Prompt photon production at 7 TeV with CMS

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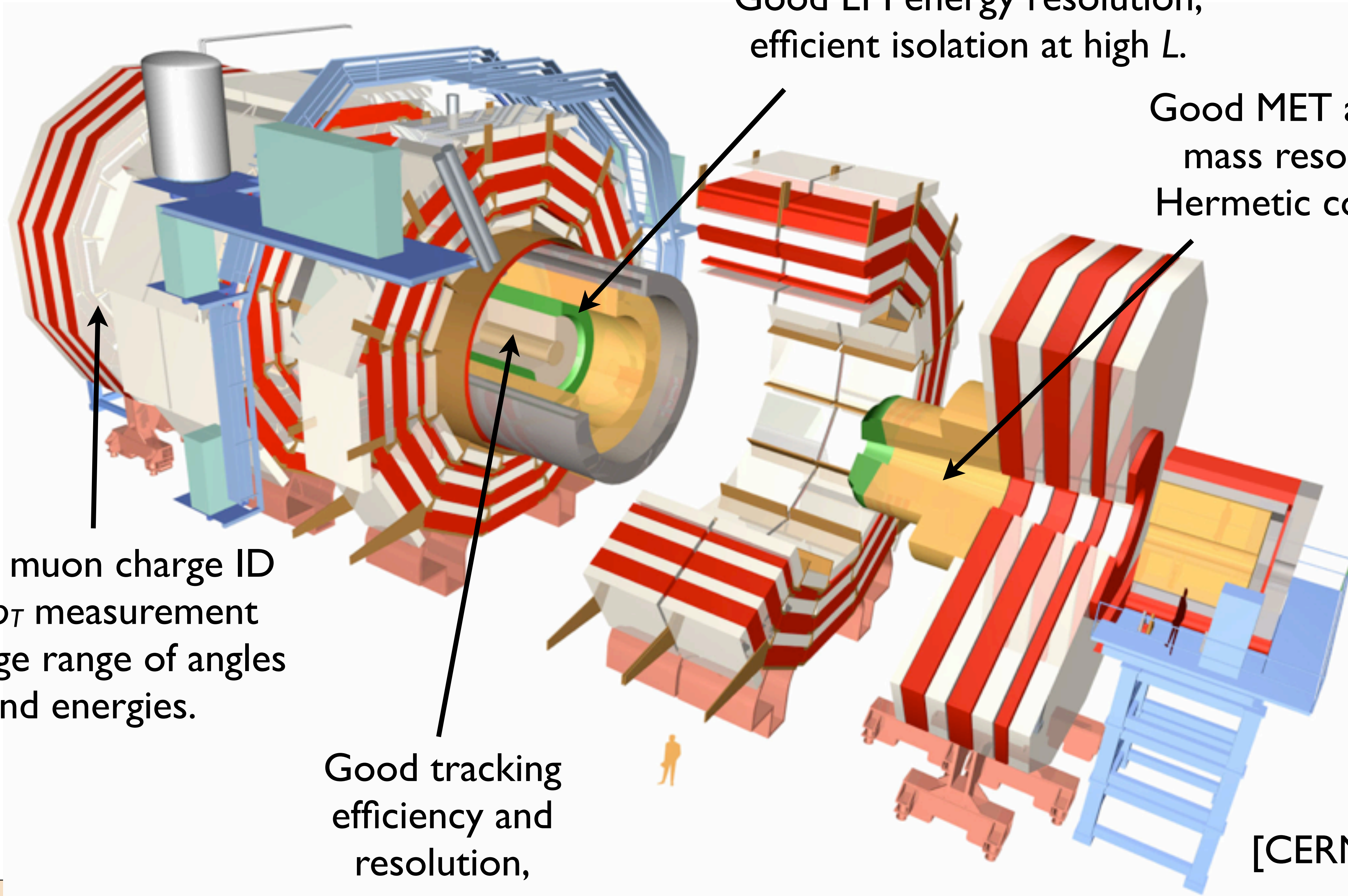
Overview

CMS produced the first measurement of the isolated photon cross section at the LHC for $|\eta| < 1.45$ and $21 < p_T < 300$ with 2.9 pb^{-1}:

- CMS and ECAL features.
- Photon isolation at CMS.
- Signal extraction with shower shape method.
- Cross section measurement.

The Compact Muon Solenoid



[CERN]

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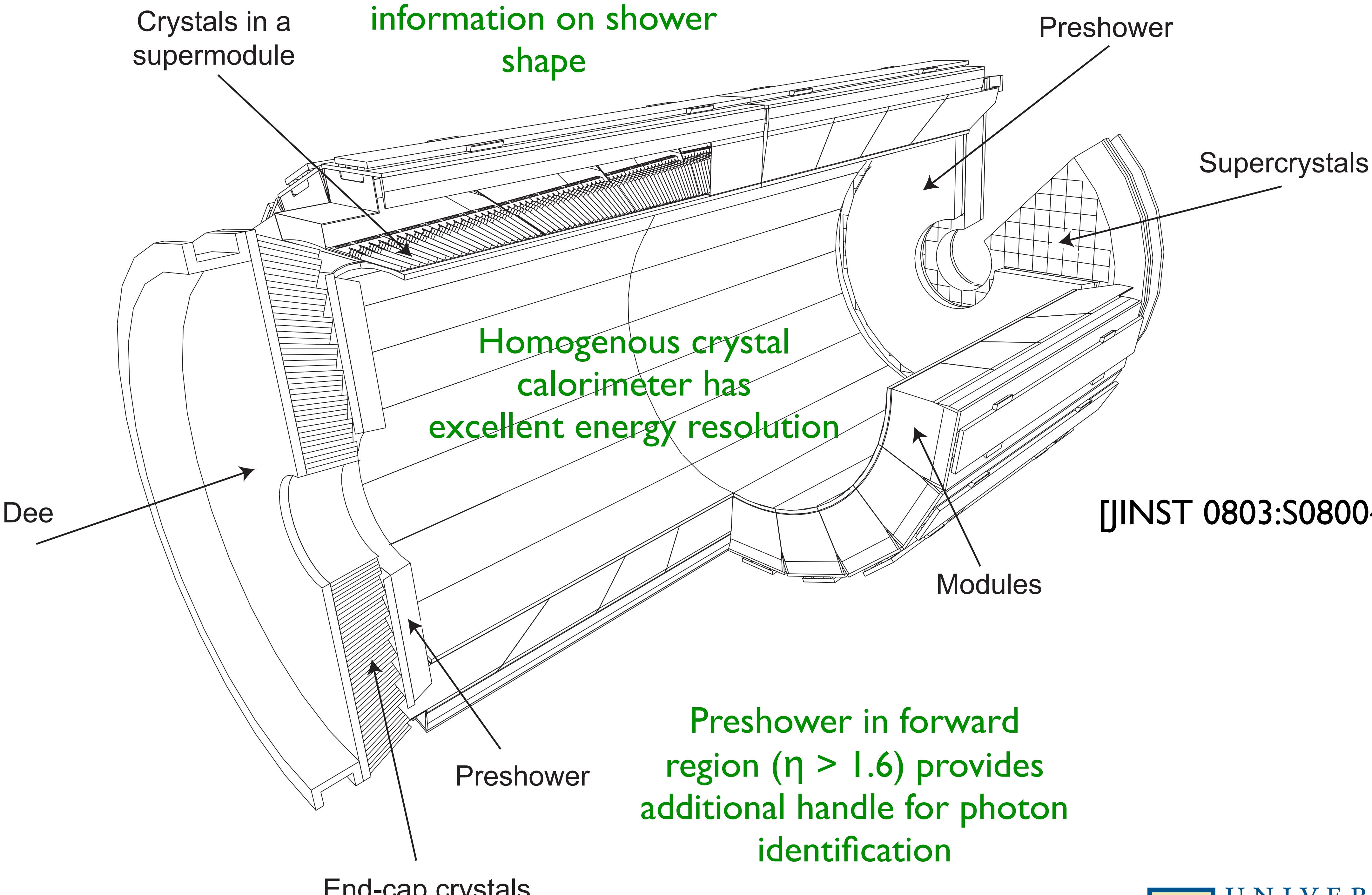
CMS ECAL

Fine segmentation produces detailed information on shower shape

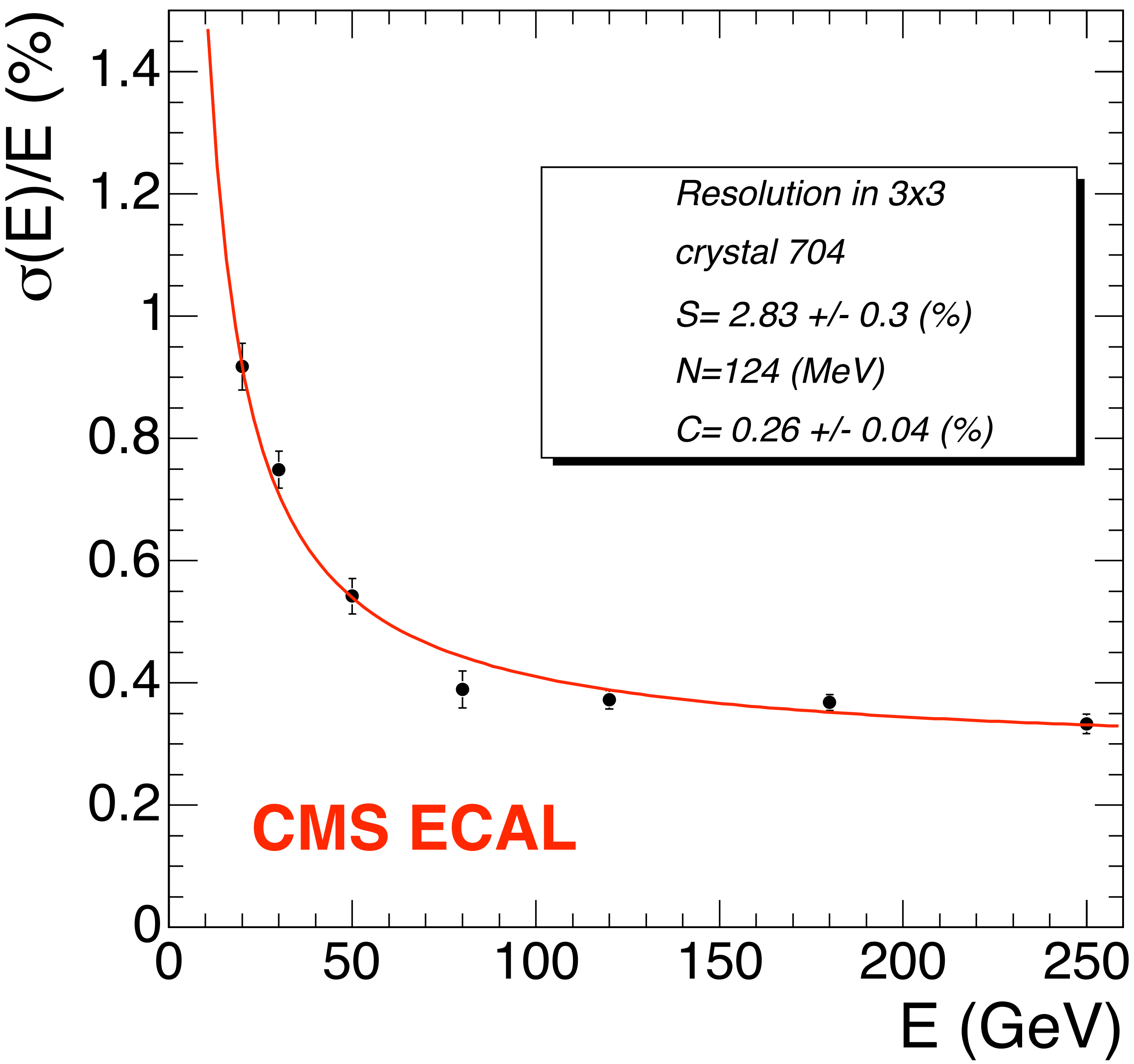


Homogenous crystal calorimeter has excellent energy resolution

[JINST 0803:S08004,2008]

Preshower in forward region ($\eta > 1.6$) provides additional handle for photon identification

CMS ECAL



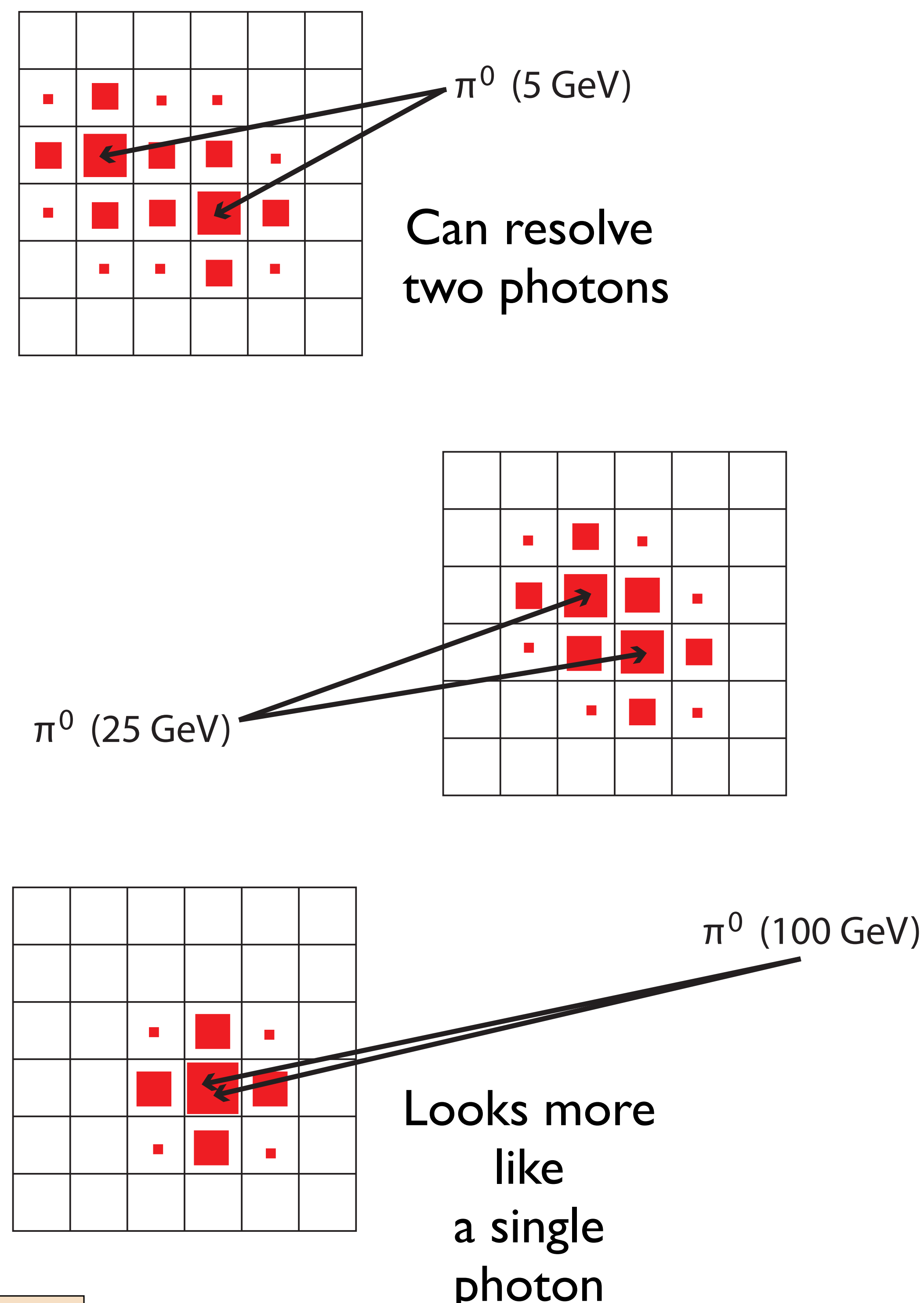
[JINST 0803:S08004,2008]

Energy resolution measured in testbeam (2006)

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. Detailed picture of shower shape can be used to identify photon signal.
- Designed specifically with $H \rightarrow \gamma\gamma$ in mind as a benchmark.

Background to photon measurements



Jets can fake photons.

- If a large fraction of initial parton energy goes into a single high energy π^0, the photon pair it decays to can look like a single photons.
- Dijet events where one jet looks like this can fake photon + jet.
- Photon plus jet where the jet looks like this may fake a two-photon final state. This forms a main reducible background to e.g. $H \longrightarrow \gamma\gamma$.
- Or jet may emit photon during fragmentation, so there is a real photon near a jet.

The QCD cross section is huge at the LHC. We want to measure these backgrounds, and learn how to reject or subtract them.

An isolation selection is used to reduce the QCD background in the sample (next page).

Event selection

Use the lowest pT unprescaled High-Level Trigger path available for a given run:

- Triggers with 10, 20, and 25 GeV thresholds were available in the dataset used for this analysis. 2.1 pb-1 for $E_T < 26$ GeV, 2.9 pb-1 for $E_T > 26$ GeV.

Require a primary vertex with > 4 ndof, and ECAL signal timing compatible with particles originating from the PV (reduces non-collision backgrounds from cosmics, beam halo, ...). Remaining contamination is estimated to be below 1%.

Use barrel ECAL ($|\eta| < 1.45$) for this analysis.

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Photon identification criteria

Sum of ECAL energy deposits in hollow cone around the photon candidate

Sum of track p_T in a hollow cone around the photon candidate

Sum of HCAL energy deposits in hollow cone around the photon candidate

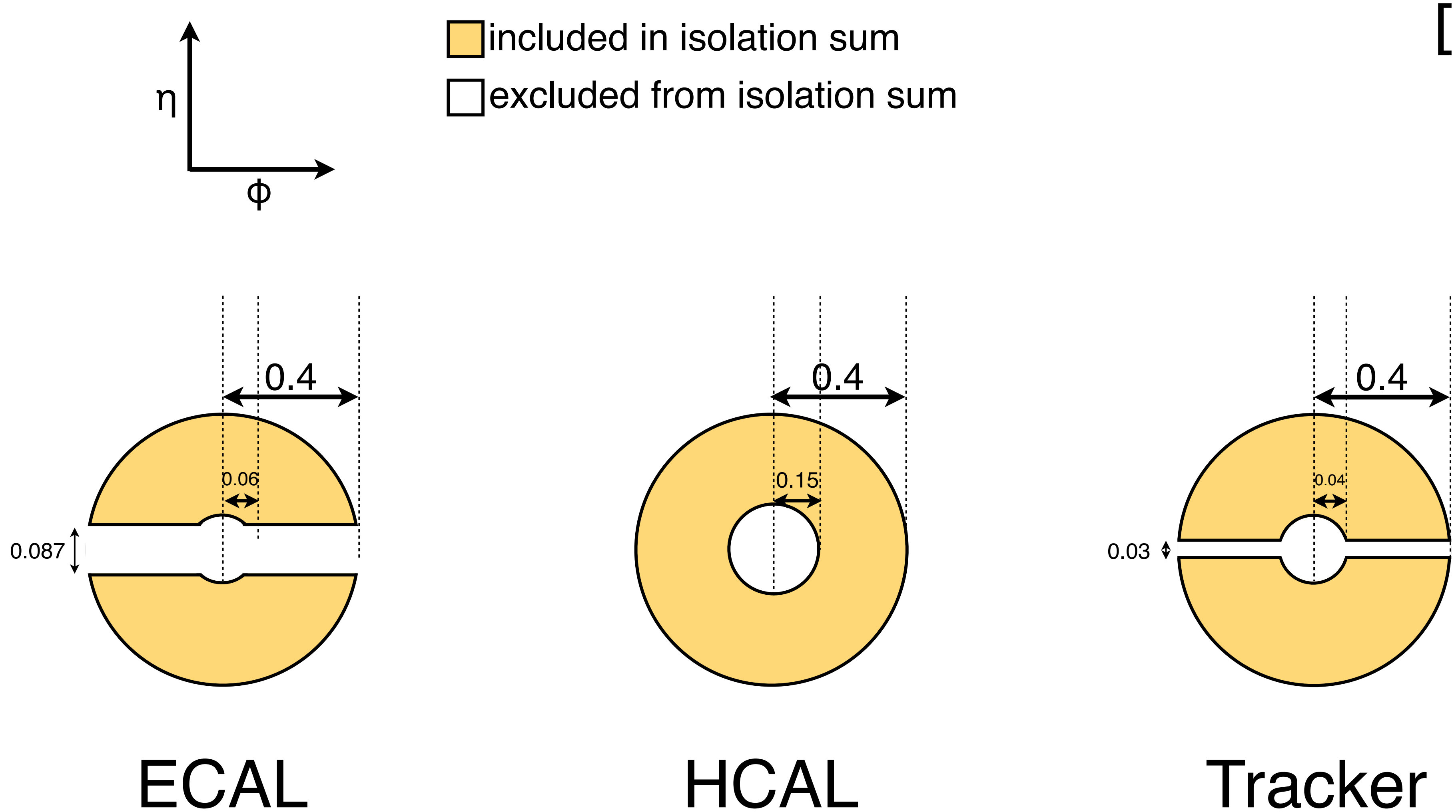
Variable	Loose		Tight	
	Barrel	Endcap	Barrel	Endcap
Iso_{TRK}	2.0 GeV		0.9 GeV	
Iso_{ECAL}	4.2 GeV		2.4 GeV	
Iso_{HCAL}	2.2 GeV		1.0 GeV	
H/E	0.05		0.03	
$\sigma_{i\eta i\eta}$	0.01	0.03	0.01	0.028

Ratio of HCAL energy behind the photon candidate to the ECAL energy

Shower shape of the candidate along the η direction

Isolation cone shapes

[R. Yohay]



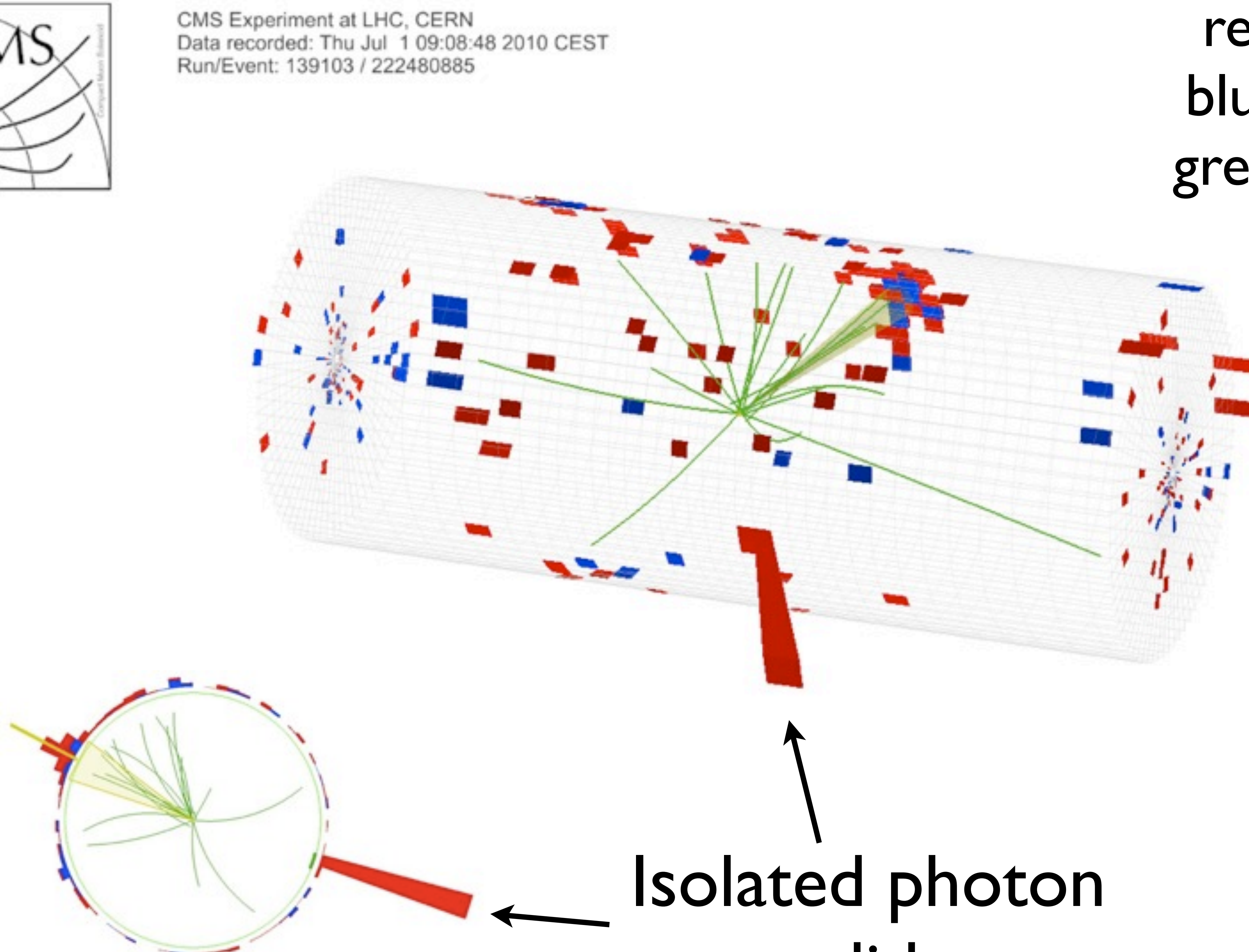
Remove phi strip for consistency between unconv γ, conv γ, and electrons

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

not to scale

Candidate event

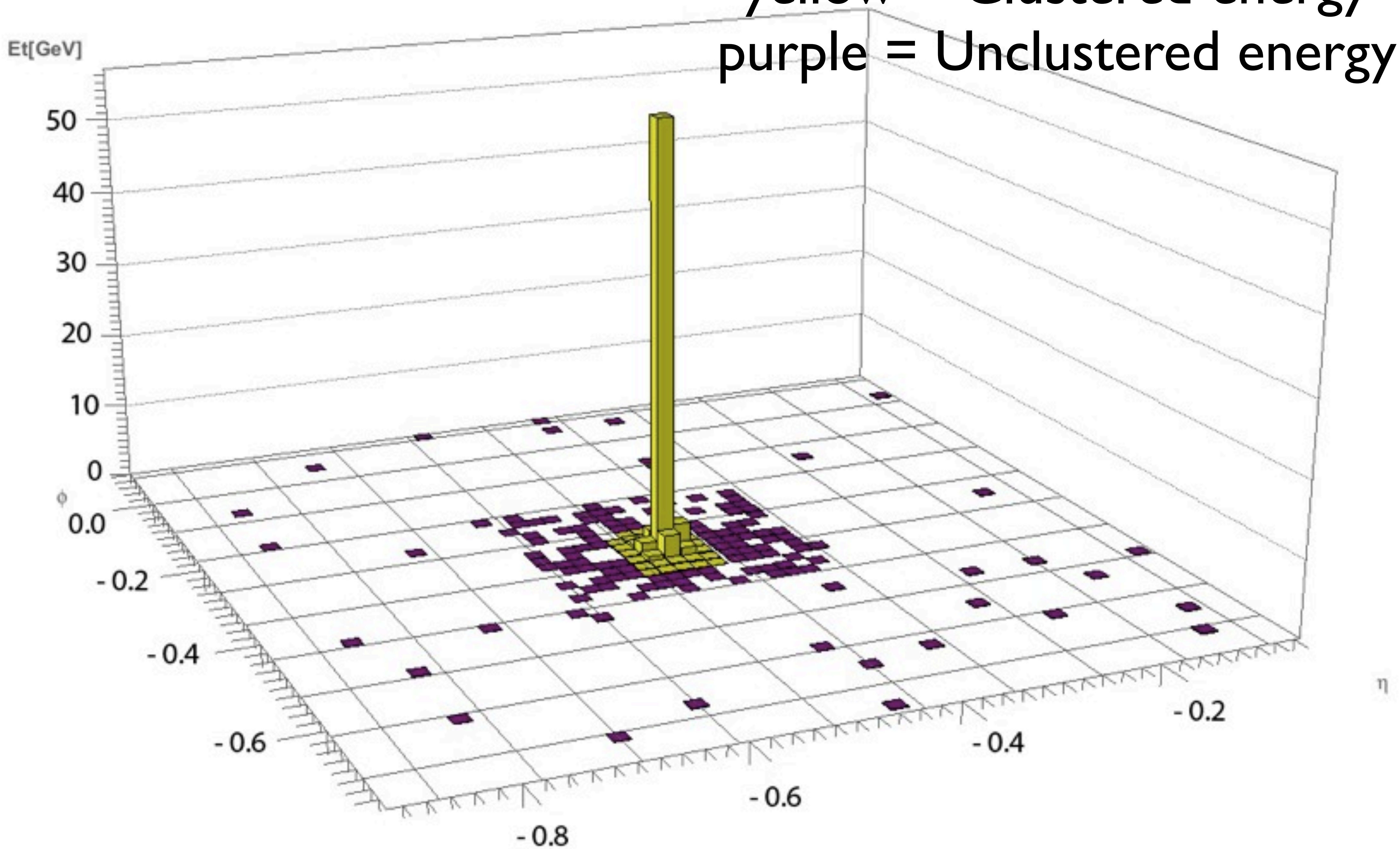
red = ECAL
blue = HCAL
green = tracks



Isolated photon candidate

Candidate event: crystal view

yellow = Clustered energy
purple = Unclustered energy



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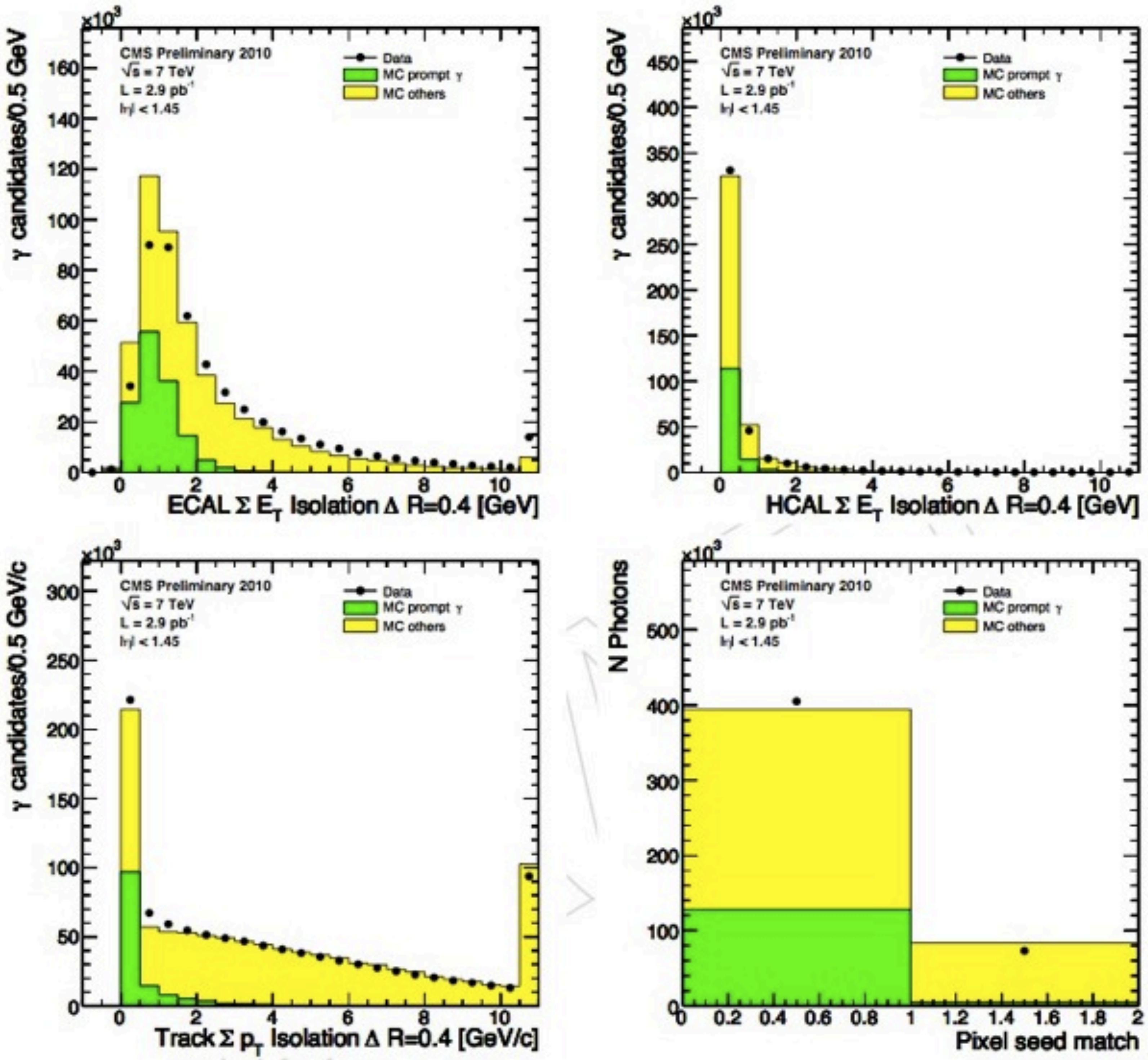
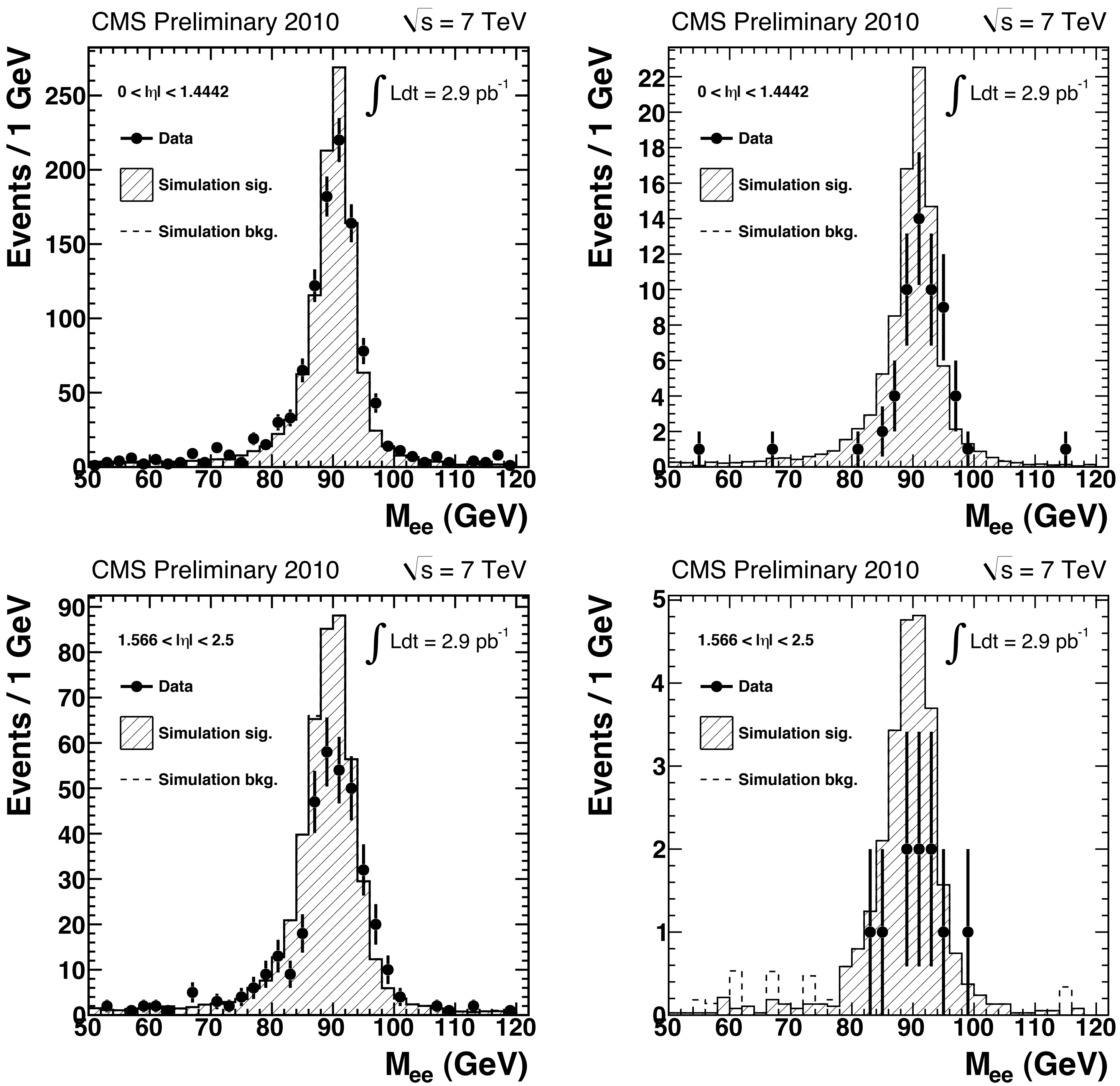
Isolation variables (N-1 plots)

MC modeling of isolation is good- additional correction applied using $Z \rightarrow e\ e$ electrons (next slide)



In addition to the isolation we veto on the presence of a pixel seed to remove prompt electrons.

Photon ID efficiency from data



Use electrons from $Z \rightarrow ee$ events as a control sample to measure the photon reconstruction and identification efficiency.

- Require a well-identified "tag" electron.
- Look for "probe" photon candidate which makes 50 < M < 120 GeV invariant mass.
- Count fraction of probes which pass the photon isolation.
- Efficiency is ~90% over whole η range covered by ECAL. Difference between MC and data isolation efficiency ~1%.

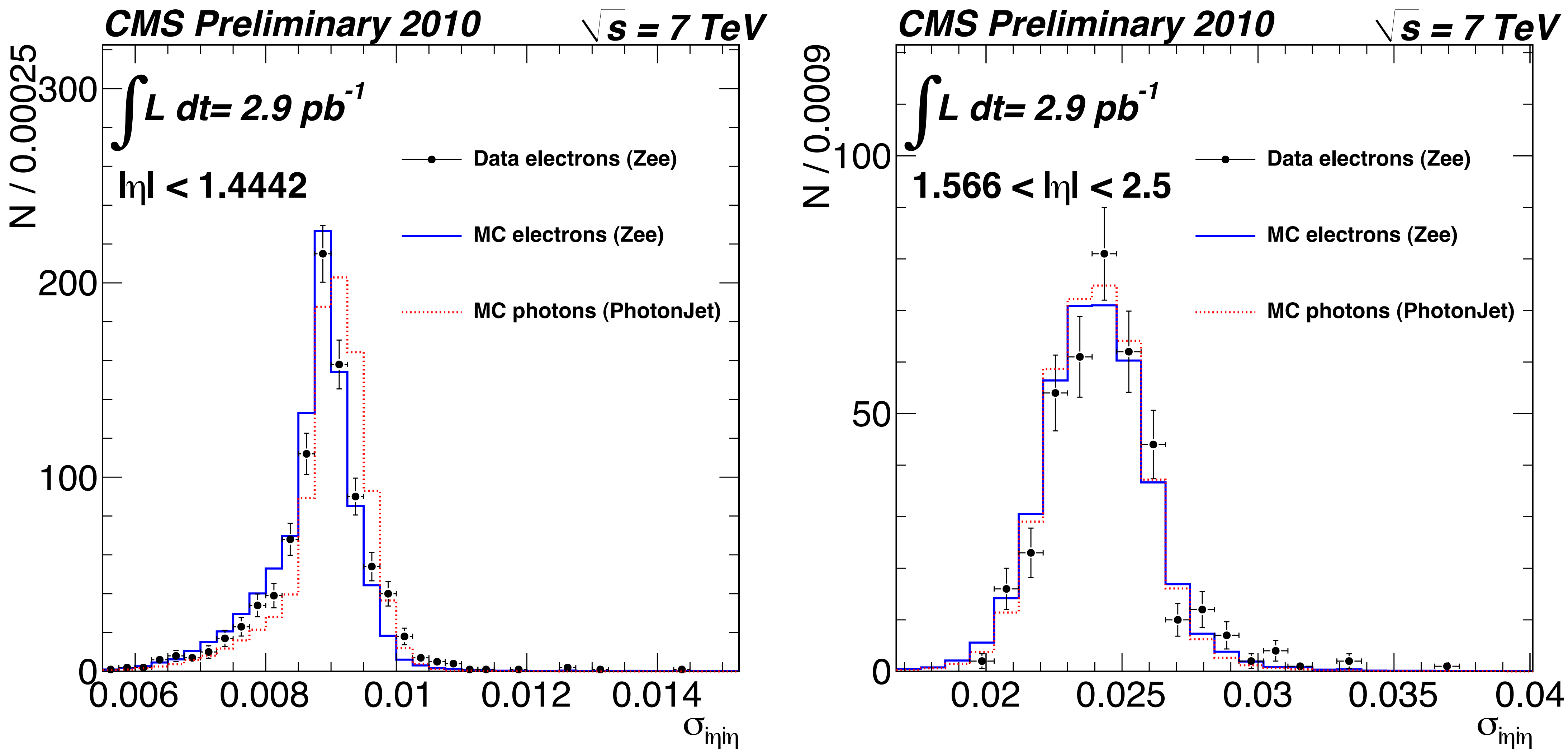
Technique used for measurement

$$\sigma^2_{i\eta i\eta} = \frac{\sum_i^{5\times5} w_i (i\eta_i - i\eta_{seed})^2}{\sum_i^{5\times5} w_i}, \; w_i = \max(0,\, 4.7 + \ln \frac{E_i}{E_{5\times5}}),$$

We use the variable "$\sigma_{i\eta i\eta}$" to discriminate the prompt photon signal from the background (e.g. π^0s).

- Log-weighted shower shape of the 5x5 array about the highest energy ("seed") crystal.
- Log weighting requires crystal to be at least ~1% of the 5x5 energy (less dependence on noise).
- Log weighting is more sensitive to details of the shower shape in low energy crystals.
- Use η shape because converted photons can spread along the φ direction in the solenoidal field, but the η shape of the shower should not change very much.
- Variable is similar for e+/- and γ which gives a control sample in data (well-identified electrons).

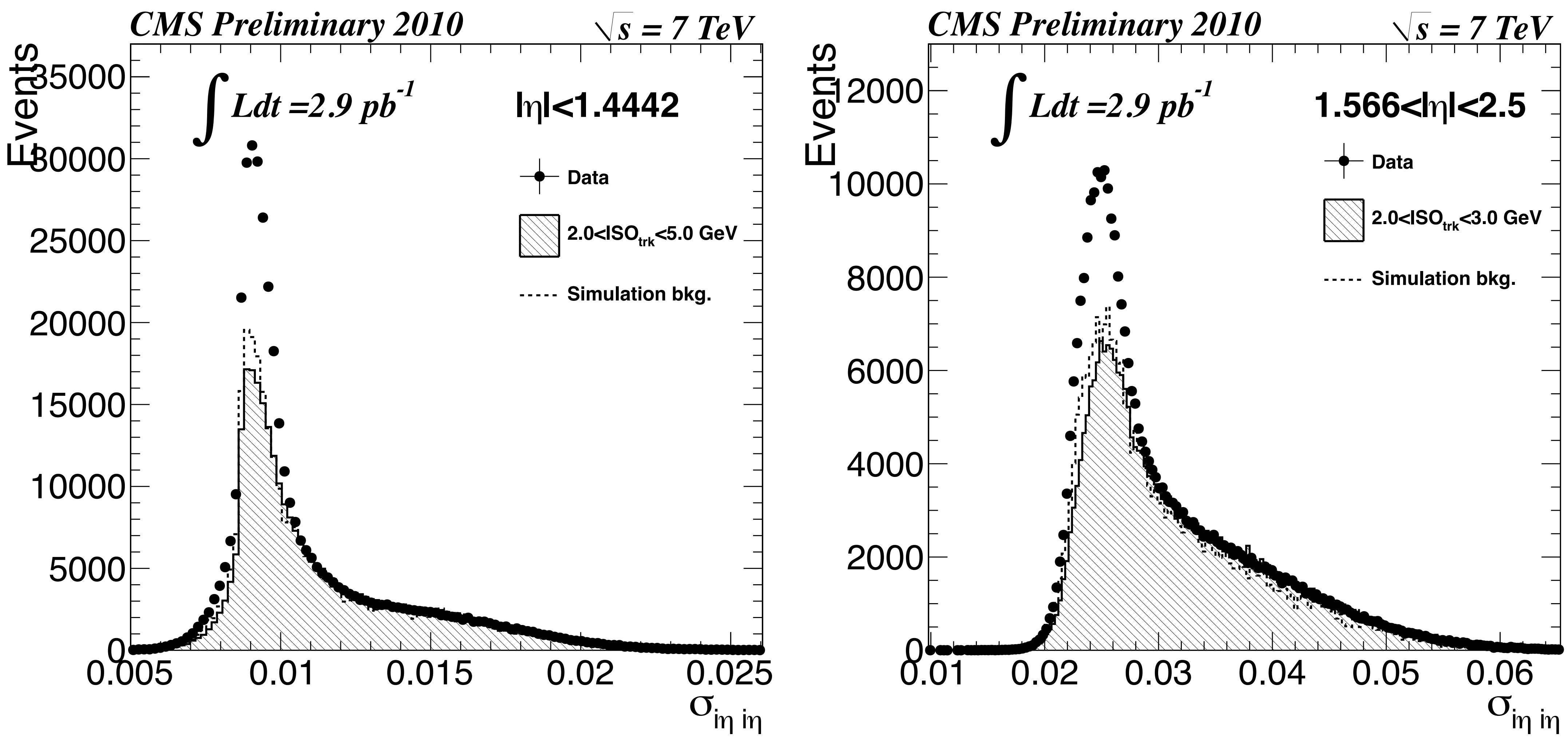
σ iη iη signal shape



Signal shape can be checked against well-identified electrons in data.

- Small positive shift (about 1%) seen for electrons in data; used as a correction to the photon signal shape from MC simulation.

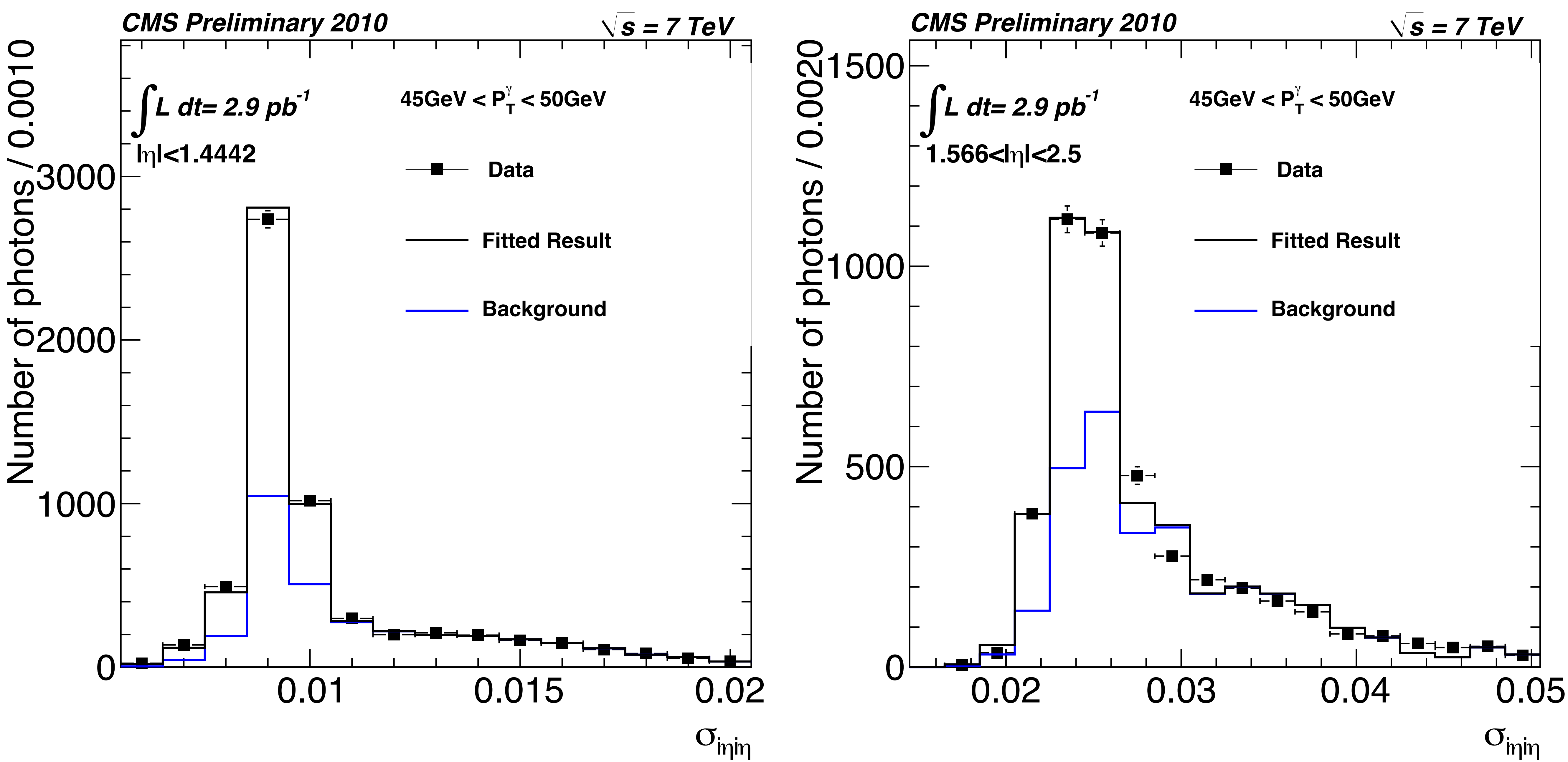
σ iη iη background shape



σ iη iη measures the spread of the shower along the η direction.

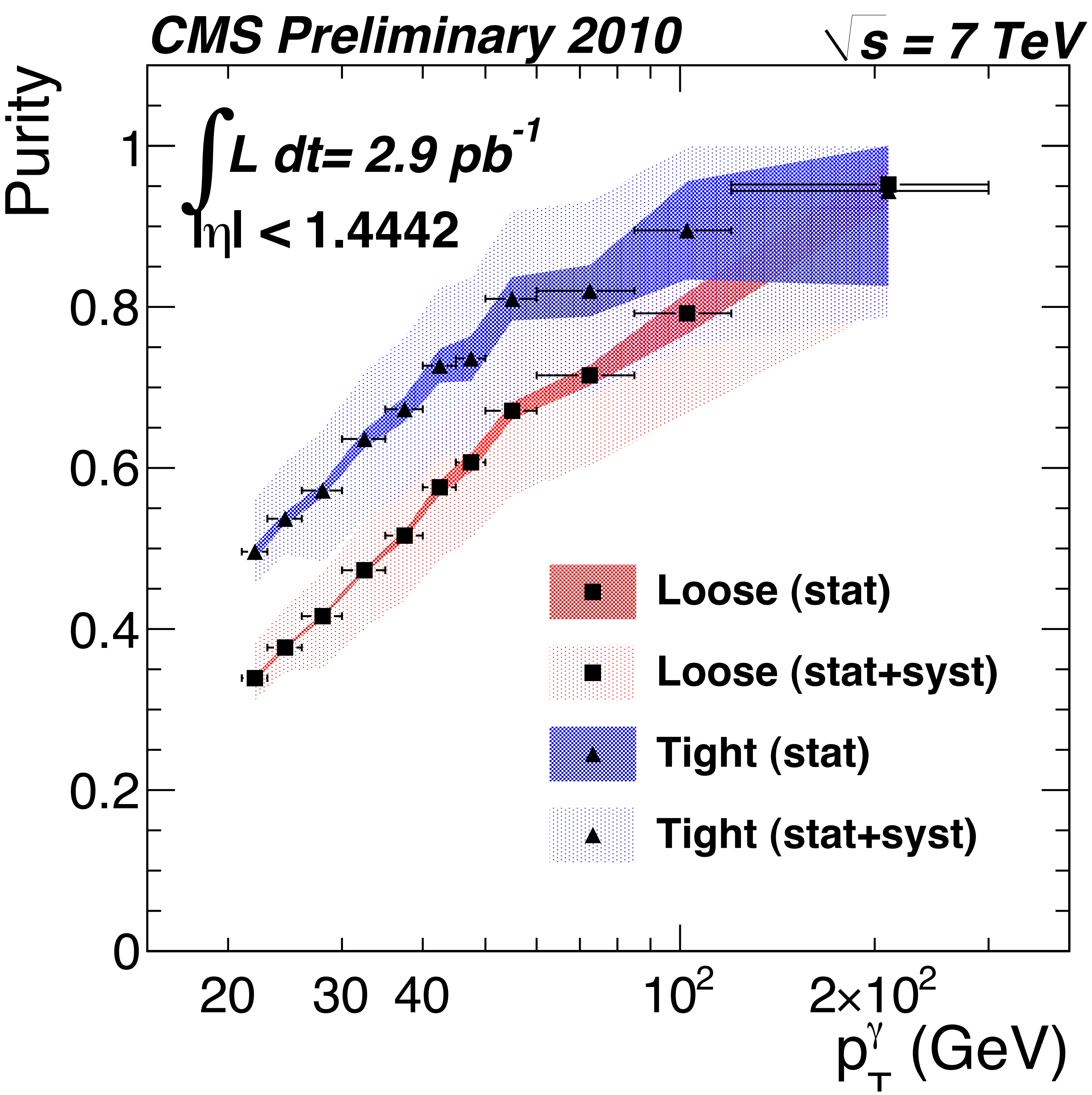
- Isolated photons peak at small values.
- QCD background (multiple energy deposits) typically has larger values.
- Background shape can be extracted from data with a control sample: the track isolation sideband 2 < track iso < 3 GeV (shaded region).

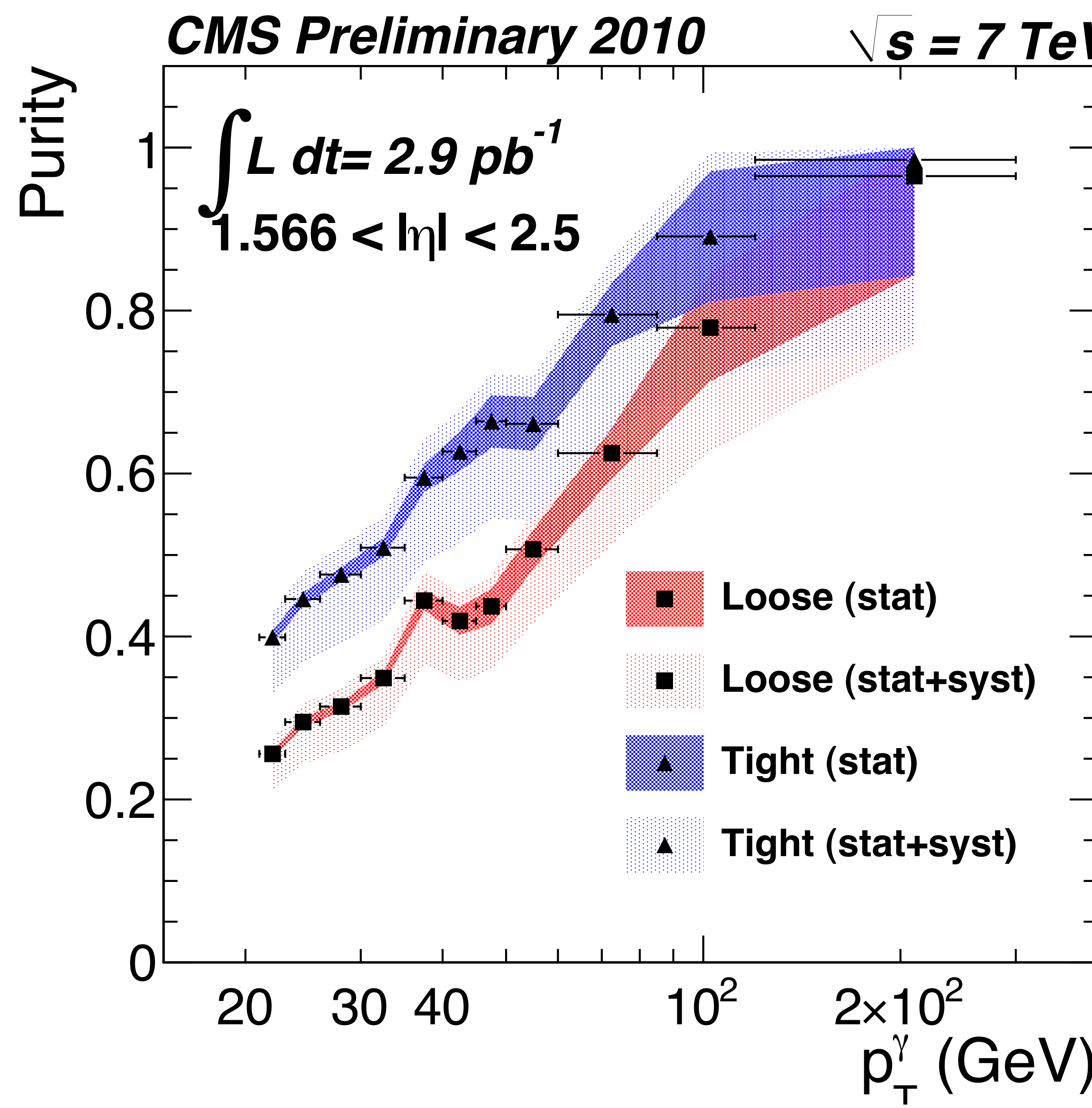
Signal extraction with σ iη iη



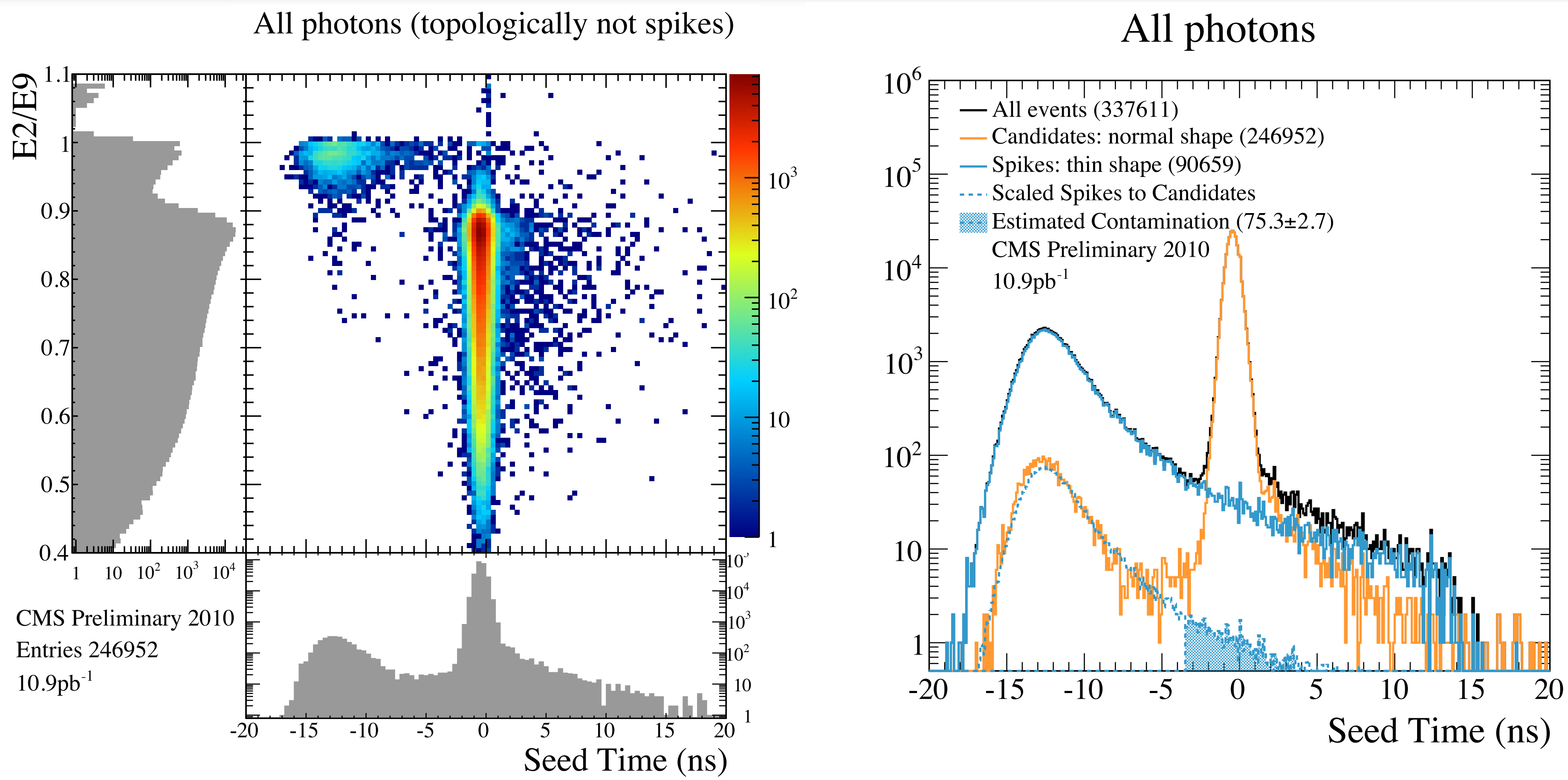
Signal contribution extracted from data with ext. ML fit using the templates.

Photon purity with σ iη iη





Background from anomalous ECAL signals



Anomalous high-energy ECAL "spikes" can produce spurious isolated candidates.

- Contribution to isolated photon signal in data can be controlled by examining the signal timing in ECAL and topological cluster variables (fraction of cluster energy in leading crystals of cluster).
- Upper limit on anomalous signal contribution to selected sample estimated as < 0.4% (0.7%) at low (high) pT.

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Signal yield with shower shape

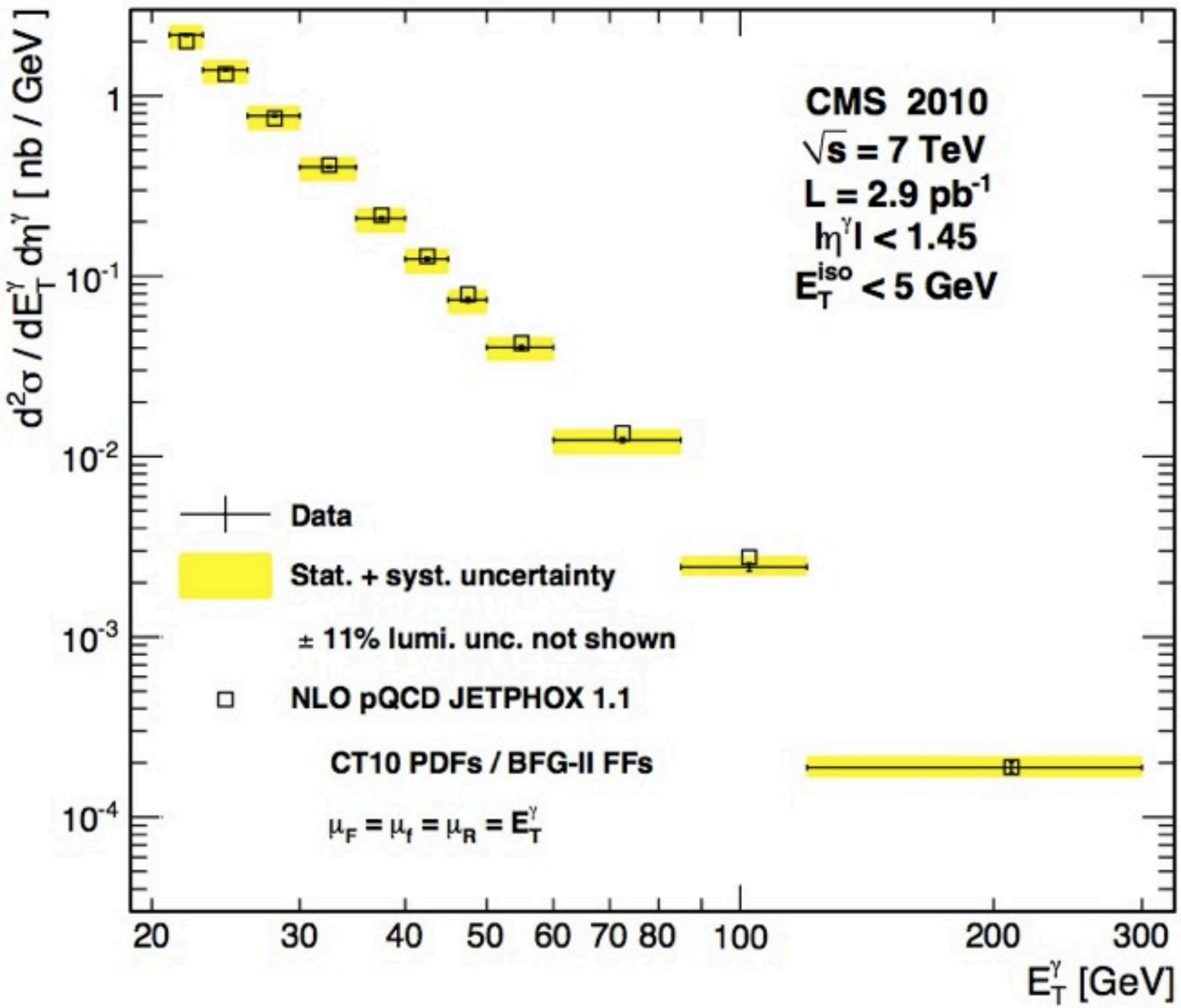
E_T^γ (GeV)	$d^2\sigma/dE_T^\gamma d\eta^\gamma$ (nb/GeV)	Syst. Unc. (%)	$\mathcal{U}$
21–23	2.17 ± 0.03	$+13, -16$	1.01
23–26	1.39 ± 0.02	$+13, -16$	1.01
26–30	0.774 ± 0.010	$+13, -16$	1.01
30–35	0.402 ± 0.006	$+13, -16$	1.00
35–40	0.209 ± 0.004	$+13, -16$	1.00
40–45	$(124.4 \pm 2.8) \times 10^{-3}$	$+13, -16$	1.00
45–50	$(74.0 \pm 2.1) \times 10^{-3}$	$+13, -16$	1.00
50–60	$(40.3 \pm 1.0) \times 10^{-3}$	$+13, -16$	1.00
60–85	$(12.36 \pm 0.35) \times 10^{-3}$	$+14, -16$	0.99
85–120	$(2.43 \pm 0.12) \times 10^{-3}$	$+14, -9$	0.98
120–300	$(0.188 \pm 0.013) \times 10^{-3}$	$+13, -9$	0.97

- Systematic uncertainties dominated by knowledge of background shape in data. Does not include additional lumi uncertainty (11%).
- *U* is correction for detector resolution.

Theory comparison

- Used JETPHOX 1.1 with CT10 PDFs and BFG II fragmentation functions. PDF uncertainty evaluated by switching between CT10, MSTW2008, and NNPDF2.0 (~6%). Frag. func. uncertainty evaluated by switching between BFG I/II (effect is negligible).
- Renormalization, factorization, and fragmentation scales all set to the photon pT. Error due to scale choice evaluated by varying all three scales between half and twice the photon pT. Scale uncertainty varies from 30% at low pT to 15% at high pT.
- Theory-level isolation < 5 GeV.
- Detector smearing/reconstruction effects (η, pT) under control at 1% level due to fine segmentation and excellent energy resolution.
- Correction due to underlying event activity in the isolation cone evaluated using multiple sets of PYTHIA parameters (Z2, D6T, DWT, Perugia-0). Correction estimated as C = 0.97 ± 0.02 (i.e. ~3% of isolated photons fail isolation due to UE activity).

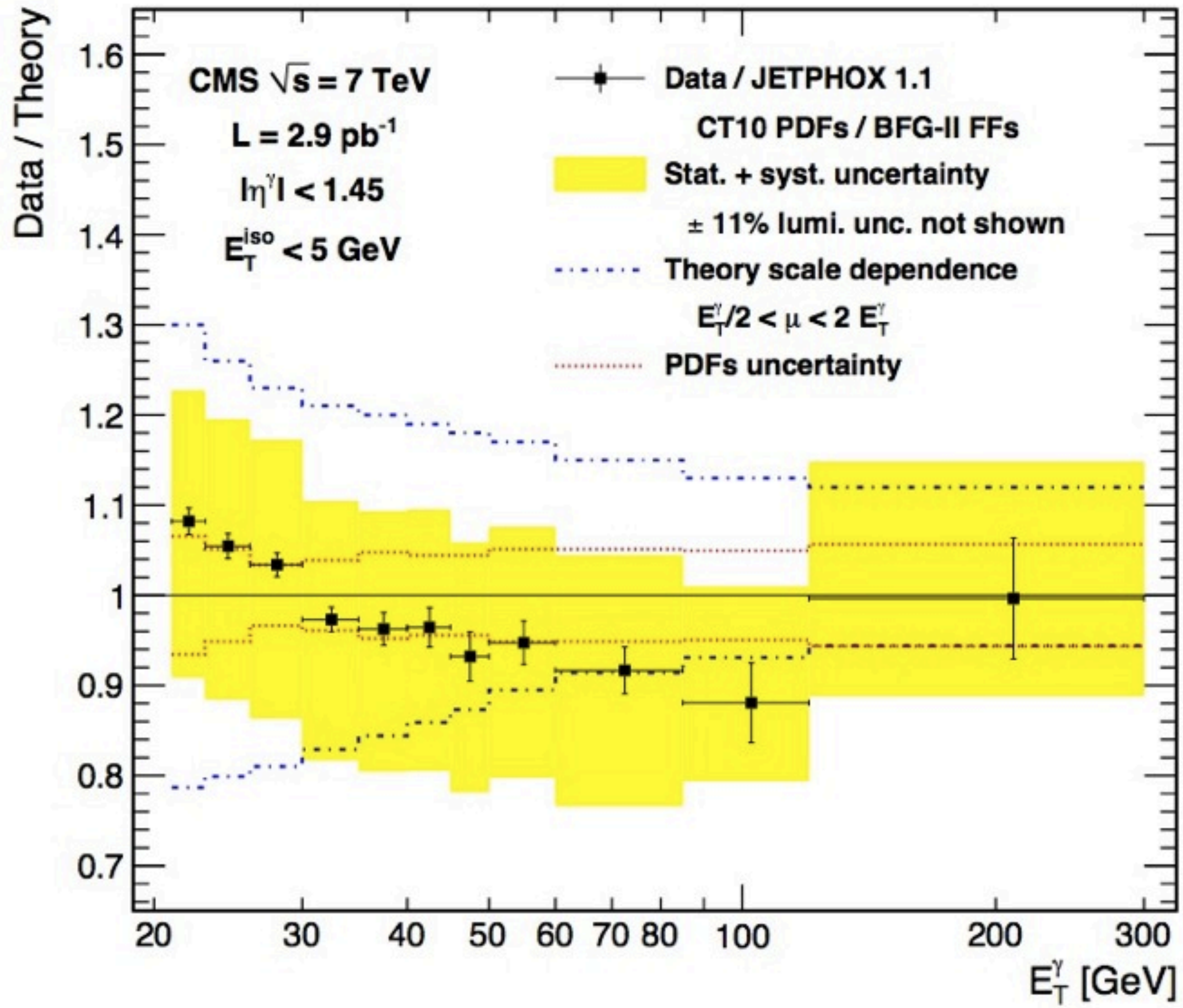
Spectrum vs. JETPHOX prediction



Data/theory ratio

Data seems well-described by the theory.

Level of agreement seems higher than previous measurements at Tevatron, but CM energy and *x* probed are different.



Conclusion

CMS produced the first measurement of the isolated photon cross section at the LHC for $|\eta| < 1.45$ and $21 < p_T < 300$ with 2.9 pb^{-1}. The cross section agrees well with the theoretical prediction over the measured range.

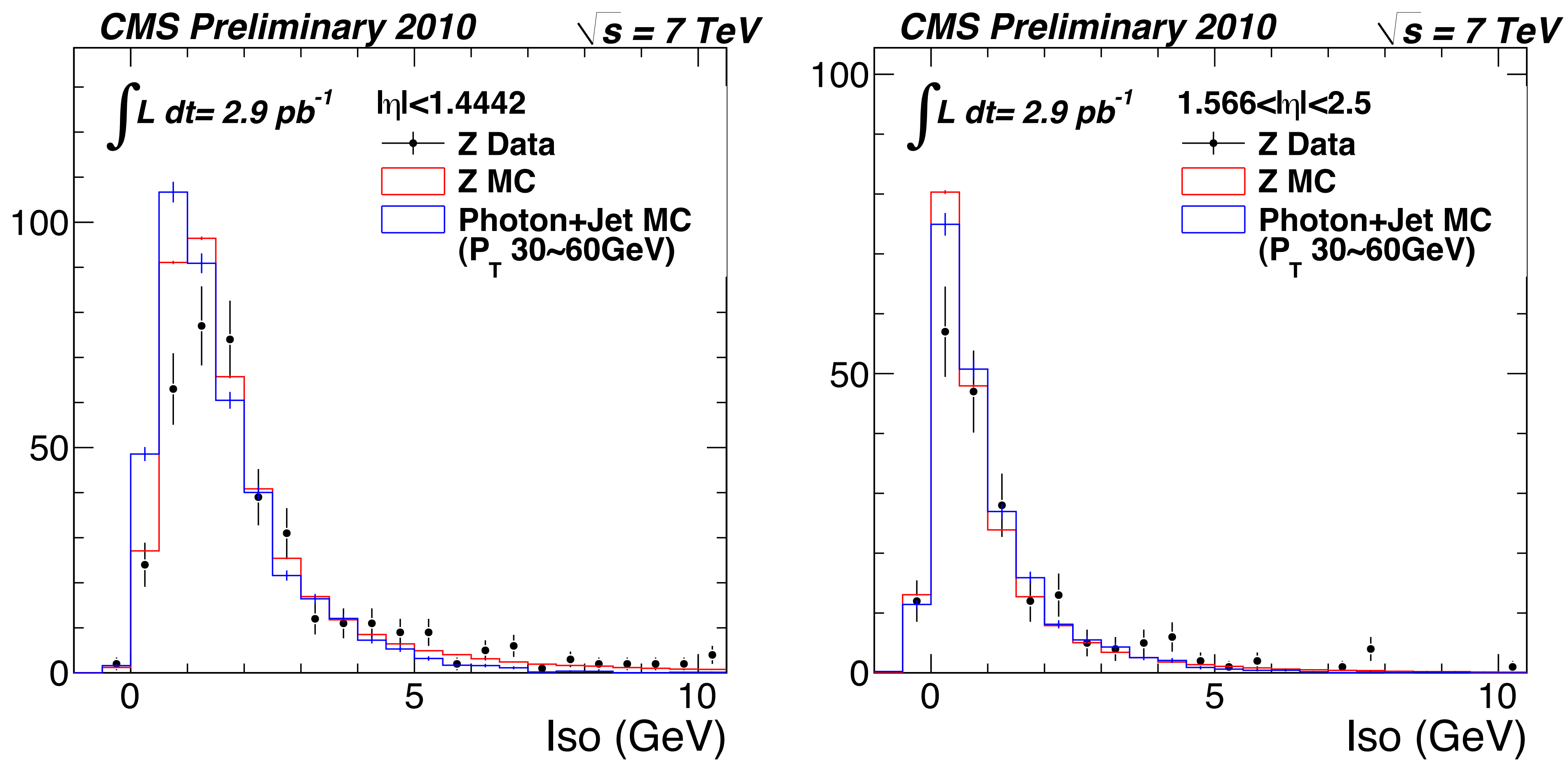
With full 2010 dataset and the upcoming 2011 data we are extending the analysis to higher η, p_T, diphotons...

References

- "Measurement of the Isolated Prompt Photon Production Cross Section in pp Collisions at sqrt(s) = 7 TeV," [arXiv:1012.0799 [hep-ex]]. Accepted by PRL.
- CMS-PAS-EGM-10-006, "Isolated Photon Reconstruction and Identification", http://cdsweb.cern.ch/record/1324545/files/EGM-10-006-pas.pdf
- CMS-PAS-EGM-10-005, "Photon reconstruction and identification", http://cdsweb.cern.ch/record/1279143/files/EGM-10-005-pas.pdf

Backup slides

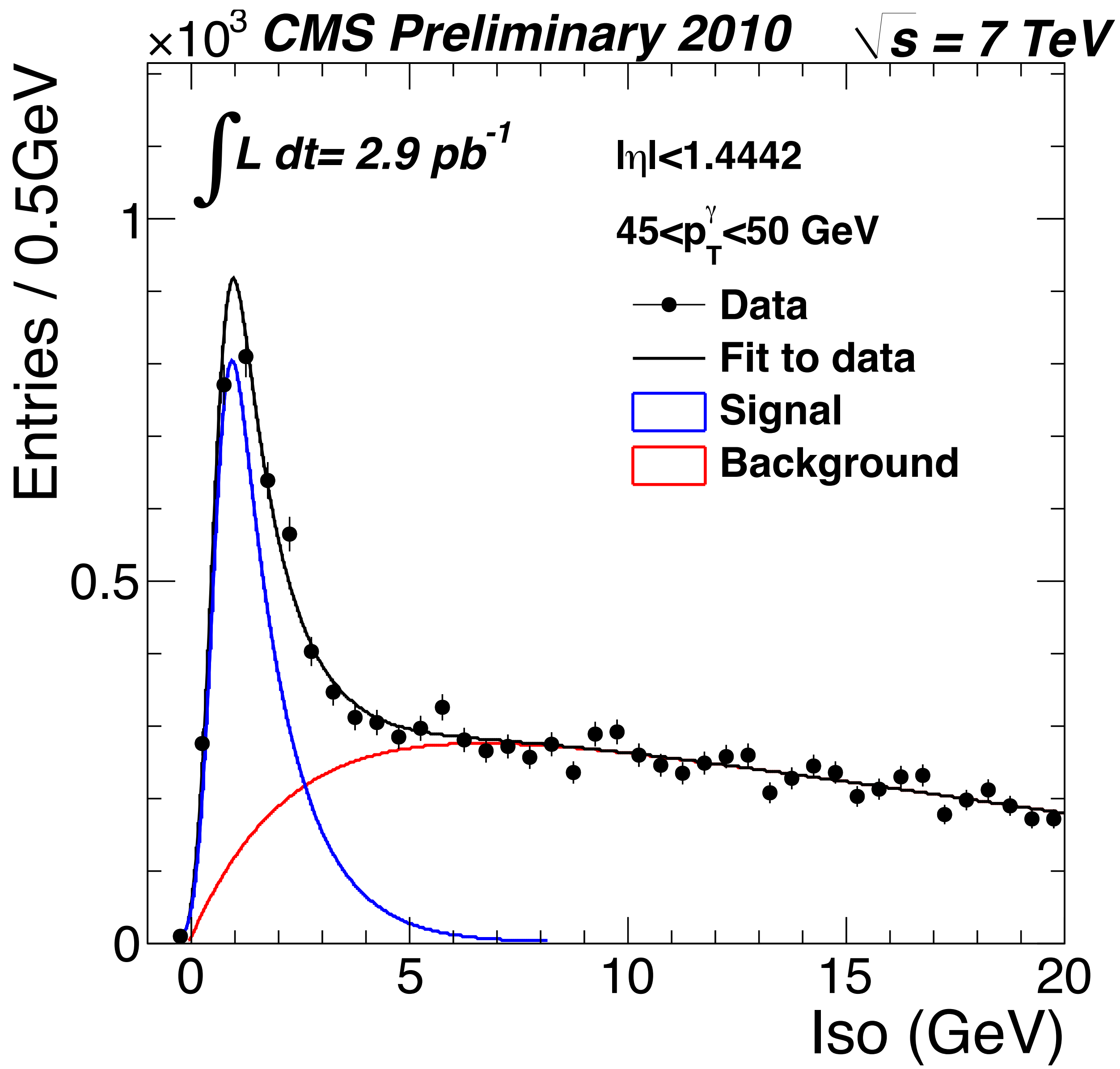
Isolation as handle for photon purity

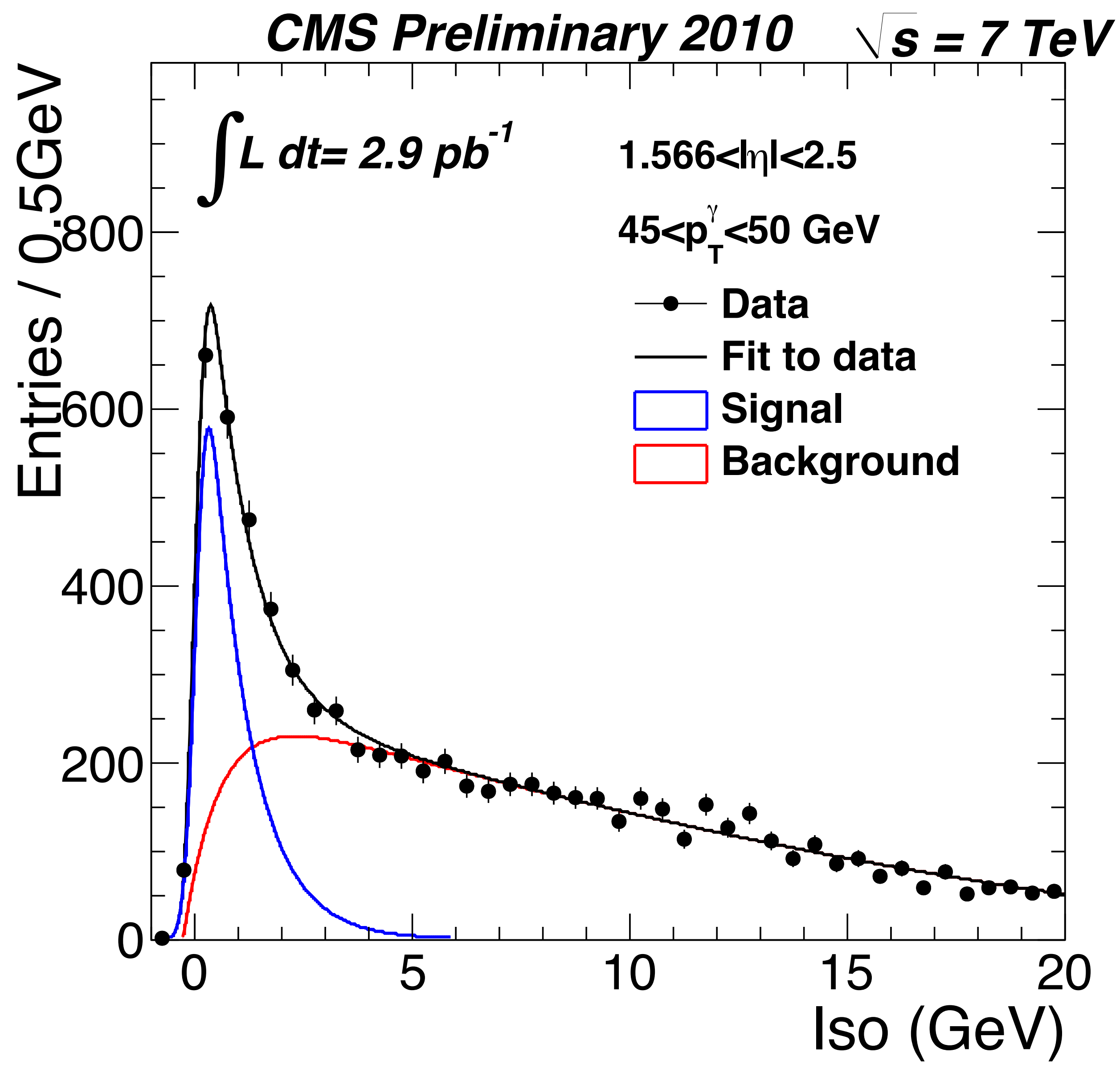


The sum of the three isolation values (ECAL, HCAL and track isolation) can be used as to discriminate signal photons from the background.

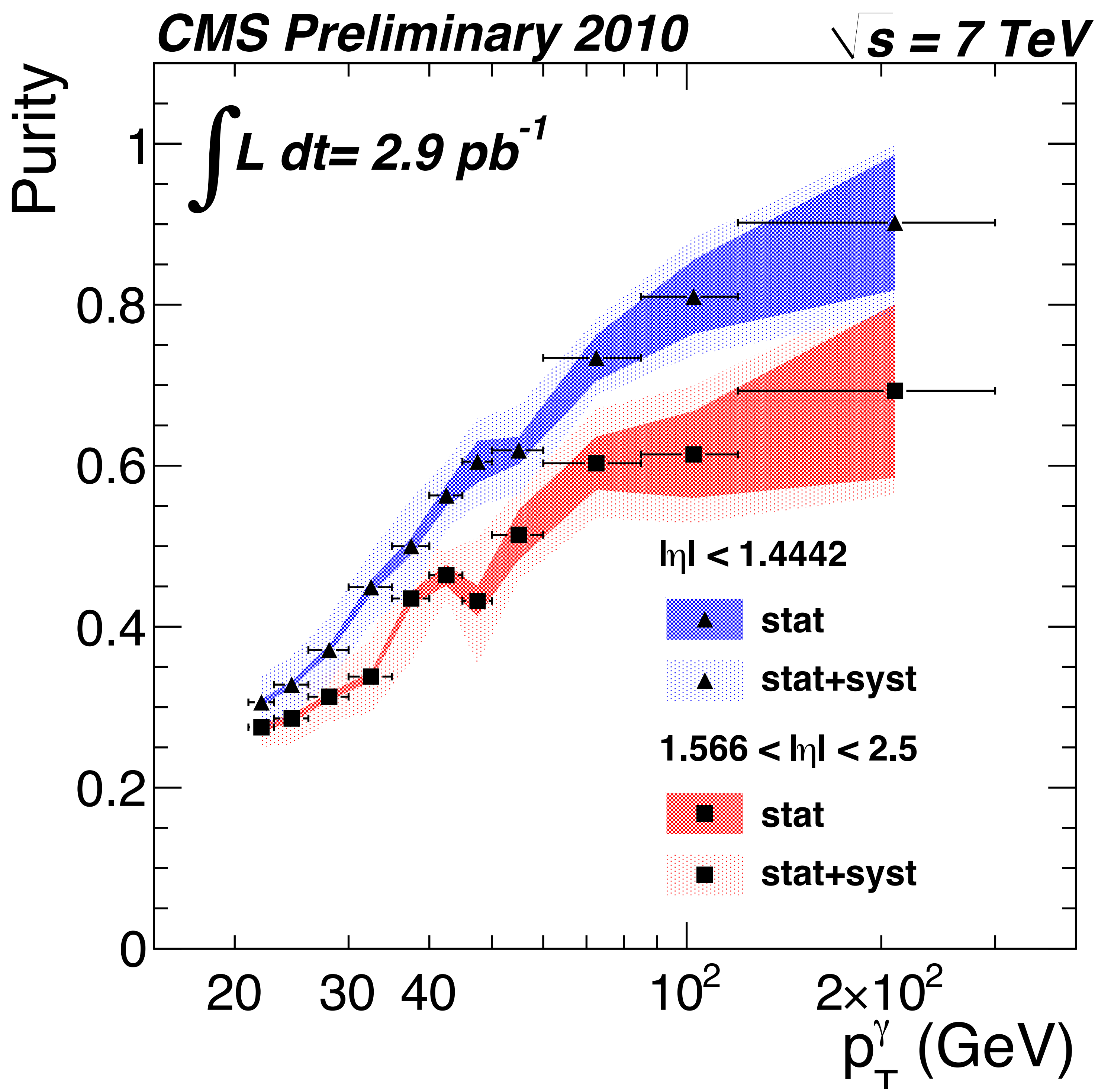
- Use σ iη iη selection to reduce background.
- Isolation distribution is peaked at small values for signal.
- Background typically has larger isolation values.
- Isolation distribution for photon signal can be checked against Z → ee electrons in data.

Signal extraction with isolation





Photon purity with isolation



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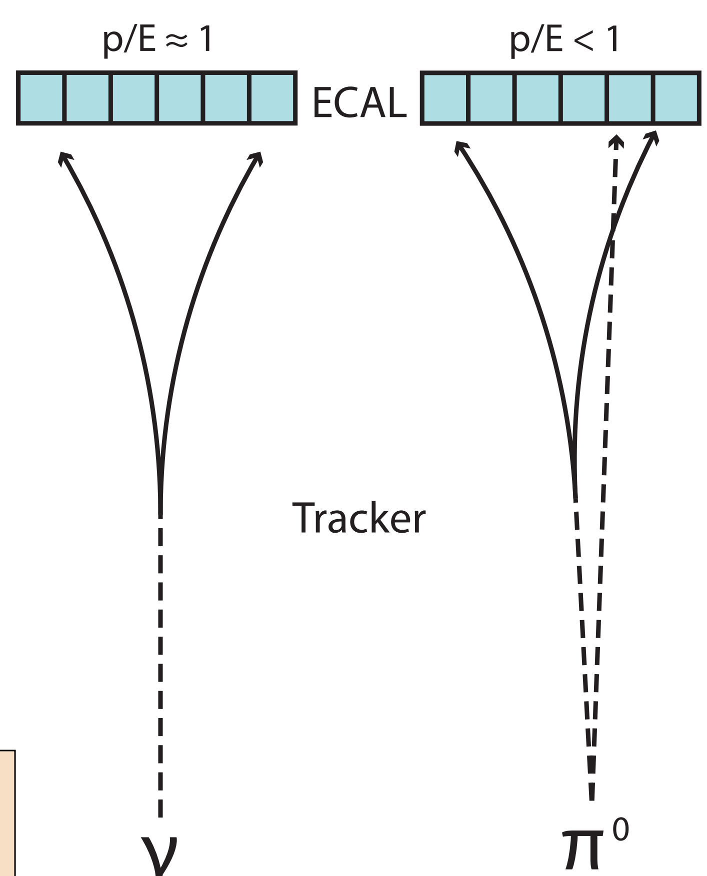
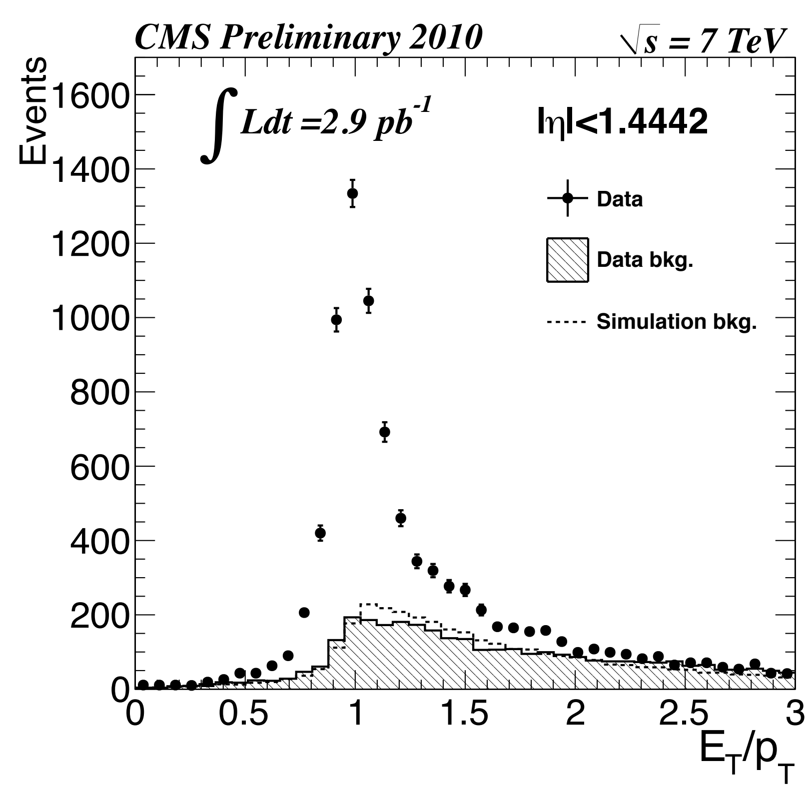
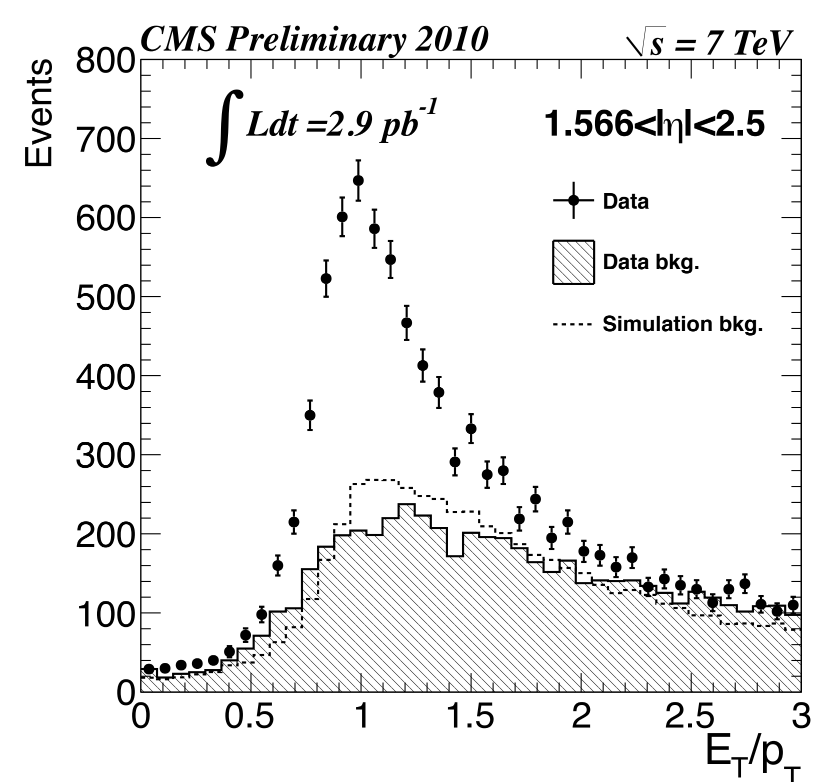
Conversion E/p

Can also use E(ECAL)/p(tracks) of photon conversions to identify signal.

- Use full (isolation and shower shape) selection.
- For single photons E/p peaks at 1. E/p distribution for single photons is taken from the MC simulation.
- For neutral meson decays, E/p typically > 1. Background shape can be obtained from data using sidebands of track isolation and σ iη iη.







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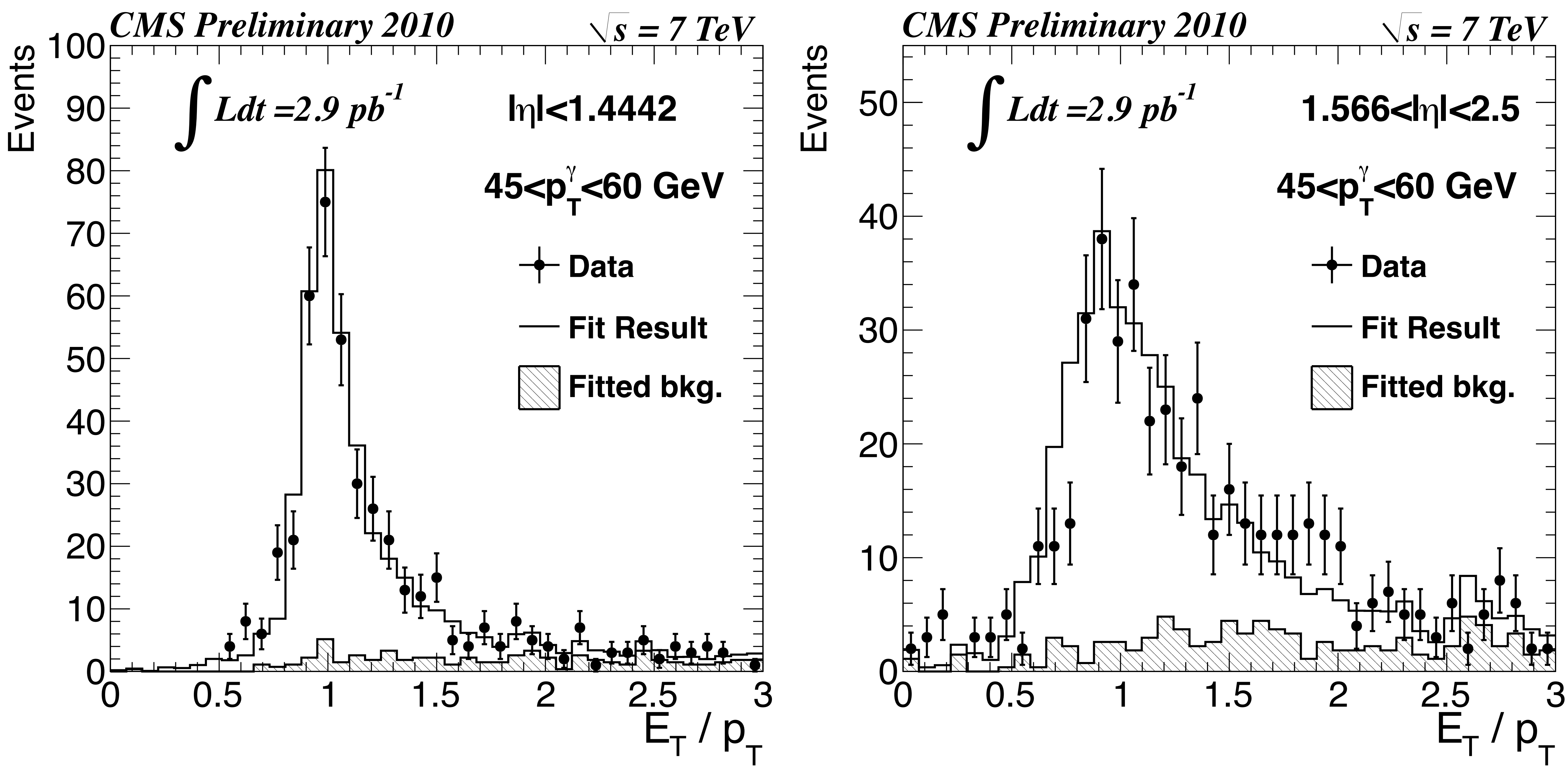
Signal extraction with E/p



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Photon purity with conversions