Scan experiments at PANDA

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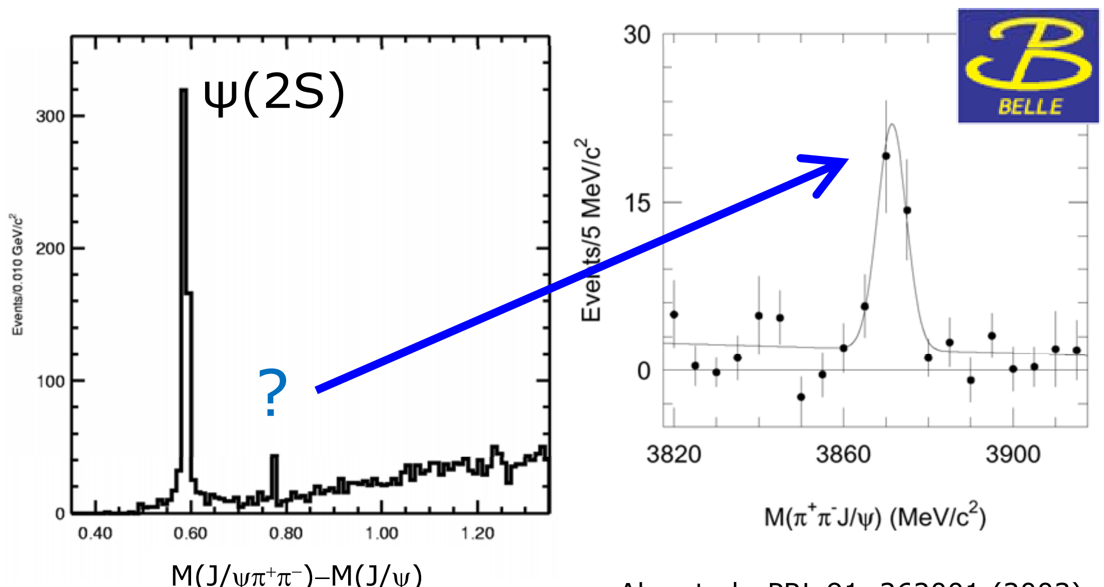
X(3872) discovery

$X(3872) \to J/\psi\pi^+\pi^-$

in $B \to X\ K$

2003



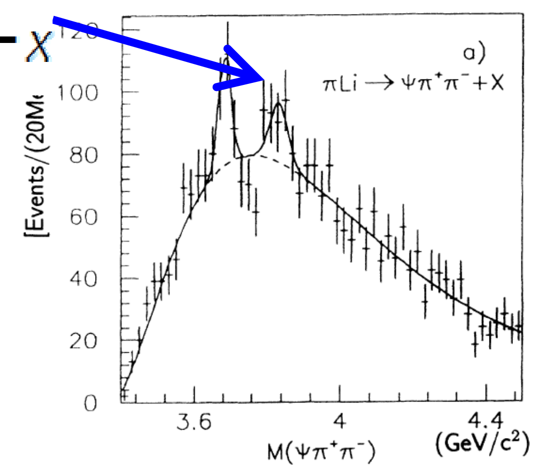
Abe et al., PRL 91, 262001 (2003)

X(3872) - PDG

X(3872) MASS FROM $J/\psi\pi\pi$ MODE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
3871.56 ± 0.22 OUR AVERAGE					
3871.61 ± 0.16 ± 0.19	6k	[1,2] AALTONEN	09AU	CDF2	$p\bar{p} \to J/\psi\pi^+\pi^- X$
3871.4 ± 0.6 ± 0.1	93.4	AUBERT	08Y	BABR	$B^+ \to K^+ J/\psi\pi^+\pi^-$
3868.7 ± 1.5 ± 0.4	9.4	AUBERT	08Y	BABR	$B^0 \to K^0_S J/\psi\pi^+\pi^-$
3871.8 ± 3.1 ± 3.0	522	[2,3] ABAZOV	04F	D0	$p\bar{p} \to J/\psi\pi^+\pi^- X$
3872.0 ± 0.6 ± 0.5	36	CHOI	03	BELL	$B \to K\pi^+\pi^- J/\psi$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
3868.6 ± 1.2 ± 0.2	8	[4] AUBERT	06	BABR	$B^0 \to K^0_S J/\psi\pi^+\pi^-$
3871.3 ± 0.6 ± 0.1	61	[4] AUBERT	06	BABR	$B^- \to K^- J/\psi\pi^+\pi^-$
3873.4 ± 1.4	25	[5] AUBERT	05R	BABR	$B^+ \to K^+ J/\psi\pi^+\pi^-$
3871.3 ± 0.7 ± 0.4	730	[2,6] ACOSTA	04	CDF2	$p\bar{p} \to J/\psi\pi^+\pi^- X$
3836 ± 13	58	[2,7] ANTONIAZZI	94	E705	300 $\pi^\pm$ Li $\to J/\psi\pi^+\pi^- X$

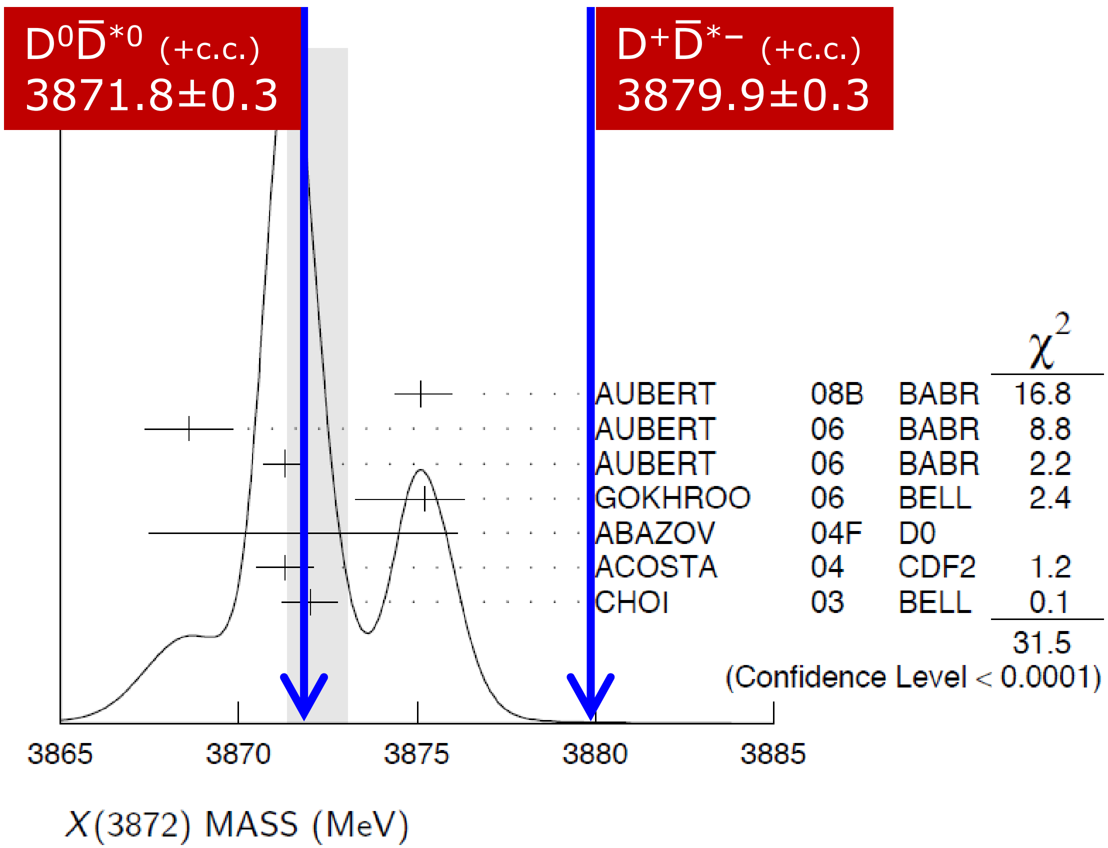
1994



Confirmed by BaBar, D0 and CDF

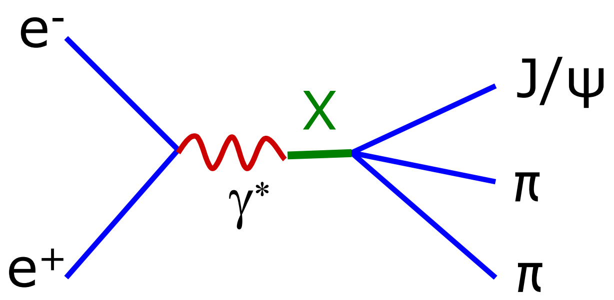
Width smaller than detector resolution
(< 2.3 MeV/c^2)

X(3872) mass measurements



X(3872) properties

A charmonium(-like) state found in X(3872) → $J/\psi\ \pi^+\pi^-$



Not found in formation in e^+e^- collision
→ Not $J^{PC} = 1^{--}$

Observation of decay into $J/\psi\ \gamma$
→ C=+1

Mass of X(3872) → $D^0\bar{D}^{*0}$ shifted by ~3 MeV/c²
→ S-wave molecular state?

Interesting properties:
breaks isospin in the decays $J/\psi\ \rho(\rightarrow \pi^+\pi^-)$, $J/\psi\ \omega(\rightarrow \pi^+\pi^-\pi^0)$
→ is it charmonium?

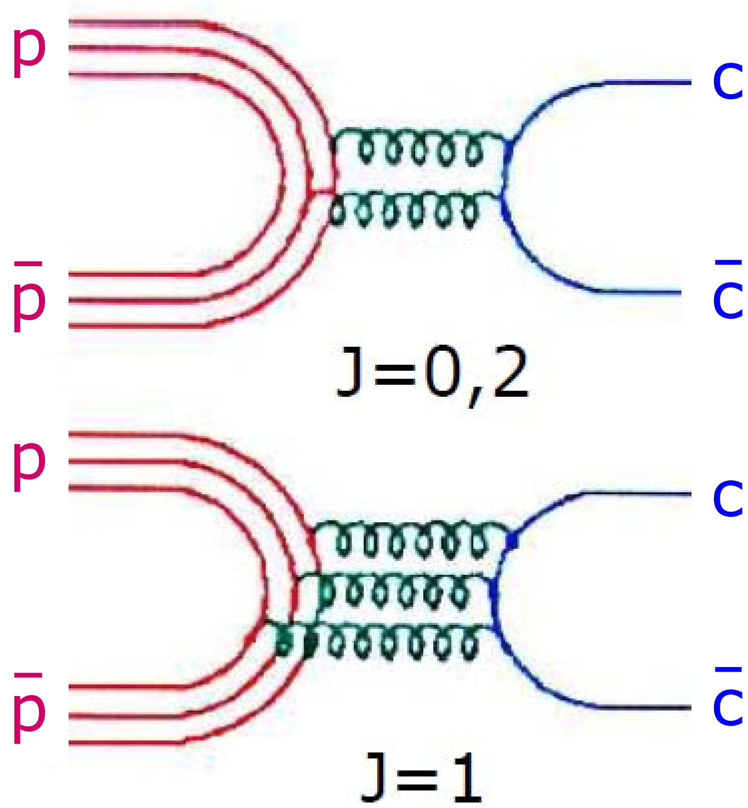
Width is unknown lower limit $\Gamma < 2.3$ MeV/c² (Belle)

Helicity amplitude analysis from CDF
→ E.g. $J^{PC} = 1^{++}$ or 2^{-+}

Properties and nature of the resonance still unclear !

Charmonium production with $\bar{p}p$ reactions

Formation



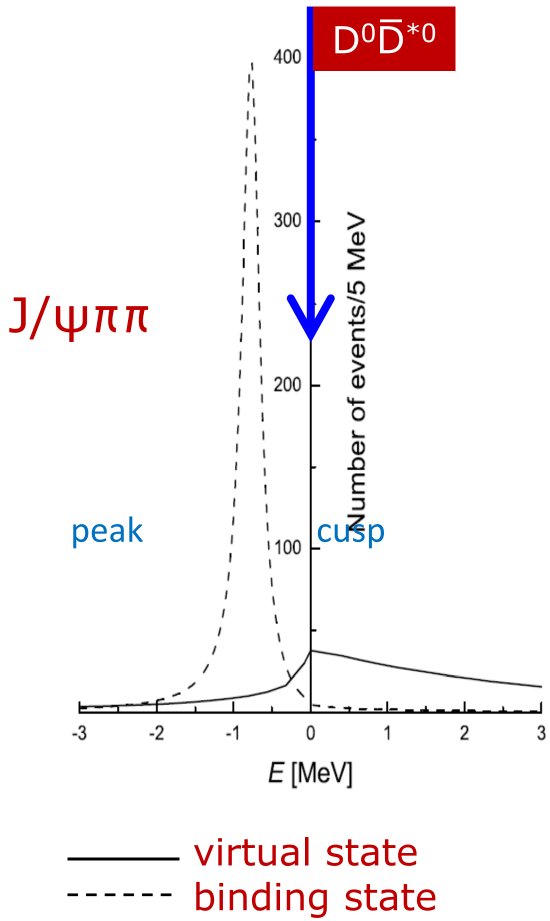
2 gluons: 0++, 1++ 2++
(L=0)
0-+, 2-+
(L=1)

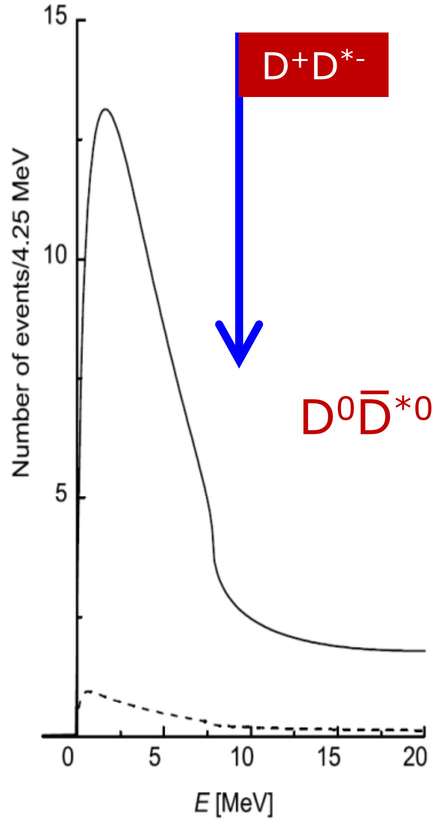
3 gluons: 1--, 1+-

Determination of quantum numbers:
→ angular distributions

X(3872) line shape

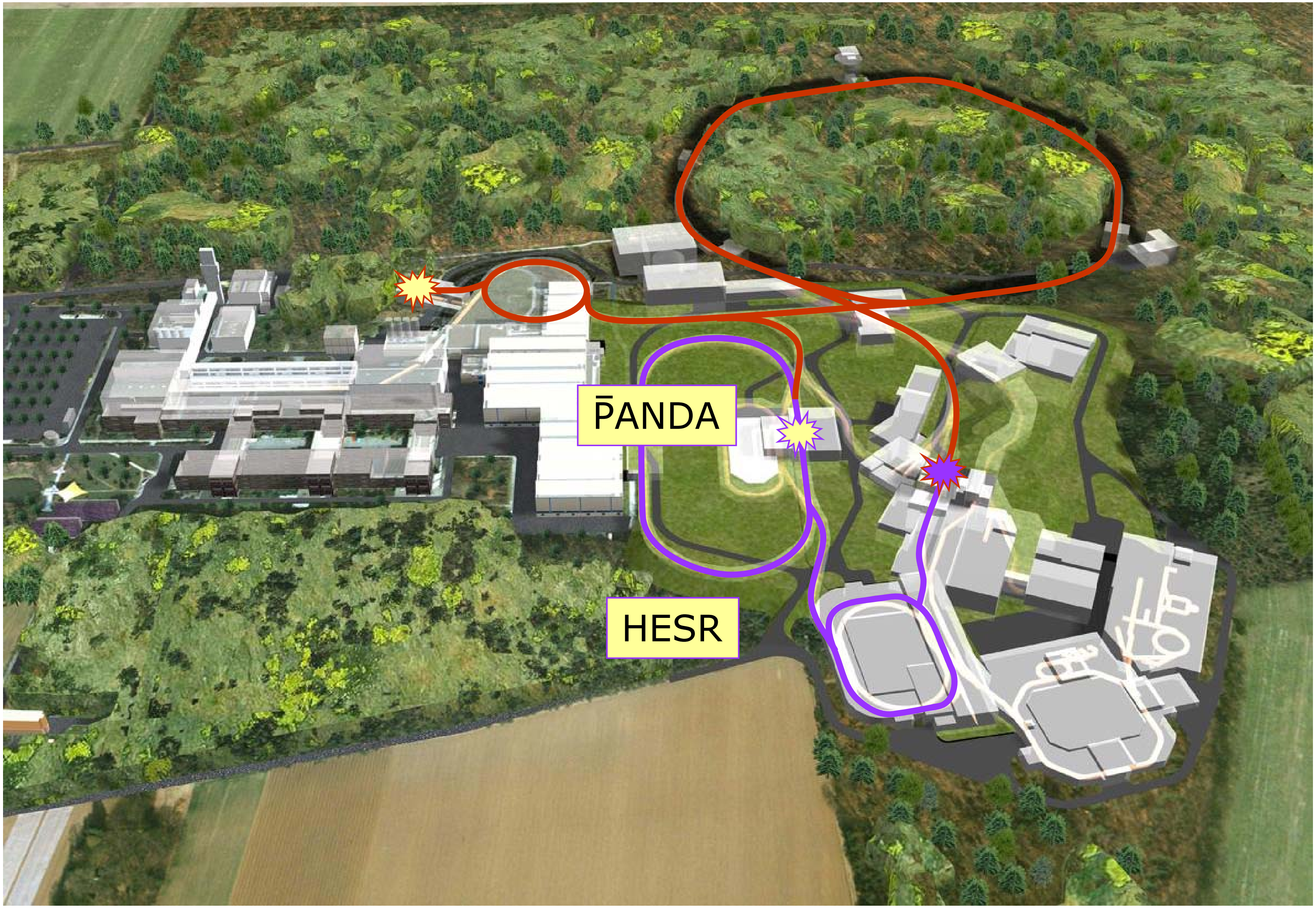
C. Hanhart et al. (2007)



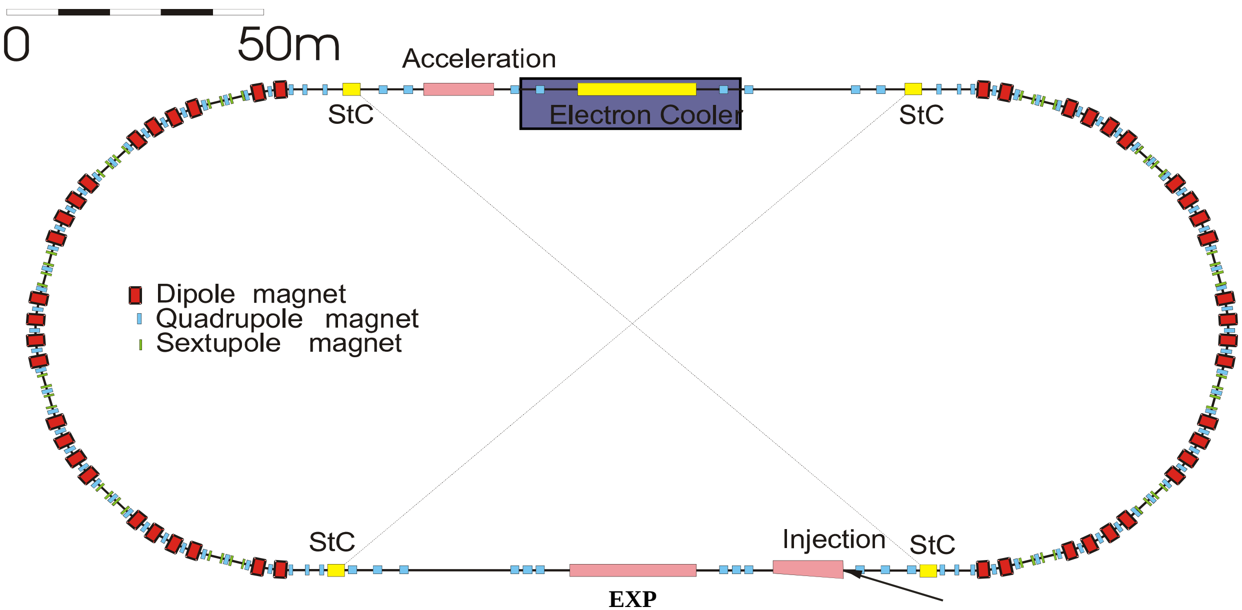


Energy scan with simultaneous extraction of all known decay channels is essential !

FAIR



HESR - High Energy Storage Ring

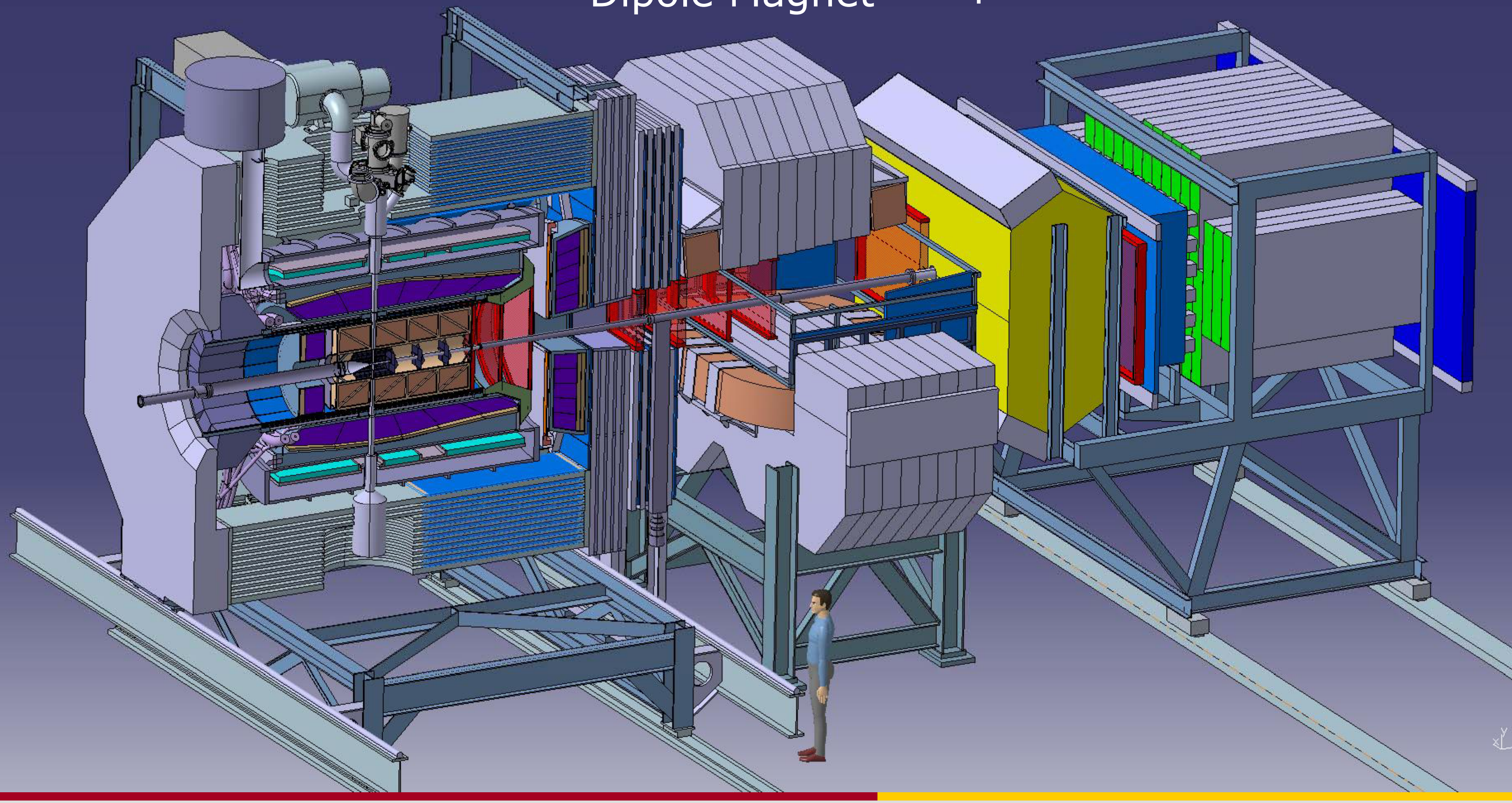


Injection of $\bar{p}$ at 3.7 GeV

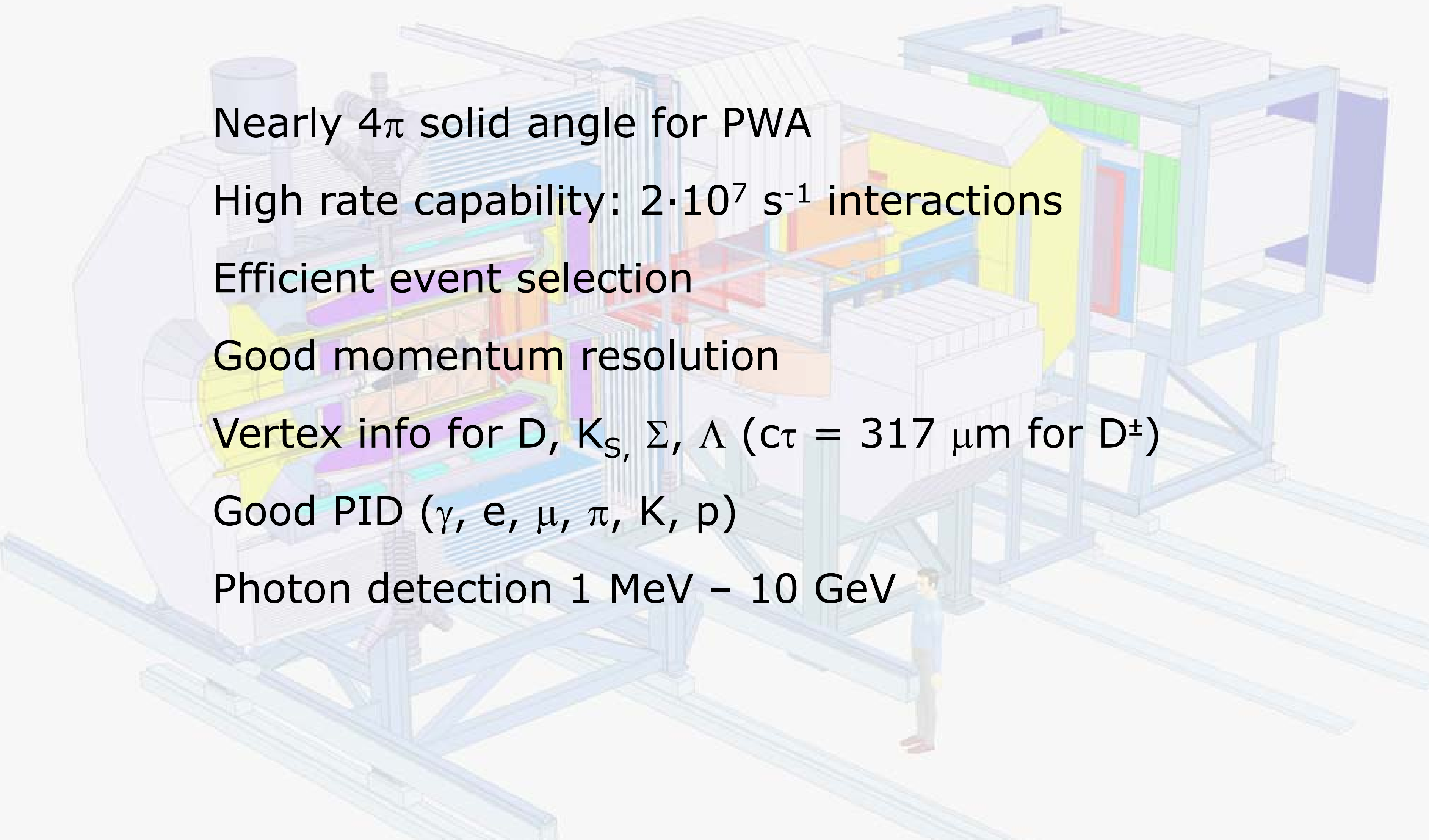
Storage ring for internal target operation

Mode	High Resolution	High Luminosity
Momentum range	**1.5 - 8.9 GeV/c**	**1.5 – 15 GeV/c**
Stored antiprotons	**10^{10}**	**10^{11}**
Luminosity	**$2 \cdot 10^{31}$ cm^{-2}s^{-1}**	**$2 \cdot 10^{32}$ cm^{-2}s^{-1}**
Mom. Resol. (rms)	**$\Delta p/p \leq 4 \cdot 10^{-5}$**	**$\Delta p/p = 1 \cdot 10^{-4}$**
Beam cooling	**Electron (≤ 8.9 GeV/c)**	**Stochastic (≥ 3.8 GeV/c)**

$\bar{P}$ANDA Detector



Detector requirements



Nearly 4π solid angle for PWA

High rate capability: $2\cdot10^7\ s^{-1}$ interactions

Efficient event selection

Good momentum resolution

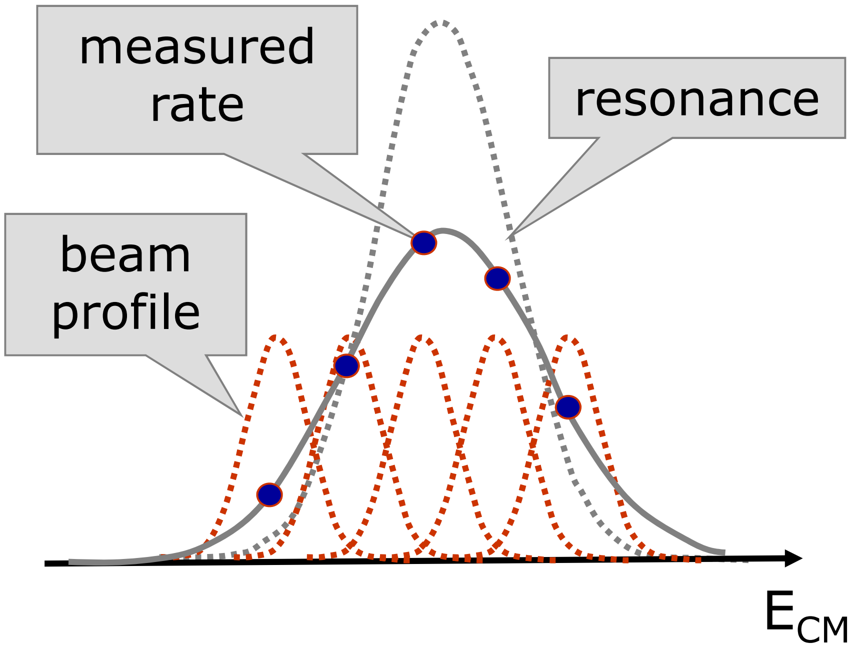
Vertex info for D, K_S, Σ, Λ ($c\tau$ = 317 μm for $D^\pm$)

Good PID (γ, e, μ, π, K, p)

Photon detection 1 MeV – 10 GeV

Energy scan technique

→ Line shape measurement



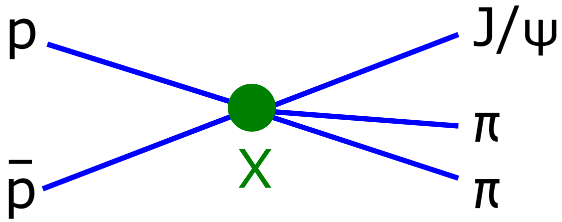
Selection of the events

Normalization

Beamtime planning

Event selection e.g. X(3872) → J/ψ $\pi^+\pi^-$

Formation



Simulation at $\sqrt{s}$ = 3872 MeV/c²
and Γ= 0 MeV/c²

J/ψ → e^+e^- or $\mu^+\mu^-$

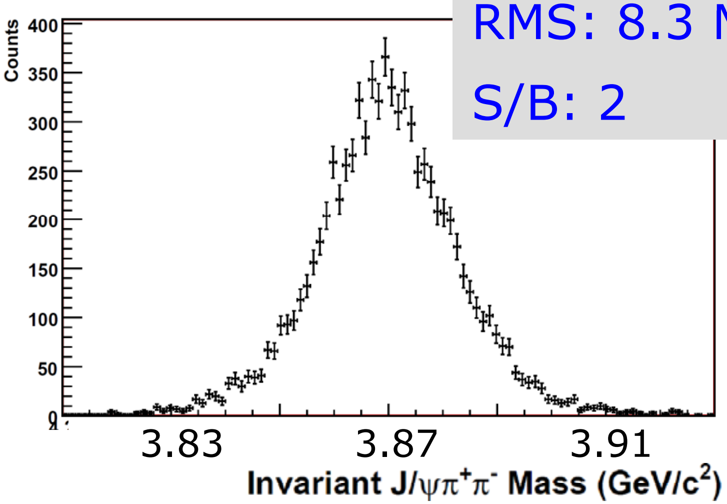
Cut round inv. J/ψ-mass

Combination with $\pi^+\pi^-$

Efficiency: 32%

RMS: 8.3 MeV/c²

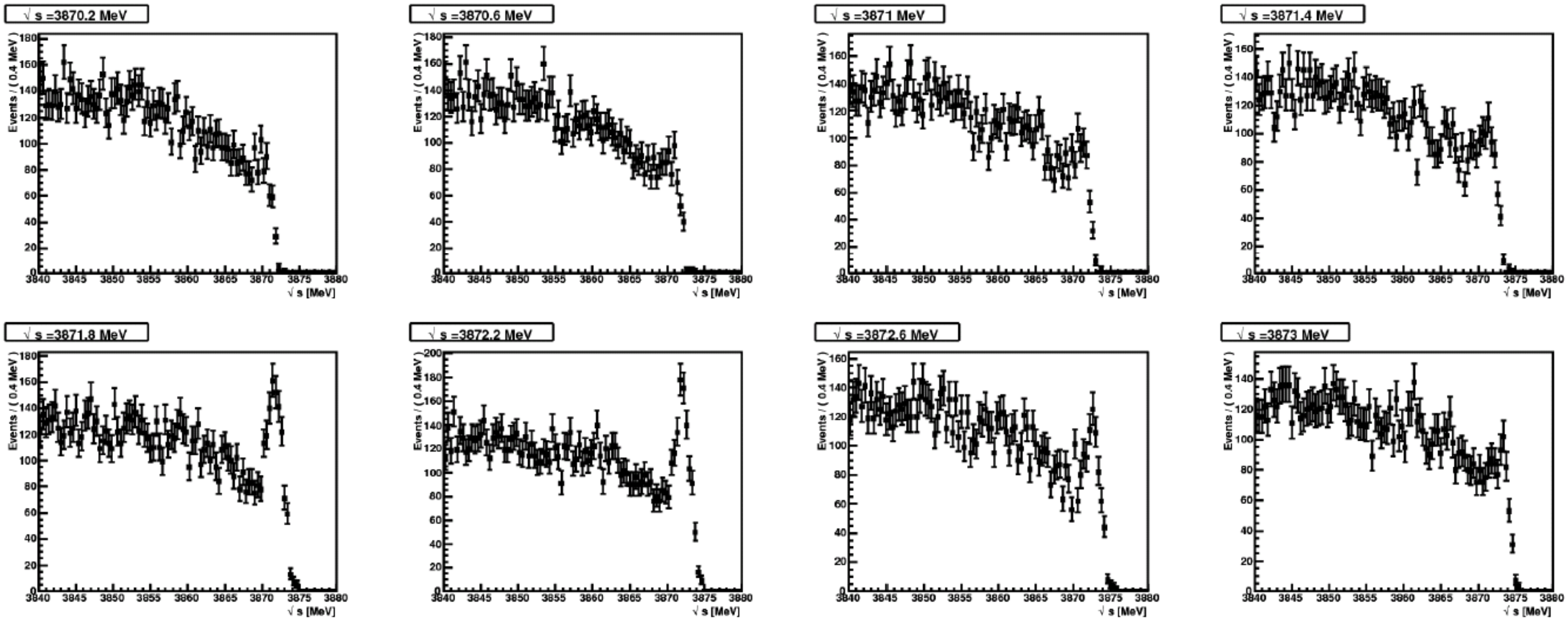
S/B: 2

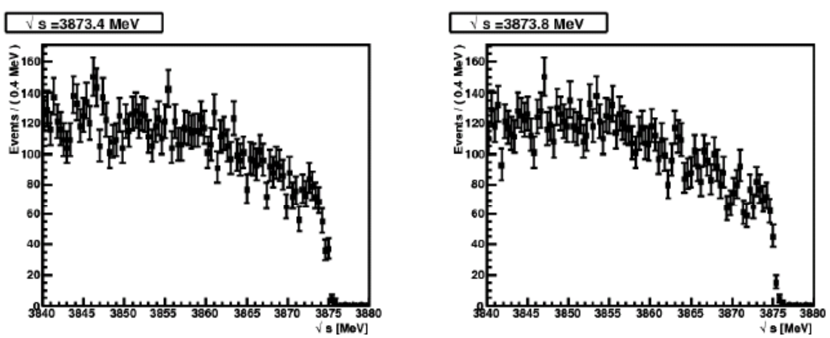


Energy scan

X(3872) input: m= 3872 MeV/c^2, Γ= 1 MeV/c^2, RMS: 8.3 MeV/c^2

S/B = 2/1 (background argus function)





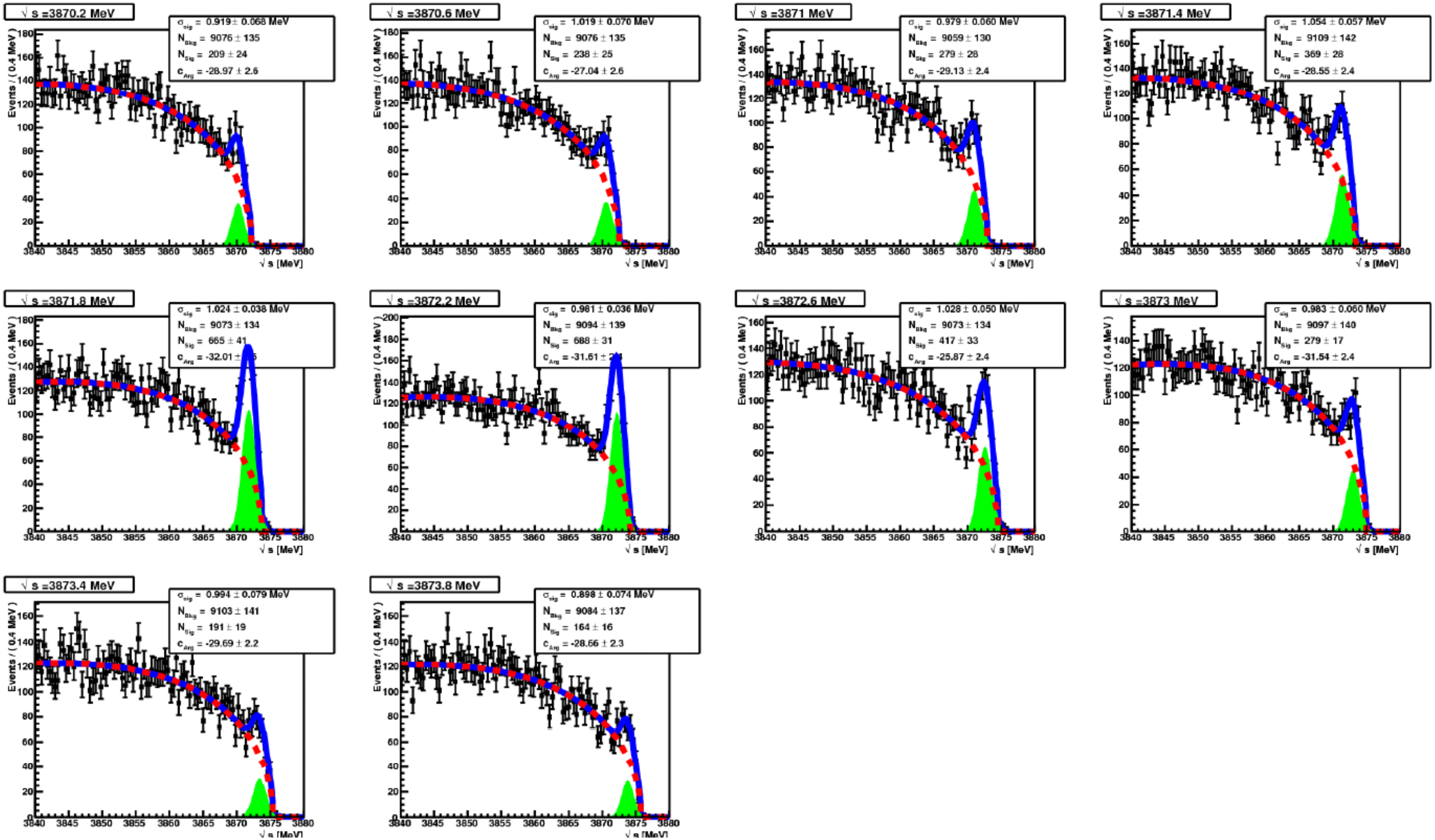
10 steps a 400 keV/c^2

3870.2 – 3873.8 MeV/c^2

$\Delta p/p = 3 \cdot 10^{-5}$

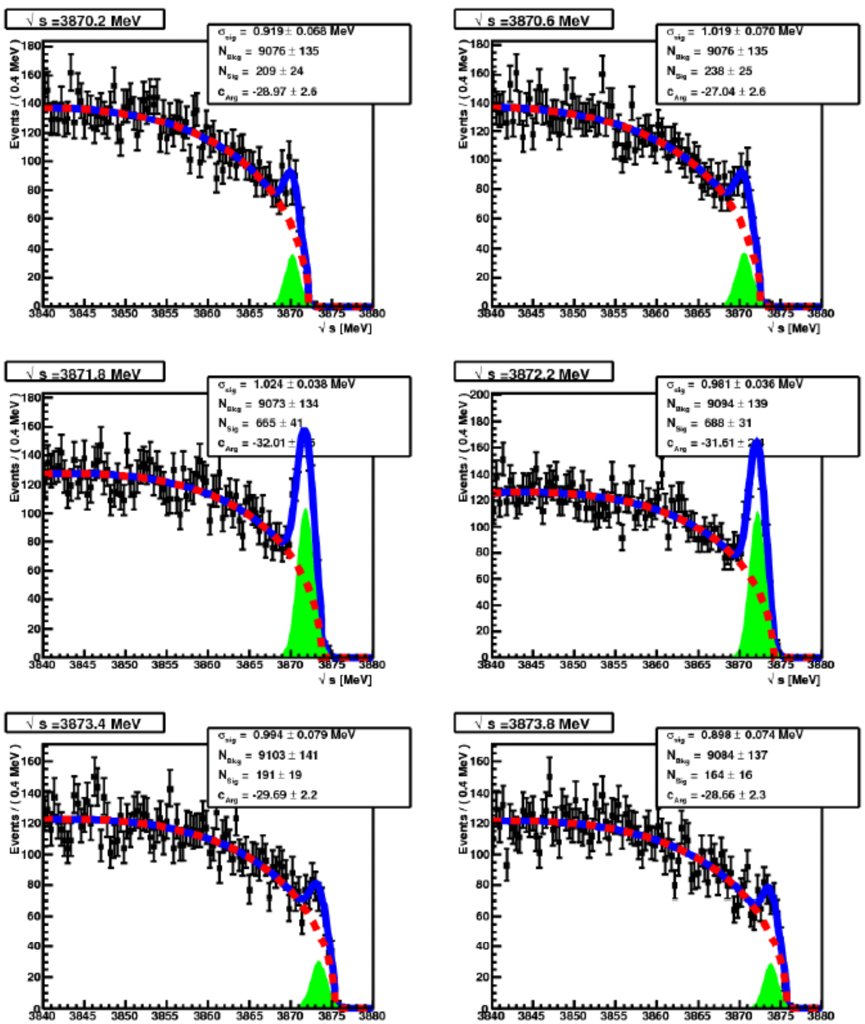
Energy scan

Fit with Gauss + Argus Function



Energy scan

Fit with Gauss + Argus Function

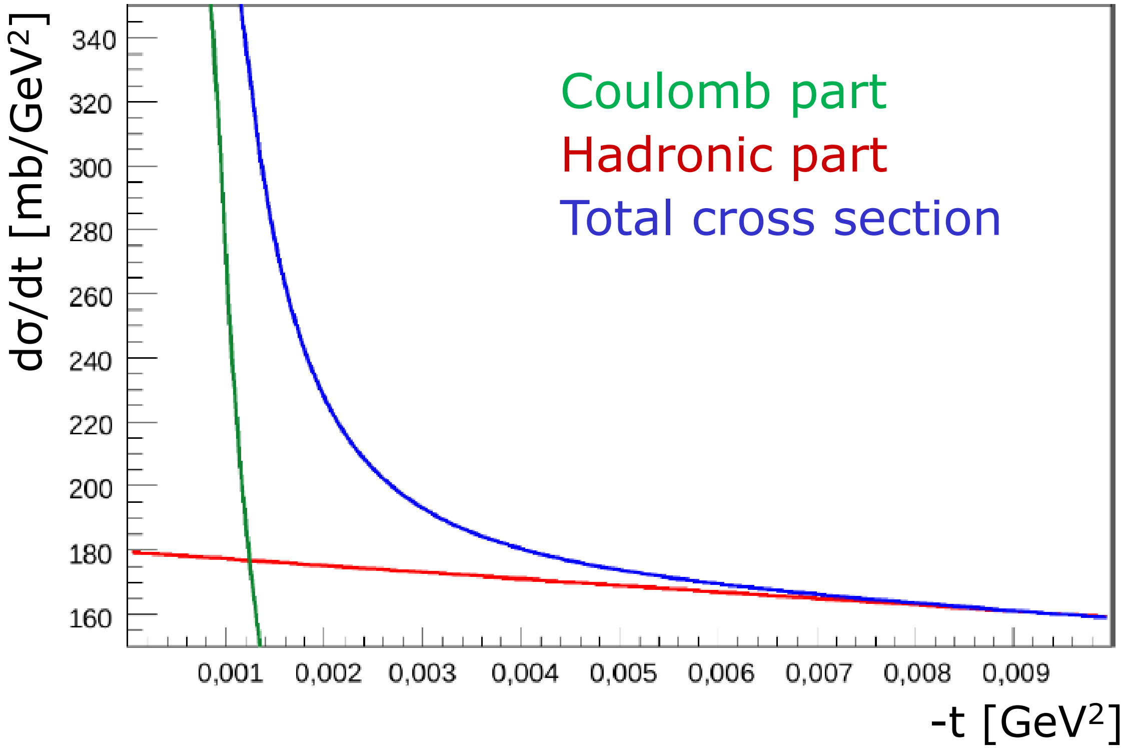


→ Normalization

→ Luminosity

Luminosity measurement at PANDA

Elastic antiproton-proton scattering



only few measurements available !!

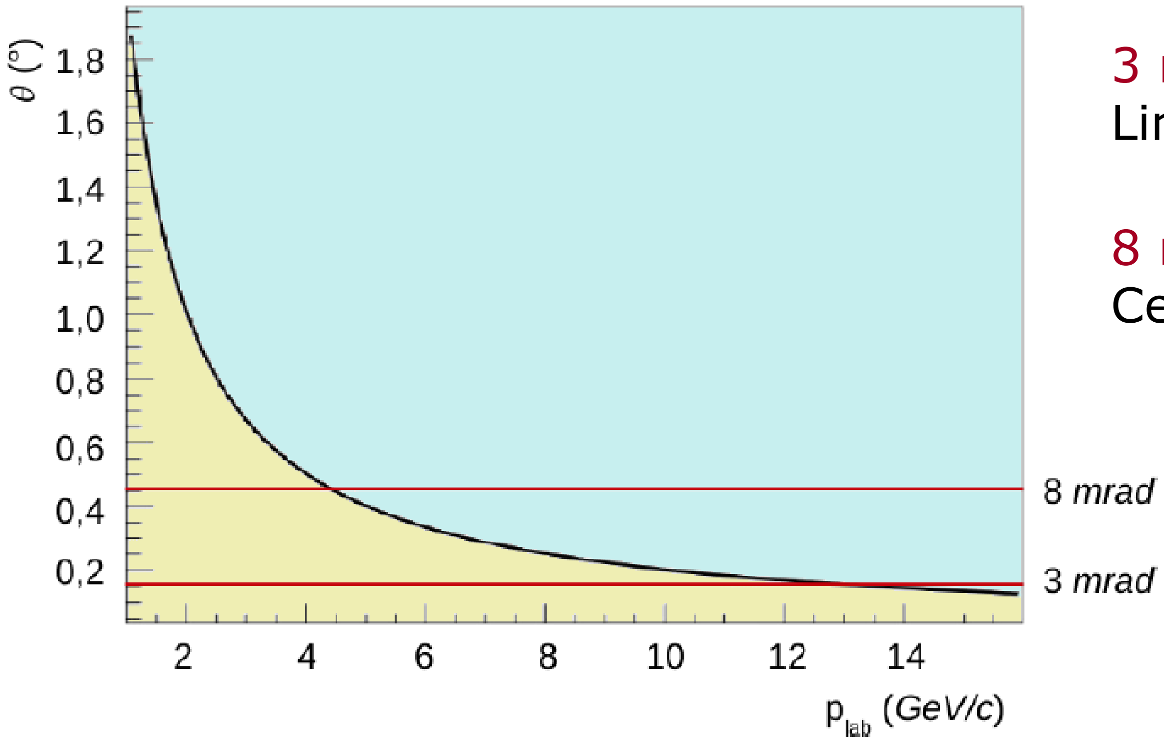
At small |t| and therefore small θ:

Coulomb scattering dominates

→ Differential cross section can be calculated

Elastic $\bar{p}p$ scattering

dσ/dθ (Coulomb) = dσ/dθ (Hadronic)



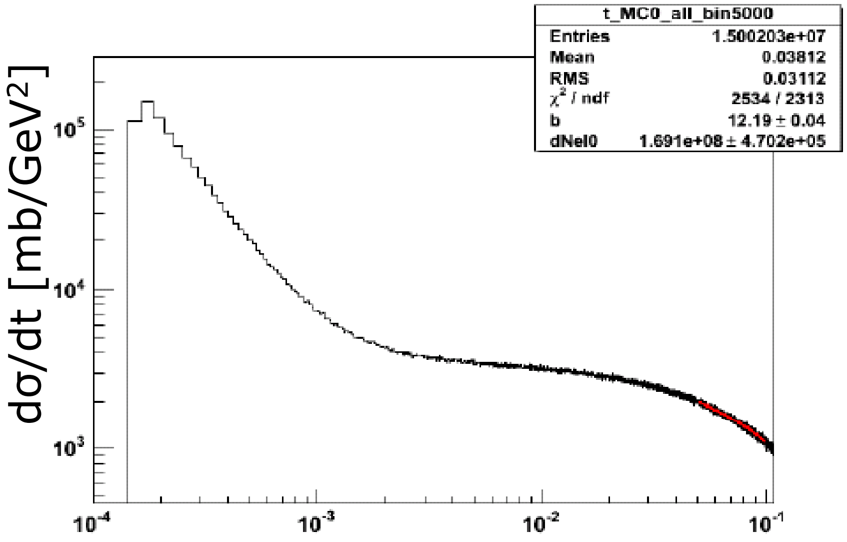
3 mrad:
Limit from the HESR

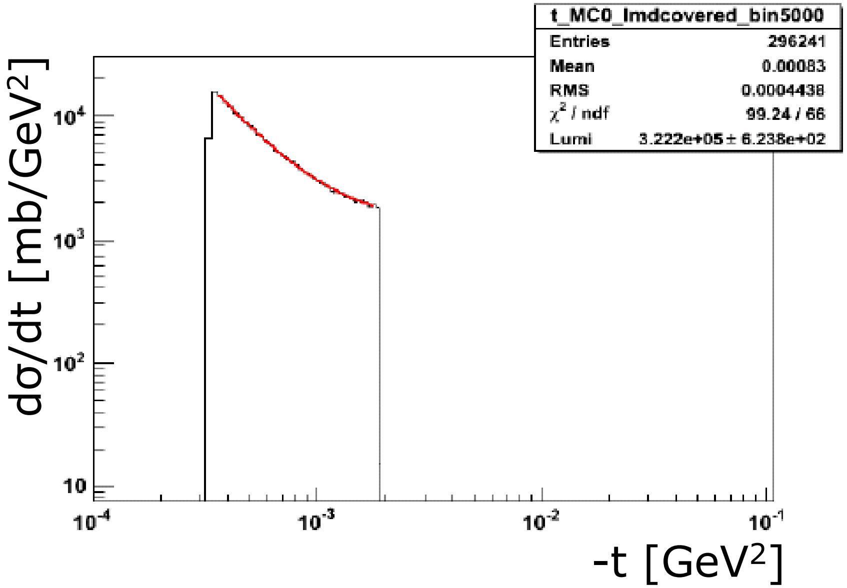
8 mrad:
Certain region of θ needed

→ Smearing effects
- coulomb scattering
- magnets
- beam and target

→ Minimize reactions of elastic antiprotons in the beam pipe

Method





- Measurement of the θ distribution in Luminosity monitor
- Subtract background
- Calculation of the |t| distribution
- Fit of the model to the data

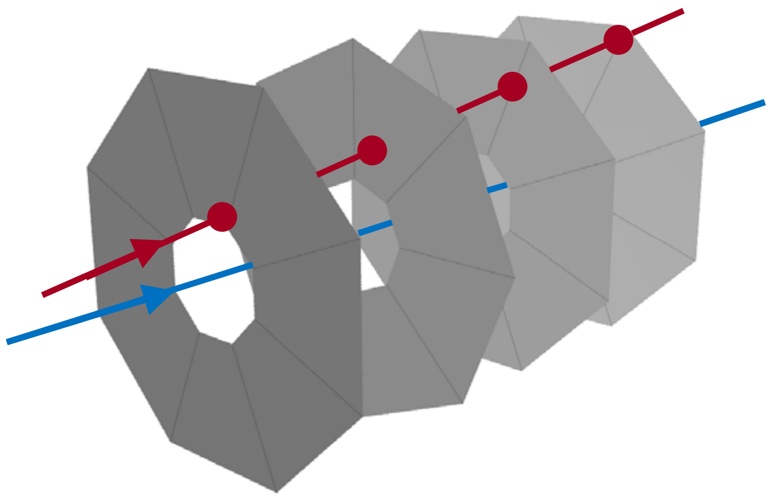
→ Luminosity

Precise measurement of θ distribution necessary !!

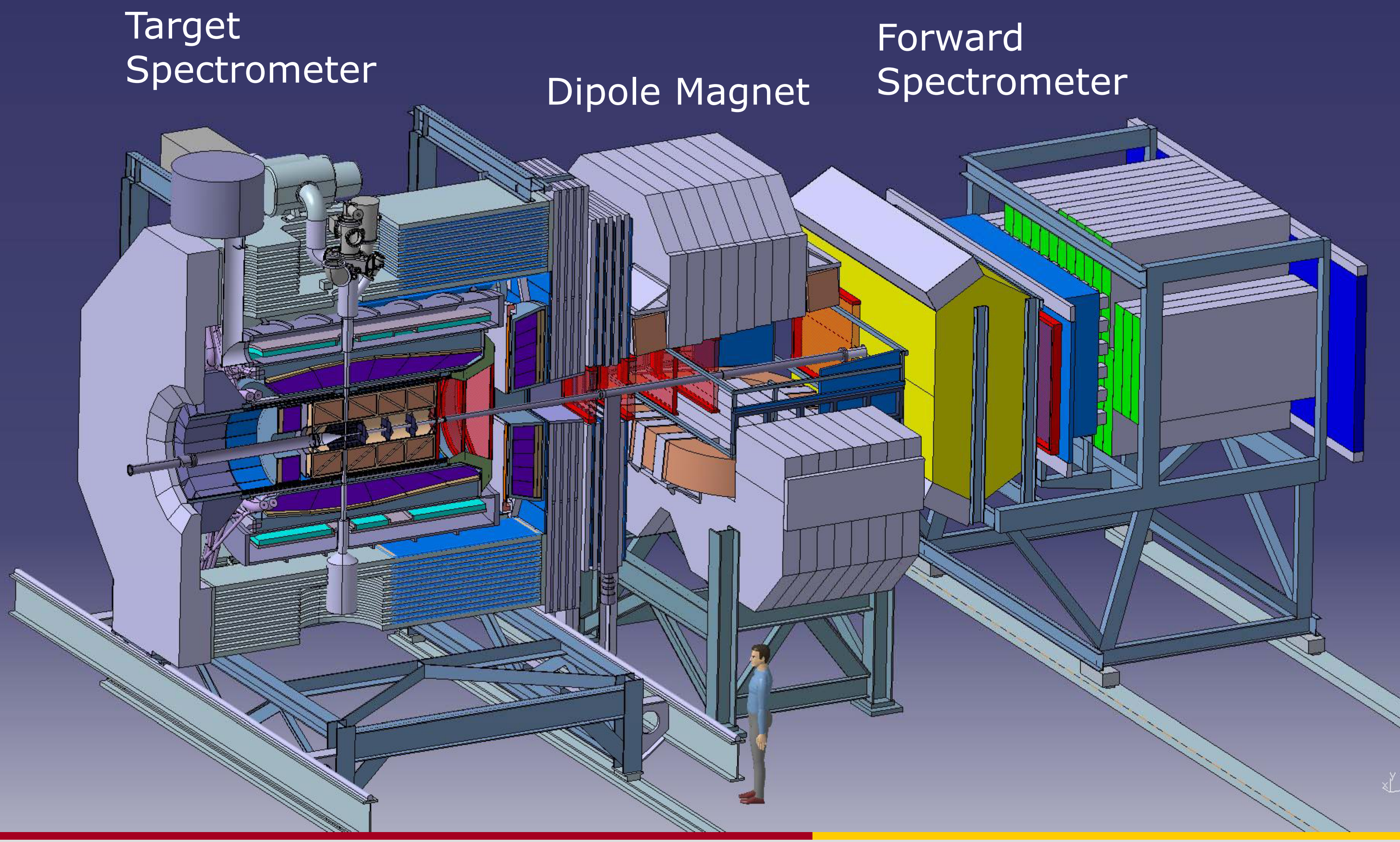
Luminosity measurement at PANDA

Luminosity design (by now)

- 4 planes of 8 silicon trapezoids, 10 cm inbetween
- 45 deg stereo angle
- starting at 11.0 m behind the IP
- 3-8 mrad within the beampipe (vacuum)
- 150/300 µm thick

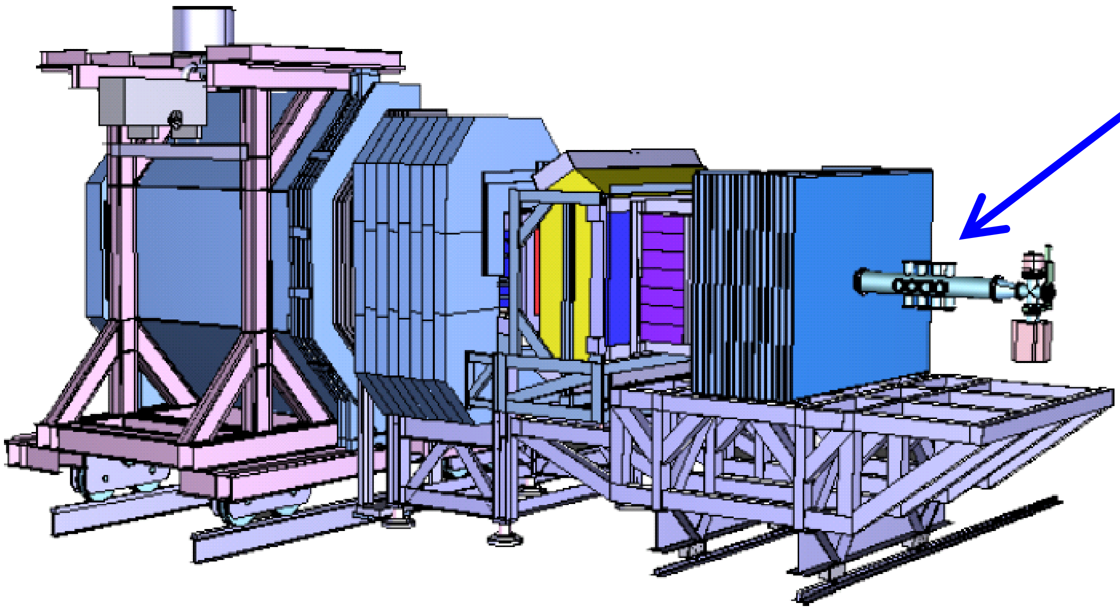


P̄ANDA Detector



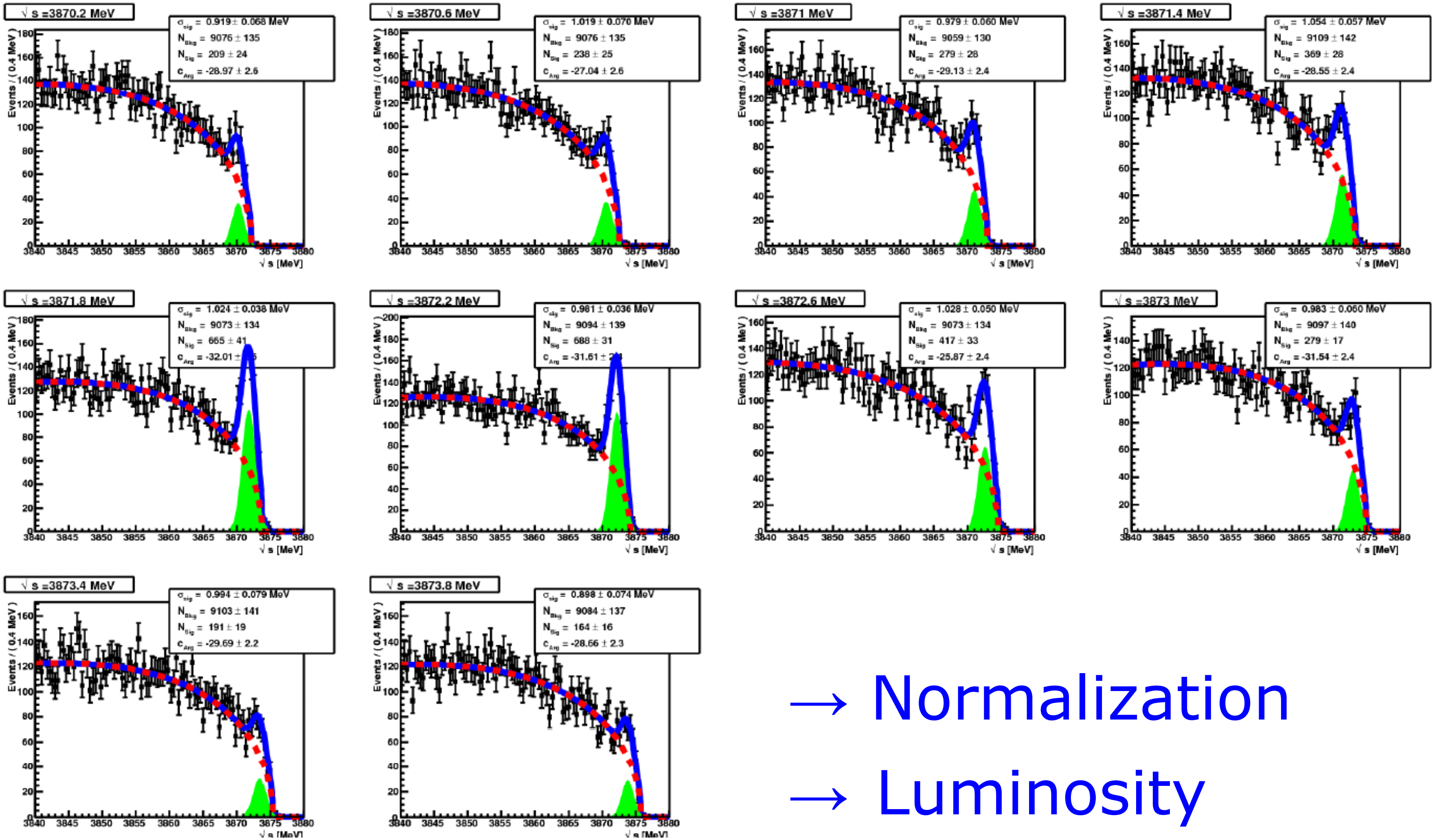
P̄ANDA Detector

Luminosity monitor



Energy scan

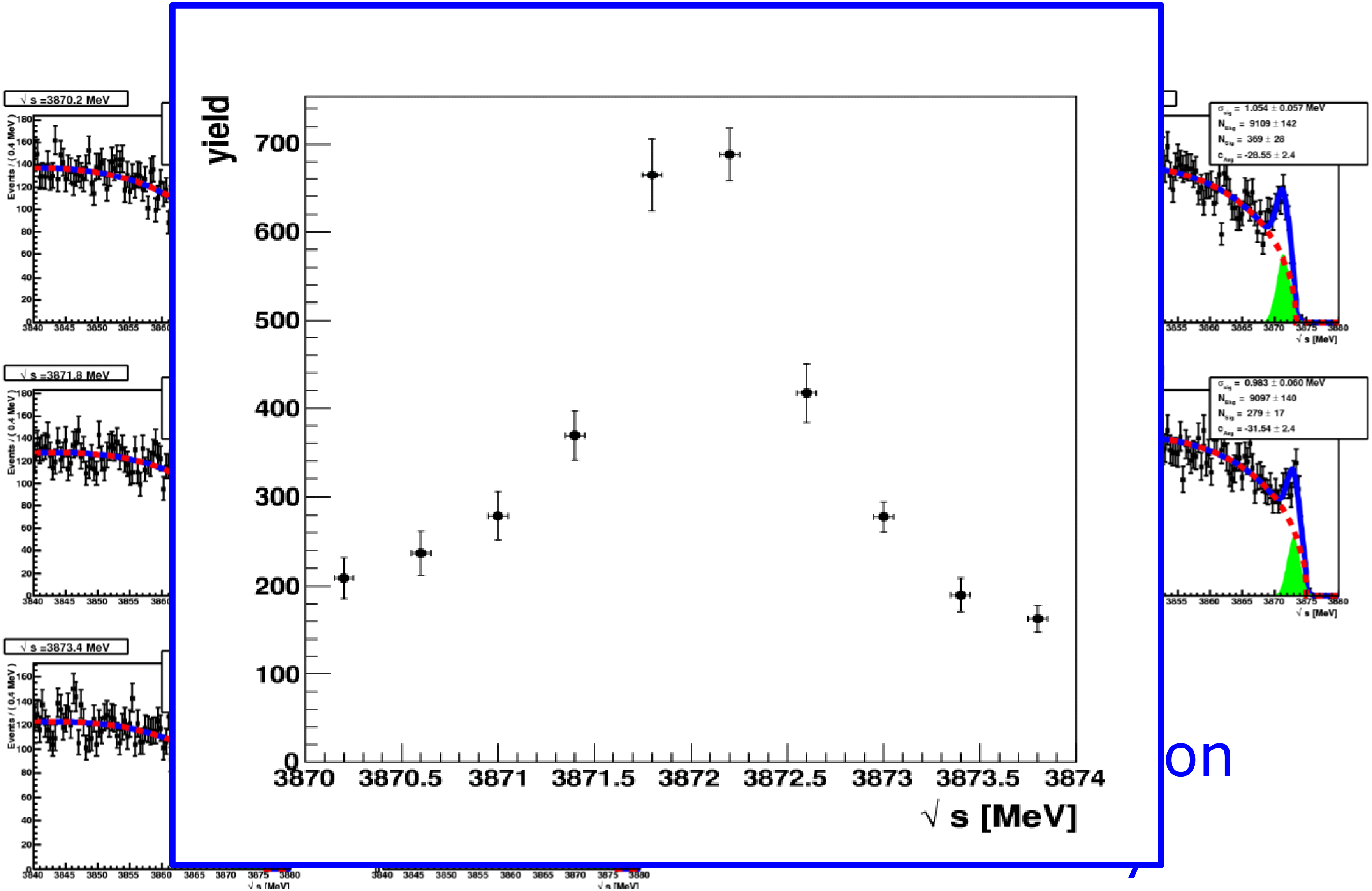
Fit with Gauss + Argus Function



→ Normalization

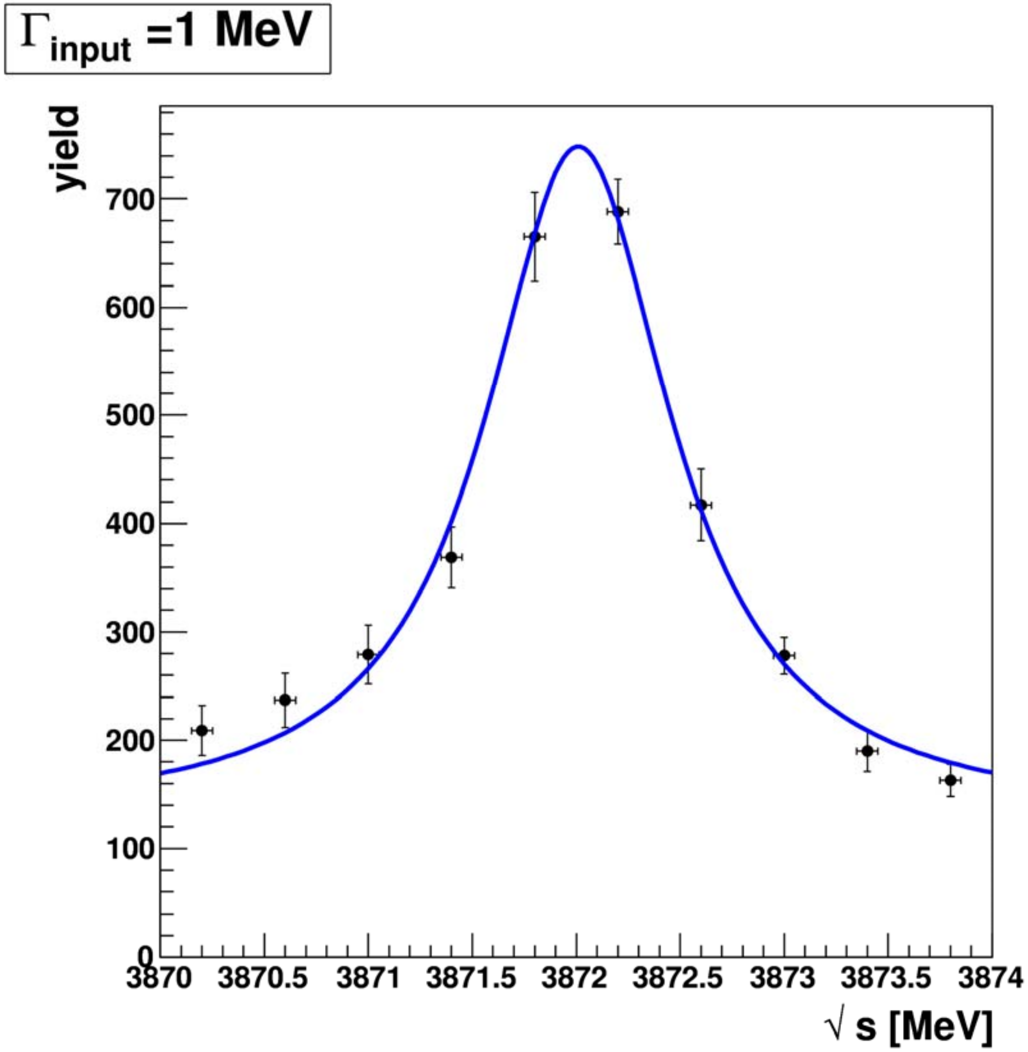
→ Luminosity

Energy scan



yield
√ s [MeV]
700
600
500
400
300
200
100
0
3870
3870.5
3871
3871.5
3872
3872.5
3873
3873.5
3874
√ s =3870.2 MeV
√ s =3871.8 MeV
√ s =3873.4 MeV
Events / (0.4 MeV)
σ_{sig} = 1.054 ± 0.057 MeV
N_{Bkg} = 9109 ± 142
N_{Sig} = 369 ± 28
c_{Arg} = -28.55 ± 2.4
σ_{sig} = 0.983 ± 0.060 MeV
N_{Bkg} = 9097 ± 140
N_{Sig} = 279 ± 17
c_{Arg} = -31.54 ± 2.4
on

Fit results



m = 3872.01 ± 0.03 MeV/c^2

Γ = 1.11 ± 0.08 MeV/c^2

→ Unfolding beam profile

($\Delta p/p = 3 \cdot 10^{-5}$)

Mass resolution ~ 50 keV/c^2

Width precision ~ 10%

Old Energy Scan results for J/ψ and ψ(2S)

E760/E835 at Fermilab

$\Gamma(J/\psi) = 99 \pm 12 \pm 6$ keV/c²
$\Gamma(\psi(2S)) = 306 \pm 36 \pm 16$ keV/c²
(B-factories: > 2.3 MeV/c²)

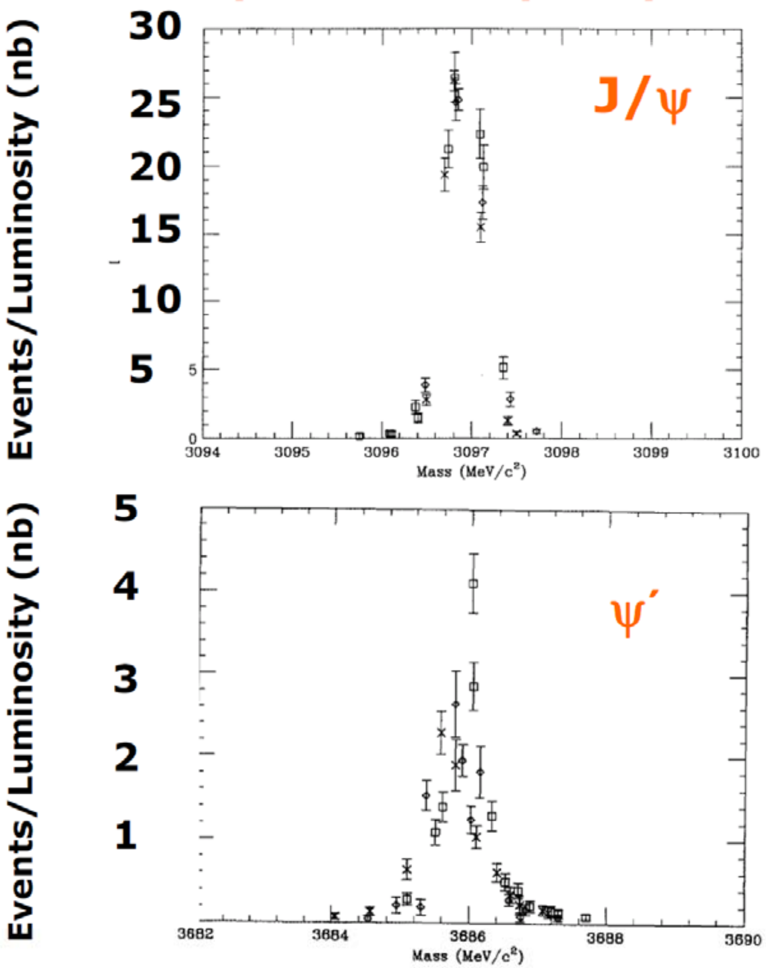
Beam momentum resolution
$\Delta p/p = 2 \cdot 10^{-4}$

$\rightarrow \sqrt{s}$ FWHM resolution ≃ 0.5 MeV

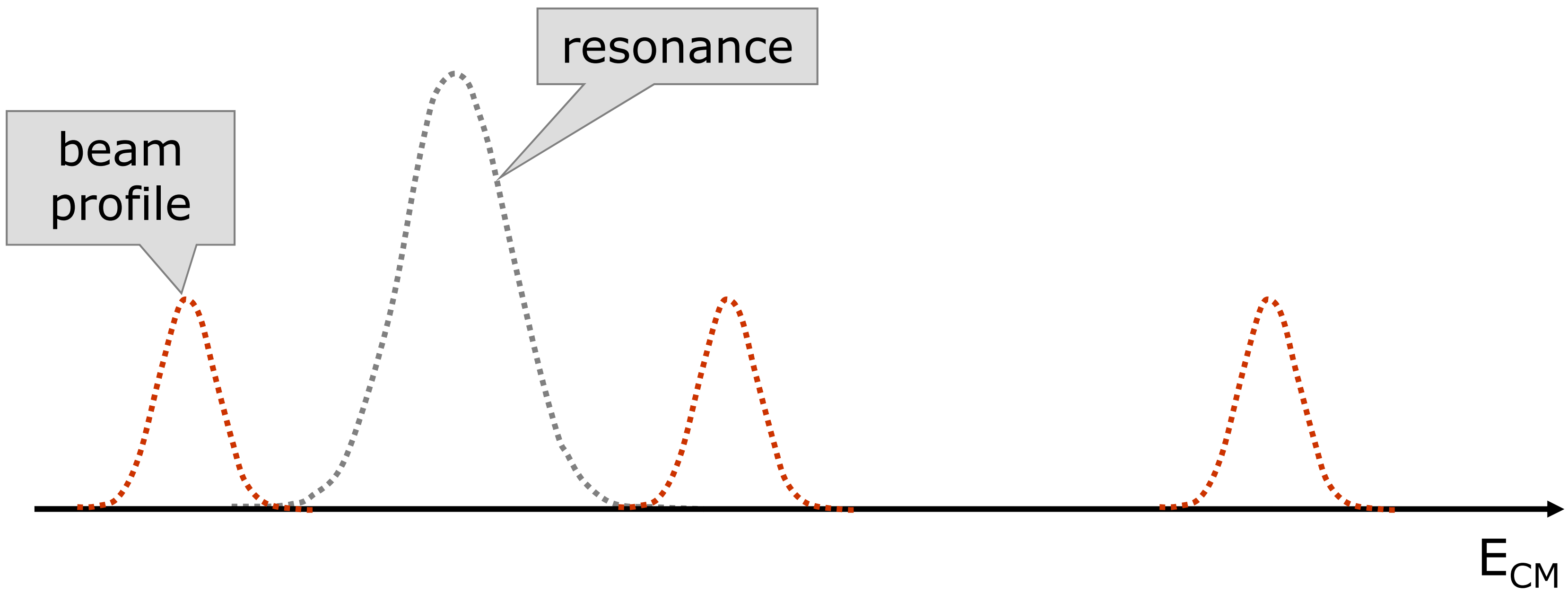
$\sigma \times$ BR (J/ψ) ≃ 630 nb

PANDA

Luminosity (x 10)
Momentum resolution (x 1/10)
Angular coverage and magnetic field



Beamtime Planning for narrow resonances



Resonance with unknown width (Γ = 100 keV/c^2)

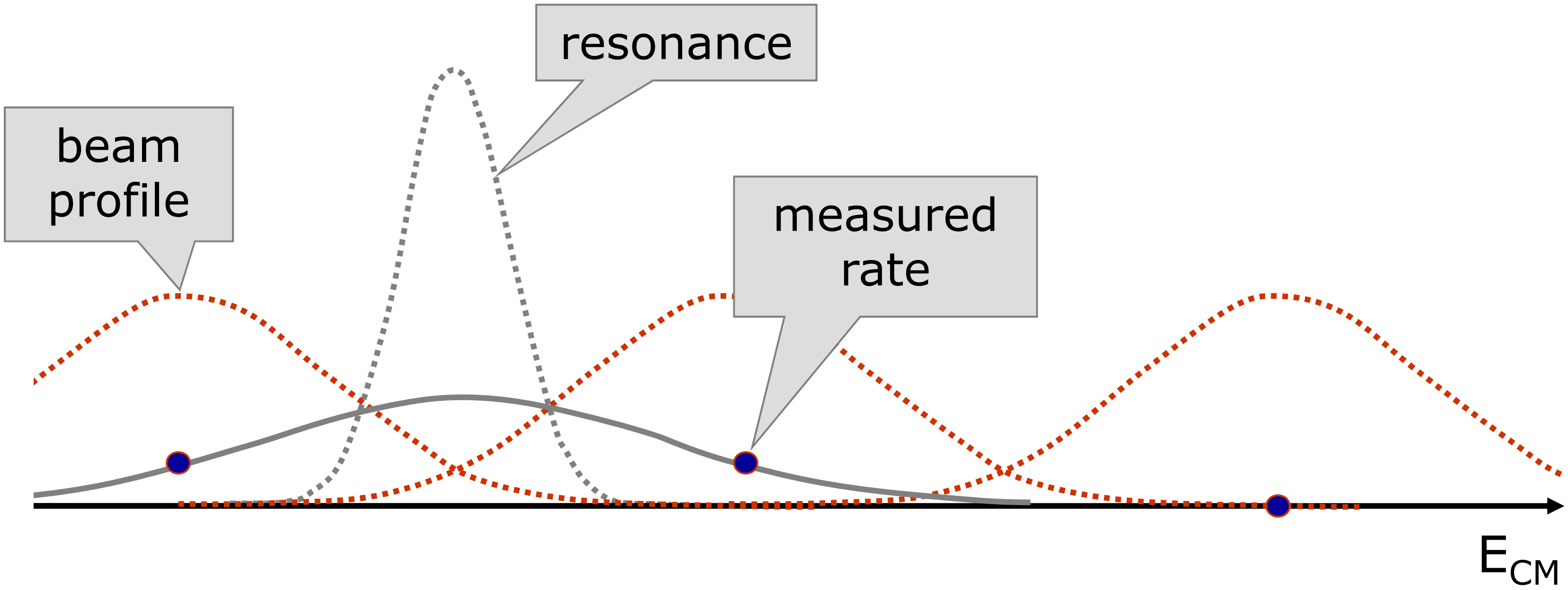
If we use:

Step size 400 keV/c^2

Beam width 50 keV/c^2

→ Big chance to miss the resonance !

Beamtime Planning for narrow resonances



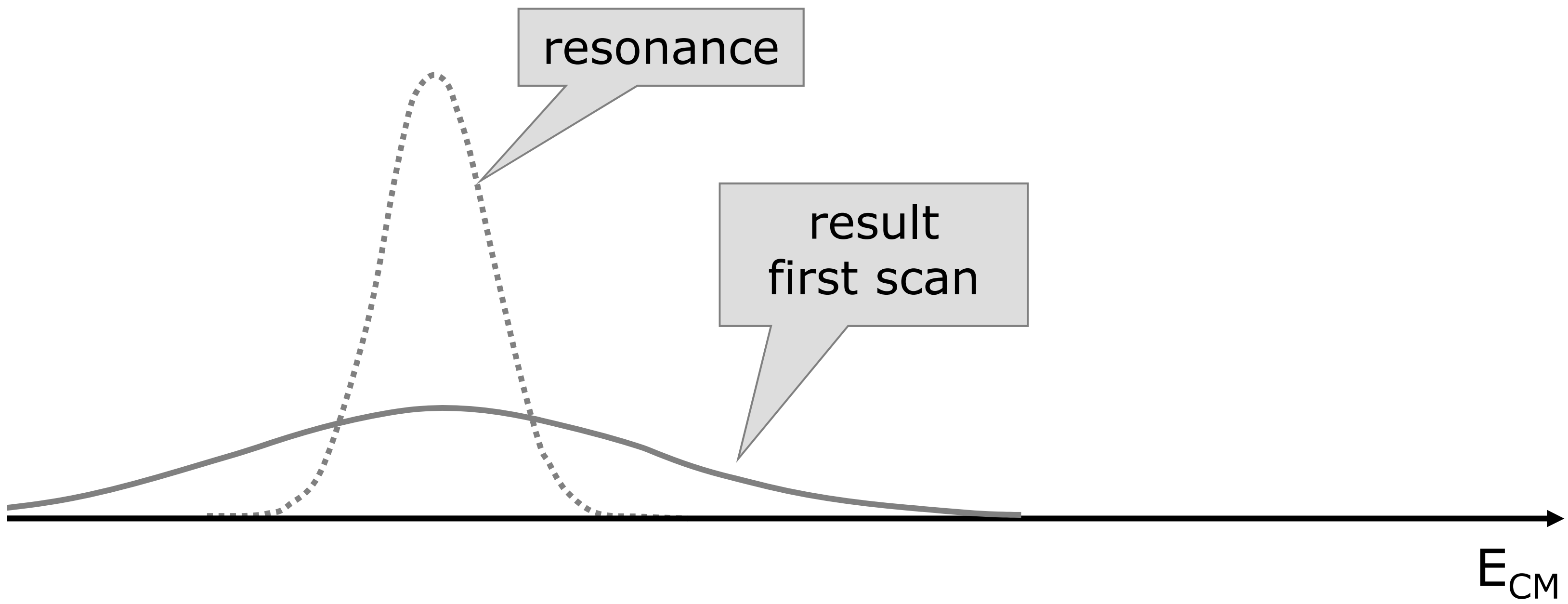
Resonance with unknown width (Γ = 100 keV/c^2)

Start with detuned beam (e.g. width 250 keV/c^2)

Overlapping beam profiles necessary (~ 4 steps)

→ Rough estimate of the mass

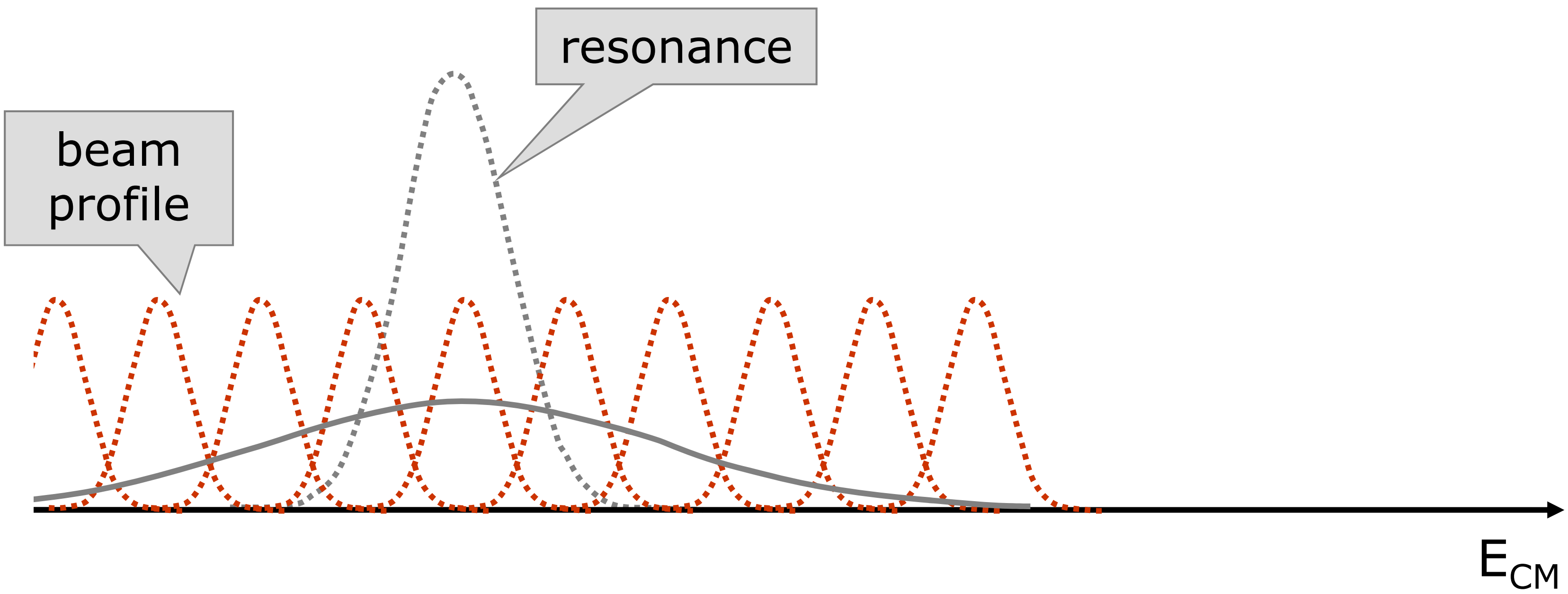
Beamtime Planning for narrow resonances



Resonance with unknown width (Γ = 100 keV/c^2)

Design of final scan

Beamtime Planning for narrow resonances

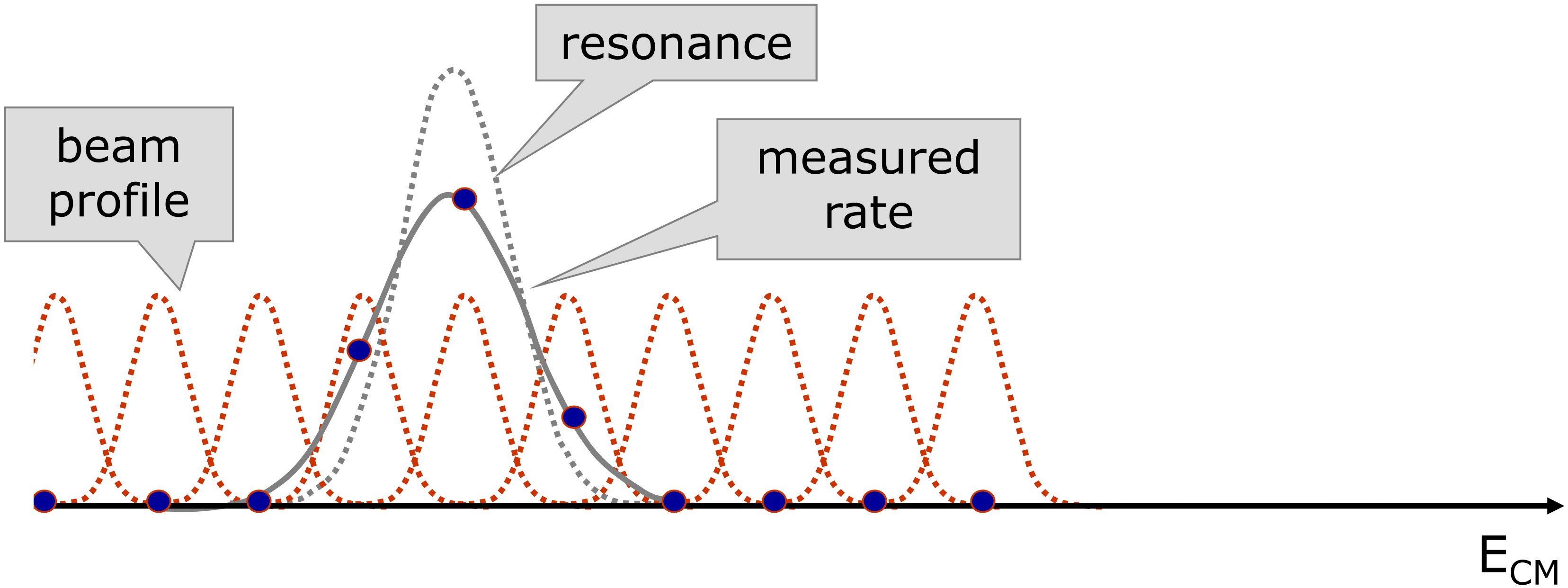


Resonance with unknown width (Γ = 100 keV/c^2)

Design of final scan

Overlapping beam profiles (10 steps, step size 150 keV/c^2)

Beamtime Planning for narrow resonances



Resonance with unknown width (Γ = 100 keV/c^2)

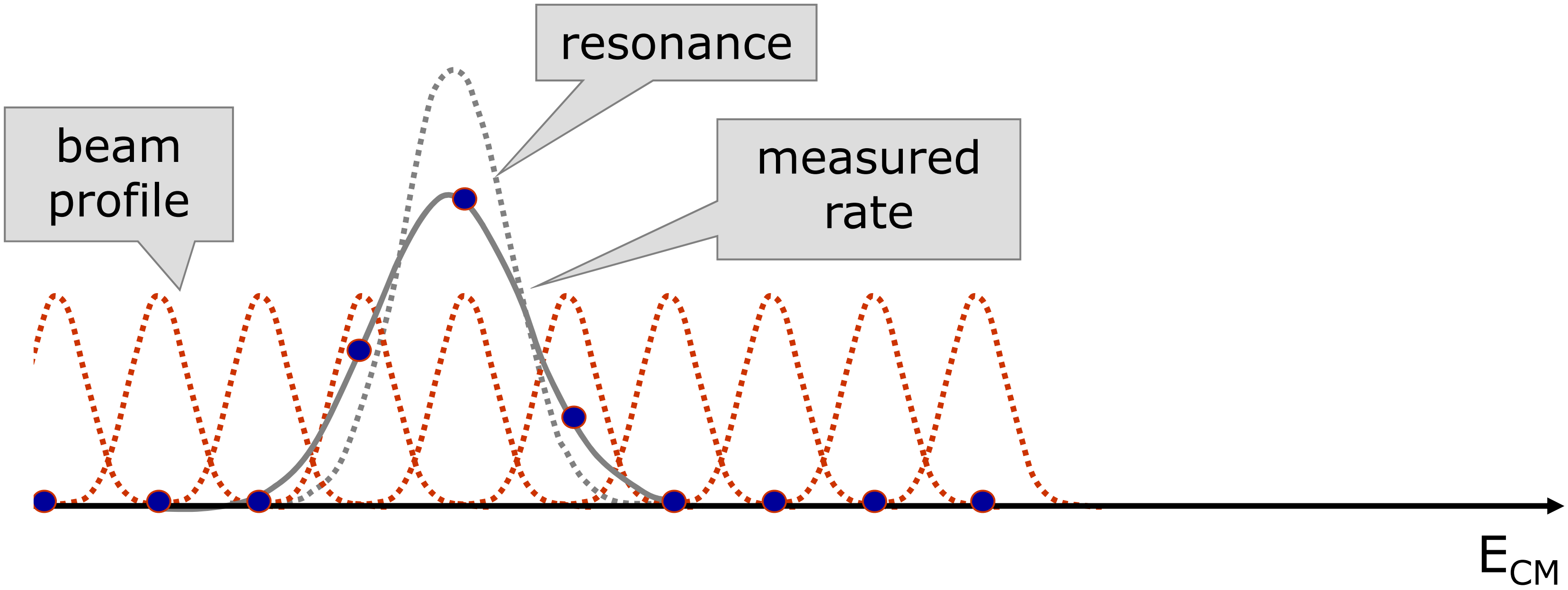
Design of final scan

Overlapping beam profiles (step size 150 keV/c^2)

Extract measured rate, unfold of the beam profile

→ Line shape of the narrow resonance

Beamtime Planning for narrow resonances



For every single resonance

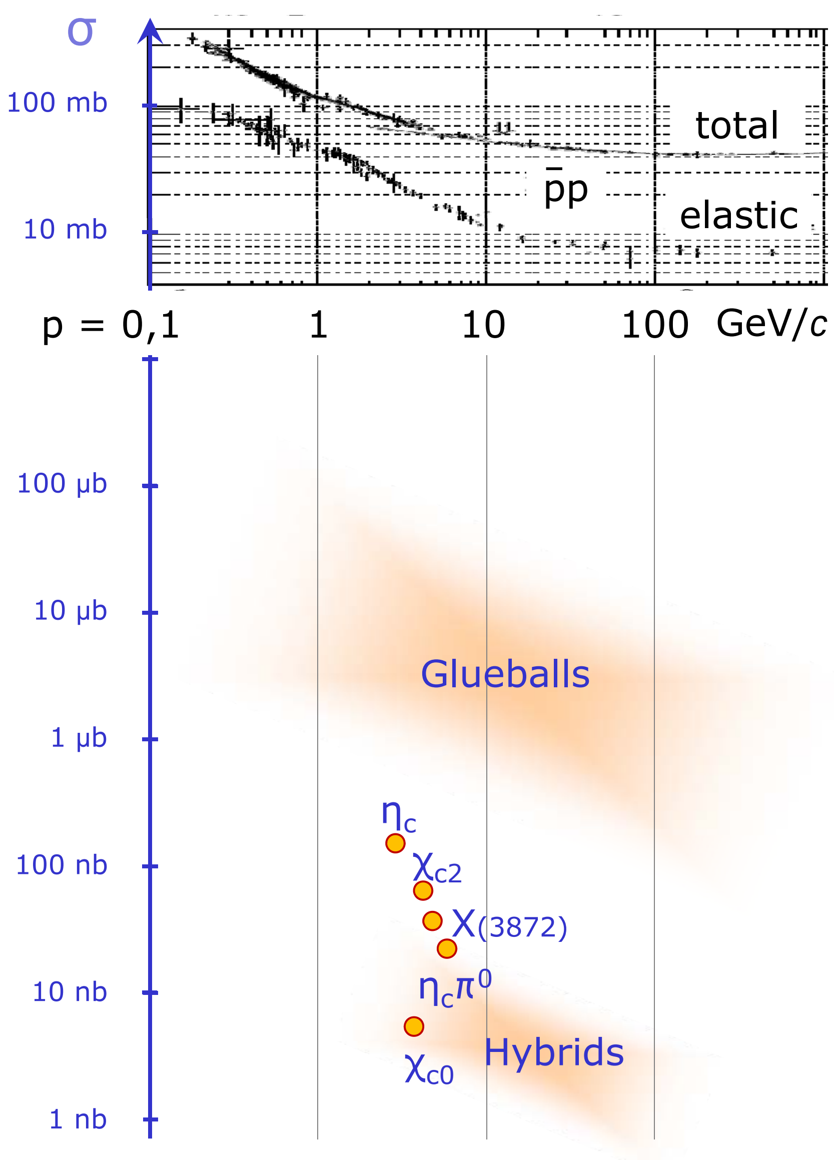
Optimization of the scan, especially by simultaneous measurements

Number of scans with different beam profiles

Number of steps and step size

Variation of step size close to thresholds

X(3872) in $\bar{p}p$ measurements



Example X(3872)

peak ~ 50 nb (E. Braaten)

$\rightarrow J/\psi\pi\pi$ 250 pb (ee and μμ)

$\rightarrow D\bar{D}\pi$ 500 pb (mult. channels)

includes eff. and BR

$L = 2\cdot10^{31}\ cm^{-2}\ s^{-1}$

peak ~ 400 ev. $J/\psi\pi\pi$
~ 800 ev. $D\bar{D}\pi$ — 2 days

20 points → 40 days

Conclusion and next steps

Energy scans at PANDA

→ Extraction of the line shape

→ Luminosity measurement

Trigger simulation

→ Event overlap

→ Temporal structure

→ Combinatorial background