Physics at CMS

DHEP Annual Meeting
May 8-9, 2018

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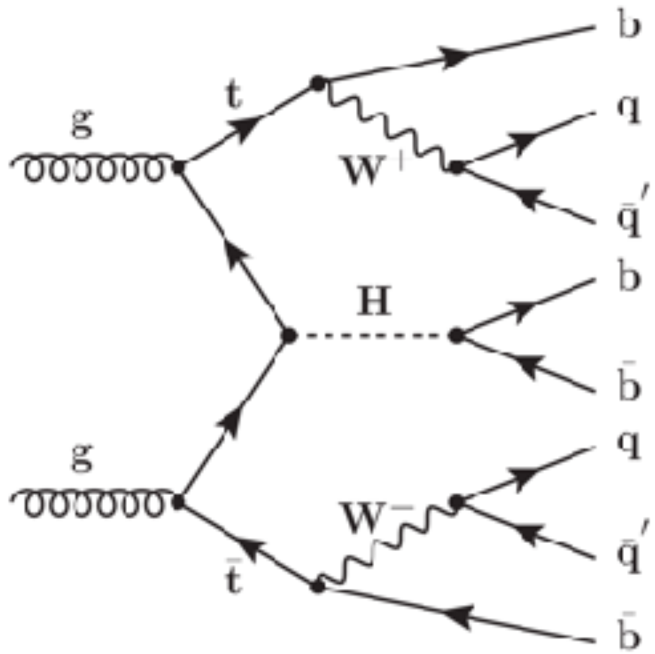
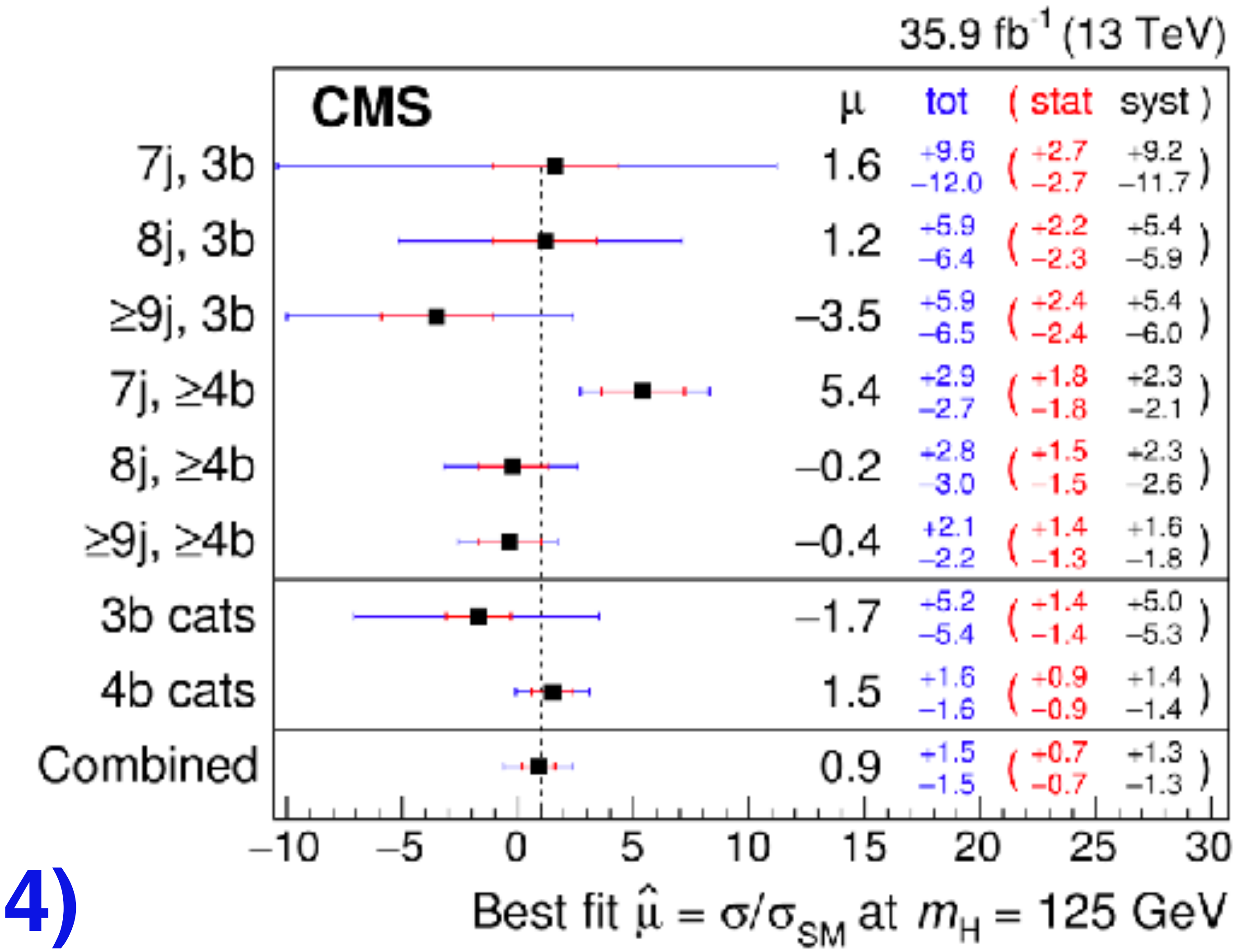
Brij Jaishwal
Puneet patel

Aravind H Vijay(not in CMS)

SM Higgs Observation in ttH

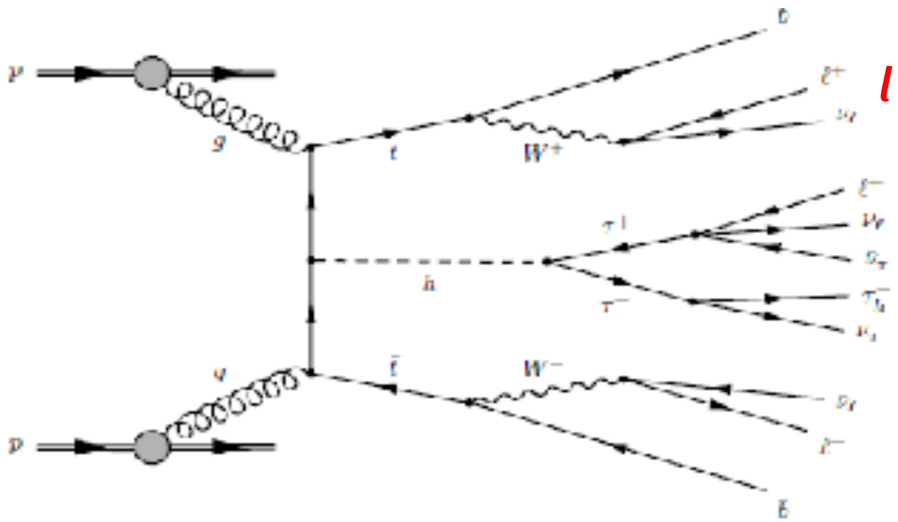




jets + b tags(3 or 4)

7 TeV + 8 TeV + 13TeV => 5 sigma observation

Search for ttH production



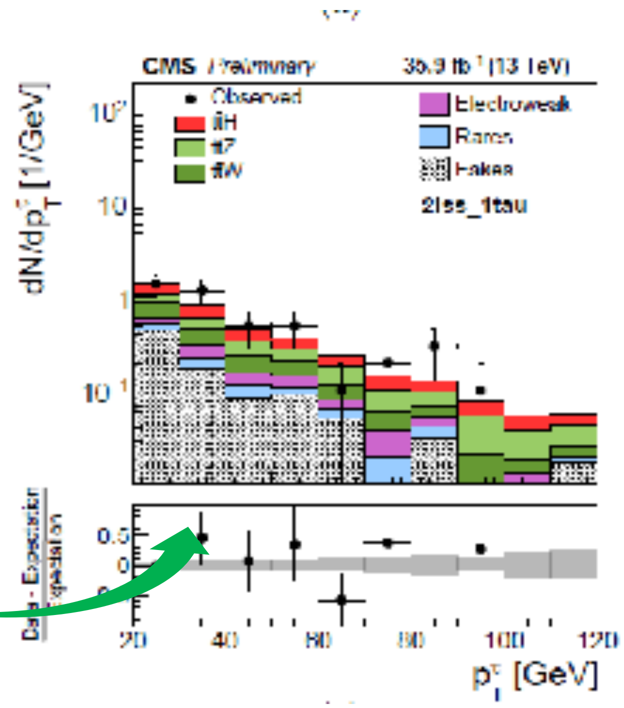
l^+ l^+ τ_h

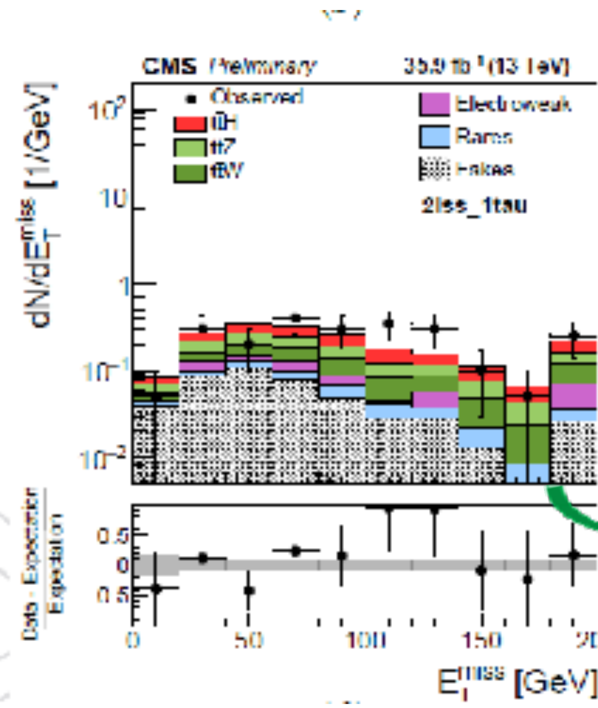
2 same sign leptons (electron or muon)

l^+ τ_h τ_h l^-

2 leptons (electron or muon)

Transverse momentum of τ lepton



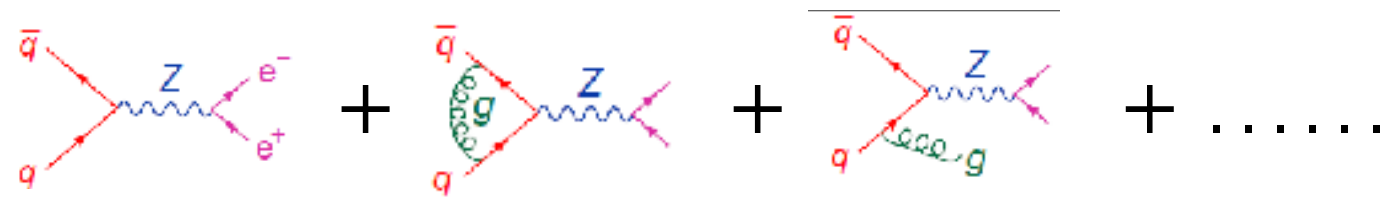


Missing energy in the event

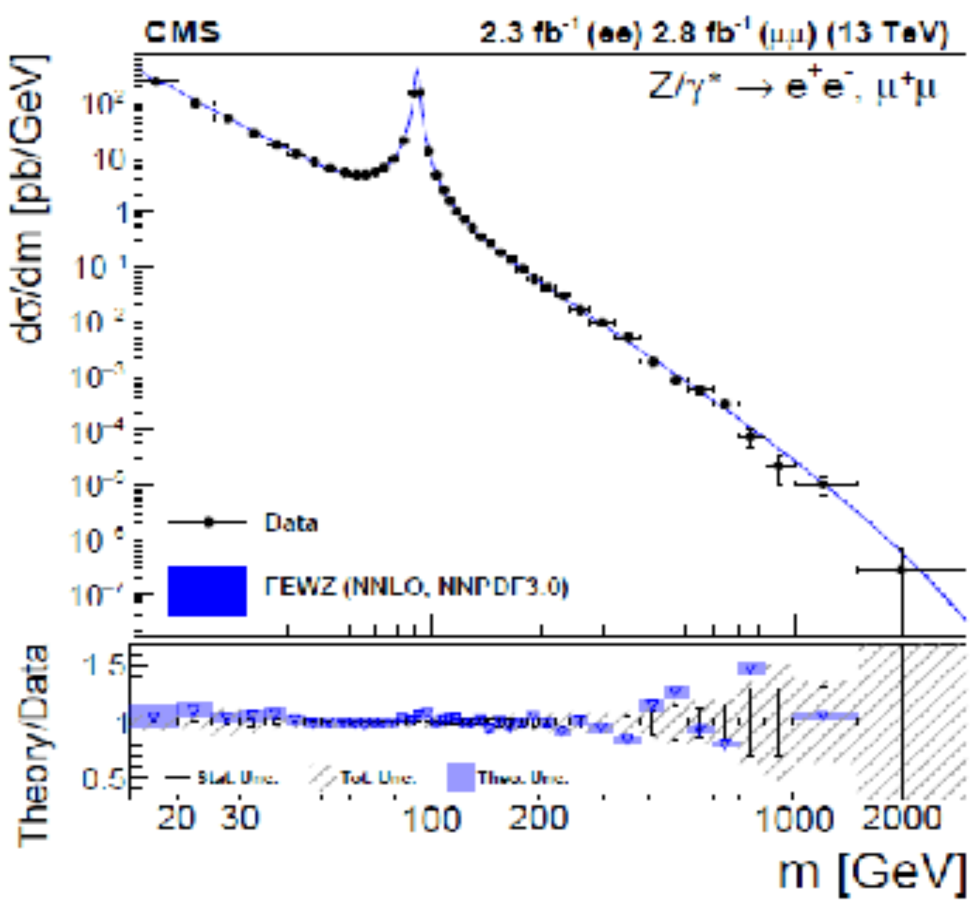
Plan: **Working on 2017 data, continue with 2018 data. Complete legacy analysis 2016+2017+2018 data**

Sudeshna Banerjee, Saikat Karmakar, Siddhesh Sawant

Measurement of Drell Yan cross sections at 13 TeV



$$PP \to Z/\gamma + X \to ee + \mu\mu + X$$



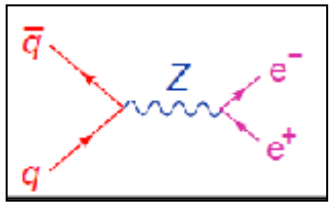
- Benchmark process at hadron colliders
- Test of perturbative calculations in SM including higher order effects.

Background to many processes, including search for beyond standard model (BSM)

- **S.Jain, G.Majumder, K.Mazumdar + Punjab Univ. + others**
- Computation for FEWZ calculation done in IndiaCMS T2, TIFR
- K.Mazumdar: language editor

SMP-17-001, to be submitted to JHEP

Measurement of ϕ^* differential cross section in DY process



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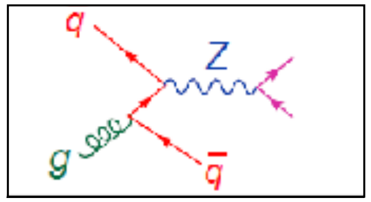

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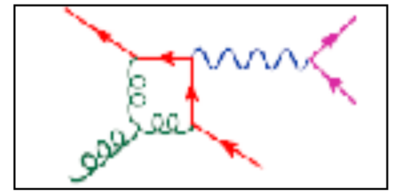
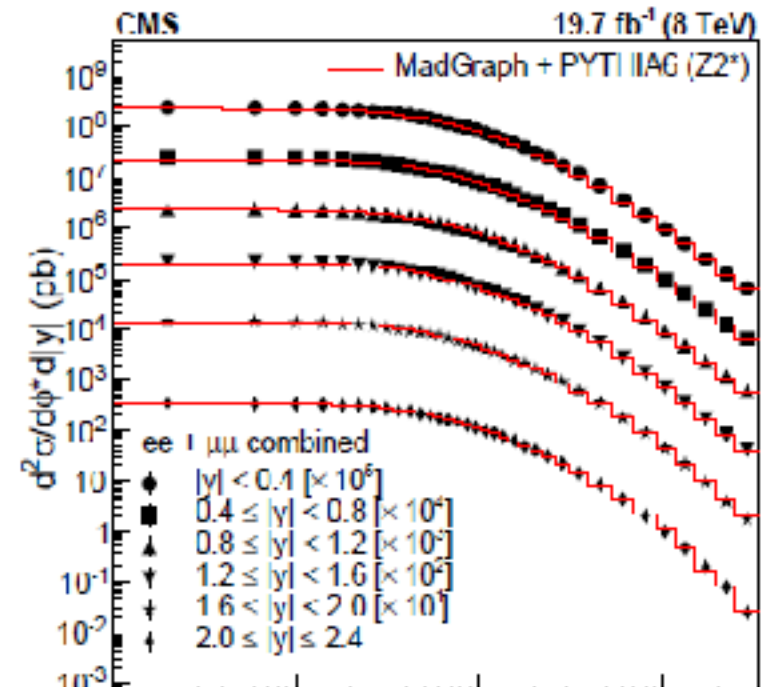
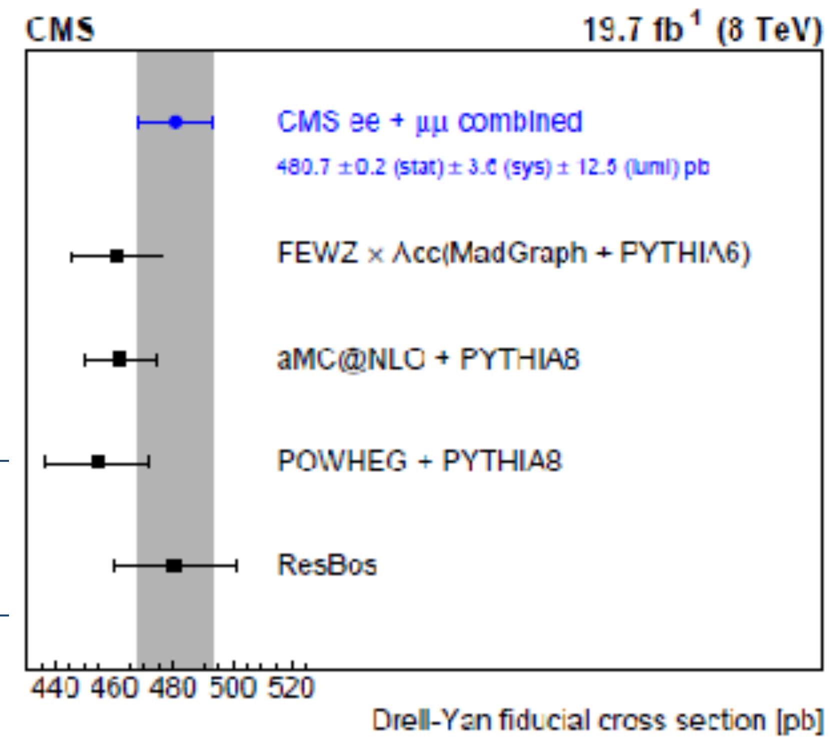

+……

- At leading order Z has only longitudinal boost
- With higher order corrections Z has also transverse boost ➔ non-zero transverse momentum
- Related variable with better accuracy

$$\phi^* = \tan\left(\frac{\pi - \Delta\phi}{2}\right)\sin(\theta^*_\eta)$$

- Precision measurement (better than 0.1%) confirms standard model predictions.



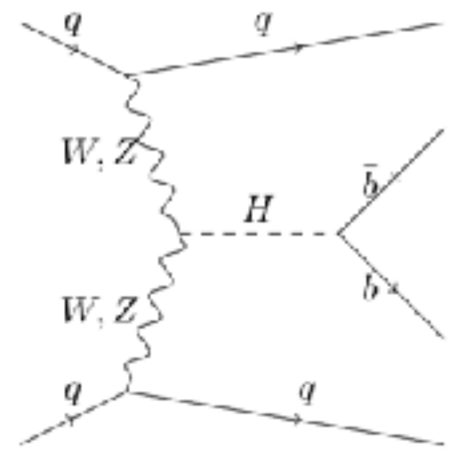


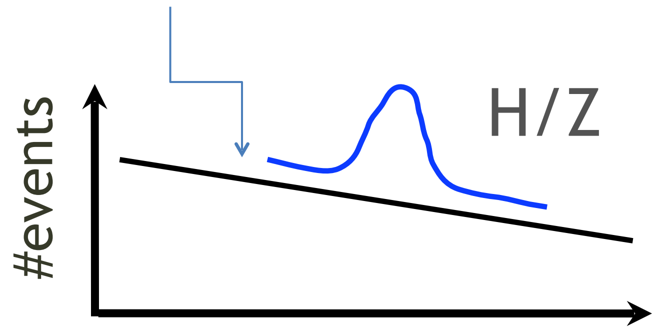
JHEP 03 (2018) 172 supporting document: AN-2014/107

R.Chatterjee , M.Guchait, K.Mazumdar + Panjab Uni. + others

Search for H → bb decay in VBF process

- H → bb decay : has the maximum branching of 60%
- Study coupling of H with b-quarks.
- VBF H process has unique topology.
- Still QCD Multijet background is larger by several orders





4-jet signal topology:

- 2 central b-jets from H decay
- 2 light q-jets (from VBF) with large Δη and m(jj)

Search strategy:

- Use BDT to exploit the differences between signal and QCD
- Perform a fit in m_{bb} spectrum (i) in Z region, & (ii) H region

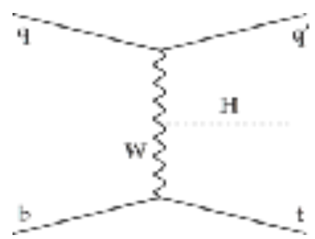
Status: on-going study with 2016 data to estimate QCD background and bias in parametrization

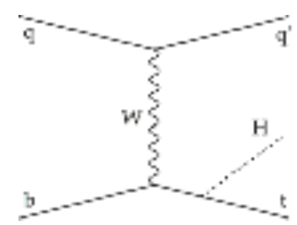
K. Mazumdar, Niladribihari Sahoo + CTS, Bangalore + others

tHq multilepton analysis

- Higgs to fermion Yukawa coupling is proportional to fermion mass, for top y_t is ~1.
  ➔ important to confirm it experimentally.

- tHq process exposes the relative sign of Htt & HWW couplings via interference. (ttH cannot)





Pallabi Das, K.Mazumdar + others

Study the coupling modifiers w.r.t. SM κ_t and κ_V

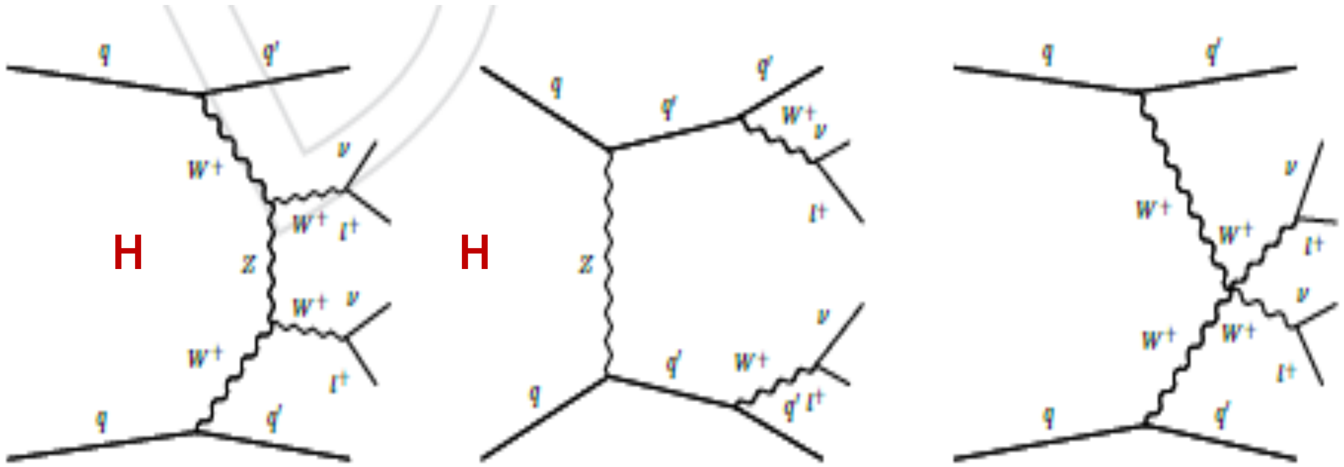
- Destructive interference in SM: $\sigma_{tHq}(\kappa_V = \kappa_t = 1)$ = 70.96 fb (at $\sqrt{s}$ = 13 TeV).
- Large enhancement for negative relative sign between κ_t and κ_V in tHq production. e.g., $\sigma_{tHq}(\kappa_V = -\kappa_t = 1)$ = 792.7 fb.

- same-sign dilepton analysis targets the H → WW etc.
- Combined limit on σ(tHq+tHW+ttH)xBR(H→WW*, $\tau\tau$, ZZ*) derived as a function of κ_t/κ_V.
- κ_t values outside (-1.25, 1.6) are excluded at 95% C.L. for κ_V = 1.0.

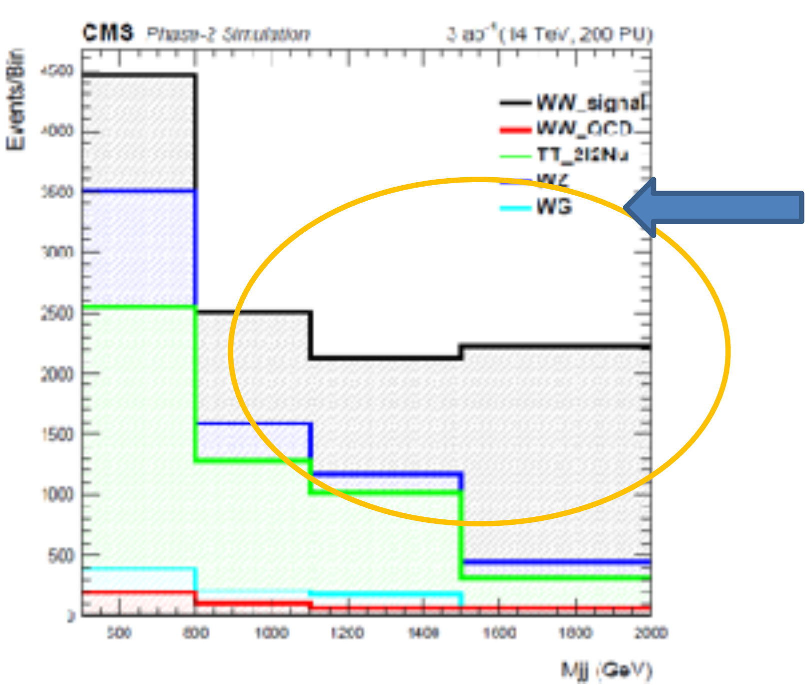
- Documentation: AN-16-378 and HIG-17-005 to be published in PRD

Vector boson scattering

- The most important process to be studied at LHC to establish the role of Higgs boson in electroweak symmetry breaking.



- Extremely low rate combined with large background.
- Best sensitivity in same sign Di-lepton final state.
  Jets have vector boson fusion topology.

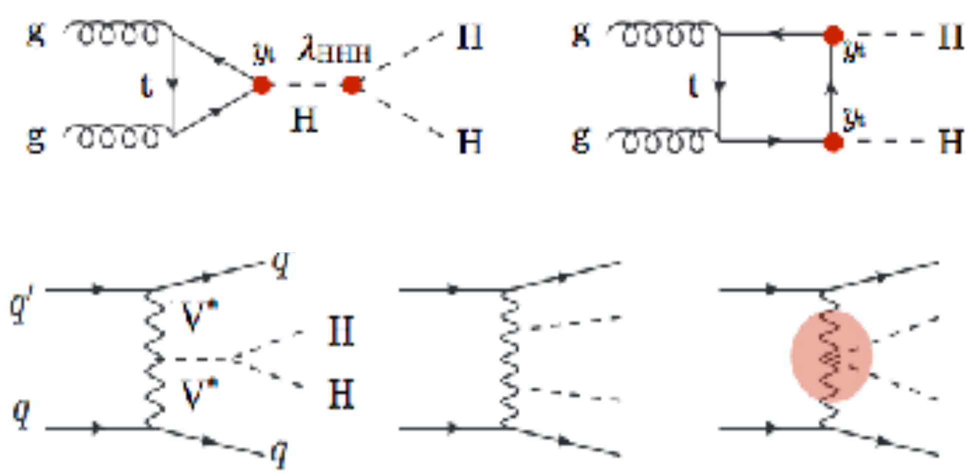


➢ Preliminary results indicate highly granular endcap calorimeter and extended coverage for lepton measurement crucial for achieving very high sensitivity of VBS at high tail of dijet mass ➔
(i) role of Higgs boson in mass generation established
(ii) effects from BSM or higher dimensional operators can be studied/constrained better.

FTR-18-005
AN-2017/306

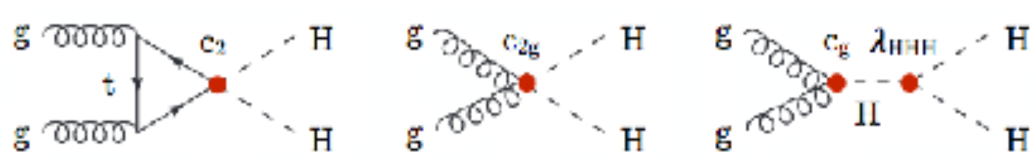
S.Jain, G.Majumder, K.Mazumdar, A.Savin, S. Uplap

Di Higgs production



- Higgs self-coupling ➔ Di–Higgs production
- Describes Higgs potential → most important parameter in Higgs sector yet to be estimated experimentally.
- Cross section very low (~ 33 fb)
  ➔ 2016 data does not have sensitivity to measure the SM rate
  ➔ need high luminosity

- Constraints can be obtained with current data on coupling modifier K_λ
- BSM can increase the cross-section value by 10 [$K_\lambda = 10 \rightarrow \sigma_{BSM} = 10 \times \sigma_{SM}$]



- On-going projection studies for HL-LHC: potential of Di-Higgs production and decay in H→ bb, H→$\gamma\gamma$ final states, when H produced in gg fusion or VBF process. Branching ratio: 0.26%, best sensitivity!

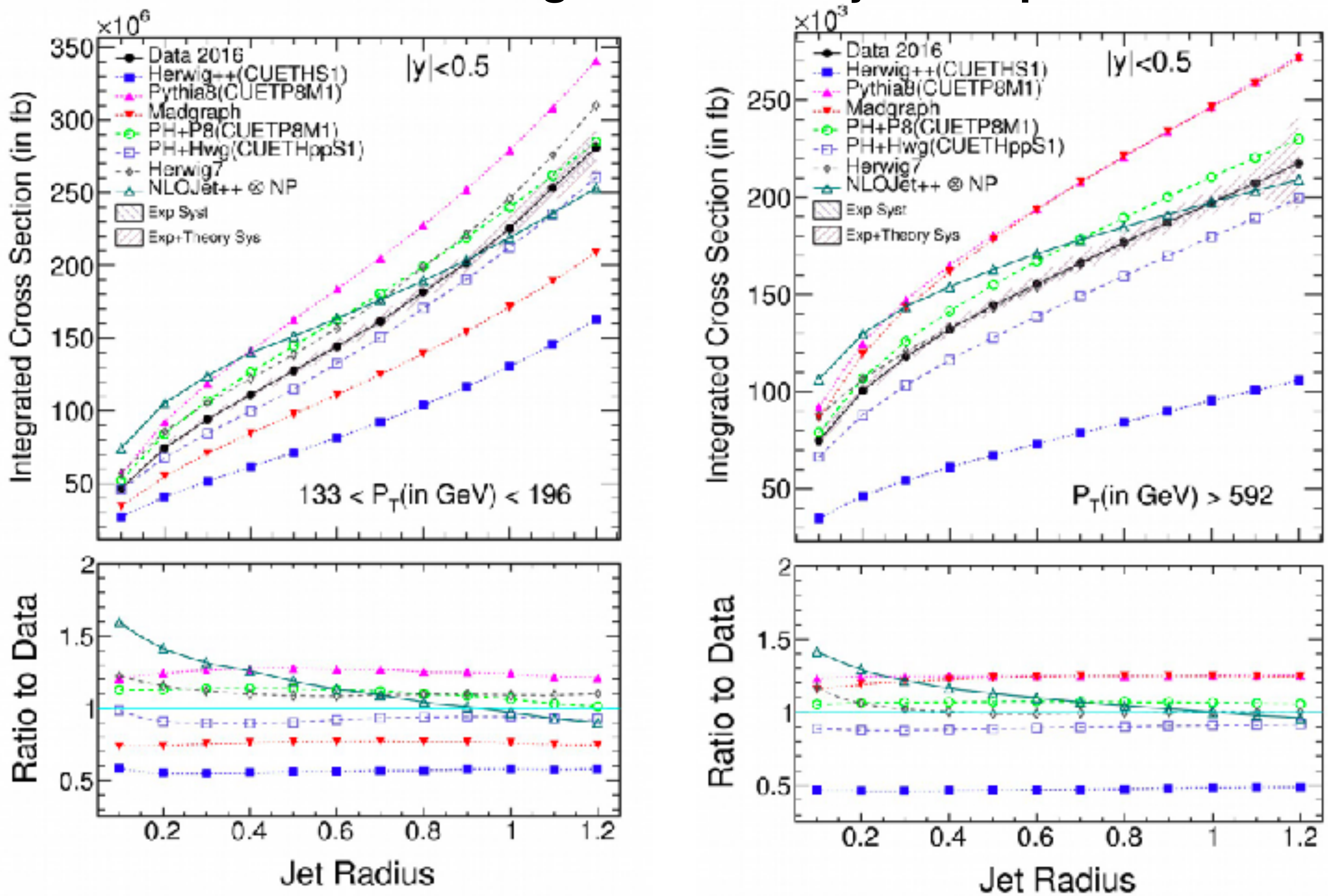
K.Mazumdar, Arnab Roy, Niladribihari Sahoo + others

Radius Scan for Inclusive Jets in CMS Experiment

Suman Chatterjee, Gobinda Majumder

$$pp \rightarrow Jets$$

Inclusive measurements using AntiKT with jet size parameter : 0.1, 0.2….1.2

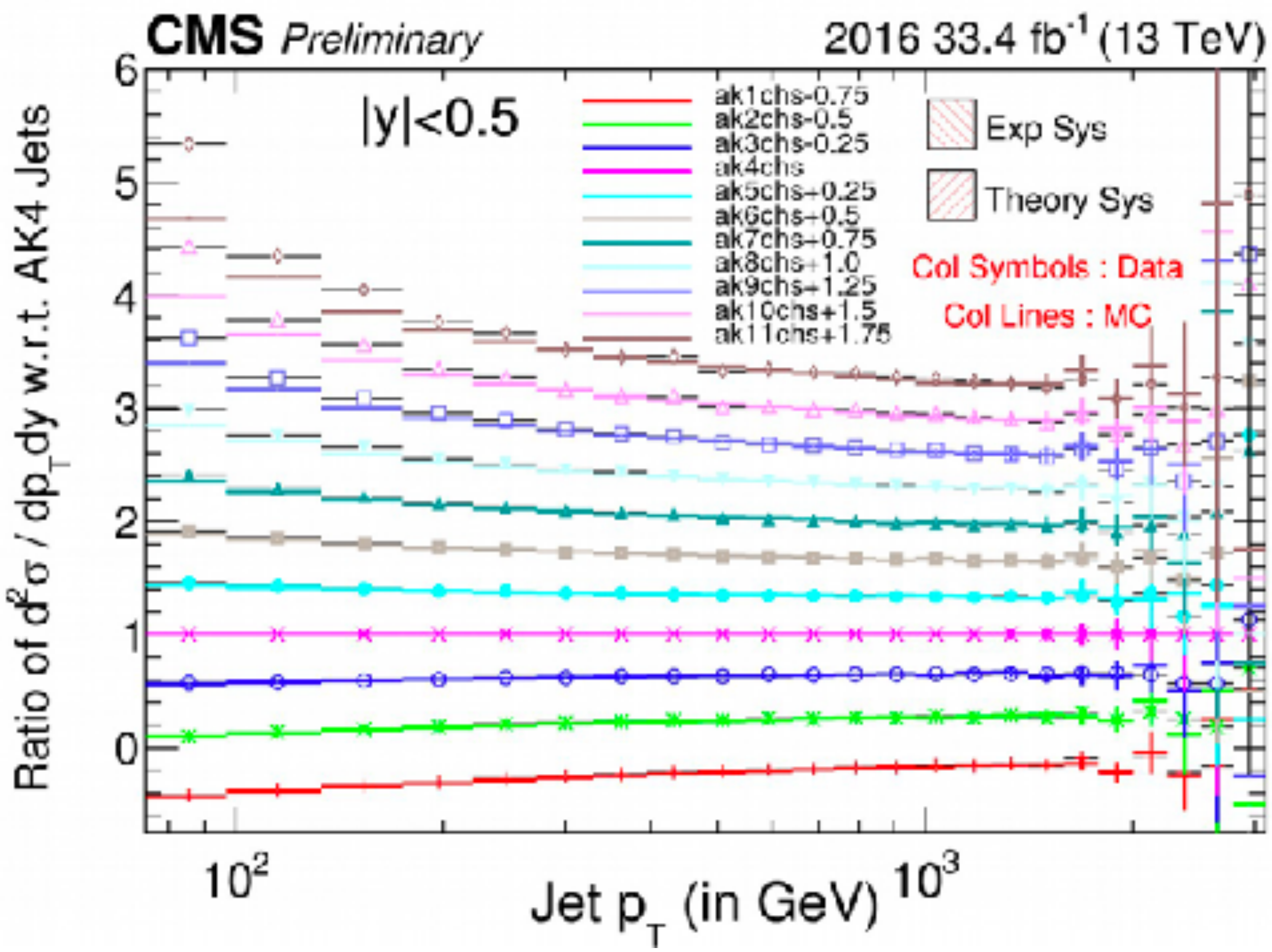


PH=Powheg
P8=Pythia8
Hwg=Herwig++

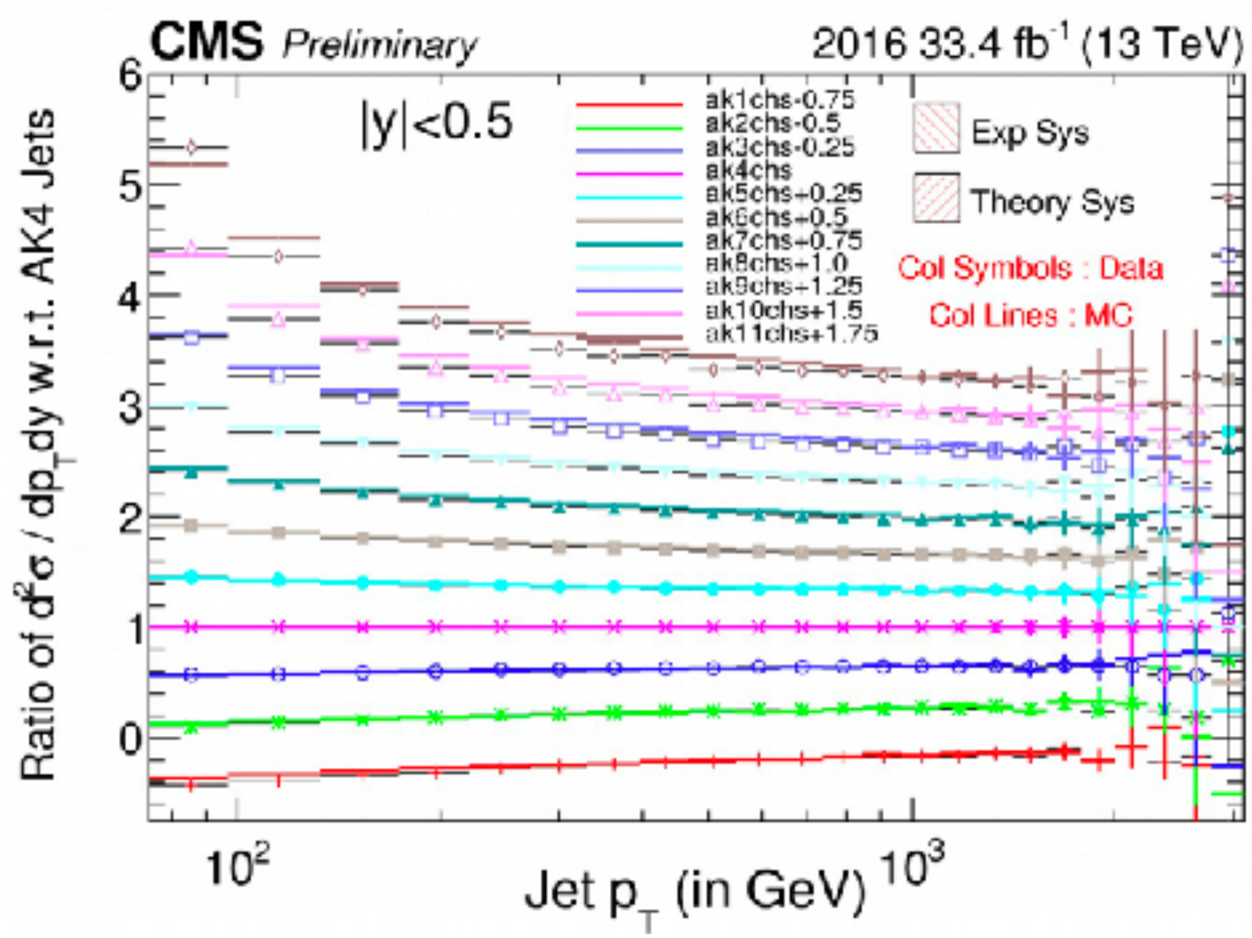
- NLO predictions (Powheg, NLOJet++, Herwig7) are closer to data compared to LO (Pythia8, Herwig++, Madgraph)
- Fixed order prediction (NLOJet++) fail to describe the trend
- Non-perturbative cor used for NLOJet++ to make hadron level prediction

Radius Scan for Inclusive Jets in CMS Experiment

Observable : Ratio of x-section w.r.t. AK4 jets



POWHEG+PYTHIA8



POWHEG+Herwig++

Powheg+Pythia8 can can describe the ratio the best but overshoots for large jet sizes at low pt

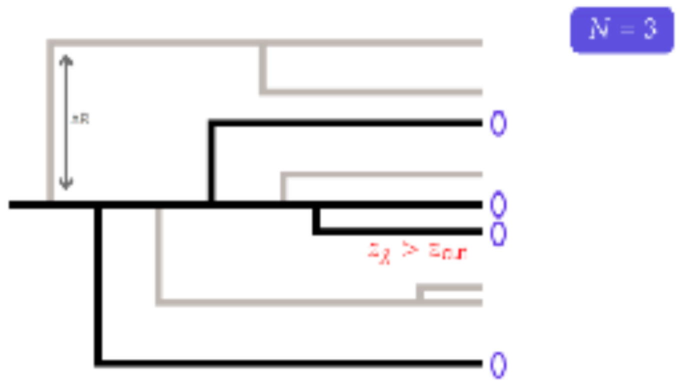
Powheg+Herwig++ is better for large jet sizes little large prediction for AK1 jets at low pt (still within systematics)

Herwig7++ can’t describe jets of very small sizes (0.1,0.2): deviate more at larger pt

Suman Chatterjee, Gobinda Majumder

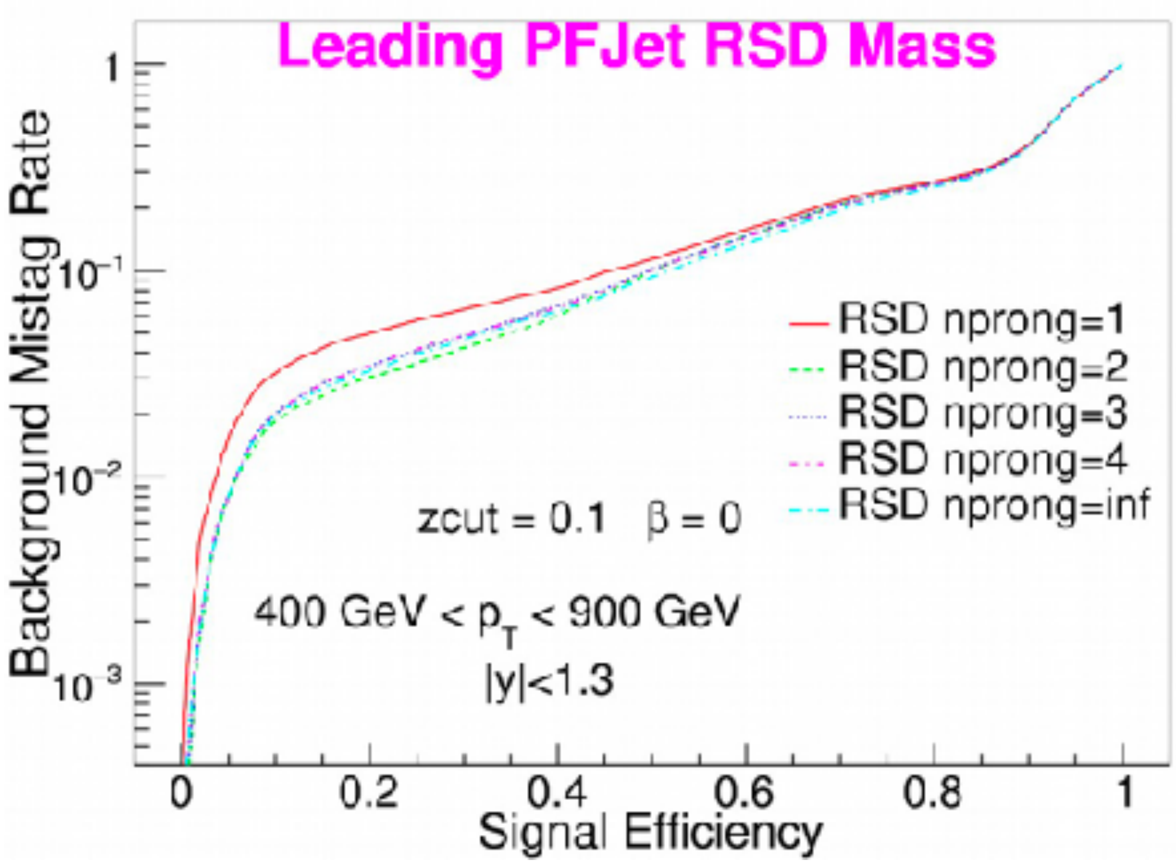
Implementation of of Recursive Soft Drop in CMS

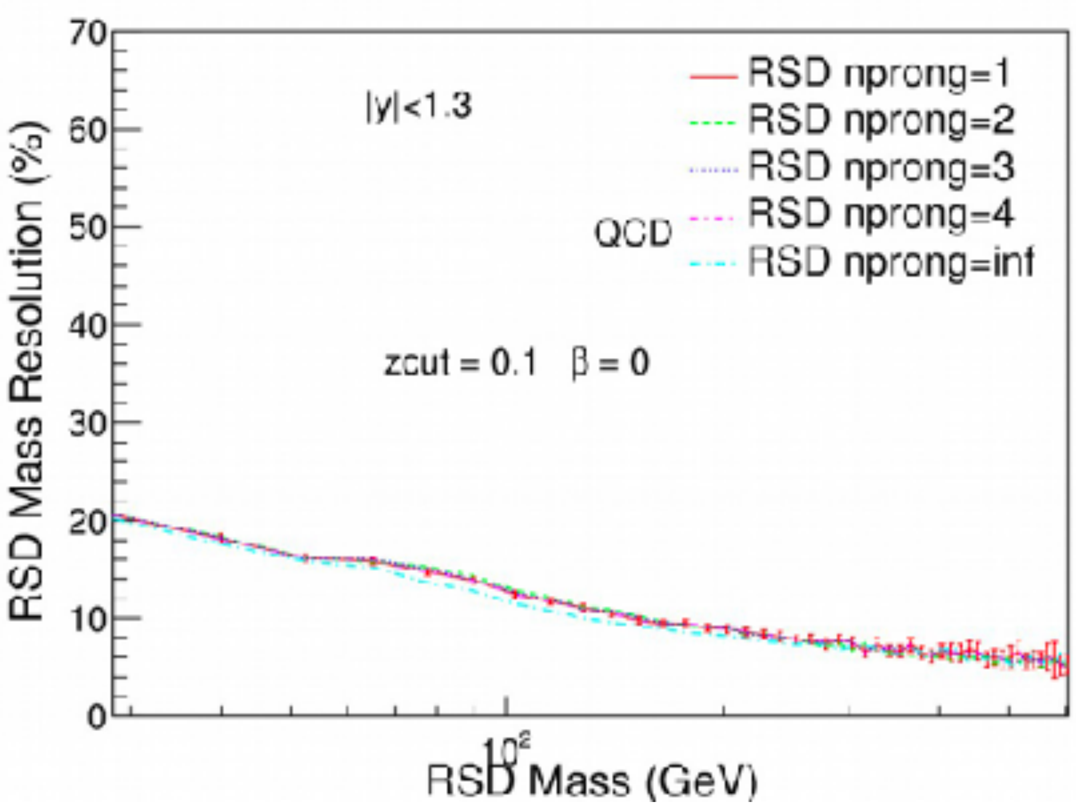
A new jet grooming technique : performs soft-drop iteratively until a specified number of subjets (nprong+1) are obtained



$$z = \frac{min(p_T^{subjet1}, p_T^{subjet2})}{p_T^{subjet1} + p_T^{subjet2}} > z_{cut}(\frac{\Delta R_{subjet1,2}}{R_0})^{\beta}$$

Soft-drop criteria is checked at each step of declustering along C-A clustering history
Stops with (N+1) subjets in final groomed jet
N=1 default soft-drop (SD)



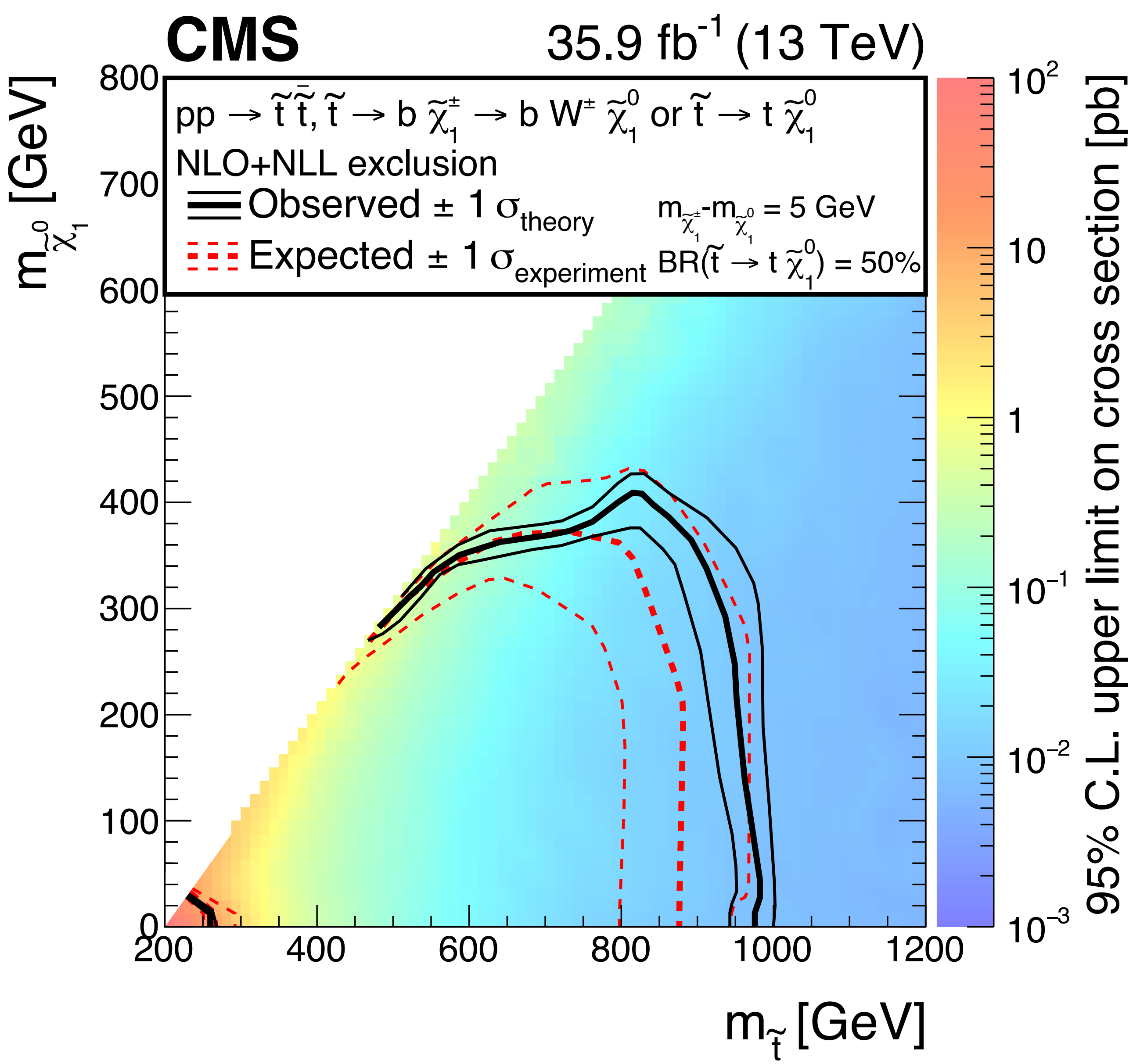


Used AK8PUPPI jets in HGCAL geometry at <PU>~200

Implemented in CMS Framework
Suman Chatterjee, G. Majumder

Top squark searches: Di-Tau final states(1)

3rd Generation squark search important in light of 125 GeV Higgs



Exclusion are valid for leptonic final states: electron or muon

High $\tan\beta$ **scenario**

$$\tilde{\chi}_1^- \to \tilde{\tau}_1^- \nu_\tau + \tilde{\nu}_\tau \tau^-;$$

$$\tilde{\tau}_1^- \to \tau^- + \tilde{\chi}_1^0; \quad \tilde{\nu}_\tau \to \nu \tilde{\chi}_1^0$$

Currents limits are not applicable

$$\tilde{t}_1 \tilde{t}_1 \to \tau\tau + X$$

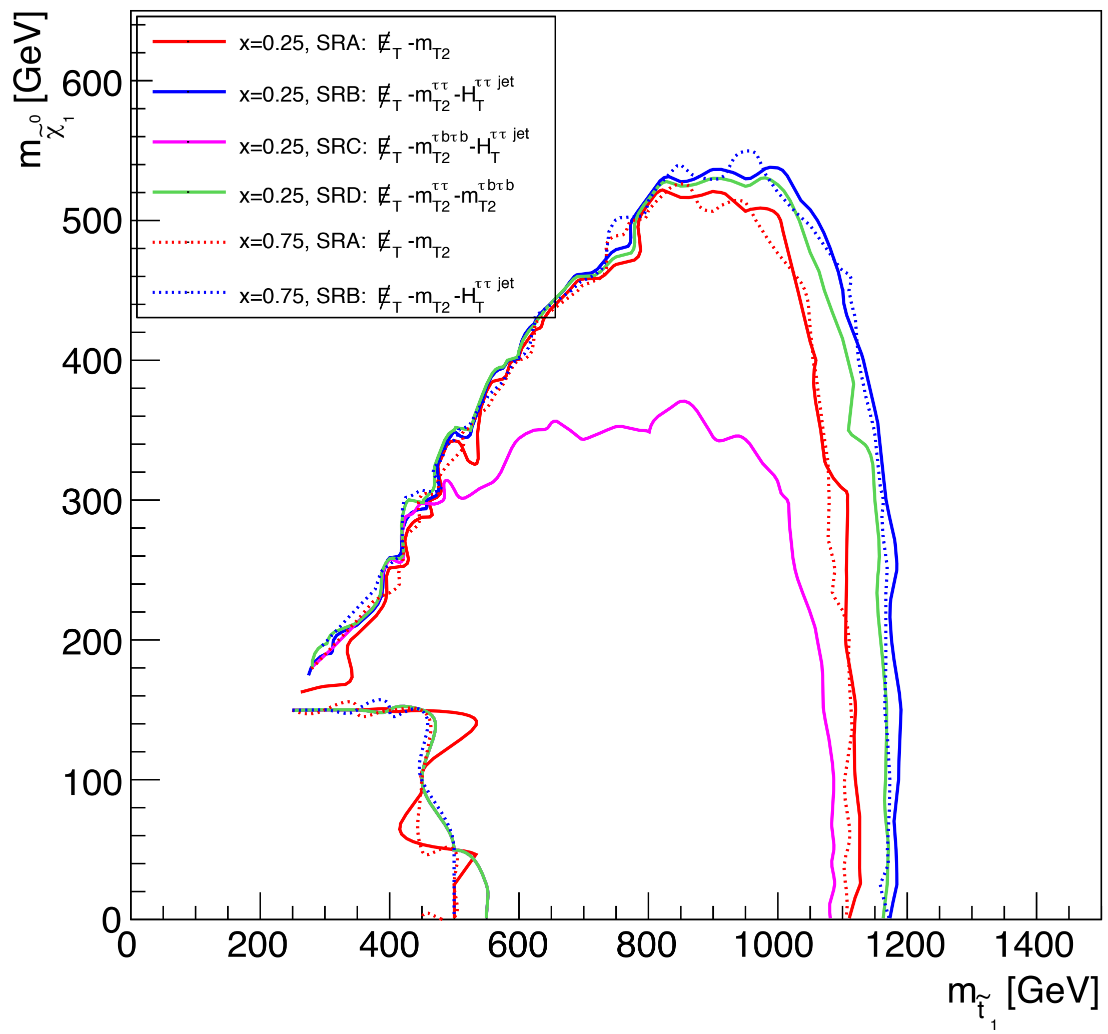
S. Banerjee, Soham Bhattacharya, MG, G. Majumder, K.Mazumdar
A Nayak, S.Sharma

Top squark searches: Di-Tau final states(2)

Signal regions are divided in various bins

Best Combination

$$n_{\tau_h} \geq 2$$
$$\not{E}_T = [50 - 200,\ 200 - \infty]$$
$$m_{T2}^{\tau_h \tau_h} = [0 - 40,\ 40 - 80,\ 80 - \infty]$$
$$H_T^{\tau_h \tau_h jet} = [100 - 300,\ 300 - 700,\ 700 - \infty]$$
$$n_b \geq 1$$



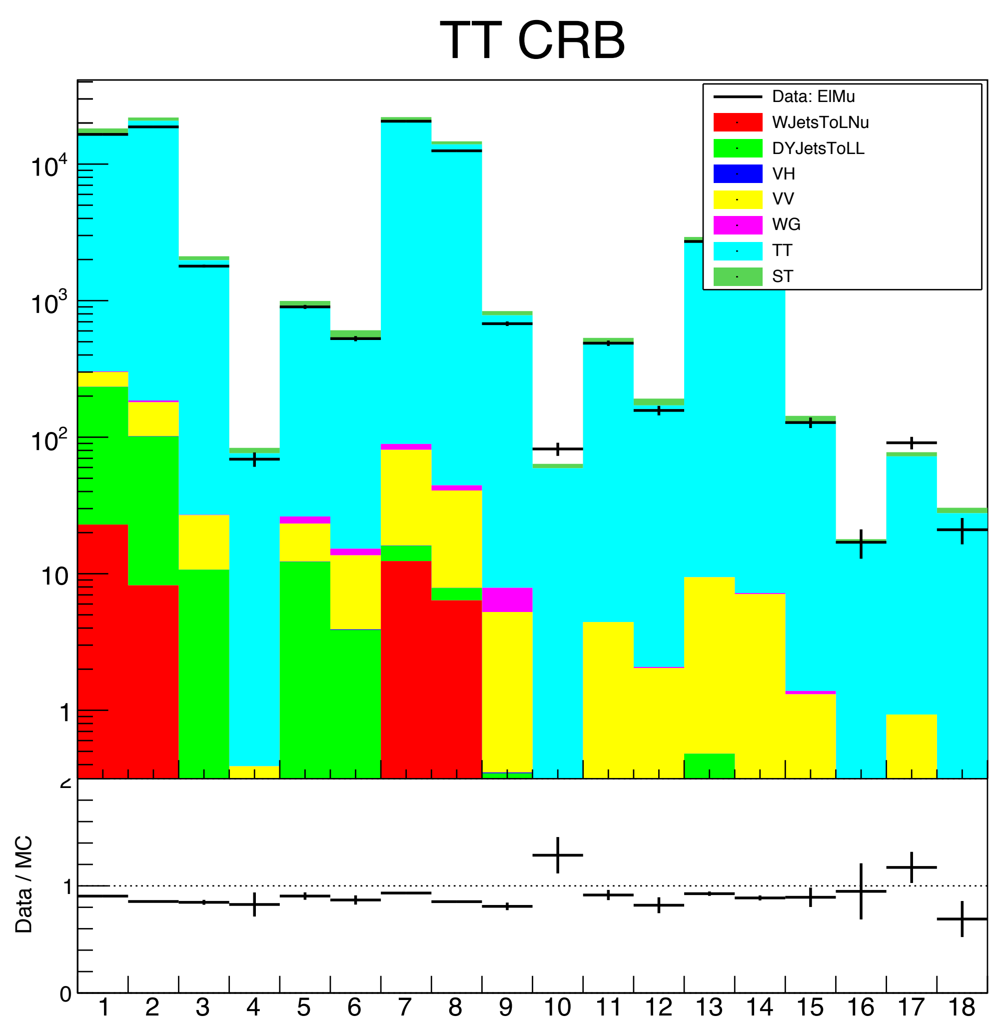
Background estimation is underway

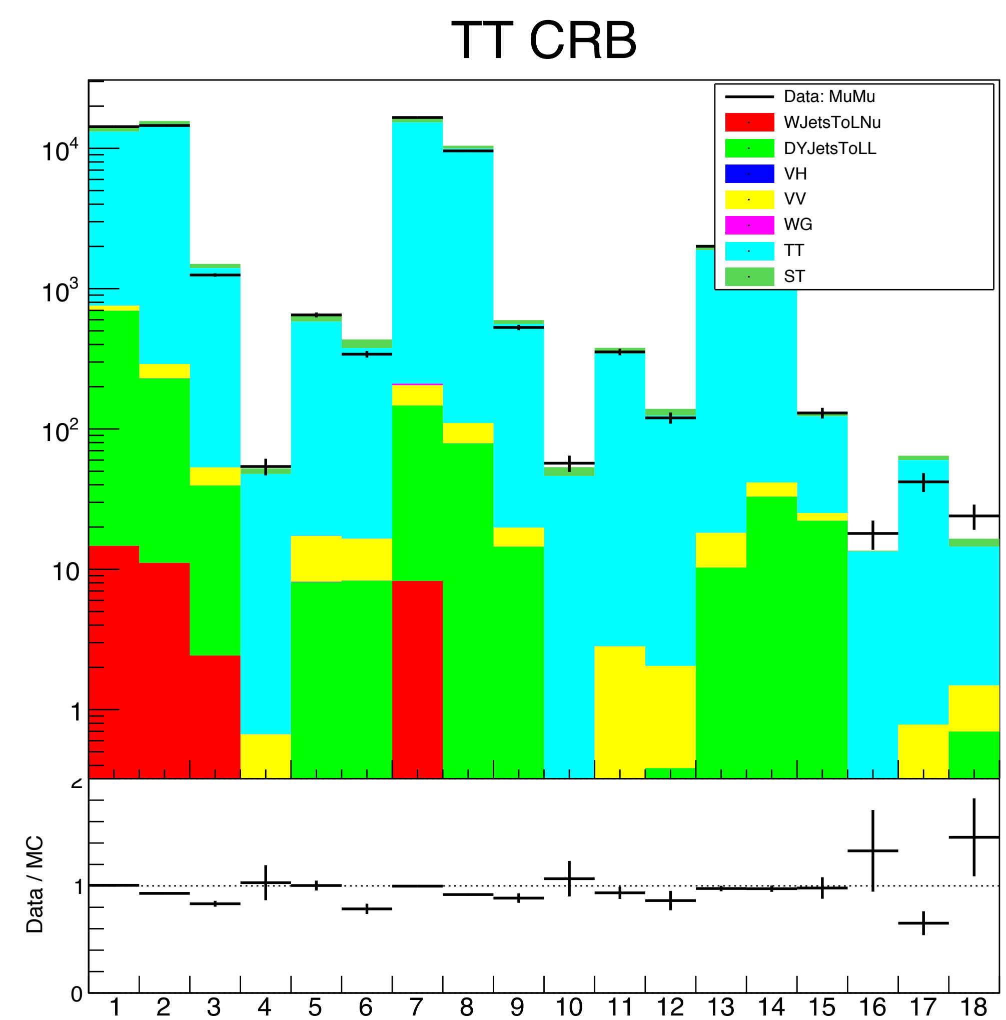
Top squark searches: Di-Tau final states(3)

Estimation of background is underway

Top background: Data driven estimation

Left: $CRB^{e\mu}$, **Right:** $CRB^{\mu\mu}$
$\mathcal{L} = 35.9$ fb^{-1}

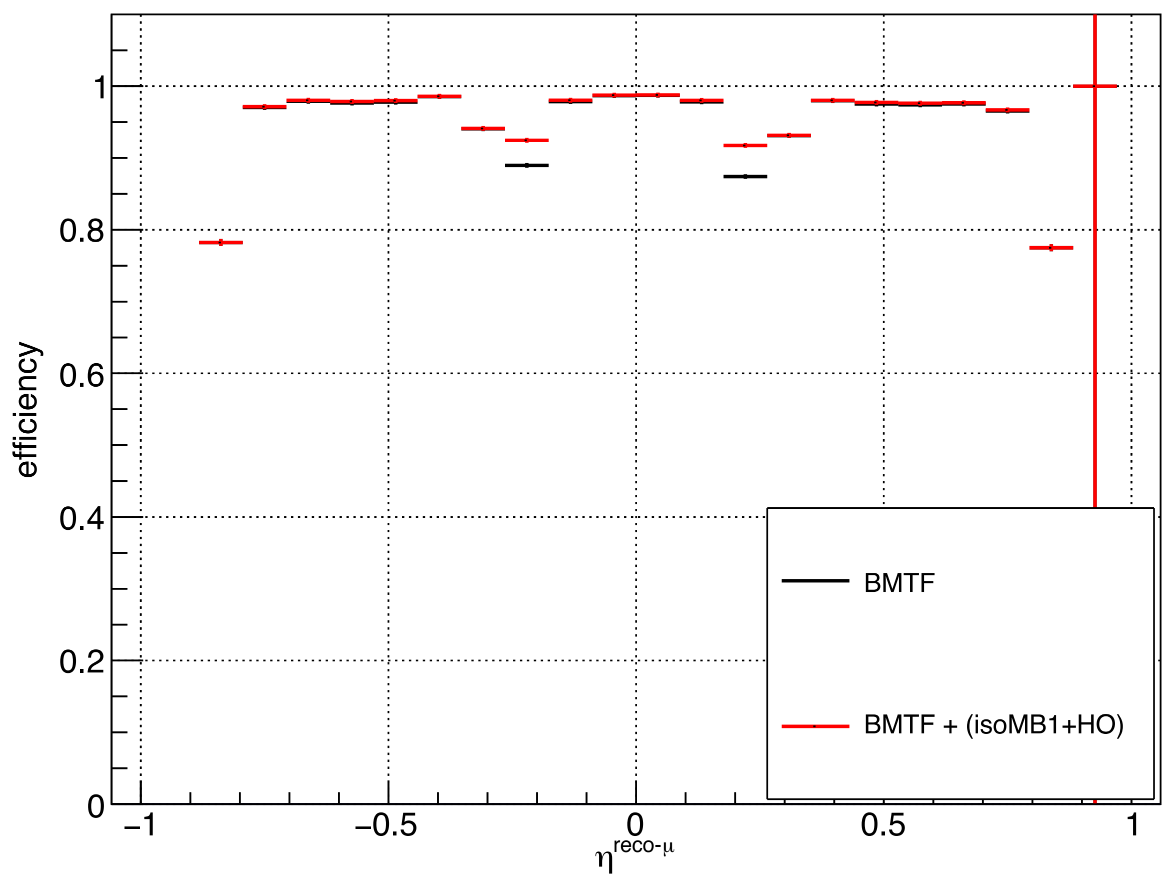




Top background: Validating using template method

Prospects of using the HO for L1 muon trigger

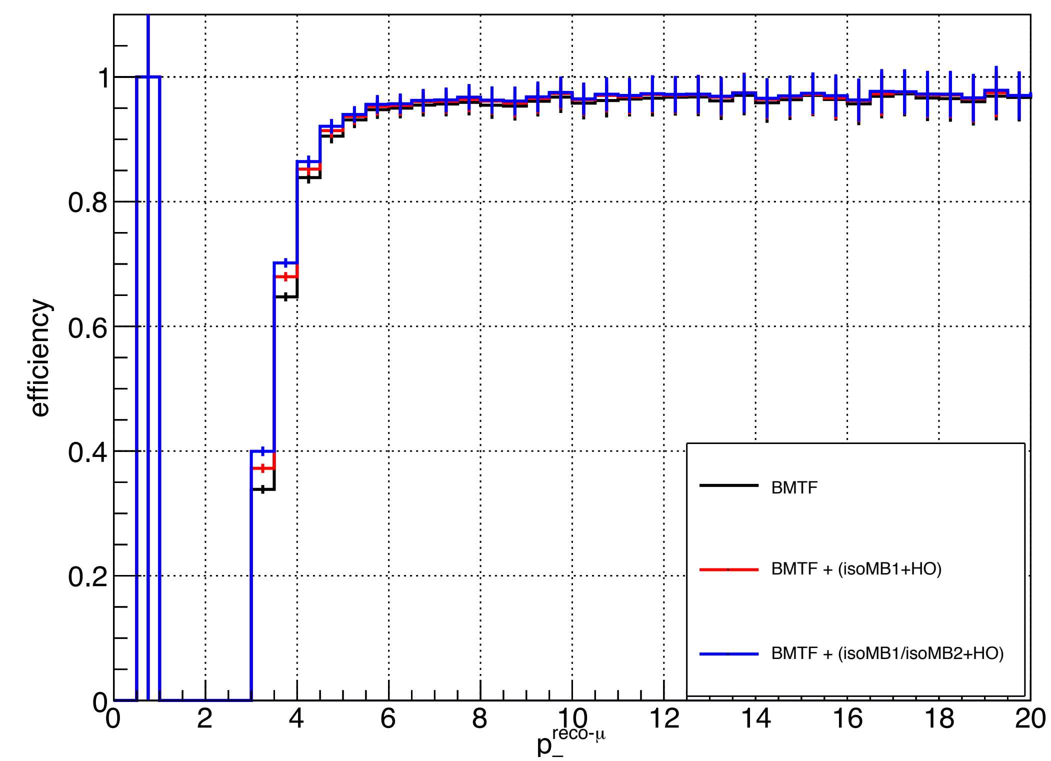
Soham Bhattacharya(TIFR),
Ashraf Mohamed(DESY)



Use the **HO+MB1 (innermost muon station) coincidence** to cover gaps of MB2/3/4 in the region $i\eta \pm 3$ $(0.174 < |\eta| < 0.261)$. Try to recover the muons in this region that have a signal in the HO and MB1 but not in any of the other muon stations. Efficiency gain of $\sim 5\%$ in this gap at the cost of $\sim 60\%$ gain in track (Barrel Muon Track) rate at 22 GeV; **large contribution from fakes (hadronic shower tails) - not a viable option.**

isoMB1+HO efficiency

)



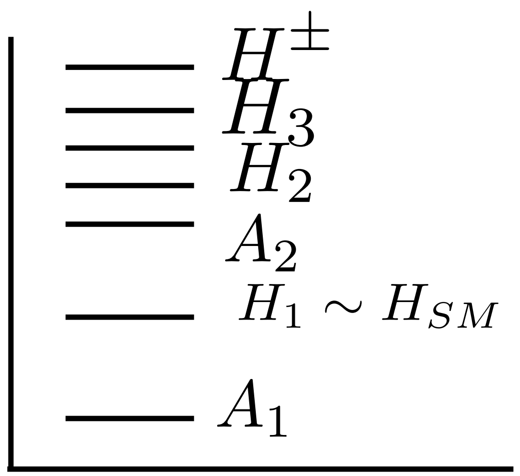
Use the MB1+HO or MB2+HO coincidence to recover very soft muons $(\sim 3-4$ GeV). Can recover only $5-7\%$ of these muons; large incident angle (due to large bending) of these muons at the muon station reduces their acceptance.

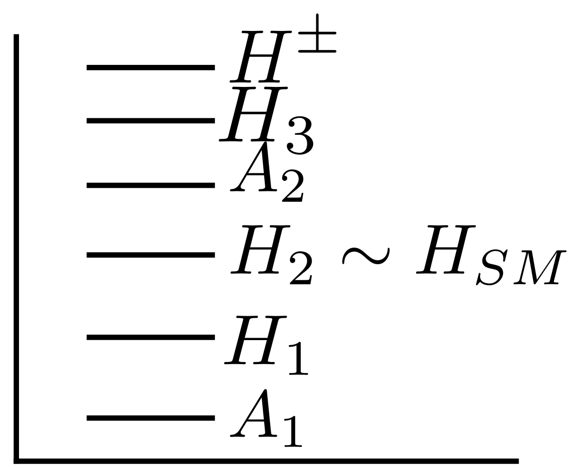
Track $\Delta\phi$ vs p_T correlation not very strong for MB34 tracks (tracks that have hits in the two outermost muon stations only).
Use the $\Delta i\phi$ between track's HO and MB3 hits for track p_T confirmation.
Requiring $\Delta i\phi \leq 1$ for tracks with $p_T > 22$ GeV reduces their rate by $\sim 19\%$ at the cost of only $\sim 0.5\%$ loss in efficiency.
Can reduce contribution from fakes without affecting real high p_T tracks.

Light Higgs at the LHC

In MSSM having a H(125) is not so easy

Next to MSSM : Two Higgs doublet + a singlet
Easy to achieve a 125 GeV SM like Higgs



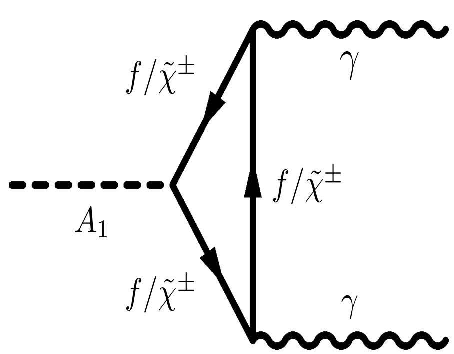


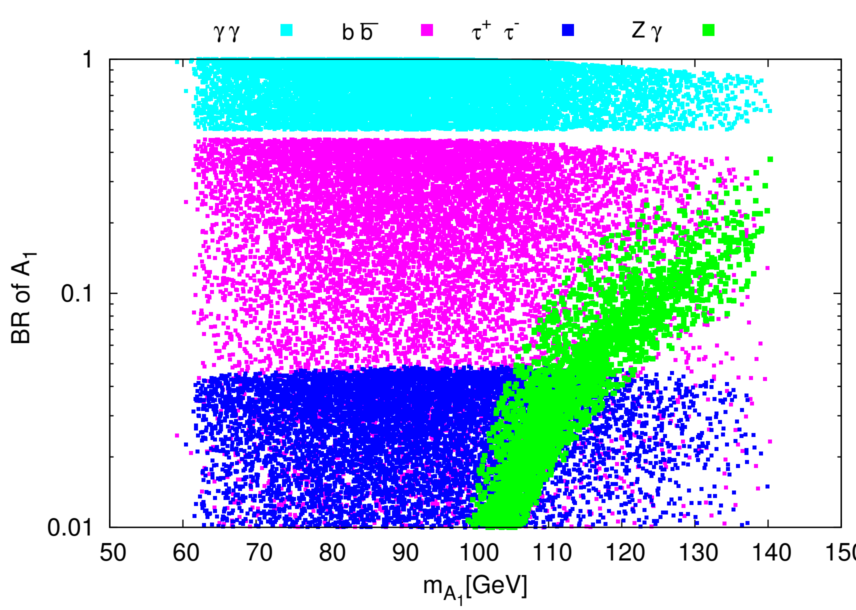
SM like

$$H_1 \quad or \quad H_2$$

Light and Non-SM like

$$A_1 \quad or \quad H_1, A_1$$





$$Br(A_1 \to \gamma\gamma) \sim 50 - 100\%$$

Multi photon signal of light Higgs

$$H \to A_1 A_1 \to 4\gamma$$

Signal

$$\begin{aligned} \mathrm{pp} &\to \mathrm{t\bar{t}H,\ WH,\ ZH,\ tH} \\ &\to \mathrm{n_\gamma \gamma + n_\ell \ell + \not{E}_T} \end{aligned}$$

Backgrounds

$$W\gamma\gamma, Z\gamma\gamma, t\bar{t}\gamma\gamma, t\bar{t}\gamma\gamma\gamma$$

Rates: $\sigma \times \beta$ $\quad \beta = \mathrm{BR(H \to A_1A_1) \times BR(A_1 \to \gamma\gamma)^2}.$

ATLAS at 8 TeV $\quad \beta \lesssim 10^{-3}$

Results: Light Higgs

Delphes Level analysis

Background

$\sigma(fb) \rightarrow$	W$\gamma\gamma$ 407.0	$Z\gamma\gamma$ 257.0	$t\bar{t}\gamma\gamma$ 13.64	$t\bar{t}\gamma\gamma\gamma$ 0.670
Selections				
$N_\gamma \geq 3$	1.11	0.16	0.12	0.11
$N_\ell \geq 1$	0.089	0.081	0.024	0.028
$\not{E}_T > 30$	0.058	0.002	0.021	0.024
$m_{\geq 3\gamma} < 130$	0.026	0.001	0.007	0.007

Details; Poster by Aravind

m_{A_1} (GeV)	Signal CS(fb) $\sigma \times \epsilon_{ac} \times \beta$	Bkg CS(fb)	$\mathcal{L}(fb^{-1})$ 100	300	1000
				S/$\sqrt{B}$	
10	0.061		3.01	5.21	9.51
30	0.081	0.041	3.97	6.88	12.57
60	0.111		5.51	9.53	17.41

Unique and robust signal, not possible in any other SUSY model

Testing this event in data might be interesting

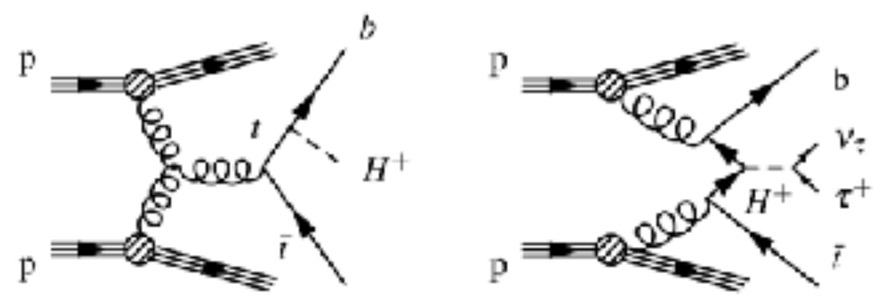
MG, Aravind Vijay, Jacky Kumar,JHEP, 1708(2017) 122
ArXiv:1705.06275

Heavy Charged Higgs at the LHC

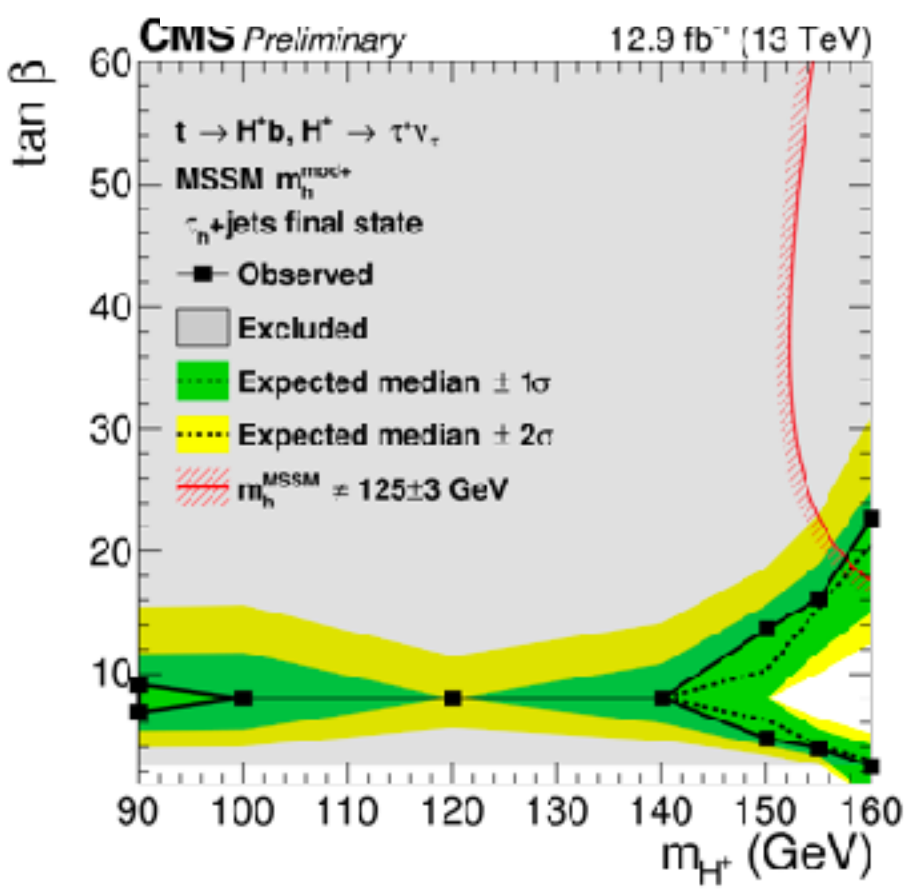
Predicted by MSSM
Any generic 2 HDM model

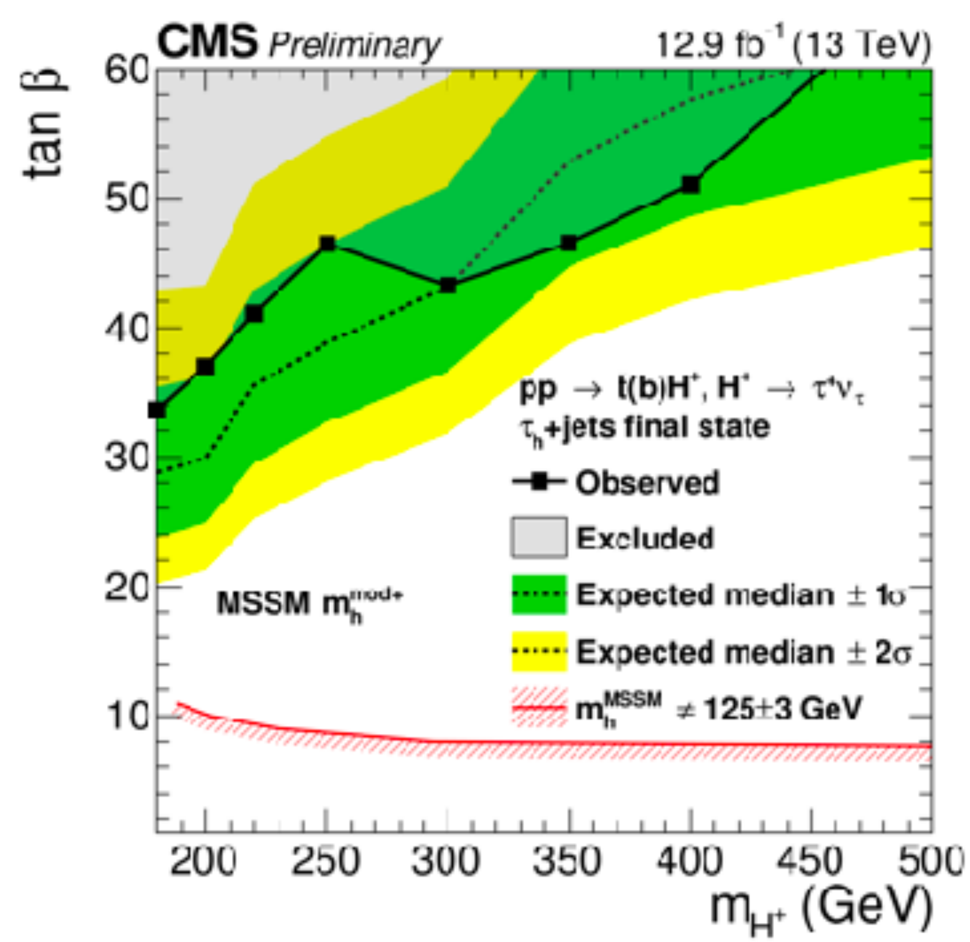
Unique and un ambiguous signature of BSM

Mass region $m_t > m_{H^\pm}$ **well studied**



$$H^- \to \tau^- \nu$$





Heavy Charged Higgs at the LHC(2)

$m_{H^\pm} >> m_t$ $\quad$ $H^- \to \bar{t}b$ $\quad$ $\sigma \sim \mathcal{O}(10 \quad fb)$

$$pp \to tH^-(b) \to t(tb)(b) \to (bW)(bWb)(b)$$

Background:

$$pp \to t\bar{t} \to (bw)(bw) \quad \sigma \sim 10^3 pb$$

$$pp \to t\bar{t}b\bar{b} \to (bW)(bW)b\bar{b} \quad \sigma \sim 10pb$$

$$pp \to jets \quad \sigma \sim 10^8 pb$$

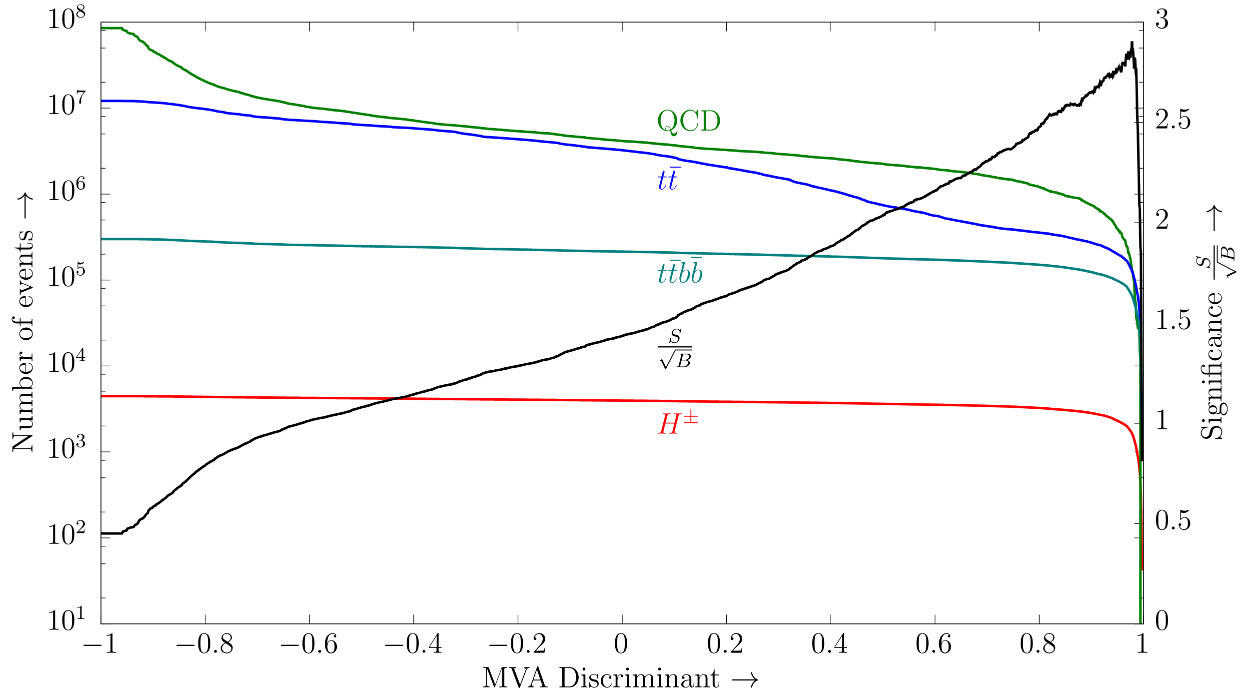
Signal: $H_{reco} + t_{reco} + b - jets$

$$H_{reco} + n_\ell(\geq 1) + b - jets$$

Cut based analysis: Sensitivity is very low, even for HL-LHC,

Heavy Charged Higgs at the LHC(3)

Boosted top reconstruction: MVA top tagging.
BDT method to separate out signal and backgrounds
Presented results for generic 2 HDM model



Hadronic:	$m_{H^\pm}$ (GeV)			
	300	500	800	1000
$\frac{S}{\sqrt{B}}$				
$\mathcal{L} = 300\ \text{fb}^{-1}$	6.05	2.65	0.61	0.22
$\mathcal{L} = 1000\ \text{fb}^{-1}$	11.04	4.84	1.05	0.40
$\mathcal{L} = 3000\ \text{fb}^{-1}$	19.13	8.39	1.93	0.70

Table 12: Sinsitivity table for Leptonic case

Leptonic:	$m_{H^\pm}$ (GeV)			
	300	500	800	1000
$\frac{S}{\sqrt{B}}$				
$\mathcal{L} = 300\ \text{fb}^{-1}$	5.22	2.94	0.96	0.39
$\mathcal{L} = 1000\ \text{fb}^{-1}$	9.54	5.37	1.70	0.71
$\mathcal{L} = 3000\ \text{fb}^{-1}$	16.52	9.31	3.04	1.23

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Summary

Contribution in CMS activities significant:

SM : 3 Higgs: 3 SUSY: 1
Upgraded(Physics): 2

Proposals are made in Higgs Physics

Activities for HL-LHC and HE-LHC along with more Co-ordinatination among ourselves