Measurement of Proton Form Factors and Baryon Pairs ($p\bar{p}$, $\Lambda\bar{\Lambda}$, $\Lambda_c^+\bar{\Lambda}_c^-$) Production in e^+e^- annihilation at BESIII

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The doctoral dissertation defense

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Particle Physics and Nuclear Physics

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Something About Me First

Background

- Born in Dec. 1988, in Jiangsu Province
- Got a Bachelor's degree in July 2010, in USTC
- Being a graduate student since Sep. 2010, in USTC
- Join BESIII collaboration since 2011

Research on BESIII

- First observation of $J/\psi \to p\bar{p}a_0(980)$, $a_0(980) \to \pi^0\eta$, published in Phys. Rev. D
- Measurement of the proton form factor by studying $e^+e^- \to p\bar{p}$, submitted to Phys. Rev. D
- Cross section measurement of $e^+e^- \to \Lambda\bar{\Lambda}$ near threshold, under internal review, draft preparing
- Cross section measurement of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ near threshold, under internal review
- Cross section measurement of $e^+e^- \to \pi^+\pi^-\psi(3686)$, under internal review

Something About Me First

- **Academic activities**
  - 2011.10.07-10.21, Third France-Asia Particle Physics School (FAPPS11), in Les Houches, France
  - 2013.10.07-12.07, academic communication in INFN, Italy
  - 2014.06.22-06.27, gave two posters on OCPA8, in Singapore
  - 2015.05.25-05.28, will give a talk “Proton pair production cross sections at BESIII” on NSTAR2015, in Japan

- **Award**
  - 中国科学技术大学研究生新生奖 （2010）
  - 中国科学技术大学研究生会优秀干事奖 （2011）
  - 中国科学技术大学求是研究生奖学金 （2014）
  - 第一届“五校联盟”物理学研究生学术报告 一等奖 （2014）

Outline

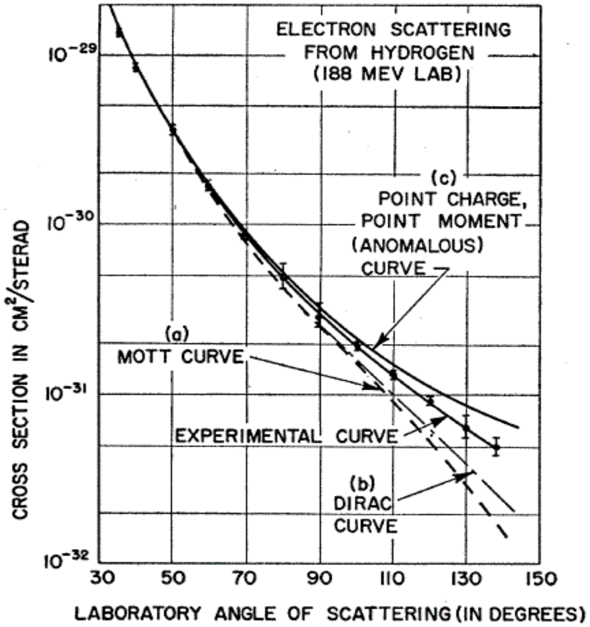
- Introduction
  - Nucleon Electromagnetic Form Factors
  - The $N\overline{N}$ Production Threshold
- BEPCII and BESIII
- Measurement of Proton Form Factors
- Baryon Pair Production Near Threshold
  - Measurement of $e^+e^- \to \Lambda\overline{\Lambda}$
  - Measurement of $e^+e^- \to \Lambda_c^+\overline{\Lambda}_c^-$
- Other works on BESIII
- Summary and Prospect

Introduction

- Evidence of the nucleons are not point-like particles
- The anomalous magnetic moment **(Stern, Nobel Prize 1943)**
  - Point-like proton and neutron have magnetic moment of μ_N and 0
  - The measured magnetic moment of proton and neutron are $2.79\mu_N$ and $-1.91\mu_N$
- Elastic scattering of electron and proton **(Hofstadter, Nobel Prize 1961)**
  - Theoretically, differential cross section is:

$$\left(\frac{d\sigma}{d\Omega}\right)_{ep(point)} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \left(1 + 2\tau \tan^2\frac{\theta}{2}\right)$$

  - In experiment, scattering of 188 MeV electron with hydrogen target, differential cross section shows inconsistence with (a), (b), (c)
  - The deviation represents the effect of a form factor (FF) for the proton.



Nucleon Electromagnetic FFs

- Nucleon Electromagnetic FFs (NEFFs) are among the most basic observables of the nucleon, and intimately related to its internal structure and dynamics.
- NEFFs are semi-empirical formula in effective quantum field theories which help describe the spatial distributions of electric charge and current.
- The FFs constitute a rigorous test for the phenomenological models which consist fundamental elements in QCD.
- Models that reproduce **proton** and **neutron**, electric and magnetic form factors in **space-like** and **time-like** regions

Vector Meson Dominance (VMD) based models
R. Bijker and F. Iachello, Phys. Rev. C **69**, 068201 (2004).

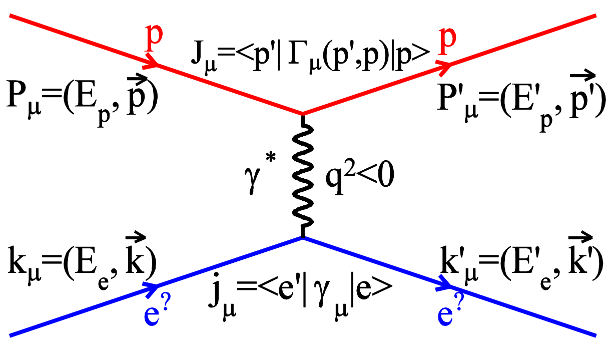
Perturbative QCD prediction
S. J. Brodsky and G. R. Farrar, Phy. Rev. D **11**, 1309 (1975).

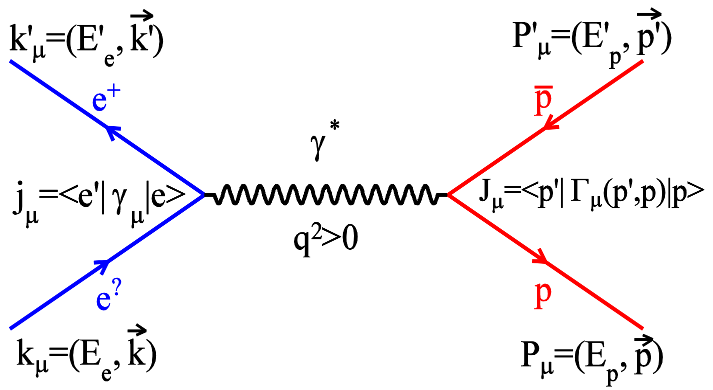
- Successful models in recent years

Chiral field theory
J. Haidenbauer, X.-W. Kang, U.-G, Meiβner, Nucl. Phys. A **929**, 102 (2014).
Lattice gauge theory
B.~Jager, *et al.*, Pos LATTICE **2013**, 272 (2014).

Nucleon Electromagnetic FFs

- The FFs are measured in space-like (SL) region or time-like (TL) region. The proton electromagnetic vertex Γ_μ describing the hadron current





- $\Gamma_\mu(p',p) = \gamma_\mu F_1(q^2) + \frac{i\sigma_{\mu\nu}q^\nu}{2m_p} F_2(q^2)$
- $G_E(q^2) = F_1(q^2) + \tau\kappa_p F_2(q^2)$
- $G_M(q^2) = F_1(q^2) + \kappa_p F_2(q^2)$

- $\tau = \frac{q^2}{4m_p^2}$, $\kappa_p = \frac{g_p - 2}{2} = \mu_p - 1$
- At $q^2=0$,
  proton: $F_1=F_2=1$ $G_E=1$, $G_M=\mu_p$
  neutron: $F_1=0$, $F_2=1$, $G_E=1$, $G_M=\mu_n$

- G_E and G_M can be interpreted as Fourier transforms of spatial distributions of charge and magnetization of nucleon in the Breit frame

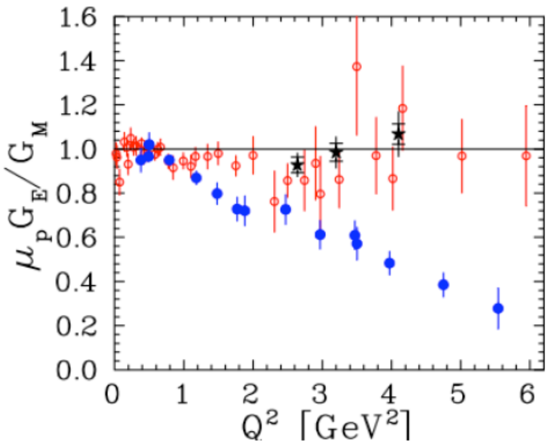
i.e $\rho(\vec{r}) = \int \frac{d^3q}{2\pi^3} e^{-i\vec{q}\cdot\vec{r}} \frac{M}{E(\vec{q})} G_E(\vec{q}^2)$

NEFFs in Space-like region

- Nucleon Electromagnetic FFs (NEFF) in Space-like region
- Unpolarized electron-proton elastic
  - In one-photon exchange approximation,

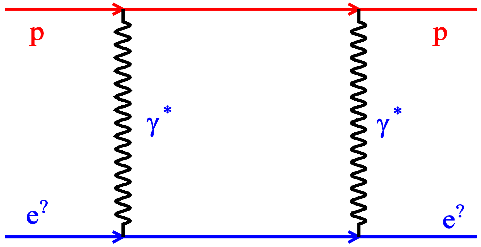
$$\frac{d\sigma}{d\Omega} = (\frac{d\sigma}{d\Omega})_{Mott}[G_E^2 + \frac{\tau}{\varepsilon}G_M^2)\frac{1}{1+\tau}, \quad \varepsilon = \frac{1}{1+2(1+\tau)\tan^2(\frac{\theta_e}{2})}$$ is the longitudinal polarization of photon.

  - Rosenbluth Separation: $\sigma_R = \frac{\varepsilon}{\tau}G_E^2 + G_M^2$



Solid circle: recoil polarization
Open circle: Rosenbluth separation

- Polarized electron-proton elastic scattering
  - Longitudinally polarized electron beam
  - Recoil proton polarization:
  - $\frac{G_E}{G_M} = -\frac{P_t}{P_l}\frac{E_e+E_{beam}}{2M_p}\tan\frac{\theta}{2}$
- The two-photon exchange contribution



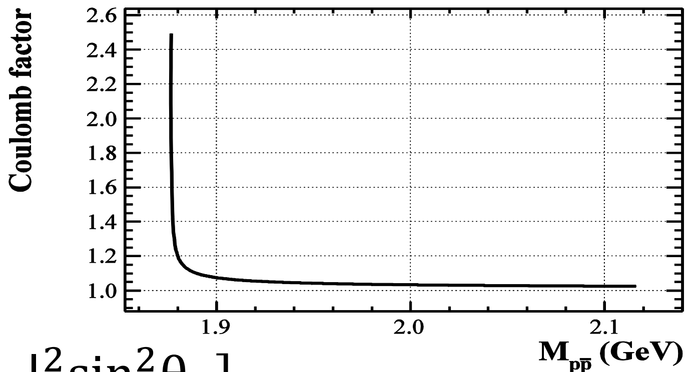
NEFFs in Time-like region

- NEFF in Time-like region
  - In one-photon exchange approximation
  - $\frac{d\sigma}{d\cos\theta_p} = \frac{\pi\alpha^2\beta C}{2s^2}[|G_M|^2(1+\cos^2\theta_p) + \frac{1}{\tau}|G_E|^2\sin^2\theta_p]$
  - velocity of proton in e^+e^- c.m. system, $\beta = \sqrt{1 - \frac{4m_p^2}{s}}$

- Sommerfeld enhancement and resummation factors:
  - Coulomb factor, C, for S-wave only
  - Step at threshold:

$$C = \frac{\alpha\pi}{\beta},$$

$$\frac{d\sigma}{d\cos\theta_p} = \frac{\pi^2\alpha^3}{2s^2}[|G_M|^2(1+\cos^2\theta_p) + \frac{1}{\tau}|G_E|^2\sin^2\theta_p]$$



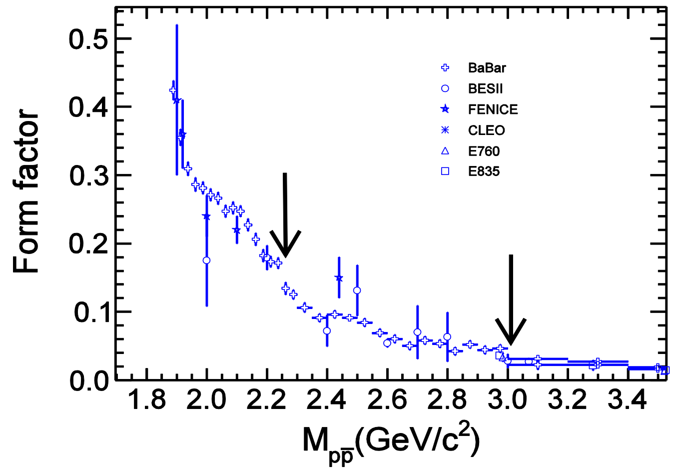
NEFFs in Time-like region

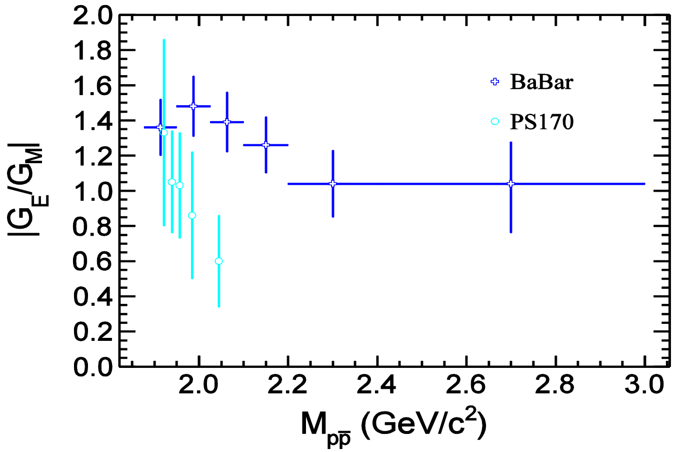
- Previous experimental results from scan method and ISR method:

Process	Date	Experiment	q^2 (GeV^2/c^4)	q^2 point	Event	Precision
$e^+e^- \to p\bar{p}$	1972	FENICE/ADONE [17]	4.3	1	27	15%
	1979	DM1/ORSAY-DCI [18]	3.75-4.56	4	70	25.0%
	1983	DM2/ORSAY-DC1 [19]	4.0-5.0	6	100	19.6%
	1998	FENICE/ADONE [20]	3.6-5.9	5	76	19.3%
	2005	BES/BEPC [21]	4.0-9.4	10	80	21.2%
	2006	CLEO/ [22]	13.48	1	16	33.3%
$p^+p^- \to e^+e^-$	1976	PS135/CERN [24]	3.52	1	29	15.7%
	1994	PS170/CERN [25]	3.52-4.18	9	3667	6.1%
	1993	E760/Fermi [26]	8.9-13.0	3	29	33.8%
	1999	E835/Fermi [27]	8.84-18.4	6	144	10.3%
	2003	E835/Fermi [28]	11.63-18.22	4	66	21.1%
$e^+e^- \to \gamma + p\bar{p}$	2006	BaBar/SLAC-PEPII [30]	3.57-19.1	38	3261	9.8%
	2013	BaBar/SLAC-PEPII [31]	3.57-19.1	38	6866	6.7%
	2013	BaBar/SLAC-PEPII [32]	9.61-36.0	8	140	18.4%

NEFFs in Time-like region

- Still questions left on the proton FFs
  - Steep rise toward threshold
  - Two rapid decreases of the FF near 2.25 and 3.0 GeV
  - The asymptotic values for SL and TL FFs should be identical at high energies, while G_M is larger than SL quantities (i.e. at $|q^2|=3.08^2$ GeV^2, $|G_{TL}|=0.031$, and $|G_{SL}|=0.011$)
- Electromagnetic FF ratio
  - Poor precision (11%, 43%) and limited energy range (1.92, 2.7) GeV
  - disagreement of $|G_E/G_M|$ ratio between PS170 and BaBar



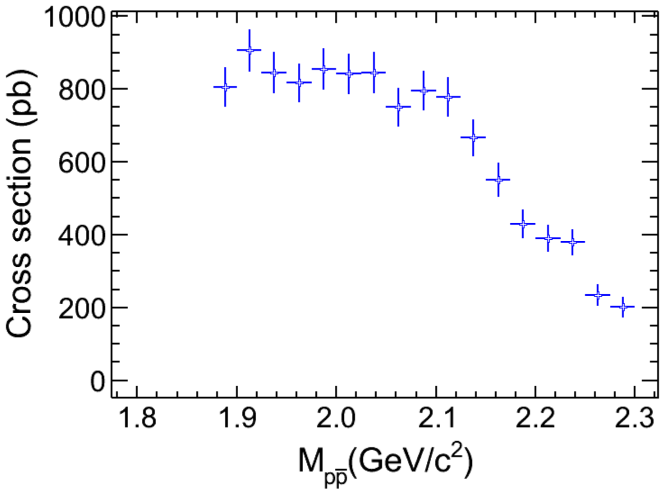


$N\bar{N}$ Production Threshold

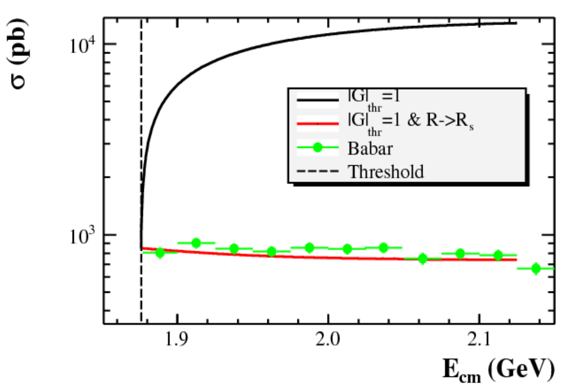
- $N\bar{N}$ production threshold
  - At threshold, $|G_E|=|G_M|=|G_{eff}|$
  - The total cross section becomes:

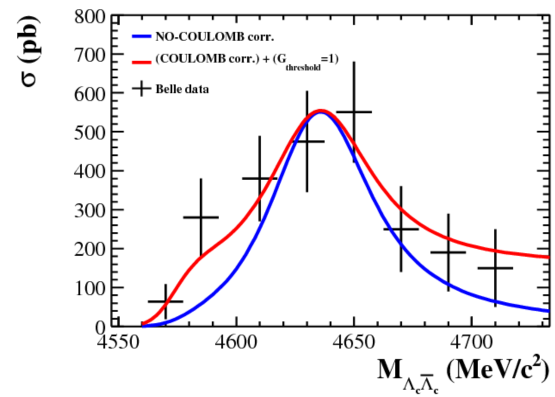
$$\sigma^{th} = \frac{\pi\alpha^2 C}{3m_p^2\tau}\left[1+\frac{1}{2\tau}\right]|G_{eff}^N(q^2)|^2 = \sigma_{point}^N(q^2)|G_{eff}^N(q^2)|^2$$

  - The point-like cross sections for proton at threshold:
  - $\sigma_{point}^p(4m_p^2) = \frac{\pi^2\alpha^3}{2m_p^2} = 0.848\ \text{nb}$



- The steep slope at $p\bar{p}$ has been explained by:
  - $p\bar{p}$ final-state interaction acting near the threshold (i.e. $J/\psi \to \gamma p\bar{p}$)
  - a narrow meson resonance below the threshold (Phys. Lett. B 643, 29 (2006))
  - $|G_{4m_p^2}| \sim 1$ (Eur. Phys. J. A 39, 315 (2009))



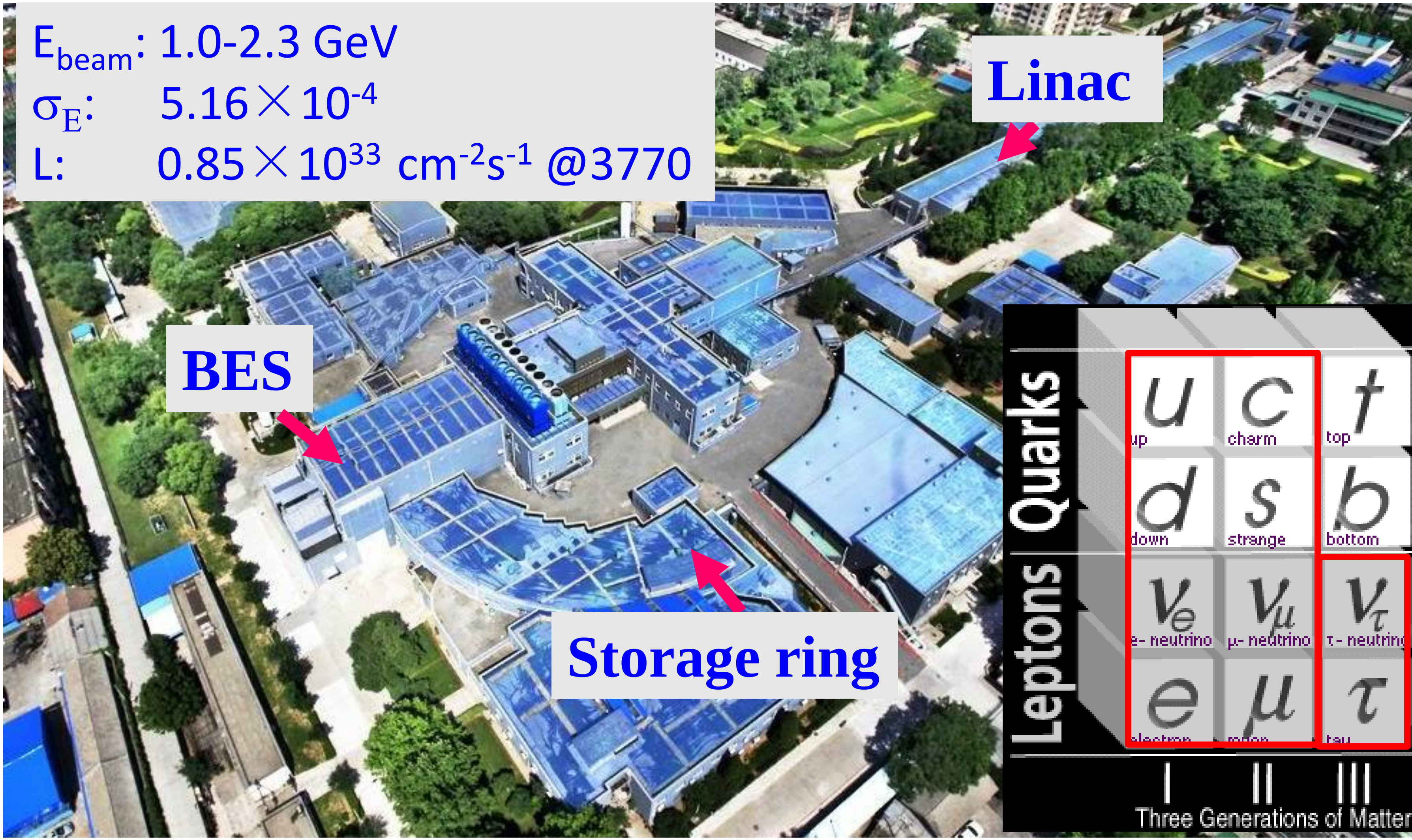


Beijing Electron Positron Collider

E_{beam}: 1.0-2.3 GeV

σ_E: 5.16×10^{-4}

L: 0.85×10^{33} cm^{-2}s^{-1} @3770



Beijing Electron Positron Collider

- Data taken in BEPCII till July 2014:

Taking data	Total Num. / Lum.	Taking time
J/ψ	225+1086 M	2009+2012
$\psi(2S)$	106+350 M	2009+2012
$\psi(3770)$	2916 pb^{-1}	2010~2011
τ scan	24 pb^{-1}	2011
Y(4260)/Y(4230)/Y(4360)/scan	806/1054/523/488 pb^{-1}	2012~2013
4600/4470/4530/4575/4420	506/100/100/42/993 pb^{-1}	2014
J/ψ line-shape scan	100 pb^{-1}	2012
R scan (2.23, 3.40) GeV	12 pb^{-1}	2012
R scan (3.85, 4.59) GeV	795 pb^{-1}	2013~2014

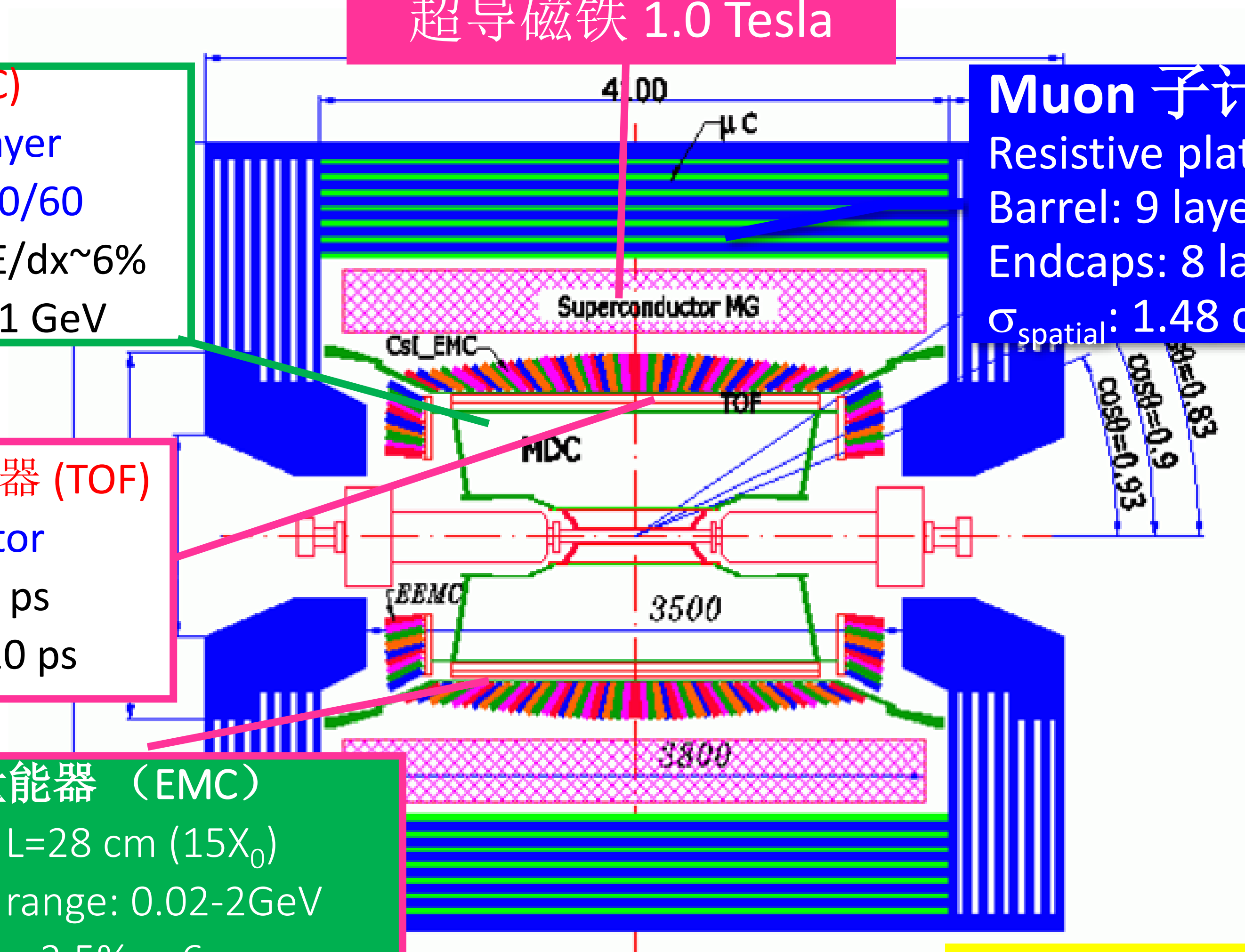
The red color marks the data sets used in my research topics.

BEijing Spectrometer (BESIII)

超导磁铁 1.0 Tesla

主漂移室(MDC)
Small cell, 43 layer
Gas He/C_3H_8=40/60
σ_{xy}=130 μm, dE/dx~6%
σ_p/p = 0.5% at 1 GeV

Muon 子计数器
Resistive plate chamber
Barrel: 9 layers
Endcaps: 8 layers
$\sigma_{spatial}$: 1.48 cm

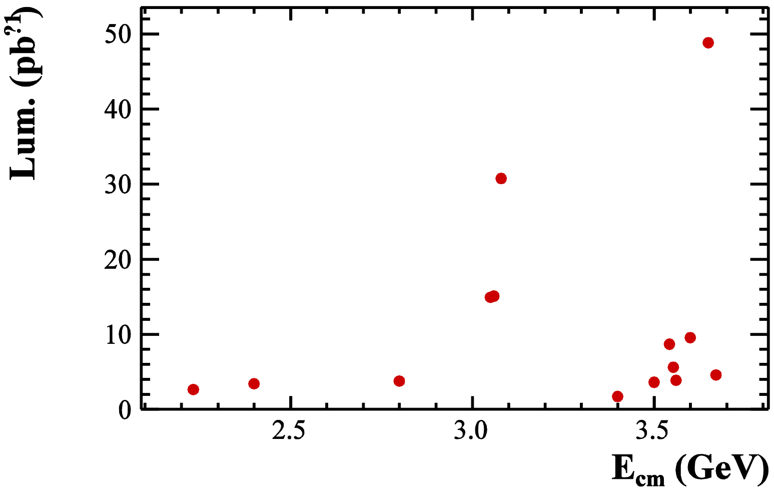


飞行时间计数器 (TOF)
Plastic scintillator
σ_T(barrel): 80 ps
σ_T(endcap): 110 ps

电磁量能器 （EMC）
CsI(Tl): L=28 cm ($15X_0$)
Energy range: 0.02-2GeV
Barrel s_E 2.5%, s_l 6mm
Endcap s_E 5.0%, s_l 9mm

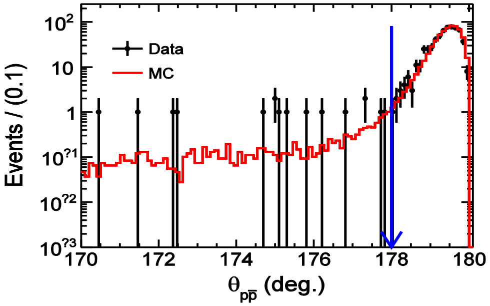
Event rate: 4000Hz

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

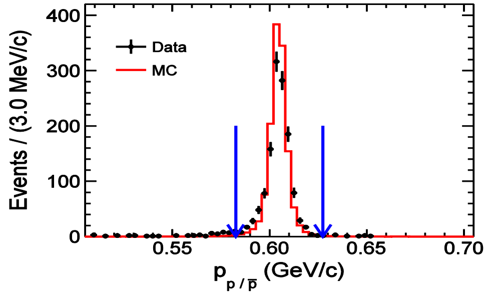


■ Event selection

- Good charged tracks
  - ➢ $|R_{xy}| < 1$ cm, $|R_z| < 10$ cm
  - ➢ $|\cos\theta| < 0.93$
- Particle identification
  - ➢ dE/dx + Tof
  - ➢ Prob(p) > Prob(K/ π)
  - ➢ For proton track, require E/p < 0.5, cosθ < 0.8

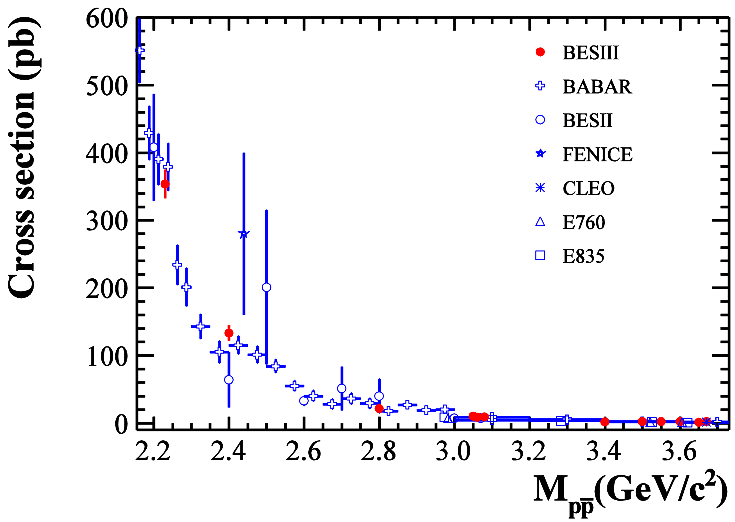


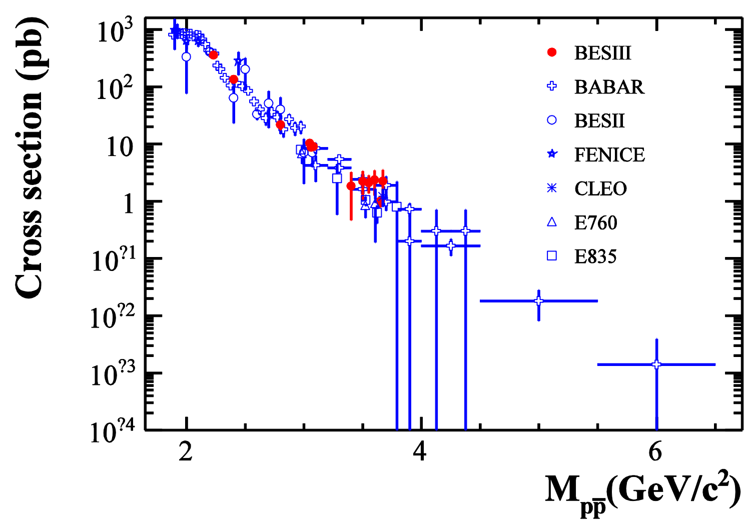
- $N_{char} = 2$ & $N_p = N_{\bar{p}} = 1$
- $|tof_p - tof_{\bar{p}}| < 4$ ns
- Two tracks angle > 179^o
- Momentum window cut for proton and anti-proton



Measurement of Proton Form Factors

- $\sigma_{Born} = \frac{N_{obs} - N_{bkg}}{L \cdot \varepsilon \cdot (1+\delta)}$
  - N_{obs}: the observed number of signal in data
  - N_{bkg}: the number of background evaluated from MC
  - L: the integral luminosity
  - ε: detection efficiency by MC sample, with Conexc generator
  - (1+δ): radiative correction factor





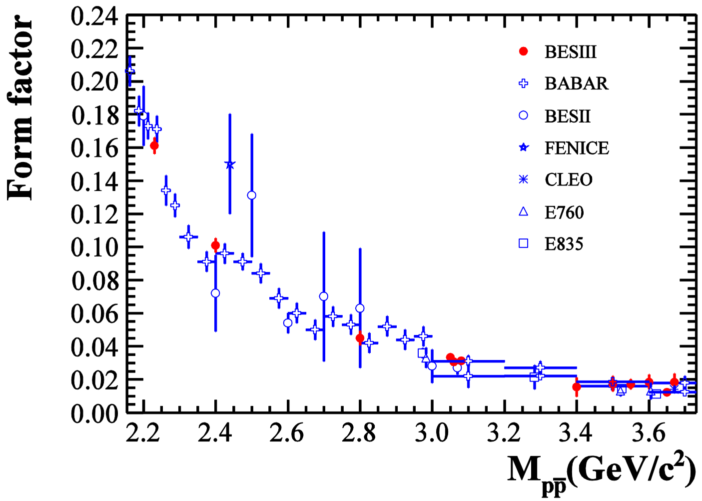
Extraction of the effective FF

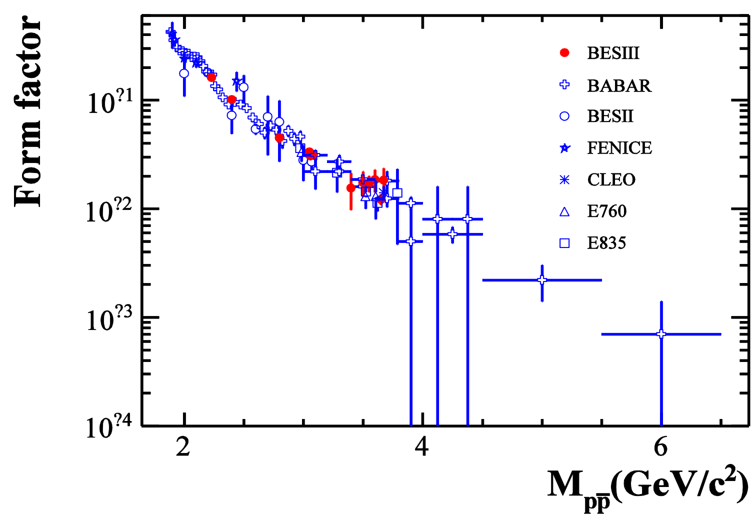
- **Effective FF**
  - Assuming $|G_E|=|G_M|=|G_{eff}|$, (which holds at $p\bar{p}$ mass threshold)

$$\sigma = \frac{\pi\alpha^2}{3m_p^2\tau}\left[1+\frac{1}{2\tau}\right]|G_{eff}|^2$$

  - After taking natural units: $1\text{m} = 5.0677\times 10^{15}\ \text{GeV}^{-1}$

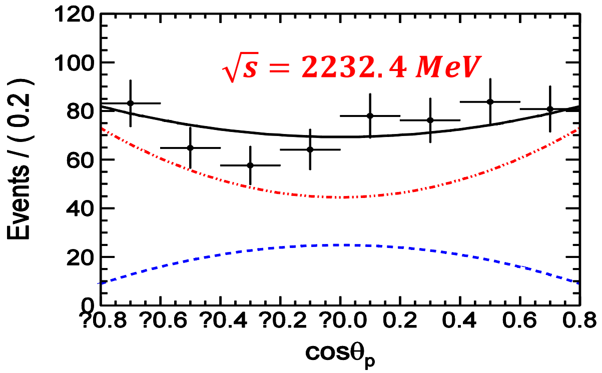
$$G_{eff} = \sqrt{\frac{\sigma_{Born}}{86.83\cdot\frac{\beta}{s}(1+\frac{2m_p^2}{s})}}$$

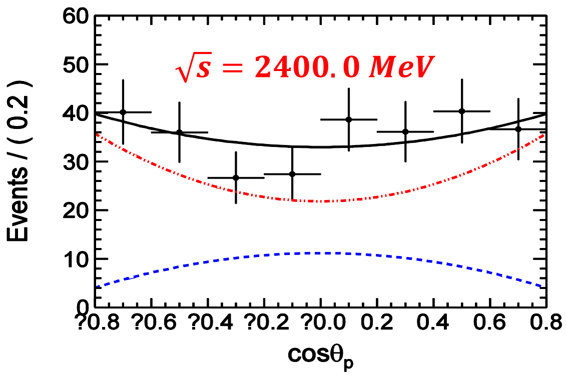


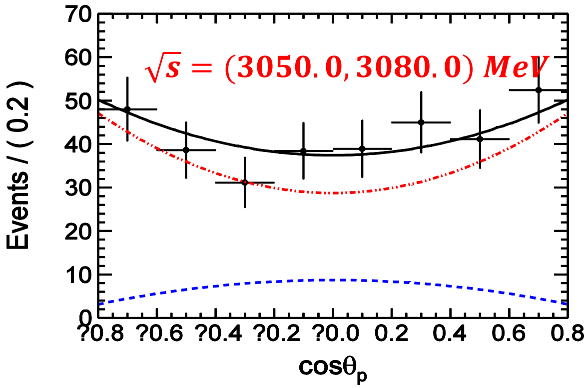


Extraction of electromagnetic $|G_E/G_M|$ ratio

- Angular analysis to extract the em FFs:
  - $\frac{d\sigma}{d\Omega}(q^2) = \frac{\alpha^2\beta}{4s}|G_M(s)|^2\left[\left(1+\cos^2\theta_p\right) + R_{em}^2\frac{1}{\tau}\sin^2\theta_p\right]$
  - $R_{em} = G_E(q^2)/G_M(q^2)$
  - θ: polar angle of proton of baryon at the c.m.system
- Fit function:
  - $\frac{dN}{d\cos\theta_p} = N_{norm}\left[\left(1+\cos^2\theta_p\right) + R_{em}^2\frac{1}{\tau}\sin^2\theta_p\right]$
  - $N_{norm} = \frac{2\pi\alpha^2\beta L}{4s}\left[1.94 + 5.04\frac{m_p^2}{s}R^2\right]G_M(s)^2$ is the overall normalization







Extraction of electromagnetic $|G_E/G_M|$ ratio

- Method of Moment
  - Given a probability density function $f(x|\theta)$ with unknown parameters θ, the r-th algebraic moment of the population is defined by:

$$\mu_r(\theta) = \int_\Omega x^r f(x|\theta)dx$$

  - An estimation of $\mu_r(\theta)$ is the arithmetic mean of the r-th power of the observation x_i

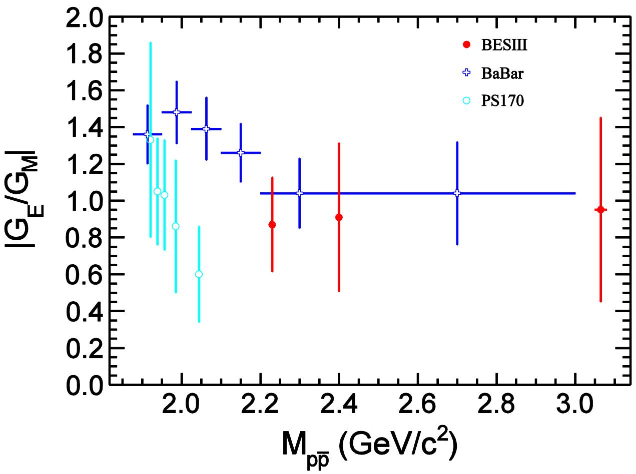
$$\mu_r(\theta) = \frac{1}{n}\sum_{i=1}^{n} x_i^r$$

  - Second Moment of $\cos\theta_{p}$: $\langle\cos^2\theta_p\rangle = \frac{1}{N_{norm}}\int \cos^2\theta_p \frac{d\sigma}{d\Omega} d\cos\theta_p$
  - The estimator of $\langle\cos^2\theta_p\rangle$: $\langle\cos^2\theta_p\rangle = \overline{\cos^2\theta_p} = \frac{1}{N}\sum_{i=1}^{N}\cos^2\theta_p/\varepsilon_i$
  - Extract $|G_E/G_M|$ ratio: $R = \sqrt{\frac{s}{4m_p^2}\frac{\langle\cos^2\theta_p\rangle - 0.243}{0.108 - 0.648\langle\cos^2\theta_p\rangle}}$
  - Uncertainty of $\langle\cos^2\theta_p\rangle$: $\sigma_{\langle cos^2\theta_p\rangle} = \sqrt{\frac{1}{N-1}[\langle cos^4\theta_p\rangle - \langle cos^2\theta_p\rangle]}$

Extraction of electromagnetic $|G_E/G_M|$ ratio

■ Results on $|G_E/G_M|$ ratio:

$\sqrt{s}$ (MeV)	$\lvert G_E/G_M \rvert$	$\lvert G_M \rvert$ ($\times 10^{-2}$)	χ^2/ndf
	Fit on $\cos\theta_p$		
2232.4	$0.87 \pm 0.24 \pm 0.05$	$18.42 \pm 5.09 \pm 0.98$	1.04
2400.0	$0.91 \pm 0.38 \pm 0.12$	$11.30 \pm 4.73 \pm 1.53$	0.74
(3050.0, 3080.0)	$0.95 \pm 0.45 \pm 0.21$	$3.61 \pm 1.71 \pm 0.82$	0.61
	method of moment		
2232.4	0.83 ± 0.24	18.60 ± 5.38	-
2400.0	0.85 ± 0.37	11.52 ± 5.01	-
(3050.0, 3080.0)	0.88 ± 0.46	3.34 ± 1.72	-



■ Conclusion:

- ➢ The Born cross sections and effective FFs are in good agreement with previous experiments, improving the overall uncertainty by ~30%.
- ➢ The measured $|G_E/G_M|$ ratio are close to unity (indicates $|G_E| = |G_M|$)

Measurement of $e^+e^- \to \Lambda\bar{\Lambda}$ at threshold

- Data set at $\sqrt{s} = 2232.4$ MeV, which is 1.0 MeV above $\Lambda\bar{\Lambda}$ threshold
- Typical event display
  - Reconstruction of $\Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}\pi^+$

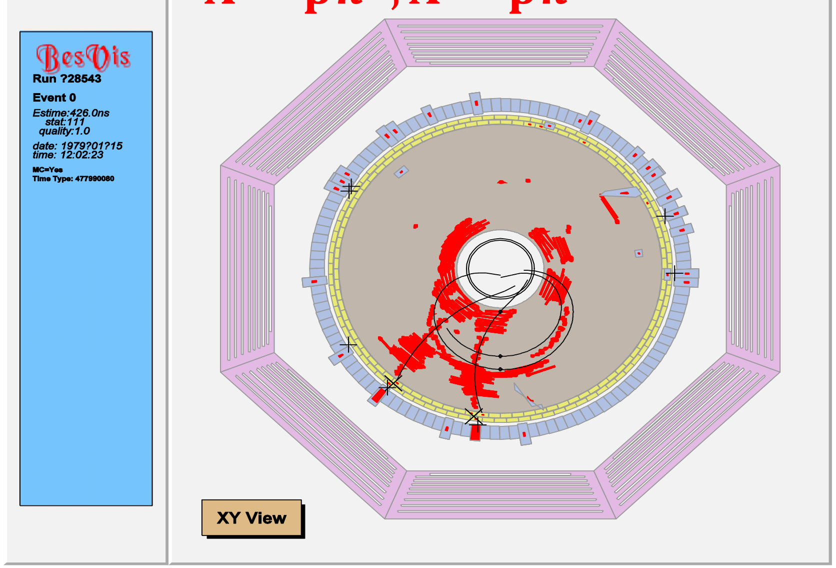
    two low momentum tracks are pions.

    no proton information left, anti-proton annihilation will produce high momentum tracks
  - Reconstruction of $\bar{\Lambda} \to \bar{n}\pi^0$

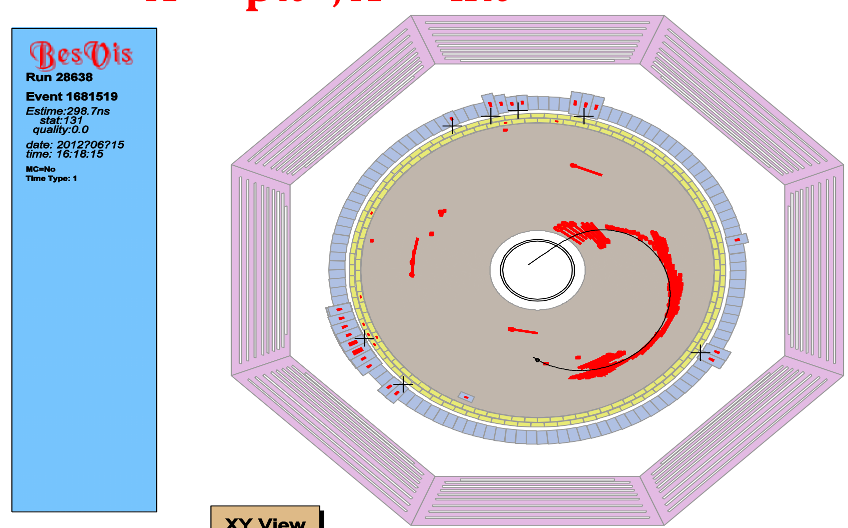
    at most two track in detector

    angle between anti-neutron and pion0 is larger than 140°

$\Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}\pi^+$

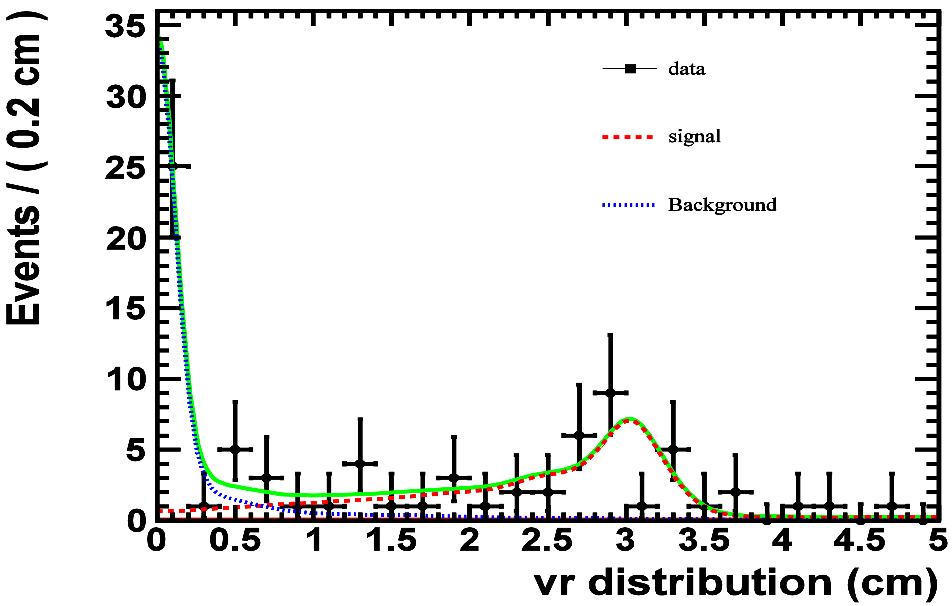


$\Lambda \to p\pi^-, \bar{\Lambda} \to \bar{n}\pi^0$



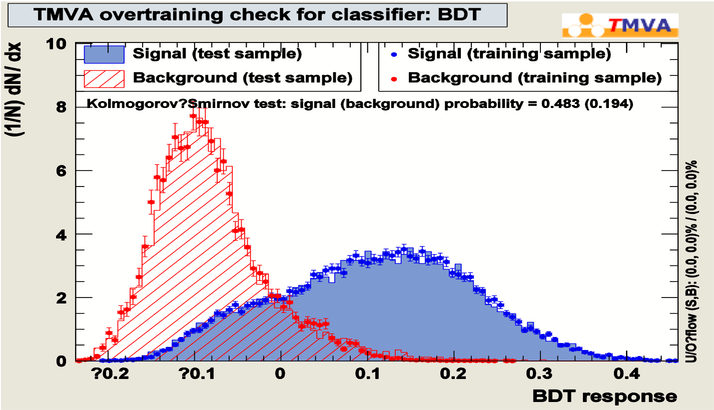
Reconstruction of $\Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}\pi^+$

- Extraction of signal events
- Fit the distribution of the largest V_r
  - Signal described by the MC shape
  - Background described by the sideband of π momentum.
  - Yields: 43 ± 7, detection efficiency: 20.1%

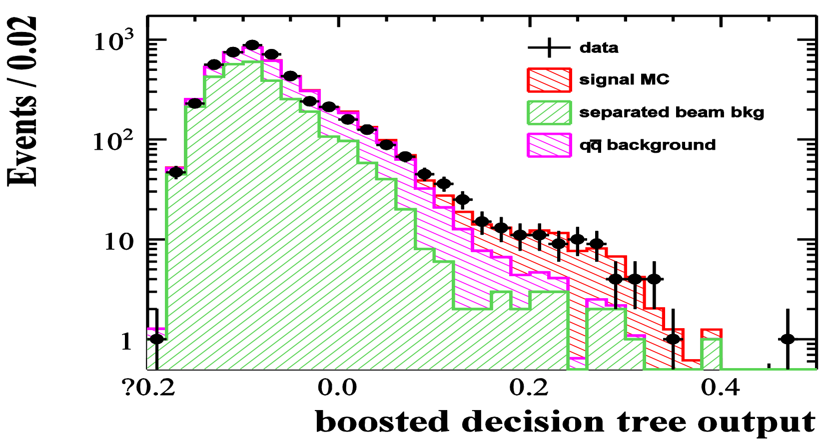


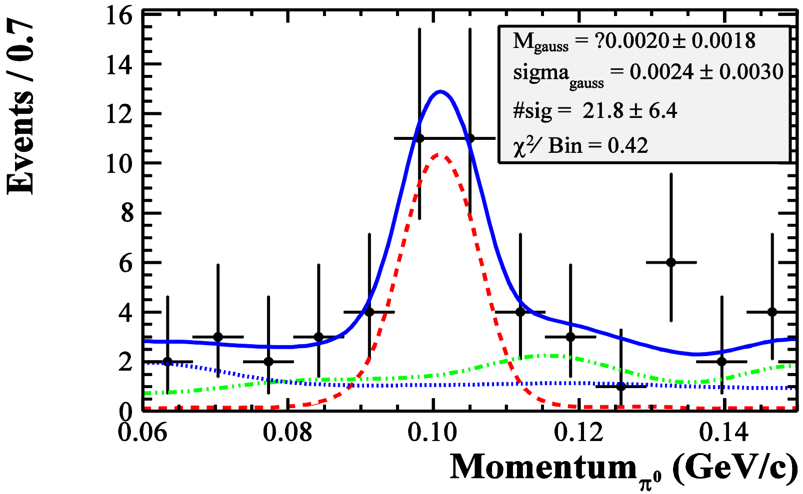
Reconstruction of $\bar{\Lambda} \to \bar{n}\pi^0$

- BDT choices
  - To separate the signal from hige background
  - ½ of MC and background for training
  - Minimum leaf size = 400 events
  - Maximum tree depth = 3
  - AdaBoost parameter β=0.5
  - Signal leaf if purity > 0.5



- BDT output





Measurement of $e^+e^- \to \Lambda\bar{\Lambda}$

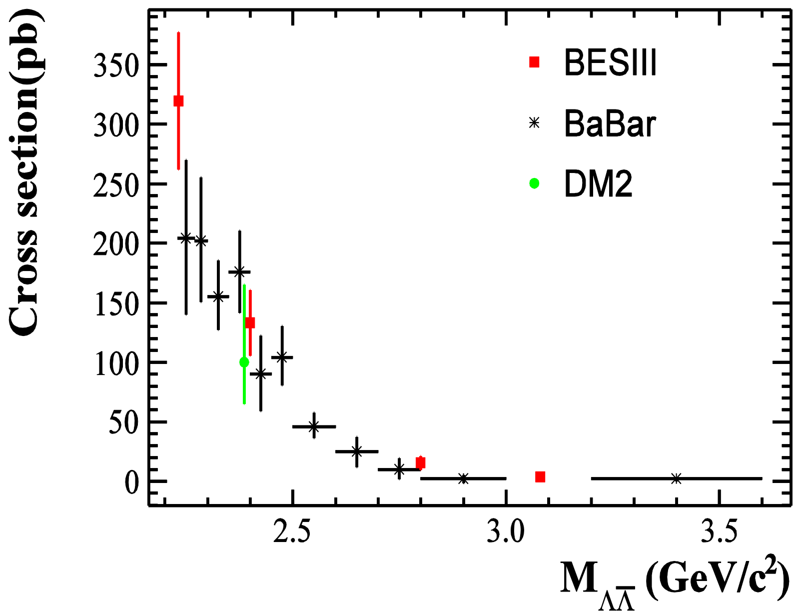
■Cross section and effective FF

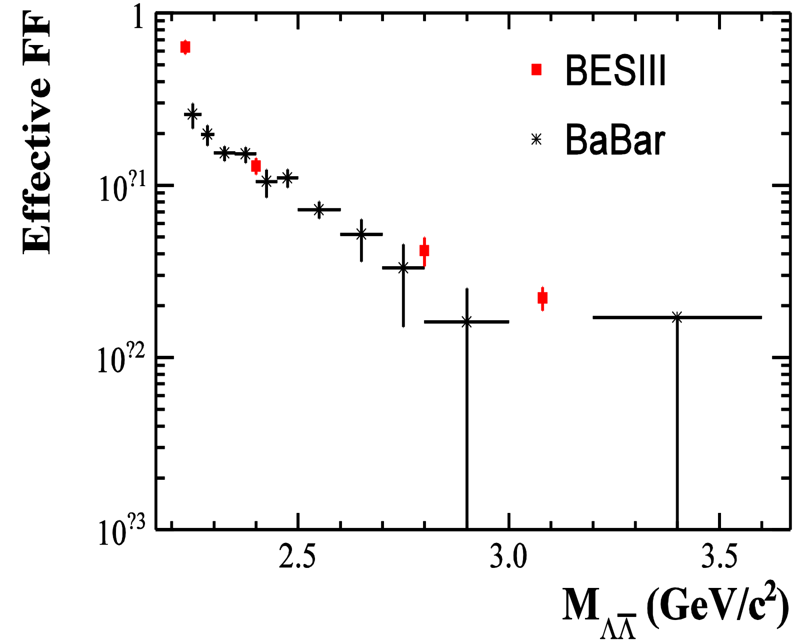
Reconstruction @ 2232.4 MeV	σ_{Born} (pb)	$\|G\|$ $(\times 10^{-2})$
$\Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}\pi^+$	$325 \pm 53 \pm 46$	
$\bar{\Lambda} \to \bar{n}\pi^0$	$300 \pm 100 \pm 40$	
Combined	$\mathbf{320 \pm 58}$	$\mathbf{63.4 \pm 5.7}$

- $(e^+e^- \to \Lambda\bar{\Lambda}) = \frac{N_{sig} - N_{bkg}}{L \cdot \varepsilon \cdot (1+\delta) \cdot B_r(\Lambda \to p\pi^-) \cdot B_r(\bar{\Lambda} \to \bar{p}\pi^-)}$
- Assuming $|G_E| = |G_M| = |G|$ (as proton FF case)

$\sqrt{s}$ (GeV)	σ_{Born} (pb)	$\|G\|$ $(\times 10^{-2})$
2.40	$133 \pm 20 \pm 19$	$12.93 \pm 0.97 \pm 0.92$
2.80	$15.3 \pm 5.4 \pm 2.0$	$4.16 \pm 0.73 \pm 0.27$
3.08	$3.9 \pm 1.1 \pm 0.5$	$2.21 \pm 0.31 \pm 0.14$

Measurement of $e^+e^- \to \Lambda\bar{\Lambda}$





- The cross section of $e^+e^- \to \Lambda\bar{\Lambda}$ shows a sudden rise near threshold
- The results are consistent with BaBar experiment at high c.m.energies
- The precision of the cross section is between 18.1% and 33.3%, while results from BaBar experiment is 32.2% and 100.0%
- The uncertainty is dominant by statistics. The dominant systematic source is the angular distribution of Λ

Measurement of $e^+e^- \to \Lambda\bar{\Lambda}$

- Discussions on the non-zero cross section 320 ± 58 pb at threshold:

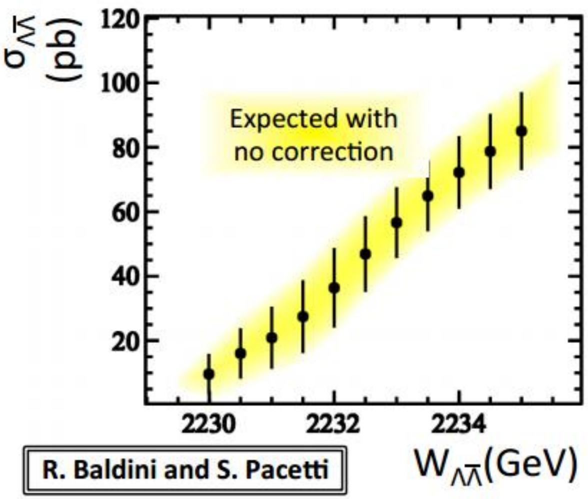
Theory prediction for neutral baryons

$$\sigma_{\Lambda\bar{\Lambda}} = \frac{2\pi\alpha^2}{W^2}\beta G^2_{eff}(W^2)$$

Cross section vanishes as the velocity

$$\beta = (1 - 4M_\Lambda^2/W^2)^{1/2}$$

when: $W^2 \longrightarrow 4M_\Lambda^2$.



Neutral baryon non-zero cross section at threshold?
Coulomb interaction at quark level!

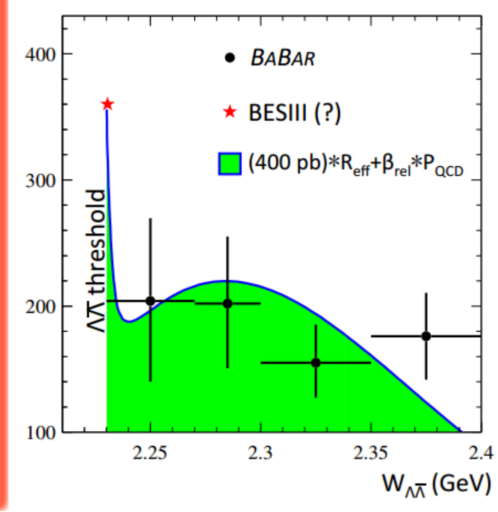
Naïve expectation — R. Baldini and S. Pacetti

- $\sigma(4M_\Lambda^2) = \sigma(4M_p^2)\dfrac{M_p^2}{M_\Lambda^2}\dfrac{e_u^2+e_d^2+e_s^2}{e_u^2+e_u^2+e_d^2} = 400$ pb
- $R_{eff} = [(\exp(\pi\alpha_{eff}/\beta_{rel})-1)^{-1/2} - (1-\exp(-\pi\alpha_{eff}/\beta_{rel}))^{-1/2}]^2$

$\Lambda\bar{\Lambda}$ case

- Cross section at threshold = 400 pb
- $\sigma(\Lambda\bar{\Lambda})$ = 200 pb, 10~20 MeV above threshold

  ⇒ **spike in the cross section**



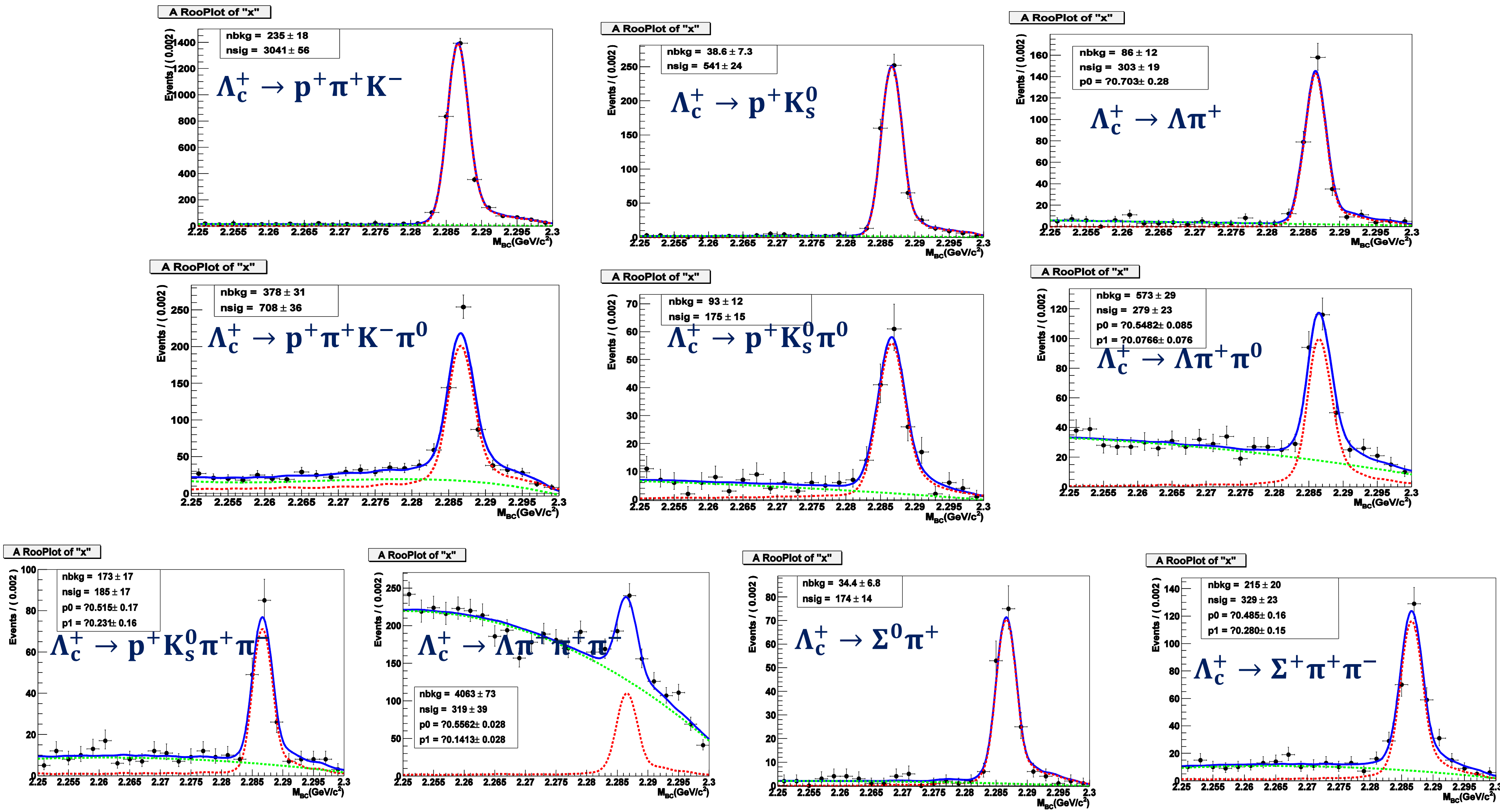
Measurement of $e^+e^- \to \Lambda_c^+\overline{\Lambda}_c^-$ near threshold

- Tag Λ_c^+ with its multiple decay modes:

Decay modes	Br(modeN)/Br(mode1)	Branching fraction
$\Lambda_c^+ \to p^+\pi^+K^-$	1	$(6.84 \pm 0.36)\%$
$\Lambda_c^+ \to p^+K_s^0, K_s^0 \to \pi^+\pi^-$	(0.46 ± 0.04)*50%*69.2%	$(1.09 \pm 0.11)\%$
$\Lambda_c^+ \to \Lambda\pi^+, \Lambda \to p^+\pi^-$	(0.21 ± 0.02)*63.9%	$(0.92 \pm 0.10)\%$
$\Lambda_c^+ \to p^+\pi^+K^-\pi^0, \pi^0 \to \gamma\gamma$	(0.66 ± 0.12)	$(4.51 \pm 0.85)\%$
$\Lambda_c^+ \to p^+K_s^0\pi^0, K_s^0 \to \pi^+\pi^-, \pi^0 \to \gamma\gamma$	(0.65 ± 0.08)*50%*69.2%	$(1.54 \pm 0.21)\%$
$\Lambda_c^+ \to \Lambda\pi^+\pi^0, \Lambda \to p^+\pi^-, \pi^0 \to \gamma\gamma$	(0.72 ± 0.18)*63.9%	$(3.15 \pm 0.80)\%$
$\Lambda_c^+ \to p^+K_s^0\pi^+\pi^-, K_s^0 \to \pi^+\pi^-$	(0.51 ± 0.06)*50%*69.2%	$(1.21 \pm 0.16)\%$
$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-, \Lambda \to p^+\pi^-$	(0.53 ± 0.03)*63.9%	$(2.32 \pm 0.18)\%$
$\Lambda_c^+ \to \Sigma^0\pi^+, \Sigma^0 \to \Lambda\gamma, \Lambda \to p^+\pi^-$	(0.20 ± 0.04)*63.9%	$(0.87 \pm 0.18\%$
$\Lambda_c^+ \to \Sigma^+\pi^+\pi^-, \Sigma^+ \to p^+\pi^0$	(0.72 ± 0.07)*51.6%	$(2.54 \pm 0.28)\%$
Sum		$(24.99 \pm 1.32)\%$

Measurement of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ near threshold

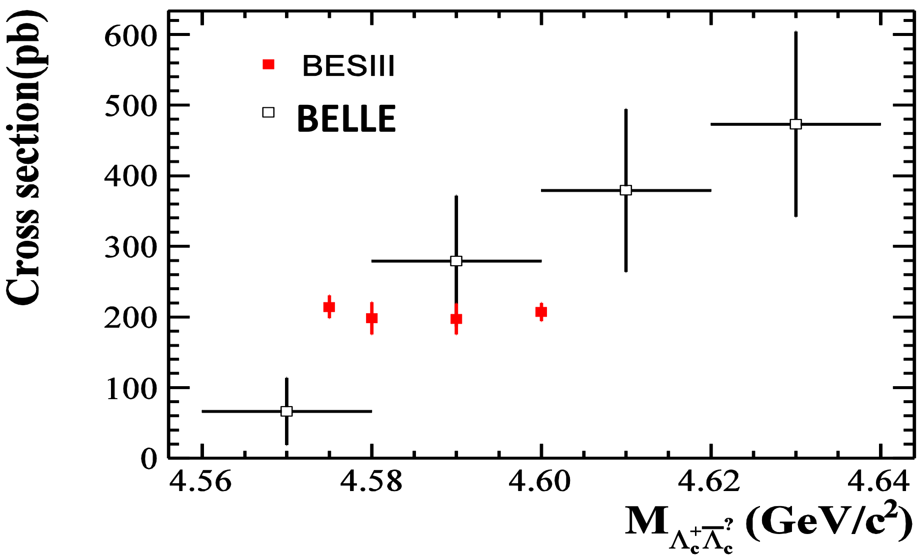
- Fit results at $\sqrt{s}$ = 4600.0 MeV for each mode:



Measurement of $e^+e^- \rightarrow \Lambda_c^+\bar{\Lambda}_c^-$ near threshold

■ Cross section measurement:

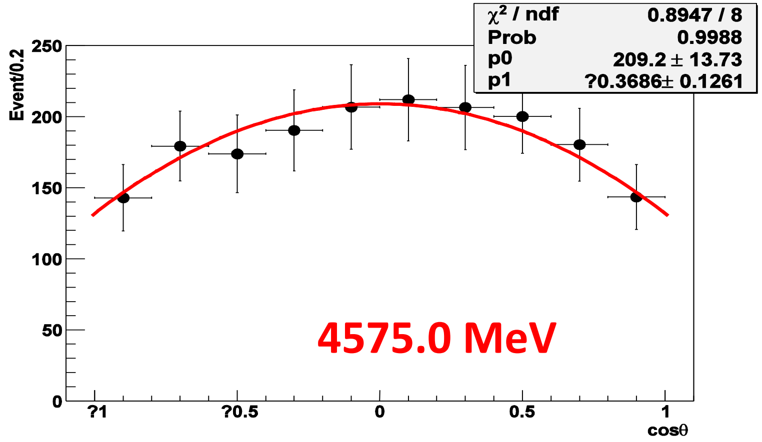
$\sqrt{s}$ (MeV)	Lumi. (pb^{-1})	$\beta = \sqrt{1 - 4m^2/s}$
4575.0	47.7	0.03
4580.0	8.5	0.05
4590.0	8.1	0.08
4600.0	567.6	0.10

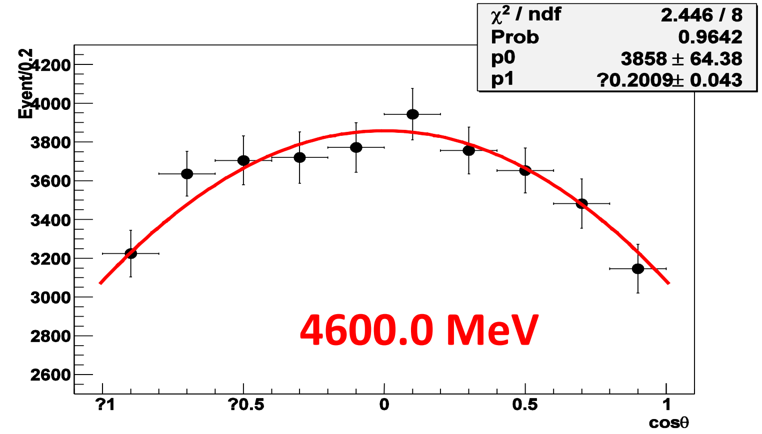


Measurement of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ near threshold

■Angular distribution

- ➢ Fitting M_{BC} in different cosθ bin, with detection efficiency corrected.
- ➢ The angular distribution is parameterized by $1 + \alpha\cos^2\theta$.





- ➢ The differential cross section can be expressed as:

$$\frac{d\sigma_{Born}(s)}{d\Omega} = \frac{\alpha^2\beta C}{4s}\left[|G_M(s)|^2(1+\cos^2\theta) + \frac{4m_p^2}{s}|G_E(s)|^2\sin^2\theta\right] \propto (1+\alpha\cos^2\theta)$$

- ➢ $\left|\frac{G_E}{G_M}\right|$ ratio can be calculated as:

$\sqrt{s}$ (MeV)	$\lvert G_E/G_M\rvert$
4575.0	**1.47 ± 0.22**
4600.0	1.23 ± 0.06

Measurement of $e^+e^- \to \Lambda_c^+\overline{\Lambda}_c^-$ near threshold

■ Discussion of the $|G_E/G_M|$ results:

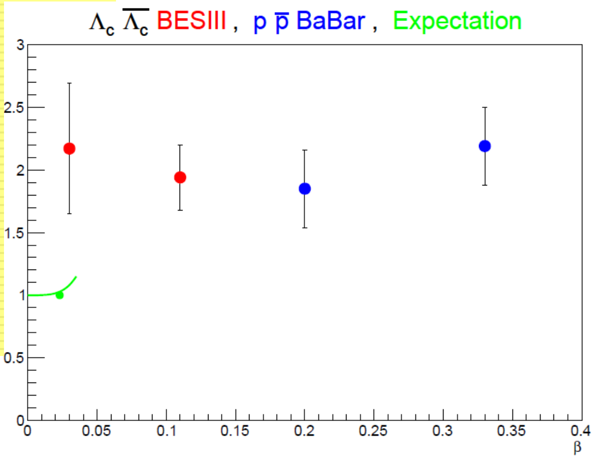
- Always postulated that in e^+e^- -> Baryon Antibaryon at threshold :

  angular distribution is isotropic, due to FF analiticity

- Outgoing Baryon spins antiparallel: G_E
  Outgoing Baryon spin parallel: G_M

- **$G_E = F_D + F_P / \tau$, $\tau = (2M_B)^2 / Q^2$**
  $G_M = F_D + F_P$

- **$d\sigma/d\cos\theta = \pi\,\alpha^2/(2\,M_B^2)\,\beta\,C_0\,[\,|G_M|^2\,(1+\cos\theta^2) + \tau\,|G_E|^2\,\sin\theta^2\,]$**



D wave contribution ?

- $J^P = 1^-$ -> L = 0 , 2

- S and D wave form factors
  (differences about $\sqrt{\tau}$ in the literature, not affecting angular distr.):
  - $\sqrt{\tau}\,G_E = G_S - 2\,G_D$
  - $G_M = G_S + G_D$

Measurement of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ near threshold

- Fitting of the line-shape — test of a hypothesis on threshold
- The function of non-resonant contribution can be parameterized as

$$\mathrm{NonR} = \frac{4\pi\alpha^2 C\beta}{3m^2}\left[|G_M|^2 + \frac{1}{2\tau}|G_E|^2\right] = A|G_M|^2\left[1 + \frac{1}{2\tau}\left(\frac{G_E}{G_M}\right)^2\right]$$

- The Coulomb factor $C = \varepsilon \cdot R$
  - $\varepsilon = \frac{\pi\alpha}{\beta}$ is the enhancement factor
  - R is the resummation factor
    - ★In the conventional prediction: $R = \frac{\sqrt{1-\beta^2}}{1-e^{-\pi\alpha/\beta}}$
    - ★From the prediction by R. Baldini Ferroli, S. Pacetti

$$R_s = \frac{\sqrt{1-\beta^2}}{1-e^{-\pi\alpha_s/\beta}}$$

The coupling constants:

α=1/137

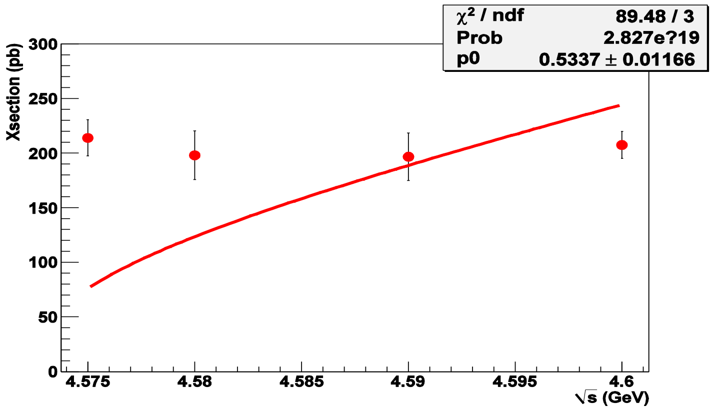
α_s=0.5

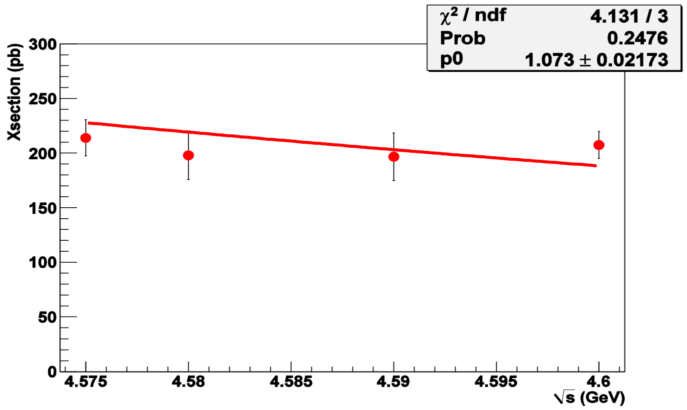
Measurement of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ near threshold

- Fitting of the line-shape: $\text{NonR} = A|G_M|^2[1 + \frac{1}{2\tau}(\frac{G_E}{G_M})^2]$
- $\left|\frac{G_E}{G_M}\right|$ ratio has been extracted as:

$\sqrt{s}$ (GeV)	$\|G_E/G_M\|$
4.575	1.47±0.22
4.6	1.23±0.06

- Assuming $|G_M|$ is a constant value from threshold to $\beta = 0.1$ GeV:

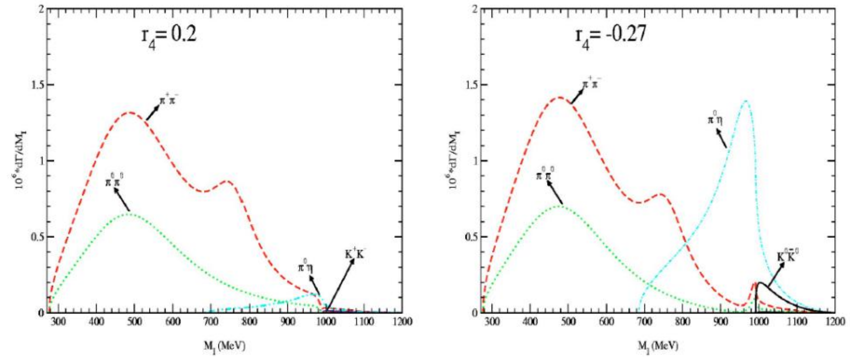




- Using the traditional R to fit line-shape, the fit status is bad
- Using the updated R_s to fit line-shape, the fit status is good, $|G_M|$ is 1.07±0.02.

Observation of $J/\psi \to p\bar{p}a_0(980)$

- Chiral Perturbative Theory (ChPT):
  - It is an effective field theory which deals with mesons and baryons
  - At low energy, the degrees of freedom are hadrons, due to the confinement of quarks
  - The effective Lagrangian is therefore expanded in powers of the external momenta of hadrons
- A chiral unitary approach from ChPT is used to investigate Four-body decays $J/\psi \to N\bar{N}MM$ with sufficient freedom in its meson-meson amplitude
- The process $J/\psi \to p\bar{p}a_0(980)$ is sensitive to fix the parameters in theoretical calculation



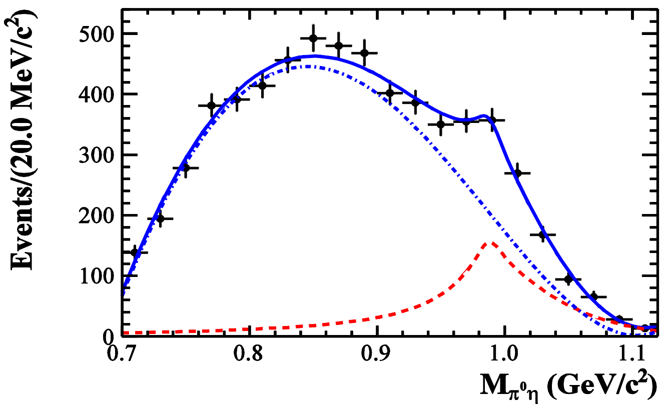
Observation of $J/\psi \to p\bar{p}a_0(980)$

- Yields:
  - PDF: $F(m) = f_{sig}\sigma(m)\otimes\left[\varepsilon(m)\times\hat{T}(m)\right] + \left(1-f_{sig}\right)B(m)$
  - Flatté formula $\hat{T}(m)$： parameterize the $a_0(980)$ amplitudes coupling to $\pi^0\eta$ and $K\bar{K}$

$$\hat{T}(m) \propto \frac{1}{(m_{a_0}^2 - m^2)^2 + (\rho_{\pi^0\eta} g_{a_0\pi^0\eta}^2 + \rho_{K\bar{K}} g_{a_0 K\bar{K}}^2)^2}$$

  - The two coupling constants

Experiments	$g_{a_0\pi^0\eta}$	$g_{a_0K\bar{K}}$
SND	$3.11^{+2.61}_{-0.40}$	$4.20^{+14.01}_{-1.35}$
BNL	2.47 ± 0.76	1.67 ± 0.29
KLOE	2.82 ± 0.05	2.15 ± 0.08
CB	2.87 ± 0.11	2.09 ± 0.11
Average	2.83 ± 0.05	2.11 ± 0.06



  - $Br(J/\psi \to p\bar{p}a_0(980) \to p\bar{p}\pi^0\eta) = (6.8 \pm 1.2 \pm 1.3) \times 10^{-5}$

Summary

- The proton effective FFs are measured at 12 c.m.energies. The overall uncertainty of cross sections is improved by about 30%. The $|G_E/G_M|$ ratio are extracted at three energy points, with uncertainty in 25% and 50% (dominant by statistics). Submitted to P. R. D.

- The cross section of $e^+e^- \to \Lambda\bar{\Lambda}$ is firstly measured near threshold, to be 320 ± 58 pb, which contradicts the standard theoretical prejudice. The result at other three energy points are measured with uncertainty in 18.1% and 33.3%, Under internal review.

- The cross sections of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ are measured near threshold. The $|G_E/G_M|$ at 4.575 GeV is measured to be 1.47 ± 0.22, while at threshold, it is supposed to be unity if the S-wave dominants. Under internal review.

- The process $J/\psi \to p\bar{p}a_0(980) \to p\bar{p}\pi^0\eta$ is observed with a significance of 6.5σ. The results provides a quantitative comparison with the chiral unitary approach. Published in P. R. D.

Prospect-I

- At BEPCII, a new scan with c.m. energy in 2.0 GeV and 3.1 GeV is ongoing, which suggest following topics:

  - Precision measurement of proton form factor

    reveal two steps around 2.25 and 3.0 GeV, structures? fluctuation?

    improve the $|G_E/G_M|$ ratio uncertainty, Babar? PS170?

  - Neutron form factor

    explain spatial distributions due to isospin difference between p and n

    a preliminary study at 2232.4 GeV yields 13 events with 2.0% efficiency

    the efficiency would be improved significantly if the TOF information can be used!

  - Baryonic pair production near threshold

    if this threshold effect universal for different baryonic pair

    source: FSI effect ? corrections on FFs?

Prospect-II

- From a series Monte Carlo study, we can predict the expected luminosity for a determined $|G_E/G_M|$ precision
- To achieve a **1.0%** precision of $|G_E/G_M|$ ratio, the expect luminosity is **1.6 fb^{-1}** **(about 690 days of data taken at BEPCII !)**
- A future high luminosity factory will be very helpful for the accurate measurement

N_{sig}	$\delta_{R_{em}}/R_{em}(\%)$	$\delta_\sigma/\sigma\ (\%)$	N_{orig}	Expect Lum. (pb^{-1})
$614 \pm 28\ (data)$	24	3.9	930	2.631
769 ± 28	22	3.6	1165	3.295
1534 ± 39	15	2.5	2324	6.573
3881 ± 62	**9.5**	**1.6**	**5880**	**16.630**
7856 ± 89	6.6	1.1	11903	33.662
23572 ± 154	3.9	0.65	35715	101.004
31286 ± 177	3.4	0.57	47403	134.058
156253 ± 395	**1.5**	**0.25**	**236747**	**669.533**
389898 ± 624	**0.96**	**0.16**	**590755**	**1670.69**

Thank you all for attending my Ph.D defense !

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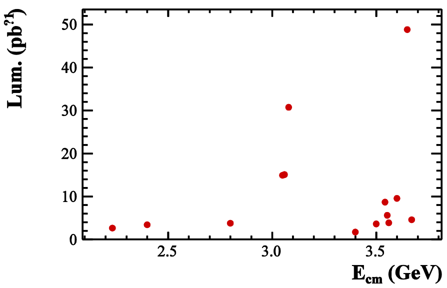
Defense reviewer:
Xiaoyan Shen (IHEP),
Haiping Peng (USTC),
Qun Wang (USTC),
Ziping Zhang (USTC),
Jianbei Liu (USTC)

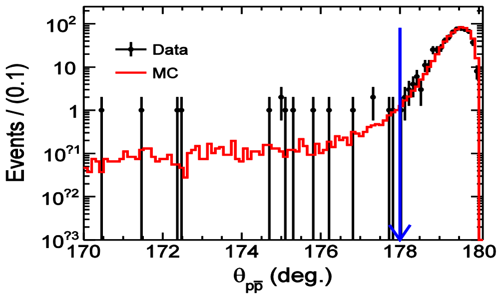
Backups

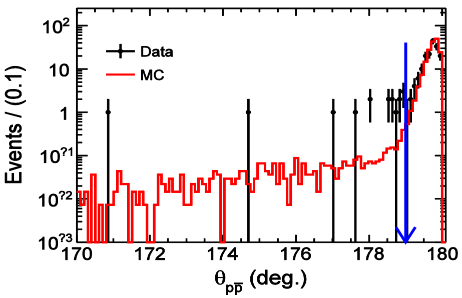
Measurement of Proton Form Factors

- 12 center-of-mass energies:

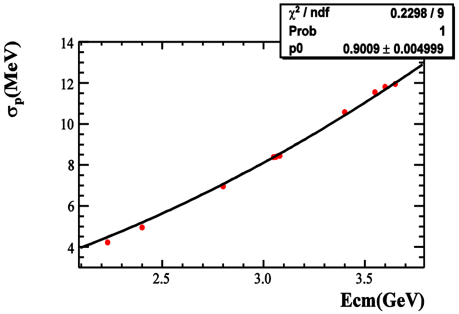


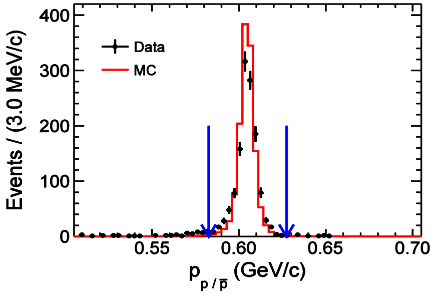
- Back-to-back angle distribution:

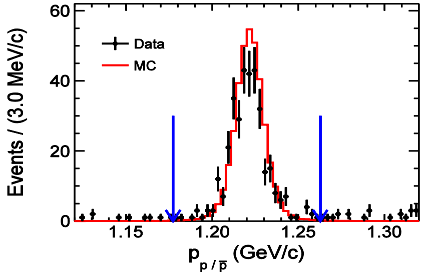




- Dependence of resolution of momentum with c.m. energy:

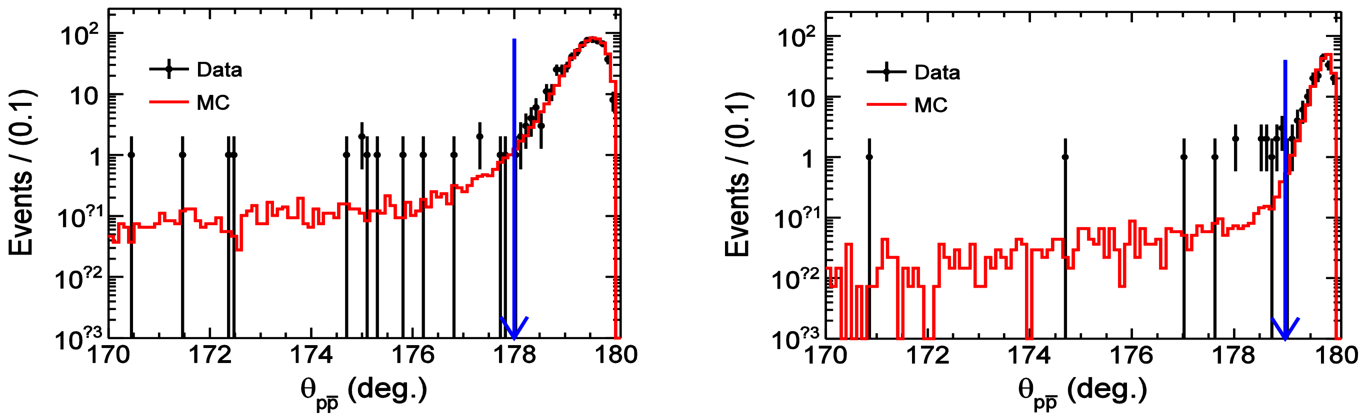




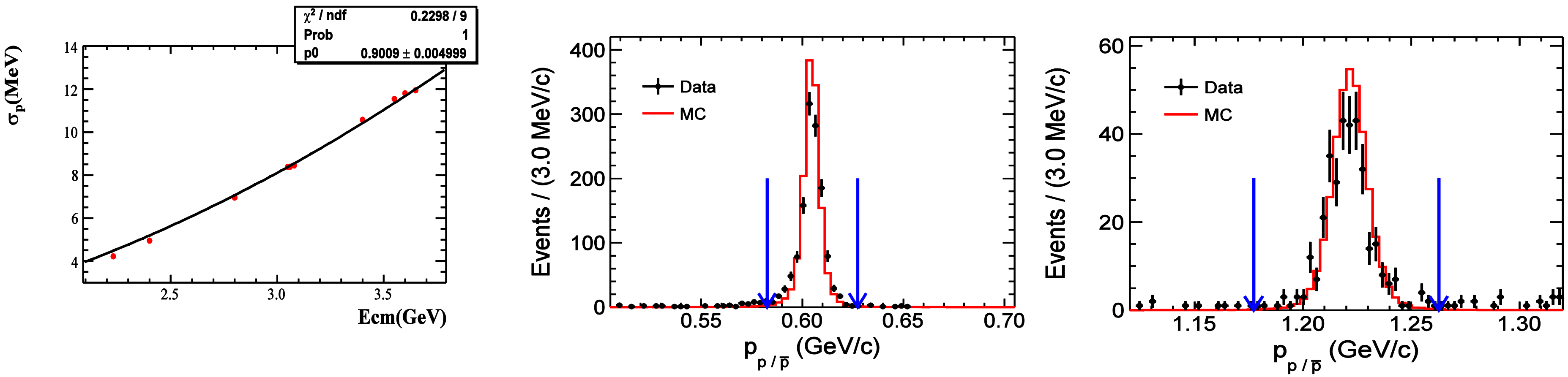


Reconstruction of $e^+e^- \to p\bar{p}$

- Back-to-back angle distribution:



- Dependence of resolution of momentum with c.m. energy:



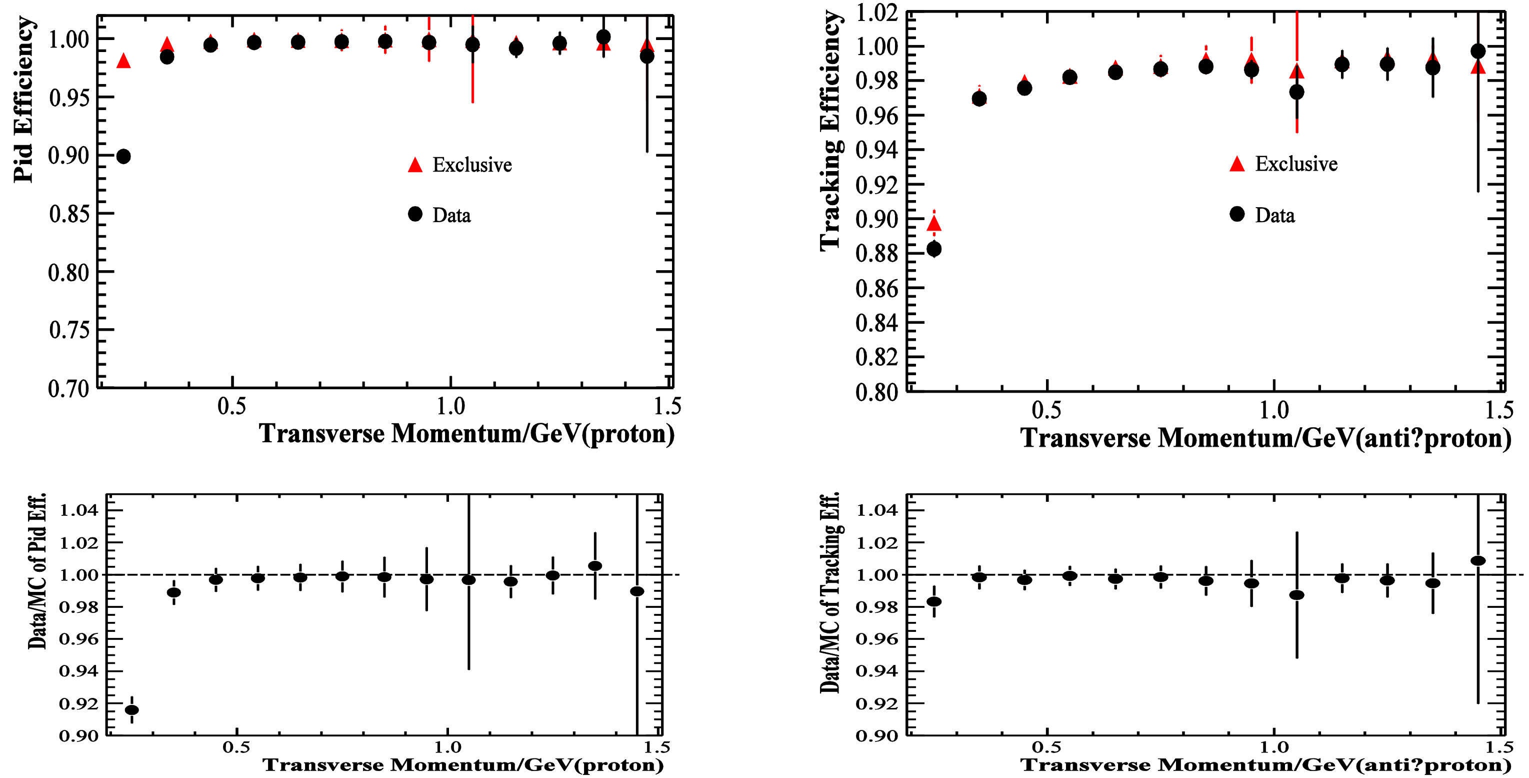
Background analysis

- Beam associated background: interaction between beam and beam pipe, beam and residual gas and the Touschek effect.
- A special data sample, with separated beam condition, are used to study such background.
- The physical background from the processes with two-body in the final state, or with multi-body include pp in the final states.

	$\sqrt{s} = 2232.4$ MeV (2.63 pb^{-1})					$\sqrt{s} = 3080.0$ MeV (30.73 pb^{-1})				
Bkg.	N^{MC}_{gen} ($\times 10^6$)	N^{MC}_{sur}	σ (nb)	$N^{MC}_{uplimit}$	N^{MC}_{nor}	N^{MC}_{gen} ($\times 10^6$)	N^{MC}_{sur}	σ (nb)	$N^{MC}_{uplimit}$	N^{MC}_{nor}
e^+e^-	9.6	0	1435.01	< 0.96	0	39.9	1	756.86	< 2.54	1
$\mu^+\mu^-$	0.7	0	17.41	< 0.16	0	1.5	0	8.45	< 0.42	0
$\gamma\gamma$	1.9	0	70.44	< 0.24	0	4.5	0	37.05	< 0.62	0
$\pi^+\pi^-$	0.1	0	0.17	< 0.01	0	0.1	0	< 0.11	< 0.02	0
K^+K^-	0.1	0	0.14	< 0.008	0	0.1	0	0.093	< 0.02	0
$p\bar{p}\pi^0$	0.1	0	< 0.1	< 0.006	0	0.1	0	< 0.1	< 0.07	0
$p\bar{p}\pi^0\pi^0$	0.1	0	< 0.1	< 0.006	0	0.1	0	< 0.1	< 0.07	0
$\Lambda\bar{\Lambda}$	0.1	0	< 0.4	< 0.02	0	0.1	0	0.002	< 0.001	0

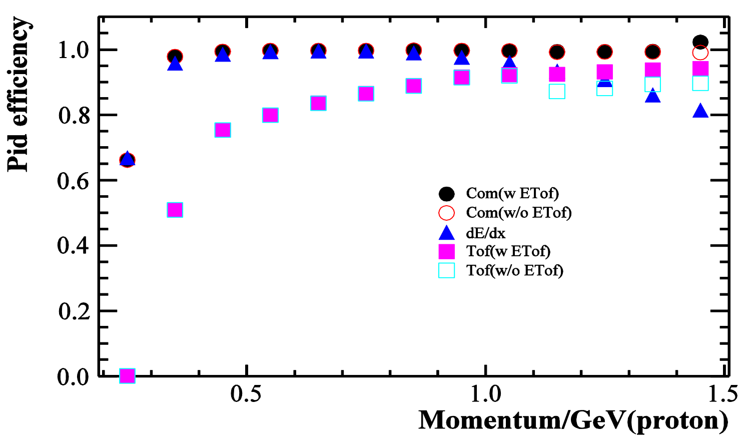
Systematic Uncertainty on σ_{Born}

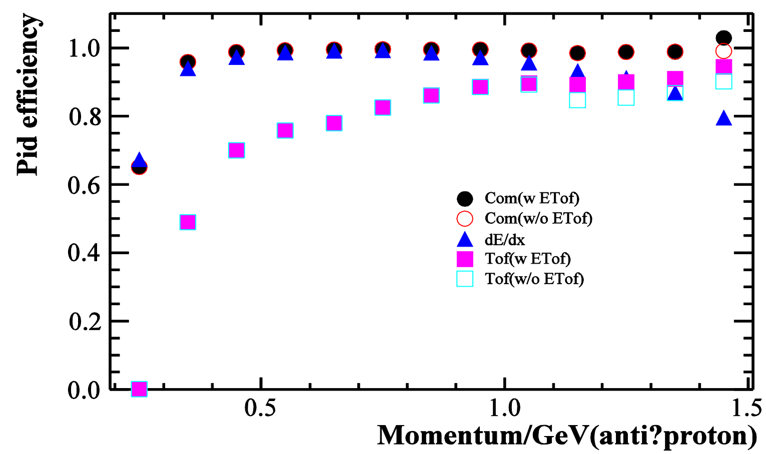
- Tracking:
  - Study from control sample $J/\psi \to p\bar{p}\pi^+\pi^-$ and $\psi(3686) \to \pi^+\pi^- J/\psi \to \pi^+\pi^- p\bar{p}$
  - Tracking efficiency: $N_{good=4}/N_{good\geq3}$

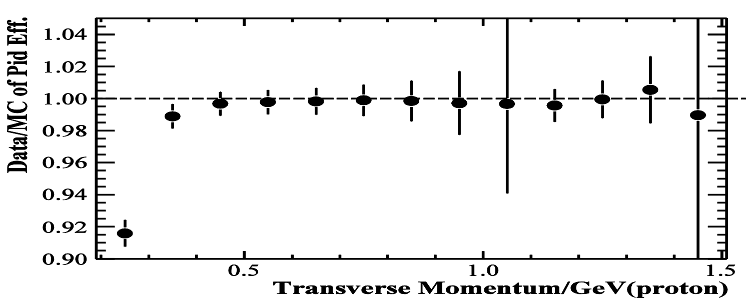


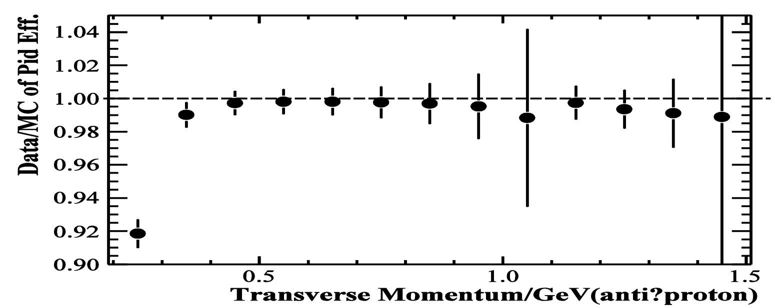
Systematic Uncertainty on σ_{Born}

- Particle identification
  - Different information on the PID method:
    - ★ 1) combined information of dE/dx, BTOF, ETOF; 2) dE/dx and BTOF; 3) dE/dx; 4)BTOF and ETOF; 5) BTOF.



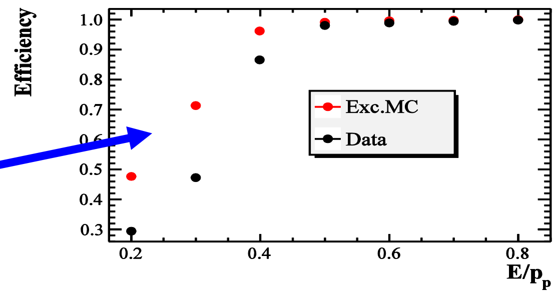


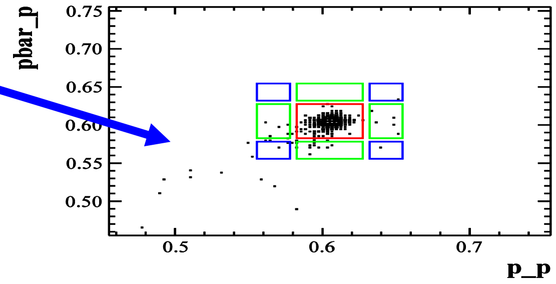


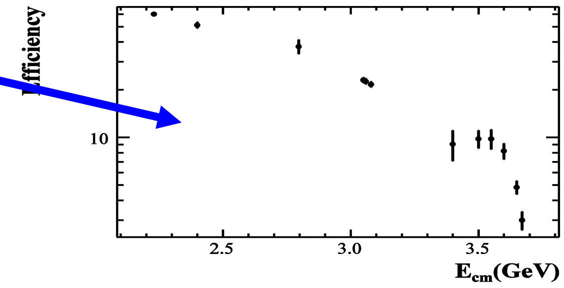


Systematic Uncertainty on σ_{Born}

- Other sources of systematic uncertainties
  - E/p requirement: select proton sample from control sample $J/\psi \to p\bar{p}\pi^+\pi^-$.
  - Background estimation: use 2D sideband to estimate the background.
  - ISR correction factor: use generator Phokhara to generate signal MC
  - Model dependence: vary $|G_E/G_M|$ ratio to obtain the detection efficiency
  - Integral luminosity: analyze large-angle Bhabha scattering process

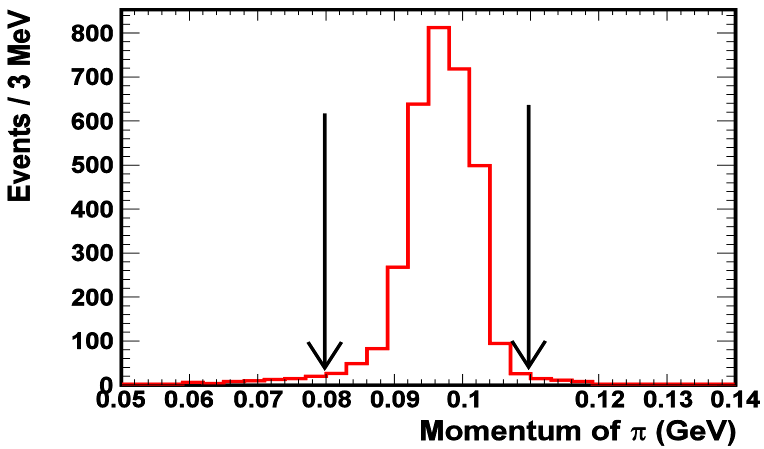


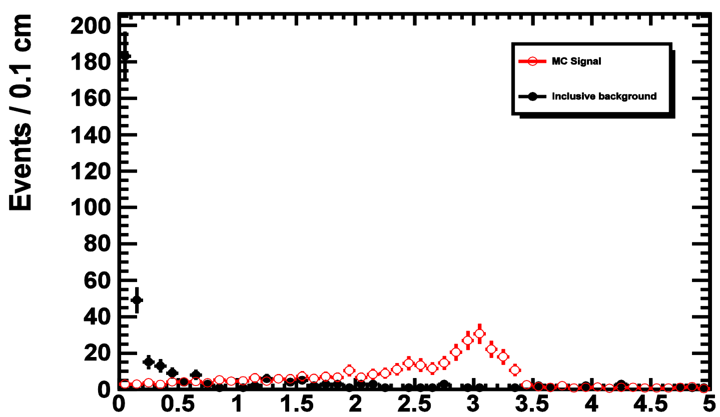




Reconstruction of $\Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}\pi^+$

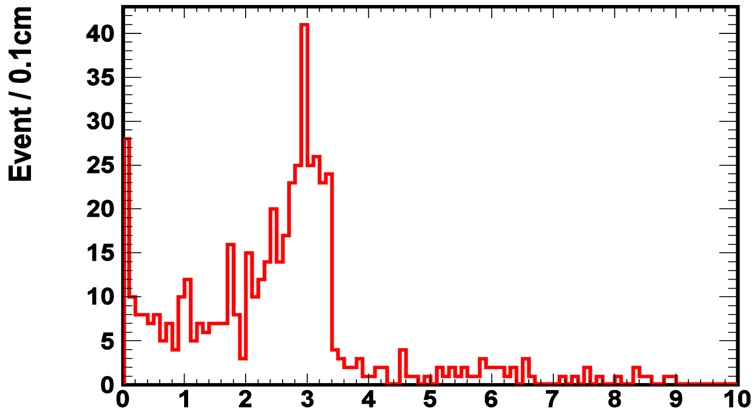
- Event selection
  - Two good charged tracks with low momentum [0.08, 0.11] GeV
  - PID: $N_{\pi^+} = N_{\pi^+} = 0$
  - The largest V_r among all the charged tracks shows an enhancement around 3 cm for signal MC
  - No significant events lie around 3 cm in the background.

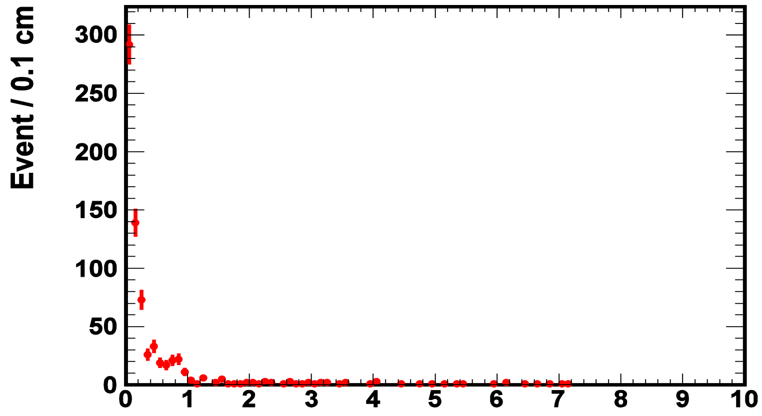




Reconstruction of $\Lambda \rightarrow p\pi^-, \bar{\Lambda} \rightarrow \bar{p}\pi^+$

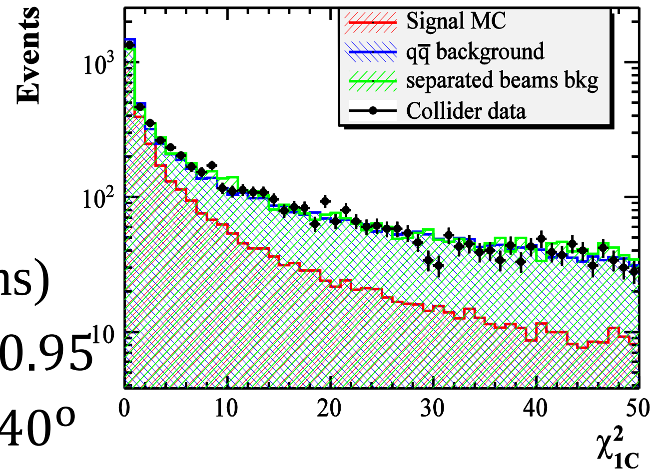
- Background process $e^+e^- \rightarrow \pi^+\pi^-p\bar{p}$
- Requirement on the momentum of pion:
  - $0.0 < p_\pi < 0.07$ GeV/c and $0.12 < p_\pi < 0.16$ GeV/c
  - The enhancement around 3 cm could still be observed in background process
  - No enhancement is observed in data
- The background of process $e^+e^- \rightarrow \pi^+\pi^-p\bar{p}$ is small and can be neglected.





Reconstruction of $\bar{\Lambda} \to \bar{n}\pi^0$

- Event selection
  - At most two good charged tracks
  - At least three good showers:
    - ★E>25 MeV in barrel and E>50 MeV in endcap
    - ★Angle related the closest charged track larger than 10^o
  - The most energetic shower is selected as $\bar{n}$ candidate



- One π^0 candidate is selected:

EMC timing requirement ($0 \le T \le 14$ in unit of 50 ns)

Energy asymmetry requirement: $|E_{\gamma_1} - E_{\gamma_1}|/p_{\pi^0} < 0.95$

The angle between photon pair and $\bar{n}$ is larger than 140^o

The minimum χ^2_{1C} of mas constrained kinematic fit is selected and $\chi^2_{1C} < 20$

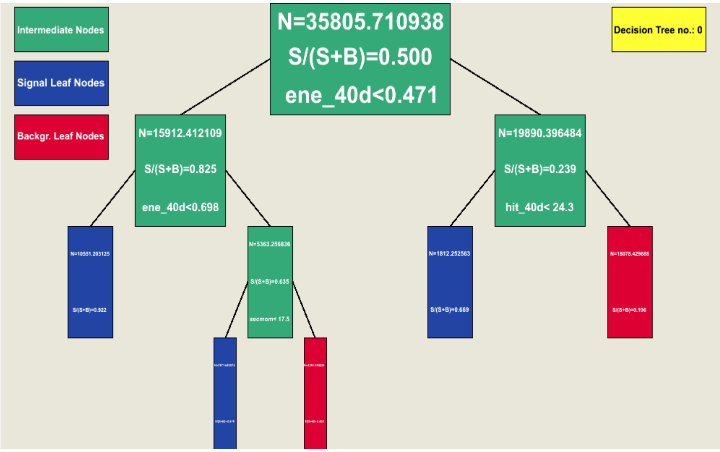
Reconstruction of $\bar{\Lambda} \to \bar{n}\pi^0$

■Boosted Decision Tree

➢ Decision Tree

An individual classifier is defined as h(x), h(x)=+1 and -1 for signal and background.

Separation criteria: Gini Index, defined by $p \cdot (1-p)$



➢ Boost (AdaBoost)

➢ Boost weight

The subsequent tree is trained using a modified event sample with a boost weights applied for misclassified events: $\alpha = \frac{1-err}{err}$

➢ Output classifier

$$y_{\mathrm{Boost}}(x) = \frac{1}{N_{\mathrm{collection}}} \cdot \sum_{i}^{N_{\mathrm{collection}}} \ln(\alpha_i) \cdot h_i(x)$$

➢ Boosting increases the statistical stability of the classifier and improve the separation performance compared to a single decision tree.

➢ The limitation of tree depth can eliminate the overtraining

Measurement of $e^+e^- \to \Lambda\bar{\Lambda}$ at threshold

- Systematic uncertainty

Reconstruct $\Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}\pi^+$ (%)		Reconstruct $\bar{\Lambda} \to \bar{n}\pi^0$ (%)	
Source	Uncertainty	Source	Uncertainty
π tracking	12.3	$\bar{n}$ selection	2.2
π PID	1.0	π^0 selection	2.3
V_r selection	0.3	BDT output	4.8
Fit procedure	4.6	Fit procedure	8.8
MC generator*	3.2	MC generator*	3.2
Energy spread*	2.0	Energy spread*	2.0
Energy scale*	3.9	Energy scale*	3.9
Trigger efficiency	0.0	Trigger efficiency	1.0
Luminosity*	1.0	Luminosity*	1.0
Total	14	Total	12

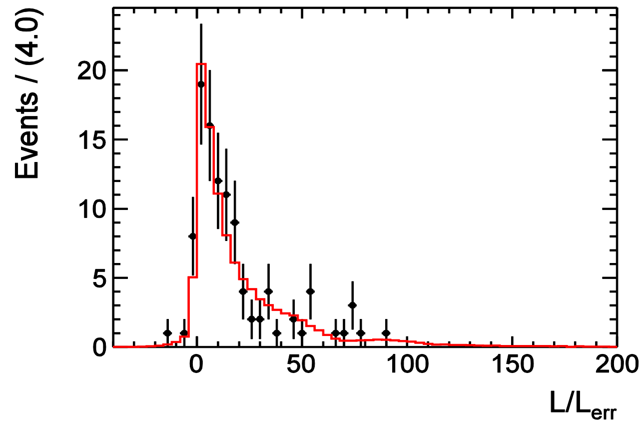
Measurement of $e^+e^- \to \Lambda\bar{\Lambda}$ at threshold

- Combined result: weighted least squares method
- $\bar{x} \pm \delta\bar{x} = \frac{\sum_j x_j \cdot \sum_i \omega_{ij}}{\sum_i \sum_j \omega_{ij}} \pm \sqrt{\frac{1}{\sum_i \sum_j \omega_{ij}}}$
- ω_{ij} is the element of V^{-1}. In case of two measurement:
- $\mathbf{V} = \begin{pmatrix} \sigma_{T1}^2 & Cov(x_1,x_2) \\ Cov(x_1,x_2) & \sigma_{T2}^2 \end{pmatrix}$, $\sigma_{Ti}^2 = \sigma_i^2 + x_i^2 \cdot \epsilon_f^2$
- Convariance sysematic error: $Cov(x_1, x_2) = x_i \cdot \epsilon_{ij} \cdot x_j \cdot \epsilon_{ji}$
- The weighted averaged measured values are:
- $x = \frac{x_1\sigma_2^2 + x_2\sigma_1^2}{\sigma_1^2+\sigma_2^2+(x_1-x_2)^2\epsilon_f^2}$, $\sigma_i^2 = \frac{\sigma_1^2\sigma_2^2+(x_1\sigma_2^2+x_2\sigma_1^2)\epsilon_f^2}{\sigma_1^2+\sigma_2^2+(x_1-x_2)^2\epsilon_f^2}$

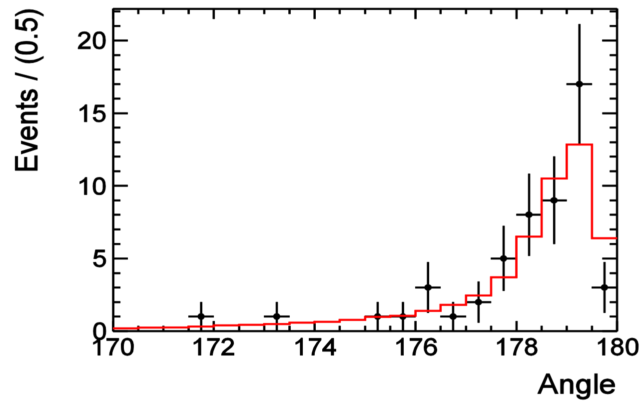
Reconstruction	σ_{Born} (pb)
$\Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}\pi^+$	$325 \pm 53 \pm 46$
$\bar{\Lambda} \to \bar{n}\pi^0$	$300 \pm 100 \pm 40$
Combined	320 ± 58

Measurement of $e^+e^- \to \Lambda\bar{\Lambda}$ at 2.40, 2.80 and 3.08 GeV

- Event selection
- Charged track
  - $|Vr|<30$ cm, $|Vz|<10$ cm, $|\cos\theta|<0.93$
  - $N_{good} \geq 4$

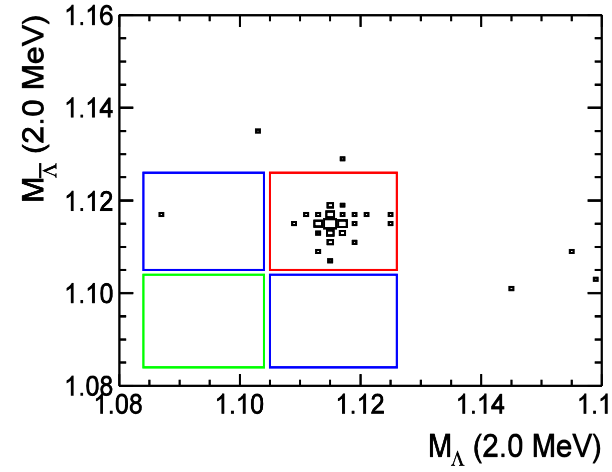


- Particle identification
  - $N_p = N_{\bar{p}} = N_{\pi^+} = N_{\pi^-} = 1$
- Second vertex fitting for $p\pi^-$ and $\bar{p}\pi^+$
- Mass window cut: $|M_\Lambda/M_{\bar{\Lambda}} - 1.115| < 0.01$ GeV
- Angle cut between Λ and $\bar{\Lambda}$ candidate
  - $\theta_{\Lambda\bar{\Lambda}} > 170^o$ at 2.40 GeV
  - $\theta_{\Lambda\bar{\Lambda}} > 176^o$ at 2.80 GeV
  - $\theta_{\Lambda\bar{\Lambda}} > 178^o$ at 3.08 GeV



Measurement of $e^+e^- \to \Lambda\bar{\Lambda}$ at 2.40, 2.80 and 3.08 GeV

- Background analysis (non-M_Λ peaking background)
- Signal region:
  - $|M_\Lambda/M_{\bar{\Lambda}} - 1.115| < 0.01$ GeV
- Sideband region:
  - $1.084 < M_\Lambda < 1.104$ GeV, $|M_{\bar{\Lambda}} - 1.115| < 0.01$ GeV
  - $|M_\Lambda - 1.115| < 0.01$ GeV, $1.084 < M_{\bar{\Lambda}} < 1.104$ GeV
  - $1.084 < M_\Lambda/M_{\bar{\Lambda}} < 1.104$ GeV



- M_Λ peaking background

E_{cm}	2.40 GeV			2.80 GeV			3.08 GeV		
Source	ε_{sel}^{MC}	σ(pb)	N_{nor}^{MC}	ε_{sel}^{MC}	σ(pb)	N_{nor}^{MC}	ε_{sel}^{MC}	σ(pb)	N_{nor}^{MC}
$e^+e^- \to \gamma\Lambda\bar{\Lambda}$	1.6%	<1.3	0.1	0.5%	<0.16	0	0.2%	<0.04	0
$e^+e^- \to \Sigma^0\bar{\Sigma}^0$	0	30	0	0.2%	17	0.1	0.2%	3.4	0.2
$e^+e^- \to \Lambda\bar{\Sigma}^0$		32			2.9			<8.7	
$e^+e^- \to \Xi^0\bar{\Xi}^0$	-	-	-	0	-	0	0	-	0
Sum			0.1			0.1			0.2

Measurement of $e^+e^- \to \Lambda\bar{\Lambda}$ at 2.40, 2.80 and 3.08 GeV

- Systematic uncertainty

Source	2.40 GeV	2.80 GeV	3.08 GeV
Reconstruction of Λ	3.8	3.8	3.8
Reconstruction of $\bar{\Lambda}$	3.4	3.4	3.4
M_{Λ} cut	2.5	2.5	2.5
$M_{\bar{\Lambda}}$ cut	3.0	3.0	3.0
Angular distribution	12.7	10.8	11.4
Input line-shape	2.2	4.0	2.9
Luminosity	1.0	1.0	1.0
Total	14	13	13

- The uncertainty of angular distribution is the largest contribution to the total uncertainty.

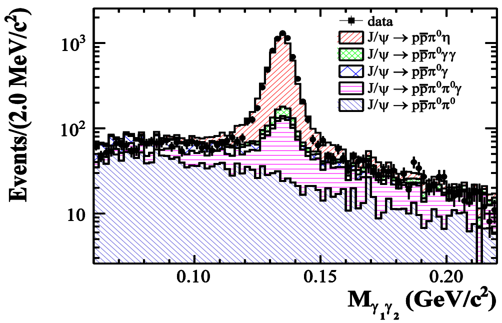
Measurement of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^+$ near threshold

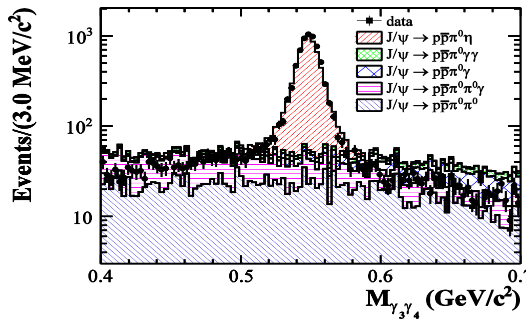
- Event selection
  - Charge track: $|\cos\theta|<0.93$, $|V_r|<1$ cm, $|V_z|<10$ cm
  - Neutral track: $0<T<14$, $E_{barrel}>25$ MeV, $E_{endcaps}>50$MeV
  - PID identification: proton, kaon, pion
  - π^0 candidates: $|M_{\gamma\gamma}-M_{\pi 0}|<0.06$ GeV, $\chi^2_{1c}<50$
  - K_s^0 candidates: $L/L_{err}>2$, $|M_{\pi\pi}-M_{Ks0}|<5\sigma$
  - Λ candidates: $L/L_{err}>2$, $|M_{p\pi-}-M_{\Lambda}|<5\sigma$
  - In each event, only the combination of Λ_c^+ candidate with least $|\Delta E| = \left|E_{\Lambda_c^+} - E_{beam}\right|$ is kept.
  - Fit $M_{BC} = \sqrt{E_{beam}^2 - p_{\Lambda_c^+}^2}$ to get the yield

Observation of $J/\psi \to p\bar{p}a_0(980)$

- Reconstruction of $a_0(980) \to \pi^0\eta$, by choosing the minimum χ^2-like variable

$$\chi^2_{\pi^0\eta} = \frac{(M_{\gamma_1\gamma_2} - M_{\pi^0})^2}{\sigma^2_{\pi^0}} + \frac{(M_{\gamma_3\gamma_4} - M_\eta)^2}{\sigma^2_\eta}$$





- The reducible background only accounts for 4.3% of the survived events, while most of them are intermediate states of N(1440), N(1535) and N(1650) are the dominant contributions to $J/\psi \to p\bar{p}\pi^0\eta$.