# Poszukiwanie barionium

S. Wycech , NCBJ

# content

- Some history
- Contemporary signals

  $J/\Psi \rightarrow N\ \bar{N}, \gamma$

  antiprotonic atoms

  radiochemical studies of $\bar{p}$

- Relation to PANDA- FAIR/FLAIR

# 30 years of experimental search

- baryonium = 2 q + 2 $\bar{q}$
- $\bar{N}$ – N quasi-bound states

# Potential model

Brian - Philips

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

G – parity transformation

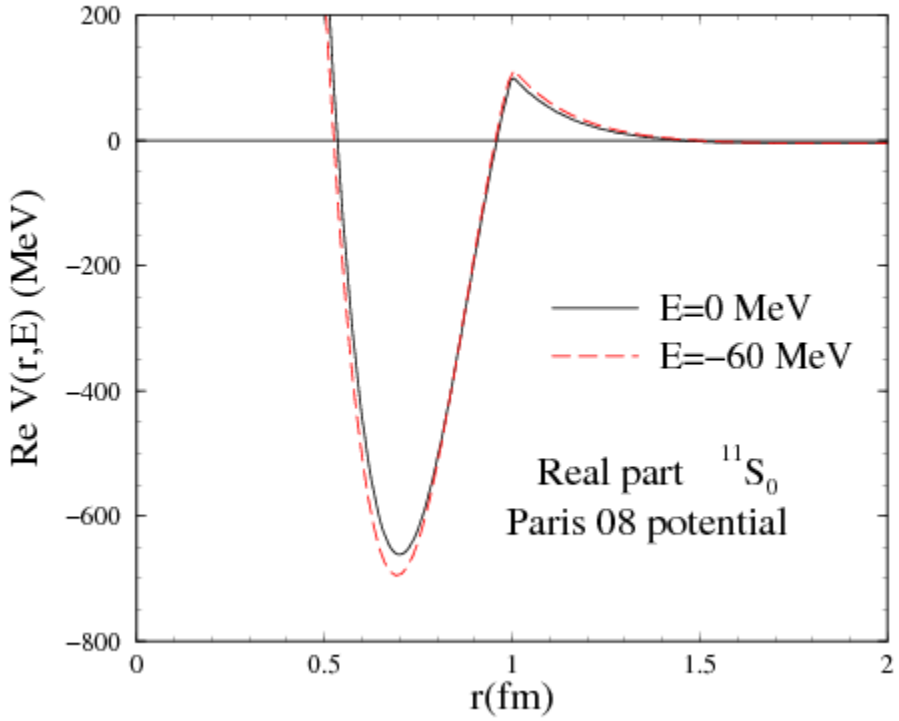
$$V_\pi \rightarrow -V_\pi$$

No Pauli exclusion - many allowed states

Strong attraction - in many states

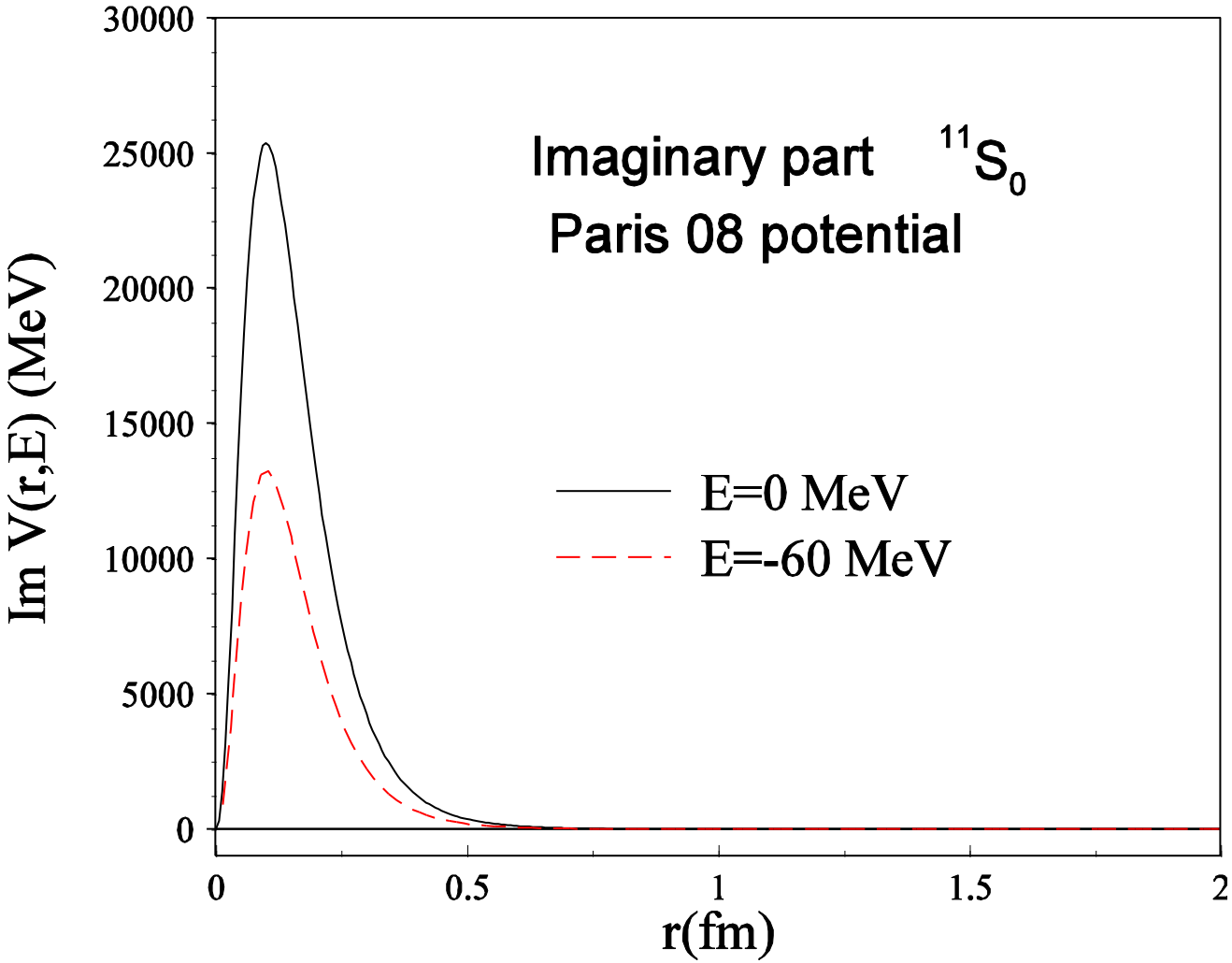
BUT : Annihilation at distances $R < 1$ fm

# Potential in $^{11}S$ Bonn , Paris



# Absorbtive potential

model dependent



# Old search - CERN

short lived discoveries

Kinks in p-pbar cross section

- s, t, u -

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

( $\bar{p}$, p) ATOM → ( $\bar{p}$, p) QBS

# More recent attempts

- 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. ,*

- l.Adiels ..Phys. Lett 182(1990)

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

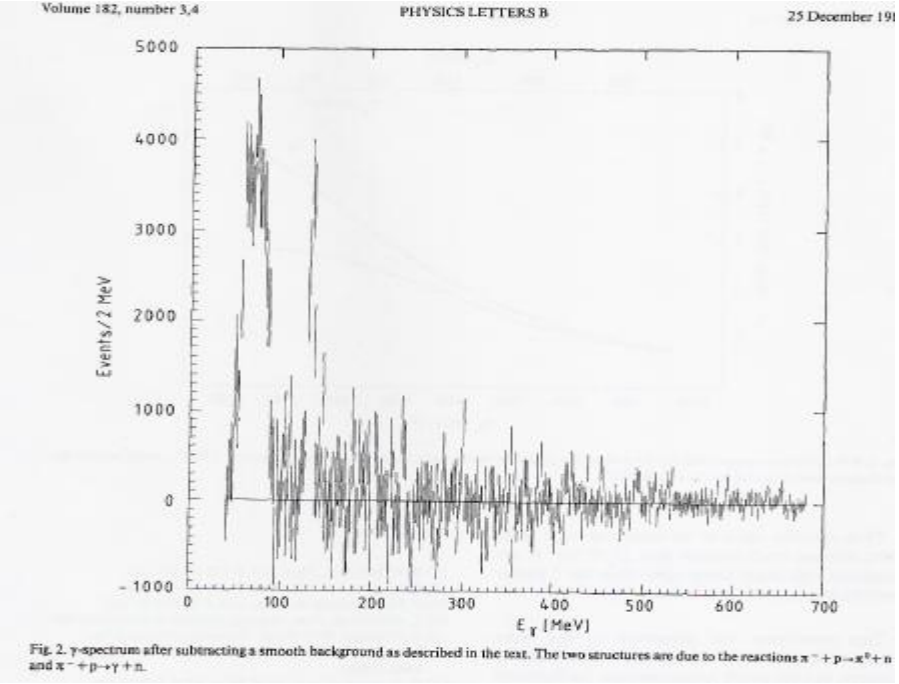



Fig. 2. γ-spectrum after subtracting a smooth background as described in the text. The two structures are due to the reactions $\pi^- + p \to \pi^0 + n$ and $\pi^- + p \to \gamma + n$.

# Experimental difficulties

No Pauli principle → many partial waves

Strong background from annihilation

# MODERN-selective- SIGNAL

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

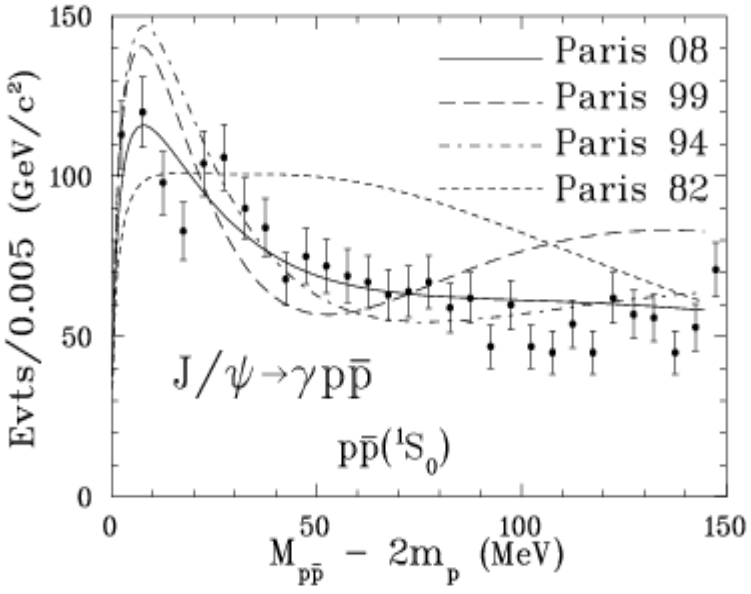
BES collaboration,

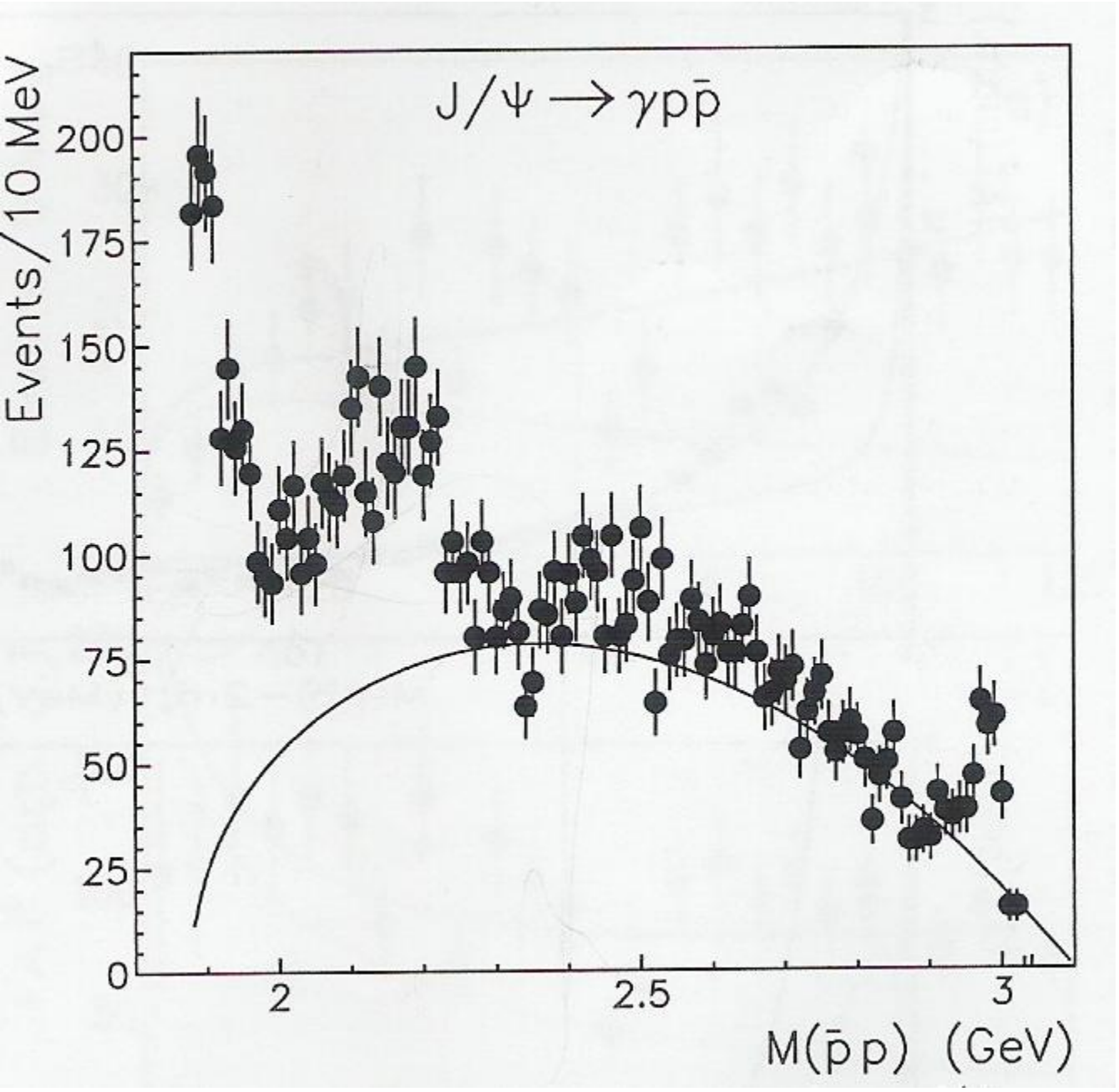
Pekin, 2005

CP : selects 3 possible partial waves

# Enhancement in $^{11}S$ wave BES experiment

reproduced by Paris and Juelich models




J/ψ → γpp̄
Events/10 MeV
200
175
150
125
100
75
50
25
0
2
2.5
3
M(p̄p) (GeV)

Quasi-bound state in Paris potential model

$E_B$ = 5 MeV , Γ ~ 50 MeV

No quasi-bound state in

Bonn potential  model

# Look below N –Nbar threshold

Additional evidence needed

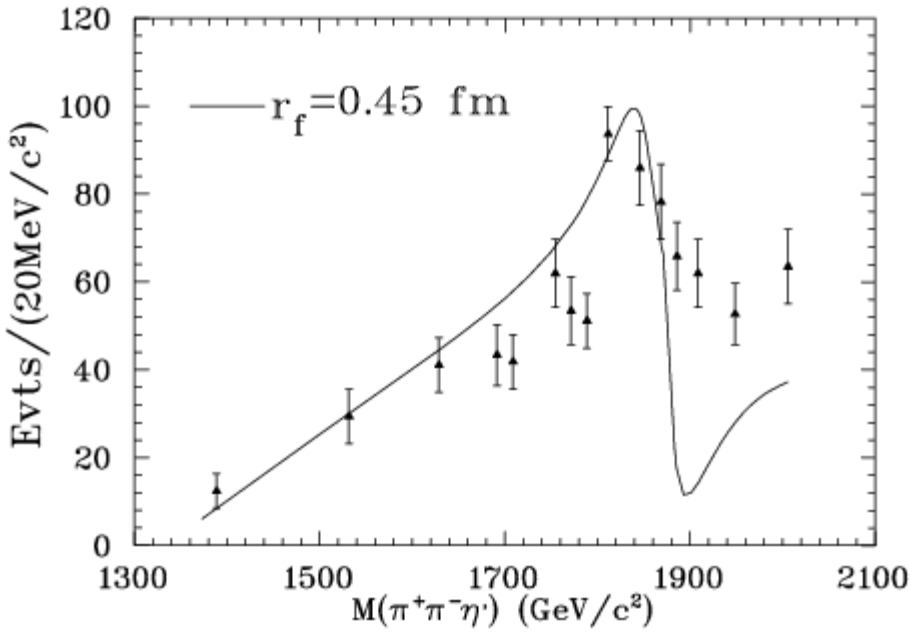
Antiprotonic atoms → bound nucleons

Final state interactions in decay channels

# J/ψ → (ππη') , γ

by BES

Named X(1835)



# A Model Dedonder,Loiseau , SW, P ReV, C72, C80

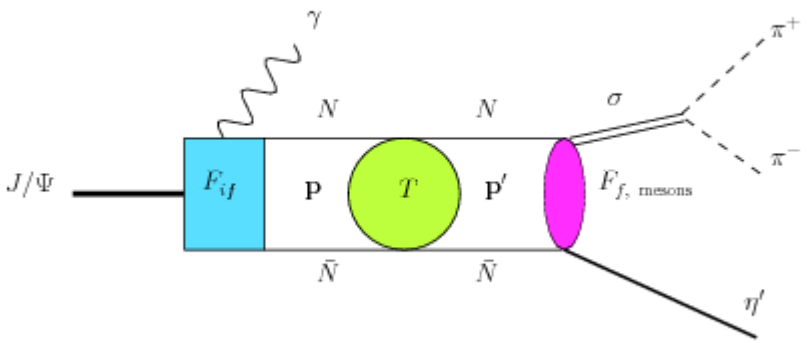
Paris potential for N- $\bar{N}$ Phys.ReV C79,054001

- c $\bar{c}$ → 3 gluons → N $\bar{N}$

  J/ Ψ spin and isospin „ inherited”
- N $\bar{N}$ → N $\bar{N}$ γ final state interactions

  photon emision in final state

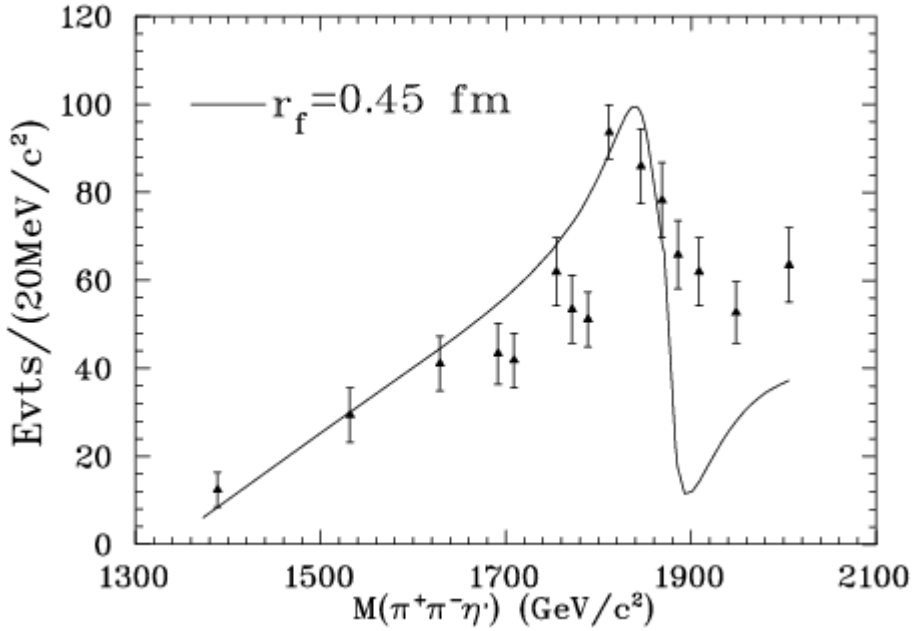
# Interference with intermediate interactive term



# J/ψ → (ππη') , γ

## BES experiment

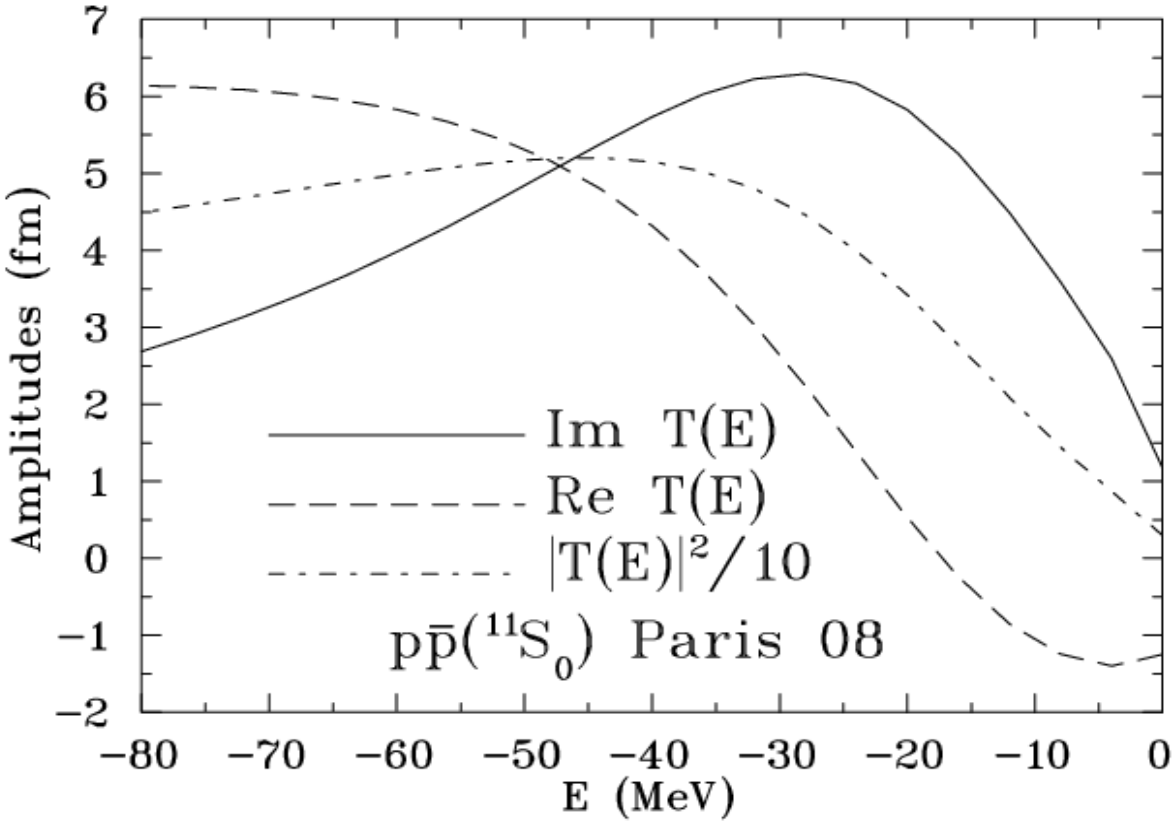
Paris model understanding



# Nature of X(1835)

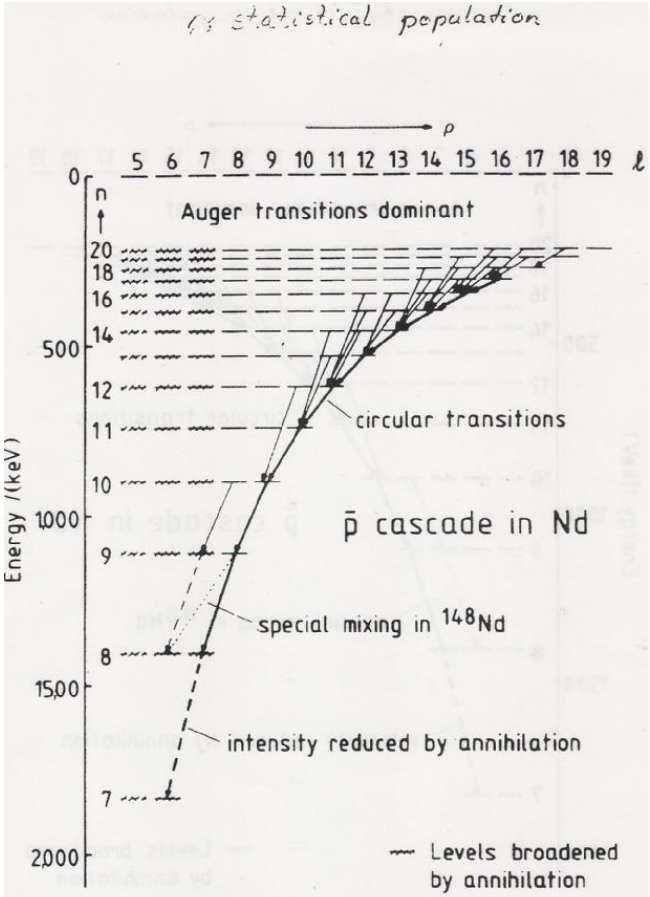
$^{11}S$ amplitude below threshold

Dedonder,Loiseau,S.W.Phys.Rev.C80



# ATOMIC EVIDENCE of BARYONIUM

# Antiprotonic atoms




Antiprotonic levels in the Nd atom.

# Atomic level shifts
# in light atoms , H,D,He

S waves

$$\Delta E - i\,\Gamma/2 \sim |\Psi(0)|^2 \; A_o$$

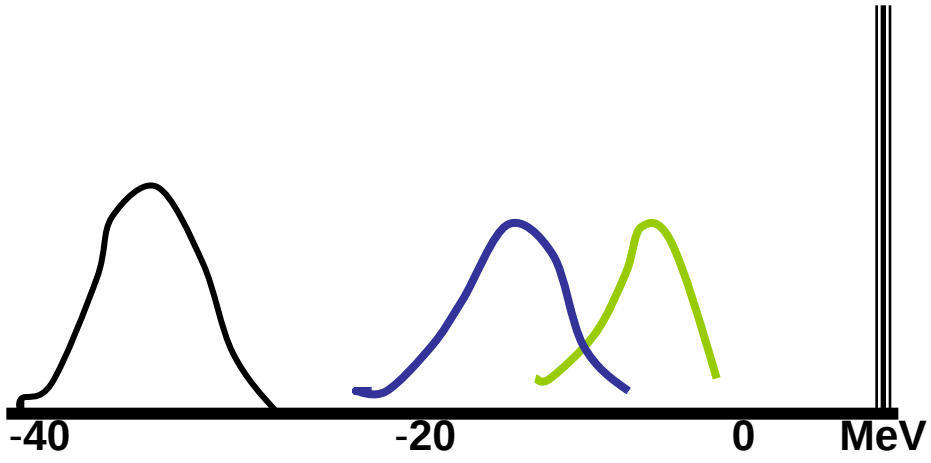
$A_o$ - hadron-nucleus scattering length

$\Psi$ - atomic wave function

P waves

$$\Delta E_1 - i\,\Gamma_1/2 \sim |\Psi/r(0)|^2 \; A_1$$

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




P

D

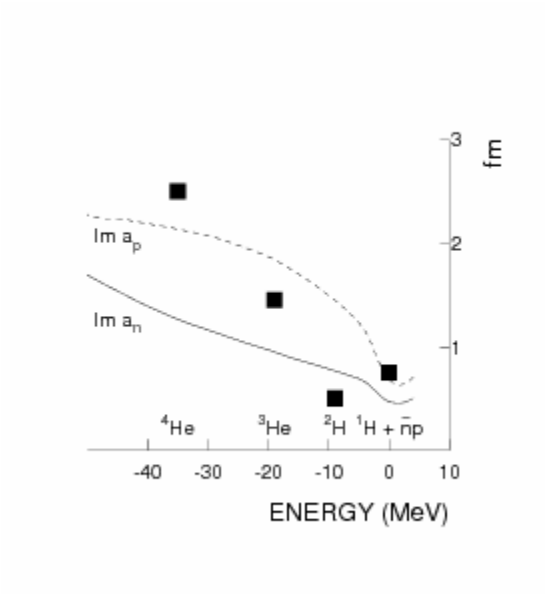
T

He 4

# 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 |

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



# Summary S-wave ( $\bar{p}$ p ) state

Two experiments select $^{11}S$ partial waves :

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

$J/\psi \rightarrow$ ($\pi\pi\eta'$) , $\gamma$ BES X(1835)

Non-selective

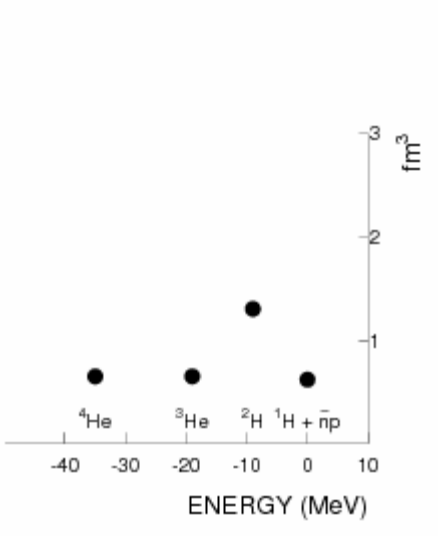
$\bar{p}$ - atomic level widths
without fine structure PS 209, PS 207

# $^{11}S$ summary evidence

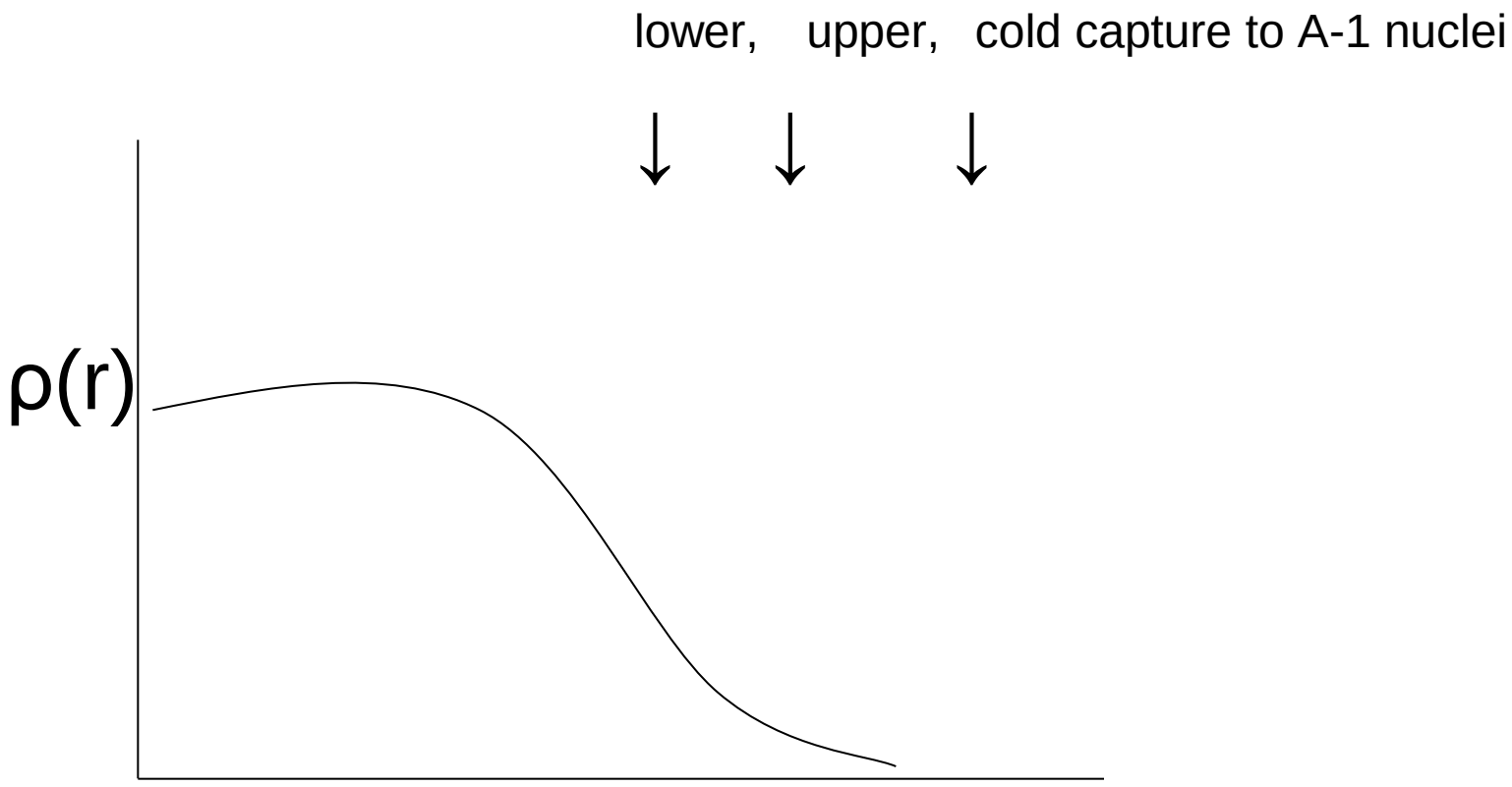
- The X(1835) peak can be generated by conventional $N\bar{N}$ potential model [7].
- Structure stems from broad and weakly bound state in the $^{11}S_0$ wave: meson exchange + G-parity.
- Same state: peaks in $J/\Psi \to \gamma pp'$ and $J/\Psi \to \gamma\pi^+\pi^-\eta'$.
- Additional confirmation in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

# P wave exotics

# 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

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

SW,PhysReVC76,034316

# 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

# PERSPEKTYWY antyprotonowe

CERN - ELENA ekstrakcja „w paczkach”
tylko anty-wodór

FLAIR / FAIR (niskie energie) > 2018
FAIR / PANDA 1-15 GeV > 2016

intensywna wiazka , pełna detekcja pionów

JPARK
CHINY ( Langczu)

# New clarifying experiments

Fine structure resolution in

deuterium, helium atoms

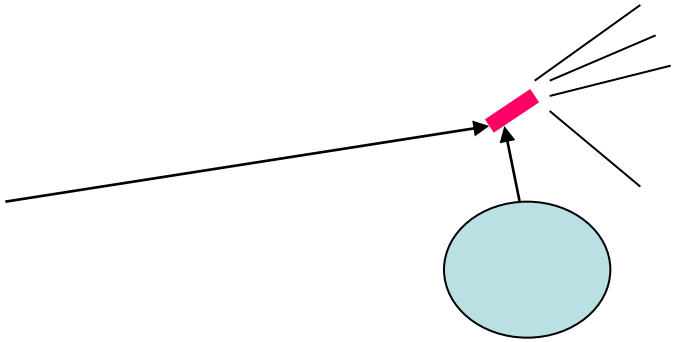
PAX – polarized beam proposal

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

Peripheral collisions

# Peripheral collisions ,PANDA

- Invariant mass of pions to measure



Peaks  at the end of heavy background

# Projekt „równoległy”

Rozpady J/ψ w materii jądrowej

PANDA / FAIR

# J/ψ in nucleus

production with fast antiproton

→ fast J/ψ leaves nucleus

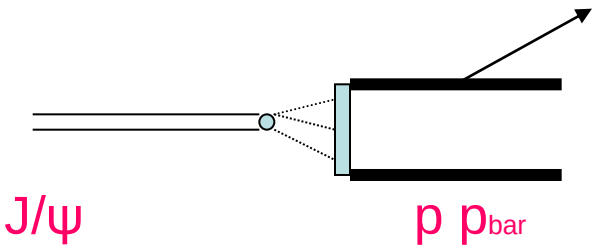
$\bar{p}\,p \rightarrow J/\Psi + \pi \;\; (\text{or } \omega)$

Magic momentum -

meson goes forward in CM

# Understanding inverse process

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

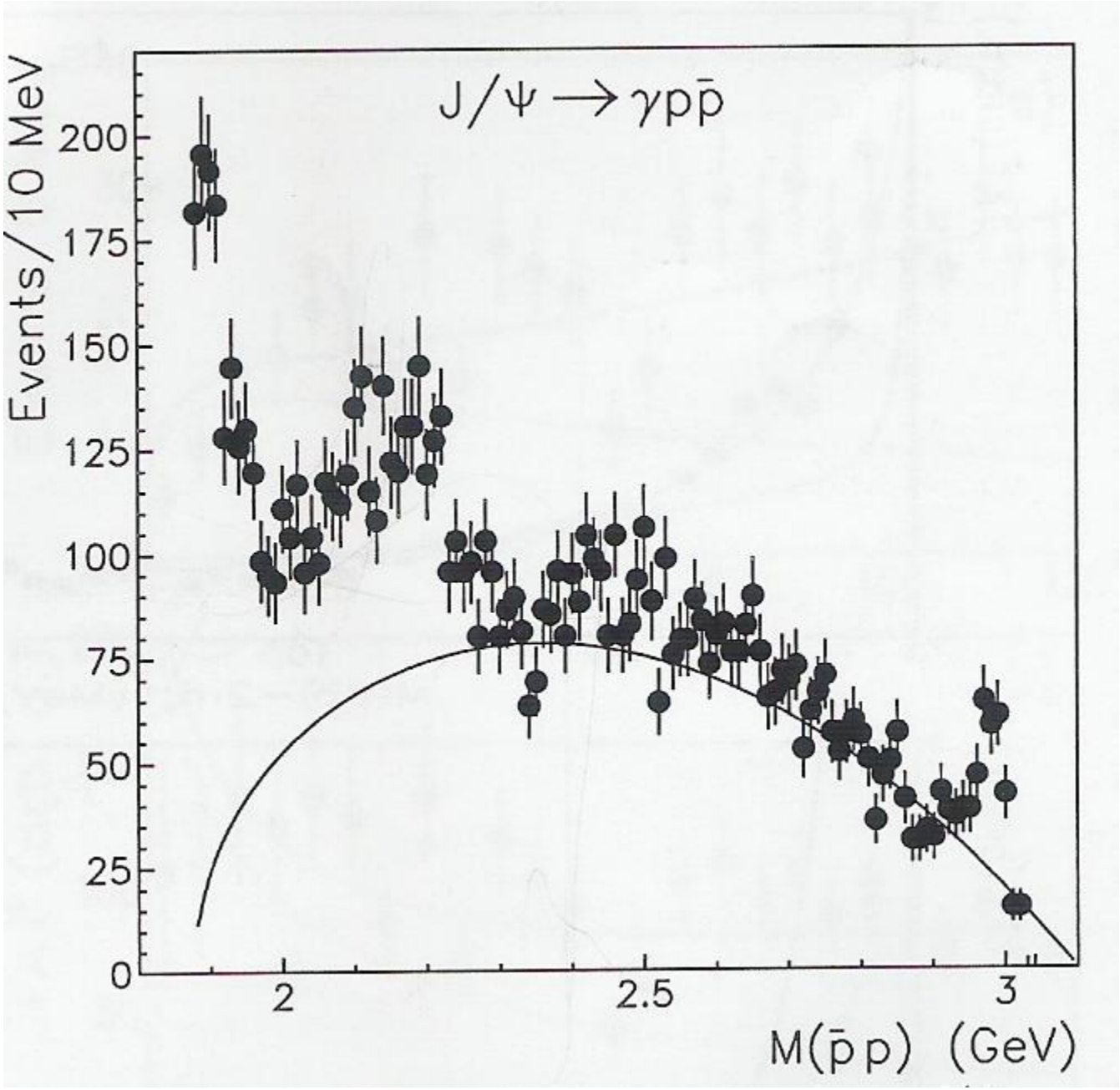



A model - emission from final state

good for : π, ω,Φ

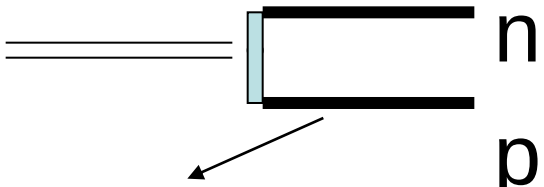
# decay modes

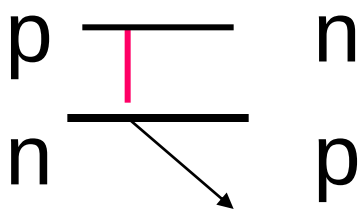
| | rate | CP allowed $p\,p_{BAR}$ |
|---|---|---|
| $J/\psi \rightarrow p\,p_{BAR}$ | $2.17(7)\ 10^{-3}$ | $^3S$ |
| $J/\psi \rightarrow n\,n_{BAR}$ | $2.2(4)\ 10^{-3}$ | $^3S$ |
| $J/\psi \rightarrow p\,p_{BAR}\,\gamma$ | $3.8(1.0)\ 10^{-4}$ | $^1S\ ^3P$ |
| $J/\psi \rightarrow p\,p_{BAR}\,\omega$ | $2.2(4)\ 10^{-3}$ | $^1S\ ^3P$ |
| $J/\psi \rightarrow p\,p_{BAR}\,\Phi$ | $4.5(1.5)\ 10^{-5}$ | $^1S\ ^3P$ |
| $J/\psi \rightarrow p\,p_{BAR}\,\pi^0$ | $1.19(8)\ 10^{-3}$ | $^3S\ ^1P$ |
| $J/\psi S \rightarrow p\,n_{BAR}\,\pi^-$ | $2.00(10)\ 10^{-3}$ | $^3S\ ^1P$ |


J/ψ → γpp̄
Events/10 MeV
200
175
150
125
100
75
50
25
0
2
2.5
3
M(p̄p) (GeV)

# Currents, exchange currents

pn →d γ




L= N* **γ**(∂–ie**A**) N

π, ρ exchange currents , subtract Riska Phys Scr. 31(1985)

$pp_{BAR}$ → X γ exchange currents add up by G parity

Electric photon $^3S \rightarrow {}^3P$ e **qε**

Magnetic photon $^3S \rightarrow {}^1S$ μ Kxσ ε

large magnetic moments

exchange currents

weak enhancement in $^1S$

Photons from quark phase ( about 50% )

final state enhancement due to „ baryonium”

# Baryinium - Conclusions

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

(the structure is less certain)

some evidence of $^{33}P$ narrow quasi bound state

Could be studied at FAIR

Dziękuję

# appendix

- Paris potential

# Potential

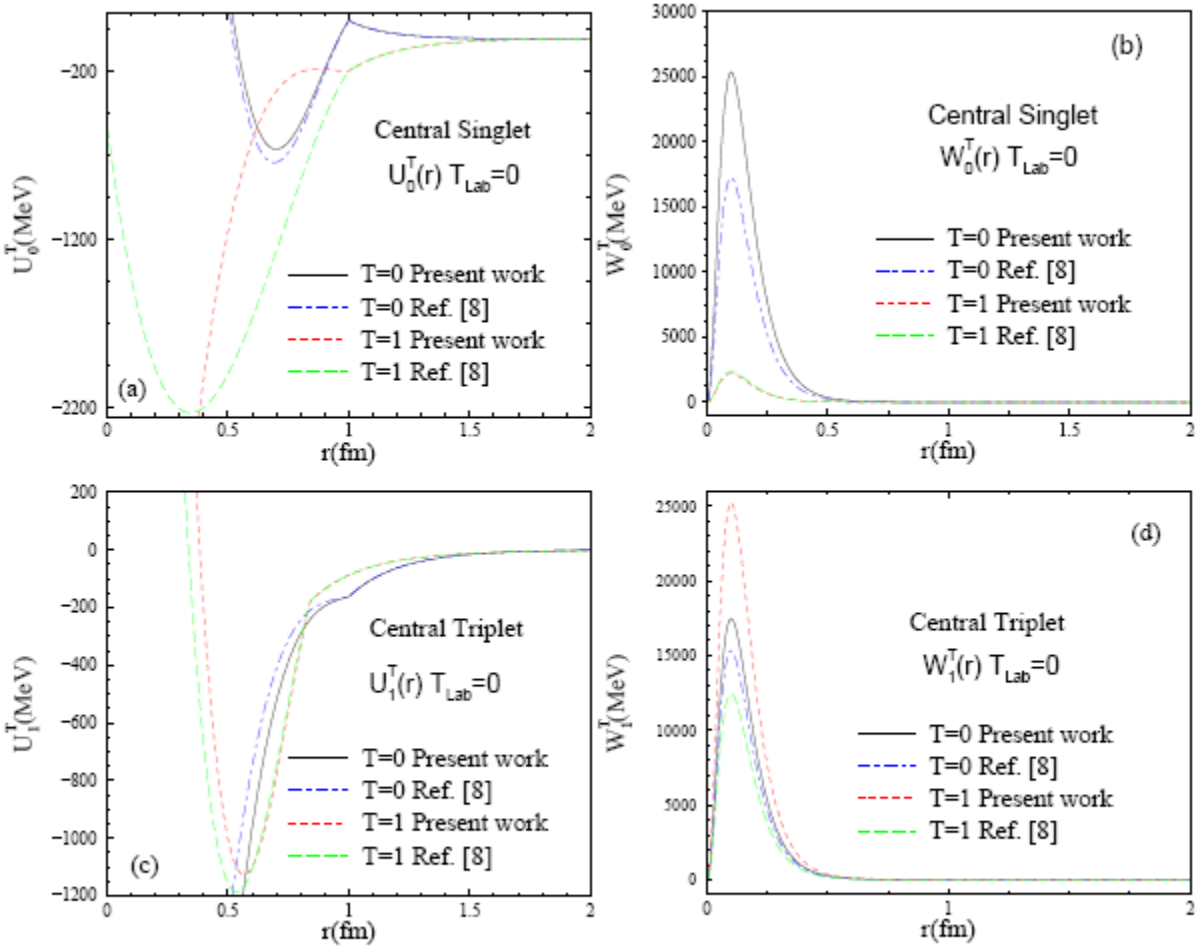



FIG. 2: Resulting real $U(r)$ and imaginary $W(r)$ potentials compare with those of Paris 99 [8]. The $N\bar{N}$ optical potential is defined as $U(r) - iW(r)$ [7].

# Scattering data

# ~4000 data + hydrogen p-bar atom



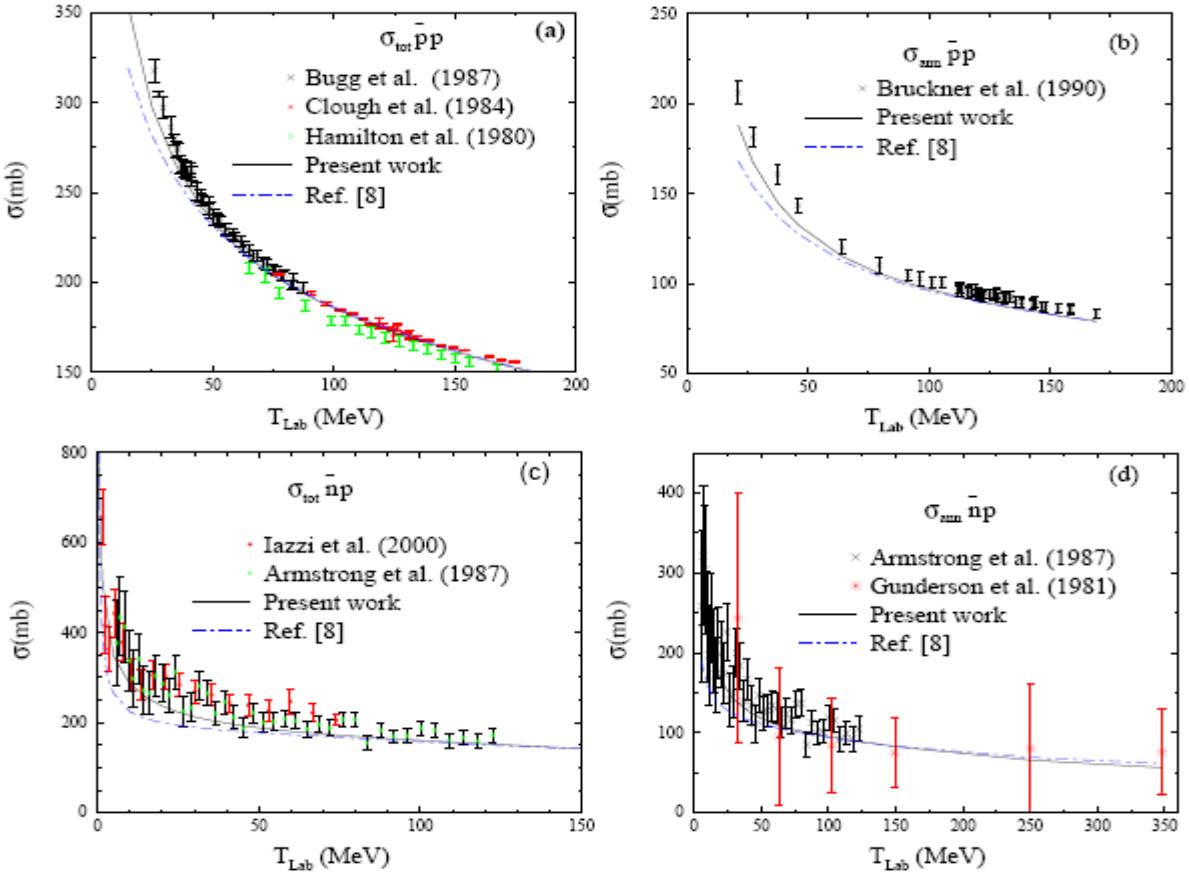



FIG. 1: Total and annihilation cross sections for the $\bar{p}p$ and $\bar{n}p$ systems. The references of the experimental data can be found in Ref. [7]. The data of Iazzi *et al.* in Fig. 1(c) are from Ref. [9].