Where do we stand? Aka Craig needs to finish his thesis!

Craig Wells

eeCC A_i

eeCC– Full Run 2 A_i Measurment

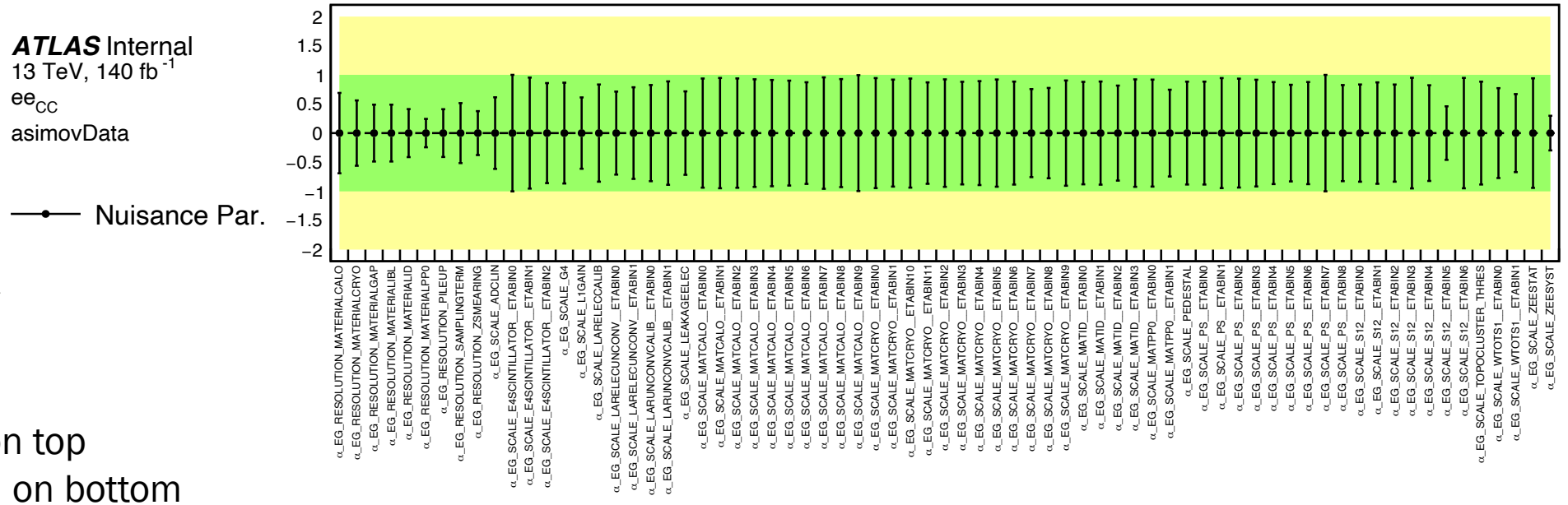
- This channel is (pretty much) finished!
  - *Full run 2 scans complete and validated.*
  - *Workspaces made.*
  - *Asimov data fitted.*
  - *Obs data fitted.*

- Obs data fits have converged and have been plotted. Results will be pushed to git.

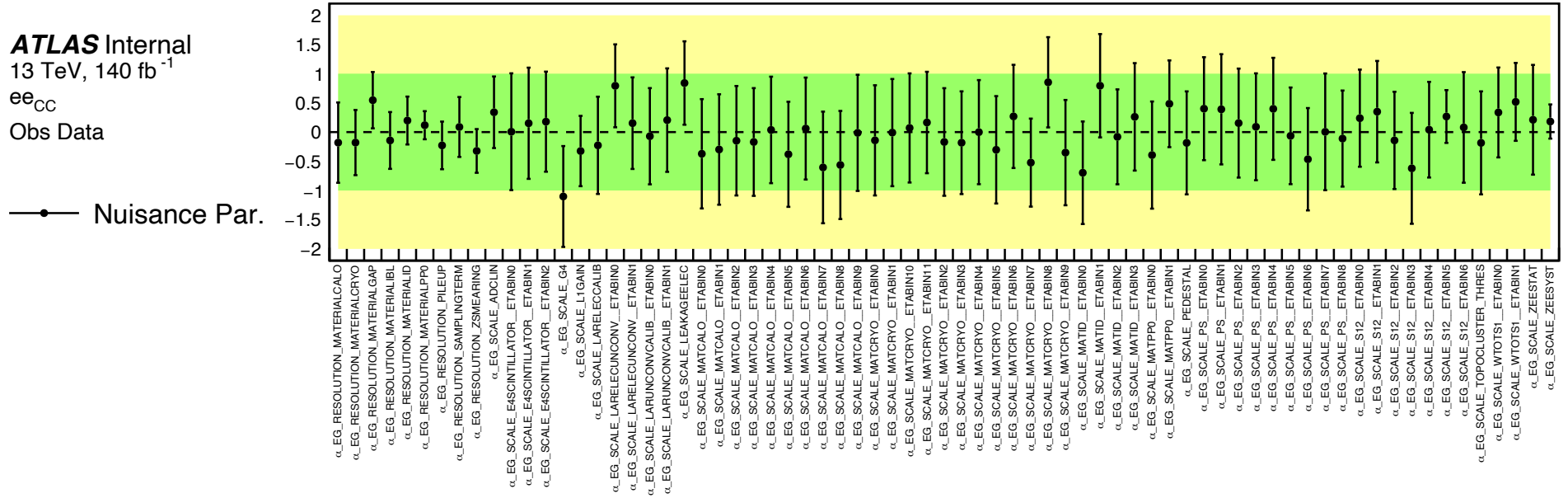
- All that's needed now is p-values for agreement between electron and muon channels.
  - *As work on the muon channel is still ongoing I won't show many combination plots.*

- Some choice obs data plots will be shown but not the full set. If interested these plots can be found on cernbox.
  - *Leaving the choice to unblind to you!*

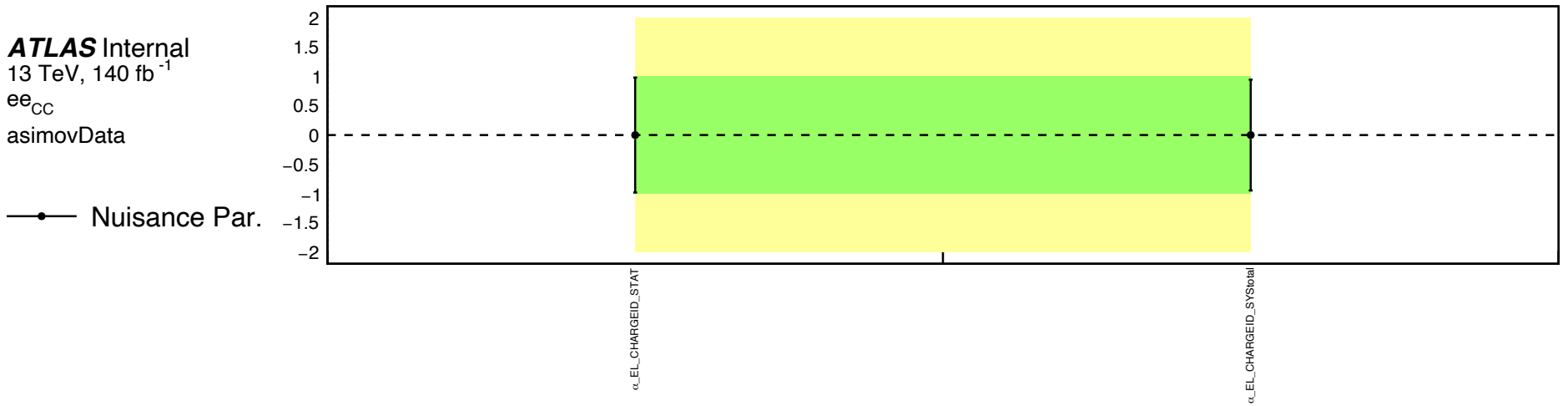
eeCC - Calibration Pulls

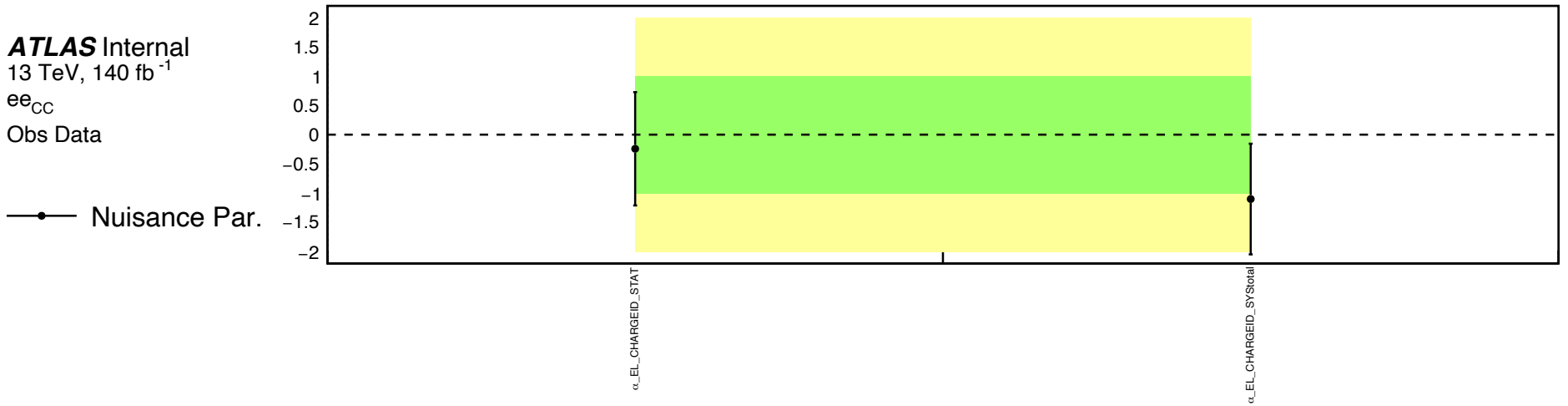


Asimov on top
Obs data on bottom

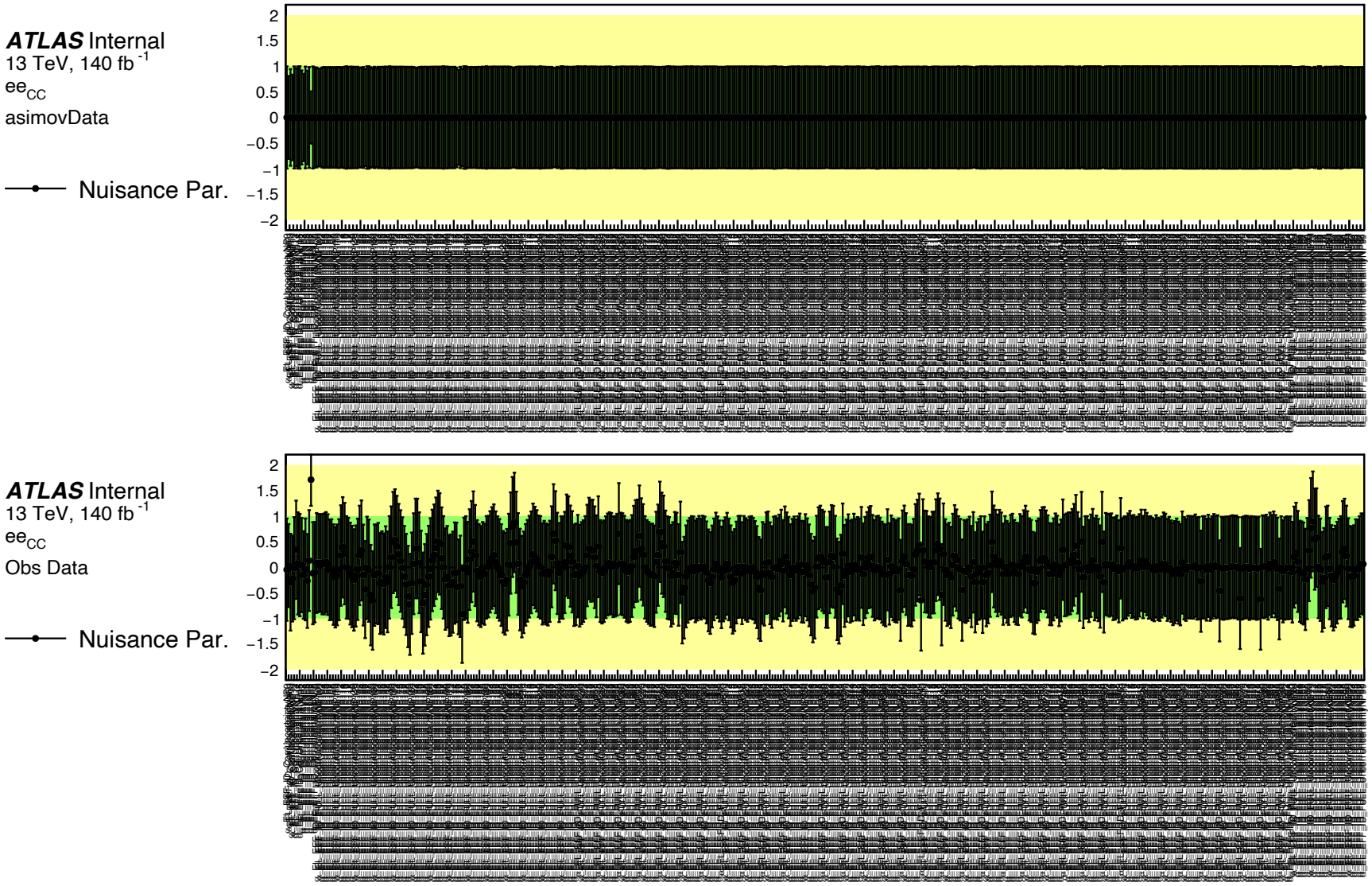


eeCC - Charge ID Pulls

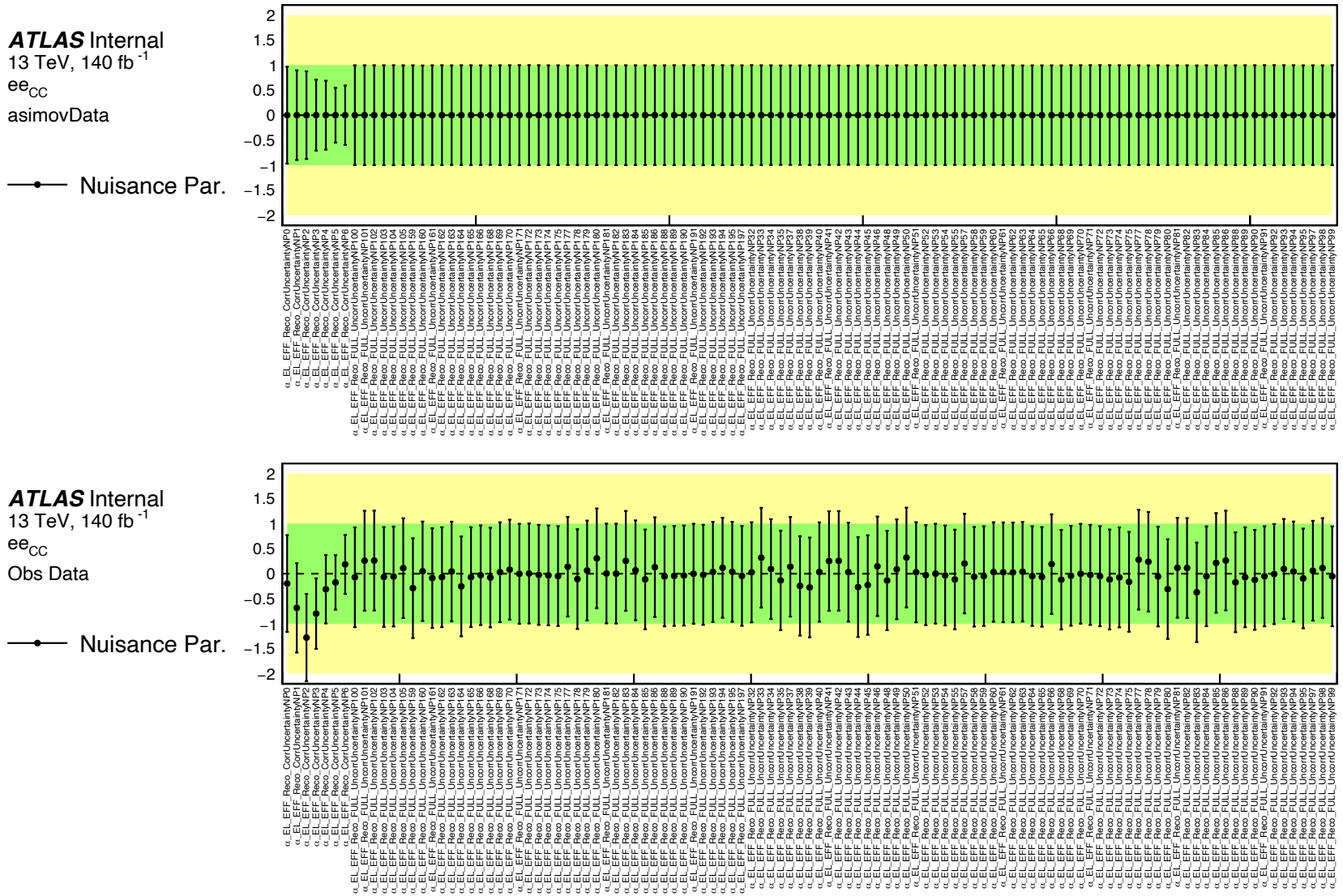




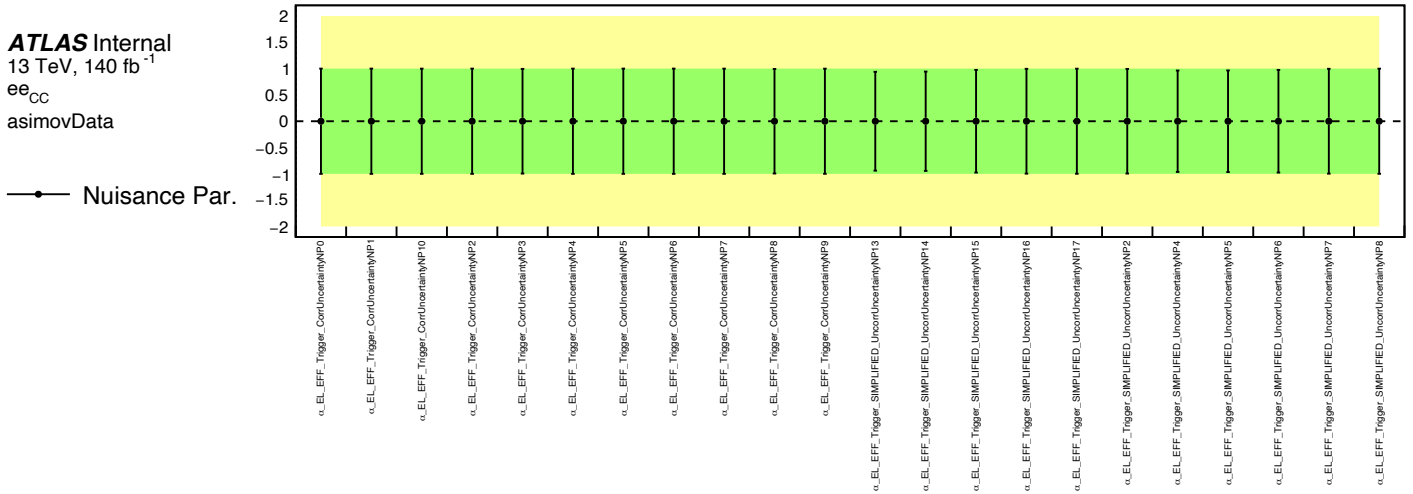
eeCC - ID Efficiency Pulls

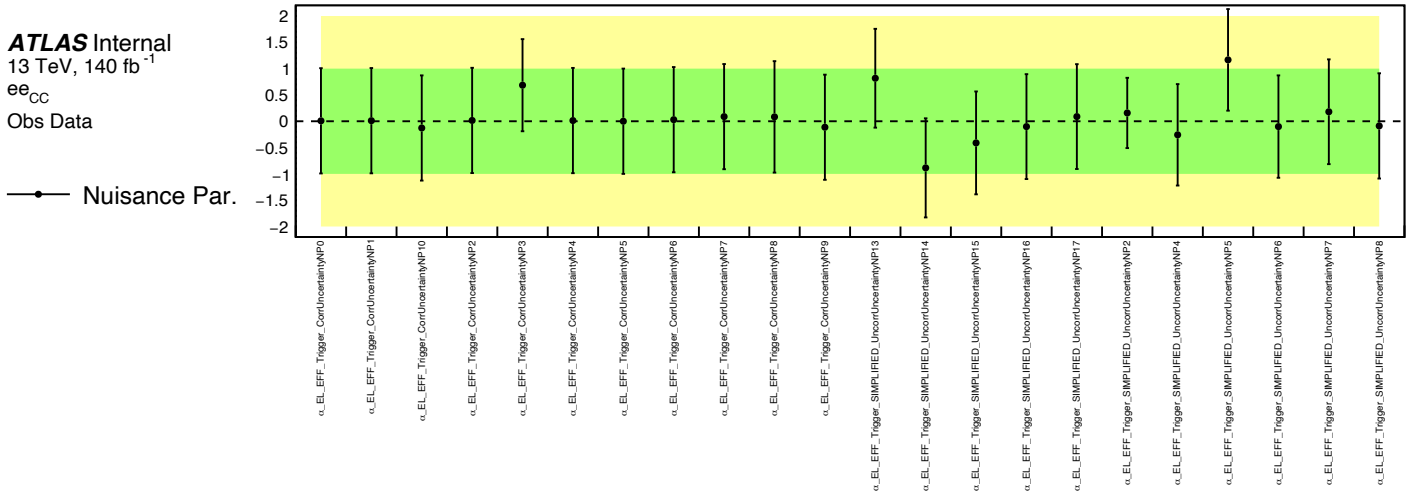


eeCC - Reco Efficiency Pulls

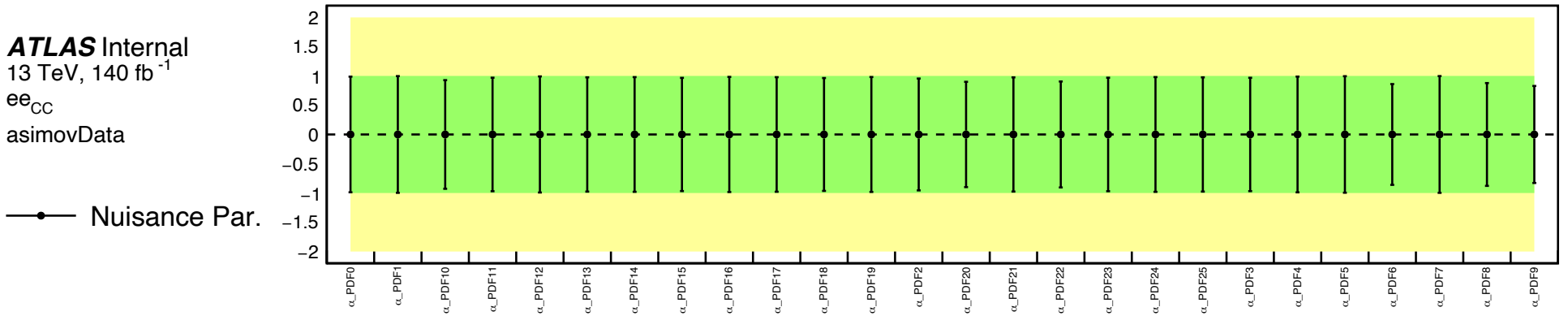


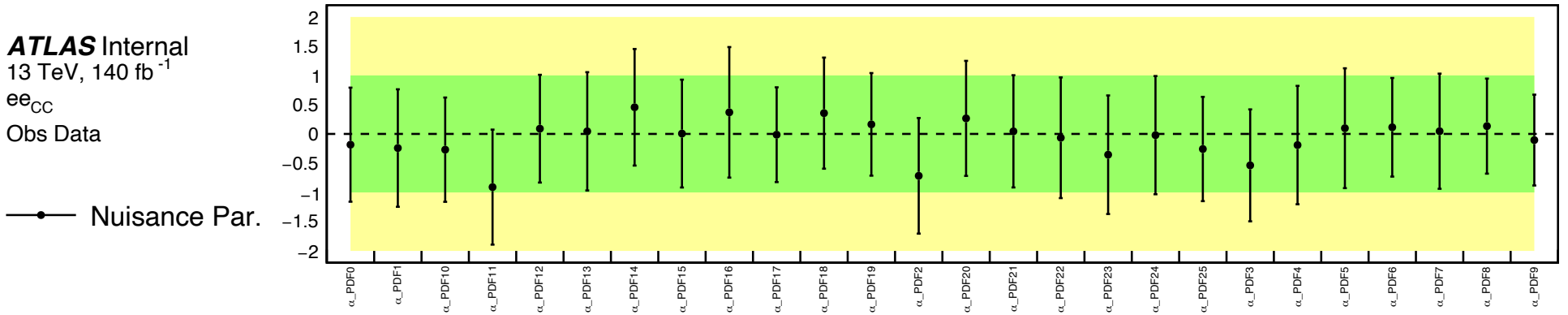
eeCC - Trigger Efficiency Pulls



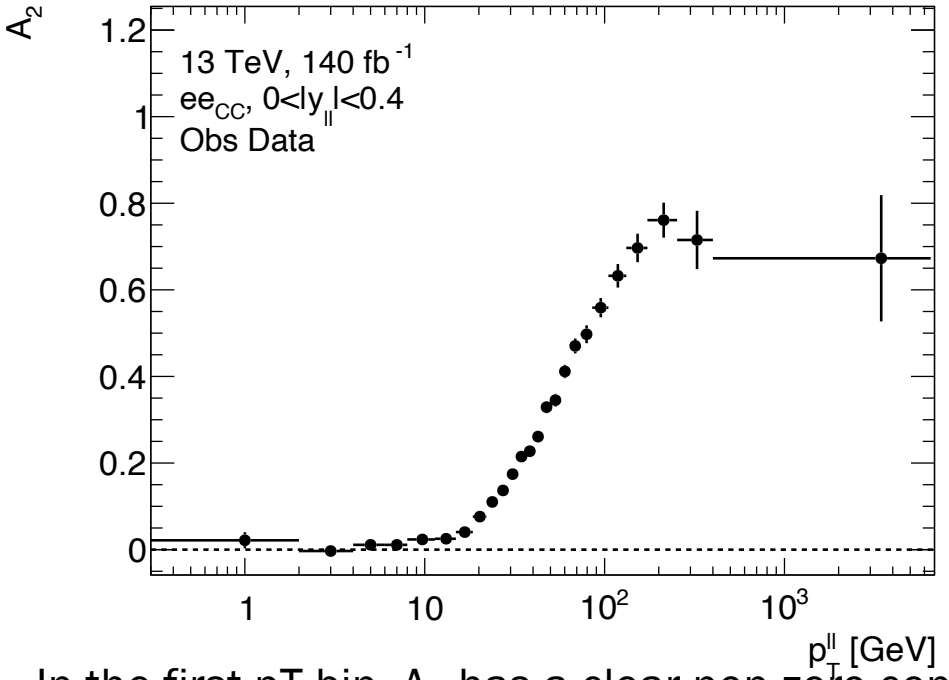


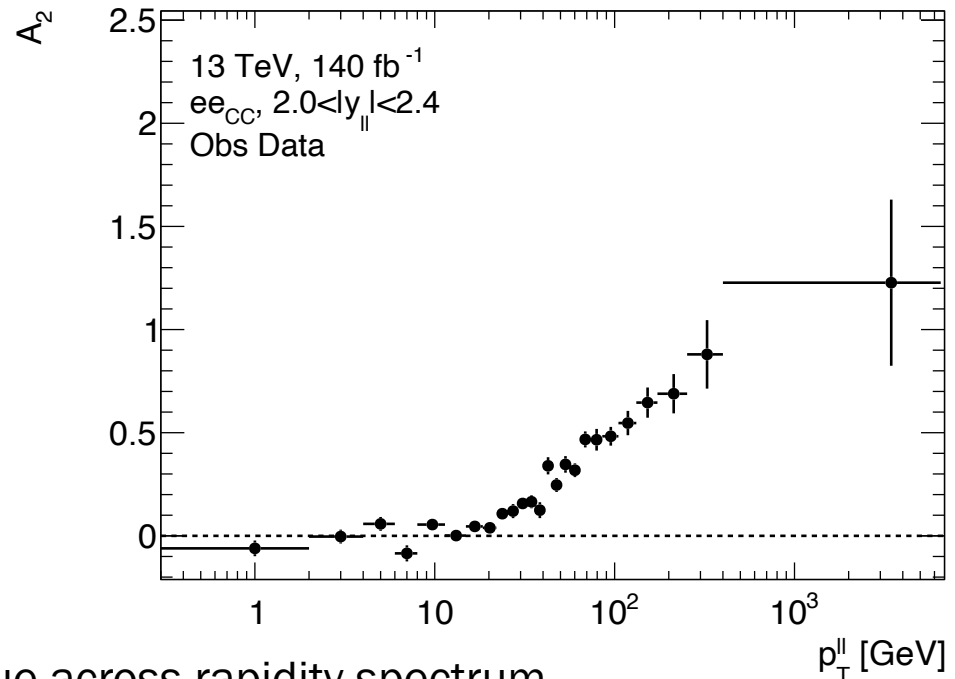
eeCC - PDF Pulls





eeCC – A2



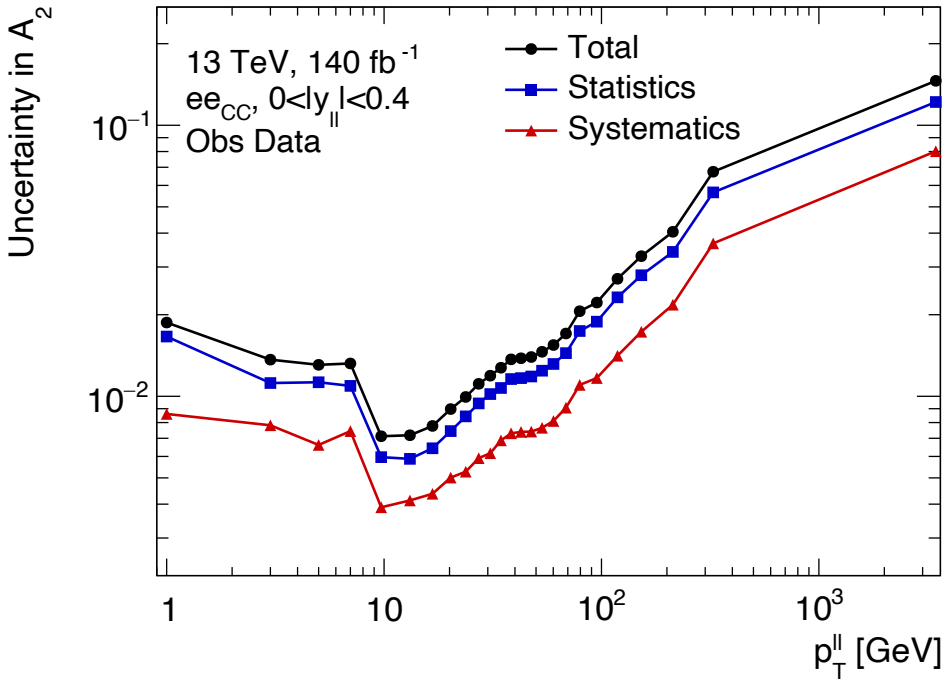


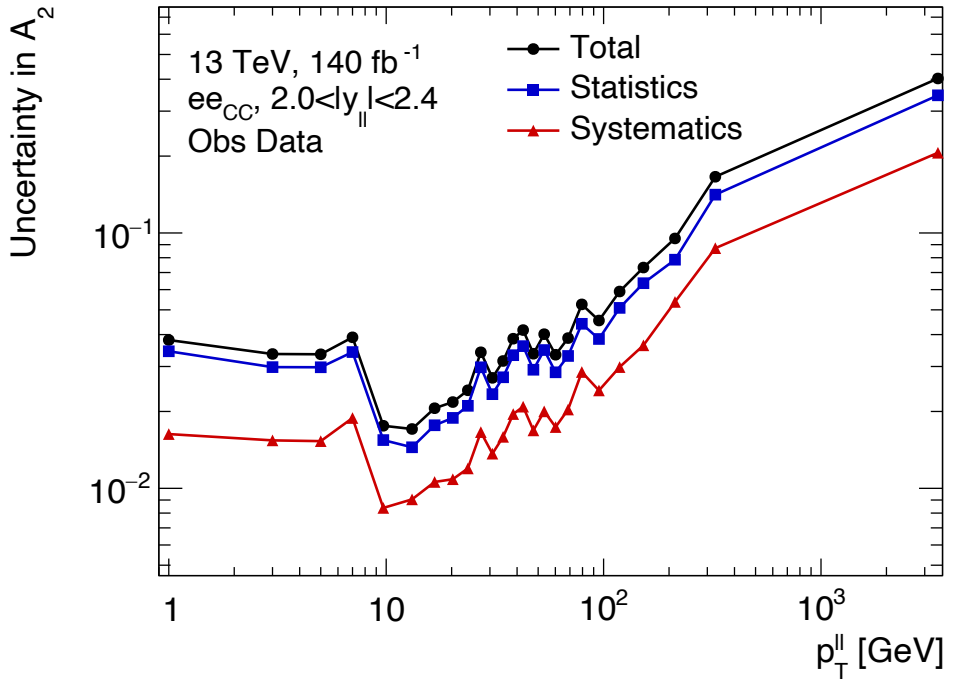
- In the first pT bin, A_2 has a clear non-zero central value across rapidity spectrum.
  - *All bins are statistically limited so the uncertainty (eeCC only) can't be improved much further.*
  - *Combination fit is also statistically limited so uncertainty is ~1/sqrt(2) lower.*
  - *Adding CF A_i extraction will be interesting to see!*

- Potential evidence for instantons!

- Value still seems compatible with zero when considering uncertainties.

eeCC – A2





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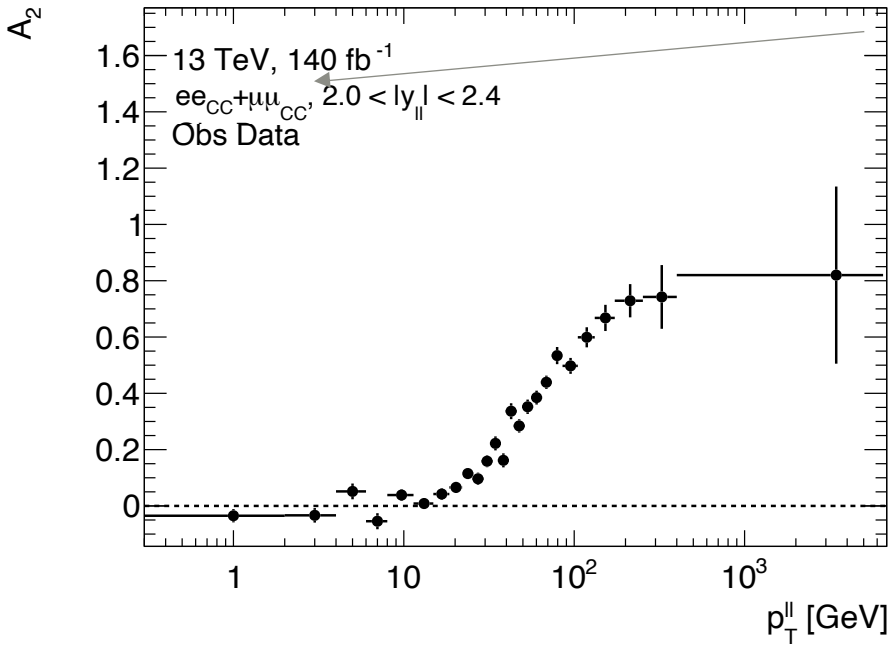
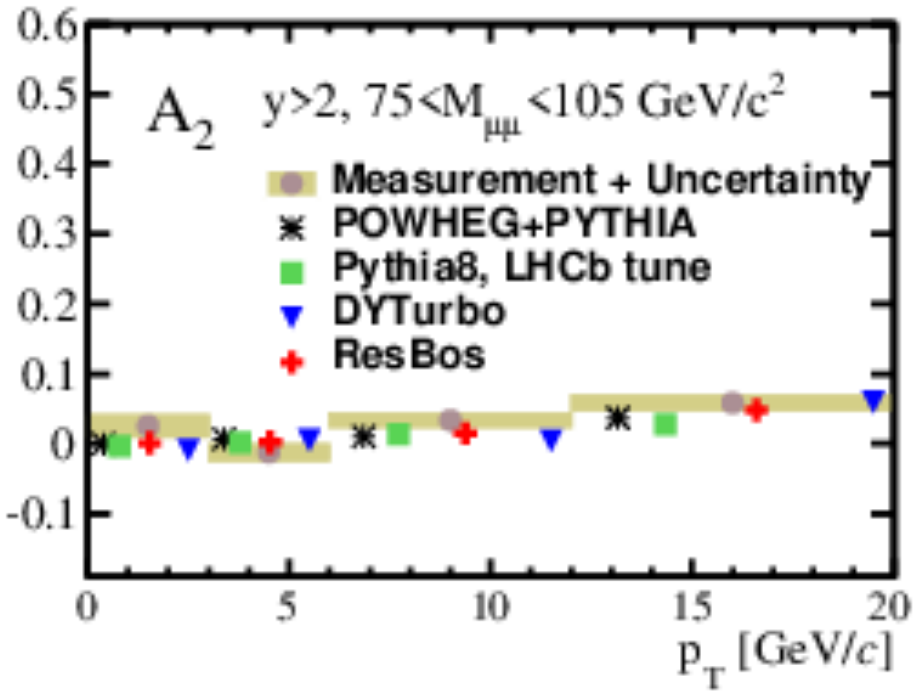
A_2 from LHCb

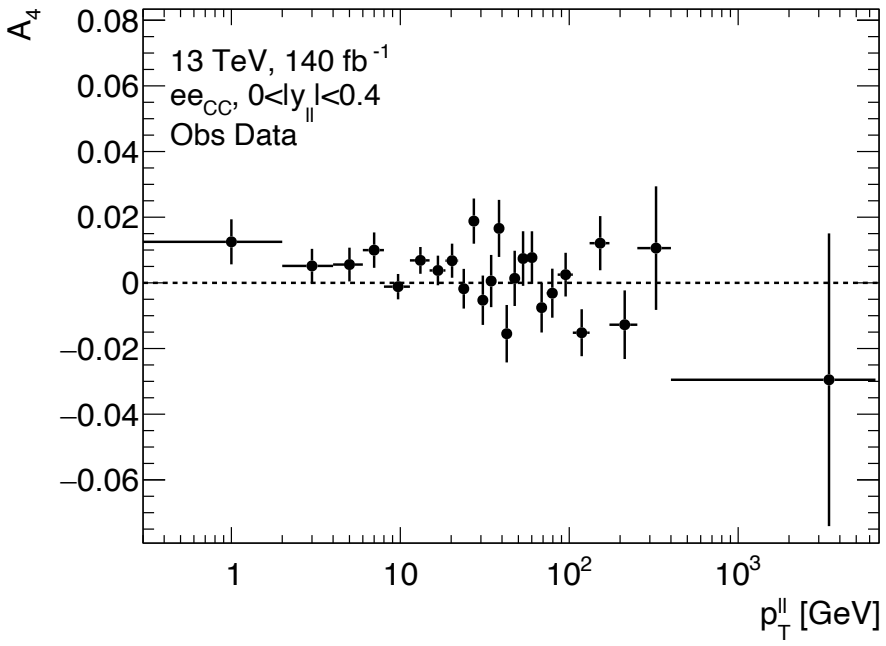
Combination for best uncertainties. Delta is good here too.

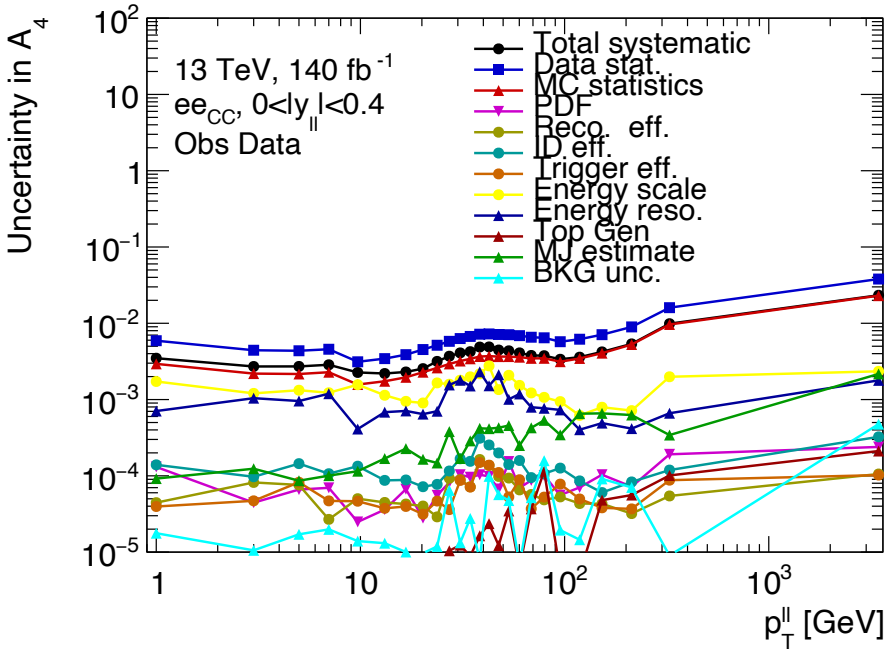




- LHCb published values of A_0, A_1, A_2, A_3, ΔA_4 and Lam-Tung in $Z \rightarrow \mu\,\mu$ decays in 2022.
- Similar to us, they see a non-zero A_2 value in the low pT Z region, but with opposite sign.
- LHCb result is rapidity integrated ($2 < |y_{ll}| < 5$) so not a perfect comparison with our $2.0 < |y_{ll}| < 2.4$ bin.
  - CF channel will provide a better comparison with the LHCb result!

eeCC – A_4





- At low rapidity, A_4 has roughly the same magnitude as seen in Asimov but with statistical variations evident.
- Uncertainties at low rapidity also match Asimov nicely.
- At high rapidity, there is much more variance around what is predicted by Asimov but magnitude remains ~ what was expected.
- Uncertainties at high rapidity are actually better than what was predicted!

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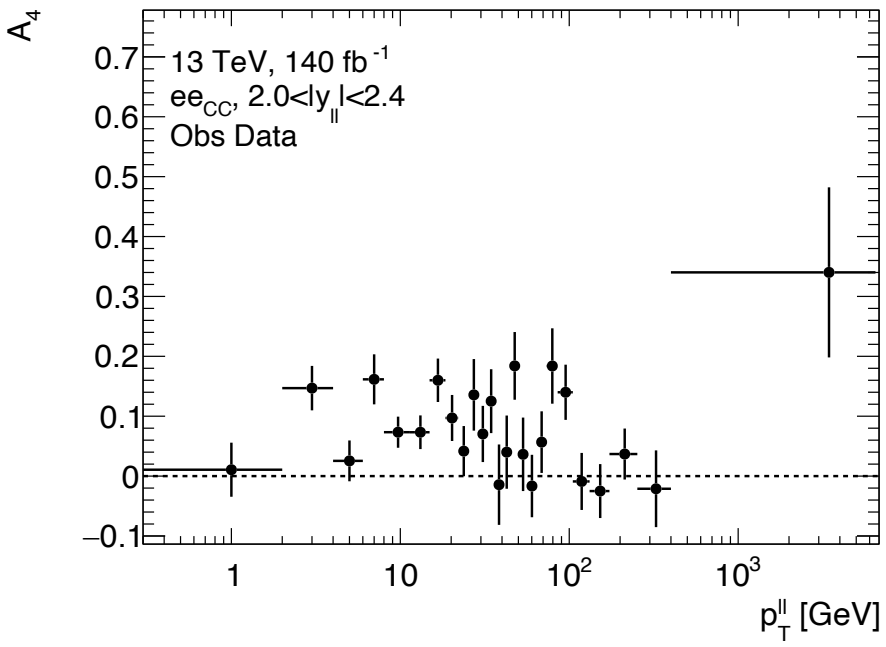

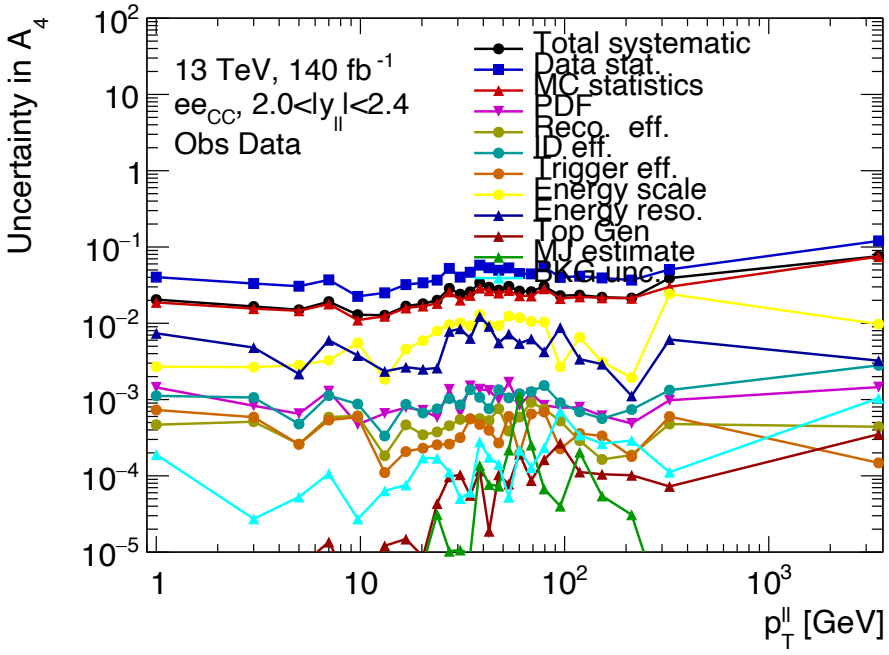

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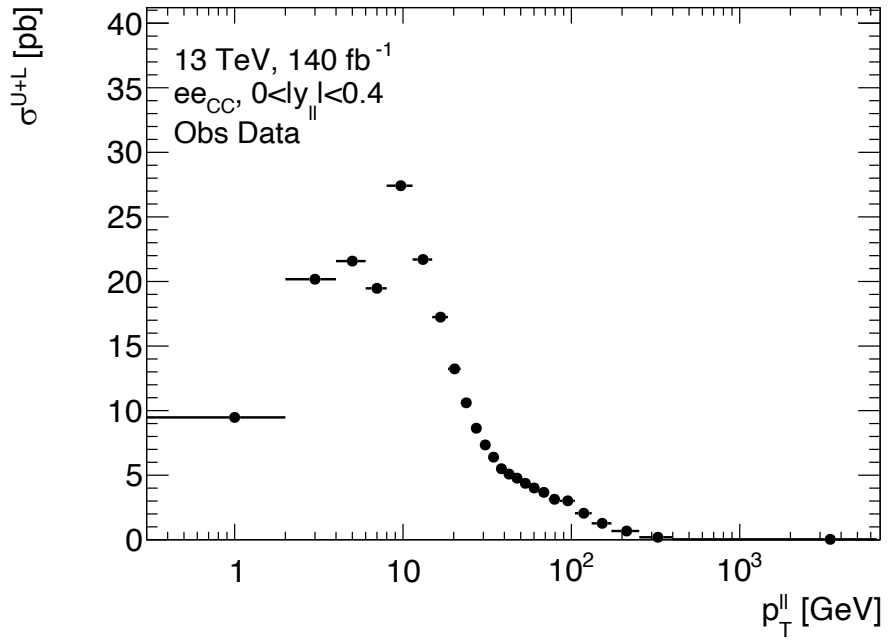
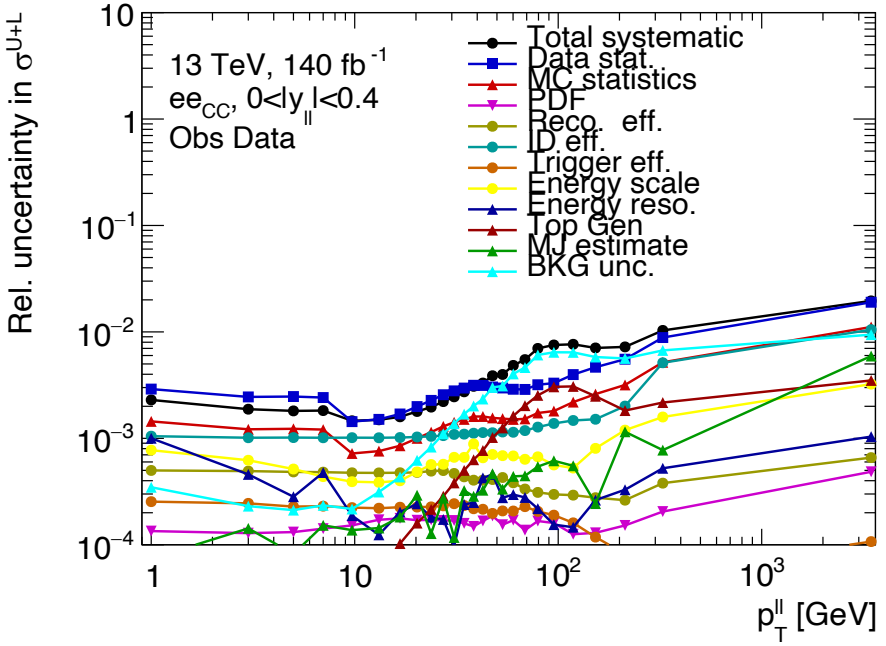
eeCC – A_9

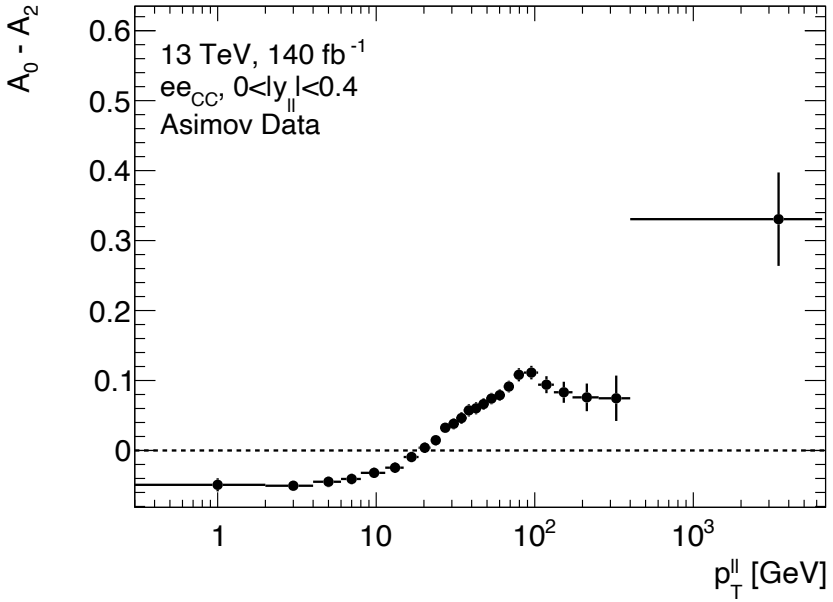


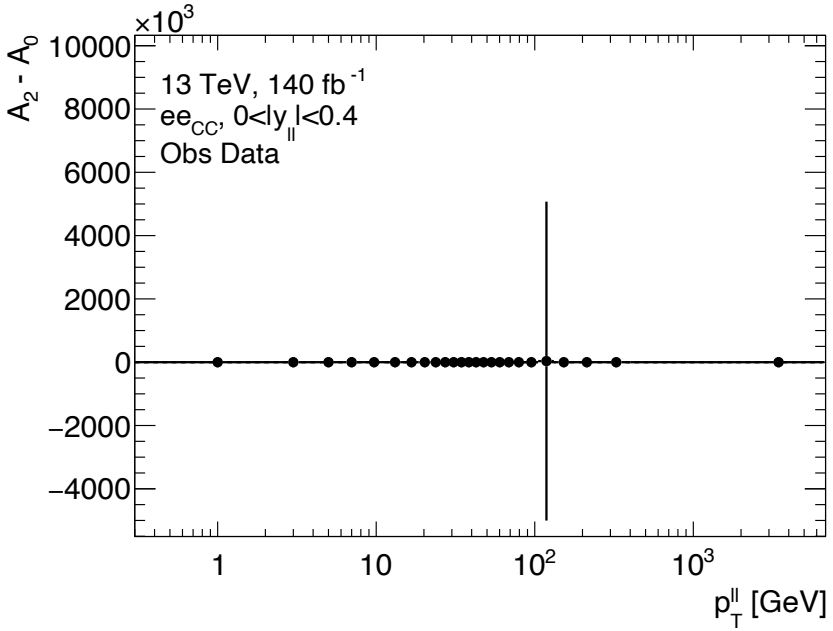


- A_9 behaves nicely in the obs data fit. Central values are much more similar to Asimov and uncertainties look good too.
- Sub-percentage precision on the cross-section is reached!

Lam – Tung Relation

- Lam – Tung (LT) relation is $A_0 - A_2 = 0$
  - *Zero at LO but is violated by QCD interactions.*
- LT can also be fitted in aidy by running the workspace config option “doA0mA2”.
- For Asimov, these fits look completely fine but for obs data they fail spectacularly for both central channels.
  - *Obs data errors are either far too large or central values do not accurately reflect the real value of $A_0 - A_2$*





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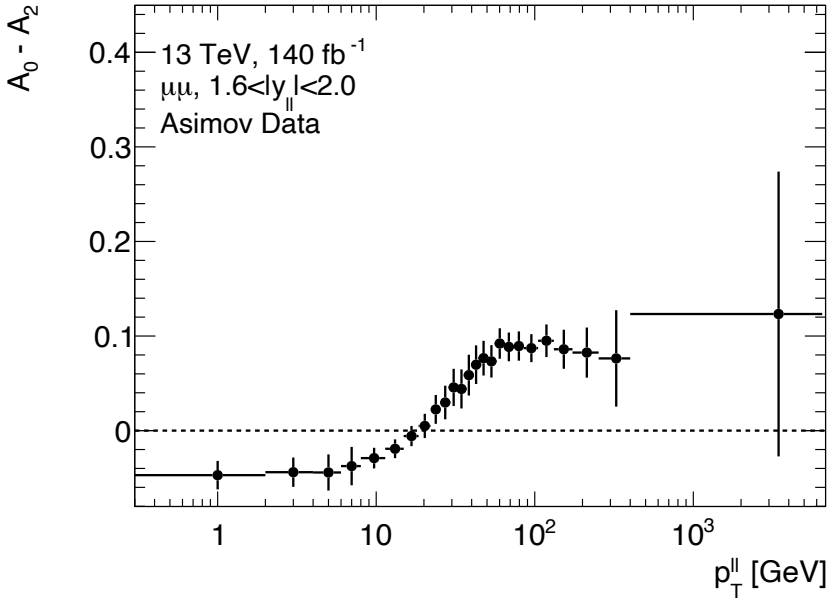
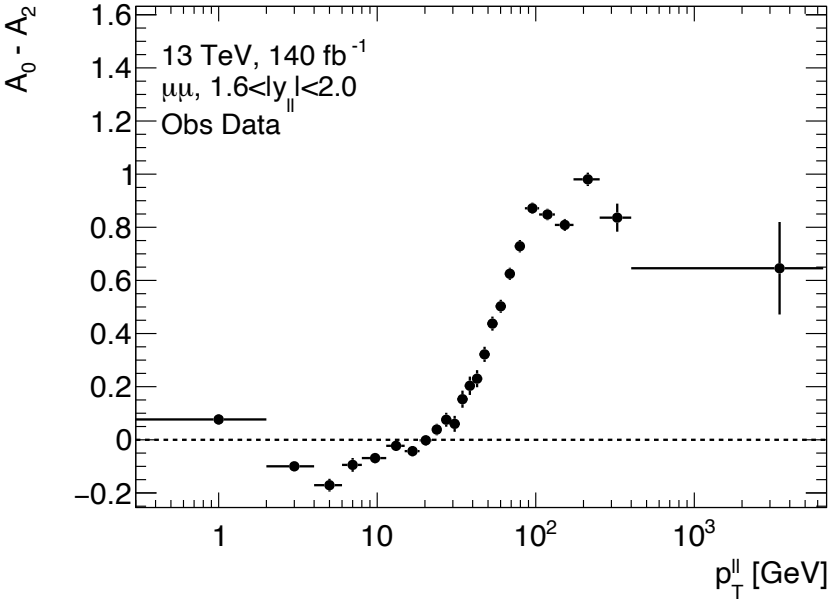
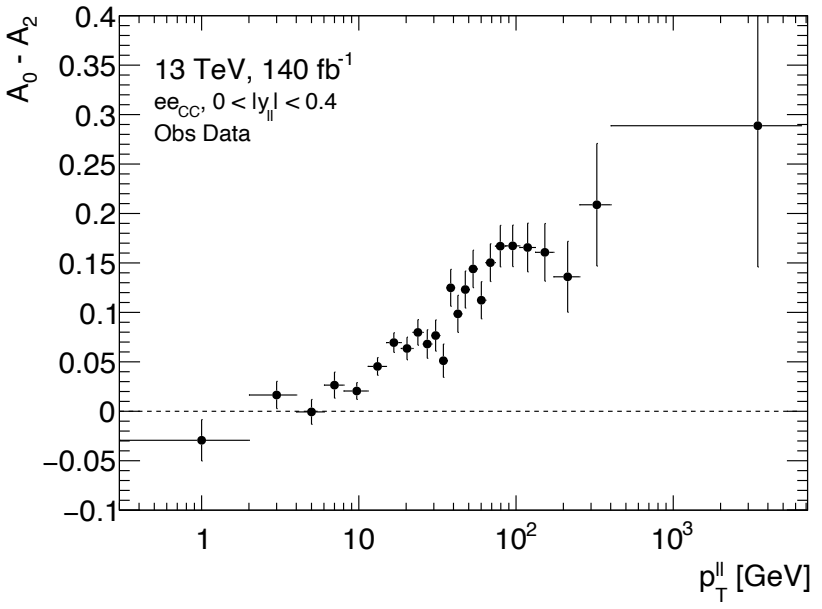
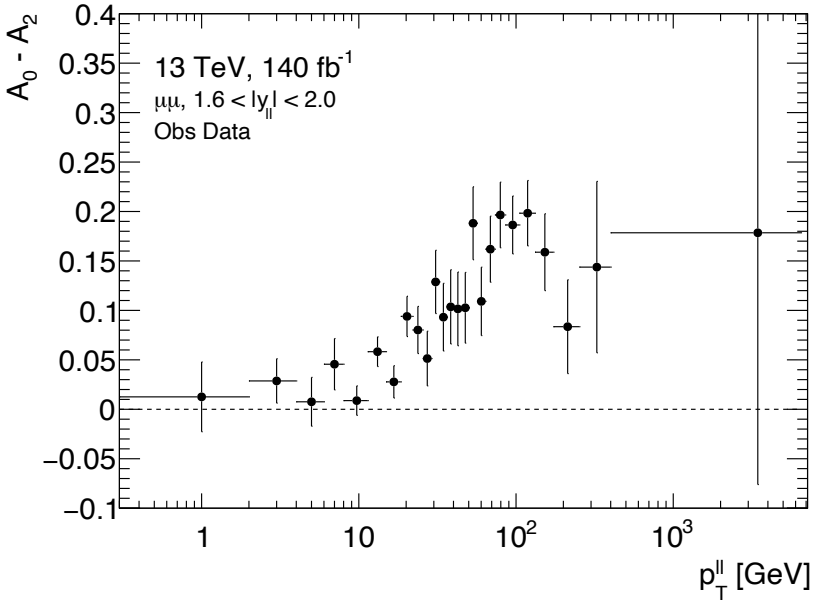




Lam – Tung Relation

- To attempt to fix this, the convergence criterion on the fit was changed to be tighter by one order of magnitude
  - *Fit took longer to converge but problematic values were not fixed.*
- Calculate it directly for a much more reasonable value!
  - *Take central values from individual A_i fits and subtract them by hand.*
  - *Calculate uncertainties including taking correlation between the two parameters (covariance matrix is saved by FTL).*
  - *This method neglects the effects of any correlations between different analysis bins.*
- It still needs to be investigated what is causing the direct fit approach to fail!





eeCC + MM Combination

CC + MM Combination Deltas

- The central channel combination has been fit and seems to work fine (stat uncertainty decreases by ~1/sqrt(2)).
  - *Won't show the plots since MM work is still ongoing.*

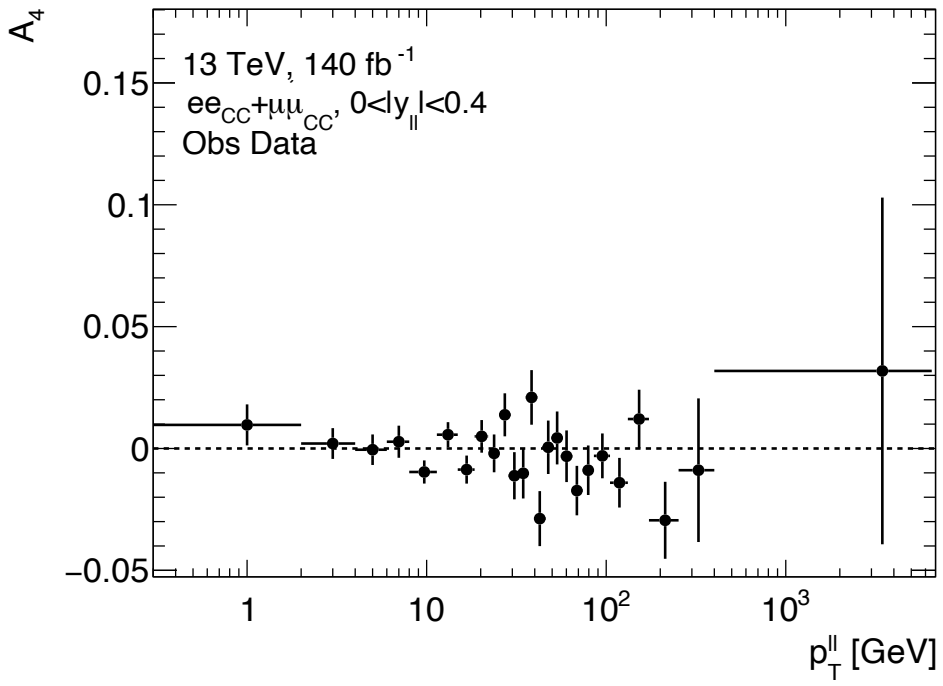
- Deltas are now being fit taking into account all systematics.
  - *Deltas defined in aidy as*

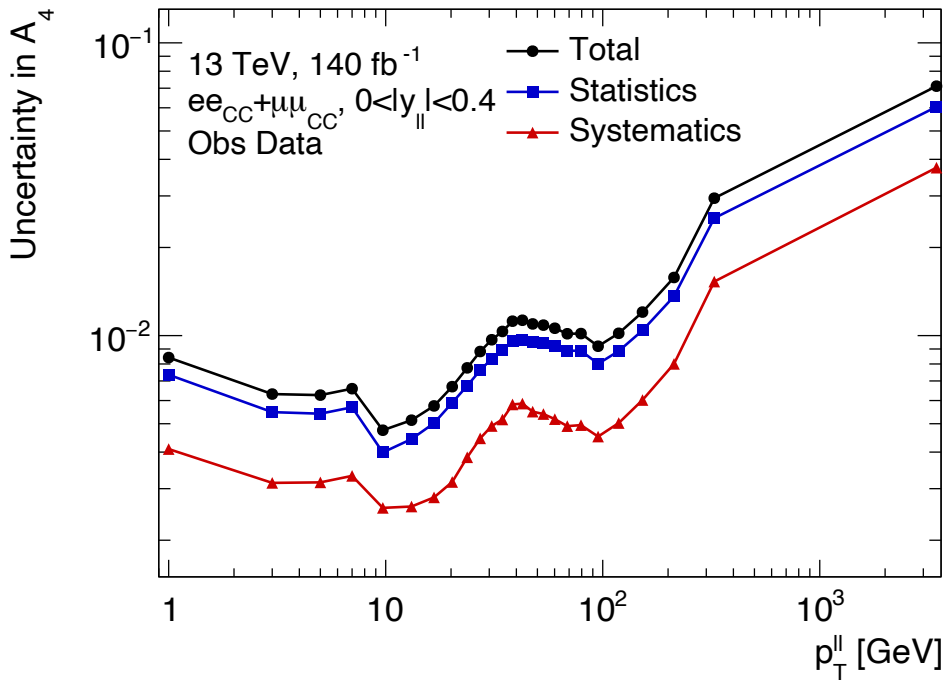
$$\Delta_{ee_{CC},\mu\mu} = \frac{A_{i,CC} - A_{i,\mu\mu}}{A_{i,CC}}$$

  - *Much improved from previous stat only fit!*

- Last step is to get p-values to test compatibility numerically.

Delta A_4 + Delta A_9



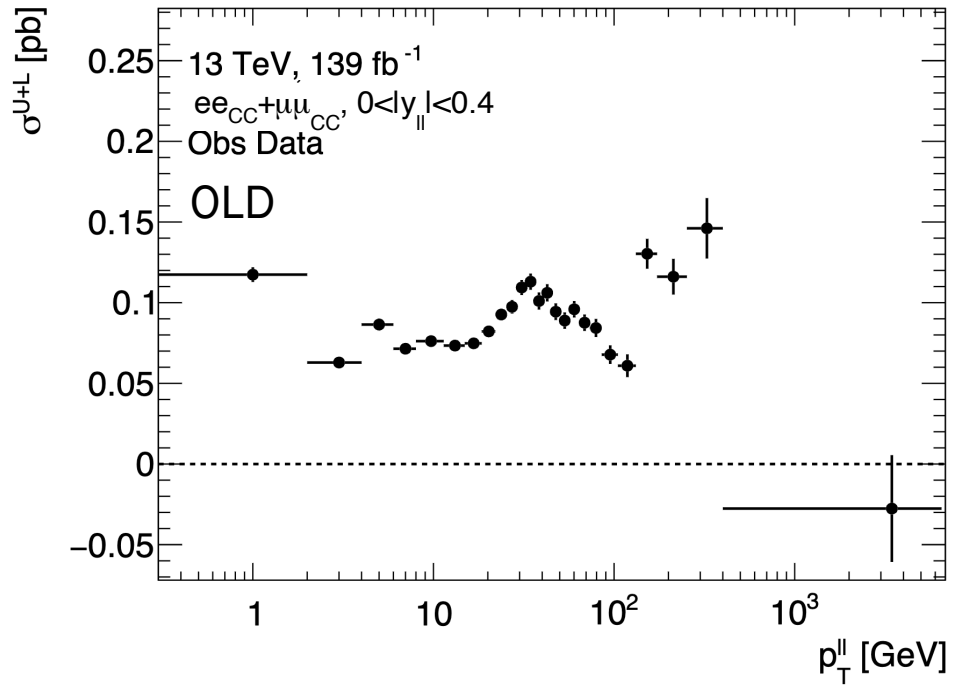


CC_v24, MM_v26 – All systematics

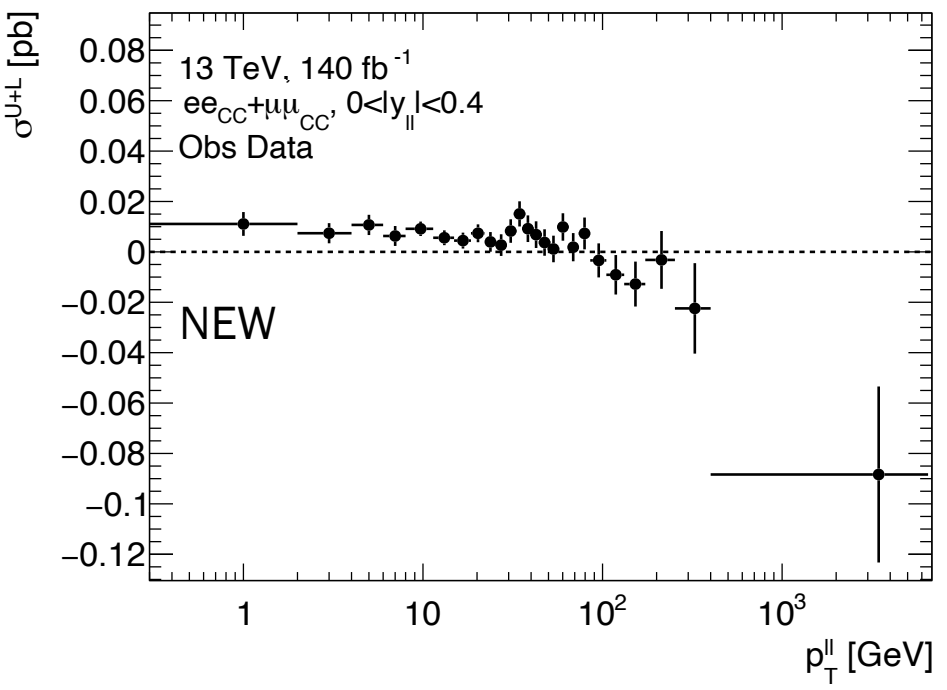
- Individual A_i look very compatible with zero, ~1% difference between eeCC and MM for A_9
  - *Thought this might be caused by using wrong luminosity for the muons but this wasn't the case.*

- Delta A_4 statistically limited rather than systematically. Both are similar for A_9 (breakdown plot is currently bugged so not showing).

Delta A_4 + Delta A_9



CC_v20, MM_v26 - stat only



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Weak Mixing Angle (eeCC)

Weak Mixing Angle

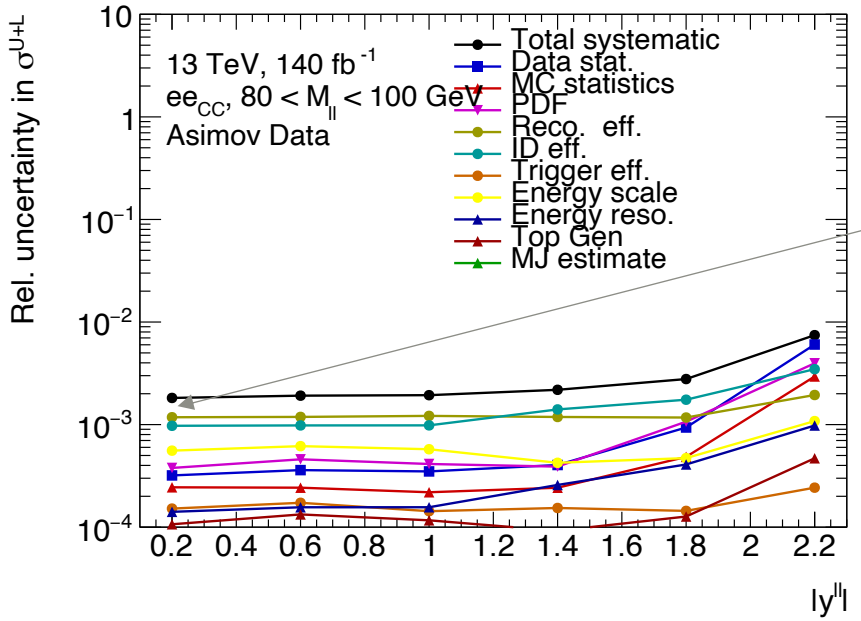
- Next stage of the analysis is the extraction of the weak mixing angle at 13 TeV, by reparameterising A_4 and including A_9 into the fit to reduce PDF uncertainties.
  - *pT: inclusive*
  - *M_{ll} : 70 – 80 – 100 – 125 GeV (may change 125 to 150 GeV in the future)*
  - *Y_{ll} : 0 – 0.4 – 0.8 – 1.2 – 1.6 – 2.0 – 2.4 – 2.8 – 3.2 – 3.6 (CC stops at 2.4, CF begins at 1.2)*

- Latest Asimov studies show that the combination of central electron and muon channels could reach an uncertainty of 36×10^{-5}!
  - *Same sensitivity as combined eeCC + MM + eeCF channels at 8 TeV*
  - *40% improvement in comparison to central channels only at 8 TeV!*

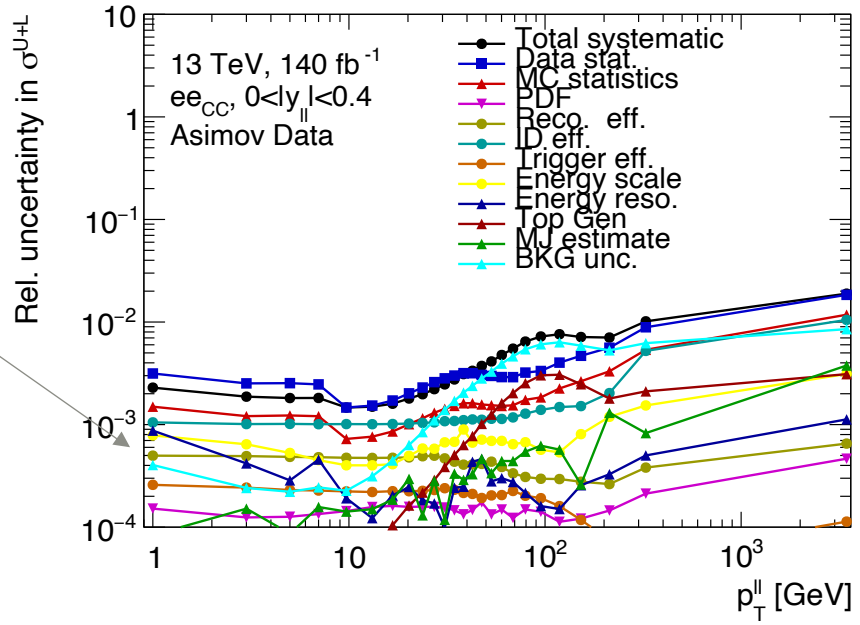
- Target to beat: 31×10^{-5} achieved by CMS at 13 TeV.
  - *Should be achievable, no pressure!* 😉
  - *If that's too easy, there's always the LEP precision levels to be targeted!*

- Results presented at ATLAS Week in June.

eeCC WMA Future Improvements



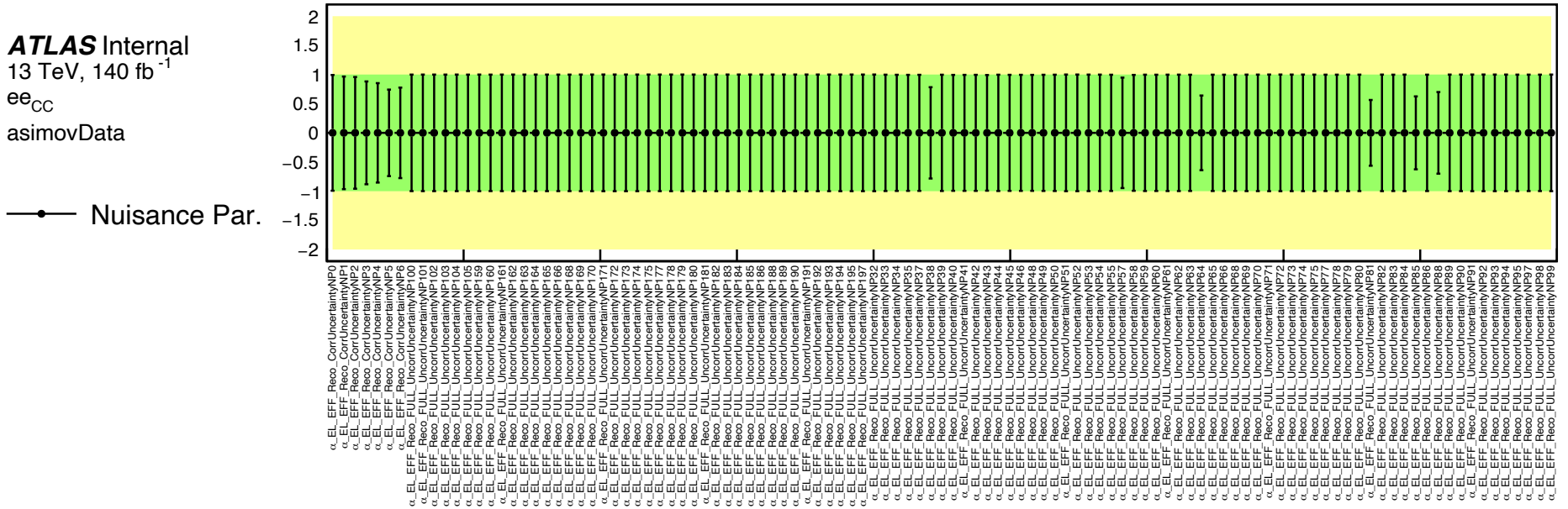
WMA Scan



A_i Scan

- From the A_i pT/Y scans we should expect reco efficiency uncertainty << 1 permille.
- Fixing this may bring us back to the sensitivity achieved by Julian (34×10^{-5}?)
- Pull plots show five uncorrelated NPs that need to be rerun.
- Potential to extend high mass region from 125 to 150 GeV to improve statistical sensitivity as well.

eeCC WMA Future Improvements



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Weak Mixing Angle (eeCF)

CF WMA – Now with systematics!

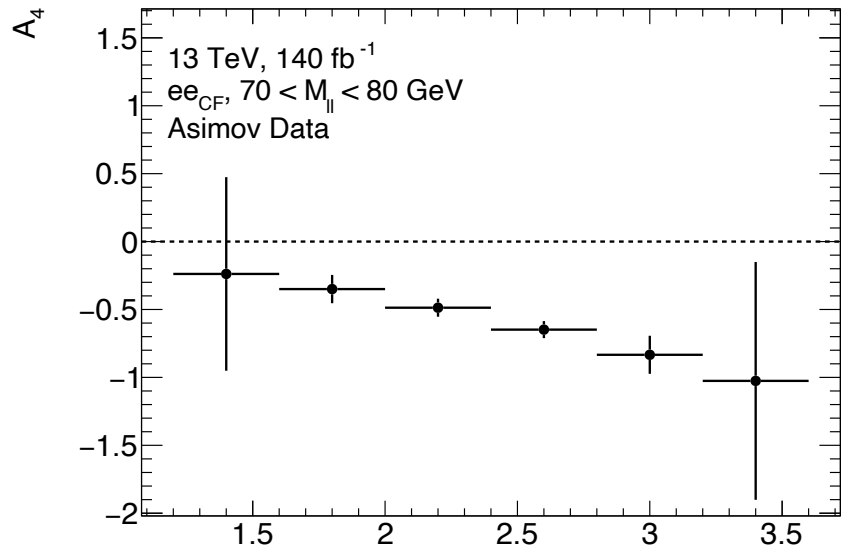
- Central electron calibration
- Central electron ID*/reco/trigger* SFs
- Top/EW background generator systematics
- Multijet estimate
  - *Fake factor statistical variations*
  - *Central ID*
  - *Forward anti-ID definition*
  - *M_{ll} range*
- PDF
- Forward ID SFs
  - *SF statistical variations*
  - *Background shape*
  - *Background extrapolation*
  - *Central ID*
  - *Signal contamination*
- Forward Calibration
  - *Parameter variations*
  - *Fit range*
  - *Calibration model*

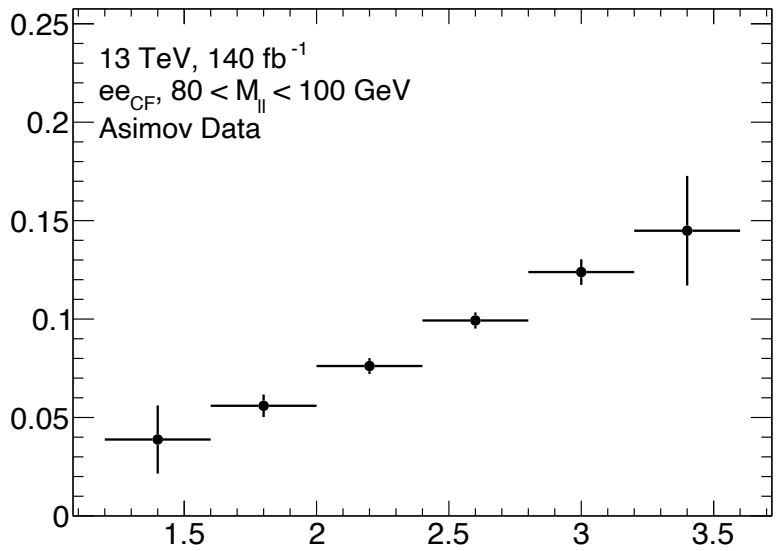
- CF branch of aidy has now been updated to be able to properly process systematics.
- A lot of bug fixing was done by me, there may still be some I haven't noticed.
- Consider the current branch state a first working version!

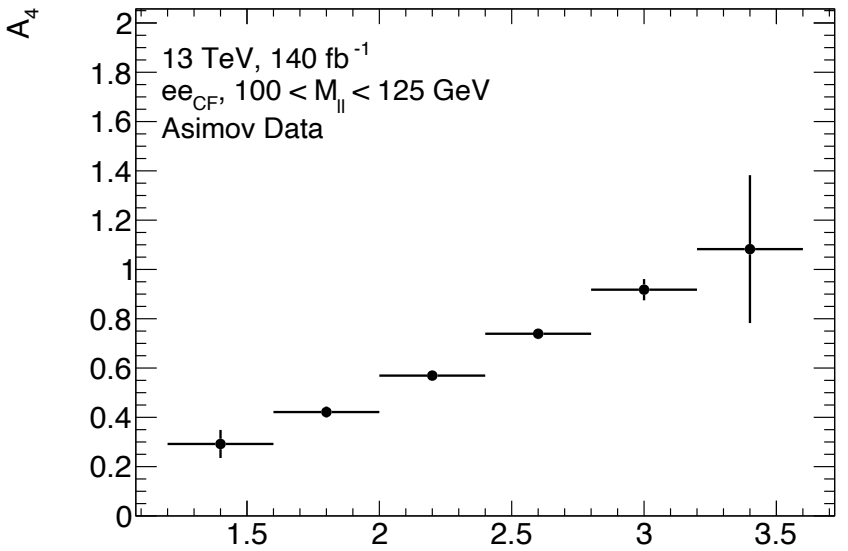
CF – General Notes

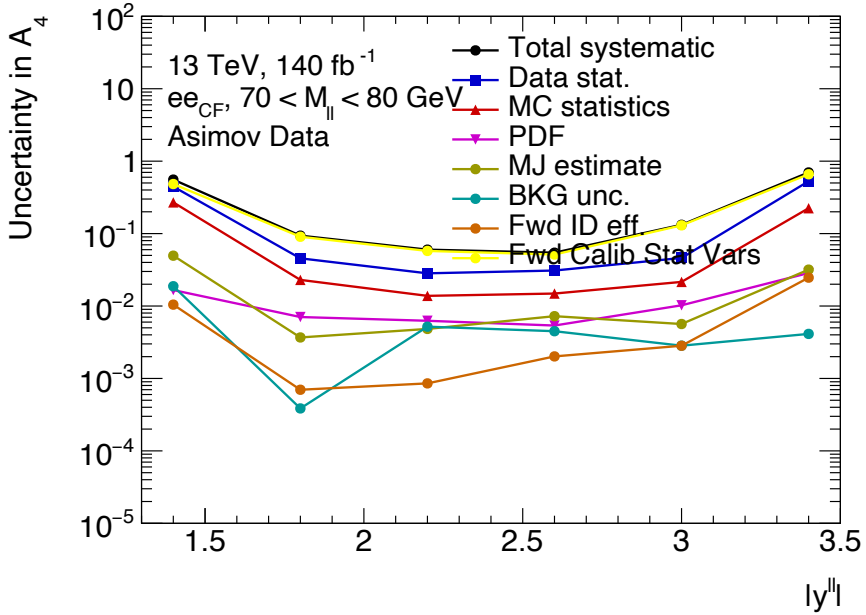
- Trigger SFs
  - *Trigger SF changed to TightID + noIso*
  - *Not properly implemented at ntuple level for CF events yet. Variables are in the output trees but the values aren't properly filled.*
  - *Currently estimating systematic effect with two NPs, one correlated and one uncorrelated.*
  - *Values estimated using CC medium + noIso trigger systematics.*
- Charge ID SFs were previously being applied.
  - *Now turned off since they make no sense for the CF channel.*
- All systematics mentioned can be submitted and templates folded. HOWEVER not all systematics are added into the workspace/used.
  - *Central ID SFs and calibration range scans are bugged currently so not in WS.*
  - *The fit discards all other central electron variations, calibration model and non-fake factor stat variation NPs since their effect on the result is very small.*

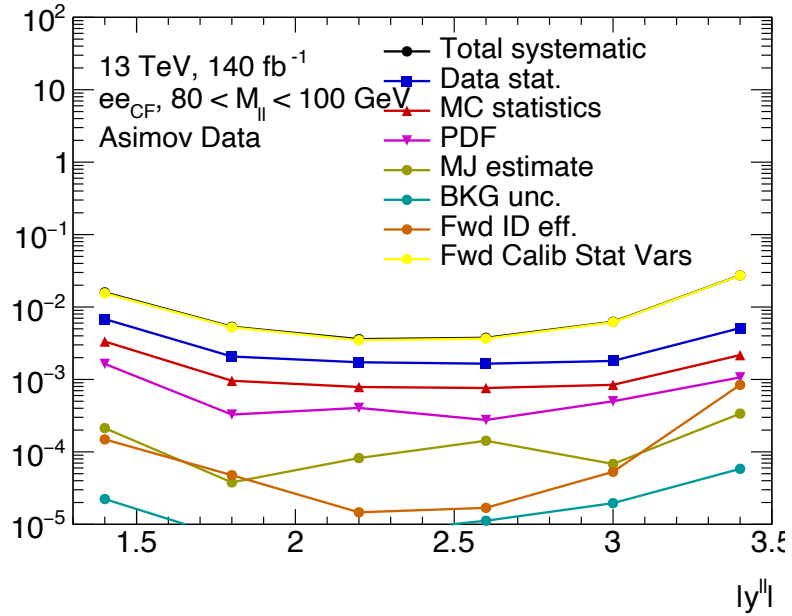
CF vs YII – A_4

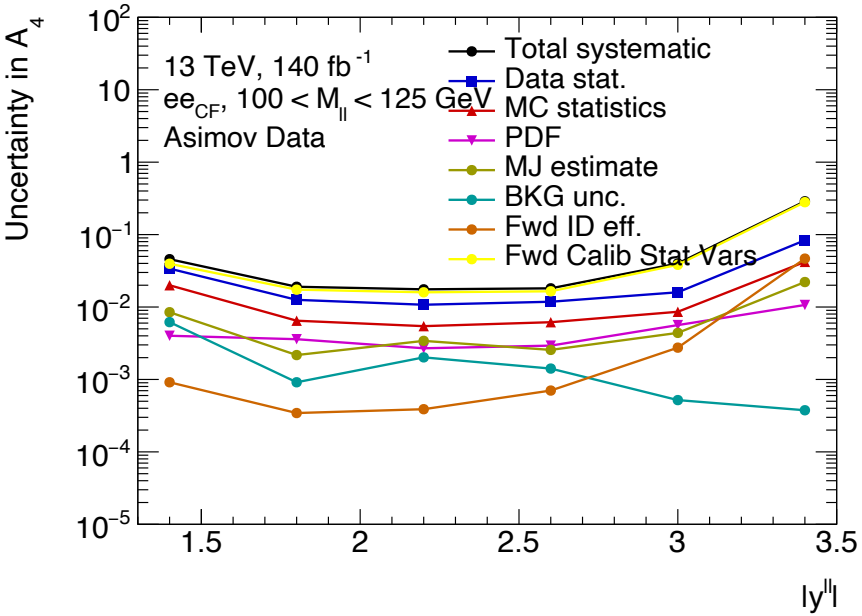

A4
13 TeV, 140 fb-1
eeCF, 70 < Mll < 80 GeV
Asimov Data


13 TeV, 140 fb-1
eeCF, 80 < Mll < 100 GeV
Asimov Data

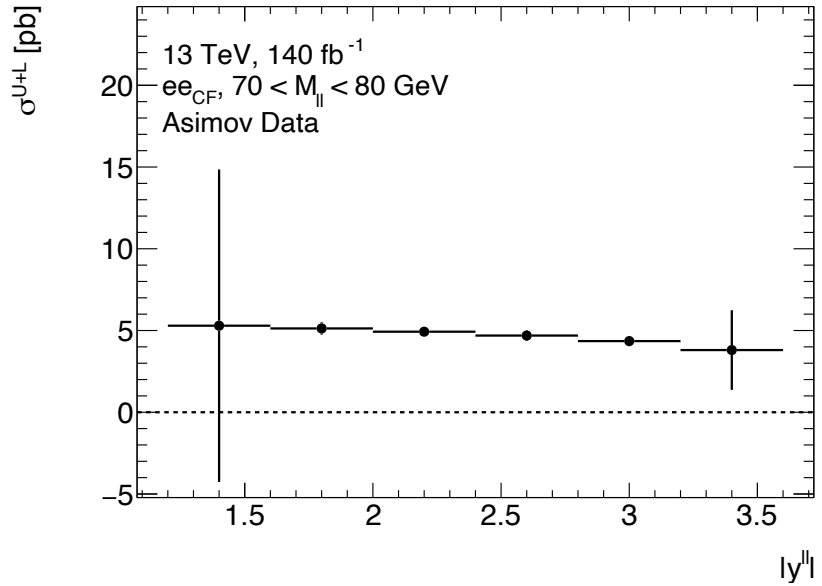

A4
13 TeV, 140 fb-1
eeCF, 100 < Mll < 125 GeV
Asimov Data

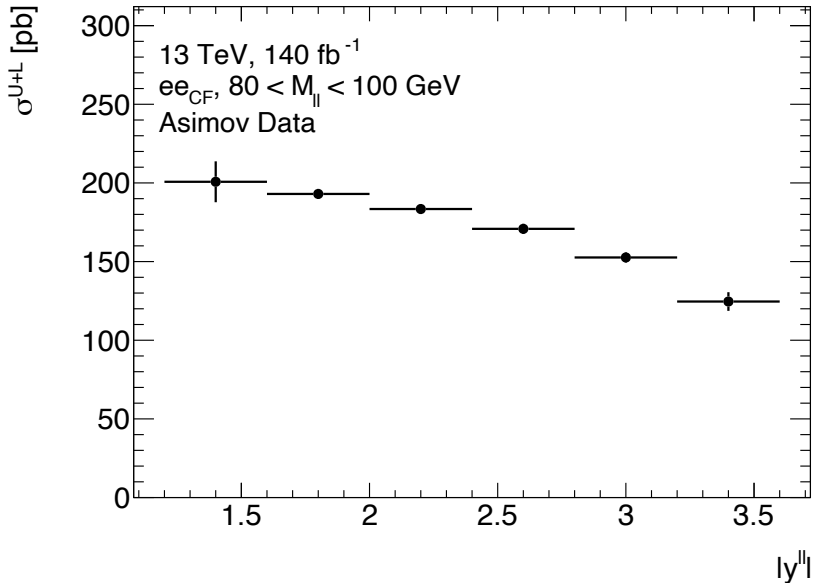

Uncertainty in A4
13 TeV, 140 fb-1
eeCF, 70 < Mll < 80 GeV
Asimov Data
Total systematic
Data stat.
MC statistics
PDF
MJ estimate
BKG unc.
Fwd ID eff.
Fwd Calib Stat Vars
|yll|

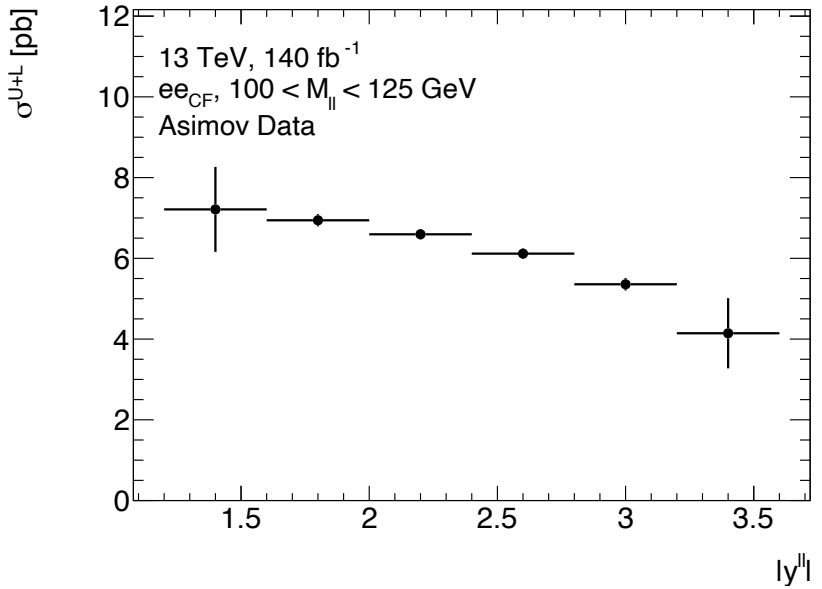

13 TeV, 140 fb-1
eeCF, 80 < Mll < 100 GeV
Asimov Data
Total systematic
Data stat.
MC statistics
PDF
MJ estimate
BKG unc.
Fwd ID eff.
Fwd Calib Stat Vars
|yll|

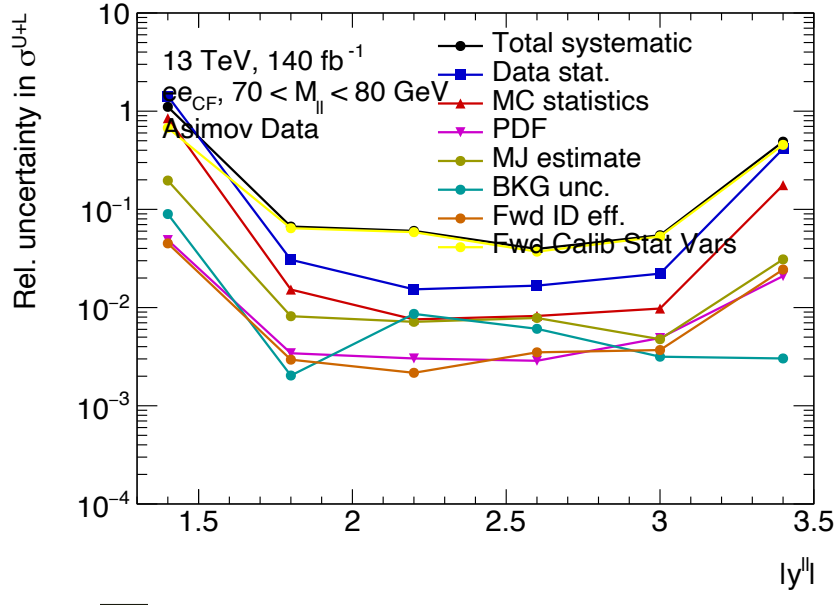

Uncertainty in A4
13 TeV, 140 fb-1
eeCF, 100 < Mll < 125 GeV
Asimov Data
Total systematic
Data stat.
MC statistics
PDF
MJ estimate
BKG unc.
Fwd ID eff.
Fwd Calib Stat Vars
|yll|

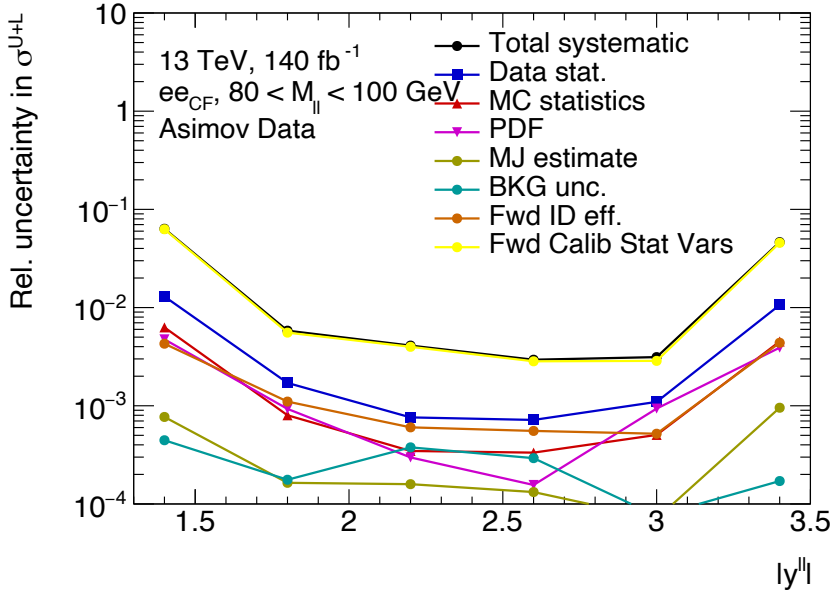
CF vs YII – A_9

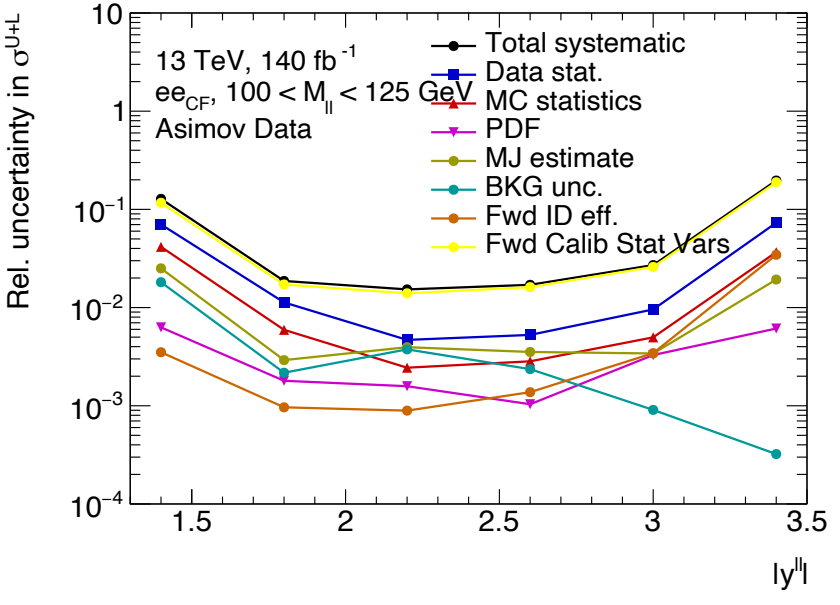

13 TeV, 140 fb^{-1}
ee$_{CF}$, 70 < M$_{ll}$ < 80 GeV
Asimov Data
σ^{U+L} [pb]
|y^{ll}|


13 TeV, 140 fb^{-1}
ee$_{CF}$, 80 < M$_{ll}$ < 100 GeV
Asimov Data
σ^{U+L} [pb]
|y^{ll}|

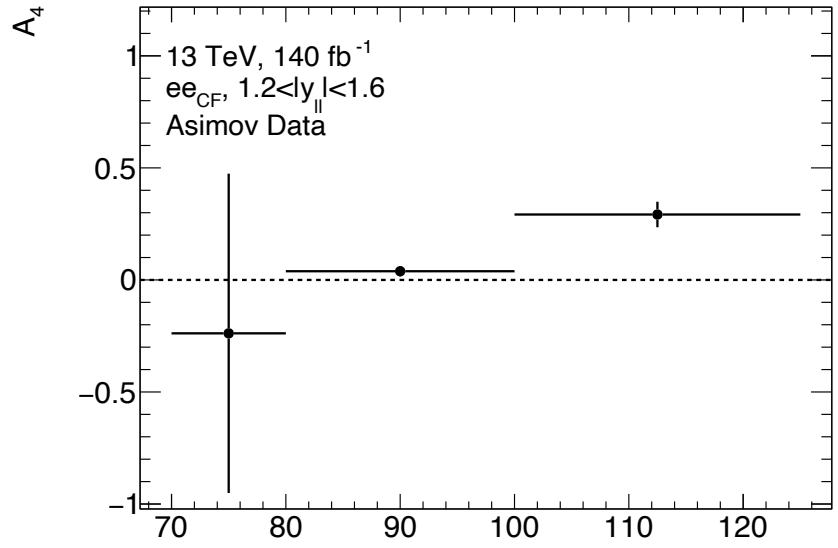

13 TeV, 140 fb^{-1}
ee$_{CF}$, 100 < M$_{ll}$ < 125 GeV
Asimov Data
σ^{U+L} [pb]
|y^{ll}|

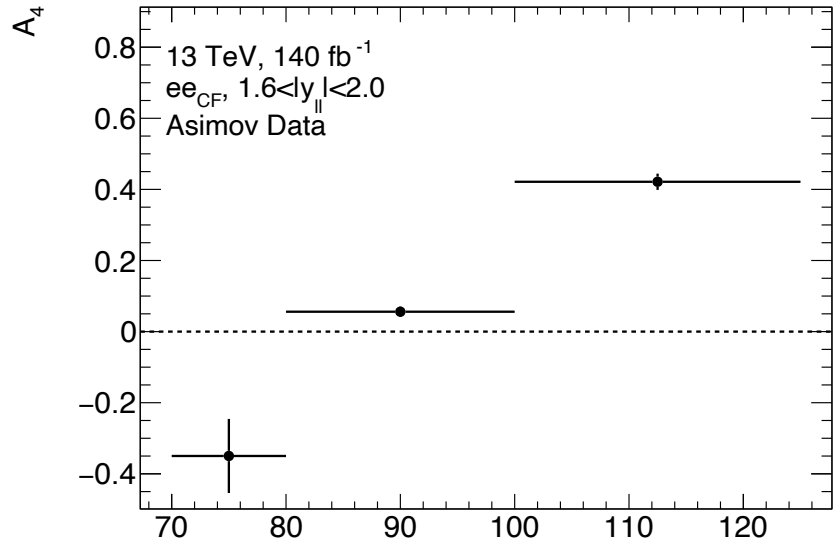

13 TeV, 140 fb^{-1}
ee$_{CF}$, 70 < M$_{ll}$ < 80 GeV
Asimov Data
Total systematic
Data stat.
MC statistics
PDF
MJ estimate
BKG unc.
Fwd ID eff.
Fwd Calib Stat Vars
Rel. uncertainty in σ^{U+L}
|y^{ll}|

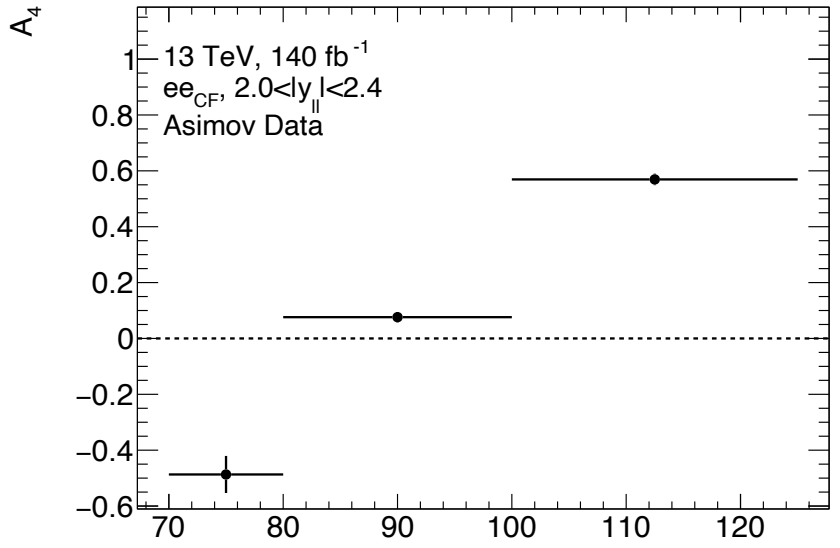

13 TeV, 140 fb^{-1}
ee$_{CF}$, 80 < M$_{ll}$ < 100 GeV
Asimov Data
Total systematic
Data stat.
MC statistics
PDF
MJ estimate
BKG unc.
Fwd ID eff.
Fwd Calib Stat Vars
Rel. uncertainty in σ^{U+L}
|y^{ll}|

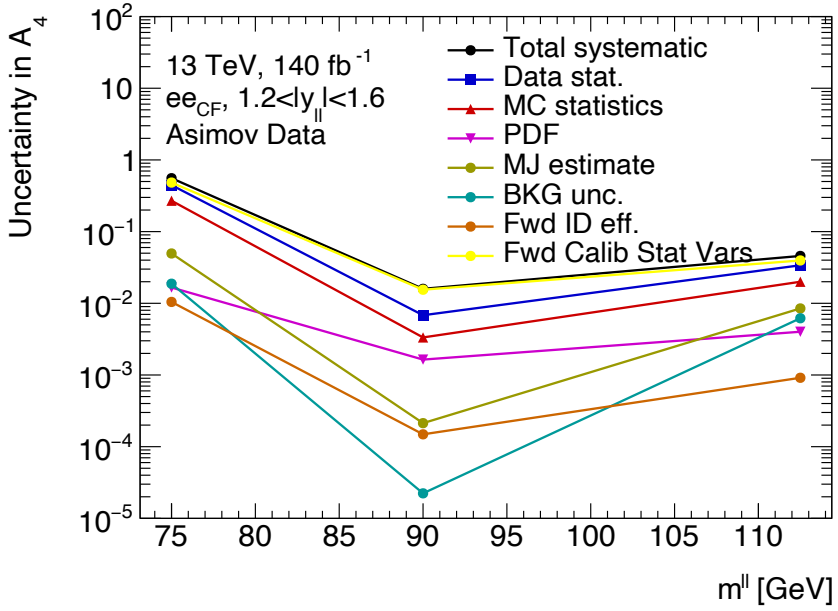

13 TeV, 140 fb^{-1}
ee$_{CF}$, 100 < M$_{ll}$ < 125 GeV
Asimov Data
Total systematic
Data stat.
MC statistics
PDF
MJ estimate
BKG unc.
Fwd ID eff.
Fwd Calib Stat Vars
Rel. uncertainty in σ^{U+L}
|y^{ll}|

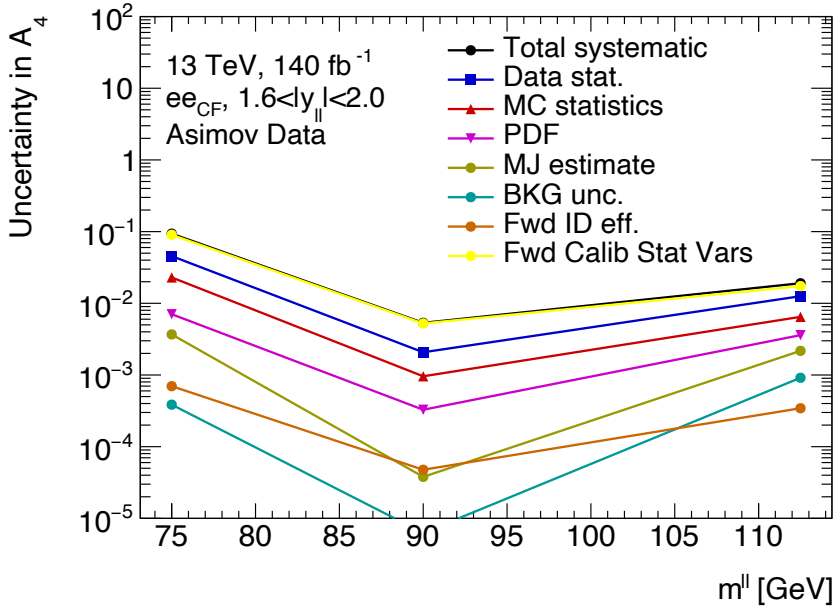
CF vs MII – A_4

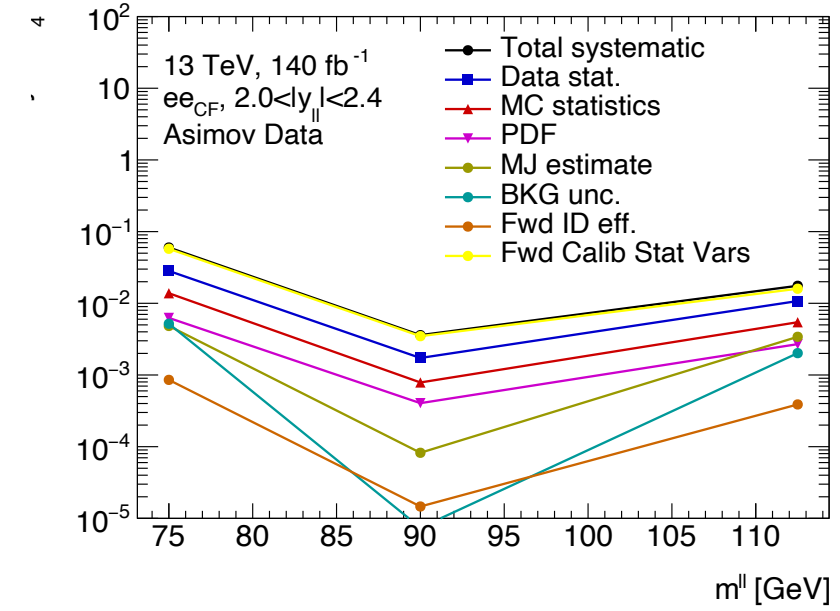

A4
13 TeV, 140 fb-1
eeCF, 1.2<|yll|<1.6
Asimov Data


A4
13 TeV, 140 fb-1
eeCF, 1.6<|yll|<2.0
Asimov Data

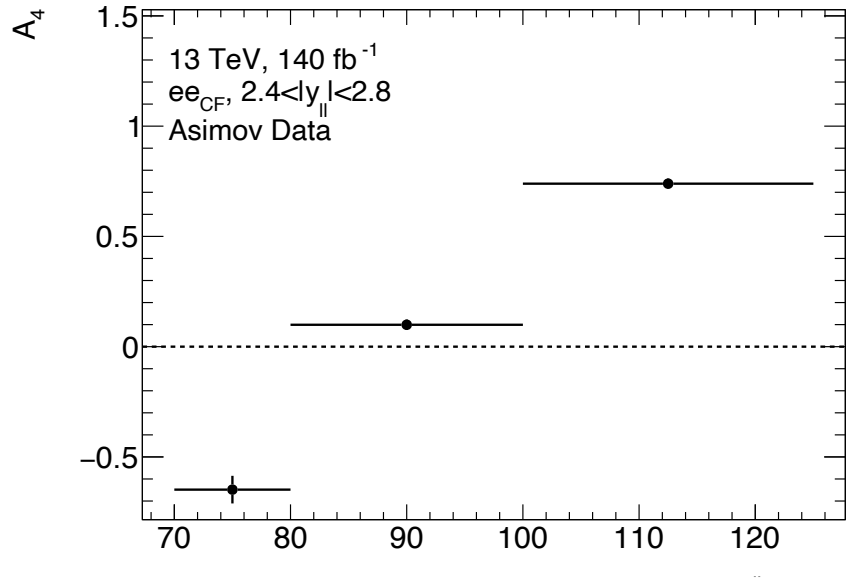

A4
13 TeV, 140 fb-1
eeCF, 2.0<|yll|<2.4
Asimov Data

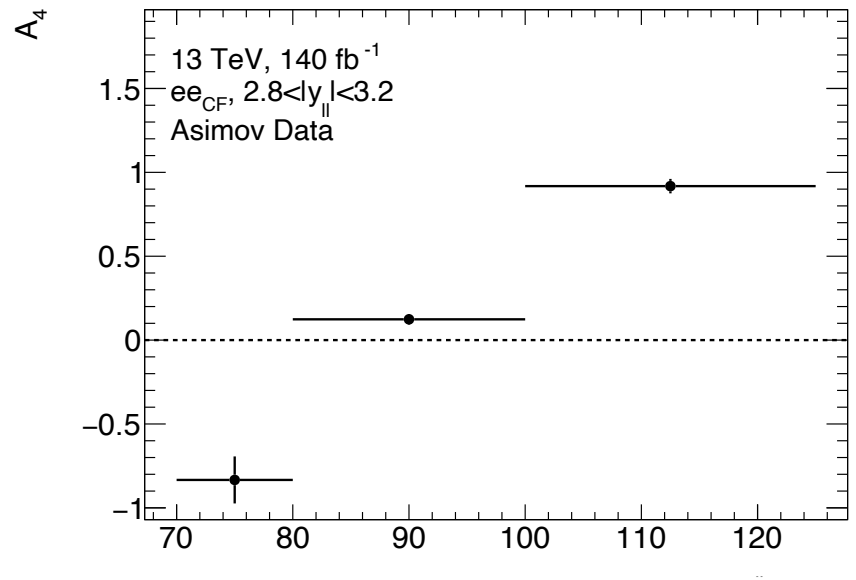

Uncertainty in A4
13 TeV, 140 fb-1
eeCF, 1.2<|yll|<1.6
Asimov Data
Total systematic
Data stat.
MC statistics
PDF
MJ estimate
BKG unc.
Fwd ID eff.
Fwd Calib Stat Vars
mll [GeV]

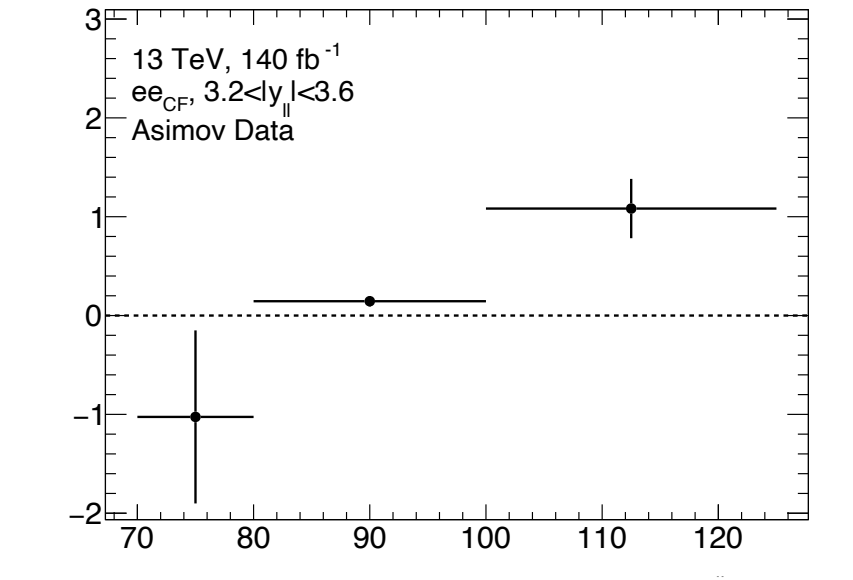

Uncertainty in A4
13 TeV, 140 fb-1
eeCF, 1.6<|yll|<2.0
Asimov Data
Total systematic
Data stat.
MC statistics
PDF
MJ estimate
BKG unc.
Fwd ID eff.
Fwd Calib Stat Vars
mll [GeV]

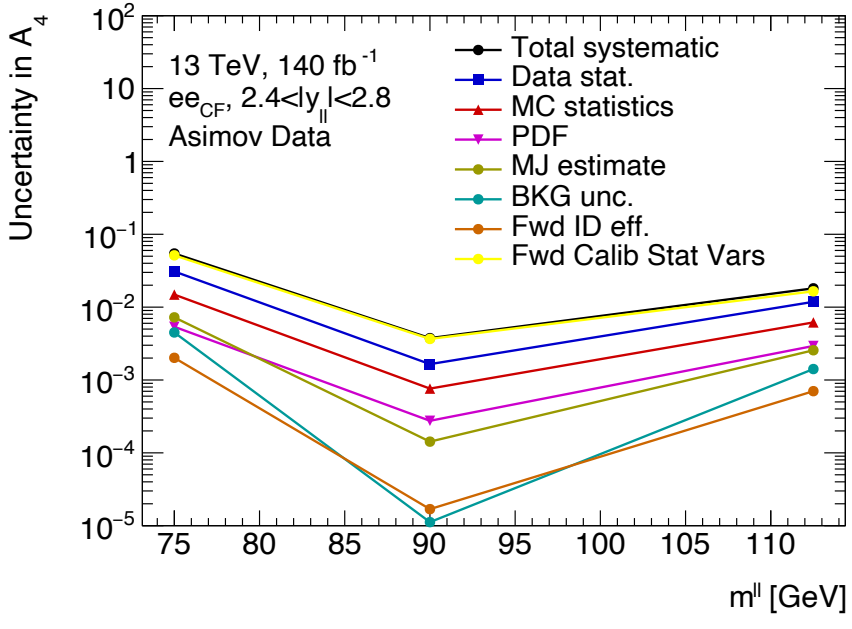

13 TeV, 140 fb-1
eeCF, 2.0<|yll|<2.4
Asimov Data
Total systematic
Data stat.
MC statistics
PDF
MJ estimate
BKG unc.
Fwd ID eff.
Fwd Calib Stat Vars
mll [GeV]

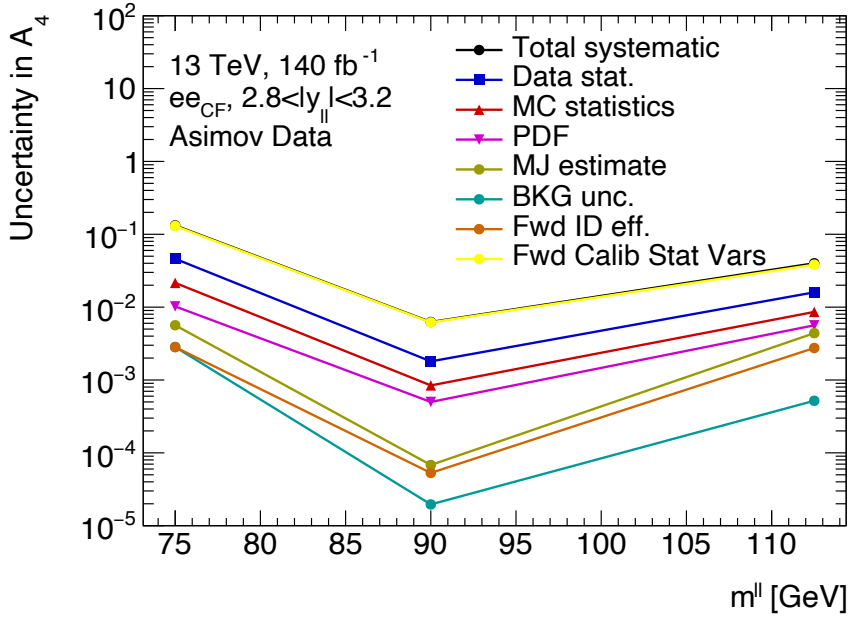
CF vs MII – A_4

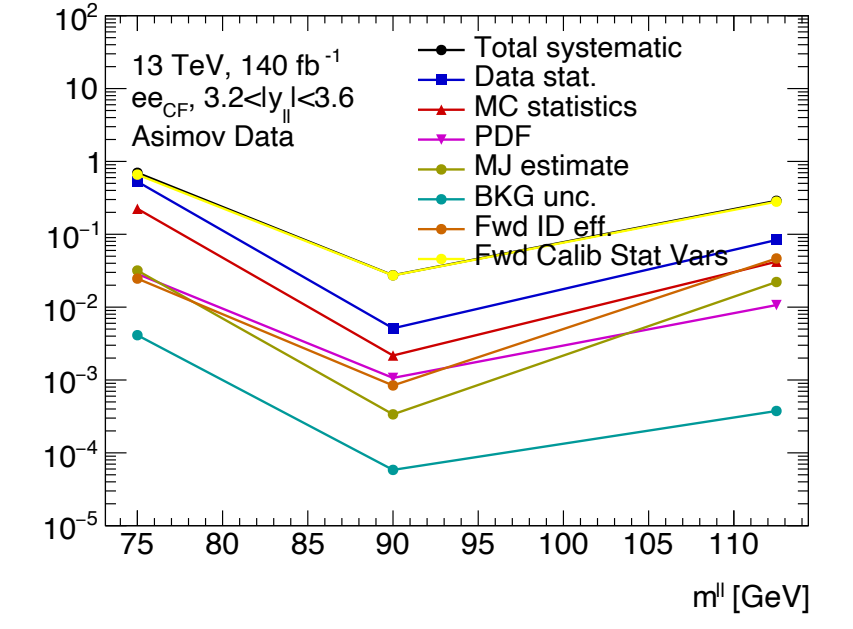

A4
13 TeV, 140 fb-1
eeCF, 2.4<|yll|<2.8
Asimov Data


A4
13 TeV, 140 fb-1
eeCF, 2.8<|yll|<3.2
Asimov Data

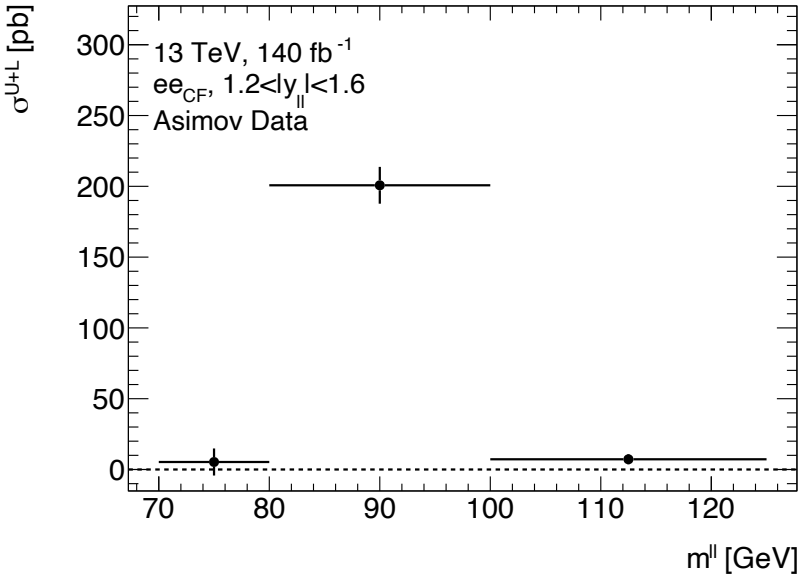

13 TeV, 140 fb-1
eeCF, 3.2<|yll|<3.6
Asimov Data

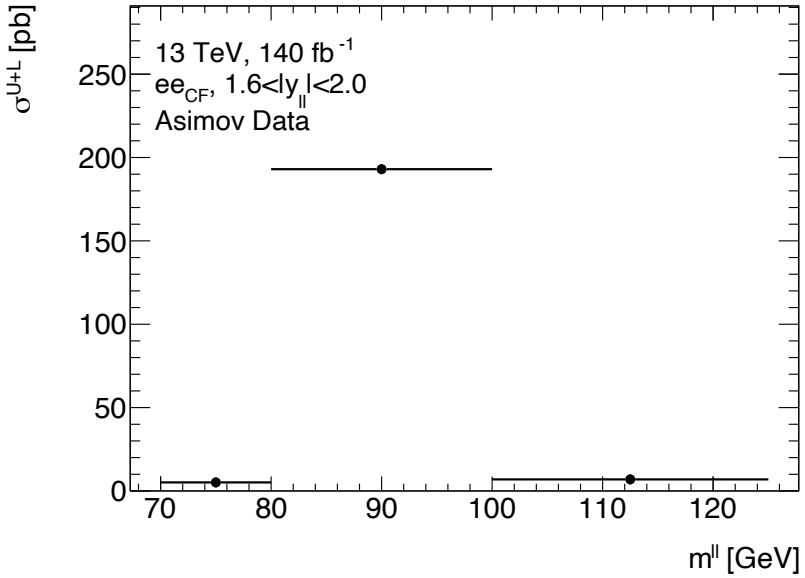

Uncertainty in A4
13 TeV, 140 fb-1
eeCF, 2.4<|yll|<2.8
Asimov Data
Total systematic
Data stat.
MC statistics
PDF
MJ estimate
BKG unc.
Fwd ID eff.
Fwd Calib Stat Vars
mll [GeV]

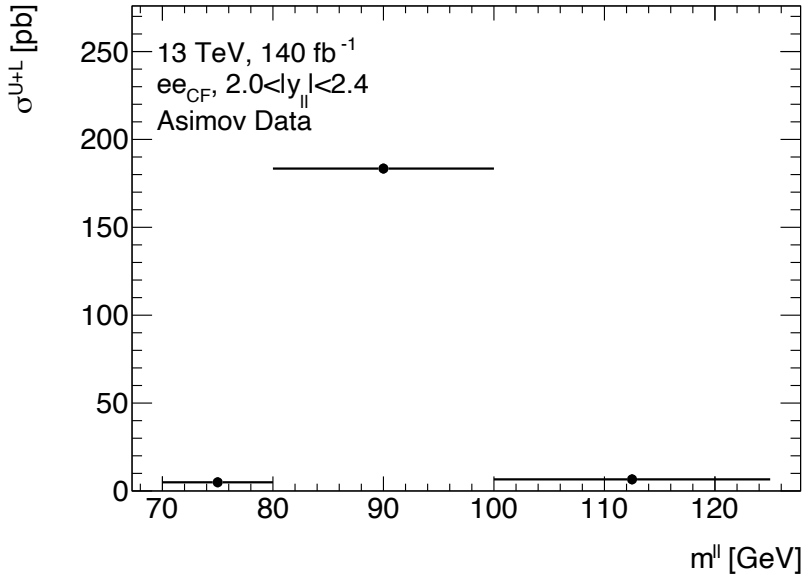

Uncertainty in A4
13 TeV, 140 fb-1
eeCF, 2.8<|yll|<3.2
Asimov Data
Total systematic
Data stat.
MC statistics
PDF
MJ estimate
BKG unc.
Fwd ID eff.
Fwd Calib Stat Vars
mll [GeV]

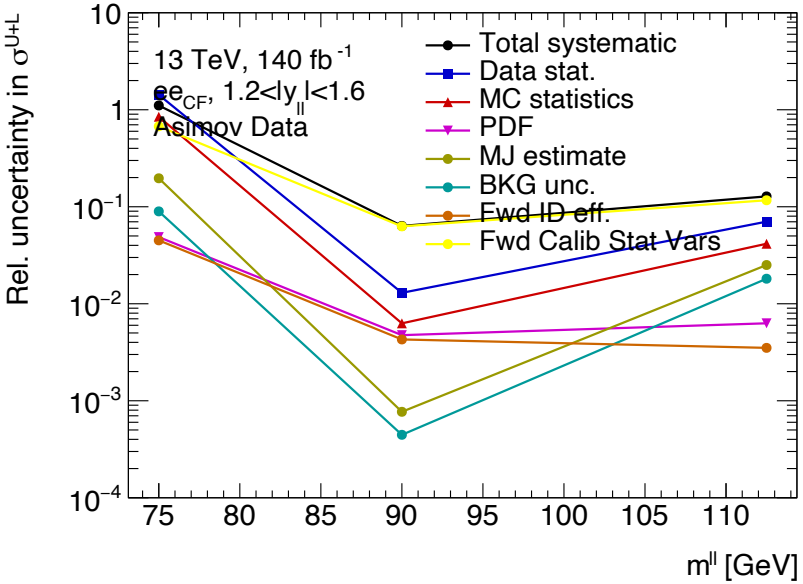

13 TeV, 140 fb-1
eeCF, 3.2<|yll|<3.6
Asimov Data
Total systematic
Data stat.
MC statistics
PDF
MJ estimate
BKG unc.
Fwd ID eff.
Fwd Calib Stat Vars
mll [GeV]

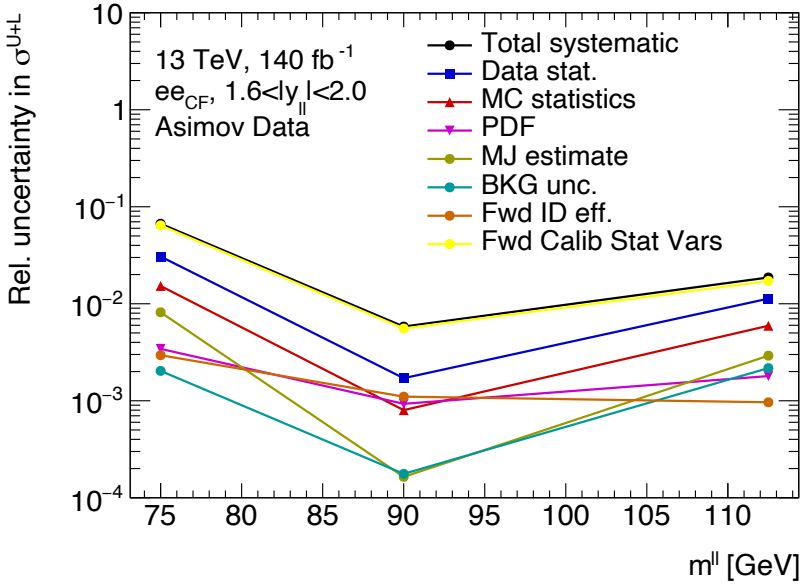
CF vs MII – A_9


13 TeV, 140 fb^{-1}
ee$_{CF}$, 1.2<|y$_{ll}$|<1.6
Asimov Data
σ^{U+L} [pb]
m^{ll} [GeV]


13 TeV, 140 fb^{-1}
ee$_{CF}$, 1.6<|y$_{ll}$|<2.0
Asimov Data
σ^{U+L} [pb]
m^{ll} [GeV]


13 TeV, 140 fb^{-1}
ee$_{CF}$, 2.0<|y$_{ll}$|<2.4
Asimov Data
σ^{U+L} [pb]
m^{ll} [GeV]


13 TeV, 140 fb^{-1}
ee$_{CF}$, 1.2<|y$_{ll}$|<1.6
Asimov Data
Total systematic
Data stat.
MC statistics
PDF
MJ estimate
BKG unc.
Fwd ID eff.
Fwd Calib Stat Vars
Rel. uncertainty in σ^{U+L}
m^{ll} [GeV]


13 TeV, 140 fb^{-1}
ee$_{CF}$, 1.6<|y$_{ll}$|<2.0
Asimov Data
Total systematic
Data stat.
MC statistics
PDF
MJ estimate
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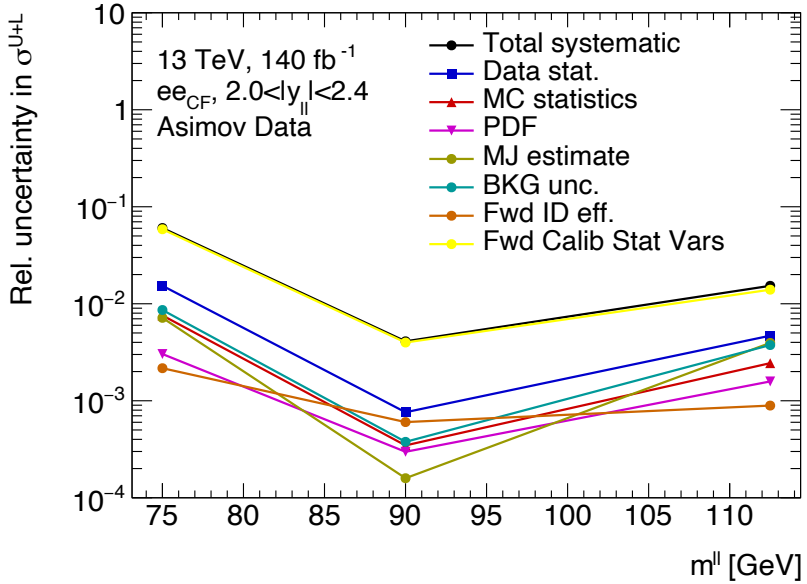
m^{ll} [GeV]


13 TeV, 140 fb^{-1}
ee$_{CF}$, 2.0<|y$_{ll}$|<2.4
Asimov Data
Total systematic
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Fwd Calib Stat Vars
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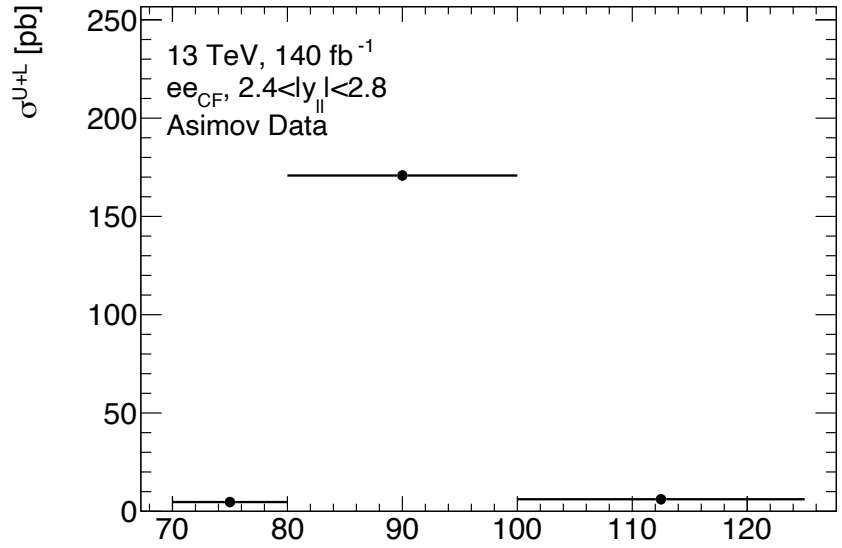
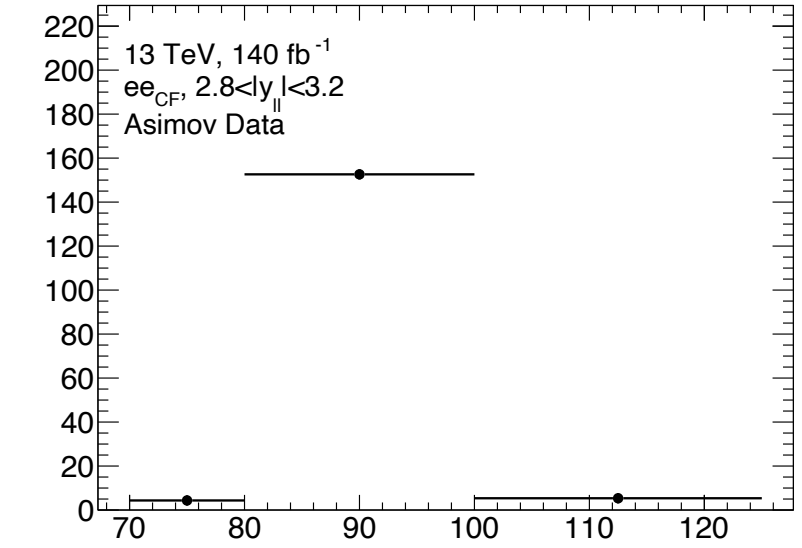
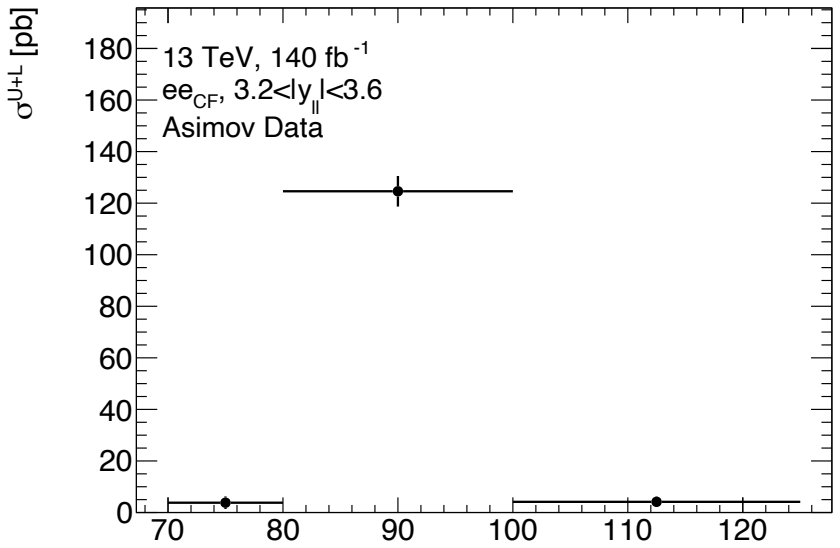
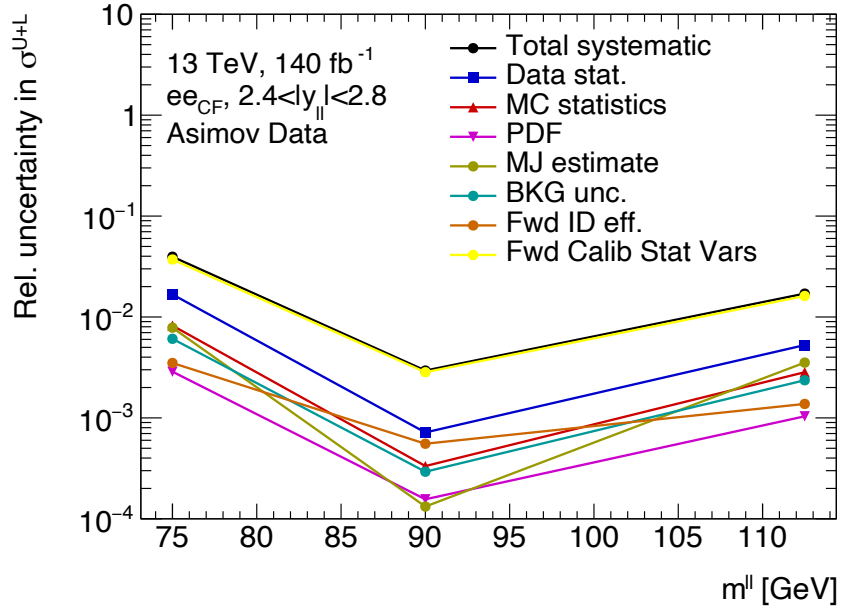
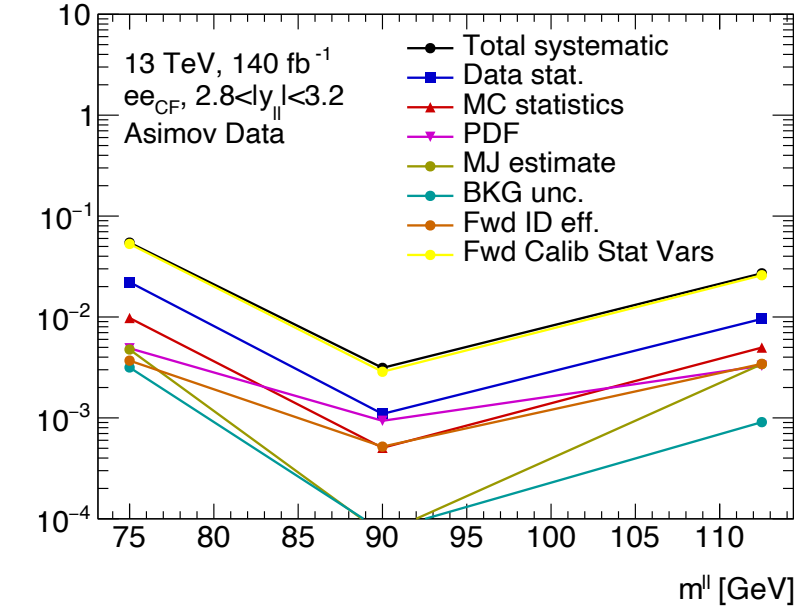
CF vs MII – A_9

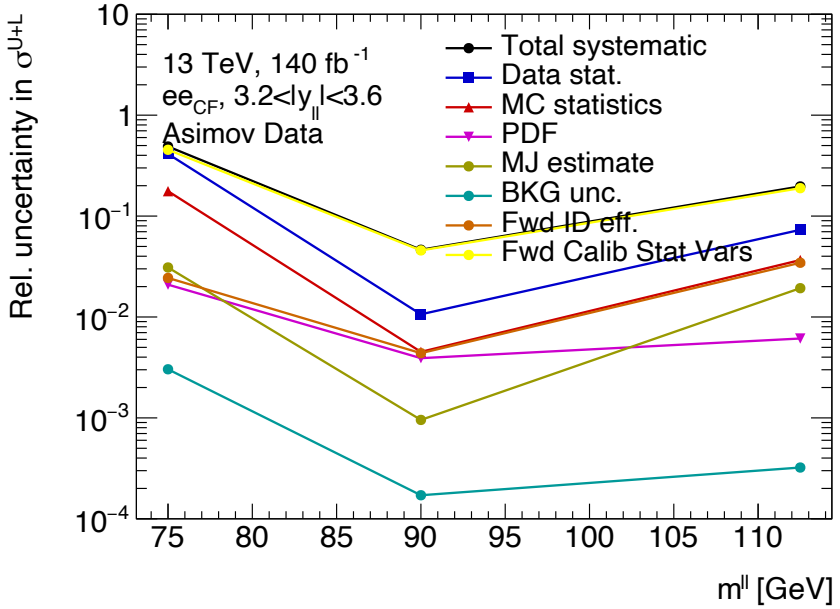

13 TeV, 140 fb^{-1}
ee$_{CF}$, 2.4<|y$_{ll}$|<2.8
Asimov Data
σ^{U+L} [pb]


13 TeV, 140 fb^{-1}
ee$_{CF}$, 2.8<|y$_{ll}$|<3.2
Asimov Data


13 TeV, 140 fb^{-1}
ee$_{CF}$, 3.2<|y$_{ll}$|<3.6
Asimov Data
σ^{U+L} [pb]


13 TeV, 140 fb^{-1}
ee$_{CF}$, 2.4<|y$_{ll}$|<2.8
Asimov Data
Total systematic
Data stat.
MC statistics
PDF
MJ estimate
BKG unc.
Fwd ID eff.
Fwd Calib Stat Vars
Rel. uncertainty in σ^{U+L}
m^{ll} [GeV]


13 TeV, 140 fb^{-1}
ee$_{CF}$, 2.8<|y$_{ll}$|<3.2
Asimov Data
Total systematic
Data stat.
MC statistics
PDF
MJ estimate
BKG unc.
Fwd ID eff.
Fwd Calib Stat Vars
m^{ll} [GeV]


13 TeV, 140 fb^{-1}
ee$_{CF}$, 3.2<|y$_{ll}$|<3.6
Asimov Data
Total systematic
Data stat.
MC statistics
PDF
MJ estimate
BKG unc.
Fwd ID eff.
Fwd Calib Stat Vars
Rel. uncertainty in σ^{U+L}
m^{ll} [GeV]

CF WMA - Observations

- On pole, we reach a total systematic uncertainty of 1% in A_9!
  - *I'm sure we can do better though* 😉

- Forward electron calibration is by far the leading systematic.
  - *Effect of variations to the fit m_{ll} range still to be evaluated.*
  - *Sensitivity at high y_{ll} could be improved by merging FCal bins in the calibration.*
  - *Effect of parameter variations can most likely be improved (e.g changing allowed fit ranges and/or fixing parameters with large uncertainties). Personally I'd look at fixing n_high/low and allowing alpha to float.*

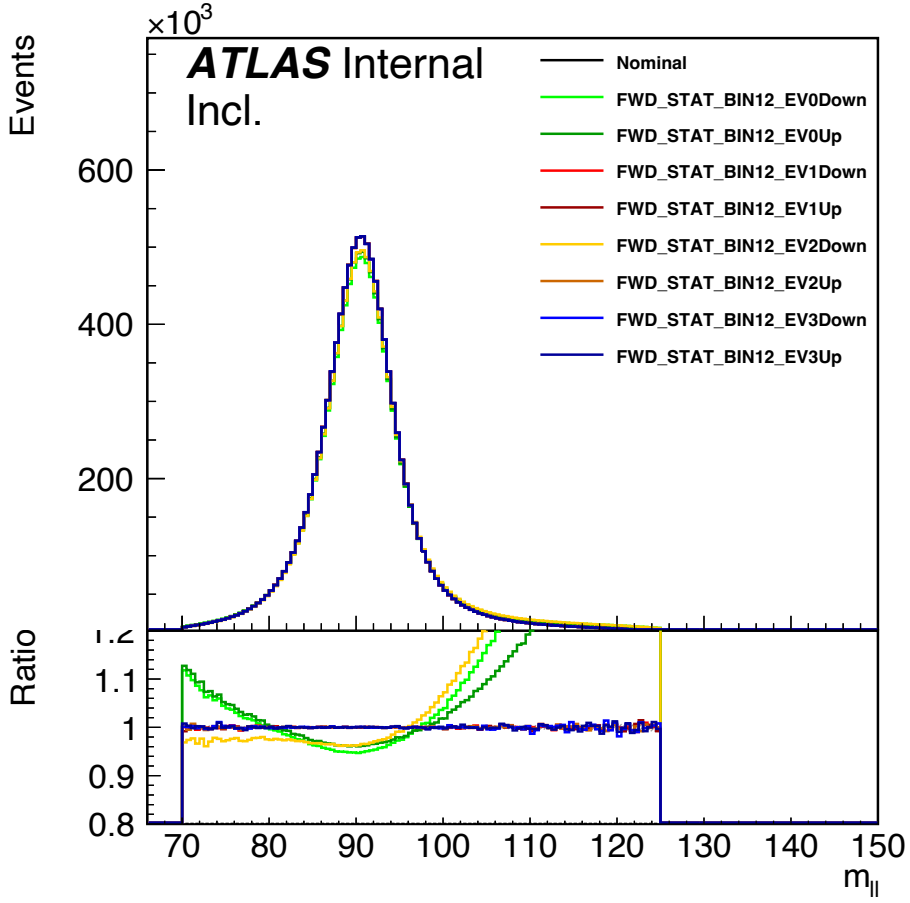
- MJ may be possible to reduce further.
  - *Use fake factors for full run 2 rather than individual years. Unlikely to yield large improvements since CF MJ >> CC MJ.*
  - *Fix issues with FF stat variations to bring it down to level of other variations. The fit will then most likely consider these variations as well.*

- These fits don't currently use the latest forward ID SFs. The newest version might improve this.

- Very low sensitivity in the $1.2 < |y_{ll}| < 1.6$ bin (10 – 100% uncertainty in A_9).
  - *This region is well covered by eeCC and MM. Could possibly be removed.*

CF – Calibration Variations

- Plot shows the impact of individual NPs on entire signal distribution.
- FWD_STAT_BIN12_EV0Down
  - *Downwards variation of eigenvector corresponding to parameter 0 from calibration bin 12 (-2.6 < η < -2.5)*
  - *Preserves correlations between parameters, rather than just varying one parameter at a time.*
- Most NPs have very small effect.
  - *To be expected when considering effects of one parameter from one calibration bin on inclusive signal distribution.*
- EV0 = μ, would expect changes here to crop up in tails but to have opposite directions from up/down.
- EV2 = alpha low. Correlations with alpha high cause ratio to nominal to shoot up?
- EV3 = alpha high, which is crazy in this bin in 2018 but not 2017, however it's stable w.rt. nominal.
- Looking at plots normalised to one shows this is not a problem with scans.



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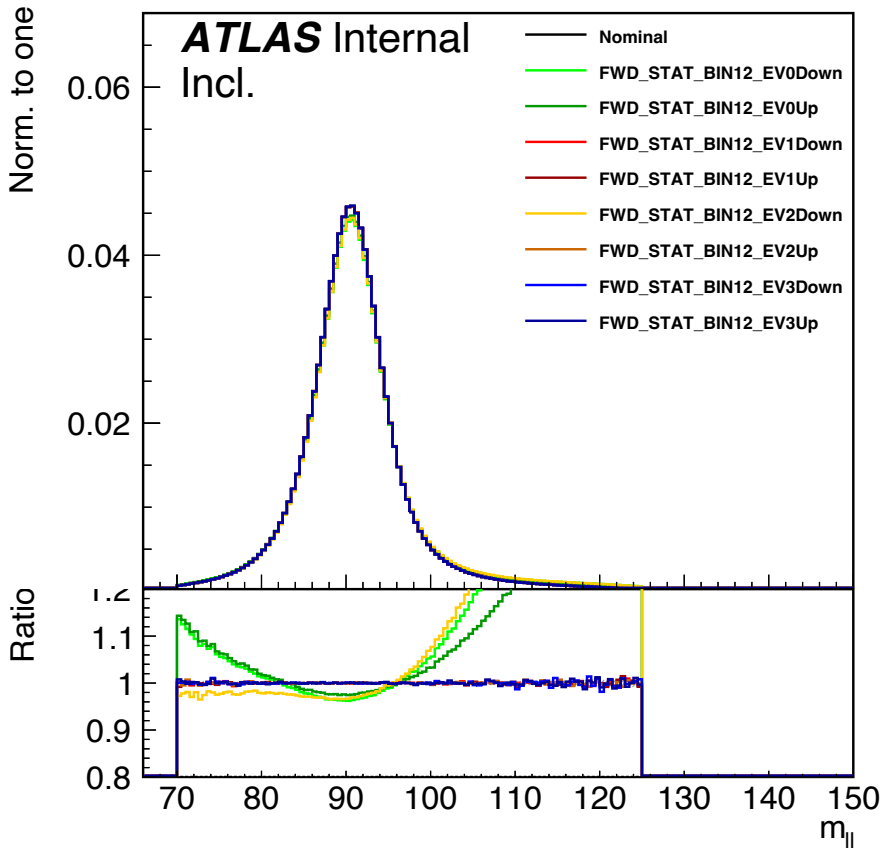
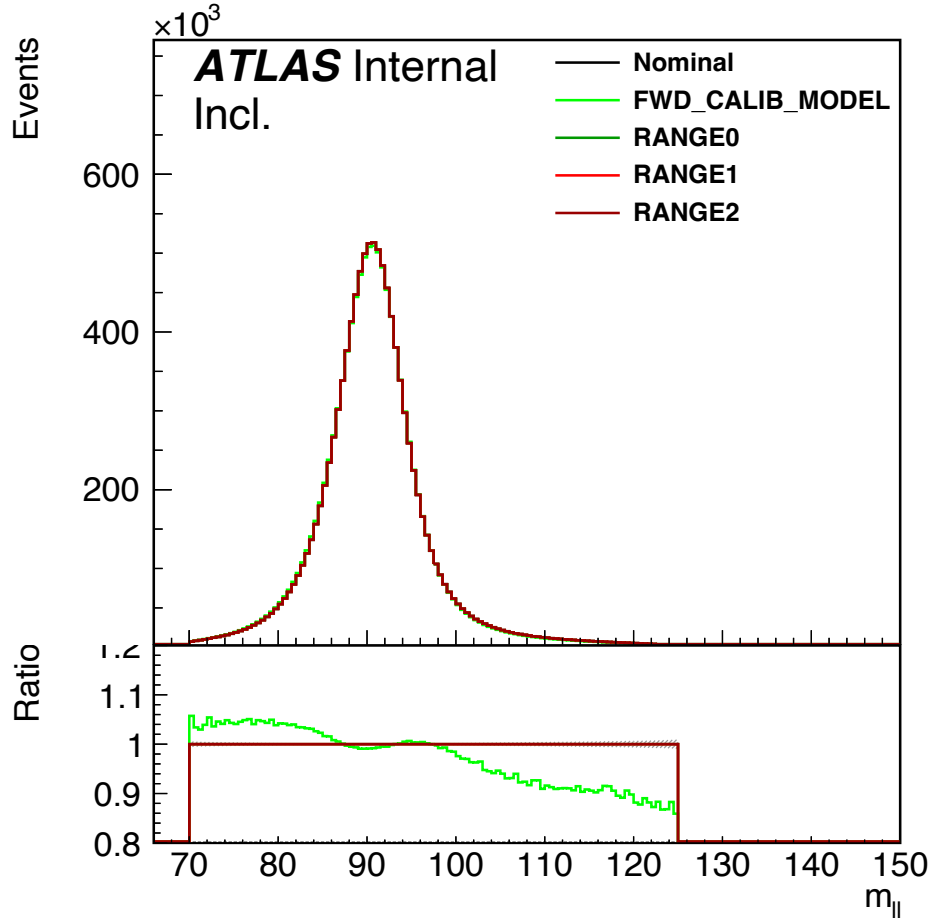


Plot normalised to one to compare shape differences.

CF – Calibration Variations

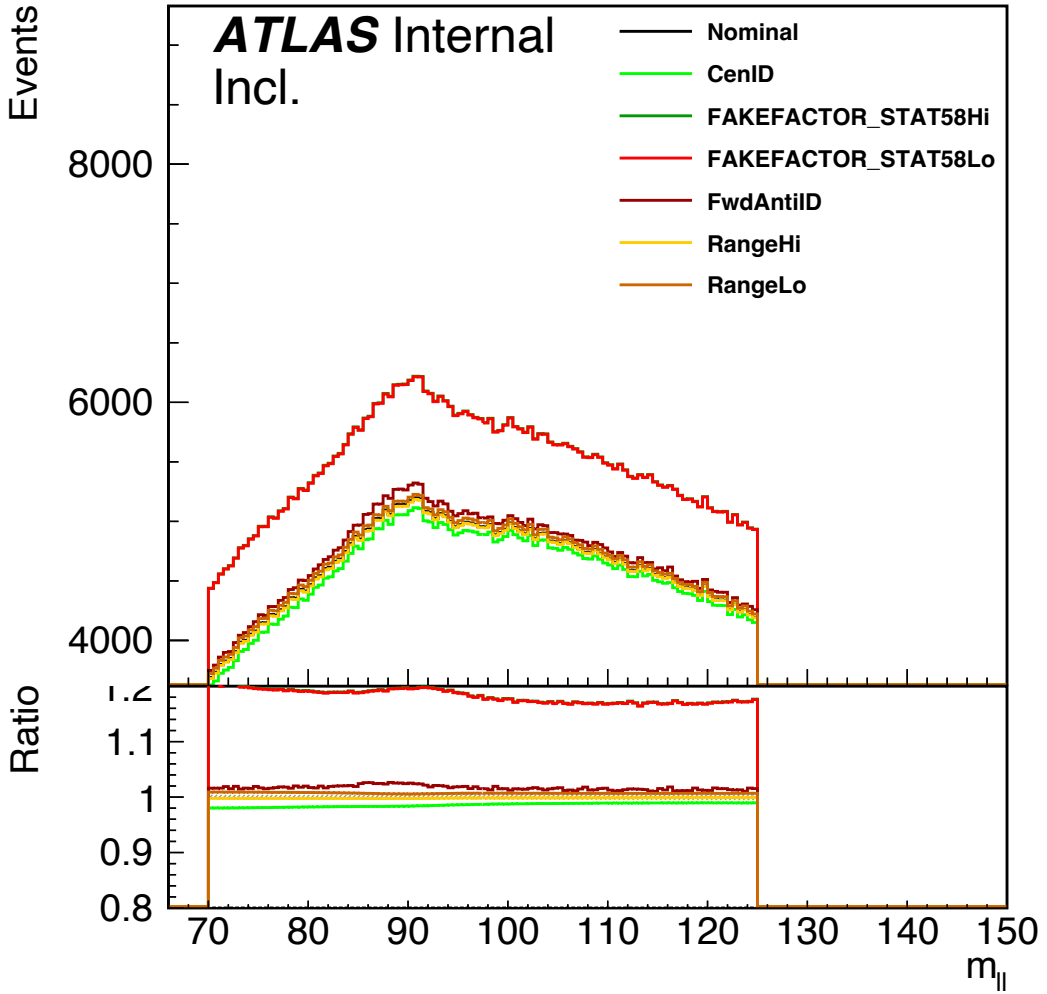
- Calibration range exactly the same as nominal.
  - *Need to check whether this is a problem with making the variations or in applying them.*

- Calibration model variation shows +5%/-10% differences in the low/high tails.
  - *Tails are where we should expect the most difference between CB/DSCB.*
  - *Unsure whether CB model was fitted using DSCB based MJ or with CB which has larger impact in the tails.*



CF – MJ Variations

- Comparing the MJ systematic variations to the nominal show ~+/- 2% difference.
  - *Reasonable!*
- Fake factor stat variations (both up and down!) are somehow 20% greater than the nominal.
  - *Down variation should be less than nominal.*
  - *Explains why only FF stat variations are considered by the fit for MJ.*
- Unclear what is causing this at the moment.
  - *First place to check is FakeEstimator.cxx*
  - *If all fine there, check that stat variations are saved properly.*



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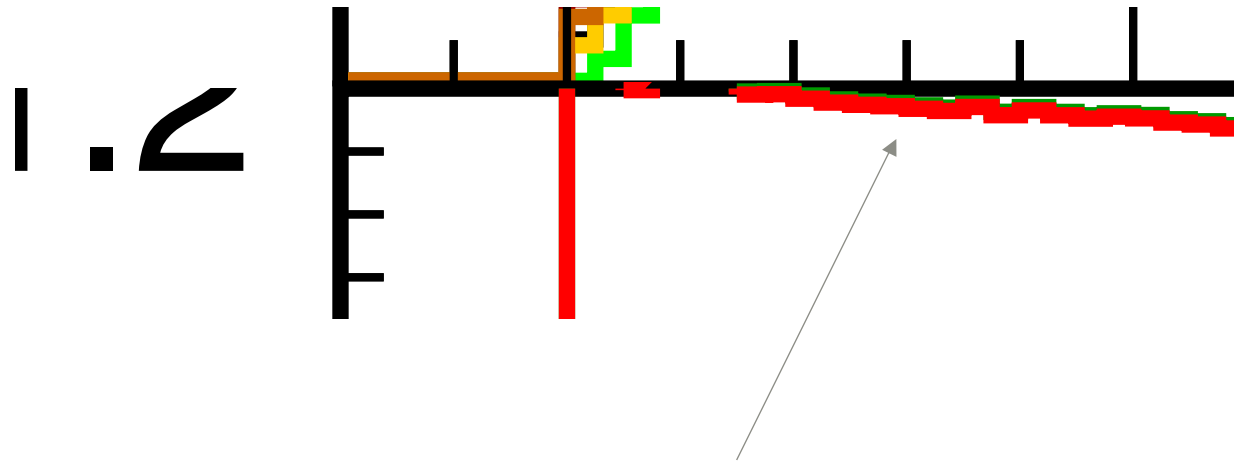
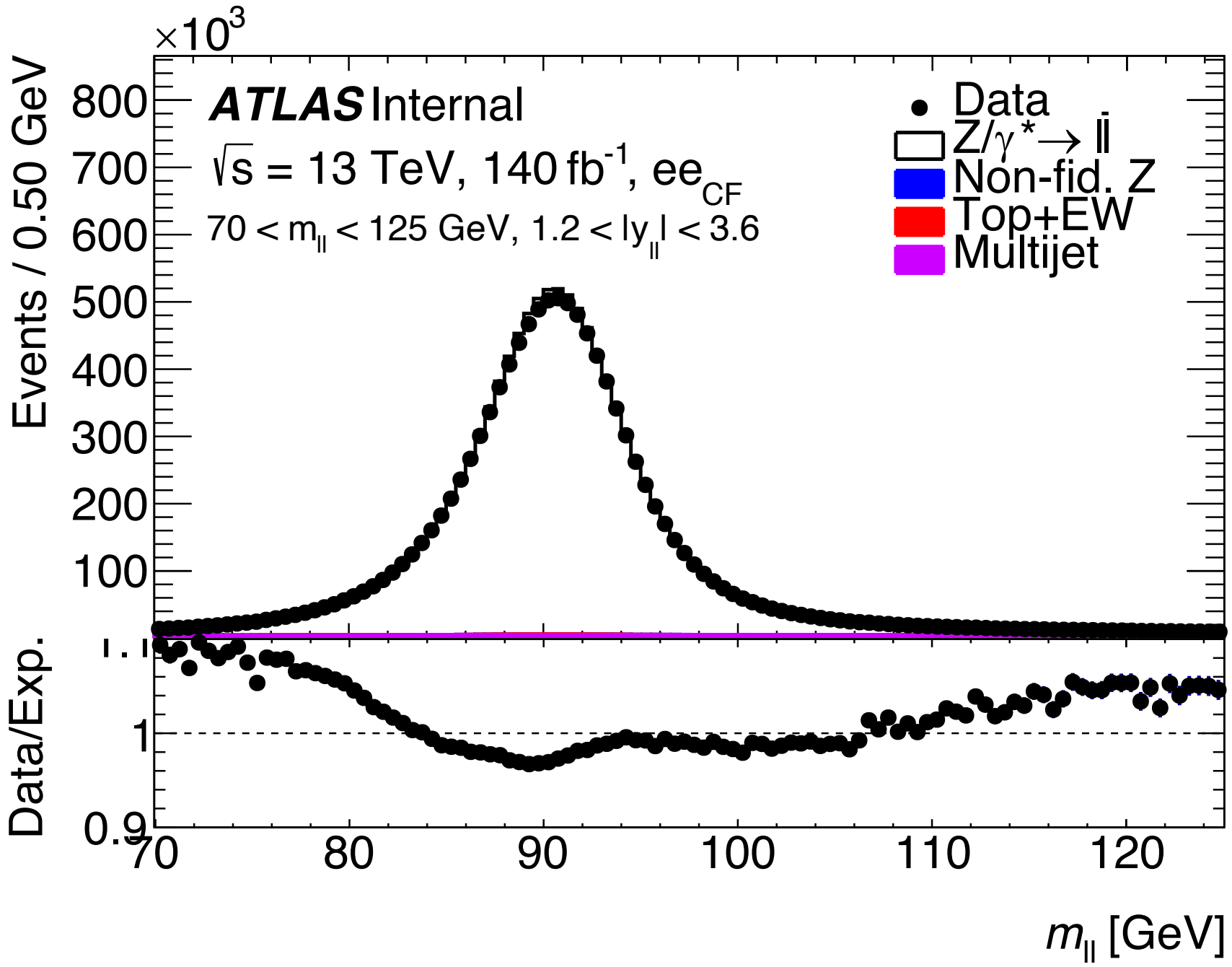


Same ratio plot at 1.2. Up variation is green, down is red.



Not a bad Z→ee mass spectrum to end on after working on this for almost four years!

Open Points

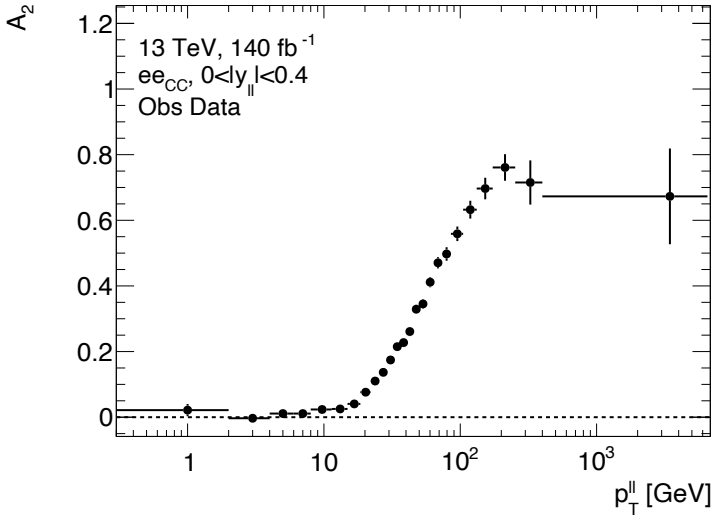
- CC/MM/CB Lam-Tung fits do not currently work for obs data.
- CC WMA reco efficiency uncertainty has a small number of NPs that need to be rerun.
- CF trigger systematics are not correctly saved in ntuples (low priority).
- CF calibration to be redone:
  - Merge FCal bins (either 4.0 – 4.9 or 4.0 – 4.3 – 4.9).
  - Revisit fit strategy
    - *Allowed parameter ranges.*
    - *Fixing some parameters that have high uncertainties to a sensible value (also reduces no. of NPs).*
- CF calibration range variations to be rerun (highly unlikely they're exactly the same as nominal!)
  - *Check files make sense*
  - *Check application/submission*
- CF MJ statistical variation scans are ~20% greater than nominal. Other variations look fine.

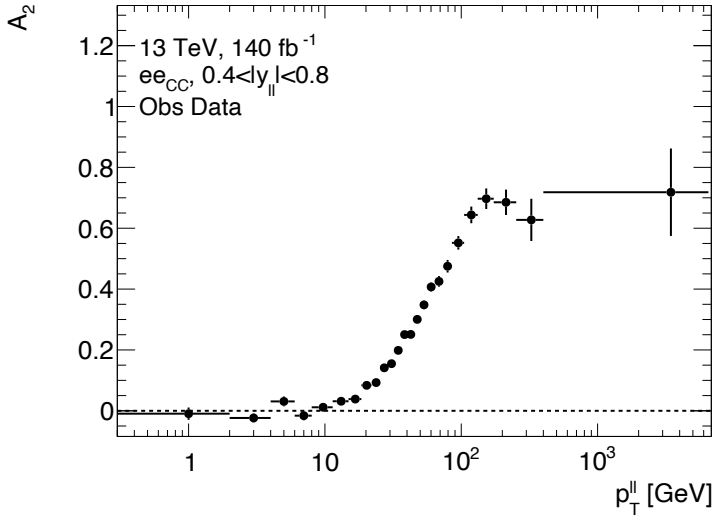
My plans going forward

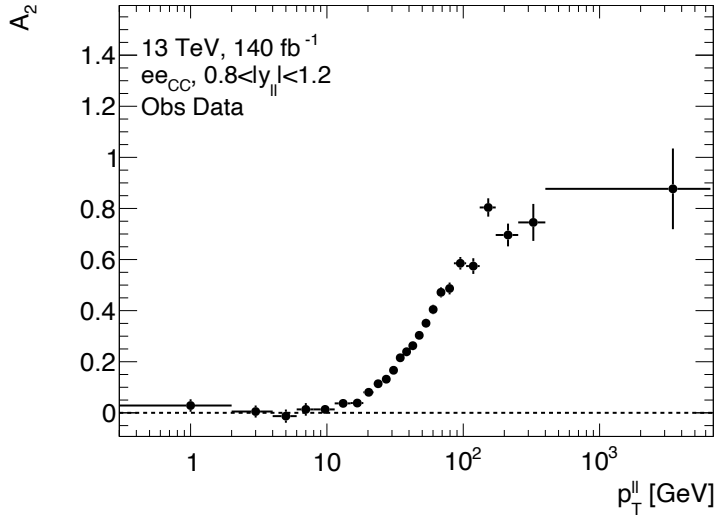
- I'll make sure everything I've done has been pushed to git (I won't leave you in the lurch!):
  - *Fake factors*
  - *Uniformity corrections*
  - *In situ calibrations*
  - *Workspaces*
  - *Fit results*
- Unfortunately I won't have any time to work on the analysis so that I can finish my thesis.
  - *One bug I want to fix but I can't promise more than that!*
  - *Will try and find time to update some old calibration documentation I wrote as well.*
  - *Still plan on attending analysis meetings to keep up to date for the moment.*
- Still not sure what I'm going to do after my PhD but I'm open to the idea of a postdoc, good chance I'll stay in the field!
- Thank you to everyone past and present who's helped me with comments/debugging/sanity checks/opportunities to present in the past four years. I truly wouldn't be able to be in the position of finishing a PhD if it wasn't for all of you!

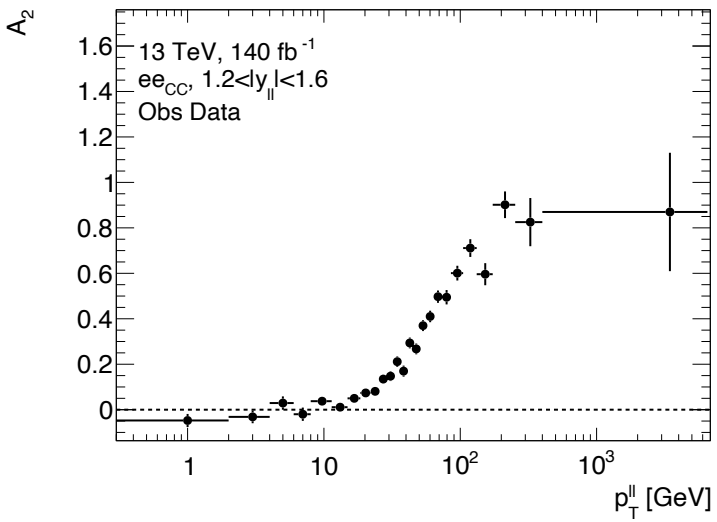
Backup

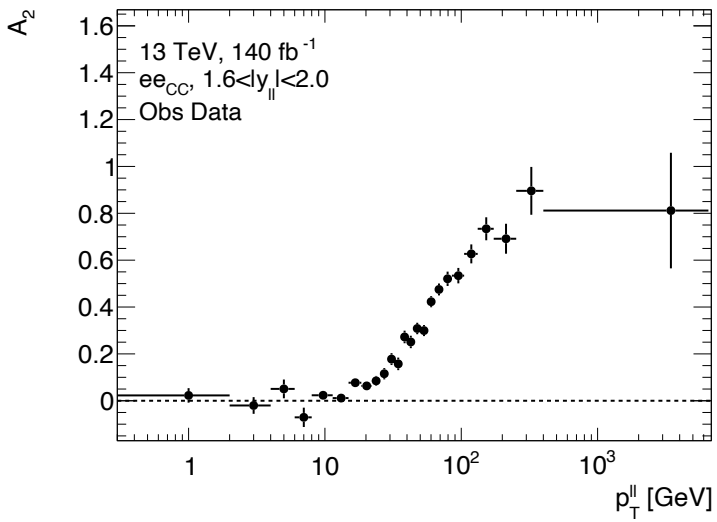
eeCC - A2, all Y bins

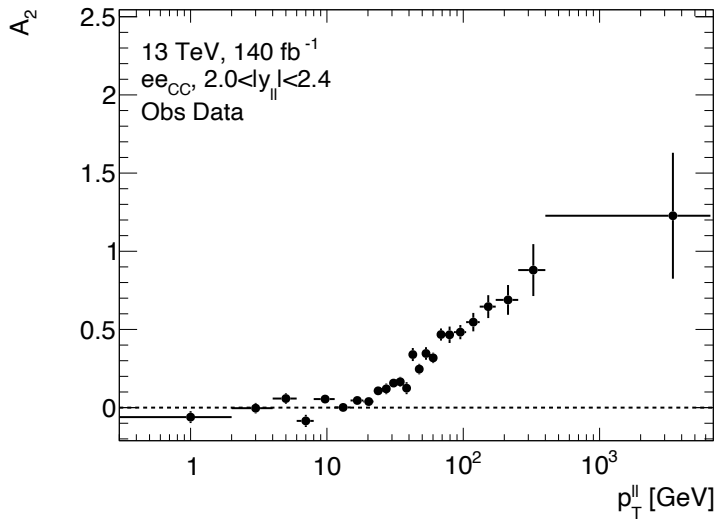




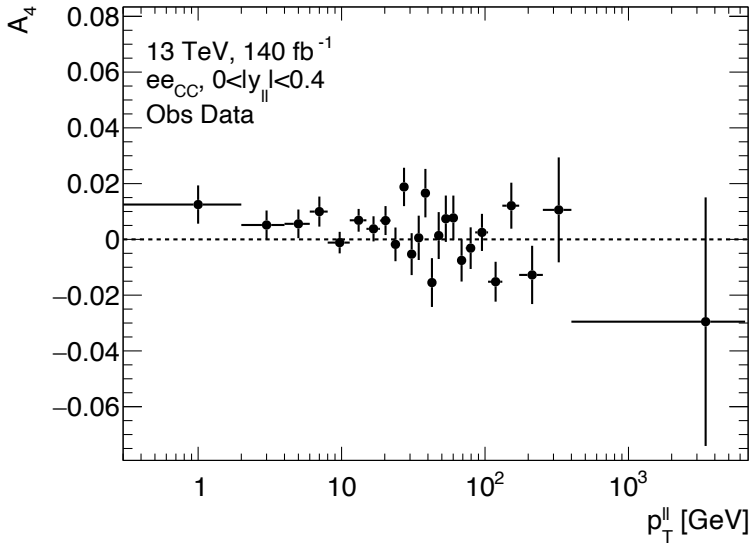


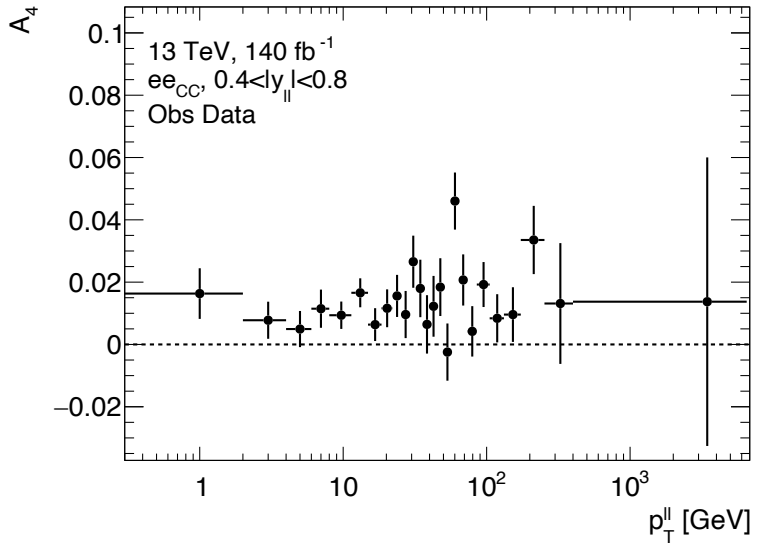


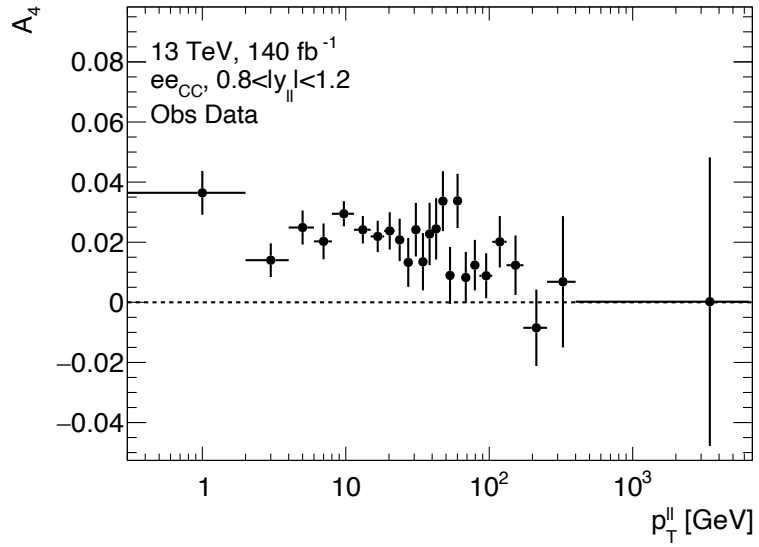


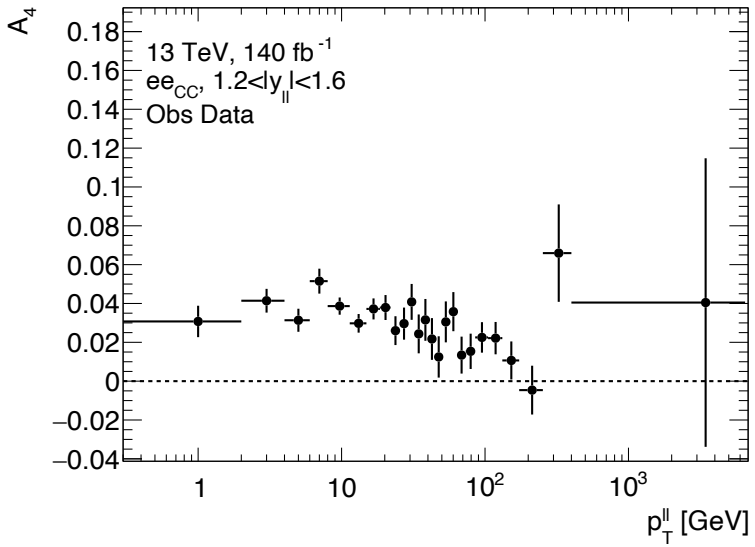


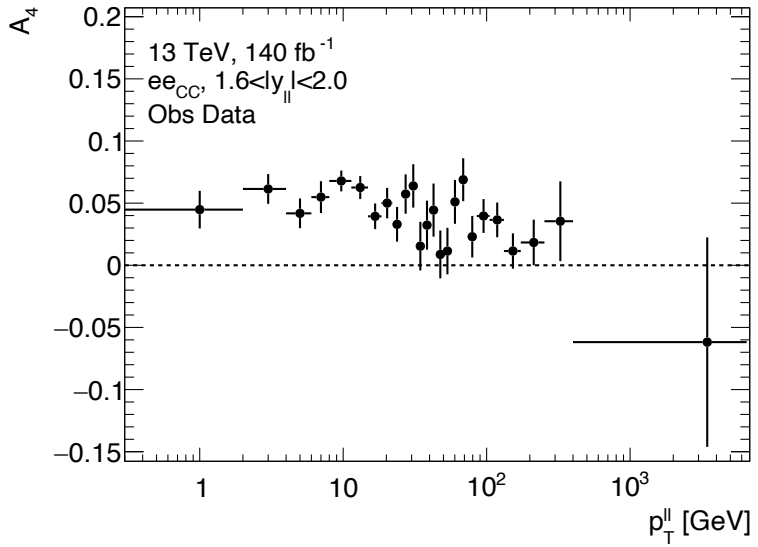
eeCC – A_4, all Y bins

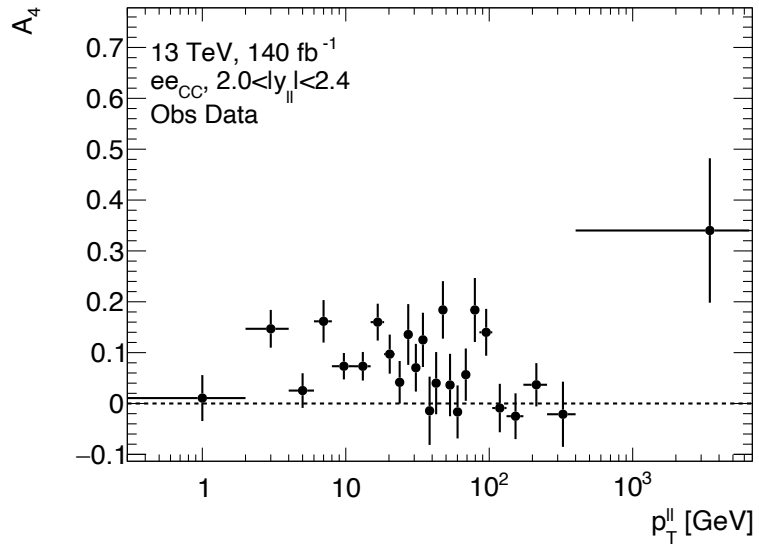




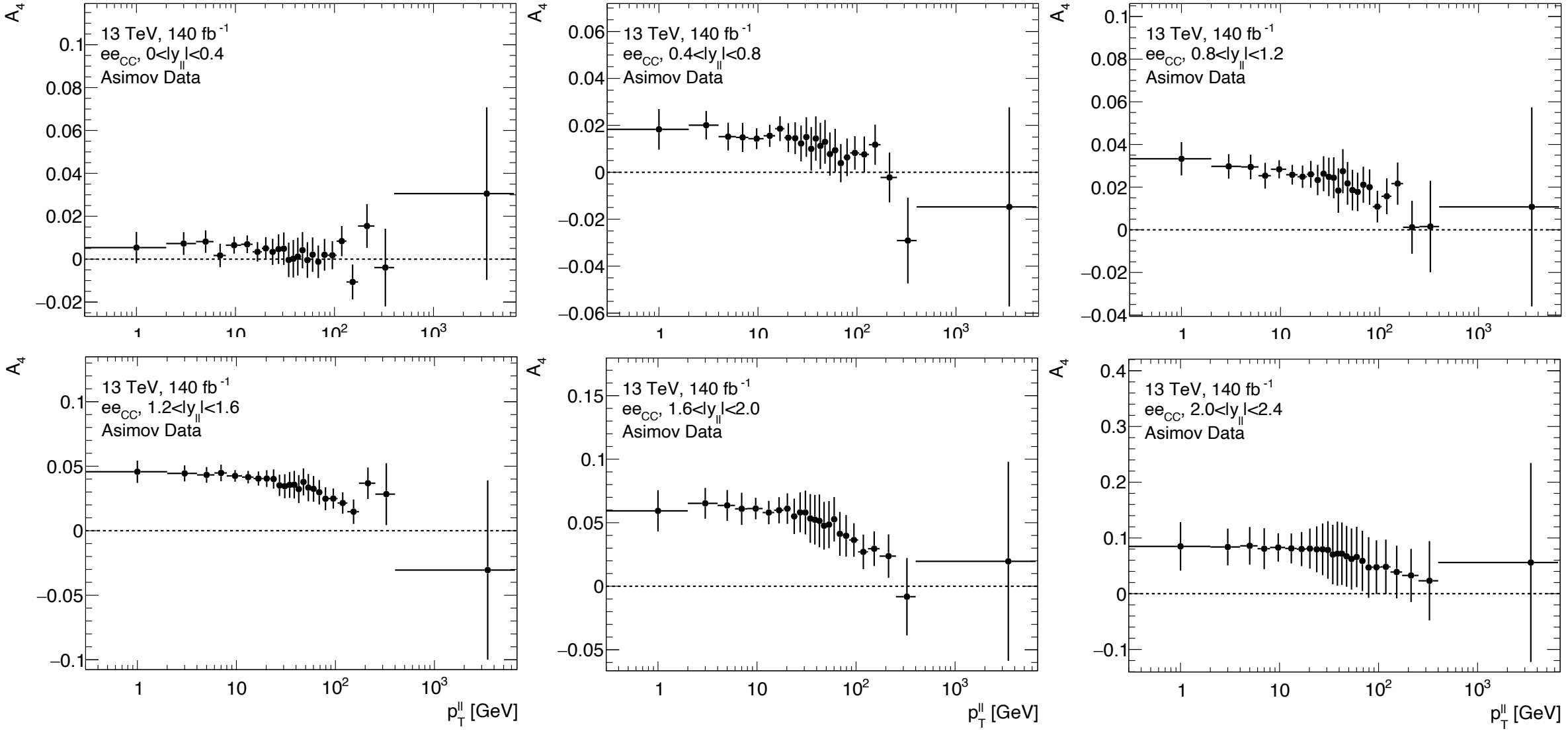








Asimov A_4


A4
13 TeV, 140 fb-1
eeCC, 0<|yll|<0.4
Asimov Data
13 TeV, 140 fb-1
eeCC, 0.4<|yll|<0.8
Asimov Data
13 TeV, 140 fb-1
eeCC, 0.8<|yll|<1.2
Asimov Data
13 TeV, 140 fb-1
eeCC, 1.2<|yll|<1.6
Asimov Data
13 TeV, 140 fb-1
eeCC, 1.6<|yll|<2.0
Asimov Data
13 TeV, 140 fb-1
eeCC, 2.0<|yll|<2.4
Asimov Data
pTll [GeV]

Delta A9 – All bins

Fit seems to fail here.
Subtracting individual central values gives reasonable result.