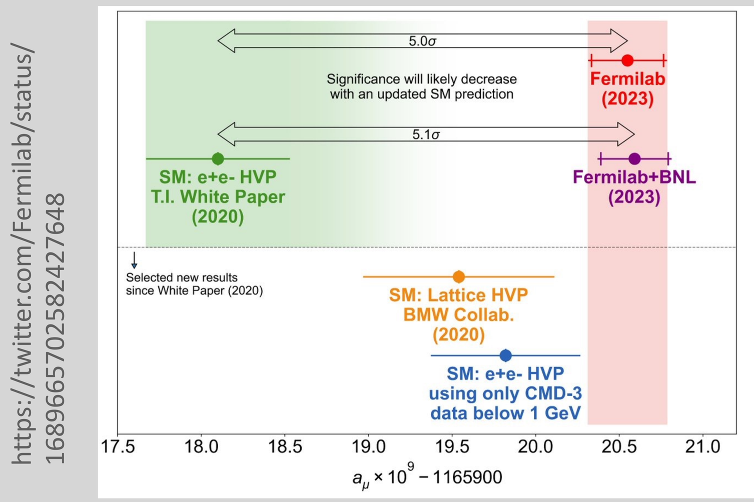
Small Angle Initial State Radiation Analysis of the Pion Form Factor at BESIII

Yasemin Schelhaas, Riccardo Aliberti & Achim Denig (JGU Mainz) on behalf of the BESIII collaboration

Anomalous Magnetic Moment of the Muon

- Magnetic moment of the muon: $\mu = g_\mu \frac{e}{2m_\mu}\vec{S}$, Dirac theory: $g_\mu = 2$
- Quantum field theory: $a_\mu = \frac{|g_\mu - 2|}{2}$ ➜ **Muon g-2 Puzzle**
- Standard Model (SM) prediction: $\boxed{a_\mu^{\mathrm{SM}} = a_\mu^{\mathrm{QED}} + \boldsymbol{a_\mu^{\mathrm{QCD}}} + a_\mu^{\mathrm{weak}}}$
- Direct measurement: Experimental average of BNAL & FNAL



Discrepancy of 5.1σ!

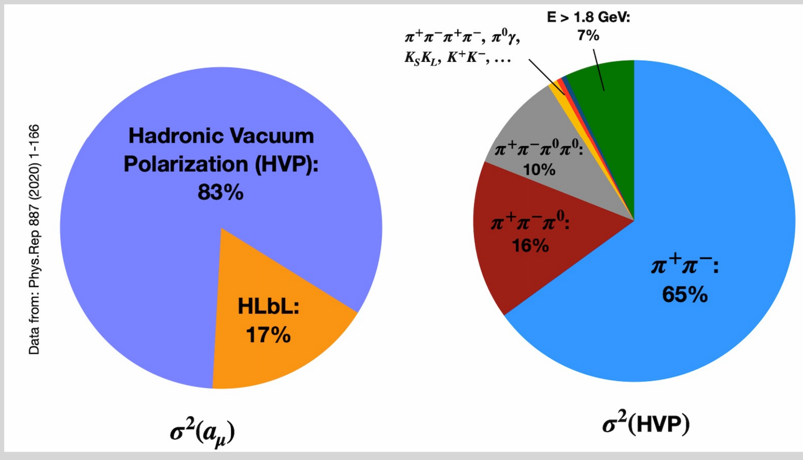
➜ Hint for new physics?

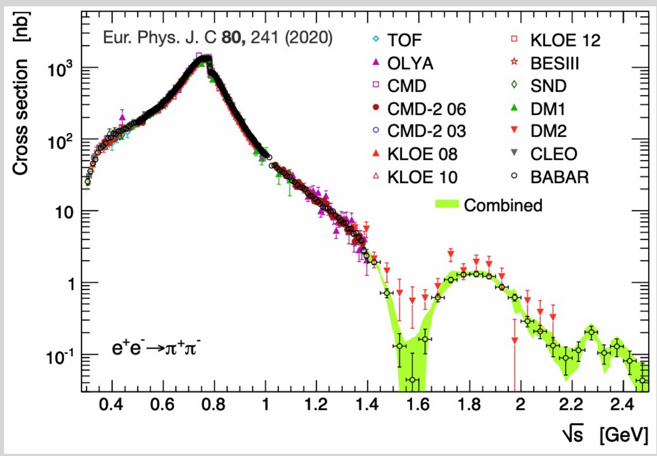
- Hadronic contributions dominate uncertainty for a_μ^{SM}
  - Hadronic Light-by-Light Scattering (HLbL)
  - **Hadronic Vacuum Polarization (HVP)**

$e^+e^- \to \pi^+\pi^-$

- Difficulty: a_μ^{HVP} cannot be calculated by perturbation theory

➜ **Dispersion relation:** $\boxed{\boldsymbol{a_\mu^{\mathrm{HVP}}} = \frac{1}{4\pi}\int_{4m_\pi^2}^{\infty} K(s)\cdot \boldsymbol{\sigma_{e^+e^-\to \mathrm{had}}}\, \mathrm{d}s}$



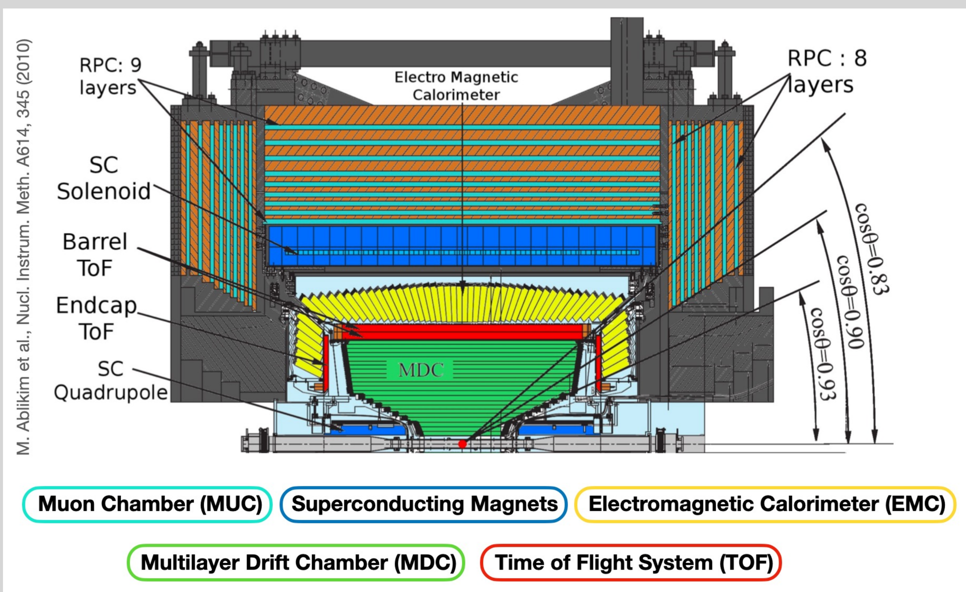


- Uncertainty for HVP dominated by multi-pion channels, mainly $\boldsymbol{\pi^+\pi^-}$
- Region below 1 GeV has largest impact for a_μ^{HVP}
- At high energies only few results, e.g. from BaBar collaboration

➜ **This analysis: Pion form factor measurement above 0.8 GeV**
➜ Aiming for improved spectrum & interesting for hadron spectroscopy

BESIII Experiment at BEPCII

- Beijing Electron Positron Collider (BEPCII):
  - CM energy: 2.0 – 5.0 GeV
  - Design luminosity: $1.0 \cdot 10^{33}$ cm^{-2} s^{-1} at $\psi(3770)$
- Beijing Spectrometer III (BESIII) at BEPCII interaction point



- Used data set in this analysis: **1.9 fb^{-1} at 3.77 GeV**

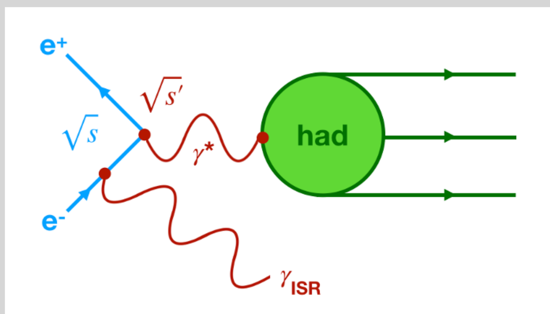
➜ Upcoming data set: **20 fb^{-1} at 3.77 GeV**

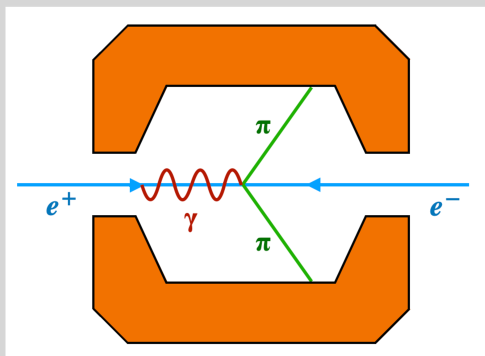
Initial State Radiation (ISR) Technique

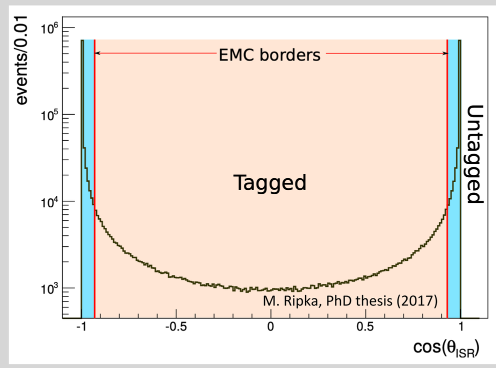
- Processes where e^- or e^+ emit γ_{ISR} before annihilation
- Measure **whole $\pi^+\pi^-$ spectrum** with one high statistics data set at fixed CM energy
- Radiator function W relates to non-radiative cross section:

$$\boxed{\frac{\mathrm{d}\sigma_{\pi^+\pi^-\gamma}(m)}{\mathrm{d}m_\gamma} = \frac{2m}{s}\cdot \epsilon(s,m)\cdot W(s, E_\gamma, \theta_\gamma)\cdot \boldsymbol{\sigma_{\pi^+\pi^-}(m)}}$$

- **Small angle untagged ISR analysis** (ISR photon undetected) ➜ High statistics!





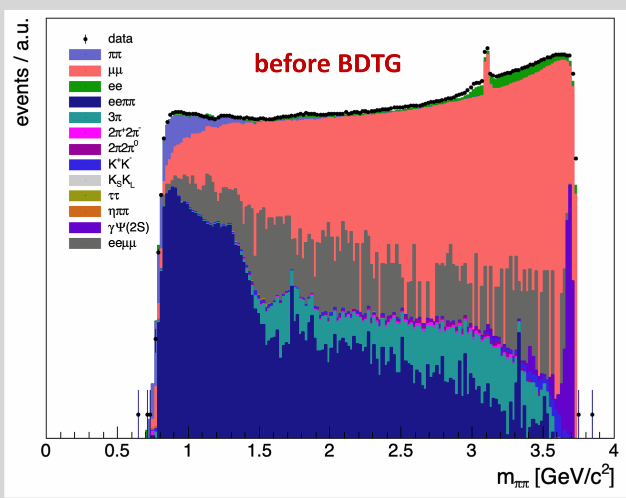


- Selection Scheme:
  - Up to four charged tracks
  - Vertex fit: intersection of charged tracks
  - Kinematic 1C fit: assume missing γ_{ISR}
  - Particle ID (PID): electron rejection

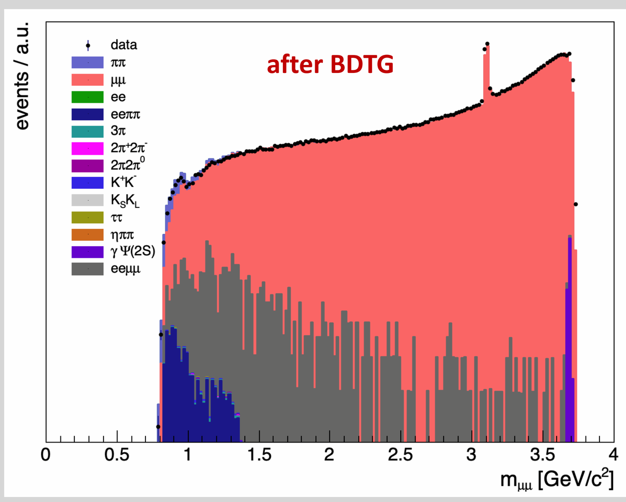
π/μ Separation Using a Multivariate Analysis Approach

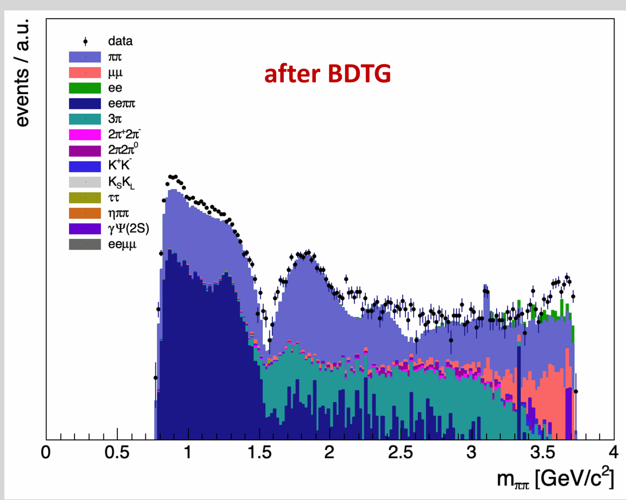
- Signal: $\boxed{e^+e^- \to \pi^+\pi^-\gamma_{\mathrm{ISR}}}$
- Main background contribution: $\boxed{e^+e^- \to \mu^+\mu^-\gamma_{\mathrm{ISR}}}$
- Difficult to distinguish pions from muons at BESIII

➜ Optimized PID algorithm for π/μ separation needed!
➜ Multivariate analysis using **machine learning** tools
➜ ROOT Toolkit for Multivariate Data Analysis

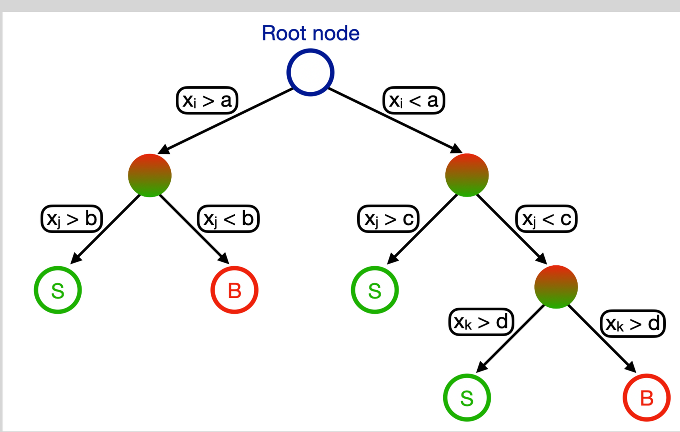


Cross check with invariant μμ-mass





Boosted Decision Tree with Gradient Boost (BDTG)



- Two answers per question (node)
- Final state (leaf) after max. nodes
- **Discriminating variables:**
  - Information from EMC
  - Track Momentum
  - Prob. for π & e by $\mathrm{d}E/\mathrm{d}x$ & TOF
- BDTG is a very powerful tool and suppresses a lot of muons

Next step: **2D PID corrections** for pions & muons:

$$\boxed{\mathrm{scaling}(|\vec{p}|,\theta) = \frac{\epsilon_{\mathrm{data}}(|\vec{p}|,\theta)}{\epsilon_{\mathrm{MC}}(|\vec{p}|,\theta)}}$$

- Independent control samples for pions & muons:
  - $\pi^+\pi^-\pi^+\pi^-$ with untagged γ_{ISR}
  - $\mu^+\mu^-$ with tagged γ_{ISR}

Presented by Yasemin Schelhaas, PhD Student at JGU Mainz (yaschelh@uni-mainz.de)