Longitudinal Λ Polarization in Tagged Z → ss Events with the CEPC AGORA Detector

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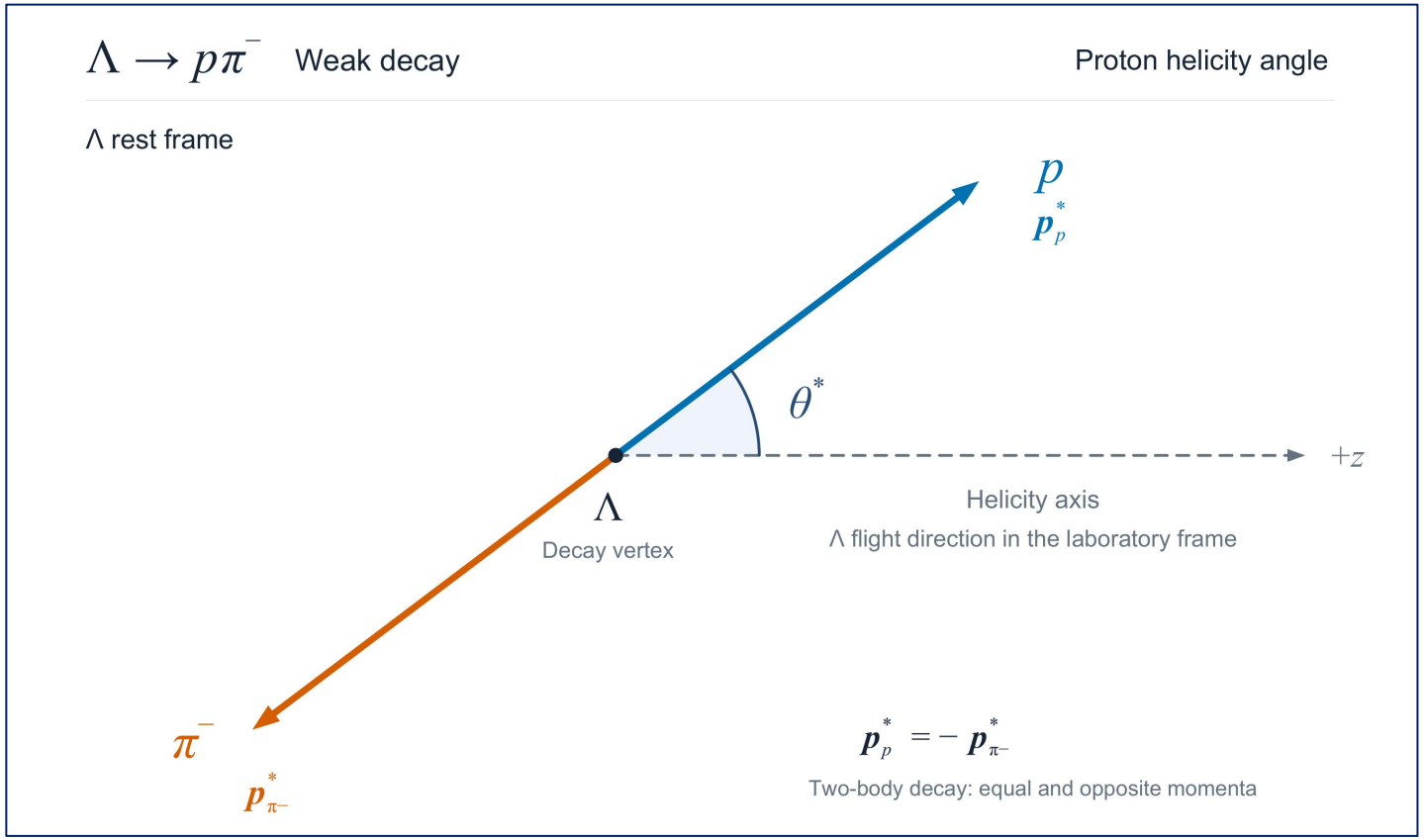


Introduction

- In Z^0 decays, longitudinal polarization of the primary strange quark will be transferred to a directly produced leading Λ.
- In $\Lambda \rightarrow p\pi$ decay, the angular distribution of the proton:

$$\frac{1}{N}\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^*} = 1 + \alpha P_L \cos\theta^*$$

θ*: the angle between the momentums of proton and Λ



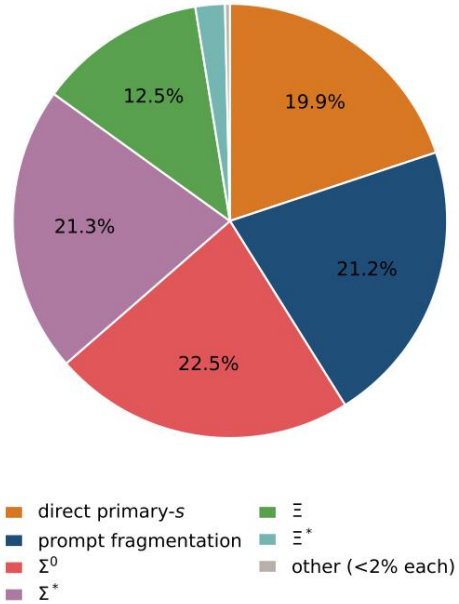
Motivation

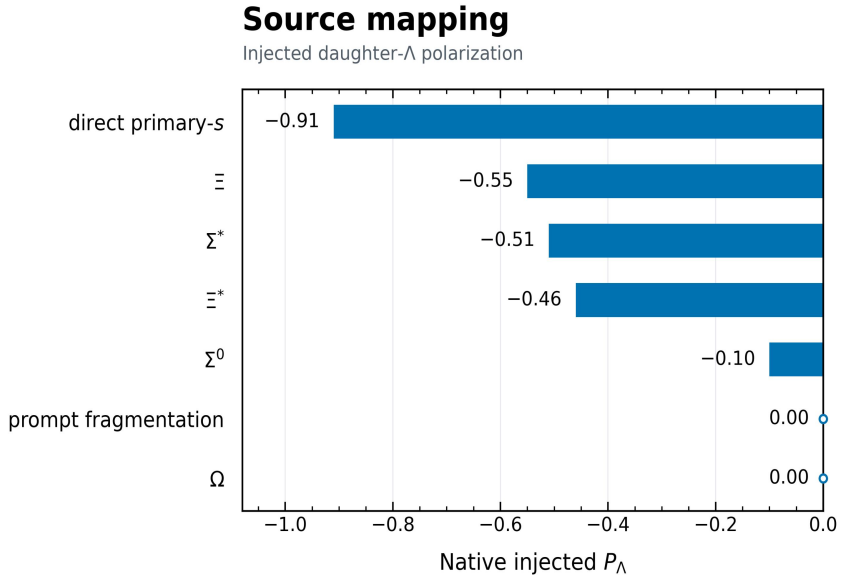
- **Λ Polarization measurement reveal the spin transference between strange quark and final state hadron.**

- Several Λ sources have different contributions to Λ Polarization.
  - Primary s quark in $Z \rightarrow ss$(direct-s contribution)
  - Parent strange hadron: Σ^0, Σ^*, Ξ, Ξ^*
  - Quarks from fragmentation: no polarization

- The measurement result from OPAL experiment(at LEP) can't be directly interpreted as the spin retention rate of the strange quark.
  - Based on mixed Λ sample, $x_E = 2E_\Lambda/\sqrt{s} > 0.3$ region.
  - $-0.329 \pm 0.055\ (\text{stat.}) \pm 0.052\ (\text{sys.})$.

- We want to **develop a measurement method for direct-s polarization on CEPC AGORA Detector(high luminosity at Z pole, advanced s-tagging technology).**





Sample Preparation

Event Generation

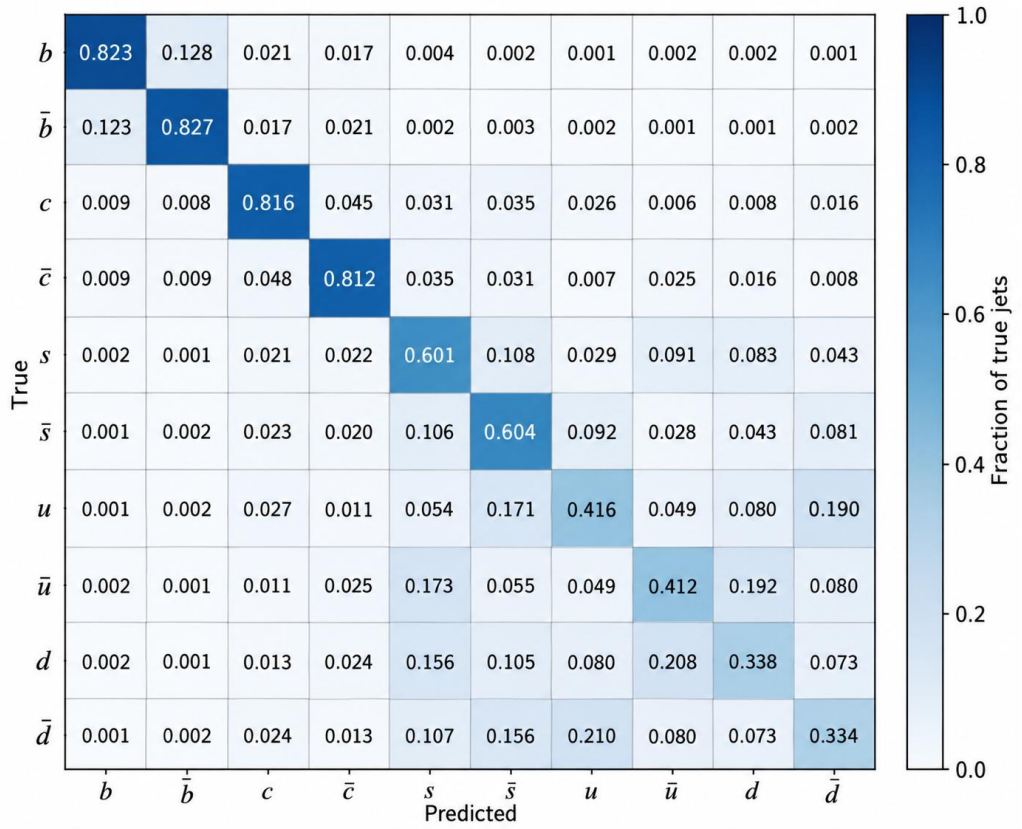
- **Polarized signal sample:** use OPAL Λ source model in PYTHIA8 to inject polarization to truth Λ
- **P = 0 signal sample:** evaluate angular response of the detector.
- **Background sample:** $Z \rightarrow$bb/cc/uu/dd.

Detector full simulation: GEANT4 and CEPCSW(TDR)

Sample	Events	Generation	Statistical role
native OPAL $Z \rightarrow s\bar{s}$	1 999 233	WHIZARD 3.1.7 + PYTHIA 8.310; source-dependent decay injection; schema-v9 full simulation	pseudo-observation for the disjoint fit categories
$Z \rightarrow s\bar{s}$, $P = 0$	1 799 243	same chain; no hard events shared with signal	source-resolved angular response; mass spectrum initializes DSCB only
current five-flavour $Z \rightarrow q\bar{q}$	2 500 000	WHIZARD 3.1.7 + PYTHIA 8.310; identity $P_\Lambda = 0$; schema-v9 full simulation	four non-$s\bar{s}$ flavours: input dilution and direct-fit rate/angle constraints; $s\bar{s}$: exposure reference and tag bookkeeping

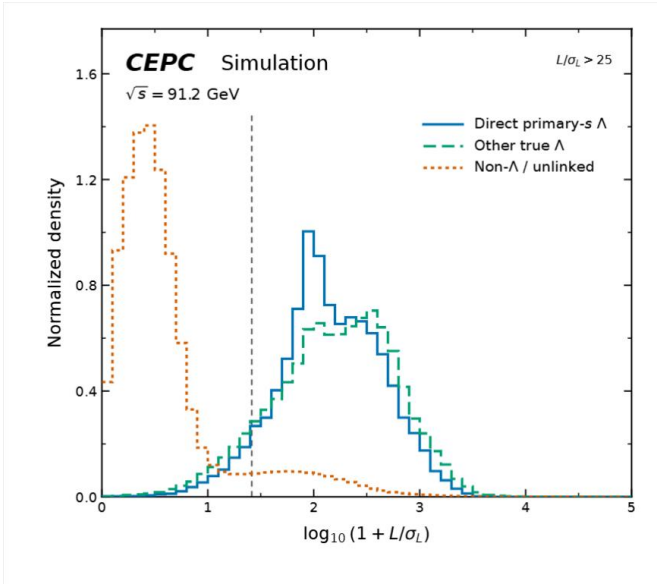
Event selection

- **Integrates Jet Origin Identification(TDR) for s-tagging**
  - Particle Transformer: training variables reconstructed from PFO information.
  - Criteria: 2 distinct jets classified as either s or sbar; same-sign tag pairs are accepted.
  - Good Efficiency and purity for signal channel.

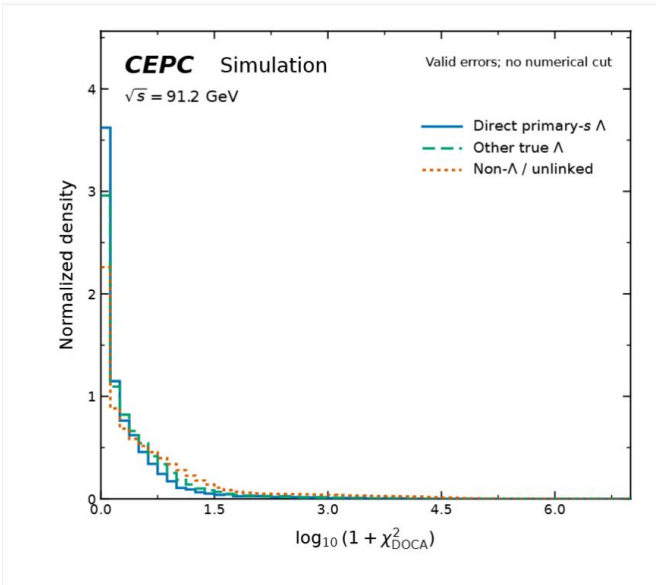


Generated process	N_{gen}	$N_{2(s/\bar{s})\text{-tag}}$	ε_f [%]	Selected composition [%]
$Z \to s\bar{s}$	1,999,233	915,834	45.809 ± 0.035	78.07
$Z \to d\bar{d}$	500,000	39,347	7.869 ± 0.038	13.41
$Z \to u\bar{u}$	500,000	29,443	5.889 ± 0.033	7.84
$Z \to c\bar{c}$	500,000	2,488	0.498 ± 0.010	0.66
$Z \to b\bar{b}$	500,000	48	0.010 ± 0.001	0.02

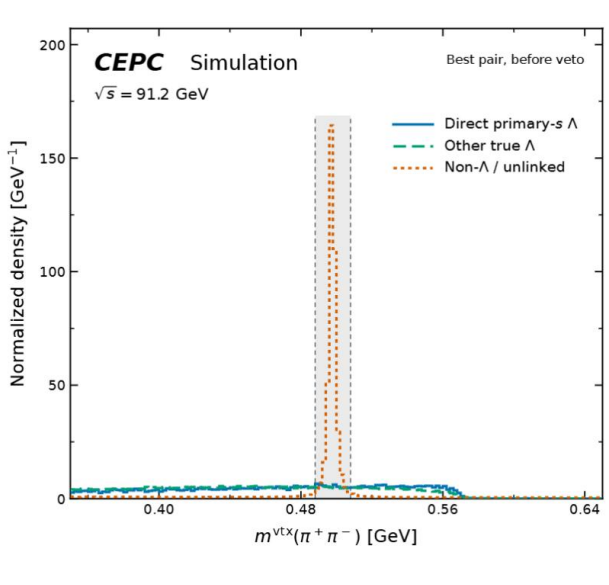
Λ candidates reconstruction



Decay length significance



Vertex fitting χ^2

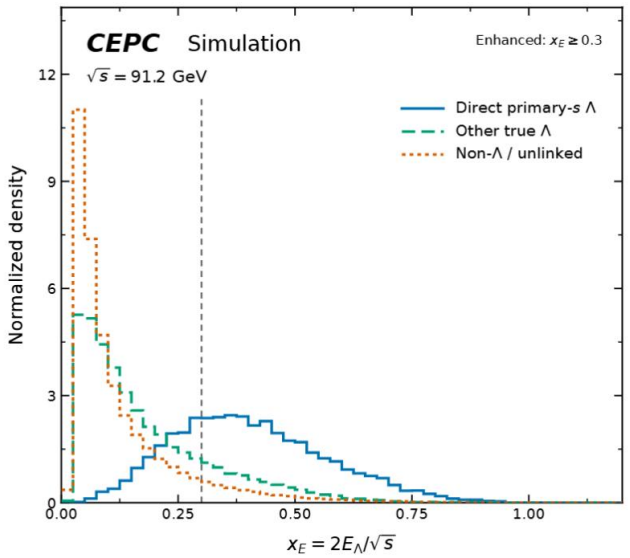


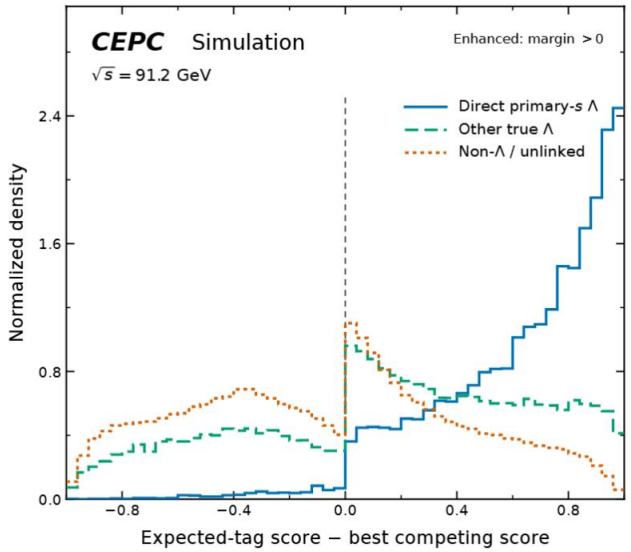
Invariant mass in ππ hypothesis

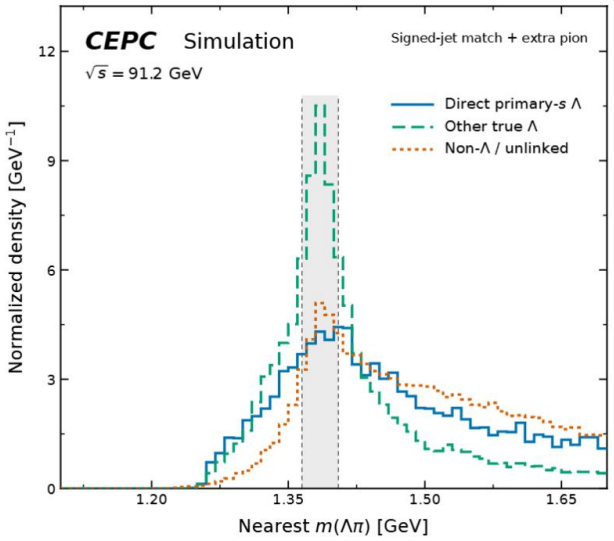
Λ candidates reconstructed from oppositely charged track pairs.

- $L/\sigma_L > 25$, minimum-χ^2 pair, $M(\pi\pi)$ out of K^0_S mass window
- The higher-momentum daughter particle is assigned as p or pbar, and its charge uniquely determines the $p\ \pi^-$ or $\pi^+\ \bar{p}$ hypothesis.
- Finally, only the M(pπ) and reconstructed angle of the selected hypothesis are passed into the fit.

Category Dividing Strategy







Divide Candidates into two disjoint categories

- **Signal enrichment condition:** $x_E = 2E_\Lambda/\sqrt{s} \geq 0.3$, charge hypothesis matches parent s-jet, $M(\Lambda\pi)$ out of $\Sigma(1385)$ window
- Enriched category: candidates pass all the conditions.
- Complement category: at least one failed.

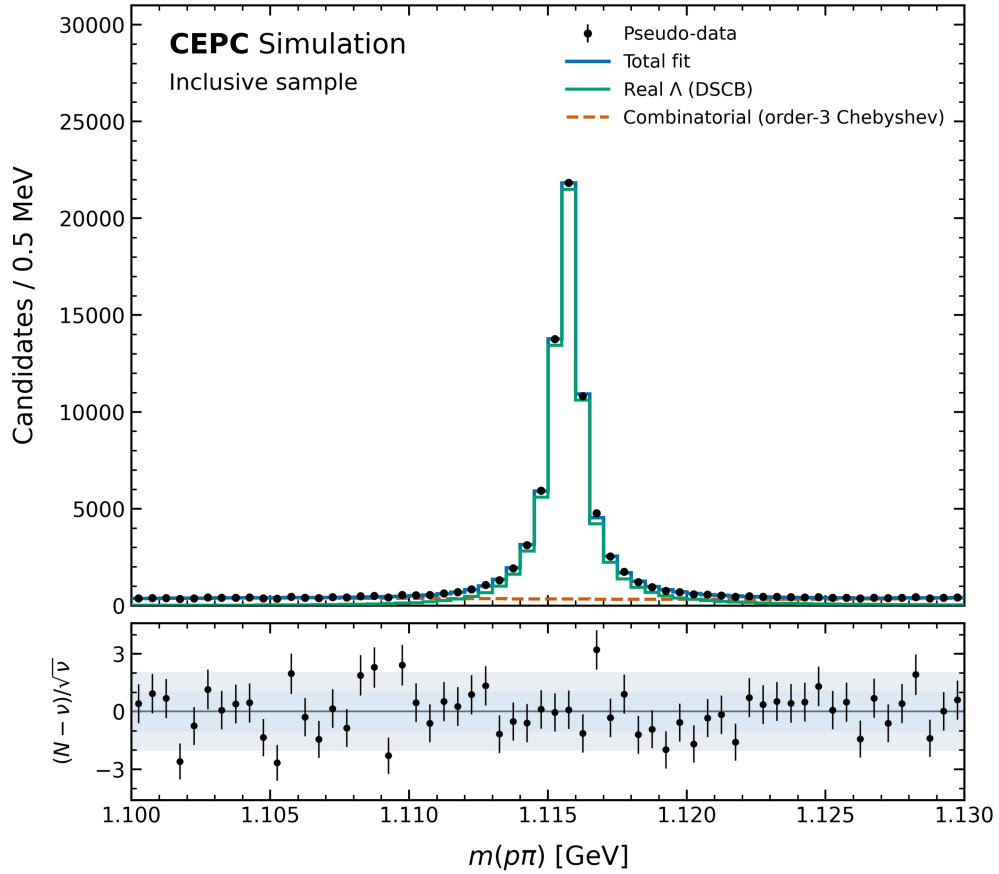
Entire Cutflow

Executed stage / final subset	Entries	Λ purity [%]	direct-primary-s [%]
Event gate			
input reconstructed events	1,999,233	–	–
two $s/\bar{s}$-like jets (same sign allowed)	915,834	–	–
tagged events with at least one reconstructed V0	915,804	–	–
Candidate chain inside tagged events			
tagged V0: $L/\sigma_L > 25$, valid errors, $\cos\theta_{\text{point}} > 0.50$	3,732,584	2.74	–
minimum-χ^2 pair	661,441	9.11	–
K^0_S veto	330,983	16.50	–
choose one signed p-π hypothesis	330,983	16.49	–
common mass–angle range (inclusive)	71,473	75.89	15.25
enhanced: $x_E \geq 0.3$, signed-s jet, $\Sigma(1385)$ veto	12,929	97.13	54.10
complement: fails at least one enrichment condition	58,544	71.20	6.67

Polarization fit based on mass-angle distribution

Separate signal(real Λ) from smooth background

- 10 bins for $\cos\theta^*$, [-1,1] ; 60 bins for $M(p\pi)$, [1.100, 1.130] GeV
- Fit the mass distribution in each $\cos\theta^*$ region: Double-side crystal ball(DSCB) for real-Λ peak, Chebyshev for smooth background.

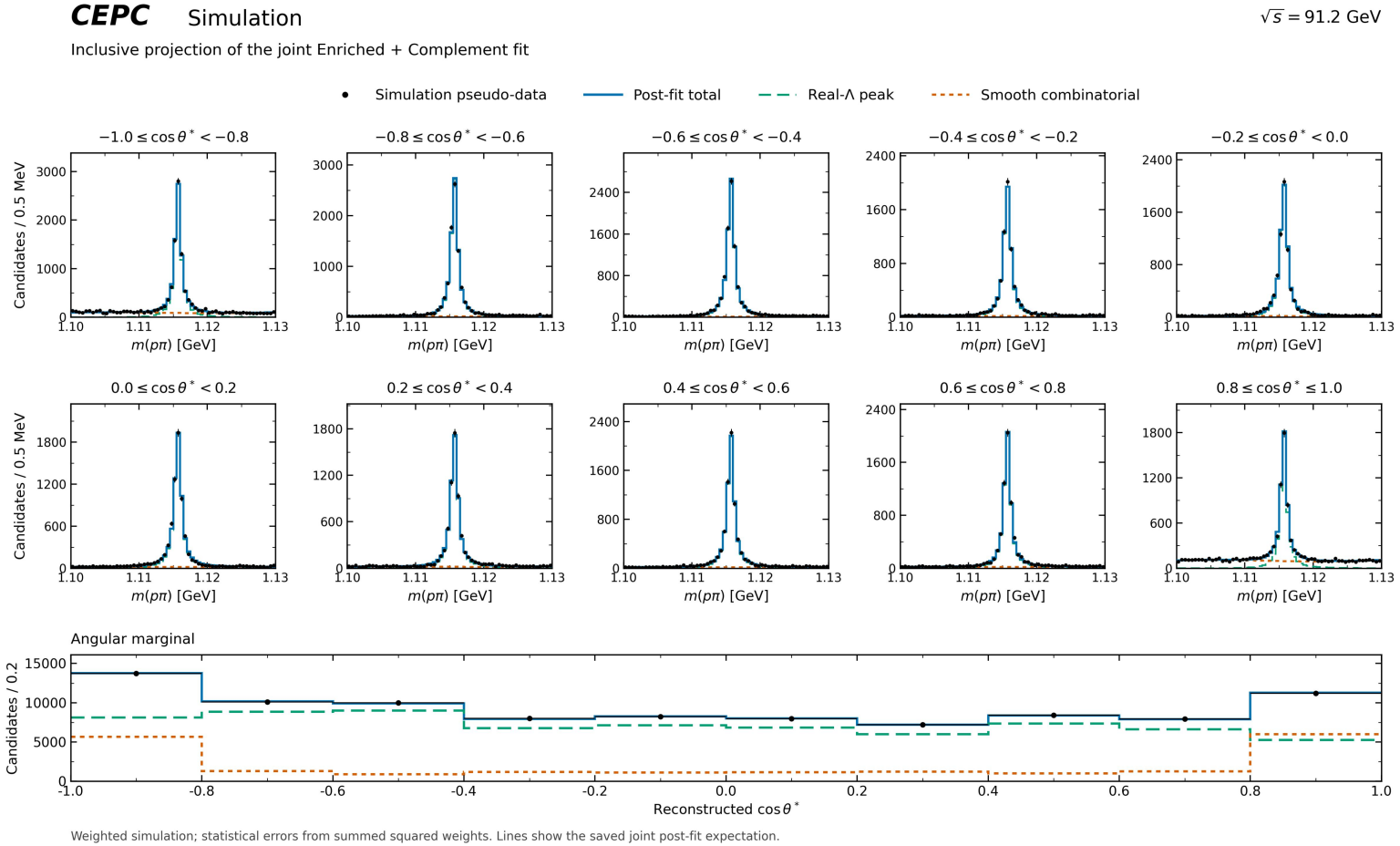


Polarization fit based on mass-angle distribution

Fit the angular distribution of separated signal

$$\widetilde{A}_i(P) \propto A_i\left(1 + \alpha_\Lambda P \cos\theta^*\right).$$

- A_i is the angular response of the detector(based on P = 0 $Z \rightarrow ss$ sample)

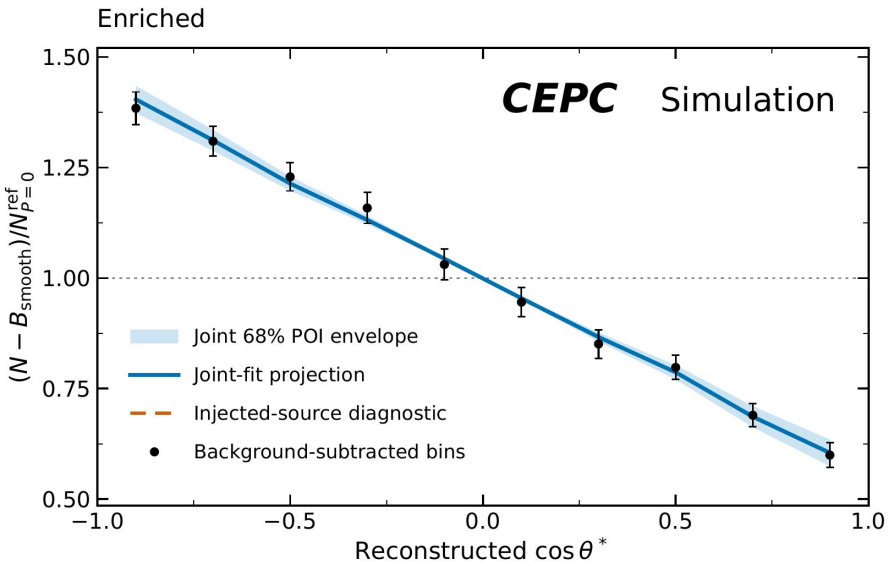


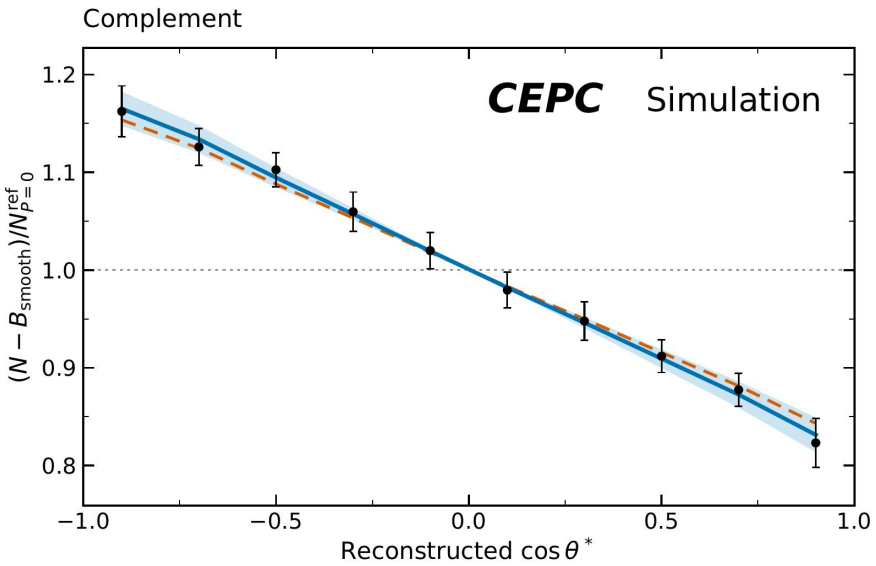
Systematic uncertainties

- Systematic uncertainties are passed into the likelihood function by Gaussian terms.
- Use Poison term to constrain the P=0 MC statistical uncertainty in angular response.

Source	$P_{direct\text{-}s}$ lower	$P_{direct\text{-}s}$ upper	Max. variance share:$P_{direct\text{-}s}$
External α_{Λ}	0.00982	0.00814	1.51%
Angular resolution	0.00000	0.00000	0.00%
Tag response (composition)	0.00905	0.00962	1.45%
Response MC (P0 acceptance + shared denominator)	0.04392	0.04452	31.02%
Current Zqq MC (numerator rate + angular shape)	0.04097	0.04022	26.23%
Mass-angle peak	0.00889	0.00899	1.27%
Mass order	0.00000	0.00000	0.00%

Fitting result of P_{eff} in two categories: enriched and complement





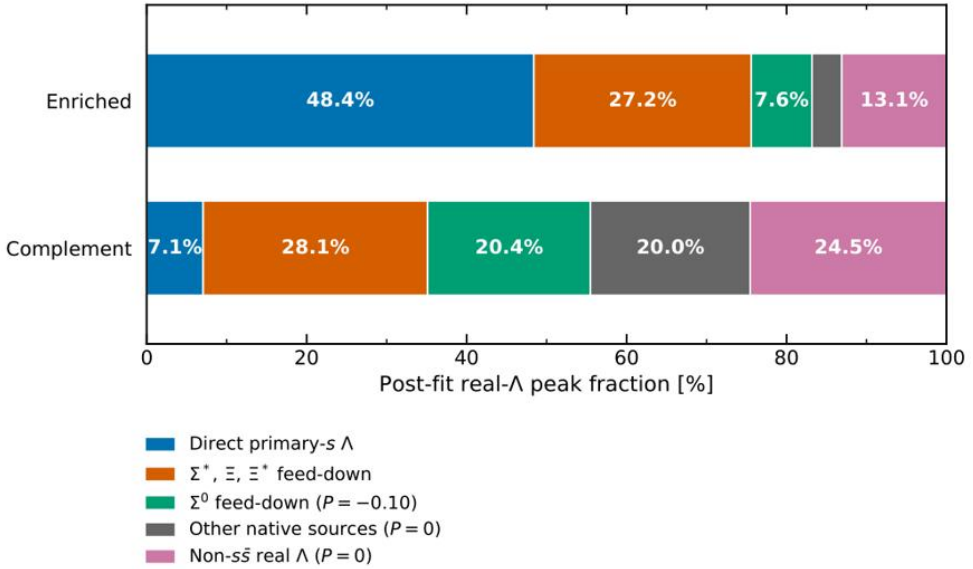
selected category	current input	fitted P_{eff}
inclusive	-0.3047	$-\mathbf{0.3137}^{+0.0097}_{-0.0097}\,(\mathrm{stat})\,^{+0.0103}_{-0.0102}\,(\mathrm{MC\ stat})\,^{+0.0048}_{-0.0050}\,(\mathrm{syst})$
enriched	-0.5893	$-\mathbf{0.5813}^{+0.0191}_{-0.0190}\,(\mathrm{stat})\,^{+0.0192}_{-0.0189}\,(\mathrm{MC\ stat})\,^{+0.0097}_{-0.0101}\,(\mathrm{syst})$
complement	-0.2302	$-\mathbf{0.2382}^{+0.0110}_{-0.0110}\,(\mathrm{stat})\,^{+0.0119}_{-0.0119}\,(\mathrm{MC\ stat})\,^{+0.0027}_{-0.0030}\,(\mathrm{syst})$

Measurement of direct-s Λ polarization

- A joint fit framework is built based on enriched and complement region.

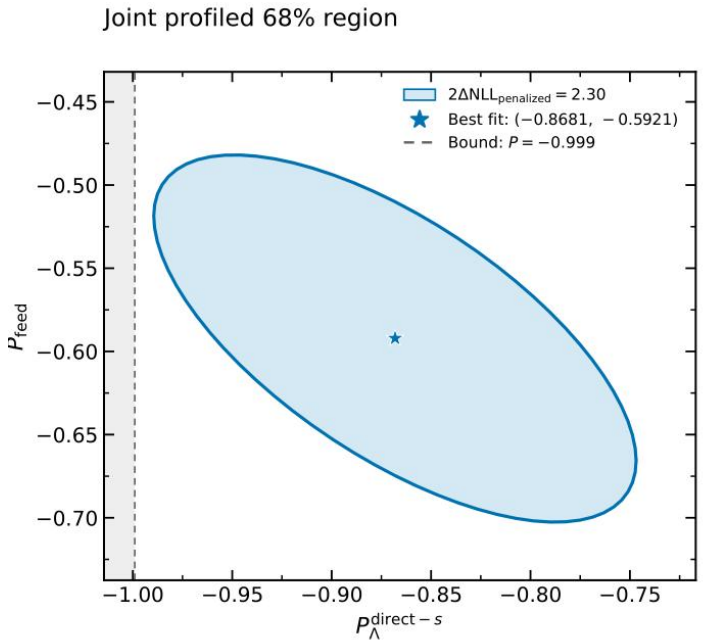
- Define four polarization components:
  - direct s quark contribution, $P_{\text{direct-s}}$
  - Σ^* , Ξ, Ξ^*contribution, P_{medium}
  - Σ^0 contribution, fixed to -0.10
  - zqq background contribution, fixed to 0.

- The proportion of each sources is different between two region: Constrain two polarization value.



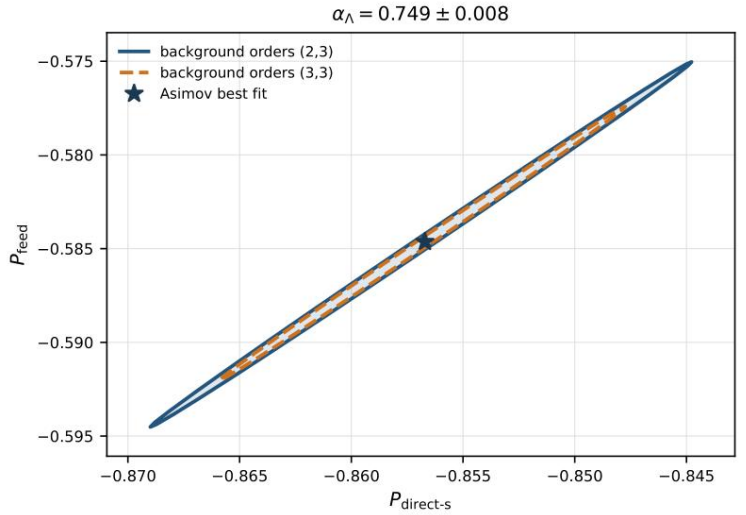
$$P_D = -0.868114^{+0.05228}_{-0.05213}\,(\text{stat})^{+0.05914}_{-0.05917}\,(\text{MC stat})^{+0.01262}_{-0.01337}\,(\text{syst})$$

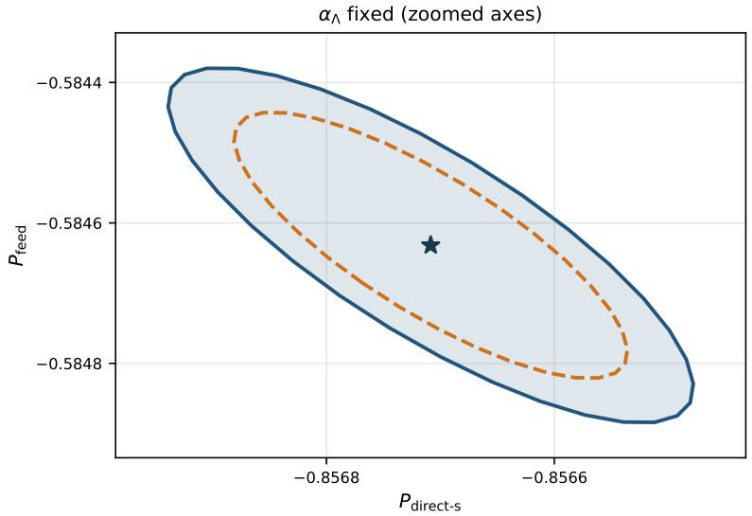
$$P_M = -0.592067^{+0.04688}_{-0.04686}\,(\text{stat})^{+0.05515}_{-0.05516}\,(\text{MC stat})^{+0.00681}_{-0.00820}\,(\text{syst})$$



Tera-Z

- According to TDR, CEPC running at Z pole will produce 4×10^{12} Z bosons.
- In Tera-Z statistics, the uncertainty can be reduced to 10^{-3} level, dominated by theoretical uncertainty from decay parameter α_Λ.





Same quantity	Current fit full 68% profile result	Tera-Z expected errors lower / upper, full 68% profile	Tera-Z Only α_Λ fixed
Reconstructed mixtures (pp. 13–14)			
inclusive P_{eff}	$-0.3137^{+0.0144}_{-0.0145}$	$-0.00334/+0.00327$	$-0.000025 / +0.000025$
enriched P_{eff}	$-0.5813^{+0.0278}_{-0.0277}$	$-0.00628/+0.00614$	$-0.000052 / +0.000052$
complement P_{eff}	$-0.2382^{+0.0162}_{-0.0163}$	$-0.00253/+0.00248$	$-0.000030 / +0.000030$
Source interpretation (p. 15)			
$P_{\text{direct-s}}$	$-0.8681^{+0.0783}_{-0.0785}$	$-0.00810/+0.00795$	$-0.000153 / +0.000153$
P_{medium}	$-0.5921^{+0.0701}_{-0.0702}$	$-0.00652/+0.00639$	$-0.000168 / +0.000168$

Fixing only α_Λ reduces the direct-s 1D half-width from 0.008025 to 0.000153; all other retained uncertainties remain.

Summary

- **The first direct-s Λ polarization measurement based on CEPC full-simulation data**
  - Based on 2 million polarized events: $P_{\text{direct-s}} = -0.868114^{+0.05228}_{-0.05213}\,(\text{stat})^{+0.05914}_{-0.05917}\,(\text{MC stat})^{+0.01262}_{-0.01337}\,(\text{syst})$.
  - In Tera-Z statistics, this method can be used to measure the spin transference from strange quark with high precision.

- **Future Plan**
  - Complete the systematic uncertainty.
  - Consider polarization of zqq background.
  - Try to apply this method on LEP open data.

Thank you for your attention!