



Photon-induced QCD@FCC-ee

QCD@LHC, 28th Sep 2026, Oxford

Mostly based on [[Th. Gehrmann, PM; Eur.Phys.J.C 86 \(2026\) 2, 171](#)]

Peter Meinzinger, University of Zurich



Photon-induced processes

An incomplete survey of LEP measurements

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/2002-056
17-July-2002

**Measurement of the Cross-Section for
the Process $\gamma\gamma \rightarrow p\bar{p}$ at
 $\sqrt{s_{ee}} = 183 - 189 \text{ GeV}$ at LEP**

The OPAL Collaboration

UROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/2003-035
22 Mai 2003

**The $\eta_c(2980)$ formation in
two-photon collisions at LEP
energies**

DELPHI Collaboration

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/2003-058
2 September 2003

**Study of Tau-pair Production in
Photon-Photon Collisions at LEP
and Limits on the Anomalous
Electromagnetic Moments of the
Tau Lepton**

DELPHI Collaboration

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/2002-064
August 2, 2002

**Production of Single W Bosons at LEP and
Measurement of $WW\gamma$ Gauge Coupling Parameters**

L3 Collaboration

EUROPEAN LABORATORY FOR PARTICLE PHYSICS

CERN-EP-2001-053
10 July 2001

**Measurement of Z/γ^* production in
Compton scattering of quasi-real
photons**

The OPAL Collaboration

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP-2001-064
31 August 2001

**Measurement of the Hadronic
Cross-Section for the Scattering of
Two Virtual Photons at LEP**

The OPAL Collaboration

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/2001-012
January 30, 2001

Total Cross Section in $\gamma\gamma$ Collisions at LEP

The L3 Collaboration

9015v1 9 Sep 2002

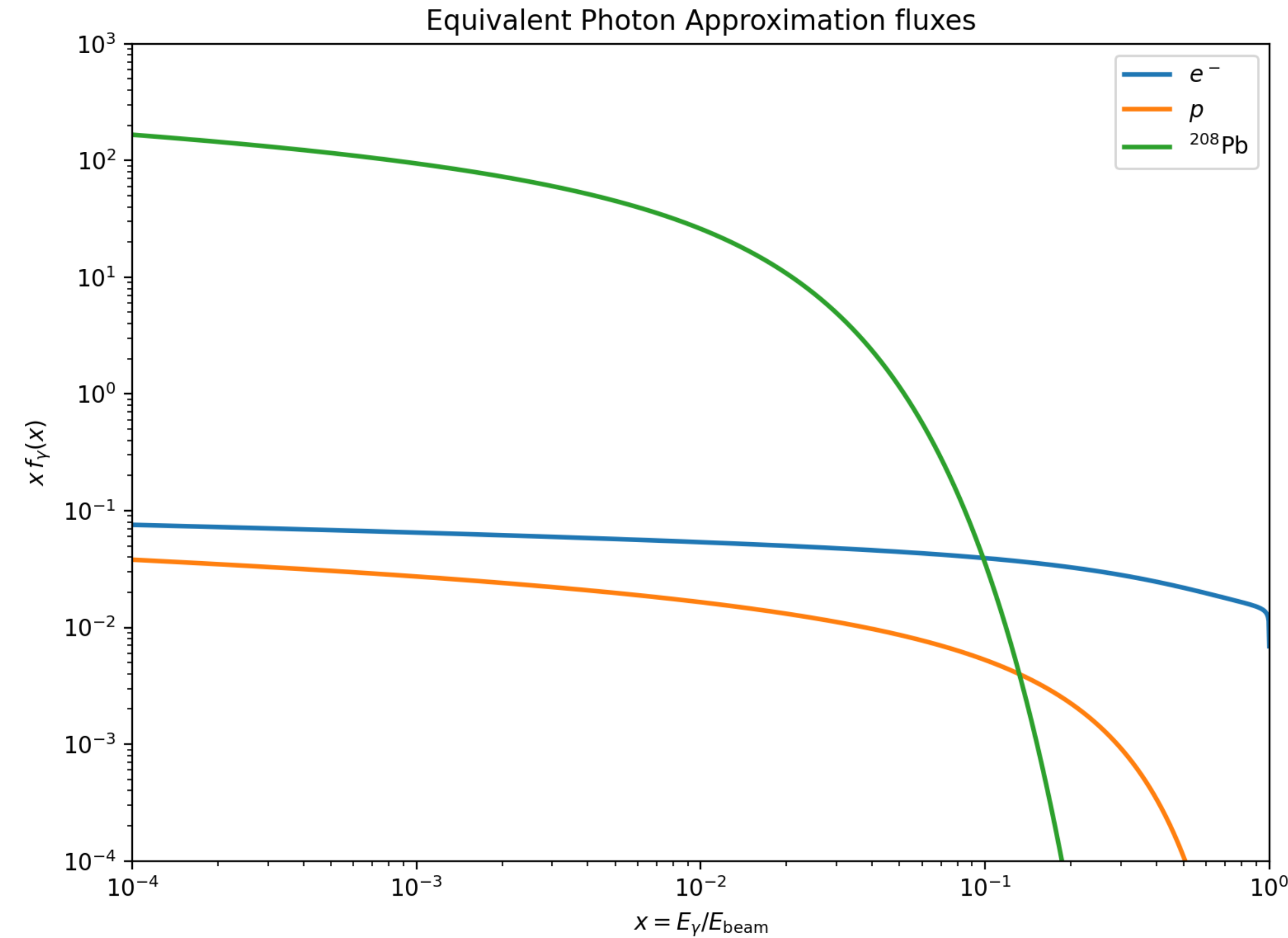
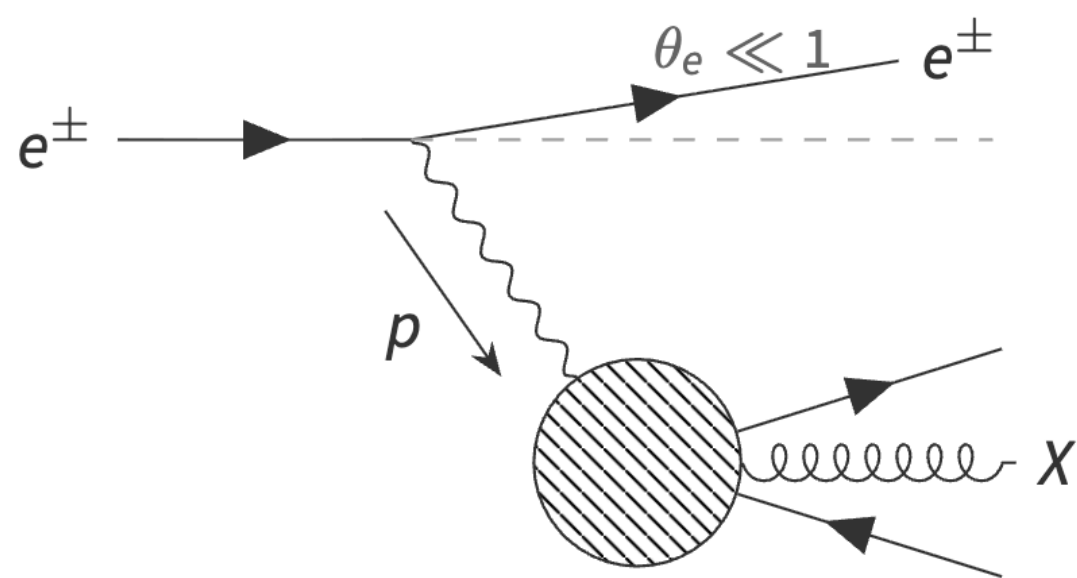
9015v1 9 Sep 2002



Quasi-real photon emissions

- can be calculated in the Equivalent Photon Approximation (EPA)
- Idea: factorise the photon emission, possible if photon virtuality $P^2 \ll \mu^2$
- See **photoproduction at HERA** and **Ultra Peripheral Collisions at LHC**
- Electrons exhibit the hardest photon flux, given by

$$f_{\gamma/e}(z) \simeq \frac{\alpha}{2\pi} \frac{1 + (1 - z)^2}{z} \ln \frac{P_{\max}^2}{P_{\min}^2}$$



Let's focus on two
examples for jet final states



Photon-induced jets

A quick primer from my talk earlier today

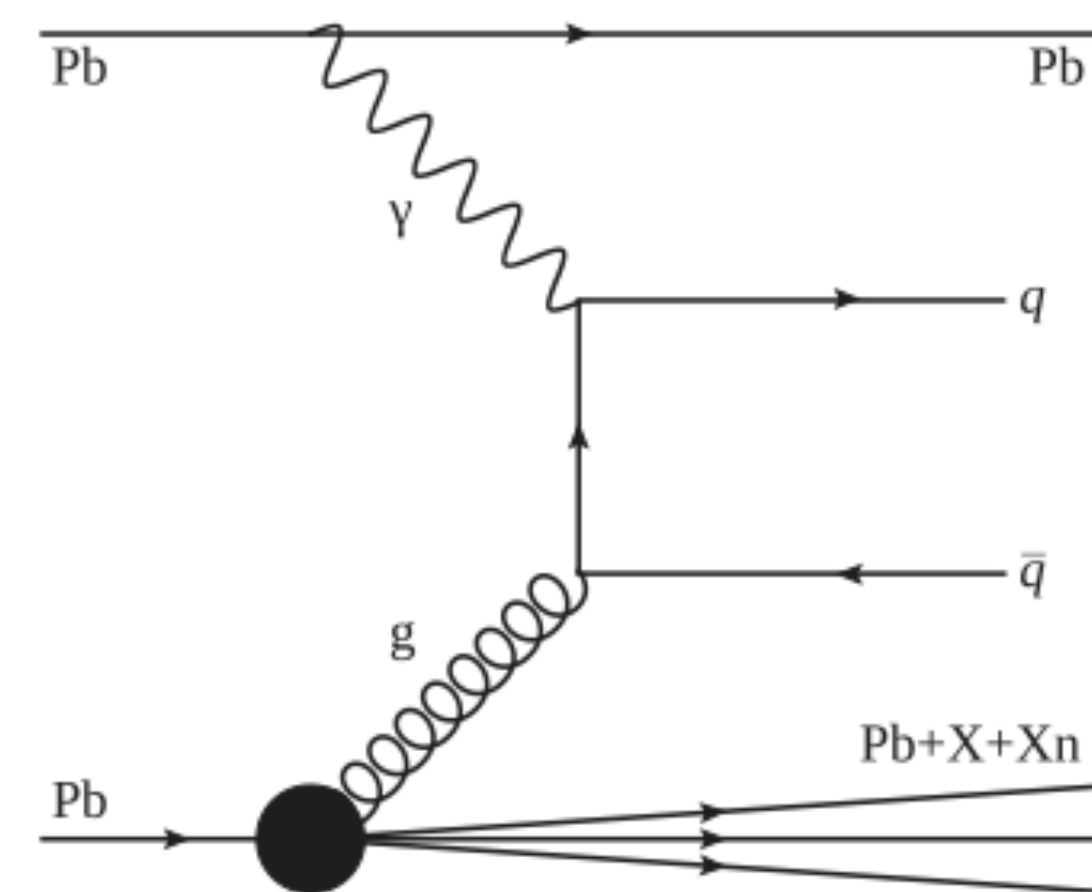
- Earlier colliders, like LEP and HERA, had numerous measurements of such processes; only first such measurements at LHC

- The photon can undergo a DGLAP-evolution:

$$\frac{\partial f_i^{(\gamma)}(x, \mu)}{\partial \log \mu} = \frac{\alpha_{\text{em}}(\mu)}{2\pi} P_{\gamma i}(x) + \frac{\alpha_S(\mu)}{2\pi} \sum_j \int \frac{dx'}{x'} P_{ji} \left(\frac{x}{x'} \right) f_j^{(\gamma)}(x', \mu)$$

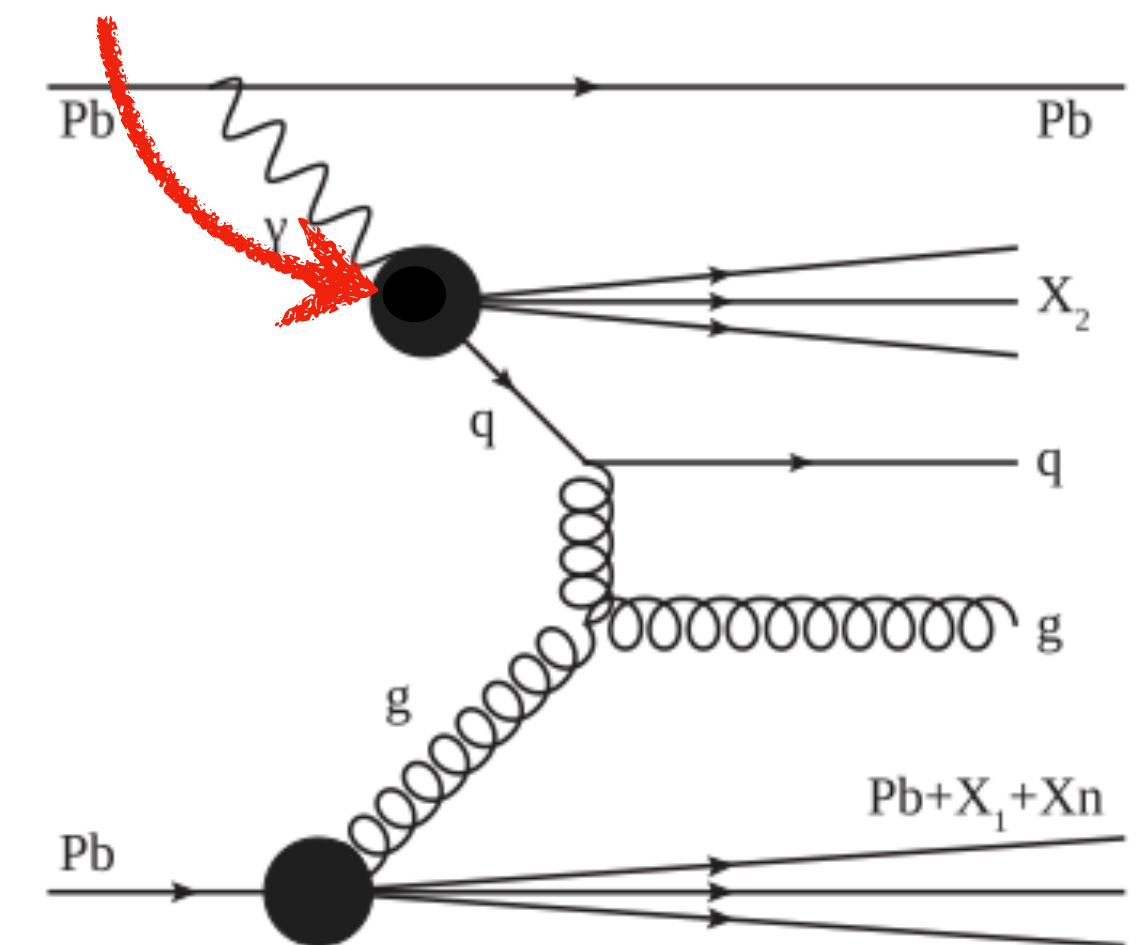
- This gives the notion of **partons inside the photon**
- Got mostly forgotten after shut-downs of LEP and HERA
- see review [[Rev.Mod.Phys. 74 \(2002\) 1221-1282](#)]

„**direct**“ photon interaction



„**resolved**“ photon interaction

This is a photon PDF

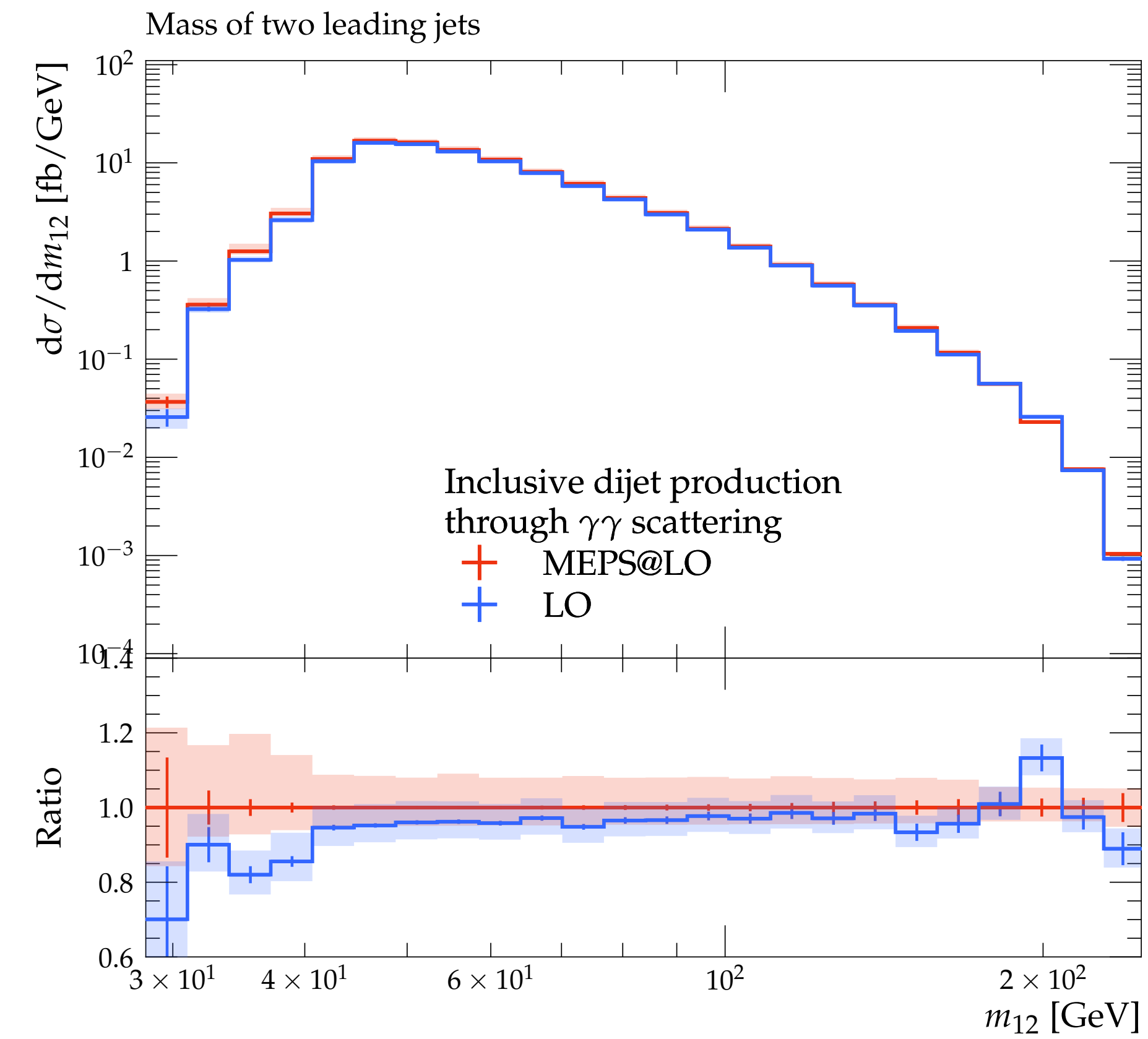
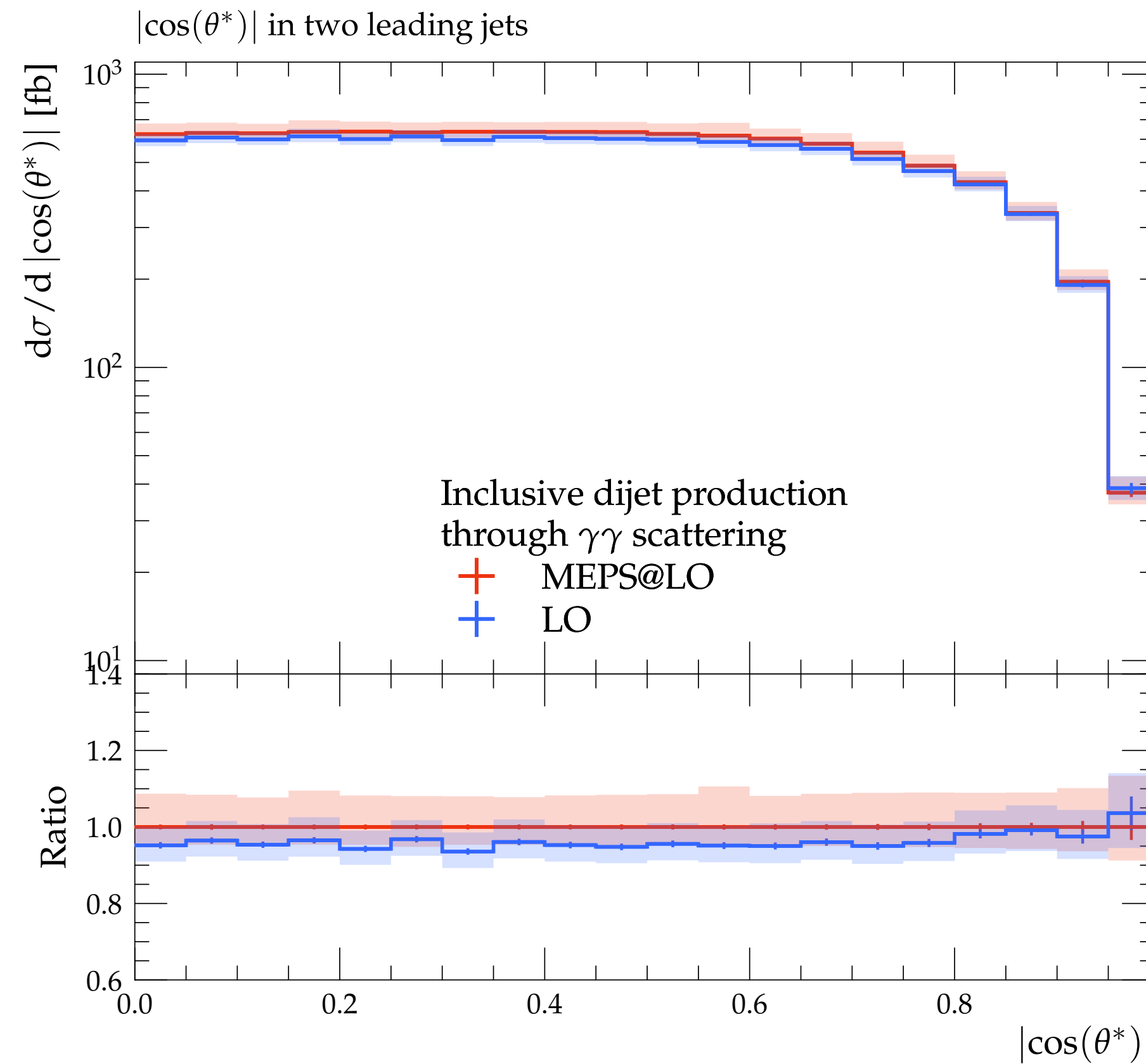


Only the sum is physical!



Example 1: photon-induced dijets at FCC-ee

- Assuming $\sqrt{s} = 250$ GeV,
 p_T cuts of 20 and 10 GeV
- Using legacy SAS1M
photon PDF
- Summing four components:
direct + 2 x single-resolved
+ double-resolved
- Opens up possibilities for
jet substructure
measurements,
fragmentation at lower
energies,
 α_s determinations etc.
- See ref. [[Eur.Phys.J.C 84 \(2024\) 2, 178](#)] for validation
against LEP data at NLO+PS



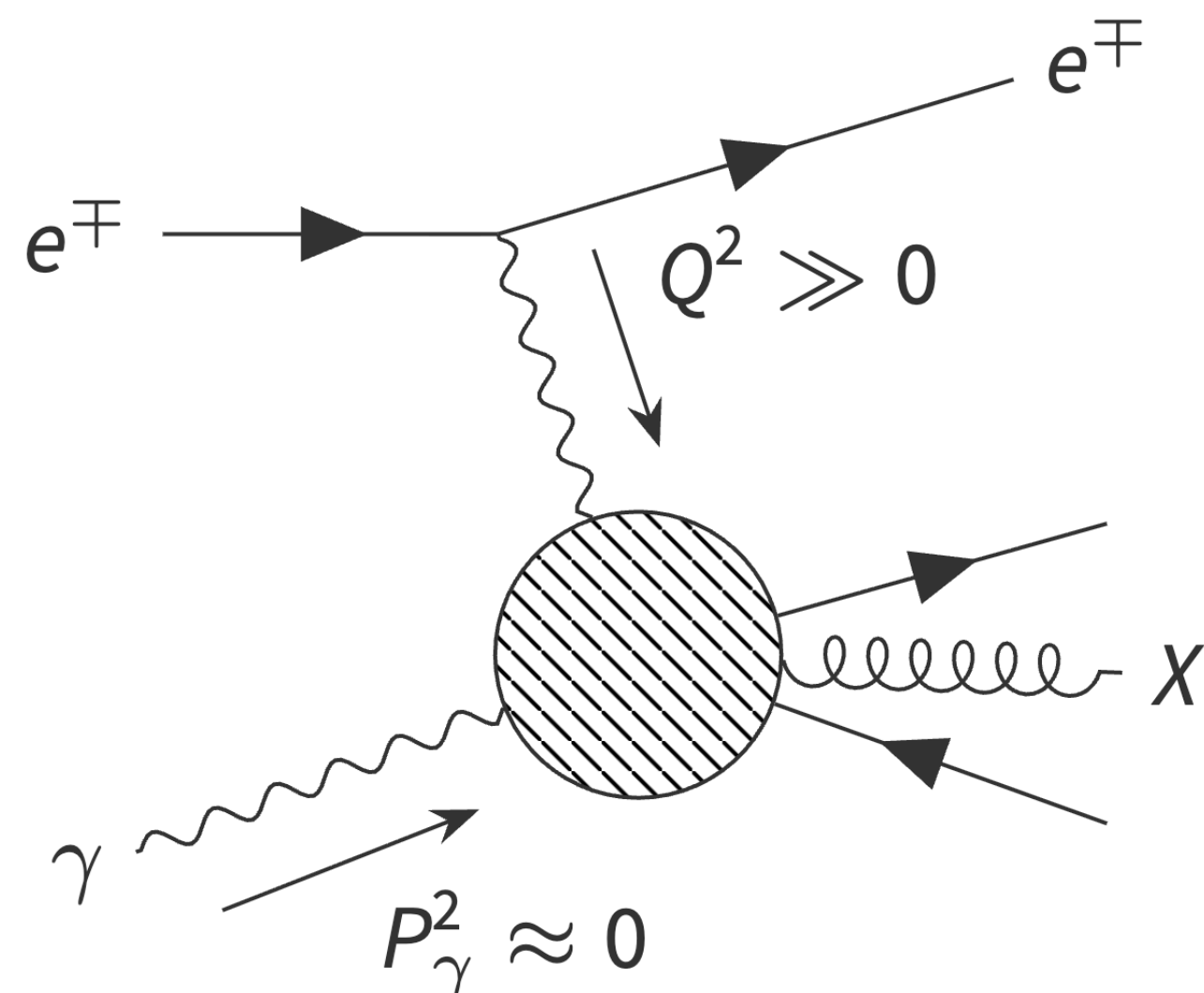


Example 2: Inclusive DIS on the photon

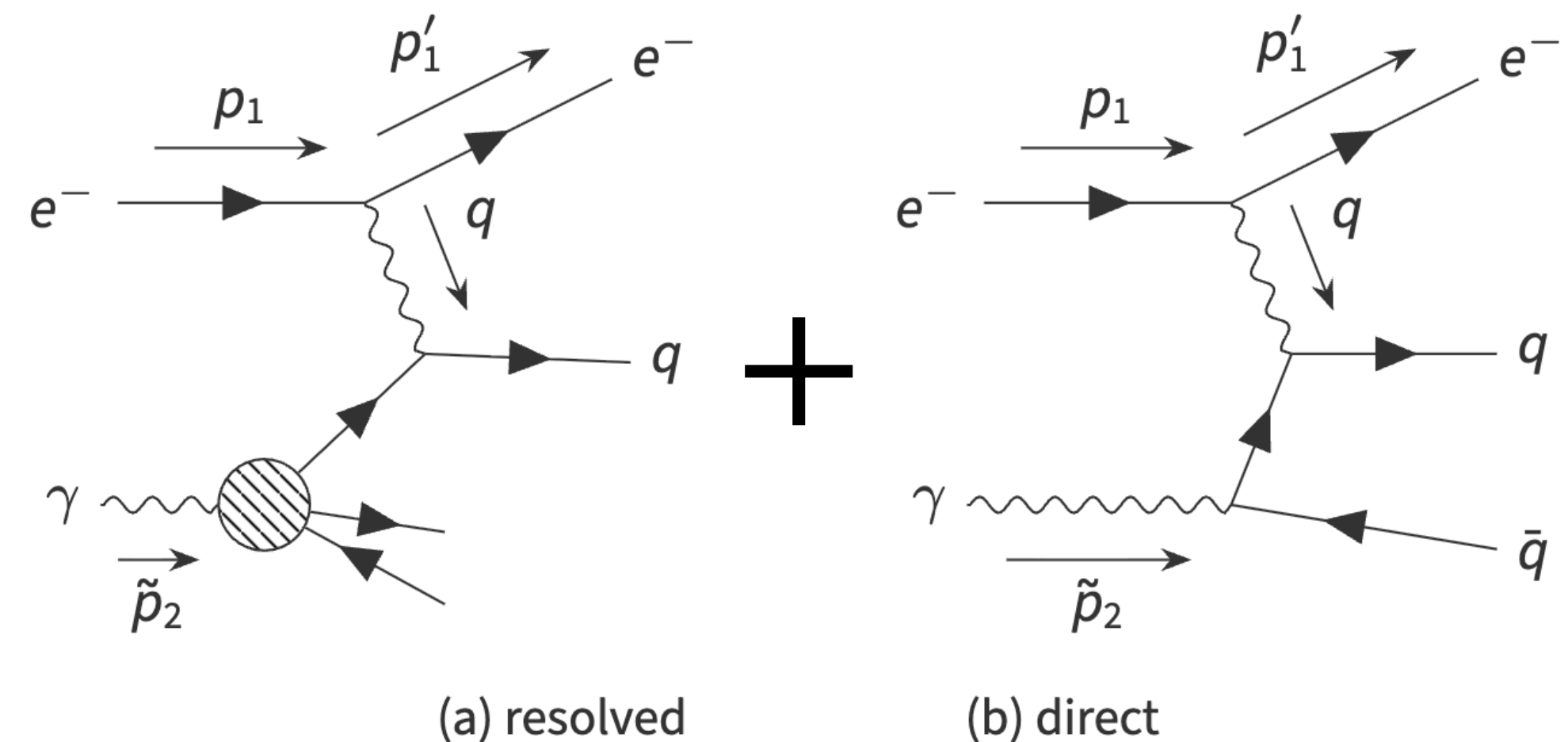
- In $e\gamma$ -DIS, one beam lepton provides the quasi-real photon emission; the scattered second beam lepton supplies hard probe Q^2 of the photon and gives access to F_2^γ structure function

- Kinematic variables:

$$Q^2 = -q^2 \text{ and } x_\gamma = \frac{Q^2}{Q^2 + W^2} \text{ (Bjorken variable w.r.t. the photon)}$$



=





Why it's useful and needed

For illustration purposes, let's look at what's currently available:

VALO 1.0 [[2606.07189](#)]

- First new photon PDF fit in >20years!
- They fitted to inclusive $e\gamma$ -DIS: **data is very sparse and mostly low-energy**
- FCC-ee might fill a big gap in this data, enable new precision determinations of photon structure

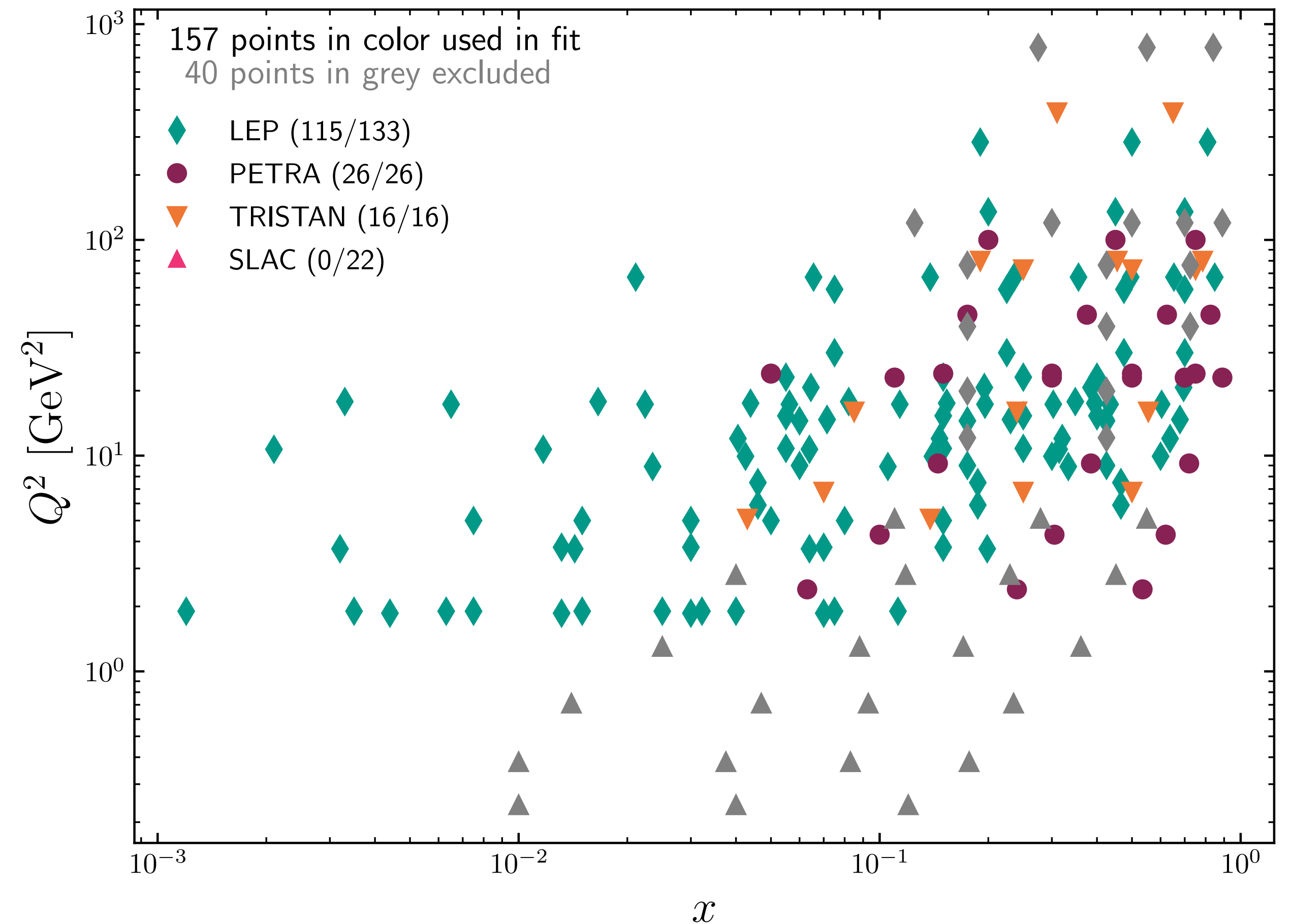


Figure from [[2606.07189](#)]



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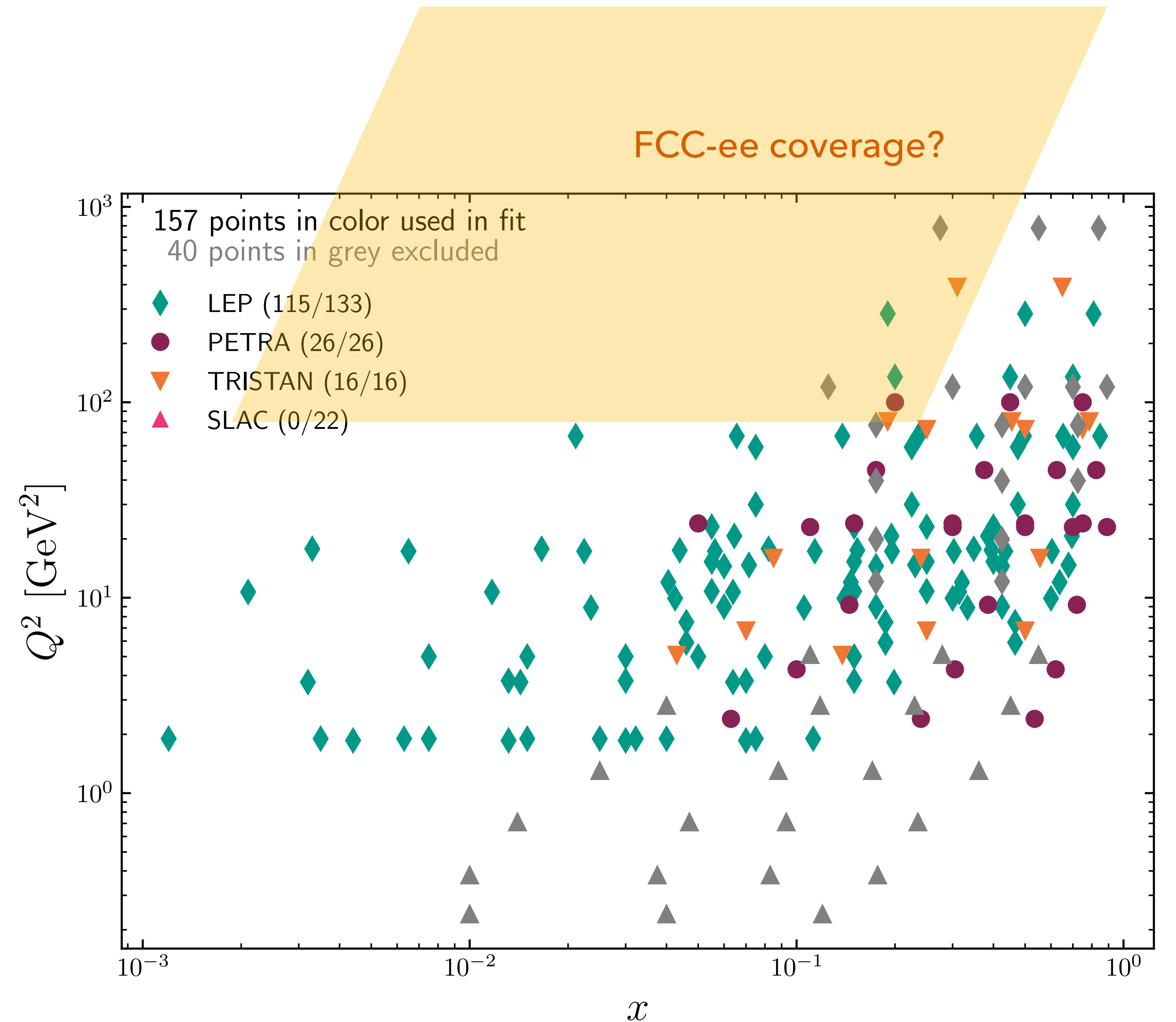


Figure from [[2606.07189](#)]

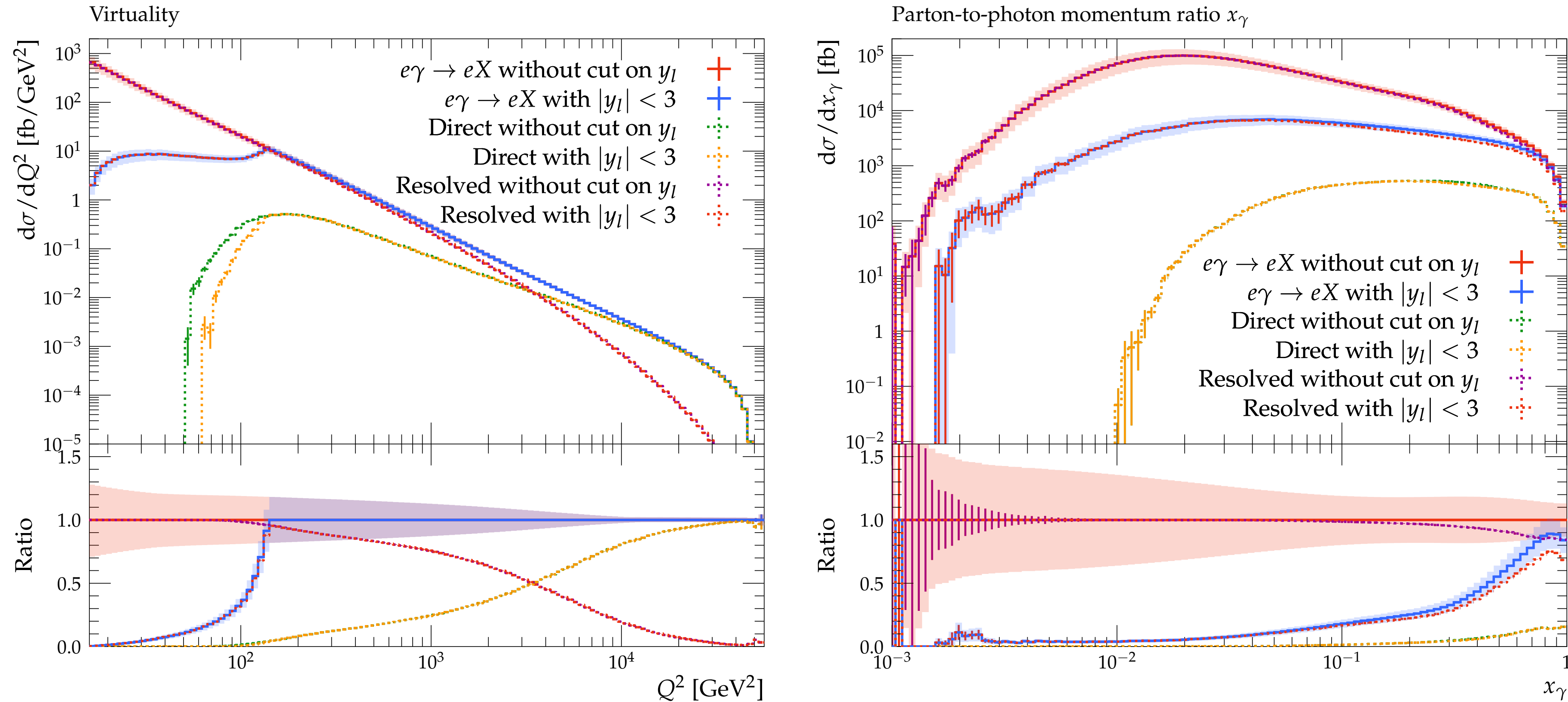


Predictions

- Assuming again $\sqrt{s} = 250$ GeV, detector acceptance of $|\eta| < 3$
- Fiducial cuts inspired by DIS measurements at HERA:
virtuality $Q^2 > 16 \text{ GeV}^2$ and inelasticity $0.1 < y < 0.9$
- Where applicable, jets clustered with anti- k_T , $R=1$, $p_T > 5 \text{ GeV}$
- Photon PDF is the legacy SAS1M set
- Particle-level Sherpa 3.1. α MEPS@LO: direct and resolved samples with up to three jets, parton shower and hadronisation; bands show scale variation

Kinematic reach

Forward-lepton coverage will be important

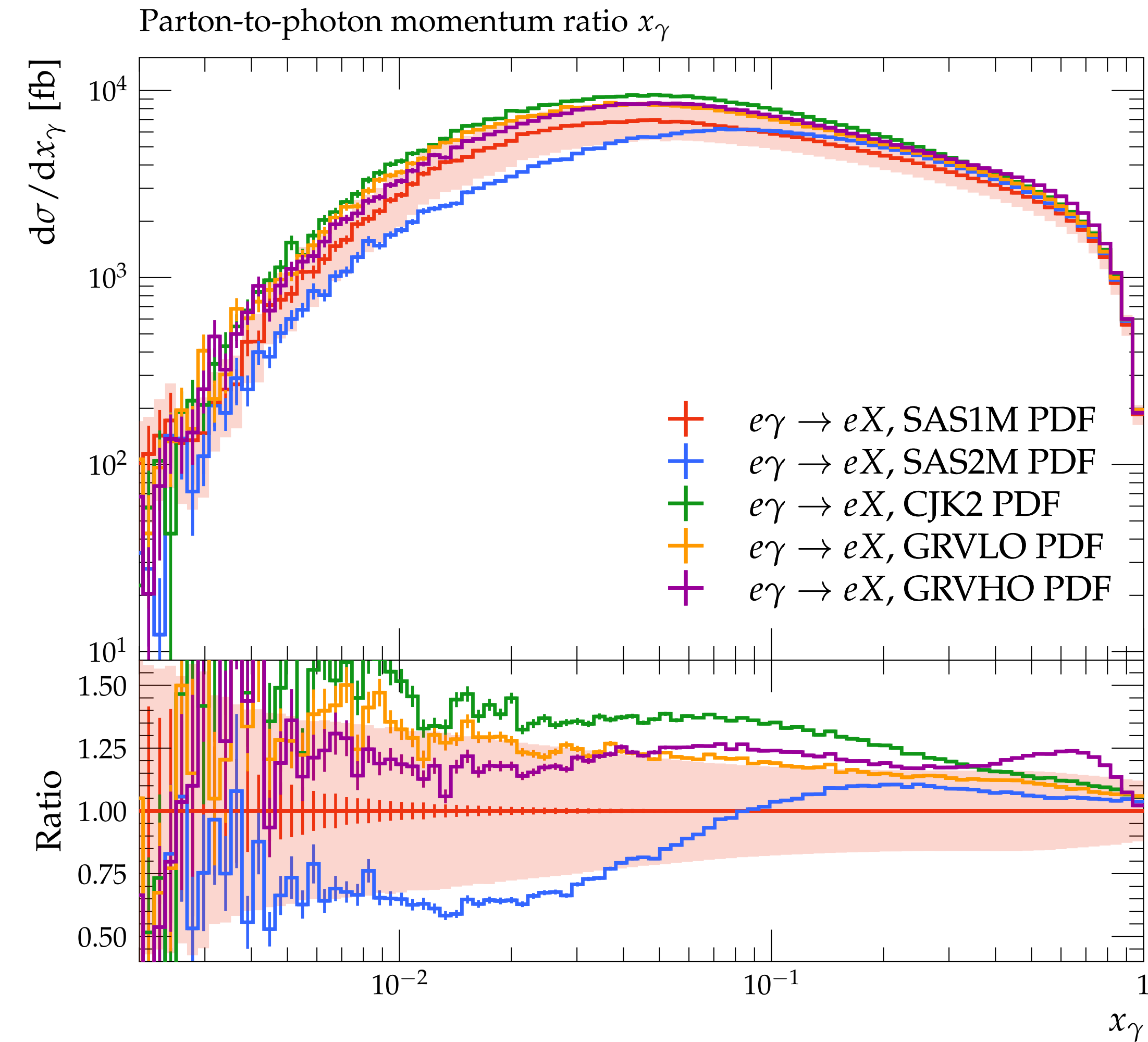


- Resolved dominates over large parts of phase space
- cut on forward-lepton $\eta_l < 3$ removes much of the high-rate small- Q^2 /small- x_γ phase space



Scan over legacy PDFs

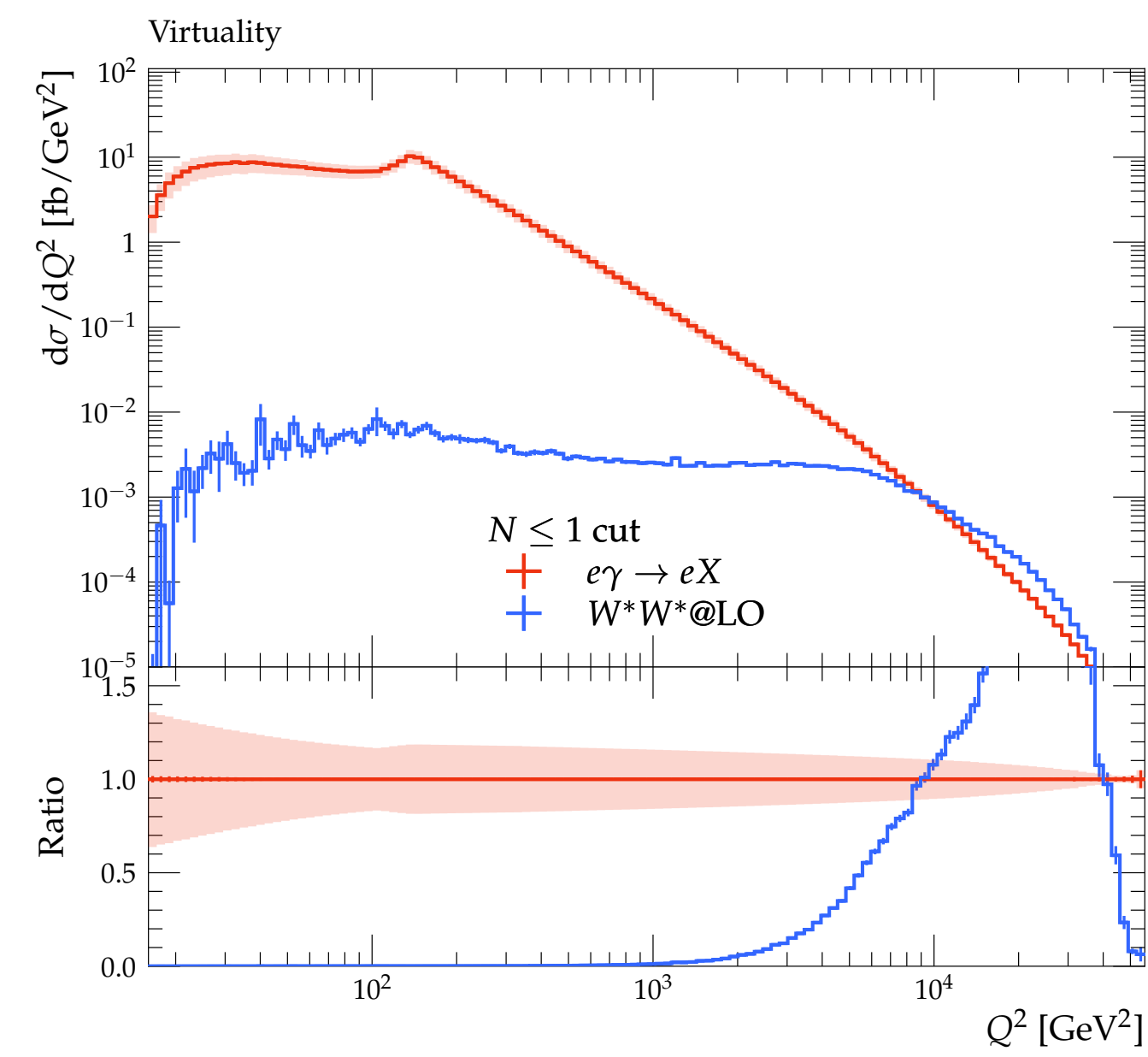
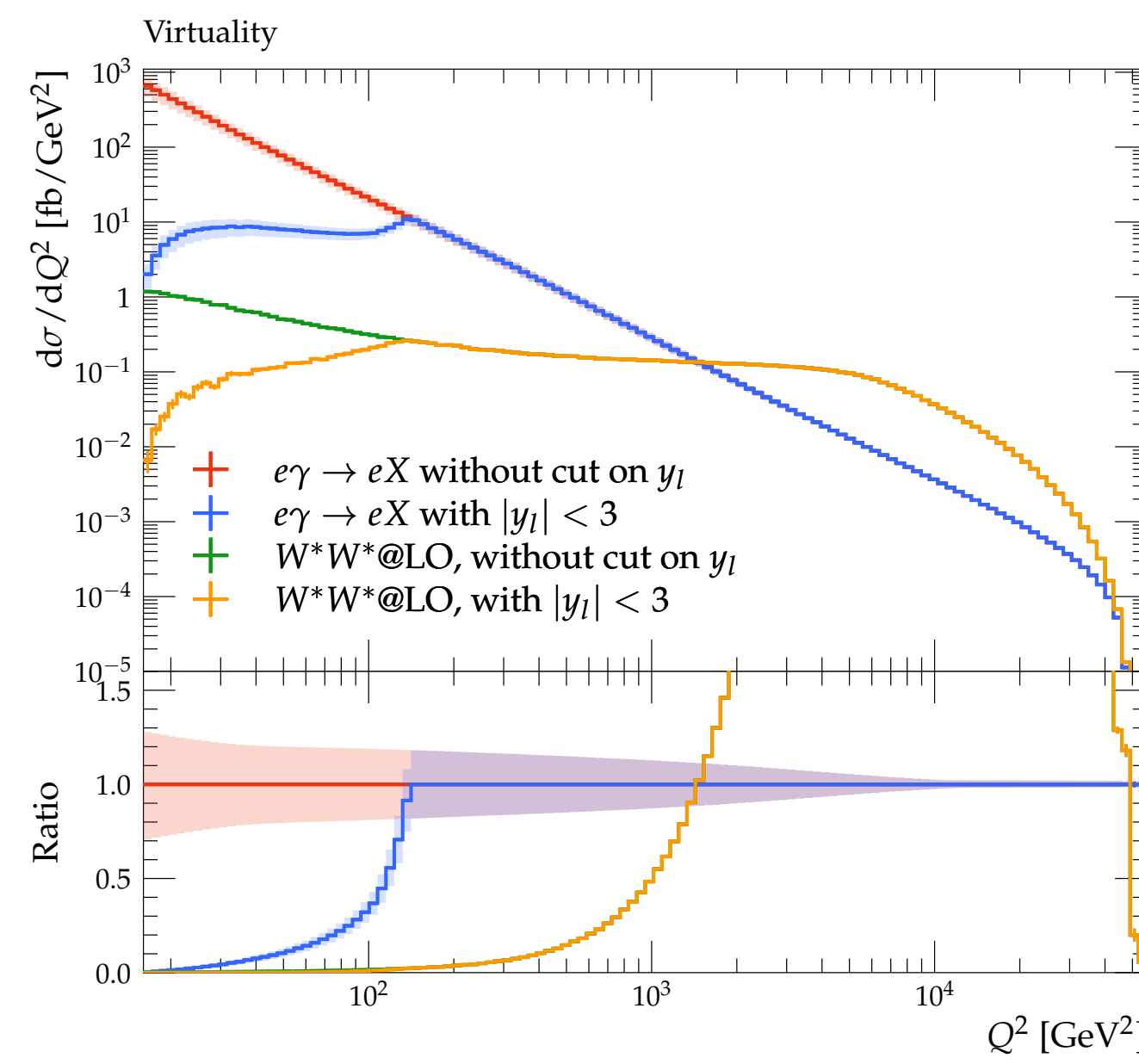
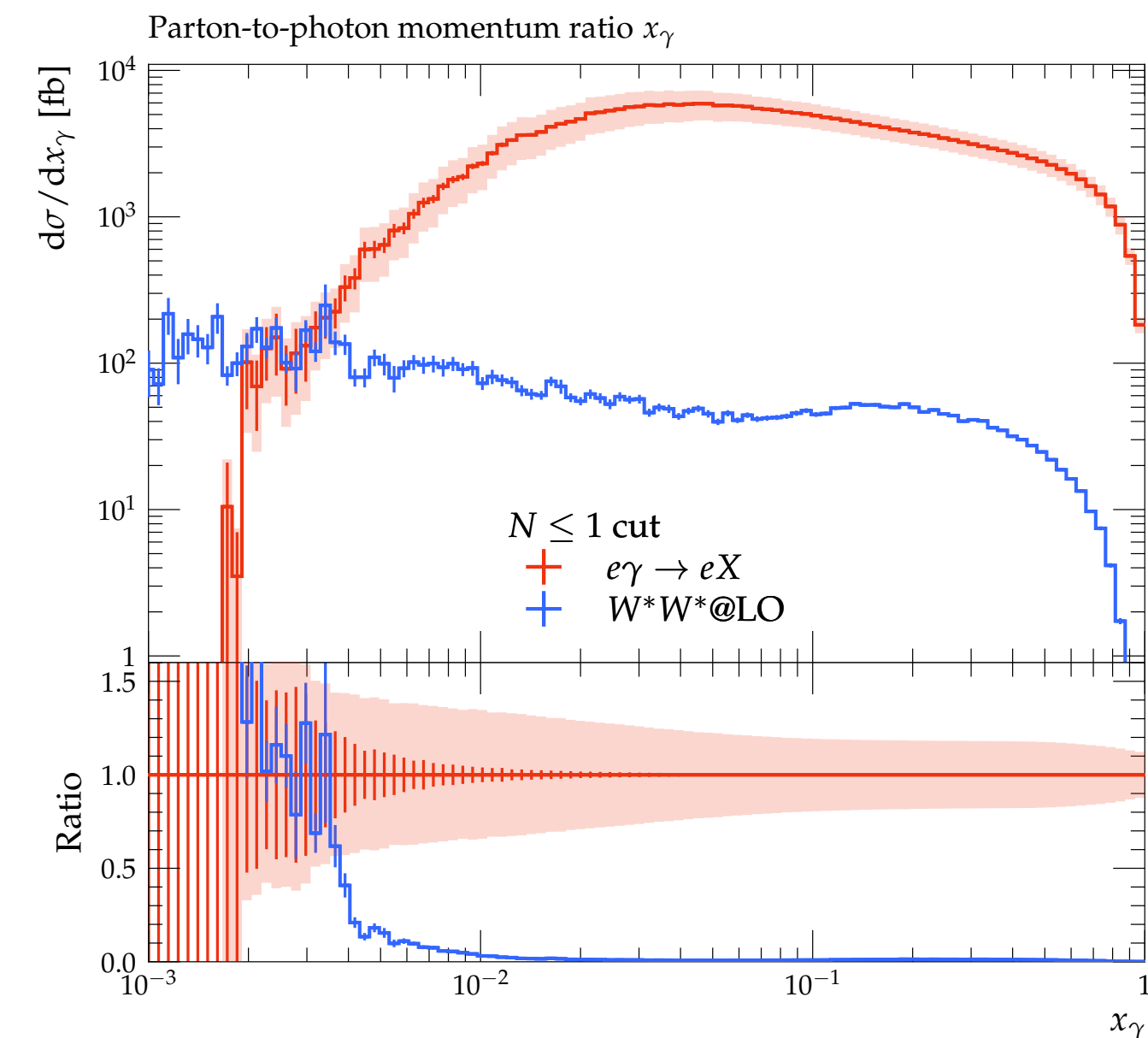
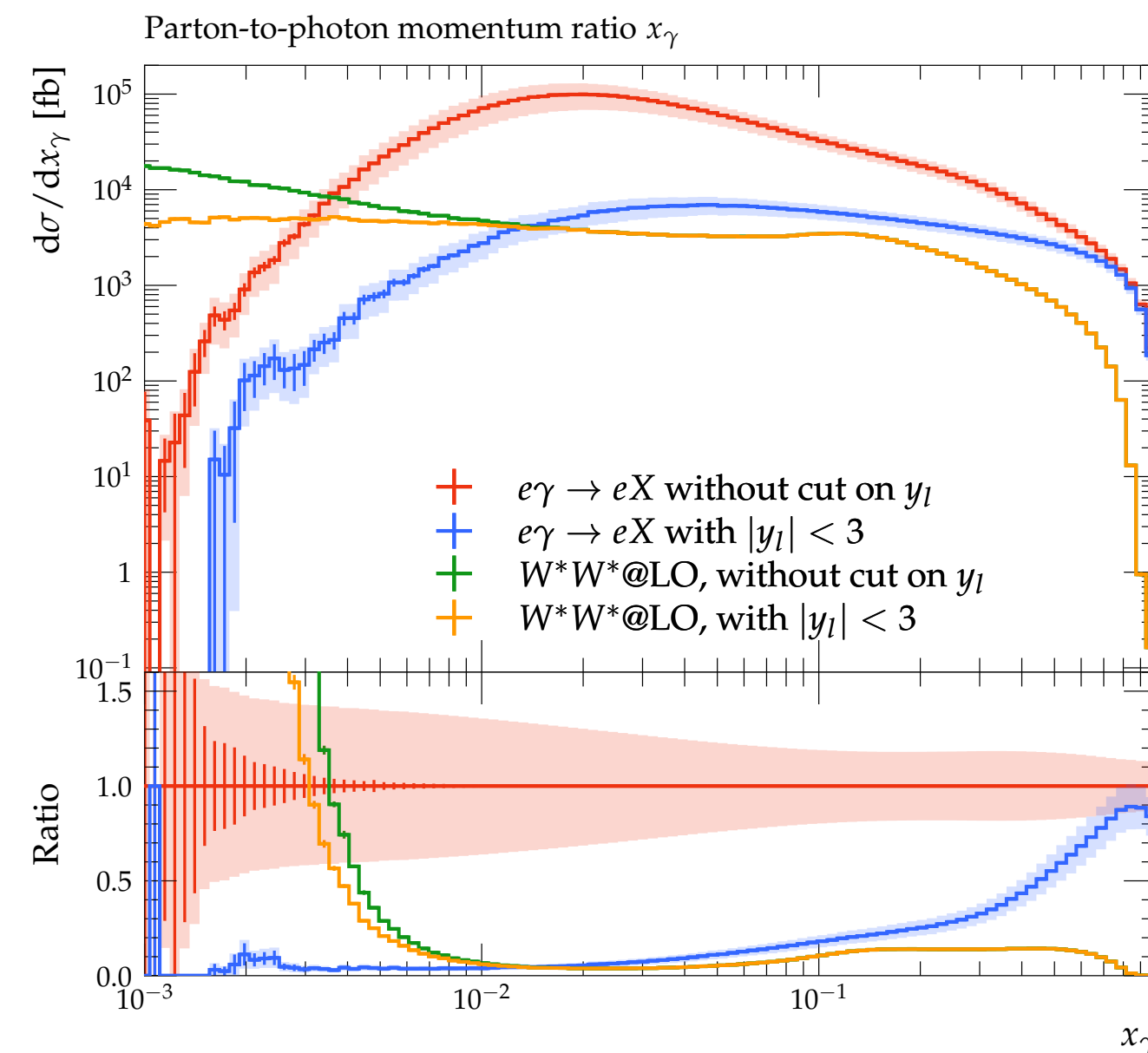
- For illustration purposes, we ran with different PDF sets
- Legacy SAS, GRV and CJK parametrisations shift the prediction by up to 40%, especially at small x_γ ; more than the LO scale envelope
- This emphasizes the importance this data could play in this poorly-understood phenomenon!





WW as background

- $e^+e^- \rightarrow W^*W^* \rightarrow e\nu jj$ has same signature
- **Forward coverage limits signal but not the background**
After cut, WW has same order of magnitude or even larger than signal
- We studied three different possible cuts to remove the background:
 $\eta^{(\text{jet1})} > 0$ or
 $p_T^{\text{miss}} < 35 \text{ GeV}$ or
 $N_{\text{jets}} \leq 1$
- The latter offers the best performance





Summary

- There is **broad landscape for photon-induced processes** at FCC-ee
- Fluxes will be relatively hard, enabling large-mass measurements, including **jet production**
- **$e\gamma$ -DIS gives access to the partonic structure of the photon**
- Forward-lepton coverage could be limiting factor in this measurement
- $N_{\text{jets}} \leq 1$ gives handle on background from WW production

