Probing the $H^{\pm}$ with the μ_x boosted-bottom-jet tag

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Two-Higgs doublet models (2HDM)

Two-Higgs doublet models (2HDM) are common features in extensions to the SM, especially in SUSY (which needs at least two Higgs doublets). Symmetry breaking produces three scalar Higgs (h, H, $H^{\pm}$) and a pseudo-scalar (A).

$\tan(\beta)$: the ratio of the two VEVs $\beta-\alpha$: the doublet mixing angle

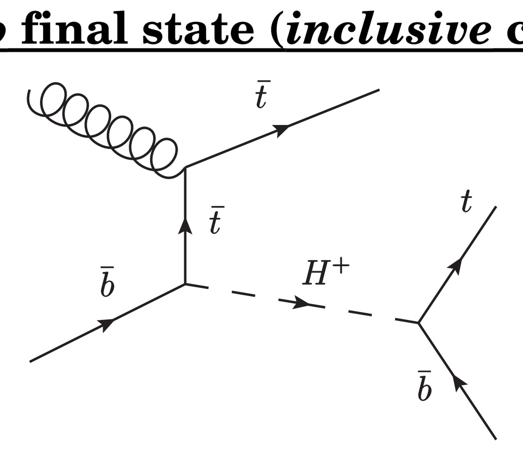
Realistic 2HDM

- **FCNC** are absent at tree level in **type-II** 2HDM; these also respect SUSY's requirement that u_R and d_R couple to opposite doublets.
- There's a **126 GeV boson** that **couples** like a Standard Model Higgs! 2HDM must exist close to the "alignment" limit ($\cos(\beta-\alpha)\to 0$), so that h is the SM Higgs.

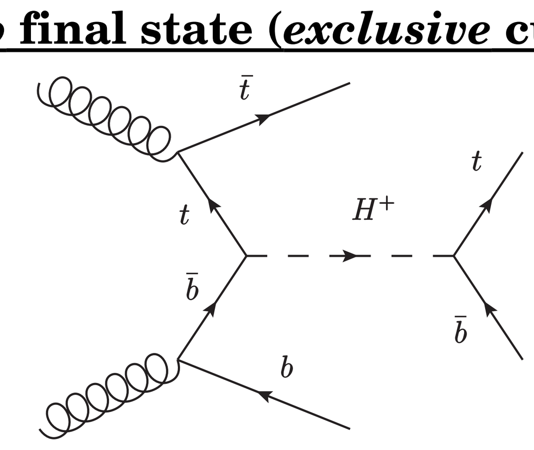
Phenomenological considerations

- If H, A and $H^{\pm}$ have similar masses (a consequence of SUSY in the alignment limit), they won't decay to each other, but to the SM particles with the largest Yukawa couplings ... **top** and **bottom** quarks (there is no $ZW^{\pm}H^{\pm}$ vertex in 2HDM).
- Interference with SM background makes H and A difficult to detect and model. Associated $H^{\pm}$ production avoids this, and adds more heavy-flavored jets to tag.

3b final state (*inclusive* cuts)

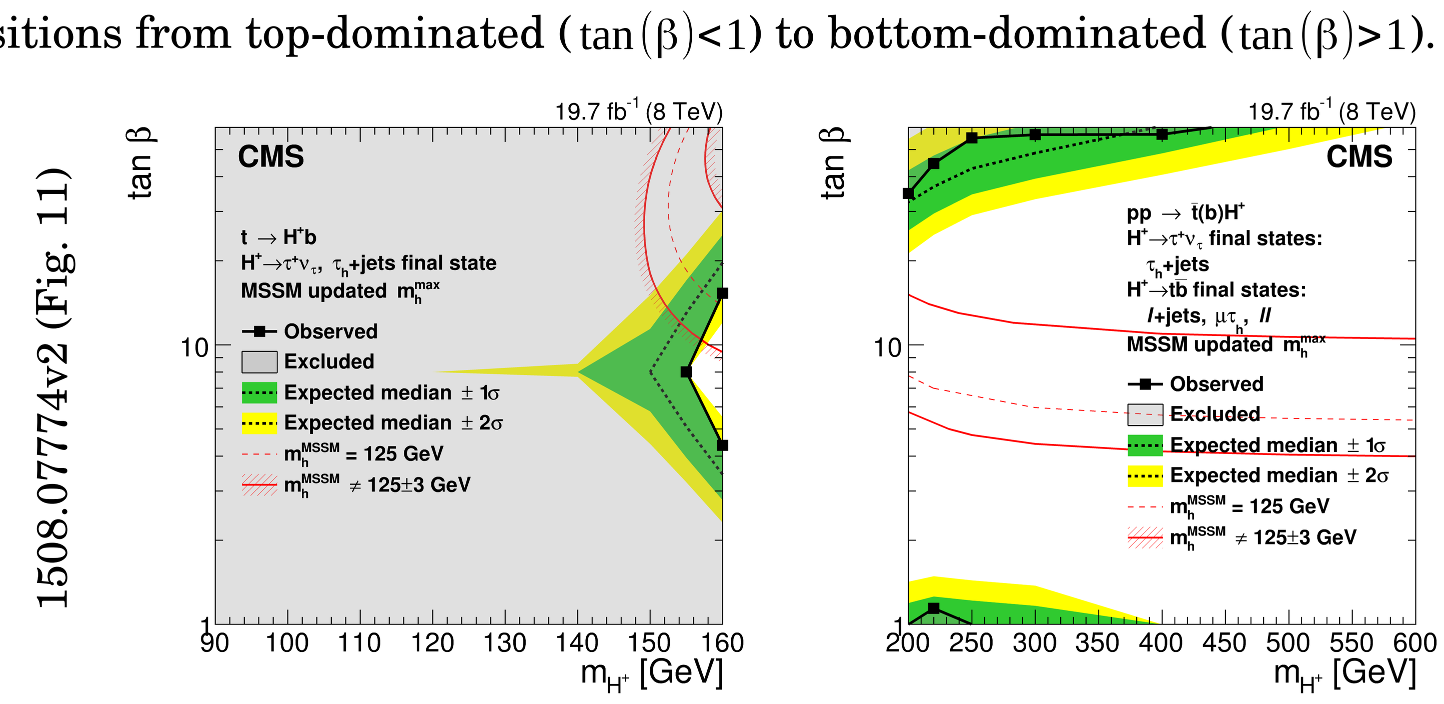


4b final state (*exclusive* cuts)



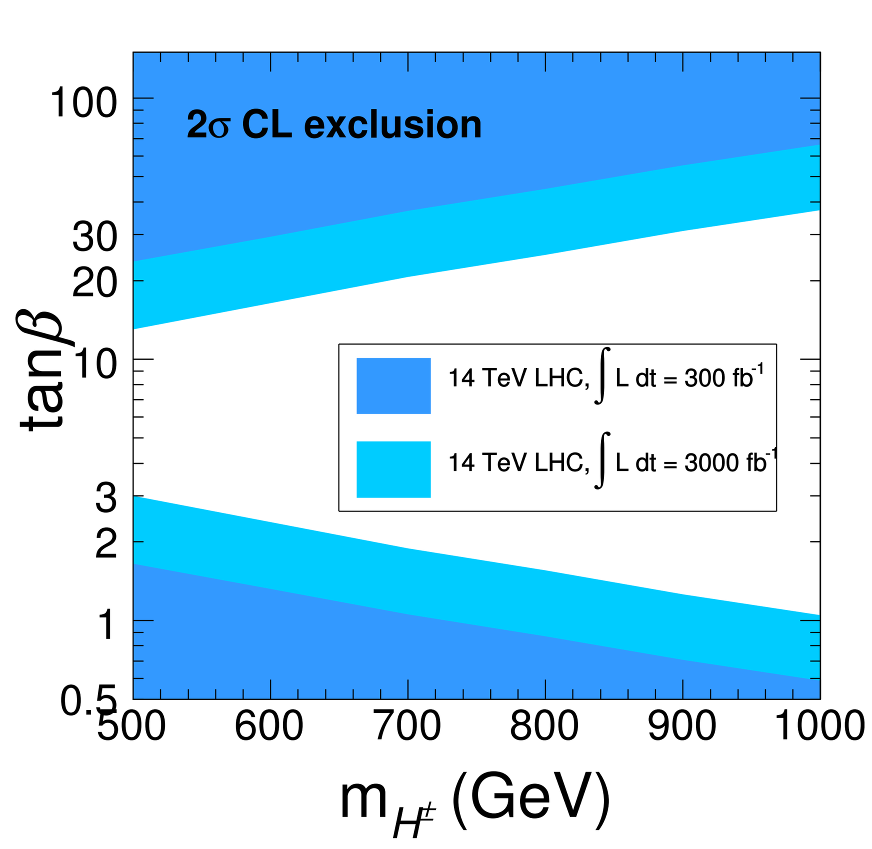
Experimental challenges

1. The wedge: A "natural" 2HDM should have $\tan(\beta)=O(.1-10)$. This range covers a "wedge" of low production cross section, where the Yukawa coupling to $H^{\pm}$ transitions from top-dominated ($\tan(\beta)<1$) to bottom-dominated ($\tan(\beta)>1$).

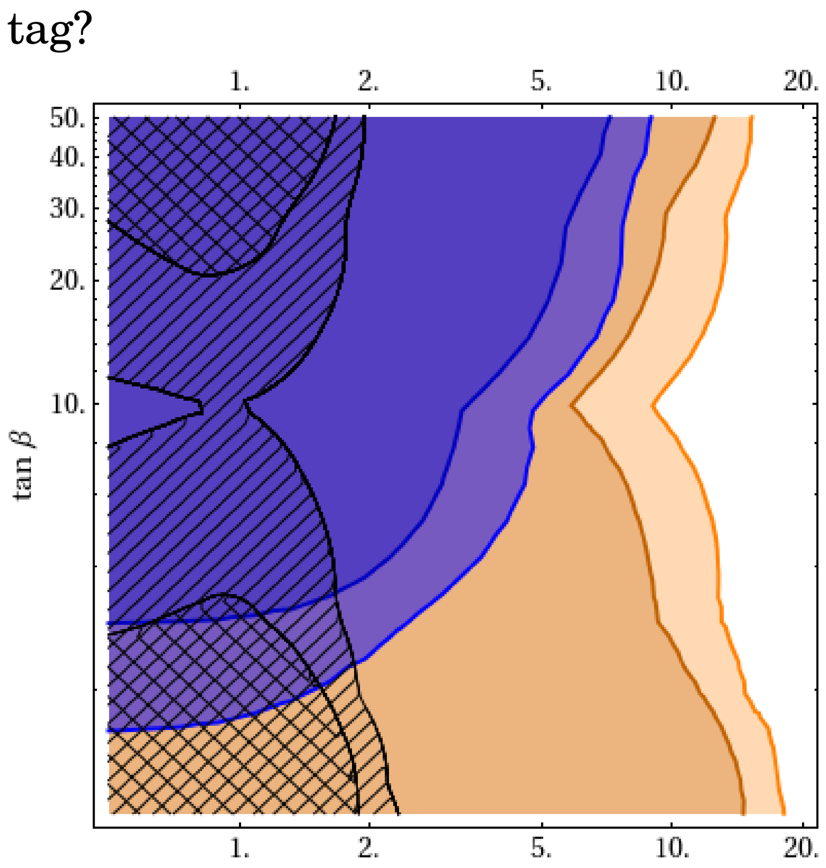


2. The boosted b: As $H^{\pm}$ searches push towards TeV masses, the $H^{\pm}$ bottom jet becomes increasingly boosted. Unfortunately, standard **track-vertex** bottom jet tags (which use charged tracks to find evidence of a decay vertex slightly displaced from the beam) degrade for boosted b jets. As jet p_T increases, the probability to tag a b jet *decreases*, while the probability to mis-tag a light jet *increases*.

Several groups have made predictions for excluding an $H^{\pm}$ heavier than 500 GeV. These predictions rely on simulating track-vertex b tags inside very boosted jets. What happens when we use a more robust b tag?



Craig et al. JHEP**06**(15)137[1504.04630]



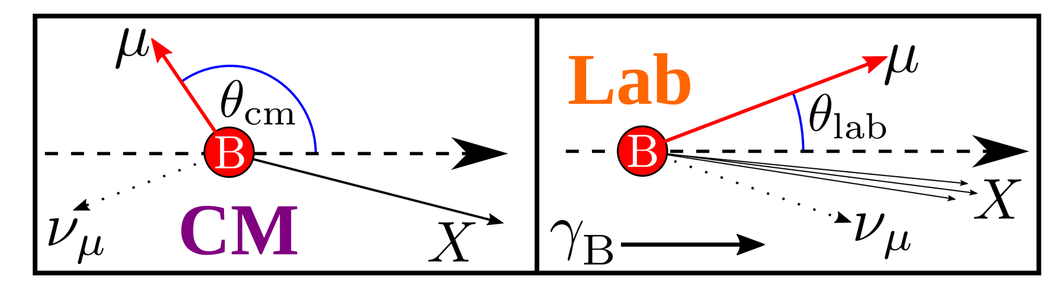
Hajer et al. JHEP**11**(15)124[1504.07617]
Checkered: 95% @ 14 TeV (300/3000 fb^{-1})
Tan/orange: 95% @ 100 TeV (3/30 ab^{-1})

The μ_x boosted-bottom-jet tag†

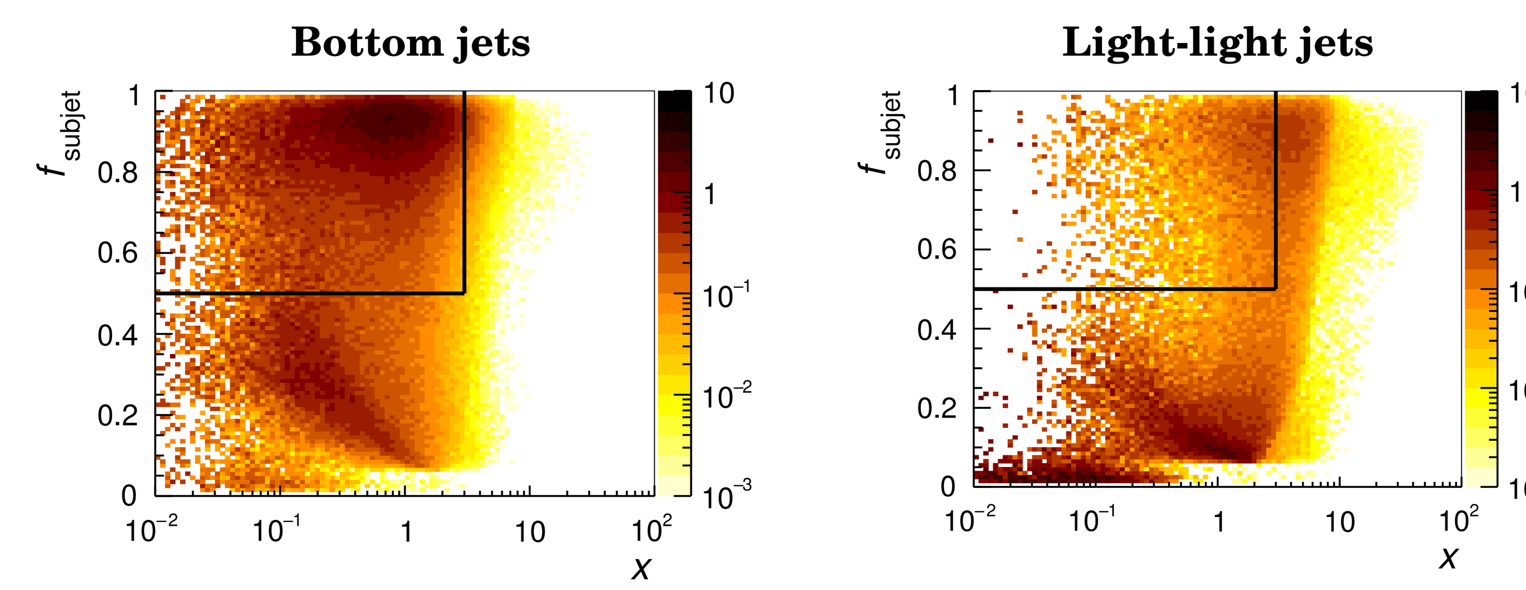
Consider a jet containing a B meson decaying semi-leptonically. In the center-of-momentum (CM) frame, a muon is emitted at some angle θ_{cm} w.r.t. the boost axis. In the lab frame, the boost γ_B compresses the B meson products into a subjet. Reconstructing this subjet allows the measurement of a lab frame observable.

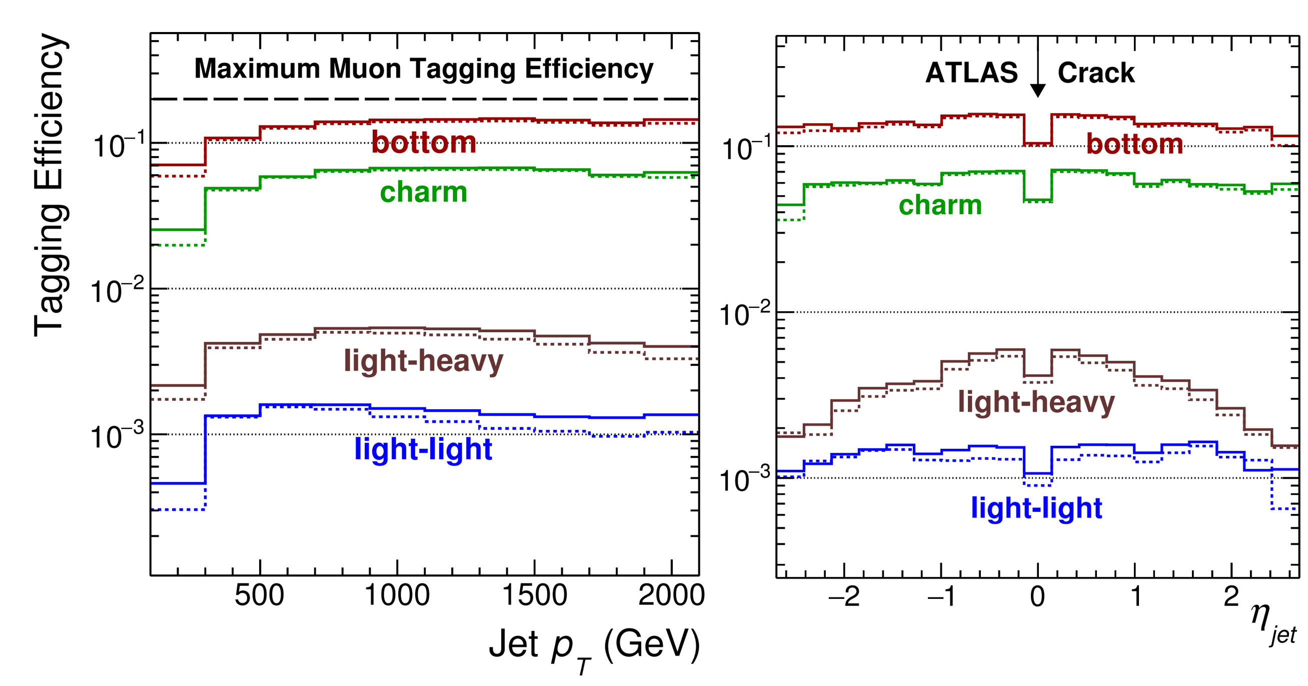
$$x\equiv\gamma_B\tan(\theta_{lab})\approx\frac{\sin(\theta_{cm})}{1+\cos(\theta_{cm})}$$

$$\frac{dN}{N\,dx}\approx\frac{2x}{(x^2+1)^2}$$



At least 90% of muons arrive in a cone defined by $x\leq 3$. In addition, the boosted subjet should carry a large fraction of its jet's momentum $f_{subjet}=p_{T,subjet}/p_{T,jet}\geq 0.5$.

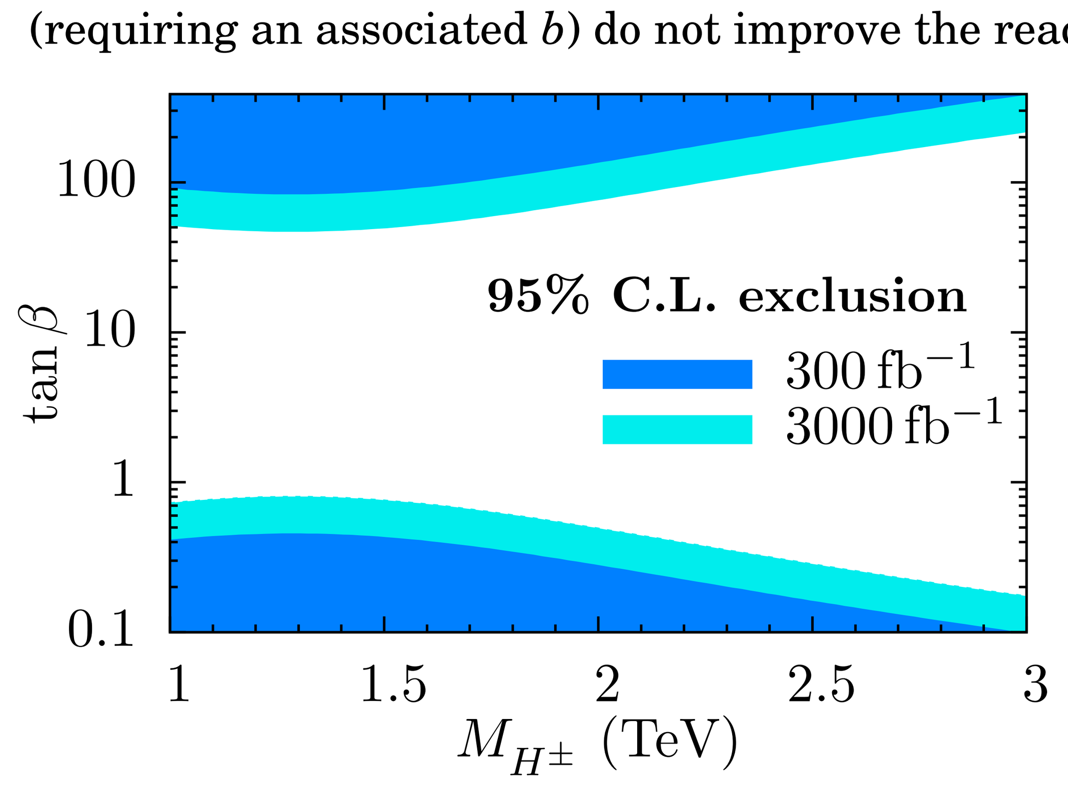




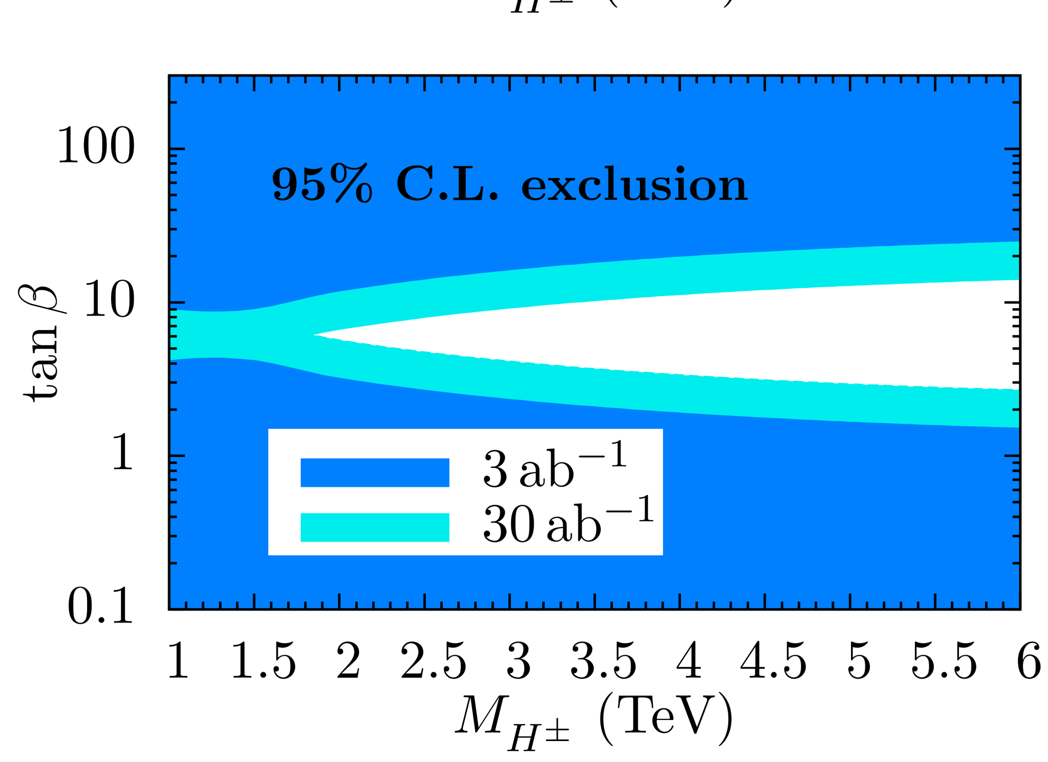
The μ_x tag is robust across p_T and η. The dotted efficiency is with 40 pileup events. **Light-heavy** jets are light jets where the muon came from a bottom or charm hadron ($g\to b\bar{b}$).

Exclusion predictions at 14 and 100 TeV

We analyzed $H^{\pm}$ at LO using MadGraph5, Pythia8, and Delphes3. For the inclusive final state, the $H^{\pm}$ is reconstructed from (i) a "narrow" jet (anti-kt, *R=0.4*) tagged with μ_x and (ii) a "fat" jet (CA, *R=0.8*) tagged by a boosted hadronic top tag. The associated top is reconstructed as a resolved, leptonic top. The dominant background is *ttj+X*, with *tt(bb/cc)* about five times smaller. Since the *3b* final state accounts for at least 60% of the cross section, we determine that **exclusive** cuts (requiring an associated *b*) do not improve the reach of a search.



We find that at **14 TeV**, the search is entirely limited by the $H^{\pm}$ cross section, due to the *O*(10%) branching ratio of the semi-leptonic *tt* channel and the *O*(1%) acceptance of the inclusive cuts. However, the signal is quite pure, with signal-over-background ranging from 1/3 to above 1.



At **100 TeV**, the search is background limited, with *S/B* ranging from 1% to 5%.

We conclude that our 14 TeV results are comparable to Craig et al., and that the search for $H^{\pm}$ in the TeV regime is a strong motivation for a 100 TeV collider.

This work was supported by **D.O.E. # DE-SC0008347**

† K. Pedersen and Z. Sullivan PRD**93**(16)014014[1511.05990]