Baryonium
a common ground for atomic and high energy physics

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Content

Old failures

Contemporary signals

$J/\Psi \rightarrow N \bar{N} \gamma$ $J/\Psi \rightarrow (\pi\pi\eta')_x \gamma$

antiprotonic atoms

radiochemical studies of $\bar{p}$ absorption in nuclei

TOPICS at CERN 1980-90

- 2 quark – 2 antiquark

- ●● $\bar{N}$ – N quasi-bound states

  N N → N $\bar{N}$

  G – parity transformation $V\pi$ → - $V\pi$

  No Pauli exclusion - many quasi-bound states

p-pbar$_{STOPPED}$ → γ + X ADIELS/ CERN

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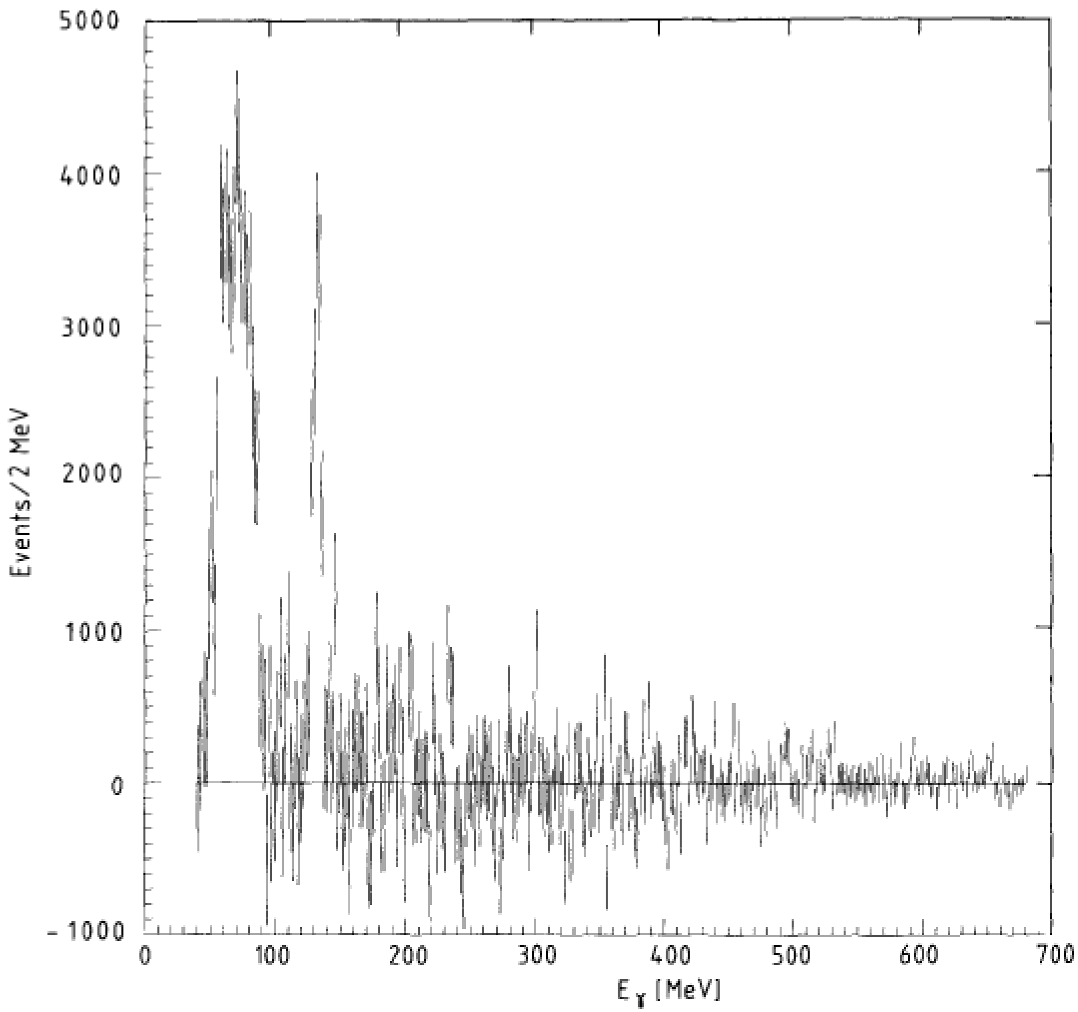


Fig. 2. γ-spectrum after subtracting a smooth background as described in the text. The two structures are due to the reactions $\pi^- + p \to \pi^0 + n$ and $\pi^- + p \to \gamma + n$.

LARGE

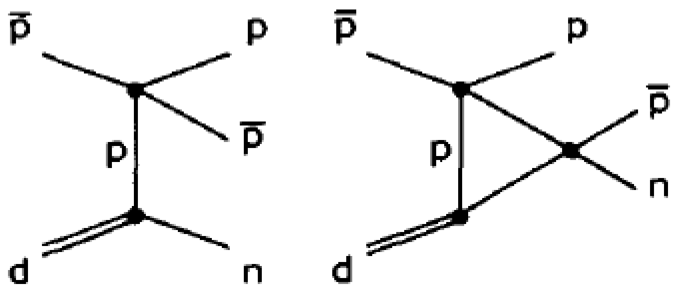
BACKGROUND

could be better

at higher energy

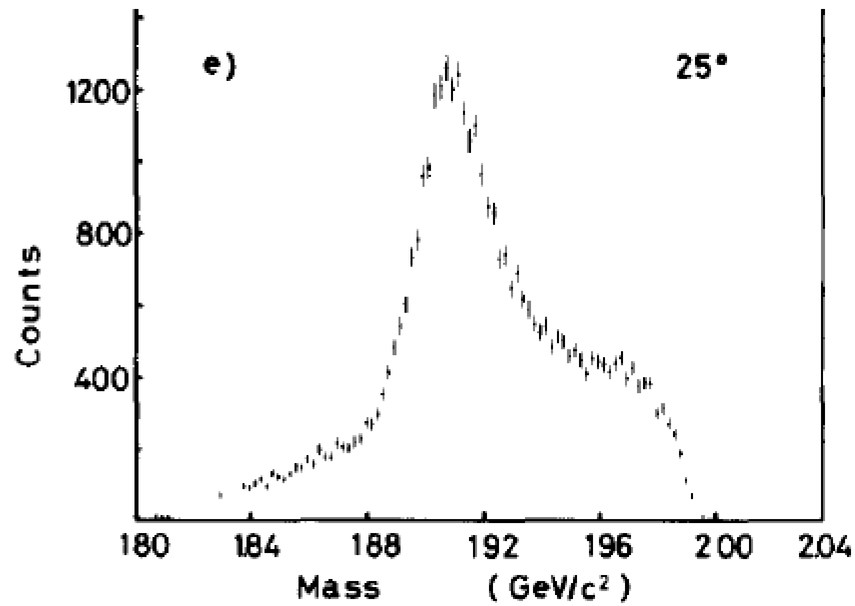
R. Bertini… Nucl.Ph. B209(82)269

1.3 GeV/c   p-bar d → p X



Missing mass
dσ/dω <8 μb/str

too many partial waves
at lower momentum
It would be better



NEW ERA

Decays of charmonium $\rightarrow$

nucleon – antinucleon

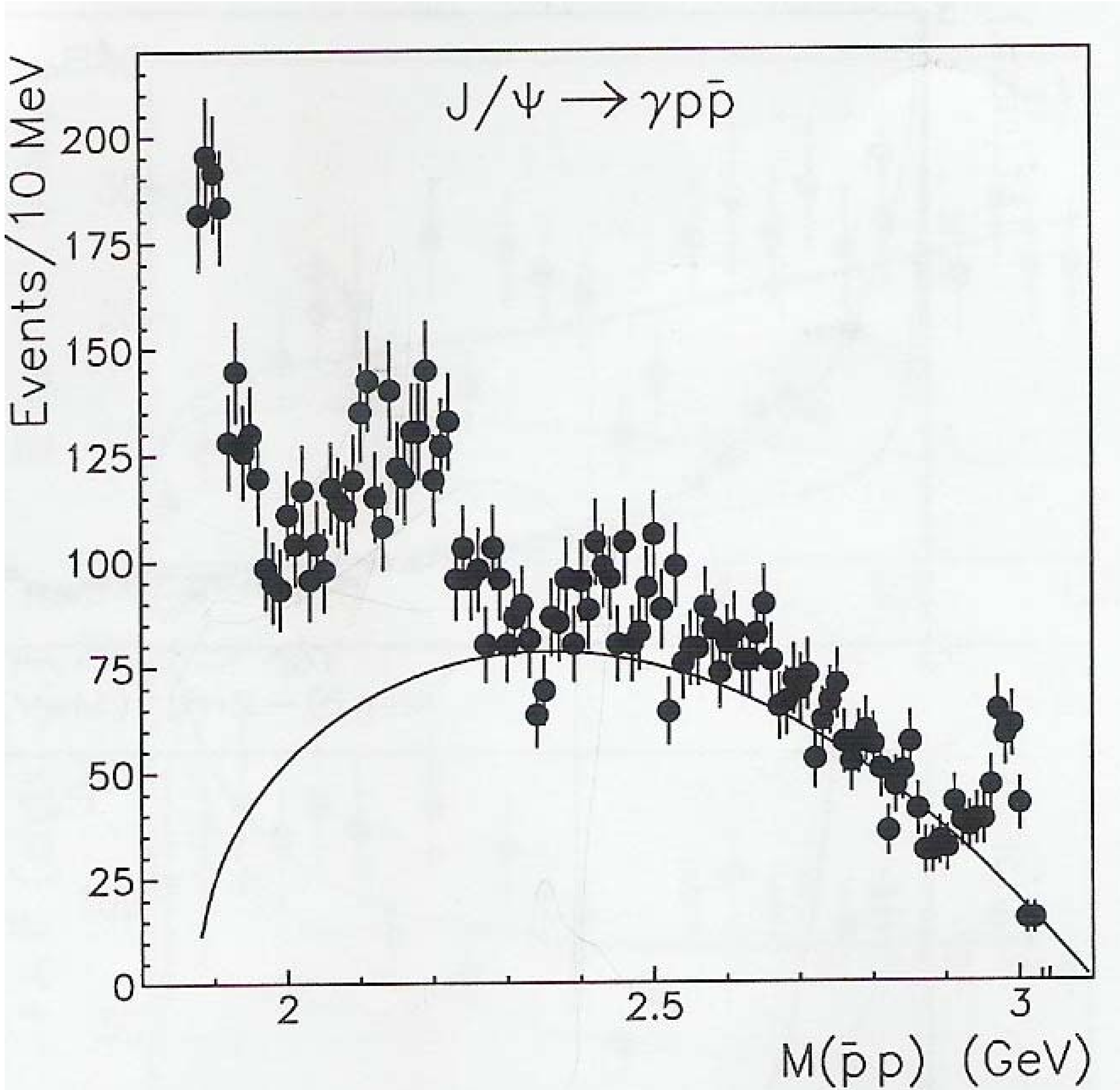
Selective BES experiments

$$J/\psi \to \gamma p\bar{p}$$

decay mode	analogue	$J^{PC}[\gamma \text{ or } \pi^0]$	$J^{PC}[p\bar{p}]$	relative l
$\gamma p\bar{p}(^1S_0)$	$\gamma\eta(1405)$	1^{--}	0^{-+}	1
$\gamma p\bar{p}(^3P_0)$	$\gamma f_0(1710)$	1^{--}	0^{++}	0
$\gamma p\bar{p}(^3P_1)$	$\gamma f_1(1285)$	1^{--}	1^{++}	0

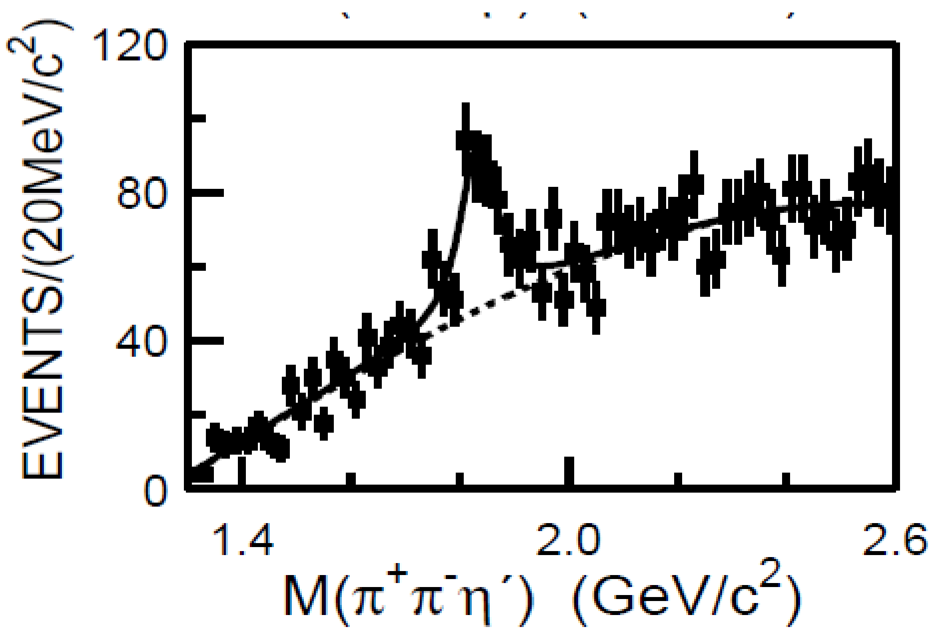
Strong final state
attraction in $1\ S_0$ in particular in isospin 0

BES:
X(1878)
X(2170)



X(1835) by BES

$$\mathrm{J}/\psi \to \gamma\pi^+\pi^-\eta'$$



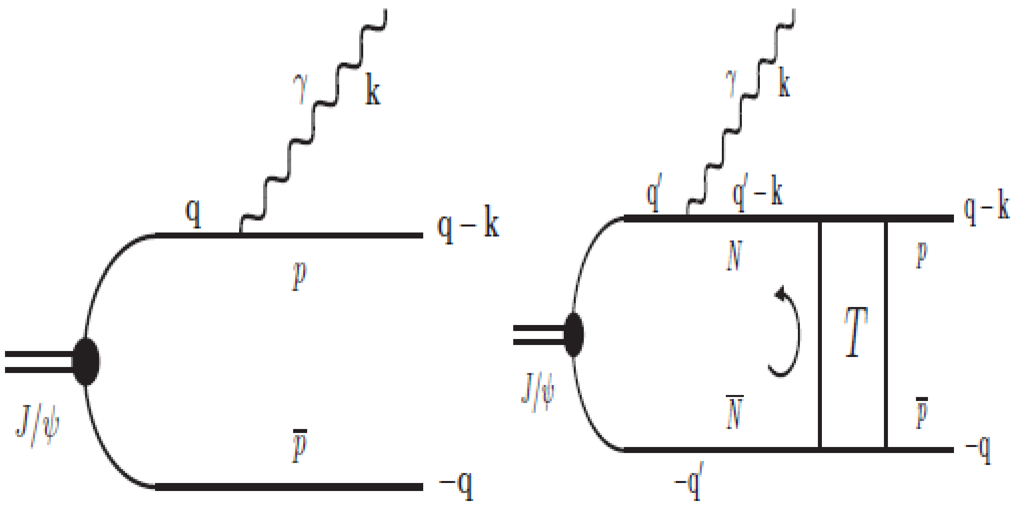
A model for final state meson emission

works for π, ω, Φ -   spectrum and rate

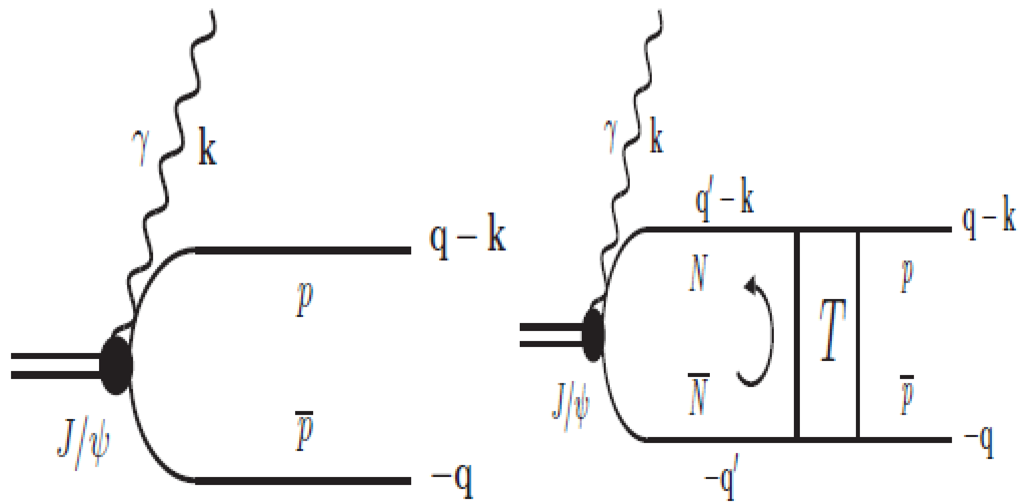
fails for γ – no peaks, rate too small

J-P.D,B.L,SW

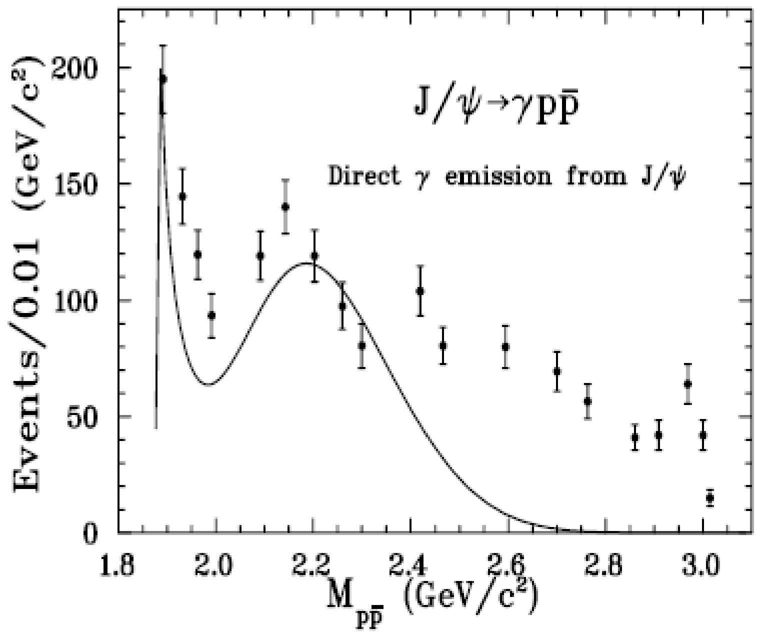
$$J/\psi \to N\bar{N}$$



Radiation before/during hadronisation

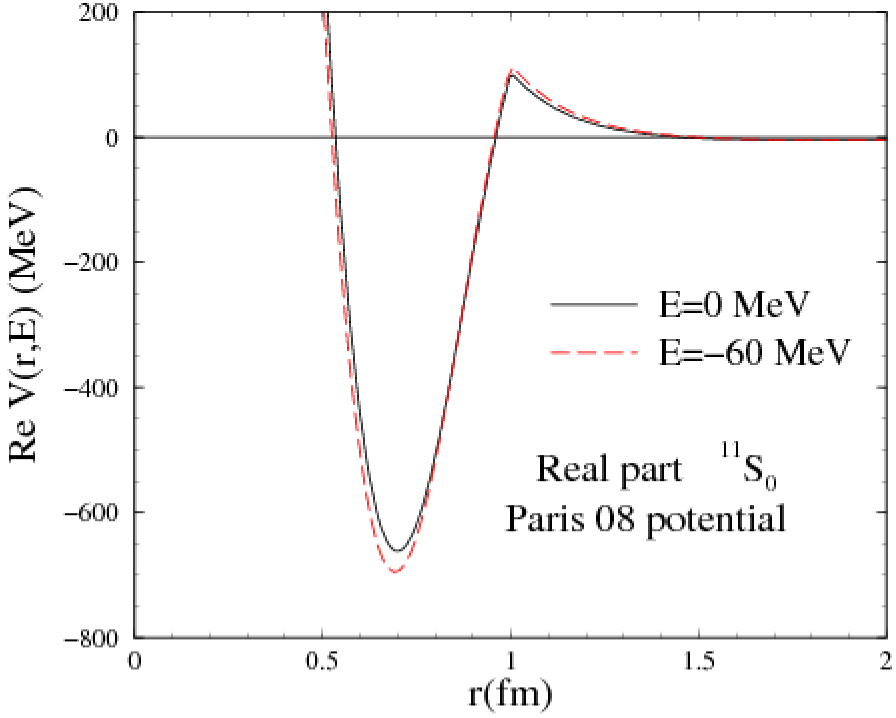


Two Peaks bound (or virtual state) and Shape resonance



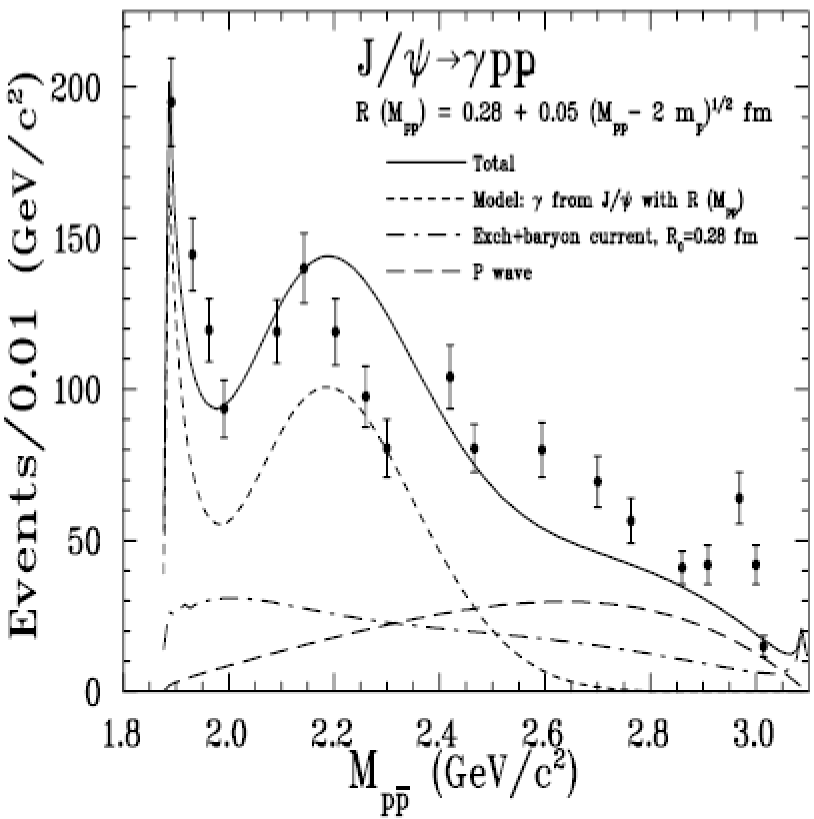
Nature of the peak may be seen under the

Potential in ^{11}S Paris



Paris,Bonn, Paris,K-W, D-R, B-P potentials

To discern – go under threshold

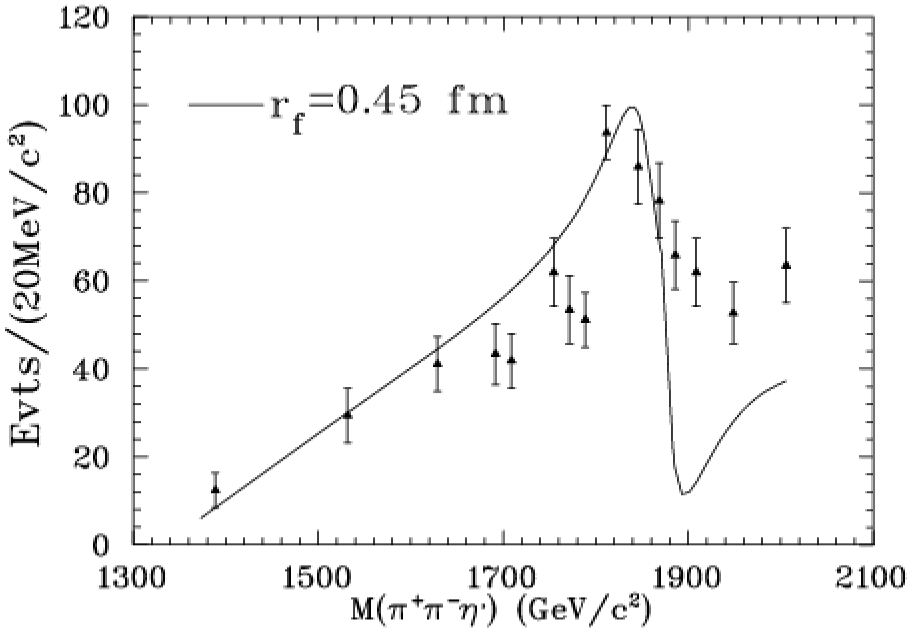


$J/\psi \to \gamma pp$
R (M_{pp}) = 0.28 + 0.05 (M_{pp} – 2 m_p)$^{1/2}$ fm
Total
Model: γ from J/ψ with R (M_{pp})
Exch+baryon current, R_0=0.28 fm
P wave
Events/0.01 (GeV/c^2)
$M_{p\bar{p}}$ (GeV/c^2)

Below threshold

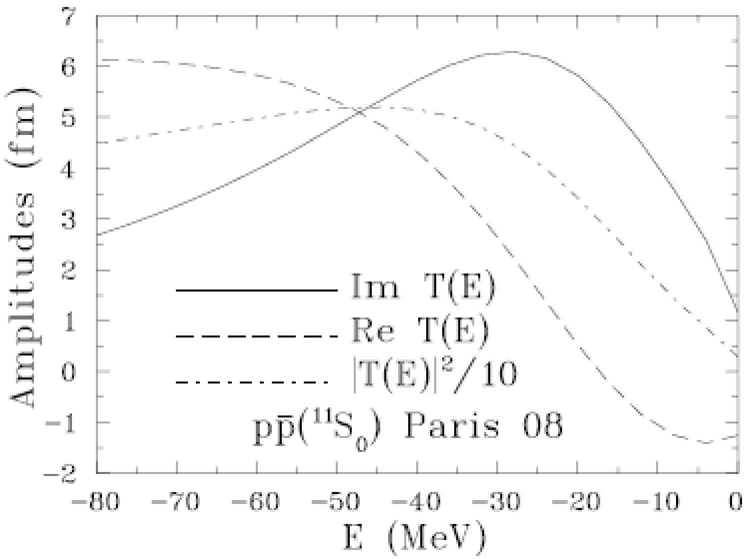
X(1835) is an interference of „extended „ bound state

PARIS POTENTIAL INTERPTETATION



^1S amplitude below threshold

broad state , strong $\Gamma(E)$ dependence



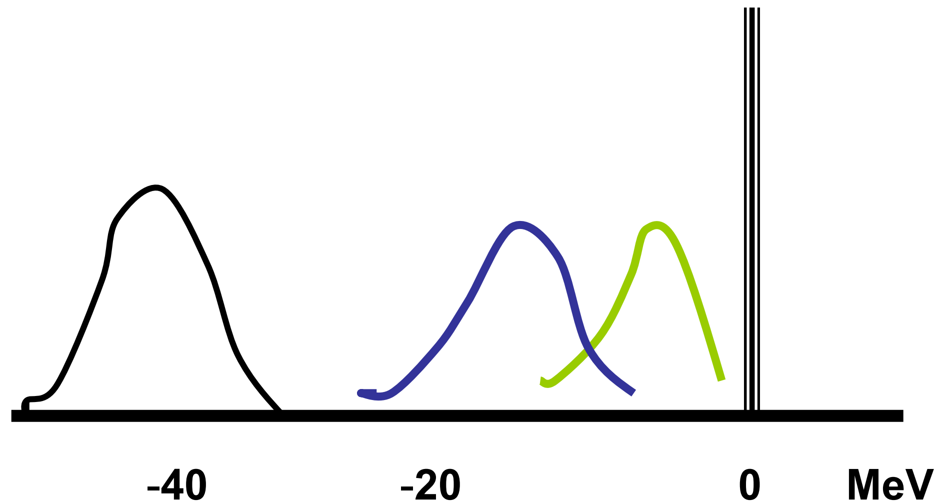
OOOOOOOOOO

ATOMIC REGION

ATOMIC HINTS

$\bar{p}$ N subthreshold

energies in antiprotonic atoms



P

D

T

He 4

E=-Binding -Recoil

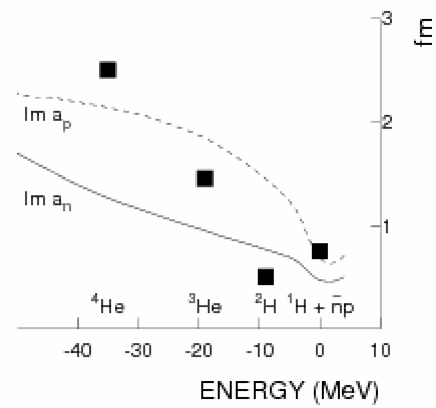
Antiprotonic atom data widths and lower level shifts

Hydrogen	1s , 2p fine structure	CERN -PS- 207
Deuteron	1s, 2p	CERN -PS- 207
^{3}He , ^{4}He	2p, 3d	M.Schneider

Calculation with length a_s , a_P

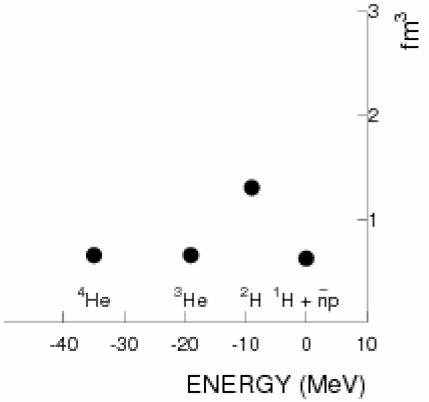
Absorptive parts of S-wave $\bar{p}$ N scattering lengths extracted from light atoms

The rise consistent with
baryonium but
not a proof



Imaginary part of P-wave p-bar amplitude from light atoms

something happens on deuterium

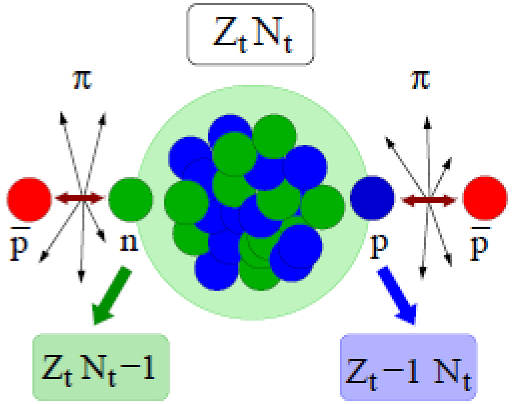


P wave exotics

PS 203/CERN

stopped antiprotons, A.Trzcinska

Annihilation



in the experiment we measure:

$$\text{yields} \begin{cases} Y_{N_t-1} \sim \rho_n(r_{\text{anih.}}) \\ Y_{Z_t-1} \sim \rho_p(r_{\text{anih.}}) \end{cases}$$

$$f_{\text{halo}} = \frac{Y_{N_t-1}}{Y_{Z_t-1}} \cdot \frac{Z}{N} \cdot \frac{\text{Im}\, a_{p\bar{p}}}{\text{Im}\, a_{n\bar{p}}}$$

$$f_{\text{halo}} \sim \frac{\rho_n}{\rho_p}(\text{at annihilation place})$$

annihilation place $\simeq c_p + 2.5$ fm

Radiochemical measurements of residual nuclei after p-bar absorption

density $_n$ / density $_p$ in nuclei PS203

	↓ Lower level ,	↓ Upper level ,	↓ cold capture	
96 Zr	1.61(6)	1.91(6)	2.6(3)	reflect
116 Cd	2.60(35)	3.33(37)	5.6(5)	neutron
124 Sn	3.09(7)	3.43(25)	5.4(7)	halo

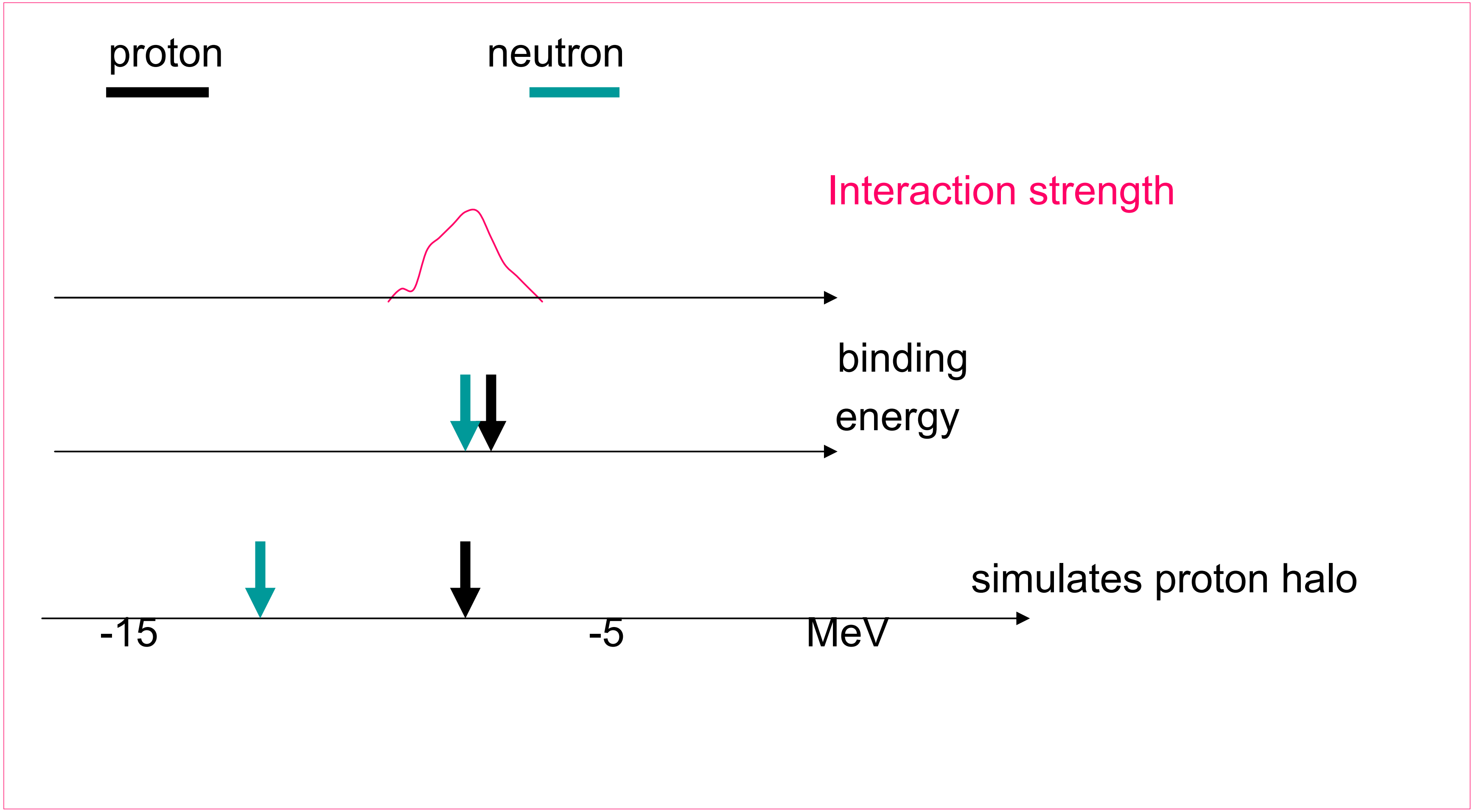
Anomalies (4 cases)

===

106 Cd	1.65(80)	5.13(80)	0.5(1)	proton halo ???

weakly bound proton , strongly bound neutron

Proton halo simulated



^{11}S summary

Paris potential approach

- X(1835) and X(1876)

Interpreted as the same effect of quasi –bound state

- generated by conventional meson exchange forces

- X(2170) shape resonance

generated by conventional meson exchange forces

+ assumption that system expands slightly during radiation

Guidelines : Paris N-Nbar potential

model 2009: 4000 data

M. Lacombe, B. Loiseau, S.W. …C79(09)054001

TABLE III: Binding energy in MeV of the close to threshold quasi-bound states of the present model and of the Paris 99 potential [8].

$^{2T+1\ 2S+1}L_J$	Present work	Paris 99
$^{11}S_0$	-4.8-i26	
$^{33}P_1$	-4.5-i9.0	-17-i6.5

Model dependence is sizeable

P wave quasi-bound state indications

Evidence

- $\bar{p}$ atomic level widths in
  H, ^{2}H, ^{3}He , ^{4}He PS 207

- Radiochemical studies of
  N-1, Z-1 nuclei in
  nuclear $\bar{p}$ capture PS 203, 208

Helpful experiments

- Fine structure resolution in antiprotonic light atoms
- Peripheral antiproton-nucleus collisions
- p-pbar → γ + X at ~ 200 MeV , polarized
- d-pbar → p + X at low energies
- Atomic transitions to nuclear states

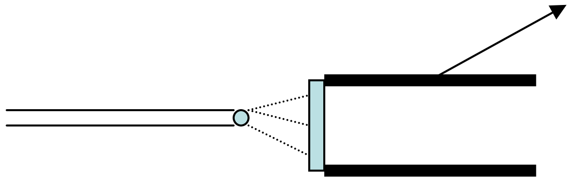
X(1835) difficult, P –wave state easier

Thank you

appendix

Inverse process - PANDA

$\bar{p}\, p \rightarrow J/\psi + \text{meson}$



J/ψ p p_{bar}

Reasonable description :π, γ, ω,Φ

Decays of J/ψ in nucleus

production with fast antiproton

→ fast J/ψ leaves nucleus

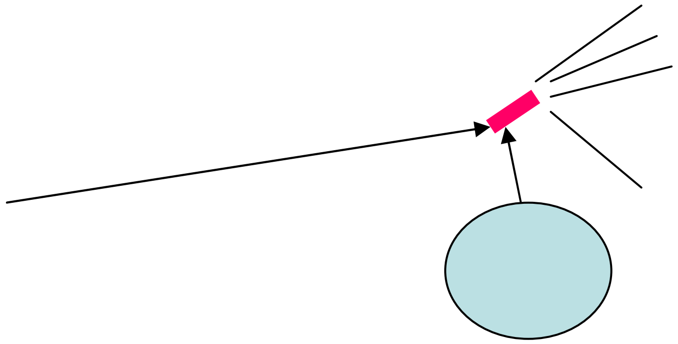
$\bar{p}\, p \rightarrow J/\Psi + \pi$ (or ω)

Special momentum : meson goes forward in CM

~20nb/str

Peripheral collisions ,PANDA

- Invariant mass of pions to measure



Peaks at the end of heavy background