Anomalies
in Baryon Time-like Form Factors

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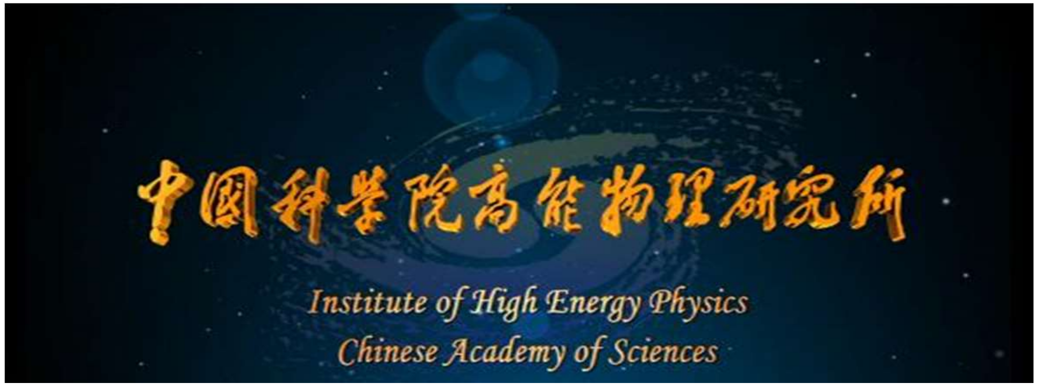


I.H.E.P.   2018, May 31

Preamble

- Baryon mass is the main component of the mass of the Universe
  It comes from the strong force, not from the Higgs mechanism

- Baryons, what they really are, is 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)]

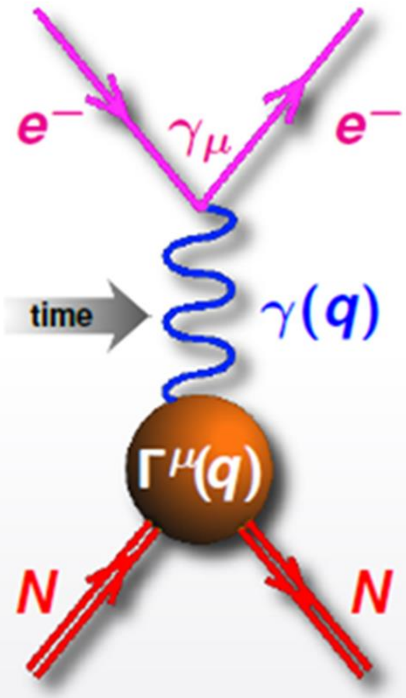
- Therefore it is meaningful to point out open questions, concerning Baryon structure, and Timelike Baryon Form Factors are plenty of

Outline

- Definitions and Main Expectations

- $e^+ e^- \to p\, p_{bar}$
  - FF oscillations. Jump at threshold? Coulomb enhancement ?
- $e^+ e^- \to \Lambda_c\, \Lambda_{cbar}$
  - Jump at threshold. Charmed "Baryonium" ?
- $e^+ e^- \to \Lambda\, \Lambda_{bar}$
  - Jump at threshold. Narrow resonance close by ?
- $J/\psi \to \gamma\, NN_{bar}$
  - Light Quarks "Baryonium" ?
- $e^+ e^- \to n\, n_{bar}$
  - News from SND,CMD3 and BESIII
- G_E / G_M phase
  - Relationship with spacelike zeros

Definitions and Main Expectations
Spacelike ($q^2 < 0$)



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

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

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

$$\begin{cases} p = (E, -\vec{q}/2) \\ p' = (E, \vec{q}/2) \\ q = (0, \vec{q}) \end{cases} \qquad \begin{cases} \rho_q = J^0 = e\left[F_1 + \frac{q^2}{4M^2}F_2\right] \\ \vec{J}_q = e\,\overline{u}(p')\vec{\gamma}u(p)\,[F_1 + F_2] \end{cases}$$

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

- **Sachs form factors**

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

- **Normalizations**

$$F_1(0) = Q_N \qquad G_E(0) = Q_N$$
$$F_2(0) = \kappa_N \qquad G_M(0) = \mu_N$$

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

Polarization observables

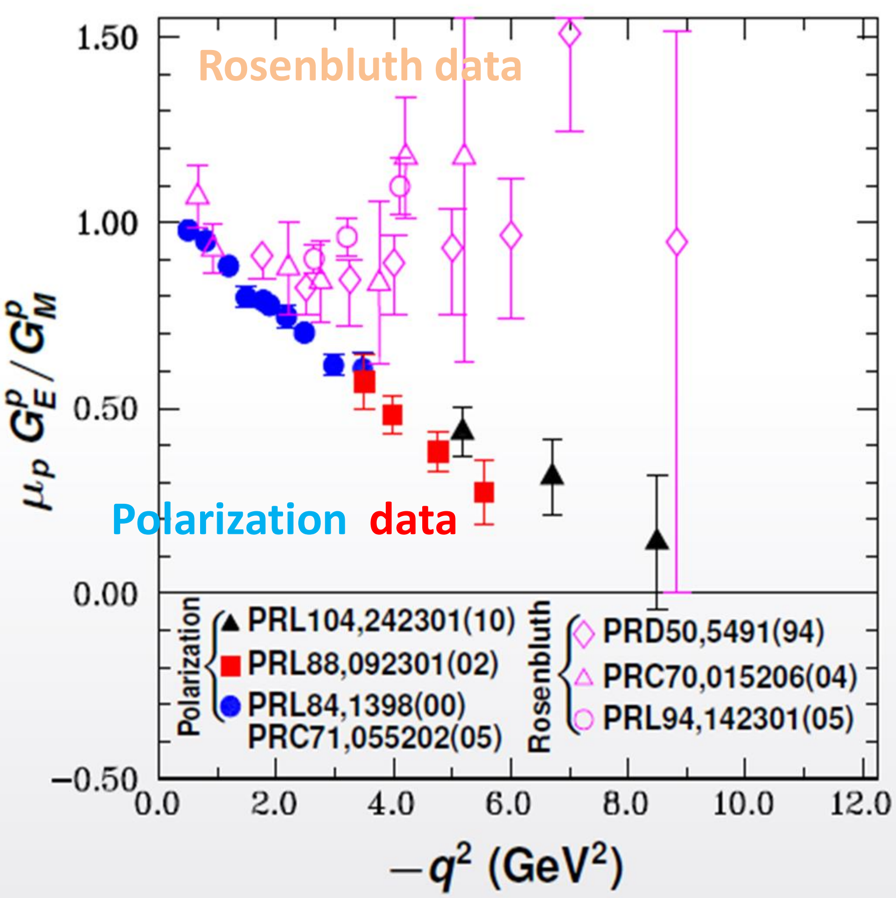
A.I. Akhiezer, M.P. Rekalo, Sov. Phys. Dokl. 13, 572 (1968)

- Elastic scattering of **longitudinally polarized electrons** ($h = \pm 1$) on nucleon targe
- 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:

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

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

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

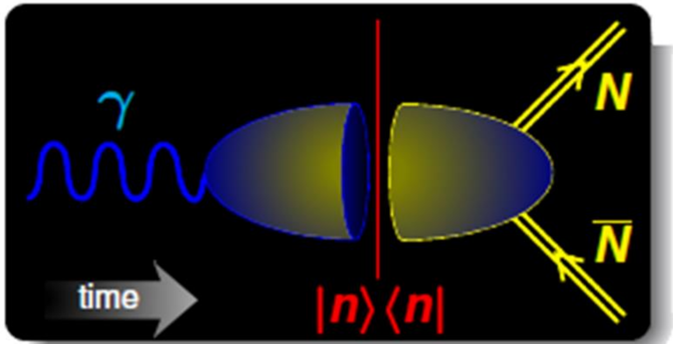


Polarization data do not agree with old Rosenbluth data (◊)

New Rosenbluth data (△, ○) from JLab still do not agree with polarization data

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

Definitions and Main Expectations
Timelike ($q^2 > 0$)



- **Crossing symmetry:**

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

- **Form factors are complex functions of q^2**

Optical theorem

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

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

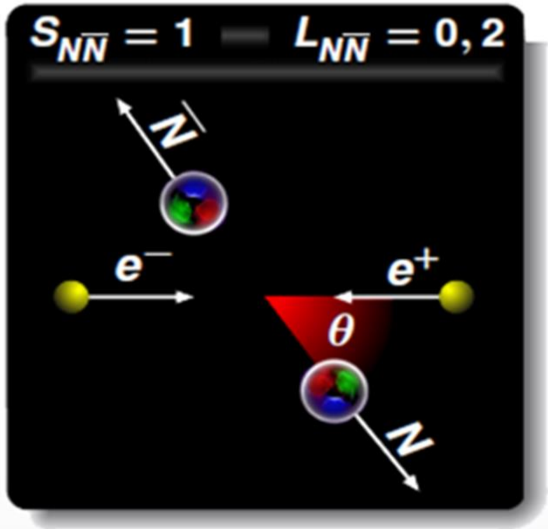
Time-like asymptotic behavior

Phragmèn 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.**

- $$\underbrace{\lim_{q^2 \to -\infty} G_{E,M}(q^2)}_{\text{space-like}} = \underbrace{\lim_{q^2 \to +\infty} G_{E,M}(q^2)}_{\text{time-like}}$$

- $$G_{E,M} \underset{q^2 \to +\infty}{\sim} (q^2)^{-2}$$ **real**

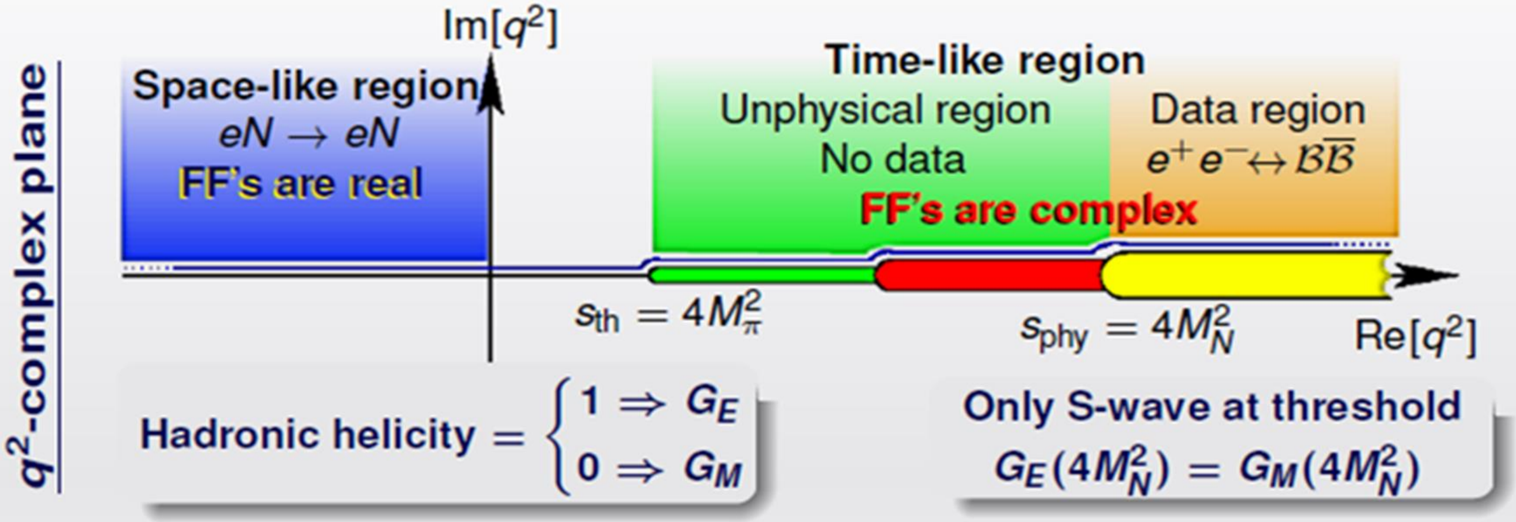
Definitions and Main Expectations
Timelike ($q^2 > 0$)



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: $\mathcal{C} = \dfrac{\pi\alpha/\beta}{1 - \exp(-\pi\alpha/\beta)}$



$G_E(q^2)/G_M(q^2)$: D wave at thr or early onset ?

- $G_E = F_1 + q^2/4M^2\ F_2$
  $G_M = F_1 + F_2$
  if F_1 and F_2 analitic -> $G_E(4M^2) = G_M(4M^2)$

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

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

$e^+ e^- \to pp_{bar}$

$e^+ e^- \to pp_{bar}$

- There are many sets of data on $e^+ e^- \to pp_{bar}$ 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 $pp_{bar} \to e^+ e^-$ 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, taking into account that it would be expected

  $\mathbf{G_E (4 M^2) = G_M (4 M^2)}$, it is defined

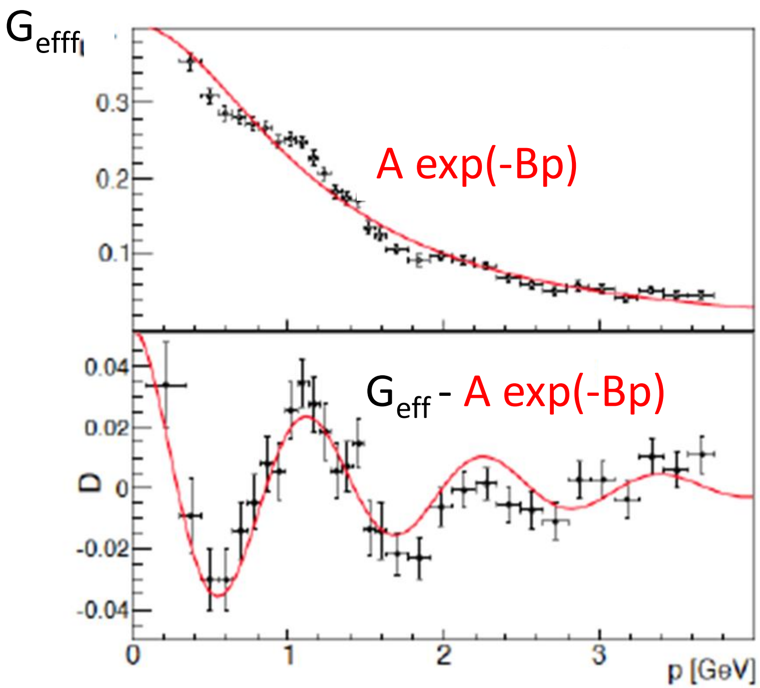
  $|G_{eff}| = \sqrt{ \{ \sigma (e^+e^- \to BB_{bar}) (3W_B^2) / [4\pi \alpha^2 \cdot C \cdot \beta(1+2M_B^2/W^2))] \} }$

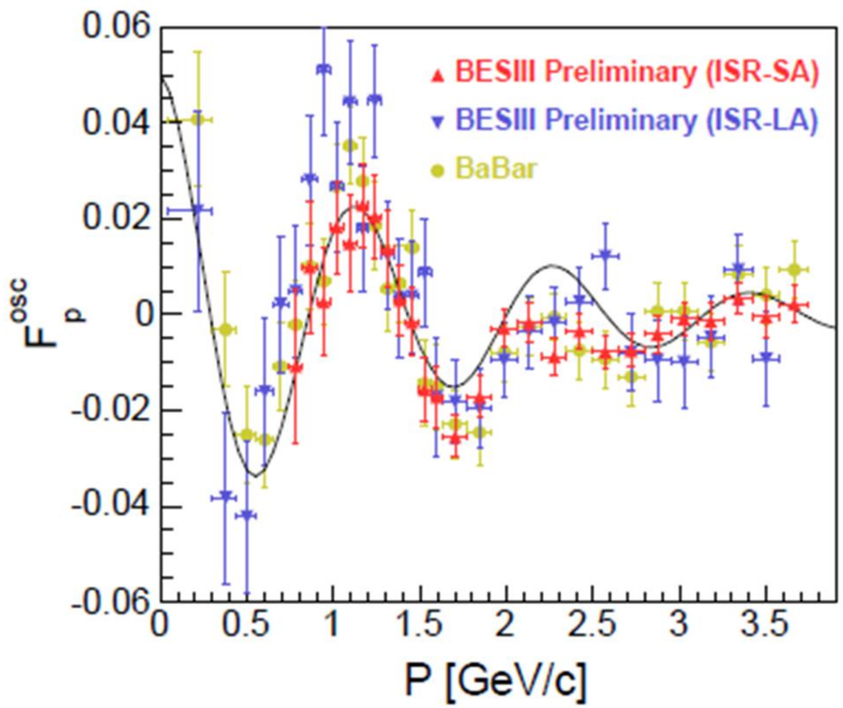
-

Oscillations in G_{eff} ($e^+e^- \to p p_{bar}$) !

- Oscillations in G_{eff} ($e^+e^- \to p p_{bar}$) seen by BaBar and confirmed by BESIII

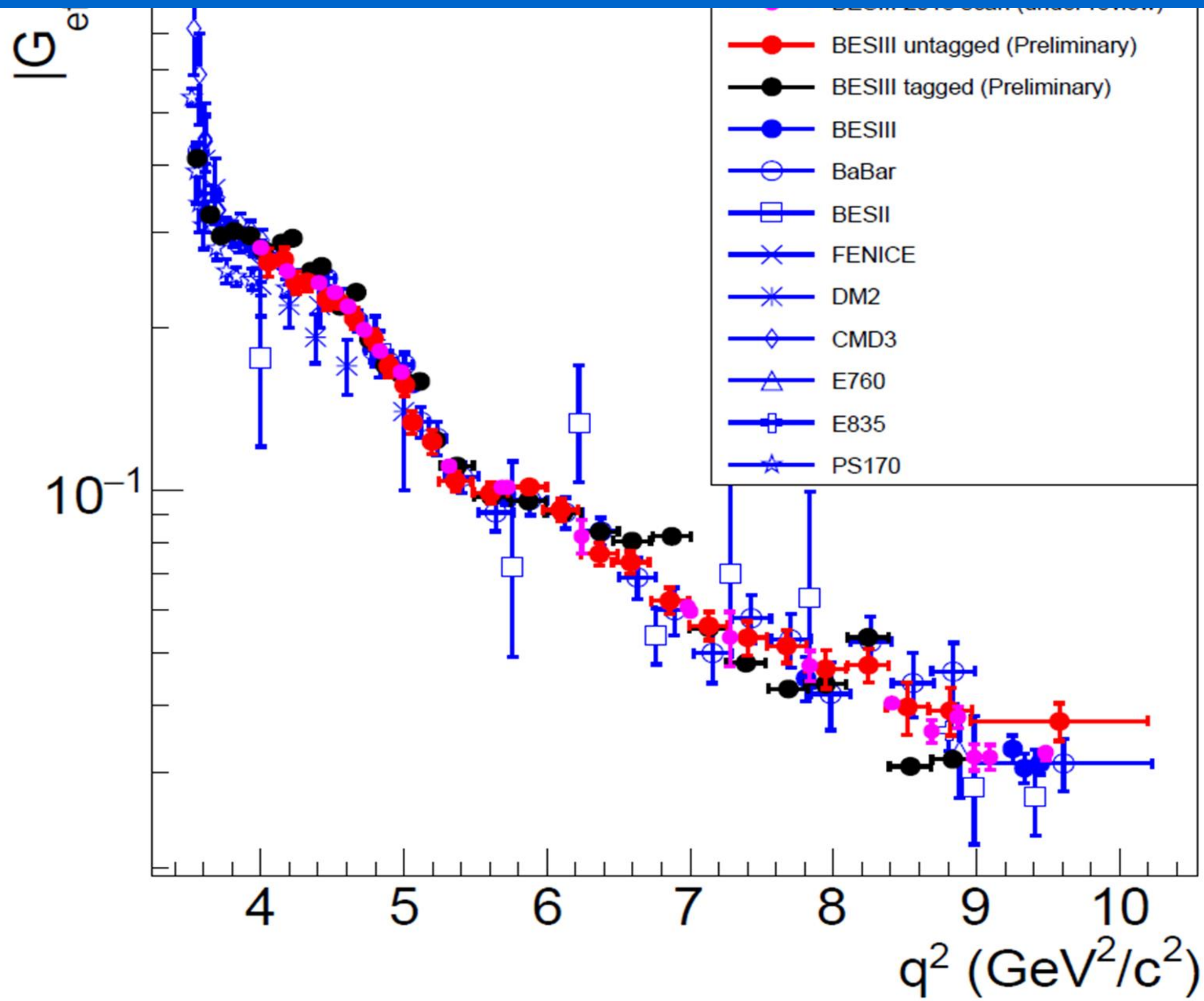
[A. Bianconi, E. Tomasi-Gustafsson PRL114,232301(2015)]





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

Present data on G_{eff} ($e^+ e^- \to pp_{bar}$)



G_{eff} steep drop at thr: Coulomb Enhacement Factor !

CEF Hypotheses

- In principle Coulomb interaction between the outgoing B^+B^- (**C** Enhancement Factor) should plays an important role. However there is no full consensus on that.

- $\sigma\ (e^+e^- \to BB_{bar}) = 4\pi\ \alpha^2/(3W_B^2) \cdot \boxed{C} \cdot \beta[|G_M(W_B^2)|^2 + 2M_B^2/W^2|G_E(W_B^2)|^2]$

- C: Coulomb Enhancement Factors (CEF).

  Non Perturbative Correction to include Coulomb Interaction

  between the outgoing charged fermions

- Hypotheses to achieve CEF:

- In $<i|T_0+T_C|f>$: the final state is not a plane wave $|f>$, but $|\phi>$ where ϕ is the wave function after Coulomb scattering

- T_0 (before Coulomb interaction) is a short range interaction, hence $\phi(r) \to \phi(0)$: **Coulomb affects S wave only**.

CEF Hypotheses

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

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

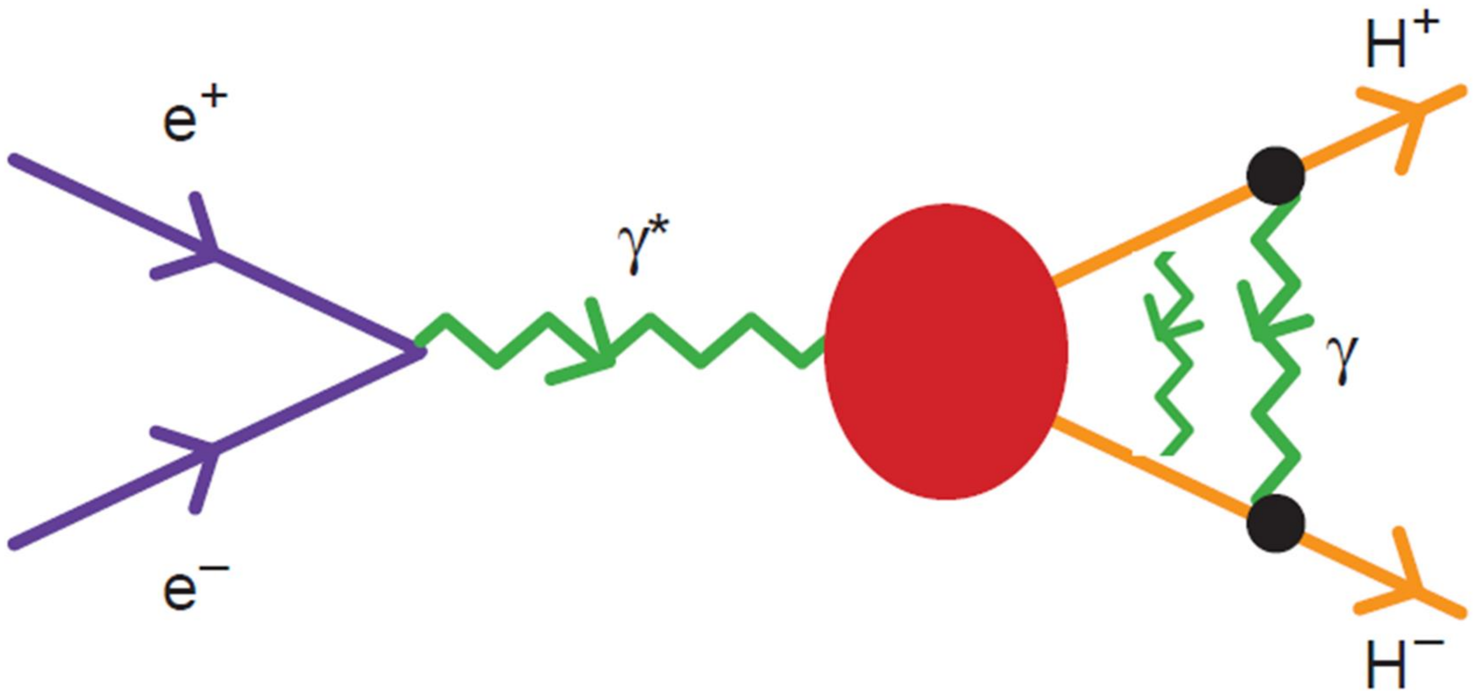
  F is a relativistic correction (not very important close to thr),
  according to Arbuzov $F = 2\,\beta/(1+\beta^2)$.
  Some also assume $F = \sqrt{(1-\beta^2)}$

- Photon exchanges among $B^+ B^-$ are taken into account by the
  Enhancement Factor $E = \pi\alpha\, F/\beta$
  E predicts a jump 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

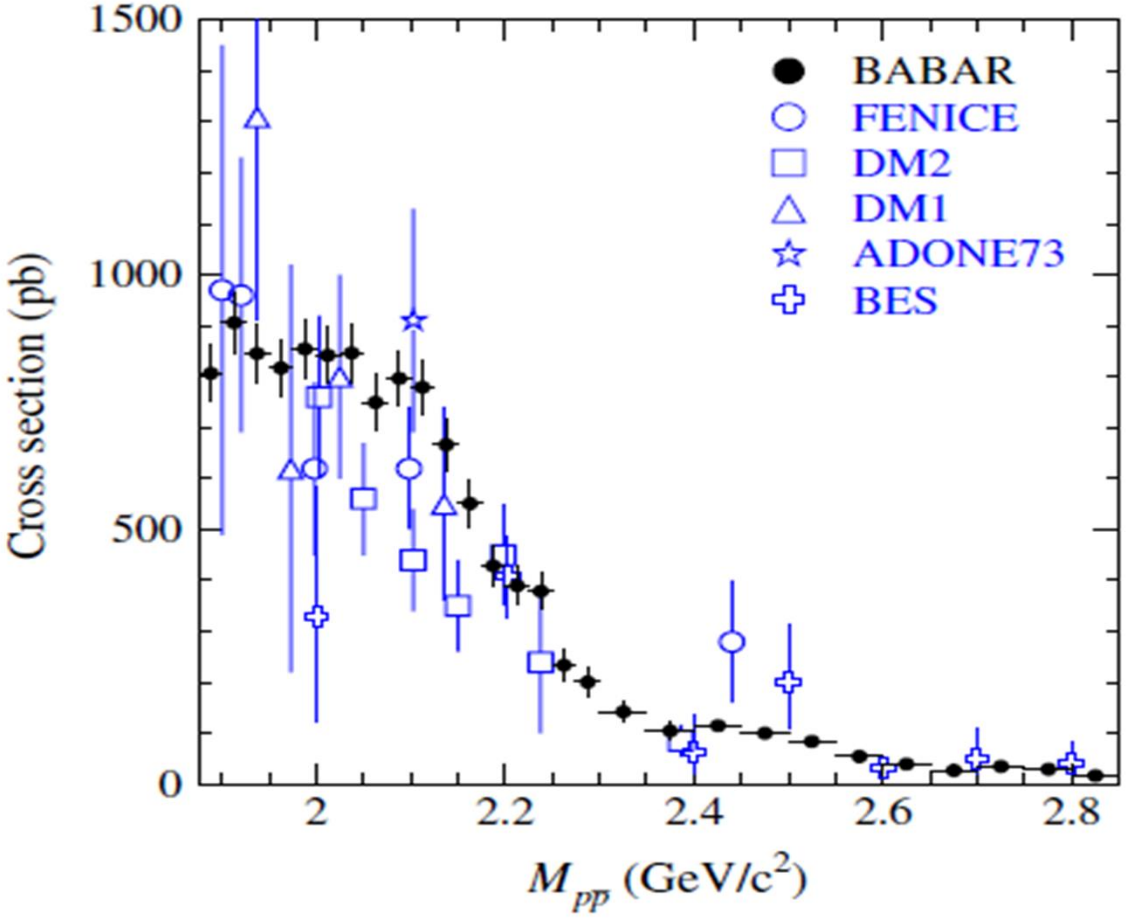
- An argument justifying pointlike CEF (never quoted explicitly):
  Coulomb has a long range, while Strong Force is a short one.
  Hence Coulomb acts when the hadron pair is already built.

Coulomb Enhancement Factor (CEF)



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

- To be updated with BESIII data



BaBar $\sigma(e^+ e^- \to pp_{bar})$ close to thr

- BaBar $\sigma(e^+ e^- \to pp_{bar})$ close to thr

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

- $\sigma(e^+ e^- \to pp_{bar})$ ≈ 0.85 nb flat (≤ 2 sd if extrapolated to first bin)
- CEF expects $\sigma_{thr} = 0.85 \cdot |G_S(4M_p^2)|^2$ nb

  Very tantalizing to infer that $G_S(4M_p^2)$ is close to 1 !

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

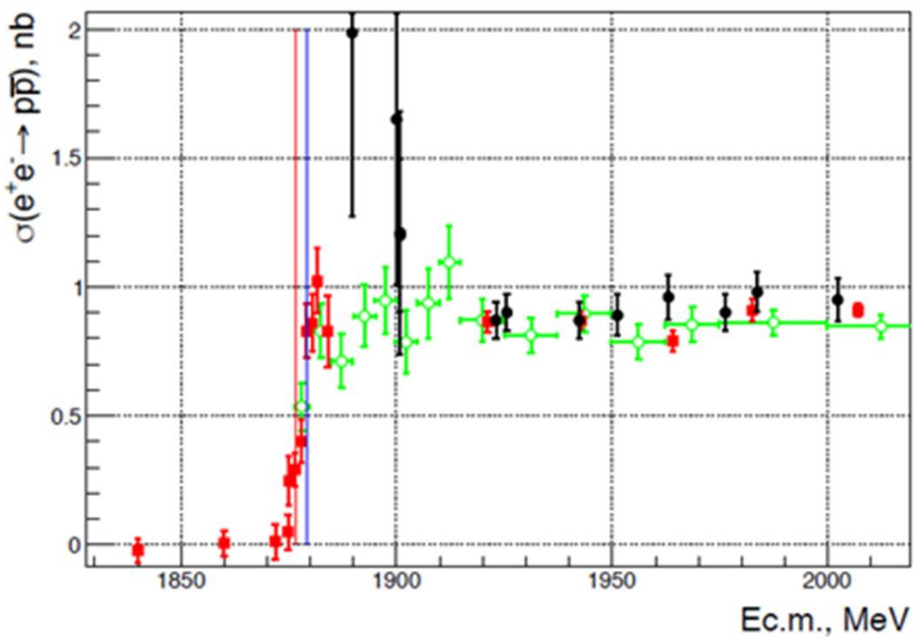
- Our Friend Genia Solodov settled the question

- Energy scan by CMD3:
  - $\sigma(e^+ e^- \to pp_{bar})$ at thr has indeed a jump ($\leq$ 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

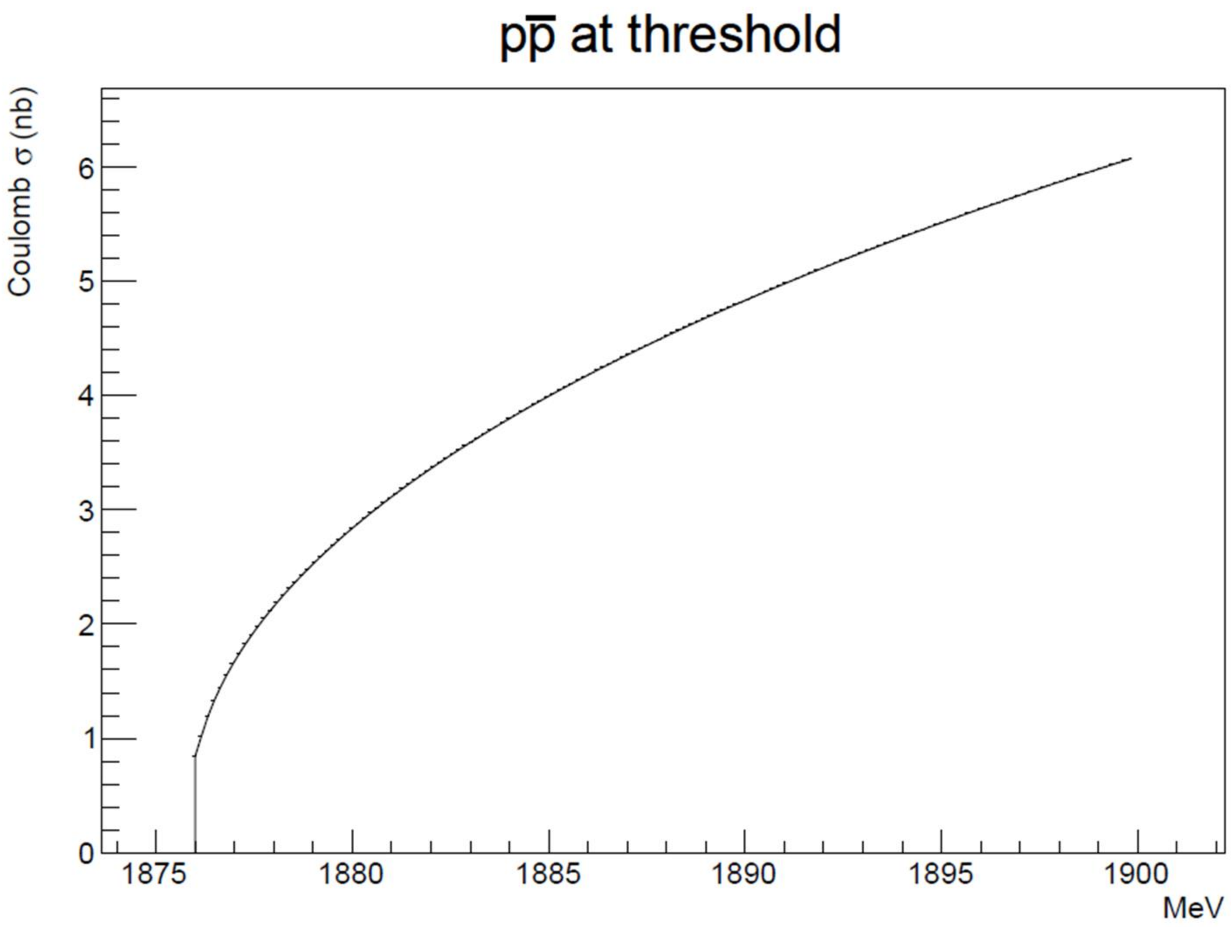
e+e- -> ppbar Born cross section



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).)

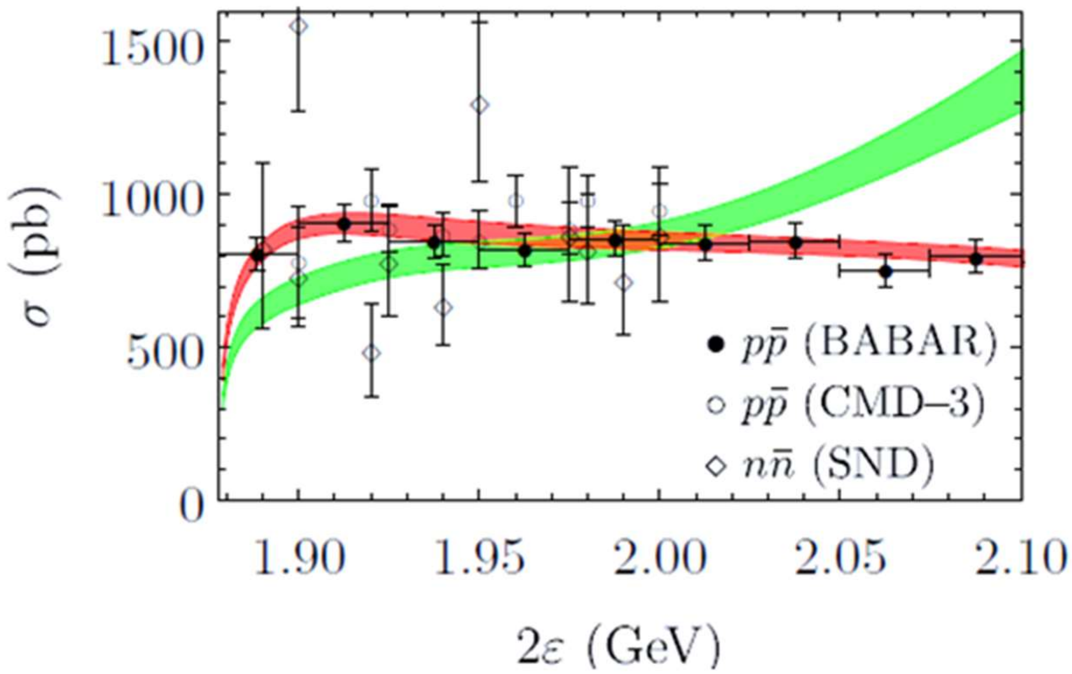
Coulomb interaction above trh

- Simple Coulomb interaction does explain a jump at thr but it is at odd with the flat $\sigma(e^+ e^- \to pp_{bar})$ above thr:



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

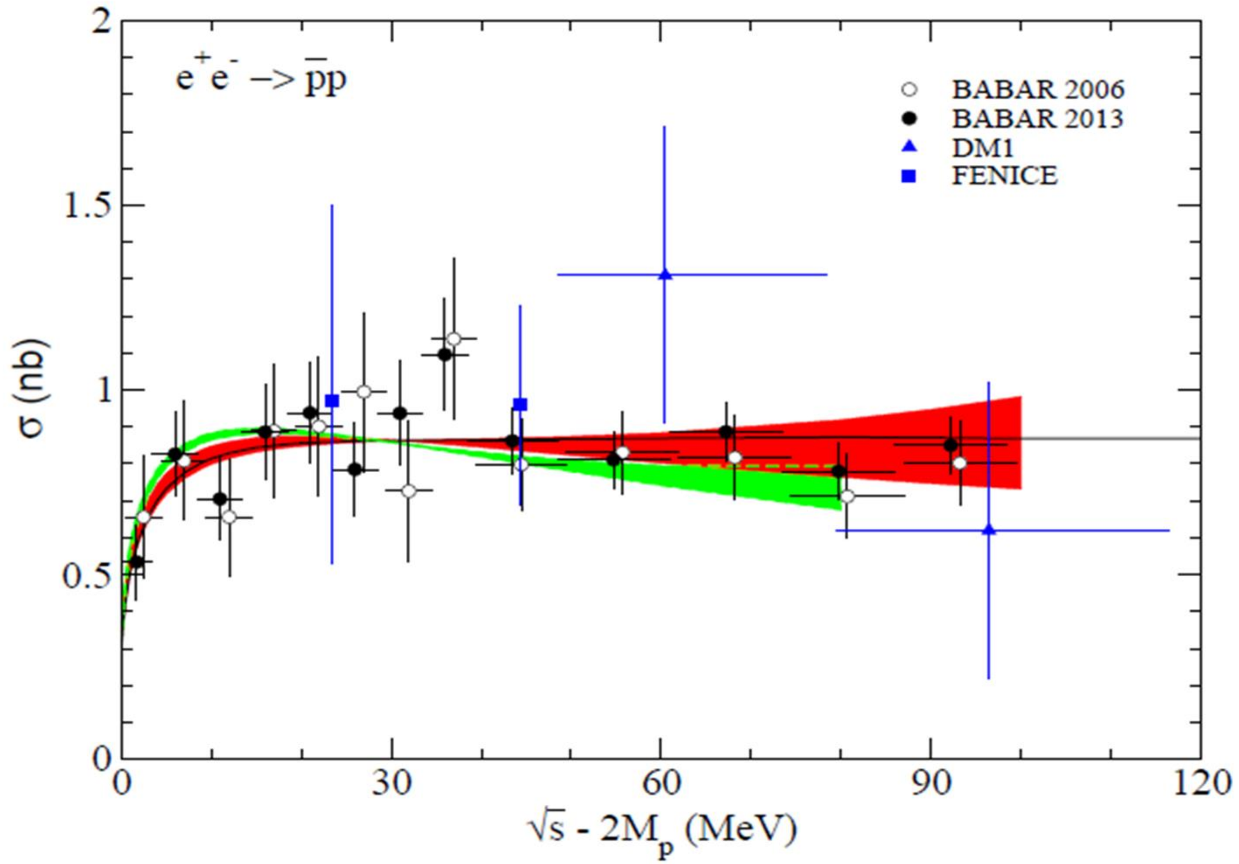
- FSI get a flat $\sigma(e^+ e^- \to pp_{bar})$ from the steep behaviour of elastic $\sigma(pp_{bar} \to pp_{bar})$ at low energies.
- FSI expect a sharp rise but not a jump on thr and no relationship with the pointlike FF
- A. Milstein in PhitoPsi17, Mainz :



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

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

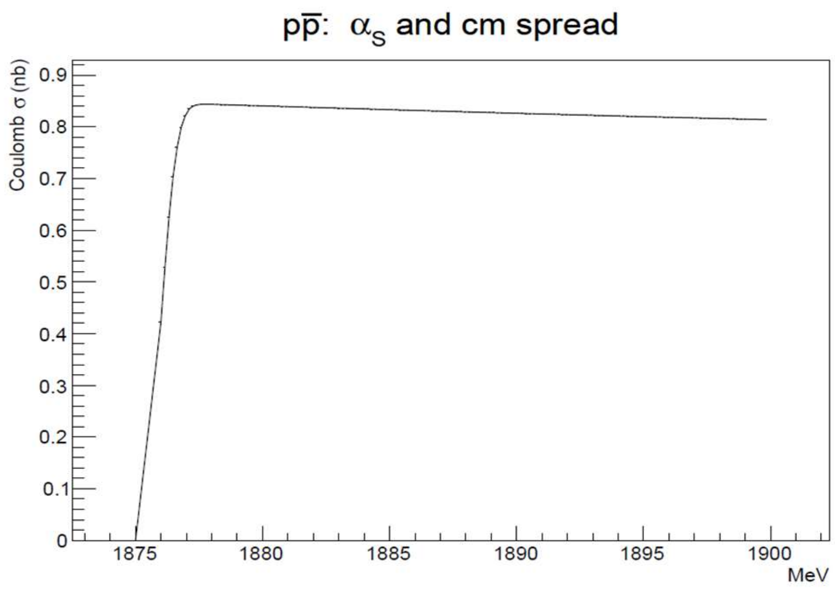
arXiv:1405.1628v1 [nucl-th] 7 May 2014



An Alternative Approach to CEF

- FSI approaches predict a vanishing $\sigma(e^+ e^- \to pp_{bar})$ at thr
- BaBar $\sigma(e^+ e^- \to pp_{bar})$ first bin not zero,
  but too wide (3.5 MeV) to check at the MeV level
  if the cross section vanishes or not 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 $\alpha_S \gg \alpha$)

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



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

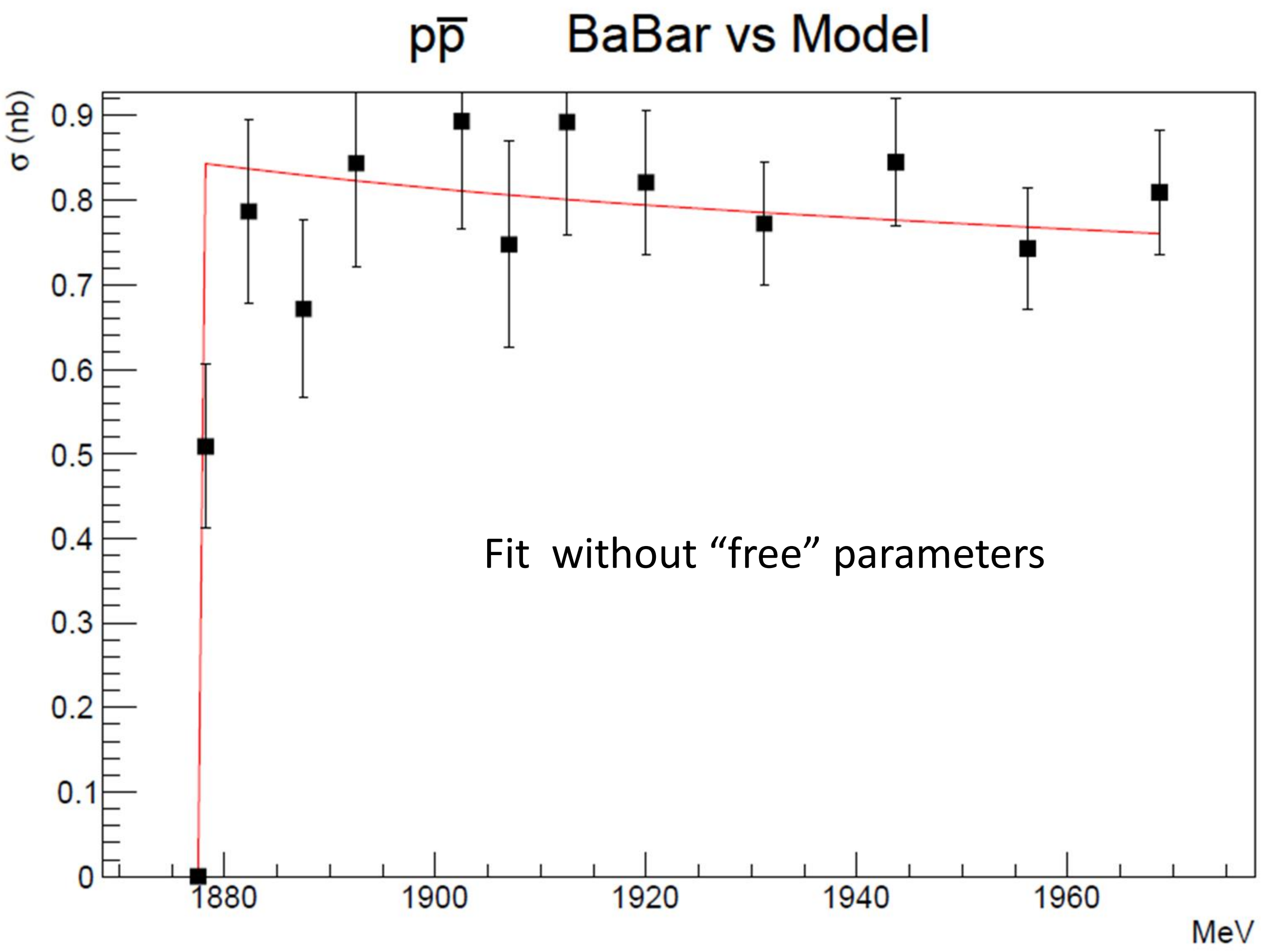
- Willing to include the asymptotic G_p expected behavior, according to PQCD: $\sigma(e^+ e^- \to pp_{bar}) \sim 1/[W^2 (W/\Lambda_{QCD})^8]$ a simple parametrization could be:

  $\sigma(e^+ e^- \to pp_{bar}) \sim [\pi^2 \alpha^3 F/ /W^2] /[1- \exp(- \pi\alpha_S F/\beta)] \cdot$

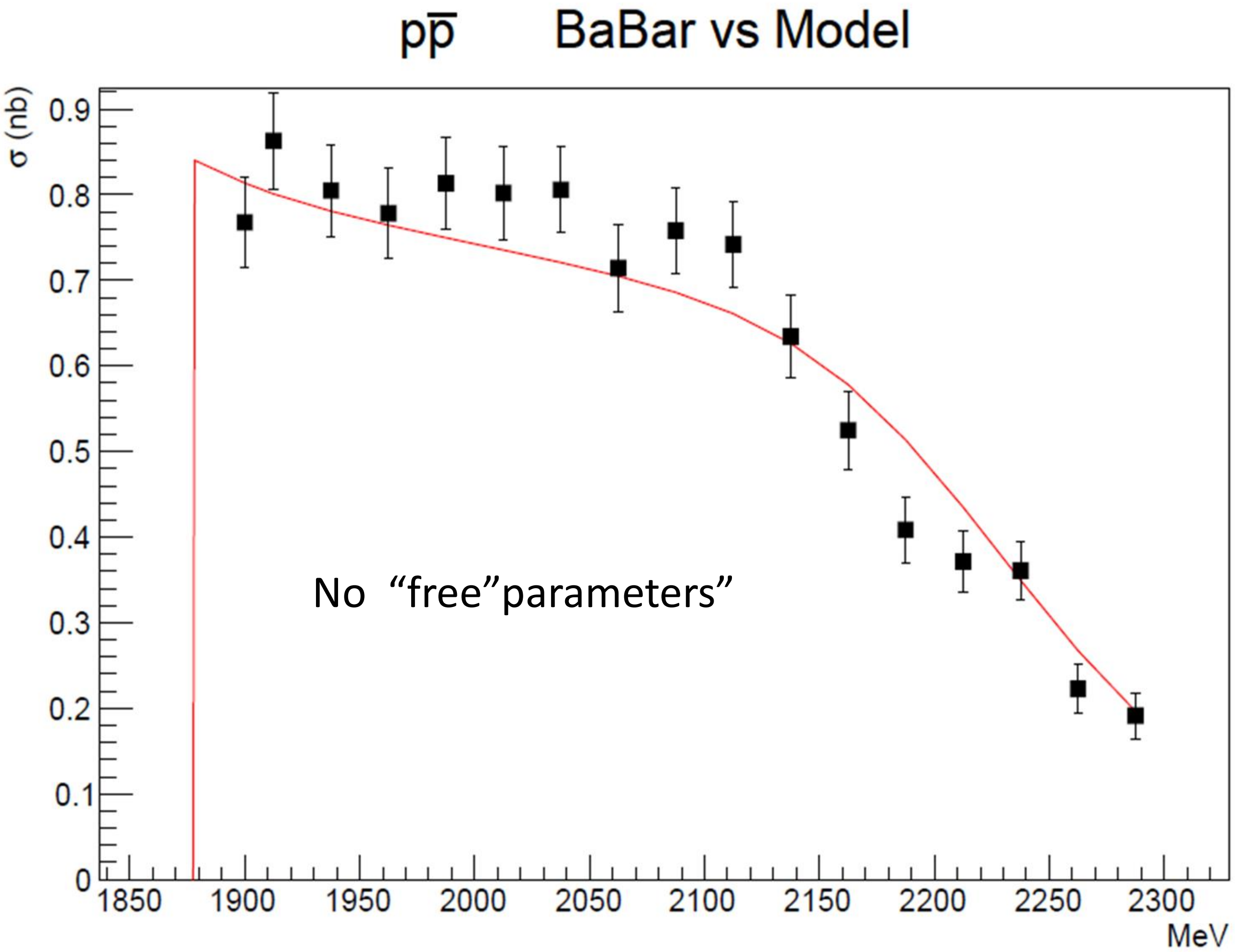
  $$\mathbf{1/[1 +((W-W_{thres})/\Lambda_{QCD})^N]}$$

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

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



σ (e^+e^- -> pp_{bar}) (BaBar vs Model)



$e^+ e^- \to \Lambda_c \Lambda_{cbar}$

$e^+ e^- \to \Lambda_c \Lambda_{cbar}$

- $e^+ e^- \to \Lambda_c \Lambda_{cbar}$ **might be the ideal process to check the previous prejudices, achieved interpreting $e^+ e^- \to pp_{bar}$:**

- Because of the weak decay , $e^+ e^- \to \Lambda_c \Lambda_{cbar}$ can be detected with good efficiency even exactly at thr.

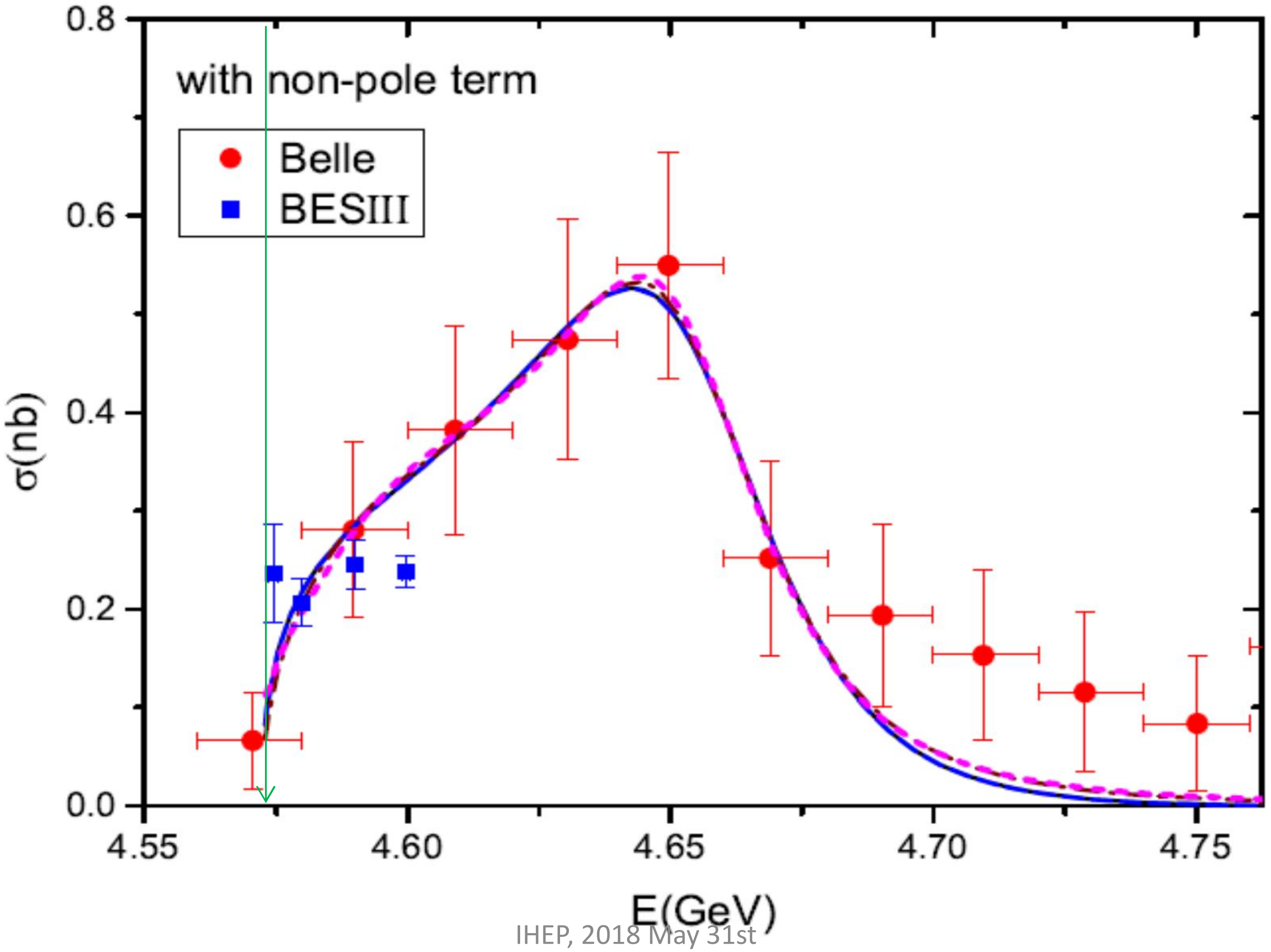
- The region sensitive to Coulomb interaction is enlarged, depending on the baryon velocity β_B only, since β_B scales like $1/ \sqrt{M_B}$, close to a thr

- BESIII results (**Phys. Rev. Lett. 120, 132001)** are summarized and shown in the following .

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

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

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



BESIII s (e+ e- -> Lc Lcbar)

- The BESIII measurements indicate that:

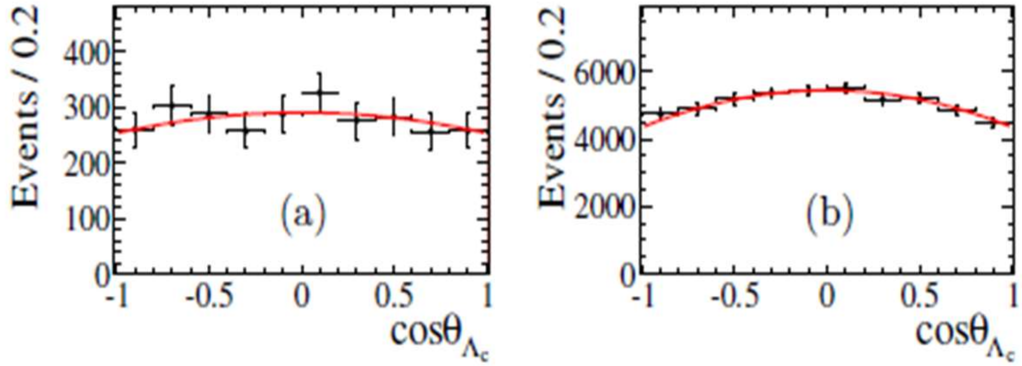
- At thr there is indeed a jump in $\sigma(e^+ e^- \to \Lambda_c \Lambda_{cbar})$,

- Followed by a kind of a plateau

- At thr $\sigma(e^+ e^- \to \Lambda_c \Lambda_{cbar})$ is close to the pointlike value, once the Coulomb enhancement factor is taken into account:
  $\sigma(e^+ e^- \to \Lambda_c \Lambda_{cbar})_{pointl} \approx \pi^2\alpha^3/(2M_B) \approx 145$ pb

- Qualitatively, If $\sigma(e^+ e^- \to BB_{bar})$ would be driven by strong interaction, [asymptotically scaling as $(M_p / M_{\Lambda c})^{10}$] a quite smaller value (< 1 fb) would be expected [$\sigma(e^+ e \to pp_{bar}) \approx 0.85$ nb, at thr].

BESIII $e^+ e^- \to \Lambda_c \Lambda_{cbar}$ angular distributions

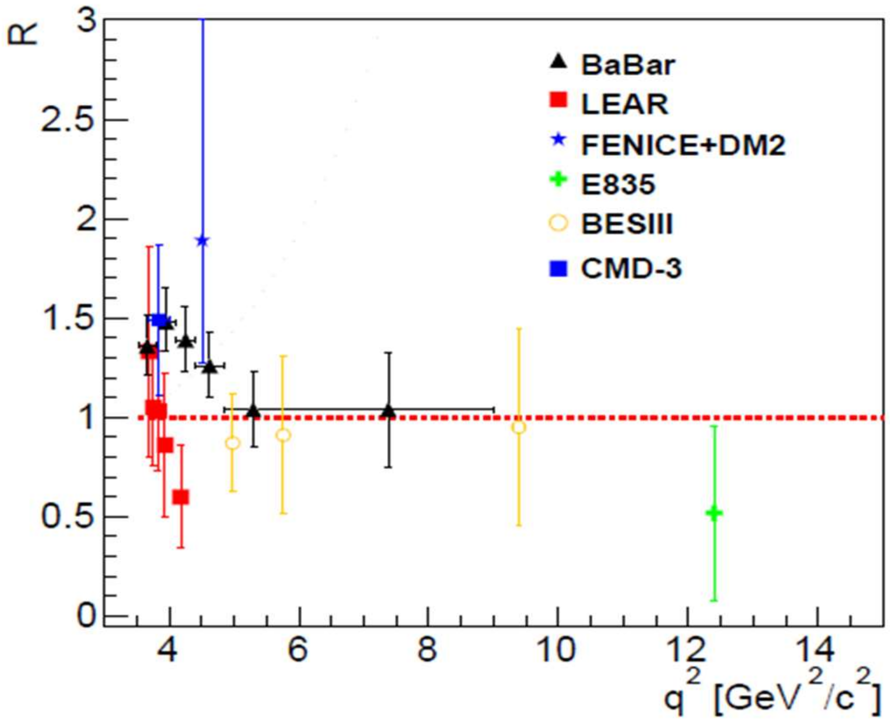


Angular distribution after efficiency correction and results of the fit to data at $\sqrt{s}$ = 4574.5 MeV (a) and 4599.5 MeV (b).

- 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 $e^+ e^- \to pp_{bar}$ at W=1.91 GeV (β_p = 0.20), there is a **very early onset of the D wave**.

$G_E(q^2)/G_M(q^2)$: D wave at thr or early onset ?

- $R(q^2) = G_E(q^2)/G_M(q^2)$



- Present data on $R(q^2)$ (in the case of BaBar unfortunately integrated on a too large Q^2 interval) indicate that

$G_D(q^2)$ seems not vanishing, close to thr :

$G_D(q^2) \neq 0 \;\; q^2 \approx 4M_B^2$?

BESIII versus Belle in $e^+ e^- \to \Lambda_c \Lambda_{cbar}$

- Not settled yet, since there is some tension between BESIII and Belle in $\sigma(e^+ e^- \to \Lambda_c \Lambda_{cbar})$, 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 $e^+ e^- \to \psi(3686) \pi^+ \pi^-$,

  hardly compatible with BESIII flat behaviour up to 4.6 GeV

- Belle data are fit by means of a resonance on top

  of $\Lambda_c\Lambda_{cbar}$ FSI, that predicts again a fast rise at thr,

  but not a jump.

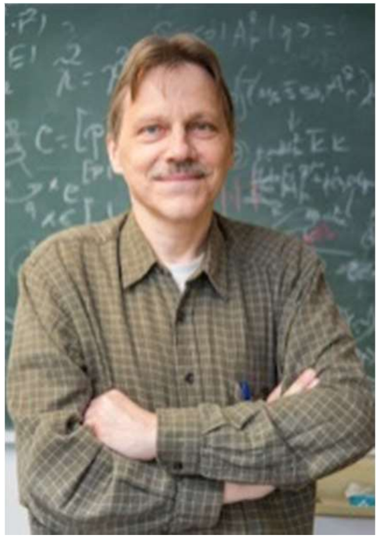
- **More data at thr and above are needed and BESIII already got funds to increase maximum energy up to W = 4.9 GeV**

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 ± 3.4) MeV
  Γ = (62.6 ± 5.6) MeV
  σ_{peak} ~ 0.55 nb [comparable to $\sigma(e^+ e^- \rightarrow pp_{bar})$ ~ 0.8 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)

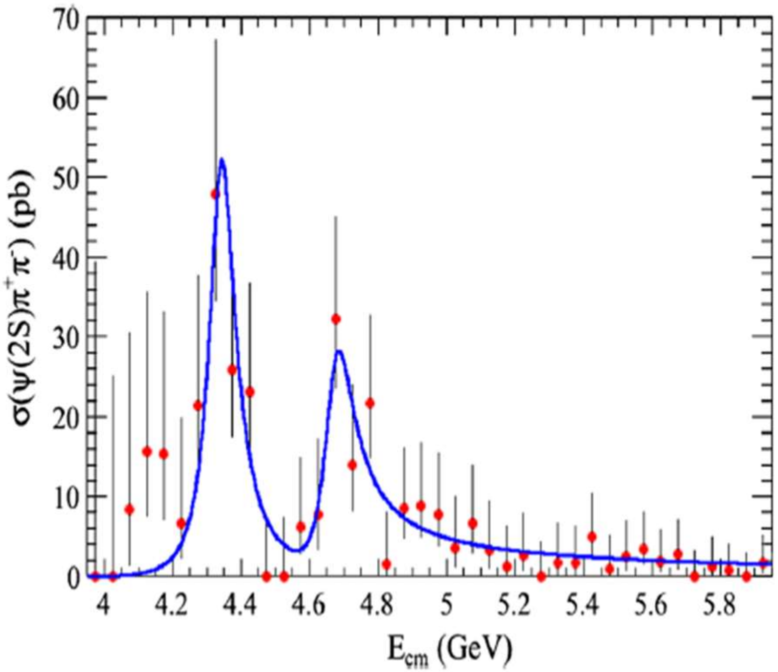
Other evidences of the Y(4660)

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

BaBar

M=4669 ± 22 , Γ=104 ± 49

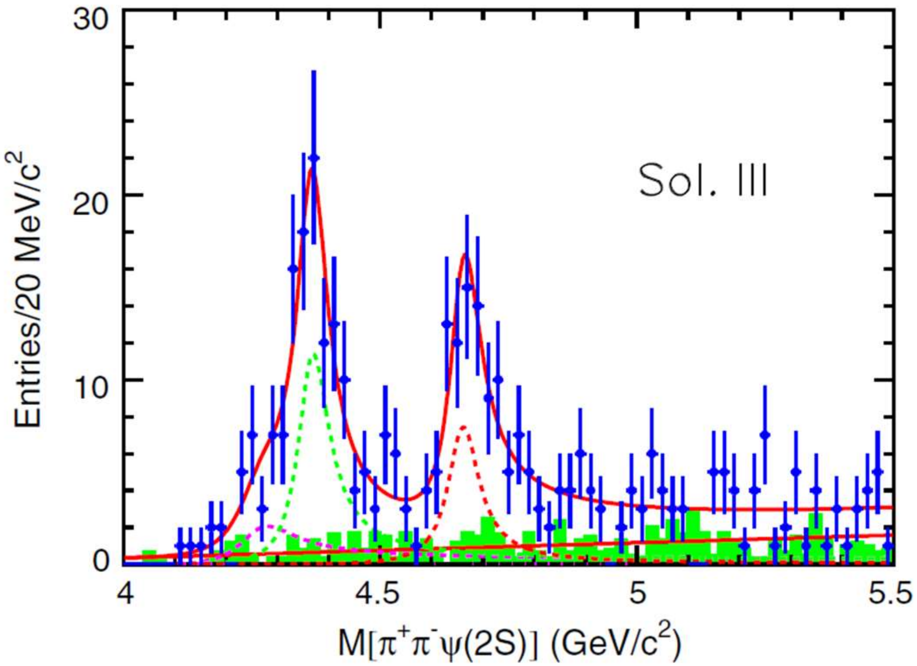
PHYSICAL REVIEW D **89,** 111103(R) (2014)



Belle

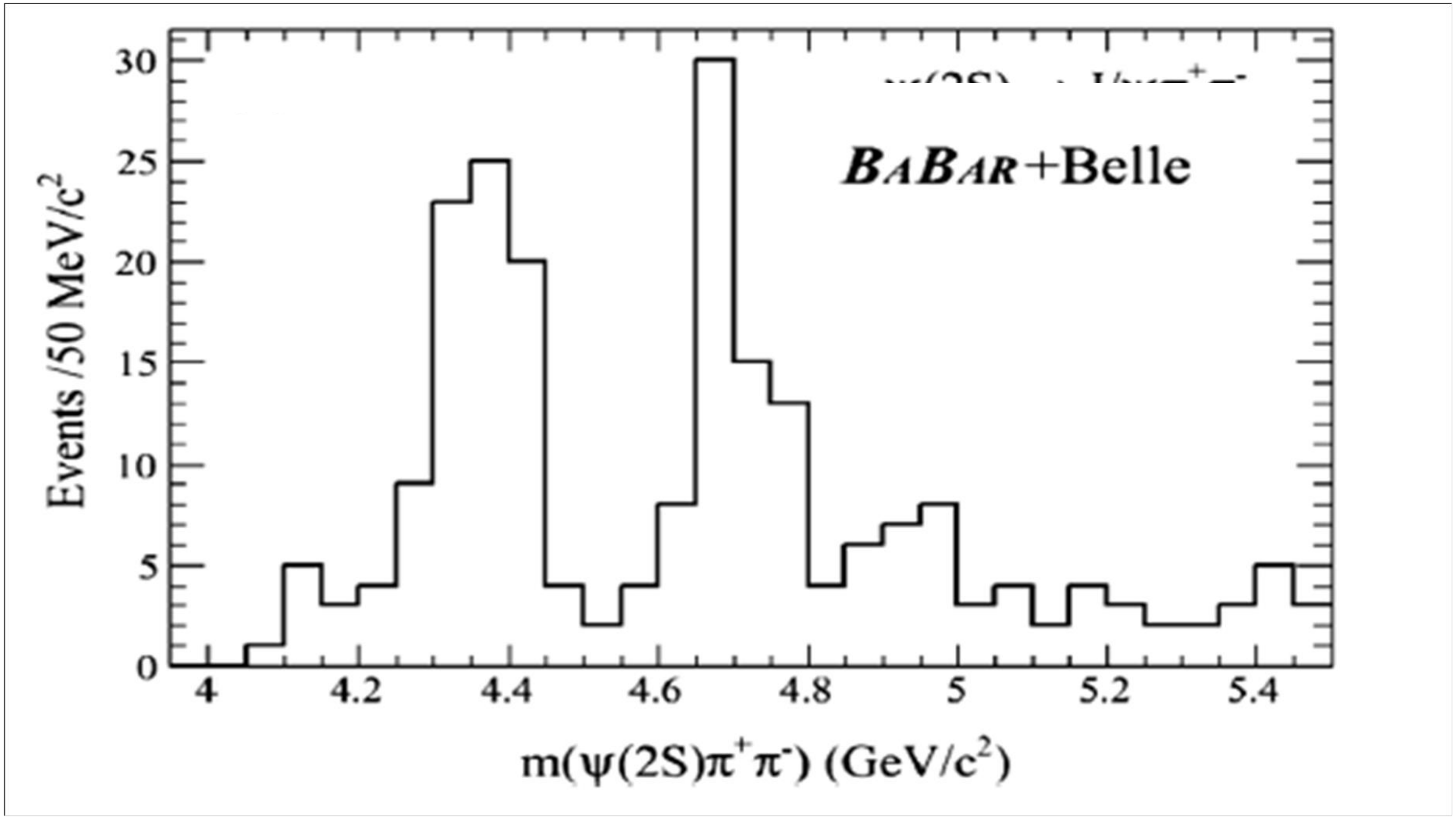
M=4652 ± 13 , Γ=68 ± 11

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



Other evidences of the Y(4660)

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



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

- M = (4667 ± 7) MeV

  Γ = [36+32 (-14)] MeV (updated in PDG: 72 ± 11 MeV)

  $B\Gamma_{ee}$ = (1.4± 0.5) eV

- $\sigma_{peak} = 12\,\pi / M^2\, B\Gamma_{ee} / \Gamma$ x 1.5 (incl $\pi^0 \pi^0$) ~ **0.04** ± 0.025 nb
  to be compared to $e^+ e^- \to \Lambda_c \Lambda_{cbar}$ σ_{peak} ~ **0.55** nb

- **Y(4660) baryonic coupling ≥ 10 mesonic coupling**
  Unexpected !

  There is another mesonic decay
  with much larger BR than $\psi(3686)\, \pi\, \pi$?

  or

  Y(4660) is a charmed baryonium ?

Y(4660) Charmed Baryonium ?

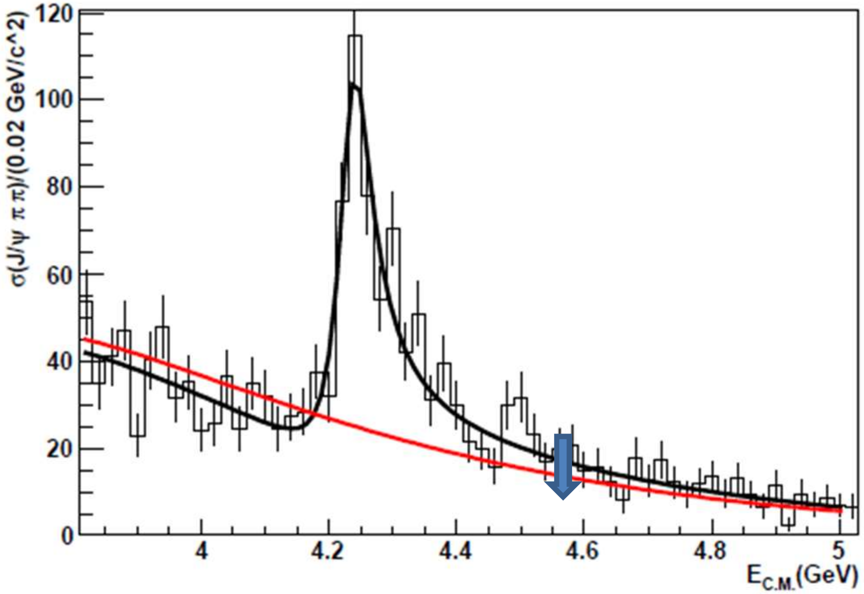
- The decay Y(4660)-> $J/\psi\ \pi\pi$ would be expected to be large if it is a cc_{bar} state, while at 90 % C.L.

  BR[Y(4660)-> $J/\psi\ \pi\pi$] /BR[Y(4660)-> $\psi(3686)\ \pi\pi$] < 0.46,

  according to BaBar data (arXiv:0808.1543 [hep-ex]) ,

  as elaborated in arXiv:0911.2178v5 [hep-ph] (2017).

$e^+ e^- \to J/\psi\ \pi^+ \pi^-$



Y(4660) Charmed Baryonium ?

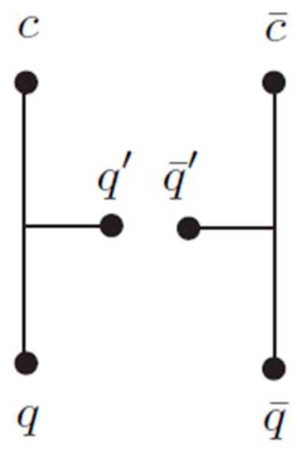
- According to R. Faccini et al. arXiv:0911.2178(2017),

  [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 hidden charm tetraquark (charmed baryonium) decay: mostly poping up from the vacuum a light quark pair and falling apart as a charmed baryon pair

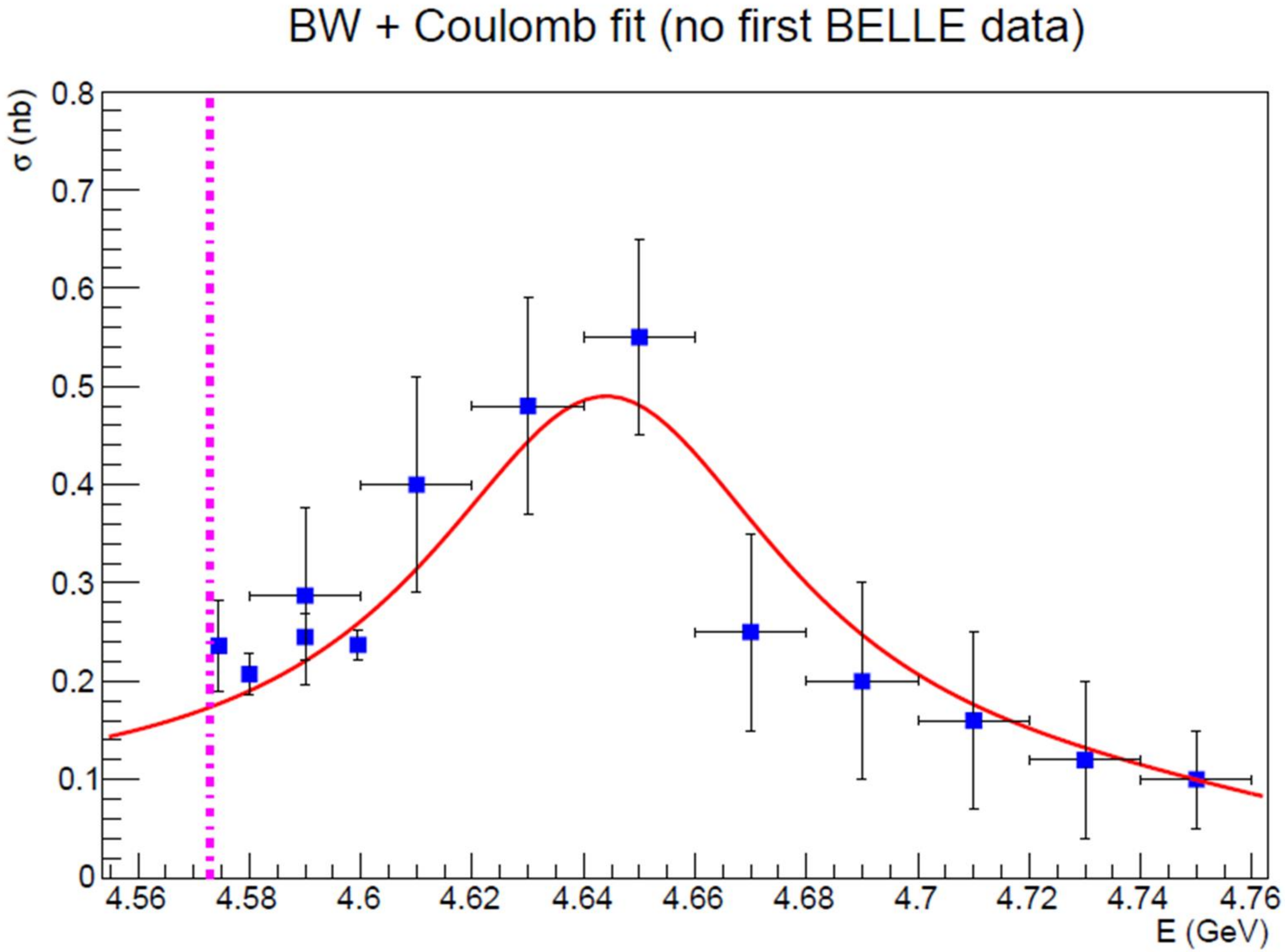


Y(4660) Charmed Baryonium ?

- Y(4660) mass, close to the Λ_c Λ_{cbar} threshold, is in favour of its interpretation as a charmed baryonium.
- Y(4660)-> Λ_c Λ_{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) -> Λ_c Λ_{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 Λ_c Λ_{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

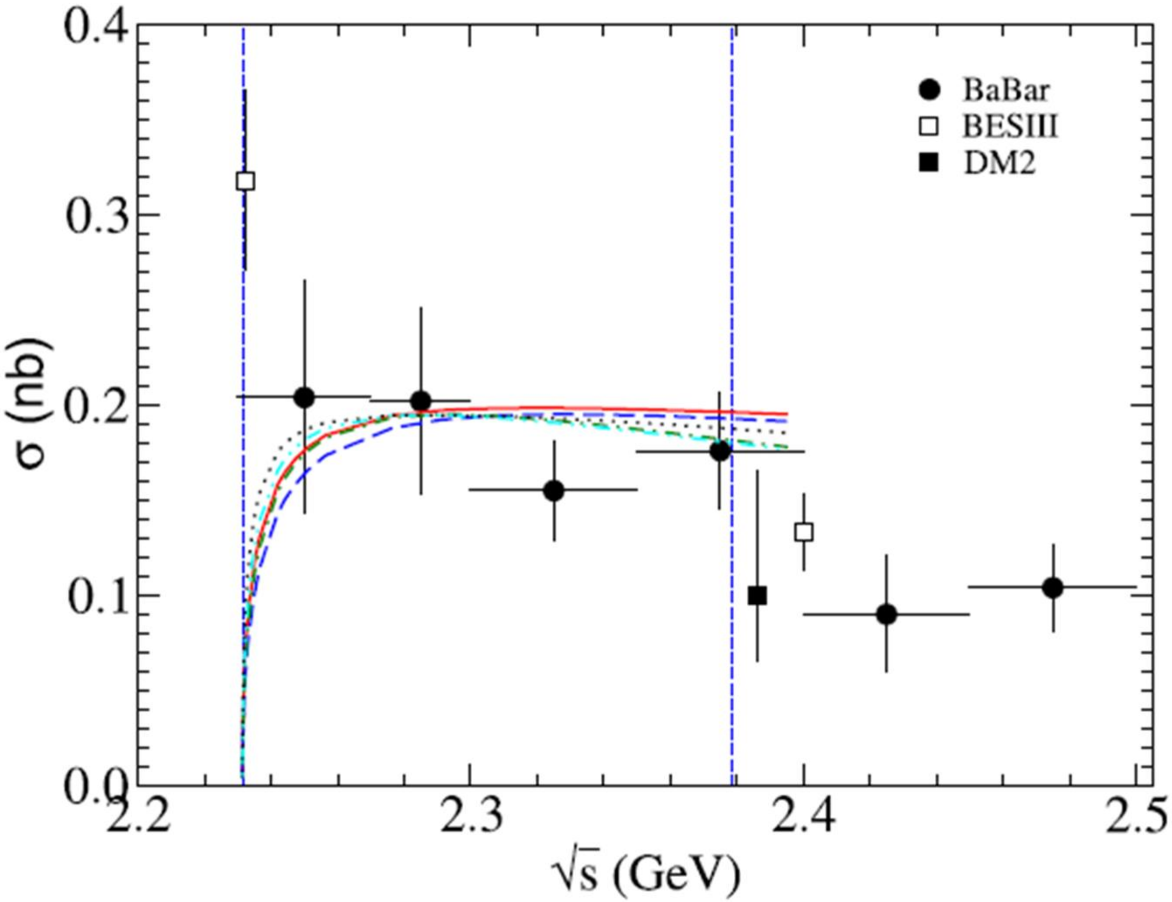
- Belle+ BESIII: M = 4644 ± 6 MeV , Γ= 80 ± 17 MeV P= 63 %



The mystery of
Neutral Baryon Pairs at thr

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

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

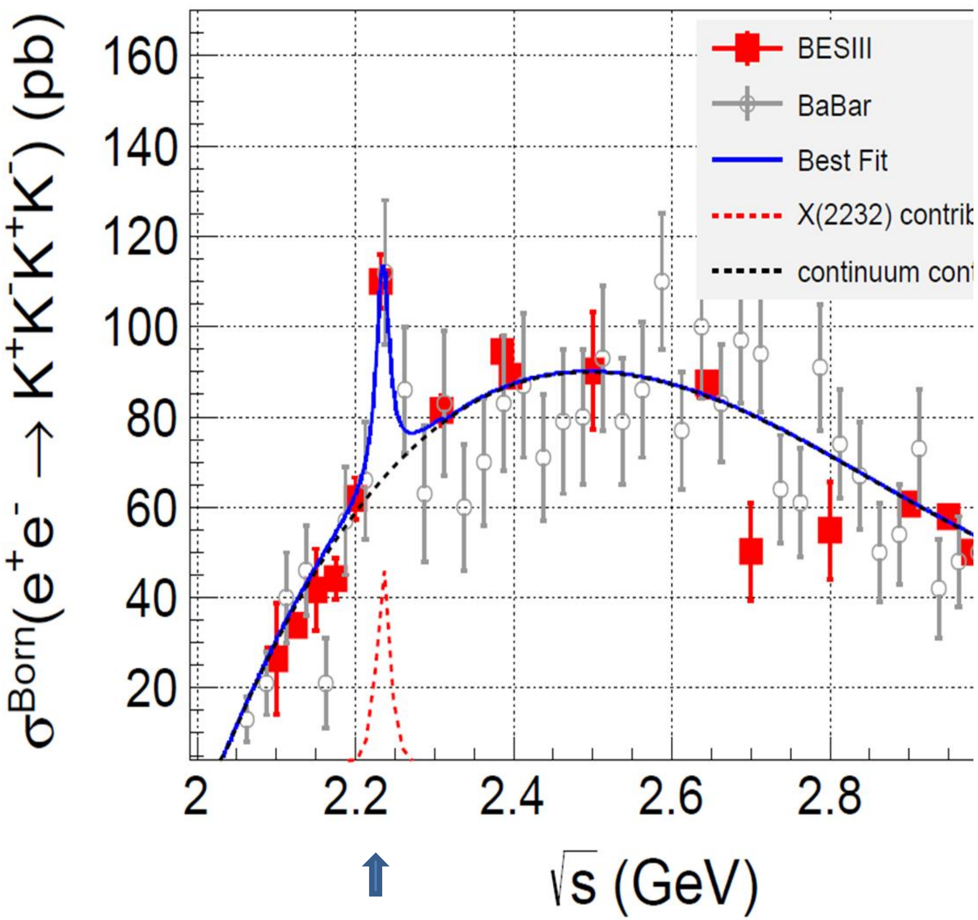


FSI fit to $e^+ e^- \to \Lambda\ \Lambda_{bar}$

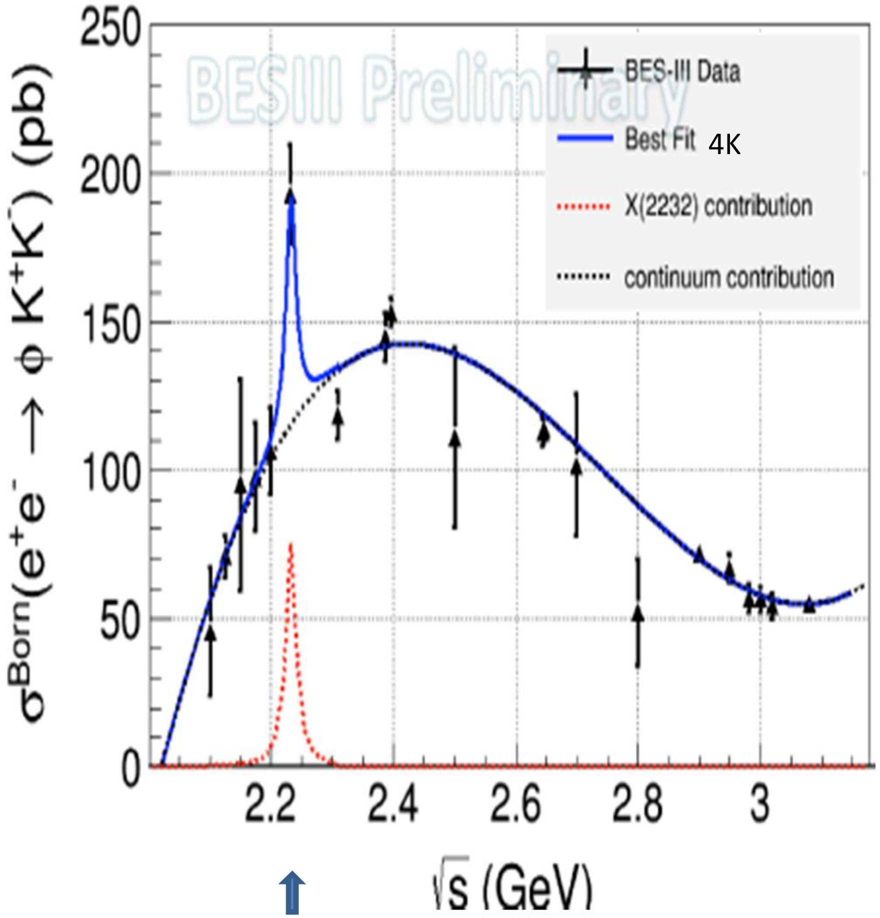
- J.Haidenbauer and U.G. Meissner [Phys.Lett B761 (2016)] FSI model fit BaBar, (even if the first point energy error is suspicious, it should already show a trend to zero), but not BESIII data.
- *"BESIII data suggest a very different trend for the energy dependence . Specifically, a large finite value 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 $e^+ e^- \to \Lambda \Lambda_{bar}$ thr ?

- $e^+e^- \to K^+K^- K^+K^-, \phi K^+K^-$ M=2232 ± 3.5 MeV , Γ = 7.5(+13.5) MeV
  (A hint for such a resonance, more data needed)



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

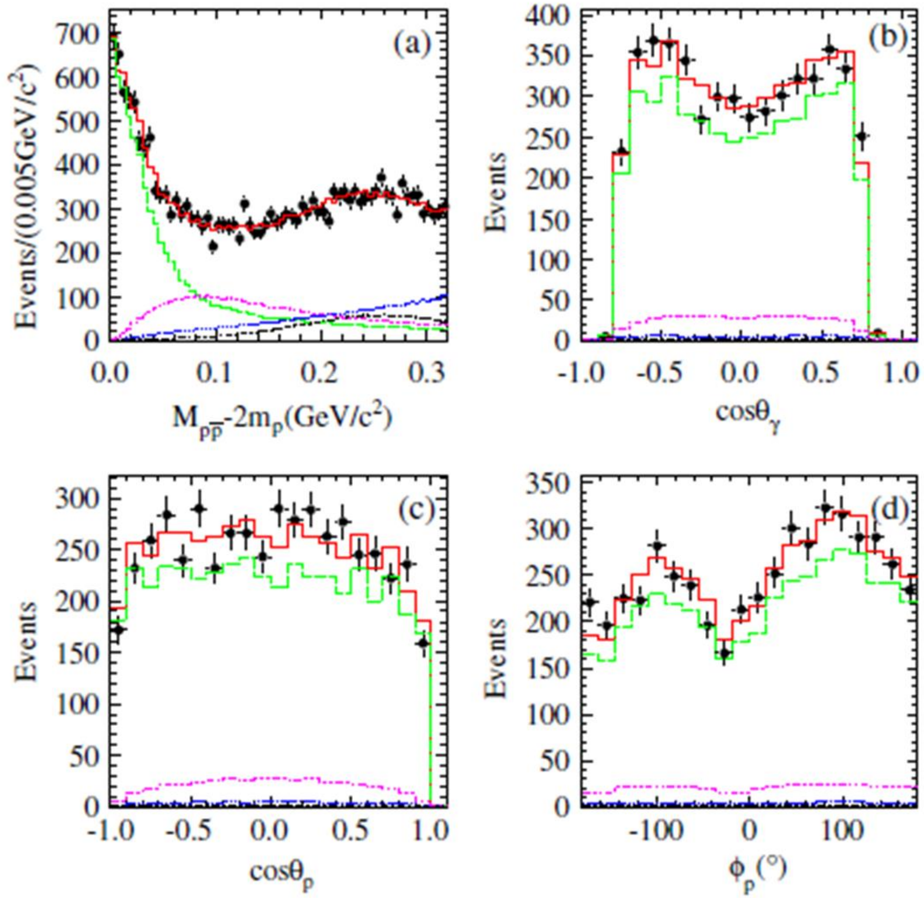


$e^+ e^- \to \Lambda \Lambda_{bar}$ threshold

Light Quarks “Baryonium” ?

BESIII J/ψ -> γ pp$_{bar}$
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 $M_{p\bar{p}} - 2m_p < 50$ 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 $J/\psi \to \gamma NN_{bar}$ @ thr ?

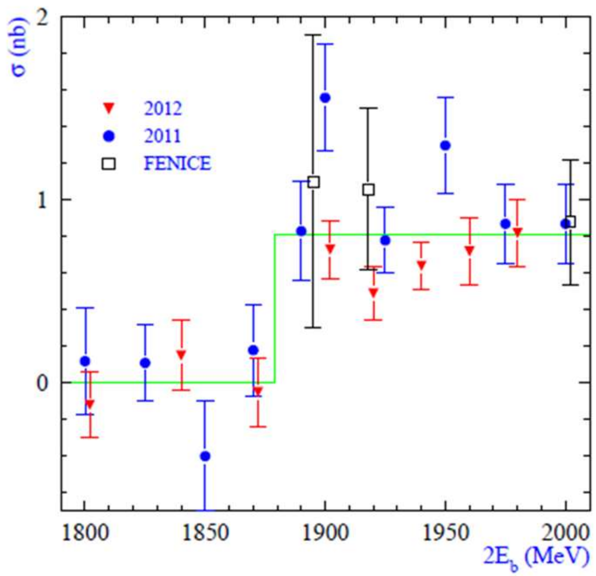
- Meissner et al, FZJ–IKP(TH)–2004–20, HISKP-TH-04-24
  from $\sigma(pp_{bar} \to pp_{bar})$ scattering lengths:
  $a_0 = -0.18 - 1.18\,i$
  $a_1 = 1.13 - 0.61\,i$
- **If FSI :**
  $BR(J/\psi \to \gamma pp_{bar}) \approx \sigma(\gamma NN_{bar}) \times |a_0 + a_1|^2$
  $BR(J/\psi \to \gamma nn_{bar}) \approx \sigma(\gamma NN_{bar}) \times |a_0 - a_1|^2$
  $BR(\gamma pp_{bar}) / BR(\gamma nn_{bar}) \approx$ 2
- **If NN_{bar} resonance below thr (light quarks "baryonium"):**
  $BR(\gamma pp_{bar}) / BR(\gamma nn_{bar}) \approx$ 1
- **$BR(J/\psi \to \gamma nn_{bar})$ measured by BESIII (under review)**

$e^+ e^- \to n n_{bar}$

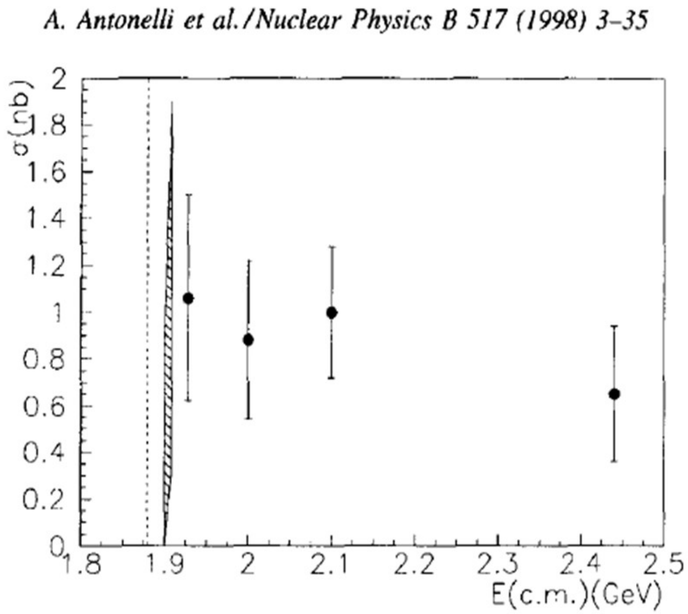
$e^+ e^- \rightarrow n n_{bar}$

- Published data

SND



FENICE



- 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

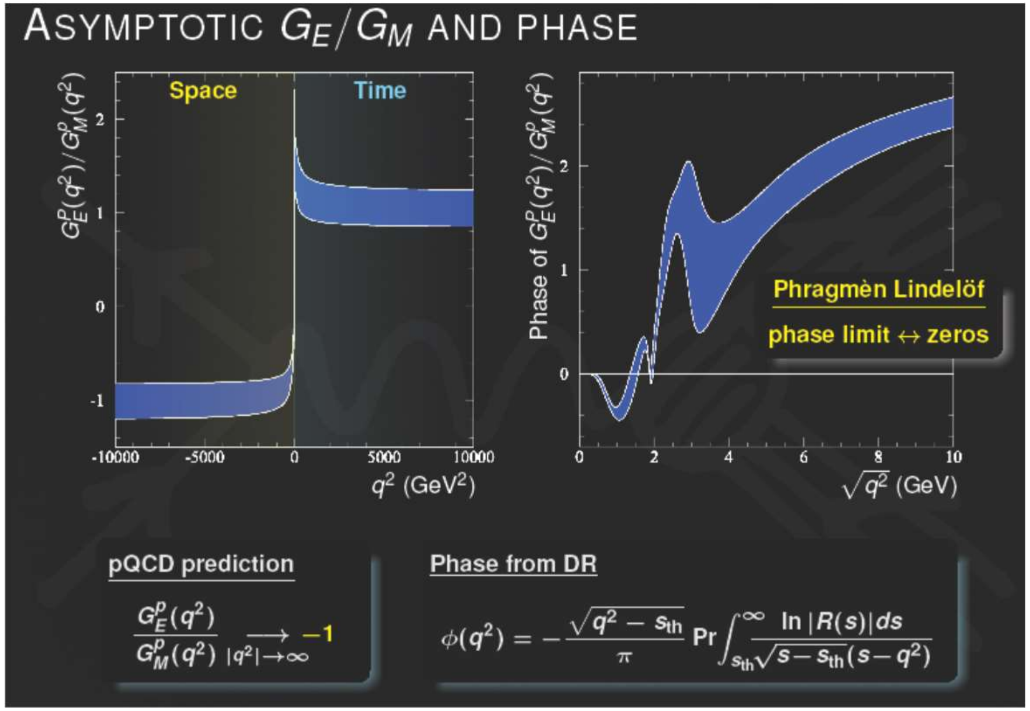
G_E / G_M phase @ BESIII

- Possible to get G_E/G_M phase ϕ_{EM}:
- $e^+e^- \to \Lambda\Lambda_{bar}$, $e^+e^- \to \Sigma\Sigma_{bar}$, shown in detail by Karin Schönning , from the decay angular distribution , due to Λ, Σ polarization.
  BESIII results in $e^+e^- \to \Lambda\Lambda_{bar}$ at 2.3 GeV, $J/\psi \to \Lambda\Lambda_{bar}$ under review
- $e^+e^- \to pp_{bar}$, 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 $e^+e \to pp_{bar}$ $\phi_{EM} \approx 0^0$ or 180^0
- But, applying Dispersion Relations, with a possible zero contribution to G_E/G_M spacelike, it has been found (Simone Pacetti):
  in $e^+e \to pp_{bar}$ $\phi_{EM} \approx 45^0$
  depending if there is indeed a zero in the G_E/G_M spacelike.
  Hence the G_E/G_M timelike phase tells about a spacelike zero !!

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

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



Waiting for

Future

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

Thanks for

谢谢

your attention

Backup slides

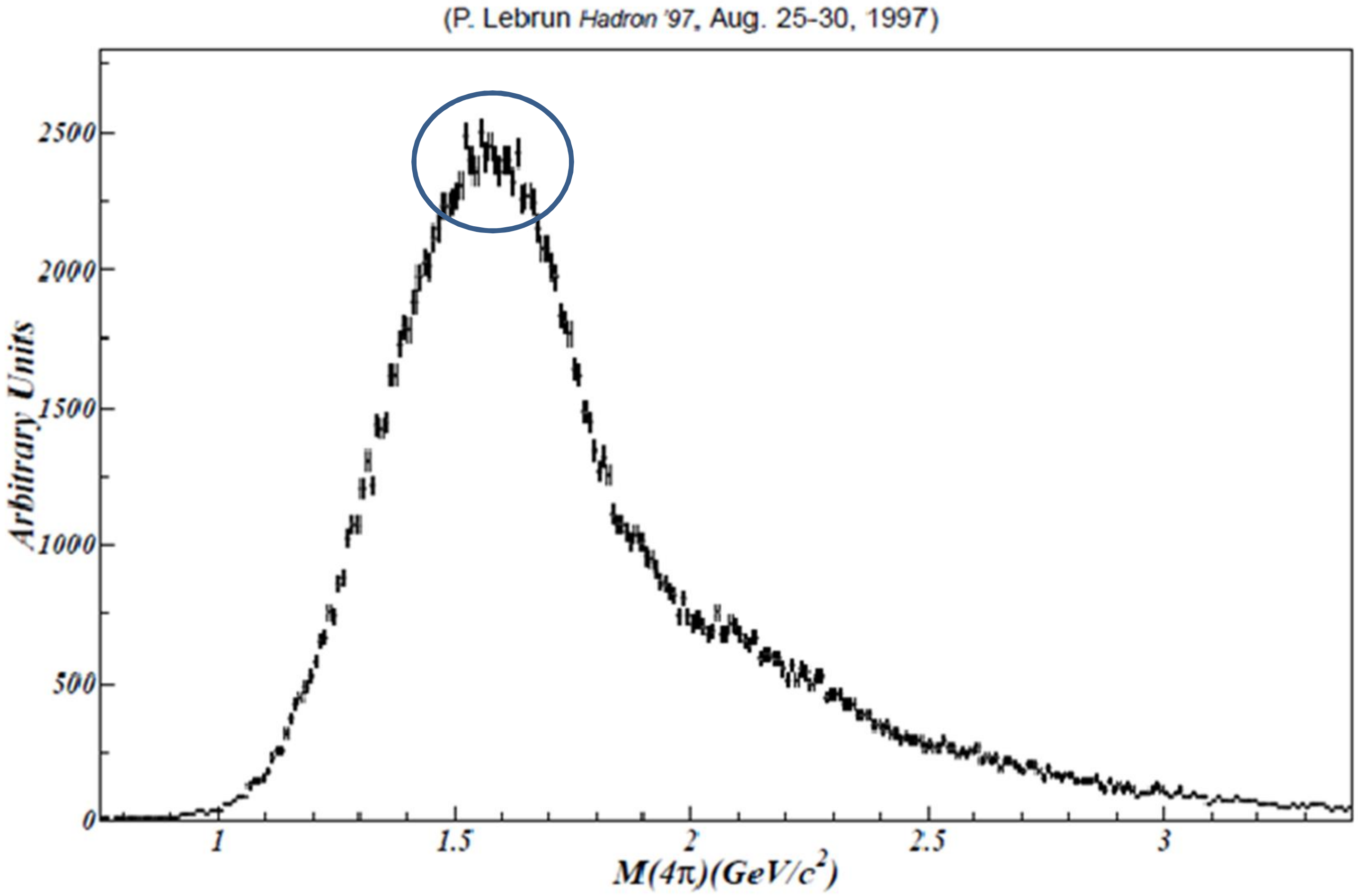
Long long time ago, in another galaxy.....

- E687 at FNAL in High Statistics Diffractive Photoproduction (like e^+e^- according to VMD) showed structures (for instance a dip in $3\pi^+3\pi^-$, later confirmed by BaBar and CMD3).

Among them the ones showed at a DAΦNE Workshop (Alghero2006): oscillations (?) in **Diffractive Photoproduction of $2\pi^+2\pi^-$**

Long long time ago, in another galaxy…..

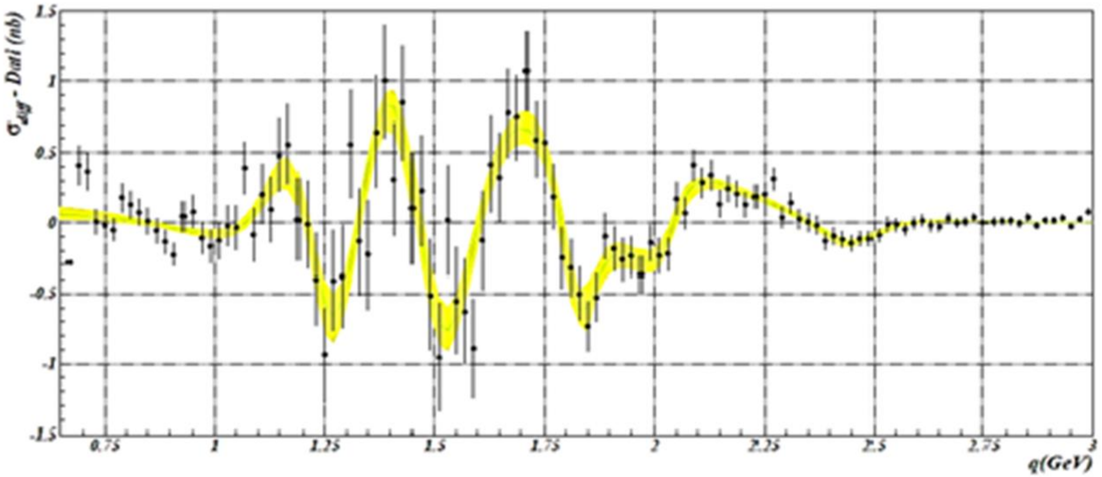
$2\pi^+2\pi^-$ E687 data



E687 at FNAL
$2\pi^+2\pi^-$ Diffractive Photoproduction

Fit of the residual

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



Resonances	$\Gamma_{e^+e^- j} B_{j 2\pi^+ 2\pi^-} (KeV)$	$m(MeV)$	$\Gamma(MeV)$	$\phi(rad)$
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