Measurement of the space-like π^0 transition form factor at BESIII
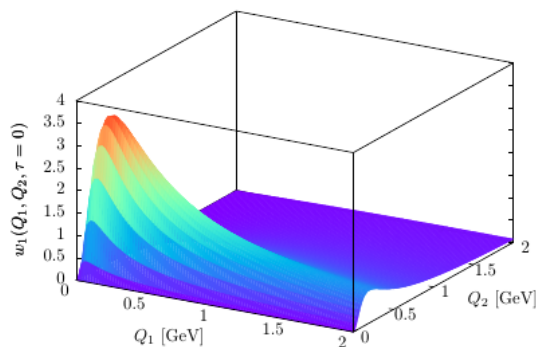
June 19, 2018 | Christoph Florian Redmer
for the BESIII collaboration
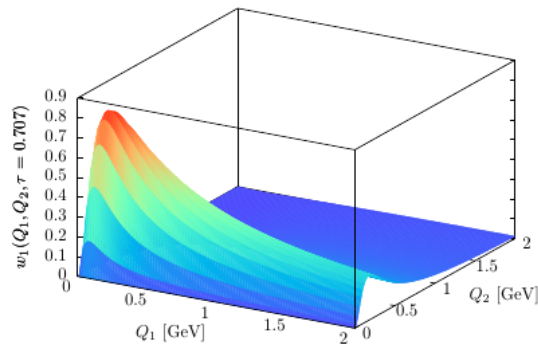
Second Workshop of the Muon g-2 Theory Initiative

3D integral representation for PS-pole contribution: (Nyffeler, PRD94,053006, 2016)

$$a_\mu^{\text{HLbL};\pi^{0(1)}} = \int_0^\infty dQ_1 \int_0^\infty dQ_2 \int_{-1}^1 d\tau \, w_1(Q_1, Q_2, \tau) \mathcal{F}_{\pi^0\gamma^*\gamma^*}(-Q_1^2, -(Q_1+Q_2)^2)\mathcal{F}_{\pi^0\gamma^*\gamma^*}(-Q_2^2, 0)$$
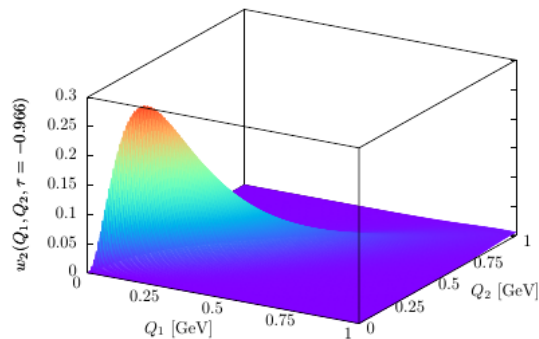
$$a_\mu^{\text{HLbL};\pi^{0(2)}} = \int_0^\infty dQ_1 \int_0^\infty dQ_2 \int_{-1}^1 d\tau \, w_2(Q_1, Q_2, \tau) \mathcal{F}_{\pi^0\gamma^*\gamma^*}(-Q_1^2, -Q_2^2)\mathcal{F}_{\pi^0\gamma^*\gamma^*}(-(Q_1+Q_2)^2, 0)$$
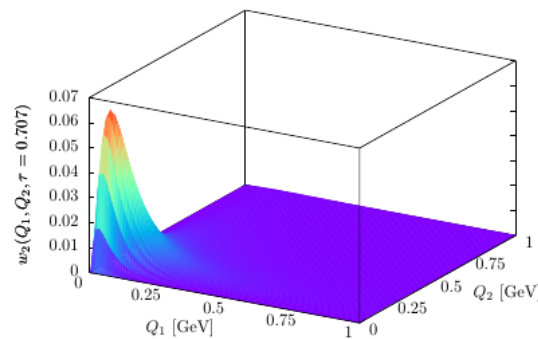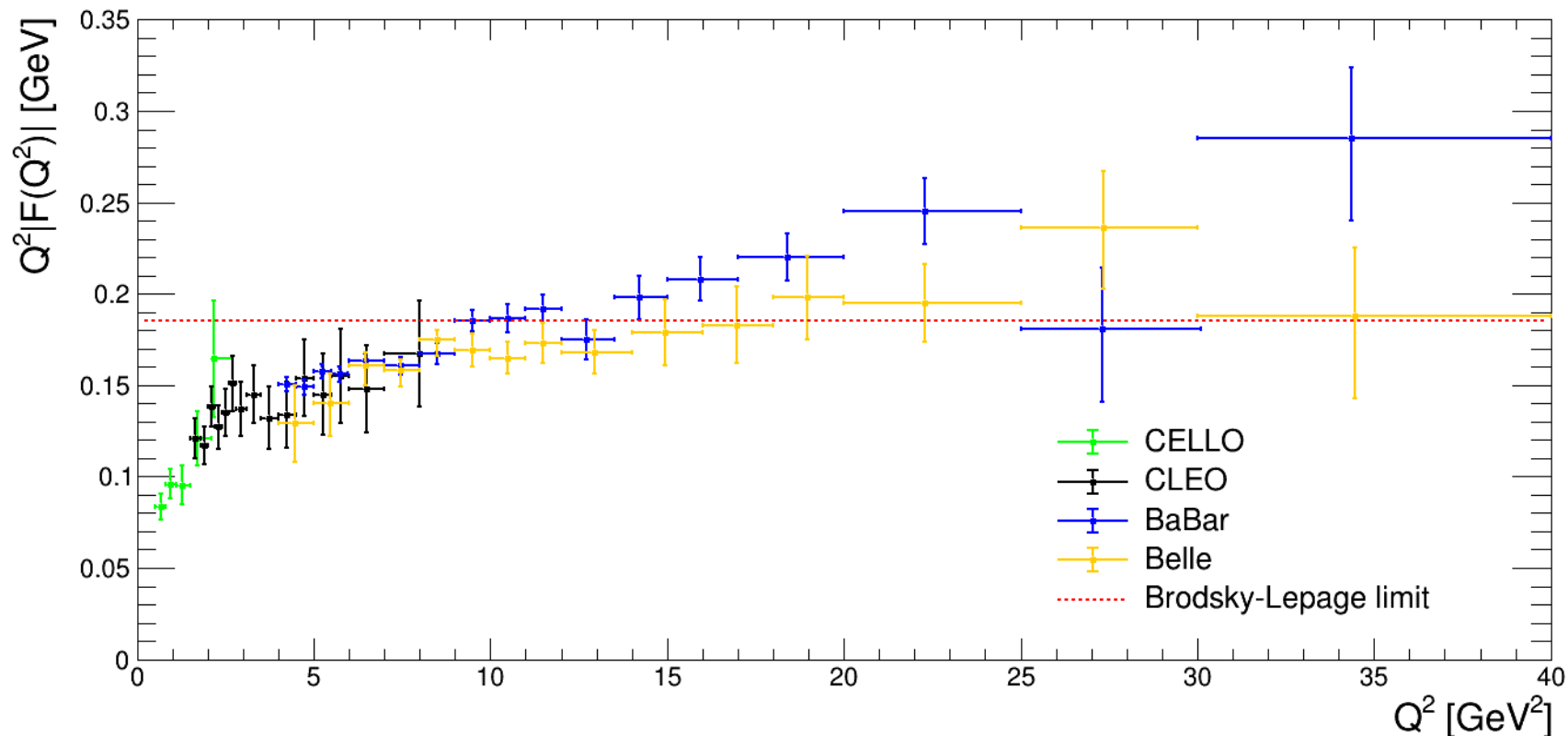

- Universal weight functions w_1, w_2
- Form factor dependence F

Relevant momentum region:

0.25 – 1.25 GeV

Existing Data
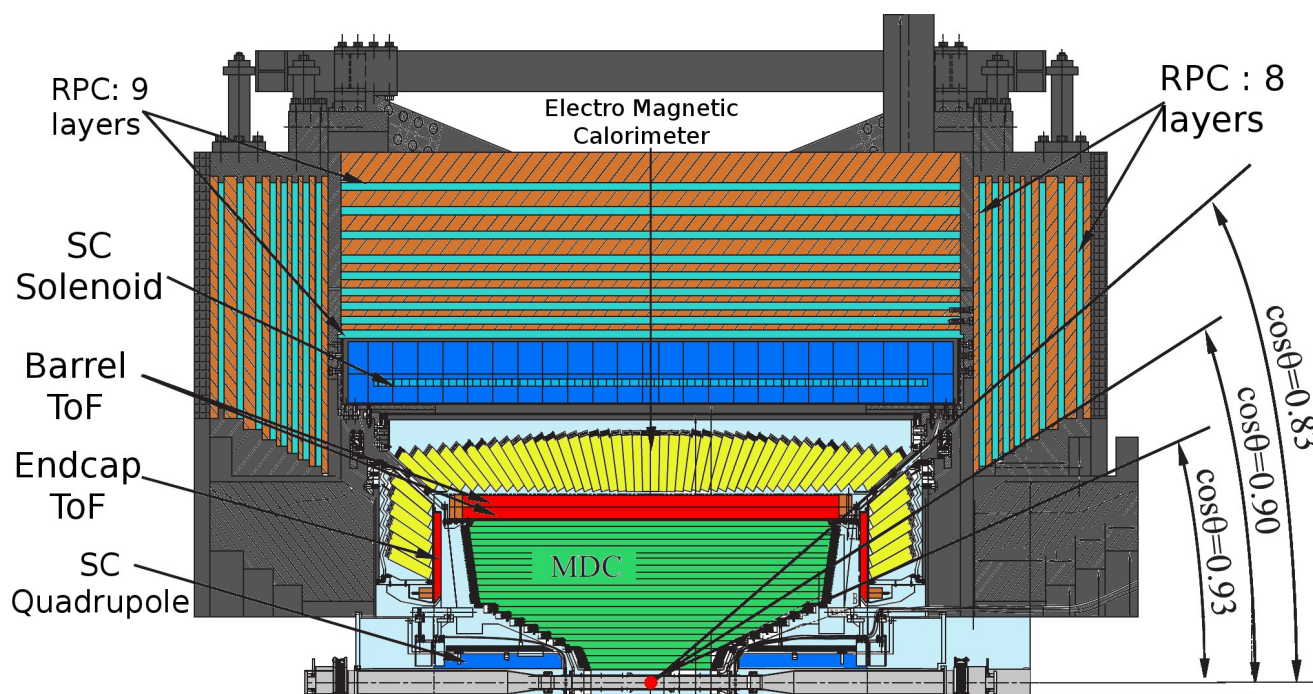
- Recent results from B-factories cover only large Q^2 ($5 < Q^2$ [GeV²] < 40)

  - Discrepancy for π^0 between BaBar and Belle

- Data scarce at lowest Q^2

  - Region of relevance for (g-2)μ

CELLO: Z.Phys.C49 (1991) 401
CLEO: Phys.Rev.D57 (1998) 33
BaBar: Phys.Rev.D80 (2009) 052002
        Phys.Rev.D84 (2011) 052001
Belle: Phys.Rev.D86 (2012) 092007

BESIII Detector

Muon Chambers
- 8 – 9 layers of RPC
- p>400 MeV/c
- $\delta R\Phi = 1.4 \sim 1.7$ cm

Superconducting Magnet
- 1 T magnetic field

EM Calorimeter (EMC)
- 6240 CsI(Tl) crystals
- $\sigma(E)/E = 2.5\%$
- $\sigma_{Z,\Phi}(E) = 0.5 - 0.7$ cm

Time-of-flight system (TOF)
- $\sigma(t) = 90$ps   (barrel)
- $\sigma(t) = 110$ps (endcap)

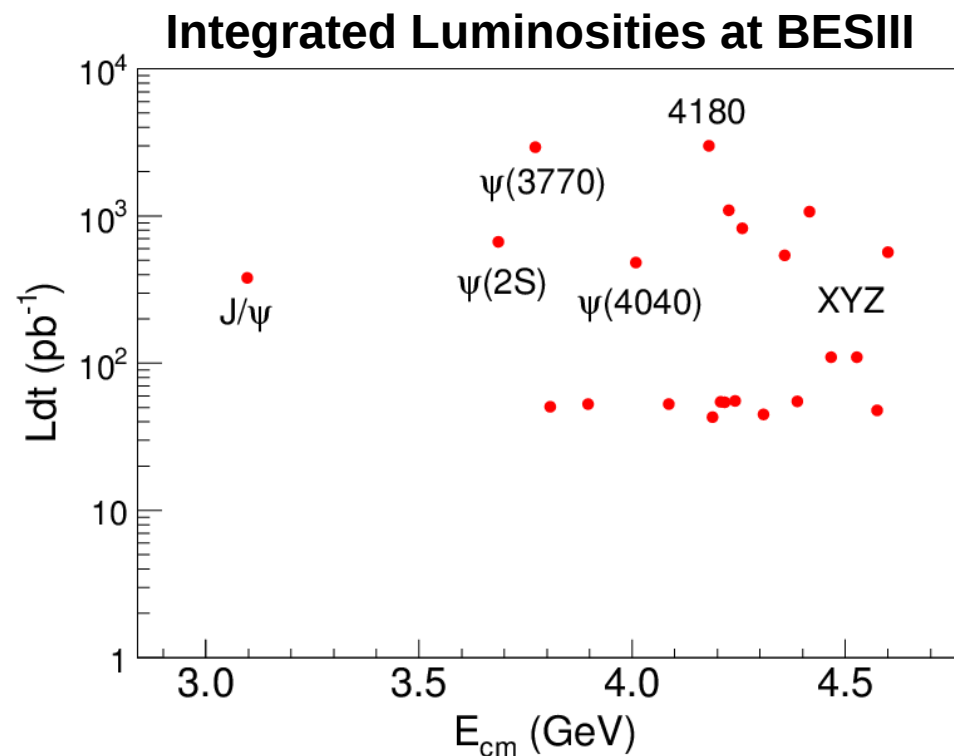**Drift Chamber   (MDC)**
- $\sigma(p)/p = 0.5\%$
- $\sigma_{dE/dx} = 6.0\%$

BESIII Data

- Operated at BEPCII collider
  - $2.0 \leq \sqrt{s} \, [\text{GeV}] \leq 4.6$
  - Design luminosity achieved
    - $\mathcal{L} = 1.0 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$ at $\psi(3770)$

- Large data sets for
  - Charmonium spectroscopy
  - Charm physics
  - Light hadrons
  - τ and R-scan

$\gamma\gamma$ studies mainly on 2.9 fb^{-1} at $\psi(3770)$

Integrated Luminosities at BESIII

Two-Photon Collisions

- Exchange of two photons in e^+e^- collisions

- Pseudoscalar, axial, and tensor states accessible

- $M_x \ll \sqrt{s}$

- $\sigma \propto \alpha^2 \ln^2 E$

- $\sigma \propto F^2(Q_1^2, Q_2^2)$, with $Q_i^2 = -q_i^2$

- Forward peaked kinematic
  - Experimentally challenging
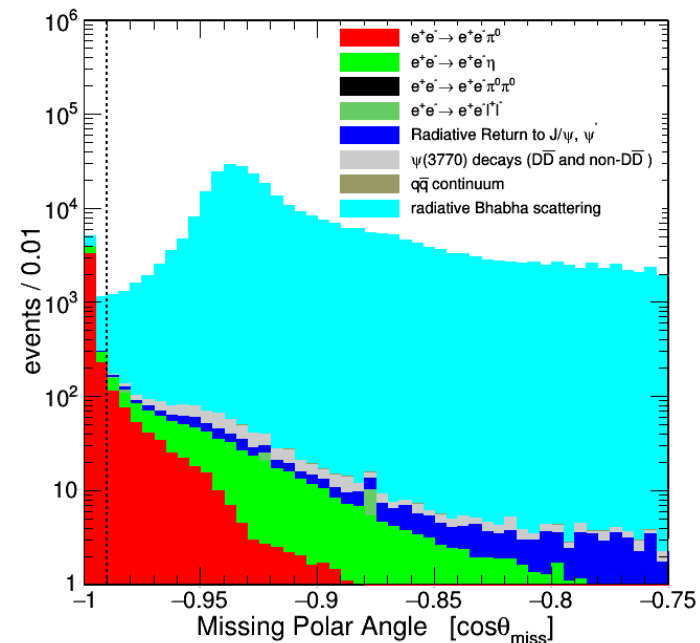
Single-Tag Measurements
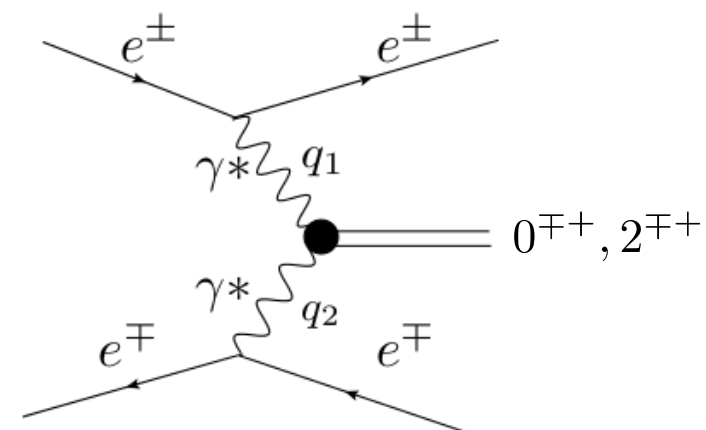
- Reconstruct
  - only one scattered lepton
  - Produced system

- Unmeasured lepton from momentum conservation
  - Require scattering angle to be small
  - Small virtuality

  - $F(q_1^2, q_2^2) \to F(q_1^2, 0) \to F(q^2)$
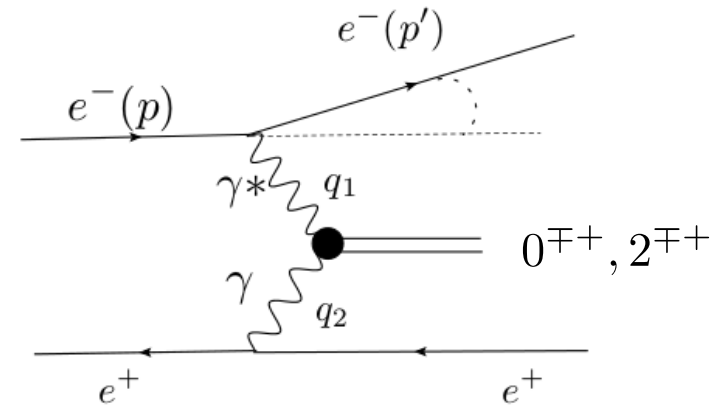
Example: π^0 transition form factor at BESIII

Monte Carlo, L_{int}: 2.93 fb^{-1} @ Ψ(3770)

Tagged Lepton: e$^+$
Reconstructed decay: $\pi^0 \to \gamma\gamma$

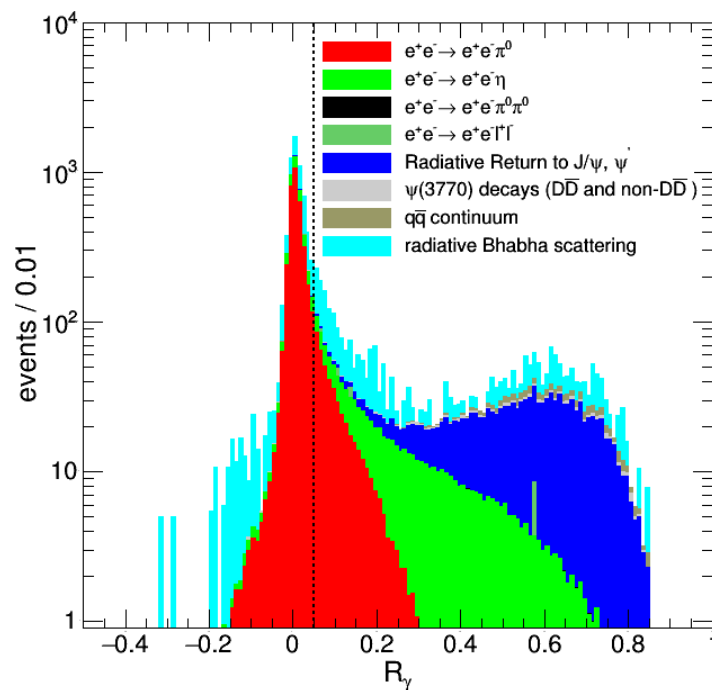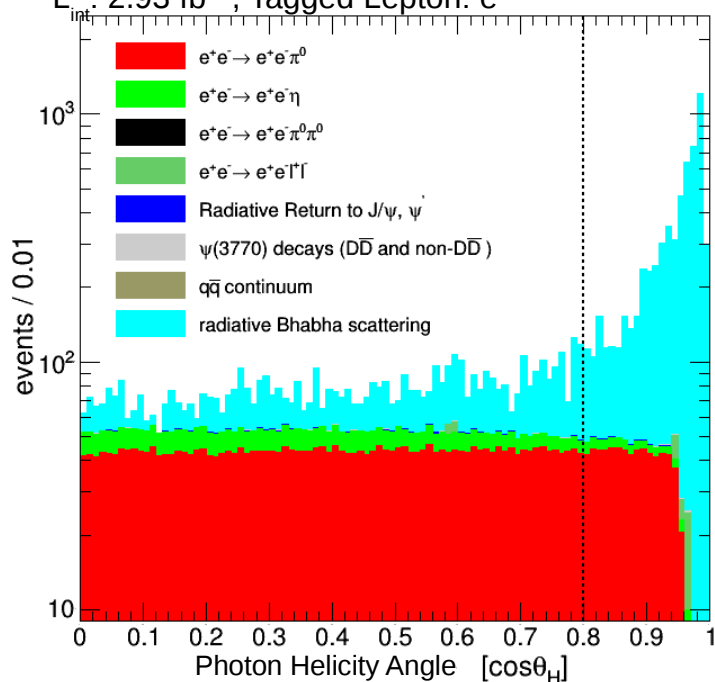# Space-like π^0 Transition Form Factor

JG|U

Event selection:
- Exactly one lepton
- Two to four photons
- $\cos\theta_{untagged} < -0.99$

BESIII

BESIII Monte Carlo, $\Psi(3770)$
L_{int}: 2.93 fb^{-1}, Tagged Lepton: e$^+$

Legend:
- $e^+e^- \rightarrow e^+e^-\pi^0$
- $e^+e^- \rightarrow e^+e^-\eta$
- $e^+e^- \rightarrow e^+e^-\pi^0\pi^0$
- $e^+e^- \rightarrow e^+e^-l^+l^-$
- Radiative Return to J/ψ, ψ'
- $\psi(3770)$ decays ($D\bar{D}$ and non-$D\bar{D}$)
- $q\bar{q}$ continuum
- radiative Bhabha scattering

- Angle between γ in π^0 rest frame and π^0 in lab
- $\cos\theta_{Helicity} < 0.8$

- Radiative effects result in wrong Q^2
- Useful observable: $R_\gamma = \dfrac{\sqrt{s} - E^{CMS}_{e^\pm \pi^0} - p^{CMS}_{e^\pm \pi^0}}{\sqrt{s}}$
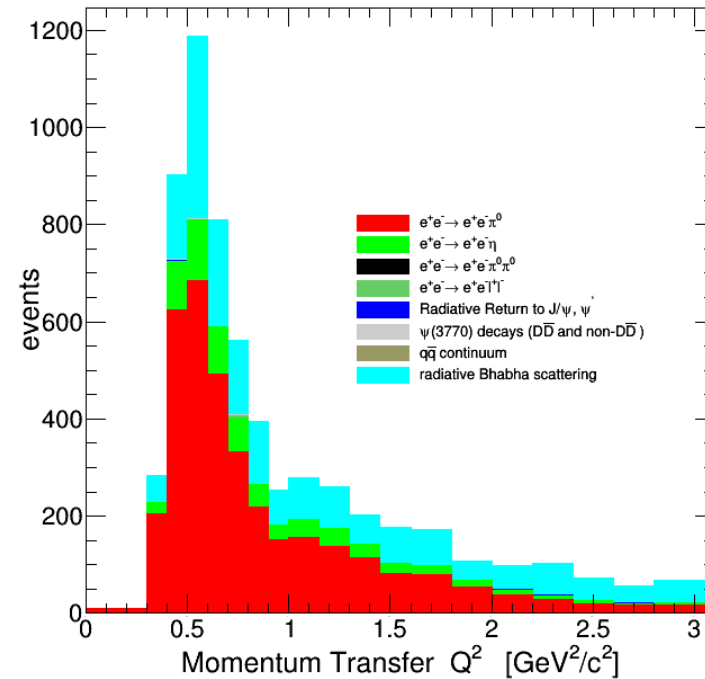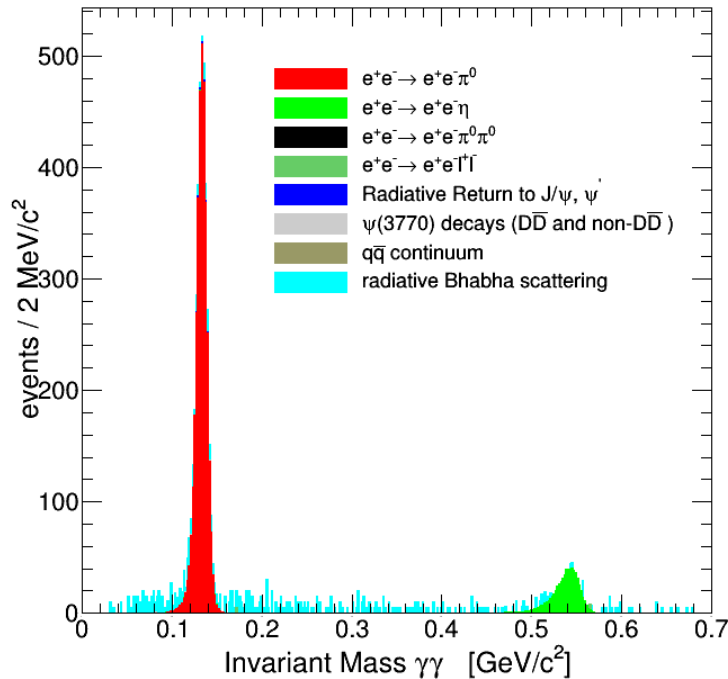- Reject events with $R_\gamma > 0.05$
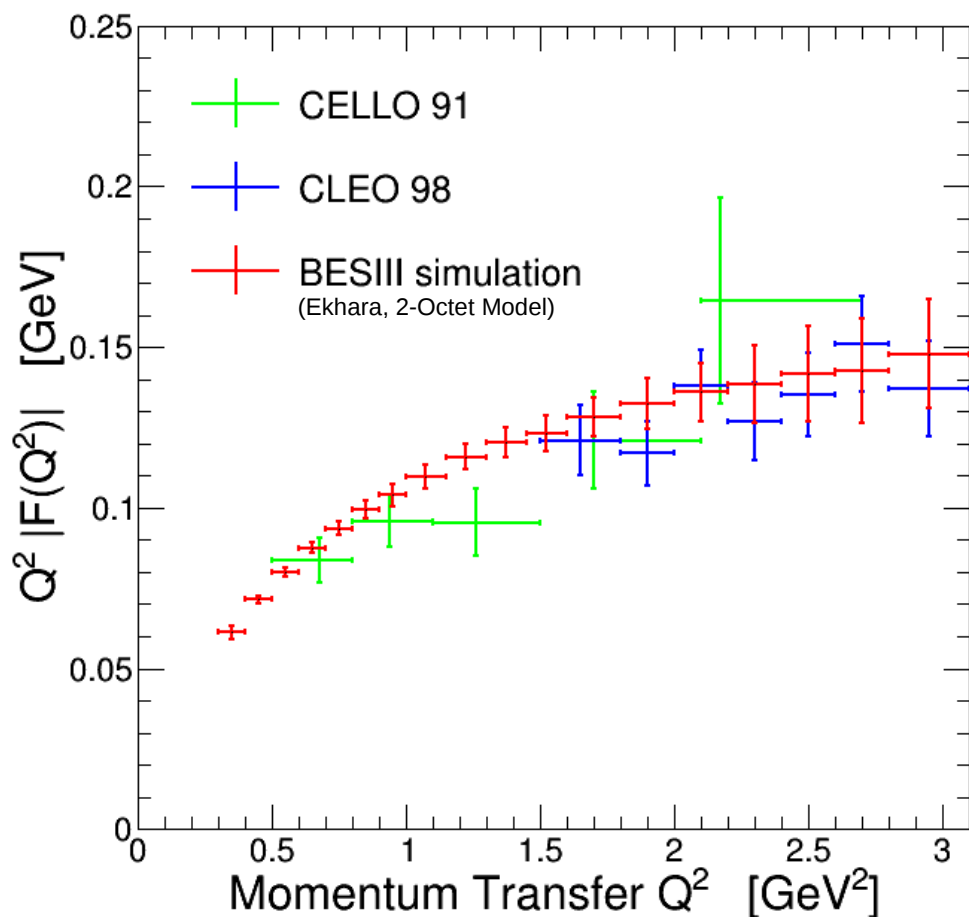
Space-like π^0 Transition Form Factor

BESIII Monte Carlo, $\Psi(3770)$
L_{int}: 2.93 fb^{-1} , Tagged Lepton: e$^+$

- Analysis useful for π^0 and η

- Monte Carlo description of background incomplete
  - Small angle Bhabha scattering

- Bkg subtr. by counting π^0 yield per Q^2 bin

- Divide out point-like cross section for $|F(Q^2)|^2$

Space-like π^0 Transition Form Factor

- 2.9 fb^{-1} at $\Psi(3770)$ analyzed

- Covering $0.3 \leq Q^2 [\text{GeV}^2] \leq 3.1$

- Statistical accuracy:
  - Competitive up to 3.1 GeV²
 - Unprecedented below 1.5 GeV²

Most relevant for a_μ^{hLbL}!

- Systematic Uncertainties
  - Dominated by background subtraction

- Radiative effects to be included
  - Based on Ekhara 3.0

Expecting the release of preliminary result any minute!

Double-tag measurements

- Measurement of $F_{\gamma^*\gamma^*\pi^0}(Q_1^2, Q_2^2)$ never done before!

  - Contains full information
  - model independent input

- BESIII collected > 10 fb^{-1} at 3.77 < √s [GeV] < 4.6

  - Double-tag measurement possible

    - Low statistics expected
    - 1st Step: Test TFF models
      - e.g. VMD vs. LMD+V
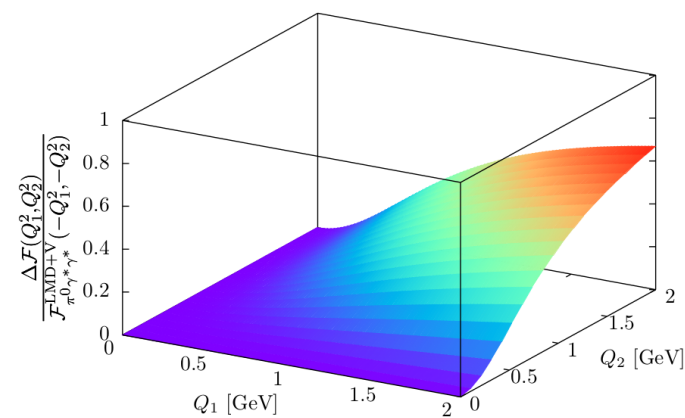
Calculations: A. Nyffeler
Phys.Rev. D94, 2016, 053006

Summary

- Two-photon physics program at BESIII to measure space-like meson TFF

    - Single-tag measurements for singly virtual TFF

        - π^0 TFF measured in 2.93 fb^{-1} at $\sqrt{s}$=3.773 GeV

            - 0.3 < Q² [GeV²] < 3.1

            - unprecedented statistical accuracy below Q² < 1.5 GeV²

            - Preliminary results awaiting release

        - Analysis of η, η', and $\pi^0\pi^0/\pi^+\pi^-$ ongoing

    - Double-tag measurements started $\gamma^*\gamma^* \rightarrow \pi^0$