Prospect of Charm Physics at STCF

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On behave of STCF working group

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Outline

- ✍ **STCF** STCF CDR, arXiv: 2303.15790 [hep-ex]

- ✍ $D_s^+ \to \tau^+ \nu_\tau$

  H. J. Li, T. Luo, X. D. Shi and X. R. Zhou, EPJC **82,** 310 (2022).

- ✍ $D_s^+ \to \mu^+ \nu_\mu$

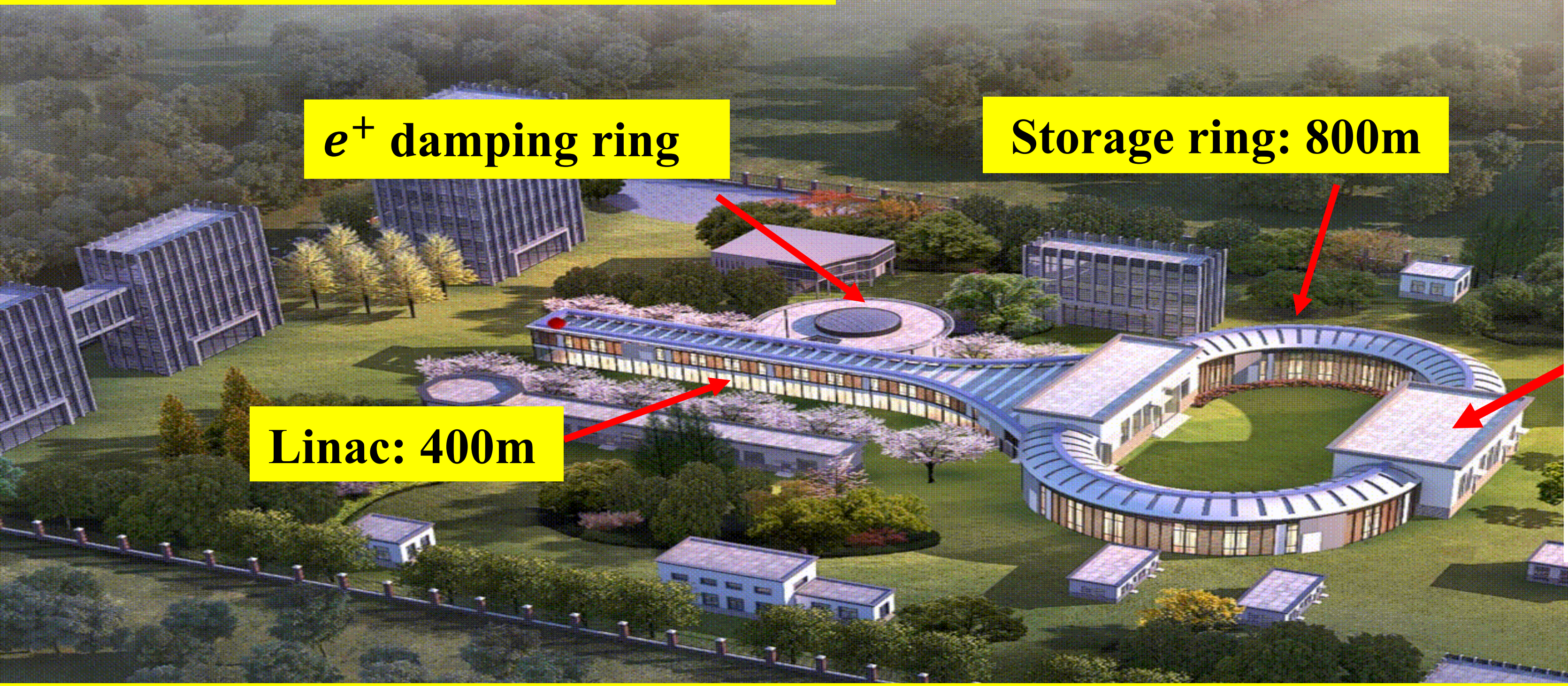
  J. J. Liu, X. D. Shi, H. J. Li, X. R. Zhou, and B. Zheng, EPJC **82,** 337 (2022).

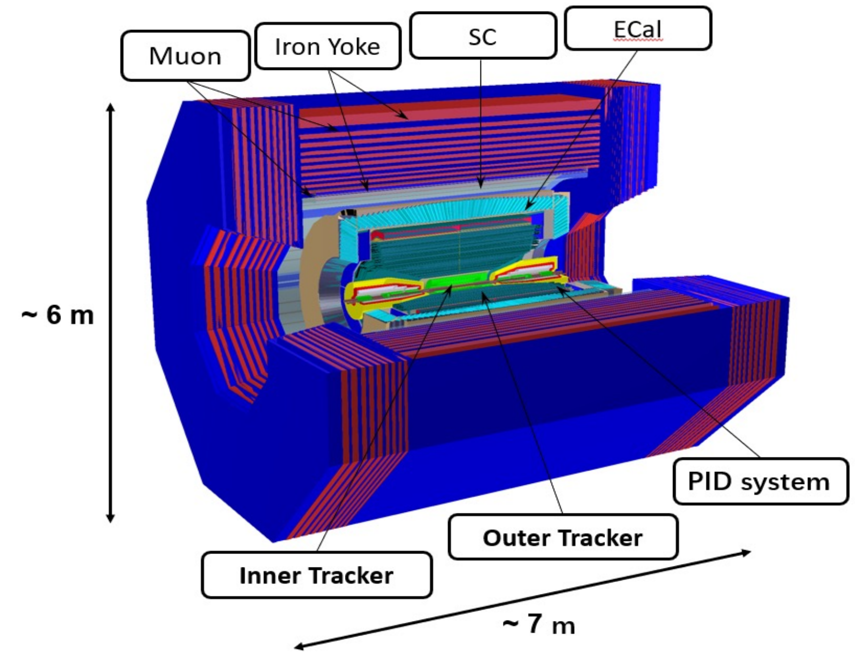
- ✍ $b \to s\,\gamma$ **photon polarization**

  Y. L. Fan, X. D. Shi, X. R. Zhou, and L. Sun, EPJC **81**, 1068 (2021).

Super Tau-Charm Facility (STCF) in China

Energy range: E_{cm} = 2 - 7 GeV





- **Peaking luminosity: > 0.5×10^{35} cm^{-2} s^{-1} @ 4 GeV**
- **Potential to increase luminosity & realize beam polarization**
- **Total cost: 5.5B RMB**

STCF Detector

STCF CDR, arXiv: 2303.15790 [hep-ex]

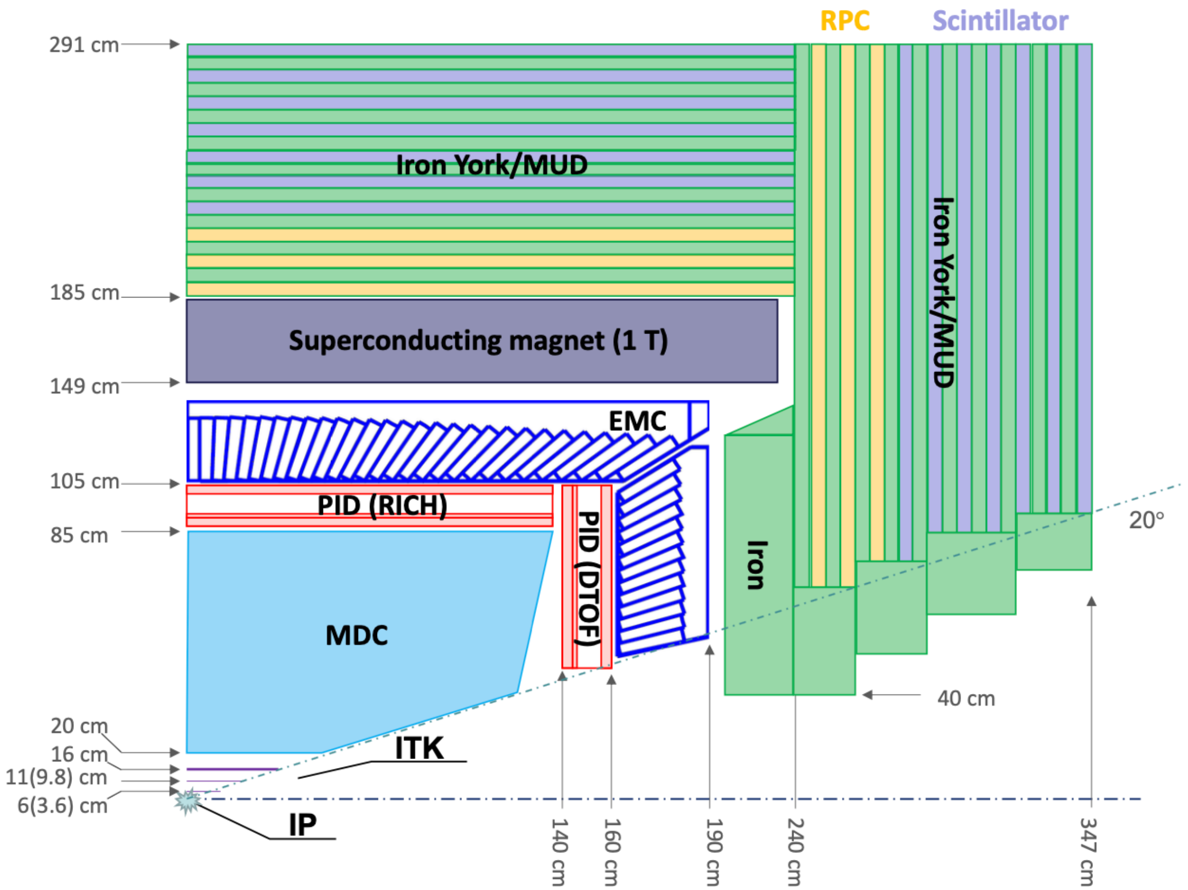
ITK:
$< 0.25\% X_0$ / layer ,
$\sigma_{\gamma\phi} < 100\ \mu m$

MDC:
$\sigma_{\gamma\phi} < 130\ \mu m$ @ 1 GeV
$\sigma_p/p < 0.5\%$ @ 1 GeV,
$\sigma (dE/dx) < 6\%$

PID :
π/K (and K/p) 3-4σ separation up to 2GeV/c

EMC:
E range: 0.025 - 3.5 GeV
$\sigma_E = 2.5\%$ @ 1 GeV
Pos. Res. : ~ 5 mm @ 1 GeV

MUD:
0.4 - 1.8 GeV
μ/π suppression power >30



Requirement:

- High detection efficiency and good spatial resolution
- Superior PID capability
- Tolerance to high rate/background environment

Expected Data Samples at STCF

Data sample produced per year

CME (GeV)	Lumi (ab^{-1})	Samples	σ(nb)	No. of Events	Remarks
3.097	1	J/ψ	3400	3.4×10^{12}	
3.670	1	$\tau^+\tau^-$	2.4	2.4×10^{9}	
3.686	1	$\psi(3686)$ $\tau^+\tau^-$ $\psi(3686)\to\tau^+\tau^-$	640 2.5	6.4×10^{11} 2.5×10^{9} 2.0×10^{9}	
3.770	1	$D^0\bar{D}^0$ $D^+\bar{D}^-$ $D^0\bar{D}^0$ $D^+\bar{D}^-$ $\tau^+\tau^-$	3.6 2.8 2.9	3.6×10^{9} 2.8×10^{9} 7.9×10^{8} 5.5×10^{8} 2.9×10^{9}	Single tag Single tag
4.009	1	$D^{*0}\bar{D}^0+c.c$ $D^{*0}\bar{D}^0+c.c$ $D_s^+D_s^-$ $\tau^+\tau^-$	4.0 4.0 0.20 3.5	1.4×10^{9} 2.6×10^{9} 2.0×10^{8} 3.5×10^{9}	$CP_{D^0\bar{D}^0}=+$ $CP_{D^0\bar{D}^0}=-$
4.180	1	$D_s^{+*}D_s^-$+c.c. $D_s^{+*}D_s^-$+c.c. $\tau^+\tau^-$	0.90 3.6	9.0×10^{8} 1.3×10^{8} 3.6×10^{9}	Single tag
4.230	1	$J/\psi\pi^+\pi^-$ $\tau^+\tau^-$ $\gamma X(3872)$	0.085 3.6	8.5×10^{7} 3.6×10^{9}	
4.360	1	$\psi(3686)\pi^+\pi^-$ $\tau^+\tau^-$	0.058 3.5	5.8×10^{7} 3.5×10^{9}	
4.420	1	$\psi(3686)\pi^+\pi^-$ $\tau^+\tau^-$	0.040 3.5	4.0×10^{7} 3.5×10^{9}	
4.630	1	$\psi(3686)\pi^+\pi^-$ $\Lambda_c\bar{\Lambda}_c$ $\Lambda_c\bar{\Lambda}_c$ $\tau^+\tau^-$	0.033 0.56 3.4	3.3×10^{7} 5.6×10^{8} 6.4×10^{7} 3.4×10^{9}	Single tag
4.0–7.0	3	300-point scan with 10 MeV steps, 1 fb^{-1}/point			
> 5	2–7	Several ab^{-1} of high-energy data, details dependent on scan results			

XYZ Factory

XYZ	$Y(4260)$	$Z_c(3900)$	$Z_c(4020)$	$X(3872)$
No. of events	10^{10}	10^9	10^9	5×10^6

Light meson Factory

Decay mode	$\mathcal{B}$ ($\times10^{-4}$) [177]	η/η' events
$J/\psi\to\gamma\eta'$	52.1 ± 1.7	1.8×10^{10}
$J/\psi\to\gamma\eta$	11.08 ± 0.27	3.7×10^{9}
$J/\psi\to\phi\eta'$	7.4 ± 0.8	2.5×10^{9}
$J/\psi\to\phi\eta$	4.6 ± 0.5	1.6×10^{9}

Hyperon Factory

Decay mode	$\mathcal{B}$ (units of 10^{-4})	Angular distribution parameter α_ψ	Detection efficiency	No. of events expected at the STCF
$J/\psi\to\Lambda\bar{\Lambda}$	$19.43\pm0.03\pm0.33$	0.469 ± 0.026	40%	1100×10^6
$\psi(2S)\to\Lambda\bar{\Lambda}$	$3.97\pm0.02\pm0.12$	0.824 ± 0.074	40%	130×10^6
$J/\psi\to\Xi^0\bar{\Xi}^0$	11.65 ± 0.04	0.66 ± 0.03	14%	230×10^6
$\psi(2S)\to\Xi^0\bar{\Xi}^0$	2.73 ± 0.03	0.65 ± 0.09	14%	32×10^6
$J/\psi\to\Xi^-\bar{\Xi}^+$	10.40 ± 0.06	0.58 ± 0.04	19%	270×10^6
$\psi(2S)\to\Xi^-\bar{\Xi}^+$	2.78 ± 0.05	0.91 ± 0.13	19%	42×10^6

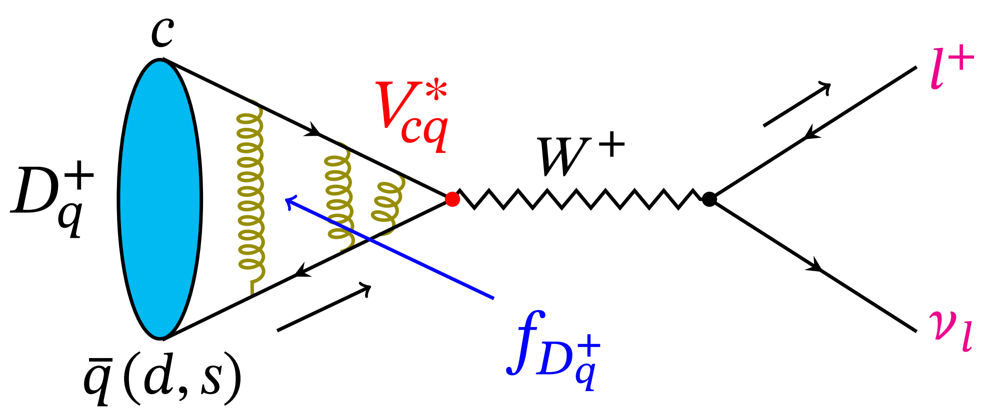
Pure leptonic $D_{(s)}^+$ decays

Comparison of D_s^+ events

Colla.	Type	$\sqrt{s}$	Luminosity	No. of D_s^+ events	Efficiency
CLEO	e^+e^-	4.17 GeV	0.6 fb^{-1}	0.6×10^6	$\sim10-30\,\%$ ★★★
BESIII		4.18 – 4.23 GeV	6(9) fb^{-1}	$6(9)\times10^6$	
STCF		4.009 GeV	1 ab^{-1}	2×10^8 ★	
Belle(II)	e^+e^-	10.58 GeV	1 (50) ab^{-1}	$1.3(65)\times10^9$ ★★	★★ $\sim5-10\,\%$
BaBar		10.58 GeV	0.5 ab^{-1}	6.5×10^8	
CDF	$p\bar{p}$	1.96 TeV	9.6 fb^{-1}	$1.3.\times10^{11}$	$<0.5\,\%$ ★
LHCb	pp	7 TeV+8 TeV	$1.0+2.0$ fb^{-1}	5.0×10^{12} ★★★	

- BelleII (50/ab) has more statistics;
- LHCb has much more statistics, but huge background;
- STCF is expected to have higher detection efficiency and low bkgs for productions at threshold;
- Additionally, STCF has excellent resolution, kinematic constraining.

Pure leptonic $D^+_{(s)}$ decays



- **Axial current (nonperturbative)**

$$< 0|\bar{s}\,\gamma_\mu\,\gamma_5\,c\,|D^+_s> = i\,p_\mu\,f_{D^+_{(s)}}$$

($f_{D^+_{(s)}}$: $D^+_{(s)}$ decay constant)

- **$V_{cd(s)}$: CKM matrix element, fundamental SM parameter, measured from experiments.**

- **In the SM, ignoring radiative corrections, the decay width:**

$$\Gamma = \frac{G_F^2}{8\pi} f^2_{D^+_{(s)}} \left|V_{cd(s)}\right|^2 m^2_\ell\, m_{D^+_{(s)}} \left(1 - \frac{m^2_\ell}{m^2_{D^+_{(s)}}}\right)^2 \quad (\ell = e, \mu, \tau)$$

- **Branching fraction:** $Br(D_{(s)}^{+} \to \ell^{+}\nu_{\ell}) = \Gamma \cdot \tau_{D_{(s)}^{+}}$ **($\tau_{D_{(s)}^{+}}$: lifetime)**

$$Br(D_{(s)}^{+} \to \ell^{+}\nu_{\ell}) \propto \left[f_{D_{(s)}^{+}} \cdot |V_{cd(s)}| \right]^2$$

- **Input $f_{D_{(s)}^{+}}$ from LQCD calculations, extract $|V_{cd(s)}|$**
- **Input $|V_{cd(s)}|$ from SM global fit, extract $f_{D_{(s)}^{+}}$**

□ **The decay constants $f_{D_{(s)}^{+}}$: help to calibrate the LQCD calculations;**

□ **The CKM matrix elements $|V_{cd(s)}|$: help to test the unitarity of CKM.**

□ Lepton flavor universality (LFU):

$$R = \frac{\Gamma\left(D_{(s)}^{+} \to \tau^{+}\nu_{\tau}\right)}{\Gamma\left(D_{(s)}^{+} \to \mu^{+}\nu_{\mu}\right)} = \frac{m_{\tau^{+}}^{2}\left(1-\frac{m_{\tau^{+}}^{2}}{m_{D_{(s)}^{+}}^{2}}\right)^{2}}{m_{\mu^{+}}^{2}\left(1-\frac{m_{\mu^{+}}^{2}}{m_{D_{(s)}^{+}}^{2}}\right)^{2}}$$

Expectations in the SM:

$$R\left(D^{+} \to \tau^{+}\nu_{\tau}:\ \mu^{+}\nu_{\mu}:\ e^{+}\nu_{e}\right) = 2.67:\ 1:\ 2.35\times10^{-5}$$

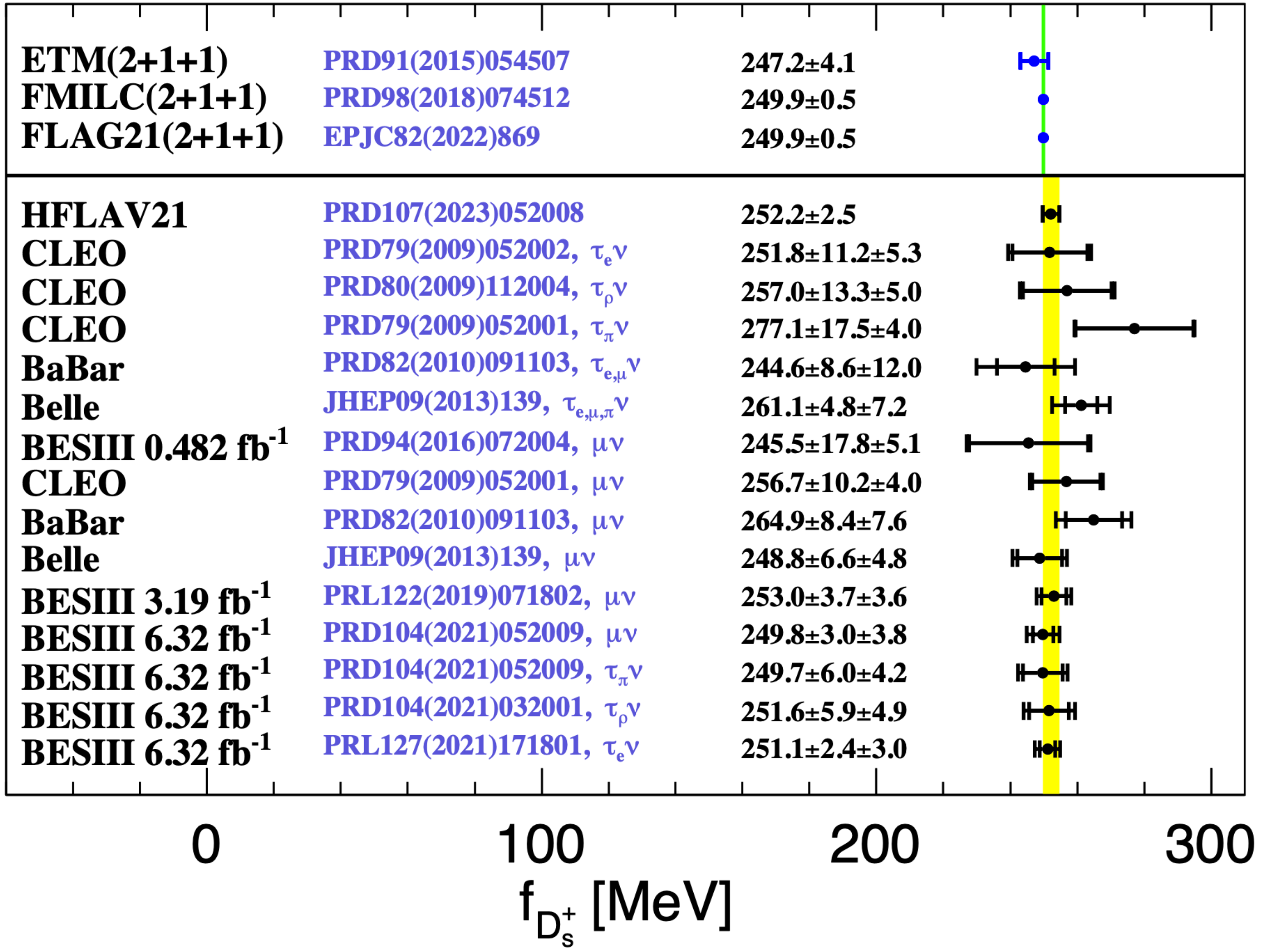
$$R\left(D_{s}^{+} \to \tau^{+}\nu_{\tau}:\ \mu^{+}\nu_{\mu}:\ e^{+}\nu_{e}\right) = 9.75:\ 1:\ 2.35\times10^{-5}$$

Any deviation from experimental measurements potentially indicates the existence of New Physics beyond SM.

SM predicted: $B(D_{(s)}^{+} \to e^{+}\nu_{e}) < 10^{-8}$**, not yet experimentally observed so far.**

Comparison of $f_{D_s^+}$

Taking $|V_{cs}| = 0.97320 \pm 0.00011$ [1] from SM global fit:



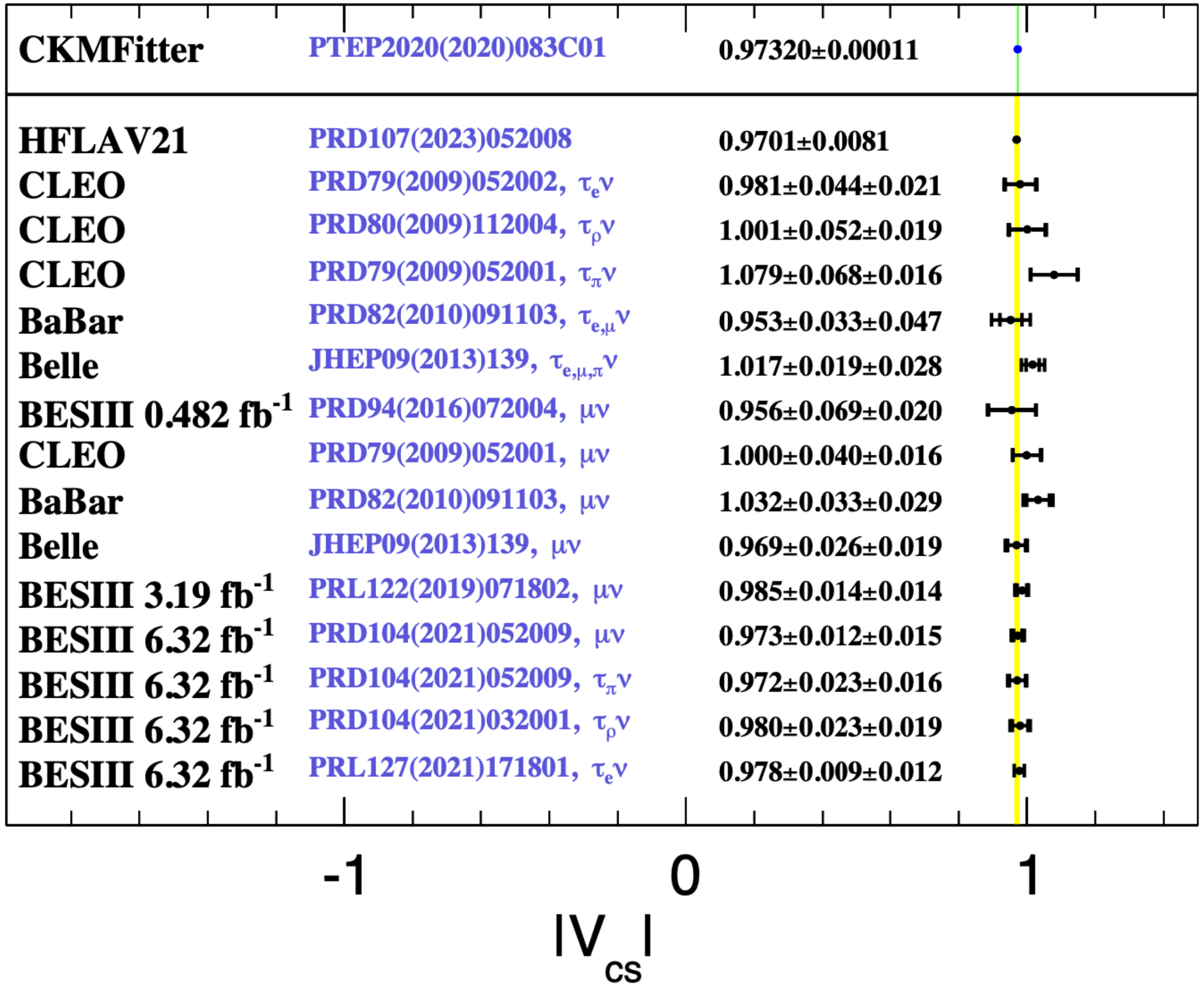
Theorical precision: 0.2%.

Experimental precision: 1.0%.

[1] P. A. Zyla *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. 2020, 083C01 (2020) and 2021 update.

Comparison of $|V_{cs}|$

Taking $f_{D_s^+} = 249.9 \pm 0.5$ [1] from LQCD calculations:

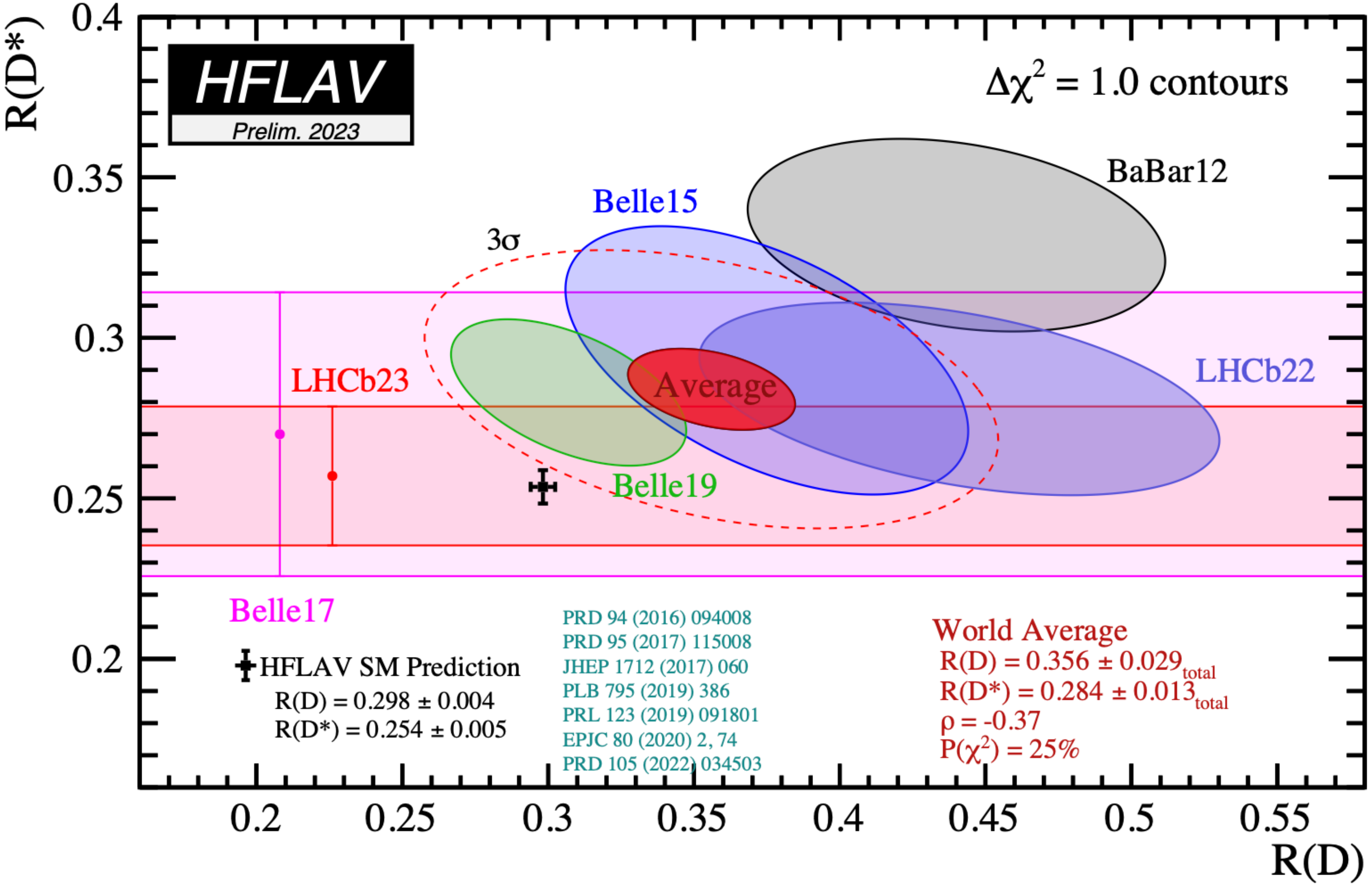


Experimental precision: 0.8%.

[1] Y. Aoki *et al.* (Flavour Lattice Averaging Group), Eur. Phys. J. C 82,10 (2022).

LFU in B decays

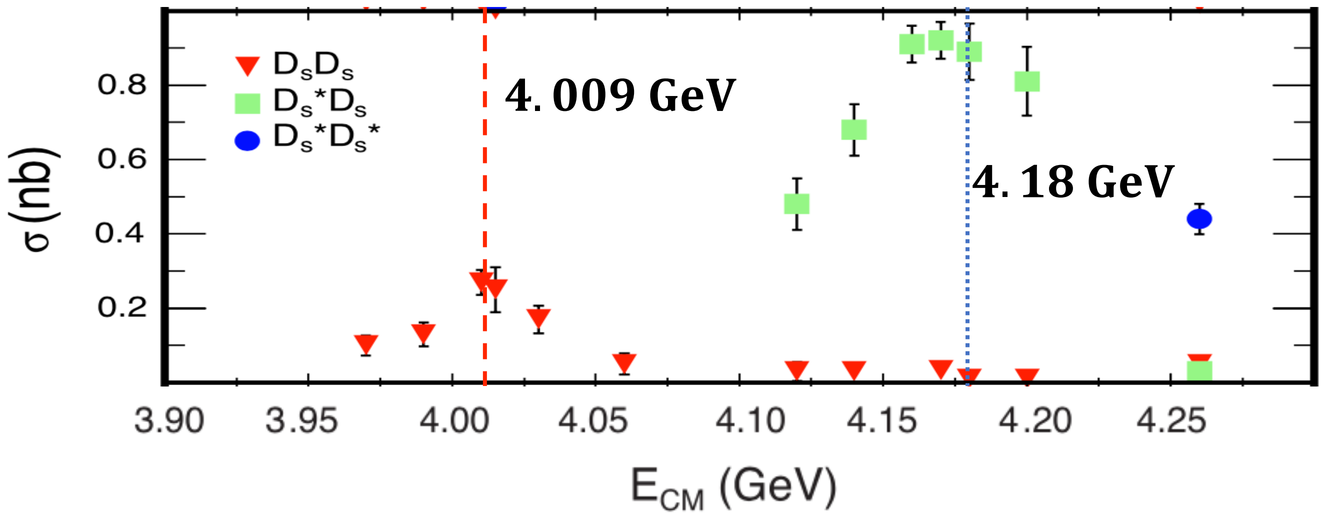
$$R\left(D^{(*)}\right) = Br\left(B \to D^{(*)}\tau\,\nu_\tau\right)/\mathrm{BF}\left(B \to D^{(*)}\ell\nu_\ell\right)$$



Generic MC (Pseudo-data) samples at STCF

$\sqrt{s}$ (GeV)	Luminosity (ab^{-1})	Decay of interest
4.009	0.1	$e^+e^- \to D_s^{\pm} D_s^{\mp}$

The data samples at $\sqrt{s} = 4.009$ GeV with larger statistics can avoid the systematic uncertainty caused by γ/π^0 reconstruction directly from D_s^* decays at $\sqrt{s} = 4.18$ GeV.



$$\frac{\sigma(e^+e^- \to D_s D_s)_{4.009\ \mathrm{GeV}}}{\sigma(e^+e^- \to D_s^* D_s)_{4.18\ \mathrm{GeV}}} \sim 0.3$$

CLEO Collaboration, Phys. Rev. D 80, 072001(2009)

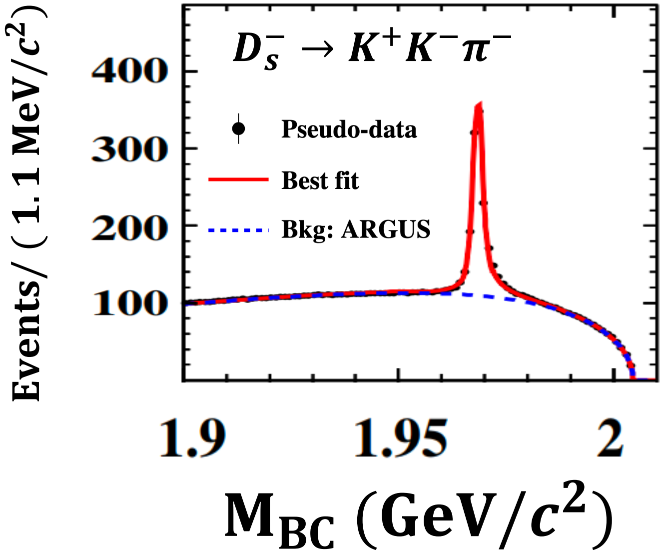
Analysis method for D_s^+ decays at STCF

Single tag (ST):

Fully reconstruct one D_s^-.

$$\Delta E = E_{D_s^-} - E_{\text{beam}}$$

$$M_{\text{BC}} = \sqrt{E_{\text{beam}}^2 - |\vec{p}_{D_s^-}|^2}$$



Double tag (DT):

In the recoil side against D_s^-:

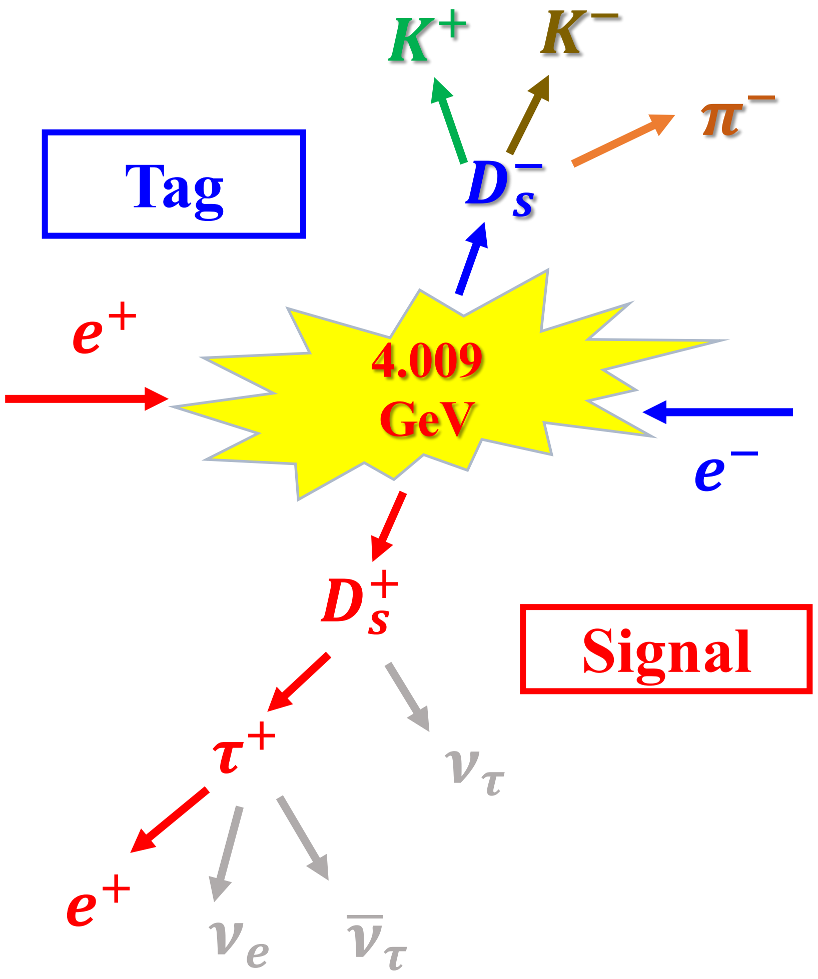
- $D_s^+ \to \tau^+\nu_\tau$ via $\tau^+ \to e^+\nu_e\bar{\nu}_\tau$:

  $E_{\text{extra}}^{\text{tot}}$: the total deposited energy for all of the extra good showers in the EMC.

- $D_s^+ \to \mu^+\nu_\mu$

  Missing mass squared:

$$\text{MM}^2 = \sqrt{(E_{\text{beam}} - E_{\mu^+})^2 - |-\vec{p}_{D_s^-} - \vec{p}_{\mu^+}|^2}$$



The charge conjugated channels are also implied.

$D_s^+ \to \tau^+\nu_\tau$ via $\tau^+ \to e^+\nu_e\bar{\nu}_\tau$

Double tag (DT)

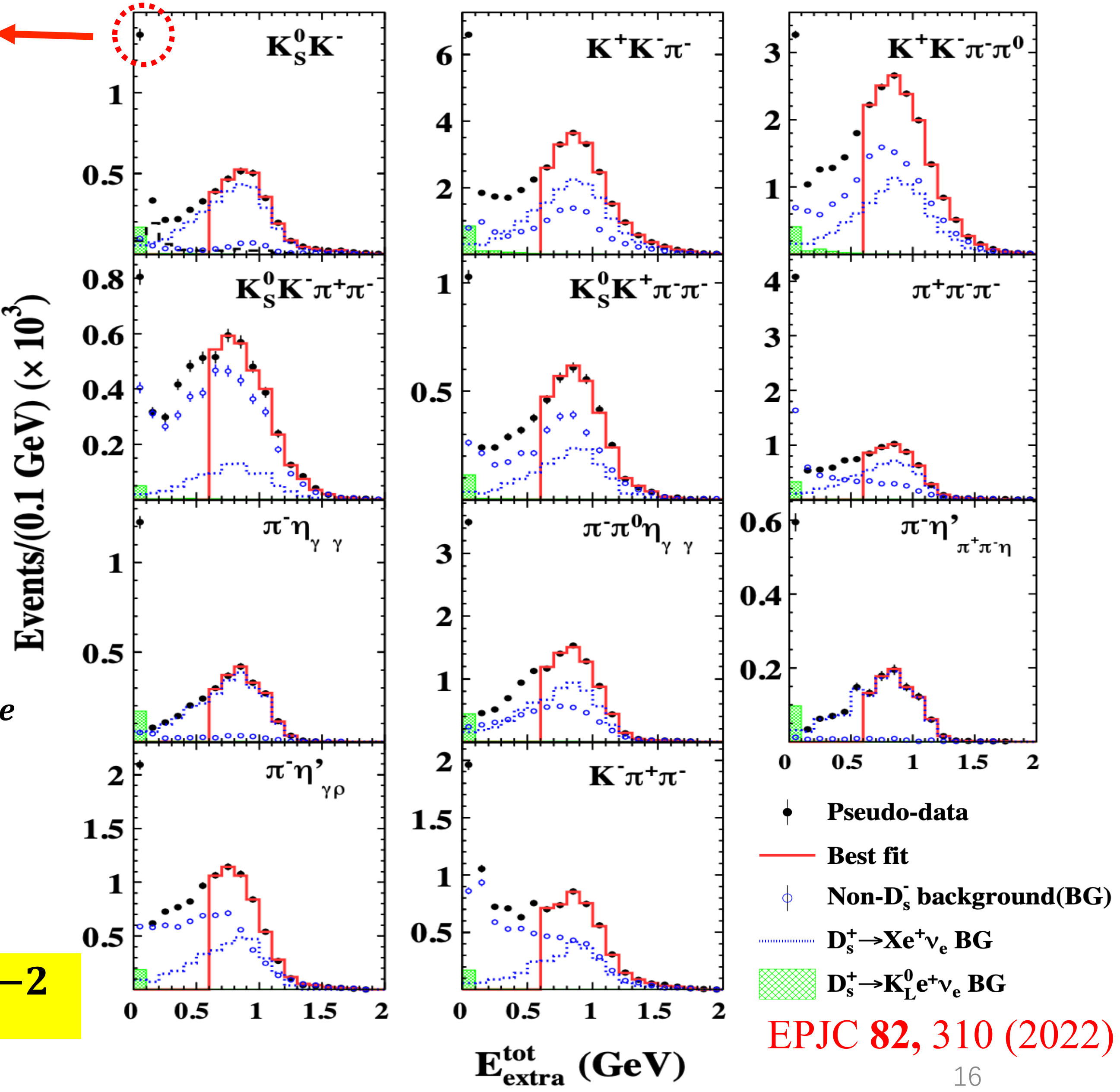
Signal peak

- Only one e^+.
- $E_{\rm extra}^{\rm tot}$: the total energy of the extra good EMC showers.
- DT yield ($N_{\rm DT}$) in the signal $E_{\rm extra}^{\rm tot} < 0.4$ GeV :

$$N_{\rm DT} = N_{\rm DT}^{\rm tot} - N_{\rm DT}^{{\rm non-}D_s^-} - N_{\rm DT}^{K_L^0 e^+\nu_e} - N_{\rm DT}^{Xe^+\nu_e}$$

$$N_{\rm DT} = 18,771 \pm 249_{\rm stat.}$$

$$Br(D_s^+ \to \tau^+\nu_\tau) = (5.49 \pm 0.07_{\rm stat.})\times 10^{-2}$$

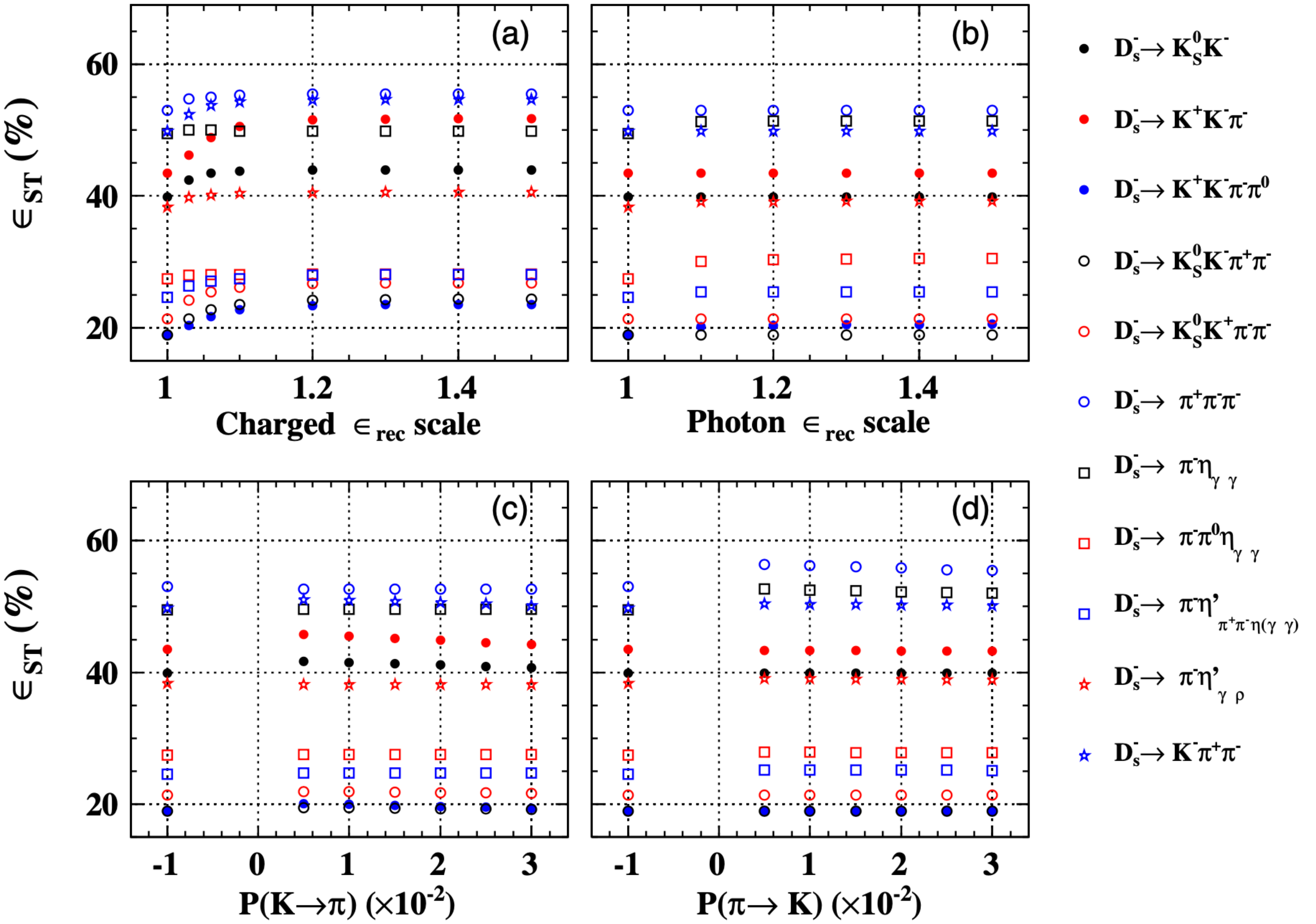


EPJC **82,** 310 (2022)

Optimizations of detector response

EPJC **82**, 310 (2022)

- ➢ **The parameters can be adjusted flexibly by a scale factor;**
- ➢ **Check the change on the single tag efficiency with the parameters;**



Optimization results:

- **reconstruction efficiencies:** **10%↑;**
- **misidentification rate (π/K):** **1.0% at 1 GeV/*c*.**

Results

EPJC **82**, 310 (2022)

Luminosity (ab^{-1})	0.1		1
Optimization	without	with	with
$Br(D_s^+ \to \tau^+\nu_\tau)$ $(\times 10^{-2})$	$5.49 \pm 0.07_{\text{stat.}}$	$5.49 \pm 0.06_{\text{stat.}}$ (Improved by 14.3%)	$\pm 0.02_{\text{stat.}}$ (scaled by luminosity)

Source	BESIII [1] 6 fb^{-1} at 4.178 GeV		BelleII [1] 50 ab^{-1} at $\Upsilon(nS)$		$D_s^+ \to \tau^+\nu_\tau$ (STCF) 1 ab^{-1} at 4.009 GeV	
	Stat. (%)	Syst. (%)	Stat.(%)	Syst.(%)	Stat.(%)	Syst.(%)
$Br_{D_s^+ \to \tau^+\nu_\tau}$	1.6	2.4	0.6	2.7	0.3	1.0
$f_{D_s^+}$ (MeV)	0.9	1.4	--	--	0.2	0.6
$\lvert V_{cs} \rvert$	0.9	1.4	--	--	0.3	0.7
$\frac{Br_{D_s^+ \to \tau^+\nu_\tau}}{Br_{D_s^+ \to \mu^+\nu_\mu}}$	2.6	2.8	0.9	3.2	0.5	1.1

[1] M. Ablikim *et al.*, (BESIII Collaboration), Chin. Phys. C 44, 040001 (2020).

scaled according to Ref.[1].

$D_s^+ \to \mu^+\nu_\mu$

EPJC **82**, 337 (2022)

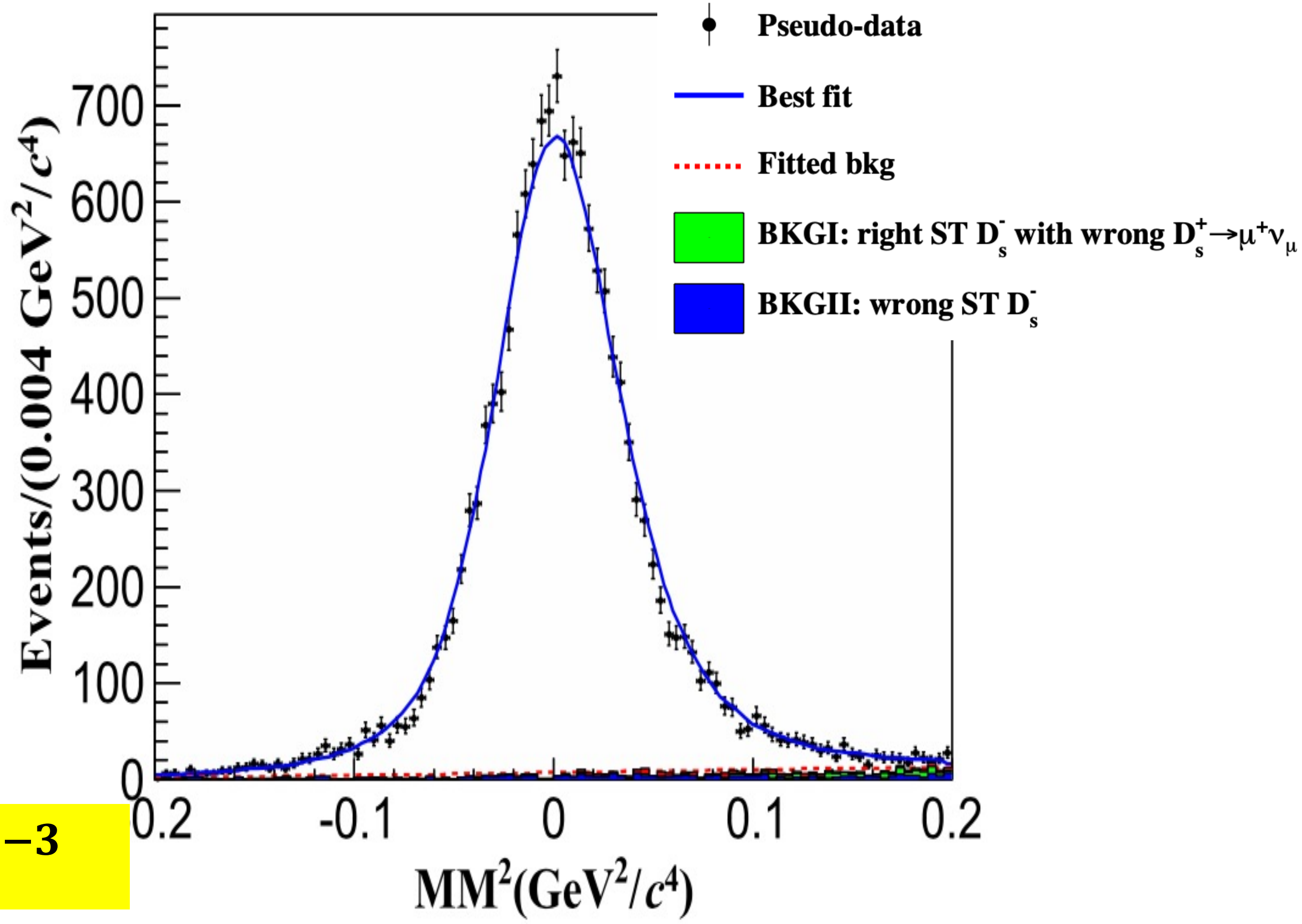
Double tag (DT)

- Only one μ^+.
- Missing mass squared (MM^2):

$$\mathrm{MM}^2 = \sqrt{\left(E_{\mathrm{beam}} - E_{\mu^+}\right)^2 - \left|-\vec{p}_{D_s^-} - \vec{p}_{\mu^+}\right|^2}$$

$$N_{\mathrm{DT}} = 14,687 \pm 142_{\mathrm{stat.}}$$

$$\mathrm{BF}\left(D_s^+ \to \mu^+\nu_\mu\right) = \left(5.61 \pm 0.05_{\mathrm{stat.}}\right)\times 10^{-3}$$



Optimizations of detector response

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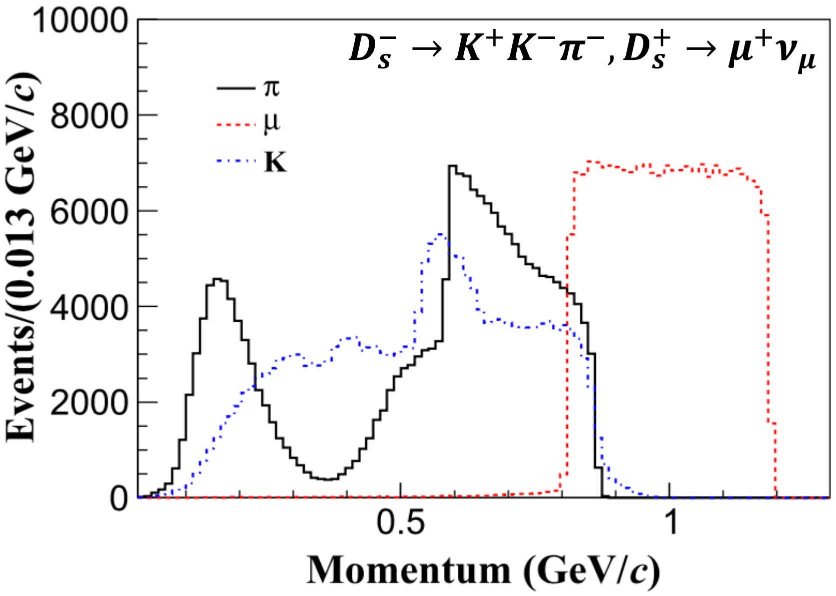

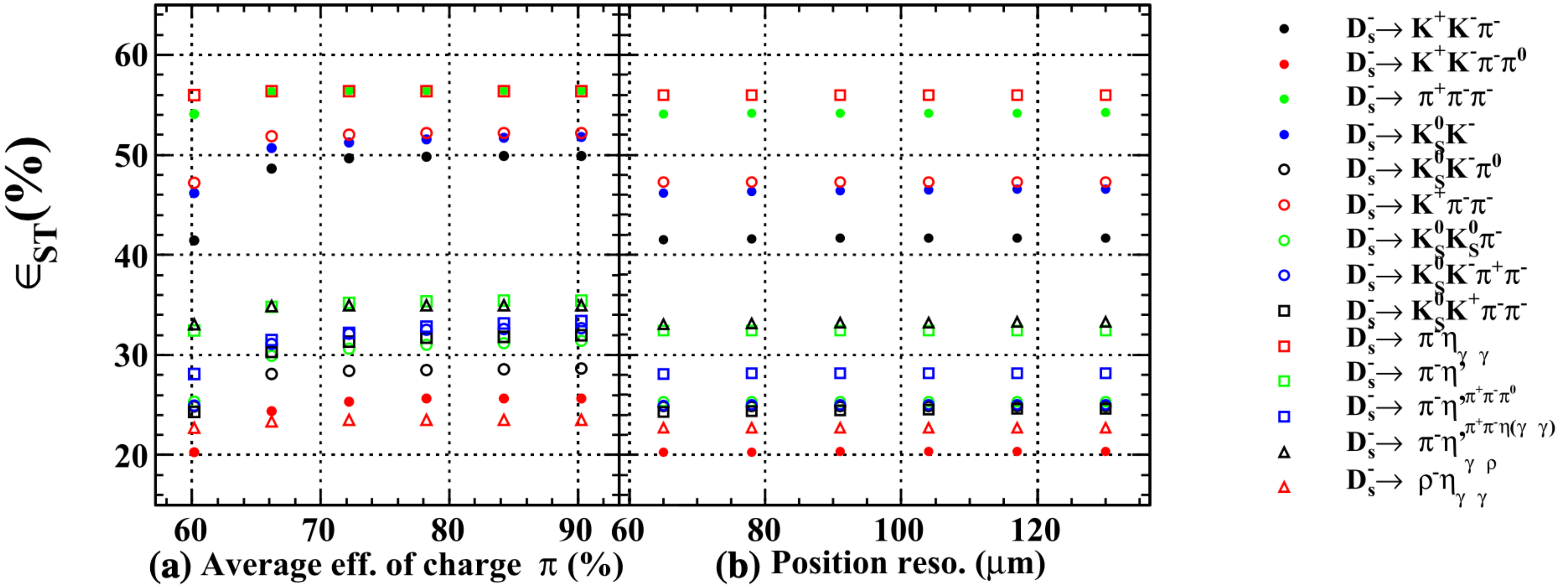

Optimization results:

- The average tracking efficiency for charged pions: 66.18% at $p_T \in (0.05, 0.1)\mathrm{GeV}/c$;
- Weak dependence from different spatial resolutions is observed, the optimization of momentum resolution of charged tracks is not changed.

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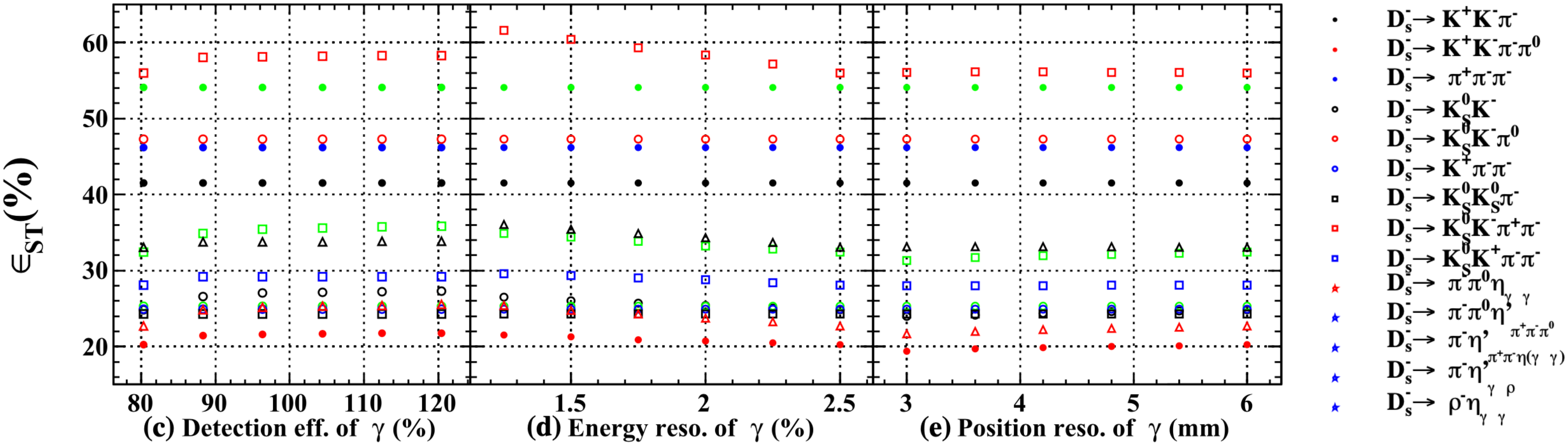

- **The photon detection efficiency: 88.33% for $E_\gamma \in (50, 200)$ MeV.**
- **The photon energy resolution: 1.75%;**
- **The photon position resolution: 6mm.**
- **π/K misidentification rate: 1% at 0.8 GeV/c, with the dE/dx resolution of 6%;**
- **μ/π misidentification rate: 3% at 1 GeV/c, with the muon identification efficiency of 97%.**

Results

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- **Stat.** : combine $D_s^+ \to \tau^+\nu_\tau$ and $D_s^+ \to \mu^+\nu_\mu$ together

Source (1 ab^{-1})	$Br_{D_s^+\to\tau^+\nu_\tau}$	$Br_{D_s^+\to\mu^+\nu_\mu}$	$\frac{Br_{D_s^+\to\tau^+\nu_\tau}}{Br_{D_s^+\to\mu^+\nu_\mu}}$	Combined τ and μ (STCF)	
				$f_{D_s^+}$ (MeV)	$\lvert V_{cs}\rvert$
Relative stat.	0.3%	0.2%	0.5%	0.1%	0.2%

Comparable to uncertainty (0.2%) of the LQCD calculation (249.9 ± 0.5) MeV.

- Syst.: a relative uncertainty (0.4%) from the D_s^+ lifetime $\tau_{D_s^+} = (504 \pm 4)\times 10^{-15}$ s.

$b \to s\,\gamma$ photon polarization

$b \to s\,\gamma$ photon polarization

EPJC **81**, 1068 (2021)

- **In SM, the photon emitted from the electroweak penguin loop in $b \to s\,\gamma$ transitions is predominantly polarized, and predominantly left-handed.**
- **New physics (NP): an observation of right-handed photon helicity in $b \to s\,\gamma$ transitions would be a clear indication for NP.**

- **The photon polarization parameter (λ_γ) in $B \to K_1\,\gamma$ [1]:**

Wilson coefficients

$$\lambda_\gamma = \frac{|C_{7R}|^2 - |C_{7L}|^2}{|C_{7R}|^2 + |C_{7L}|^2}$$

$$\simeq \begin{cases} -1, & b \to s\,\gamma \\ +1, & \bar{b} \to \bar{s}\,\gamma \end{cases} \quad \text{(SM predictions)}$$

- **In Ref.[2], an up-down asymmetry ($A_{\rm UD}$)**

$$\lambda_\gamma = \frac{4\,A_{\rm UD}}{3\,A'_{\rm UD}}$$

in $B^+ \to K_1^+(\to K^+\pi^-\pi^+)\,\gamma$

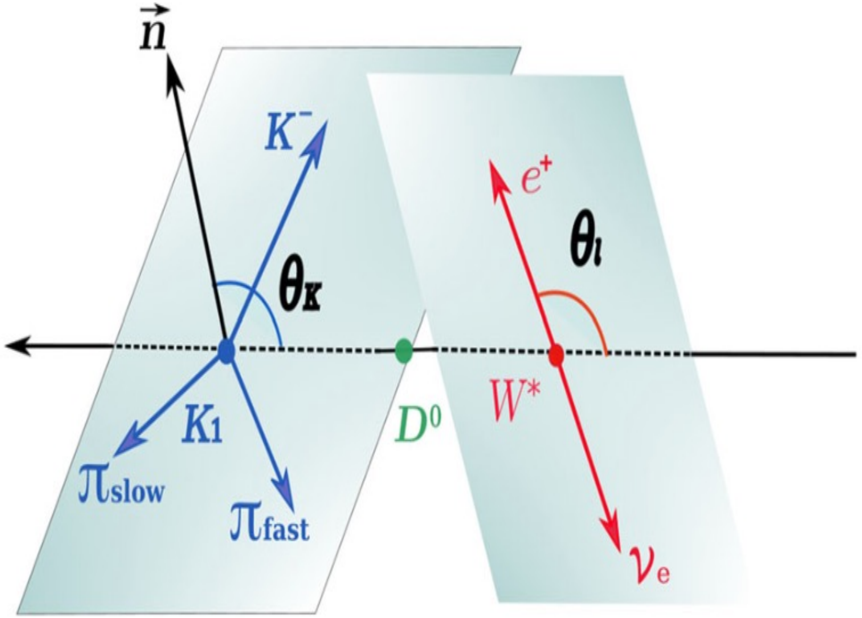
in $D^0 \to K_1^-(\to K^+\pi^-\pi^+)e^+\nu_e$

The model-independent way to determine photon polarization in $b \to s\,\gamma$.

[1] M. Gronau and D. Pirjol, Phys. Rev. D 66, 054008 (2002).
[2] W. Wang, F. S. Yu, and Z. X. Zhao, Phys. Rev. Lett. 125, 051802 (2020).

- **The ratio of up-down asymmetry A'_{UD} in $D^0 \to K_1(1270)^-(\to K^-\pi^+\pi^-)e^+\nu_e$**

$$A'_{\mathrm{UD}} = \frac{\Gamma_{K_1^- e^+\nu_e}(\cos\theta_K > 0) - \Gamma_{K_1^- e^+\nu_e}(\cos\theta_K < 0)}{\Gamma_{K_1^- e^+\nu_e}(\cos\theta_l > 0) - \Gamma_{K_1^- e^+\nu_e}(\cos\theta_l < 0)}$$



- **The $D^0 \to K_1(1270)^- e^+\nu_e$ has been observed for the first time with a statistical significance greater than 10σ by using $2.93\ \mathrm{fb}^{-1}$ of e^+e^- collision data at $\sqrt{s} = 3.773$ GeV by BESIII Collaboration[1]:**

$$Br(D^0 \to K_1(1270)^- e^+\nu_e) = (1.09 \pm 0.13^{+0.09}_{-0.16} \pm 0.12)\times 10^{-3}$$

External uncertainty from the assumed branching fractions of $K_1(1270)^-$ subdecays.

- **Due to limited statistics of the current BESIII data set, A'_{UD} has not been measured.**

[1] M. Ablikim *et al*. (BESIII Collaboration), Phys. Rev. Lett. 127, 131801 (2021).

STCF : $e^+e^- \to \psi(3770) \to D^0\bar{D}^0$ @$\sqrt{s} = 3.773$ GeV with a MC of 1 ab^{-1}

EPJC **81**, 1068 (2021)

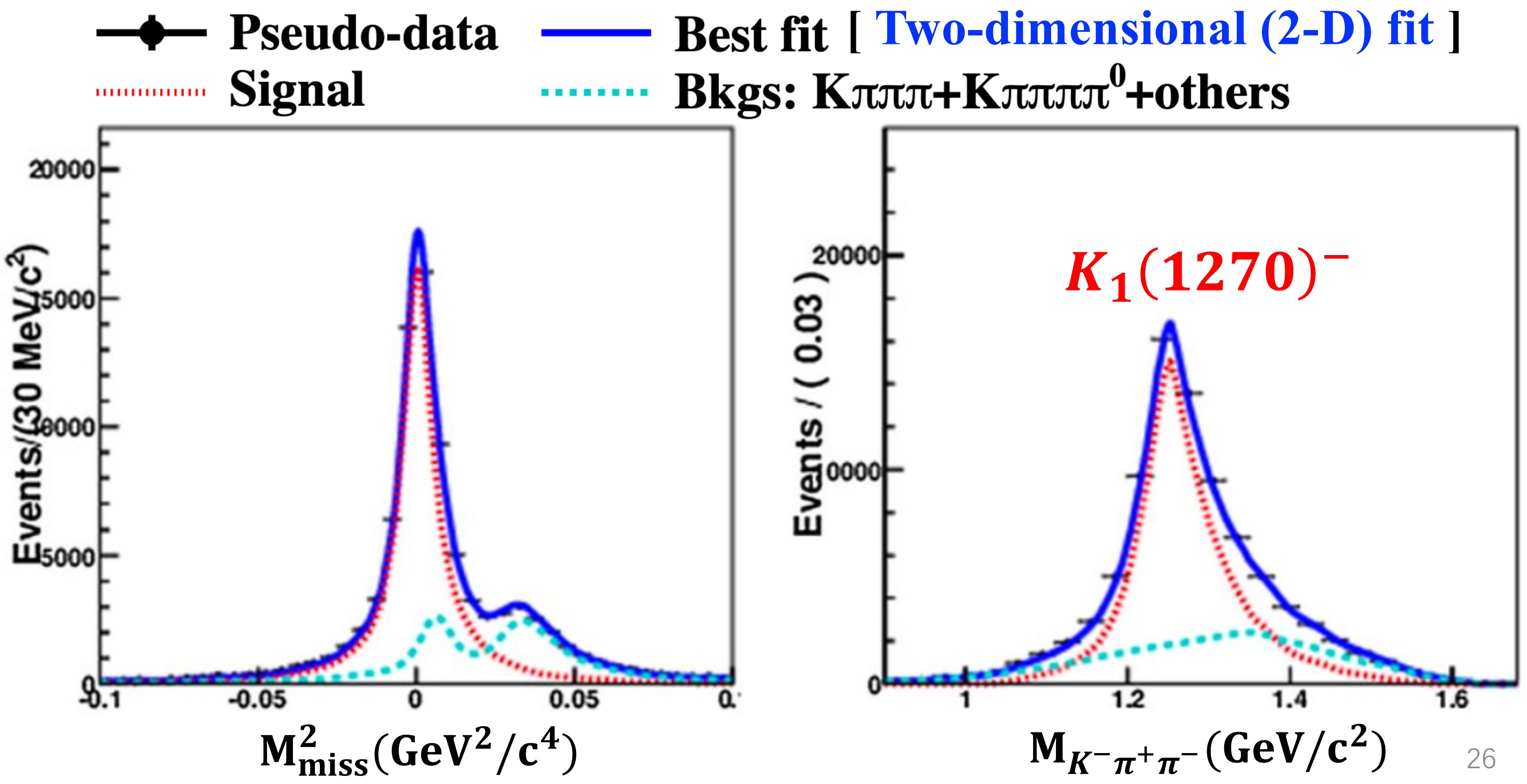
- **Single tag:** $\bar{D}^0 \to K^+\pi^-, K^+\pi^-\pi^0, K^+\pi^-\pi^+\pi^-$, **with a similar method as that using in D_s^+ decays @$\sqrt{s} = 4.009$ GeV**
- **Double tag:** $D^0 \to K_1(1270)^- e^+\nu_e,\ \ K_1(1270)^- \to K^-\pi^+\pi^-$

$$M_{\text{miss}}^2 = E_{\text{miss}}^2 - |\vec{p}_{\text{miss}}|^2$$

$$E_{\text{miss}} = E_{\text{beam}} - \sum_j E_j$$

$$\vec{p}_{\text{miss}} = -\vec{p}_{\bar{\mathrm{D}}^0} - \sum_j \vec{p}_j$$

j: K^-, π^+, π^-, e^+



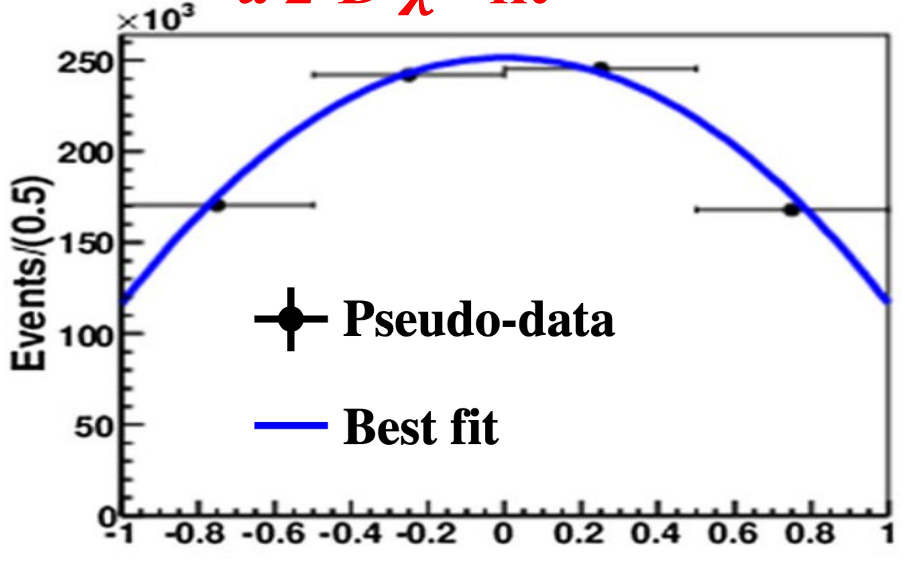
EPJC **81**, 1068 (2021)

- **Efficiency corrected signal yields in bins of $\cos\theta_K$ and $\cos\theta_\ell$**

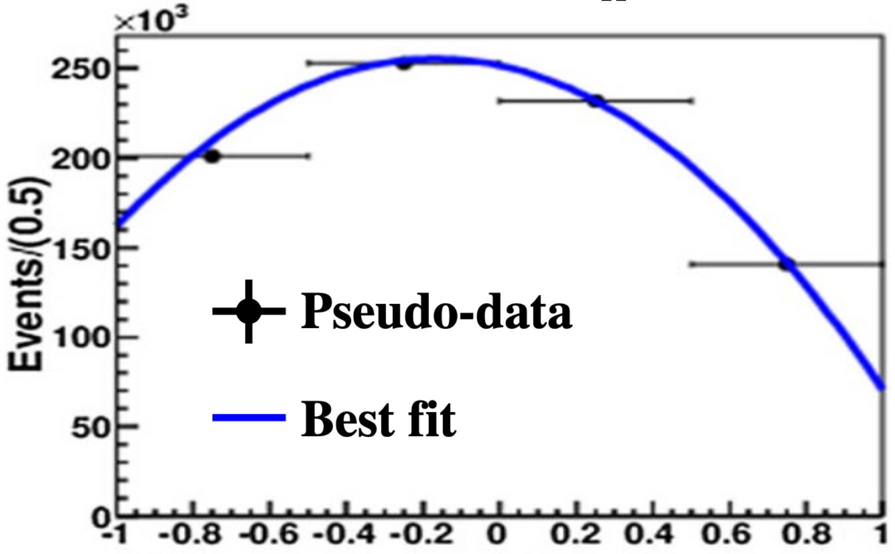
a 2-D χ^2 fit

Fit function:

$$
\begin{aligned}
f(\cos\theta_K, \cos\theta_l; A'_{\mathrm{UD}}, d_+, d_-) = &(4+d_+ + d_-)\\
&[1+\cos^2\theta_K\cos^2\theta_l]\\
&+2(d_+ - d_-)[1+\cos^2\theta_K]\cos\theta_l\\
&+2A'_{\mathrm{UD}}(d_+ - d_-)\cos\theta_K[1+\cos^2\theta_l]\\
&+4A'_{\mathrm{UD}}(d_+ + d_-)\cos\theta_K\cos\theta_l\\
&-(4-d_+ - d_-)[\cos^2\theta_K + \cos^2\theta_l].
\end{aligned}
$$



$\cos\theta_K$



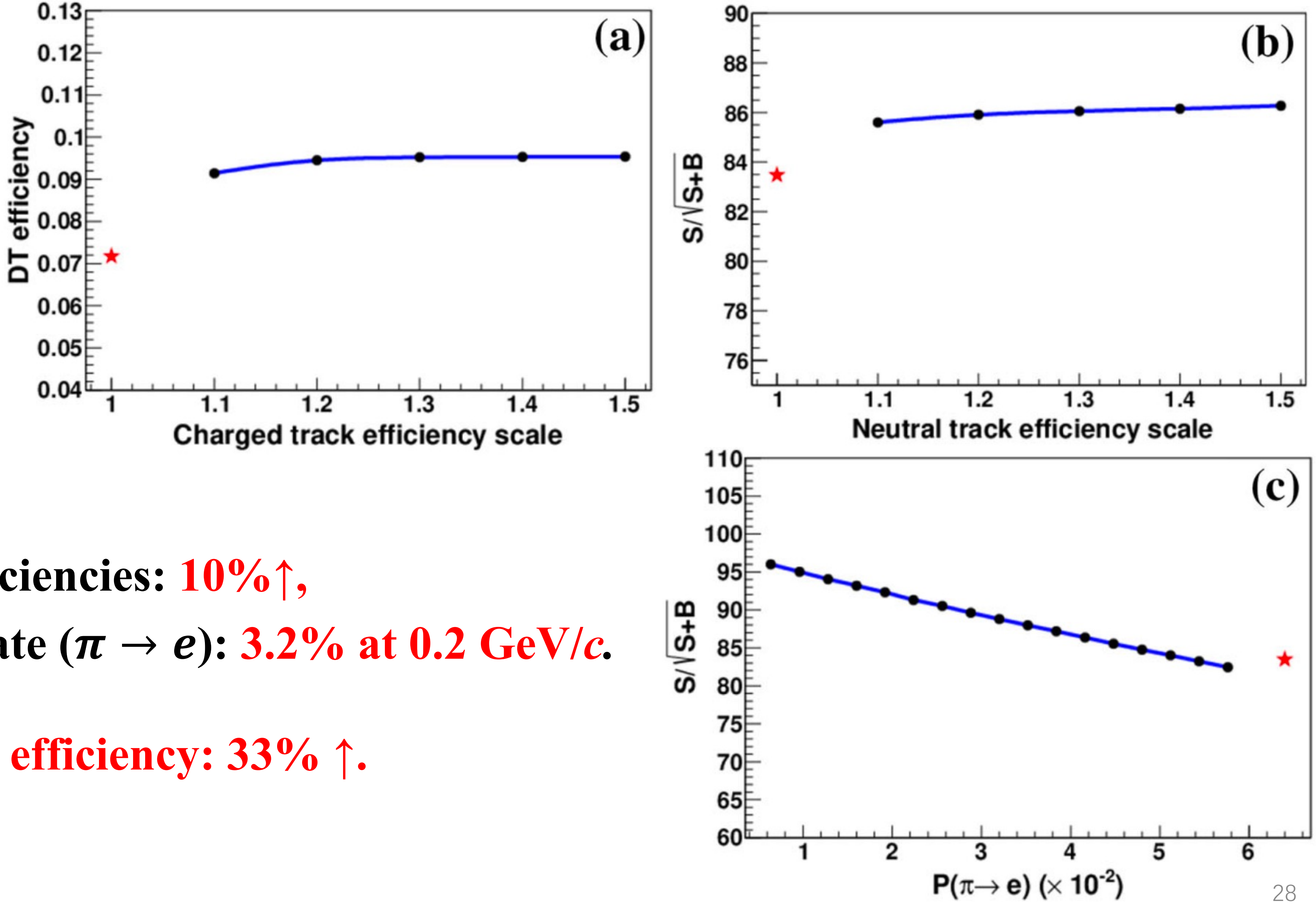
$\cos\theta_\ell$

The statistical sensitivity of A'_{UD} is determined to be in the order of 1.8×10^{-2} based on 1 ab^{-1} MC sample.

Optimizations of detector response

EPJC **81**, 1068 (2021)

- Check the change on the DT efficiency and signal-to-background ratios with the parameters;



- **Optimization results:**
  - **reconstruction efficiencies: 10%↑,**
  - **misidentification rate ($\pi \rightarrow e$): 3.2% at 0.2 GeV/*c*.**

With optimizations, DT efficiency: 33% ↑.

Results

EPJC **81**, 1068 (2021)

1 ab^{-1} MC samples	The statistical uncertainty of A'_{UD}	
Default (no optimizations)	1.8×10^{-2}	
With optimizations	1.5×10^{-2}	Improved by 17%
Prediction	$A'_{\mathrm{UD}} \simeq (9.2 \pm 2.3)\times10^{-2}$	

$$\lambda_\gamma = \frac{4\,A_{\mathrm{UD}}}{3\,A'_{\mathrm{UD}}}$$

$\lambda_\gamma \simeq 1$ for $\bar{b} \to \bar{s}\gamma$ in SM

$A_{\mathrm{UD}} = (6.9 \pm 1.7)\times10^{-2}$ from $B^+ \to K^+\pi^-\pi^+\gamma$ in $\mathrm{M}_{K^+\pi^-\pi^+} \in [1.1, 1.3]$ GeV$/c^2$ [1]

[1] R. Aaij *et al.* (LHCb Collaboration), Phys. Rev. Lett. 112, 161801 (2014).

Other works [1]

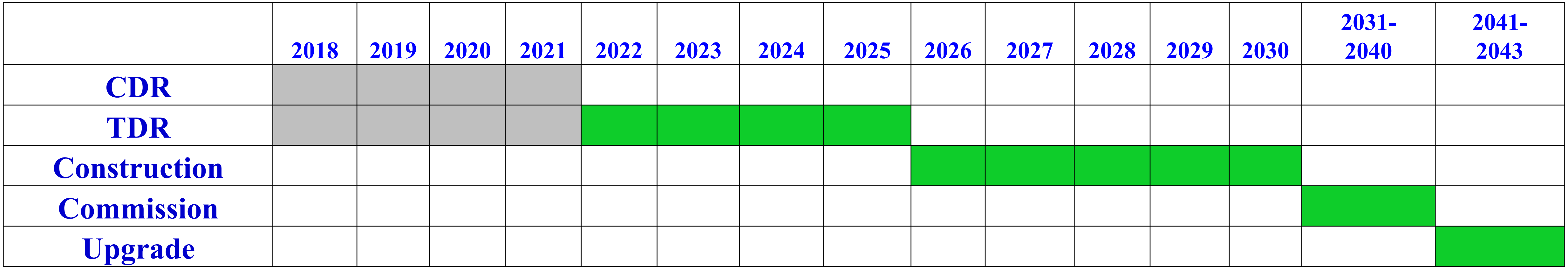
Source	Goals
$D \to \pi \ell^+ \nu_\ell$	LFU test, form factor
Multi-body D decays	Study CP-violating asymmetries in local Dalitz region
$e^+e^- \to D^0\bar{D}^0$ @ 3.773 GeV	Study $D^0 - \bar{D}^0$ mixing and CP violating parameters; strong-phase difference between CF and DCS amplitudes
$e^+e^- \to \gamma D^0\bar{D}^0$ @ 4.009 GeV	Constraints on $D^0 - \bar{D}^0$ mixing and CP violating parameters
Strong phase of D decays	Important for the precision measurement of CKM unitary triangle angle γ.
Rare and forbidden decays	Probe new physics beyond the SM
$e^+e^- \to D^{**}\bar{D}^{(*)}$ (π) @4.1 ~ 7.0 GeV	Study excited charmed meson states
$\Lambda_c^+, \Xi_c^{+,0}, \Omega_c^0 \to$ non-leptonic decays	Decay asymmetries with high precision
$\Lambda_c^+, \Xi_c^{+,0}, \Omega_c^0 \to$ semi-leptonic decays	Form factor
5 ~ 7 GeV	Study the excited states of $\Lambda_c^+, \Sigma_c, \Xi_c^{(\prime)}, \Omega_c^0$
> 7.4 GeV	Study double charmed baryons, like Ξ_c^{++}.
…	…

[1] STCF CDR, arXiv: 2303.15790 [hep-ex].

Summary

<table>
<tr><th colspan="2">Channel (1 ab^{-1})</th><th>Highlights</th></tr>
<tr><td rowspan="2">$e^+e^- \to D_s^+D_s^-$
@ 4.009 GeV</td><td>$D_s^+ \to \tau^+\nu_\tau$</td><td rowspan="2">• The relative stat. of $f_{D_s^+}$ is 0.1%, which is comparable to uncertainty (0.2%) of the LQCD calculation (249.9 ± 0.5) MeV.
• The relative stat. of $|V_{cs}|$ is 0.2%;
• The relative stat. of τ^+/μ^+ LFU is 0.5%;
• The results will be limited by the uncertainty (0.8%) of the D_s^+ lifetime $\tau_{D_s^+} = (504 \pm 4)\times10^{-15}$ s.</td></tr>
<tr><td>$D_s^+ \to \mu^+\nu_\mu$</td></tr>
<tr><td colspan="2">$D^0 \to K_1(1270)^-e^+\nu_e$
@3.773 GeV</td><td>• The stat. of ratio of up-down asymmetry is 1.5×10^{-2};
• Combined with that in $B^+ \to K_1^+(K^+\pi^-\pi^+)\,\gamma$, the photon polarization in can be measured to probe the new physics.</td></tr>
</table>

Thanks for your attention!



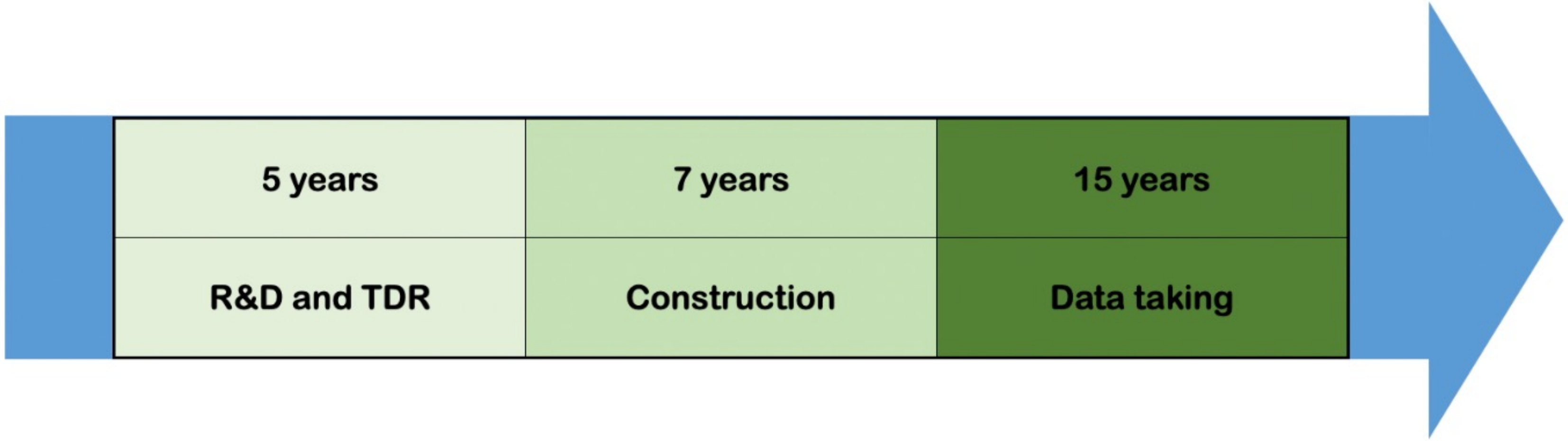


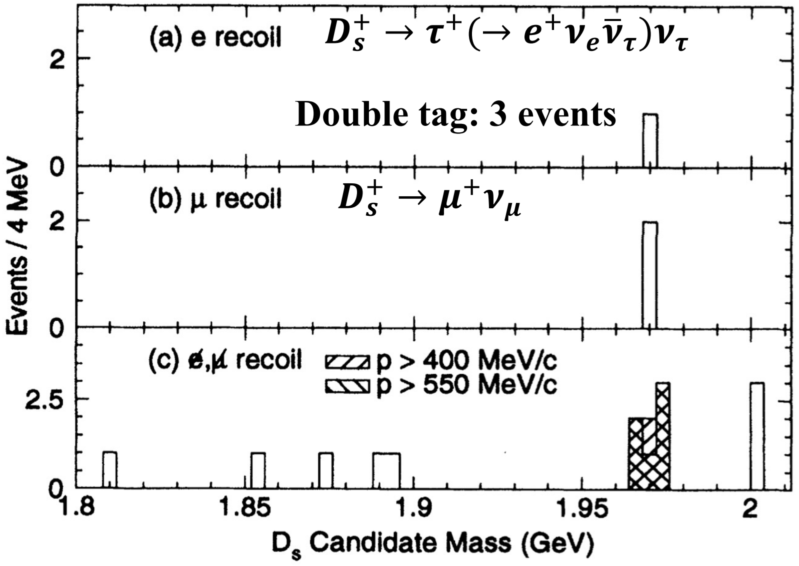
Figure 5.1: Expected timeline for the STCF project.

1. Decay constant $f_{D^+_{(s)}}$, if inputting the $|V_{cd(s)}|$ from SM global fit.

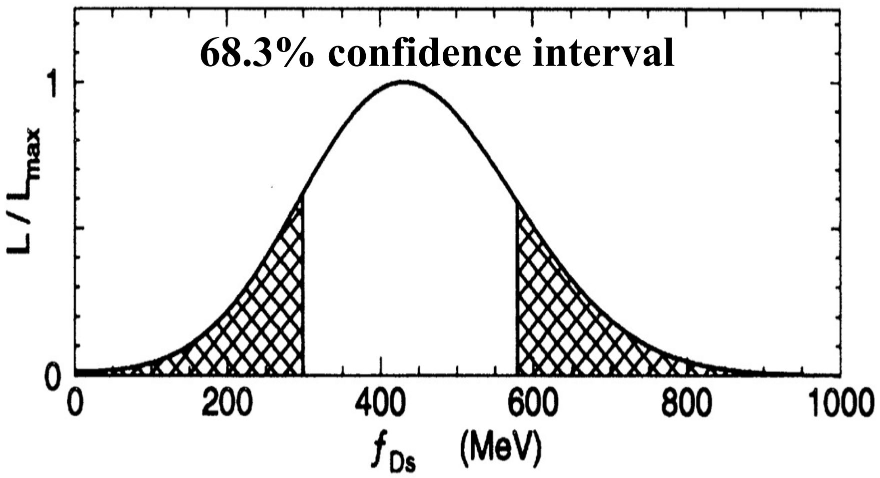
- Helpful to precisely calibrate Lattice QCD (LQCD) calculations.

The first absolute measurement on $f_{D_s^+}$ from BESI [PRL74(1995)4599].

$e^+e^- \to D_s^+ D_s^-$ @ 4.03 GeV with 22.3 pb^{-1}



$$f_{D_s^+} = (4.3^{+1.5+0.4}_{-1.3-0.4})\times 10^2 \text{ MeV}$$



- improve the theoretical precision on the decay constant of B meson[1].
  - $B^0\bar{B}^0$ mixing parameter $x_B = \frac{\Delta M_B}{\Gamma_B}$ can be well measured.
  - In the SM, assuming $|V_{tb}| = 1$, $x_B \propto f_B |V_{td}|^2$
  - a precise determination of f_{B^+} is important for extracting $|V_{td}|$
  - The ratio f_{D^+}/f_{B^+} has a better precision from LQCD calculations

2. CKM matrix element $|V_{cd(s)}|$, with the $f_{D^+_{(s)}}$ predicted by Lattice QCD.

- **Helpful to test the unitarity of the CKM matrix.**

$$V_{CKM} = \begin{array}{c} \\ \\ \\ \end{array}\begin{array}{cccc} d & s & b & \\ \left(\begin{array}{c} V_{ud} \\ V_{cd} \\ V_{td} \end{array}\right. & \begin{array}{c} V_{us} \\ V_{cs} \\ V_{ts} \end{array} & \left.\begin{array}{c} V_{ub} \\ V_{cb} \\ V_{tb} \end{array}\right) & \begin{array}{c} u \\ c \\ t \end{array} \end{array} =$$

Relative magnitudes

Unitarity ($V^\dagger V = 1$) prescribes 6 complex equations:

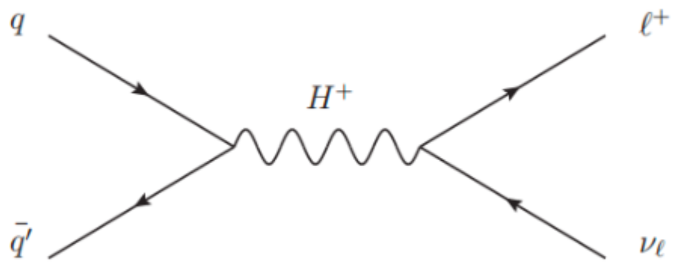
$$V_{ud}^* V_{cd} + V_{us}^* V_{cs} + V_{ub}^* V_{cb} = 0 \qquad V_{us}^* V_{ud} + V_{cs}^* V_{cd} + V_{ts}^* V_{td} = 0$$

$$V_{ud}^* V_{td} + V_{us}^* V_{ts} + V_{ub}^* V_{tb} = 0 \qquad V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0$$

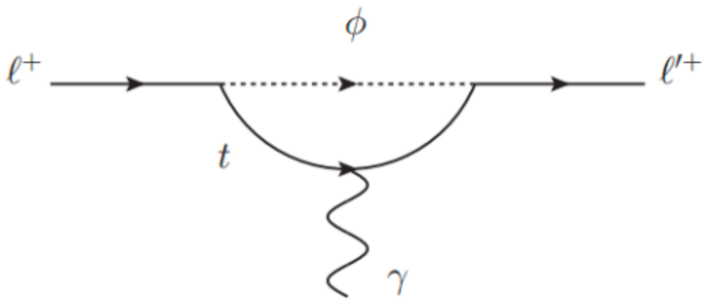
$$V_{cd}^* V_{td} + V_{cs}^* V_{ts} + V_{cb}^* V_{tb} = 0 \qquad V_{ub}^* V_{us} + V_{cb}^* V_{cs} + V_{tb}^* V_{ts} = 0$$

象[5]，理论上也利用一些超出标准模型的新物理模型来解释该迹象[6]，比如双 Higgs 二重态模型、leptoquark 模型和Z'模型等。但这些理论模型仍需在实验上进一步验证[7]。另外，文献[8]预言，在$c \to s$跃迁过程中，双 Higgs 二重态模型中的带电 Higgs 玻色子参与的振幅与标准模型中的W^+玻色子参与的振幅可能存在干涉，这将有可能导致轻子普适性被破坏。因此，实验上可以通过研究$D_s^+ \to l^+\nu_l$过程检验 D 物理中的轻子普适性是否被破坏，从而为精确检验标准模型和寻找超出标准模型的新物理提供实验依据。

Possible source of LFUV



Charged Higgs



Leptoquark