Ferrara/FENICE and e^+e^- Rebirth in Frascati

A workshop to mark
the 70th birthday of Gianni Fiorentini
and
the 80th birthday of Piero and Paola Dal Piaz

Representing the old FENICE Collaboration

Rinaldo Baldini Ferroli

INFN-LNF, Frascati / CAS-IHEP, Beijing

Outline

- **FENICE**: the baryon puzzle and e^+e^- rebirth in Frascati

  Reminding how FENICE started

  Building the Collaboration by Piero and Paola

  $\sigma(e^+ e^- \to n\, n_{bar})$: first measurement of the neutron timelike FF

- FENICE outstanding by-product: The Φ-Factory **DAΦNE**

  KLOE/KLOE2

  FINUDA

  AMADEUS/SIDDARTHA

- Baryons FF at present:

  $\sigma(e^+ e^- \to p\, p_{bar})$: step at threshold (are Coulomb interactions understood?)

  $\sigma(e^+ e^- \to \Lambda_c\, \Lambda_{c\,bar})$: step at threshold

  the Y(4660) puzzle (are XYZ really tetraquarks?)

  $\sigma(e^+ e^- \to \Lambda\, \Lambda_{bar})$: still step at threshold (no Coulomb!)

  $\sigma(e^+ e^- \to n\, n_{bar})$: SND, BESIII

Foreword

- Baryons are a unique feature of QCD.
  Mesons have a QED analogue, unlike Baryons.
  Skyrme Baryon's model (no quarks), Proton Spin Crisis (who is carrying the spin?), FF:
  are Baryon really understood ?

- $\sigma(p\bar{p} \to e^+e^-)$ measured by PS170 (Ferrara, Padova, Cagliari,….)
  at LEAR for the first time from threshold up to 2 GeV

- Voci et al predicted **$\sigma(ee \to n\bar{n}) >> \sigma(ee \to p\bar{p})$** by means of VDM
  According to VDM:
  hadrons produced via ρ and ω recurrences,
  $g_\rho^{ee} = 9\, g_\omega^{ee}$, $g_\rho^{NN} = 1/9\, g_\omega^{NN}$ -> $G_e^n(0) = 0$, $\sigma_E(en \to en) << \sigma_E(ep \to ep)$
  but $g_\omega^{NN\bar{N}}$ change sign -> no more cancellation between ρ and ω
  and it might be $\sigma(ee \to n\bar{n}) >> \sigma(ee \to p\bar{p})$

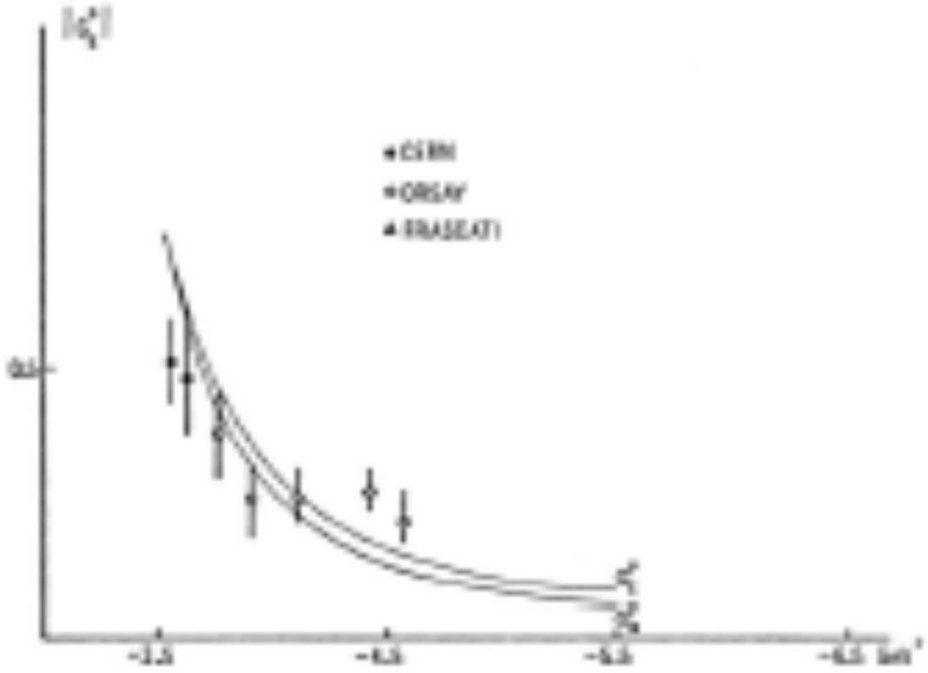
  Cabibbo and Gatto (1961) suggested a similar conclusion

  Conversely, if leading quark holds (u for p, d for n): **$\sigma(ee \to n\bar{n}) \approx \frac{1}{4}\, \sigma(ee \to p\bar{p})$**

- But nobody measured yet $\sigma(ee \to n\bar{n})$

$\sigma(pp_{bar} \rightarrow e^+e^-)$ by PS170 at LEAR

- PS170: Ferrara, Padova, Cagliari, Orsay, Saclay Collaboration



Fit to the time-like data.

A FIVE POLE FIT TO THE PROTON AND NEUTRON ELECTROMAGNETIC FORM FACTORS AND ITS IMPLICATIONS FOR THE REACTION $\bar{n}n \to e^+e^-$

Paolo Cesselli, Massimo Nigro and Cesare Voci

Istituto di Fisica and Istituto Nazionale di Fisica Nucleare, Padova, Italy

Proton spacelike data

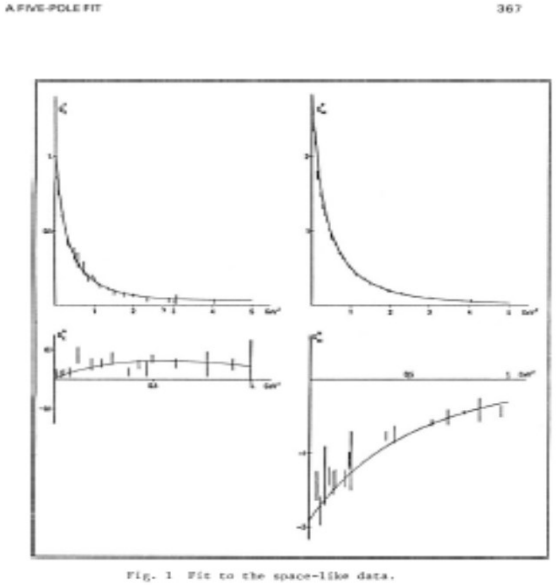
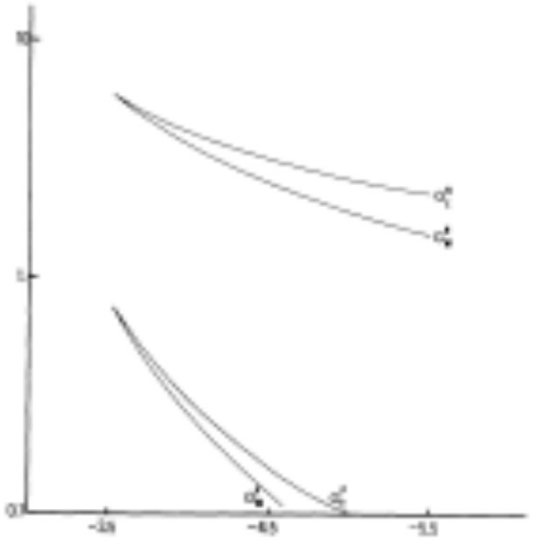


Fig. 1 Fit to the space-like data.

Neutron vs Proton Prediction

$\sigma(ee \to nn_{bar}) >> \sigma(ee \to pp_{bar})$!



Estimates of proton and neutron form factors in the time-like region.

N. Cabibbo, R. Gatto (1961)

Spacelike data at that time

[14] D. N. Olson, H. F. Schopper, and R. R. Wilson, Phys. Rev. Letters **6**, 286 (1961); R. Hofstadter, C. De Vries, and R. Herman, *ibid.* **6**, 290 (1961); R. Hofstadter and R. Herman, *ibid.* **6**, 293 (1961).

Cabibbo Gatto (1961) argument:

$\times 3.6 \times (m_\pi/\Gamma)^2$ for p-$\bar{p}$ production and $\sigma \cong (\pi/3)\alpha^2 \lambda^2 \beta$ $\times 50 \times (m_\pi/\Gamma)^2$ for n-$\bar{n}$ production. If, for instance, $\Gamma \cong m_\pi$, these values are about 3.6 and 50 times bigger than the perturbation theory value for $e^+ + e^- \to f^+ + f^-$

How FENICE started

- By chance I met Piero flying back from Geneva to Rome and the idea to measure $\sigma(ee->nn_{bar})$ came to light
- Piero decided the Collaboration: Cagliari (Serci), Ferrara (DalPiaz), Frascati(Ferrer), Padova (Voci), Torino (Bressani), joined by Roma1 (Paoluzi), Roma2 (Santonico), Trieste (Pauli), Udine (Santi)

  The leadership was unanimously decided to be given to Cesare Voci.
- At that time all the storage rings were used as sources of Synchrotron Light:
  Some mild proposals were been done to DORIS (DESY), SPEAR (SLAC), DCI (Orsay),
  In the end Piero proposed **ADONE**, at that time no more $e^+ e^-$ collider.
  He talked with Cabibbo and Tazzari.
  They agreed and the **Frascati renaissance of $e^+ e^-$ started**
- The acronym was proposed by Giangriso Sciacca:

  Fattore di forma Elettromagnetico del Neutrone In Collisioni $e^+ e^-$

  FENICE: Padova, Ferrara, Torino, Cagliari, Frascati, Roma1, Roma2, Udine, Trieste

Fattore di Forma Elettromagnetico Neutrone In Collisioni e+ e-

FENICE COLLABORATION

A. Antonelli[3], R. Baldini Ferroli[3], M. E. Biagini[3], V. Bidoli[5], T. Bressani[6], R. Calabrese[2], R. Cardarelli[5], R. Carlin[4], C. Cernigoi[7], S. Costa[6], L. Cugusi[1], B. Dainese[4], P. Dalpiaz[2], S. De Simone[3], G. De Zorzi[5], U. Dosselli[4], B. Dulach[3], P. Ferretti Dalpiaz[2], R. Giantin[4], S. Guiducci[3], F. Iazzi[6], E. Luppi[2], S. Marcello[1], A. Masoni[1], G. Milani[7], B. Minetti[6], M. Morandin[4], M. Nigro[4], L. Paoluzi[5], G. Pauli[7], F. Petrucci[2], G. Pitacco[4], M. Posocco[4], M. A. Preger[3], G. Puddu[1], L. Santi[7], R. Santonico[5], P. Sartori[4], M. Savrie`[2], M. Schioppa[3], S. Serci[1], M. Serio[3], M. Spinetti[3], L. Tecchio[6], V. Tricomi[6], C. Voci[4].

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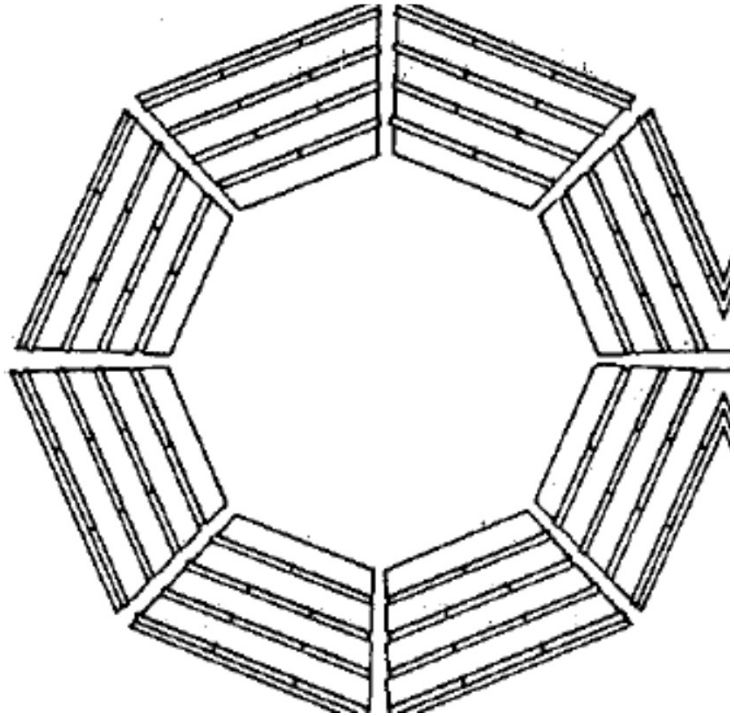
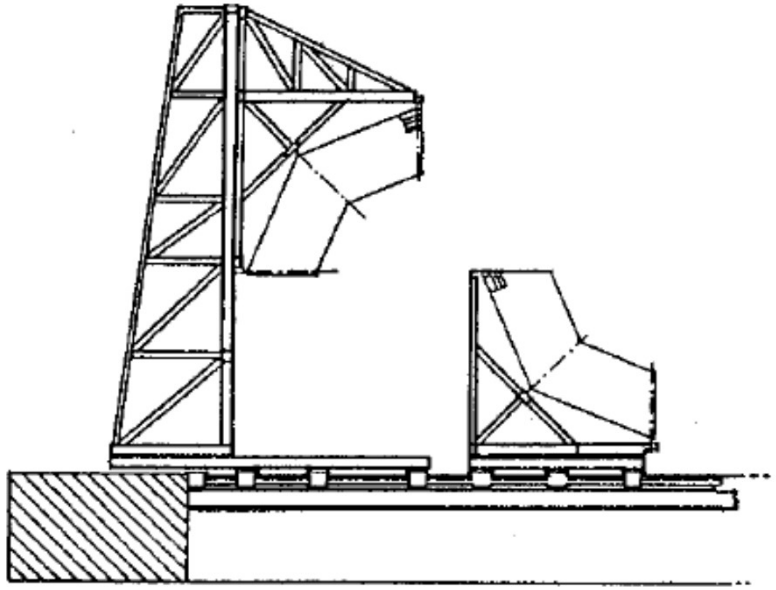
2. Ferrara University and Sezione INFN
3. INFN National Laboratory, Frascati
4. Padova University and Sezione INFN
5. Rome Universities and Sezione INFN
6. Torino University and Sezione INFN
7. Trieste University and Sezione INFN

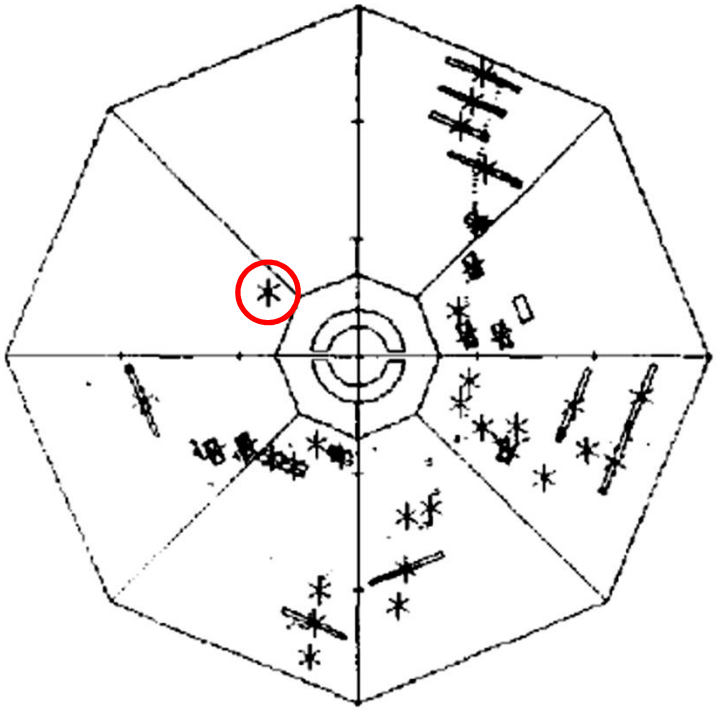
FENICE Detector

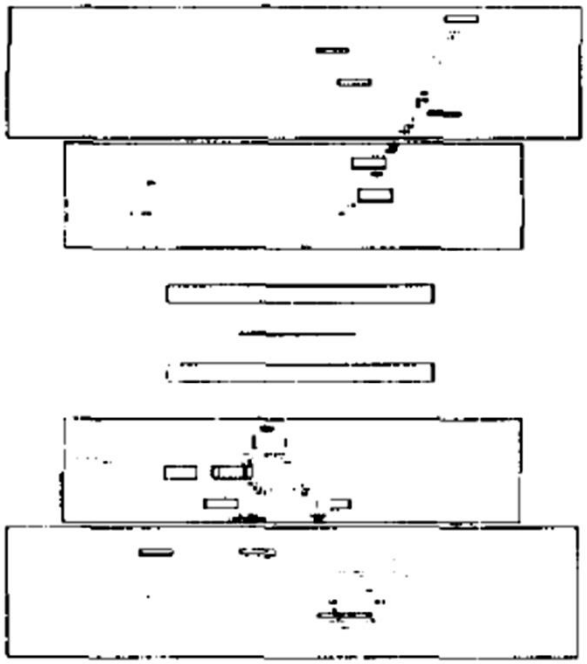
Scintillators (Trigger and hadron, n TOF detection)
Iarocci tubes (n_{bar} and p_{bar} shower detection)



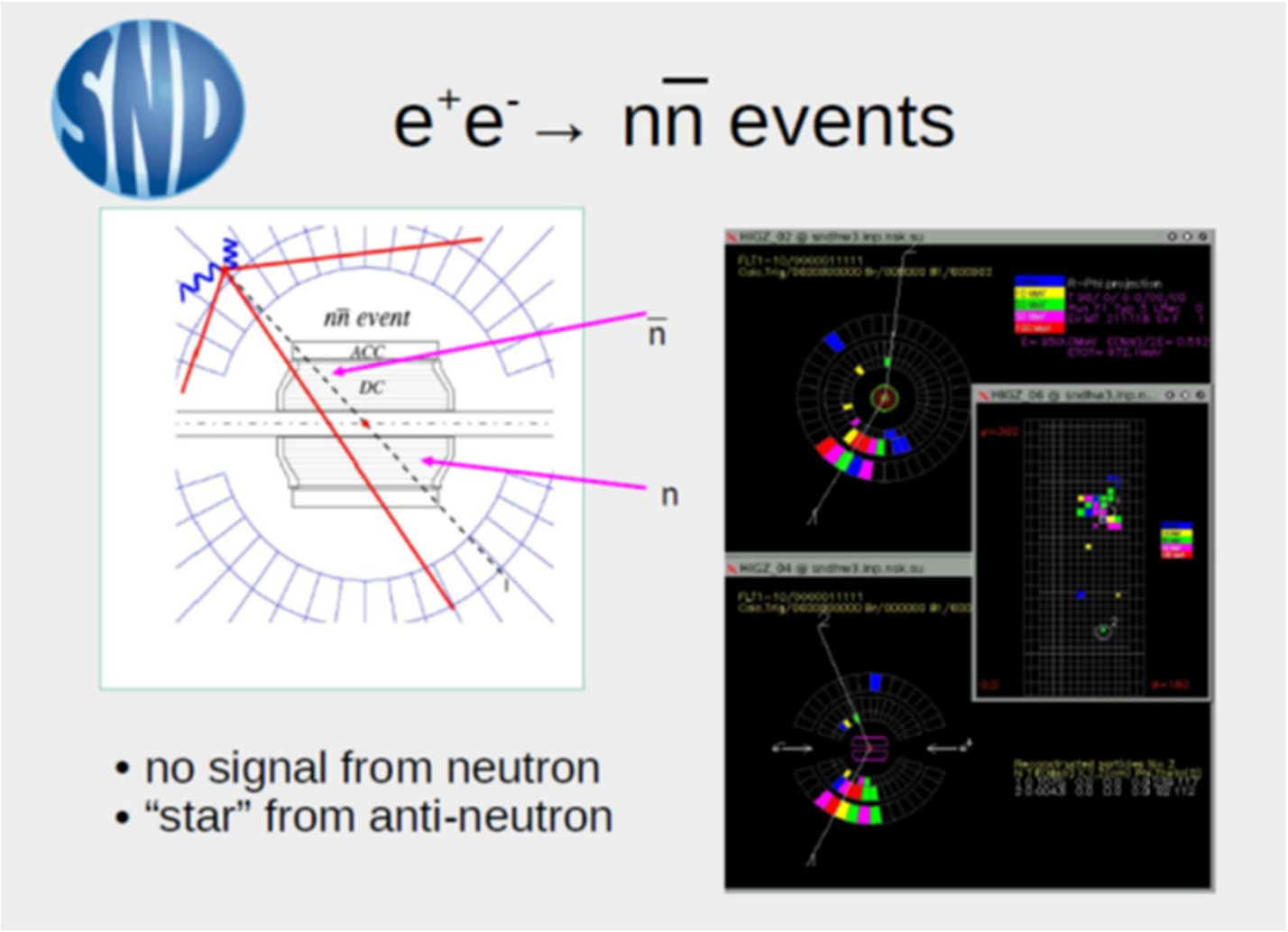


FENICE nn_{bar}





SND 20 years after
and 50 times more integrated luminosity



ELSEVIER

Nuclear Physics B 517 (1998) 3–35

NUCLEAR PHYSICS B

The first measurement of the neutron electromagnetic form factors in the time-like region

A. Antonelli [a], R. Baldini [a], P. Benasi [b], M. Bertani [b], M.E. Biagini [a], V. Bidoli [c], C. Bini [d,1], T. Bressani [e], R. Calabrese [b], R. Cardarelli [c], R. Carlin [f], C. Casari [g], L. Cugusi [g], P. Dalpiaz [b], A. De Falco [g], S. De Simone [a], G. De Zorzi [d], A. Feliciello [e], M.L. Ferrer [a], P. Ferretti [b], P. Gauzzi [d], P. Gianotti [a], F. Iazzi [h], E. Luppi [b], S. Marcello [e], A. Masoni [g], R. Messi [c], M. Morandin [f], L. Paoluzi [c], E. Pasqualucci [c], G. Pauli [i], N. Perlotto [f], A. Perrone [c], F. Petrucci [b], M. Posocco [f], M. Preger [a], G. Puddu [g], M. Reale [c], L. Santi [j], R. Santonico [c], P. Sartori [f], M. Savrié [b], S. Serci [g], M. Spinetti [a], S. Tessaro [i], C. Voci [f], F. Zuin [f]

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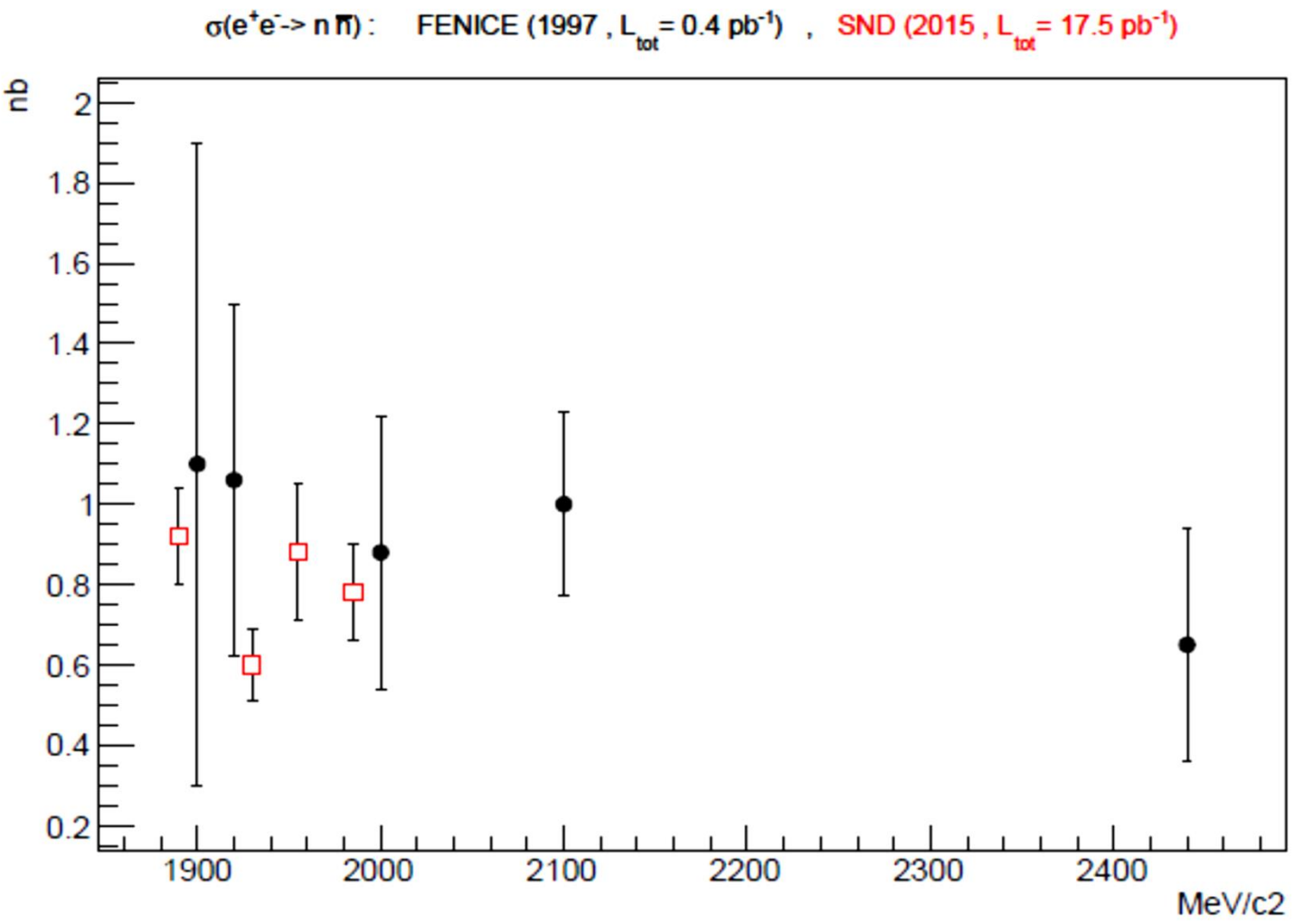
Abstract

The electromagnetic form factors of the neutron in the time-like region have been measured for the first time, from the threshold up to $q^2 \cong 6$ GeV^2. The neutron magnetic form factor turns out to be larger than the proton one; the angular distribution suggests that for the neutron, at variance with the proton case, electric and magnetic form factors could be different. Further measurements are also reported, concerning the proton form factors and the $\Sigma\overline{\Sigma}$ production, together with the multihadronic cross section and the J/ψ branching ratio into $n\overline{n}$. © 1998 Elsevier Science B.V.

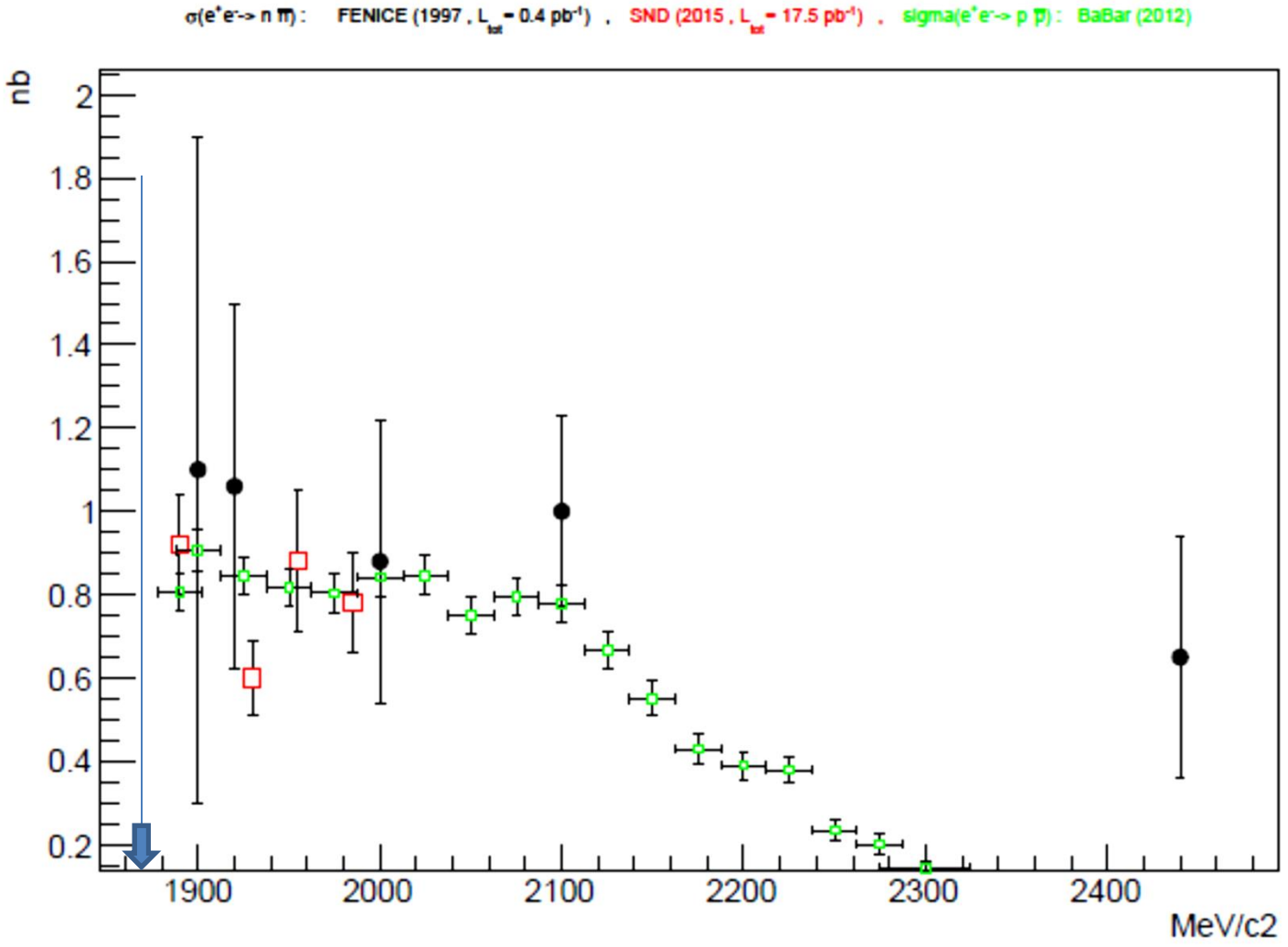
PACS: 13.40.G; 28.20
Keywords: Neutron; Form factors; Time-like

PII S0550-3213(98)00083-2

FENICE $\sigma(ee->nn_{bar})$ [1997] and SND [2015] results



FENICE and SND σ (e^+e^- -> n n_{bar}) versus BaBar σ (e^+e^- -> p p_{bar})

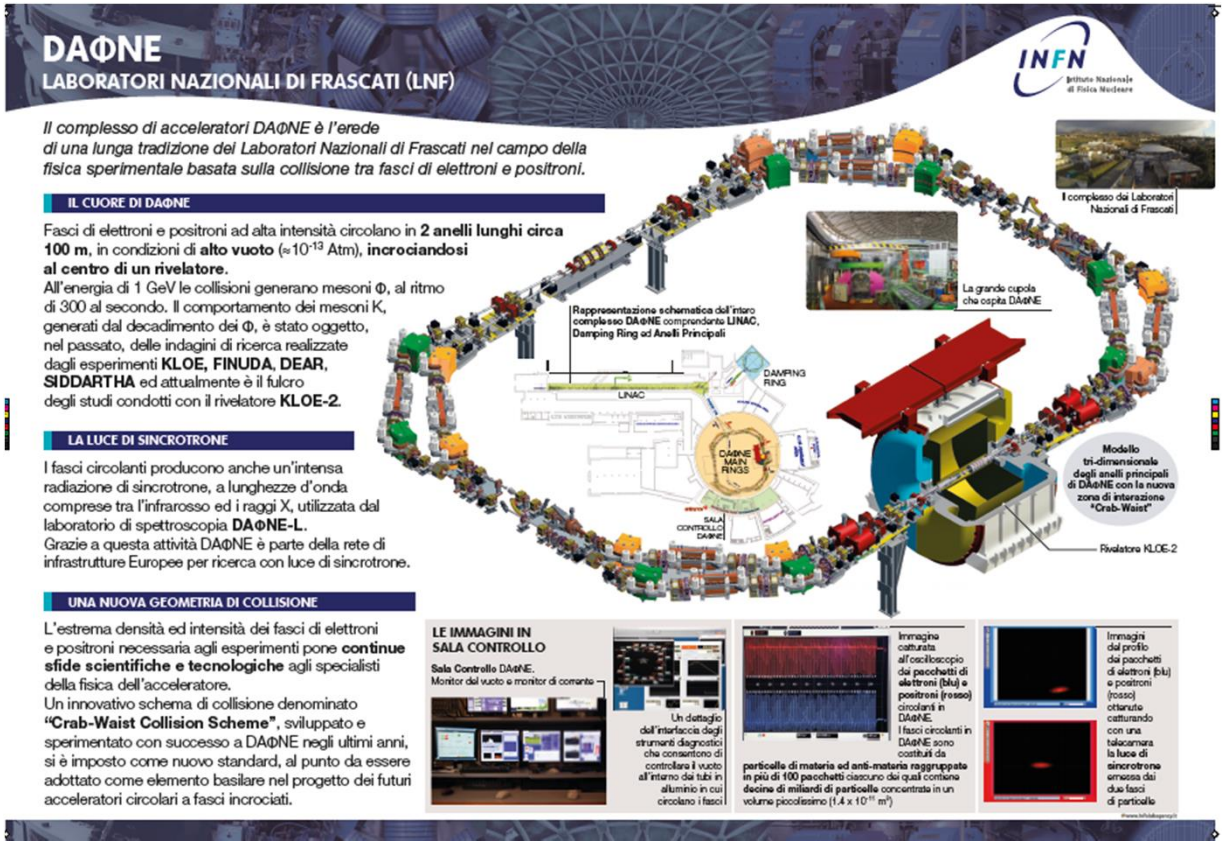


Frascati e^+ e^- Renaissance

Continuing the Frascati e^+ e^- renaissance the Φ Factory DAΦNE

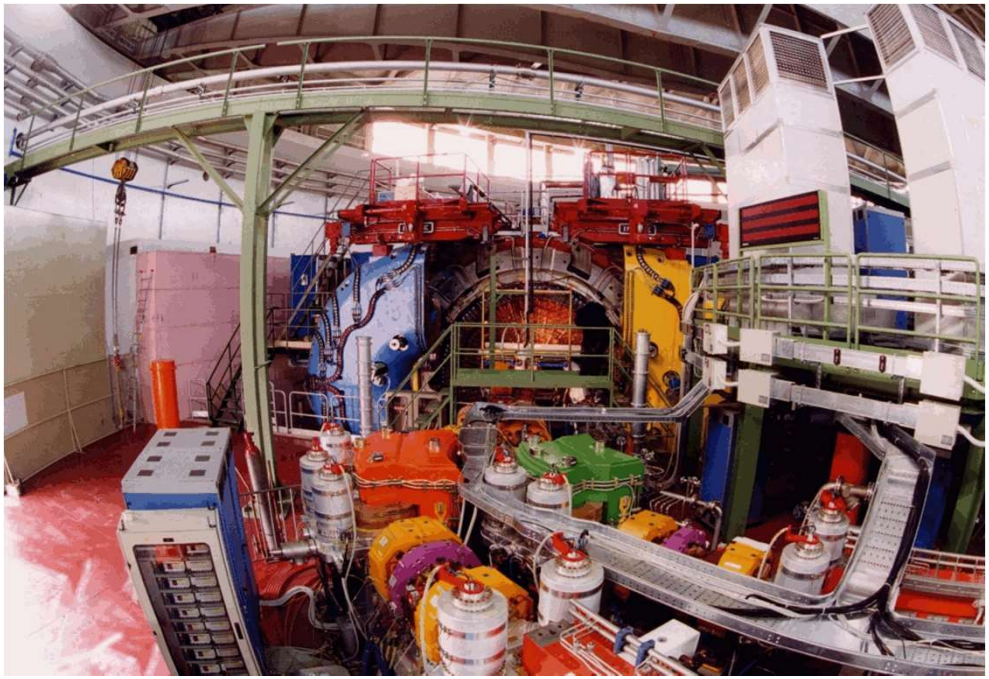
- DAΦNE is (was) a Φ Factory (W ≈ 1.05 GeV) with a huge luminosity (L ≈ $5x10^{32}$ cm^{-2} s^{-1}), taking into account that L naturally decreases at least like W^2 .

  DAΦNE replaced ADONE.



KLOE/KLOE2

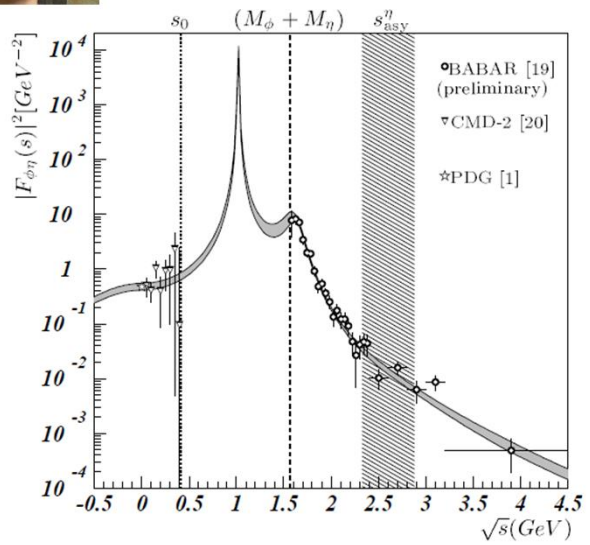
- KLOE/KLOE2 is a huge detector with the largest Drift Chamber ever built (4 m diameter), to detect as much as possible K_L from Φ–> K_S K_L , a very light spherical wedge endcap (Carbon Fiber 1 cm thick) to reduce γ conversion and a special trick to avoid deformations during wires stringing.
  The em calorimeter is made of scintillation fibers, with high time resolution to get K_L decay vertex from K_L time of flight (≈ 1 cm) and good shower energy resolution, put inside a superconducting coil, which provides a 0.5 T magnetic field.

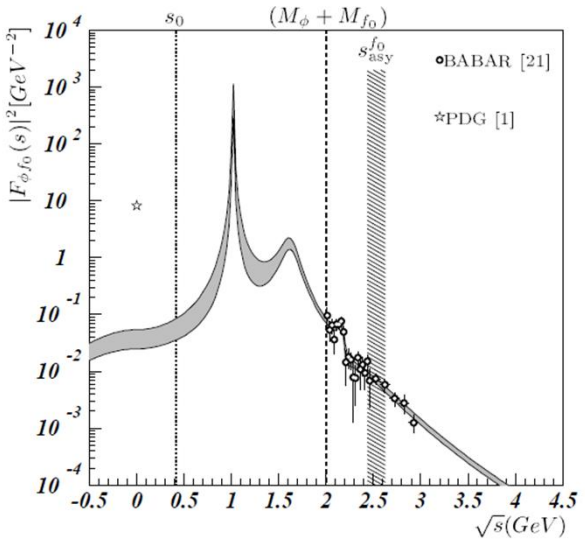


An example of the many KLOE achievements
A physics item relating KLOE and BaBar

- The power law that fits the slope in W is related to the number n of the meson valence quarks.
- The point at W=0 comes from Φ -> M γ (KLOE),
  the point at W > $M_F + M_M$ comes from ee-> M Φ (BaBar)
- In the case M is $\eta(548)$ the slope indicates n= 2, as expected ,
  if M is $f_0(980)$ the slope indicates n= 4 -> **$f_0(980)$ is mostly a 4 quark meson !**

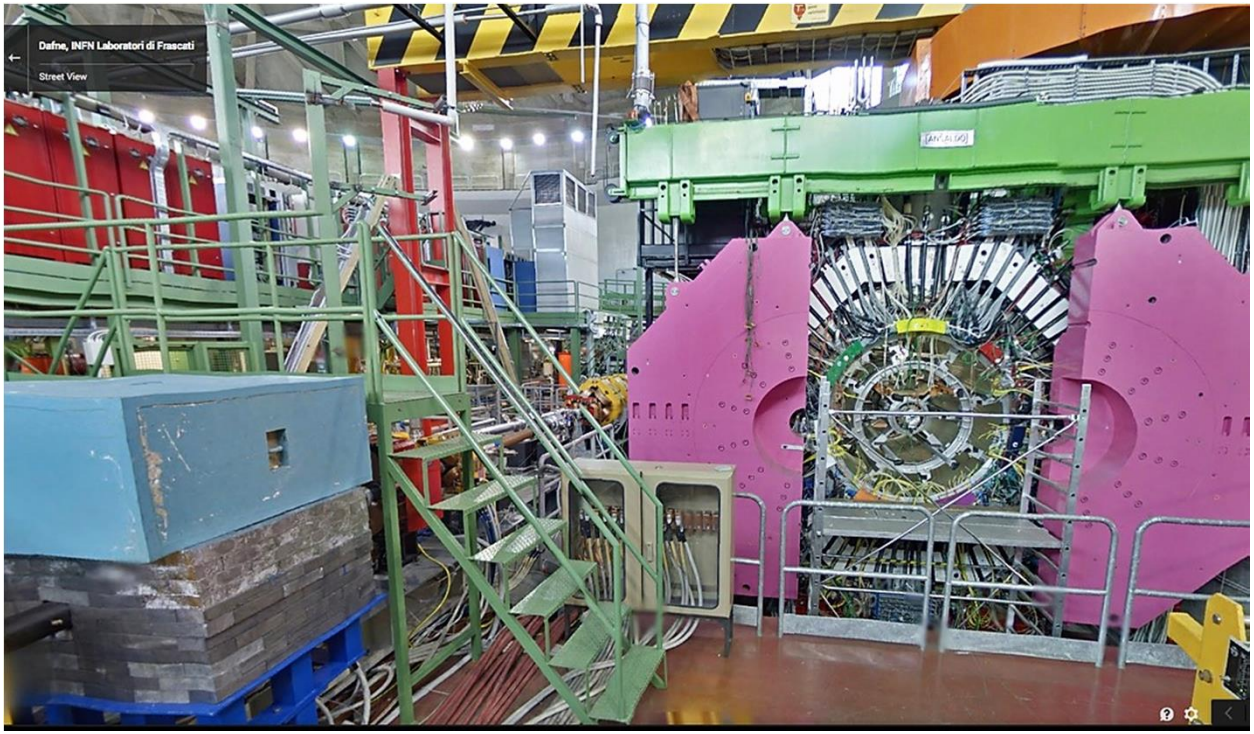
S. Pacetti Eur. Phys. J. A **31**, 665–671 (2007)





FINUDA
A Φ factory as a source of Kaons suitable for hypernuclei formation

- FINUDA studied hypernuclei formation by means of $K^{\pm}$, from $\Phi \rightarrow K^{+} K^{-}$, interacting on a target around the beam pipe.
- Planar drift chambers detect the hypernuclei decay products.



AMADEUS/SIDDARTHA
A Φ factory as a source of Kaons suitable for Kaonic atoms formation

- AMADEUS/SIDDARTHA studied the formation and the binding energy of kaonic atoms, stopping K^- and looking, by means of a CDD system, to the γ energy from Kp interaction.

SOUNDS of SILENCE

BARYON TIMELIKE FORM FACTORS TODAY

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

Coulomb Enhancement Factor

- Coulomb Enhancement Factor, a key point:
- After BaBar: $\sigma(e^+e^- \to B\bar{B}) = 4\pi\alpha^2/(3W_B^2)\cdot \boxed{C} \cdot\beta[|G_M(W_B^2)|^2+2M_B^2/W^2|G_E(W_B^2)|^2]$

  C: **Coulomb Enhancement Factors (CEF) ,**
  due to Coulomb Interaction between outgoing charged fermions

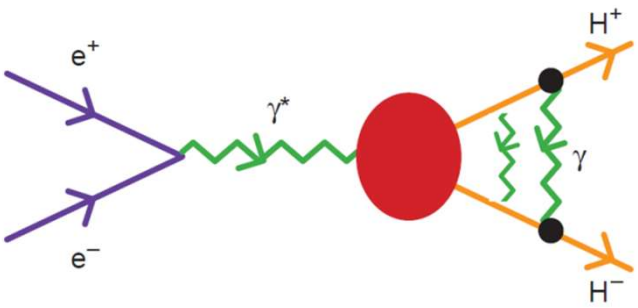
- CEF as a Long Range FSI: $\sigma \to \sigma_0\ |\phi(0)|^2$
  where ϕ is the wave function after Coulomb scattering
  Usually CEF is assumed to be the one for pointlike fermions (L.Landau,E.Lifschitz, 1950)

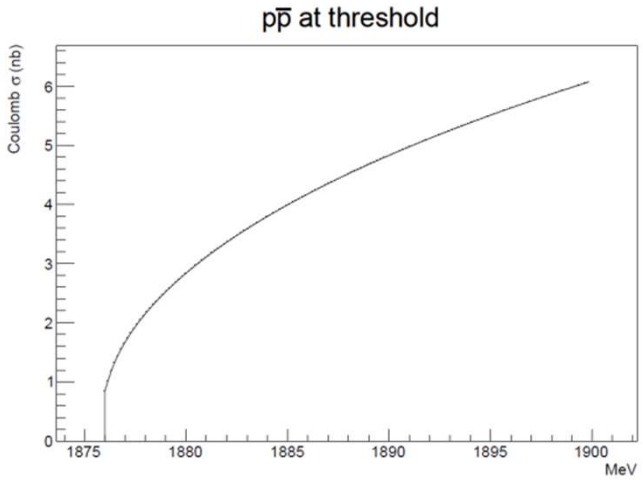
  $|\phi(0)|^2 = \pi\alpha\ \sqrt{(1-\beta^2)}/\beta \cdot 1/[1-\exp(-\pi\alpha\sqrt{(1-\beta^2)}/\beta)]$.

- One photon exchange among B^+B^- is taken into account by the Enhancement Factor
  $E = \pi\alpha\sqrt{(1-\beta^2)}/\beta$. E predicts a step at thr: $1/\beta$ factor cancels the phase space β :
  In agreement with data
- Many photons exchanges are taken into account by the Sommerfield
  Resummation Factor **$R = 1/[1-\exp(-\pi\alpha\sqrt{(1-\beta^2)}/\beta)]$**
  R is so that very soon the phase space β should be restored **:**
  not in agreement with data

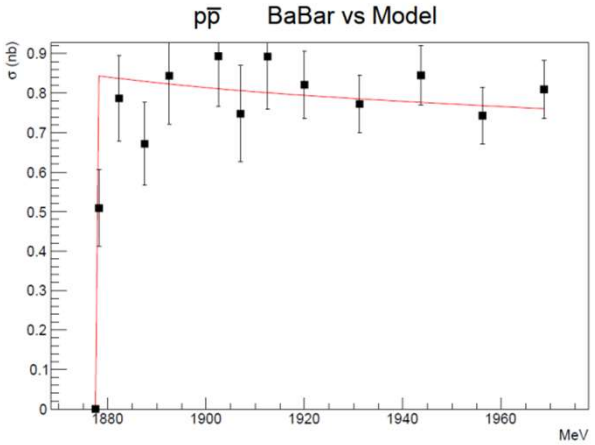
Coulomb Enhancement Factor

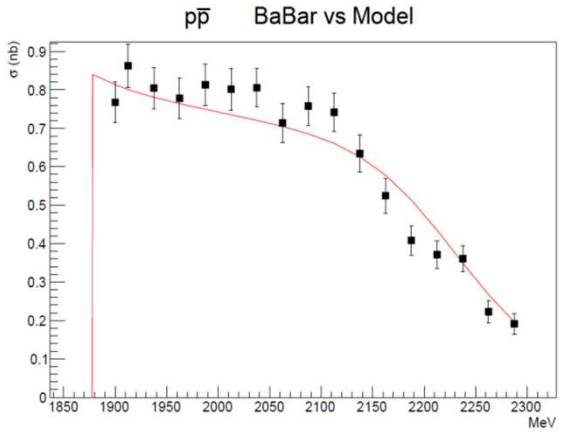
Pointlike ResummationFactor





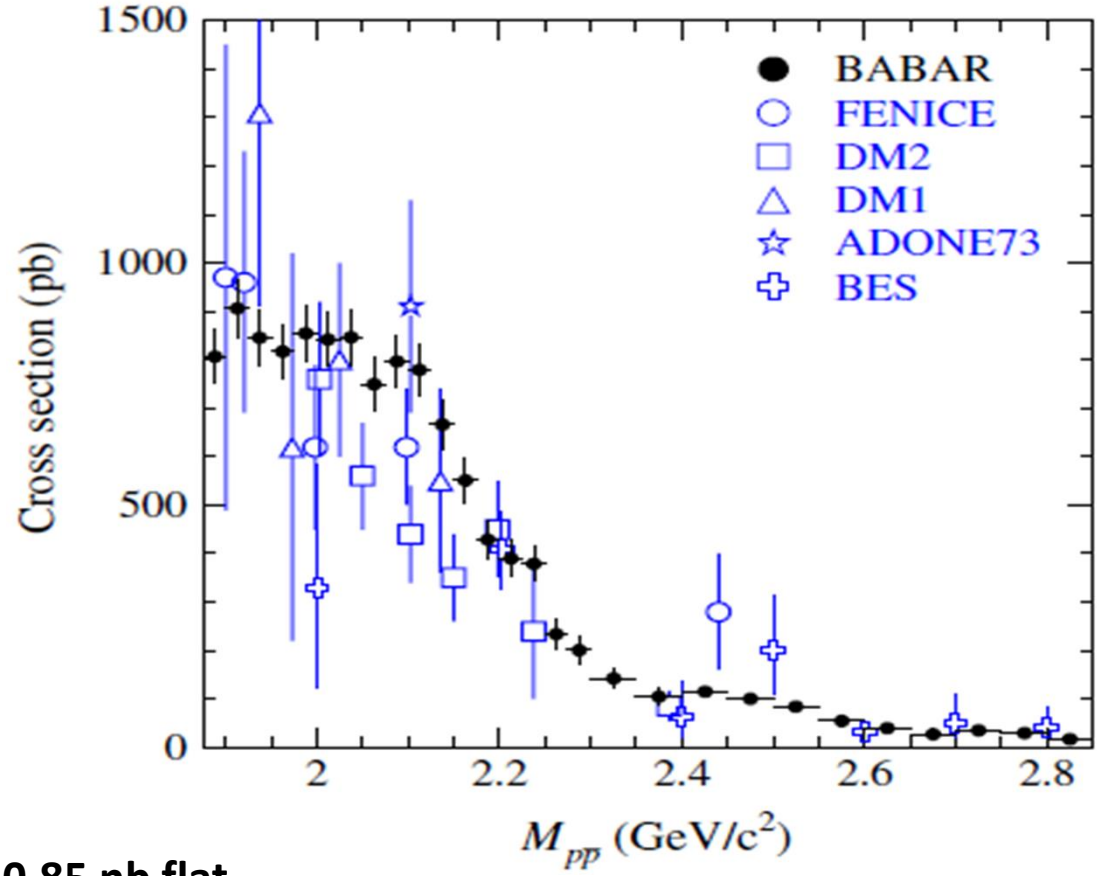
- Assuming E (Coulomb step at thr), in R many gluons (pions) exchanged too. α_S instead of α should be considered (actually any value of $\alpha_S >> \alpha$) (?):
  $R \approx 1/ [1- \exp(- \pi\alpha_S \sqrt{(1-\beta^2}/\beta)]$





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

- To be updated with BESIII data

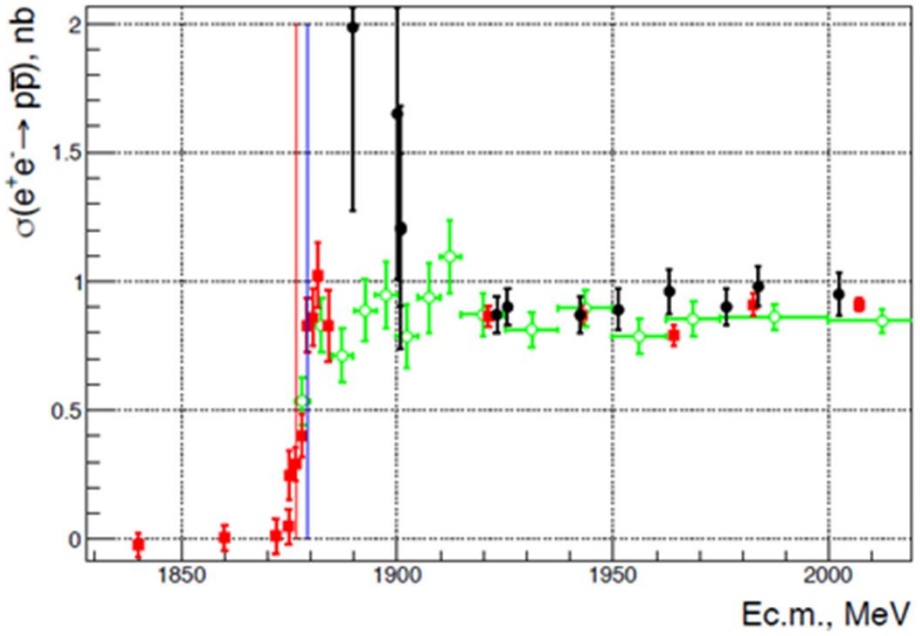


- **$\sigma(e^+ e^- \rightarrow pp_{bar})$ ≈ 0.85 nb flat**
- **CEF expects $\sigma_{thr} = 0.85 \cdot |G_S(4M_p^2)|^2$ nb**

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

CMD3 at threshold: Step and $G_S(4M_p^2)$ close to 1

$\sigma\ (e^+\ e^-\text{-> } pp_{bar})$



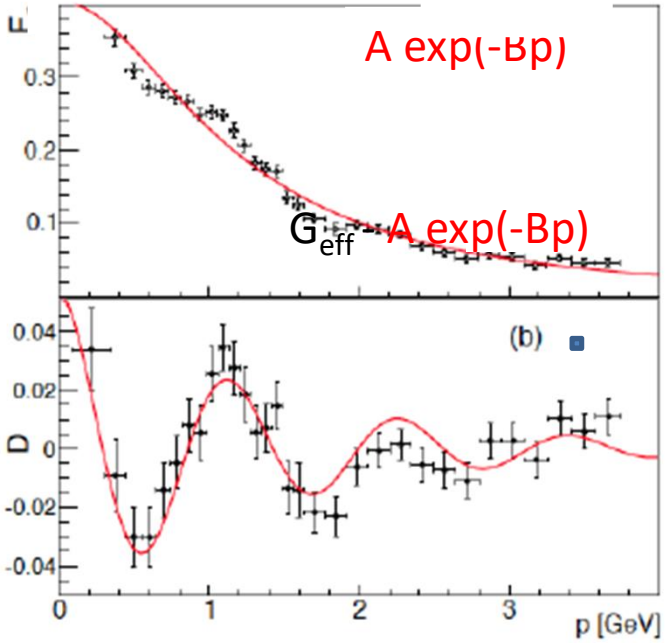
Our new 2017 data in comparison with BaBar and CMD-3 2011-2012 scans
(R.R. Akhmetshin et al., (CMD-3 Collaboration), Phys. Lett. B759, 634 (2016).)

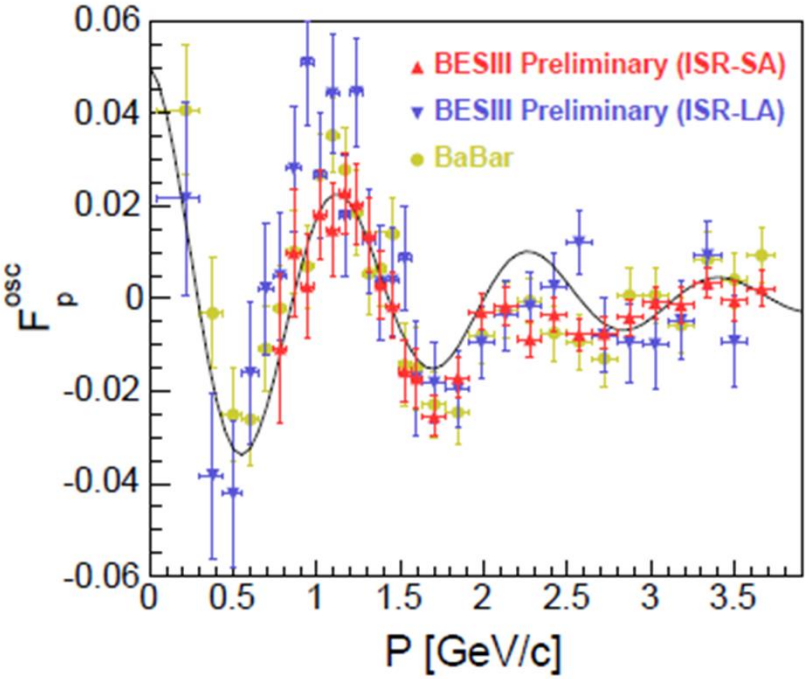
Oscillations in $G_{eff}(e^+e^- \rightarrow pp_{bar})$!

- **Oscillations in G_{eff} (e^+e^- -> pp_{bar}), seen by BaBar and confirmed by BESIII**

A. Bianconi and E. Tomasi-Gustafsson, Phys. Rev.C 93, 035201 (2016).

G_{eff}





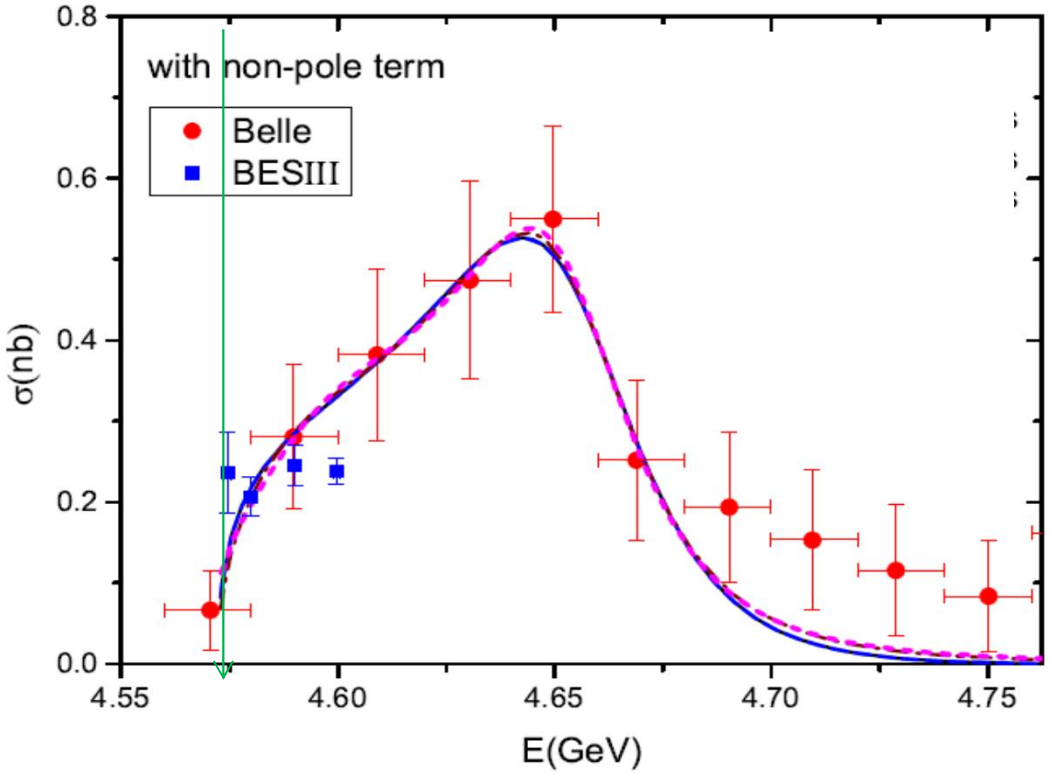
$$F_{\mathrm{osc}}(p) \equiv A\exp(-Bp)\cos(Cp + D).$$

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

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

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

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



Fit by BESIII friend U. Meissner

BESIII $\sigma(e^+ e^- \to \Lambda_c \Lambda_{cbar})$ has a step at threshold followed by a plateau, like $\sigma(e^+ e^- \to p p_{bar})$

The fit assumes a resonance Y(4660) + $\Lambda_c \Lambda_{cbar}$ FSI.

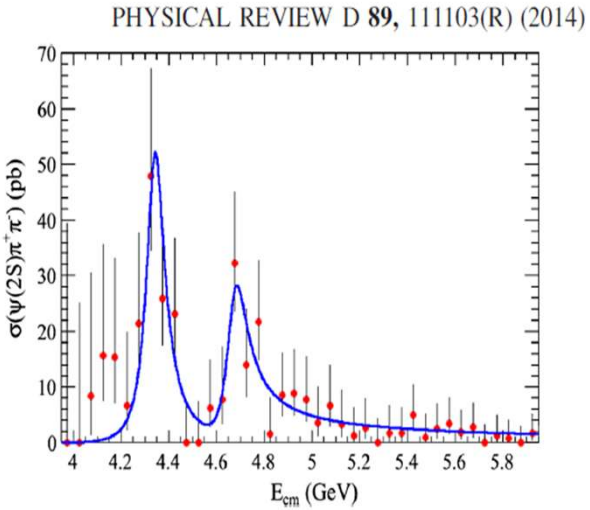
Among XYZ new resonances, Y(4660) is strongly needed if they are tetraquarks

Other evidences of the Y(4660)

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

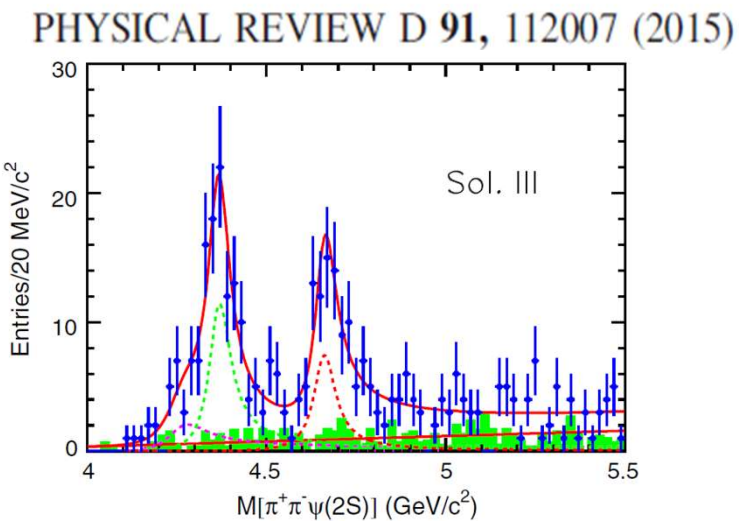
BaBar

M=4669 ± 22 , Γ=104 ± 49

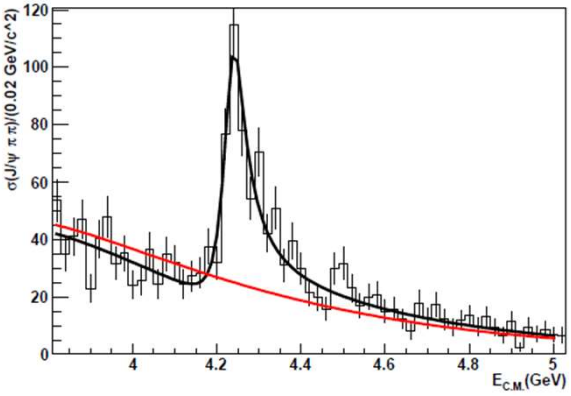


Belle

M=4652 ± 13 , Γ=68 ± 11

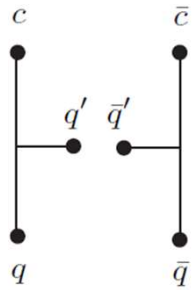


The decay Y(4660)-> J/ψ ππ would be expected to be large, if it is a cc_{bar} state, while no evidence of Ψ(4660) at 90 % C.L



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

- σ_{peak} [Y(4660) ->$\psi\,(3686)\, \pi^+\, \pi^-$] ~ **0.04** nb
  σ_{peak} [Y(4660) -> $\Lambda_c\, \Lambda_{cbar}$] ~ **0.55** nb
- **Y(4660) baryonic coupling ≥ 10 mesonic coupling: Unexpected, unless Y(4660) is a Hidden Charm Baryonium !**
- Y(4660) fulfills the old Rossi Veneziano paradigm of a tetraquark decay:

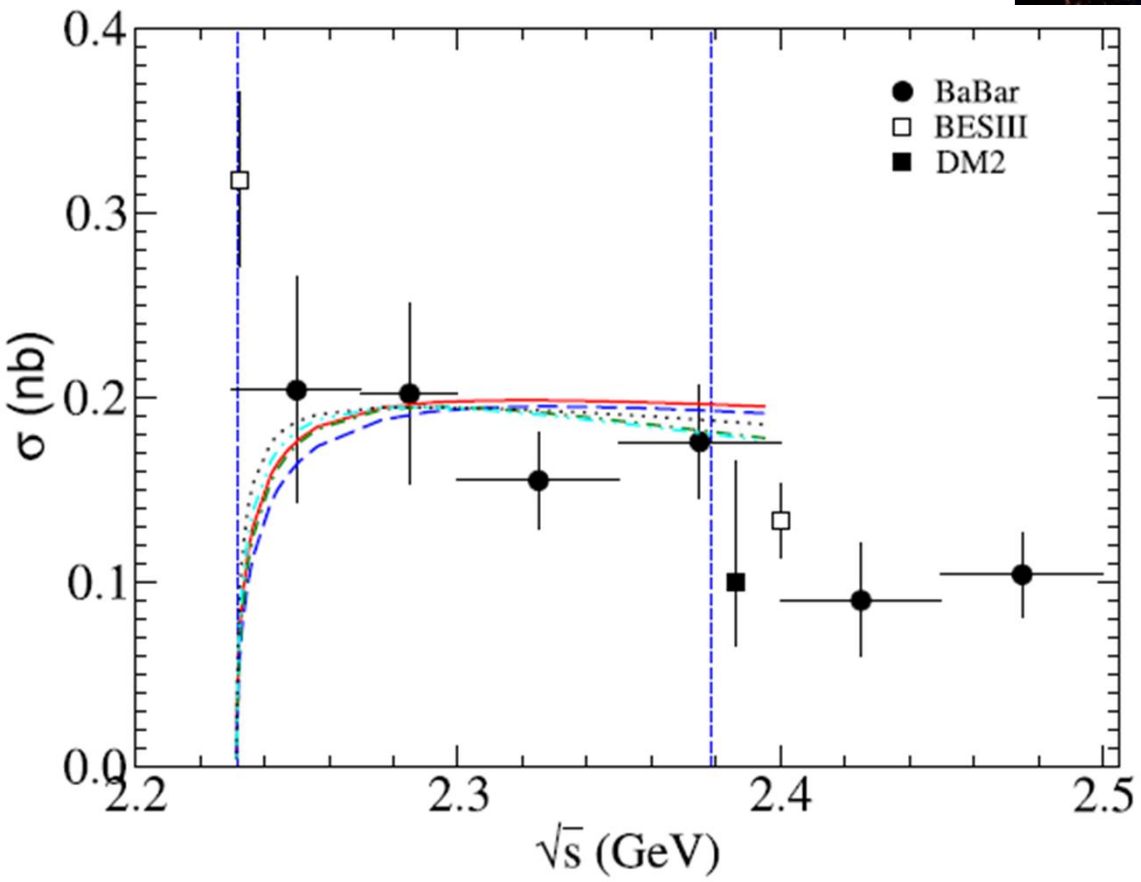


- **But**:
  Light quarks baryonium, dreamed for a long time, never clearly confirmed
  BESIII $e^+ e^-$ -> $\Lambda_c\, \Lambda_{cbar}$ flat cross section reminds $e^+ e^-$ -> pp_{bar}, close to threshold
- **BESIII will increase soon the maximum energy to settle this open question**
  If the cross section would be still flat, XYZ tetraquark interpretation is in trouble

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

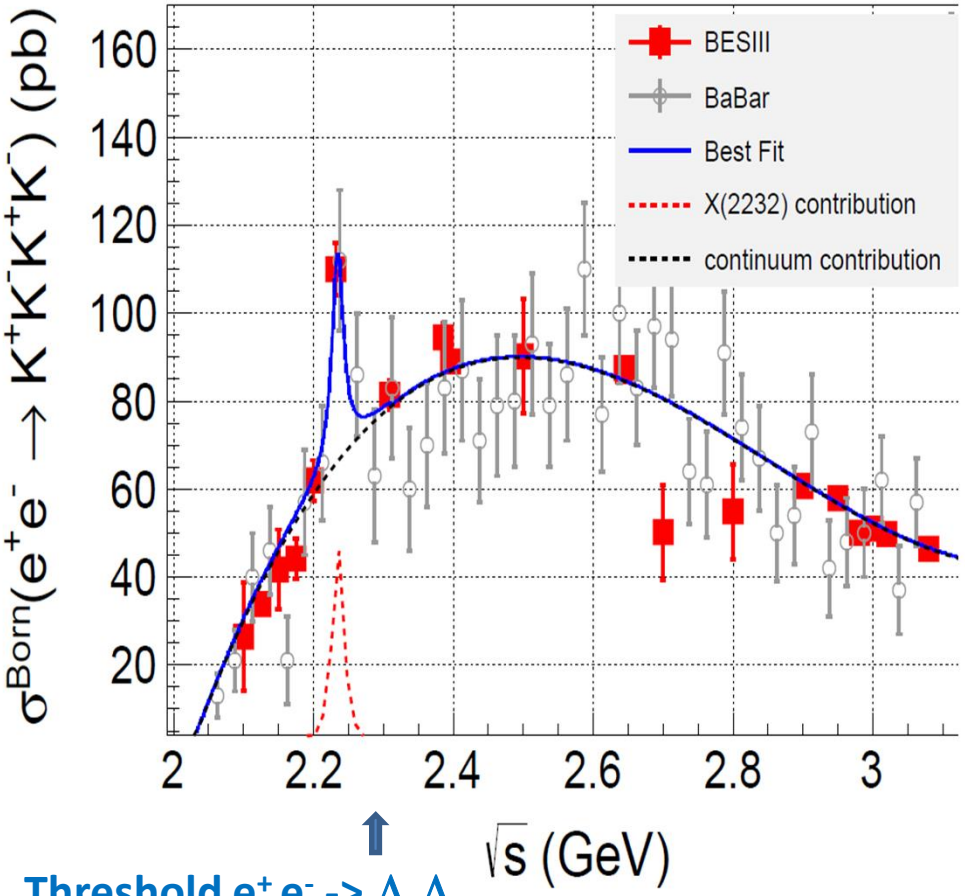
Present data on $e^+ e^-$ -> $\Lambda\ \Lambda_{bar}$

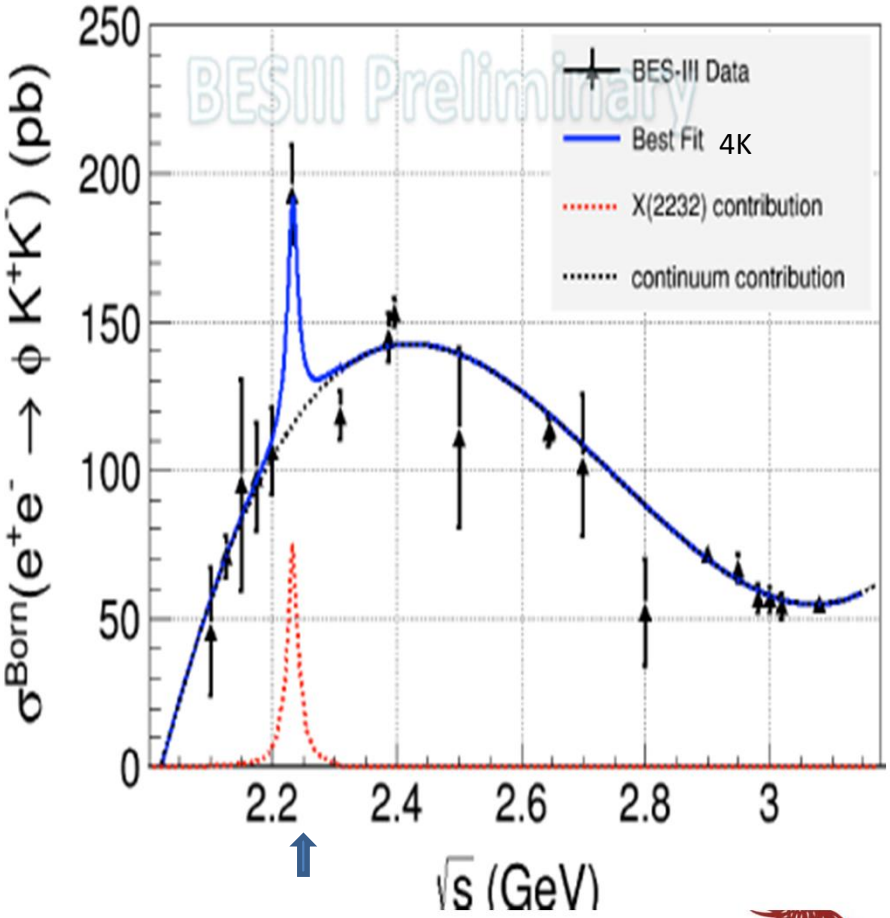
- BESIII results (**Phys. Rev. D 97, 032013)**
- Neutral Baryon: no Coulomb, but still step at threshold
- A narrow resonance close to the threshold **(U. Meissner)** ?



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

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





Threshold $e^+ e^- \to \Lambda \bar{\Lambda}$

J/ ψ phase

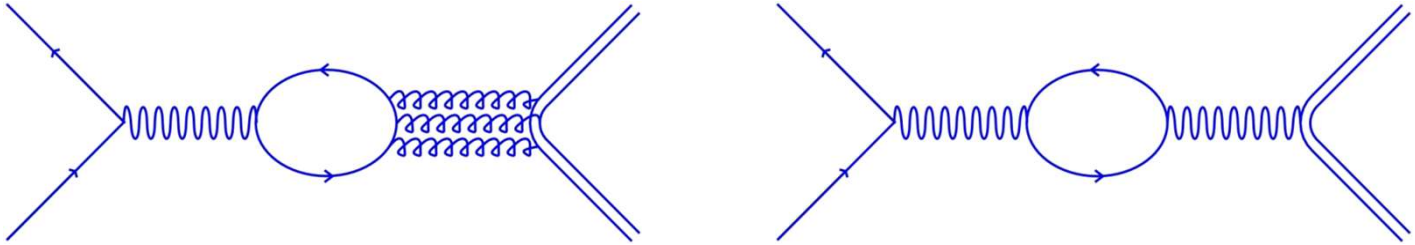
between

strong and em decay amplitudes

From a calibration to a discovery by FENICE

- **J/ψ -> n n_{bar} as a calibration:** many events with a n_{bar} and ~ 20 % events with a n
- $I_{J/\psi} = 0$ -> **$B(J/\psi -> n\ n_{bar}) / B(J/\psi -> p\ p_{bar}) \sim 1$**

  However J/ψ -> "γ " -> n n_{bar} , p p_{bar} interferes with the strong amplitude so that it should be expected: **$B(J/\psi -> n\ n_{bar}) / B(J/\psi -> p\ p_{bar}) \sim 0.5$**



- FENICE found: $B(J/\psi -> n\ n_{bar}) / B(J/\psi -> p\ p_{bar}) = 1 \pm 0.25$ -> $\Phi_{strong} - \Phi_{em} \sim 90^0$!

  Now we know from BESIII it is true for all the decay modes, that is:

$$\Gamma_{J/\psi} = \Gamma_{em} + \Gamma_{strong}$$

- May be J/ψ is a narrow resonance (~ 13 KeV) mixed with a large one (≥ 100 MeV)

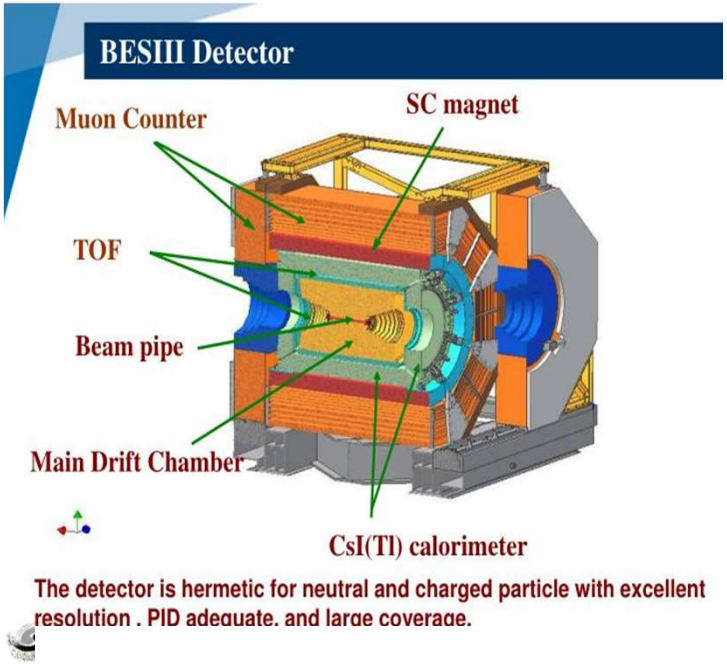
  Other interpretations are under study

nn_{bar}

Still J/ψ

BESIII measurement of $e^+e^- \to n\bar{n}$

- n_{bar} detected by means of hadronic shower pattern and TOF
- n detected by means of hadronic shower pattern and TOF at W ≥ 2.5 GeV
- n detected by means of TOF only at 2.0 ≤ W ≤ 2.5 GeV
- Unfortunately SND up to 2.0 GeV and BESIII above 2.0 GeV (at the moment)
- BESIII has measured and published $J/\psi \to n\bar{n}$ and $\psi(3686) \to n\bar{n}$
- Also $\sigma(e^+e^- \to n\bar{n})$ has been measured at 2.0 ≤ W ≤ 2.5 GeV, ***but still under check***



Charmonium Decay into Baryon Pairs

- $J/\psi \rightarrow \Sigma\,\Sigma_{bar}$ anomalous angular distribution,
- Λ, Σ polarization -> G_E/G_M relative phase -> **a spacelike zero from a non zero phase !**
- ……

- Next episode……..

Conclusions

- **Baryons are a unique feature of QCD (not fully understood), on the other hand the Universe is mostly made of.**
- **Thanks to Piero and Paola the FENICE Collaboration was realized and σ (e^+e^- -> nn_{bar}) measured for the first time.**

  That was the rebirth of e^+e^- in Frascati, where it was born
- **The renaissance of e^+e^- in Frascati continued with DAΦNE and KLOE, FINUDA, AMADEUS/SIDDARTHA and KLOE2.**
- **For your curiosity present data on e^+e^- -> Baryon Antibaryon are also reported, emphasizing the unexpected ones.**
- **I learnt a lot from Piero, his wisdom, his skill in disentangling personal and scientific opinions, and for me Piero was ..**

Not a Master
THE MASTER !