THE COULOMB FORCE AWAKENS

Coulomb Enhancement Factors Revisited

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THE COULOMB FORCE IS GOING TO WAKE UP…..

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Outline

- Coulomb Enhancement Factors (CEF) hypotheses
- Properties of CEF
- pp_{bar} at threshold
- Present approaches to CEF
- An alternative approach to CEF
- Application to pp_{bar}
- Other Charged Baryons
- The case of Neutral Baryons
- Very Temporary Conclusions

CEF Hypotheses

- $\sigma\,(e^+e^- \to B\bar{B}_{bar}) = 4\pi\,\alpha^2/(3W_B{}^2)\cdot C$

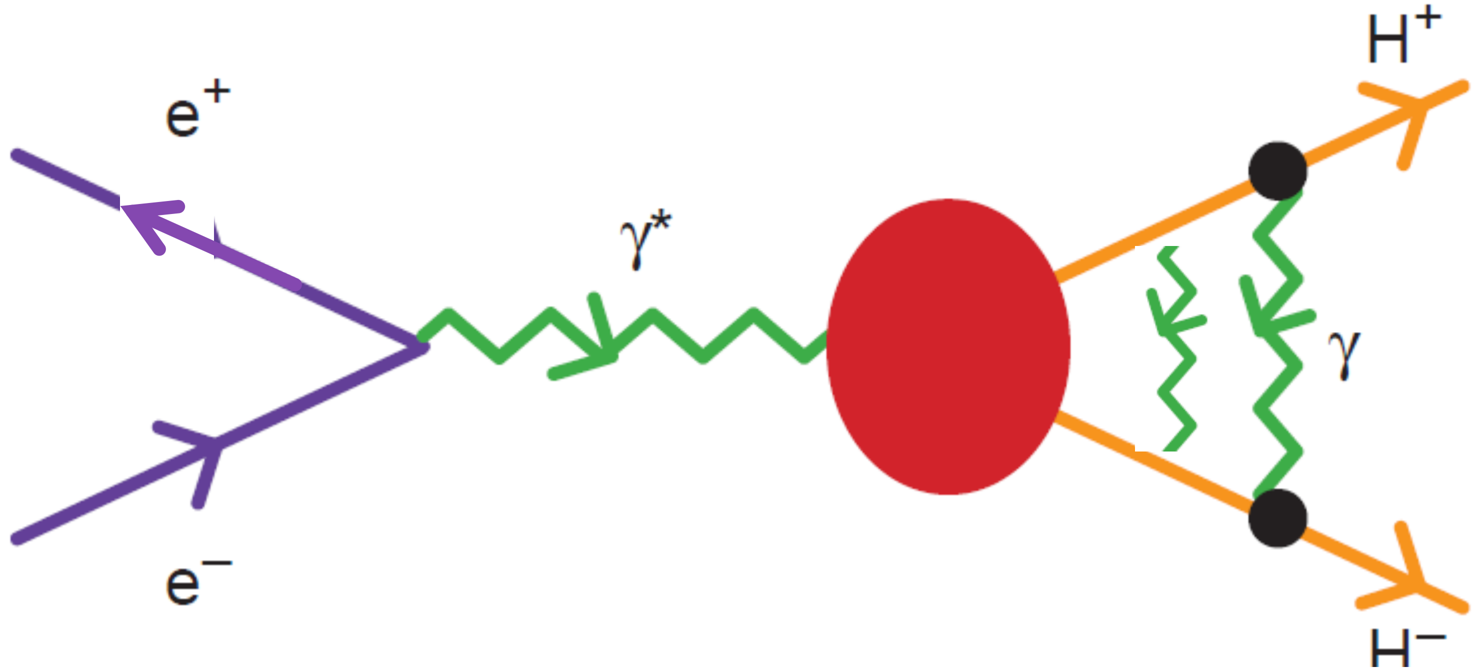
  $\cdot\beta[|G_M(W_B{}^2)|^2 + 2M_B{}^2/W^2|G_E(W_B{}^2)|^2]$

- C: **Coulomb Enhancement Factors (CEF).**
  Non Perturbative Correction to include Coulomb Interaction between the outgoing fermions

- Hypotheses to achieve the usual 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,** on the other hand:
- Analyticity: $G_E(4M_B{}^2) = G_M(4M_B{}^2) = G_S(4M_B{}^2) \to$ $\mathbf{G_D(4M_B{}^2) = 0}$ **(?)**

CEF



CEF Hypotheses

- **Usually CEF is the pointlike fermions one (L.Landau,E.Lifschitz, 1950)**

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

E · R

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

- ❑ Some FF features, close to the threshold, still to be exploited:
- D wave sharp increase
- Near by thresholds: $pp_{bar} \leftrightarrow nn_{bar}$, $\Sigma^+\Sigma_{bar} \leftrightarrow \Sigma^-\Sigma_{bar}$, (not in $\Lambda_c\Lambda_{cbar}$)
- Periodic Structure (E. Tomasi-Gustafsson et al, PRL114, 232301, 2015)

- ❑ Work in progress ……

CEF

- E: Enhancement Factor

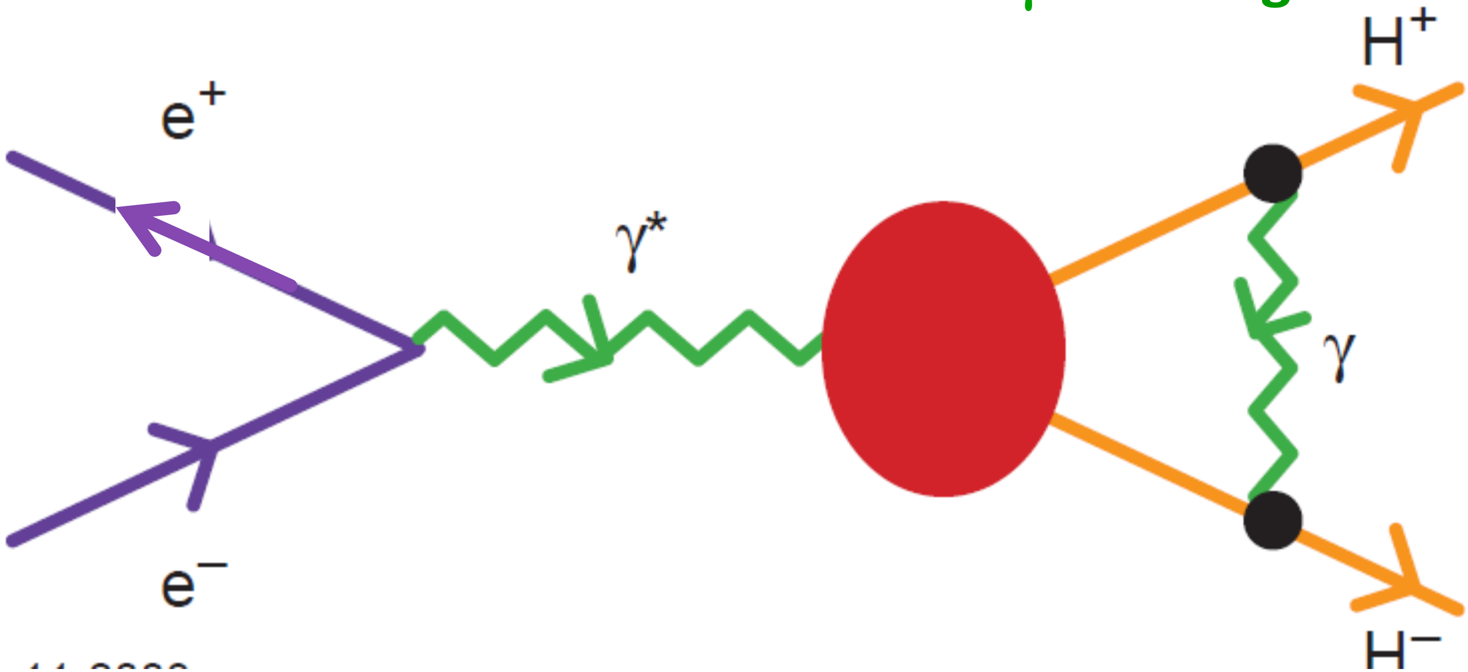
- It takes into account 1 γ exchange between outgoing fermions
- $1/\beta$ denominator cancels IPS factor β in the cross section, hence a jump at threshold, from 0 to $\pi^2 \alpha^3/(2M_B^2) \cdot G(4M_B^2)$
- For charged mesons $M^\pm$ CEF must not be included: $L \equiv 1 \to \phi(0)=0$, still $\sigma(e^+e^- \to M^+M^-) \approx \beta^{2L+1} \approx \beta^3$

- R: Resummation Factor

- It takes into account many γ exchange.
- Because of the Resummation Factor, after $\beta \sim \pi\alpha$, the cross section rises again like β

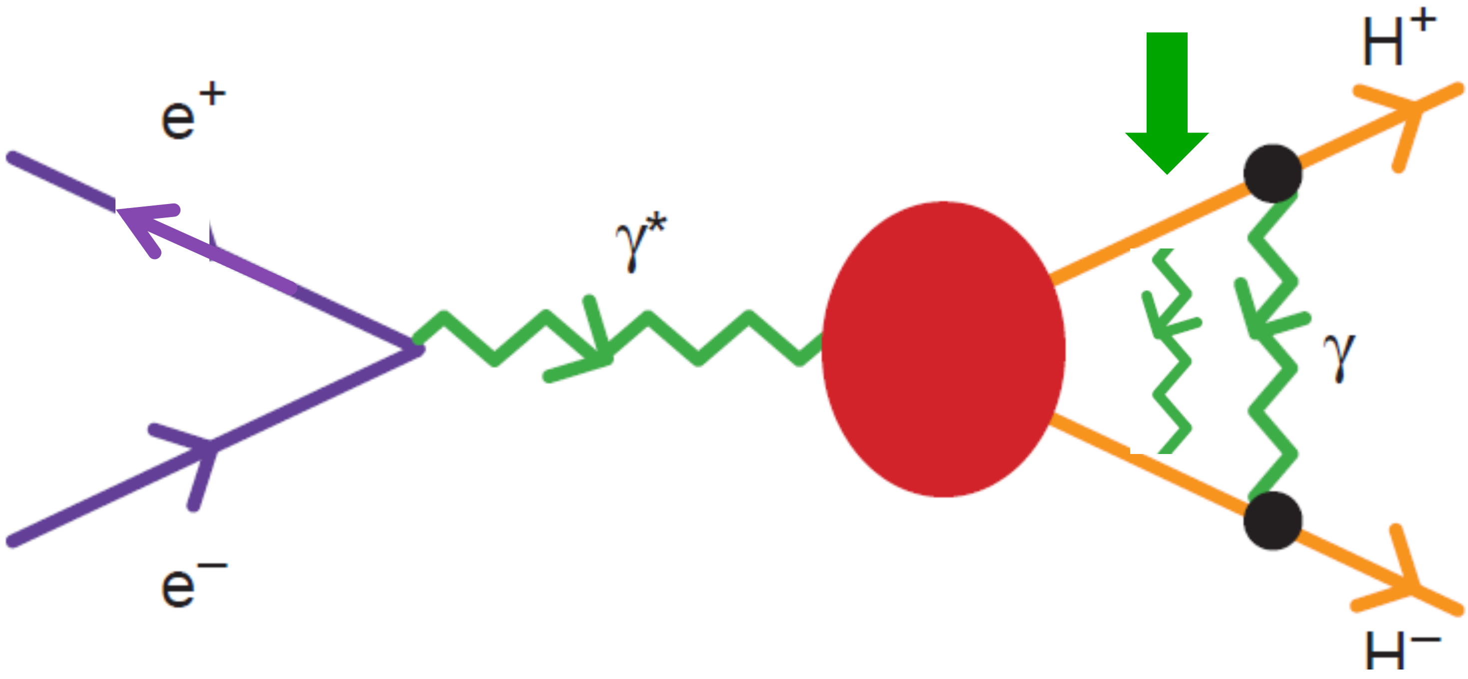
Enhancement Factor E

1 γ exchange



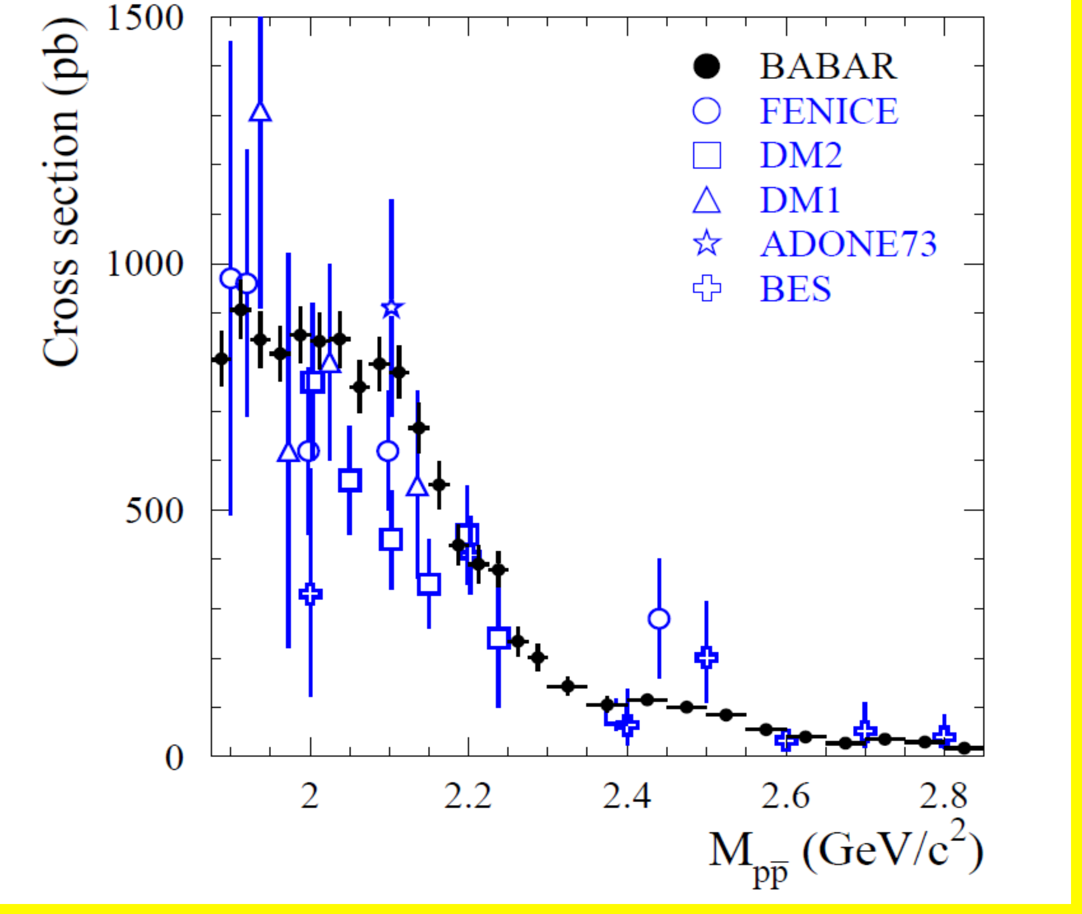
Resummation Factor R

More than 1 γ exchange



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

arXiv:1302.0055[hep-ex]2013



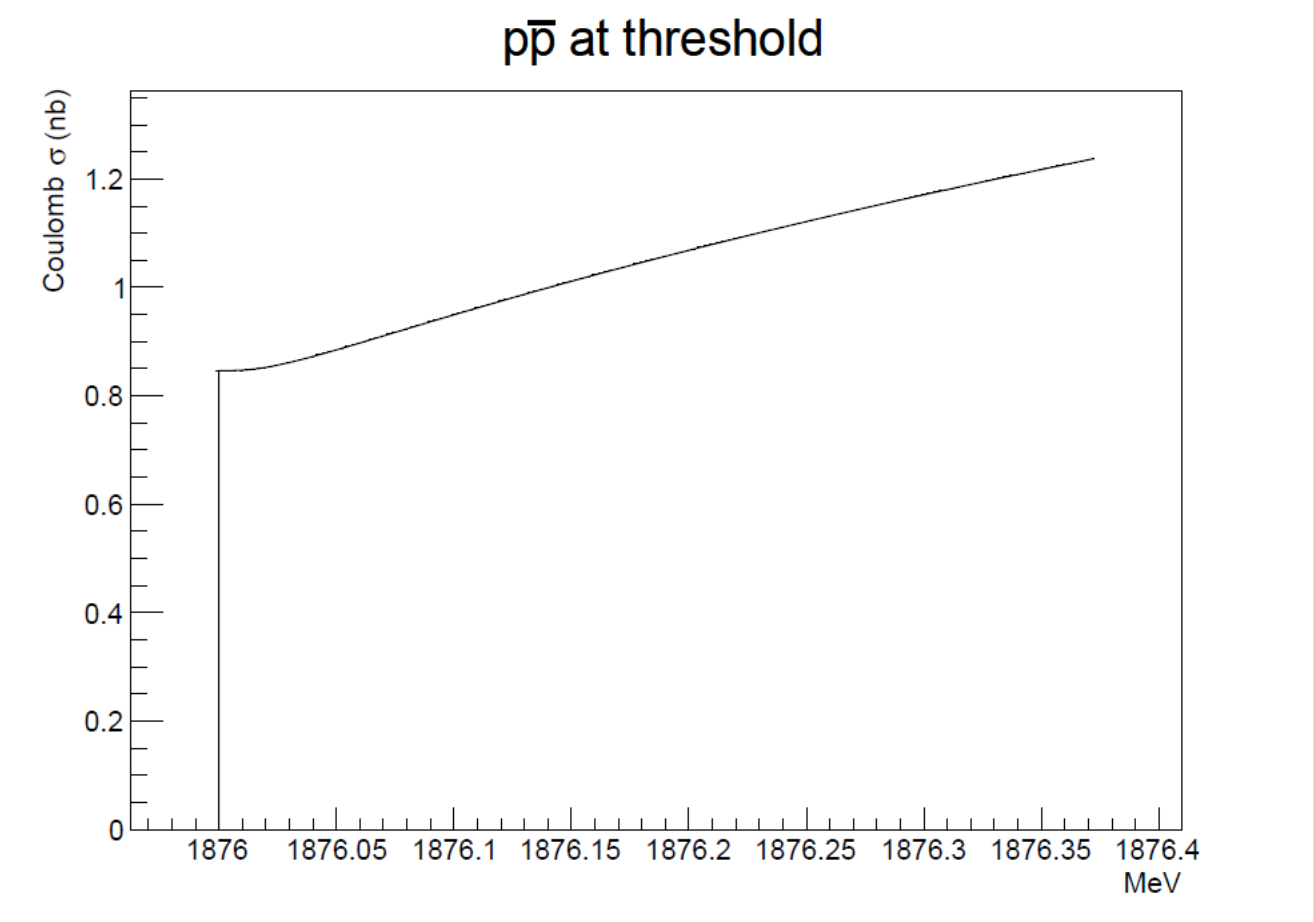
$p\bar{p}$ close to threshold

- In $e^+ e^- \to pp_{bar}$ σ is flat for about $\Delta W \sim 300$ MeV ,
  $\sigma(e^+ e^- \to pp_{bar})$ $\sigma_0 \sim \underline{0.85}$ nb , extrapolated at threshold
  CEF predicts $\sigma_0 = \underline{0.85} \cdot |G_S(4M_p^2)|^2$ nb (R=1)
  -> **$G(4M_p^2) \sim 1$!?**

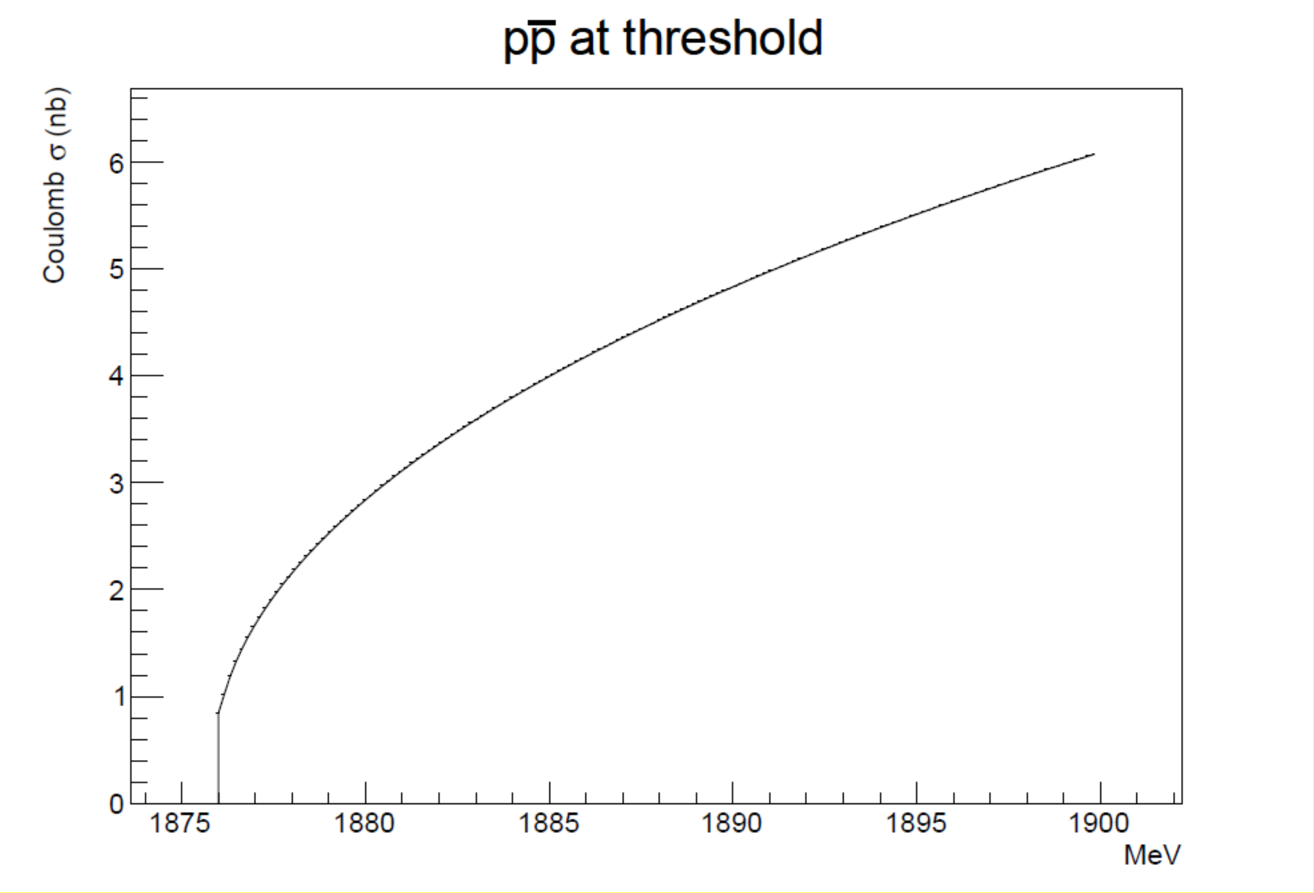
- CM energy spread ΔW:

- At J/ψ: $\Delta W \sim 0.9$ MeV -> at 2 GeV: $\Delta W \sim 0.4$ MeV, ($\Delta W \approx cW^2$)
- Efficiency, very close to threshold, reduced by a factor ~ 0.6.
- Unclear how much BaBar efficiency is affected, since the measurement performed by means of ISR from Y(4S)

$p\bar{p}$ very very close to threshold



$p\bar{p}$ very close to threshold



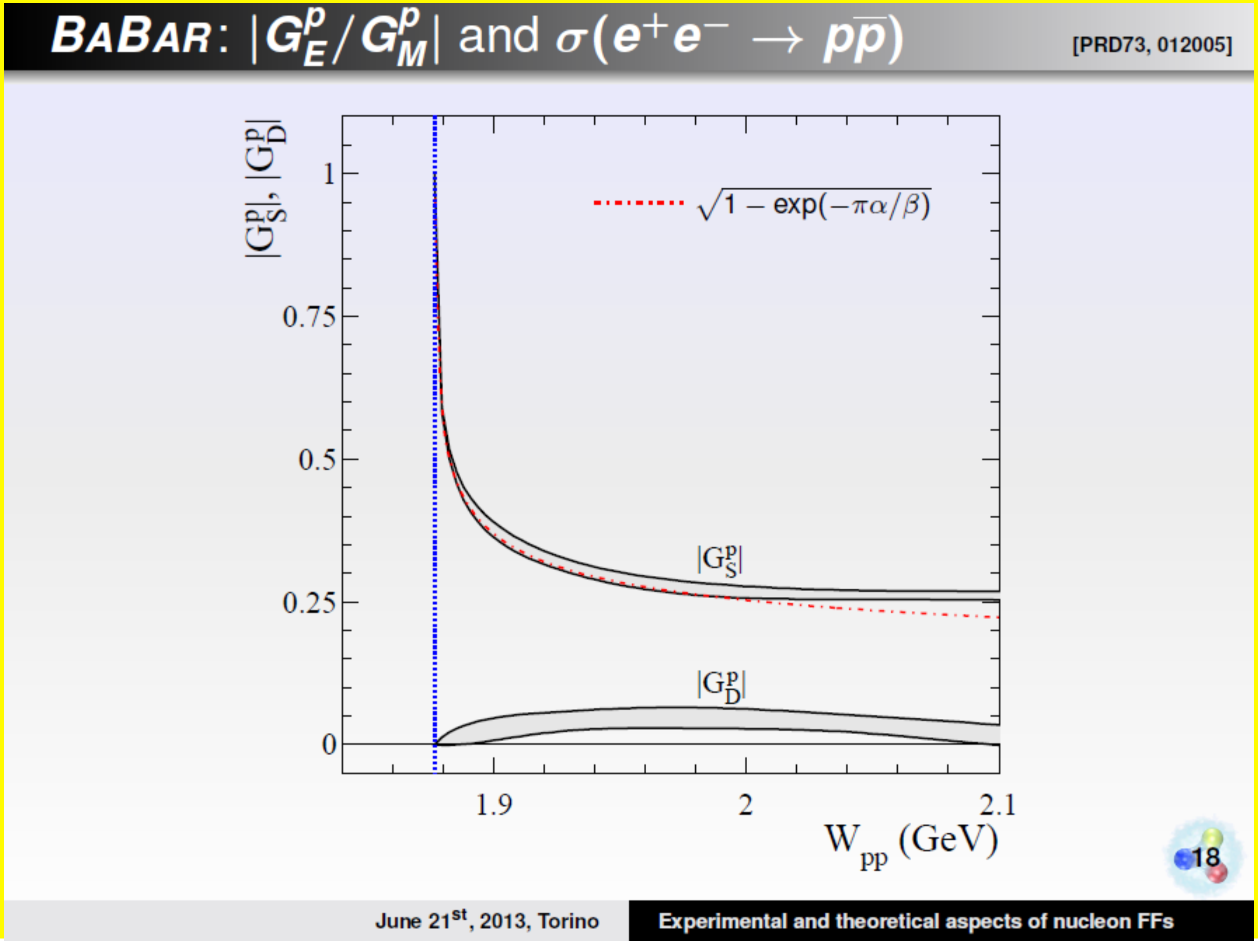
Present Approaches to CEF

- No unanimous agreement.
  Two approaches have been chosen toward CEF:

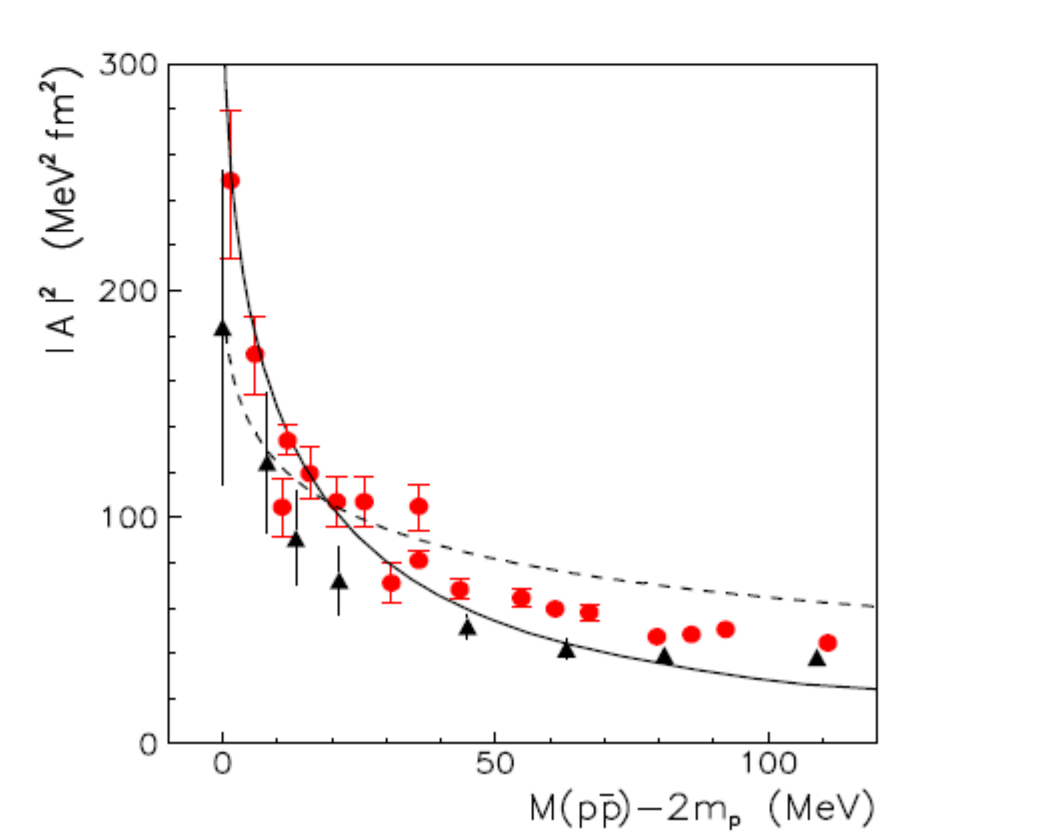
- Assume pointlike CEF:
  to get a flat cross section $|G_p(W^2)|$ must scale exactly like $1/\sqrt{C}$ (BaBar PRD73, 012005):
  (related to QED not to Strong Interactions)
  However another interpretation of $G_p(W^2)$ drop:
  fit by $e^+e^- \to pp_{bar}$ pointlike + FSI

- Ignore CEF:
  Jump vanishing because of cm energy spread , hence it is assumed a vanishing cross section at threshold
  (PHOKARA, H.Czyz et al. PRD90, 014121, 2014)
  (Dmitriev and Milstein Φ to Ψ, September, 2013)

σ_{tot} S wave part (BaBar PRD73, 012005) with respect to 1/√C



$p\bar{p}$ close to threshold



- J.Haidenbauer et al ArXiv:hep-ph/0606064, June 2006

$p\bar{p}$ close to threshold

- PHOKARA, H.Czyz et al. PRD90, 014121 (2014)

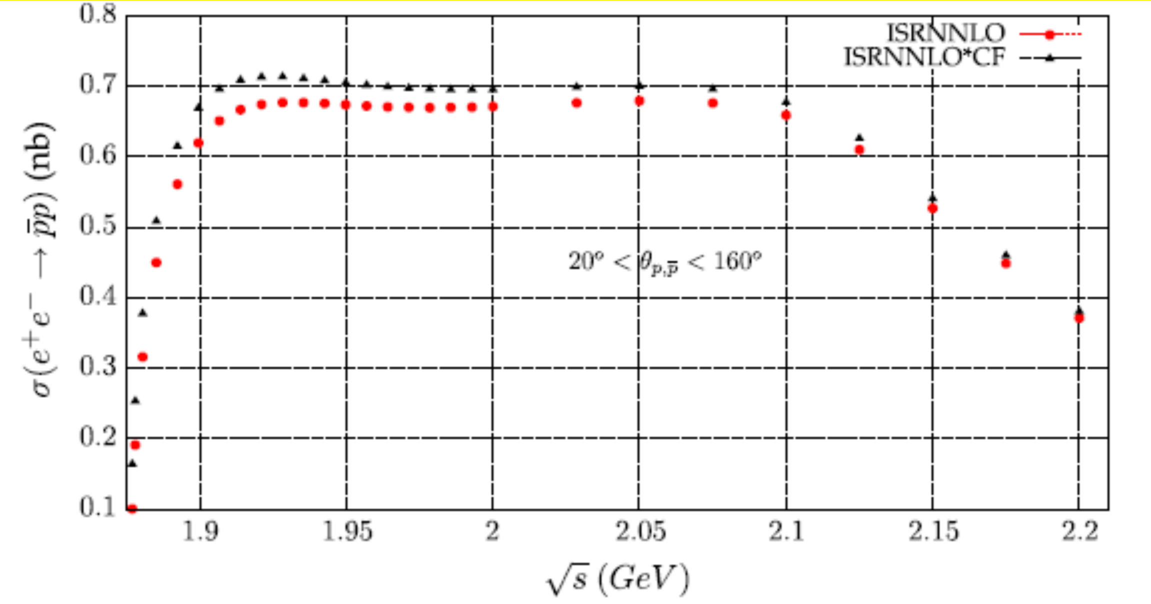
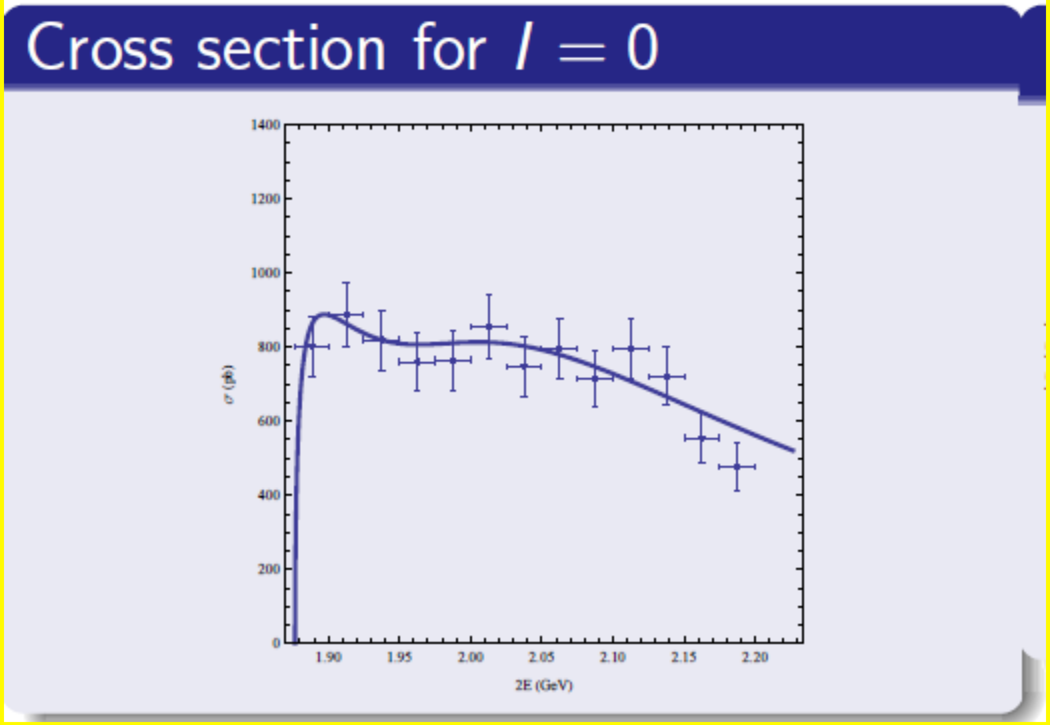


Fig. 8. From this figure, one can see that in any scan experiment in the region close to the threshold where, in principle, one can test the resummation of radiative corrections, the beam energy smearing effects (where the beam spread is typically 1–2 MeV) will obscure the effect.

$p\bar{p}$ close to threshold

- V.F. Dimitriev, A.I. Milstein, Φ to Ψ , September (2013)



An Alternative Approach to CEF

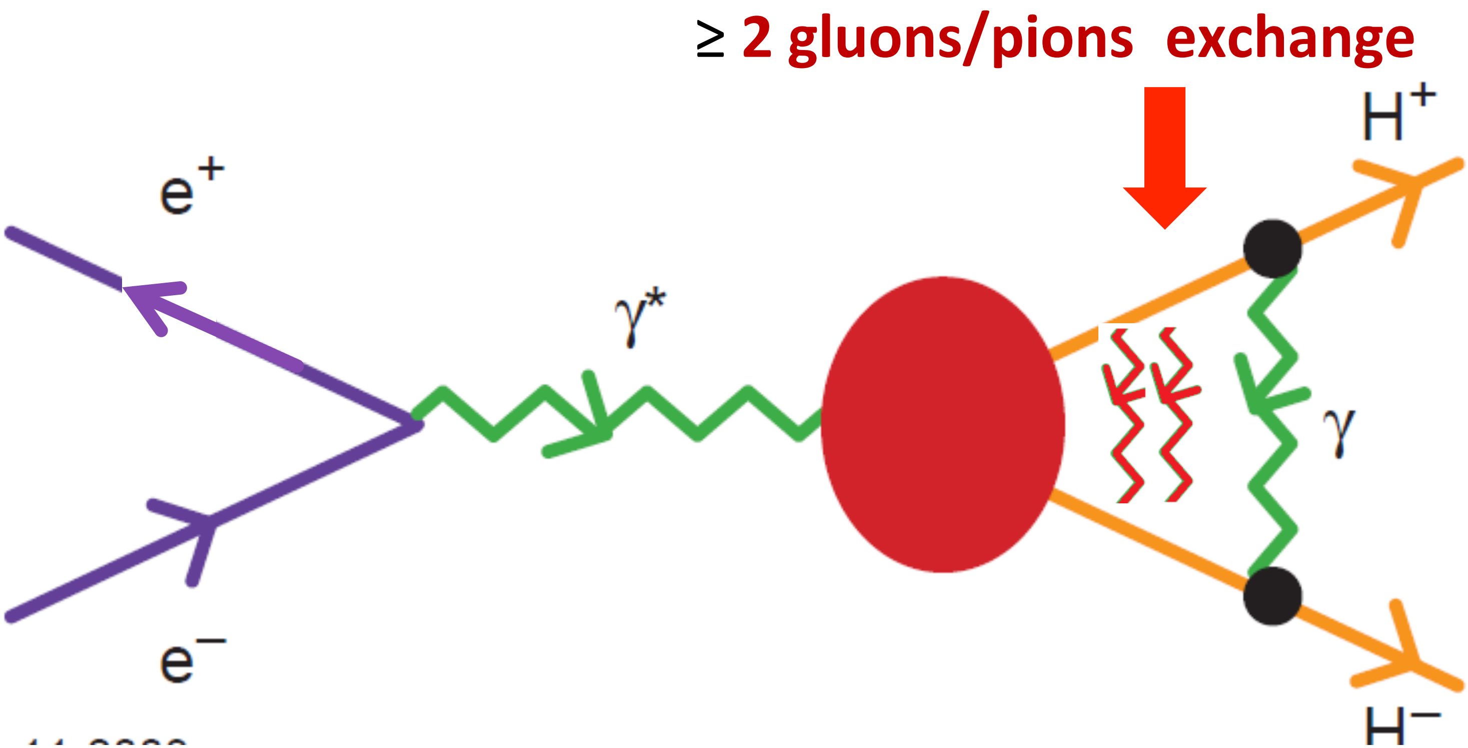
- Hard to assume as an accidental one the coincidence between σ_0 = <u>0.85</u>·|G(4M_p^2)|^2 nb , σ_0 ~ <u>0.85</u> nb, extrap. at threshold.

- **Consider another possible, empirical, approach:**
  The Resummation Factor R concerns many γ exchange,
  but gluons (pions) might be exchanged too, concerning BB_{bar} .
  If it is so, α_S and not α=1/137 has to be considered:

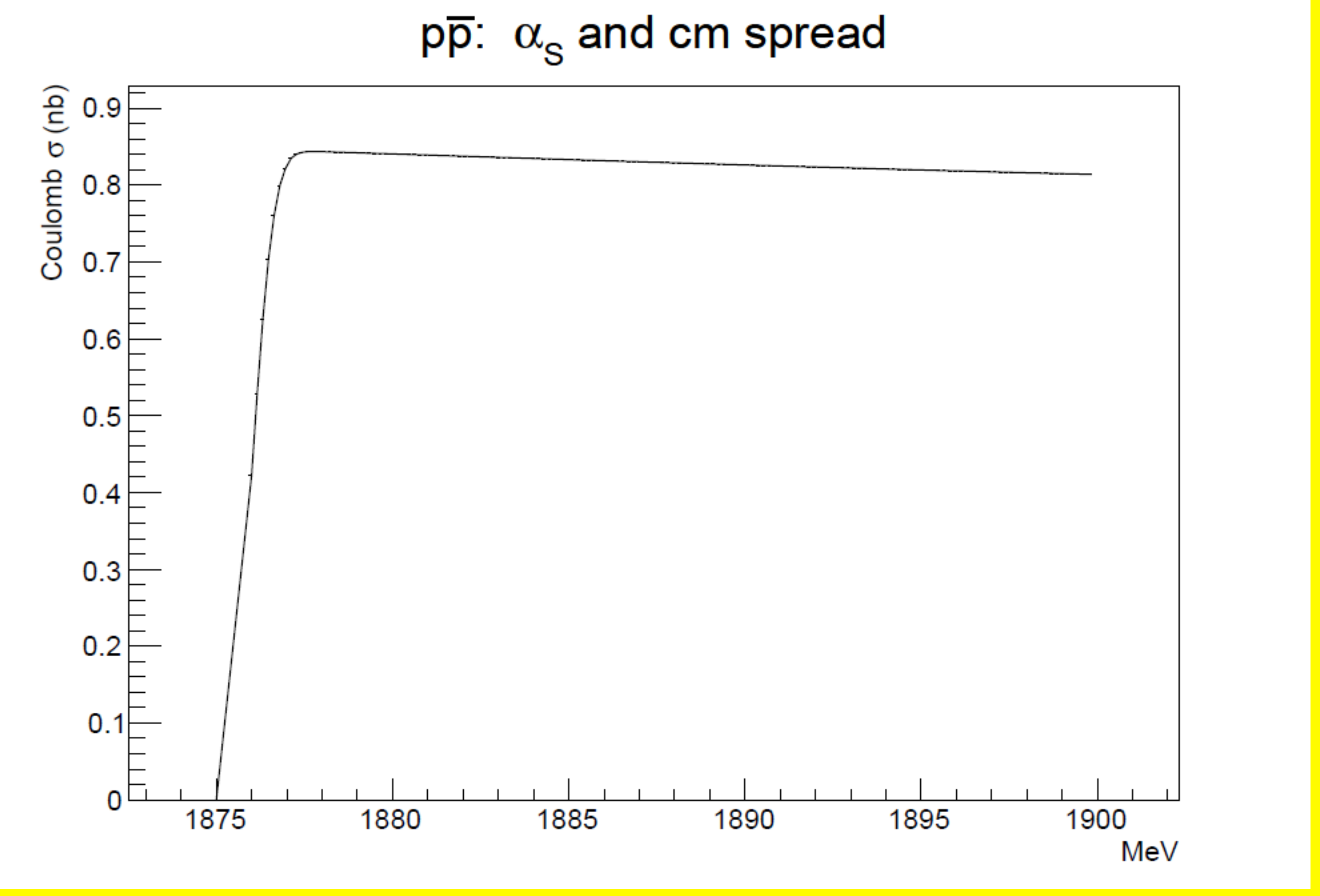
  $R = 1/ [1- \exp(- \pi\alpha_S \sqrt{(1-\beta^2)}/\beta)]$

  It is assumed α_S ~ 0.3, **but α_S dependence is very very mild.**
  Actually any "effective α_S", compatible with a not sharp transition between strong and Coulomb regime, is the same.

Resummation Factor R



$p\bar{p}$ close to threshold



$p\bar{p}$ close to threshold

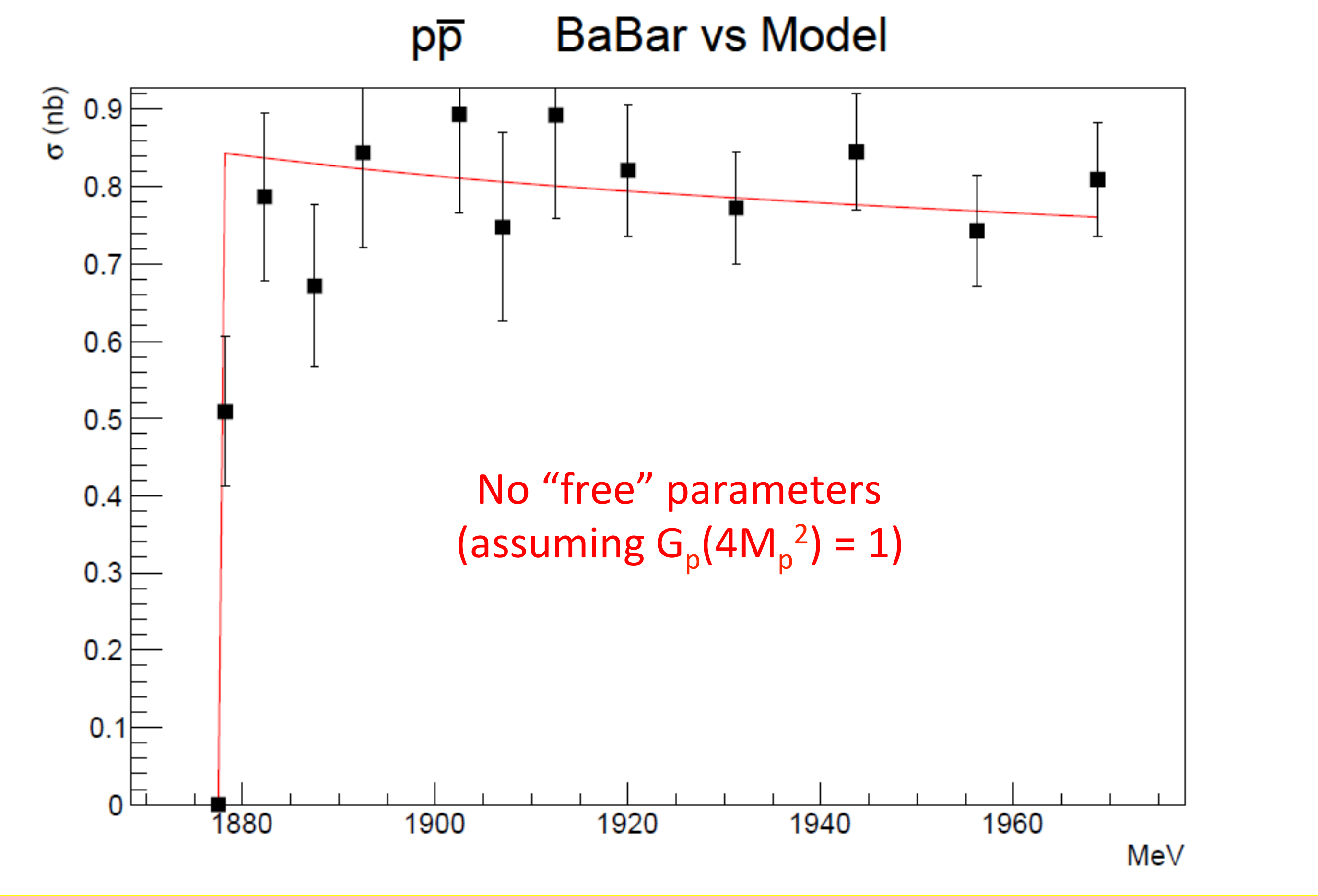
- Willing to include the asymptotic G_p expected behaviour, according to PQCD: $\sigma(e^+ e^- \to pp_{bar}) \sim 1/ [W^2 (W/\Lambda_{QCD})^8]$ a simple parametrization would be:

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

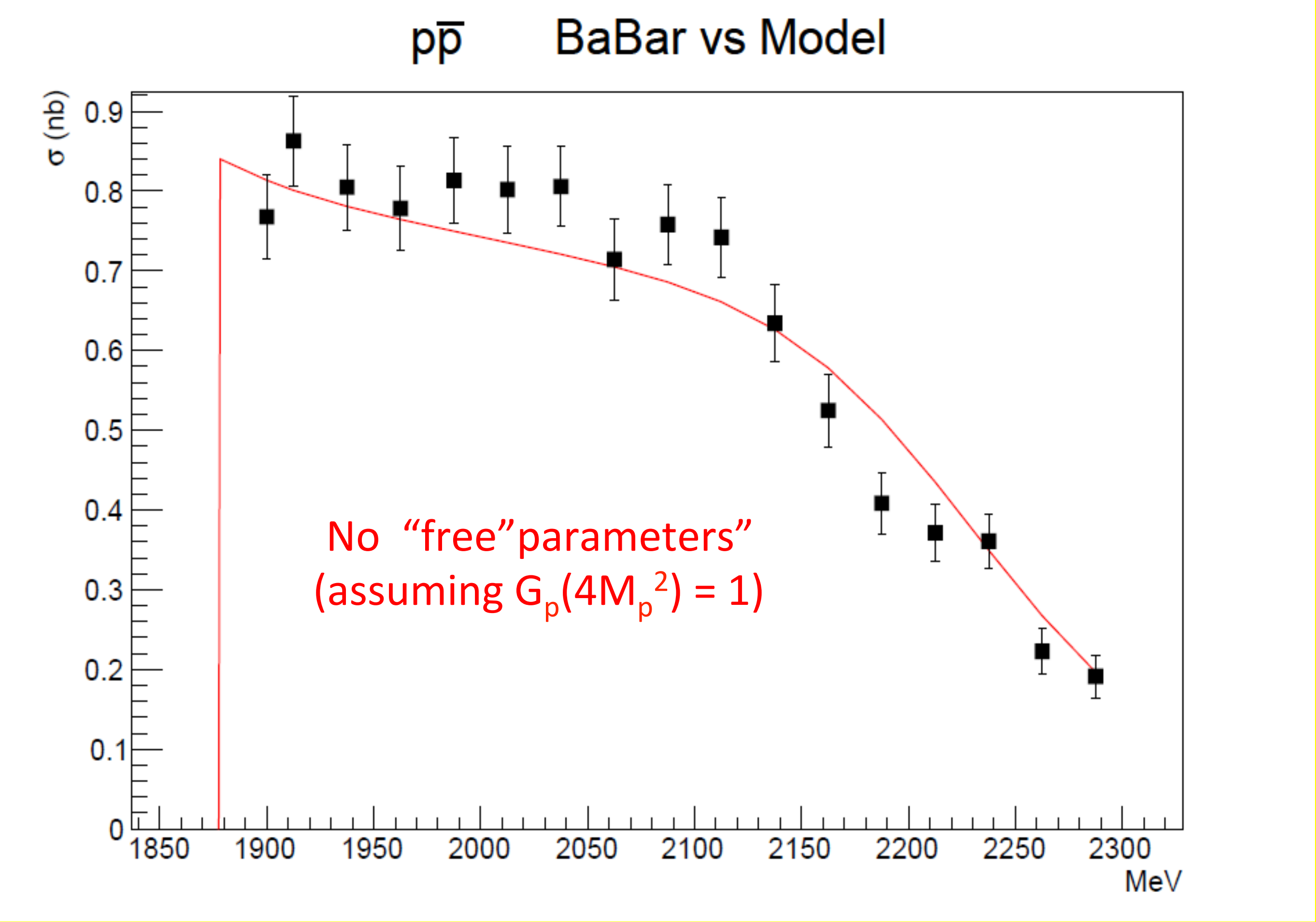
- BaBar data (ΔW included) can be fit with such a formula, leaving as "free" param Λ_{QCD} and the exponent N in $(W/\Lambda_{QCD})^N$. The result is Λ_{QCD} = 364 ± 7 MeV, N = 7.0 ± 0.3, in very good agreement with the expectation

Λ_{QCD} ~ 300 MeV , N ~ 8 .

$p\bar{p}$ close to threshold



$e^+e^- \to p\bar{p}$ (BaBar vs Model)



Other Charged Baryons

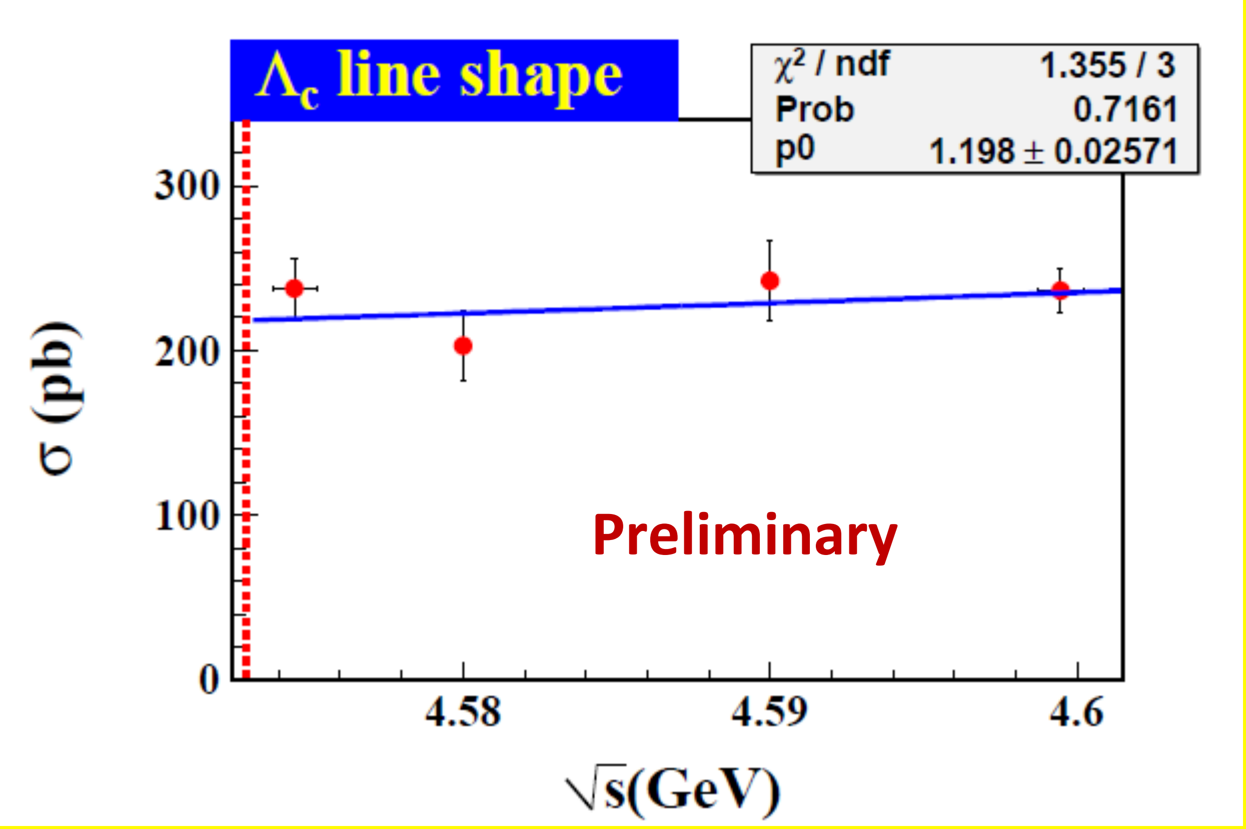
- Former model might be applied to other charged baryons, like, for instance: Λ_c , Σ^+, Σ^-.

- These baryons decay weakly into lighter particles and a *measurement exactly at threshold can be done*, taking into account cm energy spread.

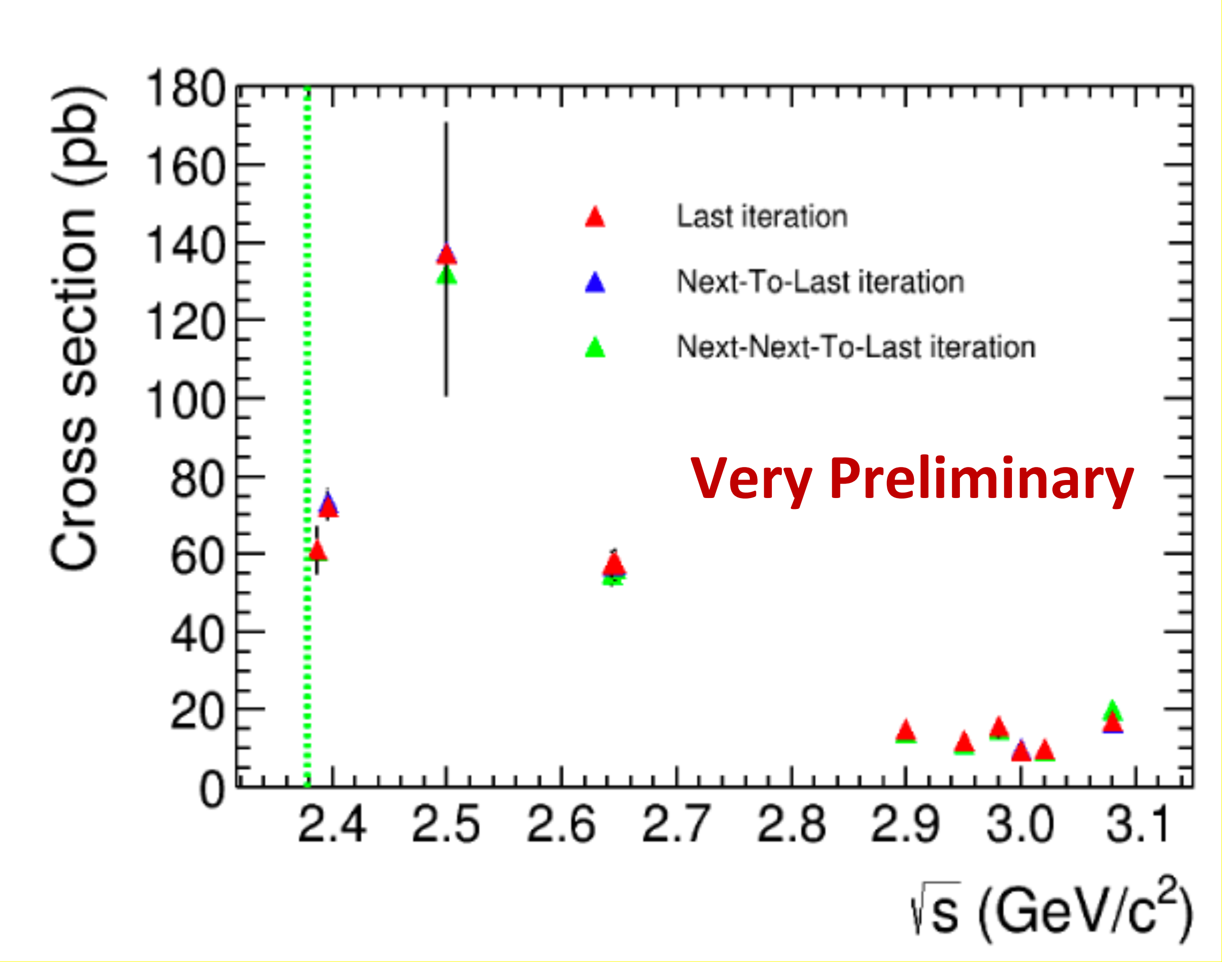
- **Λ_c case is a test if the proposed approach is right:**
  - **expected step at threshold, followed by a flat σ !**
  - the β scale is enlarged by ~ $\sqrt{(M_{\Lambda c} / M_p)}$, gaining in sensitivity (in part worsened by a wider cm energy spread).

- *Might be $G(4\ M_B^2)$ ~ 1 is a property of a light quarks baryon.*

$\Lambda_c \Lambda_{cbar}$



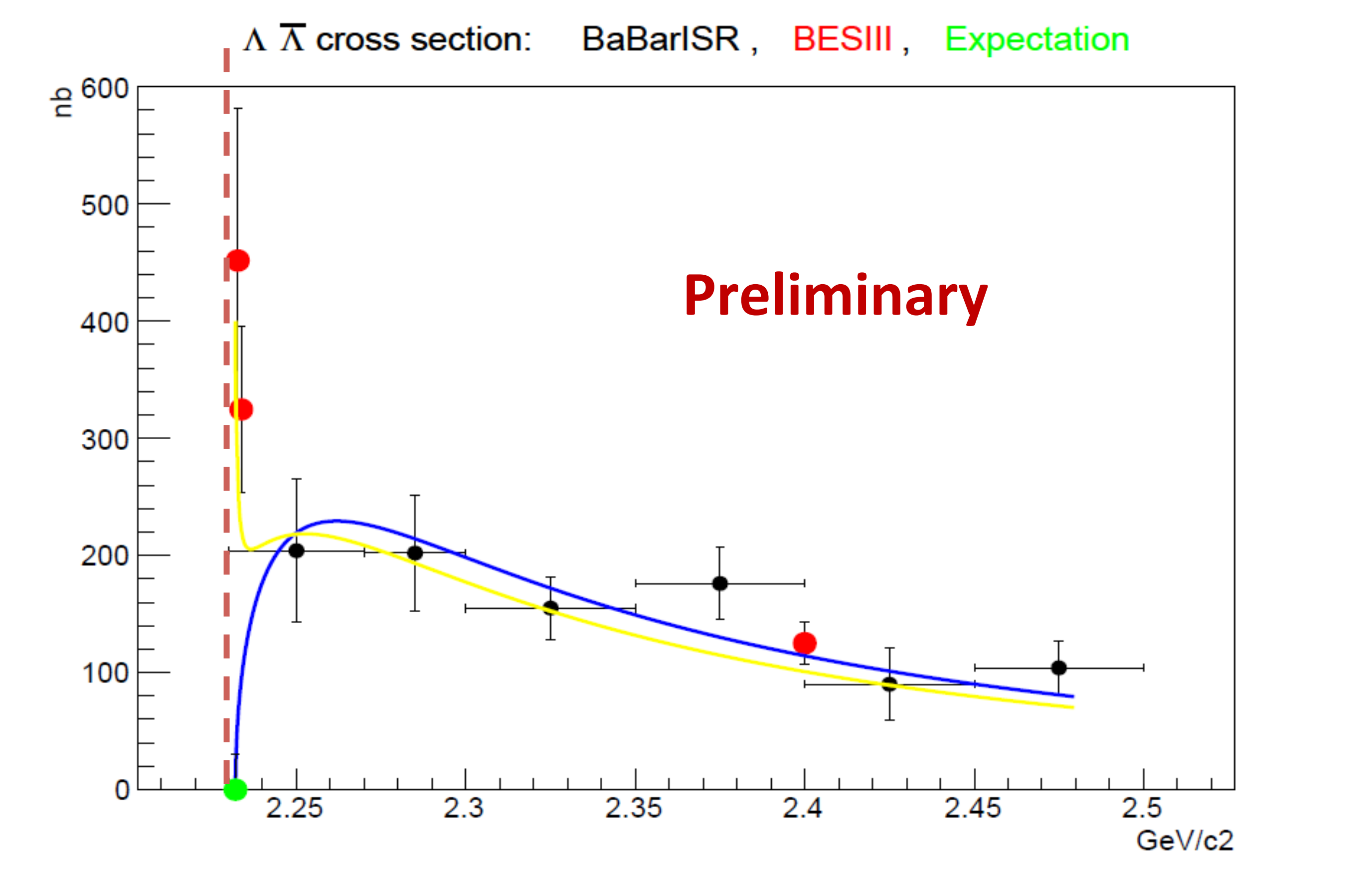
$\Sigma^{+}\Sigma_{bar}$



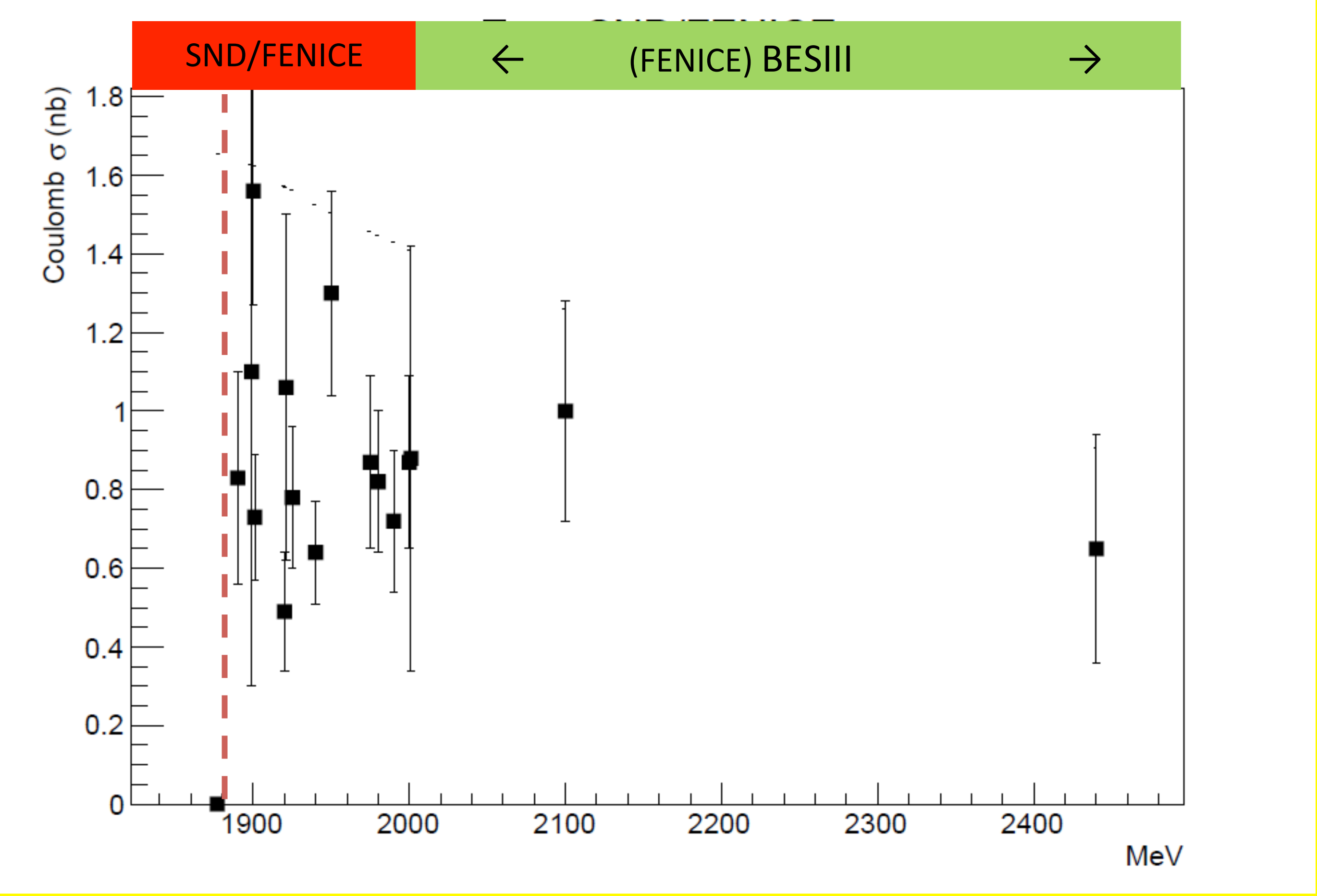
The case of Neutral Baryons

- Surprisingly enough even in the case of neutral baryons a non vanishing cross section at threshold has been found.
- That is the case of BESIII measurement of $\sigma(e^+e^- \to \Lambda\lambda_{bar})$ and very likely, the case of $\sigma(e^+e^- \to nn_{bar})$ (arXiv:1410.3188v1 [hep-ex])
- Willing to persist on Coulomb Enhancement a Coulomb interaction between outgoing quarks might be foreseen, that might be fit by a generalization of former formula.
- **Work in progress….**

$\Lambda\ \Lambda_{bar}$



nn_{bar}



SND/FENICE
← (FENICE) BESIII →
Coulomb σ (nb)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1900
2000
2100
2200
2300
2400
MeV

A Proposal to Change Baryon Formula

- In the general formula used to represent σ ($e^+e^- \to BB_{bar}$) Coulomb enhancement factorization is arbitrary. Look at *N.Cabibbo, PR 124 (1961)1577, M.Gourdin* PREP,11(1974) 29,…

$$\sigma(e^+e^- \to BB_{bar}) = 4\alpha^2/(3W_B^2)\cdot$$

$$\beta[|G_M(W_B^2)|^2+2M_B^2/W^2\,|G_E(W_B^2)|^2]$$

- The one/many γ exchange and strong as well as em ones should be embedded in G_E and G_M as FSI.
- Coulomb enhancement factorization is still consistent in the pointlike fermions case, but it is arbitrary in the Baryon case.
- Most of the previous controversial arguments are removed, avoiding such a factorization.

Very Temporary Conclusions

- A jump at threshold has been found in all the $\sigma\,(e^+ e^- \to B^+B^-_{bar})$ measured until now
- Coulomb Enhanced Factors are a natural explanation, (not factorized a priori) provided "α_S" is considered in the Resummation Factor
- A pp_{bar} cross section model close to threshold, that fits the data, without "free parameters", but physical ansatz only, is proposed.
- Work in progress:
  - D wave, nearby poles, periodic oscillations
  - The puzzle of $B^0B^0_{bar}$ non vanishing at threshold
- **HOWEVER..**

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.....THE COULOMB FORCE AWAKENS
SAID OBIWAN KENOBI

Alias Steve Olsen, who stimulated this work

Thanks for

谢谢

your attention

BaBar detection efficiency vs M_{pp}

Note the anomalous efficiency at threshold