Measurement of the differential isolated prompt photon production cross section at 7 TeV

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CMS

Overview

- Prompt photon physics
- CMS and our photon reconstruction/identification algorithms
- Cross section measurement techniques
  - Conversion method
  - Isolation method
- Results of the measurement

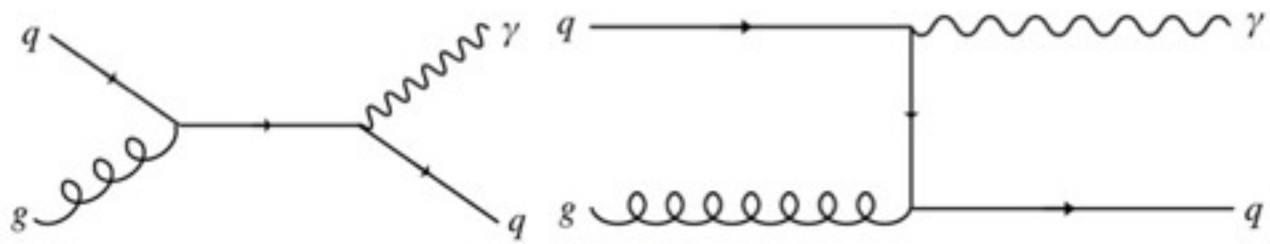
Prompt photon physics

Isolated photon cross section measurement probes our understanding of perturbative QCD.

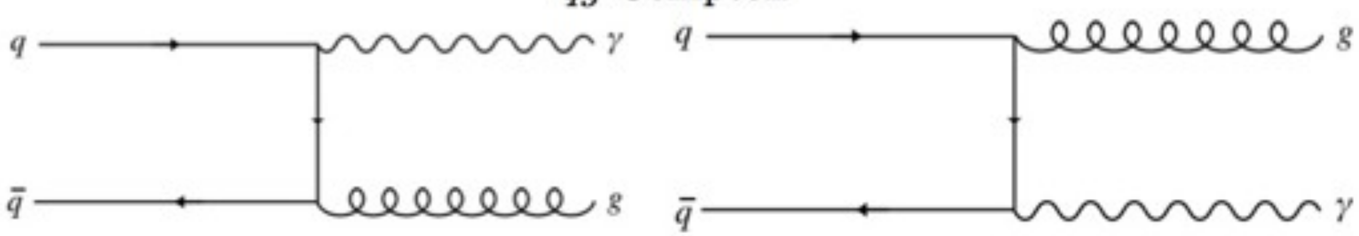
Photons are also an important ingredient in searches for new phenomena: $H \rightarrow \gamma\gamma$, SUSY, gravitons... Inclusive cross section measurement demonstrates the effectiveness of photon reconstruction & selection, and increases our understanding of the SM backgrounds to these rare processes.

QCD photon production

"Direct"

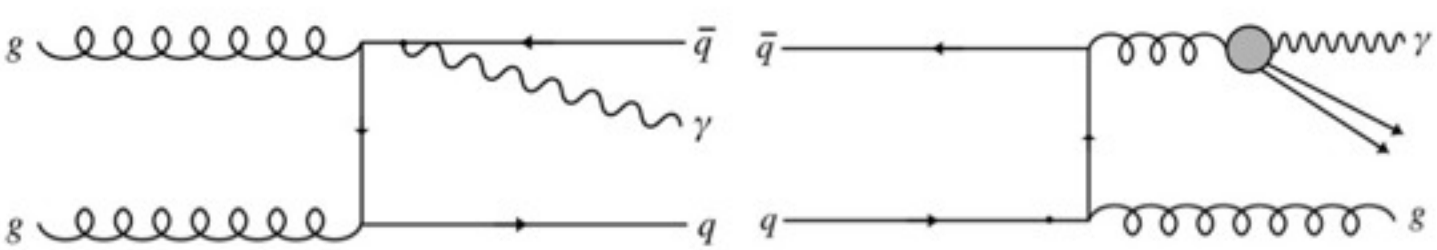


qg Compton



$q\bar{q}$ annihilation

"Fragmentation"



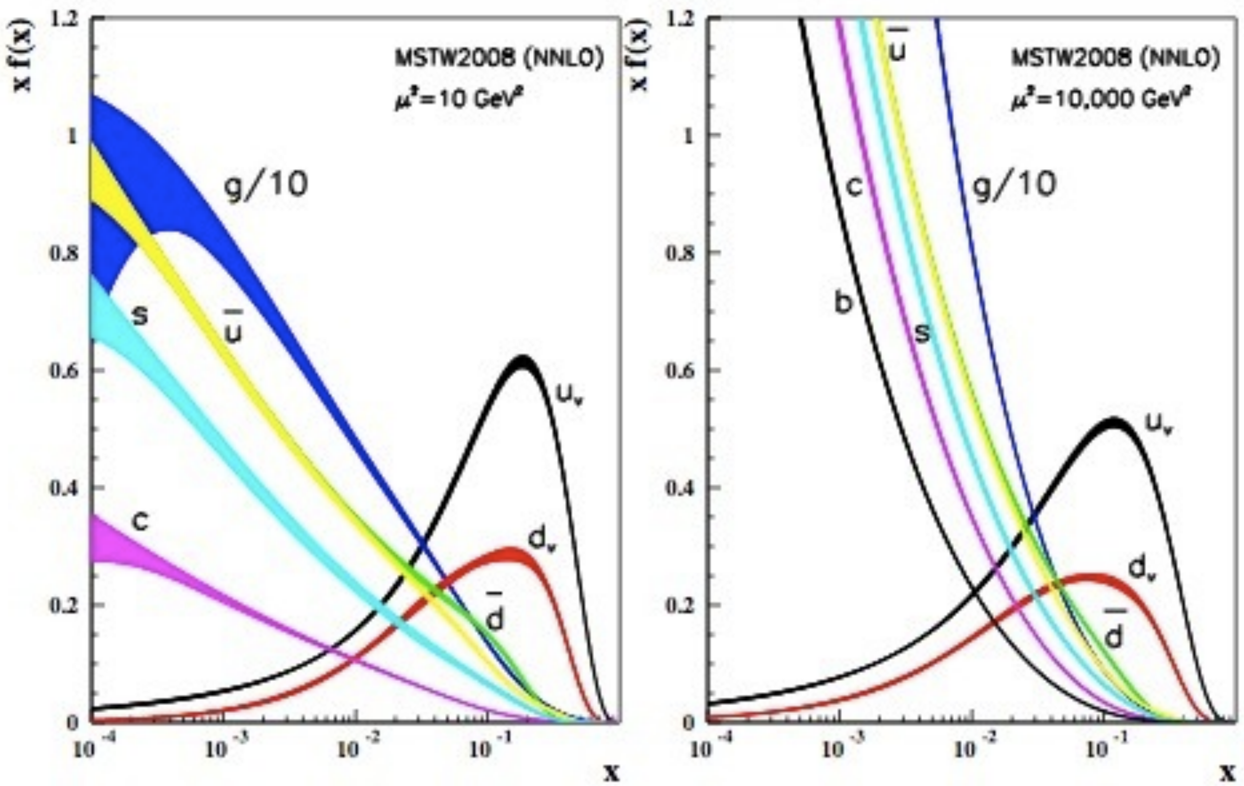
"Direct" production involves quark annihilation or quark-gluon scattering. In LHC collisions the gluon scattering process should dominate.

"Fragmentation" production from partons fragmenting into photons. Applying isolation reduces the component from fragmentation.

Distinction between them is not physically meaningful past LO.

CMS measures the cross section, differential in η (|η| < 2.5) and p_T (25-400 GeV). Main experimental challenge is to subtract the background from jets with a large EM component.

Probing the PDFs



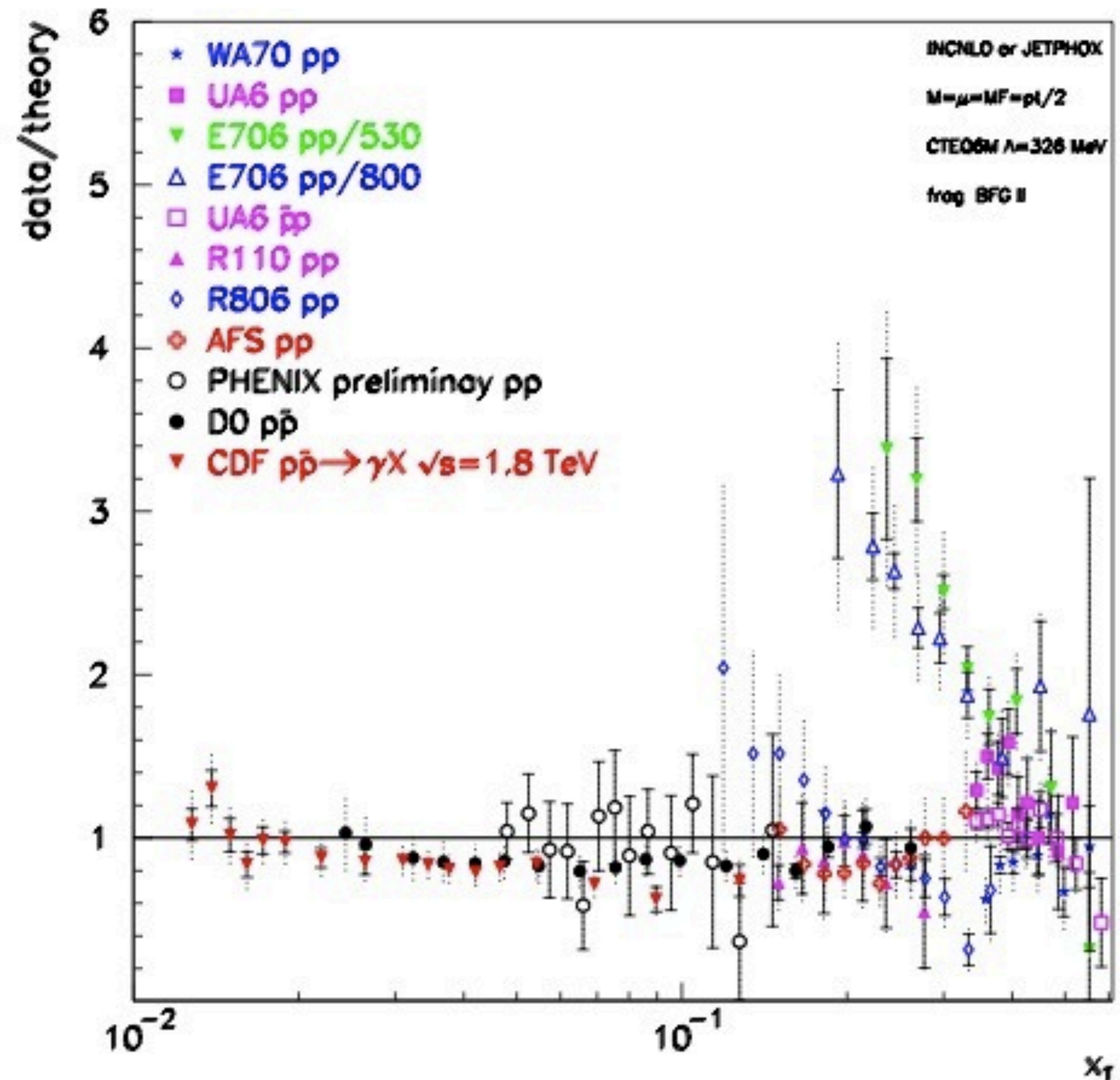
One of the primary motivations for measuring the isolated prompt photon cross section is to probe the parton distribution functions that describe the momentum fraction carried by the various constituents of the proton.

- Gluon component dominates PDFs at relevant values of Q^2 for LHC physics.
- *qg* "Compton" production process dominates isolated photon production at LHC.
- So photon cross section measurement gives information on the gluon distribution.

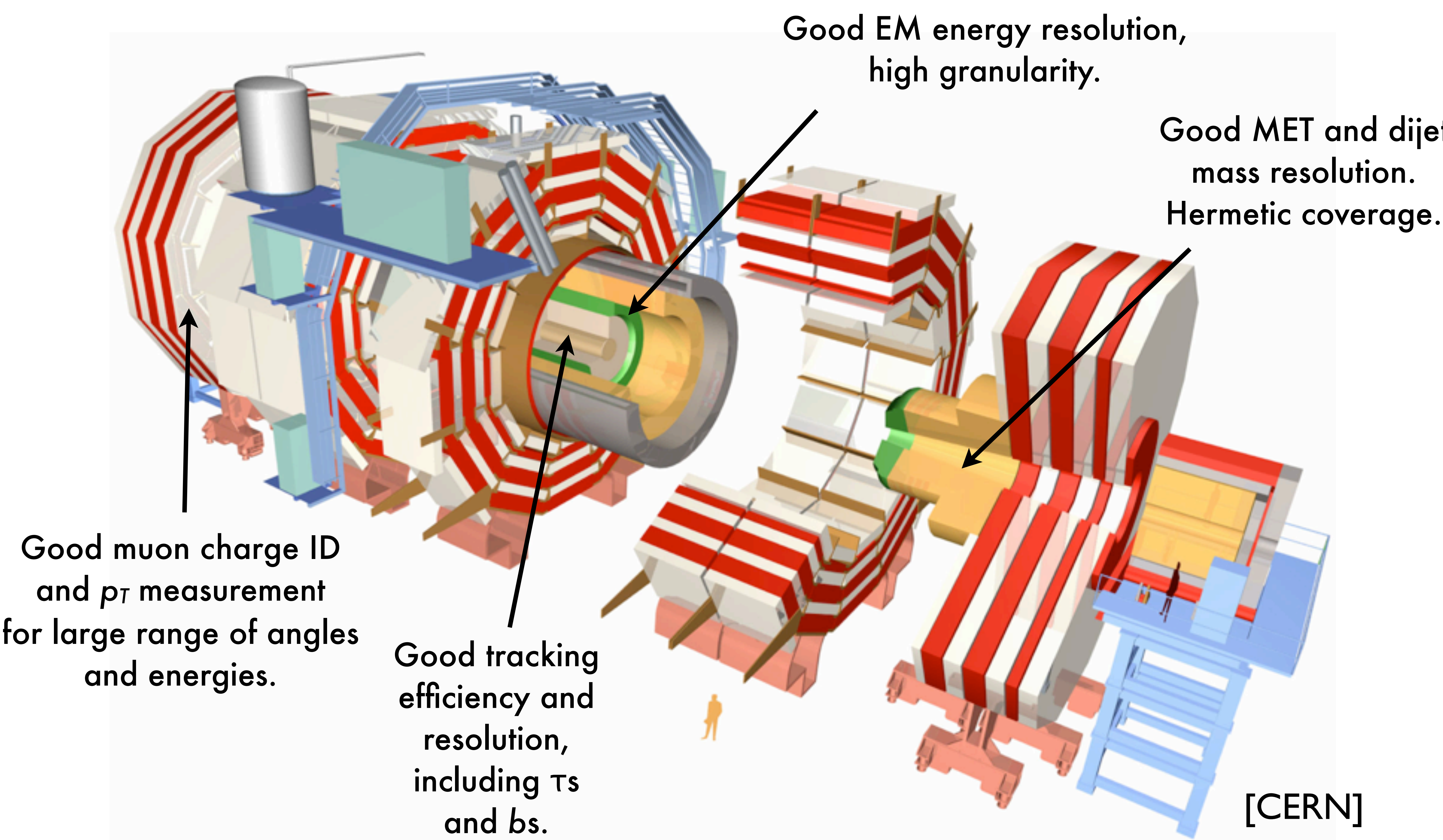
Recent measurements

Photon cross section has been measured at a variety of energies in both fixed target and collider experiments.

- In general the agreement with NLO QCD computations is good.
- E706 (Tevatron fixed target) measured a cross section up to 3 times higher than theory.
- Intrinsic k_T hypothesis put forward in an attempt to explain the disagreement.
- Later measurements have not been able to confirm the effect.



The CMS detector



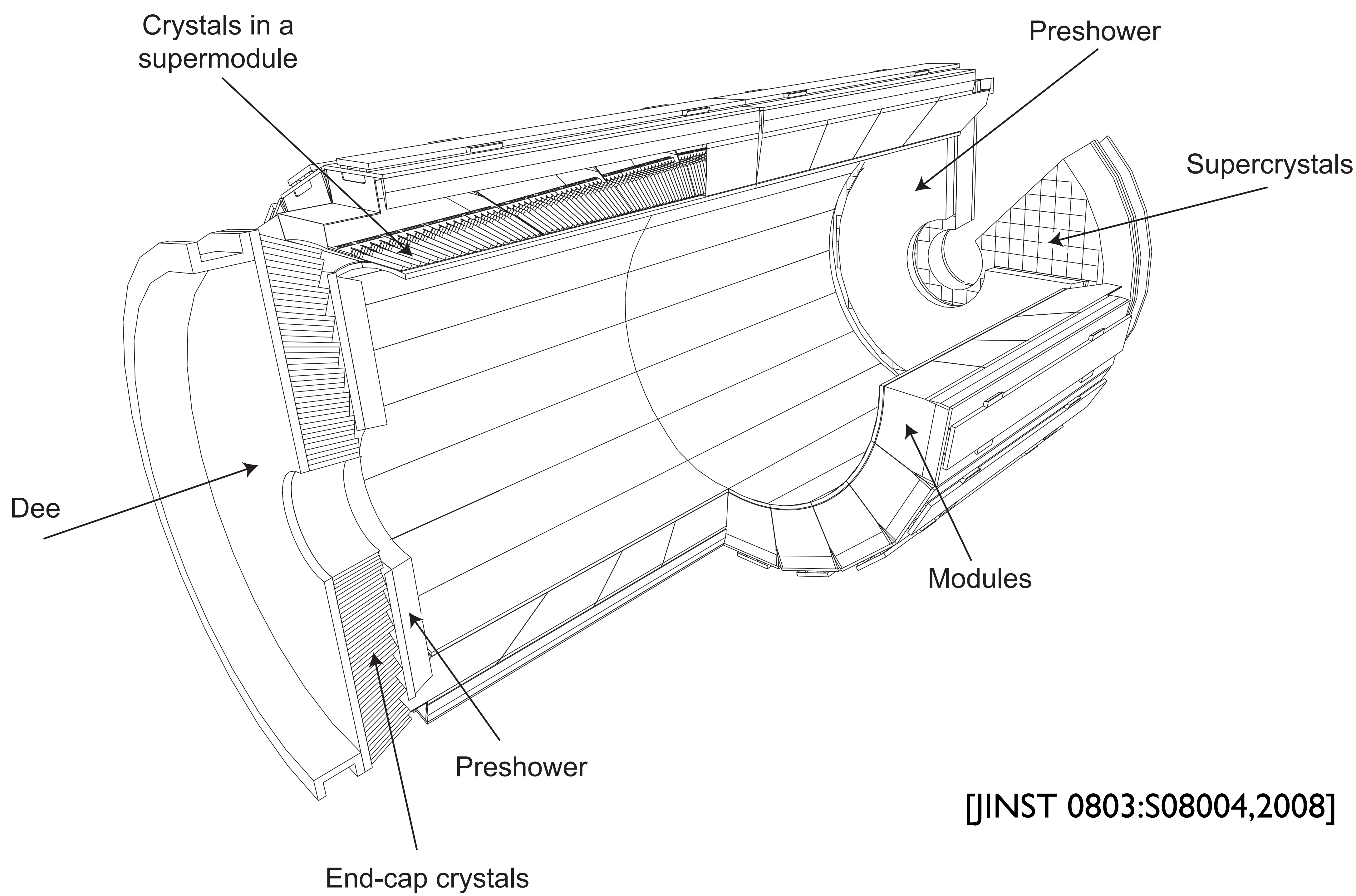
[CERN]

The CMS detector

For the study we will look at today, two of these subdetectors will be the most relevant:

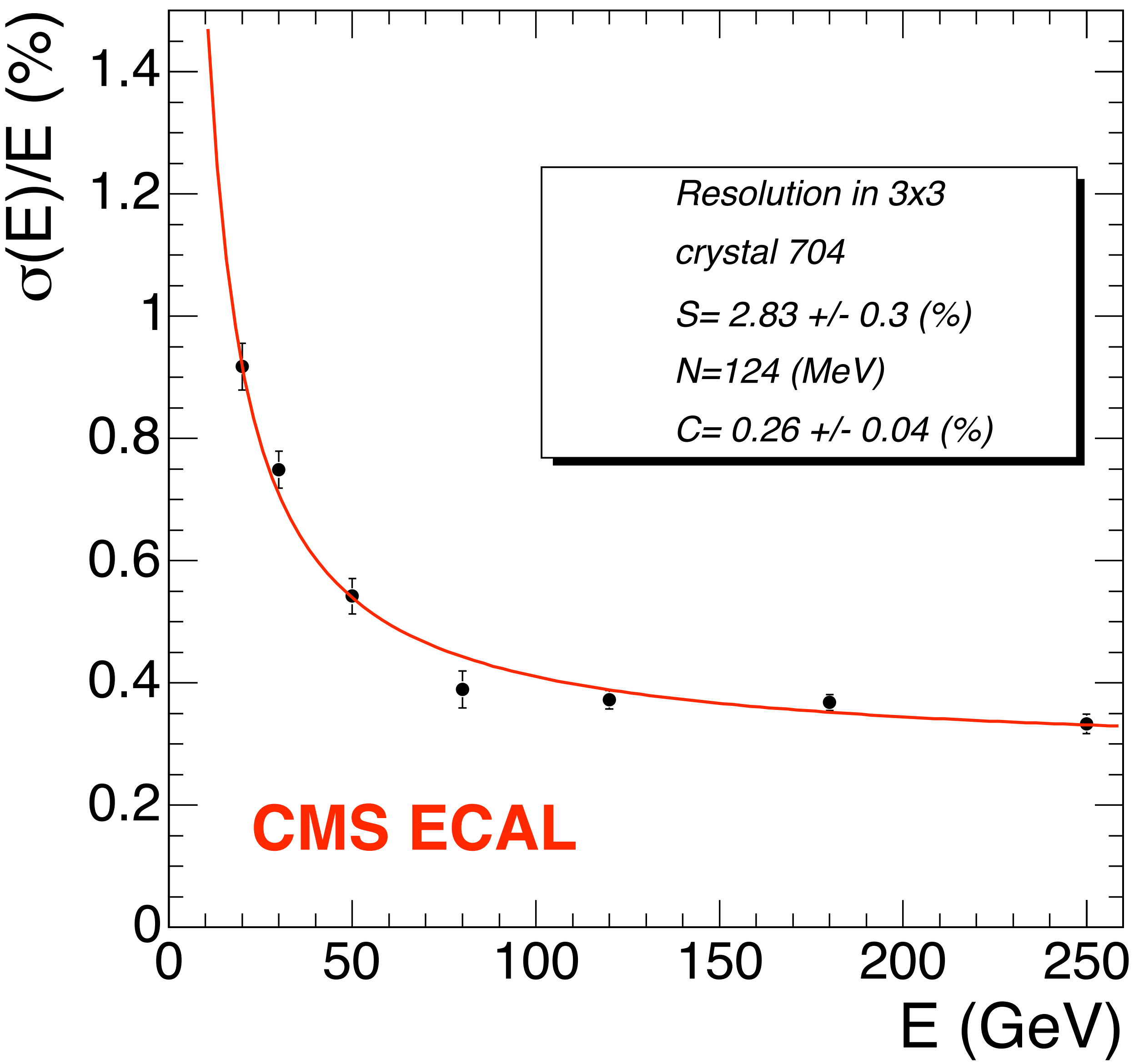
- The electromagnetic calorimeter (ECAL),
- and the inner tracking detector.

CMS ECAL



[JINST 0803:S08004,2008]

CMS ECAL



[JINST 0803:S08004,2008]

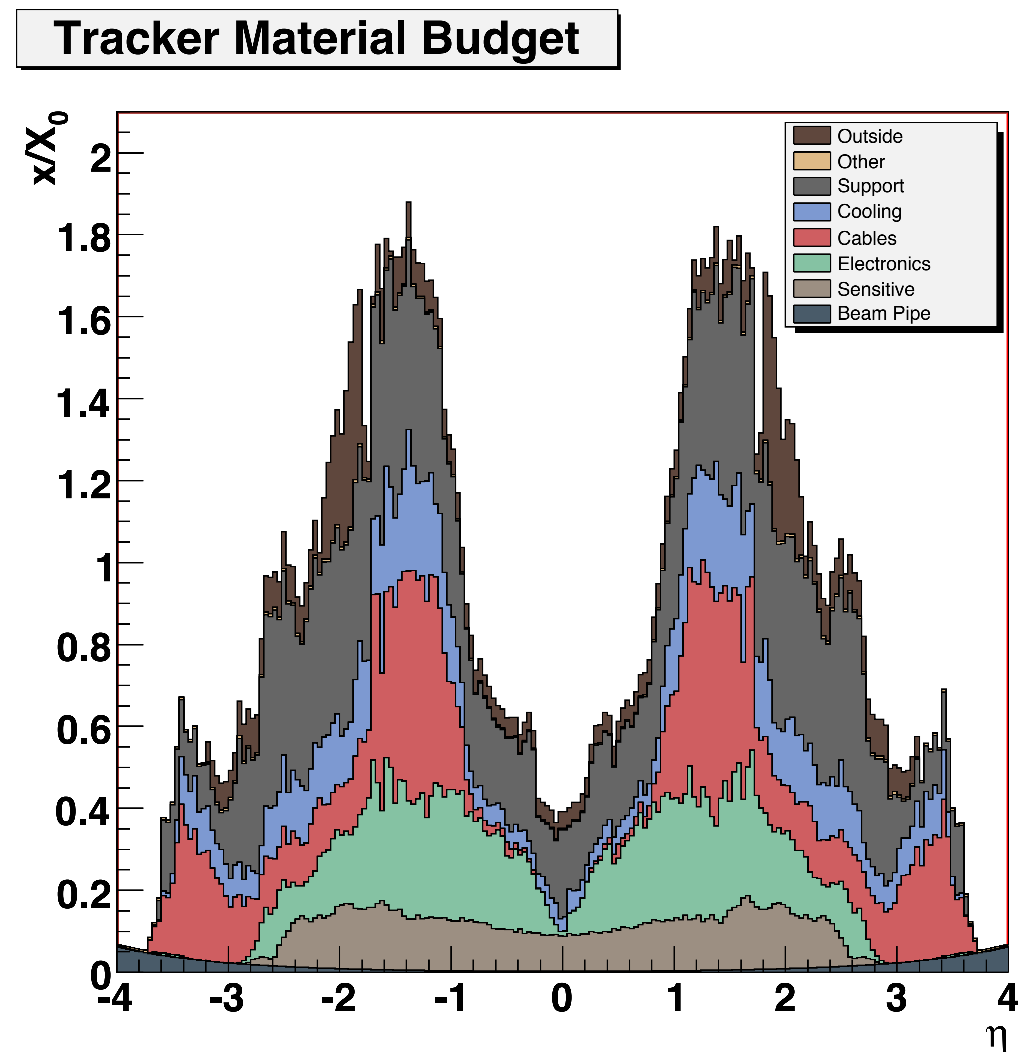
The ECAL is a hermetic, homogenous crystal calorimeter.

- Excellent energy resolution (~0.5% at 100 GeV).
- Nearly 80,000 channels provide the high granularity and low average occupancy needed to operate at high luminosities.
- Designed specifically with H → γγ in mind as a benchmark.

CMS inner tracker

The CMS inner tracker is designed to provide good performance in a very harsh environment (high occupancy and large radiation doses).

- All-silicon technology gives high granularity and fast response that is needed.
- Tracker requires a support structure to hold the sensors precisely, deliver a large amount of power (60 kW) and to cool the sensors and readout electronics.
- Resulting material is a medium for photon conversion and electron bremsstrahlung.



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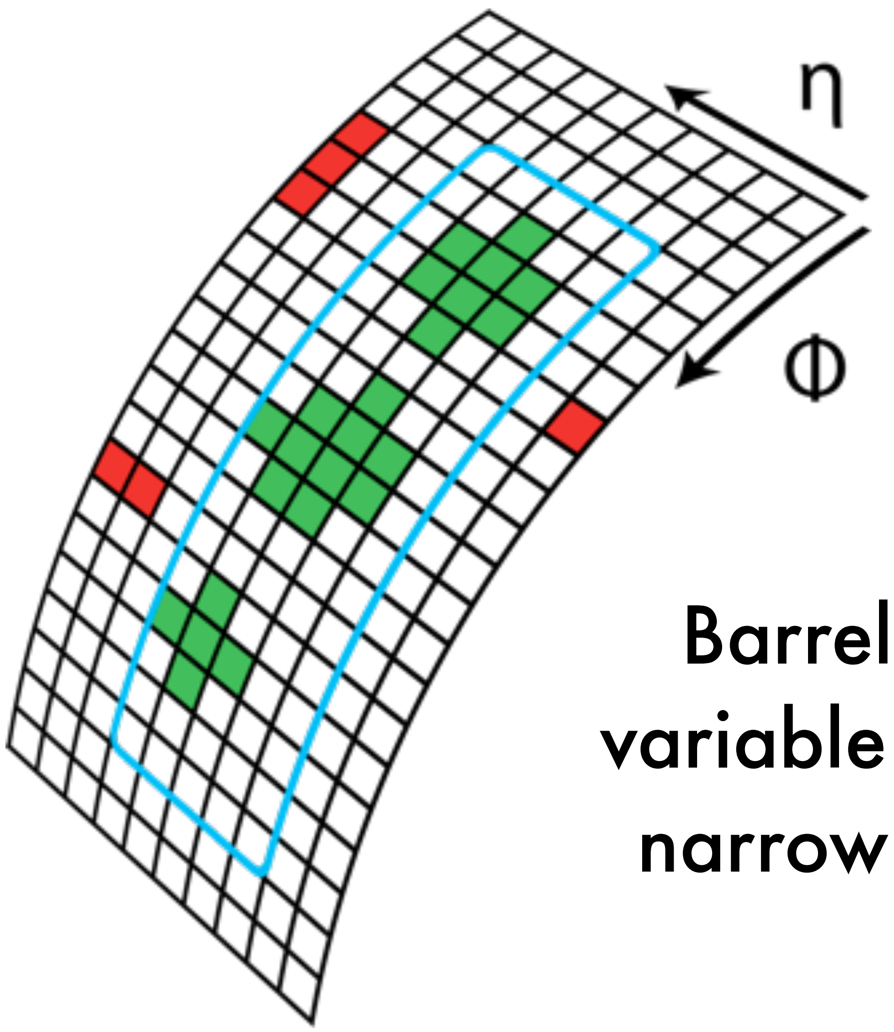
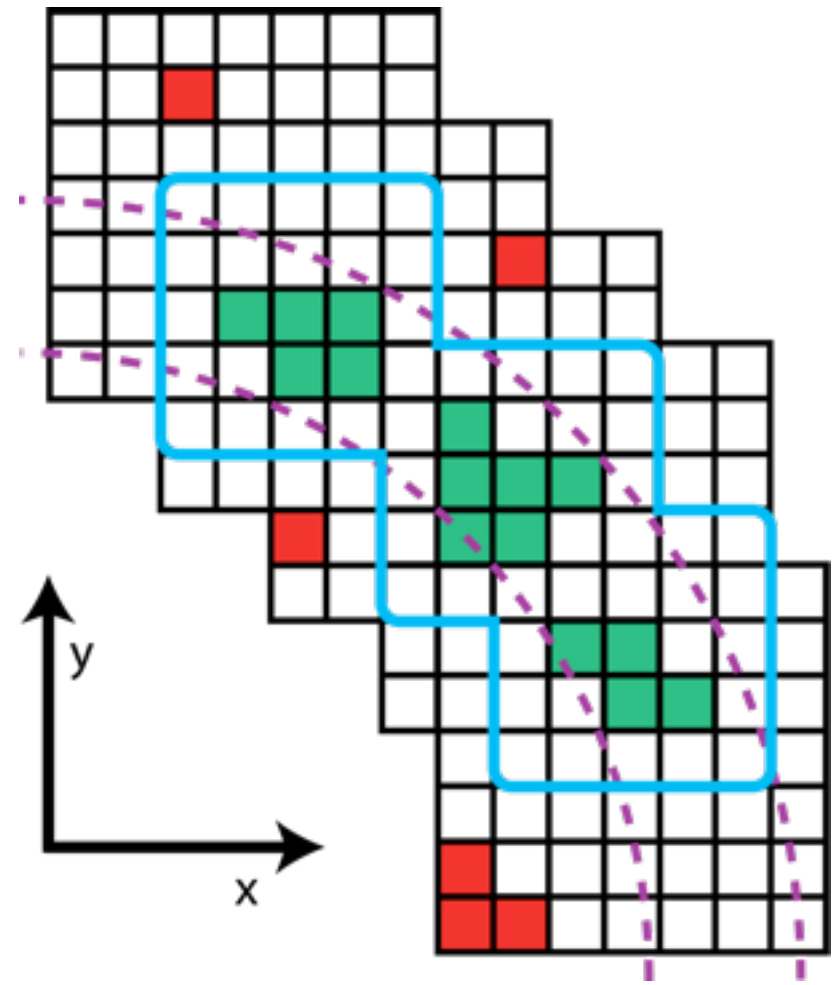
Photon reconstruction

Photon reconstruction algorithm ("superclustering") gathers the energy spread along φ by electrons from photon conversions and their radiation.

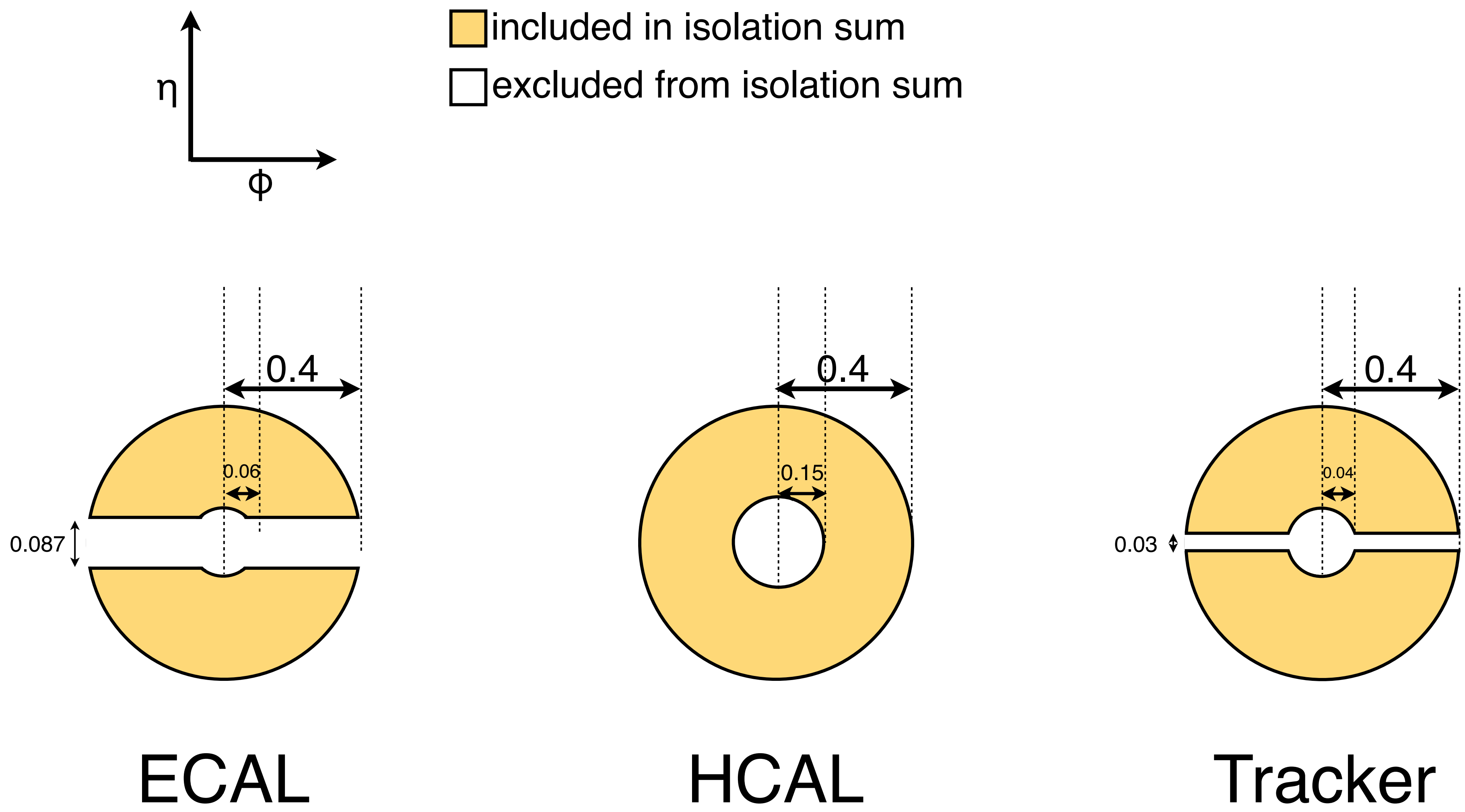


Barrel:
variable φ,
narrow η



Endcap:
merge 5x5s
along φ

Isolation cone shapes



Remove phi strip for consistency between unconv γ, conv γ, and electrons

Mapping between these cones and theory-level isolation understood with MC

not to scale

[figure courtesy R.Yohay]

Isolation criteria

The isolation criteria (following page) were chosen based on MC studies to provide a robust selection in data with (mostly) flat efficiency vs. candidate momentum and rapidity.

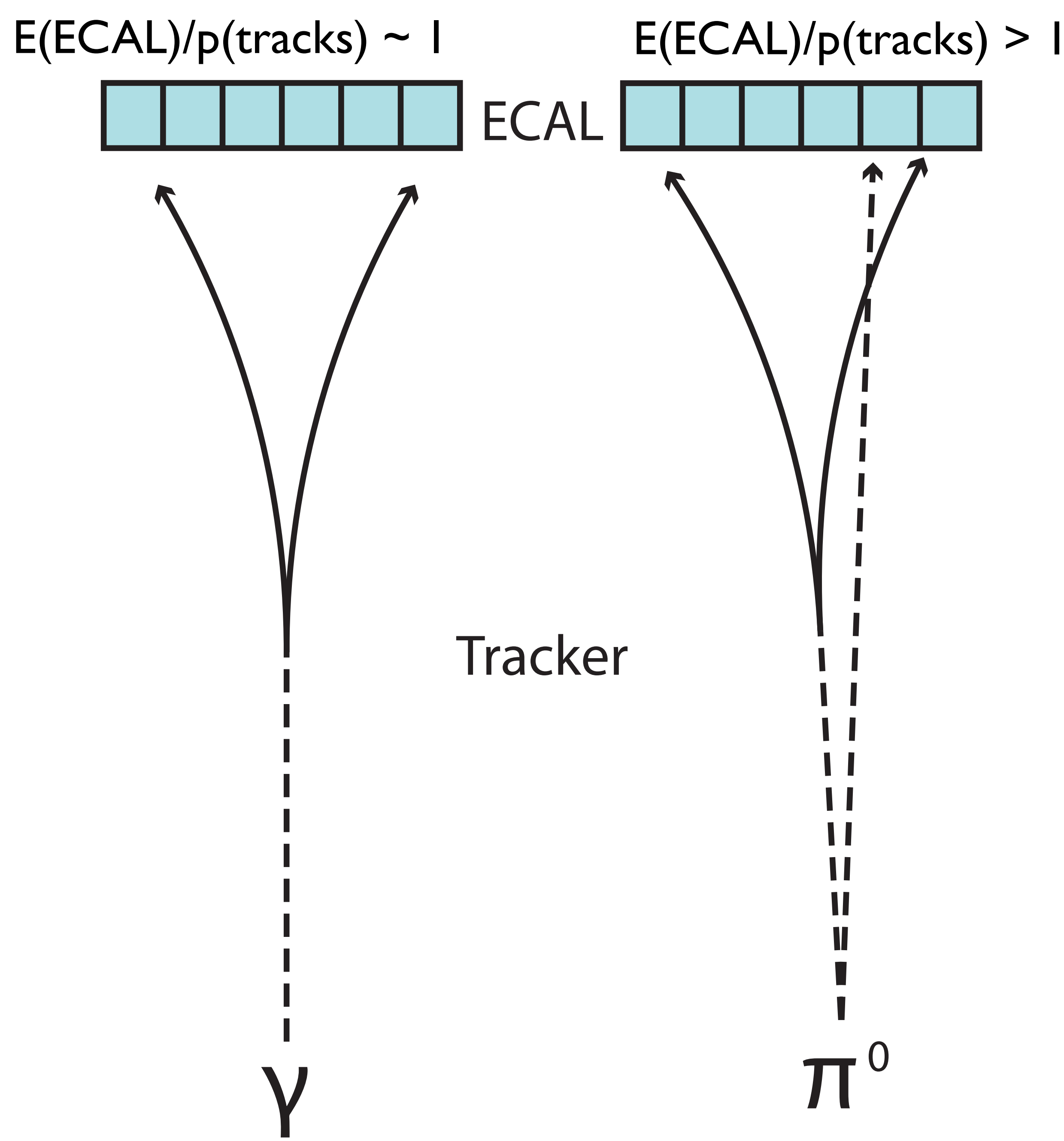
- Using isolation variables which work the same on photons and electrons allow us to use Z decays to electrons to measure the performance of the isolation criteria in data.

Selections

Cut	Signal region	Sideband region
	Photon conversion method	
H/E	< 0.05	< 0.05
$\mathrm{Iso}_{\mathrm{TRK}}$(GeV)	$< (2.0 + 0.001E_T)$	$(2.0 + 0.001E_T) \sim (5.0 + 0.001E_T)$
$\mathrm{Iso}_{\mathrm{ECAL}}$(GeV)	$< (4.2 + 0.003E_T)$	$< (4.2 + 0.003E_T)$
$\mathrm{Iso}_{\mathrm{HCAL}}$(GeV)	$< (2.2 + 0.001E_T)$	$< (2.2 + 0.001E_T)$
barrel: $\sigma_{i\eta i\eta}$	< 0.010	$0.010 \sim 0.015$
endcap: $\sigma_{i\eta i\eta}$	< 0.030	$0.030 \sim 0.045$
	Isolation method	
H/E	< 0.05	< 0.05
barrel: $\sigma_{i\eta i\eta}$	< 0.010	$0.0110 \sim 0.0115$
endcap: $\sigma_{i\eta i\eta}$	< 0.028	> 0.038

Conversions required to have a valid reconstructed vertex with $P(\chi^2) > 5 \times 10^{-4}$

Conversion method



For single photons, all momentum of the initial photon goes into the conversion tracks.

ECAL and tracker measurements agree.

For neutral pions, only one of the two photons is likely to convert.

In this case, the energy in ECAL will be more than the track pair momentum.

Best at low ET where the available statistics are largest

Conversion method

Conversion method uses a component fit of signal and background E/p distributions to determine the purity of the selected sample.

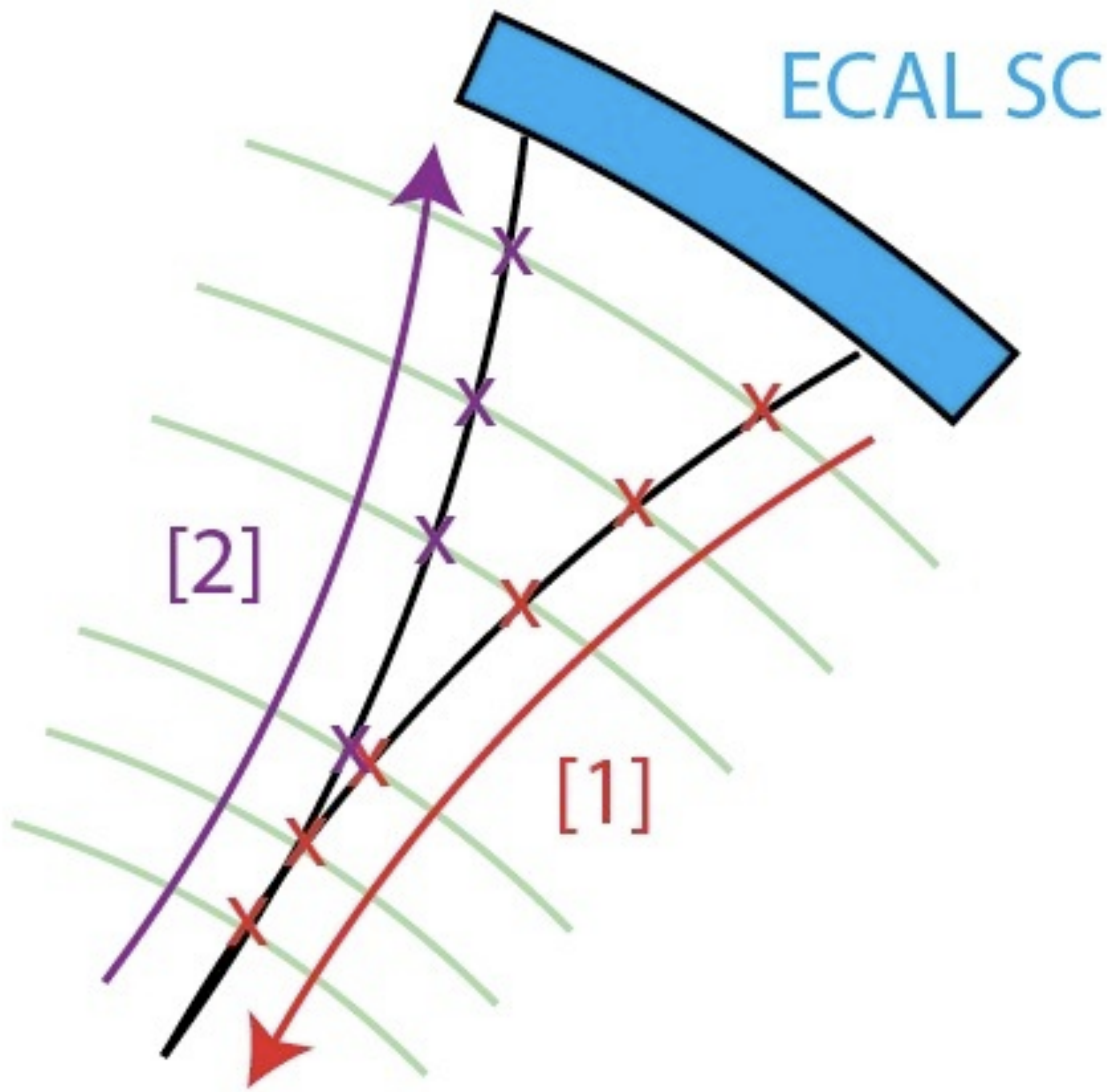
Main advantage:

- Tighter selection + requirement of a high quality conversion = can perform the measurement at lower pT with reasonable systematics.

Main challenge:

- Not all photons convert and not all conversions can be reconstructed, so available statistics are lower. Have to understand the efficiency of the conversion selection in data.

Reconstructing conversions



Here we use the ECAL-seeded conversion reconstruction.

- ECAL information can be used to seed a track-finding designed specifically to reconstruct conversion tracks.
- In the first step, we look for hits in the outer tracker layers which are consistent with an ECAL supercluster. Tracks are built by looking inward and collecting hits.
- In the second step, we assume the innermost hit of the first track is the conversion vertex, and look outwards for hits from the second track.
- Track pairs are fitted to a common vertex imposing the constraint that they are parallel at the vertex, and the tracks are refit with the vertex constraint.

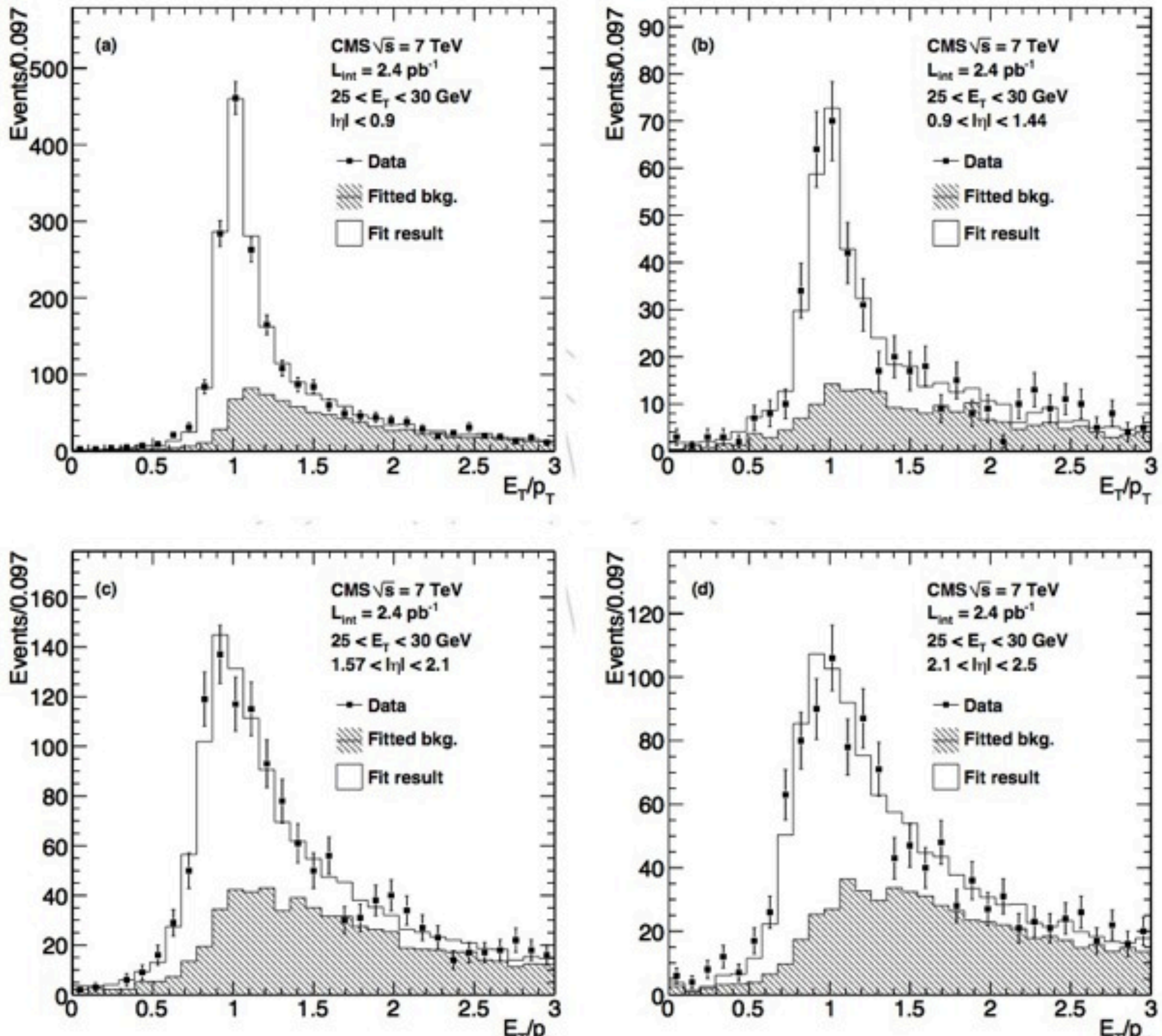
Conversion template fits

Apply selection on isolation and shower shape of photon candidate and then fit for the signal yield using E/p.

Conversions are required to pass quality cuts on reconstructed vertex.

Signal and background templates come from MC and are checked against data:

- Signal - vary peak position/width
- Background - get template from sideband region in data



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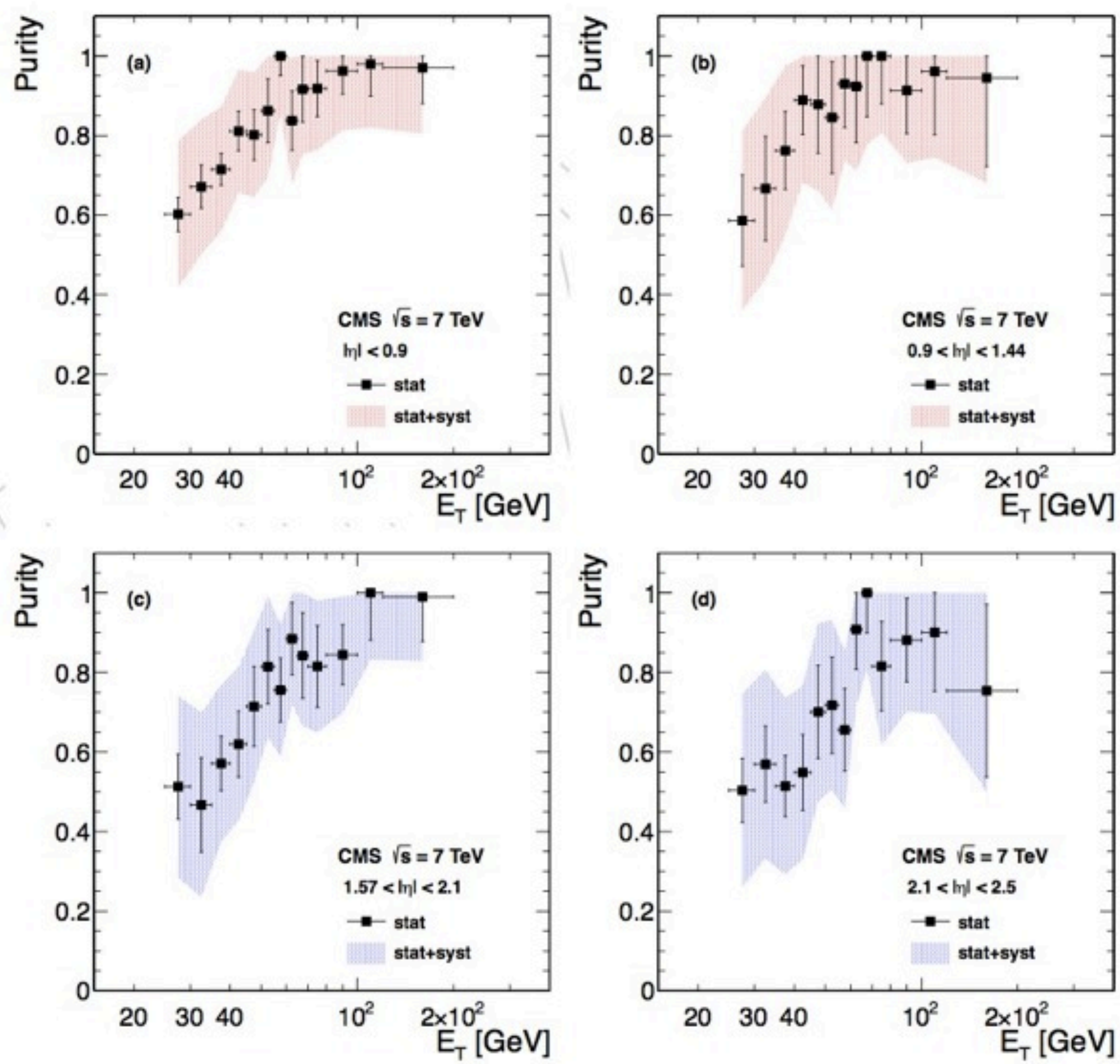
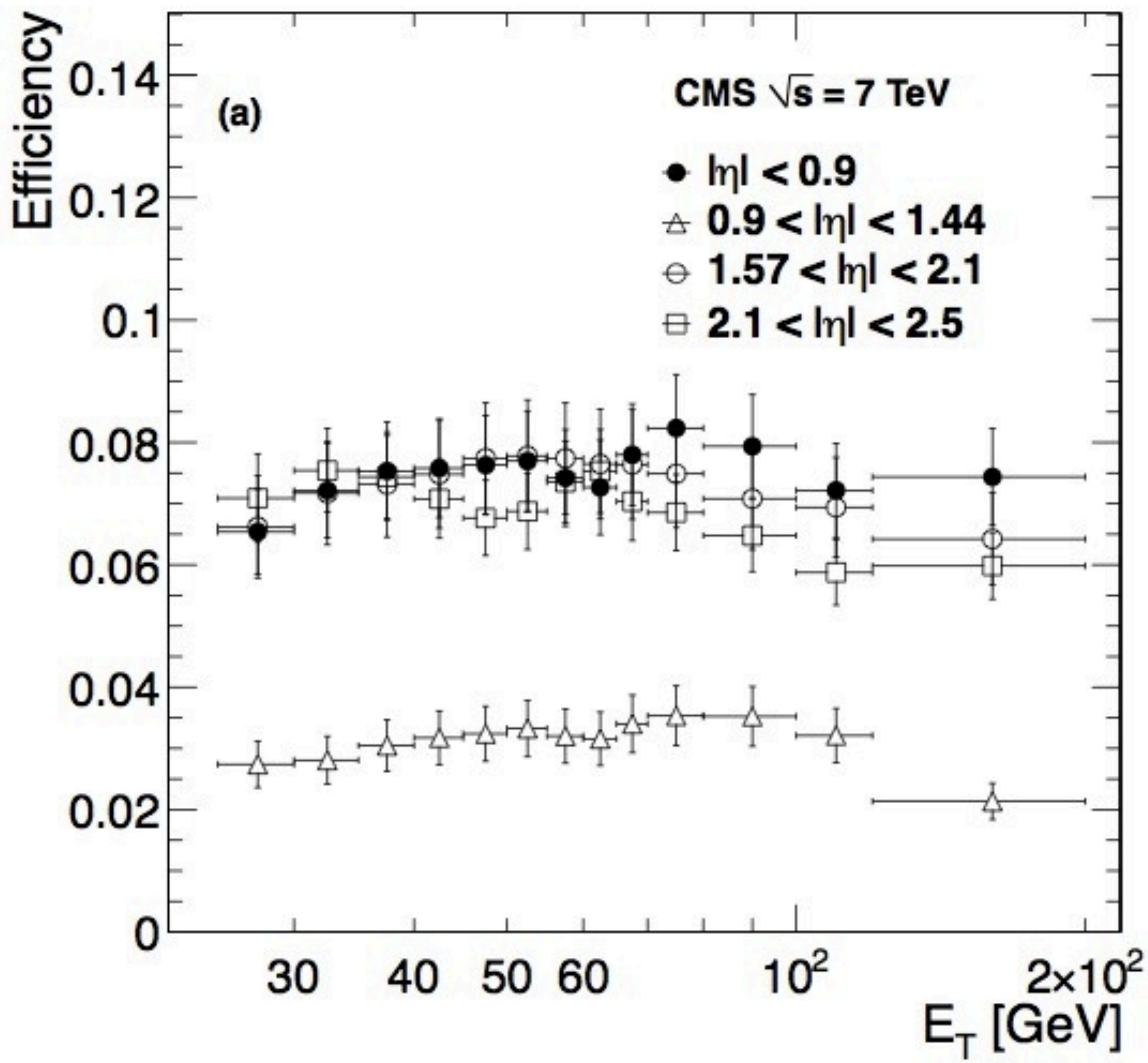
Conversion purity

Using full conversion, isolation and shower shape selection means that purity in data is high, leading to lower systematic uncertainties on the signal yield.



Conversion efficiency



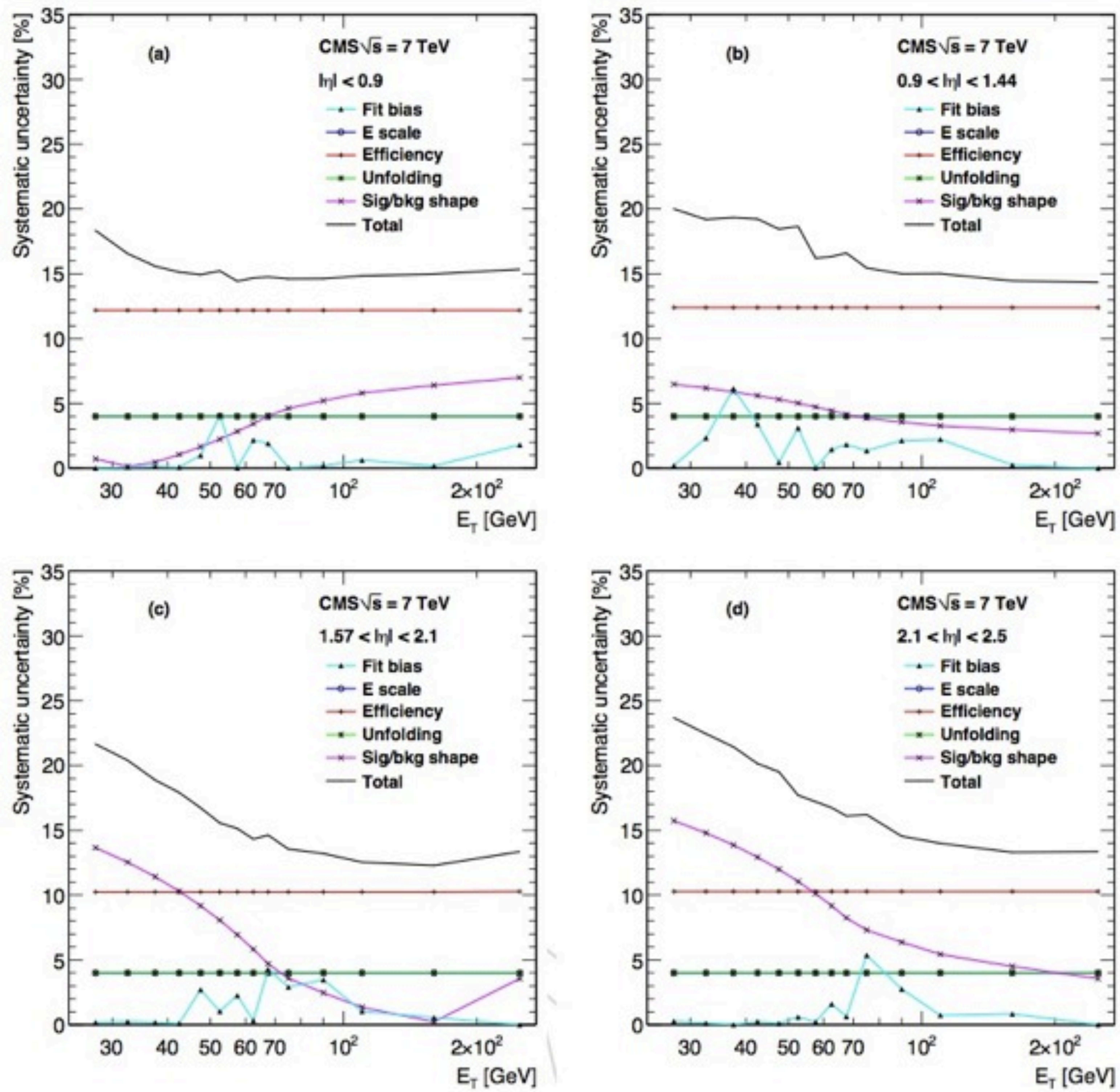
Efficiency of conversion selection is a product of the trigger, reconstruction, and isolation efficiencies, and conversion fraction.

- Trigger: simple trigger requiring a photon candidate with minimum E_T. Measured to be ~100% efficient using Z→ee electrons.
- Reconstruction: ~100% (simulation).
- Identification: use Z→ee electrons to measure the efficiency of the isolation selection. Use MC to correct for differences between electrons and photons.
- Conversion fraction: Product of conversion probability, conversion reco efficiency, and conversion quality selection. Estimated in data by comparing isolation of candidates before/after the conversion selection.

Conversion systematics

Dominant systematic uncertainties:

- Sig/bkg shape (vary signal shape and bkg template source)
- Efficiency estimate (vary selections & samples used)
- Unfolding correction (bin-by bin unfolding of E_T response)
- ECAL energy scale (vary within uncertainty)

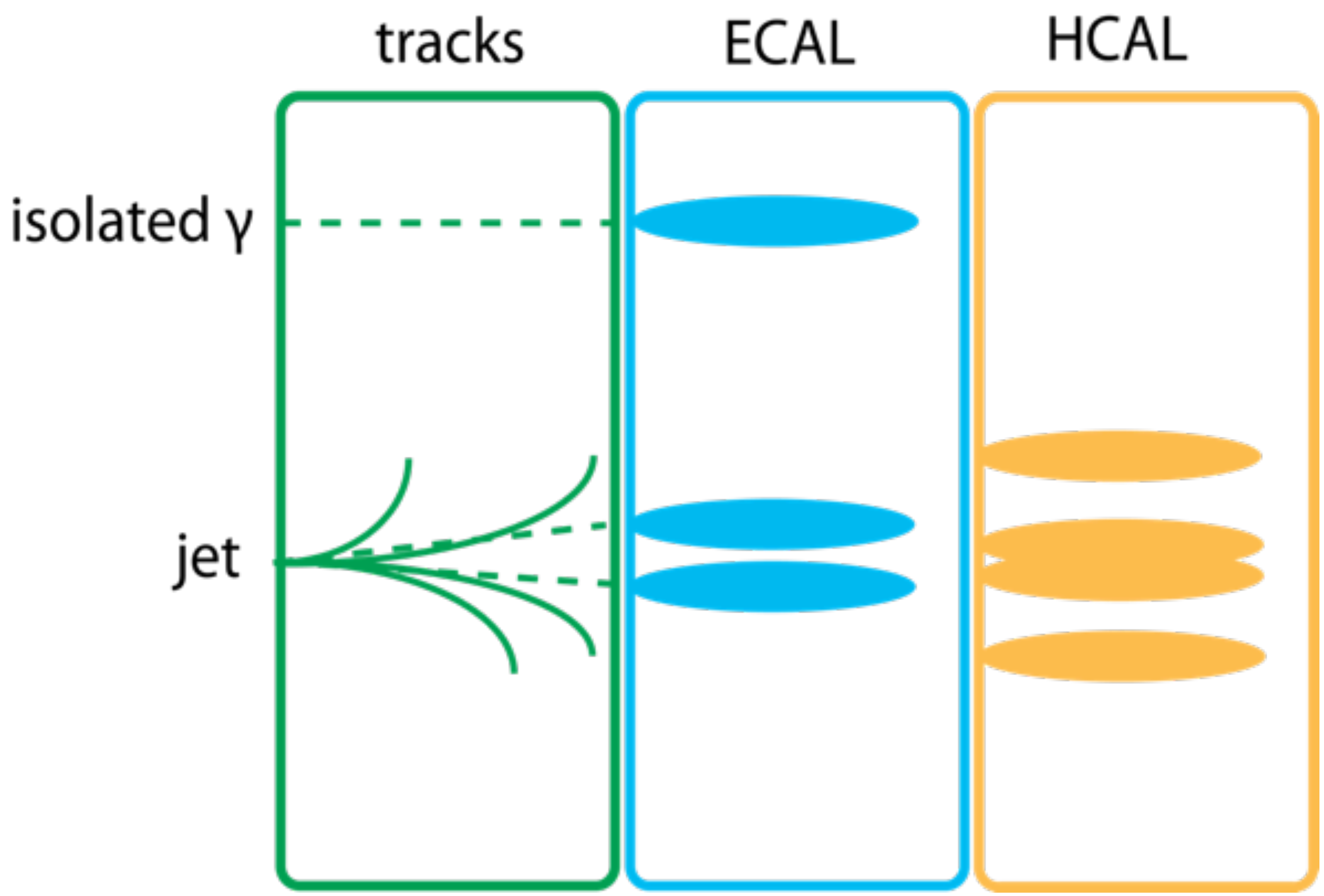


Isolation method

Isolated prompt photons typically have a total isolation (ECAL+HCAL +tracks) less than 5 GeV.

Neutral meson background typically has larger isolation sum.

Method is more powerful at high E_T where isolation distribution shape systematics are smallest.

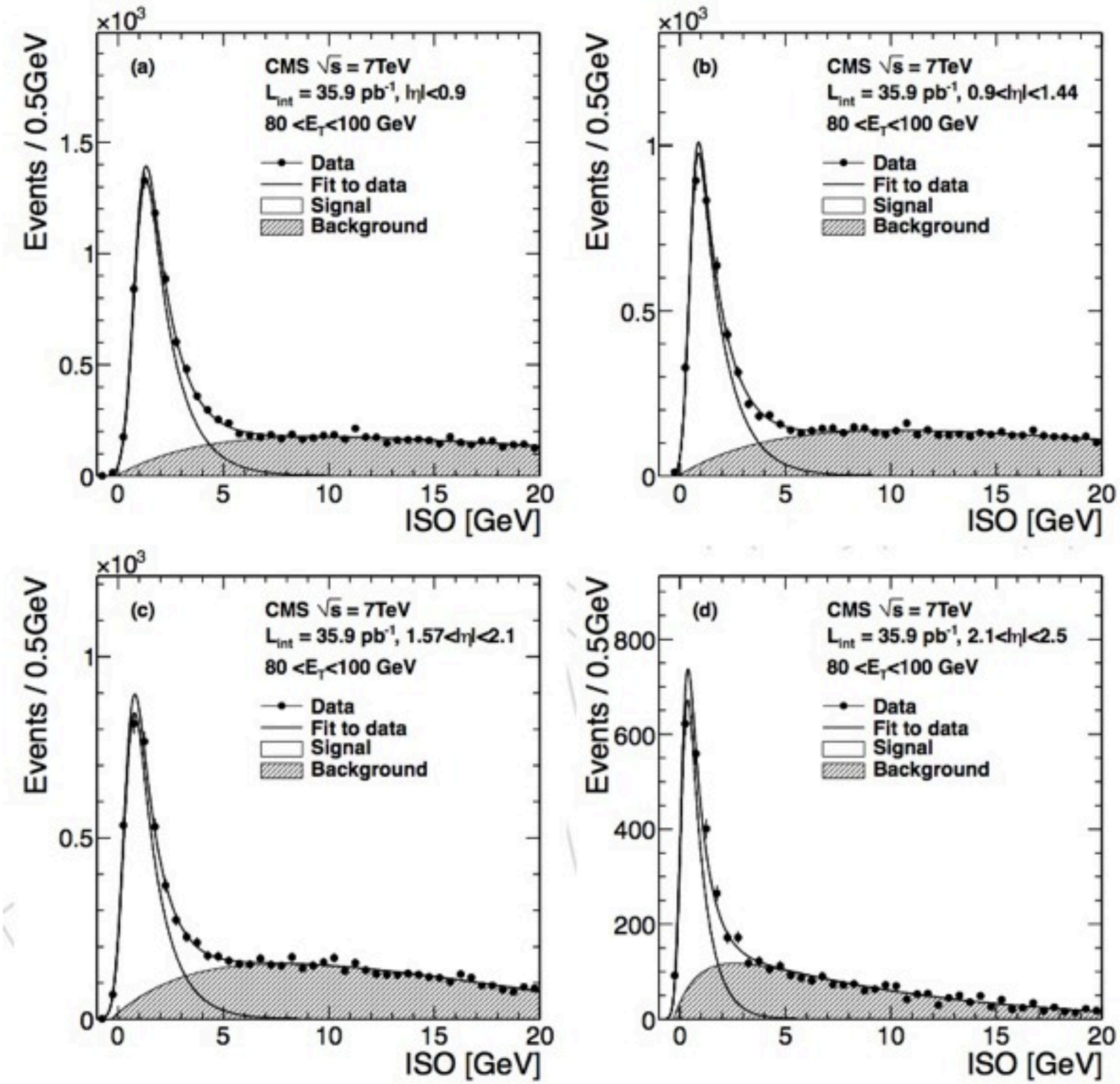


Isolation template fits

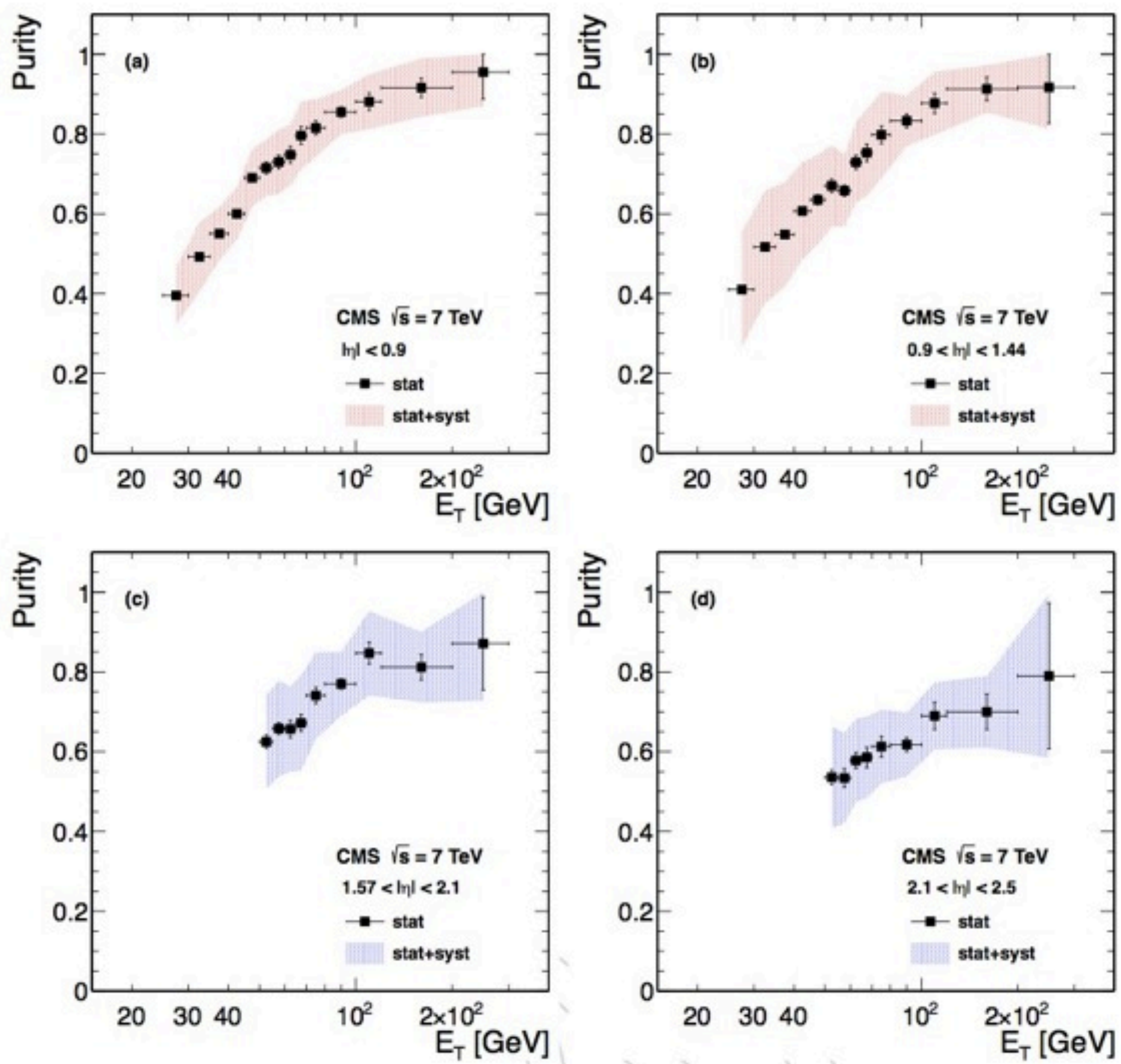
Select photon candidates based on shower shape and then extract the signal using the isolation distribution.

Veto on matching hits in the pixel layer ("pixel seed") excludes prompt electrons.

- Signal shape comes from MC and is corrected for MC/data differences using Z→ee electrons.
- Background shape constrained with sidebands in the cluster shape selection.



Isolation method purity



Purity of isolation sample less than for conversions.

Low E_T bins at high rapidity are not used–purity becomes too low to extract signal well.

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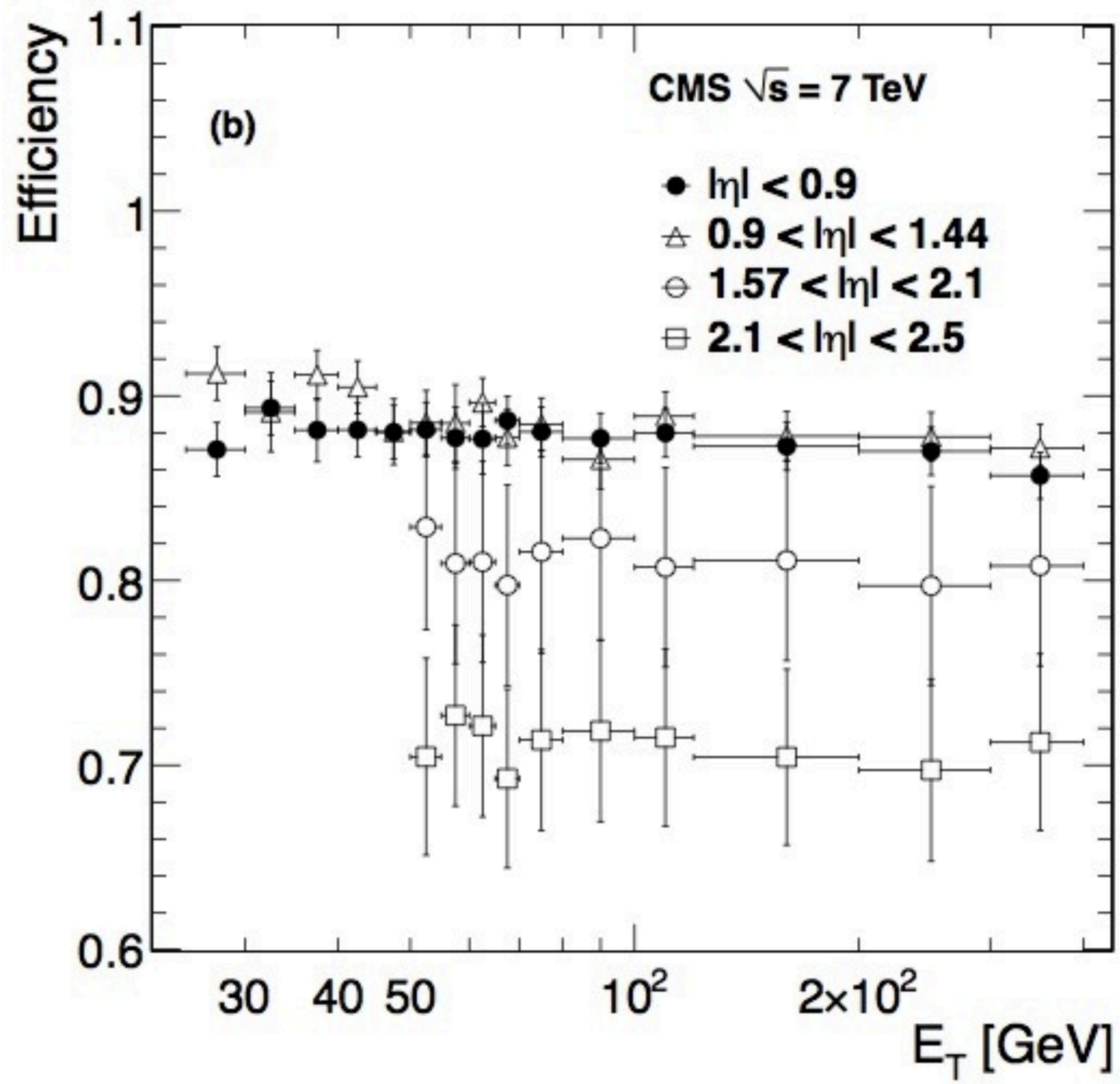
Isolation efficiency

Efficiency of the isolation selection measured in data:

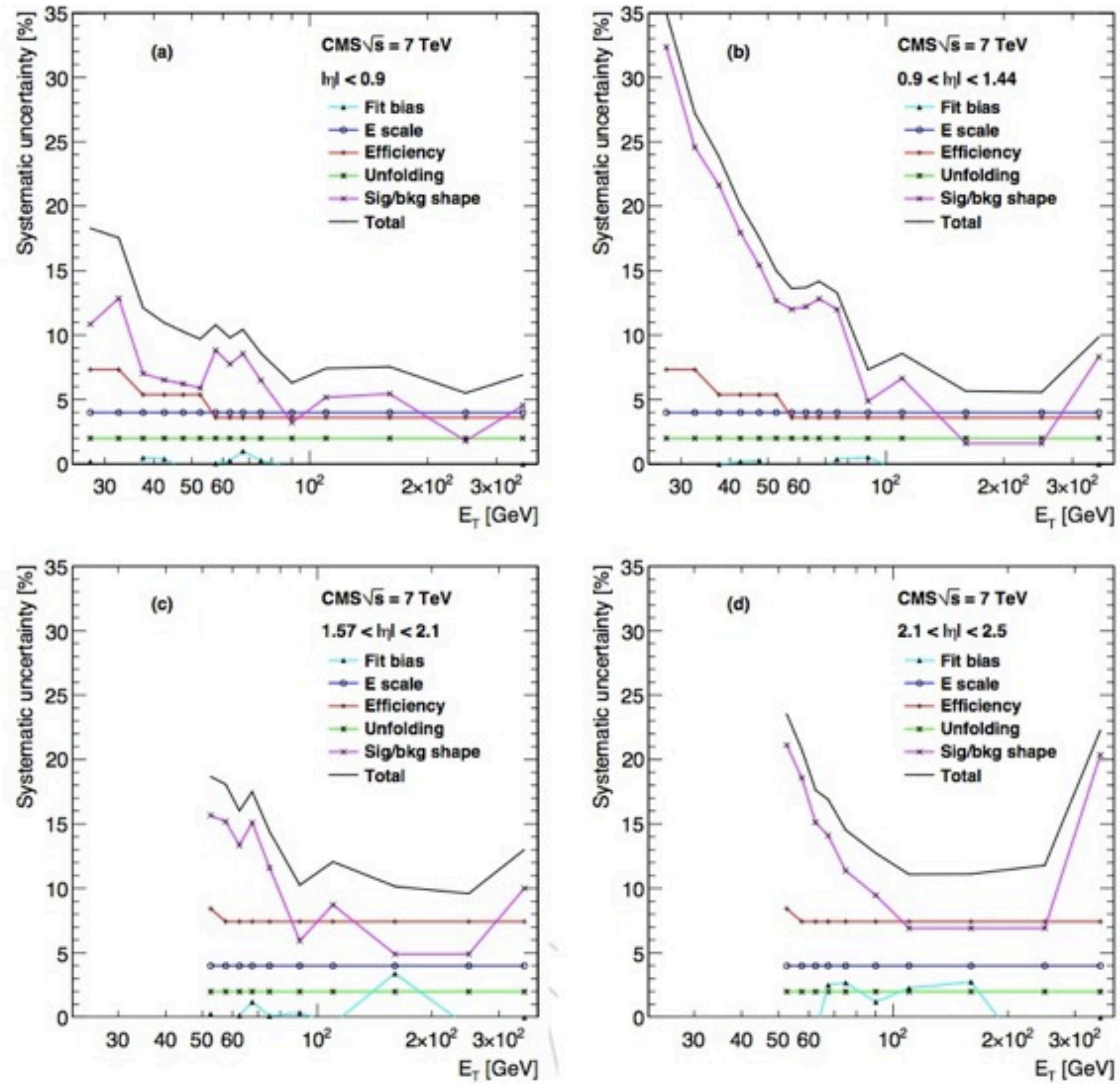
- Z→ee events used to estimate efficiency of shower shape cuts, corrected for e/γ differences.
- Z→μμγ events are used to estimate the efficiency of the veto on pixel seed.



Isolation systematics

Dominant uncertainties:

- Sig/bkg shape (estimated using control samples in data)
- Selection efficiency (from $Z \rightarrow ee$ events)
- ECAL energy scale (vary within uncertainty)



Luminosity

Due to the constantly increasing LHC luminosity, it was necessary to raise the pT threshold for photon triggers. The amount of data in each pT bin depends on the trigger menus deployed.

E_T(GeV)	Integrated luminosity (pb^{-1})
25–35	2.4 ± 0.1
35–55	8.2 ± 0.3
55–80	17.6 ± 0.7
> 80	35.9 ± 1.4

JETPHOX prediction

JETPHOX is a NLO cross section integrator for photon + X processes [2].

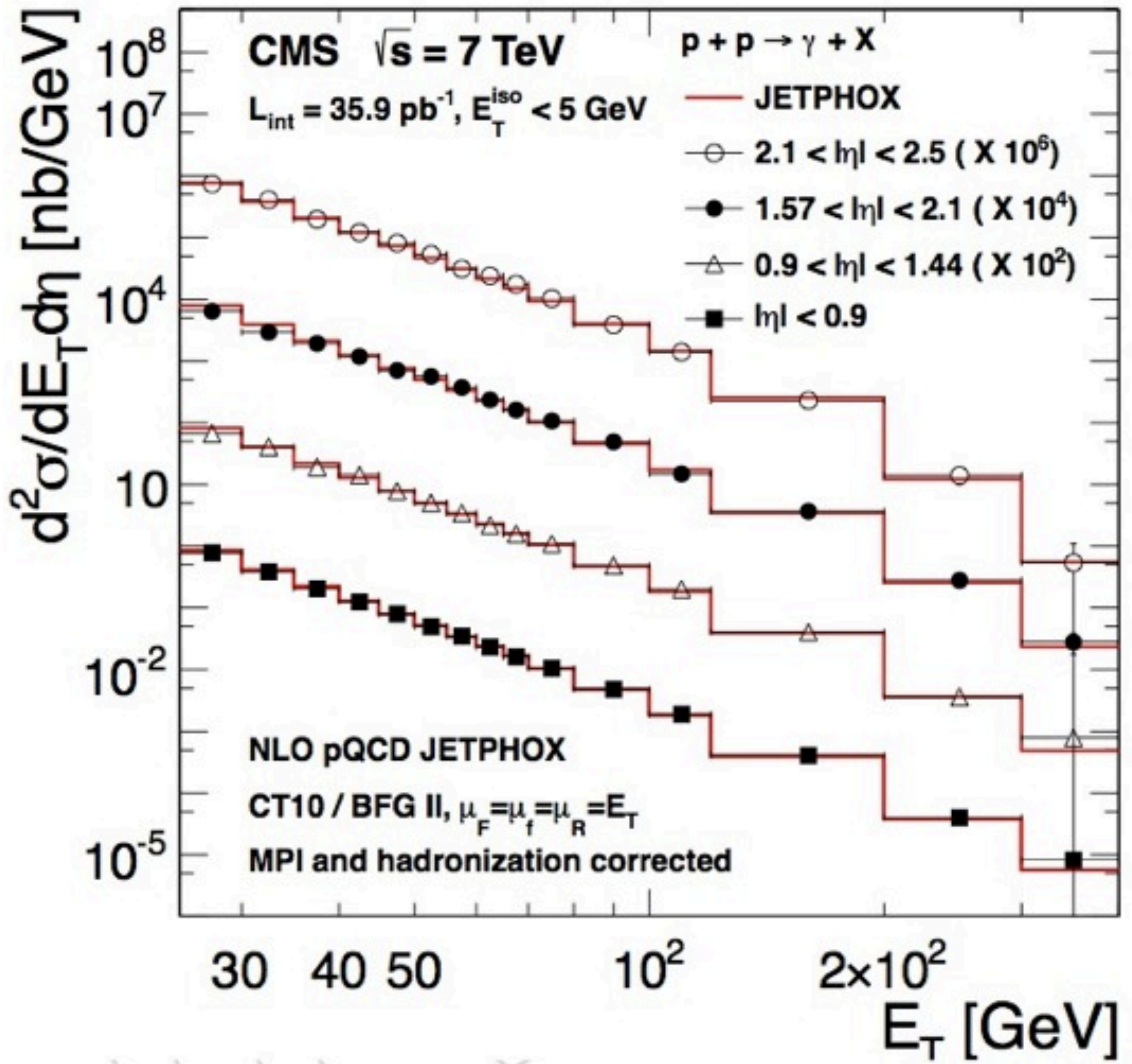
- Used most recent stable version 1.3.0.
- CT10 PDF sets are used. Uncertainty is estimated using the 52+1 CT10 sets at 68% CL. $\alpha_s(M_Z)$ uncertainty is added in quadrature.
- BFGII fragmentation functions used for fragmentation processes. Uncertainty estimated by swapping between BFGII and BFGI sets.
- Require $\Sigma_{pT} < 5$ GeV of momentum inside DR < 0.4 around photon direction–matches the isolation selection used in data.
- Renormalization, factorization, and fragmentation scales are varied between 1/2 the photon ET and twice the photon ET allowing the difference between any two to be at most 2. Resulting scale uncertainty is between 7% and 22% (worst at low ET).
- Additional correction C for other event activity is estimated by switching off the UE and hadronization in PYTHIA simulated events and swapping between Z2, D6T, DWT, and Perugia0 tunes–factor is 0.975 ± 0.006 and does not exhibit any pT or η dependence.

Combined results

Results of the two methods are compatible at the 1σ level.

To leverage the complementarity of the two methods (conversion more precise at low E_T, isolation at high E_T) we combine the results using the BLUE method [1].

Differential cross section compared to JETPHOX [2] is shown.

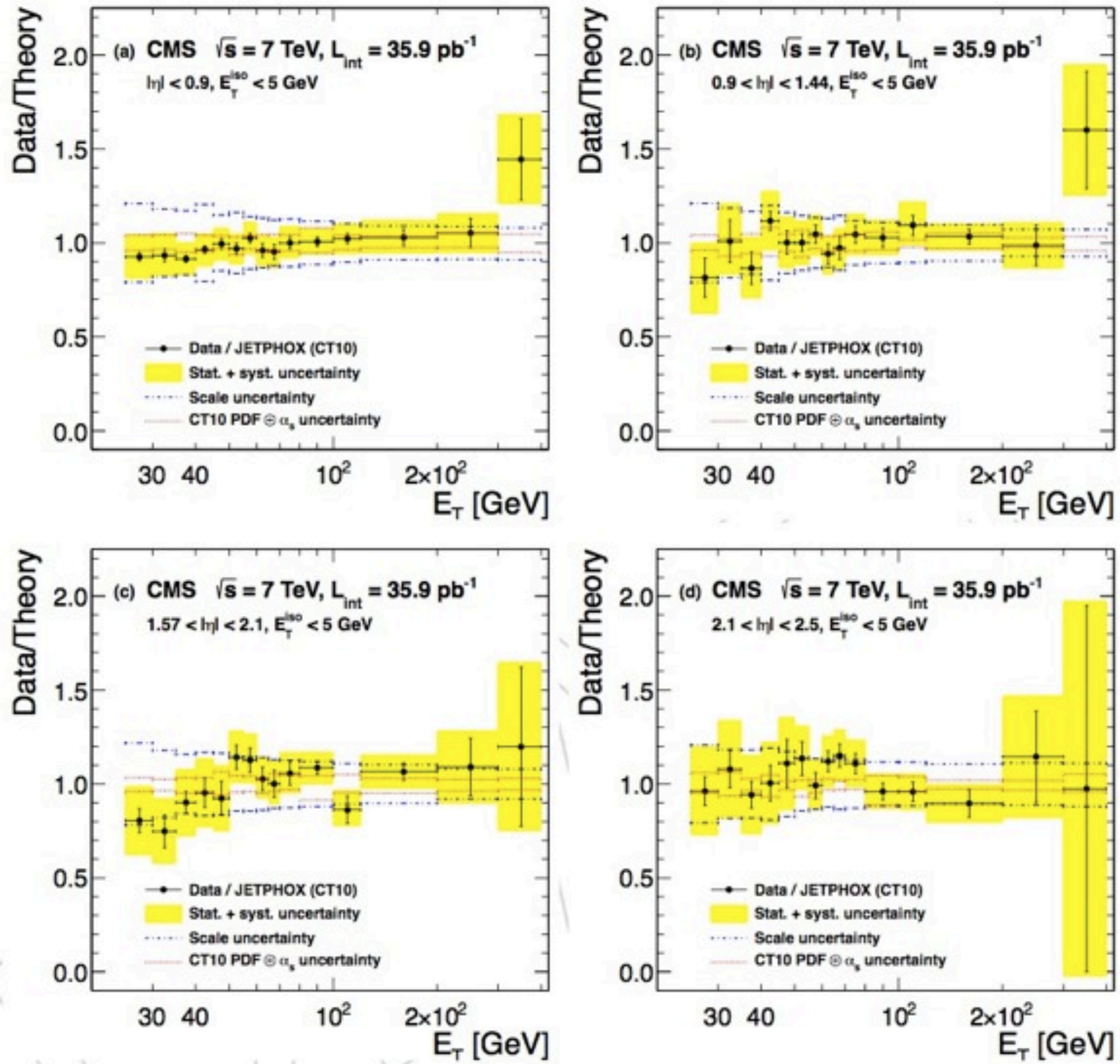


Ratio to JETPHOX

Data/theory ratios for JETPHOX 1.3.0 with CT10 [3] PDF set.

- Theory uncertainties dominated by scale uncertainty (μ_F, μ_R, μ_f varied between $2E_T$ and $E_T/2$).
- PDF uncertainties from CT10 eigenvectors and α_s uncertainty.

Data agrees with theory within uncertainties.



Conclusions

We have measured the inclusive isolated prompt photon cross section, differential in E_T and η, using the full 36 pb^{-1} collected in 2010.

The η coverage is extended to $|\eta| < 2.5$ and divided into four bins. The E_T coverage is extended from 25-400 GeV.

We combine two methods: conversion (best at low E_T) and isolation (best at high E_T).

We find agreement with the NLO predictions computed by JETPHOX over the whole range.

Measurement has been published by PRD on 29 September: http://prd.aps.org/abstract/PRD/v84/i5/e052011

References

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[2] S. Catani, M. Fontannaz, J. P. Guillet et al., "Cross section of isolated prompt photons in hadron-hadron collisions", JHEP 05 (2002) 028, arXiv:hep-ph/0204023. doi:10.1088/1126-6708/2002/05/028.

[3] H.-L. Lai, M. Guzzi, J. Huston et al., "New parton distributions for collider physics",Phys. Rev. D82 (2010) 074024, arXiv:1007.2241.doi: 10.1103/PhysRevD.82.074024.

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