Experimental Issues @ 100 TeV

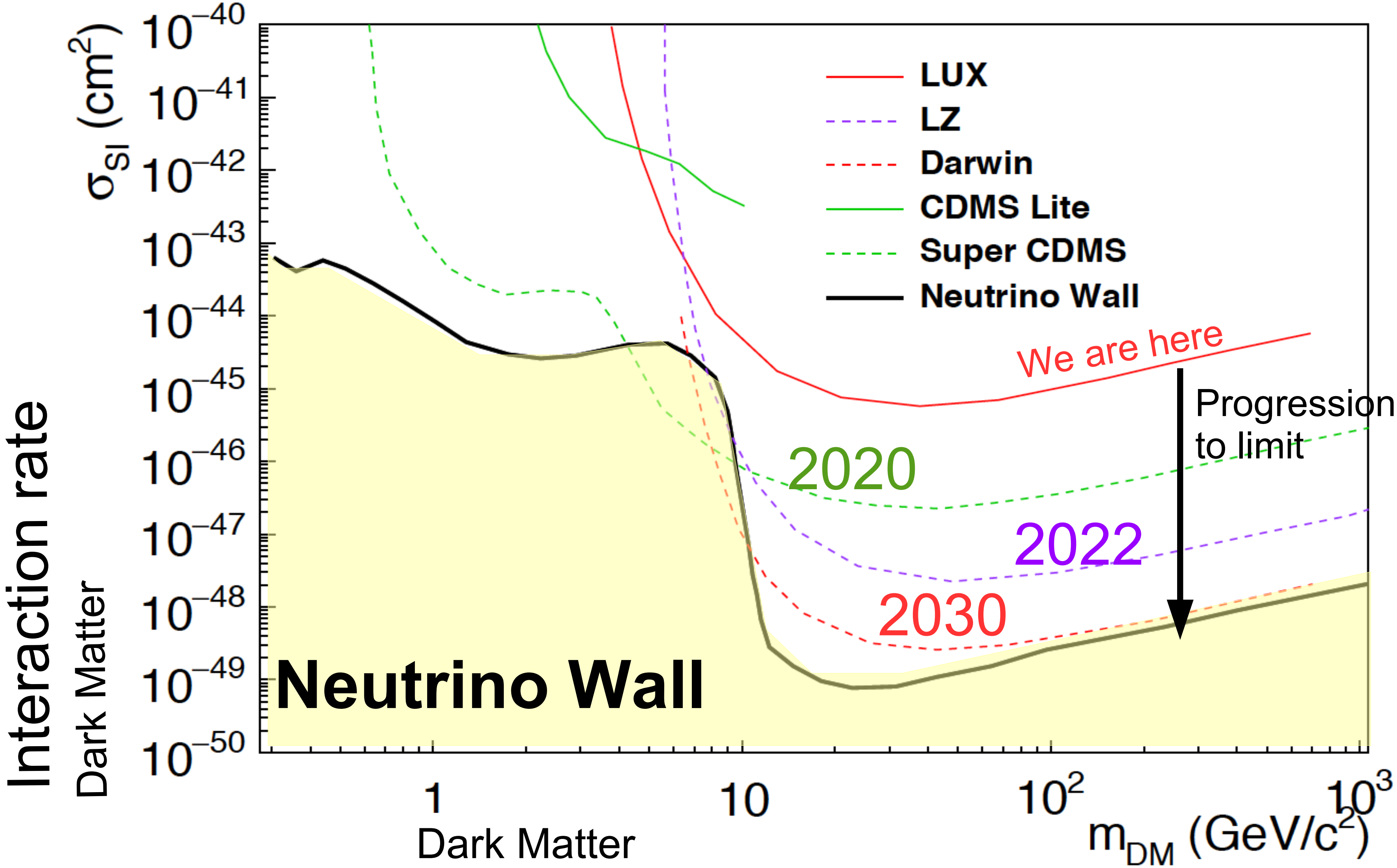
Phil Harris

Targeting Dark matter

- Currently there are 3 industries looking for DM
  - Direct detection
  - Indirect detection
  - Collider searches
- For each of these approaches :
  - Benchmarks have been established to drive search
    - For collider this is not as well formed
- For collider searches :
  - New benchmark to be established based precision SM
    - Turns out DM search is best way to measure high p_T V prod
  - This talk looks at this benchmark for the 100 TeV

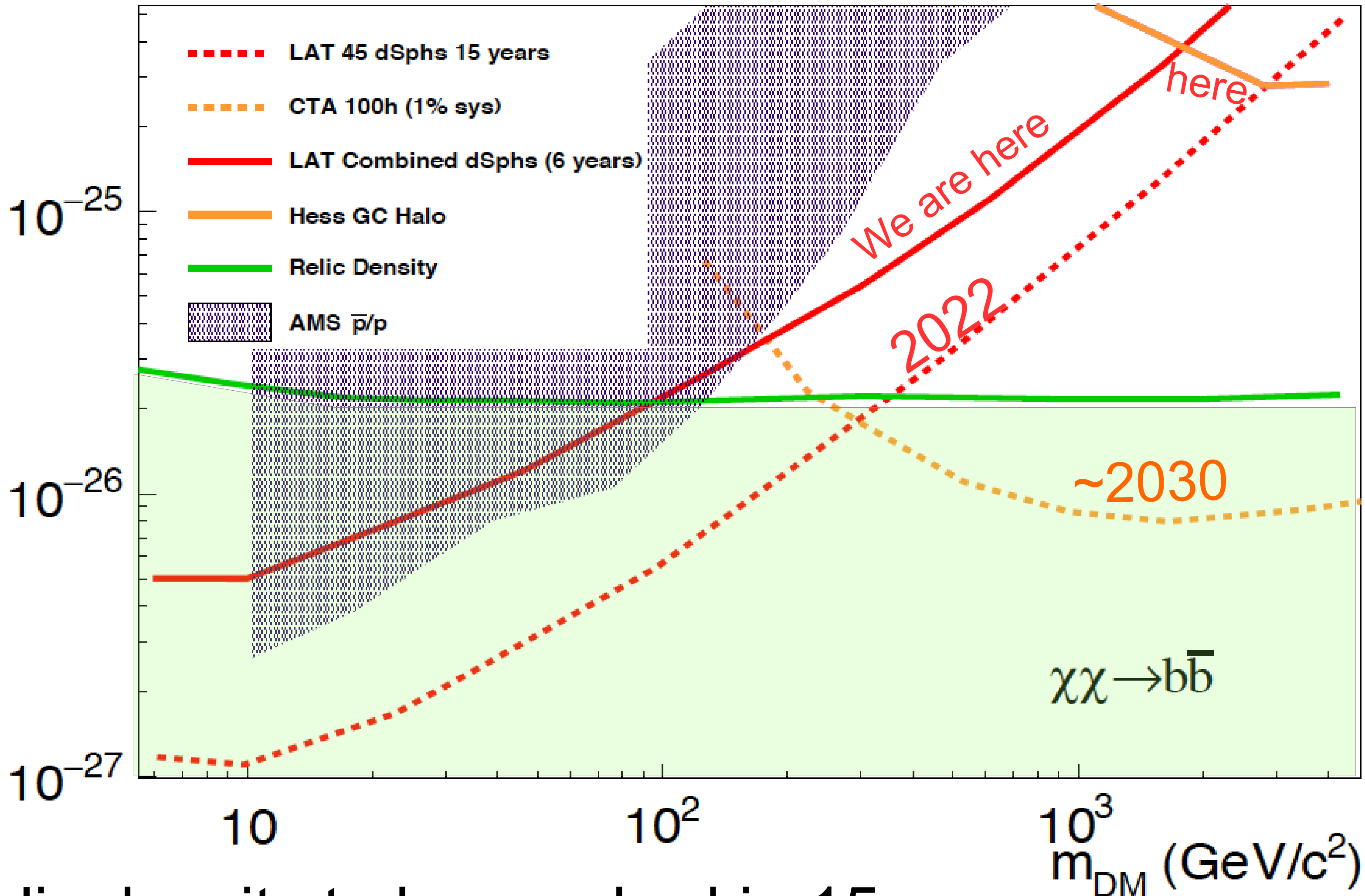
What are the ulitmate bounds?

- Ultimate bounds exist for each experiment
  - Direct detection this ultimate bound is the neurino wall



Whatr are ultimate bounds?

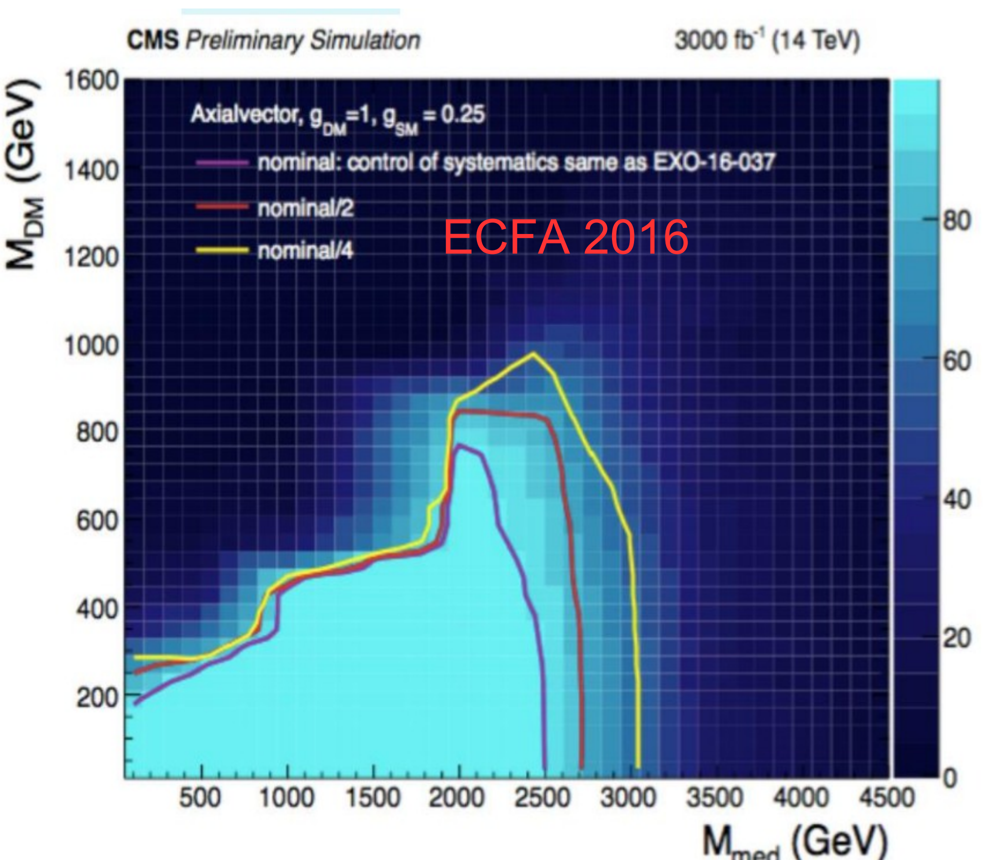
- Indirect detection ultimate bound is relic density

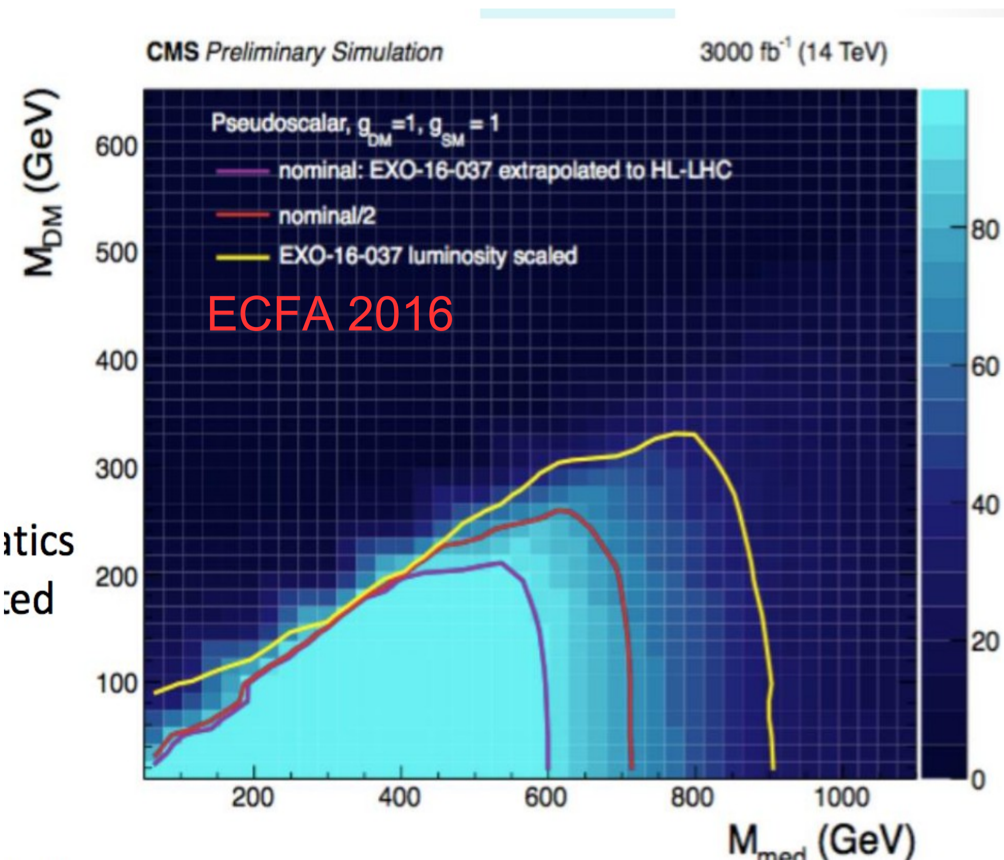


Relic density to be reached in 15 years

And for collider?

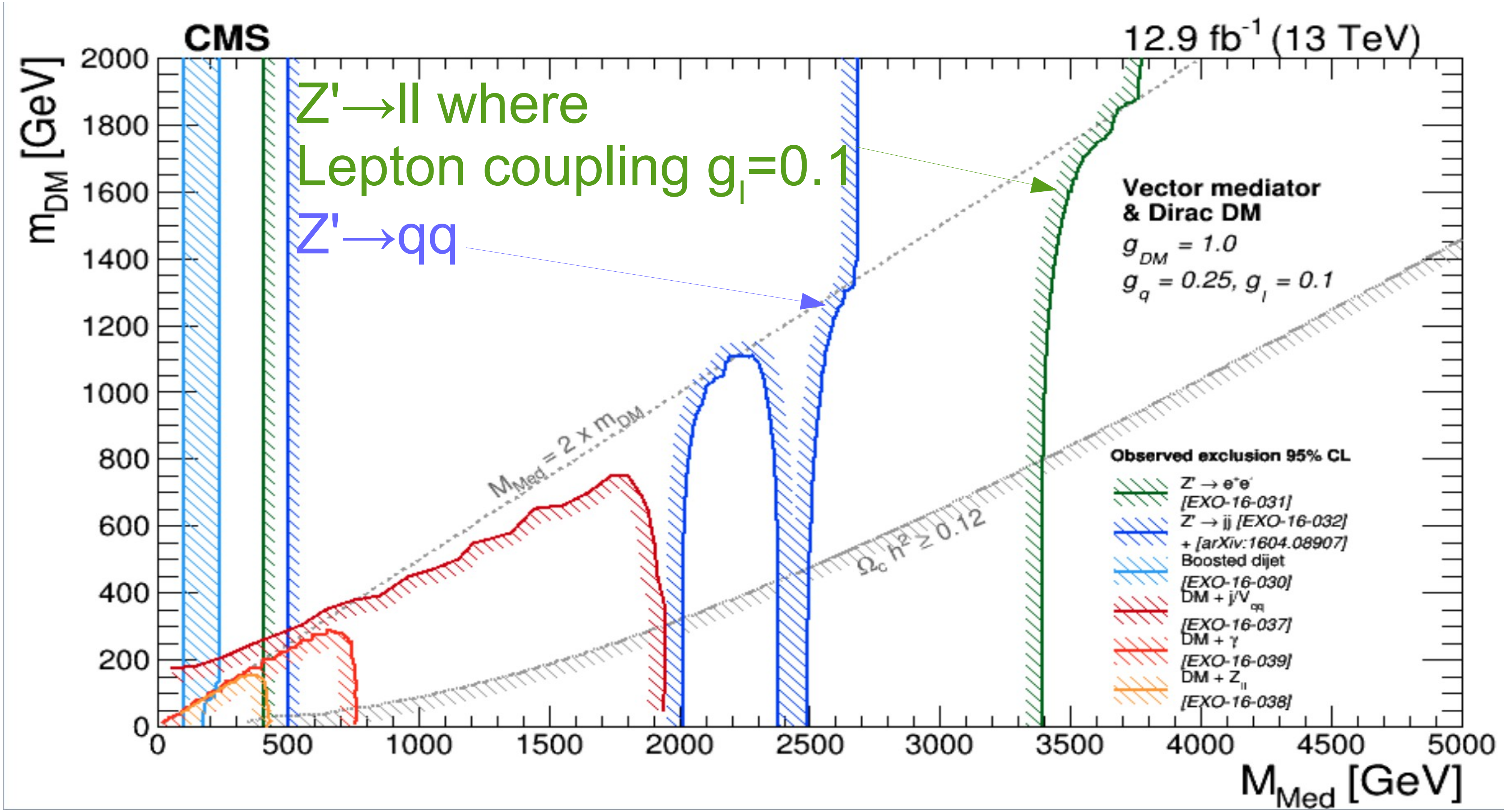
- For LHC
  - Our bounds are a bit more model dependent
  - We can start from the 14 TeV projections





For spin 1 med reach is 3 TeV For spin 0 med reach is 1 TeV

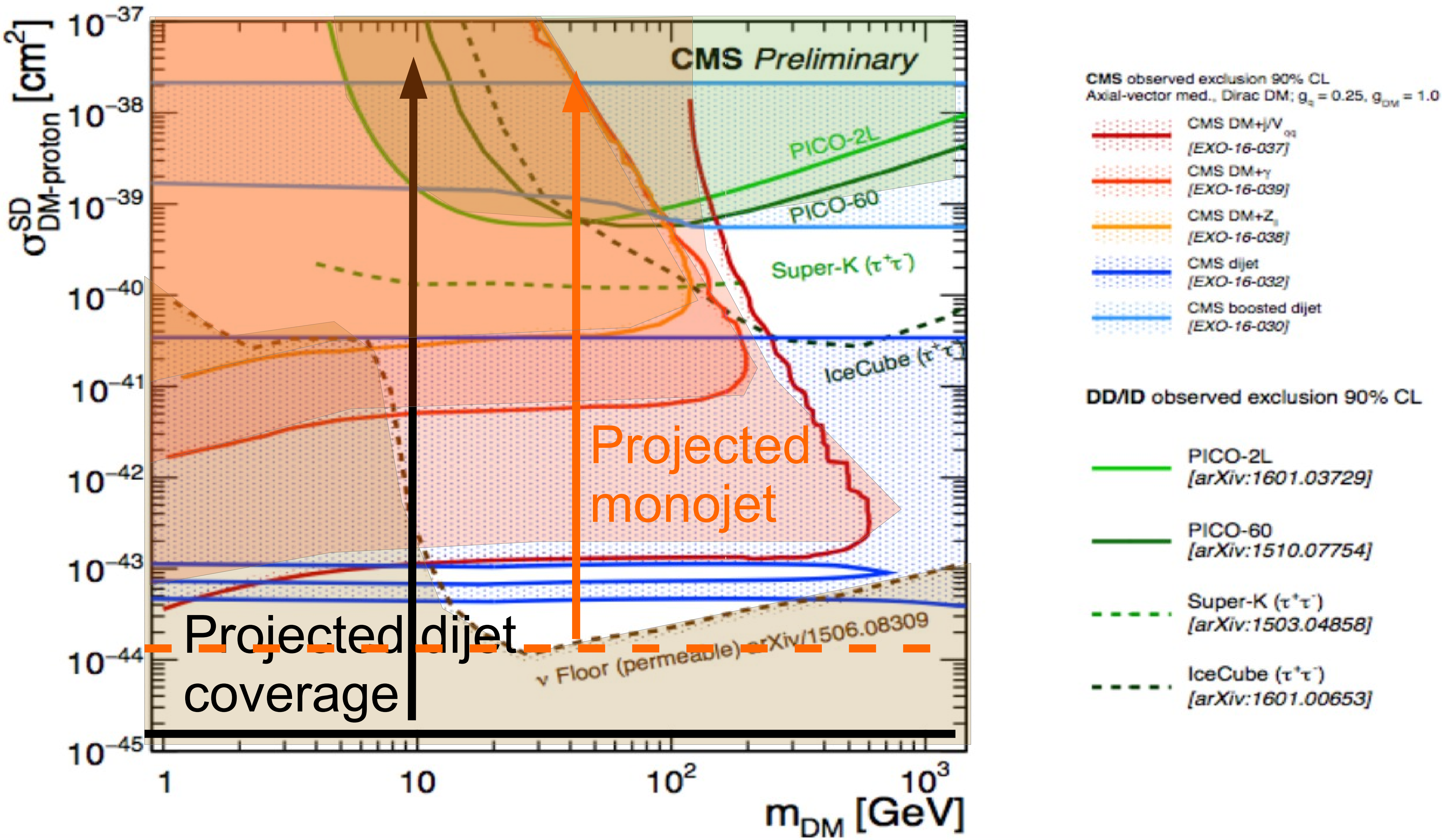
What about visible bounds?



Dijet reach : 2.5 TeV → Becomes 5 TeV with 3ab^{-1} M_{now} $(L_{future}/L_{now})^{1/8}$

Dilepton reach : 3.5 TeV → Becomes 7 TeV with 3ab^{-1} and coupling 0.1

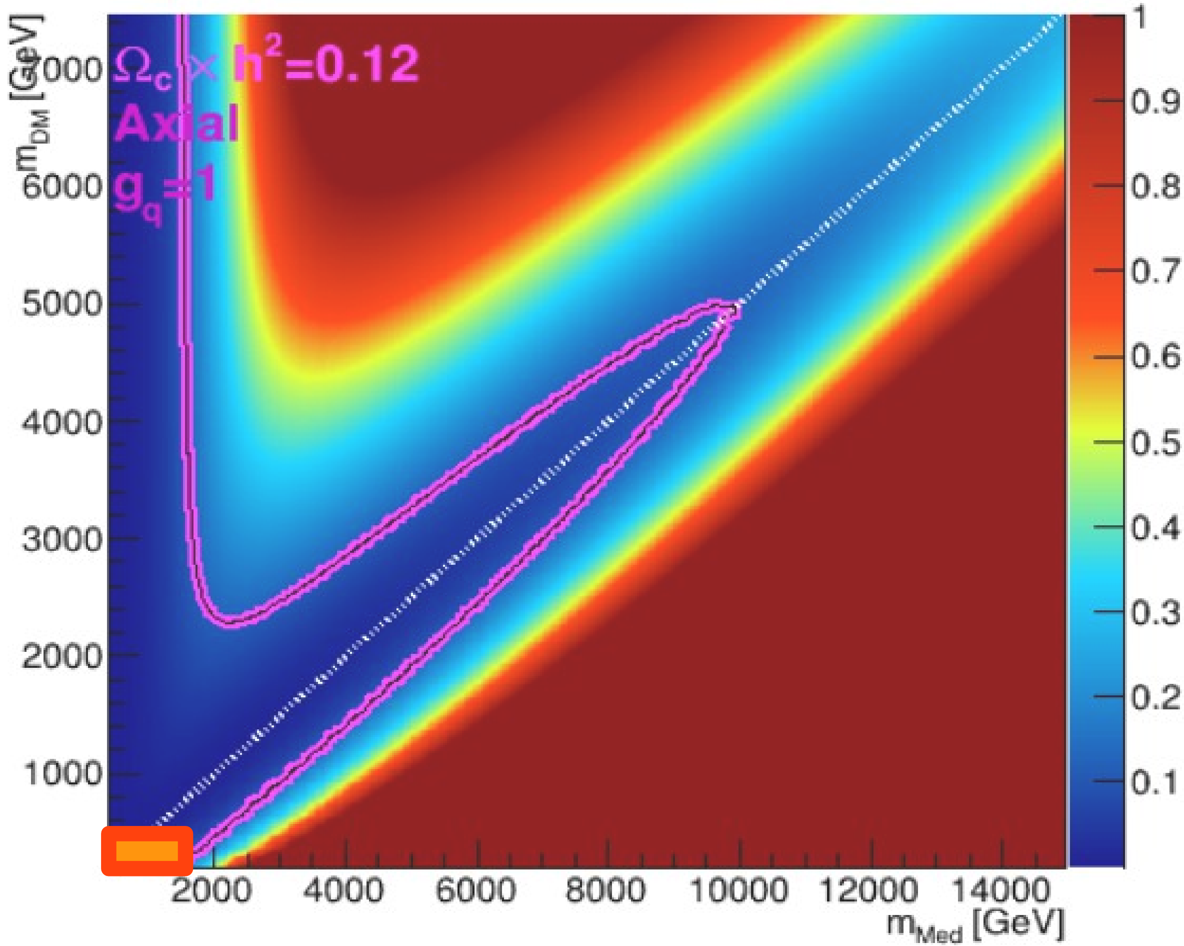
How does this compare?



Dijet alone at 14 TeV exceed spin-dependent direct detection

How about relic density?

For a benchmark model we start to cover with LHC :
At FCC this is definitive
Note : Model is oversimplified bounds can loosen w/particles



Mediator mass Maxes out around 8-9 TeV

Smaller for coupling g_q<1

Approximate Dilepton reach

Approximate dijet reach

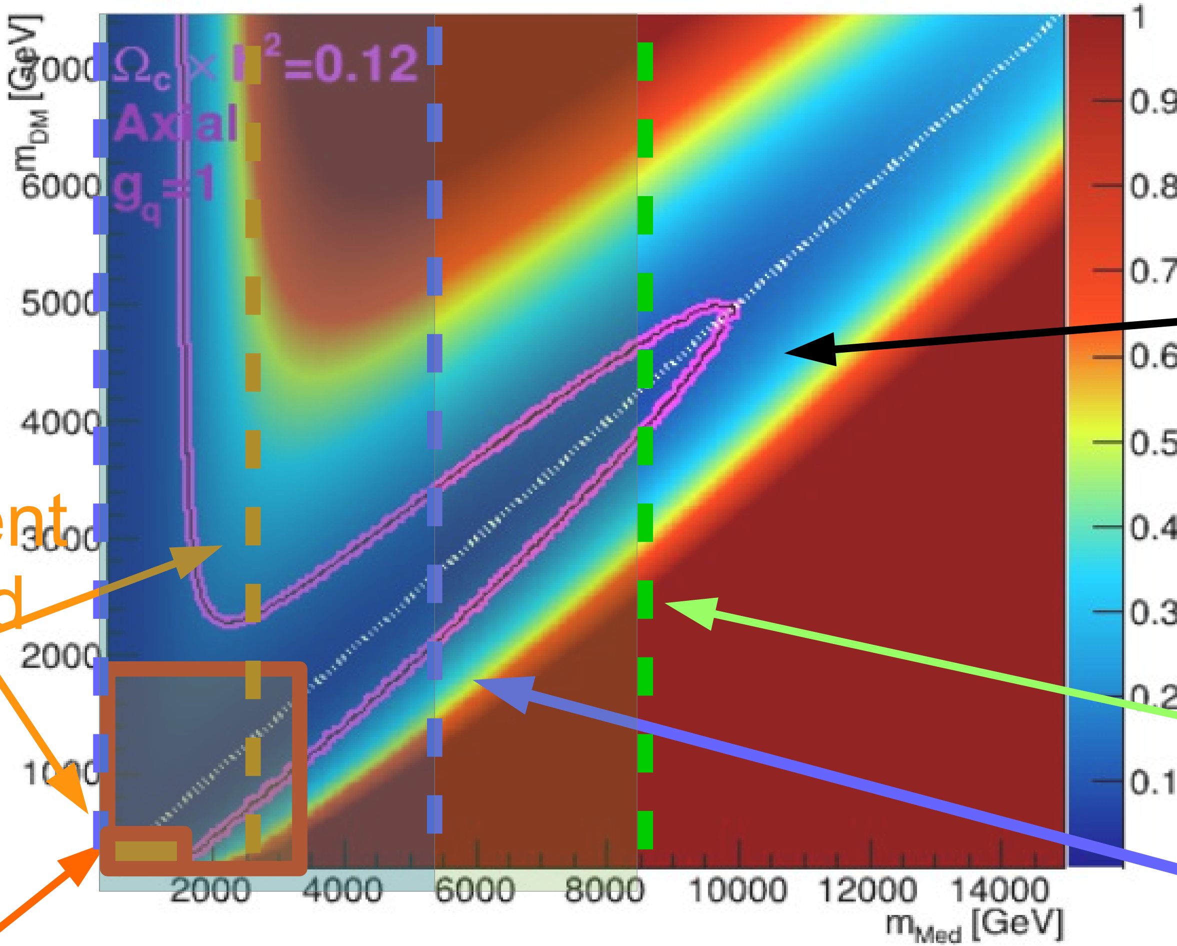
Approximate region monojet can probe

How about relic density?

For a benchmark model @ LHC : Spin 1 Axial-vector med

At FCC this is definitive

Note : Model is oversimplified bounds can loosen w/particles



Mediator mass Maxes out around 8-9 TeV

Smaller for coupling g_q<1

Current bound

Approximate Dilepton reach

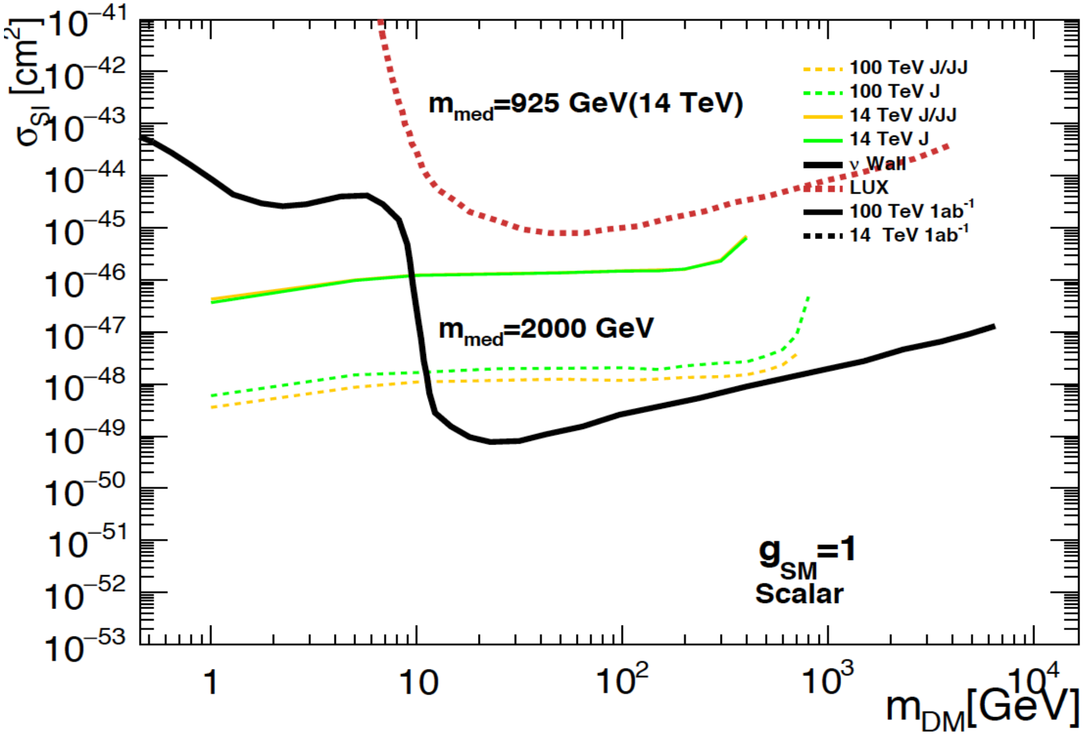
Approximate dijet reach

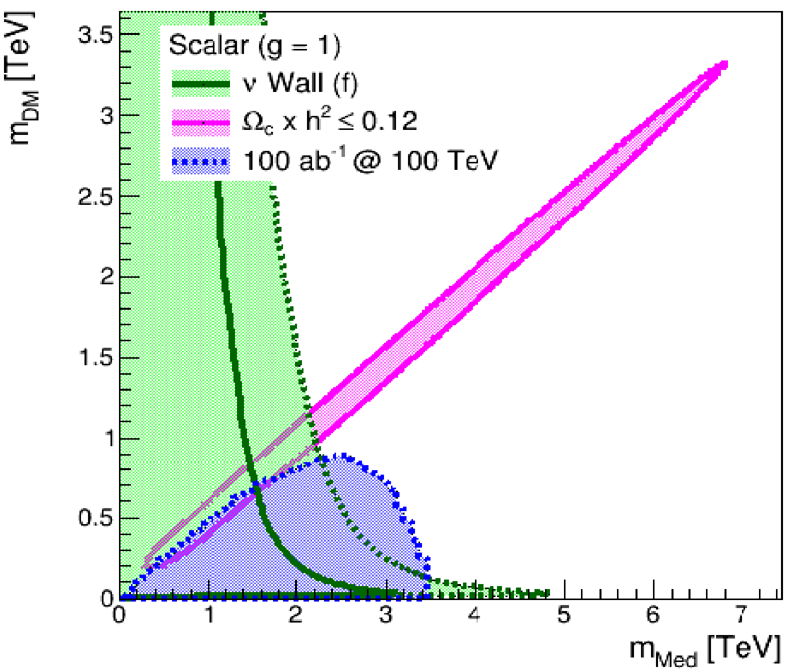
Approximate region monojet can probe

Benchmark
Higgs invisible search

Spin 0

- For spin-0 the bounds are more challenging





Projections with a scalar simplfiied model indicate :

Close to crossing the neutrino wall with the FCC detector

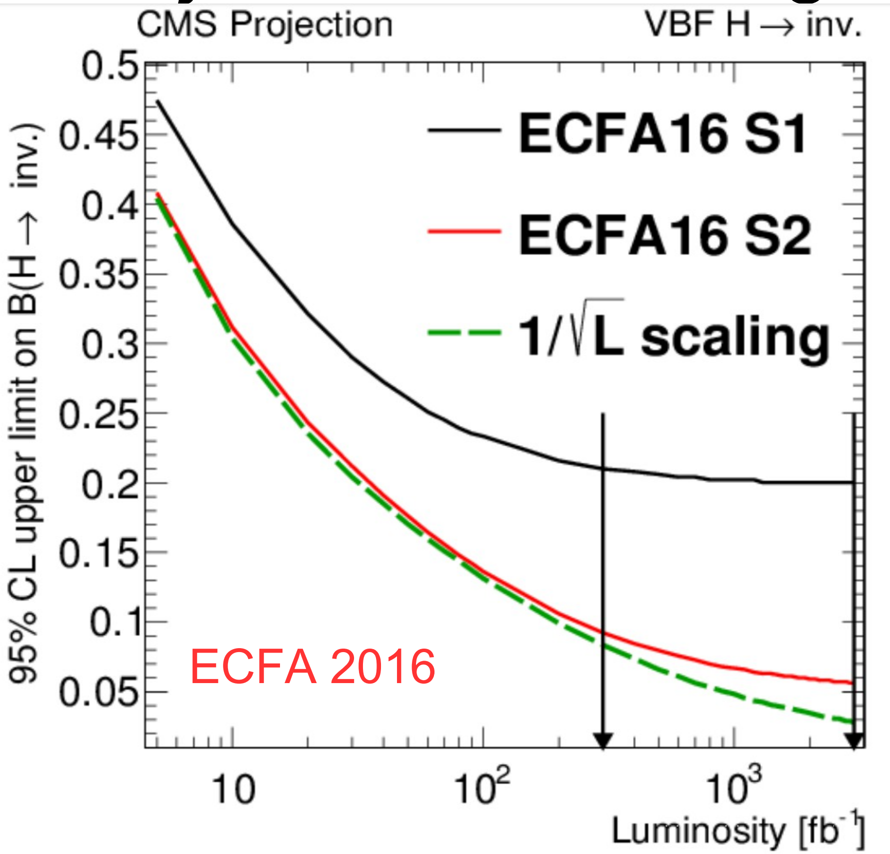
Close to reaching the bounds of direct detection

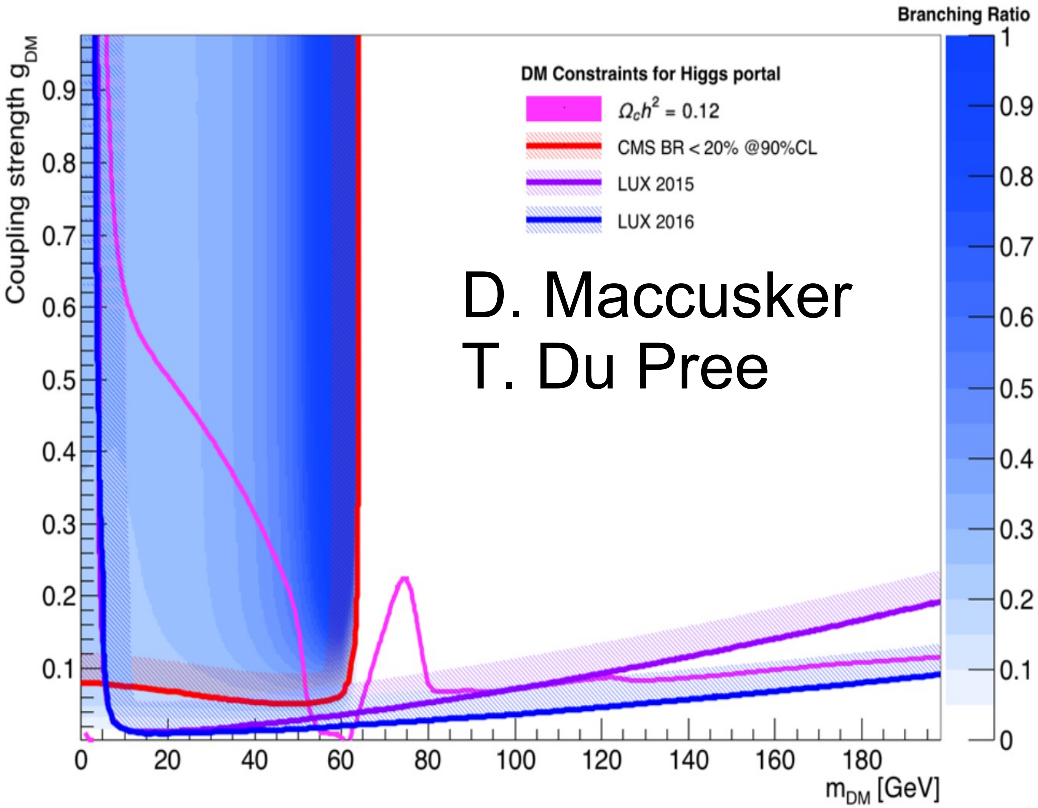
Rest of this talk : How do we impove these bounds?

We will do this in the context of Higgs invisible

Higgs Invisible benchmarks

- Projections at LHC go to <3%

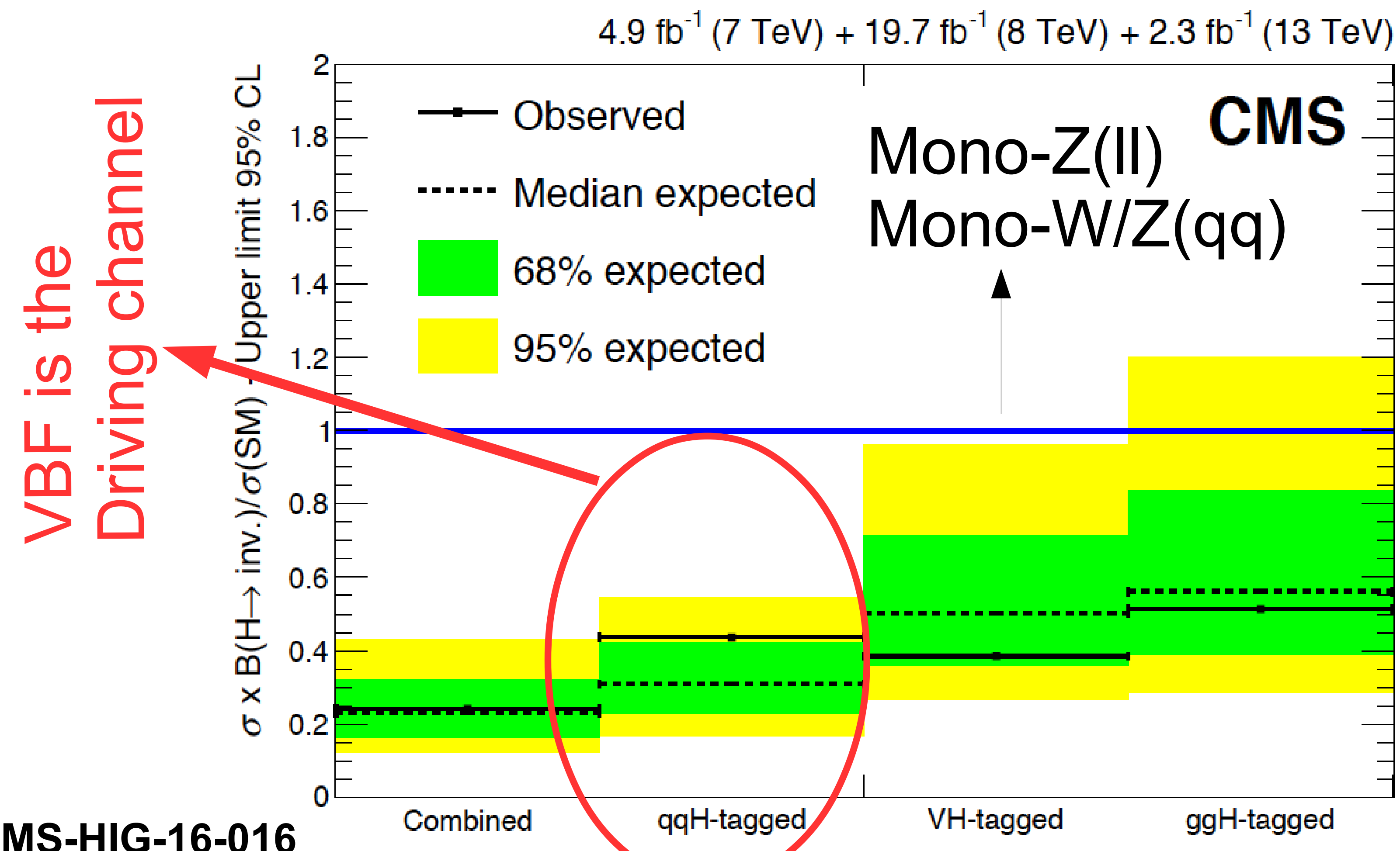




	ECFA16 S1	ECFA16 S2	$1/\sqrt{L}$ scaling
300 fb^{-1}	0.210	0.092	0.084
3000 fb^{-1}	0.200	0.056	0.028

Higgs Invisible Search @ LHC

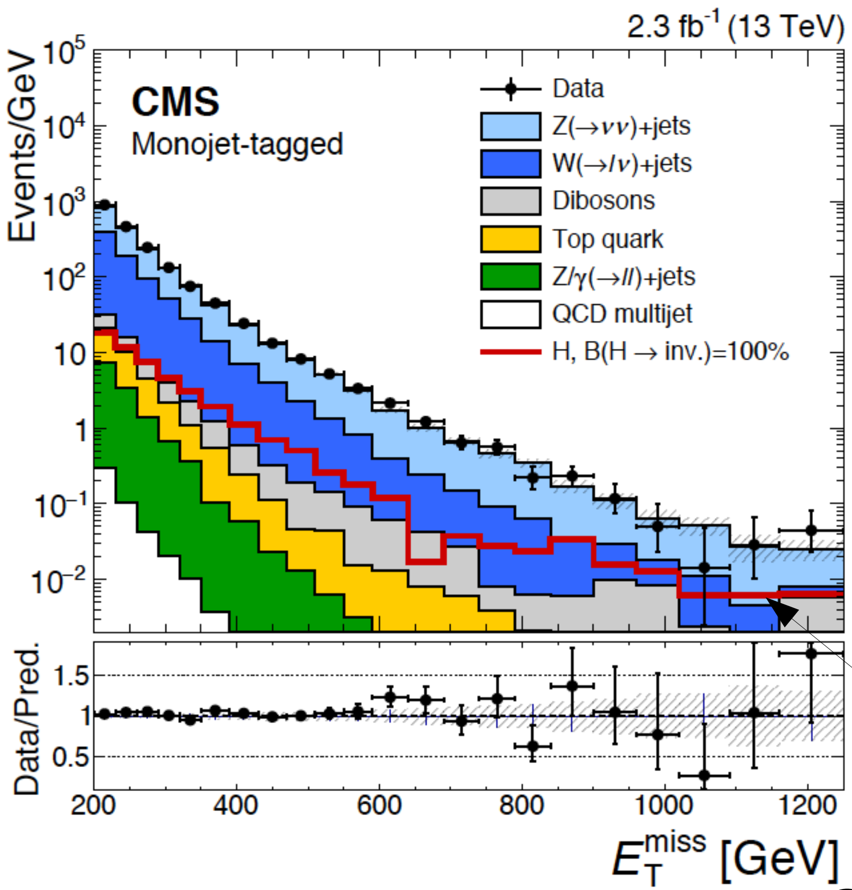
- 4 main categories drive the analysis:
  - Current bounds BR(H→inv) < 24%

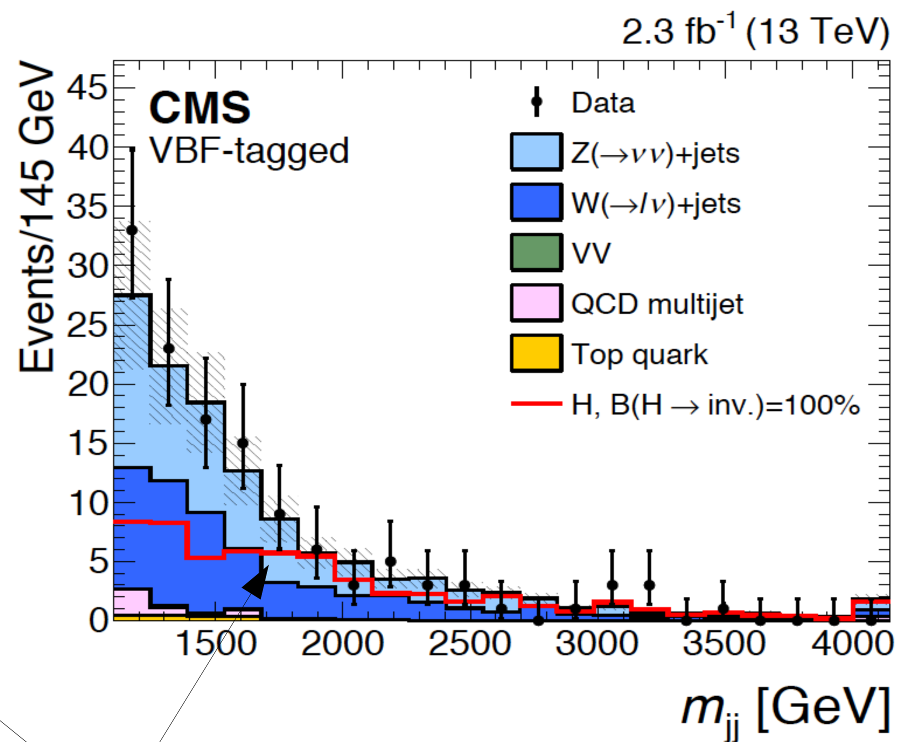


CMS-HIG-16-016
arXiv:1610.09218

Higgs Invisible Search @ LHC

- 4 main categories drive the analysis:
  - Current bounds BR(H→inv) < 24%

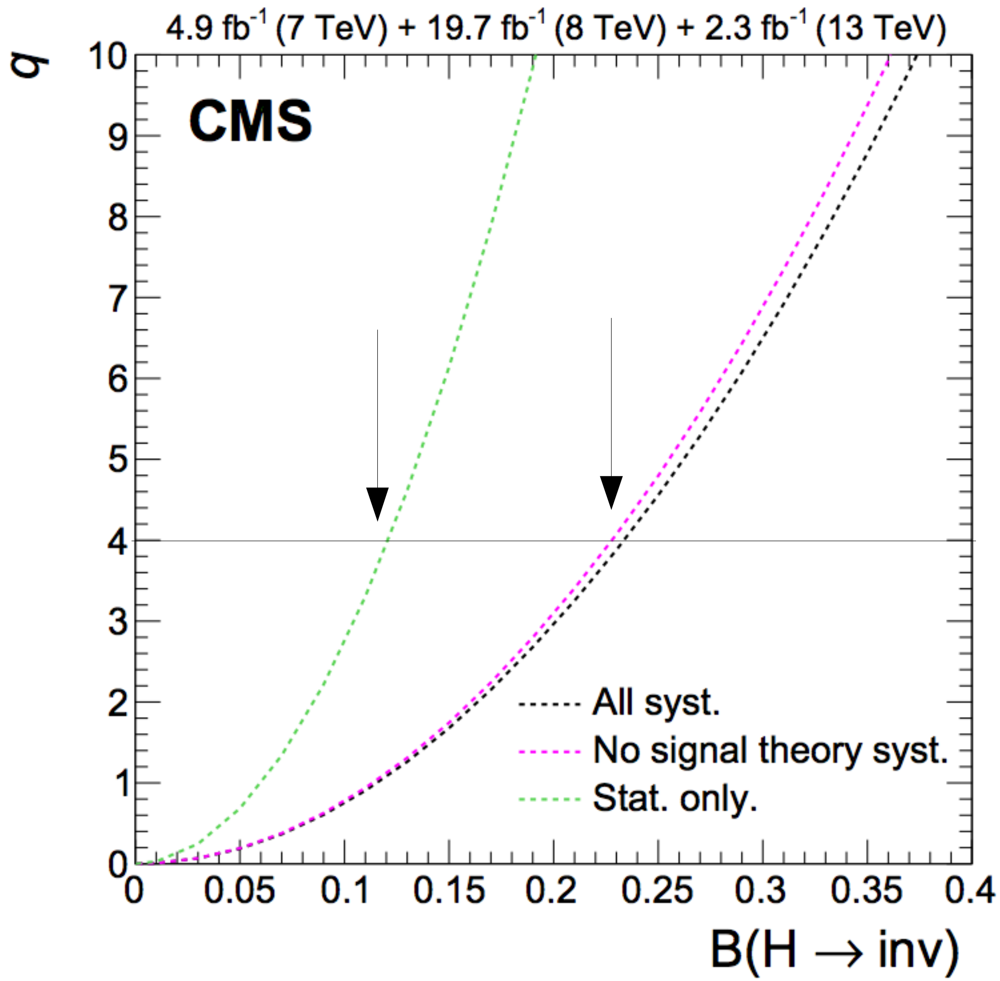




Signal/Background is considerably larger for the VBF Channel

Higgs Invisible Search @ LHC

- Bounds are largely systematics limited
  - If we turn off systematics we are almost 3x better



Large variation is coming from the monojet

Large signal and large systematics make analysis difficult

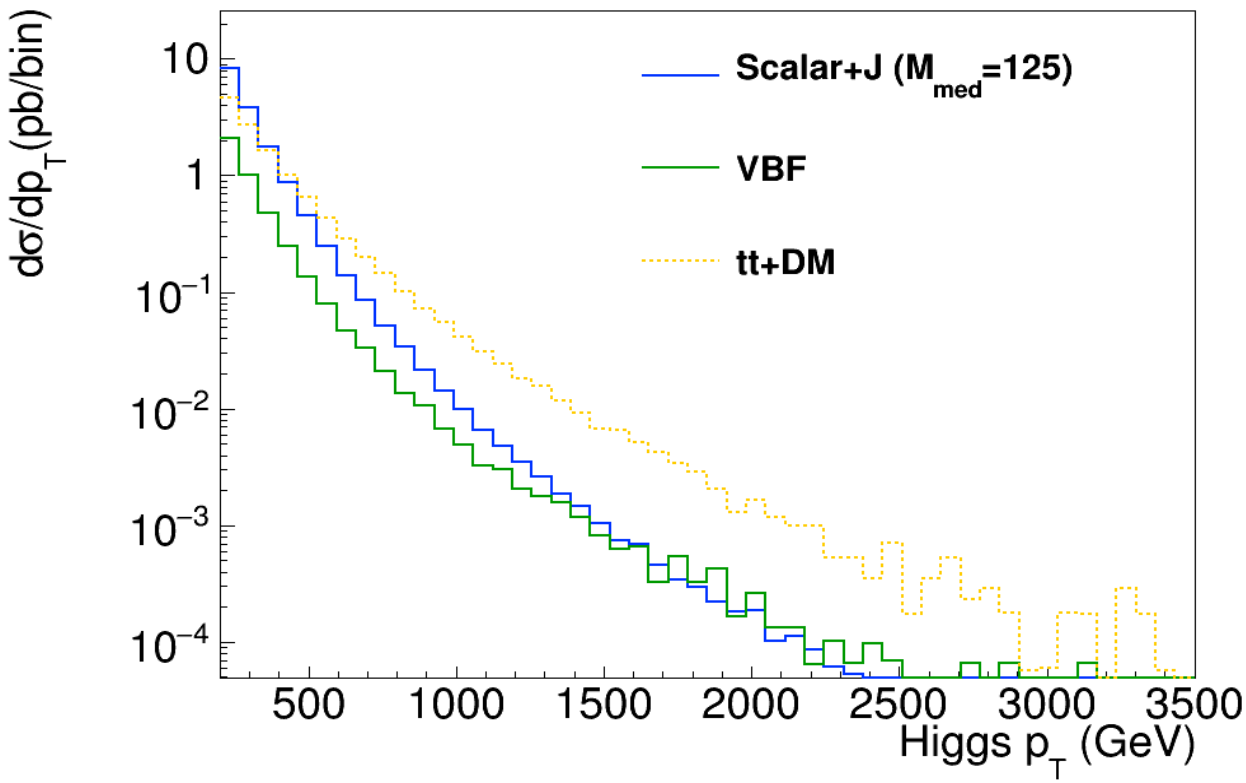
Going to 100 TeV

What about the cross sections?

- The relative rate to all processes is similar
  - σ(100 TeV/14 TeV) : ggH : 14.7
  - σ(100 TeV/14 TeV) : VBF : 18.6
  - σ(100 TeV/14 TeV) : WH : 9.8
  - σ(100 TeV/14 TeV) : ZH : 12.5
  - σ(100 TeV/14 TeV) : ttH : 60.8
  - σ(100 TeV/14 TeV) : bbH : 14.8
  - σ(100 TeV/14 TeV) : HH : 42.0
  - Except for ttH
- Means we expect VBF to give similar improvement
- Benchmarking agains ggH means ttH/VBF have a lot of room to gain

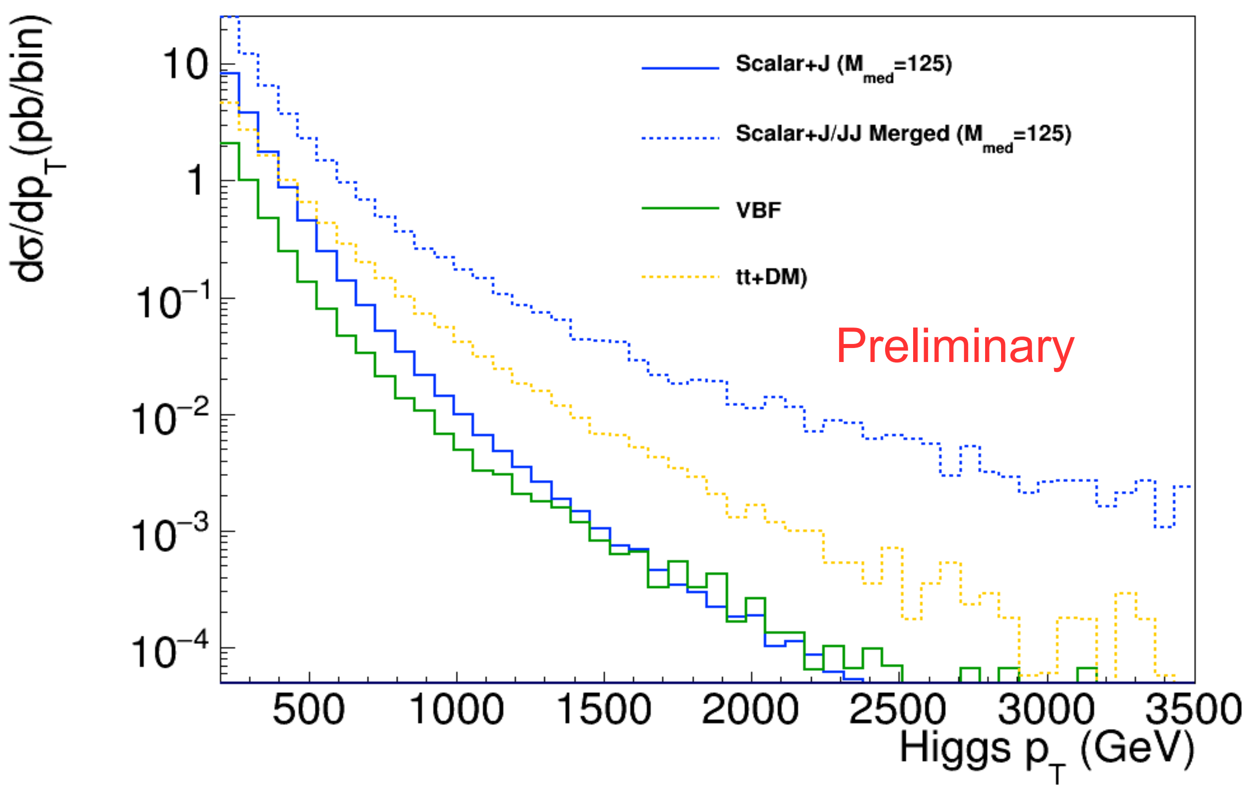
What are the production modes?

- At 100 TeV :
  - ttH is hugely enhanced
  - When compared with H+1j form gluon fusion it wins



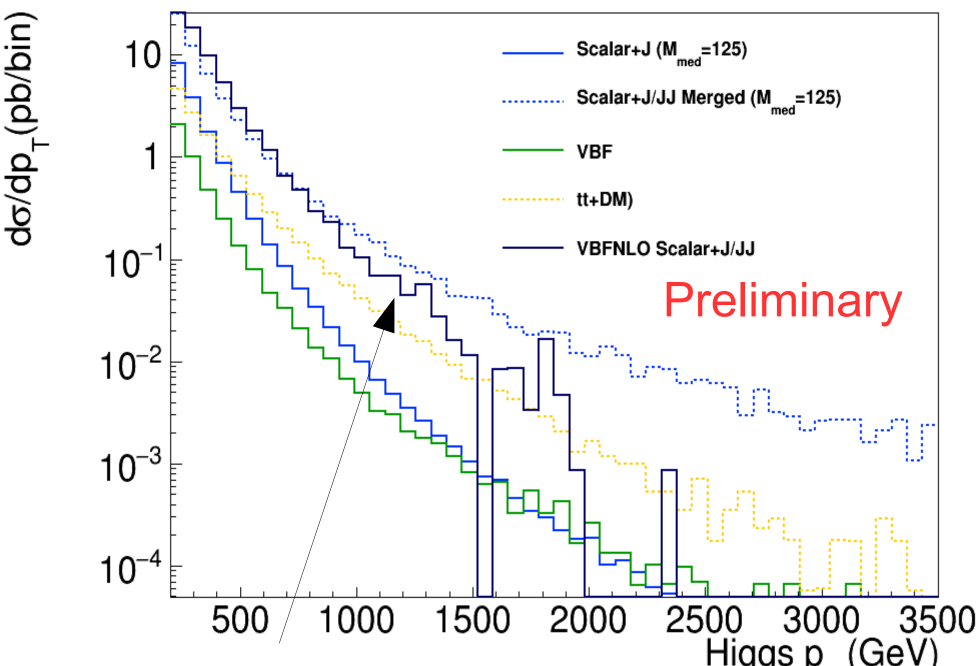
What are the production modes?

- At 100 TeV :
  - ttH is hugely enhanced
  - When compared with H+1j form gluon fusion it wins
  - However H+2j is also hugely enhanced

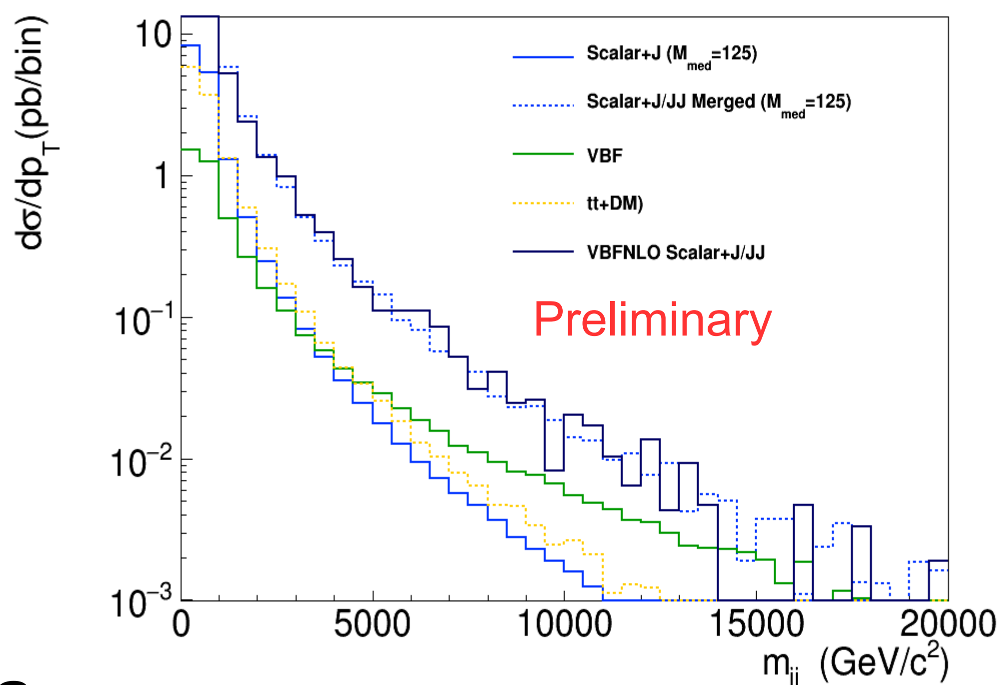


Cross checking the 2jet model

- At 100 TeV :
  - ttH is hugely enhanced
  - When compared with H+1j form gluon fusion it wins



Differences at high p_T are a result of scale in generation



Good agreement in m_{jj}

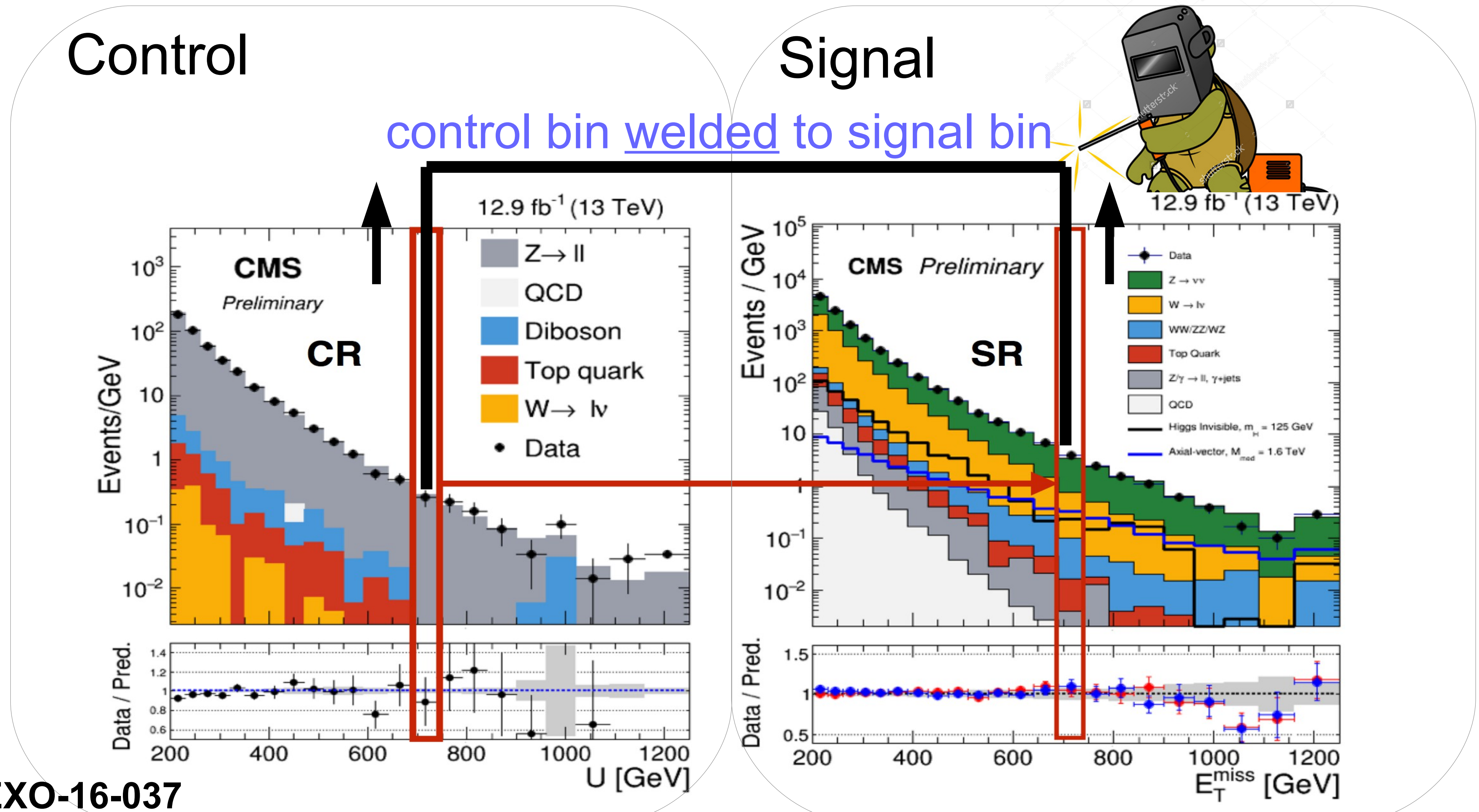
Essence of the search

- Rely on control regions to model signal region
  - Control regions have small signal fraction
  - Use the control region to derive :
    - Corrections to the *MET* scale and resolution
    - Missing higher order corrections in the MC
  - This eliminates the dominant uncertainties
  - Analysis scales with statistical power of control regions
    - As long as they continue to grow : not systematics limited

- All the control regions are fit simultaneously
  - By fitting simultaneously rely on the ratio of production

What is the transfer factor?

Propagate the data/MC agreement of the hadronic recoil
From a control region to a signal region



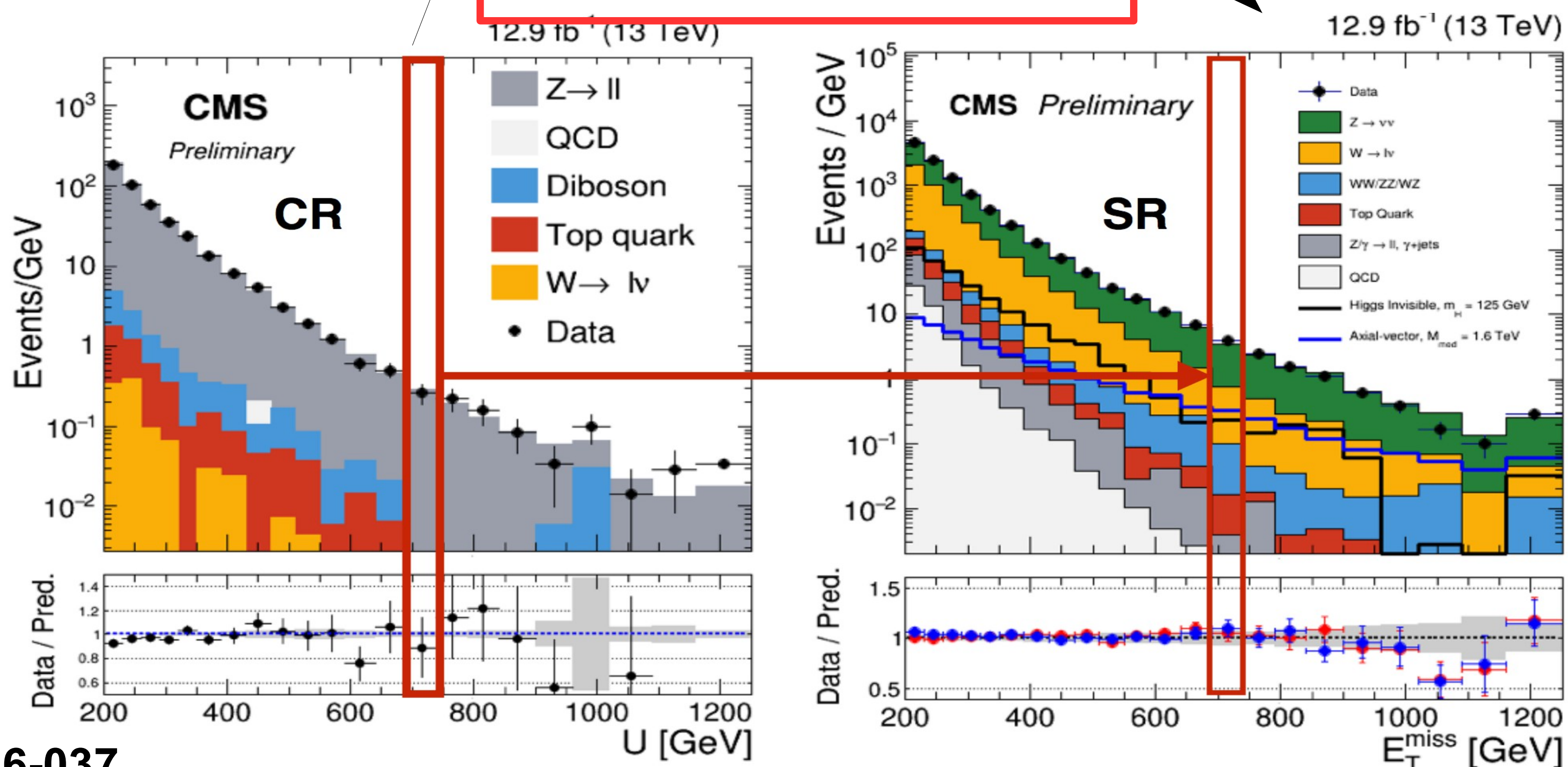
CMS-EXO-16-037

What is the transfer factor?

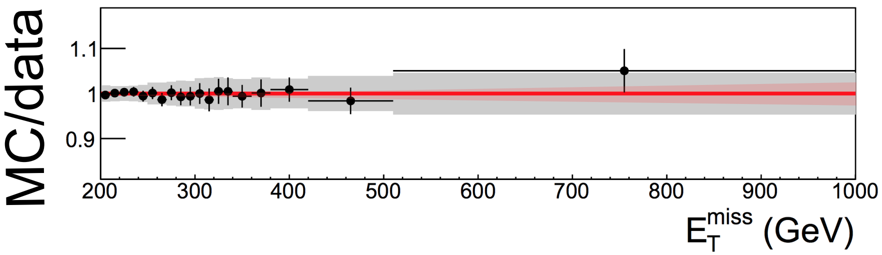
Do this formally by embedding transfer factors R_i

Easily propagate these into fitted likelihood for signal

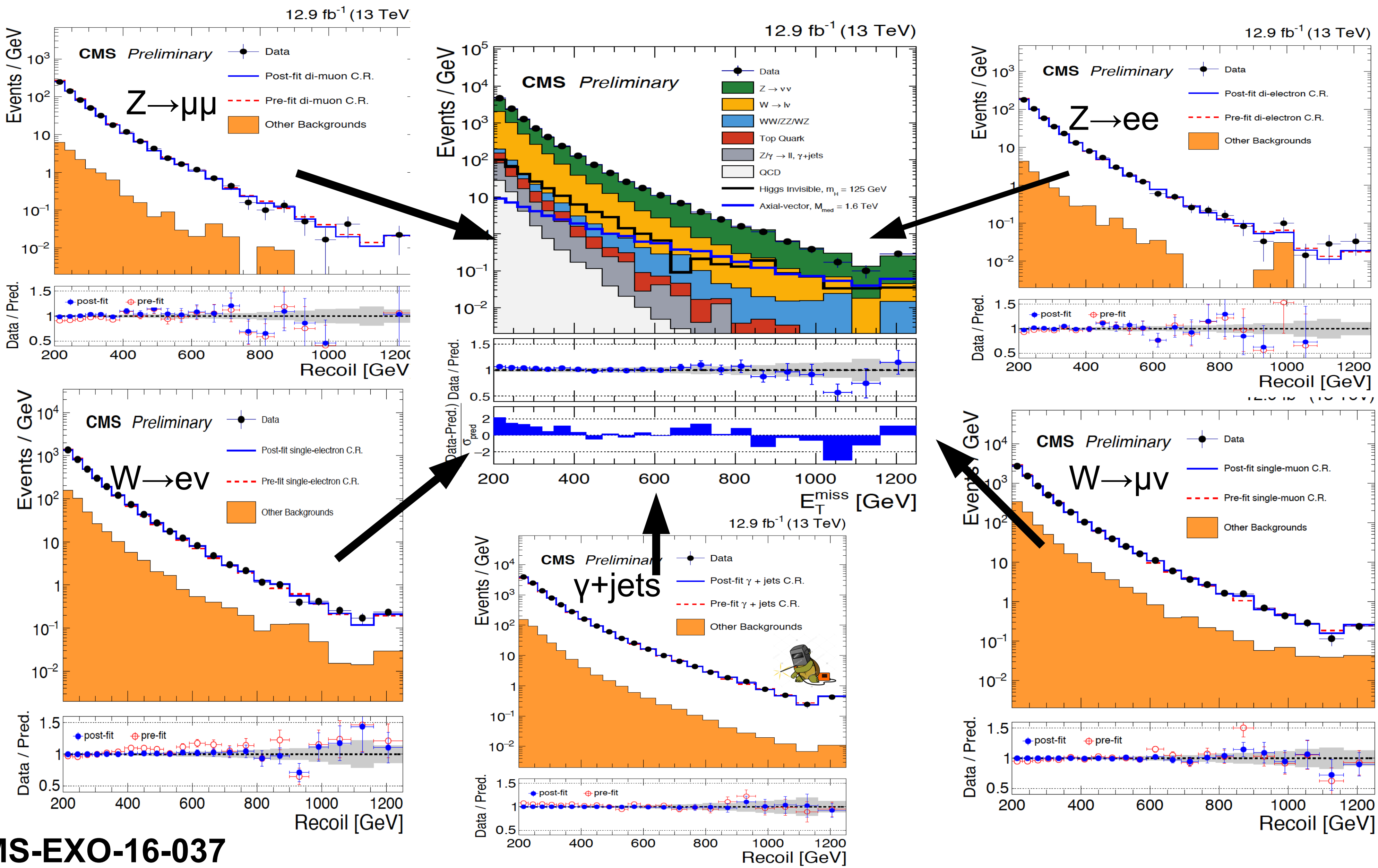
$$R_i^Z = \frac{N_{i,MC}^{Z\rightarrow\mu^+\mu^-}}{N_{i,MC}^{Z\rightarrow\nu\nu}}$$



CMS-EXO-16-037



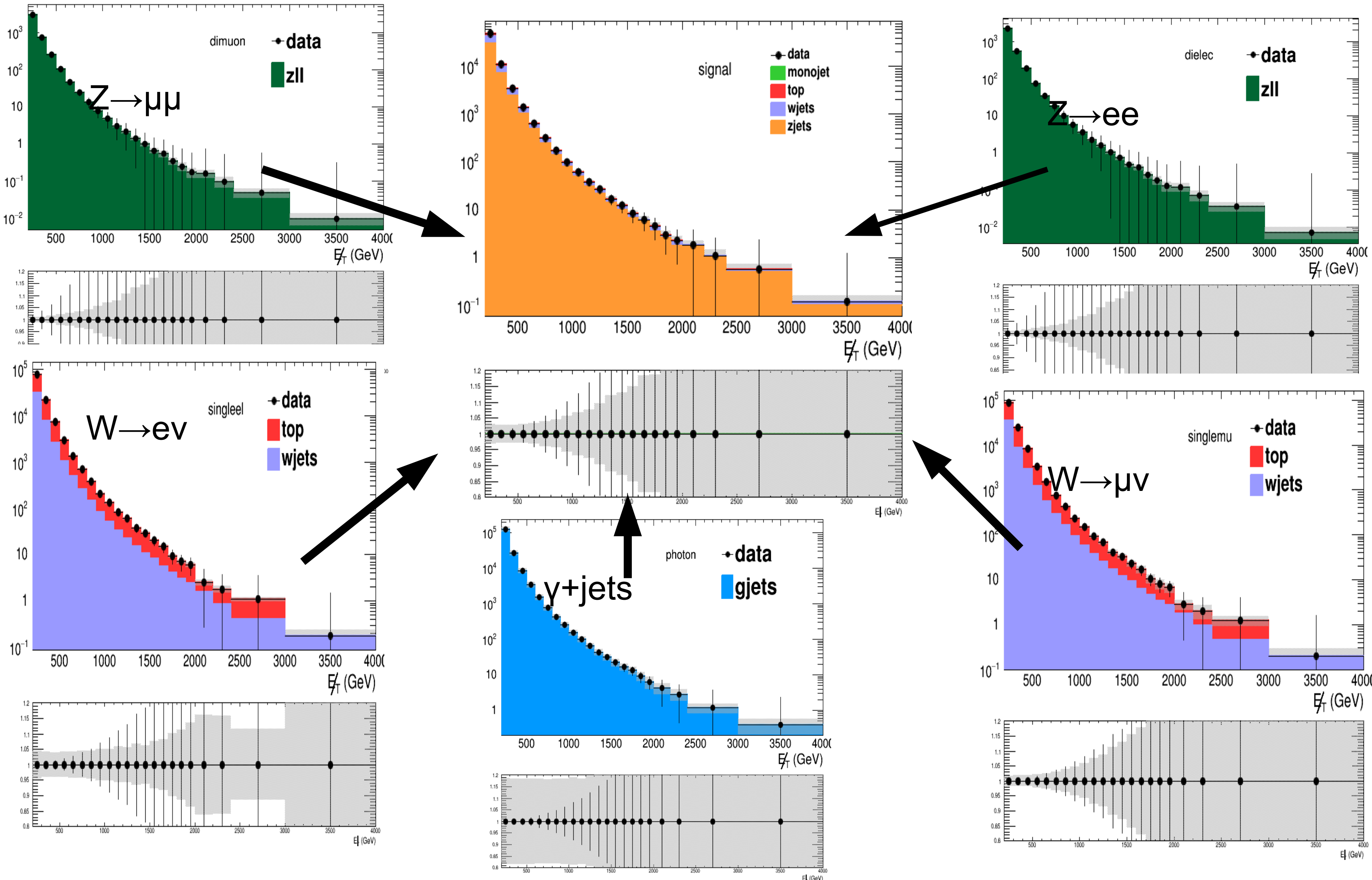
5 Control regions
15% uncertainty @ 1 TeV



CMS-EXO-16-037

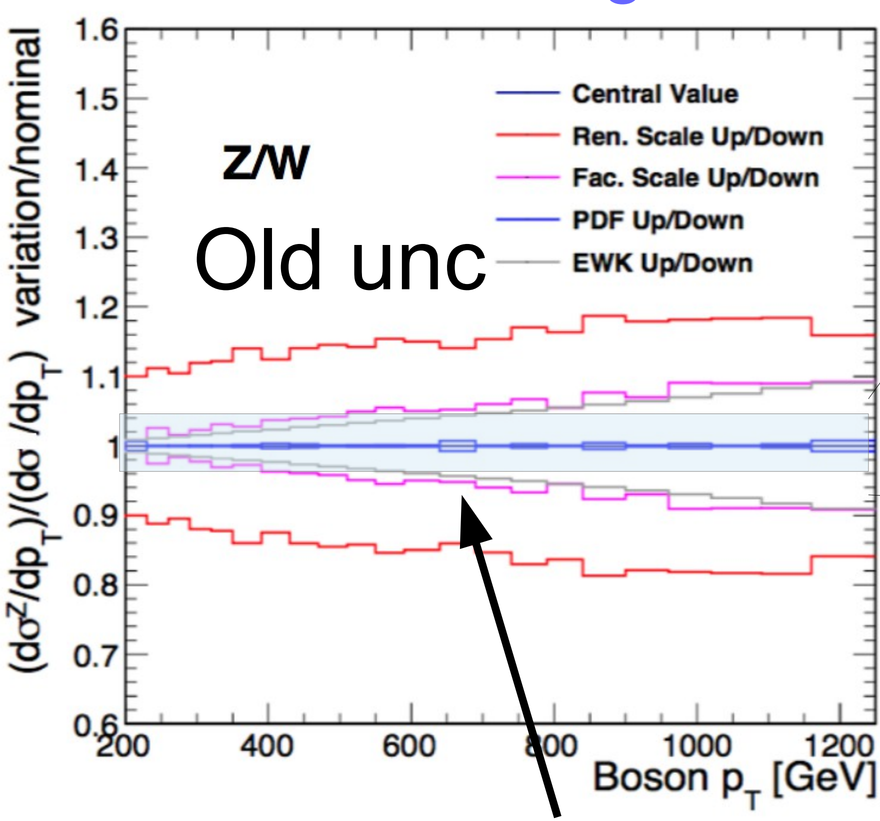
Similar unc Scheme 100pb^{-1}

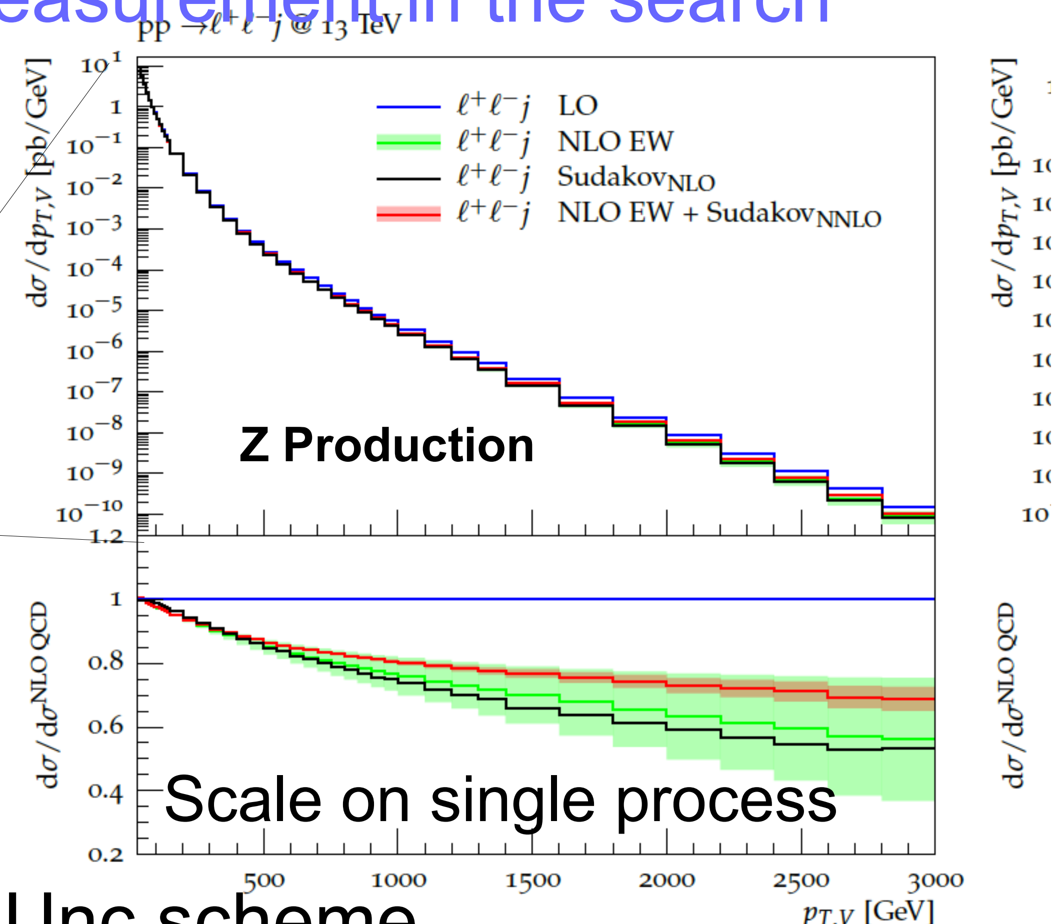
The same fitting scheme applies to 100 TeV



What drives systematics?

- Dominant systematics for this measurement originates on the ratio
  - We are doing the ratio measurement in the search

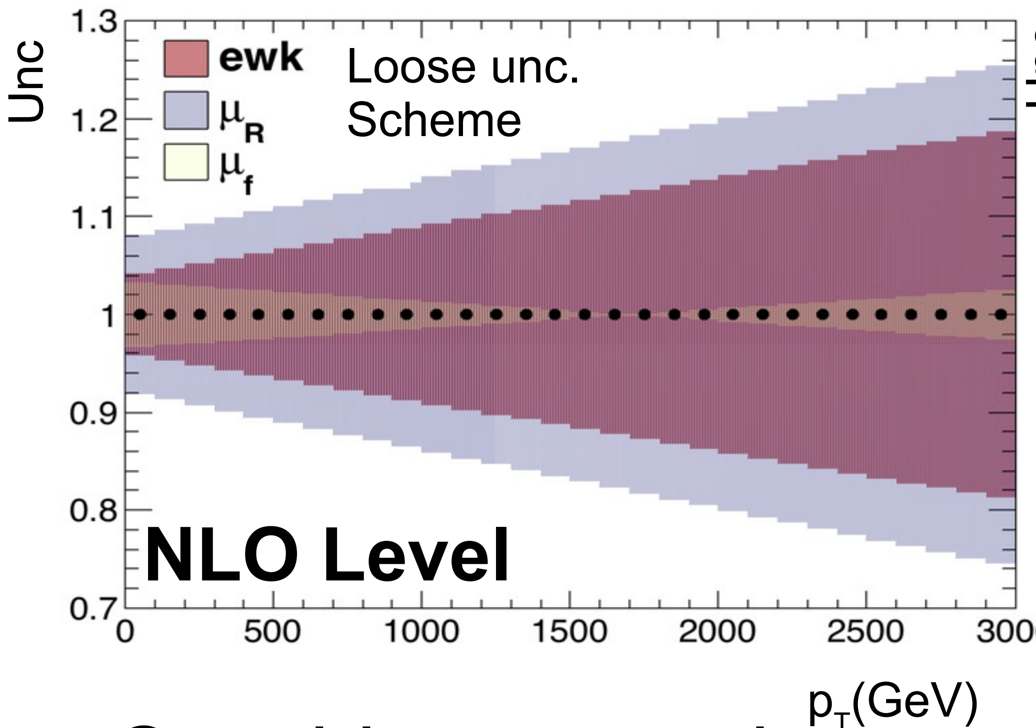


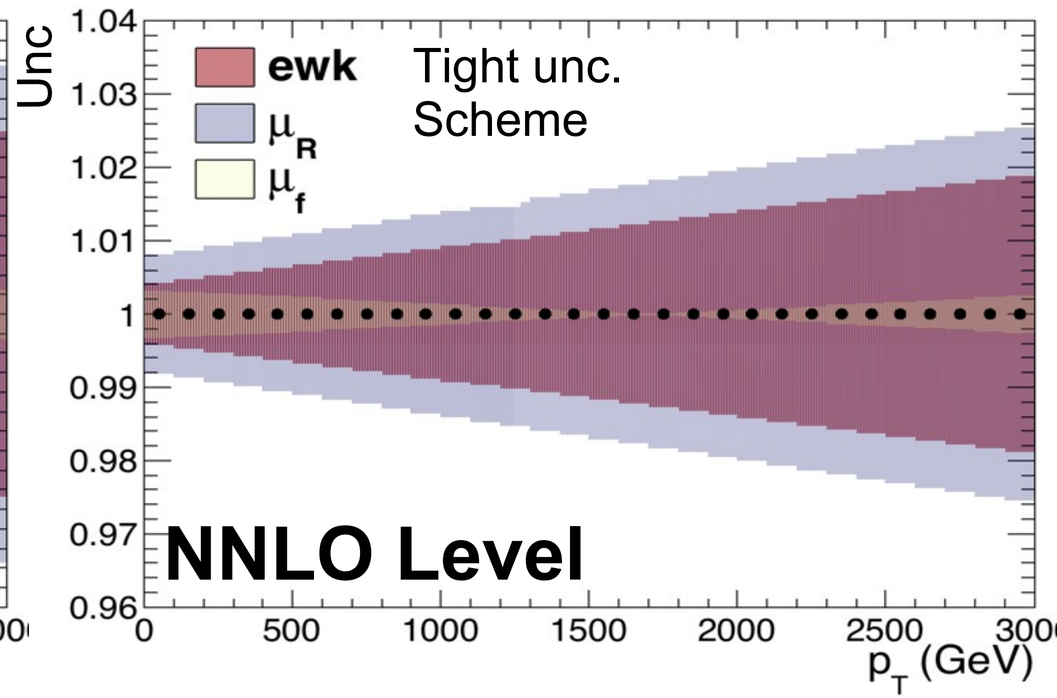


Rough expectation with new Unc scheme
NNLO scale+NLO EW + Sudakov+Mixed terms

Benchmarks for this study

- What are reasonable uncertainty choices

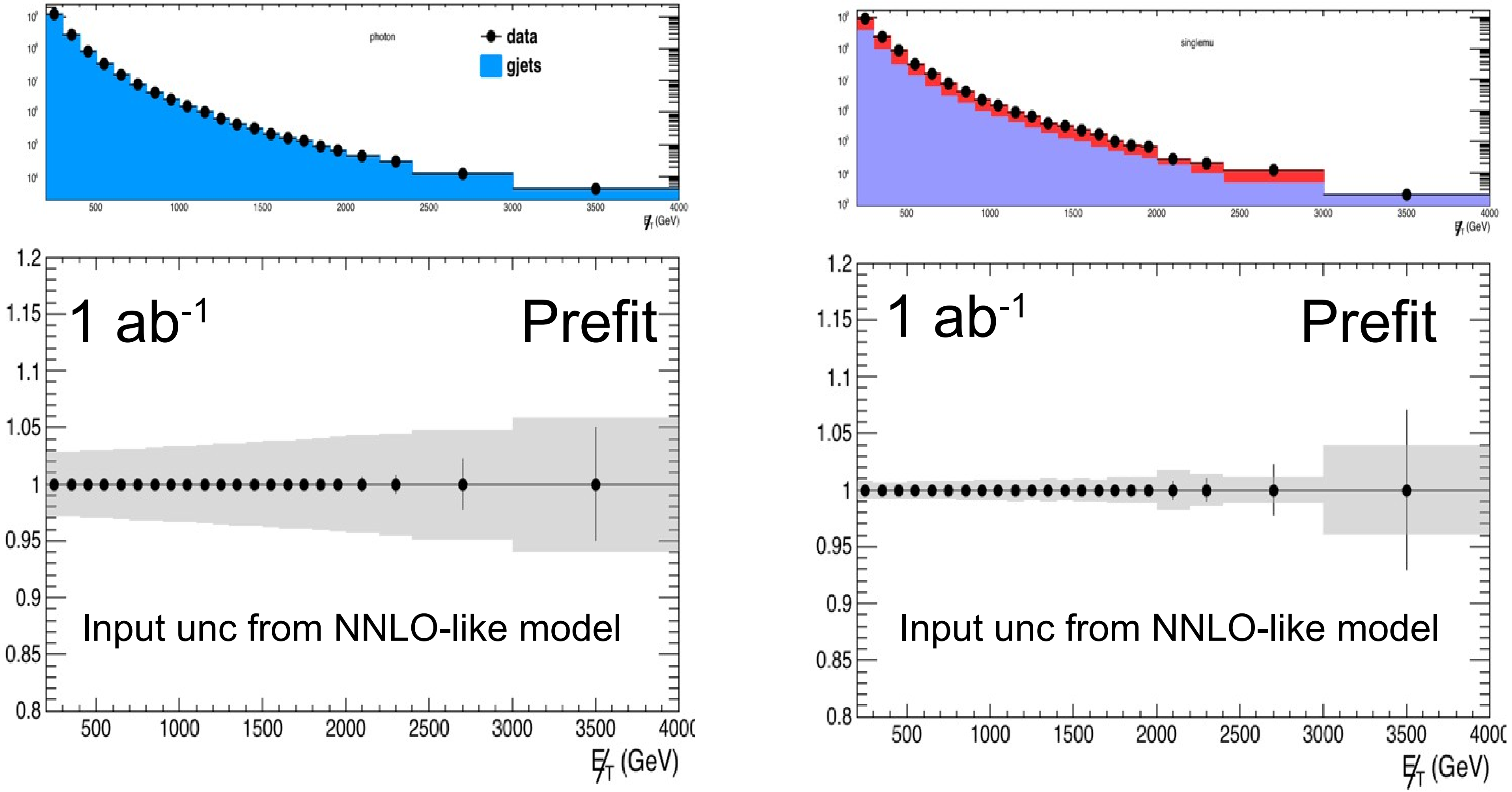




- Consider two options :
  - A Loose uncertainty →Comparable to NLO
  - A Tight uncertainty →Comparable to NLO
- Using : 0.5%/0.25%/5% e/μ/τ efficiency & 1% lumi

What is the precision?

- Can probe a few % effects (NNLO precision)



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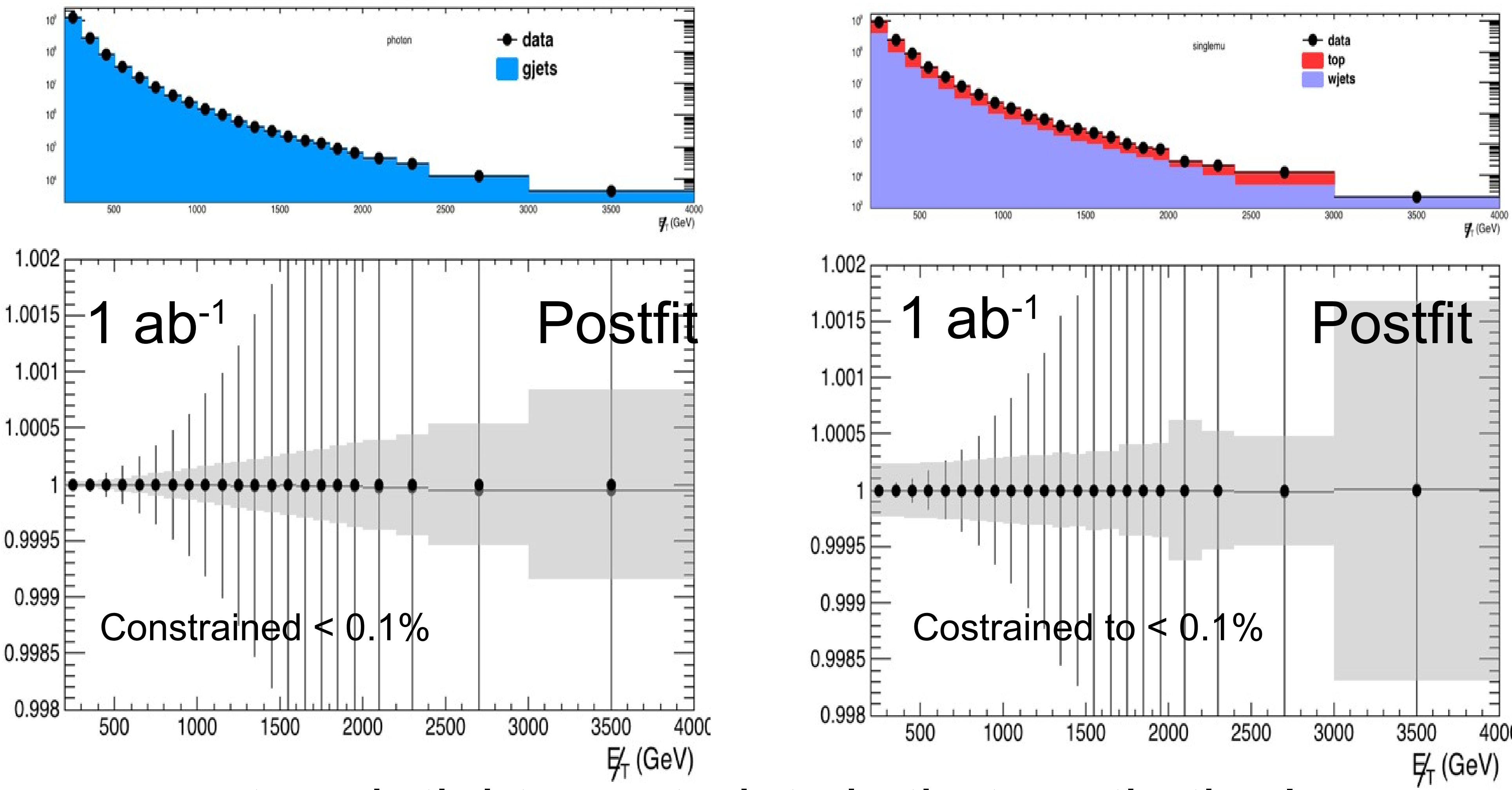
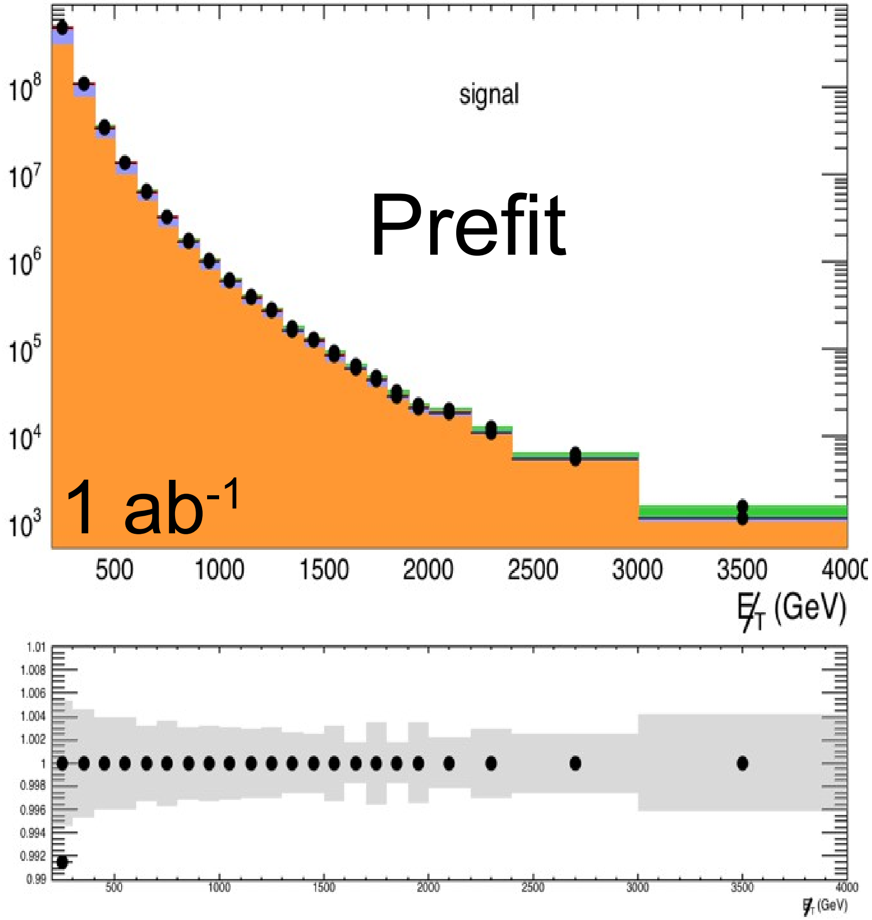
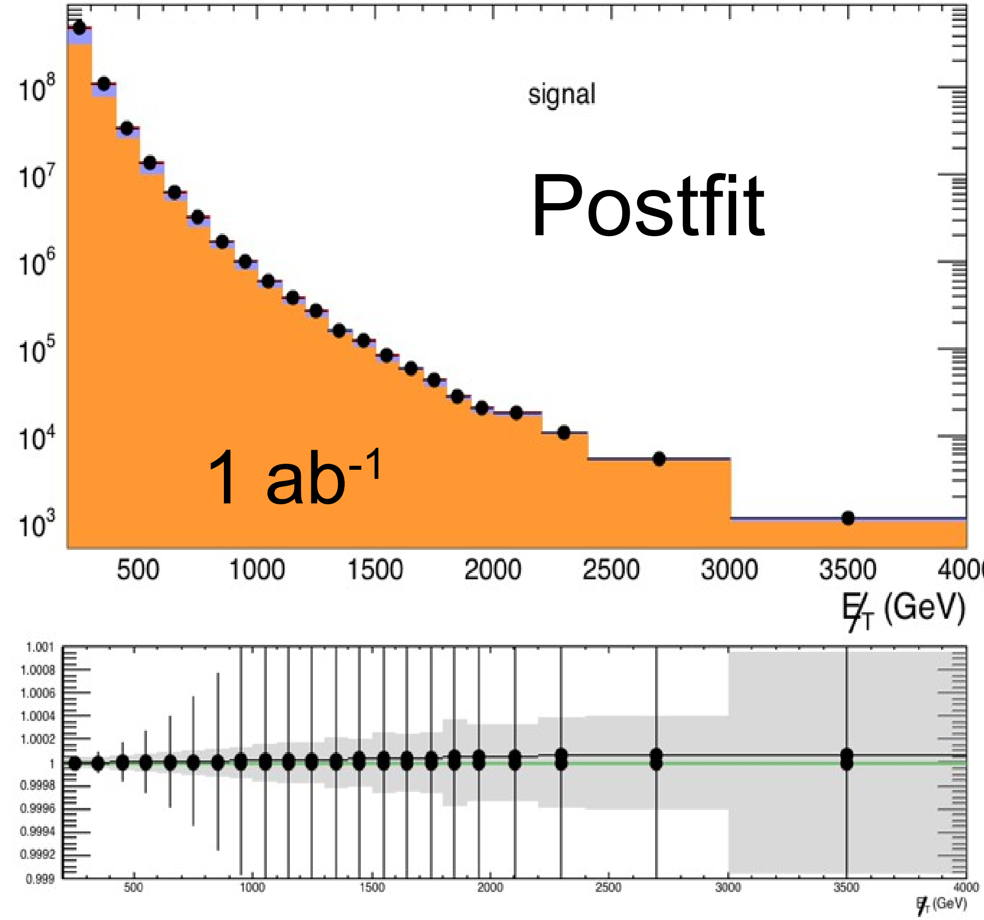


Reason get such tight constraints is that we tie the low pT with the high p_T

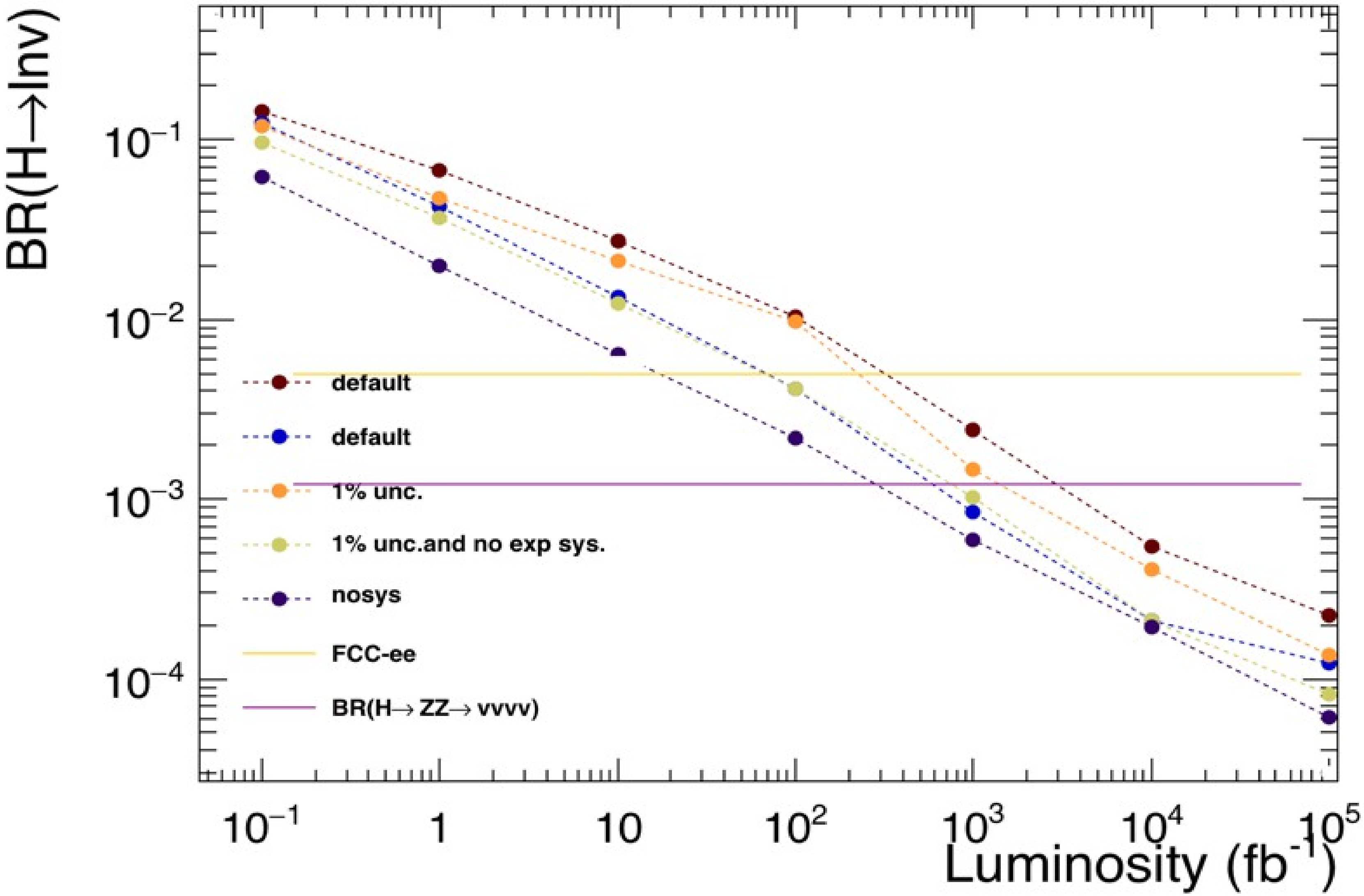
How strong are constraints?





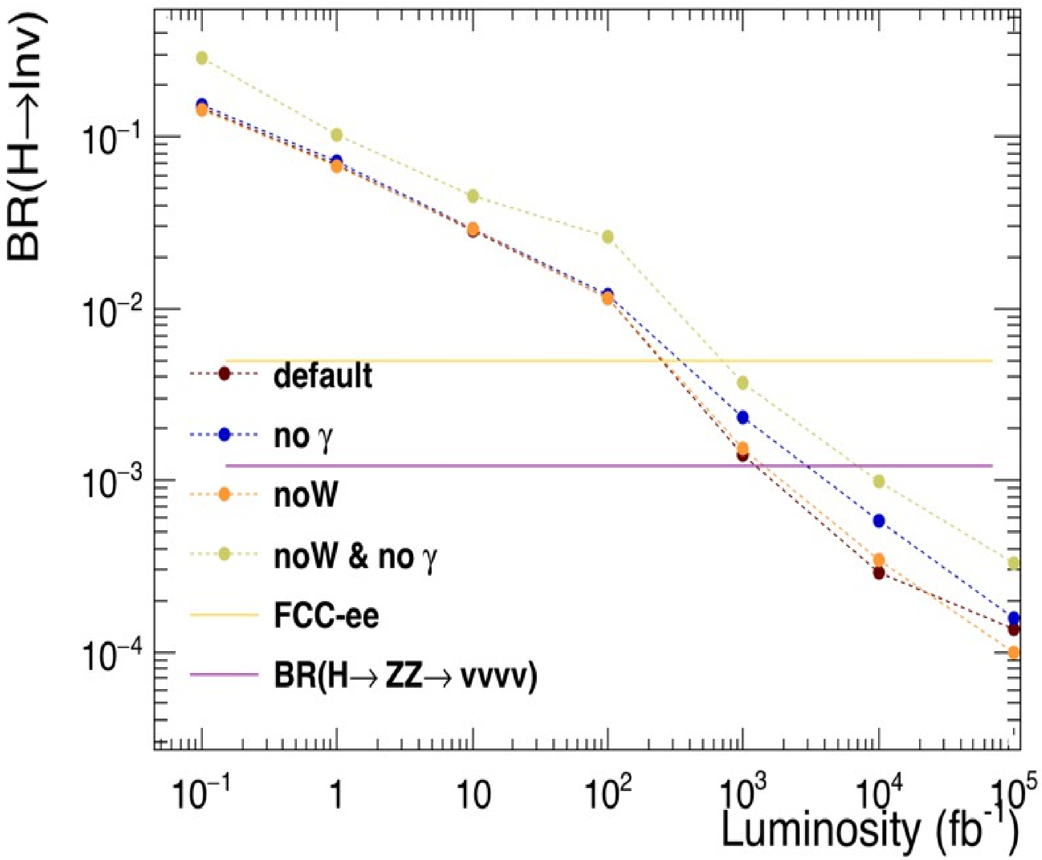
These translate well to the signal region

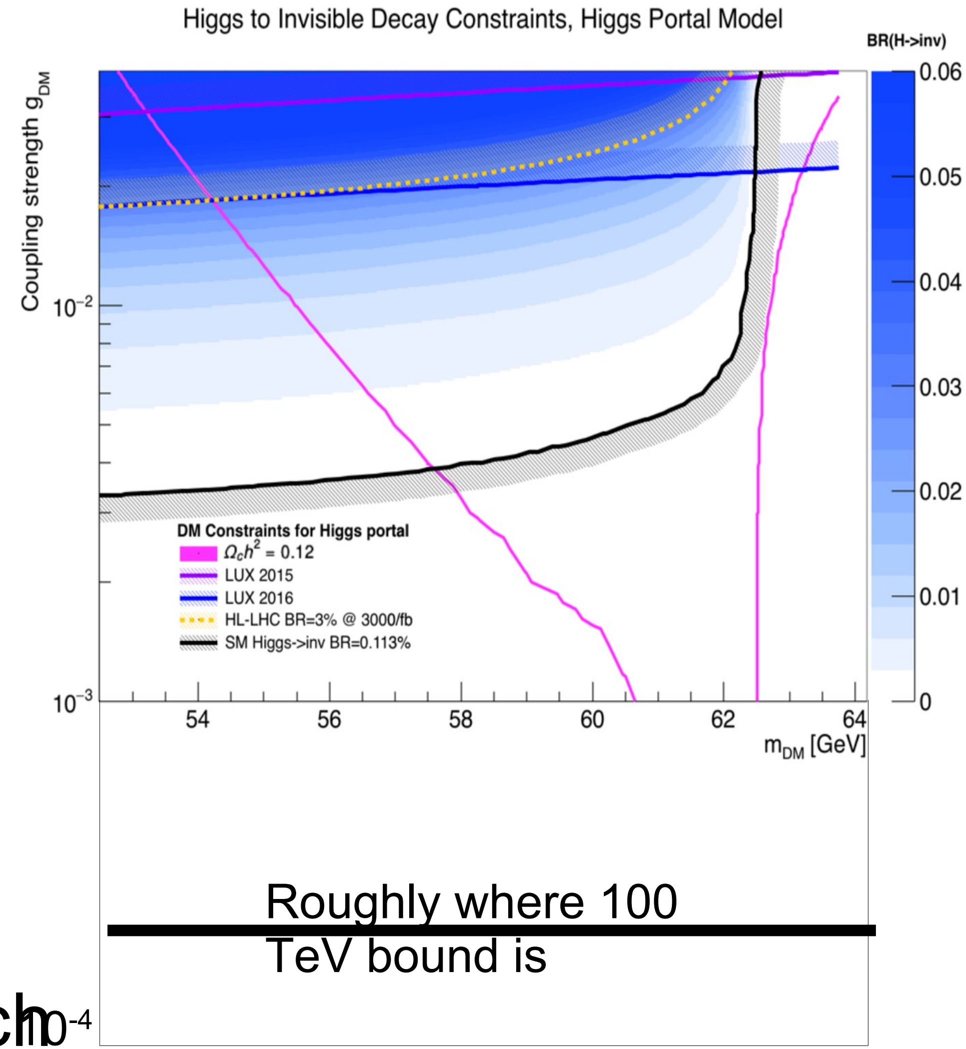
How do things scale?



Cross the SM neutrino wall at FCC with < 1 ab^{-1}

What is the impact?

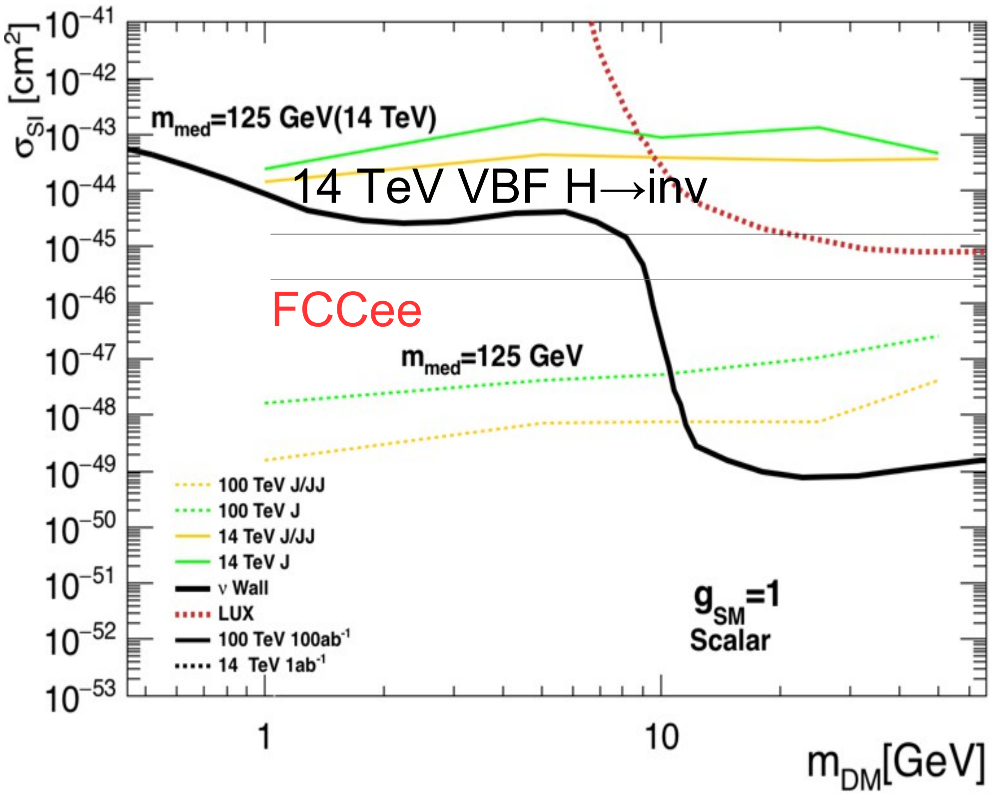


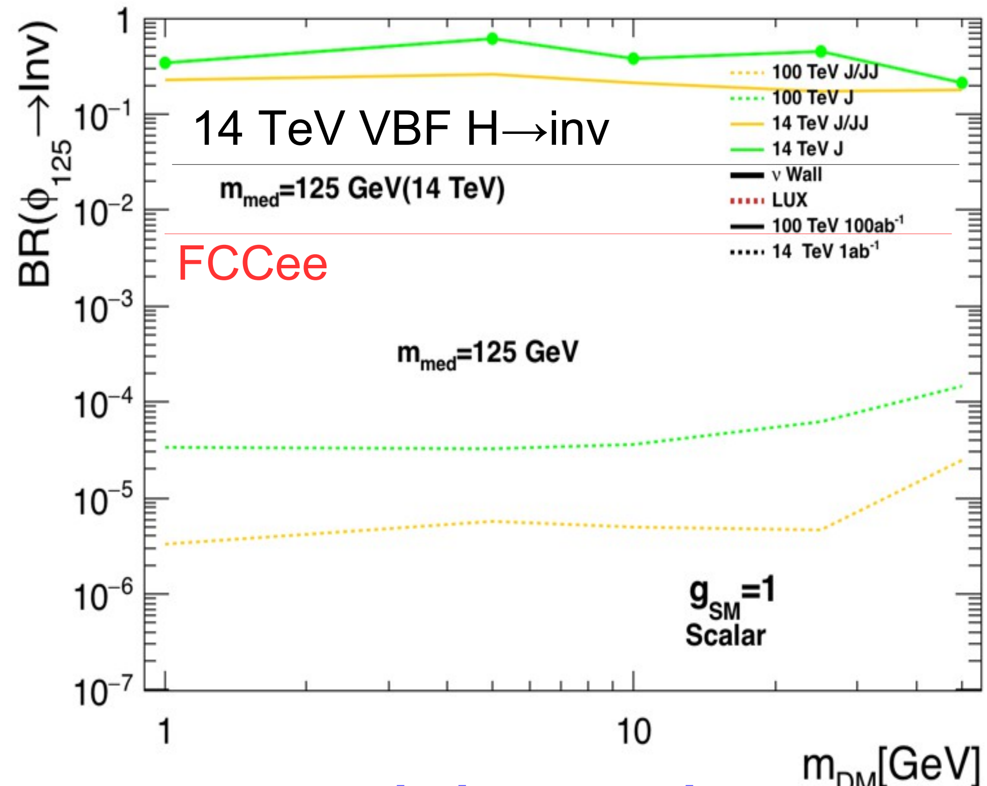


Relying on the Z boson gives a substantial reduction in the search

Higgs to invisible

- A nice benchmark is the Higgs invisible:





100 TeV machine has far more senstivity to the invisible decays of a Higgs

https://arxiv.org/abs/1603.07739
https://indico.cern.ch/event/438866/contributions/1085169/attachments/1258088/1858101/FCCwe k_Hinv_MDG_14042016.pdf

Looking beyond monojet final state

- Deep understanding of monojet extends to many models
  - Disappear track
    - Monojet+track
  - Displaced jets

Final State	Analysis	section
jet+MET	Wino, Higgsino DM	4.3.1 - 4.3.4
jet+MET	Higgs Portal	4.3.5
jet+MET	Simplified Vector/Axial	4.4.1 - 4.4.3
jet+MET	Simplified Scalar/Pseudo	4.4.1 - 4.4.3
jet+MET	Gluion/stop coannihalation	4.5.1
VBF jets +MET	Wino, Higgsino DM	4.3.1 - 4.3.2
VBF jets +MET	Higgs Portal	4.3.5
photon+MET	Wino	4.3.2
Disappearing tracks	Wino,Higgsino	4.3.1 - 4.3.2
Disappearing tracks	Fiveplet DM	4.3.3
Disappearing tracks	Relic-Neutralino	4.3.4
lepton+γ+MET	Relic-Neutralino	4.3.4
$Z_D \to ll$+($Z_D \to ll$)	Dark Photons	4.4.4, 4.6.3
displaced jets	Dark QCD/Hidden Valley	4.6.2
long lived charged particle	Super-WIMPS/Gravitino	4.6.4
dijet	Simplified Vector/Axial	4.4.1 - 4.4.3

Table 5: Overview of the final states and the associated model, with a link to the respective section.

Conclusion

- Benchmarks are driving the ID and DD
  - @FCC try to establish one or more benchmarks
- Benchmarks of three options :
  - Neutrino wall : Not perviously considered
  - Relic density : FCC can cover the relic density
  - Exceed DD/ID : Scalar SI and SD and ID can probe

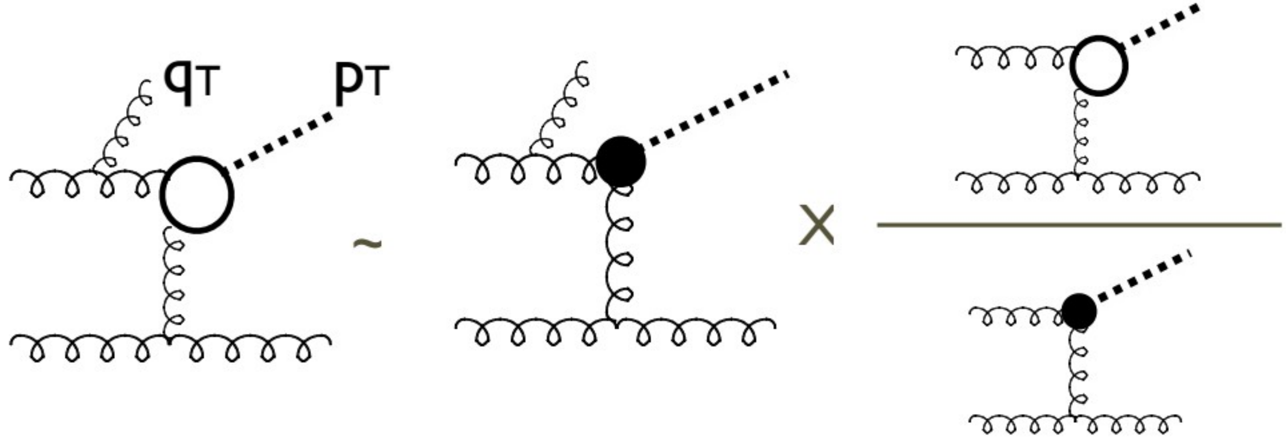
- For Higgs Invisible we find that :
  - We can reach the neutrino wall SM H→Invisible
    - Best BR(H→Invisible) < 5×10^{-5}
    - Likely we can do a little better

Backup

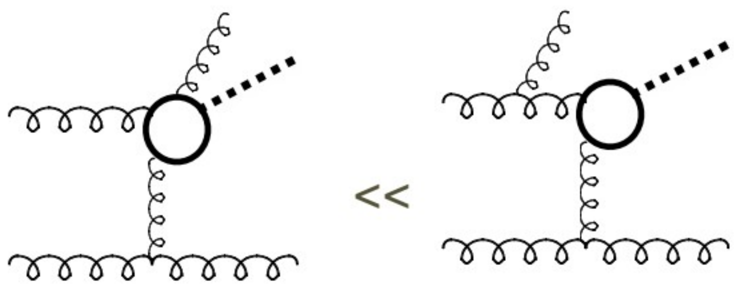
Justification for this approximation:

For $q_T < p_T$

(a)

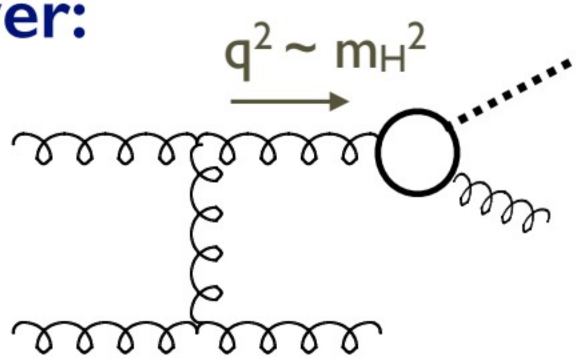


(b)

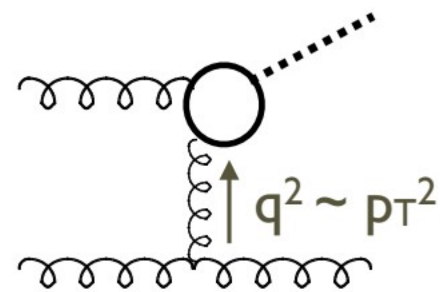


From Michelangelo Mangano

However:

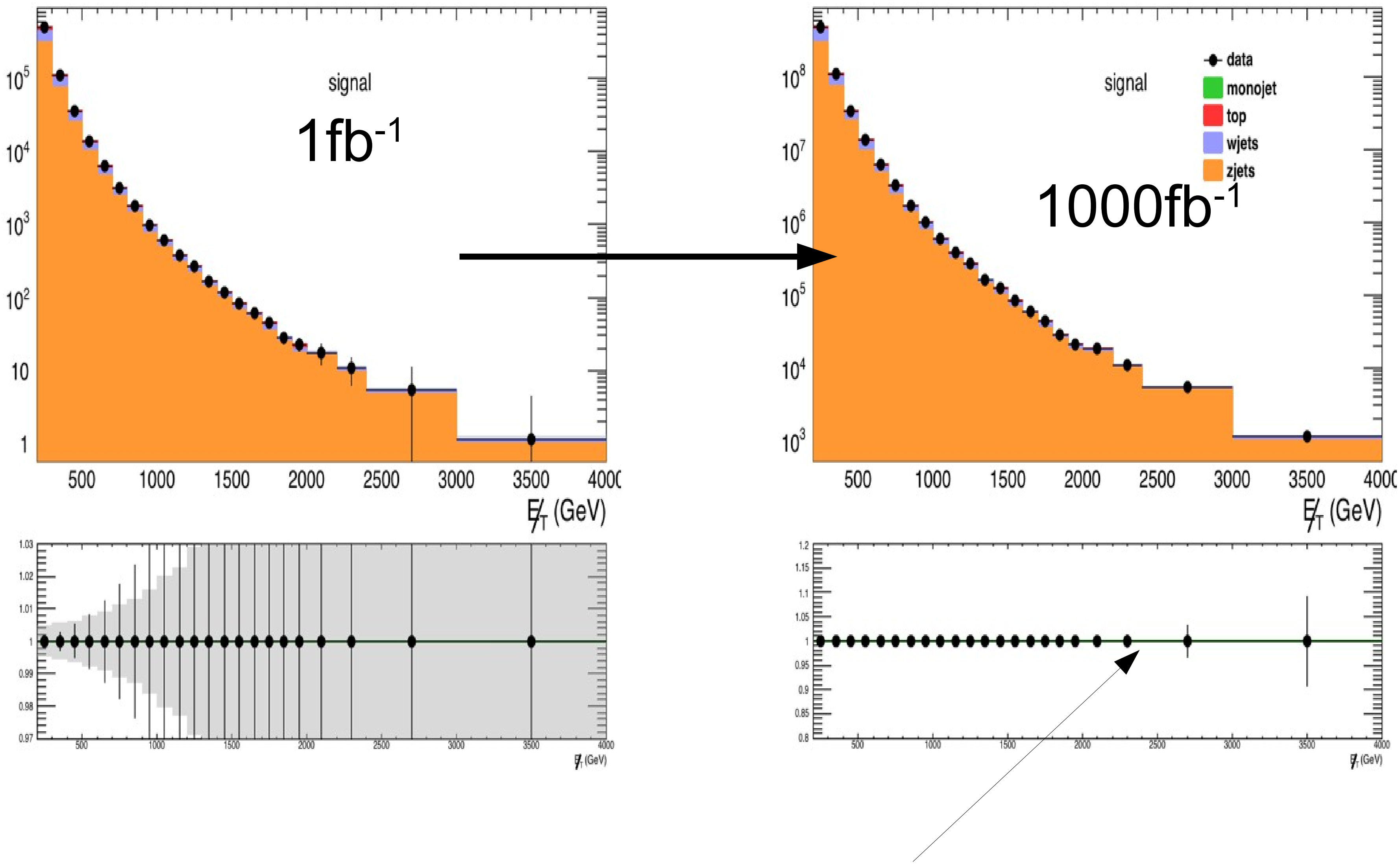


$\sim \# \, \alpha_S \frac{m^2 + p_T^2}{m^2}$



These diagrams will eventually take over at very large p_T.
They are not covered by the "merging" approach …. this should be looked at in some more detail ….

Whats the precision?



To ensure full use of the statistcal prediction needs to be a at few % level → This works now with fully correlated shape