University of Colorado Boulder

Search for supersymmetry using boosted Higgs bosons and missing transverse momentum in proton-proton collisions at 13 TeV

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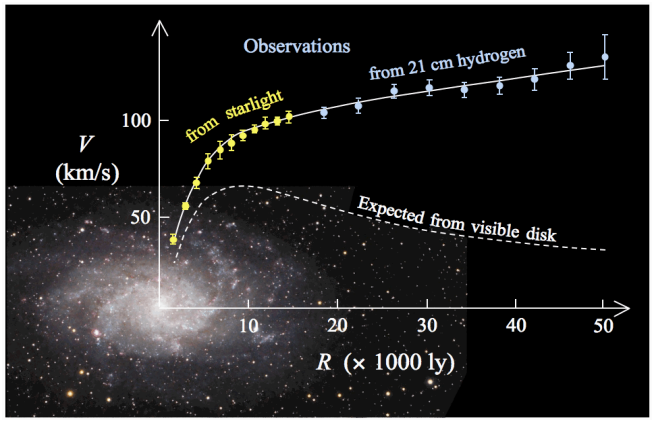
APS DIVISION OF PARTICLES & FIELDS

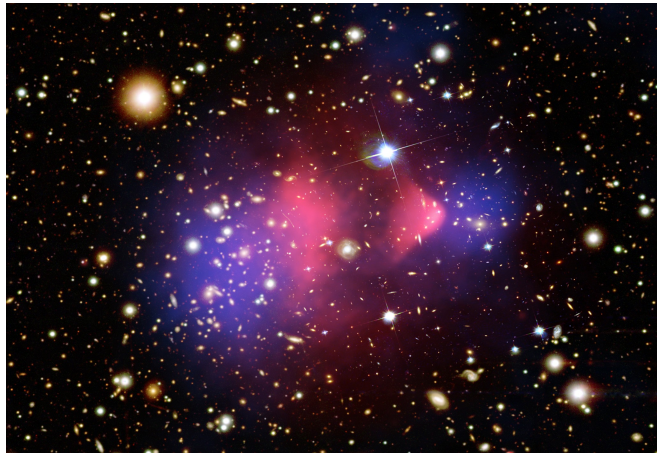
DPF 2017

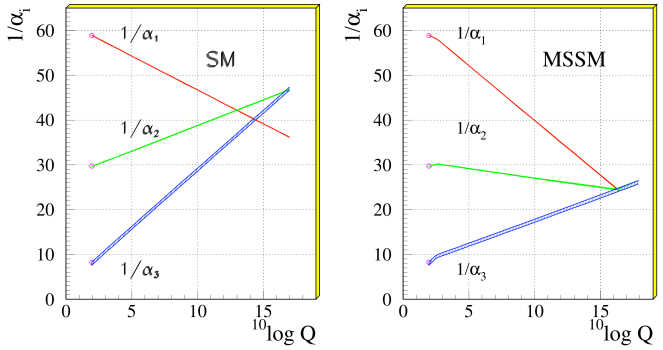
MEETING OF THE AMERICAN PHYSICAL SOCIETY DIVISION OF PARTICLES AND FIELDS

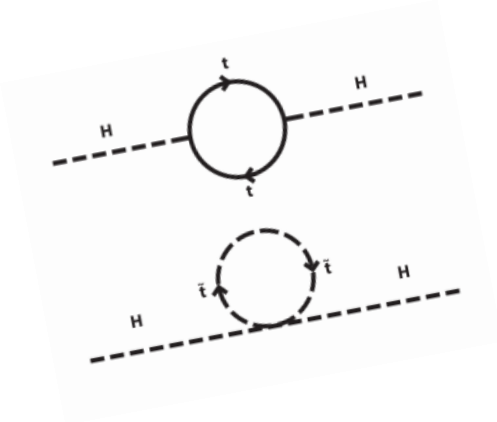
SUSY

- The existence of an additional type of matter which does not directly couple to photons is suggested by observations of galactic rotation curves & gravitational lensing, for example.
- There is a need for delicate fine-tuning in the quantum corrections of the Higgs mass calculation to achieve the measured value of 125 GeV.
- Supersymmetry helps the convergence of the gauge coupling constants.



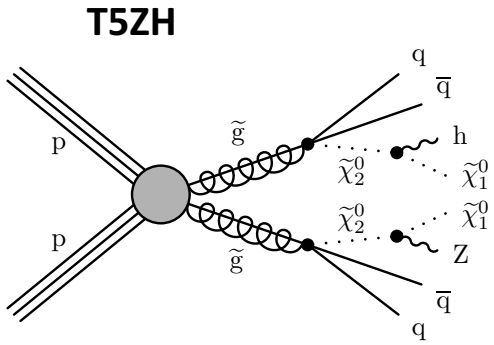






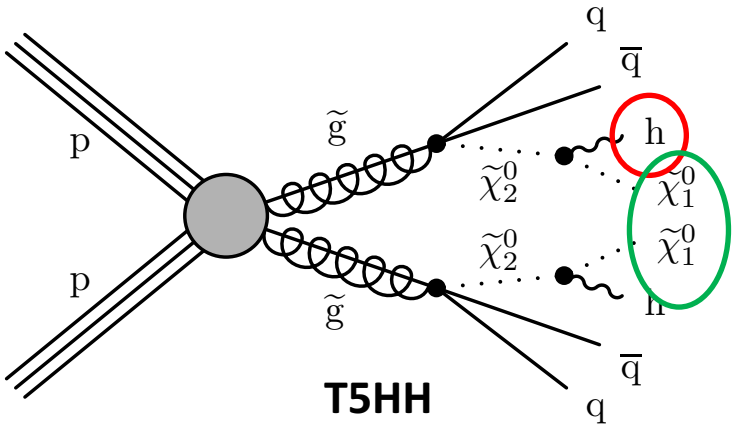
- **Super Symmetry (SUSY) is an extension to the Standard Model which is able to address these issues.**

Search topologies



- Searches for SUSY have yet to discover new physics.
  - Searches are pushing potentially new particles to larger and larger masses.
- Need to explore all regions of SUSY parameter space.
- We have devised a search strategy to look for new physics with high p_T Higgs bosons and missing energy (MET) in the final state.

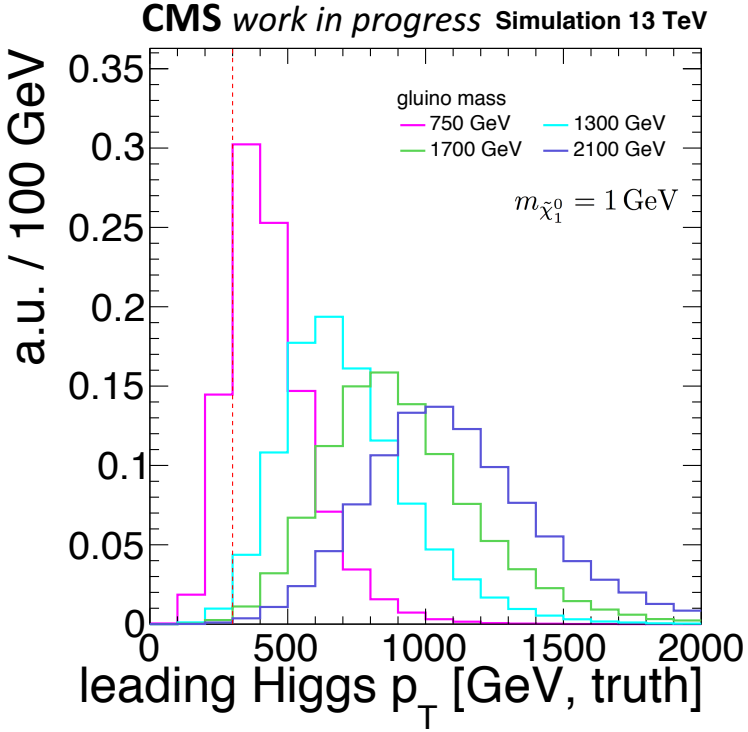
example model:

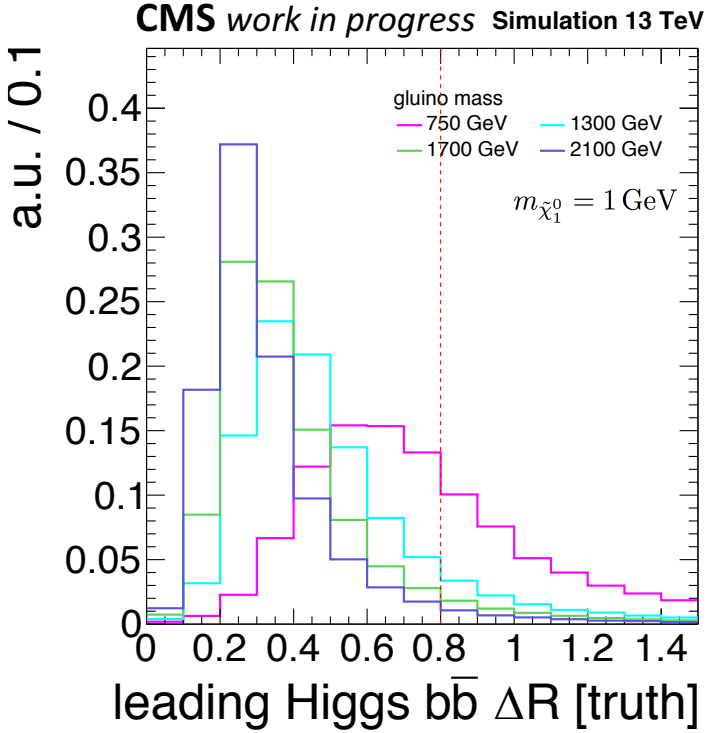


boosted Higgs bosons decaying to bb (57% branching fraction)

supersymmetric particles escape detection creating missing energy

Higgs kinematics



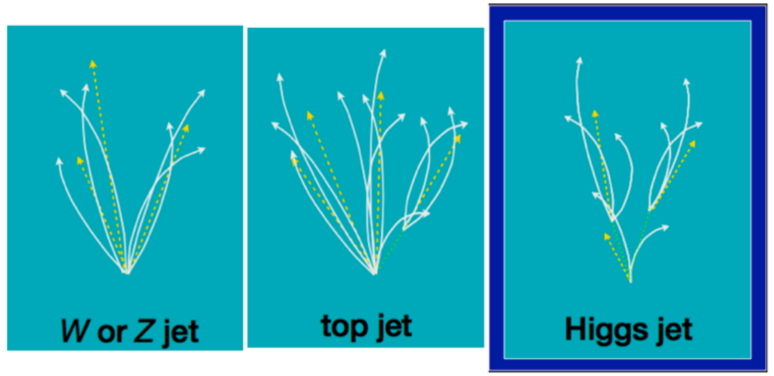


- Higgs bosons generally have p_T > 300 GeV in our models of interest.
- b-quark daughters are typically contained in a cone of **ΔR < 0.8**

no HT or jet requirement selection

- Decay products of high p_T objects are emitted at small angles.

$$\Delta R \approx 2m/\,p_T$$

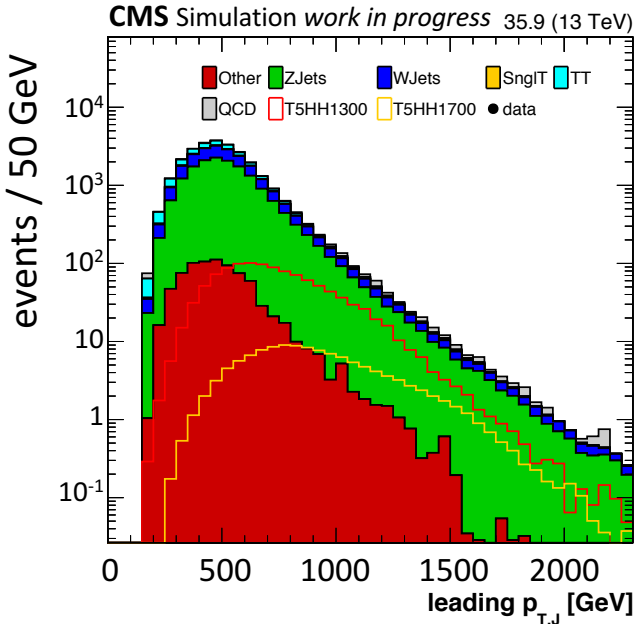


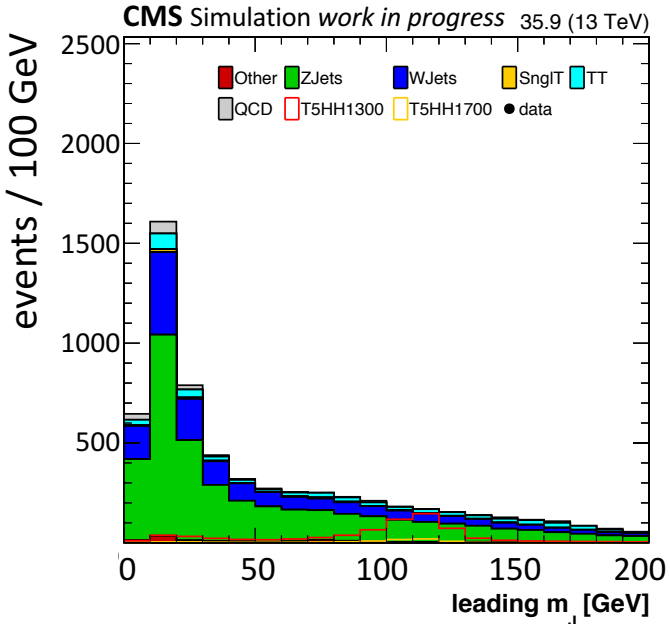
- Underlying jet structure can be used for particle identification...

$$\Delta R^2 = \Delta\phi^2 + \Delta\eta^2$$

Higgs tagging (jet selection)

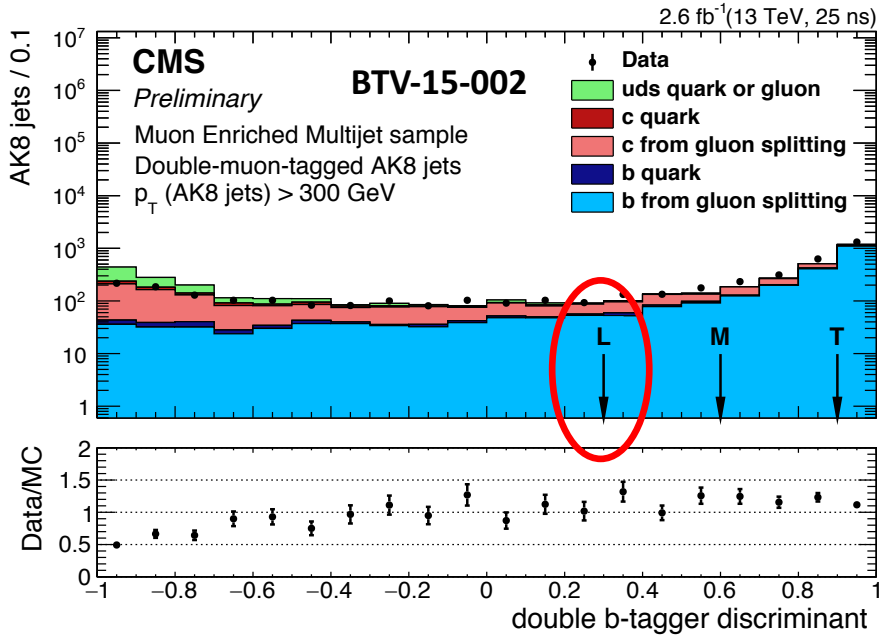
- Reconstruct jets with characteristic size of 0.8 using anti-k_T algorithm (AK8 jets).



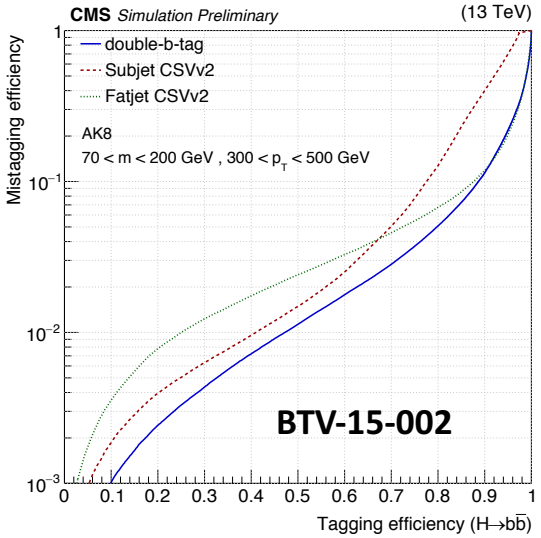


- p_T of leading AK8 jet in event: cut at p_T> 300 GeV keeps most signal
- Mass of leading AK8 jet in event: cut at 50 < M < 250 GeV to include Higgs region

baseline selection without mass or p_T requirements



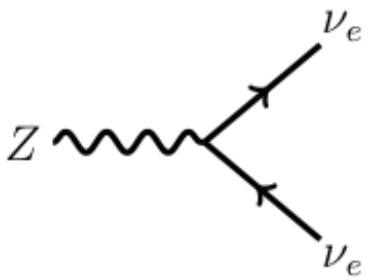
loose working point
bb-disc > 0.3
~80-90% signal efficiency



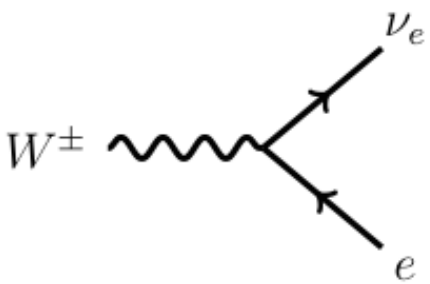
- Dedicated MVA used to find compatibility of jet coming from the decay of two B-hadrons.

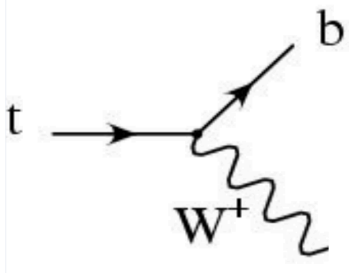
Backgrounds

true MET



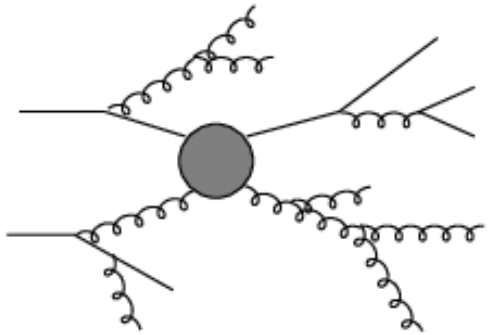
unidentified leptons + true MET





fake MET

mis-measured jets

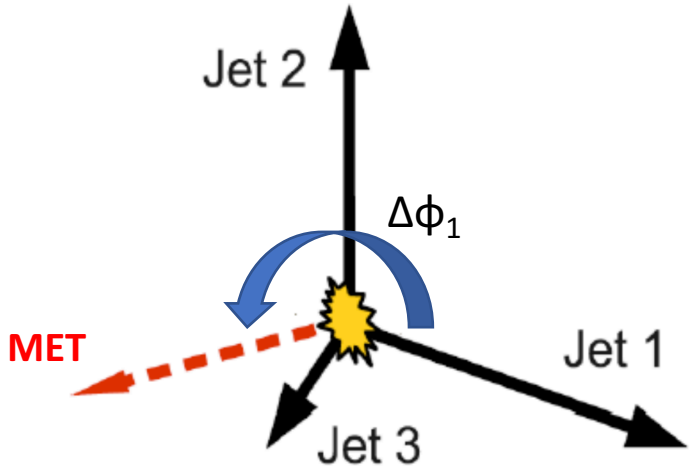


Baseline Selection

$$\mathrm{MET} = \| \sum_{\text{candidates}} \vec{p_T} \|$$

$$\mathrm{HT} = \sum_{\text{AK4 jets}} \| \vec{p_T} \|$$

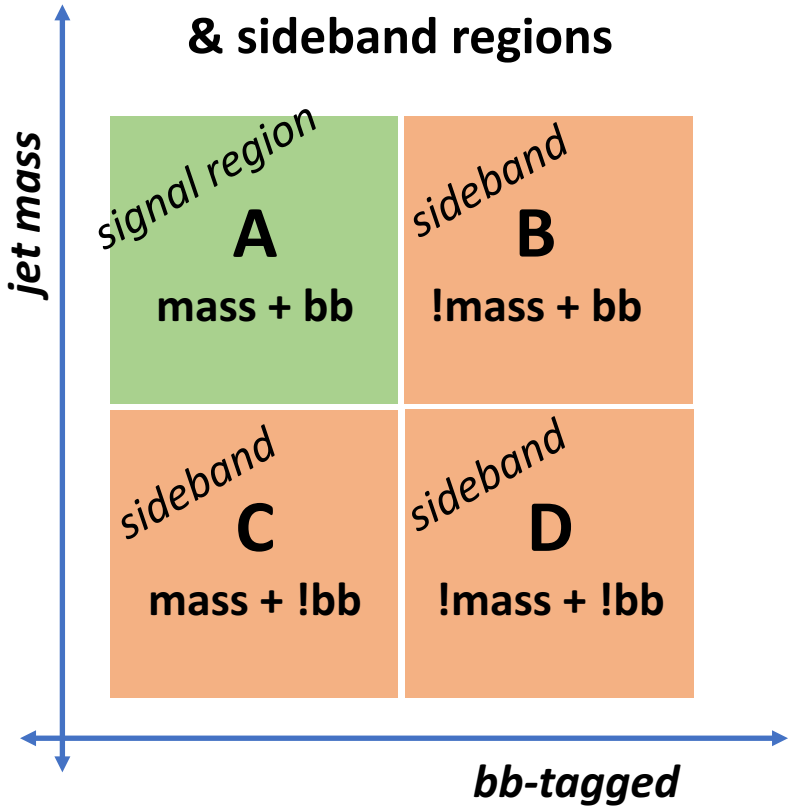
- HT > 600 GeV (AK4 jets)
- MET > 300 GeV
- 2 or more AK8 jets
  - p_T > 300 GeV, 50 < mass < 250 GeV
- All hadronic search
  - veto electrons, muons & isolated tracks
- Suppress QCD: $\Delta\phi_{1,2,3,4}$ > 0.5, 0.5, 0.3, 0.3 (AK4 jets)



Background estimation

- **Estimate the background as an ensemble**

- **Data are binned in signal & sideband regions**

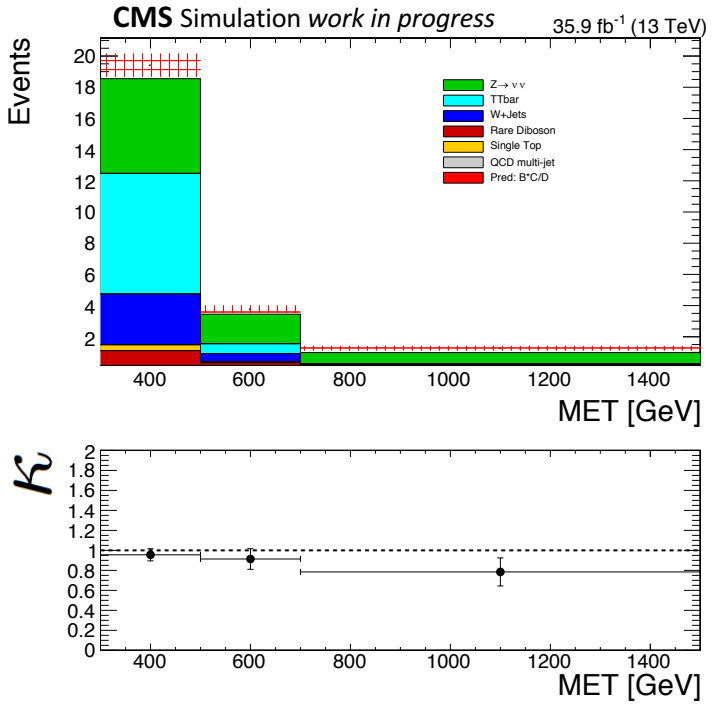


$$\frac{A}{B} = \frac{C}{D} \quad \rightarrow \quad A = B\frac{C}{D}$$

assumption to be validated!

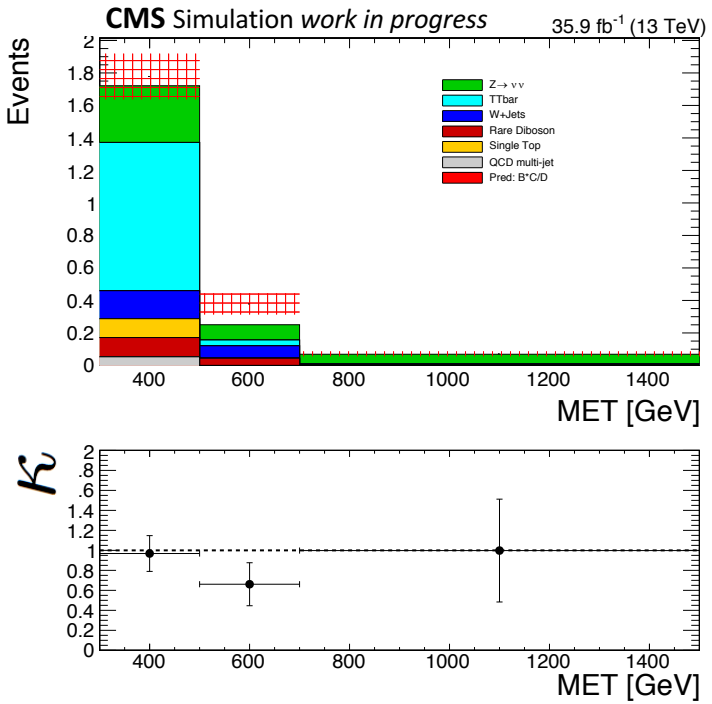
single Higgs tag

both jets pass mass requirements one and only one pass b-tagging



double Higgs tag

both jets pass mass and b-tagging requirements



MC validation of the background estimation procedure

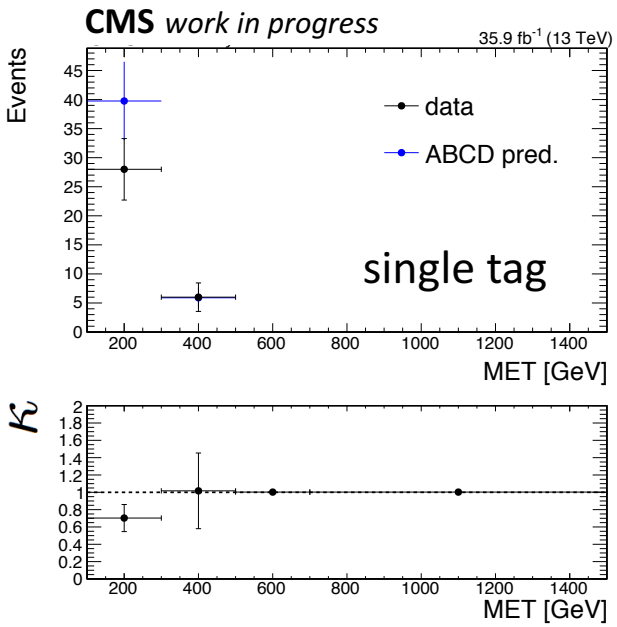
$$\kappa \equiv \frac{(BC/D)_{\text{prediction}}}{A_{\text{truth}}}$$

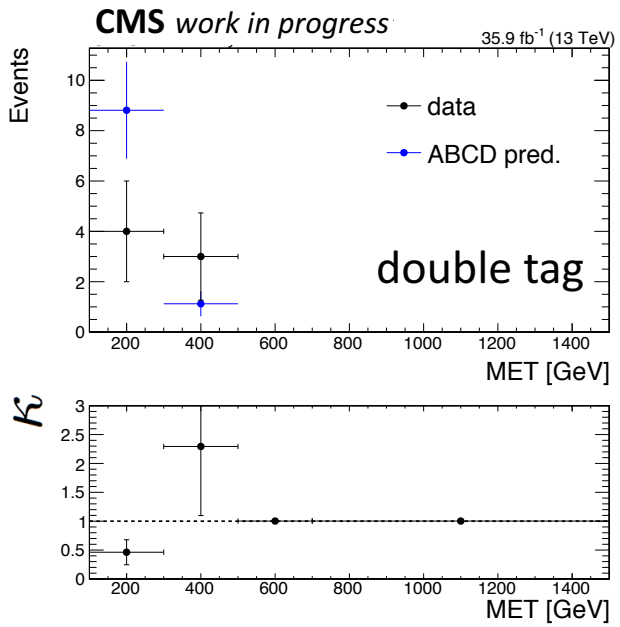
Agreement of κ with unity indicates consistency of the method. Corrections could be applied for large deviations.

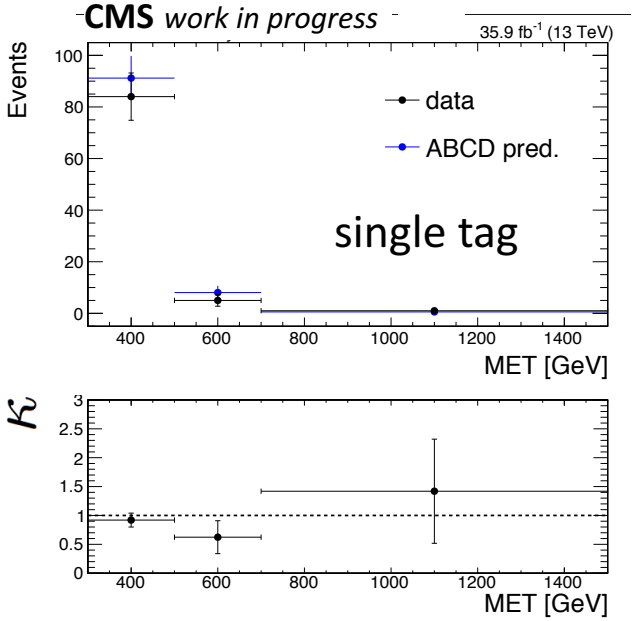
Data validation regions

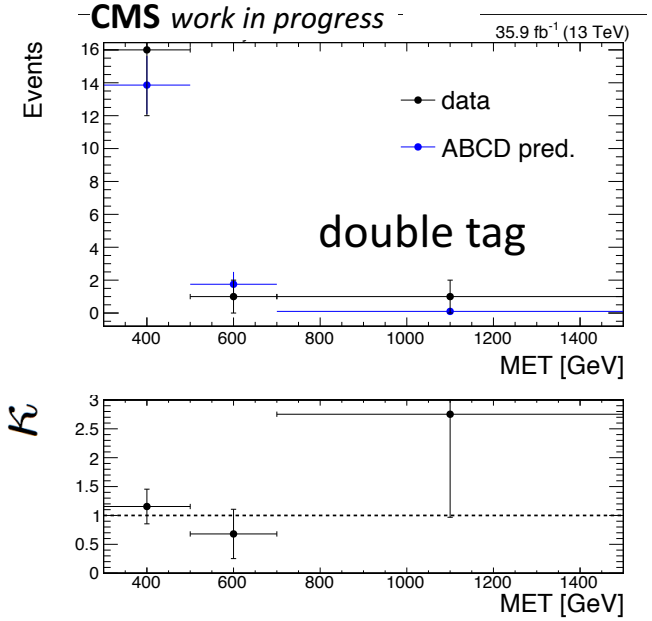
- **Validation regions allow us to test the background estimation procedure on real data before looking in the search regions.**

- The **low Δϕ validation region** is obtained by inverting any of the Δϕ cuts - it is a **QCD enriched sample**.







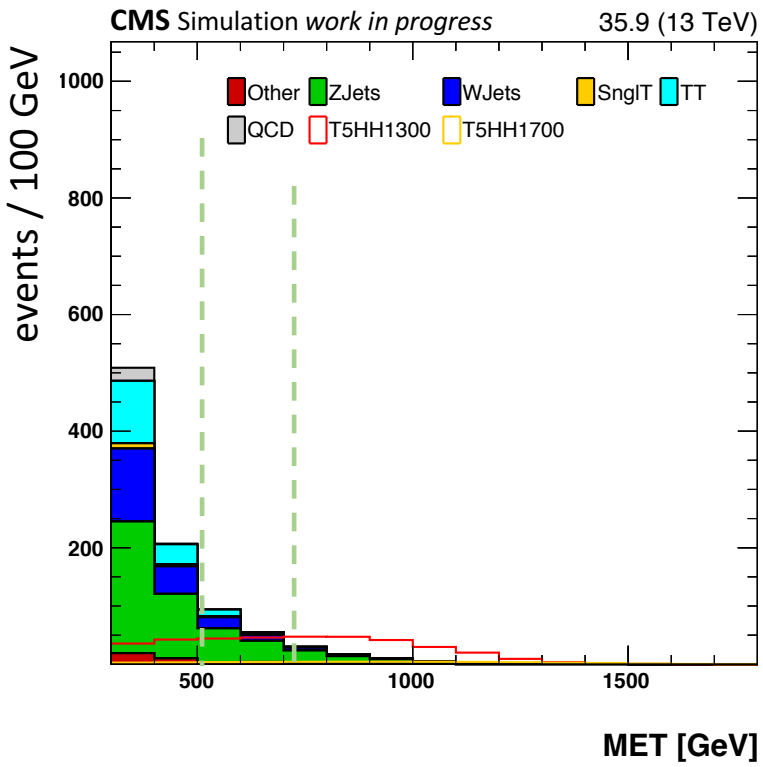


- The **single-lepton validation region** requires a single lepton in the event - **sample enriched in W and top events**.
- We also make use of a **single-photon validation region** with similar kinematics to **Z boson events**.

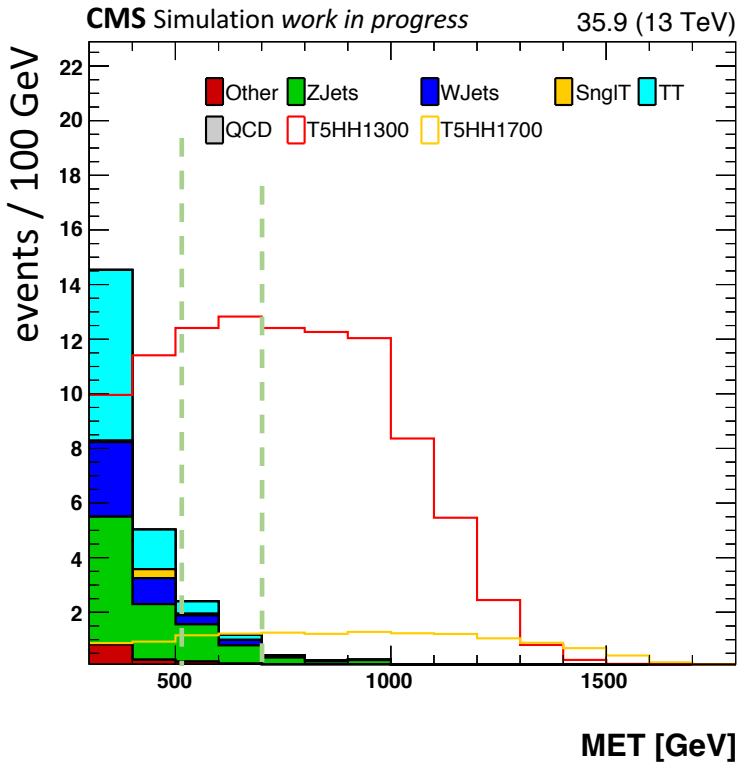
- **The background prediction method is observed to work well in the validation regions.**

MET distributions

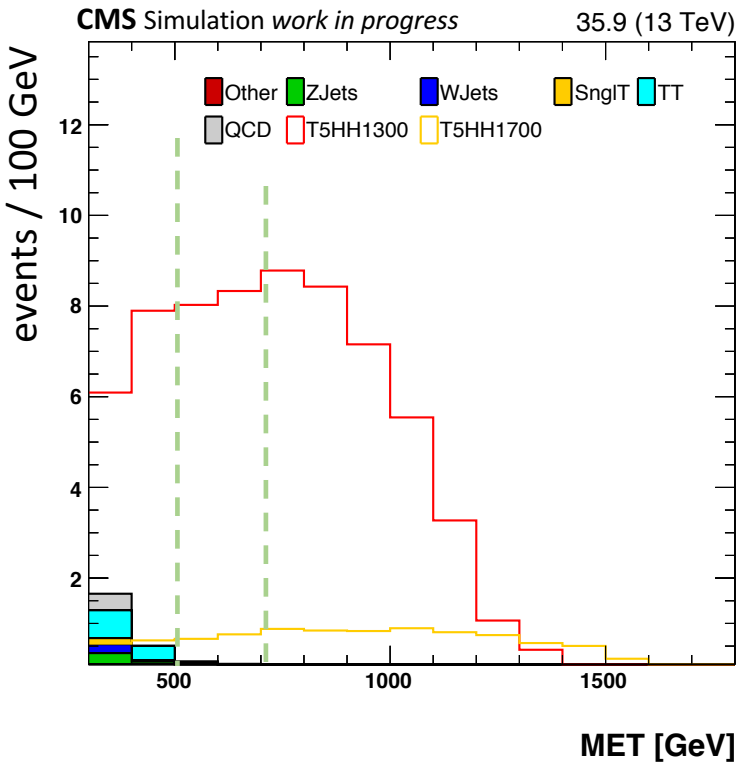
- Yields for the statistical treatment are placed in a 3-bin MET histogram in both a single and double-Higgs tagged region.



baseline selection



single Higgs tag

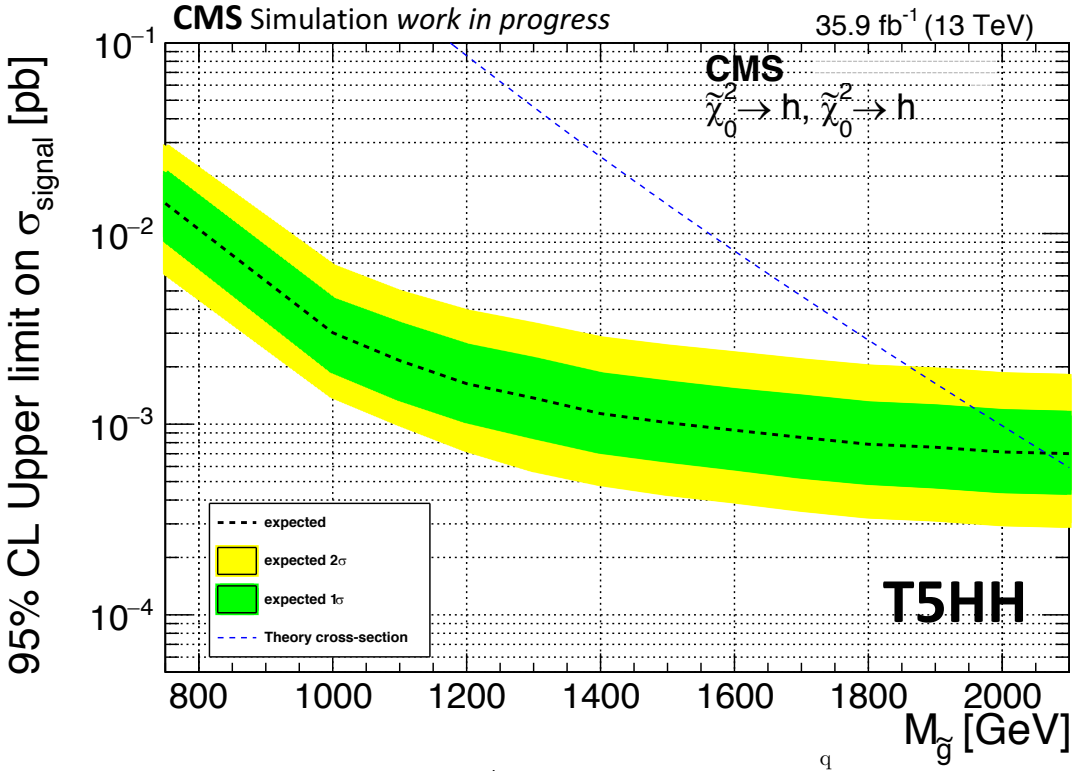


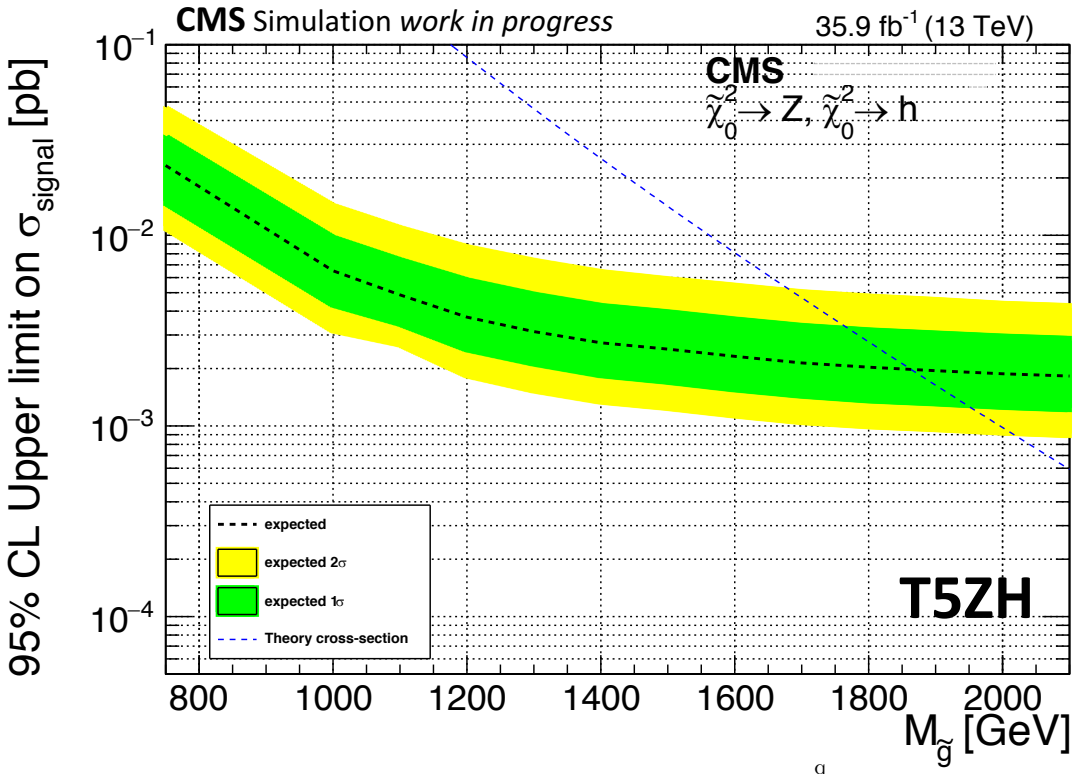
double Higgs tag

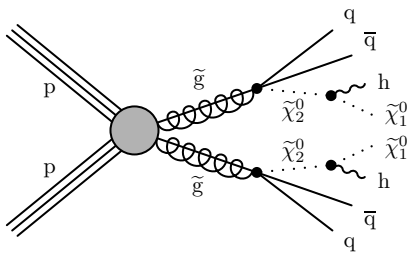
very low backgrounds!

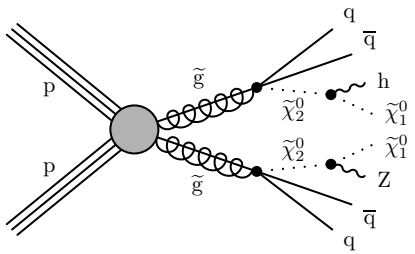
Expected limits

$$m_{\tilde{g}} - m_{\tilde{\chi}_2^0} = 50\,\mathrm{GeV}$$
$$m_{\tilde{\chi}_1^0} = 1\,\mathrm{GeV}$$









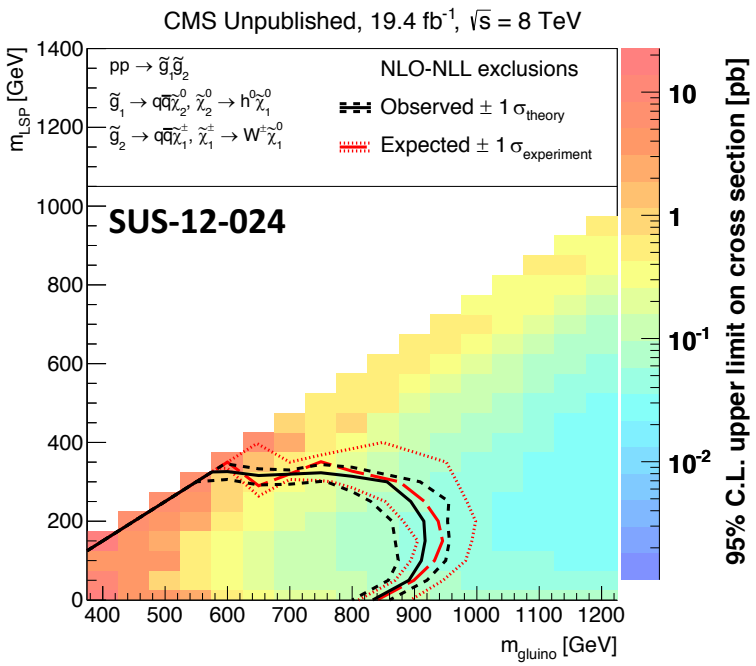
the signal region is still blind

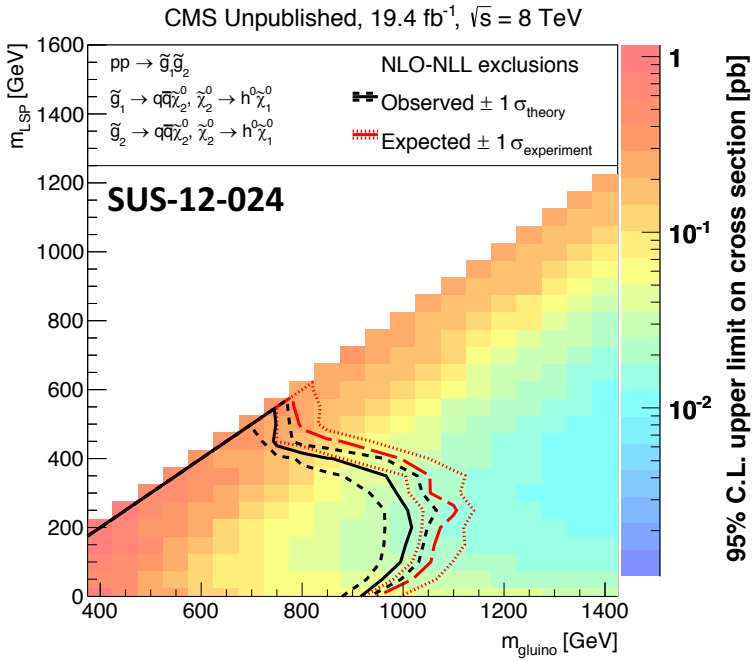
Summary

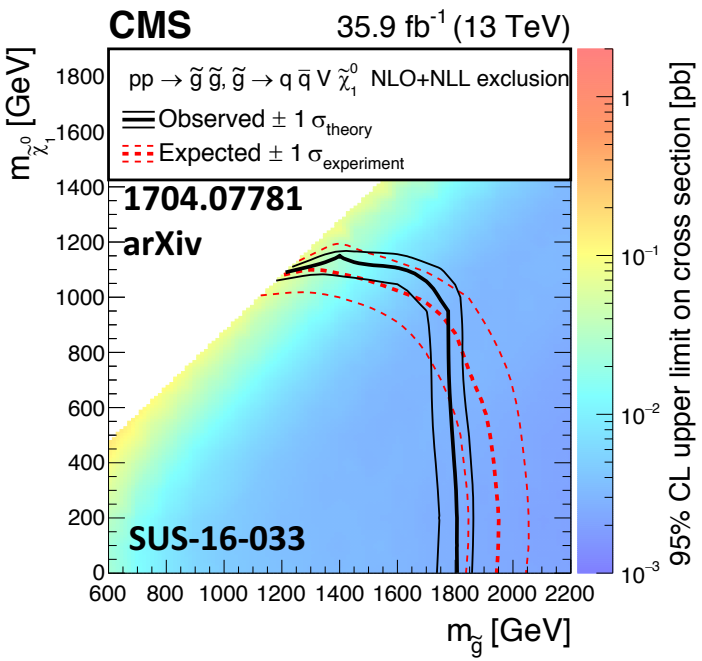
- Presented a search for supersymmetry in events with boosted Higgs bosons and missing transverse energy
  - fully hadronic final states with Higgs decays to b-quarks
- Very low expected background, especially in high MET bins.
- Sensitivity to gluinos with masses up to 2100 or 1900 GeV for the Higgs-Higgs or Higgs-Z final states, respectively.
- Expect to unblind the signal region for the 2016 dataset soon!

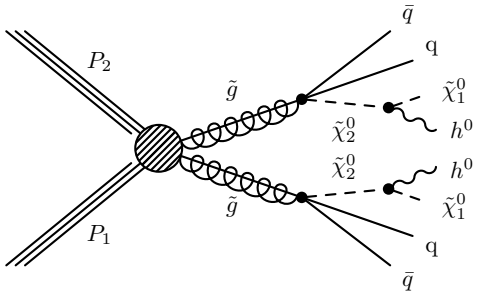
backup

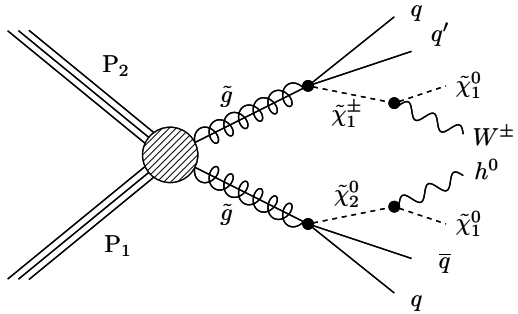
Some current limits…

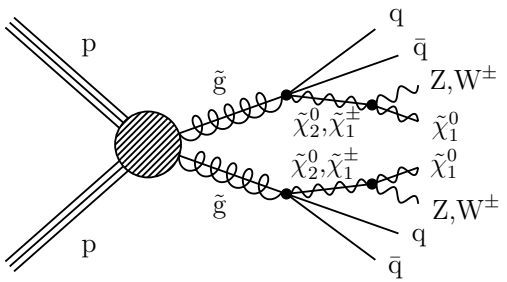










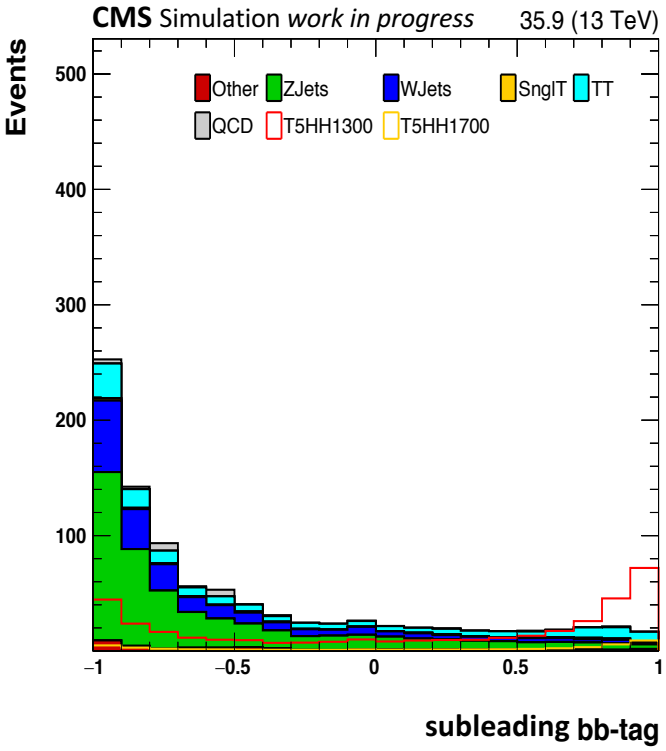


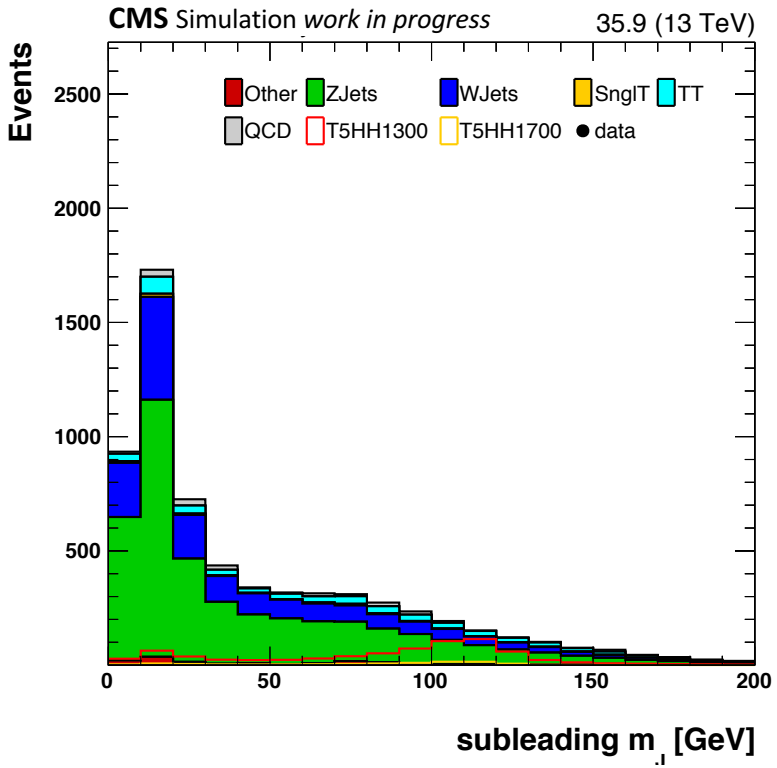
unboosted!

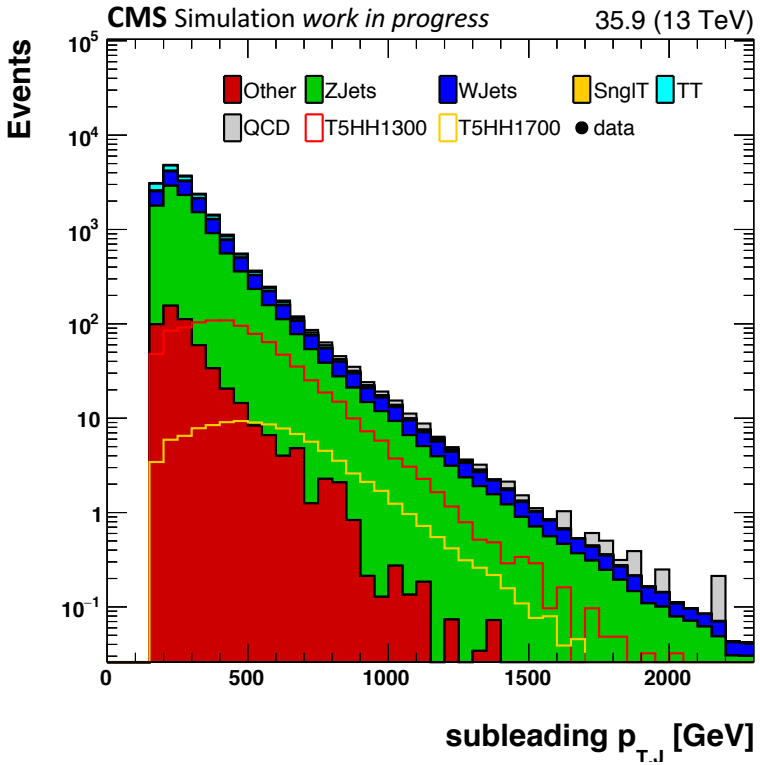
$m(\tilde{\chi}_2^0) = m(\tilde{\chi}_1^\pm) = m(\tilde{\chi}_1^0) + 200\ \mathrm{GeV}$

$m_{\tilde{\chi}^\pm,\tilde{\chi}_2^0} = 0.5(m_{\tilde{\chi}_1^0} + m_{\tilde{g}})$

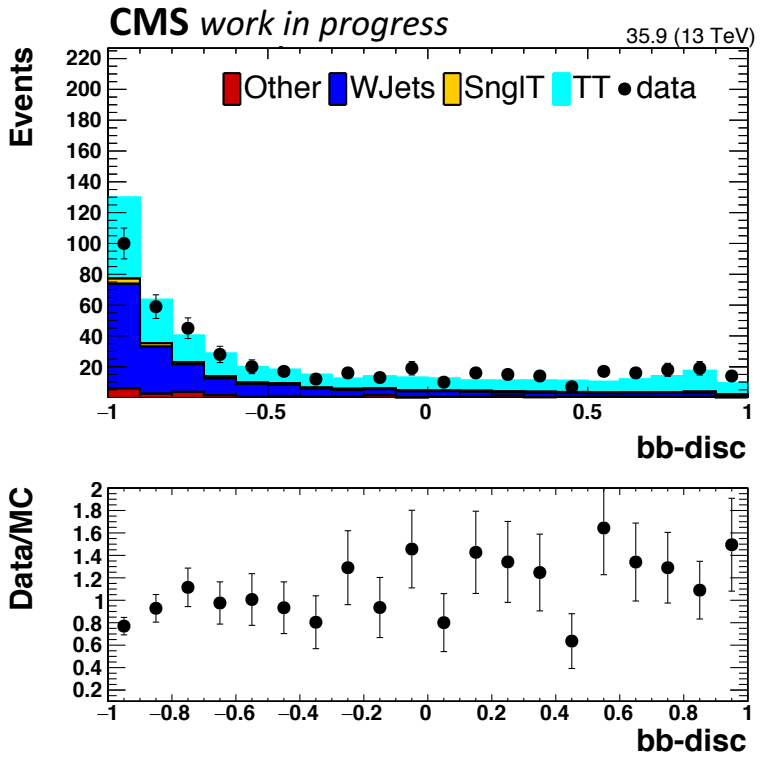
Higgs Tagging (sub-leading jet selection)

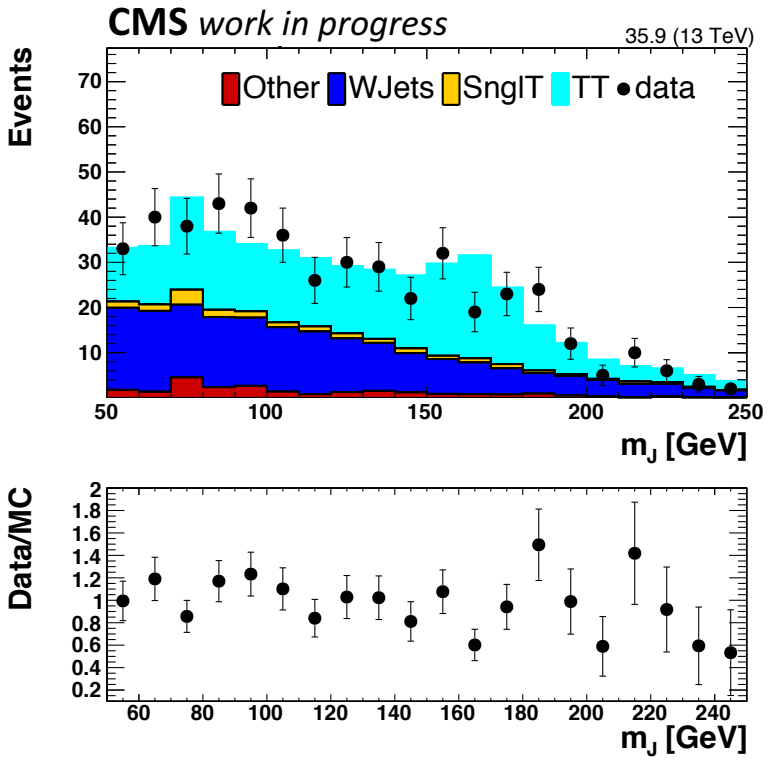




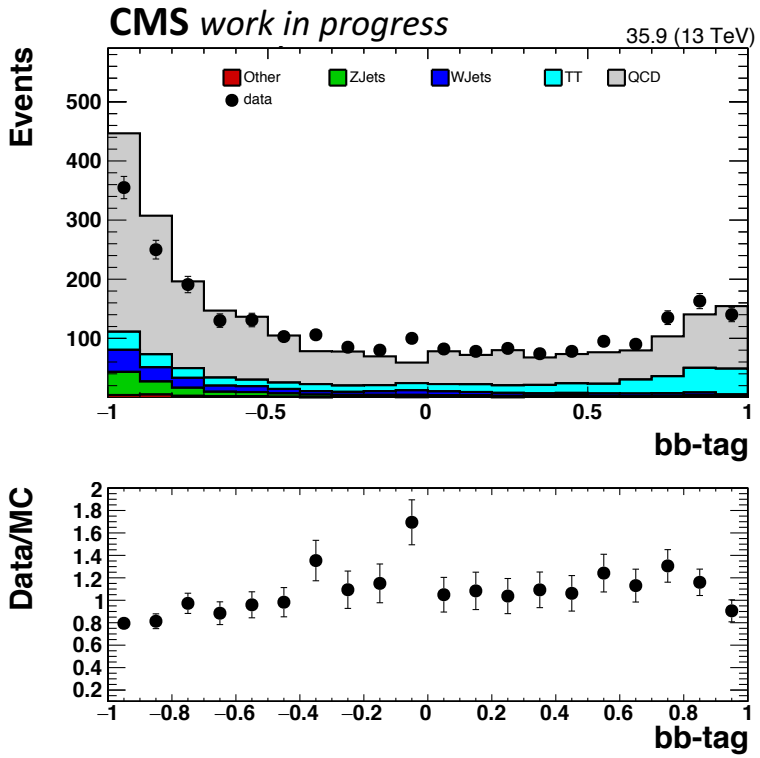


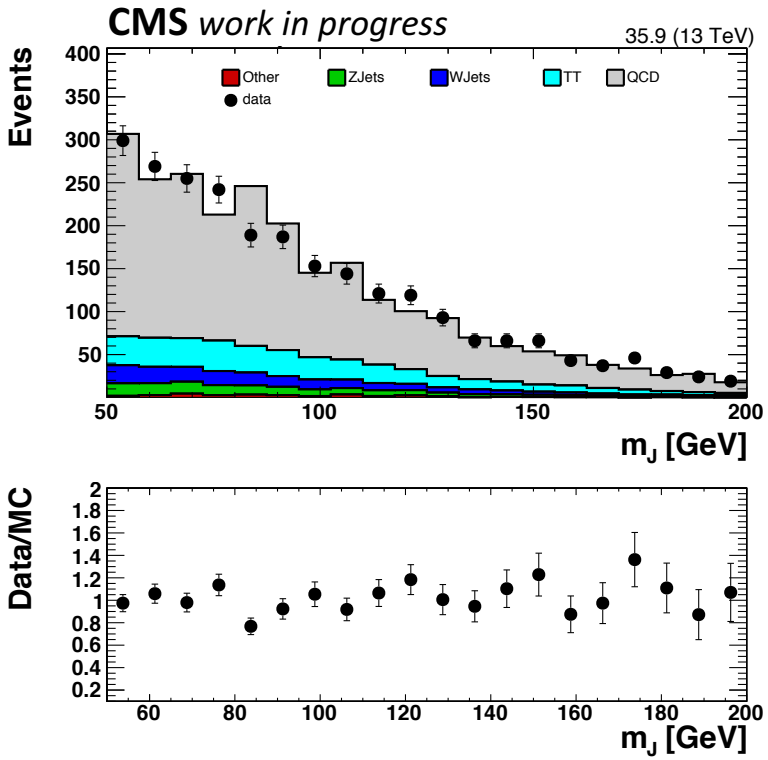
single μ validation region - data / MC comparison leading jet



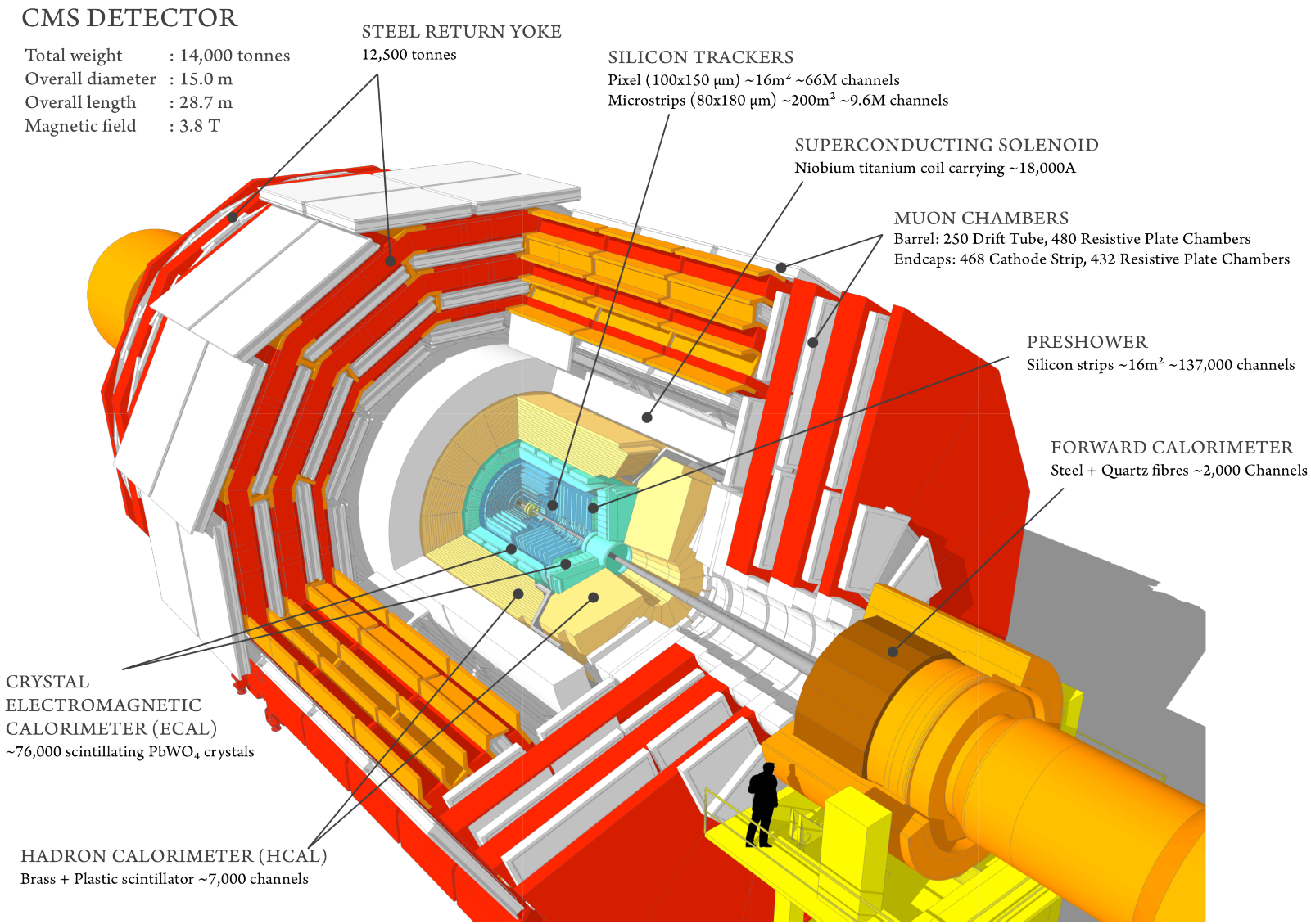


low Δϕ validation region - data / MC comparison subleading jet

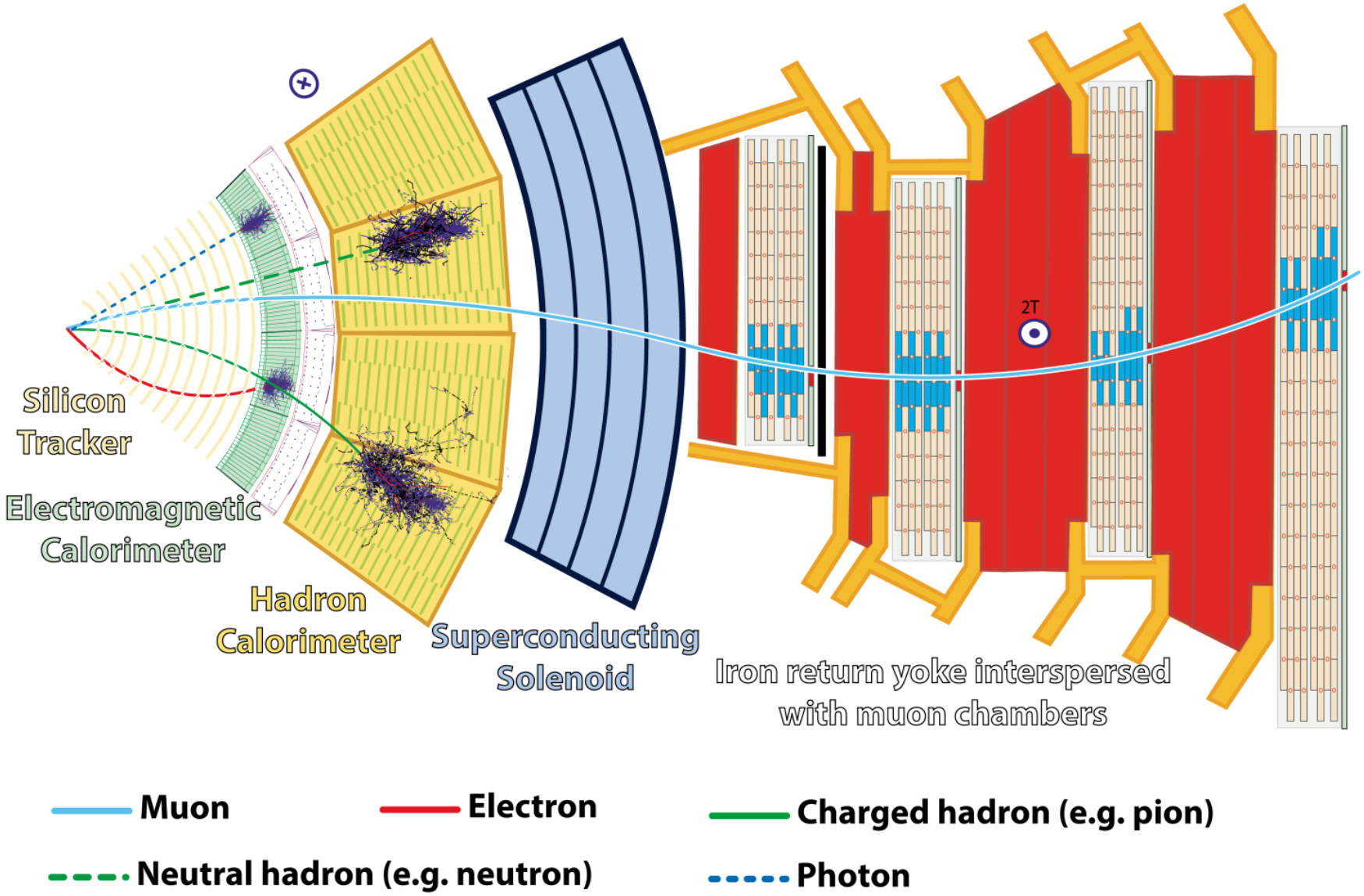




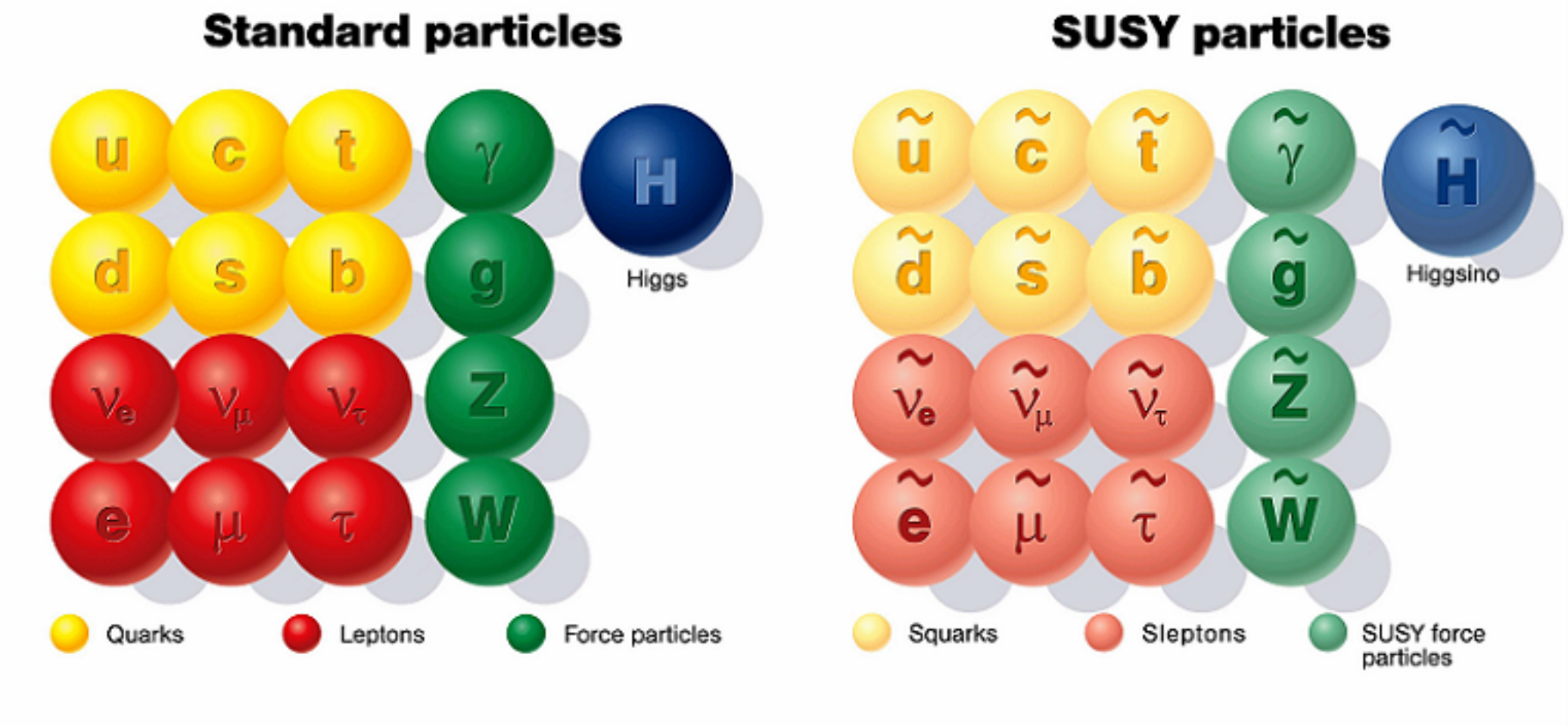
Compact Muon Solenoid - CMS



Compact Muon Solenoid - CMS



SUSY


Standard particles
u
c
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H
d
s
b
g
Higgs
ν_e
ν_μ
ν_τ
Z
e
μ
τ
W
Quarks
Leptons
Force particles
SUSY particles
$\tilde{u}$
$\tilde{c}$
$\tilde{t}$
$\tilde{\gamma}$
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$\tilde{d}$
$\tilde{s}$
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$\tilde{g}$
Higgsino
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$\tilde{\nu}_\mu$
$\tilde{\nu}_\tau$
$\tilde{Z}$
$\tilde{e}$
$\tilde{\mu}$
$\tilde{\tau}$
$\tilde{W}$
Squarks
Sleptons
SUSY force particles