中国科学技术大学
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STCF上超子半轻衰变过程$\Xi^- \to \Lambda e^- \bar{\nu}_e$研究

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2025.9.21

Outline

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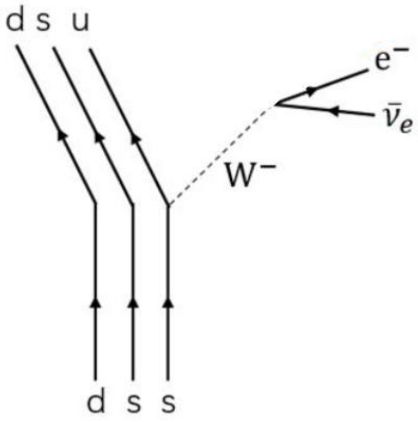
- Simulated data sets
- Analysis strategy
- Single tag analysis
- Double tag analysis
- Summary

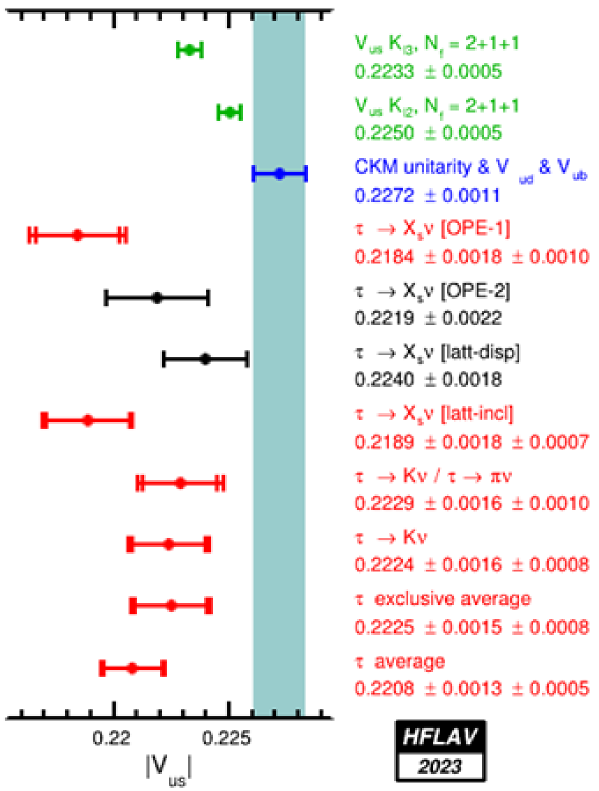
Motivation

- Determination of CKM matrix element V_{us} or Cabibbo-angle θ_c. In fact, different previous measurements of θ_c, have poor mutual agreement which is so-called "Cabibbo-angle anomaly".
- $\Xi^- \to \Lambda e^- \bar{\nu}_e$ can provide a complementary method to determine the Cabibbo angle θ_c and to test the Unitarity of the CKM matrix.
  - ✓ Determine the branching fraction
  - ✓ Determine the form factors

$$\Gamma_{e,\mathrm{SM}} \simeq \frac{G_F^2 |V_{us} f_1(0)|^2 \Delta^5}{60\pi^3}\left[\left(1-\frac{3}{2}\delta\right) + 3\left(1-\frac{3}{2}\delta\right)\frac{g_1(0)^2}{f_1(0)^2} - 4\delta \frac{g_2(0)}{f_1(0)}\frac{g_1(0)}{f_1(0)}\right]$$

PRL 114, 161802 (2015)





Motivation

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- Study of SU3 breaking effects.
  - ✓ $g_1(0)/f_1(0)$ has intriguingly **small SU3 breaking effects**. Lots of phenomenology models are waitting for more experiments.
  - ✓ g_2 is 0 or not. Could be the first observation of a second-class weak-interaction current.
- Proton spin content
  - ✓ Provide complementarity to polarized deep inelastic scattering experiments for the determination of the proton spin content.

- **实验：**深度非弹性轻子-核子散射过程

$$\int_0^1 dx\ g_1^p(x,Q^2) = \left(\frac{1}{12}g_A^{(3)} + \frac{1}{36}g_A^{(8)}\right)\left\{1+\sum_{\ell\geq 1} c_{\mathrm{NS}\ell}\,\alpha_s^\ell(Q)\right\} + \frac{1}{9}g_A^{(0)}|_{\mathrm{inv}}\left\{1+\sum_{\ell\geq 1} c_{\mathrm{S}\ell}\,\alpha_s^\ell(Q)\right\} + \mathcal{O}\left(\frac{1}{Q^2}\right) - \beta_1(Q^2)\frac{Q^2}{4M^2}.$$

Decay	Scale	$f_1(0)$	$g_1(0)$	g_1/f_1	f_2/f_1
$n \to pe^-\bar{\nu}$	V_{ud}	1	$D+F$	$F+D$	$\frac{M_n}{M_p}\frac{(\mu_p-\mu_n)}{2} = 1.855$
$\Xi^- \to \Xi^0 e^-\bar{\nu}$	V_{ud}	-1	$D-F$	$F-D$	$\frac{M_{\Xi^-}}{M_p}\frac{(\mu_p+2\mu_n)}{2} = -1.432$
$\Sigma^\pm \to \Lambda e^\pm \nu$	V_{ud}	0^{b}	$\sqrt{\frac{2}{3}}D$	$\sqrt{\frac{2}{3}}D$	$-\frac{M_{\Sigma^\pm}}{M_p}\sqrt{\frac{3}{2}}\frac{\mu_n}{2} = 1.490$
$\Sigma^- \to \Sigma^0 e^-\bar{\nu}$	V_{ud}	$\sqrt{2}$	$\sqrt{2}F$	F	$\frac{M_{\Sigma^-}}{M_p}\frac{(2\mu_p+\mu_n)}{4} = 0.534$
$\Sigma^0 \to \Sigma^+ e^-\bar{\nu}$	V_{ud}	$\sqrt{2}$	$-\sqrt{2}F$	$-F$	$\frac{M_{\Sigma^0}}{M_p}\frac{(2\mu_p+\mu_n)}{4} = 0.531$
$\Xi^0 \to \Sigma^+ e^-\bar{\nu}$	V_{us}	1	$D+F$	$F+D$	$\frac{M_{\Xi^0}}{M_p}\frac{(\mu_p-\mu_n)}{2} = 2.597$
$\Xi^- \to \Sigma^0 e^-\bar{\nu}$	V_{us}	$\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2}}(D+F)$	$F+D$	$\frac{M_{\Xi^-}}{M_p}\frac{(\mu_p-\mu_n)}{2} = 2.609$
$\Sigma^- \to ne^-\bar{\nu}$	V_{us}	-1	$D-F$	$F-D$	$\frac{M_{\Sigma^-}}{M_p}\frac{(\mu_p+2\mu_n)}{2} = -1.297$
$\Sigma^0 \to pe^-\bar{\nu}$	V_{us}	$\frac{-1}{\sqrt{2}}$	$\frac{1}{\sqrt{2}}(D-F)$	$F-D$	$\frac{M_{\Sigma^0}}{M_p}\frac{(\mu_p+2\mu_n)}{2} = -1.292$
$\Lambda \to pe^-\bar{\nu}$	V_{us}	$-\sqrt{\frac{3}{2}}$	$-\frac{1}{\sqrt{6}}(D+3F)$	$F+D/3$	$\frac{M_\Lambda}{M_p}\frac{\mu_p}{2} = 1.066$
$\Xi^- \to \Lambda e^-\bar{\nu}$	V_{us}	$\sqrt{\frac{3}{2}}$	$-\frac{1}{\sqrt{6}}(D-3F)$	$F-D/3$	$-\frac{M_{\Xi^-}}{M_p}\frac{(\mu_p+\mu_n)}{2} = 0.085$

Annu. Rev. Nucl. Part. Sci. 2003.

Motivation

- Searching for new physics

PRL 114, 161802 (2015)

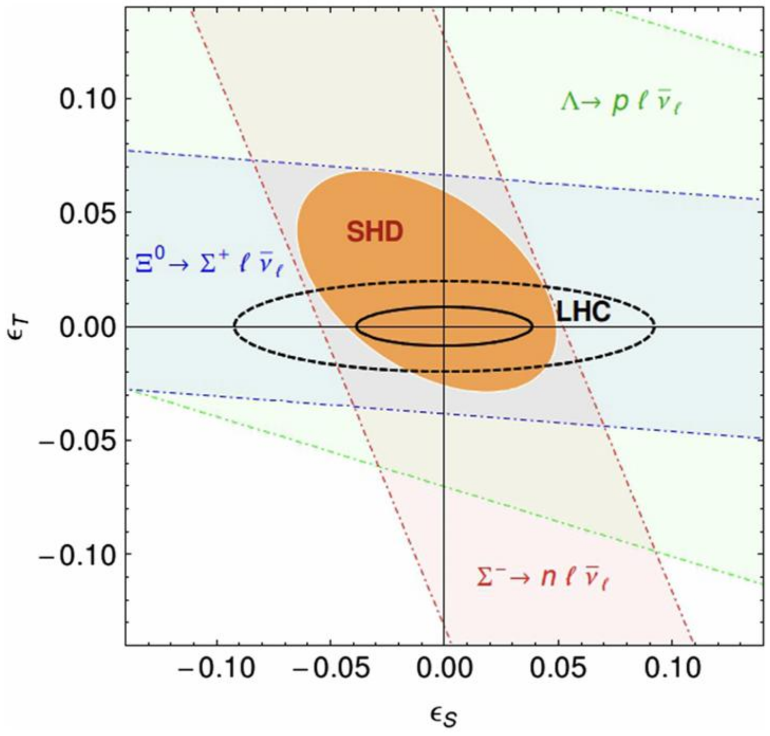
- ✓ Provide extremely stringent constraints on the Wilson coefficients (ϵ_S, ϵ_T) of new physics.
- ✓ Complement the search for new physics at high-energy experiments such as the LHC.

$$R^{\mu e} = \frac{\Gamma(B_1 \to B_2 \mu^- \bar{\nu}_\mu)}{\Gamma(B_1 \to B_2 e^- \bar{\nu}_e)}.$$

$$R^{\mu e}_{\rm SM} = \sqrt{1 - \frac{m_\mu^2}{\Delta^2}}\left(1 - \frac{9}{2}\frac{m_\mu^2}{\Delta^2} - 4\frac{m_\mu^4}{\Delta^4}\right) + \frac{15}{2}\frac{m_\mu^4}{\Delta^4}\,\mathrm{arctan\,h}\left(\sqrt{1 - \frac{m_\mu^2}{\Delta^2}}\right).$$

$$\frac{R^{\mu e}}{R^{\mu e}_{\rm SM}} = 1 + r_S \epsilon_S + r_T \epsilon_T,$$

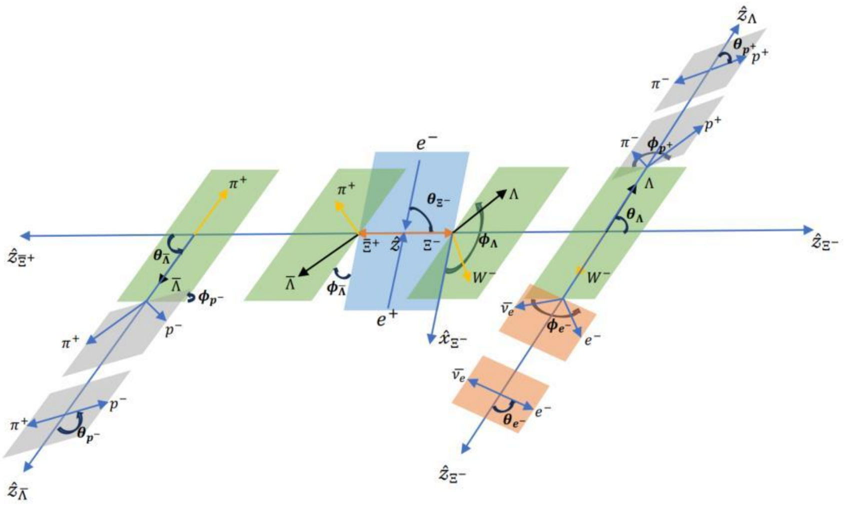
	$\Lambda \to p$	$\Sigma^- \to n$	$\Xi^0 \to \Sigma^+$	$\Xi^- \to \Lambda$
$g_1(0)/f_1(0)$	0.718(15)	−0.340(17)	1.210(50)	0.250(50)
$f_S(0)/f_1(0)$	1.90(10)	2.80(14)	1.36(7)	2.25(11)
$f_T(0)/f_1(0)$	0.72	−0.28	1.22	0.22
r_S	1.60	4.1	0.56	3.7
r_T	5.2	1.7	7.2	1.1



Simulated data sets

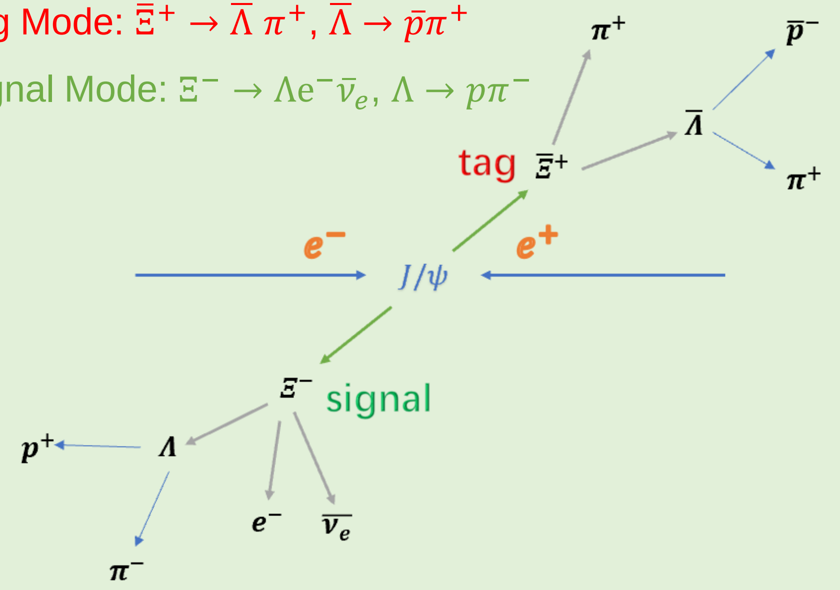
- ✓ OSCAR version: 2.6.2
- ✓ CDR J/ψ:3.4×10^{12}
- ✓ Simulated signal MC and dominant BKG sample: 5.0×10^{5}
- ✓ Signal MC : $e^+e^- \rightarrow J/\psi \rightarrow \bar{\Xi}^+\Xi^-, \bar{\Xi}^+ \rightarrow \bar{\Lambda}\pi^+, \Xi^- \rightarrow \Lambda e^- \bar{\nu}_e, \bar{\Lambda} \rightarrow \bar{p}\pi^+, \Lambda \rightarrow p\pi^-$
- ✓ Background MC: $e^+e^- \rightarrow J/\psi \rightarrow \bar{\Xi}^+\Xi^-, \bar{\Xi}^+ \rightarrow \bar{\Lambda}\pi^+, \Xi^- \rightarrow \Lambda\pi^-, \bar{\Lambda} \rightarrow \bar{p}\pi^+, \Lambda \rightarrow p\pi^-$

  - ST-MC: $J/\psi \rightarrow \bar{\Xi}^+(\bar{\Lambda}\pi^+(\bar{\Lambda} \rightarrow \bar{p}\pi^+))\Xi^-(anything)$
  - DT-MC: $J/\psi \rightarrow \bar{\Xi}^+(\bar{p}\pi^+\pi^+)\Xi^-(\Lambda e^-\bar{\nu}_e(\Lambda \rightarrow p\pi^-))$



✓ Double Tag Method:

Double tag method can reduce several terms of systematic uncertainty.



- ST-MC: $J/\psi \to \bar{\Xi}^+(\bar{\Lambda}\,\pi^+(\bar{\Lambda} \to \bar{p}\pi^+))\Xi^-(anything)$
- DT-MC: $J/\psi \to \bar{\Xi}^+(\bar{p}\pi^+\pi^+)\Xi^-(\Lambda e^-\bar{\nu}_e(\Lambda \to p\pi^-))$

Yield of each side:

- $N_{ST} = N_{J/\psi} \times \mathrm{Br}_{J/\psi\to\bar{\Xi}^+\Xi^-} \times \mathrm{Br}_{\bar{\Xi}^+\to\bar{\Lambda}\,\pi^+} \times \mathrm{Br}_{\bar{\Lambda}\to\bar{p}\pi^+} \times \varepsilon_{ST}$
- $N_{DT} = N_{J/\psi} \times \mathrm{Br}_{J/\psi\to\bar{\Xi}^+\Xi^-} \times \mathrm{Br}_{\bar{\Xi}^+\to\bar{\Lambda}\,\pi^+} \times \mathrm{Br}_{\bar{\Lambda}\to\bar{p}\pi^+} \times \mathrm{Br}_{\Xi^-\to\Lambda e^-\bar{\nu}_e} \times \mathrm{Br}_{\Lambda\to p\pi^-} \times \varepsilon_{DT}$
- $\boldsymbol{Br_{\Xi^-\to\Lambda e^-\bar{\nu}_e} = \frac{N_{DT}}{N_{ST}} \times \frac{\varepsilon_{ST}}{\varepsilon_{DT}} \times \frac{1}{Br_{\Lambda\to p\pi^-}}}$

Single tag analysis

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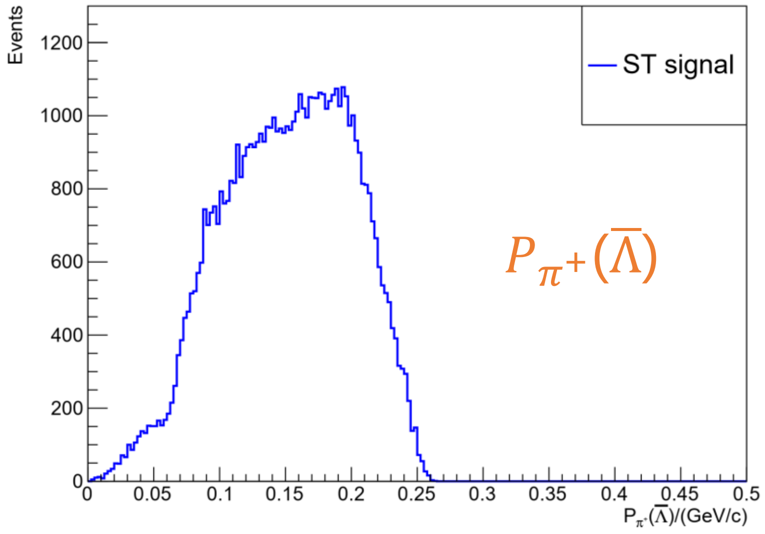
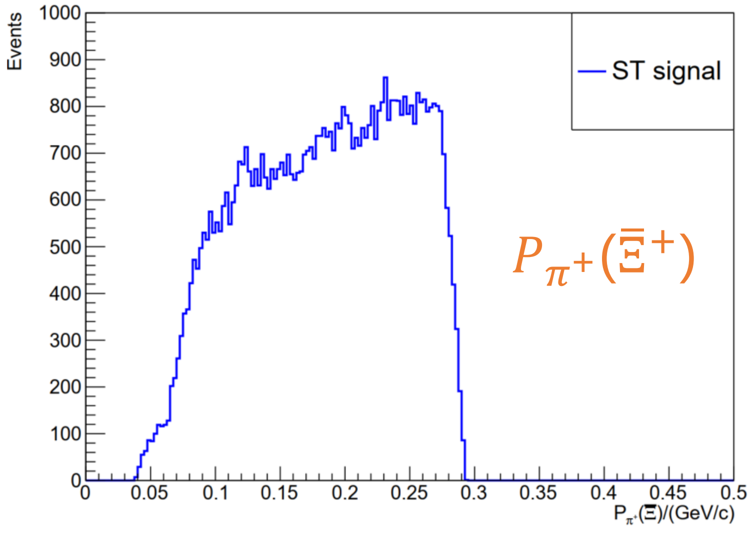
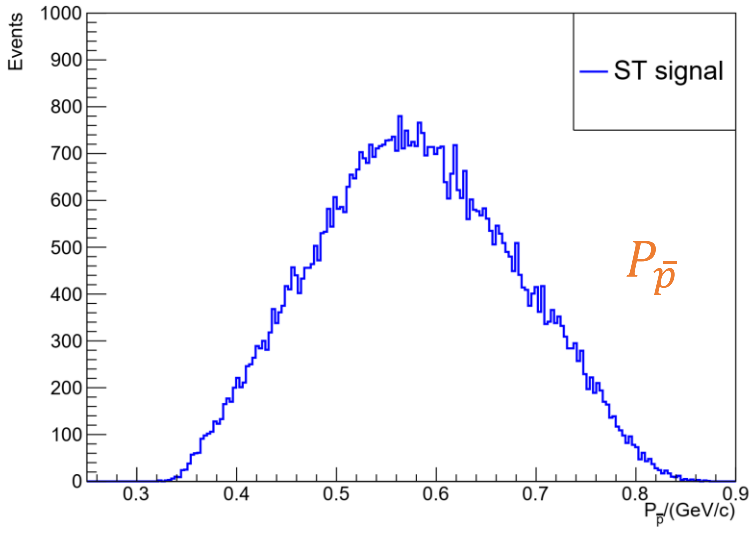
➢ ST signal MC truth information(final state particles):







- ST-MC: $\mathrm{J}/\psi \to \bar{\Xi}^+(\bar{\Lambda}\,\pi^+(\bar{\Lambda} \to \bar{p}\pi^+))\Xi^-(anything)$

Single tag analysis

- ST Event Selection

Tag Mode: $\bar{\Xi}^+ \to \bar{\Lambda}\,\pi^+, \bar{\Lambda} \to \bar{p}\pi^+$

✓ **Good charged track :** No Vertex requirement; $|\cos\theta| < 0.93$, $N_{charge^+} \geq 2$; $N_{charge^-} \geq 1$

✓ **Particle ID:** For proton: $p_{\bar{p}} > 0.32 GeV/c$; $N_{\bar{p}} \geq 1$;
For pion: $p_{\pi^+} < 0.30\ GeV/c$; $N_{\pi^+} \geq 2$;

✓ **Vertex fit for $\bar{\Lambda}, \bar{\Xi}^+$:** Primary vertex fit : $\bar{p}\pi^+$ for $\bar{\Lambda}$, $\bar{\Lambda}\,\pi^+$ for $\bar{\Xi}^+$
Secondary vertex fit : $\bar{\Lambda}\,\pi^+$ and $\bar{\Xi}^+$, $\bar{\Xi}^+$ and initial vertex

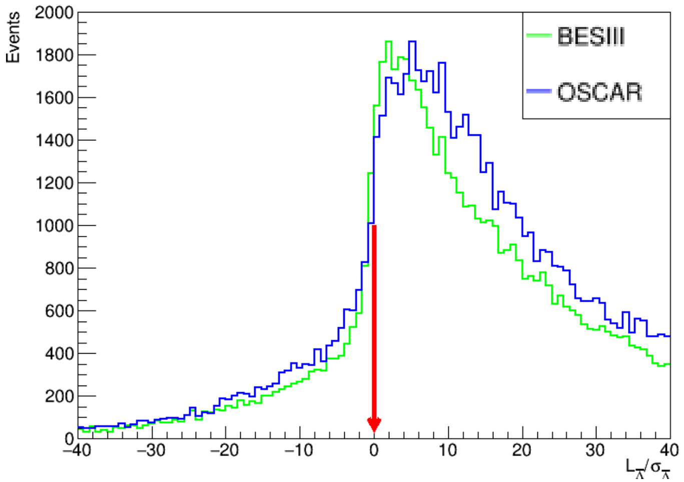
Loop all the combinations, select the minimum $\chi^2 = \frac{\left(M_{\bar{p}\pi^+} - M_{\bar{\Lambda}_{PDG}}\right)^2}{\sigma_{\bar{\Lambda}}^2} + \frac{\left(M_{\bar{p}\pi^+\pi^+} - M_{\bar{p}\pi^+} + M_{\bar{\Lambda}_{PDG}} - M_{\bar{\Xi}^+{}_{PDG}}\right)^2}{\sigma_{\bar{\Xi}}^2}$

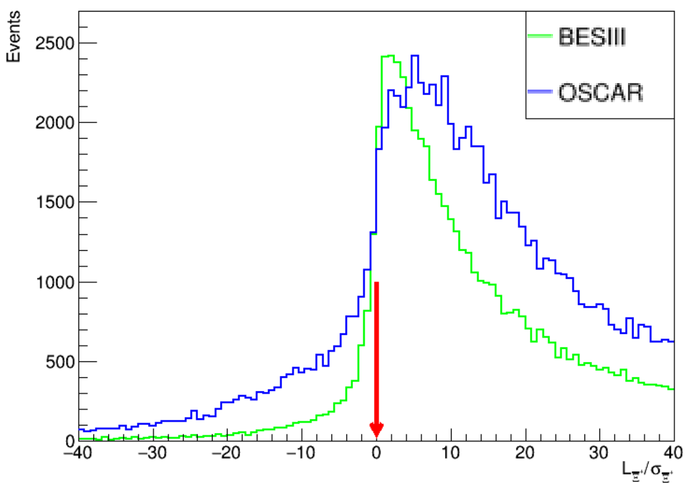
✓ **Decay length:** $L_{\bar{\Lambda}}/\sigma_{L_{\bar{\Lambda}}} > 0$ && $L_{\bar{\Xi}^+}/\sigma_{L_{\bar{\Xi}^+}} > 0$

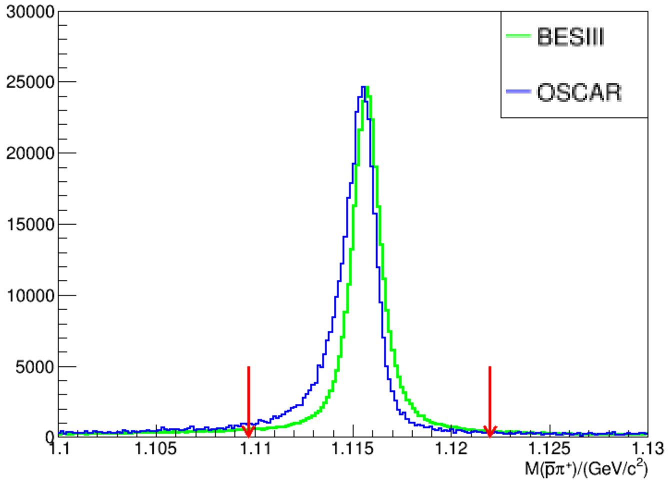
✓ **Mass distribution :** $|M_{\bar{\Lambda}} - M_{\bar{\Lambda}_{PDG}}| < 0.006\text{GeV}$; $\left|M_{\bar{p}\pi^+\pi^+} - M_{\bar{p}\pi^+} + M_{\bar{\Lambda}_{PDG}} - M_{\bar{\Xi}^+_{PDG}}\right| < 0.008\text{GeV}$
$1.273 GeV < M_{recoil} < 1.363 GeV$

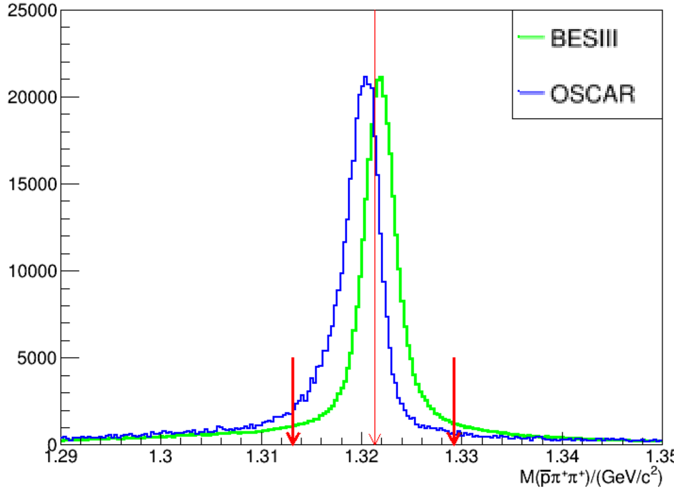
Single tag analysis

- ST Event Selection



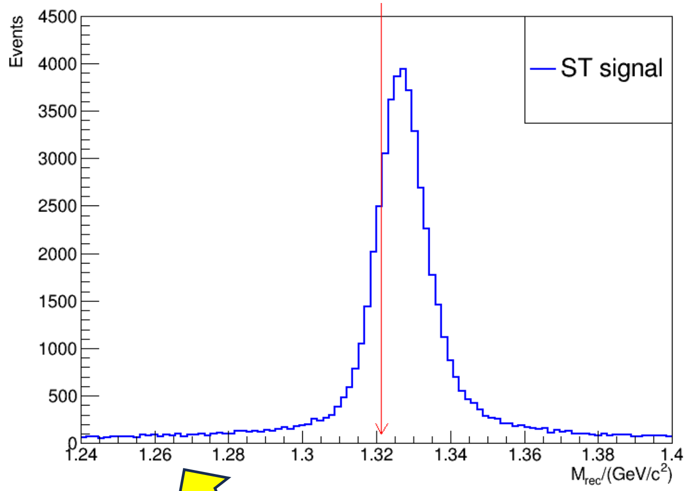






$$1.273GeV < M_{rec} < 1.363GeV$$

$$M_{recoil} = (ecms - P_{\bar{\Xi}^+}).M();$$



recoil

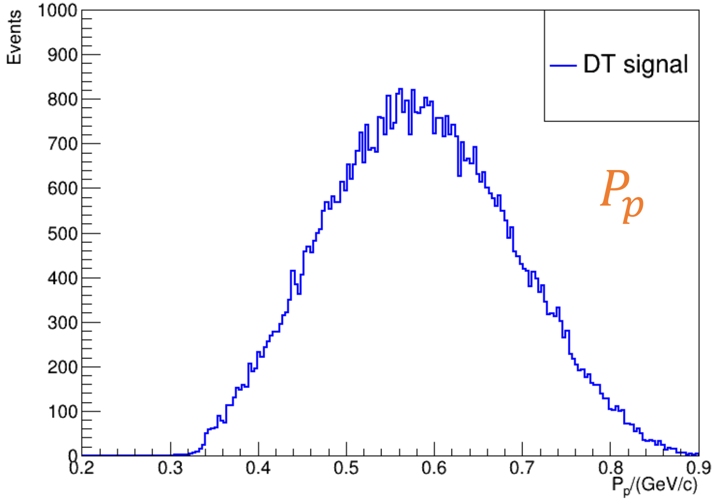
Single tag analysis

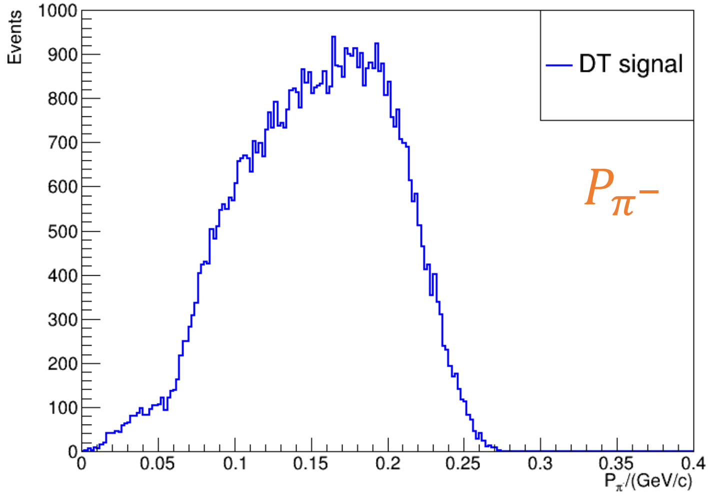
➢ Cut flow

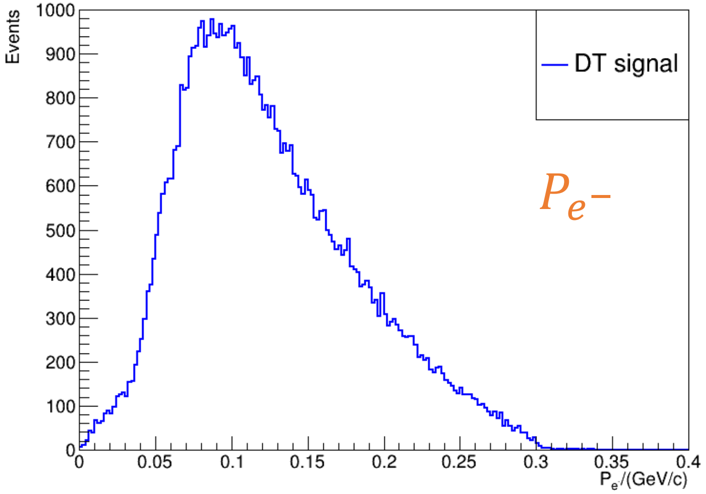
Selection Criteria	Event number	OSCAR		BESIII	
		Absolute Efficiency(%)	Relative Efficiency(%)	Absolute Efficiency(%)	Relative Efficiency(%)
Total Number	500000	100	------	100	------
Good charged track	489759	97.95	97.95	92.81	92.81
$N_{\bar{p}} \geq 1$	452302	90.46	92.35	80.53	86.77
$N_{\pi^+} \geq 2$	357857	71.57	79.12	54.27	67.39
$\bar{\Xi}^+$ Vertex	291457	58.29	73.20	48.01	88.47
Further cut	179939	36.00	61.76	27.27	56.80

Double tag analysis

➢ DT signal MC truth information(final state particles):







- DT-MC: $J/\psi \to \bar{\Xi}^+(\bar{p}\pi^+\pi^+)\Xi^-(\Lambda e^-\bar{\nu}_e(\Lambda \to p\pi^-))$

Double tag analysis

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- DT Event Selection

Signal Mode: $\Xi^- \to \Lambda e^- \bar{\nu}_e$, $\Lambda \to p\pi^-$

✓ **Particle ID:** Proton:$p_p > 0.32GeV/c$; $N_p \geq 1$;

Pion or electron:$p/\pi^- < 0.30\ GeV/c$; $N \geq 2$

✓ **Vertex fit for simulated decay $\Xi^- \to \Lambda\pi^-$ candidate:**

Primary vertex fit :$p\pi^-$ for Λ, $\Lambda\pi^-$ *for* Ξ^-

Secondary vertex fit : $\Lambda\pi^-$and Ξ^-, Ξ^- and Primary Vertex

Loop all the pairs, select the minimum chisqure

✓ **Vertex fit for signal candidate :**

Primary vertex fit :$p\pi^-$ for Λ, Λe^- *for* Ξ^-.

Secondary vertex fit :Λ and Ξ^-, Ξ^- and Primary Vertex.

Loop all the pairs, select combination by minimizing $|M_{p\pi^-} - M_{\Lambda_{PDG}}|$ and then minimizing primary vertex fit χ^2 of Ξ^-

✓ **Mass distribution:** Veto $|M_{p\pi^-\pi^-} - M_{p\pi^-} + M_{\Lambda_{PDG}} - M_{\Xi^-_{PDG}}| < 0.006GeV$

$|M_\Lambda - M_{\Lambda_{PDG}}| < 0.006GeV$

✓ **Further cut**: $L_\Lambda/\sigma_{L_\Lambda} > 0$ && $L_\Xi/\sigma_{L_\Xi} > 0$; $\chi^2 < 20$

Double tag analysis

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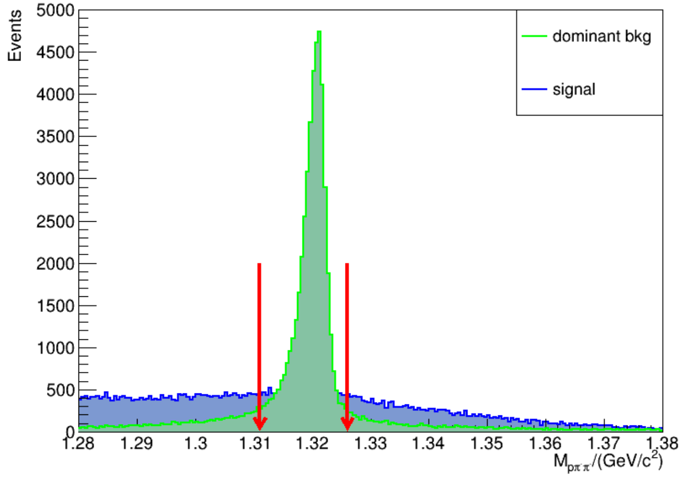
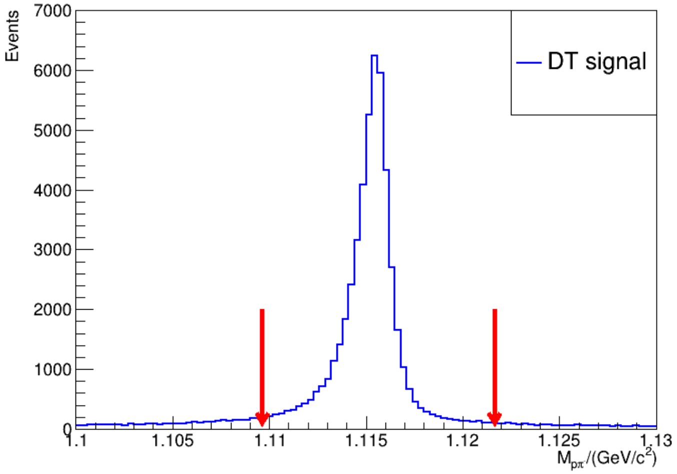
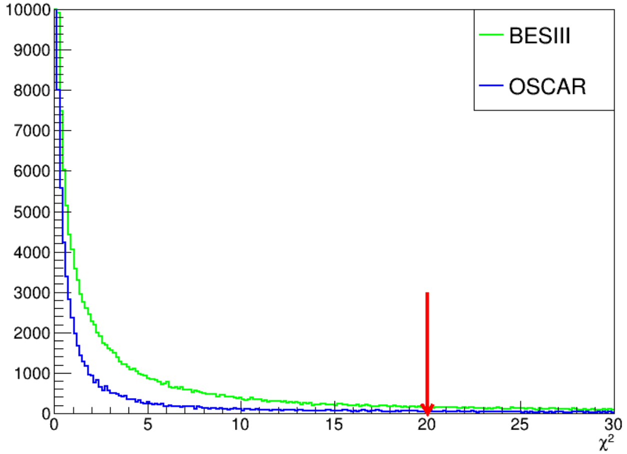
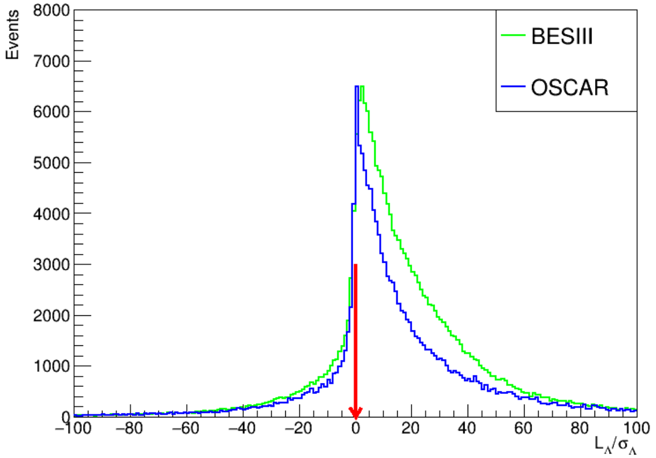
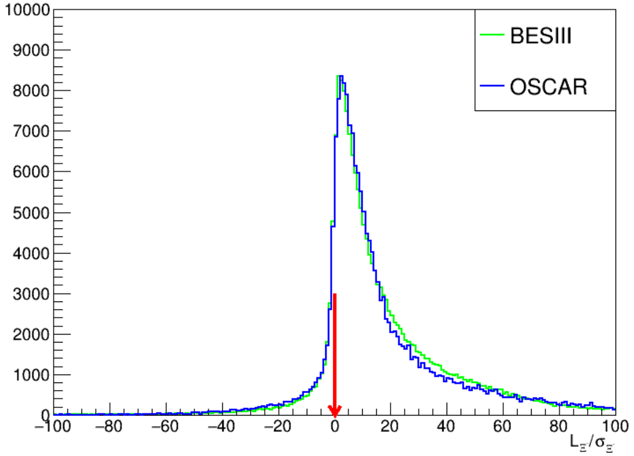
- DT Event Selection











Double tag analysis

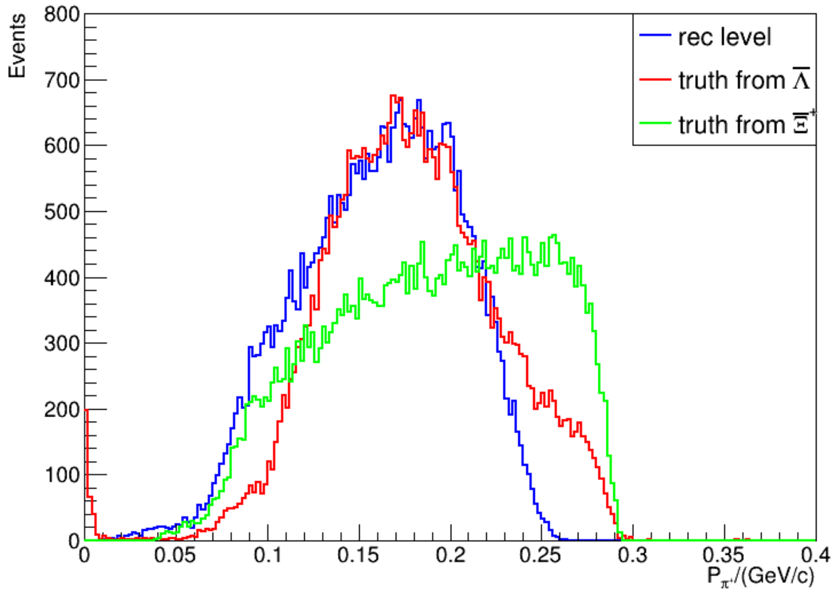
- Cut flow

Selection Criteria	OSCAR			BESIII		
	Absolute Efficiency(%) signal	Relative Efficiency(%) signal	Absolute Efficiency(%) dominant bkg	Absolute Efficiency(%) signal	Relative Efficiency(%) signal	Absolute Efficiency(%) dominant bkg
After DT Vertex fit	19.38	49.05	21.83	13.58	49.80	15.69
veto dominant bkg	15.87	81.88	5.02	11.99	88.29	2.97
$\frac{L_\Lambda}{\sigma_{L_\Lambda}} > 0$	12.74	80.15	2.14	9.98	83.24	2.39
$\frac{L_{\Xi^-}}{\sigma_{L_{\Xi^-}}} > 0$	9.69	75.87	1.01	8.60	86.17	1.26
χ^2<20	8.99	93.01	0.57	6.77	78.72	0.422
$\lvert M_{p^+\pi^-} - M_\Lambda^{\mathrm{PDG}}\rvert < 6MeV$	8.63	95.85	0.42	6.50	96.01	0.417

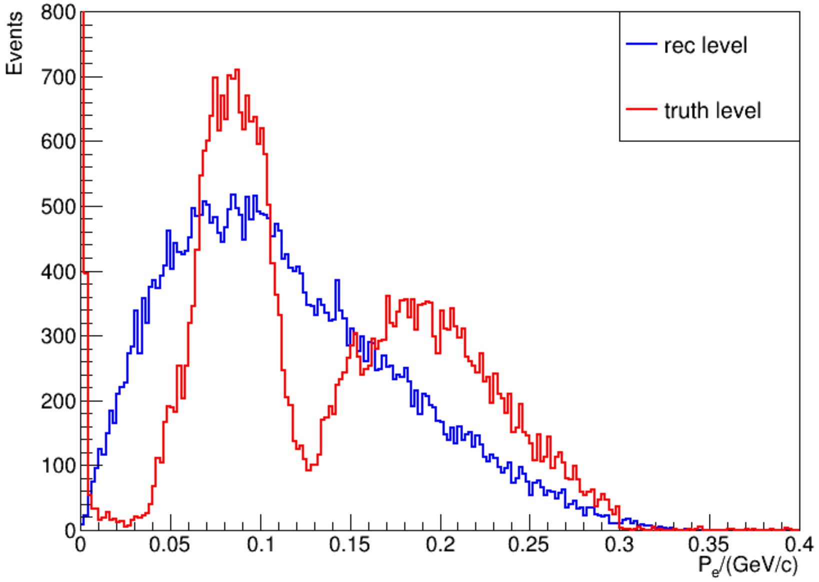
OSCAR : $\frac{S}{\sqrt{S+B}} \approx 27.10$

BESIII : $\frac{S}{\sqrt{S+B}} \approx 1.12$

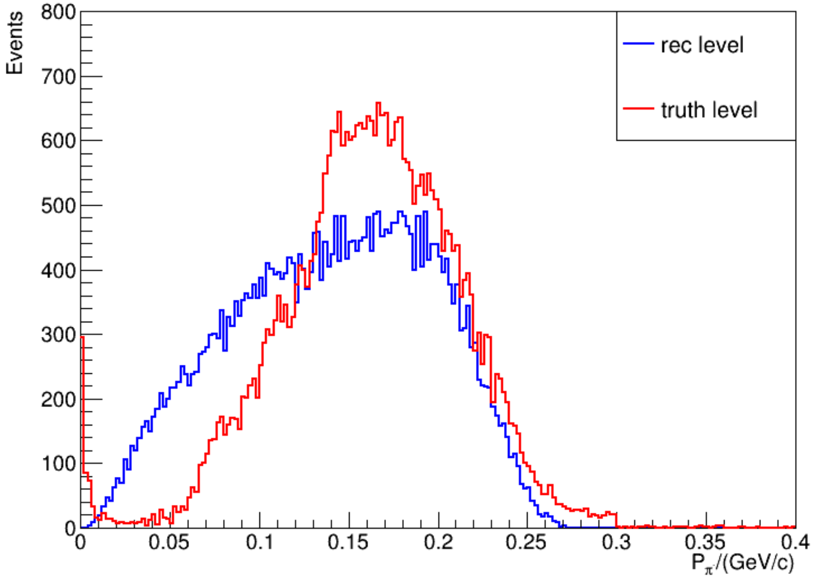
Truth VS Rec level(after GlobalPID)



P_{π^+}



P_{e^-}



P_{π^-}

Summary

- This work is now ready to study at the STCF under the OSCAR framework.
- Efficiency and signal-to-noise ratio have both been significantly improved compared to BESIII before GlobalPID. However, we hope to further improve GlobalPID in future studies.
- Understanding the reasons for the deviations in the central values and the asymmetry in the distribution of the numerous reconstructed mass spectra, and make further corrections.
- Improving efficiency, especially in electronic identification.

Thanks!