Poszukiwanie baryonium a fizyka FAIR

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SMI -12-11-09

30 lat poszukiwań

Opcje

- baryonium = 2 q + 2 $\bar{q}$

- $\bar{N}$ – N quasi-bound states

Model potencjalny

Brian - Philips

$N \ N \rightarrow N \ \bar{N}$

G –parzystość

$V_\pi \rightarrow - V_\pi$

Silne przyciaganie w stanach niedostepnych NN,

Stany quasi-związane,

anihilacja na odległosciach

1/2M ~ 01.fm

?

Stare próby
„short lived discoveries”

Kinks in p-pbar cross section

(s, t, u)

($\bar{p}$, p) on nuclei

$(\bar{p}, p)_{ATOM} \rightarrow (\bar{p}, p)_{QBS} + \gamma$

Nowsze próby

- A.Abele , Crystal Barrel..Eur Phys Journ.C 17(2000) 583
- $\bar{p}d$ annihilation into mesons
- nB(1855) → 3pi0+n
- Gamma < 10 MeV could not be seen on 5*10^(-4)
- level from n momentum distribution

- *B.Bertini N.Phys B209 (1982) 269*
- *p $\bar{p}$ -> pi- , X*
- *no signal , X not excluded. ,*

- I.Adiels ..Phys. Lett 182
- ppbar → gamma +X ,
- no X Below 1770 MeV , Gamma < 25 Mev

p-pbar → γ + X

Adiels /LEAR (1990) no baryonium E < 1770 , Γ< 25 MeV

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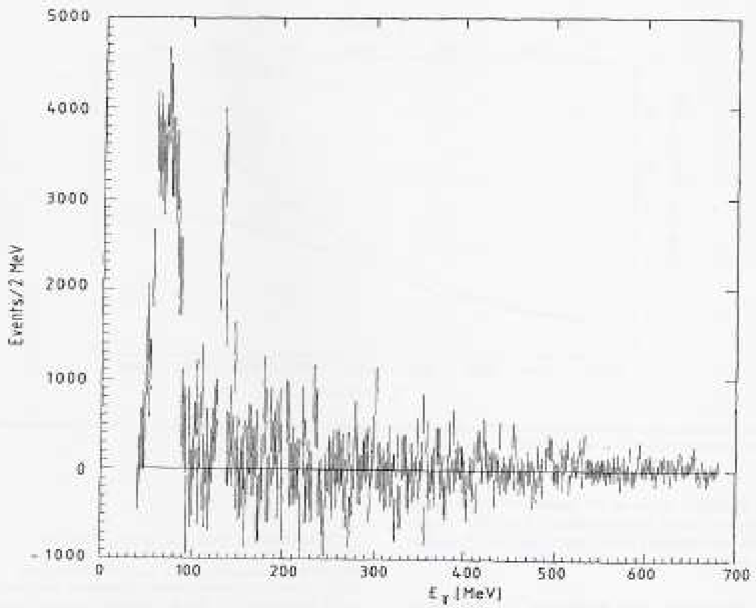


Fig. 2. γ-spectrum after subtracting a smooth background as described in the text. The two structures are due to the reactions $\pi^- + p \to \pi^0 + n$ and $\pi^- + p \to \gamma + n$.

trudnosci

Wiele fal parcjalnych – nie ma zakazu Pauli

Silne tło anihilacyjne

MODERN-selective- SIGNAL

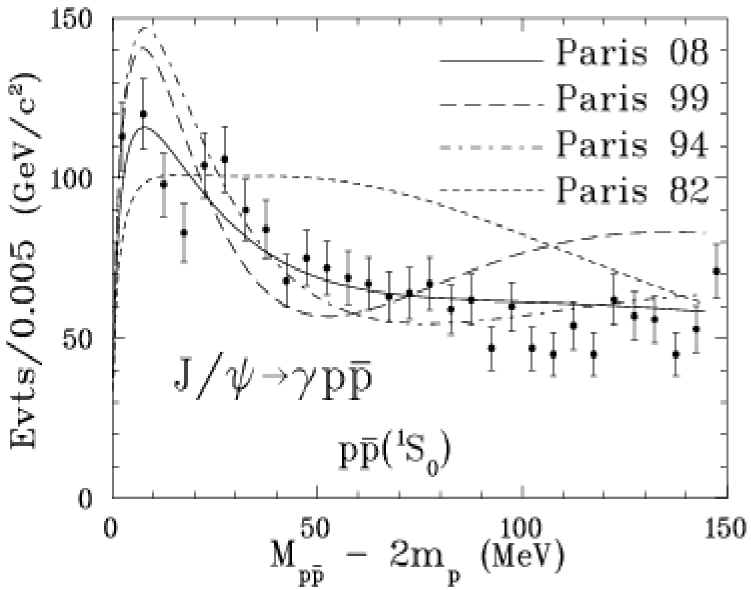
$J/\psi \rightarrow (\bar{p}\, p), \gamma$

BES collaboration,

Pekin, 2005

CP : selects 3 possible partial waves

Enhancement in ^{11}S wave
BES experiment
reproduced by Paris and Juelich models



What happens below N –Nbar threshold

An additional evidence needed

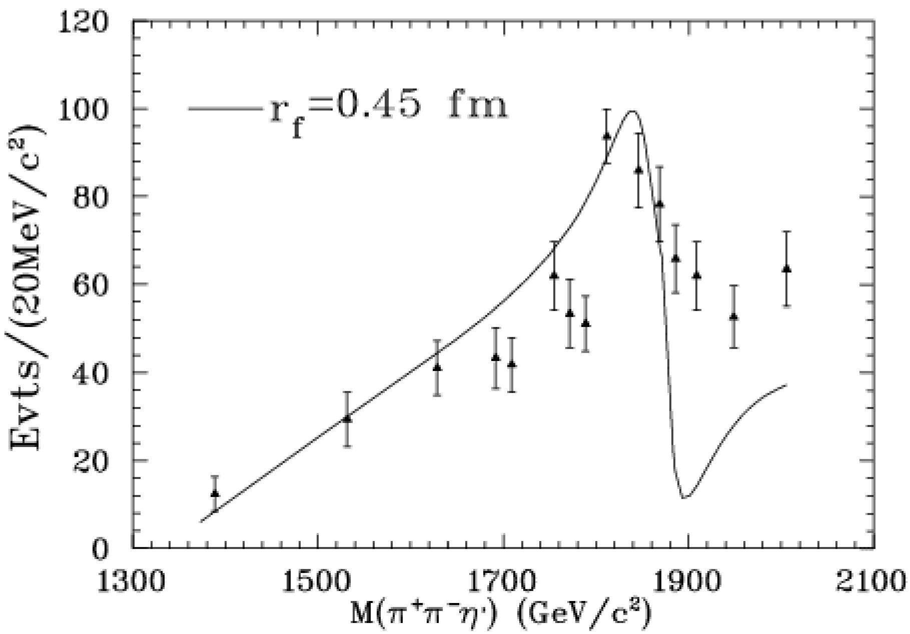
Antiprotonic atoms

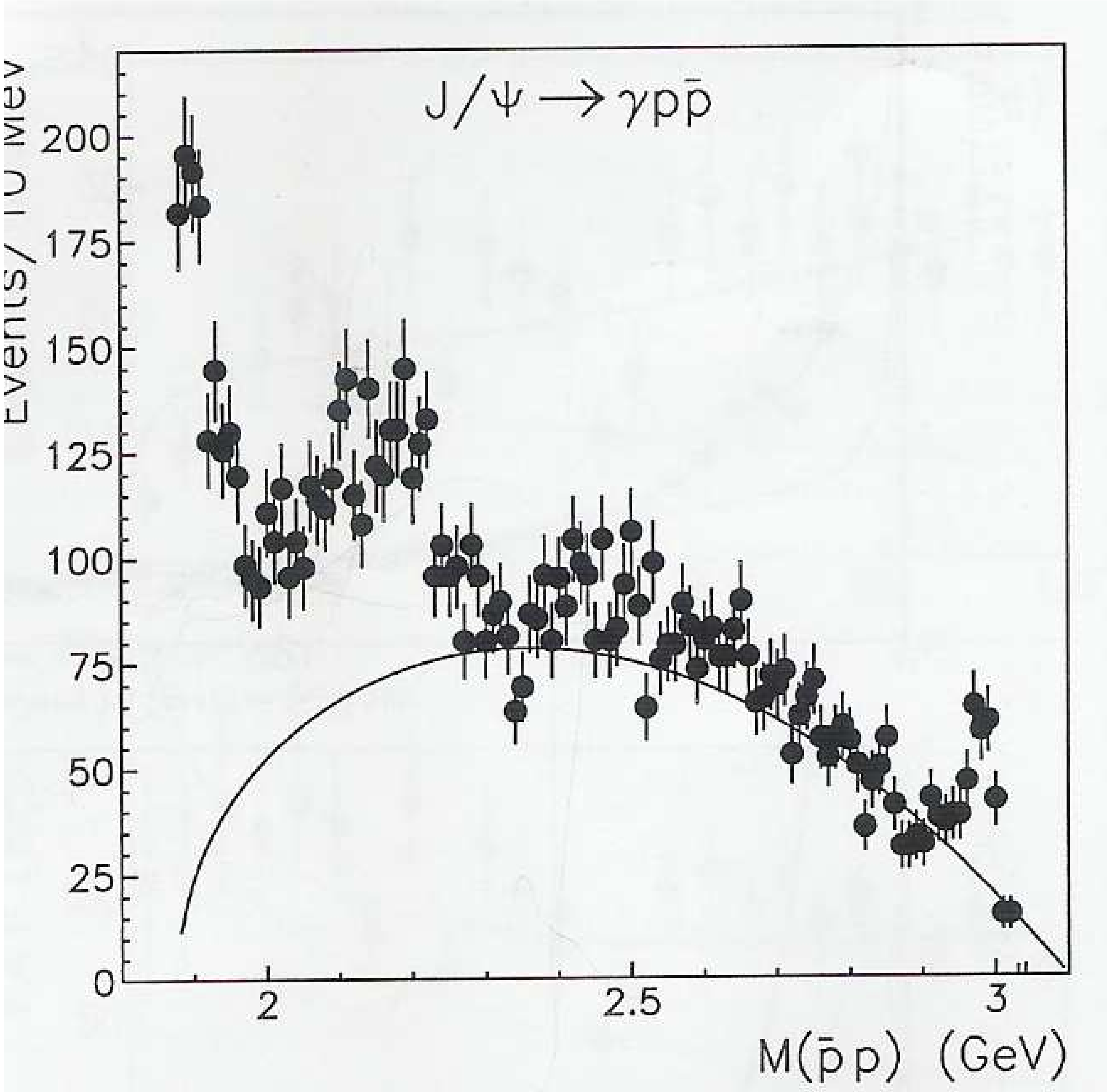
Final state interactions in decay channels

$J/\psi \rightarrow (\pi\pi\eta') , \gamma$

by BES

Named X(1835)





BES ●

^1S , ^3P

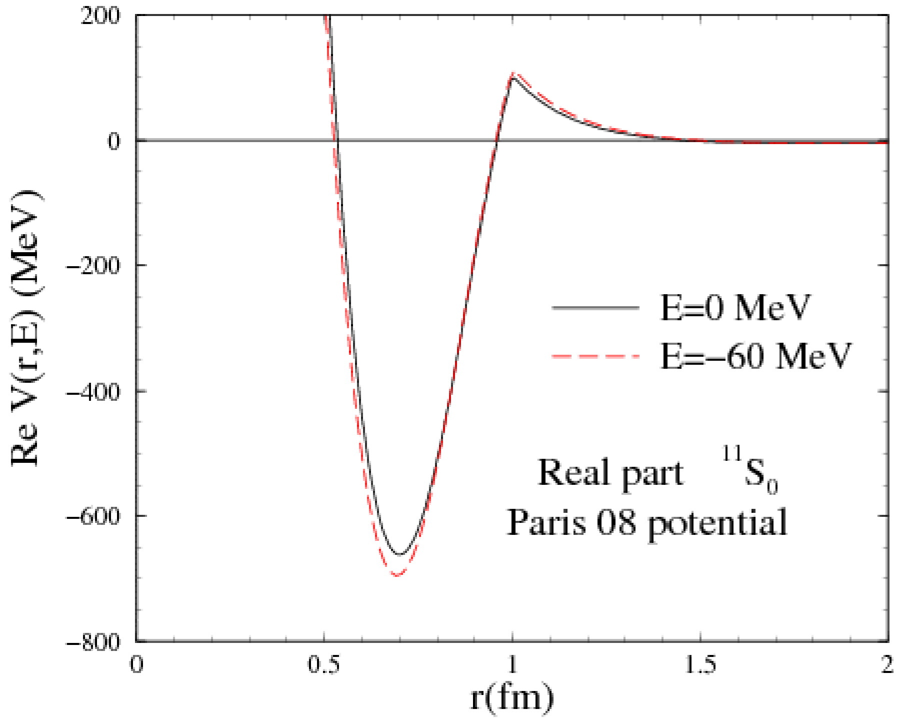
Juelich --

- Model calculations
- Paris potential for $N-\bar{N}$
- $c\bar{c}$ → 3 gluons → $N-\bar{N}$

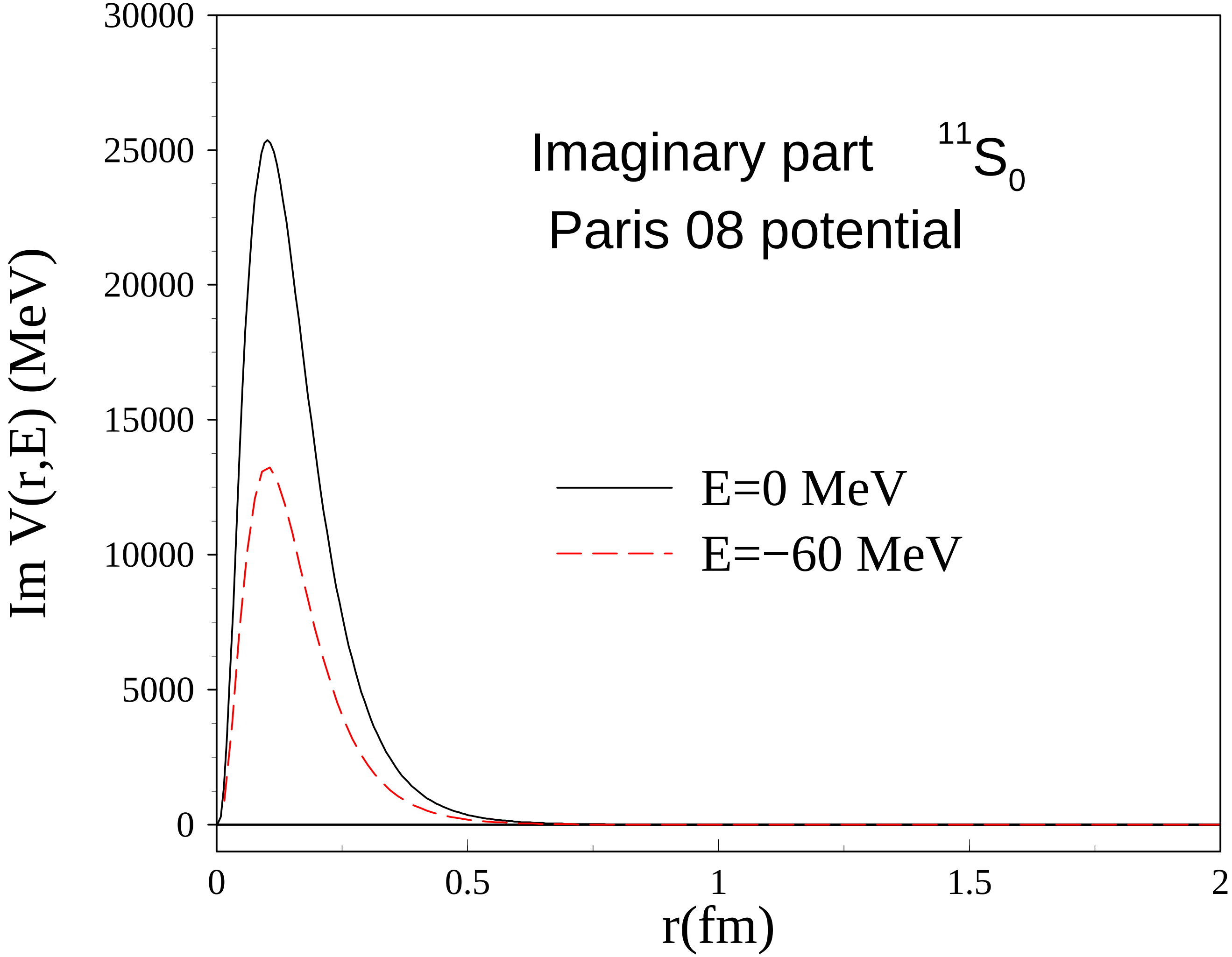
  J/Ψ spin and isospin „ inherited”

  → $N-\bar{N}\gamma$ final state interactions

Potential in ^{11}S

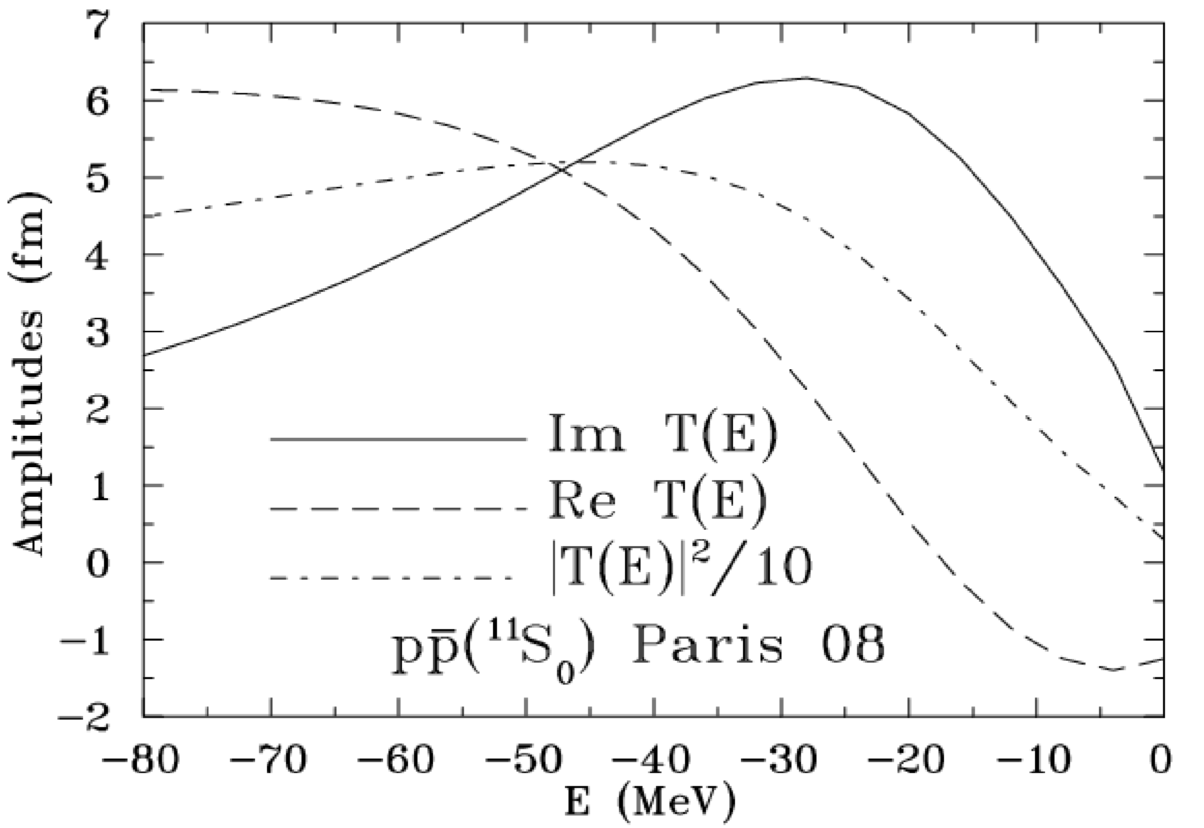


An effect of energy dependent potential



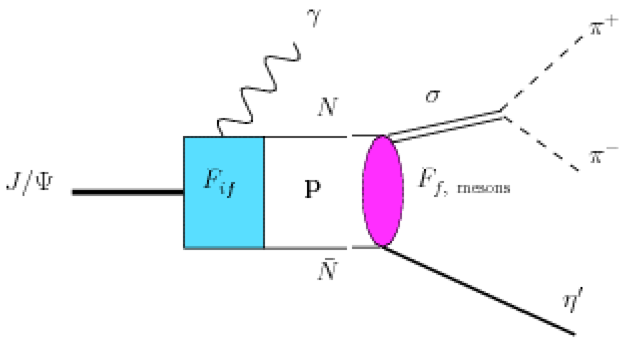
Nature of X(1835)

11S amplitude below threshold

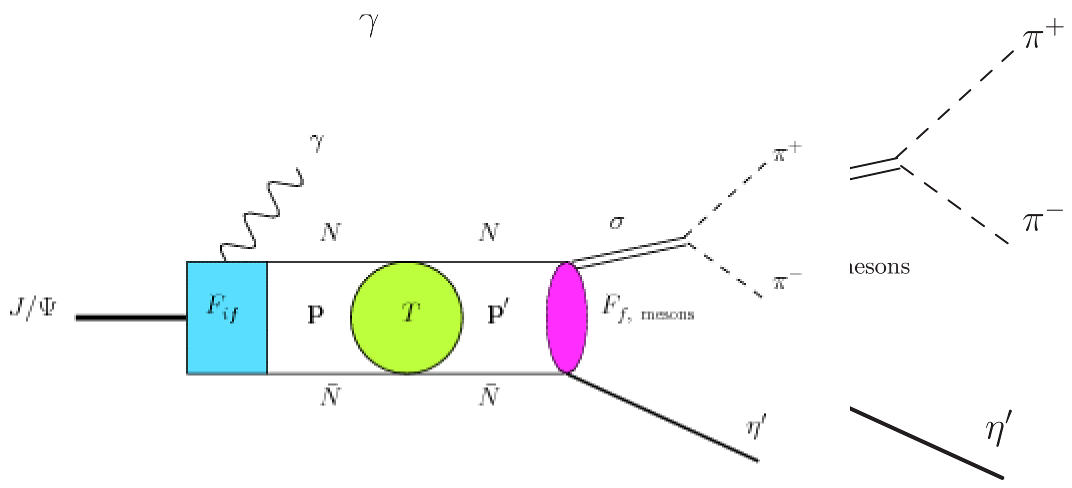


Direct decay

- F_{if} used before –free range parameter,
- F_f - fr .

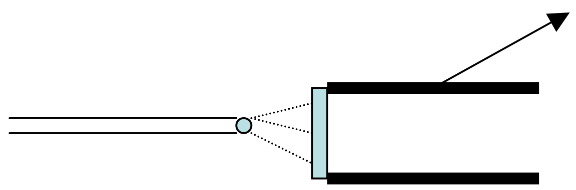


Interference with intermediate interactive term



Inverse process - PANDA

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



J/ψ p p_{bar}

Reasonable description : π, γ, ω, Φ

ATOMIC EVIDENCE

Atomic level shifts ≈ low energy scattering parameters

S waves

$$\Delta E - i\,\Gamma/2 = |\Psi_A(0)|^2 \; A_o \; 2\pi / M\,(1 + O(A/B))$$

AO- hadron-nucleus scattering length
B - atomic radius
ΨA - atomic wave function

Higher L atomic states

$$\Delta E_L - i\,\Gamma_L/2 = \theta \; A_L$$

Low energy expansion for scattering amplitudes

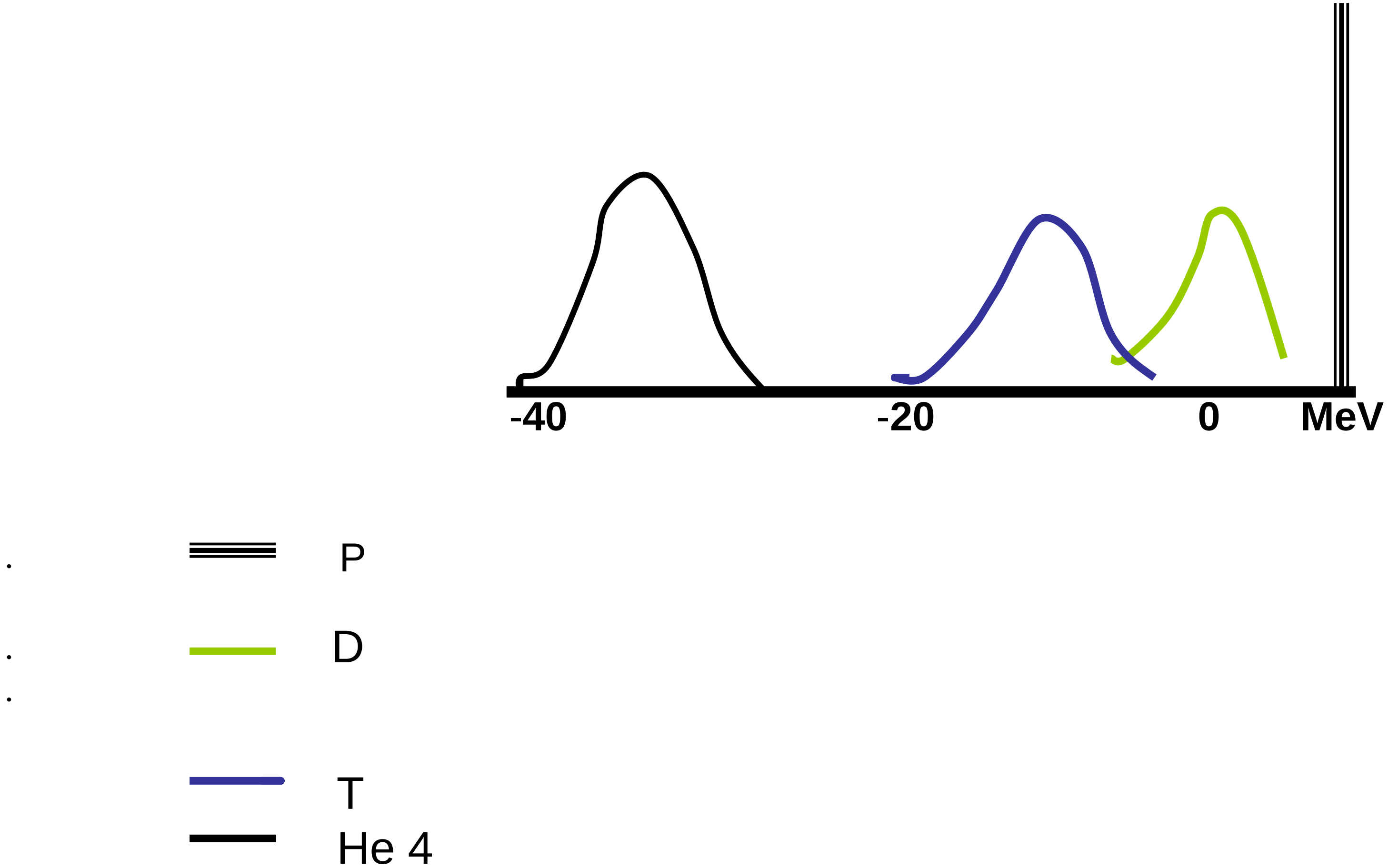
$$F_{SCATTERING} = A_o + 3\,\mathbf{kk'}\,A_1 + \ldots$$

On a nucleus $A_i\,(E = 0)$

In a $\bar{p}\,p$ sub-system

$F_{(\bar{p}\,p)}\,(-B_{BINDING} - E_{RECOIL})$ negative energies

$\bar{p}$ N subthreshold energies involved in p-bar atoms



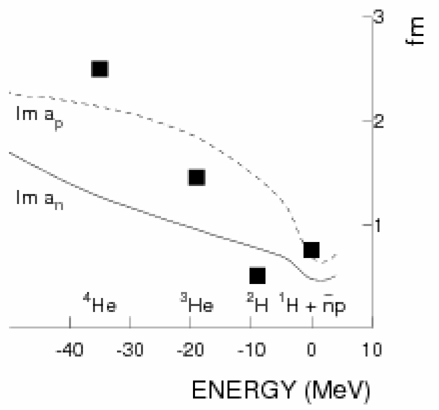
Antiprotonic atom data widths and lower level shifts

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

- Partial waves not resolved
  by antoprotonic levels

New BES experiment , 2007

Absorptive parts of S-wave $\bar{p}$ n ampltiude obtained from light atoms



S wave ($\bar{p}$ p) state

Two experiments select ^{11}S partial waves :

J/ψ → ($\bar{p}$ p) , γ BES

J/ψ → (ππη') , γ BES X(1835)

Non-selective

$\bar{p}$ - atomic level widths
without fine structure PS 209, PS 207

^{11}S summary evidence

- The X(1835) peak can be generated by conventional $N\bar{N}$ potential model [7].
- Structure stems from broad and weakly bound state in the $^{11}S_0$ wave: meson exchange + G-parity.
- Same state: peaks in $J/\Psi \rightarrow \gamma pp'$ and $J/\Psi \rightarrow \gamma\pi^+\pi^-\eta'$.
- Additional confirmation in level widths of anti-protonic atoms.

P wave exotics

Guidelines : Paris N-Nbar potential model 2009

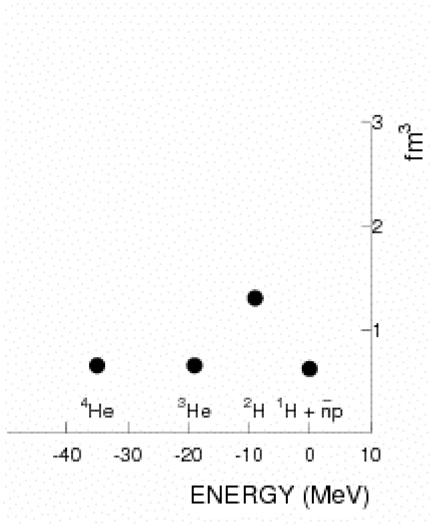
TABLE III: Binding energy in MeV of the close to threshold quasi-bound states of the present model and of the Paris 99 potential [8].

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

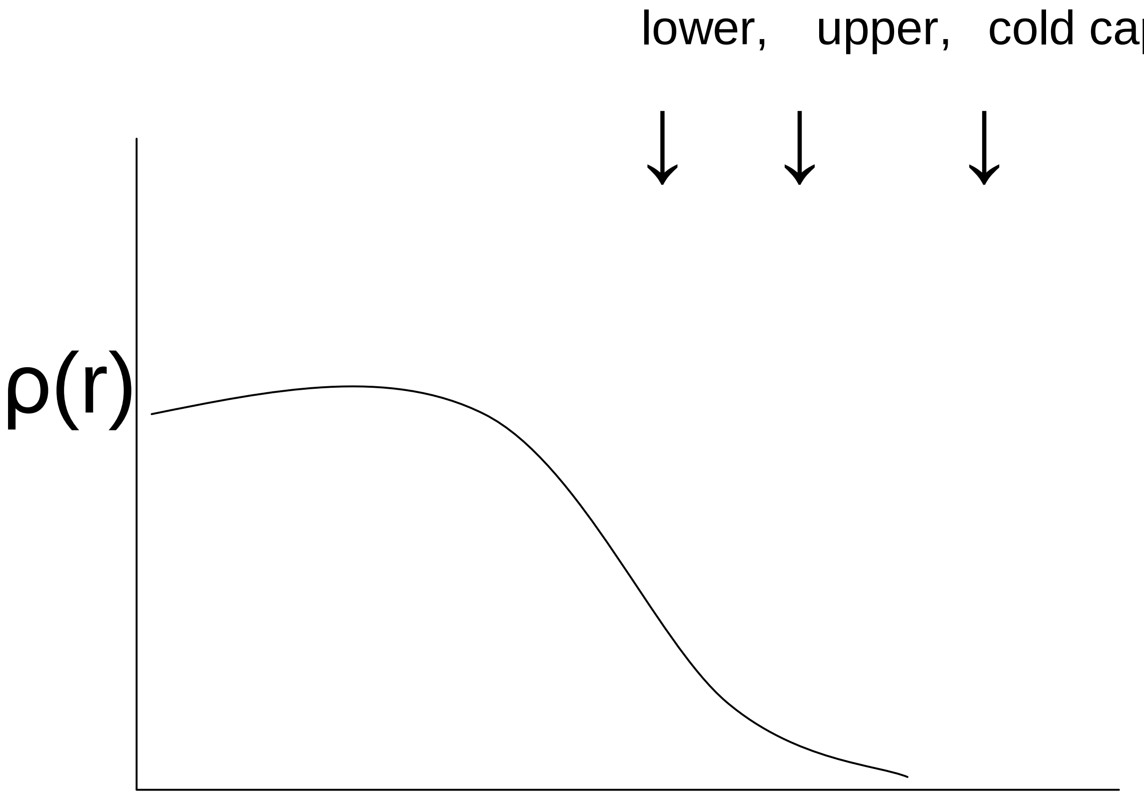
- But no bound state in ^{11}S Juelich potential

- Paris potential : M. Lacombe, B. Loiseau, S.W. . . .

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



Nuclear regions studied in atoms



Radiochemical measurements of residual nuclei after p-bar absorption

Warsaw-Munich

Ratio $\sigma(\bar{p}\, n)/\sigma(\bar{p}\, p)$ in nuclei

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

- Anomalies (4 cases)
- ==

- 106 Cd 1.65(80) 5.13(80) 0.5(1)

- weakly bound proton , strongly bound neutron

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

Conclusions

- Consistent evidence of ^{11}S broad quasi-bound state

(the structure is less certain)

- Indications of ^{33}P quasi bound state

To be continued at FAIR (or CERN)

New clarifying experiments

Fine structure resolution in deuterium, helium atoms

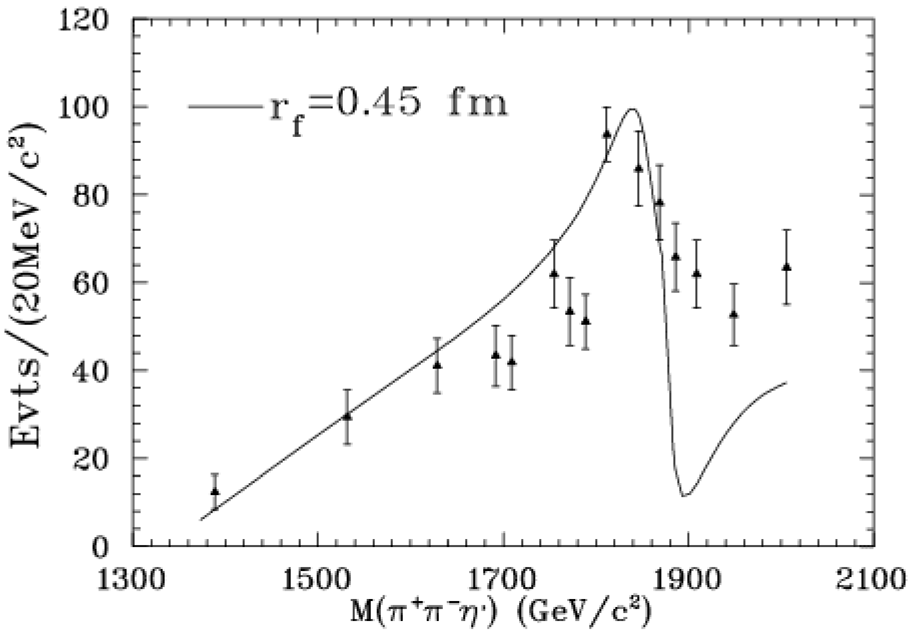
PAX – polarized beam proposal

$\bar{p}\,p \rightarrow (\bar{p}\,p)\,,\,\gamma$

J/ψ → (ππη') , γ

BES experiment

Paris model understanding



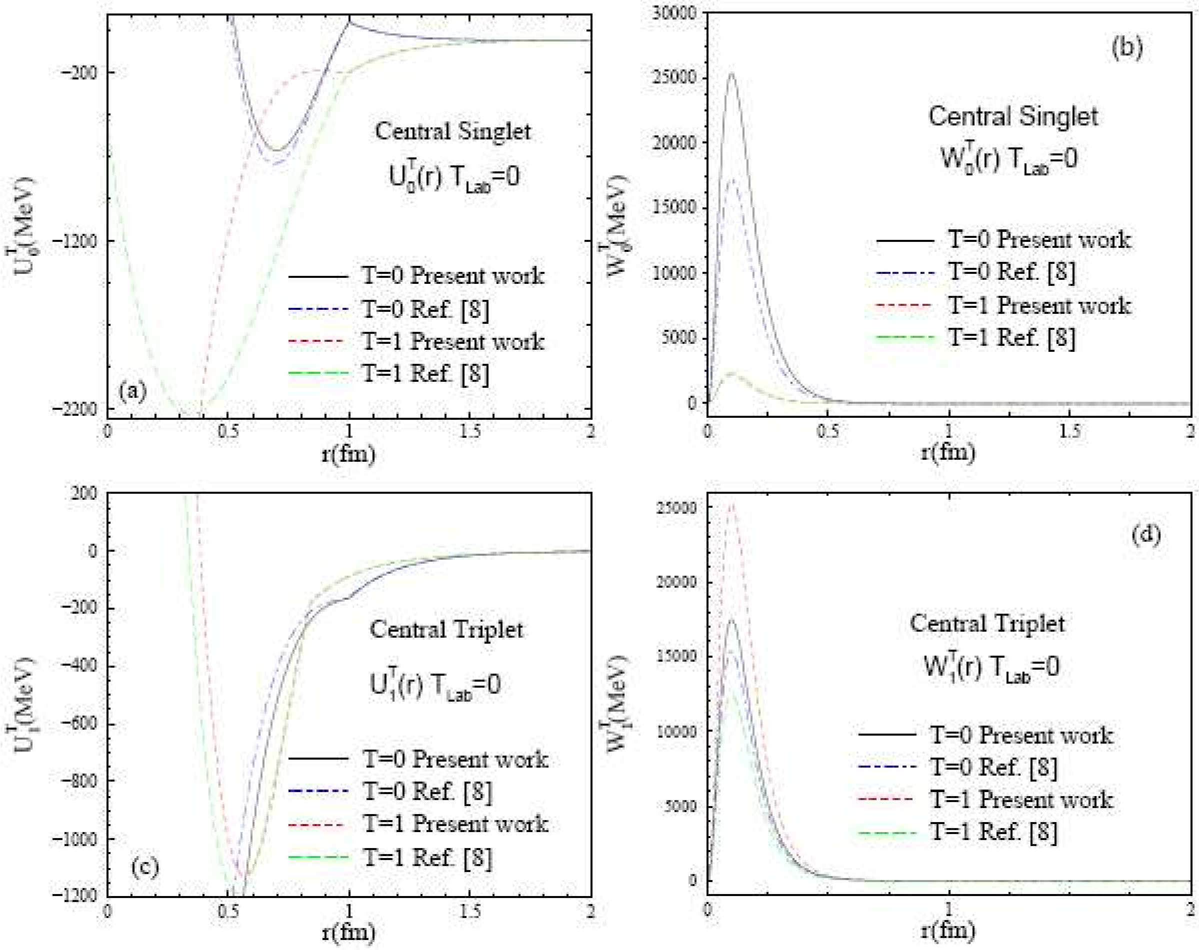


FIG. 2: Resulting real $U(r)$ and imaginary $W(r)$ potentials compare with those of Paris 99 [8]. The $N\bar{N}$ optical potential is defined as $U(r) - iW(r)$ [7].

Resonances $^{13}P_o$

- Paris model resonances

TABLE IV: Close to threshold resonances of the present model. The numbers in parenthesis correspond to the $^{11}P_1$ resonance of Paris 99. The $^{13}P_0$ and $^{13}P_1$ resonances have identical positions in the Paris 99 model. There is no $^{33}P_0$ resonance in the Paris 99 potential.

$^{2T+1\ 2S+1}L_J$	$^{11}P_1$	$^{13}P_0$	$^{13}P_1$	$^{33}P_0$
Mass (MeV)	1877 (1872)	1876	1872	1871
Width (MeV)	26 (12)	10	20	21

- „atomic” $^{13}P_o$ disagrees with all models
- may give nuclear states of antiproton

Scattering data

~4000 data + hydrogen p-bar atom

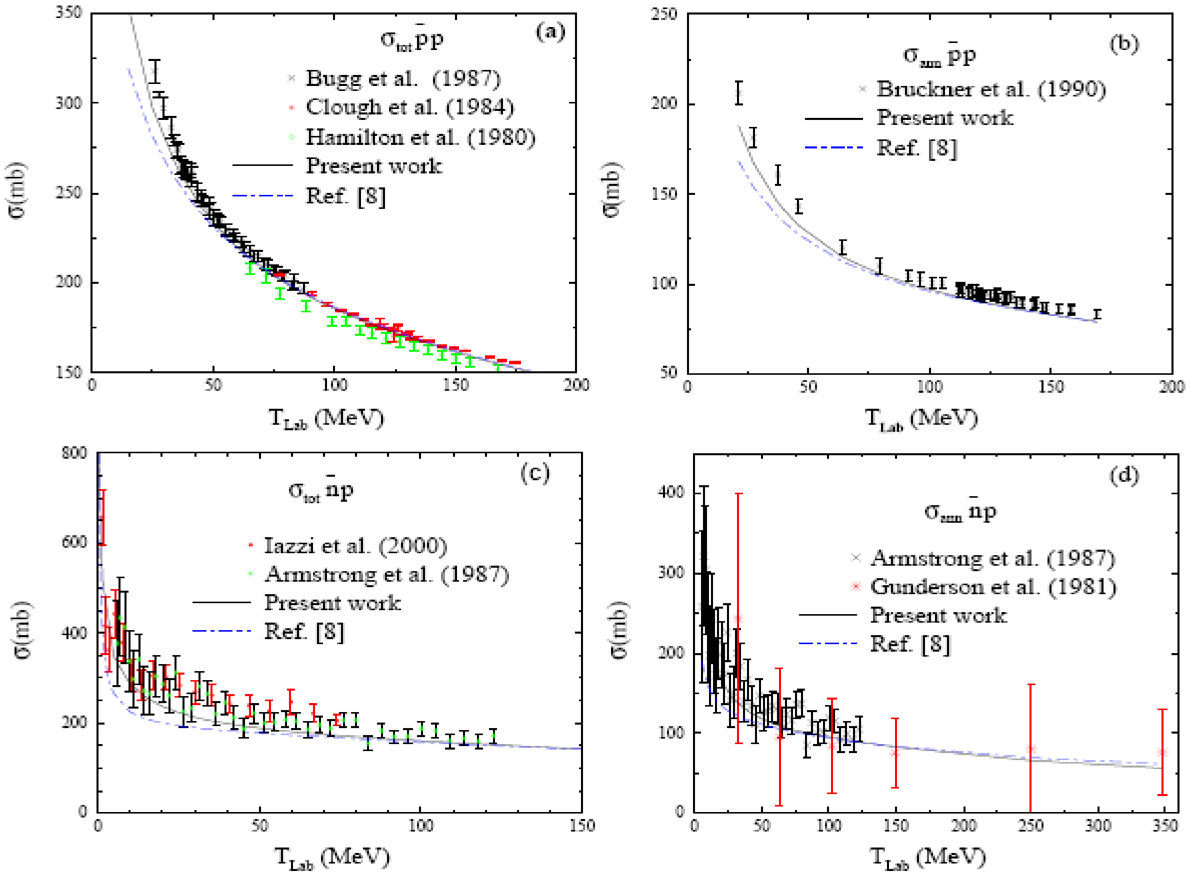


FIG. 1: Total and annihilation cross sections for the $\bar{p}p$ and $\bar{n}p$ systems. The references of the experimental data can be found in Ref. [7]. The data of Iazzi *et al.* in Fig. 1(c) are from Ref. [9].