ICHEP 2024 | PRAGUE

Unpolarized fragmentation function studies at BESIII

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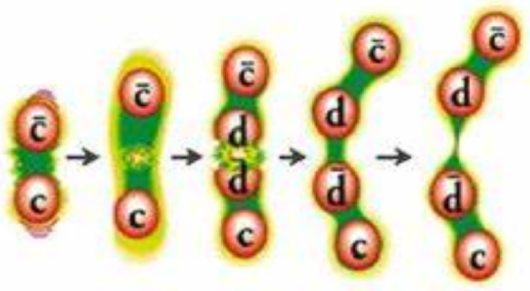
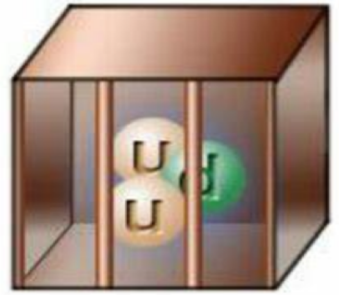
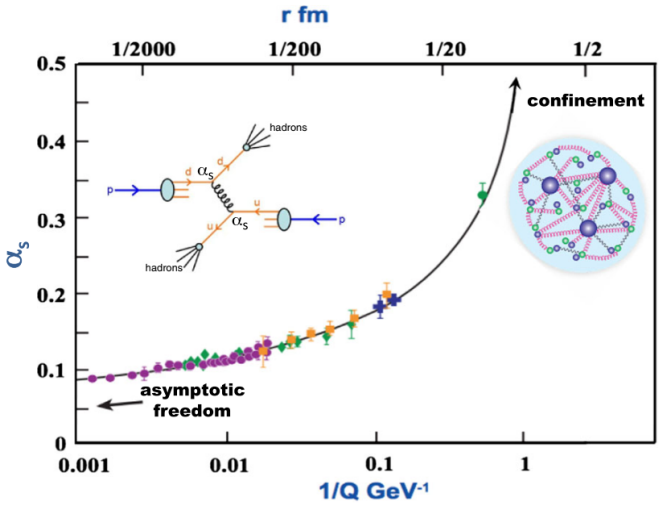
Several open questions about QCD

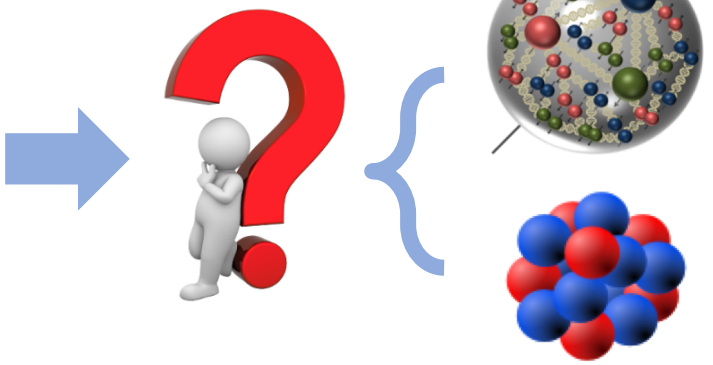
Confinement, no existing isolated quarks or gluons





Nucleon structure, the origin of nucleon spin and mass

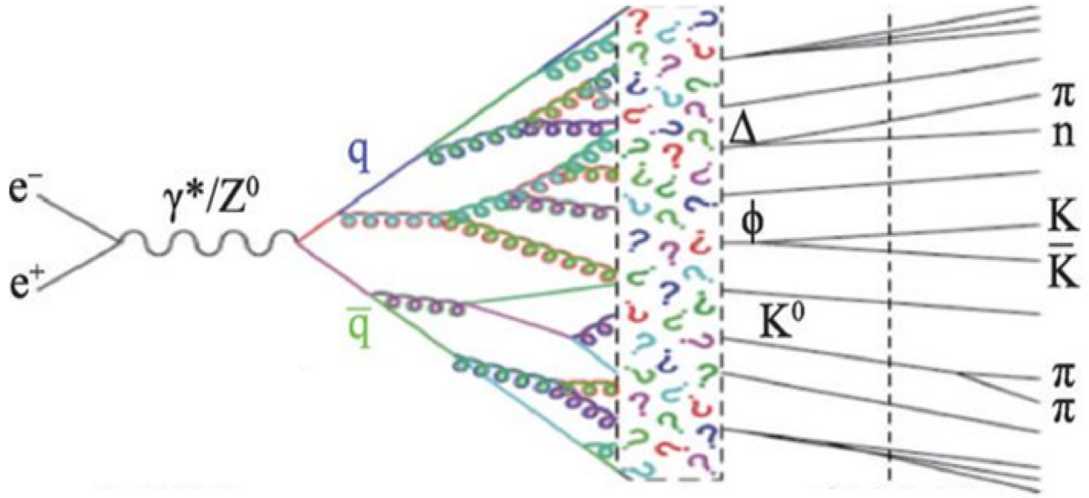


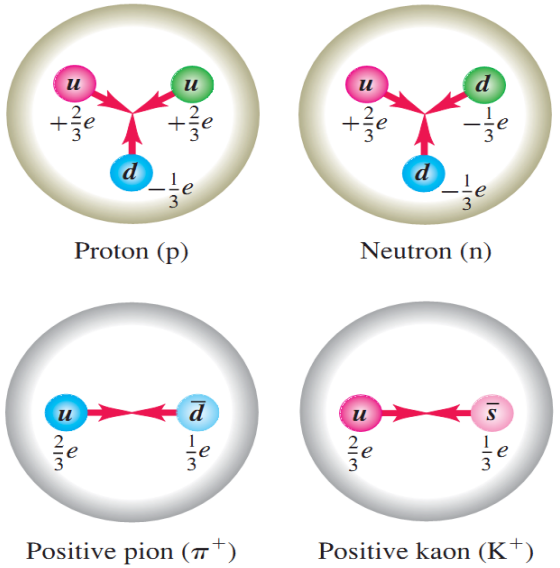


Spin: how does nucleon spin emerge

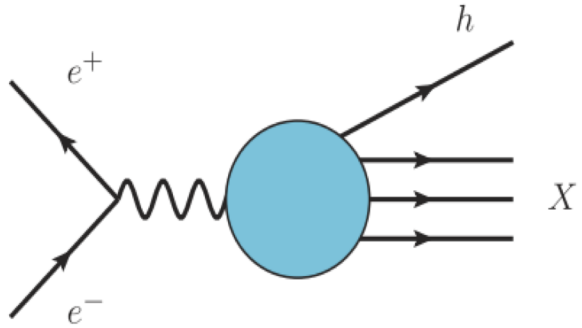
Mass: Higgs mechanism gives only ~few%

Fragmentation Functions (FFs)



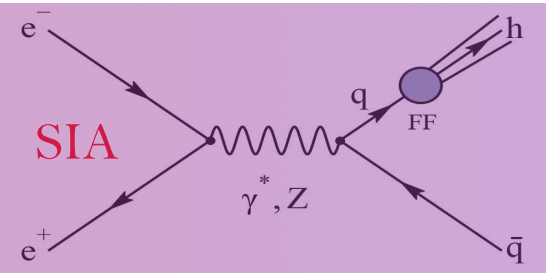


- $\boldsymbol{D_q^h(z)}$: describe the fragmentation of a quark into a hadron, where the hadron carries a fraction $\boldsymbol{z = 2E_h/\sqrt{s}}$ of parton's momentum



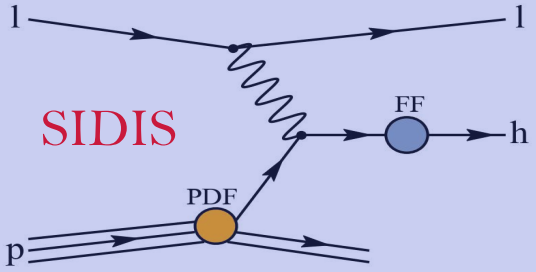
$$\boldsymbol{e^+e^- \to h + X}: \sum_q \boldsymbol{e_q^2\, D_q^h(z)}$$

Access FFs with QCD factorization



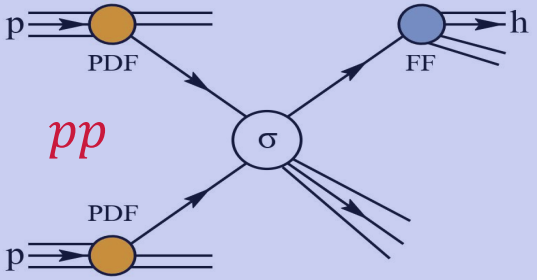
e^+e^-: $s = \sum_q \sigma(e^+e^- \to q\bar{q}) \otimes FF$

- No PDFs necessary
- Calculations know at NNLO
- Flavor structure not directly accessible



SIDIS: $s = \sum_q PDF \otimes \sigma(eq \to e'q') \otimes FF$

- Depend on unpolarized PDFs
- Flavor structure directly accessible
- FFs and PDFs



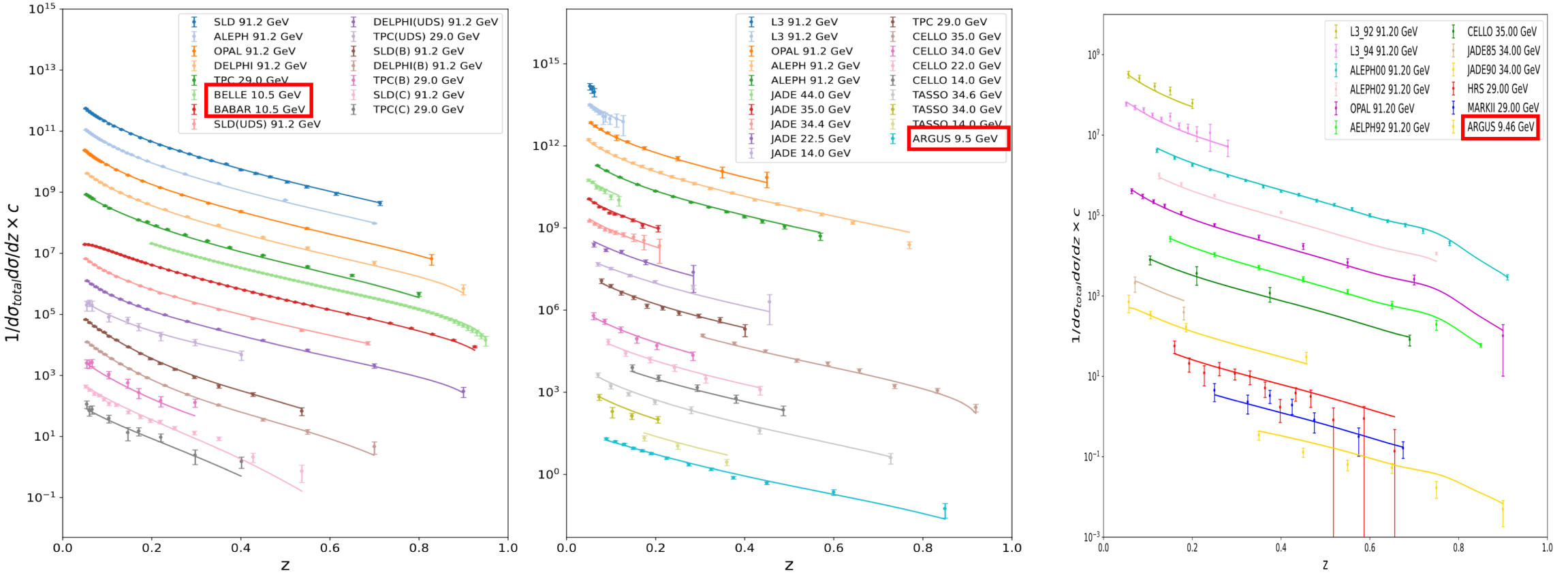
pp: $s = \sum_q PDF \otimes PDF \otimes \sigma(q_1 q_1 \to q_1' q_2') \otimes FF$

- Depend on unpolarized PDFs
- Leading access to gluon FF
- Parton momenta not directly known

SIA @ e^+e^- : the cleanest process for FFs studying

World data: $\pi^{\pm}$, π^{0}, and η

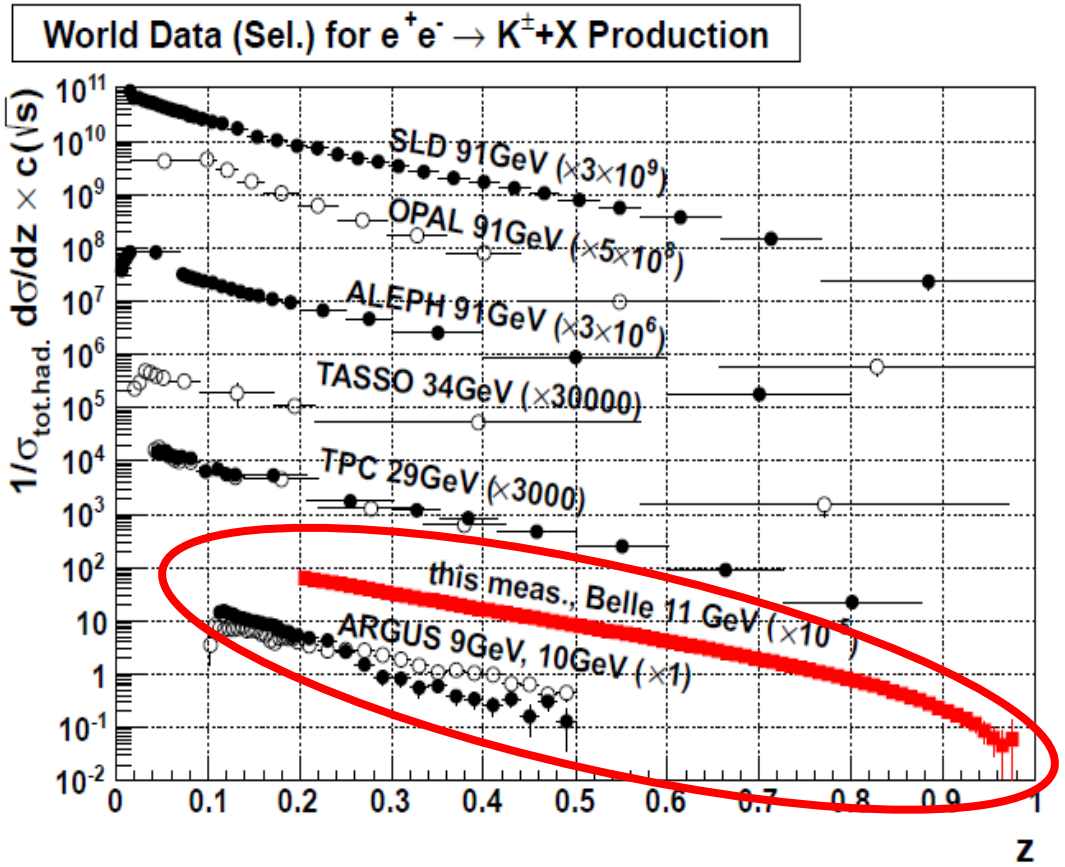
arxiv:2404.11527



Lack of precise data at low energy, where BESIII could contribute

World data: $K^{\pm}$ and K^0_S

PRL **111** 062002 (2013)



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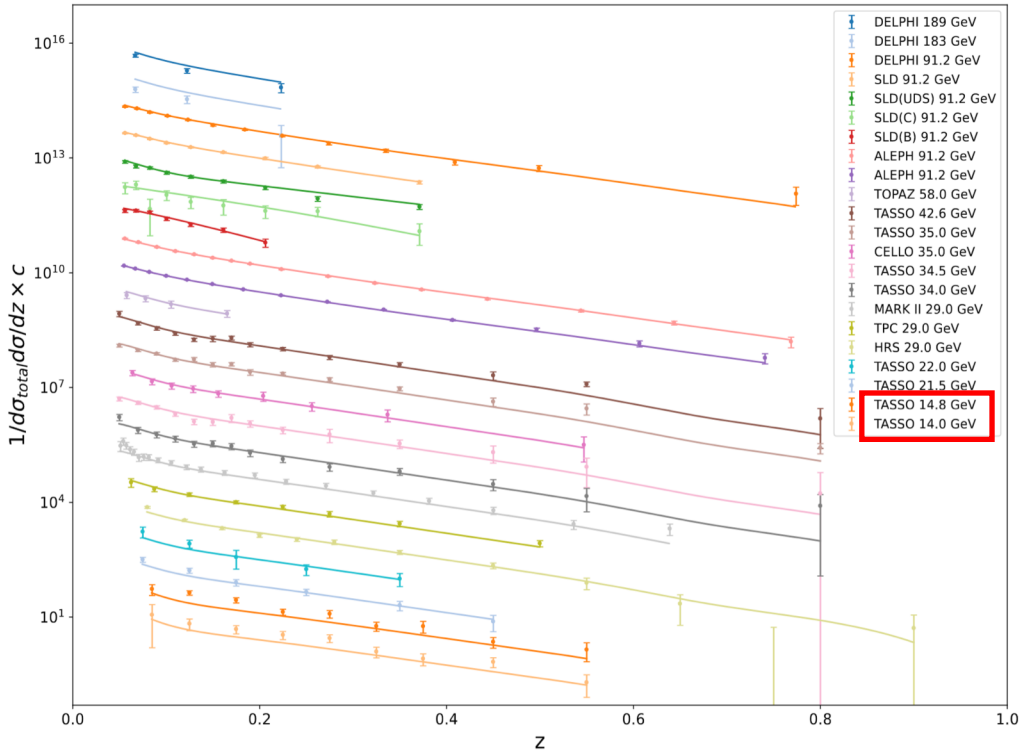


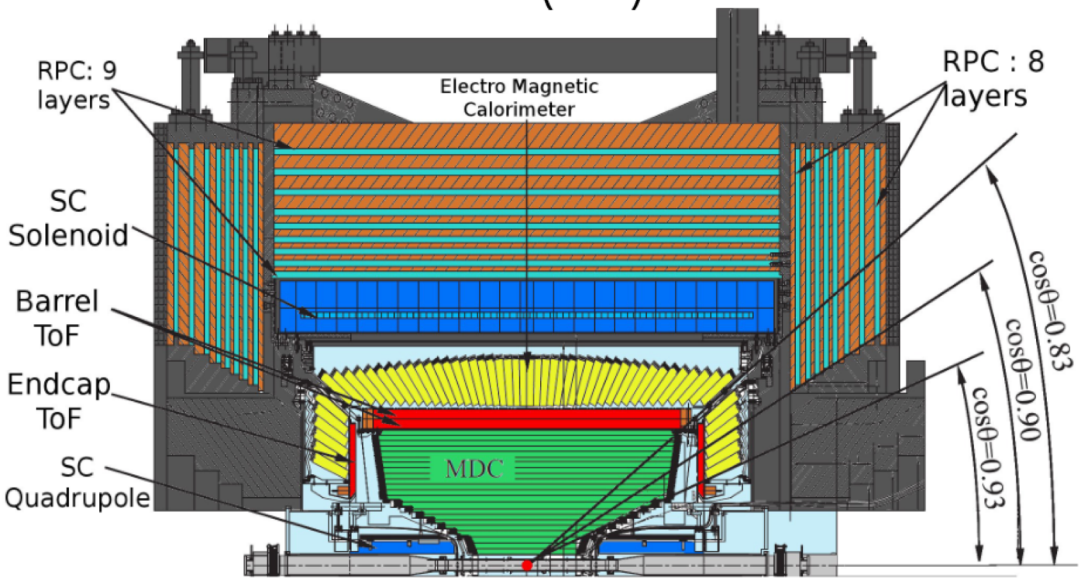
Lack of precise data at low energy, where BESIII could contribute

BEPCII and BESIII

BEPC = Beijing Electron Positron Collider

- Located at the BEPCII collider (Beijing/China)
- Symmetric beams (2-5 GeV C.M. Energy)
- Maximum Luminosity: 1 nb^{-1}/s
- 93% coverage of the solid angle

NIM A614 (2010) 345



Superconducting Solenoid:
- 1T magnetic field

Time-of-Flight System:
- 68 - 110 (65 after upgrade) ps

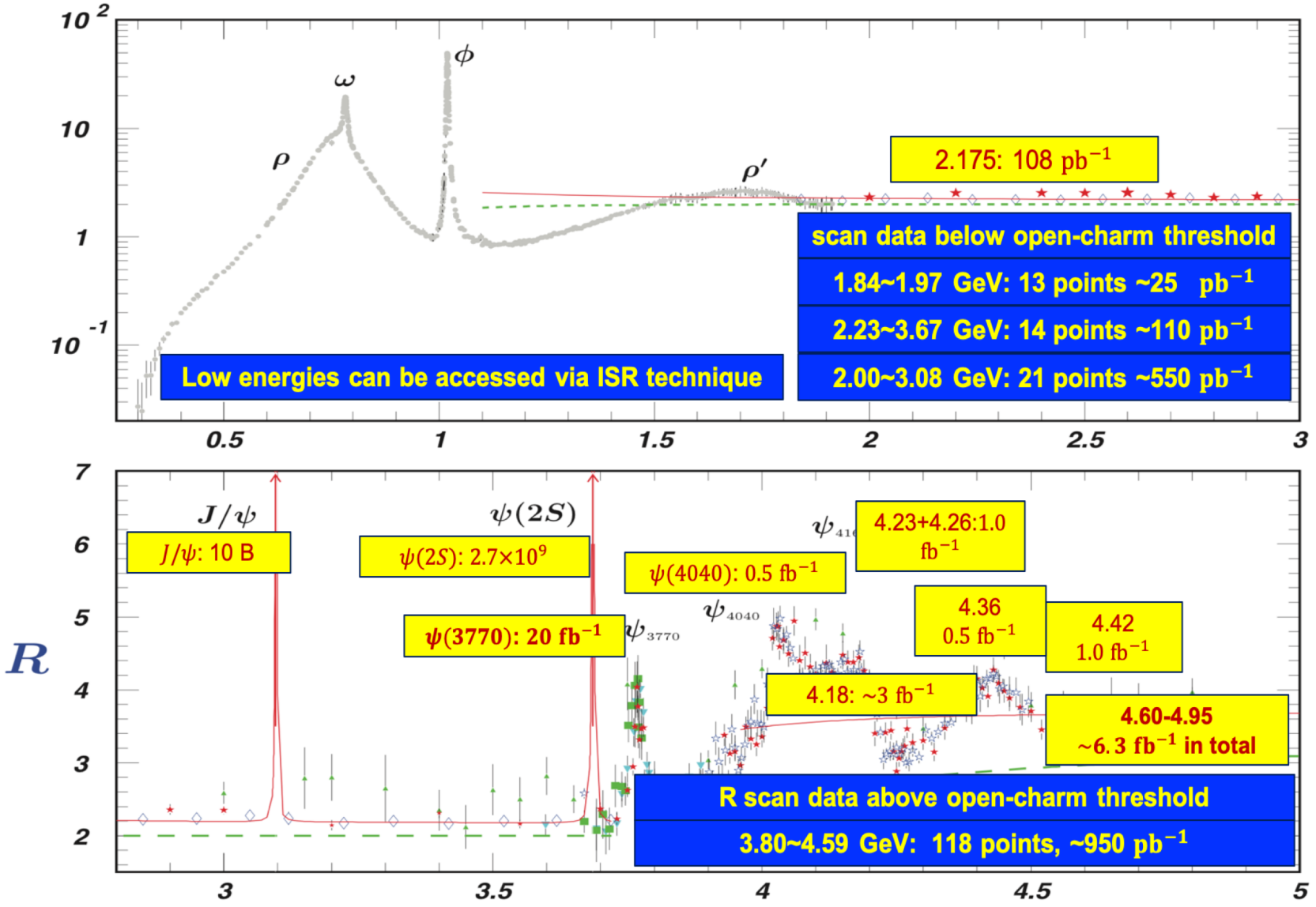
Drift Chamber:
- 0.5% momentum resolution
- 6% dE/dx resolution

Muon Chambers:
- 8-9 layers of RPCs
- 1.4-1.7 cm resolution
- P > 400 MeV

Electromagnetic Calorimeter:
- 6240 CsI(Tl) crystals
- 2.5% energy resolution
- 0.5 – 0.7 cm spatial resolution

BESIII = Beijing Spectrometer III

Data collected at BESIII



R-scan data:

- 1.84 ~ 4.95 GeV, ~170 points
- Extensive R ratio measurement
- Near-threshold Baryon pair-production mechanism

J/ψ and $\psi(2S)$ data:

- Largest sample in the world
- Light (exotic) hadron spectrum

$\psi(3770)$ data:

- 20 fb^{-1}
- Charm meson decays
- ISR technique for g-2 physics

XYZ data:

- Large open-charm samples
- Charmonium (-like) states

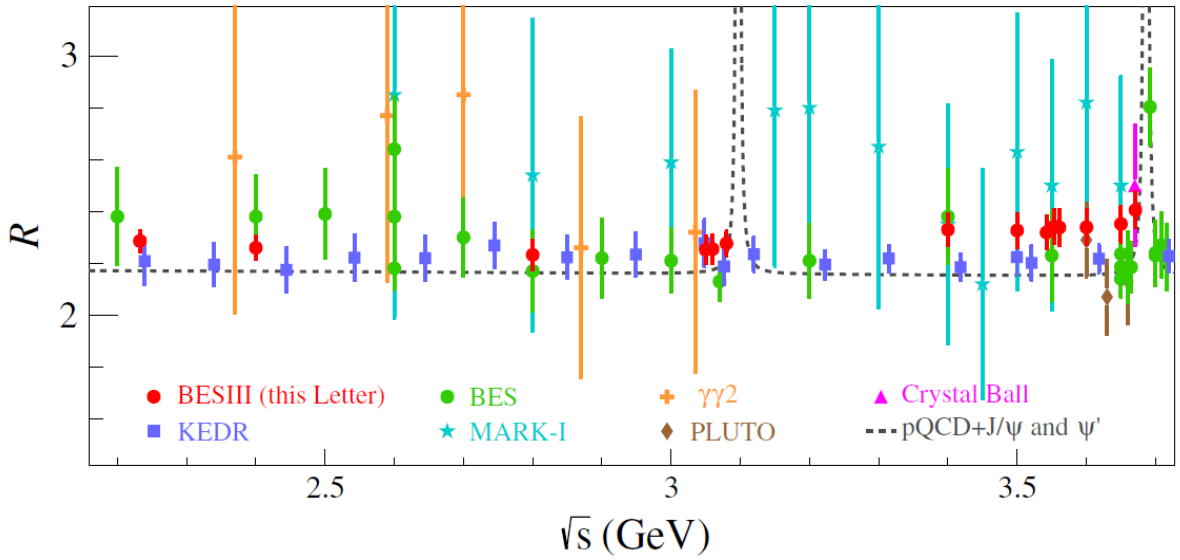
Measurement strategy at BESIII

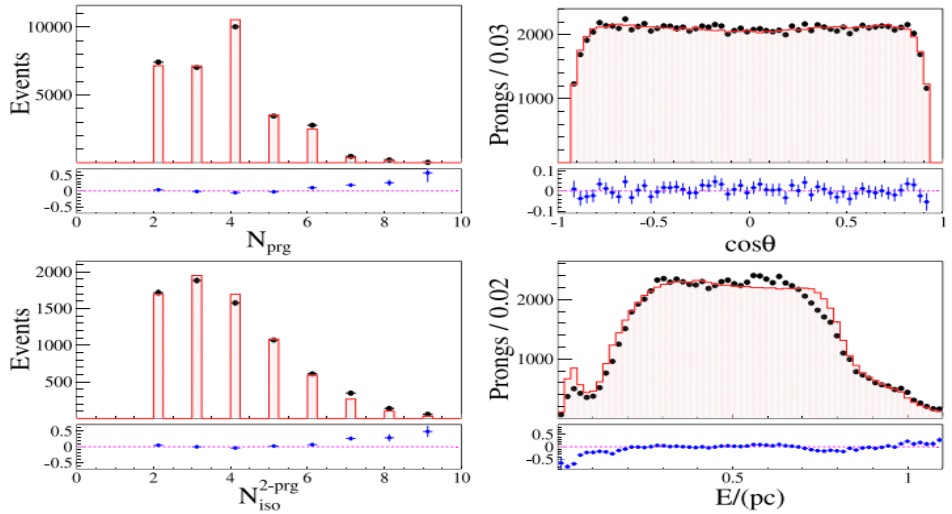
- Normalized differential cross section (taking ***h*** as the hadron under investigation):

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

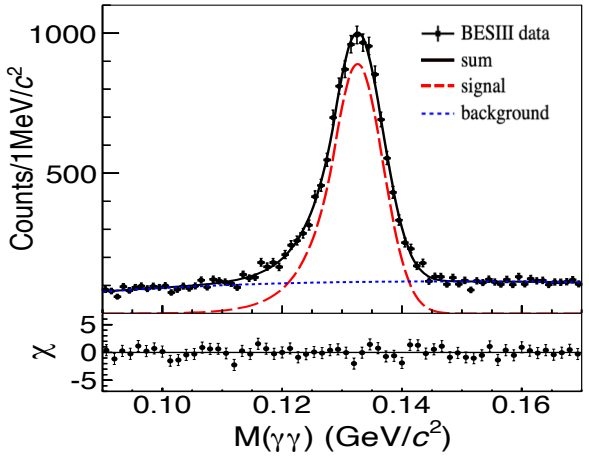
- Hardronic events N_{had} : $R \equiv \sigma(e^+e^- \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$
- Two relatively independent inclusive MC models are developed to determine f_h

PRL **128** 062004 (2022)

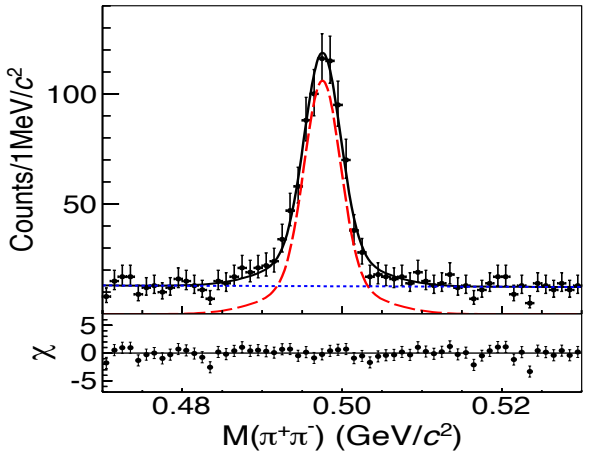




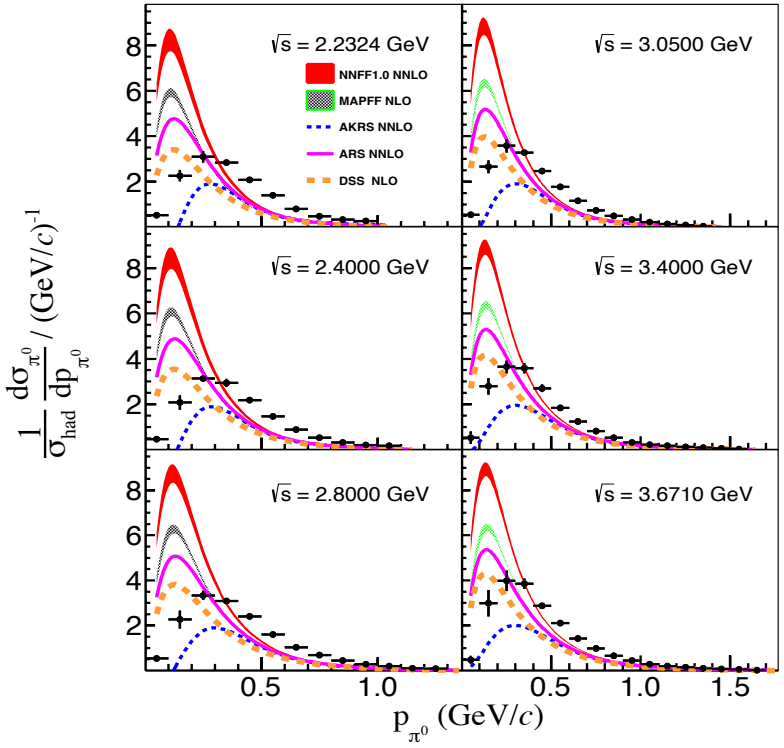
Measurement results: π^0 and K_S^0

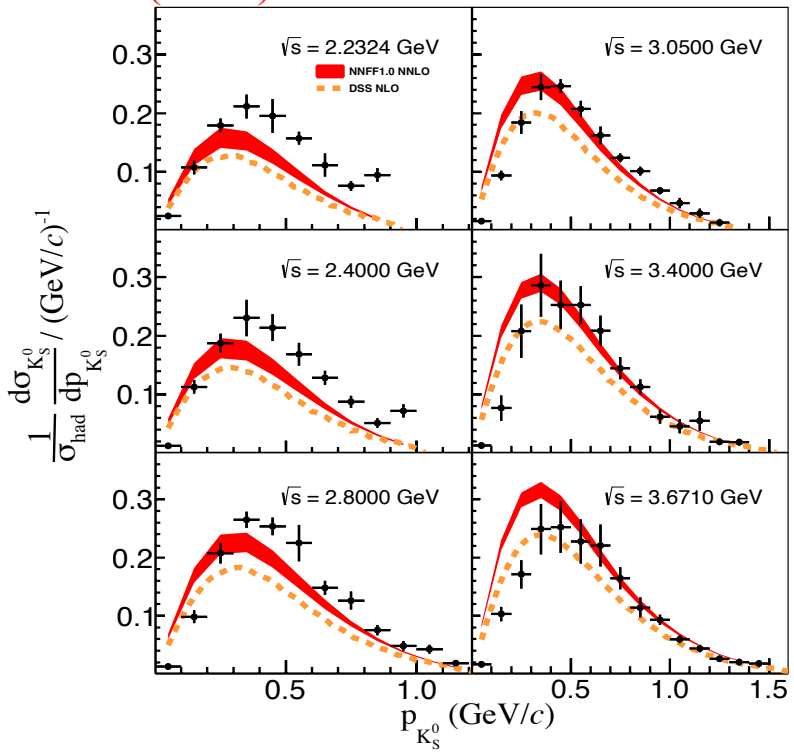


$p \in (0.4, 0.5)$ GeV/c



PRL **130** 231901 (2023)

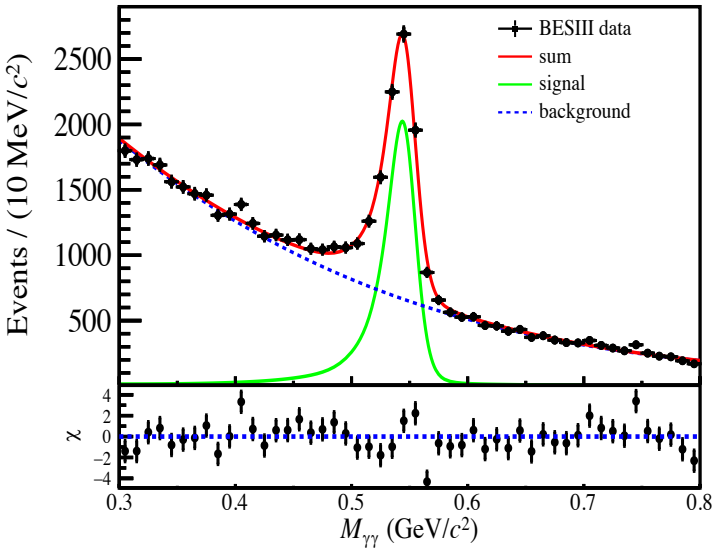




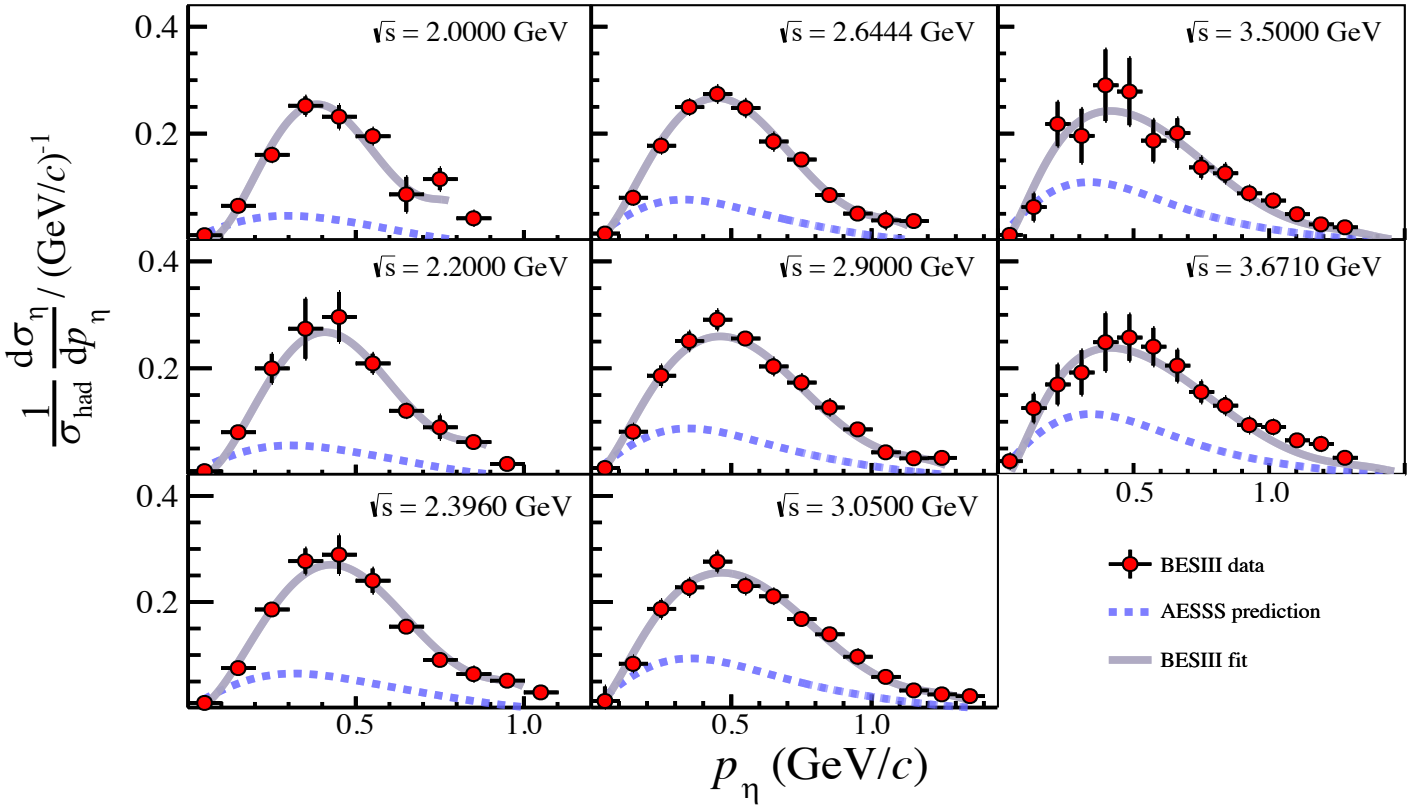
- Dominant uncertainty is from simulation of $e^+e^- \to \pi^0/K_S^0 + X$:
- Disagreement between FF fits and data depends on both $\sqrt{s}$ and p_h
- Leading twist calculation not sufficient? quark and hadron mass correction? small-z resumption? problem in the extrapolation of FFs to lower energy?

Measurement results: η

PRL **133** 021901 (2024)



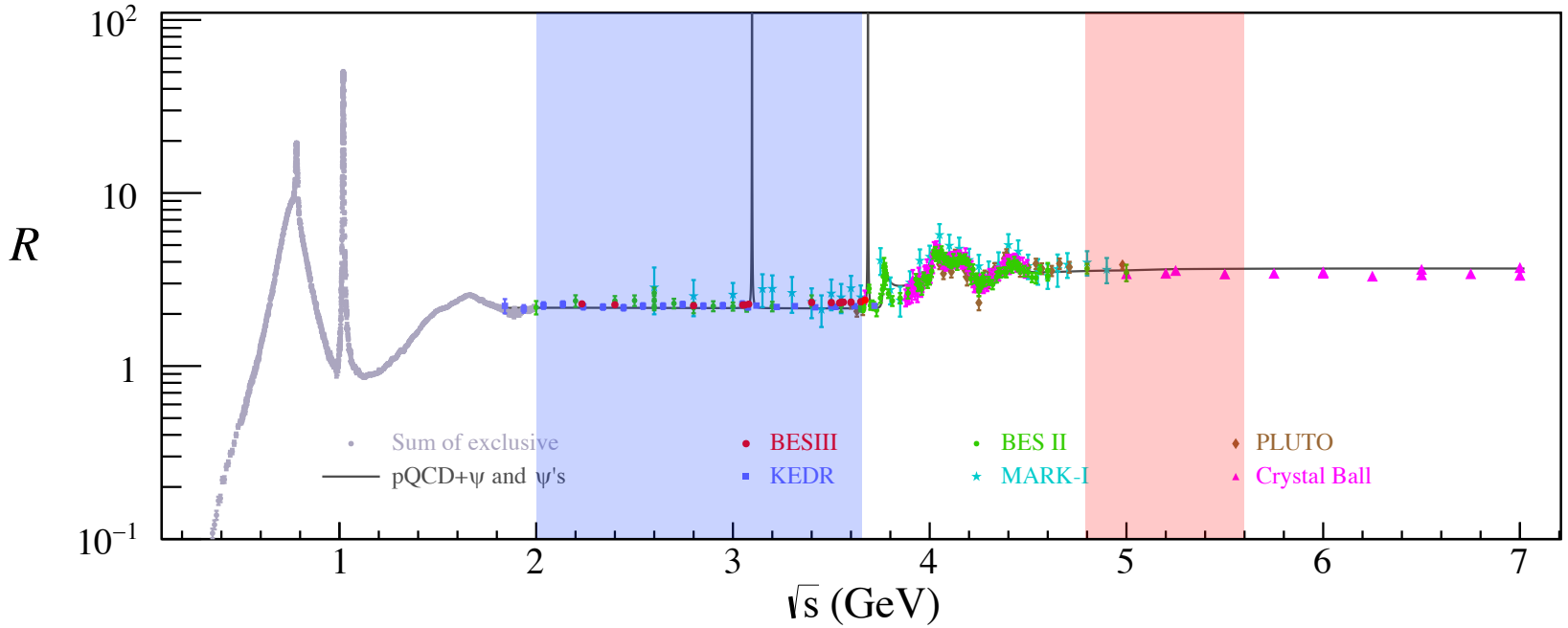
(0.4, 0.5) GeV/c @ $\sqrt{s}$ = 2.9 GeV



- Significant disagreement between FF fits given in PRD 83, 034002 (2011) and data
- A new fit performed by BESIII (arXiv: 2404.11527):
  - ✓ Incorporated new BESIII data and previous world e^+e^- data with $\sqrt{s} > 10$ GeV
  - ✓ Implemented higher-twist effects and hadron mass correction in NNLO accuracy

More results are ongoing

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



Summary

- Precise knowledge of FFs helps us to understand the non-perturbative QCD dynamics.

  The e^+e^- annihilation experiments provide the cleanest environment to measure FFs.

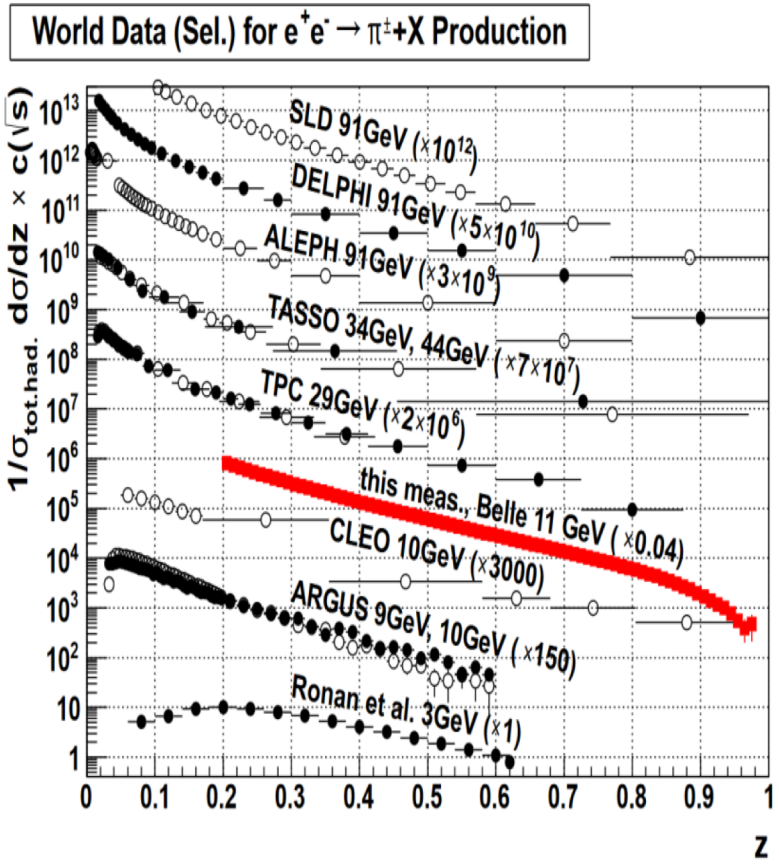
- BESIII contributes to the study of unpolarized FFs at $\sqrt{s} < 5$ GeV

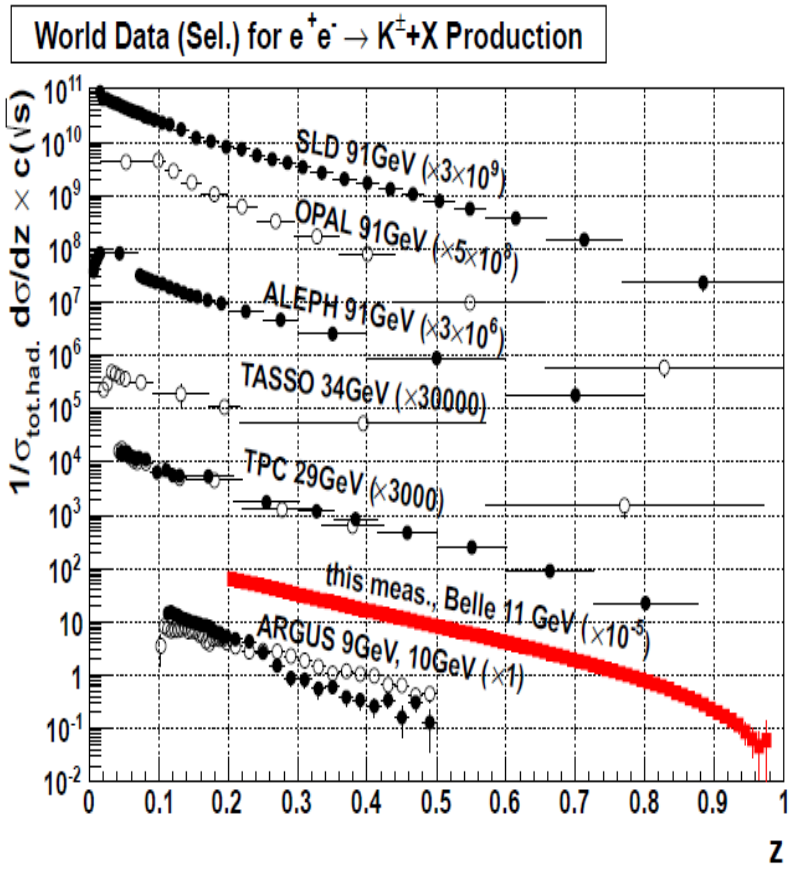
  - ✓ Normalized differential cross sections of inclusive $\pi^0/K_S^0/\eta$ production are measured
  - ✓ The results provide broad z coverage from 0.1 to 0.9 with precision of 3% at z ~ 0.4
  - ✓ Large discrepancy from predictions of the existing fragmentation functions are observed, which requires more study.
  - ✓ More results for $\pi^{\pm}, K^{\pm}, \phi, K^*$ at continuum region and $\eta'/\Lambda/\Sigma$ at higher energy region are currently in progress

Thank you!

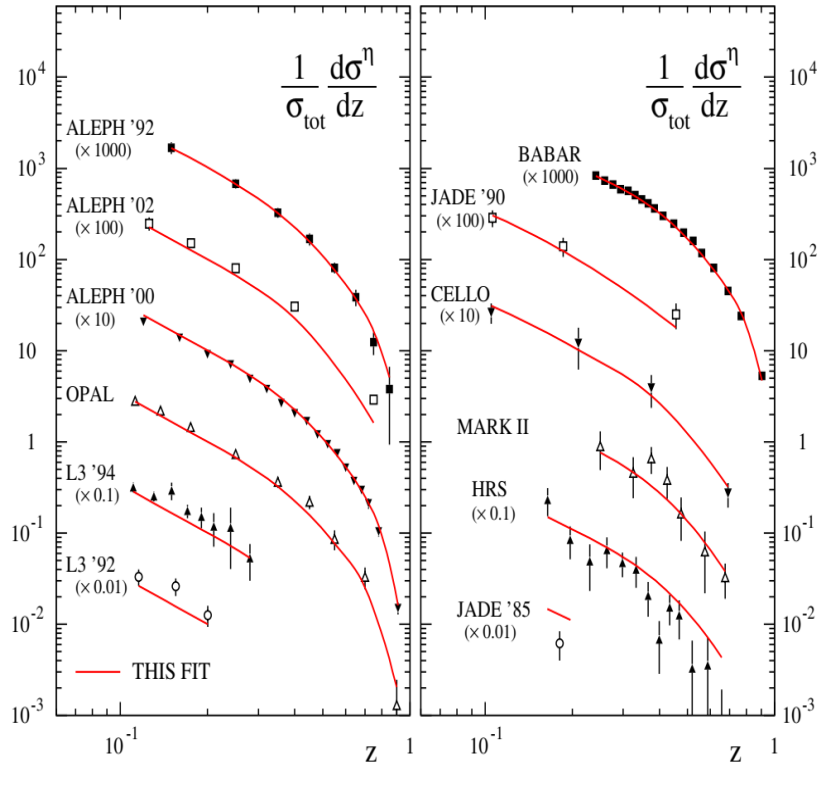
World data

PRL **111** 062002 (2013)





PRD **83** 034002 (2001)



Lack of precise data at low energy and with high z value, where BESIII could contribute