A narrow $p\bar{p}$ enhancement near $M_{p\bar{p}} \approx 2m_p$ in $J/\psi \rightarrow \gamma p\bar{p}$

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Representing

BES & BELLE

Nihon-Dai Symposium on Hadron Spectroscopy, etc… (Tokyo, Feb 24-26, 2003)

Fermi & Yang (1949; 7 years before $\bar{p}$ discovery):

if $N\bar{N}$ potential is attractive, they could bind to form π-like states.

THE
PHYSICAL REVIEW

A journal of experimental and theoretical physics established by E. L. Nichols in 1893

SECOND SERIES, VOL. 76, NO. 12 DECEMBER 15, 1949

Are Mesons Elementary Particles?

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(Received August 24, 1949)

The hypothesis that π-mesons may be composite particles formed by the association of a nucleon with an anti-nucleon is discussed. From an extremely crude discussion of the model it appears that such a meson would have in most respects properties similar to those of the meson of the Yukawa theory.

This was a very good idea

→**Sakata** **(1956, after strange particles seen):**

make all mesons from bound
(p, n, Λ) + ($\bar{p}$, $\bar{n}$, $\bar{\Lambda}$) states

→**Ikeda, Ohnuki, Ogawa** (1959) **;**
Yamaguchi(1959)**; Neemann** (1961);
Gell-Mann (1962)**:**

Sakata model→U(3)→SU(3)

→**Gell-Mann & Zweig** (1963):

SU(3)→ quarks

Although the basic motivation of the Fermi-Yang idea is gone

(i.e. $\pi = q\,\bar{q}$ not $N\bar{N}$),

the underlying idea remains:

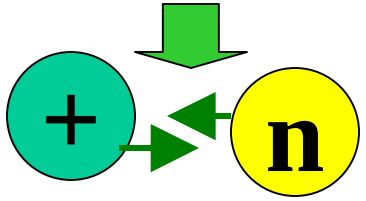
(i.e. N & $\bar{N}$ can bind to form non-$q\bar{q}$ mesons).

$N\bar{N}$ bounds states (baryonium)??

There is lots & lots of literature about this possibility

deuteron:

attractive nuclear force

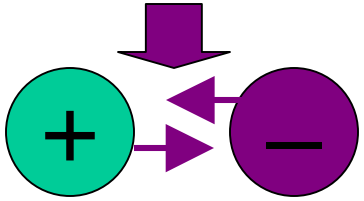


loosely bound 3-q 3-q color singlets with

$M_d = 2m_p - \varepsilon$

baryonium:

attractive force??



loosely bound 3-q 3-$\bar{q}$ color singlets with

$M_b = 2m_p - \delta$?

Is there a narrow $J^{PC}=1^{--}$ $p\bar{p}$ system near $M_{p\bar{p}} = 2m_p$?

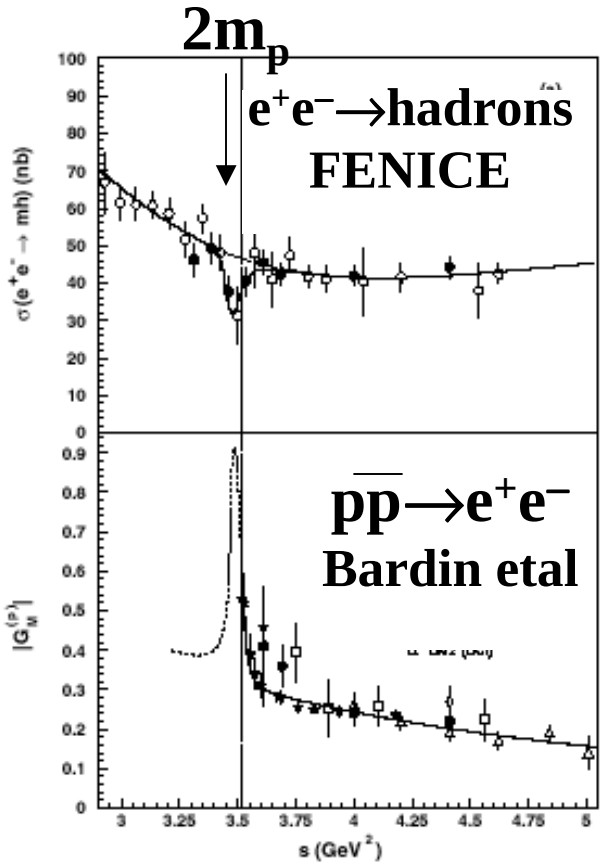


Figure 6: (a) Total multihadronic cross section (FENICE data and the average over previous experiments) with superimposed the result of the fit to a narrow resonance close to the $N\overline{N}$ threshold; (b) comparison of the proton FF data to the expected behaviour for the presence of such a resonance.

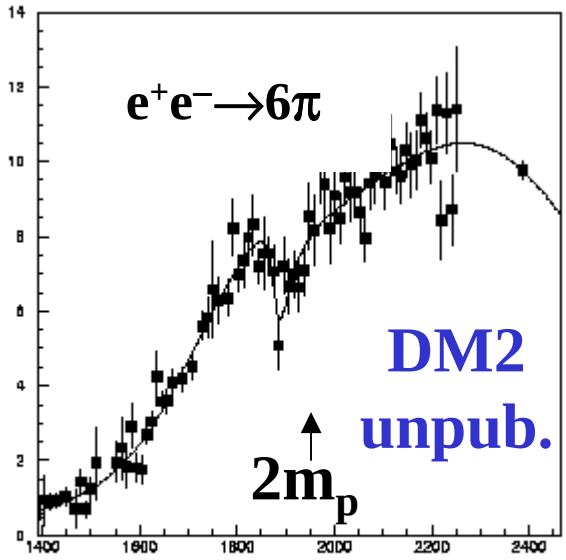


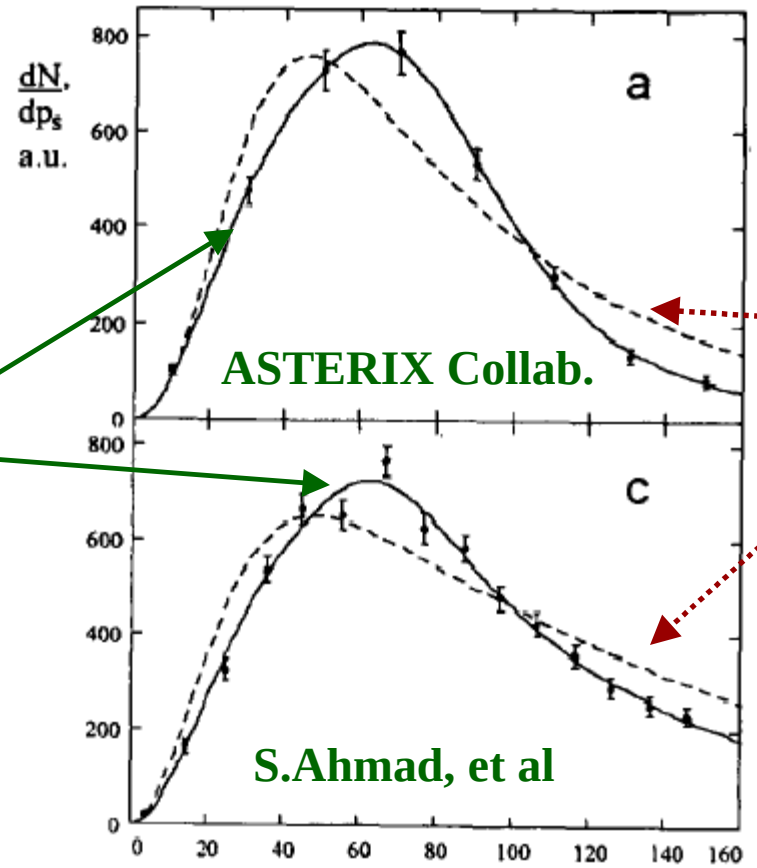
Figure 7: Cross section for the reaction $e^+e^- \to 6\pi$ measured by the DM2 experiment.

Fit: M = 1870 ± 10 MeV
Γ = 10 ± 5 MeV

R. Calabrese PEP-N work-shop proceedings

$\bar{p}d \rightarrow 5\pi + p_s$ at rest

O.D.Dalkarov et al, PLB392, 229 (1996)
[also D.Bridges et al, PLB180, 313(1986)]

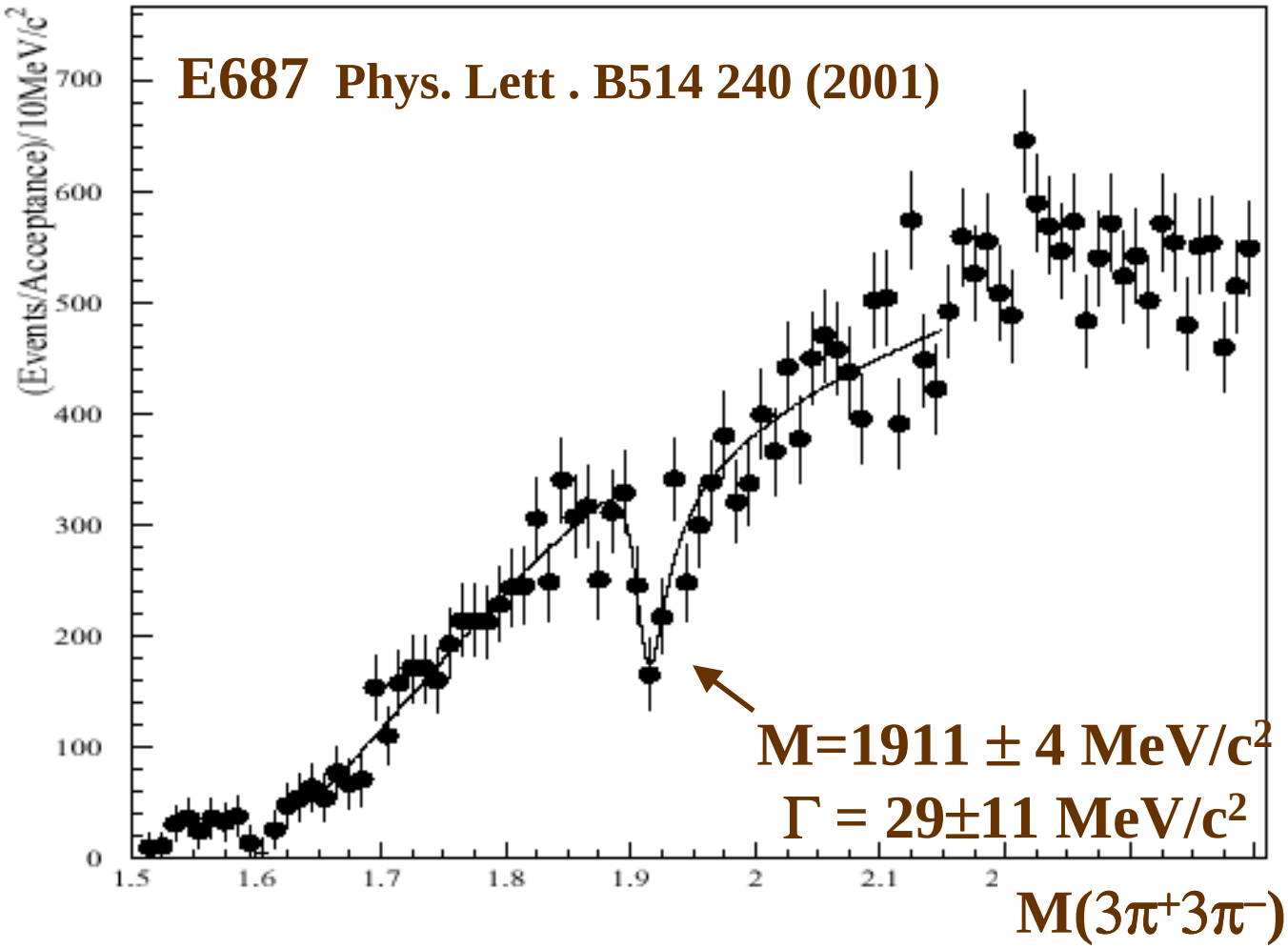


M=1870, Γ=10 resonance included

spectator model

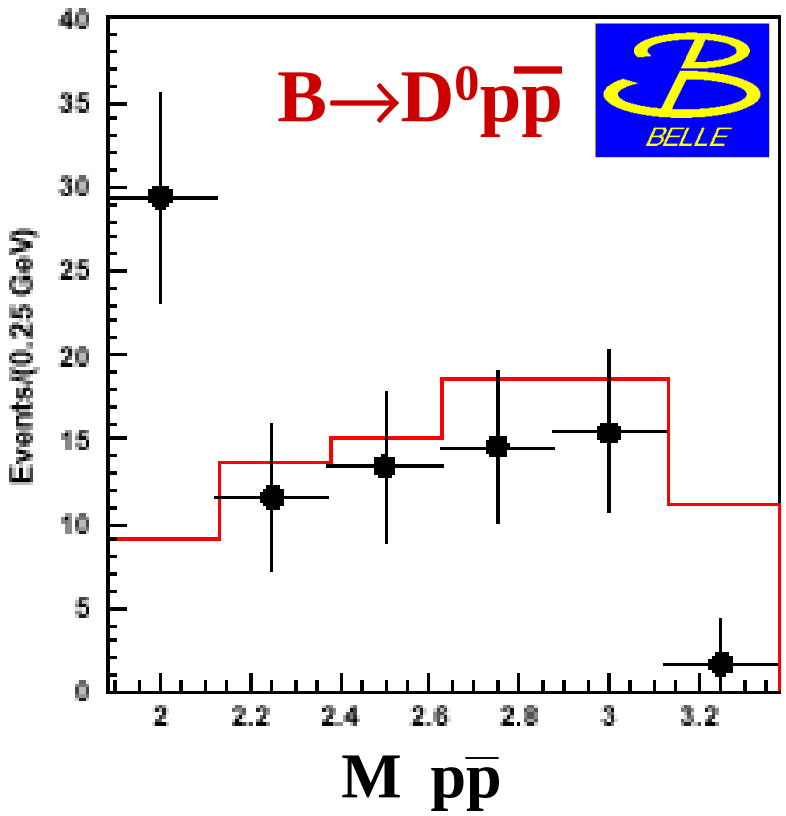
P_{ps}(MeV)

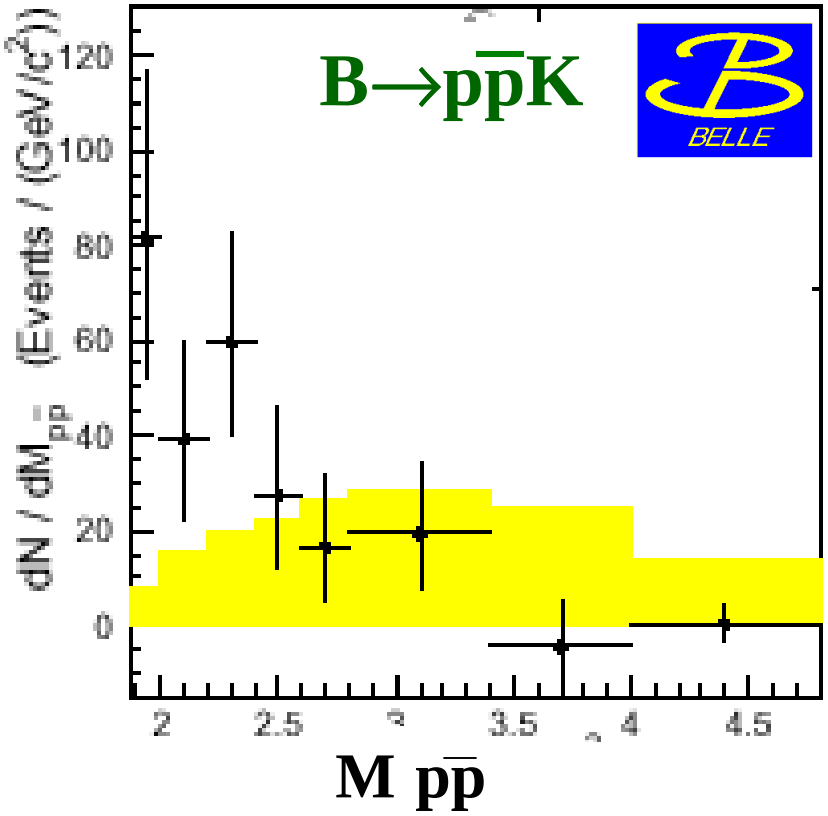
$\gamma p \rightarrow 3\pi^+3\pi^-$ diffractive



not seen in $2\pi^+2\pi^-$

Belle sees low-mass $p\bar{p}$ systems in B decays

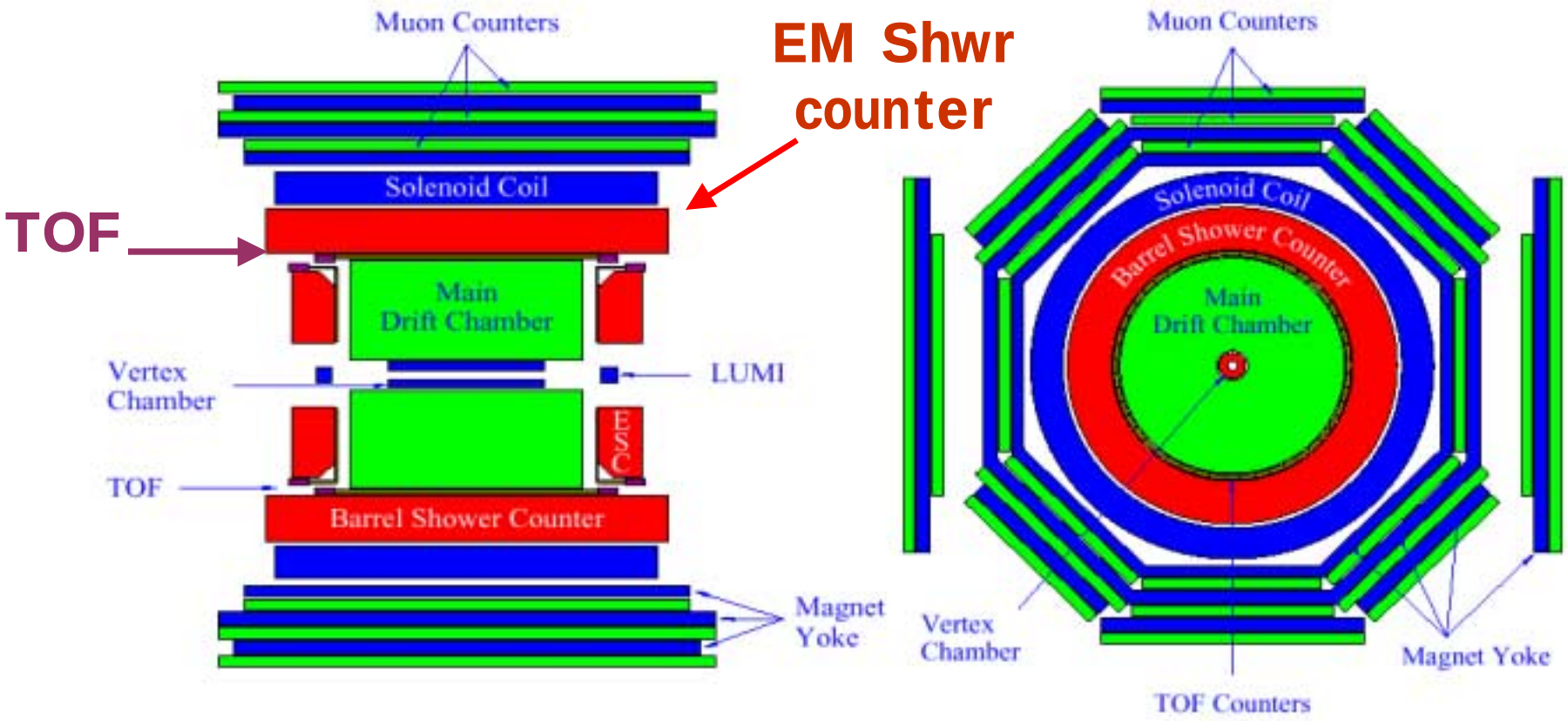




study $p\bar{p}$ from $J/\psi \rightarrow \gamma p\bar{p}$

- ***C*-parity = +**
- ***S (P?)*-wave (for $M_{p\bar{p}} \approx 2m_p$)**
- **$\therefore$ probes $J^{PC} = 0^{-+}$ (0^{++}?)states**
  - **complements $p\bar{p} \rightarrow e^+e^-$ and e^+e^- annihilation**
- **unpolluted (by other hadrons) environment**

The BES Detector



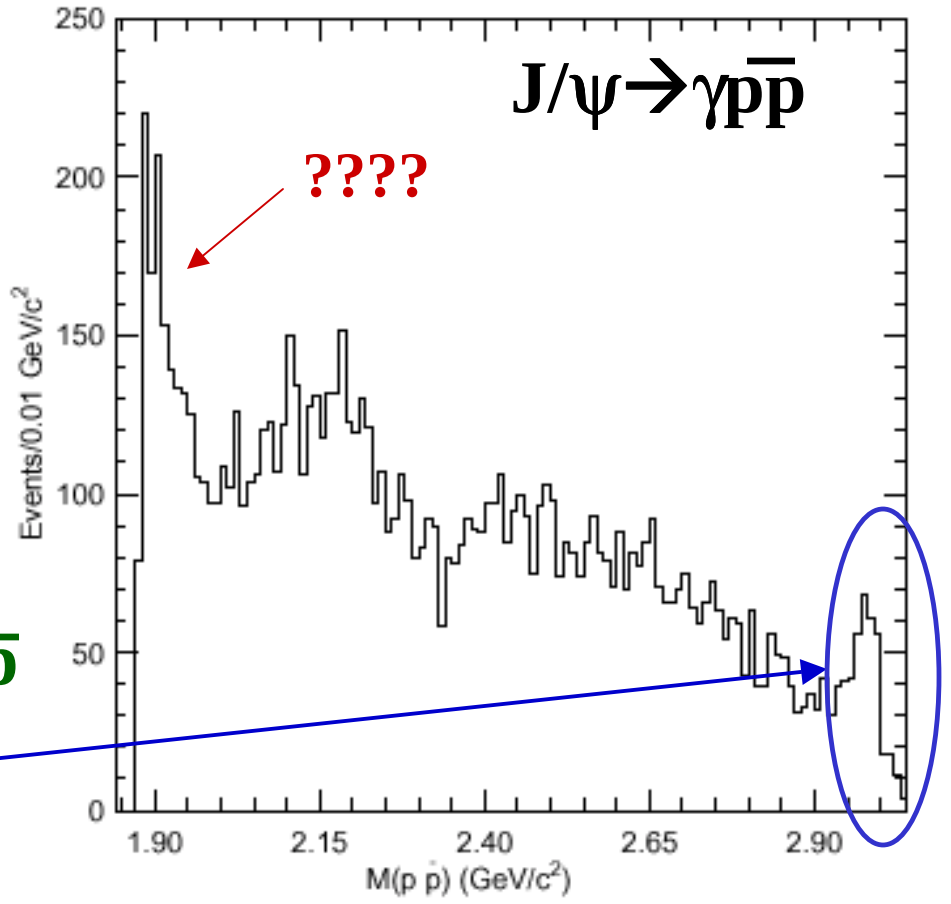
Side view of the BES detector

End view of the BES detector

Use BESII's 58M J/ψ decays

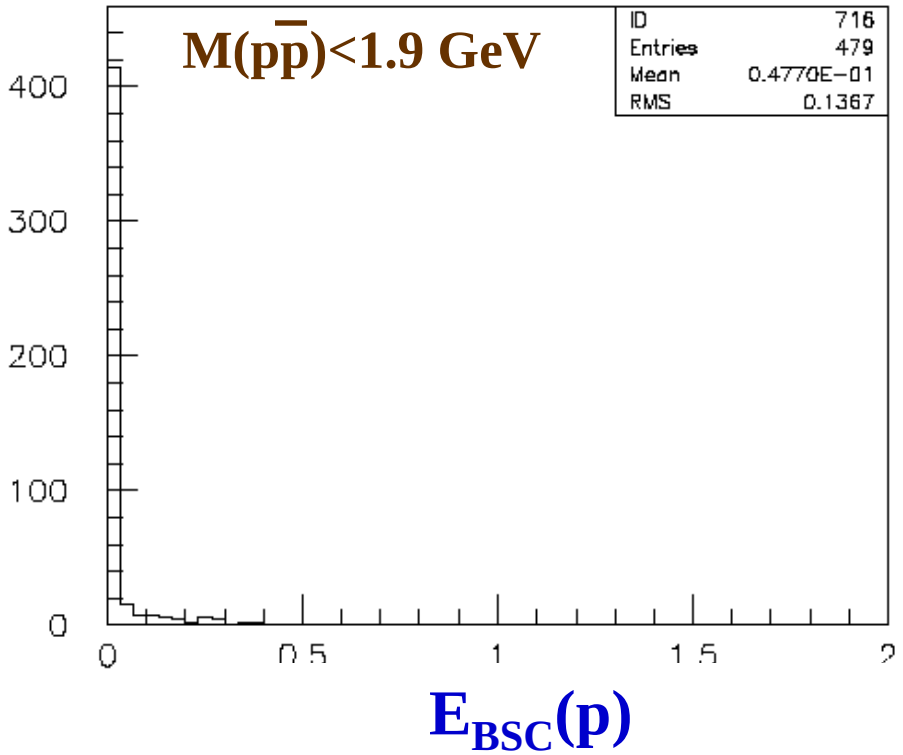
Select $J/\psi \rightarrow \gamma p\bar{p}$

- 4-C kinematic fit
- *dE/dx* for proton id
- non-$p\bar{p}$ bkg small
- main bkg from $J/\psi \rightarrow \pi^0 p\bar{p}$
- $J/\psi \rightarrow \gamma\eta_c$; $\eta_c \rightarrow p\bar{p}$
  (calibration reaction)

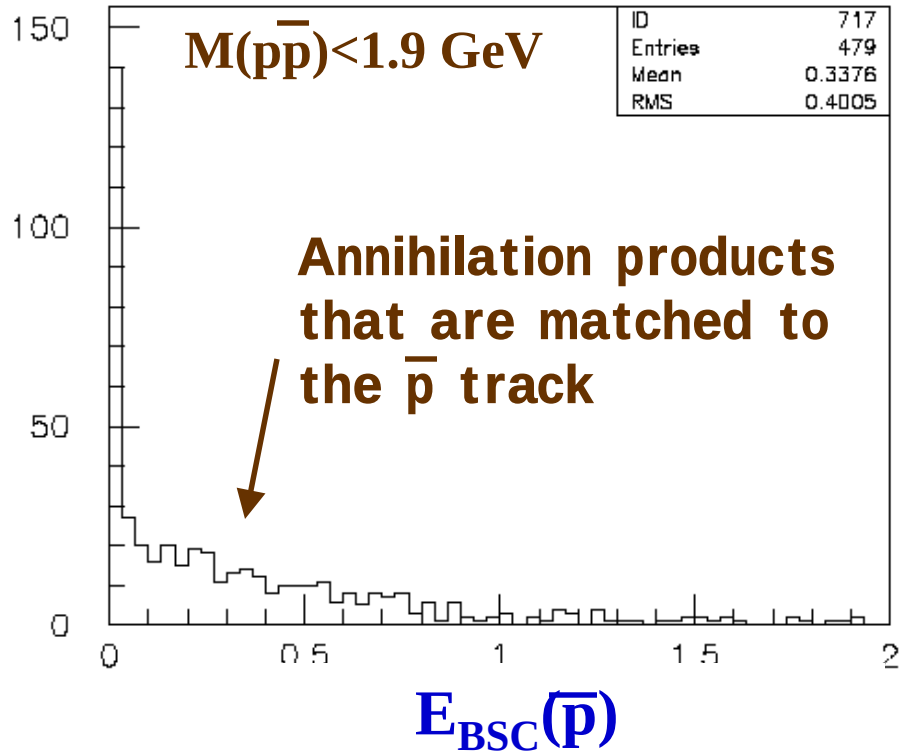


Are these really p's & $\bar{p}$'s ?

p and $\bar{p}$ in signal region mostly stop in TOF counters in front of the BSC. The p does nothing; the $\bar{p}$ annihilates.



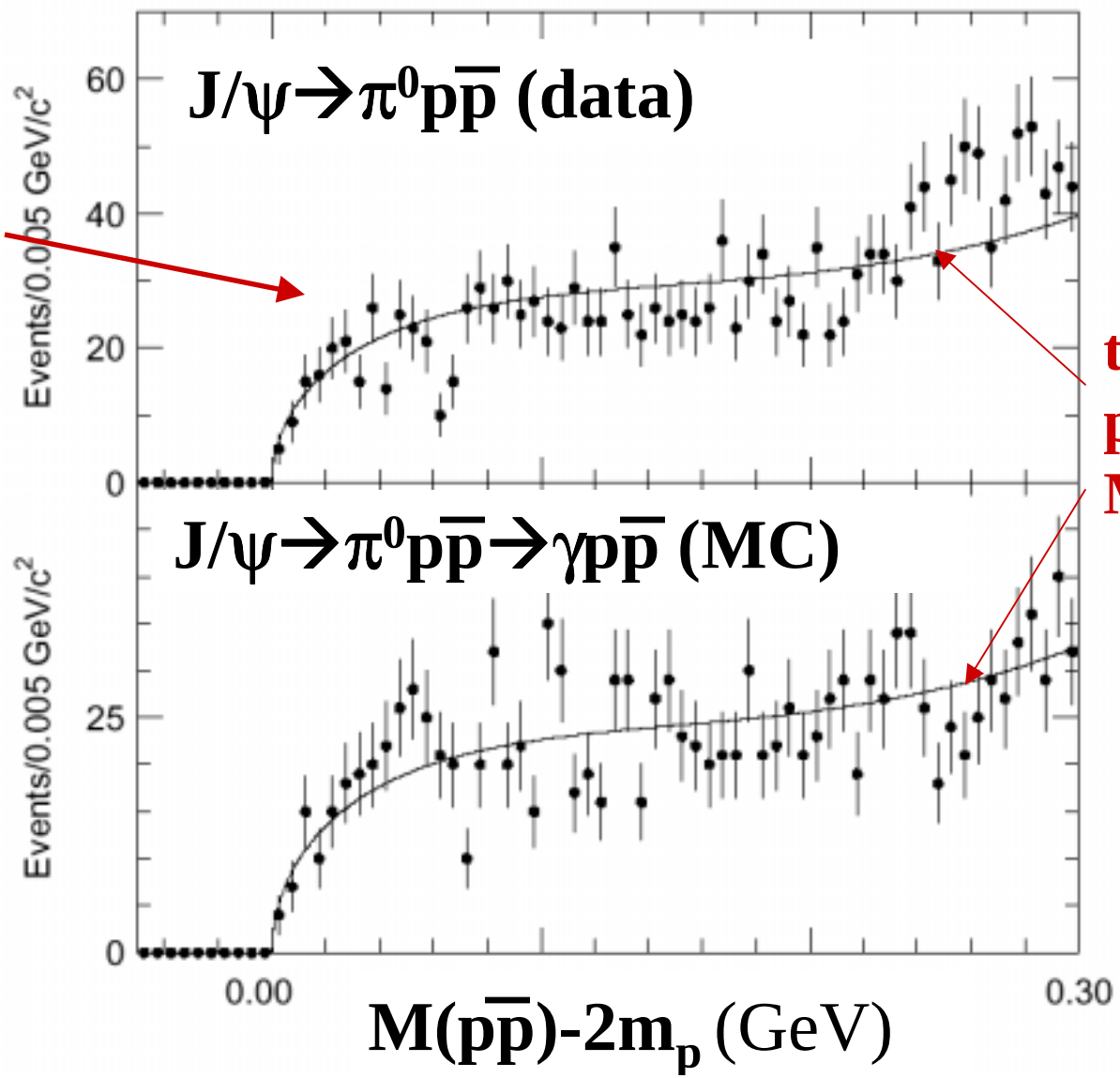
$E_{BSC}(p)$



$E_{BSC}(\bar{p})$

Study $J/\psi \rightarrow \pi^0 p\bar{p}$ bkg with MC & data

no peak!!



three-body phase space Monte Carlo

experimental summary

- real protons and antiprotons
  - *dE/dx* pid verified by BSC response
- not bkgd from J/ψ → hadrons
  - no hint of peaking in J/ψ →π^0 $p\bar{p}$ data
- not a QED background
  - E_γ pulls are symmetric
  - $\cos\theta_\gamma$ distribution not peaked
  - not seen in off-J/ψ data

the signal is real

Fit signal with an *S*-wave BW

threshold factor

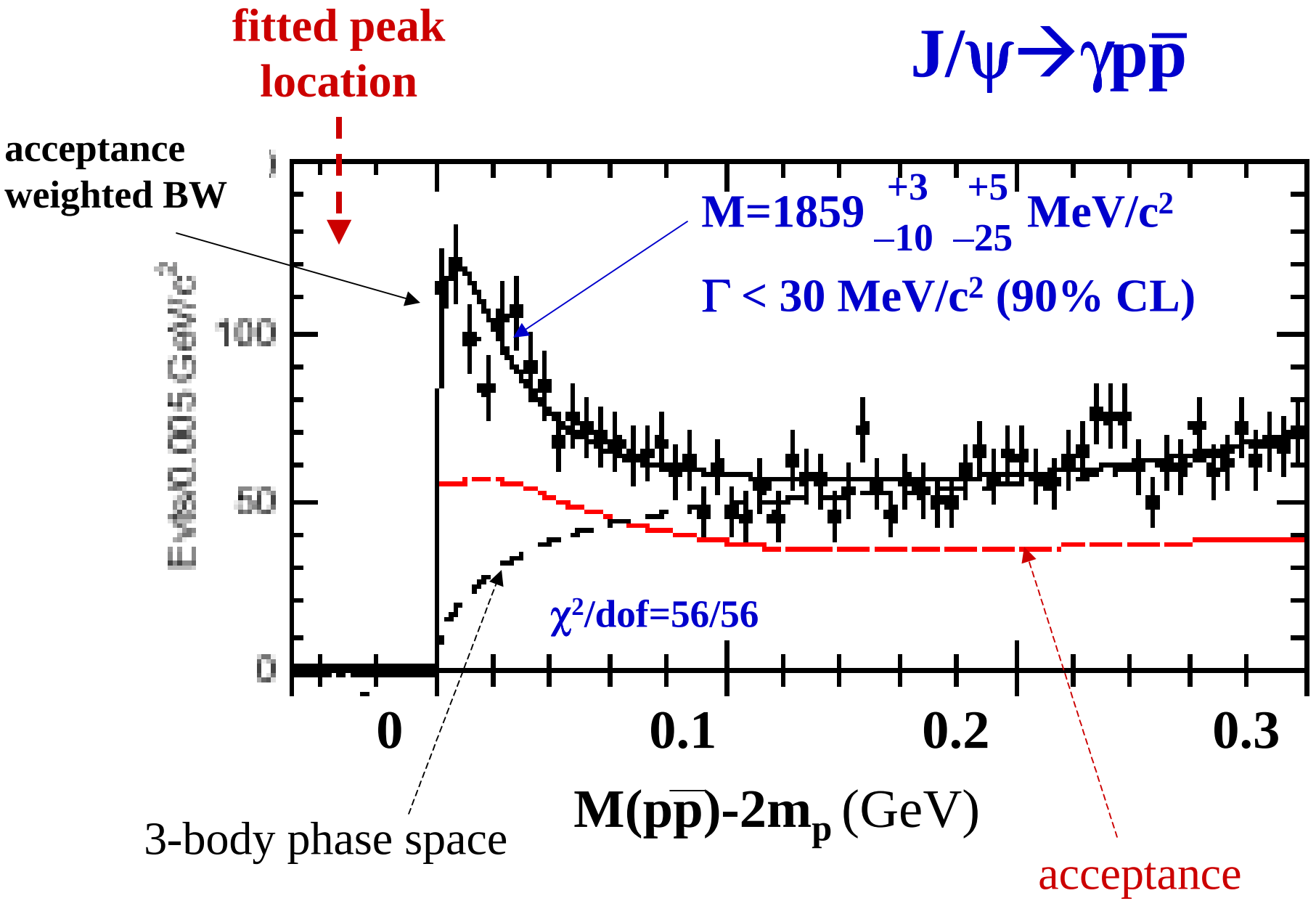
$$BW \propto \frac{M_0\Gamma_0(q/q_0)}{(M^2 - M_0^2)^2 + (M_0\Gamma_0)^2}$$

keep constant

q = daughter momentum

q_0 = daughter momentum @ peak

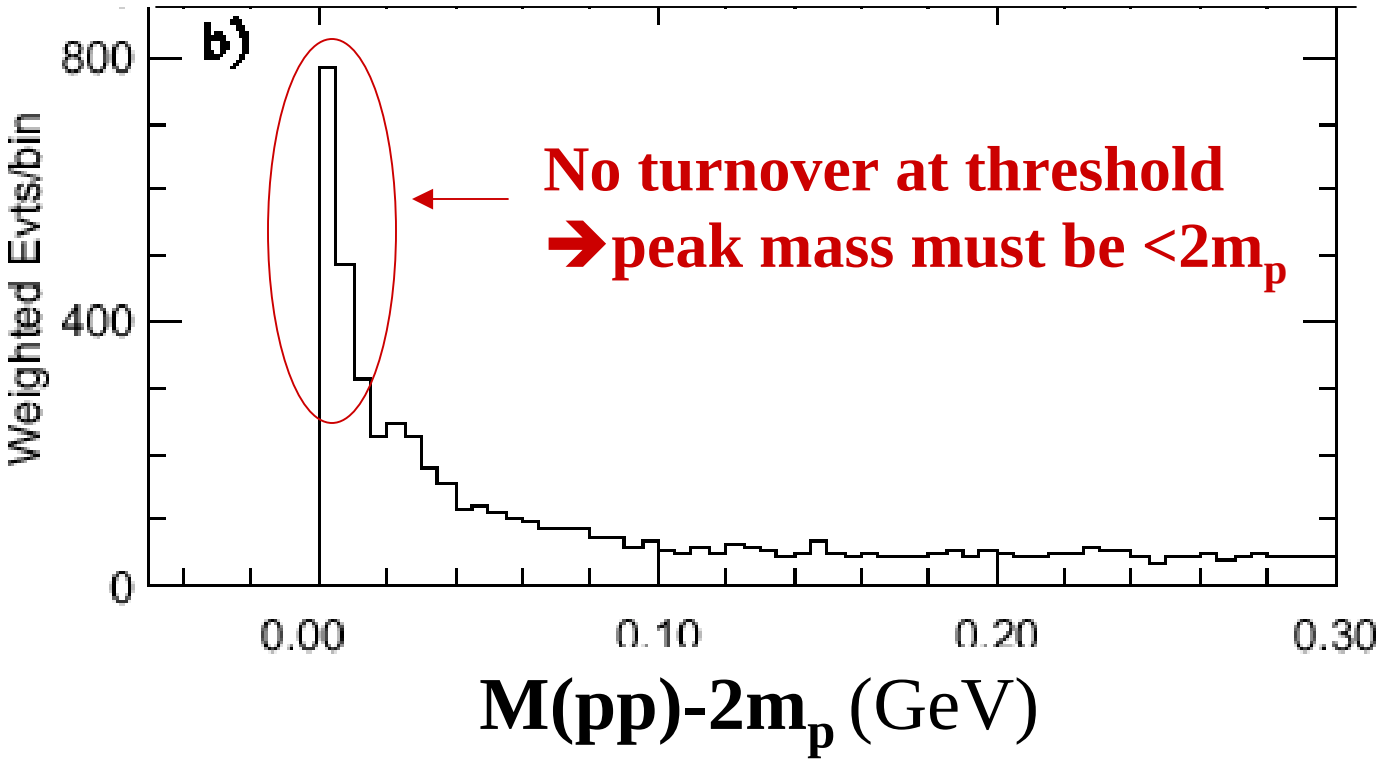
Fit to data


fitted peak location
J/ψ→γpp̄
acceptance weighted BW
M=1859 +3 +5 –10 –25 MeV/c²
Γ < 30 MeV/c² (90% CL)
χ²/dof=56/56
Events/0.005 GeV/c²
100
50
0
0
0.1
0.2
0.3
M(pp̄)-2m_p (GeV)
3-body phase space
acceptance

Is M_{peak} really less than $2m_p$?

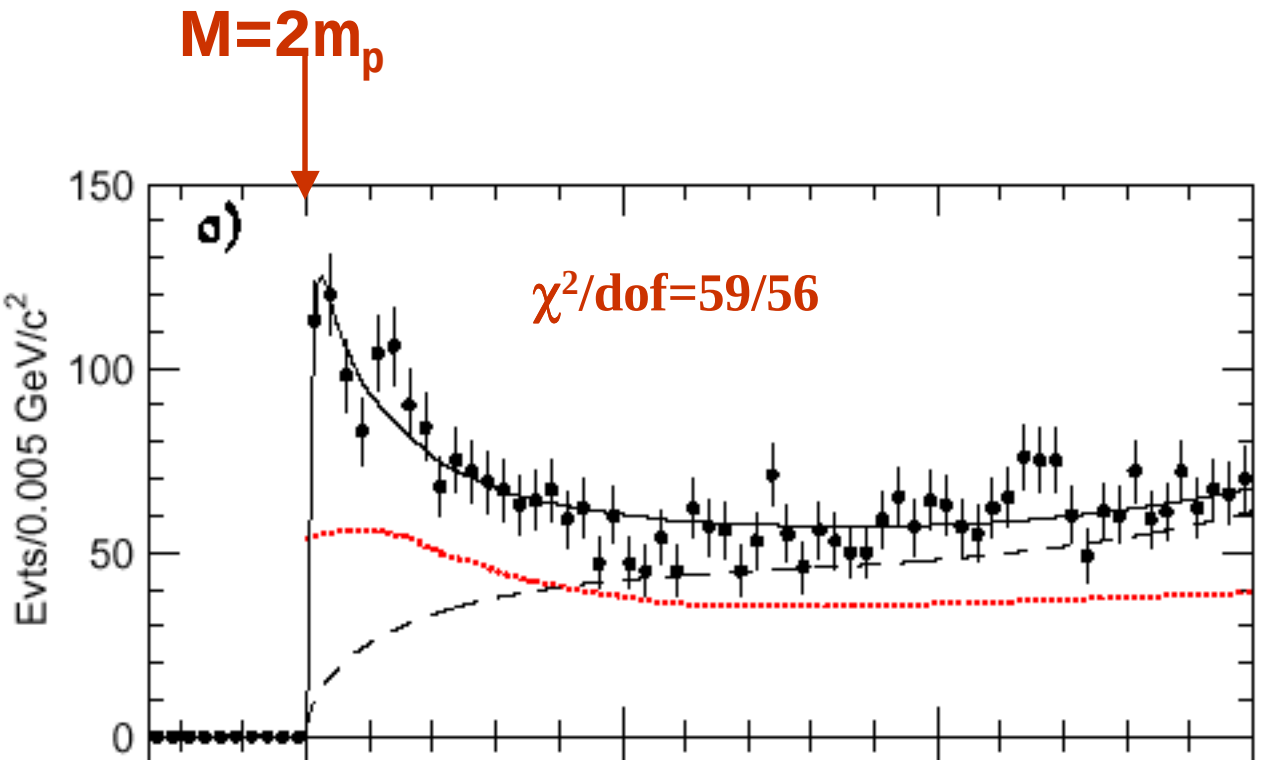
weight events by q_0/q:

(i.e remove threshold factor)



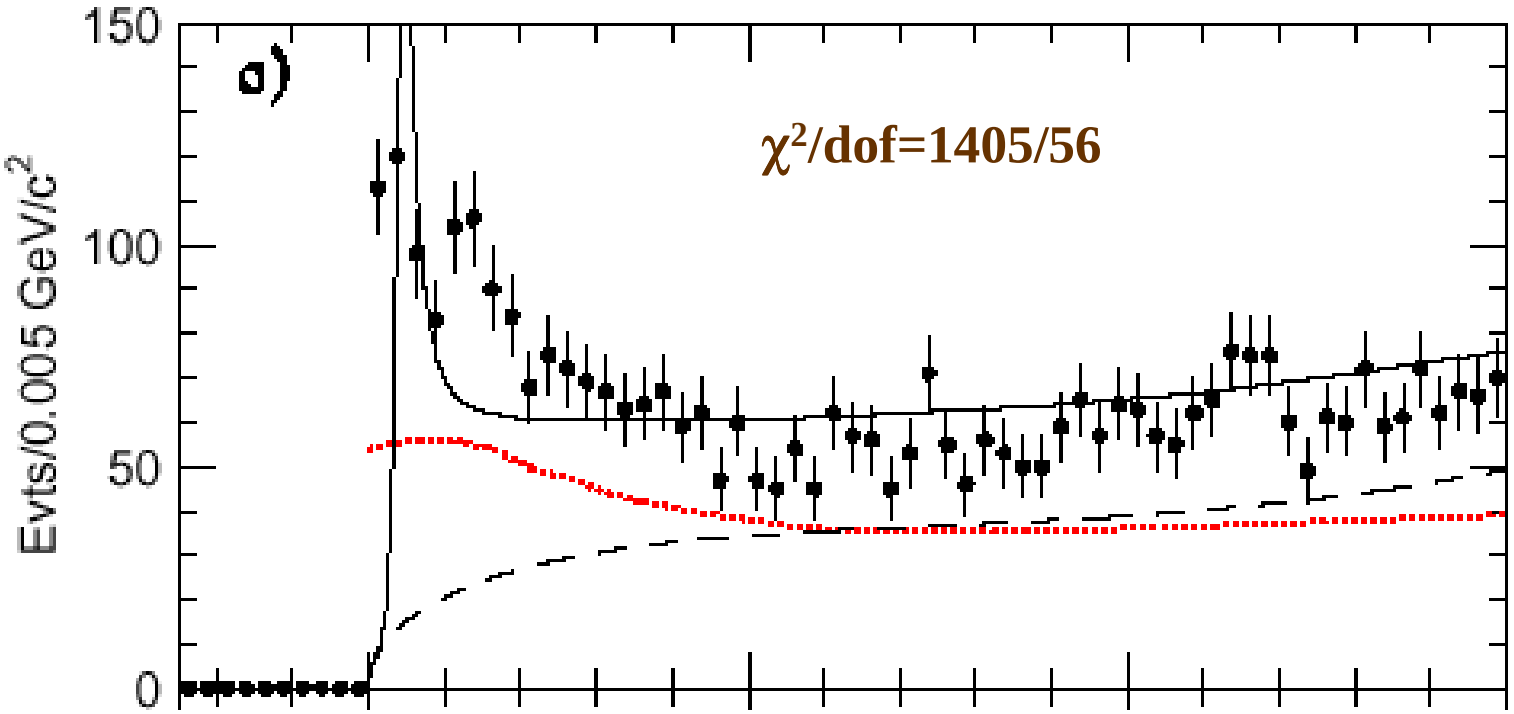
P-wave fit?? OK!

M=1876 ± 3 $^{+?}_{-??}$ MeV
Γ < 30 MeV (90% CL)



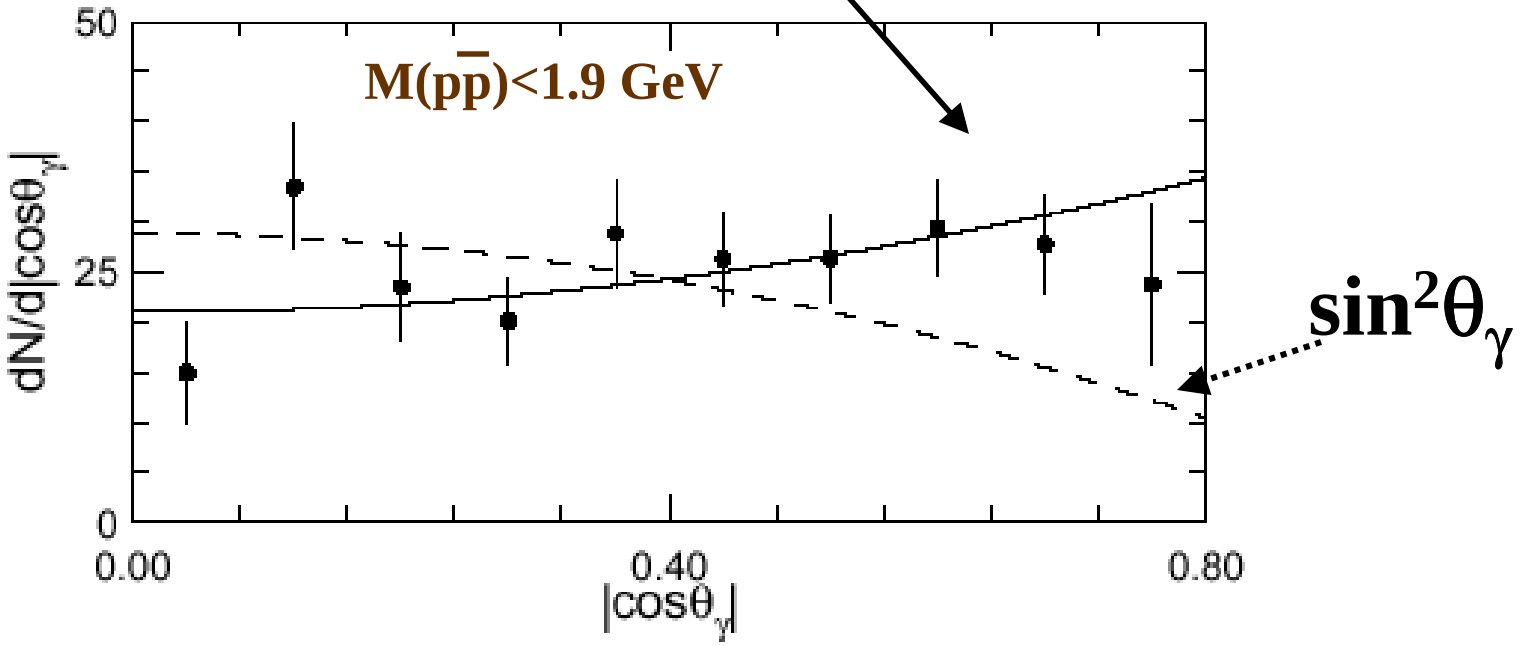
D-wave fit?? NG!!

M=1885 ± ? $^{+?}_{-??}$ MeV
Γ < 30 MeV (90% CL)



$\cos\theta_\gamma$ distribution

$1+\cos^2\theta_\gamma$ (expected for $J/\psi \rightarrow \gamma 0^{-+}$)

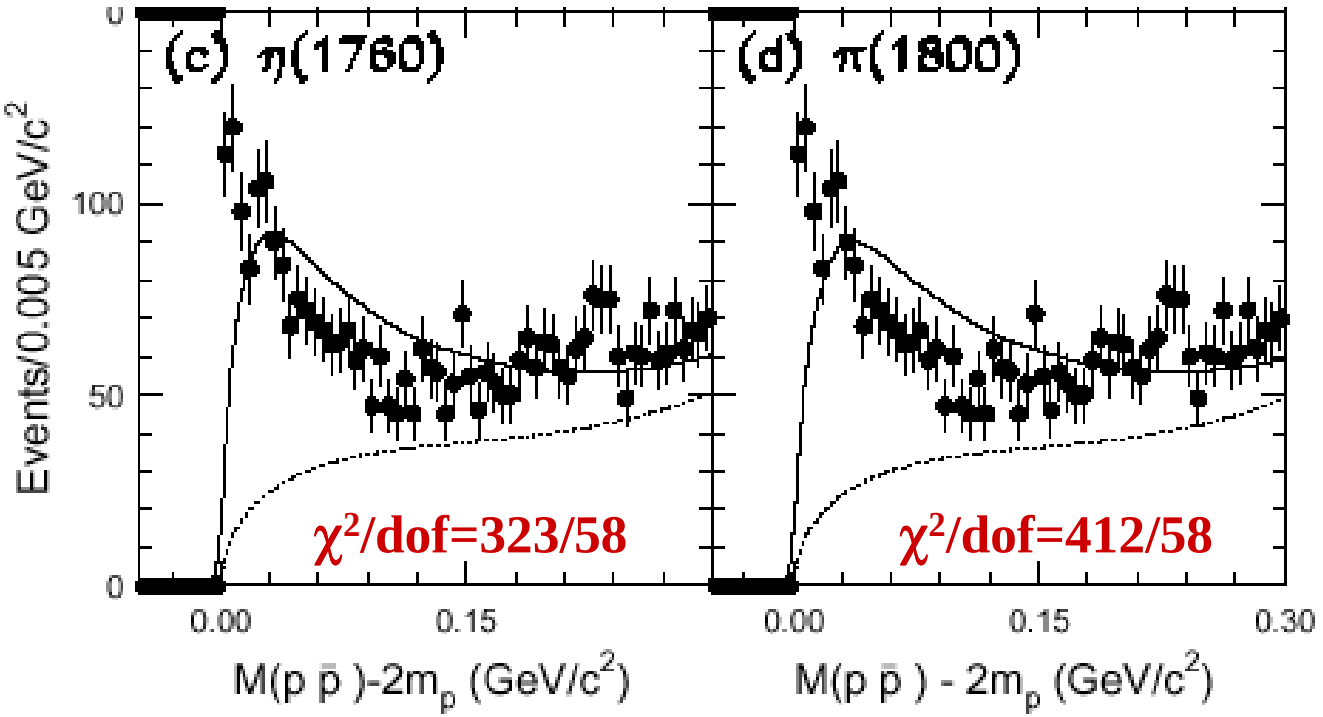


could it be a tail of a known resonance?

0^{-+} resonances in PDG tables:

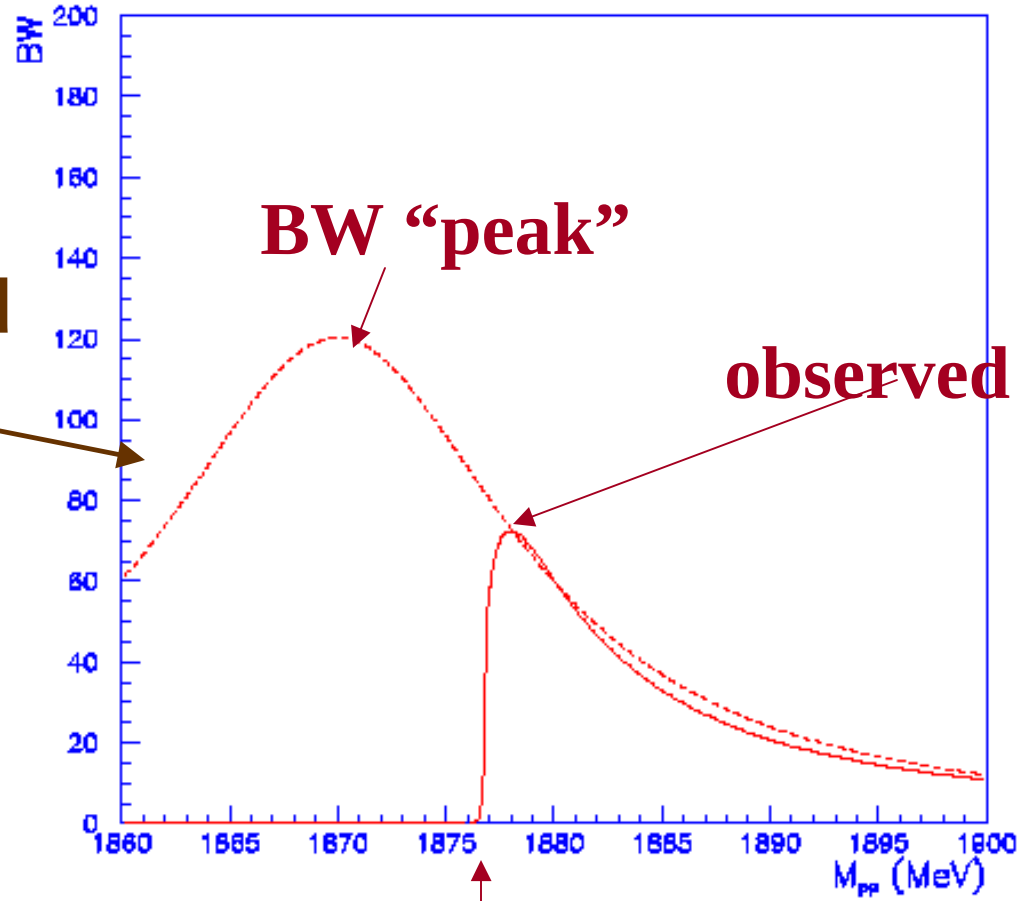
$\eta(1760)$ M=1760 Γ = 60 MeV

$\pi(1800)$ M=1801 Γ = 210 MeV



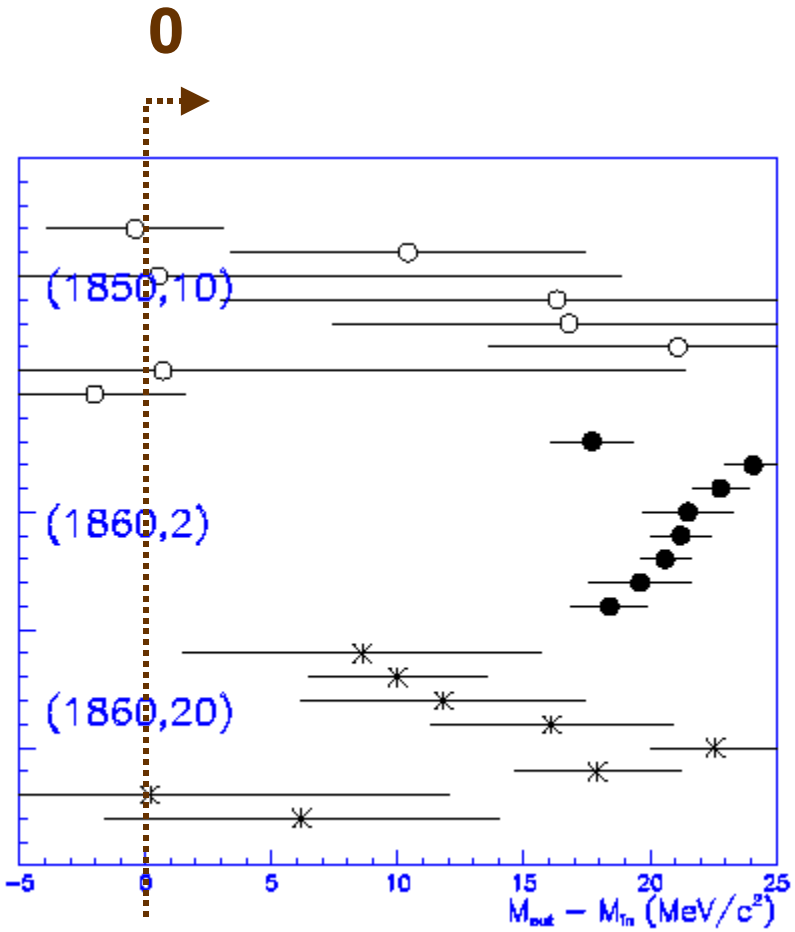
mass determination bias

below-threshold mass & widths measurements can be biased when there is background

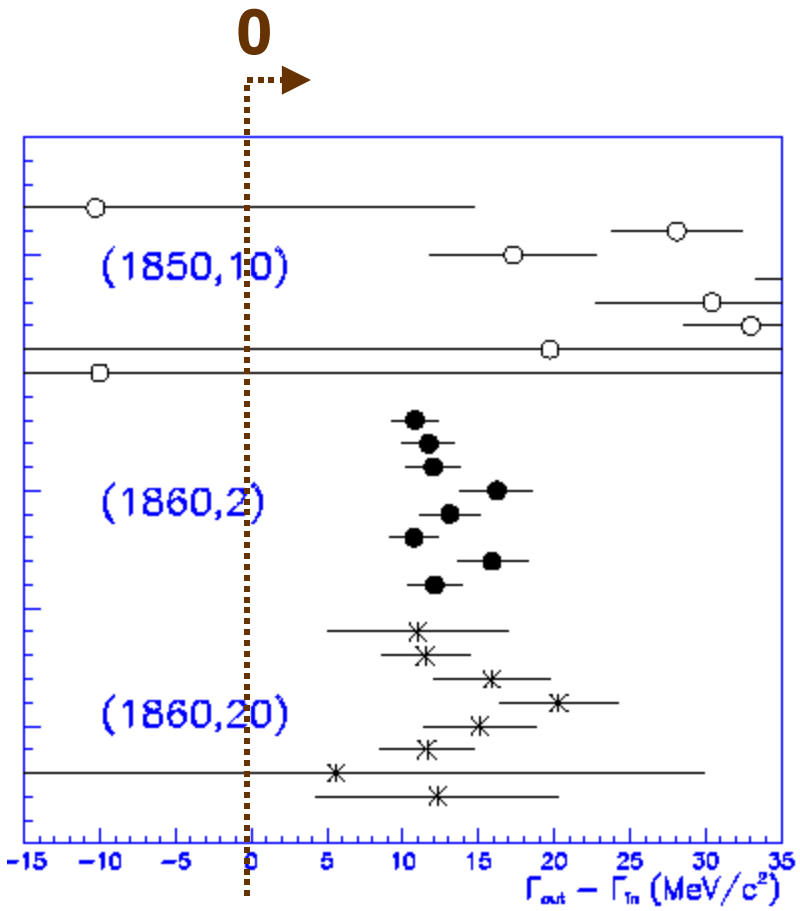


MC studies:

measured values higher than inputs



$M_{out} - M_{in}$



$\Gamma_{out} - \Gamma_{in}$

include possible biases as (asymmetric) statistical & systematic errors

if what we see is an *S*-wave resonance:

$$M = 1859\ ^{+3}_{-10}\ ^{+5}_{-25}\ \mathrm{MeV}/c^2$$

$$\Gamma < 30\ \mathrm{MeV}/c^2\ (90\%\ \mathrm{CL})$$

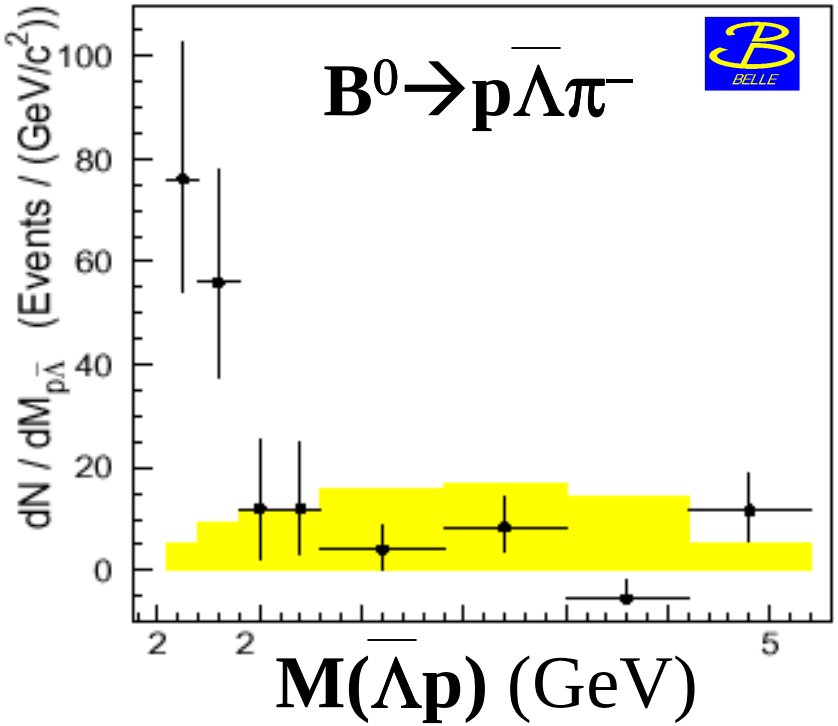
Summary

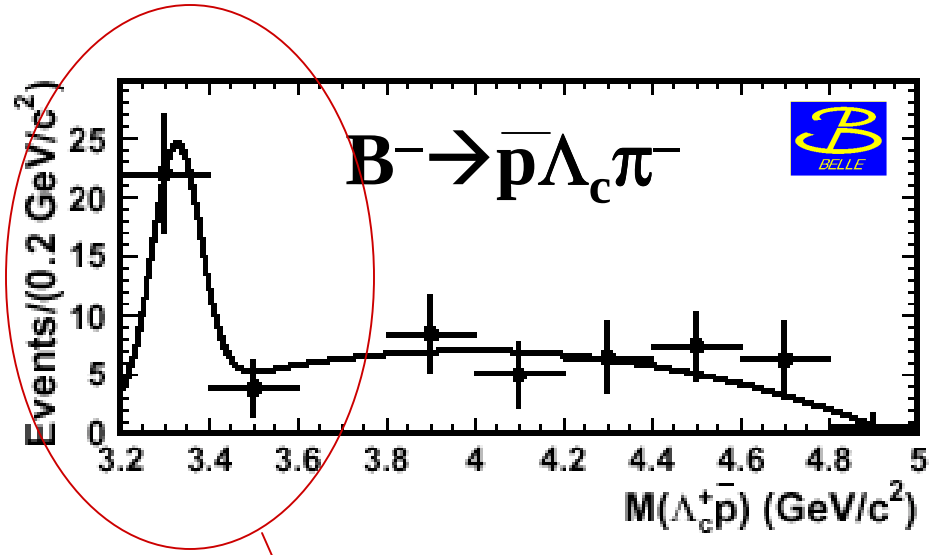
- a large enhancement seen near $2m_p$ in the $M_{p\bar{p}}$ distribution for $J/\psi \rightarrow \gamma p\bar{p}$ decays.
- not apparent in $J/\psi \rightarrow \pi^o p\bar{p}$ decays
- not consistent with any PDG meson state
- *S*- or *P*-wave can fit data
- if it is an S-wave resonance:
  - M_{peak} is below $2m_p$ ($M=1859^{+3}_{-10}{}^{+5}_{-25}$ MeV/c^2)
  - full width is narrow ($\Gamma<30$ MeV/c^2)
  - $dN/d\cos\theta_\gamma$ consistent with $J^{PC} = 0^{-+}$

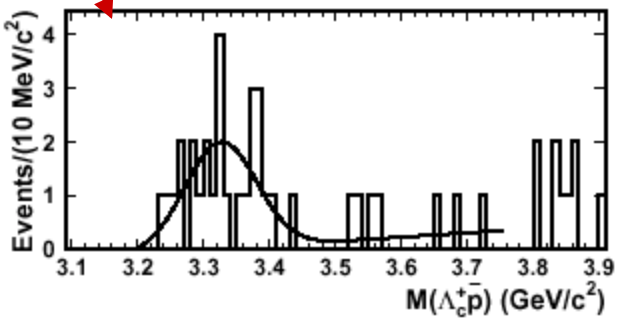
Comments

- **peak below, but near $2m_p$: baryonium?**
- **narrow width: why so long-lived?**
- **similar patterns seen in baryon-antibaryon systems produced in B meson decays**
  - **$B \to p\bar{p}K$ $B \to p\bar{p}D$ $B \to \bar{p}\Lambda\pi$ $B \to \bar{p}\Lambda_c\pi$**

Strange & charmed systems







(in these cases, the peaking doesn't seem to be right at threshold)

M($\Lambda_c^+\bar{p}$) (GeV)

maybe more B mesons will give some clues (?)


250
0
1.90
2.90
M(p p̄) (GeV/c²)
thank you

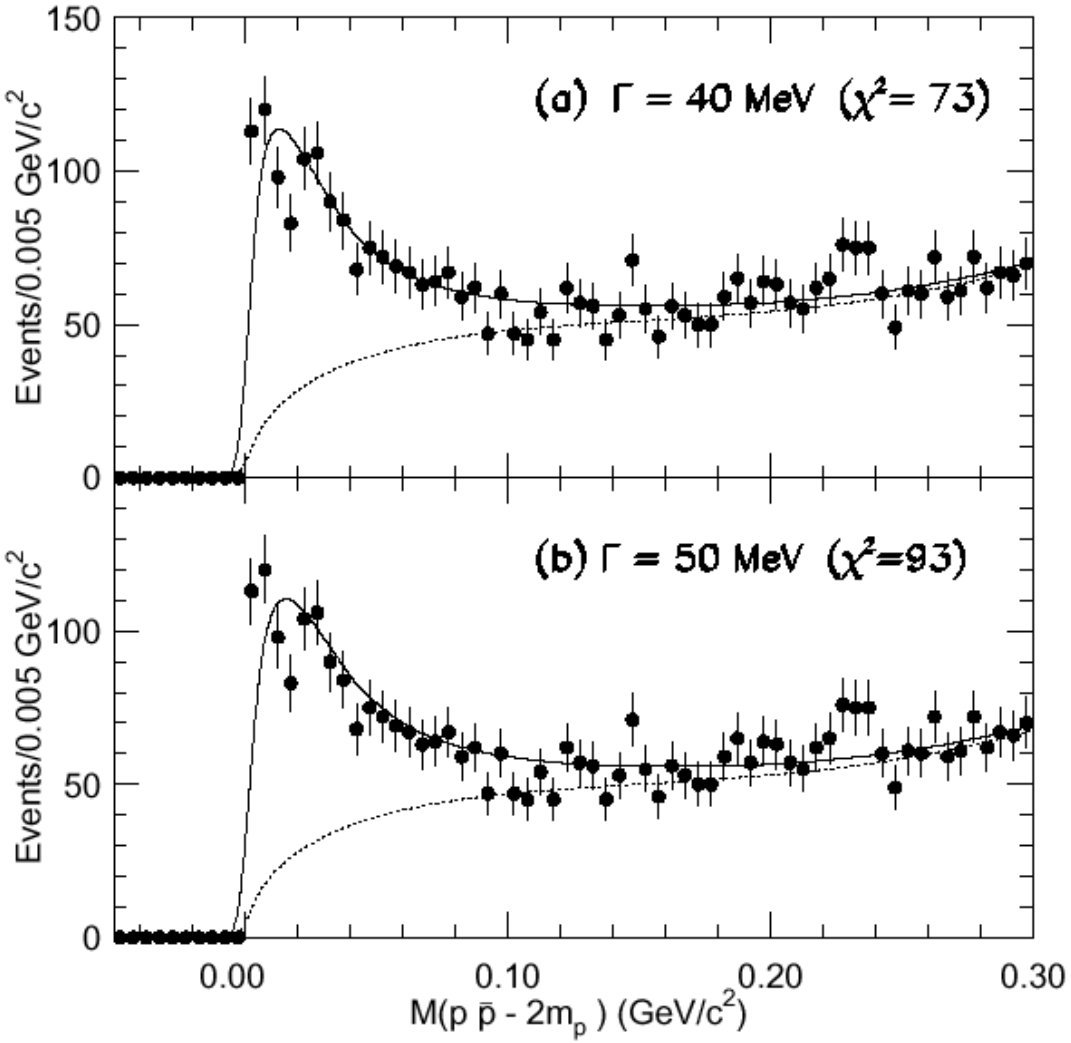
Extra Slides

is it really so narrow? (ie Γ<30MeV)

fit with other widths (Γ=0: χ^2= 56)

$\Delta\chi^2 = 17$

$\Delta\chi^2 = 37$



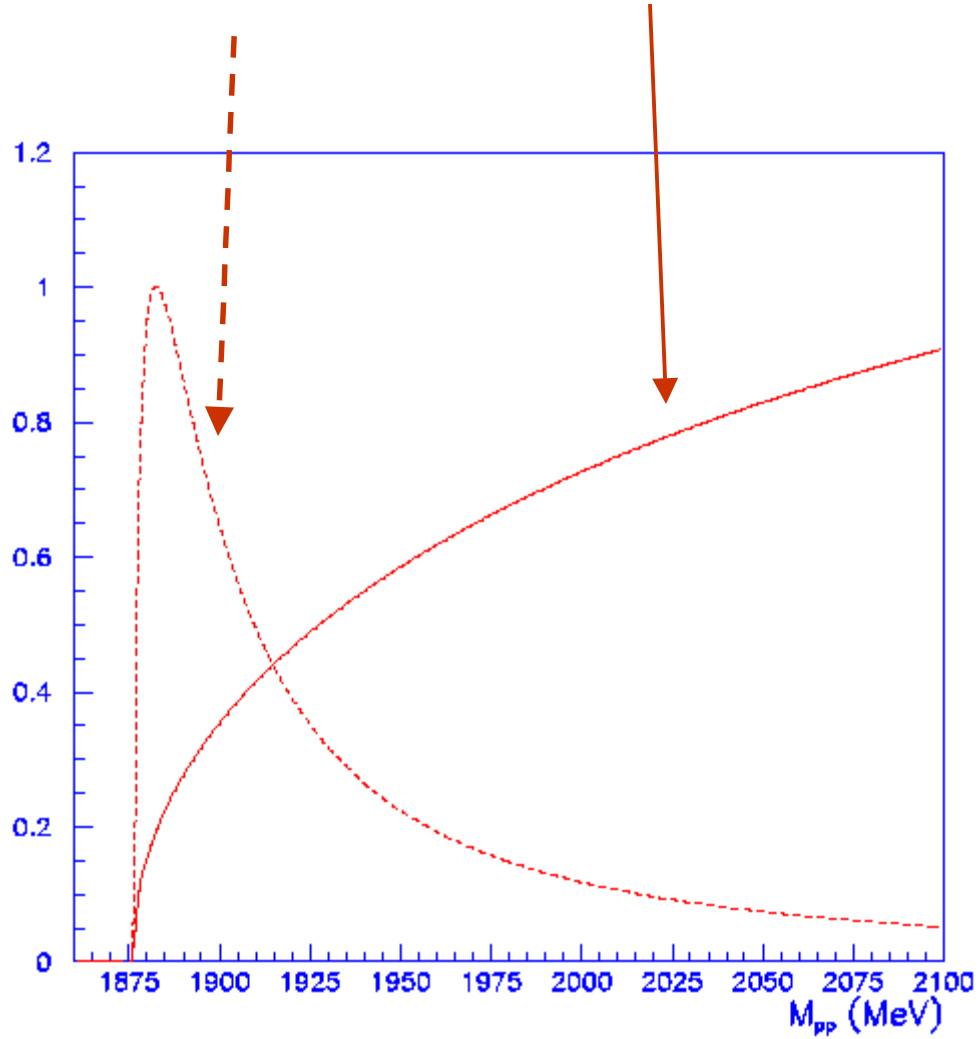
Coulomb effect?

$$\frac{\pi\alpha / v}{1-\exp(-\pi\alpha / v)} * \frac{v(3-v^2)}{2}$$

coulomb factor

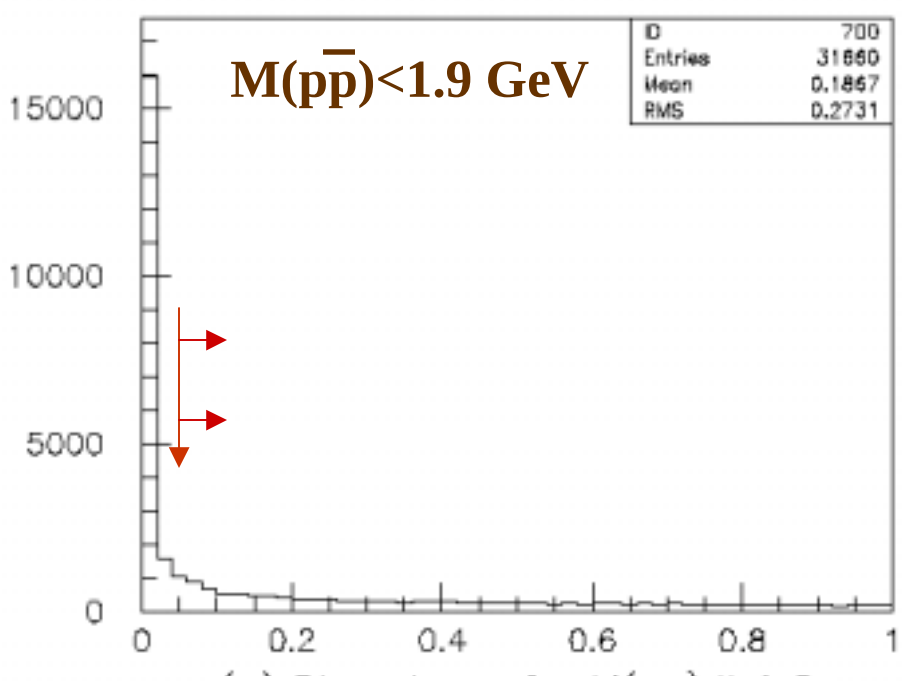
phase-space term

BW vs Coulomb

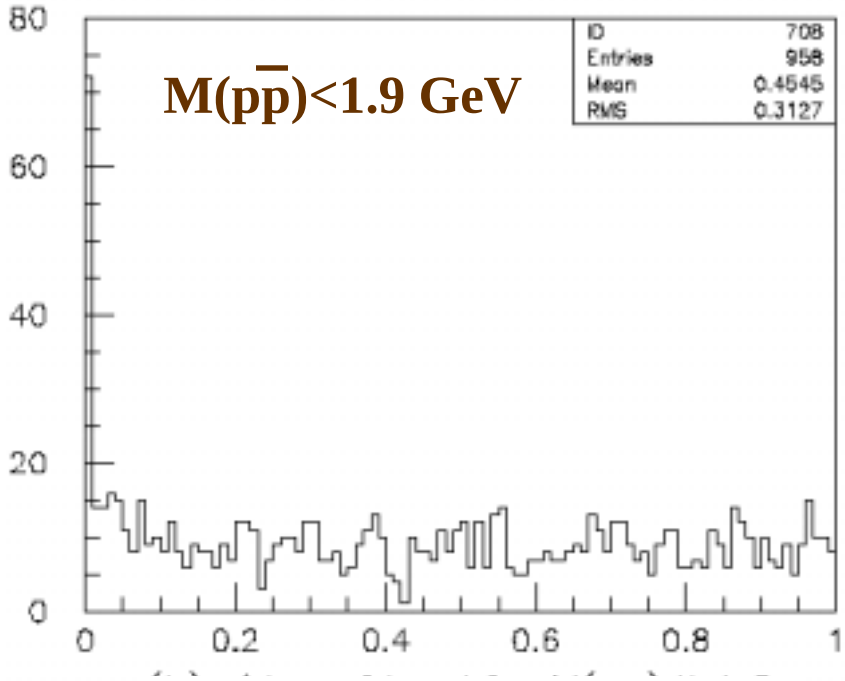


Experimental stuff

4-C fit and particle id CL distributions are flat



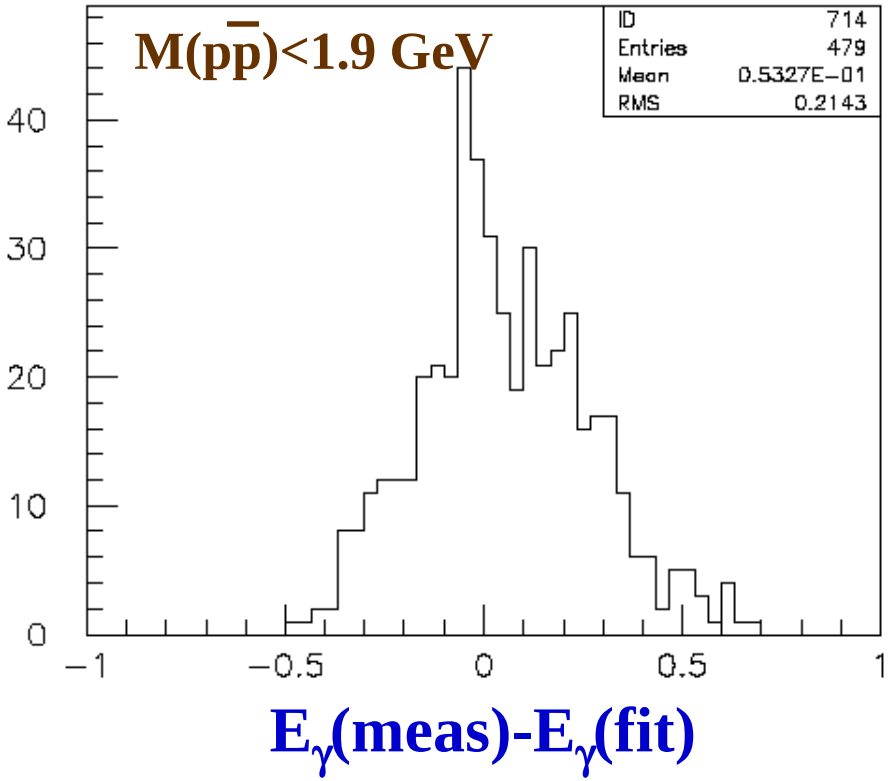
4-C fit CL



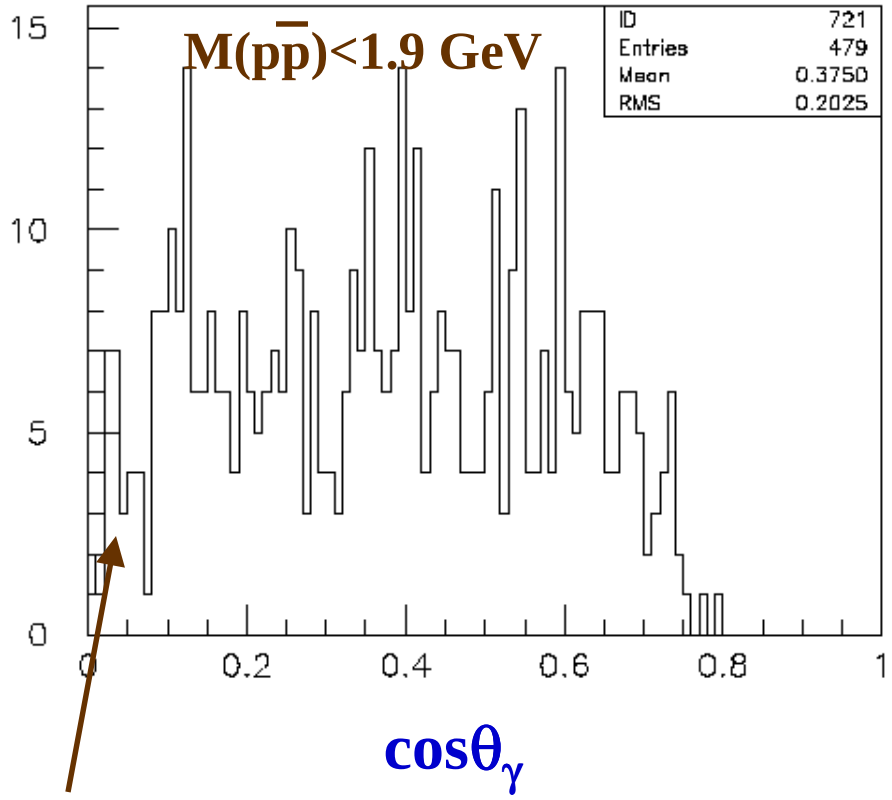
p & $\bar{p}$ id CL

more experimental stuff

Eγ pulls are ~symmetric



Polar angle dist looks ok



mass-dependent acceptance

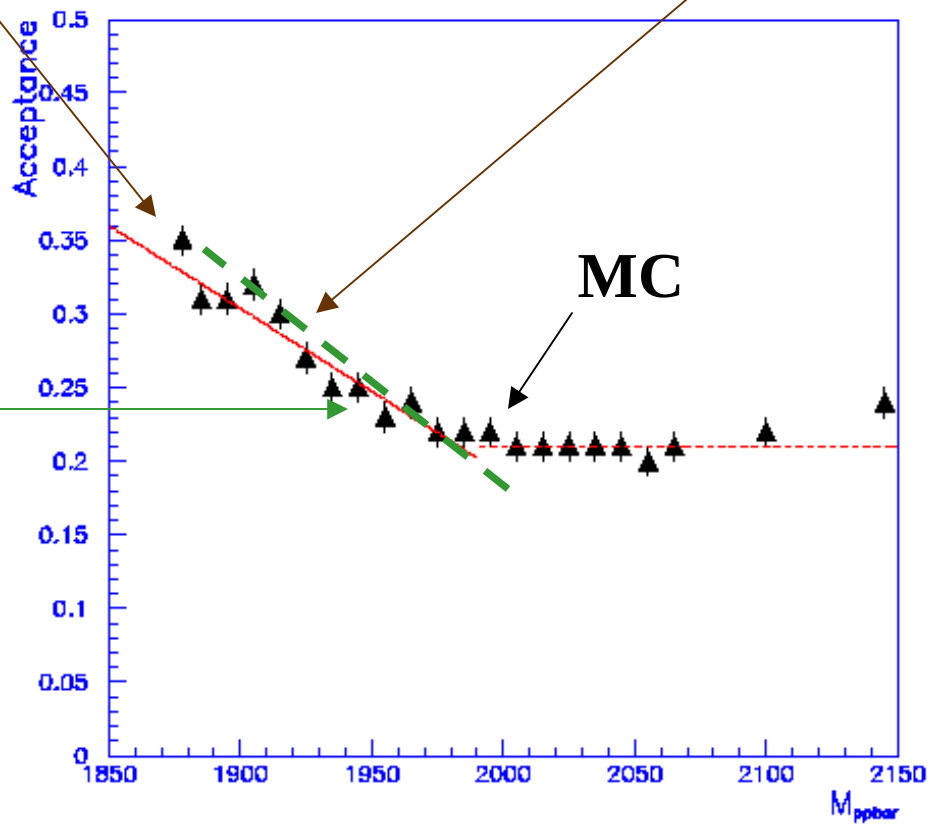
pp system has a total momentum $|\vec{p}| \approx 1$ GeV/c

p&$\bar{p}$ share momentum ~equally (~0.5 GeV/c each)

p&$\bar{p}$ momenta can be asymmetric

Acceptance

hand calculation for p_{min} = 0.3 GeV/c



Systematic errors

Fit variation	δN_{evts}	δM (MeV/c^2)	$\delta\Gamma$ (MeV/c^2)
A_1 & A_2 at $\pi^0 p\bar{p}$ values	+202	-7	0
Float A_1 & A_2	+94	-2	0
resolution$\sigma = 1$ MeV	0.0	+1	0
resolution$\sigma = 3$ MeV	+3	+3	0
resolution$\sigma = 6$ MeV	+27	+5	0
SOBER acceptance	+84	0	0
Coarser bins	+11	-2	0
BW at 2.2 GeV ($\Gamma = 0.2$ GeV)	+17	0	0
BW at 2.2 GeV ($\Gamma = 0.3$ GeV)	+43	-1	0
Likelihood$\rightarrow \chi^2$	-15	0	0
Quadrature sums	$^{+224}_{-15}$	$^{+5}_{-7}$	$^{+0}_{-0}$

vary all procedures: fit results don't change much