HELMHOLTZ | GEMEINSCHAFT

Helmholtz-Institut Mainz

Measurement of Proton em Form Factors in BES-III

Cristina Morales
Helmholtz Institut Mainz

ECT Trento, 21.03.13

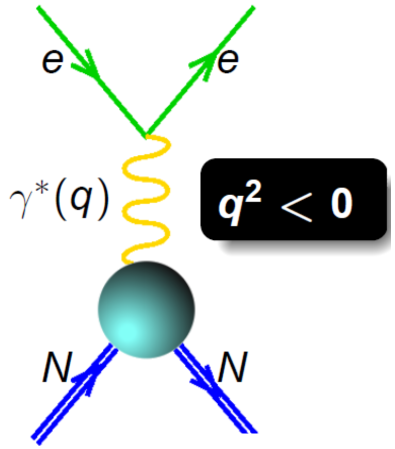
- Introduction
- Expectations from ISR Physics
- Ongoing analysis: $e^+e^- \rightarrow p\,\bar{p}\,\gamma_{ISR}$
- Expectations from energy scan
- Summary

Introduction

Electromagnetic Form Factors

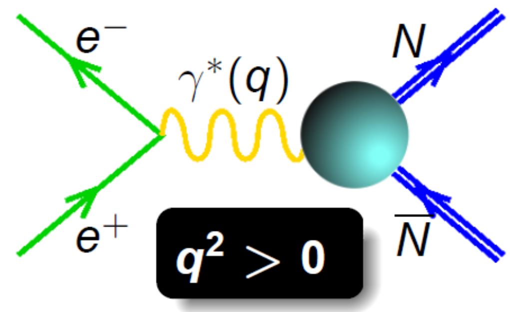
Space-like

$eN \rightarrow eN$



Time-like

$e^+e^- \leftrightarrow N\overline{N}$



Vector current, **two form factors** (F_1 and F_2)

$$\Gamma_\mu = e\bar{u}(p')[F_1(q^2)\gamma_\mu + \frac{\kappa}{2M_N}F_2(q^2)i\sigma_{\mu\nu}q^\nu]u(p)e^{iqx}$$

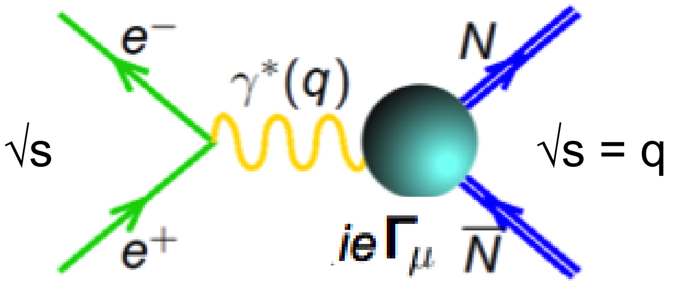
Dirac	**Pauli**
$F_1^p(q^2=0)=1$	$F_2^p(q^2)=1$
$F_1^n(q^2=0)=0$	$F_2^n(q^2)=1$

Sachs

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

How to measure

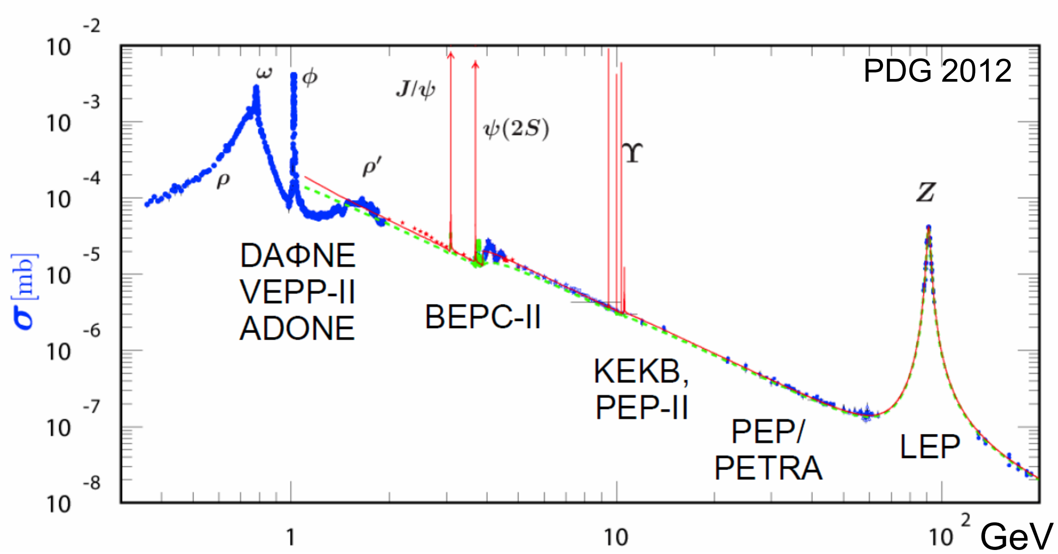
Standard technique **energy scan:** at each energy point measurement of the cross section done

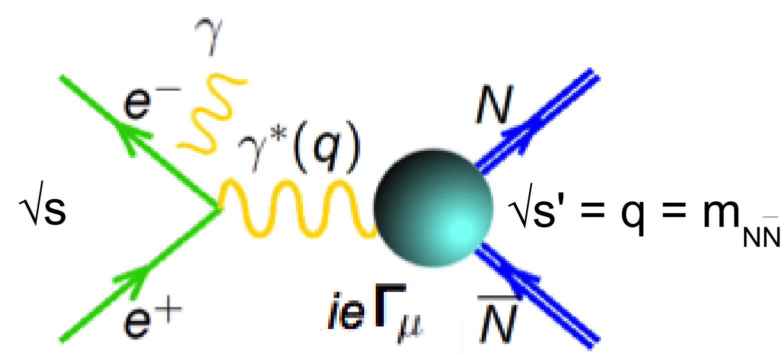


$$\sigma_{e^+e^-\to N\bar{N}} = \frac{4\pi\alpha^2\beta}{3s}\, C_N(s)\, \left[\left|G_M^N(q^2)\right|^2 + \frac{2M_N^2}{s}\left|G_E^N(q^2)\right|^2 \right]$$

The low statistics collected, didn't allow for angular analysis to extract G_E and G_M

Modern **high luminosity e+ e- particle factories** designed for (almost) **fixed cm energy**:





$$x \equiv 1 - m^2/s = 2E_\gamma/\sqrt{s}$$

$$m^2_{p\bar{p}} = s(1-x)$$

In BESIII we can make use of both techniques: **energy scan** and **initial state radiation!**

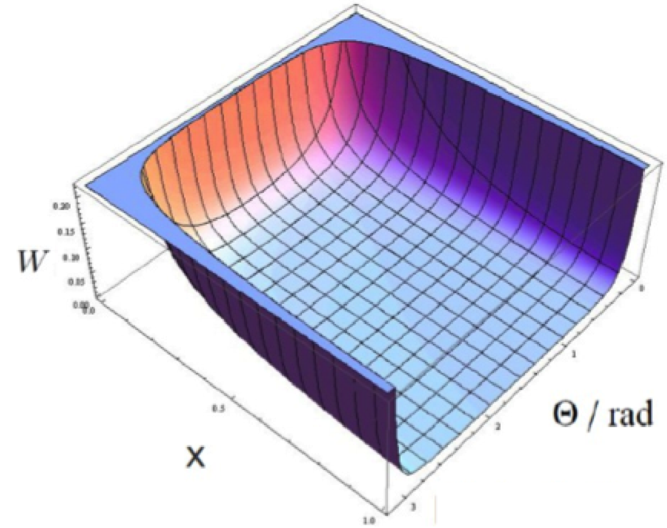
ISR vs direct e+e- annihilation

$$\frac{d^2\sigma(e^+e^-\rightarrow \gamma p\bar{p})}{dx d\theta_\gamma} = W(x,\theta_\gamma)\,\sigma_{e^+e^-\rightarrow p\bar{p}}(s)$$

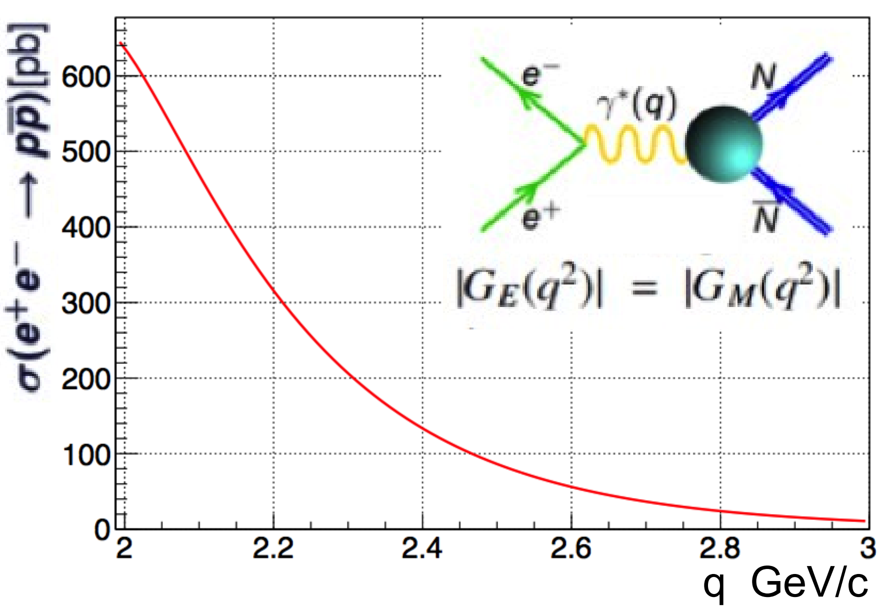
$$W(s^{LO}, x, \theta^*_\gamma) = \frac{\alpha}{\pi x}\left(\frac{2-2x+x^2}{\sin^2\theta^*_\gamma} - \frac{x^2}{2}\right)$$

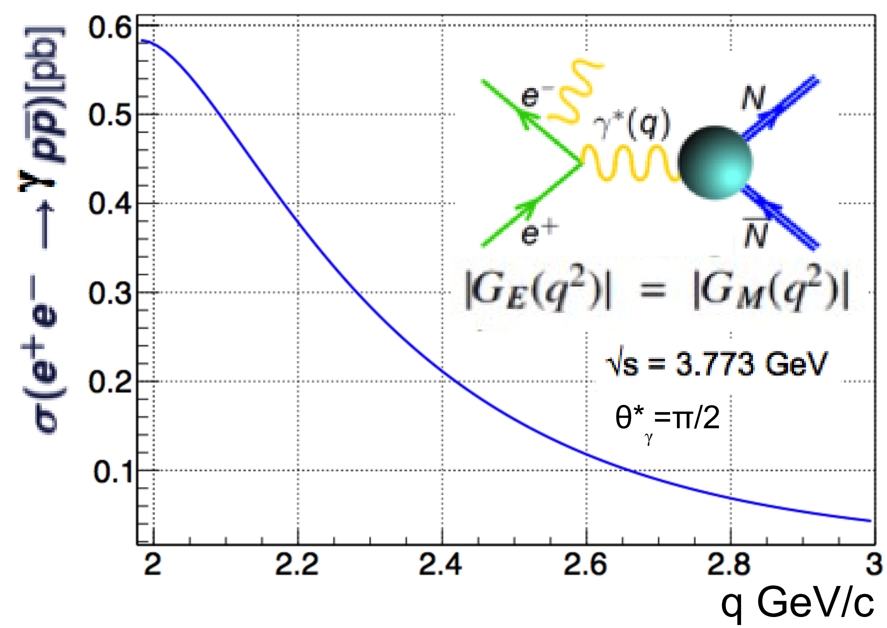
$$\frac{d\sigma}{d(\cos\theta)} = \frac{\pi\alpha_e^2 C}{8M^2\tau\sqrt{\tau(\tau-1)}}\left[\tau|G_M|^2(1+\cos^2\theta) + |G_E|^2\sin^2\theta\right]$$

C: Coulomb interaction correction at threshold



$$x \equiv 1 - m^2/s = 2E_\gamma/\sqrt{s}$$





ISR pros and cons

Advantages

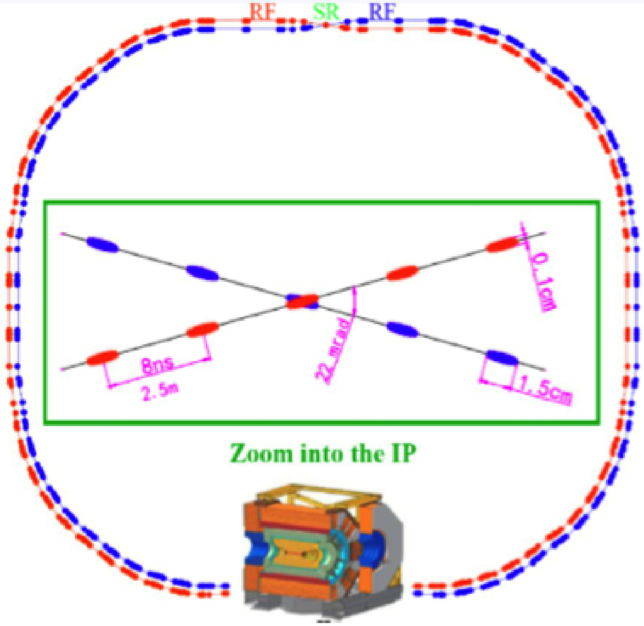
- Low $\boldsymbol{\sigma}_{ISR}$ **compensated by high luminosity** of b,c factories!!
- Same observables as dedicated experiments at low energies and within higher ranges
- Comes for free, no need for a dedicated experiment
- All q at the same time: **better control of sytematics**
- High luminosity also at threshold
- **Acceptance at threshold ≠ 0**

Drawbacks

- ISR Luminosity proportional to bin width
- More background

Expectations from ISR Physics in BES-III

BESIII @ BEPCII



Design Features:

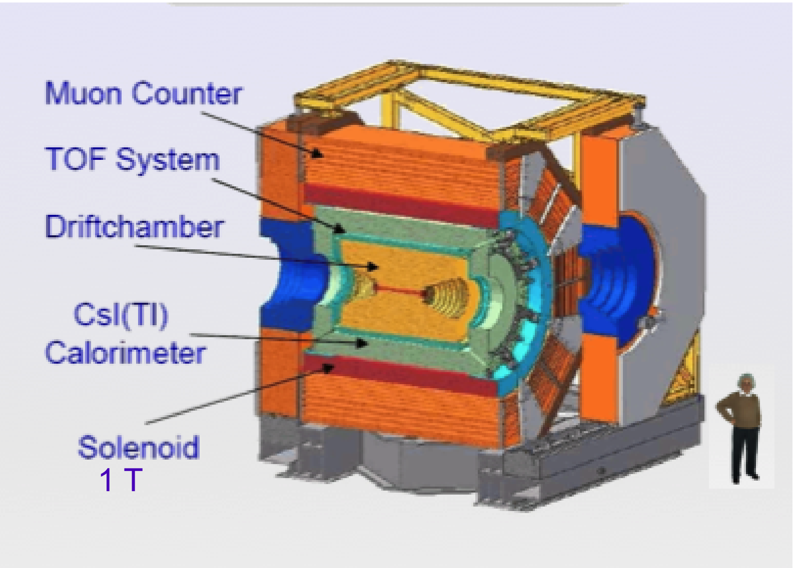
- Beam energy: 1.0 – 2.3 GeV
- Crossing angle: 22 mrad
- **Luminosity: 10^{33} cm^{-2} s^{-1}**
- **Optimum energy: 1.89 GeV**
- Energy spread: $5.16 \cdot 10^{-4}$
- Number of bunches: 93
- Bunch length: 1.5 cm
- Total current: 0.91 A

MDC: main drift chamber (He 60% + propane 40%):
$\sigma(p)/p < 0.5\%$ for 1GeV tracks, $\sigma(xy) = 130$ μm
$\sigma(dE/dx)/(dE/dx) < 6\%$

TOF: time of flight (two layers plastic scintillator): $\sigma(t) < 90$ ps

EMC: Cs I(Tl), barrel+2 end caps:
$\sigma(E)/E < 2.5$ %, $\sigma(x) < 6$mm for 1 GeV e-

MUC: time of flight (RPC): $\sigma(xy) < 2$ cm



Typical resolutions: **$\sigma(J/\psi) = 9$ MeV , $\sigma(\pi^0) = 5$ MeV**

Phokhara generator

[H.Czyz,J.H.Kühn,E.Nowak,G.Rogrigo, Eur. Phys. J. C35, 527 (2004)]

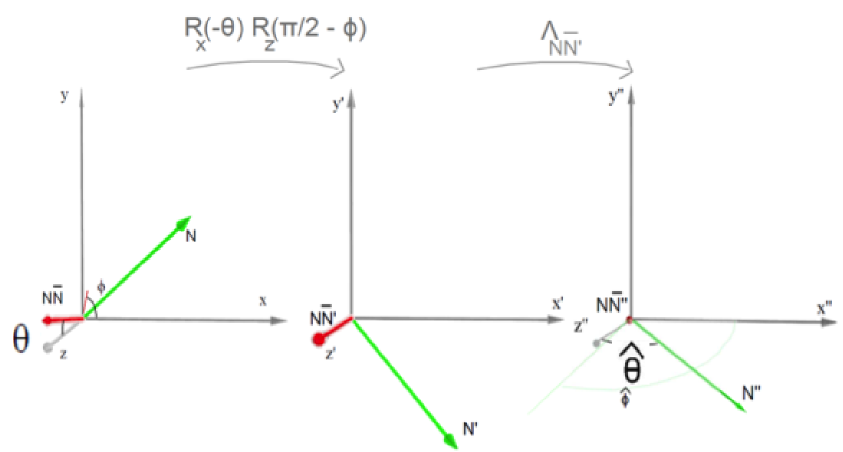
- Parametrization of form factors taken from F. Iachello et al., Phys. Lett. B43, 191 (1973)
- Analitycal continuation to time-like region as in F. Iachello, nucl-th/0312074 and S.J. Brodsky et al., hep-ph/3010277

$$e^+(p_1) + e^-(p_2) \to \bar{N}(q_1) + N(q_2) + \gamma(k)$$

Form factors decomposed in isoscalar and isovectorial parts: $F^p_{1,2} = F^s_{1,2} + F^v_{1,2}\,, \qquad F^n_{1,2} = F^s_{1,2} - F^v_{1,2}$

Differential cross section including ISR: $\mathrm{d}\sigma = \frac{1}{2s} L_{\mu\nu} H^{\mu\nu} \mathrm{d}\Phi_2(p_1 + p_2; Q, k)\mathrm{d}\Phi_2(Q; q_1, q_2)\frac{\mathrm{d}Q^2}{2\pi}$

- In a particular frame, the electric and magnetic contributions can be well separated:



$Q^2 \ll s$

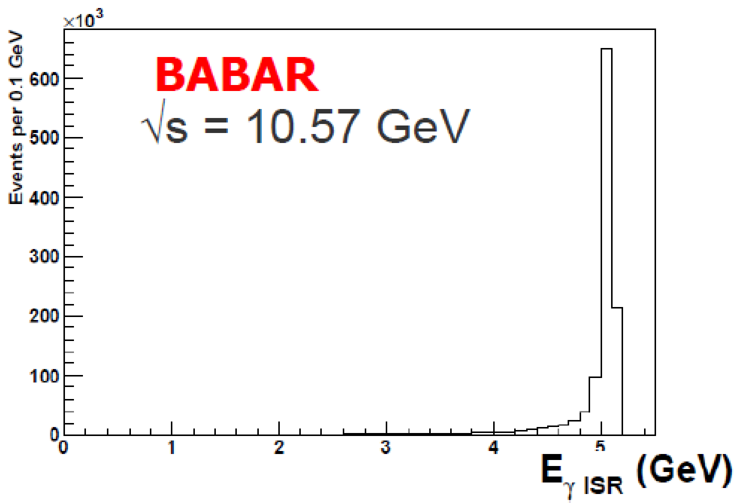
$$L_{\mu\nu}H^{\mu\nu} = \frac{(4\pi\alpha)^3}{Q^2}\frac{(1+\cos^2\theta_\gamma)}{(1-\cos^2\theta_\gamma)} \times 4\left(\left|G_M^N\right|^2(1+\cos^2\hat{\theta}) + \frac{1}{\tau}\left|G_E^N\right|^2\sin^2\hat{\theta}\right)$$

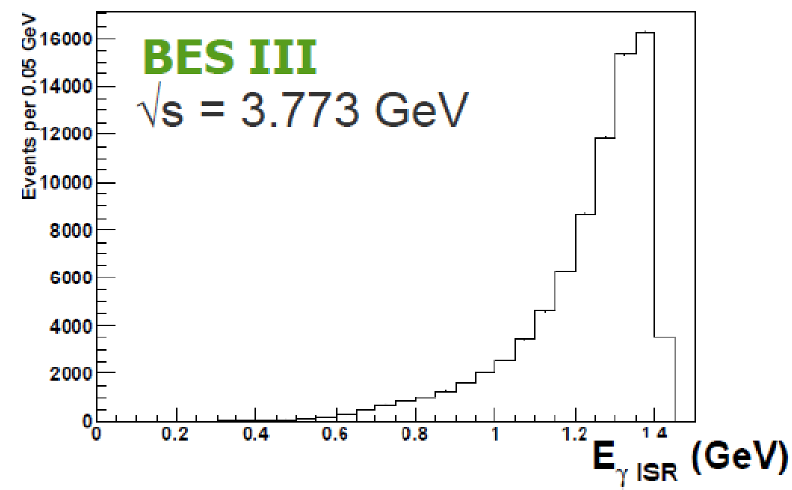
ISR @ BABAR / BESIII

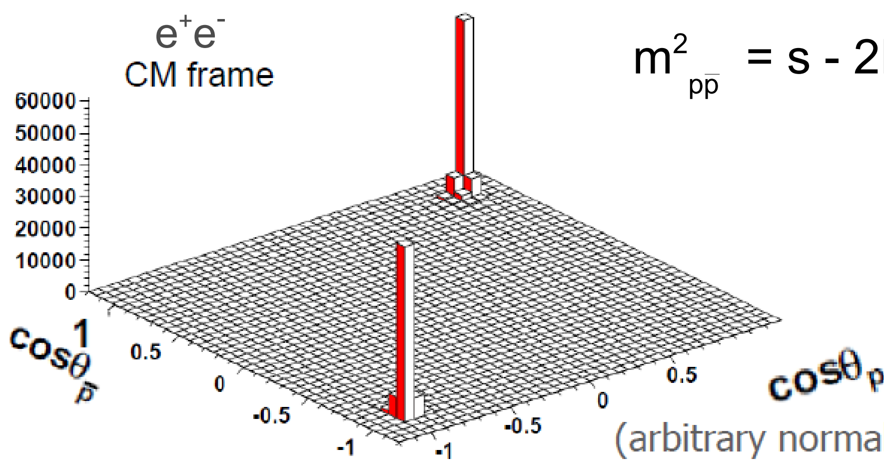
Geometrical acceptance: $p\bar{p}$ system boosted opposite to the ISR photon

$M_{hadr} << \sqrt{s}$ → need high luminosities
<u>Photon tagging unavoidable</u>

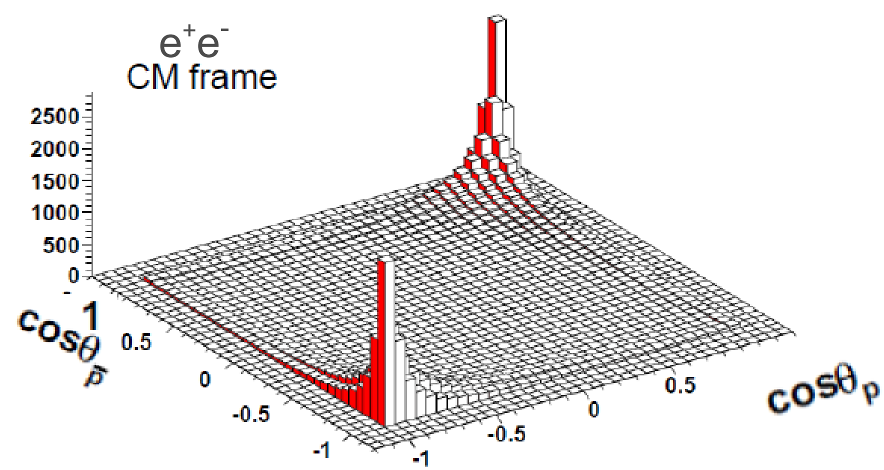
M_{hadr} < but close to $\sqrt{s}$
untagged measurement possible







$$m^2_{p\bar{p}} = s - 2E_\gamma\sqrt{s}$$



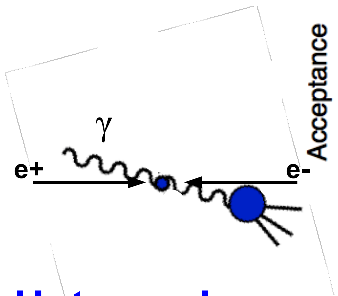
(arbitrary normalization)

ISR @ BABAR / BESIII

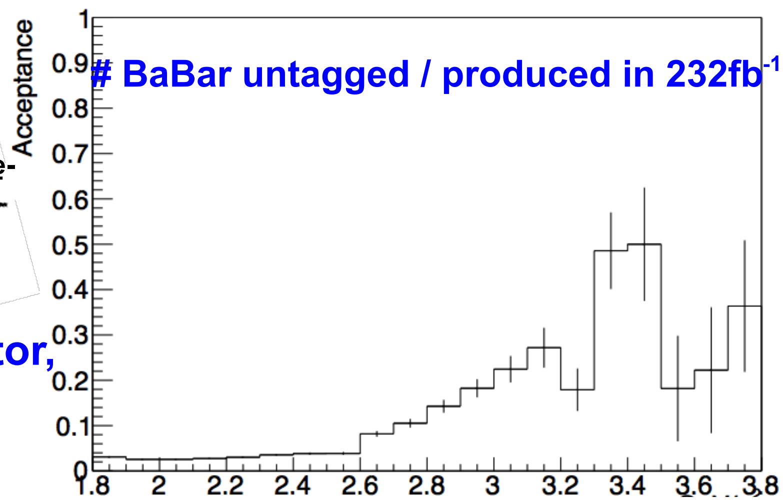
Geometrical acceptance:

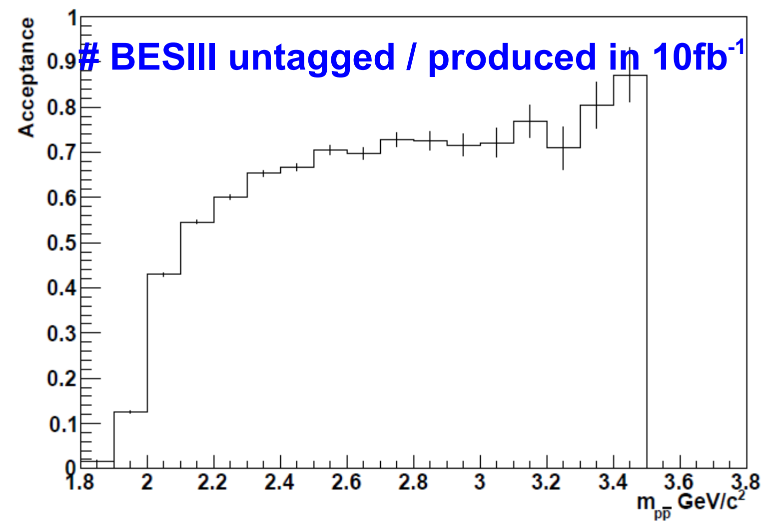
$M_{hadr} << \sqrt{s} \rightarrow$ need high luminosities
Photon tagging unavoidable

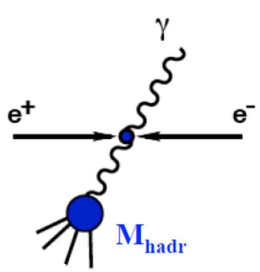
$M_{hadr} <$ but close to $\sqrt{s}$
untagged measurement possible



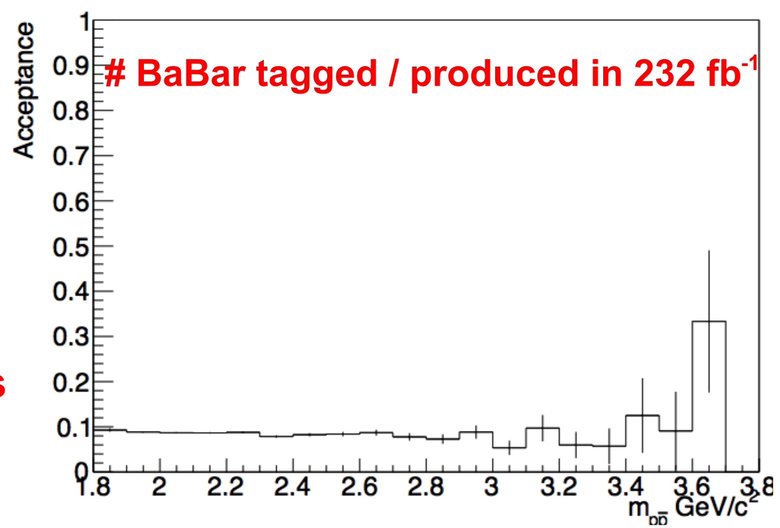
Untagged γ:
γ not in detector, hadrons in detector

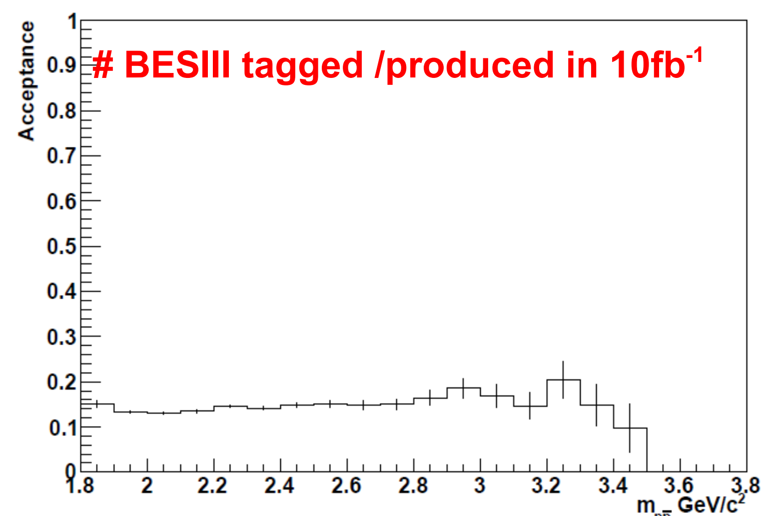






Tagged γ:
γ and hadrons in detector



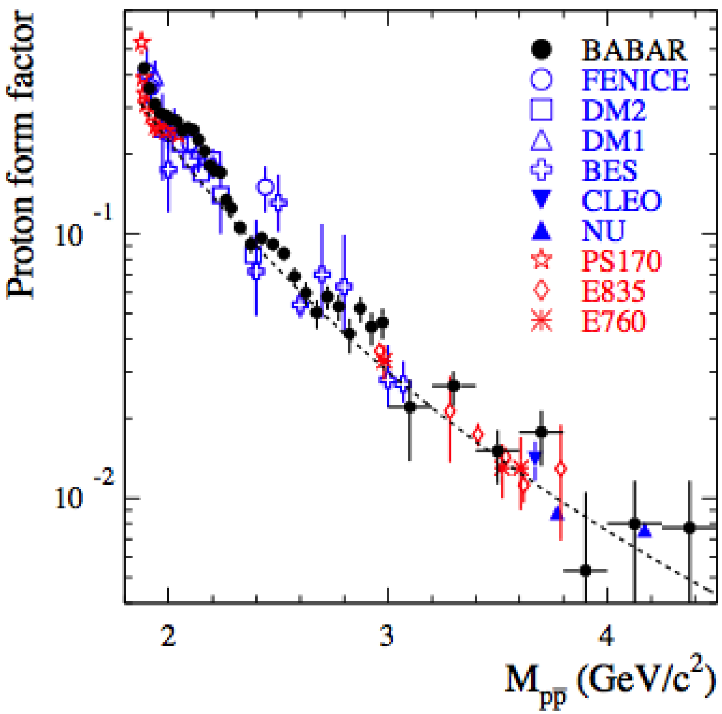


Proton em FFs in TL region

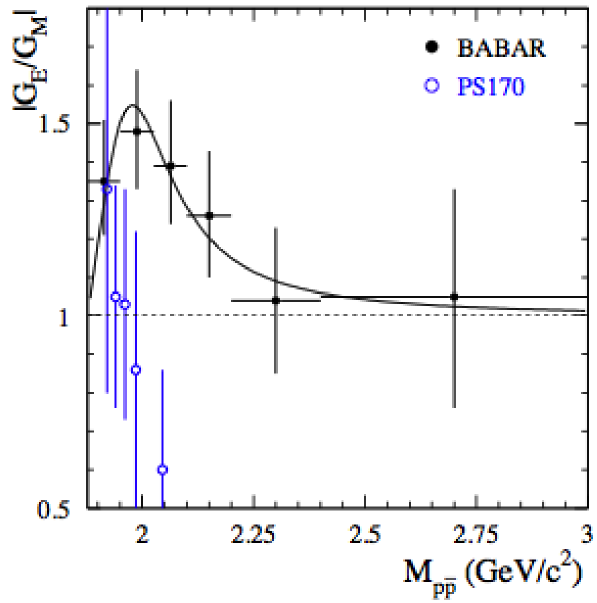
[BaBar collaboration. ArXiv: 1302.0055v1 [hep-ex]]

- **Effective form factor:**
  - **extracted from σ measurement**
  - **Separation between G_E and G_M not possible**

$$\sigma(m_{p\bar{p}}) = \frac{dN/dm_{p\bar{p}}}{\varepsilon R\, dL/dm_{p\bar{p}}} = \frac{4\pi\alpha^2\beta C}{3\,q^2}\left[\left|G_M(q^2)\right|^2 + \frac{1}{2\tau}\left|G_E(q^2)\right|^2\right]$$



- **$|G_E(q^2)/G_M(q^2)|$ extracted from angular analysis**

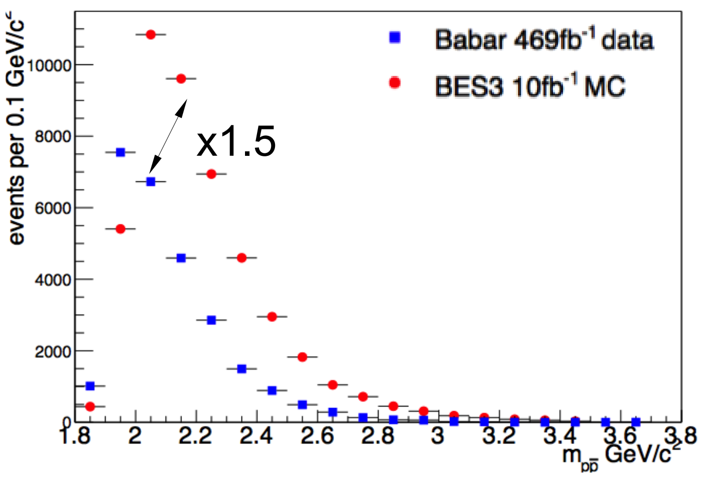


- Maximum at 2 GeV/c^2
- $G_E > G_M$ for all $M_{p\bar{p}}$ (≠ space-like)
  - Inconsistent with PS170
  - Agreement at threshold
- Consistent with $|G_E/G_M|$ =1 at large M_{pp}

ISR @ BESIII

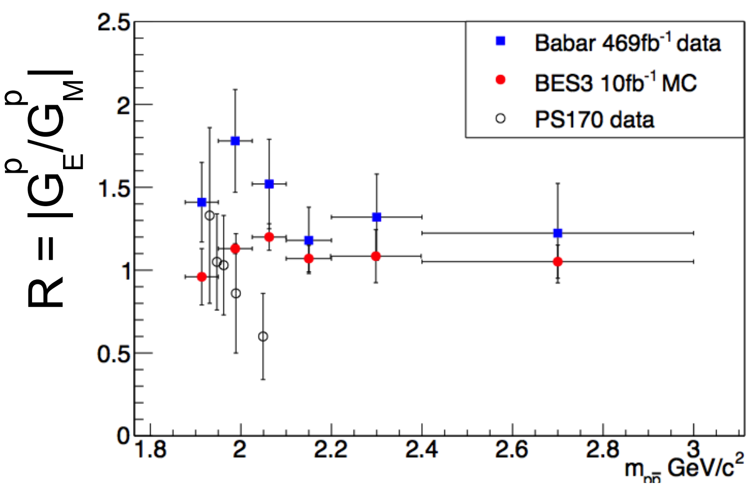
What could BES-III do for this channel?

	BES-III	BABAR
$\sqrt{s}$(GeV))	3.77	10.57
$\sigma_{ISR,NLO}$(nb)	8.12×10^{-3}	0.7×10^{-3}
$L(\text{fb}^{-1})$	10	469
$N_{gen} = L \times \sigma$	81261	553917
measurement	"untagged + tagged"	"tagged"
geometry cuts (degrees)	$21.6 < \theta^{cm}_{p,\bar{p}} < 158.7$	$30 < \theta^{cm}_{p,\bar{p}} < 160$
	$0 < \theta^{cm}_{\gamma ISR} < 180$	$30 < \theta^{cm}_{\gamma ISR} < 160$
$N_{expected}$	45623 (34070 + 11553)	31013



About 24000 evts after additional 70% selection efficiency on untagged and 40% selection efficiency on tagged evts. **Which resolution in $|G_E/G_M|$ can BESIII achieve in 10fb^{-1}?**

	F_0	F_1	χ^2	R
$1.877 < m_{p\bar{p}} \leq 1.950$	204 ± 11	188 ± 32	68.7	0.96 ± 0.17
$1.950 < m_{p\bar{p}} \leq 2.025$	926 ± 32	1175 ± 91	59.6	1.13 ± 0.03
$2.025 < m_{p\bar{p}} \leq 2.1$	1319 ± 39	1898 ± 113	57.2	1.20 ± 0.08
$2.1 < m_{p\bar{p}} \leq 2.2$	1591 ± 43	1836 ± 121	43.6	1.07 ± 0.08
$2.2 < m_{p\bar{p}} \leq 2.4$	206 ± 12	242 ± 34	82.5	1.08 ± 0.16
$2.4 < m_{p\bar{p}} \leq 3.0$	989 ± 34	1081 ± 95	42.6	1.05 ± 0.10



BESIII: 70% selection efficiency applied on untagged data and 40%on tagged data

Ongoing $e^+e \to p\,\bar{p}\,\gamma_{ISR}$ @ 3.773 GeV in BES-III

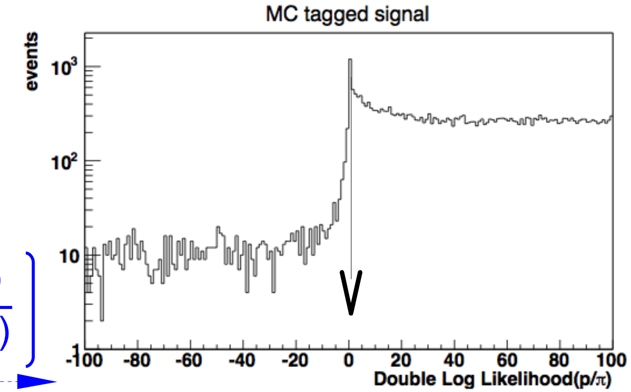
$e^+e \rightarrow p\,\bar{p}\,\gamma_{ISR}$

- **Data sample used: 2.9 fb-1 data collected at 3.773 GeV**
- Selection of **tagged** events: **photon, proton and pbar detected**

Tracks identification:

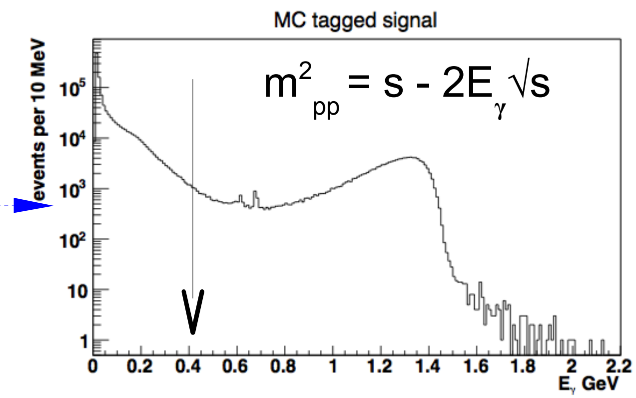
Well inside MDC detector acceptance,
Kalman reconstructed,
should come from interaction point (IP),
identified as proton

$$DLL(p/pi) = 2 \times \log \left(\frac{prob(p)}{prob(pi)} \right)$$



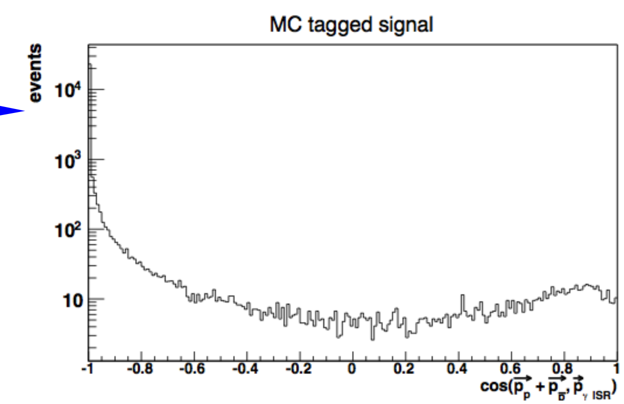
ISR Photon identification:

Well inside em calorimeter acceptance,
minimum Energy requirement,
in time window corresponding to collission



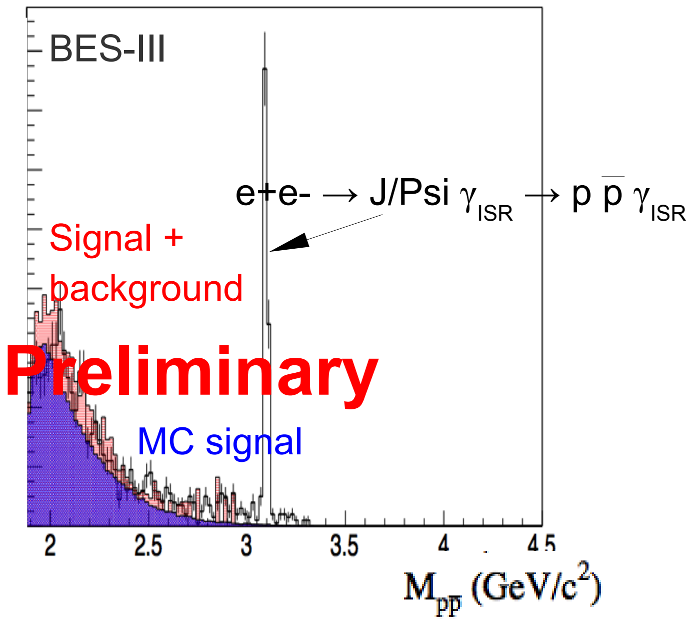
Event reconstruction:

Exactly two tracks from IP, with opposite charge.
At least one ISR photon candidate (E > 0.4 GeV).
ISR geometry: 180° between ISR photon and ppbar at e+e- CM
No missing momentum and energy,
Pi0 Veto
Eta Veto
Track mass compatible with proton mass

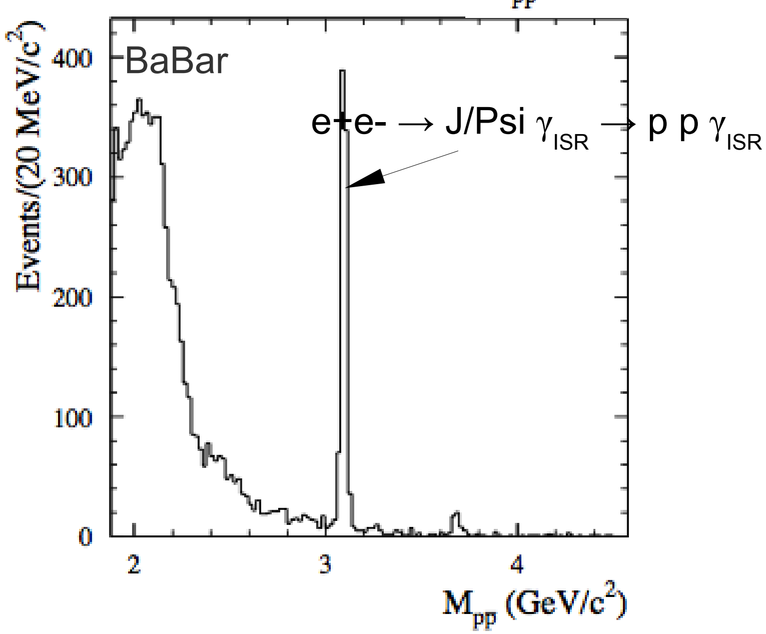


$e^+e \to p\,\bar{p}\,\gamma_{ISR}$

Selected event candidates:



- **2.9fb^{-1}** data available at √s = 3.77 GeV
- Only selected **tagged** events in this plot
- **Still background from $p\bar{p}\pi^0$ and $p\bar{p}\pi^0\gamma_{ISR}$ and FSR**
- With **10fb-1 we will improve BABAR stat. resolution by 2**
- **Three times more statistics available from the untagged analysis**

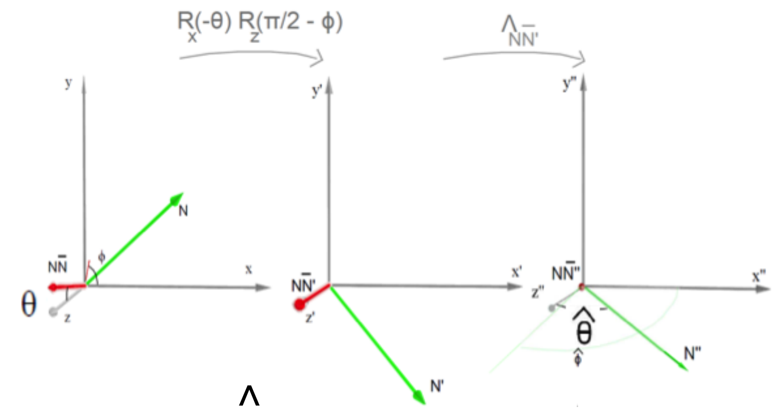


- **469fb^{-1}** data at √s = 10.6 GeV
- **Only tagged** events **possible**
- About **2 times more data** being analyzed.
- Remaining **background from $p\bar{p}\pi^0$ (6%)**

$e^+e \rightarrow p\,\bar{p}\,\gamma_{ISR}$

- **Ongoing next steps:**
  - **Angular analysis in**

$$\frac{\mathrm{d}N}{\mathrm{d}cos\hat{\theta}} = A(H_M(cos\hat{\theta},m) + |\frac{G_E}{G_M}|^2 H_E(cos\hat{\theta},m))$$



Strategy:

1.- **Subtract background** in bins of m_{pp} and $cos\hat{\theta}$

2.- **Correct** data (or MC) with **selection efficiencies, data - MC resolution effects, etc**

3.- Fit according to previous formula using **MC distributions as theoretical function**

$$F((cos\hat{\theta},m)) = F_0\,\frac{\sigma_0}{\sigma_1}\cdot|G_M|^2\cdot H_M(cos\hat{\theta},m) + F_1\cdot|G_E|^2\cdot H_E(cos\hat{\theta},m)$$

Reconstructed data without background corrected with selection efficiency

Ratio of tagged cross sections

Normalized true MC with GE = 0

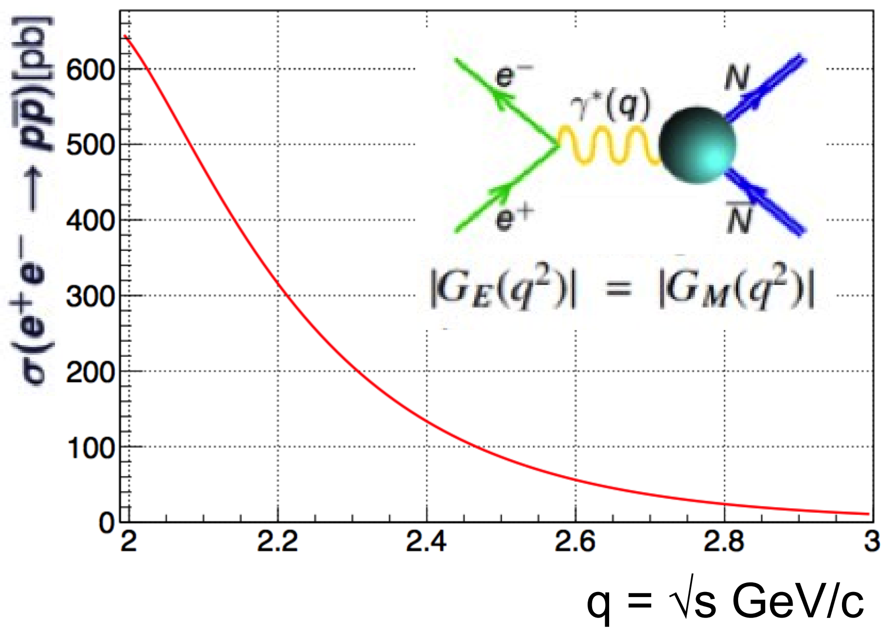
Normalized true MC with GM = 0

Expectations from energy scan in BES-III

Energy scan

- There is an approved proposal to do an energy scan between sqrt(s) = 2 to 3 GeV in steps of 100 MeV
- This scan started already last year collecting little statistics and will take place presumaby next year
- What will this suppose for the e+e- → ppbar channel?

Ecm	L(1/pb)	Signal events produced:
2.0	7.1	4576
2.1	10.2	4826
2.2	13.5	4294
2.3	20.9	4340
2.4	25.1	3770
2.5	29.4	2550
2.6	37.9	2132
2.7	48.0	1762
2.8	60.3	1456
2.9	69.9	1118

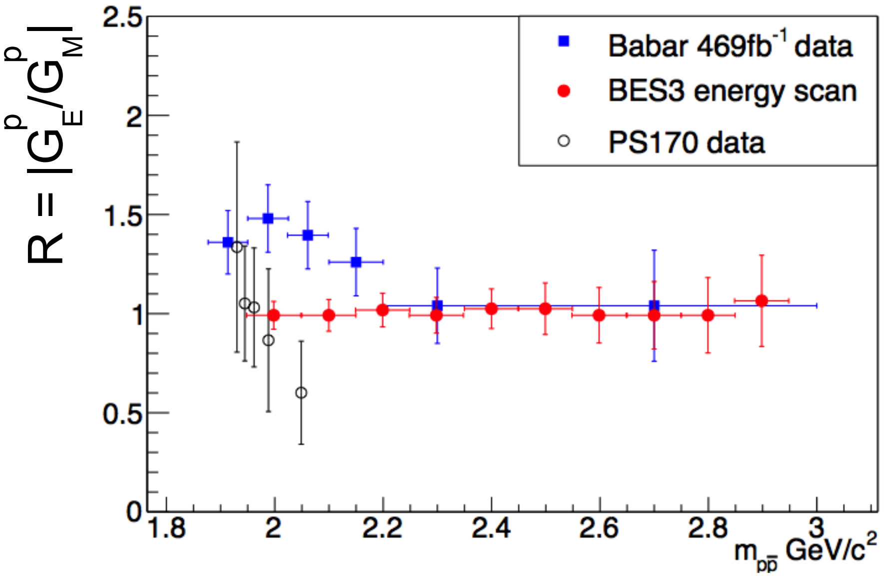


Let us assume we collect **the events produced with 50%** efficiency (conservative approach),
what would be the resolution we can achive in the measrument of |GE| / |GM|

Energy scan

- Assuming a detection efficiency of 50% for the expected data at each q, we obtain an expected resolution on |GE|/|GM|:

	R	χ^2
$q = m_{p\bar{p}} = 2.0$	0.99 ± 0.07	0.26/8
$q = m_{p\bar{p}} = 2.1$	0.99 ± 0.08	0.26/8
$q = m_{p\bar{p}} = 2.2$	1.01 ± 0.09	0.22/8
$q = m_{p\bar{p}} = 2.3$	0.99 ± 0.09	0.10/8
$q = m_{p\bar{p}} = 2.4$	1.02 ± 0.10	0.21/8
$q = m_{p\bar{p}} = 2.5$	1.02 ± 0.13	0.12/8
$q = m_{p\bar{p}} = 2.6$	0.99 ± 0.14	0.04/8
$q = m_{p\bar{p}} = 2.7$	0.99 ± 0.17	0.04/8
$q = m_{p\bar{p}} = 2.8$	0.99 ± 0.19	0.04/8
$q = m_{p\bar{p}} = 2.9$	1.06 ± 0.23	0.03/8



Where as data, a toy MC with GE = GM has been generated according to:

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

and no Coulomb correction at threshold has been considered

The so generated MC was fitted with the 2-parameter function: **f(x) = Norm · [tau (1+x^2) +R^2· (1-x^2)]**

Energy scan

E_{cm}	L(1/pb)	N_{ppbar} * 50%Eff	$N_{ppbarISR}$(10fb^{-1}produced)	6% Eff_{tagg} +30%Eff_{untagg}
2.0	7.1	2333	21417 (1.95 < E'_{cm} <= 2.05 GeV)	1285 + 6425 = 7710
2.1	10.2	2451	16842	1011 + 5053 = 6063
2.2	13.5	2177	11474	688 + 3442 = 4131
2.3	20.9	2197	7450	447 + 2235 = 2682
2.4	25.1	1705	4573	274 + 1372 = 1646
2.5	29.4	1290	2763	166 + 829 = 995
2.6	37.9	1078	1631	98 + 489 = 587
2.7	48.0	891	1025	62 + 308 = 369
2.8	60.3	735	612	37 + 184 = 220
2.9	69.9	565	403	24 + 121 = 145

MORE STATISTICS, MUCH FASTER

	R	χ^2
$q = m_{p\bar{p}} = 2.0$	0.99 ± 0.07	0.26/8
$q = m_{p\bar{p}} = 2.1$	0.99 ± 0.08	0.26/8
$q = m_{p\bar{p}} = 2.2$	1.01 ± 0.09	0.22/8
$q = m_{p\bar{p}} = 2.3$	0.99 ± 0.09	0.10/8
$q = m_{p\bar{p}} = 2.4$	1.02 ± 0.10	0.21/8
$q = m_{p\bar{p}} = 2.5$	1.02 ± 0.13	0.12/8
$q = m_{p\bar{p}} = 2.6$	0.99 ± 0.14	0.04/8
$q = m_{p\bar{p}} = 2.7$	0.99 ± 0.17	0.04/8
$q = m_{p\bar{p}} = 2.8$	0.99 ± 0.19	0.04/8
$q = m_{p\bar{p}} = 2.9$	1.06 ± 0.23	0.03/8

	F_0	F_1	χ^2	R
$1.877 < m_{p\bar{p}} \leq 1.950$	204 ± 11	188 ± 32	68.7	0.96 ± 0.17
$1.950 < m_{p\bar{p}} \leq 2.025$	926 ± 32	1175 ± 91	59.6	1.13 ± 0.03
$2.025 < m_{p\bar{p}} \leq 2.1$	1319 ± 39	1898 ± 113	57.2	1.20 ± 0.08
$2.1 < m_{p\bar{p}} \leq 2.2$	1591 ± 43	1836 ± 121	43.6	1.07 ± 0.08
$2.2 < m_{p\bar{p}} \leq 2.4$	206 ± 12	242 ± 34	82.5	1.08 ± 0.16
$2.4 < m_{p\bar{p}} \leq 3.0$	989 ± 34	1081 ± 95	42.6	1.05 ± 0.10

Conclusions & Outlook

- **Hadronic form factors measurements using ISR highly competitive** (with 10fb-1, 2-3 times more statistics than BABAR with 469 fb-1)
- The analysis $e^+e^- \to p\bar{p}\,\gamma_{ISR}$ channel is ongoing . Next steps would be to get the fit working for data with background subtracted, correct for different reconstruction efficiencies Data and MC. The untagged analysis is also ongoing and can increase the available statistics by a factor 3
- The analysis of $e^+e^- \to n\bar{n}\,\gamma_{ISR}$ channel is very challenging. Only tagged measurement possible. With the currect selection efficiency we expect in 2.9 fb^{-1} about 100 signal events but with background still to be estimated. However in 10 fb^{-1} we can have a measurement with unprecedented statistics
- Once the **Z**ero **D**egree **D**etector is operative (1.4 mrad – 13 mrad), the number of tagged events will increase by 1.5. This could be specially interesting for the ISR neutron channel, since the ZDD is 14 cm long PbWO4 (ρ =8.3 g/cm^3, λ_I = 168.3 g/cm^2 and 15.7X_0)
- **The energy scan in the 2-3 GeV** region will **increase the statistics by a factor 2-4 in the last bins making possible the measurement of 6 additional points at the end of the spectrum. A finer binning at 2.25 and 3 GeV is also foreseen.** An energy scan up to 4.5 GeV is also scheduled
- Some data were already collected during June 8-16th , 2012 at Ecm: 2.23, 2.4, 2.8, 3.4 GeV. Ongoing analysis: $e^+e^- \to p\bar{p}$, $e^+e^- \to n\bar{n}$, $e^+e^- \to \Lambda\bar{\Lambda}$ at different stages