Communications, common PWG session:
Light Mesons (LM), Charmonium (CC) and Charmonium-like Exotics (CCE)

Frank Nerling, Marc Pelizaeus
GU Frankfurt / GSI Darmstadt, RU Bochum

Outline

- Publication / release issues
- Ongoing analyses and new manpower
- CCE-SubTask force with theorists started

Publication / release issues

Phase One Paper

- Drafting ongoing, see report by physics coordinators
  - CCE: Xscan P1 → *delivered from our side*
  - CC, LM physics cases P1 → *delivered from our side*

Dedicated X(3872) scan paper (CCE)

- Precision energy scan measurements using the example X(3872)
  - ✓ Extension and completion of release
    - *Parameter space extended, and*
    - *Systematics estimated and included*
  - ✓ Presented and discussed in PWG
  - ✓ Release Note draft circulated within PWG
  - ✓ Review Committee formed by PubCom:
    - *M. Fritsch (chair)*
    - *J. Meschendorp (replacing K.Schoenning, representing PubCom)*

→ Collaboration wide talk: Plenary talk on Fri by Klaus Goetzen et al.

Publication / release issues

Phase One Paper

- Drafting ongoing, see report by physics coordinators
  - CCE: Xscan P1 → *delivered from our side*
  - CC, LM motivations → *delivered from our side*

Dedicated X(3872) scan paper (CCE)

- Precision energy scan measure

Status as of today:
+ Analysis (note) approved by RC
+ Journal paper draft written, handed in to RC >2 weeks ago
+ Panda authorslist, EPJ style centrally provided (Udo)

--> Goal: Submission to EPJ soon (in time for P1 paper & LHCb update)
--> Appetizer for CWR, next slides

ubCom:

ritsch (chair)

- *J. Meschendorp (replacing K.Schoenning, representing PubCom)*

→ Collaboration wide talk: Plenary talk on Fri by Klaus Goetzen et al.

Publication

- **14+3 pages**
- **14 Figs., 7 Tabs., 50 Refs.**
- **Outline:**

EPJ manuscript No.
(will be inserted by the editor)

Precision resonance energy scans with the PANDA experiment at FAIR

Sensitivity study for width and line shape measurements of the X(3872)

K. Götzen[1], R. Kliemt[2], F. Nerling[1,3] and K. Peters[1,3], for the PANDA Collaboration

[1] GSI, Darmstadt, Germany
[2] HIM, Mainz, Germany
[3] GU Frankfurt, Germany

Received: date / Revised version: date

Abstract. This paper summarises a comprehensive PANDA Monte Carlo simulation study for precision resonance energy scan measurements, using the example of the charmonium-like $X(3872)$ state discussed to be exotic. Apart from the proof of principle for natural width and line shape measurements of very narrow resonances with PANDA, the achievable sensitivities are quantified for the concrete example of the $X(3872)$, and for a larger parameter space of various assumed signal-cross sections, input widths and luminosity combinations. The discussed measurement is uniquely possible with a $\bar{p}p$ annihilation experiment such as PANDA — it is not feasible with any existing, running experiment.

PACS. 01.52.+r International laboratory facilities – 13.25.-k Hadron decays, mesons – 13.75.-n Hadrons, interactions induced by low and intermediate energy – 14.40.Rt Exotic mesons – 14.40.-n Hadrons, properties of mesons – 14.40.Pq Quarkonia heavy quarkonia – 25.40.Ny Resonance reactions, nucleon-induced – 25.43.+t Antiproton-induced reactions

1 Introduction

Since the beginning of the millennium, many charmonium-like states have been observed experimentally, the so-called XYZ states, showing characteristics different from the predictions of the charmonium states in the potential model, and being therefore largely discussed to be of exotic nature. The first and most intriguing one is the famous $X(3872)$ that was discovered by the Belle Collaboration in $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}J/\psi$ in 2003 [1], and has been subsequently confirmed by other experiments [2–5].

The vector states $Y(4260)$, $Y(4360)$ and $Y(4660)$ have been discovered by the BABAR, Belle and CLEO Collaborations in the decays to the final states $J/\psi\,\pi^{+}\pi^{-}$ and $\psi(3686)\,\pi^{+}\pi^{-}$, comprising low-mass charmonia [6–10].

The manifestly exotic charged charmonium-like states, and neutral partners, such as $Z_c(3900)$, $Z_c(3885)$, $Z_c(4020)$, $Z_c(4025)$, $Z_c(4200)$ have also been observed meanwhile by several experiments [11–21]. For a recent overview on these experimental findings and the resulting XYZ puzzle, see *e.g.* [22].

Various interpretations on the nature of these states have been proposed, including molecular, hybrid, multi-quark and also other explanations, such as threshold enhancements or some other configurations, see *e.g.* [23].

Send offprint requests to: F. Nerling (f.nerling@gsi.de)

The nature of these states is, however, still unclear. Especially for the $X(3872)$, the to-date measured mass is indistinguishable from the DD^{*} threshold [24]. It is even not clear yet, whether it lays beneath or above this threshold, and due to the rather narrow natural decay width, merely an experimental upper limit of 1.2 MeV (CL90) [25] exists. To understand the nature and distinguish between the various theoretical models, an absolute width measurement with sub-MeV resolution is required for this $J^{PC} = 1^{++}$ state [26]. For $J^{PC} != 1^{--}$ states, such a precision measurement can only be performed with a $\bar{p}p$ experiment such as PANDA, *cf. e.g.* [27], currently being under construction at the future FAIR facility in Darmstadt/Germany.

2 The PANDA experiment at FAIR

The PANDA (antiproton ANnihilation in DArmstadt) experiment [28] will be located at the FAIR (Facility for Antiproton and Ion Research) complex under construction in Darmstadt, Germany. The physics programme is dedicated to hadron physics. Apart from hadron spectroscopy in the charmonium and light quark regime, nucleon structure will be studied as well as *e.g.* in-medium modifications of charm in nuclear matter and physics of strangeness production.

Publication / release issues

2 The PANDA experimen at FAIR

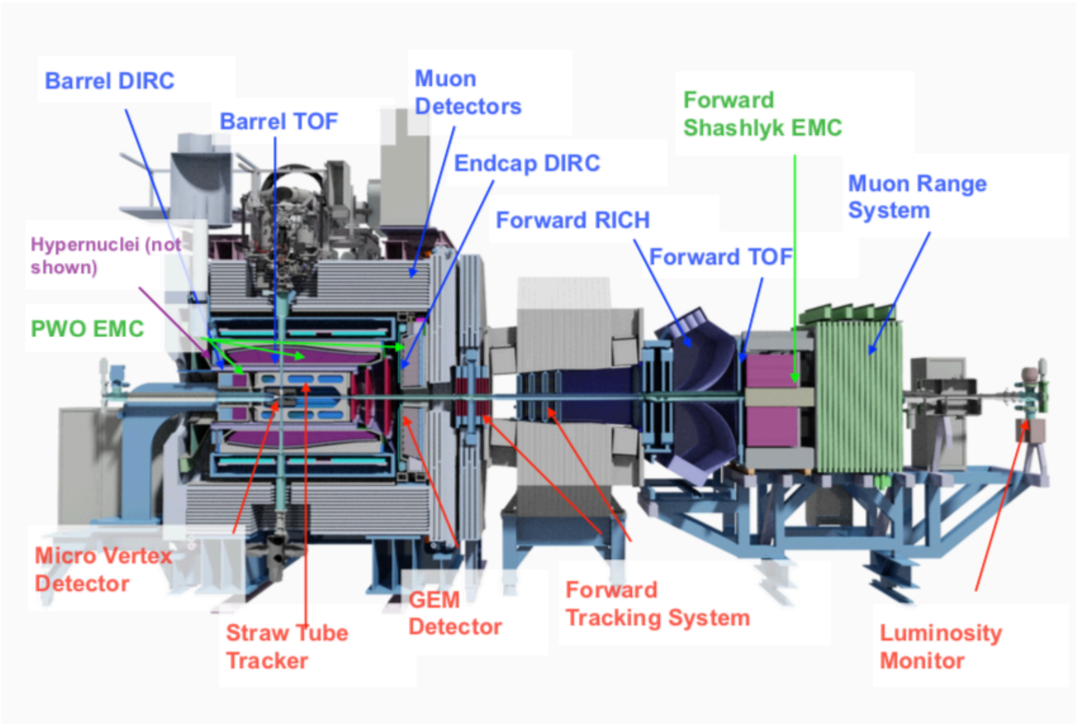

Fig. 1. Cross-section sketch of the proposed PANDA experimental setup.

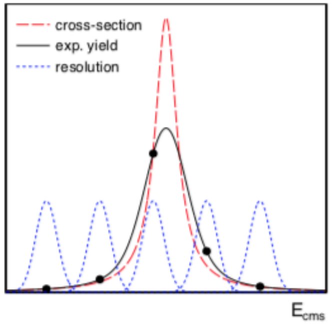

Fig. 2. Schematics of a resonance energy scan: The true energy dependent cross-section (dashed line), the beam momentum spread (dotted line), the measured yields (markers), and the effective measured energy dependent event rate (solid line) are illustrated.

Publication / release issues

3 Event simulation and reconstruction

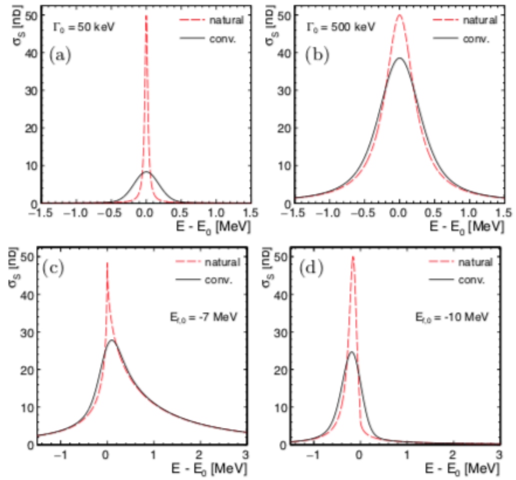

Fig. 3. True physical (dashed red) and beam resolution convoluted line shapes (solid black) for different examples of Breit-Wigner Γ_X (a, b) and the molecule scenario (c, d).

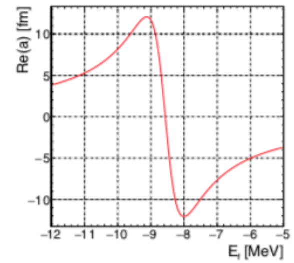

Fig. 4. Functional dependence of the real part of the scattering length $\Re(a)$ on the parameter E_f. The condition $\Re(a) = 0$ defines the threshold energy $E_{f,th} = -8.5651$ MeV, separating between the $X(3872)$ being a bound ($\Re(a) > 0$) or virtual ($\Re(a) < 0$) state [34,35].

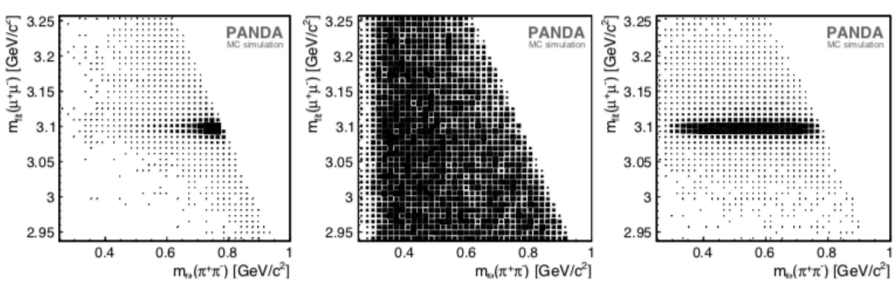

Fig. 5. Di-lepton *vs.* di-pion invariant mass spectra after a kinematic 4-constraint fit for the three different event types. Two-dimensional distributions of the reconstructed events in $m_{\text{fit}}(\mu^+\mu^-)$ vs. $m_{\text{fit}}(\pi^+\pi^-)$ for signal events *(left)*, generic hadronic background *(centre)* and non-resonant J/ψ background *(right)* after pre-selection, exemplary shown for the muon channel. The correlation between the variables is clearly visible.

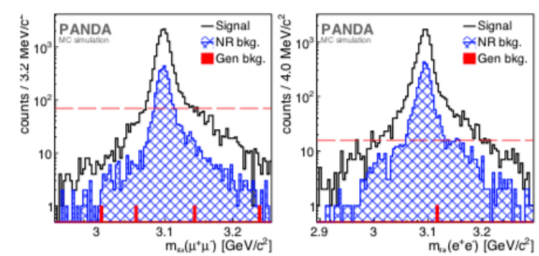

Fig. 6. Reconstructed invariant di-lepton mass distribution for the muon *(left)* and electron *(right)* channel for signal *(black)*, non-resonant (blue) and generic DPM background *(red)* MC data, after final selection. The mass ranges shown have been chosen to be about $\pm 10\sigma$ and define the regions of interest for the maximum-likelihood fits performed (Sec. 4.3). The dashed red lines indicate the level of generic background as it would appear for a signal cross-section of 100 nb, given the efficiency numbers according to Tab. 3.

Publication / release issues

4 Simulation of resonance energy scans

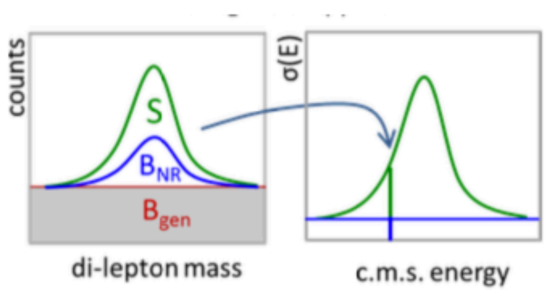

Fig. 7. By fitting the yield of J/ψ in the di-lepton candidate mass distribution *(left)*, one is able to remove the flat generic DPM background $B_{\rm gen}$ (red) and keeps contributions from the non-resonant backgrounds $B_{\rm NR}$ (blue) in form of a constant background contribution in the result of the energy dependent cross-section *(right)*.

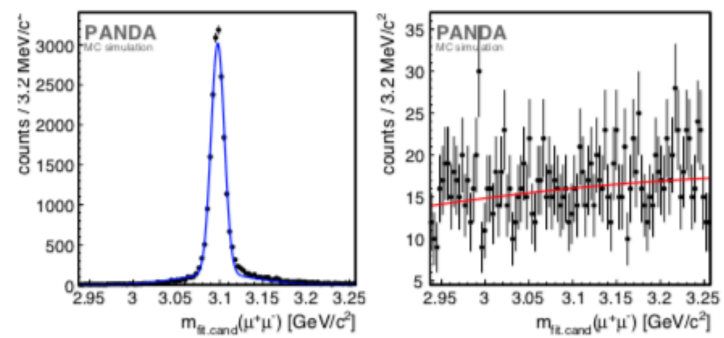

Fig. 8. Determination of the probability density function needed to describe event distributions with J/ψ *(left)* and without J/ψ *(right)* for the maximum-likelihood approach to determine the energy dependent event yields. The distributions are based on a less tight event selection as compared to the final selection, in order to be able to extract a well defined background shape *(right)*.

4 Simulation of resonance energy scans

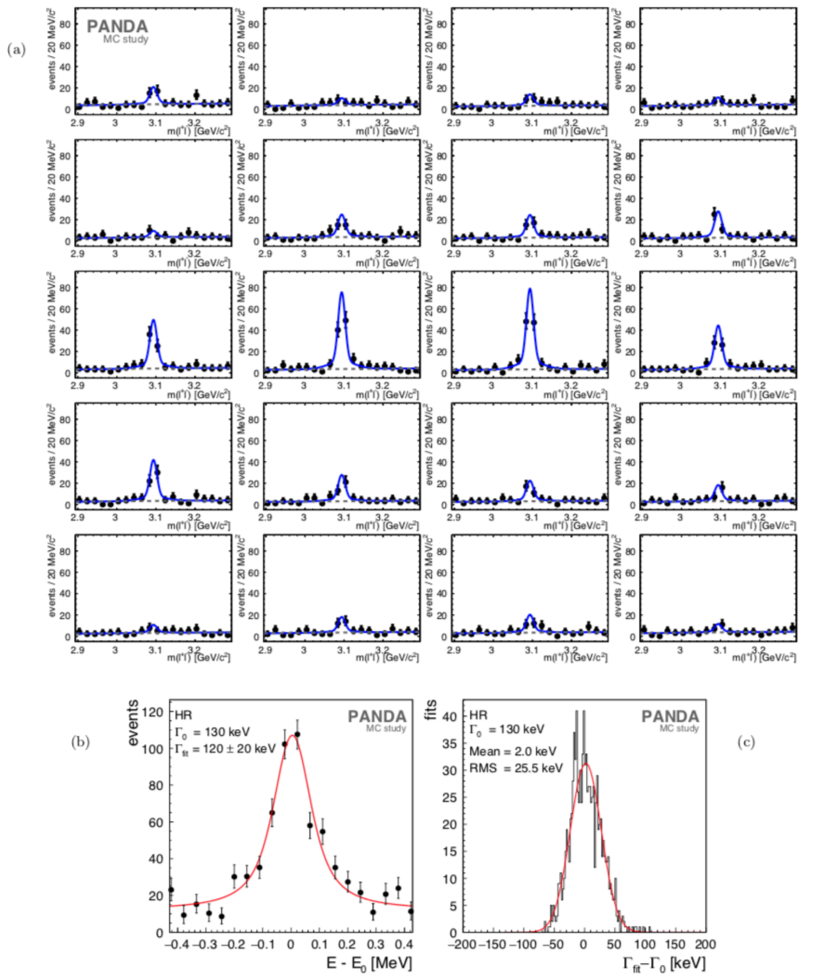

Fig. 9. Illustration of a scan process for the parameter setting: $\sigma_{S,\max} = 100$ nb, $\Gamma_0 = 130$ keV, 20 energy scan positions (step size $dE \approx 50$ keV), 2 days of data taking per position, High Resolution mode. The set of 20 small plots (a) represent the energy dependent simulated distributions (going from left to right, top to bottom steps through the energy range $(E - E_0)$ shown in (b)) of the reconstructed invariant di-lepton candidate mass containing signal, non-resonant and generic DPM background. (b) shows the resultant energy dependent yield distribution fitted with a function to extract the parameter of interest, here the Breit-Wigner Γ, around the nominal centre-of-mass energy $E_0 = 3.872$ GeV. (c) shows the distribution of this extracted parameter compared to the input value Γ_0 for 300 toy Monte Carlo experiments, allowing the determination of the expected precision (root-mean-square of the distribution) and the accuracy (shift of distribution). The additional Gaussian fitted to the distribution indicates proper statistic conditions.

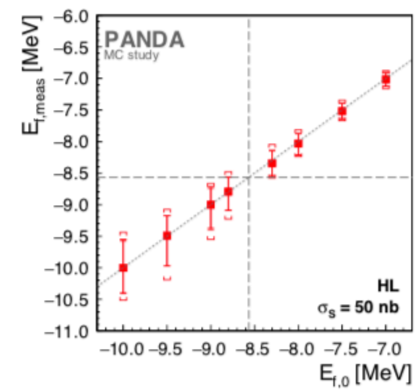

Fig. 10. Input/output diagram for the molecule line shape sensitivity study. Exemplarily shown is the measurement for the cross-section assumption $\sigma_X = 50$ nb and the HESR running mode HL. The inner error bars represent the statistical errors, the outer bars the systematic ones, and the outer brackets indicate the upper limits on the error bars based on background upscaling (Sec. 4.5). The vertical and horizontal dashed lines mark the threshold energy $E_{f,\mathrm{th}} = -8.56516$ MeV, where the bound state ($E_f < E_{f,\mathrm{th}}$) turns into a virtual state.

4 Simulation of resonance energy scans

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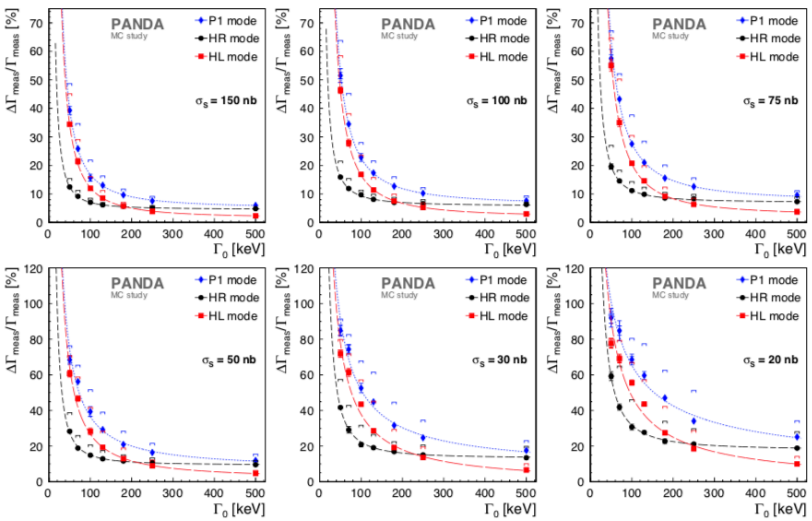


Fig. 11. Sensitivity measurements for the Breit-Wigner case study. Shown are the obtained sensitivities as a function of the assumed natural decay width Γ_0 of the state under study for the six different signal cross-section assumptions, each for the three different HESR running modes. The inner error bars represent the statistical and the outer ones the systematic errors, and the bracket markers indicate the estimated corresponding numbers for the case of generic hadronic and non-resonant background upscaling (on the data points, ignoring statistical and systematic errors) according to [50].

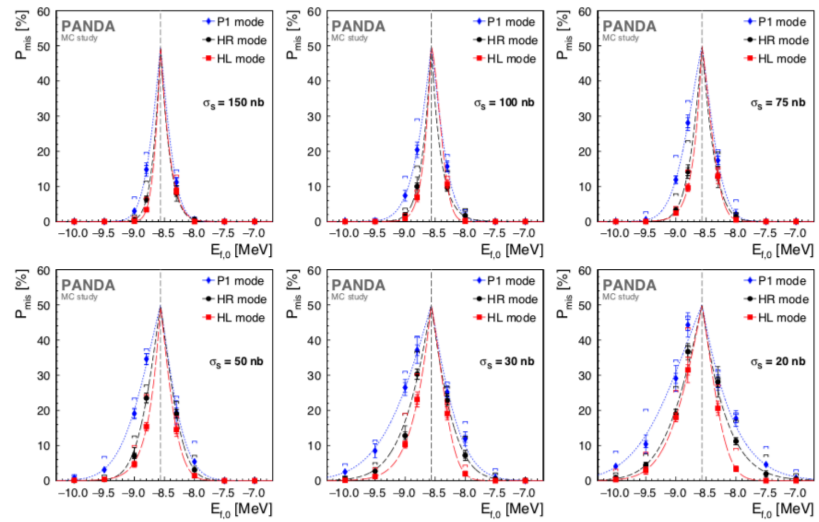


Fig. 12. Sensitivity measurements for the Molecule case study. Shown are the obtained sensitivities in terms of the mis-identification probability P_{mis} as a function of the assumed Flatté parameter $E_{f,0}$ of the state under study for the six different signal cross-section assumptions, each for the three different HESR running modes. The inner error bars represent the statistical and the outer ones the systematic errors, and the bracket markers indicate the estimated corresponding numbers for the case of generic hadronic and non-resonant background upscaling (on the data points, ignoring statistical and systematic errors) according to [50].

Publication / release issues

4 Simulation of resonance energy scans

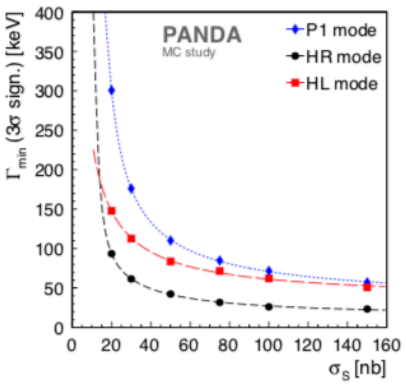


Fig. 13. Sensitivity plot for a 33% relative error (3σ) Breit-Wigner width measurement.

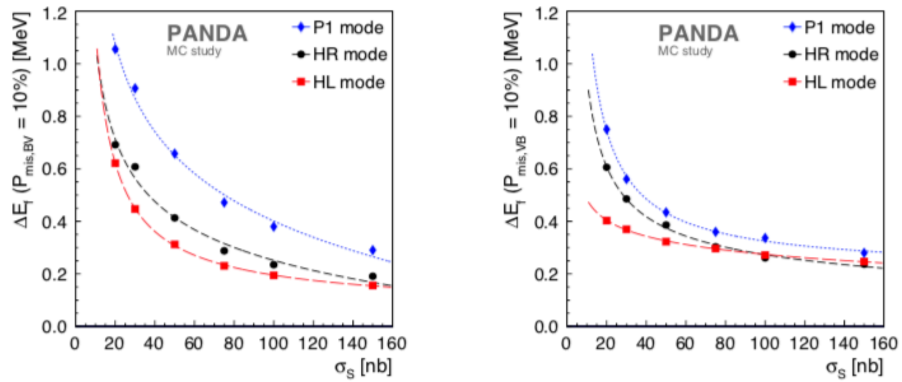


Fig. 14. Sensitivity plot for a mis-identification $P_{\rm mis} = 10\,\%$ for the molecular line shape measurement, *(left)* bound molecular state wrongly identified to be a virtual state ($P_{\rm mis,BV}$) and *(right)* virtual state wrongly identified to be a bound molecular state ($P_{\rm mis,VB}$).

Ongoing Analyses

CC:

- $\psi(^3D_2) \rightarrow \gamma\chi_{c1}\,\pi^{-/+} \rightarrow \gamma\gamma J/\psi$ (Z.Liu, U Mainz))
  - D wave charmonium states (X(3823))
  - Sim studies started/ongoing
  - FullSim studies started/ongoing
  - First draft of a release note since a while

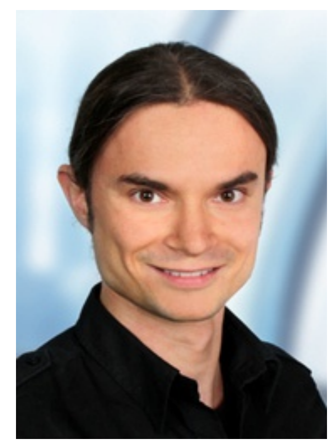
Update:
+ Release talk at last PWG meeting
--> Some issues raised, input received
=> Update note expected to come soon

Ongoing Analyses

CCE ctnd:

- ppbar → $\tilde{\eta}_{c1}\eta$, with $\tilde{\eta}_{c1} \rightarrow \chi_{c1}\pi^0\pi^0$ (Markus Moritz, U Giessen)
  - Charmonium hybrid state
  - Studied for old performance report and fastSim (MP)
    - *A good channel showing importance of fully equipped EMC*
  - FullSim studies started

    (inline with needs of extending the fastSim studies to fullSim)
  - First status report today



New active analyst on a CCE channel:

→ Welcome, Markus!

Ongoing Analyses

LM:

- ppbar → ϕϕ (Iman Keshk, RU Bochum)
  - Gluon rich (OZI suppressed) process
  - Search for a tensor glueball (m~2.5 GeV) by means of a resonance scan and a partial-wave analysis (PWA)
  - Feasibility of reconstruction previously studied for ph report and using FastSim (KG)
  - Extend FastSim studies to FullSim
  - Anlaysis started in November 2017 (update of status
  - Address PWA in the future (after finalising backgrour

New active analyst on a CCE channel:
→ Welcome, Iman!

Ongoing Analyses

LM:

- ppbar → $\phi\phi\pi^0$ (Jana Rieger, TU/GSI Darmstadt)
  - Gluon rich process
  - Search for a tensor glueball (m~2.5 GeV), partial-wave analysis (PWA)
  - Similar but complementary to Iman's channel
  - Extend FastSim studies to FullSim
  - Anlaysis started in Mai 2017 (first report soon)
  - Address PWA in the future
  - Collaboration with Bochum

New active analyst on a Light Meson channel:
→ Welcome, Jana!

CCE SubTask Force with theoreticians

- Started during the scrutiny process and in view of a future physics book
  → *sharpening the uniqueness and competetiveness of PANDA*

- FullSim physics analyses to be carried out
  → *New, up-to-date material for conferences, and*
  → *Set of physics paper planned ... (towards physics book)*

Charmonium-like exotics at PANDA

- uniquely gluon rich
  → *high cro[...] gluonic excitations / exotics*
- unique in precise measurement of widths
  → *sub-MeV range, needed to understand X,Y,Z nature*
- unique in discovery potential for high spins:
  → *no angular momentum barrier (and no restriction spin)*

=> see next talk

=> Only PANDA will enable to explore complete multiplets and clarify nature of X,Y,Z

Summary

- Only a few analyses ongoing, or rather "ongoing" ....
  - At least two progressing rather slowly
  - Three new channels picked up (Bochum, Giessen, GSI)

- One released result progressing to a dedicated journal publication
  - X(3872) energy scan
  - EPJ paper draft written, under review in RC
  - Collaboration wide review soon

- Need more channels being analysed in fullSim
  - Also, better coverage of the our 3 physics topics, improving ...
  - Key channels and results to be worked out

- CCE SubTask Force with theorists successfully launched
  - Prioritised list of channels with dedicated input from theory
  - Expect first related report at the June CM → *next talk*