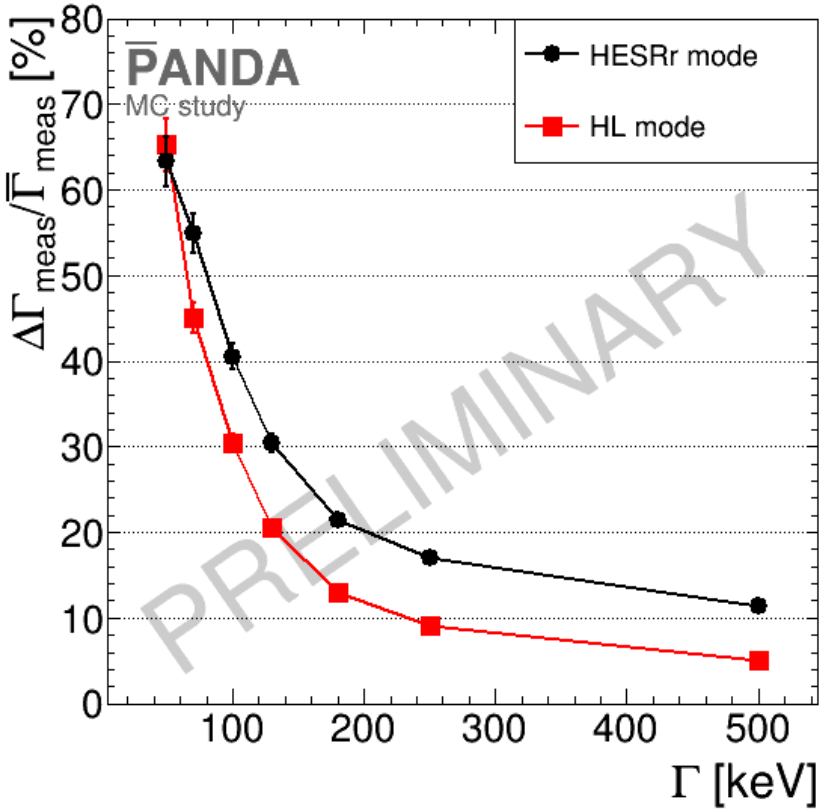
P_{HL} > 95% → 93%
P_{HESRr} > 95% for $\Delta E_f \gtrsim 0.75$ MeV → 1MeV

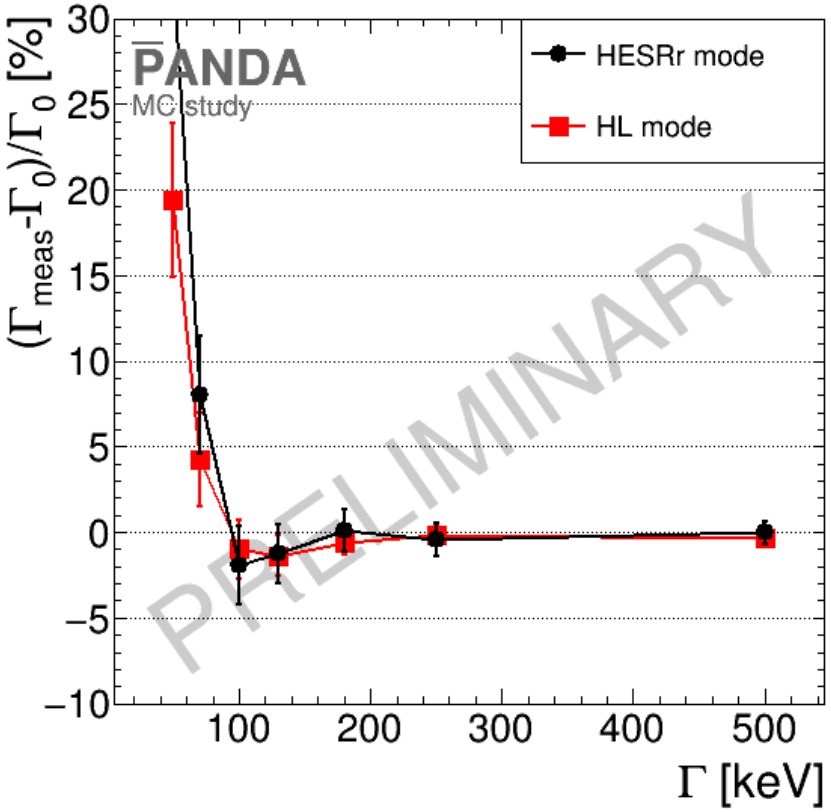
New Summary

- X(3872) - Scan valid for new LHCb results
  - Serves as proof of principle for scan experiments at PANDA!
- Determined sensitivity for BW width measurement
  - Sensitivity $\Gamma/\Delta\Gamma > 5$ at $\Gamma \gtrsim 130 \ldots 200$ keV *(was 90...120 keV)*
    [or: $\Gamma/\Delta\Gamma > 3$ at $\Gamma \gtrsim 90 \ldots 120$ keV]
  - Bias $(\Gamma - \Gamma_0)/\Gamma_0$ no problem for $\Gamma \gtrsim 70$ keV *(was w/o limit)*
  - HL mode superior over investigated range
- Determined sensitivity for molecular lineshape measurement
  - Possible to distinguish bound/virtual state (1st time study!)
  - $P_{HL} > 93\%$ (all investigated settings) *(was 95%)*
  - $P_{HESRr} > 95\%$ for $|E_f - E_{f,th}| \gtrsim 1$ MeV *(was 0.75 MeV)*
  - HL mode superior over investigated range
- **Proposal:** Extend released material by Figs. 19(d) + 20(d)

Existing Plots to be released (BW)

- App. B, Fig 19(d) (already added 'preliminary' here)





Existing Plots to be released (Lineshape)

- App. B, Fig 20(d) (already added 'preliminary' here)