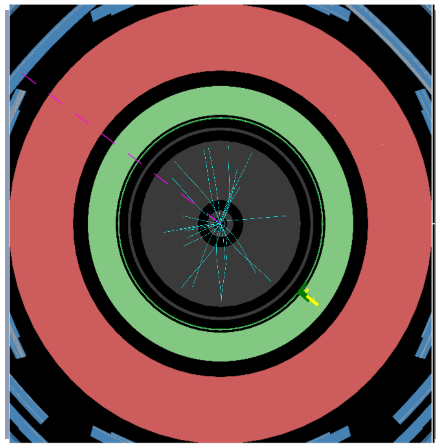
Search for Dark Matter in Mono-Photon events with ATLAS



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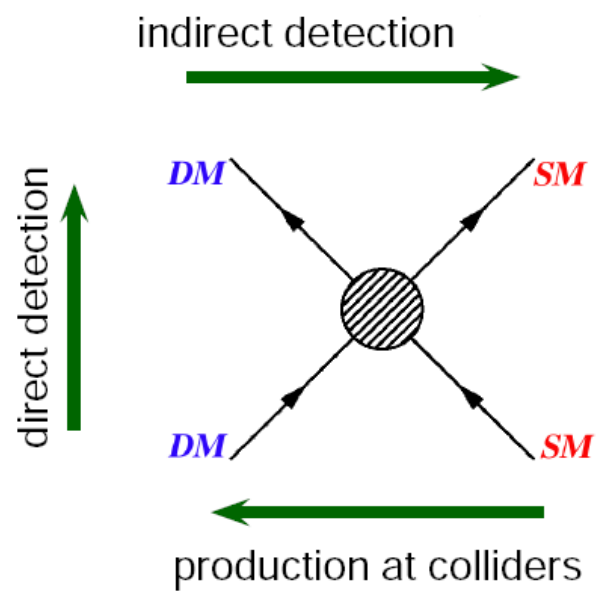
FIRST YEAR PHD WORKSHOP - MILANO

OCTOBER 12TH, 2015

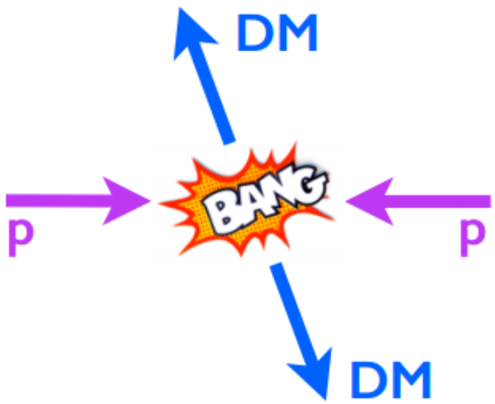
+ Why Dark Matter at the LHC ?

- Compelling evidence of Dark Matter from astrophysical probes
- But what is the nature of the Dark Matter? How does it interact with Standard Model particles ?
- Complementary strategies for the detection of DM particles:
  - Direct searches
  - Indirect searches
  - Production at colliders



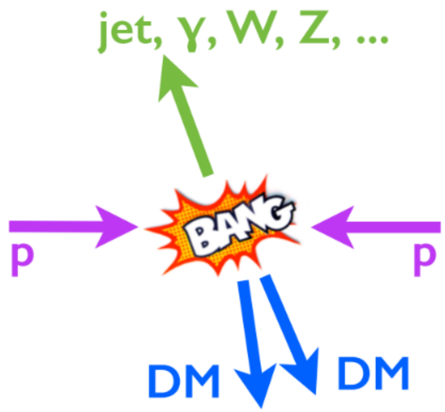
- Grounding assumption:
  - DM and SM interact other than gravitationally, otherwise none of the strategies is effective

+ Mono-X Signatures



- DM goes out undetected

Mono-X Signatures

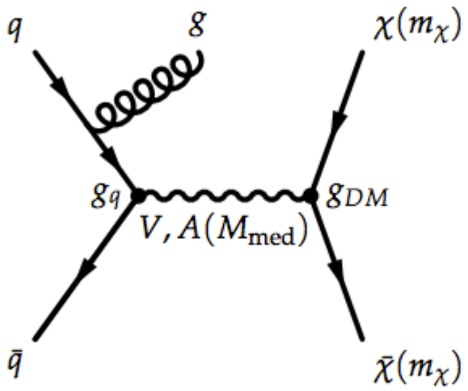


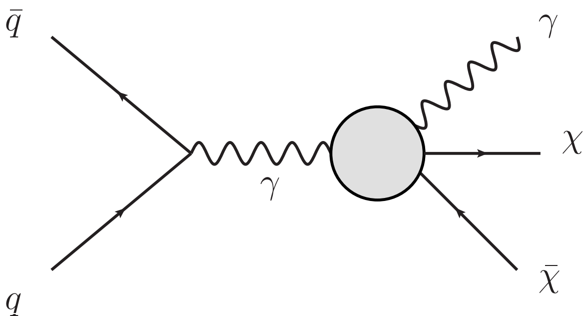
- DM goes out undetected

  => need a visible SM particle to tag the event

- Mono-X signatures: E_T^{miss} + X=jet, γ ,W, Z, H

+ Mono-X Signatures





- DM goes out undetected

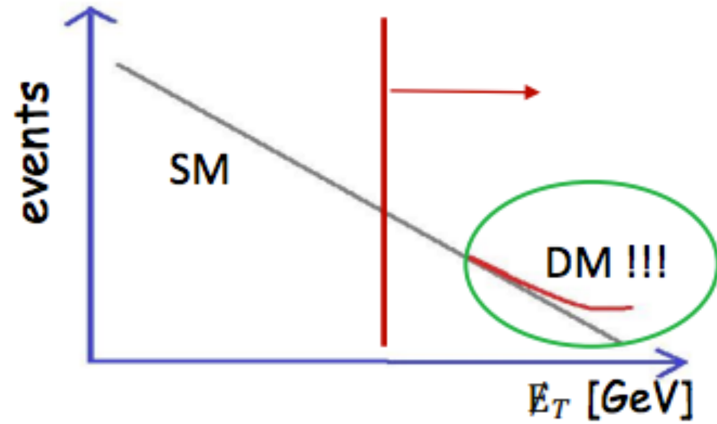
  => need a visible SM particle to tag the event

- Mono-X signatures: E_T^{miss} + X=jet, γ ,W, Z, H

- X object irradiated by the initial state or, in the case of electroweak bosons, involved in the interaction

+ Mono-Photon Search

- Cut & Count analysis
- Look for a deviation in data from prediction of the SM => Signal over Background
- Essential a very accurate background estimation
- Quantify the level of agreement/disagreement by means of a statistical analysis
- Set limits on parameter space of various models



Which SM processes have the same signature ?

How are they estimated ?

Z(→ν ν) + γ irreducible background **O(70%)**
W(→lν) + γ **O(15%)**

from **DATA/MC RATIOS** in appropriate Control Regions

W/Z + jets electron or jet taken as a photon **O(15%)**

purely **DATA-DRIVEN** techniques

γ + jets and other remaining bkgs **O(1%)**

pure **MC** simulation

Mono-Photon Search

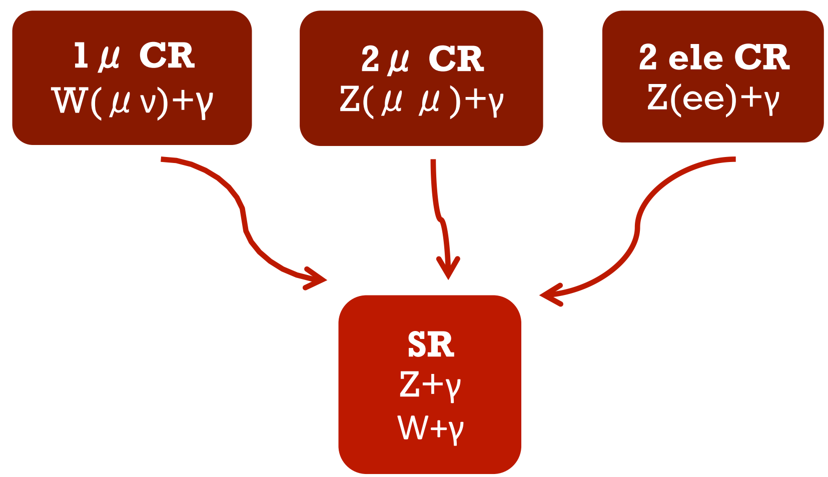
Signal Region (SR)

- Trigger and Event cleaning
- Jet cleaning
- Energetic photon with $p_T > 150$ GeV
- $E_T^{miss} > 150$ GeV
- $\Delta\varphi(\gamma, E_T^{miss}) > 0.4$
- leading photon "tight", isolated
- at most one jet well separated from the E_T^{miss}
- Veto on electrons and muons

Control Regions (CRs)

- keep the same cuts as SR
- **revert one or more cuts** at a time to define regions enriched in a particular source of background

W/Z + γ Backgrounds



- Data/MC ratios in the CRs
- Extrapolate to the SR
- Normalize the yields in the SR

+ Mono-Photon Search

Signal Region (SR)

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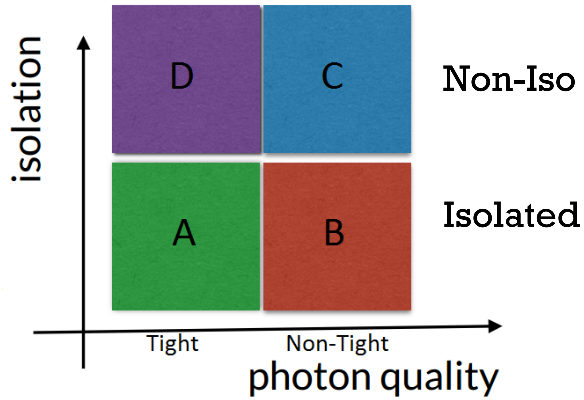
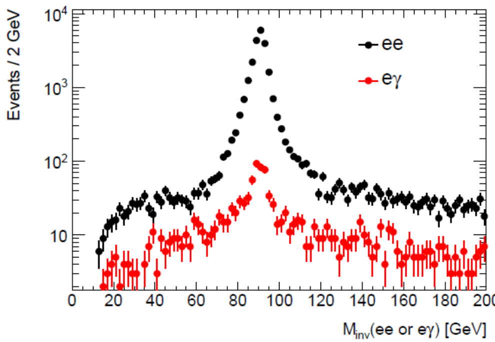
Jets faking Photons

- Two-dimensional Sideband method
- $$N_A^{bkg} = N_B \frac{N_D}{N_C}$$



Electrons faking Photons

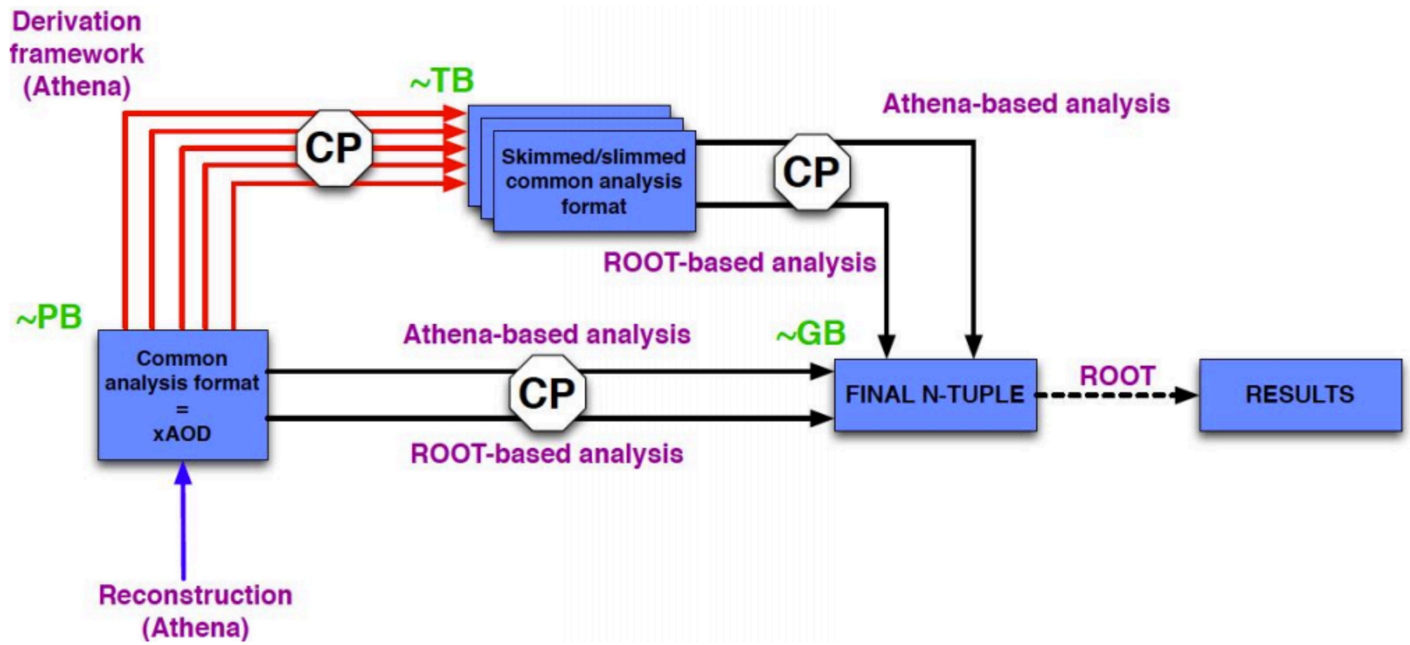
- EFR = probability of electron to fake a photon with a Tag & Probe method
- Scale a mono-electron CR with this probabulity



1ele CR no photon × **EFR**

Data Analysis in ATLAS

- A huge and continuously evolving framework is needed for data analysis:
  - Big amount of data in various formats spread over the grid
  - Smaller datasets, called "derivations", optimized for each analysis, to be replicated at local sites
  - Reconstruction software maintained by the Combined Performance groups
  - Analysis software developed by each analysis group for their needs

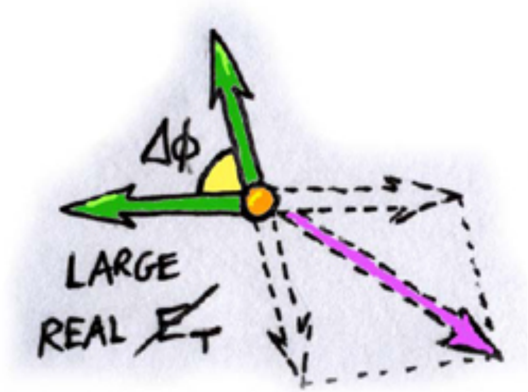


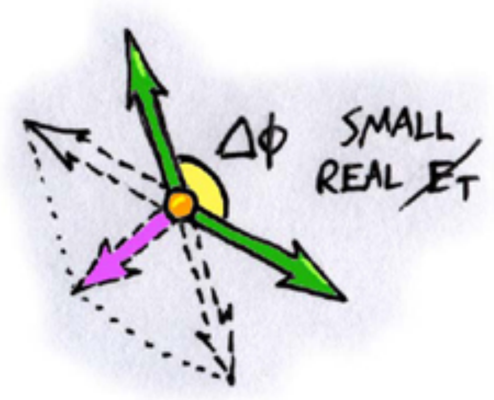
+ What is E_T^{miss} ?

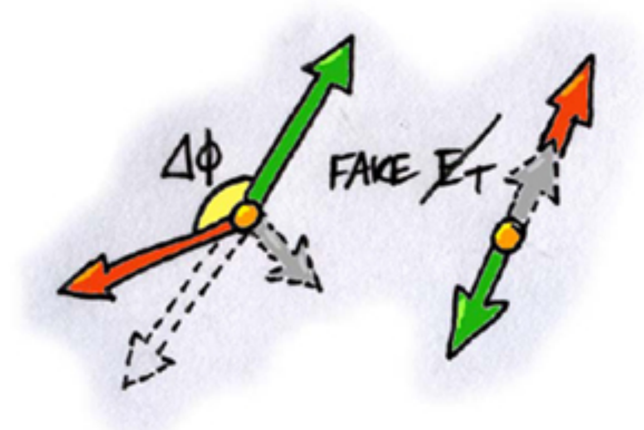
⊙ E_T^{miss} = Missing Transverse Momentum

- Negative ***vector*** sum of the ***transverse*** momenta of ***all*** detected particles
- Global quantity of the event
- In a parton-parton scatter the initial transverse momentum is ≃ 0

  => Measured imbalance of the total transverse momentum is the handle for the ***invisible*** part of the event







Real E_T^{miss}:

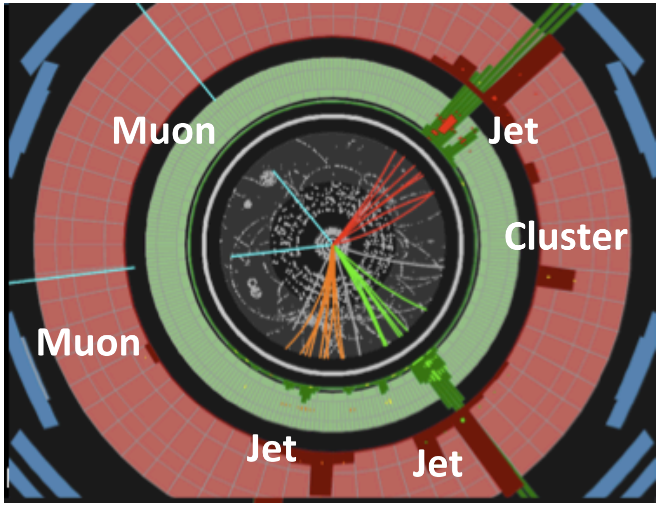
- New particles
- Neutrinos

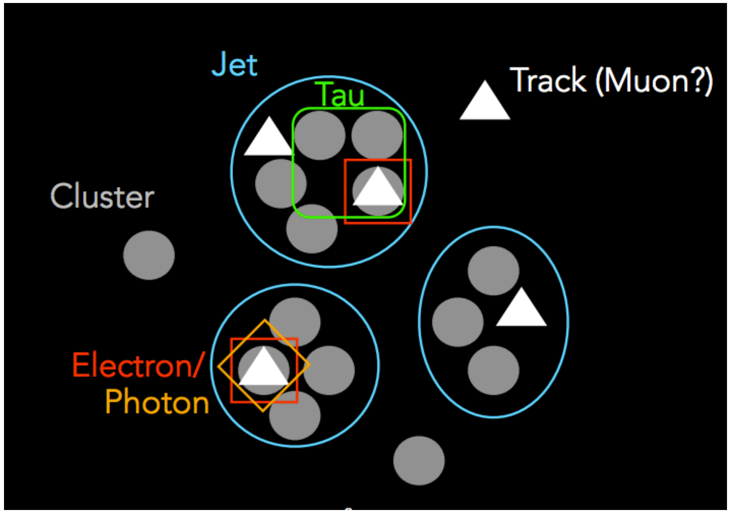
E_T^{miss} is the discriminating variable for many searches for new physics

Fake E_T^{miss}:

- Miscalibrations
- Mismeasurements
- Limited detector acceptance
- Detector Noise

E_T^{miss} Reconstruction: *Ingredients*





- Reconstructed and calibrated ***"physics objects"***:
  - electrons, photons, taus, muons
    - Selected as recommended from the various CP groups
    - analyses can optimize the selections for their needs
  - ***Jets***:
    - Fully calibrated Anti-kt4 with $p_T > 20$ GeV
    - Anti-kt4 with $p_T > 7$ GeV for handling the overlap between physics object
- ***Signal objects:***
  - ***tracks*** and ***clusters***

E_T^{miss} Reconstruction: *Term by Term*

$$E_{x(y)}^{miss} = E_{x(y)}^{miss,\,e} + E_{x(y)}^{miss,\,\gamma} + E_{x(y)}^{miss,\,\tau} + E_{x(y)}^{miss,\,jets} + E_{x(y)}^{miss,\,\mu} + E_{x(y)}^{miss,\,Soft}$$

$$E_{x(y)}^{miss,\,k} = - \sum_k p_{x(y)}^{k}$$

- Reconstructed and calibrated ***"physics objects"***:
  - electrons, photons, taus, muons
    - Selected as recommended from the various CP groups
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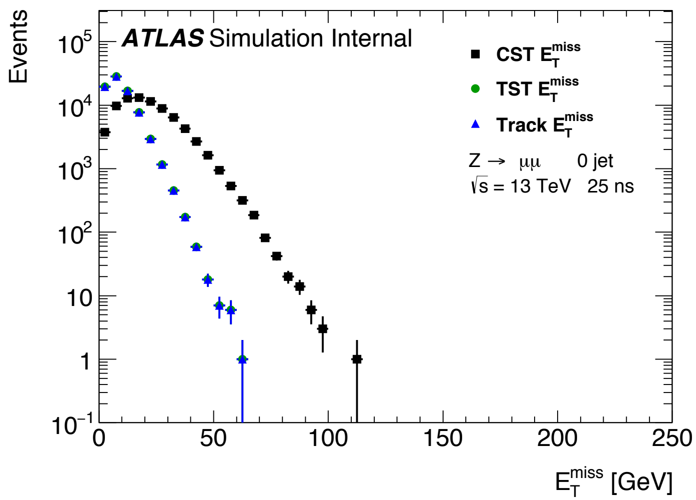
  - ***Jets***:
    - Fully calibrated Anti-kt4 with p_T > 20 GeV

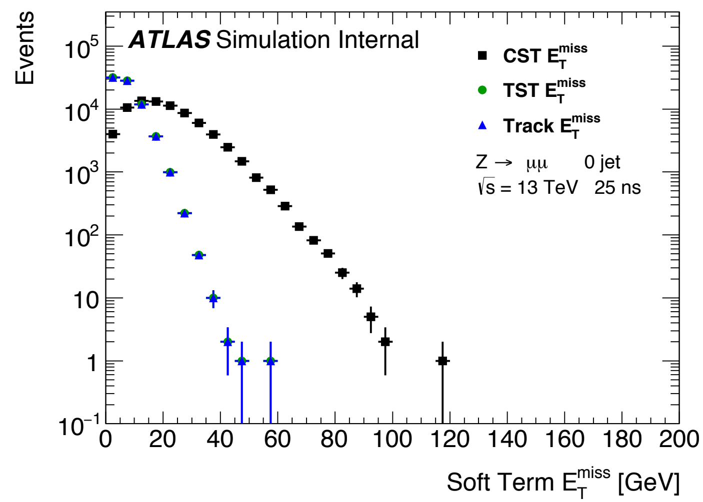
Hard Terms

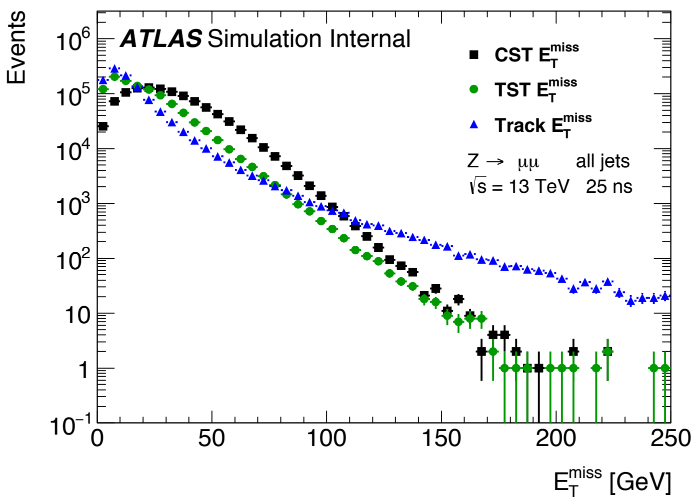
- ***Tracks*** from primary vertex => **TST E_T^{miss}**
- Unmatched ***clusters*** + ***soft jets*** => **CST E_T^{miss}**

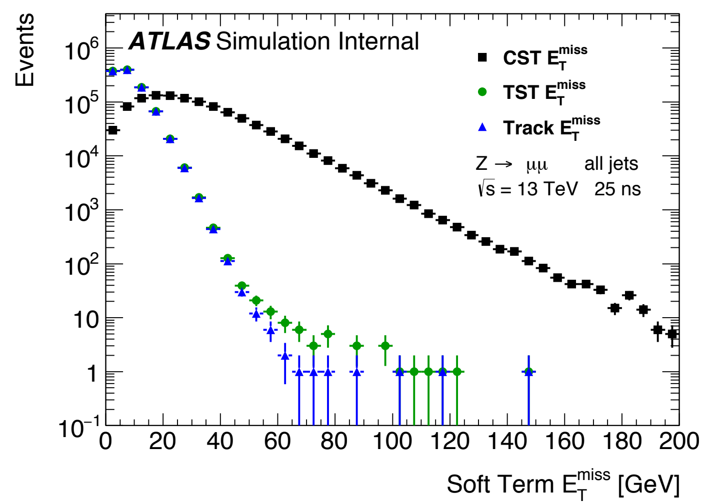
Soft Terms

+ E_T^{miss} Performance





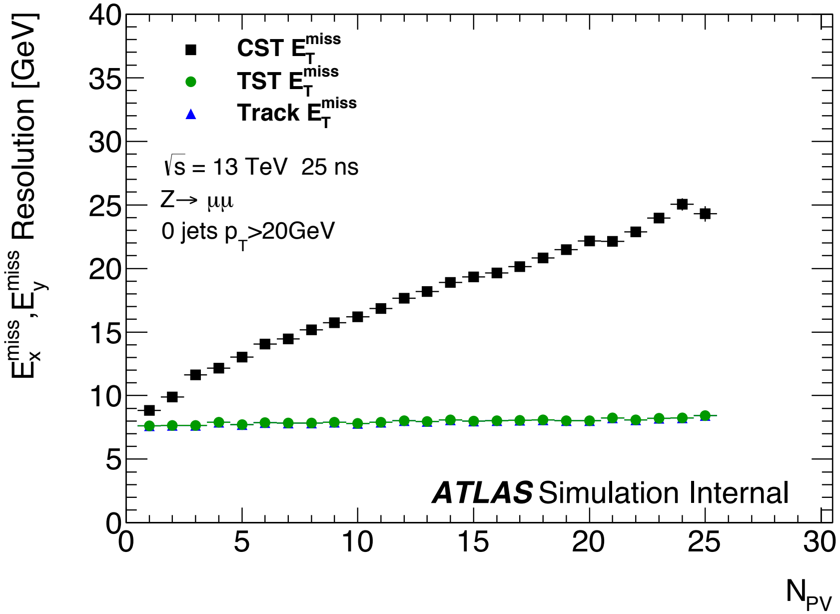


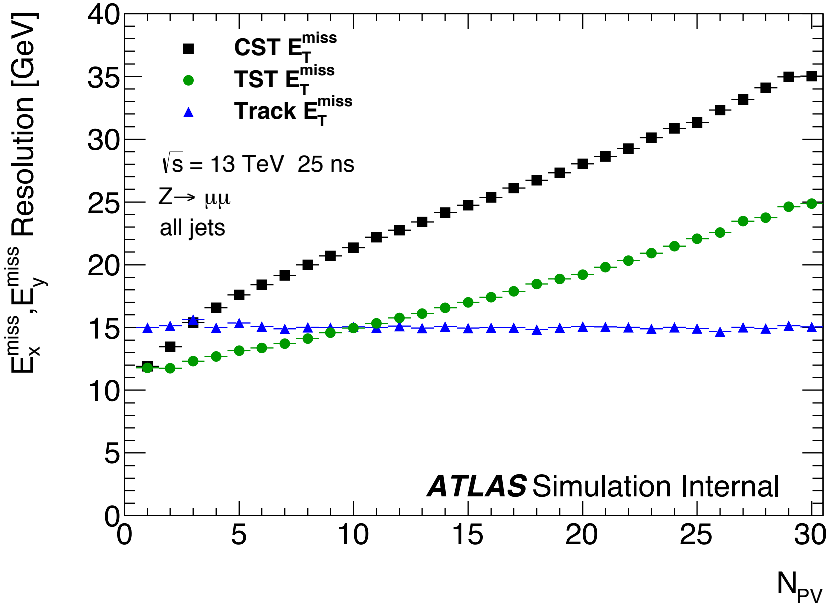


- TST E_T^{miss} performing best
- Higher value of the E_T^{miss} and Soft Term at higher jet multiplicity

E_T^{miss} Performance: *Resolution*

- Width of the $E_{x,y}^{miss}$ is a sensitive quantity to pile-up effects
- Measured as a function of the number of primary vertices, N_{PV}, in 0-jet (left) and inclusive jet (right) topologies

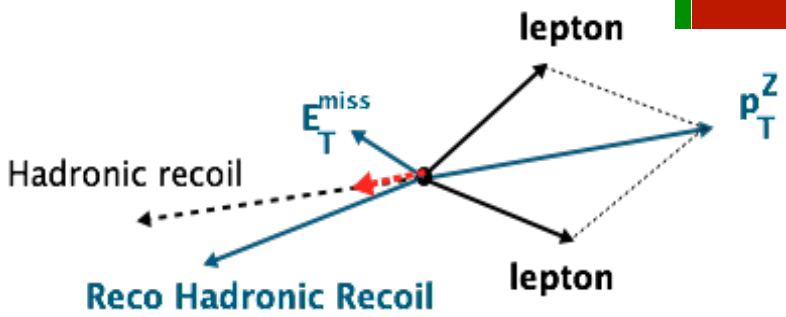


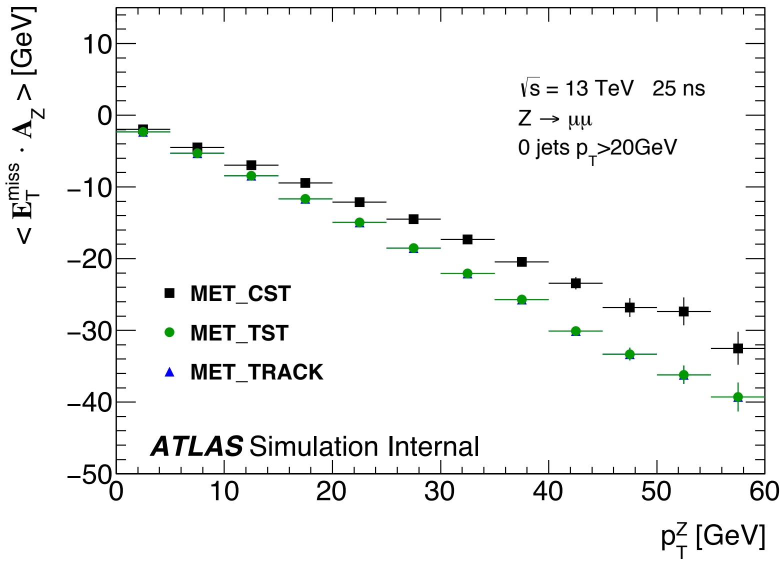


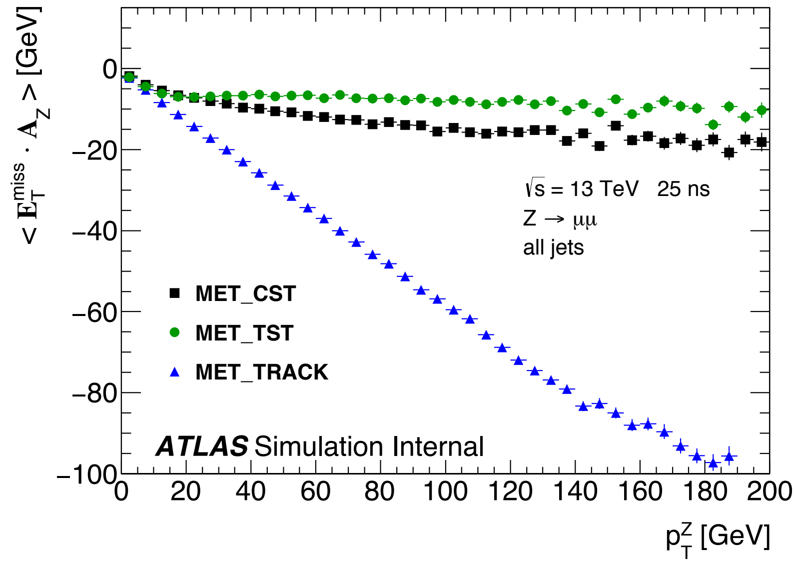
- In 0-jet events TST and Track E_T^{miss} perform very similar, insensitive to pile-up
- In inclusive jet events, CST and TST E_T^{miss} both depend on pile-up
- Track E_T^{miss} stable wrt pile-up

+ E_T^{miss} Performance: *Scale in Z → ll*

- Well calibrated E_T^{miss} in Z→*ll* events projected along any axis should be zero
- Projection of the E_T^{miss} onto the Z axis is sensitive to the imbalance between Hard and Soft part of the event







- Bias is bigger in 0-jet events indicating underestimation of the Soft Term
- In events with jets, TST E_T^{miss} performs best

Conclusions and Plans

- Analysis of mono-photon events in good progress:
  - Most analysis tools in place: derivations, software, selections and background estimation techniques
  - Big effort in understanding the E_T^{miss}, invisible part of the collision event
  - Work in progress in the statistical interpretation of the results
  - Almost 2.5 fb^{-1} of data already collected by ATLAS and ready for analysis

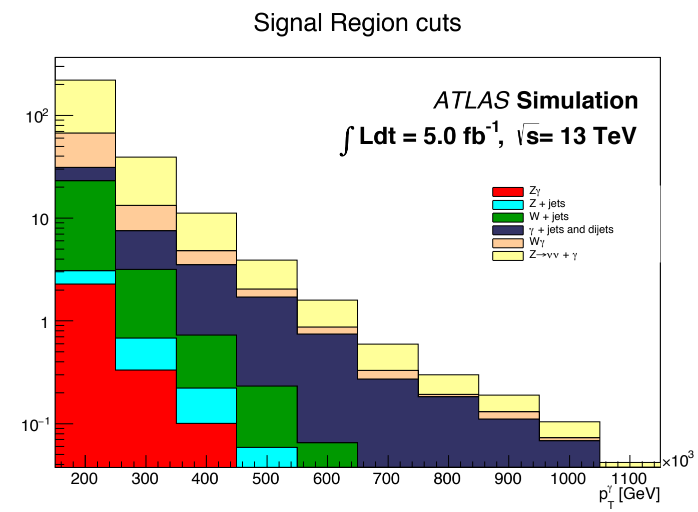
    => will need the entire 2015 data to improve the Run 1 results

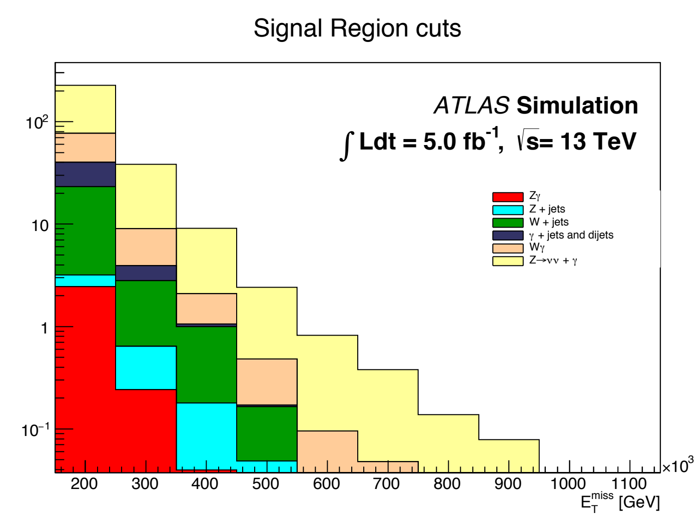
BACK-UP

+ Background projections with 5 fb^{-1}

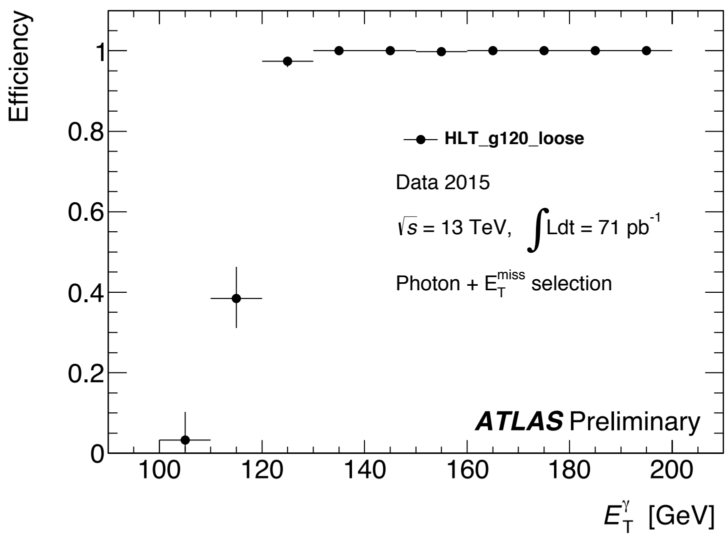
table.results.yields channel	SR	ONEmuCR	TWOmuCR	TWOeleCR
Fitted bkg events	277.06 ± 28.72	134.08 ± 11.58	28.87 ± 3.91	31.23 ± 4.08
Fitted Znunugamma events	188.08 ± 28.28	0.79 ± 0.12	0.00 ± 0.00	0.00 ± 0.00
Fitted Zgamma events	2.76 ± 0.42	10.89 ± 1.62	26.38 ± 3.91	27.60 ± 4.05
Fitted Wgamma events	43.67 ± 5.16	102.44 ± 11.74	0.52 ± 0.06	0.48 ± 0.06
Fitted Wjets events	23.18 ± 0.54	15.90 ± 0.21	0.21 ± 0.00	0.01 ± 0.00
Fitted Zjets events	1.31 ± 0.03	0.26 ± 0.00	1.09 ± 0.03	2.92 ± 0.18
Fitted gammajets events	17.70 ± 0.42	3.81 ± 0.05	0.66 ± 0.02	0.21 ± 0.01
Fitted dijets events	0.37 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
MC exp. SM events	277.06	134.08	28.87	31.23
MC exp. Znunugamma events	188.08	0.79	0.00	0.00
MC exp. Zgamma events	2.76	10.89	26.38	27.60
MC exp. Wgamma events	43.67	102.44	0.52	0.48
MC exp. Wjets events	23.18	15.90	0.21	0.01
MC exp. Zjets events	1.31	0.26	1.09	2.92
MC exp. gammajets events	17.70	3.81	0.66	0.21
MC exp. dijets events	0.37	0.00	0.00	0.00

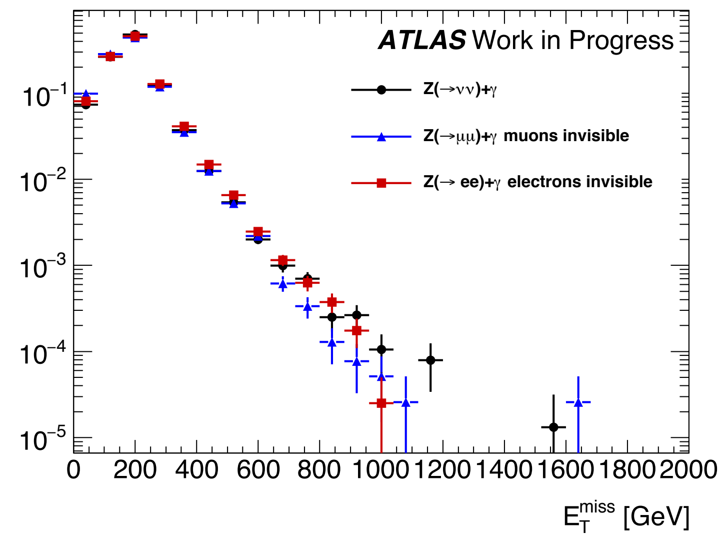
Tabella 2: SR expected yields for 5 fb^{-1} , fixed isolation cut on the photon

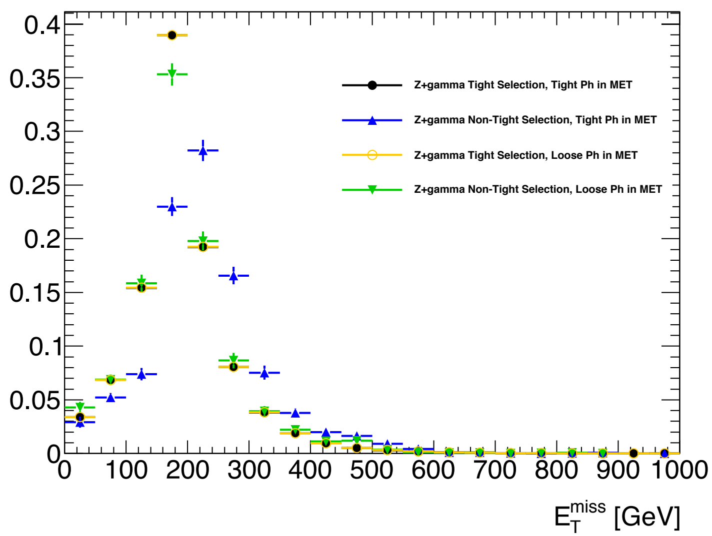


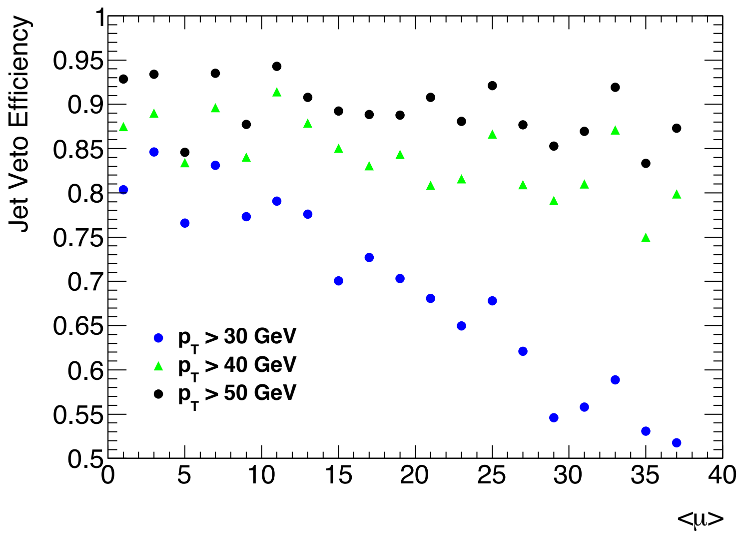


+ Mono-Photon Studies





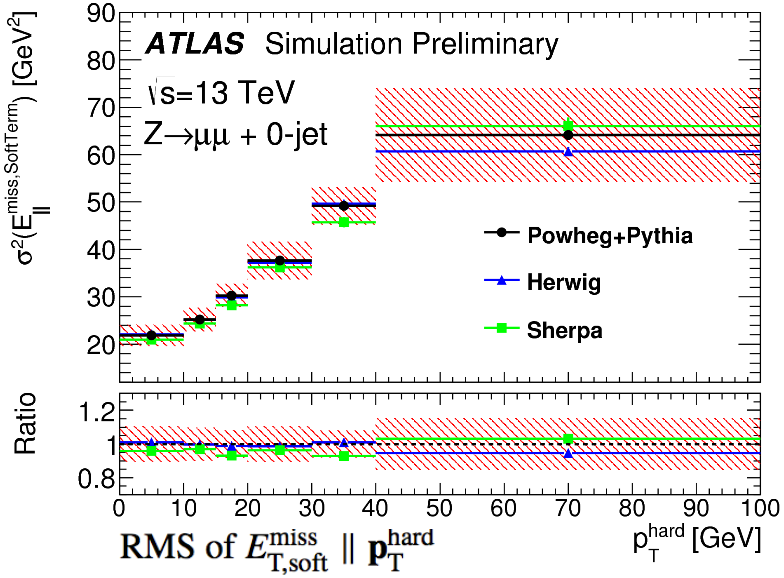


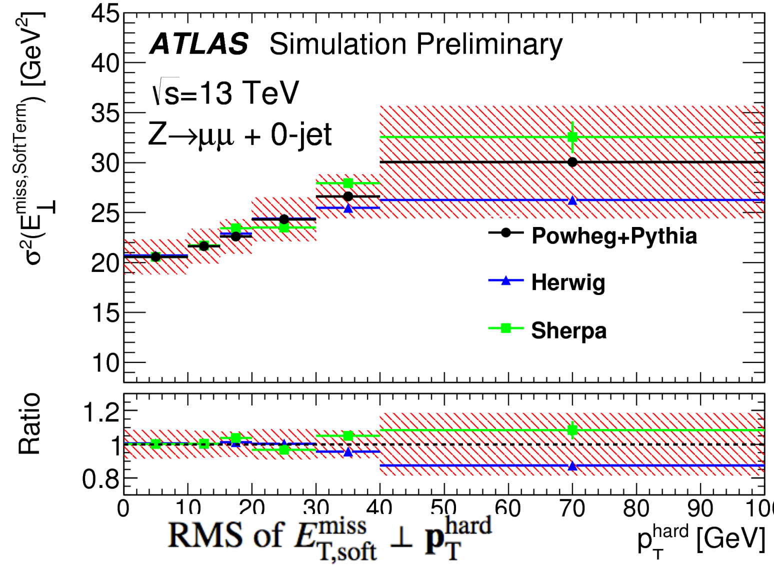


+ TST Soft term systematics

- Systematics on the E_T^{miss} measurement quantify the level of agreement between data and MC
- Component originated from the measurement of the other physics objects can be propagated through the E_T^{miss} computation
- TST Soft term uncertainties are provided on MC-based studies
- Expected to cover discrepancies between data and MC at 13 TeV
  - Modelling of the generators
  - Full vs Fast simulation
  - Experimental conditions: geometry of the detector, bunch spacing …

+ TST Soft term systematics





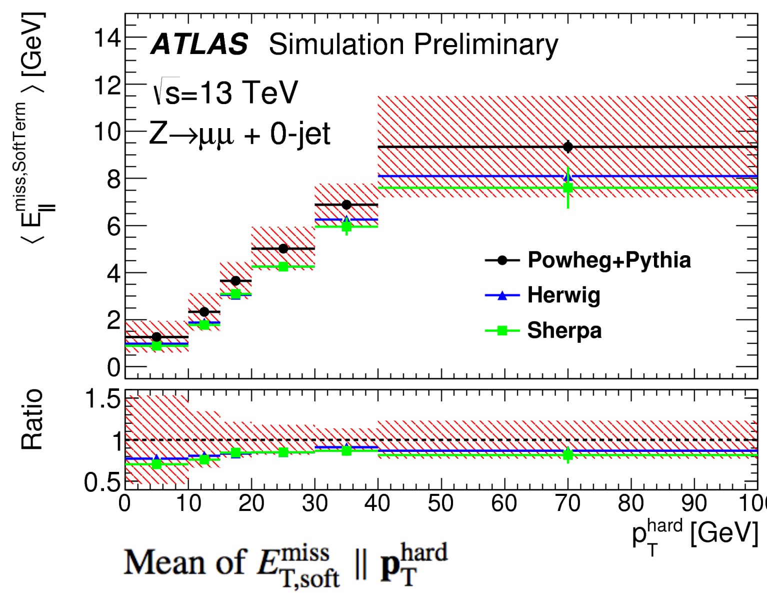
Soft Term projections onto p_T^{hard}:

- Mean of longitudinal component

  => scale uncertainty

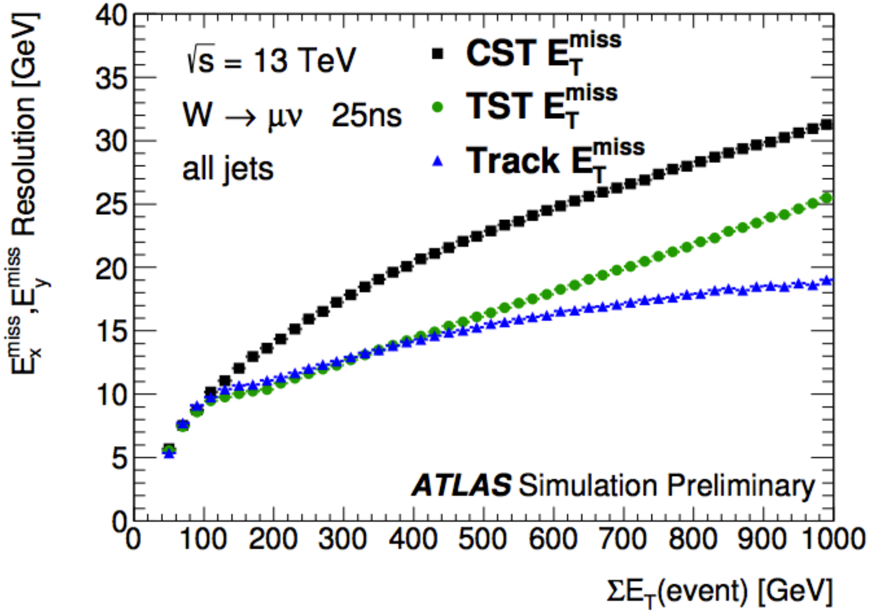
- RMS of transverse and longitudinal components

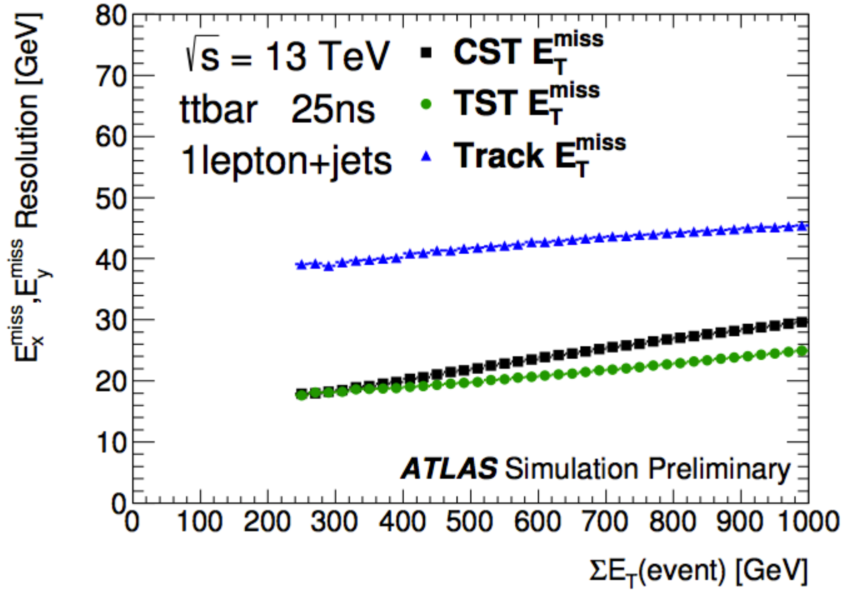
  => resolution uncertainty



E_T^{miss} Performance: *Resolution*

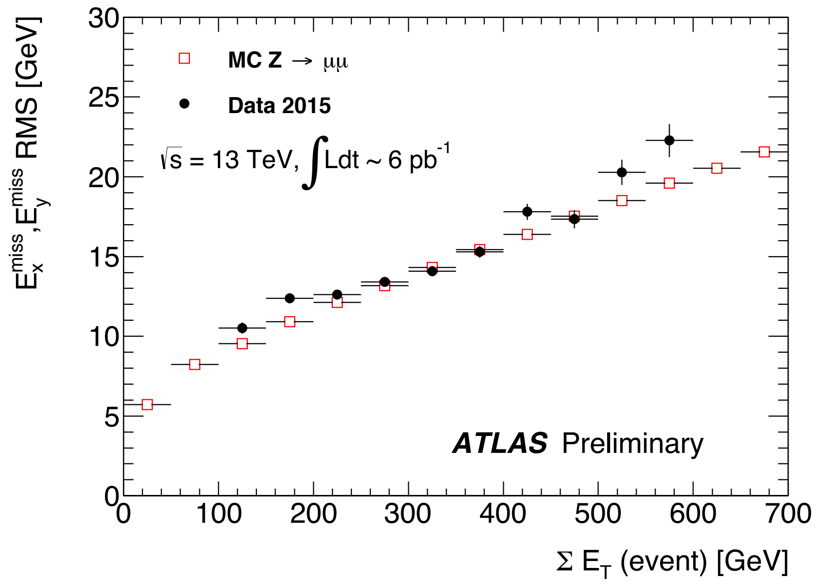
- W → *lν* inclusive jets (left), ttbar inclusive jets (right)

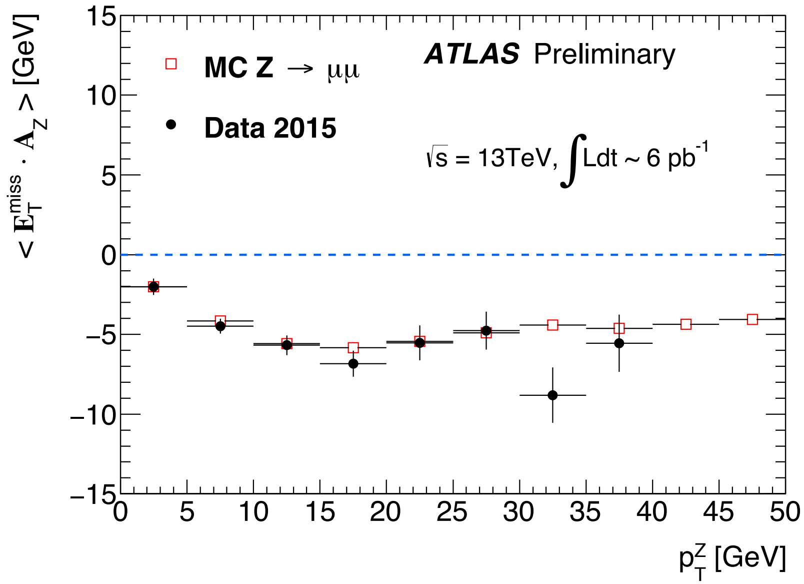




- In inclusive jet events, all variants suffer by the increased event activity in higher pile-up regions
- TST and CST show similar values of the resolution among various topologies, while Track resolution suffers in high-jet multiplicity events

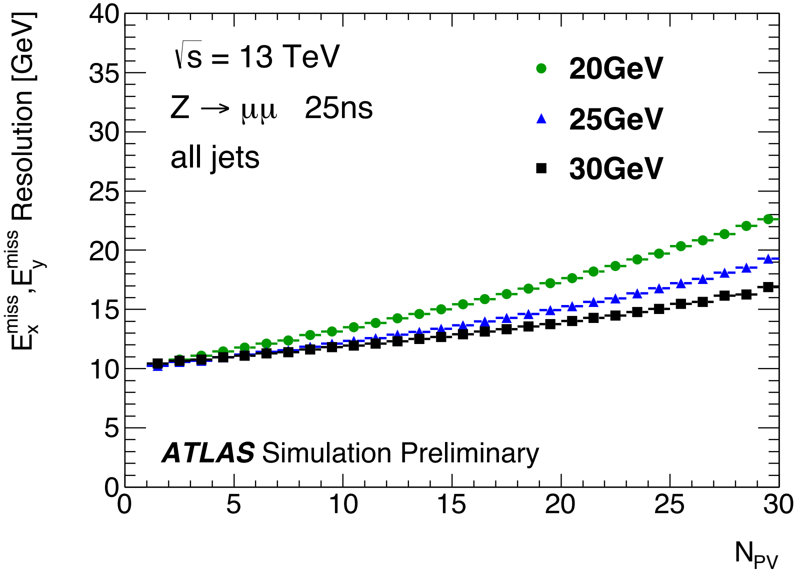
TST E_T^{miss} : *Resolution and Scale in 2015 data and MC*

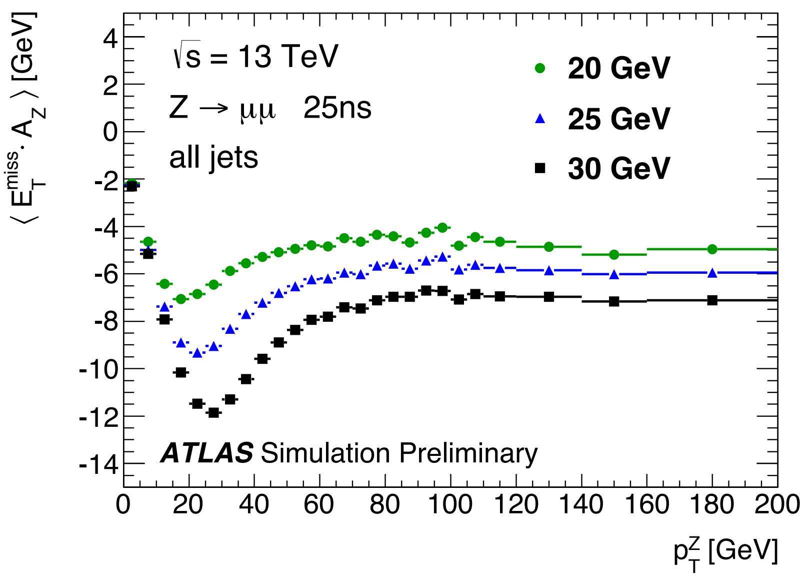




- Agreement between data and MC with very first data, Z ➔ $\mu\mu$ events

+ Jet Selection in E_T^{miss}





- Higher p_T threshold for jets going into the jet term can improve the resolution at high N_{PV}
- but also increases the bias at all p_T^Z

+ E_T^{miss} Reconstruction: *Association Map*

⇒ There must be a mechanism to keep track of the overlaps between physics/signal objects:

- Run 2 ***Association Map***:
  - Contains the spatial association of each physics object to anti-kt4 jets
  - Within each jet, object overlaps are identified
  - Unassociated tracks/clusters go into the core soft terms