HIM
Helmholtz-Institut Mainz

BESIII

PRISMA
Cluster of Excellence

Collins asymmetry and proton form factors at BESIII

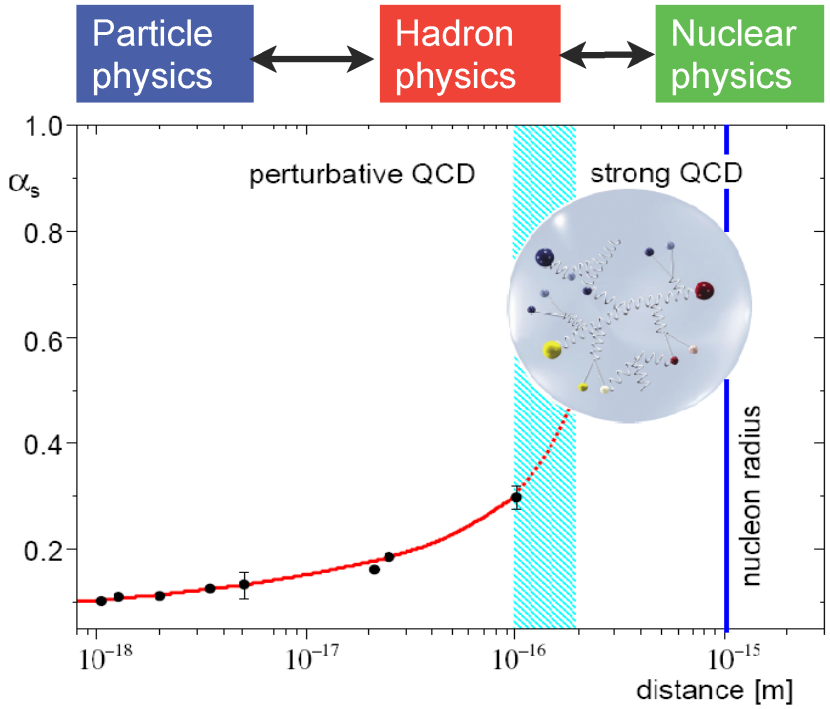
Alaa Dbeyssi (Helmholtz-Institut Mainz)

On behalf of the BESIII Collaboration

Baryons 2016,16-20 May 2016, Florida State University Alumni Center

The structure of hadrons

- Hadrons: non-perturbative systems



- Their interactions can be described by long distance functions:
  - Electromagnetic form factors,
  - Parton Distribution Amplitudes,
  - Fragmentation Functions,
  - Generalized Parton Distributions,
  - …..

- Only by a global analysis of scattering and annihilation experiments we can determine these functions and test their **analyticity and universality**

Crossing symmetry channels: - different kinematical regions
- observables are counterparts

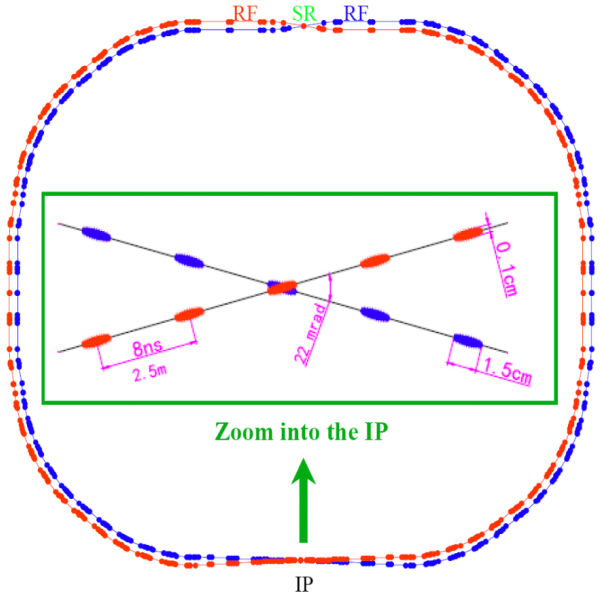
Outline

Probing the structure of hadrons at BESIII by the annihilation of electron-positron beams of 1.0 - 2.3 GeV:

- BEPC-II and BESIII detector
- Baryons **electromagnetic form factors** at BESIII
  - Proton form factors
  - Lambda_c from factors
- Collins asymmetry (Collins **fragmentation function**) measurement at BESIII
- Summary

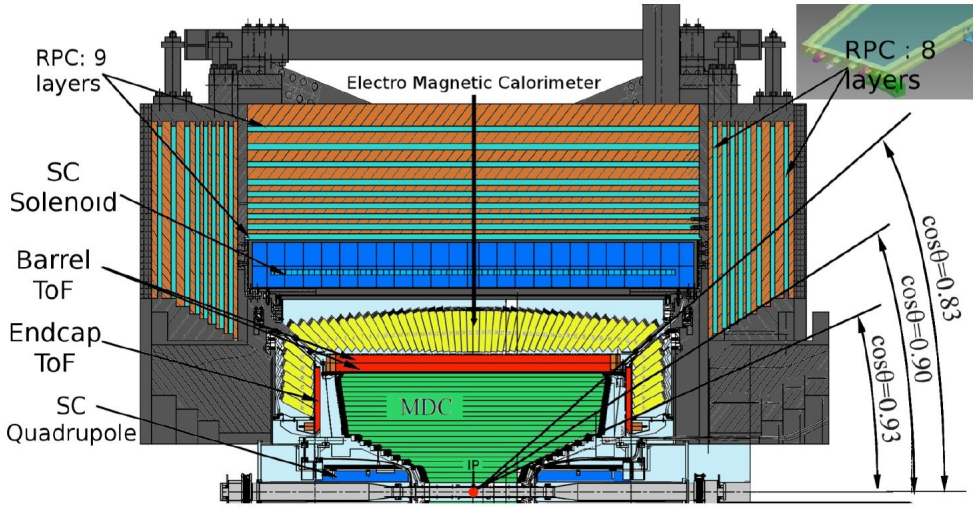
BEPC-II and BESIII detector

Beijing Electron Positron Collider



- Symmetric e^+e^- collider
- Beam energy: 1.0 - 2.3 GeV
- Optimum energy: 1.89 GeV
- Design luminosity: 10^{33} cm^{-2} s^{-1}
- Crossing angle: 22 mrad

BESIII detector



Electromagnetic Calorimeter
$\sigma_E/\sqrt{E}(\%)$=2.5% (1 GeV),
(CsI) $\sigma_{z,\phi}$(cm)=0.5-0.7 cm/$\sqrt{E}$

Muon Counter
σ_{xy}<2 cm

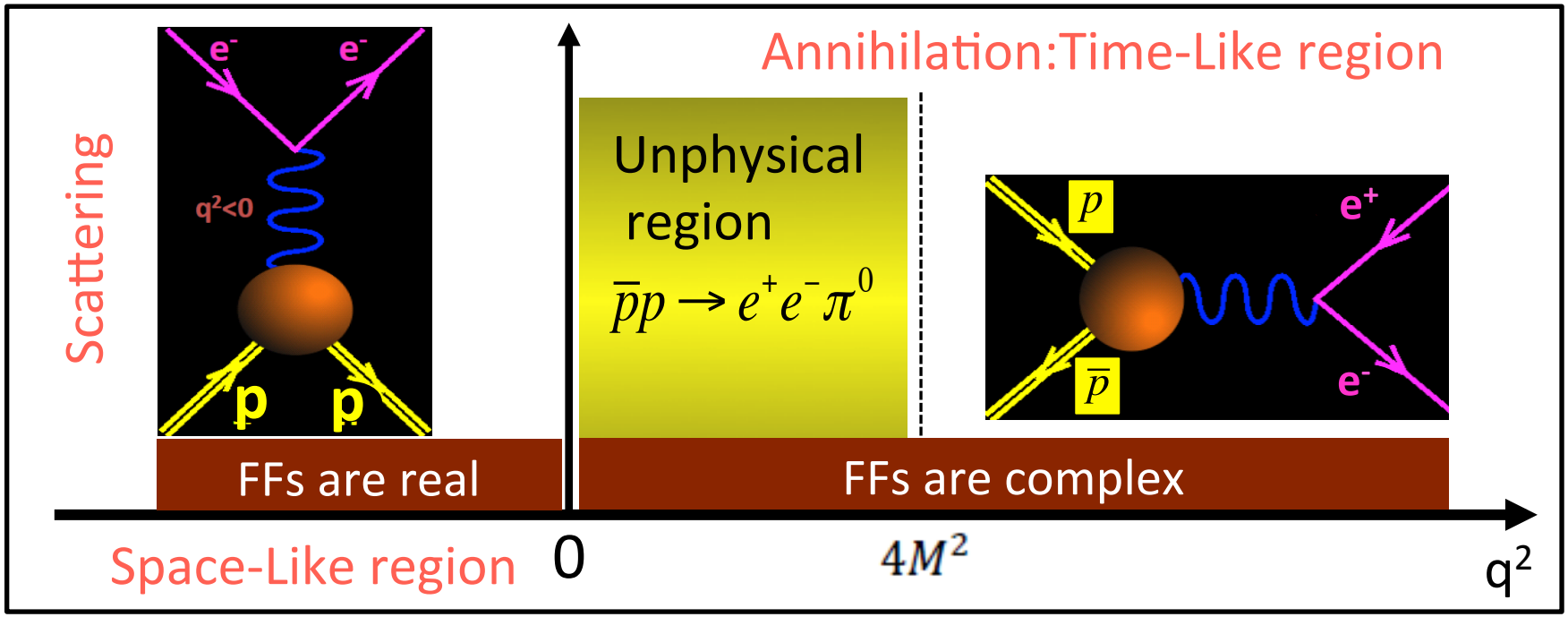
Time Of Flight
σ_T(barrel)=90 ps
σ_T(endcap)=110 ps

Main Drift Chamber
σ_{xy}=130 mm, dE/dx~6%
σ_p/p = 0.5% at 1 GeV

PROTON ELECTROMAGNETIC FORM FACTORS at BESIII

Measurement of proton form factor by $e^+e^- \rightarrow p\bar{p}$
PHYSICAL REVIEW D 91, 112004 (2015)

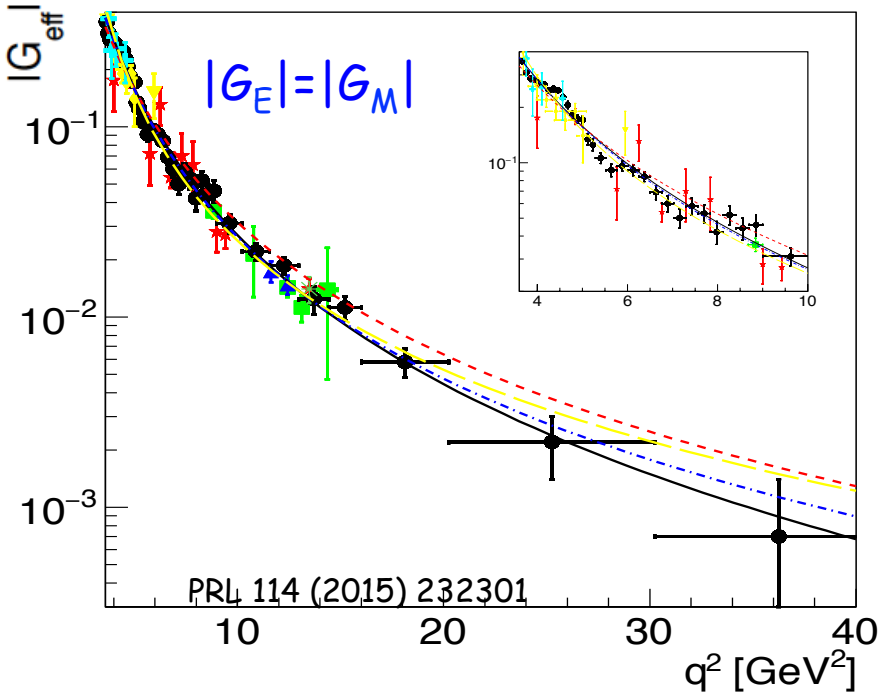
Proton electromagnetic form factor: the analyticity

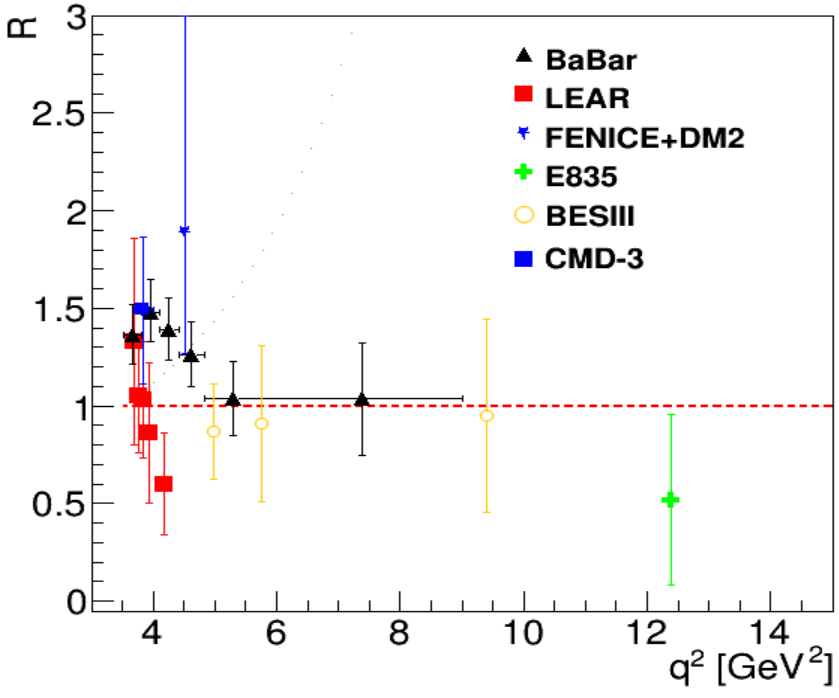


- **Electric G_E and magnetic G_M** proton form factors (FFs) are analytical functions of the momentum transfer squared q^2

- Playground for theory and experiment:
  - at low q^2, probe the size of the nucleus,
  - at high q^2, test QCD scaling

Time-Like proton electromagnetic form factors





- No individual determination of G_E and G_M
- Steep behaviour of the **effective form factor (G_{eff})** at threshold
- Structures appeared in BaBar data?
  - Resonances (PRD 92 (2015) 034018)
  - Rescattering processes between few coherent sources (PRL 114 (2015) 232301)
- **Form factor ratio (R)**: discrepancy between LEAR and BaBar data

Measurement of $e^+e^- \to p\bar{p}$ at BESIII Phys. Rev. D91, 112004 (2015)

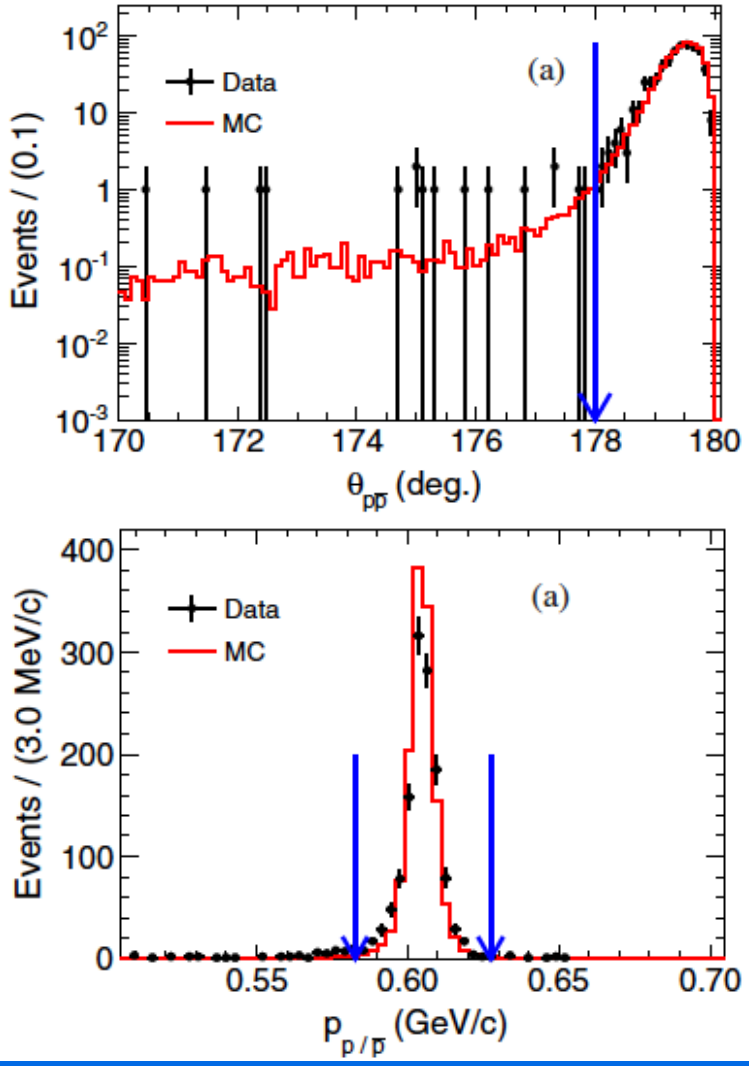
Based on **157 pb^{-1}** collected in 12 scan points between **2.22 – 3.71 GeV** in 2011/2012:

Event selection

I. Good charged tracks from the MDC
II. Particle identification:
   - dE/dx and TOF (Prob(p) > Prob(K/ π)
   - Proton: $E_{EMC}/p<0.5$, $\cos\theta < 0.8$
III. Two charged tracks
   - $|tof_p - tof_{pbar}<|$ 4ns, back-to-back in c.m.s
   - Momentum window cut for p and pbar

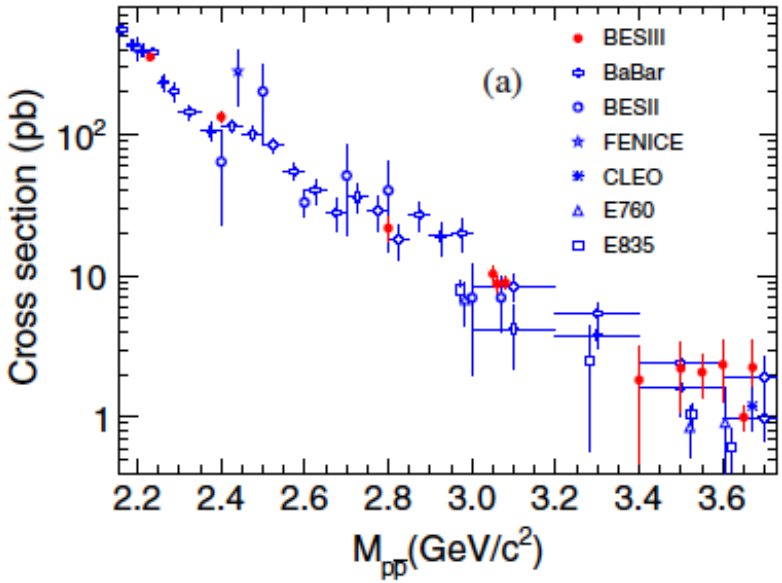
Background and signal efficiency

- Beam associated background
- Physical background: charged pair production, *ppbarπ^0*, *ppbarπ^{0}π^0*, *ΛΛbar*
- Background negligible or subtracted
- Signal efficiency between 60% and 3%

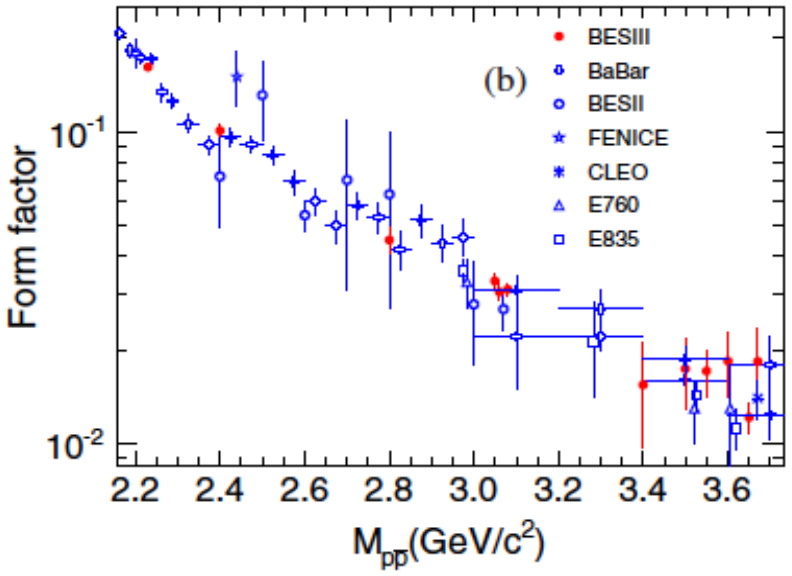


Measurement of $e^+e^- \to p\bar{p}$ at BESIII Phys. Rev. D91, 112004 (2015)

(a) The Born cross section



(b) The effective FF ($|G_E|=|G_M|$)



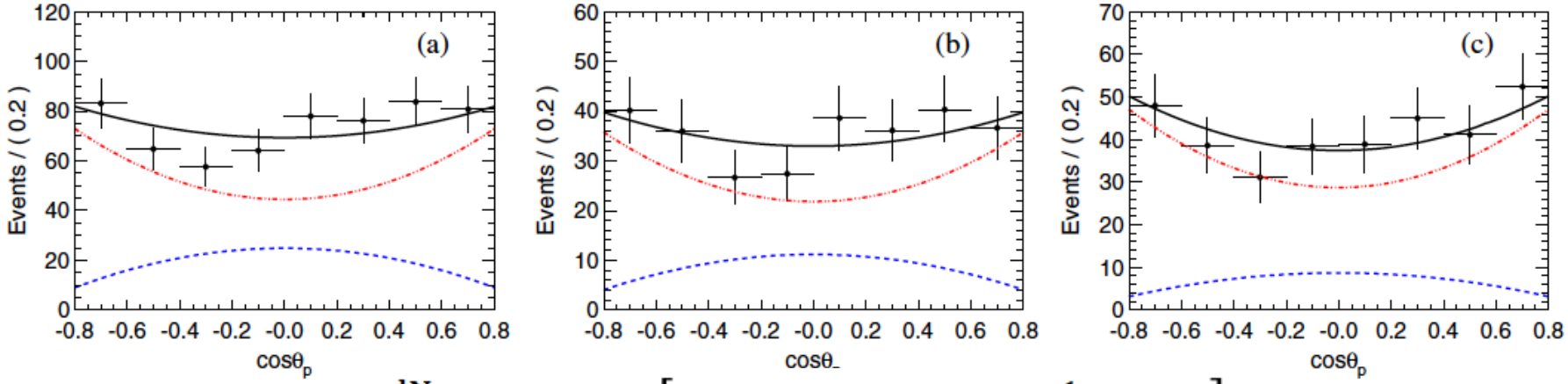
$$\sigma_{Born} = \frac{N_{obs} - N_{bkg}}{L \cdot \varepsilon \cdot (1+\delta)} \Rightarrow \sigma = \frac{\pi\alpha^2}{3m_p^2\tau}\left[1+\frac{1}{2\tau}\right]|G_{eff}|^2$$

N_{obs}: observed number of data
N_{bkg}: background evaluated from MC
L: luminosity; ε: detection efficiency; (1+δ): radiative correction factor

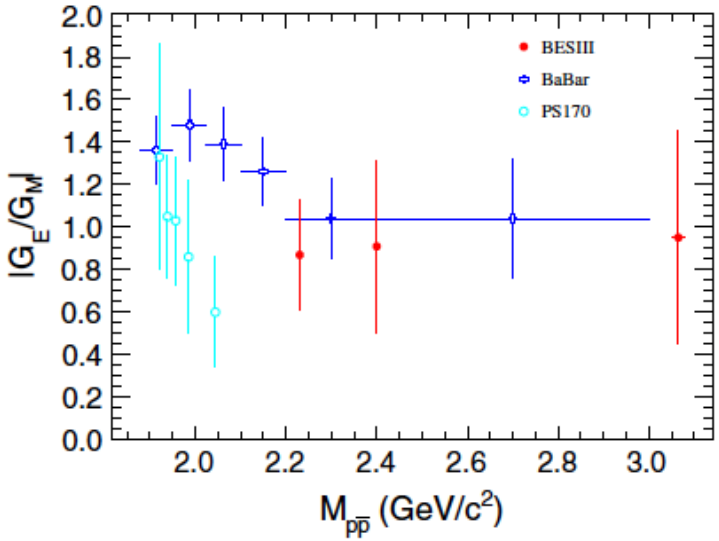
The measured born cross sections and the effective FFs are in good agreement with previous experiments, improving the overall uncertainty by ~30%

Measurement of $e^+e^- \to p\bar{p}$ at BESIII Phys. Rev. D91, 112004 (2015)

Extraction of the electromagnetic $R_{em}=|G_E|/|G_M|$ ratio



$$\frac{dN}{d\cos\theta_p} = N_{norm}\left[(1+\cos^2\theta_p) + R_{em}^2\frac{1}{\tau}\sin^2\theta_p\right]$$

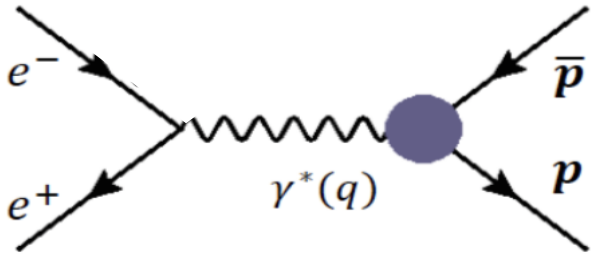


$\sqrt{s}$ (MeV)	$\lvert G_M\rvert$ $(\times 10^{-2})$
	Fit on $\cos\theta_p$
2232.4	$18.42 \pm 5.09 \pm 0.98$
2400.0	$11.30 \pm 4.73 \pm 1.53$
(3050.0, 3080.0)	$3.61 \pm 1.71 \pm 0.82$

Prospects: Proton FFs @ BESIII

➢ Direct production (**scan data 2015**):

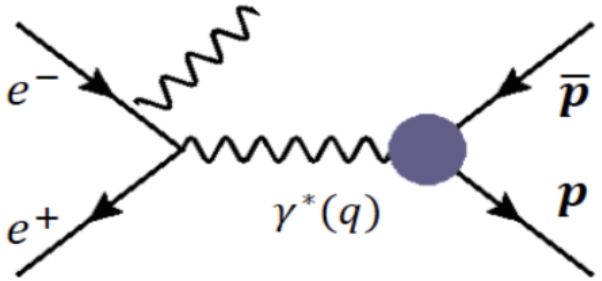
- 21 points between 2.0 and 3.08 GeV (552 pb^{-1})
- Expected (MC) statistical accuracies on $R_{em}=|G_E|/|G_M|=1$, between 9 % and 35%
- Measurement of $|G_M|$ and $|G_E|$ separately



➢ Initial state radiation (ISR) technique:

- Data samples collected at ψ(3770),ψ(4040), Y(4230), Y(4260), Y(4360), Y(4420), Y(4600). Total: **7.408 fb-1**
- Tagged + untagged photon analysis
- Continuous q^2-range available from the threshold
- Angular distribution measurements (FF ratio)
- **Final statistics are competitive with BaBar:**

  Possibility to examine the structures seen in the total cross section



LAMBDA_C FORM FACTORS AT BESIII

Cross section measurement of $e^+e^- \rightarrow \Lambda_c^+ \bar{\Lambda}_c^-$ near threshold at BESIII

Baryon pair production: unexpected behavior near threshold

Annihilation cross section

$$\sigma_{B\bar{B}}(q) = \frac{4\pi\alpha^2 C\beta}{3q^2}\left[|G_M(q)|^2 + \frac{1}{2\tau}|G_E(q)|^2\right]$$

$$C = \varepsilon \times R, \qquad \beta = \sqrt{1 - 4m_B^2/q^2}$$

Enhancement factor: $\varepsilon = \pi\alpha/\beta$

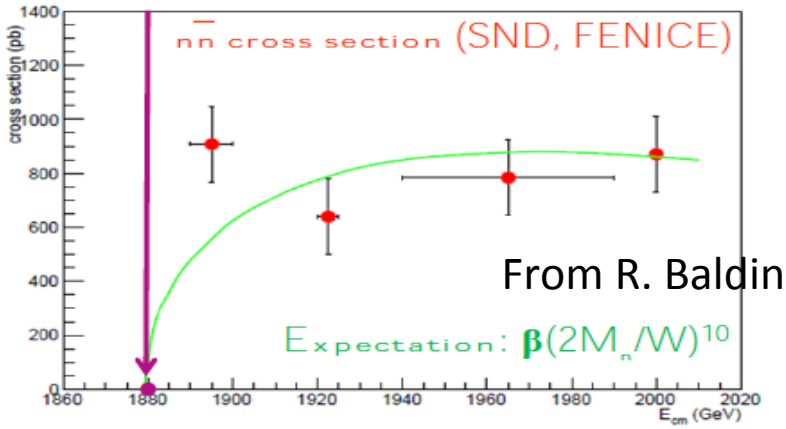
- Dominates at threshold and cancel the phase space factor

Resummation factor: $\sqrt{1-\beta^2}/(1 - e^{-\pi\alpha/\beta})$

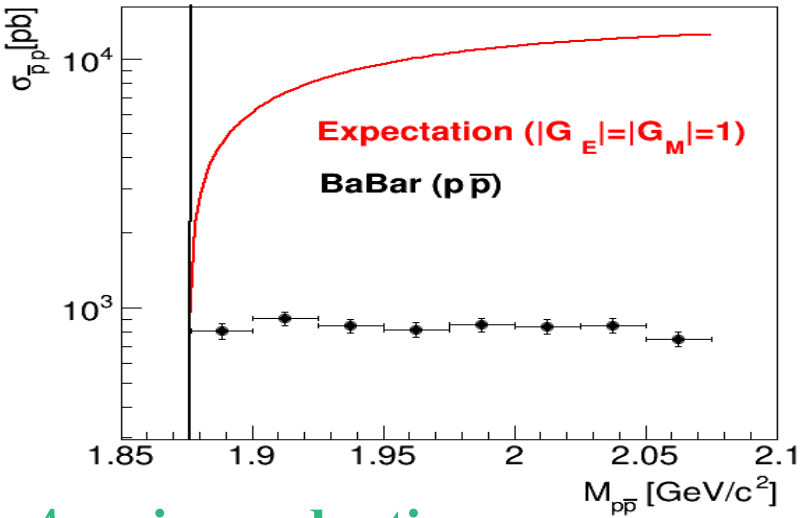
- Becomes ineffective few MeV above threshold

Coulomb factor: $C = \varepsilon R$

- Non-perturbative correction
- Neutral baryons: $C=1$, $\sigma=0$
- Predicts non flat behavior close to threshold



From R. Baldini



Λ_c pair production:

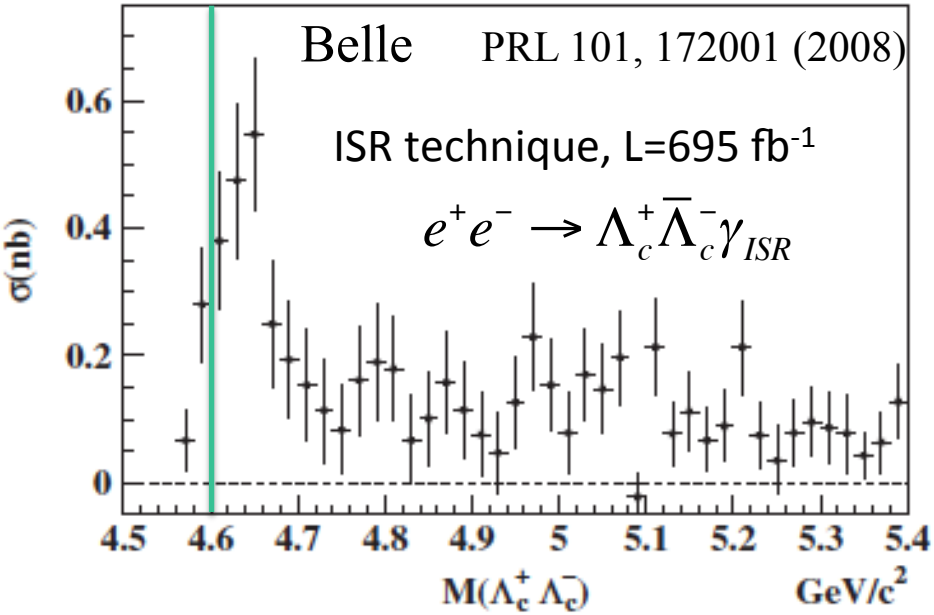
Possibility to be much closer to the threshold than the proton case

Cross section measurement of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ at BESIII

BESIII has collected in 2014 significant data sample close to the Λ_c threshold:

$$e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$$

$\sqrt{s}$ (GeV)	Luminosity (pb^{-1})
4.5745	47.67
4.580	8.545
4.590	8.162
4.5995	566.9



Statistical uncertainties (<4.6 GeV): ~ 30% −70%

- Measurement of the Born cross section at 4 energy points below 4.6 GeV with **unprecedented statistical accuracy (**~2% at 4.6 GeV **)**
- **First measurement** of the Λ_c form factor ratio (at 4.57 and 4.6 GeV)

Cross section measurement of $e^+e^- \to \Lambda_c^+ \bar{\Lambda}_c^-$ at BESIII

- Always Postulated in e+e- -> baryon-antibaryon at threshold: angular distribution is isotropic ($|G_E|=|G_M|$), due to the FF analyticity
- Anisotropic angular distribution ($|G_E| \neq |G_M|$): leads to analytical violation of coulomb interaction (D-wave contribution)
- Hint for non isotropic angular distribution at threshold from proton data (PRD 73, 012005)

Analyticity Violation in $e^+e^- \to \Lambda_c \bar{\Lambda}_c$?
A request for
additional integrated luminosity at threshold

Rinaldo Baldini, Guangshun Huang, RongGang Ping, Weimin Song, Weiping Wang, Liang Yan, Zhengguo Zhao, Xiaorong Zhou, Kai Zhu,

and the BESIII Italian Collaboration Team

COLLINS ASYMMETRY AT BESIII

Measurement of Azimuthal Asymmetries in Inclusive Charged Dipion Production in e^+e^- Annihilations at $\sqrt{s} = 3.65\,\text{GeV}$

PRL 116, 042001 (2016)

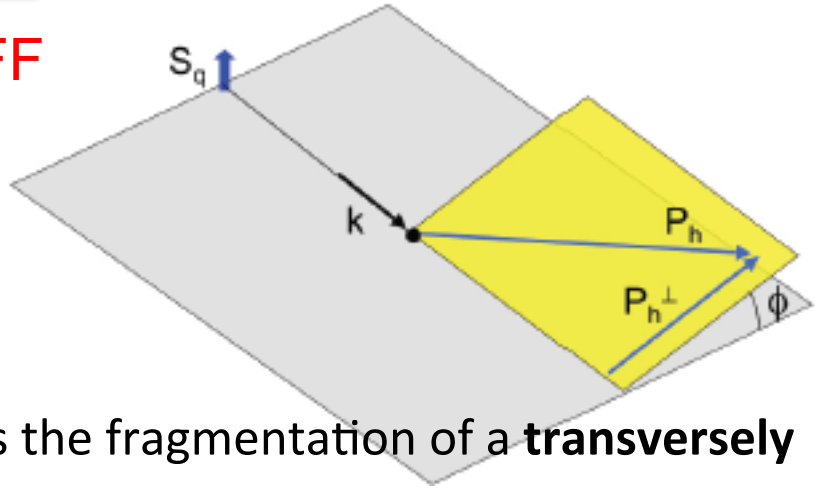
Collins Fragmentation Function

- The parton (quark, gluon)-hadron fragmentation process is parametrized with the help of **Fragmentation Functions** (FFs):

(Spinless hadron)

$$D_h^{q\uparrow}(z, \mathbf{P}_h^{\perp}) = D_1^q(z, \mathbf{P}_h^{\perp 2}) + H_1^{\perp q}(z, \mathbf{P}_h^{\perp 2}) \frac{(\hat{\mathbf{k}} \times \mathbf{P}_h^{\perp}) \cdot \mathbf{S}_q}{z M_h},$$

Unpolarized FF Collins FF



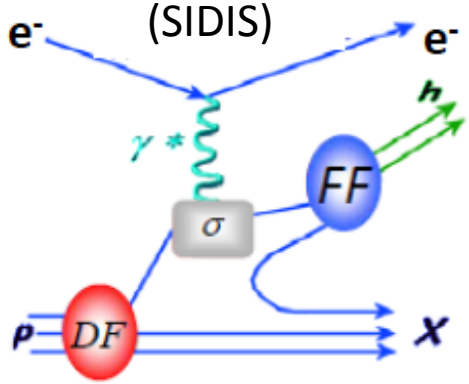
Fractional energy of hadron:

$$z = 2E_h / Q = 2E_h / \sqrt{s}$$

- Collins FF: chiral-odd function that describes the fragmentation of a **transversely polarized** quark ($q^{\uparrow}$) into a **spinless** hadron
  - Incorporate long distance non perturbative physics
  - Assumed to be universal functions (process-independent)

Measurements of Collins asymmetry: the universality

Semi Inclusive Deep Inelastic Scattering (SIDIS)



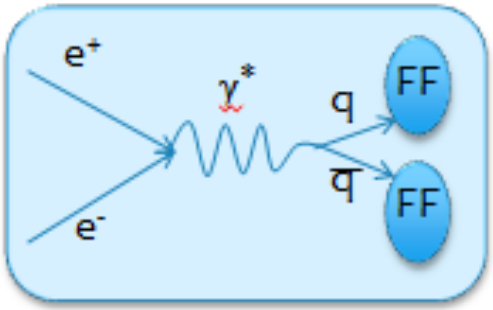
Collins FF ⊗ transversity

COMPASS

HERMES

JLAB

Unpolarized e+e- annihilation



Collins FF ⊗ Collins FF

BESIII

BaBar

Belle

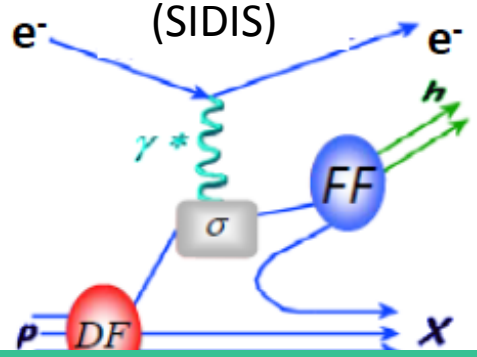
- Direct access to Collins functions
- Clean environment to study fragmentation processes

(u,d,s)

1-10 GeV^2 25 GeV^2 100 GeV^2

Measurements of Collins asymmetry: the universality

Semi Inclusive Deep Inelastic Scattering (SIDIS)



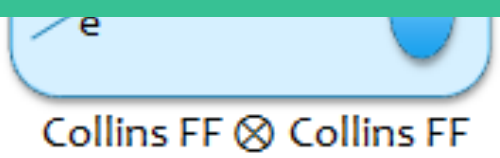
COMPASS

HERMES

JLAB

Combined data from e+e- (at different energies) and SIDIS

- Universality of Collins fragmentation functions
- Quark transversity distribution inside the nucleon
-Energy evolution of the spin dependent fragmentation functions



Collins FF ⊗ Collins FF

fragmentation processes

(u,d,s)

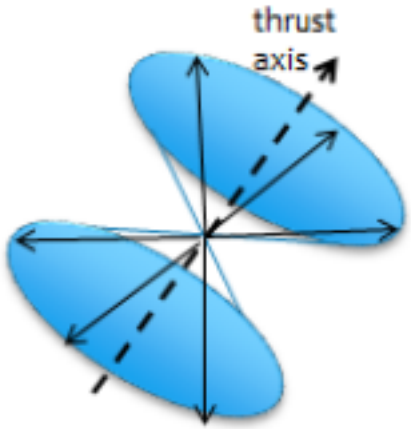
1-10 GeV^2 25 GeV^2 100 GeV^2

Collins asymmetry in "$e^+ e^- \rightarrow p\ p\ X$" (event selection)

Based on **62 pb^{-1}** collected at c.m. energy 3.65 GeV

Event selection for $e^+ e^- \rightarrow p\ p\ X$
• Good charged tracks from MDC • Photons from EMC • PID by combined information of dE/dx and TOF
•$N_{trk} \geq 3$ & $N_{\pi} \geq 2$ & $N_e = 0$ •$E_{tot\text{-}traks} > 1.5$ GeV
Pion pair • Fractional energy $0.3 < z < 0.9$ ($z \equiv 2\ E_h/\mathrm{sqrt}(s)$) • Open angle $\theta_{\pi\pi} > 120°$ • Save all possible combinations

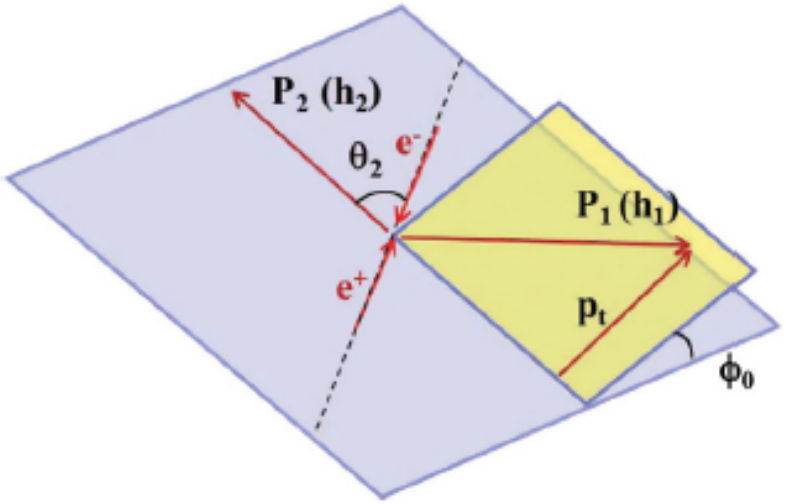
No clear jet event shape at BESIII (low energy scale):



Backgrounds are suppressed to a negligible level, less than 2.5%

Collins asymmetry in "$e^+ e^- \rightarrow p\ p\ X$" at BESIII

Collins effect: transverse quark spin relates to an azimuthal asymmetry (ϕ_0)



Parameterization: $a\ \mathbf{cos(2\phi_0)}+b$

$a=a(\theta_2, z_1, z_2),\ \ z=2E_h/Q$

- **Normalized ratios:** $R = \dfrac{N(2\phi_0)}{\langle N_0 \rangle}$
  - $N(2\phi 0)$: the dipion yield in each $2\phi_0$ subdivision
  - $\langle N_0 \rangle$: the averaged bin content
  - Three types of ratio:
    - Unlike-sign ($\pi^{\pm}\pi^{\mp}$): R^U
    - Like-sign ($\pi^{\pm}\pi^{\pm}$): R^L
    - All pion-pairs ($\pi\pi$): R^C

- **Double ratios :**

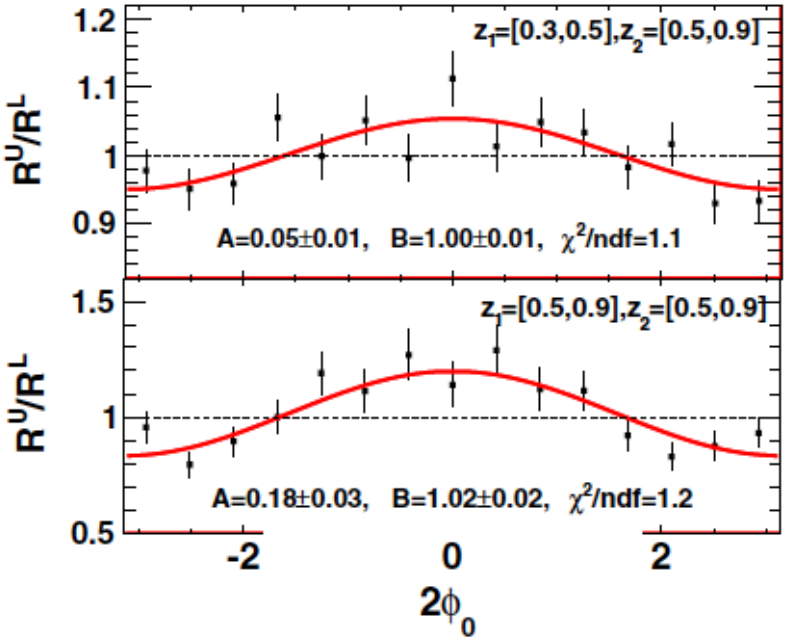
$$\frac{R^U}{R^{L(C)}} = A\cos(2\phi_0) + B$$

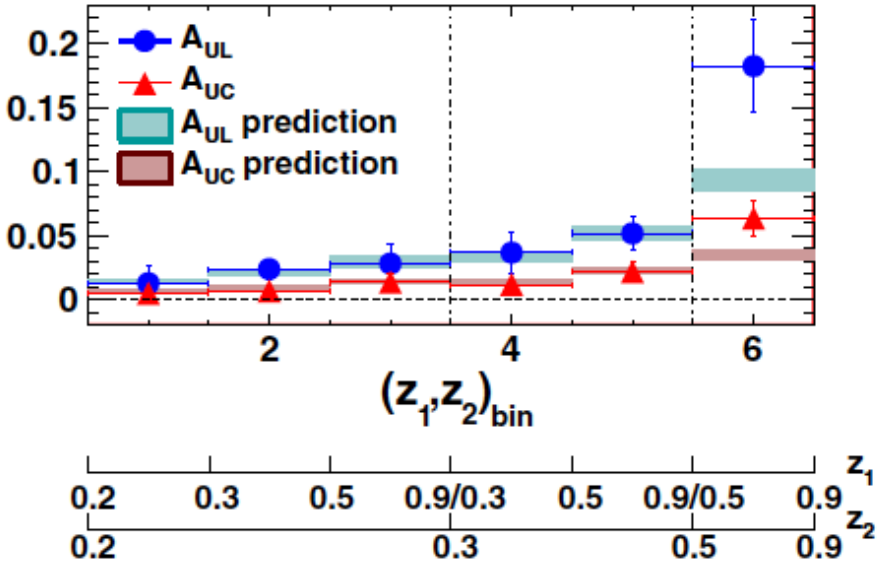
A: contains the Collins effect (A_{UL}, A_{UC})
B: should be consistent with unity

Collins asymmetry in "$e^+ e^- \rightarrow p\ p\ X$" at BESIII (Results)

- **Analysis of Collins asymmetry in bins of the fractional energy of hadrons (z_1,z_2)**

$$\frac{R^U}{R^L} = A_{UL}\cos(2\phi_0) + B, \frac{R^U}{R^C} = A_{UC}\cos(2\phi_0) + B$$



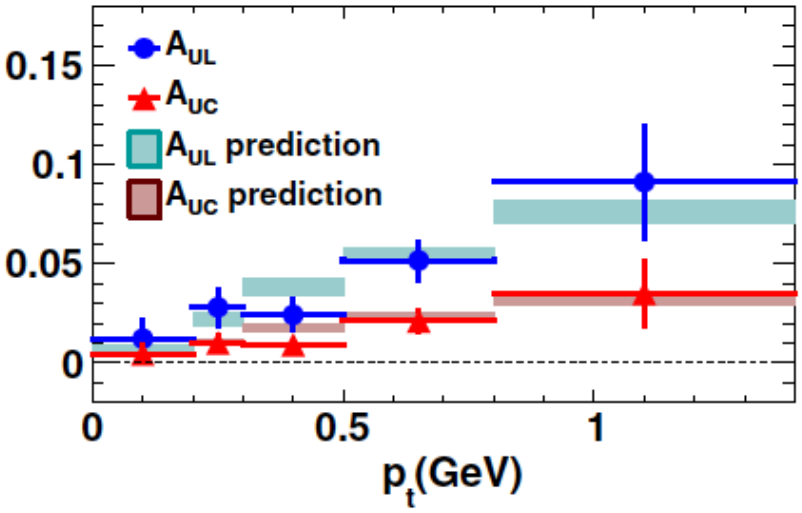


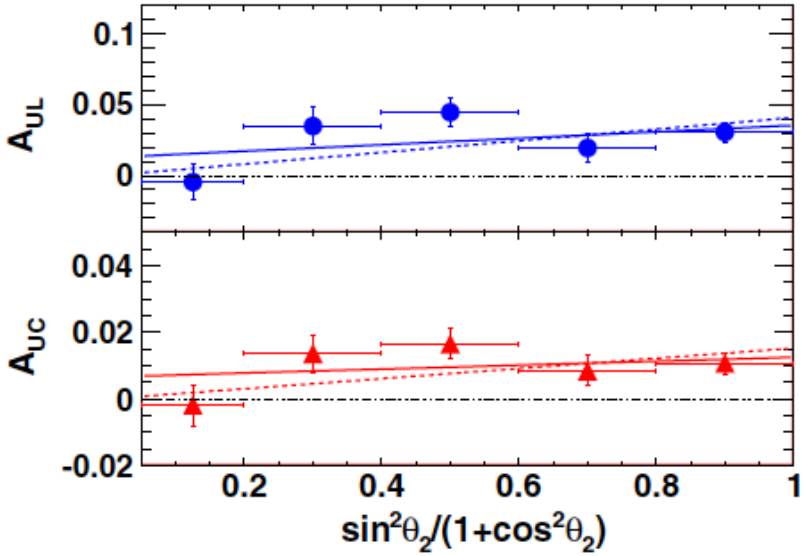
- Adding statistical and systematic uncertainties, **significant nonzero Collins asymmetries** are observed

*Prediction is from Z.-B. Kang, etc arXiv: 1505.05589

Collins asymmetry in "$e^+ e^- \rightarrow p\ p\ X$" at BESIII (Results)

- **Asymmetry dependence on transverse momentum and $\sin^2\theta_2/(1+\cos^2\theta_2)$**





- The asymmetries rise with fractional energies and p_t as expected theoretically, and seen in higher-energy e^+e^- experiments
- Linear dependence on $\mathbf{\sin^2\theta_2/(1+\cos^2\theta_2)}$

*Prediction is from Z.-B. Kang, etc arXiv: 1505.05589

Summary

- The **proton effective FF** is measured at 12 c.m. energies. The Born cross section and effective FF are in good agreement with previous experiments, improving the overall uncertainty by ~30%.

- The **| GE|/GM| ratio** is extracted at three energy points, with uncertainty in 25% and 50% (dominated by statistics).

- Promising results from the ISR and new scan 2015 data will be released soon

  - Based on the BESIII data collected close to the Λ_c pair threshold, the first measurement of Λ_c **FFs** will be possible

- The **Collins asymmetry** is measured @ 3.65 GeV using 62 pb^{-1} BESIII data : Obvious asymmetry is observed