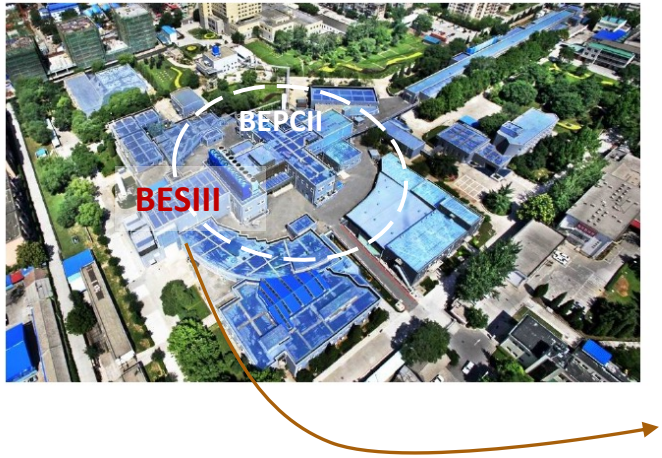
Status and Plans for Experimental Inputs to HVP at BESIII

Riccardo Aliberti

Muon g-2 Theory Initiative Spring 2024 meeting

Online, 22.04.2024

The BESIII Experiment



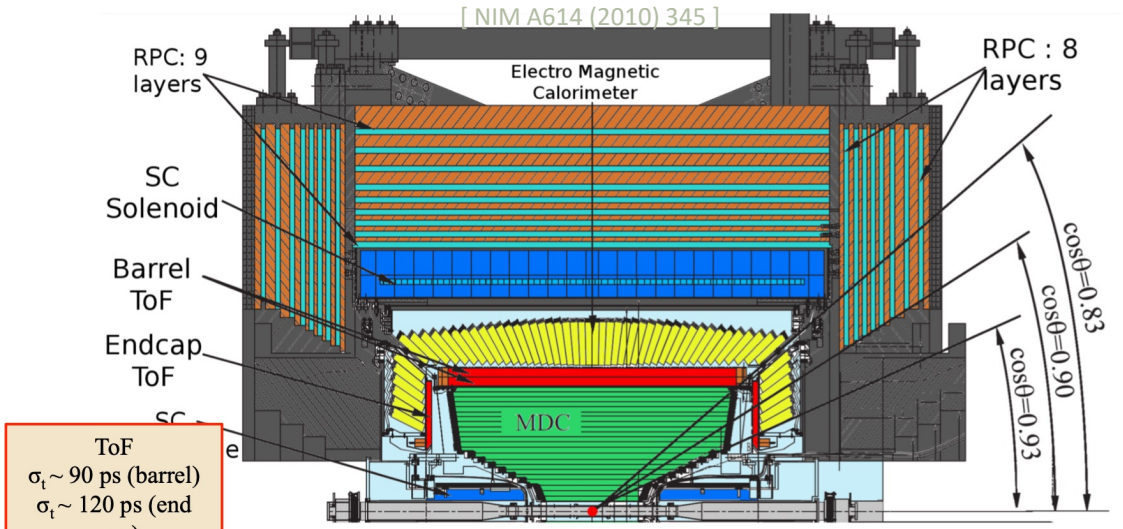
Located at the BEPCII collider (Beijing, China)

Symmetric e^+e^- beams

ECM between 2-5 GeV

Maximum luminosity: 1 nb^{-1}/s

93% coverage of the solid angle



ToF
$\sigma_t \sim 90$ ps (barrel)
$\sigma_t \sim 120$ ps (end caps)

Drift Chamber
$\sigma_{r\phi} \sim 130$ μm (single wire)
$\sigma_{pt}/p_t \sim 0.5$ % @ 1 GeV

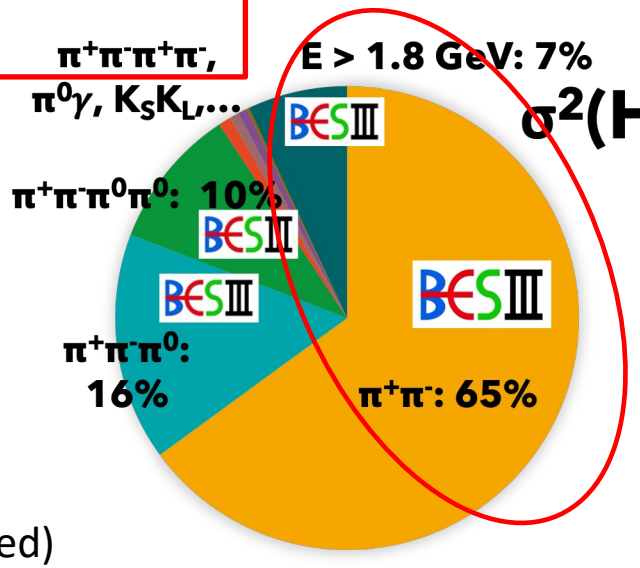
Electromagnetic CsI(Tl) Calorimeter
$\sigma_E/E < 2.5\%$ @ 1 GeV (barrel)
$\sigma_E/E < 5\%$ @ 1 GeV (end caps)
$\sigma_{xy} \sim (6\text{ mm})/E^{1/2}$ @ 1 GeV

RPC Muon Detector
$\Delta\Omega/4\pi = 93\%$

BESIII Contributions to HVP

Published measurements:

- Time-like Pion Form Factor – 600 to 900 MeV – Phys.Lett.B753 (2016) 629
- R Measurement – 2 to 3.7 GeV – Phys. Rev. Lett. 128 (2022) 062004
- Several exclusive channels between 2 and 3 GeV ($\pi^+\pi^-\pi^0$, $K_SK_L\pi^0$, $\Phi\pi\pi$, $\eta'\pi\pi$, …)



Preliminary results:

- ISR e^+e^- -> $\pi^+\pi^-\pi^0$ – 0.7 to 3 GeV – arXiv:1912.11208
- ISR e^+e^- -> $\pi^+\pi^-\pi^0\pi^0$ – 0.9 to 3.3 GeV

On going and future measurements:

- ISR e^+e^- -> $\pi^+\pi^-$ – 0.3 to 1 GeV (tagged) and > 1 GeV (untagged)
- ISR e^+e^- -> K K – 1 to 3.3 GeV (tagged and untagged)
- ISR R measurement – 0.3 to 2 GeV
- R measurement – 1.8 to 2 GeV (future)

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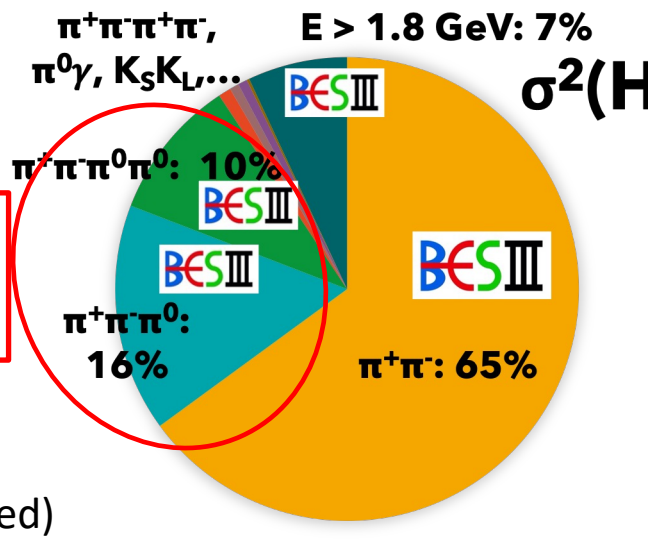

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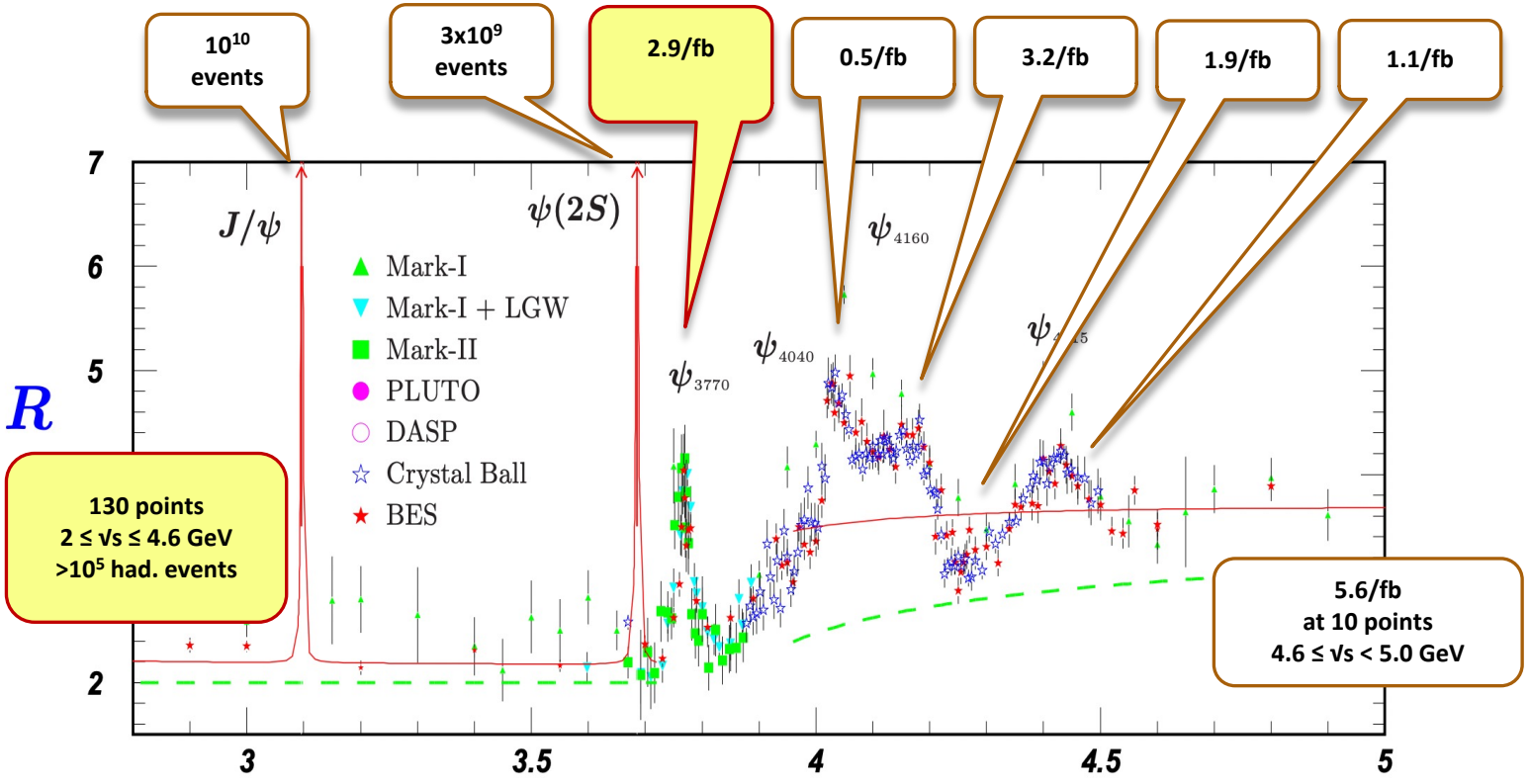
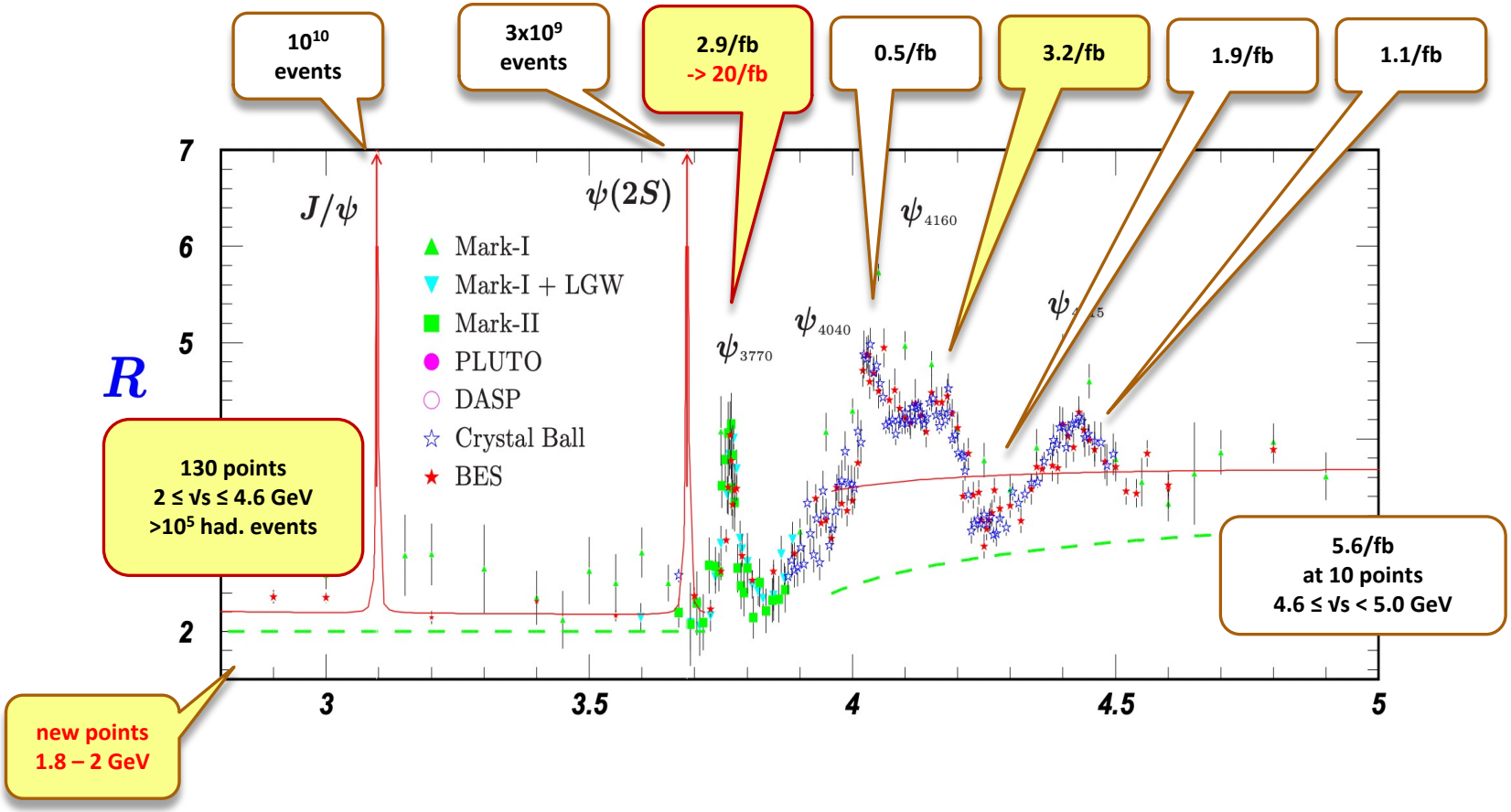


World largest τ-charm dataset in e^+e^- annihilation …

BESIII Contributions to HVP



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… and still growing

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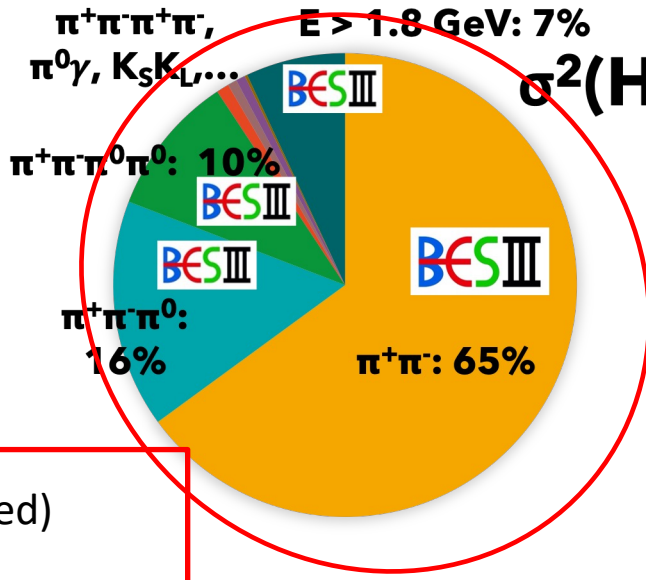

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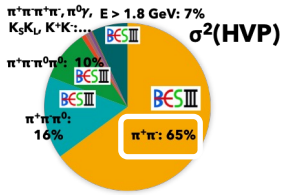
Pion Form Factor at BESIII



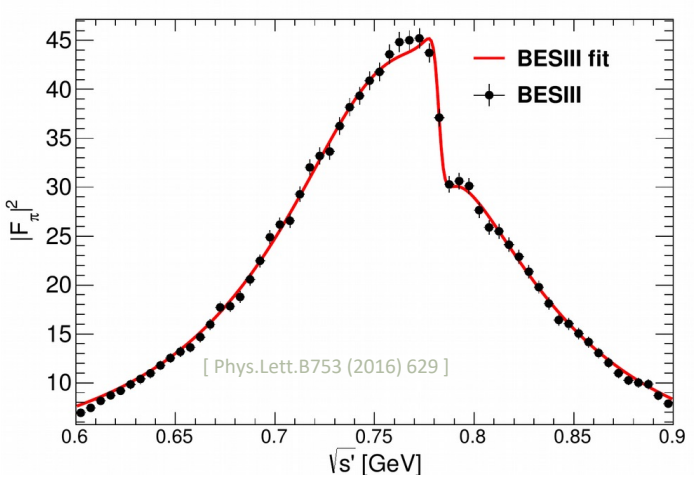
[Phys.Lett.B753 (2016) 629]

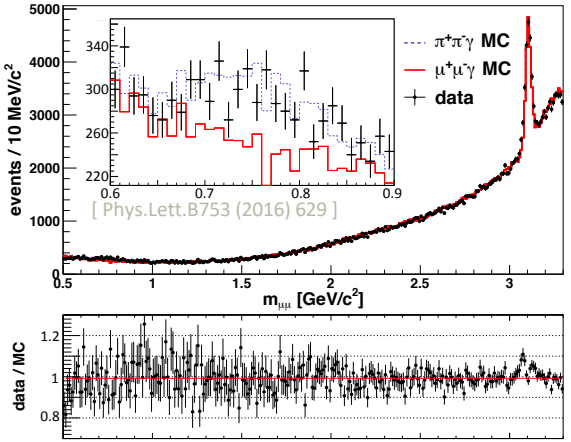
Tagged ISR analysis

4C Kinematic Fit ($\pi\pi\gamma$ hypothesis)

Background only from $\mu\mu(\gamma)$ events

π/μ separation based on neural network (ANN)





- **Form factor evaluation for $0.6 \leq m_{\pi\pi} \leq 0.9$ GeV**
  - 70% of total 2π contribution
  - 50% of a_μ^{HVP} contribution
  - Fit with Gounaris-Sakurai parameterization

- Cross check with muons:
  - Selecting muons using ANN
  - Perfect agreement with QED prediction
  - **Measurement of J/ψ electronic width**

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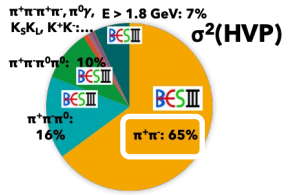

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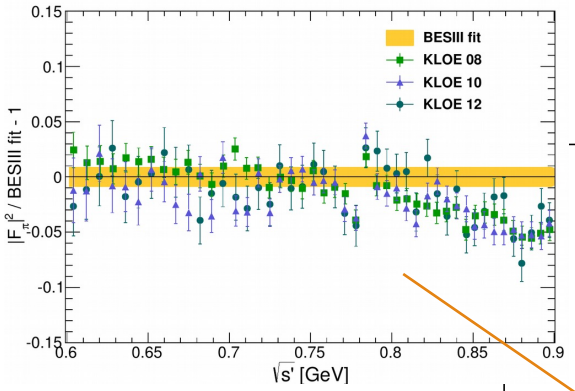
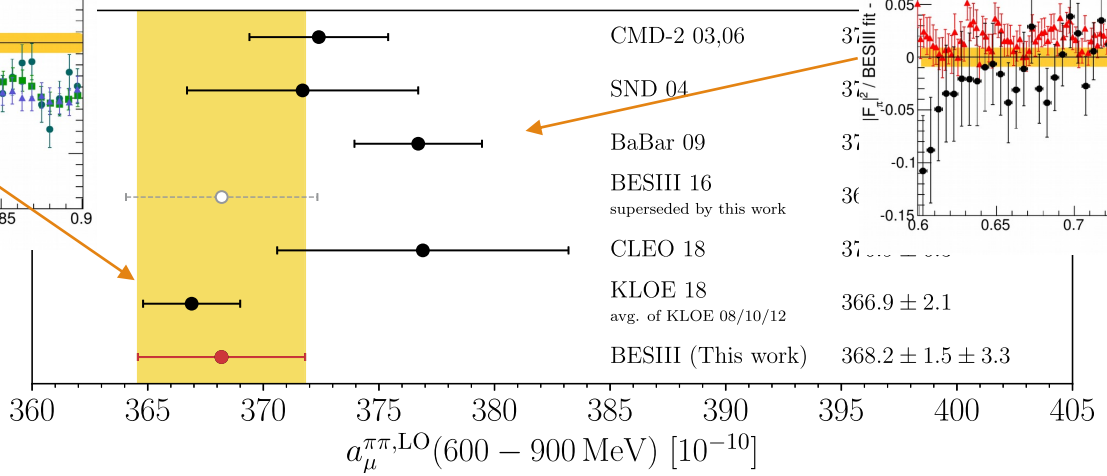
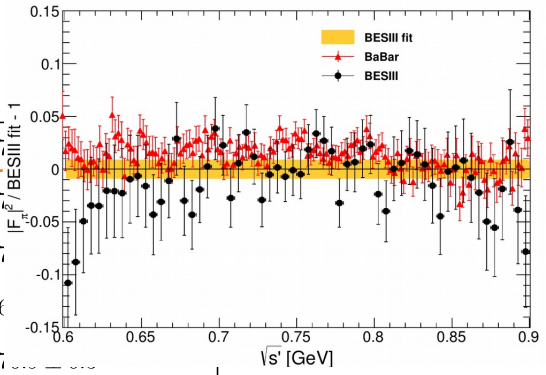
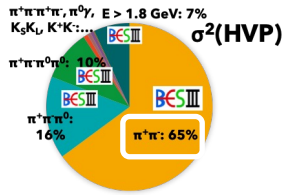




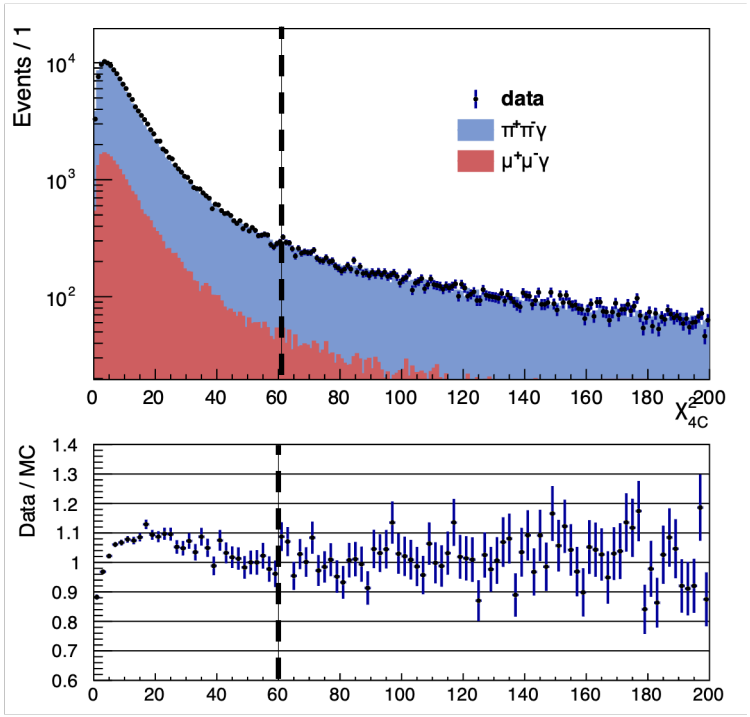


- **Precision competitive** with current best results:
  - BESIII: 1.0%
  - BaBar: 0.7%
  - KLOE: 0.6%
- Evaluation of covariance matrix corrected [Phys.Lett.B812 (2021) 135982]
  - Lower statistical uncertainty
- **Work** on going **to reach *O*(0.5%)** accuracy

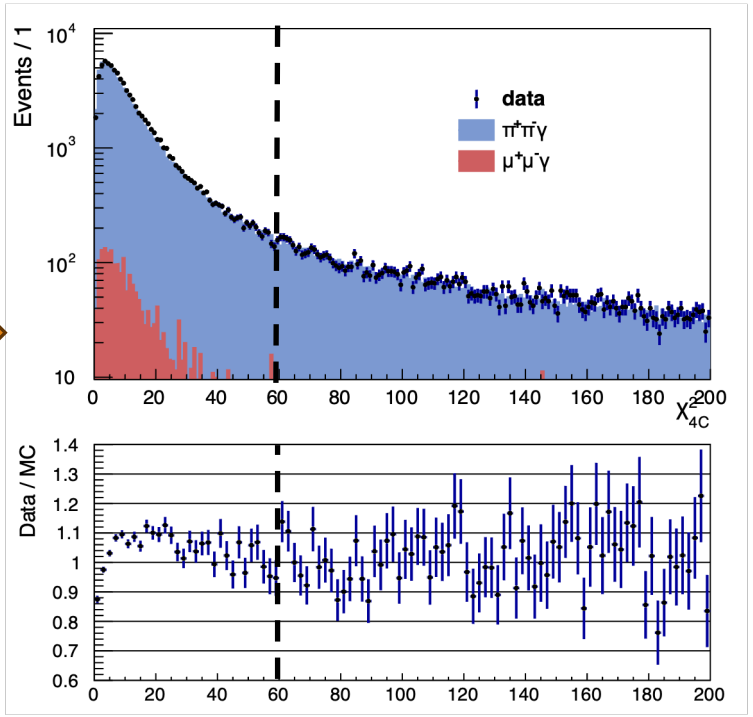
Pion Form Factor at BESIII



- Do Phokhara shortcomings in (N)NLO ISR affect the analysis significantly?
- Check Data-MC kinematic fit χ^2 to spot eventual (large) systematic effects!



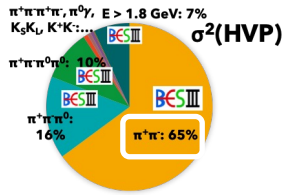
ANN



- Excellent agreement for χ^2> 40 (cut < 60):

No sign of overlooked systematics in kinematic fit

Pion Form Factor at BESIII



New analysis on going!

Staged approach:

2024 **2025** **2026** **2027** 2028

Pion FF @ 0.7%

Pion FF @ 0.5%
Normalization to $e^+e^- \rightarrow \mu^+\mu^-$
Helicity Angle Fit

First result with O(0.7%) accuracy (beg. 2025):

- Data sets at √s = 3.77 and 4.18 GeV
- Integrated luminosity ~6 fb^{-1}
- **Different selection strategies** (1C and 4C Kinematic Fits)
- Investigation of NLO effects (?)
- **Partial blinding**
- **Normalization to luminosity**

Cross check of:

- Previous measurement (same data set)
- Different CM energies (3.77 vs 4.18 GeV)
- Radiative effect (1C vs 4C kinematic fits)

Source	Uncertainty (%)
~~Photon efficiency~~	~~0.2~~
Tracking efficiency	0.3
Pion ANN efficiency	0.2
~~Pion e-PID efficiency~~	~~0.2~~
Angular acceptance	0.1
Background subtraction	0.1
Unfolding	0.2
FSR correction δ_{FSR}	0.2
Vacuum polarization correction δ_{vac}	0.2
Radiator function	0.5
Luminosity $\mathcal{L}$	~~0.5~~ 0.3
Sum	~~0.9~~ 0.7

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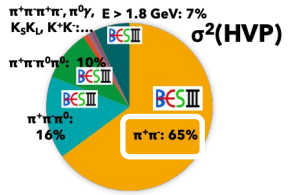

New analysis on going!

Staged approach:

Final accuracy O(0.5%) (≈ 2028):

- New data sets at √s = 3.77
- Integrated luminosity ~**17 fb^{-1}**
- **Different selection strategies** (1C, 4C, full PID, Helicity Angle Fit)
- Investigation of NLO effects
- **Blind analysis**
- **Normalization to muons**

Plenty of internal consistency checks:

- 1C vs 4C Kinematic Fit
- PID vs Helicity Angle
- Luminosity vs Muon
- Data taking periods

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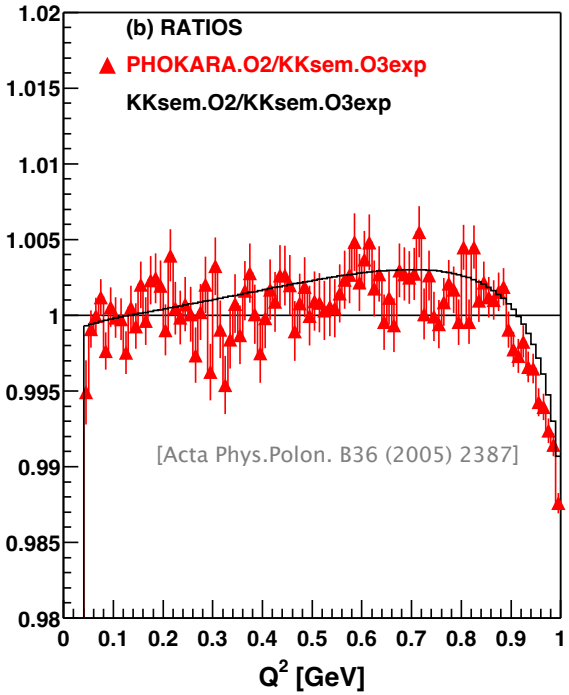
Studies of NLO Effects

- Investigation of events with two radiative photons started few years ago
- Observed effect similar to BaBar:
  - **Phokhara** works at **LO on 2-photon events,** thus no surprise!
  - Need to **quantify the impact on the selection**
  - **KKMC** best candidate (complete LL) …



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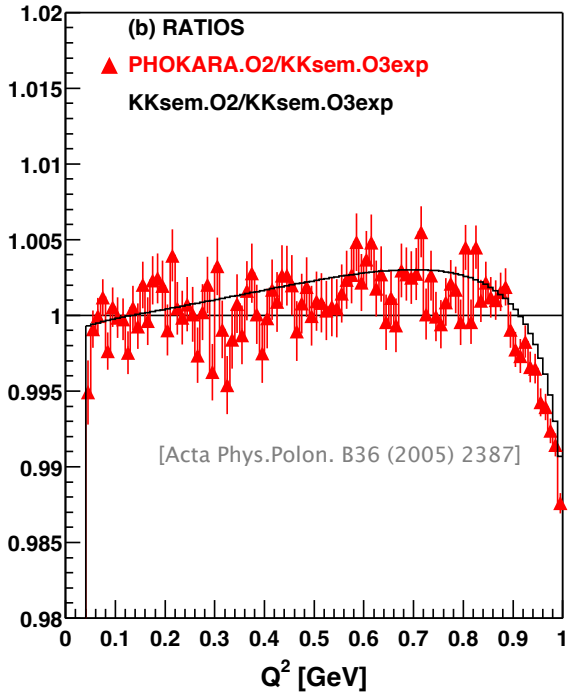

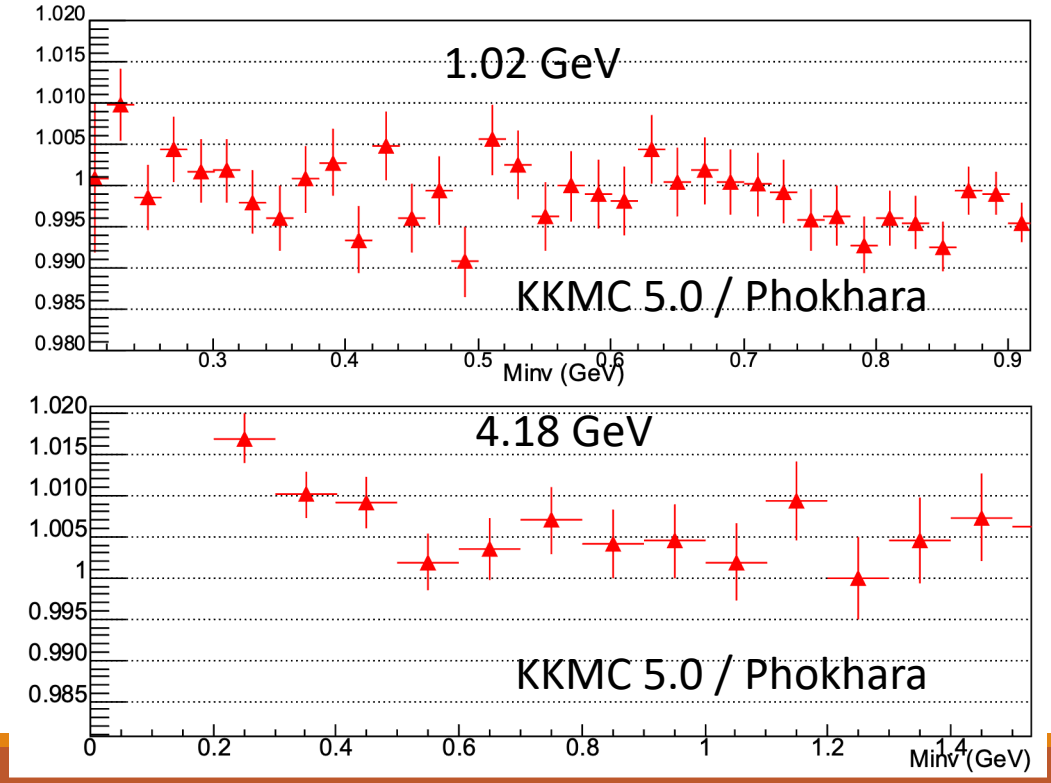

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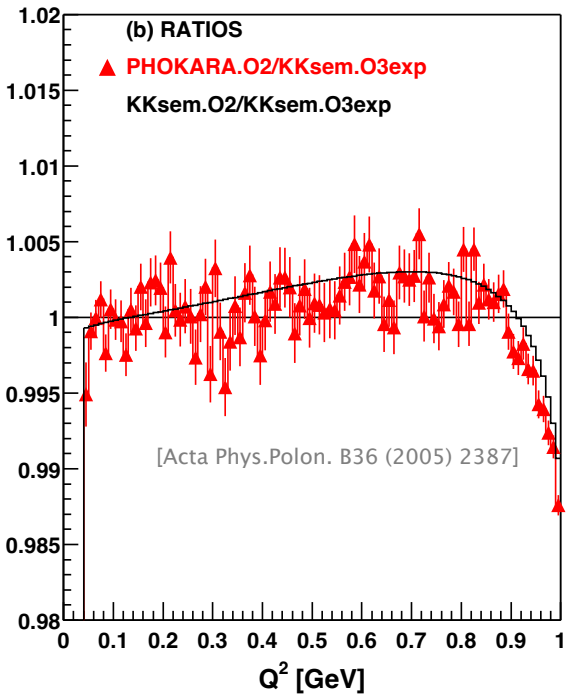

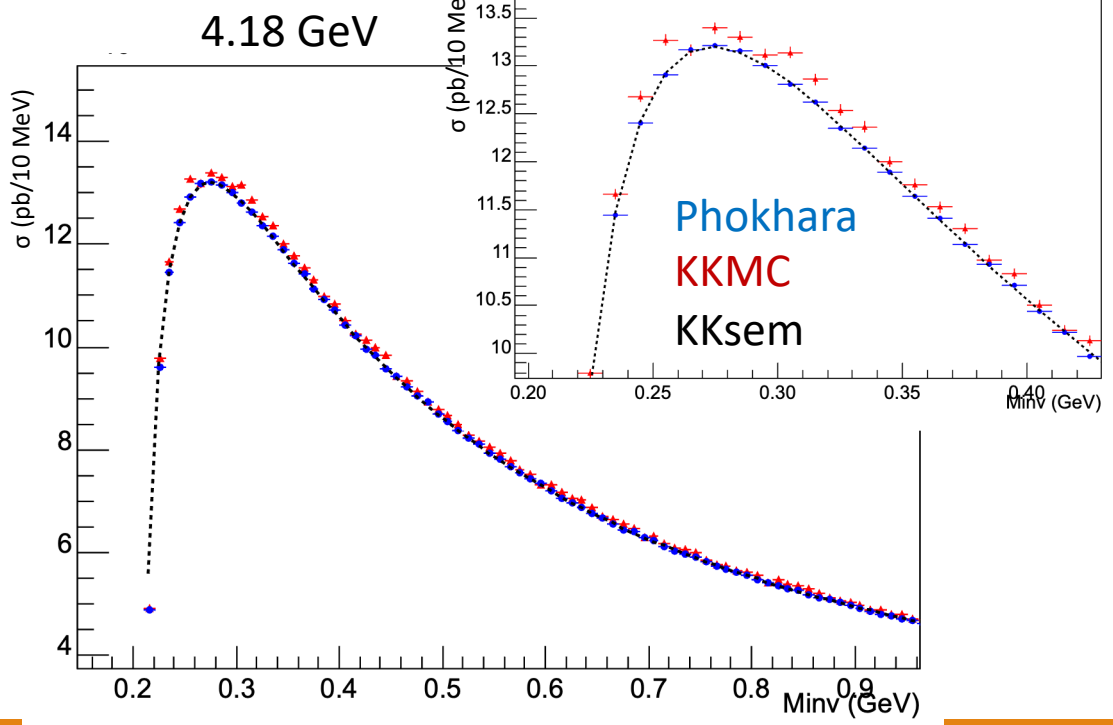

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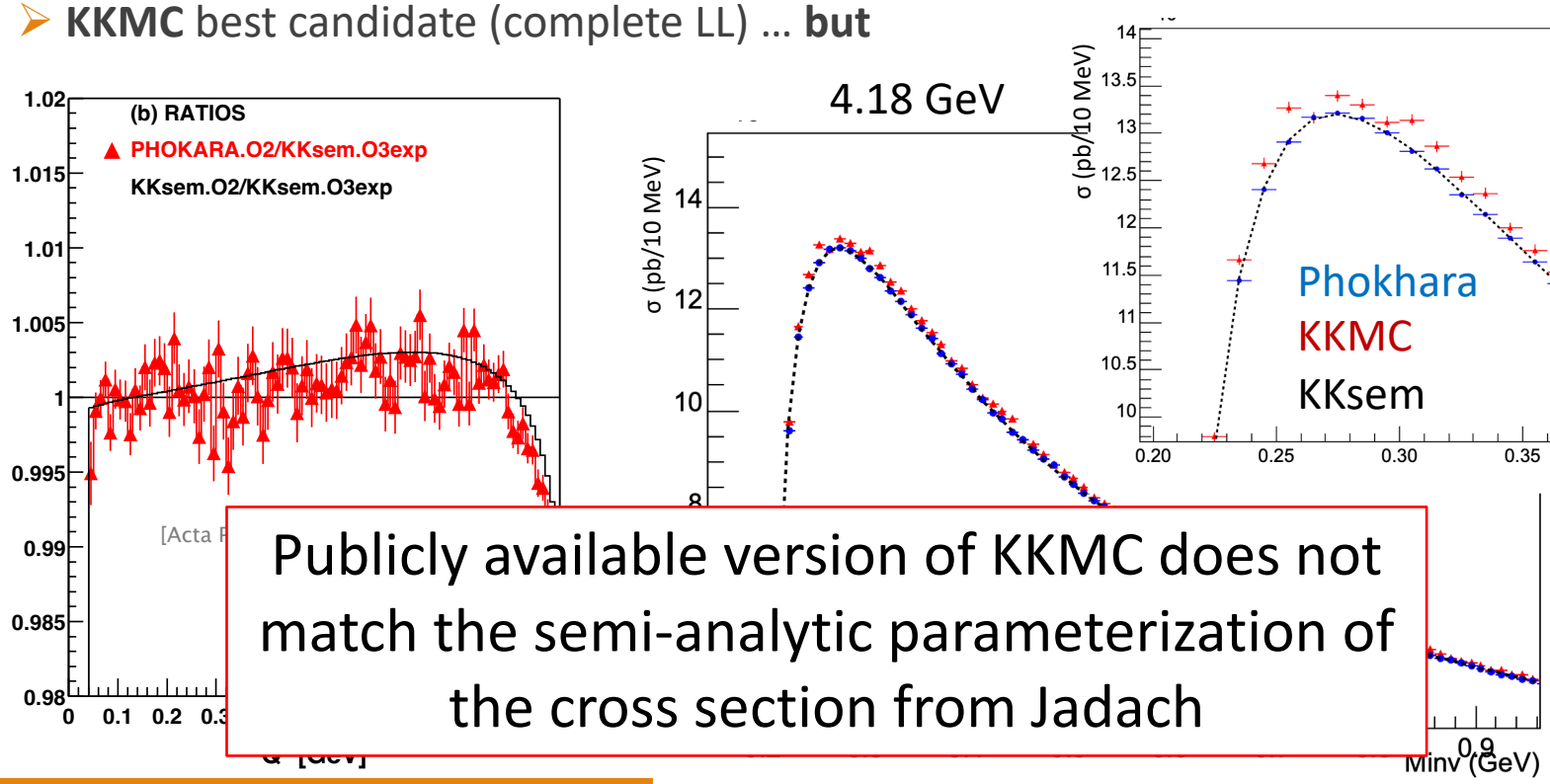
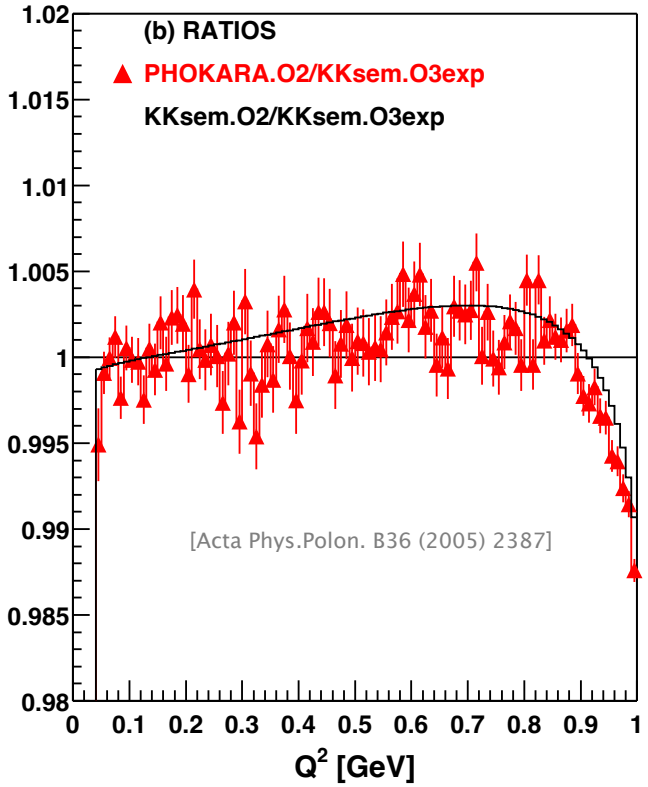


Publicly available version of KKMC does not match the semi-analytic parameterization of the cross section from Jadach

Studies of NLO Effects

- **Phokhara – KKMC comparison** in Acta *Phys.Polon. B36 (2005) 2387* performed with **private version of KKMC**
- Public versions of KKMC do implement ISR (FSR) form factors (f_0) in the approximation of $Q^2 >> m_l$
- **Mass corrections** were **evaluated and published** in Phys. Rev. D65, 073030
  - ISR: Eq 2.21
  - FSR: Eq 2.39
- Confirmed by S. A. Jost, who was performing the comparison
- **Original code** seems to have been **lost** (data corruption)
- Trying to implement the corrections in the new version of KKMC

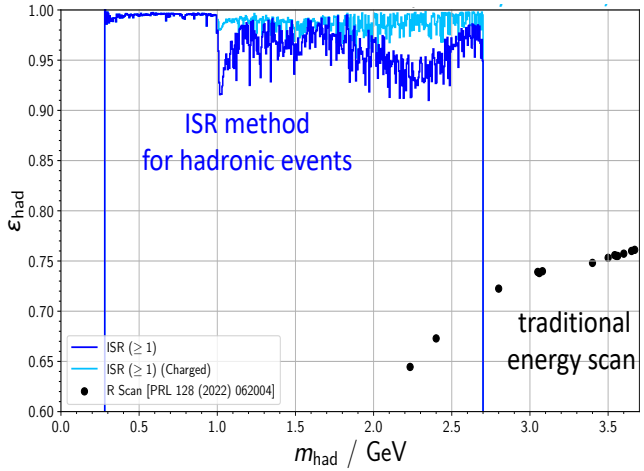


ISR R Measurement below 2 GeV

<u>New concept</u>: Determine **hadronic mass from ISR** photon **only**

Simple selection criteria:

- 1 high energetic photon (E > 1.2 GeV)
- At (very) large angle (37º-143º)
- At least 1 charged particle

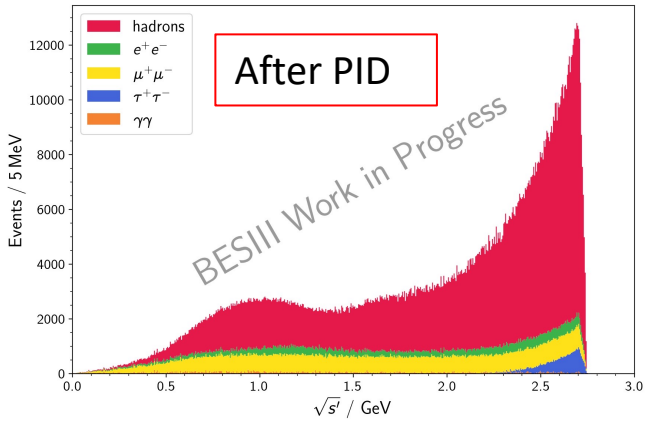


<u>Extremely high efficiency</u>

- **Limited reliance on generators**

Main backgrounds

- **QED** (Bhabha,di-muon)
- Non-ISR hadronic events



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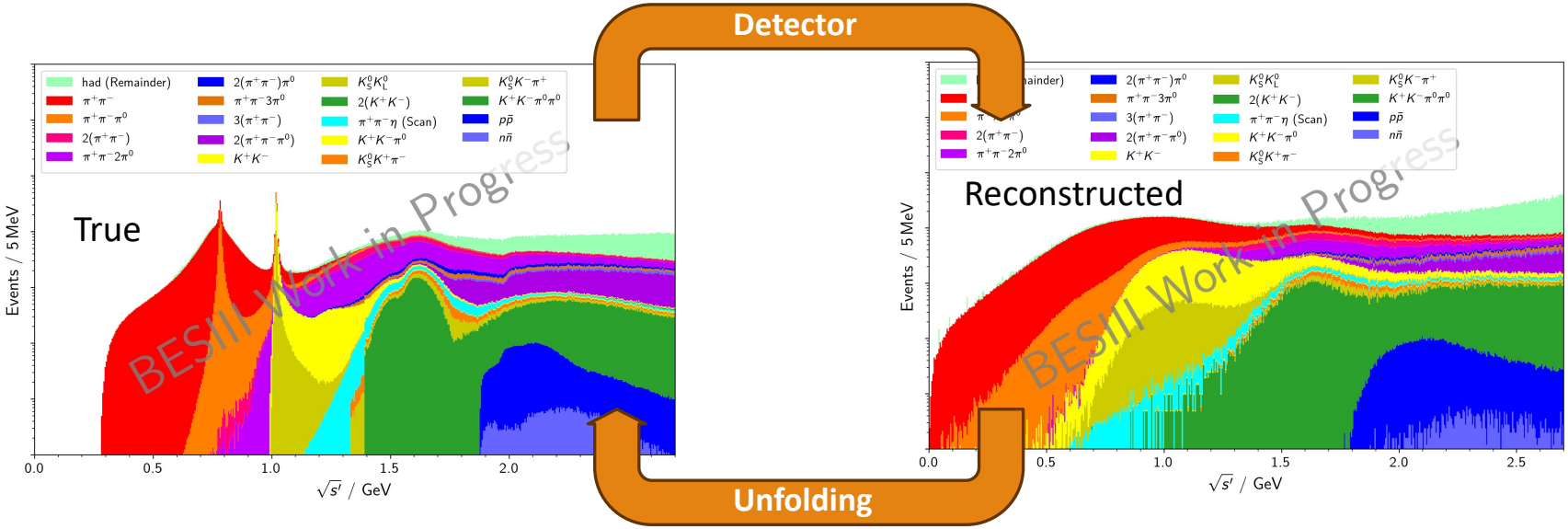

Large smearing introduced by detector resolution

Apply **unfolding** technique to recover the "true" spectrum

Quantifying (eventual) bias introduced by unfolding

- ✓ First results suggest **negligible impact** on a_μ

Aiming for few percent accuracy

Summary

- **BESIII** strongly **engaged in** providing experimental inputs to **HVP**
- **Published**:
  - **Pion FF** measurement with sub-percent precision
  - Most precise **R measurement** between 2 and 3.7 GeV
- Checks on 2π measurement:
  - **No** sign of **overseen systematics** in kinematic fit
  - Found **missing corrections** in distributed **KKMC** versions
- **The best is still to come:**
  - **Pion FF with O(0.7%)** precision next year
  - **R measurement below 2 GeV** via ISR next year
  - **Kaon FFs** via ISR (on going)
  - **Pion FF with O(0.5%)** already planned (time scale ≈4 years)