News from BABAR

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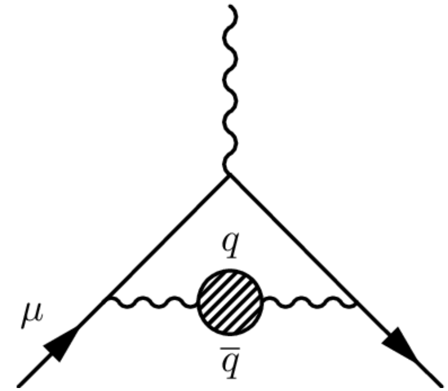
Outline of the talk

1. Reminder of BABAR's high-order radiation study [1]
2. New landscape of HVP evaluations [2]
3. Answers to raised questions
4. Status of the BABAR ongoing analysis



HVP
Hadronic Vacuum Polarisation

References:
[1] BABAR, Phys. Rev. D 108, L111103 (2023)
[2] Davier-Hoecker-Lutz-Malaescu-Zhang, arXiv:2312.02053

1. Reminder of the BABAR's High-Order Radiation Study (Ref. [1])

Use the full BABAR data sample (424.2 fb^{-1} [@Υ(4S)], 43.9 fb^{-1} [below Υ(4S)])

Compared with two MC samples Phokhara (full NLO) and AfkQED (NNLO+)

Same loose selection as the ongoing analysis of the $\mu\mu$ & $\pi\pi$ cross section measurement except for particle identification applied for this radiation study

Five kinematic fits performed for events with one or two hard photons in addition to the ISR photon

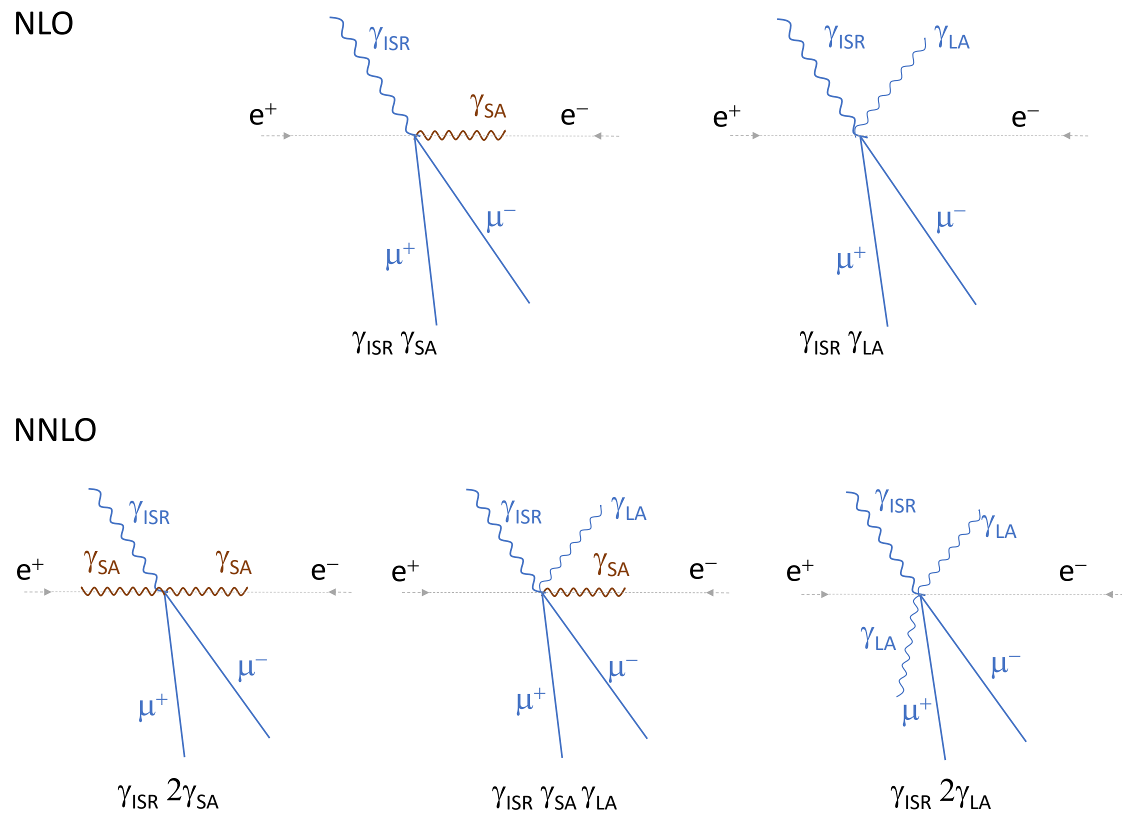
Measured relative fraction of each event category and compared with the MC predictions

1. Overview of Different Kinematic Fits

- Two NLO fits
  - Small Angle (SA) fit
  - Large Angle (LA) fit

- Three NNLO fits
  - 2SA fit results
  - SA+LA fit results
  - 2LA fit results

Collinear approximation for all SA-related fits.
Measured $E_{\gamma,\,LA}$>50 MeV for all LA-related fits



- Two tracks with opposite charges, each with
  - θ: 0.4–2.45 rad
  - p_T > 0.1 GeV/c
  - at least 15 hits in DCH
  - $doca_{xy}$ < 5mm, $|\Delta_z|$ < 6 cm
  - Particle identification applied

- ISR photon candidate:
  - θ: 0.35–2.4 rad
  - Largest E*, with E* > 4 GeV

1. BABAR Overall Results

TABLE I: Event fractions in data for the $\mu\mu$ and $\pi\pi$ processes in all fit categories. The numbers in parentheses represent uncertainties, where the first is statistical and the second systematic. The results, except for NNLO 2LA (which is not simulated by any generator currently available) are corrected using efficiencies that vary category-by-category between 99% and 72%, except for NLO FSR $\pi\pi$ (40%) and NNLO FSR $\pi\pi$ (22% due to BDT selection.)

Category	$\mu\mu$ $m_{\pi\pi} < 1.4\,\mathrm{GeV}/c^2$	$\pi\pi$ $0.6 < m_{\pi\pi} < 0.9\,\mathrm{GeV}/c^2$
LO	0.7716(4)(14)	0.7839(5)(12)
NLO SA-ISR	0.1469(3)(36)	0.1401(2)(16)
NLO LA-ISR	0.0340(2)(9)	0.0338(2)(9)
NLO ISR	0.1809(4)(35)	0.1739(3)(20)
NLO FSR	0.0137(2)(7)	0.0100(1)(16)
NNLO ISR [a]	0.0309(2)(38)	0.0310(2)(39)
NNLO FSR [b]	0.00275(6)(9)	0.00194(12)(50)
NNLO 2LA [c]	0.00103(3)(1)	0.00066(4)(4)

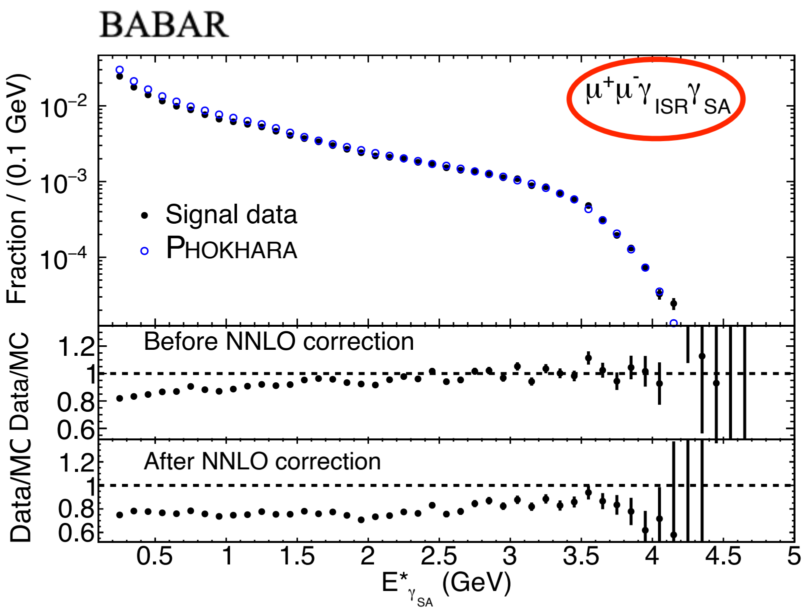
[a] NNLO ISR = 2SA-ISR or SA-ISR + LA-ISR
[b] NNLO FSR = SA-ISR + LA-FSR
[c] NNLO 2LA = 2LA-ISR, LA-ISR + LA-FSR or 2LA-FSR

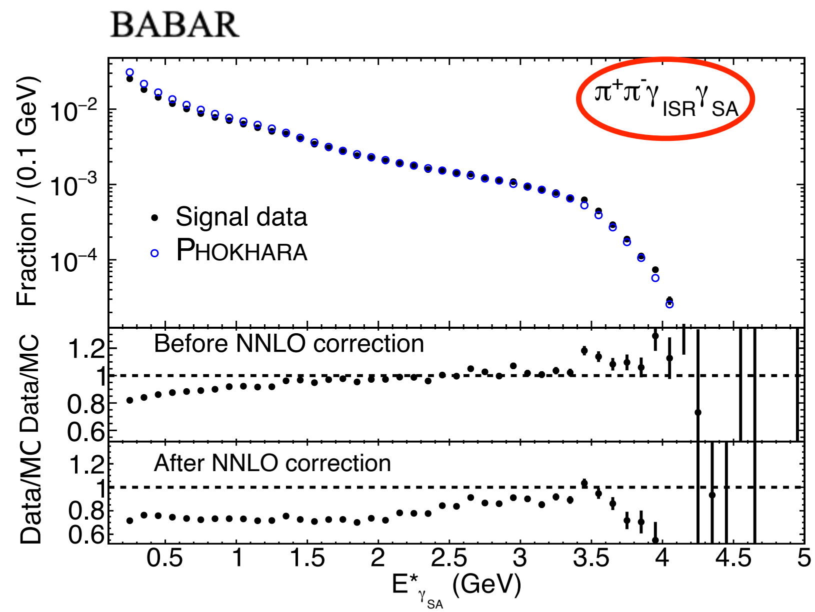
LA categories are separated into LA-ISR and FSR (final state radiation) with template fits

Systematic uncertainties include those from efficiency corrections, background subtraction and feed-through corrections with the latter two being the dominant contributions

BABAR's key result No. 1: NNLO radiation observed with a fraction ~3.5%

1. Energy spectra of NLO SA Photons





$E^*_{\gamma SA}$ data/Phokhara ratios become flatter (bottom panel) in both $\mu\mu$ & $\pi\pi$ processes after subtracting NNLO contributions to NLO data spectra

Phokhara excess in NLO with 2 hard photons remains after the NNLO correction

➔ BABAR's key result No. 2: Phokhara prediction for small angle ISR photons at NLO order is too high by ~25%

A recent Belle II paper (arXiv:404.04915) on the 3π channel confirms BABAR's findings and assigned 1.2% uncertainty

2. Overview of Ref. [2]

Checked possible consequences of the BABAR's findings on BABAR, KLOE, BESIII

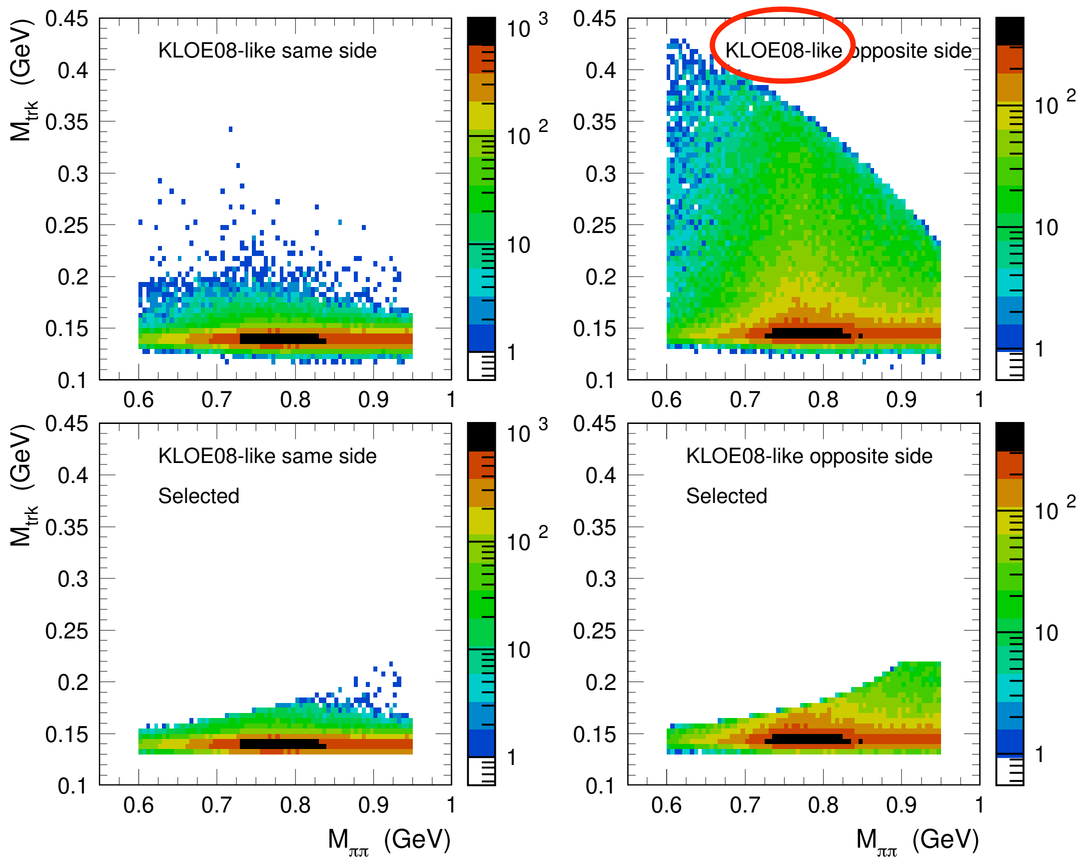
Performed a new combination including CMD-3, SND20, and updated BESIII (error matrix)

Showed the new landscape of HVP predictions including tau data

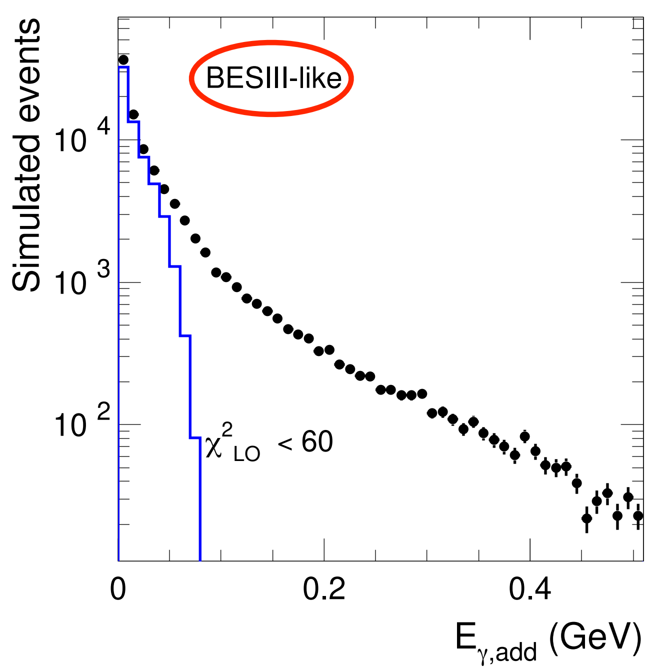
2. Consequences of BABAR's Results (Ref. [2])

- BABAR analysis performed with loose selections, efficiencies obtained with data
  - ➔ The effect of missing NNLO and NLO excess in Phokhara on acceptance (0.03±0.01)% well below the quoted syst. uncertainty
- Using fast simulations, studied possible effects for the KLOE and BESIII analyses
  - ➔ Found larger effects beyond the quoted uncertainty of 0.5%
  - ➔ Actual size of the effects can only be accessed by the KLOE and BESIII themselves

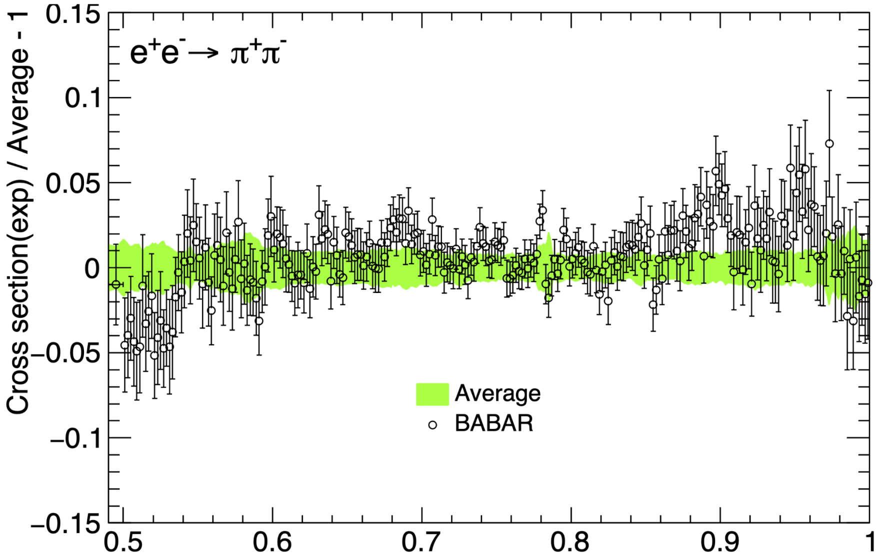
Left/right: additional γ is on the same/opposite side of ISR γ

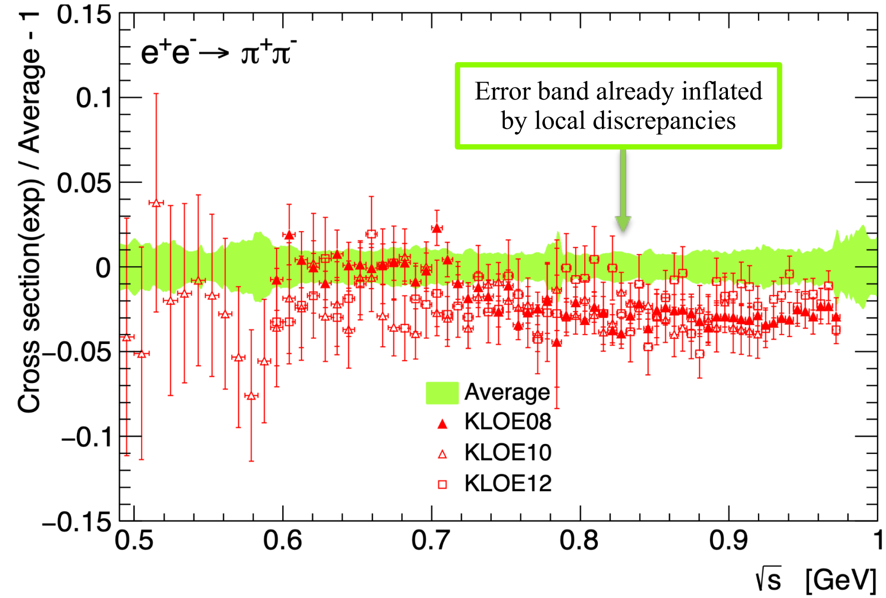


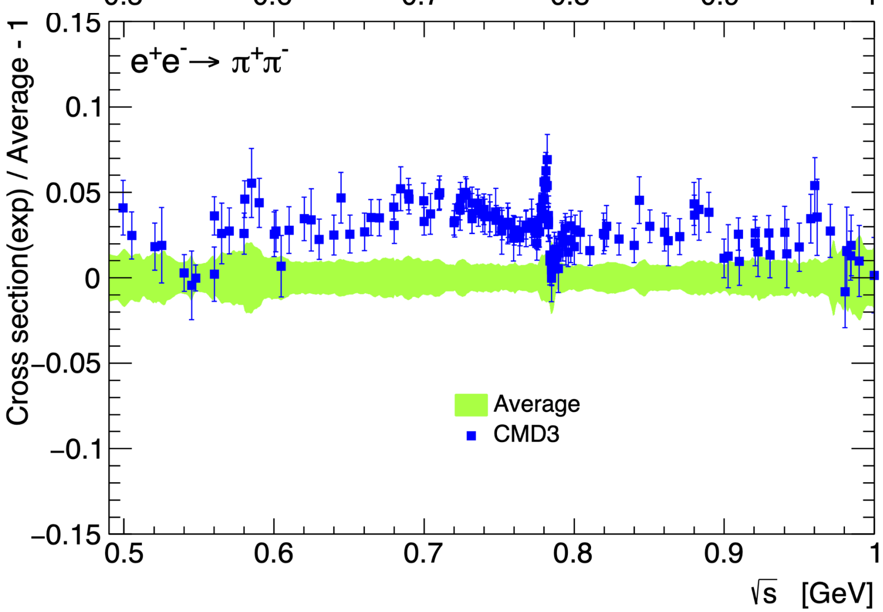
KLOE and BESIII do not study additional photons and rely on Phokhara for radiative corrections



2. New Combination (Ref. [2])



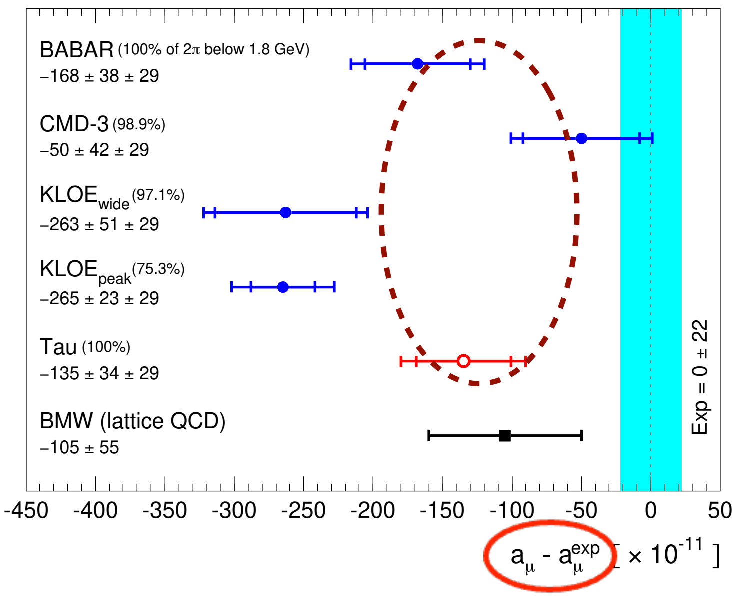




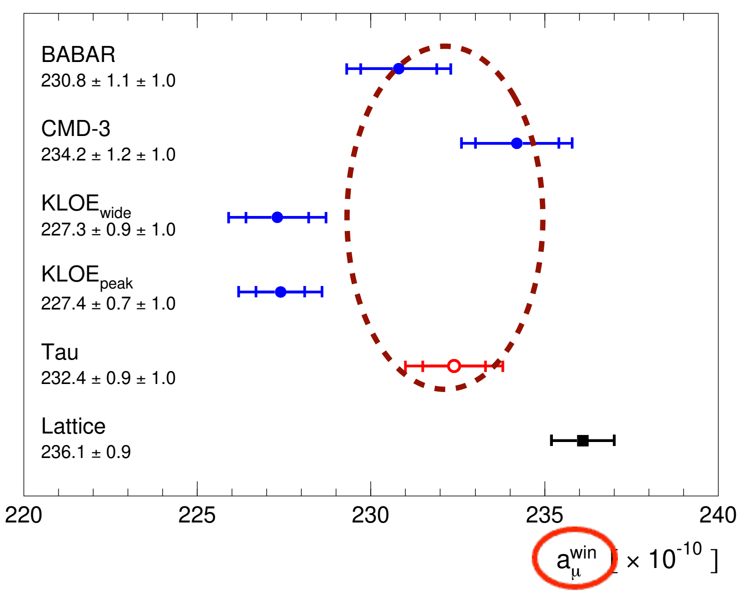
➔ The discrepancy among the three most precise measurements BABAR, CMD-3 and KLOE goes well beyond the uncertainties

Quantitative comparisons available on page 16

2. The New Landscape of the HVP Evaluations (Ref. [2])



- ➢ The τ-based HVP contribution close to BABAR and CMD-3
- ➢ BABAR+CMD-3+τ compatible with BMW; 2.5σ below the measurement ↔ 5.1σ (with KLOE but w/o CMD-3, τ)
- ➢ BABAR+CMD-3+τ+BMW 2.8σ below
- ➢ KLOE is 4.2σ (wide) or 6.2σ (peak) below



For a_μ^{win}

- ➢ BABAR+CMD-3+τ are 2.9σ below lattice ↔ 4.2σ (with KLOE but w/o CMD-3, τ, see page 18)
- ➢ KLOE is 5.4σ (wide) or 5.8σ (peak) below lattice

3. Question No. 1

Question: The muon **asymmetry** for the BABAR is **inconsistent** with prediction **at 2-3% level** as was shown in arxiv:1508.04008. This means that the number of muons is not well described at this level. And looks like according to the paper itself at least half of this inconsistency comes from detector effects. Can it be clarified how this inconsistency an systematic error is solved in the pion form factor measurement?

Answer: The inconsistency you refer to in our measurement of ISR-FSR interference (arXiv:1508.04008) is observed for **large $\mu\mu$ masses (2-4 GeV)** as a difference between our measurement and the AfkQed prediction. At these masses the asymmetry is large (~ −0.50). In the range of interest for the pion form factor **(0−1 GeV)** the asymmetry is one order of magnitude smaller and the difference with AfkQed is **(0.50 ± 0.33)%, consistent with 0**.

We have studied extensively sources of experimental bias. The main charge-asymmetric detector effects are 2-track overlap in the drift chamber and track-ISR photon overlap in the calorimeter. The first source affects the measurement at low mass (0−1.5 GeV), while the second operates at large mass (>5.5 GeV). Our interference observable A0, the slope in cos(phi*) of the asymmetry as defined p6-7, and obtained from a linear fit, is very robust against these biases. We also have the test with J/psi events (right in the mass range where the difference is the largest) yielding a value of A0=(0.3 ± 1.6)%, consistent with 0, as expected for a purely ISR-produced J/psi at Upsilon(4S) energies. The observed difference could originate from the fact that in AfkQed only the LO interference is taken into account. Using Phokhara we did find a 1−2% effect from NLO contributions.

Thus **we do not see reasons to expect significant effects on the pion cross section BABAR measurement**.

3. Question No. 2

Question: Fig.2 from arXiv:2308.05233v1 shows that consistency between simulation and data on the **polar angle** distribution of **additional photons** is quite pure at level **5-10%**. Probably it was shown somewhere and I just can't find it now, but how this **comparison** look like on the polar angle distribution **for the first ISR photon**? Can please point where such plots were shown with data/MC comparison (and which known corrections should be applied in addition here from efficiency corrections) for the polar angle of ISR photon and as well for the polar angle of Mpipi/Mmumu system, separately for 2pi and 2mu? (both polar angle distribution for photons and the charged tracks system is interesting to see as selection cuts are applied on all of them).

Answer: The 5-10% effect is due to the slightly worse **resolution tails** in data than in MC as shown in Fig. 5 of arXiv:2308.05233v2. This angular distribution of the additional photon is derived using the energy-momentum conservation and it has nothing to do with the primary ISR photon which is directly measured in the acceptance of the detector.

Comparison plots (Figs. 29, 31) are **available for muons** in arXiv:1205.2228. We also have the cos(theta*) distributions for both muons and pions. **These plots will be provided for the current analysis**. **Any ISR photon inefficiency bias with respect to the MC as a function of angle and energy anyway cancels in the pipi cross section**.

3. Question No. 3

Question: According to the arXiv:1205.2228v1, the additional **corrections of 2%** level are applied on the invariant mass spectra according to Phokhara prediction as relative to **AfkQED**(Fig.28). According to the 2312.02053, the AfkQED better describes the data. Can it be clarified, should this correction be reverted back? And which systematics uncertainty comes from this AfkQED/Phokhara difference for this correction, knowing now that both generators are incomplete in precision?

Answer: This is an interesting question. In the 2009 BABAR analysis reported in detail in arXiv:1205.2228 the AfkQed event generator was used for computing the acceptance. However we realized that the **limitations of collinear additional ISR and the cut on the mass of the (pi pi/mu mu)-ISR photon system at 8 GeV** introduced a systematic bias that could be corrected with Phokhara without these problems. Indeed it resulted in a **2% correction** applied to the mu mu or pi pi acceptance, however **canceling in the ratio used to derive the pi pi cross section**. Thus this 2% correction only affected the mu mu cross section and the corresponding QED test.

In our recent study of radiative processes arXiv:2308.05233v2 we concluded that AfkQed was better than Phokhara to describe our measured NLO and NNLO hard-photon fractions. However the collinear and hard cut-off limitations of AfkQed remains and consequently **Phokhara remains our best generator to compute acceptance**. The biases induced by the missing NNLO and/or incorrect NLO have been studied and it was shown that they have an effect on the mu mu cross section measurement less than 1 per mil. The effect on the pi pi cross section, taken from the pi pi/mu mu ratio, is even smaller and negligible (see appendix F).

4. Status of the BABAR Cross-Section Measurement

- Based on full data sample around $\Upsilon(4S)$ as the high-order radiation study
  - 424.2 fb^{-1} [@$\Upsilon(4S)$], 43.9 fb^{-1} [below $\Upsilon(4S)$]

- $\pi\pi/\mu\mu$/KK separation relies on template fits of $\cos(\theta^*)$ distributions (instead of particle identification)
  - Closure test of the fits performed
  - Each fitted data spectrum is **blinded** by a random normalisation factor
  - Treatment of the $ee\gamma$ background improved

- Ongoing studies
  - χ^2 selection efficiency
  - Trigger efficiency correction with the normalisation **blinded**
  - Track efficiency correction with the normalisation **blinded**
  - Unfolding of the fitted mass spectrum to true mass spectrum

- Expected time scale: end of the year or early next year

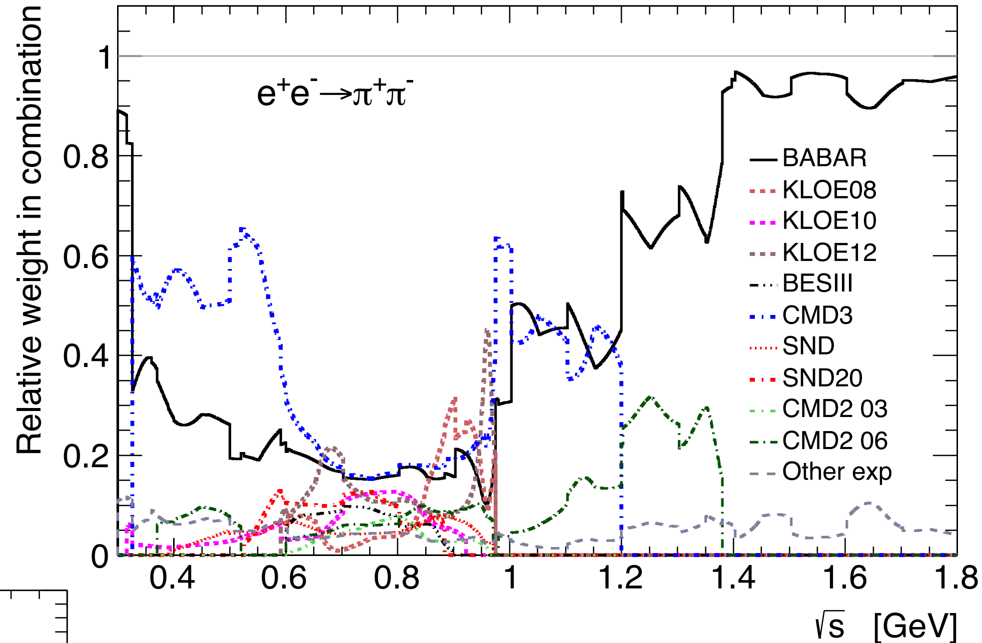
Additional Slides

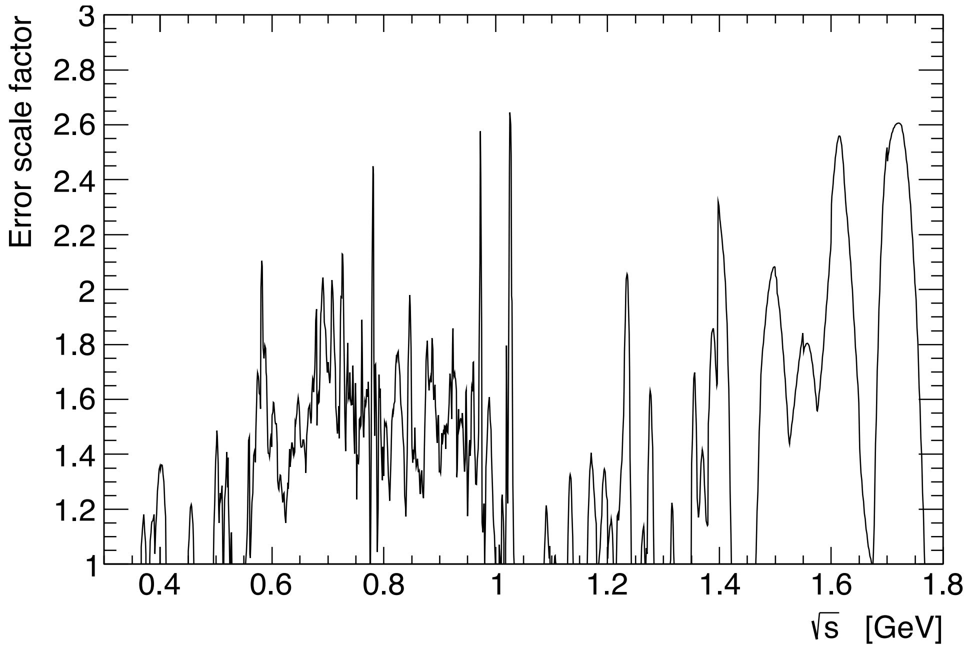
Additional reference:

[3] Davier et al., arXiv:2308.04221 (to appear in PRD)

Relative Weights and Local Discrepancy (Ref. [2])

BABAR, CMD-3, KLOE have Largest weights depending on mass regions

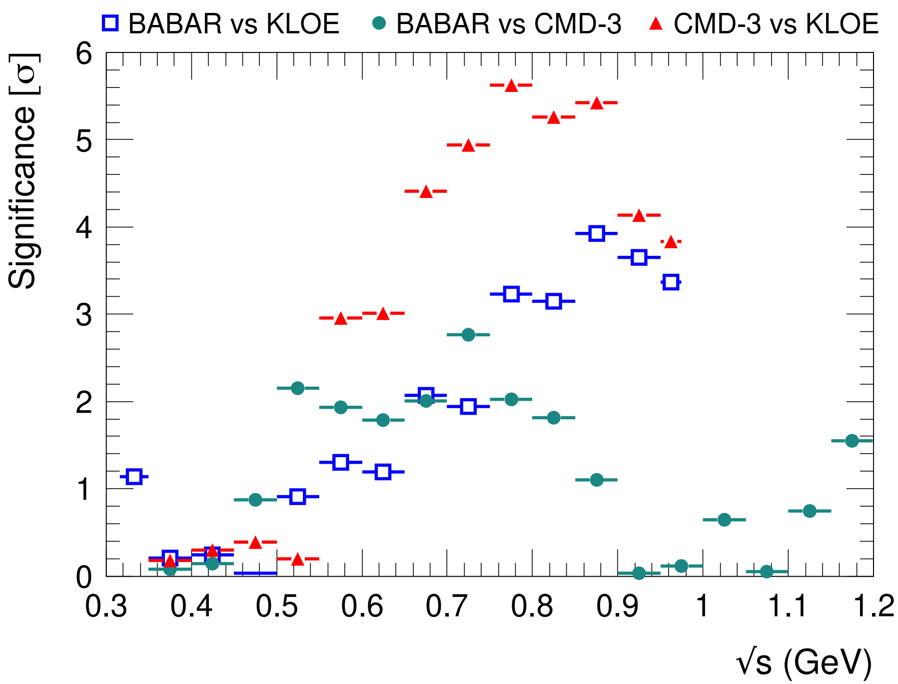


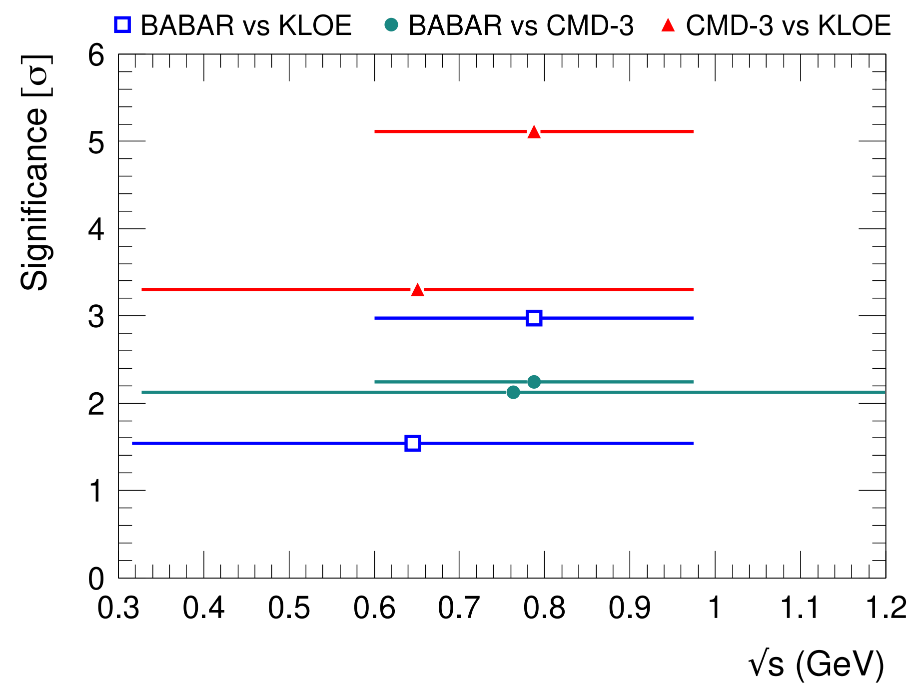


Local error scale factors are large in some of the mass regions despite large numbers of degree of freedom

Tensions Among Most Precise Measurements (Ref. [2])

Ref. [2]





Discrepancy between CMD-3 and KLOE over 5σ in the ρ mass peak region!

BABAR and CMD-3 in better agreement, below 3σ

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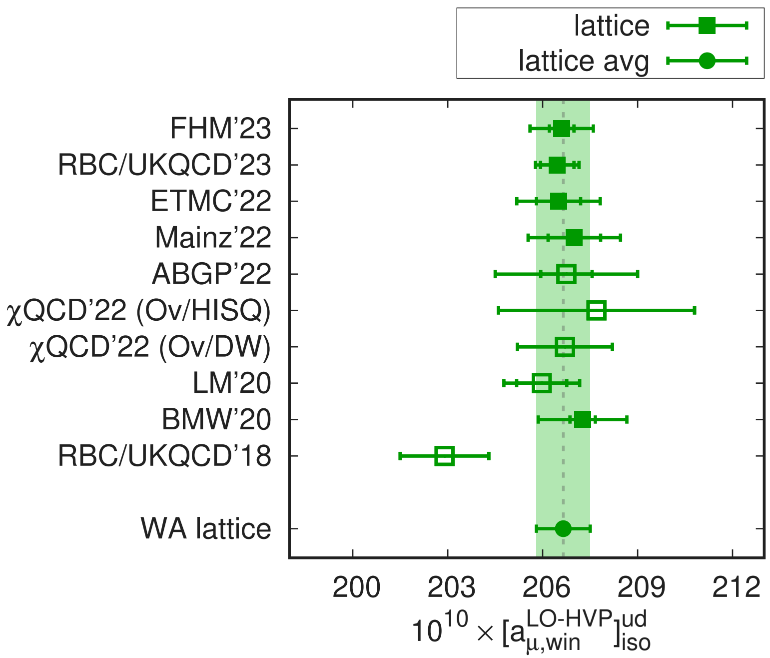
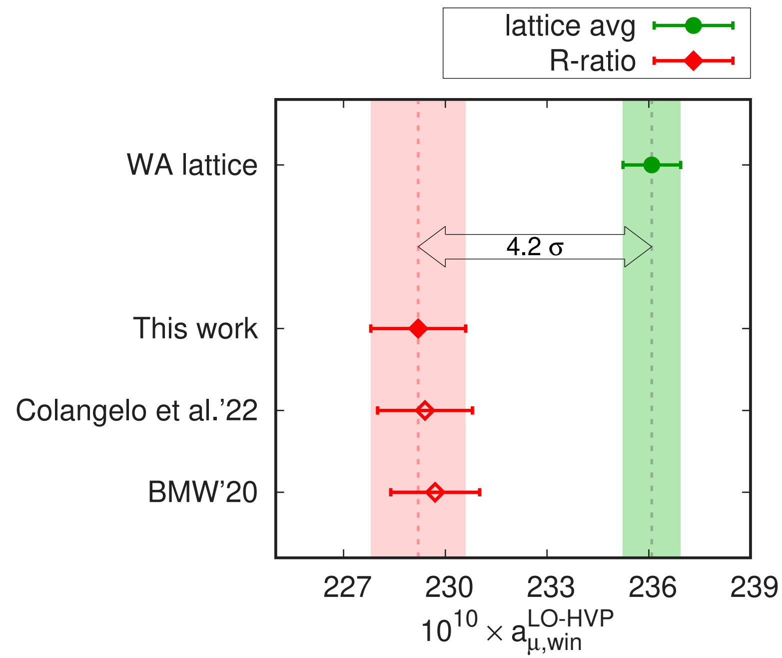
Comparing Lattice QCD and Data-Driven Results (Ref. [3])

- Joint project between DHMZ and BMW
- Motivated to understand the difference between lattice QCD and data-driven results
- Considered three observables a_μ, a_μ^{win}, and running α
- Studied scaling factors in different energy regions
- Proposed possible extension of the methods and observables (including its limit)

Motivation (Ref. [3])





In the intermediate window, there are several consistent calculations

Larger tension lattice vs data-driven predictions in $a_{\mu,\text{win}}$ than in a_μ to be understood

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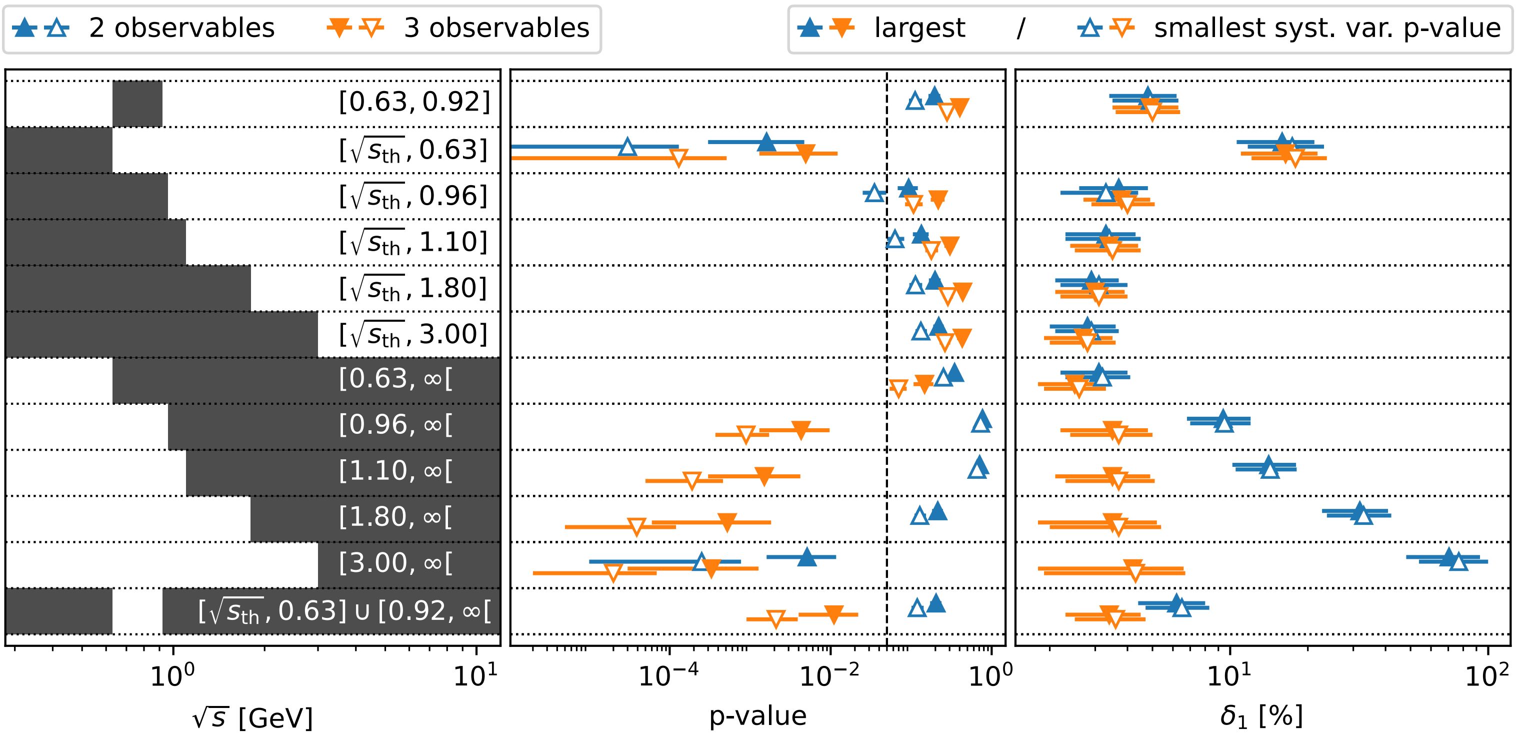
Scaling Corrections in Different Energy Regions (Ref. [3])



A few percent of corrections would be sufficient to bring data-driven results in agreement with lattice results

The corrections are however far beyond the quoted uncertainty of each e+e− measurement

Figs. 2 & 5 from Ref. [2]

In the published version, Fig. 2 → Fig. 3

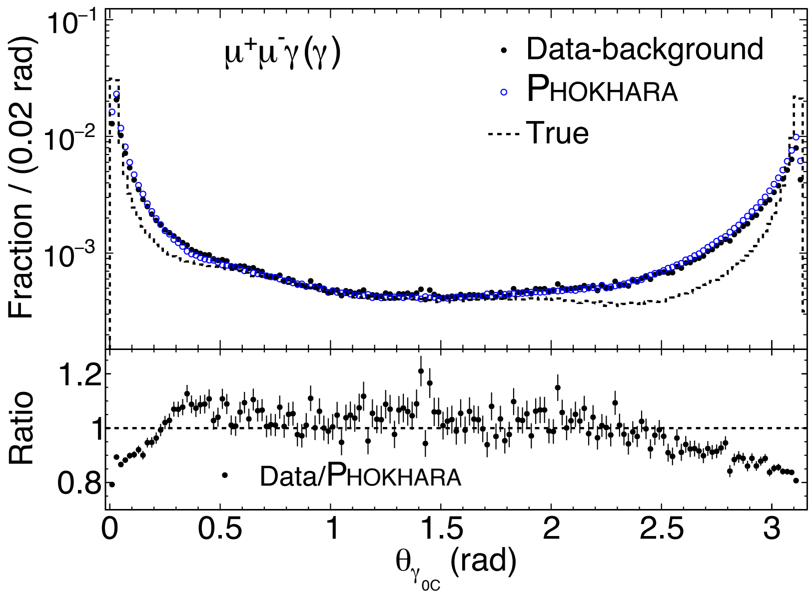
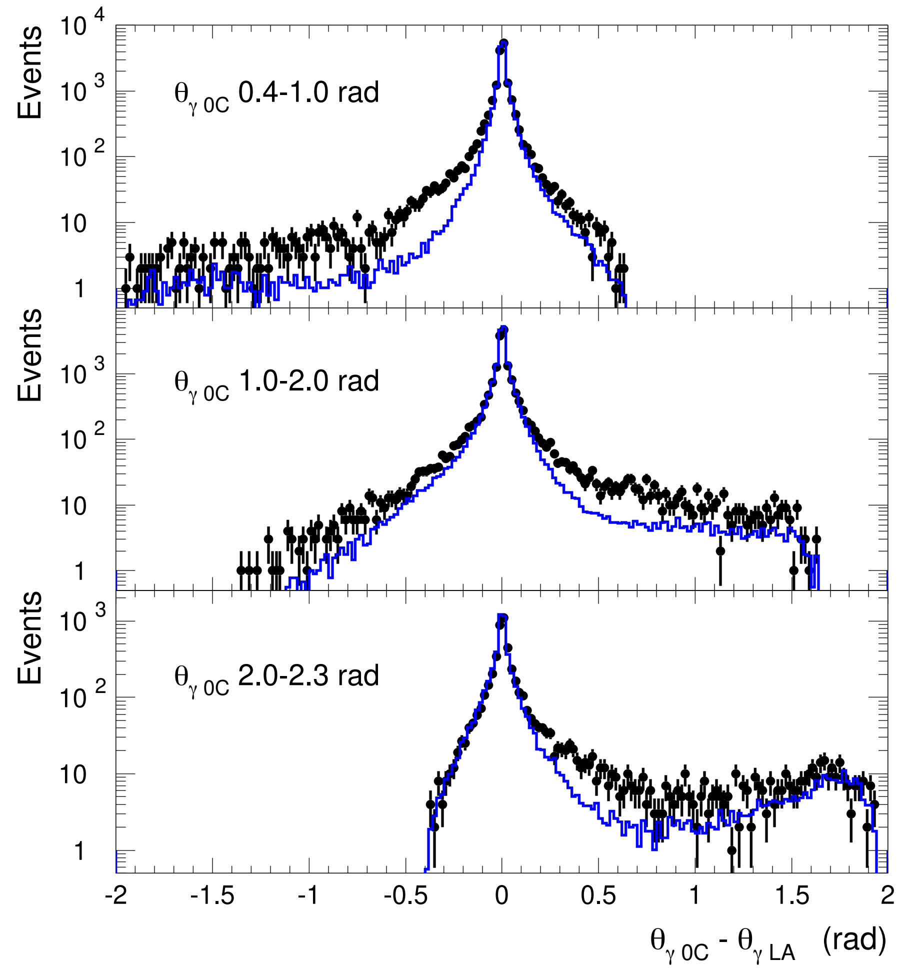


Fig. 5



The angle of the additional photon in the "0C" study is derived from energy-momentum conservation
Contrary to the main ISR photon that is directly detected within detector acceptance

The 5-10% data-MC difference is expected due to the larger data resolution tails

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Fig. 29 from arXiv:1205.2228

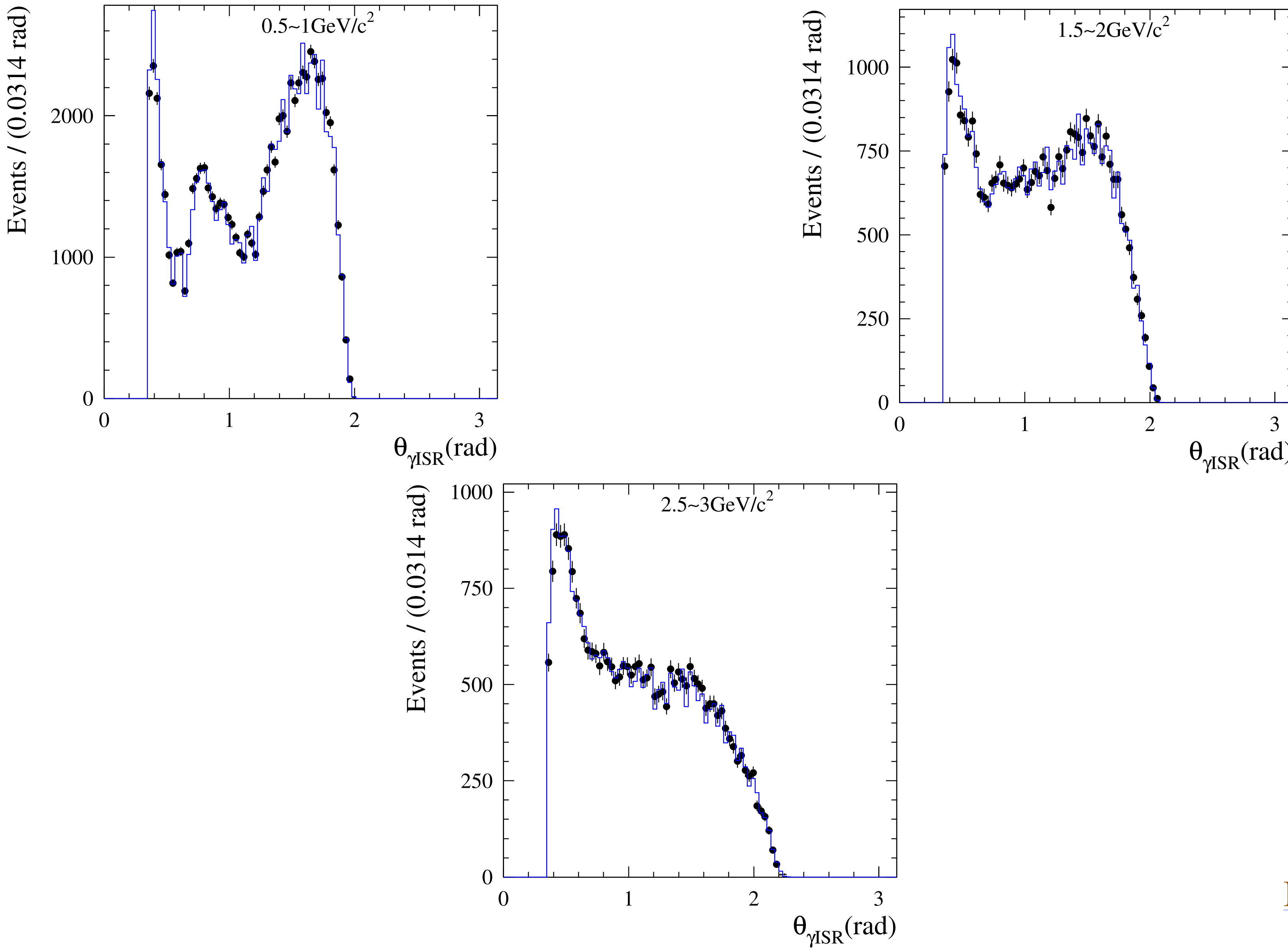

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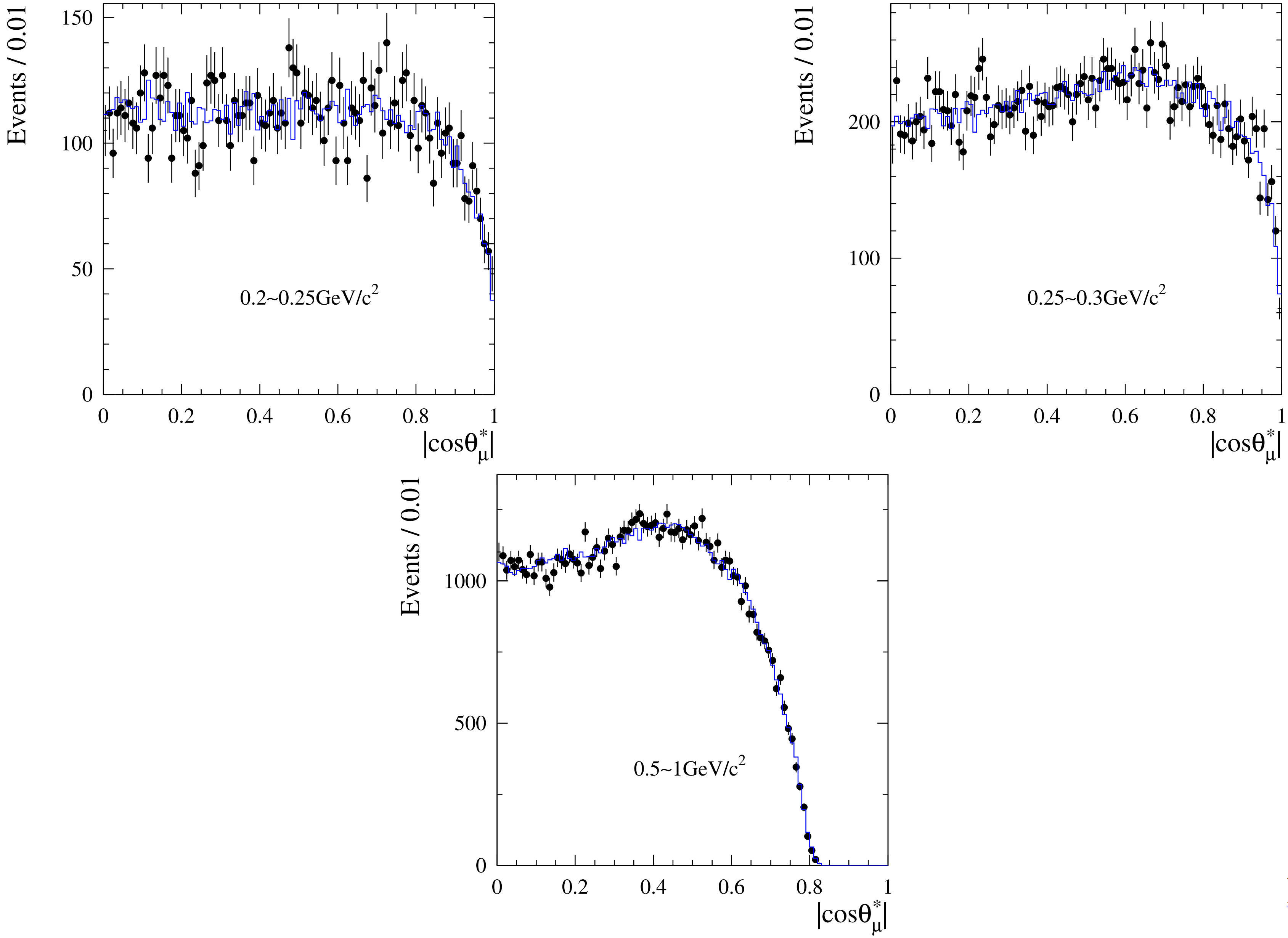
Fig. 31 from arXiv:1205.2228



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