

Progress Report

Di-Higgs Topical Group Meeting | 2026/04/01

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Validation of 4f Event Generation

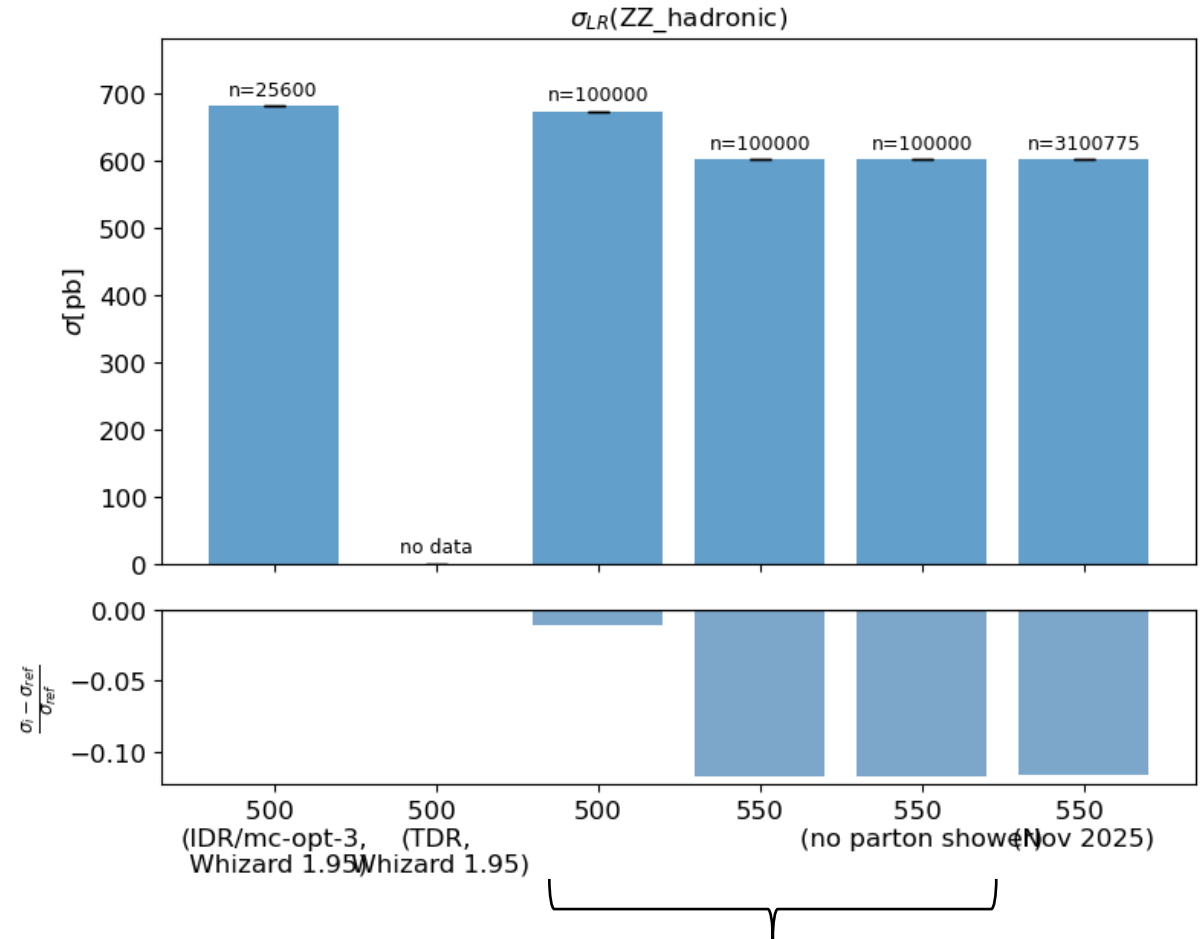
- 4 fermion events are an important background in the Higgs self-coupling analysis
- Recently, a potential problem was identified in the 4f hadronic samples (4 quarks)
 - In the 550 GeV central production, a deficit of nearly 30% bbbb events was found. [expectation comes from previous ZHH study at 500 GeV COM energy]
- ➔ Check the flavor combinations in the ZZ_hadronic* process
 - *Note: Despite the name, in ZZ_hadronic, the production via two Z bosons is **not enforced**. The same final states can also be produced via WW production and transitions allowed through the CKM matrix (see later)
- ➔ Production of test sample with 100k events @ eL pR only (for all comparisons)

Comparison of Nov2025 and Test Sample

➤ Technical details:

- All samples newer than TDR use Whizard 3.1.5

While the $\sigma_{LR}(ZZ_hadronic)$ cross section is consistent...

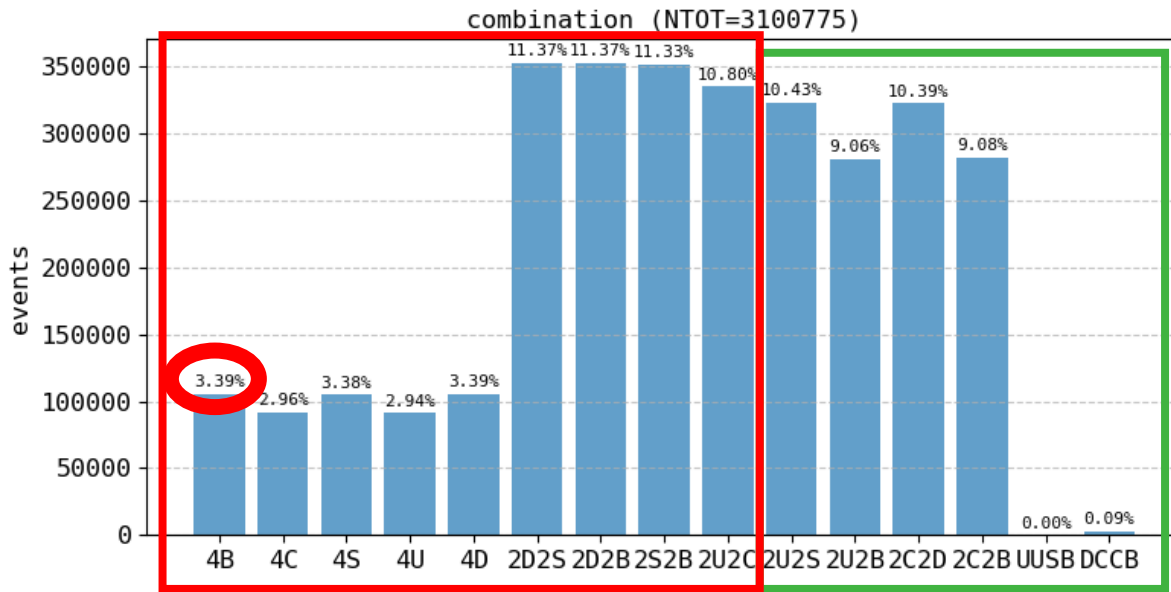


Test productions

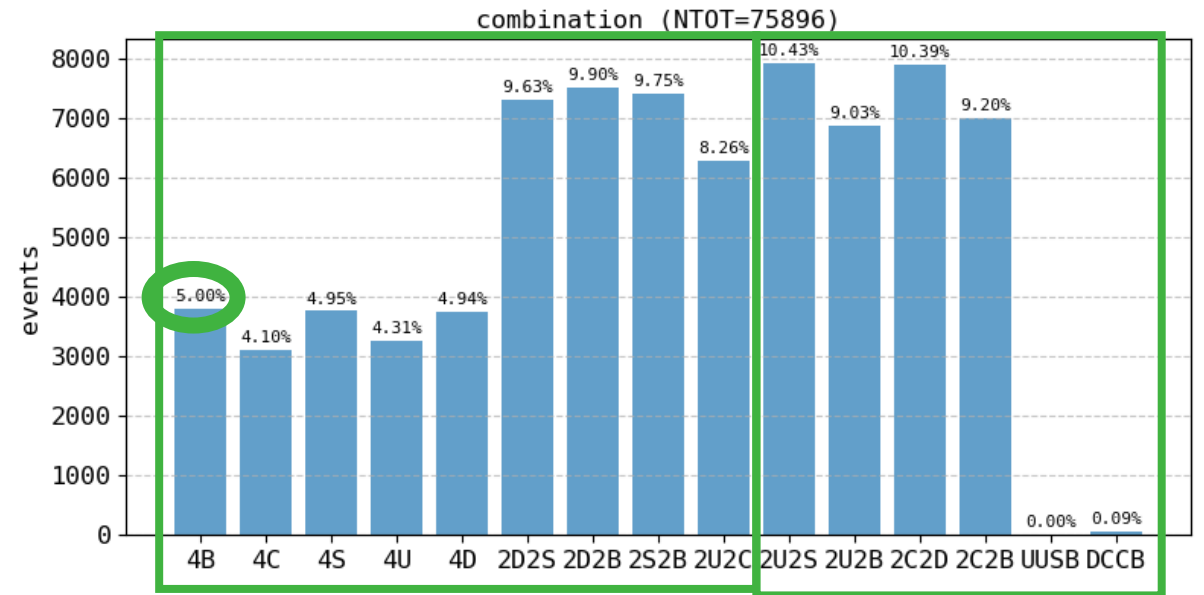
Comparison of Nov2025 and Test Sample

Nov2025 Sample

Test Sample @ 550 GeV



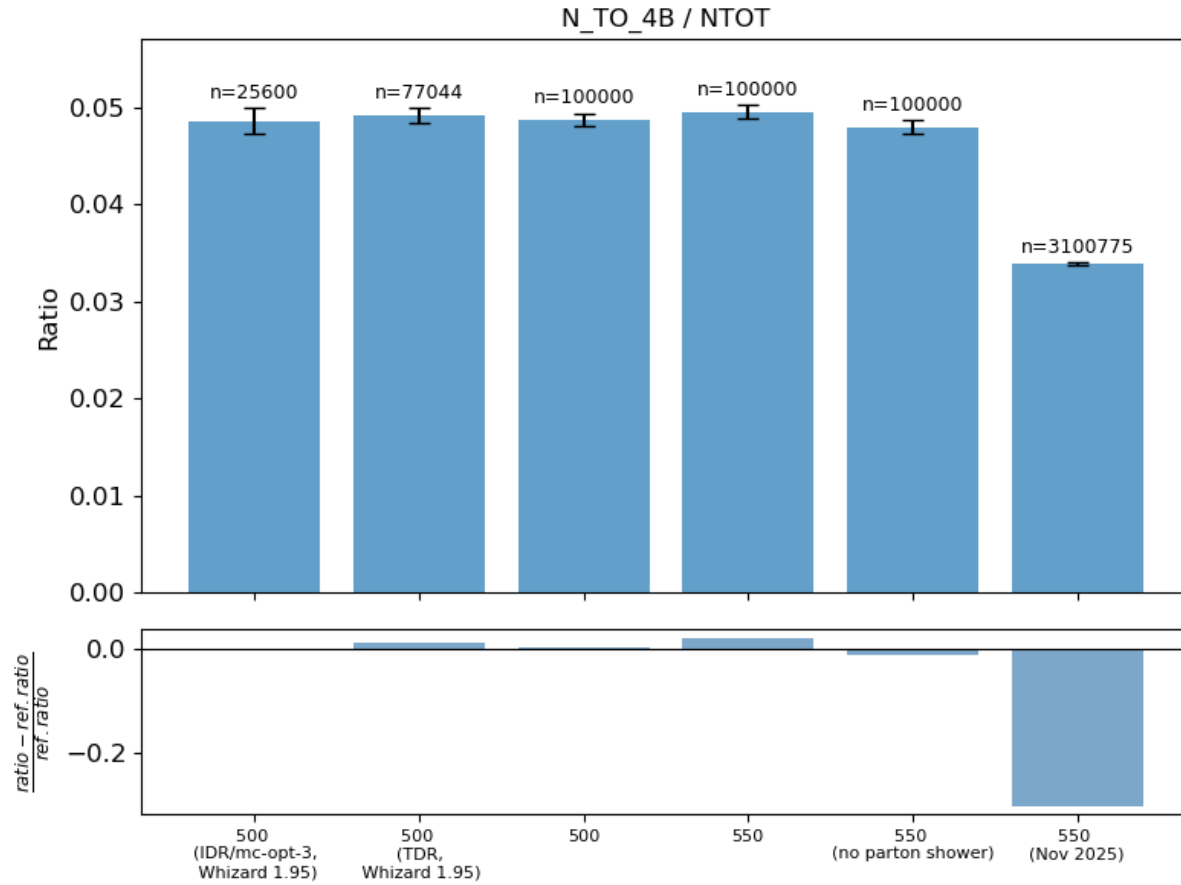
$$\sigma_{LR}(ZZ_{\text{hadronic}}) = 601.28 \text{ fb}$$



$$\sigma_{LR}(ZZ_{\text{hadronic}}) = 600.72 \text{ fb}$$

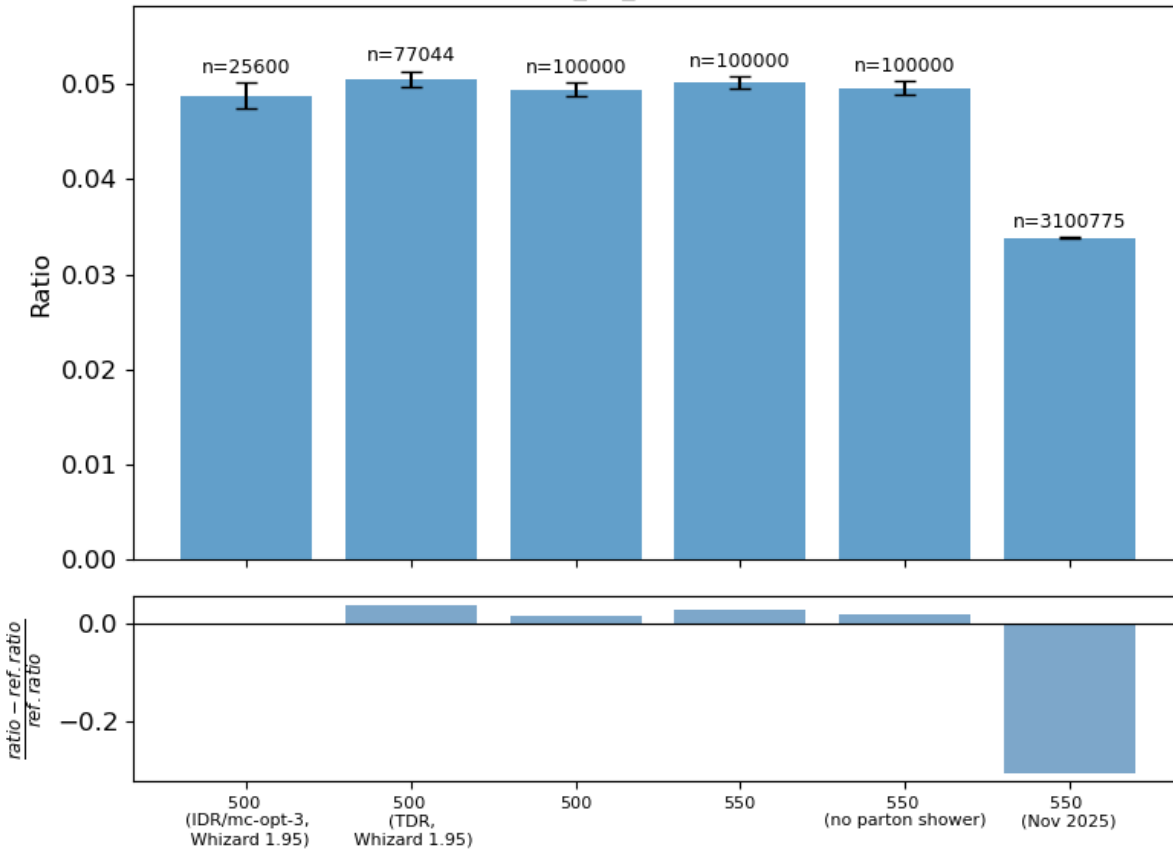
...the branching fractions are not!

Branching Fractions

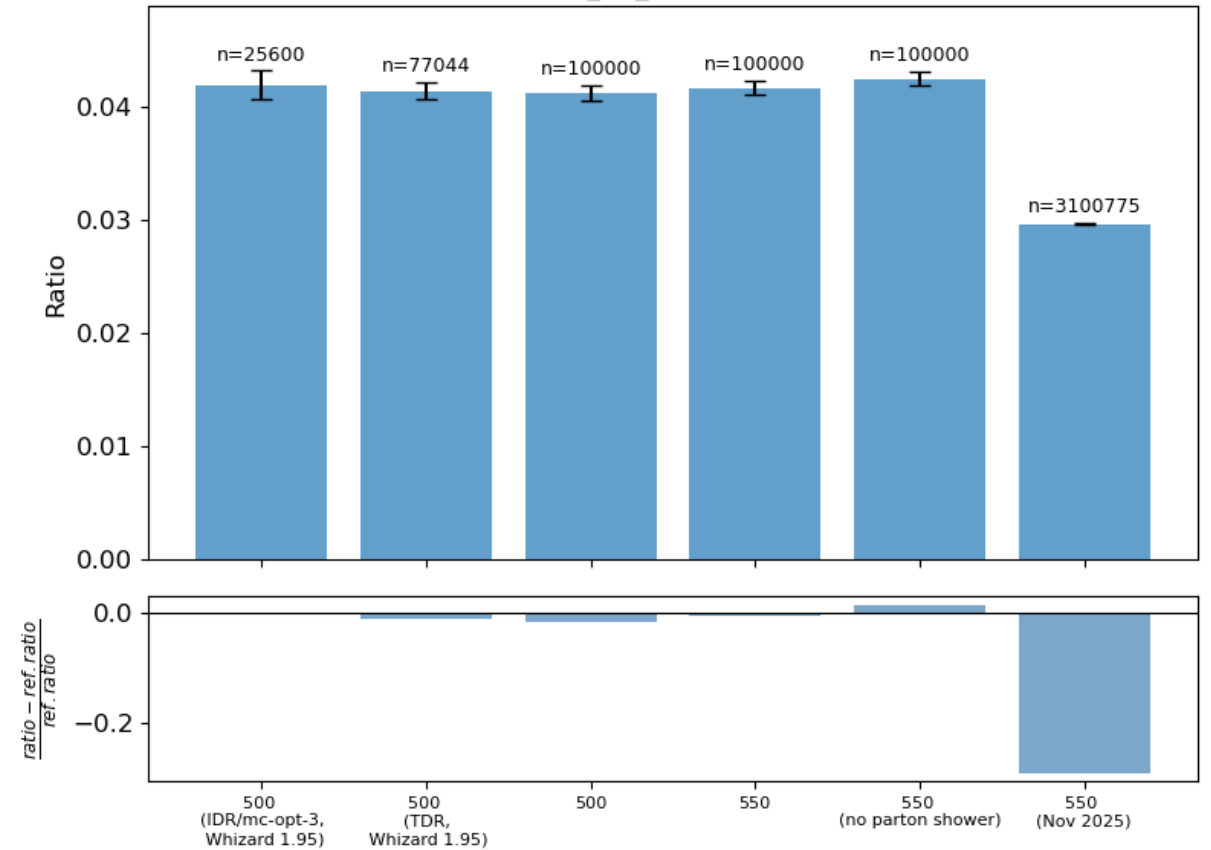


Branching Fractions

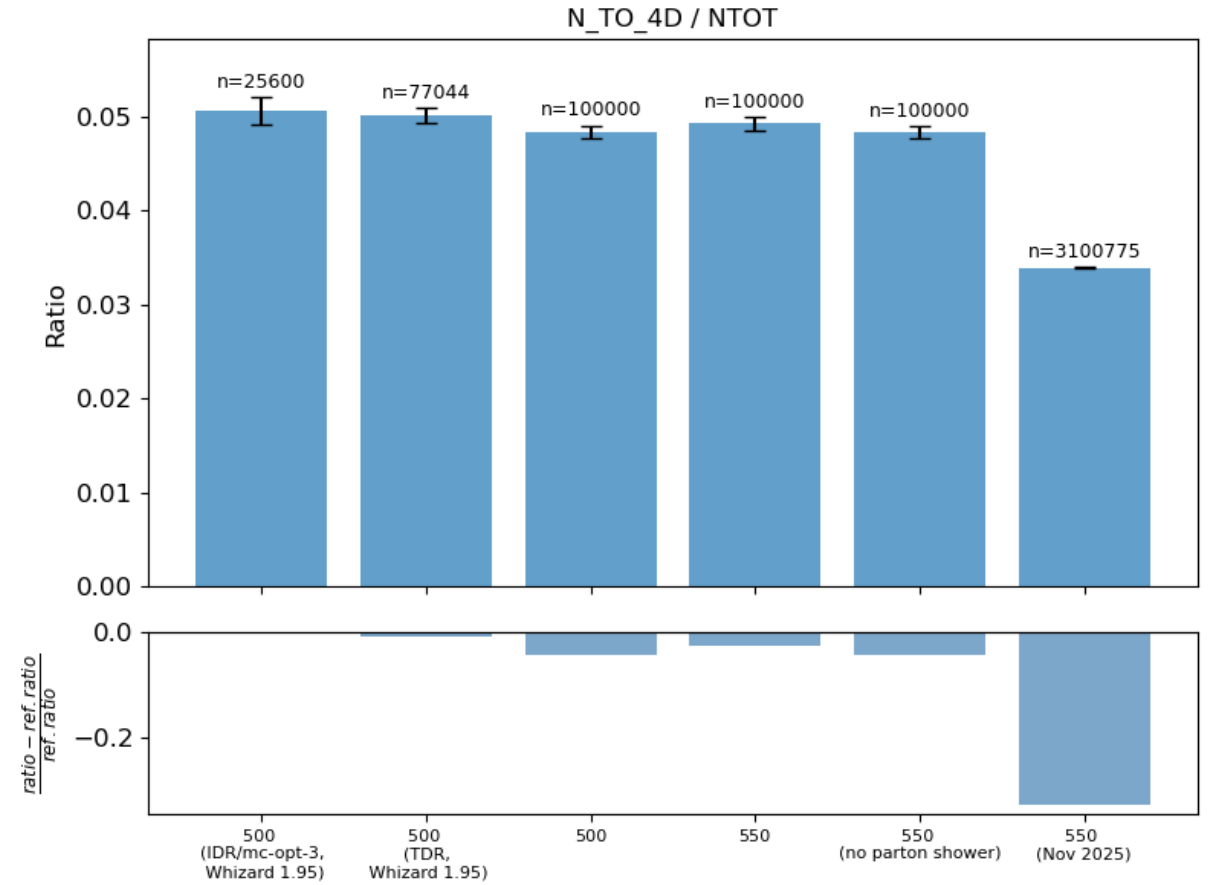
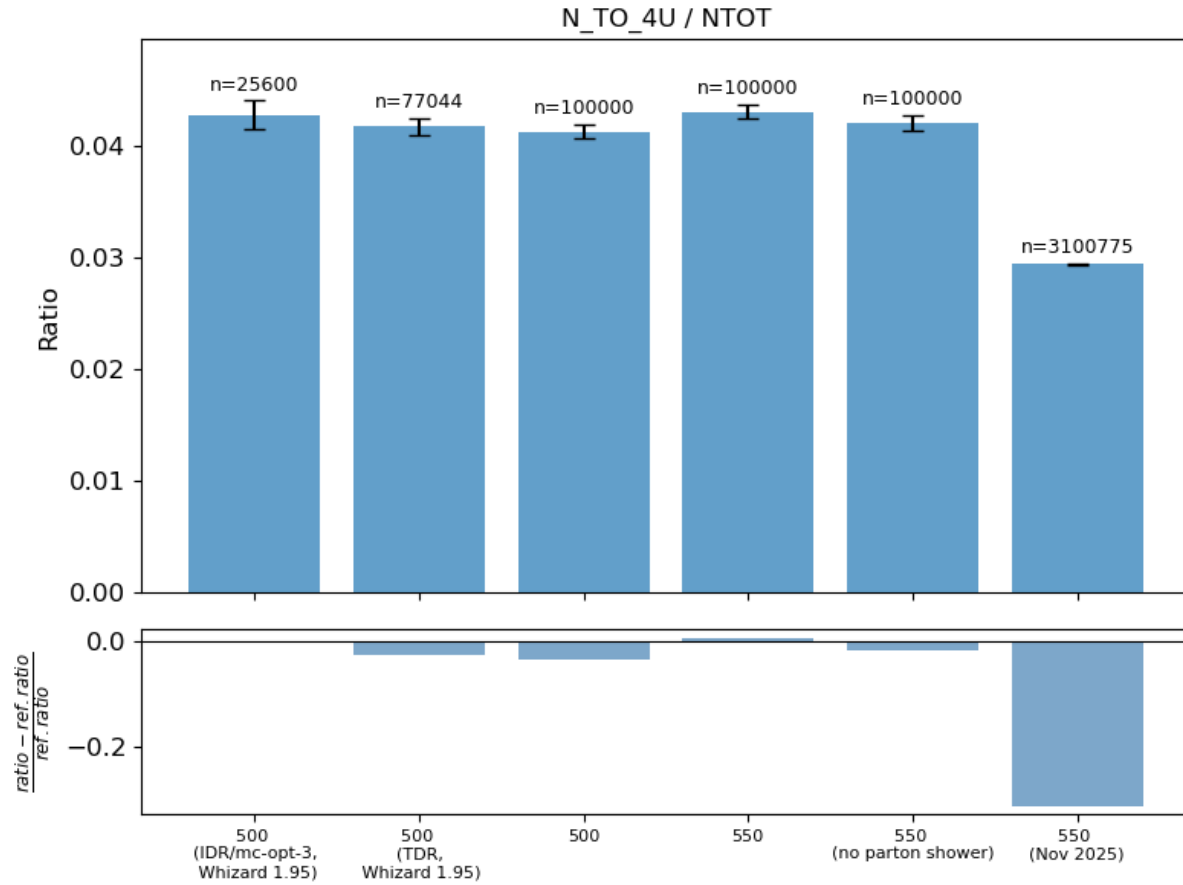
N_TO_4S / NTOT



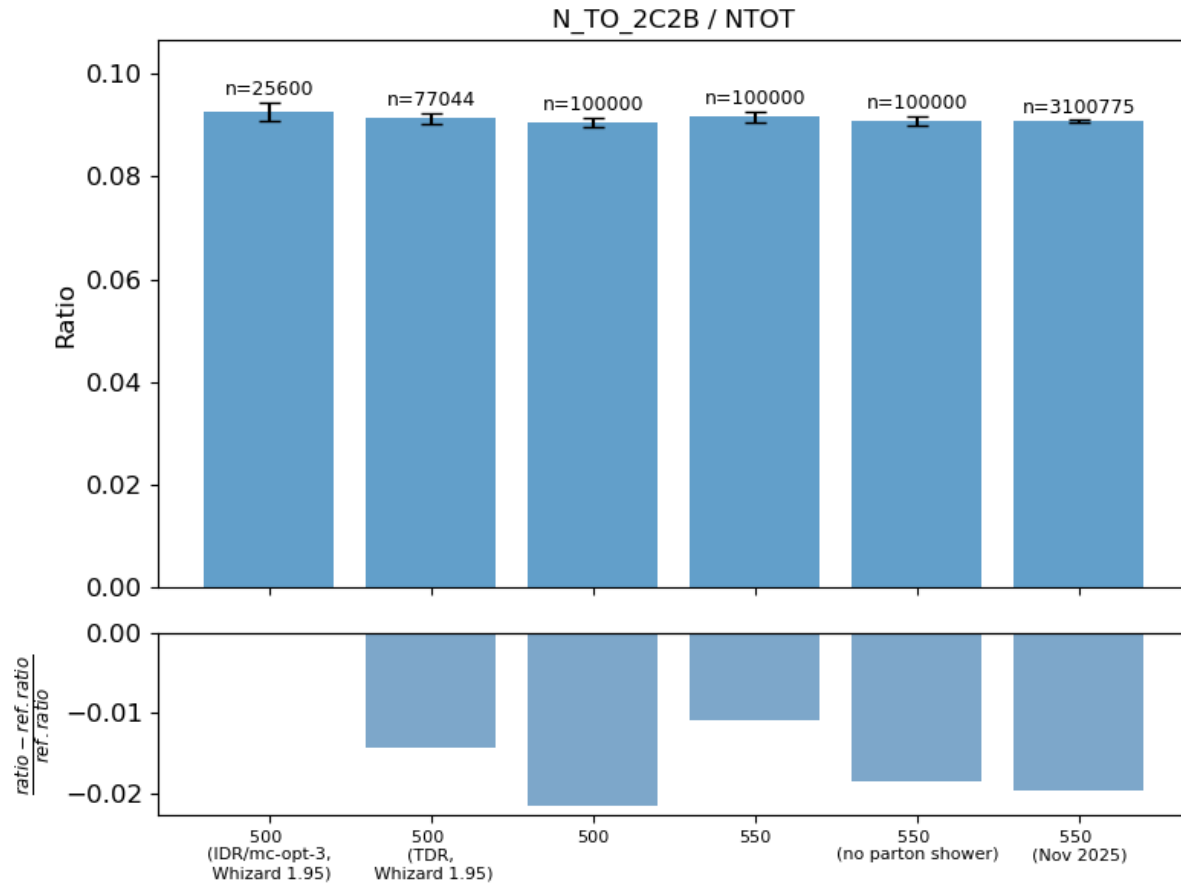
N_TO_4C / NTOT



Branching Fractions



Branching Fractions



- ZZ_hadronic is defined in Whizard Sindarin as

```
alias uq = u:U
alias dq = d:D
alias cq = c:C
alias sq = s:S
alias bq = b:B
alias up_type_q = u:c:U:C
alias down_type_q = d:s:b:D:S:B
alias not_dq = s:b:S:B
alias not_sq = d:b:D:B

process zz_h0      =   e1,E1 => (up_type_q,up_type_q,up_type_q,up_type_q) +
                          (down_type_q,down_type_q,down_type_q,down_type_q) +
                          (uq,uq,not_dq,not_dq) +
                          (cq,cq,not_sq,not_sq)      { $omega_flags = "-model:constant_width" }
```

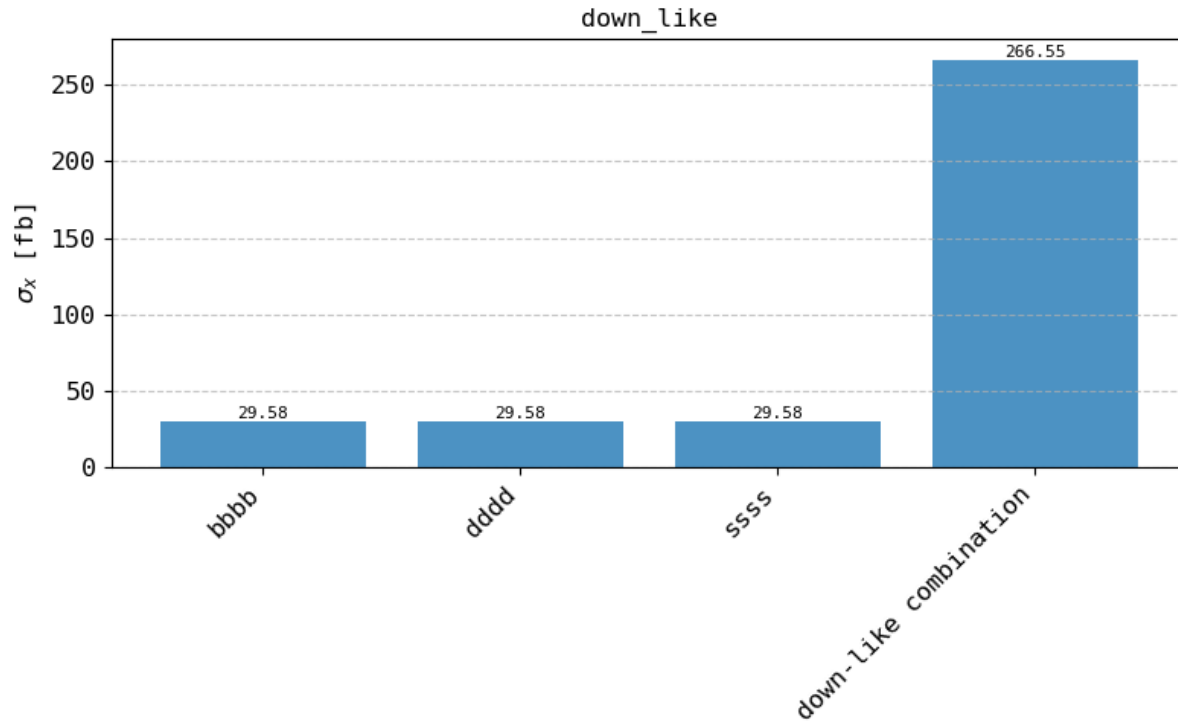
- Four sub combinations:

Name	Final States
1 Down like combination	uuuu, cccc
2 Up like combination	dddd, ssss, bbbb
3 $2u + 2s/2b$	uuss, uobb
4 $2c + 2d/2b$	ccdd, ccbb

Cross Check: Make sure all sub-combinations are correct.

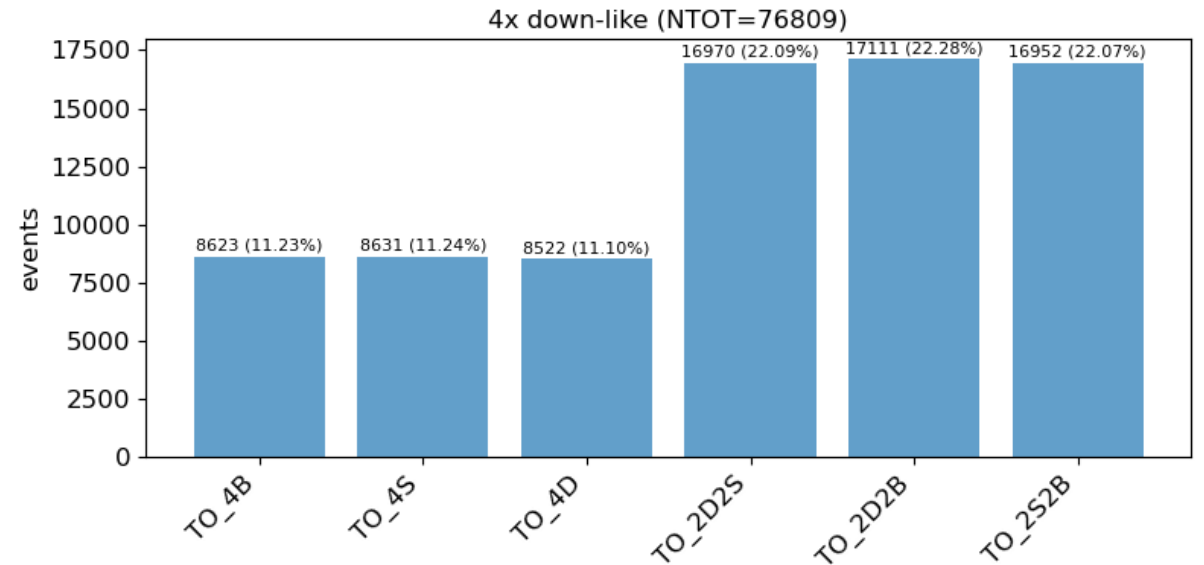
Down like combination

Cross sections



Branching Fraction in combination

Combination: 4x (down type quark)

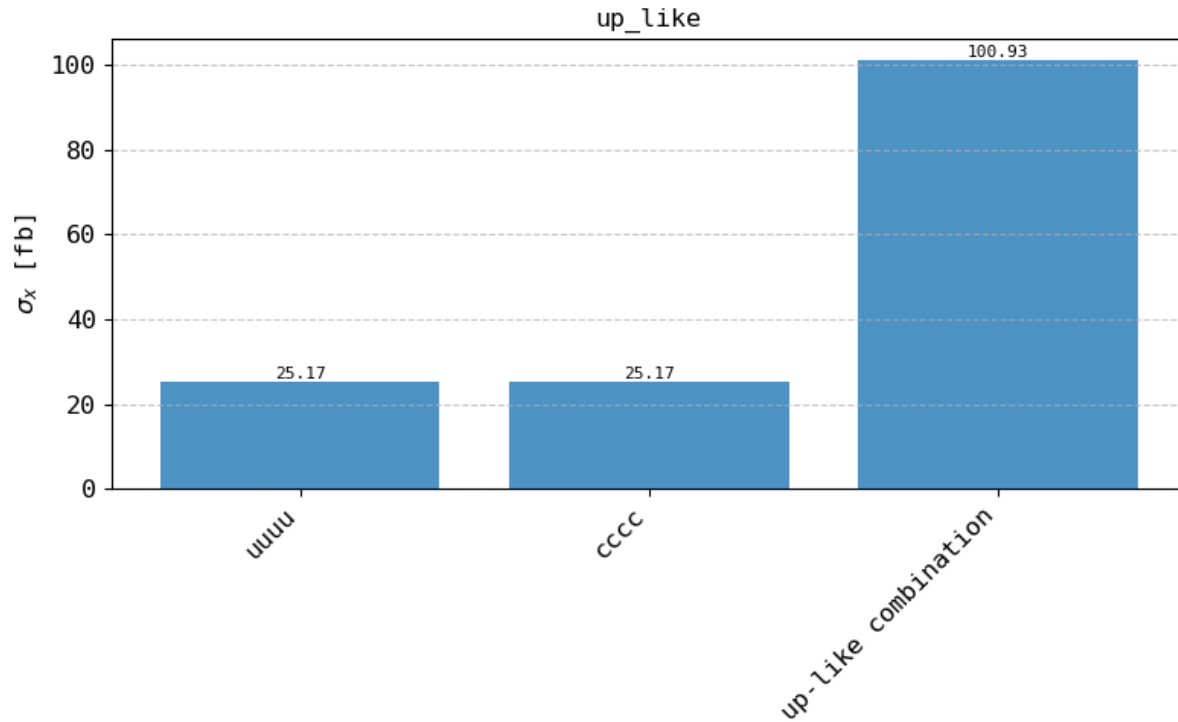


$$\frac{\sigma_{bbbb}}{\text{BR}(\text{all} \rightarrow \text{bbbb})} = 263.40 \text{ fb}$$

Combined cross section: 266.55 fb

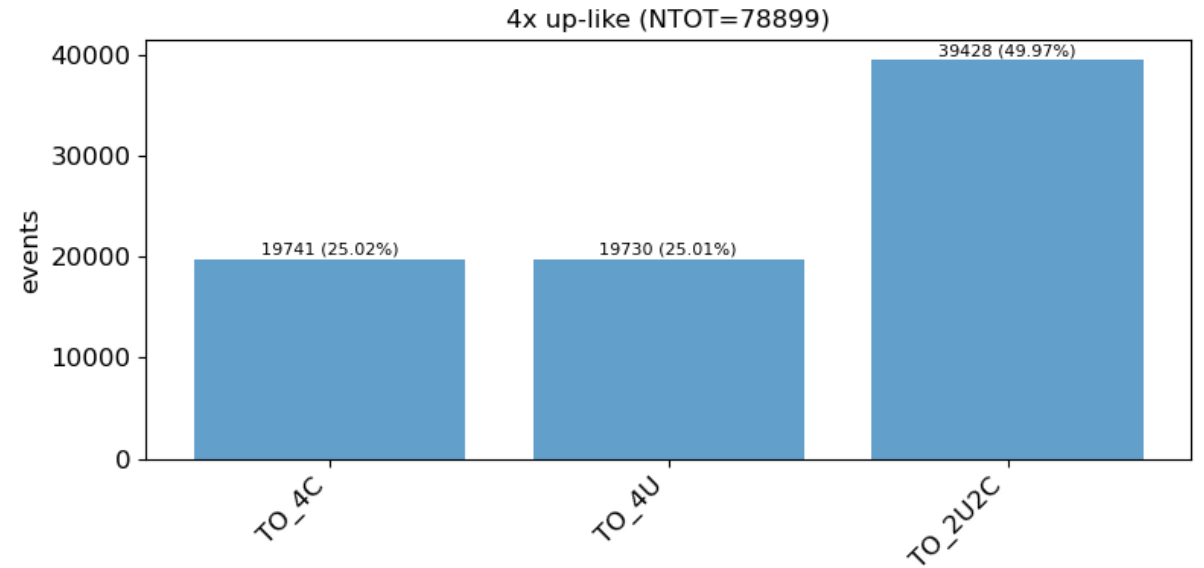
Up like combination


Cross sections



Branching Fraction in combination

Combination: 4x (up type quark)

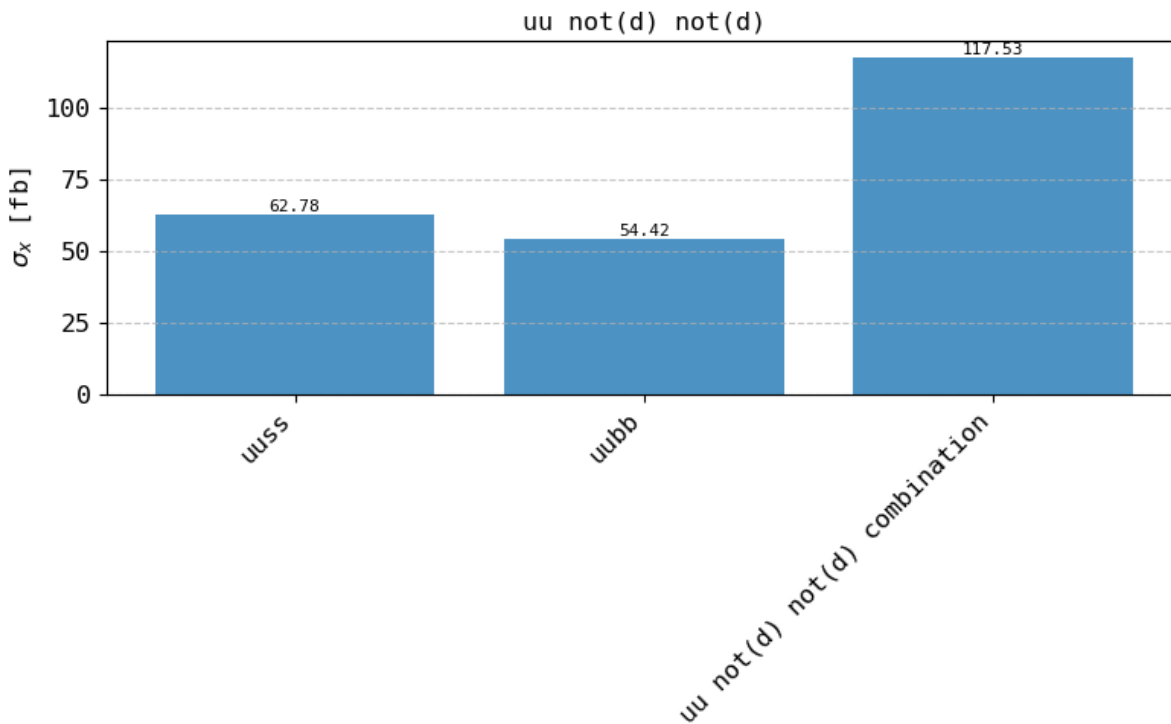


$$\frac{\sigma_{uuuu}}{\text{BR}(\text{all} \rightarrow \text{uuuu})} = 100.60 \text{ fb}$$


Combined cross section: 100.93 fb

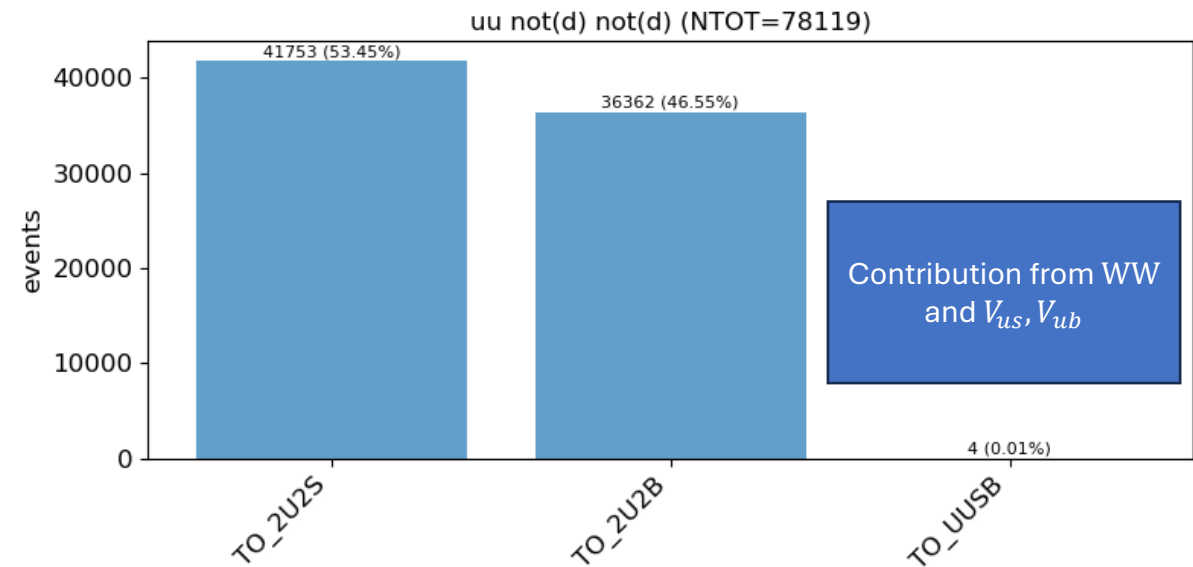
2u + 2s/2b combination

Cross sections




Branching Fraction in combination

Combination: uu s/b s/b



$$\frac{\sigma_{uuss}}{\text{BR}(\text{all} \rightarrow \text{uuss})} = 117.46 \text{ fb}$$

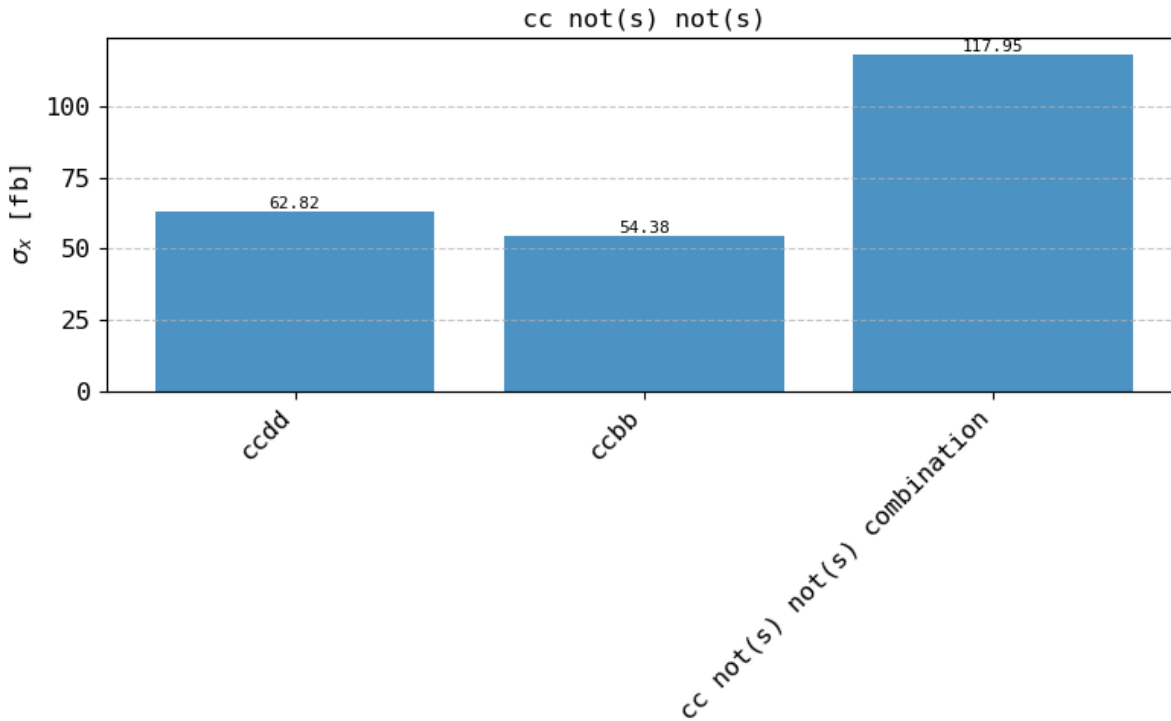
$|V_{us}| \cdot |V_{ub}| = 0.00083$



Combined cross section: 117.53 fb

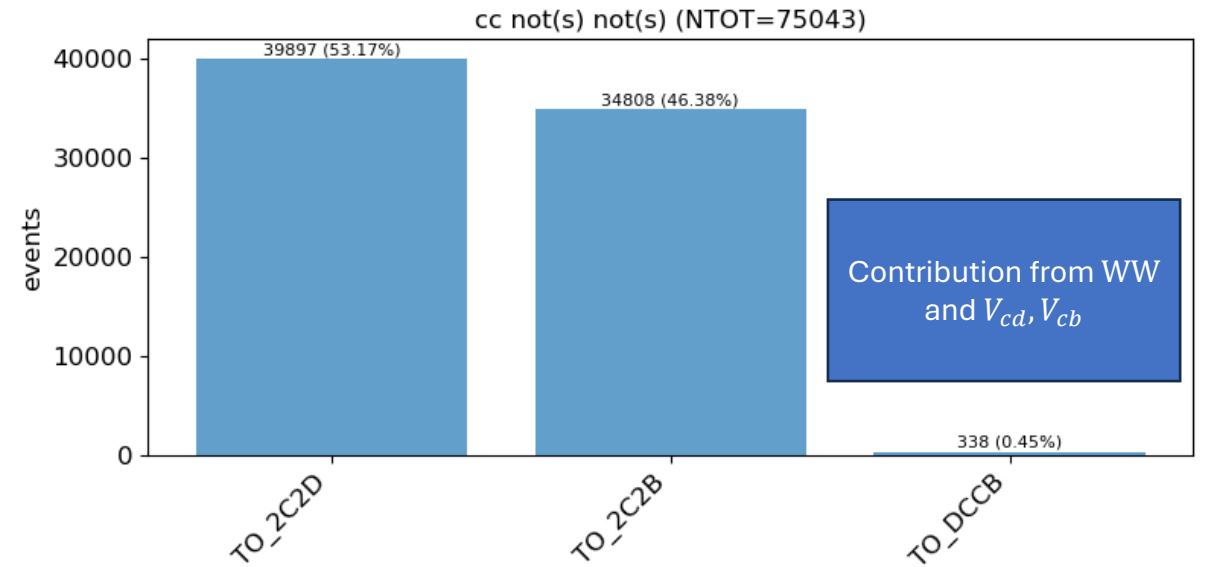
2c + 2d/2b combination

Cross sections



Branching Fraction in combination

Combination: cc not(s) not(s)



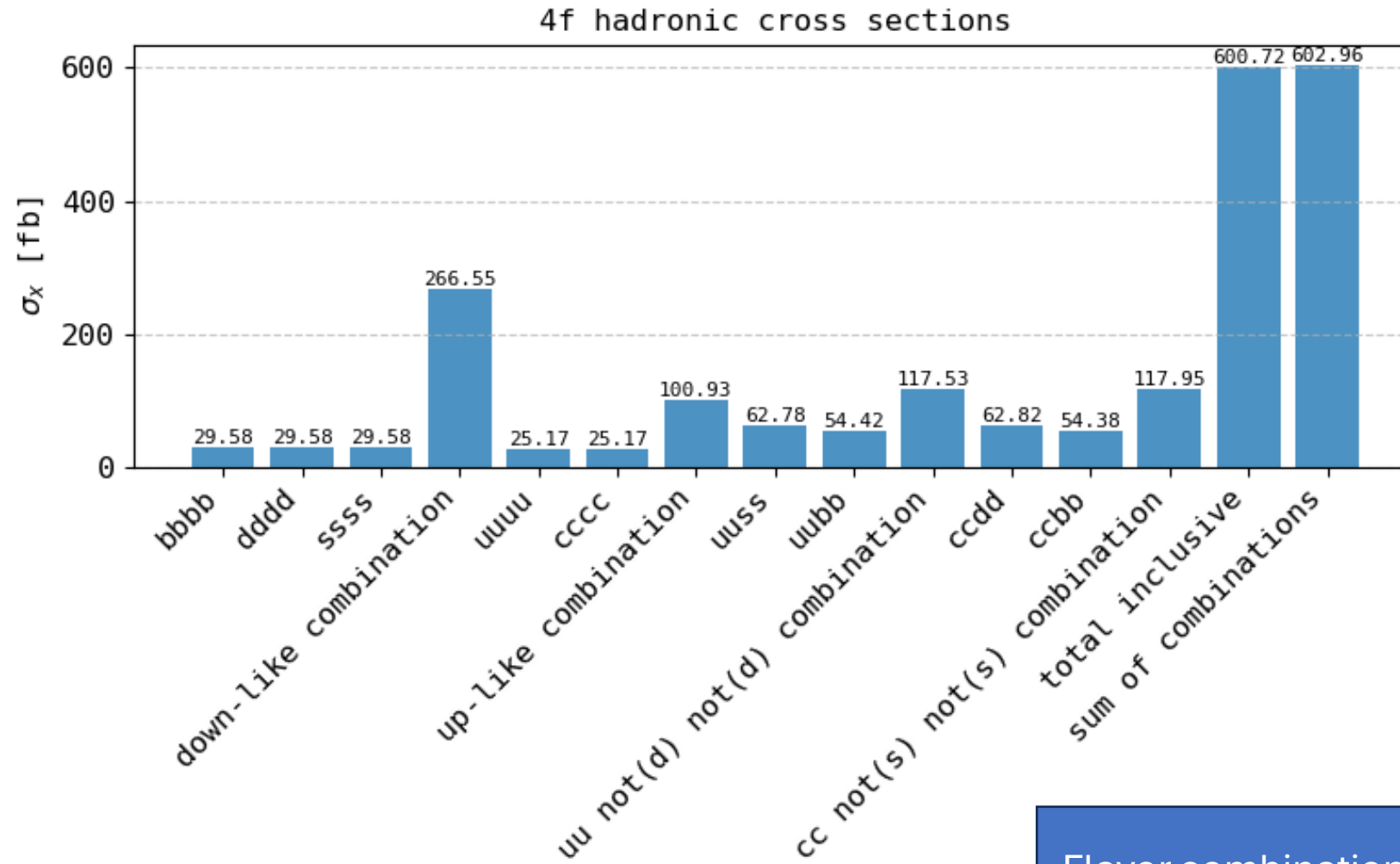
$$|V_{cd}| \cdot |V_{cb}| = 0.0094$$

$$\frac{\sigma_{ccdd}}{\text{BR}(\text{all} \rightarrow \text{ccdd})} = 118.15 \text{ fb}$$



Combined cross section: 117.95 fb

Flavor Combination



Flavor combination in the 550 GeV test production is fully consistent

- Run small-scale 4f production (each process with 100k events or so)
 - Validate found cross sections and branching fractions with the current production
 - Runtime example: ZZ_hadronic eL pR has 4M events in 2025 prod
 - @ 100k events/file → 44 files
 - On KEK CC: 1 file needed approx. 30minutes
 - → computing time negligible
 - However: total 4f fully hadronic + leptonic production ca. 180M events

Other Progress

- Ongoing work on MarlinMLFlavorTagging and FlavorTagging_ML
 - Inputs now compatible with LCFIPlus
same feature names, same preprocessing/standardization file
 - Many changes to make inference with ParT easier
 - → important for Ibai's tau-tagging implementation
 - → also useful to use the same framework for my own work about jet clustering

Backup