Search for doubly charged Higgs using Tau leptons with ATLAS at $\sqrt{s}$ =13 TeV

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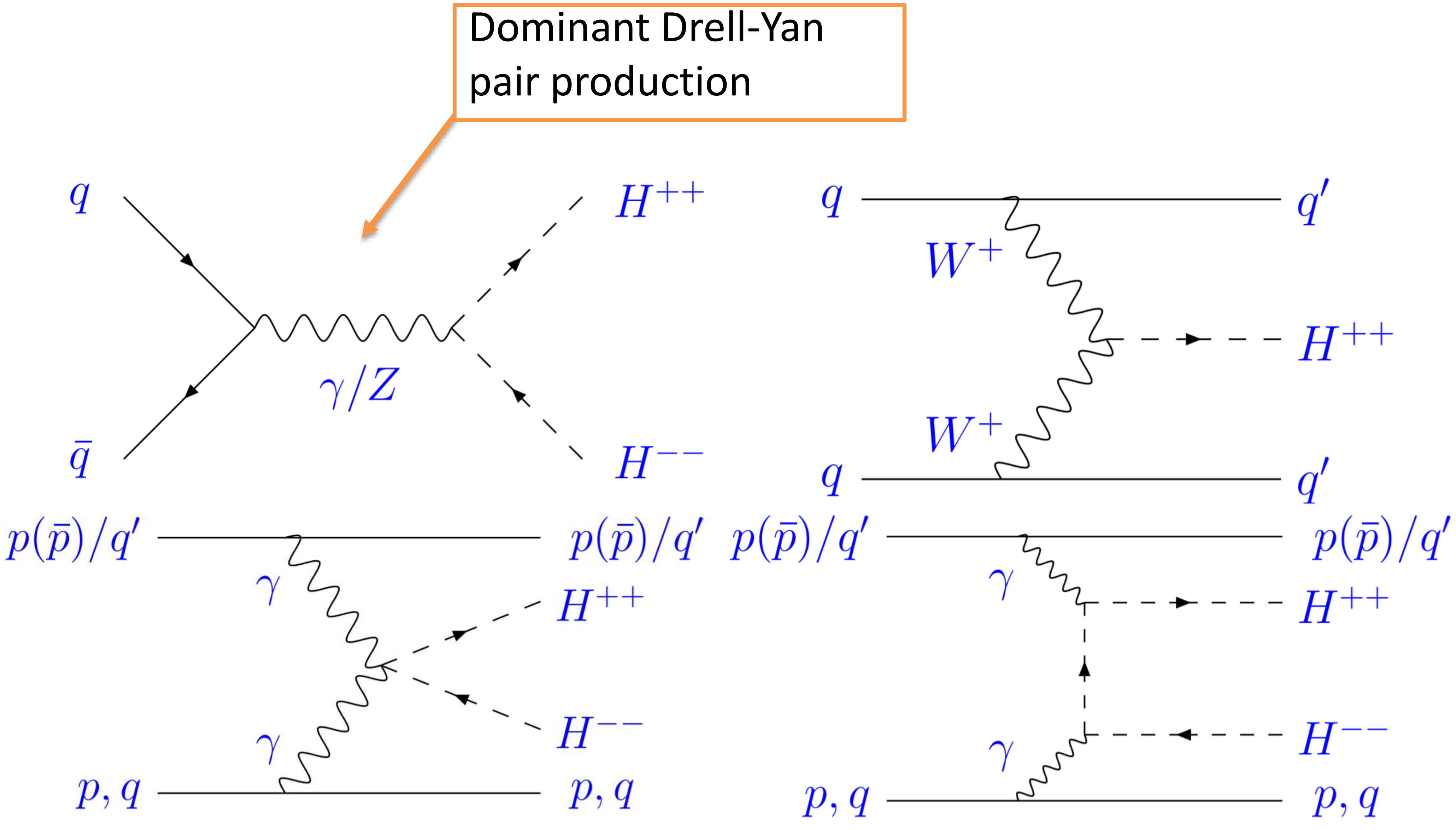
Partikeldagarna, Lund, 2018

Why search for doubly charged Higgs?

- Doubly charged Higgs bosons can arise in various BSM theories
  - Left-right symmetric models, Higgs triplet models, little Higgs model, type-II seesaw models, …
- Closely related to generation mechanism of neutrino mass.
- Hint for the existence of supersymmetry.
- Can decay to a pair of same-sign leptons which are rare in SM.



Feynman diagrams for several doubly charged Higgs production channel. arXiv:1105.1379v1

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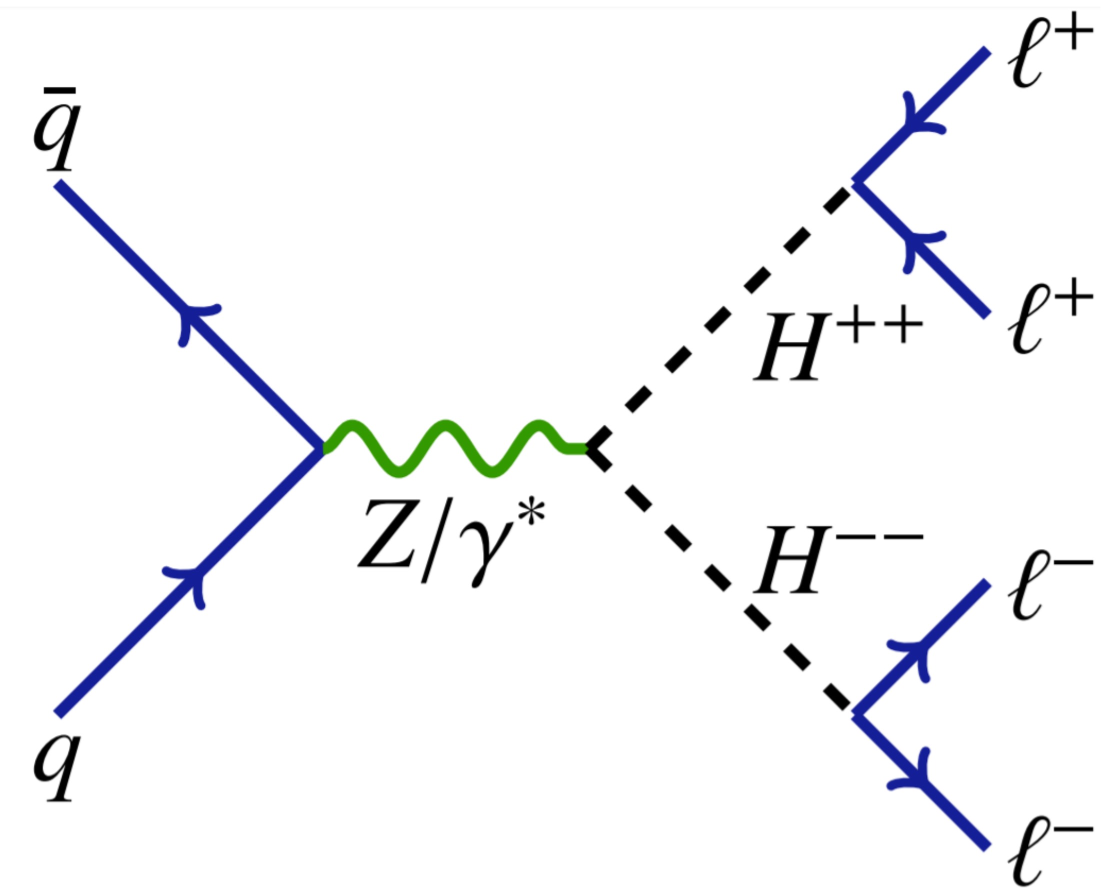
Previous study by ATLAS on $H^{\pm\pm} \rightarrow l^{\pm}l'^{\pm}$

- Used pp data sample with Integrated luminosity 36.1 fb^{-1} collected in 2015 and 2016 by the ATLAS detector at the LHC at $\sqrt{s}$=13 TeV
- Only pair production via the Drell–Yan process was considered
- Total assumed branching ratio of $H^{\pm\pm}$ is $B(H^{\pm\pm} \rightarrow l^{\pm}l'^{\pm}) + B(H^{\pm\pm} \rightarrow X) = 100\%$, while “$X$" does not enter any of the SRs. Only e and μ were considered.
- Partial decay width of $H^{\pm\pm}$ to leptons is given by:

$$\Gamma(H^{\pm\pm} \rightarrow l^{\pm}l'^{\pm}) = \frac{1}{1+\delta_{ll'}} \frac{|\tilde{h}_{ll'}|^2 m_{H^{\pm\pm}}}{16\pi}, \tilde{h}_{ll'} = \begin{cases} 2h_{ll'} & l = l' \\ h_{ll'} & l \neq l' \end{cases}$$

- Masses studied: $200 \leq m_{H^{\pm\pm}} \leq 1300$ GeV



Drell-Yan pair production

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$$|\tilde{h}_{ll'}|^2 = 2\left|m_\nu^{ij}\right|^2 / v_\Delta^2$$

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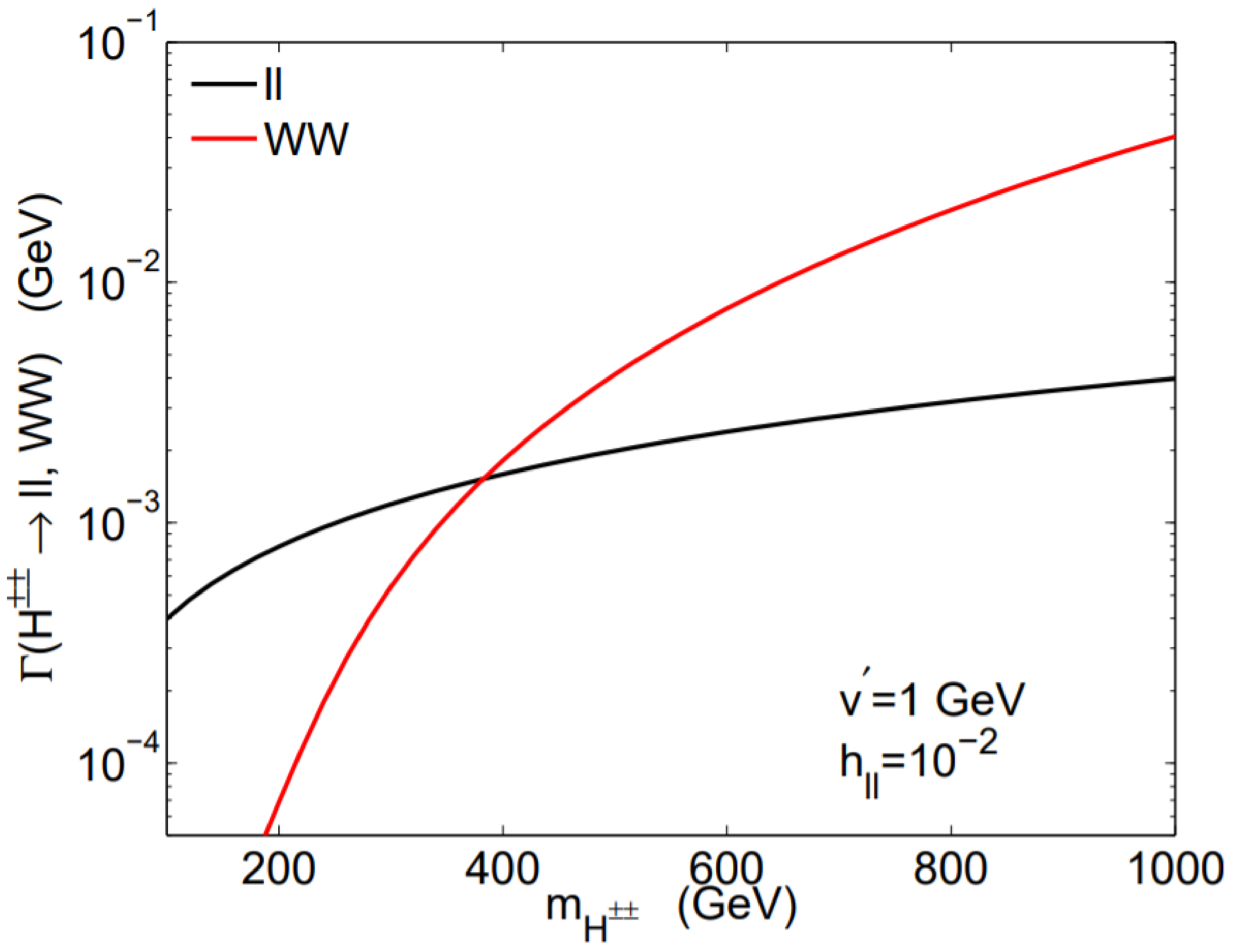

Branching ratios of $H^{\pm\pm}$ into different final states vs. mass of $H^{\pm\pm}$ for $v_\Delta = 1$ GeV, $h_{ll} = 0.01$. arXiv:1105.1379v1

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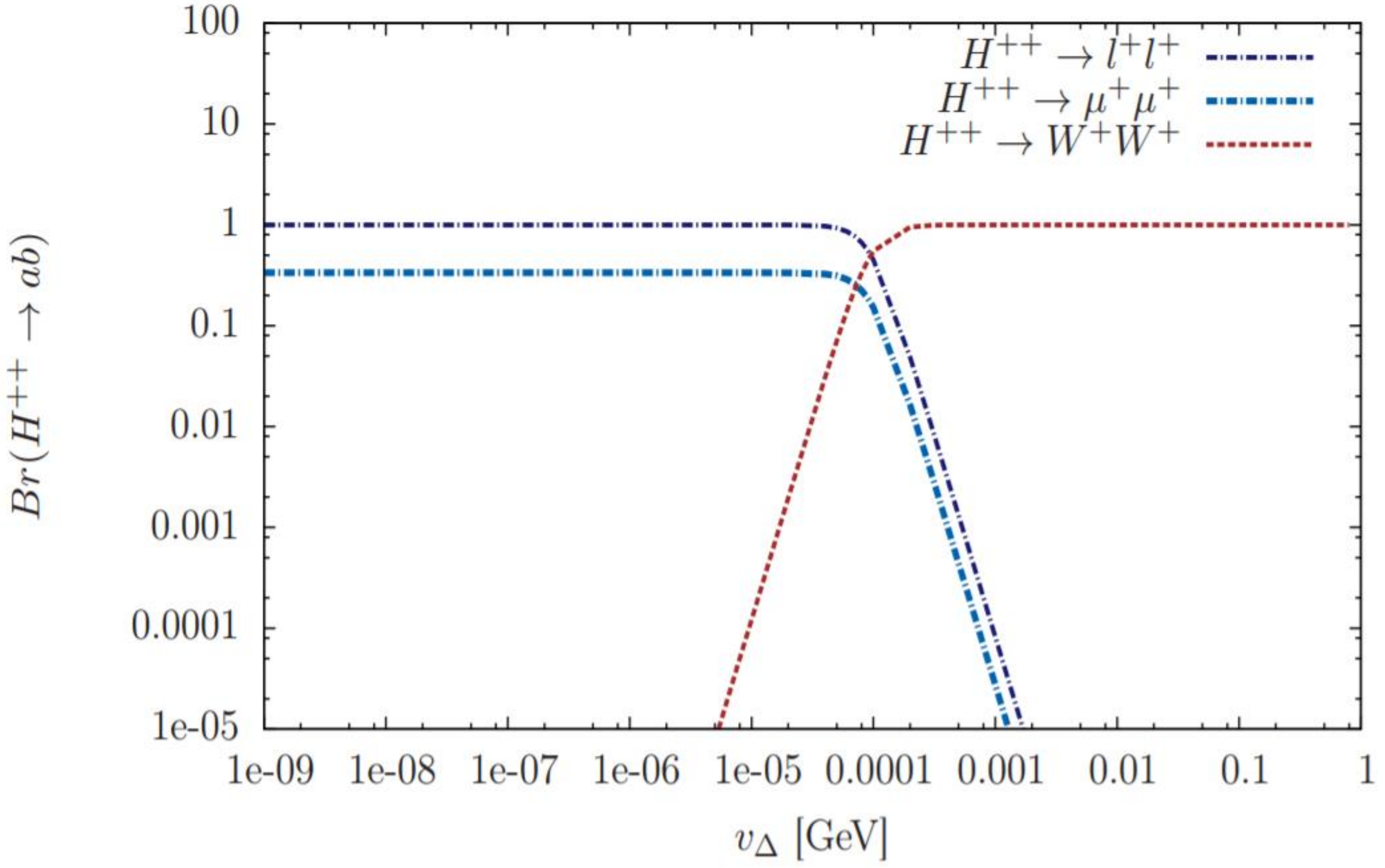

Branching ratios of $H^{\pm\pm}$ into different final states vs. vacuum expectation value. arXiv:1611.09594v2

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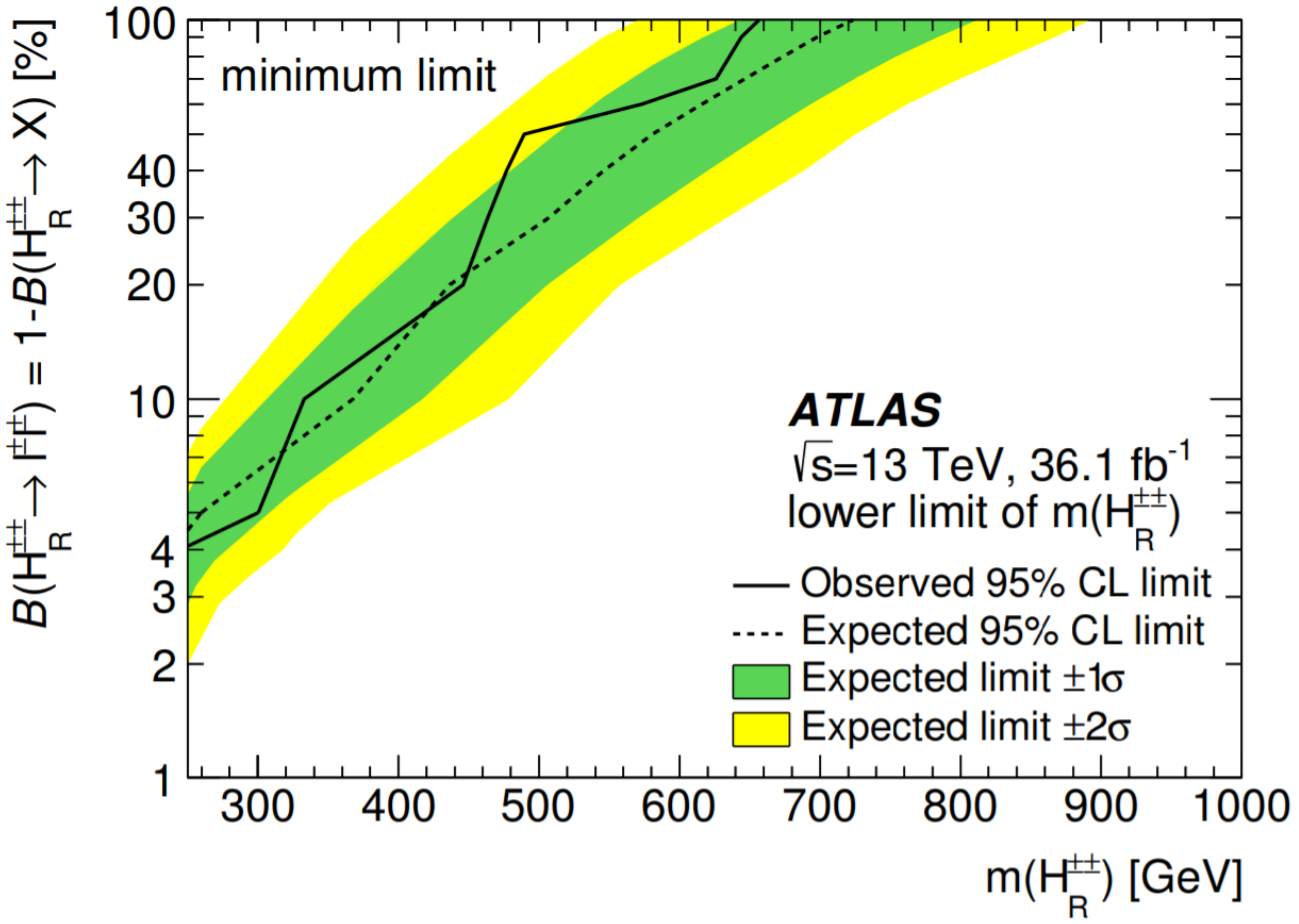
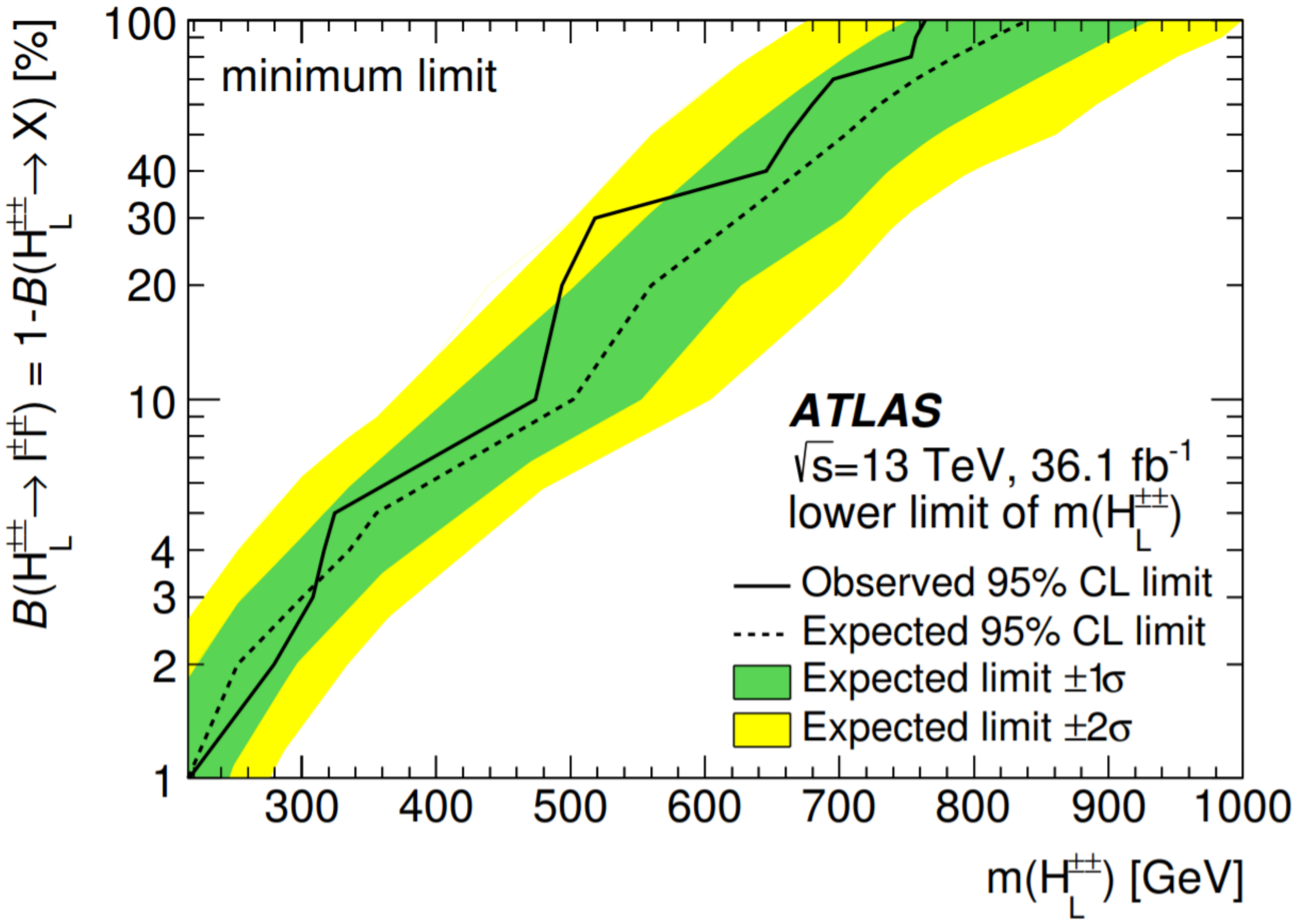
Lower-limit plots on $H_L^{\pm\pm}$ and $H_R^{\pm\pm}$ mass





arXiv: 1710.09748v1

What’s next??

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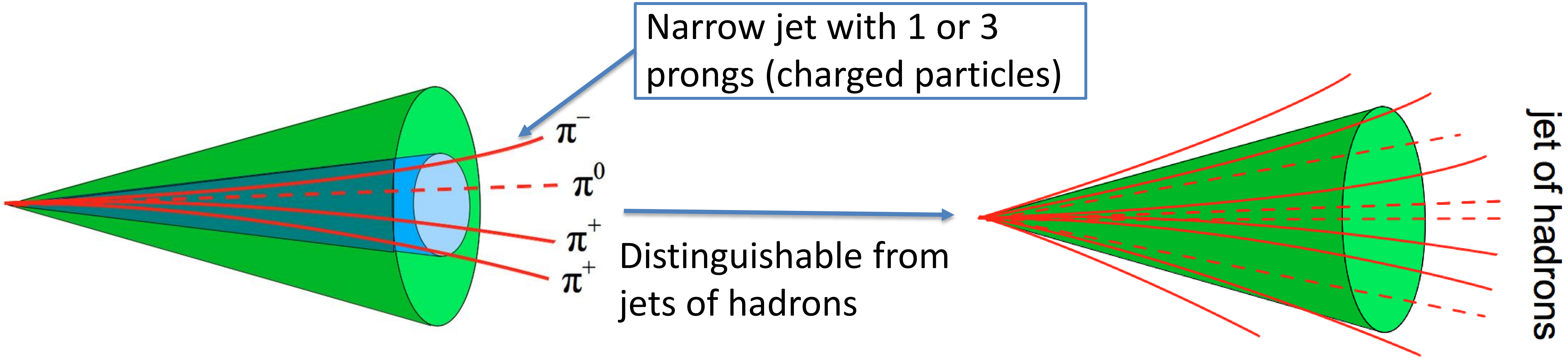
Add tau to the analysis!

- Excellent probe to new physics due to heavy mass (larger coupling to the SM Higgs)
- Based on the lower limits on $H^{\pm\pm}$, it's likely that tau appears in the decay products
- Only interested in hadronic decay modes of tau



What am I working on..

- Add hadronically decaying taus to the current analysis framework (TNAnalysis)
- Apply selections on the ntuples (Sherpa 2.2.1 $Z \rightarrow \tau\tau$ and data taken from 2015 to 2017)
  - $p_T \geq 30$ GeV
  - Trigger matching (HLT_tau35_medium1_tracktwo_tau25_medium1_tracktwo)
  - Truth info matching (only for MC)
- Use data-driven method to perform charge flip rate estimation

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Charge flip for tau

- Types of charge flip for electrons
  - Stiff tracks (high p_T → straighter tracks)
  - Trident events
- Assume Poissonian distribution for expected number of charge flipped events λ

$$P(N_{SS};\lambda) = \frac{\lambda^{N_{SS}} e^{-\lambda}}{N_{SS}!}$$

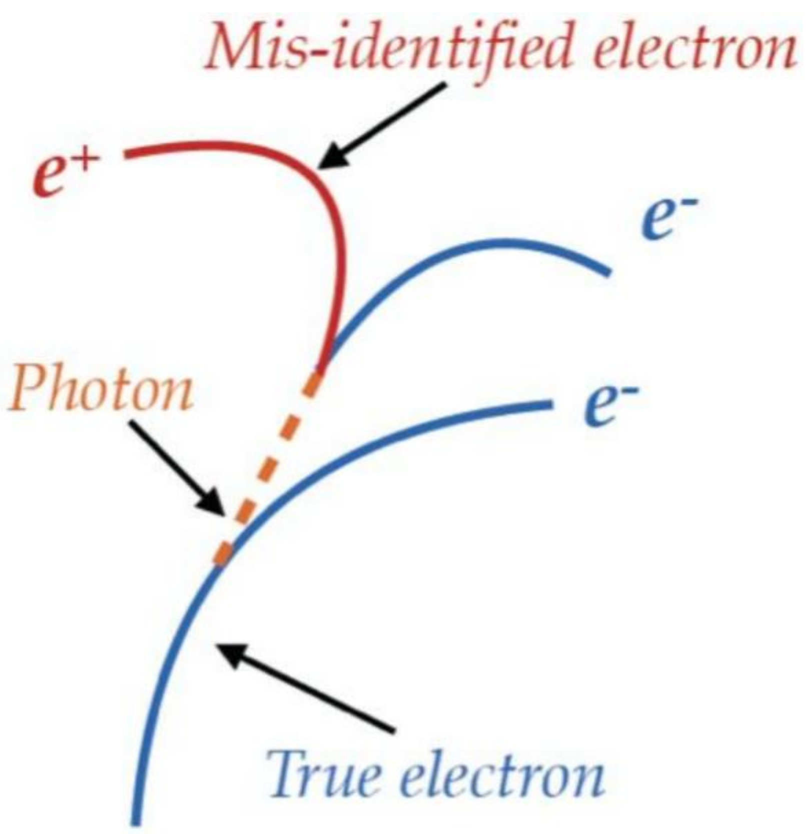
where λ is a function of the charge flip probability $\epsilon(p_T, \eta) = f(\eta) \cdot \sigma(p_T)$. Require $f(\eta)$ to be normalized.

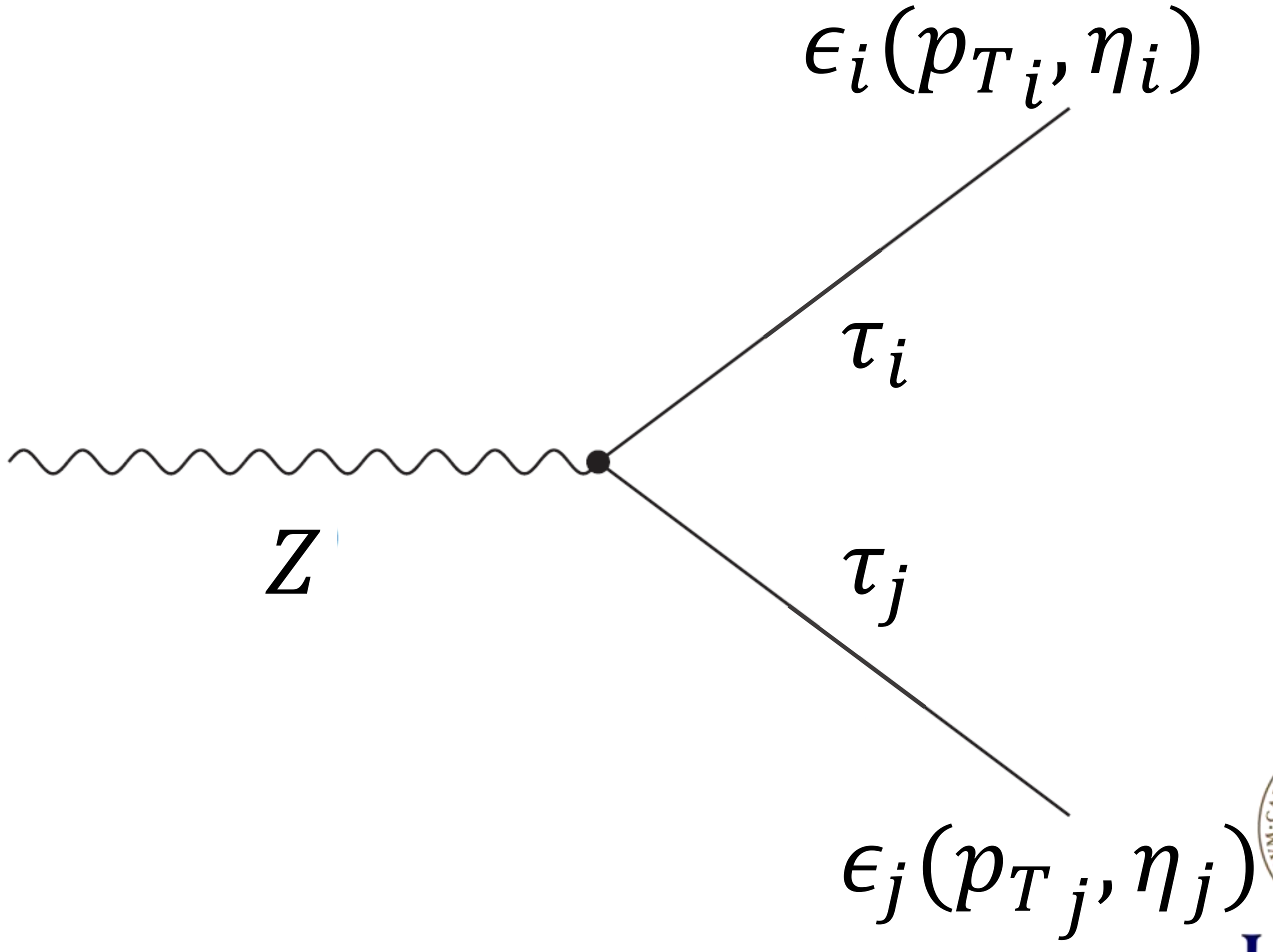
- The expected number of charge flipped events:

$$\lambda_{i,j} = \epsilon_i (1 - \epsilon_j) N_{AS}^{ij} + (1 - \epsilon_i) \epsilon_j N_{AS}^{ij}$$

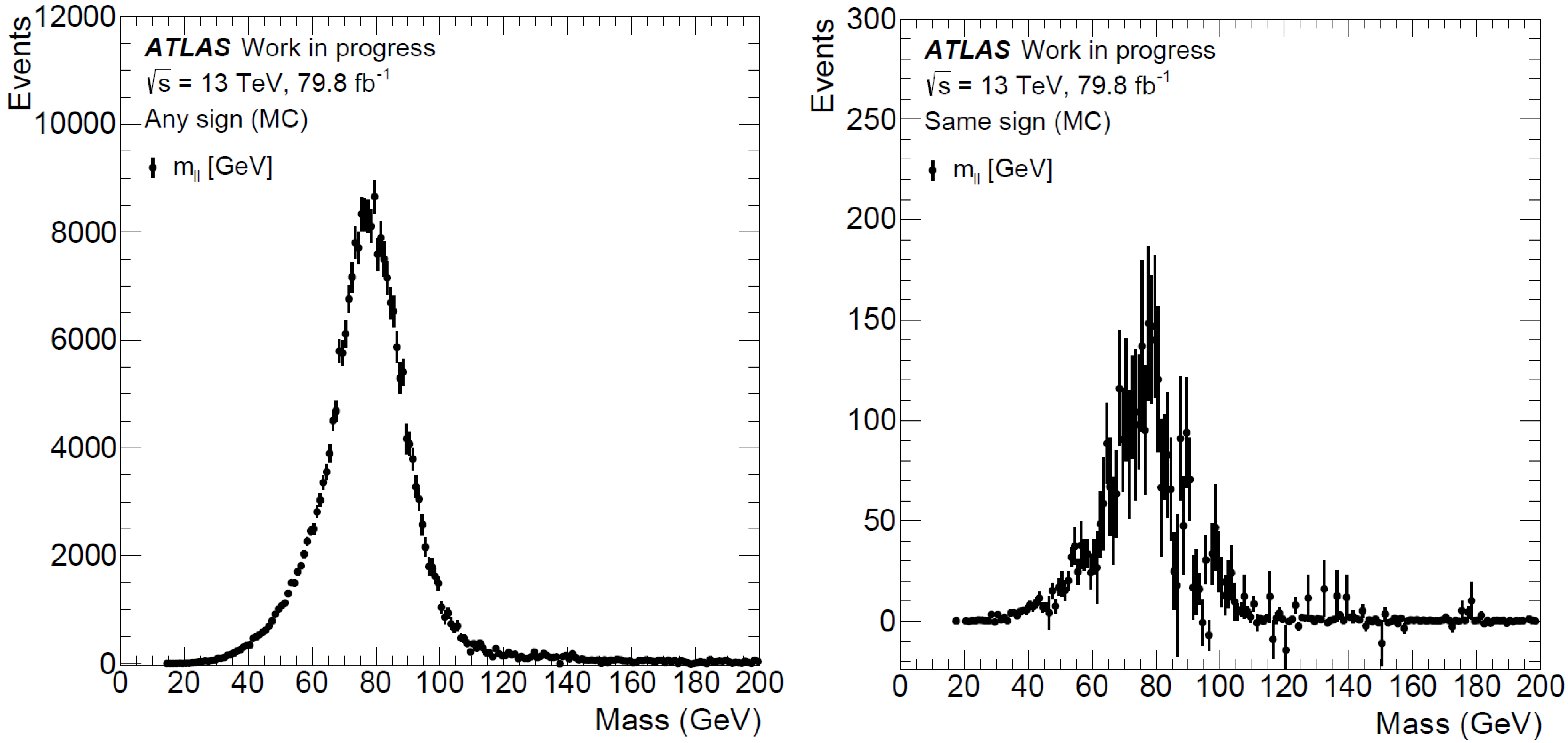
- Maximum likelihood method

$$\mathcal{L}(\lambda; N_{SS}) = \prod_{N_{SS}} P(N_{SS};\lambda) = \prod_{N_{SS}} \frac{\lambda^{N_{SS}} e^{-\lambda}}{N_{SS}!}$$





$Z \to \tau\tau$ mass spectrum of MC



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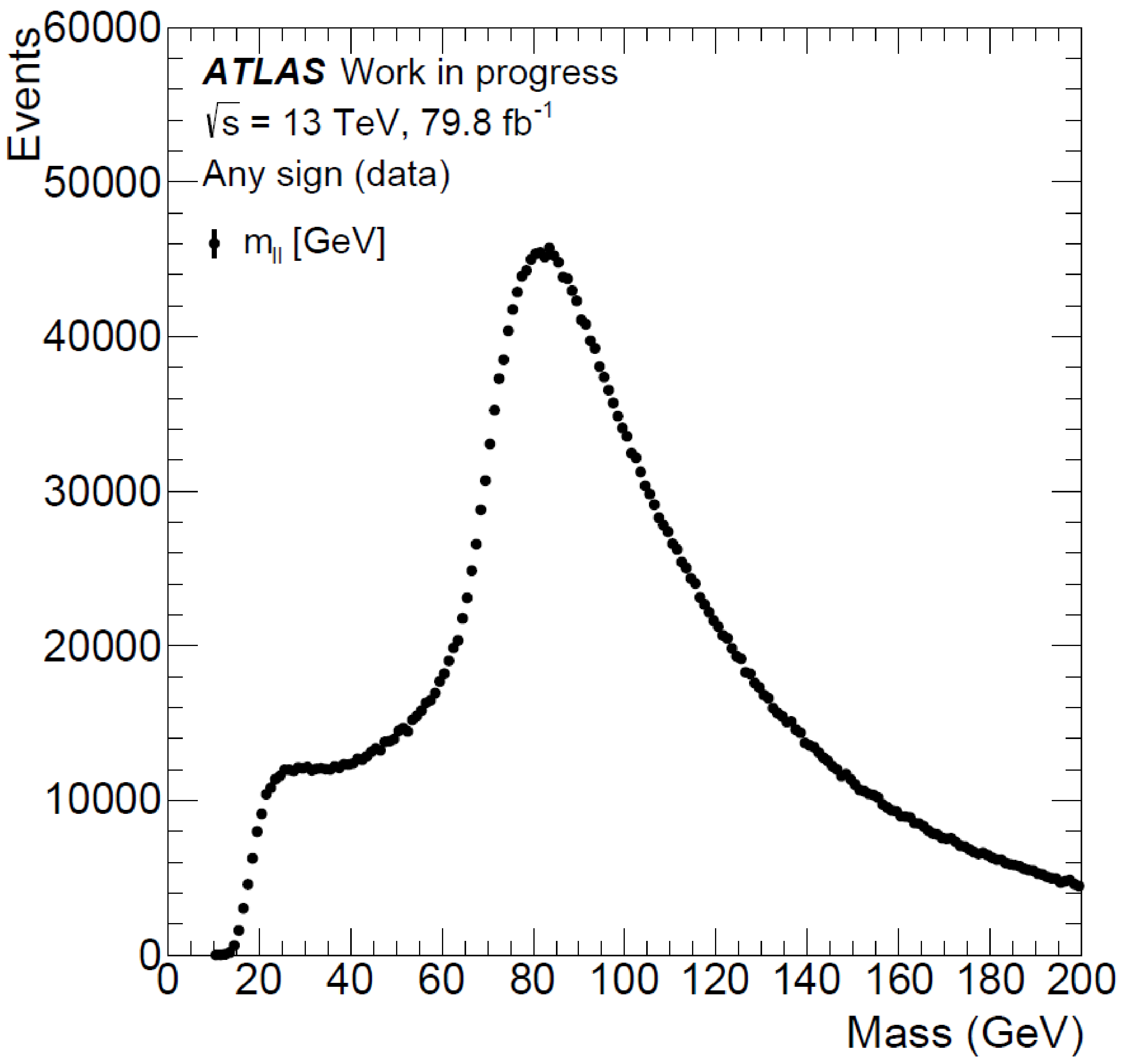
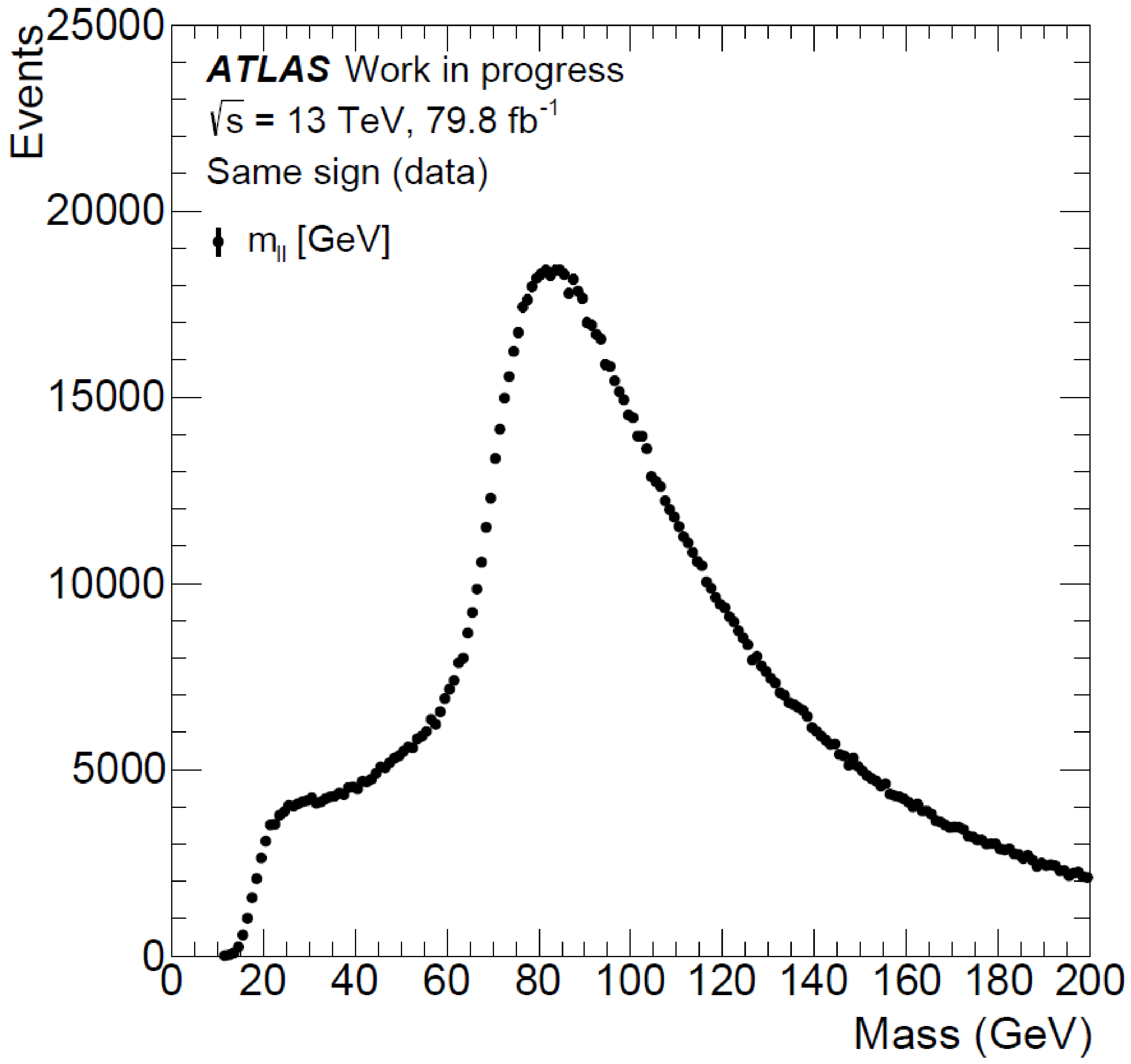
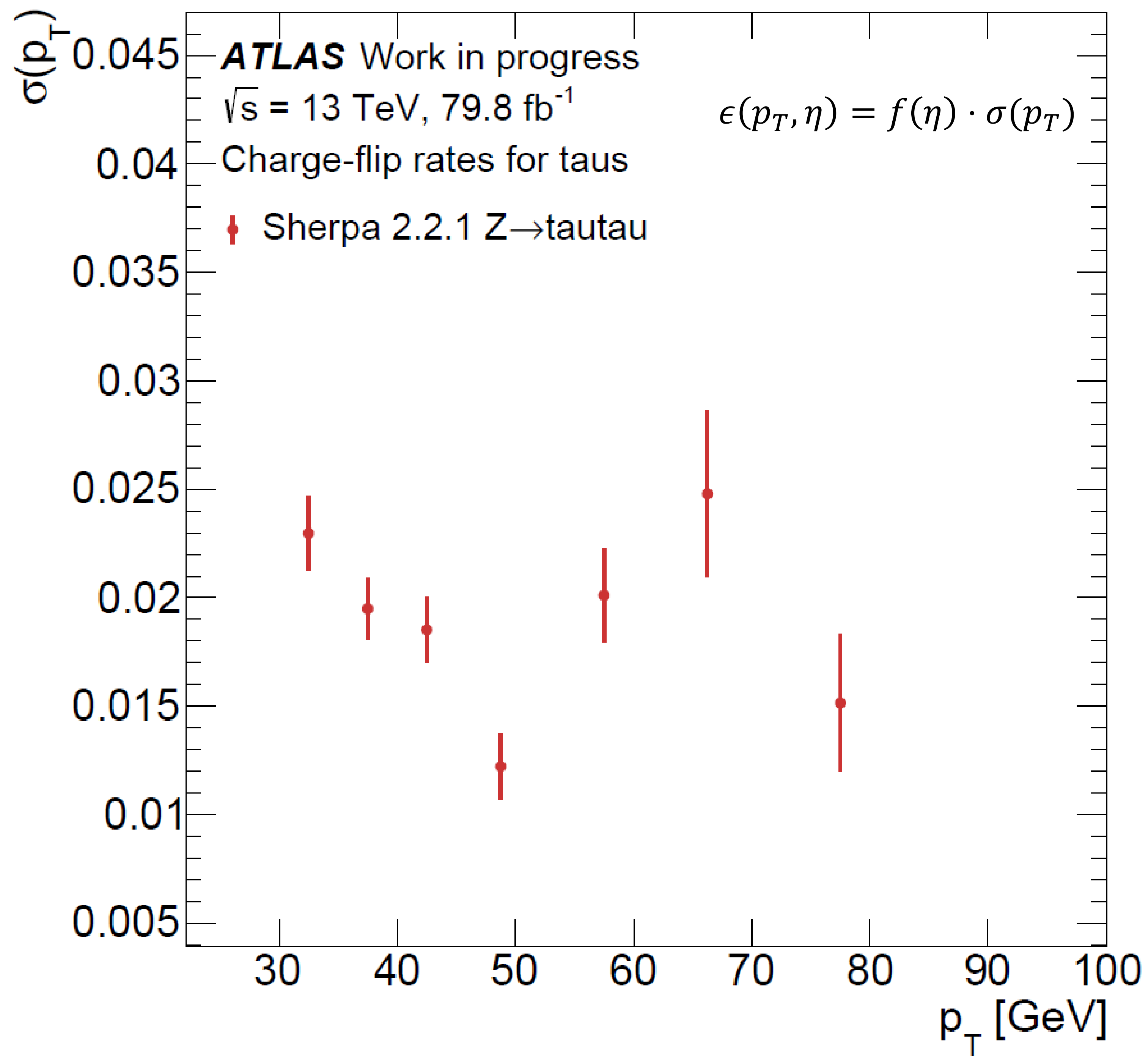
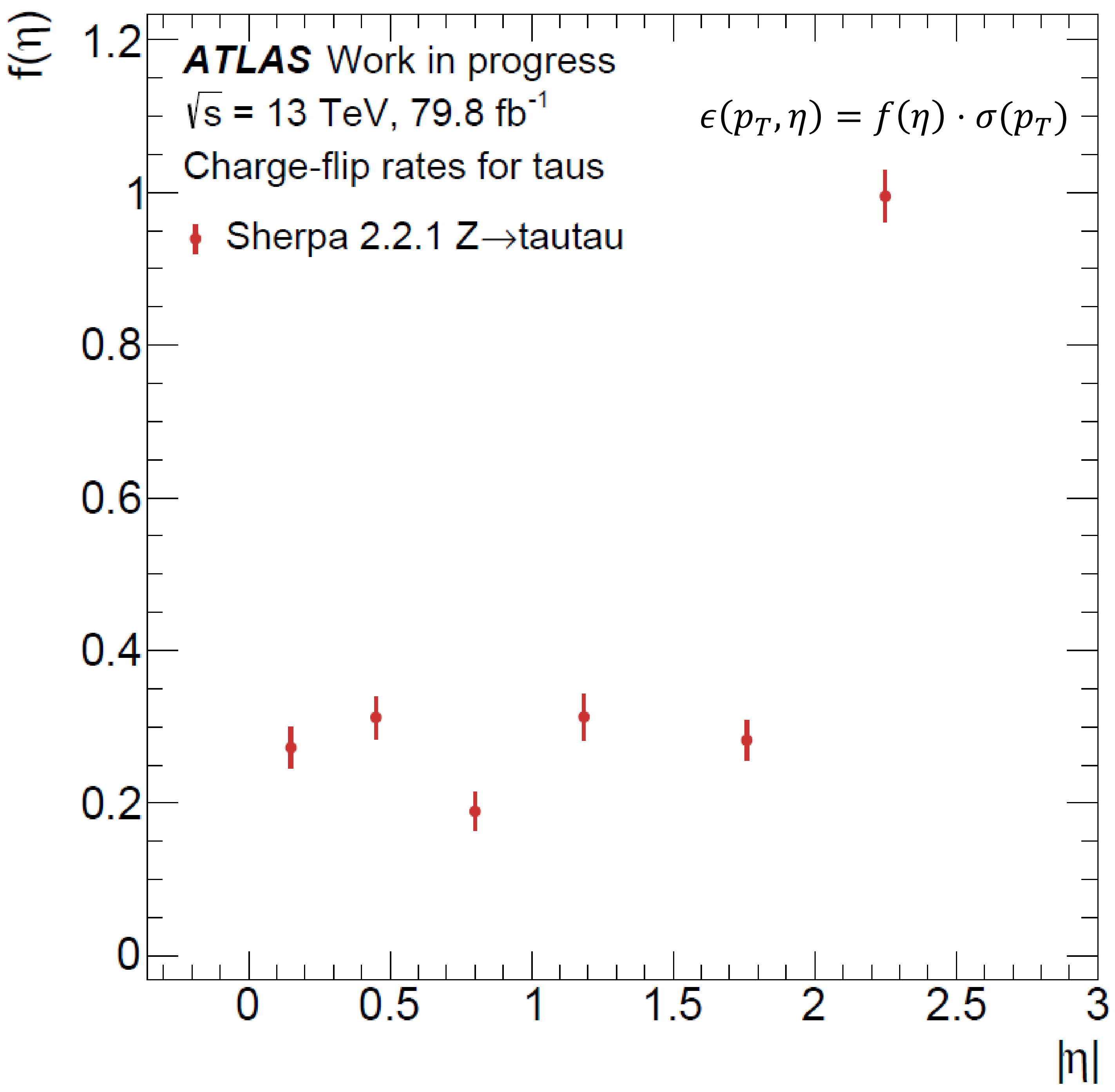
$Z \to \tau\tau$ mass spectrum of data





Current results on charge-flip rate for MC without prongness





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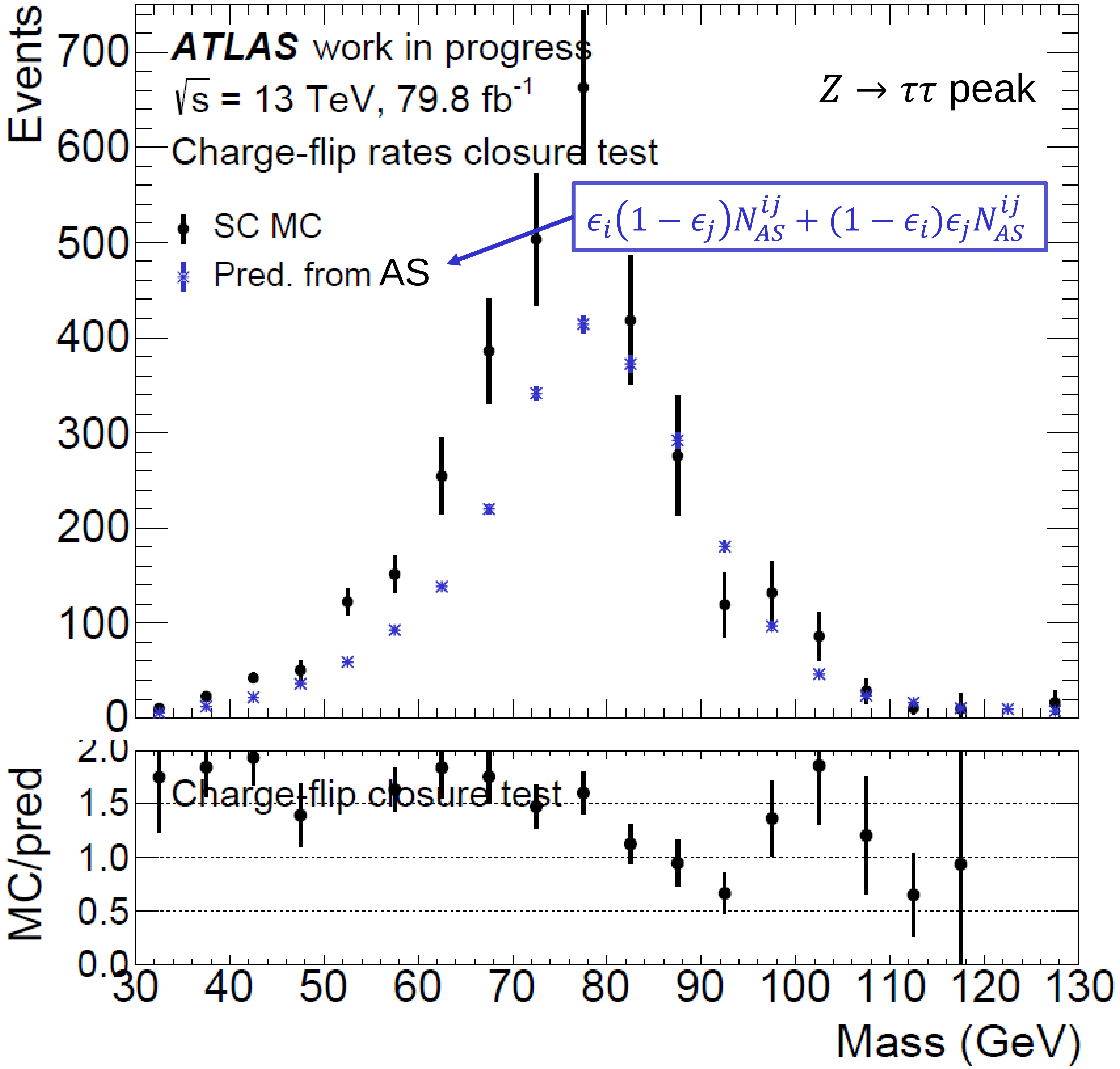
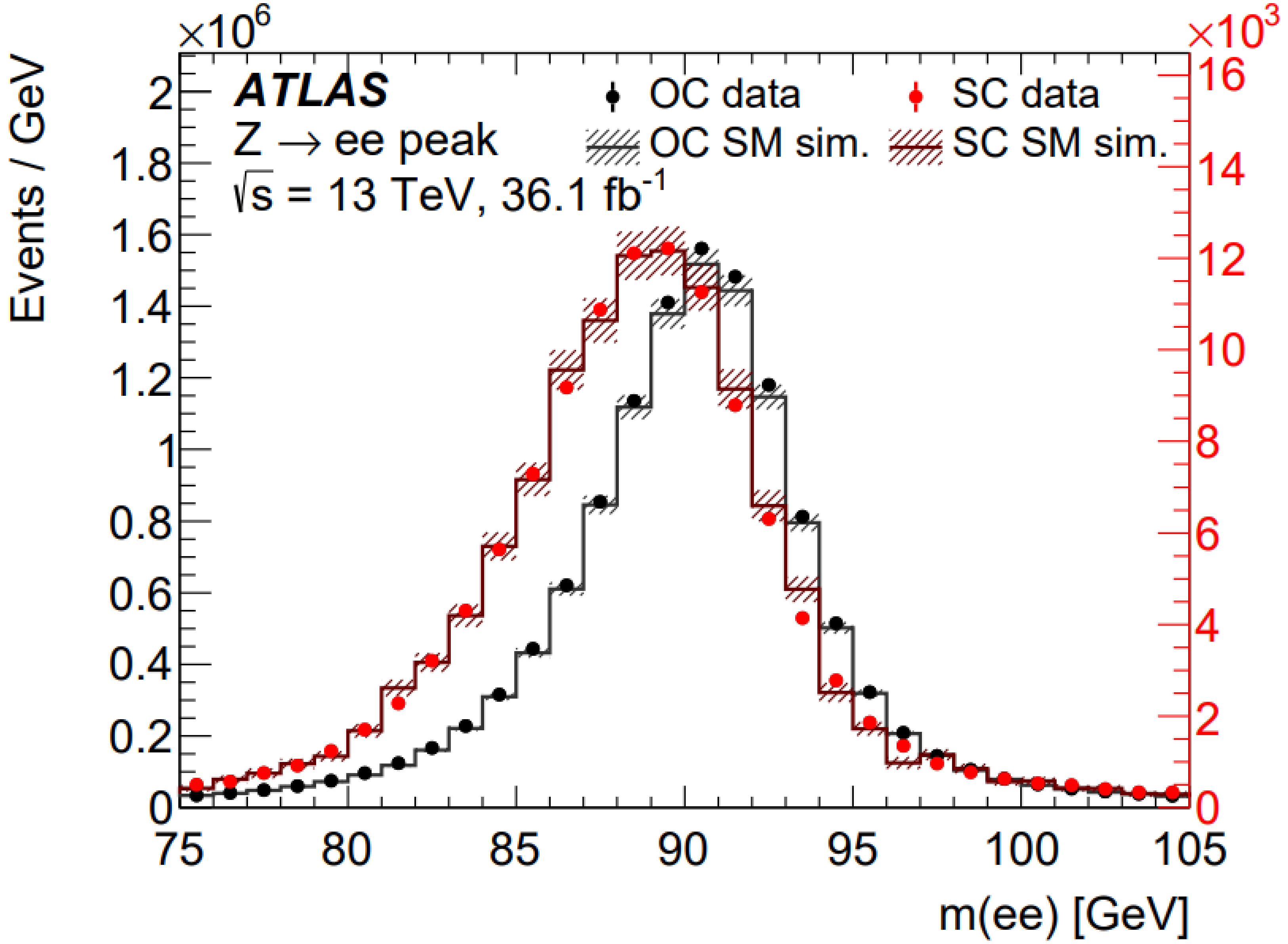
Closure test on the charge-flip rate of taus





arXiv: 1710.09748v1

What about charge-flip rate including prongness?

- Still working on it…
- Challenges
  - Two times more parameters to minimize
    - $\epsilon(p_T, \eta, prongness\ ) = f(\eta) \cdot \sigma(p_T) \cdot Y(prongness)$
  - The current minimization method need to be modified as normalization requirement on η does not seem to work well if we have $\eta_{1-prong}$ and $\eta_{3-prong}$

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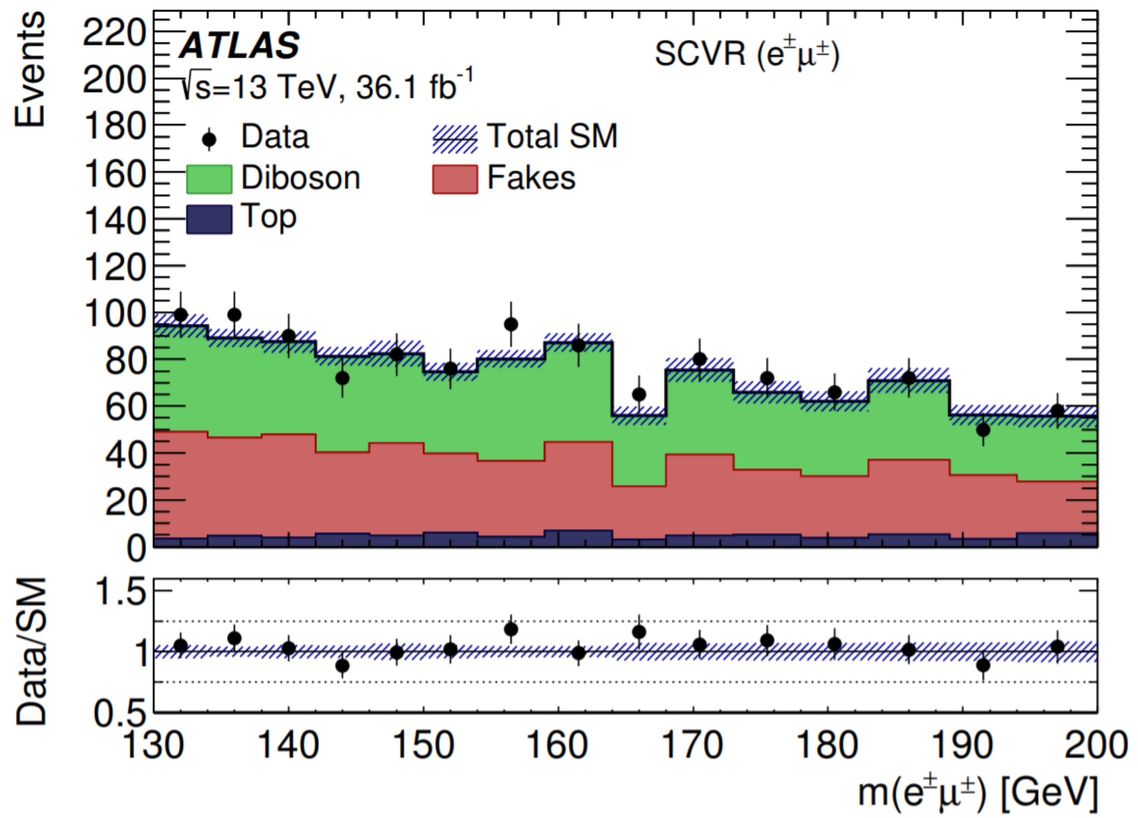
Future plans

- Perform charge-flip rate on 1-prong and 3-prong taus.
- Data have huge background. More studies on the background is required.

Backup slides

Previous $H^{++} + H^{--} \rightarrow l^+l^+l^-l^-$ analysis

- Selection:
  - e and μ
  - 2-, 3-, and 4-lepton final states
  - b-jet veto
  - Z veto on 1P3L & 2P4L
  - ΔR, p_T cuts
- Signal regions
  - 1P2L, 1P3L, 2P4L
- Control regions
  - Opposite-charge control region
  - Diboson control region
  - Diboson in $4l$ region
- Validation regions
  - Same-charge validation region
  - $3l$ validation region
  - $4l$ validation region



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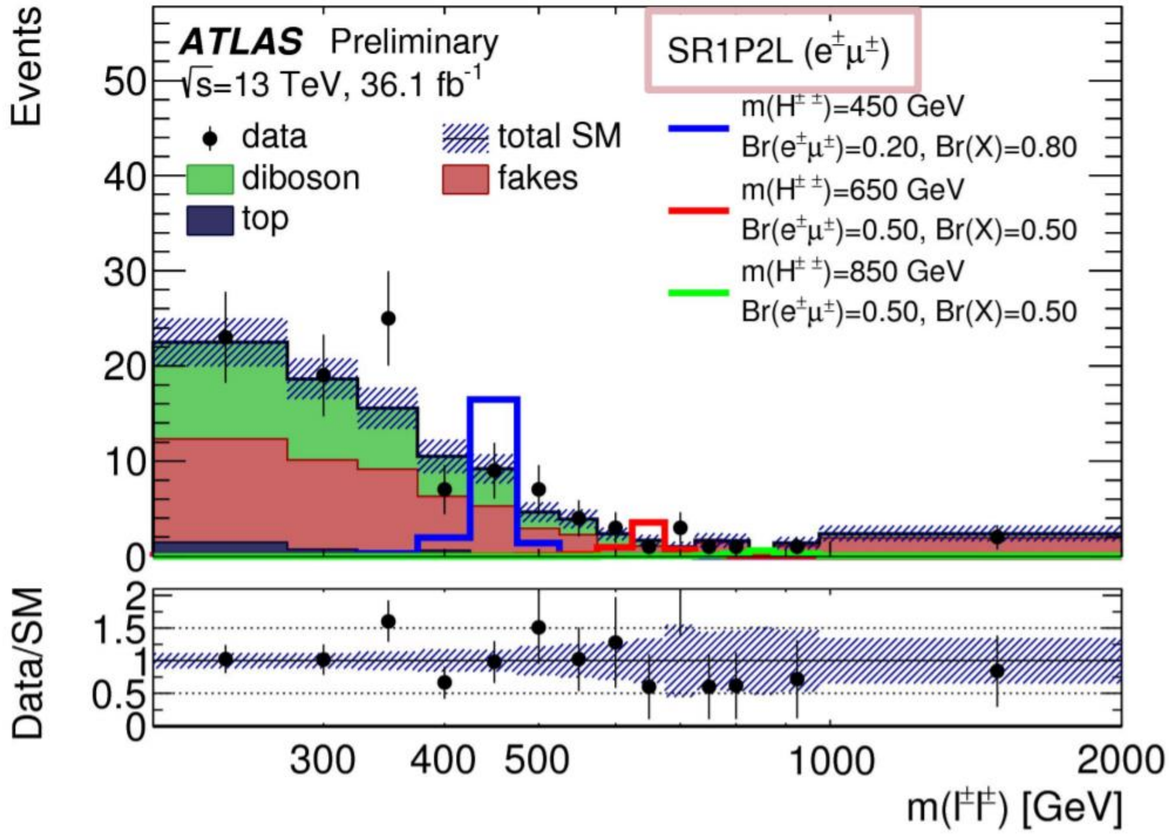
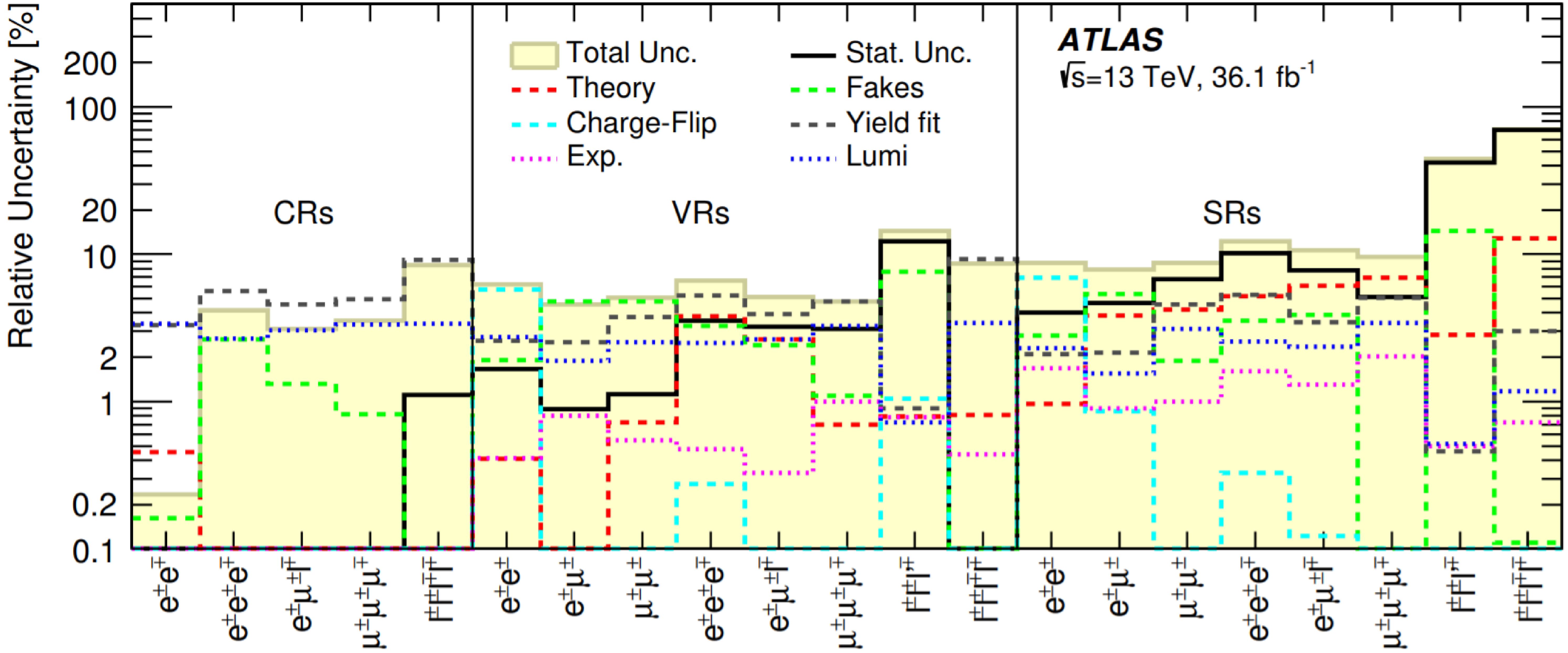


ATLAS-CONF-2017-053

Relative uncertainties in the total background yield estimation



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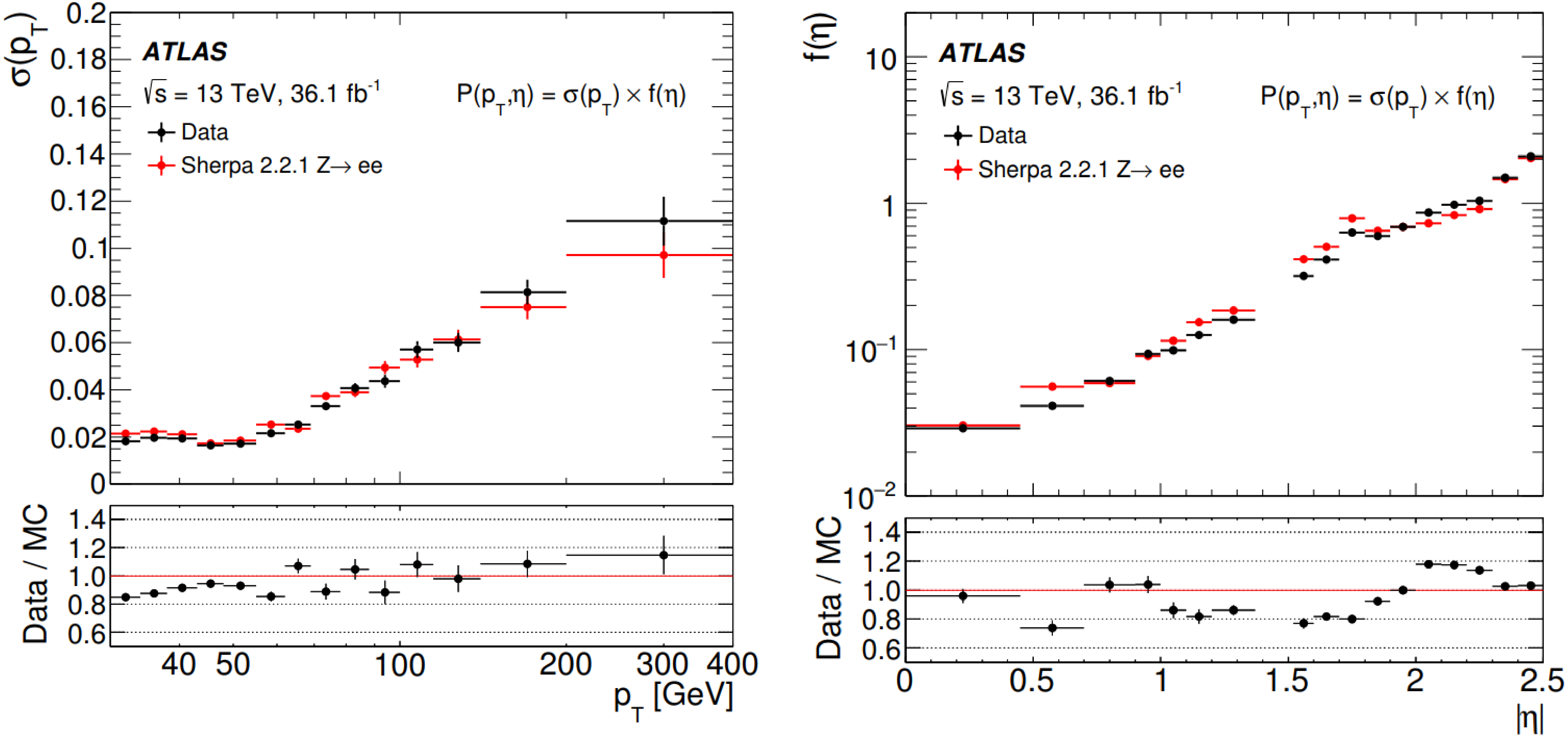
Summary of the results from previous study

Branching ratio assumption	Type of $H^{\pm\pm}$	Lower limit for mass
$Br(H^{\pm\pm} \rightarrow l^{\pm\pm}) = 100\%$	$H_L^{\pm\pm}$	Vary between 770 and 870 GeV
$Br(H^{\pm\pm} \rightarrow l^{\pm\pm}) = 10\%$	$H_L^{\pm\pm}$	450 GeV
$Br(H^{\pm\pm} \rightarrow l^{\pm\pm}) = 100\%$	$H_R^{\pm\pm}$	Vary between 660 and 760 GeV
$Br(H^{\pm\pm} \rightarrow l^{\pm\pm}) = 10\%$	$H_R^{\pm\pm}$	320 GeV

Charge-flip rate for electrons



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