Study of Inclusive η Production at BESIII

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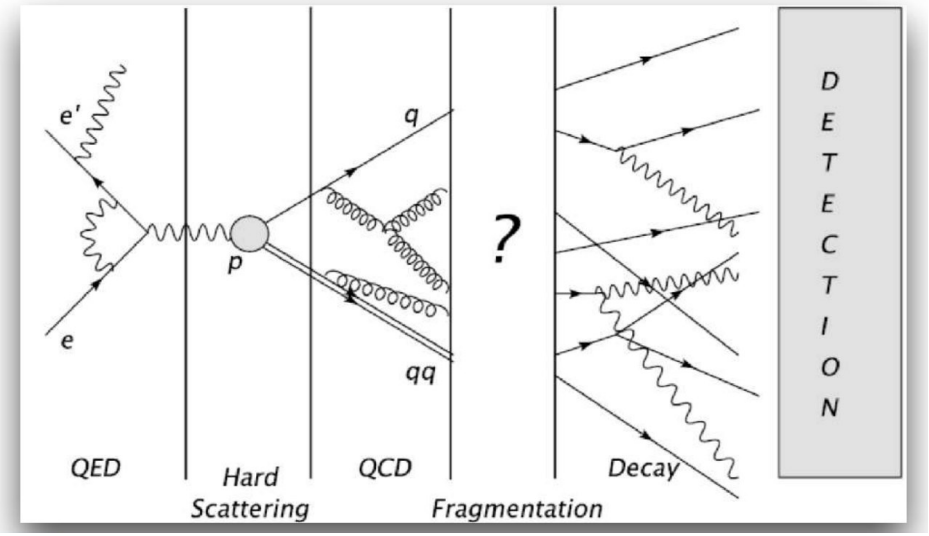
Outline

- Introduction
- Study of inclusive η production
- Summary

Fragmentation Function

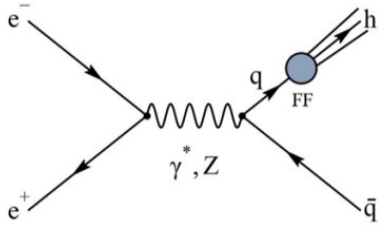
- **Fragmentation Function (FF) $D_p^h(z, Q^2)$: describes the probability to find a hadron h in the debris of a parton p, where $z = 2E_h/\sqrt{s}$ is the energy fraction of the hadron**
  - **Key ingredient for hadronization**
  - **Non-perturbative QCD, parametrization**
  - **Transverse-momentum dependent (TMD) FFs: polarized partons/hadrons**



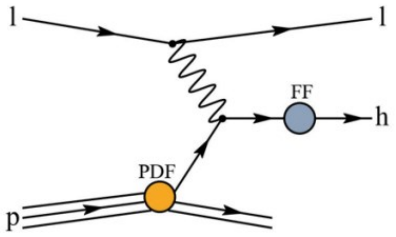
hadron\parton	Unpolarized	Longitudinally	Transversely
Unpolarized	$D_1^{h/p}$		$H_1^{\perp h/p}$
Longitudinally		$G_1^{h/p}$	$H_{1L}^{\perp h/p}$
Transversely	$D_{1T}^{\perp h/p}$	$G_{1T}^{h/p}$	$H_1^{h/p}$ $H_{1T}^{\perp h/p}$

Fragmentation Function

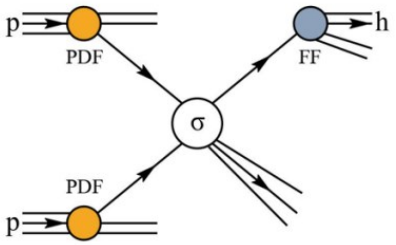
- **Universality: measured in e^+e^-, DIS, pp and $p\bar{p}$**
- **$\hat{\sigma}$: perturbative parts**



$$\sim \sum_q \hat{\sigma} \otimes FF$$



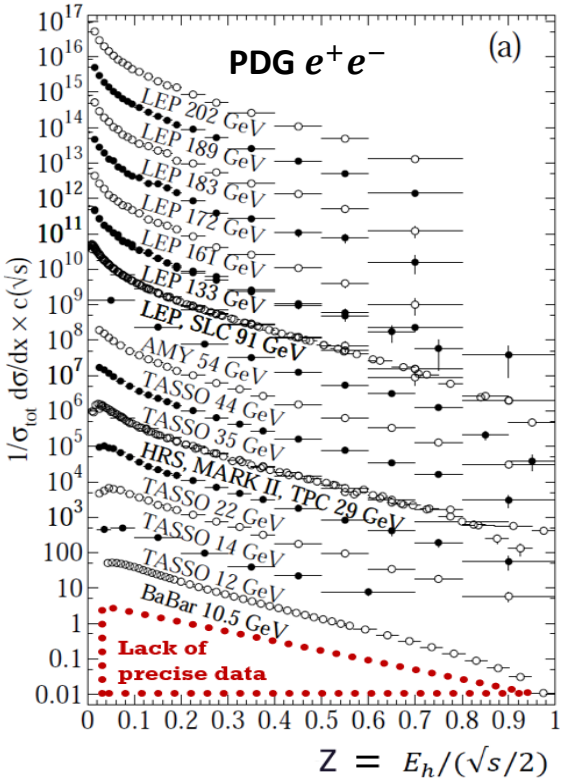
$$\sim \sum_q \hat{\sigma} \otimes PDF \otimes FF$$

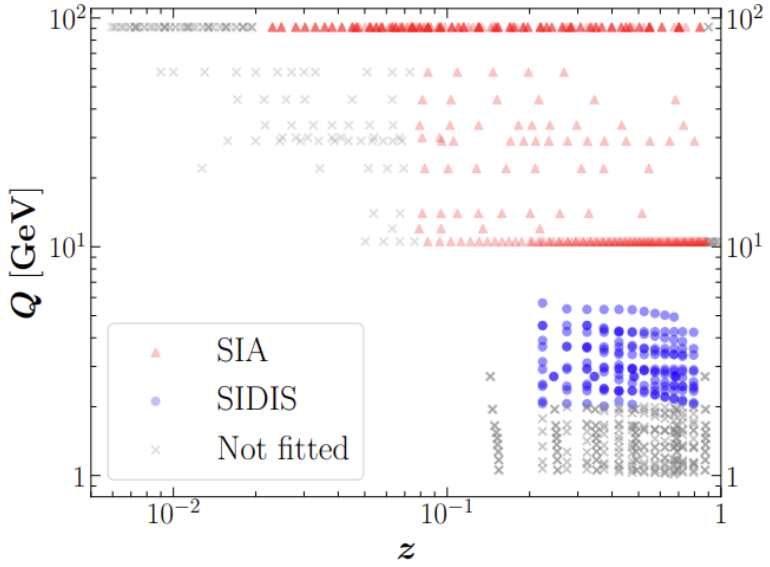


$$\sim \sum_q \hat{\sigma} \otimes PDF \otimes PDF \otimes FF$$

Study of π/K FFs

- **The most studied FFs**
- **Global data fit:**
  - e^+e^- **annihilation:** lack of $\sqrt{s} < 10$ GeV data
  - **DIS:** low Q^2
  - **What about e^+e^- annihilation below 10 GeV?**

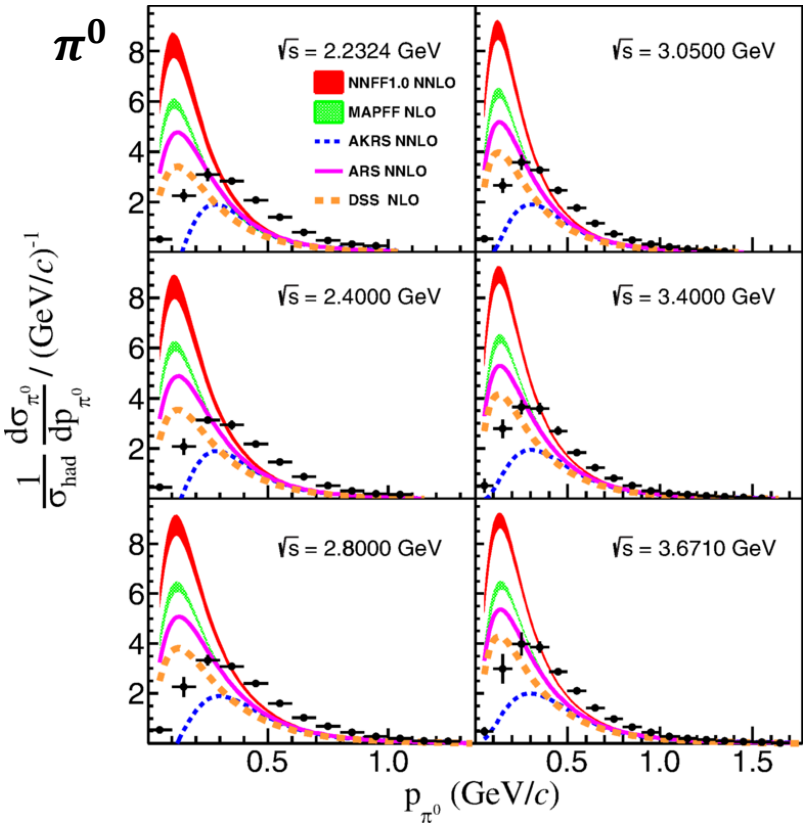


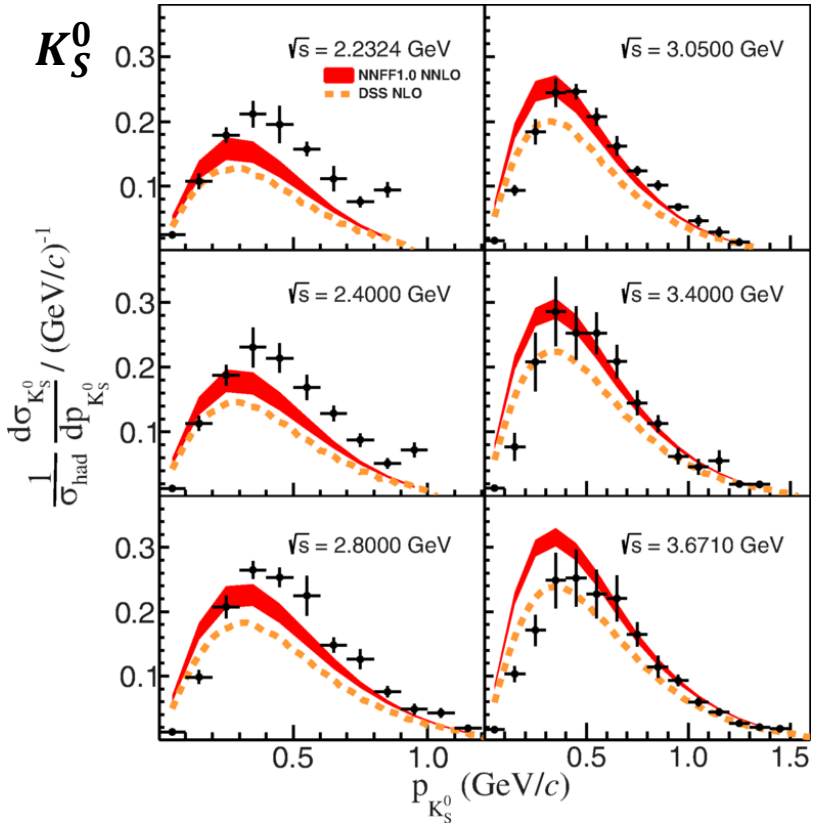


Phys. Rev. D 104, 034007 (2021)

Study of π^0 / K_S^0 FFs on BESIII

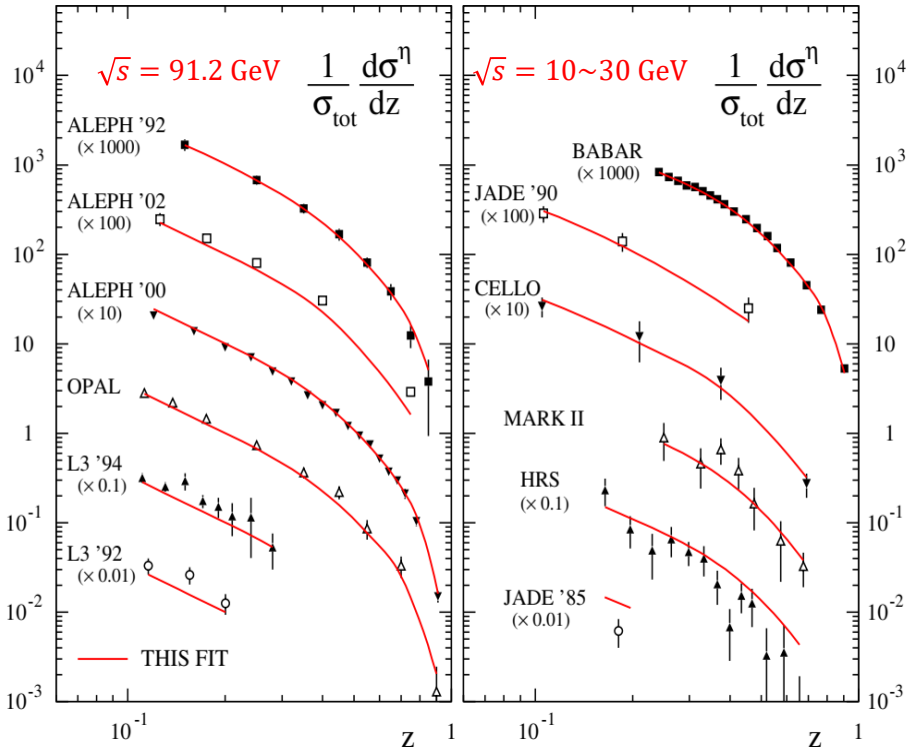
- 6 energy points between 2.2324 and 3.6710 GeV
- Phys. Rev. Lett. 130, 231901 (2023)
- Discrepancy found between measured results and theoretical calculations





Study of η FF

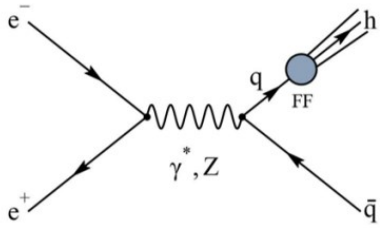
- η: Pseudoscalar meson containing u, d, s quarks
- Lack of precise measurements at $\sqrt{s} < 10$ GeV
  - Necessary to be studied at BESIII



Experiment	$\sqrt{s}$ (GeV)	Data points	fitted	χ^2
BABAR [36]	10.58	18		8.1
HRS [25]	29	13		51.6
MARK-II [26]	29	7		3.8
JADE '85 [27]	14, 22.5, 29.9-38.7	1		9.6
JADE '90 [28]	35	3		1.2
CELLO [29]	35	4		1.1
ALEPH '92 [30]	91.2	8		2.0
ALEPH '00 [31]	91.2	18		22.0
ALEPH '02 [32]	91.2	5		61.6
L3 '92 [33]	91.2	3		5.1
L3 '94 [34]	91.2	8		10.5
OPAL [35]	91.2	9		9.0
PHENIX 2γ [17]	200 (ion collision)	12		4.1
PHENIX 3π [17]		6		2.9
PHENIX '06 [18]	200 ($p+p$)	25		13.3
TOTAL		140		205.9

Phys. Rev. D 83, 034002 (2011)

Study of FFs on BESIII

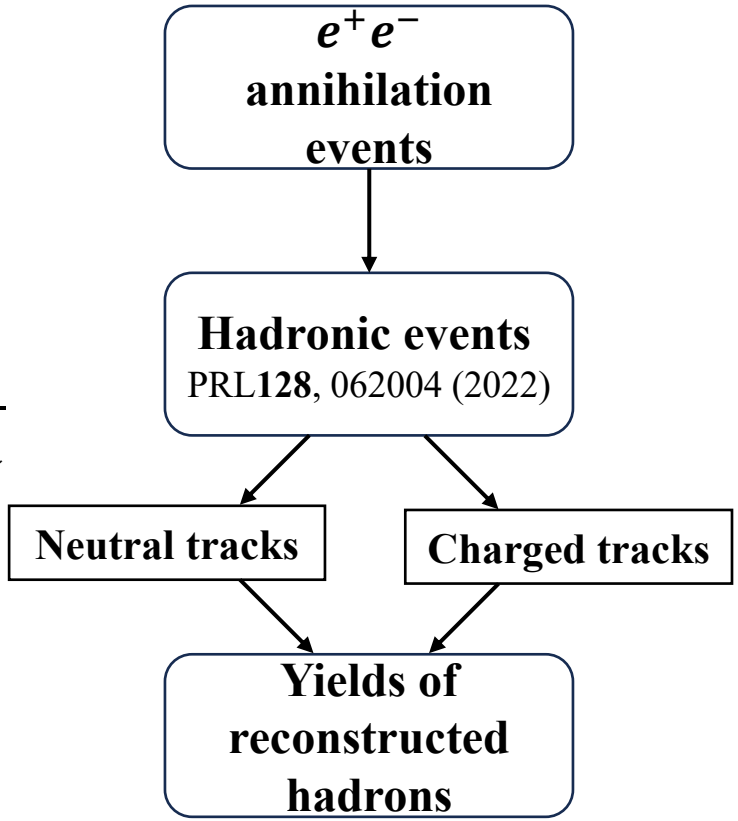


$$\sim \sum_q \hat{\sigma} \otimes FF$$

- **Observable:**

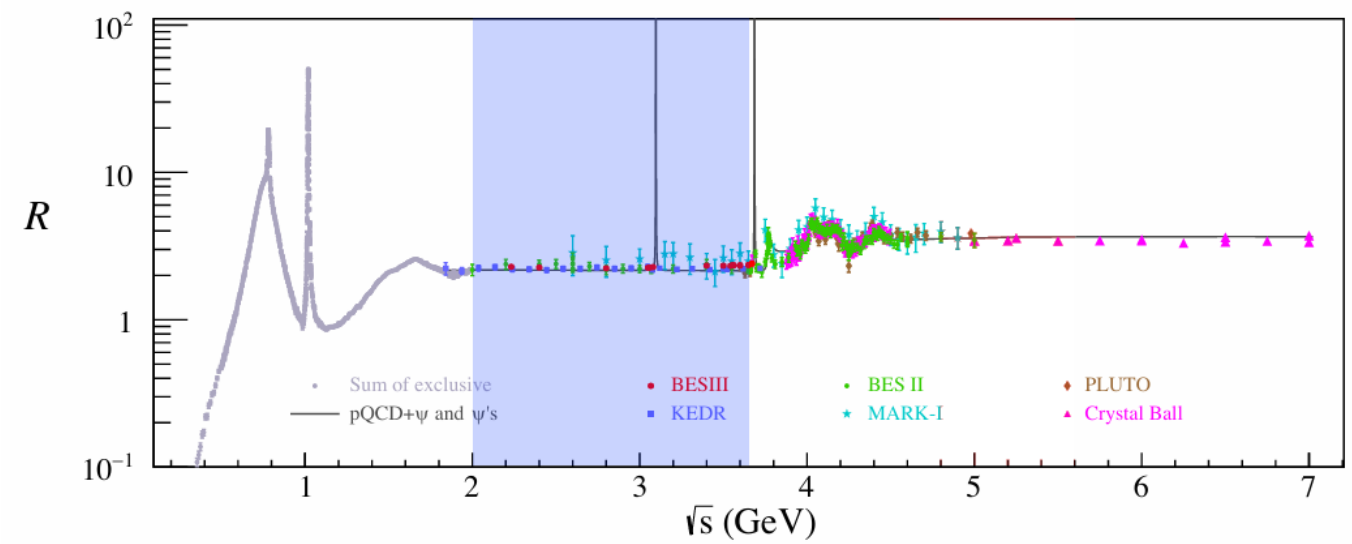
$$\frac{1}{\sigma(e^+e^- \to \text{hadrons})} \frac{\mathrm{d}\sigma(e^+e^- \to h + X)}{\mathrm{d}p_h} = f \frac{N_{h+X}^{\text{obs}}}{N_{\text{had}}^{\text{obs}}} \frac{1}{\Delta p_h}$$

- **f:** correction factor extracted from MC



Data Samples

- **Experimental data:**



$\sqrt{s}$ (GeV)	$\mathcal{L}_{\text{int}}$ (pb^{-1})
2.0000	10.074
2.2000	13.699
2.3960	66.869
2.6444	33.722
2.9000	105.253
3.0500	14.893
3.5000	3.633
3.6710	4.628

- **Monte-Carlo simulation:**

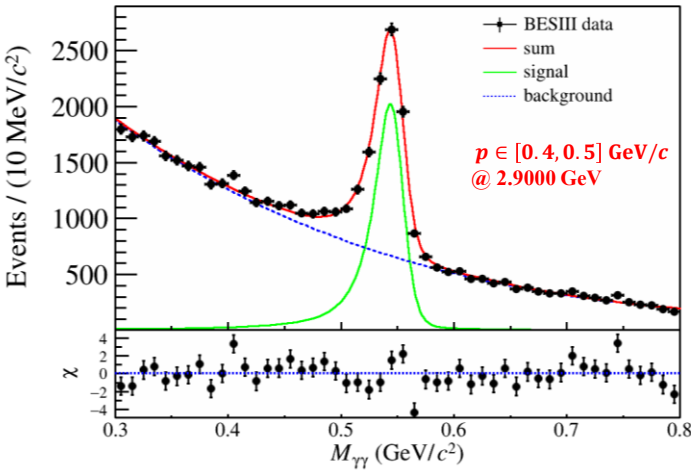
$e^+e^- \to q\bar{q}$ by **LUARLW/HYBRID**

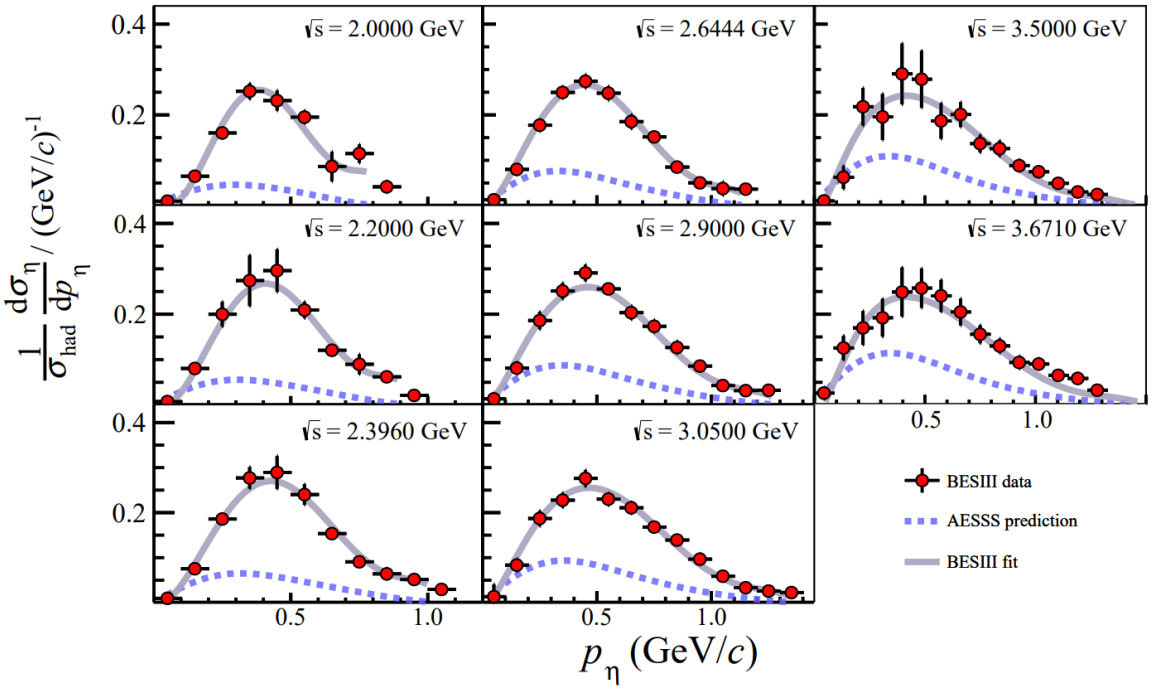
QED BKG:
- $e^+e^- \to e^+e^-/\gamma\gamma/\mu^+\mu^-$ by **Babayaga v3.5**
- $e^+e^- \to \tau^+\tau^-$ by **KKMC**
- $e^+e^- \to e^+e^- + X$(X: leptons and hadrons) by **DIAG36**, **EKHARA**, **GALUGA 2.0**

Measurement Results

中国科学技术大学
University of Science and Technology of China

- Published in Phys. Rev. Lett. **133**, 021901 (2024)
- **First measurements** below 4 GeV
- **Obvious discrepancy** compared with predictions from previous study

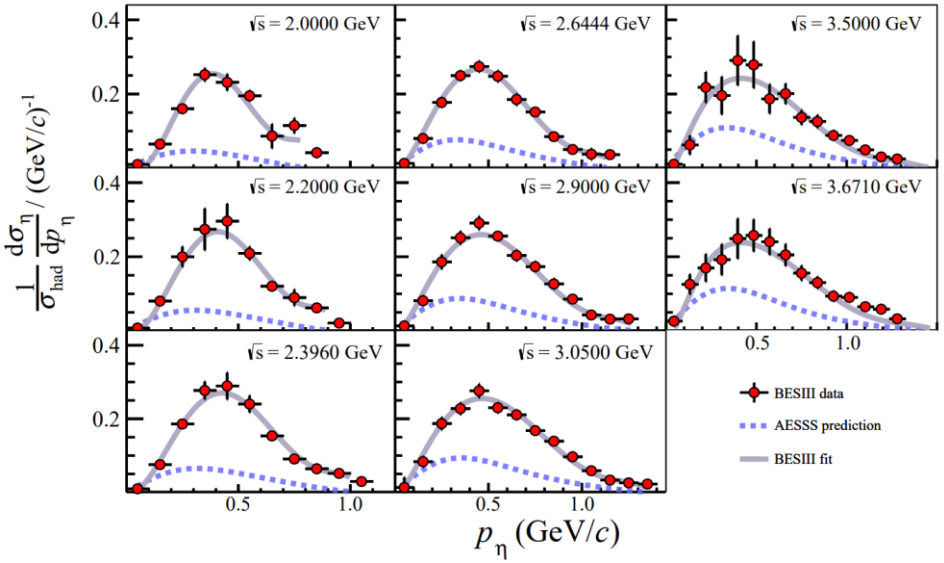




Theoretical Calculations

- **Finished by cooperators from SCNU theoretical group**
- New fit using both BESIII data and other high energy e^+e^- data
  - Extend QCD calculation **from NLO to NNLO**
  - With **higher-twist effects (HT)** and **hadron mass corrections (HMC)**
- **arxiv: 2404.11527** for details

precision	$N_{data\ points}$	total χ^2	χ^2/N_{dp}
NLO (AESSS)	179	2289.36	12.79
NLO+HMC	195	1334.19	6.84
NNLO+HMC	195	791.16	4.06
NNLO+HMC+HT($1/Q^2$)	195	463.24	2.35
NNLO+HMC+HT($1/Q^4$)	**195**	**306.00**	**1.52**



New fit agrees well for both high energy world data and BESIII data

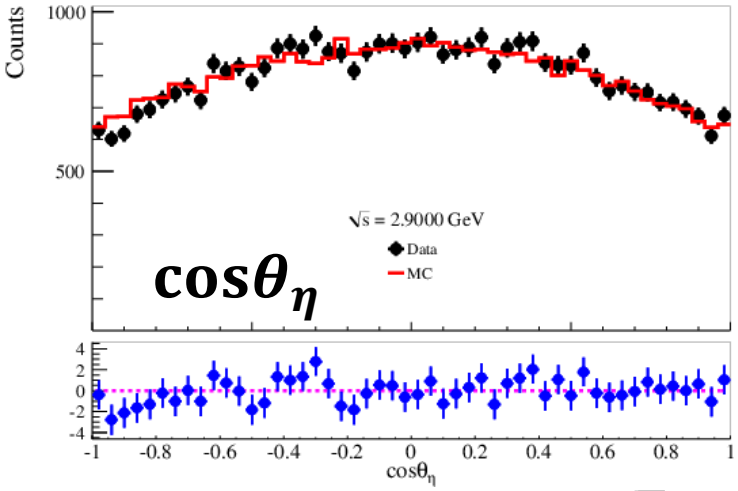
Summary

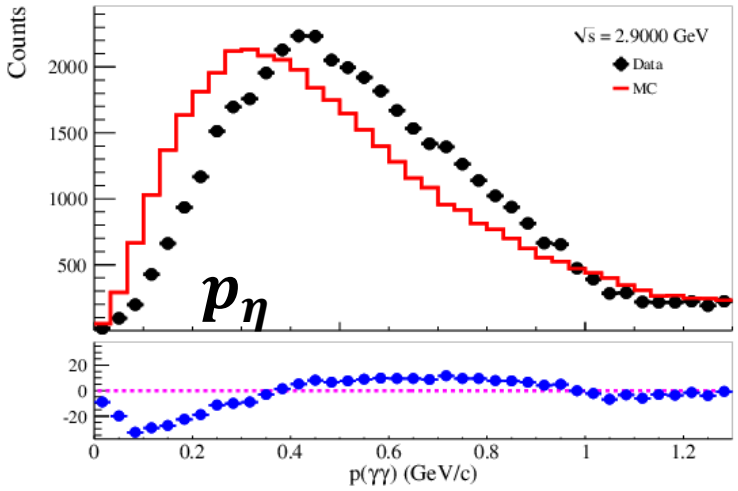
- **Inclusive η production:**
  - **First measurements with momentum dependence at $\sqrt{s} < 10$ GeV**
  - **Obvious discrepancy between BESIII data and current QCD-based η FF calculations, challenging the existing knowledge for the hadronization in low energy region**

Thanks for your attention!

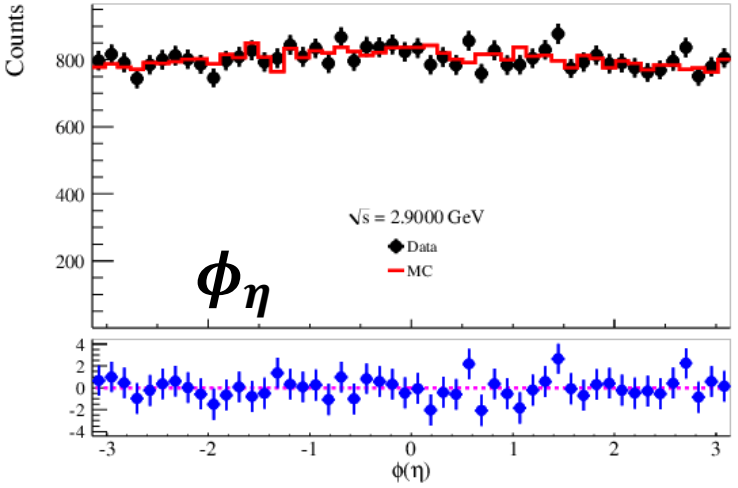
Backups

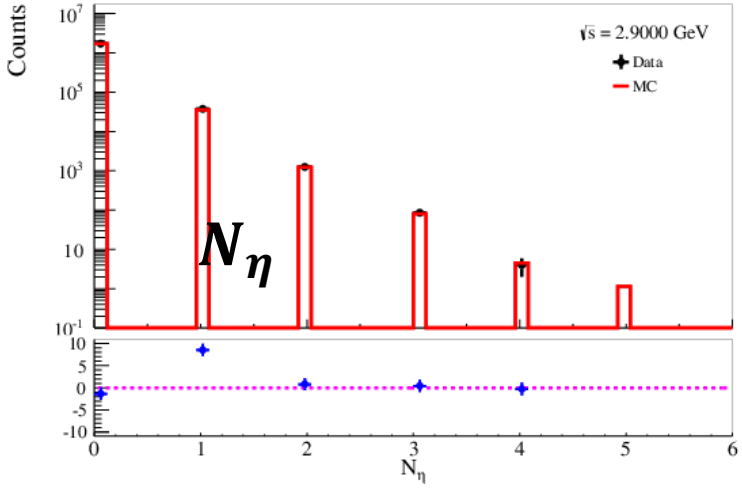
Data vs. LUARLW MC





$$\sqrt{s} = 2.9000\ \text{GeV}$$

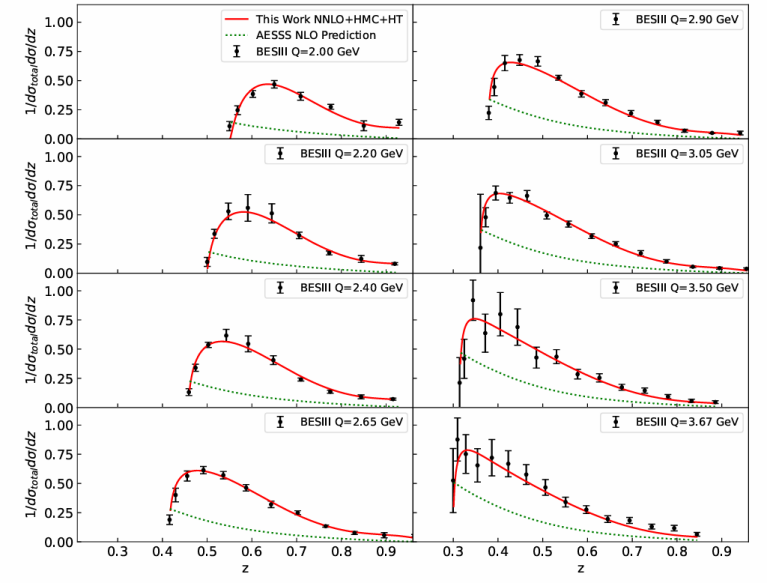




Systematic Uncertainties

- **Hadronic event selection:** $< 5\%$
- **π^0 photons veto:** $< 1\%$
- **η helicity:** $\sim 2.17\%$, estimated with η control sample
- **η reconstruction:** $\sim 2.06\%$
  - Single photon reconstruction
  - $BR(\eta \to \gamma\gamma)$
- **Fit scheme:** $< 5\%$
  - η match angle
  - Fit models
- **Signal MC model (dominant): LUARLW→HYBRID**

Backup



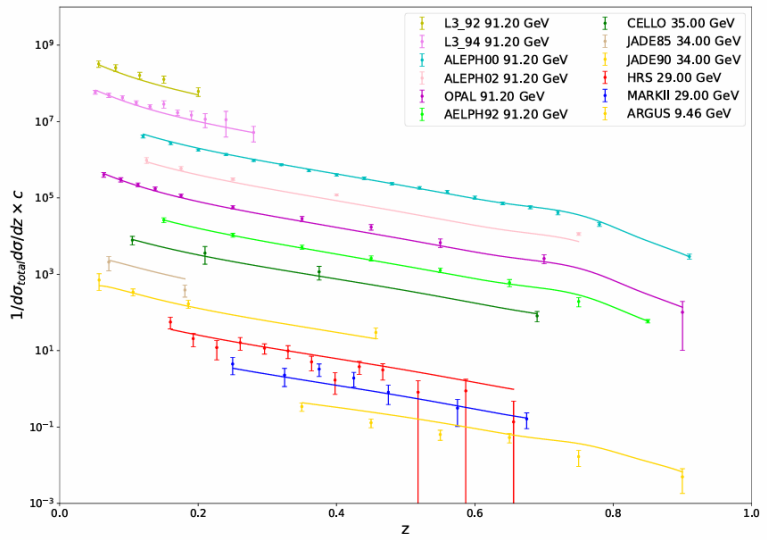


FIG. 6: Same as Fig.4, but for η.

TABLE VI: Same as Tab.IV, but for η.

Exp(η)	$\sqrt{s}$ [GeV]	N_{dp}	χ^2/N_{dp}
ARGUS [44]	9.46	6	5.69
HRS [67]	29.0	13	3.10
MARK II [68]	29.0	7	0.56
JADE [50]	34.4	2	3.77
JADE [51]	35.0	4	0.44
CELLO [48]	35.0	4	0.18
ALEPH [69]	91.2	8	0.59
ALEPH [53]	91.2	18	1.07
ALEPH [70]	91.2	5	11.18
L3 [71]	91.2	5	1.11
L3 [56]	91.2	11	1.19
OPAL [54]	91.2	11	0.90
BESIII [8]	2.00	8	2.38
BESIII [8]	2.20	9	0.67
BESIII [8]	2.39	10	1.25
BESIII [8]	2.64	11	0.36
BESIII [8]	2.90	13	0.67
BESIII [8]	3.05	13	0.55
BESIII [8]	3.50	15	0.72
BESIII [8]	3.67	15	1.42
TOTAL		188	1.52

Backup