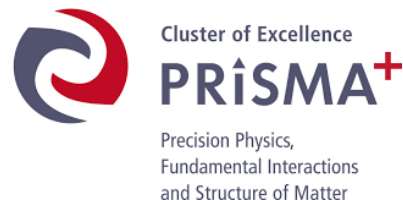




Measuring hadronic corrections to the muon $g-2$ at BESIII

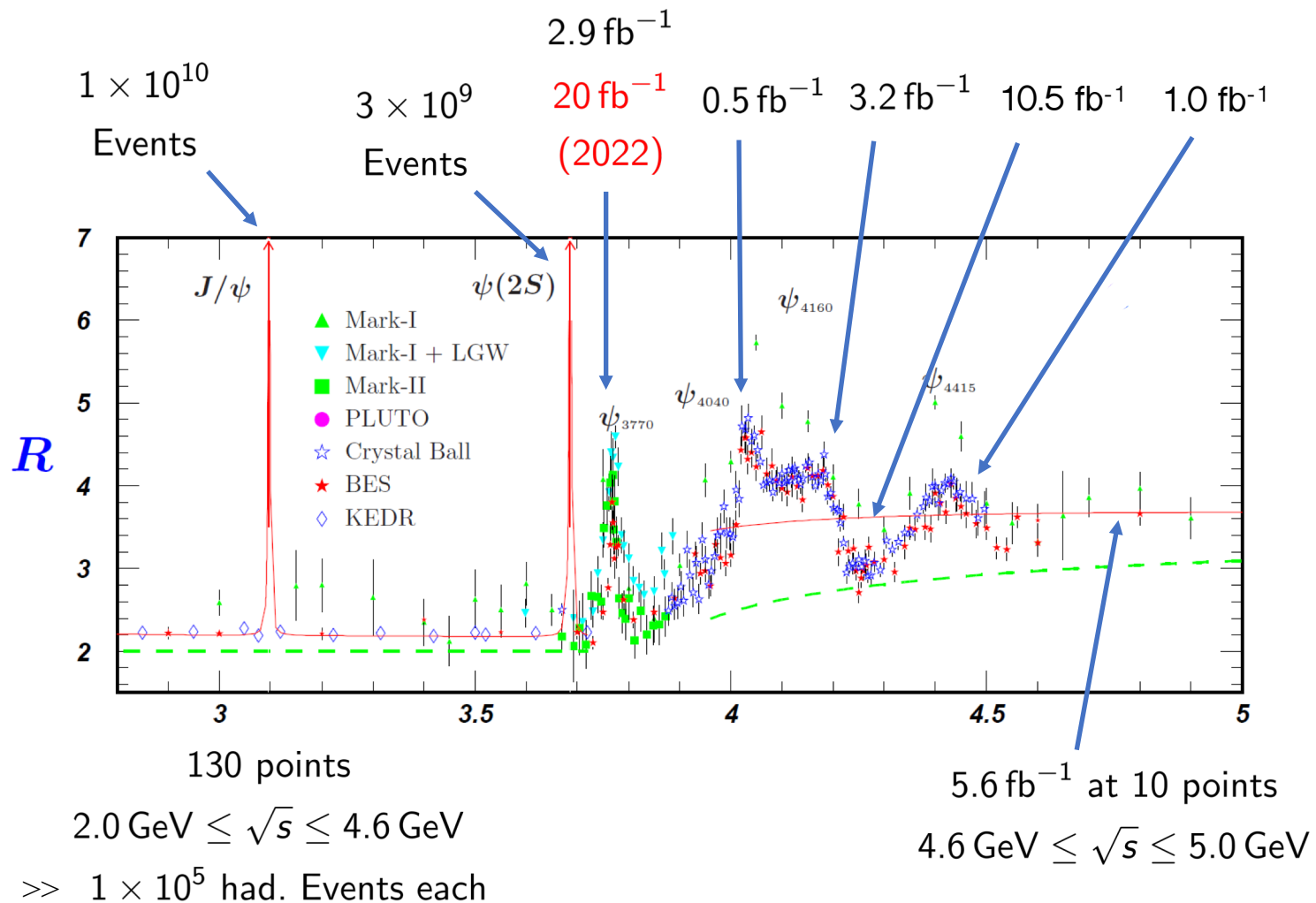
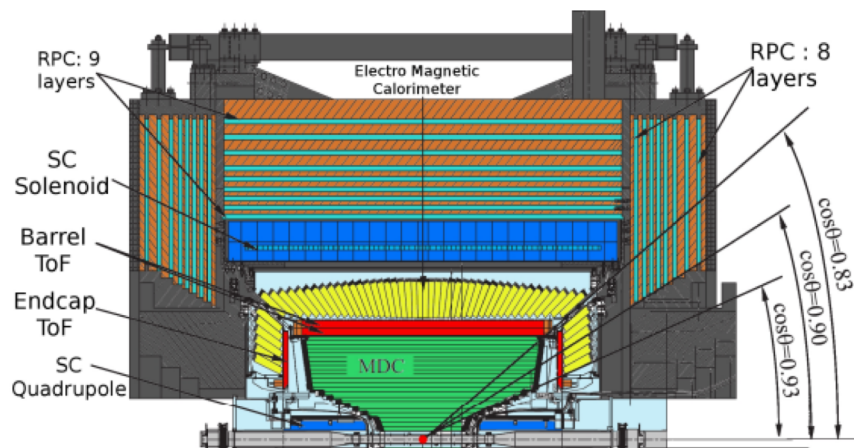


September 30, 2021
Achim Denig
Johannes Gutenberg University Mainz

BESIII Experiment at the tau-charm Factory BEPC-II

World's by far largest τ -charm dataset in e^+e^- annihilation:

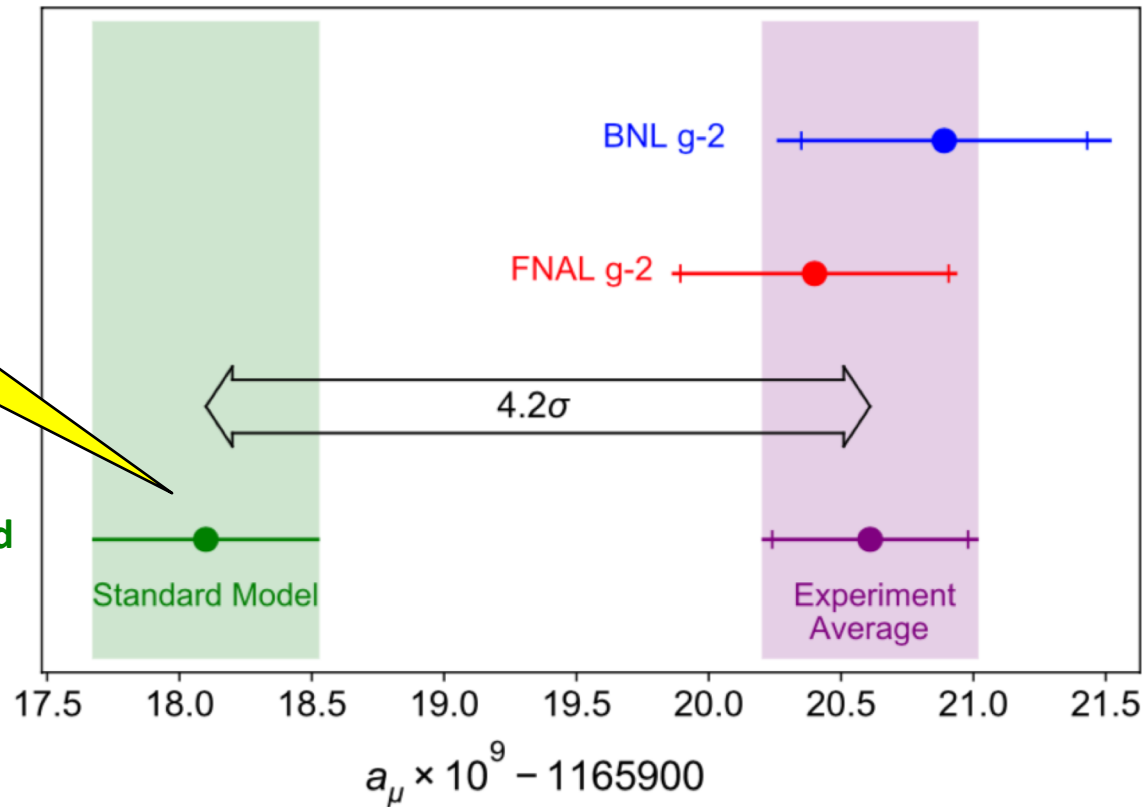
- Symmetric e^+e^- collider
- Located at the BEPCII collider (Beijing, China)
- CMS energy: 2 GeV to 5 GeV
- Maximum luminosity: $1 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$
- 93% coverage of the solid angle



New direct $(g-2)_\mu$ Measurement FNAL

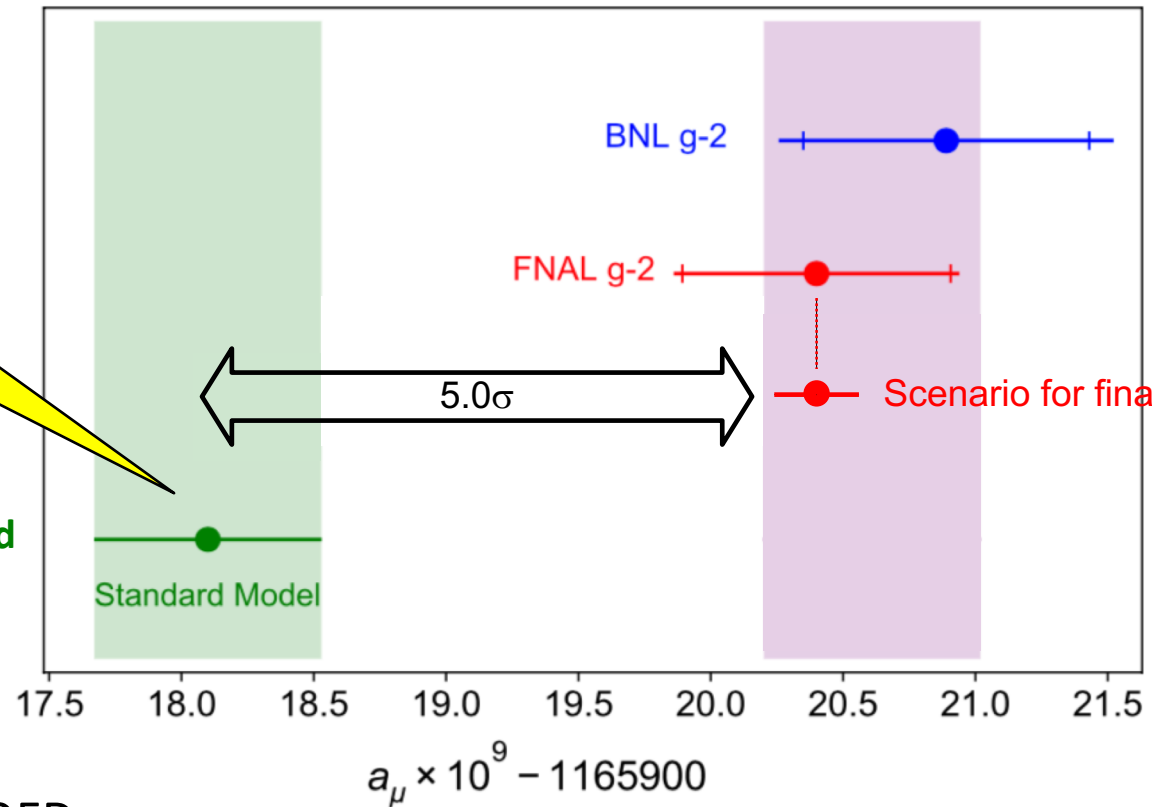
Reduction of SM uncertainty!
 → **This talk!**

$$a_\mu^{SM} = a_\mu^{QED} + a_\mu^{weak} + a_\mu^{had}$$



New direct $(g-2)_\mu$ Measurement FNAL

Reduction of SM uncertainty!
 → **This talk!**



$$a_\mu^{SM} = a_\mu^{QED} + a_\mu^{weak} + a_\mu^{had}$$

Absolute contribution: dominated by QED

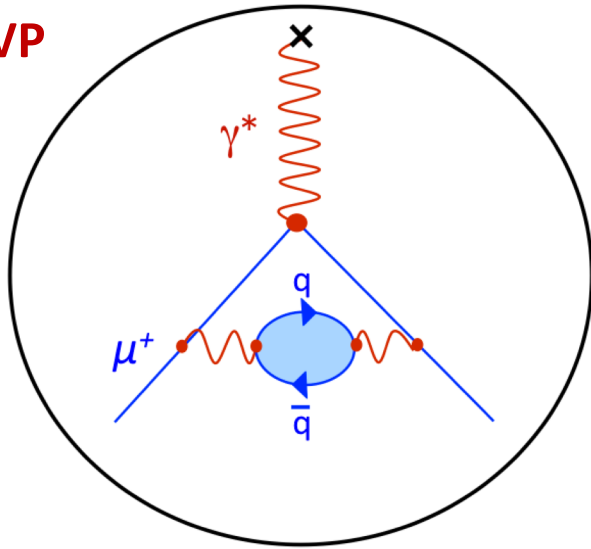
- Uncertainty: dominated by **strong interactions**
- **Hadronic Vacuum Polarization** $(693.1 \pm 4.0 \cdot 10^{-10})$
 - **Hadronic Light-by-Light** $(9.2 \pm 1.8 \cdot 10^{-10})$

Physics Reports 887 (2020) 1-166

talk
 Colangelo

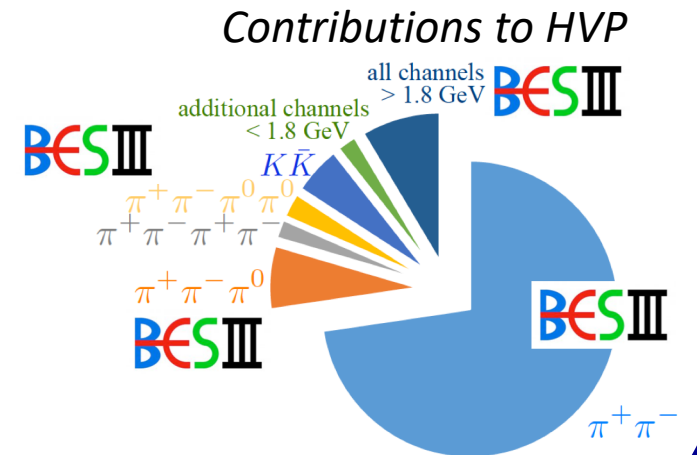
Hadronic Vacuum Polarization (HVP)

HVP

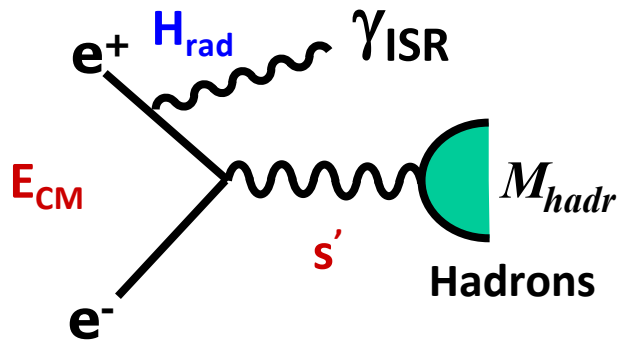


$$a_{\mu}^{HVP} = \frac{1}{4\pi^3} \int_{4m_{\pi}^2}^{\infty} ds K(s) \sigma_{had}(s)$$

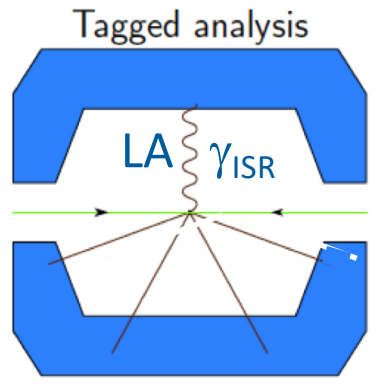
$\sigma_{had}(s) = \sigma_{tot}(e^+e^- \rightarrow \text{Hadrons})$
 relevant mass range $< 2...3 \text{ GeV}$



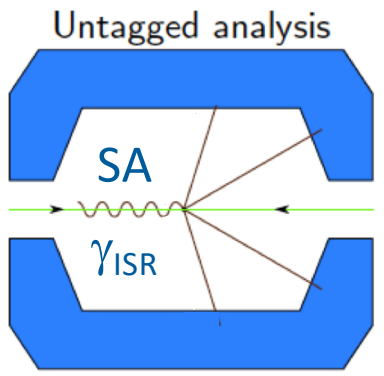
Initial State Radiation (ISR)



- High statistics thanks to high luminosity
- Precise knowledge of radiative corrections
- Large angle (LA) and small angle (SA) ISR analyses



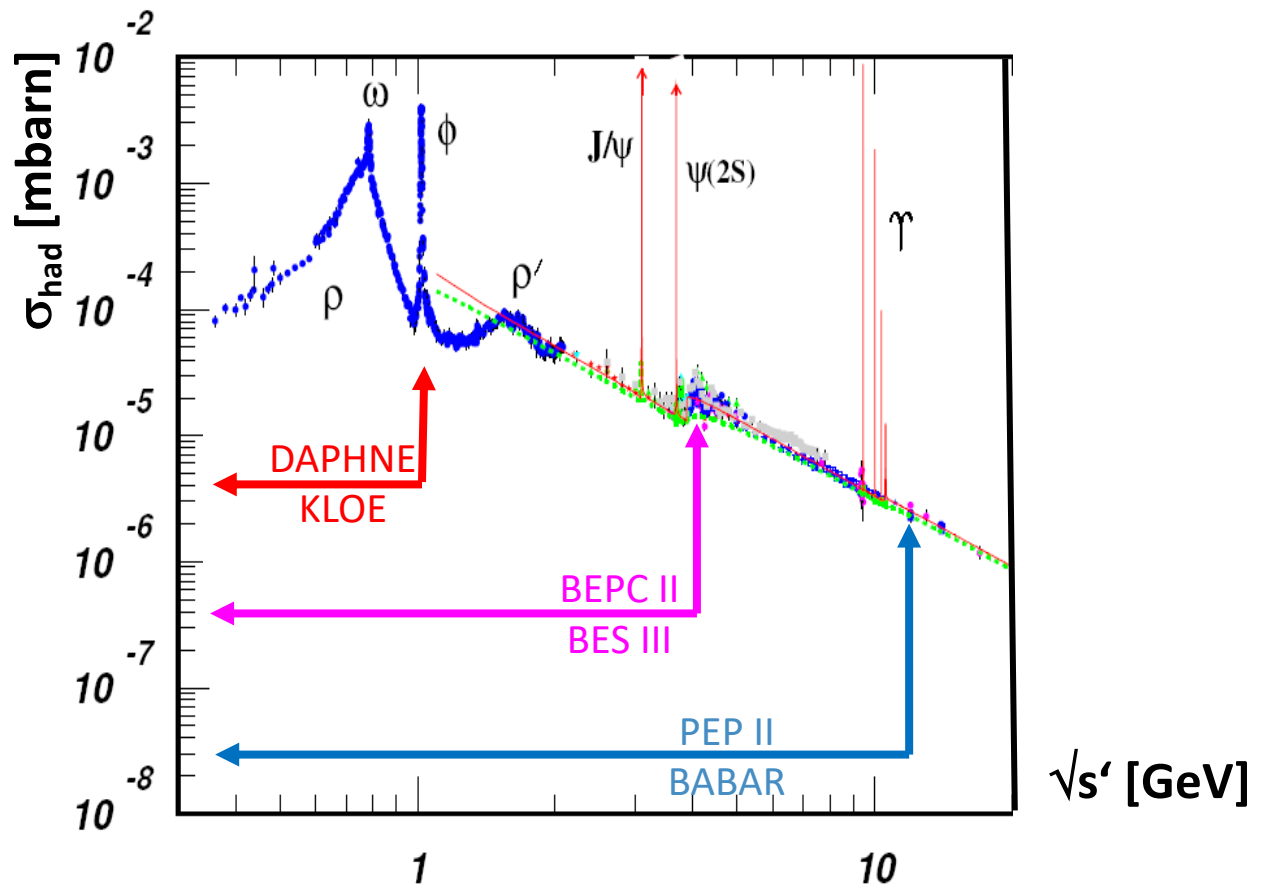
- + exclusive reconstruction
- increased background
- reduced statistics
- + mass range $\sqrt{s'} < E_{CM}$



- cut on angle of missing momentum
- + reduced background
- + very high statistics (x5)
- mass range $E_{th} < \sqrt{s'} < E_{CM}$ (BESIII: $E_{th} = \sim 1$ GeV)

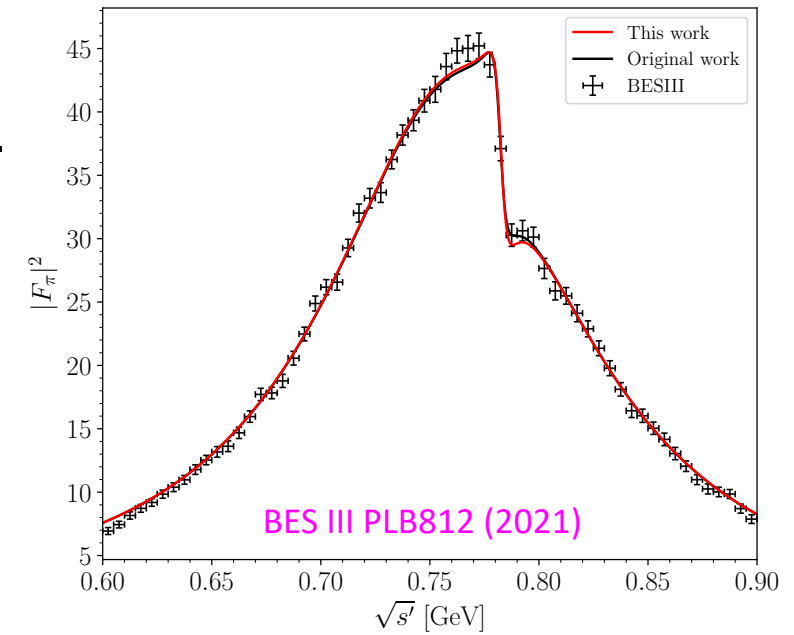
$$\frac{d\sigma_{ISR}(\sqrt{s'})}{d\sqrt{s'}} = \frac{2\sqrt{s'}}{s} W(s, E_\gamma, \theta_\gamma) \sigma(\sqrt{s'})$$

PHOKHARA event generator

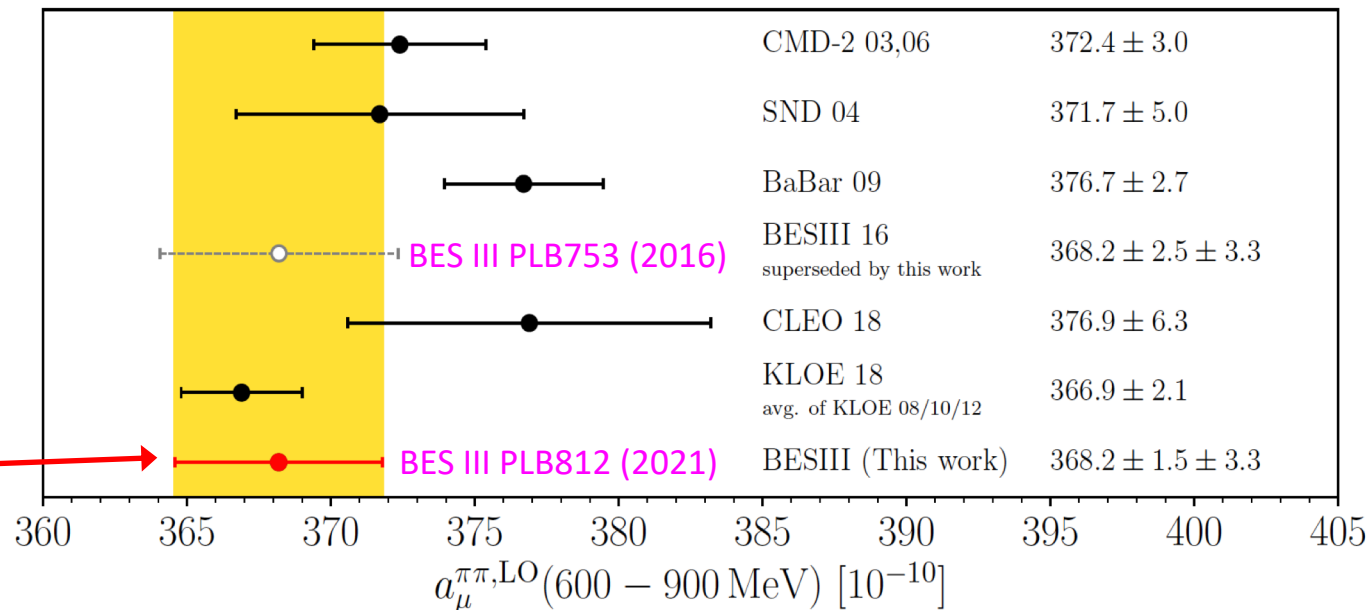


Measuring hadronic corrections to the muon g-2 at BESIII

BESIII Analysis $e^+e^- \rightarrow \pi^+\pi^-\gamma_{ISR}$

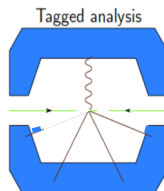


Source	BESIII 2016 2.9/fb (Update)
Photon efficiency	0.2
Pion tracking efficiency	0.3
Pion ANN efficiency	0.2
Pion e-PID efficiency	0.2
Angular acceptance	0.1
Background subtraction	0.1
Unfolding procedure	0.2
Luminosity \mathcal{L}	0.5
FSR correction	0.2
Vacuum polarization	0.2
Radiator function	0.5
Sum Systematics	0.9
Statistical error	0.4



BESIII Analysis $e^+e^- \rightarrow \pi^+\pi^-\gamma_{ISR}$

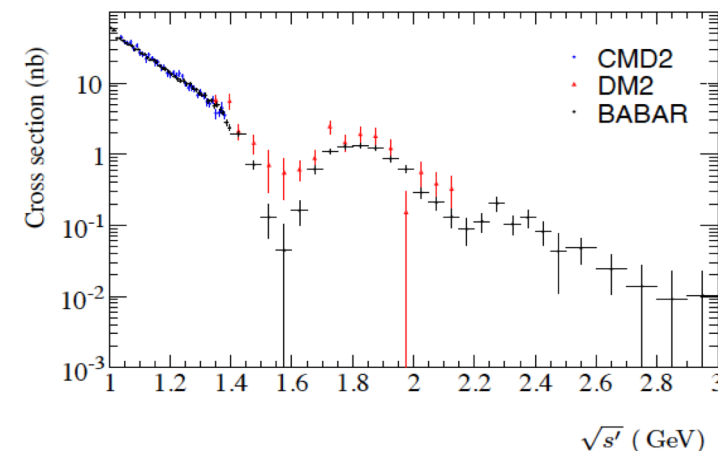
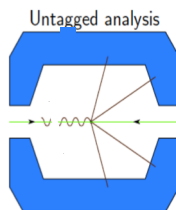
- BESIII aims for new two-pion analysis with precision goal of 0.5% (tagged analysis)



- 20/fb of data at 3.77 GeV available soon
- Normalization to $\mu^+\mu^-\gamma$ events
- Improved pion-muon separation

$$R = \frac{N_{\pi^+\pi^-}}{N_{\mu^+\mu^-}} \cdot \frac{\epsilon_{\mu^+\mu^-} \cdot (1 + \delta_{\mu^+\mu^-}^{\text{FSR}})}{\epsilon_{\pi^+\pi^-} \cdot (1 + \delta_{\pi^+\pi^-}^{\text{FSR}})}$$

- BESIII aims for an improved measurement of the mass range above 1 GeV (untagged analysis)

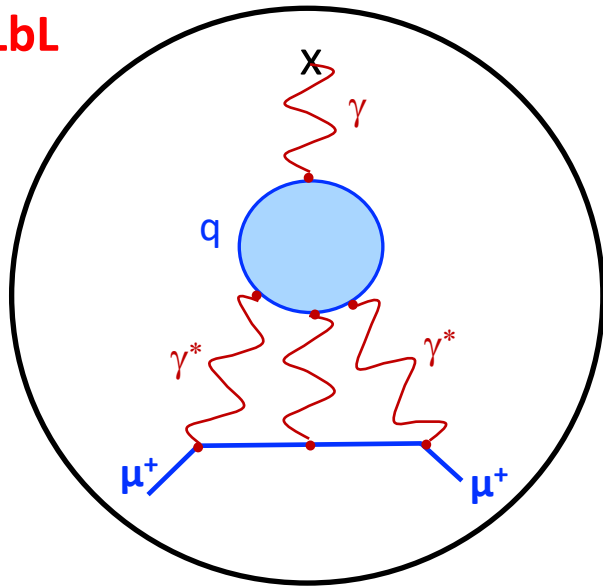


Source	BESIII 2016 2.9/fb (Update)	LA Analysis Normalization to $\mu^+\mu^-\gamma$ events
Photon efficiency	0.2	-
Pion tracking efficiency	0.3	0.2
Pion ANN efficiency	0.2	0.3
Pion e-PID efficiency	0.2	0.1
Angular acceptance	0.1	0.1
Background subtraction	0.1	0.1
Unfolding procedure	0.2	0.2
Luminosity \mathcal{L}	0.5	-
FSR correction	0.2	0.2
Vacuum polarization	0.2	-
Radiator function	0.5	-
Sum Systematics	0.9	0.5
Statistical error	0.4	0.3

Hadronic Light-by-Light Contribution (HLbL)

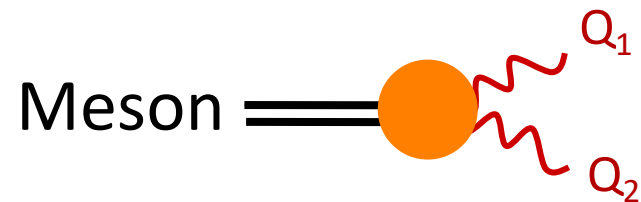


HLbL



Data-driven approach!

Exp. Input: **Transition Form Factors TFF** $F(Q^2)$
momentum transfer Q^2 below $\sim 2 \text{ GeV}^2$

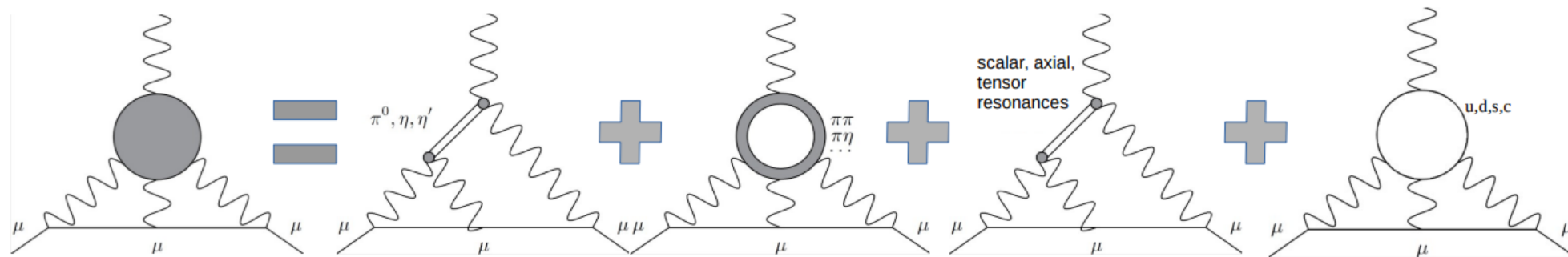


Estimate of (g-2) Theory Initiative:

$$(9.2 \pm 1.8) \cdot 10^{-10}$$

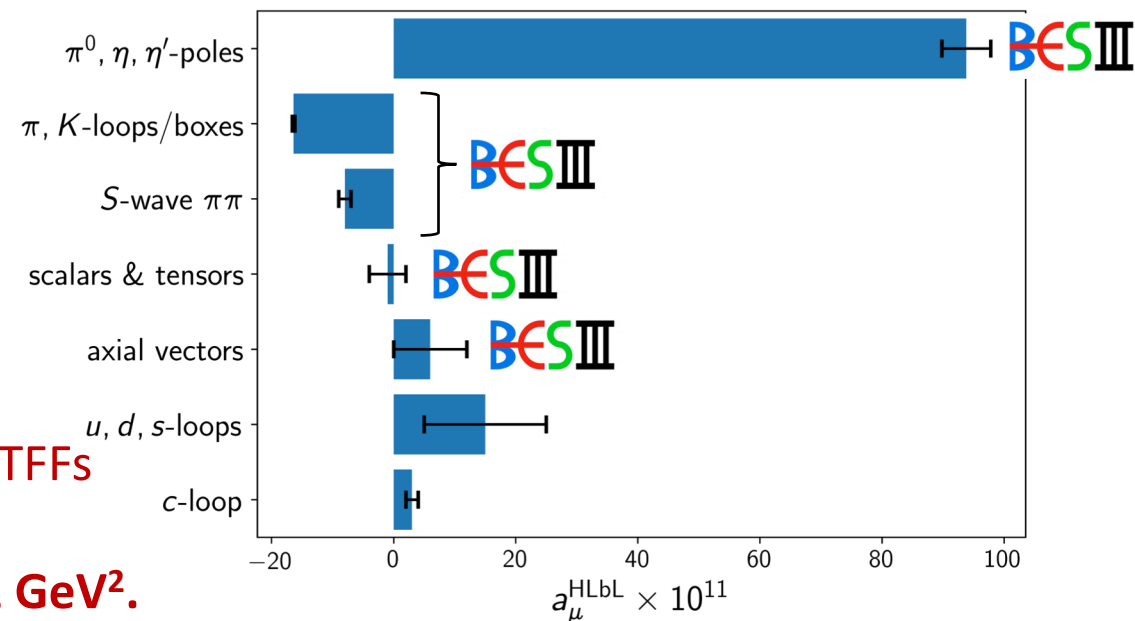
was $(10.5 \pm 2.6) \cdot 10^{-10}$

HLbL and Impact of BESIII Data



- Uncertainties for pseudoscalar and π – box contributions significantly reduced
 → **Validate theoretical TFFs with unique BESIII data set!**
- Currently, axial vector, scalar, and tensor contributions together with short distance contributions limiting overall accuracy
 → **BESIII measurements of axial vector, scalar, and tensor TFFs**

Physics Reports 887 (2020) 1-166



In very many cases no previous TFF measurements for $Q^2 < 2 \text{ GeV}^2$.

Two-Photon Physics Programme at BESIII

Selection criteria

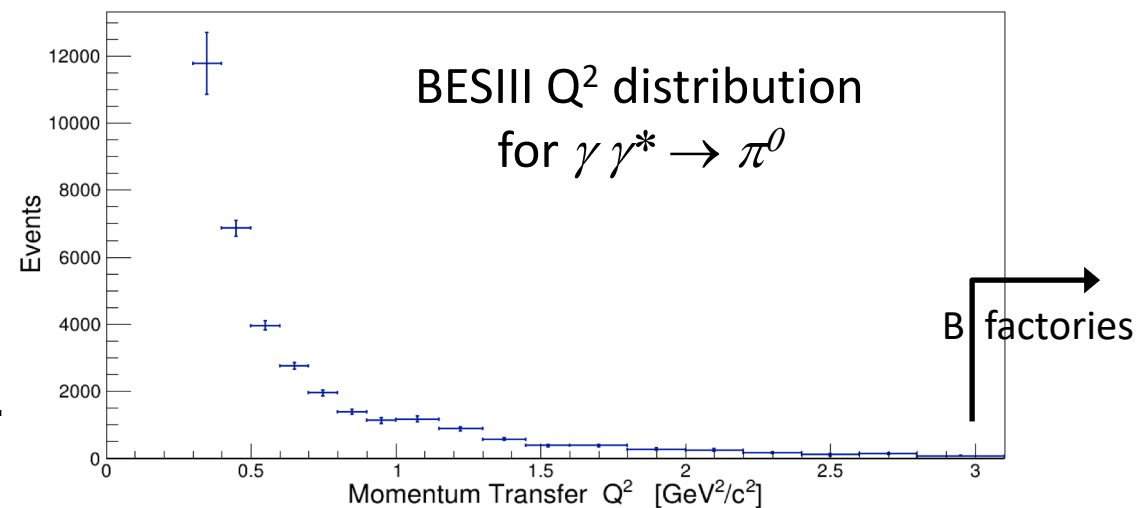
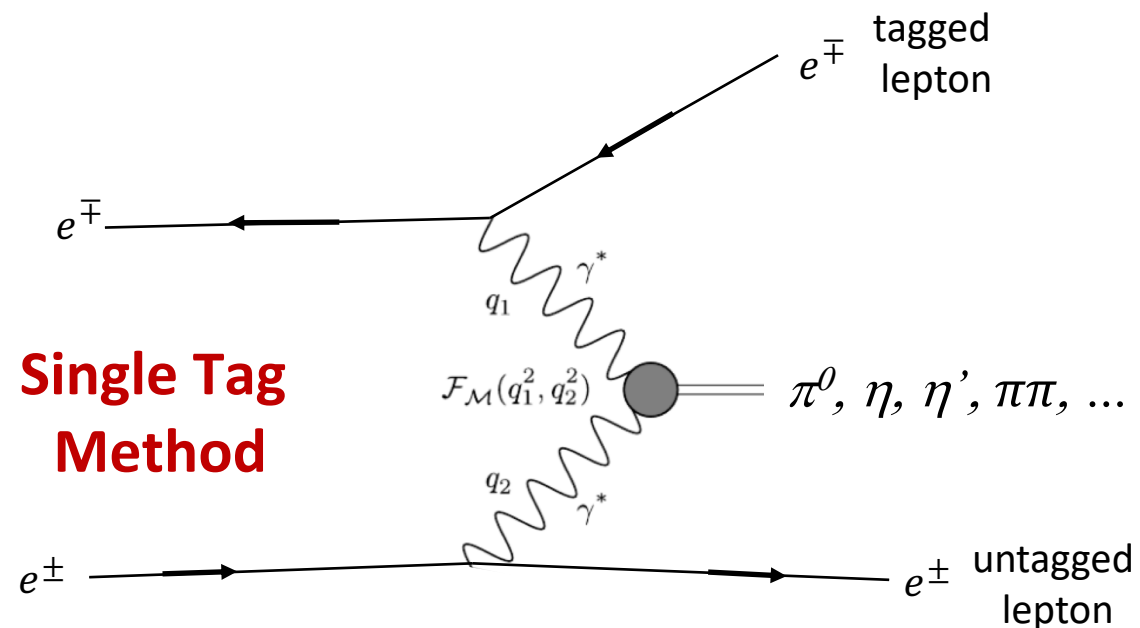
- 1 electron (positron) detected
 - 1 positron (electron) along beam axis
 - Meson fully reconstructed
- **cut on angle of missing momentum**

Momentum transfer

- tagged: $Q^2 = -q_1^2 = -(p - p')^2$
→ Highly virtual photon
- untagged: $q^2 = -q_2^2 \sim 0 \text{ GeV}^2$
→ Quasi-real photon

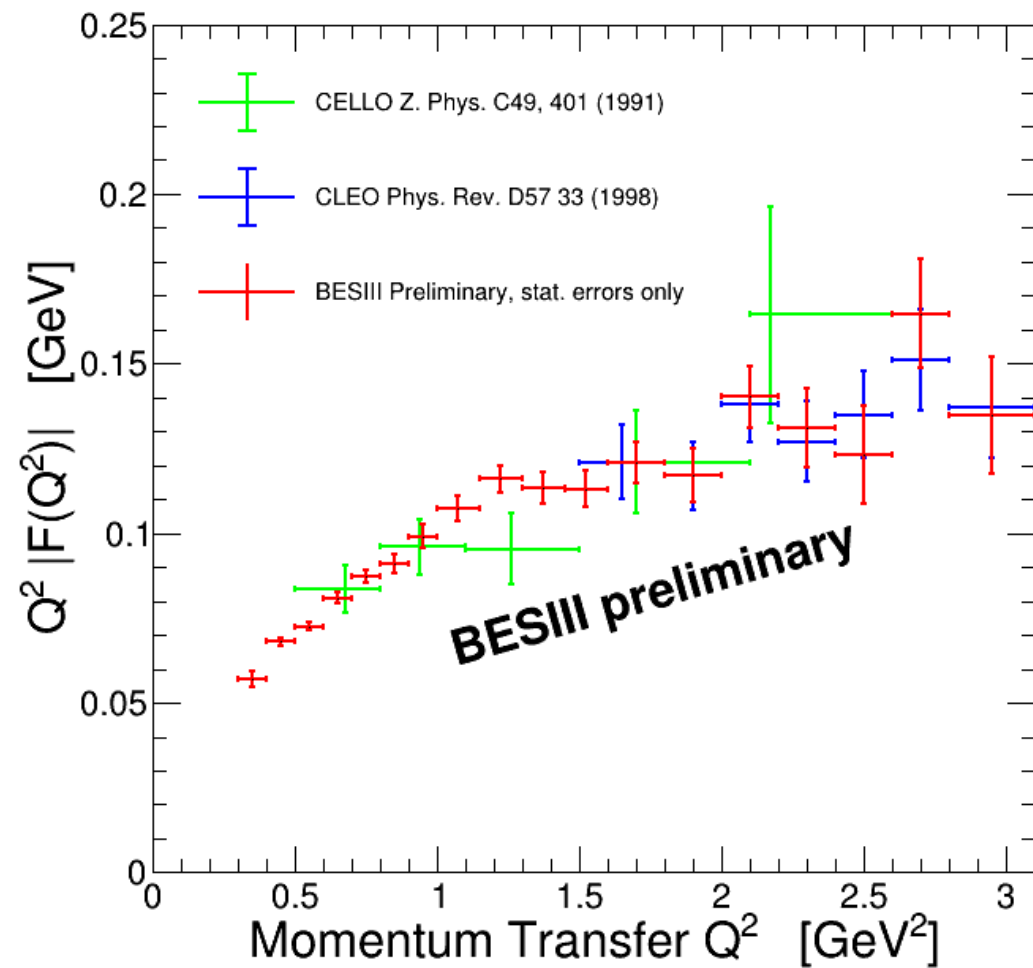
EKHARA event generator

$$Q^2 = 4 \cdot E \cdot E' \cdot \sin^2(\theta/2)$$



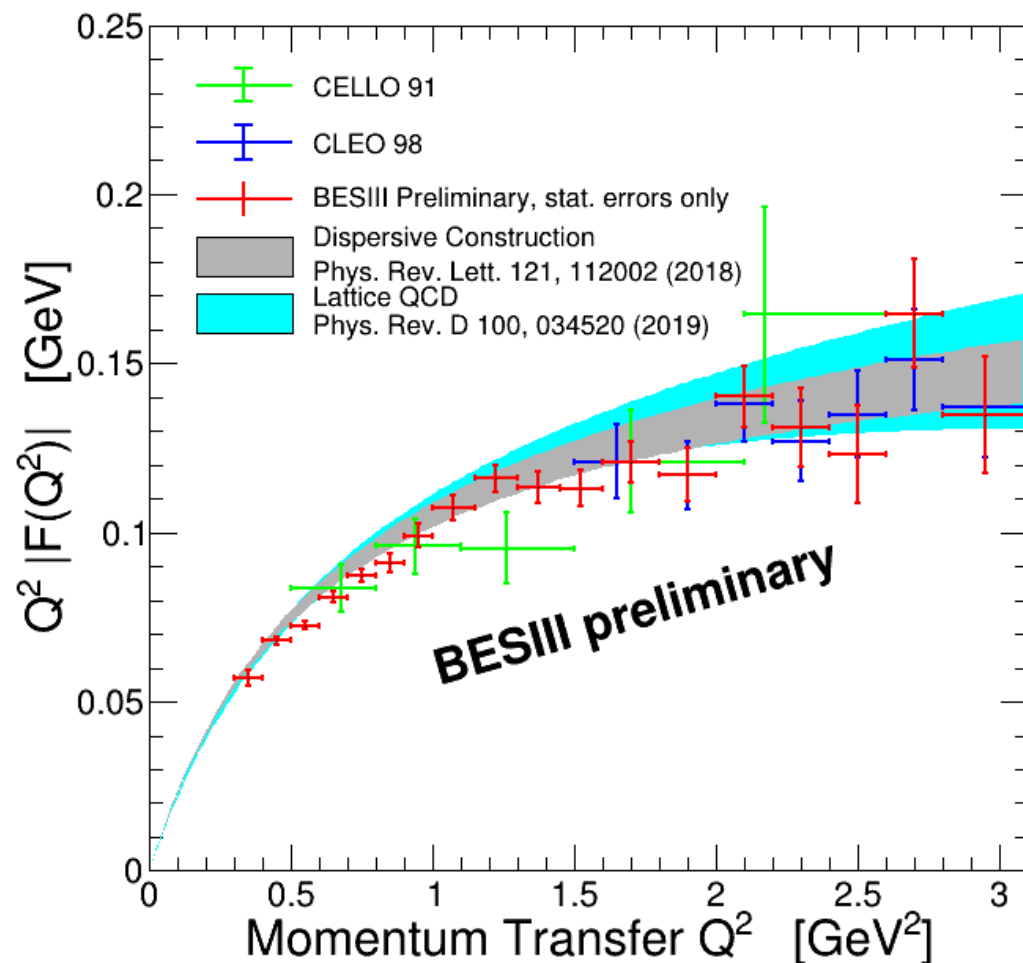
BES III Analysis: $\gamma \gamma^* \rightarrow \pi^0$

PPNP107 (2019) 20



BES III Analysis: $\gamma \gamma^* \rightarrow \pi^0$

PPNP107 (2019) 20



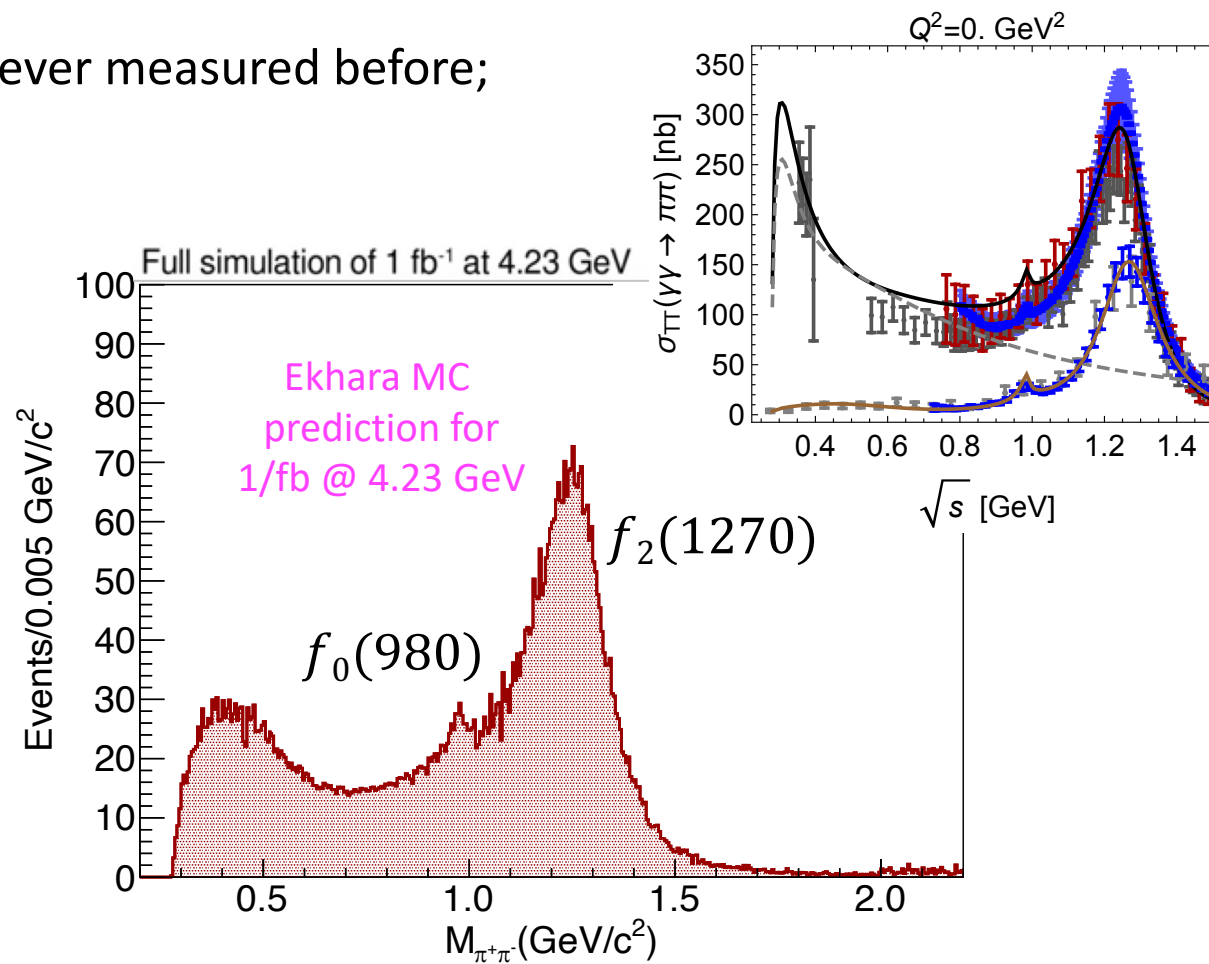
- $\sqrt{s}_{\text{BESIII}} = 3.77 \text{ GeV}$, $L = 2.9/\text{fb}$
- Unprecedented accuracy of BESIII
- Relevant Q^2 range for HLbL
- ➔ **Very good agreement with recent dispersive analysis and of Lattice QCD calculation**
- Q^2 range below 0.3 GeV^2 accessible at BESIII with data from lower c.m. energy

similar results for η and η' TFFs

Upcoming BES III Analysis: $\gamma\gamma^* \rightarrow \pi^+\pi^-$

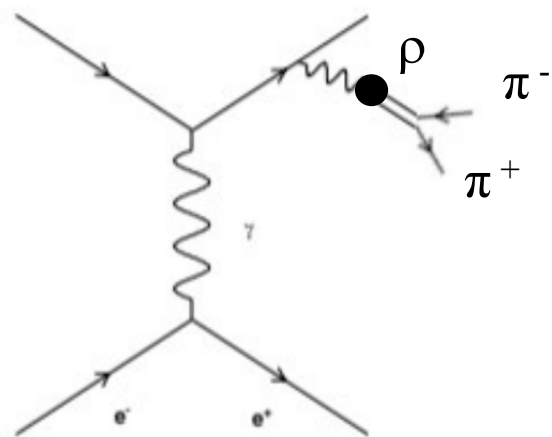
- Transition form factor for process $\gamma\gamma^* \rightarrow \pi^+\pi^-$ never measured before; only untagged measurements with $Q^2=0 \text{ GeV}^2$ existing
- BESIII aims for:
 - first TFF measurement in Q^2 range 0.1 ... 3 GeV^2 in single-tag analysis
 - full coverage of the mass range up to 2 GeV
 - full coverage of the helicity angle
- Analysis in a very advanced state (7/fb):
 - 7/fb of data at cms energies $\geq 3.77 \text{ GeV}$
 - construction of MC generator Ekhara (H. Czyz)
 - detailed phenomenology program @ Mainz
 - subtraction of background channels !

talk
Danilkin

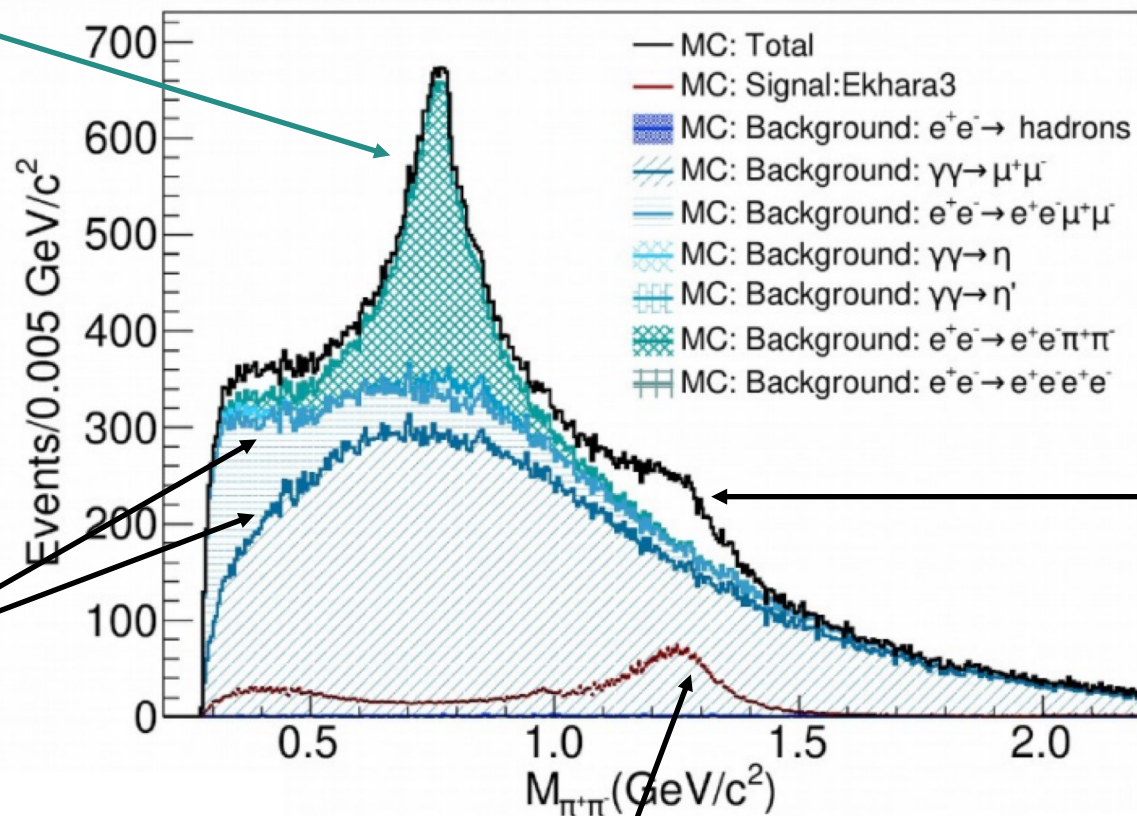


BES III Analysis: $\gamma\gamma^* \rightarrow \pi^+\pi^-$

Radiative Bhabha scattering
with production of rho meson

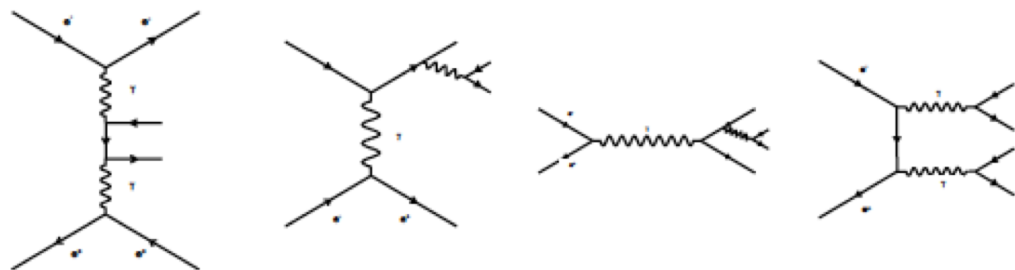


Full simulation of 1 fb^{-1} at 4.23 GeV



sum of all MC
contributions

Process
 $e^+e^- \rightarrow e^+e^- \mu^+\mu^-$



signal process
(see slide before)

Measuring hadr

**confident to publish
 $\pi^+\pi^-$ analysis shortly!
ongoing PhD project
for $\pi^0\pi^0$ and $\pi^0\eta$ channels**

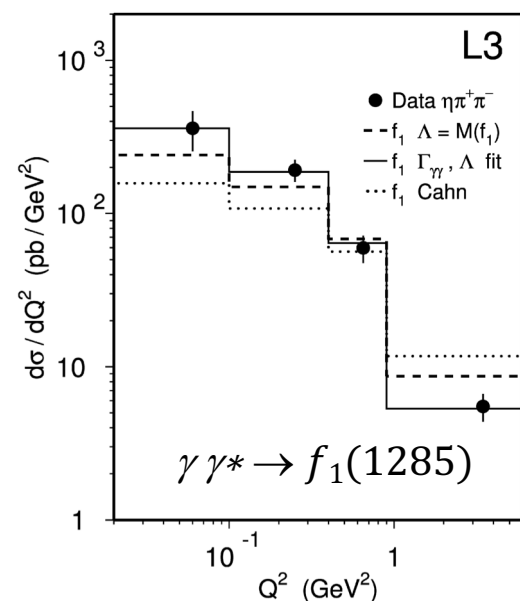
Upcoming BES III Analysis $\gamma\gamma^* \rightarrow f_1(1285) \rightarrow \pi^+\pi^-\eta$

- Design study recently completed

- single-tag analysis
- $f_1(1285) \rightarrow \pi^+\pi^-\eta$ ($\eta \rightarrow \gamma\gamma$)
- 10/fb of data at cms energies > 4 GeV

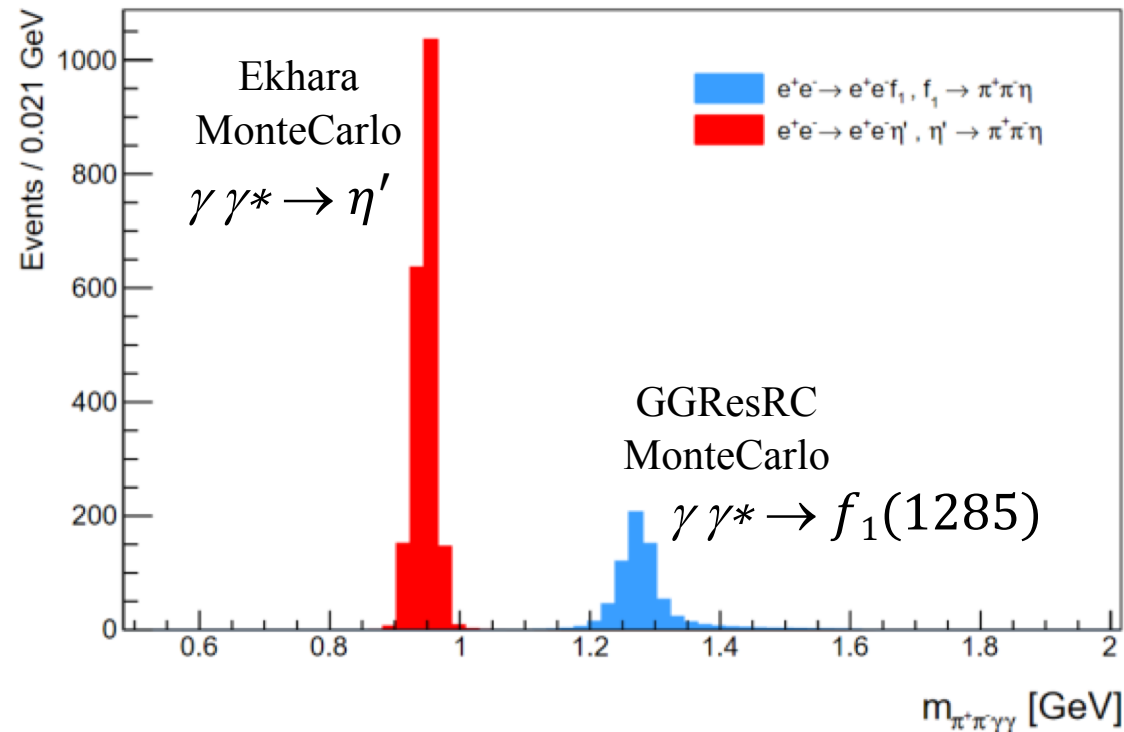
- BESIII aims for:

- TFF measurement in Q^2 range 0.24 ... 3 GeV²
- separation of LT and TT contribution by means of helicity angle
- improved accuracy wrt. existing L3/LEP data below 6 GeV² (4 data points)

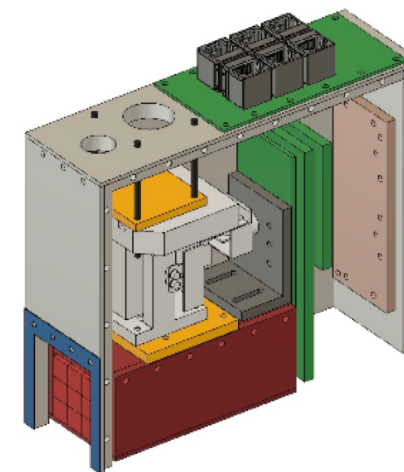


- In addition investigations of higher lying states in preparation (different decay channels)

Simulation 10/fb, mass spectrum $\pi^+\pi^-\gamma$



- BESIII program of **hadronic cross section measurements relevant for HVP**
 - $e^+e^- \rightarrow \pi^+\pi^-$ (1% total uncertainty)
 - $e^+e^- \rightarrow \pi^+\pi^-\pi^0$
 - $e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0$
 - upcoming new measurement of R_{incl} between 2.0 – 3.7 GeV (3% error)
- New ongoing analysis of channel $e^+e^- \rightarrow \pi^+\pi^-$ with goal to reach **0.5% total accuracy**
- BESIII has a **program of $\gamma\gamma$ measurements relevant for HLbL**
 - $\gamma\gamma^* \rightarrow \pi^0, \eta, \eta'$ (unprecedented accuracy at low Q^2)
 - $\gamma\gamma^* \rightarrow \pi^+\pi^-$ (first TFF measurement ever, cover full $M_{\pi\pi}$)
 - $\gamma\gamma^* \rightarrow \pi^0\pi^0 / \pi^0\eta$ (first TFF measurement at low Q^2)
 - $\gamma\gamma^* \rightarrow f_1(1285), \dots$
 - double virtual TFFs
- Most results based so far on data set of 2.9/fb taken at 3.77 GeV
 → **20/fb of data at 3.77 GeV upcoming (2022) + ~20/fb > 4 GeV**
- Preparation of a **small angle tagger for improved ISR and $\gamma\gamma$ analyses**



crystal Zero Degree Detector