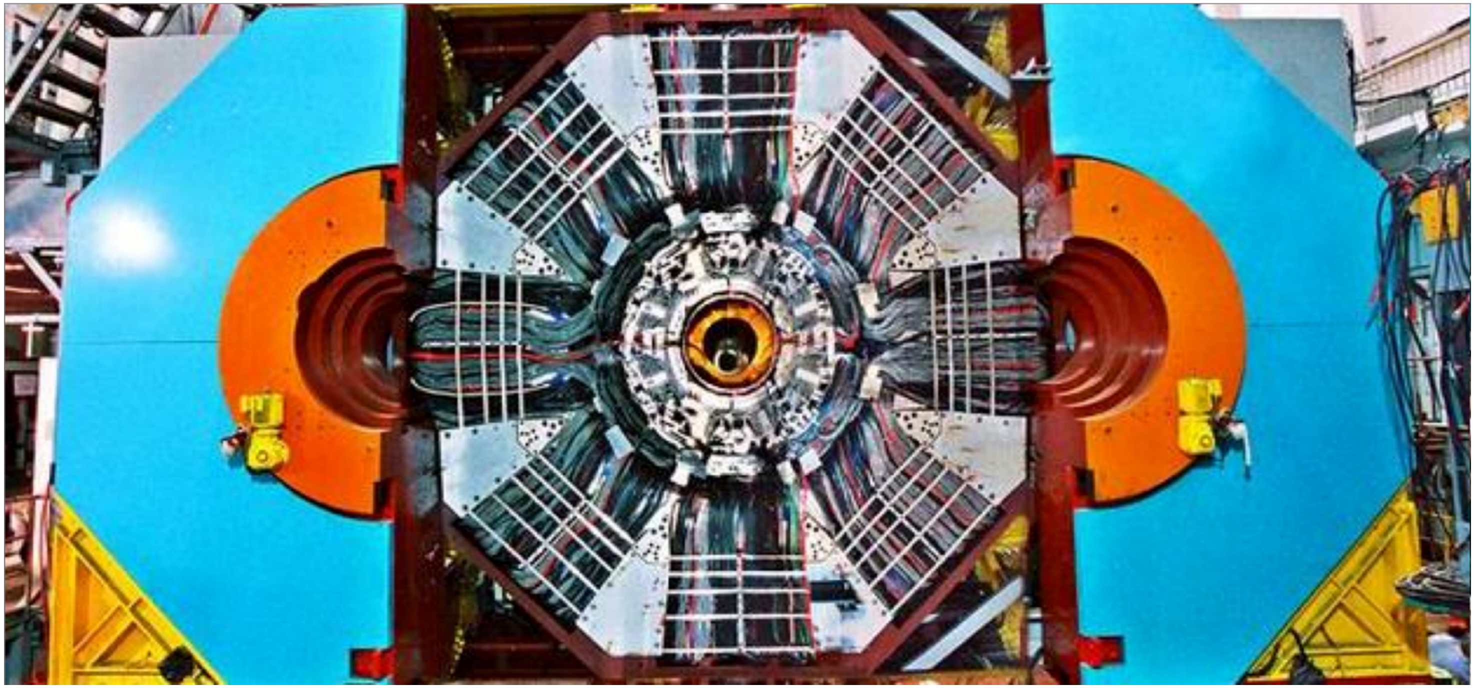

Prospects of Charm physics at BESIII and Beyond

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中国科学院大学

(On behalf of the BESIII collaboration)

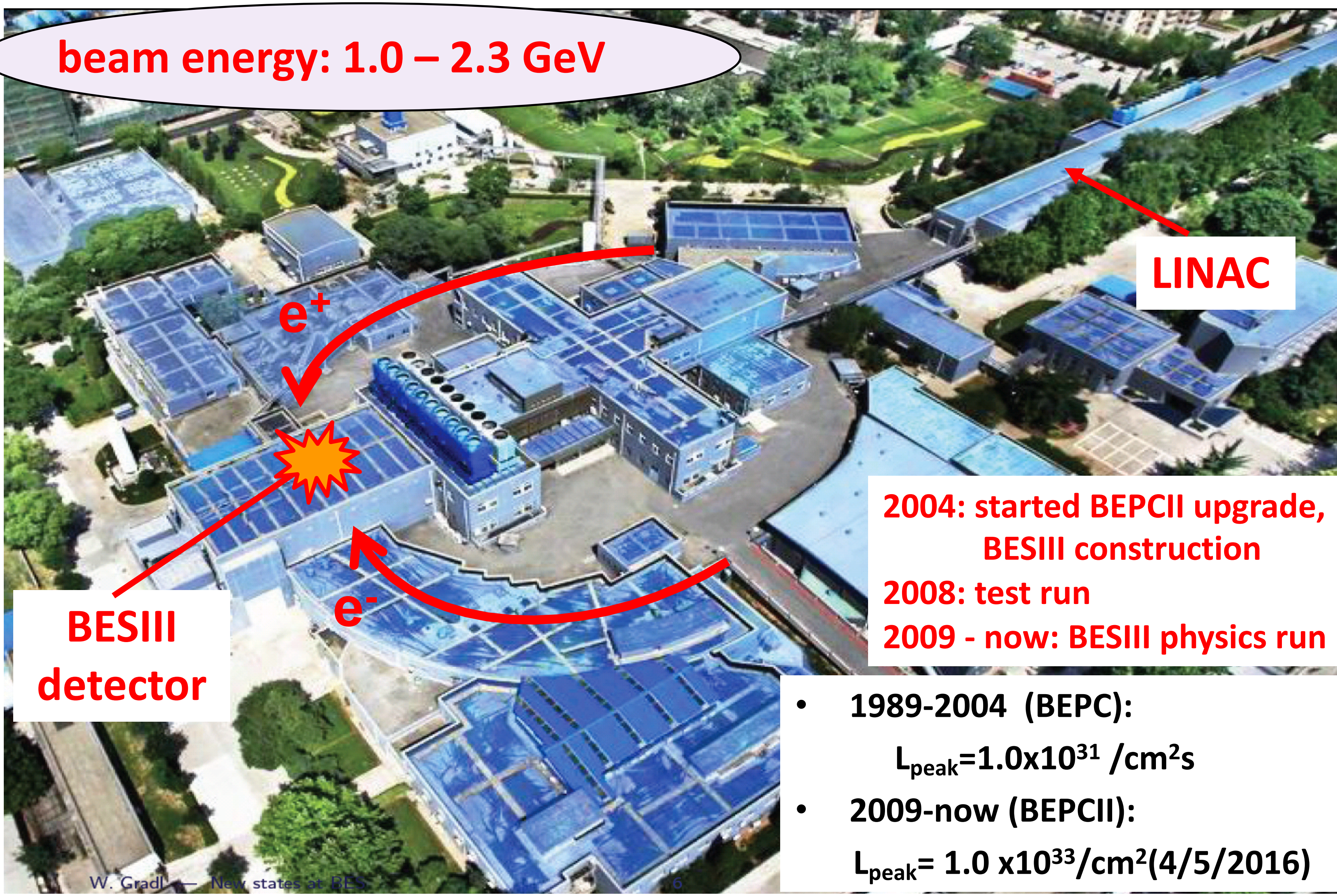
Outline

- Introduction
- Status of BESIII
- Upgrade plan
- Physics prospects
- Summary

Charm facilities

- Hadron colliders (huge cross-section, energy boost)
  - Tevetron (CDF, D0)
  - LHC (**LHCb**, CMS, ATLAS)
- e^+e^- Colliders (more kinematic constrains, clean environment, ~100% trigger efficiency)
  - B-factories (Belle(-II), BaBar)
  - Threshold production (CLEOc, BESIII)
    - Can not compete in statistics with Hadron colliders & B-factories!!!
    - Quantum Correlations (QC) and CP-tagging are unique
    - Only D meson pairs, no extra CM Energy for pions
    - Systematic uncertainties cancellations while applying double tag technique

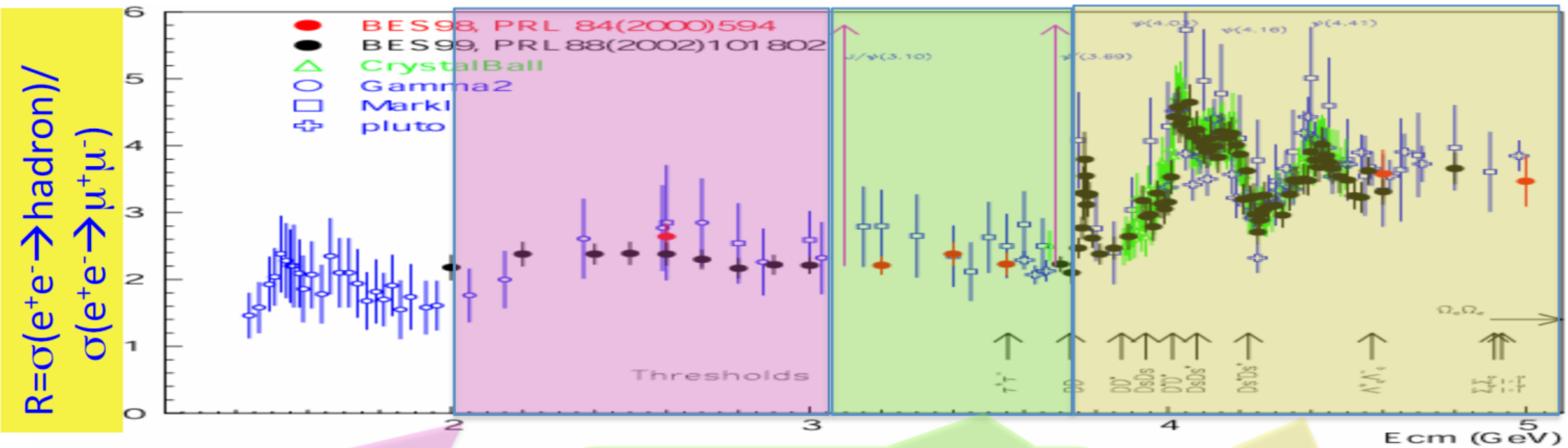
Beijing Electron Positron Collider (BEPC)



2004: started BEPCII upgrade, BESIII construction
2008: test run
2009 - now: BESIII physics run

- 1989-2004 (BEPC):
  L_{peak}=1.0x10^{31} /cm^{2}s
- 2009-now (BEPCII):
  L_{peak}= 1.0 x10^{33}/cm^2(4/5/2016)

Physics at tau-charm Energy Region



- Hadron form factors
- Y(2175) resonance
- Mutltiquark states with s quark, Zs
- MLLA/LPHD and QCD sum rule predictions

- Light hadron spectroscopy
- Gluonic and exotic states
- Process of LFV and CPV
- Rare and forbidden decays
- Physics with τ lepton

- XYZ particles
- D mesons
- f_D and f_{Ds}
- D_0-D_0 mixing
- Charm baryons

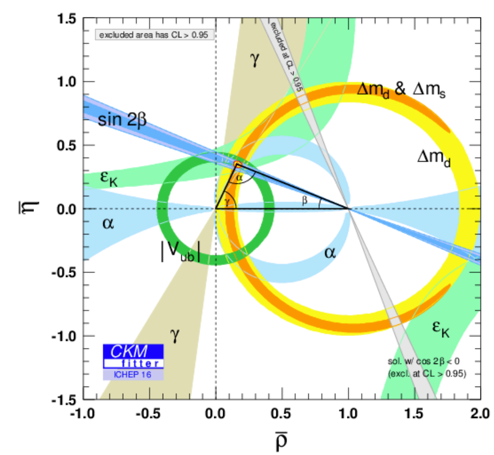
More on charmed hadron decays

Leptonic and hadronic decays of charmed hadrons (D^0, D^+, D_s^+ and Λ_c^+) provide an ideal test-bed to explore weak and strong effects

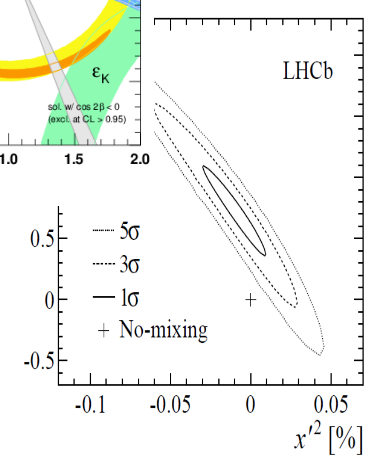
- **leptonic decays**
  - **$f_{D(s)+}$, $f^{K(\pi)}_{+}(0)$: better calibrate LQCD**
  - **$|V_{cs(d)}|$: better test on CKM unitarity**

$$U = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- **hadronic decays**
  - **Hadronic decays: structure, SU(3) symmetry**
  - **$D^0\bar{D}^0$ mixing parameters and CP violation**
  - **Strong phase in D^0 decays: Constraint on γ/ϕ_3 in B decays and D mixing parameters**



- **BFs of Λ_c^+ decays**
  - **No absolute BF measurements of Λ_c^+ using near threshold data before BESIII**



Precision measurement of CKM elements -- Test EW theory

CKM matrix elements are fundamental SM parameters that describe the mixing of quark fields due to weak interaction.

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

CKM matrix

BESIII + B factories + LQCD

Three generations of quark?

Unitary matrix?

Expected precision < 2% at BESIII

BESIII + B factories + LHCb + LQCD

- **Precision measurement of CKM matrix elements**
- **A precise test of SM model**
- **New physics beyond SM?**

$D_{(s)}$ & Λ_c decays

δ and γ/ϕ_3 input

- D hadronic parameters for a final state

$$f:\ \frac{A(\bar{D}^0 \to f)}{A(D^0 \to f)} \equiv -r_D e^{-i\delta_D}$$

- Charm mixing parameters: $x = \frac{\Delta M}{\Gamma}$, $y = \frac{\Delta\Gamma}{2\Gamma}$
  - Time-dependent WS $D^0 \to K^+\pi^-$ rate $\Rightarrow$
    $y' = y\cos\delta_{K\pi} - x\sin\delta_{K\pi}$ (LHCb)
  - $\delta_{K\pi}$: QC measurements from Charm factory
- γ/ϕ_3 measurements from $B \to D^0 K$
  - b→u : γ/ϕ_3 = argV^*_{ub}
  - most sensitive method to constrain γ/ϕ_3 at present
  - GLW, ADS method
    - r_D, δ_D : QC measurements from Charm factory
  - GGSZ method
    - c_i, s_i : QC measurements from Charm factory

Time-integrated decay rates

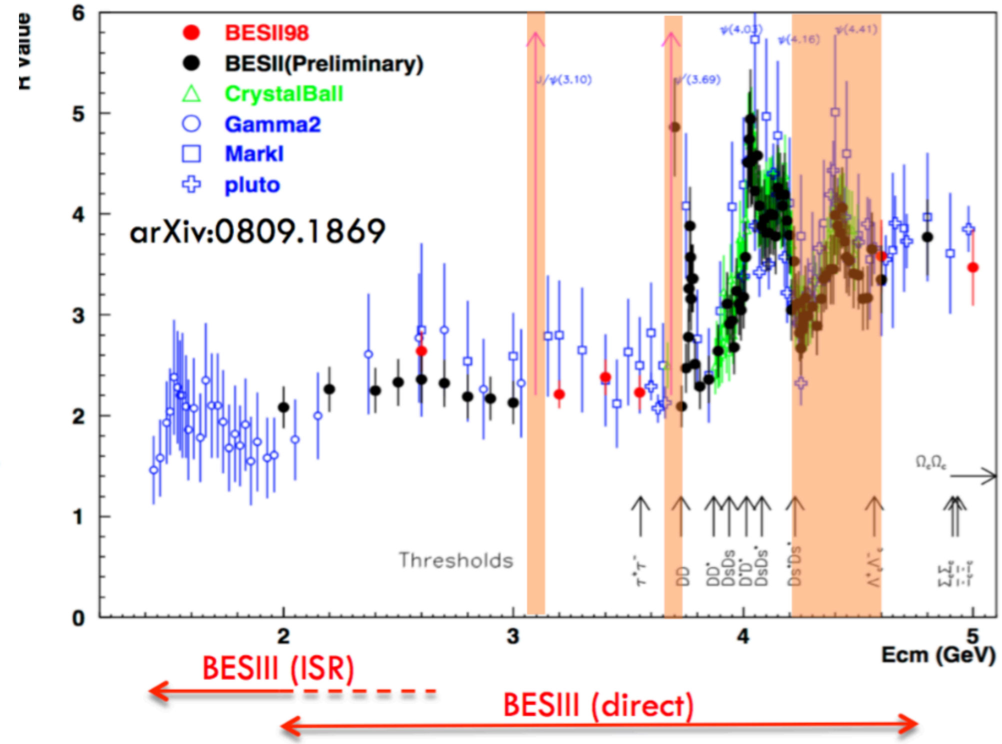
- **No time dependent information at Charm threshold**
- **Anti-symmetric wavefuction:**
  $\Gamma^2_{ij} = |\langle i|D^0\rangle\langle j|\bar{D}^0\rangle - \langle j|D^0\rangle\langle i|\bar{D}^0\rangle|^2$
- **Double tag rates:**
  $A_i^2 A_j^2[1 + r_i^2 r_j^2 - 2r_i r_j \cos(\delta_i + \delta_j)]$
  - **CP tag: r=1, δ=0 or π; $l^\pm$ tag: r=0**
- **Single and Double tag rates**
  - $z_f \equiv 2\cos\delta_f$, $r_f \equiv \frac{A_{DCS}}{A_{CF}}$, $R_M \approx \frac{x^2+y^2}{2}$

$$\psi(3770) \to [D^0\bar{D}^0 - \bar{D}^0 D^0]/\sqrt{2}$$
$$= -[D_{CP+}D_{CP-} - D_{CP-}D_{CP+}]/\sqrt{2}$$
$$D_{CP\pm} = [D^0 \pm \bar{D}^0]/\sqrt{2}$$

C-odd	f	$\bar{f}$	l^+	l^-	*CP+*	*CP-*
f	$R_M[1 + r_f^2(2 - z_f^2) + r_f^4]$					
$\bar{f}$	$1 + r_f^2(2 - z_f^2) + r_f^4$	$R_M[1 + r_f^2(2 - z_f^2) + r_f^4]$				
l^+	r_f^2	1	R_M			
l^-	1	r_f^2	1	R_M		
CP+	$1 + r_f(r_f + z_f)$	$1 + r_f(r_f + z_f)$	1	1	0	
CP-	$1 + r_f(r_f - z_f)$	$1 + r_f(r_f - z_f)$	1	1	4	0
Single Tag	$1 + r_f^2 - r_f z_f(A - y)$		1		$2[1 \pm (A - y)]$	

BESIII data samples

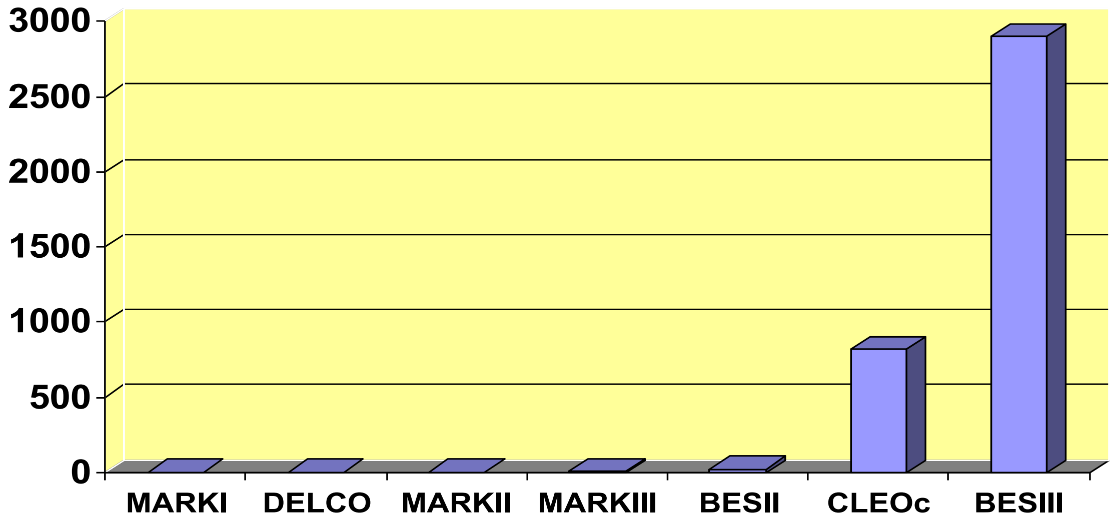
2009: 106M $\psi(2S)$
225M J/ψ
2010: 975 pb^{-1} at $\psi(3770)$
2011: 2.9 fb^{-1} at **$\psi(3770)$** *(total)*
482 pb^{-1} at **4.01 GeV**
2012: 0.45B **$\psi(2S)$** *(total)*
1.3B **J/ψ** *(total)*
2013: 1092 pb^{-1} at **4.23 GeV**
826 pb^{-1} at **4.26 GeV**
540 pb^{-1} at **4.36 GeV**
~50 pb^{-1} at **3.81, 3.90, 4.09, 4.19, 4.21, 4.22, 4.245, 4.31, 4.39, 4.42 GeV**
2014: 1029 pb^{-1} at **4.42 GeV**
110 pb^{-1} at **4.47 GeV**
110 pb^{-1} at **4.53 GeV**
48 pb^{-1} at **4.575 GeV**
567 pb^{-1} at **4.6 GeV**
0.8 fb^{-1} **R-scan** from 3.85 to 4.59 GeV (104 points)
2015: **R-scan** from 2-3 GeV + **2.175 GeV** data
2016: ~3fb^{-1} at 4.18 GeV (for **D_s**)
2017: 500/pb each for 7 energy points between 4.19~4.28 GeV
400/pb around chic_c1
200/pb around X(3872)



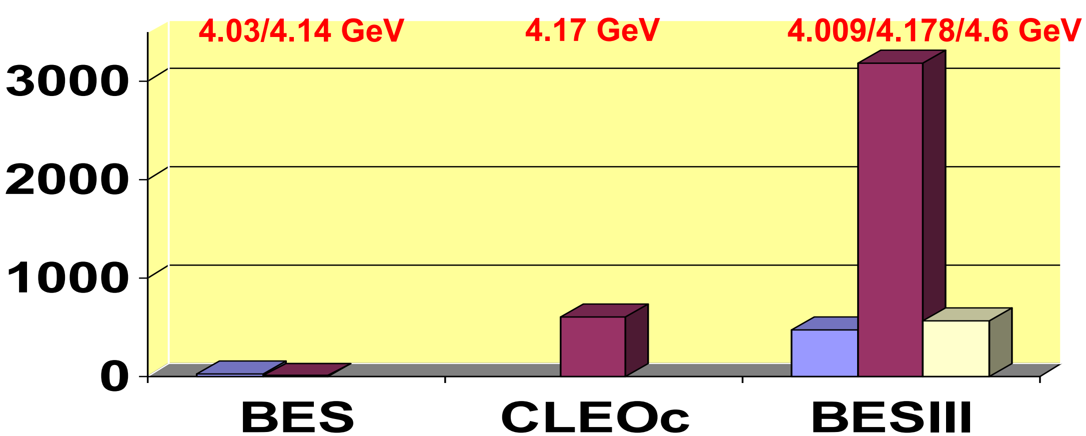
+ Initial State Radiation (ISR)

$D^{0(+)}$, D_s^+, Λ_c^+ samples (pb^{-1})

➢ $D^{0(+)}$ samples



➢ $D_s^+/D_s^+/\Lambda_c^+$ samples



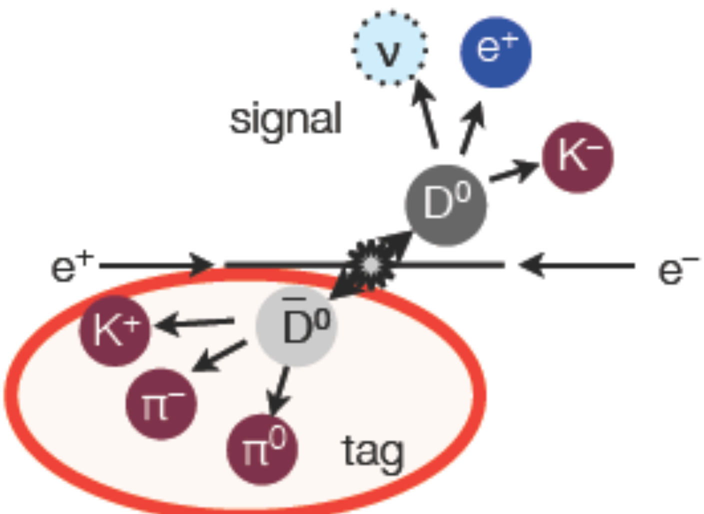
Physics at Charm threshold

- Decay constants & form factors for Charmed meson
- Quantum correlations at ψ(3770)
  - CPV measurements
  - Strong phase measurements
- Rare decays
- Charm baryons
- D^0-$\underline{D}^0$ mixing & CPV @ψ(4040)

Many new BESIII results have been released!
See Peirong, Dayong, Lei and Yi's talks.

Double Tag (DT) techniques

- 100% of beam energy converted to *D* pair (Clean environment, kinematic constrains ν Recon.)
- *D* generated in pair ⇒ absolute Branching fractions
- At ψ(3770) charm production is $D^0\bar{D}^0$ and D^+D^-
- Fully reconstruct about 15% of $D_{(S)}$ decays



$$\Delta E = E_D - E_{\text{Beam}}$$

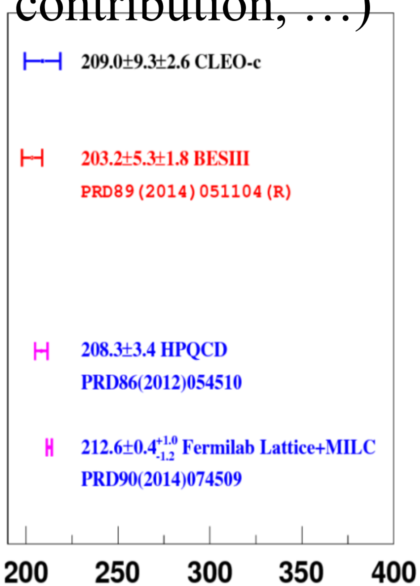
$$M_{\text{BC}} = \sqrt{E_{\text{Beam}}^2 - p_D^2}$$

◆ **Double tag techniques: Hadronic tag on one side, on the other side for leptonic/semileptonic studies. Neutrino is reconstructed from missing energy and momentum (Double tag efficiency is high.)**

$D_{(S)}$ Leptonic decays

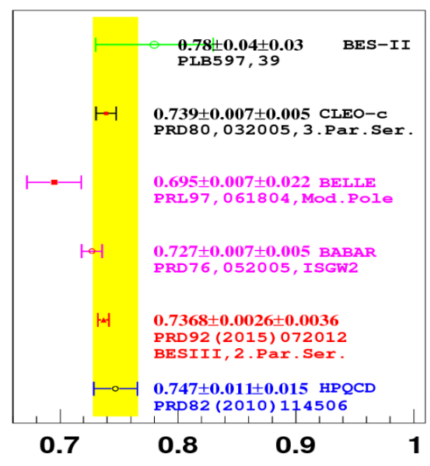
Purely Leptonic:

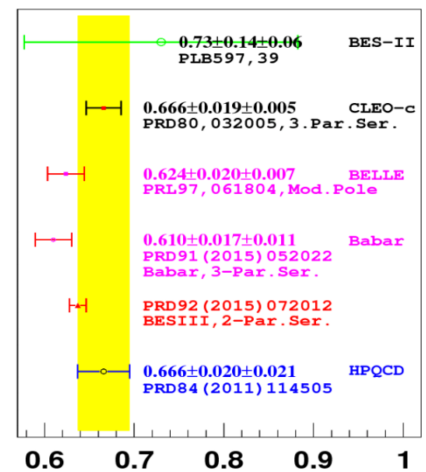
- Extract decay constant $f_{D(s)}$ incorporates the strong interaction effects (wave function at the origin)
- Multiple tests with charm: f_D, f_{Ds} and f_D/f_{Ds}
- To validate Lattice QCD calculation of $f_{B(s)}$ and provide constrain of CKM-unitarity
- Sensitive to New Physics (Charged Higgs contribution, …)



Semi-leptonic: form facotr (FF)

- $D_{(s)} \to P\, l\, \nu$ (Theoretically clean)
- Measure $|V_{cx}|$ x FF
- Charm physics:
  - CKM-unitarity $\Rightarrow$ $|V_{cx}|$, extract FF, test LQCD
  - Input LQCD FF to test CKM-unitarity





Λ_c^+ decays

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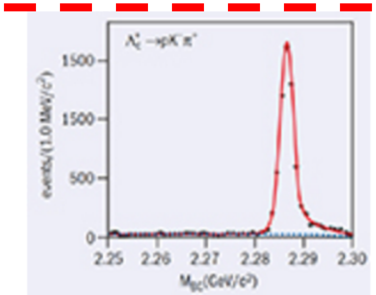
Mar 18, 2016

BESIII makes first direct measurement of the Λ_c at threshold

The charmed baryon, Λ_c, was first observed at Fermilab in 1976. Now, 40 years later, the Beijing Spectrometer (BESIII) experiment at the Beijing Electron–Positron Collider II (BEPCII) has measured the absolute branching fraction of $\Lambda^+_c \rightarrow pK^-\pi^+$ at threshold for the first time.



Beam-constrained mass distribution

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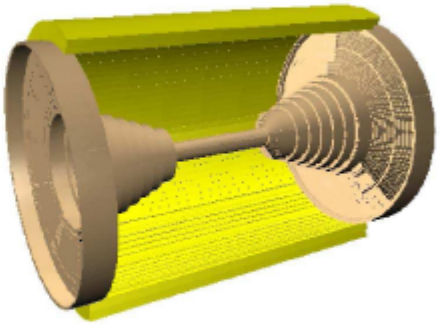
KEY SUPPLIERS

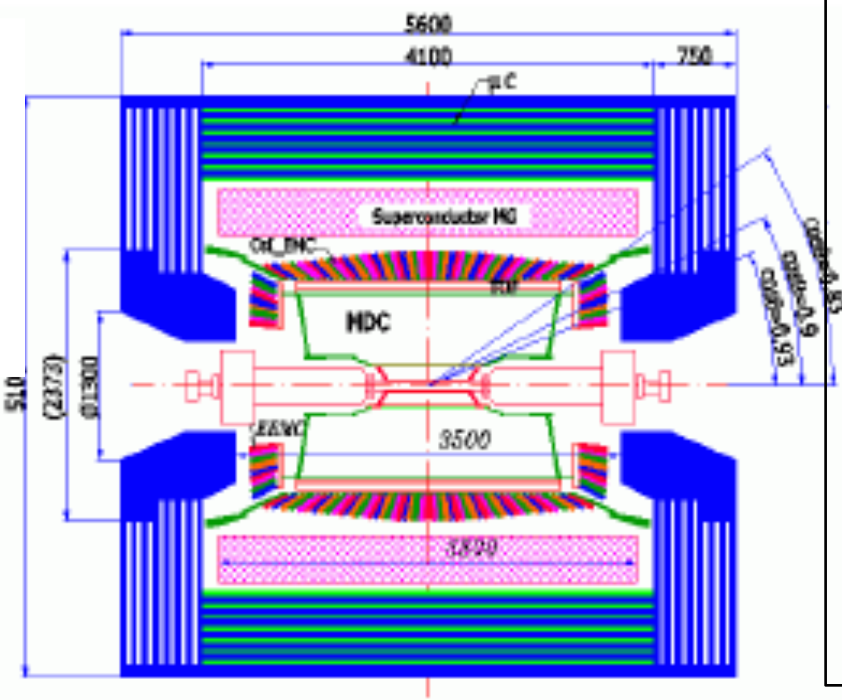
FEATURED

BESIII Detector

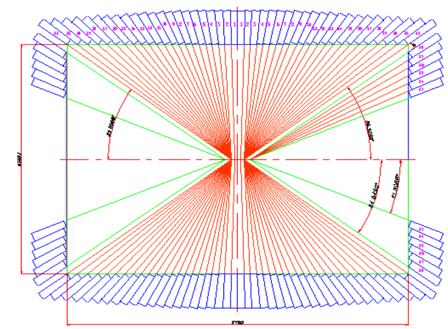
MDC



R inner: 63mm ;
R outer: 810mm
Length: 2582 mm
Layers: 43

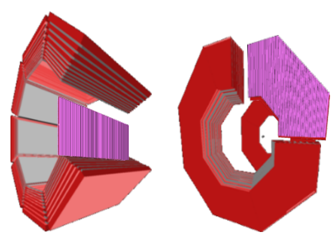


CsI(Tl) EMC



Crystals: 28 cm(15 X_0)
Barrel: |cosθ|<0.83
Endcap:
0.85 < |cosθ| < 0.93

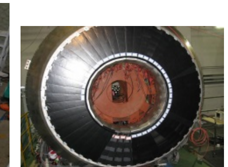
RPC MUC



BMUC: 9 layers – 72 modules
EMUC: 8 layers – 64 modules

TOF

BTOF: two layers
ETOF: 48 crys. for each

BESIII Detector Performance

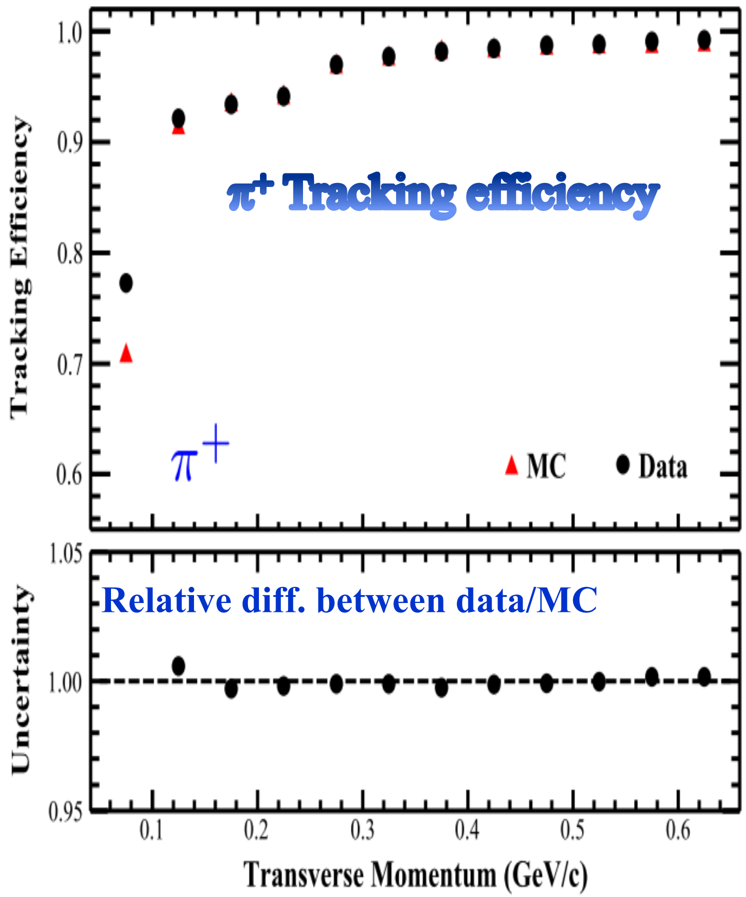
Exps.	MDC Spatial resolution	MDC dE/dx resolution	EMC Energy resolution
CLEO-c	110 μm	5%	2.2-2.4 %
BaBar	125 μm	7%	2.67 %
Belle	130 μm	5.6%	2.2 %
BESIII	115 μm	<5% (Bhabha)	2.4%

Exps.	TOF Time resolution
CDFII	100 ps
Belle	90 ps
BESIII	68 ps (BTOF) 60 ps (ETOF)

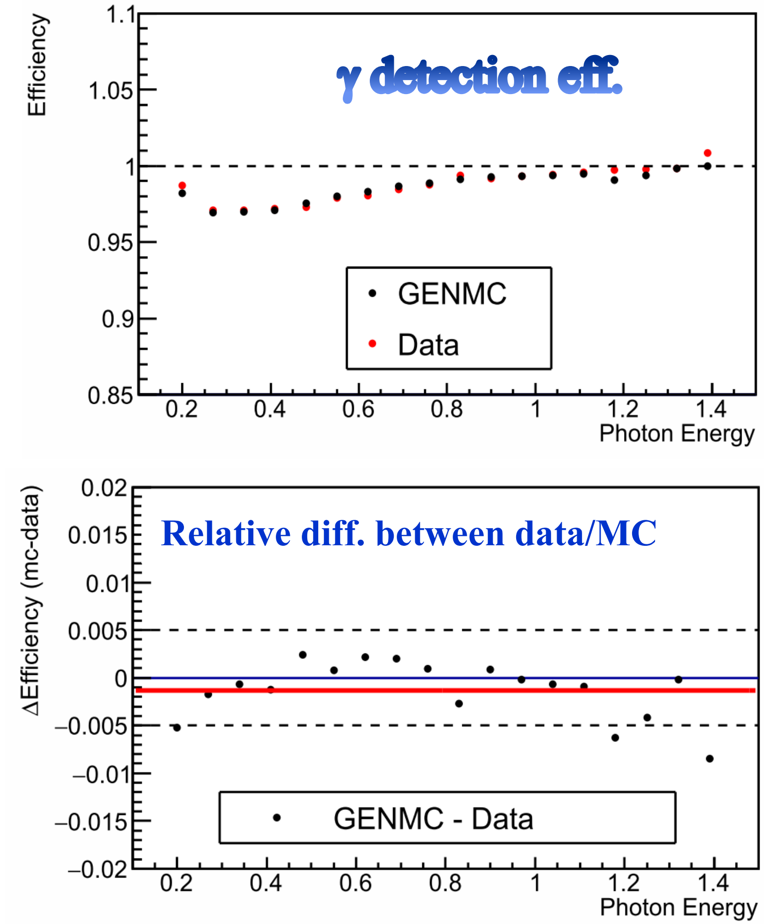
MUC: Efficiency ~ 96%
backgroun level: < 0.04 Hz/cm^2(B-MUC), < 0.1 Hz/cm^2(E-MUC)

Data/MC consistency

- **For tracking efficiency data/MC difference < 1%**



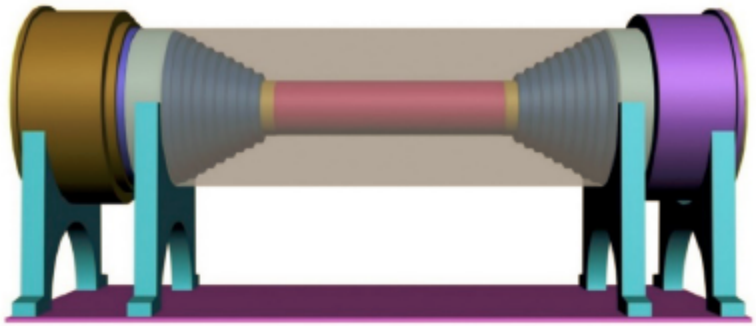
- **For photon detection efficiency data/MC difference < 1%**

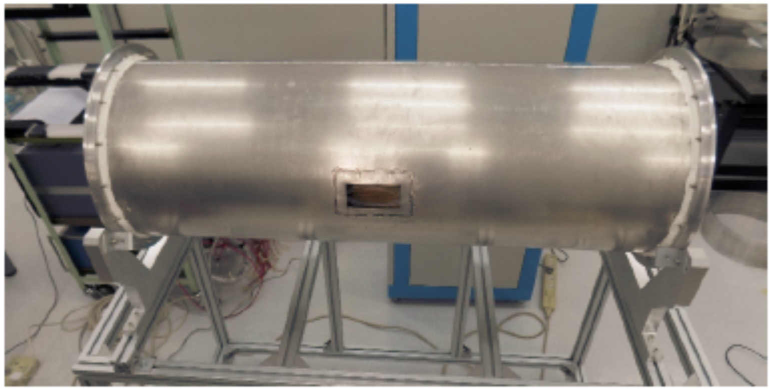


BESIII upgrade

- MDC: Malter effect found in inner chamber in 2012, add water vapor to the chamber to cure the aging problem.
  - New inner chamber, built by IHEP, is ready now.
  - CGEM as the inner chamber ongoing : Italy group in collaboration with other groups.
- New ETOF (built by USTC & IHEP) was installed in 2015 to improve the time resolution.
- Other possible upgrade plan is under discussion

New Inner Drift Chamber



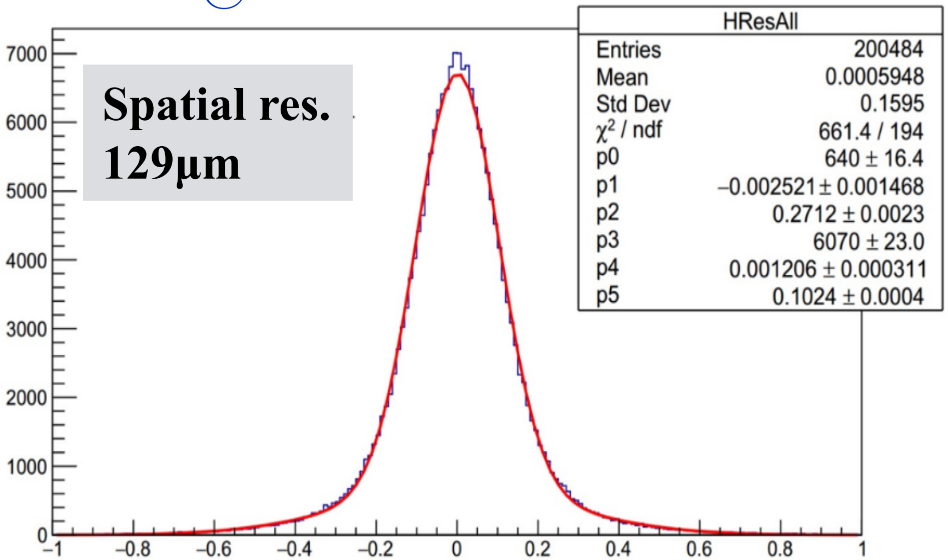


- An aluminum outer cylinder was manufactured for the chamber cosmic-ray test
- The outer cylinder was assembled after wiring had been finished

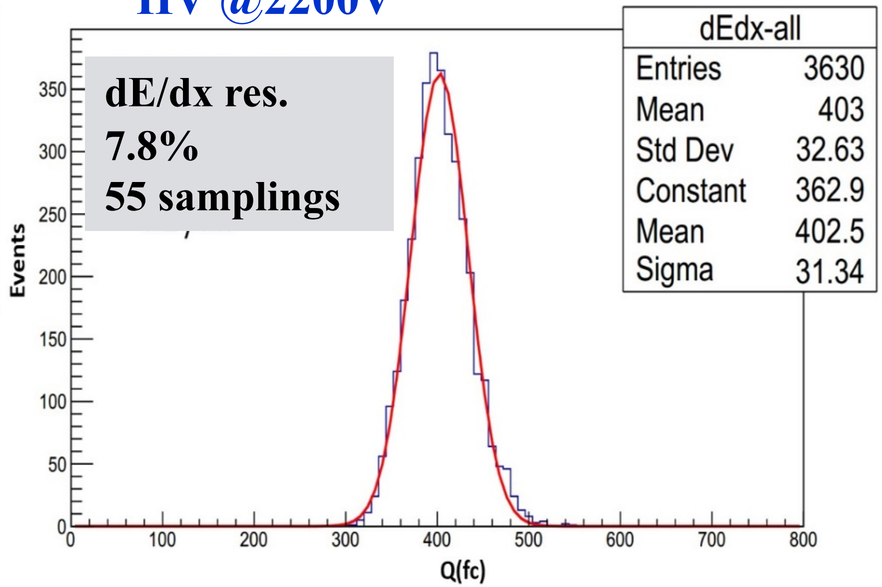
The performance of the new chamber

After half year's cosmic ray test, the efficiency > 99%

HV @2200V



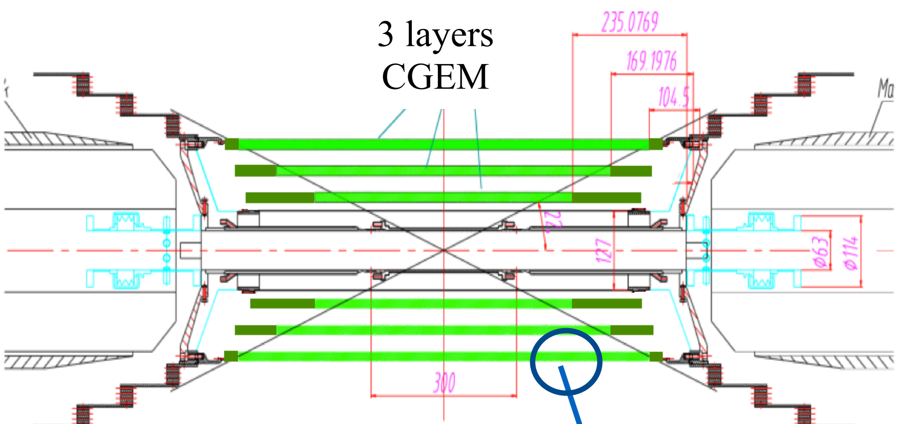
HV @2200V



The chamber is stored in a clean room and is ready to be replaced.

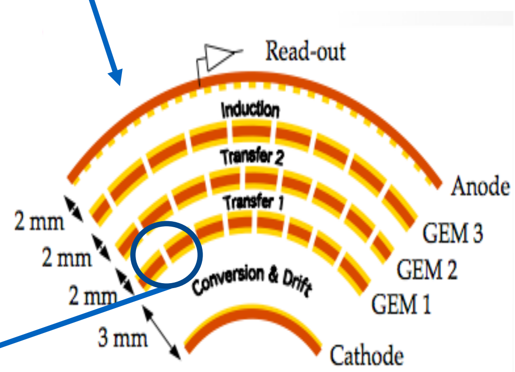
Cylindrical GEM Inner Tracker in a nutshell

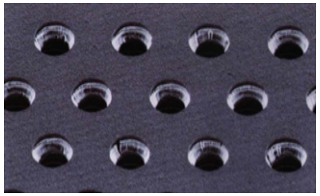
BESIII is building a cylindrical GEM detector (CGEM-IT) to replace the BESIII Inner MDC to recover some efficiency loss due to aging and to improve the secondary vertex resolution.



- **Low Material budget ≤ 1.5% of X_0 for all layers**
- **High Rate capability: ~10^4 Hz/cm^2**
- **Coverage: 93%**
- **Spatial resolution s_{rf} ~130 mm in 1 T magnetic filed**
- **Operation duration at least 5 years**

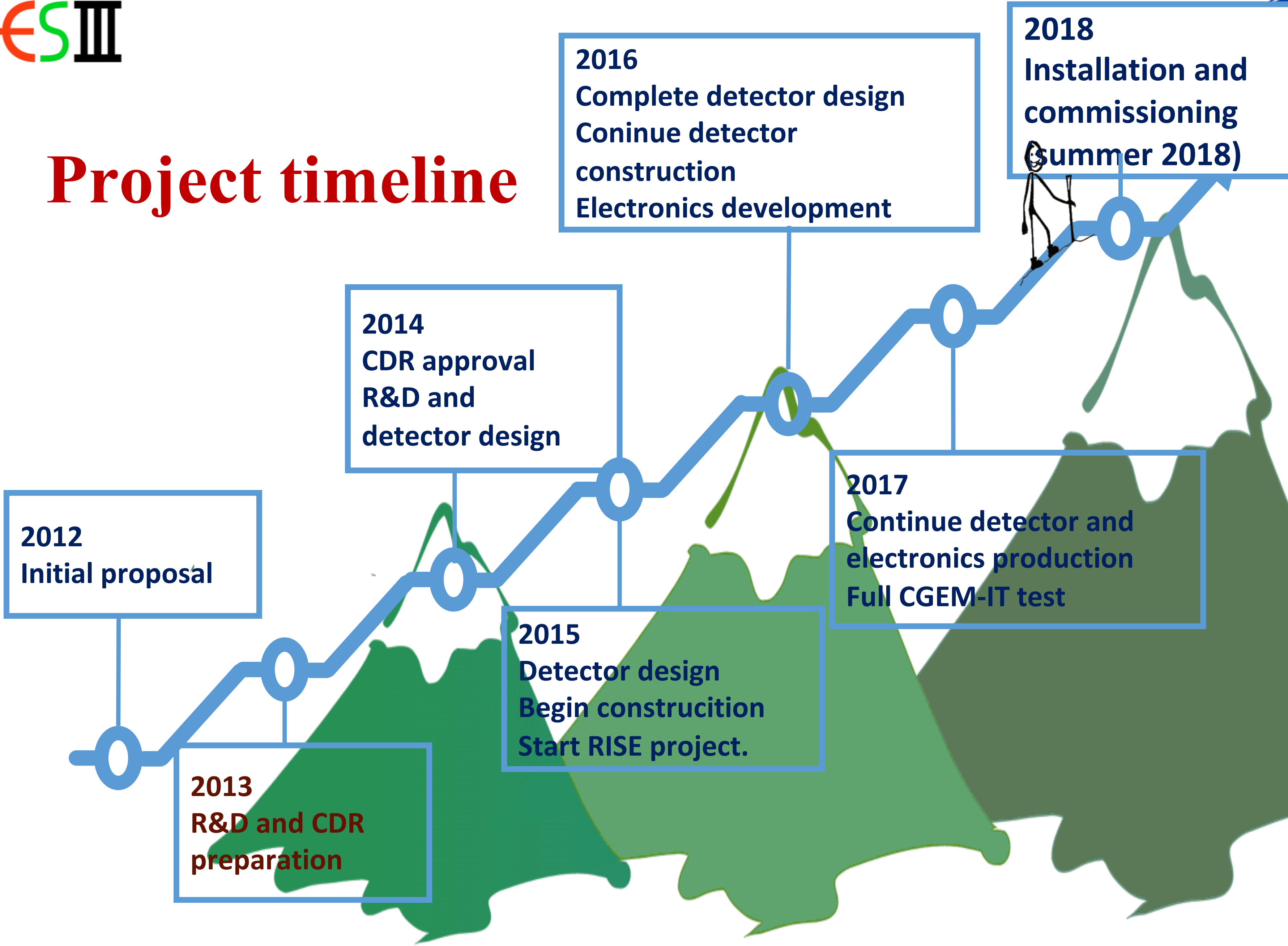
Each layer composed by a triple cylindrical GEM





The CGEM is co-funded by the European Commission Research and Innovation Staff Exchange (RISE) project 2015-2018.

Project timeline

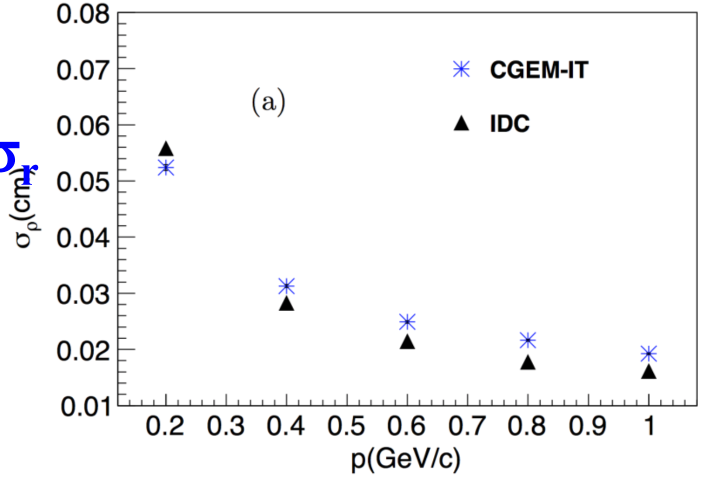


Expected performance of CGEM

Track fitting with Kalman Filter

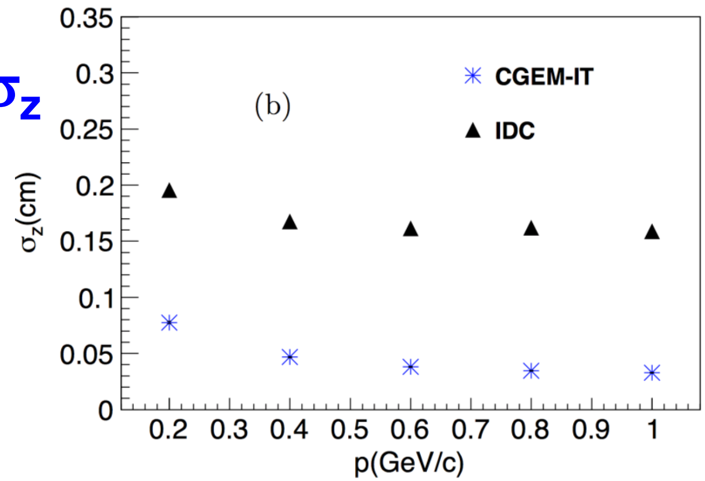
Approaching point resolution

σ_r

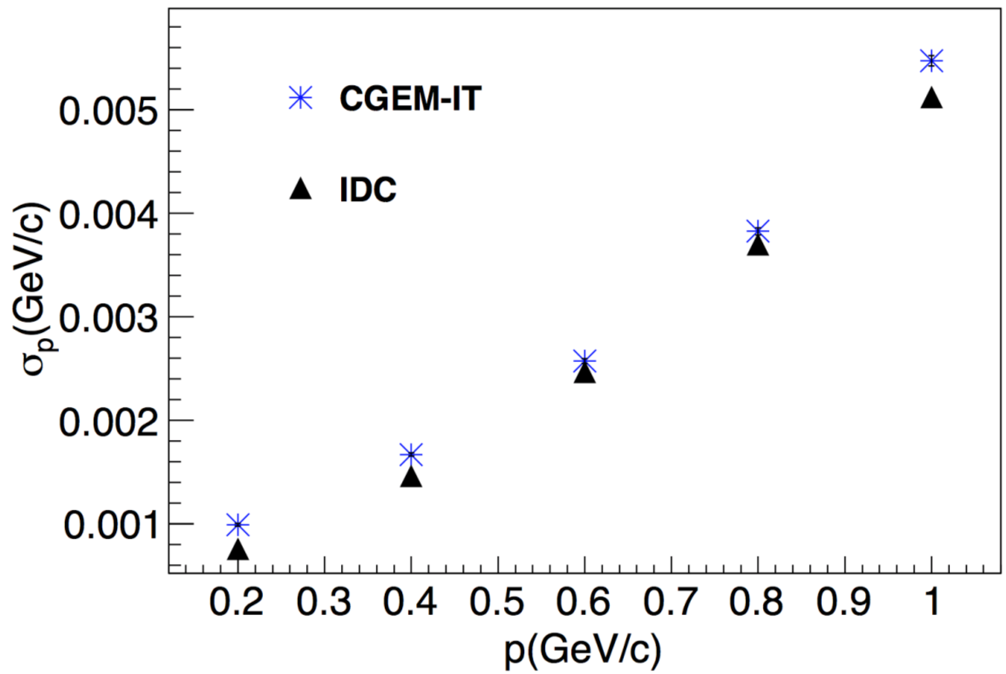


Approaching point resolution

σ_z

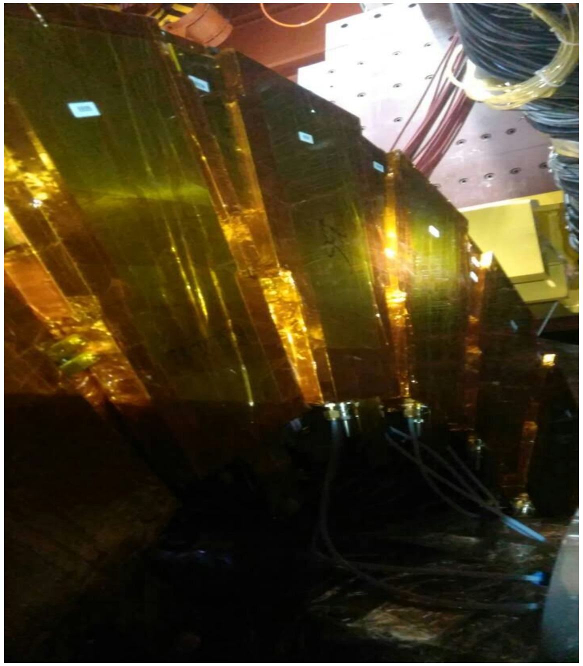


Momentum resolution

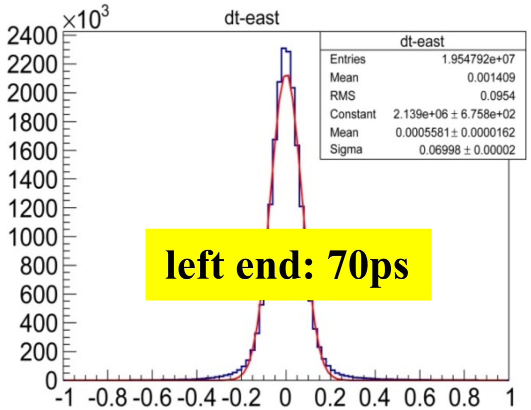


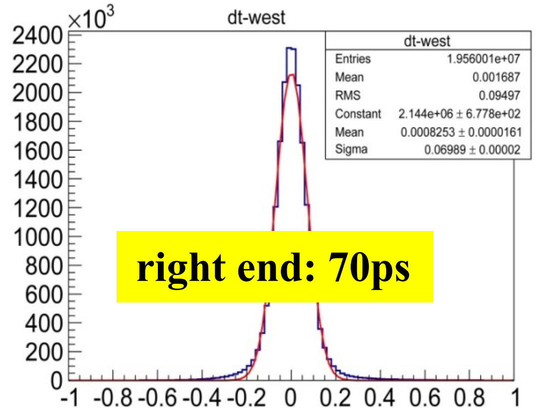
Installation of MRPC Endcap TOF

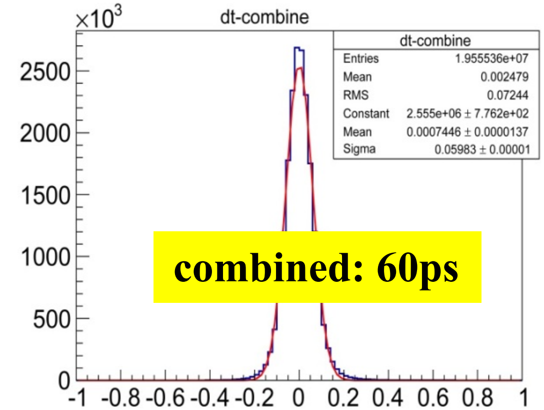
- **Scintillator Endcap TOF: time resolution for π is 138ps.**
- **New MRPC Endcap-TOF built**
- **The installation of MRPC ETOF completed in the Oct. of 2015**

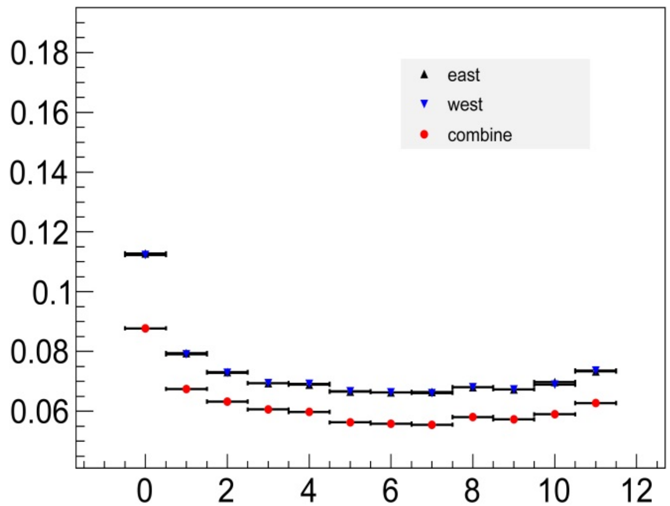


MRPC Endcap TOF

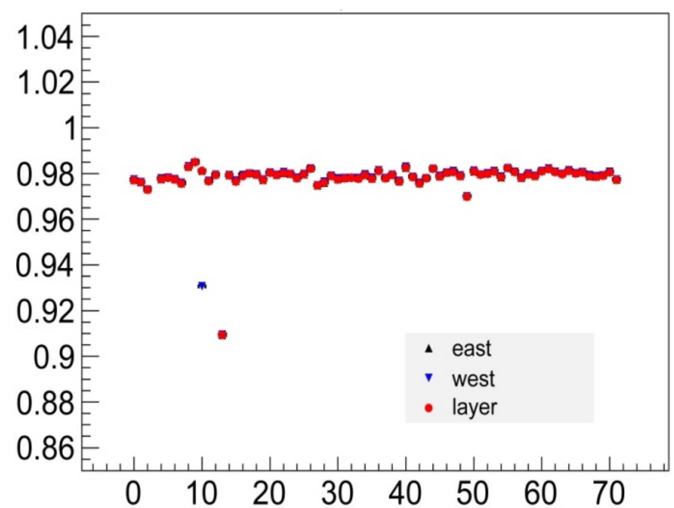








Time resolution vs Strip Number



Efficiency vs Module Number

Time resolution of 60ps achieved; Efficiency ~97%

Data/MC discrepancy

$\varepsilon_{data}/\varepsilon_{MC}$-1	2010	2016	2019?
Tracking eff./track	~2%	~1%	~0.5%
PID/track	~2%	~1%	~0.5%
Photon eff./photon	~1%	0.5-1%	~0.5%

Control of systematic errors.

- **BEPCII Upgrade**
  - **Top up plan → funding approved**
  - **No need of beam fill time**
  - **improve data luminosity by ~30%**
  - **Increase the maximum beam energy → funding approved**

currently: 2.30 GeV

I: → 2.35 GeV (power cooling hardware replacement, ….)

II: 2.35 GeV < E < 2.45 GeV

bottleneck: ISPB, new magnet and power supply

Prospects for Λ_c decays

Can BEPCII challenge the CM energy limit at 4.6 GeV?

With larger Λ_c data sample

- **PWA $\Rightarrow$ intermediate structures in 3-body decays**
- **More semileptonic decays: $nl\nu$, $\Lambda^* l\nu$, $\Sigma X l\nu$ …**
- **Decay asymmetry parameters α $\Leftarrow \Lambda_c^+ \rightarrow BP/BV$**
- **Λ_c^+ Rare decays search**
  - **Weak radiative decay $\Lambda_c^+ \rightarrow \gamma \Sigma^+$**
  - **FCNC $\Lambda_c^+ \rightarrow p l^+ l^-$**
  - **LNV $\Lambda_c^+ \rightarrow p e \mu$**

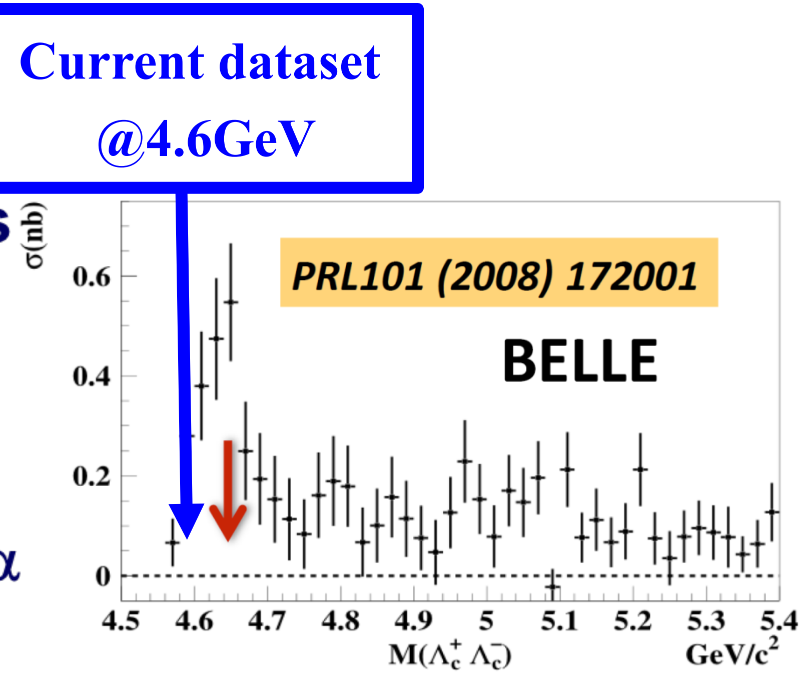


FIG. 4: The cross section for the exclusive process $e^+e^- \rightarrow \Lambda_c^+ \Lambda_c^-$.

How about @peak 4.64Gev?

Prospects of charmed hadron decays

Data at 3.773, 4.18 GeV and 4.63GeV

	Systematic	Statistical	
		~3 fb^{-1}	+10 fb^{-1}
$\Delta f_{D+}/f_{D+}$	~0.9%^{BESIII}	2.6%	1.3%
$\Delta f_{Ds+}/f_{Ds+}(\mu+\tau)$	~1.6%$^{BESIII\text{-}pre.}$	~1.5%	~0.7%
$\Delta f_{D\to K}/f_{D\to K}$	~0.5%^{BESIII}	0.4%	0.2%
$\Delta f_{D\to \pi}/f_{D\to \pi}$	~0.7%^{BESIII}	1.3%	0.6%
$\lvert V_{cs}\rvert^{Ds+\to l+v}(\mu+\tau)$	~1.6%$^{BESIII\text{-}pre.}$	~1.4%	~0.7%
$\lvert V_{cs}\rvert^{D0\to K\text{-}e+v}$	2.5%^{BESIII}(2.4%^{LQCD})	0.4%	0.2%
$\lvert V_{cd}\rvert^{D+\to \mu+v}$	2.1%^{BESIII}(1.9→0.5%^{LQCD})	2.6%	1.3%
$\lvert V_{cd}\rvert^{D0\to \pi\text{-}e+v}$	4.5%^{BESIII}(4.4%^{LQCD})	1.3%	0.6%
(c_i,s_i) in $D^0\to K^0\pi^+\pi^-$	Uncertinaty for γ/ϕ_3	1%	0.5%
$\Lambda_c^+\to pK^-\pi^+$		4.8% (0.6fb^{-1}@4.6)	~2% (3fb^{-1}@4.6X)

Strong phases in D hadronic decays

Status	Decay mode	Quantity of interest	Comments
➢	$D \to K^0_S\pi^+\pi^-$ *prel. release*	c_i and s_i	Binning schemes as those used in the CLEO-c analysis. With future, very large $\psi(3770)$data sets, it might be worthwhile to explore alternative binning.
➢	$D \to K^0_S K^+K^-$	c_i and s_i	Binning schemes as those used in the CLEO-c analysis. With future, very large $\psi(3770)$data sets, it might be worthwhile to explore alternative binning.
➢	$D \to K^\pm\pi^\mp\pi^+\pi^-$	R, δ	In bins guided by amplitude models, currently under development by LHCb.
➪	$D \to K^+K^-\pi^+\pi^-$	c_i and s_i	Binning scheme can be guided by the CLEO model [18] or potentially an improved model from LHCb in the future.
➪	$D \to \pi^+\pi^-\pi^+\pi^-$	F_+ or c_i and s_i	Unbinned measurement of F_+. Measurements of F_+ in bins or c_i and s_i in bins could be explored.
➢	$D \to K^\pm\pi^\mp\pi^0$	R, δ	Simple 2-3 bin scheme could be considered.
➪	$D \to K^0_S K^\pm\pi^\mp$	R, δ	Simple 2 bin scheme where one bin encloses the K^* resonance.
➢	$D \to \pi^+\pi^-\pi^0$	F_+	No binning required as $F_+ \sim 1$.
➪	$D \to K^0_S\pi^+\pi^-\pi^0$	F_+ and c_i and s_i	Unbinned measurement of F_+ required. Additional measurements of F_+ or c_i and s_i in bins could be explored.
➢	$D \to K^+K^-\pi^0$	F_+	Unbinned measurement required. Extensions to binned measurements of either F_+ or c_i and s_i possible.
➡	$D \to K^\pm\pi^\mp$	δ	Of low priority due to good precision available through charm-mixing analyses.

LHCb-PUB-2016-025

Status at BESIII
- ➡ published
- ➢ under study
- ➪ in plan

Strong phases in D hadronic decays

Decay mode	Quantity of interest	Comments
$D \to K^0_S\pi^+\pi^-$ *prel. release*	c_i and s_i	Binning schemes as those used in the CLEO-c analysis. With future, very large $\psi(3770)$data sets, it might be worthwhile to explore alternative binning.
$D \to K^0_S K^+K^-$	c_i and s_i	Binning schemes as those used in the CLEO-c analysis. With future, very large $\psi(3770)$data sets, it might be worthwhile to explore alternative binning.
$D \to K^\pm\pi^\mp\pi^+\pi^-$	R, δ	In bins guided by amplitude models, currently under development by LHCb.
$D \to K^+K^-\pi^+\pi^-$	c_i and s_i	Binning scheme can be guided by the CLEO ... the K^* resonance.
$D \to \pi^+\pi^-\pi^0$	F_+	No binning required as $F_+ \sim 1$.
$D \to K^0_S\pi^+\pi^-\pi^0$	F_+ and c_i and s_i	Unbinned measurement of F_+ required. Additional measurements of F_+ or c_i and s_i in bins could be explored.
$D \to K^+K^-\pi^0$	F_+	Unbinned measurement required. Extensions to binned measurements of either F_+ or c_i and s_i possible.
$D \to K^\pm\pi^\mp$	δ	Of low priority due to good precision available through charm-mixing analyses.

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Experimental precision reaches of the charmed hadrons

	Golden hadronic mode	δB/B	Golden SL mode	δB/B
D^0	B(Kπ)=(3.88±0.05)%	1.3%	B(Kev)=(3.55±0.05)%	1.4%
D^+	B(Kππ)=(9.13±0.19)%	2.1%	B(K^0ev)=(8.83±0.22)%	2.5%
D_s	B(KKpi)=(5.39±0.21)%	3.9%	B(φev)=(2.49±0.14)%	5.6%
Λc	B(pKπ)=(5.0±1.3)%(PDG2014) =(6.8±0.36)% (BELLE) =(5.84±0.35)% (BESIII) =(6.46±0.24)% (HFLAV)	26% 5.3% 6.0% 3.7%	B(Λev)=(2.1±0.6)%(PDG2014) =(3.63±0.43)% (BESIII) =(3.18±0.32)% (HFLAV)	29% 12% 10%

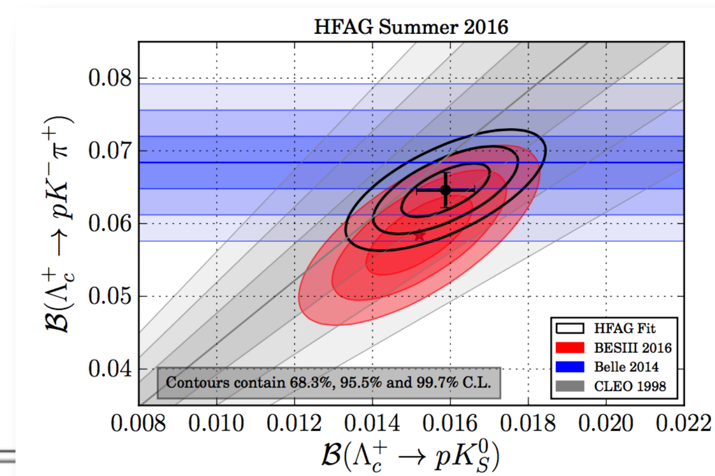
- The precisions of Λc decay rates is reaching to the level of charmed mesons!
- LHCb/BelleII data will further constrain the HFLAV fit
- However, search for more unknown modes are important

HFLAV Fit to world BF data

arXiv:1612.07233

- A fitter to constrain the 12 hadronic BFs and 1 SL BF, based on all the existing experimental data
- Correlated systematics are fully taken into account

Mode	HFAG 2016 (%)	BESIII (%)	PDG 2014 (%)	BELLE (%)
pK_S^0	1.59 ± 0.07	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30	
$pK^-\pi^+$	6.46 ± 0.24	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3	$6.84 \pm 0.24^{+0.21}_{-0.27}$
$pK_S^0\pi^0$	2.03 ± 0.12	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50	
$pK_S^0\pi^+\pi^-$	1.69 ± 0.11	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35	
$pK^-\pi^+\pi^0$	5.05 ± 0.29	$4.53 \pm 0.23 \pm 0.30$	3.4 ± 1.0	
$\Lambda\pi^+$	1.28 ± 0.06	$1.24 \pm 0.07 \pm 0.03$	1.07 ± 0.28	
$\Lambda\pi^+\pi^0$	7.09 ± 0.36	$7.01 \pm 0.37 \pm 0.19$	3.6 ± 1.3	
$\Lambda\pi^+\pi^-\pi^+$	3.73 ± 0.21	$3.81 \pm 0.24 \pm 0.18$	2.6 ± 0.7	
$\Sigma^0\pi^+$	1.31 ± 0.07	$1.27 \pm 0.08 \pm 0.03$	1.05 ± 0.28	
$\Sigma^+\pi^0$	1.25 ± 0.09	$1.18 \pm 0.10 \pm 0.03$	1.00 ± 0.34	
$\Sigma^+\pi^+\pi^-$	4.64 ± 0.24	$4.25 \pm 0.24 \pm 0.20$	3.6 ± 1.0	
$\Sigma^+\omega$	1.77 ± 0.21	$1.56 \pm 0.20 \pm 0.07$	2.7 ± 1.0	
$\Lambda e^+\nu_e$	3.18 ± 0.32	$3.63 \pm 0.38 \pm 0.20$	2.1 ± 0.6	



The least overall χ^2/ndf=30.0/23=1.3

Precise $B(pK^-\pi^+)$ is useful for constrain V_{ub} determined via baryonic mode

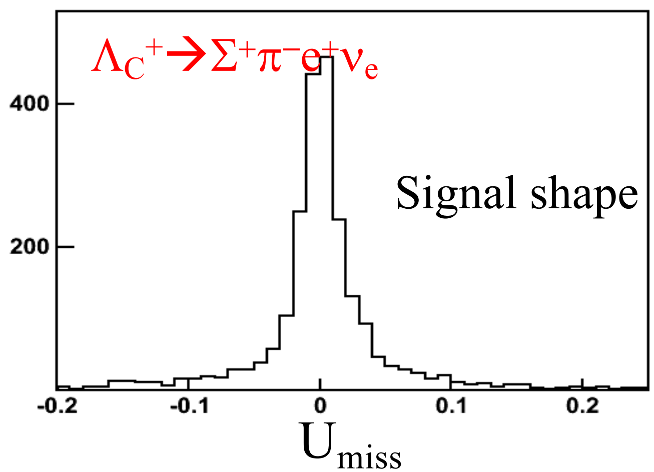
Prospects for Λ_c semi-leptonic decays

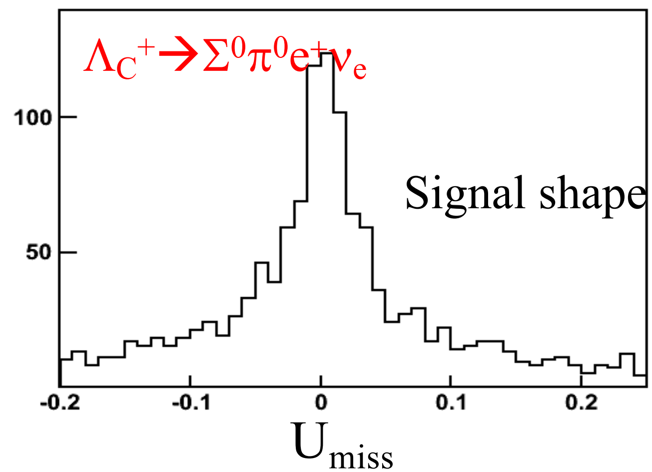
1 M Λ_c^+ pairs

- So far, only mode $\Lambda e^+\nu_e$ is measured
- Many more semi-leptonic modes can be established at BESIII!

modes	Expected B[%]	δB/B
$\Lambda l^+\nu_l$	3.6	5.4%
$\Lambda^* l^+\nu_l$	0.7	17%
$(pK^-, \Sigma\pi)\ l^+\nu_l$	0.7	17%
$n l^+\nu_l$	0.2	30%

	SL	δB/B
D0	B(Kev)=(3.55±0.05)%	1.4%
D+	B(K0ev)=(8.83±0.22)%	2.5%
Ds	B(phiev)=(2.49±0.14)%	5.6%
Λc	B(Λev)=(2.1±0.6)% (PDG2014) =(3.63±0.43)% (BESIII) **=(3.63±0.13)% (new BESIII)**	29% 12% **3%**

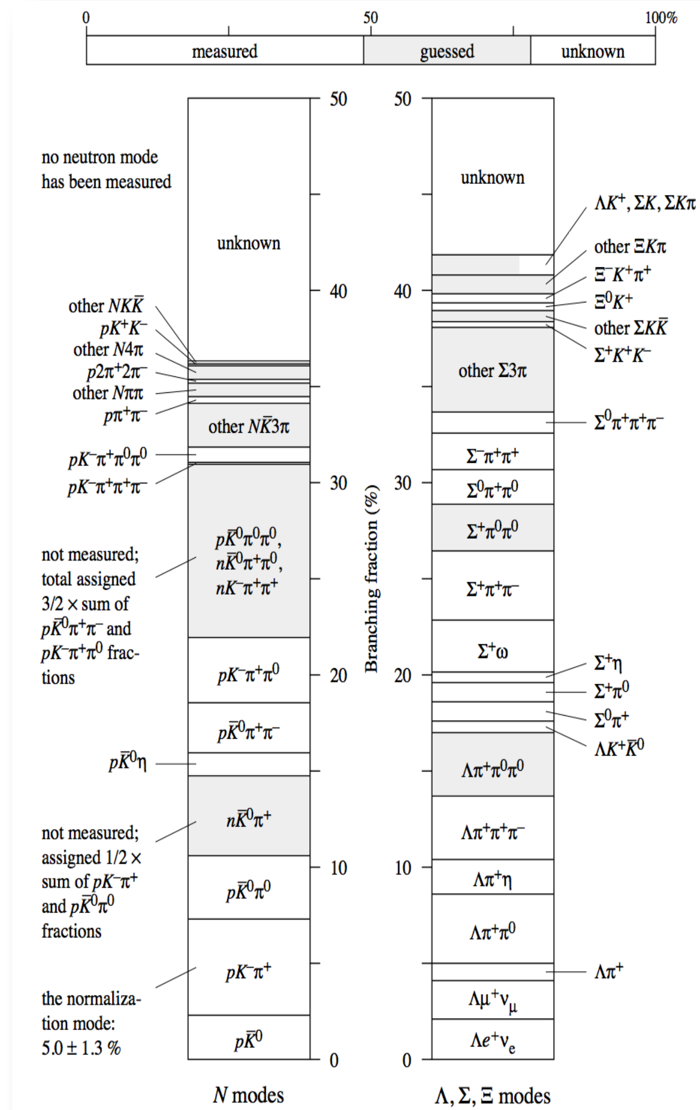




Other Relevant Λ_c^+ Potentials

10x more Λ_c^+ pairs

- **Studies on new Cabibbo-suppressed modes**
- **Many neutron modes will be firstly measured:** ***to test isospin symmetry*** PRD93, 056008 (2016)
- **Λ_c^+ hadronic weak decays**
  - ✓ Decay asymmetry parameters in two-body hadronic weak decays, such as $\Lambda_c^+ \to BP$ and $\Lambda_c^+ \to BV$ ➔ to measure the relative phase between the S- and P-wave decays
  - ✓ We can provide precise measurements on this observables
- **search for Λ_c^+ low rate decays and rare decays**
  - ✓ Weak radiative decay $\Lambda_c^+ \to \gamma \Sigma^+$; predictions of BF are 10^{-4} ~10^{-5} : expected sensitivity ~10^{-4}
  - ✓ FCNC, lepton number/family violation, baryon family violation ....: expected sensitivity~10^{-5}



We will find more the Λc-decay Mosaic!

Reaches for rare charm decays?

SM predictions and experimental reaches

10^{-0}

10^{-1}

10^{-2} Cabibbo favor

10^{-3} Single Cabibbo suppressed

10^{-4} Doubly Cabibbo suppressed

10^{-5}

10^{-6} Radiative decays: $D^0 \to \overline{K}^{*0}\gamma / \phi\gamma / \rho\gamma / \omega\gamma$; $D^+ \to K^{*+}\gamma / \rho^+\gamma$ $\quad D_S^+ \to K^{*+}\gamma / \rho^+\gamma$ — CLEO-c, BESIII, BESIII final/B factory

10^{-7} Long distance:

10^{-8} Vector meson Dominance: $D^0 \to \gamma\gamma / VV'(\to ll) / hV(\to ll) / hh'V(\to ll)$ — LHCb, Super-B, Super-τ-charm

10^{-9}

10^{-10}

10^{-11} Short distance FCNC: $D^0 / D^+ \to \gamma\gamma / Vl^+l^- / hl^+l^- / hh'l^+l^-$

10^{-12} $D^0 \to \mu^+\mu^-$

10^{-13} $D^0 \to e^+e^-$

10^{-14}

10^{-15} $D \to (h)\mu^+e^-$

Forbidden decays: LNV, LFV, BNV $\quad D \to (hh)e^+e^+ / (hh)\mu^+\mu^+$

Prospects of data samples in the coming years

- **BESIII collected world's largest samples of J/ψ, ψ(2S), ψ(3770), Y(4260), … from e^+e^- production.**
- **It will continue to run a few years.**

	BESIII	Goal
J/ψ	$1.3*10^9$ 21x BESII	$10*10^9$
ψ'	$0.6*10^9$ 24x CLEO-c	$3*10^9$
ψ(3770)	2.9 fb^{-1} 21x CLEO-c	20 fb^{-1}
Λ_c pair	$0.1*10^6$	$1*10^6$
Above open charm threshold	0.5 fb^{-1}@ψ(4040), 1.9 fb^{-1} @~4260, 0.5 fb^{-1}@4360, 1.0 fb^{-1} @4420, 0.5 fb^{-1} @4600, **scan data @4.19~4.28GeV in 2017**	>15 fb^{-1}
R scan and tau	3.8-4.6 GeV at 105 energy points 2.0-3.1 GeV at 20 energy points	
Y(2175)	100 pb^{-1} (2015)	
ψ(4170)	3 fb^{-1} (2016)	

Opportunities for precise determination of strong phase and D mixing, and studies on Λ_c decays

Summary

- **BESIII is successfully operating since 2008**
  – Collected large data samples in the τ-charm mass region
- **$D_{(s)}$ physics:**
  – charm Leptonic and semi-leptonic decays: to more precisely calibrate LQCD and over-constrain CKM matrix
  – charm hadron decays: explore the non-perturbative QCD
- **Λ_c physics:**
  – era of precision study of the Λ_c decays using threshold data
  – to provide unique data for theorists to develop more reliable models to describe charmed baryons
- **BEPCII/BESIII upgrade**
  – beam energy increase
  – top-up mode
- **Future goals**: >15 /fb ψ(3770) data, and roughly 50M D^0, 50M D^+ , 1M Λ_c , 15M *Ds*, produced near threshold
- **More physics results will be released out;**

stay tuned

Thank you!

谢谢!

Welcome to join

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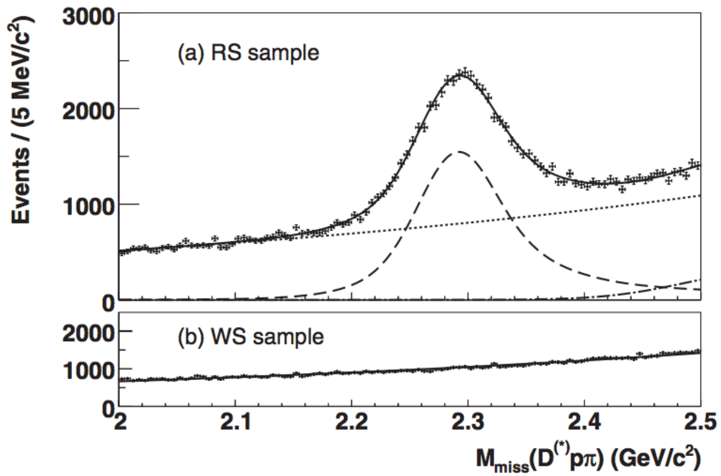
First precise measurement of $B(\Lambda_c^+ \to pK^-\pi^+)$

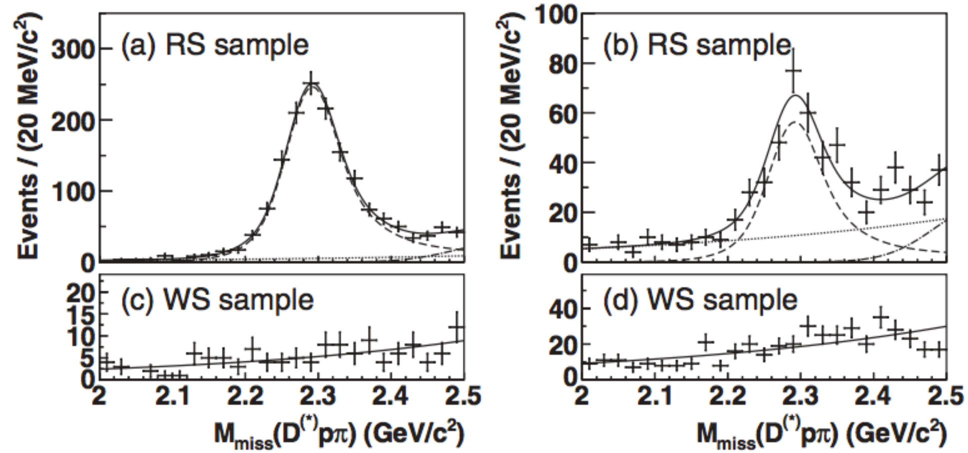
PRL 113, 042002 (2014)

The number of Λc baryons is determined by reconstructing the recoiling $D^{(*)-}\bar{p}\pi^+$ system in events of the type $e^+e^- \to D^{(*)-}\bar{p}\pi^+\Lambda_c^+$

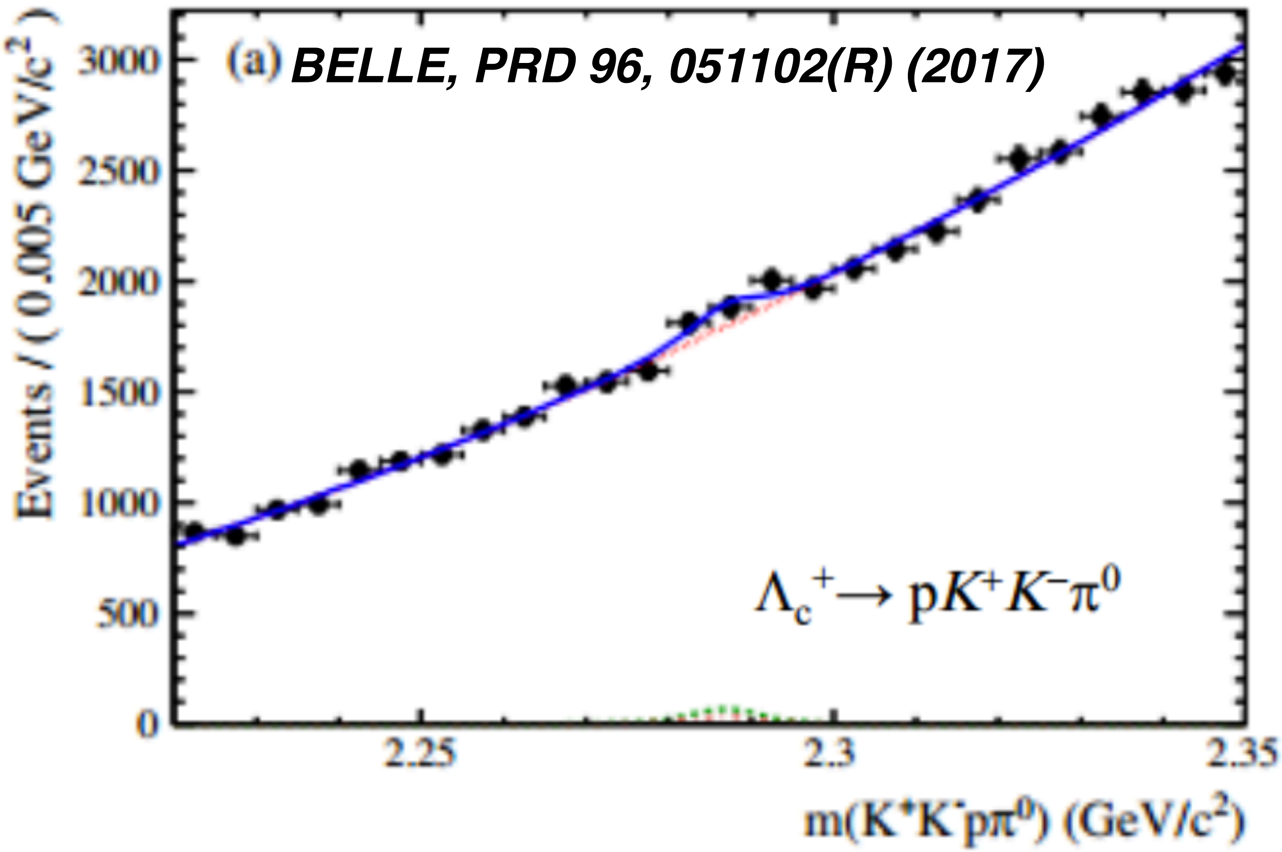
Missing Λ_c^+



Tagging $\Lambda_c^+ \to pK^-\pi^+$



$$\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+) = \frac{N(\Lambda_c^+ \to pK^-\pi^+)}{N_{\rm inc}^{\Lambda_c} f_{\rm bias}\,\varepsilon(\Lambda_c^+ \to pK^-\pi^+)} = (6.84 \pm 0.24^{+0.21}_{-0.27})\%$$


(a) BELLE, PRD 96, 051102(R) (2017)
Events / (0.005 GeV/c²)
3000
2500
2000
1500
1000
500
0
2.25
2.3
2.35
$\Lambda_c^+ \to pK^+K^-\pi^0$
m(K⁺K⁻pπ⁰) (GeV/c²)

Specialties of current ongoing experiments

BESIII:

- Threshold production & two body production
- Clean background
- Model-independent meas.
- Missing-mass technique: neutron, neutrino …
- Good photon resolution: Σ, Ξ, π^0, …

LHCb:

- Huge statistics
- High background
- Good PID and vertexing
- Complex production environment
- Poor in electron and photon reconstruction

BELLE(-II) :

- Large statistics
- High background
- Good PID and vertexing
- Good photon and electron reconstruction

Impacts in LHCb γ/ϕ_3 measurement

Run Period [E_{CM}]	Collected / Projected luminosity per run	Cumulative yield factor compared to Run 1	Year attained
Run 1 [7,8 TeV]	3 fb^{-1}	1	2012
Run 2 [13 TeV]	5 fb^{-1}	4	2018
LHCb phase-1 upgrade [14 TeV]	50 fb^{-1}	60	2030
LHCb phase-2 upgrade [14 TeV]	300 fb^{-1}	~400	2035(?)

- By considering the evolution of the LHCb measurements, which may differing among modes, this strong phase uncertainty is
  - 1.7 to 2.2^{o} at the end of Run 2
  - 1.8 to 2.5^{o} at the end of the phase 1 upgrade
- So now compared to the total precision an γ from LHCb expected
  - Run I – σ(γ) = 7^{o} - limited impact of strong phase measurements
  - Run II - σ(γ) = 3.5^{o} - becomes significant
  - **Upgrade phase I σ(γ) ~ strong phase uncertainty**