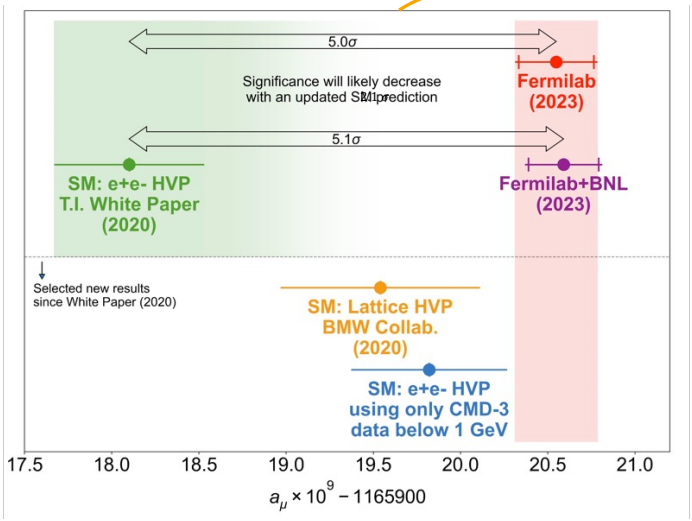
Experimental Inputs to HVP from the BESIII Experiment

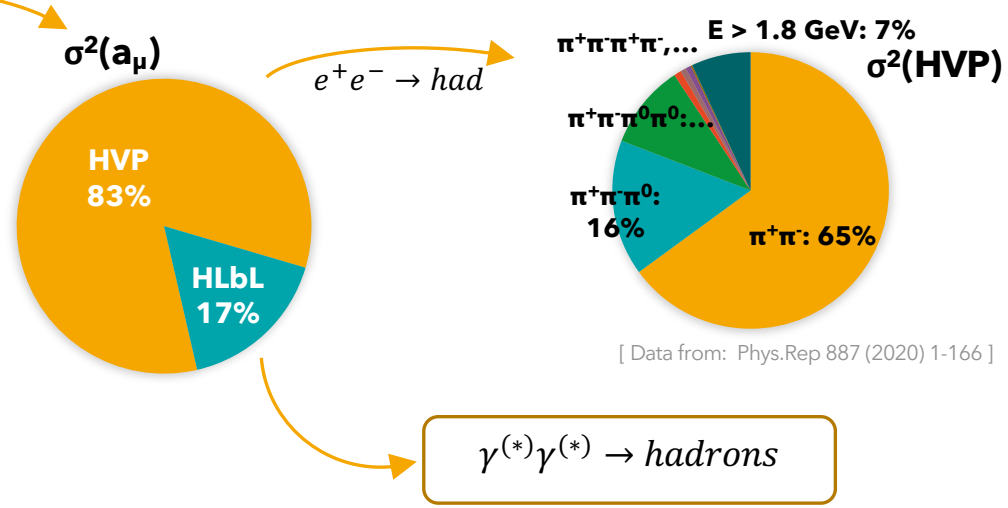
Riccardo Aliberti

II Workshop on Muon Precision Physics

Liverpool, 7-10 November 2023

Muon (g-2): SM and Experiment





[Data from: Phys.Rep 887 (2020) 1-166]

- Tension Experiment - SM (WP 2020) has now reached 5σ!
- Puzzling discrepancies in HVP evaluation:
  - Dispersive – Lattice QCD
  - KLOE – BaBar in $e^+e^- \to \pi^+\pi^-$
  - New CMD-3 measurement vs ALL the others in $e^+e^- \to \pi^+\pi^-$
- Better understanding strictly needed!

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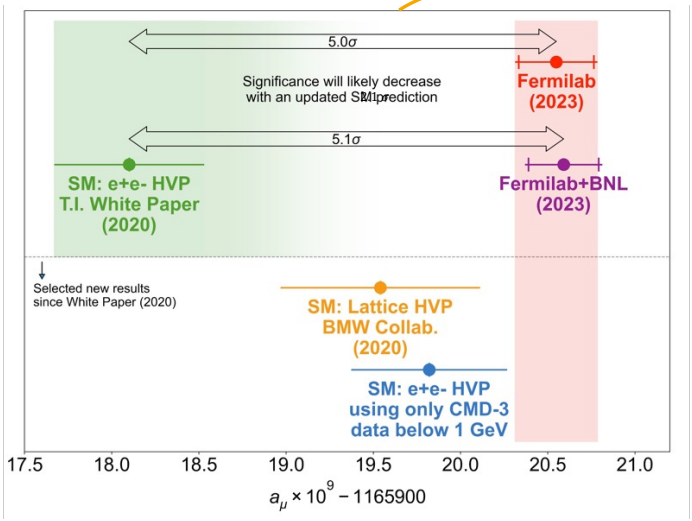

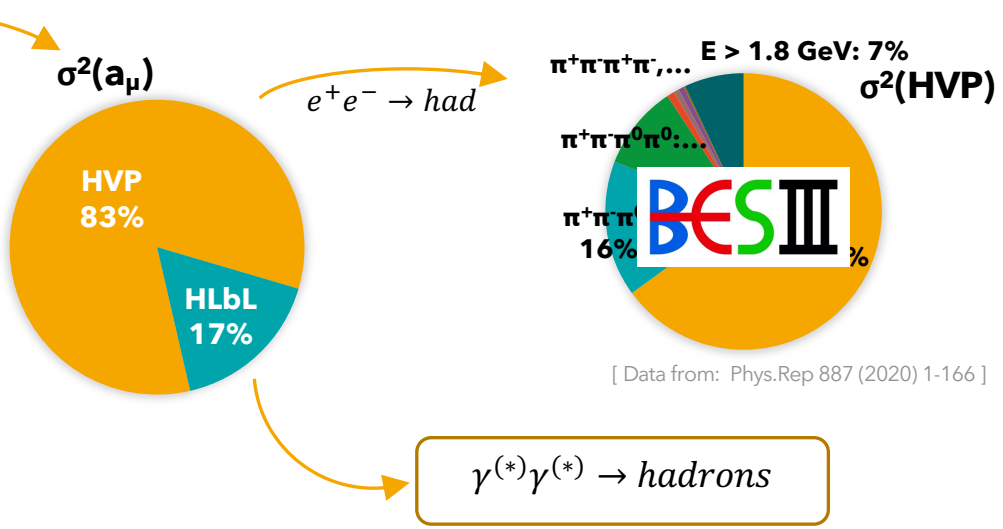

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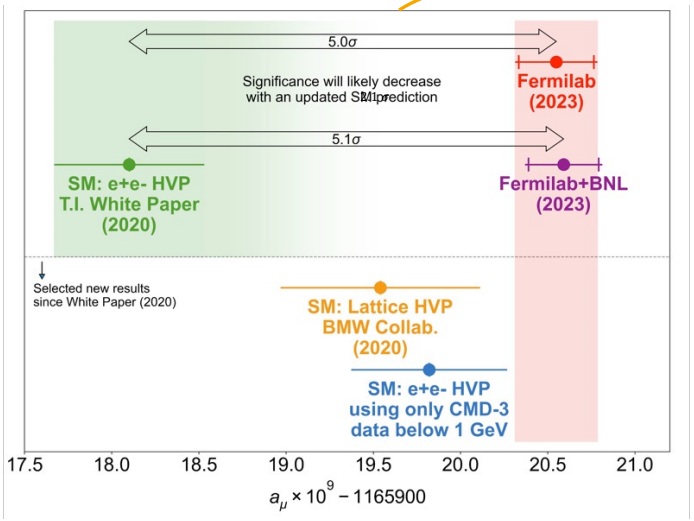

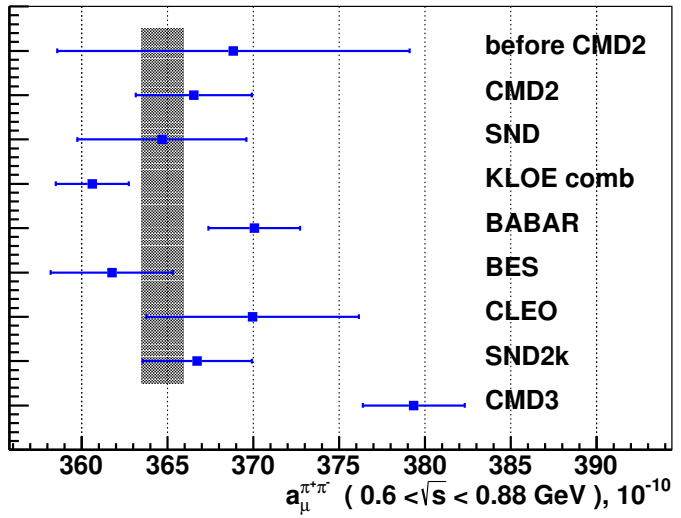

HVP)

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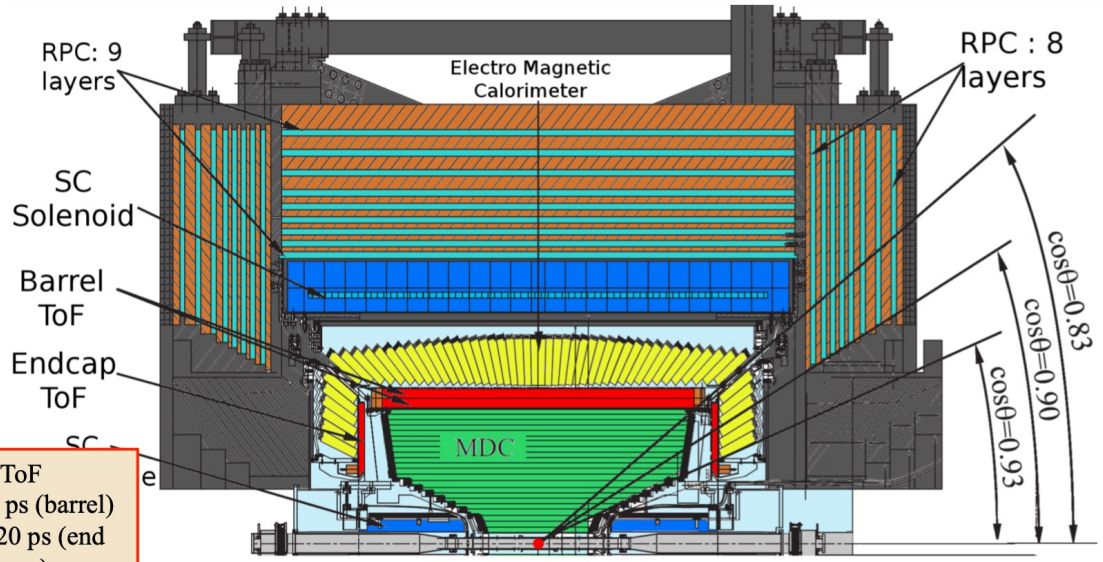
The BESIII Experiment (1)

[NIM A614 (2010) 345]



- Located at the BEPCII collider (Beijing, China)
- Symmetric e^+e^- beams
- ECM between 2-5 GeV
- Maximum luminosity: 1.1 nb^{-1}/s
- 93% coverage of the solid angle

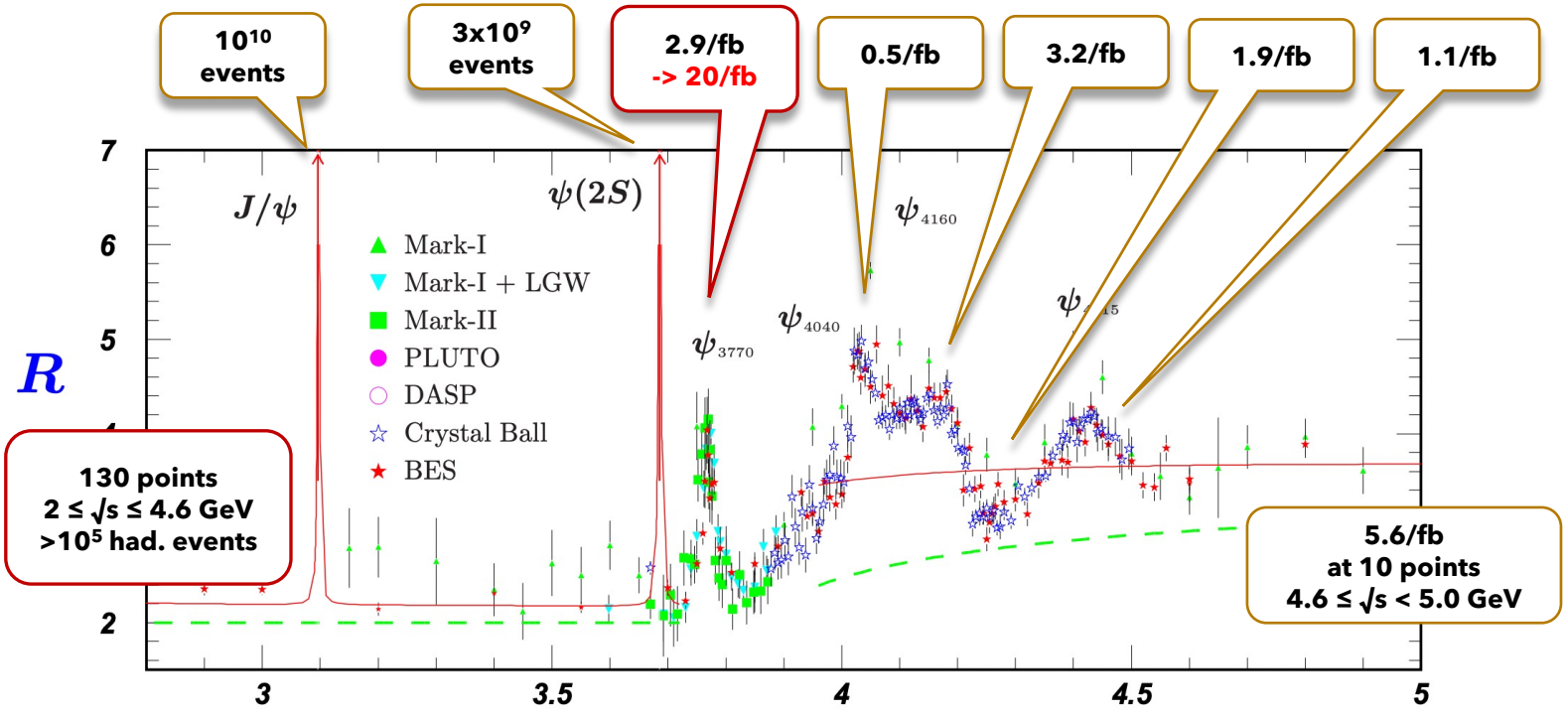
ToF
$\sigma_t \sim 90$ ps (barrel)
$\sigma_t \sim 120$ ps (end caps)

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
$\Delta\Omega/4\pi = 93\%$

The BESIII Experiment (2)

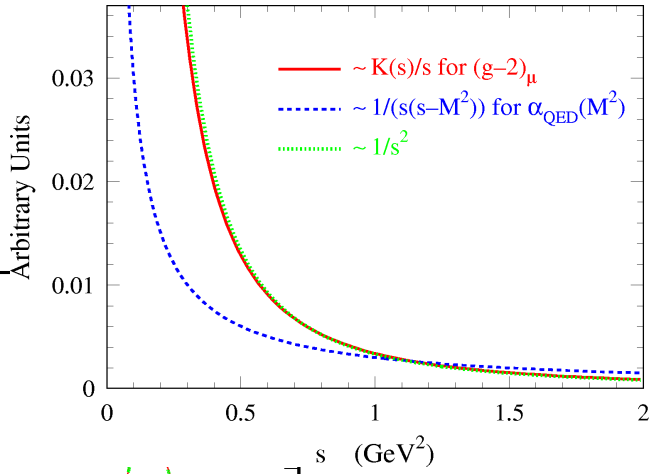


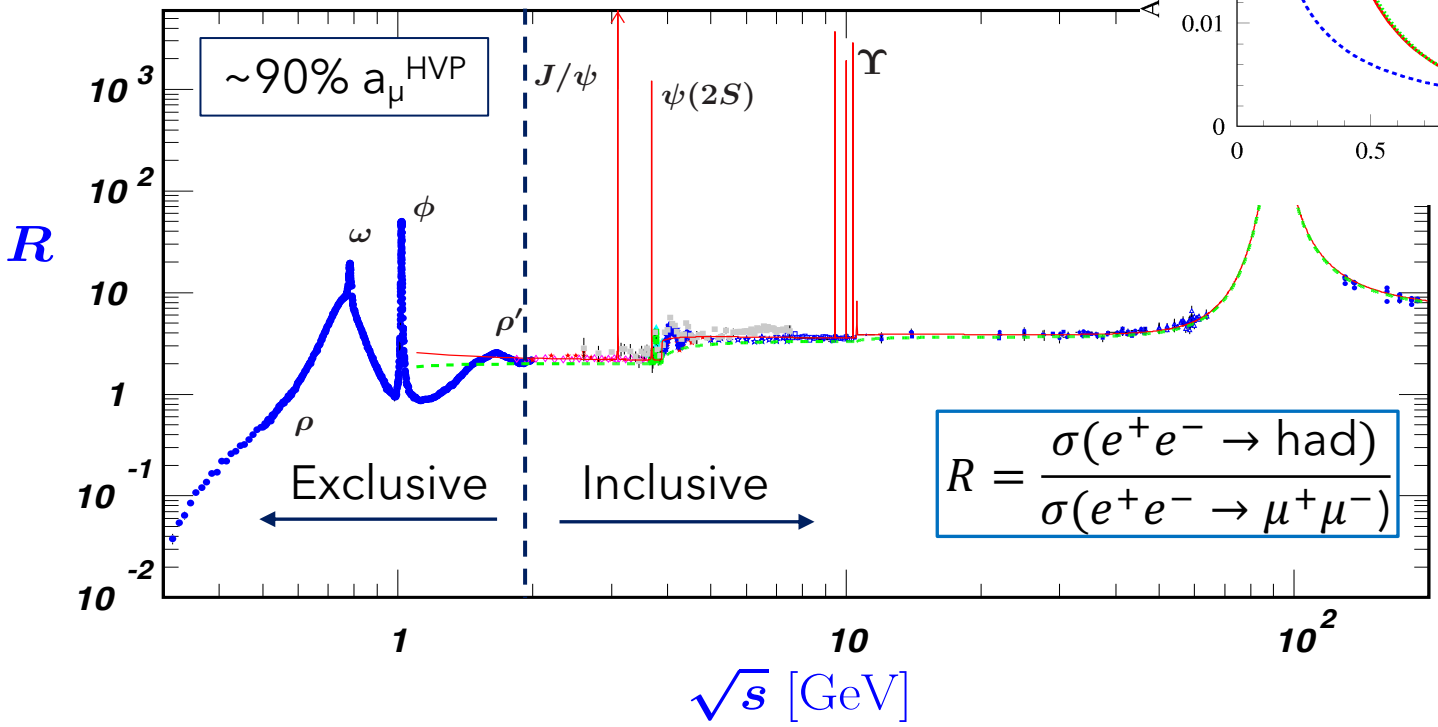
- **World largest τ-charm dataset in e^+e^- annihilation**
- Detailed studies in:
  - Charmonium spectroscopy and charm physics
  - Light hadron dynamics
  - τ-physics
  - **R-scan**

R Measurements and HVP

$$a_\mu^{HVP,LO} = \frac{1}{3}\left(\frac{\alpha}{\pi}\right)^2 \int_{m_\pi^2}^{\infty} ds \frac{K(s)}{s} R(s)$$

[Brodsky, de Rafael, 1988]





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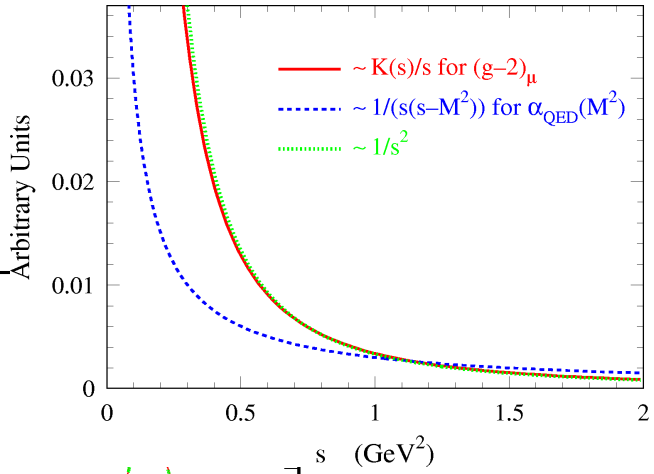
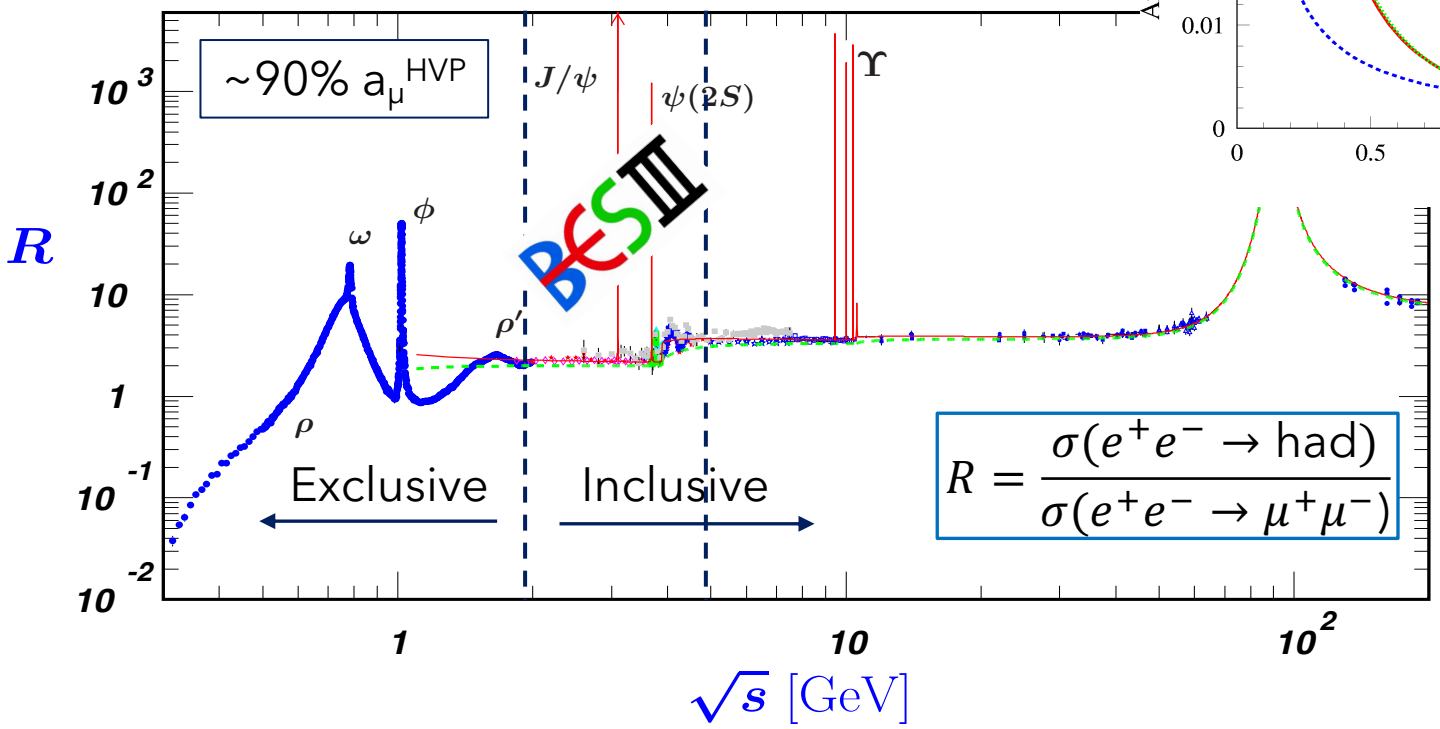
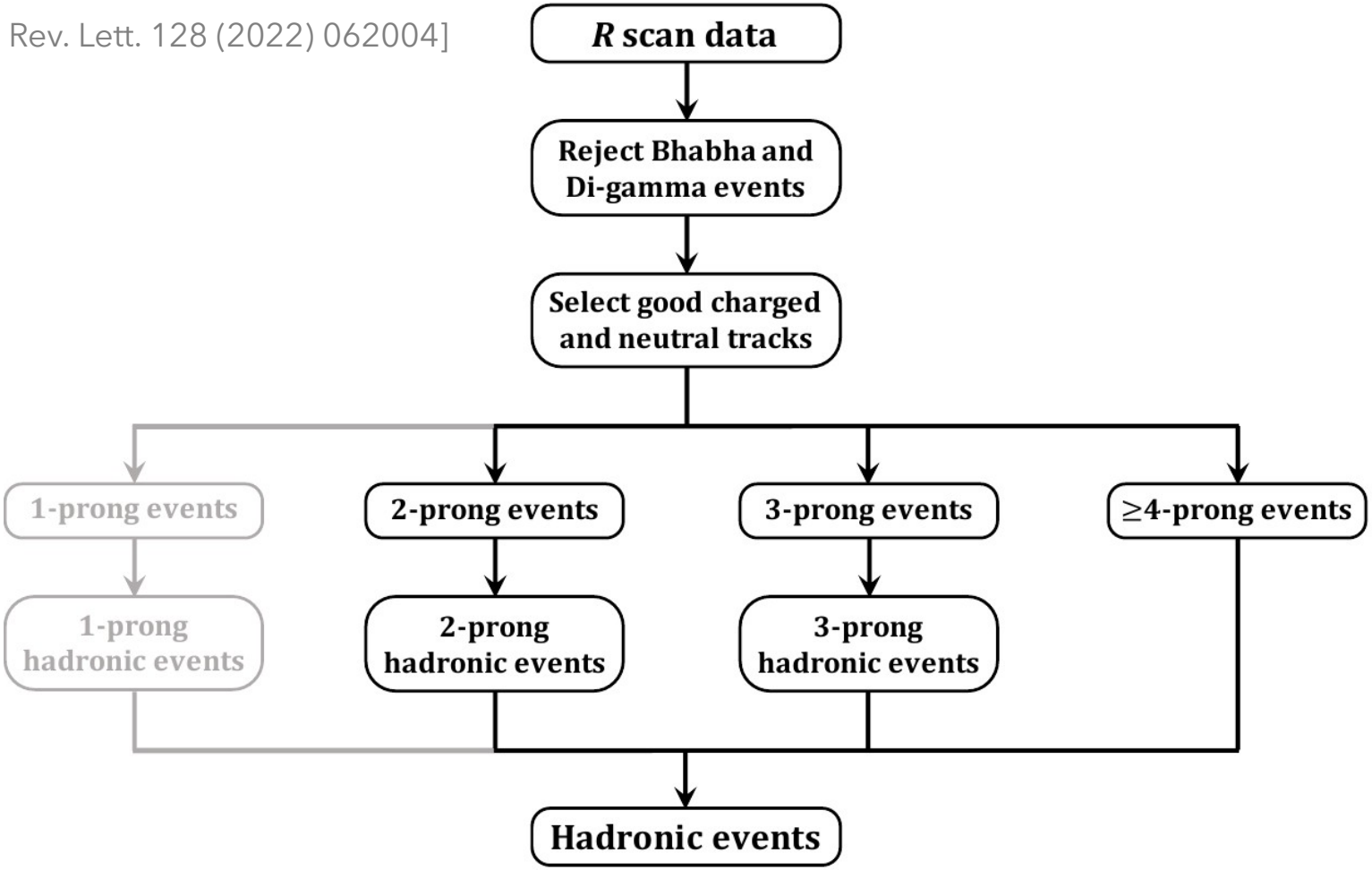




$$R = \frac{\sigma(e^+e^- \to \text{had})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

Inclusive R Measurement at BESIII

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



Inclusive R Measurement at BESIII

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

Dataset
14 energy points
$2.2 \leq \sqrt{s} \leq 3.7$ GeV
$>10^5$ had. events

Background contributions
- Evaluated with MC:
  - Babayaga, Phokhara, KKMC (ee,μμ,gg,tt)
  - BdkRC, Diag36, Galuga, Ekhara (ee -> ee + X)
- Beam related background

$$R = \frac{1}{\sigma_{\mu\mu}} \cdot \frac{N_{had} - N_{bkg}}{\mathcal{L} \cdot \varepsilon_{had} \cdot (1+\delta)}$$

Normalization
$\sigma_{\mu\mu}(s) = 86.85$ nb/s

Luminosity
Large angle Bhabha

Radiative corrections
- Two schemes tested
  - Feynman diagram
  - Structure functions
- Agreement better 1.4%

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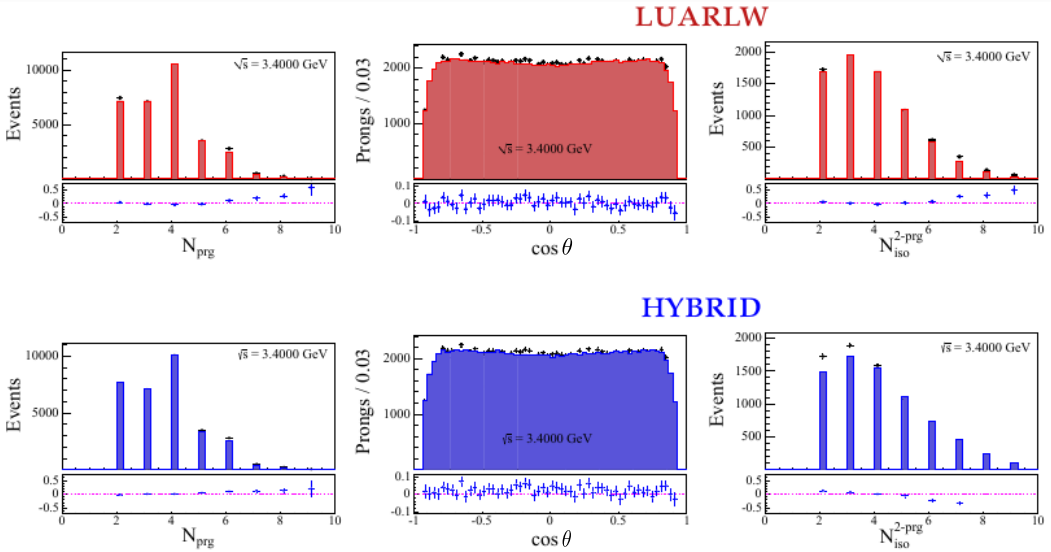

Efficiency

Ratio of generated and reconstructed events

Fully inclusive generator

- Lund Area Law
  - Low energy hadronization
  - Continuum, ISR, $J^{PC}=1^{--}$ resonances
  - Tuned to data

Hybrid generator

- Phokhara (10 excl. processes)
- ConExc (60 excl. proc. measured)
- Lund Area Law (unknown)

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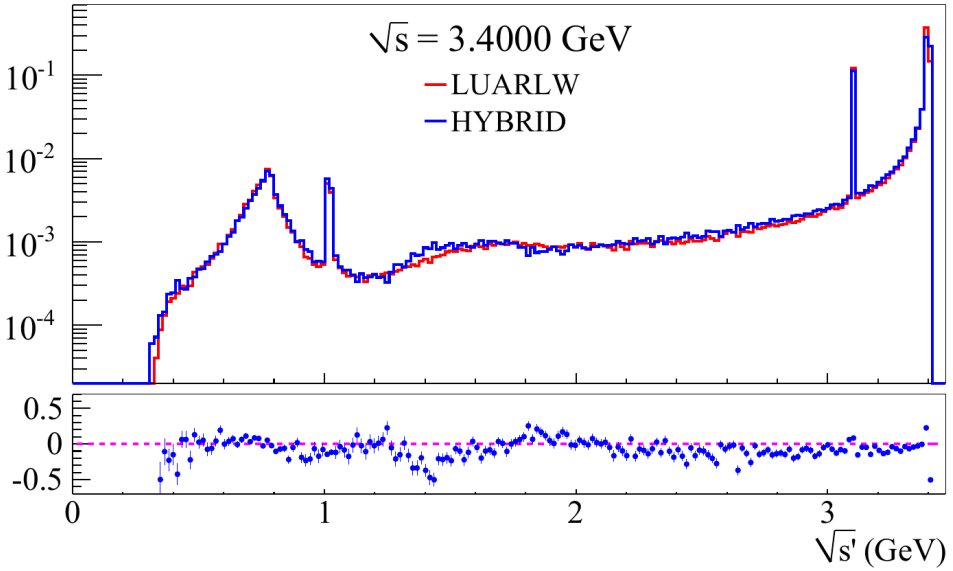

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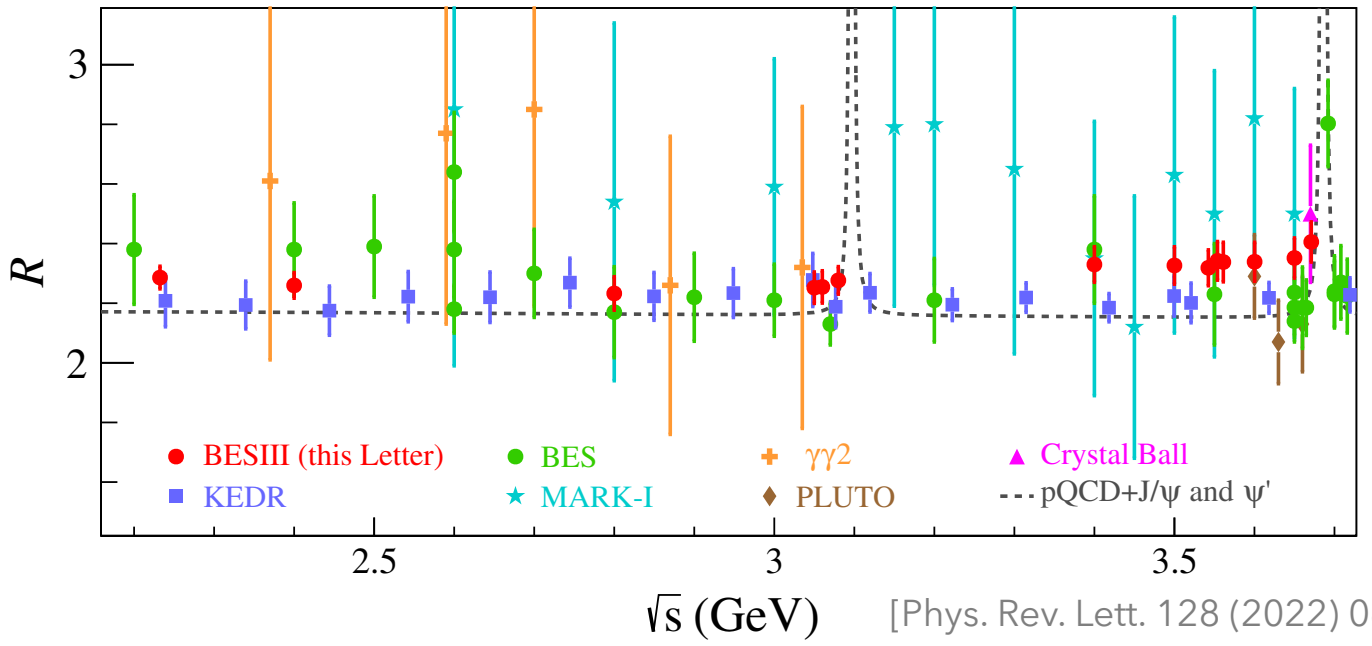

[Phys. Rev. Lett. 128 (2022) 062004]

- **Accuracy better than 2.6%** below 3.1 GeV and better than 3% above
- Exceeding pQCD predictions (2.7σ above 3.4 GeV)
- More to come in near future:
  - Result with **just 14 energy points out of 130**
  - Feasibility studies for **low energy (<2 GeV) measurement via ISR**

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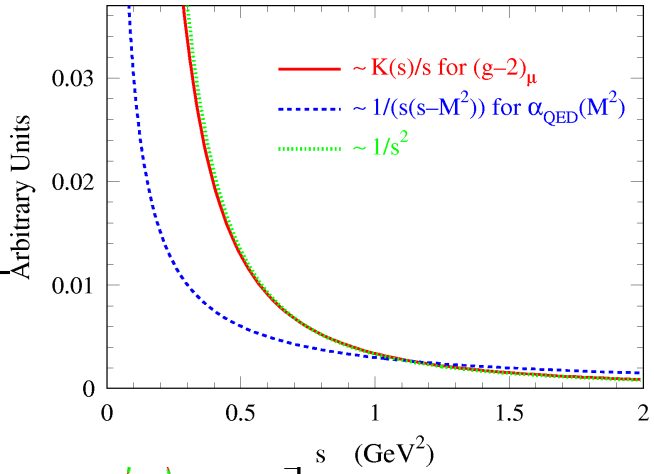

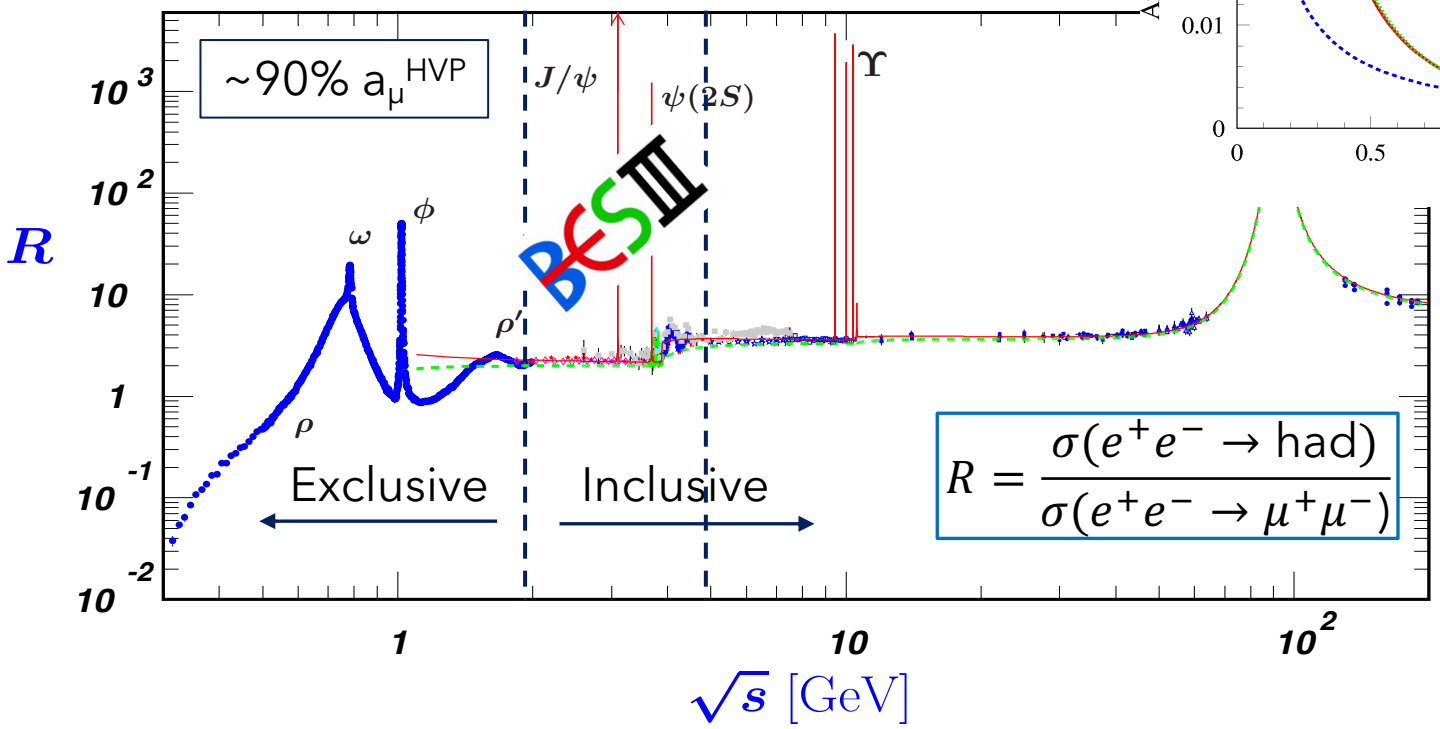

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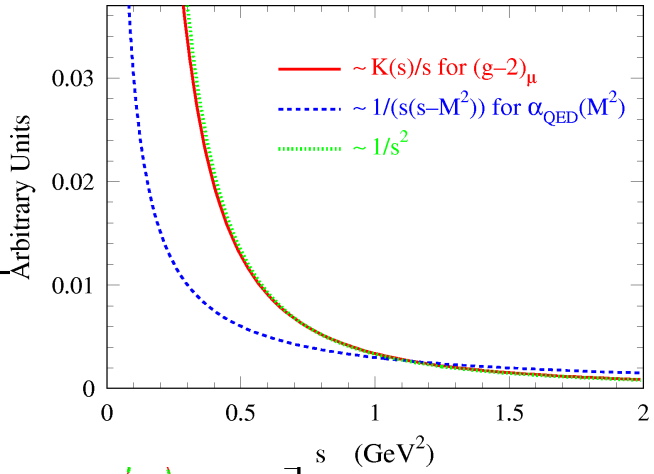

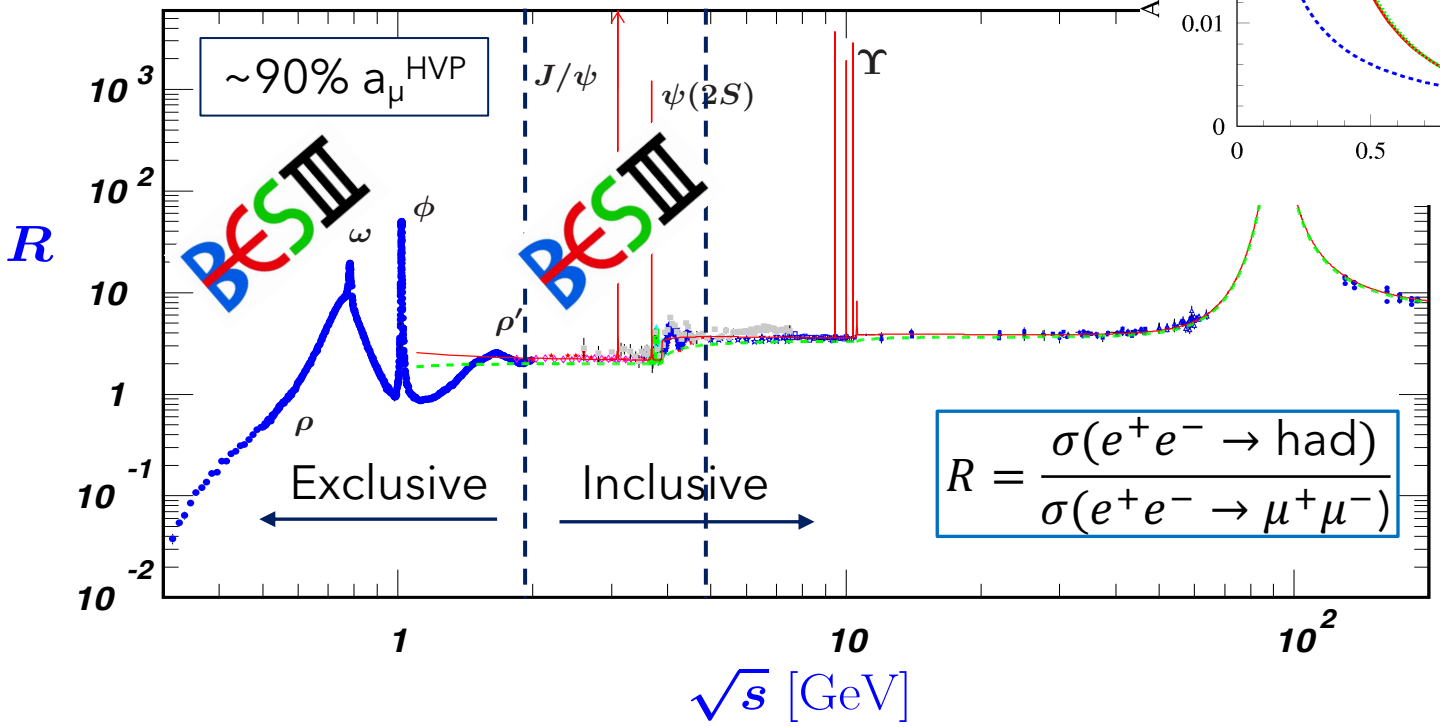

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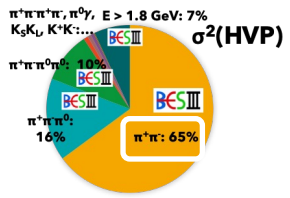
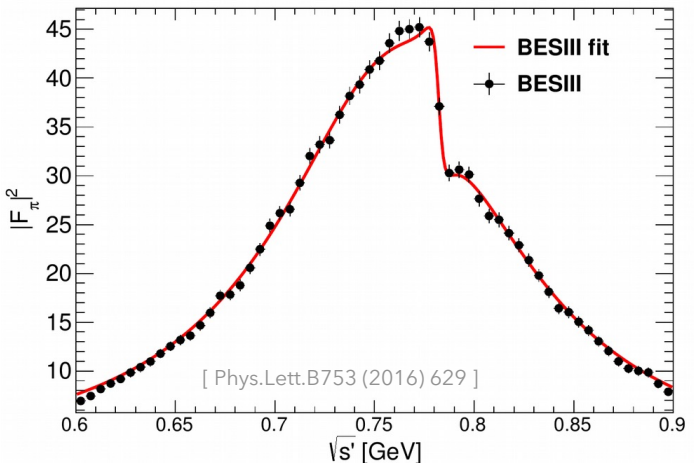
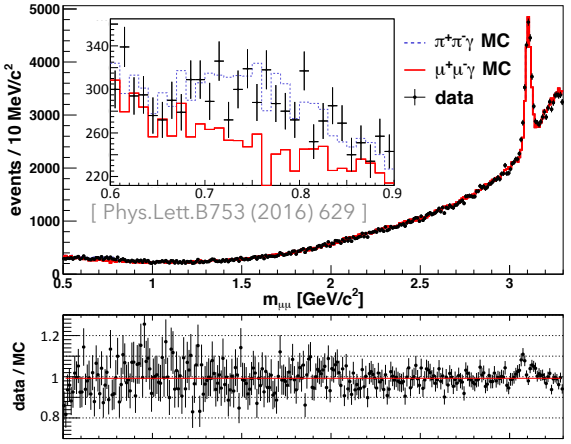
Pion Form Factor at BESIII



- **Tagged analysis**
- Background only from μμ(γ) events
- π/μ separation based on neural network (ANN)

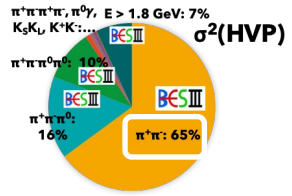


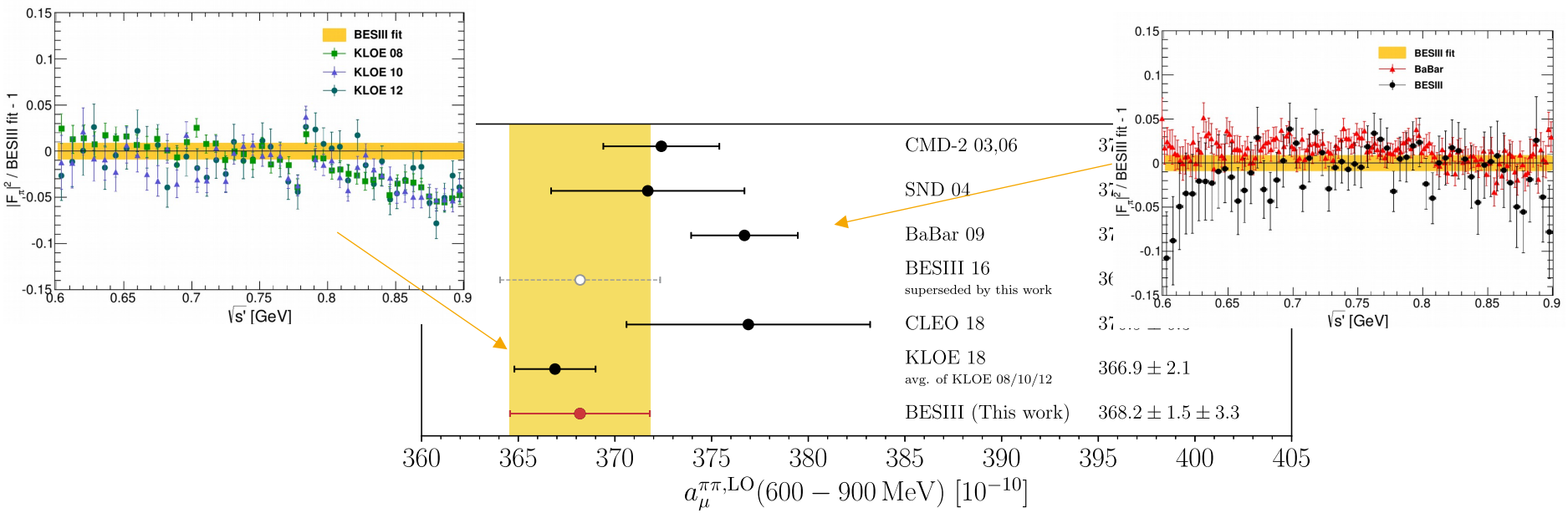


- **Form factor** evaluation **for 0.6 ≤ $m_{\pi\pi}$ ≤ 0.9 GeV**
  - 70% of total 2π contribution
  - 50% of a_μ^{HVP} contribution
  - Fit with Gounaris-Sakurai parameterization

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

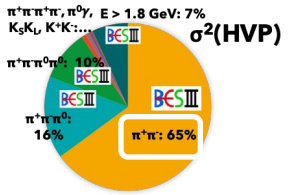
Pion Form Factor at BESIII





- **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: Perspectives

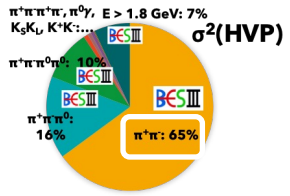


New measurements foreseen:

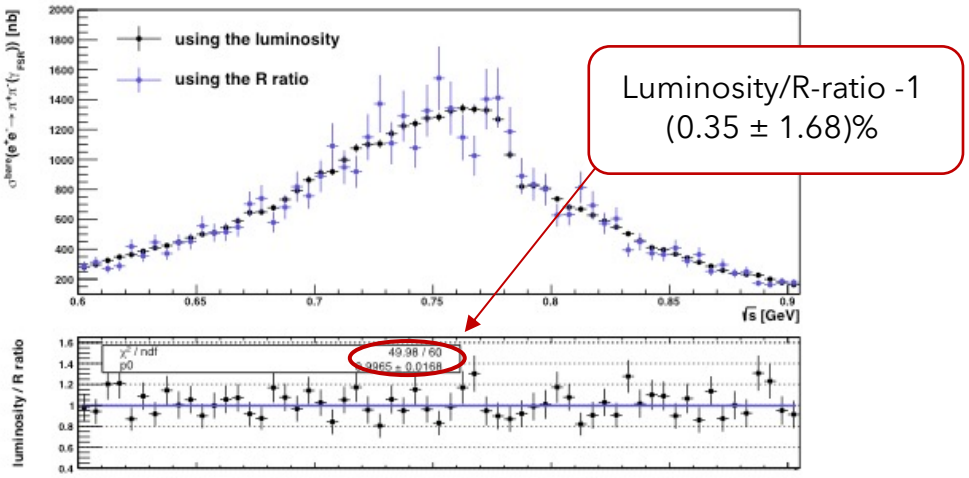
- ***O*(0.7%) accuracy**
  - Data sets at $\sqrt{s}$ = 3.77 and 4.18 GeV
  - Integrated luminosity ~6 fb^{-1}
  - **Normalization to luminosity**
  - Different selection strategies
  - Investigation of NNLO effects
  - Partial blinding

Source	Uncertainty (%)
~~Photon efficiency~~	~~0.2~~
Tracking efficiency	~~0.3~~ **0.2**
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**

Pion Form Factor: Perspectives



Two new measurements foreseen:



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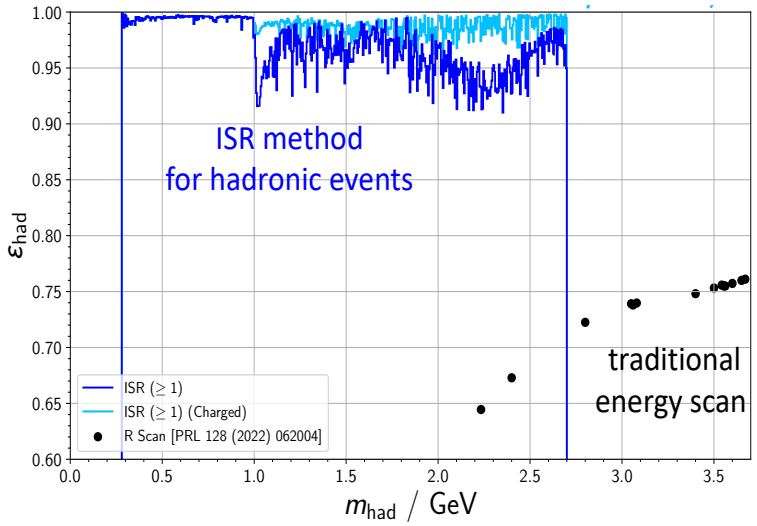
~~Vacuum polarization correction δ_{vac}~~	~~0.2~~
~~Radiator function~~	~~0.5~~
~~Luminosity $\mathcal{L}$~~	~~0.5~~
Sum	~~0.9~~ **0.5**

- **O(0.5%) accuracy**
  - New data at $\sqrt{s}$ = 3.77
  - Integrated luminosity ~17 fb^{-1}
  - **Normalization to di-muon events**
  - Blind analysis

Turning the Table: Inclusive below 2 GeV

- **New concept**: Determine **hadronic mass from ISR** photon **only**
- Simple selection criteria:
  - 1 high energetic photon (E > 1.2 GeV)
  - At (very) large angle (37°-143°)
  - At least 1 charged particle
- Extremely high efficiency
  - **Limited reliance on generators**
- Main backgrounds
  - QED (Bhabha)
  - Non-ISR hadronic events



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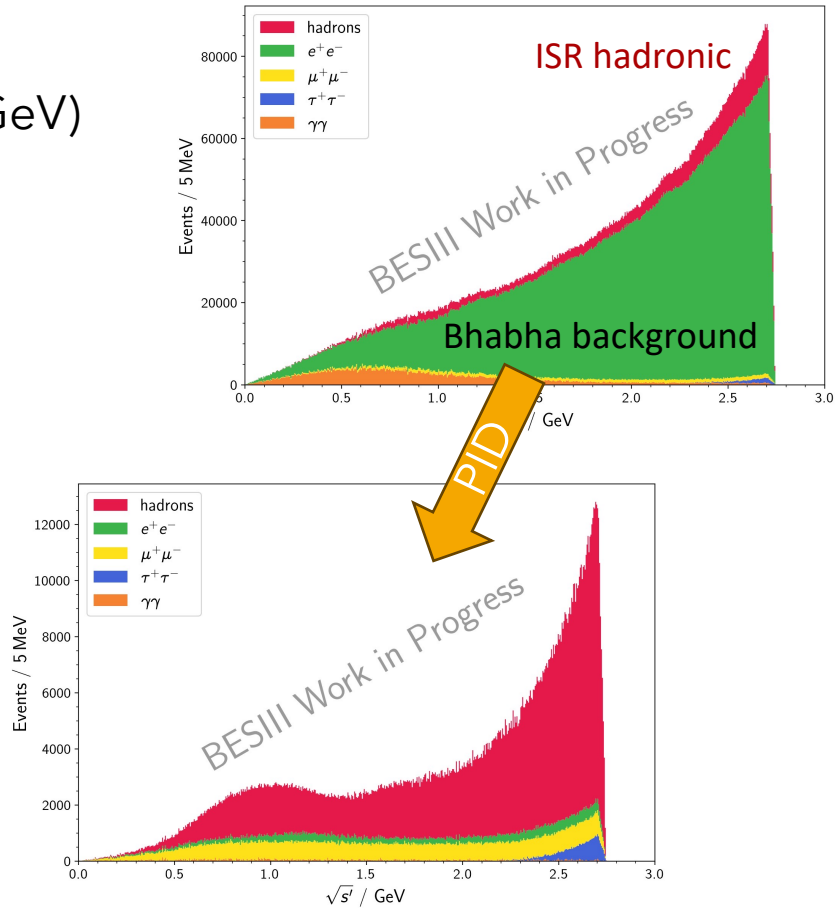

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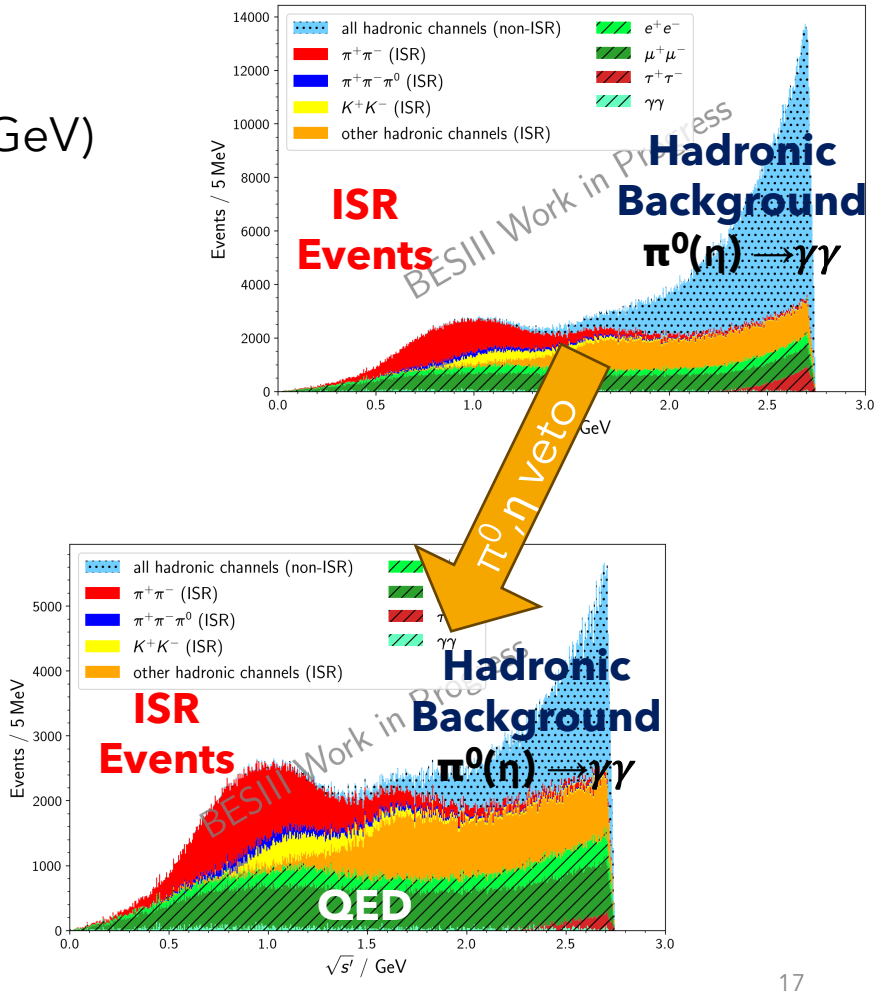

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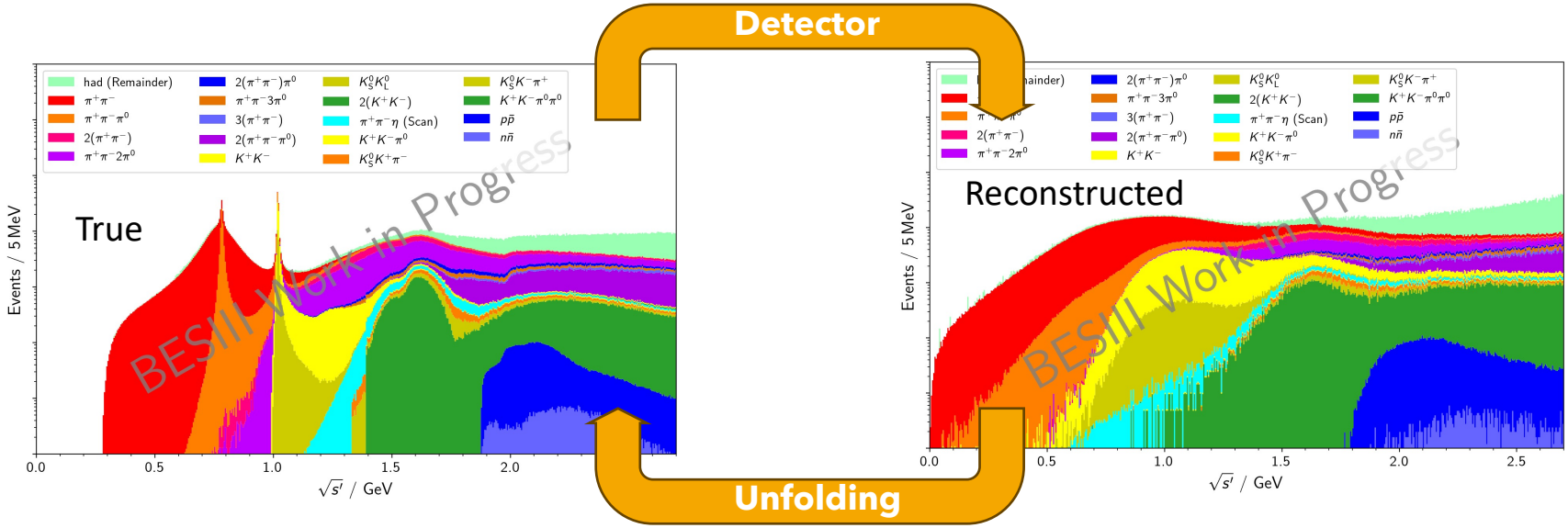

- **Large smearing** introduced by detector resolution
- Apply **unfolding** technique to recover the "true" spectrum
- Quantifying (eventual) bias introduced by unfolding
  - ✓ First results suggest **negligible impact** on a_μ

Aiming for few percent accuracy

Summary

- **Puzzling picture** in the HVP contribution to a_μ
  - Tension dispersive – lattice QCD
  - KLOE – BaBar – CMD-3 pion FF inconsistencies
- New **experimental input** are **of utmost importance**
- **BESIII** is providing **important inputs**
  - Most precise **inclusive R measurement** above 2 GeV [Phys. Rev. Lett. 128 (2022) 062004]
  - **Pion FF** measurement with 1% accuracy [Phys.Lett.B753 (2016) 629]
- **<u>But the best is still to come</u>**:
  - R measurement above 2 GeV (still >100 energy points to be analyzed)
  - **Pion FF** measurements (1% → 0.7% → **0.5%**)
  - **World first inclusive R** measurement **below 2 GeV**