

Fragmentation Function studies at **BESIII**

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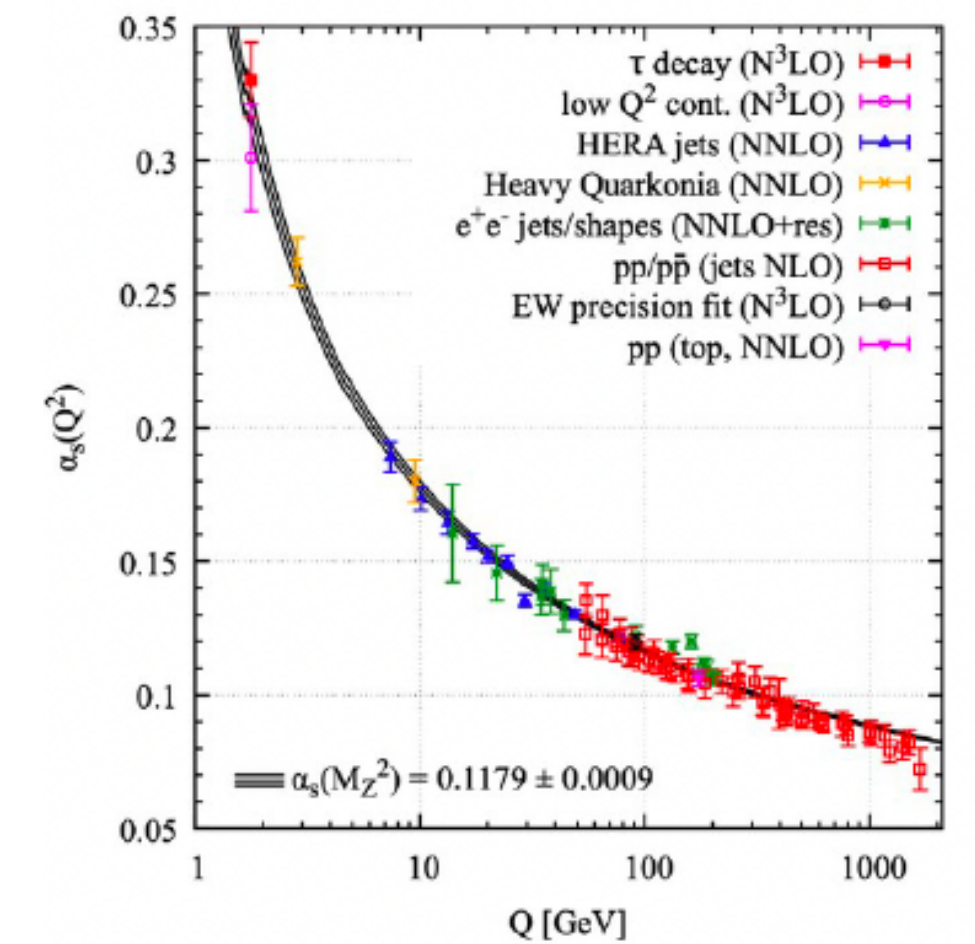
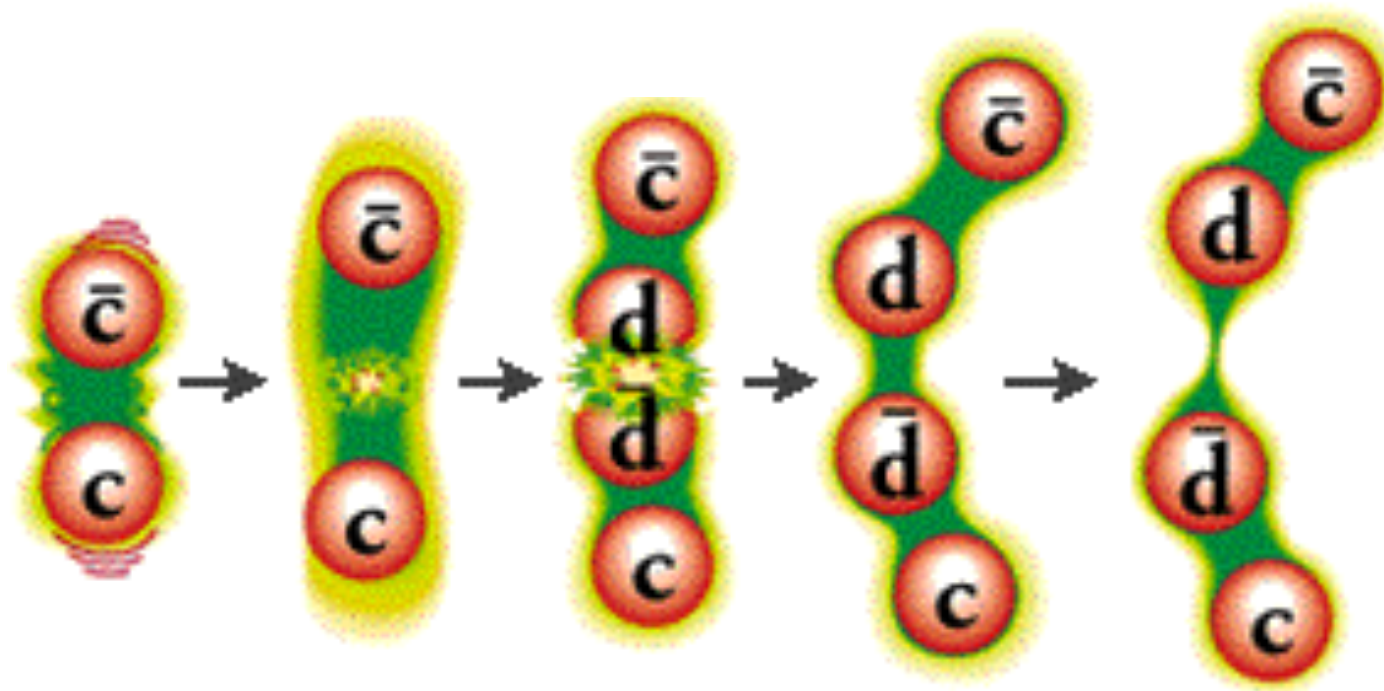


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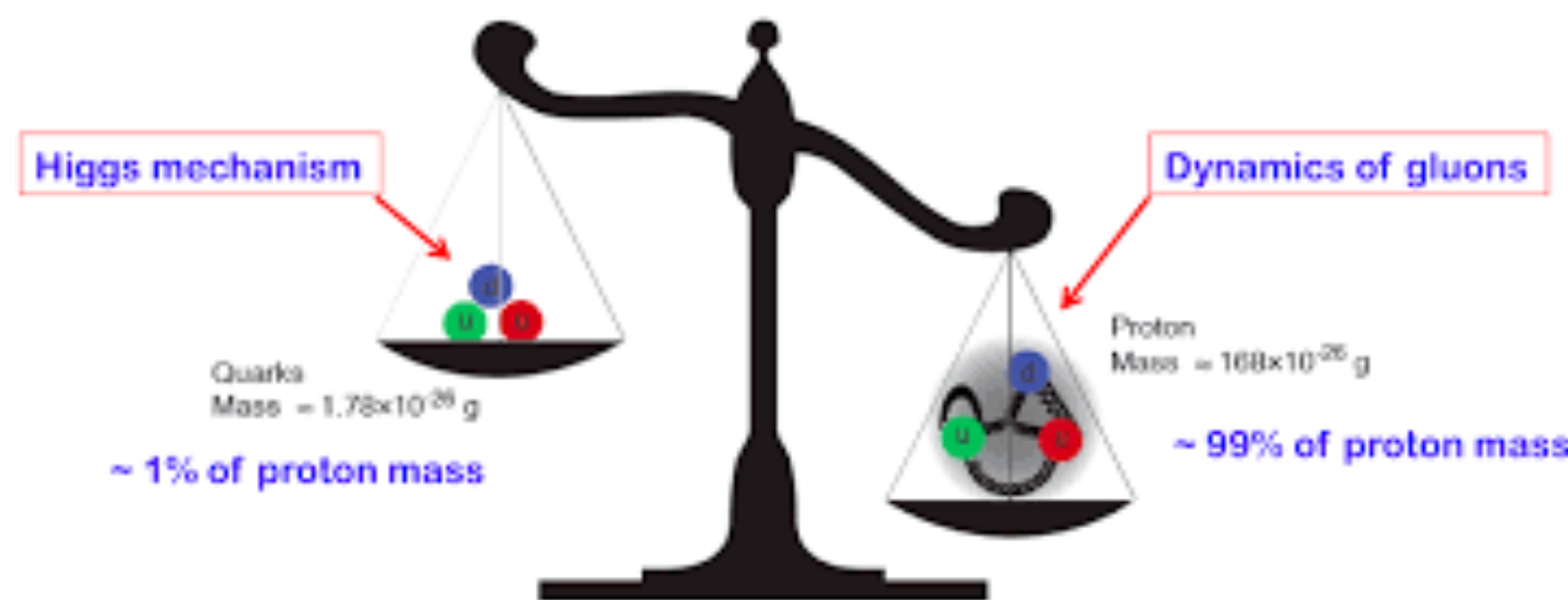
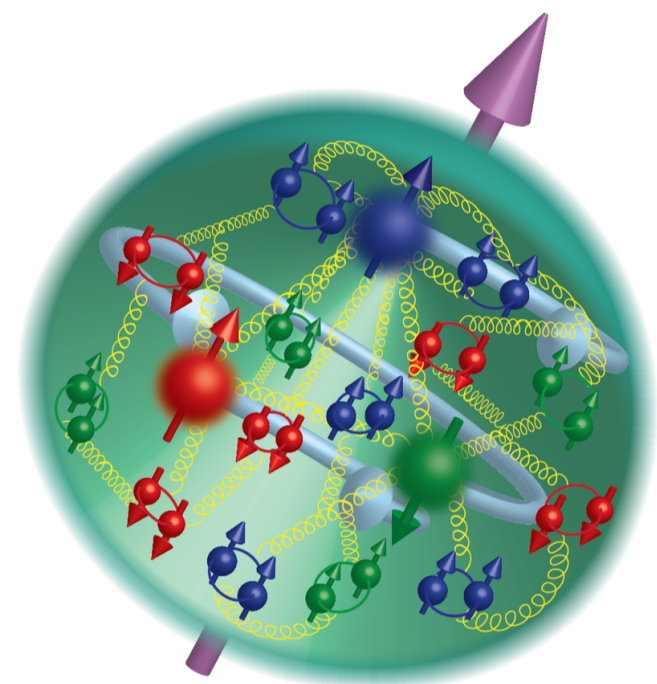


Open Questions in QCD

Confinement: quarks and gluons can not be observed separately.



Nucleon structure: how does the matter get mass and spin properties?



Spin:
How does it generate?

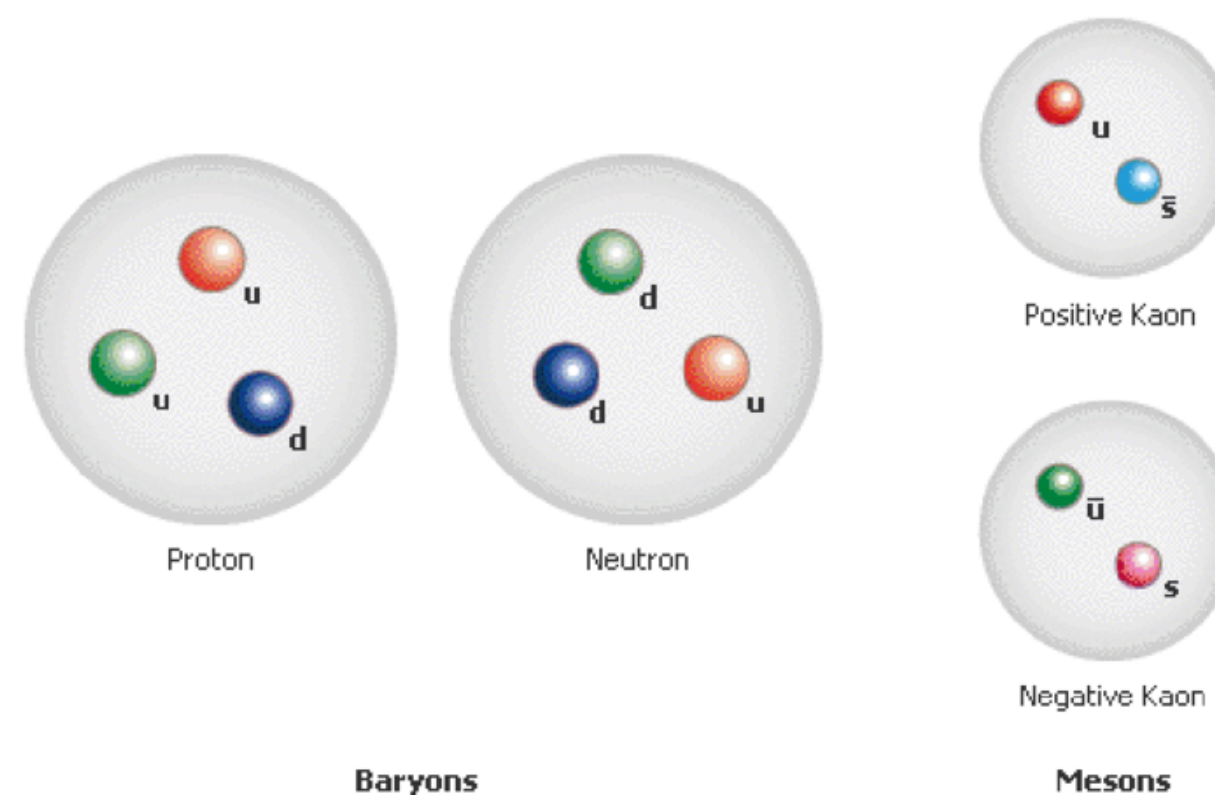
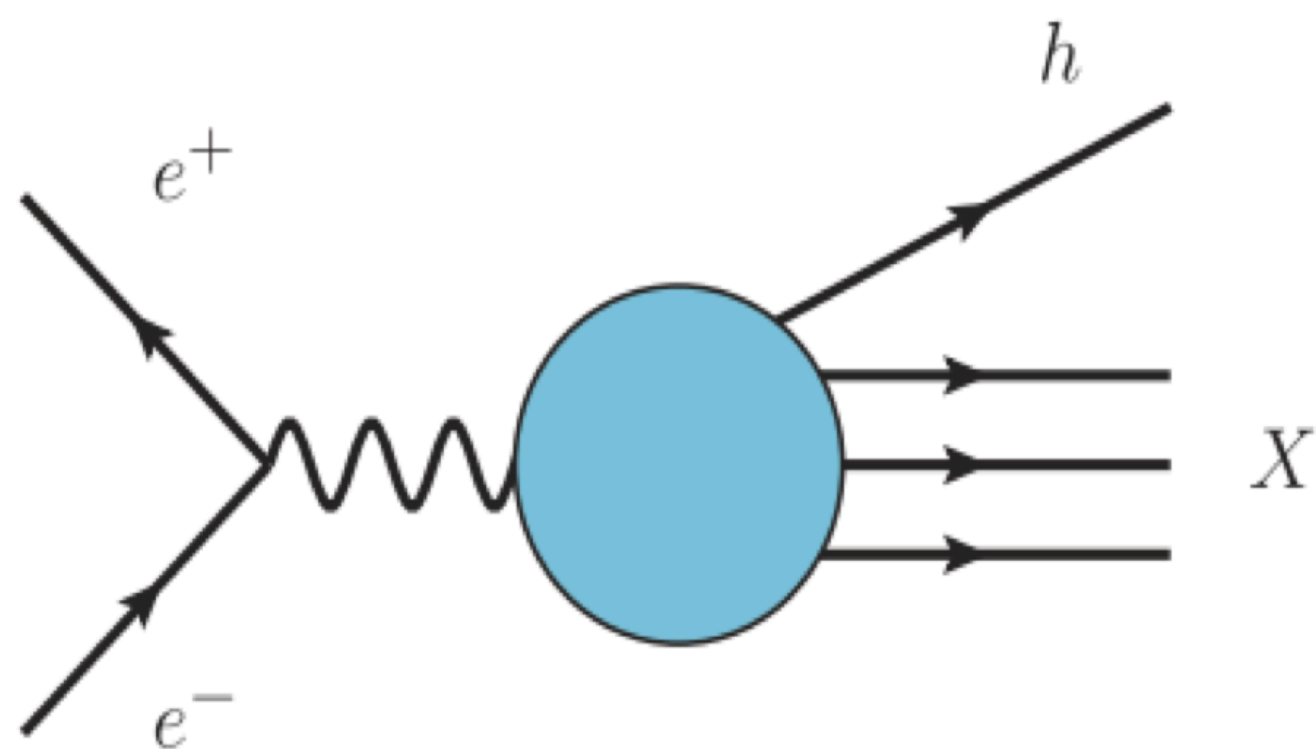
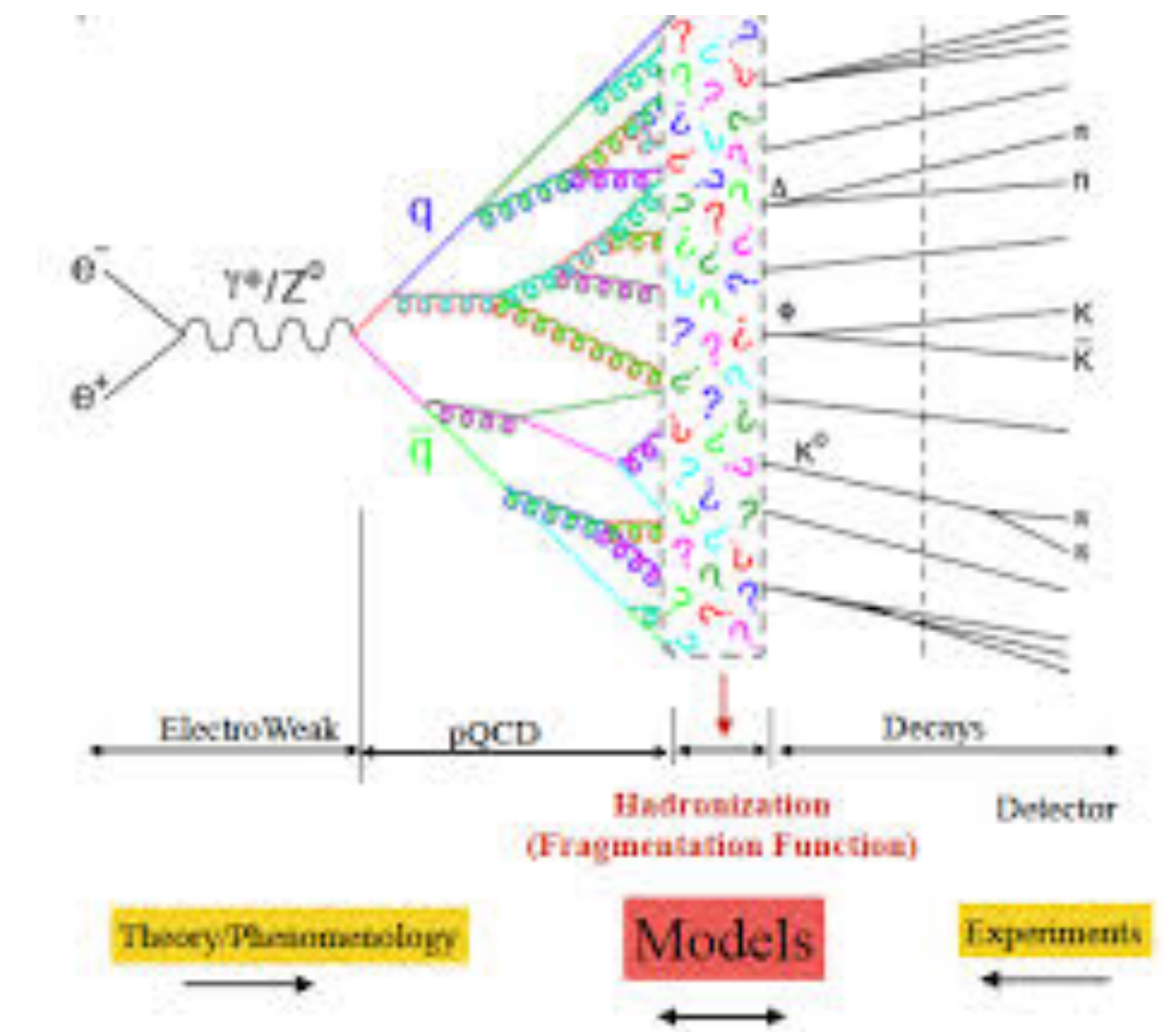
Mass:
Higgs mechanism is not sufficient.

Fragmentation Functions (FFs) $D_q^h(z)$

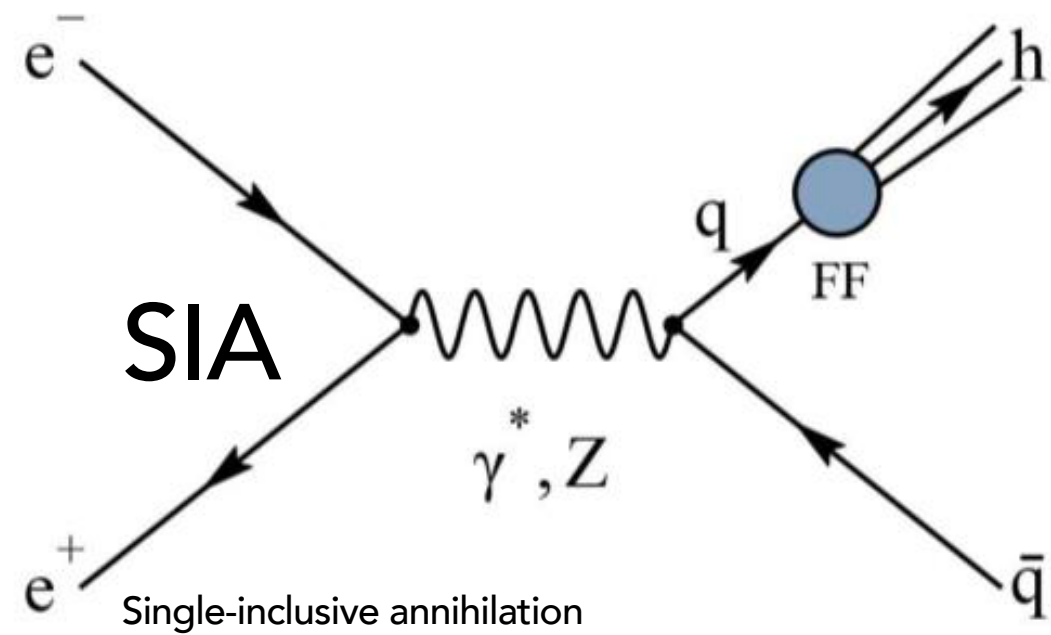
- Probability density of a parton q to fragment into a specific hadron h .
- They depend on the fraction z of the initial parton's momentum acquired by the hadron h .

$$z = \frac{2P_{hq}}{Q^2} = \frac{2E_h}{\sqrt{s}}$$

- Provide a characterization of the non-perturbative aspects of hadronization.



Accessing Fragmentation Functions in experiments

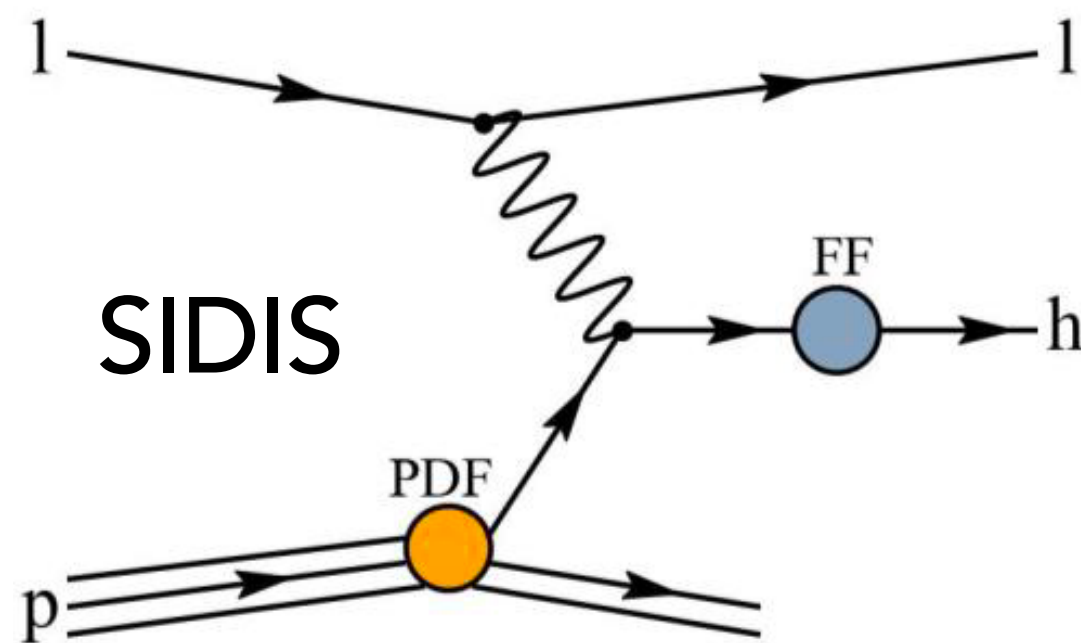


$$e^+e^-: \sigma = \sum_q \sigma(e^+e^- \rightarrow q\bar{q}) \otimes FF$$

- No PDFs' knowledge necessary
- Calculations known up to NNLO
- Flavour structure not directly accessible

Experimental observable

$$\frac{1}{\sigma_{\text{had, tot}}} \frac{d\sigma_h}{dz}$$

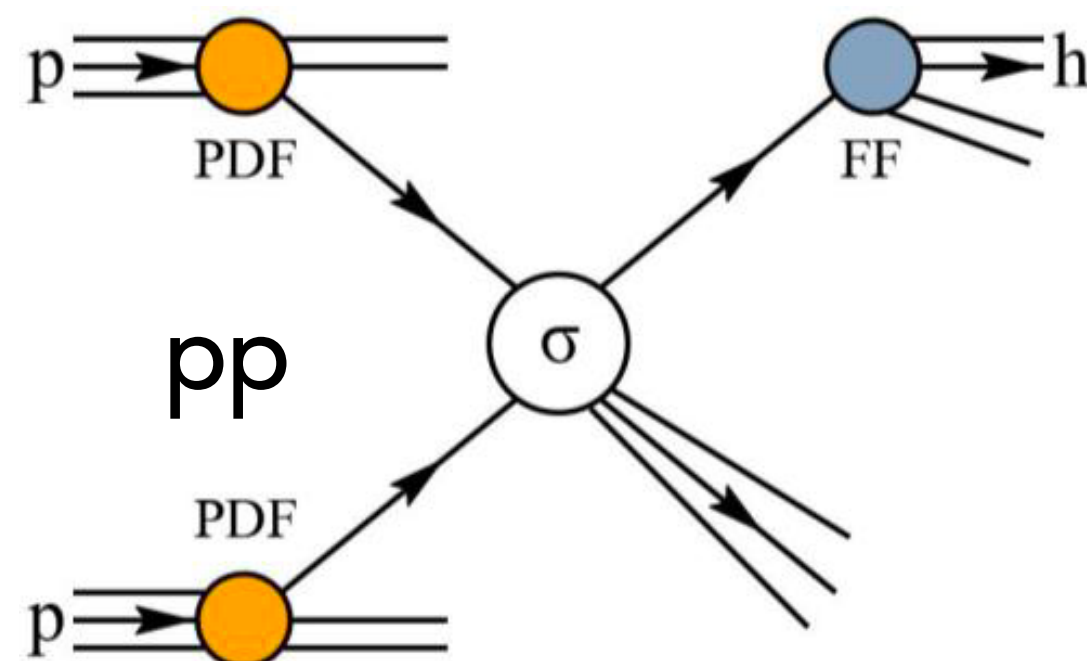


$$\text{SIDIS: } \sigma = \sum_q PDF \otimes \sigma(eq \rightarrow e'q') \otimes FF$$

- Dependence from unpolarized PDFs
- Direct access to flavour structure
- FFs and PDFs

@ Leading Order

$$e^+e^- \rightarrow hX \sim \sum_q e_q^2 D_1^{h/q}(z)$$

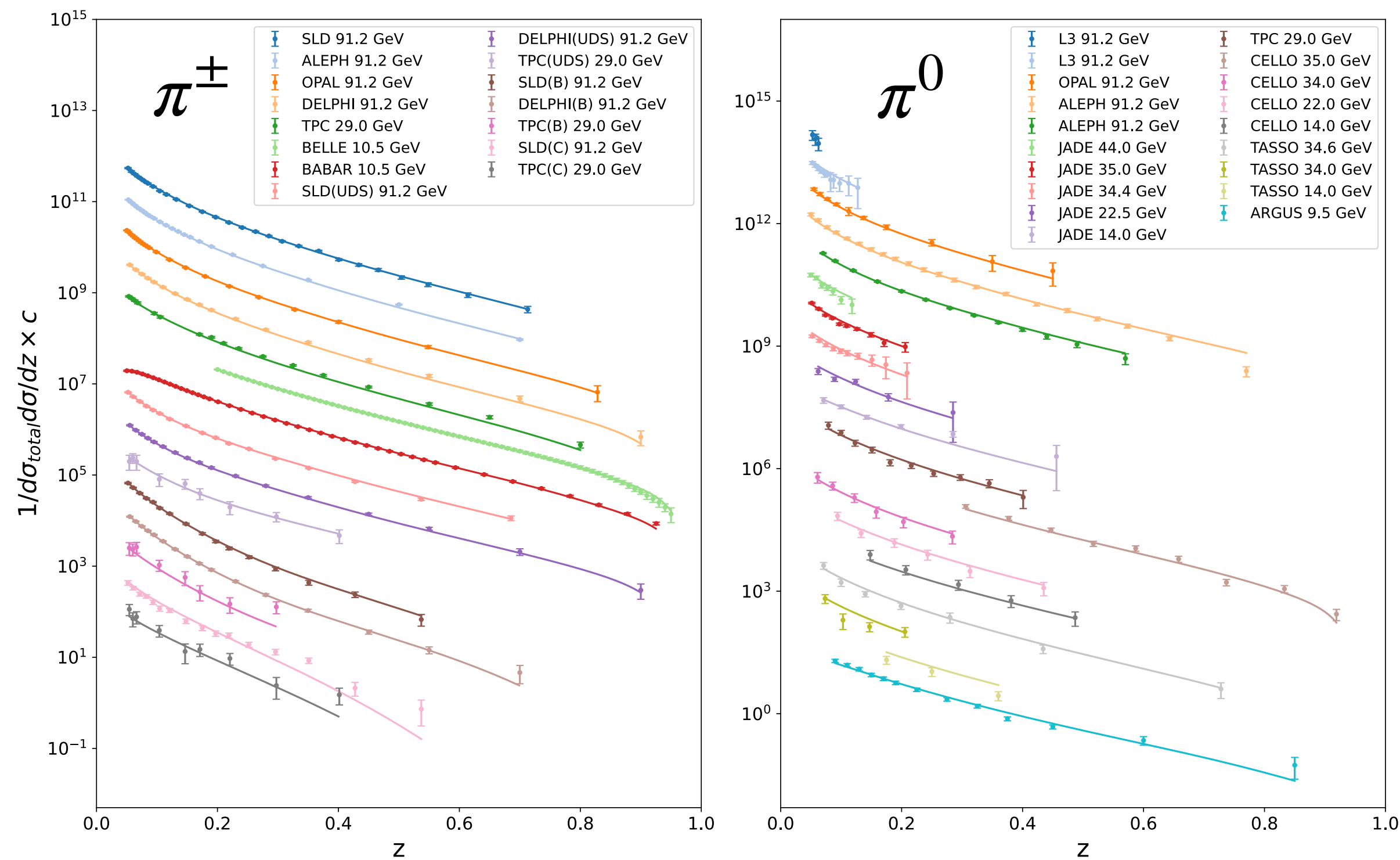


$$\text{pp: } \sigma = \sum_q PDF \otimes PDF \otimes \sigma(q_1q_2 \rightarrow q'_1q'_2) \otimes FF$$

- Dependence from unpolarized PDFs
- Leading access to gluon FF
- Parton momenta not known directly

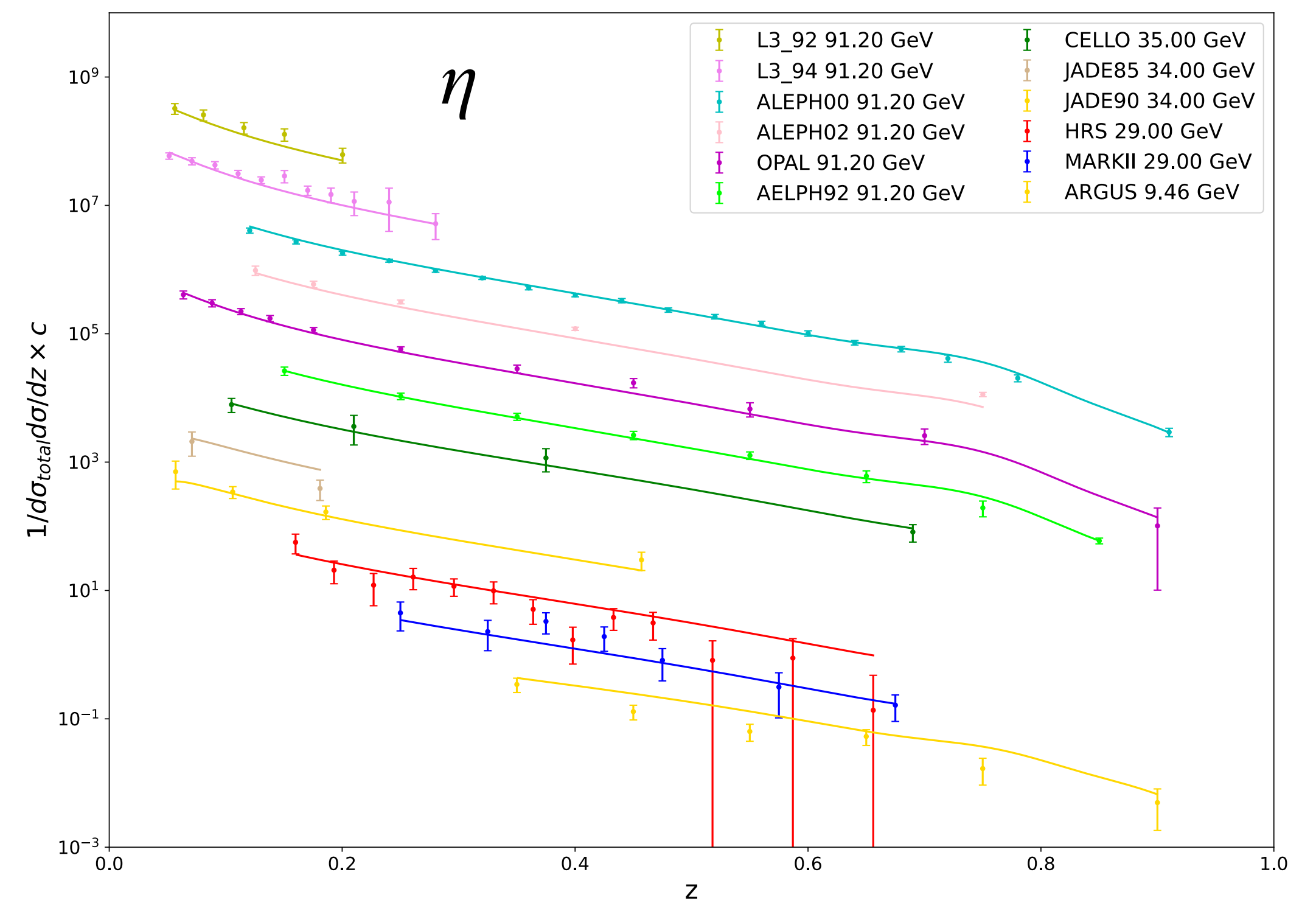
SIA @ e^+e^- : cleanest process for FFs studies.

World Data for π^\pm , π^0 and η



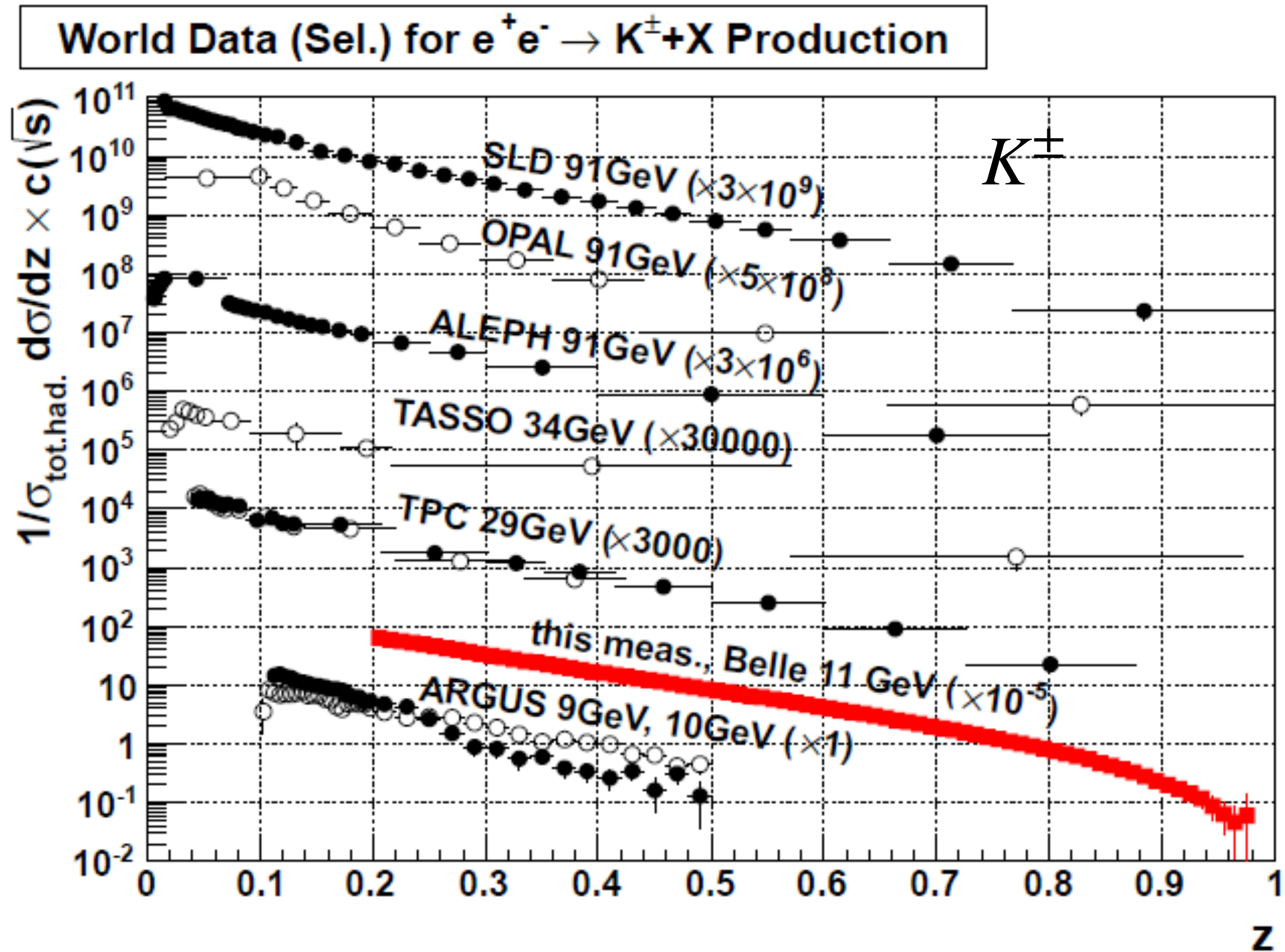
Li, Anderle, Xing, Zhao.
arXiv:2404.11527

- Most of the information at high energy (SLAC, CERN, DESY).
- Lack of data below 10 GeV.
- Possible contribution from BESIII.

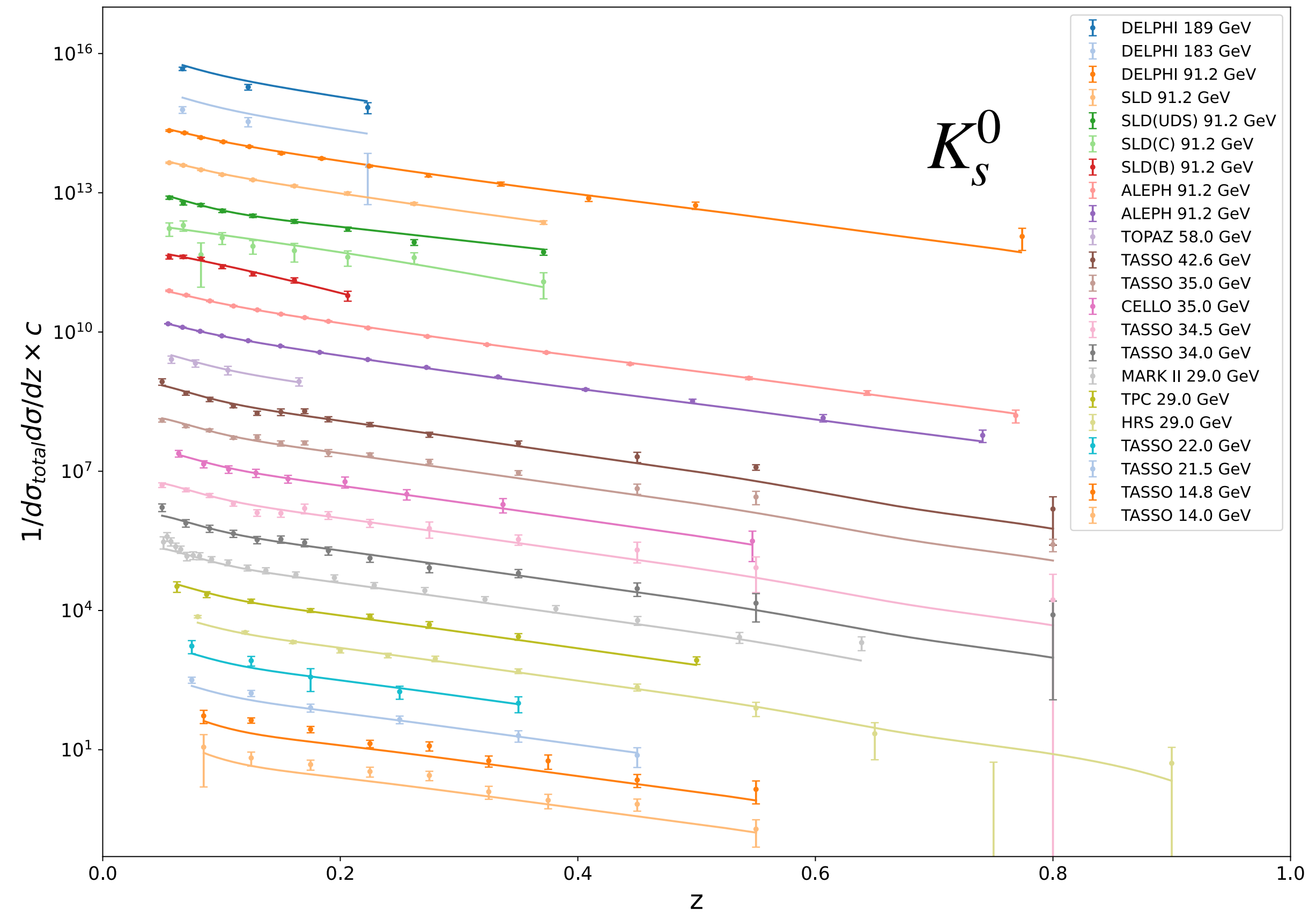


C.O.M. energy @ BESIII: $2 \text{ GeV} \leq \sqrt{s} [\text{GeV}] \leq 5 \text{ GeV}$.

World Data for K_S^0



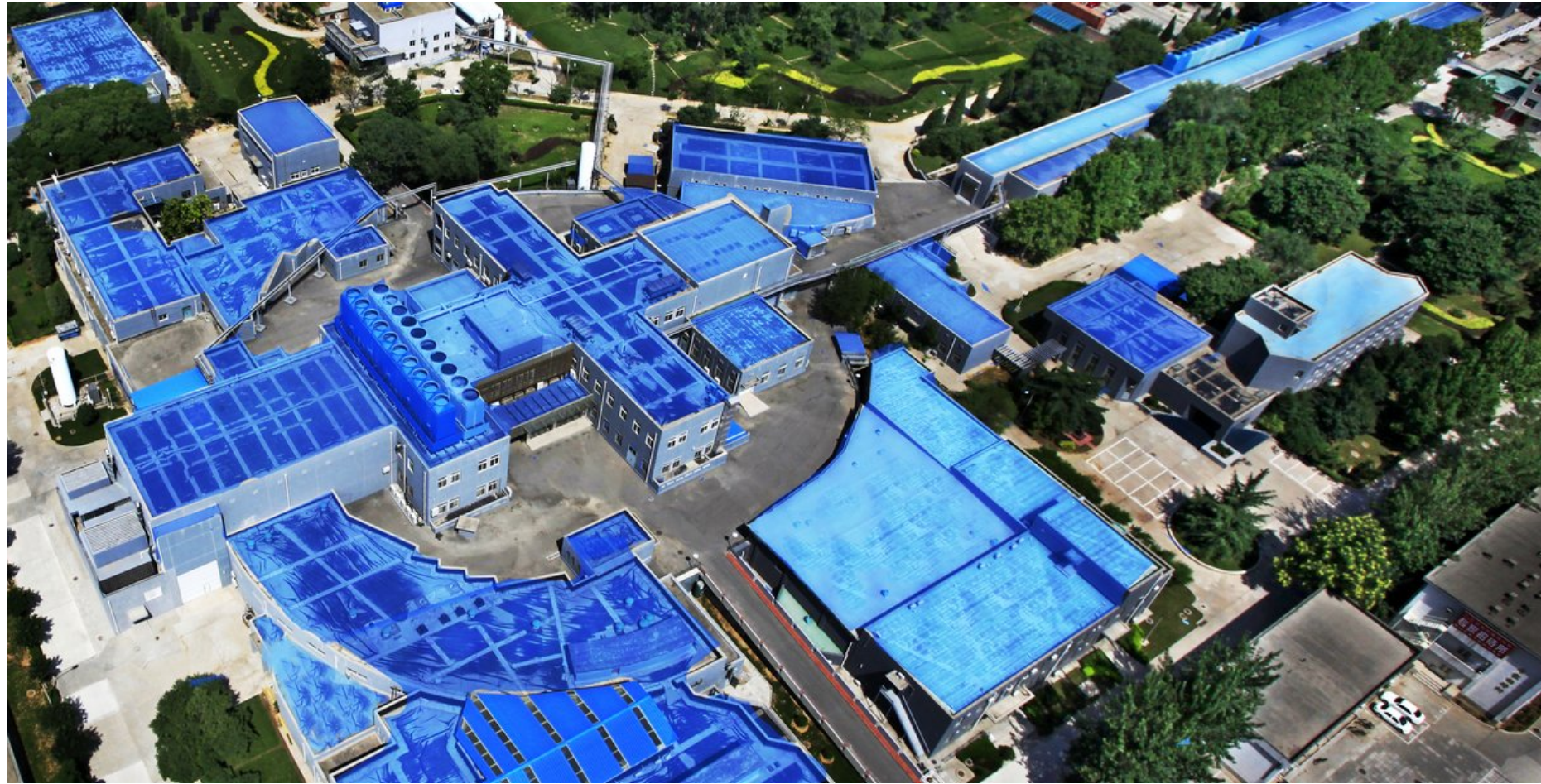
Leitgab, M et al. (Belle Collaboration), Phys. Rev. Lett 111, 062002 (2013)



Li, Anderle, Xing, Zhao. arXiv:2404.11527

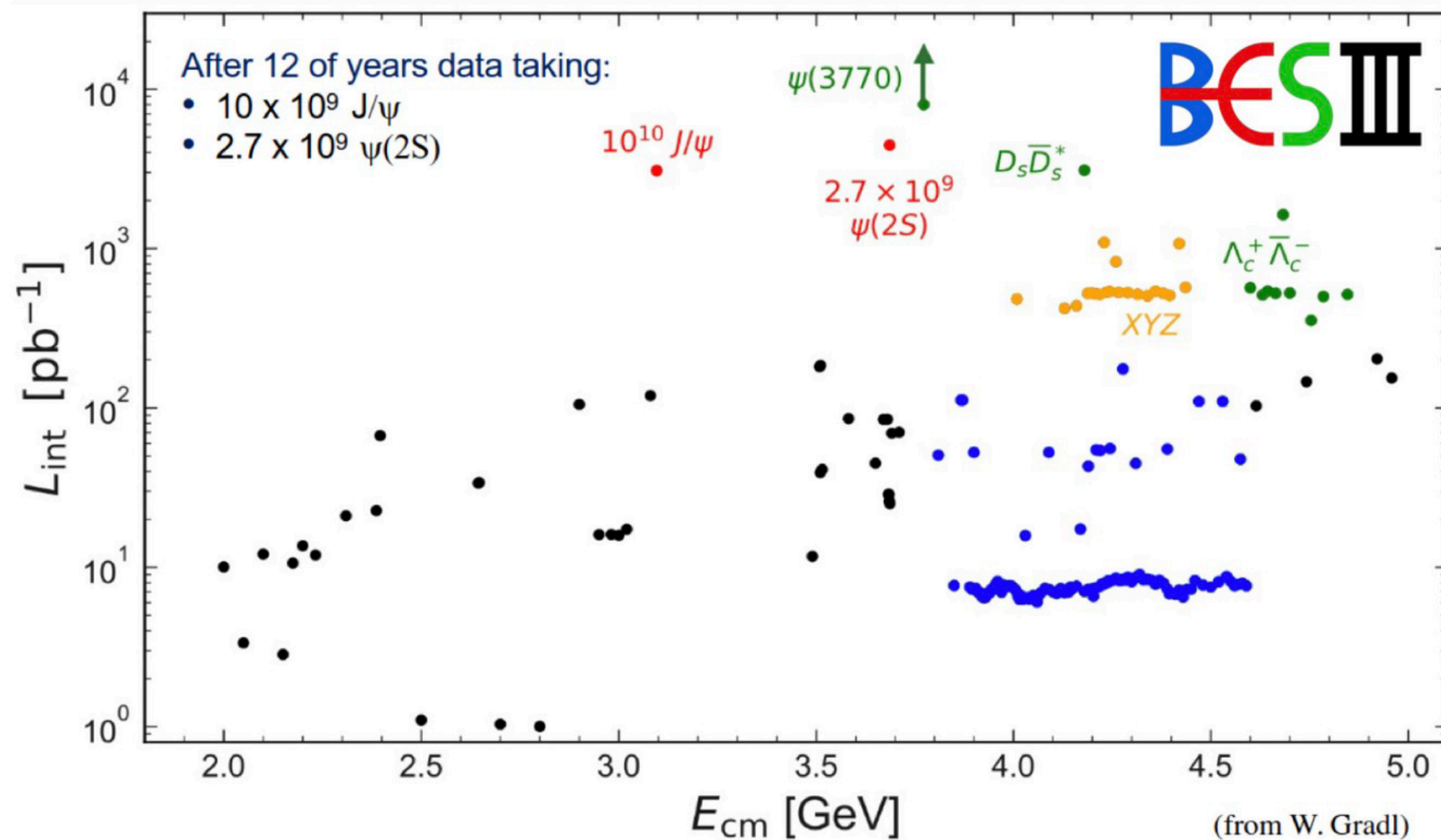
Lack of data at low energies where **BESIII** can contribute!

Beijing e^+e^- Collider - BEPCII



<http://bes3.ihep.ac.cn/>

- Center-of-mass energy in range 2-5 GeV.
- Design luminosity exceeded: $1.1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$ @ 3.77 GeV.



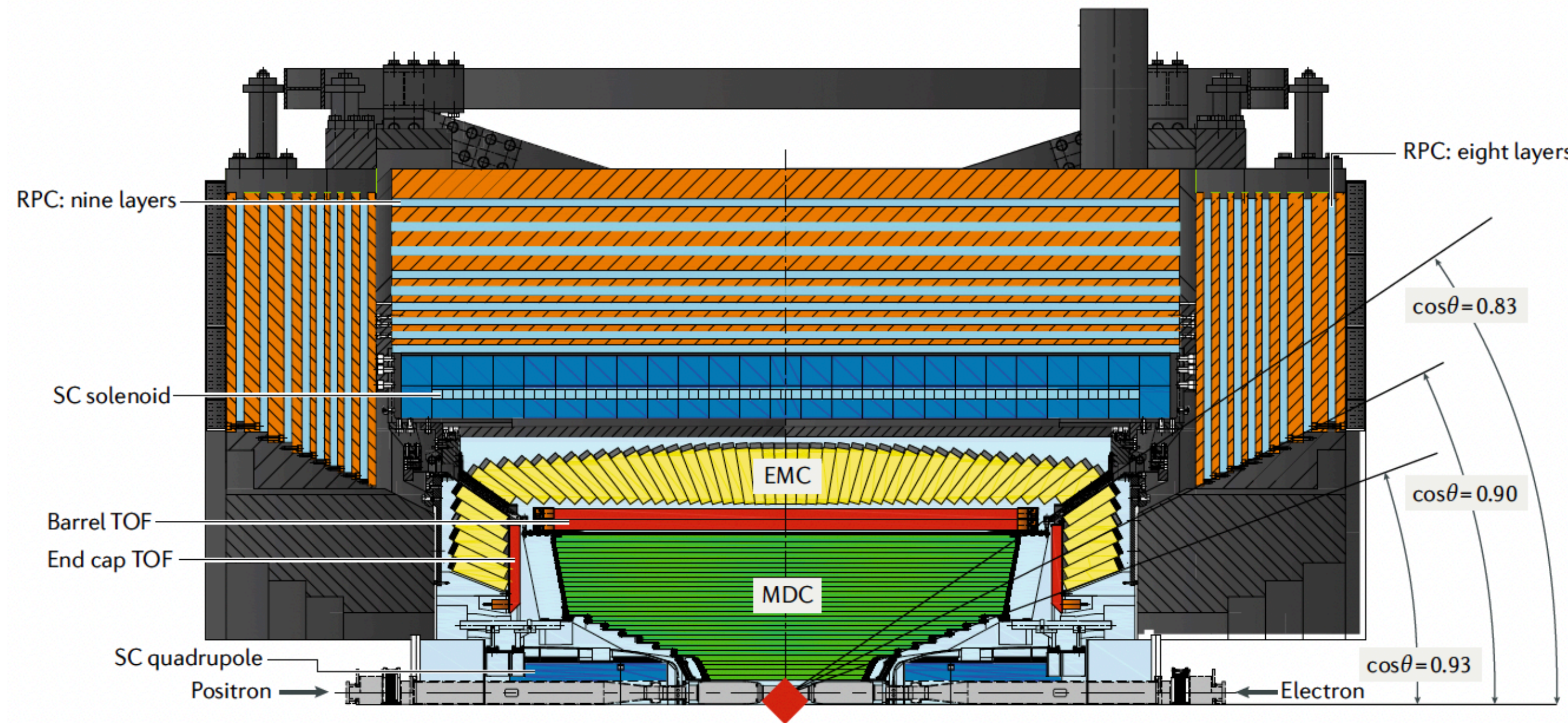
World's largest e^+e^- data sets at τ -charm energies.

- 10^{10} J/ψ and 2.7×10^9 $\psi(2s)$ samples produced.
- 20 fb^{-1} collected @ 3.77 GeV.
- More than 40 fb^{-1} collected between 3.77 and 5 GeV.
- More than 170 scan points.

Beijing Spectrometer - BESIII

Superconducting Solenoid

- 1T magnetic field



Muon Chamber

- 8 - 9 layers of RPCs
- 1.4 - 1.7 cm resolution
- $p > 400$ MeV

TOF System

- 60 - 65 ps

Drift Chamber

- 0.5% momentum resolution
- 6% dE/dx resolution

Electromagnetic Calorimeter

- 6240 CsI(Tl) crystals
- 2.5% energy resolution
- 0.5 - 0.7 cm spatial resolution

Normalized Hadronic Cross Section

$$\frac{1}{\sigma_{\text{had}}} \frac{d\sigma(e^+e^- \rightarrow h+X)}{dp_h} = \frac{N_h}{N_{\text{had}}} \frac{1}{\Delta p_h} = \frac{N_h^{\text{obs}}}{N_{\text{had}}^{\text{obs}}} \frac{1}{\Delta p_h} f_h$$

Inclusive hadronic cross section

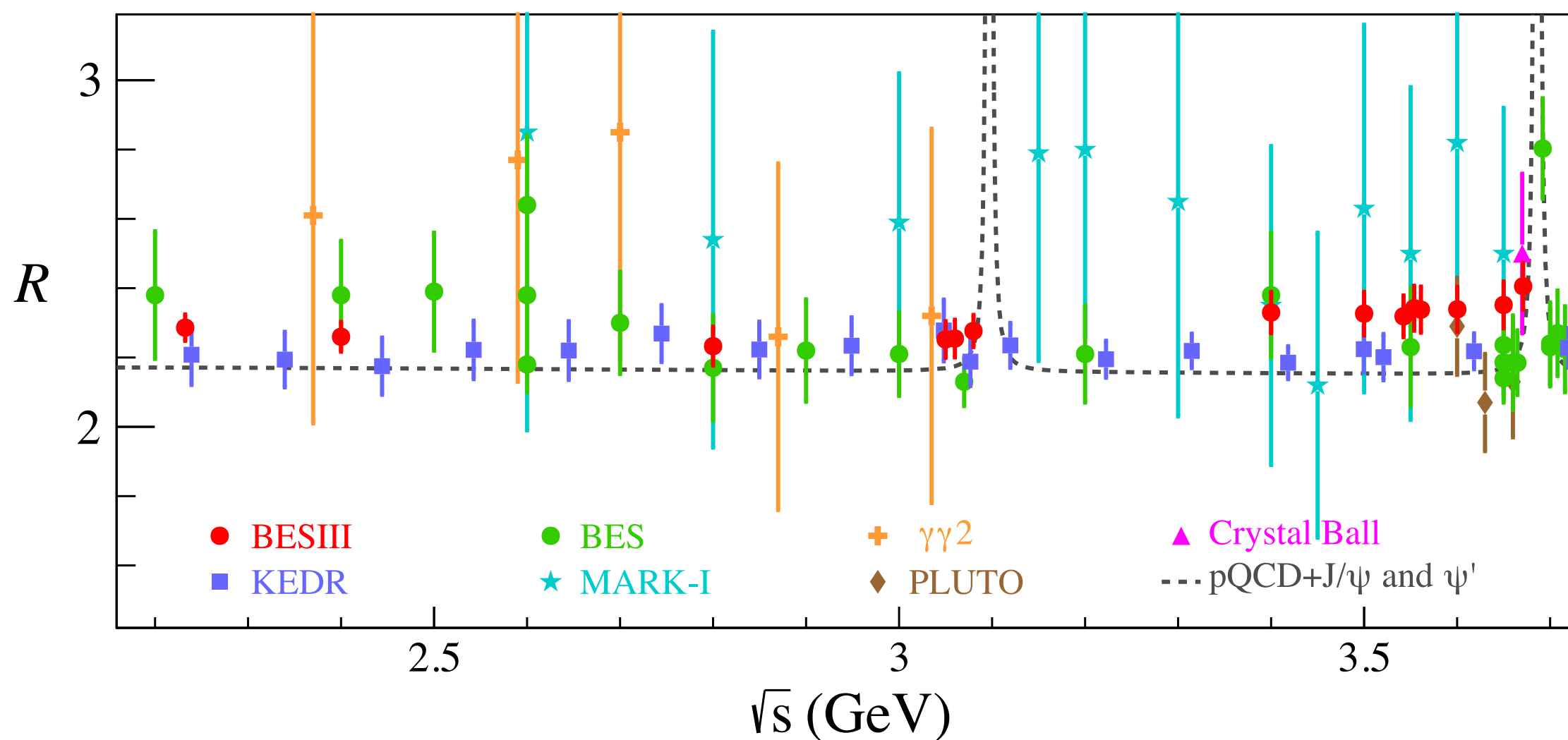
- R-Value measurements at BESIII.

$$R \equiv \sigma(e^+e^- \rightarrow \text{hadrons}) / \sigma(e^+e^- \rightarrow \mu^+\mu^-)$$

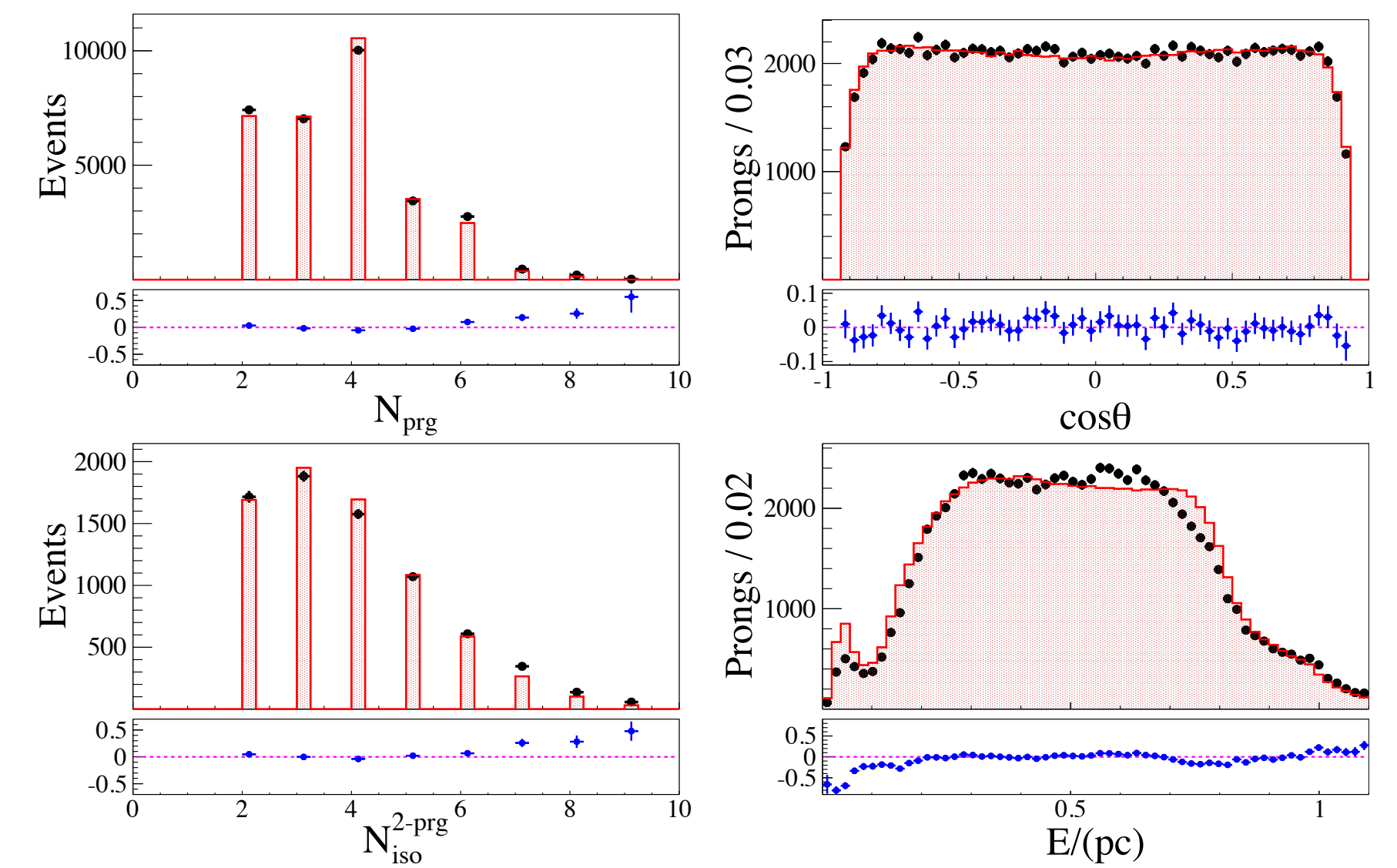
Differential inclusive production cross section of hadron h

Correction factor

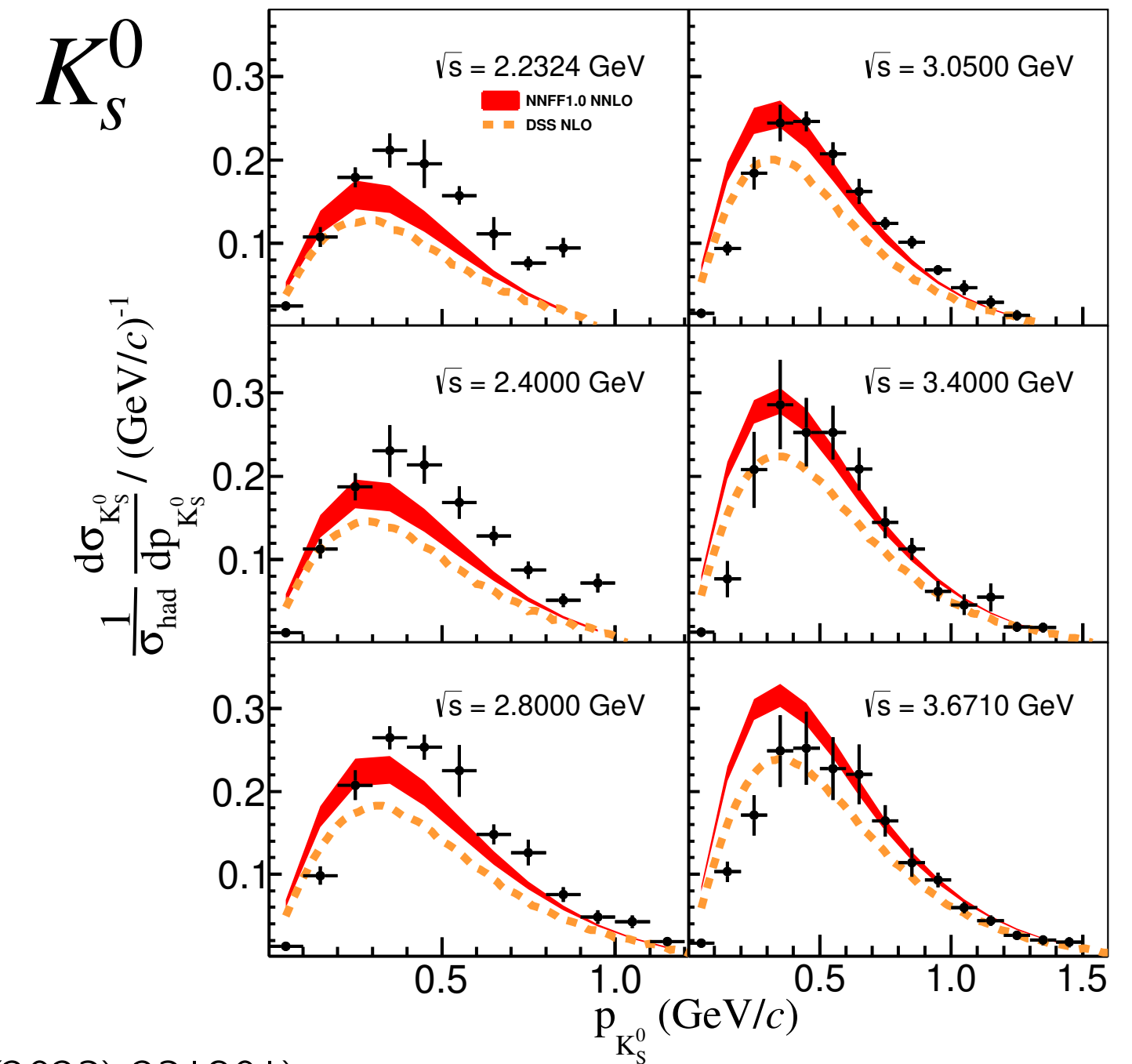
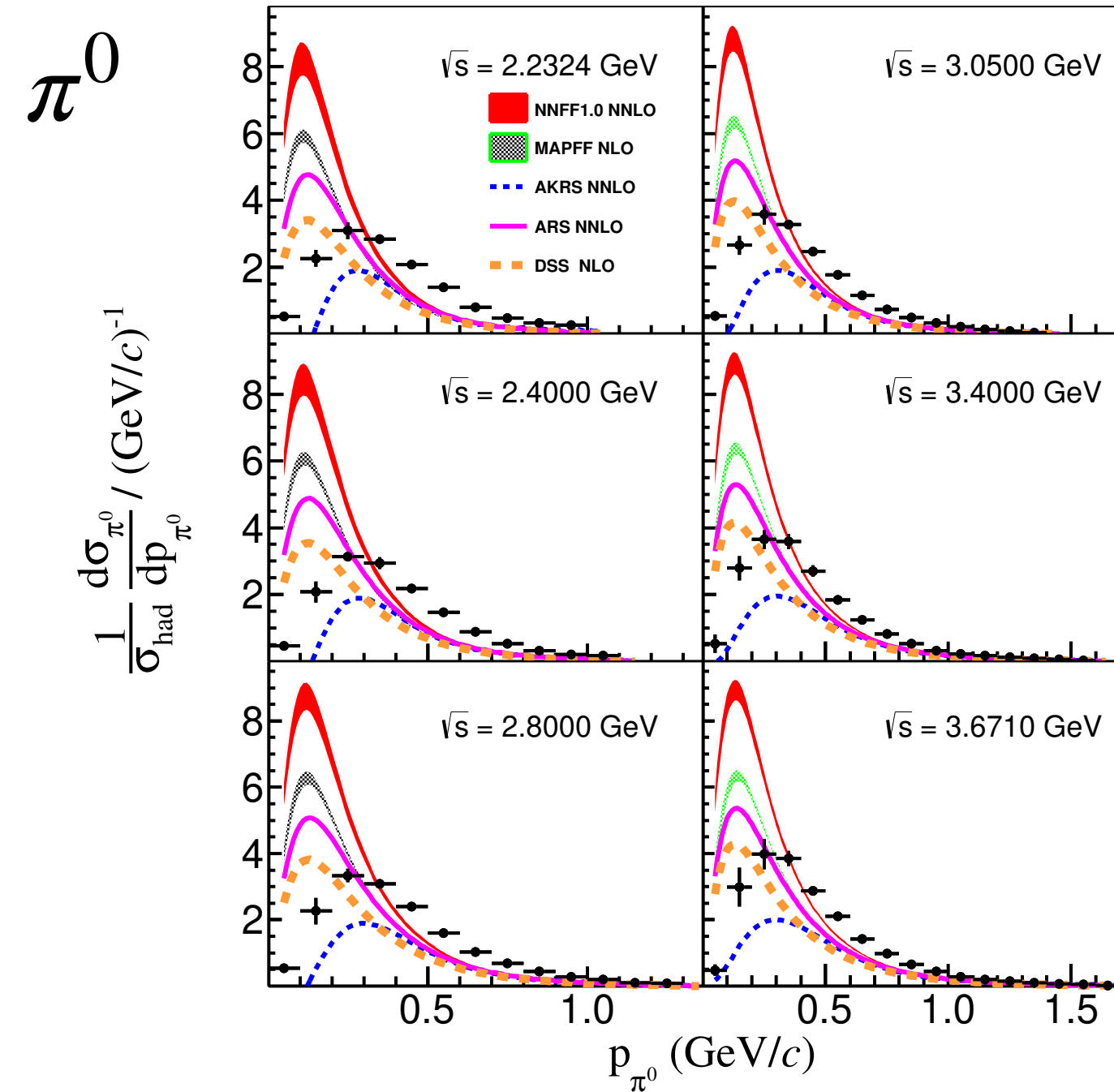
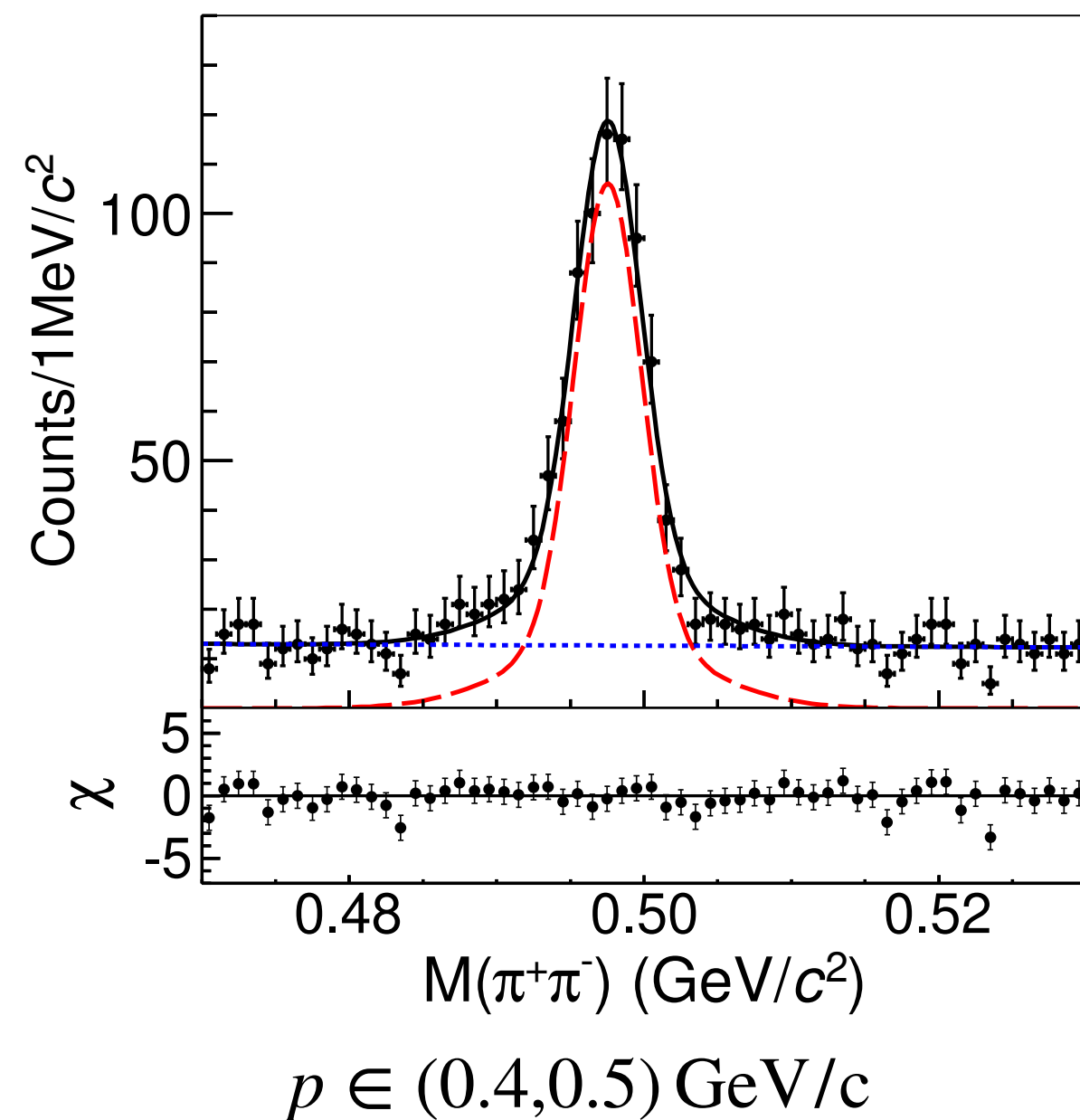
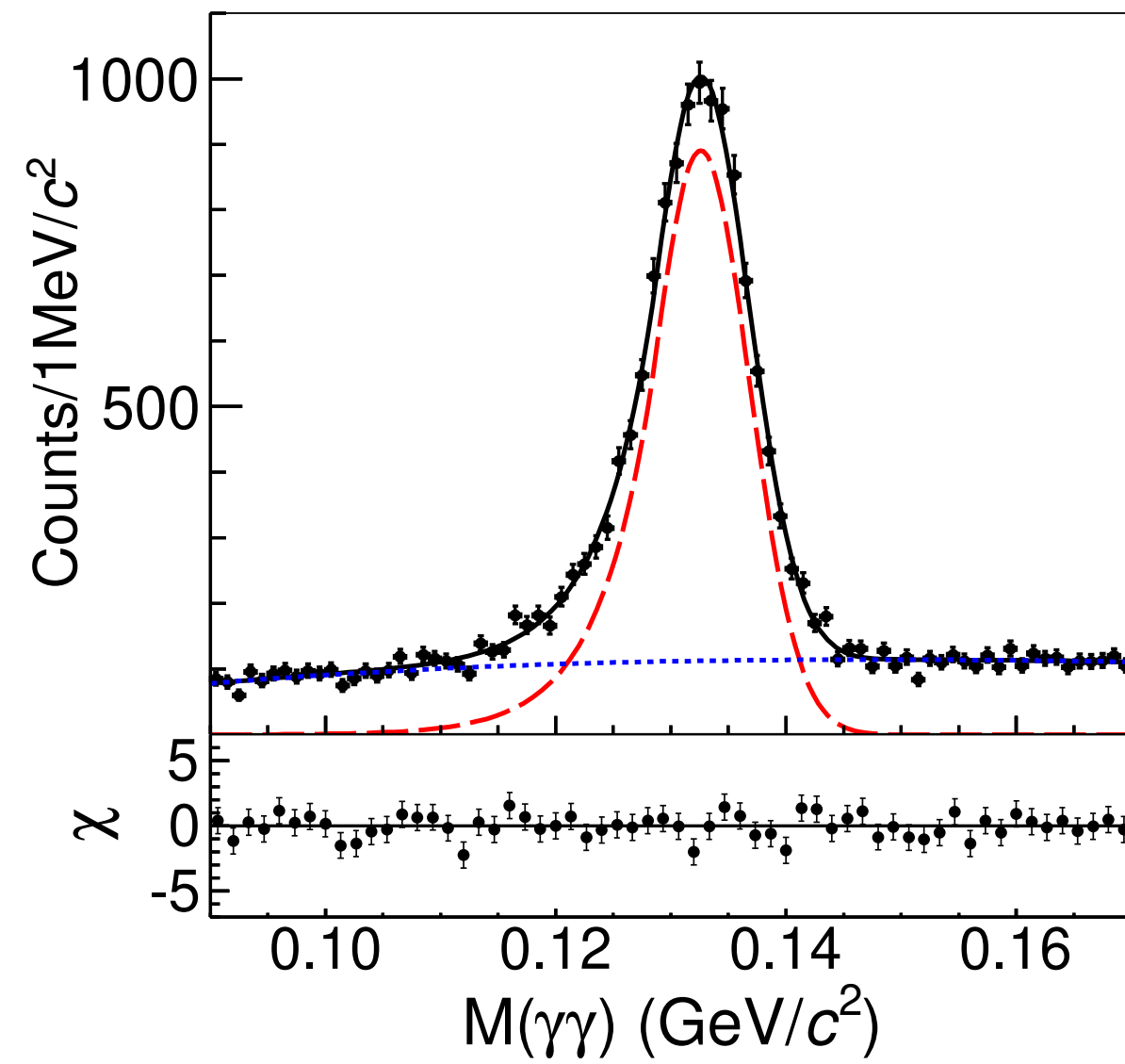
- Reconstruction efficiency.
- Radiative corrections.
- Based on generator development for R-Value measurements.



(Phys.Rev.Lett. 128 (2022) 062004)



Measurement's Results for π^0 and K_S^0

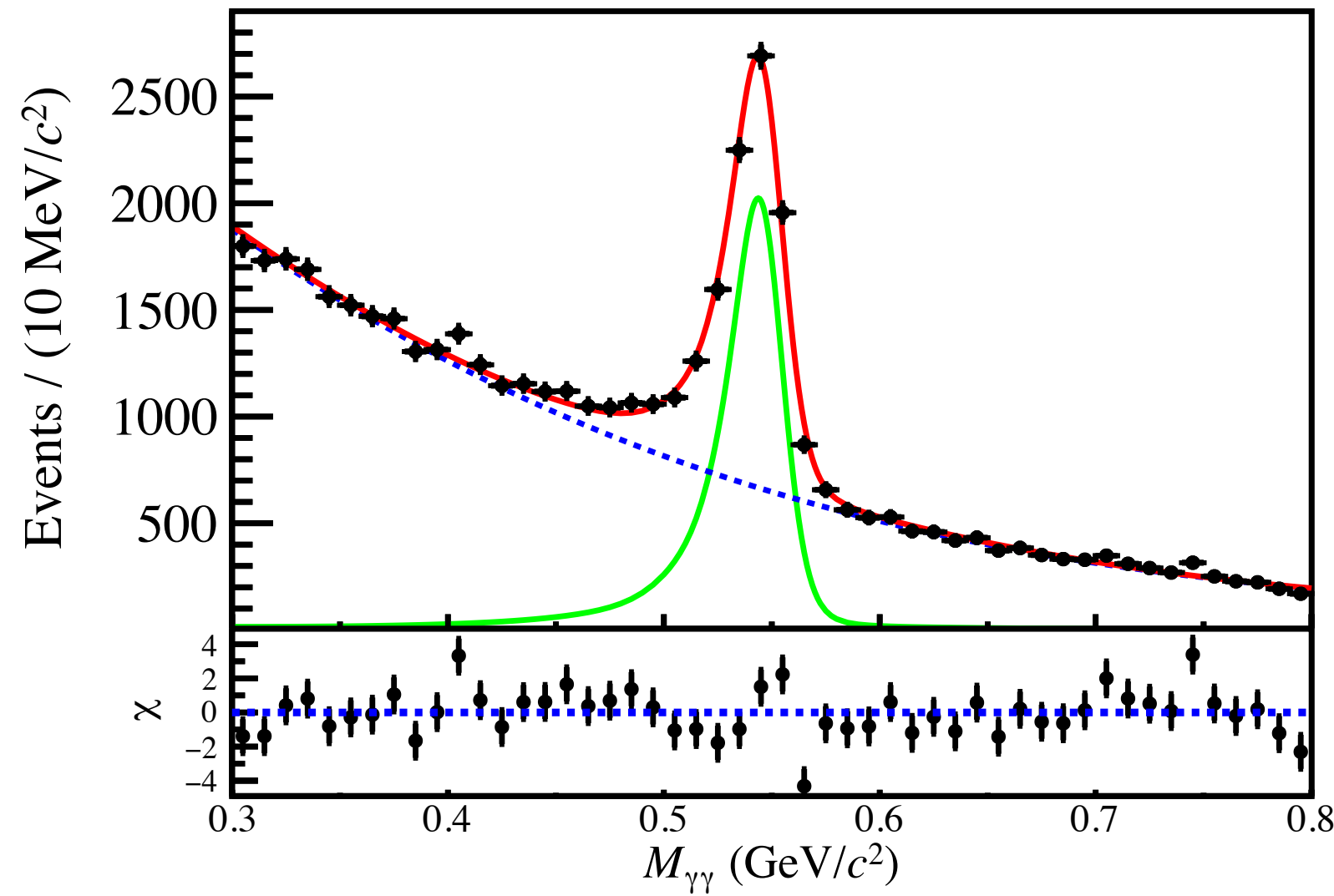


(Phys.Rev.Lett. 130 (2023) 231901)

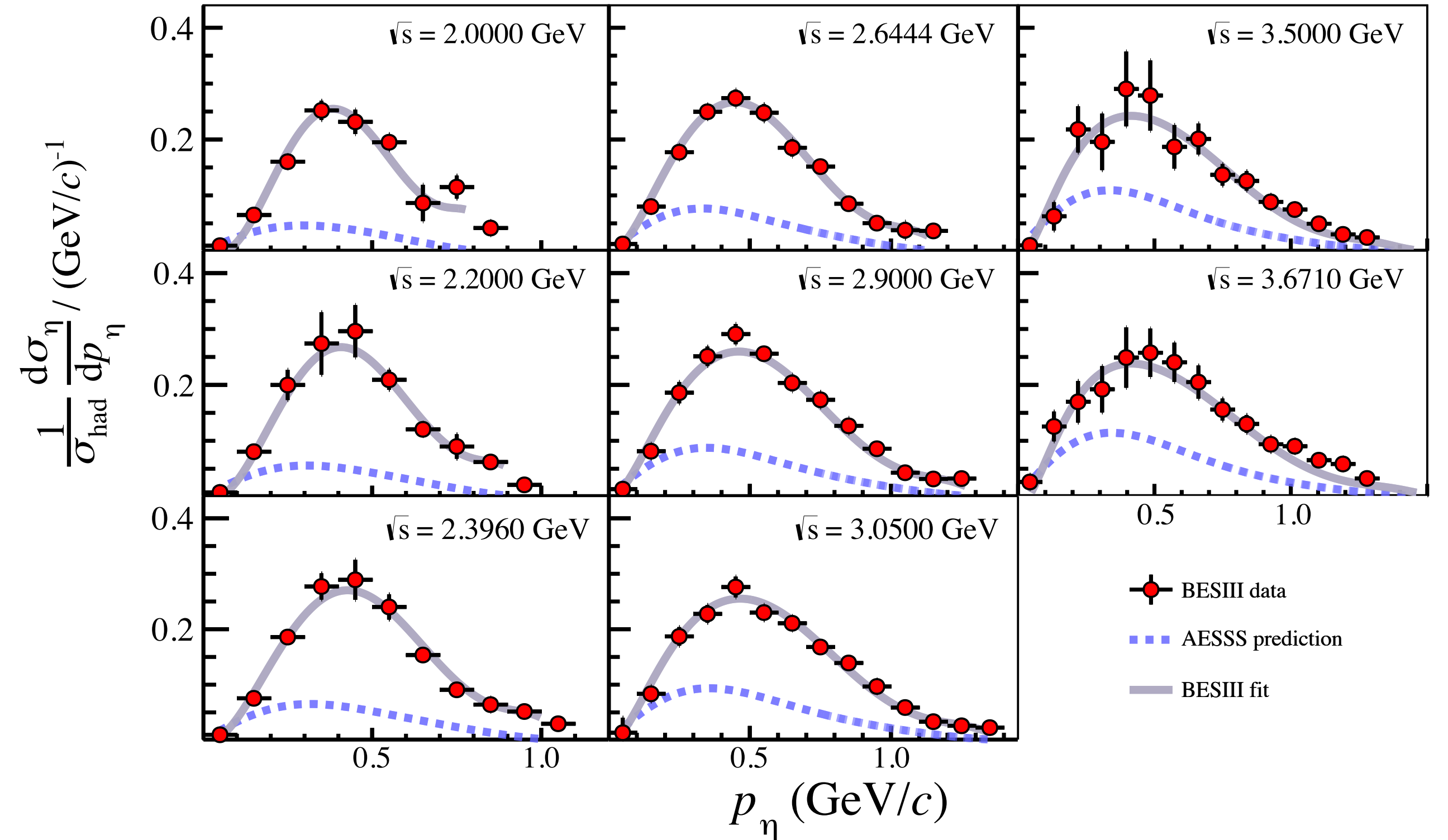
- Hadrons reconstructed from daughters.
- Background suppression:
 - Helicity angle cut.
 - Secondary vertex fit.

- Disagreement with existing fits of fragmentation functions:
 - Fragmentation functions depend on both p_h and \sqrt{s} .
 - Problem in the extrapolation of FFs at low energies.

Measurement's Results for η



(Phys.Rev.Lett. 133 (2024) 021901)

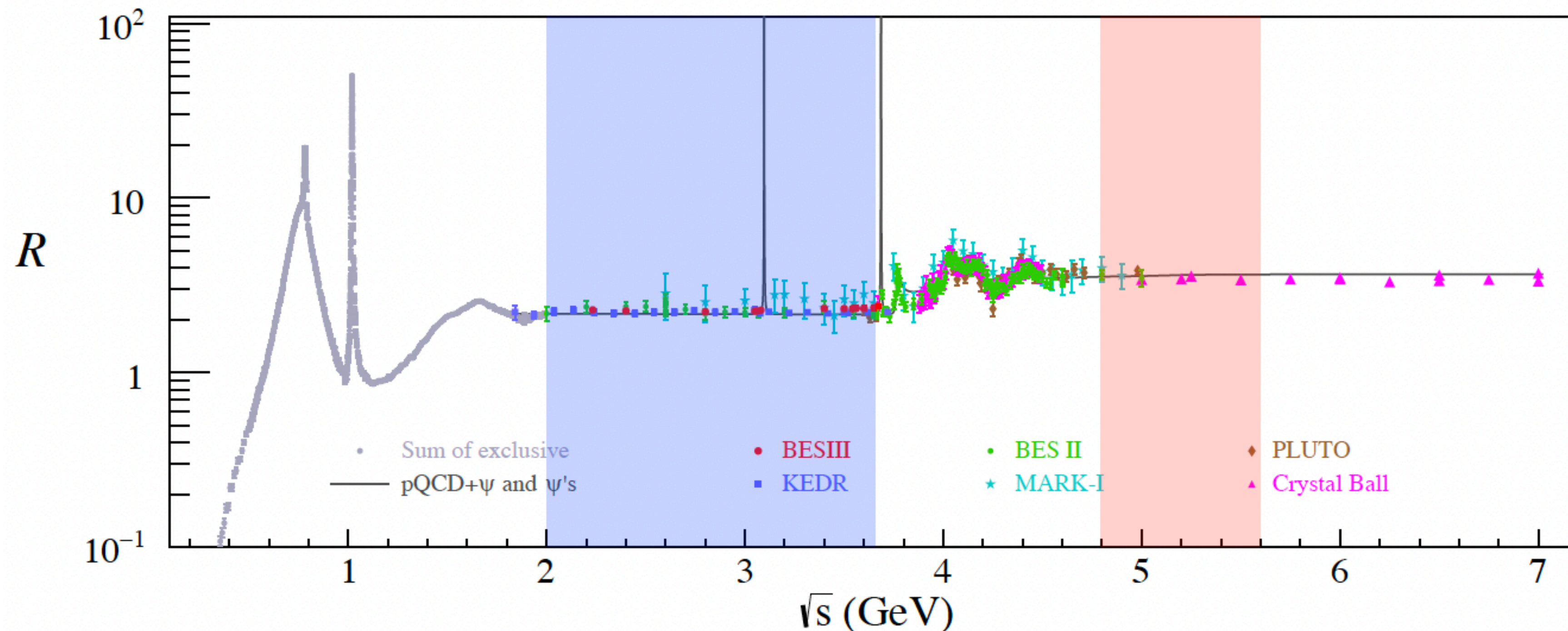


- Hadrons reconstructed from daughters.
- Helicity angle cut for background suppression.

- Disagreement with fit of Fragmentation Functions in Phys.Rev. D83 (2011) 034002.
- Agreement with a new fit by Li, Anderle, Xiao, Zhang (arXiv:2404.11527).
 - Includes NNLO accuracy, higher-twist effects and hadron mass correction.

Further **M**easurements at **BESIII**

- In continuum region 2.00 – 3.67 GeV:
 - 1D and 2D (p vs. p_t) inclusive production of charged particles: $e^+e^- \rightarrow \pi^\pm/K^\pm + X$.
 - Search for spin-alignment effect for vector mesons: $e^+e^- \rightarrow \phi/K^* + X$.
- In higher-energy region (above 4.8 GeV):
 - High luminosity data: $>150 \text{ pb}^{-1}$ on the tape and more on the schedule.
 - Possible measurement of heavier strange mesons and hyperons: $e^+e^- \rightarrow \eta'/\Lambda/\Sigma + X$.



Large amounts of data already collected: 170 energy scan points with $>10^5$ hadrons.

Summary

- Fragmentation Functions are an important tool for the understatement of non-perturbative-QCD dynamics.
- The cleanest access is provided by e^+e^- annihilation experiments.
- BESIII provides valuable information at low energies $\sqrt{s} < 5$ GeV:
 - Normalized differential cross sections of inclusive $\pi^0/K_s^0/\eta$ production already published (Phys.Rev.Lett. 130 (2023) 231901, Phys.Rev.Lett. 133 (2024) 021901).
 - Results provide wide z coverage from 0.1 to 0.9 with a precision of 3 % at $z \sim 0.4$.
 - Large discrepancies with predictions for Fragmentation Functions are observed.
- More results for $\pi^\pm, K^\pm, \phi, K^*$ at continuum region and $\eta'/\Lambda/\Sigma$ at high energies are currently in progress.

Thanks for Your Attention!

谢谢您的关注!