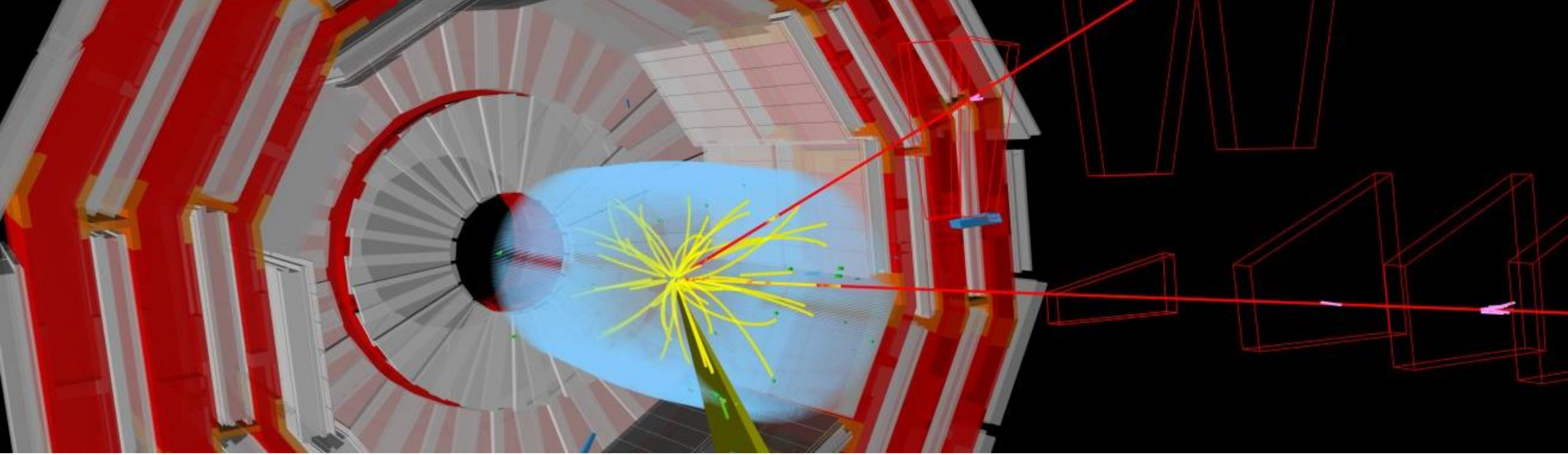

Search for pair production of excited top quarks in the dileptonic final state in proton-proton collision at $\sqrt{s}$=13 TeV

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FLORIDA TECH

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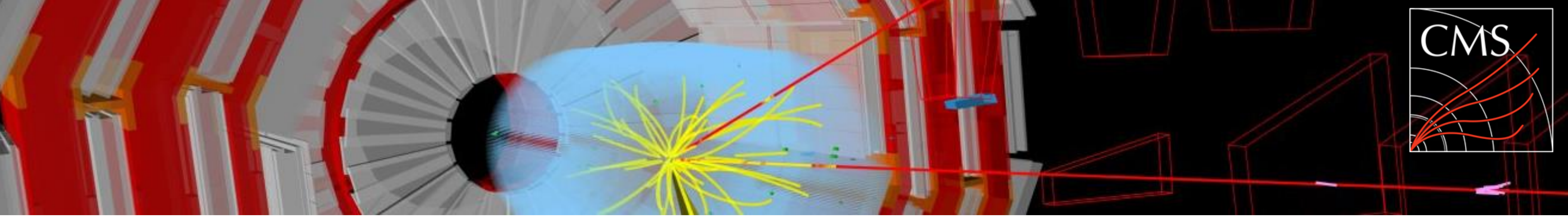
CMS Compact Muon Solenoid

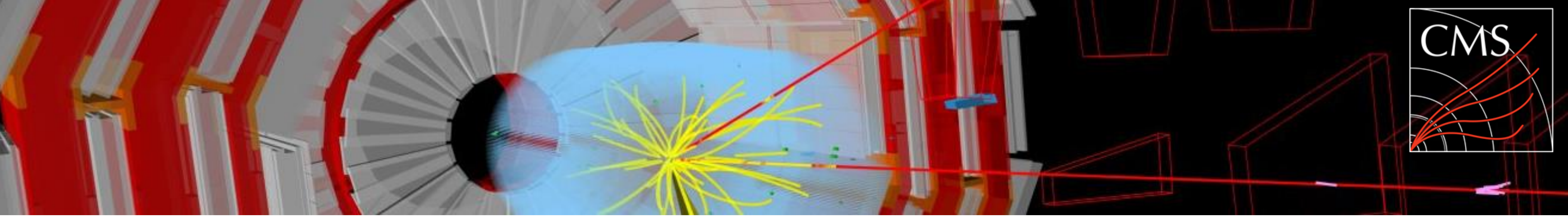
CERN



Physics Motivation

- Many theories beyond the Standard Model (BSM) postulate the existence of fourth generation of quarks
    - constrained by the Higgs boson cross section measurement
    - would deviate the Yukawa couplings
    - no explanation for the hierachy problem
- Vector-like quarks (VLQ) escape these constrains and provide a fesible solution
    - predicted in various theoretical models such as Little Higgs models, models with extra dimensions, composite Higgs models, etc.
    - left- and right-handed components transform equally under SU(2)
    - they are heavy fermions (of TeV), and can be produced at the Large Hadron Collider (LHC)

This analysis searches for vector-like T (or t*) quarks: TT -> tg tg (2ℓ + jets):

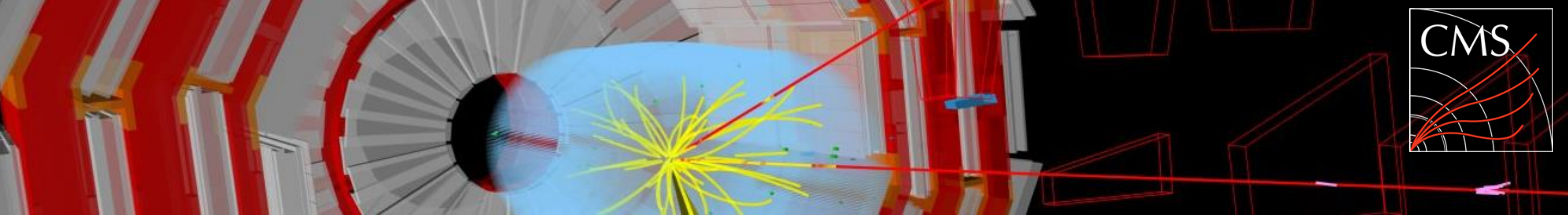


Production and Decay Modes

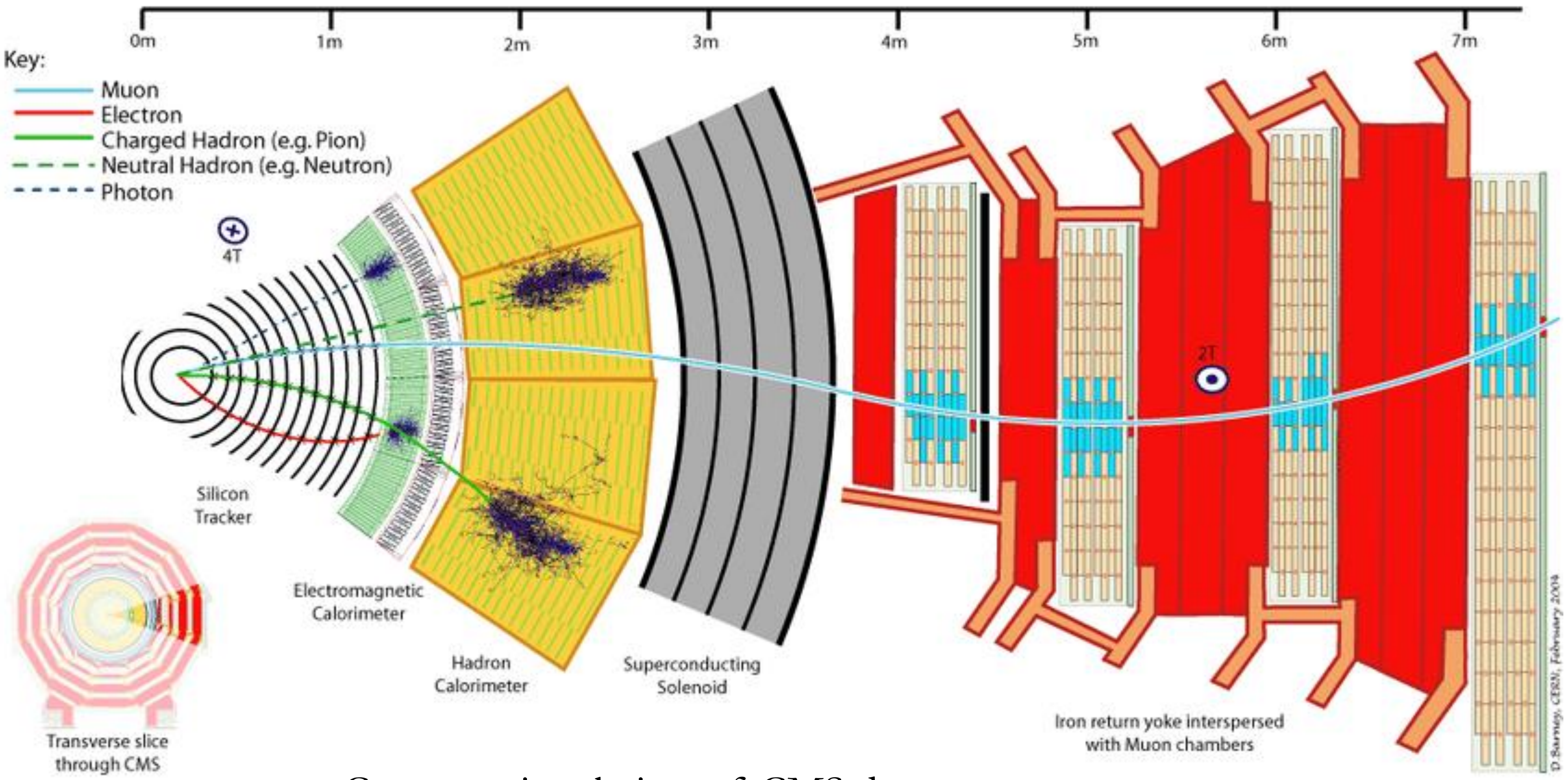
- Most LHC searches focus on the conventional decay modes: T → Wb, T → tZ, and and T → tH (region (1))
  - the conventional decays are getting tightly constrained
  - need to explore other channels
- Other modes are rarely searched
- Looking for top partner in region (2) :TT -> tg tg

	Wb	tZ	tH	tg	$t\gamma$
Wb	(1)			(5)	(6)
tZ					
tH					
tg	(5)			(2)	(3)
$t\gamma$	(6)			(3)	(4)

Possible final states from the pair-produced excited top quark [1].



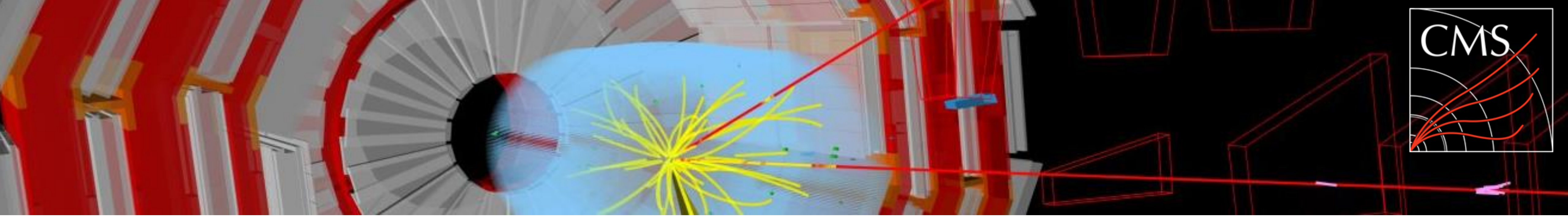
Compact Muon Solenoid (CMS) Experiment at LHC



Cross-sectional view of CMS detector

- Built around a huge solenoid magnet
- Designed to detect a wide range of particles and phenomena
- Measure the properties of well-known particles with unprecedented precision

In "hunt" for excited top quarks here!



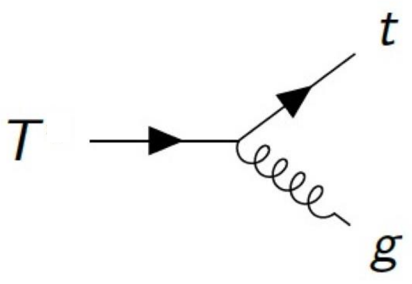
Current Searches in tg and tγ channels in CMS

Channel	Group	Signal xs (pb)
$t^*t^* \to \mathbf{tgtg}(\ell + jets)$	Hamburg	3.9
$t^*t^* \to \mathbf{tg}t\gamma(\gamma + jets)$	Notre Dame	0.26
$t^*t^* \to \mathbf{tg}t\gamma(\ell + \gamma + jets)$	Florida Tech	0.12
$t^*t^* \to \mathbf{tgtg}(2\ell + jets)$	Florida Tech	1.78
$t^*t^* \to \mathbf{tg}t\gamma(2\gamma + jets)$	None	0.004

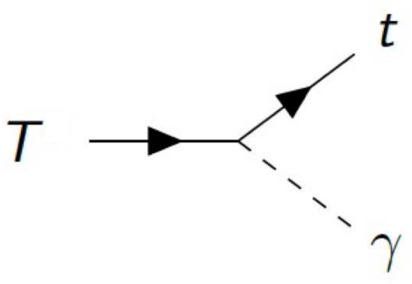
Previously searched in CMS using 2016 dataset

Expect less multijet background due to the presence of photon

Not searched at the LHC yet
Both tops decay leptonically :
dilepton + jets final state
Dilepton => less background, cleaner signal



$BR(T \to tg) \approx 97\%$

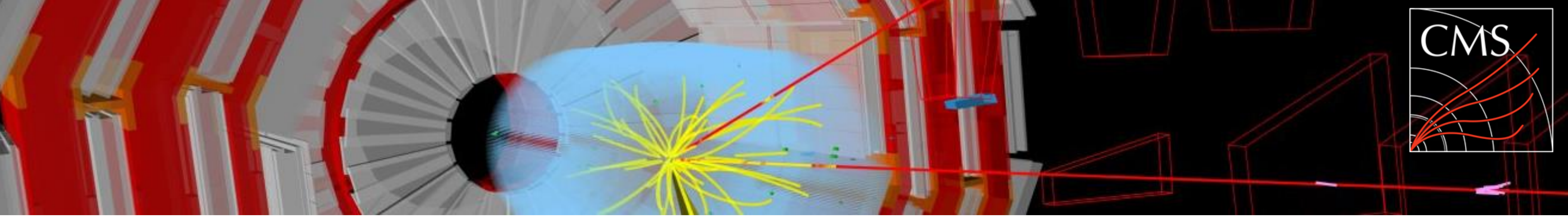


$BR(T \to t\gamma) \approx 3\%$

Two spin scenarios of T: $\frac{1}{2}$ and $\frac{3}{2}$

Main focus on spin $\frac{1}{2}$

Other spin is also of interest, will be considered in the future



Data and Monte Carlo (MC) Samples

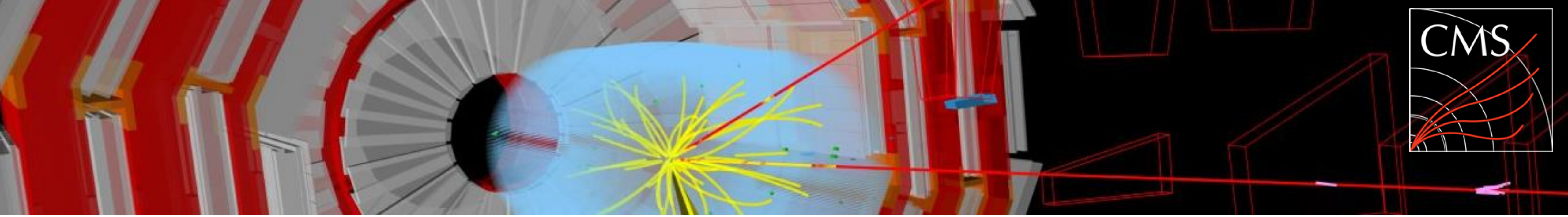
Some of the MC samples are at Leading Order (LO) and some of them at Next-To Leading Order (NLO)

- Processing LHC Run II data
  - 2017: 1.2 Billion events (41.5 fb^{-1})
  - 2018: 2.4 Billion events (59.7 fb^{-1})
  - 2016 data will be added in the future
- MC Signal Samples:
  - The signal mass m_{T^*} is considered in 700-3000 GeV range
  - 6.74 M events

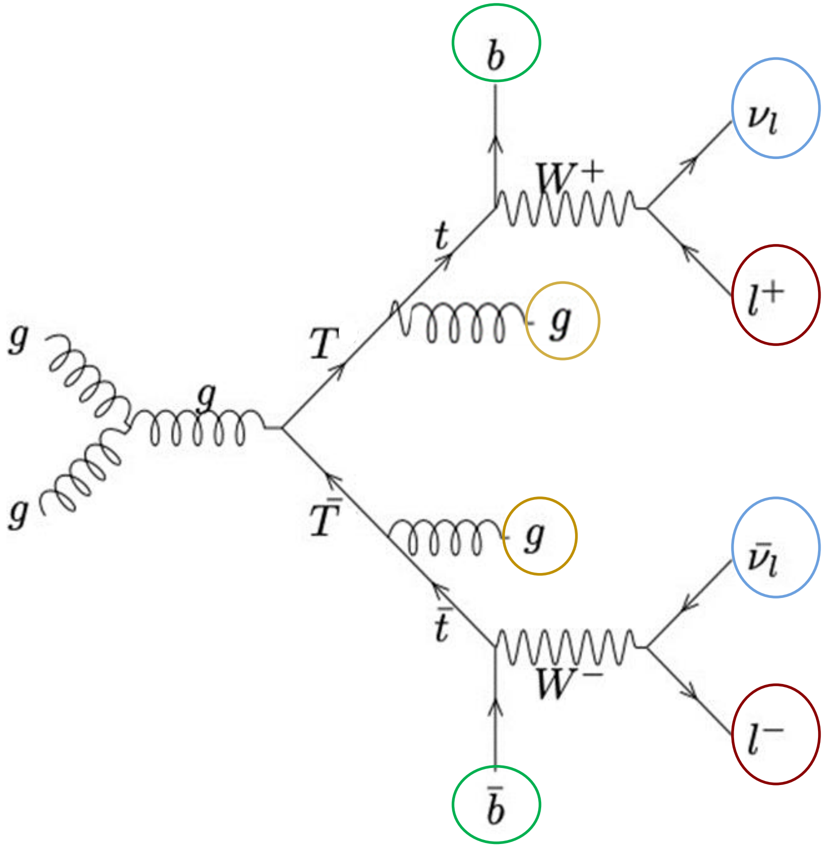
- MC Background Samples:
  - $t\bar{t}$ pair production: dileptonic, hadronic, semileptonic
  - Single t production: s channel, t channel
  - W+jets: W+1jet, W+2jets, W+3jets, W+4jets
  - Drell-Yan (DY)+jets
  - QCD multijet
  - Vector-vector boson fusion (VV): WW, WZ, ZZ
  - Others: $t\bar{t}$ +W, $t\bar{t}$ +Z

Total simulated background events: ~ **4.4 Billion**!!

How will we “hunt” for this particle in billions of events?!



Object and Event Selection



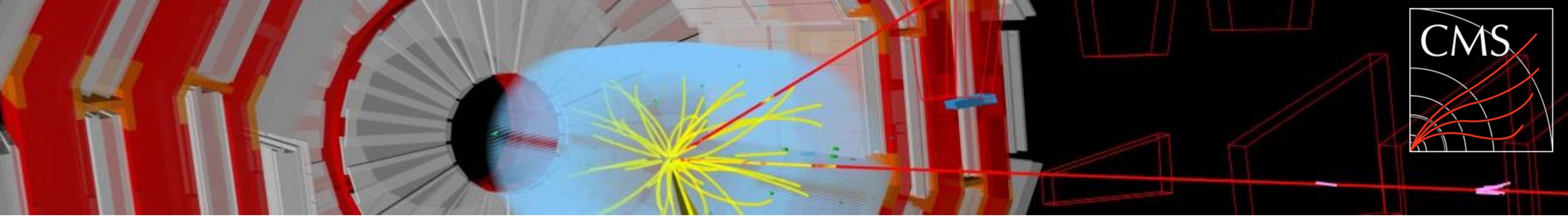
Feynman diagram $T\bar{T} \to tg\bar{t}g(2l + jets)$

Select good quality physics objects:

- 2 leptons ($\mu\mu, ee, or\ \mu e$)
- 2 b jets
- 2 light jets (gluons)
- Treat missing energy (E_T^{miss}) as neutrino

Events passing the above criteria are selected

Our goal is to reconstruct the T mass!



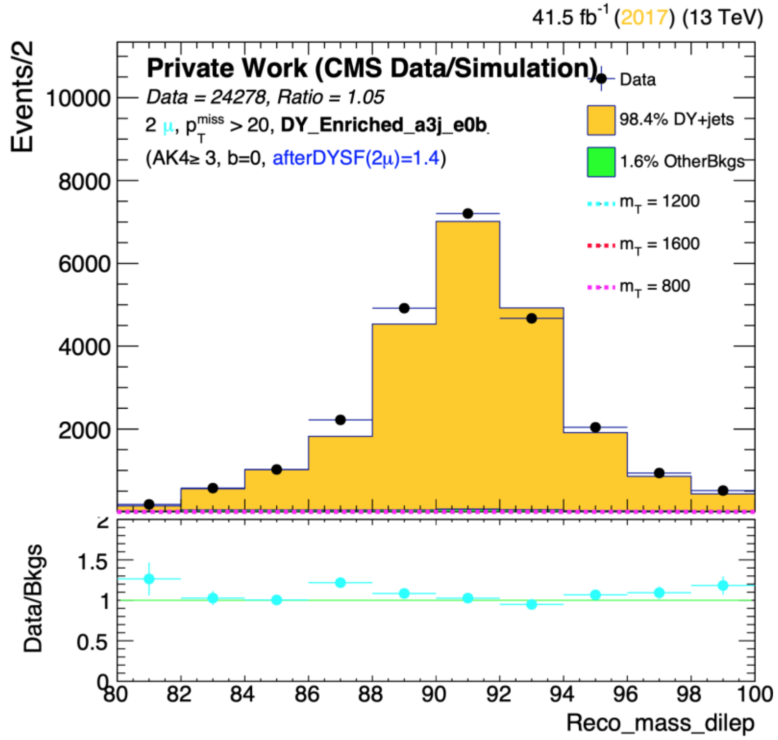
Control Region (CR)

Signal-free regions

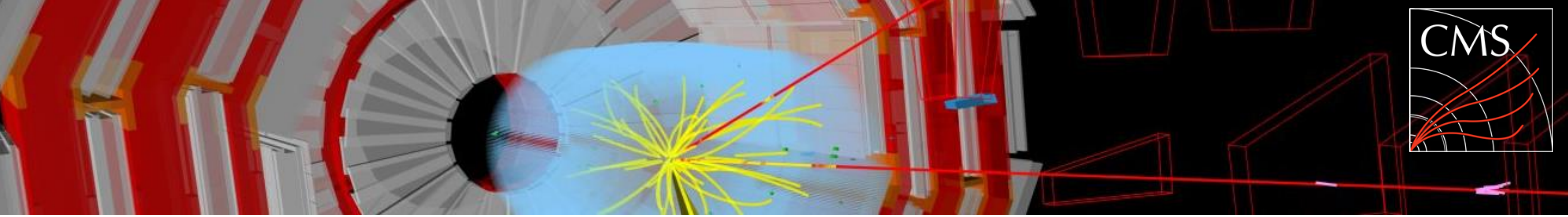
- to estimate and study backgrounds
- to check the agreement between data and backgrounds

Plot kinematics distributions in various defined control regions to apply proper corrections to the discrepancies

Good agreement => validates various object, event selections and corrections



Distribution of dilepton mass in CR (at least 3 jets, no b-quark) of the muon channel.



Signal Region (SR)

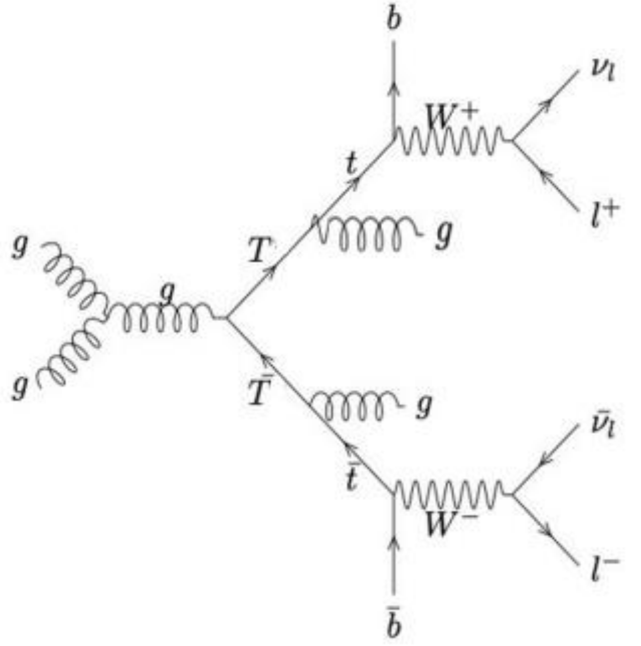
Reconstructions of top partner invariant masses

Challenging: due to presence of 2 neutrinos, the traditional χ^2 approach does not work!

This final state is being looked at for the first time in CMS

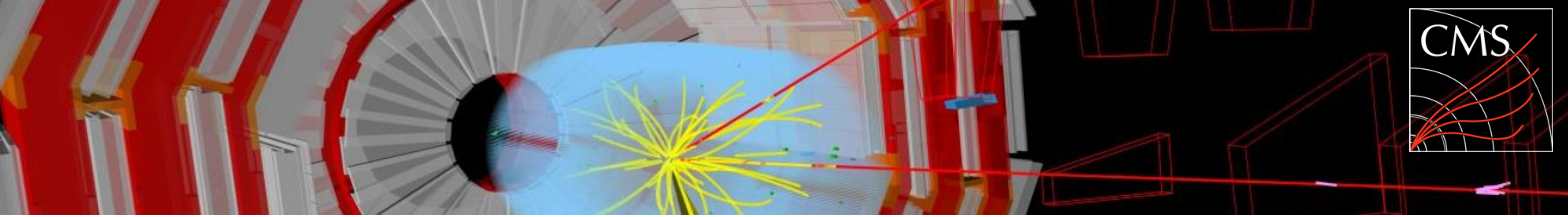
Methods being explored:

- Analytical reconstruction of dilepton $t\bar{t}$
- Categorize events into boosted/non-boosted regions based on lepton and jet angular distance, fit S_T variable
- Instead of an event reconstruction, use deep neural network DNN to reconstruct tt+jet invariant mass



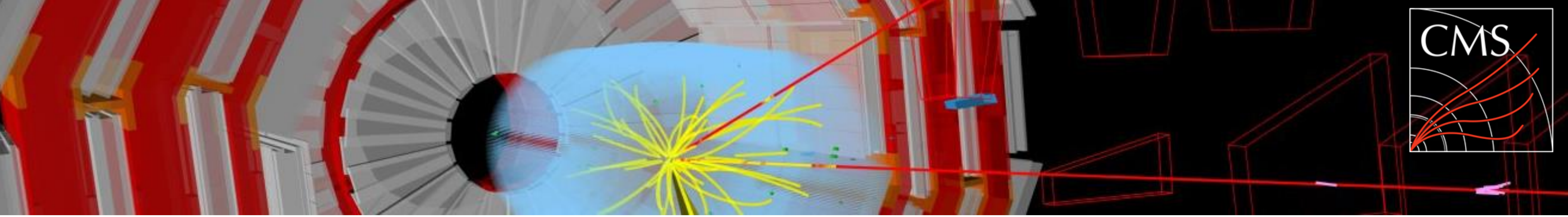
Feynman diagram $T\bar{T} \rightarrow tg\bar{t}g(2l + jets)$

Use Machine Learning techniques or Multi Variate Analysis (MVA) to discriminate background from signal



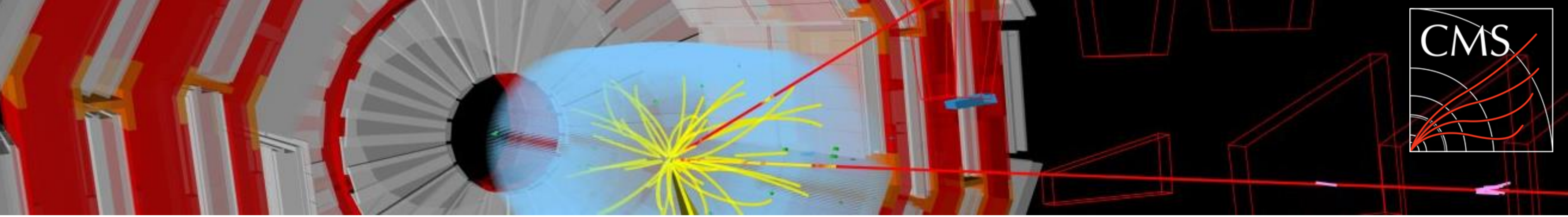
Summary & Outlook

- The analysis framework is in place
- Try to understand and validate Control Region
- Reconstruct the signal mass of the excited top quark
- Utilise possible ML techniques to discriminate between signal and background
- Add systematic uncertainty and limits
- Include spin $\frac{3}{2}$ signal samples
- Add Run 3 data

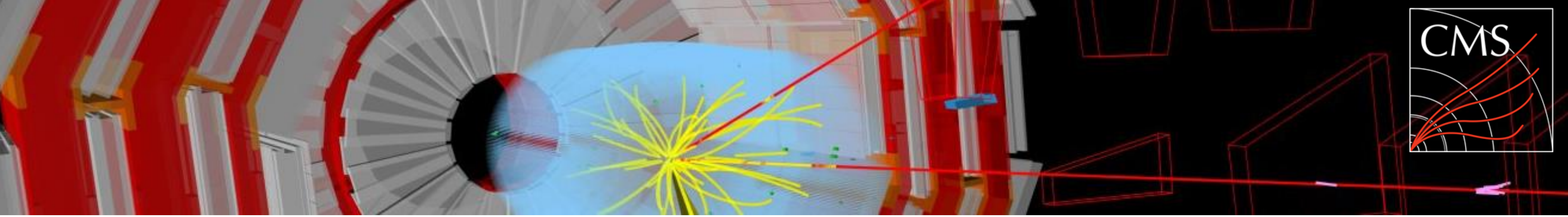


Thank you for your attention!

Questions?



Backup



Object & Event Selection

Muon

- Have $p_T \geq 55\ GeV$ (Loose $p_T \geq 30\ GeV$)
- Be contained in $|\eta| < 2.4$
- Pass tight cutbased muon criteria
- Pass tight particle flow isolation

Electron

- Have $p_T \geq 40\ GeV$ (Loose $p_T \geq 30\ GeV$)
- Be contained in $|\eta| < 2.4$
- Pass the MVA ID

Resolved Jet

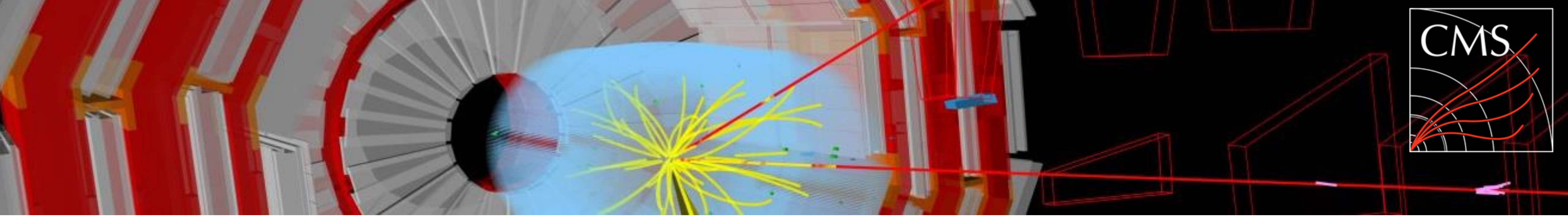
- Have $p_T \geq 30\ GeV$
- Be contained in $|\eta| < 2.4$
- Fulfill tight ID criteria

Boosted Jet

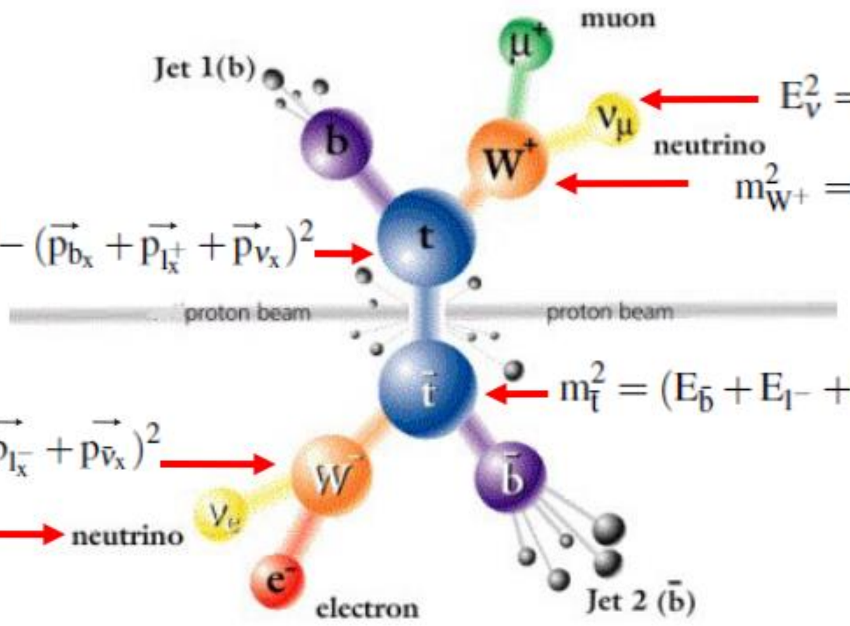
- Have $p_T \geq 350\ GeV$
- Be contained in $|\eta| < 2.4$
- Fulfill tight ID criteria

Event Selection

- Exactly two leptons ($\mu\mu, ee, or\ \mu e$, opposite sign)
- At least 4 $jets$
- Exactly $2\ b - jets$
- DeepCSV for b-jets
- Lepton Isolation
- $E_T^{miss} > 20\ GeV$



Analytical Solution of Dilepton Top Pairs



(1) $m_t^2 = (E_b + E_{l^+} + E_\nu)^2 - (\vec{p}_{b_x} + \vec{p}_{l_x^+} + \vec{p}_{\nu_x})^2$

(2) $E_\nu^2 = p_{\nu_x}^2 + p_{\nu_y}^2 + p_{\nu_z}^2$

(3) $m_{W^+}^2 = (E_{l^+} + E_\nu)^2 - (\vec{p}_{l_x^+} + \vec{p}_{\nu_x})^2$

(4) $m_{\bar{t}}^2 = (E_{\bar{b}} + E_{l^-} + E_{\bar{\nu}})^2 - (\vec{p}_{\bar{b}_x} + \vec{p}_{l_x^-} + \vec{p}_{\bar{\nu}_x})^2$

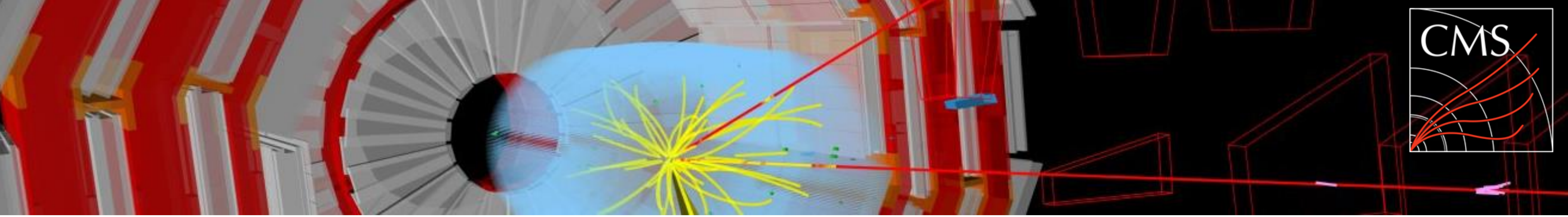
(5) $m_{W^-}^2 = (E_{l^-} + E_{\bar{\nu}})^2 - (\vec{p}_{l_x^-} + \vec{p}_{\bar{\nu}_x})^2$

(6) $E_{\bar{\nu}}^2 = p_{\bar{\nu}_x}^2 + p_{\bar{\nu}_y}^2 + p_{\bar{\nu}_z}^2$

+ missing energy

(7) $M_{ET_y} = p_{\nu_y} + p_{\bar{\nu}_y}$

(8) $M_{ET_x} = p_{\nu_x} + p_{\bar{\nu}_x}$



References

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