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Feasibility Studies for an Inclusive R-Measurement using ISR with BESIII

Thomas Lenz on behalf of the BESIII Collaboration
Johannes Gutenberg University of Mainz, Germany

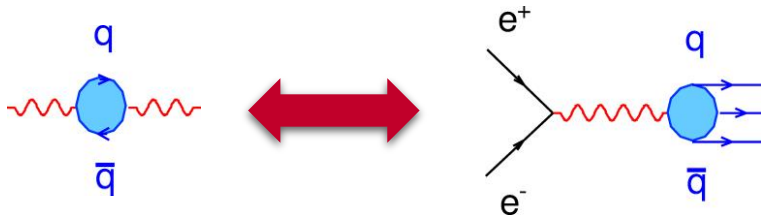
Radiative corrections and Monte Carlo tools for low-energy hadronic cross sections in e^+e^- collisions
07.06.2023

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Dispersive Approaches

- Uses experimental data for systematic improvements of theory predictions
  - Hadronic R value

- Optical Theorem
  - Relation between vacuum polarization and hadronic cross sections



- a_μ^{HVP}
  - Dominated by low energy domain

$$a_\mu^{\mathrm{HVP;LO}} = \frac{\alpha(0)^2}{3\pi^2} \int_{m_\pi^2}^{\infty} \frac{\mathrm{d}s}{s} K(s)\, R(s)$$

- $\Delta\alpha_{\mathrm{had}}(M_Z^2)$
  - Dominated by higher energies

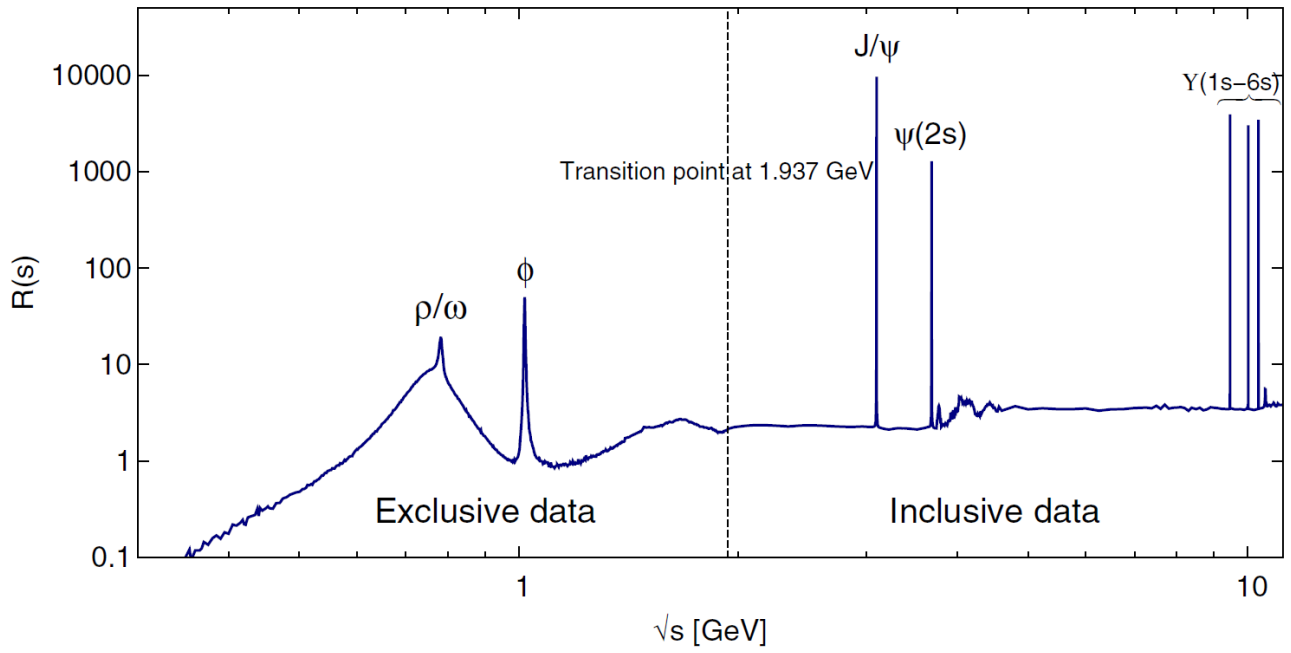
$$\Delta\alpha_{\mathrm{had}}^{(5)}(q^2) = -\frac{\alpha(0)\, q^2}{3\pi}\, \mathrm{P} \int_{m_\pi^2}^{\infty} \frac{\mathrm{d}s}{s} \frac{R(s)}{s - q^2}$$

Measurement of the Hadronic R Value

- Exclusive measurement
  - Individually highly precise
  - Energy scan or initial state radiation
  - Large number of channels at higher energies
  - Sum over multiple channels

- Inclusive measurement
  - Covers all possible channels
  - Reliant on good Monte Carlo generator
  - Energy scan
  - Subtract QED background

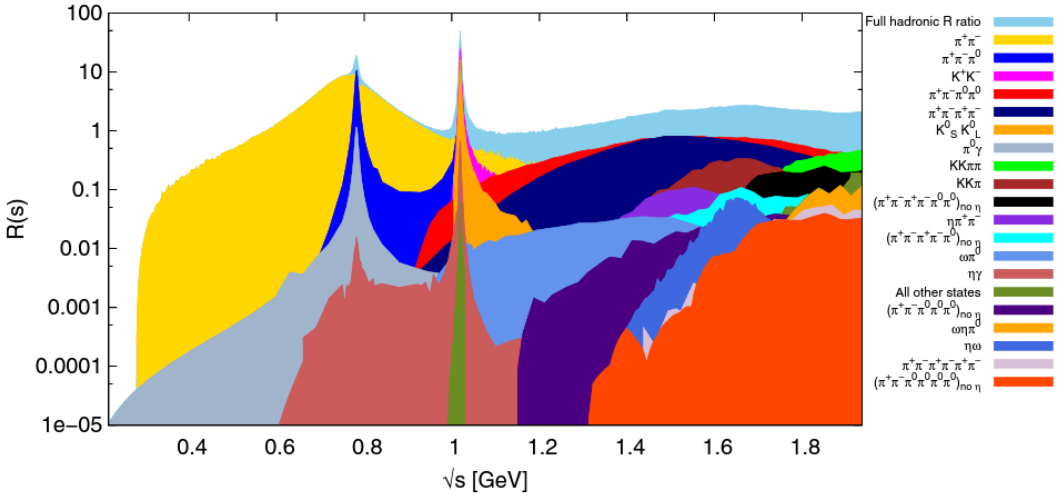
Phys.Rev.D **97** (2018) 11, 114025



Measurement of the Hadronic R Value

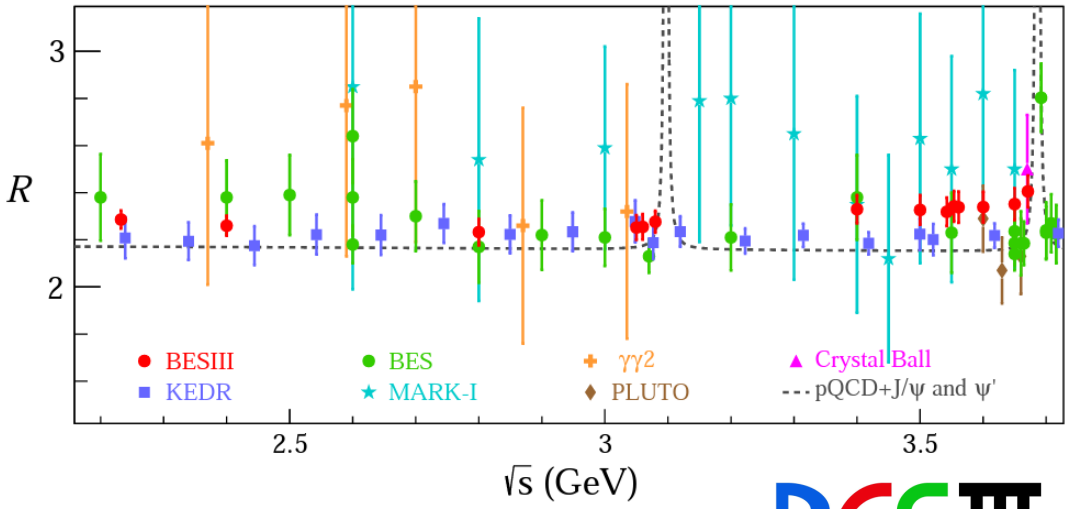
Exclusive

Phys.Rev.D **97** (2018) 11, 114025



Inclusive

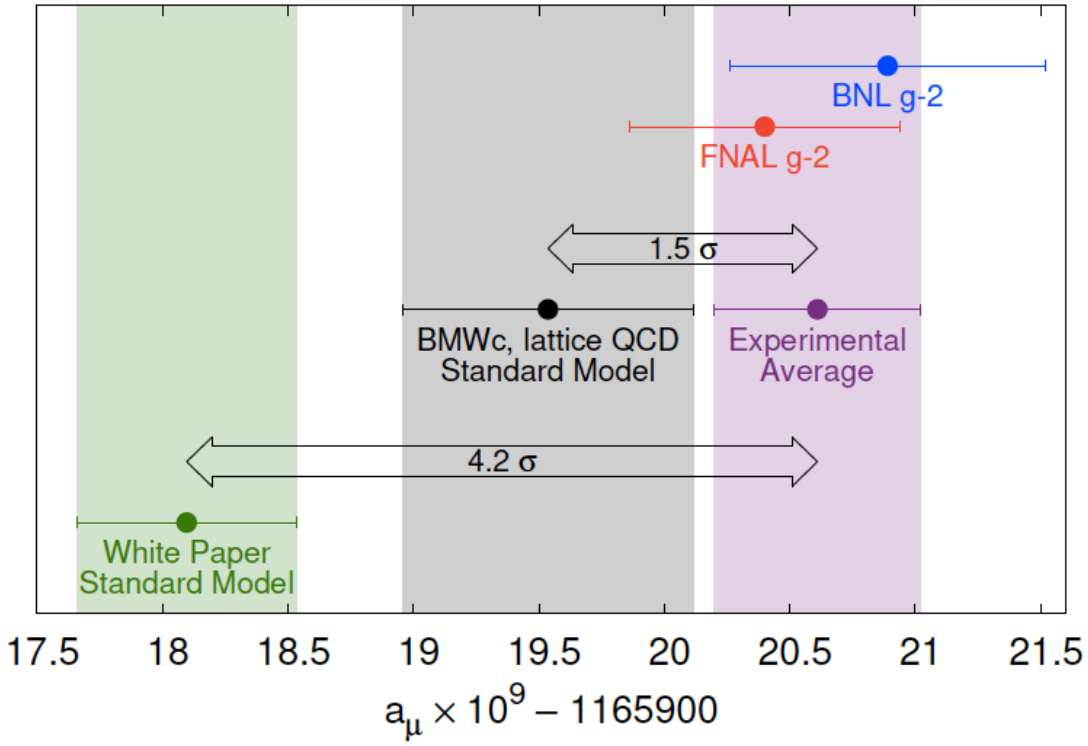
Phys.Rev.Lett. **128** (2022) 6, 062004



Dispersion vs Lattice

- Anomalous magnetic moment of the muon
- Discrepancy of $4.2\,\sigma$ between experimental world average and dispersive evaluation
- First Lattice evaluation (BMW) with competitive precision only $1.5\,\sigma$
- Large discrepancy between dispersive and Lattice approaches

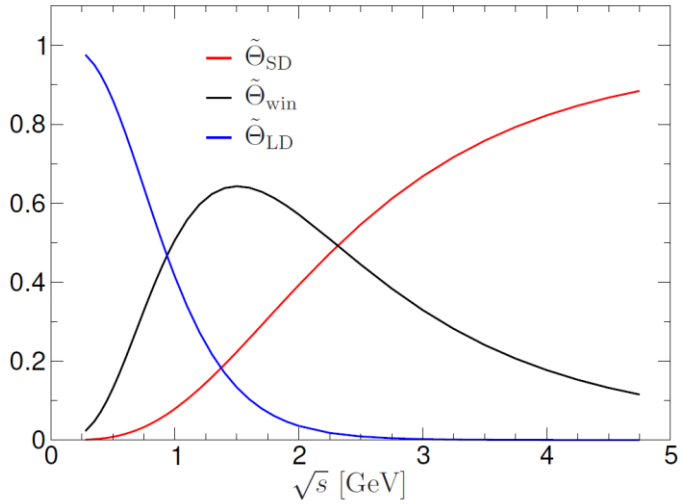
Nature **593** (2021) 7857, 51-55



Window Observable

- Window observable allows comparison between different Lattice results
  - Intermediate mass range
  - Sensitive to $\rho-\omega$ region ($\pi^+\pi^-$ channel)
  - Small statistical and systematic uncertainties
- Multiple Lattice groups agree with BMW value
- Full HVP evaluation by BMW expected to get confirmed
- Significant discrepancy between BMW/Lattice and dispersion also in window observable

Phys.Lett.B **833** (2022) 137313



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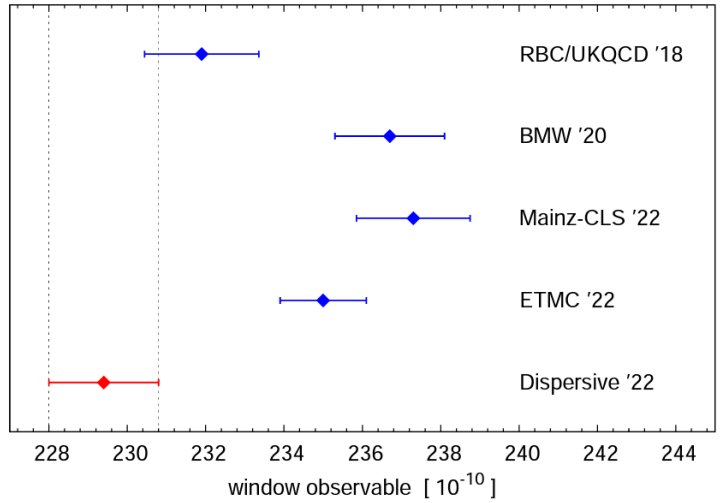

KLOE-BaBar-Puzzle

- Long standing tension between KLOE and BaBar measurements in the $\pi^+\pi^-$ channel
  - Two most precise measurements
  - Most important channel of the dispersive approach (70% of the HVP value)
  - Tension absorbed into conservative uncertainty of dispersive evaluation

- Recent CMD-3 measurement increases tension further
  - Much larger value than KLOE and BaBar

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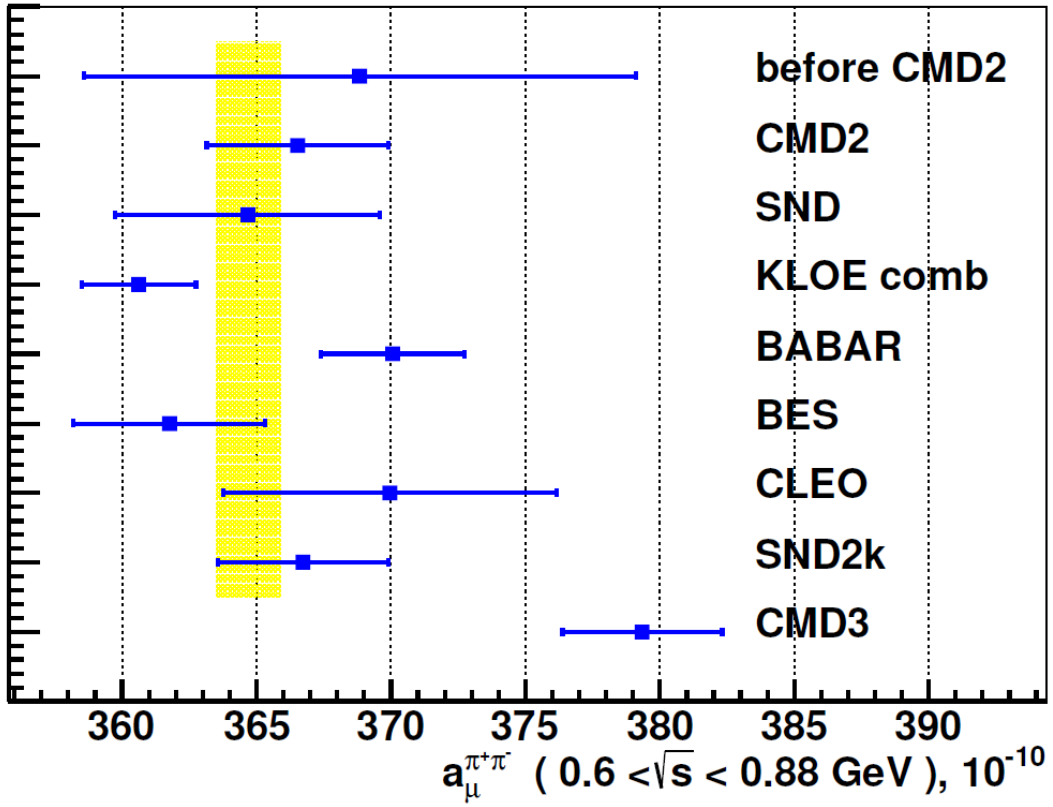


Puzzles on the Experimental Side

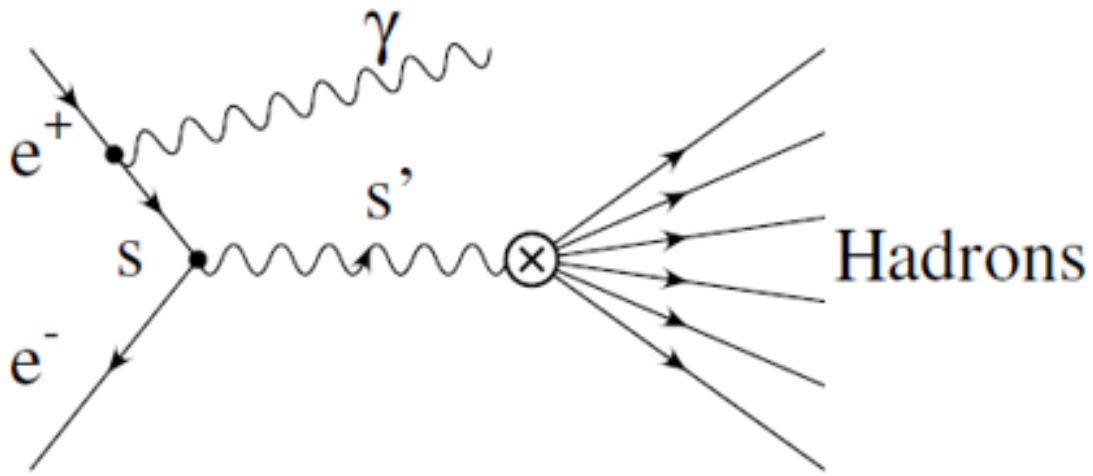
- Deviation between dispersive data from e^+e^- experiments and Lattice on the percent-level
- Deviation between e^+e^- cross section measurements
- **Independent verification** of dispersive estimate of Muon g-2 Theory value highly desirable
- Check for missing channels in e^+e^- highly desirable too

Initial State Radiation (ISR)

- Initial state particle emits energy through a photon

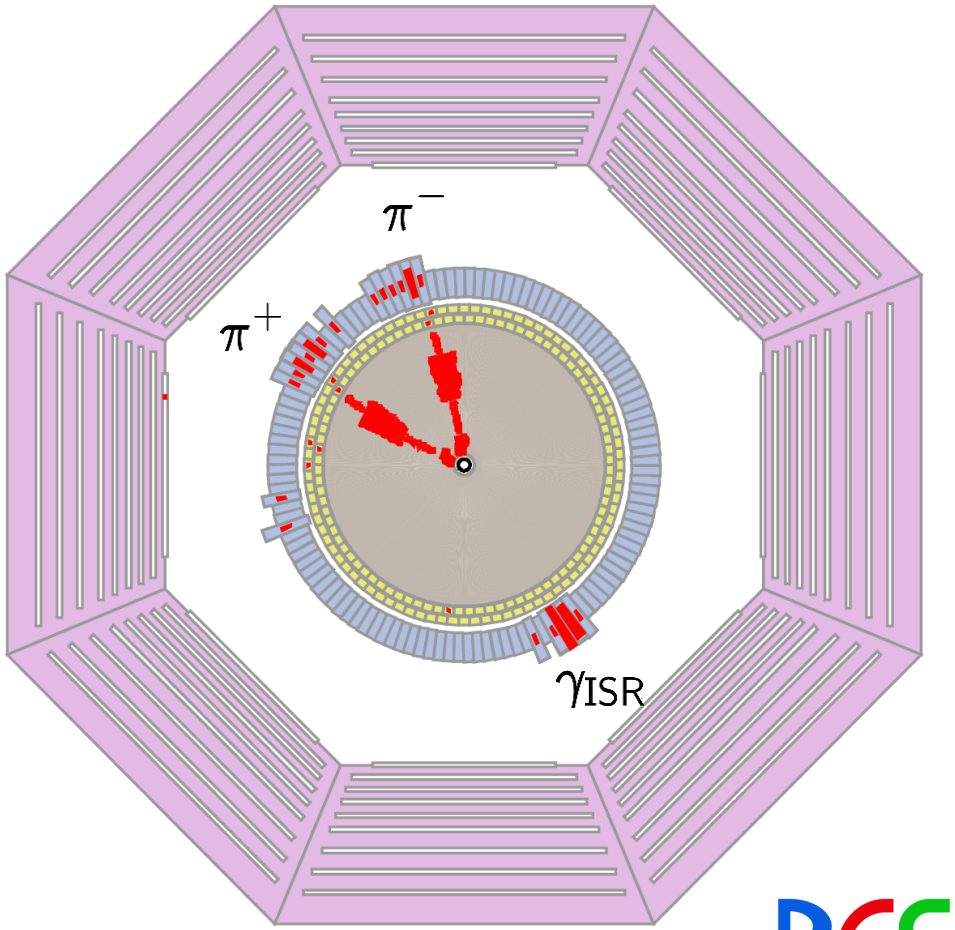
- Direct relation between ISR photon and invariant mass of the hadronic system

$$s' = m_{\text{had}}^2 = s - 2E_\gamma \sqrt{s}\,\frac{1 - \sin\alpha\cos\theta_\gamma\cos\varphi_\gamma}{\cos\alpha}$$



New Inclusive Approach Using ISR

$e^+e^- \to \gamma_{ISR}\pi^+\pi^-$



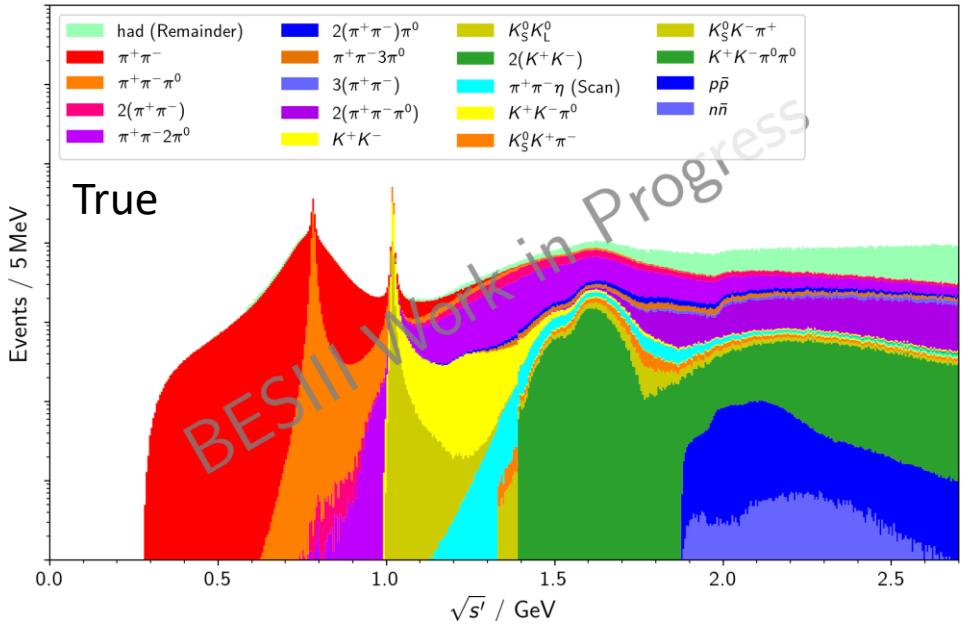
Take advantage of ISR:

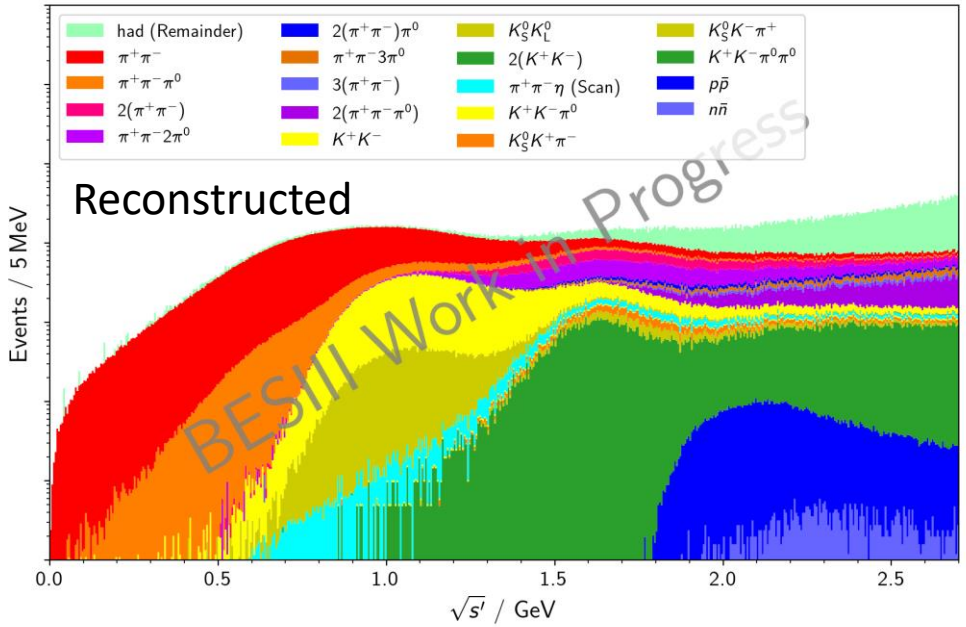
- ISR boost confines particles into narrow cone (at high energies)
  - Very high probability to detect tracks of hadronic particles if ISR photon is tagged
- Less reliant on description of hadronic MC
  - ISR description in MC under control
- Single measurement from threshold
- Also able to measure fully neutral channels (if QED background under control)

New Inclusive Approach Using ISR

Challenges:

- Background from radiative charmonia and high-energetic π^0/η decays
  - Upper limit to mass range
- Mass resolution limited by EMC
  - Requires unfolding
- Subtract QED events using MC simulation
  - High precision QED MC needed





New Inclusive Approach Using ISR

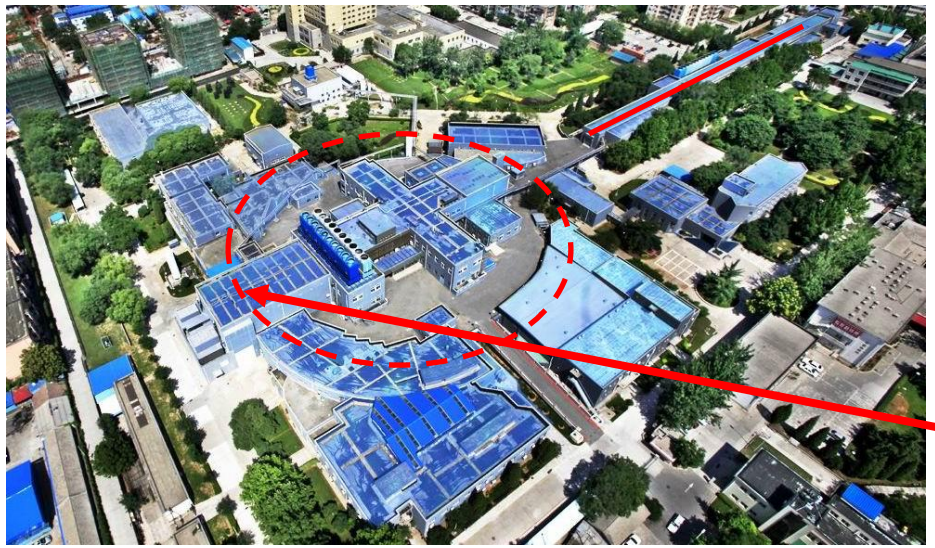
- 1st Goal:
  Independent confirmation of hadronic mass spectrum
  used by KNT/DHMZ groups with inclusive ISR method below 2 GeV
  - Precision goal on the few-percent-level

- Currently: Feasibility study with MC of potential of method at BESIII
  - **Cannot show any unpublished data**

- Also applicable for other e^+e^- experiments

BESIII Experiment

- Symmetric e^+e^- experiment
- Located at the BEPCII collider (Beijing, China)
- CMS energy: $2\,\text{GeV}$ to $5\,\text{GeV}$
- Maximum luminosity: $1 \times 10^{33}\,\text{cm}^{-2}\,\text{s}^{-1}$
- 93% coverage of the solid angle

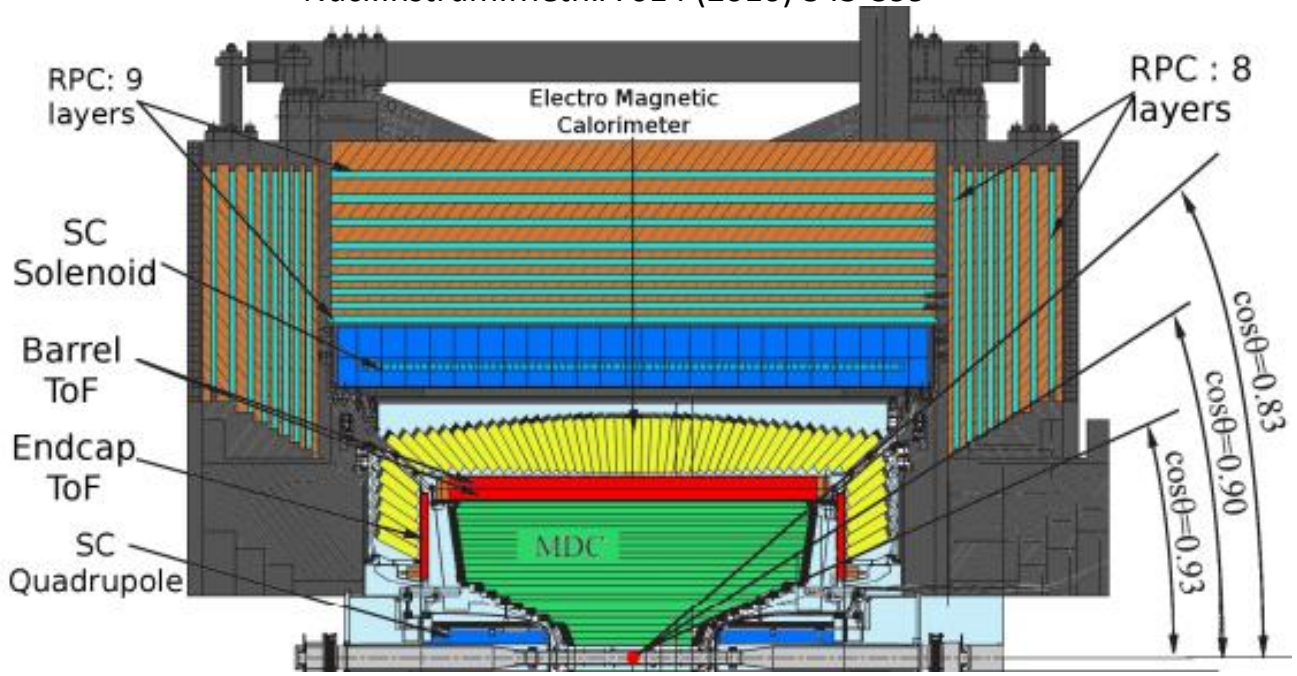


RPC Muon Detector
$\Delta\Omega/4\pi$ = 93 %

Electromagnetic CsI(Tl) Calorimeter
Barrel: σ(E)/E < 2.5 % @ 1 GeV
End caps: σ(E)/E < 5 % @ 1 GeV
σ(xy) ~ (6 mm)/√E @ 1 GeV

Superconducting Solenoid
B = 1T

Nucl.Instrum.Meth.A 614 (2010) 345-399



Time of Flight
Barrel: 90 ps
End caps: 120 ps

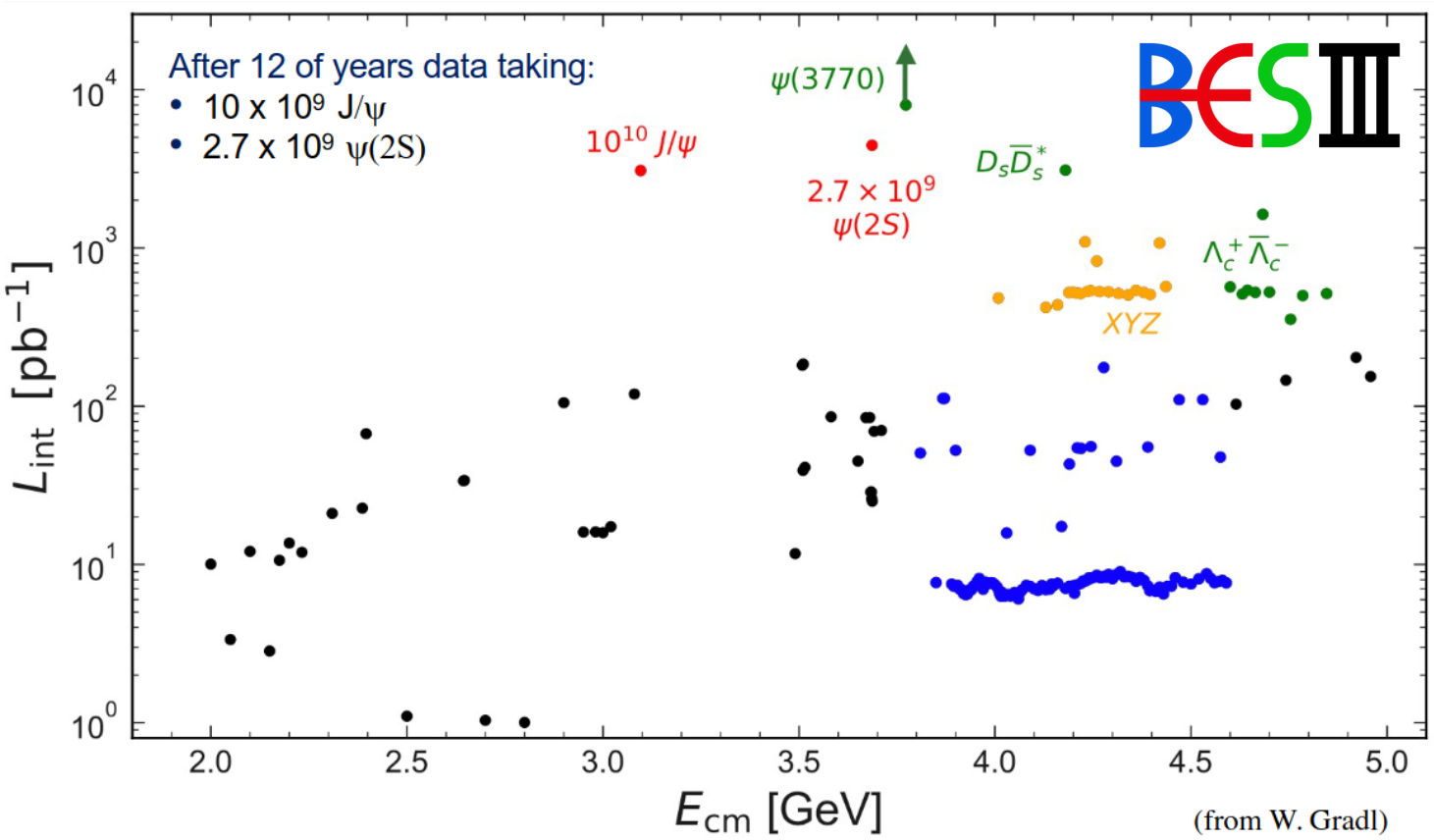
Drift Chamber
σ(rϕ) ~ 130 μm (single wire)
σ(pt)/pt ~ 0.5 % @1 GeV

BESIII Data Sets

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

- Research focuses:
  - Charmonium spectroscopy
  - Charm physics
  - Light hadron dynamics
  - τ physics
  - R scan
  - Hadronic cross sections (ISR)

- Currently taking $20\,\mathrm{fb}^{-1}$ at $\psi(3770)$

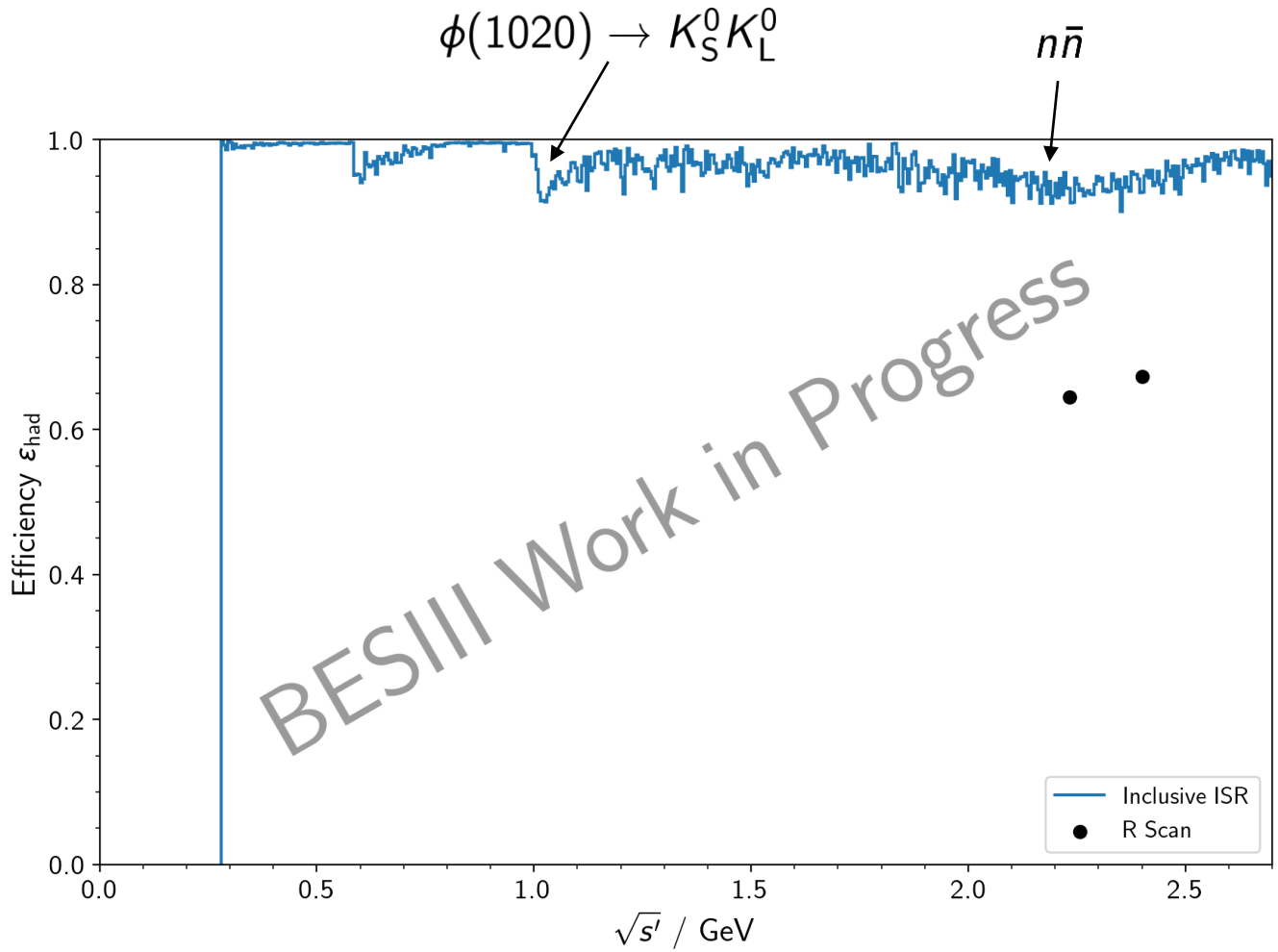


Event Generators

- Exclusive hadronic:
  - Phokhara:
    $\pi^+\pi^-$, $\pi^+\pi^-\pi^0$, $2(\pi^+\pi^-)$, $\pi^+\pi^-2\pi^0$
    $\pi^+\pi^-\eta$, K^+K^-, $K^0_S K^0_L$,
    $\gamma(\pi^0, \eta, \eta'(958))$, $p\bar{p}$, $n\bar{n}$
  - ConExc:
    $2(\pi^+\pi^-)\pi^0$, $\pi^+\pi^-3\pi^0$, $3(\pi^+\pi^-)$, $2(\pi^+\pi^-\pi^0)$,
    $K^+K^-\pi^0$, $K^0_S K^\pm\pi^\mp$, $K^+K^-\pi^0\pi^0$
  - Ekhara:
    $e^+e^-\pi^0\pi^0$
- Inclusive hadronic:
  - Lund Area Law
- QED:
  - BabaYaga@NLO: e^+e^-, $\gamma\gamma$
  - Phokhara: $\mu^+\mu^-$
  - KKMC: $\tau^+\tau^-$

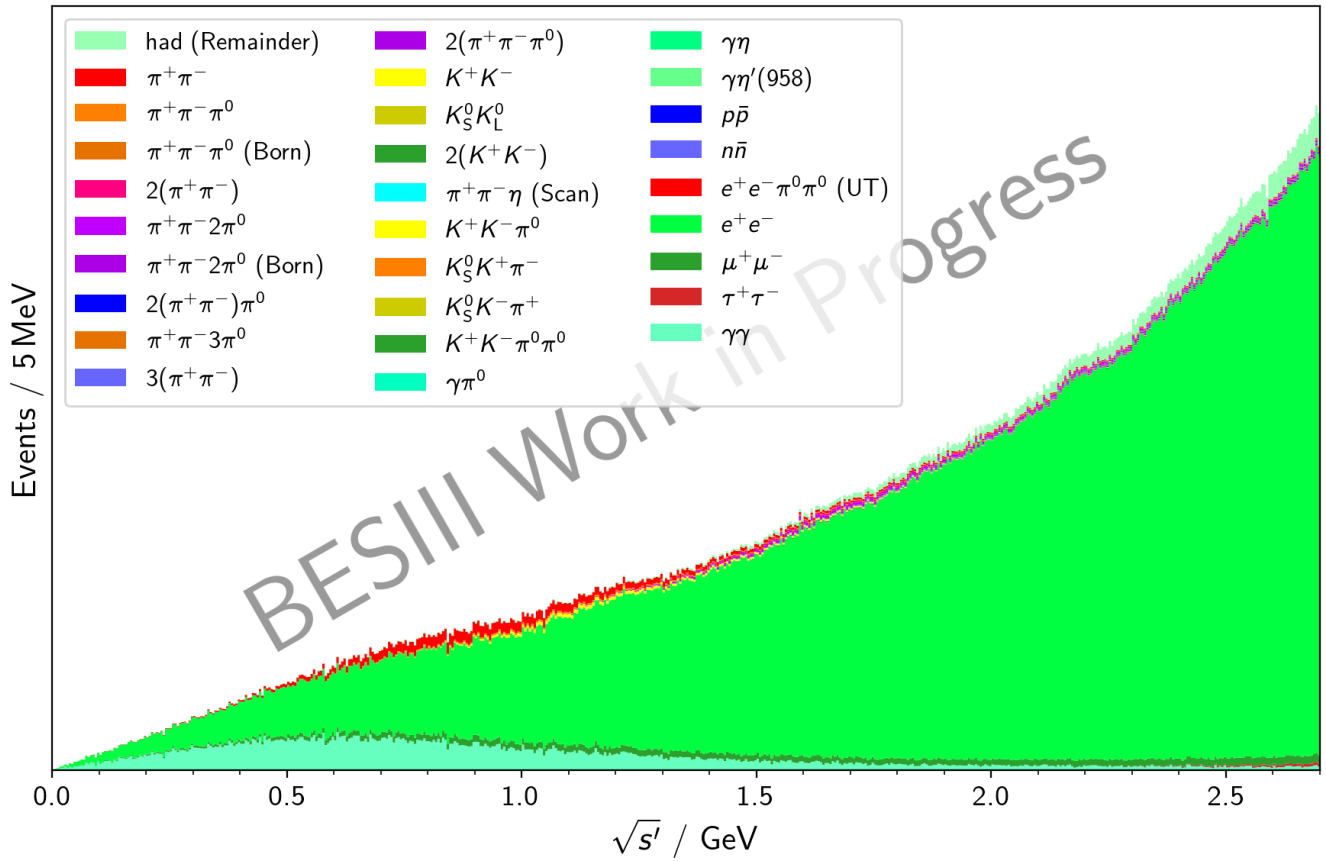
Hadronic Efficiency

- Require ISR photon to be detected in EMC
- Very high efficiency to find hadronic tracks over whole mass range
  - Higher than traditional R scans
  - Less dependent on hadronic MC
- Minor inefficiencies from neutral decays



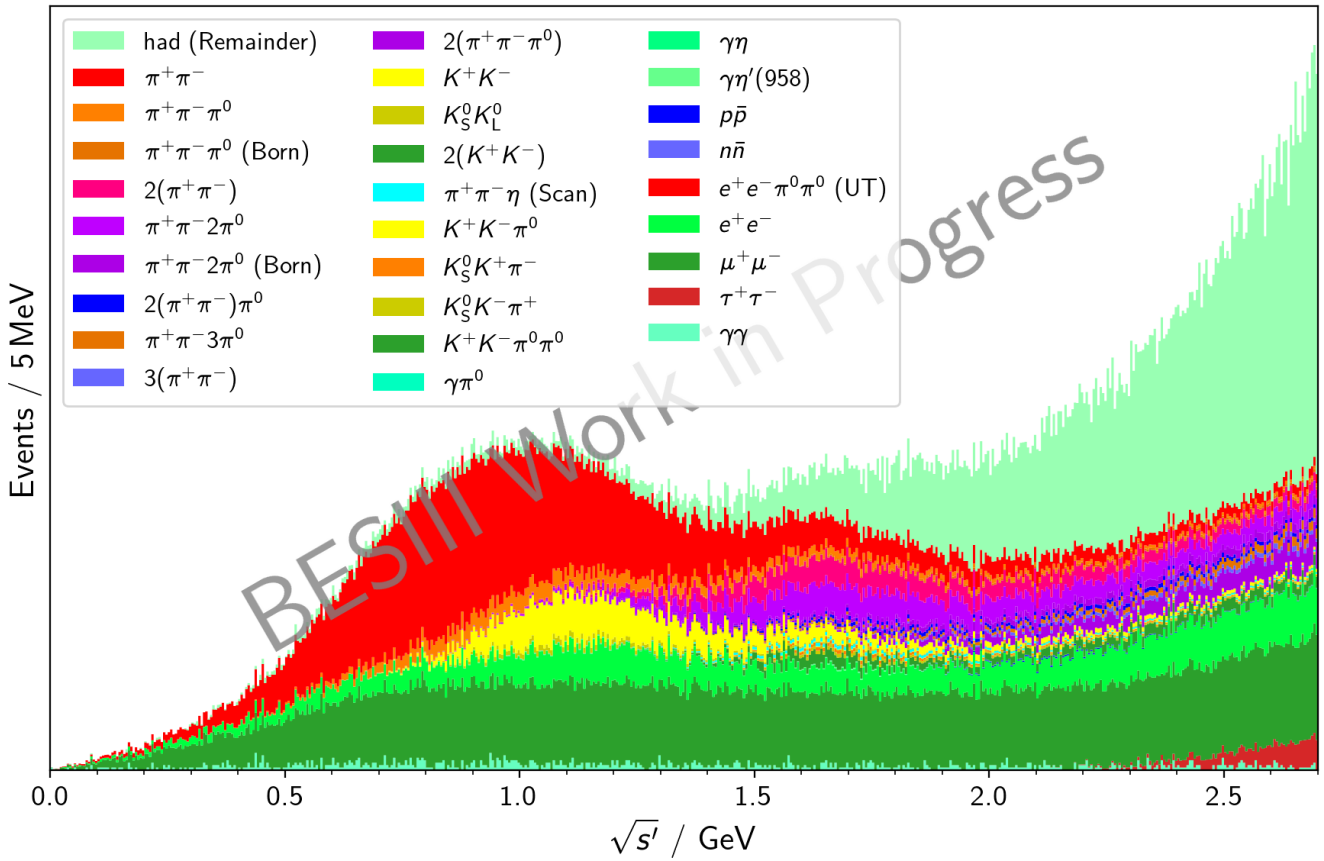
Hadronic Mass Spectrum

- Require ISR photon to be in the barrel
  - Better resolution
  - Higher efficiency
- Select at least 1 charged track
- Dominated by QED (e^+e^- and $\gamma\gamma$)
- Small hadronic contributions visible



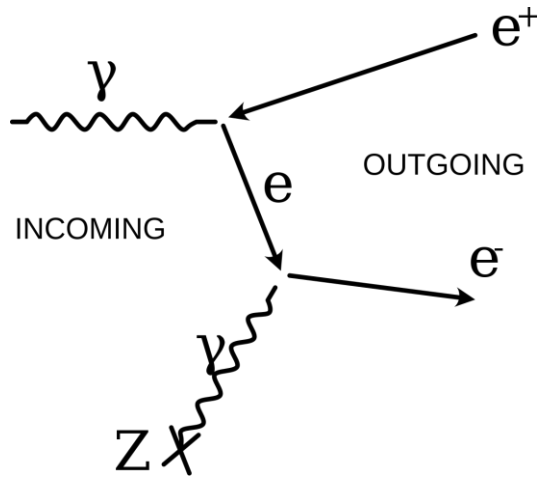
Hadronic Mass Spectrum

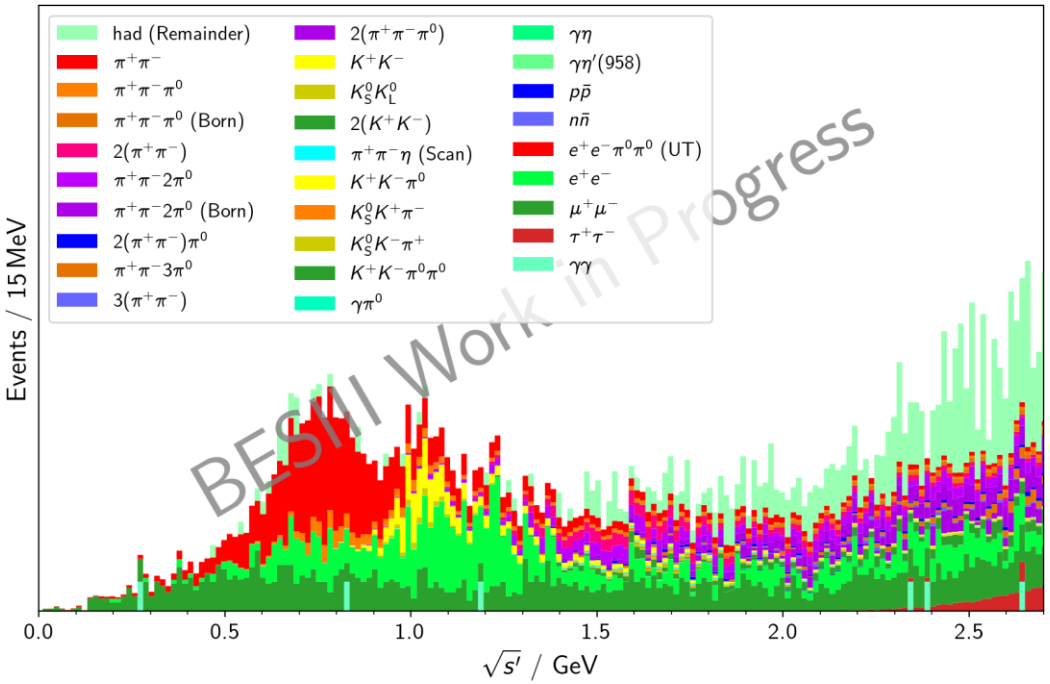
- Introduce cuts to reduce QED contributions
  - Reject tracks identified as electrons
  - Reject Bhabha signature
  - Reject $\gamma\gamma$ signature
- Hadronic channels can be reconstructed with high statistics and low backgrounds
  - Allows for unfolding to improve resolution
- No narrow resonances visible
  - $\rho(770)^0/\omega(782)$
  - $\phi(1020)$



Photon Conversion

- Utilize conversion of ISR photon in detector material
  - Reduction of statistics
- Tracks of produced e^+e^- pair to be reconstructed in the MDC
  - Improvement of mass resolution
- Narrow resonances now separately visible
- Potential for the new high-statistics data sets at BESIII





Summary

- Tensions between dispersive and Lattice evaluations
- Tensions within e^+e^- cross section measurements
- New **independent** approach to measure hadronic R value
  - Inclusive measurement below 2 GeV
  - Initial state radiation
  - Very high efficiency
  - Less reliant on hadronic MC
- Resolution of EMC requires unfolding to extract narrow resonances
- Photon conversion offers promising opportunity

Thank you for your attention!