2025年BESIII粲强子物理研讨会

Research on inclusive decay of charm hadron at BESIII

Dong Xiao (肖栋)
Lanzhou University (兰州大学)

(On behalf of the BESIII Collaboration)

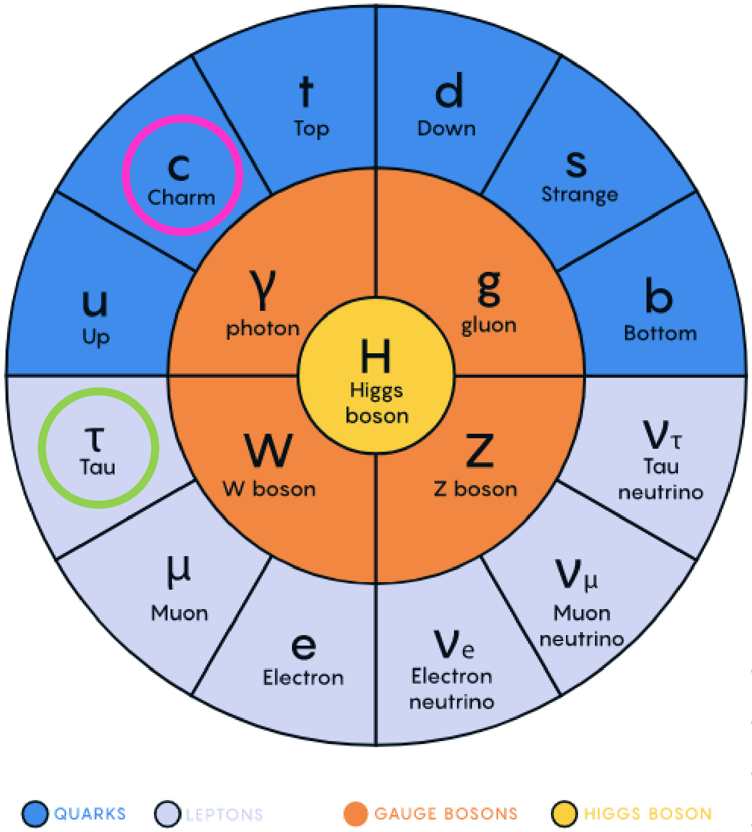
2025.08.06

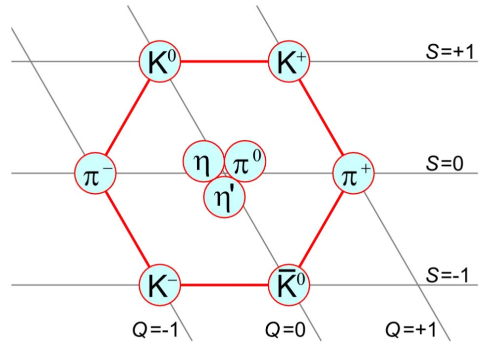
Outline

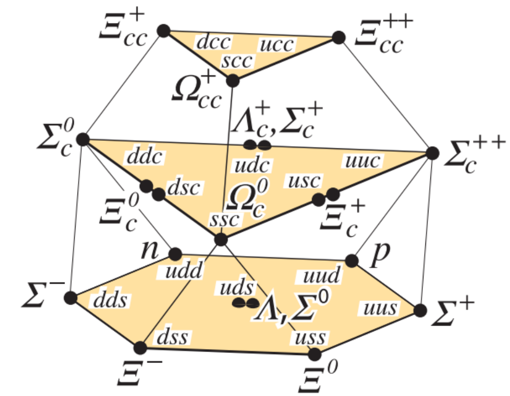
- Introduction to inclusive decay
- Methods for inclusive decay
- Inclusive decays at BESIII
- Summary & prospect

Standard model

- **Standard model(SM):**







Success and shortage of SM:

- ✓ A good framework of particle physics based on 3 interactions and 61 basic particles；
- ✓ Agreement well with many experiments；
- ✓ Successful predictions.

- No gravity;
- Parameters;
- CP violation;
- Neutrino oscillation;
- Non-perturbative;
- …

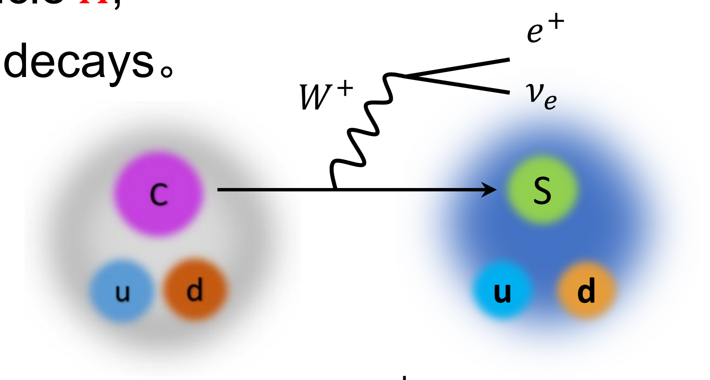
Higher precision

More situations

New physics

What is inclusive decay?

- **Inclusive decay:**
- Decay as $A \to B + X$, B is a certain particle, X contains any possible particles, then this decay is called an inclusive decay of particle A;
- Inclusive decay is the sum of a series of exclusive decays。



$c \to s e^+ \nu_e$ $|V_{cs}|$

- **Motivation:**
- Guide for undiscovered exclusive decays;
- Provide verifications for SM parameters;
- Extract HQE parameters for charm hadron lifetime.

$$\Lambda_c^+ \to \Lambda X_{(exclusive)} \approx (31.98 \pm 0.89)\%$$

$$\Lambda_c^+ \to \Lambda X_{(inclusive)} = (38.07 \pm 0.38 \pm 0.46)\%$$

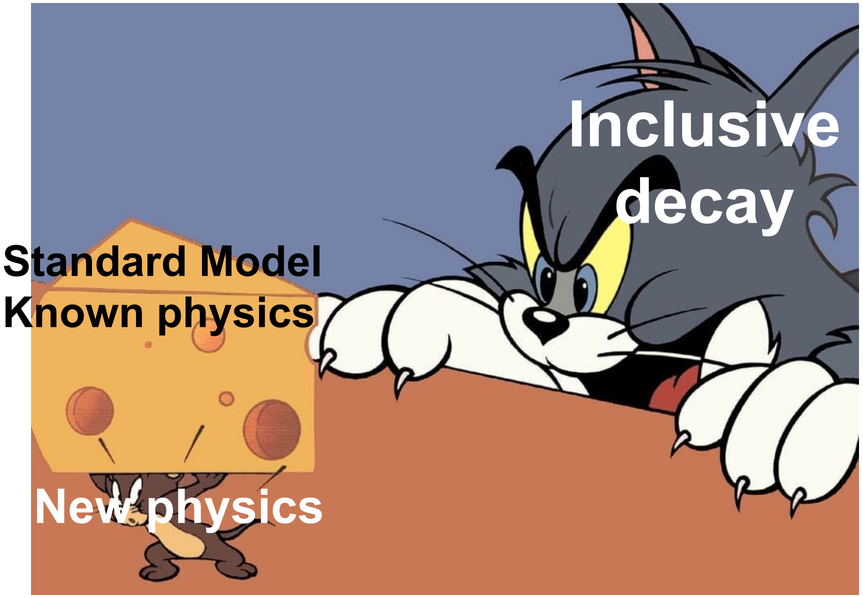
$$\frac{\mathfrak{B}(\Lambda_c^+ \to \Lambda X)_{exclusive}}{\mathfrak{B}(\Lambda_c^+ \to \Lambda X)_{inclusive}} = (80.4 \pm 2.6)\%$$

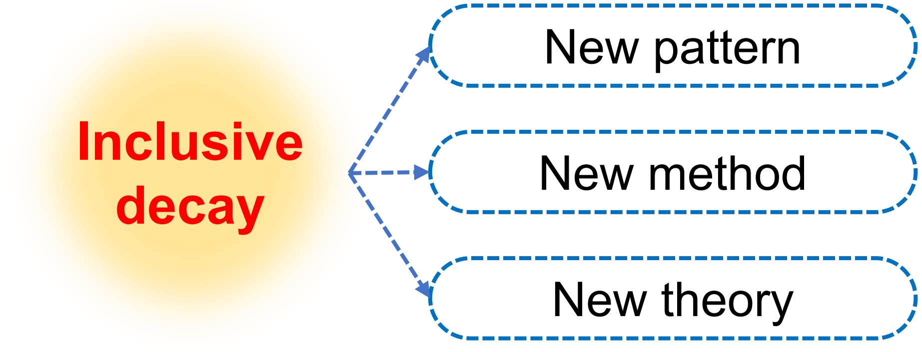
=> Any other decay modes?

- **Research objects:**
- BF;
- Decay parameter α;
- CPV
- CKM parameter
- HQE non-perturbative parameter…

Why inclusive decay

- **Why study inclusive decay?**



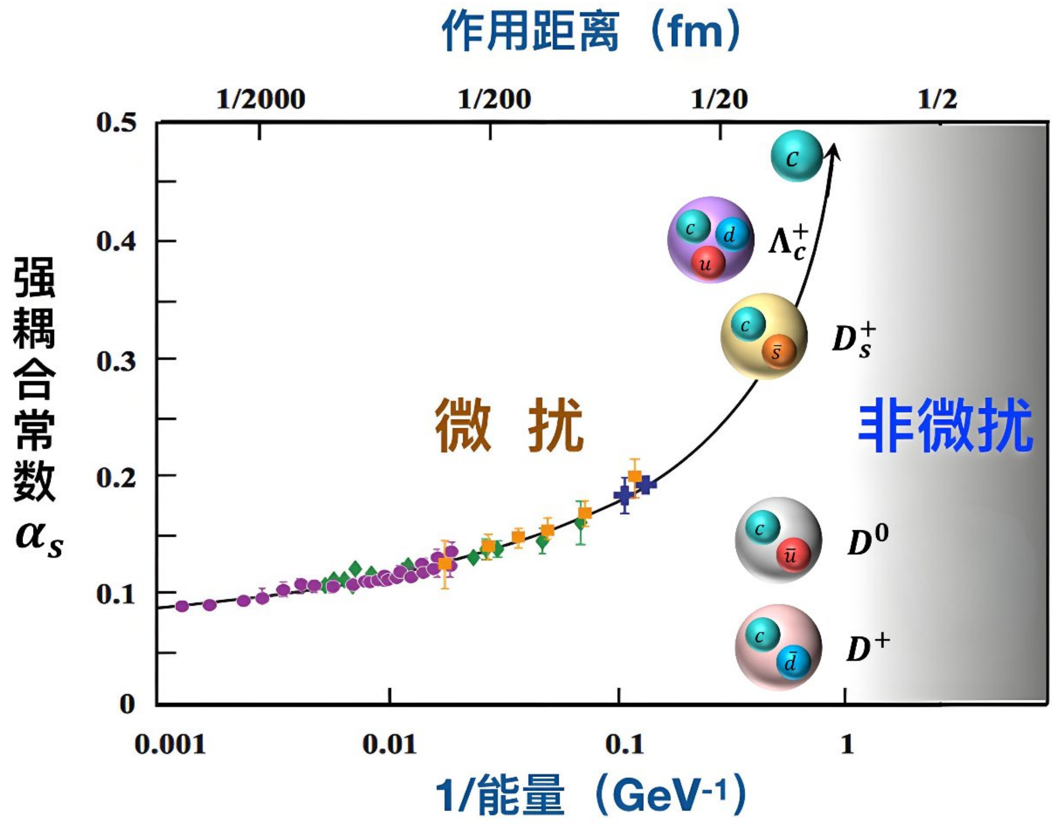


Increasing attention on inclusive decay!

Growing numbers of experimental research, but less theoretical.

Motivation

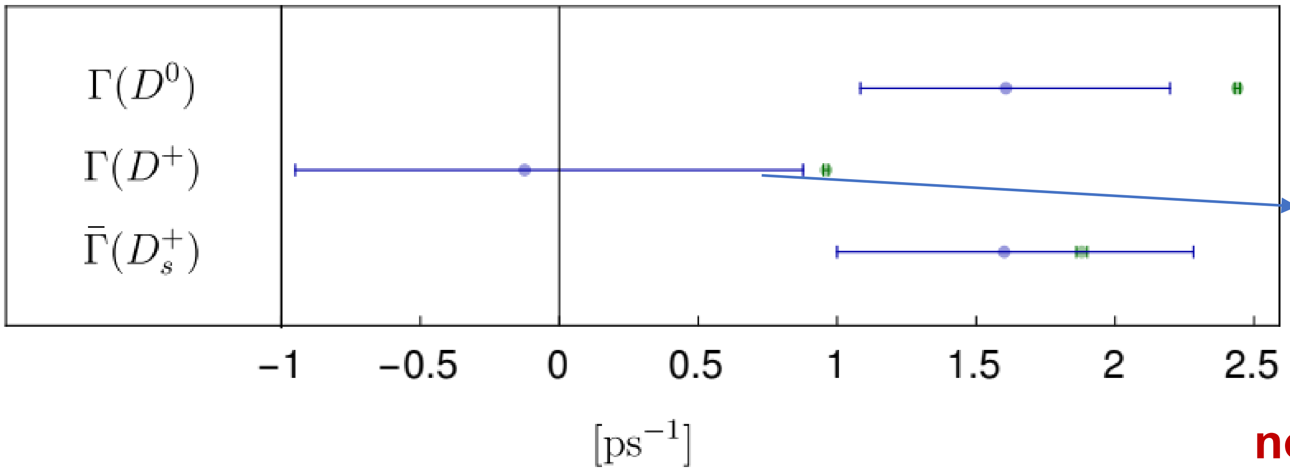
- The non-perturbative effects in the low-energy regime of QCD are one of the important frontier research topics in particle physics.



- Heavy quark expansion(HQE) works well for B physics, however there are some abnormal in theoretical predictions of both charm mesons and charm baryons.

Motivation

- **The lifetimes of D mesons suffer from large uncertainty of input parameters:**



JHEP 08 (2022) 241

Especially D^+ has negative theoretical prediction

- **The decay widths of D mesons can be expanded as:**

non-perturbative parameters:

$$\Gamma_{SL} = \frac{G_F^2 m_c^5}{192\pi^3}|V_{cs}|^2\left[f_0(r) + \frac{\alpha_S}{\pi}f_1(r) + \frac{\alpha_S^2}{\pi^2}f_2(r) + \frac{\mu_\pi^2}{m_c^2}f_\pi(r) + \frac{\mu_G^2}{m_c^2}f_G(r) + \frac{\rho_{LS}^3}{m_c^3}f_{LS}(r) + \frac{\rho_D^3}{m_c^3}f_D(r) + \frac{32\pi^2}{m_c^3}B_{WA}\right]$$

α_S: Strong coupling constant

μ_π^2: Kinetic operator

μ_G^2: Chromomagnetic operator

ρ_{LS}^3: Spin-orbital operator

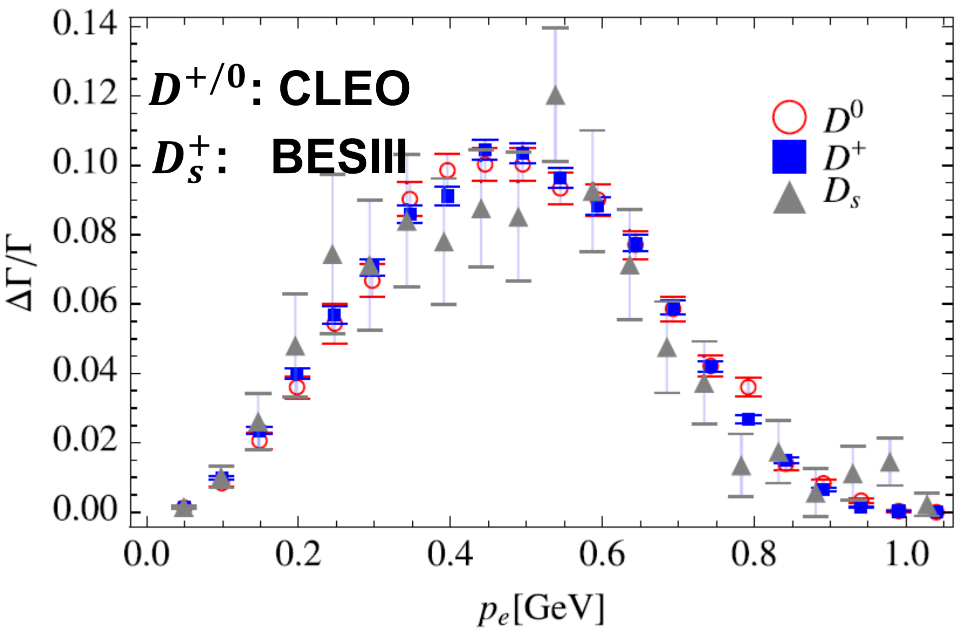
ρ_D^3: Darwin operator

B_{WA}: Weak annihilation contribution

Motivation

- The **non-perturbative parameters** can be extracted from the **lepton energy moment** in the center-of-mass system of charm hadron:

K.K. Shao, Q. Qin, et al.
arXiv:2502.05901v1



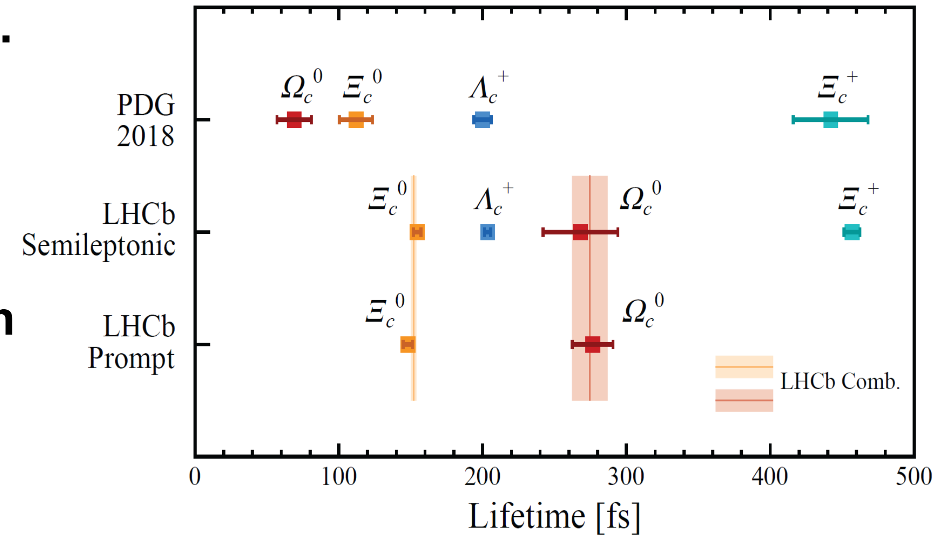
$$\mu_\pi^2(D^{0,+}) = (0.09 \pm 0.05)\mathrm{GeV}^2,$$
$$\mu_G^2(D^{0,+}) = (0.32 \pm 0.02)\mathrm{GeV}^2,$$
$$\rho_D^3(D^{0,+}) = (-0.003 \pm 0.002)\mathrm{GeV}^3,$$
$$\rho_{LS}^3(D^{0,+}) = (0.004 \pm 0.002)\mathrm{GeV}^3,$$
$$\mu_\pi^2(D_s^+) = (0.11 \pm 0.05)\mathrm{GeV}^2,$$
$$\mu_G^2(D_s^+) = (0.43 \pm 0.02)\mathrm{GeV}^2,$$
$$\rho_D^3(D_s^+) = (-0.004 \pm 0.002)\mathrm{GeV}^3,$$
$$\rho_{LS}^3(D_s^+) = (0.005 \pm 0.002)\mathrm{GeV}^3.$$

- However the previous experiments only provide **roughly binned energy spectra** in the **laboratory frame**, and suffer from **statistic fluctuation**.
- BESIII can provide **energy spectra with finer bin** of e^+/μ^+ in the **rest frame of** $D^{+/0}$、D_s^+、Λ_c^+, avoid distortion by the averaged Lorentz boost.

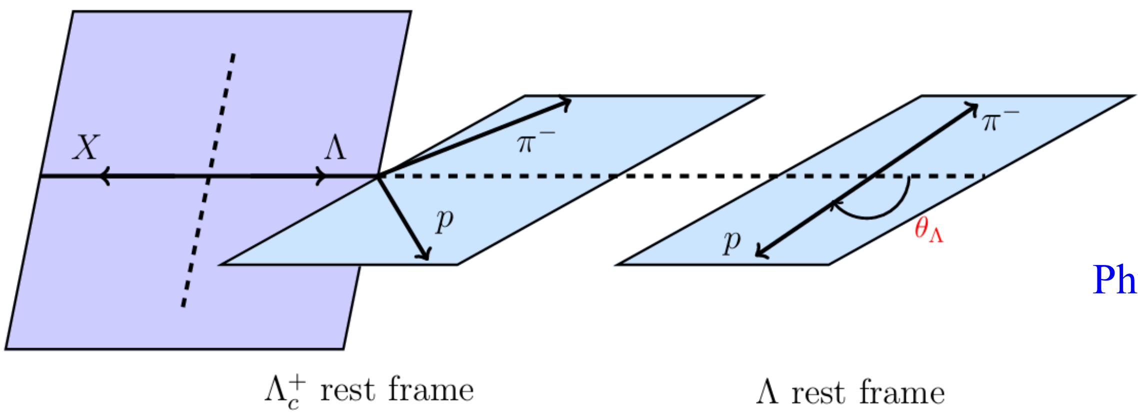
Motivation

- **The lifetime puzzle of charmed baryon.**

  H.Y. Cheng, *The strangest lifetime: a bizarre story of* $\tau(\Omega_c^0)$, **Sci. Bull. 67, 445 (2022).**



- **The α-induced CPV can be searched in inclusive decay of charm hadron.**



Phys. Lett. B 849 (2024) 138460

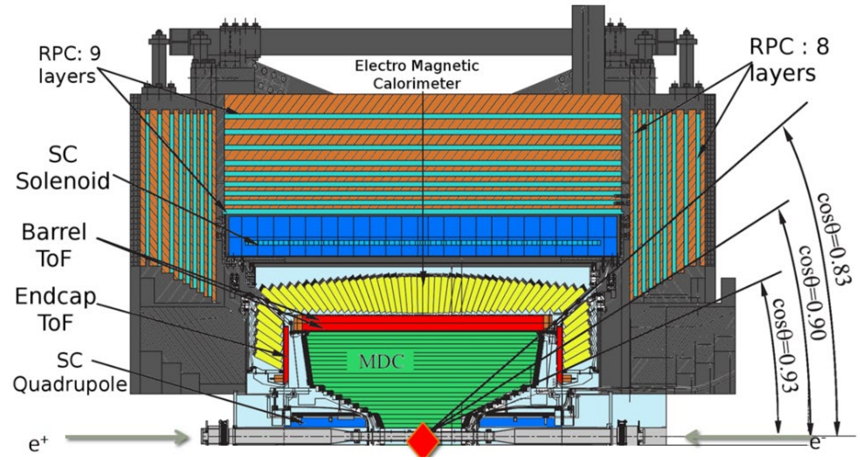
J.P. Wang, F.S. Yu, et al.

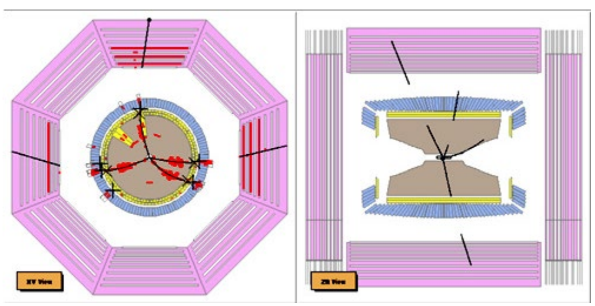
$$\frac{d\Gamma}{d\cos\theta} \propto 1 + \mathcal{P}\alpha_\Lambda \cos\theta \;\Rightarrow\; \mathcal{P} = \langle \mathcal{P}(q^2) \rangle \;\Rightarrow\; A_{CP}^{\alpha}(\Lambda_c \to \Lambda X) = \frac{\mathcal{P}\alpha - \bar{\mathcal{P}}\bar{\alpha}}{\mathcal{P}\alpha + \bar{\mathcal{P}}\bar{\alpha}}$$

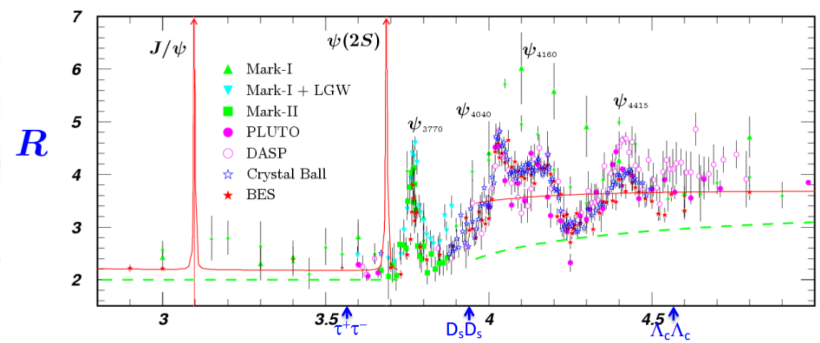
BEPCII & BESIII

- BEPCII

BESIII







First HEP collider in China (1988)
c.m.s energy: 2 ~ 5 GeV
Max luminosity: $1\times10^{33}cm^{-2}s^{-1}$

Non-perturbative
$\tau - charm$ region
$\tau^{\pm}$、D/D_s、$\Lambda_c^+\ldots$

J/ψ: 2.97 fb^{-1}(10B)
$\psi(3686)$: 4.07 fb^{-1}(2.7B)
$\psi(3770)$: 20.3 fb^{-1}
4.6~4.95GeV: 6.4 fb^{-1}

Status of inclusive decay

- D^+:

Inclusive modes

Γ_1	e^+ semileptonic	CLEO,2010	$(16.07 \pm 0.30)\%$
Γ_2	μ^+ anything	BES2,2008	$(17.6 \pm 3.2)\%$
Γ_3	K^- anything	BES2,2007	$(25.7 \pm 1.4)\%$
Γ_4	$\overline{K}^0$ anything + K^0 anything	BES3,2023	$(61 \pm 5)\%$
Γ_5	K^+ anything	BES2,2007	$(5.9 \pm 0.8)\%$
Γ_6	$K^*(892)^-$ anything	BES2,2006	$(6 \pm 5)\%$
Γ_7	$\overline{K}^*(892)^0$ anything	BES,2005	$(23 \pm 5)\%$
Γ_8	$K^*(892)^0$ anything	BES,2005	$< 6.6\%$
Γ_9	η anything	CLEO,2006	$(6.3 \pm 0.7)\%$
Γ_{10}	η' anything	CLEO,2006	$(1.04 \pm 0.18)\%$
Γ_{11}	ϕ anything	BES3,2019	$(1.12 \pm 0.04)\%$

D^0:

Inclusive modes

Γ_5	e^+ anything	CLEO,2010	[4] $(6.49 \pm 0.11)\%$
Γ_6	μ^+ anything	BES2,2008	$(6.8 \pm 0.6)\%$
Γ_7	K^- anything	BES2,2007	$(54.7 \pm 2.8)\%$
Γ_8	$\overline{K}^0$ anything + K^0 anything	BES3,2023	$(47 \pm 4)\%$
Γ_9	K^+ anything	BES2,2007	$(3.4 \pm 0.4)\%$
Γ_{10}	$K^*(892)^-$ anything	BES2,2006	$(15 \pm 9)\%$
Γ_{11}	$\overline{K}^*(892)^0$ anything	BES,2005	$(9 \pm 4)\%$
Γ_{12}	$K^*(892)^+$ anything	BES2,2006	$< 3.6\%$
Γ_{13}	$K^*(892)^0$ anything	BES,2005	$(2.8 \pm 1.3)\%$
Γ_{14}	η anything	CLEO,2006	$(9.5 \pm 0.9)\%$
Γ_{15}	η' anything	CLEO,2006	$(2.48 \pm 0.27)\%$
Γ_{16}	ϕ anything	BES3,2019	$(1.08 \pm 0.04)\%$

- Λ_c^+:

Inclusive modes

Γ_{76}	e^+ anything	$(3.95 \pm 0.35)\%$	→ BESIII, PRL
Γ_{77}	p anything	$(50 \pm 16)\%$	→ BESIII, on-going
Γ_{78}	n anything	$(50 \pm 16)\%$	→ BESIII, PRD
Γ_{79}	Λ anything	$(38.2^{+2.9}_{-2.4})\%$	→ BESIII, PRL
Γ_{80}	K^0_S anything	$(9.9 \pm 0.7)\%$	→ BESIII, EPJC, JHEP
Γ_{81}	3prongs	$(24 \pm 8)\%$	→ BESIII, PRD

Status of inclusive decay

• D_s^+:

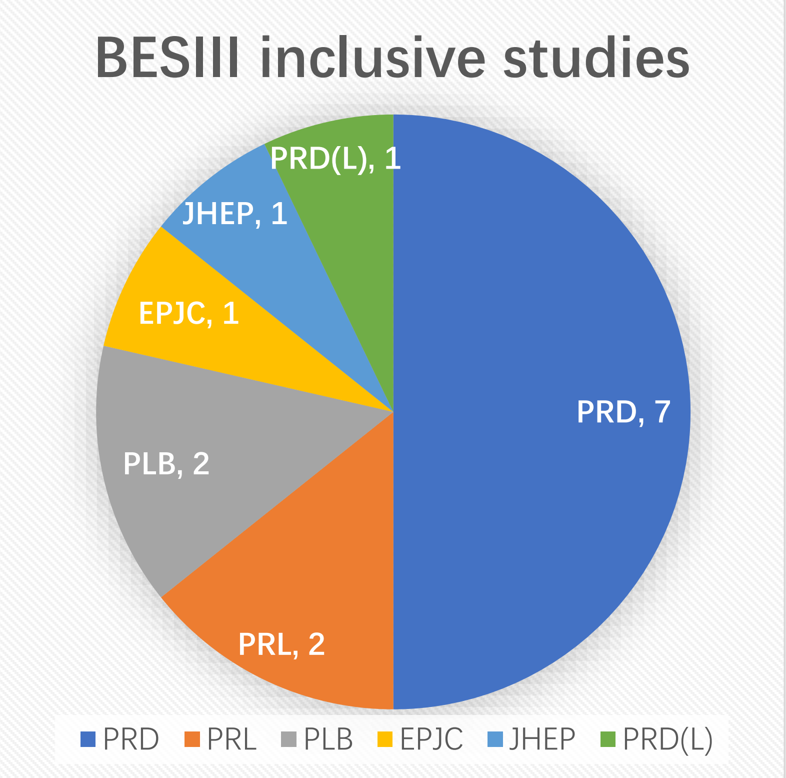
Inclusive modes

Γ_1	e^+ semileptonic	BES3,2021	[1]	$(6.33 \pm 0.15)\%$
Γ_2	π^+ anything	CLEO,2009		$(119.3 \pm 1.4)\%$
Γ_3	π^- anything	CLEO,2009		$(43.2 \pm 0.9)\%$
Γ_4	π^0 anything	CLEO,2009		$(123 \pm 7)\%$
Γ_5	K^- anything	CLEO,2009		$(18.7 \pm 0.5)\%$
Γ_6	K^+ anything	CLEO,2009		$(28.9 \pm 0.7)\%$
Γ_7	K_S^0 anything	CLEO,2009		$(19.0 \pm 1.1)\%$
Γ_8	η anything	CLEO,2009	[2]	$(29.9 \pm 2.8)\%$
Γ_9	ω anything	CLEO,2009		$(6.1 \pm 1.4)\%$
Γ_{10}	η' anything	BES3,2015	[3]	$(10.3 \pm 1.4)\%$
Γ_{11}	$f_0(980)$ anything, $f_0 \to \pi^+\pi^-$	CLEO,2009		$< 1.3\%$
Γ_{12}	ϕ anything	CLEO,2009		$(15.7 \pm 1.0)\%$
Γ_{13}	K^+K^- anything	CLEO,2009		$(15.8 \pm 0.7)\%$
Γ_{14}	$K_S^0 K^+$ anything	CLEO,2009		$(5.8 \pm 0.5)\%$
Γ_{15}	$K_S^0 K^-$ anything	CLEO,2009		$(1.9 \pm 0.4)\%$
Γ_{16}	$2 K_S^0$ anything	CLEO,2009		$(1.70 \pm 0.32)\%$
Γ_{17}	$2 K^+$ anything	CLEO,2009		$< 2.6 \times 10^{-3}$
Γ_{18}	$2 K^-$ anything	CLEO,2009		$< 6 \times 10^{-4}$

J/ψ: none

ψ': $K_S^0 X$ (BES3, 2021)

PDG not record yet



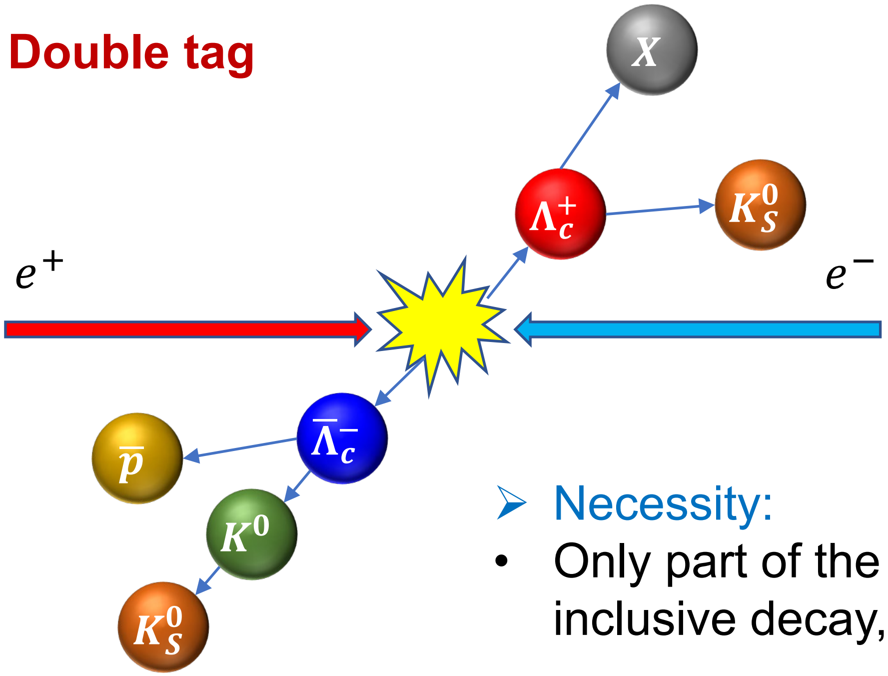
Inclusive decays at BESIII

	D^0/D^+	D_s^+	Λ_c^+	Others (J/ψ, ψ', $hyperon$)
Single charged track		$Xe^+\nu_e$	$Xe^+\nu_e$	
Multi charged tracks	$\pi^+\pi^+\pi^-X$	$\pi^+\pi^+\pi^-X$		
Long lived inter-particle	K_S^0X		ΛX, K_S^0X	$\psi(3686)\to K_S^0X$
Short lived inter-particle	ϕX	$\eta' X$		$\Sigma^-\to\Sigma^+X$
Neutron			$\bar{\Lambda}_c^-\to\bar{n}X$	

Will be introduced in this report.

Methods for inclusive decay

- **Double tag**



➢ Necessity:
- Only part of the final states are reconstructed in inclusive decay, single-tag(ST) is not executable.

➢ Reasonability:
- The Λ_c are produced in pairs at threshold on BESIII, no other accompanied particles, 4-momentum conservation.

➢ Advantage:
- Absolute BF, decay parameter, CPV；
- Less background than ST；
- Cancel out some systematic uncertainties.

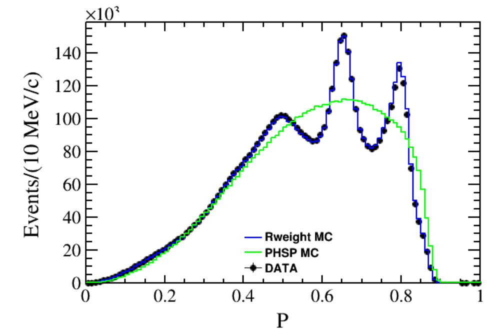
Methods for inclusive decay

- **Data driven** Using control sample from data to determine the efficiency of inclusive decay.

➢Necessity:

- The inclusive decay contains multiple exclusive decays, of which the phase space is complicated.
- There are still undiscovered exclusive decays.
- The efficiency in different phase space may vary greatly.

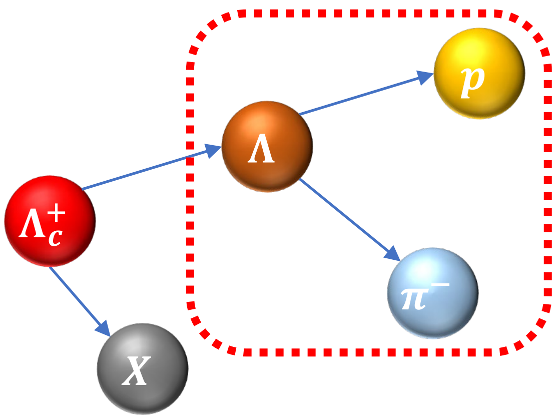
MC can not simulate the real data well.



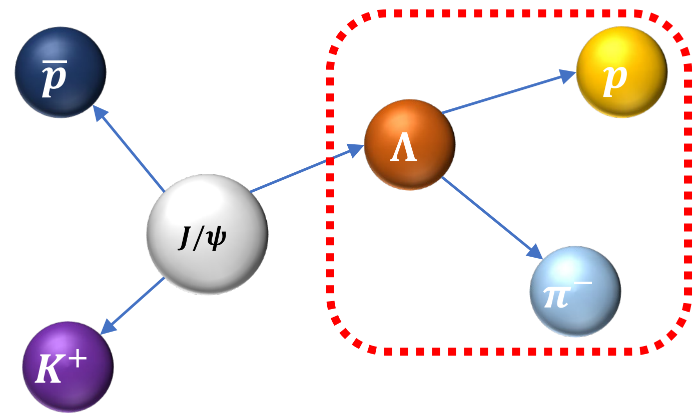
➢Reasonability:

- The detector doesn't matter the history of particles.

Signal sample



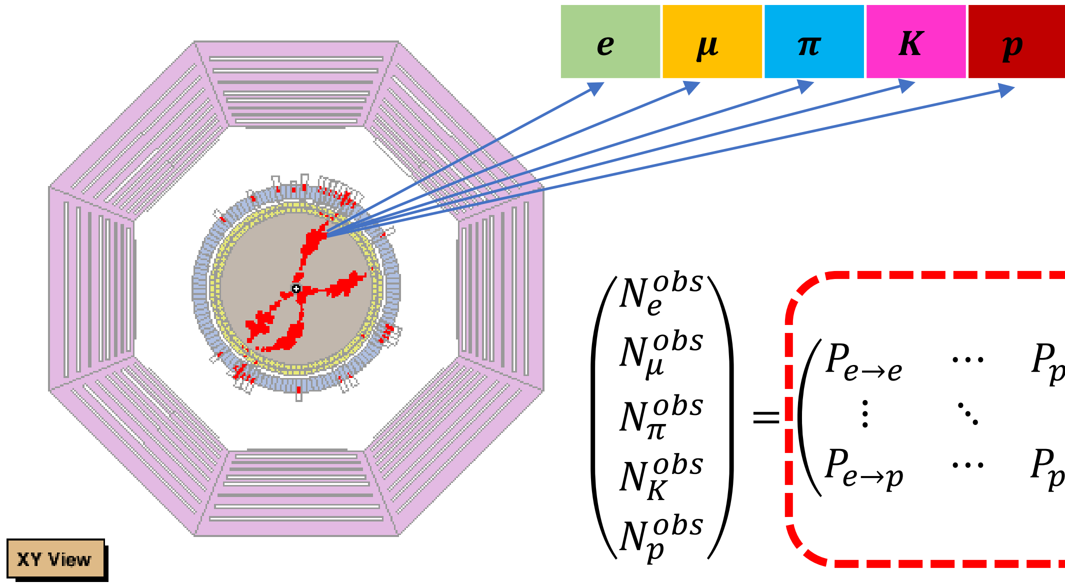
Control sample



Methods for inclusive decay

- **Unfolding**

Apply for single charged particles (e, μ, π, K, p)



$$\begin{pmatrix} N_e^{obs} \\ N_\mu^{obs} \\ N_\pi^{obs} \\ N_K^{obs} \\ N_p^{obs} \end{pmatrix} = \begin{pmatrix} P_{e\to e} & \cdots & P_{p\to e} \\ \vdots & \ddots & \vdots \\ P_{e\to p} & \cdots & P_{p\to p} \end{pmatrix} \cdot \begin{pmatrix} N_e^{true} \\ N_\mu^{true} \\ N_\pi^{true} \\ N_K^{true} \\ N_p^{true} \end{pmatrix}$$

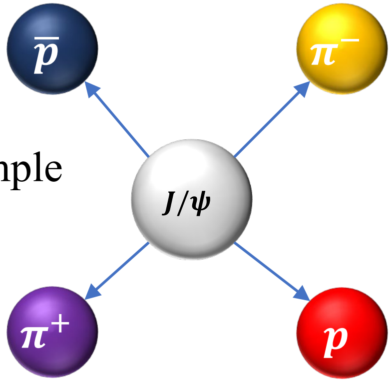
➢ Necessity:

- The stable charged particle can only be confirmed by PID.
- Loss and mistakes in PID.

➢ Difficulties:

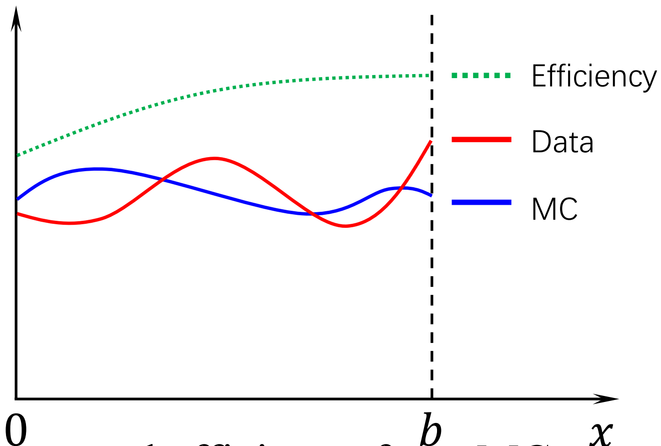
- Study control samples of 5 particles (e, μ, π, K, p) to obtain 5x5 elements of PID matrix;
- Unfolding in each phase space point.

Control sample



Methods for inclusive decay

- **Reweight**



Suppose that a variable x distribute differently in MC and data: $\rho_{MC}(x)$ $\rho_{data}(x)$

Problem:

How much of the difference of yields between using the efficiency from MC N'_{data} and real data N_{data} ?

- Averaged efficiency from MC:

- $\overline{\varepsilon_{MC}} = \frac{n_{MC}}{N_{MC}} = \frac{\int_b N_{MC}(x)\varepsilon_{MC}(x)dx}{\int_b N_{MC}(x)dx} = \int_b \rho_{MC}(x)\varepsilon_{MC}(x)dx\,, \quad \rho_{MC}(x) = \frac{N_{MC}(x)}{\int_b N_{MC}(x)dx}$

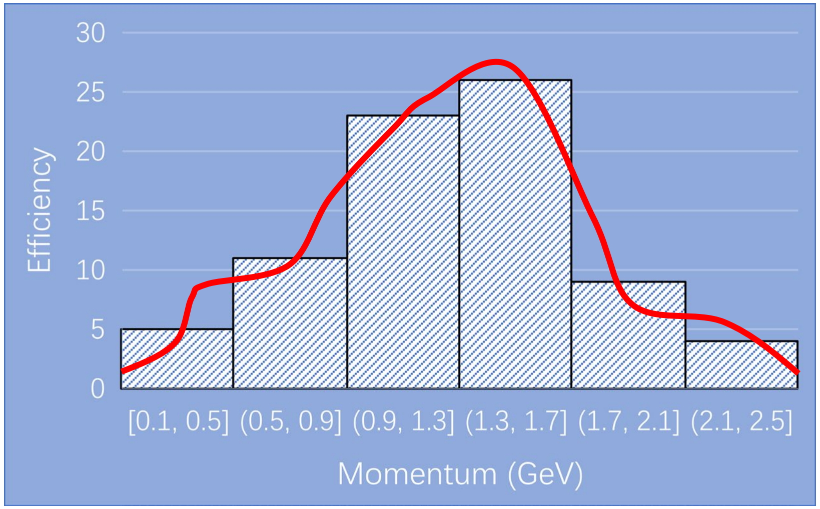
- Using averaged efficiency from MC to obtained the yields:

- $N'_{data} = \frac{n_{data}}{\overline{\varepsilon_{MC}}} = \frac{\int_b N_{data}(x)\varepsilon_{data}(x)dx}{\int_b \rho_{MC}(x)\varepsilon_{MC}(x)dx} = N_{data} \cdot \boxed{\frac{\int_b \rho_{data}(x)\varepsilon_{data}(x)dx}{\int_b \rho_{MC}(x)\varepsilon_{MC}(x)dx}}\,, \quad \rho_{data}(x) = \frac{N_{data}(x)}{\int_b N_{data}(x)dx}$

Methods for inclusive decay

- **Dynamic binning**

The efficiency varies greatly in phase space.



$$\bar{\varepsilon} = \frac{\sum_{b_i} n_{b_i}}{\sum_{b_i} N_{b_i}}, \quad \varepsilon_{b_i} = \frac{n_{b_i}}{N_{b_i}}$$

The averaged efficiency is influenced by the phase space distribution. If the efficiency varies largely, the binning scheme will bring sizable bias.

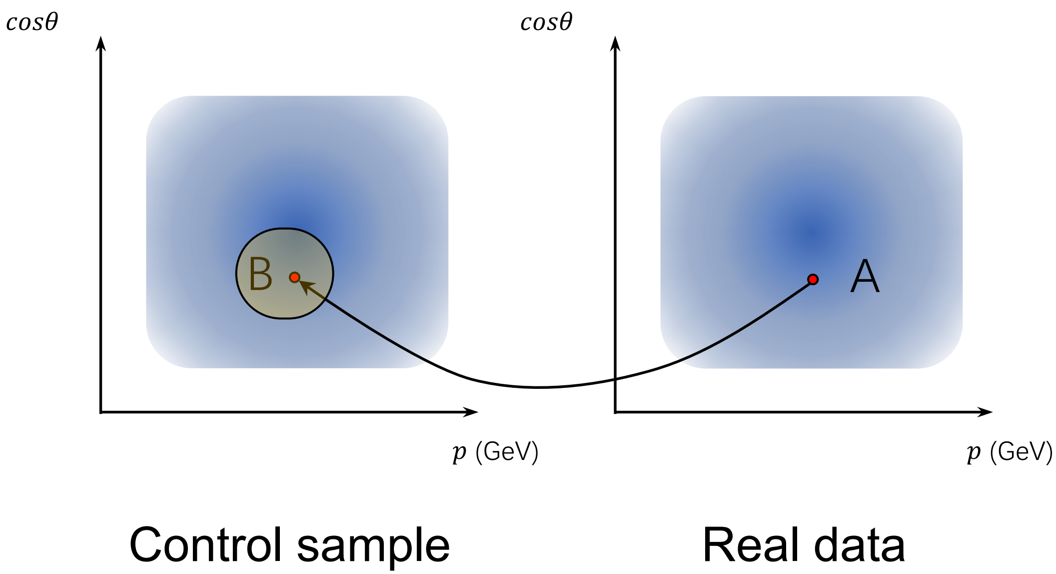
Loose binning => systematic uncertainty
Tight binning => statistical uncertainty.

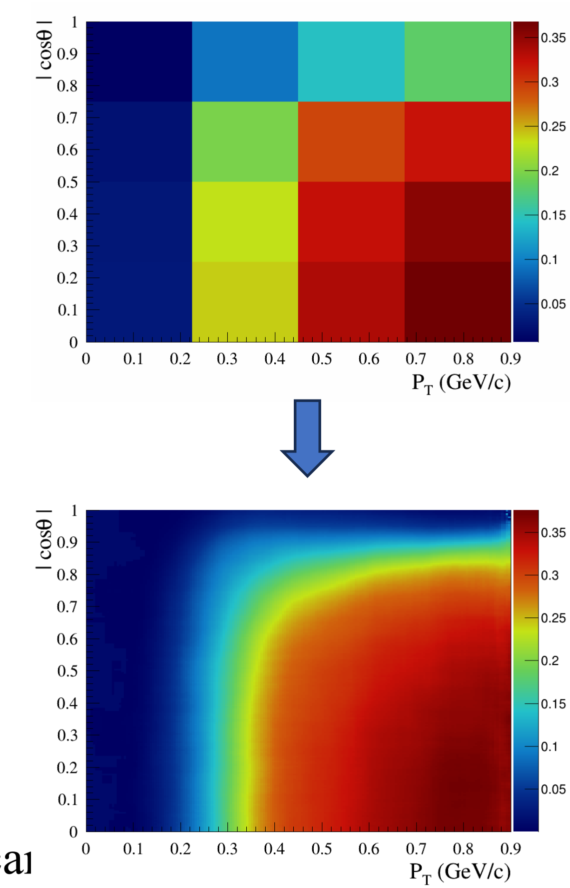
➢ Necessity:
- Efficiency varies with the phase space distribution, MC differs with data;
- The binning scheme will influence the uncertainty.

➢ Difficulties:
- Reduce the sys. & sta. uncertainties simultaneously.

Methods for inclusive decay

- **Dynamic binning**





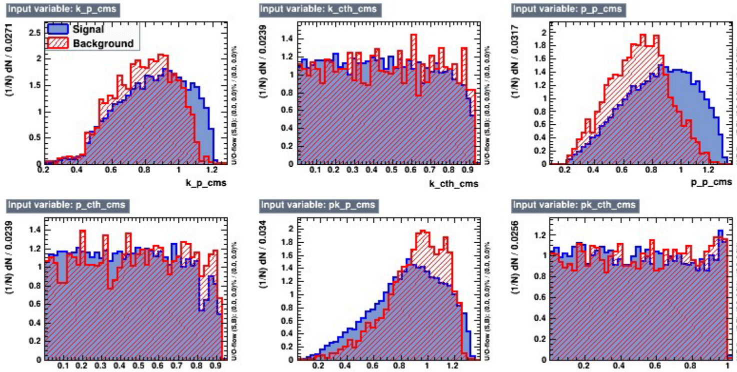
4×4

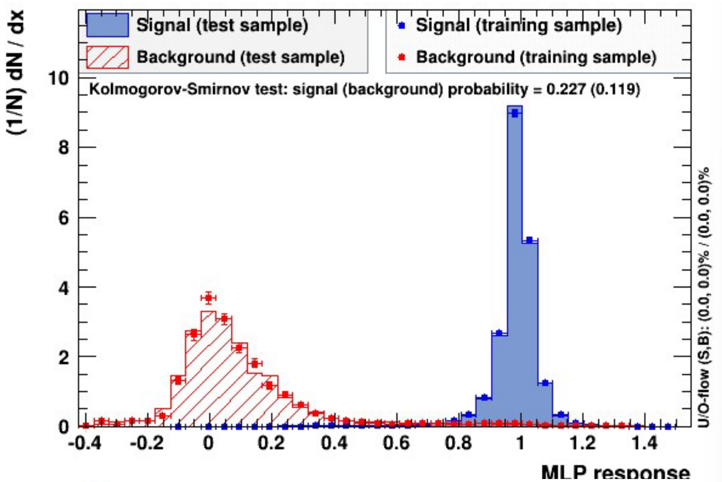
$unbin$

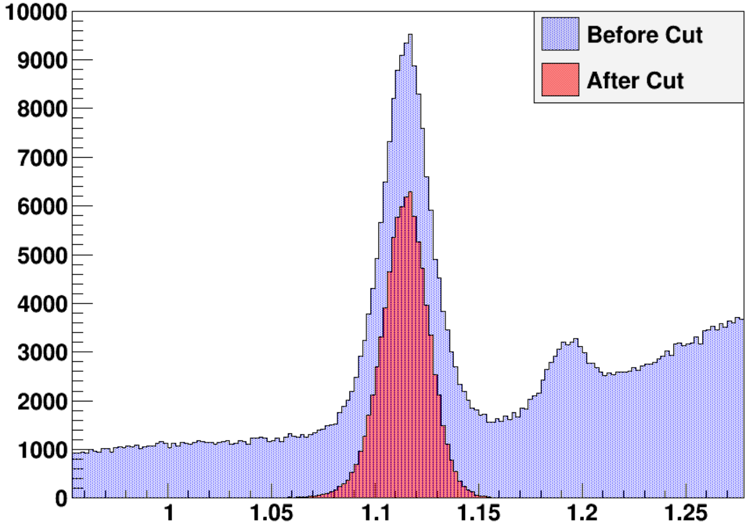
- For a certain point A in the phase space of real data, we ca… oint B in the control sample, then calculate the efficiency using the neighborhood region of B. The systematic and statistic uncertainty can be balanced by varying the size of neighborhood of B.

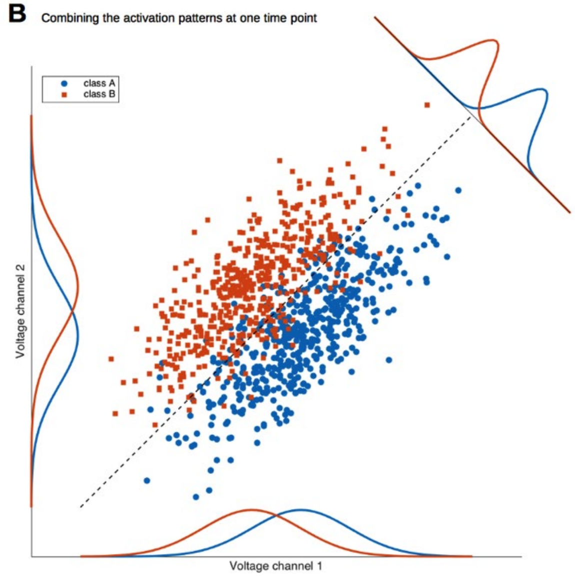
Methods for inclusive decay

- **Multivariate Analysis**





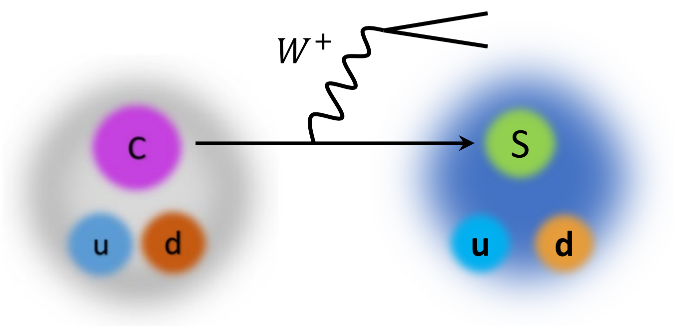




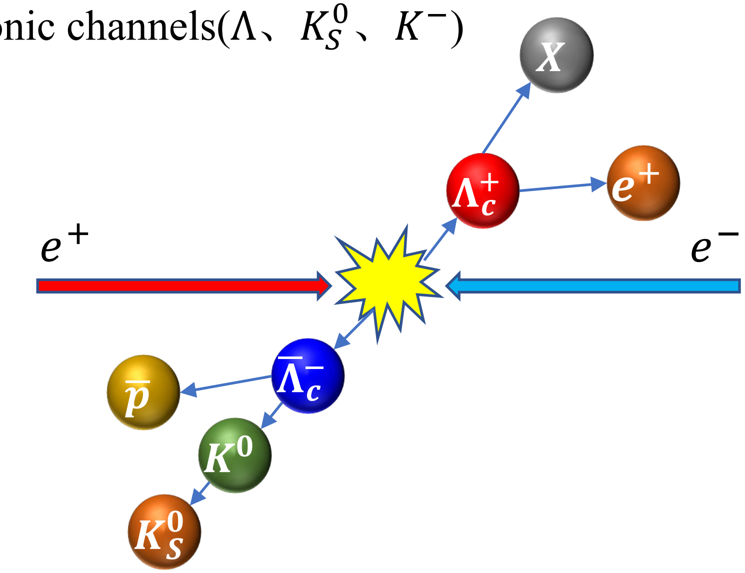
$\Lambda_c^+ \to Xe^+\nu_e$

- $\Lambda_c^+ \to Xe^+\nu_e$: [Phys. Rev. Lett. 121 251801](#) **X.Z. H, et al. BESIII 2018**
  [Phys. Rev. D 107 052005](#) **Lei Li, et al. BESIII 2023**

In HQET, the u、d plays as passive quarks, the decay of Λ_c^+ is dominated by $c \to s$ transition, including are semi-leptonic channels ($e^+\nu_e$ or $\mu^+\nu_e$) and non-leptonic channels(Λ、K_S^0、K^-)



$c \to s(d)W^+$



Example: $\Gamma(\Lambda_c^+ \to Xe^+\nu_e)/\Gamma(D^+ \to Xe^+\nu_e)$, theories provide different predictions, effective-quark predicts it to be 1.67, heavy-quark expansion predicts it to be 1.2. Precise measurement can distinguish different theories.

- **PID Unfolding**:

$$\begin{pmatrix} n_e^{obs} \\ n_\mu^{obs} \\ n_\pi^{obs} \\ n_K^{obs} \\ n_p^{obs} \end{pmatrix} = \begin{pmatrix} \varepsilon_{e\to e} & \varepsilon_{\mu\to e} & \varepsilon_{\pi\to e} & \varepsilon_{K\to e} & \varepsilon_{p\to e} \\ \varepsilon_{e\to\mu} & \varepsilon_{\mu\to\mu} & \varepsilon_{\pi\to\mu} & \varepsilon_{K\to\mu} & \varepsilon_{p\to\mu} \\ \varepsilon_{e\to\pi} & \varepsilon_{\mu\to\pi} & \varepsilon_{\pi\to\pi} & \varepsilon_{K\to\pi} & \varepsilon_{p\to\pi} \\ \varepsilon_{e\to K} & \varepsilon_{\mu\to K} & \varepsilon_{\pi\to K} & \varepsilon_{K\to K} & \varepsilon_{p\to K} \\ \varepsilon_{e\to p} & \varepsilon_{\mu\to p} & \varepsilon_{\pi\to p} & \varepsilon_{K\to p} & \varepsilon_{p\to p} \end{pmatrix} \cdot \begin{pmatrix} N_e^{truth} \\ N_\mu^{truth} \\ N_\pi^{truth} \\ N_K^{truth} \\ N_p^{truth} \end{pmatrix}$$

Basic idea： matrix inversion to estimate the number of each kind of particle.

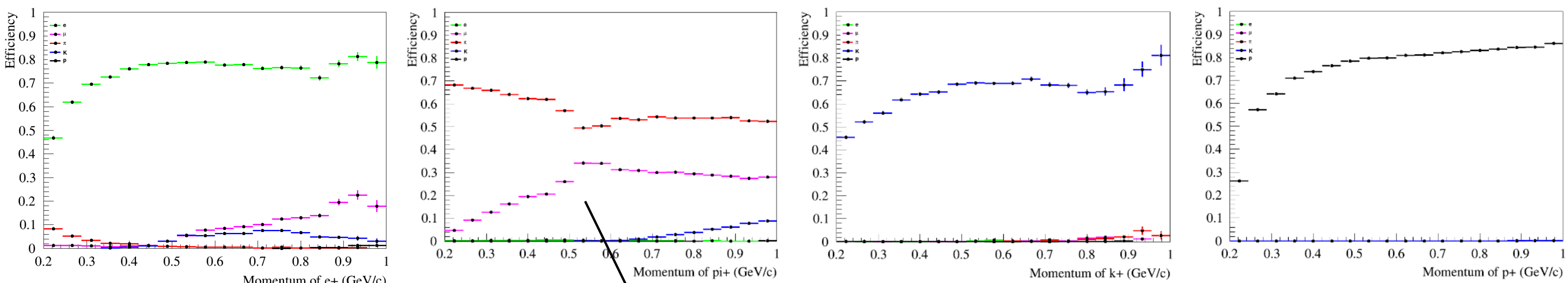
$\Lambda_c^+ \to X e^+ \nu_e$

- **Control sample:**

Pure control sample is essential for PID unfolding:

- $e^\pm$: $e^+e^- \to \gamma e^+ e^-$;
- $\pi^\pm$: $J/\psi \to K^+K^-\pi^+\pi^-(\pi^0)$ and $J/\psi \to p\bar{p}\pi^+\pi^-(\pi^0)$;
- $K^\pm$: $J/\psi \to K^+K^-\pi^+\pi^-(\pi^0)$ and $J/\psi \to K^+K^-K^+K^-(\pi^0)$.
- $p(\bar{p})$: $J/\psi \to p\bar{p}\pi^+\pi^-(\pi^0)$.

Then calculate the efficiency for each track identified as a certain particle.

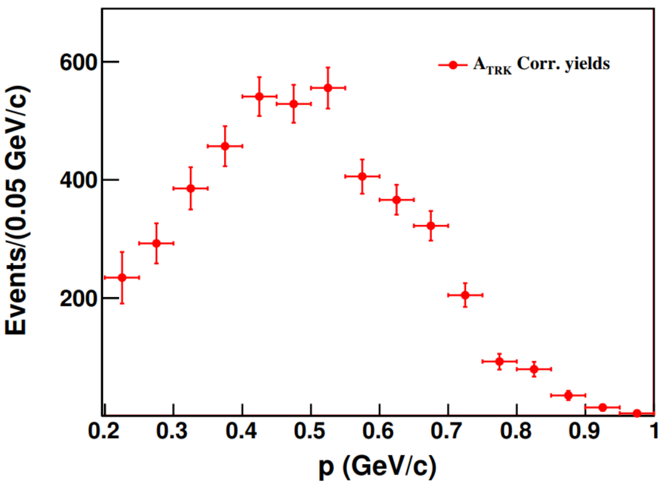


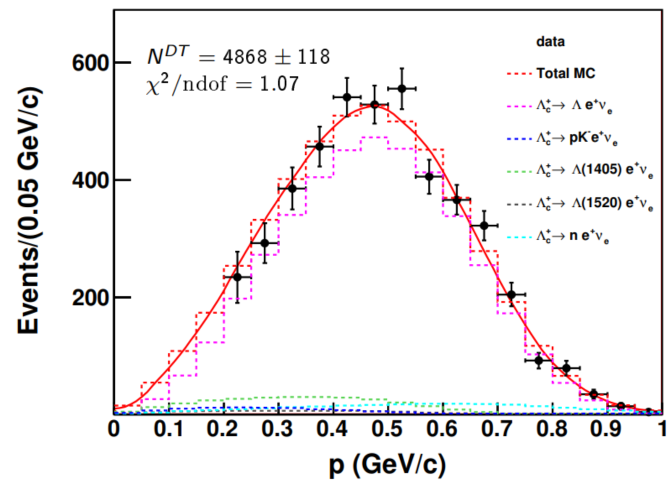
Can be improved by **Deep ParticleID**. (SDU group)
See in Xiaoshuai Qin's talk.

$\Lambda_c^+ \to Xe^+\nu_e$

• Inverse & extension:

By solving the matrix equation, the yield of $\Lambda_c^+ \to Xe^+\nu_e$ can be obtained.





The electron with momentum below 0.2 GeV can not be detected by the spectrometer， the efficiency is extremely low. Extension to the whole region is essential to obtain the total yield.

Latest result from BESIII is $\mathcal{B}(\Lambda_c^+ \to Xe^+\nu_e) = (4.06 \pm 0.10 \pm 0.09)\%$, the ratio with $D^+ \to Xe^+\nu_e$ is 1.28 ± 0.05.

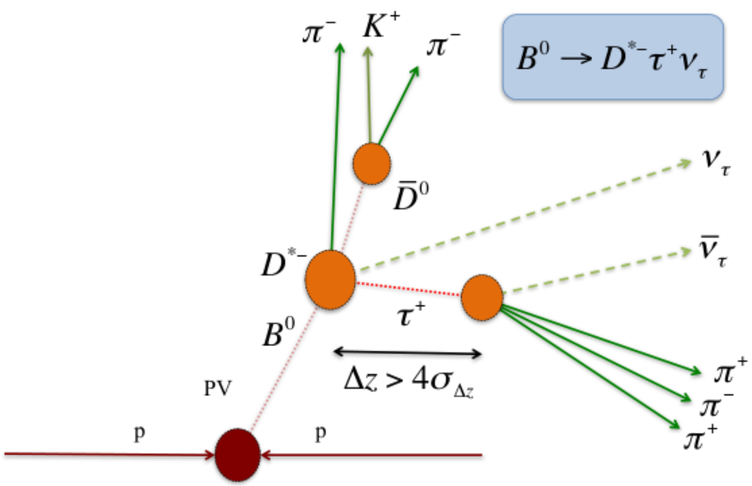
Effective-quark theory: 1.67
Heavy-quark expansion theory: 1.2

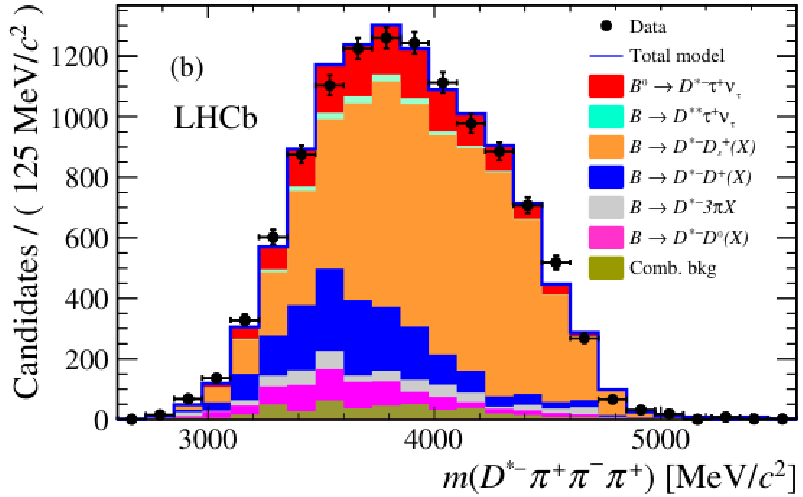
[Phys. Rev. D **107**, 052005]

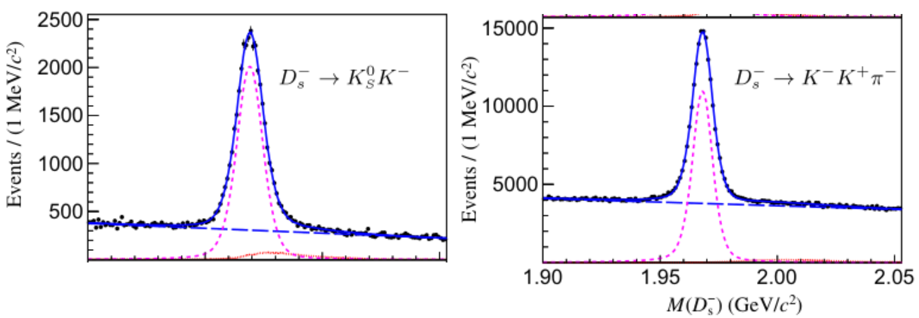
$D_s^+ \to \pi^+\pi^+\pi^- X$

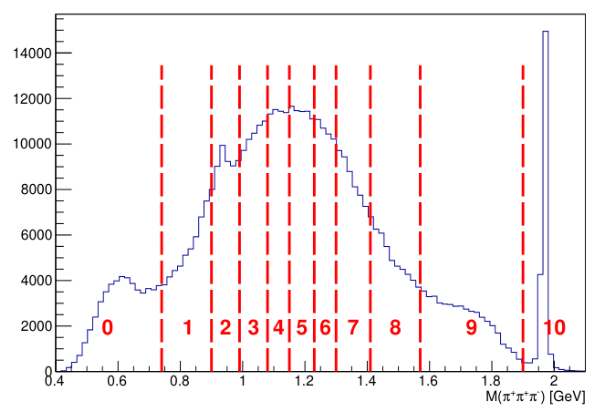
- $D_s^+ \to \pi^+\pi^+\pi^- X$: Phys. Rev. D 108 032001 H.Cai, L.Y. Dong, L. Sun, et al. BESIII 2023

Estimate the leading background in $B^0 \to D^{*-}\tau^+\nu_\tau, \tau^+ \to \pi^+\pi^+\pi^-\nu_\tau$ (test LFU).









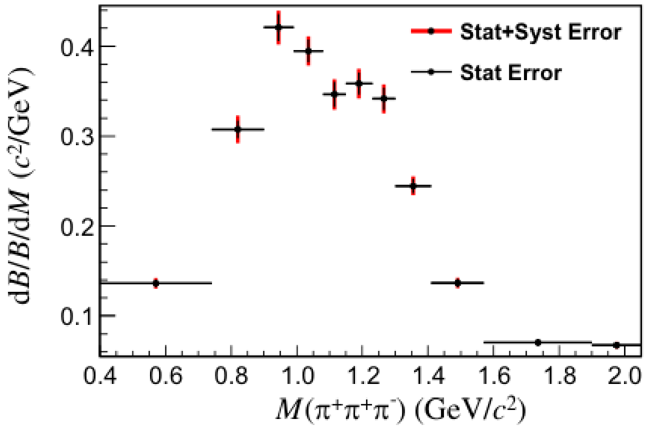
$D_s^+ \to \pi^+\pi^+\pi^- X$

- $D_s^+ \to \pi^+\pi^+\pi^- X$:

$M(\pi^+\pi^+\pi^-)$ interval	1	2	3	4	5	6
Raw yield	2300.8 ± 71.1	2883.4 ± 85.8	2405.7 ± 77.6	2630.0 ± 81.3	1944.3 ± 70.6	2276.2 ± 74.3
K_S^0 contribution	59.1 ± 1.3	148.2 ± 2.1	115.0 ± 1.8	93.6 ± 1.7	47.7 ± 1.2	48.4 ± 1.2
MisID contribution	190.1 ± 2.4	297.3 ± 3.0	214.6 ± 2.5	226.6 ± 2.6	164.3 ± 2.2	171.8 ± 2.2
Total background	249.2 ± 2.7	445.5 ± 3.6	329.6 ± 3.1	320.2 ± 3.1	212.0 ± 2.5	220.2 ± 2.5
Background subtracted yield	2051.6 ± 71.1	2437.9 ± 85.9	2076.1 ± 77.7	2309.8 ± 81.4	1732.2 ± 70.7	2056.0 ± 74.4
$M(\pi^+\pi^+\pi^-)$ interval	7	8	9	10	11	
Raw yield	1924.3 ± 65.2	2182.5 ± 68.8	1926.0 ± 65.5	1993.0 ± 63.7	767.7 ± 34.0	
K_S^0 contribution	31.1 ± 1.0	36.9 ± 1.0	31.1 ± 1.0	10.7 ± 0.6	1.4 ± 0.2	
MisID contribution	127.5 ± 1.9	169.0 ± 2.2	168.3 ± 2.2	126.3 ± 1.9	3.9 ± 0.3	
Total background	158.7 ± 2.2	205.9 ± 2.5	199.4 ± 2.4	137.0 ± 2.0	5.3 ± 0.4	
Background subtracted yield	1765.6 ± 65.2	1976.6 ± 68.8	1726.6 ± 65.5	1856.0 ± 63.7	762.4 ± 34.0	

Results:

$$\mathcal{B}(D_s^+ \to \pi^+\pi^+\pi^- X) = (32.81 \pm 0.35_{\rm stat} \pm 0.63_{\rm syst})\%.$$

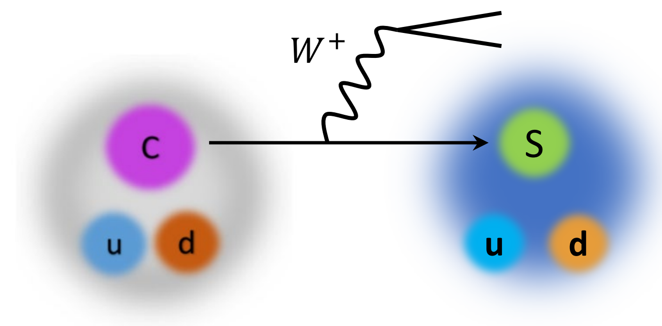


$\Lambda_c^+ \to \Lambda X$

- $\Lambda_c^+ \to \Lambda X$:

Phys. Rev. Lett. 121 062003

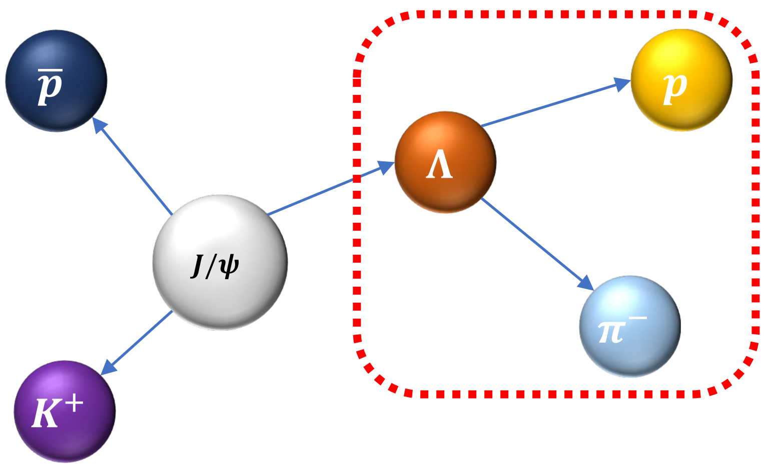
D. Xiao, et al. BESIII 2018

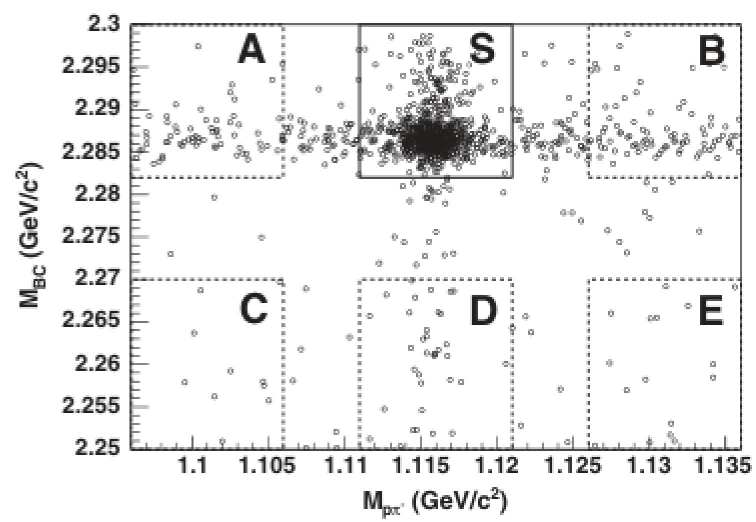


Sum of all exclusive: $(30.1 \pm 1.2)\%$.

Challenge: efficiency of Λ reconstruction.

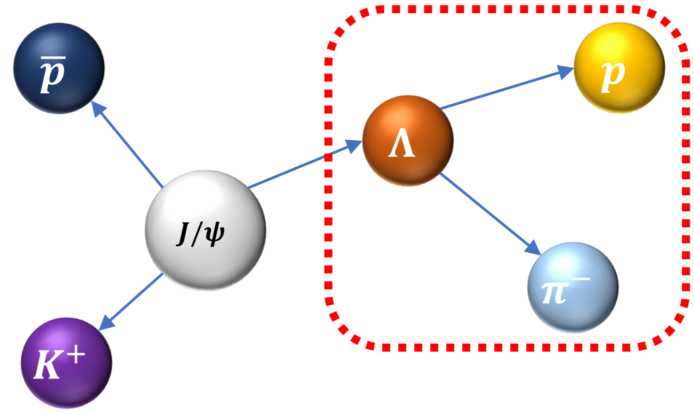
Data Driven:





$\Lambda_c^+ \to \Lambda X$

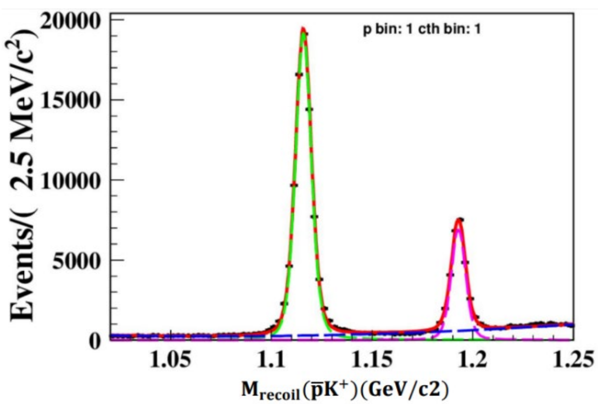
- **Control sample & binning:**

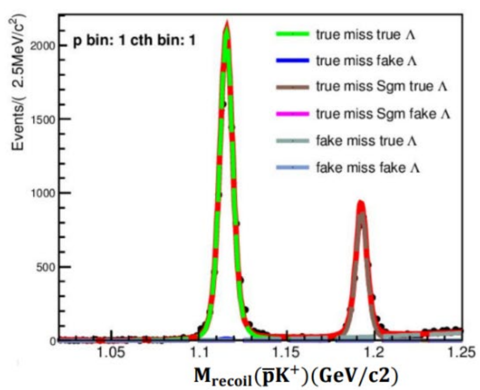


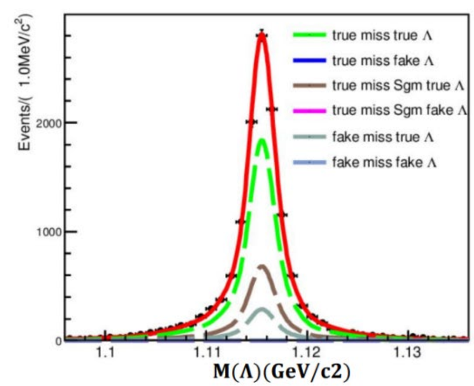
Taking advantage of high statistics of J/ψ (10^{10})

Control channel: $J/\psi \to \bar{p}K^+\Lambda$

Fit the spectrum of recoil mass of $\bar{p}$ and K^+ before find a Λ:







Results:

Then fit the $M_{recoil}(\bar{p}K^+)$ v.s. $M_{p\pi^-}(\Lambda)$ after finding a Λ.

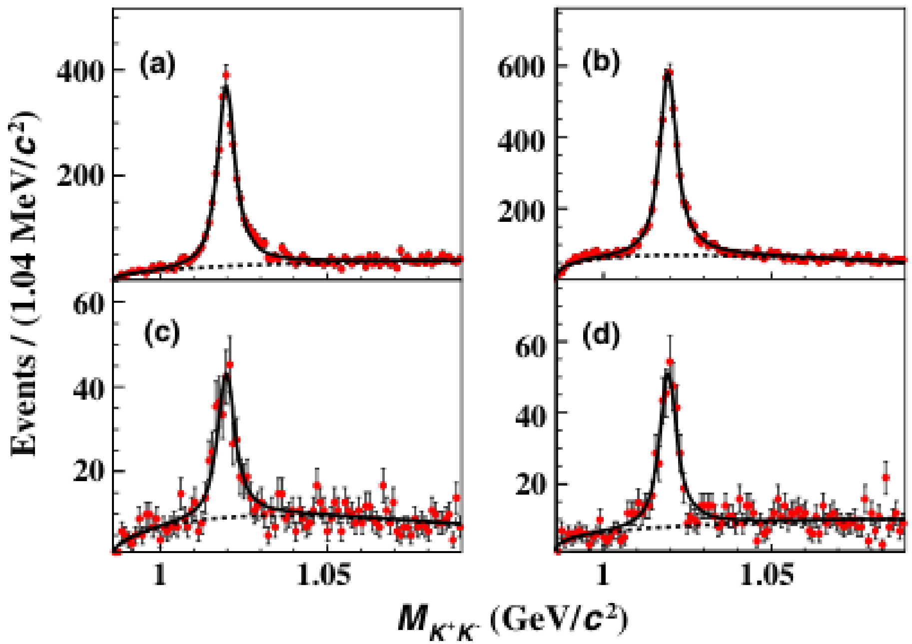
$$\mathcal{B}(\Lambda_c^+ \to \Lambda + X) = (38.2^{+2.8}_{-2.3})\%$$

$D^{0/+} \to \phi X$

- $D^{0/+} \to \phi X$: Phys. Rev. D 100 072006 **S.Q. Qu, J.H. Wei, et al. BESIII 2019**

The efficiency is also obtained from MC. The remaining difference between data and MC is studied with data-driven hadronic events.

- **Fit & sideband subtraction**



Decay mode	$\mathcal{B}$
$D^+ \to \phi\pi^+\pi^0$	$(2.3 \pm 1.0)\%$
$D^+ \to \phi\rho^+$	$< 1.5\%$
$D^+ \to \phi\pi^+$	$(5.70 \pm 0.14) \times 10^{-3}$
$D^+ \to \phi K^+$	$(8.86 \pm 1.14) \times 10^{-6}$
Sum	$(2.87 \pm 1.00)\%$
$D^0 \to \phi\gamma$	$(2.81 \pm 0.19) \times 10^{-5}$
$D^0 \to \phi K_S^0$	$(4.13 \pm 0.31) \times 10^{-3}$
$D^0 \to \phi K_L^0$	$(4.13 \pm 0.31) \times 10^{-3}$
$D^0 \to \phi\omega$	$< 2.1 \times 10^{-3}$
$D^0 \to \phi(\pi^+\pi^-)_{\text{S-wave}}$	$(20 \pm 10) \times 10^{-5}$
$D^0 \to (\phi\rho^0)_{\text{S-wave}}$	$(14.0 \pm 1.2) \times 10^{-4}$
$D^0 \to (\phi\rho^0)_{\text{D-wave}}$	$(8.5 \pm 2.8) \times 10^{-5}$
$D^0 \to (\phi\rho^0)_{\text{P-wave}}$	$(8.1 \pm 3.8) \times 10^{-5}$
$D^0 \to \phi\pi^0$	$(1.17 \pm 0.04) \times 10^{-3}$
$D^0 \to \phi\eta$	$(1.81 \pm 0.46) \times 10^{-4}$
Sum	$(1.14 \pm 0.09)\%$

Results:

	This work	CLEO [2]
$D^+ \to \phi X$	$1.135 \pm 0.034 \pm 0.031$	$1.03 \pm 0.10 \pm 0.07$
$D^0 \to \phi X$	$1.091 \pm 0.027 \pm 0.035$	$1.05 \pm 0.08 \pm 0.07$

$\bar{\Lambda}_c^- \to \bar{n}X$

- $\bar{\Lambda}_c^- \to \bar{n}X$: Phys. Rev. D 108 L031101 L.Q. Zhang, et al. BESIII 2023

Γ_{77}	p anything	$(50 \pm 16)\%$
Γ_{78}	n anything	$(50 \pm 16)\%$

from PDG

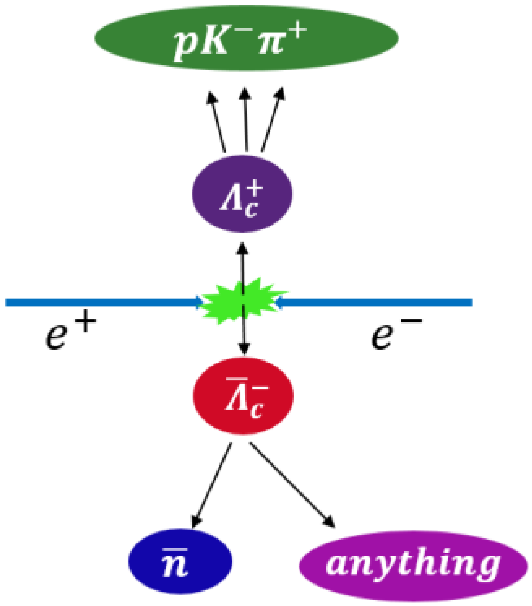
The sum of exclusive decays of $\Lambda_c^+ \to pX$ and $\Lambda_c^+ \to nX$ are 44.5%、25.4%. Precise determination of inclusive decay may help search for undiscovered exclusive decays.

- **Tag mode:**

Only choose the $\Lambda_c^+ \to pK^-\pi^+$ as tag mode.
(Highest statistics, lowest background)

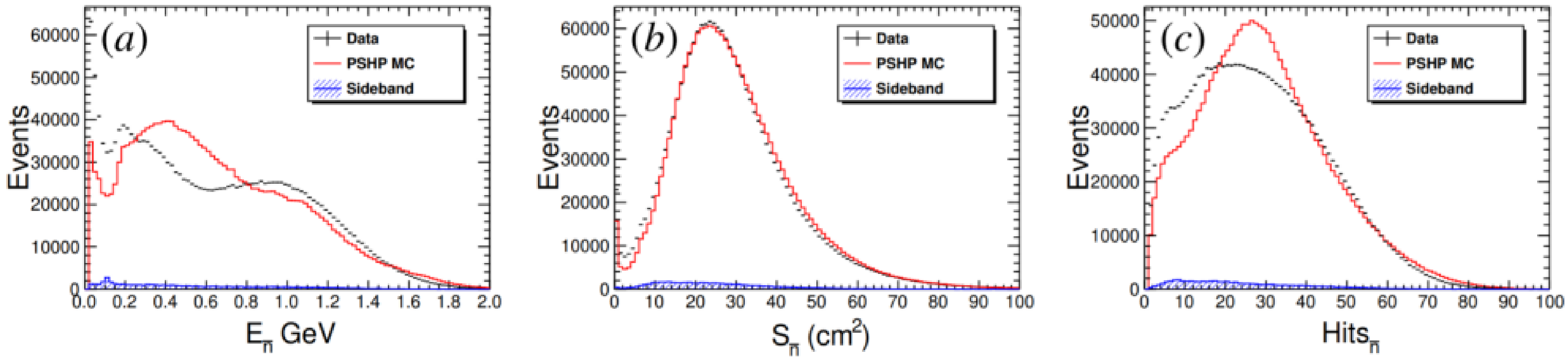
- **Control sample:** choose $J/\psi \to p\bar{n}\pi^-$.

  - $E_{\bar{n}} > 0.48\ GeV$
  - Number of hits $Hits_{\bar{n}} > 20$
  - second moment $S_{\bar{n}} > 18\ cm^2$
  - $N_{\bar{p}} = 0$

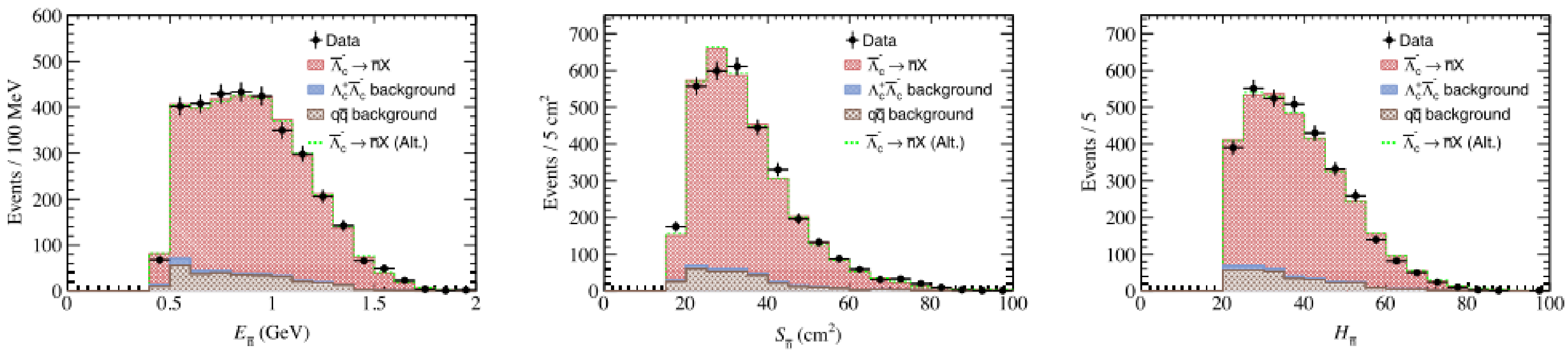


$\bar{\Lambda}_c^- \to \bar{n}X$

- **Reweight:**



Discrepancy between MC and data => Reweight the MC using data-driven.



Results: $\mathcal{B}(\bar{\Lambda}_c^- \to \bar{n} + X) = (32.4 \pm 0.7 \pm 1.5)\%$ **Sum of exclusive:** (25.4 ± 0.8) %

Summary & Prospect

- BESIII has obtained a series of achievement on inclusive decays, mature analytical techniques are developed.
- Inclusive decays of Λ_c^+ are widely studied, published results:
  - $\Lambda_c^+ \to \Lambda X$、 $\Lambda_c^+ \to K_S^0 X$、 $\bar{\Lambda}_c^- \to \bar{n} X$、 $\Lambda_c^+ \to X e^+ \nu_e$、 $D_s^+ \to X e^+ \nu_e$
- Some on-going analyses of inclusive decay at BESIII:
  - $\Lambda_c^+ \to p X$、 $\Lambda_c^+ \to \Sigma^+ X$、 $\Lambda_c^+ \to \Sigma^0 X$、 $D^{0/+} \to X e^+ \nu_e$、 $D^{0/+} \to X \mu^+ \nu_\mu$、 $J/\psi \to \Lambda X$
- Inclusive decays of charmed meson are performed mainly on BES2 and CLEO, waiting for update:
  - $D^{0/+} \to K^\pm X$、 $D^{0/+} \to K_S^0 X$、 $D^{0/+} \to K^{*0/-} X$、 $D^{0/+} \to \eta^{(\prime)} X$、 $D^{0/+} \to \phi X$ …
  - $D_s^+ \to K^\pm X$、 $D_s^+ \to K_S^0 X$、 $D_s^+ \to K^{*0/-} X$、 $D_s^+ \to \eta^{(\prime)} X$、 $D_s^+ \to \phi X$ …
- Inclusive decays of charmonium remain blank, possible analyses:
  - $J/\psi \to p X$、 $J/\psi \to n X$ 、 $J/\psi \to K_S^0 X$、 $J/\psi \to \phi X$ 、 $J/\psi \to \Xi^- X$ …
- Some rare decay channels(BNV…) can be searched via inclusive decay:
  - $J/\psi \to \Lambda_c^+ X$、 $D^{0/+} \to p X$、 $J/\psi \to D_s^+ X$、 $J/\psi \to D^{0/+} X$…

Summary & Prospect

- **Dataset at BESIII: (from BESIII physics page)**

For J/Ψ

Sample type	Ecms (GeV)	Run ID	Event number (Int. luminosity)
On-J/ψ (2009)	3.097	9947-10878	224.0±1.3M (80 pb-1)
On-J/ψ (2012)	3.097	27255-28236	1088.5±4.4M (315 pb-1)
On-J/ψ (2017-2019)	3.097	52940-54976 55861-56546 56788-59015	8774.0±39.4M (2571 pb-1)

For $\Psi(3686)$

Sample type	Ecms (GeV)	Run ID	Event number (Int. luminosity)
On-ψ(3686) (2009)	3.686	8093-9025	107.0±0.8M (161.63±0.13 pb-1)
On-ψ(3686) (2012)	3.686	25338-27090	341.1±2.1M (506.92±0.23 pb-1)

For $\Psi(3770)$

Sample type	Ecms (GeV)	Run ID	Int. luminosity
On-ψ(3770) (2010)	3.773	11414-13988 14395-14604	2931.8±0.2±13.8 pb-1
On-ψ(3770) (2011)	3.773	20448-23454	

For above 4.6 GeV:

Energy points	4.600 GeV	4.612 GeV	4.628 GeV	4.641 GeV	4.661 GeV	4.682 GeV	4.698 GeV
Lumi(pb^{-1})	566.90	103.45	519.93	548.15	527.55	1664.34	534.40

- **BESIII is an ideal platform to study inclusive decay!**

- **Eager for theoretical research!**

Thanks for your attention!