Higher Order Radiative Corrections and Experimental Activities: Examples from BESIII

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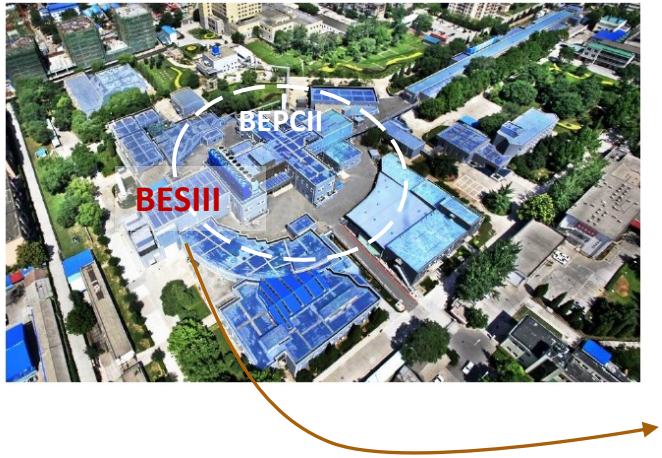
The BESIII Experiment



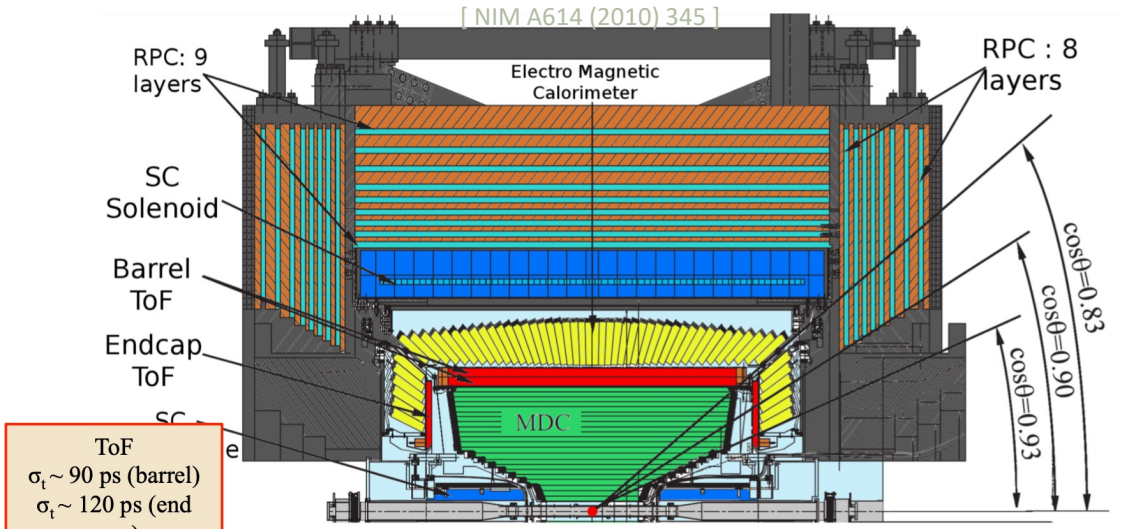
Located at the BEPCII collider (Beijing, China)

Symmetric e^+e^- beams

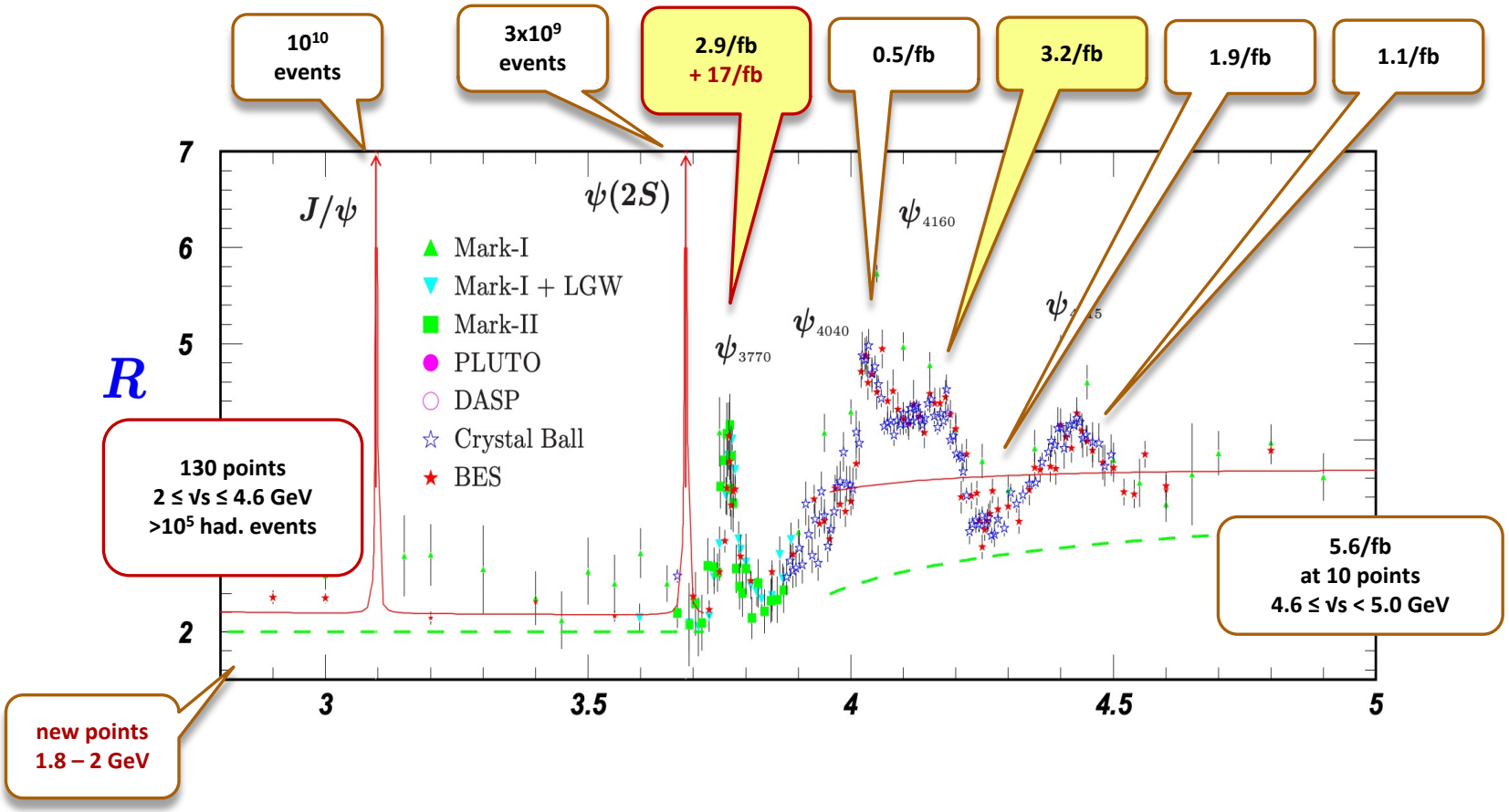
ECM between 1.8-5 GeV

Maximum luminosity: > 1 nb^{-1}/s

93% coverage of the solid angle



BESIII Contributions to HVP

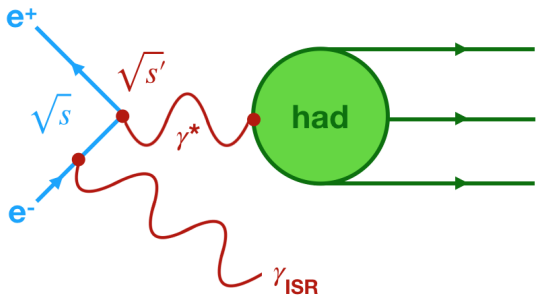


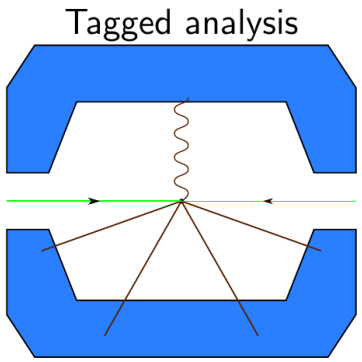
World largest τ-charm dataset in e^+e^- annihilation …

… and still growing

Pion Form Factor: impact of beyond NLO contributions

Measurement Strategy: Old and New





- Employ initial state radiation to access relevant energy range
- Radiated photon at large angle – kinematic threshold
- Two charged tracks, identified as pions (PID), originating from IP

Published: [Phys.Lett.B753 (2016) 629]

- Detect ISR photon
- 4C Kinematic Fit (ππγ)
- Phokhara **Accuracy: 0.9%**

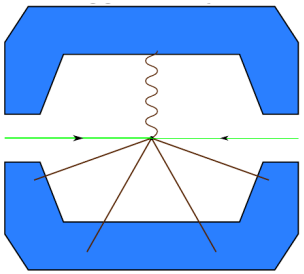
New:

Aiming to 0.7%

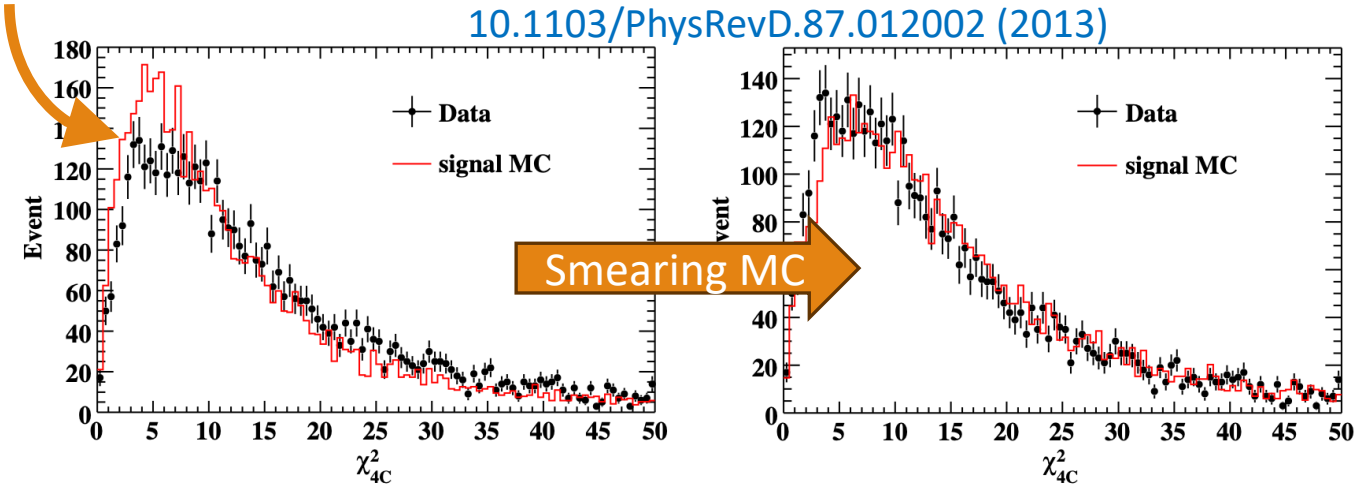
- Do not look for ISR photon
- 1C Kinematic Fit (ππγ)
- Babayaga@NLO (new), Phokhara

Kinematic Fit Corrections

- Small differences between detector response in data and MC expected
- Correction/calibration factor to take this into account
- Two components for kinematic fit:
  - Photon detection efficiency (only 4C)
  - Track momentum resolution → χ^2 (1C & 4C)



10.1103/PhysRevD.87.012002 (2013)



- Use control sample to correct for the difference

Photon Detection Efficiency

Using radiative **ee → μμ events**:

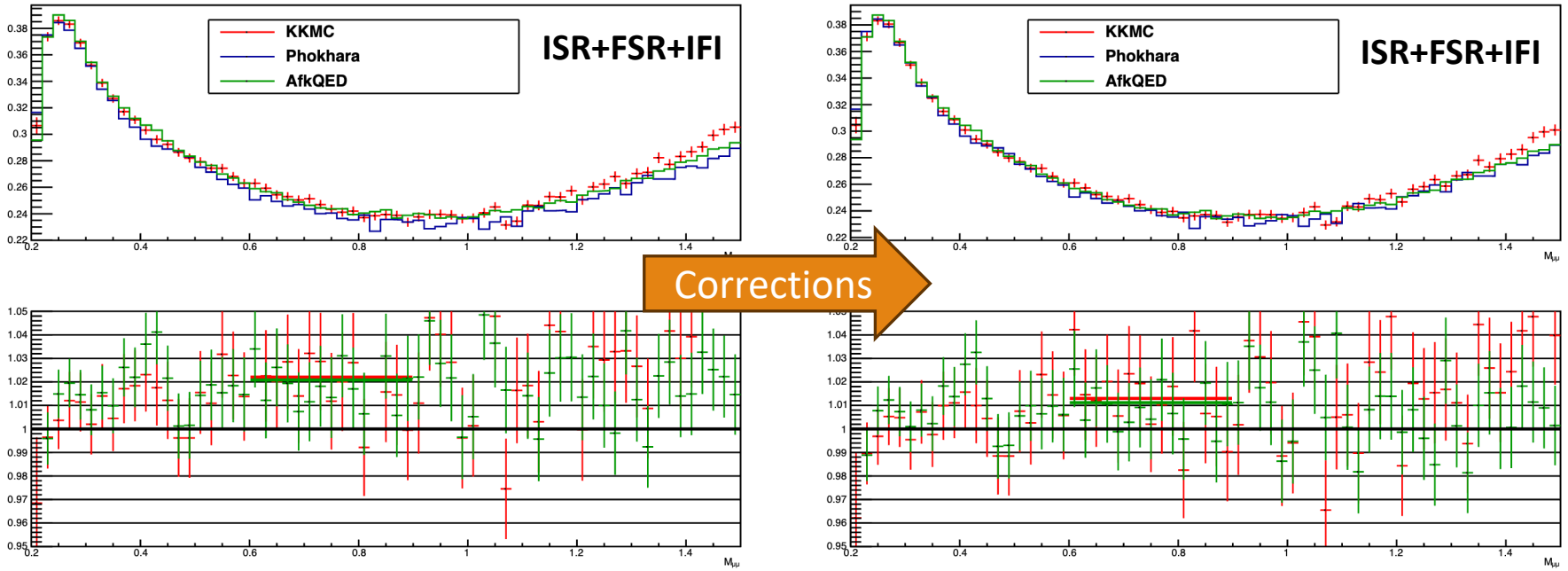
- Perform **1C Kinematic fit** (**photon** momentum **prediction**, $\chi^2<10$)
- **Look for a photon** closing the kinematics (**4C** Kinematic fit)
- **Determine** efficiency (and relative **corrections**) for data and MC in bins of energy and polar angle

Such procedure corrects for differences in:

- Detection efficiency
- Resolution
- **Missing radiative corrections, as long as accepted by 1C**

Tested using KKMC/AfkQED as data and correcting Phokhara

Impact of Correction



Corrections have an impact on the agreement!

Discrepancy reduced from 2% to 1%

- Still **1% of higher order contributions lost** by kinematic fit

New inputs: Babayaga@NLO

New version of **Babayaga@NLO** provides **now full NLO + PS** matching for **μμγ/ππγ**:

- Full set of corrections, includes correctly VP
- **Can verify pion/muon differences**

Compare Phokhara 10.0 vs Babayaga@NLO (2026)

Generator settings:

- Ecm = 3.773 GeV
- Charged particles in [15°,165°]
- Photons in [0°,180°]
- Pion FF: Phokhara (“new GS” in Phokhara 10.0)
- VP: nsk (Babayaga), hadr5 (Phokhara)
- Unweighted events

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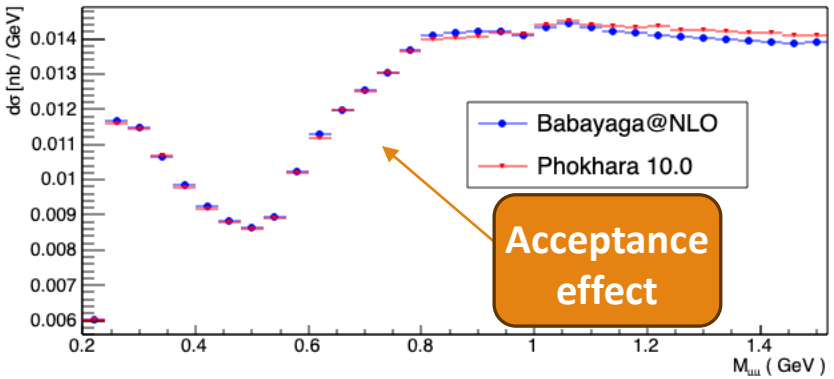
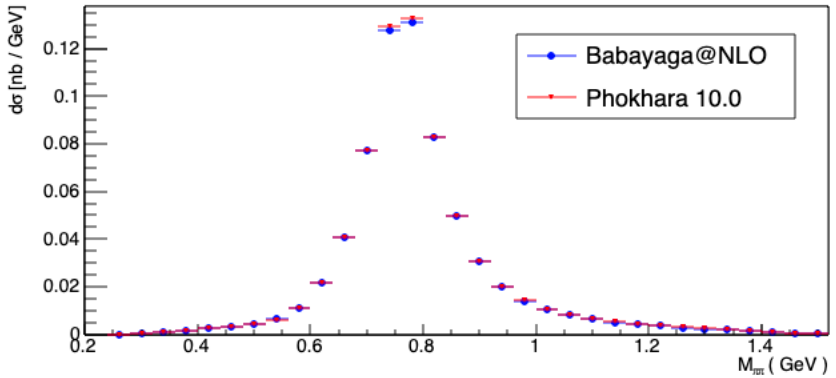
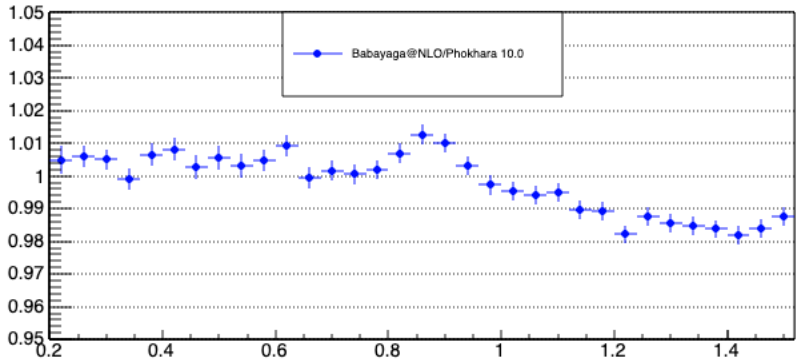
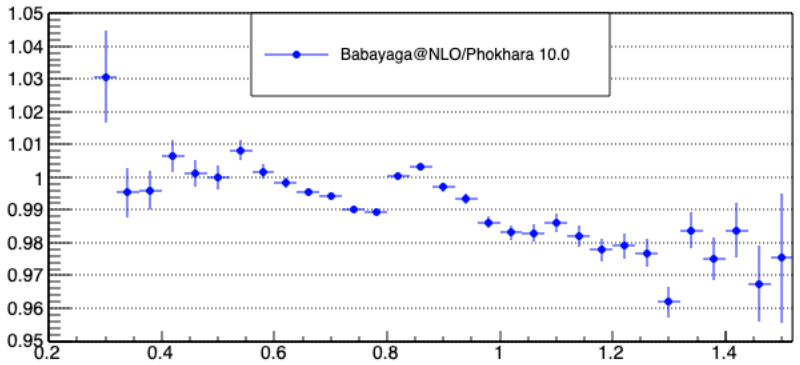
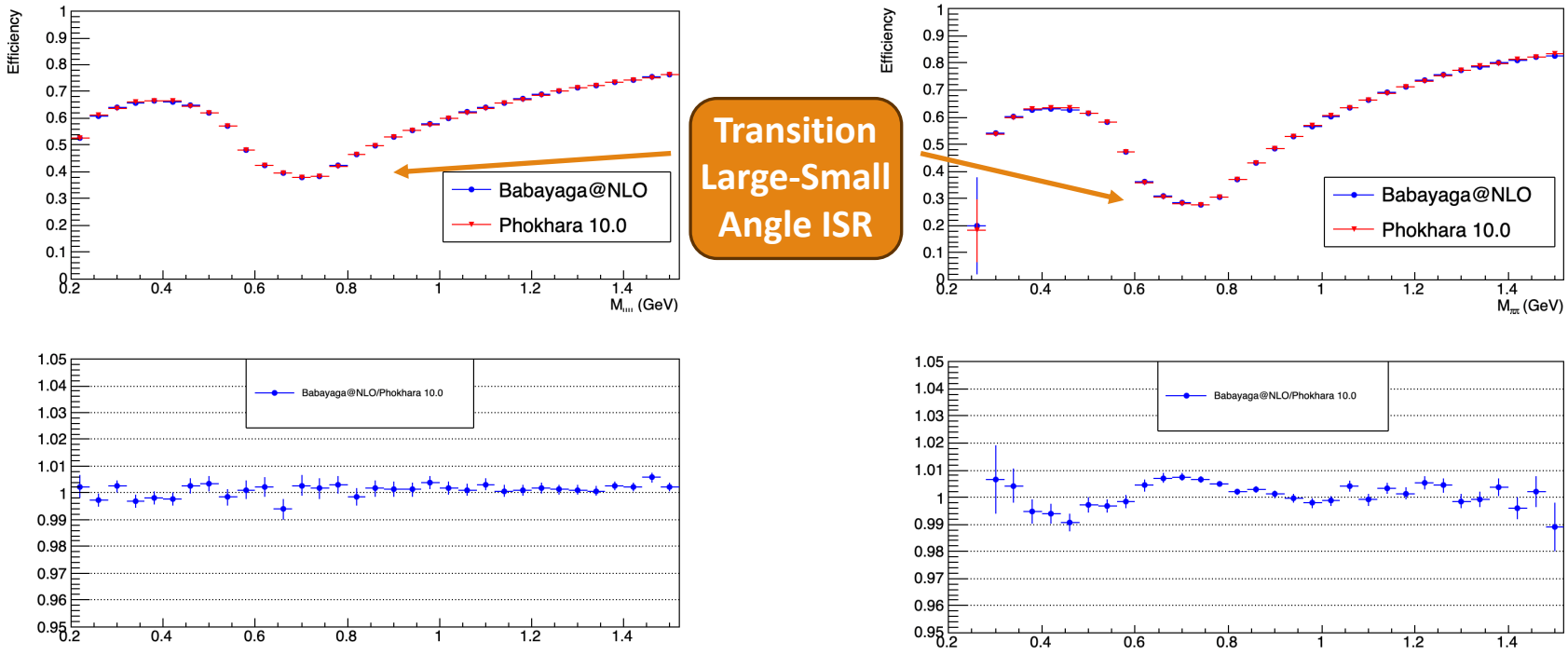






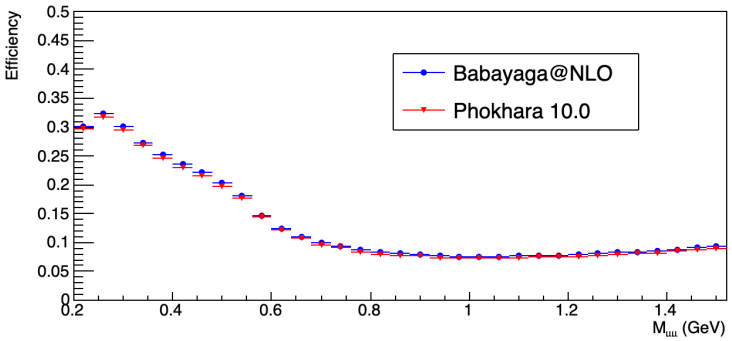


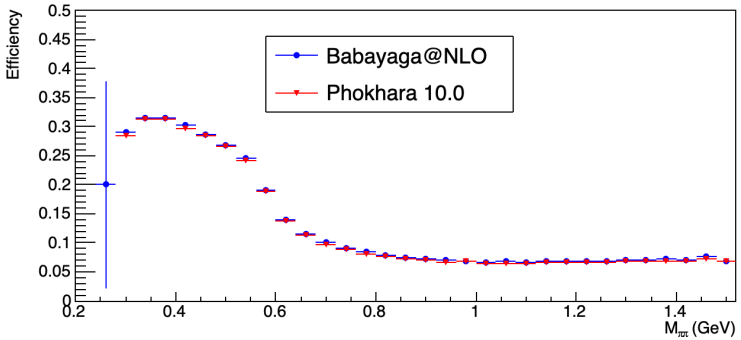
Geometrical Selection

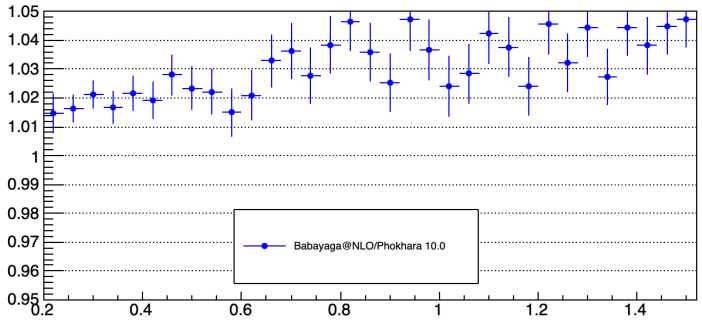


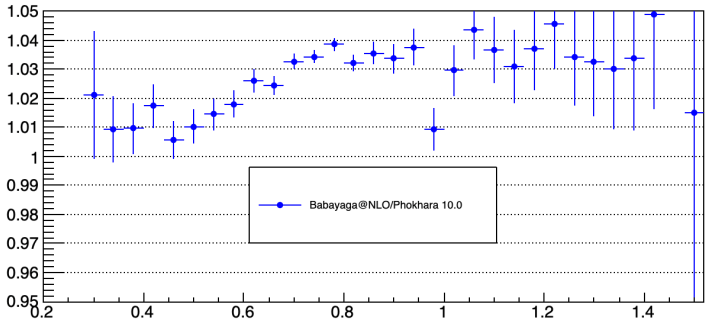
- Small differences in the cross section do not propagate to the efficiency (μμ)
  - Better than 0.5% agreement!
- A larger effect is observed for pion, still well within 1%

Introduce Kinematic Fit: 4C





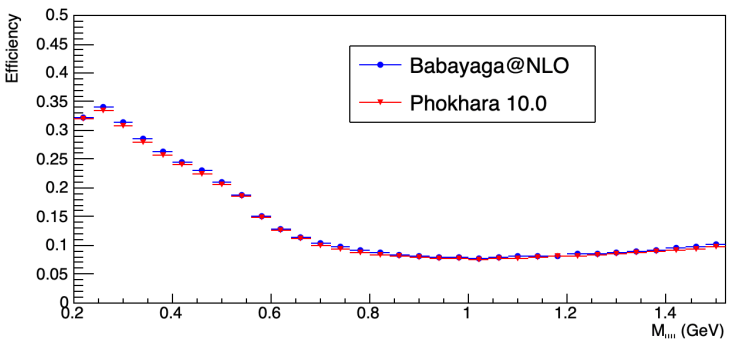




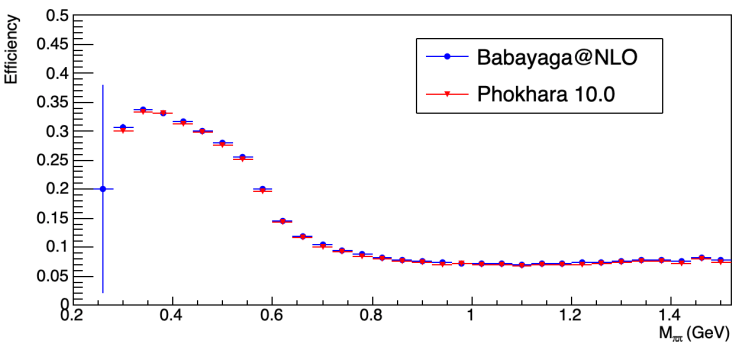
The imposition of the kinematic fit has a significant impact!

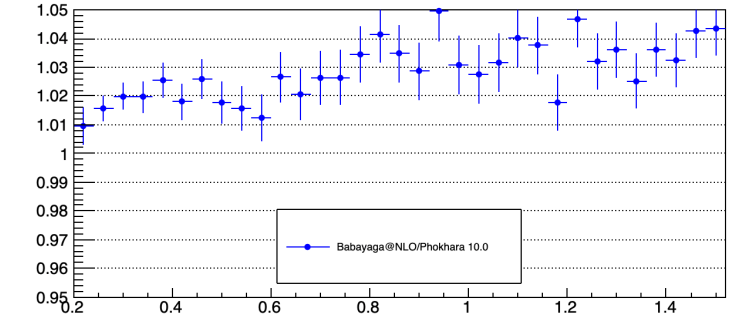
- Discrepancies in the 3% to 4% level close to rho, larger than expected
- Possible differences when approaching the threshold

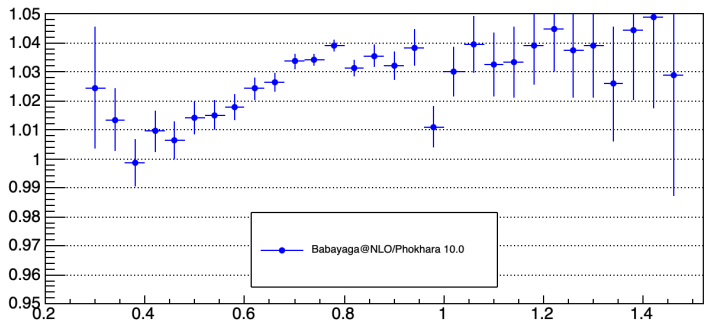
Photon Corrections: 1C Kin. Fit



$\chi^2 < 10$





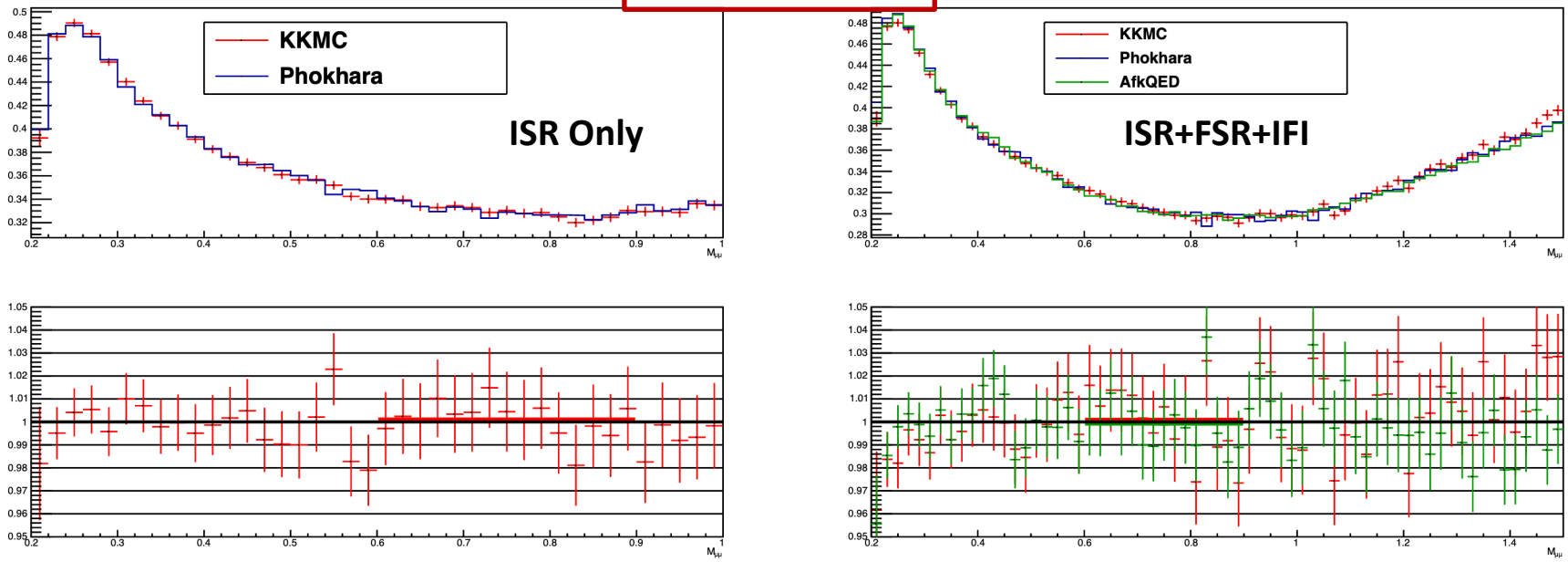


Large discrepancies are still observed!

- The tight selection does not allow to recover the missing contributions
- Different conclusion wrt to previous comparisons
  - ! Effect goes in the wrong direction, higher efficiency → smaller FF !

Reducing Constraints: 1C Fit

20 < θγ < 160



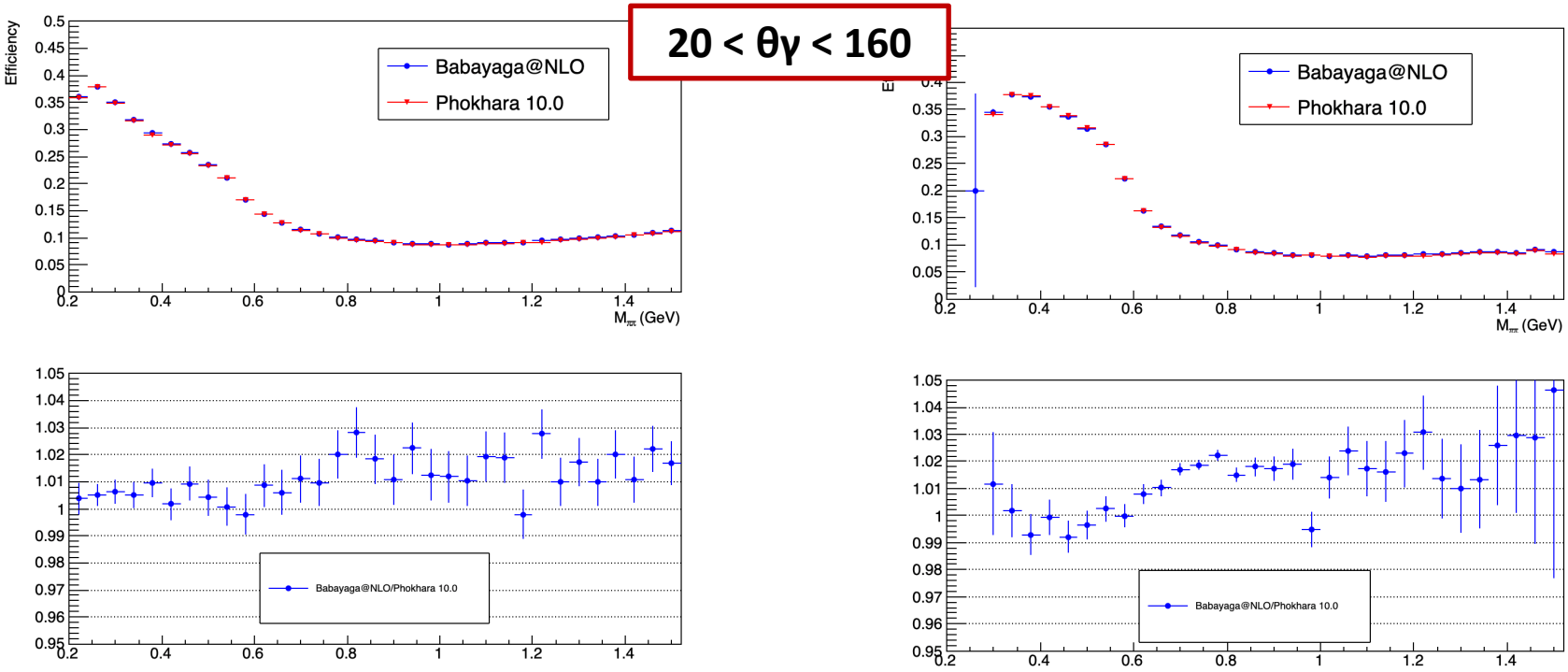
Reduce the sensitivity to additional radiation (new measurement)

Looser χ^2 cut with respect to photon efficiency (40 vs 10)

- **Good agreement** between Phokhara, KKMC, and AfkQED (at **0.1%**)

Allow for cross check and determination of eventual bias of published result

Reducing Constraints: 1C Fit



Different picture than estimated before!

- Differences at the 1-2% level
- Similar behavior for muons and pions, but unclear close to threshold
- Smaller than 4C fit, still a very useful cross checks

Summary

- **First measurement** of the pion FF by **BESIII** published in 2015
- Claimed **accuracy: 0.9%**
- Impact of Phokhara limitations on the result seems to be much larger than expected **O(3%)** introduced by the **4C Kinematic Fit**
- **New analysis** on going
  - **First result** based on about **6 fb^{-1}** of data **aiming at 0.7% accuracy** (soon)
  - **Final measurement** based on 20 fb^{-1} **with 0.5% precision** (normalization to muons)
- Looser constraint on kinematics (**1C Kinematic Fit**)
- Still, **we observe** differences at the 1-2% level between NLO and NLO+PS!

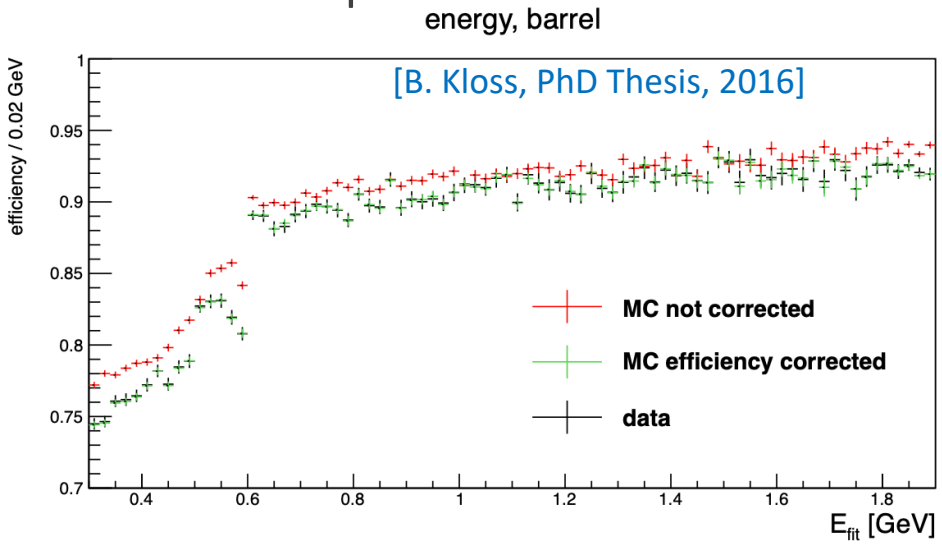
➢ **Looking forward to further MC generator advancements**: Phokhara (+YFS or @NNLO), …

Radiative Corrections and Photon Detection Efficiency

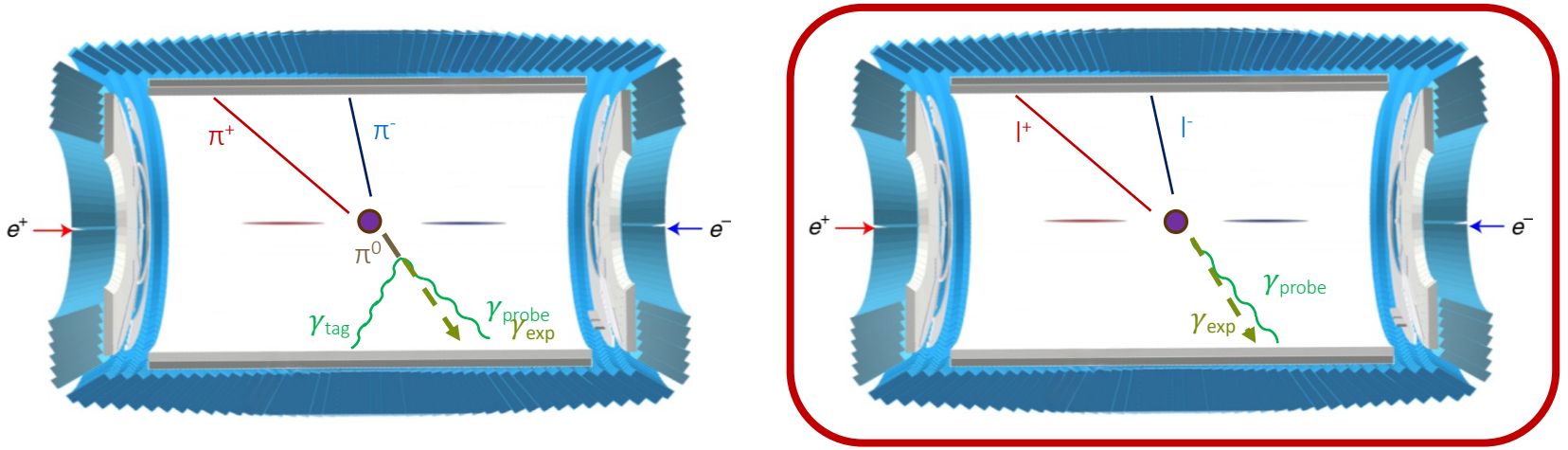
Why do we need corrections?

- **MC** simulations are **critical for precision** measurements:
  - Efficiency determination, background subtraction, radiative corrections, …
- Geant 4 is an excellent tool for particle interaction with matter, but
  - Small gaps/displacement not foreseen in detector design, electronics, aging, …

➢ **Need to** verify and (eventually) **account for differences** between real experiment and simulation



How to compute?



A **tag and probe strategy** is applied:

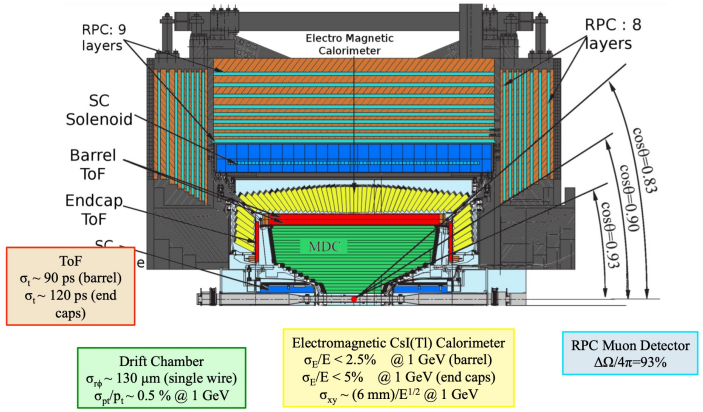
- Select processes for which the production of a photon can be tagged
- Use available information to **predict the photon** energy and direction
- **Look in the detector** for signals compatible with the predicted photon
- **Compare** how often the photon is detected in **data and MC** (efficiency)

In our work, we use $\mathbf{e^+ e^- \rightarrow l^+ l^- \gamma}$ events

Selection and Generators

Event Selection:

- Exactly **2 charged particles** from the IP
- Not back-to-back (angle < 170°)
- Both **identified as muons** (EMC&MUC) **or electrons** (EMC)
- **Kinematic fit (1C)** in the assumption of eeγ/$\mu\mu\gamma$
- Look for photon closing the kinematics (**4C fit**)



Generators and Radiative Corrections

Radiative process	eeγ	$\mu\mu\gamma$
PS	Babayaga 3.5	Babayaga 3.5
LO + PS	Babayaga@NLO	Babayaga@NLO
NLO	Babayaga@NLO (2026)[1]	Phokhara
NLO + PS	Babayaga@NLO (2026)[2]	Babayaga@NLO (2026)

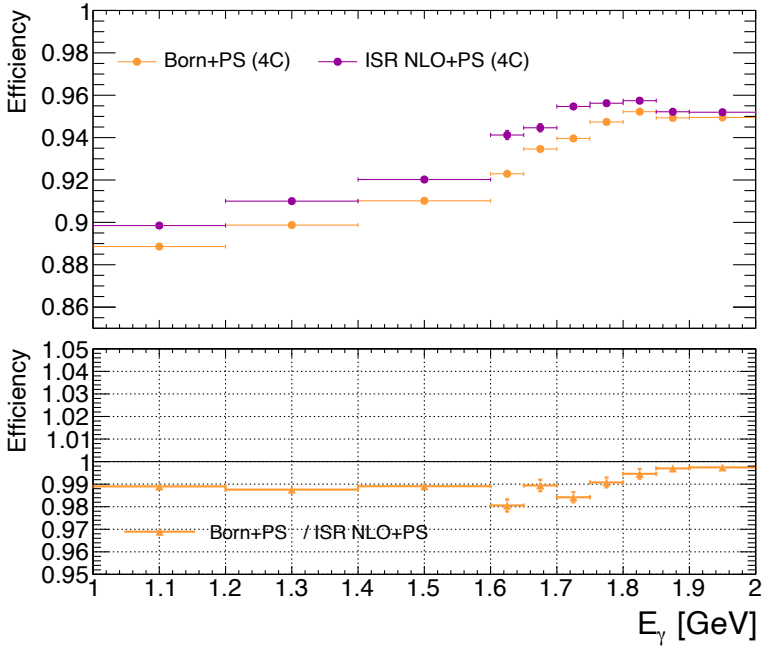
1: private version
2: pre-alpha test version, not validated!!!

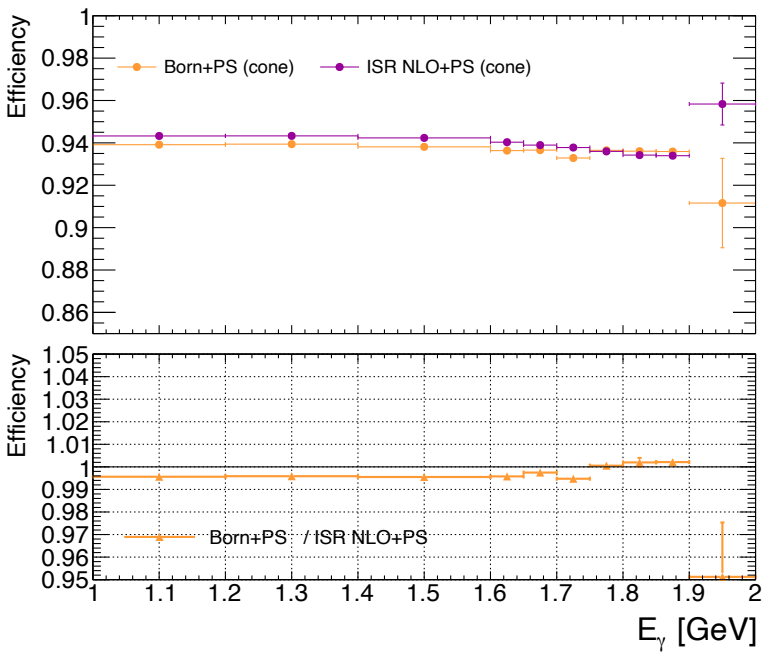
Efficiency at different orders

Assume Babayaga@NLO (2026) perfectly reproduce data:

- Compare impact of missing corrections

Bhabha **Barrel** (large angles) **Di-Muon**





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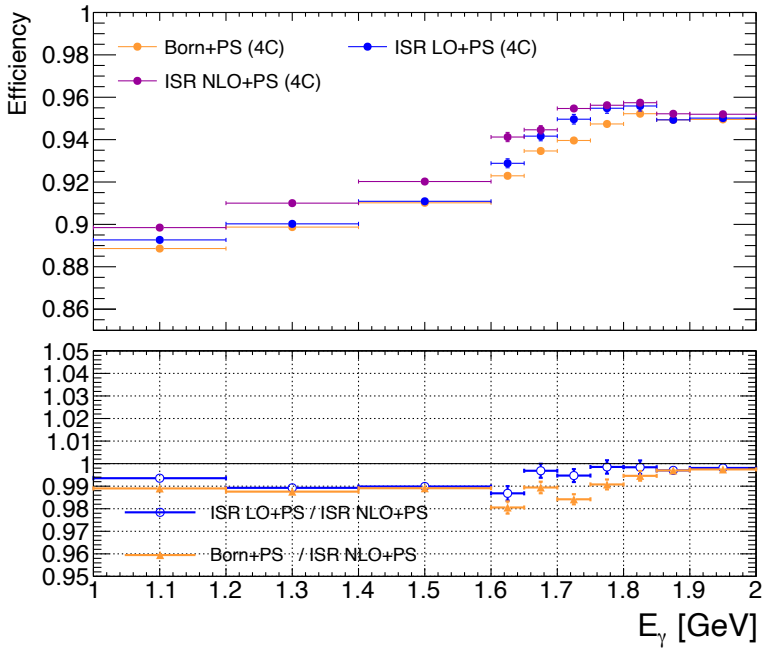

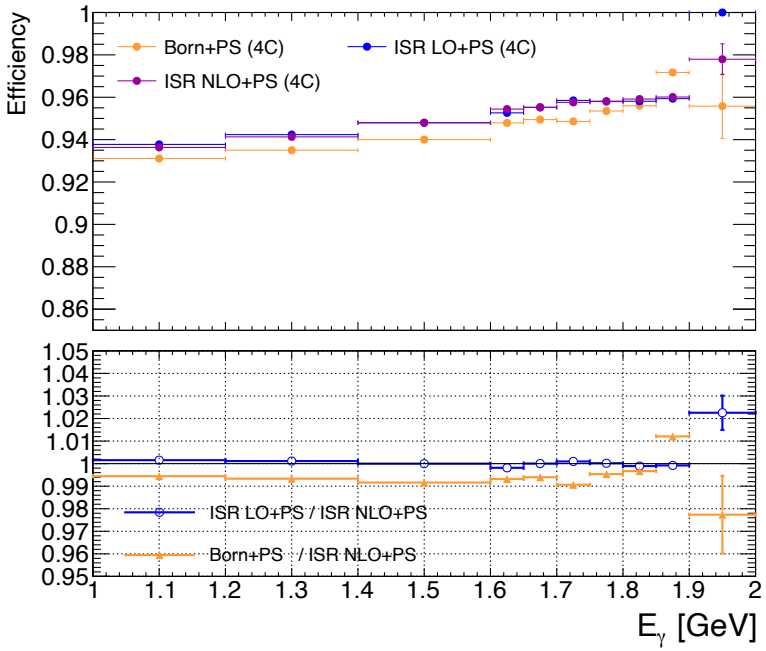

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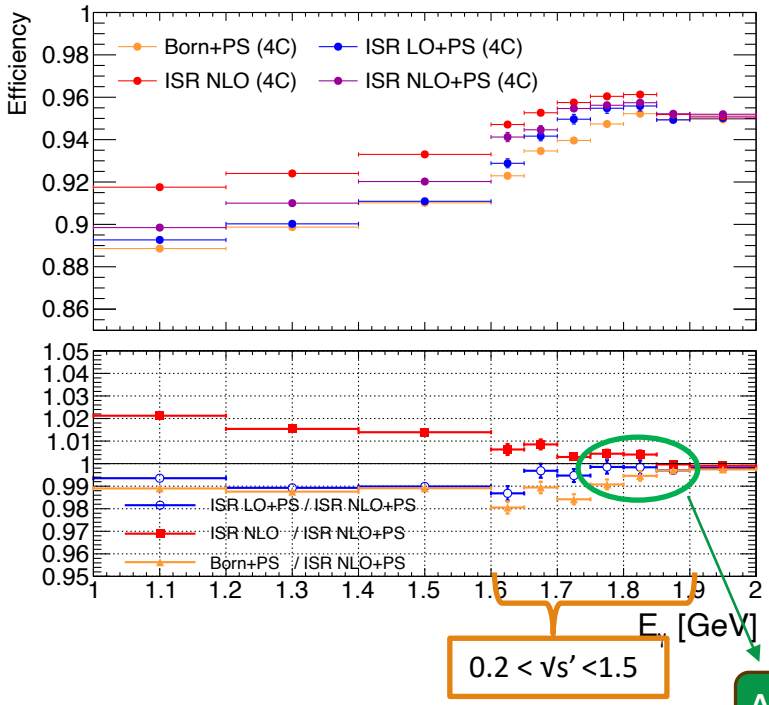

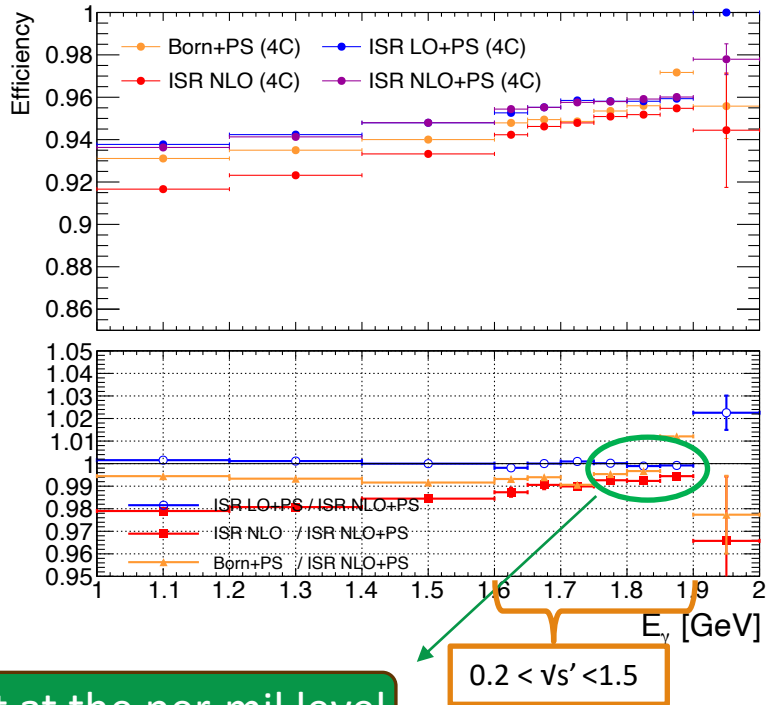

Agreement at the per-mil level

Efficiency at different orders

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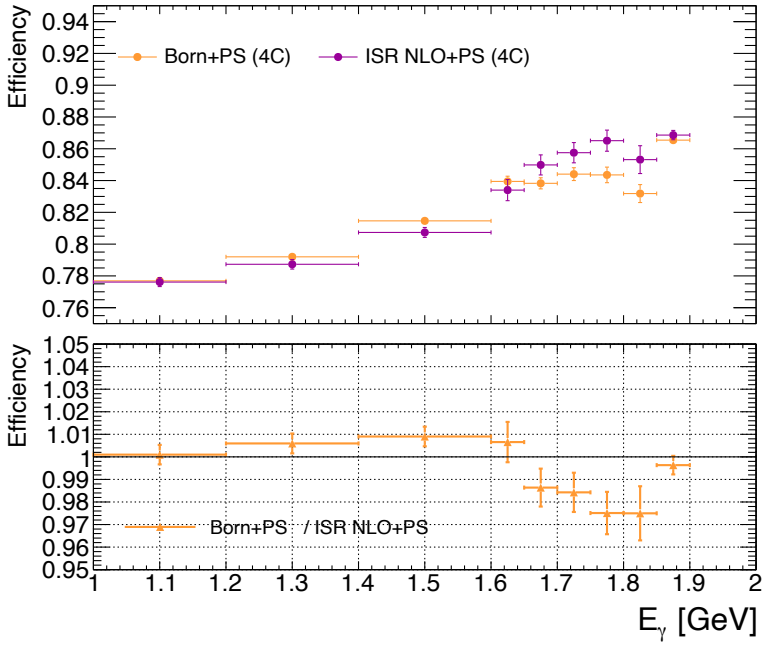
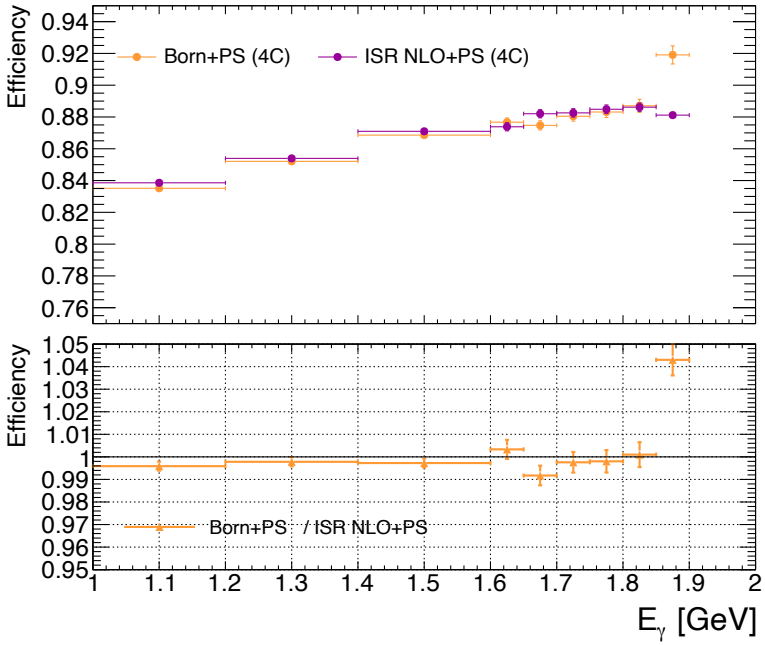
Bhabha **End Caps** (smaller angles) **Di-Muon**





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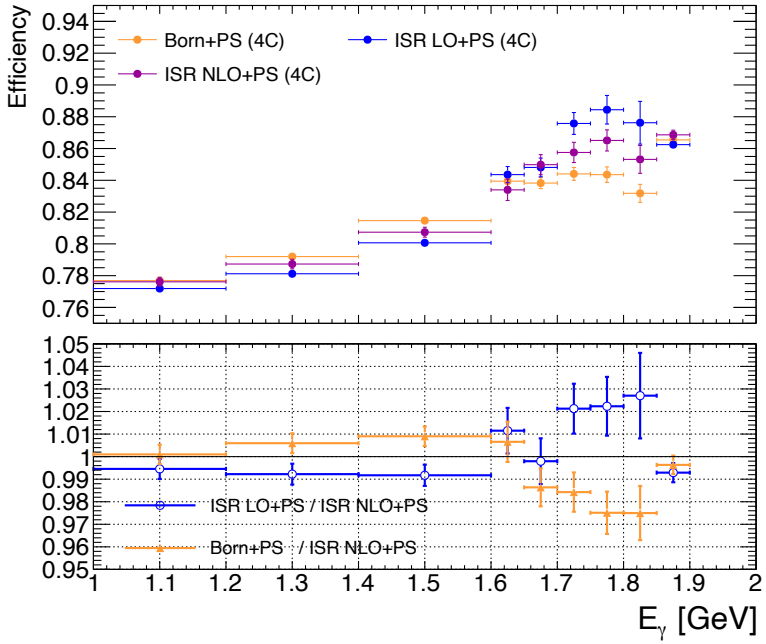

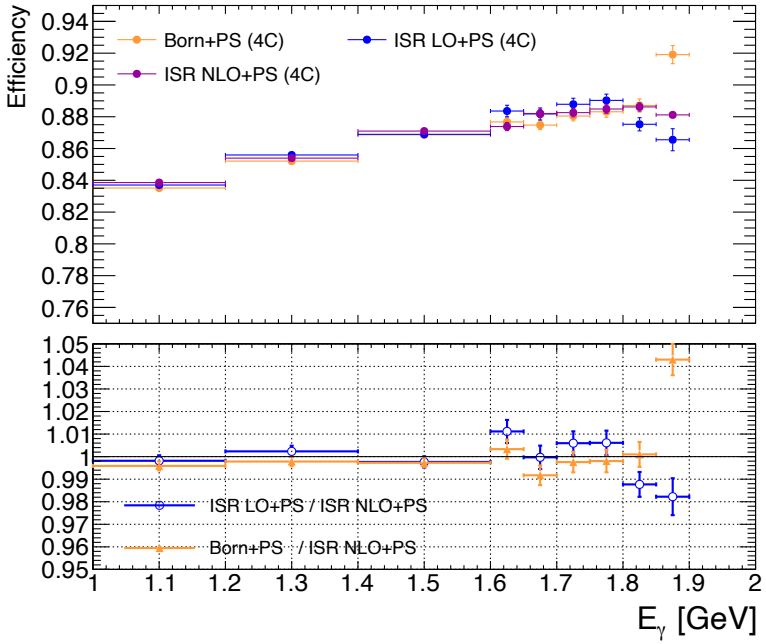

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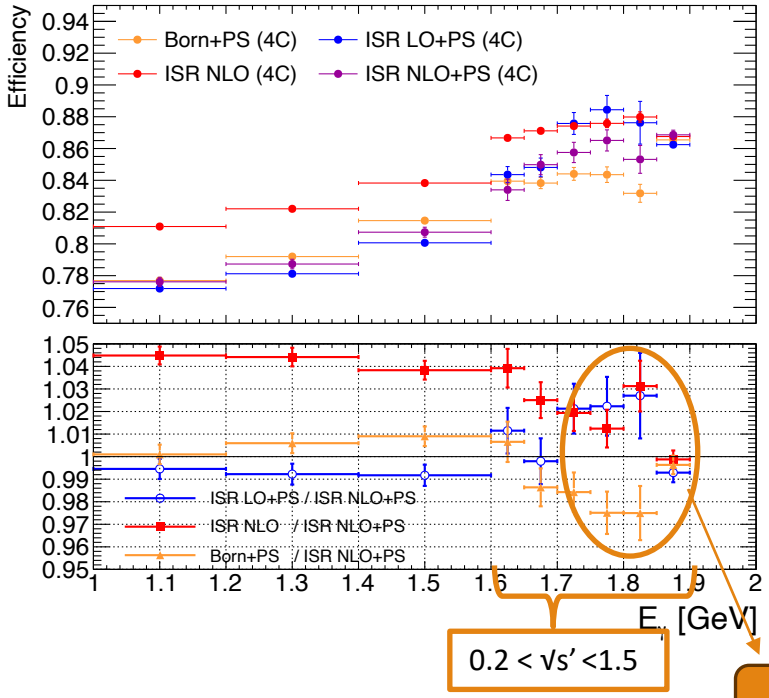

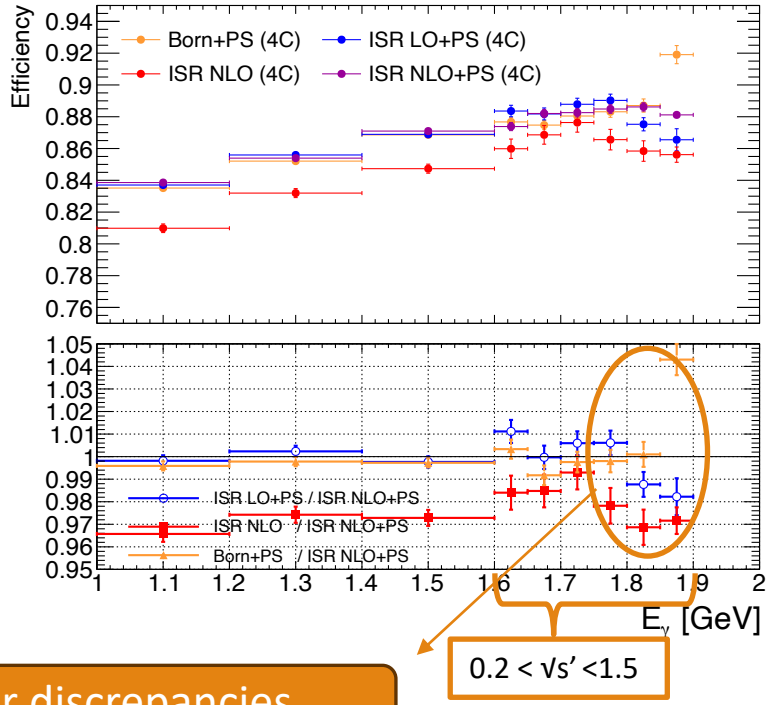

Larger discrepancies

What do we learn?

- Photon detection efficiency is highly sensitive to radiative corrections!
- PS matching has a much larger impact than radiator function!
- Di-muon production seems to converge faster than Bhabha
- The barrel region is less sensitive to higher order effect
  - ➢ We look forward to the release of NLO+PS for radiative Bhabha
  - ➢ Cross check for radiative Bhabha scattering beyond NLO would be extremely important

We thank the Babayaga team for the help and availability!