Production of $X(3872)$ at $\overline{\mathrm{P}}$ANDA

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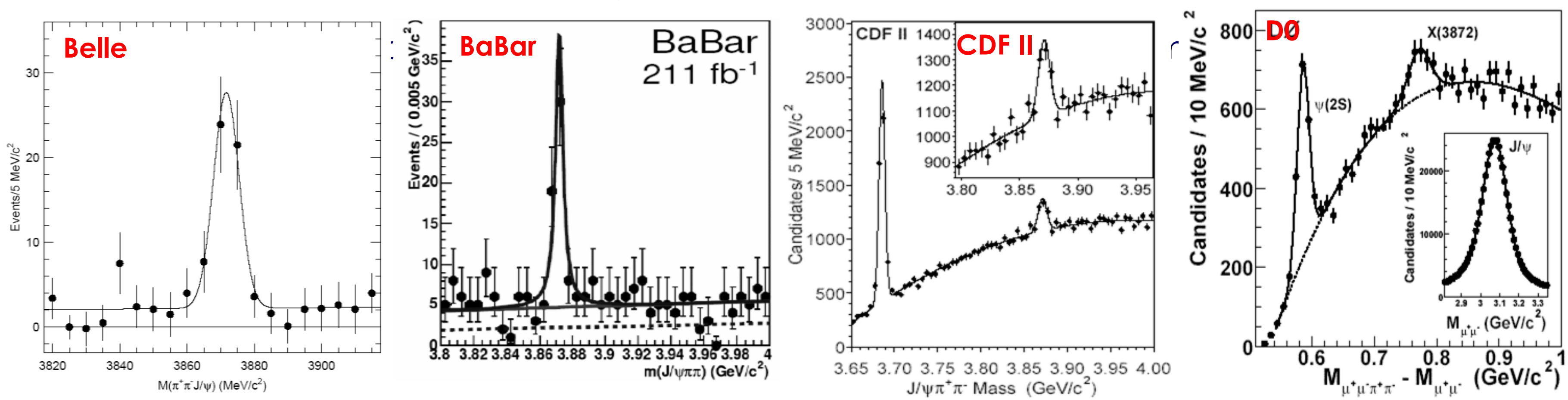
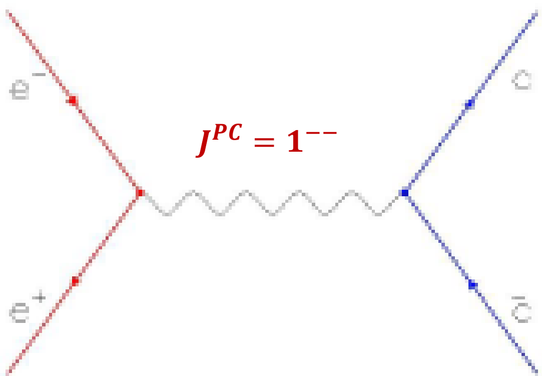
The $X(3872)$ State

- A charmonium(-like) state found in $X(3872) \to J/\psi\pi^+\pi^-$ by Belle (2003)
- confirmed by experiments of Babar, CDF and D0.
- narrow ($\Gamma_{X(3872)} \leq 1.2$ MeV at 90% C.L.) and closed to the $D^0\bar{D}^{*0}$ threshold (m_x = 3871.68 ± 0.17 MeV)
- $J^{PC} = 1^{++}$ determined by LHCb (2012)
- The structure of X(3872) is still unclear.
- Possible interpretations
    - a loosely-bound molecule of D-mesons : $D^0\bar{D}^{*0}$
    - a 2P charmonium state $\chi_{c1}(2P)$

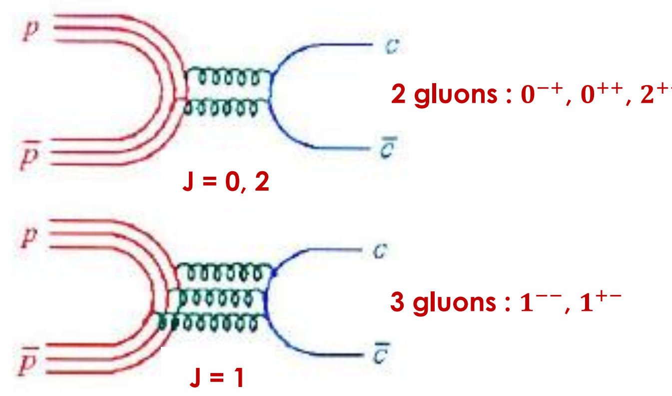


Charmonium Production in $\bar{p}p$ collisions

- In e^+e^- experiments only neutral $J^{PC} = 1^{--}$ resonances can be directly produced, and production of exotic charmed states through other mechanisms is suppressed.
- In $\bar{p}p$ experiments direct production of exotic resonant states with various quantum numbers, including charged ones is possible.



e^+e^- collisions



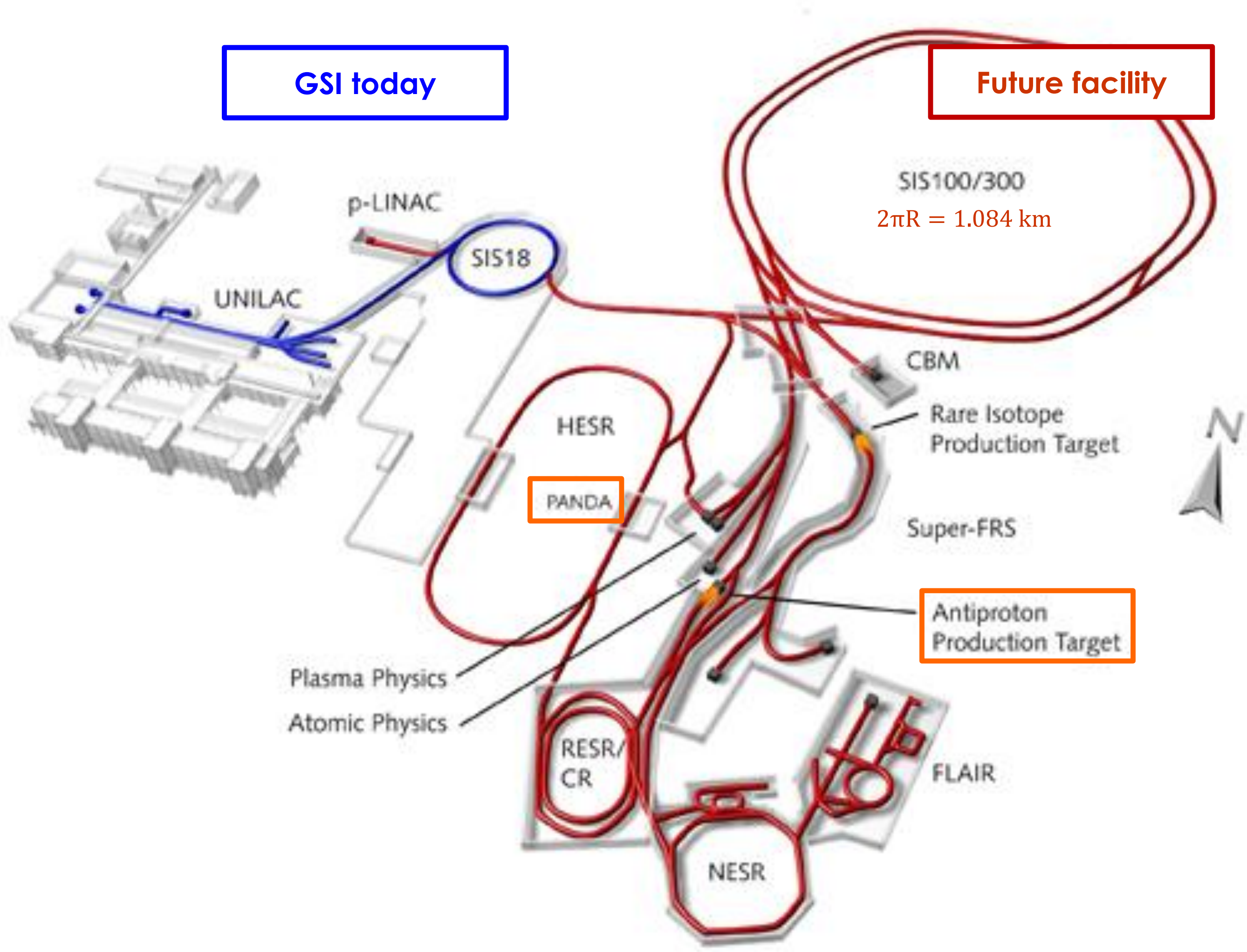
$\bar{p}p$ collisions

I. Introduction

$\bar{\text{P}}$ANDA experiment

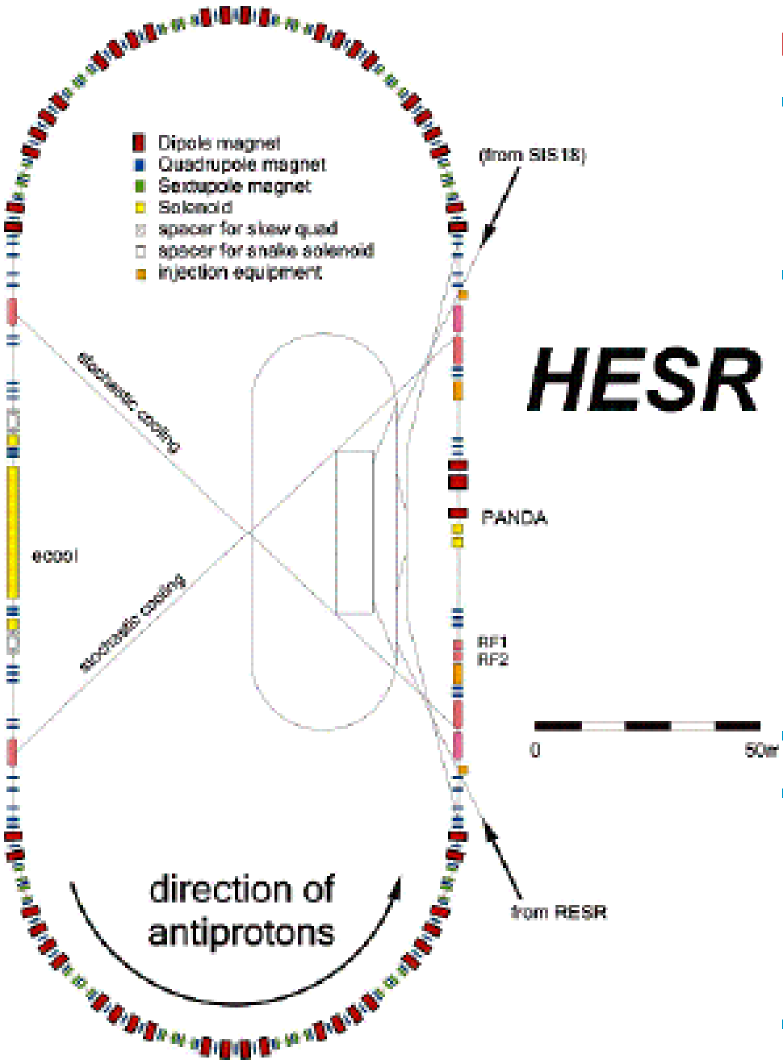
- $\bar{P}$ANDA (Anti-Proton ANnihilation at DArmstadt)
- The future experiment at FAIR (Facility for Antiproton and Iron Research) at GSI in Darmstadt (Frankfurt, Germany).
- fundamental questions of hadron and nuclear physics in the interactions of antiprotons with nucleons and nuclei.
- very high intensity antiproton beam with momentum ranging from 1.5 GeV/c to 15 GeV/c on a fixed proton target ($2.2 \leq \sqrt{s} \leq 5.5$ GeV)
- high reaction rates $2 \times 10^7 interactions/s$ and high mass resolution 20 times better compared with the B-factories.
- → suited for charmonium studies thanks to the high capability rate and the excellent mass resolution
- complementary to the studies performed at B-factories.

$\overline{\text{P}}$ANDA experiment at FAIR



I. Introduction

HESR (High Energy Storage Ring) with $\overline{\text{P}}$ANDA



For Antiprotons

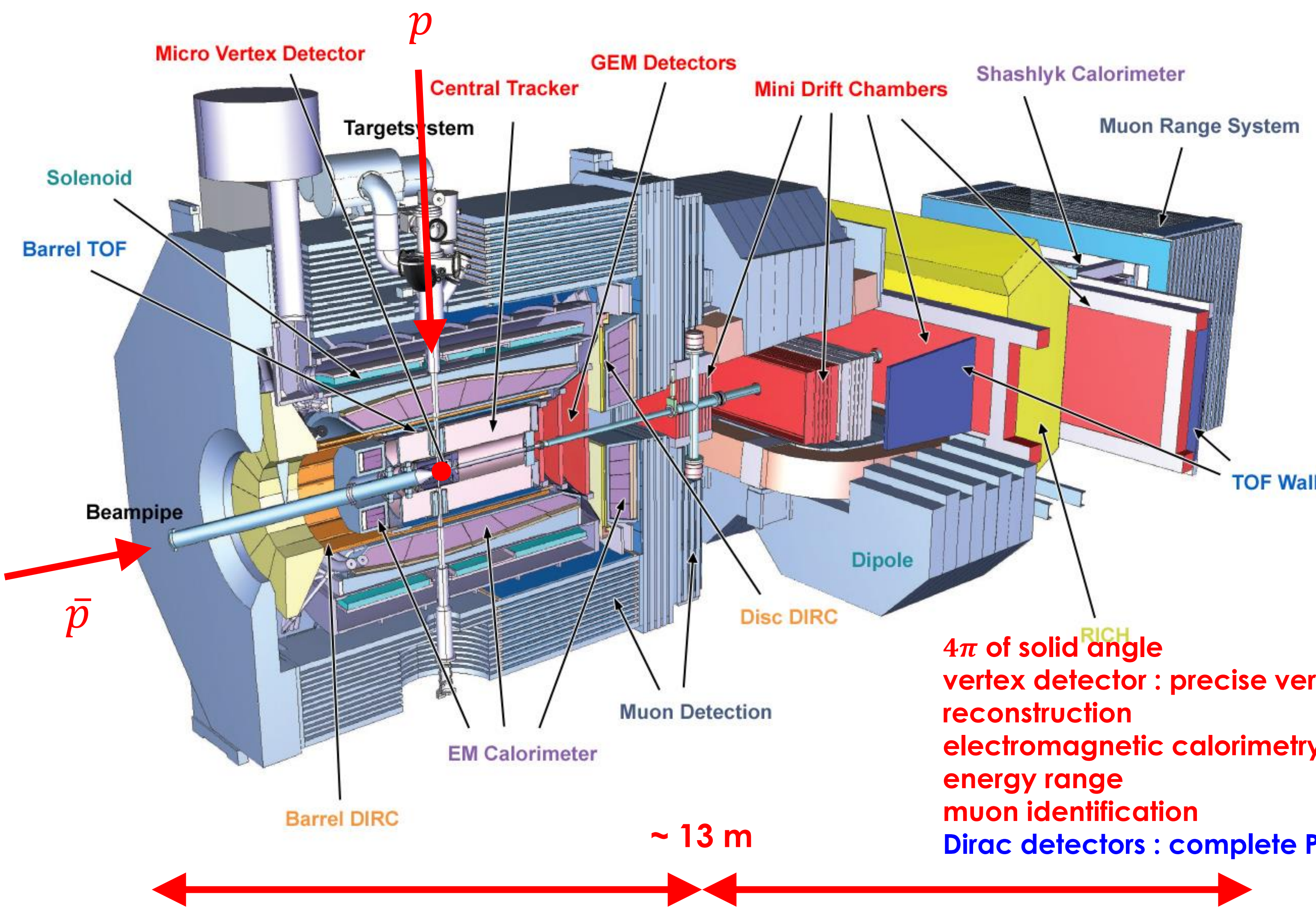
- Antiprotons are produced by a secondary target and then stored and cooled in the HESR (High Energy Storage Ring).

- **Two HESR operation modes**

High intensity mode	High resolution mode
10^{11} antiprotons stored	10^{10} antiprotons stored
stochastic cooling	electron cooling
$p \geq 1.5\ GeV/c$	$1.5 \leq p \leq 8.9\ GeV/c$
$\mathcal{L}$ up to $2 \cdot 10^{32} cm^{-2} s^{-1}$	$\mathcal{L}$ up to $2 \cdot 10^{31} cm^{-2} s^{-1}$
$\boldsymbol{\Delta p/p = 10^{-4}}$	$\boldsymbol{\Delta p/p = 10^{-5}}$

- **Three different types of targets under discussion**
- hydrogen pellets :
  - $10^{15} atoms/cm^3$
  - a peak luminosity of $\mathcal{L} = 2 \times 10^{32}\ cm^{-2}\ s^{-1}$ ($\cong 2 \times 10^9$ J/ψ per year)
- a cluster jet target
- fixed nuclear targets : $Be, C, Si\ or\ Al$.

$\overline{\text{P}}$ANDA Detector Overview

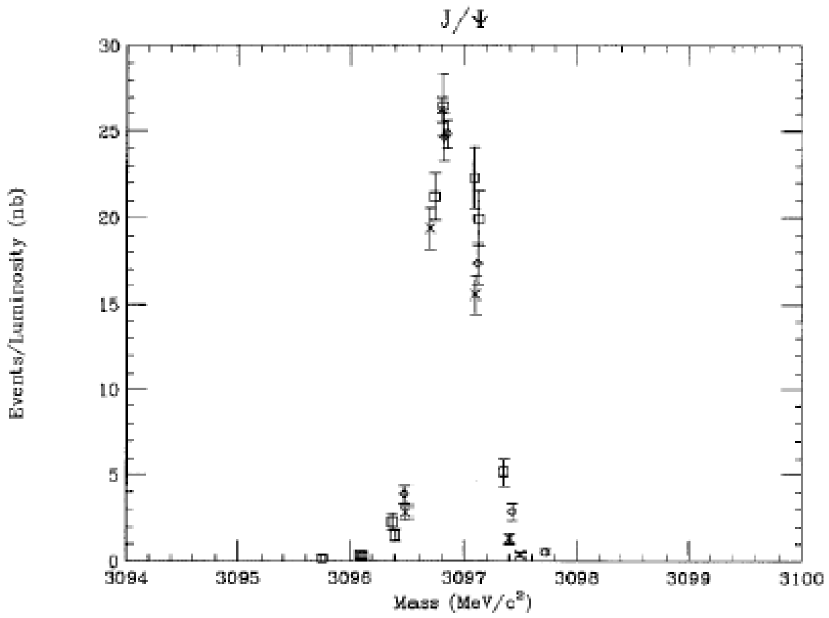


4π of solid angle
vertex detector : precise vertex reconstruction
electromagnetic calorimetry : wide energy range
muon identification
Dirac detectors : complete PID

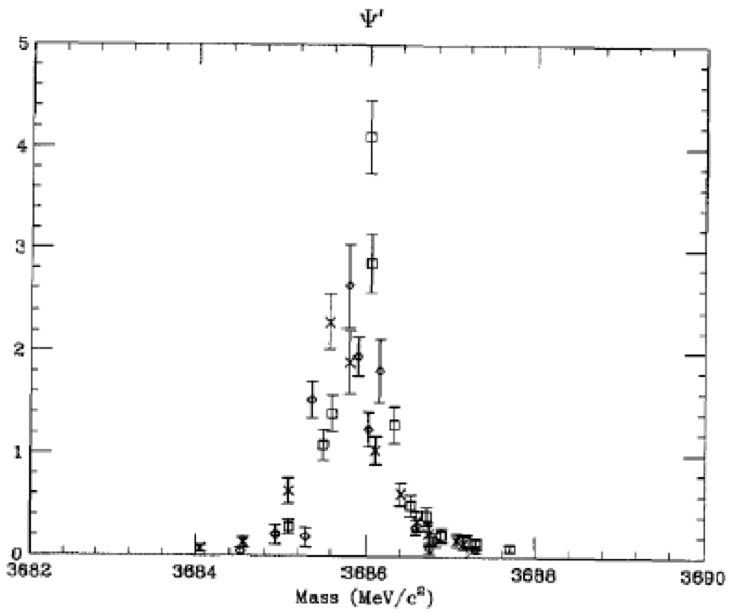
PANDA Collaboration, arXiv:0903.3905 [hep-ex]

Charmonium Width Measurements

- The resonance scan with the cooled beam could provide a measurement of the $X(3872)$ width.
- The technique pioneered by the Fermilab experiments E760 and E835.
  - Measurement of the J/ψ and ψ' resonance parameters in $\bar{p}p$ annihilation
  - beam momentum resolution $\Delta p/p = 2\times10^{-4} \rightarrow \sqrt{s}$ FWHM resolution $\cong 0.5$ MeV.



$\Gamma(J/\psi) = 99 \pm 12 \pm 6$ keV



$\Gamma(\psi') = 306 \pm 36 \pm 16$ keV

E760 Collaboration, Phys. Rev. D 47 (1993) 772

Estimates for the $X(3872)$ Cross Section at $\overline{\mathrm{P}}\mathrm{ANDA}$

- Detailed balance method:

$$\sigma[\bar{p}p \to R] \cdot BR(R \to f) = \frac{(2J+1)\cdot 4\pi}{s-4m_p^2} \cdot \frac{BR(R \to \bar{p}p)\cdot BR(R \to f)\cdot \Gamma_R^2}{4(\sqrt{s}-m_R)^2+\Gamma_R^2}$$

- resonance $R = X(3872)$, spin parity $J^p = 1^+$

$$\sigma[\bar{p}p \to X(3872)] \cdot BR(X(3872) \to f) = \frac{3\cdot 4\pi}{s-4m_p^2} \cdot \frac{BR(X(3872) \to \bar{p}p)\cdot BR(X(3872) \to f)\cdot \Gamma_{X(3872)}^2}{4(\sqrt{s}-m_{X(3872)})^2+\Gamma_{X(3872)}^2}$$

- $\sqrt{s} = m_{X(3872)}$= 3.872 GeV/c^2

$$\sigma[\bar{p}p \to X(3872)] = \frac{3\cdot 4\pi}{m_{X(3872)}^2 - 4m_p^2} \cdot BR(X(3872) \to \bar{p}p)$$

- $BR(X(3872) \to \bar{p}p)$ published by LHCb (2013)

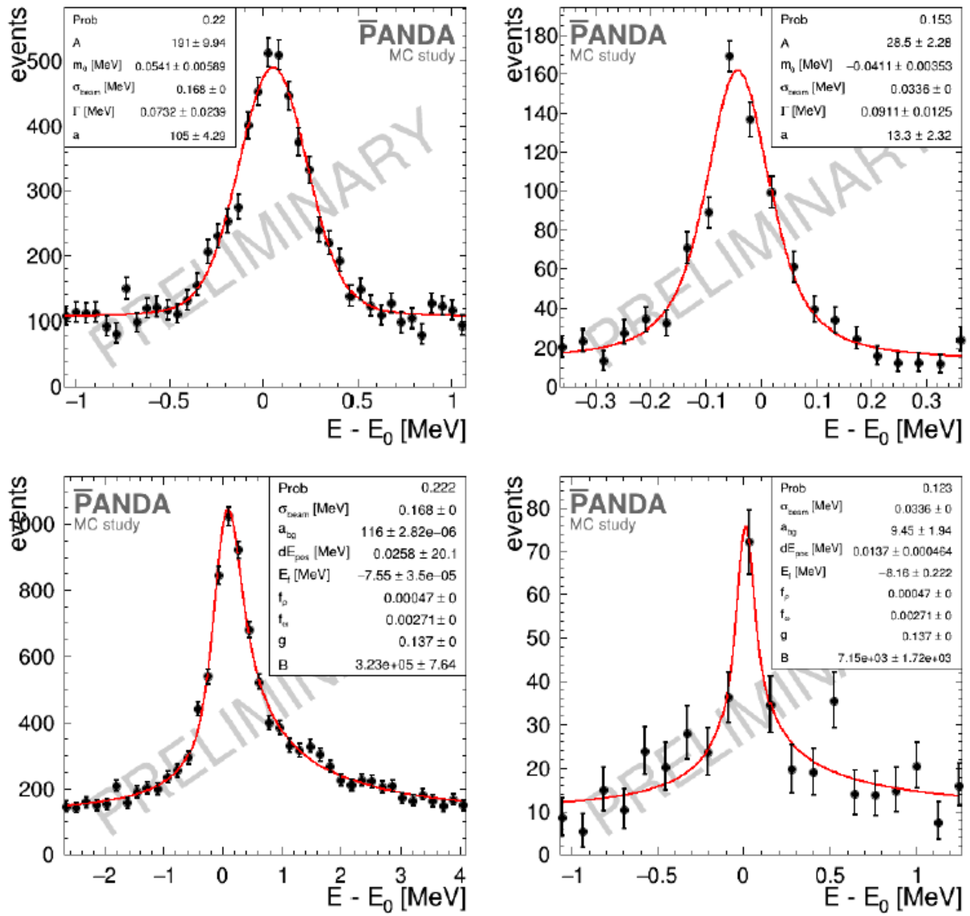
$$\sigma\big(\bar{p}p \to X(3872)\big) < (68 \pm 0.4)\, nb \;(95\%\; C.L)\;;\; \sigma\big(\bar{p}p \to X(3872)\big) = 50\, nb$$

- The expected $X(3872)$ production rates per day

	high luminosity mode	high resolution mode	
Resonance	$\mathcal{L} = 8.64\, pb^{-1}/day$	$\mathcal{L} = 0.864\, pb^{-1}/day$	$\mathcal{L} = 0.432\, pb^{-1}/day$
$X(3872)$	432000	43200	21600

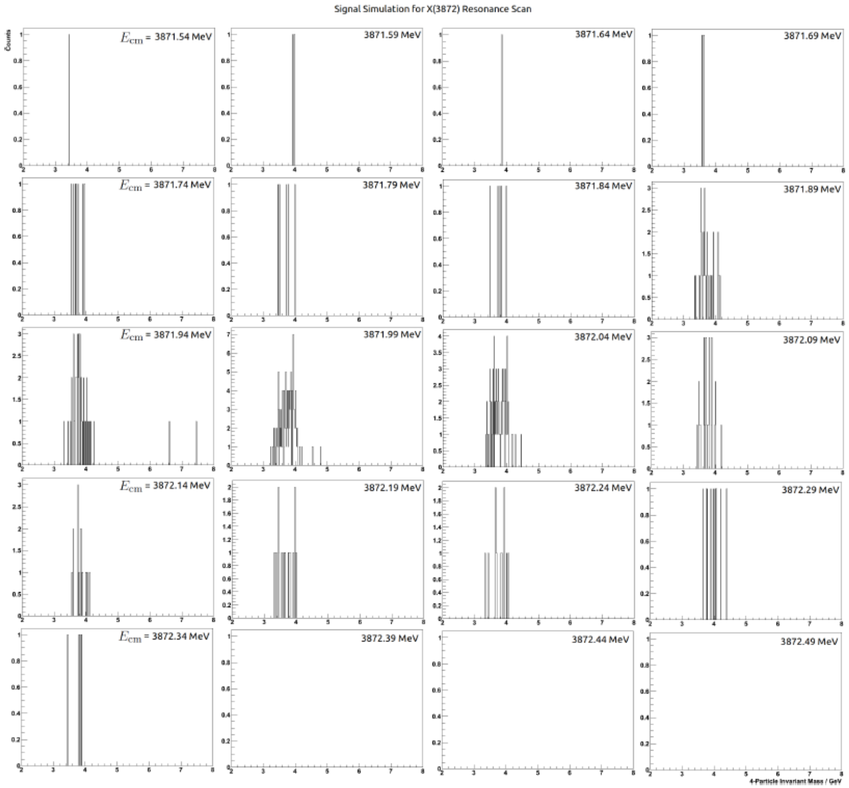
E. Prencipe, J. Lange, and A. Blinov, AIP Conference Proceedings 1735 (2016) 060011

Resonance Scan of $X(3872)$ at $\overline{\text{P}}$ANDA

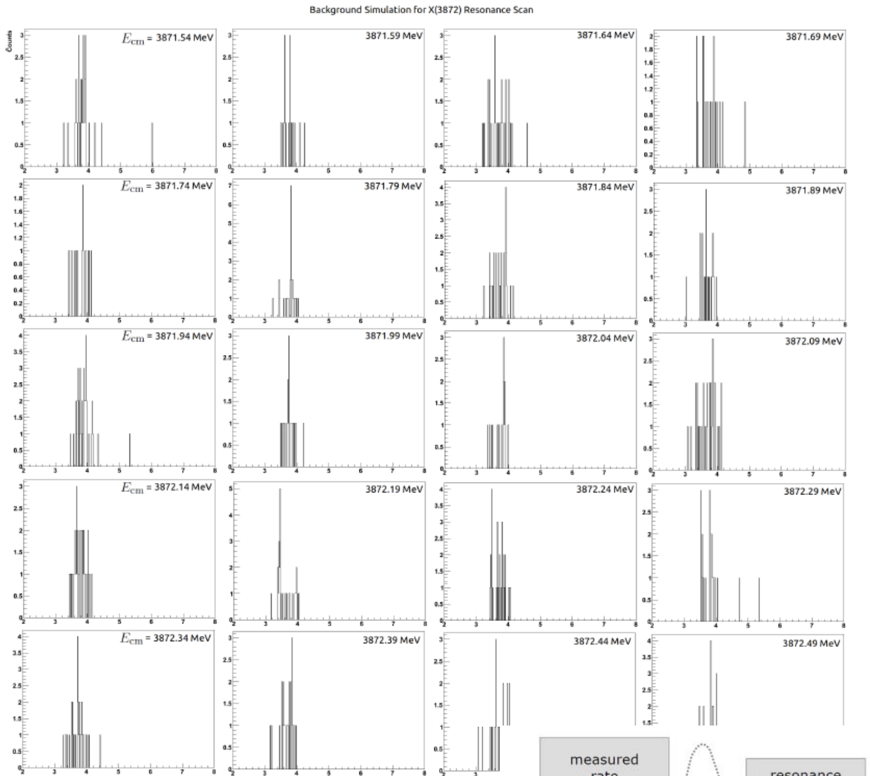


Resonance Scan of $X(3872)$ at $\overline{\text{P}}\text{ANDA}$

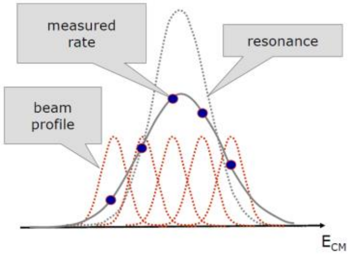
Signal Simulation for $X(3872)$ Resonance



Background Simulation for $X(3872)$ Resonance

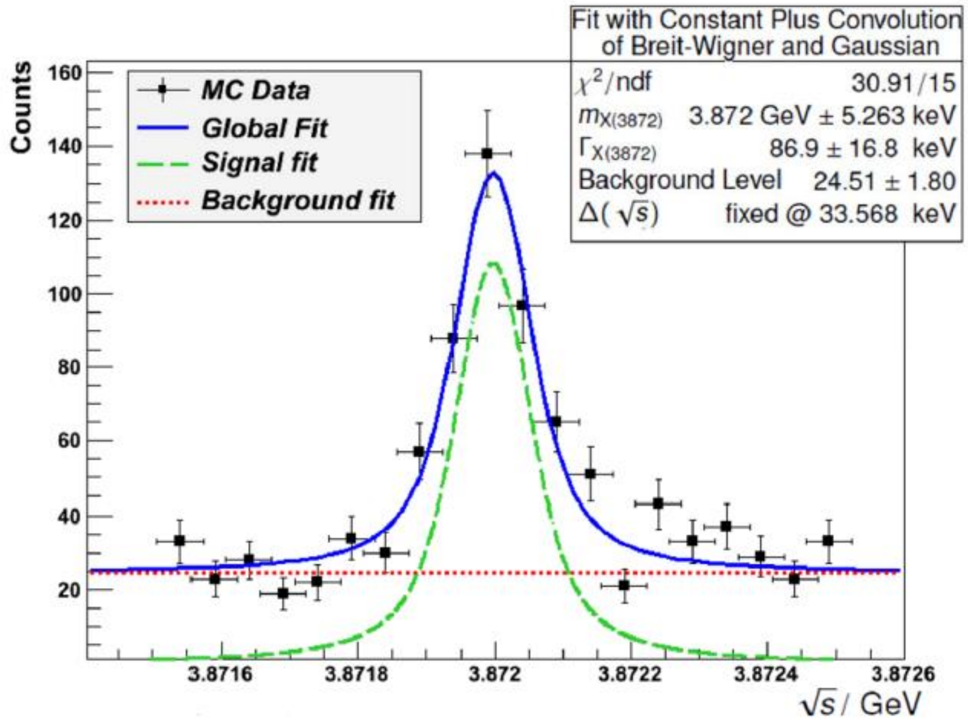


$$\bar{p}p \to X(3872) \to J/\psi\pi^+\pi^-$$



I. Introduction

Resonance Scan of $X(3872)$ at $\overline{\text{P}}$ANDA



- Reconstructed width of 86.9 ± 16.8 keV is consistent with input width of 100 keV.
- $\overline{\text{P}}$ANDA is well suited for resonance scan investigations of narrow resonances which can be directly formed in $\bar{p}p$.
- $\overline{\text{P}}$ANDA will be able to either measure $\Gamma_{X(3872)}$ or at least significantly improve the current upper limit of $\Gamma_{X(3872)} \leq 1.2$ MeV at 90% C.L.