Search for a vector like quark in the full hadronic final state at CMS experiment

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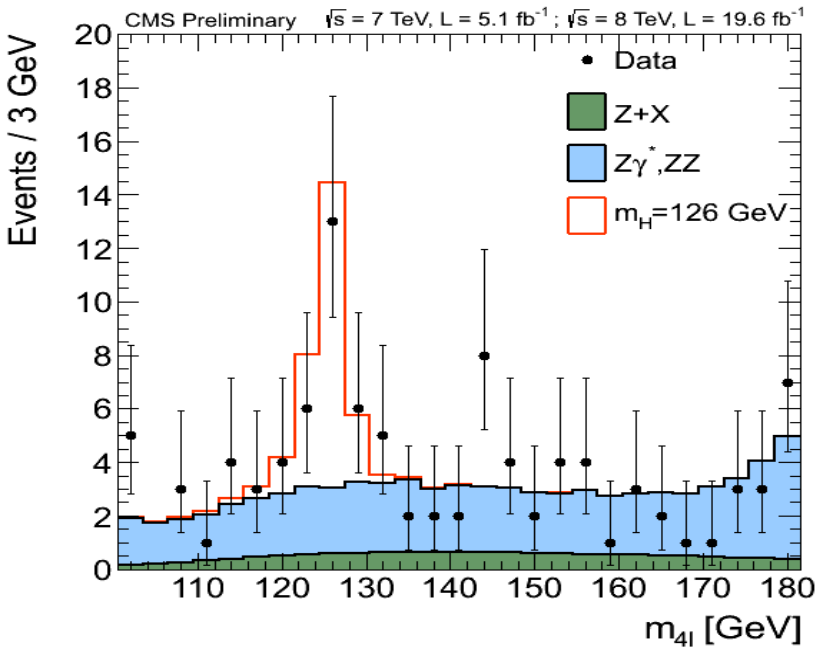
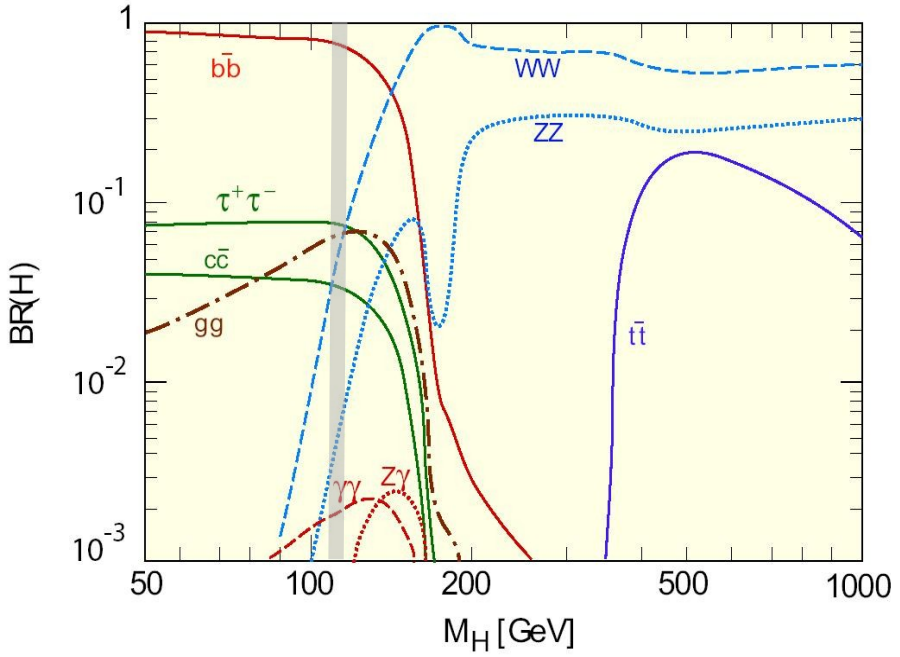
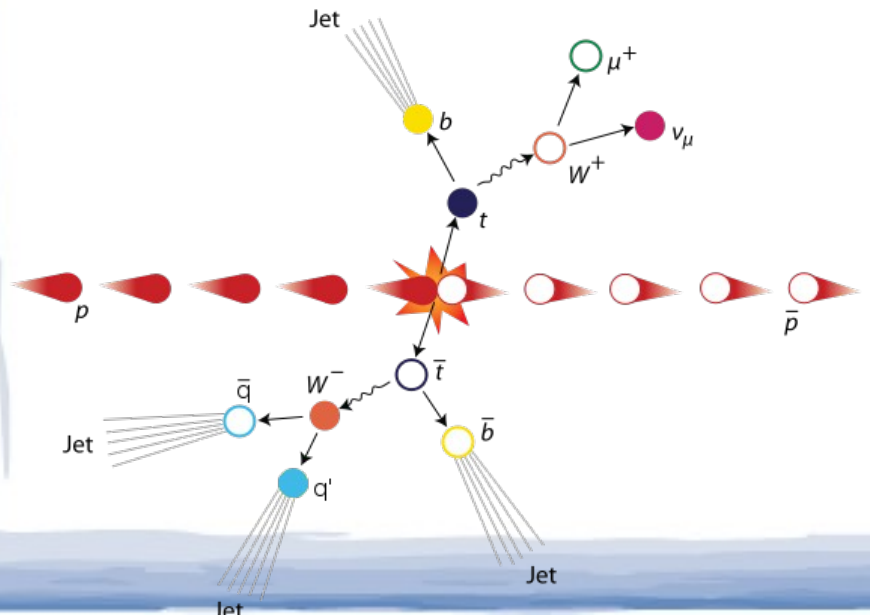
Outline

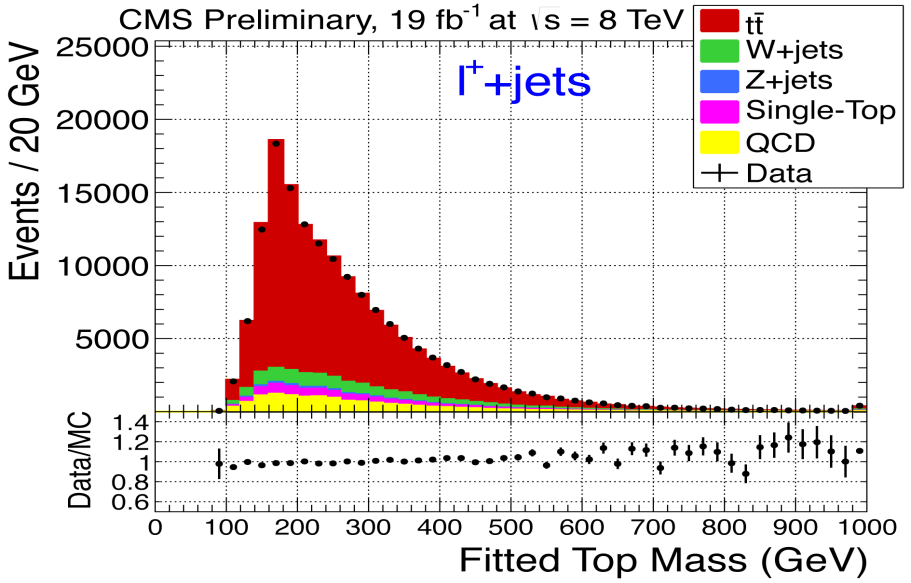
- Generalities
  - Standard Model
  - CMS
- T' vector like search
  - Pheno search design
  - Towards data @ CMS
- Conclusions

Higgs & Top

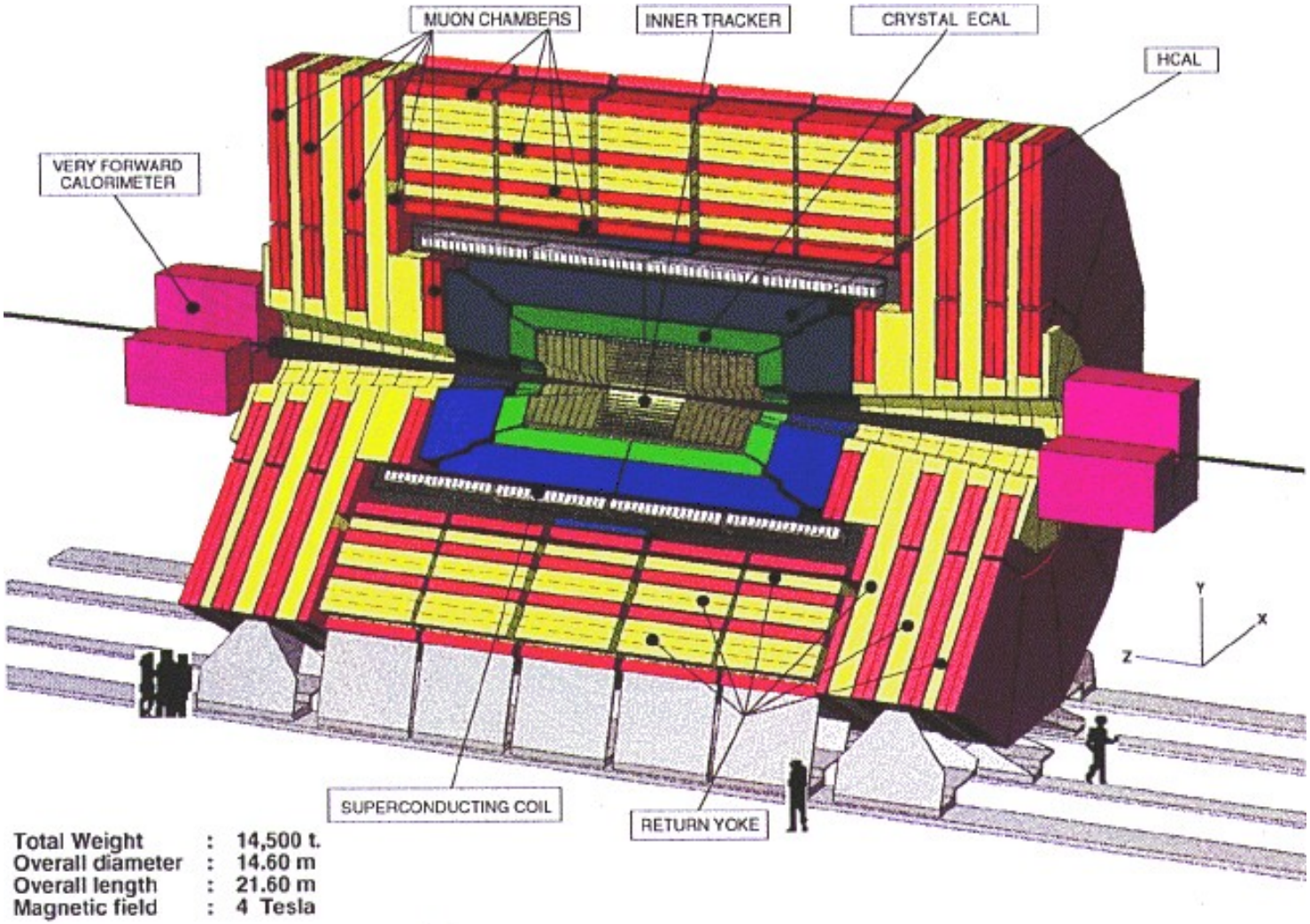

CMS Preliminary √s = 7 TeV, L = 5.1 fb⁻¹ ; √s = 8 TeV, L = 19.6 fb⁻¹
Data
Z+X
Zγ*,ZZ
m_H=126 GeV
Events / 3 GeV
m_4l [GeV]


bb̄
WW
ZZ
τ⁺τ⁻
cc̄
gg
tt̄
γγ
Zγ
BR(H)
M_H [GeV]


Jet
μ⁺
b
ν_μ
W⁺
t
p
p̄
W⁻
t̄
q̄
Jet
b̄
q'
Jet
Jet

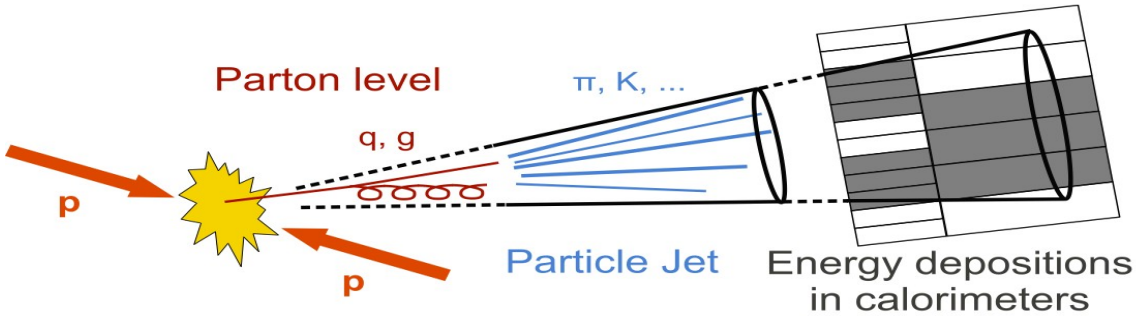

CMS Preliminary, 19 fb⁻¹ at √s = 8 TeV
l⁺+jets
tt̄
W+jets
Z+jets
Single-Top
QCD
Data
Events / 20 GeV
Data/MC
Fitted Top Mass (GeV)

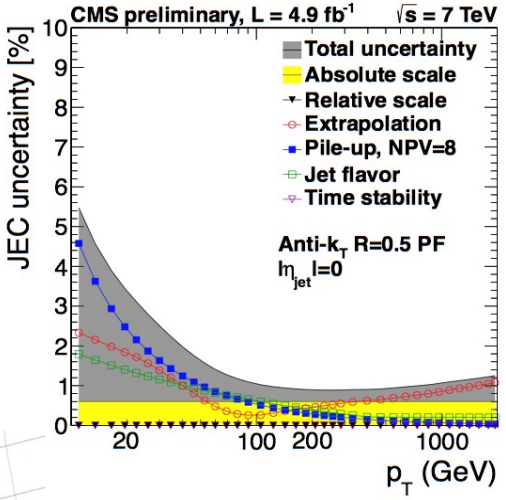
CMS: Compact Muon Solenoid

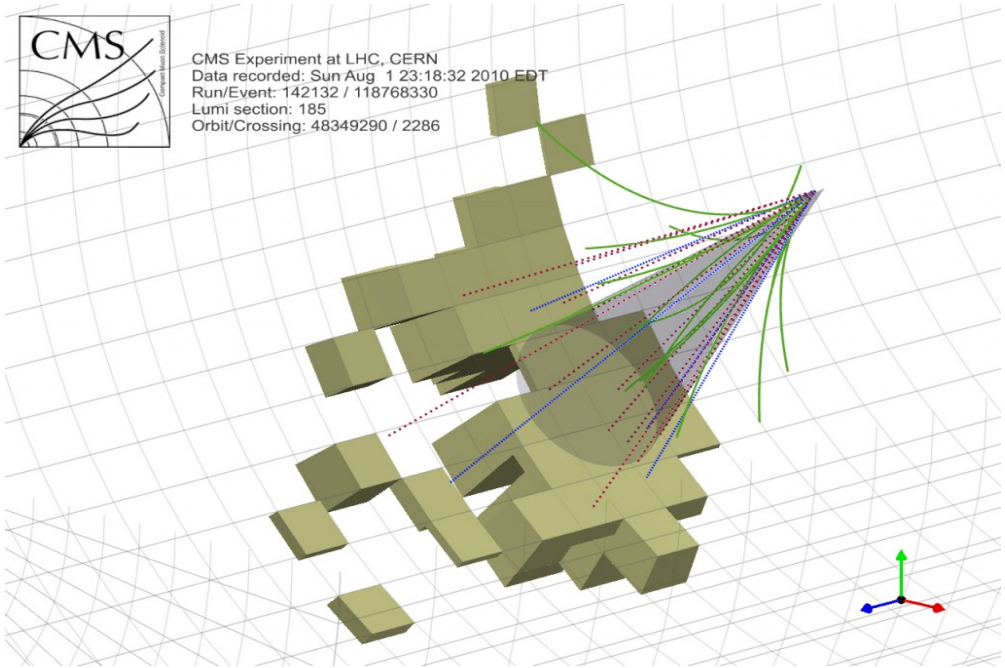


Jets

- Extract parton structure from final state



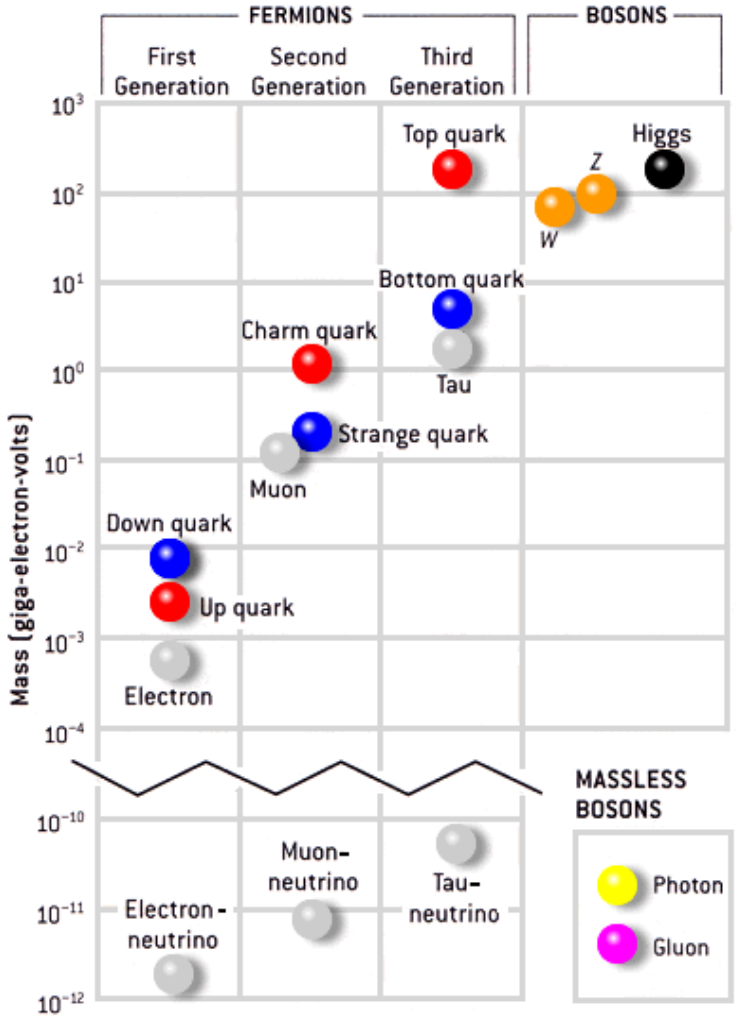




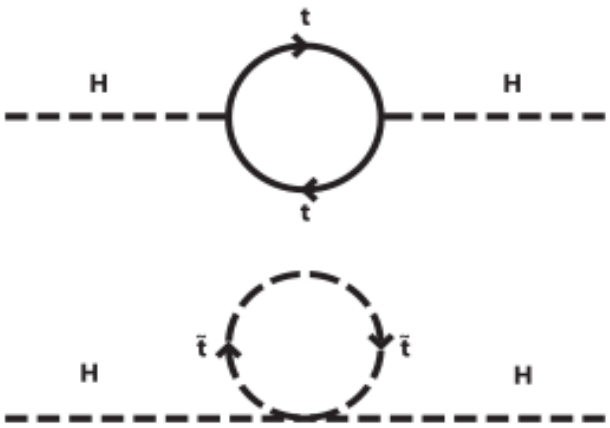
VLQ analysis

- Physics introduction
- Phenomenological studies
- Data Analysis

Vector Like Quarks

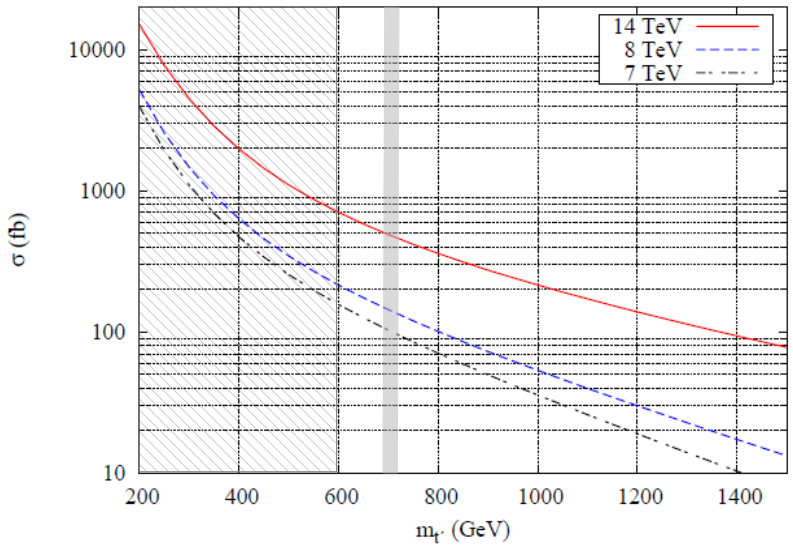


Motivation
→ New physics probably related to top and/or Higgs,
the heaviest sector of the SM
→ Introduce a top partner to cancel contribution to Higgs mass

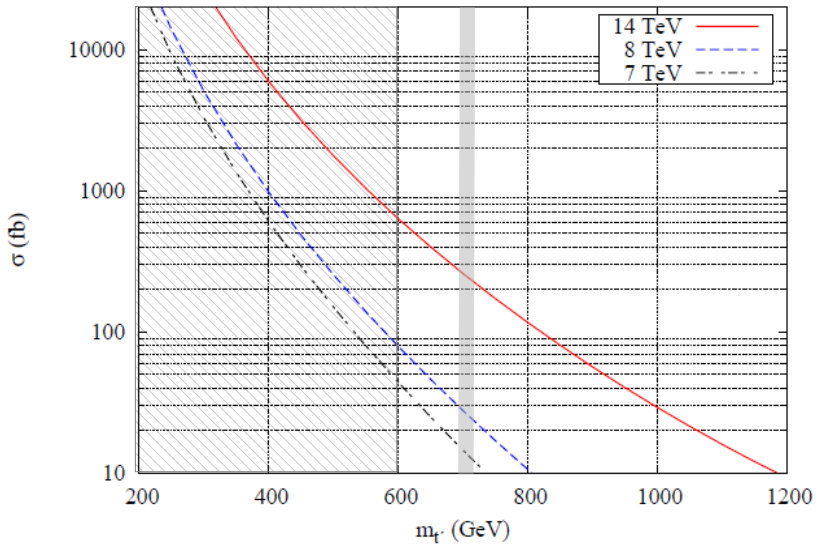


T' production and decay

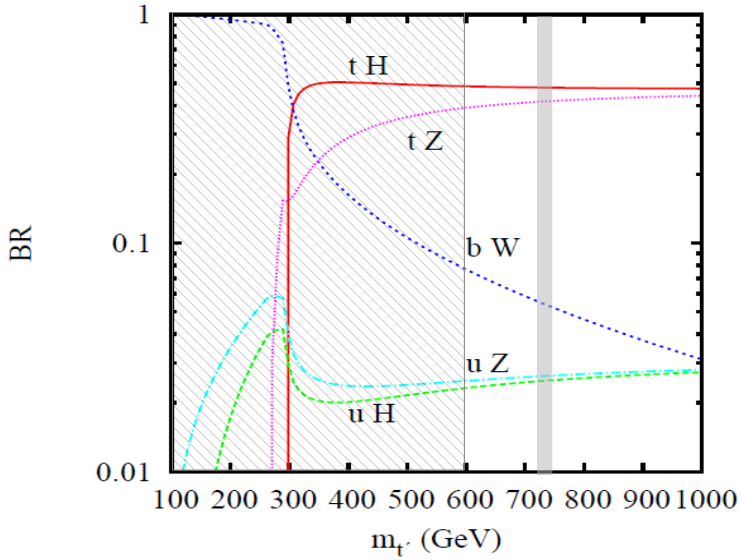
Single production



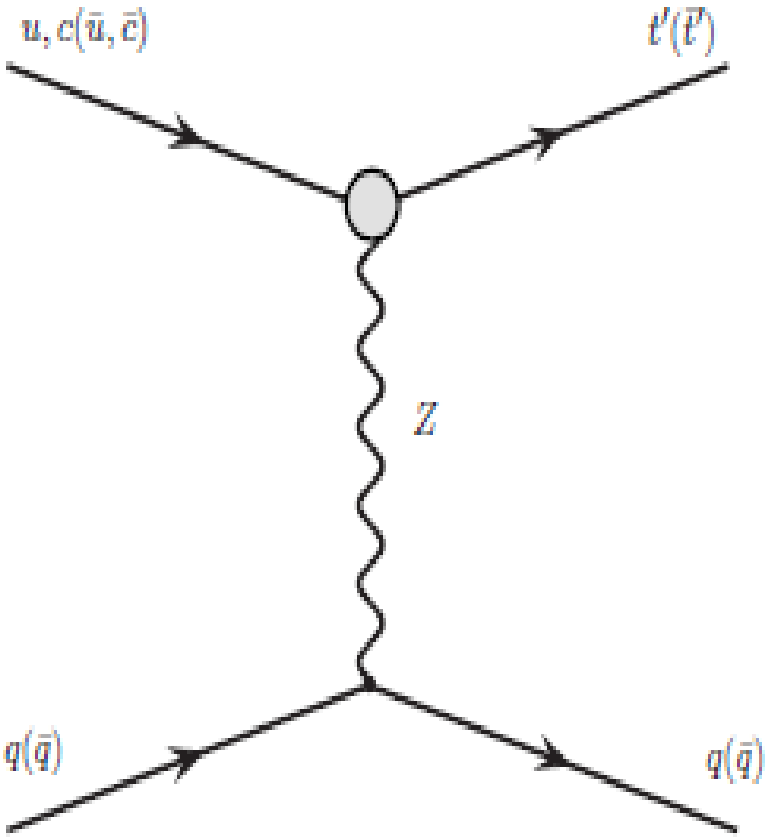
Pair production



→ Mixing with light quarks enhance the cross-section of production
→ mT' >300 GeV,
tH becomes the preferential decay channel
→ Leading analysis for single production

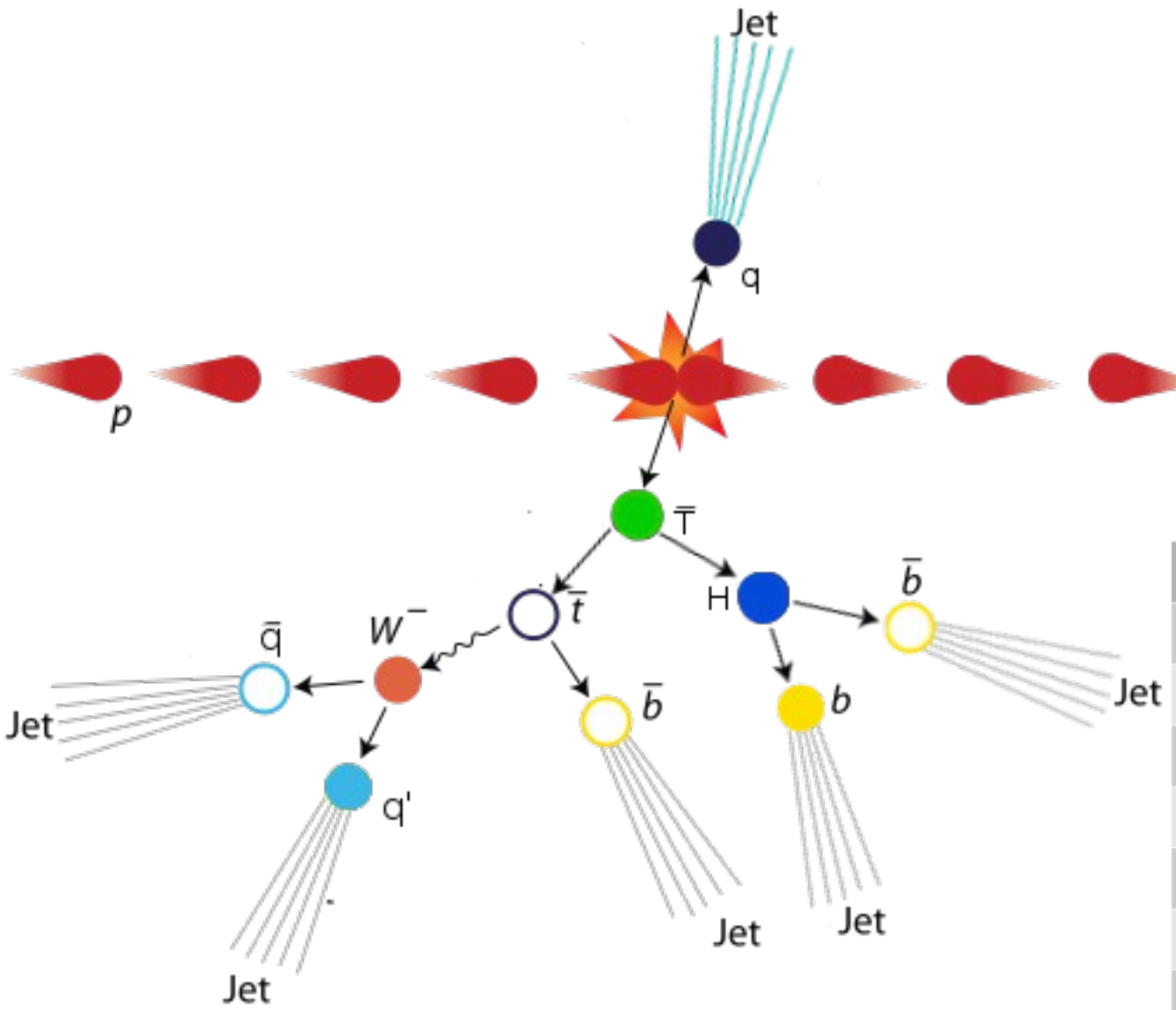


Pheno search design: Single T'



- L=20fb^{-1}, xs=150fb @8TeV
  BR(T'→t,H)=0.5
  m(T')=734.1 GeV
- Jet association (below)
- Fully hadronic (5+1 jets)
- Final state:
  tH → Wbbb → jjbbb

Single T' search



BKG	XS(pb)
QCD [bbb]	500
Wjets	37509
Zjets	3504
TTbar	234
SingleT	115
Diboson	97
Signal	0.15

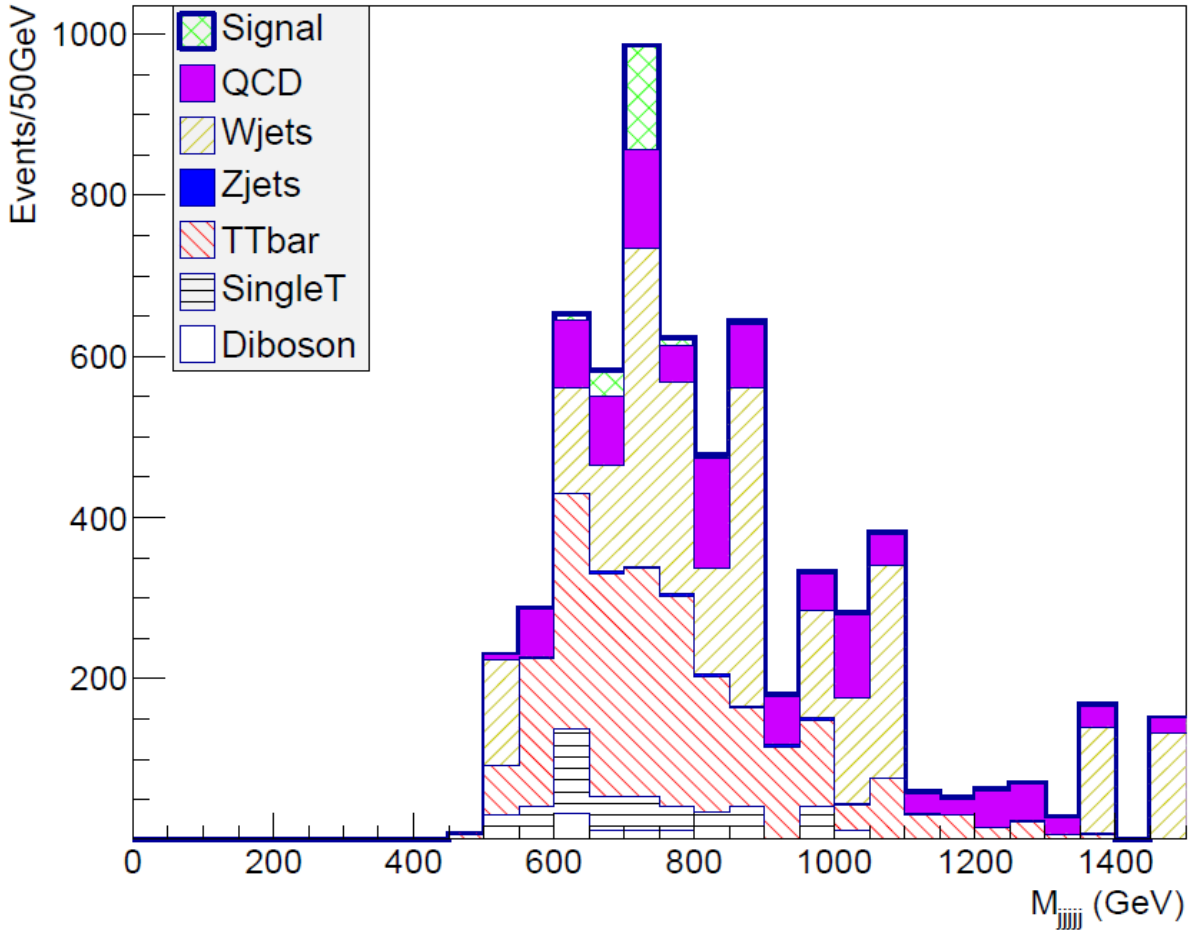
Phenomenological studies

Pheno

- Study done up to hadronization step in the MC.
- **Analysis strategy:**
  - 20 fb^{-1} @ 8 TeV → Full hadronic channel: Highest expected number of events for the signal [~700 events] → Full mass reconstruction of T'
  - Background reduction: Higgs and top as handles.
  - Event selection: Keep high efficiencies on signal.
  - Cuts based on angular distributions → Preservation from hadronization to fullsim

Five Jets Invariant Mass

Pheno

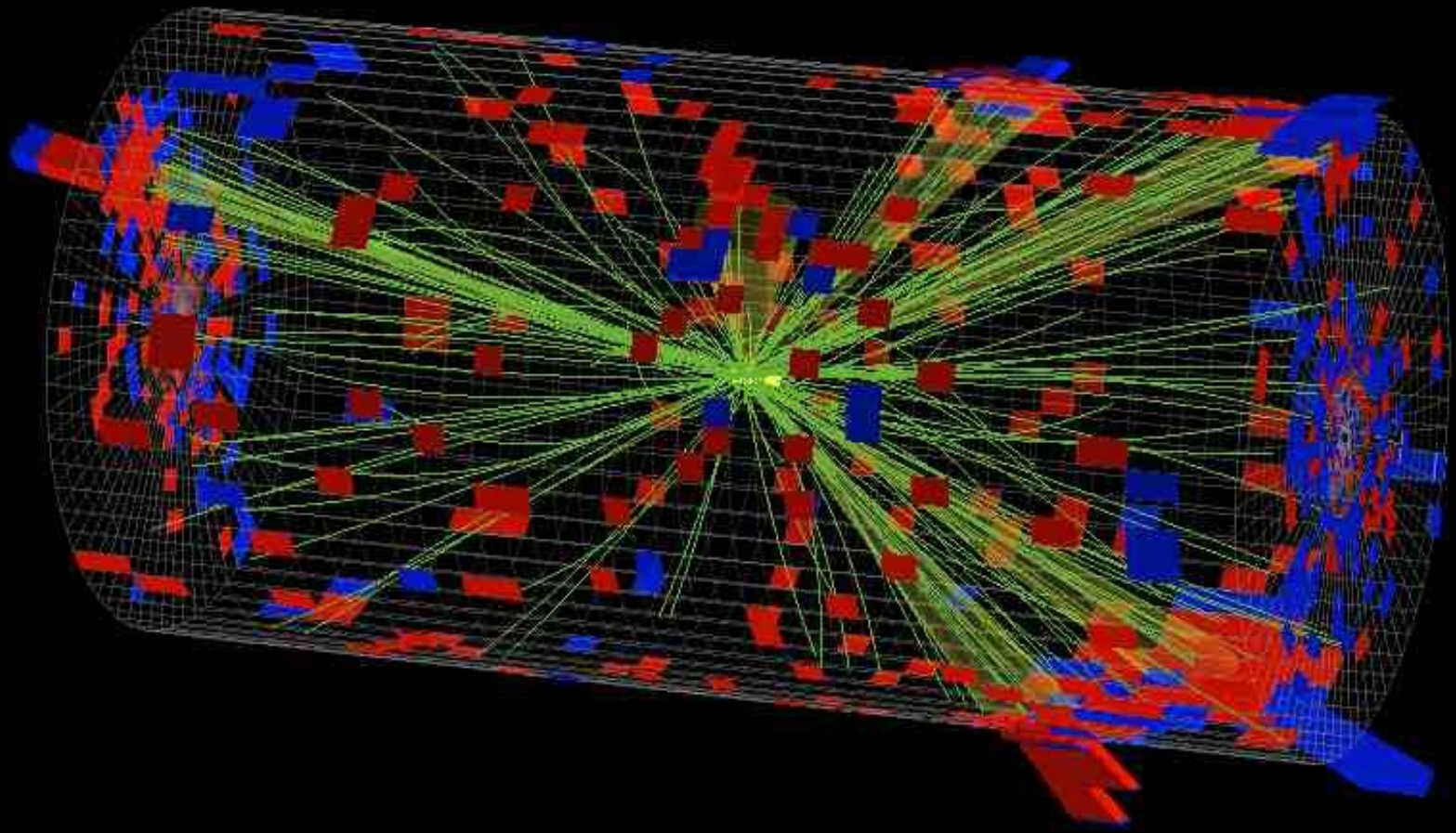


Five jets invariant mass for backgrounds and signal (stacked) after full event selection.

J. Ruiz-Alvarez et al.
arXiv: 1401.5979

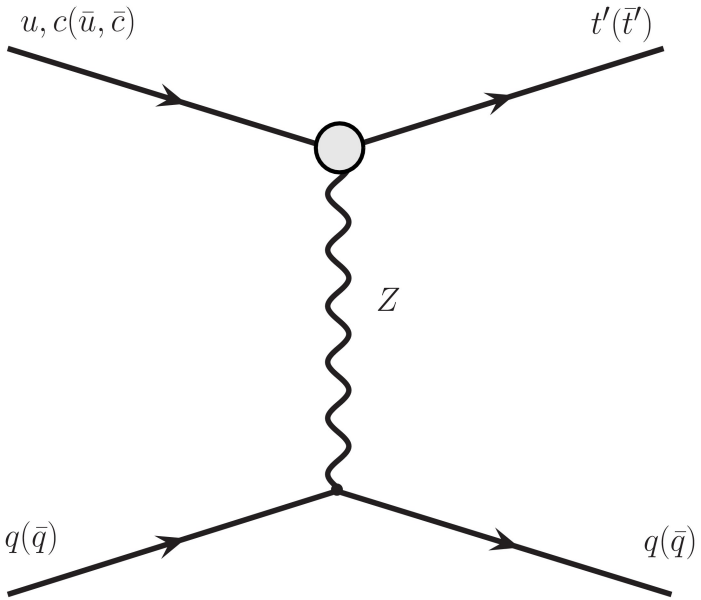
$$\frac{S}{\sqrt{S+B}} = 3.04 \pm 0.04\,, \qquad \text{and} \qquad \frac{S}{B} = 0.12 \pm 0.02$$

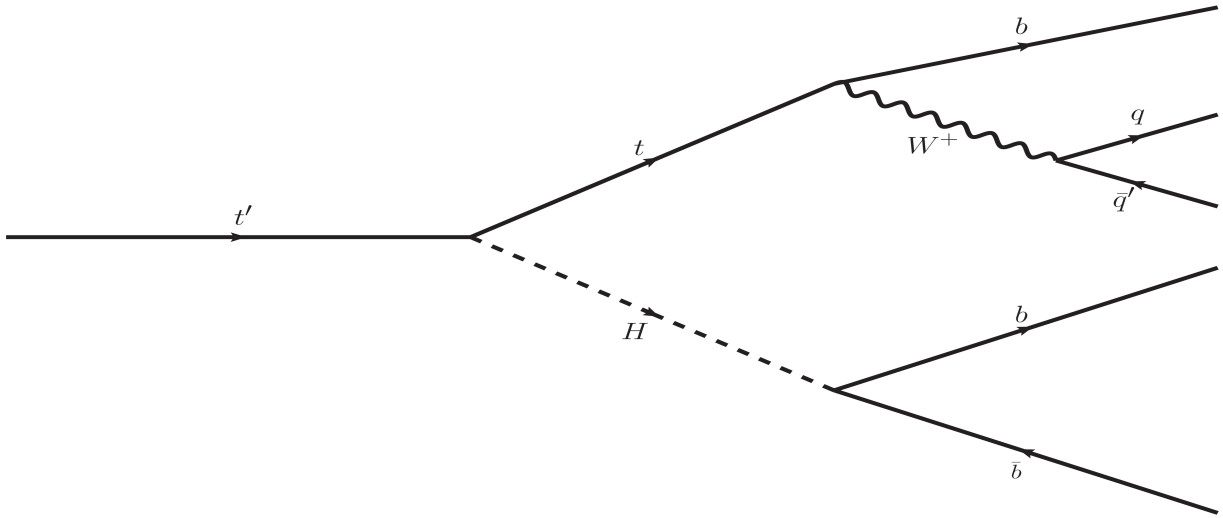
Analysis @ CMS



The analysis

- Single T' → t H → W b H
  → 3b j j + accompanying jet
- Main selection:
  - 3 b-tags
  - 2 b's → higgs
  - 3rd b for top,
    2 non-btagged jets
    from W

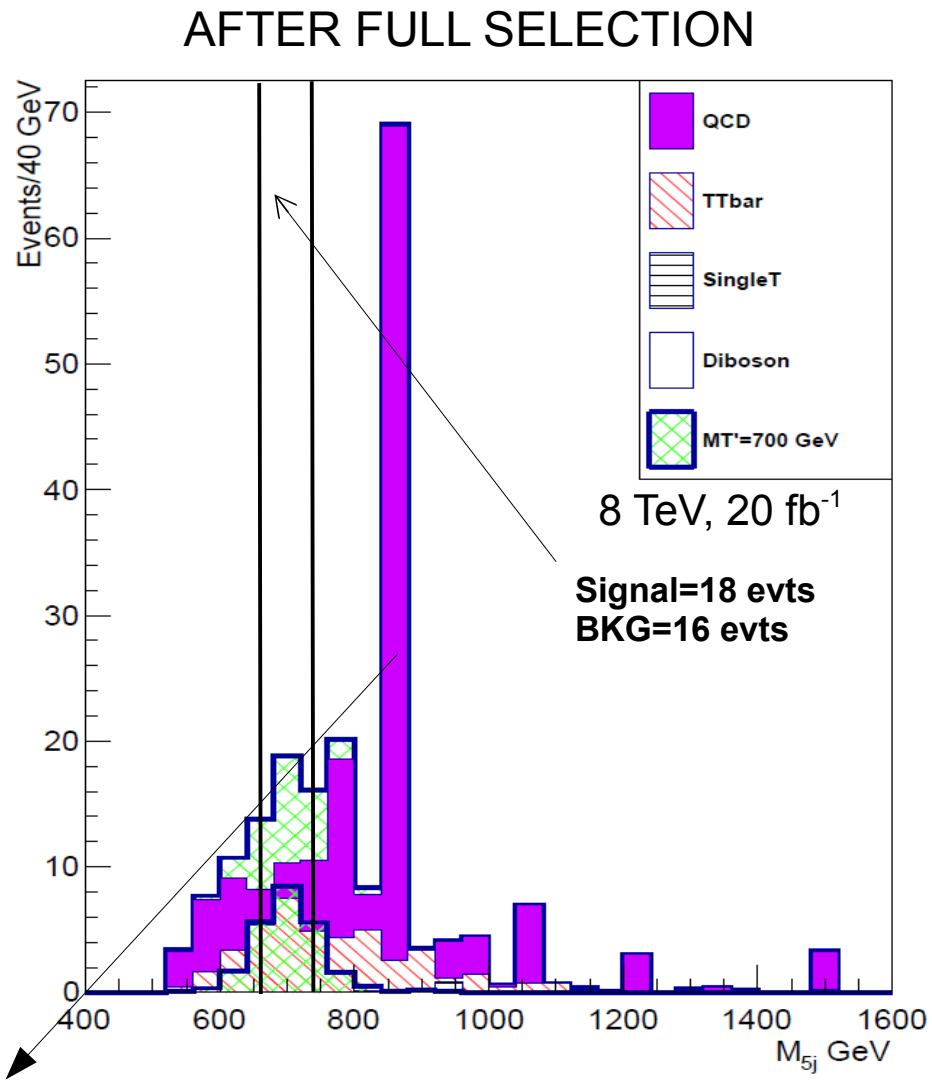




The analysis

- Main variable: 5 jets invariant mass M(5J)
- After selection → Main background: TTbar (~50%) + QCD (~50%)
- Based on a pheno study [1]:

  S. Beauceron et al. arXiv:1401.5979



Spike from one QCD mc event with ~70 as weight

Pre-Selection

Full hadronic final state with 3b's and 2j's (making W, Top, Higgs) + 1 accompanying jet

- Trigger: Dijet_80_Dijet_60_Dijet_20
- Jet pt: 1st pt>150 GeV, 2nd pt>90 GeV, 3rd and 4th pt>70 GeV, 5th and 6th pt>30 GeV
- HT>630 GeV
- >= 3 b-tag

Reconstruction

- Chi2 sorting algorithm → T' reconstruction via H, W and top reconstruction:

$$\chi^2 = \frac{(M_H - M_{bb})^2}{\sigma_H^2} + \frac{(M_W - M_{jj})^2}{\sigma_W^2} + \frac{(M_t - M_{bjj})^2}{\sigma_t^2}$$

With the following values [2]:

$$M_H = 125\ \text{GeV}/c^2,\ M_W = 84.06\ \text{GeV}/c^2,\ M_t = 175.16\ \text{GeV}/c^2$$
$$\sigma_H = 12.4\ \text{GeV}/c^2 \quad \sigma_W = 10.12\ \text{GeV}/c^2 \text{ and } \sigma_t = 17.35\ \text{GeV}/c^2$$

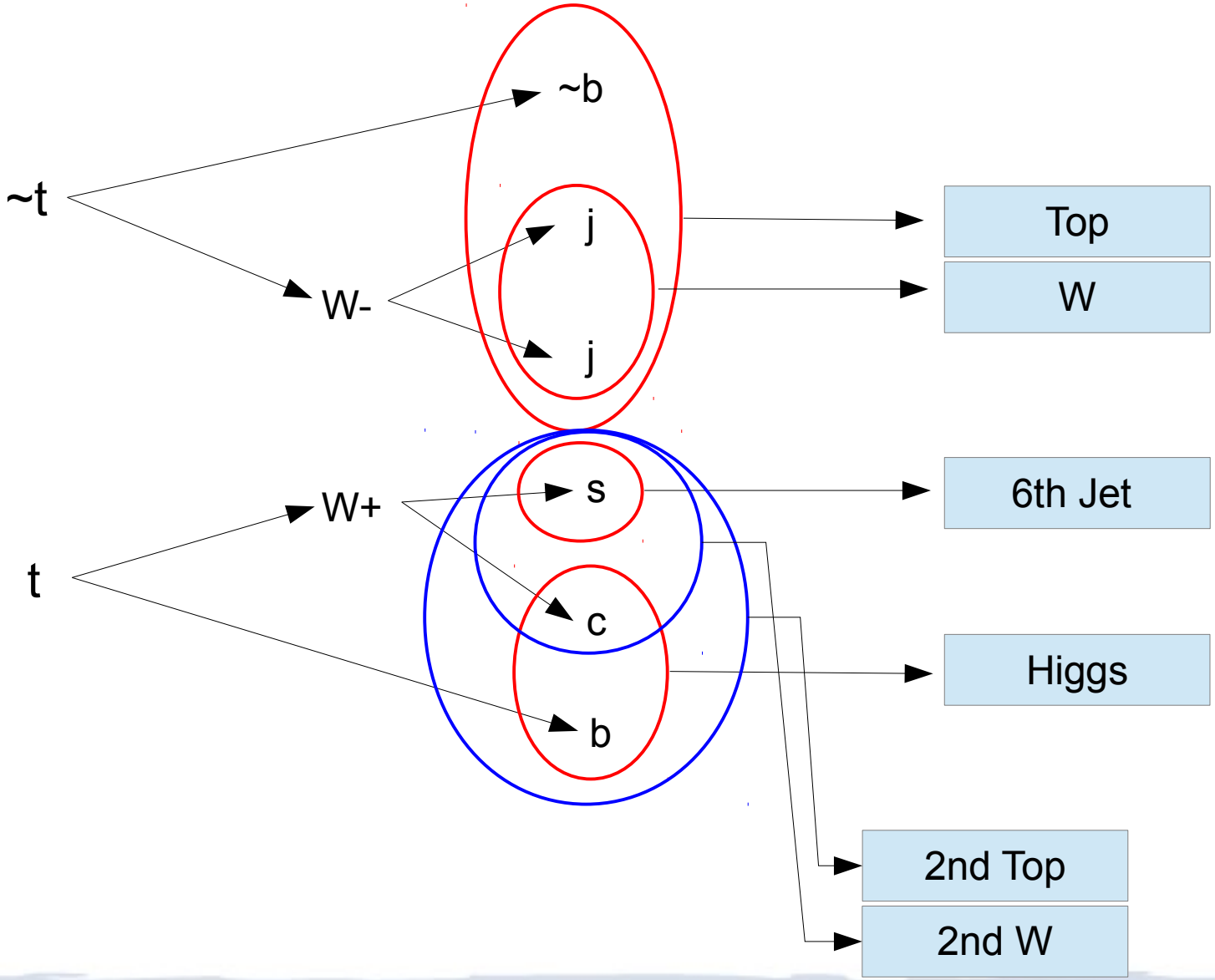
- Jet set with smallest chi2 kept
- Chi2<140 required after reconstruction

Analysis selection

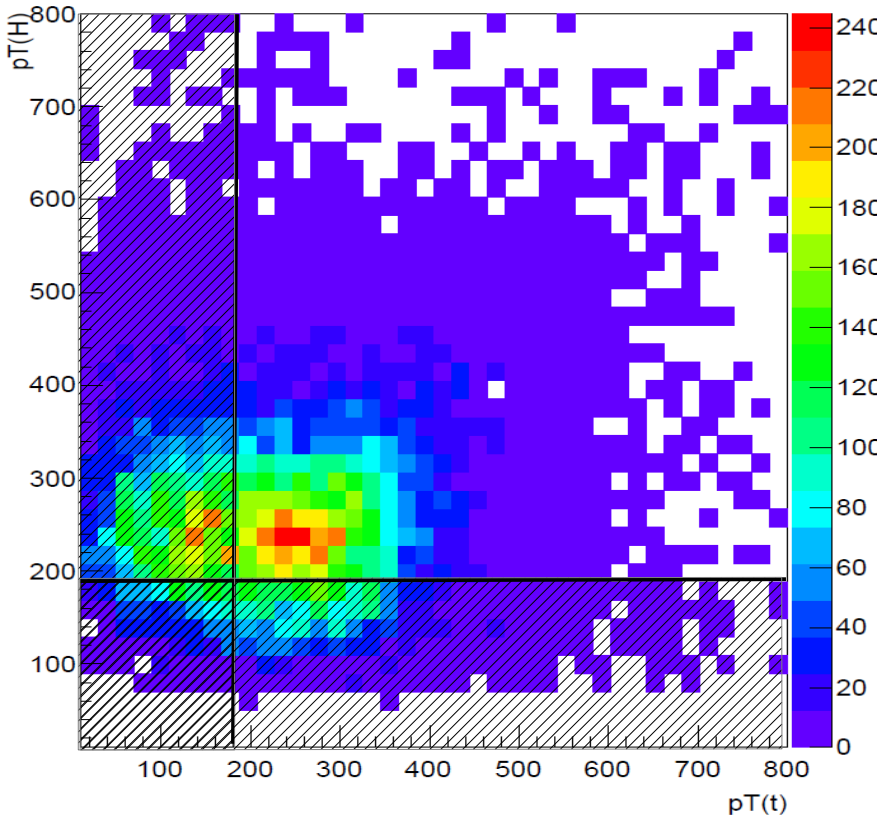
Based on Higgs, W and Top presence:

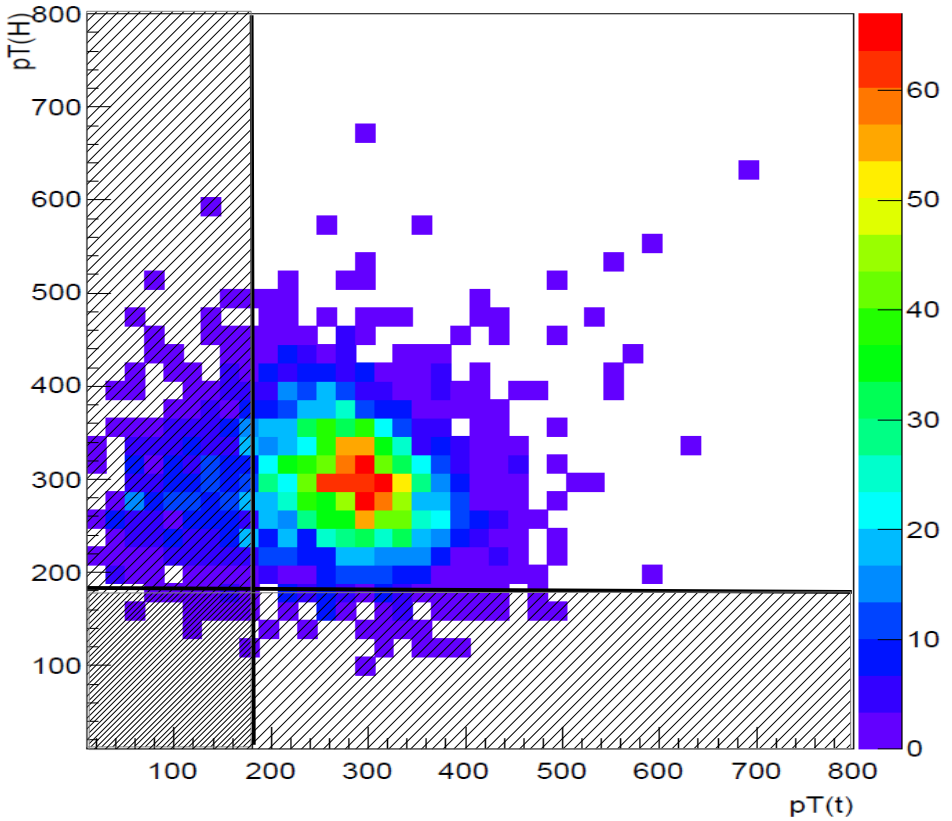
- Higgs selection:
  - $\Delta R(bb)<1.2$
  - $100\ GeV < M(bb)H^{reco} < 150\ GeV$
- W/Top selection:
  - $M(Top^{[reco\ 2nd]})/M(Higgs^{reco}) < 0.4x(M(W^{[reco\ 2nd]})/M(Higgs^{reco}))-0.2$
- T'+6th jet selection:
  - $|\eta(j^6)|>1$
  - $\Delta R(Tp^{reco}, j^6)>4.6$
- Full Event selection:
  - $Higgs^{reco}$ pT>180 GeV and Top^{reco} pT>180 GeV
  - $2.2 < \Delta R\ (W^{reco}H^{reco}) < 3.5$
  - $[(Pt(Higgs^{reco})+Pt(Top^{reco}))/HT) > 0.65$
  - $0.3<(M(Higgs^{reco})+M(Top^{reco}))/M(Tp^{reco})<0.5$

TTbar contamination



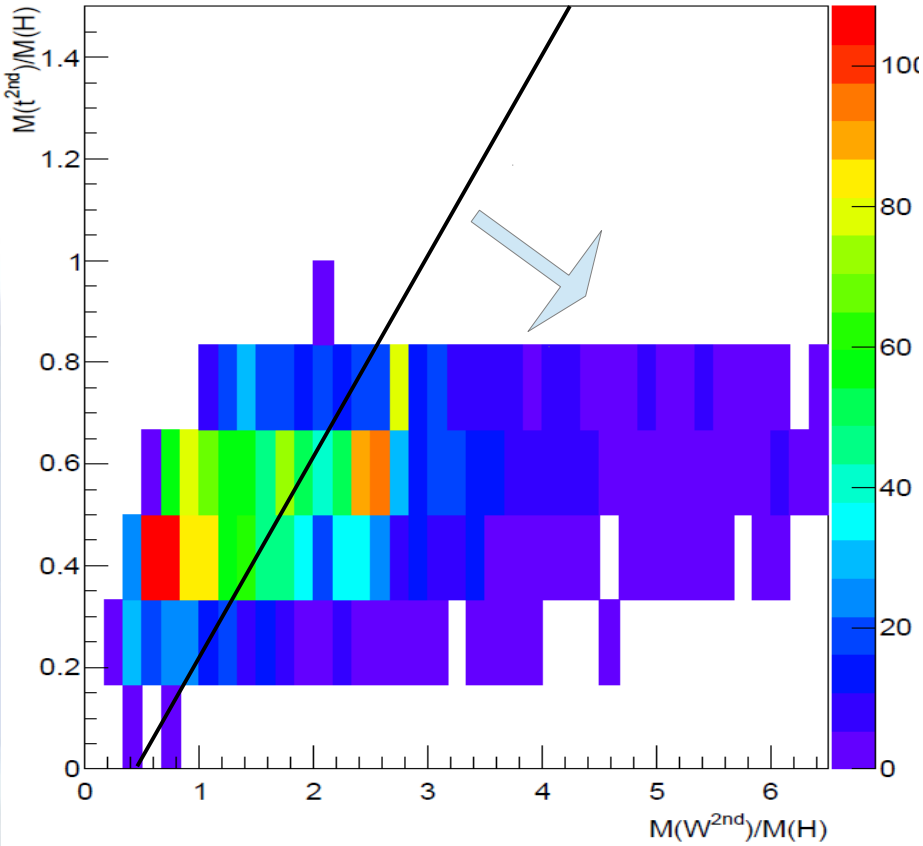
PT correlations

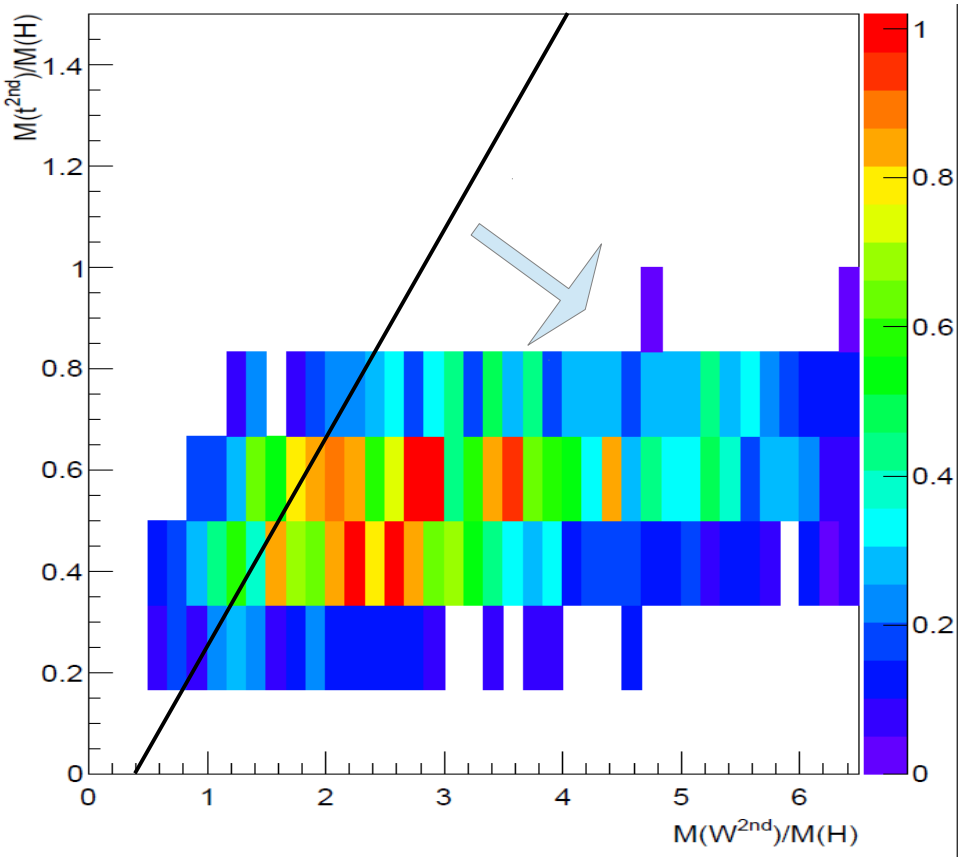




Higgs pt and top pt for backgrounds from MC (left) and signal (right).
Clear correlation that allows a good discrimination between signal and backgrounds

Mass correlations





This cut profits from the existence of a second W and top in ttbar. Backgrounds from MC (left) and signal (right). Strong correlation for background gives a good handle to discriminate background from signal.

Data driven background estimation

- Based on two samples:
  - Signal enriched sample: Selection with at least 3 CSVM, one combination of jets (smallest chi2, and chi2<140)
  - Control sample: Selection with at least 3 CSVL vetoing events with at least 3 CSVM, all combinations (Statistically enriched)
- Use M5J shape from control sample to estimate it on signal enriched sample.
- Normalize shape of control sample to signal enriched sample.

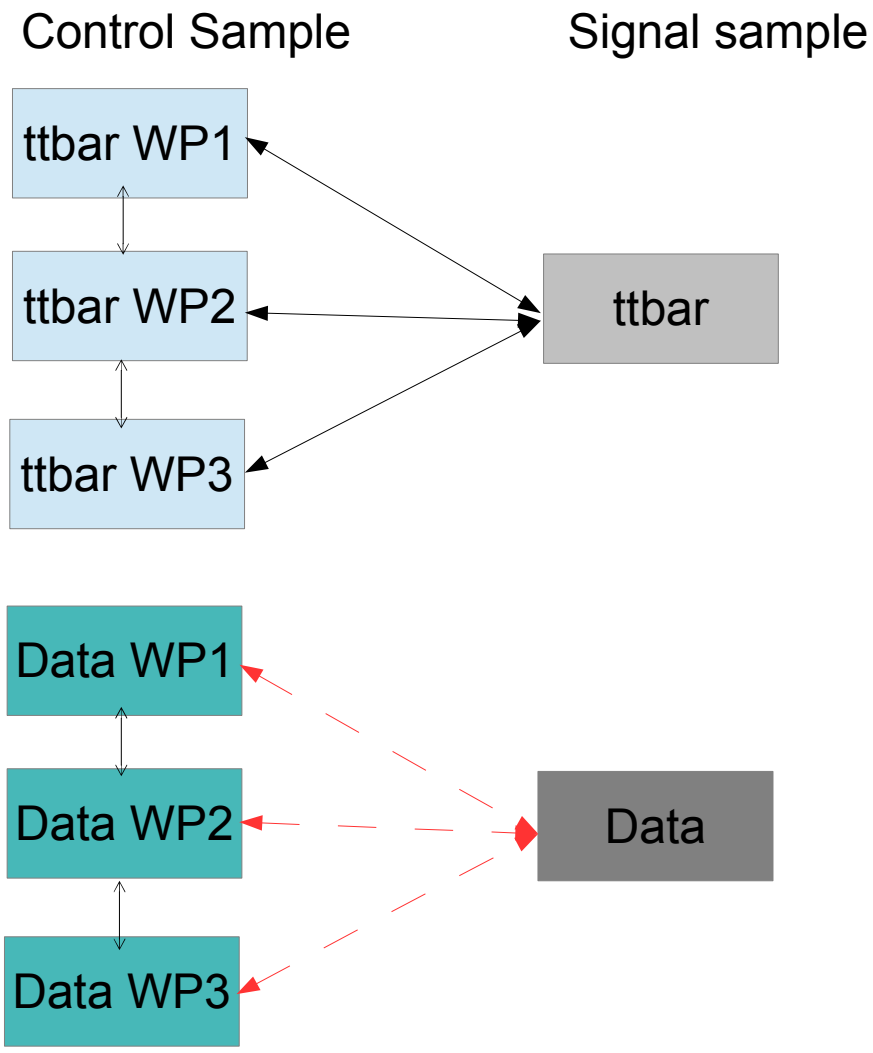
- Robust method: All backgrounds estimated in one go
- Negligible signal contamination on control sample, ~1%

  → Uncertainty in bkg shape from estimation procedure (shape compatibility)

  → Uncertainty in bkg normalization from signal contamination
- Validation on early stages of the selection (bkg dominated) due to lack of statistics in QCD MC

Testing the method

- Take different values for b-tagging working point
  → Independence of WP
- Compare M(5J) for ttbar MC (large stats) between both schema
  → Shape agreement between schema and WP for ttbar
- Compare shape M(5J) in data between different WP in estimation scheme
  → Independence of WP for BKG
- Redo at different stages of the selection, to ensure good behavior as a measure of the cuts → Validation on bkg enriched samples



Systematics

	Signal	BKG	Value (preliminar)
B-tagging	x		7%
JEC	x		6.5%
PDF	x		~10%
Theory	x		10%
Luminosity	x	x	2.6%
Trigger	x		5%
BKG shape estimation		x	~15%
Signal contamination		x	<1%
BKG normalization		x	~20%

Conclusions

- New search on single top + Higgs resonances developed for the full hadronic final state [AN-14-169]
  - New stringent limits from 8 TeV data collected by CMS
  - Insight on the most crucial part of the SM nowadays: Top - Higgs interplay
  - Original background estimation method developed
  - Possible need for new set up to extend the analysis to Run II
- Prospects:
  - Final results → Systematics, preapproval, ...

References

- [1]: S. Beauceron, G. Cacciapaglia, A. Deandrea, and J. D. Ruiz-Alvarez, "Fully hadronic decays of a singly produced vector-like top partner at the LHC", arXiv:1401.5979.
- [2]: CMS Collaboration Collaboration, "Search for the standard model Higgs boson produced in association with a W or a Z boson and decaying to bottom quarks", *Phys.Rev.* **D89** (2014), no. 1, 012003, doi:10.1103/PhysRevD.89.012003, arXiv:1310.3687.

  V. S. Sébastian Brochet, Stéphane Perriès and S. Tosi, "Search for $t\bar{t}$ resonances in semileptonic final state (low mass)",. CMS AN-12-488.