Vectorlike leptons at future pp colliders

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@Snowmass EF09 Meeting
June 26th, 2020

Based on work with Steve Martin,
arXiv: hep-ph/1905.00498

Introduction

Motivations:

- New (4th gen.) chiral leptons not allowed
- Many BSM models require vectorlike leptons
- Obeys Decoupling, for higher masses
- Why not vectorlike leptons?

As 2-component LH fermions, transform under $SU(3)_c \times SU(2)_L \times U(1)_Y$ as:

$L + \bar{L} = (1, 2, -1/2) + (1, 2, +1/2)$ Doublet VLL

$E + \bar{E} = (1, 1, -1) + (1, 1, +1)$ Singlet VLL

} minimal VLL models

See P.N.B, S.P. Martin (1905.00498) for non-minimal models

NO prospects for exclusion/discovery for any pp collider options considered!

Considered the prospects for exclusion/discovery of VLLs at:

- HL-LHC: $\sqrt{s}$ = 14 TeV with 3 ab^{-1}
- HE-LHC: $\sqrt{s}$ = 27 TeV with 15 ab^{-1}
- FCC-hh or SppC: $\sqrt{s}$ = 100 TeV with 30 ab^{-1}

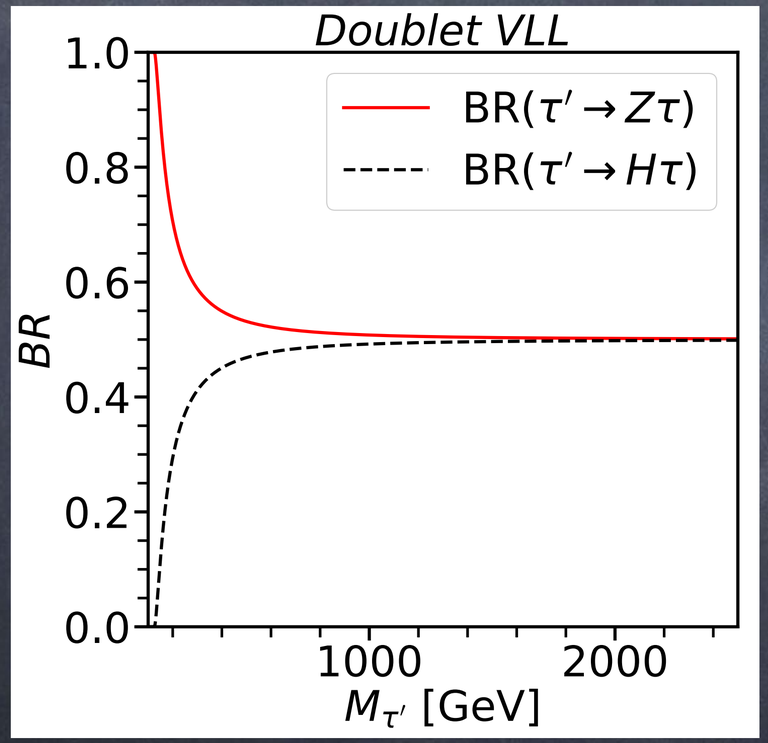
Branching Ratios

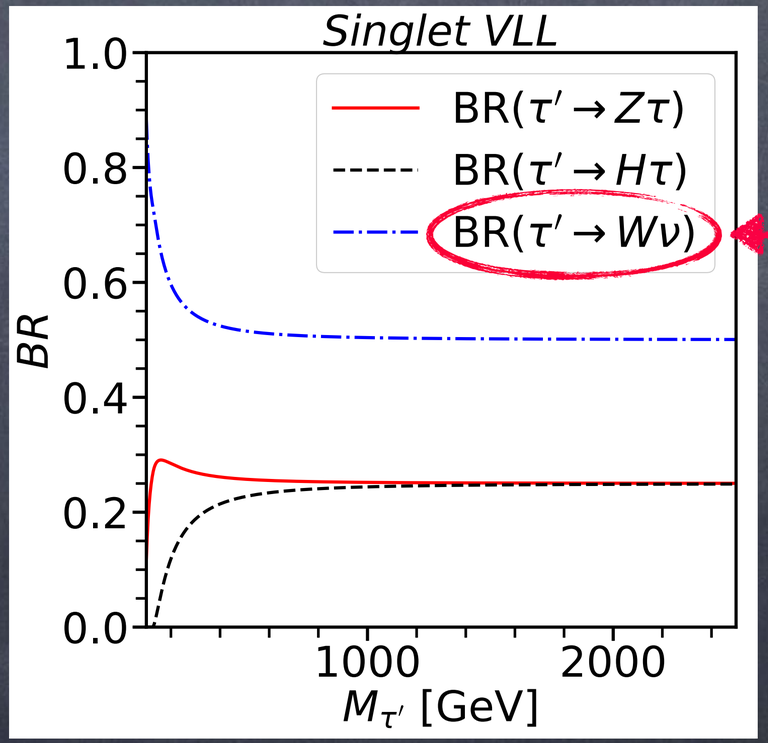
new charged VLL

Assume decays to SM by mass mixing of τ and τ' in both models.

$$\mathscr{M} = \begin{pmatrix} y_\tau v & 0 \\ \epsilon v & M_{\tau'} \end{pmatrix}$$

Assume Small, and need $\geq 10^{-7}$ for prompt τ' decays

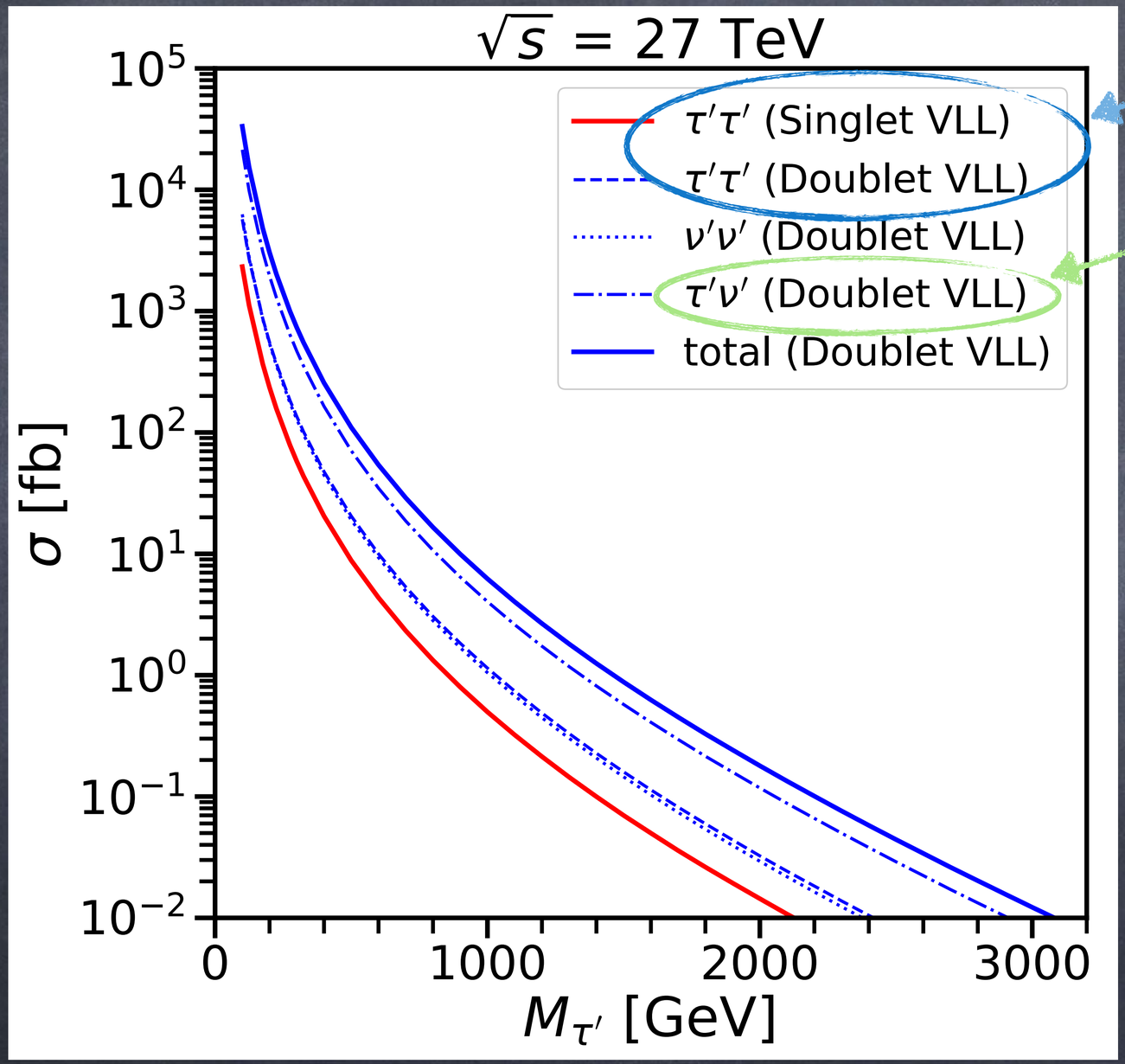




Largest! (unfavorable decays)

Also, $BR(\nu' \to W\tau) = 1$, for Doublet VLL

Production cross-sections (at LO)



much larger in Doublet VLL than in Singlet VLL

largest in Doublet VLL (mediated through W-boson)

Signal components and Backgrounds

The final states for the Doublet VLL: $pp \to \tau'\tau' \to ZZ\tau\tau, \quad hh\tau\tau, \quad Zh\tau\tau$

$pp \to \tau'\nu' \to ZW\tau\tau, \quad hW\tau\tau$

$pp \to \nu'\nu' \to WW\tau\tau$

The final states for the Singlet VLL: $pp \to \tau'\tau' \to ZZ\tau\tau, \quad hh\tau\tau, \quad Zh\tau\tau$

$ZW\tau + E_T^{\text{miss}}, \quad W\tau + E_T^{\text{miss}}$

$WW + E_T^{\text{miss}}$ (largest!)

Backgrounds: $WZ, ZZ, t\bar{t}Z, t\bar{t}W, hW, hZ, t\bar{t}h, WWW, WWZ, ZZW,$ and ZZZ contributing to multi-lepton final states.

Signal and background events were generated (at LO) by:

FeynRules -> MadGraph5 -> Pythia8 -> Delphes

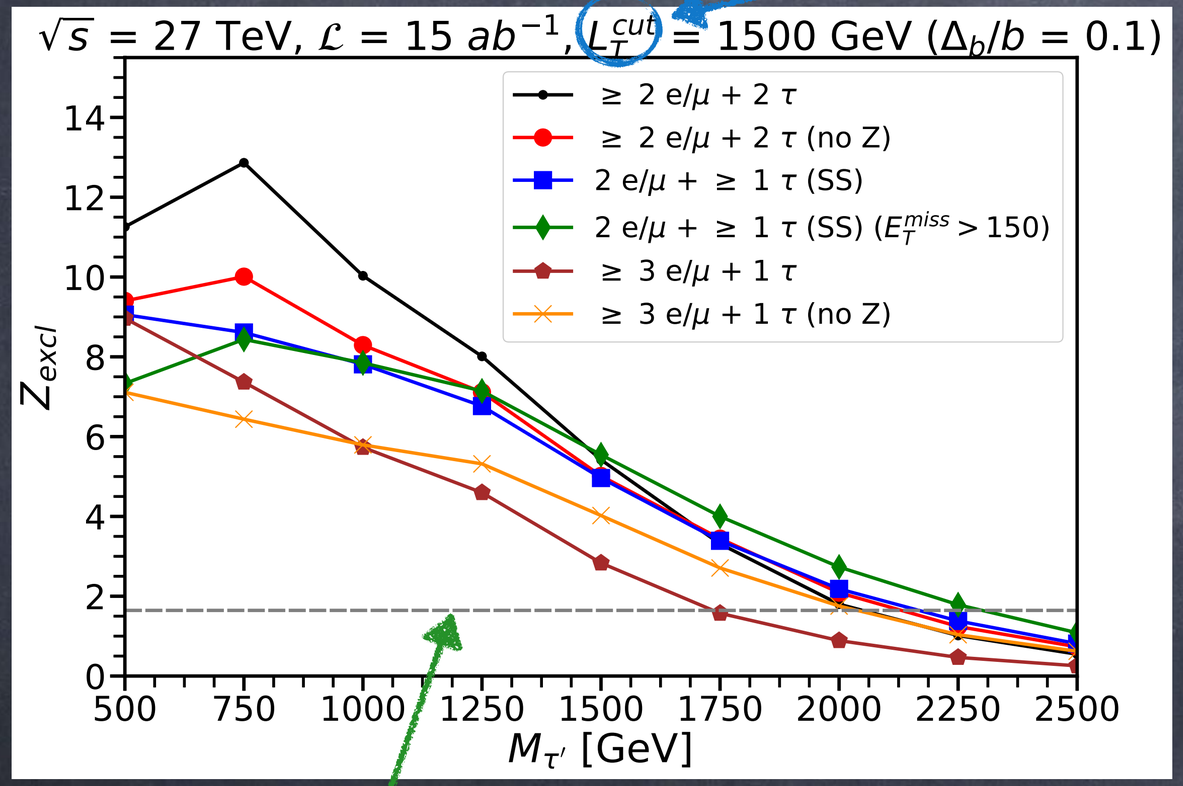
Results for HE-LHC collider (Doublet VLL)

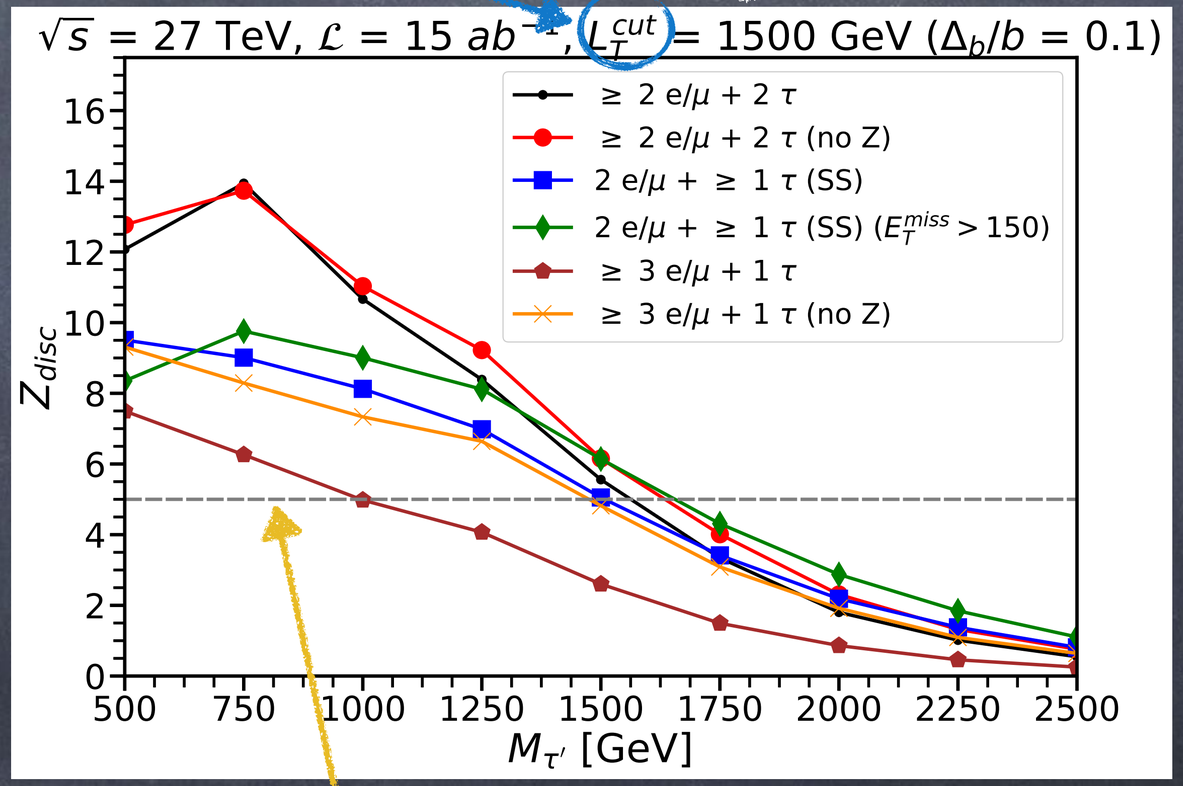
Median expected significances for:

Exclusion

L_T is the sum of lepton (incl. τ) p_Ts

Discovery



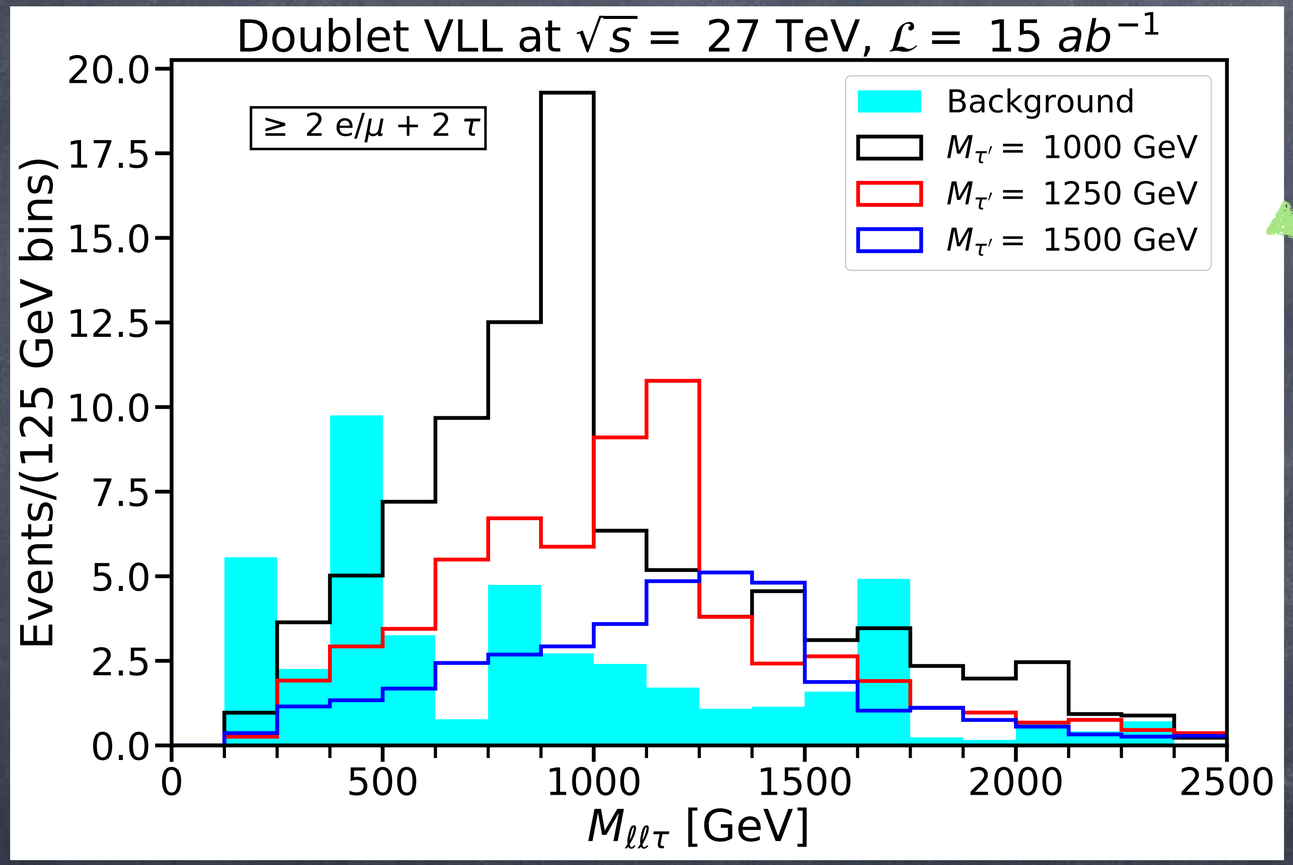


median expected significance for 95% CL exclusion

median expected significance for 5σ discovery

Mass measurements

If Doublet VLL discovered,



Require $|M_{e^+e^-\text{ or }\mu^+\mu^-} - M_Z| < 10$ GeV and $L_T > 1500$ GeV

Distributions for $M_{\tau^\pm e^+e^-}$ or $M_{\tau^\pm \mu^+\mu^-}$ for different $M_{\tau'}$, peaked below their respective masses.

Conclusion

- **Doublet VLL:** Excellent reach prospects for 95% CL exclusion or 5σ discovery. Assuming $\Delta_b/b = 0.1$, (Present LHC bounds: CMS search in 1905.10853 excludes 120 GeV < $M_{\tau'}$ < 790 GeV.)

Collider	Exclusion reach	Discovery reach
14 TeV HL-LHC, 3 ab^{-1}	1250 GeV	900 GeV
27 TeV HE-LHC, 15 ab^{-1}	2300 GeV	1700 GeV
100 TeV pp collider, 30 ab^{-1}	5750 GeV	4000 GeV

- **Singlet VLL:** No exclusion/discovery reach for isosinglet charged leptons for any pp collider options or multi-lepton signal regions considered. (Challenge! Impossible at hadron colliders?)

e^+e^- colliders should be able to see them easily!

THANK YOU!

BACKUP SLIDES

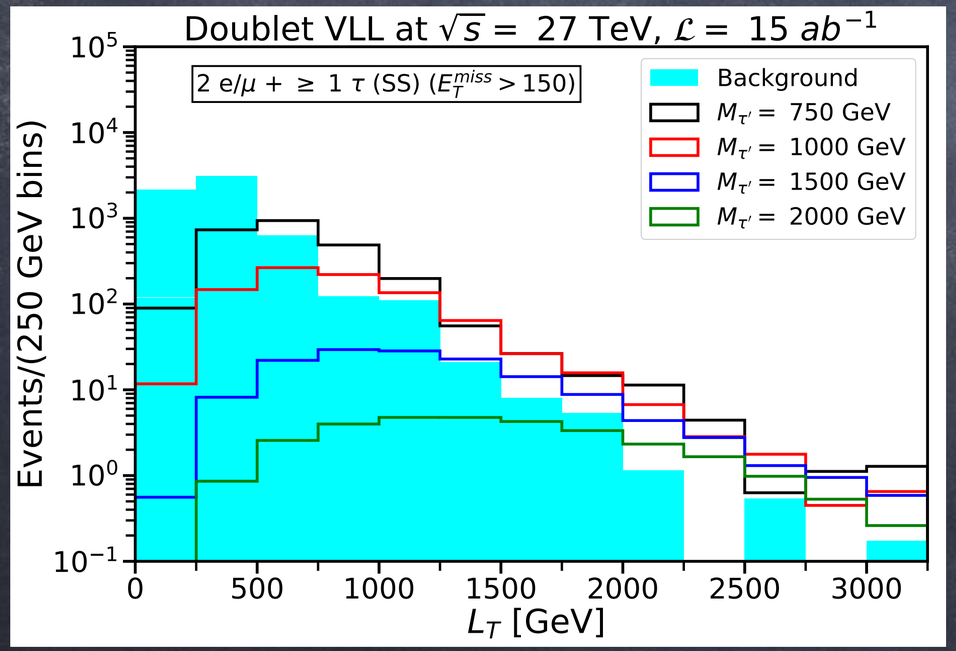
Signal Regions and L_T event distributions

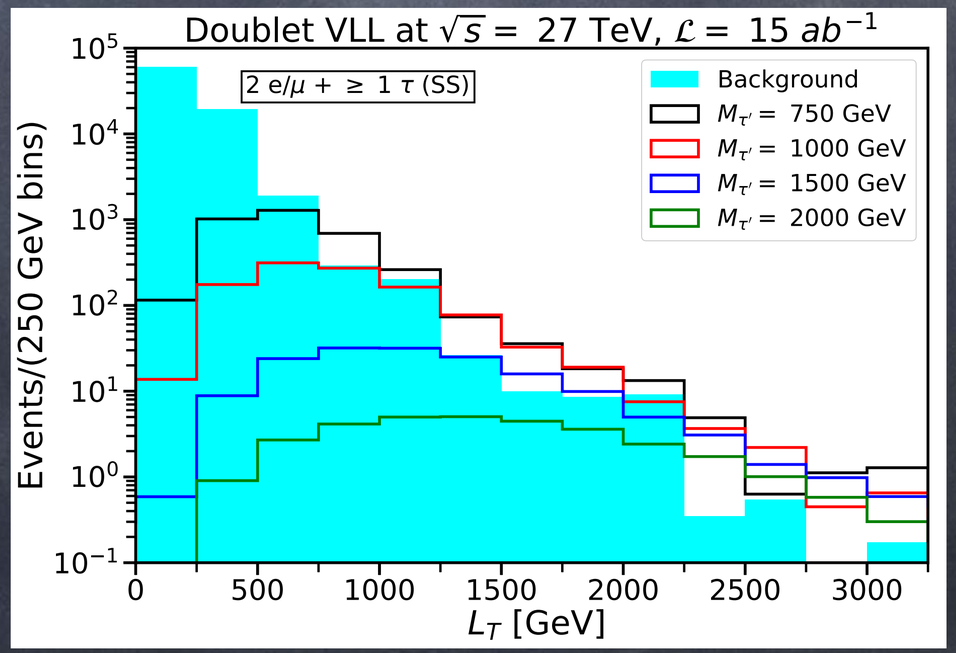
Simple cut-and-count analysis based on the kinematic variable:

$$L_T = \sum_{\ell=e,\mu,\tau} p_T^{\ell}$$

Consider the following signal regions:

- 2 same-sign e/μ + $\geq 1\tau$
- 2 same-sign e/μ + $\geq 1\tau$ with miss E_T > 150 GeV
- $\geq 3e/\mu + 1\tau$
- $\geq 3e/\mu + 1\tau$, no-Z
- $\geq 2e/\mu + 2\tau$
- $\geq 2e/\mu + 2\tau$, no-Z





Median expected significances†

Let,

- s: mean of Poisson distributed signal events
- b: mean of Poisson distributed background events
- Δ_b: variance (or "uncertainty") in the background events

The median expected significance for discovery (where the null hypothesis is background only, and the signal is assumed to be present in the data):

$$Z_{\text{disc}} = \left[2\left((s+b)\ln\left[\frac{(s+b)(b+\Delta_b^2)}{b^2+(s+b)\Delta_b^2}\right] - \frac{b^2}{\Delta_b^2}\ln\left[1+\frac{s\Delta_b^2}{b(b+\Delta_b^2)}\right]\right)\right]^{1/2}$$

For 5σ discovery, require $Z_{\text{disc}} > 5$

Similar formula for median expected significance for exclusion (Z_{excl})

For 95% CL exclusion, require $Z_{\text{excl}} > 1.645$

†For more details about median expected significances, see e.g. Cowan, Cranmer, Gross, Vitelis (1007.1727), N. Kumar, S.P. Martin 1510.03456