Perspectives of Heavy Quarks Physics

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QCD is the basic theory of strong interactions

At short distance → QCD is a perturbation theory of the point like quark and gluon constituents of hadrons. → It is the good model, works better with heavy quarks.

The lattice QCD (LQCD) → Until now have limited precision in predictions.

At intermediate distance → Hadron resonances, Regge trajectories, soft diffraction, hadronization of the partons, and many others……. → Phenomenological Theories.

Very large distance → QCD is a theory of pions and nucleons characterized by spontaneous symmetry breaking of the approximate chiral symmetry. → Considered as a difficult many body problem.

In spite of these partial success:

Strong interactions open questions:

Confinement of quarks? → It is still an open problem

Hadrons structure?

→ Spectroscopy: (qqq) and $(q\bar{q})$

→ Deep inelastic: infinite quark and gluons

Why only barions (qqq) and mesons $(q\bar{q})$ has been founded? → Other quark and gluon combinations cannot exist?

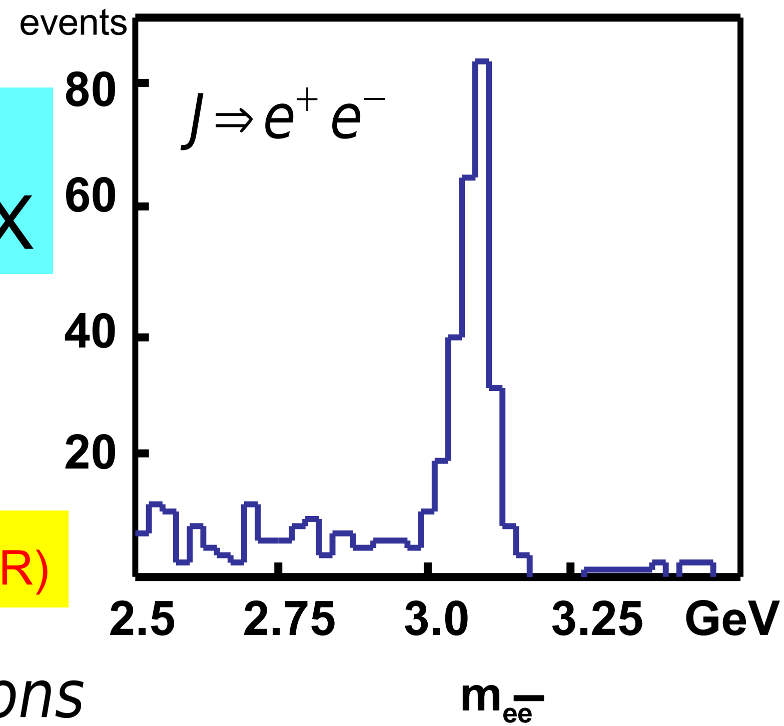
States missing from SU_3..... classifications.

Many new state don't find place in the classifications

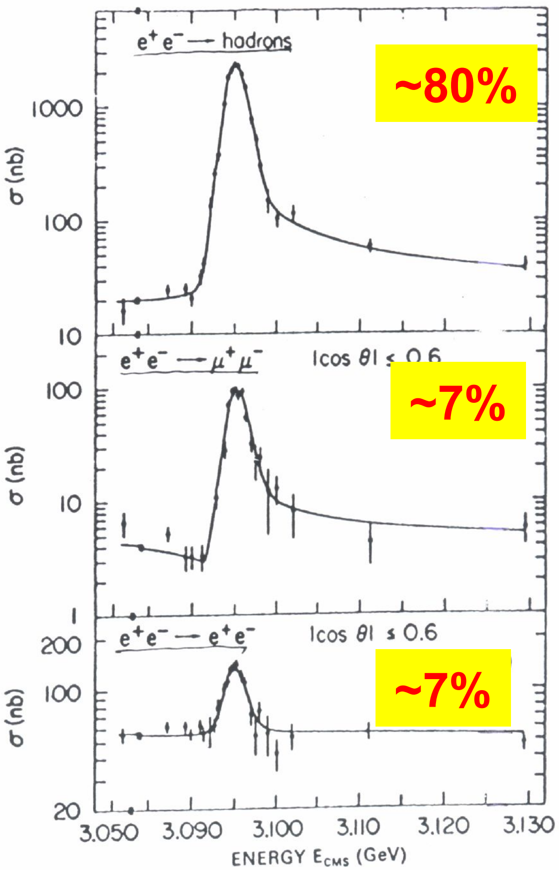
November 1974 unexpected signal

From Brookhaven

$p + Be \rightarrow e^+ + e^- + X$



from SLAC (SPEAR)



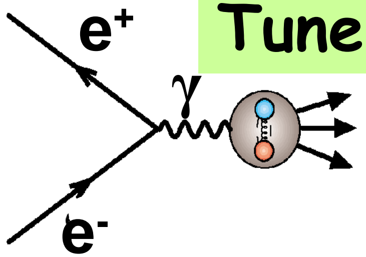
$$e^+e^- \rightarrow \psi \rightarrow hadrons$$

$$e^+e^- \rightarrow \psi \rightarrow \mu^+\mu^-$$

$$e^+e^- \rightarrow \psi \rightarrow e^+e^-$$

The new particle denominated J/Ψ was clearly a vector meson $J^{PC}=1^{--}$ because is formed or decay into e^+e^-. It was too narrow (Γ~100KeV) with respect to any expectation.

At 3686MeV/c^2 at SPEAR find Ψ' with $J^{PC}=1^{--}$



Tune $E(e^+e^-)$ on ψ′

SLAC – Crystalball γ, 4π detector

Production of $\chi_{1,2}$ with $J^{PC} \neq 1^{--}$

$J^{PC} = 1^{--}$ only

$e^+e^- \rightarrow \psi'$

↓

$\gamma\,\chi$

↓

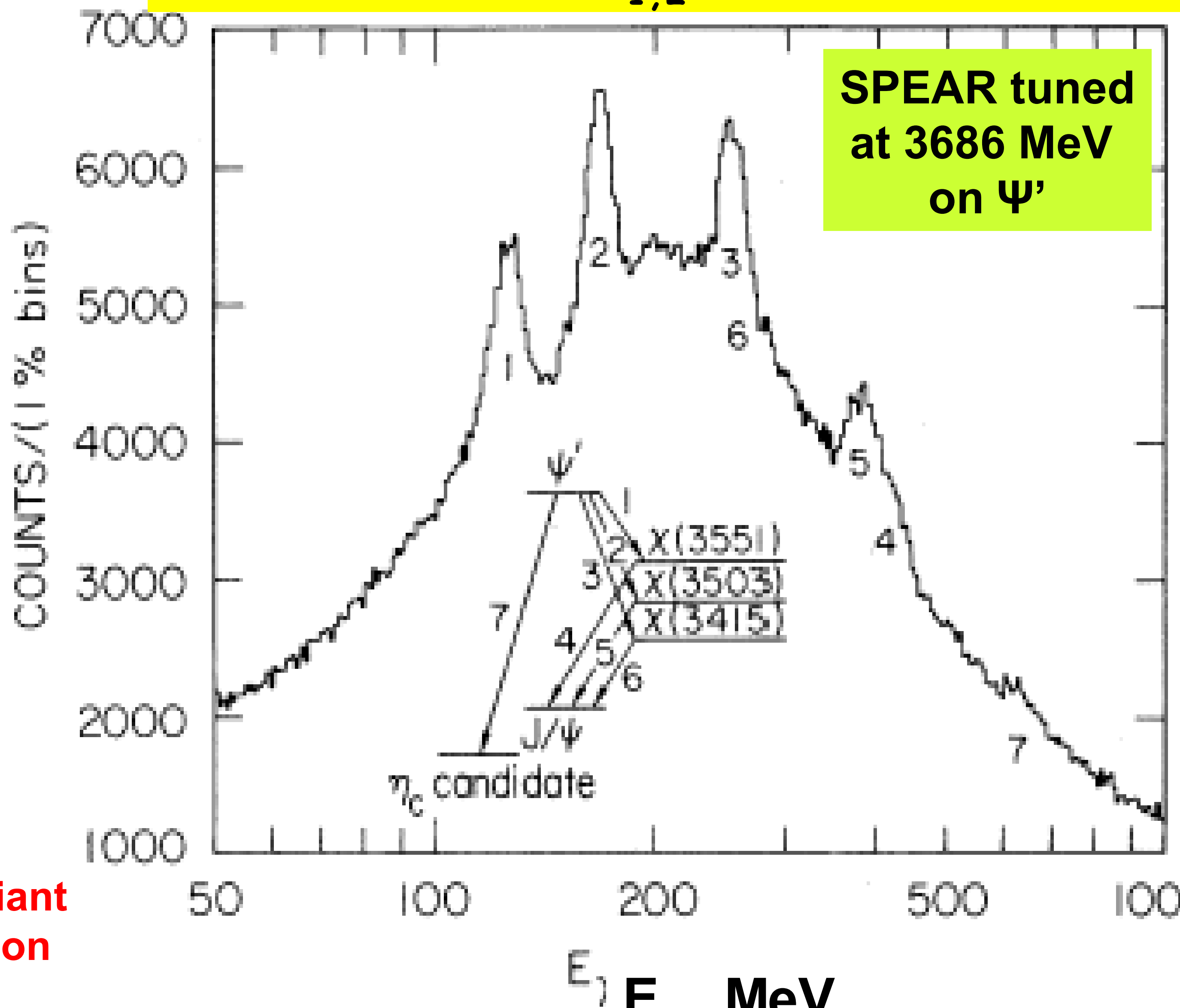
$\gamma\,(\gamma J/\psi)$

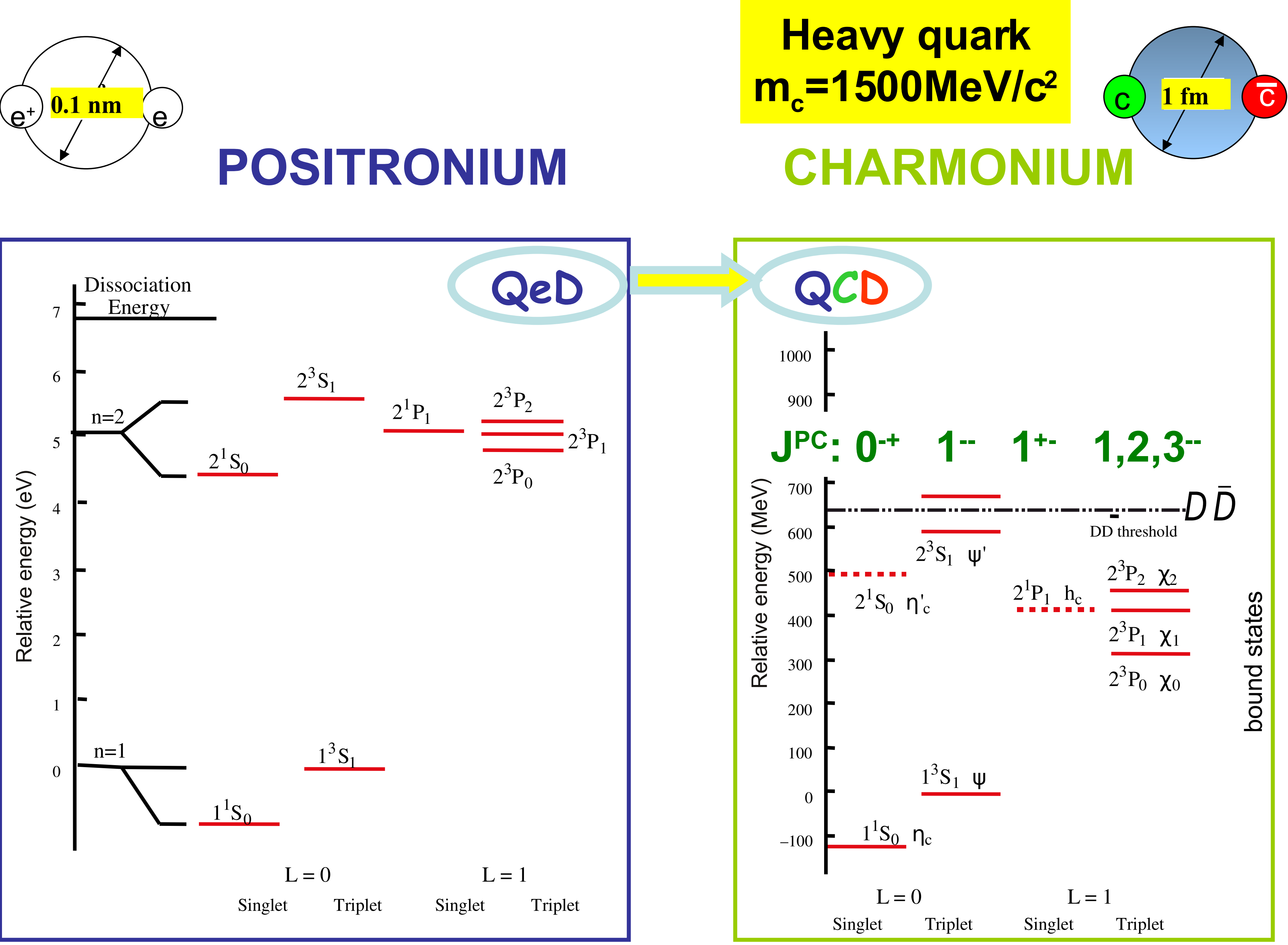
↓

$\gamma\gamma$ (hadrons)

⇩

Reconstruction of invariant mass: detector resolution dependent





Heavy quark
m_c=1500MeV/c²
0.1 nm
e+
e
1 fm
c
c̄
POSITRONIUM
CHARMONIUM
QeD
QCD
Dissociation Energy
7
6
5
4
3
2
1
0
Relative energy (eV)
n=2
n=1
2¹S₀
2³S₁
2¹P₁
2³P₂
2³P₁
2³P₀
1¹S₀
1³S₁
L = 0
L = 1
Singlet
Triplet
Singlet
Triplet
1000
900
JPC: 0-+ 1-- 1+- 1,2,3--
700
600
500
400
300
200
100
0
−100
Relative energy (MeV)
DD̄
DD threshold
2³S₁ ψ'
2¹S₀ η'c
2¹P₁ hc
2³P₂ χ2
2³P₁ χ1
2³P₀ χ0
1³S₁ ψ
1¹S₀ ηc
bound states
L = 0
L = 1
Singlet
Triplet
Singlet
Triplet

The charmonium $(c\bar{c})$ is a powerful tool for the understanding of strong interactions.

The high mass of the charm quarks (mc=1.5 GeV) makes it plausible to attempt a description of dynamical properties of the $(c\bar{c})$ in terms of non relativistic potential model, in which the functional form of the potential is chosen to reproduce the known asymptotic properties of strong interactions.

The free parameters of these models are determined by comparison with experimental data.

Non relativistic potential model + Relativistic corrections + PQCD

LQCD predicts spectrum

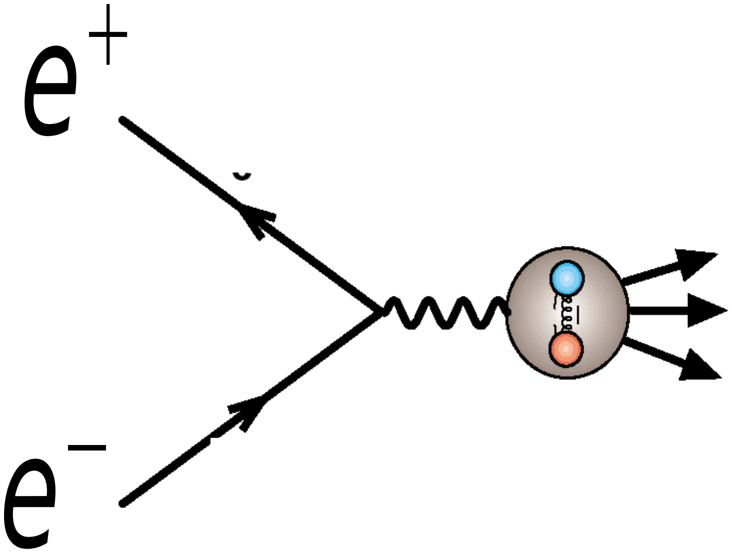
with a precision for $(c\bar{c})$

not better than **10%**

LQCD need heavy quark spectroscopy

to determine the free parameters

Production of $\chi_{1,2}$ from $e^{-}e^{+}$



$e^{+}e^{-} \rightarrow \psi'$

$\searrow \gamma\, \chi$

$\searrow \gamma\, (\gamma J/\psi)$

$\searrow \gamma\gamma\, (e^{+}e^{-})$

$J^{PC} = 1^{--}$

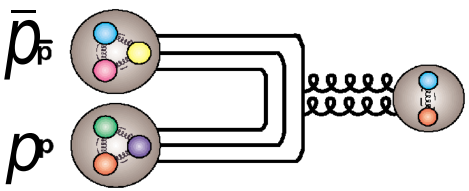
Reconstruction of invariant mass: detector resolution dependent

CHARMONIUM SEARCH

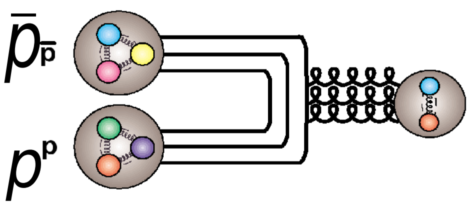
WITH ANTIPROTONS

30 years ago, the proposals of construction of sources of cooled antiproton beams with a momentum resolution much better respect the obtainable for electrons and positrons, open the possibility to use the $p\bar{p}$ annihilation to study the charmonium spectroscopy.

1979 – I proposed to study the Charmonium states with $J^{PC} \neq 1^{--}$ in formation with $\bar{p}p$ annihilation at ISR of CERN with one beam of ≤7 GeV/c of $\bar{p}$ and a Jet Gas H_2 Target.



J = 0, 2, …
C = +



J = 1
C = –

Formation of η_c and $\chi_{0,1,2}$ from $\bar{p}p$ annihilation

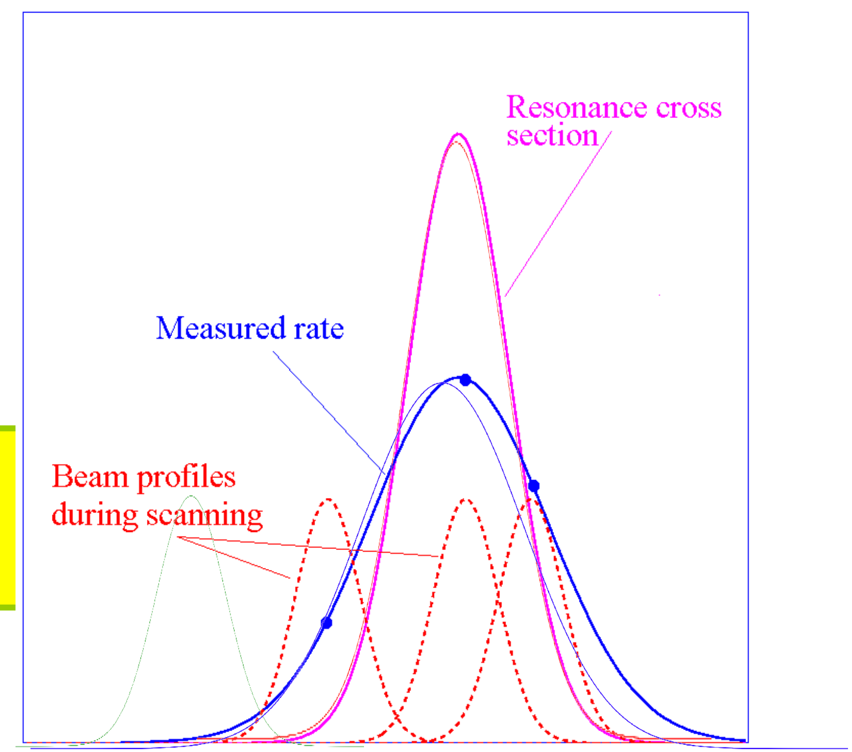
Resolution: only from beam energy dispersion.

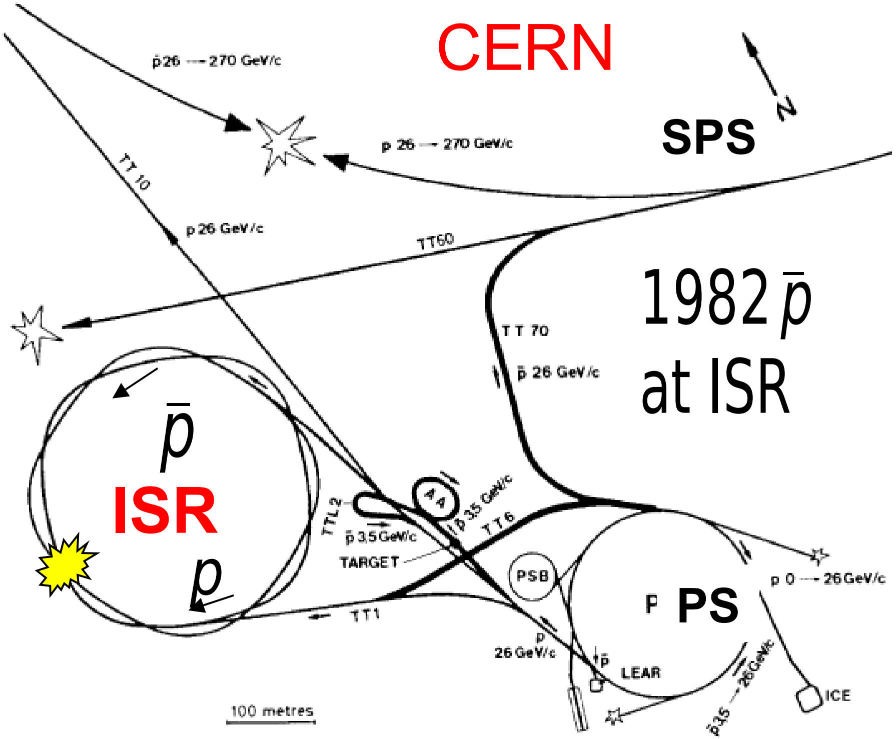
$pp \rightarrow \chi$

$\gamma + J/\psi$

$\gamma\, e^+e^-$

Detector resolution only for trigger





$$\bar{p}p \to \chi$$

$$\downarrow$$

$$\gamma + J/\psi$$

$$\downarrow$$

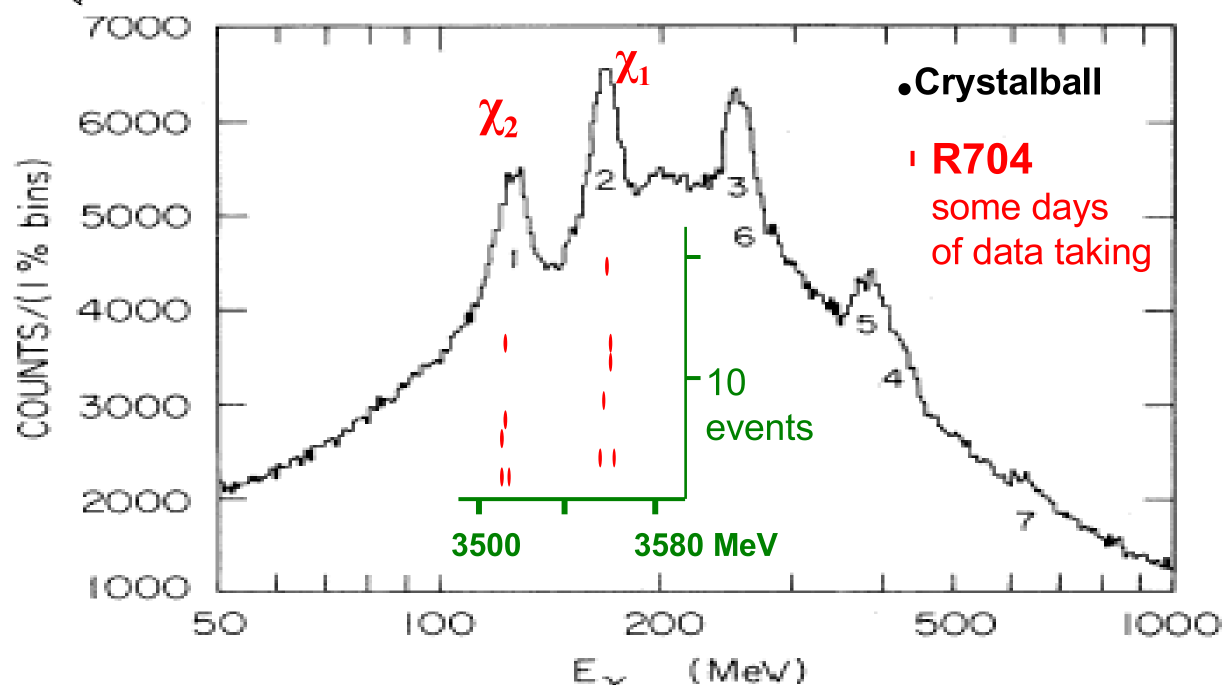
$$e^+e^-$$

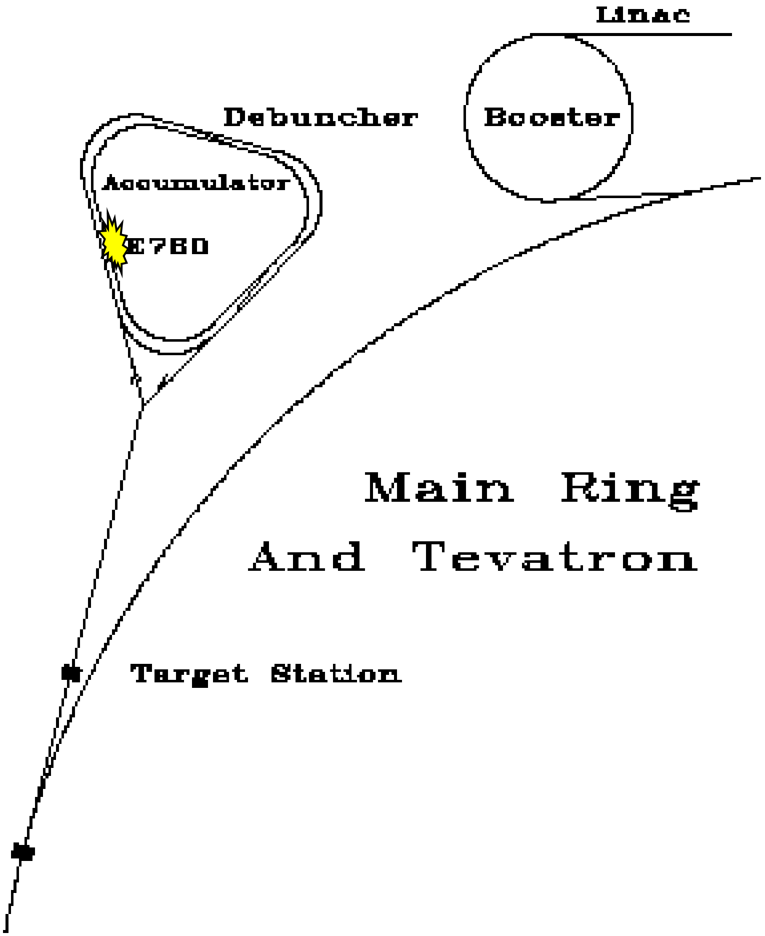
CERN

ISR

R704

charmonium formation



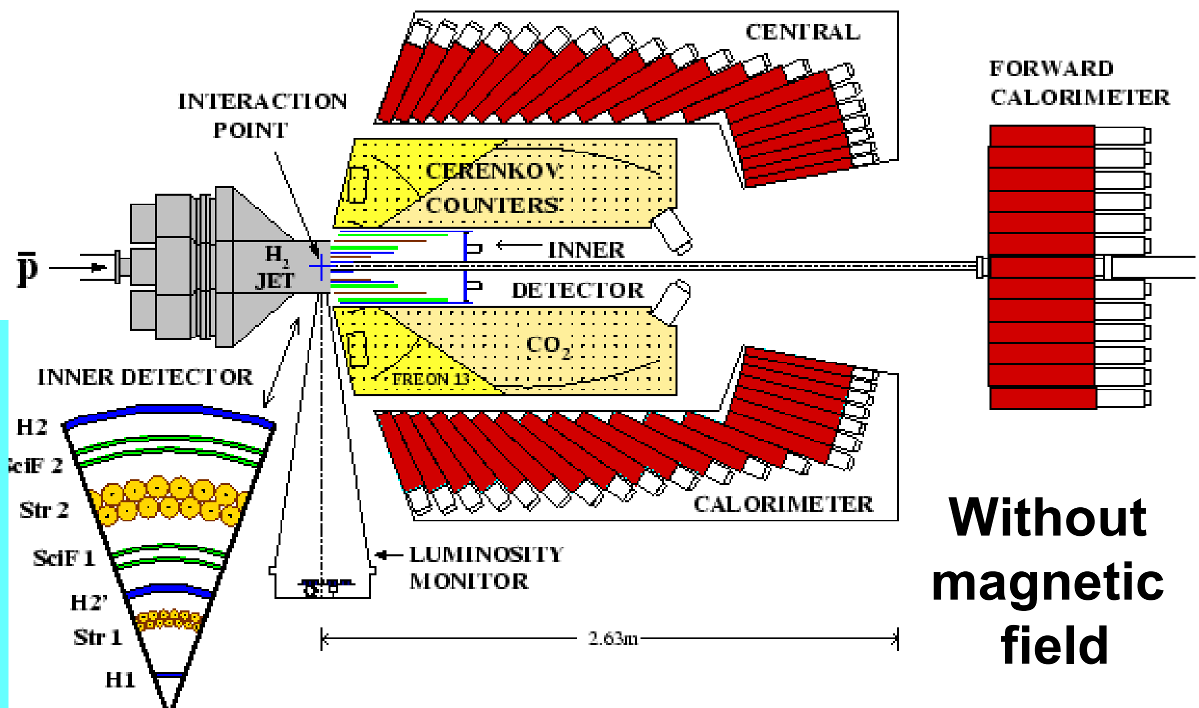


ANTIPROTONS at FERMILAB

$$3\,GeV/c < p_{\bar{p}} < 9\,GeV/c$$

From 1989 to 2000.
Bunches up to 8.10^{11} antiprotons with $\Delta p/p = 2.10^{-4}$ stability at the same level.

Experiments E760 + E835

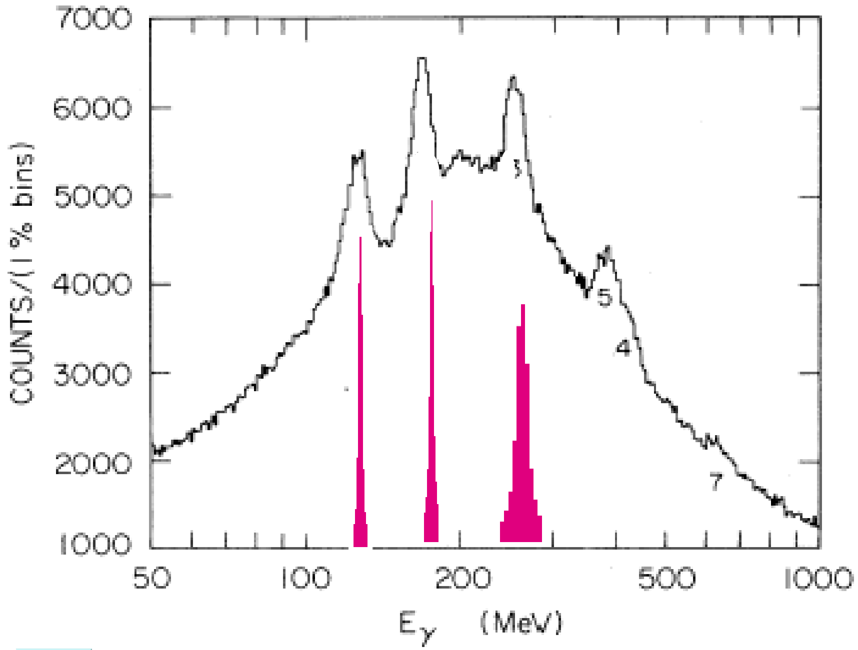


Without magnetic field

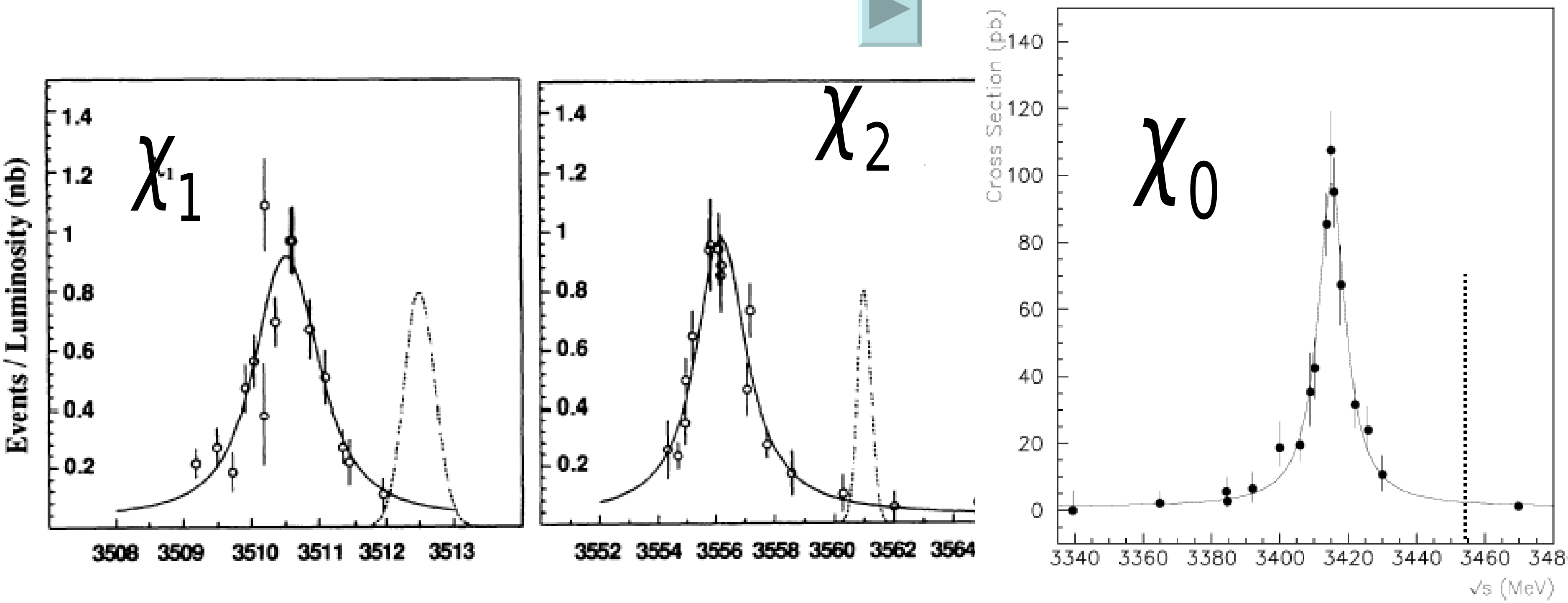
Electrons and γ's detected.

e/π rejection 10^{-4}
Energy resolution for electrons and γ's
~6%

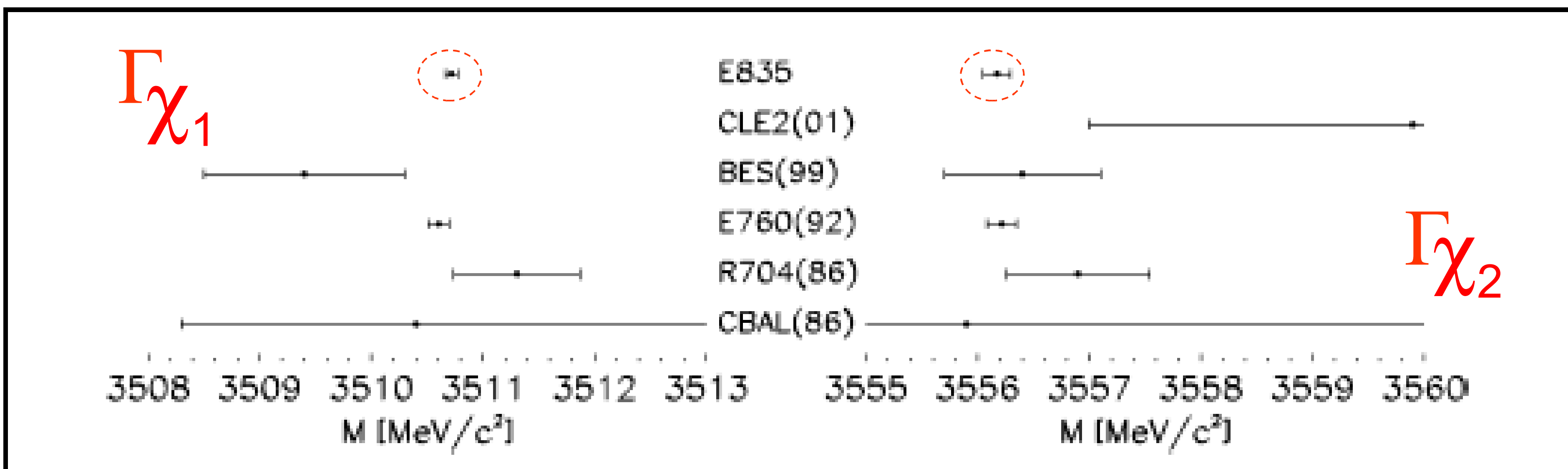
CHARMONIUM P STATES from E760 and E835

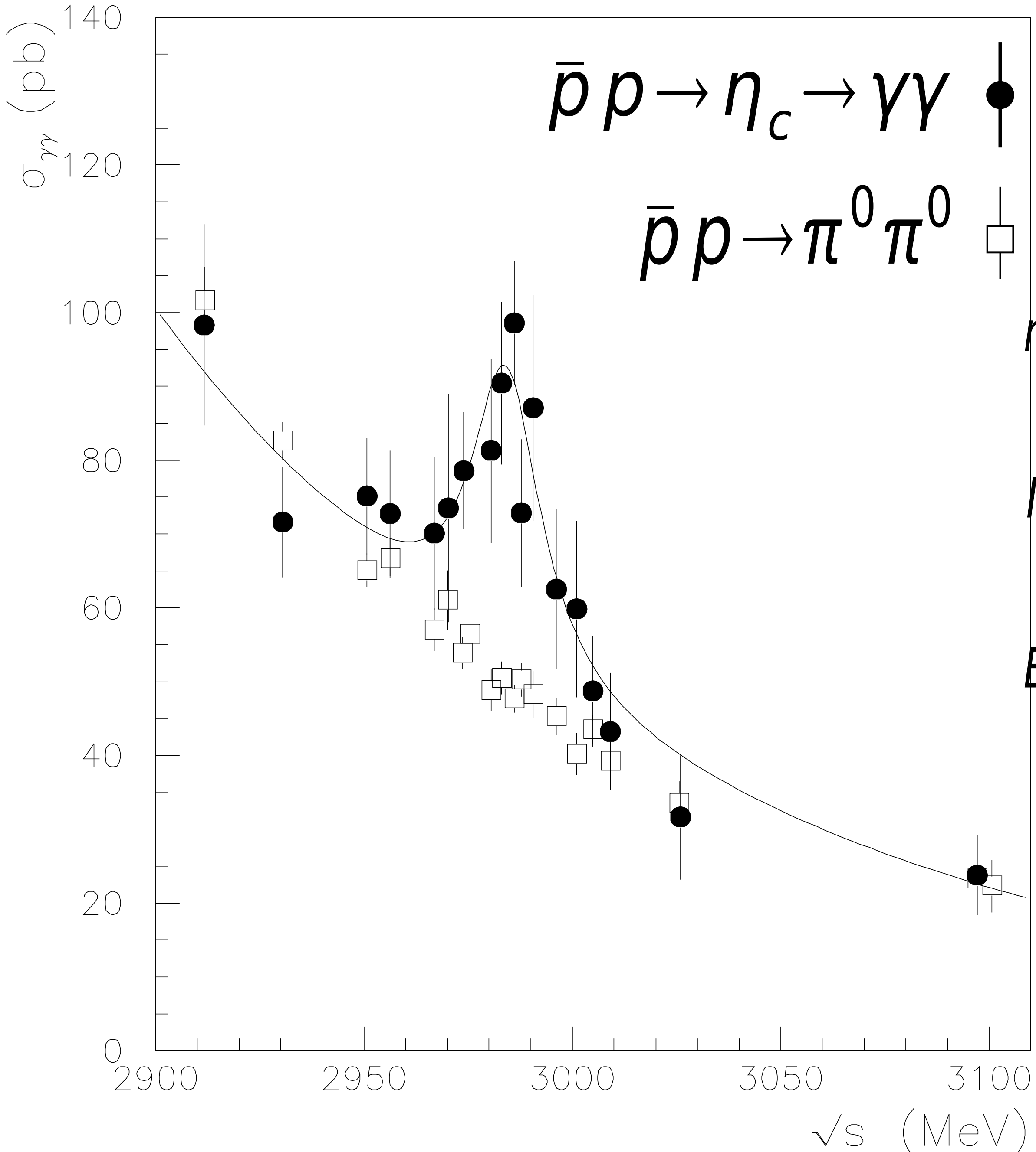


	Mass (MeV/c²)	Width (MeV)
χ_0	3415.19 ± 0.34	10.2 ± 0.9
χ_1	3510.59 ± 0.12	0.88 ± 0.14
χ_2	3556.26 ± 0.11	2.00 ± 0.18



χ_{c1}	**E835**	**E760**
M(MeV/c^2)	3510.719 ± 0.051 ± 0.019	3510.60 ± 0.09 ± 0.02
Γ(MeV)	0.876 ± 0.045 ± 0.026	0.87 ± 0.11 ± 0.08
$B(p\bar{p})\Gamma(J/\psi\gamma)$(eV)	21.5 ± 0.5 ± 0.6 ± 0.6	21.4 ± 1.5 ± 2.2
χ_{c2}	**E835**	**E760**
M(MeV/c^2)	3556.173 ± 0.123 ± 0.020	3556.22 ± 0.13 ± 0.02
Γ(MeV)	1.915 ± 0.188 ± 0.013	1.96 ± 0.17 ± 0.07
$B(p\bar{p})\Gamma(J/\psi\gamma)$(eV)	27.0 ± 1.5 ± 0.8 ± 0.7	27.7 ± 1.5 ± 2.0





E835 - η_c

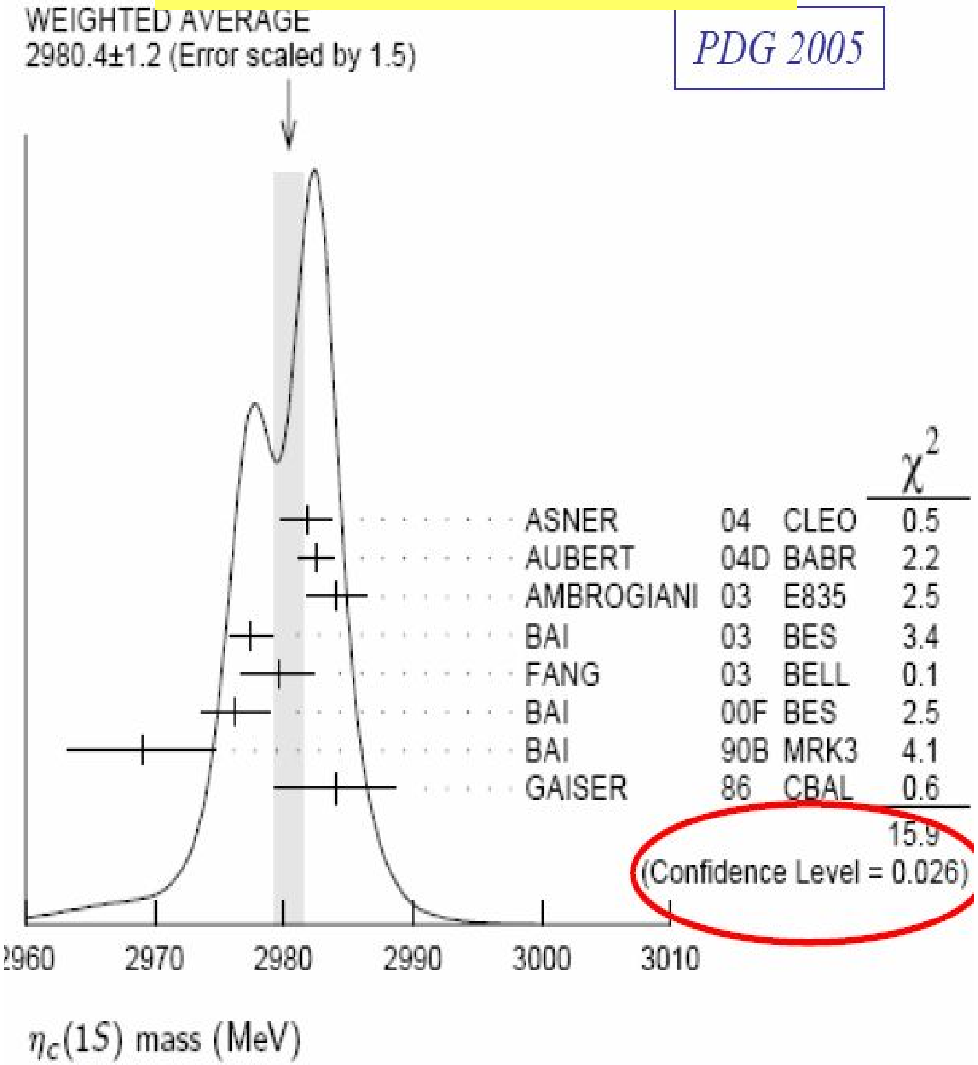
$$m_{\eta_c} = (2984 \pm 2 \pm 1)\, MeV/c^2$$

$$\Gamma_{\eta_c} = (20.4^{+7.7}_{-6.7} \pm 2)\, MeV$$

$$Br_{\eta_c \to \gamma\gamma} = (1.87 \pm 0.32^{+0.95}_{-0.50}).10^{-4}$$

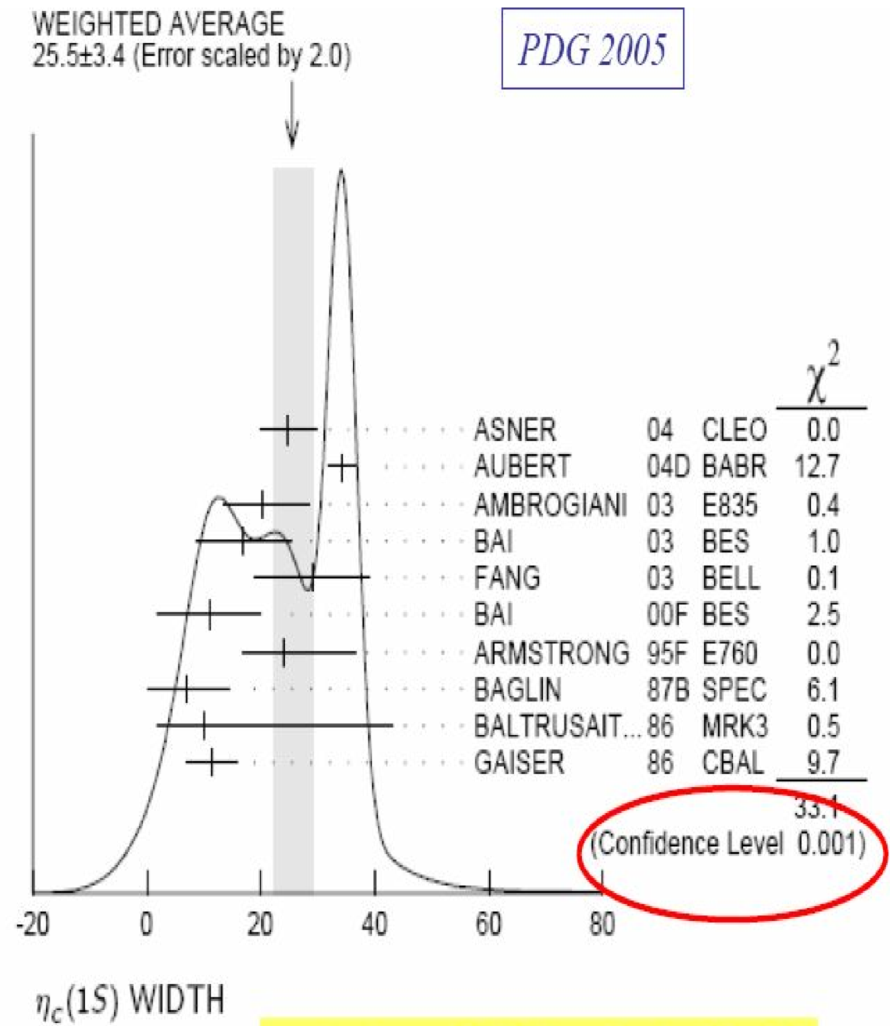
The limits of this technique is the electromagnetic trigger.

$M(\eta_c)$



$M(\eta_c) = 2980.4 \pm 1.2$ MeV/c^2

$\Gamma(\eta_c)$



$\Gamma(\eta_c) = 25.5 \pm 3.4$ MeV

Accelerators and experiments on charm physics

e^+e^- annihilation

- SLAC → SPEAR: MARK1,2,3, Cristal Ball, TPC, …
- SLAC → PEP2: BaBar
- DESY → DORIS+PETRA:PLUTO, Jade …..
- Rochester → CESR: CLEO, CLEO-c
- KEK → Belle
- Beijin → BEPC: BES

$\bar{p}\,p$ annihilation

- CERN → ISR: R704
- FNAL → AA: E760 + E835
- GSI → FAIR: PANDA…..

Hadroproduction → FNAL → TEVATRON: CDF, D0, SELEX…

Electroproduction → DESY → HERA: ……………

operation:

- terminated
- presently
- in the future

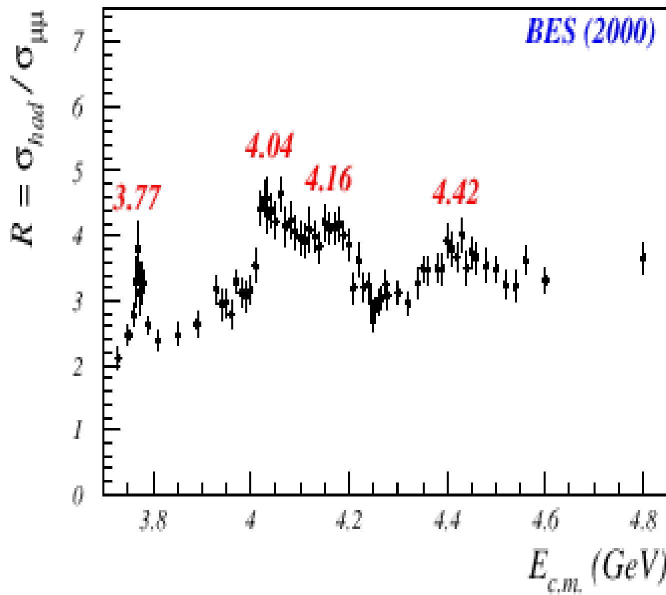
Charmonium States above the D $\bar{D}$ th.

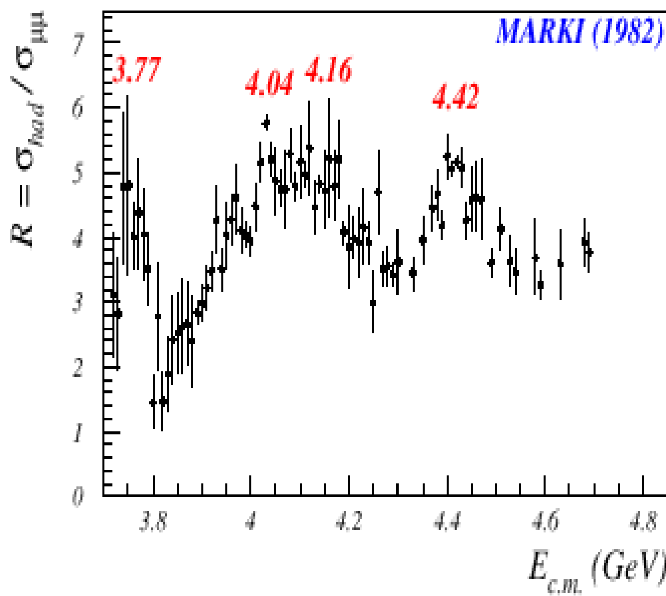
The energy region above the D $\bar{D}$ threshold at 3.73 GeV is very poorly known.

- 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.

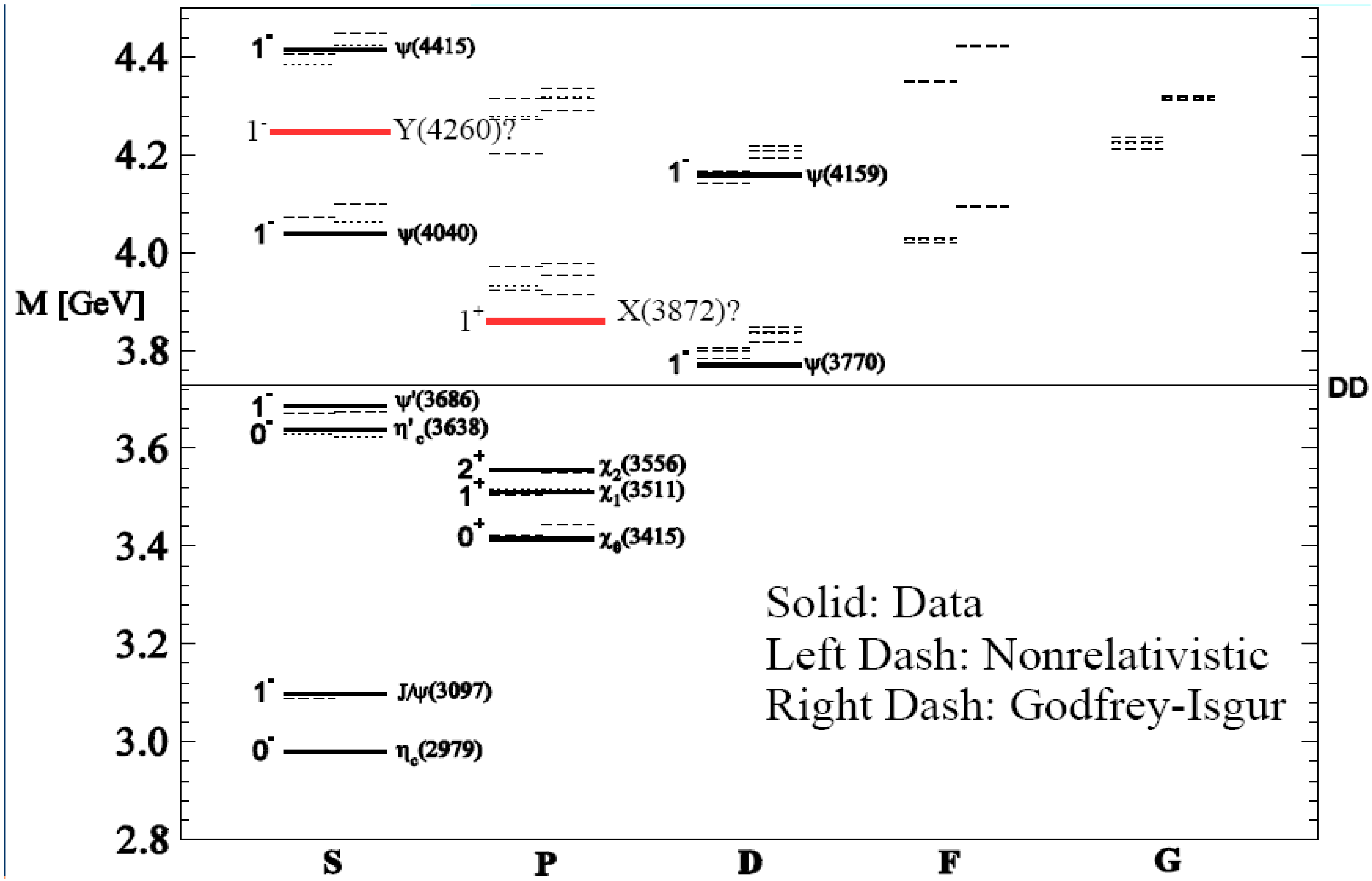
- The first radial excitations of the singlet and triplet P states are expected.

- Narrow states are expected.

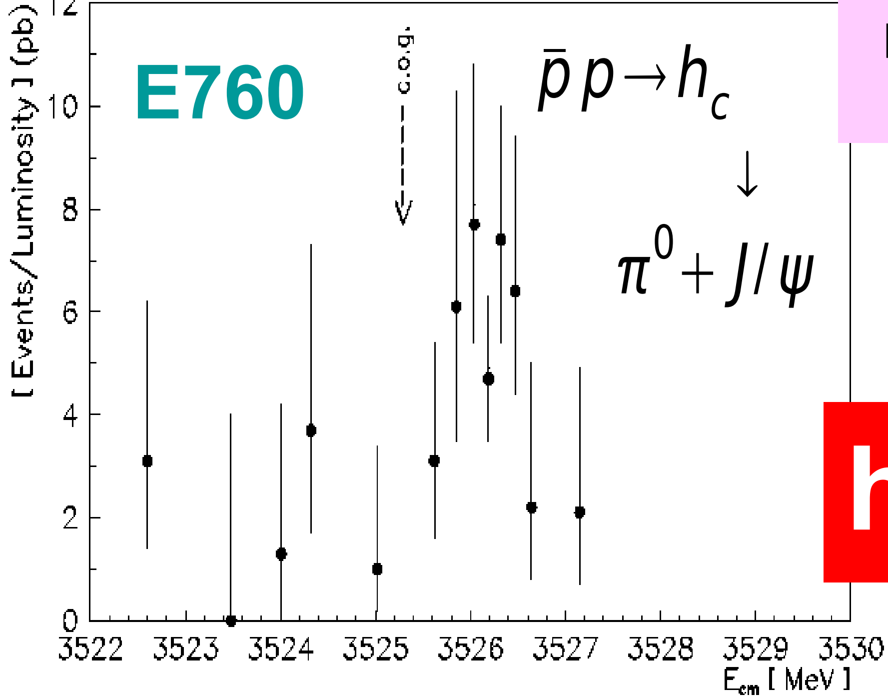




CHARMONIOUM SPECTRUM



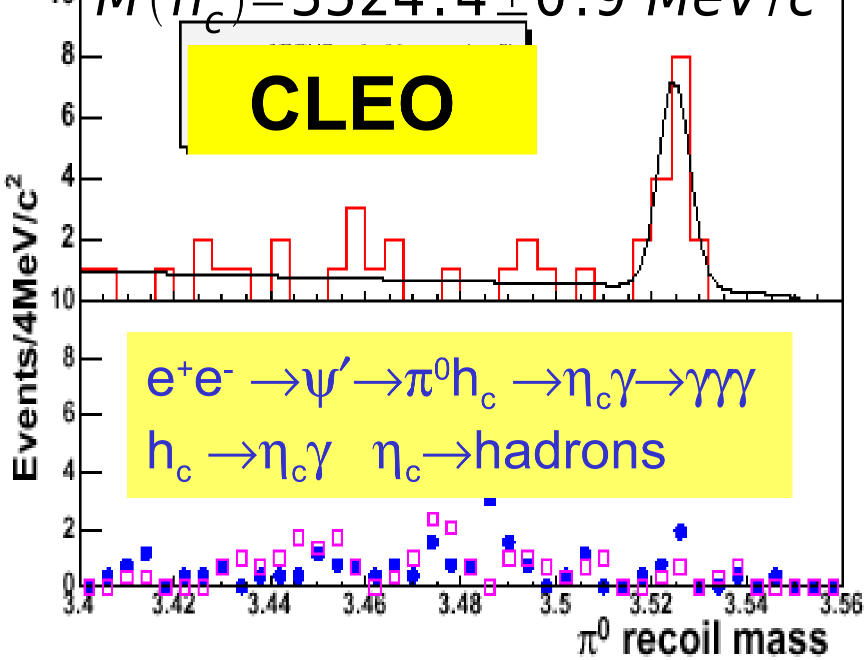
h_c for strong interaction is equivalent to the Lamb shit of the hydrogen atom for QeD

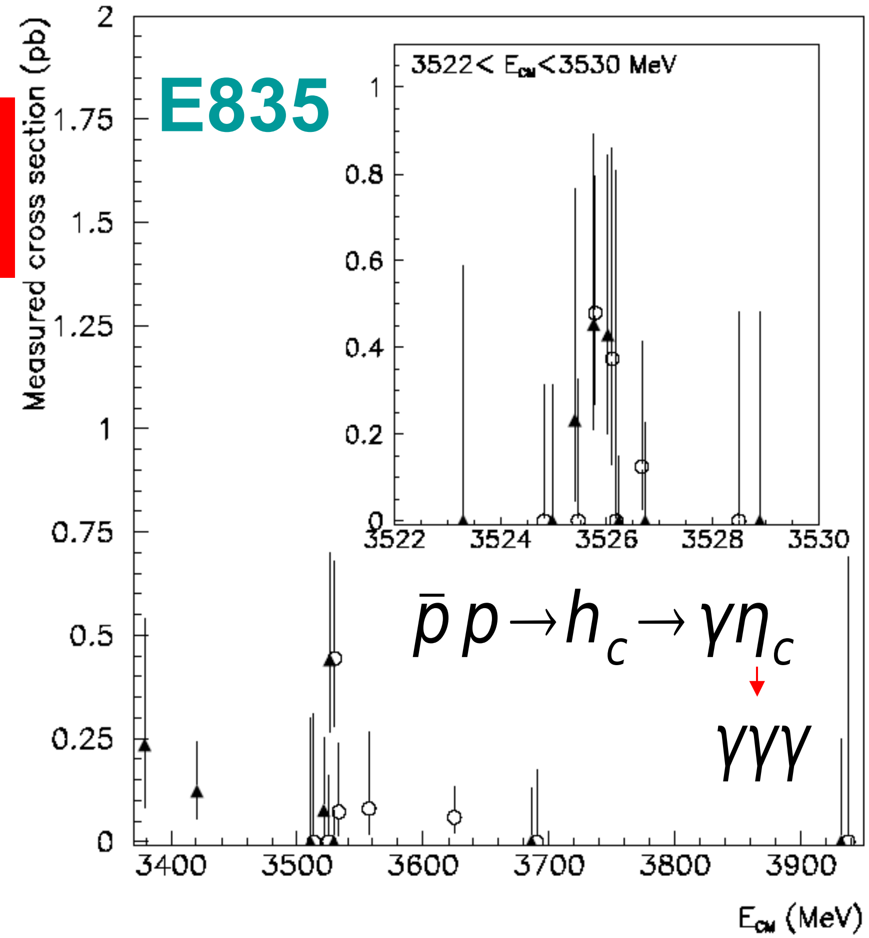


$$E760: \; M(h_c) = 3526.2 \pm 0.15 \pm 0.2 \; MeV/c^2$$

h_c?

$$M(h_c) = 3524.4 \pm 0.9 \; MeV/c^2$$





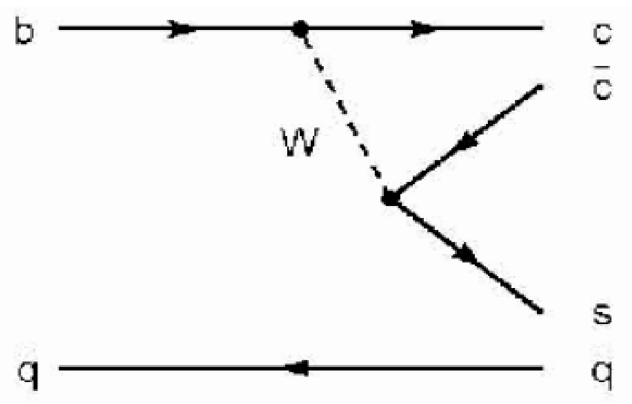
It is expected a very narrow resonance. Need still more work!

CHARMONIUM SEARCH
AT
BEAUTY FACTORIES

The beauty factories of SLAC and KEK study the charm physics from the B meson decays.

$$e^+e^- \to B\bar{B}$$

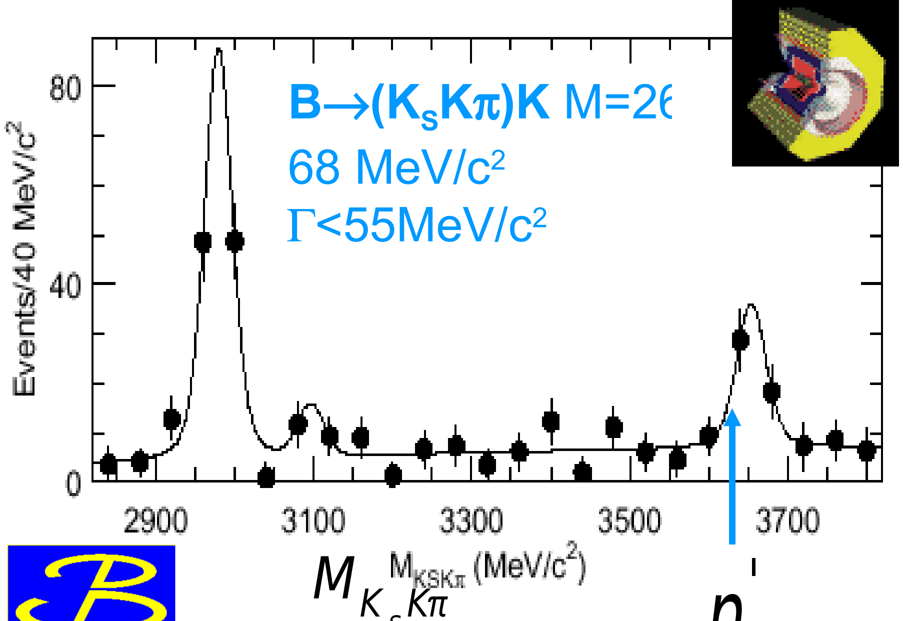
$$\hookrightarrow \chi_c + \ldots\ldots$$



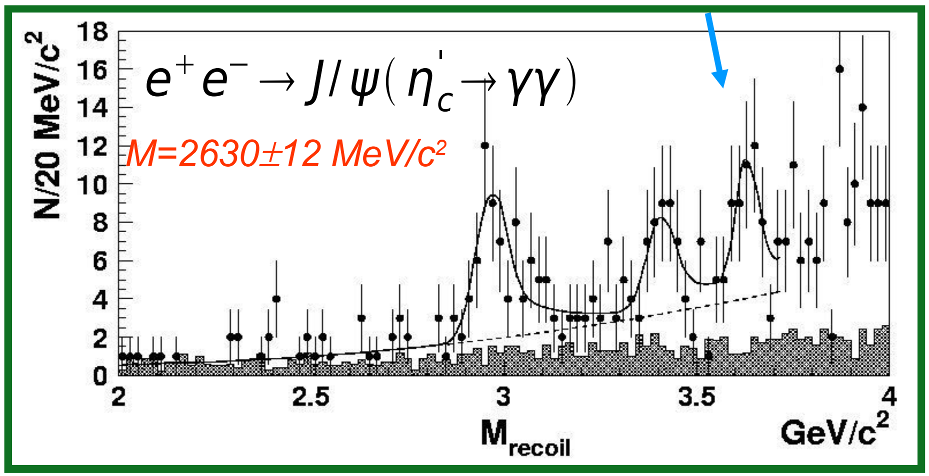
$J/\psi, \psi', \psi(3770), \eta_c, \eta'_c, \chi_{c0}, \chi_{c1}, D^{(*)}, \bar{D}^{(*)}, X(3872)$

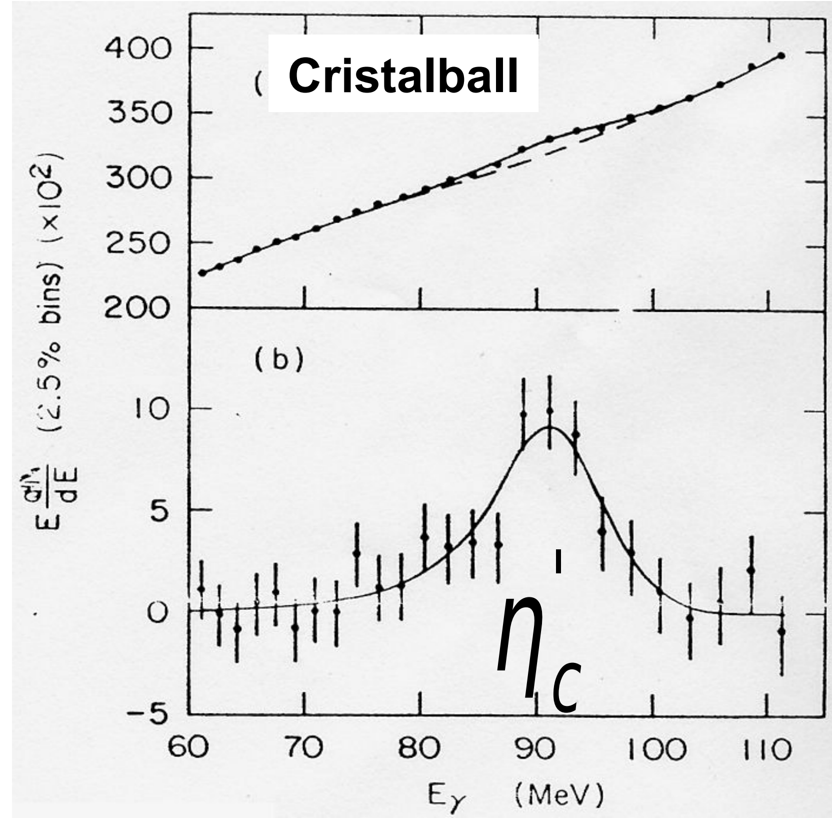
$K^{\pm}, K_S, K_L, K^*(890), K(1270)\ldots$

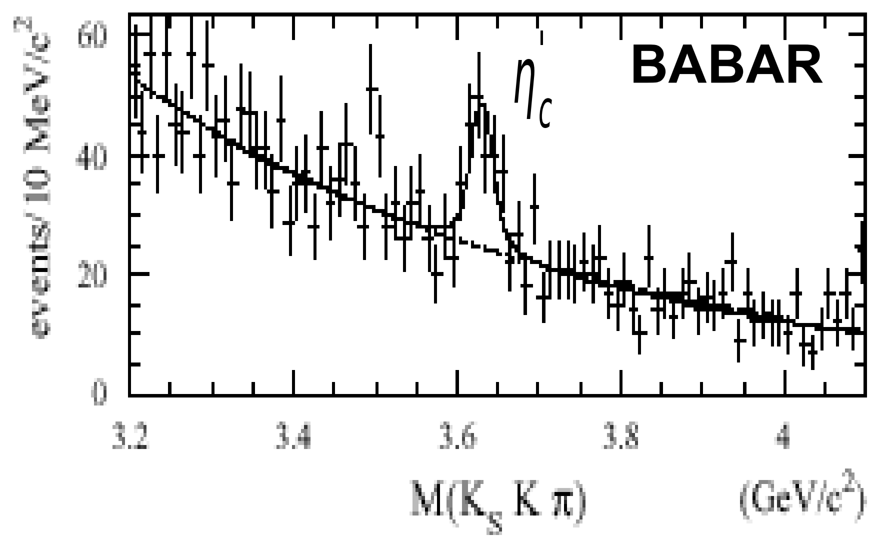
Charmonium states can be produced at the B-factories in the decays of the B-meson.



η_c'

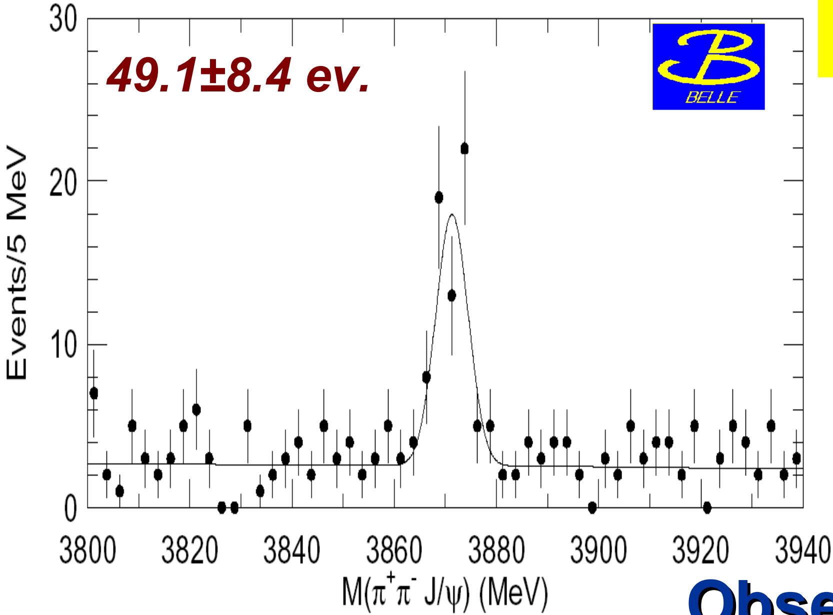


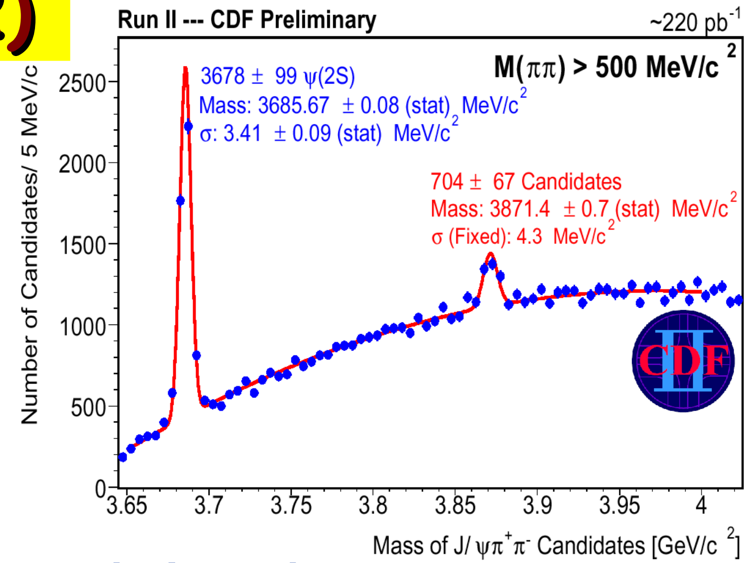




η_c' needs still work?

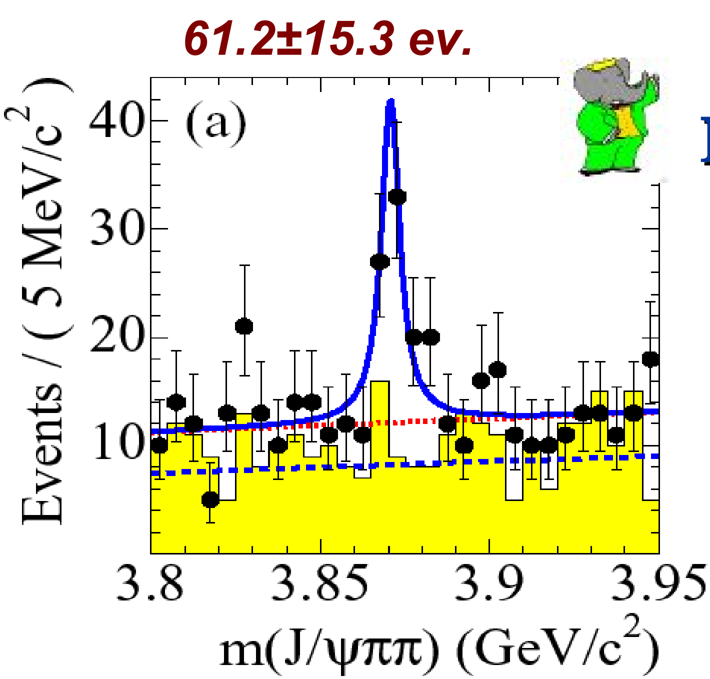
X(3872)



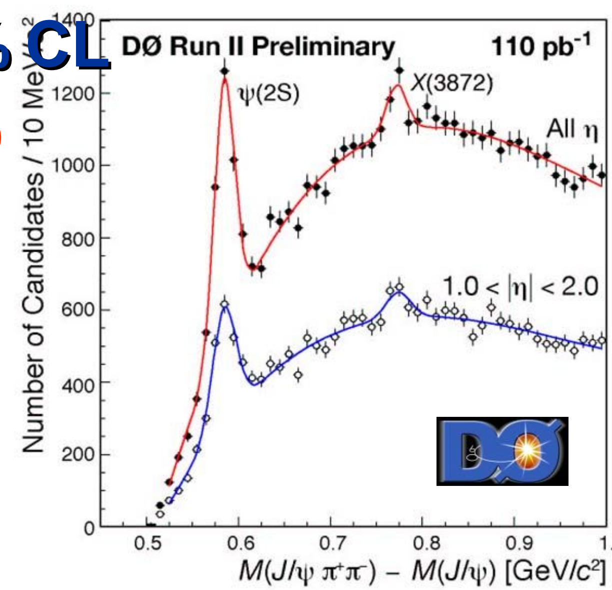


Observed in $B^+ \to (J/\psi\pi\pi)\, K^+$

$M_X = (3872.0 \pm 0.6 \pm 0.5)\,MeV/c^2$

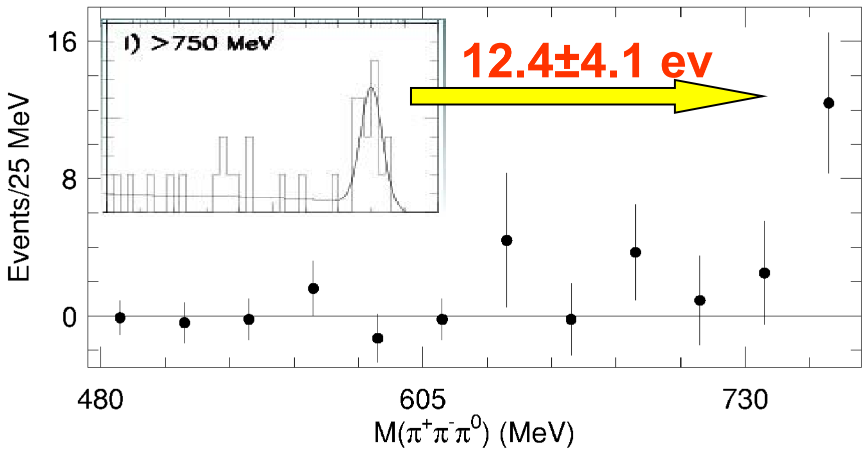


$\Gamma < 2.3\,MeV/c^2$ at 90% CL



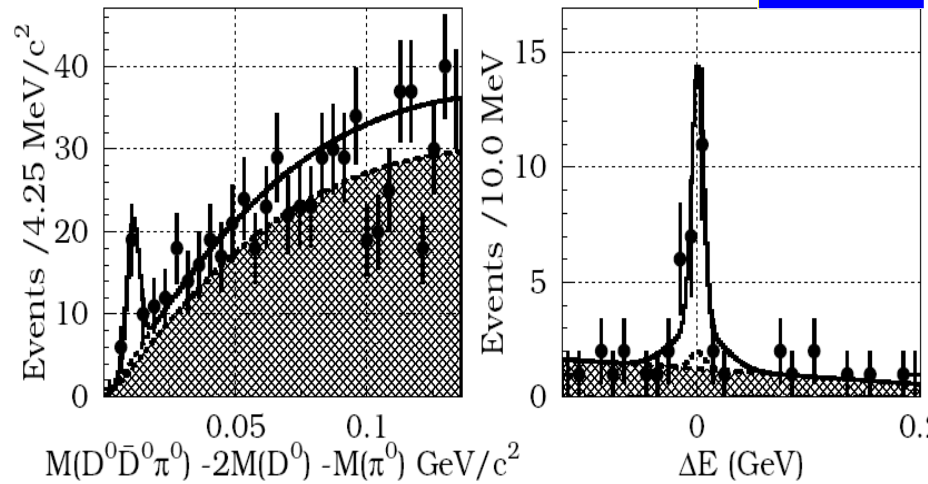
CONFIRMED BY BABAR CDF and D0

$X(3872) \to J/\psi\ (\omega \to \pi^+\pi^-\pi^0)$



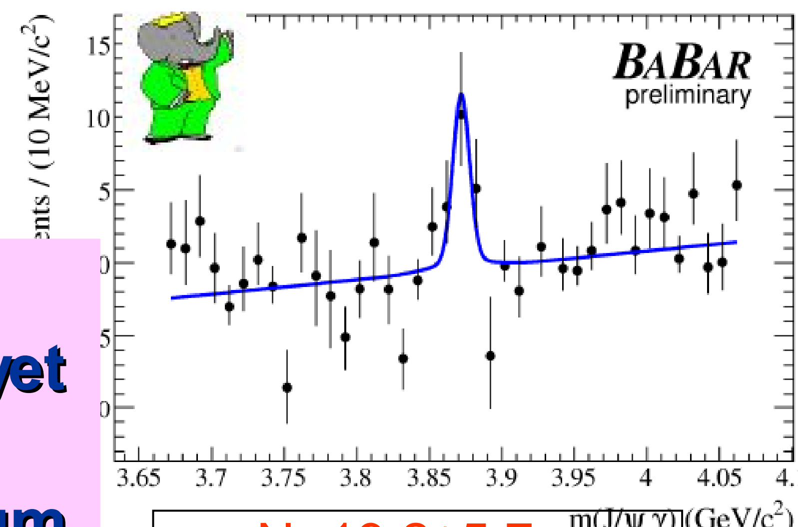
$X(3872) \to D^0 D^0 \pi^0$

N=24±6



Quantum numbers: $J^{PC}=1^{++}$

$X(3872) \to J/\psi\gamma$



N=19.2±5.7

corresponds to χ_{c1}', but

$$\frac{\chi_{c1}' \Rightarrow J/\psi + \gamma}{\chi_{c1}' \Rightarrow J/\psi + \pi} = 0.2 \quad \text{expected } \sim 30$$

- Not assigned yet to any charmonium state

- ~100MeV/c^2 lighter than expected.

Possible interpretion: $D_0D^*_0$ molecule:

large isospin violation expected

- $J^{PC}=1^{++}$ predicted

Tetraquark molecule?

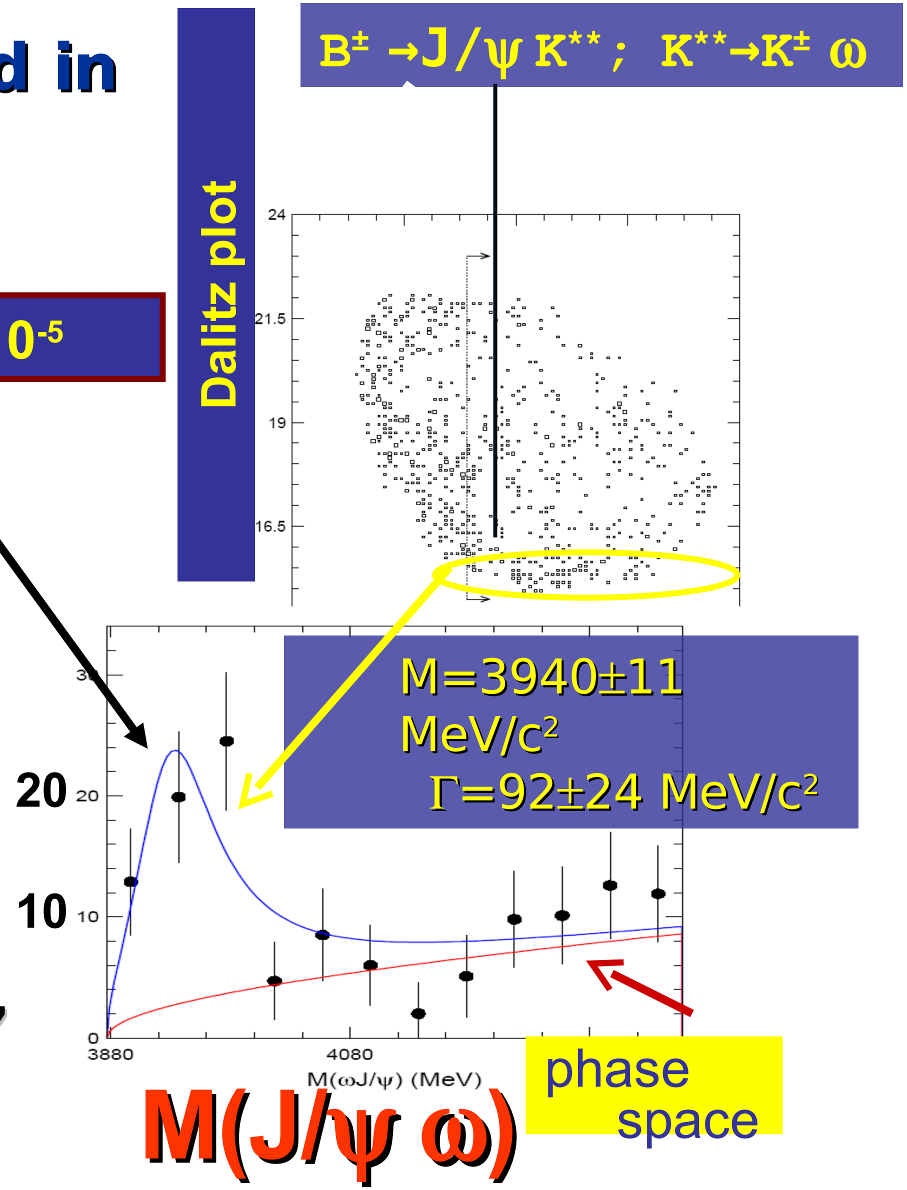
Y(3940)

2004, L=253fb^{-1}

B→J/ψ ω K signal is scanned in bins of M(J/ψ ω):

broad enhancement around threshold

B(B→YK)xB(Y→J/ψ ω)=(7.1±1.3±3.1)x10^{-5}



Threshold effect or particle ?

-The mass is well above DD* threshold and decay to J/ψω should not be dominant if Y=charmonium

cc-gluon hybrid ?

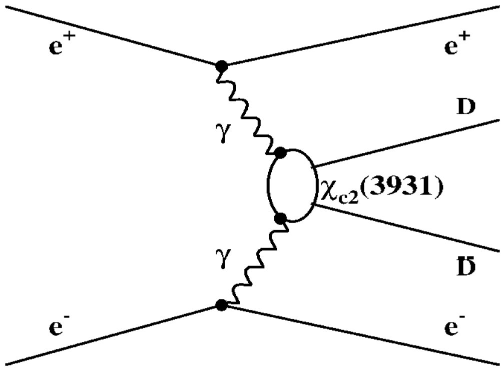
-Large B(J/ψ , ψ' + light hadrons),

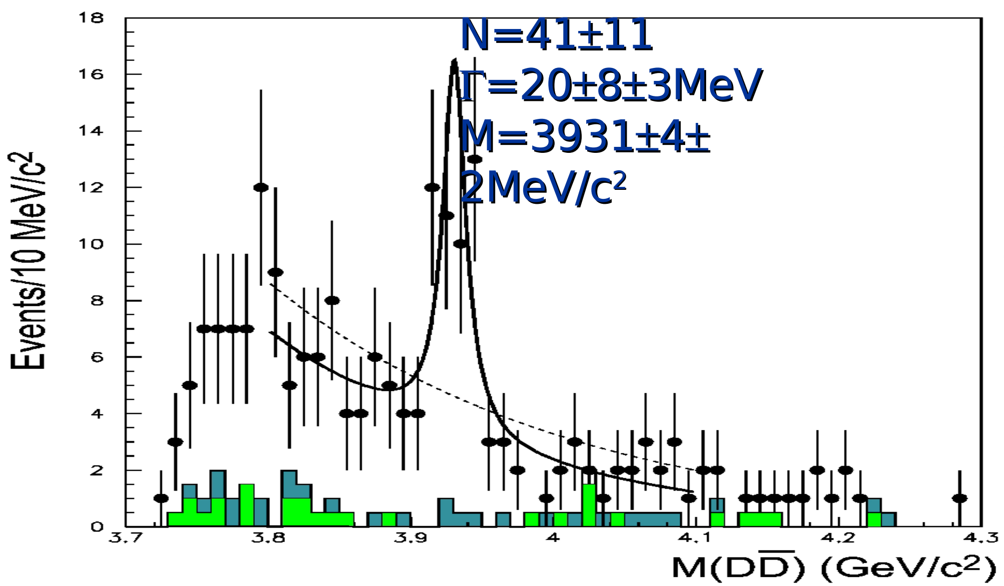
decays to DD$^{(*)}$ are suppressed, expected width is ~100MeV/c^2.

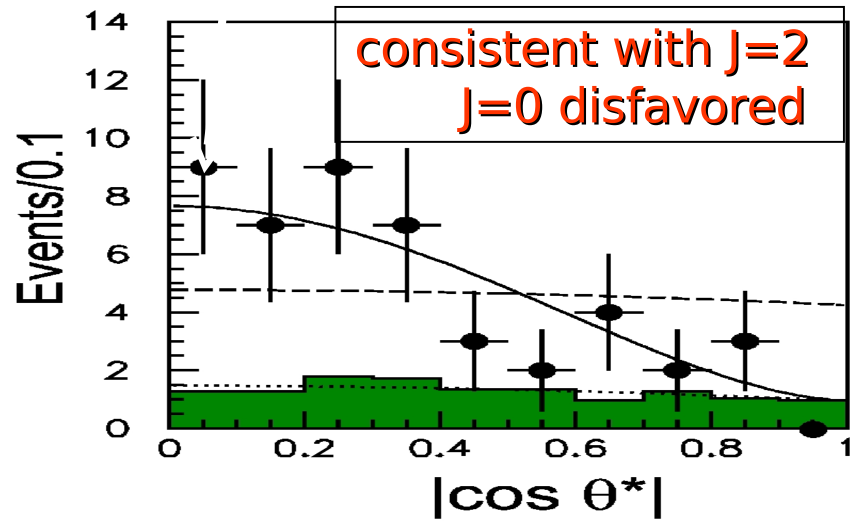
χ_{c2}' in $\gamma\gamma$ production

2005, L=395fb^{-1}

Peak at $M_{D\bar{D}}$~3.930 GeV/c^2 in selected $\gamma\gamma$ events p_t distribution consistent with $\gamma\gamma$ production







Helicity distribution favors spin 2
J=0 disfavored
χ^2/dof=23.4/9

The observed state is χ_{c2}'

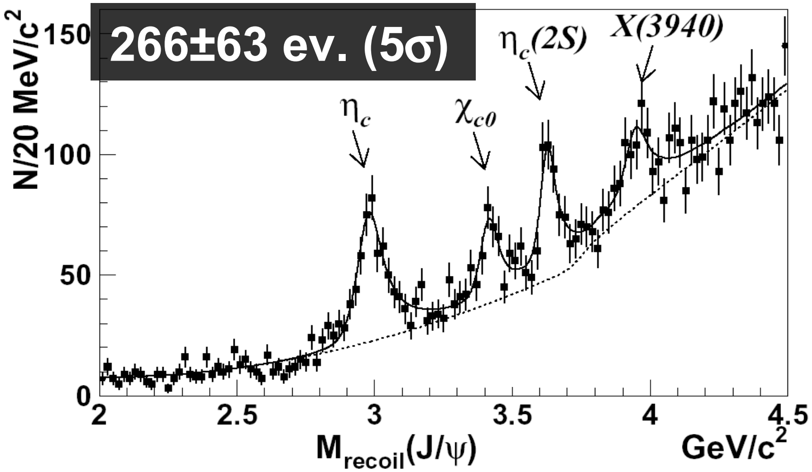
X(3940) in e^+e^- annihilation

2005, L=357fb^{-1}

Reconstruct $J/\psi \to \ell\ell$

Form $M_{recoil}(J/\psi) \equiv M_X$

$$M_{recoil} = \sqrt{(E_{cms} - E^{¿}_{J/\psi})^2 - p^{¿\,2}_{J/\psi}}$$

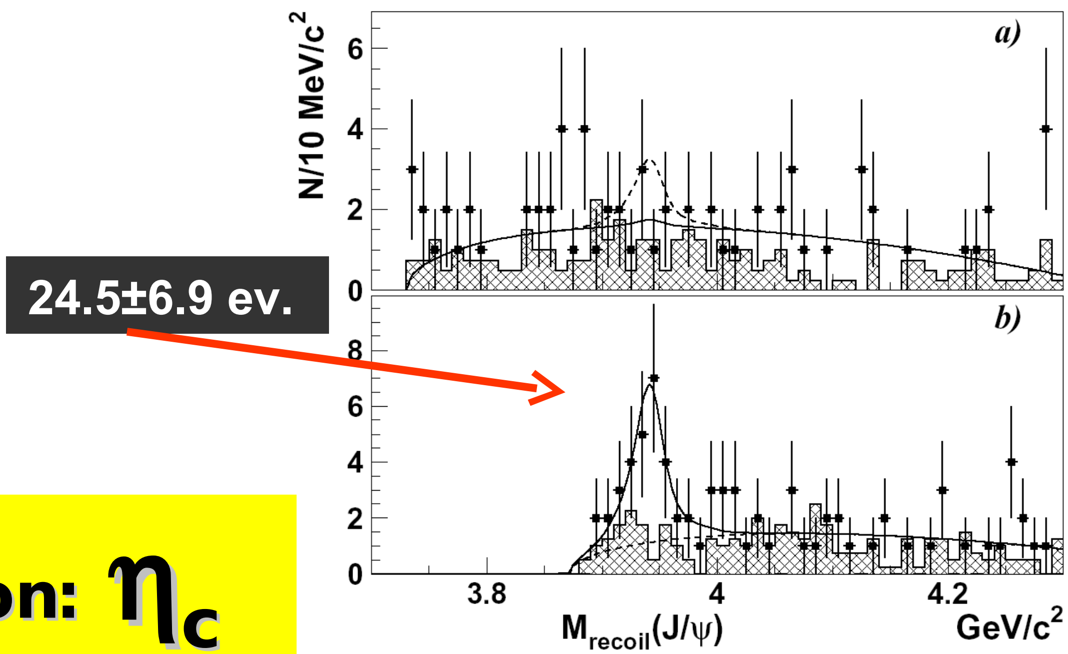


$M_{rec}(J/\psi D) \sim M(D)$ — **B(DD)<41%**

$M_{rec}(J/\psi D) \sim M(D^*)$ — **B(D*D)>45%**

- **Reconstruct J/ψ + D**
- **Refit $M_{recoil}(J/\psi) \to M_{D^{(*)}}$**

From X(3940) → D*D:
M = (3943 ± 6 ± 6) MeV
Γ < 52 MeV at 90%CL

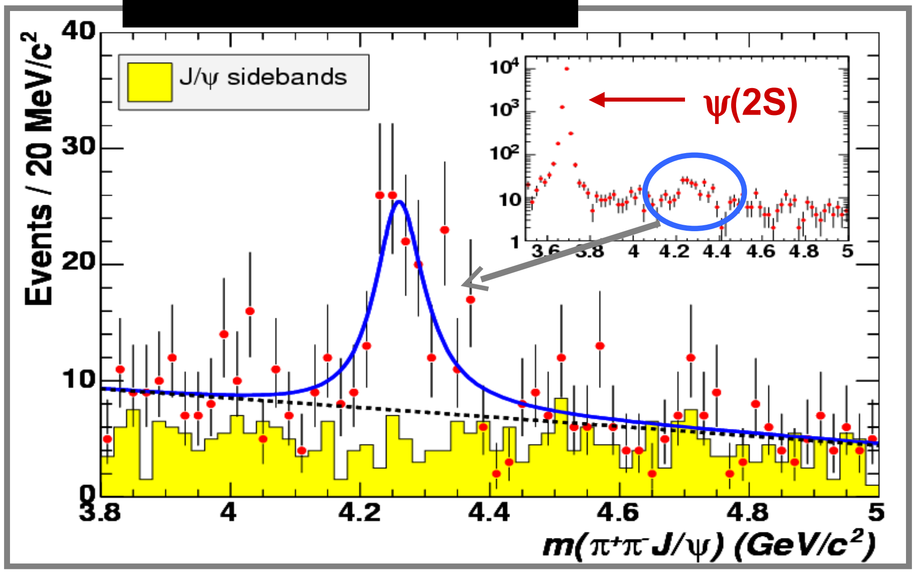


Possible interpretation: η_c

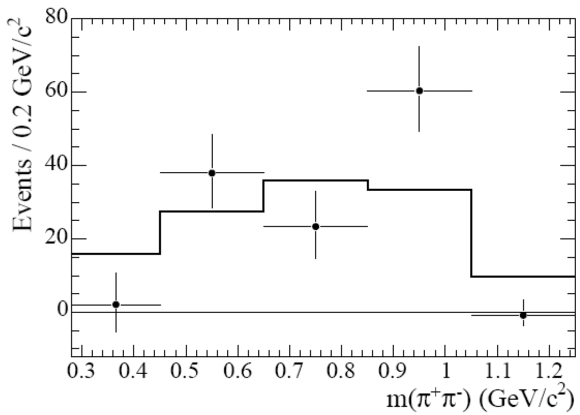
Y(4260) in ISR

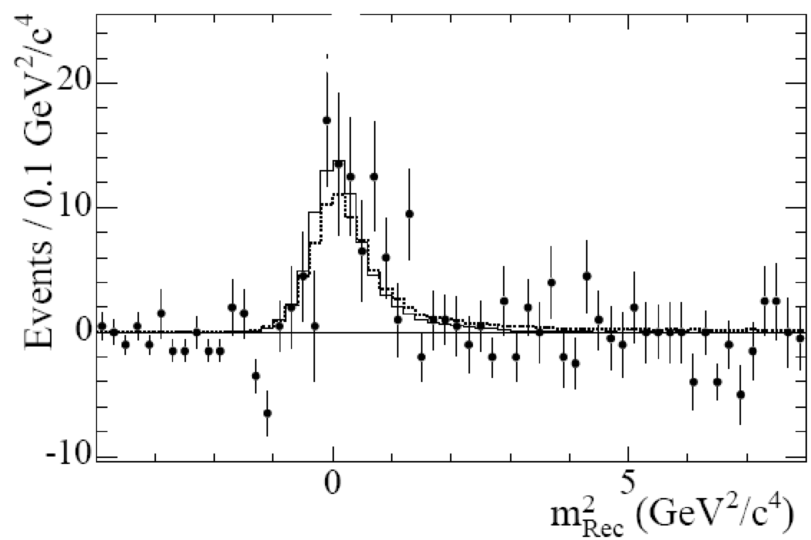
2005, L=357fb^{-1}

[redacted]



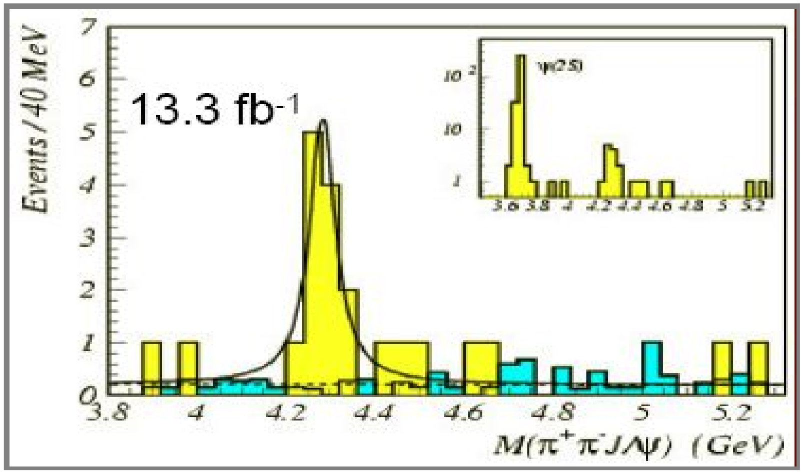
- Observed in ISR events in ($J/\psi\pi\pi$) mass spectrum
- M_Y=4260 MeV/c^2
- Γ = 90MeV/c^2
- Recoil mass ($J/\psi\pi\pi$) is consistent with ISR expectations



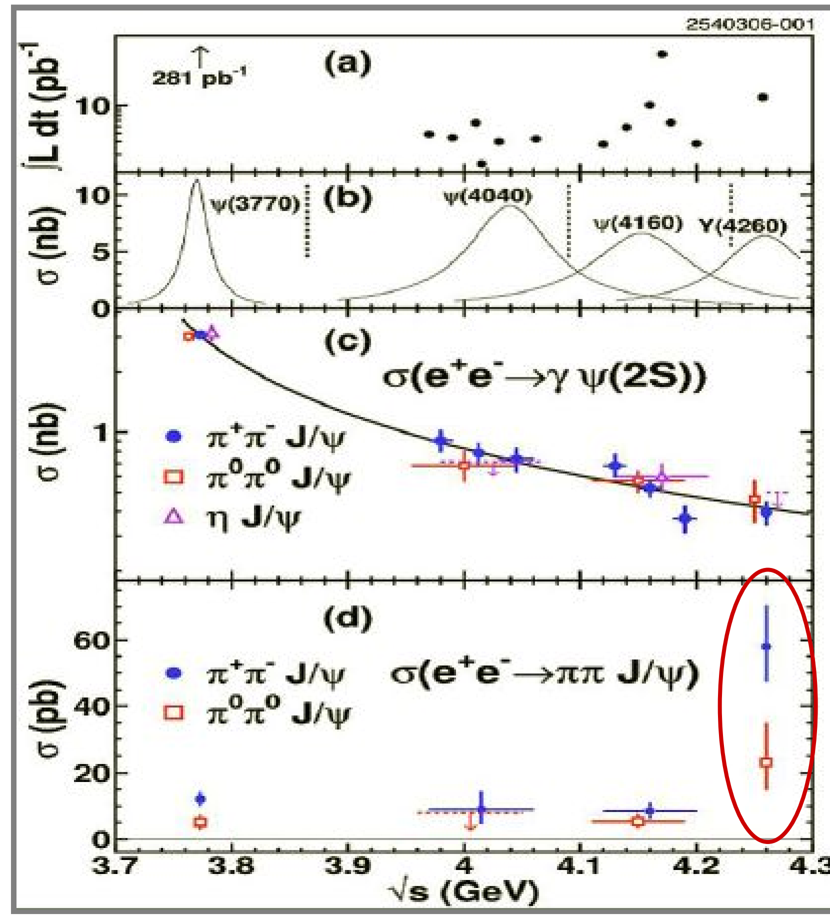


Y(4260) at CLEO

Confirmed by CLEO-III: **L=13.3fb^{-1}**



… and by CLEO-c scan:



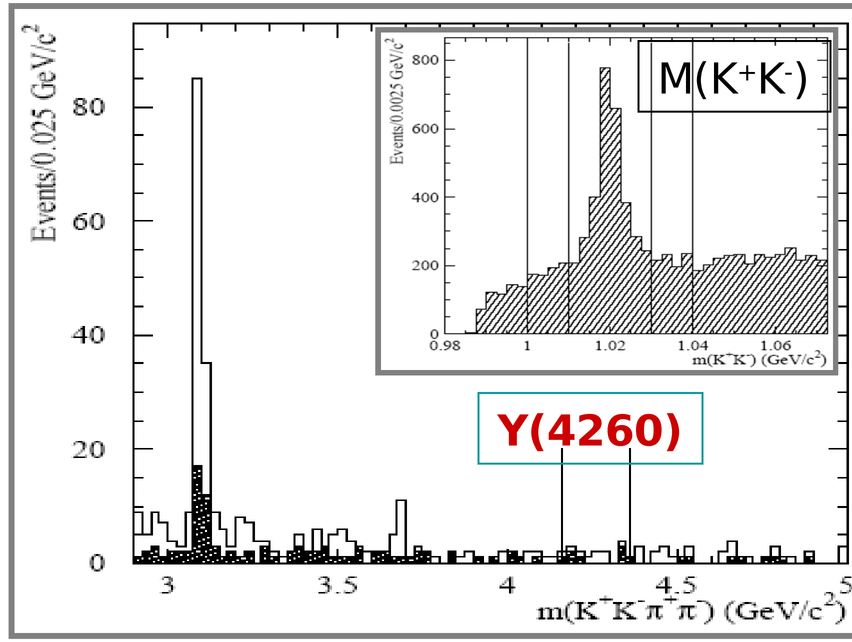
- $\sigma(ee \to J/\psi\pi^+\pi^-) = 58\pm11\pm4$ pb 11 σ
- $\sigma(ee \to J/\psi\pi^0\pi^0) = 23\pm11\pm1$ pb 5.1 σ
- $\sigma(ee \to J/\psi\pi^+\pi^-) = 9\pm9/5\pm1$ pb 3.7 σ

Y(4260): other final states

Y(4260) → $\pi\pi\phi$: no signal

$$\Gamma^{Y}_{ee} \times B(Y(4260) \to \pi^+\pi^-\varphi)$$

¿ 0.4 eV @ 90% CL



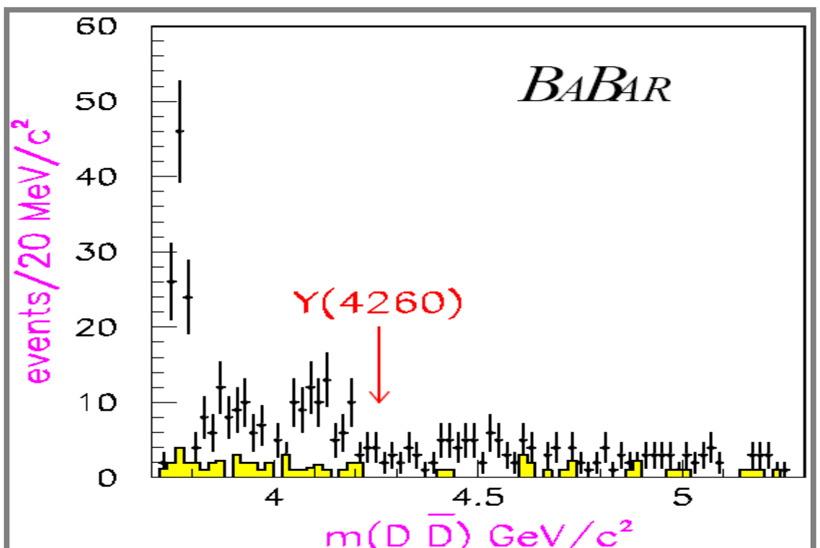
Y(4260) → $p\bar{p}$: nothing seen

$$\frac{B(Y(4260) \to p\bar{p})}{B(Y(4260) \to \pi^+\pi^- J/\psi)} < 0.13 \text{ @ 90\% CL}$$

Not found in Y(4260) → $D\bar{D}$

$$\frac{B(Y(4260) \to D\bar{D})}{B(Y(4260) \to \pi^+\pi^- J/\psi)}$$

< 7.6 @ 95% CL



New charmonium states?

State	Mass (MeV)	Width (MeV)	Decay mode(s)	J^{PC}
X(3872)	3871.2 ± 0.6	<2.3 @ 90% CL	$\pi^+\pi^- J/\psi$ $\gamma J/\psi$ $\underline{D}^0 D^0 \pi^0$	1^{++} I=0
X(3940)	3943 ± 9	<52 @ 90% CL	$D^* \underline{D}$ Not $D\underline{D}$ or $\omega J/\psi$	0^{-+} ?
Y(3940)	3943 ± 17	87 ± 34	$\omega J/\psi$	C=+1 I=0
Z(3930)	3929 ± 6	29 ± 10	$D\underline{D}$	2^{++}
Y(4260)	$4259\ ^{+8}_{-10}$	$88\ ^{+24}_{-23}$	$\pi^+\pi^- J/\psi$, $\pi^0\pi^0 J/\psi$ Not $\pi^+\pi^-\phi$, $D\underline{D}$, $p\underline{p}$	1^{--} I=0

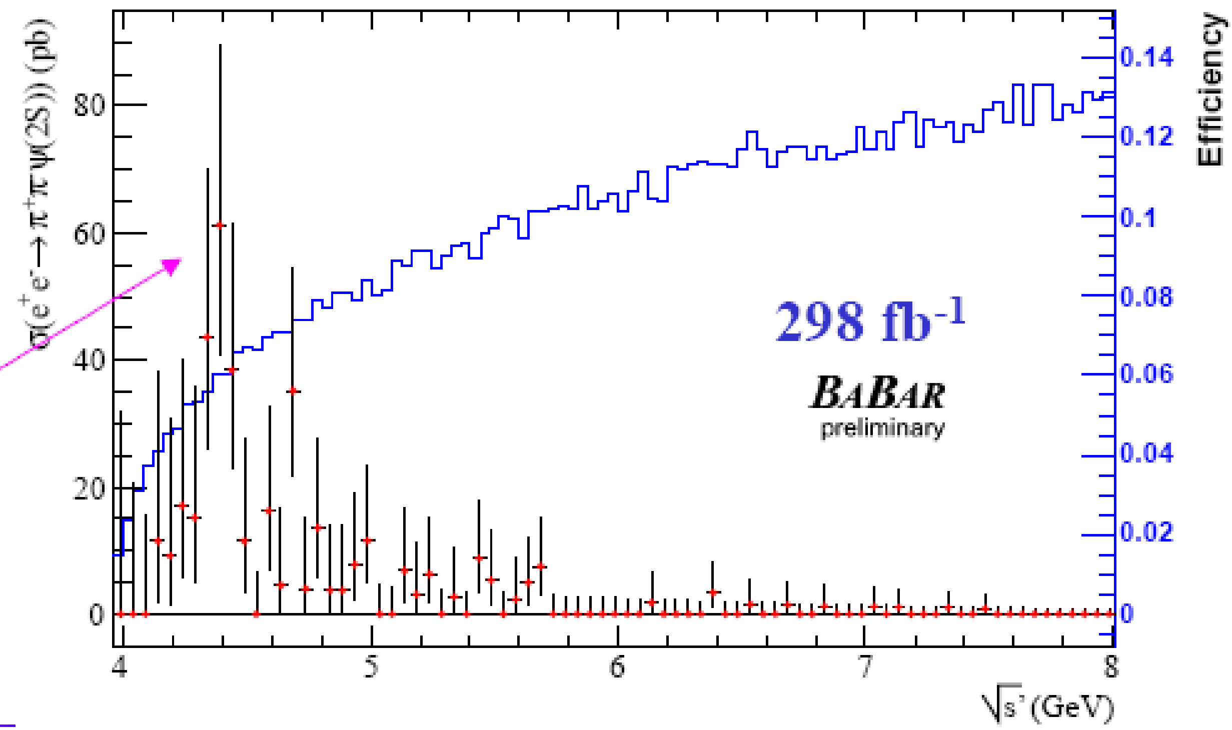
New Structure at 4320 in BaBar ISR data

Cross Section of $e^+e^- \to \psi(2S)\pi^+\pi^-$

w/ bkg subtraction

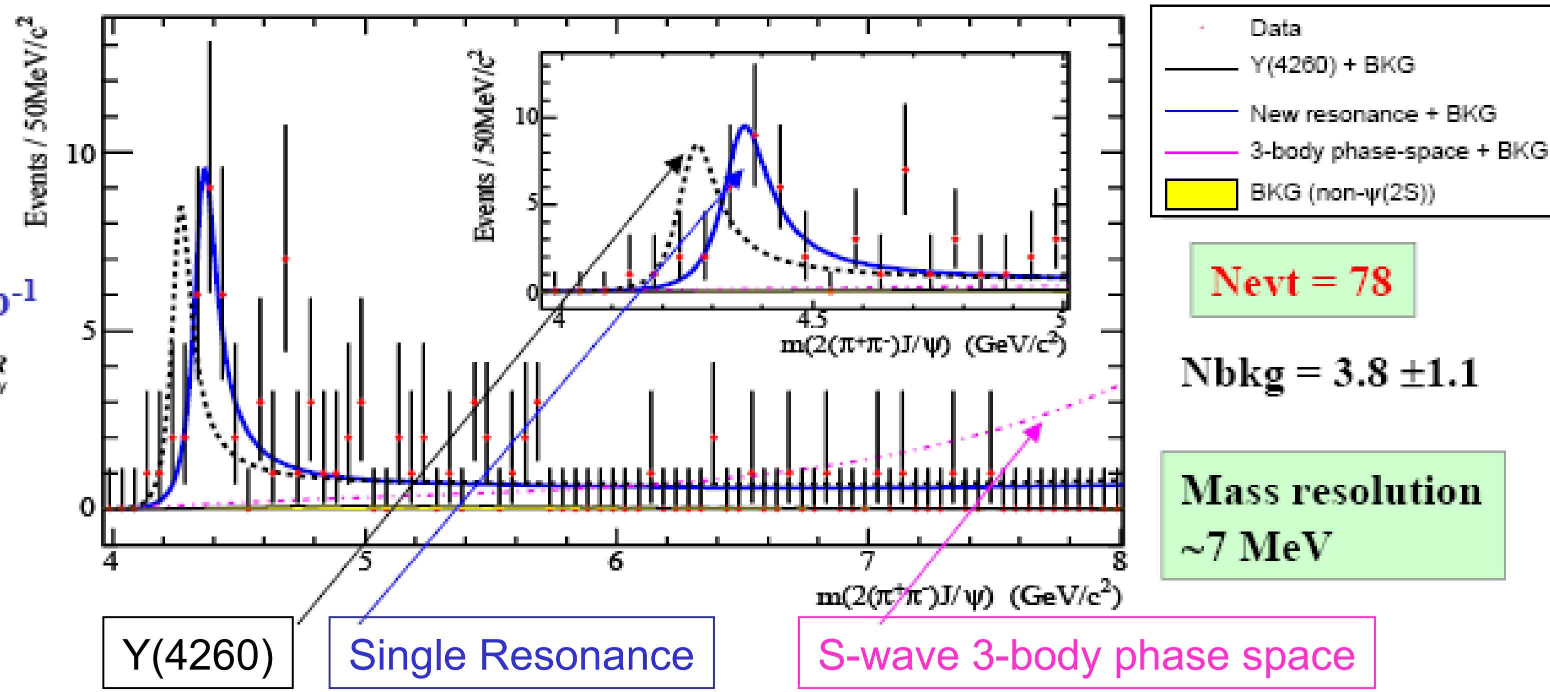
The maximum cross section is about **60 pb around 4.35 GeV**

A structure!



$298\ fb^{-1}$

BABAR preliminary



Nevt = 78

Nbkg = 3.8 ±1.1

Mass resolution ~7 MeV

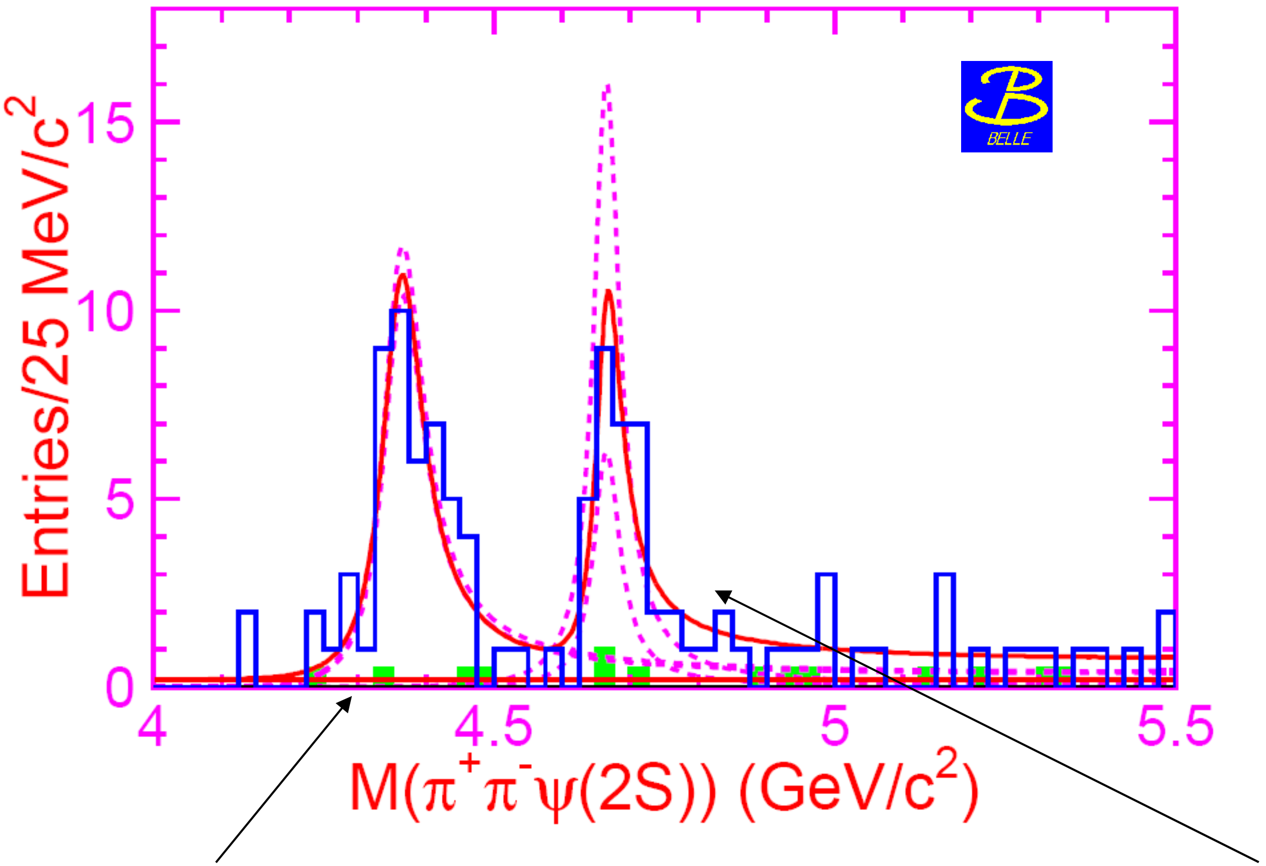
Incompatible with Y(4260), ψ(4415) or phase space.

Assuming single resonance:

$$M = 4324 \pm 24\ MeV/c^2$$
$$\Gamma = 172 \pm 33\ MeV$$

PRL 98, 212001 (2007)

New Vector State Observed by Belle



M = 4361 ± 9 ± 9 MeV
Γ = 74±15 ± 10 MeV

M = 4664 ± 11 ± 5 MeV
Γ = 48 ± 15 ± 3 MeV

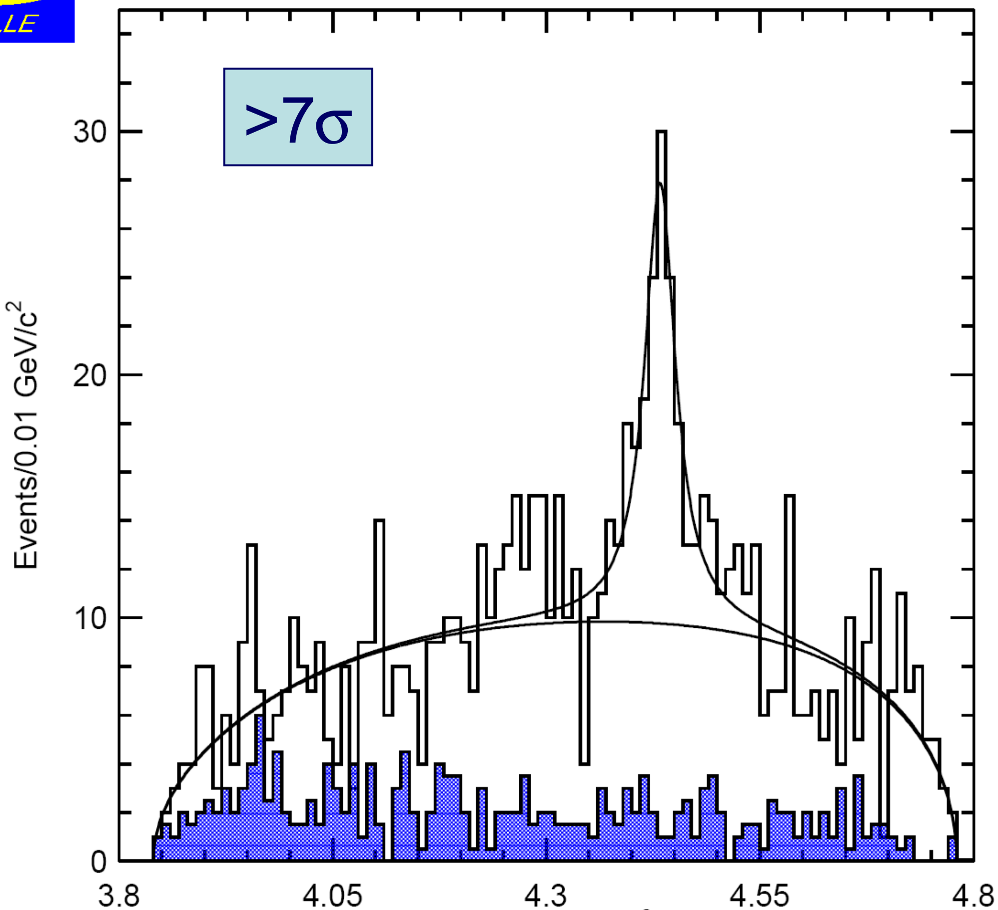
A New Charged State from Belle

- Study of $B \to K\pi^{\pm}\psi'$ decay
- Structure in $\pi^{\pm}\psi'$ invariant mass
- $B^{\pm}$ e B^0 consistent
- Too narrow for a reflection
- First evidence of a charged state in charmonium mass region
- Work in progress in BaBar

$$M = 4433 \pm 4 \pm 1 \ MeV/c^2$$

$$\Gamma = 44^{+17+30}_{-13-11} \ MeV$$

arXiv:0708.1790



$M(\pi^+\psi')(GeV/c^2)$

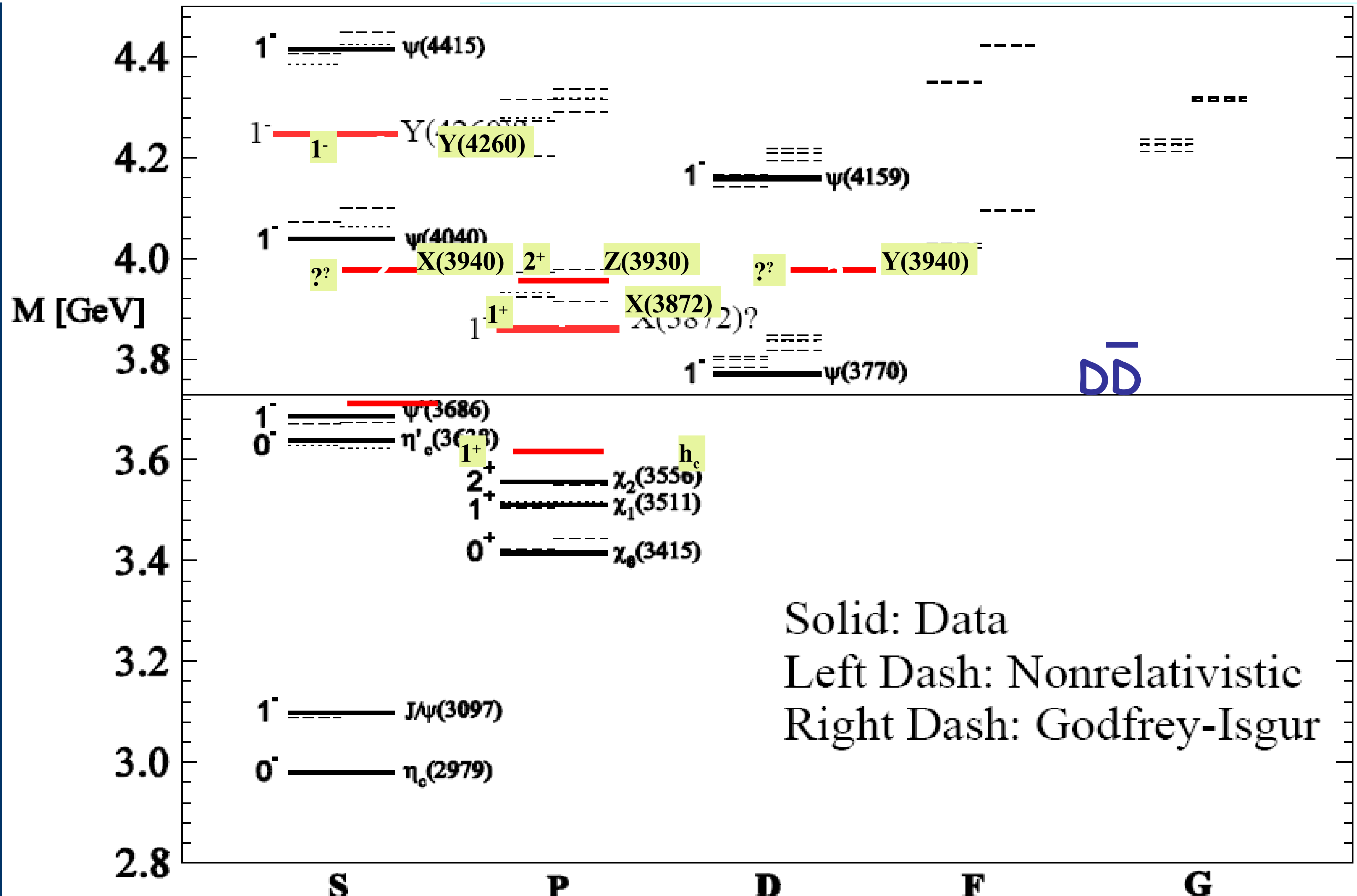
$$BR(B \to ZK) \times BR(Z \to \psi' \pi) = (4.1 \pm 1.0 \pm 1.3) \times 10^{-5}$$

The XYZ of Charmonium

- The Z(3931) is tentatively being identified with the $\chi_{c2}(2P)$
  - Width too small ?
- The X(3940) is tentatively being identified with the $\eta_c(3S)$
  - Width too large ?
- Many other states have been discovered whose interpretation is not at all clear: X(3872), Y(3940), Y(4260), Y(4320), Y(4660), Z(4430) ...
  - missing $c\bar{c}$ states
  - molecules
  - tetraquarks
  - hybrids

The situation above threshold needs to be fully understood.

Charmonium spectroscopy



Charmed and Strange Mesons

CHARMONIUM

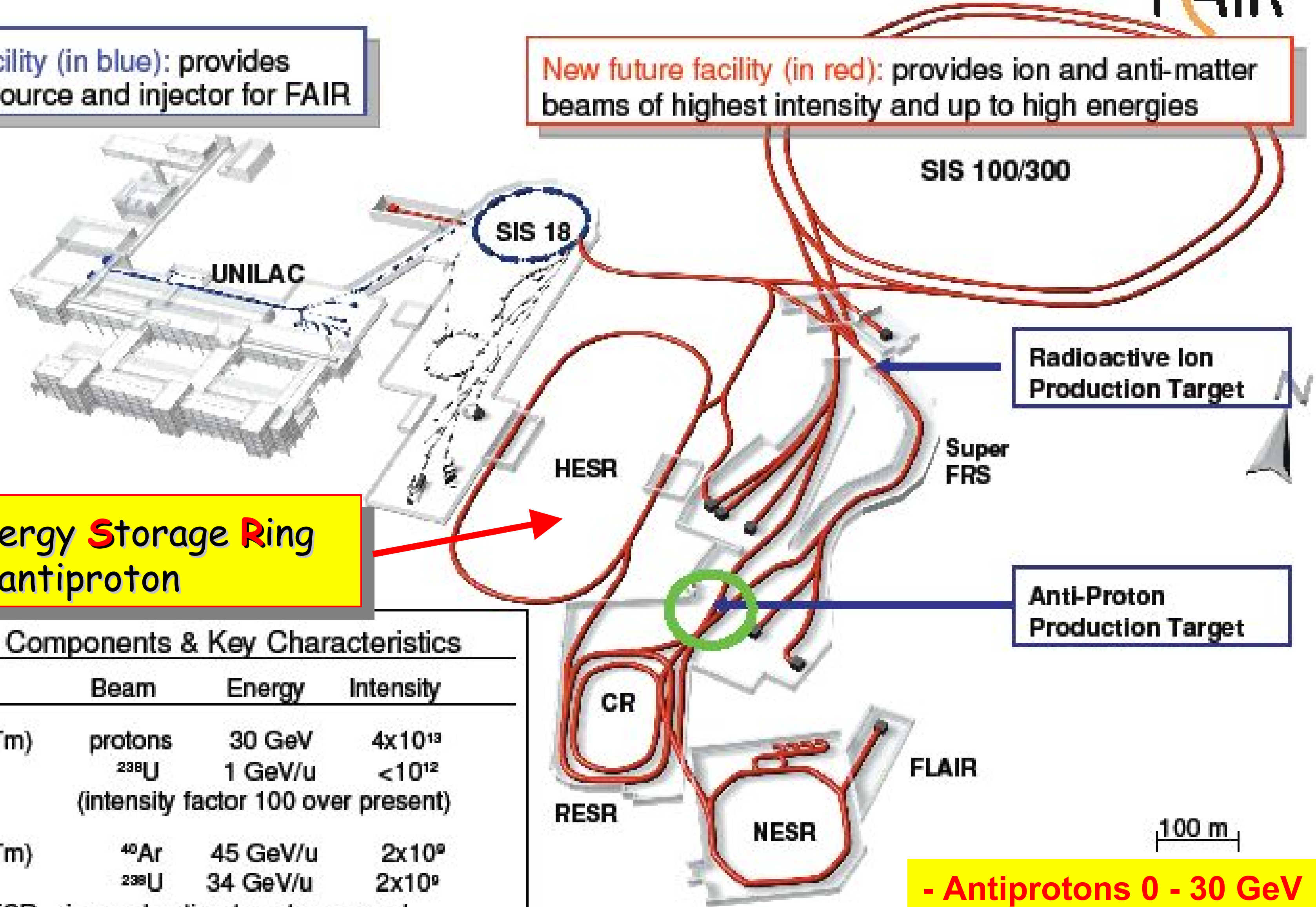
SEARCH AT FAIR

GSI-Darmstadt **FAIR:** International **F**acility for **A**ntiproton and **I**on **R**esearch

Technical Realization of FAIR

Existing facility (in blue): provides ion-beam source and injector for FAIR

New future facility (in red): provides ion and anti-matter beams of highest intensity and up to high energies



High Energy Storage Ring for antiproton

Accelerator Components & Key Characteristics

Ring/Device	Beam	Energy	Intensity
SIS100 (100Tm)	protons	30 GeV	4×10^{13}
	^{238}U	1 GeV/u	$<10^{12}$
	(intensity factor 100 over present)		
SIS300 (300Tm)	^{40}Ar	45 GeV/u	2×10^{9}
	^{238}U	34 GeV/u	2×10^{9}
CR/RESR/NESR	ion and antiproton storage and experiment rings		
HESR	antiprotons	14 GeV	$\sim10^{11}$
SuperFRS	rare-isotope beams	1 GeV/u	$<10^{9}$

- Antiprotons 0 - 30 GeV

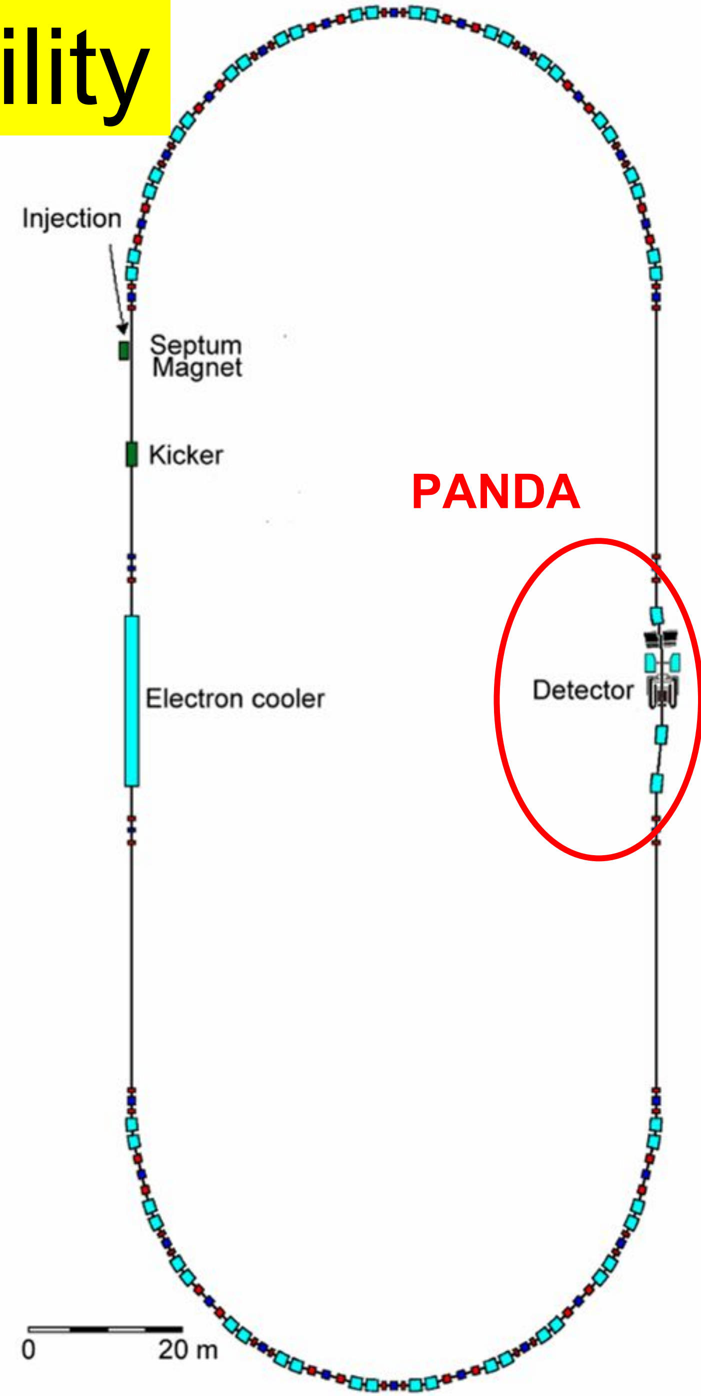
- 10^{11} stored and cooled 0.8 - 14.5 GeV antiprotons
- Polarized antiprotons(?)

HESR the Antiproton Facility

- Antiproton production similar to CERN,
- HESR = High Energy Storage Ring
  - Production rate 10^7/sec
  - P_{beam} = 1.5 - 15 GeV/*c*
  - N_{stored} = 5 x 10^{10} anti-p
- Gas-Jet (or Cluster) Target
- High luminosity mode
  - Luminosity = 2 x 10^{32} $cm^{-2}s^{-1}$

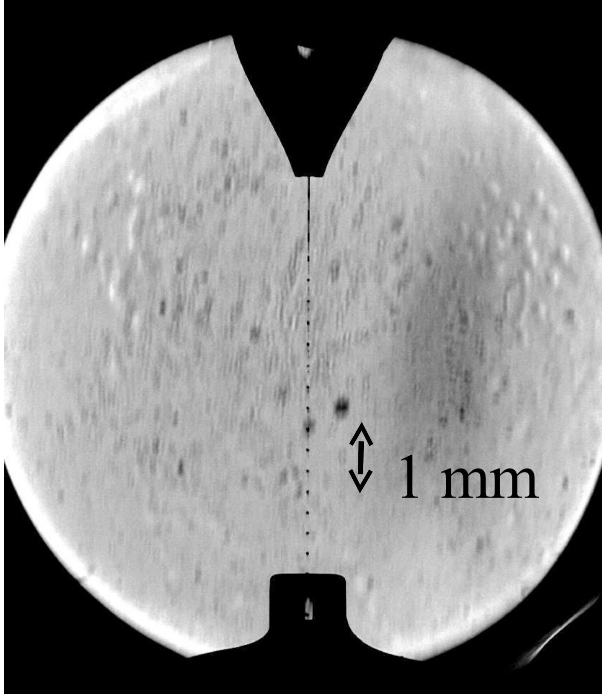
    $\Delta p/p \sim 10^{-4}$ (stochastic cooling)
- High resolution mode

    $\Delta p/p \sim 10^{-5}$(electron cooling<8 GeV/*c*)
  - Luminosity = 10^{31} $cm^{-2}s^{-1}$

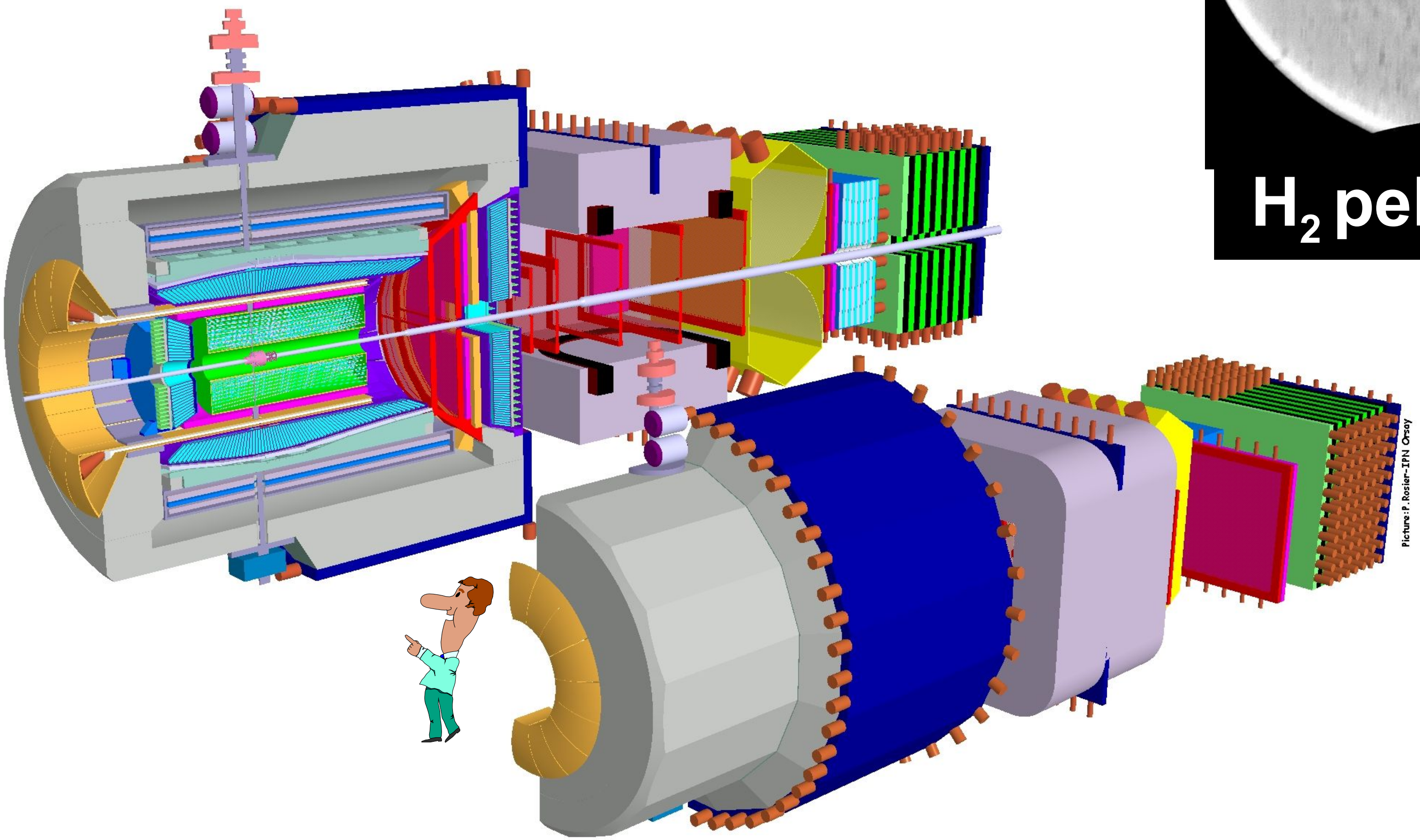


PANDA DETECTOR

- **measurement and identification of γ, $e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$, $K^{\pm}$, p, barions**
- **γ resolution < 2%** ($PbWO_4$)
- **Charged part. $\Delta p/p$ < 1%**



H_2 pellet target



The Physics Program of $\bar{P}$ANDA

∀ $\bar{p}p$ annihilation is well adapted for the systematic, precise spectroscopy of known states:
  - Mass measurements with < 100 KeV accuracy
  - Total width determination, even for very narrow states

∀ $\eta_c(1S)$ mass, total width, decays.

∀ $\eta_c(2S)$ mass, total width, decays.

- h_c mass, total width, decays.
- angular distributions in the radiative decays of the χ_c states.
- J^{PC} of newly discovered states ⇒ measure angular distribut.
- Systematic scan of region above $\bar{D}D$ threshold.
- Radiative and strong decays, e.g. $\psi(4040) \rightarrow D^* \bar{D}^*$ and $\psi(4160) \rightarrow D^* \bar{D}^*$, multi amplitude modes which can test the mechanisms of the open-charm decay.

CHARMONIUM WITH PANDA

- At $2\times10^{32}cm^{-2}s^{-1}$ accumulate 8 pb^{-1}/day (assuming 50 % overall efficiency) ⇒ $10^4\div10^7$ ($c\bar{c}$) states/day.
- Total integrated luminosity 1.5 fb^{-1}/year (at $2\times10^{32}cm^{-2}s^{-1}$, assuming 6 months/year data taking).
- Improvements with respect to Fermilab E760/E835:
  - Up to ten times higher instantaneous luminosity.
  - Better beam momentum resolution $\Delta p/p = 10^{-5}$ (GSI) vs 2×10^{-4} (FNAL)
  - Better detector (higher angular coverage, magnetic field, ability to detect hadronic decay modes).
- Fine scans to measure masses to ≈ 100 KeV, widths to ≈ 10 %.
- Explore entire region below and above open charm threshold.
- Decay channels:
  - $J/\psi+X$, $J/\psi \to e^+e^-$, $J/\psi \to m^+m^-$
  - gg
  - hadrons
  - $D\bar{D}$

With the antiproton FAIR program it is possible to study the decay mode like:

$$\eta_c \Rightarrow \eta\pi\pi$$

$$\eta_c \Rightarrow \eta'\pi\pi$$

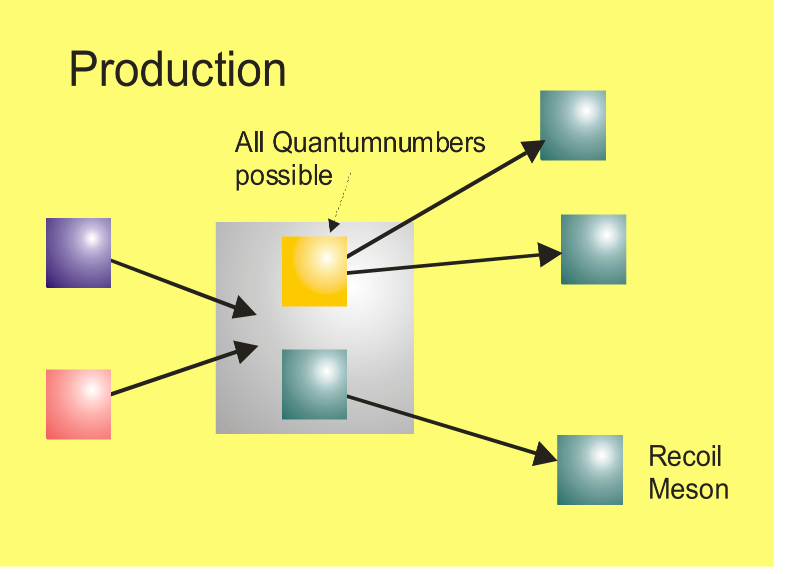
$$\eta_c \Rightarrow \bar{K}K\pi$$

each of them of the order of 5%

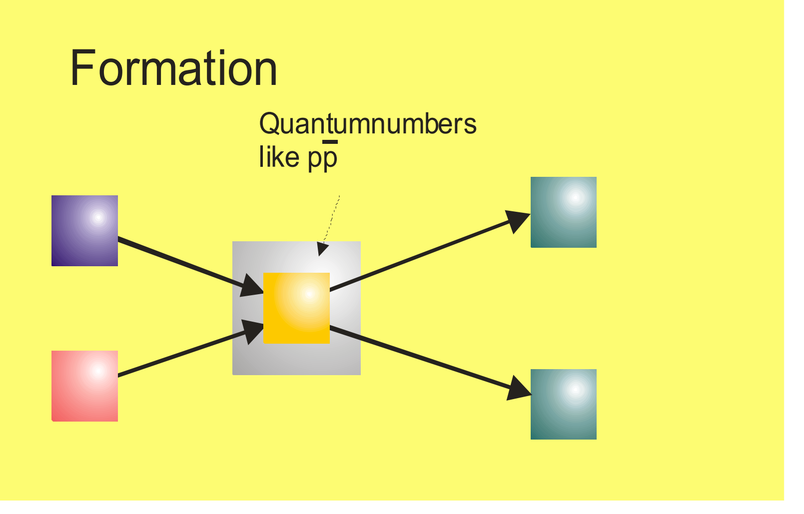
as suggested by Bjorken should be an important experimental test for models related to confinement and vacuum structure.

Charmonium Hybrids $c\bar{c}g$

- Gluon rich process creates gluonic excitation in a direct way
  - $c\bar{c}$ requires the quarks to annihilate (no rearrangement)
  - yield comparable to charmonium production

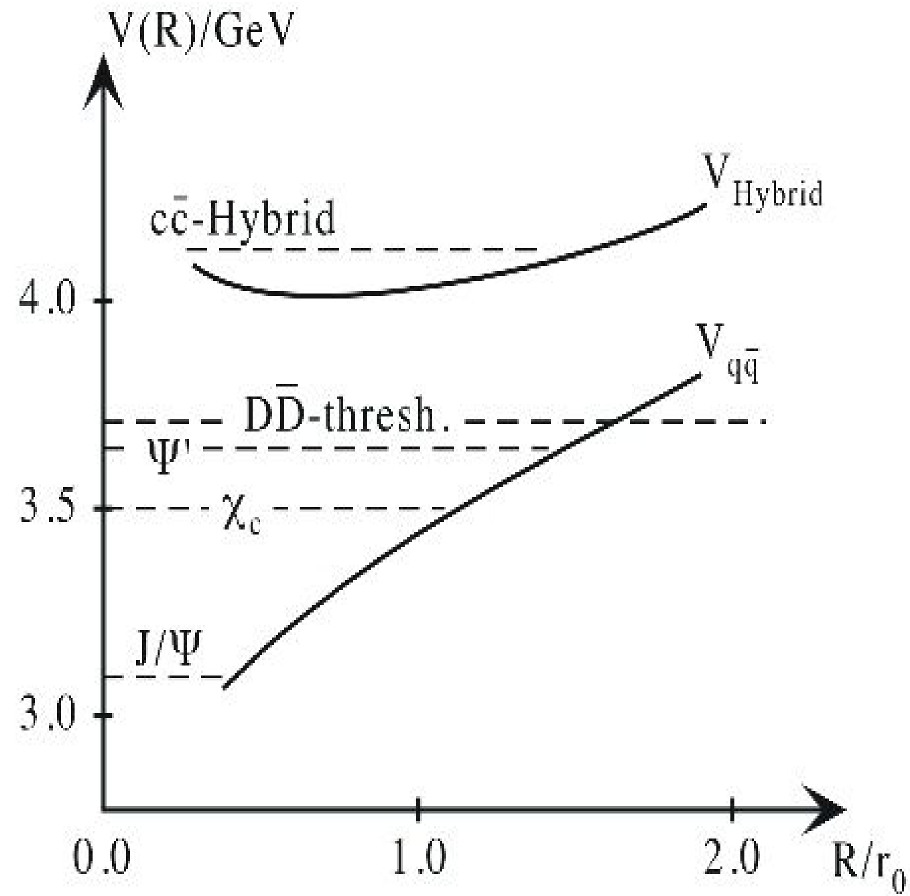


- two complementary techniques
  - Production (Fixed-Momentum)
  - Formation (Broad- and Fine-Scans)



Charmonium Hybrids

- Bag model, flux tube model constituent gluon model and LQCD.
- Three of the lowest lying $c\bar{c}$ hybrids have exotic J^{PC} (0^{+-}, 1^{-+}, 2^{+-}) $\Rightarrow$ no mixing with nearby $c\bar{c}$ states
- Mass 4.2 – 4.5 GeV/c^2.
- Charmonium hybrids expected to be much narrower than light hybrids (open charm decays forbidden or suppressed below DD** threshold).



- Cross sections for formation and production of charmonium hybrids similar to normal $c\bar{c}$ states (~ 100 – 150 pb).

More than 30 years after the discovery of the J/ψ, charmonium physics continues to be an exciting and active field of research.

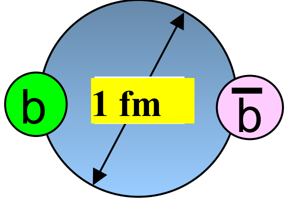
- Advances in experiment: discovery of expected and unexpected states (mostly at the B-factories)
- Advances in theory: LQCD, EFT, models ...

Still, the knowledge of the spectrum is far from complete.

A systematic high-precision study of all known states and the search for missing states will be carried out in $\bar{p}p$ annihilations by PANDA at FAIR.

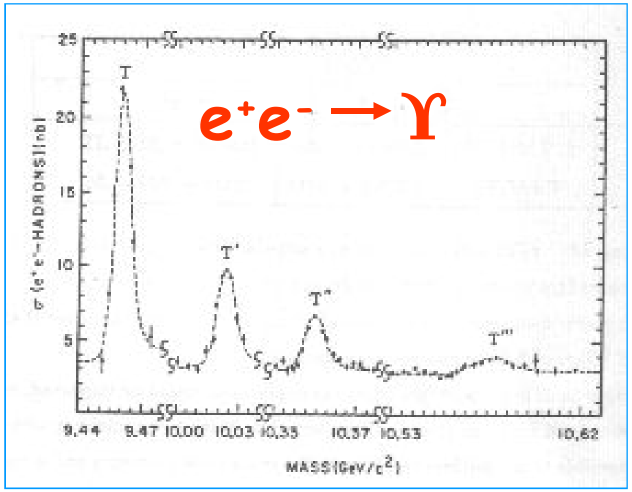
Bottomonium physics with antiprotons.

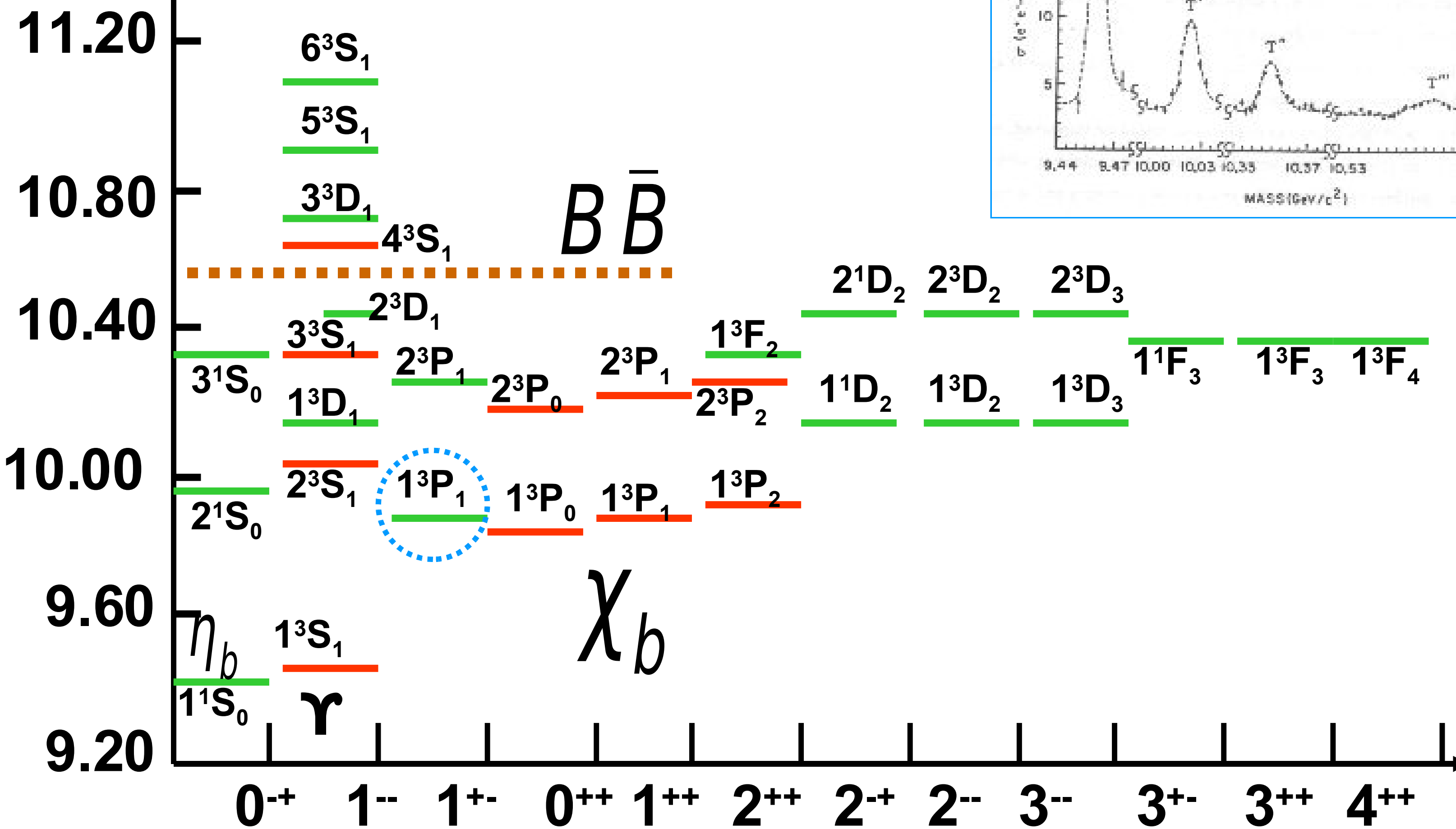
The mass: m_b=4.5GeV of the quark reduce the relativistic corrections on QCD and let theoretical prediction of the order of some %.
Some measurements of masses and width are crucial to determine the QCD potential parameters.



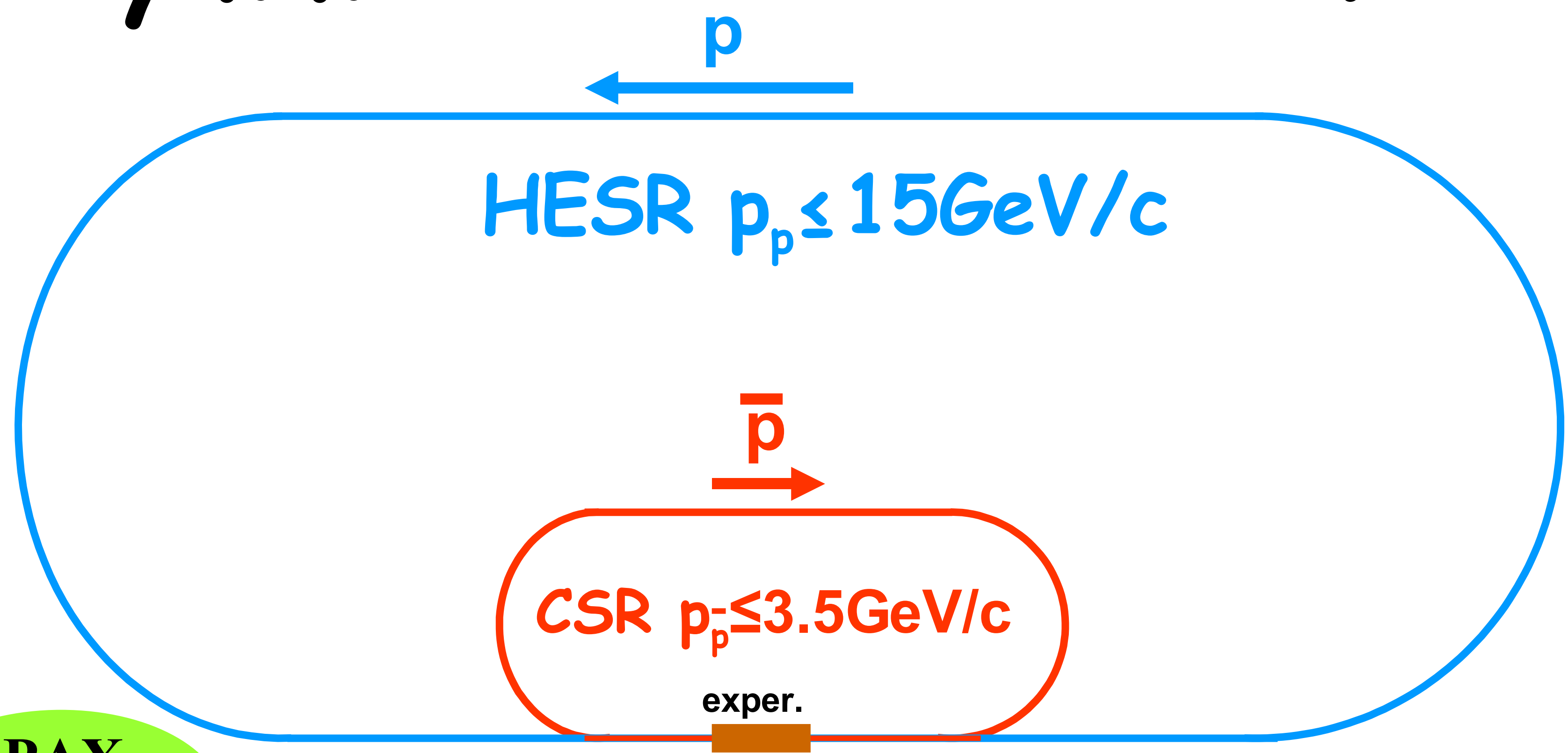
Bottomonium spectrum

Expected very narrow states





Asymmetric collider at FAIR



PAX proposal

$$p \Rightarrow \qquad \Leftarrow \bar{p}$$

$$E_{cm} \leq 14 GeV/c^2$$

The E_{cm} range cover the bottomonium states

With a high intensity antiproton source could reach a luminosity of $10^{32} cm^2 s^{-1}$

TRIGGER: It is necessary an experimental set up "Panda like" able to trigger and reconstruct baryons, pions, kaons, gammas, electrons and muons.

-A cut on large p_t should decrease the

background by a factor until of 10^7.

-The asymmetric collider magnify the distance between the formation vertex and the decay of bottomonium states

CROSS SECTIONS

not measured yet

$\sigma(\Upsilon \rightarrow hh)$

cannot evaluate

$\sigma(p\bar{p} \rightarrow \Upsilon)$

A rough and non optimistic QCD evaluation

$$\frac{\sigma(p\bar{p} \Rightarrow c\bar{c})}{\sigma(p\bar{p} \Rightarrow b\bar{b})} \approx \frac{m_c^4}{m_b^4} \approx 10^{-4}$$

Also in this case we can expect rates similar to experiment E835 at Fermilab on charmonium. We can have:

- -More than a factor ~100 using the hadronic trigger.
- -A factor ~3 in the acceptance.
- -A factor ~5 because the states are very narrow.
- -A factor ~10 in luminosity.

The experiments on heavy quark can give important contribution to the physics, for example: can determine the free parameters of QCD.

The complicated pattern of the physics of light quarks is related to the first order of vacuum perturbations.
Can we use QCD tested with heavy quarks, as a tool to study the vacuum structure?

We can expect from the FAIR $p\bar{p}$ program big contributions on heavy quarks physics.

The success will be proportional to the intensity of antiproton source.