ATLAS simulation topics

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EGamma workshop

14–17 Mar 2023, CERN

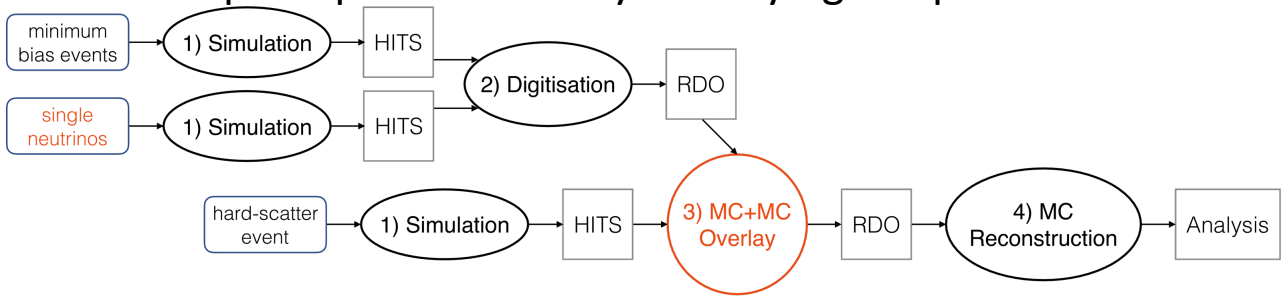
Institute of High Energy Physics Chinese Academy of Sciences

Content

- **Run 3 pile-up overlay tuning for TRT.**
- **ATLAS Fast simulation.**
- **LAr EM shower shapes.**
- **EGamma energy scale in mc21.**

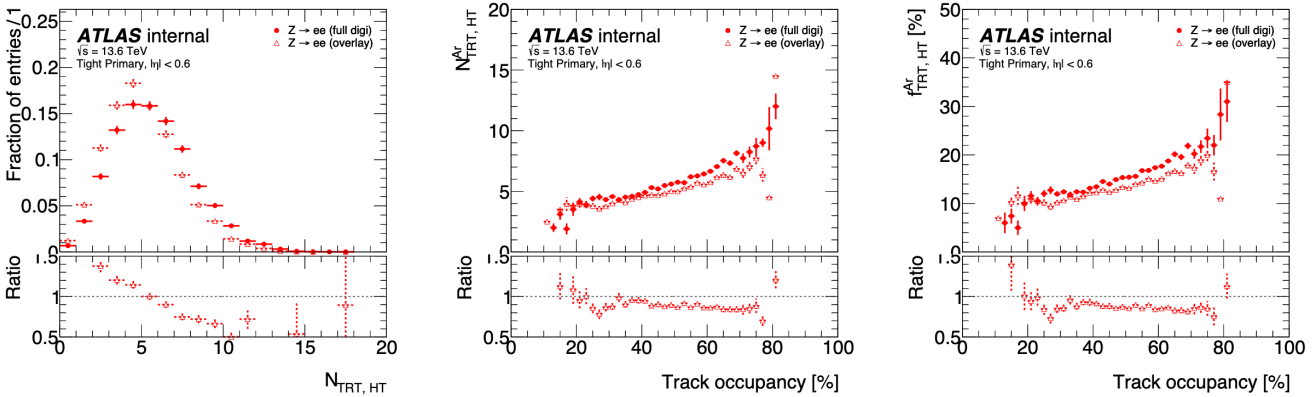
New pileup overlay for TRT

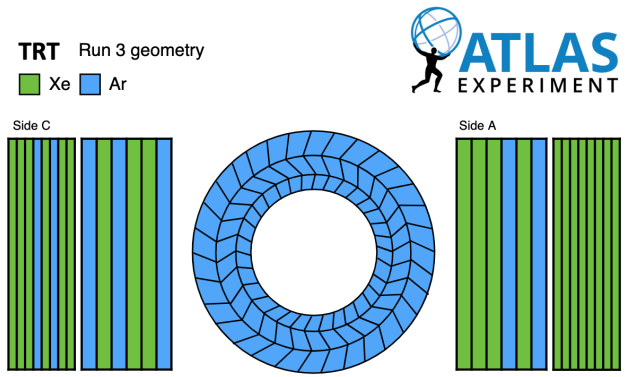
- **MC-MC overlay digitization for pile-up:**
  - Derive the pile-up simulation by overlaying the pre-mixed events. **MUCH FASTER**!



Interesting details in Christian's talk

- **TRT overlay tuning:**
  - Randomly increase HT hits. The probabilities need to be tuned.
  - In Run3: more straws use ***Ar-based*** gas mixture, while the previous parameterizations are developed for ***Xe-based*** straws only.

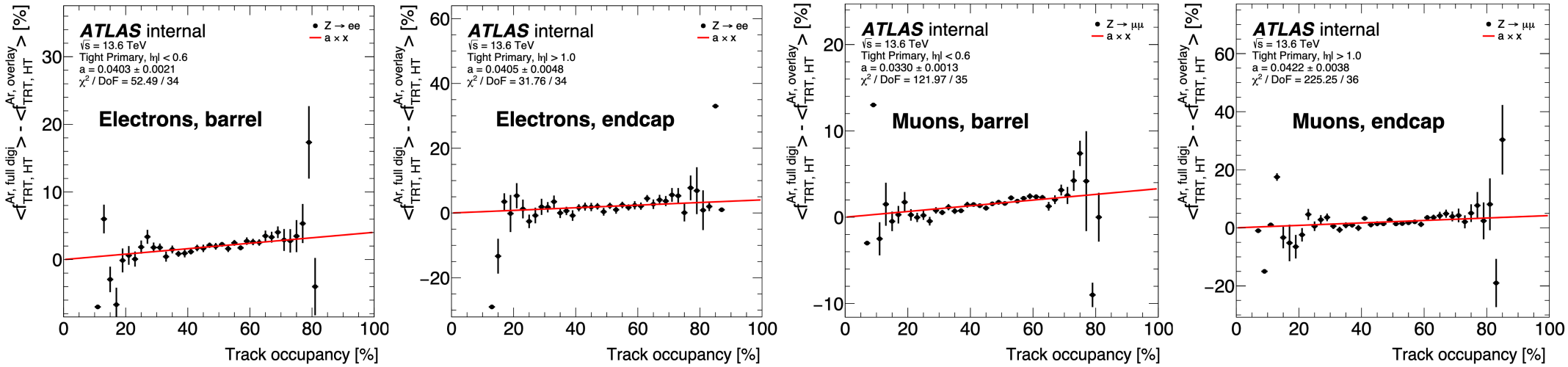




New pileup overlay for TRT

- **Parameterization tuning for Ar straws:**
  - Consider the added ionization signal over HT from pile-up multiple tracks.
  - Depending on: barrel/endcap, particle type ($e^{\pm}$ or not), and detector occupancy.
  - MC: Powheg+Pythia8 $Z \rightarrow ee$ / $Z \rightarrow \mu\mu$, Run3 gas geometry, full Digi / overlay.
  - Fit the difference to get the correction.

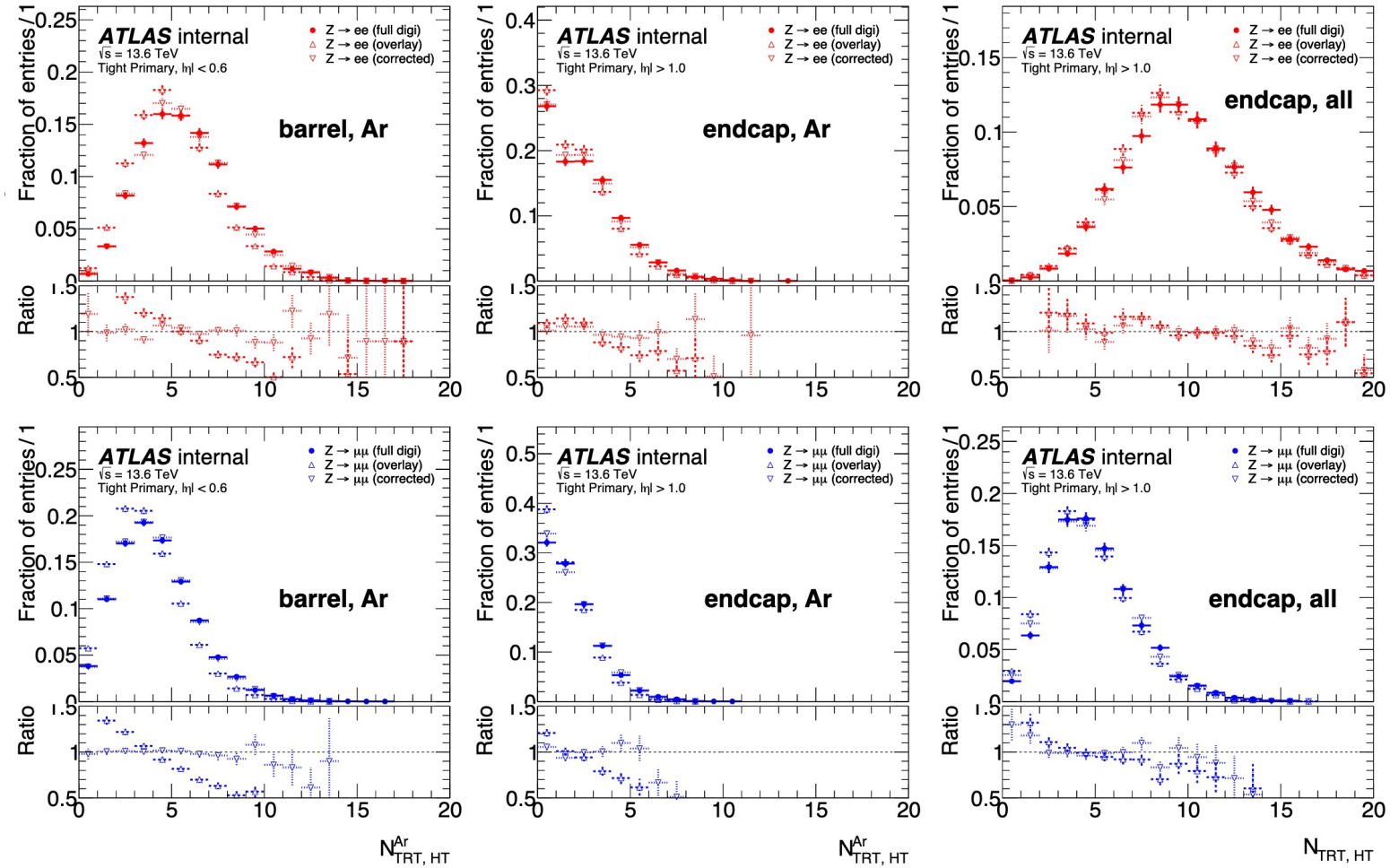
TRT overlay tuning by Christian



- Corrections have been implemented in Athena [MR].

New pileup overlay for TRT

- **Closure test with $Z \rightarrow ll$ MC:**

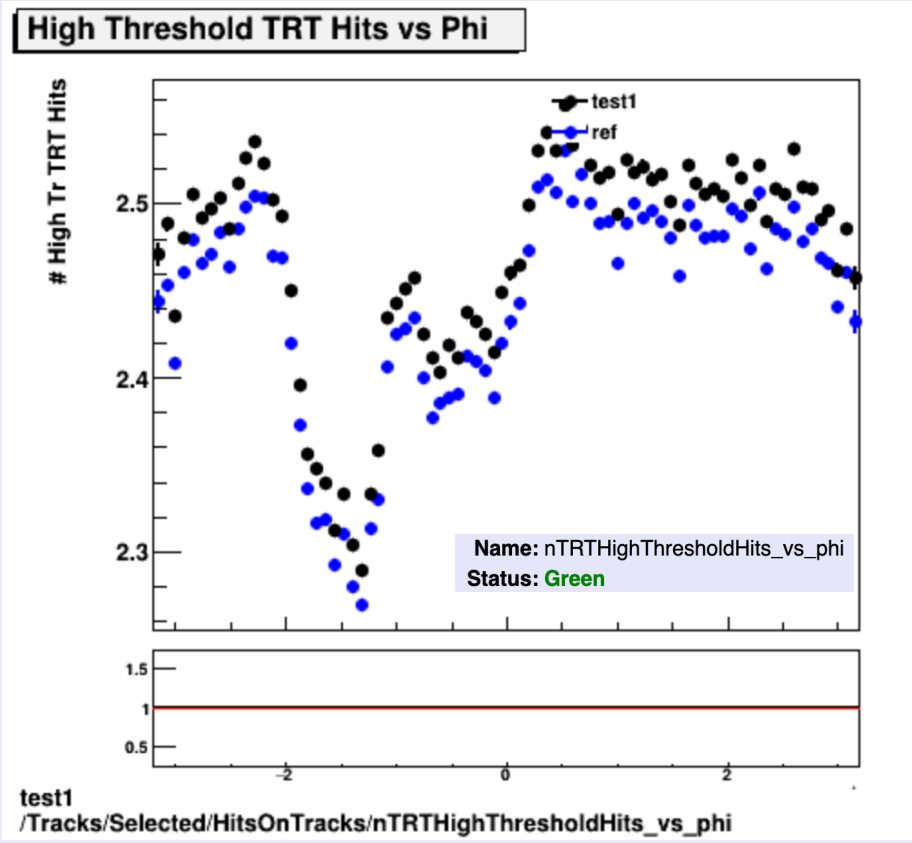


Electrons

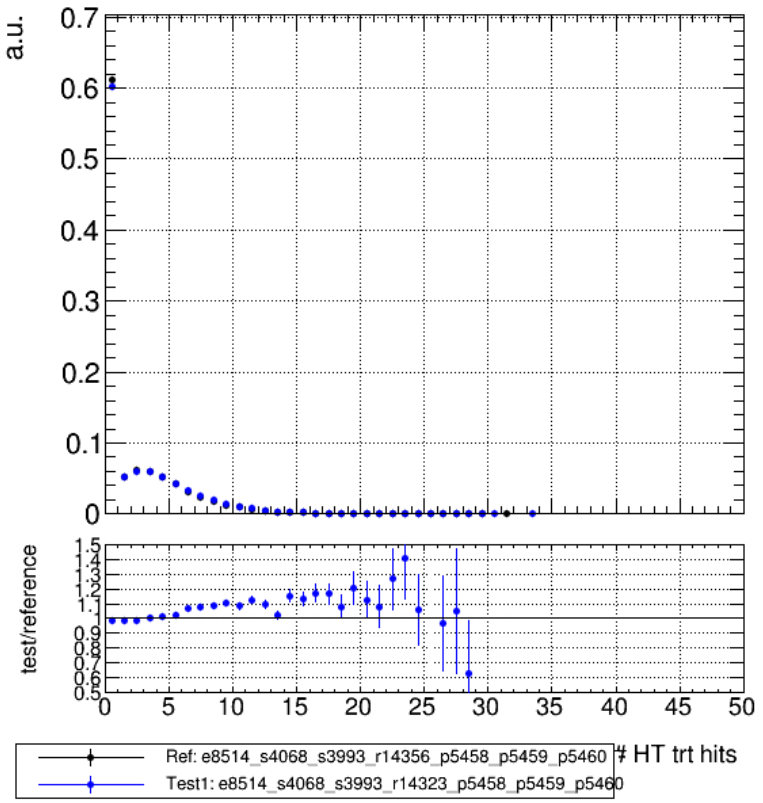
Muons

New pileup overlay for TRT

- **Physics validation:**



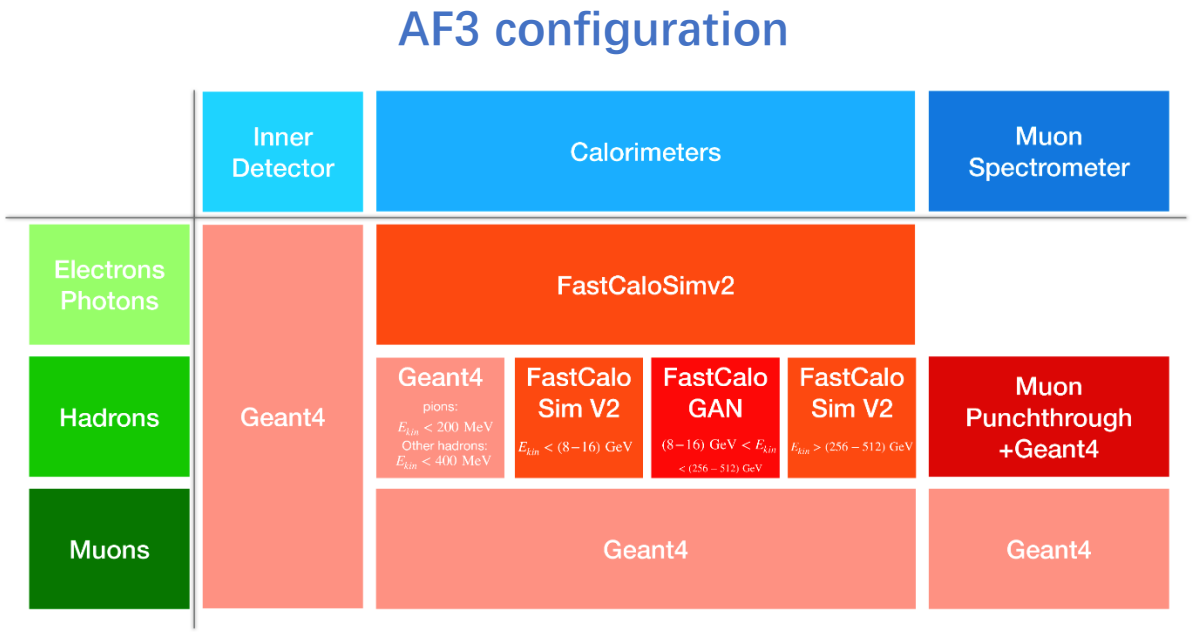
Tracking validation

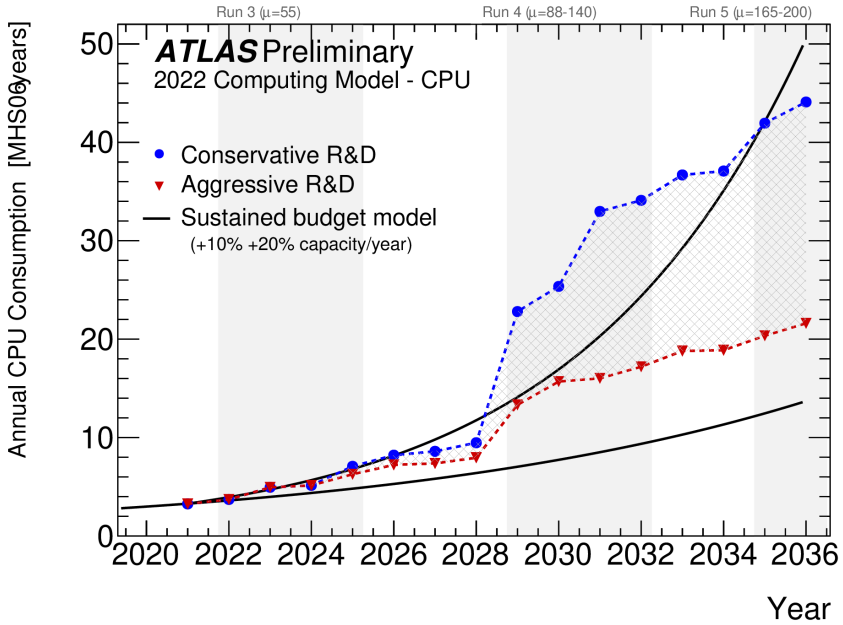


EGamma validation

ATLAS fast simulation

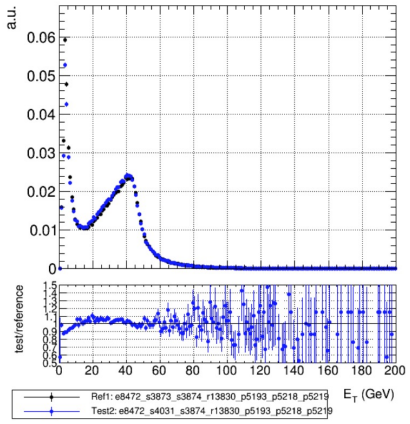
- **Fast simulation is essential for ATLAS study**
  - AtlFast2(AF2) has been used in countless ATLAS physics analyses in Run1 and Run2.
  - Parameterized calorimeter simulation FastCaloSim in AF2 has good average shower description, but can not model complex variables well.
  - AtlFast3(AF3): improve physics performance with same CPU as AF2.

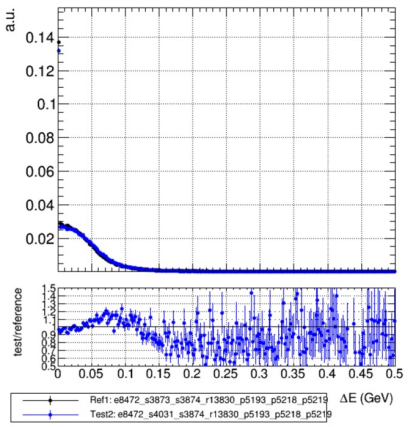


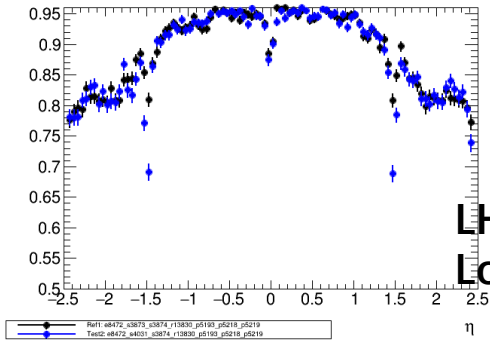


ATLAS fast simulation

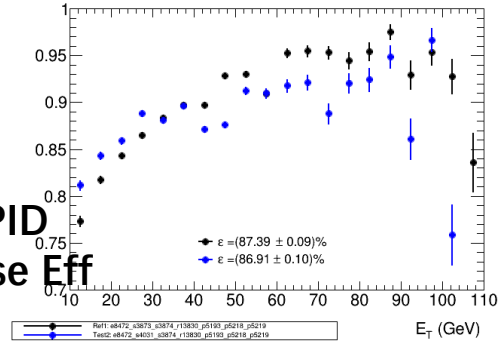
- **FastCaloSimV2 physics validation for Run3 (In progress) [indico]**
  - Good agreement in kinematic variables.
  - Notable difference in shower shapes, energy scale and efficiencies are lower @ gap.
  - Can be followed in JIRA (first round in JIRA).



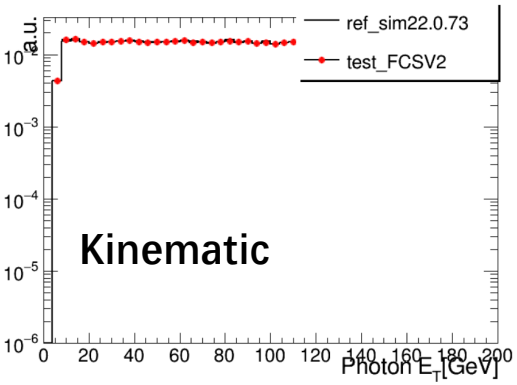




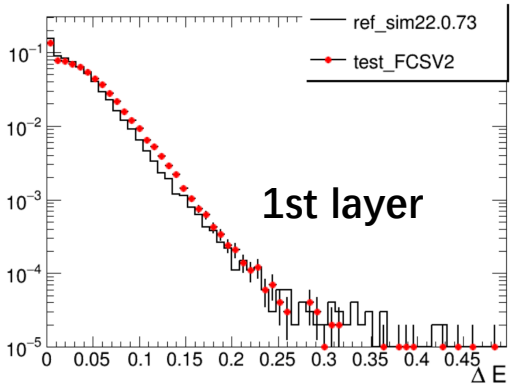
LH PID
Loose Eff



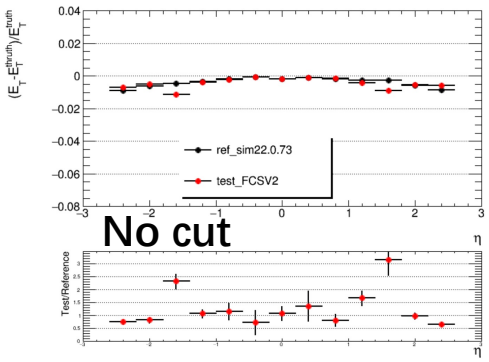
Electrons



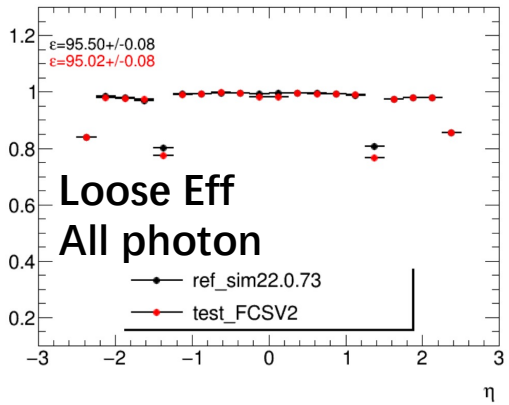
Kinematic



1st layer



No cut

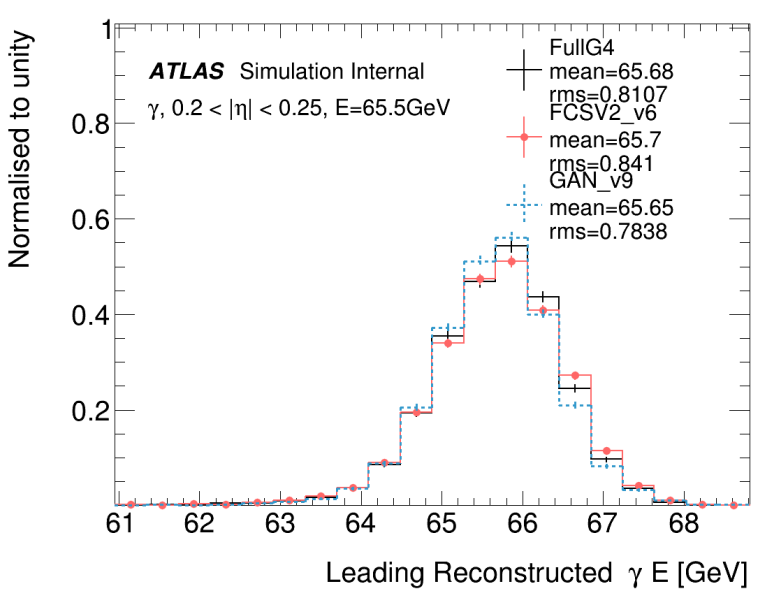


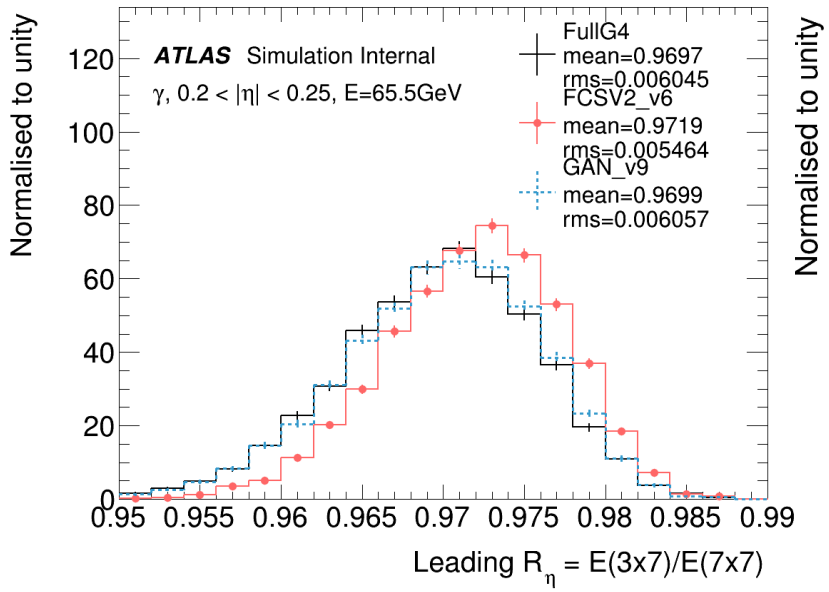
Loose Eff
All photon

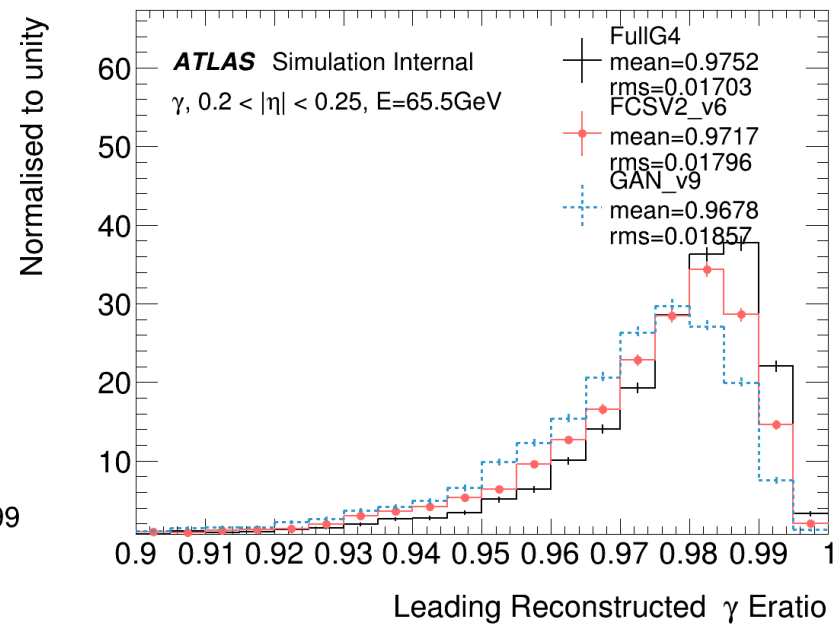
Photons

ATLAS fast simulation

- **FastCaloGAN:**
  - Improved for EM simulation in AtlFast3 & Run3.
  - Better performance for E and η-shapes than FCSV2, but a bit worse in E_{ratio}.
  - Physics validation is coming.







**FSCV2 version is not exactly the one in PhysVal.*

EM shower shape in ATLAS

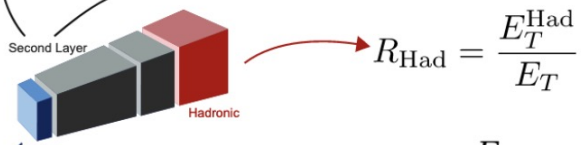
- **ATLAS EM shower shape disagreement between data and MC:**
  - Can come from: detector geometry, simulation, cross-talk, noise, pile-up, etc. [Guillaume in 2017]
  - Presently is corrected with **fudge factors**.

Variables and Position

	Strips	2nd	Had.
Ratios	f_1, f_{side}	R_η*, R_ϕ	$R_{Had.}$*
Widths	$w_{s,3}$, $w_{s,tot}$	$w_{\eta,2}$*	-
Shapes	ΔE, E_{ratio}	* Used in PhotonLoose.	

Energy Ratios

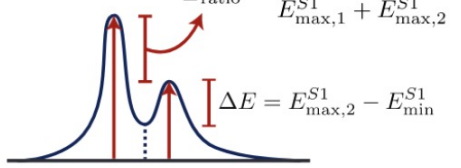
$$R_\eta = \frac{E^{S2}_{3\times7}}{E^{S2}_{7\times7}} \qquad R_\phi = \frac{E^{S2}_{3\times3}}{E^{S2}_{3\times7}}$$



$$R_{\rm Had} = \frac{E_T^{\rm Had}}{E_T} \qquad f_1 = \frac{E_{S1}}{E} \qquad f_{side} = \frac{E^{S1}_7 - E^{S1}_3}{E^{S1}_3}$$

Shower Shapes

$$E_{ratio} = \frac{E^{S1}_{max,1} - E^{S1}_{max,2}}{E^{S1}_{max,1} + E^{S1}_{max,2}}$$

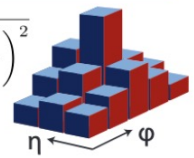


$$\Delta E = E^{S1}_{max,2} - E^{S1}_{min}$$

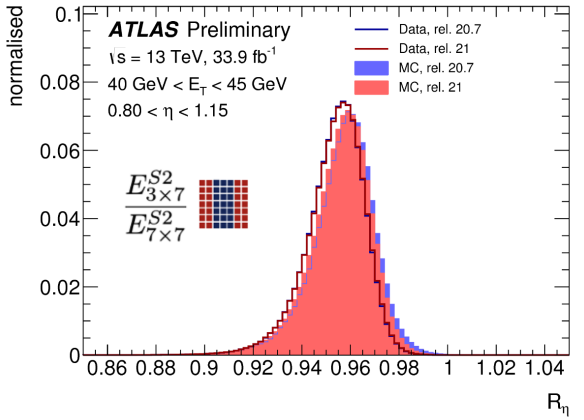
Widths

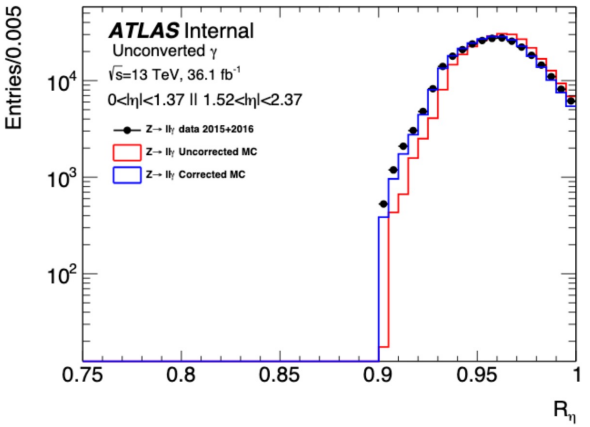
$$w_{\eta,2} = \sqrt{\frac{\sum E_i \eta_i^2}{\sum E_i} - \left(\frac{\sum E_i \eta_i}{\sum E_i}\right)^2}$$

Width in a 3×5 (Δη×Δφ) region of cells in the second layer.



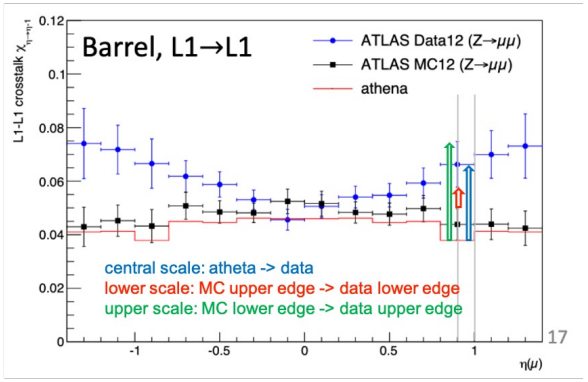
$$w_s = \sqrt{\frac{\sum E_i (i - i_{max})^2}{\sum E_i}}$$

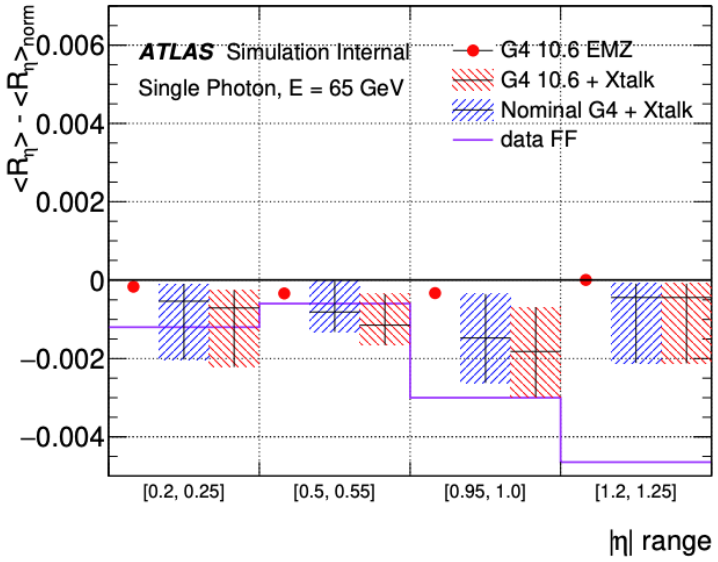


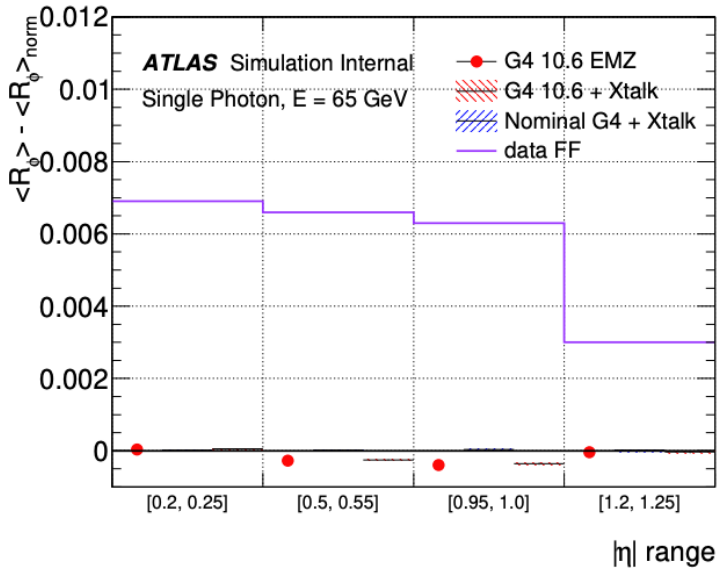


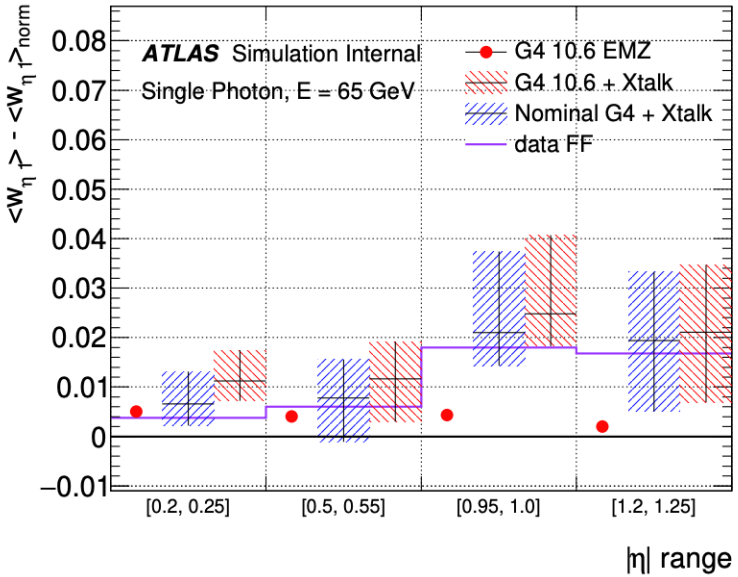
EM shower shape in ATLAS

- **Decouple the impact: cross talk amplitude**
  - Cross talk map in Athena and data $Z \rightarrow \mu\mu$ don't match.
  - Scale the cross talk amplitude, check the shower shape.
    - η direction can have visible impact.
    - cross talk can not cover the variation in ϕ direction.
  - **Cross talk can be one of the reasons.**



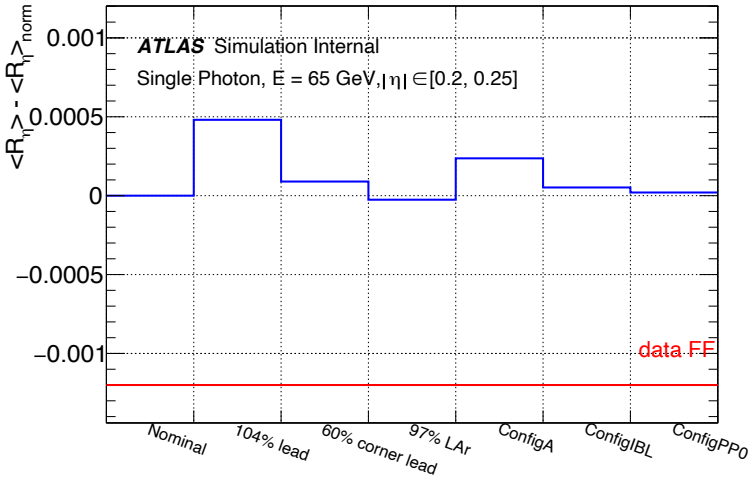


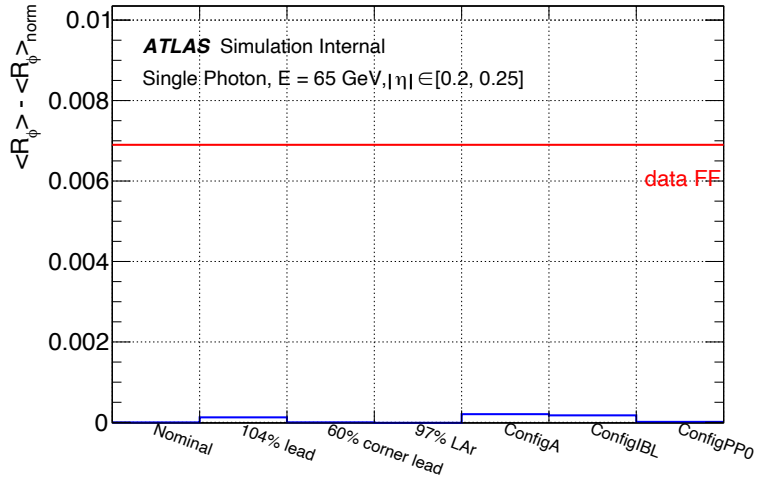


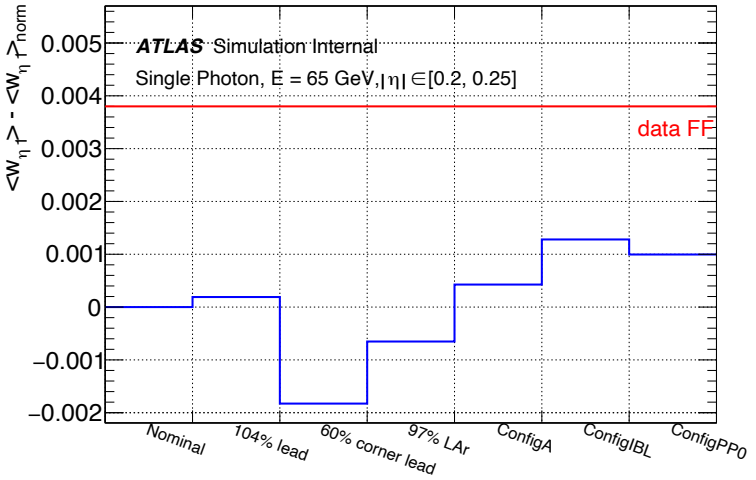


EM shower shape in ATLAS

- **Decouple the impact: detector geometry description**
  - Consider the impact of geometry material:
    - Mismodeling of total weight: increase the lead plate density 4%.
    - Mismodeling of absorber plate thickness: decrease LAr density 3%.
    - Mismodeling of absorber plate corner structure: decrease corner lead density 40%.
  - Add 3 more ATLAS config used for syst: ConfigA, ConfigIBL, ConfigPP0.





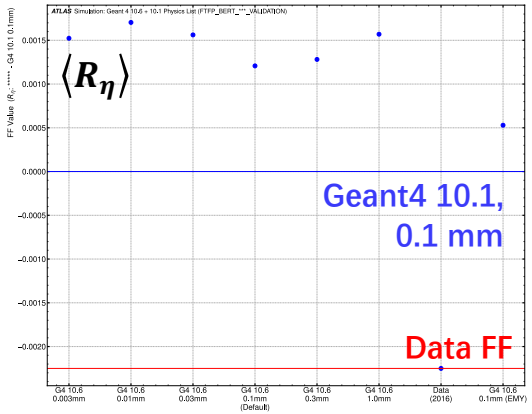


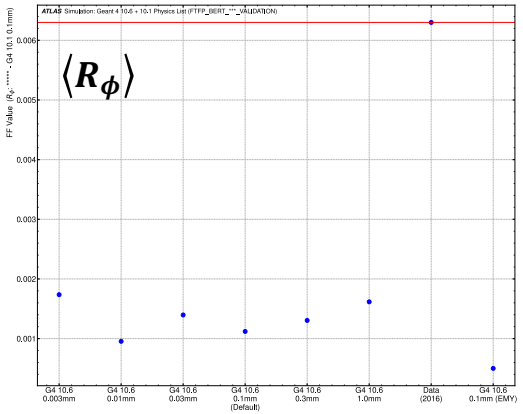
- **Impacts from the geometry are negligible.**

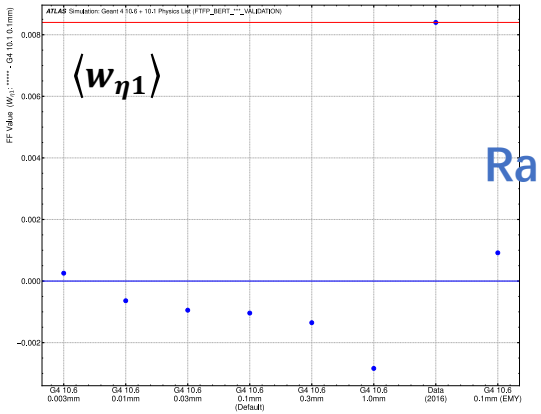
EM shower shape in ATLAS

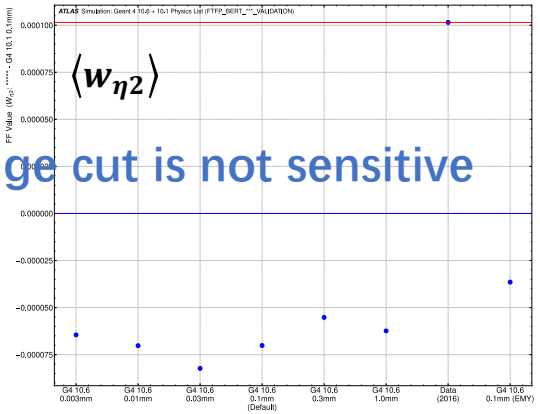
- **Decouple the impact: Geant4 simulation**
  - Check the impact from range cut and EM options in the physics list.

Scan range cut



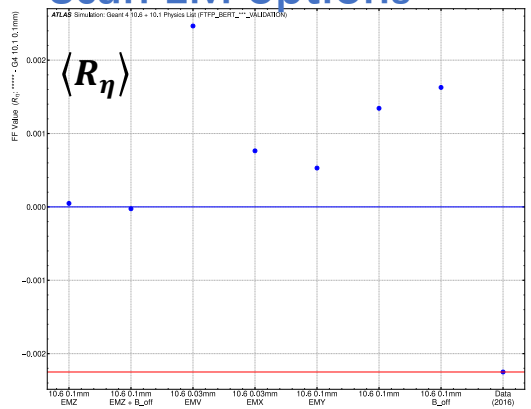


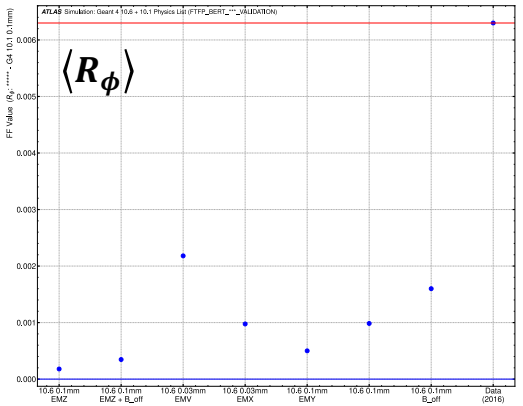


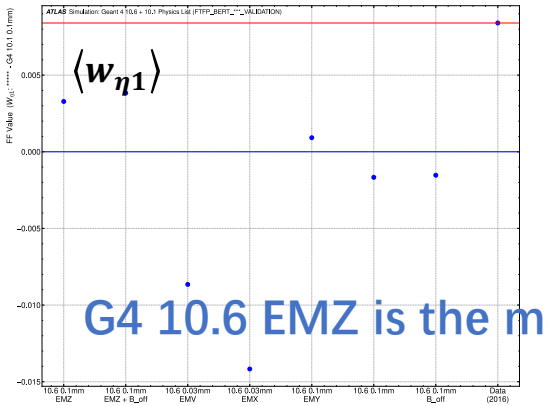


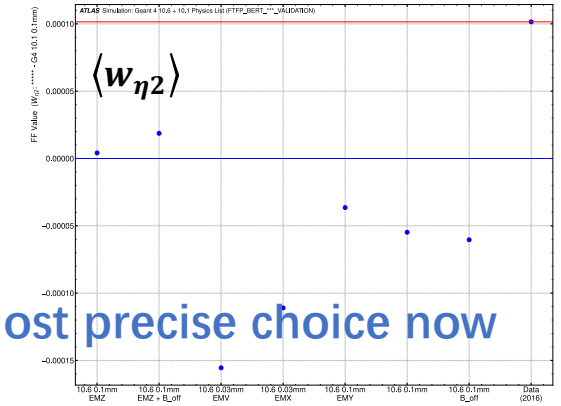
Range cut is not sensitive

Scan EM options







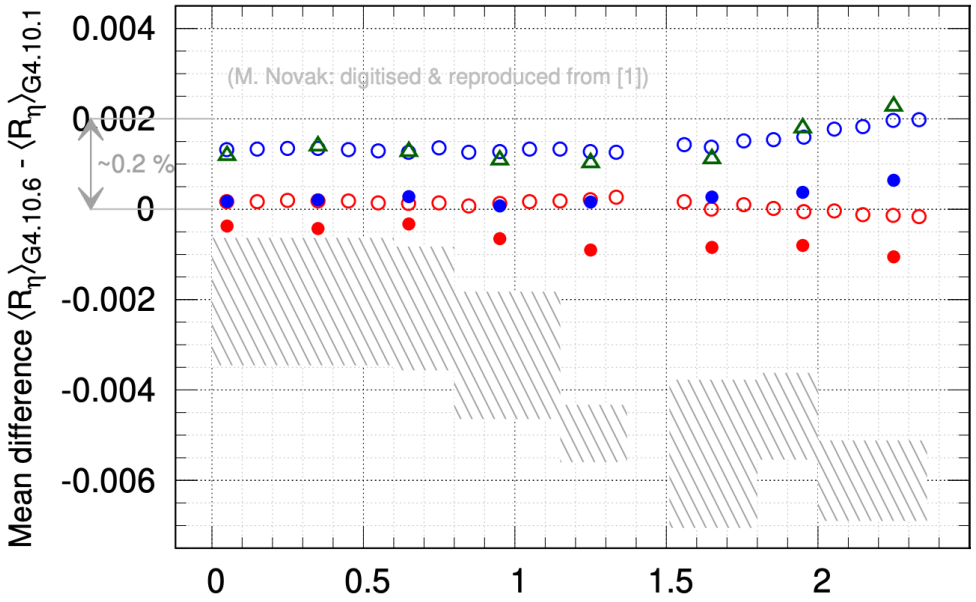


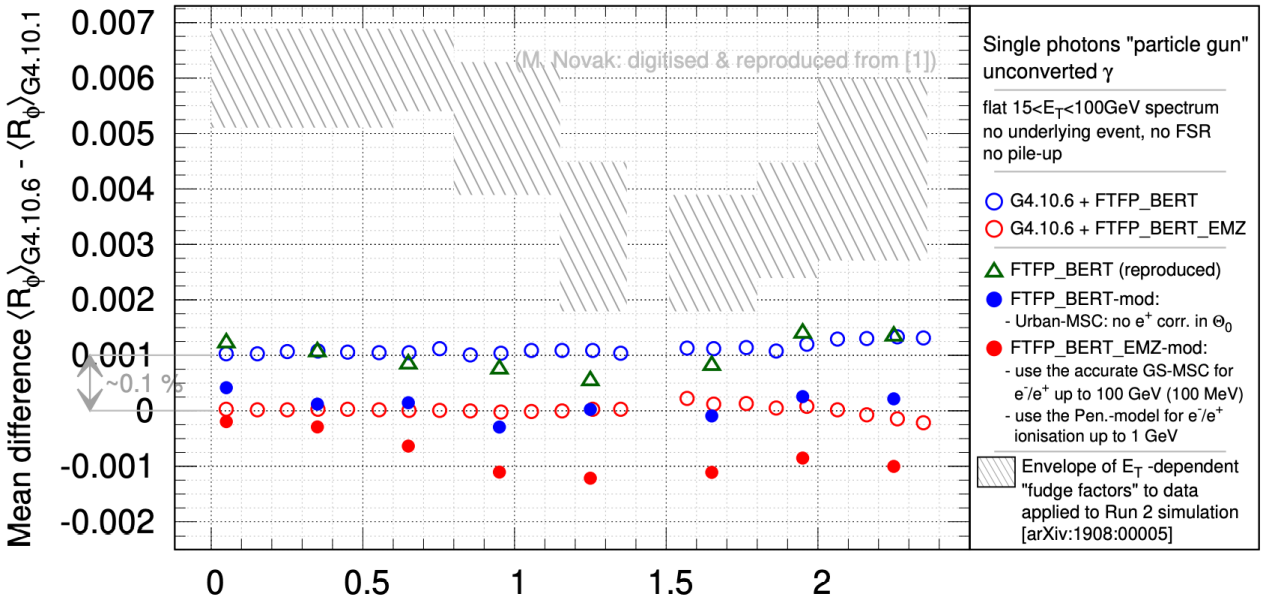
G4 10.6 EMZ is the most precise choice now

EM shower shape in ATLAS

- **Decouple the impact: Geant4 simulation**
  - Can we go closer to data?
    - Tuning the options in G4 10.6 EMZ: e^+ mean scattering angle and a theory based Goudsmit-Saunderson (GS) model for $e^\pm$ multiple Coulomb Scattering (MSC).
    - η-shape is closer to data (wider shower), ϕ-shape is not.

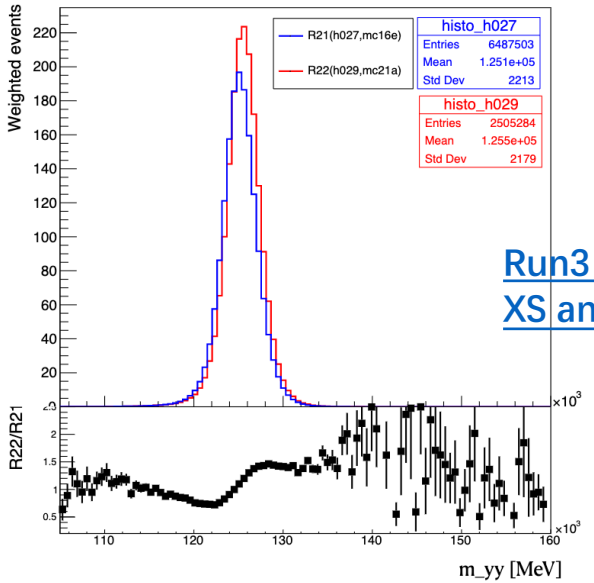
Mihaly in Simulation group



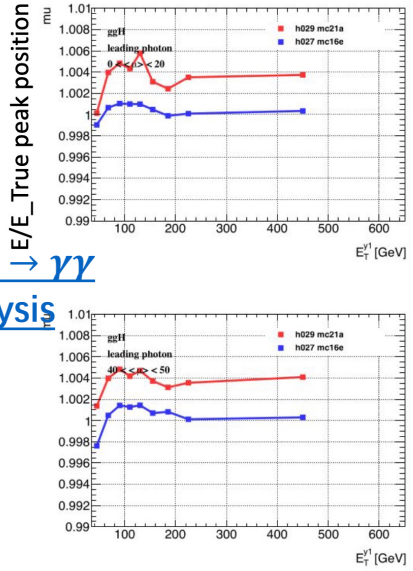


EGamma energy scale in mc21

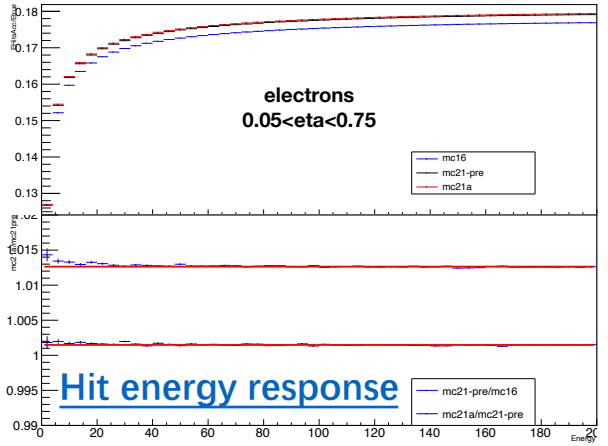
- **Energy response difference in latest mc21:**
  - Has been observed in early Run3 analysis, e.g. $H \rightarrow \gamma\gamma$. Independent with pile-up.
  - One known issue from mc16 to mc21: sampling fraction.
  - If SF is the only issue, $E_{reco} \sim E_{hit}/SF$ should not change.
  - Also difference between mc21pre and mc21a is not understood.



Run3 $H \rightarrow \gamma\gamma$ XS analysis



mc21-pre/mc16	+1.26%	expect from SF +1.34%	delta=-0.08%
mc21a/mc21-pre	+0.15%	expect from SF -0.15%	delta=+0.30%
mc21a/mc16	+1.41%	expect from SF +1.19%	delta=+0.22%



Hit energy response

EGamma energy scale in mc21

- **Sampling fraction check for single electron:**
  - Re-calculate the sampling fraction in mc21 using G4UserAction
    - Sampling fraction is identical to database → no bug in computation.
    - Total energy is higher → something else in simulation.

0.1<eta<0.75	50 GeV electrons @ R=1500								single electrons from PV 40<E<60 GeV					
											(using recomputed SF)		(using SF in DB)	
	Etot barrel		ELAr barrel		ELAr Hit		SF (ELArHit/ Etot)		ELAr Hit (no PS)/Etrue		Visible HIT / SF		Raw cluster/ Etrue	
mc16 (21.0.X)	49437	+-8	9763	+- 2	9017	+-2	0,18239	+- 0,00004	0,17254	+-0,00001	0,9460		0,9372	+-0.0001
mc21pre (22.0.47)	49434	+-7	9891	+-2	9127	+-2	0,18463	+- 0,00004	0,17475	+-0,00001	0,9465		0,9371	+-0,0001
ratio to mc16	0,9999		1,0131		1,0122		1,0123		1,0128		1,0007		0,9999	(1.0014 if using true SF)
mc21a (22.0.73)	49496	+-5	9904	+-2	9137	+-2	0,18460	+-0,00004	0,17502	+-0,00001	0,9481		0,9419	+-0,0001
ratio to mc16	1,0012		1,0144		1,0133		1,0121		1,0144		1,0025		1,0050	
mc21a (22.0.73) noRR	49485		9900	+-2	9141	+-2	0,18472	+- 0,00004						
ratio to RR	0,9998		0,9996		1,0004		1,0007							

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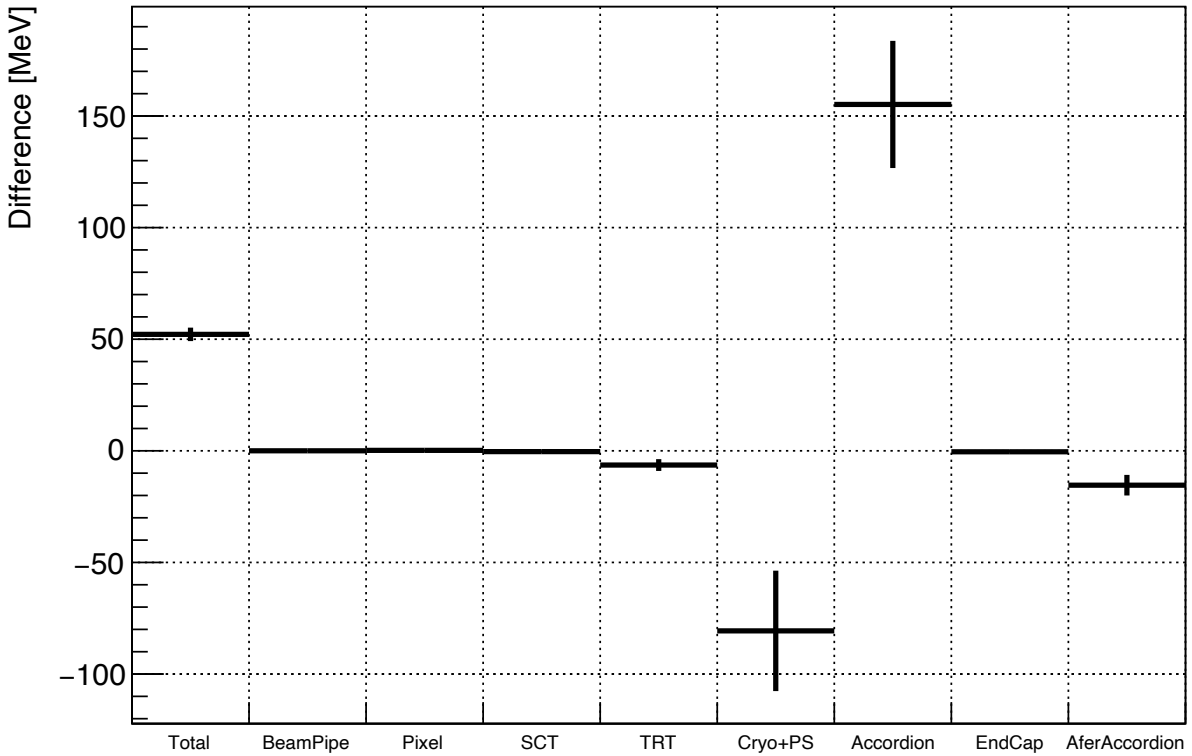
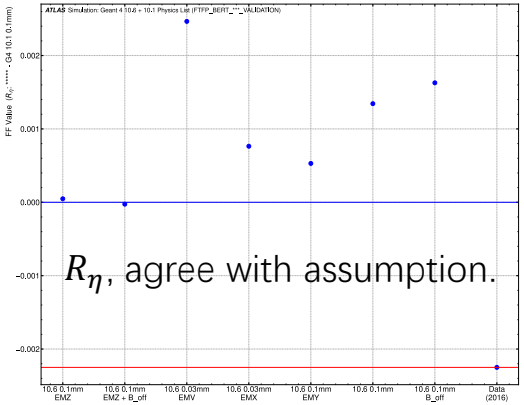
EGamma energy scale in mc21

- **Electron energy loss in detector:**
  - E_e=50 GeV from PV, difference = mc21a – mc16





- About 0.1% more total energy deposition in all ATLAS
- Extra ~0.2% effect from less energy deposited before calorimeter.
- Possibly: O(0.1%) lateral shower leakage difference between mc21a and mc16 (narrower shower shapes in mc21a => smaller cluster leakage in reconstruction level).
- Reason: EM physics list? hadronic component in EM shower?

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Summary and Conclusion

- **Many interesting topics have been studied in Simulation group:**
  - **Run3 pile-up overlay in TRT:**
    - Corrections are re-tuned with Ar-straws and implemented in latest digitization.
    - Closure test and physics validation show good agreements / expected shifts.
    - Considering to have Run3 data-MC comparison and/or full pile-up digitization comparison.
  - **New fast simulation AtlFast3 for Run3:**
    - FastCaloSimV2 shows better performance than FastCaloSim, through there are still some disagreement in detailed shower shapes (EM and hadronic).
    - FastCaloGAN is under validation.
  - **EM shower shape in LAr:**
    - Checked the simulation, geometry and the cross talk.
    - Too complex to have a straight forward answer, still long way ahead.
  - **EGamma energy scale in new MC:**
    - Should not be mis-computation of sampling fraction, but a pure simulation issue and can not influence Run 3 data after appropriate calibration.
    - Can come from update in G4 10.6 physics list? hadronic component in EM shower? Open issue.
    - Need to be careful for mc23 simulation setup.