Charmonium (-like) Spectroscopy (CC/CCE) and Light Meson Spectroscopy (LM) -- Communications

Frank Nerling
GU Frankfurt & GSI Darmstadt

Outline

- Some communications
  - Agenda
  - Publications/release
- Impact of new LHCb result on XYZ at PANDA

Agenda

Charmonium and Exotics Session at CM 20/2

Wednesday Jun 24, 2020, 11:00 AM → 12:30 PM Europe/Berlin

Online

11:00 AM → 11:10 AM **Communications**
Speaker: Frank Nerling (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI))

11:10 AM → 11:40 AM **Feasibility Study of Zc(3900) with PANDA**
Speaker: Ali Yilmaz (Giresun University(GiUn))

11:35 AM → 12:00 PM **Plans and ideas for charmonium spectroscopy with PANDA**
Speaker: Sean Dobbs (Florida State University(FSU))

Remarks:
- Absent with excuse: Aron Kripko, Iman Keshk
- Russian colleagues difficult to catch for online-only meetings
- Special „guest“: Sean becomes slowly an active member – welcome!

Publication / release issues

Phase One Paper

- Drafting finally completed
  - CCE: Xscan P1 → *delivered from our side (March 2018)*
    - *Input by a TAG member was forgotten ... (PhysCom, March 2020)*
    - *New LHCb result published on May 28th*
  - Need for revisiting the CCE Chapter
    - *I was finally asked to add and adopt it, also now iterated with CH*

=> CWR expected soon, finally

Dedicated PWA paper (LM), Iman Keshk et al.

- PWA of $p\bar{p} \rightarrow \phi\phi$ (energy scan data)
  - Rather progressed analysis
    - *Frequent status reports*
    - *Still addressing last comments/input received*
  - Next (final) presentation expected in PWG soon

=> Release note draft to be completed & circulated within PWG

LHCb study of X(3872) line shape

arXiv:2005.13419v2

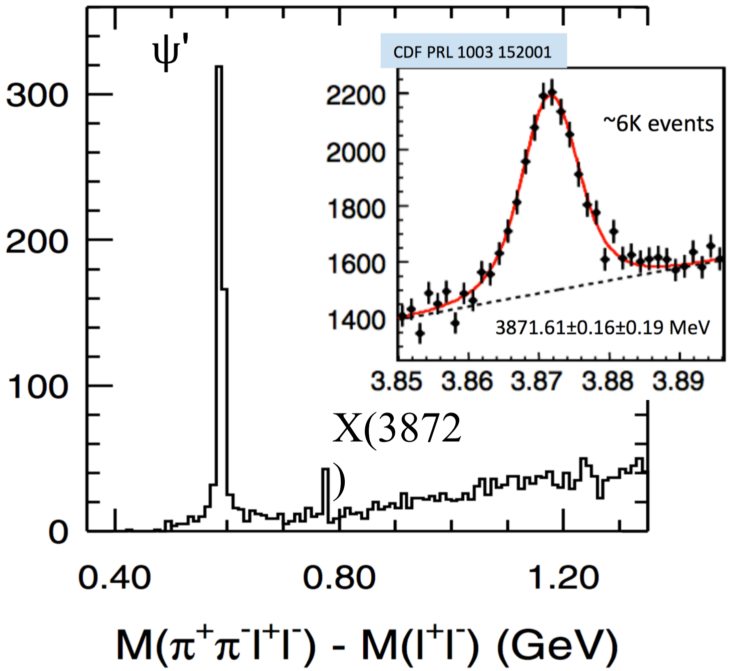
CERN-EP-2020-086
LHCb-PAPER-2020-008
May 27, 2020

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

LHCb collaboration†

Experimental Review of the X(3872)

[Belle, PhysRevLett.91 (2003) 262001]

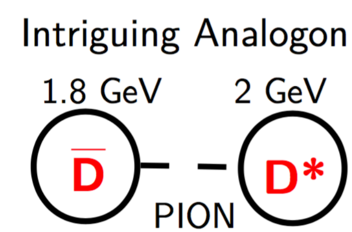


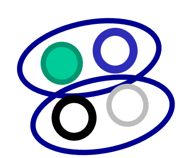
- The first unexpected states
  - and the most intriguing one
- First observed by Belle in 2003
  - $X(3872) \to J/\psi\ \pi\pi$
  - very narrow state with $J^{PC} = 1^{++}$
- Both, Belle & BaBar report signal in
  - $X(3872) \to \bar{D}^0 D^{*0}$ $(D^0 D^0 \pi^0$ and $D^0 D^0 \gamma)$

- Mass: $m(X) - m(\bar{D}^{*0}) - m(D^0) =$

  $= -0.12 \pm 0.19\ \text{MeV}/c^2$
- Width: Upper limit by Belle
  - $\Gamma_{X(3872)} < 1.2$ MeV (90% c.l., 2011)

"binding energy" of -0.12+-0.19 MeV ?





Molecule ?

$(q\bar{q})_1(q\bar{q})_1$

For clarification: Precision measurement of $\Gamma_{X(3872)}$ in the sub-MeV range needed!

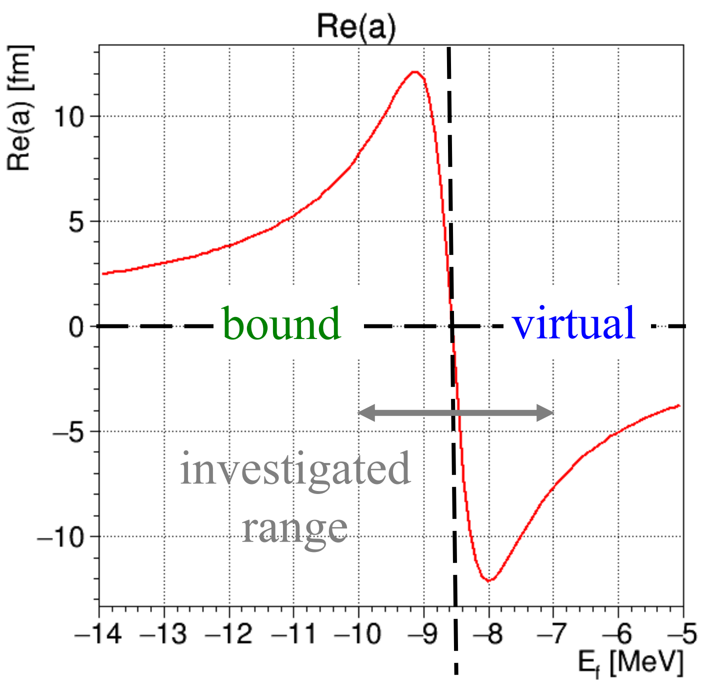
Line shapes for different E_f

Scattering length D^0D^{0*}:

$$a = -\frac{\sqrt{2\mu_2\delta} + 2E_f/g + i\Gamma(0)/g}{(\sqrt{2\mu_2\delta} + 2E_f/g)^2 + \Gamma(0)^2/g^2}$$

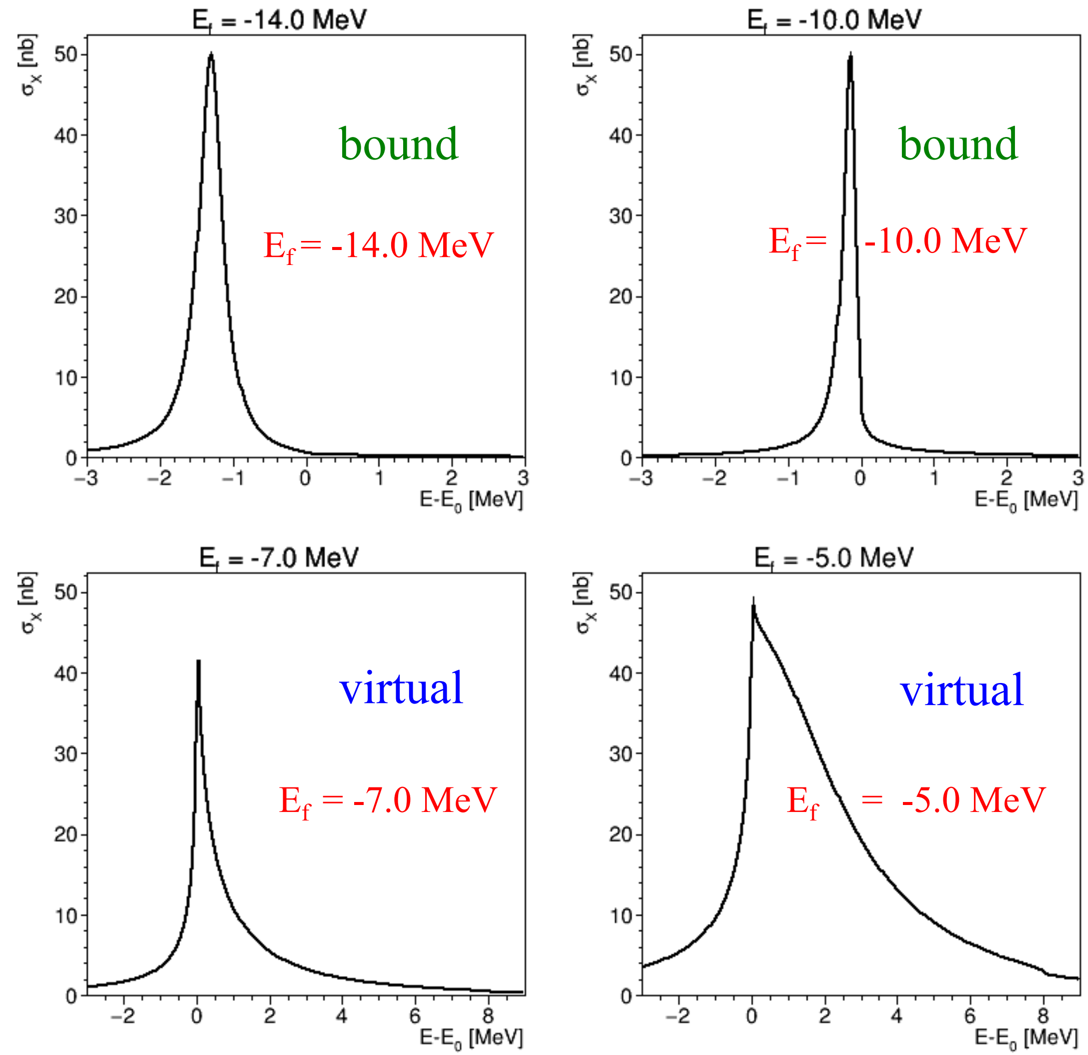
Re(a) > 0 : bound state

Re(a) < 0 : virtual state



$E_{f,th}$ = -8.56 MeV

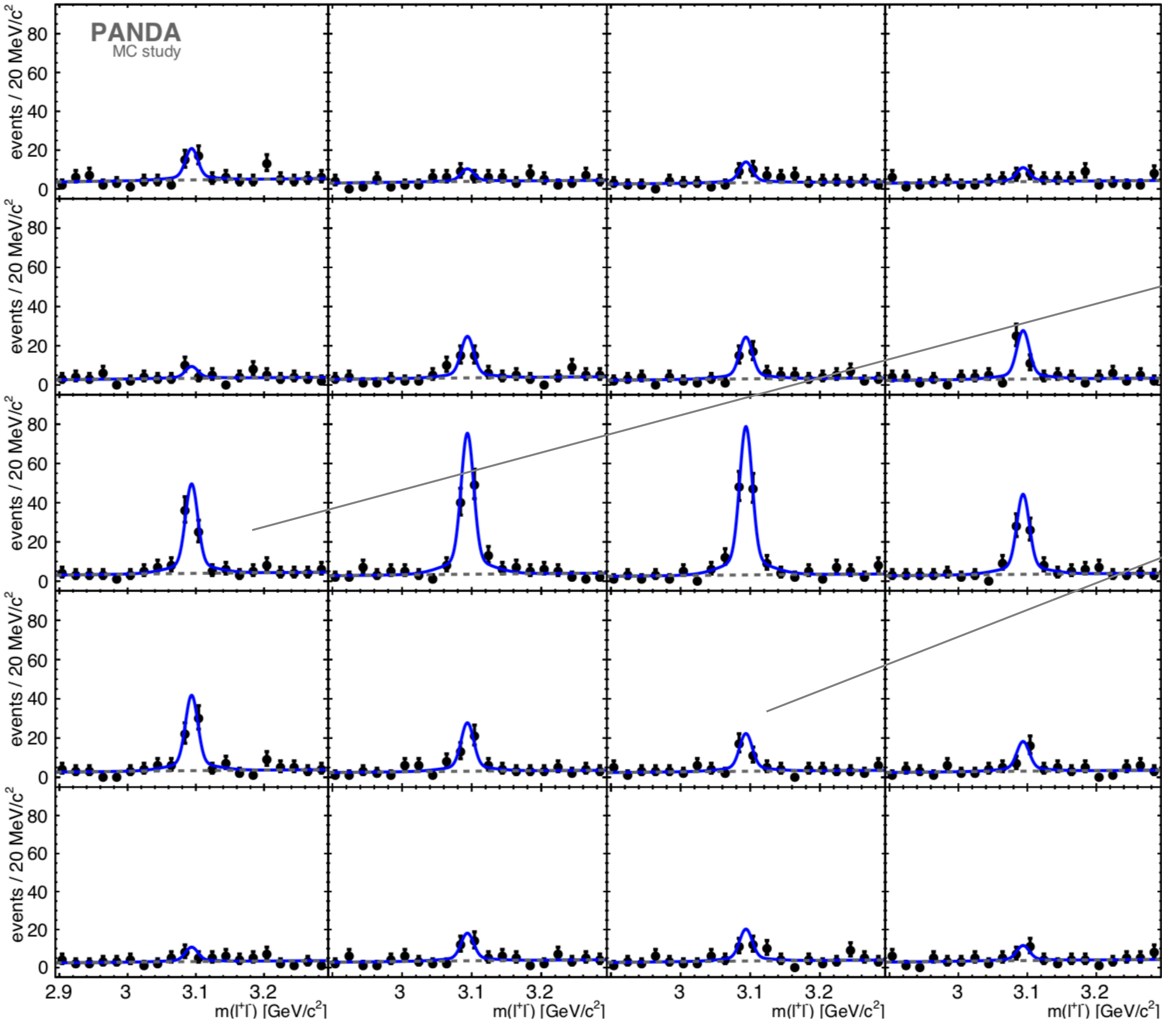
Examples always scaled to same f_{max}

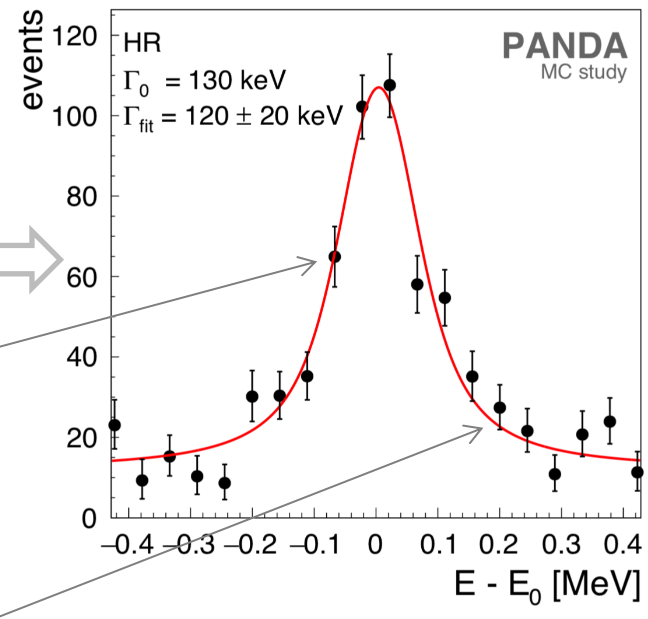


(with f_ρ=0.00047, f_ω=0.00271, g=0.137, Γ_0=1.0 MeV)

Scan Procedure Principle (Example)

20 E_{cms} scan point within ±0.4 MeV window around nominal mass





[PANDA, arXiv:1812.05132, hep-ex]

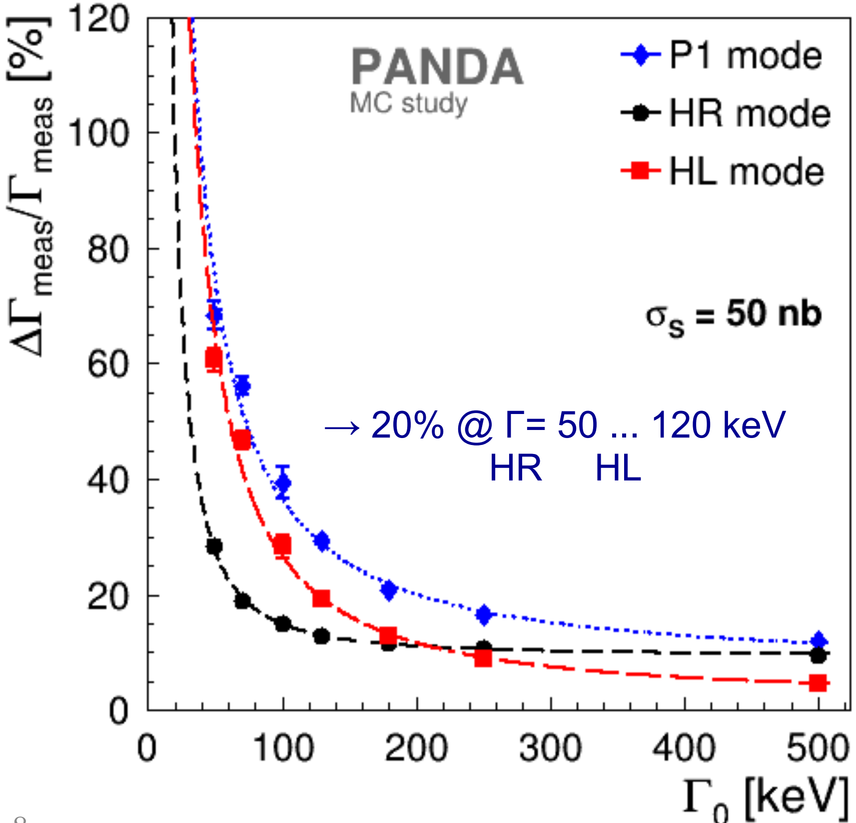
Sensitivities Breit-Wigner Γ (40 x 2d)

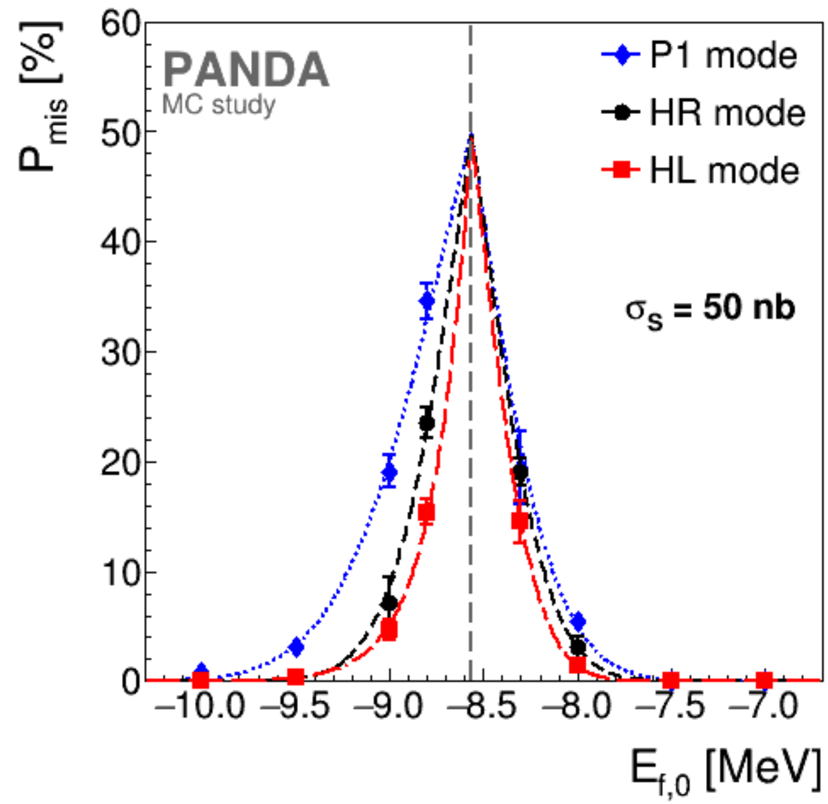
- Show relative error $rms_{fit}/\bar{\Gamma}_{fit}$ in [%]
- How well can virtual vs bound state be distinguished? → *integrate mismatch region*

$$\frac{\Delta\Gamma_{\rm meas}}{\Gamma_{\rm meas}} = \frac{\rm RMS}{\rm Mean + \Gamma_0}$$

Sensitivity

$$P_{\rm mis} = N_{\rm mis-id}/N_{\rm MC}$$





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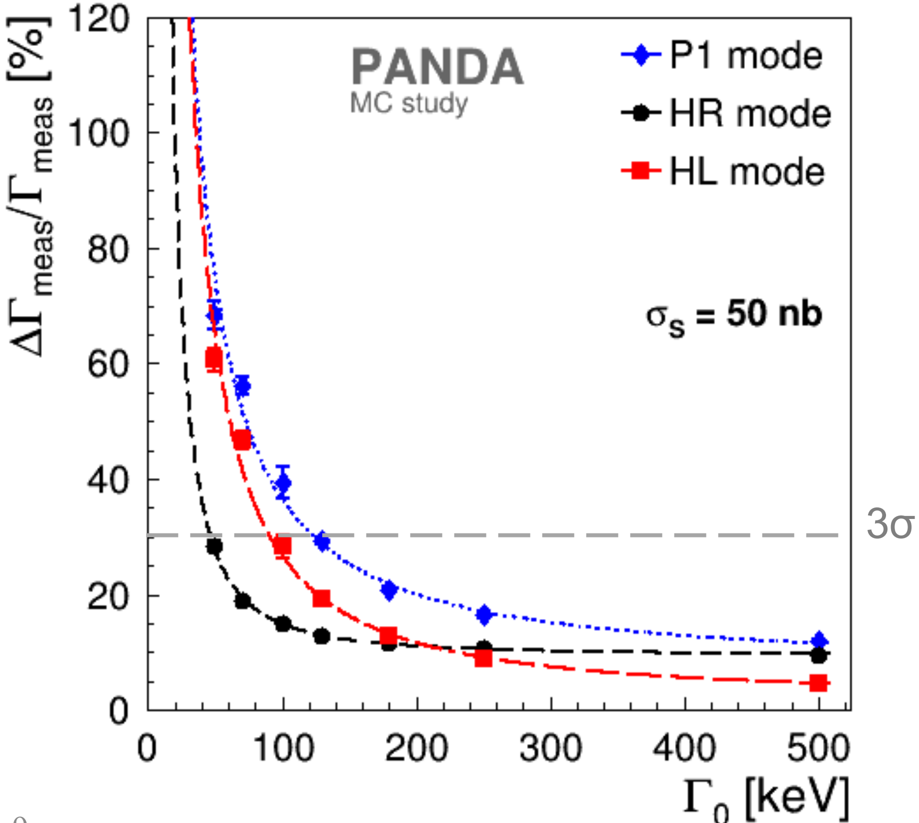

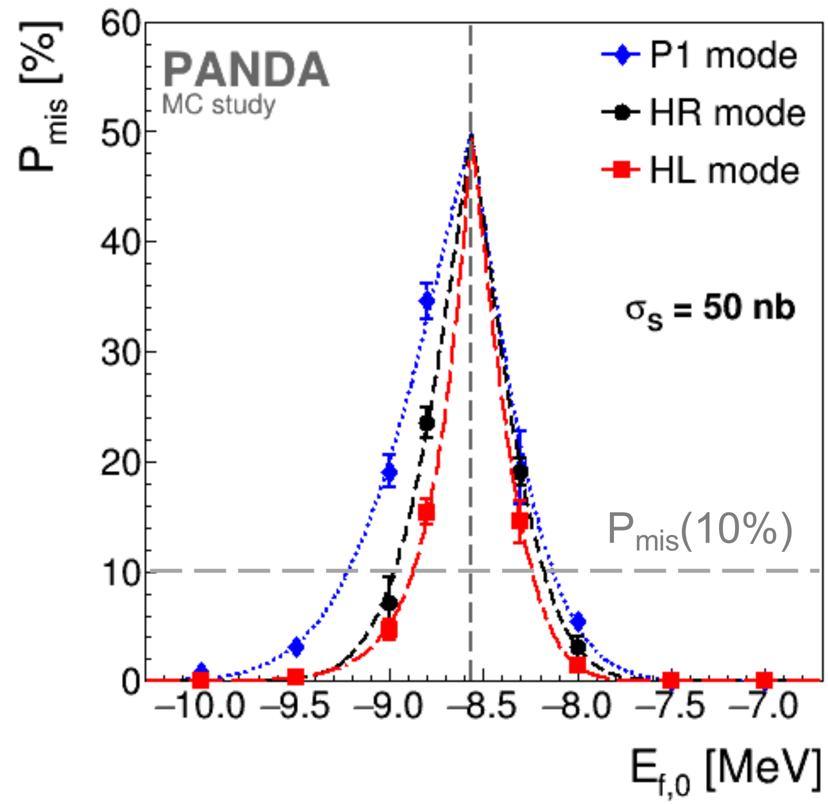

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Sensitivity

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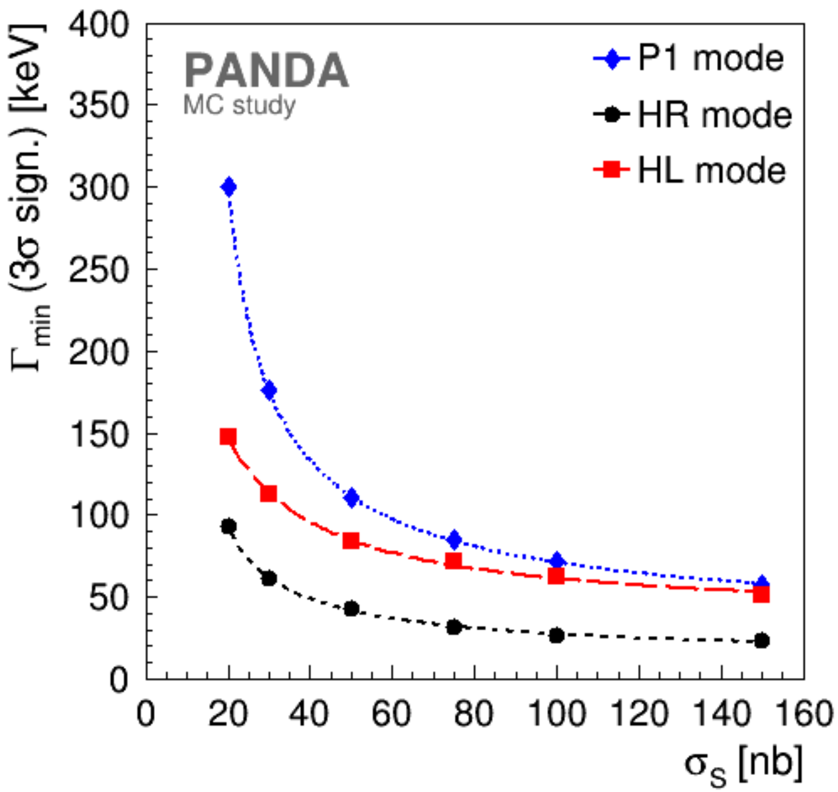
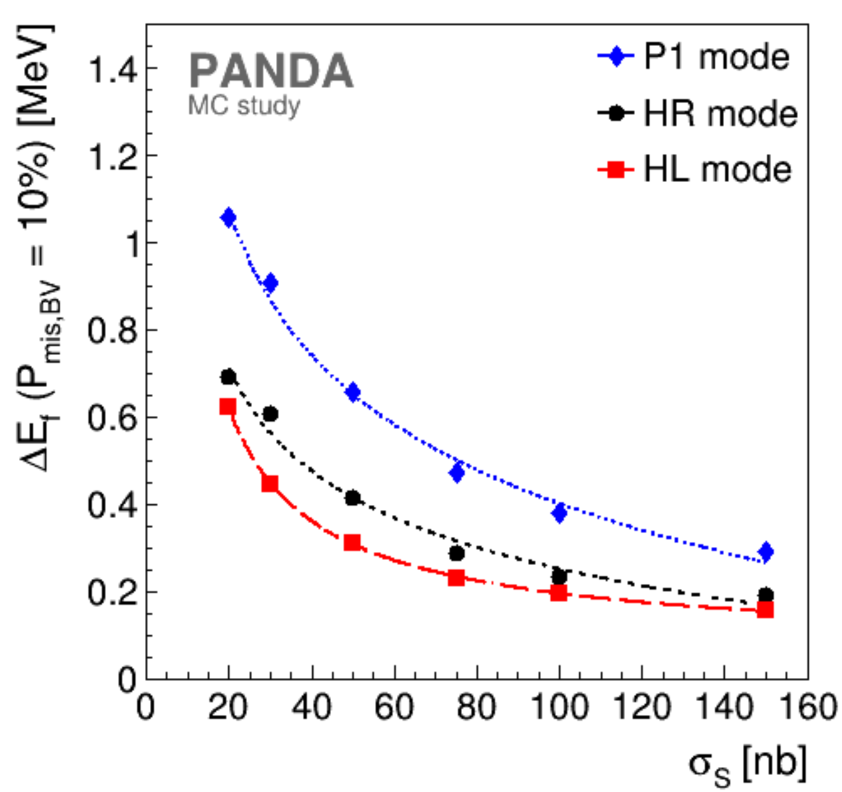




LHCb study of X(3872) line shape

arXiv:2005.13419v2

- **Two data sets integrated luminosity of 3fb^{-1}**
  - pp collisions at 7 and 8 TeV)
  - integrated luminosity of 3fb^{-1}
  - Candidate $\chi_{c1}(3872)$ from b-hadron decays
    - *$J/\psi\pi+\pi-$ decay mode*

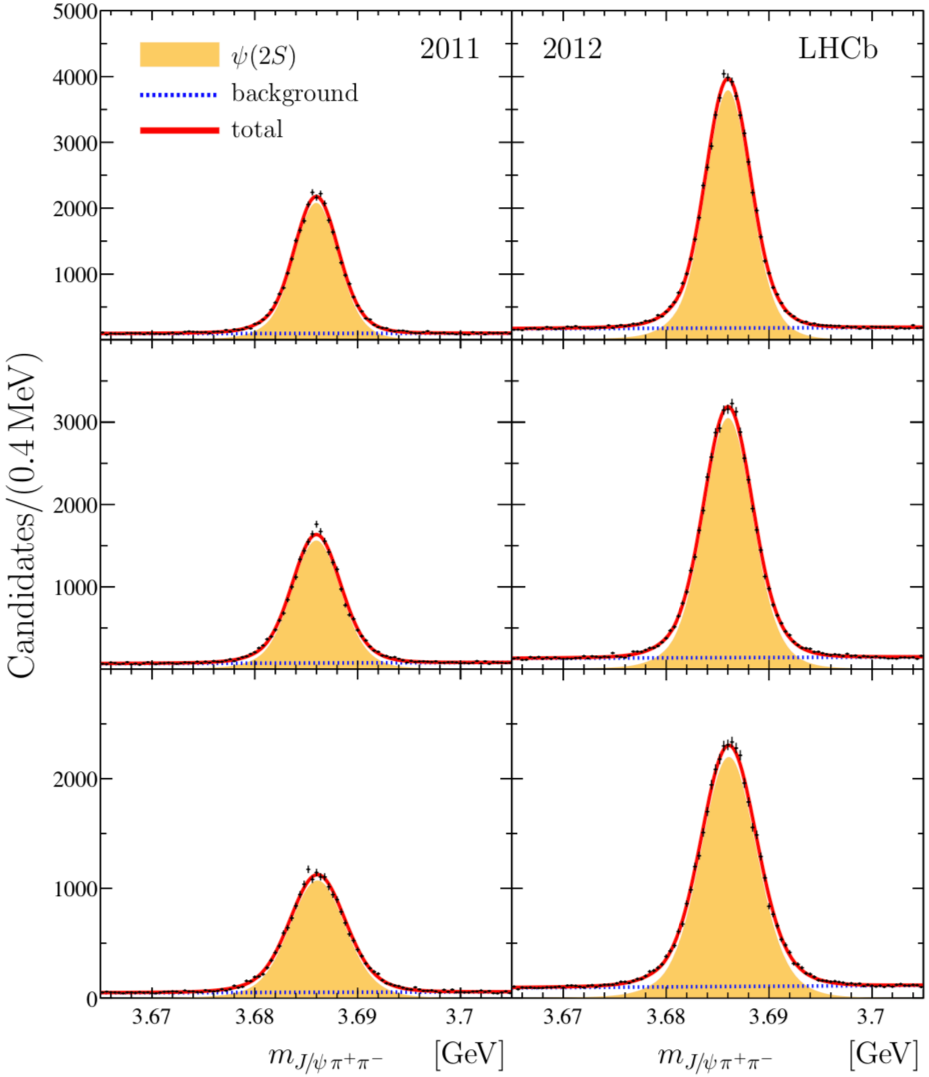
- **Measurement**
  - Mass relative to psi(2S)
    - $\Delta m = 185.588 \pm 0.067 \pm 0.068$ *MeV*
  - Width
    - $\Gamma_{BW} = 1.39 \pm 0.24 \pm 0.10$ *MeV*

- **Line shape study**
  - Flatt´e- inspired lineshape
    - *two poles for the $\chi_{c1}(3872)$ in the complex energy plane found*
    - *the dominant pole compatible with a quasi-bound D^0D^{*0} state*
    - *but a quasi-virtual state still allowed at 2σ level*

LHCb study of X(3872) line shape

arXiv:2005.13419v2

- LHCb 2011/12 data, 3 fb^{-1}
  - pp collisions at 7 and 8 TeV
  - X(3872) candidates in b-hadron decays
  - $J/\psi\ \pi\pi$ decay mode
- Selection
  - J/ψ mass constraint, 3 $p_{\pi\pi}$ bins
  - considering resolution dependency
- Observed mass spectra
  - Natural line shape convolved with detector resolution (~ 3 MeV/c^2)
  - Resolution model using $\psi(2S)$



LHCb study of X(3872) line shape

arXiv:2005.13419v2

- Relativistic Breit-Wigner fctn. (S-wave),
  - $\Delta m = m(X(3872) - \psi(2S))$ used

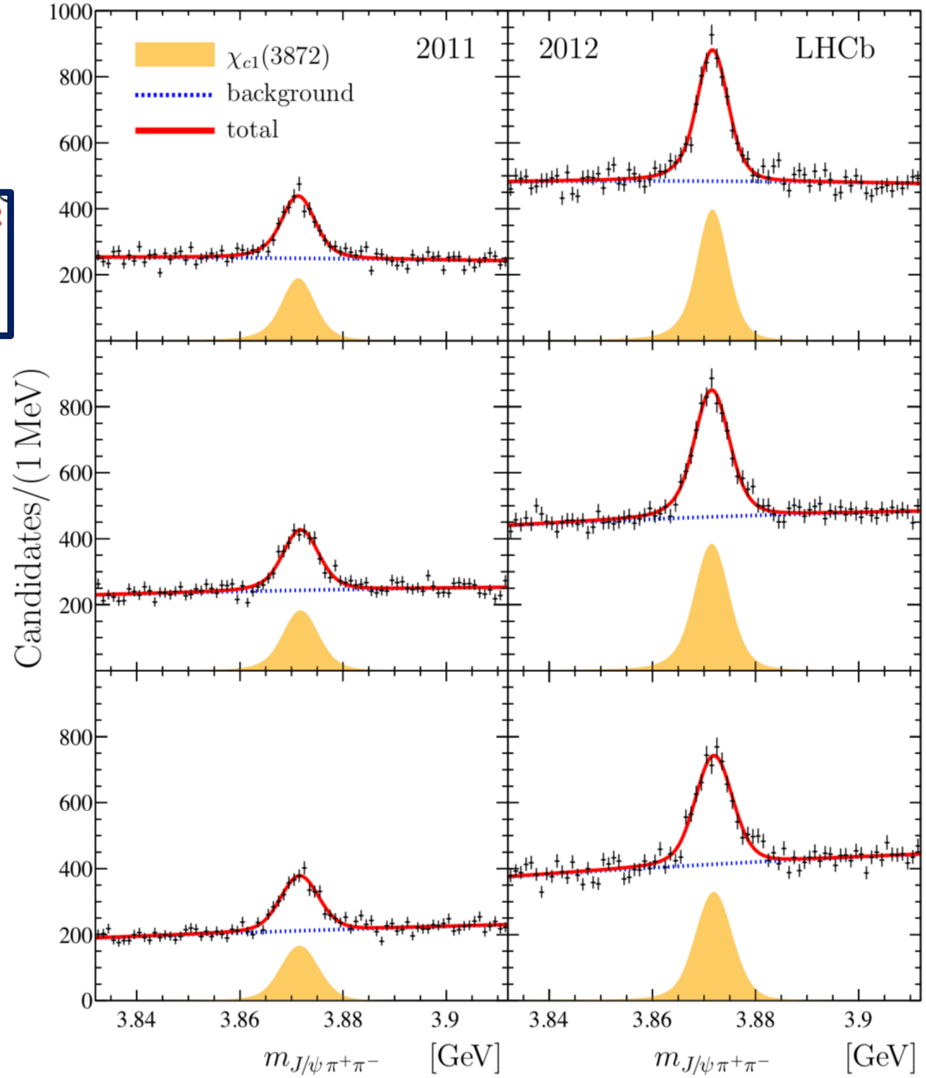
✓ $M_{BW} = 3871.695 \pm 0.067 \pm 0.068 \pm 0.010\ \text{MeV}/c^2$

✓ $\Gamma_{BW} = 1.39 \pm 0.24 \pm 0.10\ \text{MeV}/c^2$

2[nd] model:

- Flatte-like line shape
  - 2 resonance poles, one preferred with FWHM = 220 keV

Mode [MeV]	Mean [MeV]	FWHM [MeV]
$3871.69^{+0.00+0.05}_{-0.04-0.13}$	$3871.66^{+0.07+0.11}_{-0.06-0.13}$	$0.22^{+0.06+0.25}_{-0.08-0.17}$



LHCb study of X(3872) line shape

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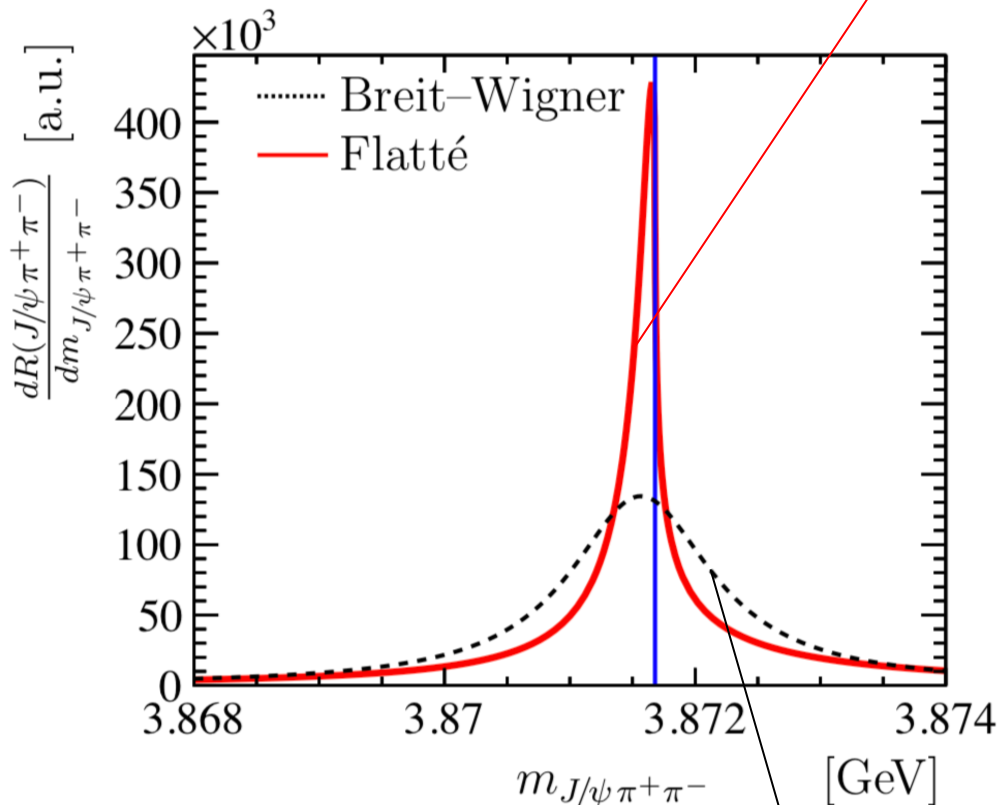
FWHM$_{Flatte}$ = 0.22 ± 0.06/0.08 ± 0.25/0.17 MeV



Γ_{BW} = 1.39 ± 0.24 ± 0.10 MeV

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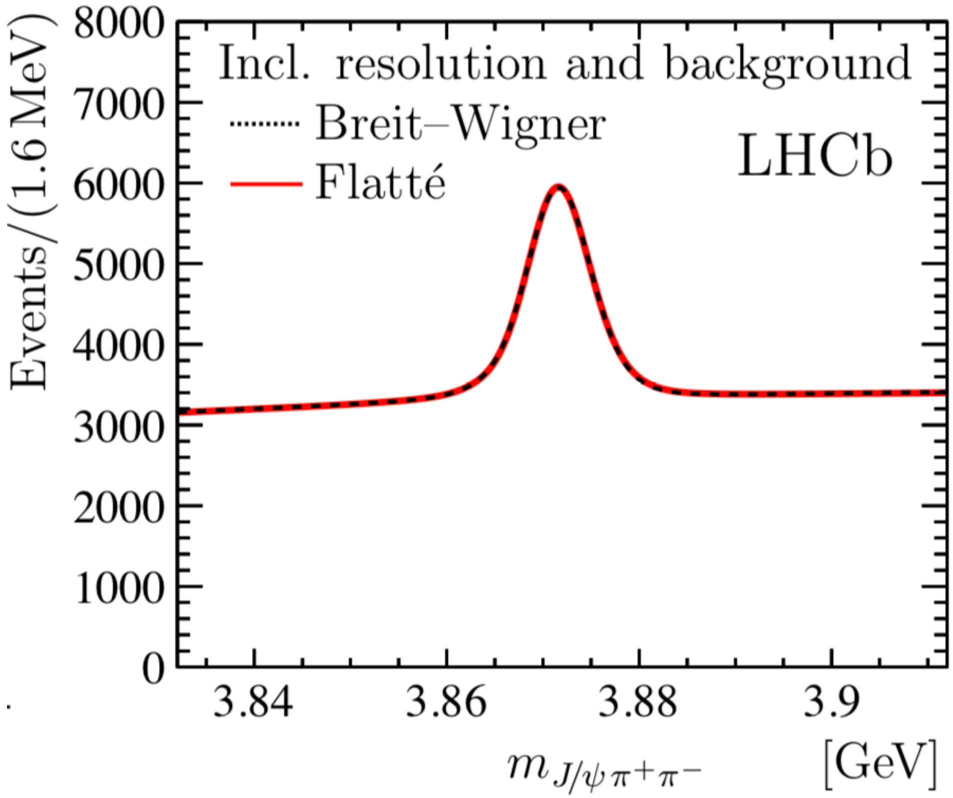


Both line shape models

- Relativistic BW fctn
- Flatte-like line shape

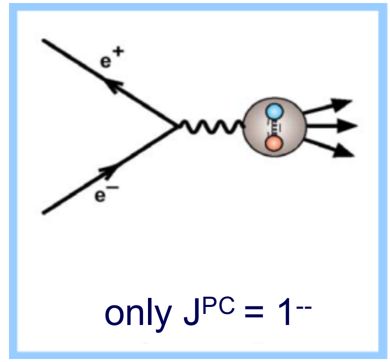
=> Compatibel with LHCb Data -- same propability

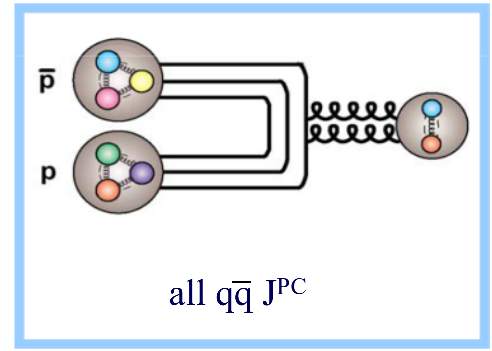
Γ_{BW} = 1.39 ± 0.24 ± 0.10 MeV

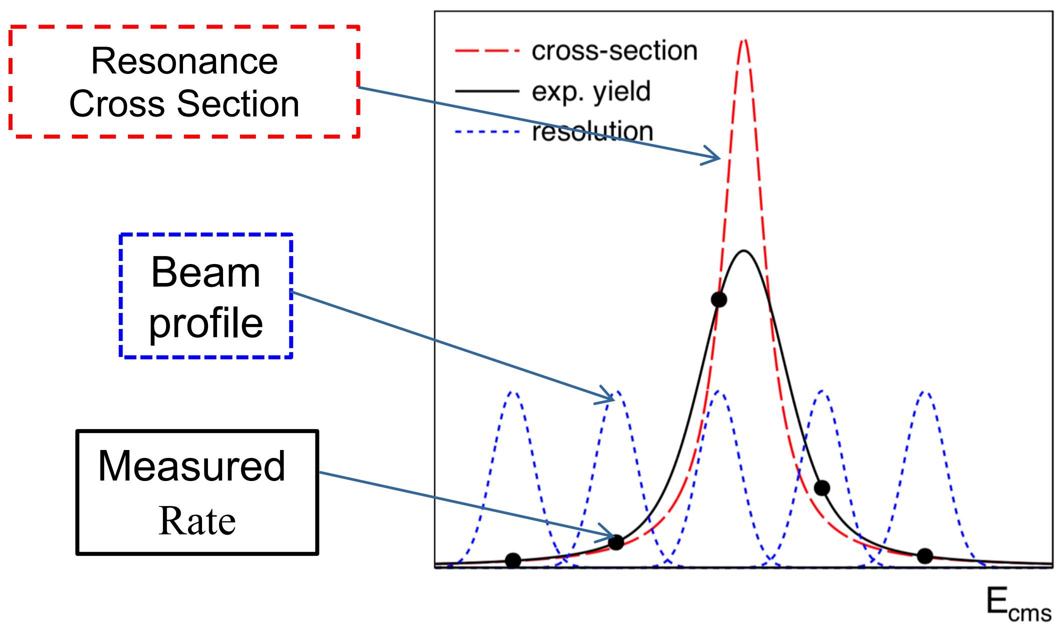
Some Advantages of Anti-Protons

- Access to all fermion-antifermion quantum numbers *(not in e^+e^-)*
- Access to states of high spin J
- Precise mass resolution in formation reactions

Formation:







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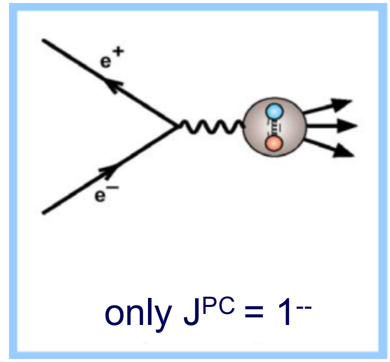

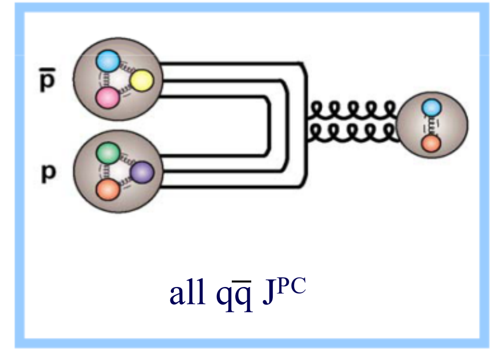

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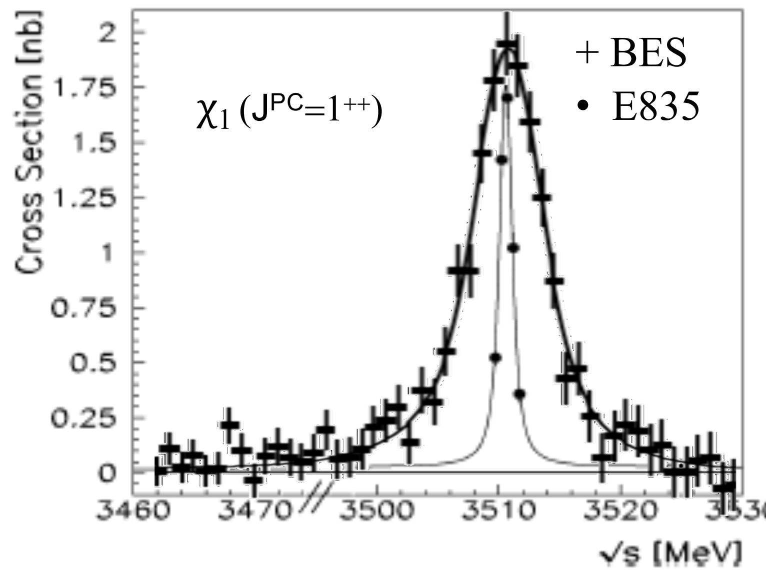

E760/835@Fermilab ≈ 240 keV

PANDA@FAIR ≈ 50 keV

Ablikim et al., Phys. Rev. D71 (2005) 092002:
BES (IHEP): 3510.3 ± 0.2 MeV/c^2

Andreotti et al., Nucl. Phys. B717 (2005) 34:
E835 (Fermilab): 3510.641 ± 0.074 MeV/c^2

LHCb study of X(3872) line shape

arXiv:1705.00141v2 [hep-ph]

the example of the $X(3872)$. This resonances with $J^{PC} = 1^{++}$ can be formed directly in $\bar{p}p$ annihilation. It has a narrow natural width, for which mostly a decade after the discovery merely an upper limit of 1.2 MeV (at 90% C.L.) was provided [158]. A new measurement just recently provided as preprint shows that the LHCb data are compatible (at equal probability) with an absolute Breit-Wigner decay width of $\Gamma = 1.39 \pm 0.24 \pm 0.10$ MeV for the $X(3872)$ as well as with a Flatté-like line shape model, in which the state is described by a resonance pole with a Full-Width-at-Half-Maximum of about 220 keV [159]. This experimental outcome demonstrates and emphasises the need for precision line shape measurements with excellent energy and mass resolution that is significantly better than the typical detector resolution of a few MeV. Only with an experiment such as PANDA/HESR, the shape of resonance cross sections can directly and thus model-independently be measured.

The details of the corresponding PANDA feasibility study can be found in Ref. [160]. Here, we focus on the outcome of these studies with the conditions expected for Phase One. This implies that

Summary

- LHCb definitely a serious competitor … (nothing new)
  - Huge statistics, excellent resolution (B decays)

- Breit-Wigner width measurement
  - LHCb: 1.4 MeV with 20% rel error (NB: sub-MeV within 2σ –> 900 keV)
  - PANDA: order 1% for 1.4 MeV (also for 900 keV)
  - Anyhow X(3872) acts as kind of a benchmark channel

- Flatte like line shape model
  - Also a FWHM = 220 keV compatible with LHCb data (same probability)
  - Underlines need for independent measurement, and direct measurement of the line shape with high resolution

=> PANDA/HESR

…. is still unique in precision line shape measurements