Impact of an extended Inner Detector Tracker and forward muon-tagger on the $W^{\pm}W^{\pm}$ measurement in pp collisions at the High-Luminosity LHC

Dr. Claire Lee[1] Raynette van Tonder[2] Dr. Sahal Yacoob[2]

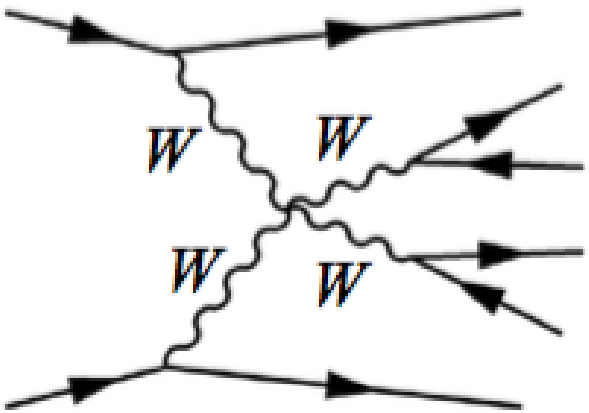
[1]Brookhaven National Laboratory

[2]University of Cape Town

July 4, 2017

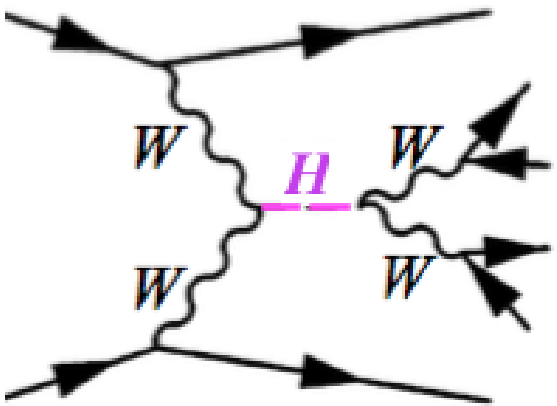
Vector Boson Scattering

- The WW scattering amplitude grows as a function of centre-of-mass energy squared and violates unitarity at $\approx 1\,\mathrm{TeV}$ in the absence of a Standard Model Higgs boson.



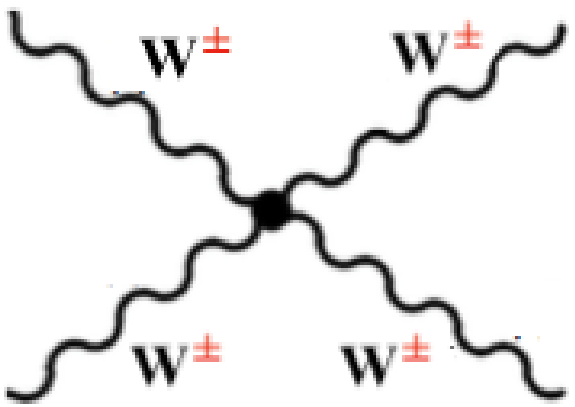
Vector Boson Scattering

- The WW scattering amplitude grows as a function of centre-of-mass energy squared and violates unitarity at $\approx 1\,\mathrm{TeV}$ in the absence of a Standard Model Higgs boson.
- Unitarity is regulated at higher energies if and only if the recently discovered Higgs boson is the SM predicted Higgs boson.



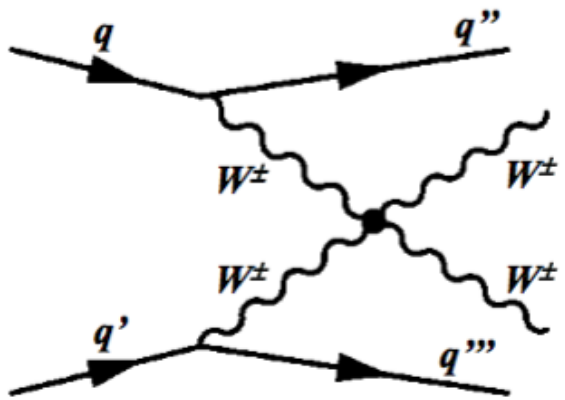
Same Sign $W^{\pm}$ Production

- $pp \to W^{\pm}W^{\pm}jj \to l^{\pm}l^{\pm}\nu\nu jj$



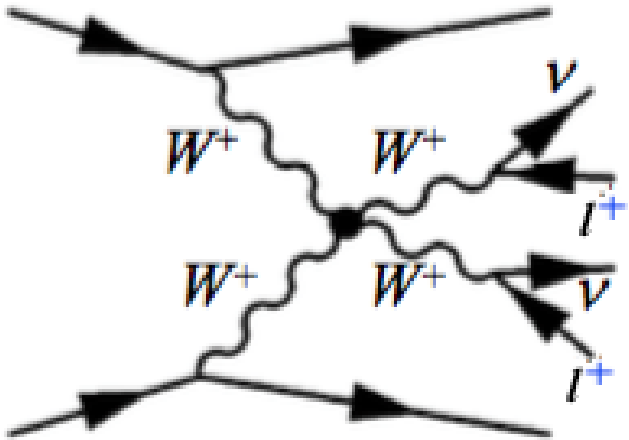
Same Sign $W^{\pm}$ Production

- $pp \rightarrow W^{\pm}W^{\pm}jj \rightarrow l^{\pm}l^{\pm}\nu\nu jj$
- W boson scattering can occur when W bosons are radiated off incoming proton beams and scatter off each other.



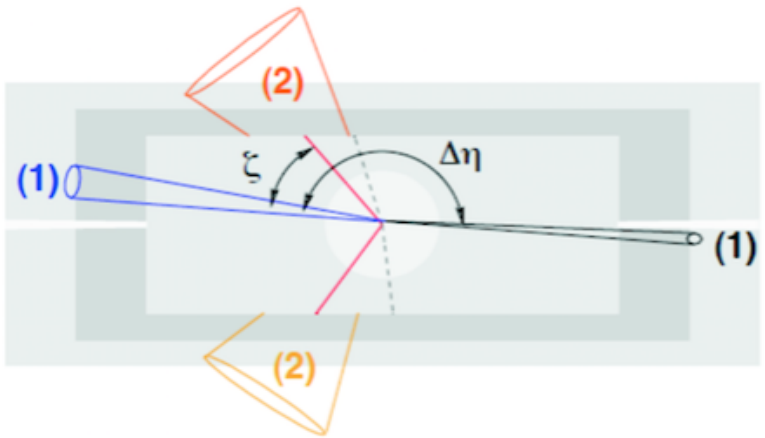
Same Sign $W^{\pm}$ Production

- $pp \rightarrow W^{\pm}W^{\pm}jj \rightarrow l^{\pm}l^{\pm}\nu\nu jj$
- W boson scattering can occur when W bosons are radiated off incoming proton beams and scatter off each other.
- These W bosons decay leptonically, i.e $W^{\pm} \rightarrow l^{\pm}\nu, l = e, \mu$.



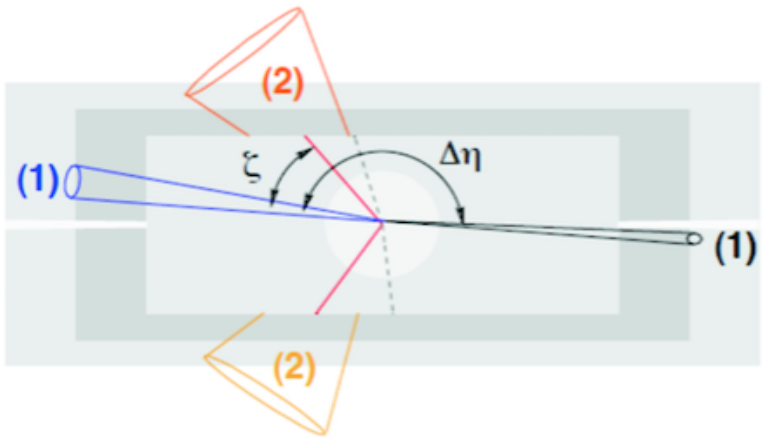
Same Sign $W^{\pm}$ Production

- The process therefore has a very distinctive experimental signature of a central lepton pair of the same electric charge and two forward jets.



Same Sign $W^{\pm}$ Production

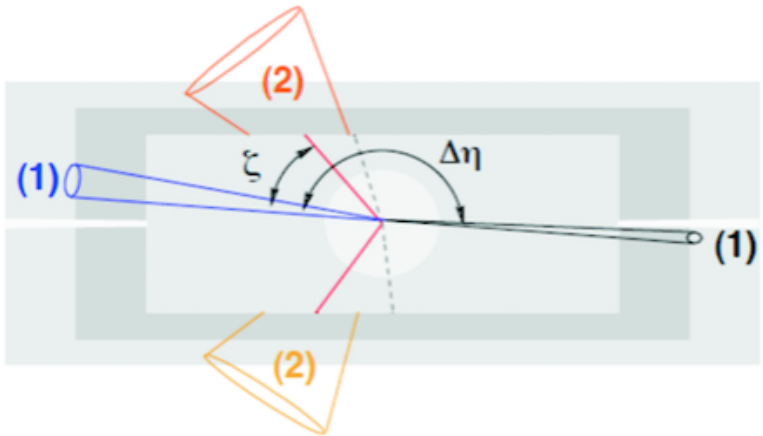
- The process therefore has a very distinctive experimental signature of a central lepton pair of the same electric charge and two forward jets.



- It is still unclear whether the SM Higgs boson unitarises the WW longitudinal scattering amplitude fully or only partially at higher energies.

Same Sign $W^{\pm}$ Production

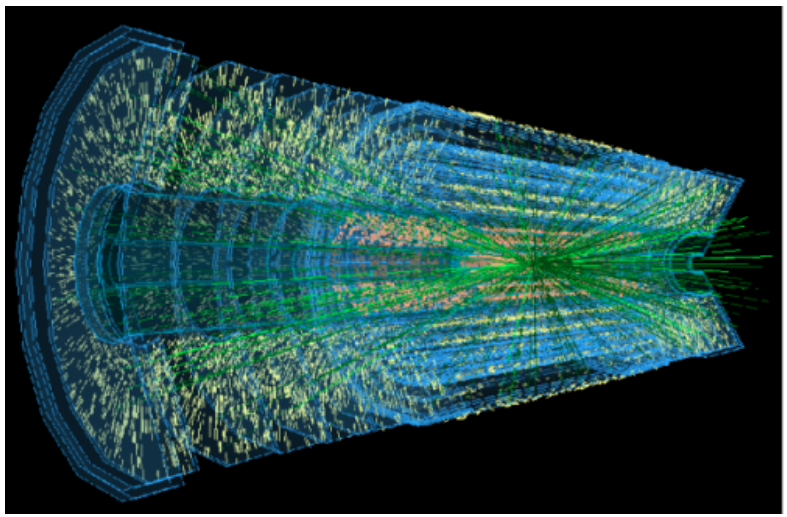
- The process therefore has a very distinctive experimental signature of a central lepton pair of the same electric charge and two forward jets.



- It is still unclear whether the SM Higgs boson unitarises the WW longitudinal scattering amplitude fully or only partially at higher energies.
- Therefore, the study of $W^{\pm}W^{\pm}$ will be continued through to the High-Luminosity LHC physics program.

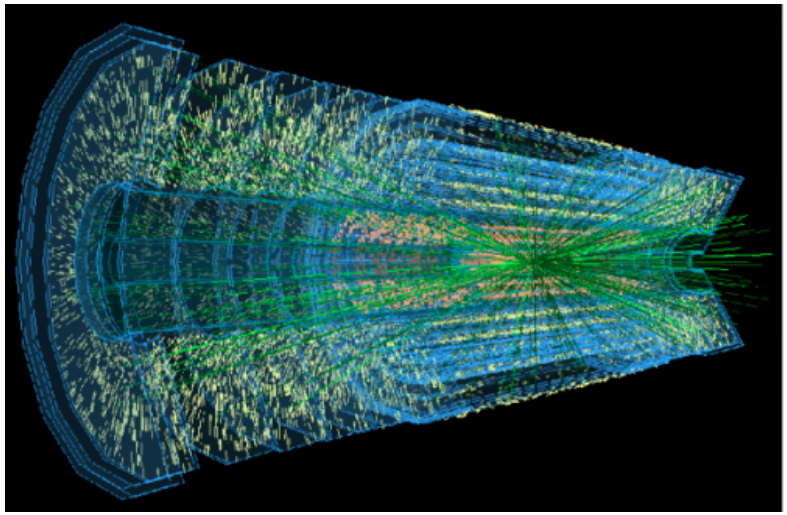
Toward the High-Luminosity LHC

- $L = 3000\,\mathrm{fb}^{-1}$ of data will be collected.
- This value corresponds to $\langle\mu\rangle = 200$ pp collisions per bunch crossing.



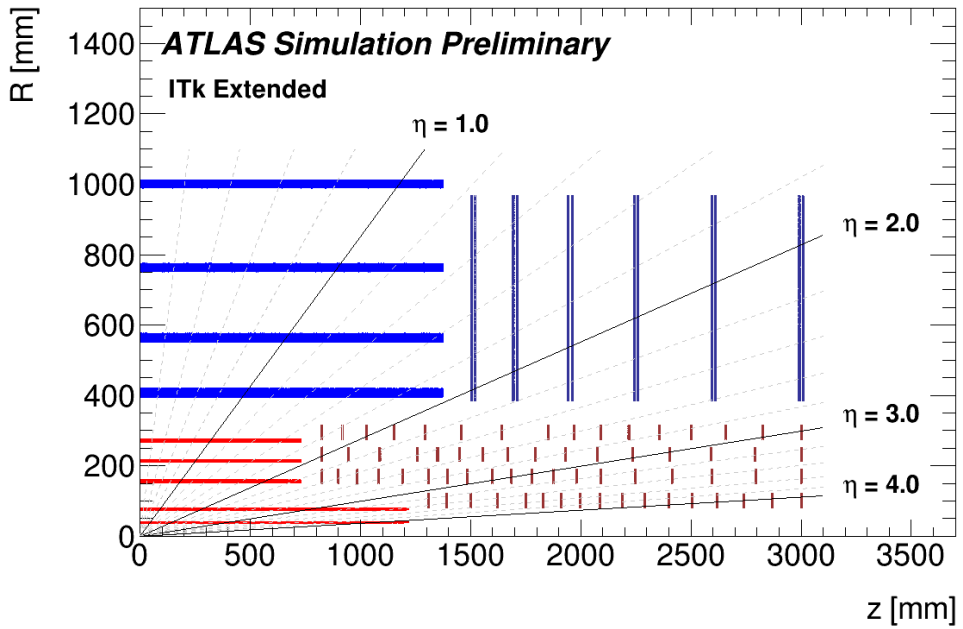
Toward the High-Luminosity LHC

- $L = 3000\,\mathrm{fb}^{-1}$ of data will be collected.
- This value corresponds to $\langle\mu\rangle = 200$ pp collisions per bunch crossing.
- Several subsystems of the ATLAS detector require significant upgrades to cope with the harsher radiation and high pileup environment.



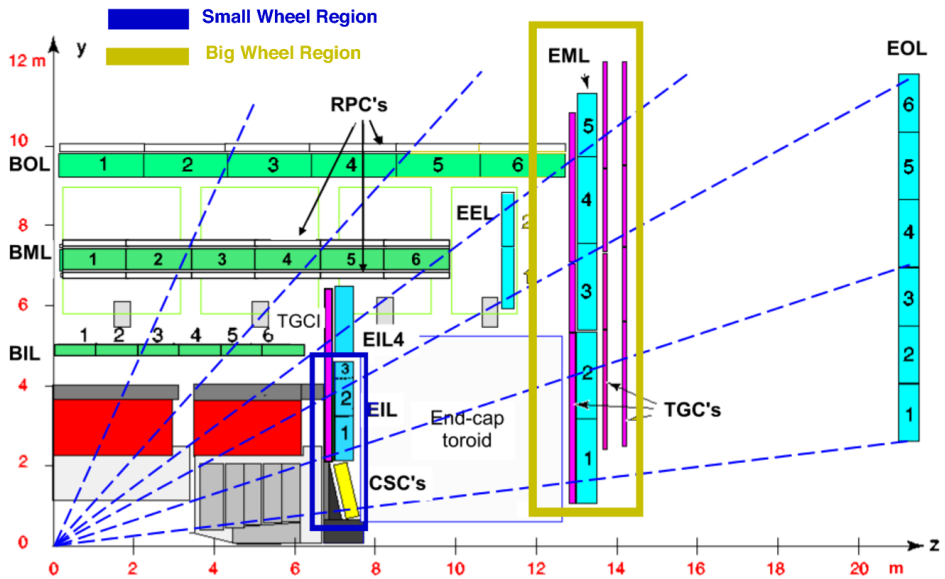
Upgrades of ATLAS sub-detectors

- The Inner Detector will be completely replaced with an all-new tracker.
- Candidate designs have been updated to cover a pseudorapidity range up the $|\eta| \leq 4.0$.



Upgrades of ATLAS sub-detectors

- Additionally, a proposed forward muon-tagger will enable reconstruction of muons up to $|\eta| \leq 4.0$.
- The forward-muon tagger will be attached to the shielding disk of the Muon Spectrometer's New Small Wheel.



Event generation $W^{\pm}W^{\pm}$ at HL-LHC

- Make use of Monte Carlo signal and background samples, with additional pileup interactions, at $\sqrt{s} = 14\,\mathrm{TeV}$ and $L = 3000\,\mathrm{fb}^{-1}$.

Event generation $W^{\pm}W^{\pm}$ at HL-LHC

- Make use of Monte Carlo signal and background samples, with additional pileup interactions, at $\sqrt{s} = 14\,\mathrm{TeV}$ and $L = 3000\,\mathrm{fb}^{-1}$.
- The largest background contribution is the WZ + jets process, followed by $W^{\pm}W^{\pm}jj$-QCD production.

Event generation $W^{\pm}W^{\pm}$ at HL-LHC

- Make use of Monte Carlo signal and background samples, with additional pileup interactions, at $\sqrt{s} = 14\,\mathrm{TeV}$ and $L = 3000\,\mathrm{fb}^{-1}$.
- The largest background contribution is the WZ + jets process, followed by $W^{\pm}W^{\pm}jj$-QCD production.
- Additional background processes were approximated by a scale factor, estimated from the $\sqrt{s} = 8\,\mathrm{TeV}$ analysis.

Event generation $W^{\pm}W^{\pm}$ at HL-LHC

- Make use of Monte Carlo signal and background samples, with additional pileup interactions, at $\sqrt{s} = 14\,\mathrm{TeV}$ and $L = 3000\,\mathrm{fb}^{-1}$.
- The largest background contribution is the WZ + jets process, followed by $W^{\pm}W^{\pm}jj$-QCD production.
- Additional background processes were approximated by a scale factor, estimated from the $\sqrt{s} = 8\,\mathrm{TeV}$ analysis.
- Upgrade Performance Functions were used to estimate the upgraded ATLAS detector's response under HL-LHC conditions.

Event Selection

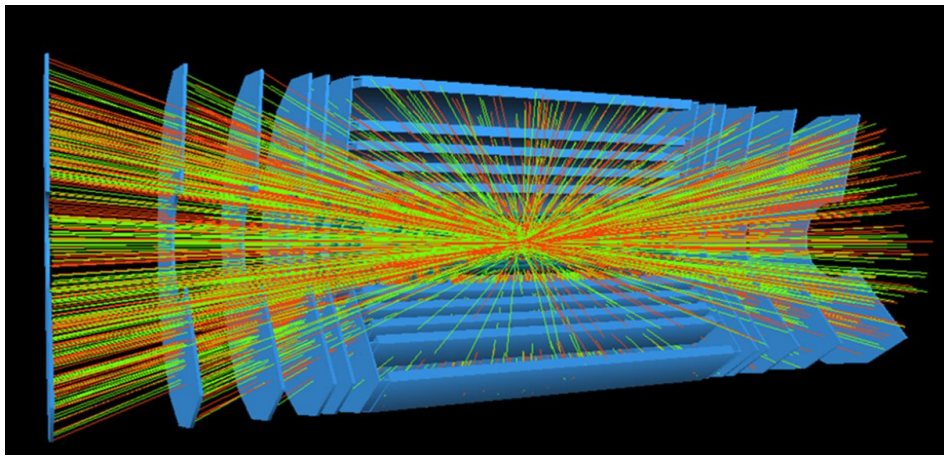
1. Two leptons with $p_T > 25\,\mathrm{GeV}$.
2. $q_{l_1} \times q_{l_2} > 0$.
3. $m_{ll} > 20\,\mathrm{GeV}$.
4. $|m_{ee} - m_Z| > 10\,\mathrm{GeV}$ in ee channel.
5. $E_T^{miss} \geq 40\,\mathrm{GeV}$.
6. At least two jets with $p_T > 30\,\mathrm{GeV}$.
7. $\Delta\eta_{jj} > 2.4$.
8. Veto additional leptons.
9. $m_{jj} > 500\,\mathrm{GeV}$.
10. Lepton centrality > 0.

Event Selection

In the backup, ask me if you care!

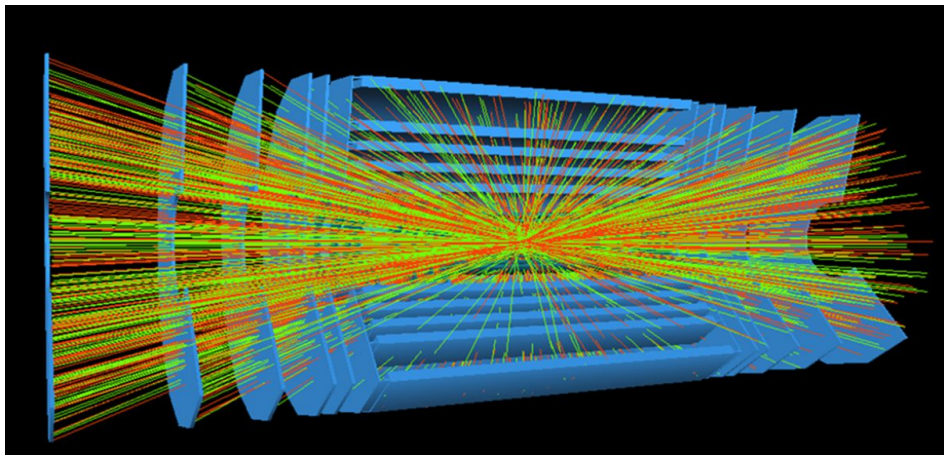
Event Selection for pileup rejection

- At least two jets with:
  - $p_T > 30\,\mathrm{GeV}$ for $|\eta| \leq 2.5$.



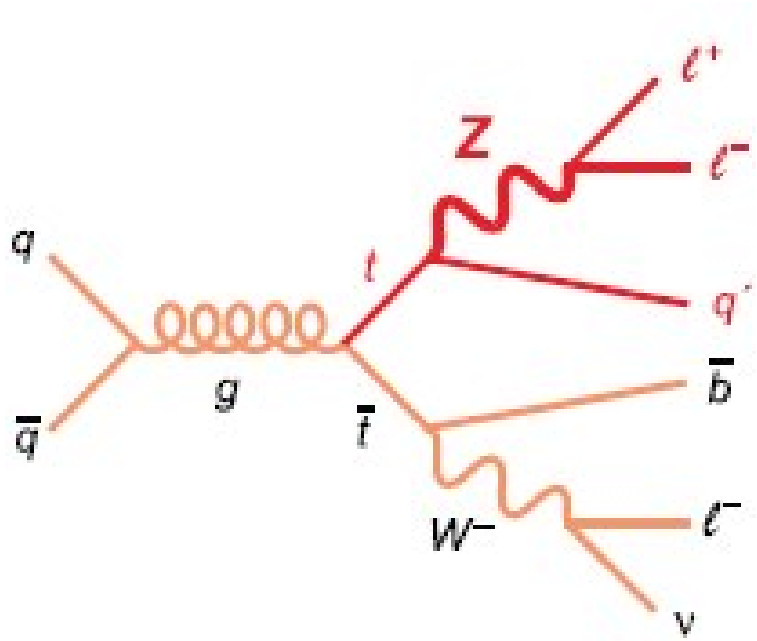
Event Selection for pileup rejection

- At least two jets with:
  - $p_T > 30\,\mathrm{GeV}$ for $|\eta| \leq 2.5$.
  - $p_T > 70\,\mathrm{GeV}$ for $2.5 < |\eta| \leq 4.5$.

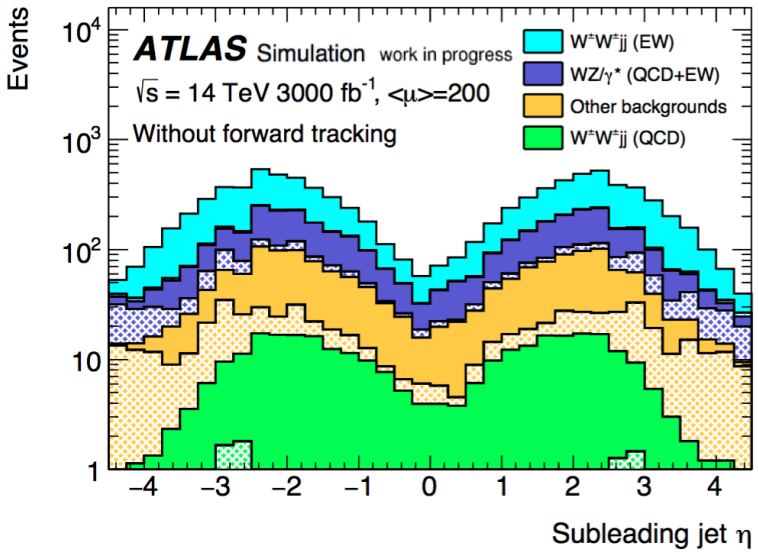


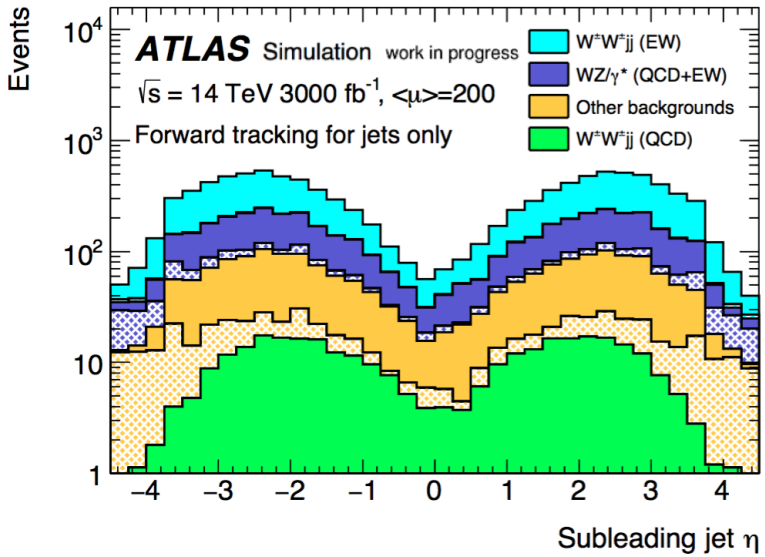
Event Selection for pileup rejection

- At least two jets with:
  - $p_T > 30\,\mathrm{GeV}$ for $|\eta| \leq 2.5$.
  - $p_T > 70\,\mathrm{GeV}$ for $2.5 < |\eta| \leq 4.5$.
- Veto additional leptons.



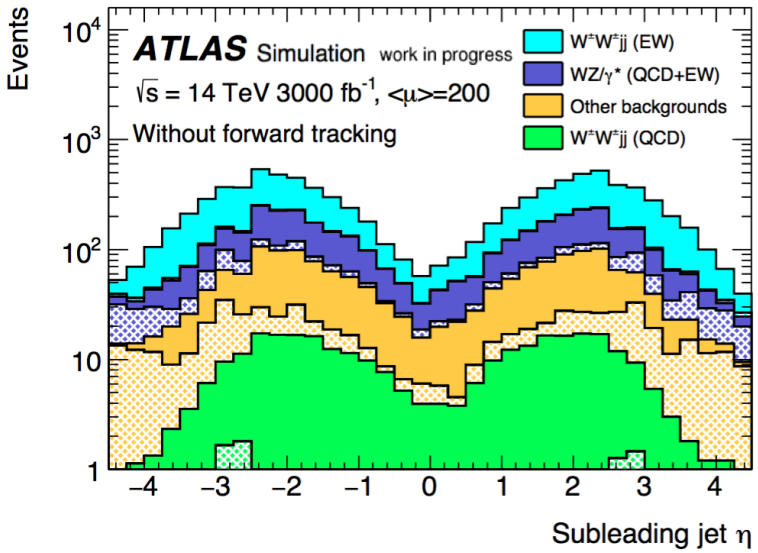
Pileup rejection

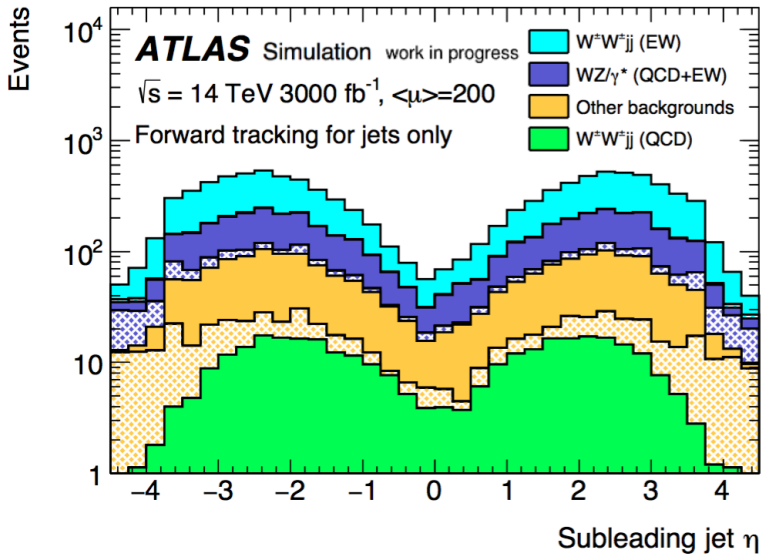




- The extended coverage up to $|\eta| \leq 3.8$ for jets provides rejection of pileup jets in the forward regions.

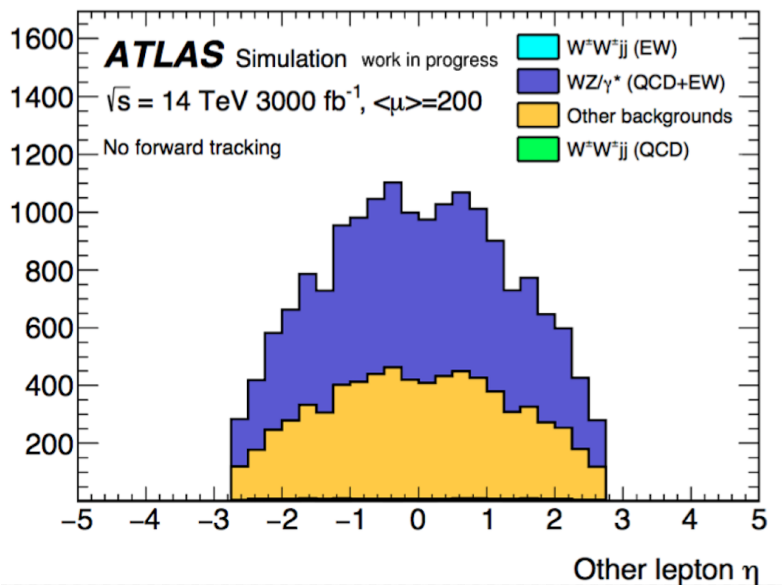
Pileup rejection

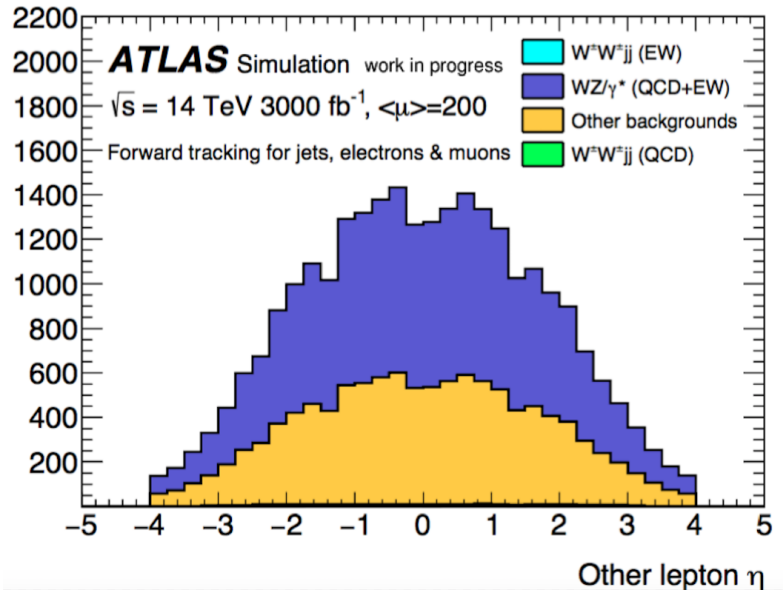




- The extended coverage up to $|\eta| \leq 3.8$ for jets provides rejection of pileup jets in the forward regions.
- Thus reducing contributions from background processes with jets.

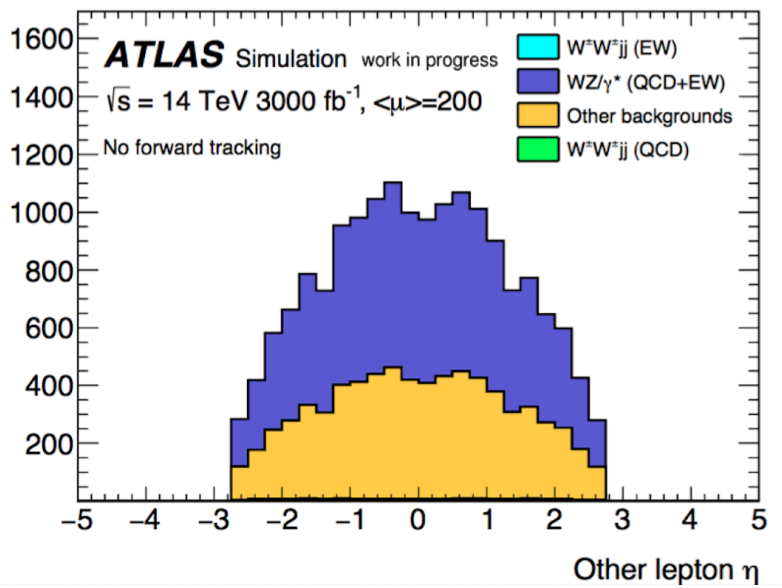
Third-lepton veto

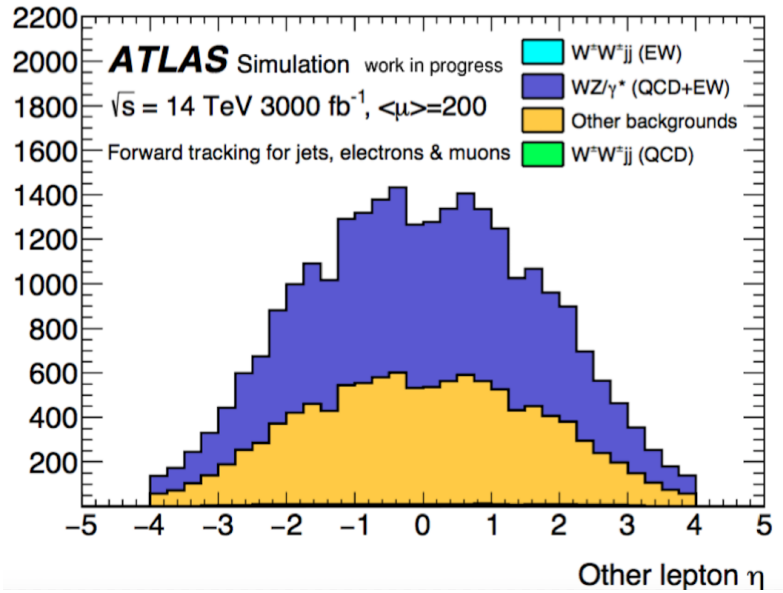




- The extended coverage up to $|\eta| \leq 4.0$ for electrons and muons enables the reconstruction of forward leptons.

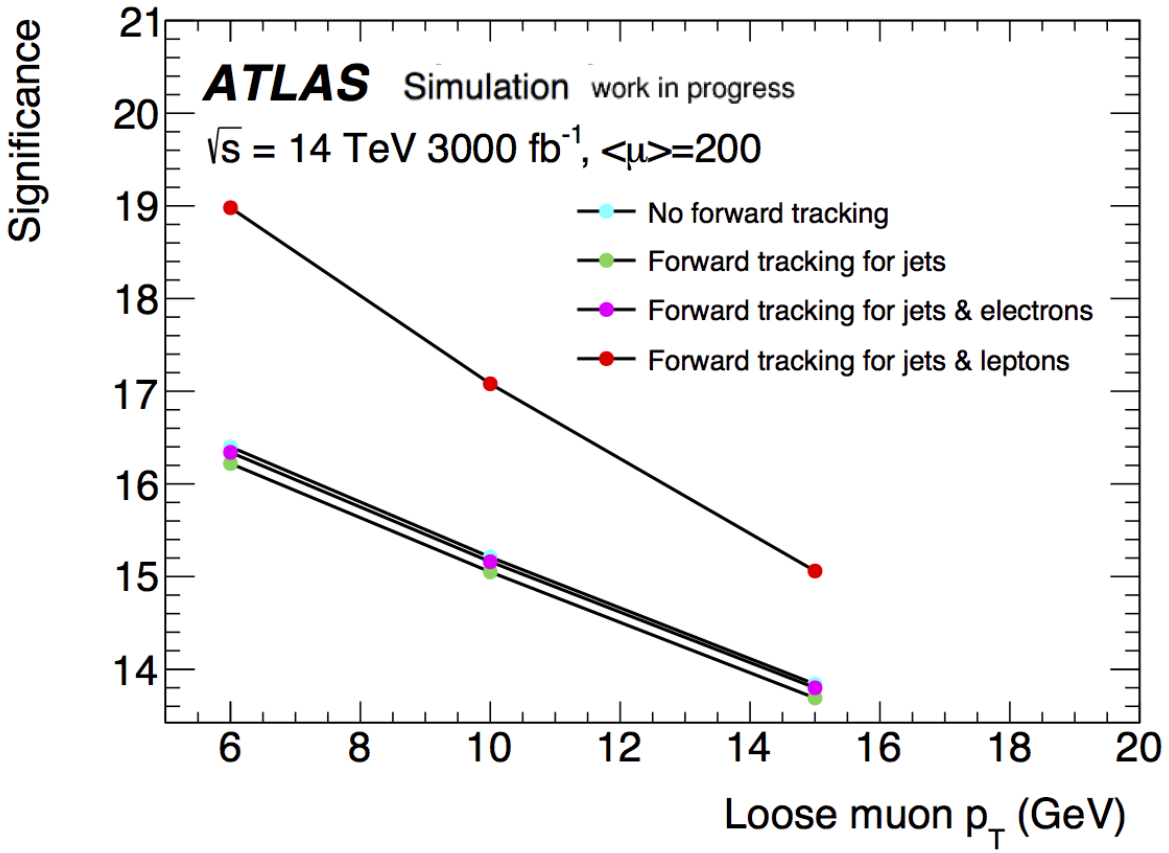
Third-lepton veto



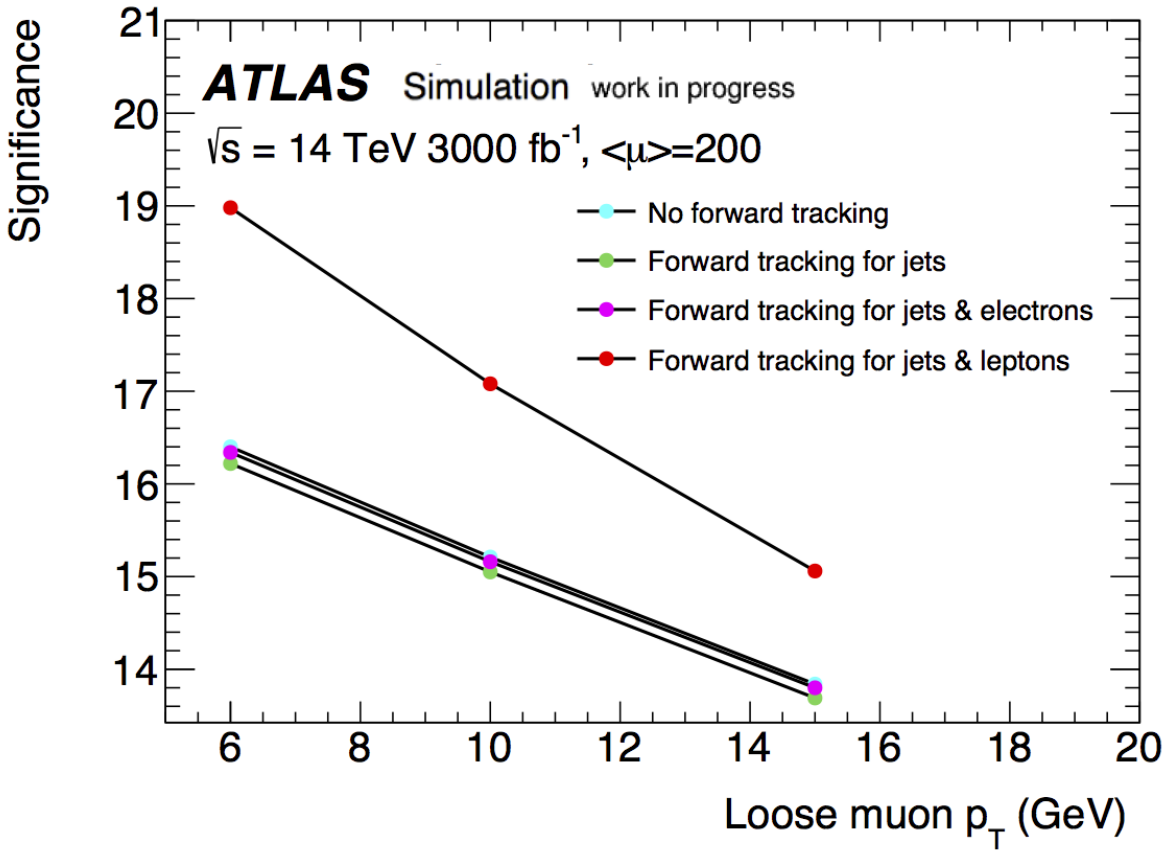


- The extended coverage up to $|\eta| \leq 4.0$ for electrons and muons enables the reconstruction of forward leptons.
- Providing a stronger third-lepton veto leading for the suppression of the WZ + jets background.

Significances



Significances



- The significance of the measurement decreases rapidly with a higher acceptance p_T, due to a less efficient third-lepton veto.

Conclusion

- The prospects of a $W^{\pm}W^{\pm}jj$-EW measurement at the HL-LHC looks promising with an extended inner tracking system and a forward muon-tagger.

Conclusion

- The prospects of a $W^{\pm}W^{\pm}jj$-EW measurement at the HL-LHC looks promising with an extended inner tracking system and a forward muon-tagger.
- The extension of the inner tracking system increases the signal yield by:
  - 12% with the increased η-coverage for jets and,

Conclusion

- The prospects of a $W^{\pm}W^{\pm}jj$-EW measurement at the HL-LHC looks promising with an extended inner tracking system and a forward muon-tagger.
- The extension of the inner tracking system increases the signal yield by:
  - 12% with the increased η-coverage for jets and,
  - 14% in combination with the additional lepton veto.

Conclusion

- The prospects of a $W^{\pm}W^{\pm}jj$-EW measurement at the HL-LHC looks promising with an extended inner tracking system and a forward muon-tagger.
- The extension of the inner tracking system increases the signal yield by:
  - 12% with the increased η-coverage for jets and,
  - 14% in combination with the additional lepton veto.
- Consequently, the expected significance of the $W^{\pm}W^{\pm}jj$-EW measurement is improved by 16%.

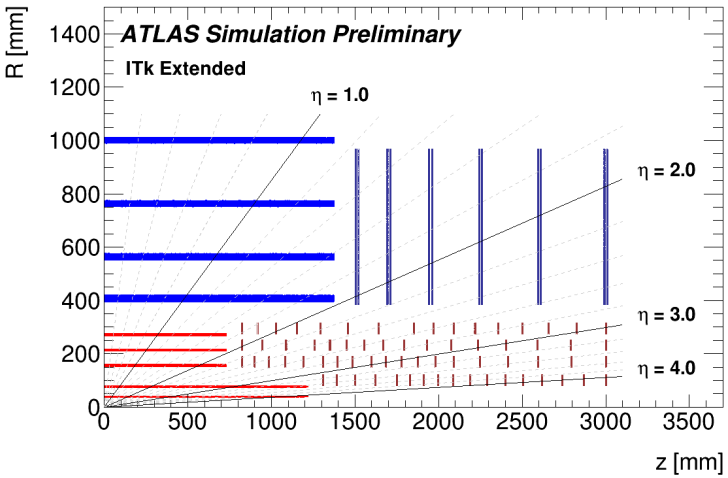
Conclusion

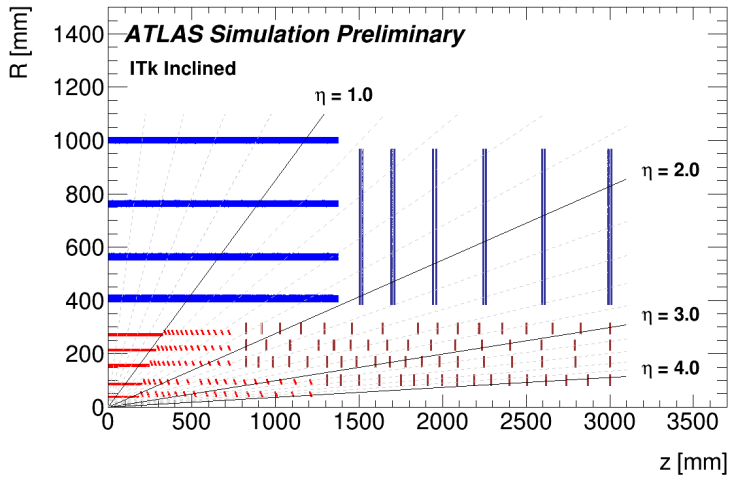
- The prospects of a $W^{\pm}W^{\pm}jj$-EW measurement at the HL-LHC looks promising with an extended inner tracking system and a forward muon-tagger.
- The extension of the inner tracking system increases the signal yield by:
  - 12% with the increased η-coverage for jets and,
  - 14% in combination with the additional lepton veto.
- Consequently, the expected significance of the $W^{\pm}W^{\pm}jj$-EW measurement is improved by 16%.
- Studies of the effect of an extended η ATLAS detector on the $W^{\pm}W^{\pm}jj$-EW measurement will continue in the future.

Back up slides

Back up!

Candidate ITk designs





Event Selection

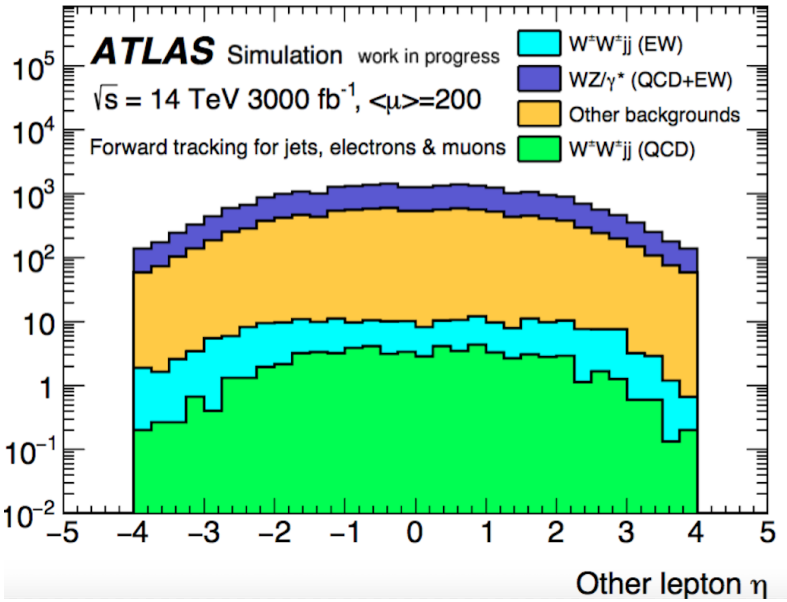
1. Two leptons with $p_T > 25\,\mathrm{GeV}$.
2. $q_{l_1} \times q_{l_2} > 0$.
3. $m_{ll} > 20\,\mathrm{GeV}$.
4. $|m_{ee} - m_Z| > 10\,\mathrm{GeV}$ in ee channel.
5. $E_T^{miss} \geq 40\,\mathrm{GeV}$.
6. At least two jets with $p_T > 30\,\mathrm{GeV}$.
7. $\Delta\eta_{jj} > 2.4$.
8. Veto additional leptons.
9. $m_{jj} > 500\,\mathrm{GeV}$.
10. Lepton centrality > 0.

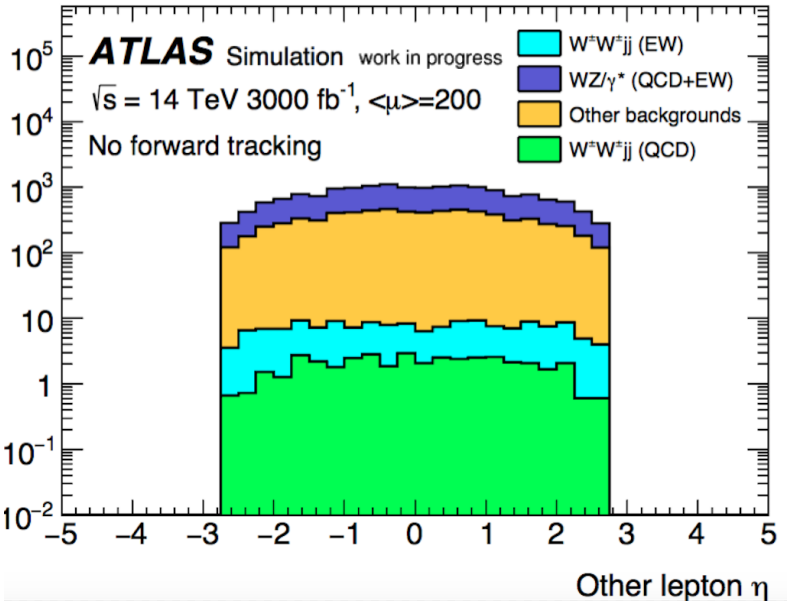
Lepton centrality

Lepton centrality is a quantity based on the kinematic signature of leptons and jets, given by:

$$\zeta = \min[\min(\eta_{l1}\eta_{l2}) - \min(\eta_{j1}\eta_{j2}), \max(\eta_{j1}, \eta_{j2}) - \max(\eta_{l1}, \eta_{l2})] \tag{1}$$

Loose leptons





Significance calculation

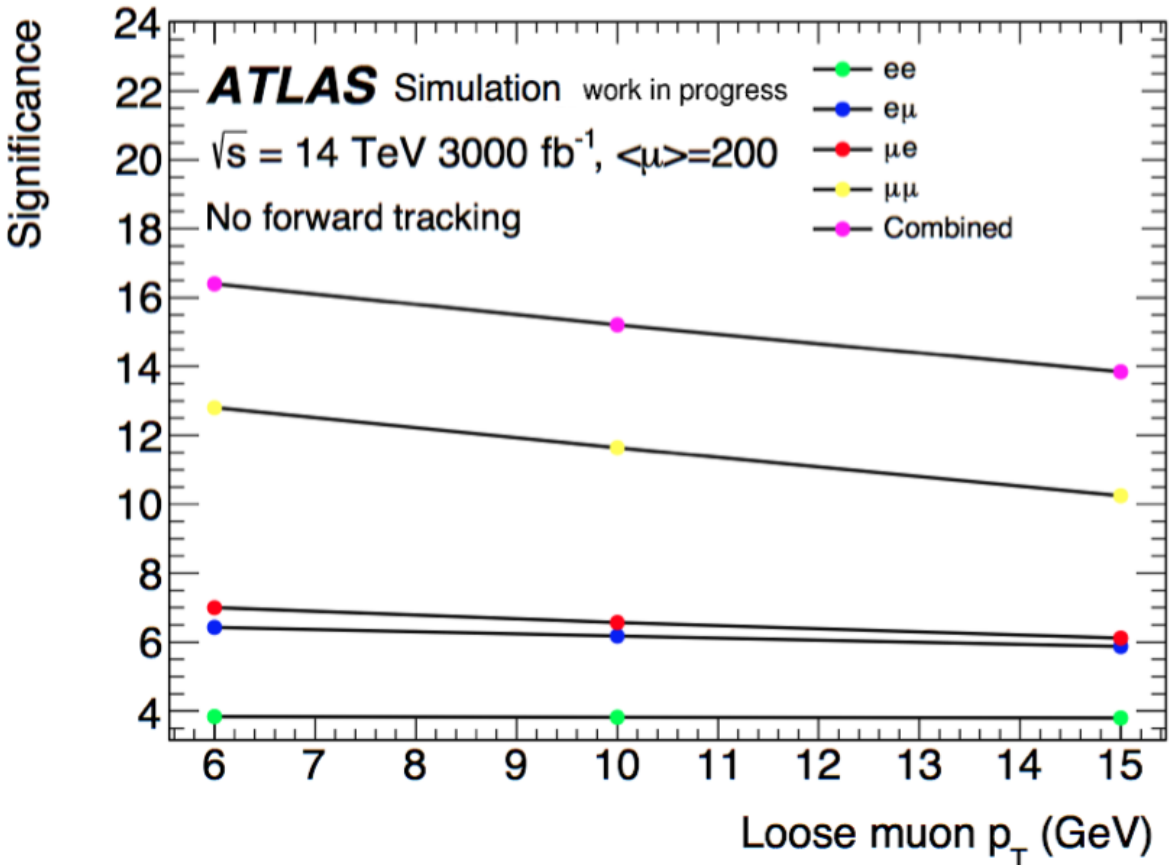
Assuming the number of events follow a Poissonian distribution and assuming an estimated background uncertainty of $\sigma_B = 15\%$, the signal significance is calculated as follows:

$$Z_\sigma = \sqrt{2[(N_{sig} + N_{bkg}) \log \frac{N_{sig} + N_{bkg}}{B_0} + B_0 - N_{sig} - N_{bkg}] \frac{(N_{bkg} - B_0)^2}{\sigma_B^2}} \quad (2)$$

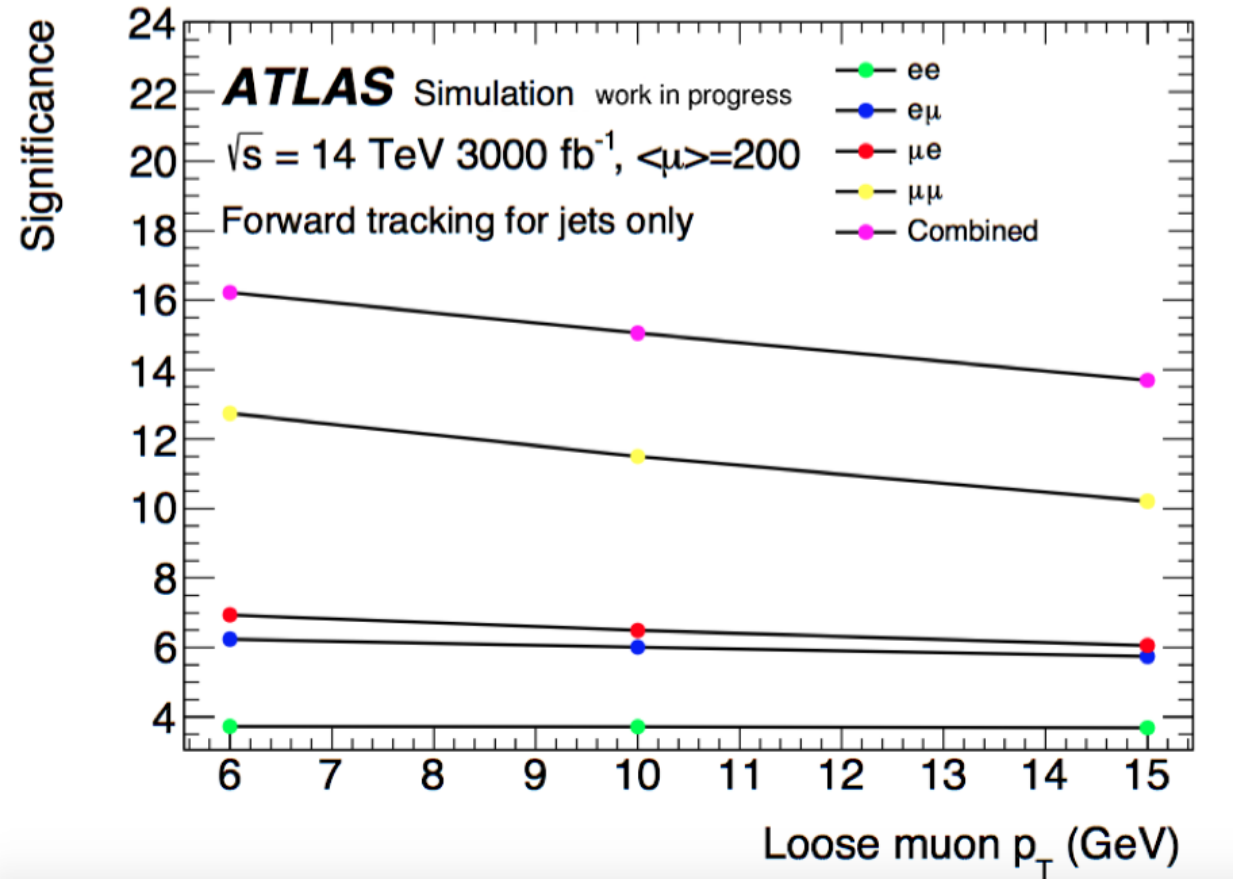
where $B_0 = \frac{1}{2}(N_{bkg} - \sigma_B^2 + \sqrt{(N_{bkg} - \sigma_B^2)^2 + 4(N_{sig} + N_{bkg})\sigma_B^2})$.

- Uncertainties related to MC statistics are neglected.
- No theoretical uncertainties were added.

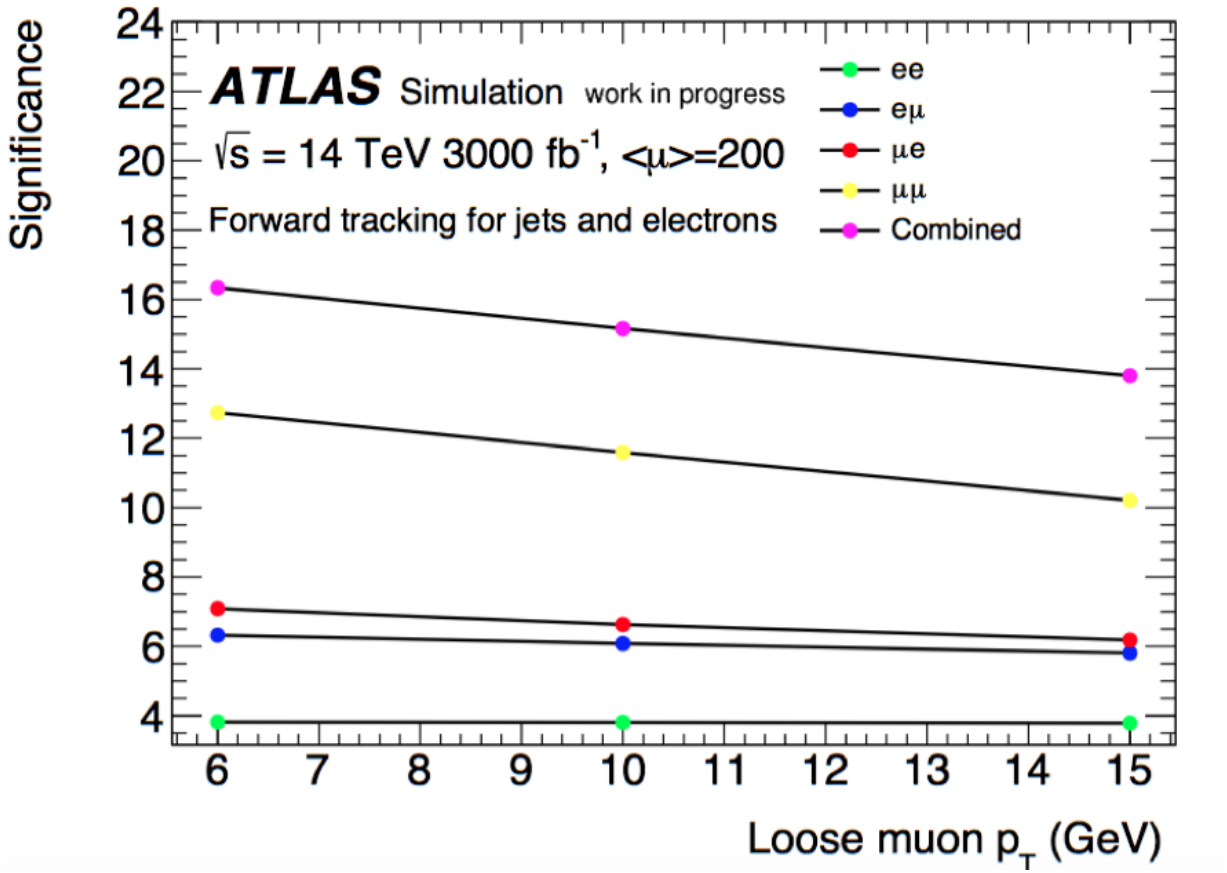
Significances by channel



Significances by channel



Significances by channel



Significances by channel