ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

ETH Institute for Particle Physics

Physics with diphoton events at CMS

Marco Peruzzi
ETH Zurich

Zurich PhD seminar
Uni Irchel, 27 August 2012

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Introduction

ETH Institute for Particle Physics

➢ Photon is a crucial object for a large physics program at CMS:

· SM measurements

· Higgs boson and its properties

· search for BSM physics

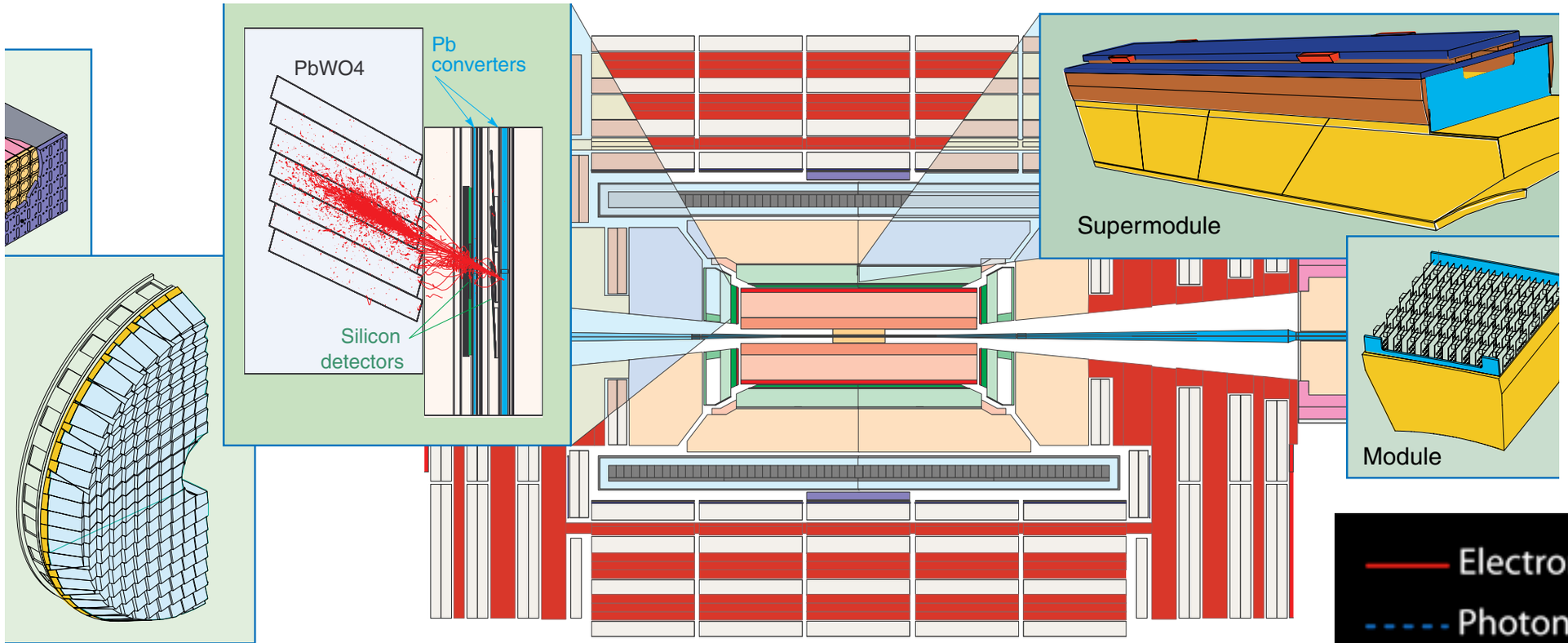
➢ Several aspects of photon reconstruction, identification and measurement affect the physics performance

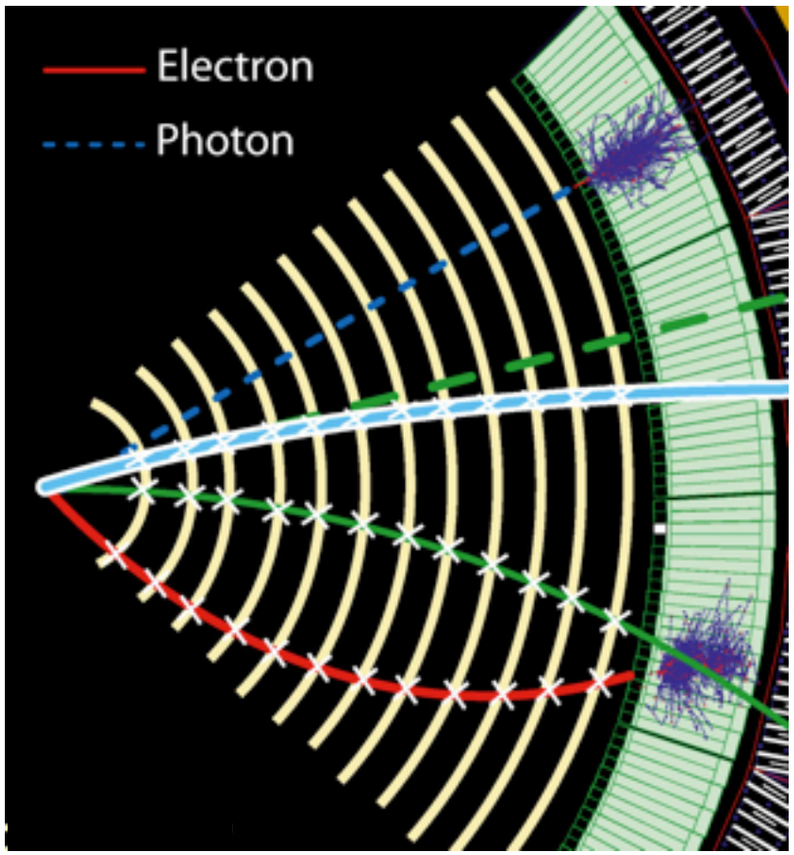
In this talk, I will focus on some of the specific topics I've most contributed to.

Important note: this presentation contains work-in-progress material that has not been reviewed nor approved by the CMS collaboration.

SuperCluster energy corrections

CMS ECAL





Photons and electrons are reconstructed from their energy deposits in the CMS electromagnetic crystal calorimeter (ECAL)

Measuring e/gamma objects

$$E_{e,\gamma}(\mathrm{GeV}) = F_{e,\gamma} \cdot G(\mathrm{GeV/ADC}) \sum_{\text{cluster crystals } i} S_i(t) \cdot C_i \cdot A_i + E_{ES}$$

Object - dependent SuperCluster energy correction:

Crystal inter - calibration and transparency correction

different response of SC algorithm for different objects and showering

Old scheme : (tuned on electrons only)

$$F_{e,\gamma} = C(\eta) \times f(\sigma_\phi/\sigma_\eta) \times f(E_T, \eta)$$

Geometric correction
in EB only
From TB data

Clustering response
shower shape-dep
From simulation

Residual correction
(η-dep material)
For now from MC

Material dependence

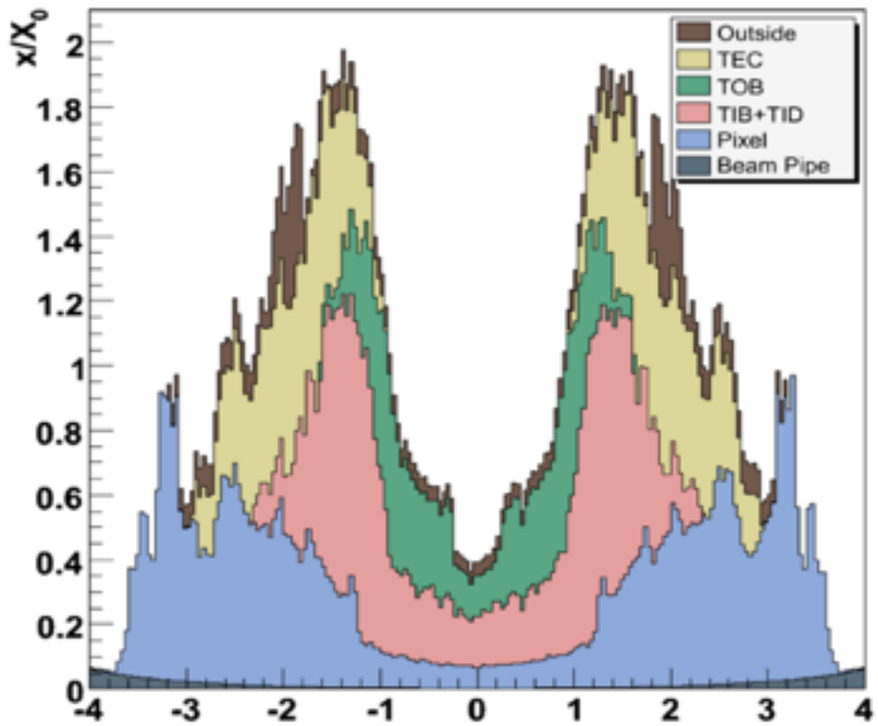
Brem shower shape:
$\sigma_\phi / \sigma_\eta$

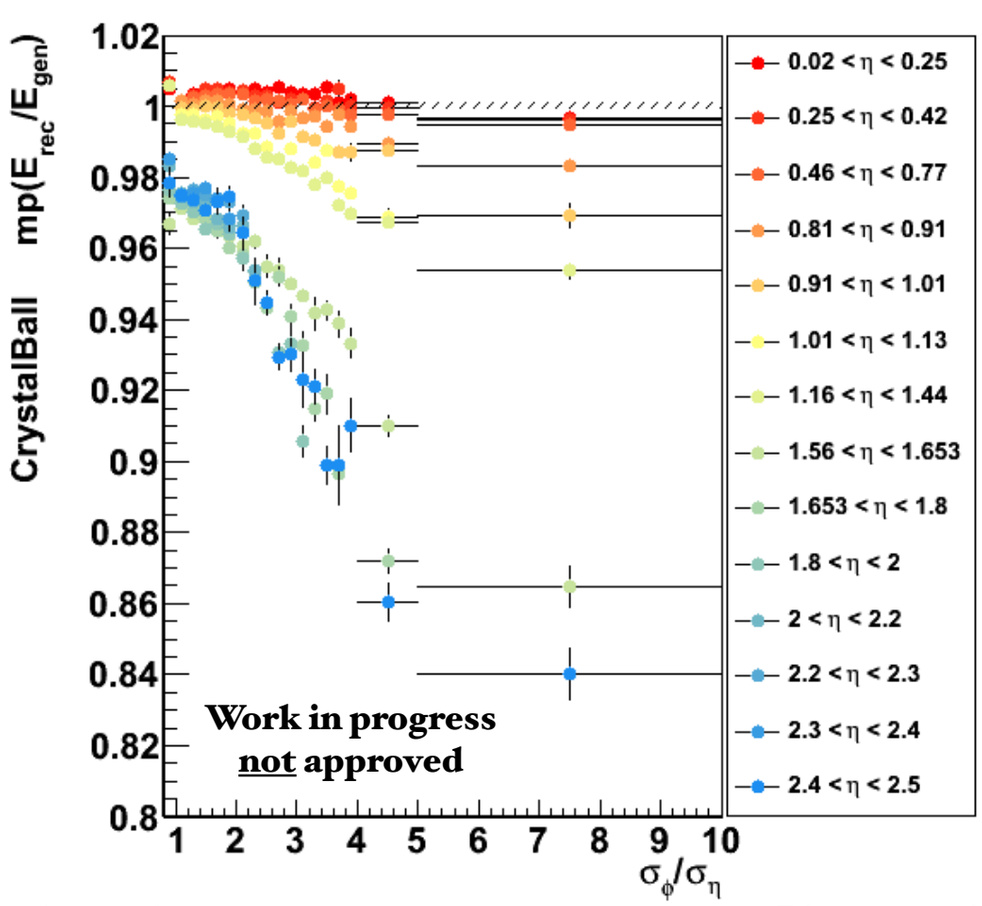
Material budget (tracker) in front of ECAL

η dependence

Interaction
($e^{\pm} \neq \gamma$)

Geometry





New factorization motivated by this physical correlation:

$$f(\sigma_\phi/\sigma_\eta) \times F(\eta, ET)$$

$$\Downarrow$$

$$f(\sigma_\phi/\sigma_\eta, \eta) \times F(ET)$$

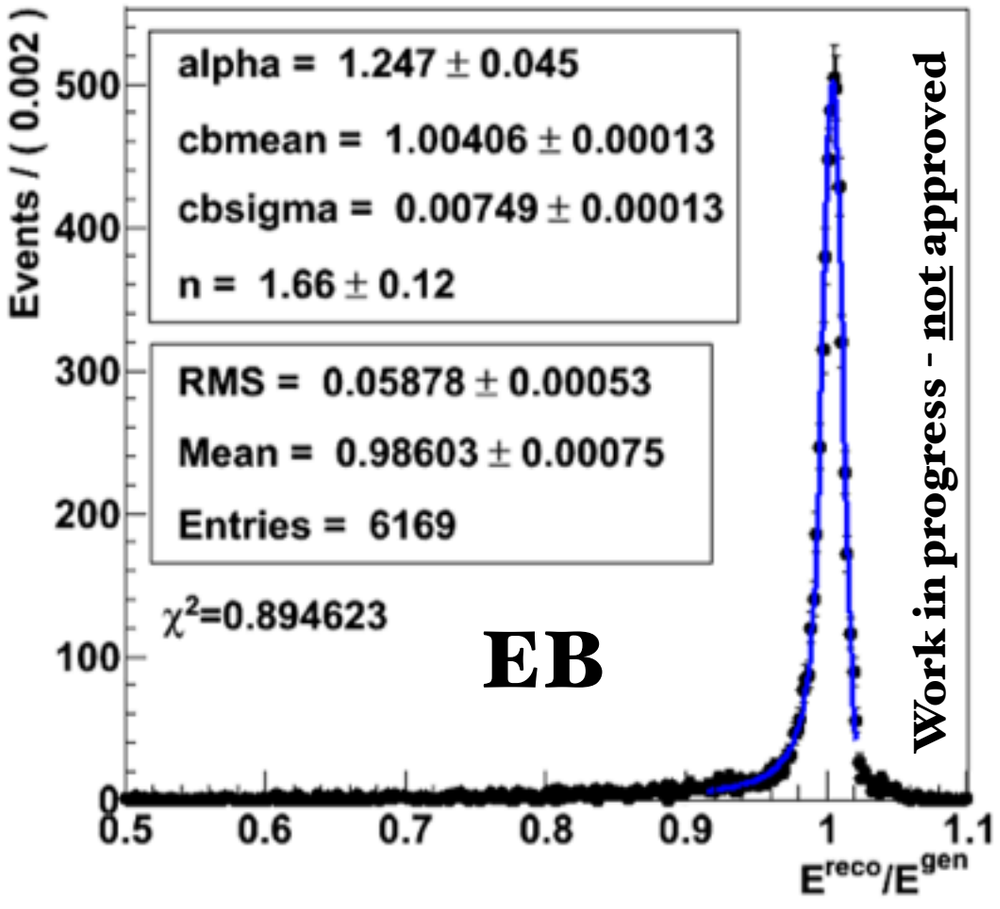
Extraction procedure

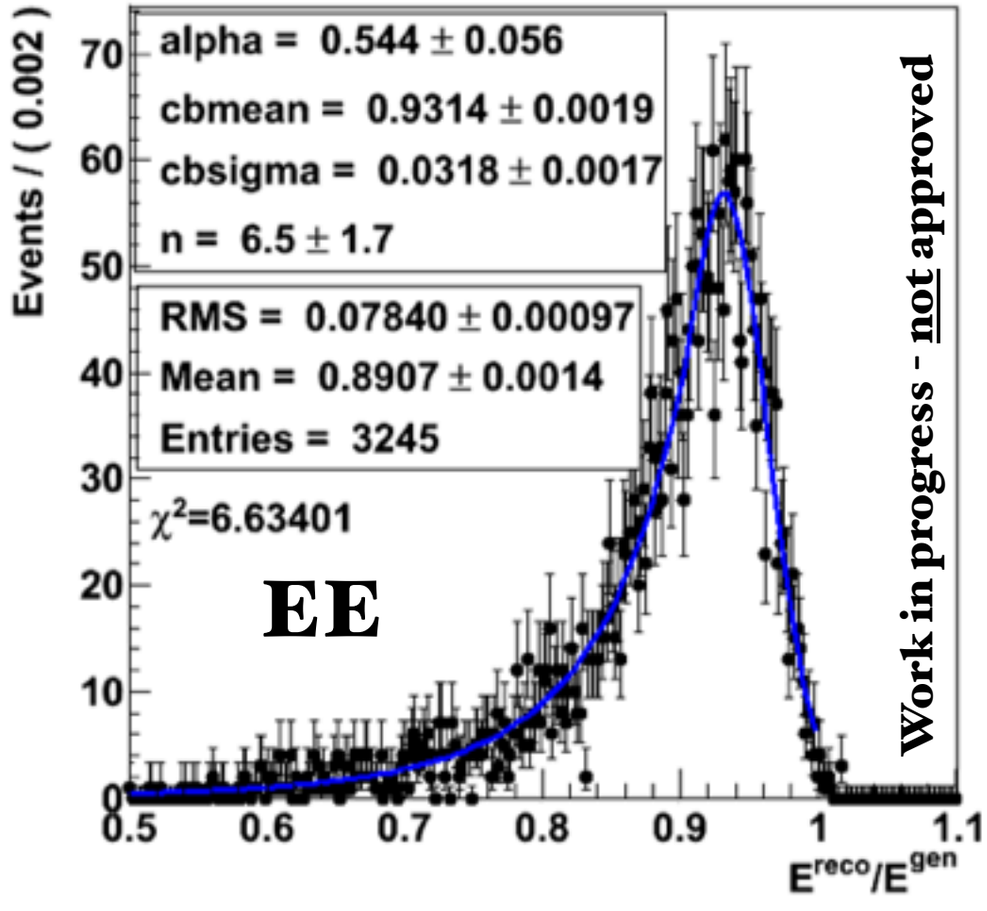
➢ MC particle gun, separately for electrons and photons

➢ Excluding η/φ cracks of the detector

➢ Crystal Ball fit of E_{rec}/E_{gen} in bins of (brem,η)

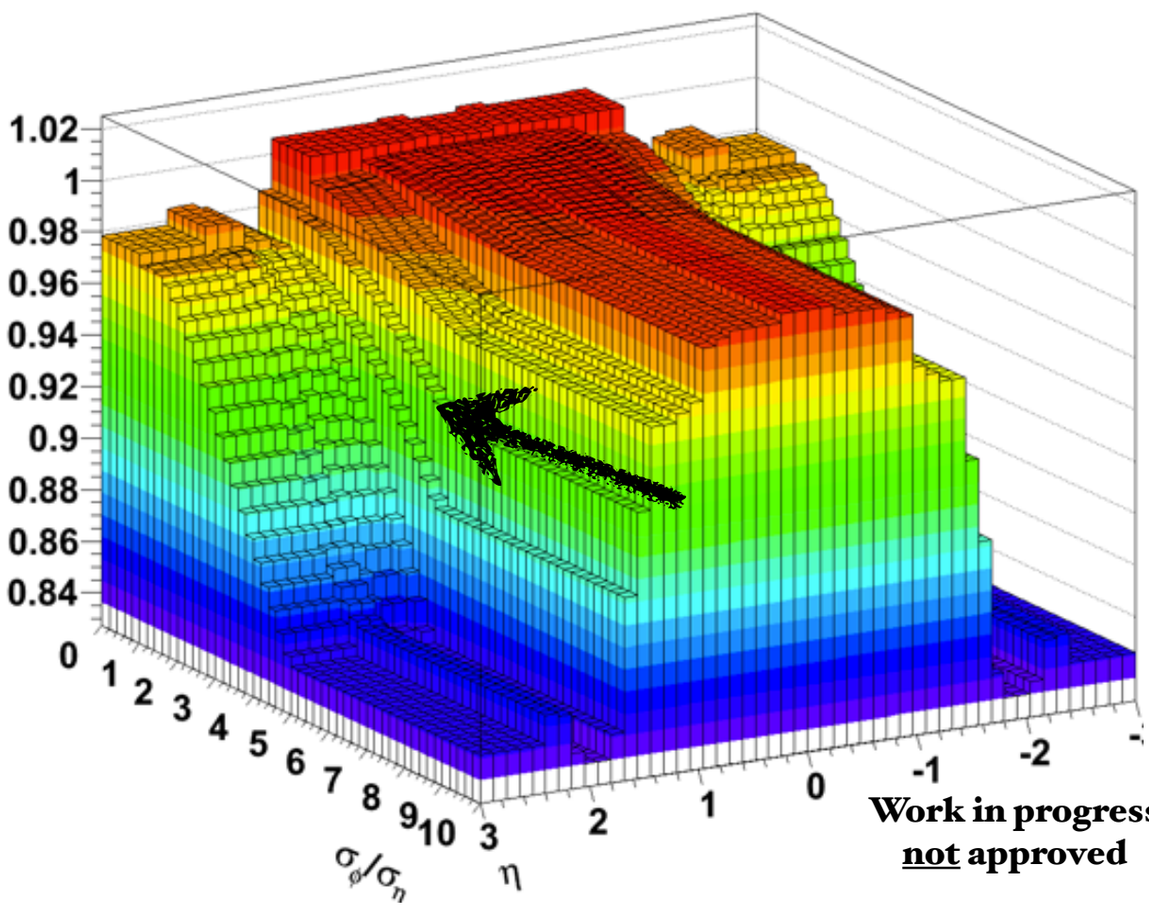
→ correction to bring the peak back to 1



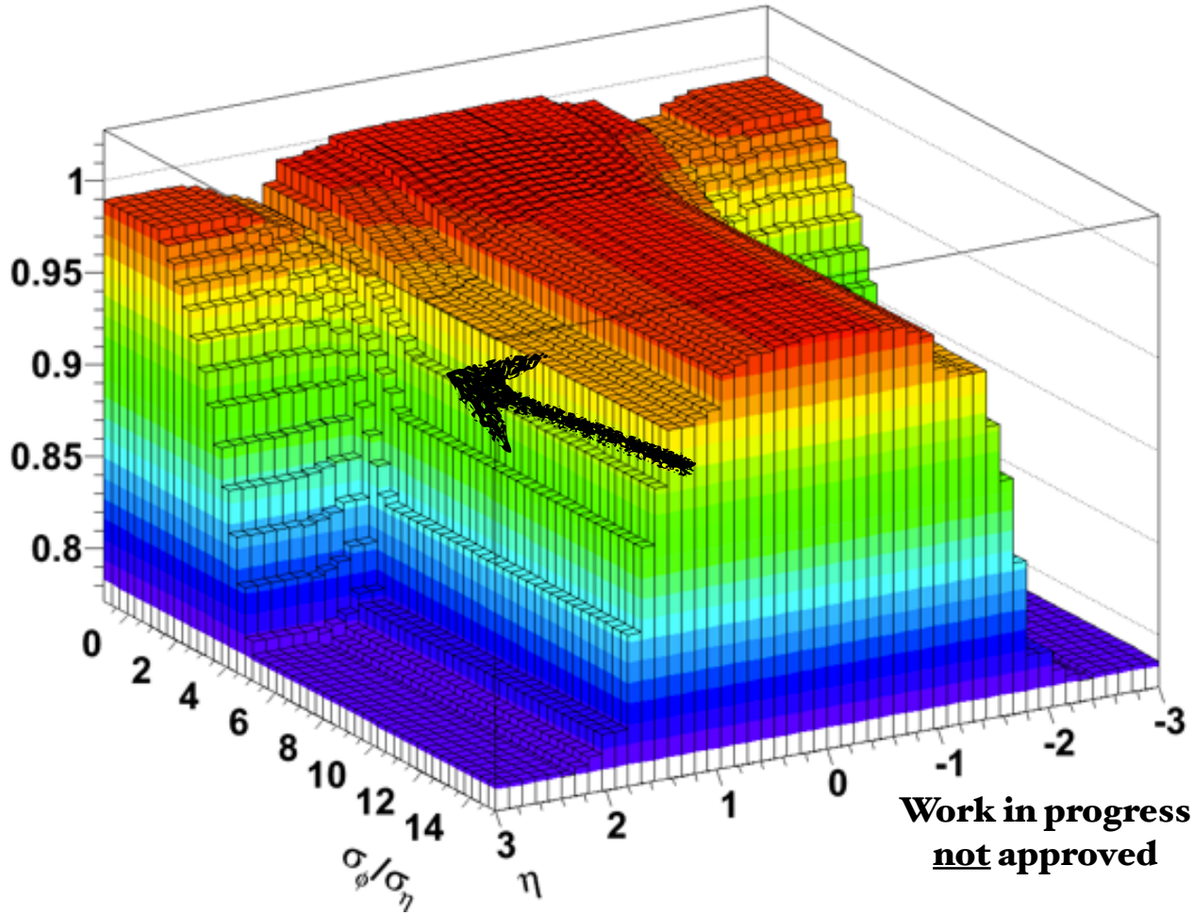


F(brem,η) corrections

Photon low R9



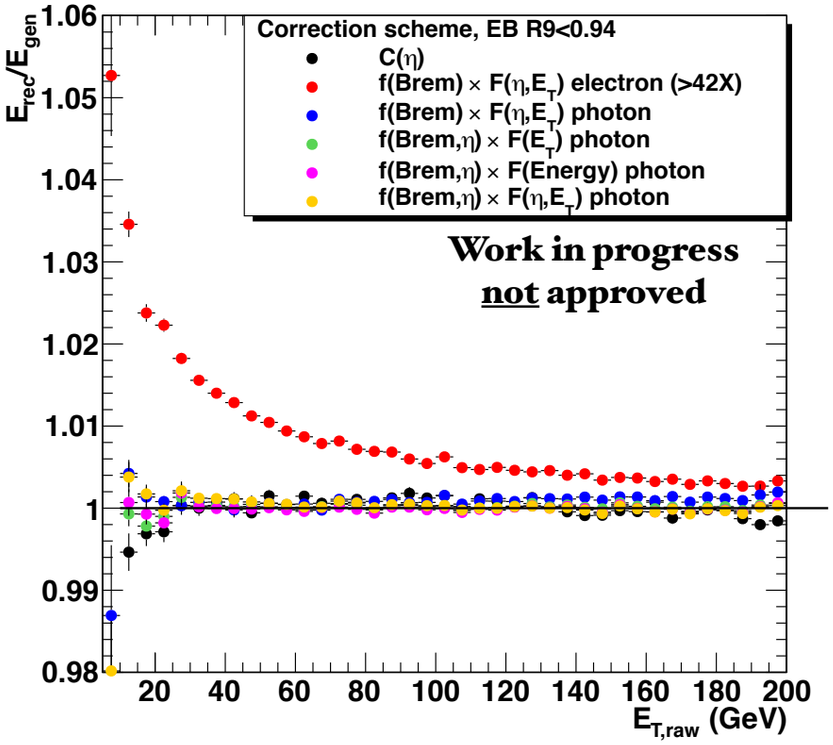
Electron

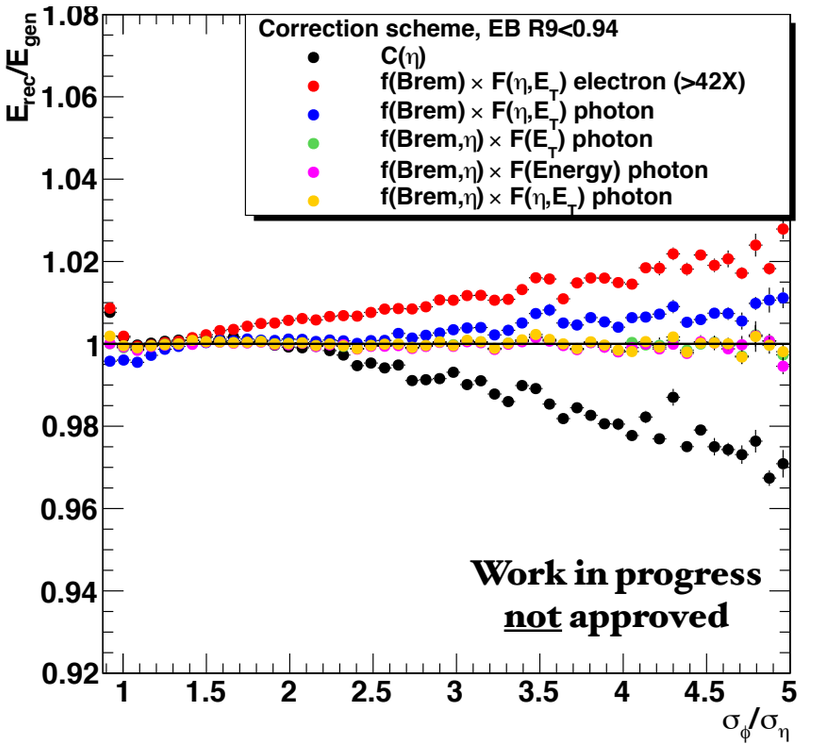


Indeed, a strong brem ⇔ η correlation is observed.

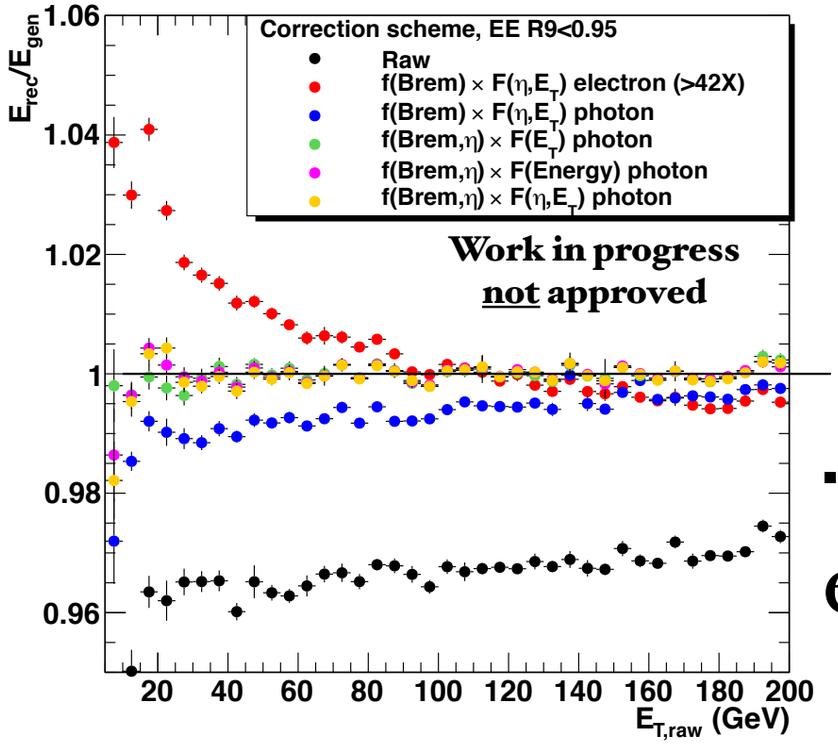
Validation on photons

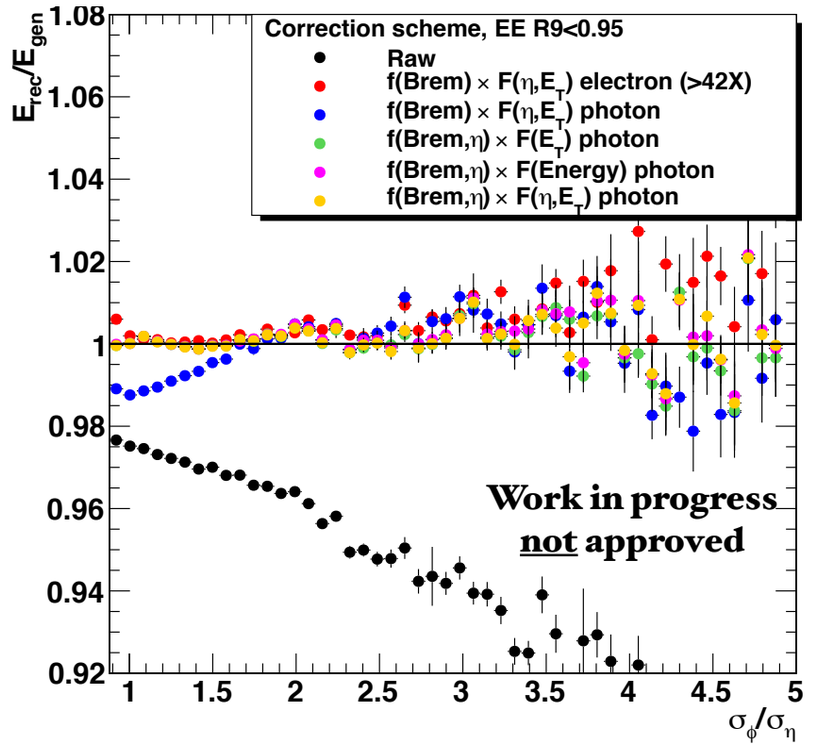
Barrel





Endcap





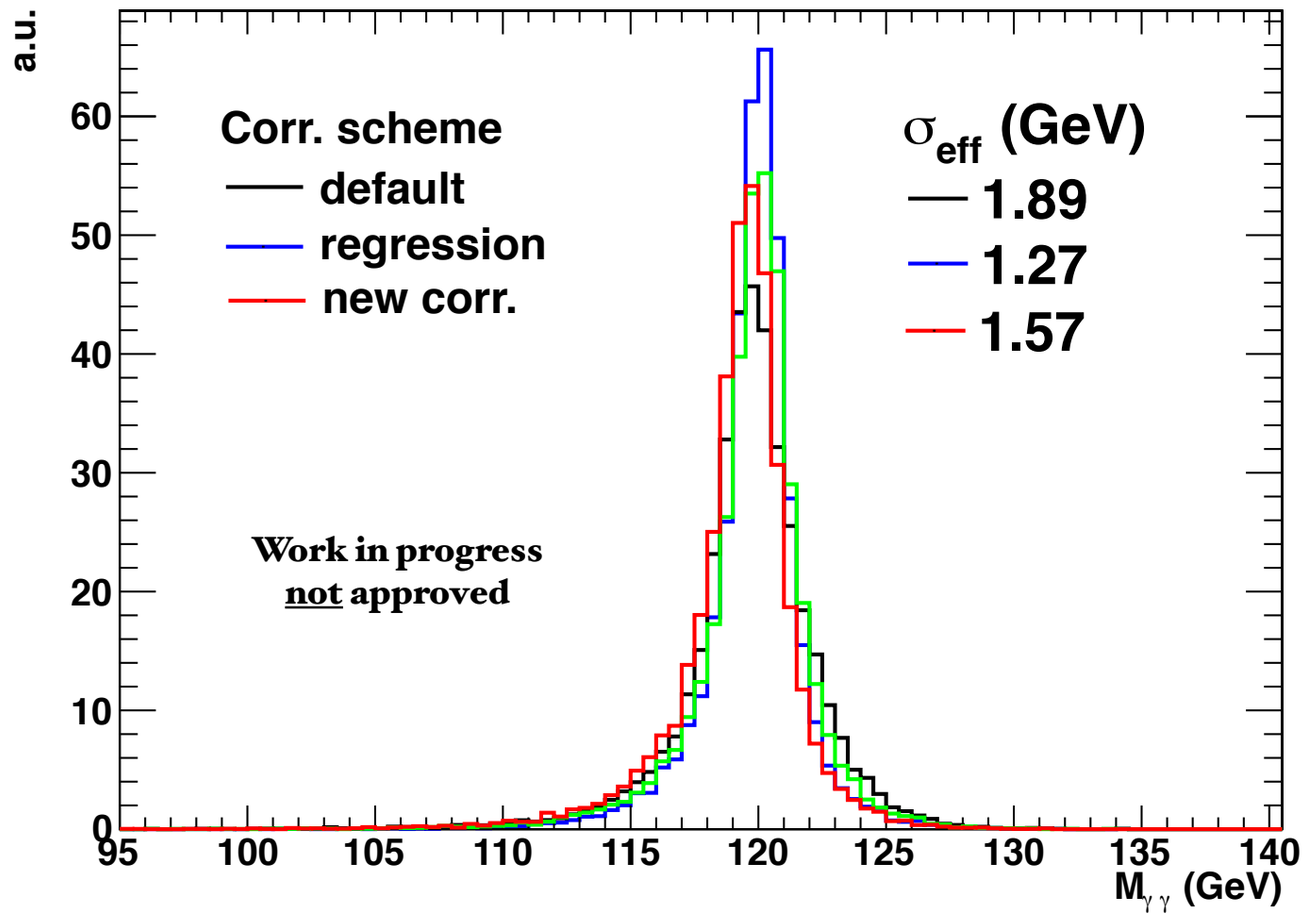
- Corrections tuned on electrons over-correct photon energy
- Scale is much flatter thanks to the new factorization scheme

Validation on Hgg

Corrections applied on MC Higgs @ 120 GeV in the diphoton decay channel

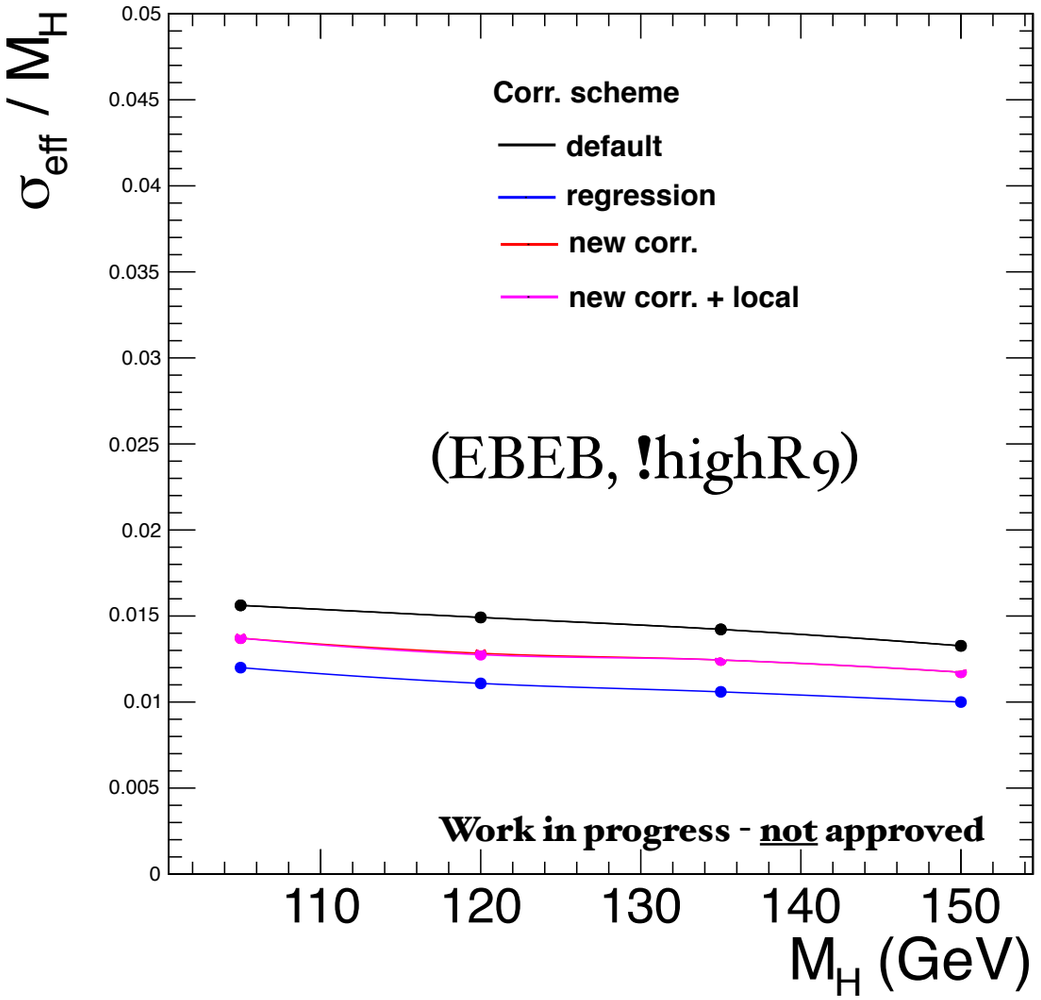
Comparison with:

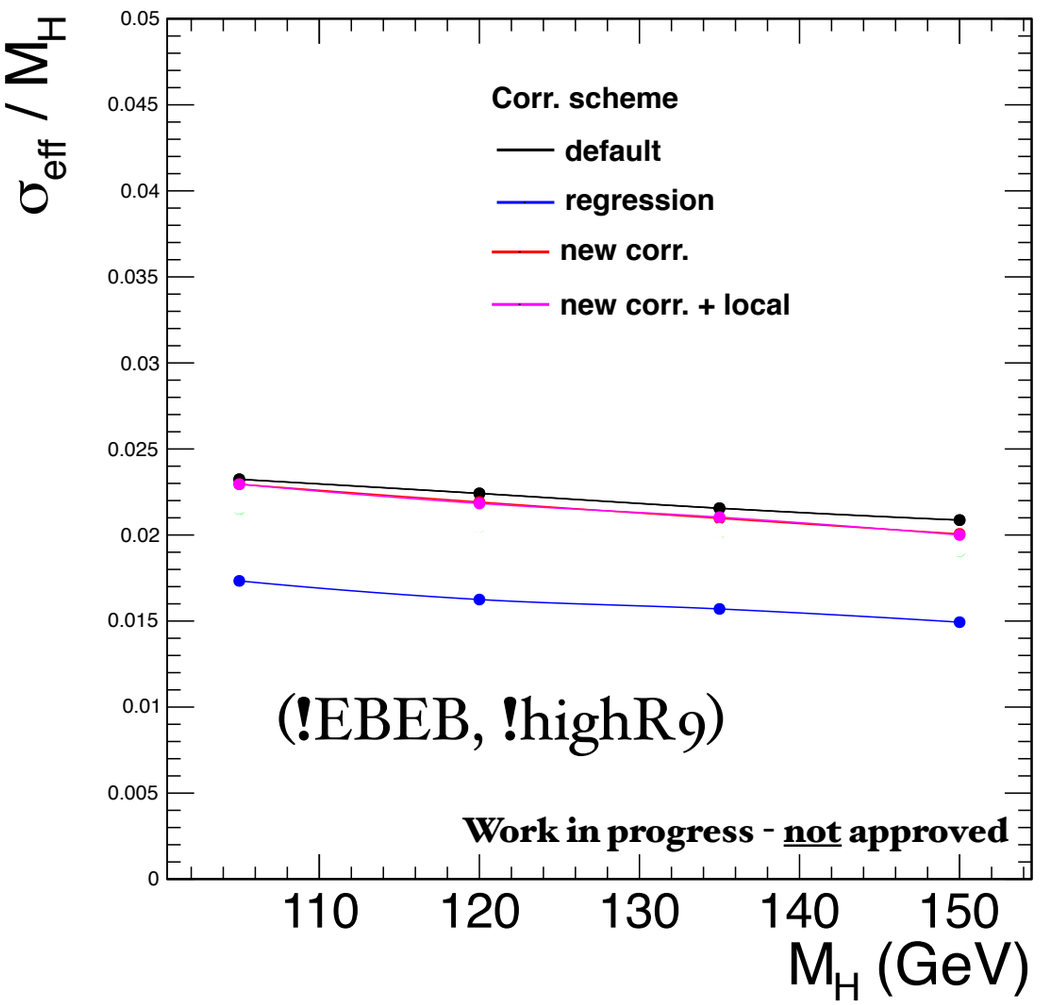
- older correction scheme
- photon energy regression used in 2011 Hgg analysis



Validation on Hgg

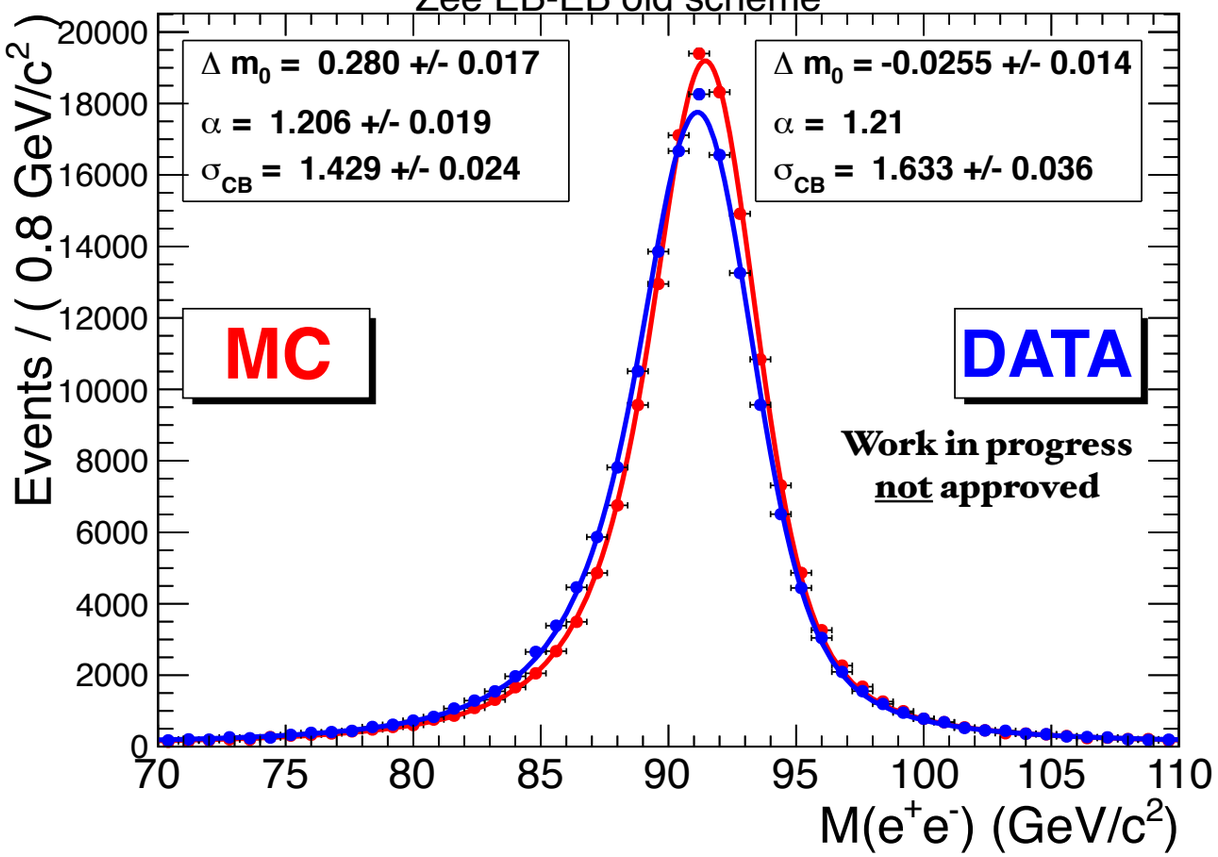
Events splitted in categories defined in terms of (eta,r9)

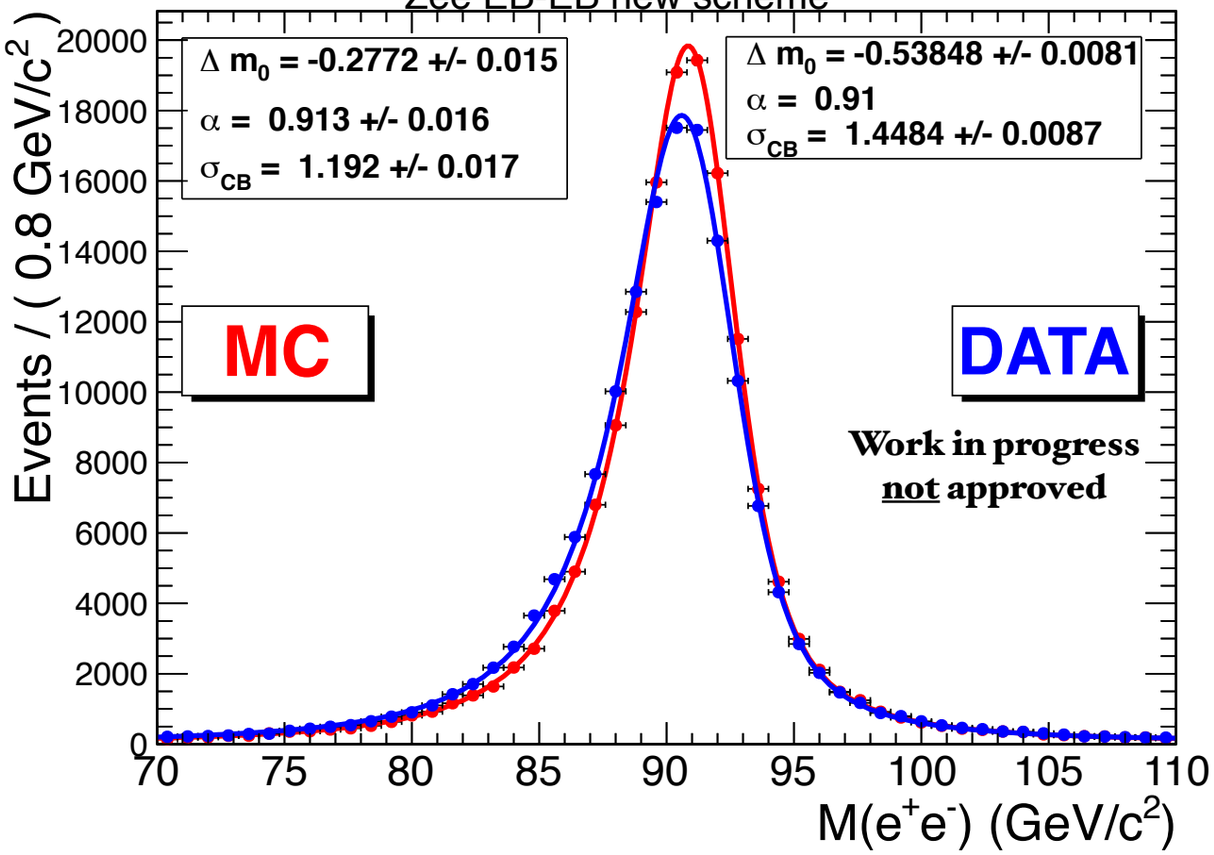




- Improvement over default photon energy
- Regression takes a large advantage from inclusion of local variables in EE and many more shower shapes

Validation on Zee





Fit: CB ⊗ BW + exp (bkg), CB n=5, α fitted in MC and fixed in data
(parameters change with different fits, only good for relative comparison)

Zee data (Run 2011A) / MC comparison:

- scale calibration comparable to older corrections
- improvement in resolution in both MC and data

Performance summary

New factorization scheme is a step forward in SC energy reconstruction at CMS:

- Performance validated in the data

- Substantial improvement in scale calibration (especially for low E_T photons) and resolution (~15% in Hgg)

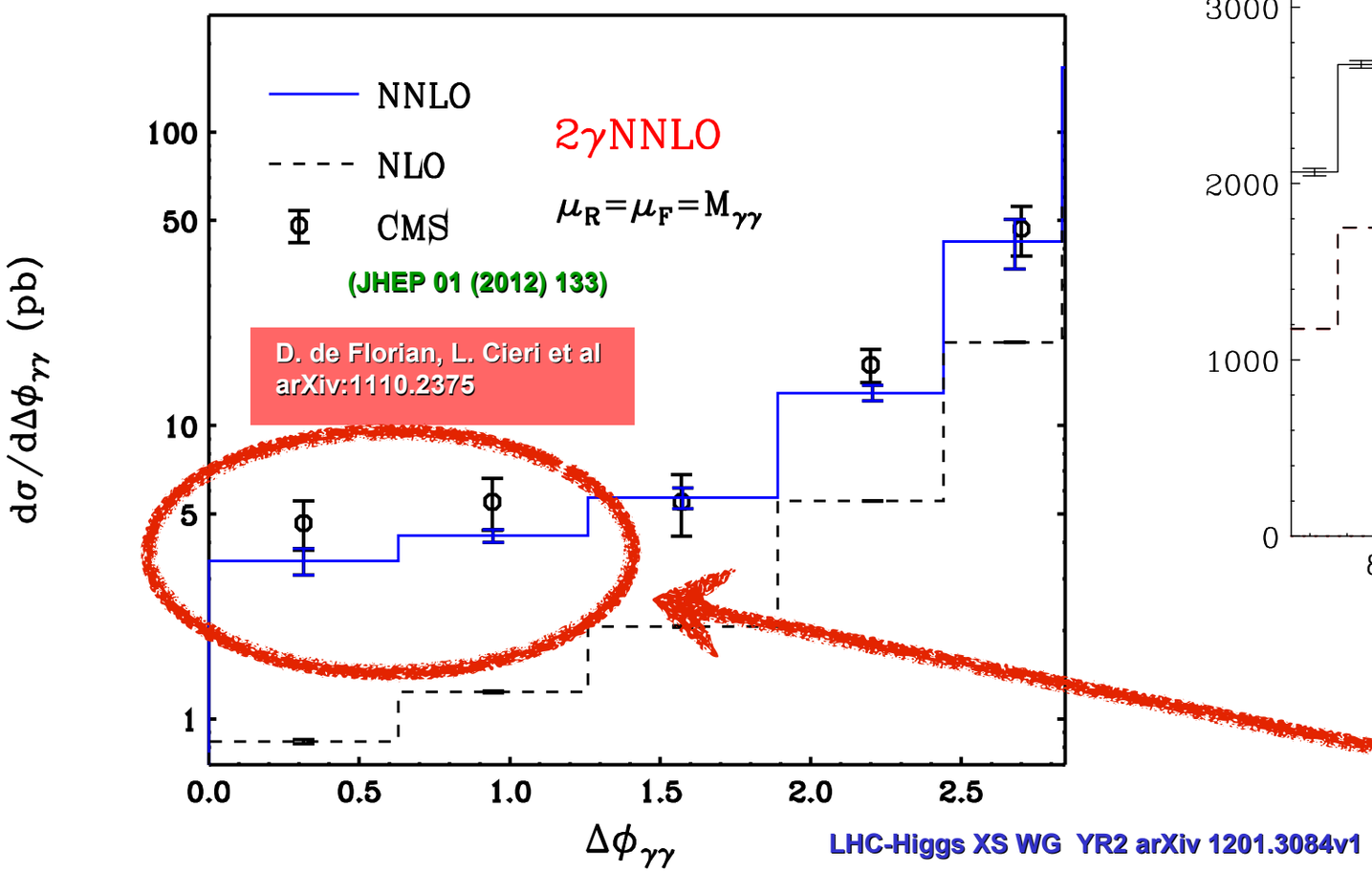
- Now used by default in the CMS event reconstruction code for photon and electron SC energy

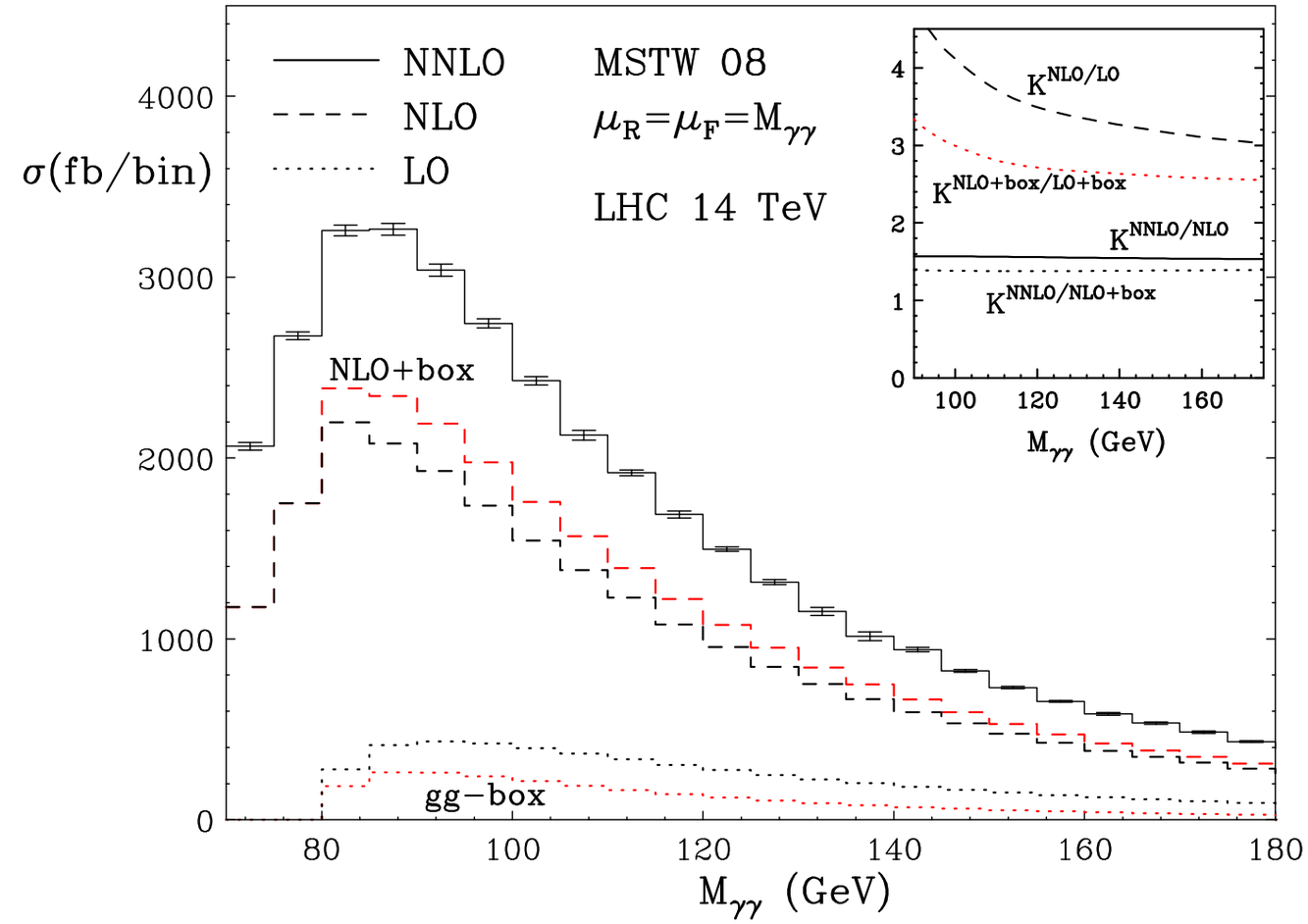
Diphoton production measurement

Motivation and theory

Diphoton events as a probe of QCD @ NNLO

- recent theory result arXiv:1110.2375 (Catani, Cieri, De Florian, Ferrera, Grazzini)

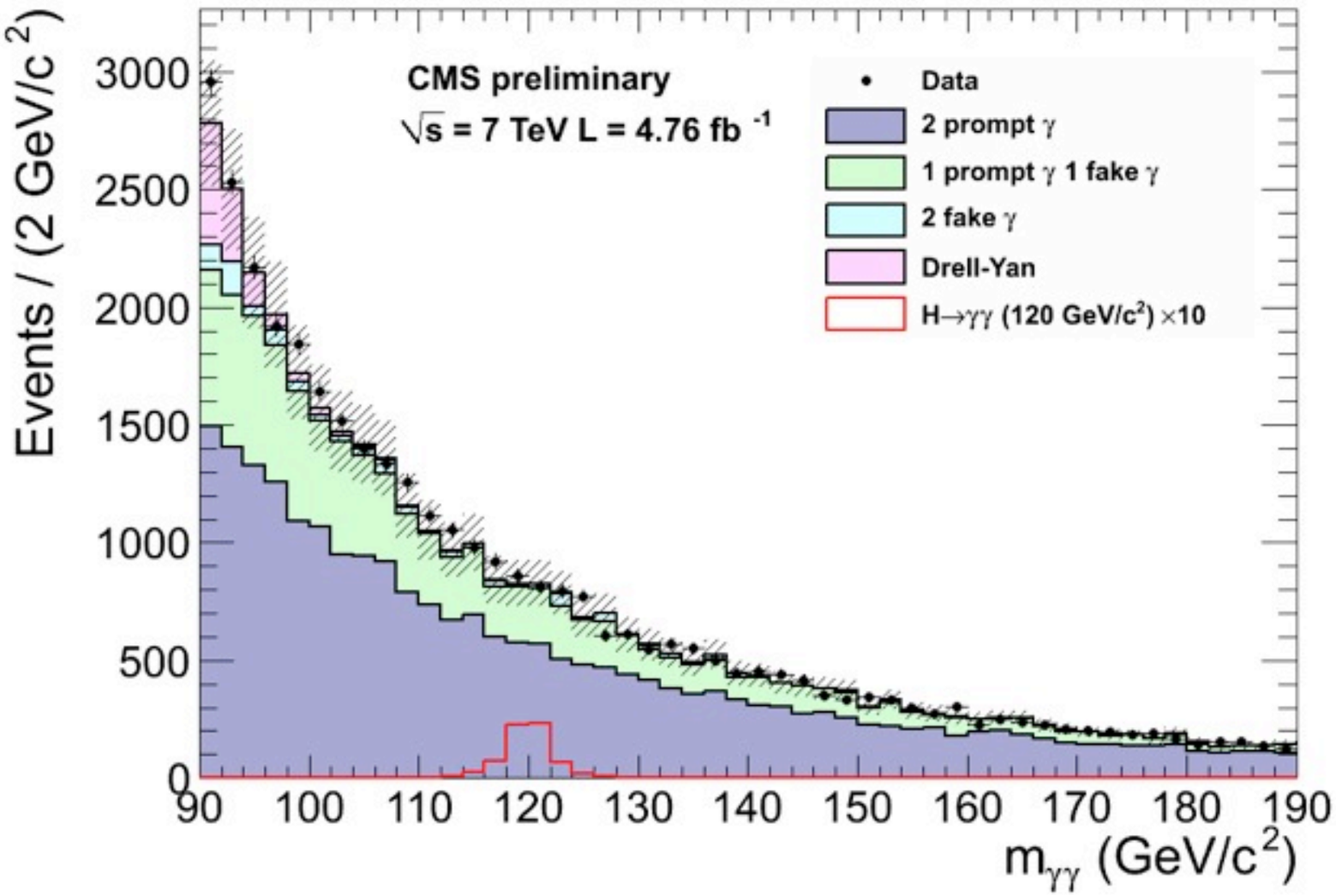




NLO is effectively only LO in this region (at LO, photons are back to back)

γγ+jets as Hgg background

Measuring relative purity of prompt-prompt, prompt-fake and fake-fake background components



General procedure

$$\frac{d\sigma}{dX}(X_i) = \frac{N^{U}_{\gamma\gamma}(X_i)}{\mathcal{L}\Delta X_i \mathcal{C}(X_i)}$$

- $N^{U}_{\gamma\gamma}(X_i)$: Unfolded signal event yield
- $\mathcal{C}(X_i)$: Acceptance x efficiency correction
- ΔX_i: Bin width
- $\mathcal{L}$: Luminosity

Interesting differential variables to compare with theory:

· diphoton p_T · $m_{\gamma\gamma}$

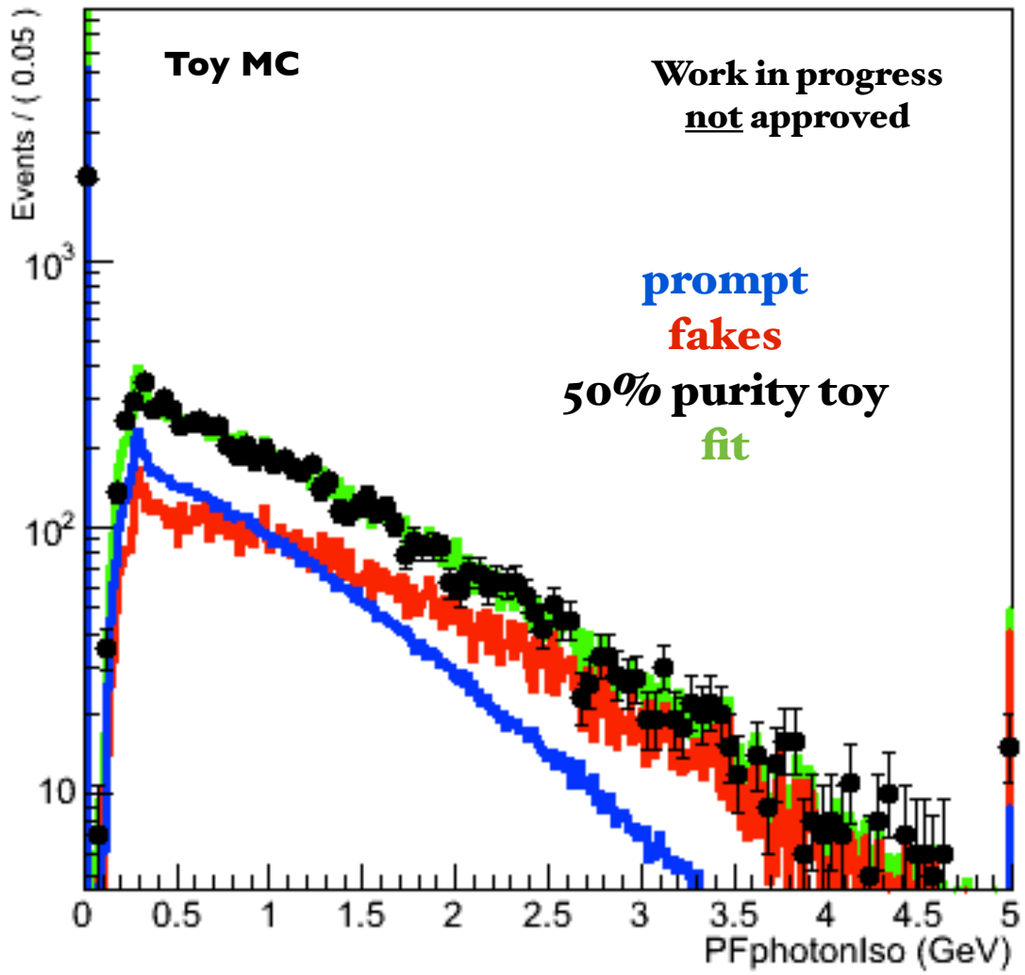
· cos θ* · delta φ

Procedure:

· Extraction of signal **purity** from templates fit

· **Unfolding**

· Correction for signal **efficiency**



Selection and templates

<u>Selection</u>:

photon $p_T^1 > 40$ GeV, $p_T^2 > 30$ GeV, $|\eta| < 2.5$

H/E < 0.05, $\sigma_{i\eta i\eta}$ (shower shape) < 0.011 (0.030)

PU-subtracted combined Particle-Flow isolation < 5 GeV

PU subtraction done with FastJet ρ and eff. area technique

<u>Templates</u>:

Photon component of PF isolation

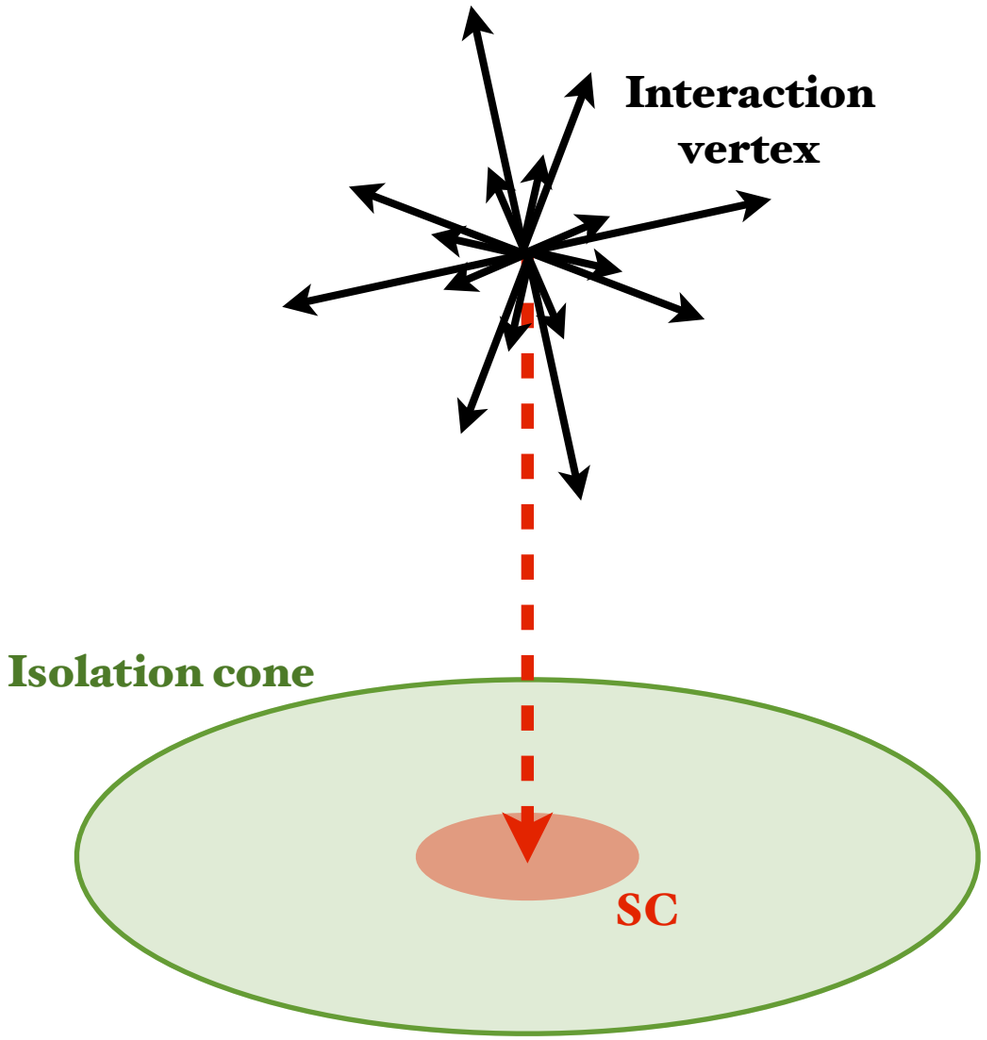
Data-driven techniques for template generation:

- random cone for prompt photon template
- $\sigma_{i\eta i\eta}$ sideband for fakes template

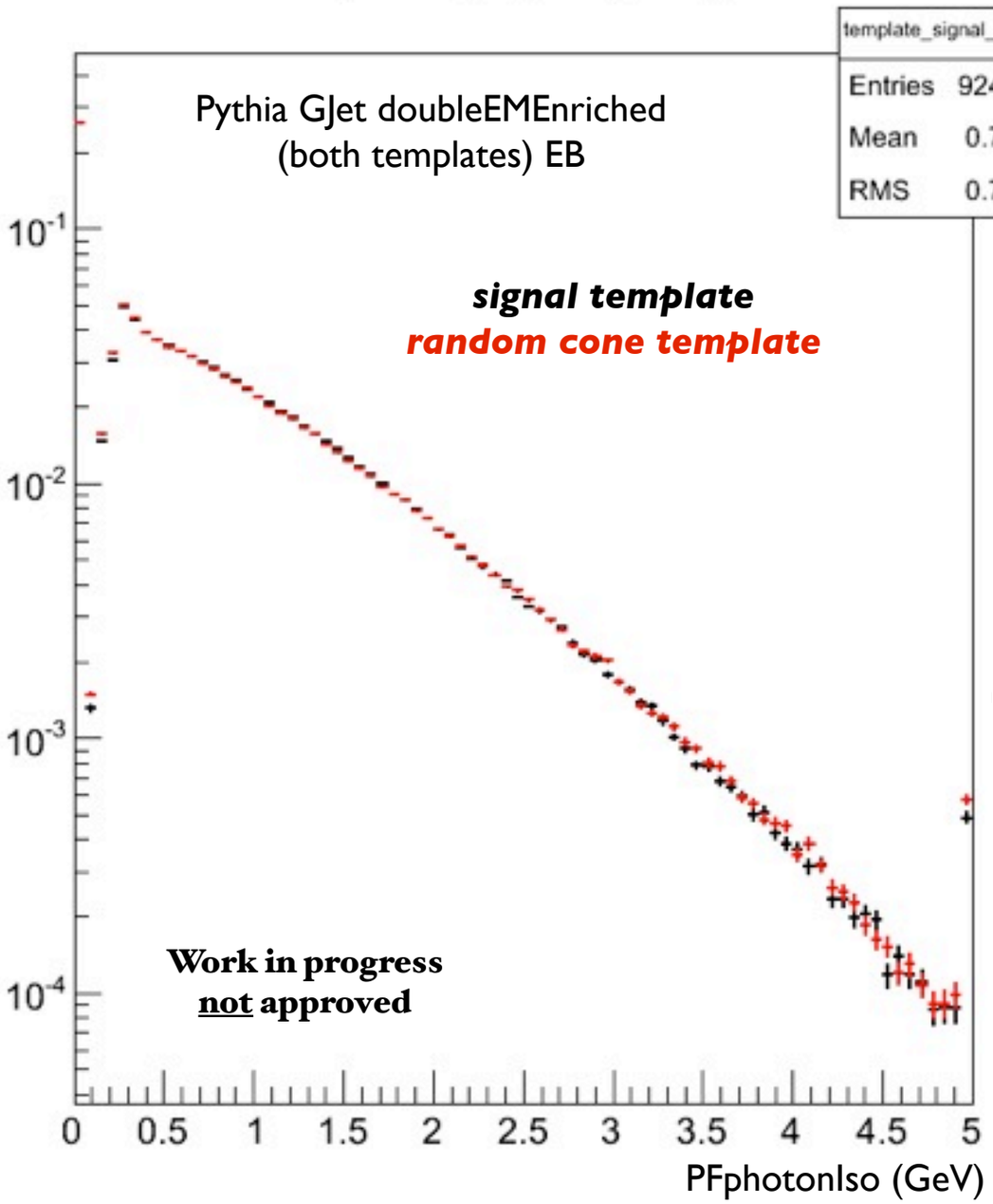
Random cone template

Ansatz:
Once the photon footprint has been removed, the PFphotonIso for prompt photons is due only to pileup and underlying event

(true if energy leakage from the photon footprint into the isolation cone is negligible)

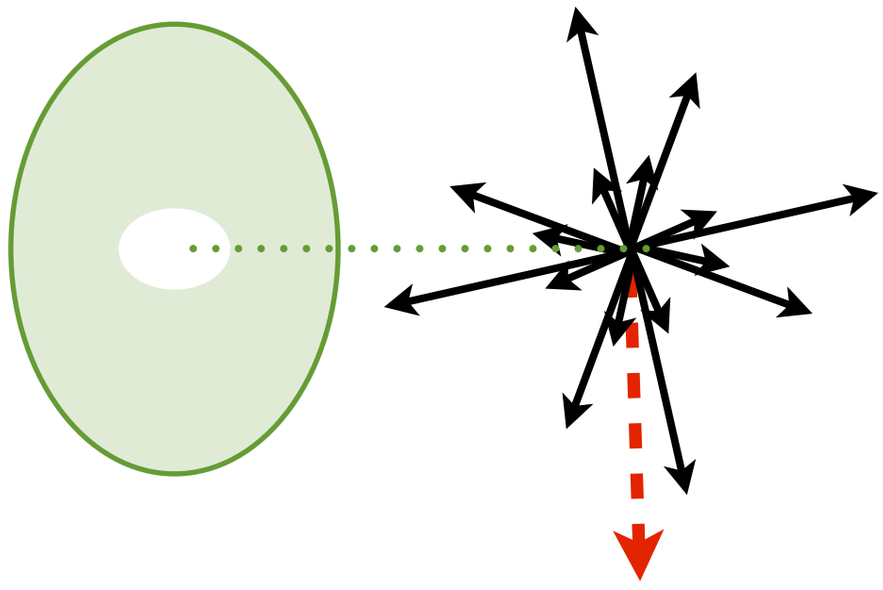


Random cone template

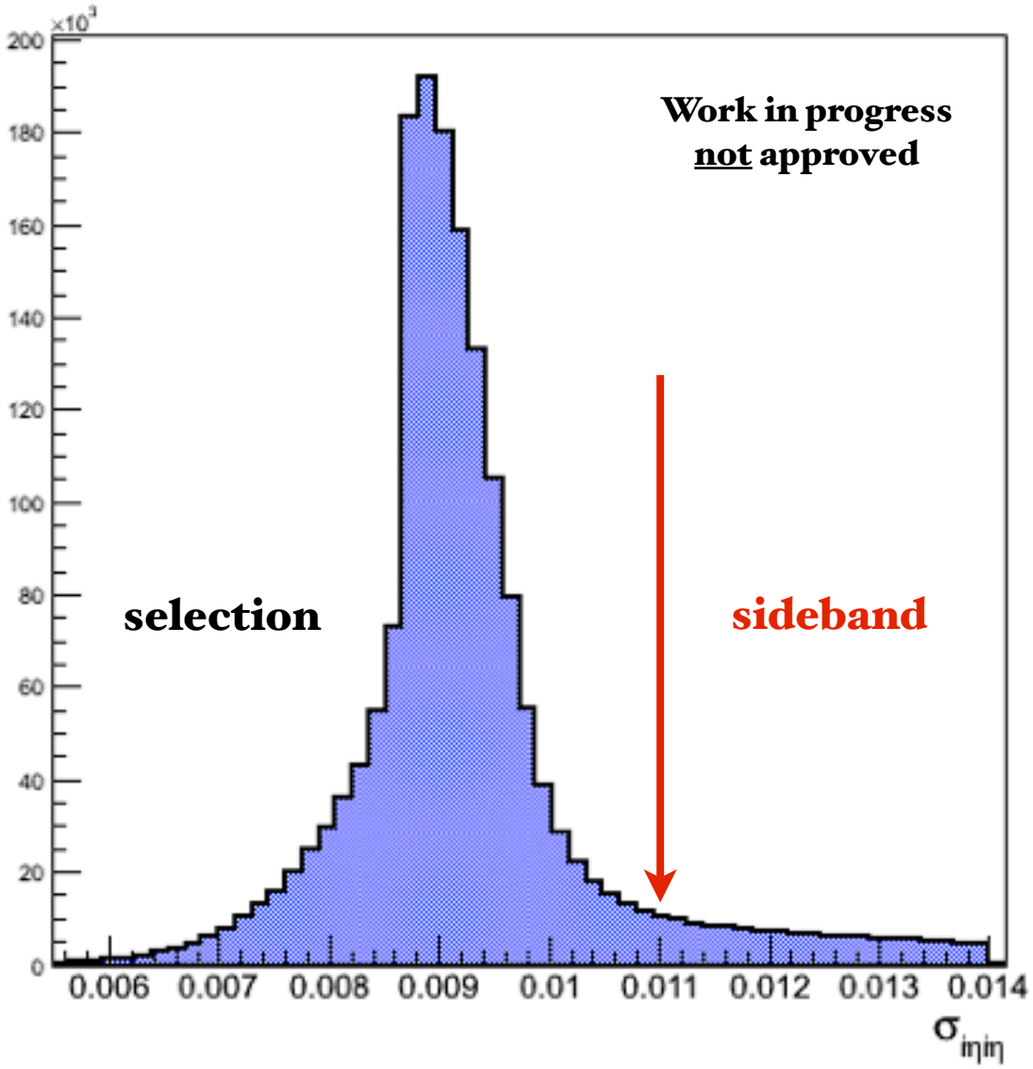


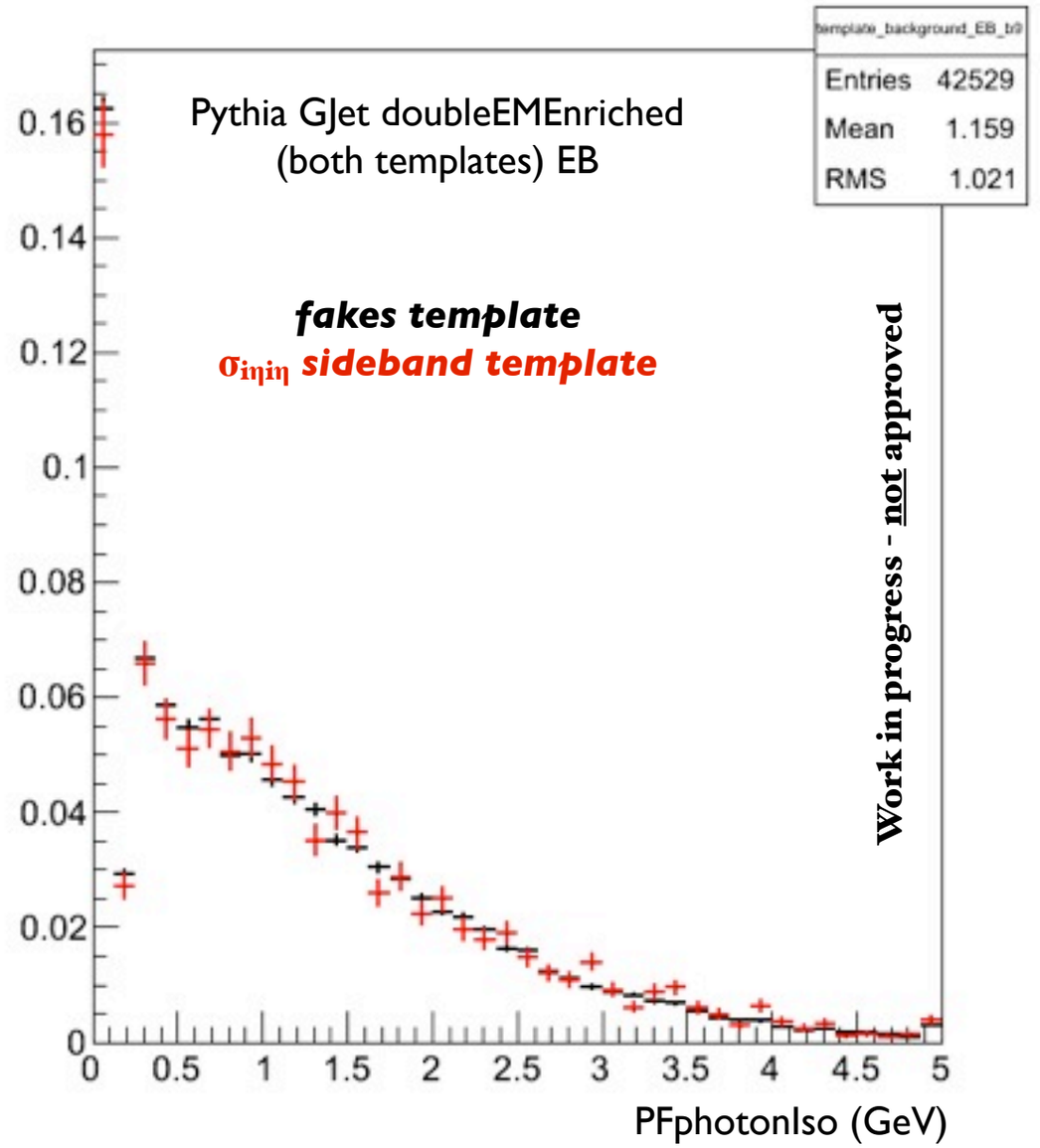
Procedure:

- rotate the isolation cone in φ by $\pi/2$
- check that no other object is nearby
- underlying activity does not change
- build the template from this isolation sum away from the photon candidate



$\sigma_{i\eta i\eta}$ sideband template





Ansatz:

- the signal contamination in a sample selected reverting the $\sigma_{i\eta i\eta}$ cut is negligible
- the template variable is not correlated with $\sigma_{i\eta i\eta}$

Conclusions

Just a couple of topics, but already some ideas emerging:

➢ understanding the physical correlations introduced among photon observables by the interaction with the detector is a **key** for accurate measurement

➢ events with photons probe a wide range of theoretical scenarios

➢ data driven techniques increase the robustness of photon measurements in physics analyses

Backup slides

Additional corrections

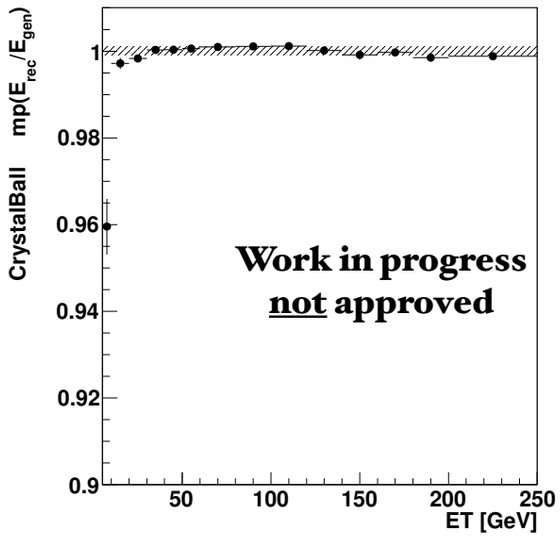
➢ Crack corrections (up to a few %, affect many crystals):
- corr. for energy leakage near module boundaries
- applied *on top of interpolated corrs already shown*
  - for every BC for electrons and low R9 photons
  - for seed BC only for high R9 photons

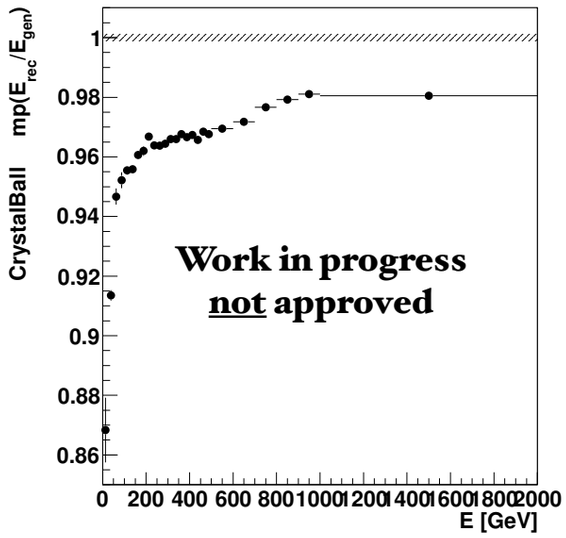
➢ Local containment corrections (not more than ~ 1 %):
- corr. for different fraction of EM energy picked up, depending on hit position in the crystal

Residual correction

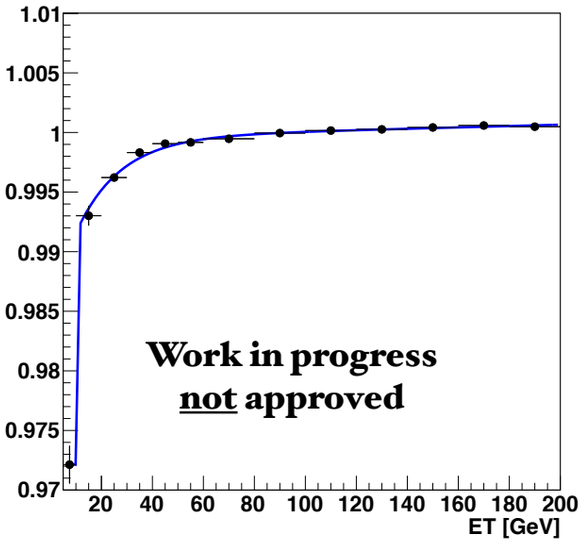
After applying (brem,eta) correction: residual ET/Energy dependence:

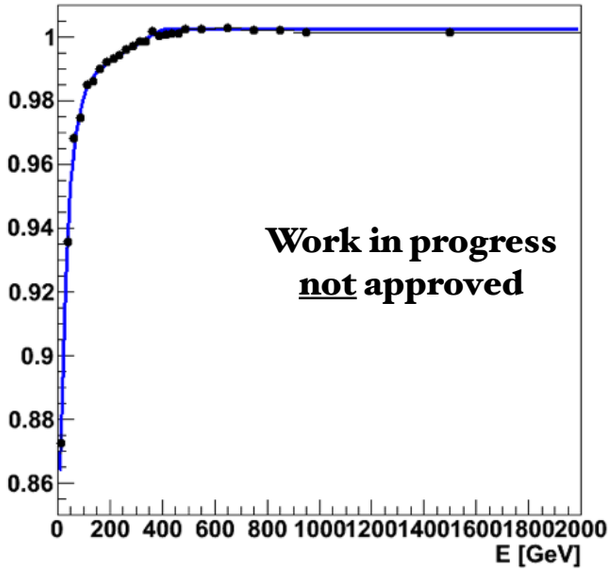
photons





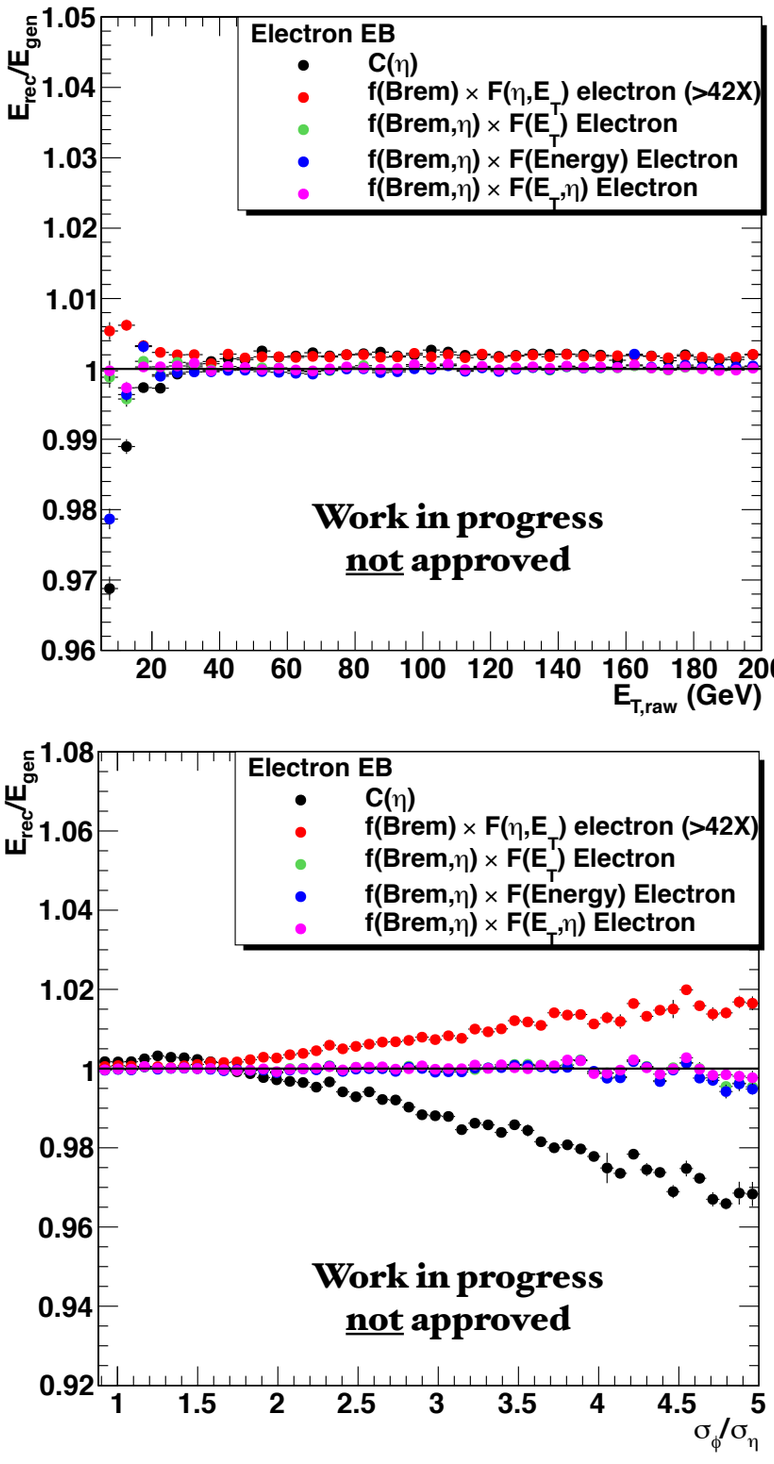
electrons



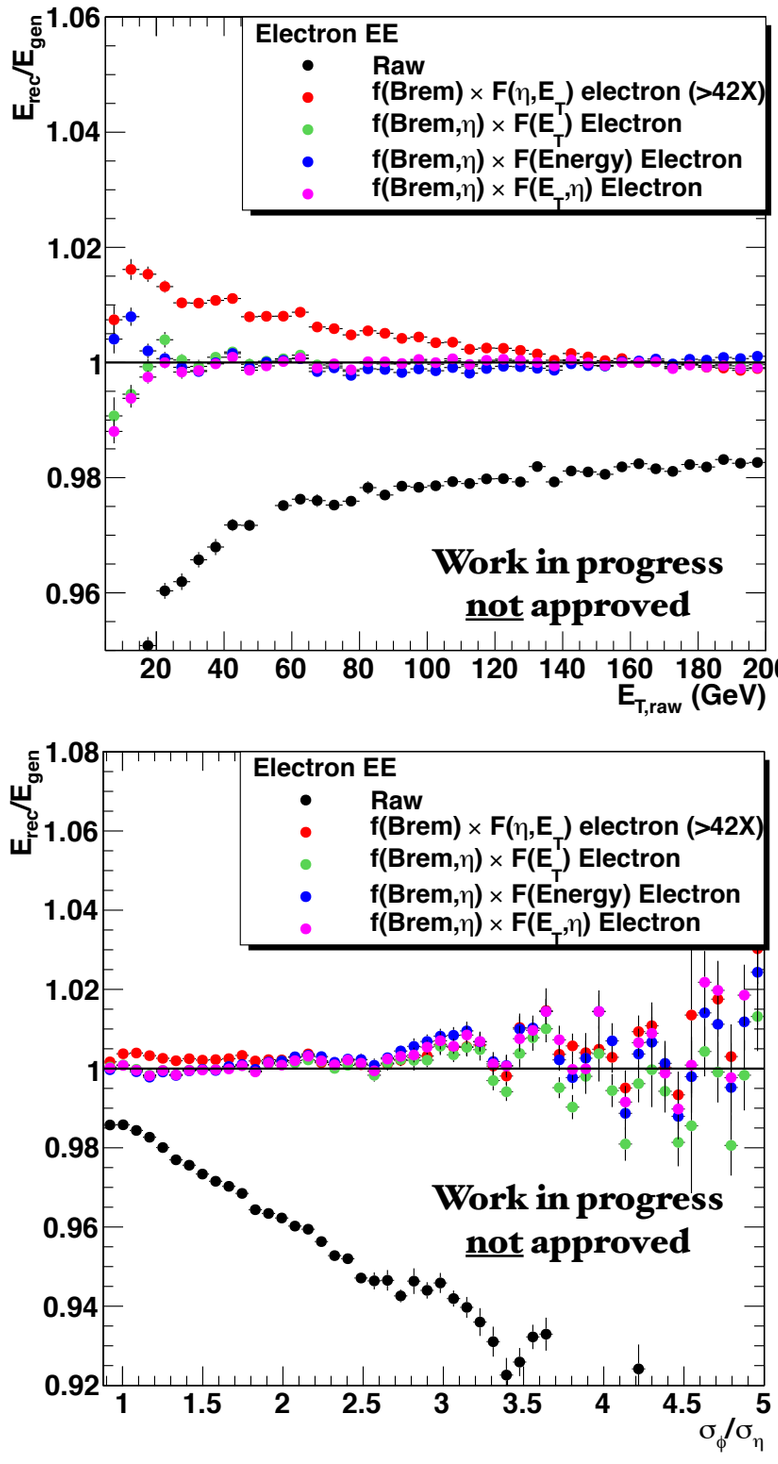


Validation: electrons

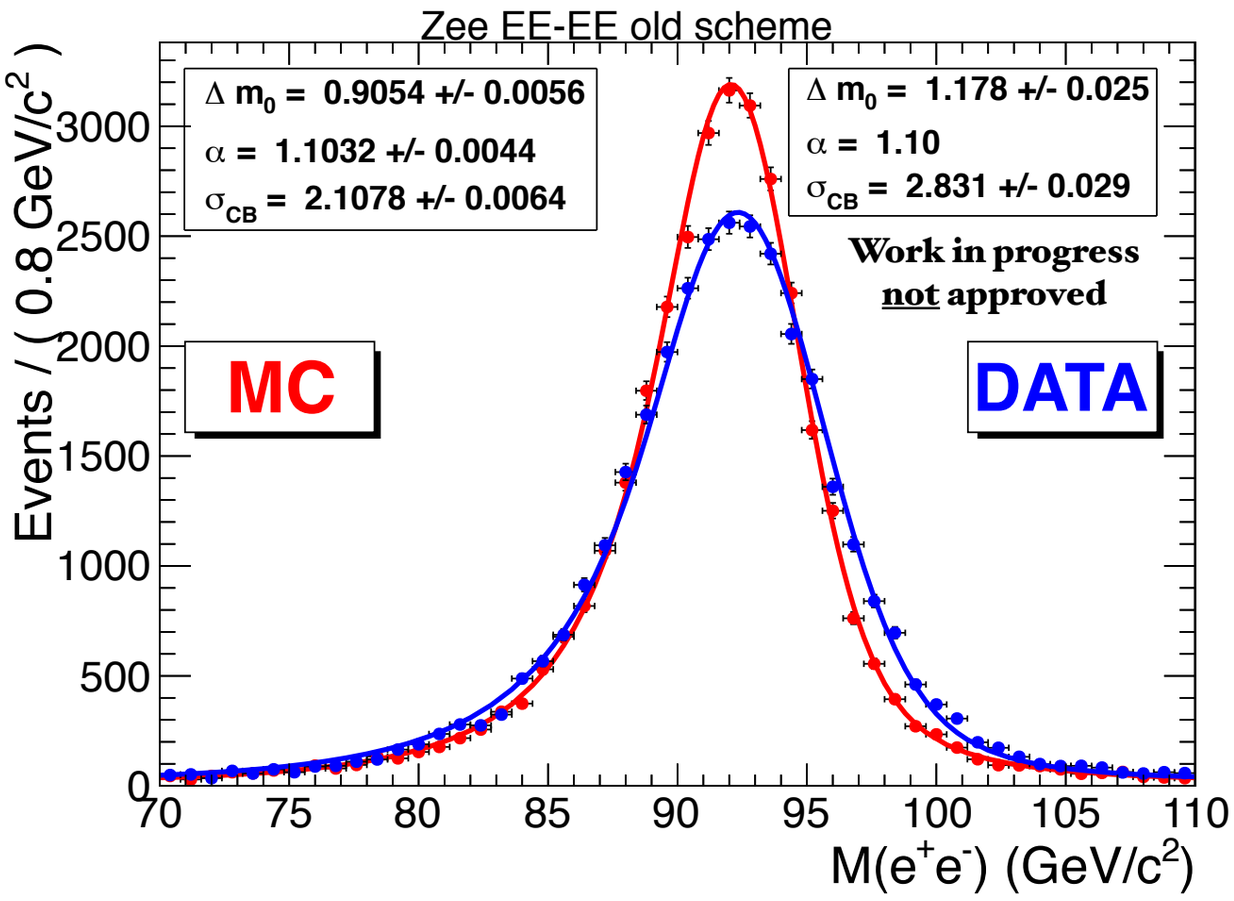
Barrel

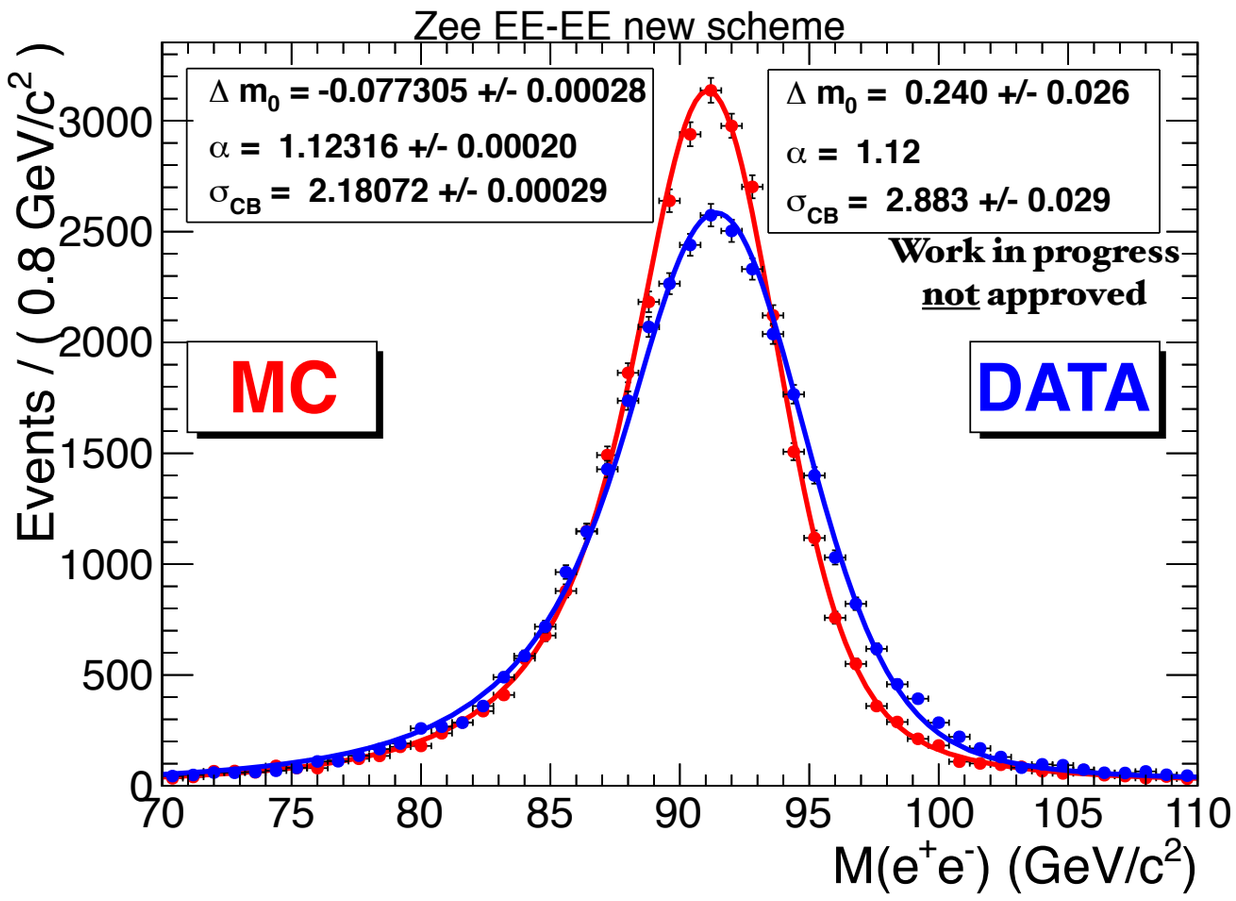


Endcap



Validation on Zee





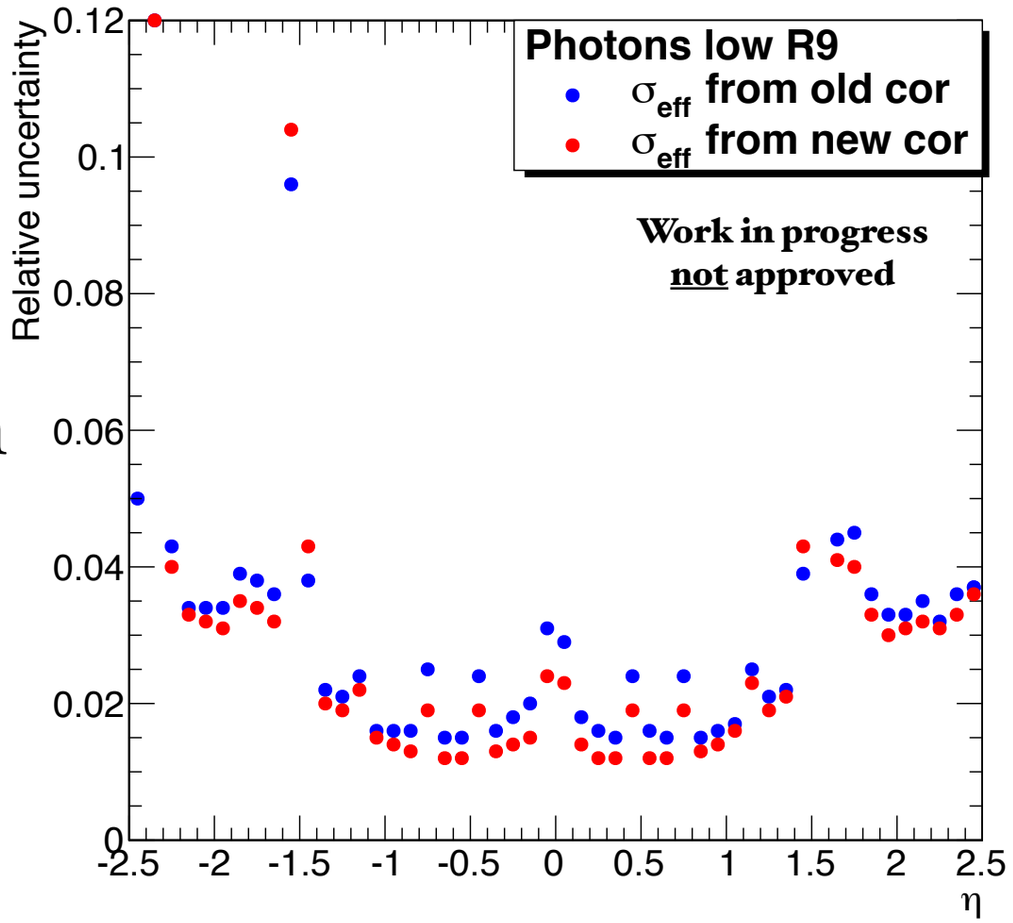
In EE:

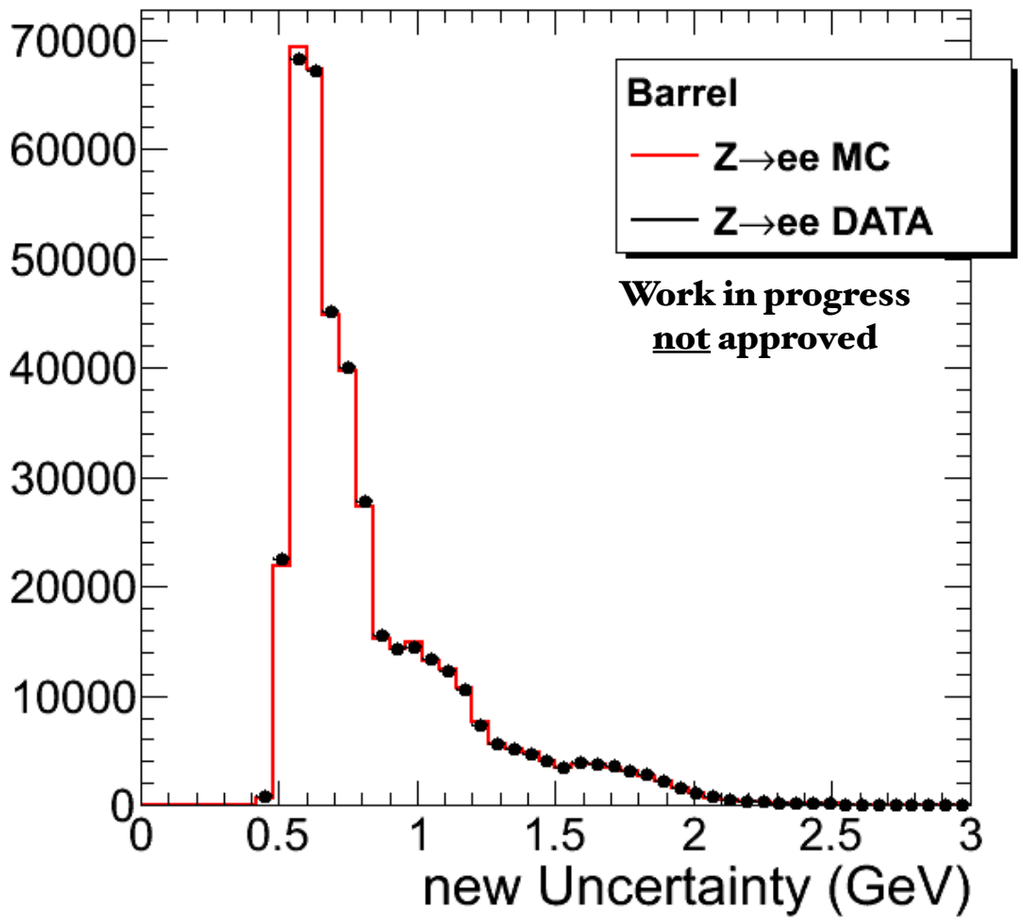
- large improvement in scale calibration
- resolution unchanged

Uncertainty on corrections

Definition: eff. sigma of E_{rec}/E_{gen} distribution after corrections

(relevant for combination of SC energy with track for electrons, fitted in (brem,η) bins)



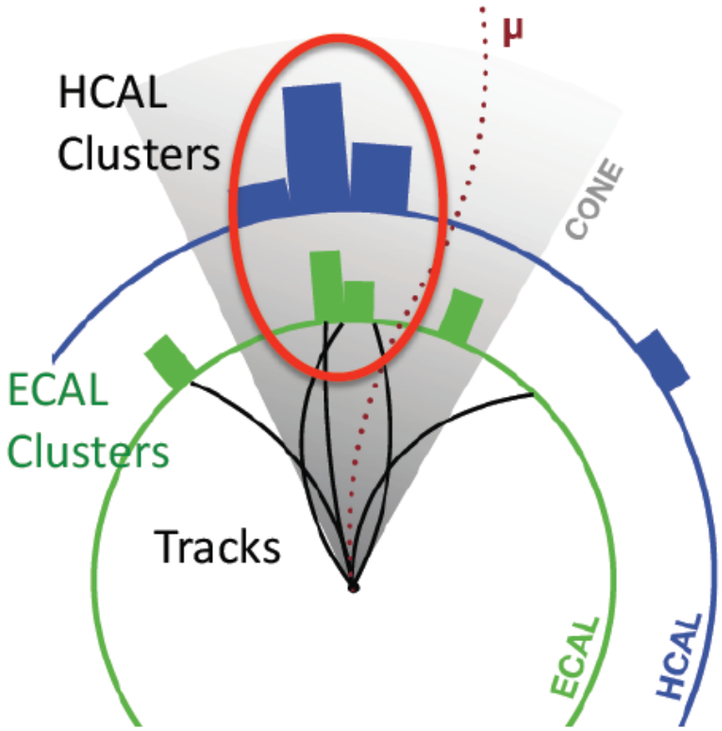


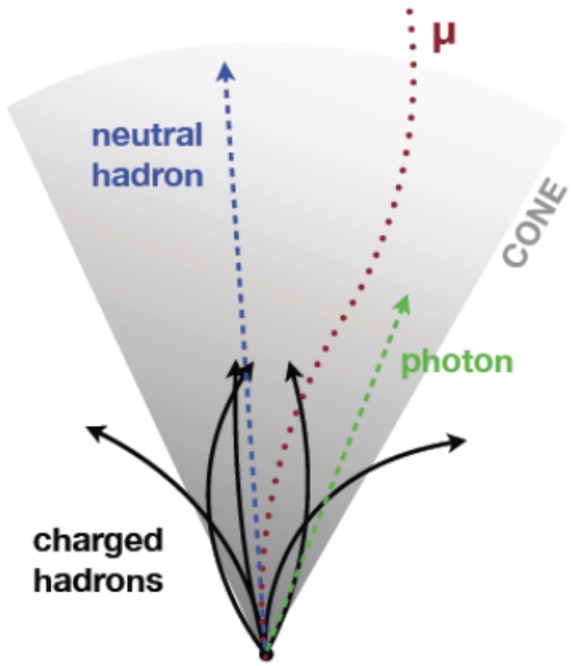
Per-event uncertainty estimation validated on Zee data/MC:

large improvement from new correction scheme

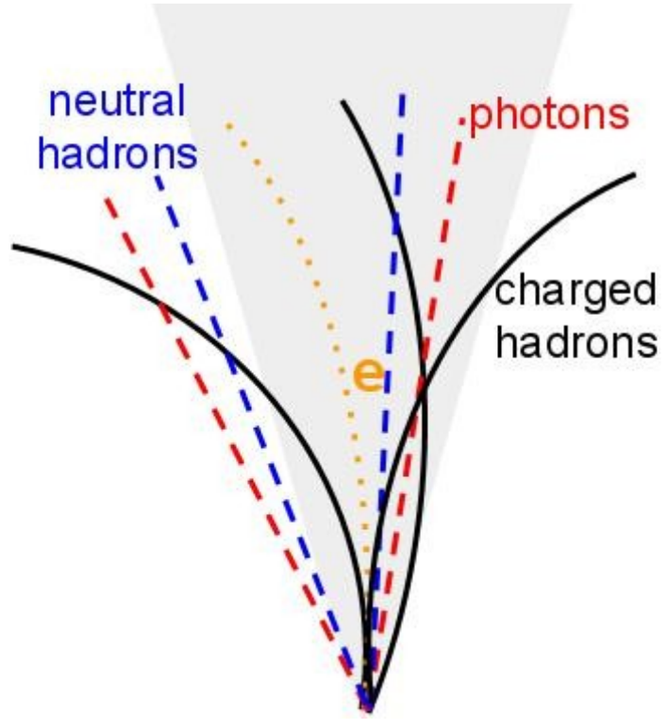
Particle Flow

Clusters and tracks <-> Particles



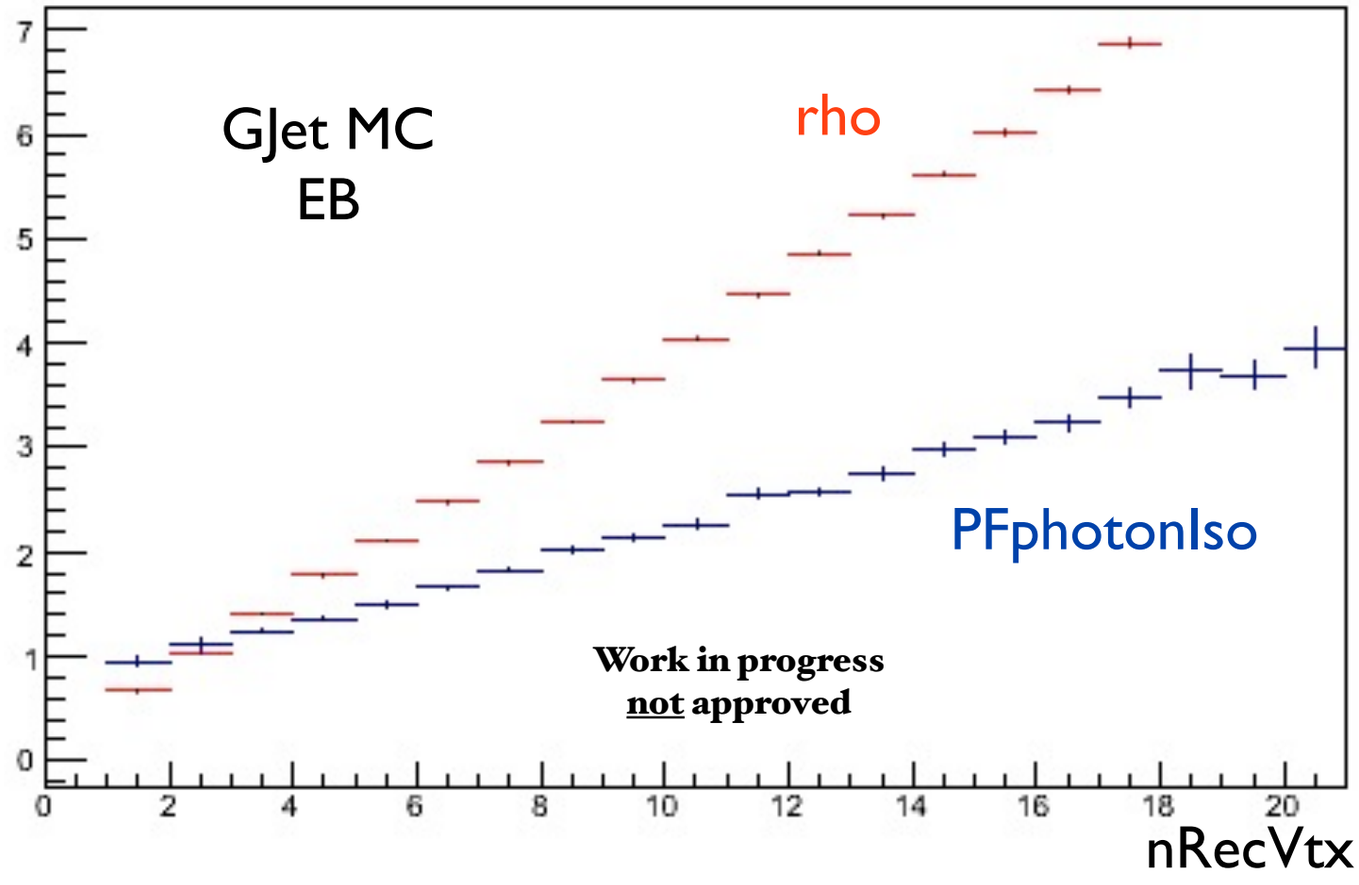


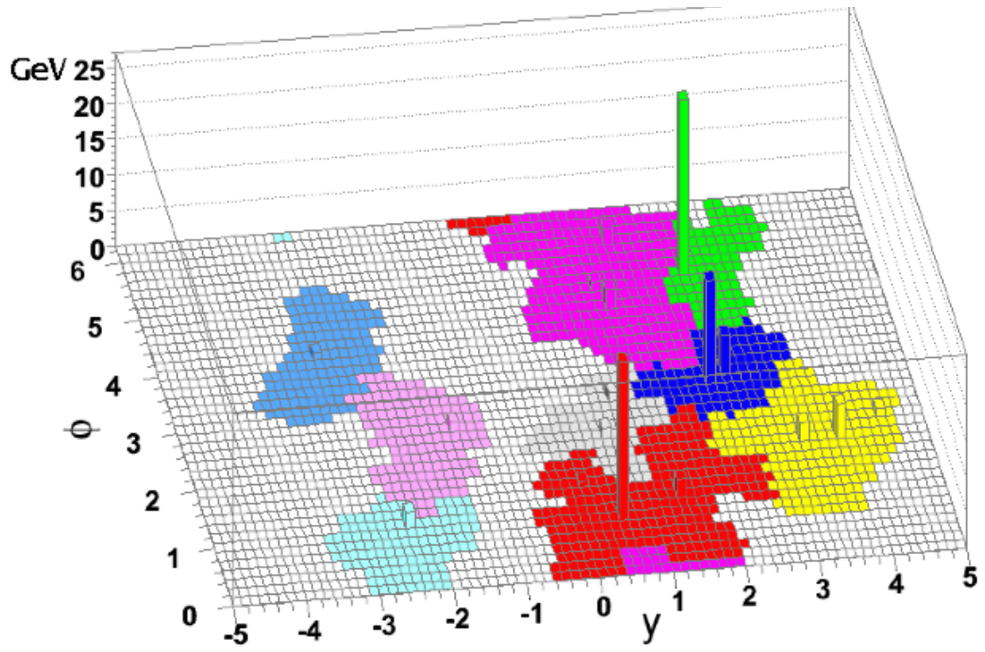
PF isolation



Effective area

eff. area = slope(PFphotonIso)/slope(rho)
Iso_corr = Iso_uncorr - pi*0.4*0.4*eff_area*rho





FastJet PU subtraction is based on two elements :

- The **area A** where PU will be subtracted
- **ρ, the PU density energy per unit area,** estimated on a per-event basis : estimated building jets from all pfcandidates, taking the median of pt^{jet}/A^{jet} distribution