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Future Perspectives on Baryon Form Factor measurements with BES III

XIIth International Conference on Quark Confinement and the Hadron Spectrum (CONF12)

Karin Schönning for the BES III collaboration

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Outline

- Introduction: Baryon structure and ElectroMagnetic Form Factors (EMFF's)
- BES III at BEPC-II
- Recent EMFF's measurements from BES III
- Future prospects: New energy scan
- Coming upgrade
- Summary

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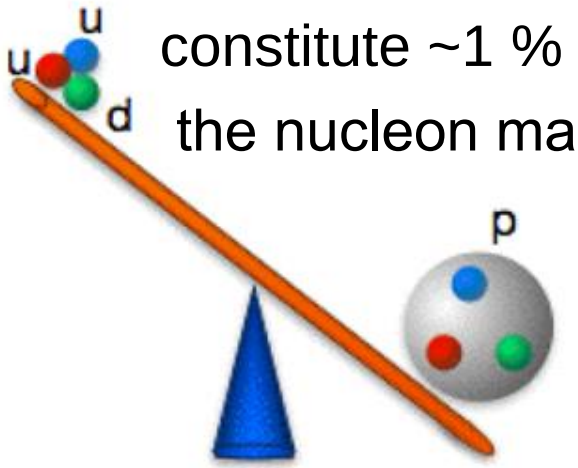
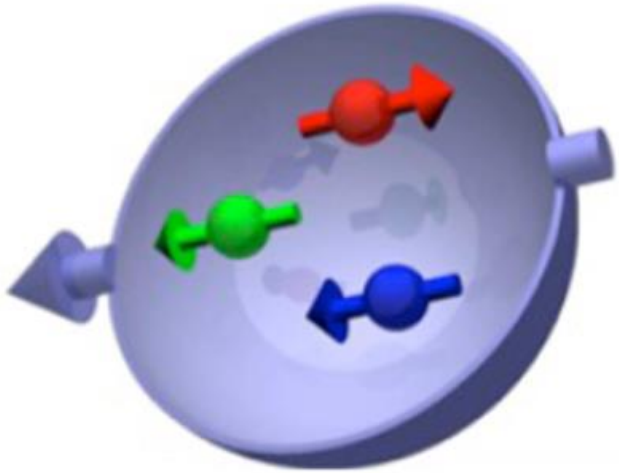
The mysterious nucleon

- Nucleons constitute the major part of the visible mass of the Universe.
- Baryons are the simplest system for which the non-abelian nature of the strong interaction is manifest.
- Yet, we don't yet understand it:

  The valence quarks only constitute ~1 % of the nucleon mass…





…and about 1/3 of the spin!

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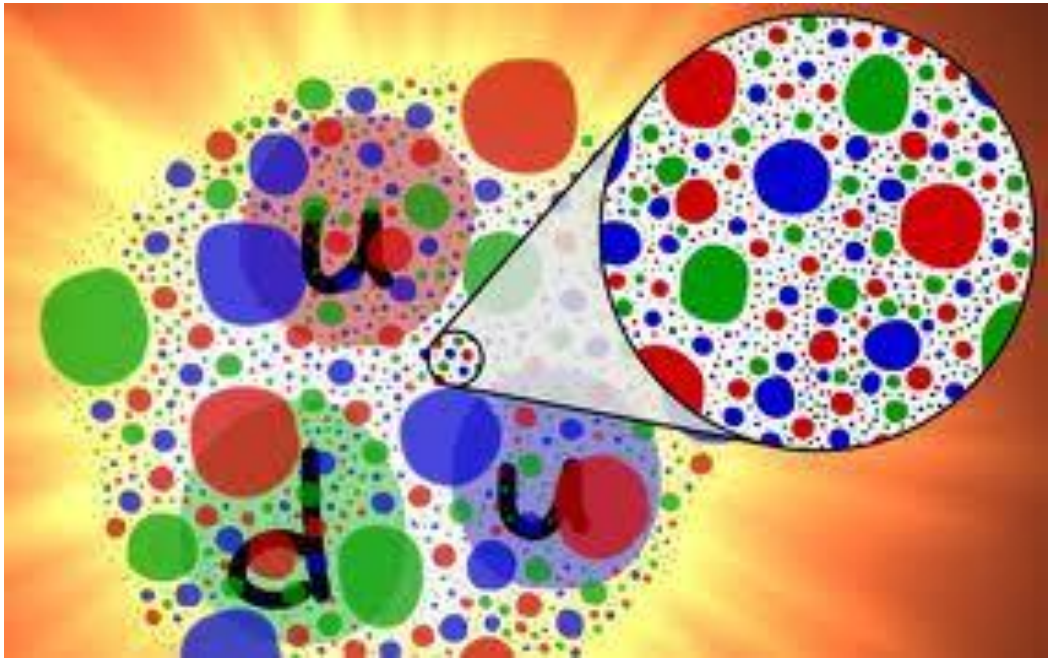
Nucleon Structure

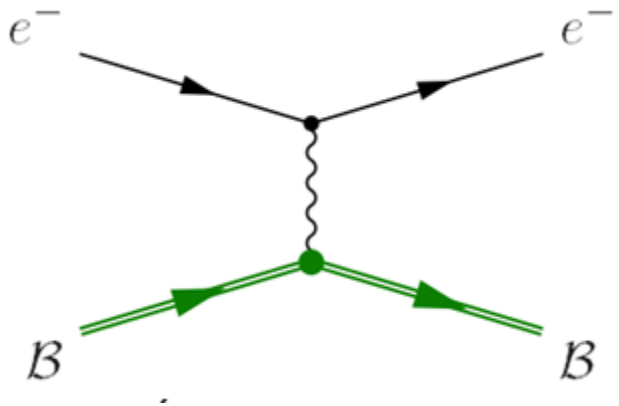
- Nucleon structure subject of rigorous studies since the 1960:es.
- Powerful observable of nucleon structure: ElectroMagnetic Form Factors (EMFF's).
  - Describes the deviation from the point-like case.
  - Spin ½ baryons: 2 FF's.
  - Sachs' FF's: G_E and G_M
  - Related to the charge- and magnetization density.



Time-like *vs.* space-like FF's

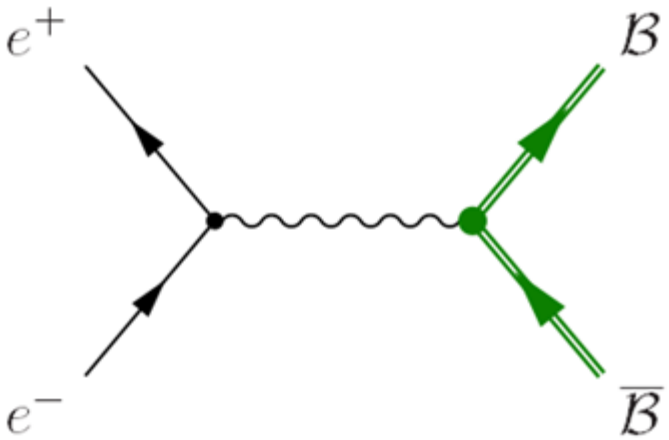
Space-like:

- Studied in $e^-B \rightarrow e^-B$ scattering.
- $q^2 = (p_{ie} - p_{fe})^2 < 0$.
- G_E and G_M real numbers.



Time-like:

- In *e.g.* $e^+e^- \rightarrow B\bar{B}$
- $q^2 = (p_{e+} + p_{e-})^2 > 0$
- G_E and G_M complex numbers.



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Time-like form factors

- Time-like FF's are complex:
  - $Im[G_E(Q^2)\, G_M^*(Q^2)] = |G_E(Q^2)|\, |G_M^*(Q^2)| \sin\Delta\Phi$
  - $Re[G_E(Q^2)\, G_M^*(Q^2)] = |G_E(Q^2)|\, |G_M^*(Q^2)| \cos\Delta\Phi$

  $\Delta\Phi$ = relative phase between G_E and G_M

- The phase between G_E and G_M – polarisation effects on the final state even when the initial state is unpolarised.

- Crucial for testing models, especially in the soft-hard transition region (Q^2 = 10-15 GeV^2).

- Space-like and time-like FF's related *via* dispersion relations.

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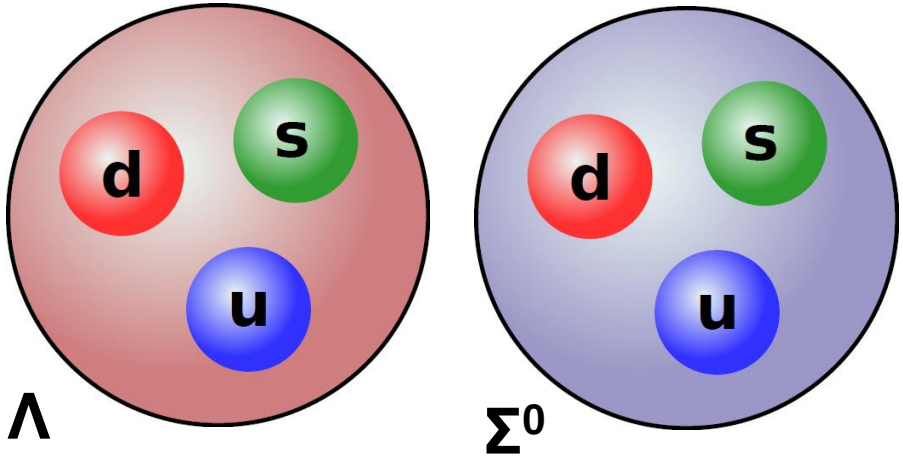
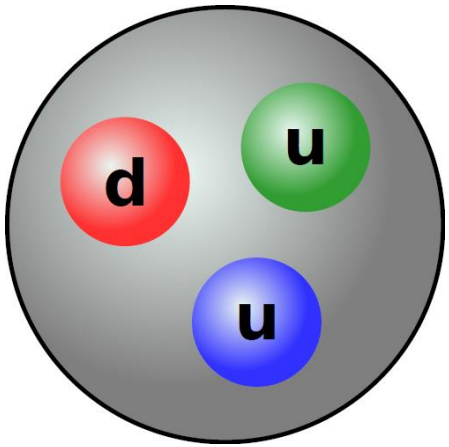
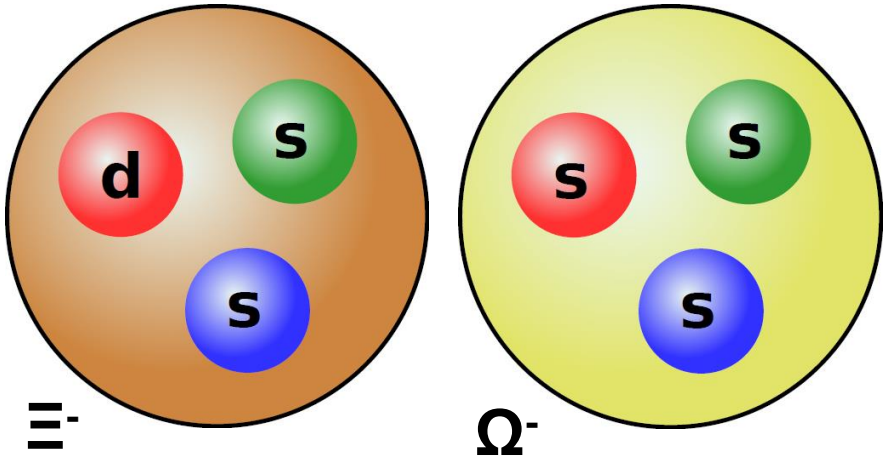
Hyperon Structure

What happens if we replace one of the light quarks in the proton with one - or many - heavier quark(s)?



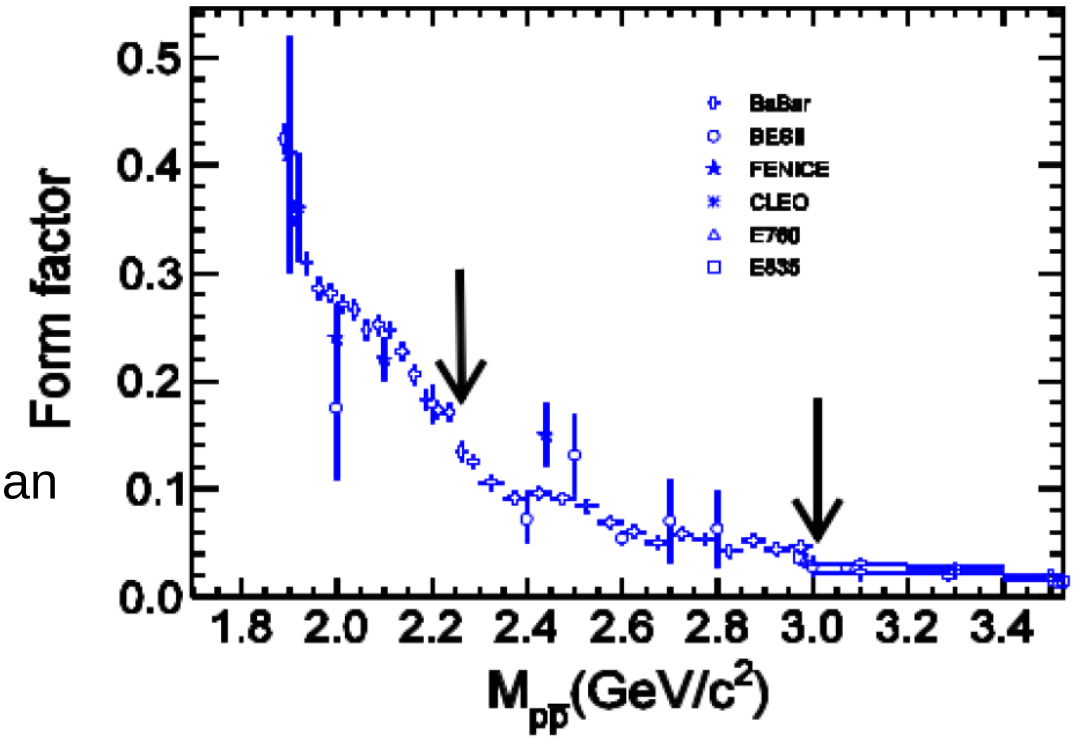


proton



Nucleon *vs* Hyperon EMFF's

- **Protons and neutrons**:
  - Time-like FF's should coincide with space-like at high $|Q^2| = |q^2|$.
  - **Data:**
    - Two steep rises
    - TL FFs 2 times larger than SL FFs at high q^2.



- **Hyperons:**
  - Difference between nucleon and hyperon FF – SU(3) symmetry?
  - Currently the best way to study hyperon structure.
  - Polarization observables experimentally accessible.
  - **Data:** very little published so far *.

* BaBar PRD **76** (2007) 092006.

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Advantages of hyperons

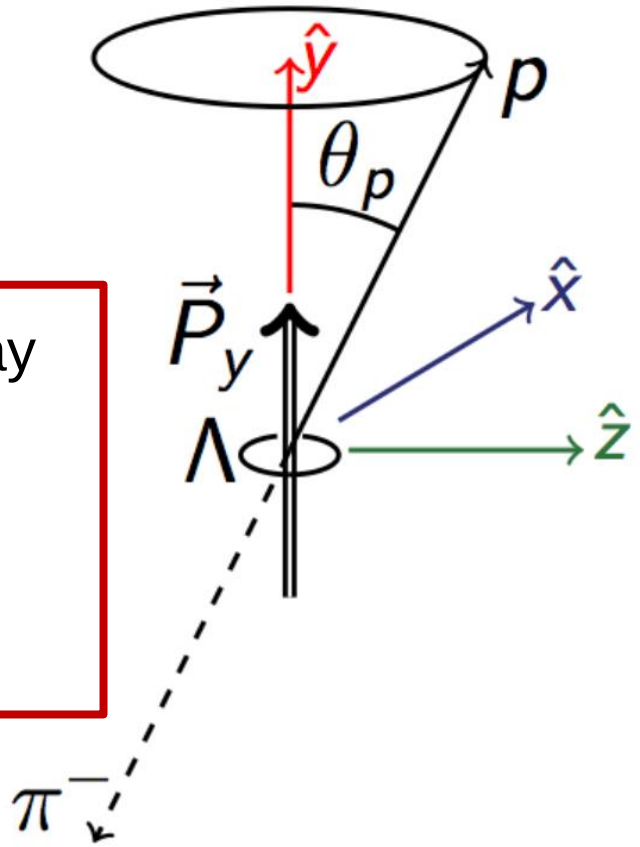
Polarization experimentally accessible thanks to the weak, parity violating decay:

Example: Angular distribution of $\Lambda \rightarrow p\pi^-$ decay

$$I(\cos\theta_p) = N(1+\alpha P_\Lambda \cos\theta_p)$$

P_Λ : polarisation

α = 0.64 asymmetry parameter



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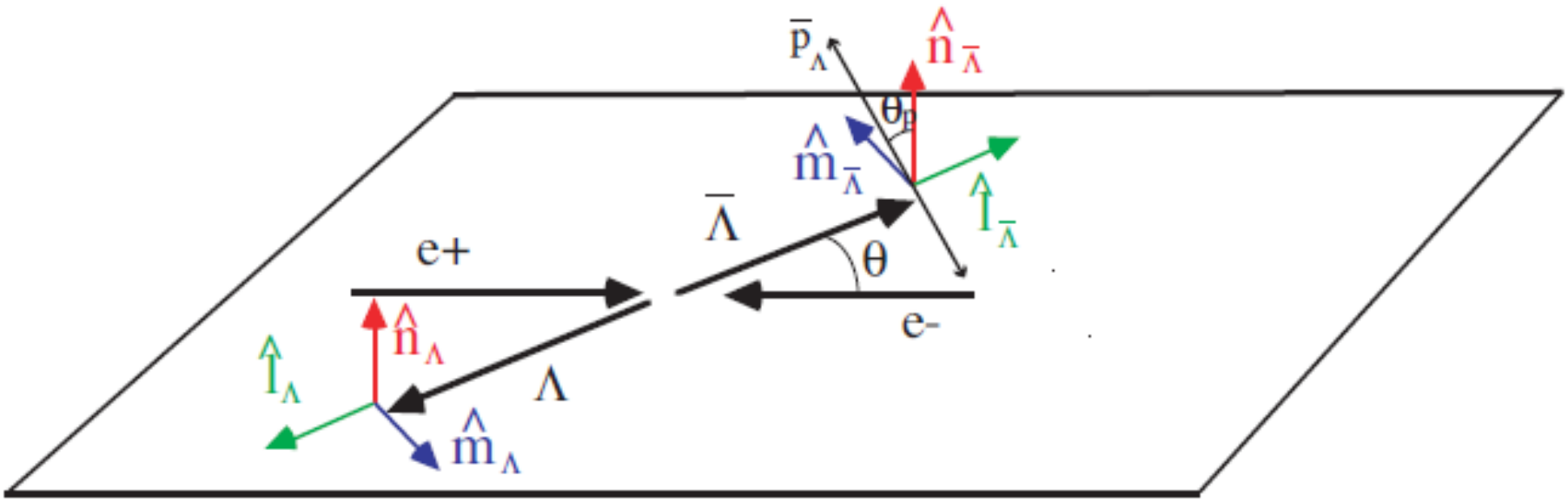
Measurement of TL EMFF's



Measurement of TL EMFF's

Energy dependence of the total cross section: Effective form factor

$$\sigma(B\bar{B}) \propto |F(Q^2)|^2 = \frac{2\tau |G_M(Q^2)|^2 + |G_E(Q^2)|^2}{2\tau + 1} \qquad \tau = Q^2/4M^2_B$$

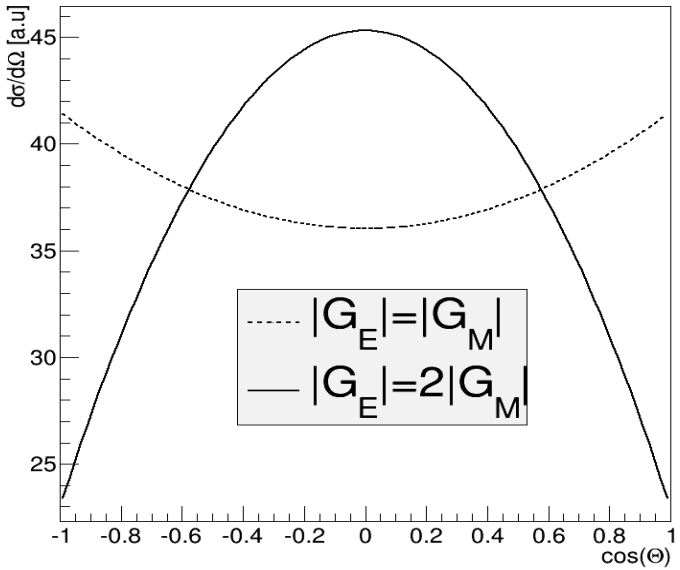
Differential cross section:

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

Angular dependence: Ratio $R=|G_E/G_M|$

$$|G_M|^2 = \frac{2\tau+1}{2\tau+R^2}|F|^2$$

$$|G_E|^2 = R^2\frac{2\tau+1}{2\tau+R^2}|F|^2$$



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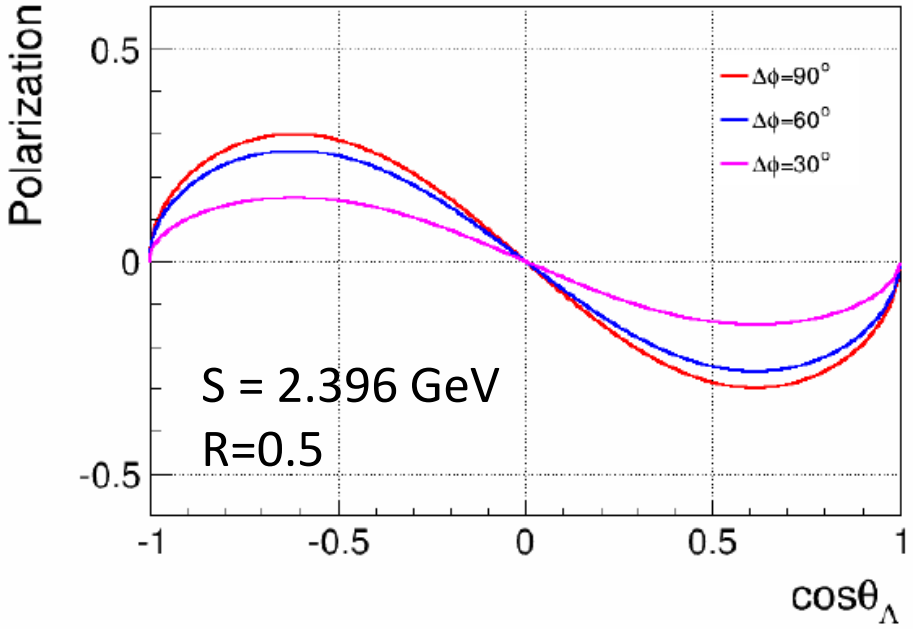
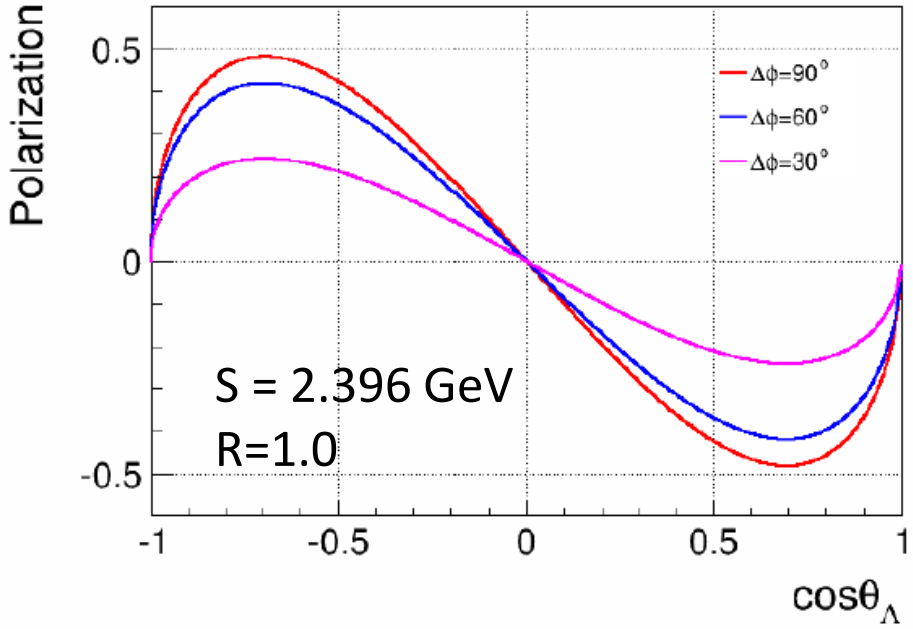
Measurement of TL EMFFs





Time-like form factors: imaginary part polarizes the final state baryons:

$$P_n = -\frac{\sin 2\theta Im[G_E(Q^2)G_M^*(Q^2)]/\sqrt{\tau}}{(|G_E(Q^2)|^2 \sin^2\theta)/\tau + |G_M(Q^2)|^2(1+\cos^2\theta)}$$

Real part related to the correlation between the baryon- and antibaryon spin:

$$C_{lm} = \frac{\sin 2\theta Re[G_E(Q^2)G_M^*(Q^2)]/\sqrt{\tau}}{(|G_E(q^2)|^2 \sin^2\theta)/\tau + |G_M(Q^2)|^2(1+\cos^2\theta)}$$

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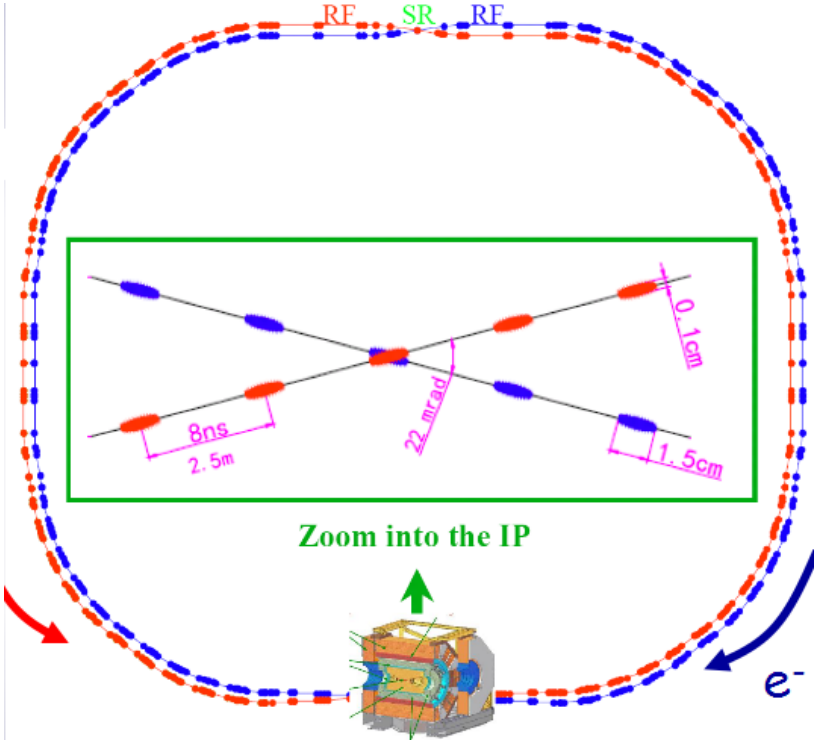
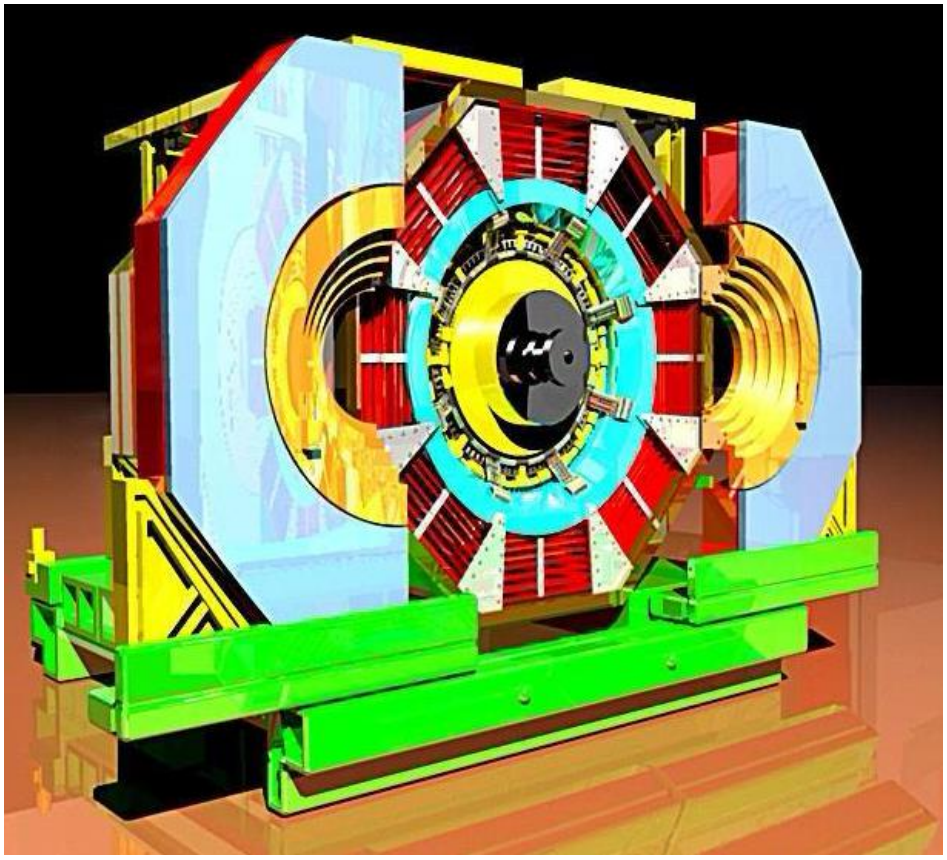
BES III @ BEPC II

BES III in Beijing, China, unique for baryon TL EMFF's!

BES III @ BEPC-II

- BEPC = Beijing Electron Positron Collider.
- Operates in the τ-charm mass region





- BES III = Beijing Spectrometer
  - Wide physics scope
  - See talk by *e.g.* A. Denig, B. Liu

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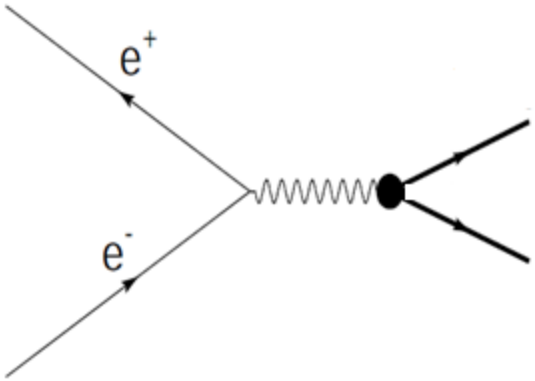
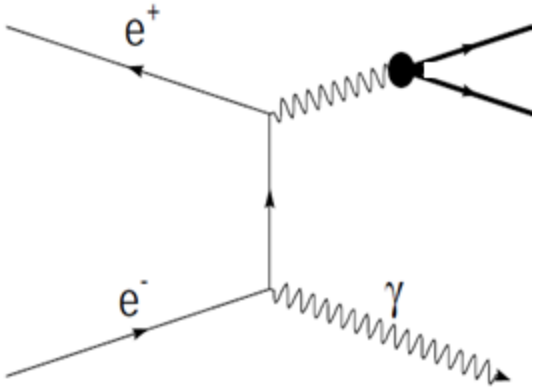
What can we do with BES III?



Direct production



Initial state radiation (ISR)

- Measure $e^+e^- \to N\overline{N}, \Lambda\,\overline{\Lambda}, \Sigma^0\overline{\Lambda}, \Sigma\overline{\Sigma},\ \Xi\overline{\Xi}, \Omega\overline{\Omega},$ and $\Lambda_c\overline{\Lambda}_c$ in direct e^+e^- annihilation in the continuum between Q ~ 2 and Q ~ 5 GeV.

- Measure $e^+e^- \to N\overline{N}, \Lambda\,\overline{\Lambda}\gamma_{ISR}, \Sigma^0\overline{\Lambda}\gamma_{ISR}, \Sigma\overline{\Sigma}\gamma_{ISR}$ in Initial State Radiation with the 2.9 fb^{-1} at Q = 3.773 GeV.

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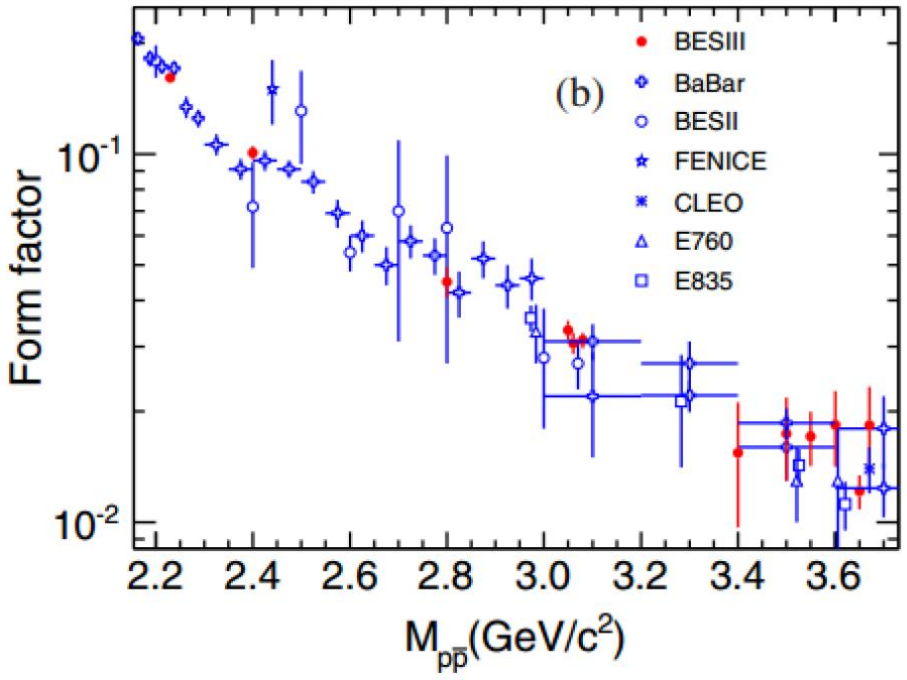
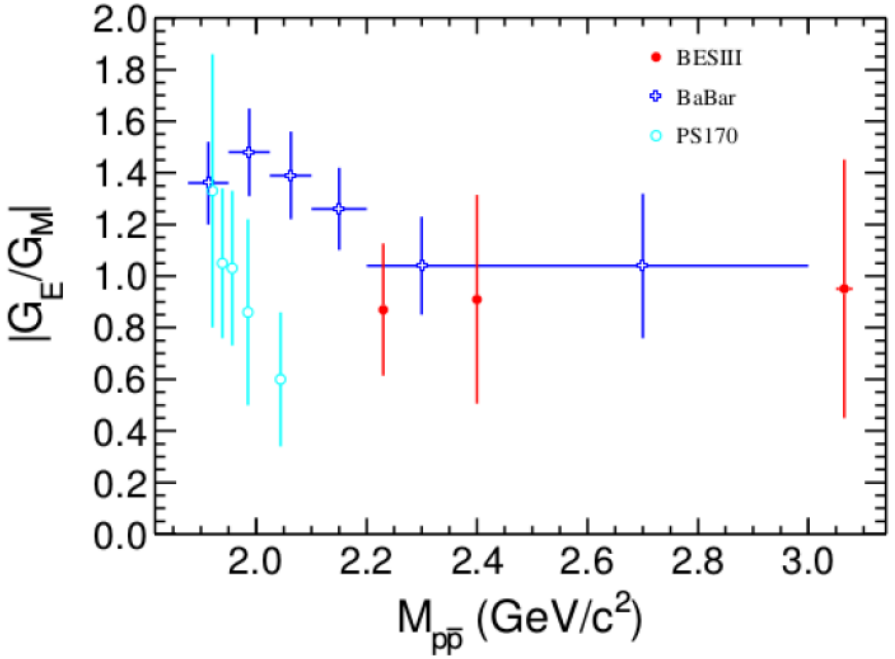
Recent results from BES III

Proton EMFF's in $e^+e^- \rightarrow p\bar{p}$



Published in PRD 91 (2013) 11 112004

- Small data scan in 2012 for EMFF measurement in $e^+e^- \rightarrow B\bar{B}$.
- Effective FF and ratio R = $^{G_E}/_{G_M}$.
- Agreement with previous experiment.



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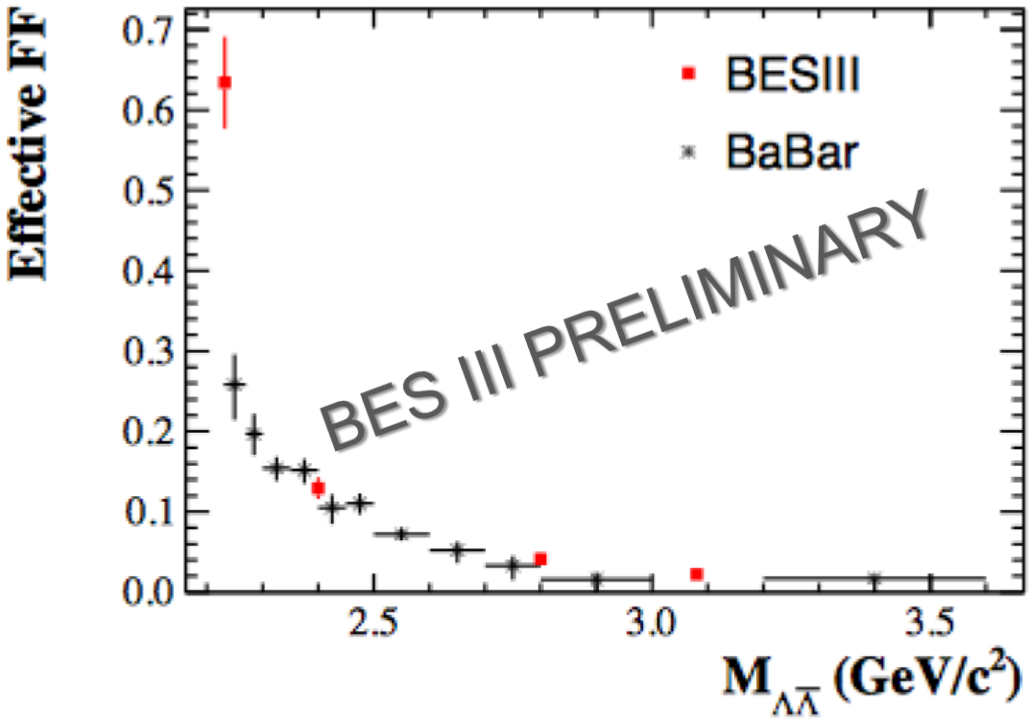
Recent results from BES III

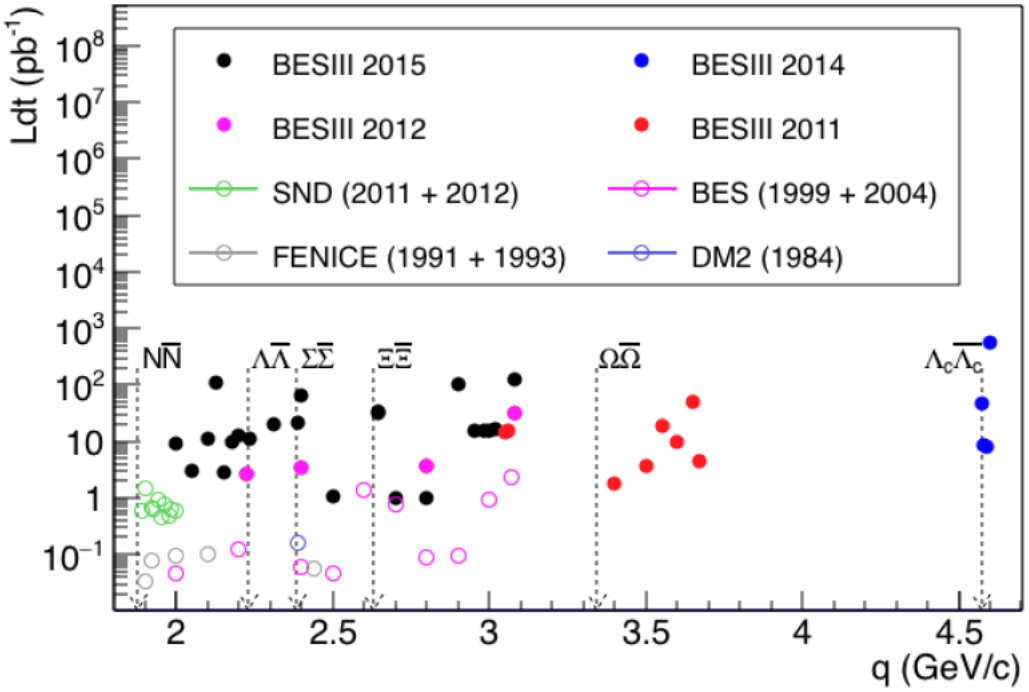
Hyperon EMFF's in $e^+e^- \to \Lambda\overline{\Lambda}$



- Same scan data as in the proton EMFF case.
- **Preliminary**: Effective FF at 4 energies.
- More precise than ISR BaBar data.
- **Preliminary:** Interesting threshold behaviour.
- Publication under preparation.

New energy scan 2014-2015

- World's largest data sample between 2.0 and 3.08 GeV.
- Nucleon and strange hyperons EMFF's available.
- Unique data sample at Λ_c^+ threshold.



BESIII high luminosity scan 2015

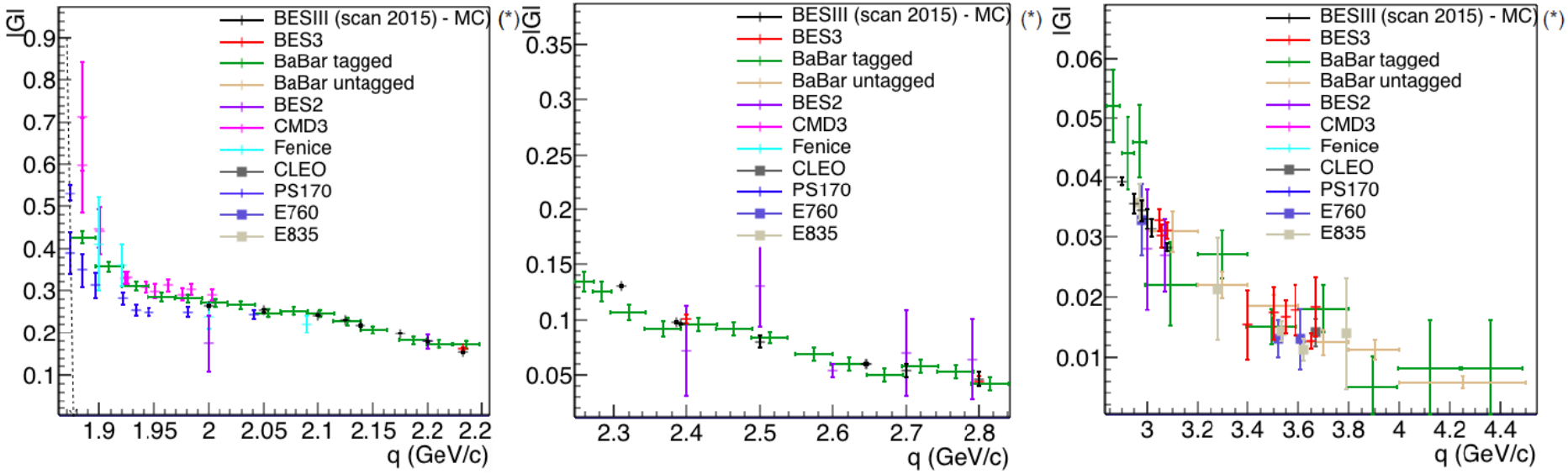
E_{cm}(GeV)	L(pb^{-1})	E_{cm}(GeV)	L(pb^{-1})
2.0000	10.074	2.0500	3.343
2.1000	12.167	2.1250	108.49
2.1500	2.841	2.1750	10.625
2.2000	13.699	2.2324	11.856
2.3094	21.089	2.3864	22.549
2.3960	66.869	2.5000	1.098
2.6444	33.722	2.6464	34.003
2.7000	1.034	2.8000	1.008
2.9000	105.253	2.9500	15.942
2.9810	16.071	3.0000	15.881
3.0200	17.290	3.0800	126.185

New energy scan 2014-2015

Proton EMFF's:

Expected precision of proton effective form factor between 0.3% (at 2.125 GeV) and 13 % (at 2.8 GeV): world-leading!

$$|G(q^2)| = \sqrt{\frac{\sigma^{\mathrm{Born}}(q^2)}{(1+\frac{2M^2}{q^2})(\frac{4\pi\alpha^2\beta C}{3q^2})}}$$



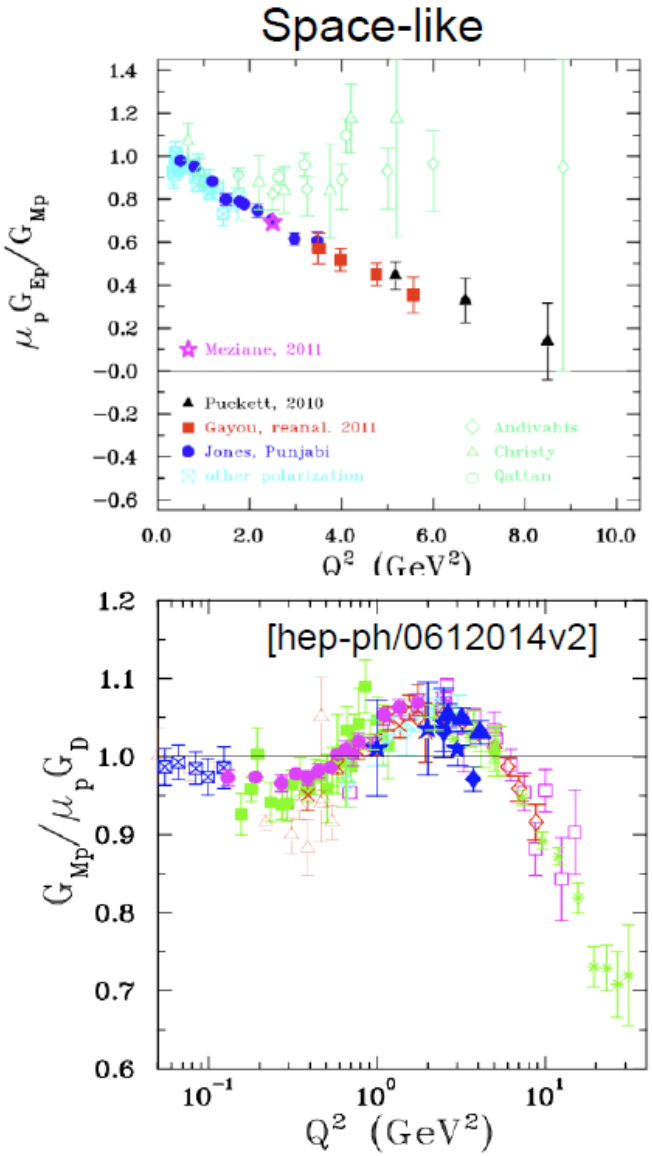
New energy scan 2014-2015

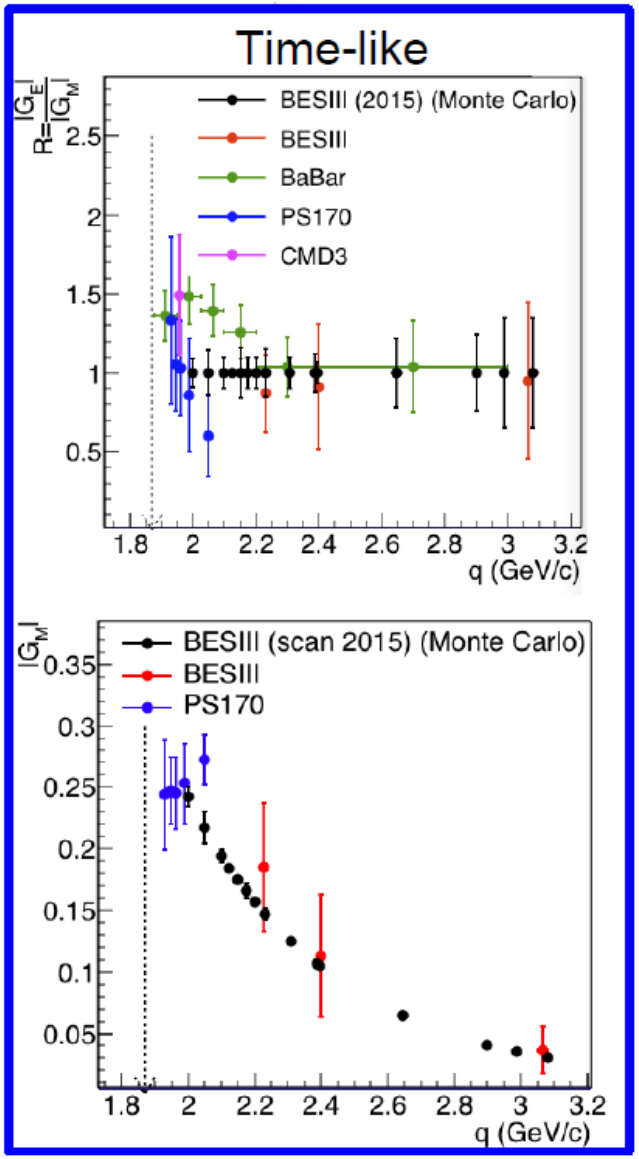
At 16 energies, data samples large enough for angular distributions

→ $R=|G_E/G_M|$ accessible!

Determination of $|G_E|$ and $|G_M|$ with similar precision as in space-like region!

Analysis in progress!

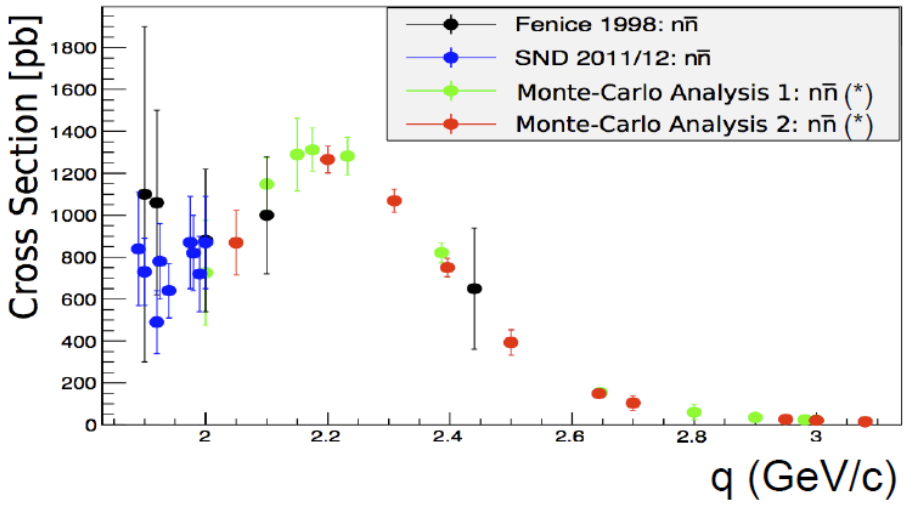


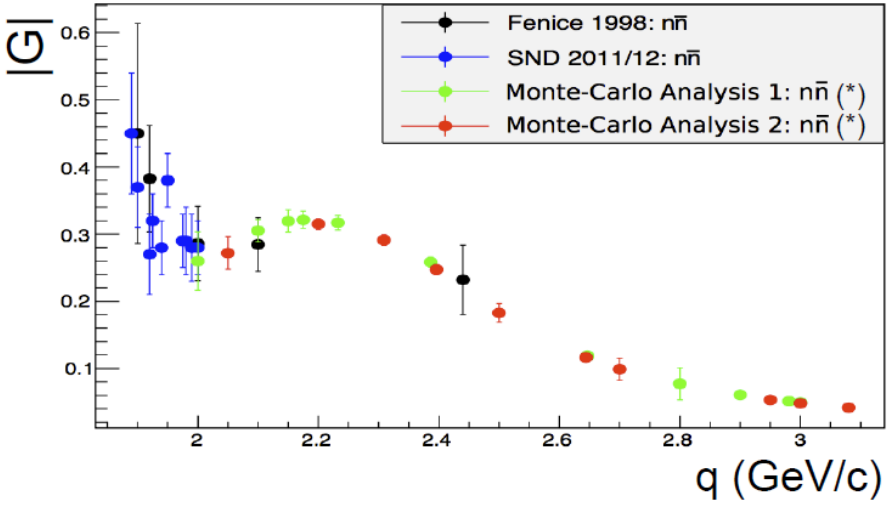


New energy scan 2014-2015

Neutron EMFF's:

- Unprecedented data samples above 2.0 GeV.
- Expected precision from 6% (at 2.396 GeV) to 13% (at 3.0 GeV).
- First measurement of neutron $R=|G_E/G_M|$ possible!
- Analysis in progress!



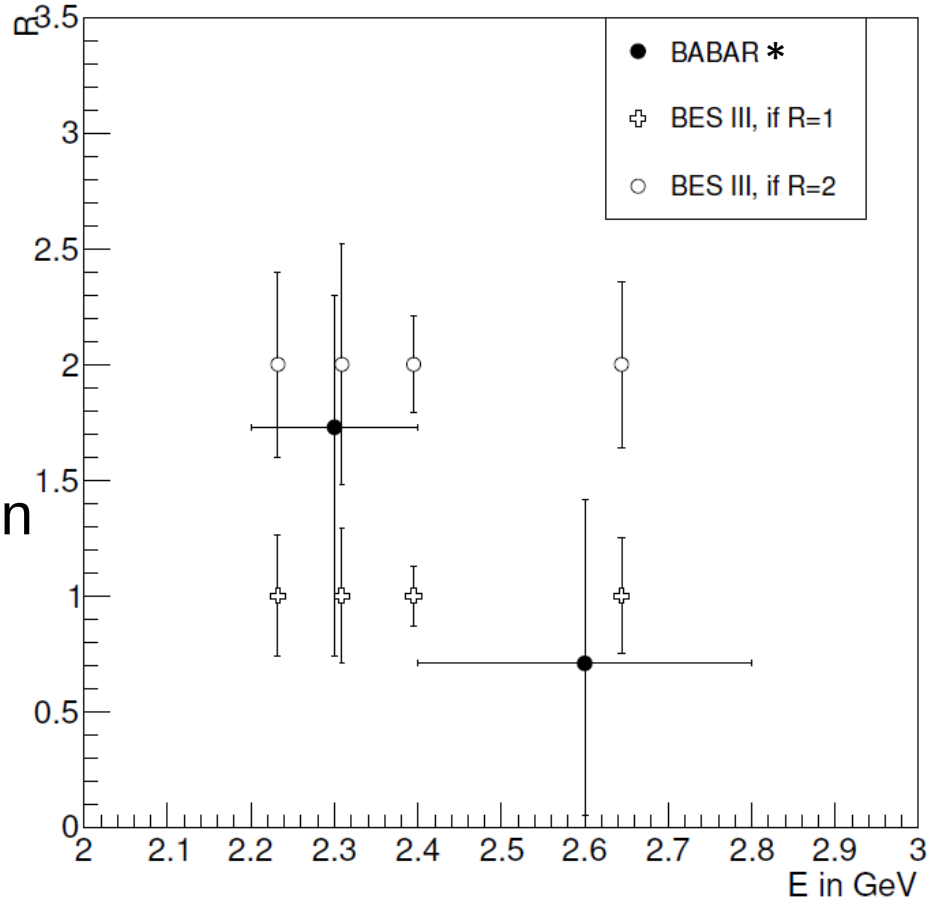


(*) Phokhara v9.1 [arXiv:1407.7995v2]

New energy scan 2014-2015

Λ Hyperon EMFF's:

- Unprecedented data samples in 6 points from between 2.23 and 2.9 GeV.
- In 4 points, large enough samples to extract $R=|G_E/G_M|$.
- At 2.396 GeV: polarisation & spin correlations enable a first determination of the phase $\Delta\Phi$ between G_E and G_M !
- Analysis in progress!



* BaBar PRD **76** (2007) 092006.

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High energy scan 2014

4 data points between 4.5745 GeV (Λ_c^+ threshold) and 4.6 GeV.

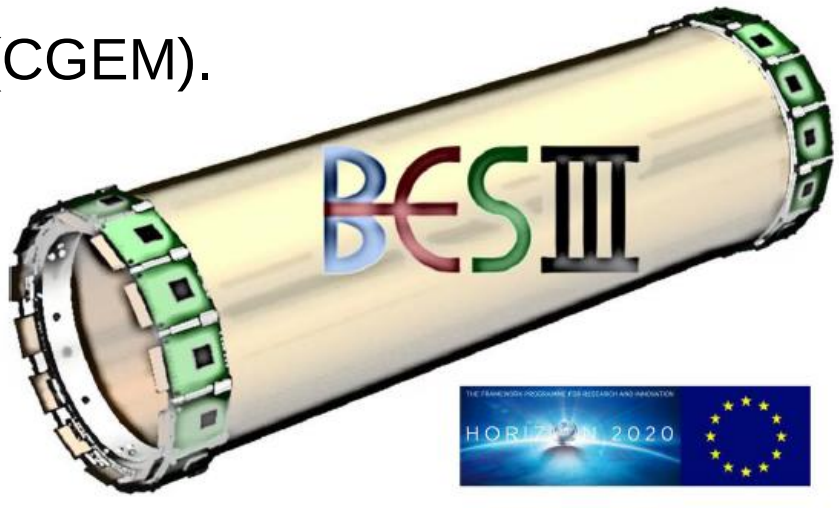
Enable measurement of

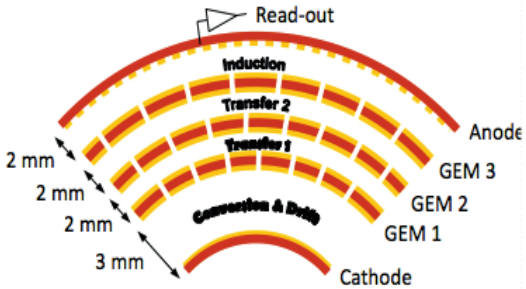
- Effective FF of Λ_c^+ in 4 points.
- The ratio $R=|G_E/G_M|$ in 2 points (first time!).
- The phase $\Delta\Phi$ accessible in one point (first time!).

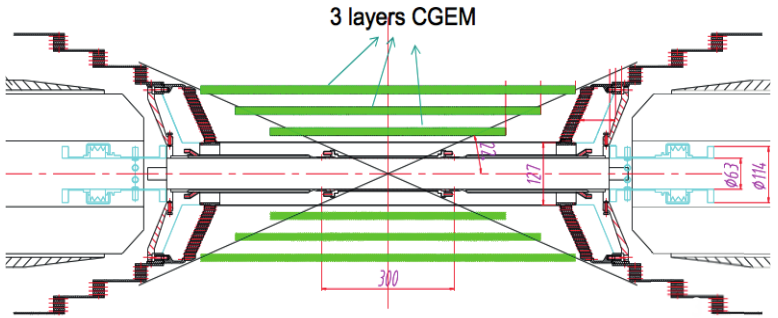
√s (GeV)	L_{int} (pb^{-1})
4.5745	47.67
4.580	8.545
4.590	8.162
4.5995	566.9

Foreseen upgrade of BES III

- For improved tracking and vertex reconstruction
  A Cylindrical Gas Electron Multiplier (CGEM).
- Similar type as recently installed
  at KLOE-II @ DAΦNE.
- Analog readout.
- Data concentrators under
  development in Uppsala.
- Collaboration between Beijing, Frascati, Ferrara, Mainz, Torino and Uppsala.







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Summary

- Electromagnetic form factors are crucial in order to understand the structure of hadrons.
- BES III is unique in its capability to measure baryon form factors, from nucleons to Λ_c^+ .
- A recent large-scale energy scan will provide world-leading data samples for baryon EMFF measurements.
- New unique measurements of the ratio $R=|G_E/G_M|$ can be performed for nucleons and hyperons.
- First measurements of the phase $\Delta\Phi$ between G_E and G_M accessible for Λ and Λ_c^+.
- Planned upgrade to improve precision in tracking and vertexing.

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Thanks for your attention!