Charmonium Physics with PANDA at FAIR

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Contents

- Overview of PANDA Physics program
- Charmonium Physics Issues with PANDA
- FAIR Accelerator Facility
- PANDA Detector
- Summary

Hadron Structure with

Precision Measurements of Charmonium (this talk)

Search for Exotic Hadrons

- Glueballs
- Charm-Hybrids

Production of Hadron-Antihadron pairs

- Production mechanisms
- D-Meson spectroscopy (later extend to CP studies)
- Tool to perform Spectroscopy of (double) Hypernuclei

Properties of Charmed-Hadrons in Nuclear Matter

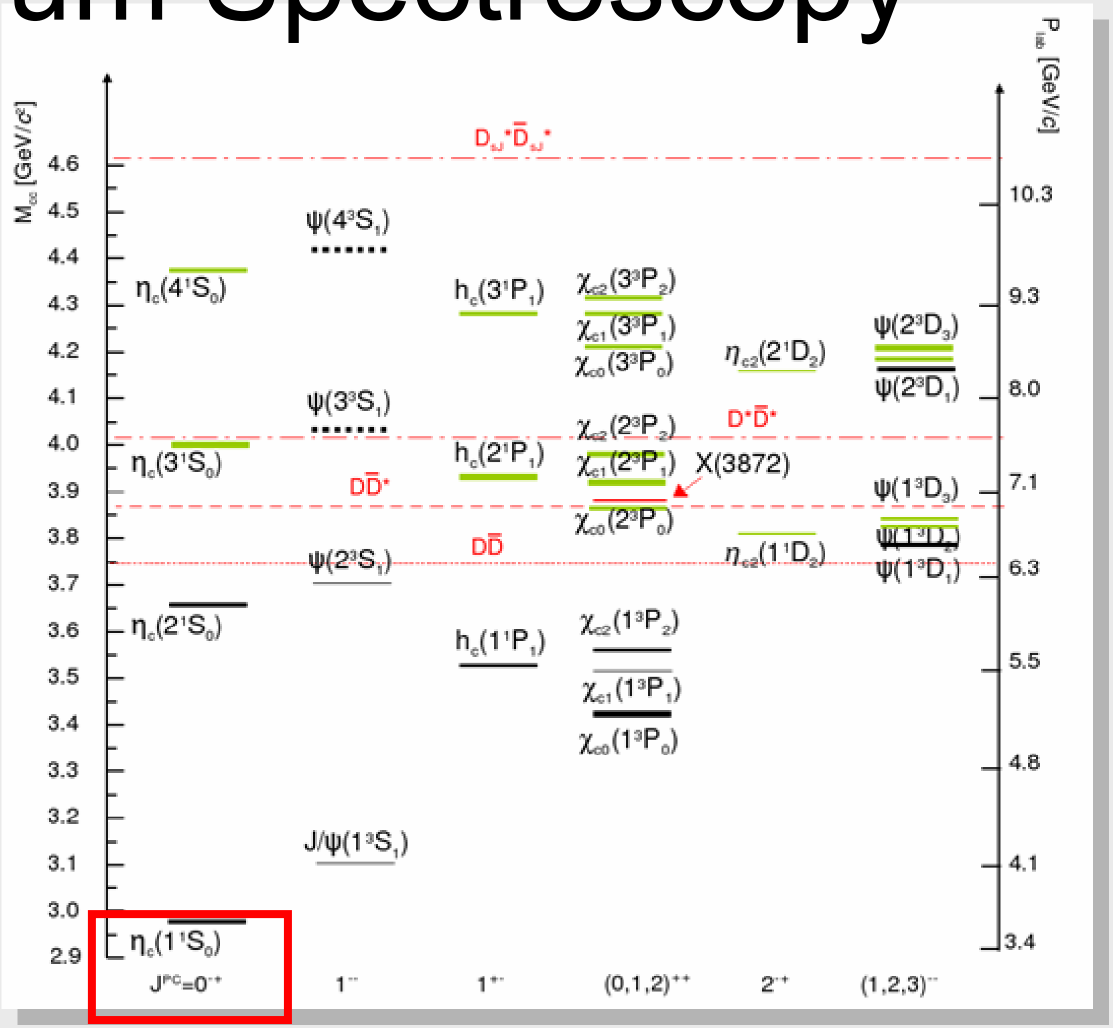
- Production of (open)Charm in Pbar-A Reactions

Electromagnetic Final States in Pbar-P Annihilation

- Drell-Yann
- Wide Angle Compton Scattering
- Polarization degrees of freedom… (⇒PAX)

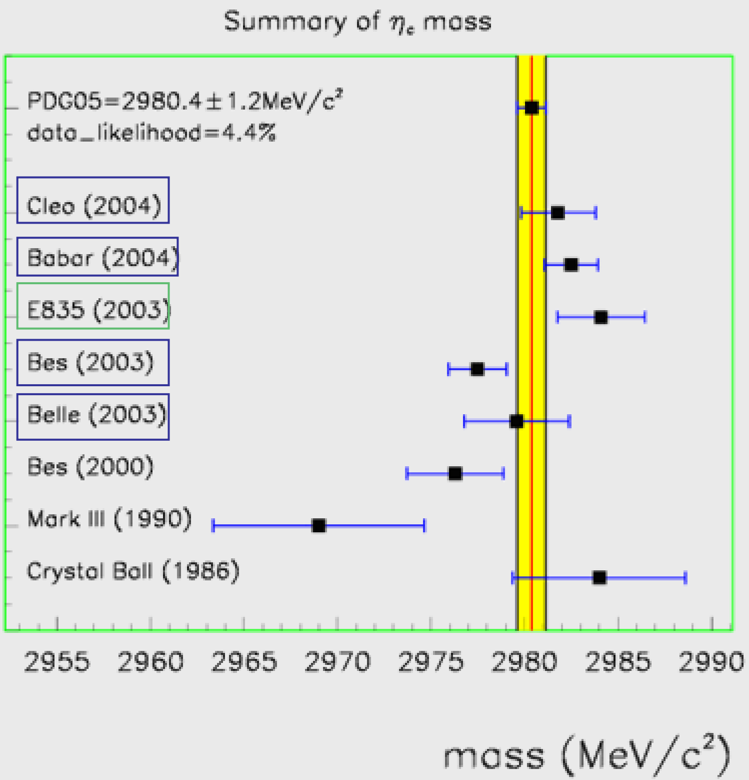
Charmonium Spectroscopy

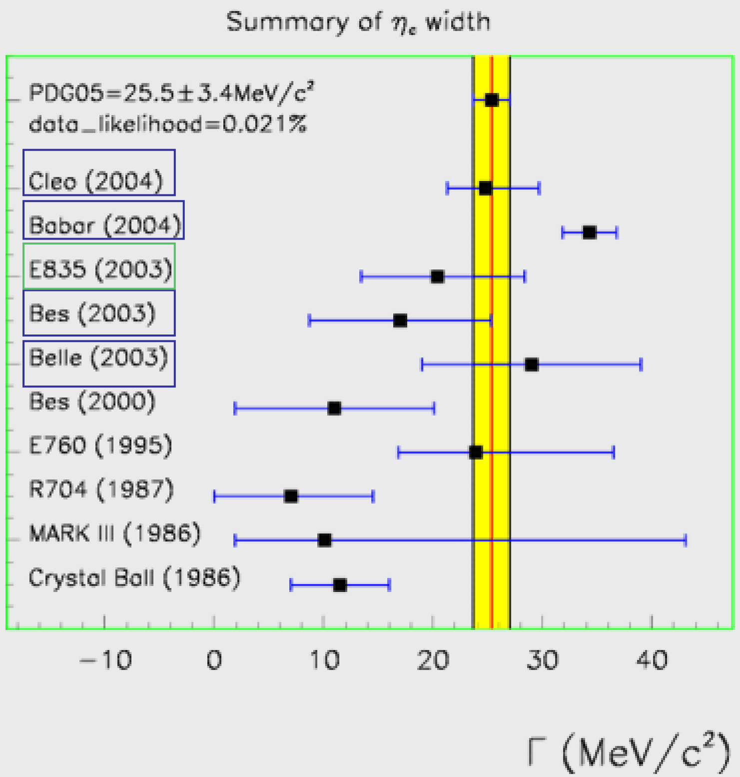
- 5 new measurement of η_c mass, but …



Charmonium Spectroscopy

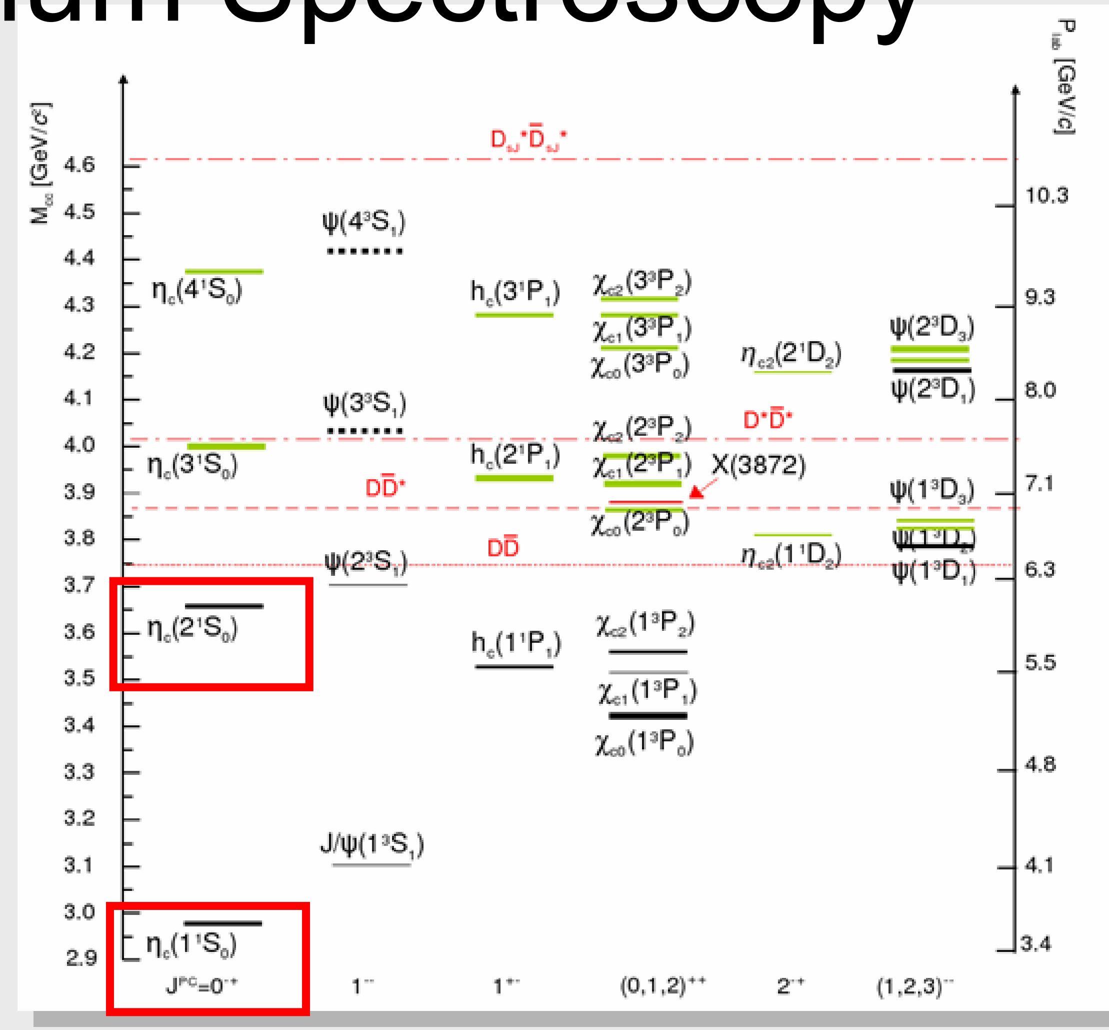
Five new measurements published 2002-2003, four by e+e- experiments



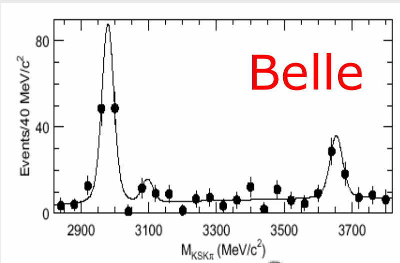


Charmonium Spectroscopy

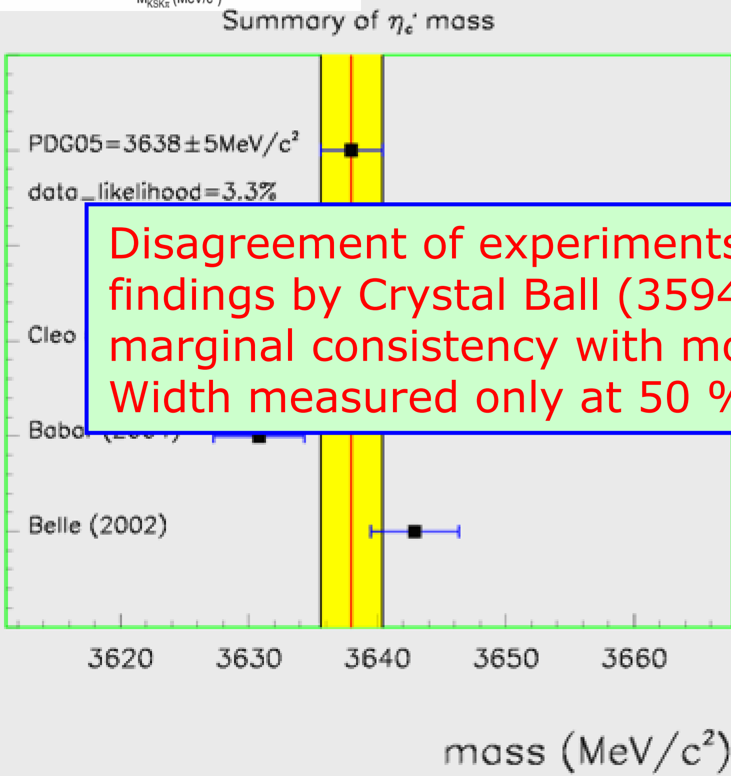
- Inconsistency in η_c mass and width
- η'_c unambiguously seen, although …

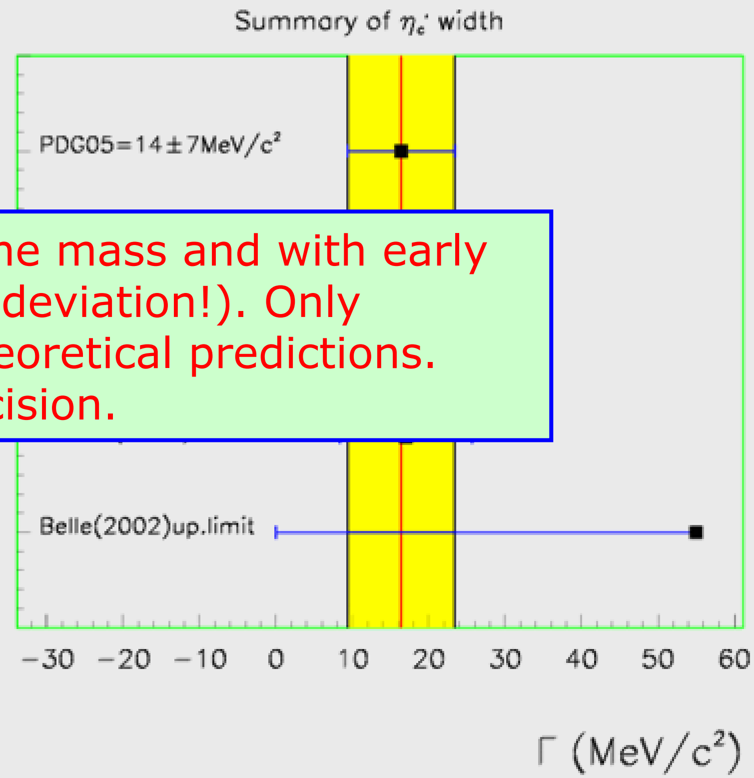


Charmonium Spectroscopy



Discovery of η'_c by Belle in $B \rightarrow \pi\eta_c'(\rightarrow KK\pi)$
confirmed by BaBar, Cleo

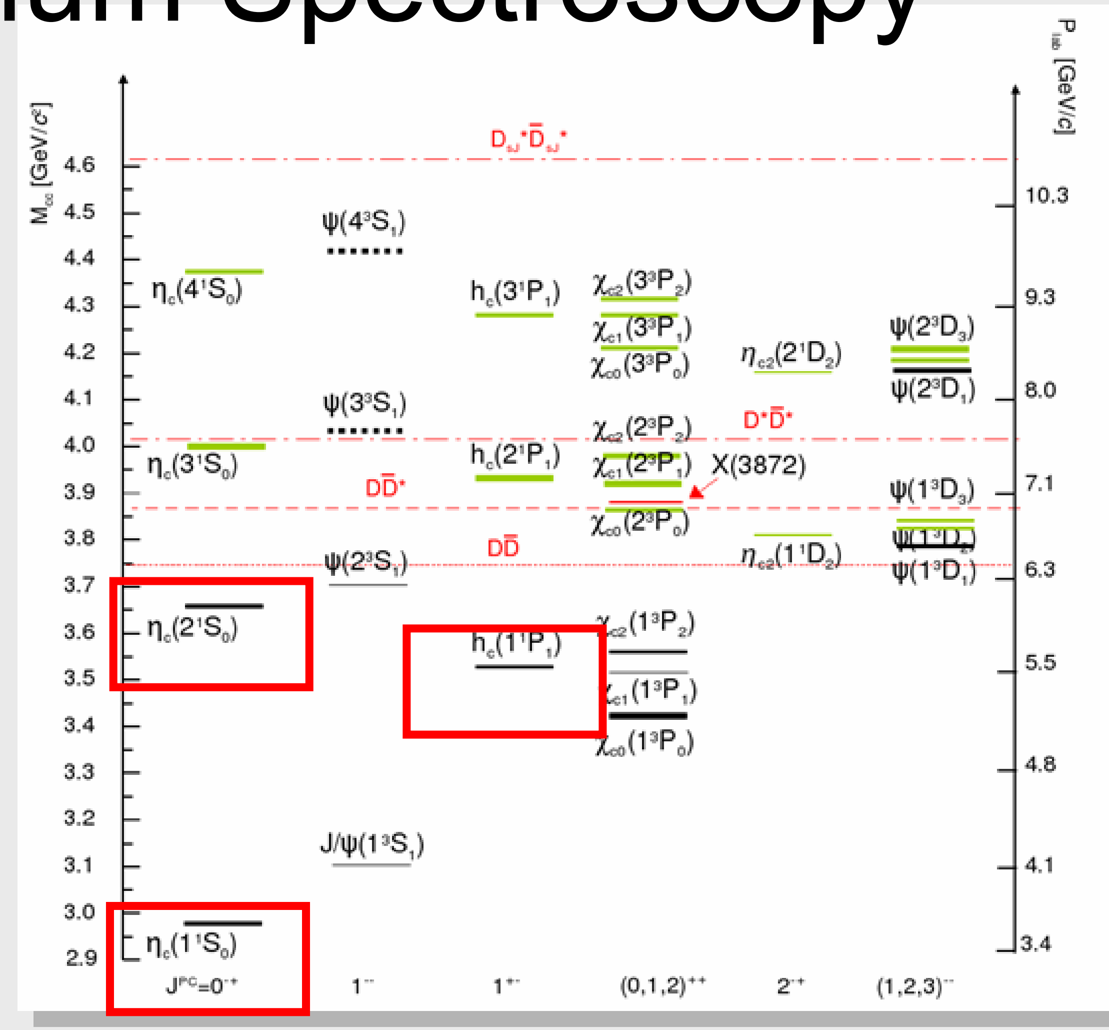




Disagreement of experiments on the mass and with early findings by Crystal Ball (3594 - 8σ deviation!). Only marginal consistency with most theoretical predictions. Width measured only at 50 % precision.

Charmonium Spectroscopy

- Inconsistency in η_c mass and width
- η_c' unambiguously seen, although …
- h_c seen with poor statistics…



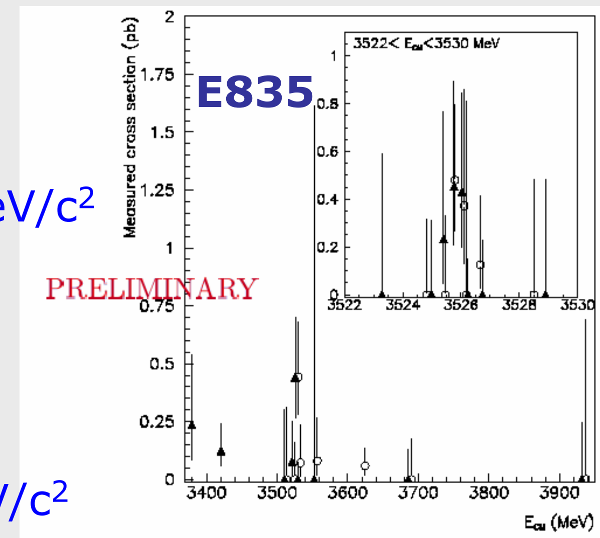
Charmonium Spectroscopy

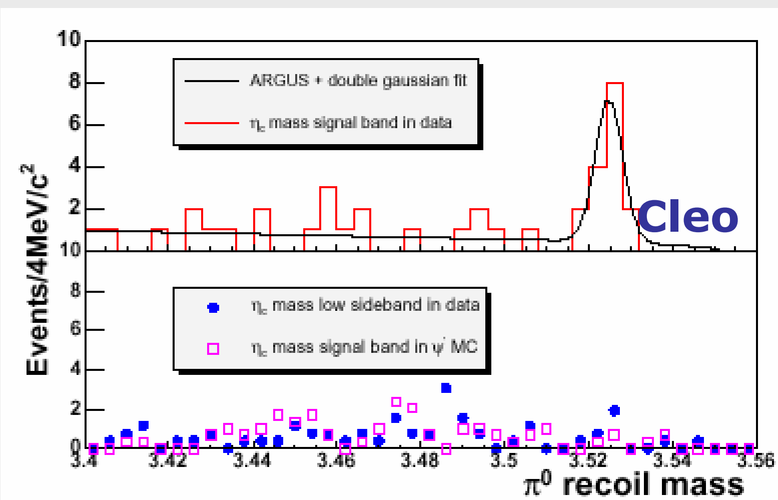
This singlet P resonance is very important in determining the spin dependent components of the the qq confinement potential.
Two recent results, and an early E760 result: Agreement on the mass at the 8.5 % level.

E760: $M=3526.28\pm0.18\pm0.19$ MeV/c^2
In $h_c \rightarrow J/\Psi\pi^0$ (1992)

$\bar{p}p \rightarrow h_c \rightarrow \eta_c\gamma \rightarrow \gamma\gamma\gamma$

$M=3525.8\pm0.2\pm0.2$ MeV/c^2





$M(h_c)=3524.4\pm0.9$MeV/c^2

$e^+e^- \rightarrow \Psi' \rightarrow \pi^0 h_c$

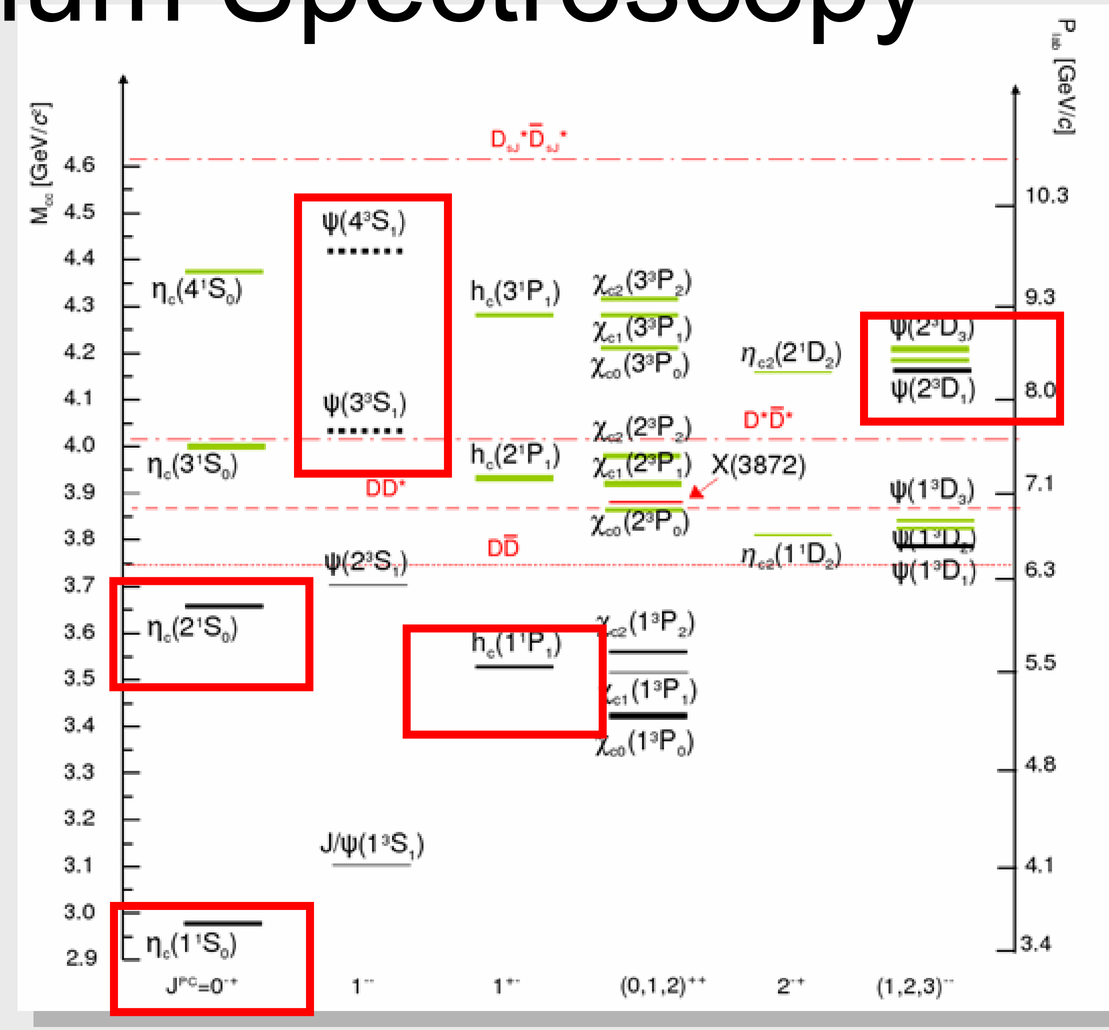
$h_c \rightarrow \eta_c\gamma \rightarrow \gamma\gamma\gamma$

$h_c \rightarrow \eta_c\gamma \quad \eta_c \rightarrow$ *hadrons*

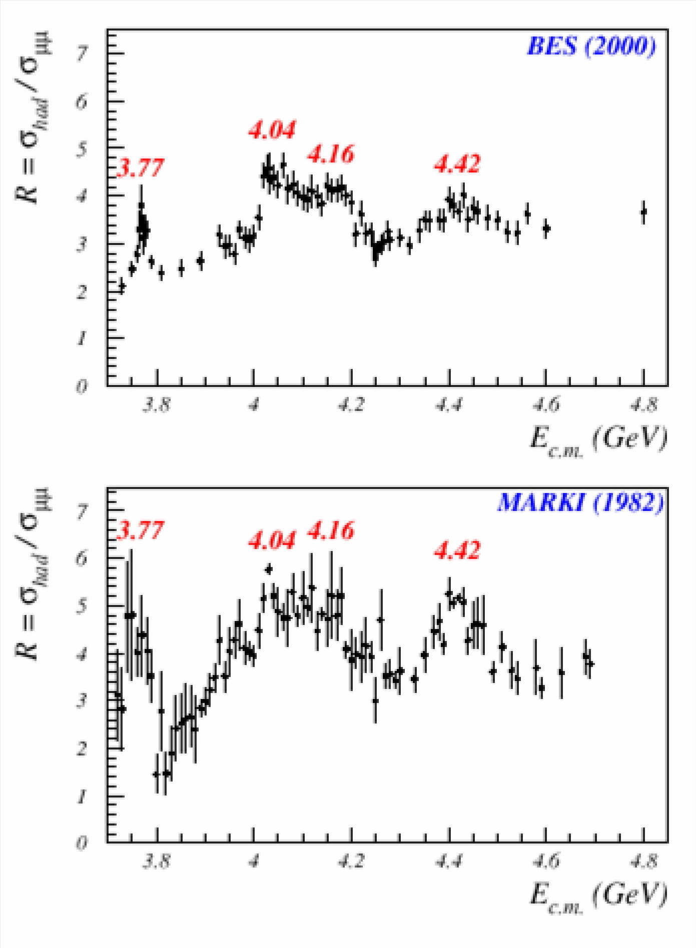
$$M_{cog} = \frac{M(\chi_0)+3M(\chi_1)+5M(\chi_2)}{9}$$

Charmonium Spectroscopy

- Inconsistency in η_c mass and width
- η'_c unambiguously seen, although …
- h_c seen with poor statistics…
- States above DD thr. are not well established



Charmonium Spectroscopy

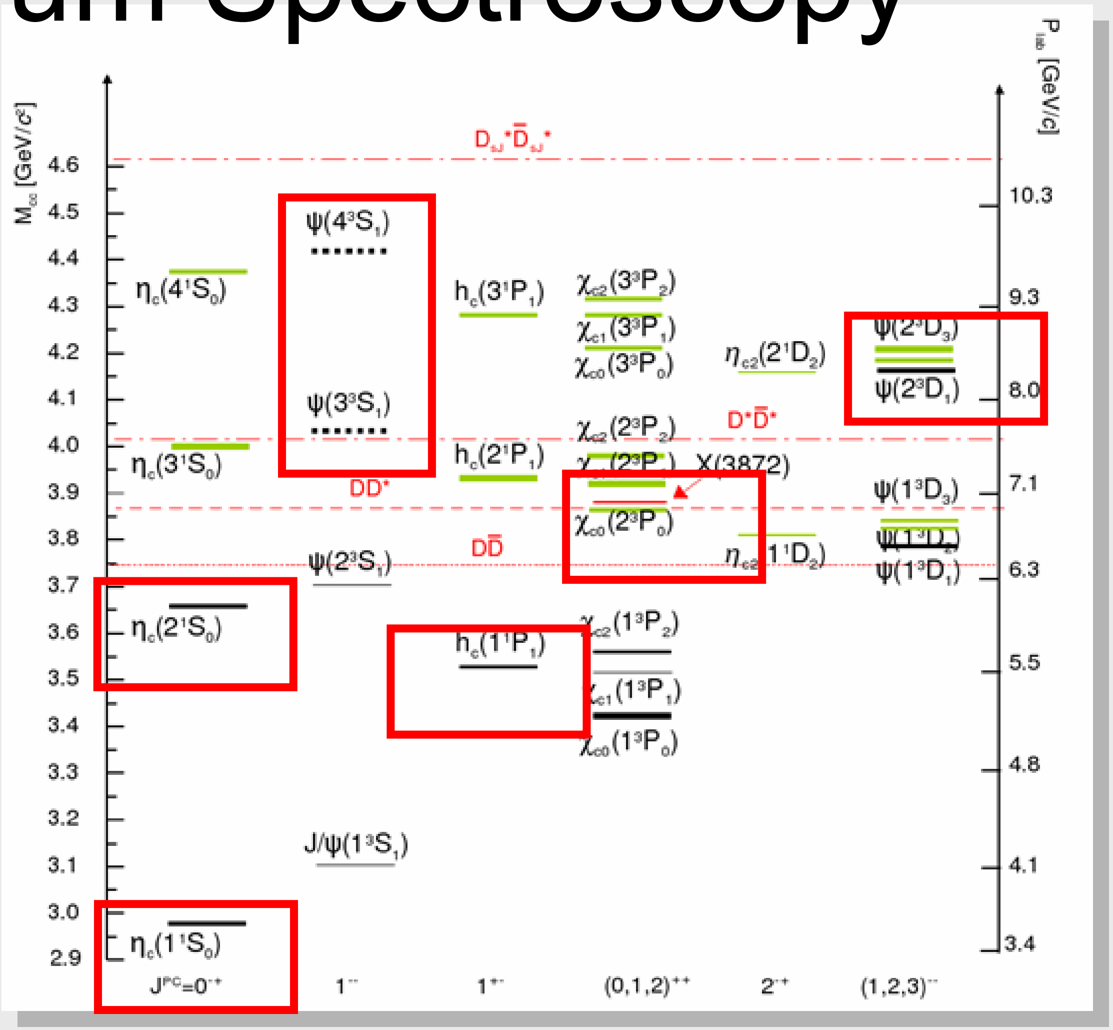


- The energy region above the DD threshold is very poorly known. Yet this region is rich in new physics.
- The structures and the higher vector states (ψ(3S), ψ(4S), ψ(5S) ...) observed by the early e^+e^- experiments have not all been confirmed by the latest, much more accurate measurements by BES.
- This is the region where the first radial excitations of the singlet and triplet P states are expected to exist.
- In this region the narrow D-states are expected!!!

	Mass [MeV/c^2]		Width [MeV/c^2]	
	predicted	measured	predicted	measured
$\psi(1D)$		3770	43	23.6±2.7
$\psi(3S)$		4040	74	52±10
$\psi(2D)$		4159	74	78±20
$\eta_c(3S)$	≈ 4070		67	
$\chi_{c0}(2P)$	≈ 3870		29	
$\psi_3(1D)$	≈ 3800		0.6	
$\chi_{c4}(1F)$	≈ 4100		9.0	
$h_{c3}(1F)$	≈ 4030		64	

Charmonium Spectroscopy

- Inconsistency in η_c mass and width
- η'_c unambiguously seen, although …
- h_c seen with poor statistics…
- States above DD thr. are not well established
- New resonances...



New Charmonium Resonances

- **X(3872),** Belle 09'2003, 1^{++}, χ_{c1}' or D^0D^* molecule
  - decays into $J/\psi\pi^+\pi^-$, $J/\psi\pi^+\pi^-\pi^0$, $J/\psi\gamma$, D^0D^*
- **Y(3940),** Belle 09'2004, JP^+, 2^3P_1??
  - decays into $J/\psi\omega$
- **Y(4260),** BaBar 06'2005, 1^{--}, 2^3D_1 (BaBar) or 4^3S_1 (CLEO) or Hybrid
  - decays into e^+e^-, $J/\psi\pi^+\pi^-$, $J/\psi\pi^0\pi^0$, $J/\psi K^+K^-$
- **X(3943),** Belle 07'2005, 0^{-+}, η_c''
  - decays into D^0D^*
- **Z(3934),** Belle 07'2005, 2^{++}, χ_{c2}'
  - decays into $\gamma\gamma$, DD
- **ψ(4415),** BaBar 06'2006, ?, ??

Production Mechanism

- e^+e^- interactions:
  - Only 1^{--} states are directly formed;
  - ISR;
  - B meson decays;
  - two photon fusion;
  - higher order process;

} low cross-section, mass resolution determined by detector performance (ISR; B meson decays; two photon fusion)

very low cross section (higher order process)

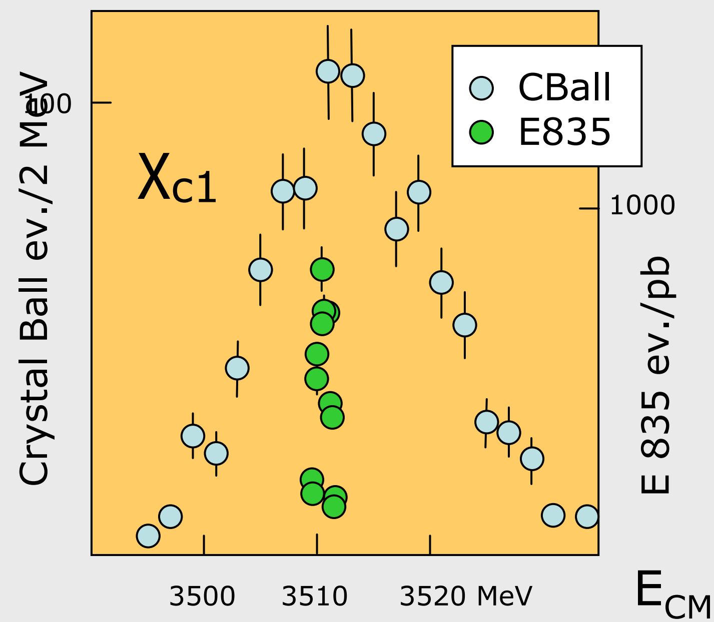
- $\bar{p}p$ reactions:
  - All meson states directly formed (very good mass resolution)
  - other states (spin exotic) can be studied using production mechanism.

Experimental Technique

$$e^+e^- \to \psi' \to \gamma\,\chi_{1,2} \to \gamma\gamma\ J/\psi \to \gamma\gamma\, e^+e^-$$

$$p\bar{p} \to \chi_{1,2} \to \gamma\ J/\psi \to \gamma\, e^+e^-$$

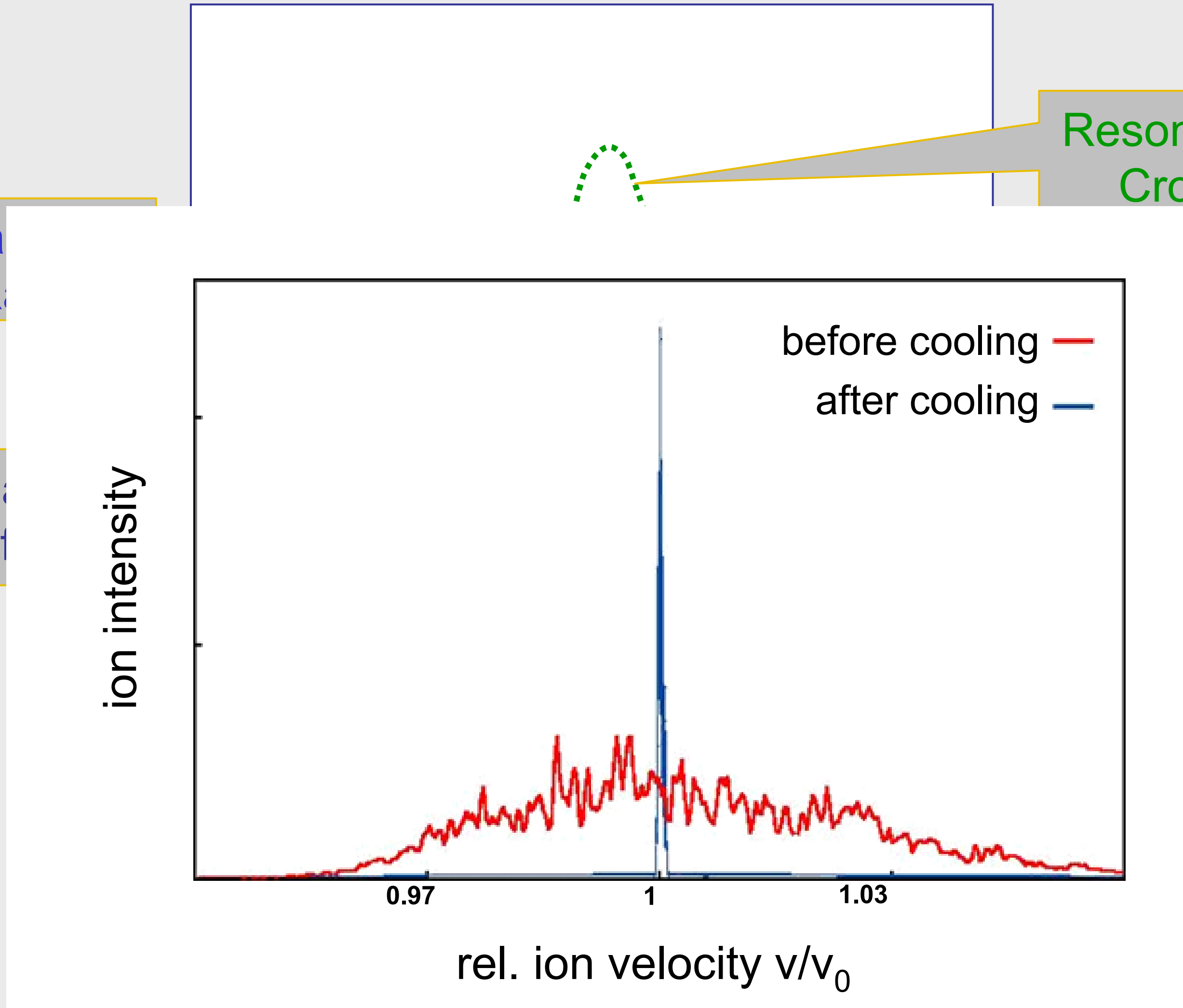
- e^+e^- interactions:
  - $\Gamma > 3.8$ MeV;
- $\bar{p}p$ reactions:
  - $\Gamma = 0.91 \pm 0.13$ MeV.



Resonance Scan

Mea
Ra

Be
Prof



Resonance
Cross
ion

well controlled
mentum spread
/p
ely important

Threshold Measurement

$p\,p \rightarrow \bar{X}\,X$:

$$\sigma(\lambda) = \sqrt{m_R\Gamma}|M|^2\frac{1}{\pi}\int_{-\infty}^{\lambda} dx \frac{\sqrt{\lambda - x}}{(x^2+1)}$$

$$\lambda = (\sqrt{s} - 2m_R)/\Gamma$$

at threshold:

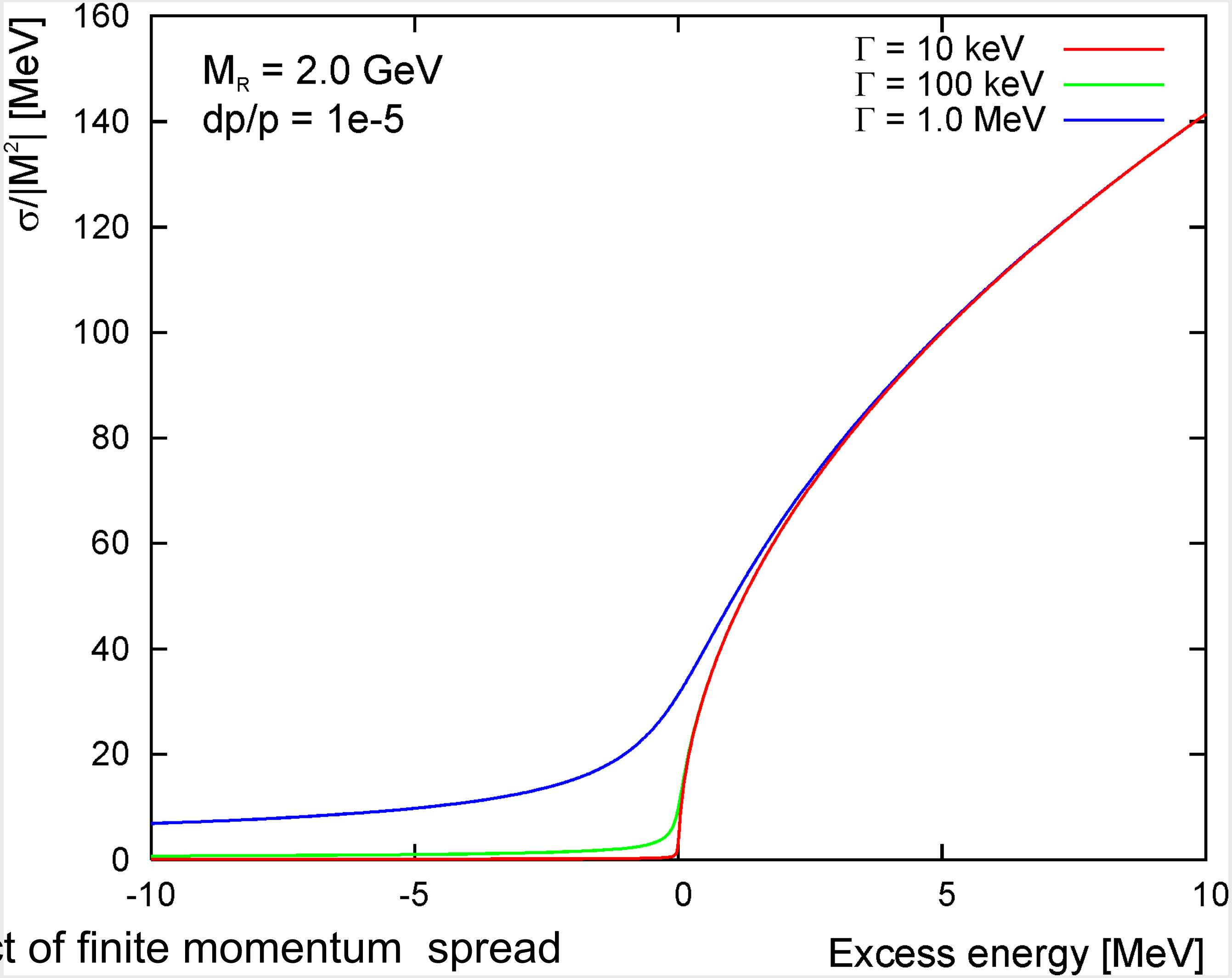
$$\sigma(0) = \sqrt{\frac{m_R\Gamma}{2}}|M|^2$$

far above threshold:

$$\lim_{\lambda\to\infty} \sigma(\lambda) = p|M|^2$$

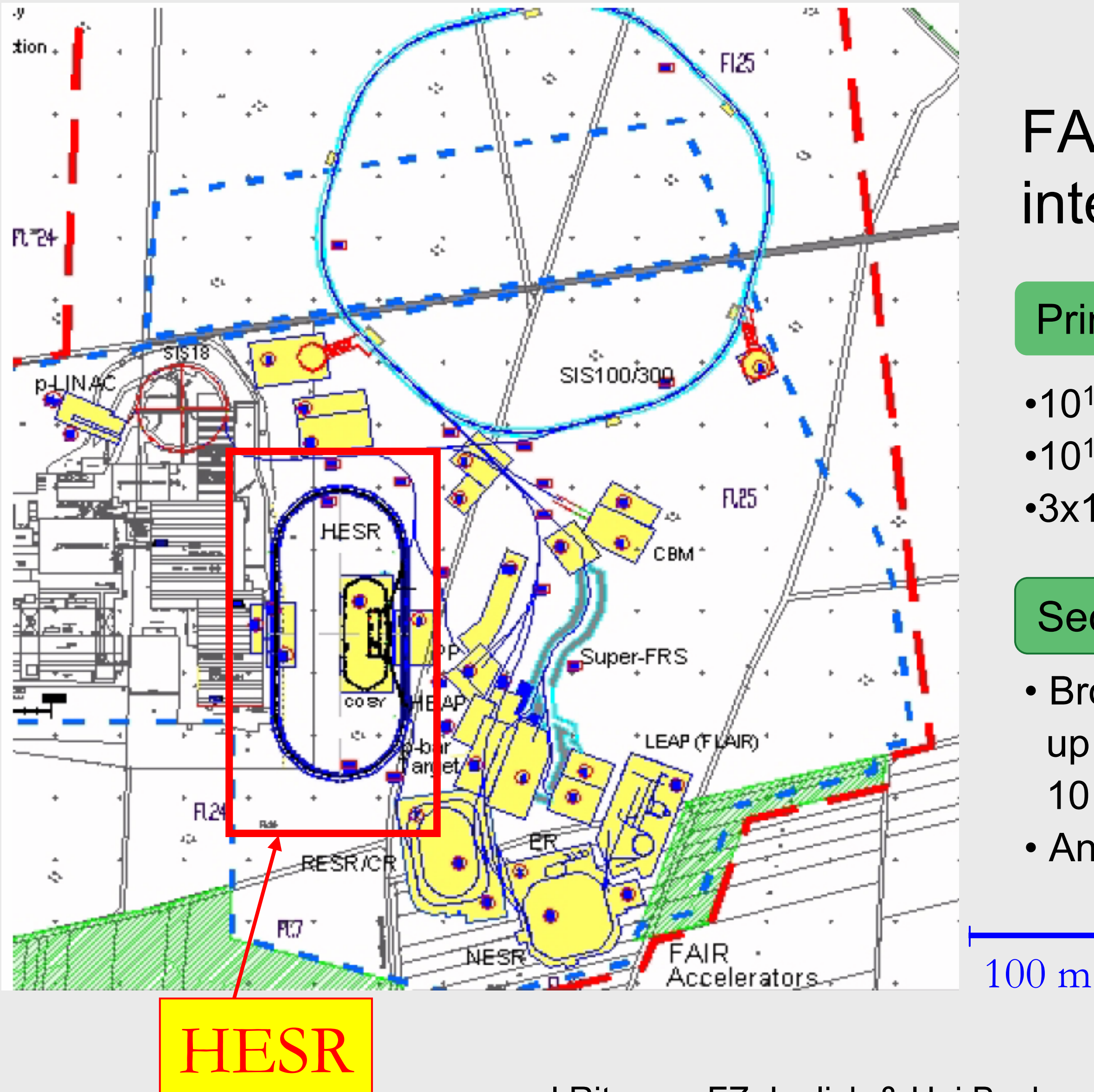
$\Rightarrow$ ratio depends only on Γ, M, and $\sqrt{s}$

Energy Dependence of Cross Section



effect of finite momentum spread

Facility for Antiproton and Ion Research



FAIR will explore the intensity frontier.

Primary Beams

- 10^{12}/s; 1.5 GeV/u; $^{238}U^{28+}$
- 10^{10}/s $^{238}U^{73+}$ up to 35 GeV/u
- $3x10^{13}$/s 30 GeV protons

Secondary Beams

- Broad range of radioactive beams up to 1.5 - 2 GeV/u; up to factor 10 000 in intensity over present
- Antiprotons 0 - 15 GeV/c

High Energy Storage Ring

Storage ring for $\bar{p}$:

$N_p = 5\times10^{10}$, $P_{beam} = 1.5\text{-}15$ GeV/c;

High density target:

pellet 10^{15} atoms/cm^3, cluster jet, wire;

High luminosity mode:

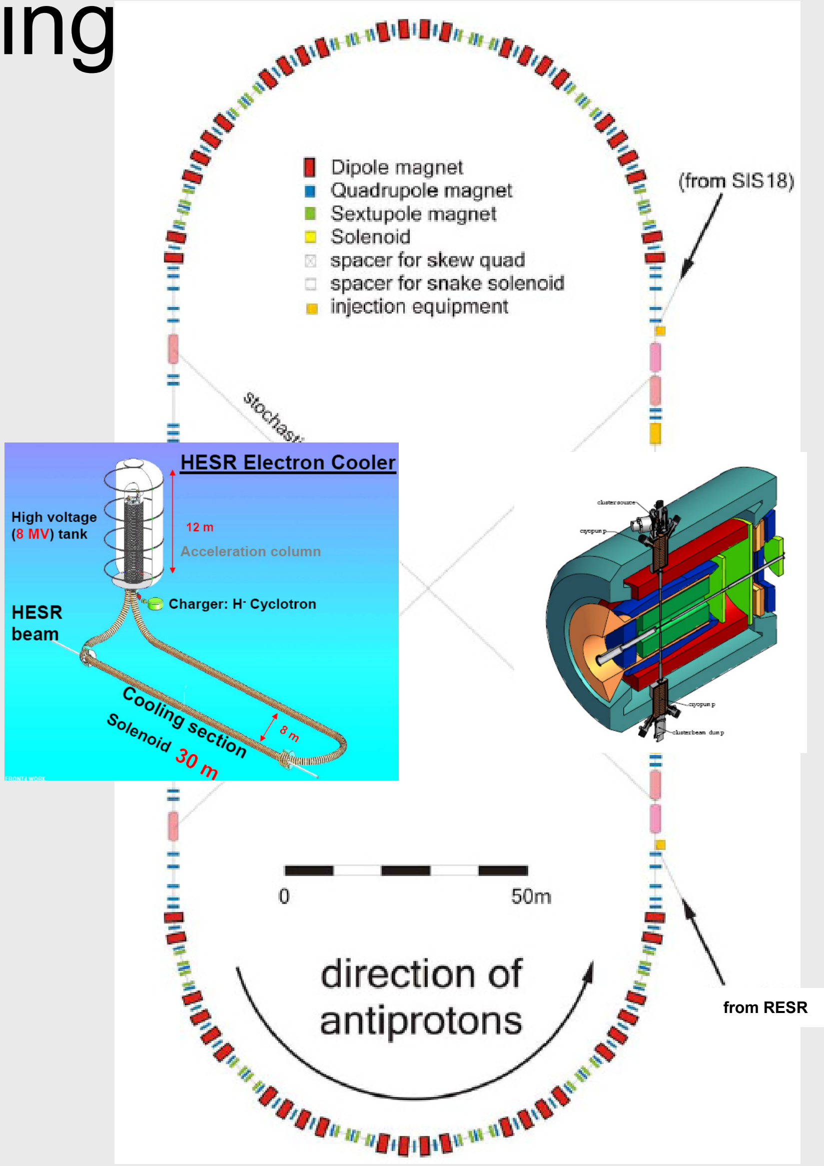
$\Delta p/p = 10^{-4}$, stochastic cooling,

$L = 10^{32}$ cm^{-2}s^{-1};

High precision mode:

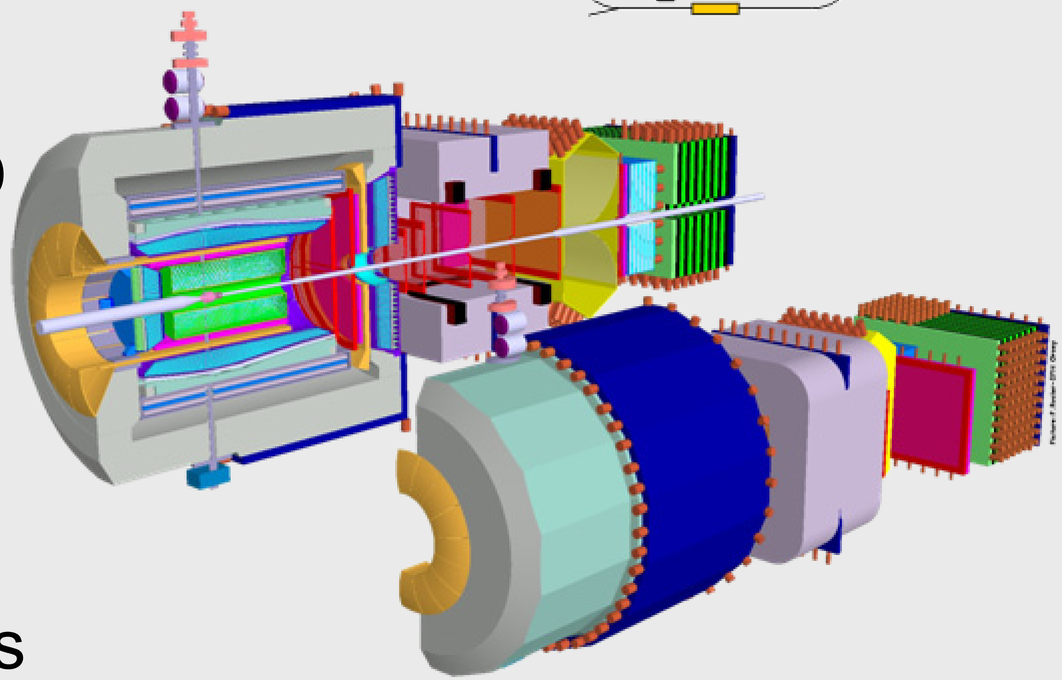
$\Delta p/p = 3\times10^{-5}$, electron cooling,

$L = 10^{31}$ cm^{-2}s^{-1}.

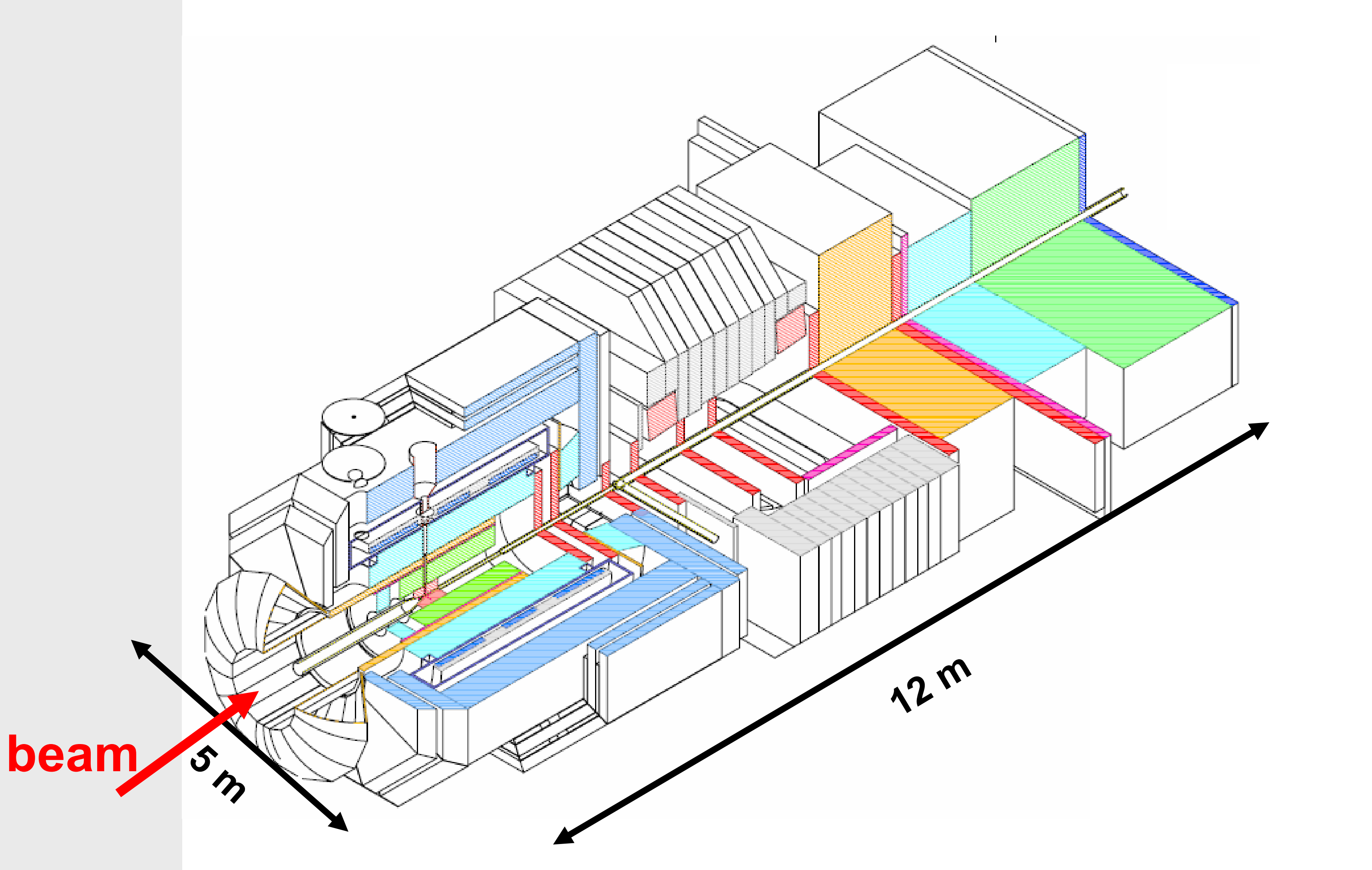


Proposed PANDA Detector

- High Rates
  - 10^7 interaction/s
- Vertexing
  - K_S^0, Y, D, …
- Charged particle ID
  - $e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$, K, p,…
- Magnetic tracking
- EM. Calorimetry
  - γ,π^0,η
- Forward capabilities
  - leading particles
- Sophisticated Trigger(s)



The PANDA Detector

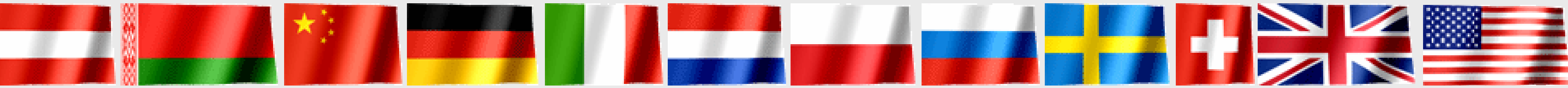


Summary

- After 30 years since c-quark discovery charmonium system still has many puzzles;
- Many new charmonium and open charm states have been recently found by e+e- colliders:
  - No coherent picture → their properties like width and decay channels have to be studied systematically with high precision.
- The PANDA detector will perform high resolution spectroscopy with p-beam and provide new data on this topic. $\sigma_M \approx 40\ keV$ at $\sqrt{s} \approx 4\ GeV$

Panda Participating Institutes

more than 350 physicists (50 institutes) from 15 countries:



U Basel
IHEP Beijing
U Bochum
U Bonn
U & INFN Brescia
U & INFN Catania
U Cracow
GSI Darmstadt
TU Dresden
JINR Dubna (LIT,LPP,VBLHE)
U Edinburgh
U Erlangen
NWU Evanston
U & INFN Ferrara
U Frankfurt
LNF-INFN Frascati

U & INFN Genova
U Glasgow
U Gießen
KVI Groningen
U Helsinki
IKP Jülich I + II
U Katowice
IMP Lanzhou
U Mainz
U & Politecnico & INFN Milano
U Minsk
TU München
U Münster
BINP Novosibirsk
LAL Orsay

U Pavia
IHEP Protvino
PNPI Gatchina
U of Silesia
U Stockholm
KTH Stockholm
U & INFN Torino
Politechnico di Torino
U Oriente, Torino
U & INFN Trieste
U Tübingen
U & TSL Uppsala
U Valencia
IMEP Vienna
SINS Warsaw
U Warsaw