

The Sounds of Silence

Anomalies in Baryon Time-like Form Factors near threshold

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Outline

○ Definitions and Main Expectations

○ $e^+ e^- \rightarrow p p_{\text{bar}}$

- FF oscillations? Step at threshold. Coulomb enhancement ?

○ $e^+ e^- \rightarrow \Lambda_c \Lambda_{\text{cbar}}$

- Step at threshold. Hidden charm “Baryonium” ?

○ $e^+ e^- \rightarrow \Lambda \Lambda_{\text{bar}}$

- Step at threshold. Narrow resonance close by ?

○ $J/\psi \rightarrow \gamma N N_{\text{bar}}$

- Light Quarks “Baryonium” ?

○ $e^+ e^- \rightarrow n n_{\text{bar}}$

- News from SND, CMD3 and BESIII

○ G_E / G_M phase

- Relationship with spacelike zeros

Preamble

- Baryon mass is the main component of the mass of the Universe
It comes from the strong force (not from the Higgs mechanism)
- But Baryons, what they really are, are far from being understood

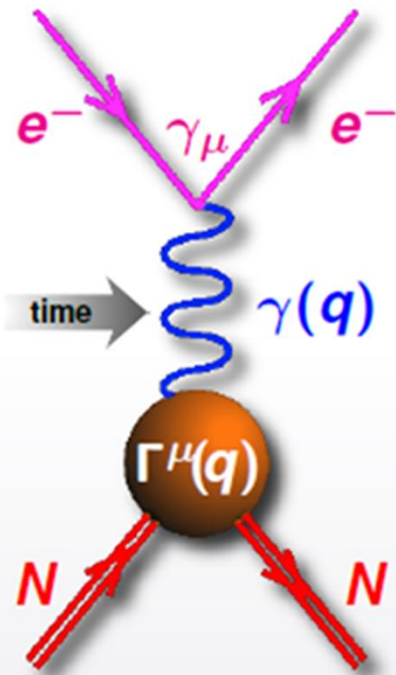


- For instance:
 - A fermion with mass, magnetic moment and other parameters close to Proton and Neutron ones can be obtained as a soliton of a π pointlike boson field, by means of a non linear lagrangian with one free parameter only !
[**Skyrme model**, T. H. R. Skyrme, Proc. Roy. Soc. A 260 (1961) 127]
 - The baryon spin is not due to the spins of the valence quarks !
[**Proton Spin Crisis**, EMC Collaboration, Phys. Lett. B206, 364 (1988)]
- Therefore it is meaningful to point out open questions, concerning Baryon structure, and Timelike Baryon Form Factors are plenty of

Definitions and Main Expectations

Spacelike ($q^2 < 0$)

- Lowest em order ($\alpha \ll 1$): one photon exchange (Born cross section)



- Electromagnetic current ($q = p' - p$)

$$J^\mu = \langle N(p') | j^\mu | N(p) \rangle = e \bar{u}(p') \left[\gamma^\mu F_1(q^2) + \frac{i \sigma^{\mu\nu} q_\nu}{2M} F_2(q^2) \right] u(p)$$

- Dirac and Pauli form factors F_1 and F_2 are real
- In the Breit frame

Nucleon Spin Flip: G_M , non Spin Flip: G_E

- $2M \bar{u}(p') \gamma^\mu u(p) = \bar{u}(p') [(p + p')^\mu + i \sigma^{\mu\nu} q_\nu] u(p)$
- $\bar{u}(-\vec{p}) u(\vec{p}) = E/M$ ● $u^\dagger(-\vec{p}) u(\vec{p}) = 1$

- Sachs form factors

$$G_E = F_1 + \frac{q^2}{4M^2} F_2$$

$$G_M = F_1 + F_2$$

- Normalizations

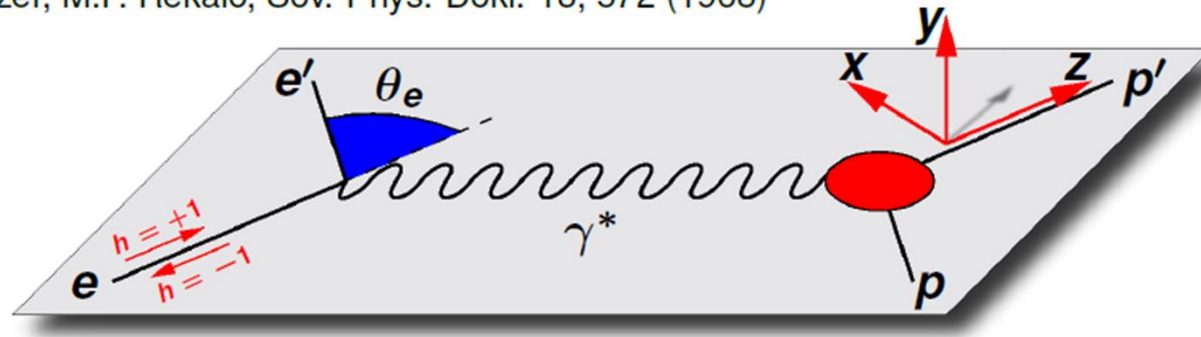
$$F_1(0) = Q_N \quad G_E(0) = Q_N$$

$$F_2(0) = \kappa_N \quad G_M(0) = \mu_N$$

Puzzle on G_E/G_M Spacelike ($q^2 < 0$)

Polarization observables

A.I. Akhiezer, M.P. Rekalo, Sov. Phys. Dokl. 13, 572 (1968)

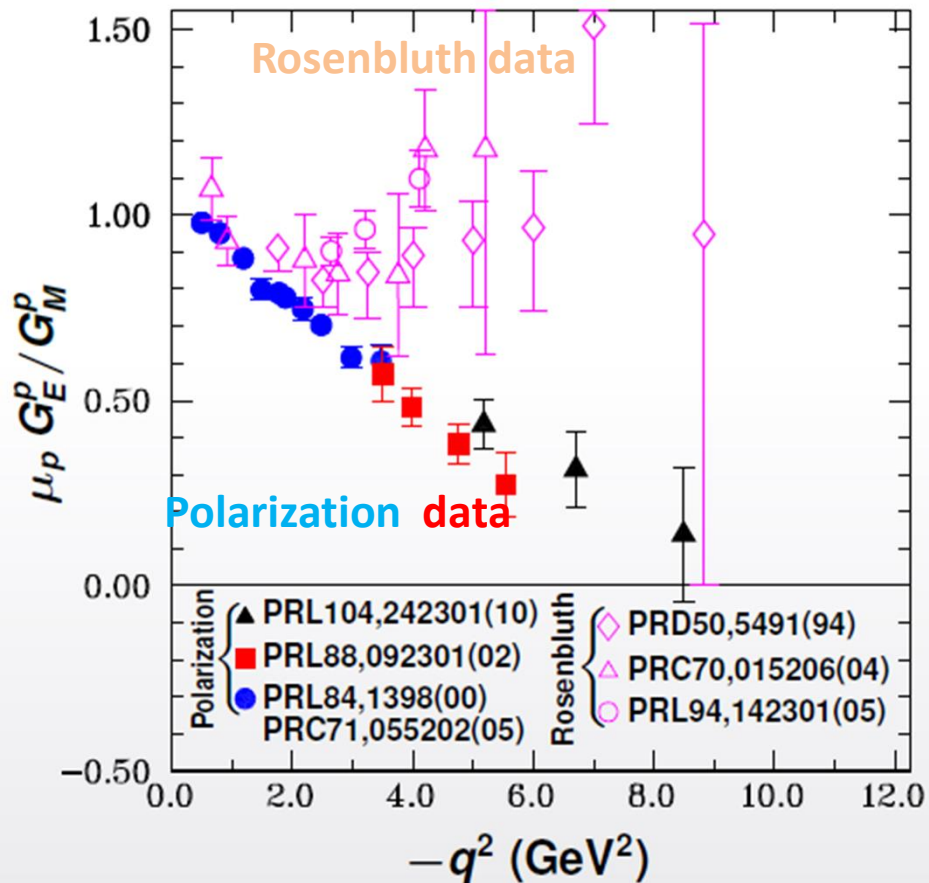


- Elastic scattering of **longitudinally polarized electrons** ($h = \pm 1$) on nucleon target
- Hadronic tensor: $W_{\mu\nu} = \underbrace{W_{\mu\nu}(0)}_{\text{no pol.}} + \underbrace{W_{\mu\nu}(\vec{P}) + W_{\mu\nu}(\vec{P}')}_{\text{ini. or fin. pol. of } N} + \underbrace{W_{\mu\nu}(\vec{P}, \vec{P}')}_{\text{ini. and fin. pol. of } N}$
- In case of **polarized electrons** ($h = \pm 1$) on **unpolarized nucleon** target:

$$P'_x = -\frac{2\sqrt{\tau(\tau-1)}}{G_E^2 - \frac{\tau}{\epsilon} G_M^2} G_E G_M \tan\left(\frac{\theta_e}{2}\right) \quad P'_z = \frac{(E_e + E'_e)\sqrt{\tau(\tau-1)}}{M(G_E^2 - \frac{\tau}{\epsilon} G_M^2)} G_M^2 \tan^2\left(\frac{\theta_e}{2}\right)$$

$$\frac{P'_x}{P'_z} = -\frac{2M \cot(\theta_e/2)}{E_e + E'_e} \frac{G_E}{G_M}$$

Puzzle on G_E/G_M Spacelike ($q^2 < 0$)



Polarization data do not agree with old Rosenbluth data (\diamond)

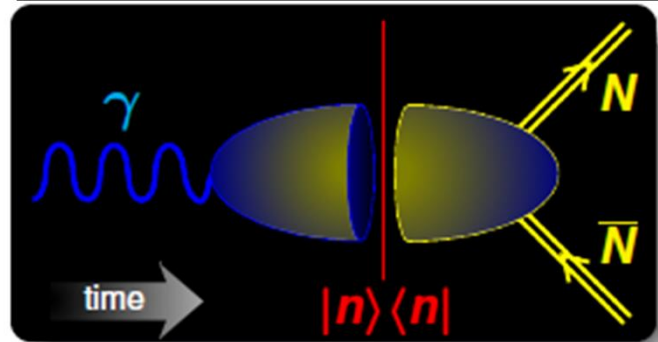


New Rosenbluth data (\triangle , \circ) from JLab still do not agree with polarization data

Spacelike G_E contribution very small.
Discrepancy due to 2γ exchange?
Radiative corrections?
Not settled yet

Definitions and Main Expectations

Timelike ($q^2 > 0$)



- Crossing symmetry:

$$\langle N(p') | j^\mu | N(p) \rangle \rightarrow \langle \bar{N}(p') N(p) | j^\mu | 0 \rangle$$

- Form factors are complex functions of q^2

Optical theorem

$$\text{Im} \langle \bar{N}(p') N(p) | j^\mu | 0 \rangle \sim \sum_n \langle \bar{N}(p') N(p) | j^\mu | n \rangle \langle n | j^\mu | 0 \rangle \implies \begin{cases} \text{Im} F_{1,2} \neq 0 \\ \text{for } q^2 > 4M_\pi^2 \end{cases}$$

$|n\rangle$ are on-shell intermediate states: $2\pi, 3\pi, 4\pi, \dots$

Time-like asymptotic behavior

Phragmén Lindelöf theorem:

If $f(z) \rightarrow a$ as $z \rightarrow \infty$ along a straight line, and $f(z) \rightarrow b$ as $z \rightarrow \infty$ along another straight line, and $f(z)$ is regular and bounded in the angle between, then $a = b$ and $f(z) \rightarrow a$ uniformly in this angle.

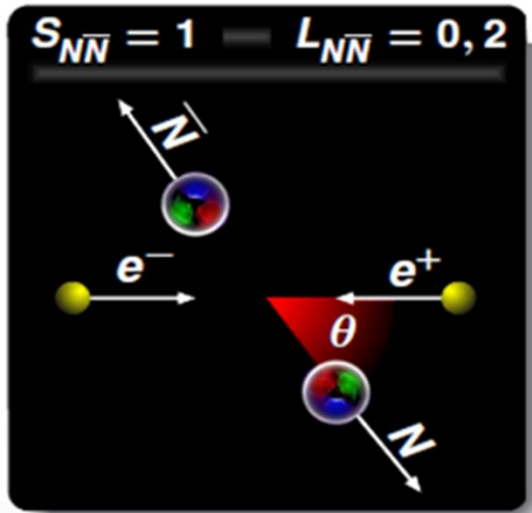
$$\lim_{q^2 \rightarrow -\infty} G_{E,M}(q^2) = \lim_{q^2 \rightarrow +\infty} G_{E,M}(q^2)$$

space-like
time-like

$$G_{E,M} \underset{q^2 \rightarrow +\infty}{\sim} (q^2)^{-2} \quad \text{real}$$

Definitions and Main Expectations

Timelike ($q^2 > 0$)

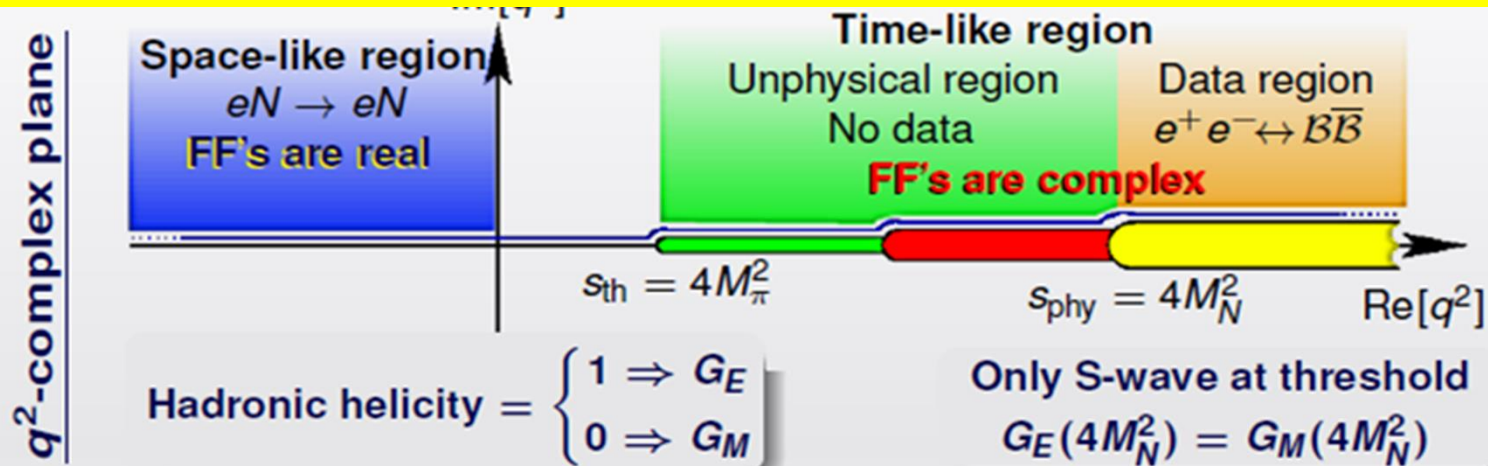


Annihilation cross section formula

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2 \beta \mathcal{C}}{4q^2} \left[(1 + \cos^2 \theta) |G_M|^2 + \frac{1}{\tau} \sin^2 \theta |G_E|^2 \right]$$

- Outgoing nucleon velocity: $\beta = \sqrt{1 - 1/\tau}$
- Coulomb correction: $\mathcal{C} = \frac{\pi\alpha/\beta}{1 - \exp(-\pi\alpha/\beta)}$?

Crossing Specelike to Timelike: N, N_{bar} same helicity $\leftrightarrow G_E$, opposite $\leftrightarrow G_M$



$G_E(q^2)/G_M(q^2)$: no D wave at thr (?)

- $G_E = F_1 + q^2/4M^2 F_2$

- $G_M = F_1 + F_2$

- if F_1 and F_2 analytic $\rightarrow G_E(4M^2) = G_M(4M^2)$**

- If $G_E(4M^2) = G_M(4M^2)$ at thr isotropy \rightarrow S wave only

- **Analyticity: $G_E(4M_B^2) = G_M(4M_B^2) = G_S(4M_B^2) \rightarrow G_D(4M_B^2) = 0$**

$$e^+ e^- \rightarrow p p_{\text{bar}}$$

$e^+ e^- \rightarrow pp_{\text{bar}}$

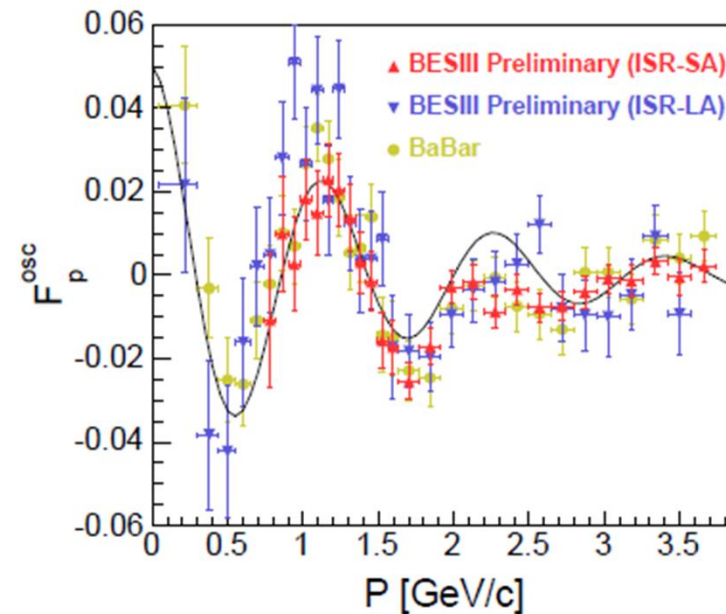
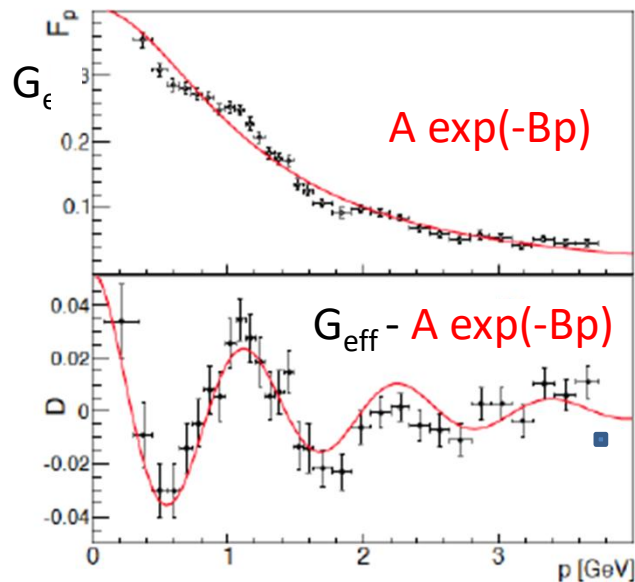
- There are many sets of data on $e^+ e^- \rightarrow pp_{\text{bar}}$ at low cm energies by PS170, BaBar, BESIII, CMD3, ADONE, DM1, DM2, FENICE, BES
- In the following the energy region close to the threshold (thr) will be mostly considered, where essentially at the moment BaBar, by means of ISR from $Y(4S)$, and now CMD3 have data. (PS170 data on $pp_{\text{bar}} \rightarrow e^+ e^-$ at thr are affected by corrections due to incident p_{bar} spin flip because of the liquid H_2 target, difficult to handle).
- Lacking accurate data on the angular distributions, it was assumed $G_E(4 M^2) = G_M(4 M^2) = G_{\text{eff}}(4 M^2)$
It was defined

$$|G_{\text{eff}}| = v \left\{ \sigma(e^+e^- \rightarrow BB_{\text{bar}}) (3W_B^2) / [4\pi \alpha^2 \cdot C \cdot \beta(1+2M_B^2/W^2)] \right\}$$

Oscillations in $G_{\text{eff}}(e^+e^- \rightarrow pp_{\text{bar}})$!

- Oscillations (?) in $G_{\text{eff}}(e^+e^- \rightarrow pp_{\text{bar}})$
seen by BaBar and confirmed by BESIII

[A. Bianconi, E. Tomasi-Gustafsson PRL114,232301(2015)]



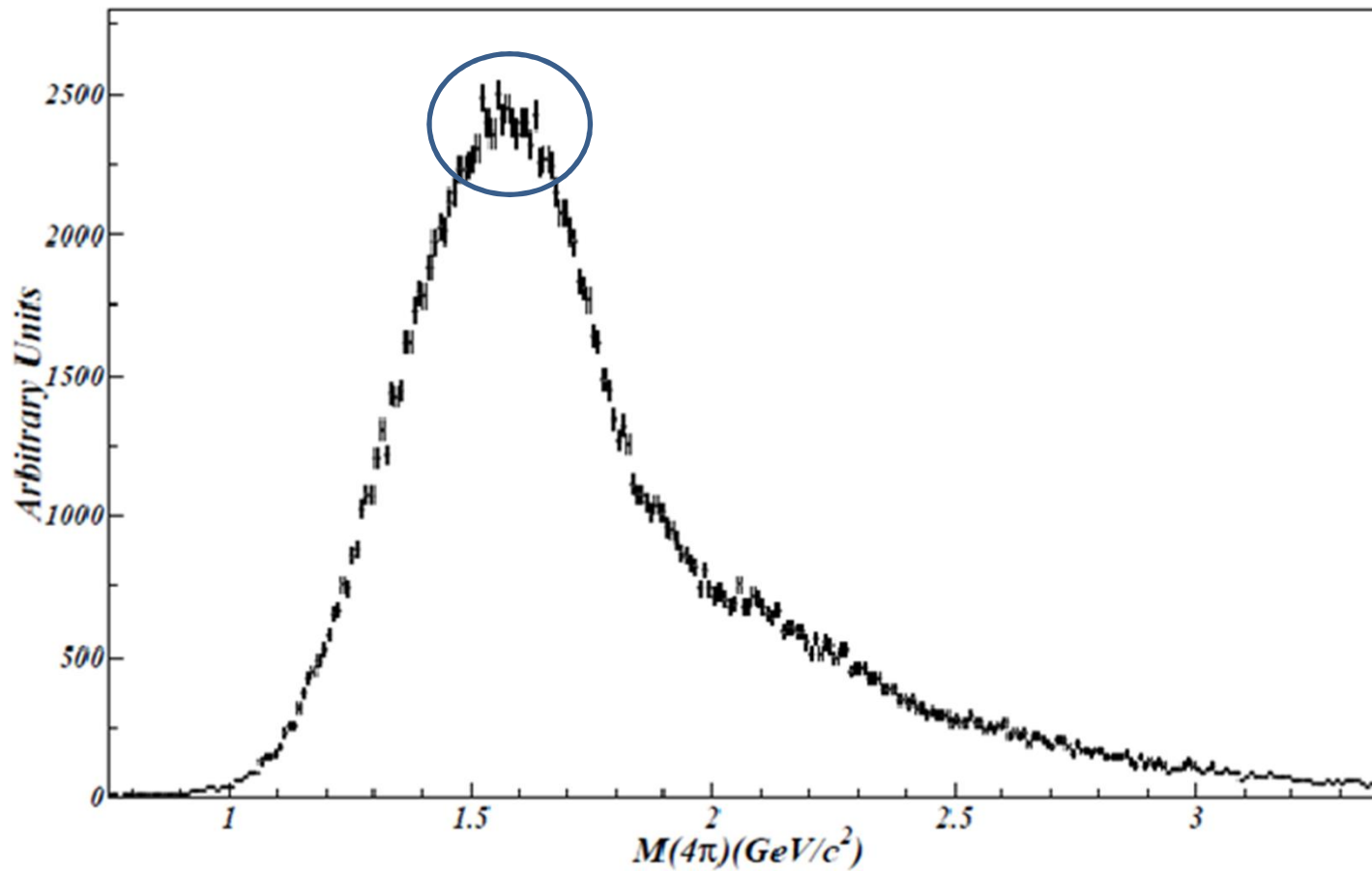
$$F_{\text{osc}}(p) \equiv A \exp(-Bp) \cos(Cp + D).$$

- Main oscillation: interference from $Y(2170)$ in $G_{\text{eff}}(e^+e^- \rightarrow pp_{\text{bar}})$?**
(Andrzej Kupsc/Ulf Meissner)

Long long time ago, in another galaxy.....

$2\pi^+2\pi^-$ E687 data

(P. Lebrun *Hadron '97*, Aug. 25-30, 1997)

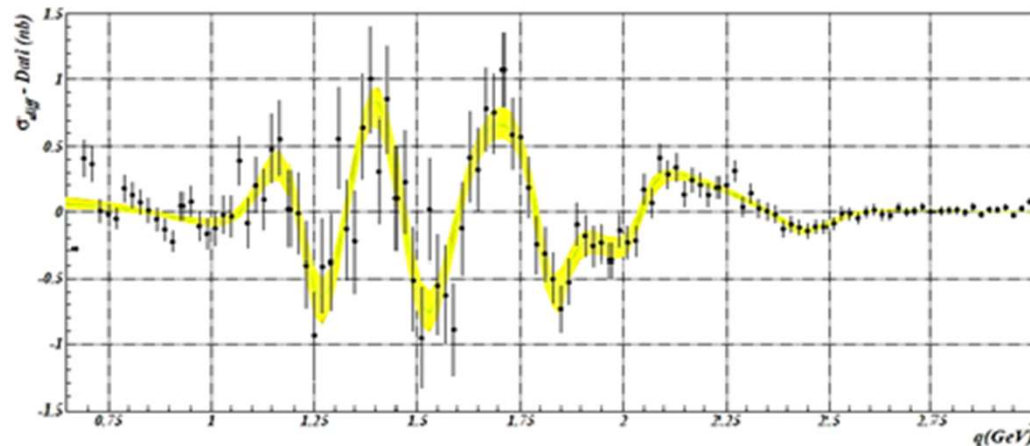


E687 at FNAL

$2p^+2p^-$ Diffractive Photoproduction

Fit of the residual

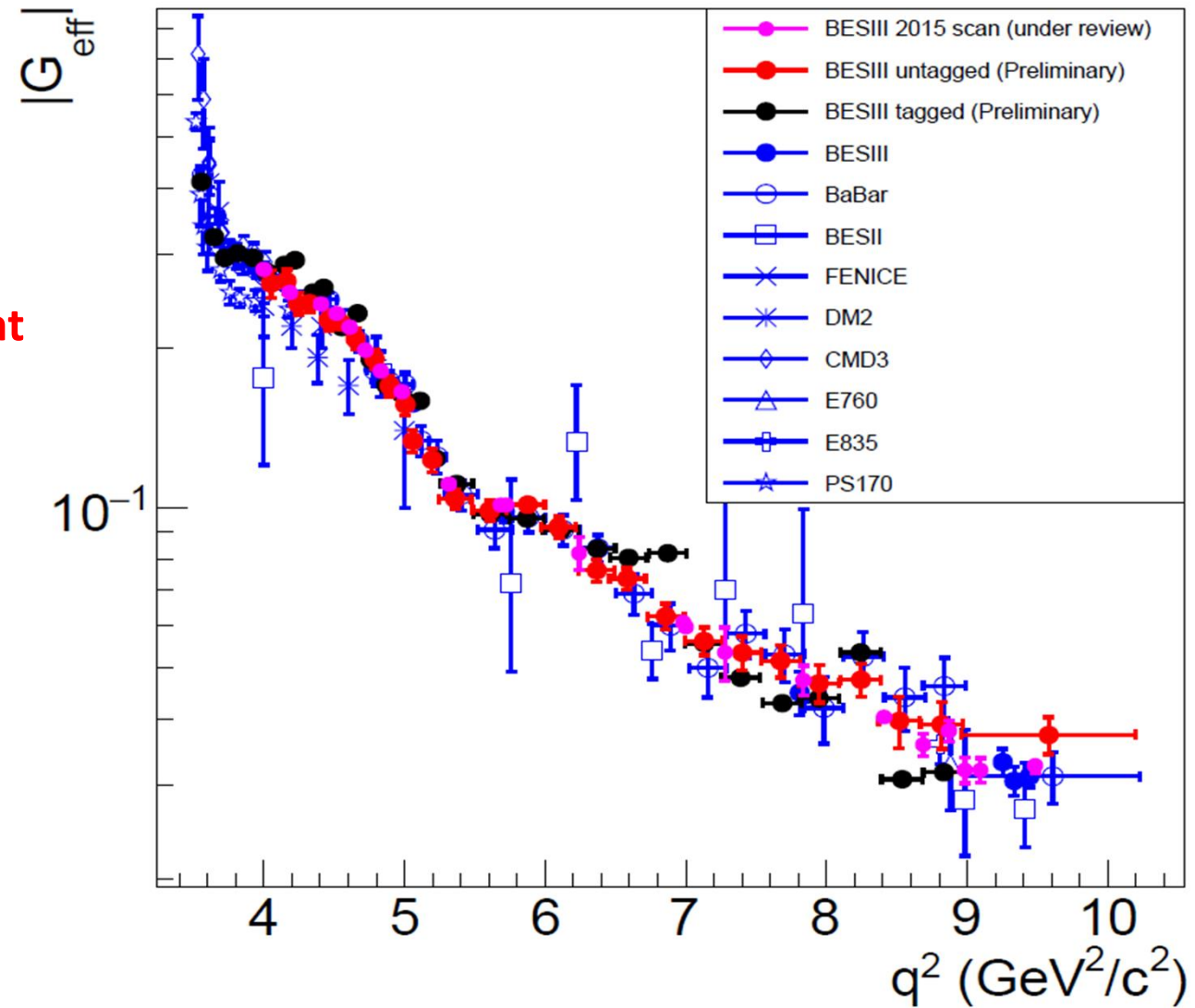
(P. Lebrun *Hadron 97*, Aug. 25-30, 1997)



Resonances	$\Gamma_{e^+e^-} B_{j2\pi+2\pi^-} (KeV)$	$m(MeV)$	$\Gamma(MeV)$	$\phi(rad)$
V_1	$(4 \pm 2) \times 10^{-2}$	1209 ± 6	218 ± 16	2.56 ± 0.04
V_2	$(5 \pm 2) \times 10^{-2}$	1465 ± 8	265 ± 23	4.26 ± 0.08
V_3	$(1.1 \pm 0.6) \times 10^{-3}$	1820 ± 25	100 ± 30	0.7 ± 0.6
V_4	$(3 \pm 2) \times 10^{-3}$	2030 ± 20	170 ± 80	2.6 ± 0.4
V_5	$(1.3 \pm 0.7) \times 10^{-3}$	2460 ± 24	190 ± 60	2.5 ± 0.3

Present data on $G_{\text{eff}} (e^+ e^- \rightarrow p\bar{p})$

G_{eff} steep drop at thr:
Coulomb Enhancement
Factor ?



CEF Hypotheses

- In principle Coulomb interaction between the outgoing B^+B^- (**C Enhancement Factor**) should play an important role. However there is no full consensus on that.
- $\sigma(e^+e^- \rightarrow BB_{\text{bar}}) = 4\pi\alpha^2/(3W_B^2) \cdot \boxed{C} \cdot \beta[|G_M(W_B^2)|^2 + 2M_B^2/W^2|G_E(W_B^2)|^2]$
- **C**: Coulomb Enhancement Factors (CEF).
Non Perturbative Correction to Born approx to include Coulomb Interaction between the outgoing charged fermions
- **Hypotheses to achieve CEF:**
 - In $\langle i|T_0+T_C|f \rangle$: the final state is not a plane wave $|f \rangle$, but $|\phi \rangle$ where ϕ is the wave function after Coulomb scattering
 - T_0 (before Coulomb interaction) is a short range interaction, hence $\phi(r) \rightarrow \phi(0)$: **Coulomb affects S wave only.**

CEF Hypotheses

- Usually CEF is assumed to be the non relativistic pointlike fermions one (L.Landau,E.Lifschitz, 1950)

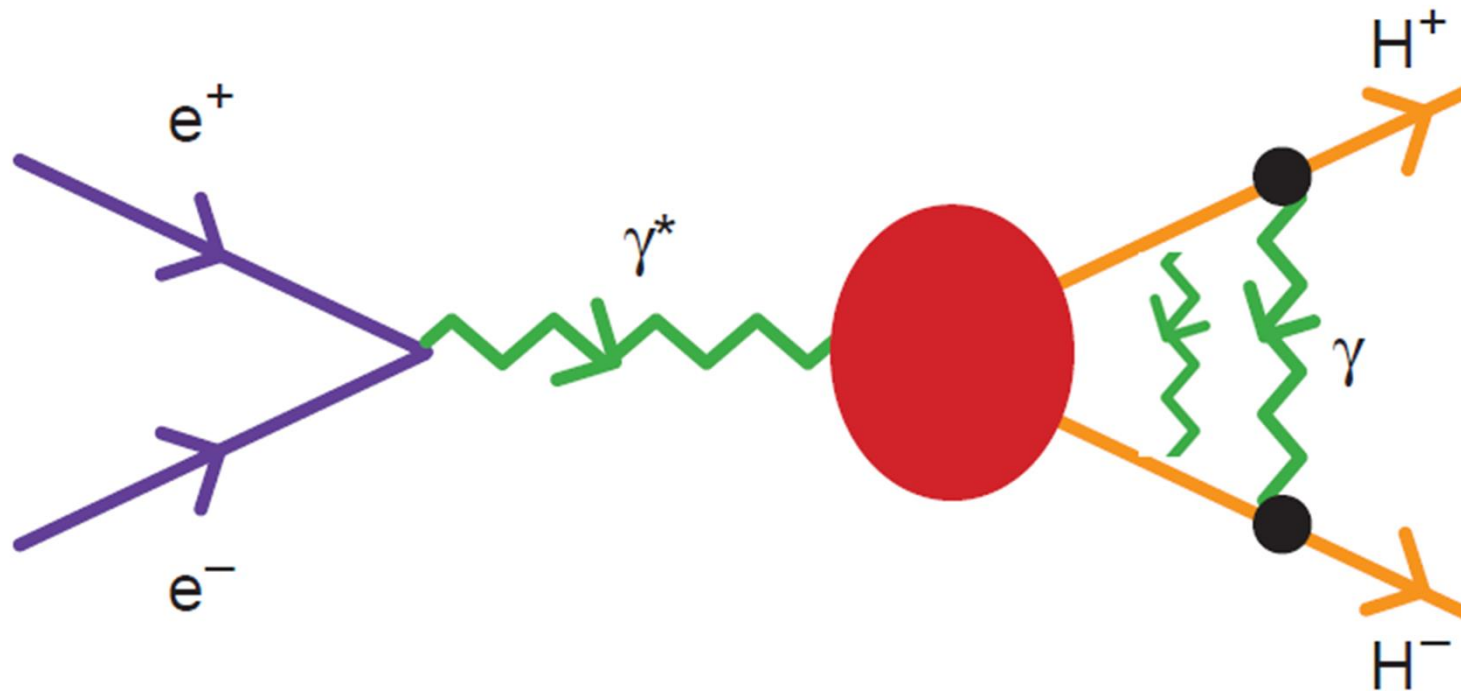
$$|\phi(0)|^2 = \pi\alpha F/\beta \cdot 1/[1 - \exp(-\pi\alpha F/\beta)],$$

F is a relativistic correction (not very important close to thr), according to **Arbuzov** $F = 1 + \beta^2$.

Some also assume $F = \sqrt{1 - \beta^2}$

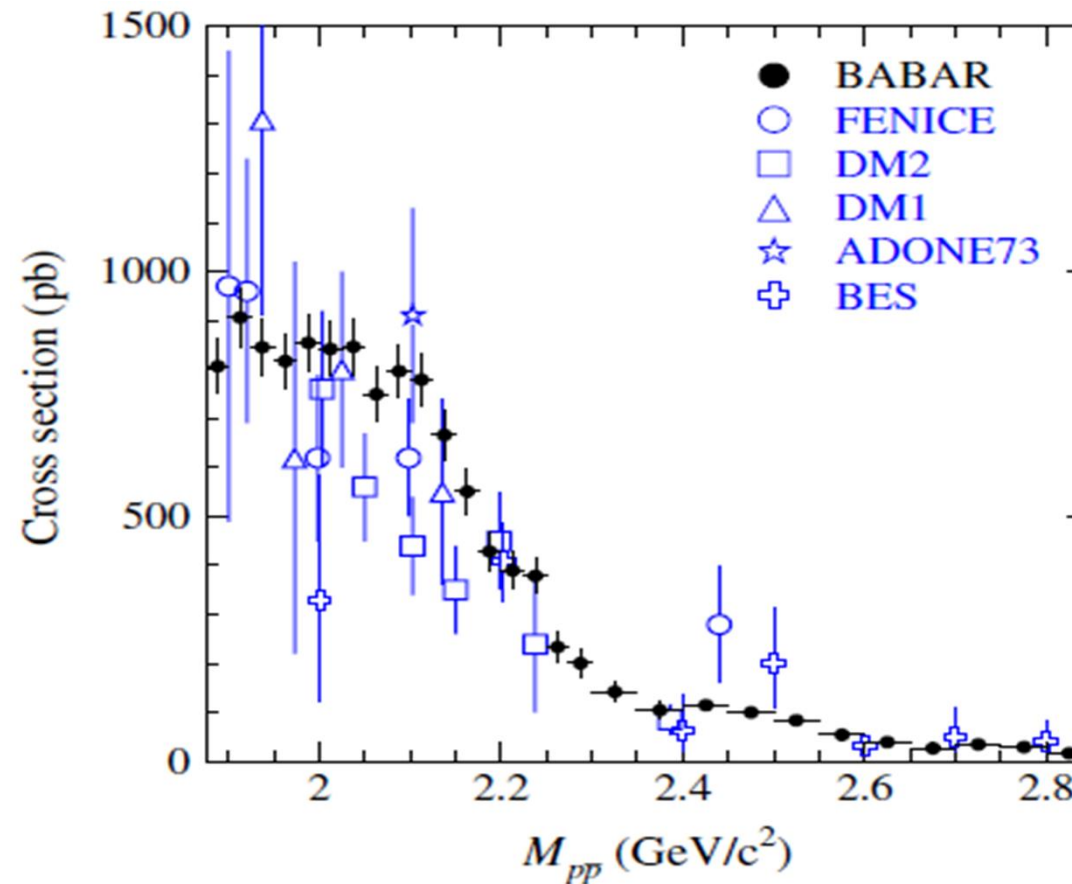
- Photon exchanges among $B^+ B^-$ are taken into account by the **Enhancement Factor** $E = \pi\alpha F/\beta$
E predicts a step at thr: $1/\beta$ factor cancels the phase space β
- Many photons exchanges are taken into account by the Sommerfield **Resummation Factor** $R = 1/[1 - \exp(-\pi\alpha F/\beta)]$
R is so that very soon the phase space β is restored
- An argument justifying pointlike CEF (never quoted explicitly):
Coulomb has a long range, while Strong Force is a short one.
Hence Coulomb acts when the hadron pair is already built.

Coulomb Enhancement Factor (CEF)



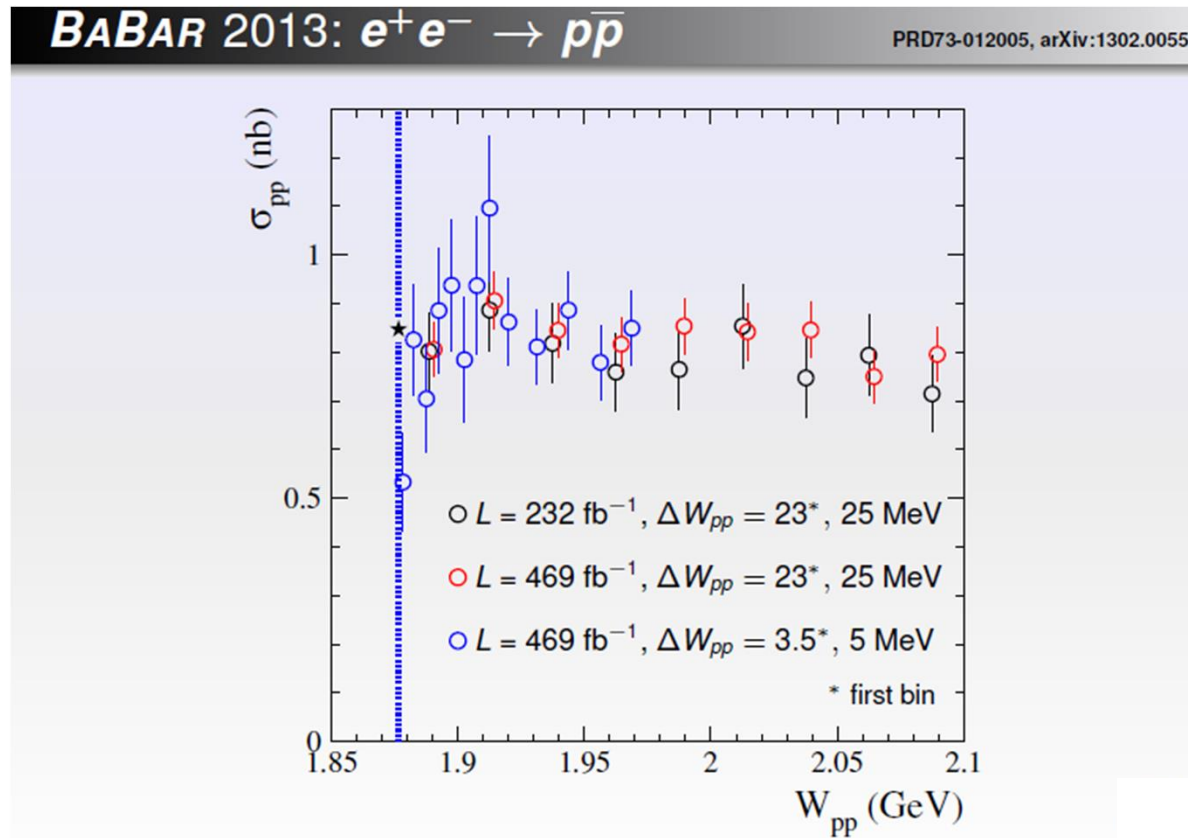
Present data on $\sigma(e^+ e^- \rightarrow pp_{\text{bar}})$

- To be updated with BESIII data



- $\sigma(e^+ e^- \rightarrow pp_{\text{bar}}) \approx 0.85 \text{ nb}$ and flat
- CEF: $\sigma_{\text{thr}} = \pi^2 \alpha^3 / (2M^2) = 0.85 \cdot |G_S(4M_p^2)|^2 \text{ nb}$
Very tantalizing to infer that $G_S(4M_p^2)$ is close to 1 !

BaBar by means of ISR from $Y(4S)$



Measurement at thr , integrated on a 4 MeV energy bin,
consistent with Coulomb expectation/ extrapolation within 2 sd (?)

E. Solodov

Baryon Form Factors: Where do we stand?

Bad Honnef, April 2018

- Our Friend Genia Solodov settled the question
(<http://arxiv.org/abs/1808.00145>)

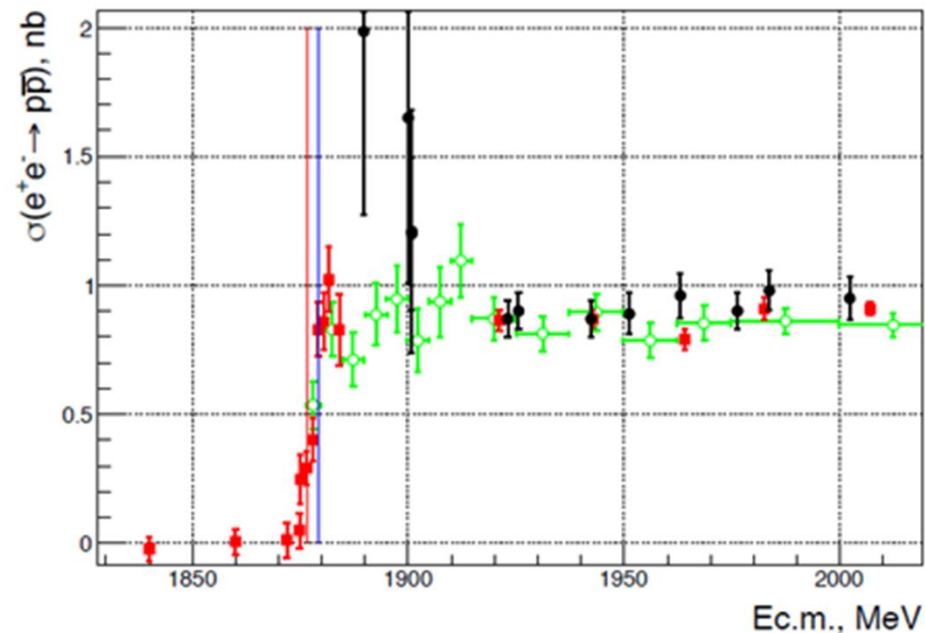


- Energy scan by CMD3:
 - $\sigma(e^+ e^- \rightarrow pp_{\text{bar}})$ at thr has indeed a step (≤ 1 MeV)
 - is consistent with Coulomb enhancement and $G_S(4M_p^2) \approx 1$
 - followed by a kind of a plateau

E. Solodov
Baryon Form Factors: Where do we stand?
Bad Honnef, April 2018

CMD3 New Results

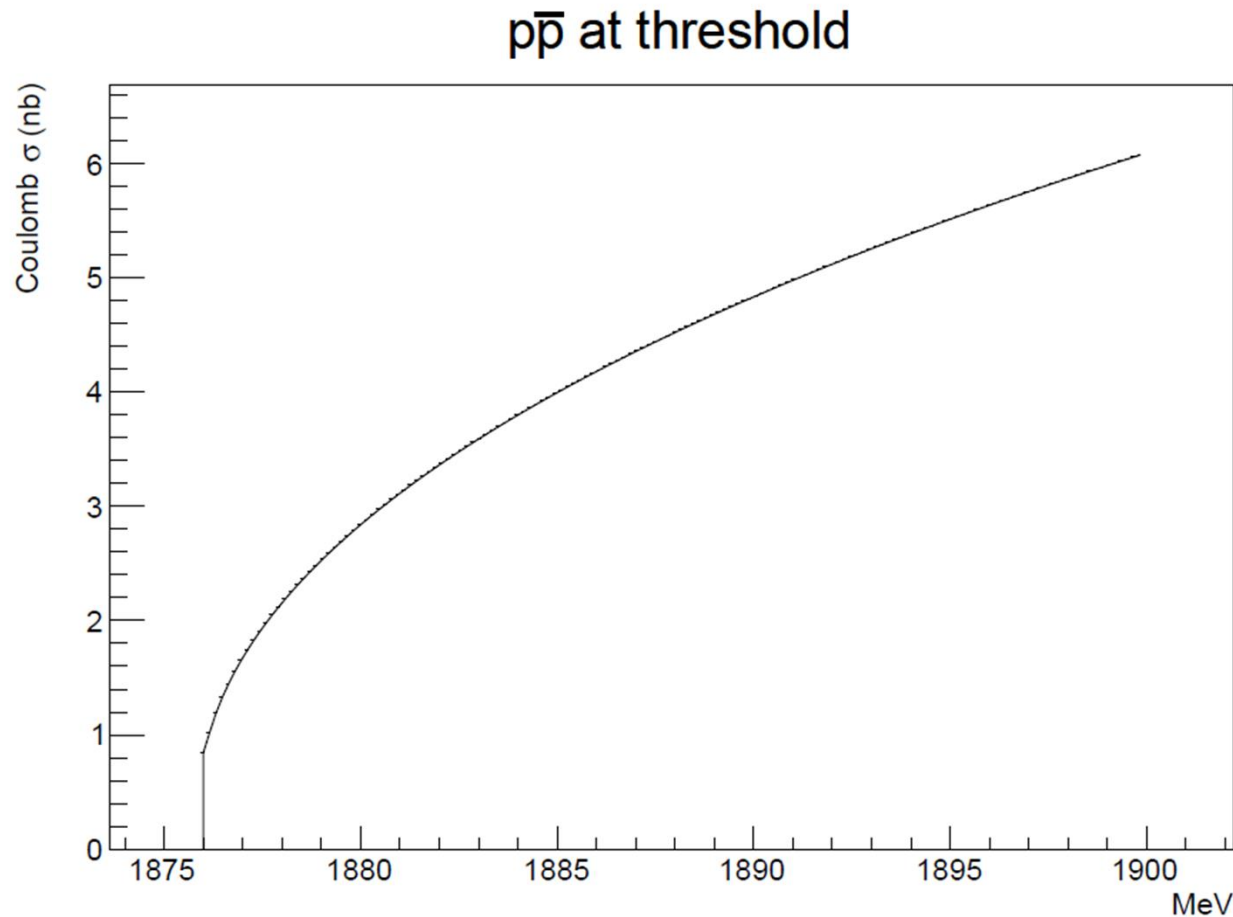
$e^+e^- \rightarrow p\bar{p}$ Born cross section



Our new 2017 data in comparison with BaBar and CMD-3 2011-2012 scans
(R.R. Akhmetshin et al., (CMD-3 Collaboration), Phys. Lett. B759, 634 (2016).)

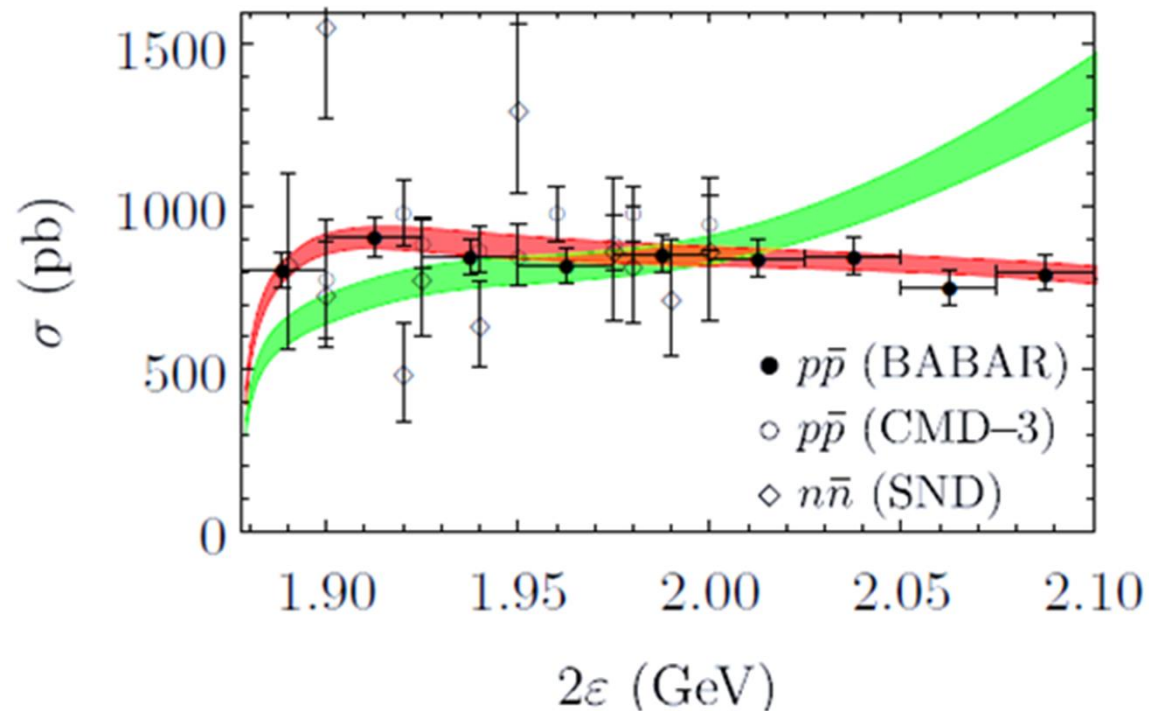
Coulomb interaction above thr

- Simple Coulomb interaction does explain a step at thr but it is at odd with the flat $\sigma(e^+ e^- \rightarrow p\bar{p}_{\text{bar}})$ above thr:



$\sigma(e^+ e^- \rightarrow pp_{\text{bar}})$ fit by means of FSI

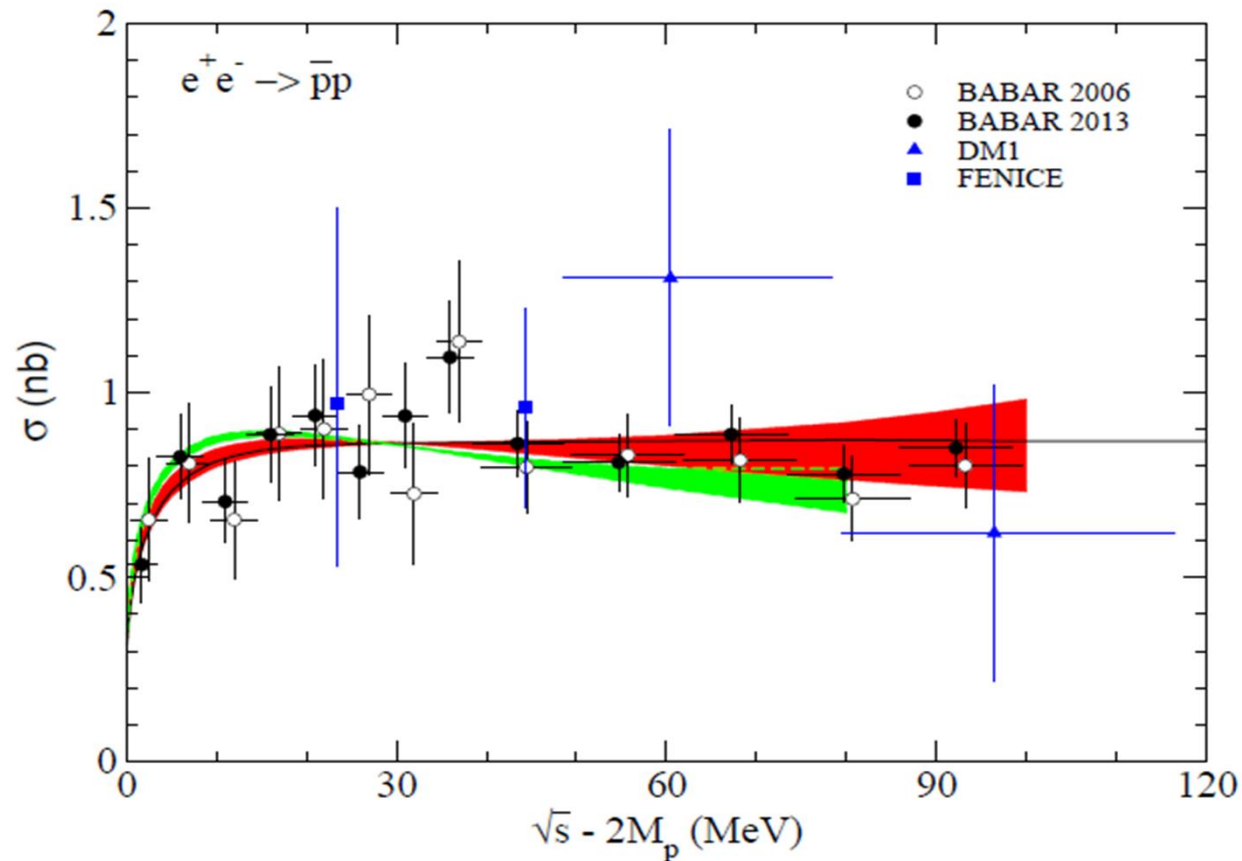
- FSI get a flat $\sigma(e^+ e^- \rightarrow pp_{\text{bar}})$ from the steep behaviour of elastic $\sigma(pp_{\text{bar}} \rightarrow pp_{\text{bar}})$ at low energies.
- FSI expect a sharp rise but not a step on thr and no relationship with the pointlike FF
- A. Milstein in PhitoPsi17, Mainz :



$\sigma(e^+ e^- \rightarrow pp_{\text{bar}})$ fit by means of FSI

○ J.Heidenbauer, X.W. Xang, U.G. Meissner

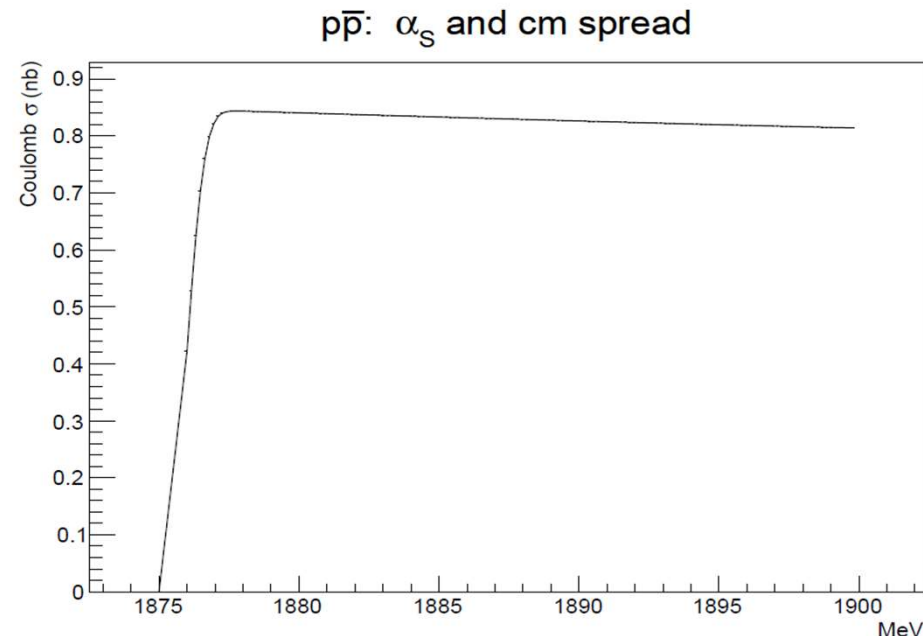
arXiv:1405.1628v1 [nucl-th] 7 May 2014



An Alternative Approach to CEF

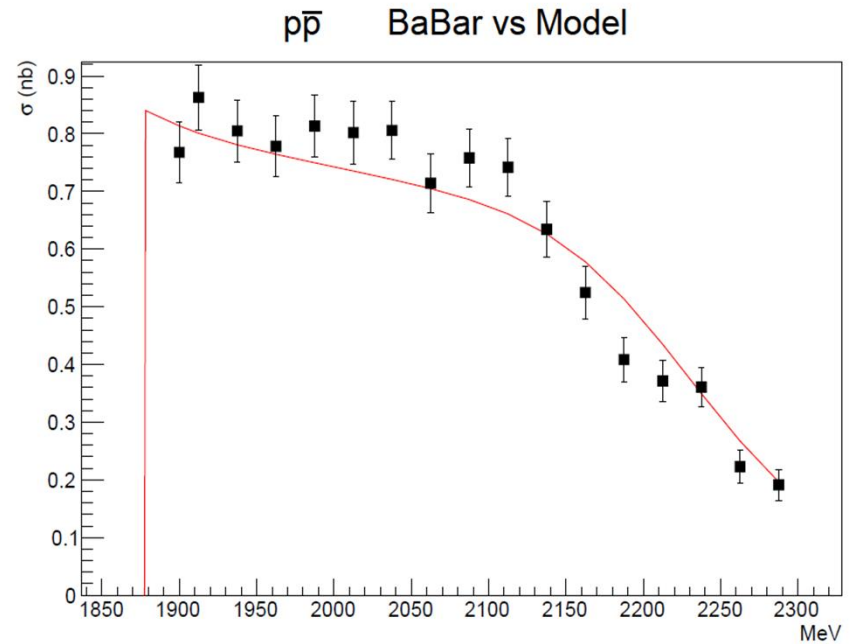
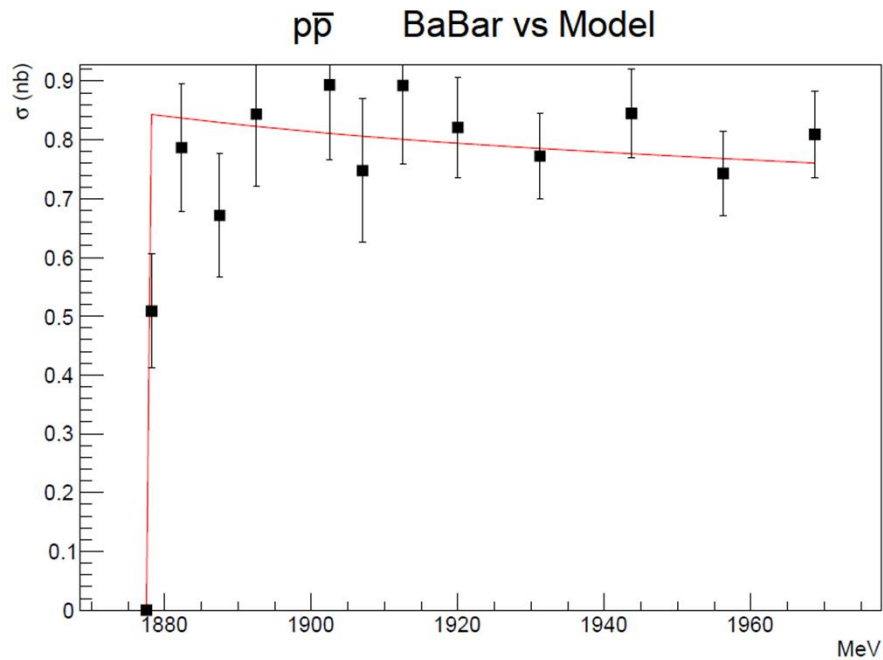
- FSI approaches predict a vanishing $\sigma(e^+ e^- \rightarrow p\bar{p})$ at thr
- Persisting on a Coulomb enhancement at thr, consider another possible, empirical, approach:
in R many gluons (pions) exchanged too.
 α_s instead of α should be considered:
(actually any value of $\alpha_s \gg \alpha$)

$$R \approx 1 / [1 - \exp(-\pi\alpha_s F/\beta)] \quad ?$$



$\sigma(e^+ e^- \rightarrow p\bar{p})$ close to thr

Fit without “free” parameters



$\sigma(e^+ e^- \rightarrow pp_{\text{bar}})$ close to threshold

- Willing to include the asymptotic G_p expected behavior, according to PQCD: $\sigma(e^+ e^- \rightarrow pp_{\text{bar}}) \sim 1/[W^2 (W/\Lambda_{\text{QCD}})^8]$ a simple parametrization could be:

$$\sigma(e^+ e^- \rightarrow pp_{\text{bar}}) \sim [\pi^2 \alpha^3 F / W^2] / [1 - \exp(-\pi\alpha_s F/\beta)] \cdot \\ \mathbf{1/[1 + ((W - W_{\text{thres}}) / \Lambda_{\text{QCD}})^N]}$$

- BaBar data (ΔW included) can be fit with such a formula, leaving as “free” param Λ_{QCD} and the exponent N in $(W/\Lambda_{\text{QCD}})^N$. The result is $\Lambda_{\text{QCD}} = 364 \pm 7$ MeV, $N = 7.0 \pm 0.3$, in good agreement with the expectation $\Lambda_{\text{QCD}} \sim 300$ MeV, $N \sim 8$
- **The persistence on Coulomb interpretation is driven by the results obtained by BESIII on $e^+ e^- \rightarrow \Lambda_c \Lambda_{\text{cbar}}$ at thr**

$$e^+ e^- \rightarrow \Lambda_c \Lambda_{c\text{bar}}$$

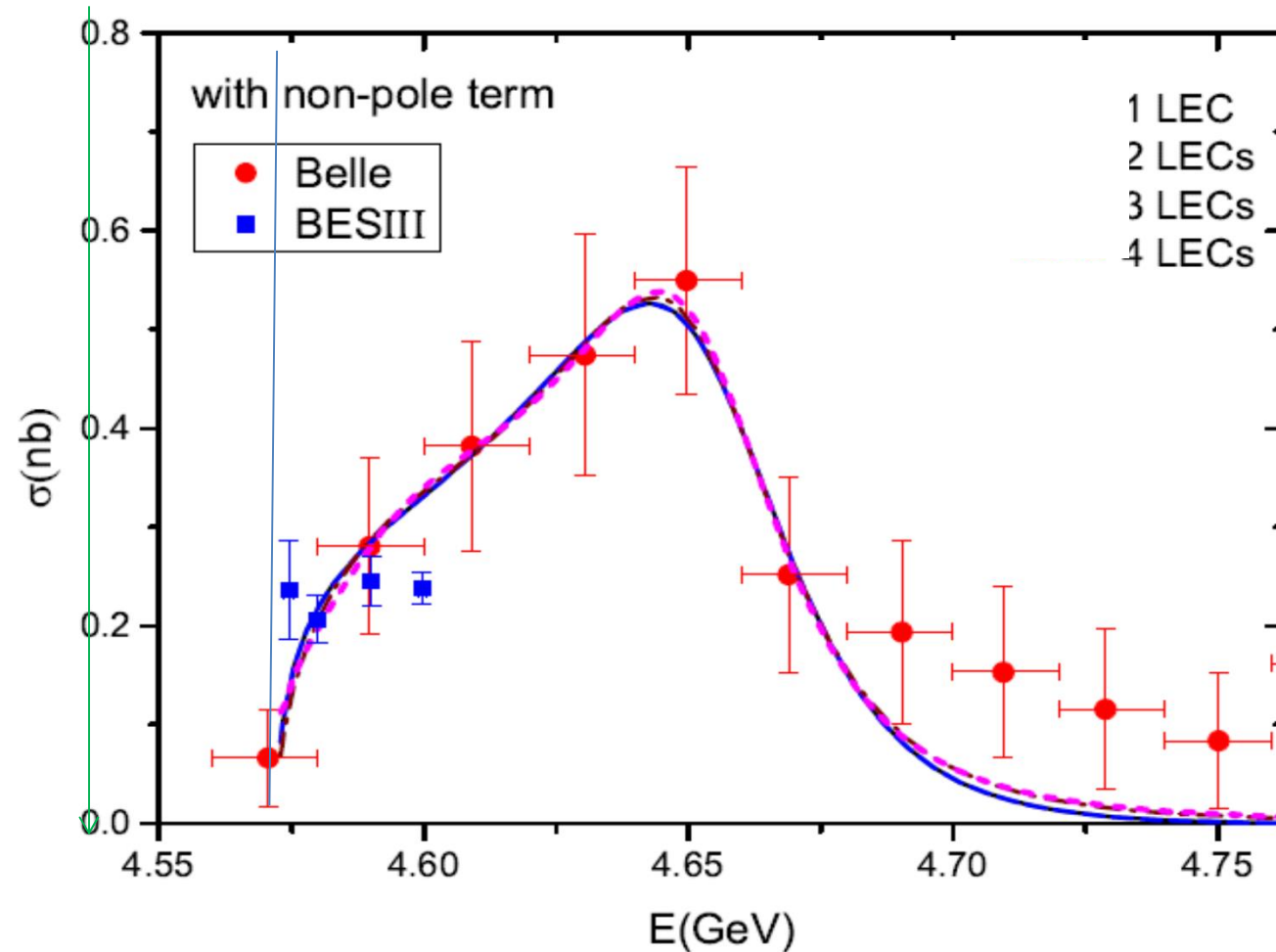
$$e^+ e^- \rightarrow \Lambda_c \Lambda_{c\text{bar}}$$

- $e^+ e^- \rightarrow \Lambda_c \Lambda_{c\text{bar}}$ might be the ideal process to check the previous prejudices, achieved interpreting $e^+ e^- \rightarrow p\bar{p}$:
- Because of the weak decay, $e^+ e^- \rightarrow \Lambda_c \Lambda_{c\text{bar}}$ can be detected with good efficiency even exactly at thr.
- The region sensitive to Coulomb interaction is enlarged, depending on the baryon velocity β_B only, since β_B scales like $1/\sqrt{M_B}$, close to a thr
- Results from **BESIII (Phys. Rev. Lett. 120, 132001)** and **Belle (Phys. Rev. Lett. 101, 172001 (2008))** are summarized and shown in the following .

Data and fit FSI+Y(4660) on $e^+ e^- \rightarrow \Lambda_c \Lambda_{c\bar{c}}$

Belle G. Pakhlova *et al.* [Belle Collaboration], Phys. Rev. Lett. 101, 172001 (2008).

BESIII Ablikim *et al.*, arXiv:1710.00150 [hep-ex].



BESIII $\sigma(e^+ e^- \rightarrow \Lambda_c \Lambda_{c\bar{b}})$

- The BESIII measurements indicate that:
 - At thr there is indeed a step in $\sigma(e^+ e^- \rightarrow \Lambda_c \Lambda_{c\bar{b}})$,
 - Followed by a kind of a plateau
 - At thr $\sigma(e^+ e^- \rightarrow \Lambda_c \Lambda_{c\bar{b}})$ is close to the pointlike value, once the Coulomb enhancement factor is taken into account:
$$\sigma(e^+ e^- \rightarrow \Lambda_c \Lambda_{c\bar{b}})_{\text{pointl}} \approx \pi^2 \alpha^3 / (2M_B) \approx 145 \text{ pb}$$
 - Qualitatively, if $\sigma(e^+ e^- \rightarrow BB_{\bar{b}})$ would be driven by strong interaction, [asymptotically scaling as $(M_p / M_{\Lambda_c})^{10}$] a quite smaller value ($< 1 \text{ fb}$) would be expected
[$\sigma(e^+ e^- \rightarrow pp_{\bar{b}}) \approx 0.85 \text{ nb}$, at thr].

BESIII versus Belle in $e^+ e^- \rightarrow \Lambda_c \Lambda_{c\bar{c}}$

- There is **some tension between BESIII and Belle** in $\sigma(e^+ e^- \rightarrow \Lambda_c \Lambda_{c\bar{c}})$, as pointed out by **Ulf Meissner and his collaborators** and shown in the following , in particular:
- Belle data show a wide resonance, consistent with the $Y(4660)$, seen by BaBar and Belle in $e^+ e^- \rightarrow \psi(3686) \pi^+ \pi^-$, hardly compatible with BESIII flat behaviour up to 4.6 GeV
- Belle data are fit by means of a resonance on top of $\Lambda_c \Lambda_{c\bar{c}}$ FSI, that predicts again a fast rise at thr, but not a step.
- **More data at thr and above are needed and BESIII already got funds to increase maximum energy up to $W = 4.9$ GeV**

Fit to Belle Measurements

- Ling-Yun Dai, Johann Haidenbauer, Ulf-G. Meißner

arXiv:1710.03142v1 [hep-ph] 9 Oct 2017

- Resonance $Y(4660)$ [called $X(4660)$ in this paper] + FSI @thr:

$$M = (4652.5 \pm 3.4) \text{ MeV}$$

$$\Gamma = (62.6 \pm 5.6) \text{ MeV}$$

$$\sigma_{\text{peak}} \sim 0.55 \text{ nb} \quad [\text{comparable to } \sigma(e^+ e^- \rightarrow pp_{\text{bar}}) \sim 0.8 \text{ nb @ threshold}]$$

- Concerning BESIII measurements they write:
“ While they agree with the Belle data, as for as cross sections magnitude, they indicate a different trend in energy.

It is impossible to fit both data.

Hopefully BESIII will extend their measurements at higher energies and thereby clarify the situation.

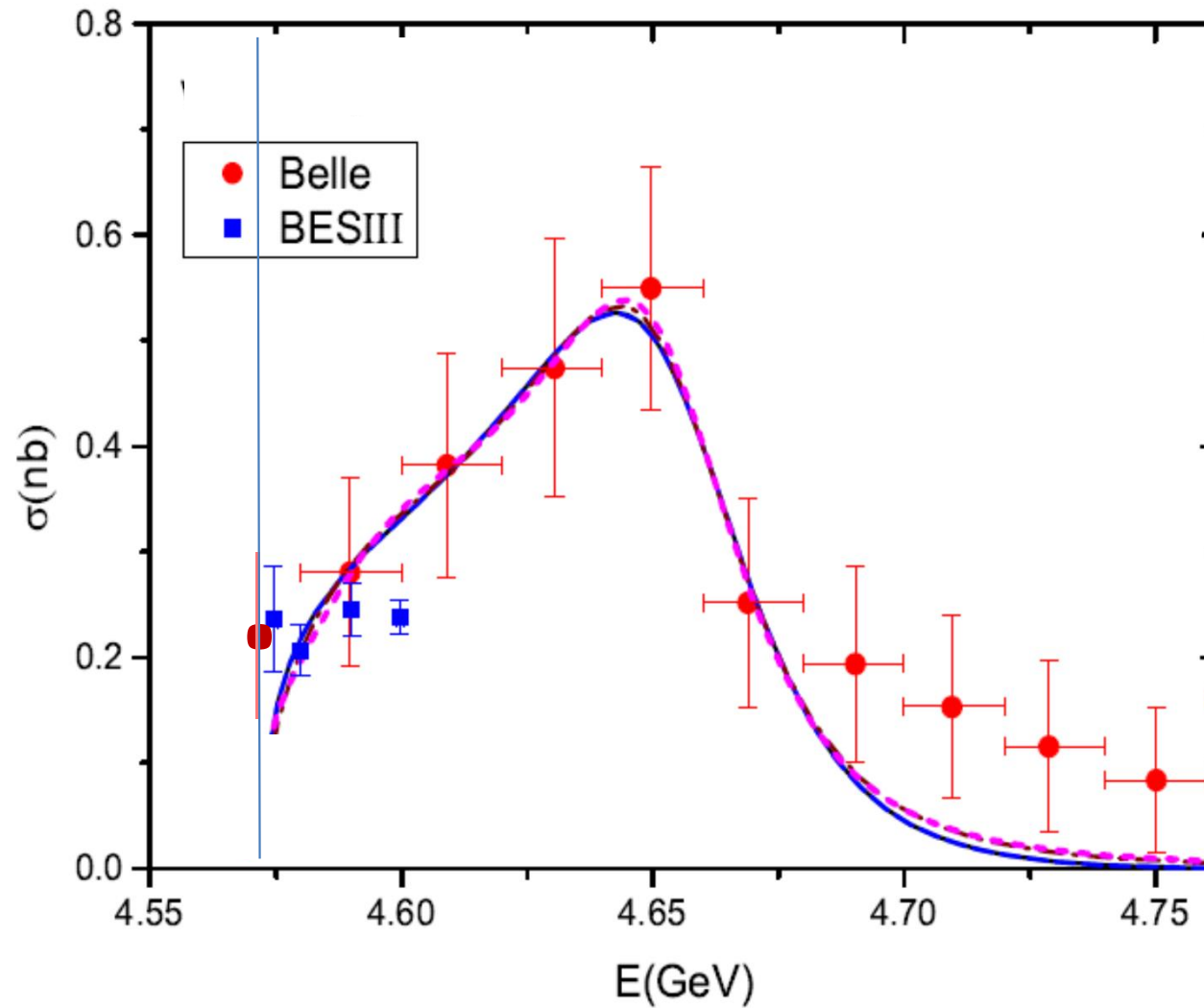
Our Friend Ulf Meissner



Attempting to reconcile Belle and BESIII

- Belle $\sigma(e^+ e^- \rightarrow \Lambda_c \Lambda_{c\bar{c}})$ @ threshold, Changzhen argument :
error bar spans below threshold $\rightarrow \sigma_{\text{thr}} \approx \sigma \times 3 \approx 0.2 \text{ nb}$
- BESIII $\sigma(e^+ e^- \rightarrow \Lambda_c \Lambda_{c\bar{c}})$ @ threshold = $0.23 \pm 0.05 \text{ nb}$
- By the way $< 2 \text{ sd}$ from $\sigma_{\text{point}} = \pi^2 \alpha^3 / (2 M_{\Lambda_c}^2) = 0.14 \text{ nb}$
[$\sigma(e^+ e^- \rightarrow p p_{\bar{c}}) \approx \sigma_{\text{point}}$ close to threshold]
[But not confirmed by $\sigma(e^+ e^- \rightarrow \Sigma^+ \Sigma_{\bar{c}})$ @ threshold]
(Xiaorong Zhou talk at BESIII Coll Meeting in Guangzhou 2016)
- Belle and BESIII might be compatible @ threshold

Attempting to reconcile Belle/BESIII @ threshold

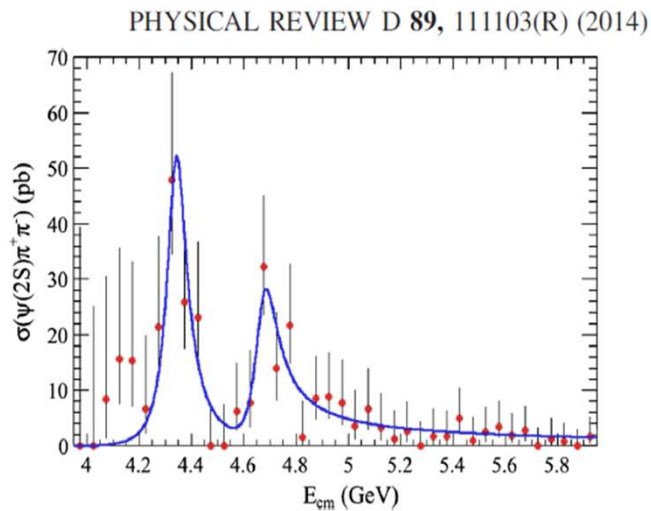


Other evidences of the $Y(4660)$

$e^+ e^- \rightarrow \psi(3686) \pi^+ \pi^-$ by means of ISR

BaBar

$M=4669 \pm 22$, $\Gamma=104 \pm 49$

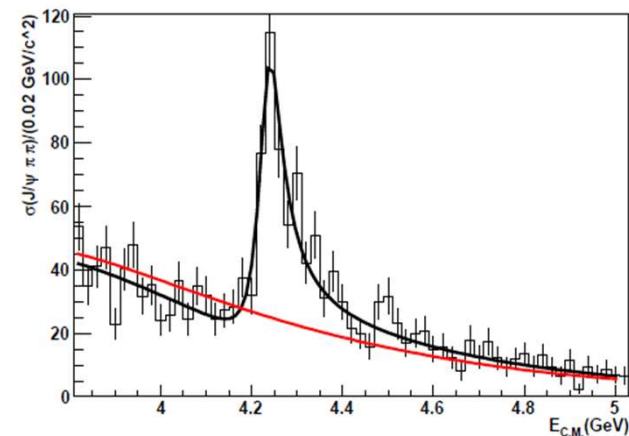
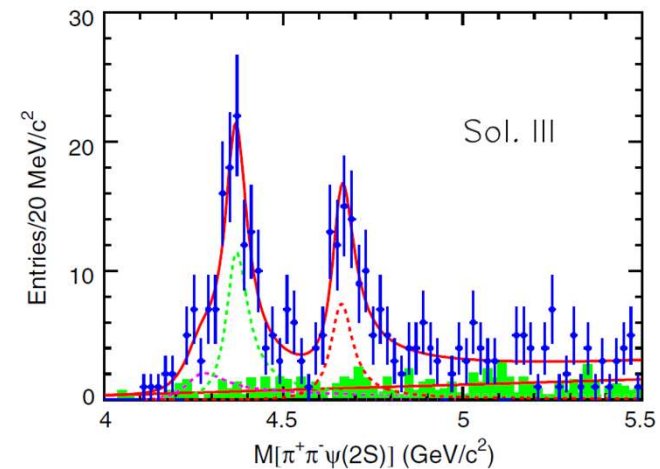


The decay $Y(4660) \rightarrow J/\psi \pi\pi$ would be expected to be large, if it is a cc_{bar} state, while no evidence of $Y(4660)$ at 90 % C.L

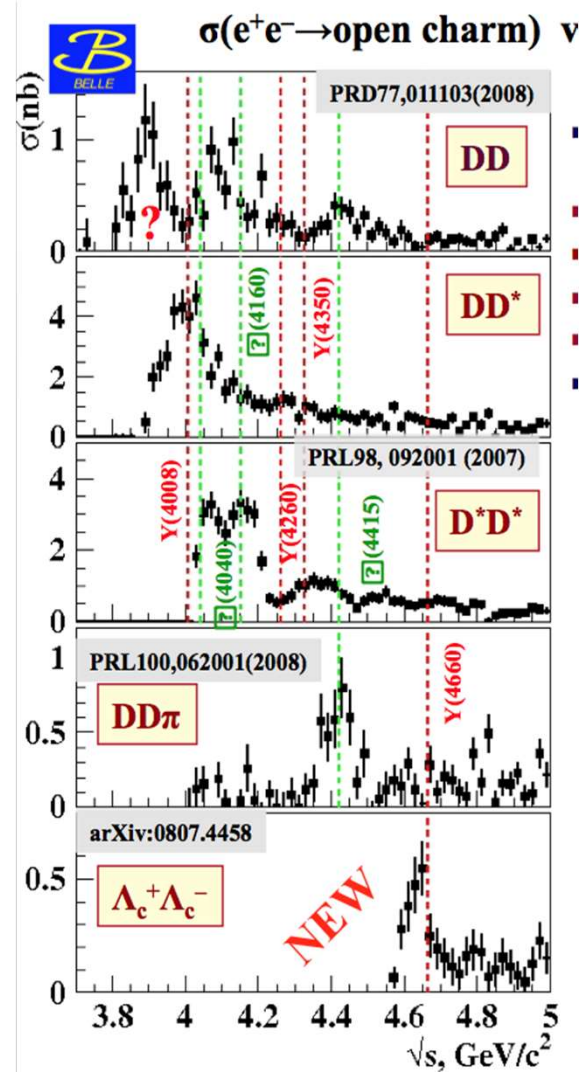
Belle

$M=4652 \pm 13$, $\Gamma=68 \pm 11$

PHYSICAL REVIEW D **91**, 112007 (2015)



No $Y(4660)$ in $e^+ e^- \rightarrow DD, DD^*, D^* D^*$ (from Steve Olsen)



Y(4660) in $e^+ e^- \rightarrow \psi(3686) \pi \pi$ cross section

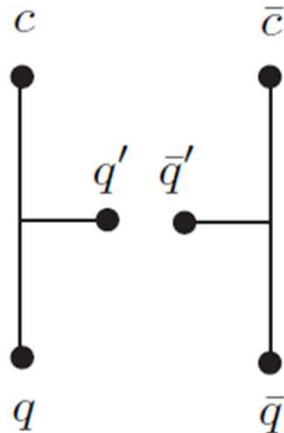
- $\sigma_{\text{peak}} = 12\pi/M^2 B\Gamma_{ee}/\Gamma \times 1.5(\text{incl } \pi^0 \pi^0) \sim 0.04 \pm 0.025 \text{ nb}$
to be compared to $e^+ e^- \rightarrow \Lambda_c \Lambda_{\text{cbar}} \sigma_{\text{peak}} \sim 0.55 \text{ nb}$
- **Y(4660) baryonic coupling ≥ 10 mesonic coupling**
Unexpected !

Y(4660) is a Hidden charm Baryonium ?

- Baryonium : that is a Baryon-Antibaryon bound state,
decaying into a Baryon-Antibaryon pair
- Baryonium made of light quarks :
dreamed for a long time and never clearly found
(might be too wide to be seen as a resonance ?)

Y(4660) Charmed Baryonium ?

- According to [R. Faccini et al. arXiv:0911.2178\(2017\)](#),
[see also [L. Maiani, F. Piccinini, A. D. Polosa and V. Riquer, Phys. Rev. D 72, 031502](#)]
Y(4660) fulfills the old [Rossi Veneziano, G.F. Chew](#) paradigm
[[Nucl.Phys. B123,507\(1977\)](#) , [G.F.Chew Nucl.Phys. B79 \(1974\) 365](#)]
of a **charm tetraquark (hidden charm baryonium)** decay:
mostly popping up from the vacuum a light quark pair and
falling apart as a charmed baryon pair

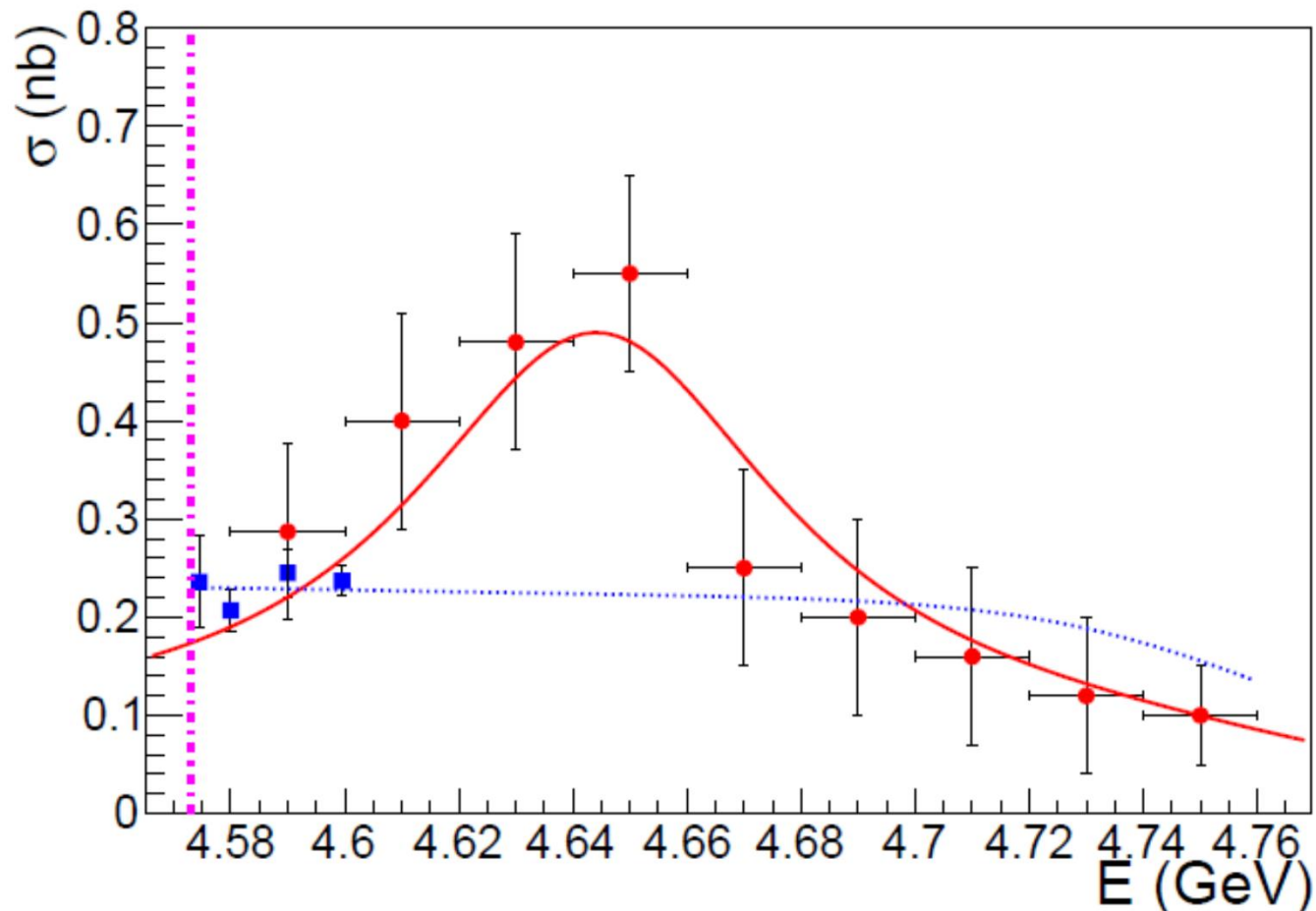


Y(4660) Charmed Baryonium ?

- Y(4660) mass, close to the $\Lambda_c \Lambda_{cbar}$ threshold, is in favour of its interpretation as a **charmed baryonium**.
- Y(4660) $\rightarrow \Lambda_c \Lambda_{cbar}$ shape and width, actually (expected large, according to the Rossi Veneziano model) is constrained by the threshold close by.
- If BESIII would not confirm the Y(4660) $\rightarrow \Lambda_c \Lambda_{cbar}$ decay a strong support of the interpretation of the XYZ states as tetraquark states would be somewhat in trouble.
- It might be that the Meissner et al conclusions are too drastic. In the following slide a fit with a Y(4660) on top of a Coulomb amplitude closer to a pointlike $\Lambda_c \Lambda_{cbar}$ at threshold is shown.
More data by BESIII at threshold and above $W=4.6$ GeV will settle all these questions.

Try to fit by means of a simple model Belle + BESIII data

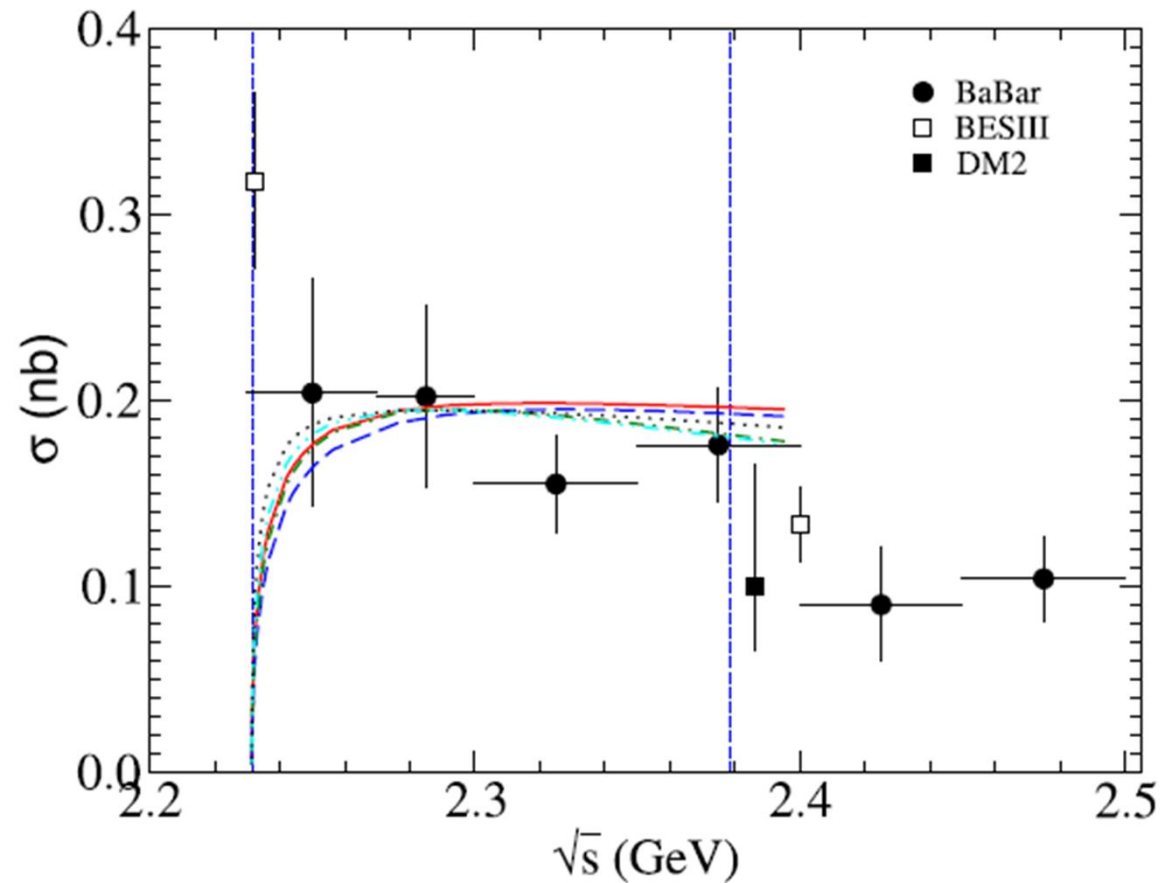
- Belle+ BESIII: $M = 4644 \pm 6 \text{ MeV}$, $\Gamma = 80 \pm 17 \text{ MeV}$ P= 63 %



The mystery of Neutral Baryon Pairs at thr

Present data on $e^+ e^- \rightarrow \Lambda \Lambda_{\text{bar}}$

- BESIII results (Phys. Rev. D 97, 032013)
- Neutral Baryon: no Coulomb, but still step at thr !

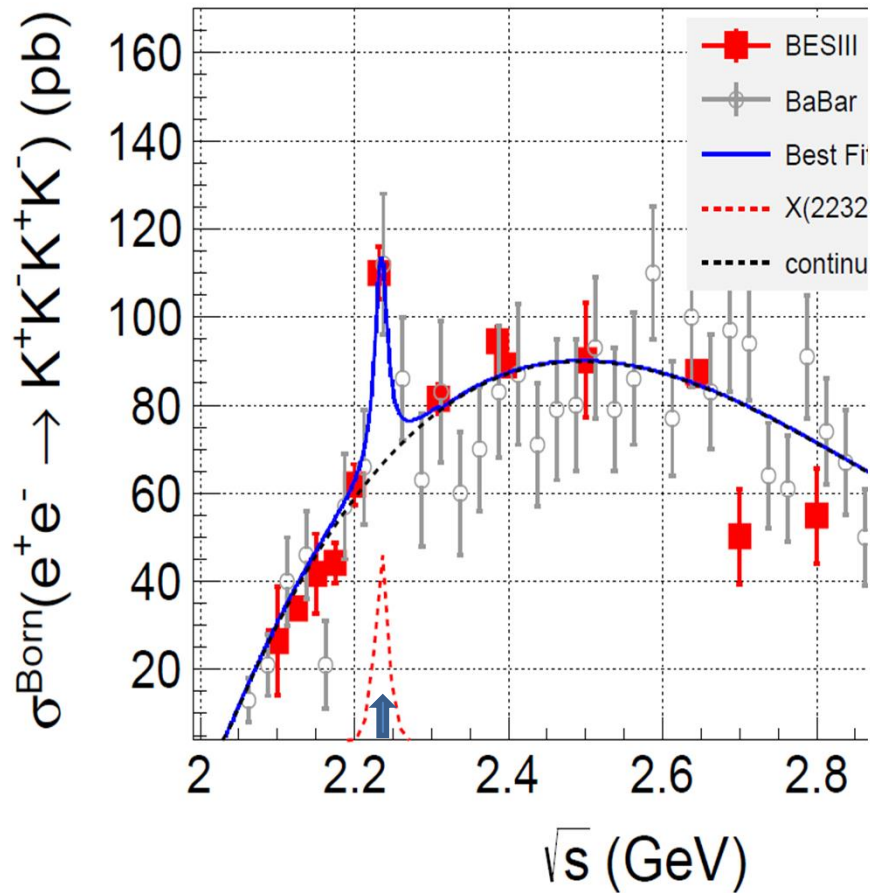


FSI fit to $e^+ e^- \rightarrow \Lambda \bar{\Lambda}$

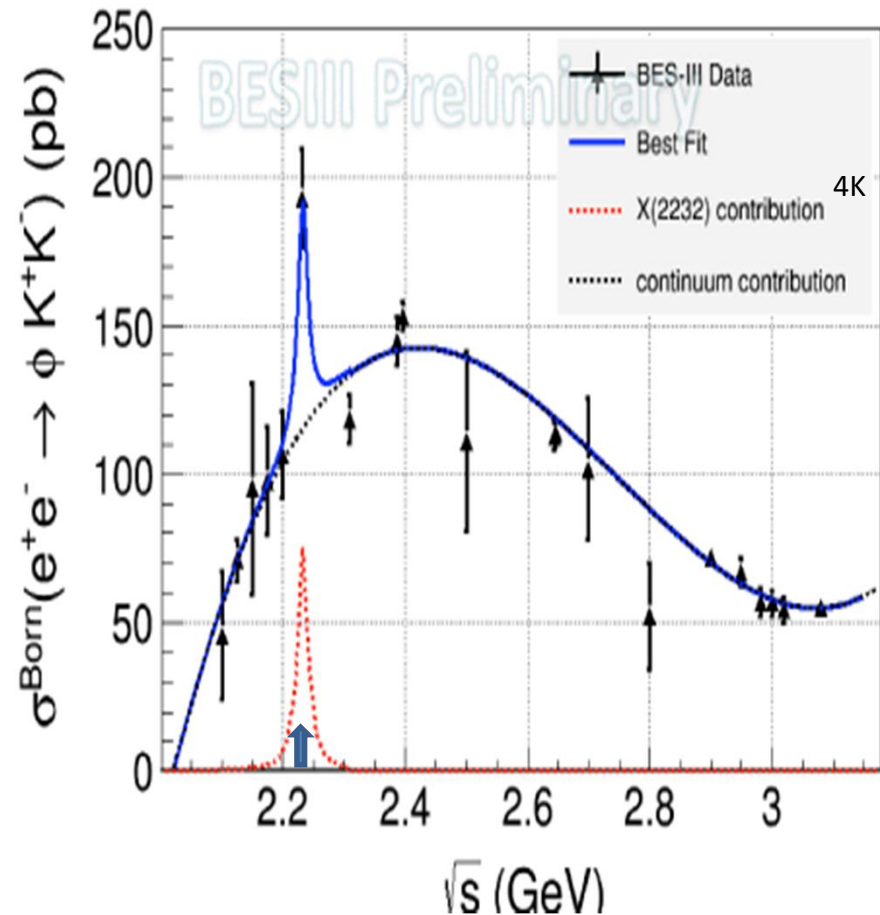
- J.Haidenbauer and U.G. Meissner [Phys.Lett B761 (2016)] FSI model fit BaBar, (even if the first point energy error is suspicious, it should already show a trend to zero), but not BESIII data.
- *“BESIII data suggest a very different trend for the energy dependence . Specifically, a large finite value for the cross section practically at the threshold is suggested. This cannot be reproduced by our model because of the phase-space β .*
- *There is no Coulomb interaction here that would change the threshold behavior*
- *The only possibility could be **a very narrow resonance sitting more or less directly at the threshold**, which would then allow to overrule the behavior from the phase space alone.”*

An anomaly related to $e^+e^- \rightarrow \Lambda \Lambda_{\text{bar}}$ thr ?

- $e^+e^- \rightarrow K^+K^- K^+K^-$, ϕK^+K^- $M=2232 \pm 3.5$ MeV, $\Gamma = 7.5(+13.5)$ MeV
(A hint for such a resonance, more data needed)



$e^+e^- \rightarrow \Lambda \Lambda_{\text{bar}}$ threshold

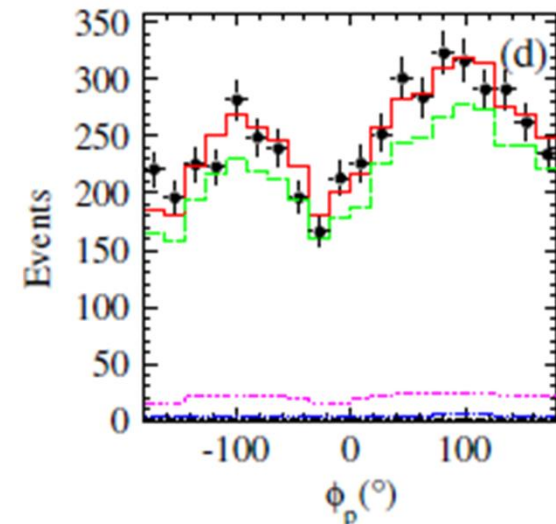
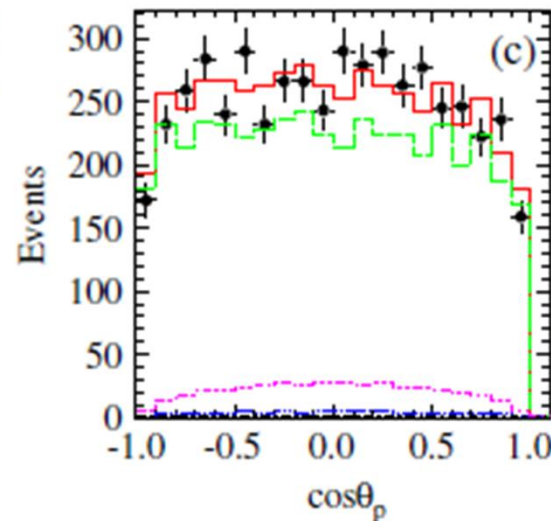
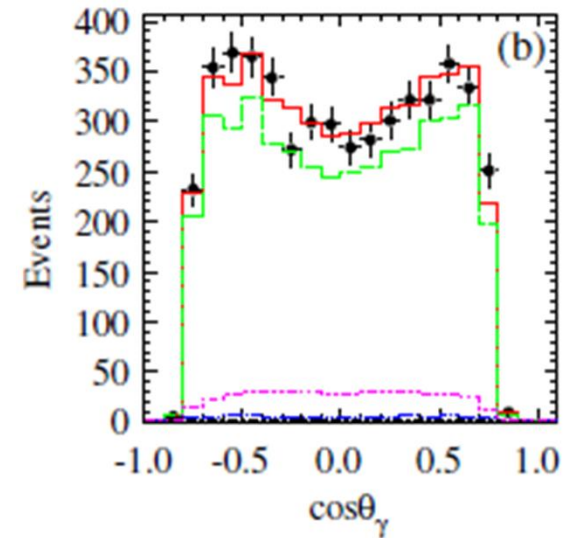
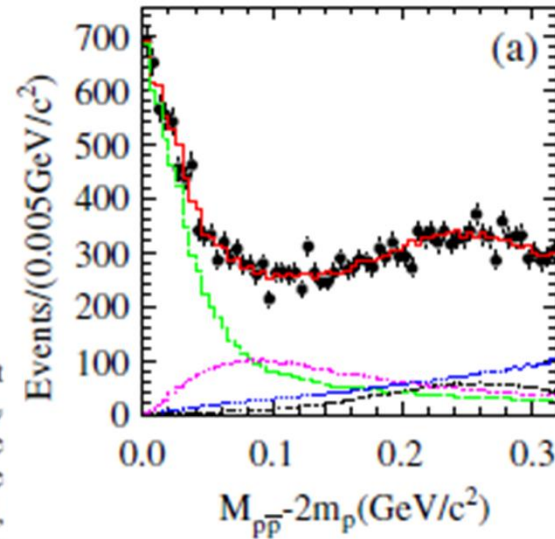


$e^+e^- \rightarrow \Lambda \Lambda_{\text{bar}}$ threshold

Light Quarks “Baryonium” ?

BESIII $J/\psi \rightarrow \gamma p\bar{p}_{\text{bar}}$ Sharp rise @ thr , light quarks “baryonium” ?

(color online). Comparisons between data and PWA fit projection: (a) the $p\bar{p}$ invariant mass; (b)–(d) the polar angle θ_γ of the radiative photon in the J/ψ center of mass system, the polar angle θ_p and the azimuthal angle ϕ_p of the proton in the $p\bar{p}$ center of mass system with $M_{p\bar{p}} - 2m_p < 50 \text{ MeV}/c^2$, respectively. Here, the black dots with error bars are data, the solid histograms show the PWA total projection, and the dashed, dotted, dash-dotted, and dash-dot-dotted lines show the contributions of the $X(p\bar{p})$, 0^{++} phase space, $f_0(2100)$ and $f_2(1910)$, respectively.



FSI or Light quarks “baryonium” in $J/\psi \rightarrow \gamma NN_{\text{bar}}$ @ thr ?

- Meissner et al, FZJ-IKP(TH)-2004-20, HISKP-TH-04-24

from $\sigma(pp_{\text{bar}} \rightarrow pp_{\text{bar}})$ scattering lengths:

$$a_0 = -0.18 - 1.18 i$$

$$a_1 = 1.13 - 0.61 i$$

- **If FSI :**

$$\text{BR}(J/\psi \rightarrow \gamma pp_{\text{bar}}) \approx \sigma(\gamma NN_{\text{bar}}) \times |a_0 + a_1|^2$$

$$\text{BR}(J/\psi \rightarrow \gamma nn_{\text{bar}}) \approx \sigma(\gamma NN_{\text{bar}}) \times |a_0 - a_1|^2$$

$$\text{BR}(\gamma pp_{\text{bar}}) / \text{BR}(\gamma nn_{\text{bar}}) \approx \mathbf{2}$$

- **If NN_{bar} resonance below thr (light quarks “baryonium”):**

$$\text{BR}(\gamma pp_{\text{bar}}) / \text{BR}(\gamma nn_{\text{bar}}) \approx \mathbf{1}$$

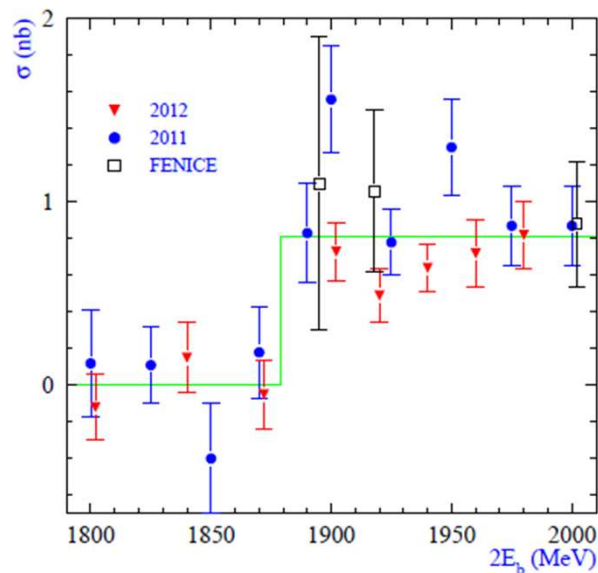
- **$\text{BR}(J/\psi \rightarrow \gamma nn_{\text{bar}})$ measured by BESIII
(under review)**

$$e^+ e^- \rightarrow nn_{\text{bar}}$$

$e^+ e^- \rightarrow nn_{\text{bar}}$

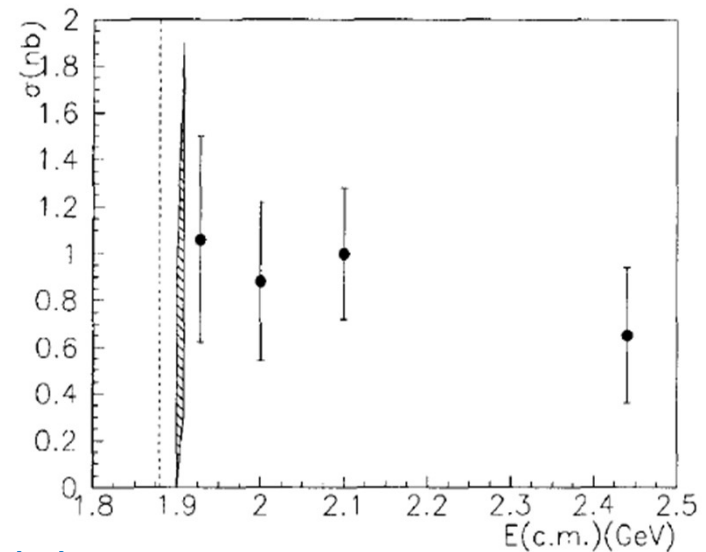
- Published data

SND



FENICE

A. Antonelli et al./Nuclear Physics B 517 (1998) 3–35



- Not vanishing cross section at thr (?)
- **New measurements by SND, CMD3**
- **New measurements by BESIII from 2 to 3 GeV ! (under review)**

G_E / G_M phase

Pp_{bar} G_E / G_M phase @ BESIII

- e⁺e⁻ → pp_{bar}, in principle from p scattering on a slab of carbon fiber, for instance the DC inner wall (few permille) after CGEM installation?
- Expectations:
 - Analiticity demands every amplitude real, asymptotically
i.e. : in e⁺e⁻ → pp_{bar} φ_{EM} ≈ 0⁰ or 180⁰
 - But, applying Dispersion Relations, with a possible zero contribution to G_E/G_M spacelike, it has been found :
in e⁺e⁻ → pp_{bar} φ_{EM} ≈ 45⁰
depending if there is indeed a zero in the G_E/G_M spacelike.

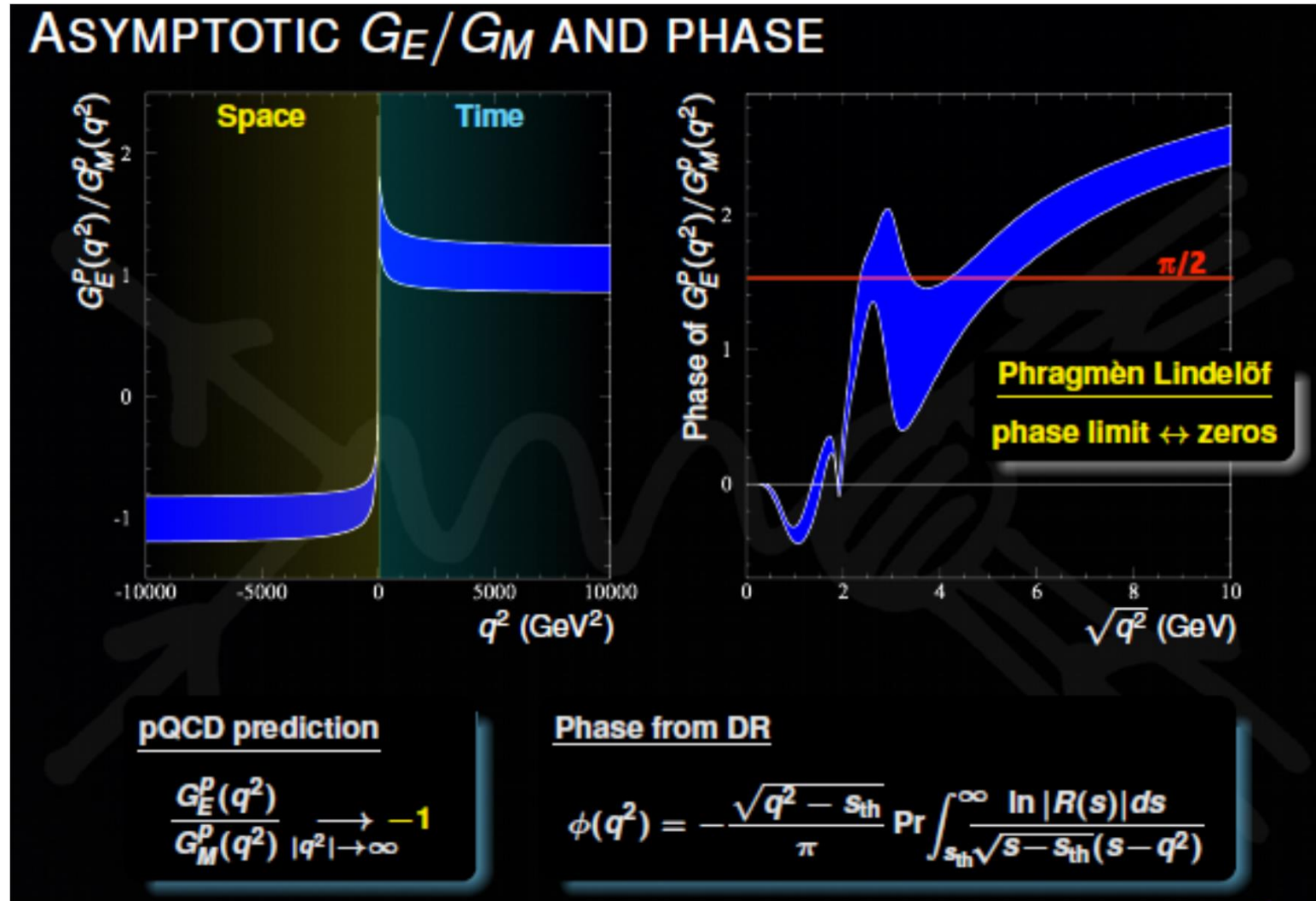
$$\delta_{\pi}(s) = -\frac{(s-s_0)^{\frac{1}{2}}}{\pi} \text{PV} \int_{s_0}^{\infty} \frac{\log |F_{\pi}(t)|}{(t-s_0)^{\frac{1}{2}}(t-s)} dt + \varphi_H(s)$$

where $\varphi_H(s)$ is the contribution coming from the zeros

Hence the G_E/G_M timelike phase tells about a spacelike faraway zero !!

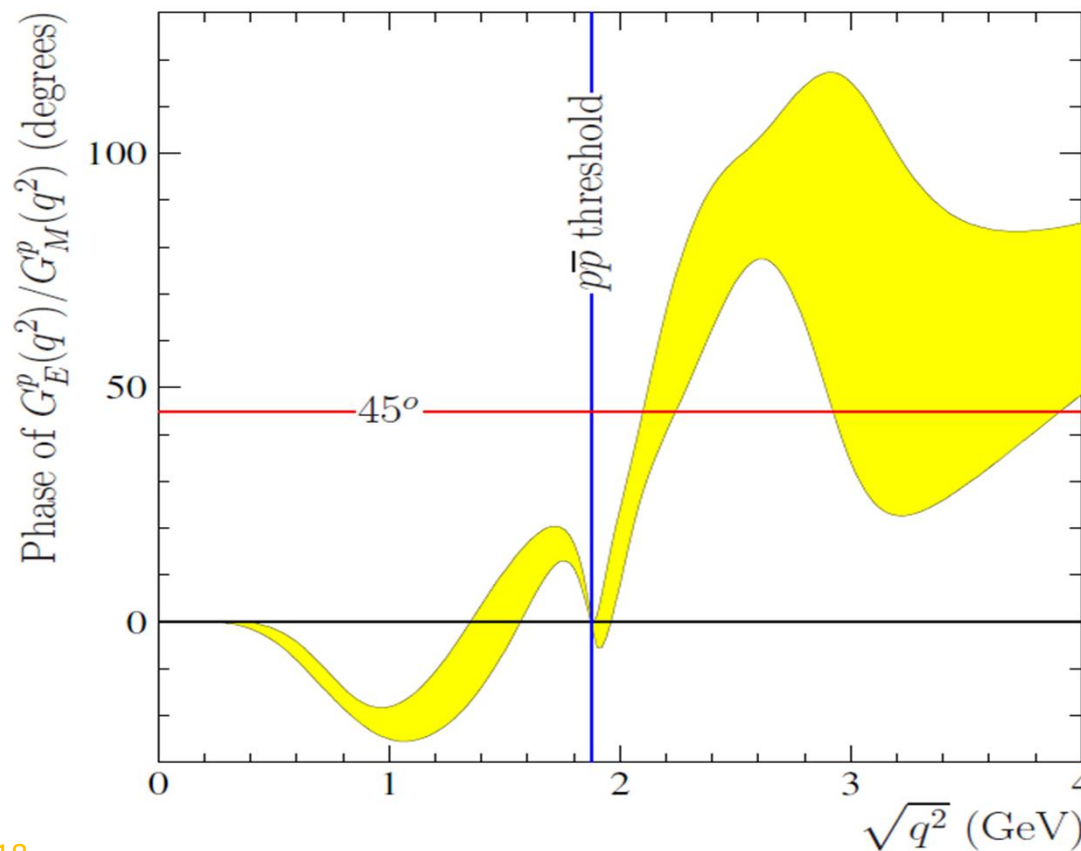
Dispersion Relation applied to $|G_E / G_M|$ to get the phase

- Dispersion Relations applied to $|G_E/G_M|$:
input spacelike \rightarrow output timelike



Dispersion Relation applied to $|G_E / G_M|$ to get the phase

- Dispersion Relations applied to $|G_E/G_M|$:
input spacelike JLAB data -> output timelike prediction
(uncertainty on q^2 zero -> timelike prediction uncertainty)



Charmonium Decay into Baryon Pairs

- $J/\psi \rightarrow \Sigma \Sigma_{\text{bar}}$ anomalous angular distribution, Σ polarization
- 90° phase between strong and em J/ψ decay amplitudes
- A_E, A_M different phase (?)
-
-
- Next episode.....



Waiting for

Future

- Near Future
- Present FSI theory is missing something
- $e^+ e^- \rightarrow p\bar{p}$: more data from CMD3 and BESIII
- $e^+ e^- \rightarrow \Lambda_c \Lambda_{c\bar{}}$: more data at thr and above by BESIII
- $e^+ e^- \rightarrow \Lambda \Lambda_{\bar{}}$ and $e^+ e^- \rightarrow \phi K^+ K^-$: more data around $\Lambda \Lambda_{\bar{}}$ thr
- $BR(J/\psi \rightarrow \gamma n\bar{n})$: publication/ more work by BESIII
- $e^+ e^- \rightarrow n\bar{n}$: more data from SND, CMD3
publication by BESIII
- G_E/G_M phase : more data from BESIII
- Far Future
- Super τ /charm : in China (Hefei ?, BEPCIII ?, inside CEPC ?
in Russia (Novosibirsk?))

感谢您的关注

Backup slides

BaBar $\sigma(e^+ e^- \rightarrow p\bar{p}_{\text{bar}})$ close to thr

- BaBar $\sigma(e^+ e^- \rightarrow p\bar{p}_{\text{bar}})$ close to thr

$M_{p\bar{p}}$ [GeV/ c^2]	N	$\sigma_{p\bar{p}}$ [pb]
1.8765–1.8800	$37 \pm 7 \pm 1$	$534 \pm 94 \pm 39$
1.8800–1.8850	$80 \pm 10 \pm 1$	$826 \pm 106 \pm 42$
1.8850–1.8900	$67 \pm 10 \pm 1$	$705 \pm 105 \pm 33$
1.8900–1.8950	$79 \pm 11 \pm 1$	$886 \pm 121 \pm 41$
1.8950–1.9000	$86 \pm 12 \pm 1$	$938 \pm 128 \pm 42$
1.9000–1.9050	$70 \pm 11 \pm 1$	$785 \pm 123 \pm 35$
1.9050–1.9100	$80 \pm 11 \pm 1$	$937 \pm 135 \pm 41$
1.9100–1.9150	$98 \pm 13 \pm 1$	$1096 \pm 142 \pm 46$
1.9150–1.9250	$156 \pm 15 \pm 2$	$862 \pm 84 \pm 32$
1.9250–1.9375	$188 \pm 16 \pm 3$	$811 \pm 69 \pm 31$
1.9375–1.9500	$208 \pm 17 \pm 3$	$887 \pm 72 \pm 33$
1.9500–1.9625	$181 \pm 16 \pm 3$	$780 \pm 70 \pm 30$
1.9625–1.9750	$209 \pm 17 \pm 3$	$850 \pm 70 \pm 32$

BESIII $e^+ e^- \rightarrow \Lambda_c \Lambda_{c\bar{b}} \text{ angular distributions}$

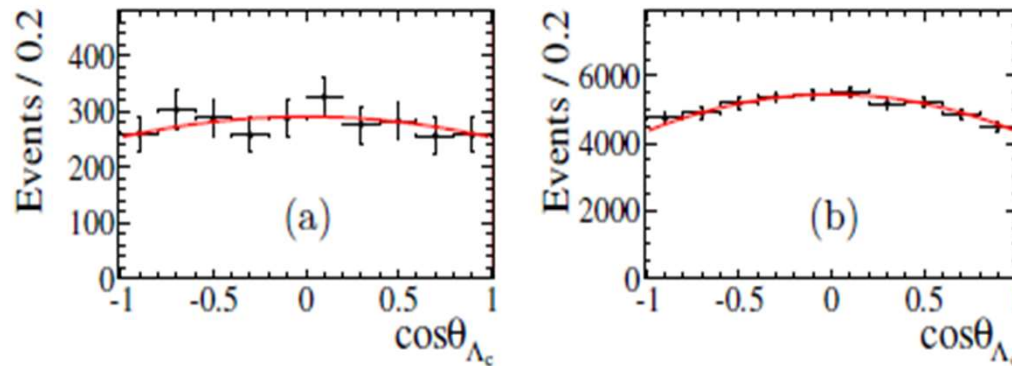


FIG. 3. Angular distribution after efficiency correction and results of the fit to data at $\sqrt{s} = 4574.5$ MeV (a) and 4599.5 MeV (b).

- The angular distr. is almost flat, as expected, at $W = 4.57$ GeV ($\beta_{\Lambda_c} = 0.026$) within the errors.
By the way very close to $\pi\alpha = 0.023$, where Coulomb should matter
- The collected statistics is quite high at $W = 4.60$ GeV ($\beta_{\Lambda_c} = 0.11$) and as already seen in $e^+ e^- \rightarrow p p_{\bar{b}}$ at $W = 1.91$ GeV ($\beta_p = 0.20$), there is a **very early onset of the D wave**.

Other evidences of the $\Upsilon(4660)$

- Adding both measurements, to reduce the statistical error as done by BaBar in their paper:

