Scale invariant resonance tagging in multijet events and New physics in Higgs pair production

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Based on: M. Gouzevich, A. O, J. Rojo, R. Rosenfeld, G. Salam, V. Sanz

arXiv:1303:6636, submitted to JHEP

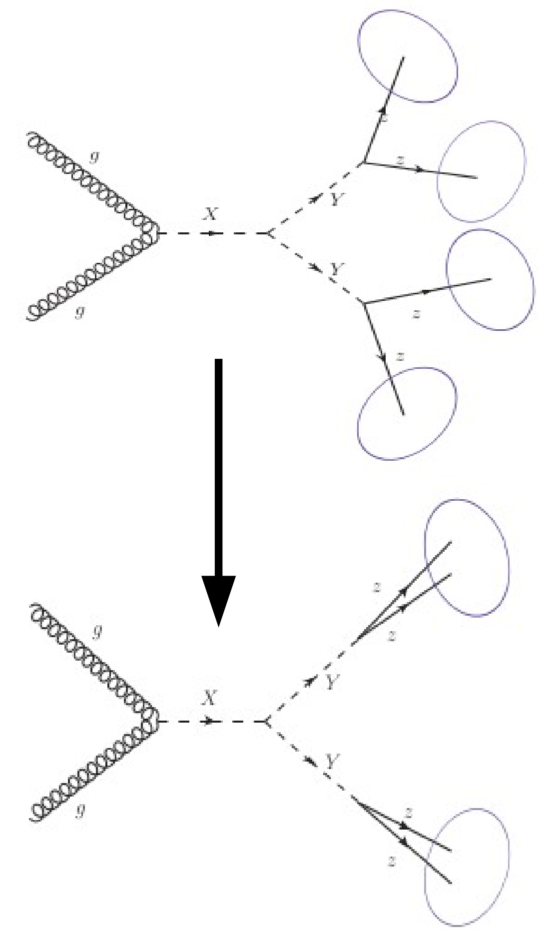
GDR Terascale@Montpellier 13 -15 May 2013

Outline

- New Physics in resonant pair production of heavy particles @ colliders
- Scale invariant tagging
  - Mass regimes: From unboosted to boosted.
  - Classifying events
- Application: HH (125 GeV) resonant production @ LHC
  - Benchmark mode → Metric excitations from WED models
- Conclusions

Search for new particles in pp → X → YY

- Additional heavy particles X appear on most extensions of electroweak SM
  - They couple preferably to the particles that participate EWSB sector
    - Y = H/W/Z
- If those final states decay hadronicaly, the signature may be challenging @ hadron colliders , despite the big QCD multi jet BKG
- However, final states from resonant production follow an definite structure, that **depends on the relation of the mass of the Heavy resonance and decay products**



The goal of this work is to show that within one same analysis (same multijet trigger) one can scan smoothly from an X mass regime to another: keeping high efficiency and BKG rejection !!!

Scale Invariant tagging

The lorentz structure on the couplings of spin 0/2 candidates with HH cannot differ from some benchmarck model

As well the kinematic distributions for HH

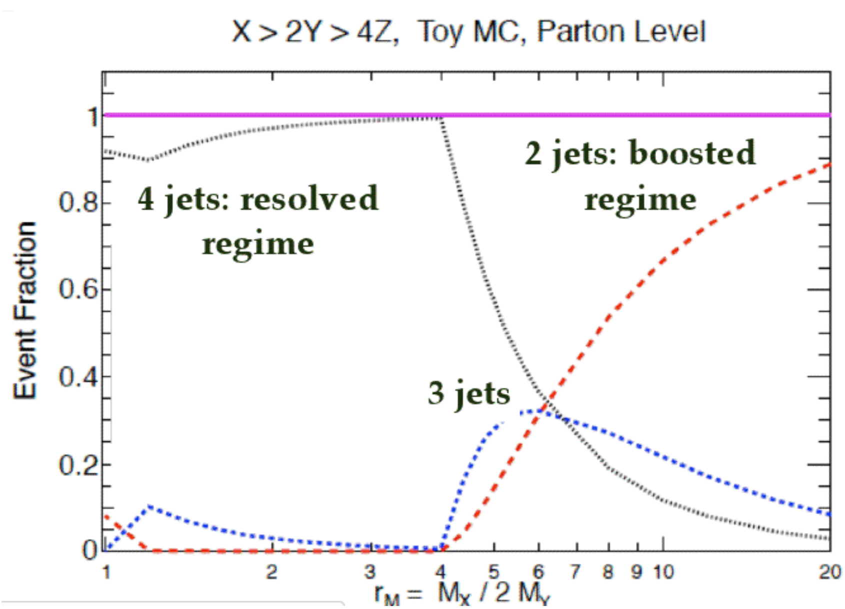
→ For event classification studies and strategy validation we constructed an toy MC to mimic production and decay of an scalar resonance.

We define scales by the boost factor $r_M = M_X / 2\,M_V$

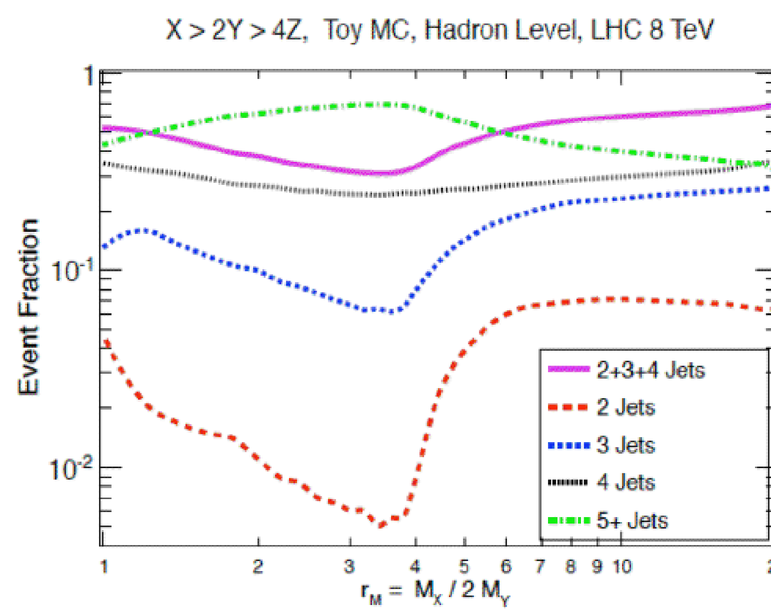
Counting jets

- Sanity check: at **parton level** the number of jets and separation of regimes is clear:

events become more boosted to Mx ~ 1.5 TeV for Y = H = 125 GeV



- Real events indeed have non fixed number of jets (radiation)
  - We need to be more careful in event classification



Tagging jets: Find the H candidates

- Do we find two fat jets among the 2 leading jets (**Mass Drop***) ?
  - Yes? **2 Tag.** After **filter** it, do we reco the H's? → **Win !**
  - No? Do we have at least one fat jet?
    - Yes? **1 Tag.** After **filter** it, do we reconstruct one H + does subsequent jets (in pt) reco one H? → **Win !**
    - No? Do we have at least 4 jets?
      - Yes? **0 Tag**. Do we reco a H in each pair? → **Win !** (details in next slide)
      - No? ok, it is good that we do not win always !!! ...

* J. Butterworth, A. Davison, M. Rubin, G. Salam arXiv 0802.2470

Numbers

Reco

- Candidate around H mass up to 15% tolerance
- Max difference in rapidity among HH = 1.3

Basic cuts		
$p_T^{\min}$	$\lvert y_{\max}\rvert$	$H_T^{\min}$
25 GeV	5.0	100 GeV

Jet Reconstruction					
R	$R_{\rm sj}$	$R_{\rm f}$	$n_{\rm filt}$	μ	$y_{\rm cut}$
0.5	1.3	0.3	3	0.67	0.09

Quality requirements			
M_Y	$\Delta y_{\max}$	$\Delta y_{\max}^{\rm res}$	f_m
125 GeV	1.3	1.5	0.15

Quality requirements in higgs tag

Jet pair choice

On fat jets: We select the 2 highest pt jets from the 3 highest filtered subjets

on 0 Tag: Among 4 leading jets we chose pairs with minimum invariant mass difference, up to a 15% tolerance.

If we have a resolved H candidate:

Require not too much asymmetry among internal jets → similar to the requirements on the subjets on the boosted mass drop tagger

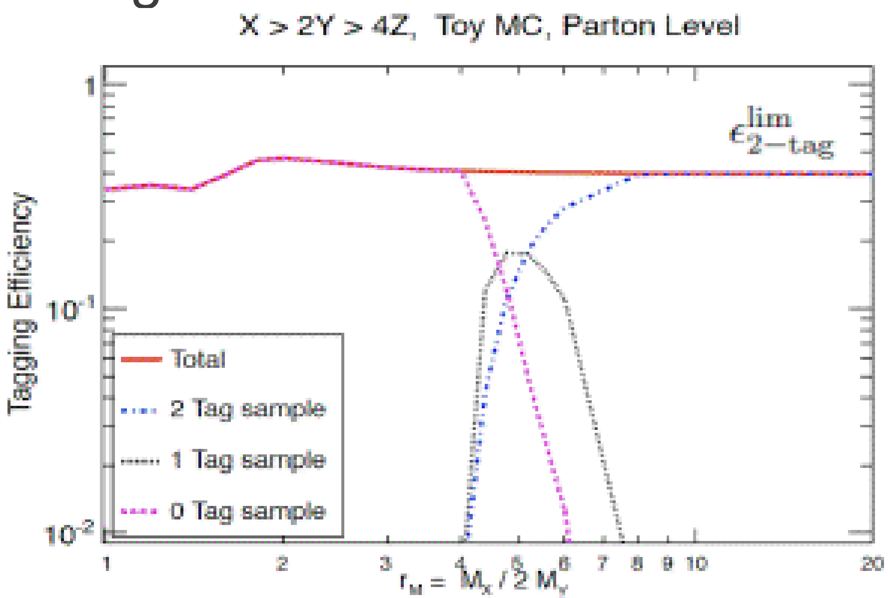
$$\max\left(m_{Y,1}, m_{Y,2}\right) \leq \mu \cdot m_Y$$

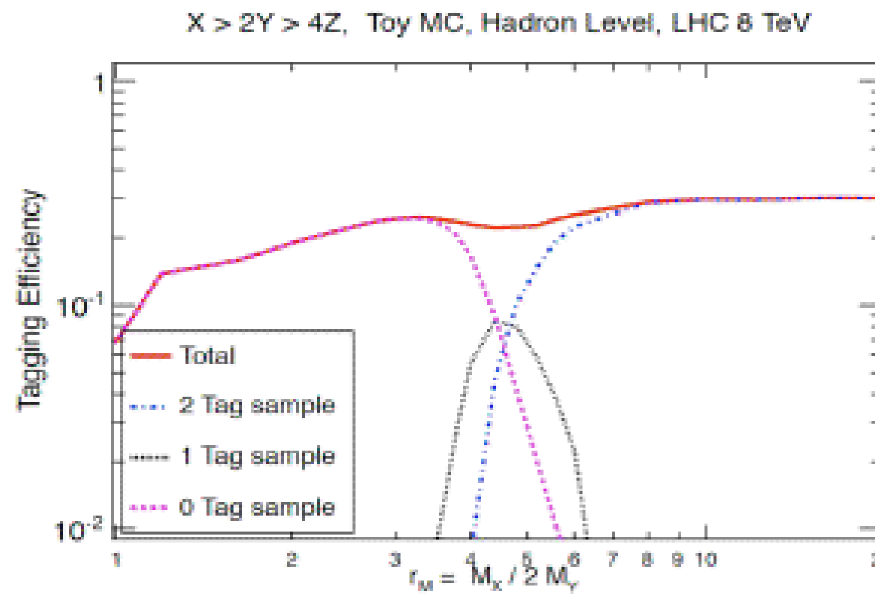
$$\Delta p_T \equiv p_T^{(1)} - p_T^{(2)} \geq \left(1 - y_{\mathrm{cut}}\right) p_T^{(1)}$$

$$\Delta y \equiv |y_{Y i,1} - y_{Y i,2}| \leq \Delta y_{\mathrm{max}}^{\mathrm{res}}$$

in numbers...

- We reach similar (parton/hadron level) efficiencies for the whole mass regime, and have an **smooth** transition of regimes
- At hadron level the signal performance is slight better on boosted regime

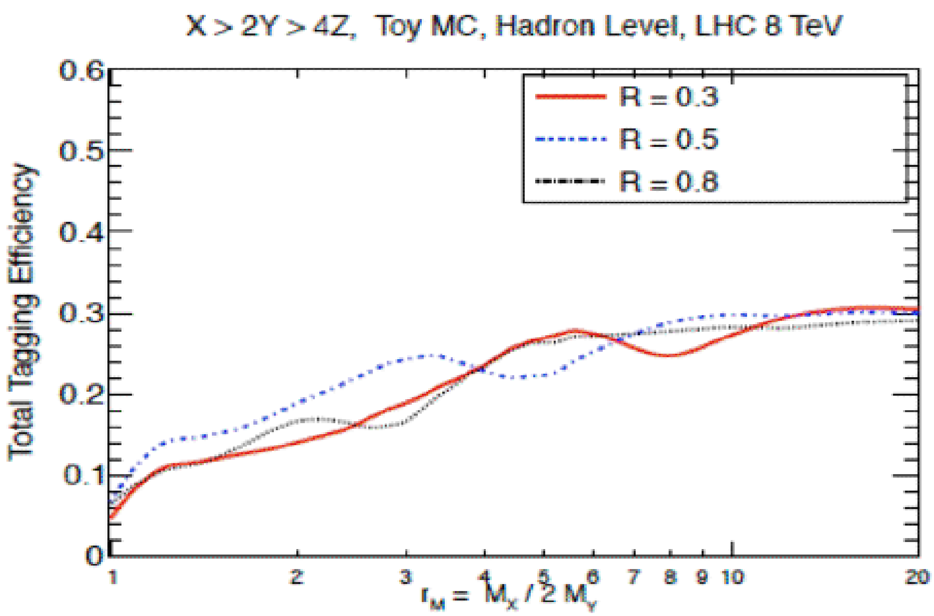




* for rm = 1 (MX = 125 GeV) tag is complicated...

To note:

- We are almost insensitive to the jet radius definition R, even if the relative classification of events depends on R



Two Higgs system
One more event discriminant: b-tag

- We approach the experimental b-tag efficiencies
  - We look inside each selected jets (we can...),

    if it have one b-quark with pt > 10 GeV , we weight the event by fb = 0.75

    if no, but have one c-quark with pt > 10 GeV , we weight the event by fc = 0.10

    if no, we weight the event by fl = 0.03

- We define a event as b-tagged when each of the H candidates have at least one b-tag

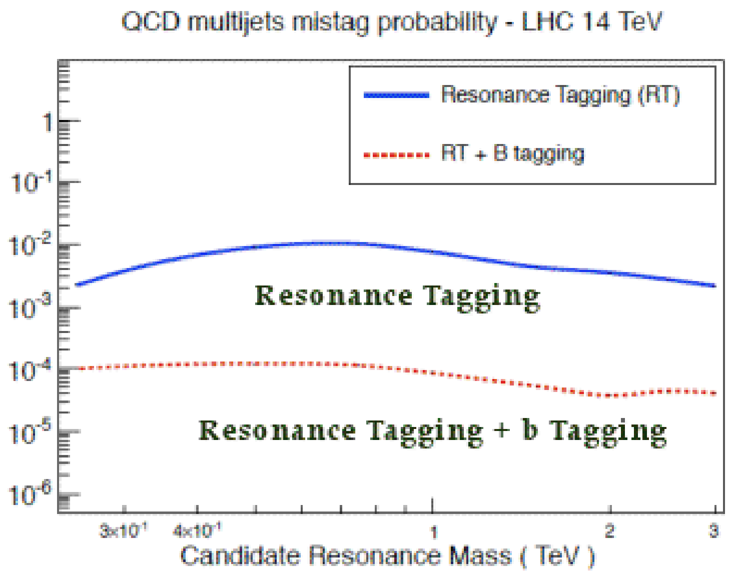
This is over-simplified: is beyond the scope of the work complicate this.

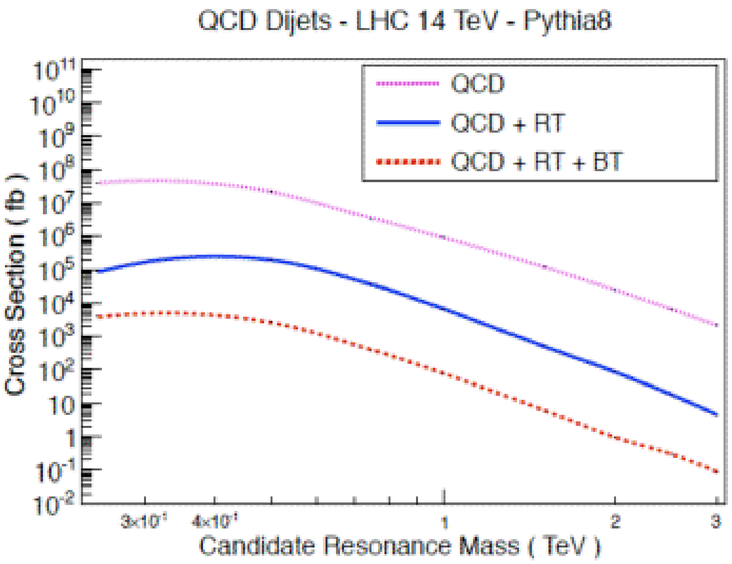
Any realistic fine tunning would depend strongly of on the experiment...

- The numbers we quote are in line with ATLAS/CMS studies

The big point: BKG rejection rates

- We simulate as BKG dijet events with Pythia8, and let radiation takes care of higher jet multiplicities
- We estimate BKG rejection by looking on a mass window for the system inv. mass around 15% of the hypothesis
- BKG rejection rate is also scale invariant, and substantial!

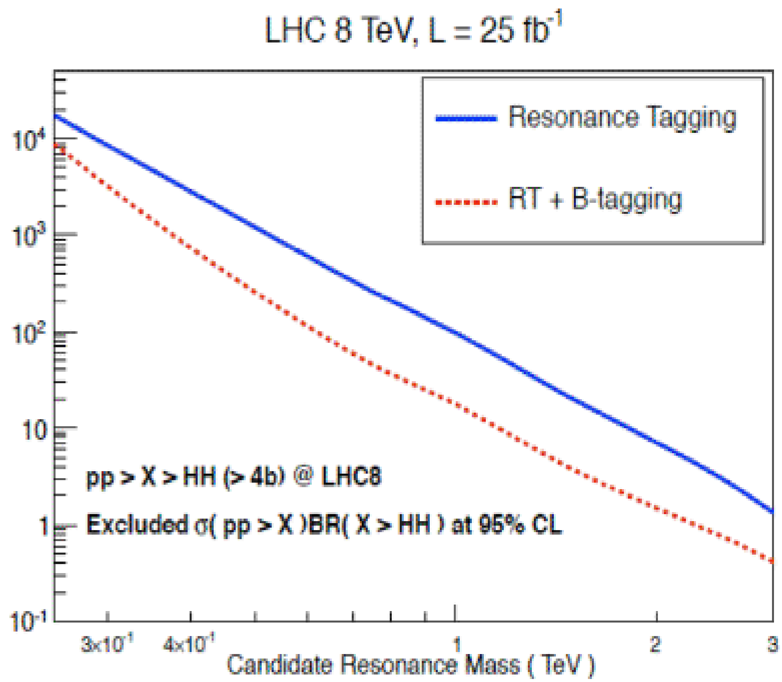


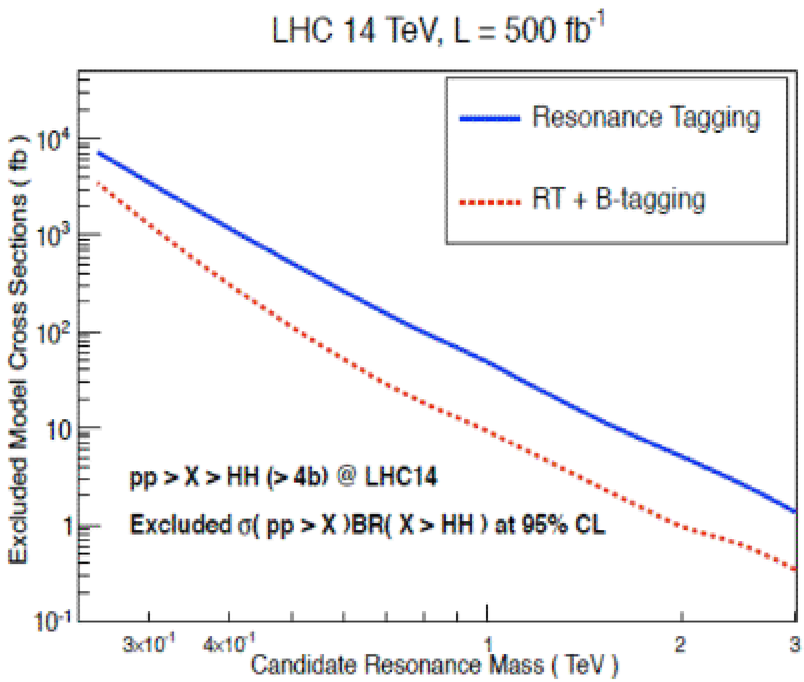


- The key ingredient BKG rejection on unboosted regime are the asymmetry requirements in between pairs.

Model independent limits

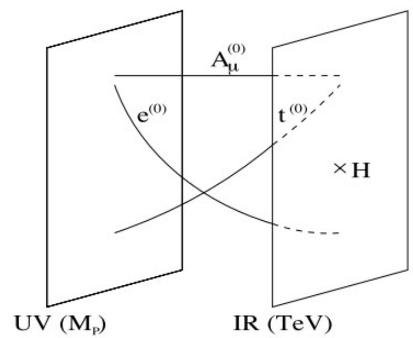
- To produce model independent limits we use the efficiencies results derived from the toy model and the window of 15% resolution around resonance mass.





Benchmark: resonant HH pair production
Extra SM spin 0,2 candidates : Extra Dimensions

Hierarchy problem (EW – Planck scales) adressed by the hipothesis of an small ED with an warp factor in between branes



The Standard Model in the warped five-dimensional bulk.

$$\boxed{ds^2 = e^{-2\sigma(y)}\eta_{\mu\nu}dx^\mu dx^\nu - b_0^2 dy^2,}$$

$$\eta_{\mu\nu} \to \eta_{\mu\nu} + \epsilon h_{\mu\nu}(x,y) \qquad b_0 \to b_0 + b(x)\,.$$

$$\boxed{\mathcal{L} = -\frac{c_i}{\Lambda_G} G^{\mu\nu(1)}\, T^i_{\mu\nu} - \frac{d_i}{\Lambda_\phi}\phi\, T^{\mu i}_\mu}$$

Both Radion/Graviton couplings strenghts are controled by the warp factor!

$$\Lambda_G = e^{-kL} M_{pl} = \mathcal{O}(1\ \mathrm{TeV}) \qquad \Lambda_r = \sqrt{6}\Lambda_G$$

See e.g. D. Dominici, B.n Grzadkowski, J. F. Gunion, M. Toharia arXiv:0206192

Radion X Graviton
gluon fusion HH pair production

Bulk (KK) Graviton

Tree level coupling to SM fields (gluon)

→ direct influences of wave-function supression

$$c_g = \frac{2(1 - J_0(x_1))}{kLx_1^2 |J_2(x_1)|} \simeq 0.02$$

in RS1 $c_g = 1$.

Radion

Like the Higgs, coupling to Gluons are 1 lool level. Plus model/bulk effects...

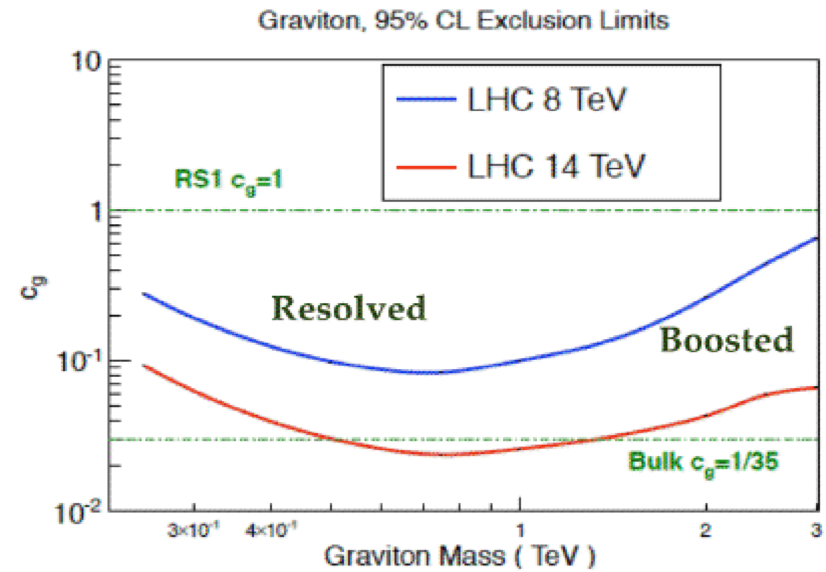
$$\kappa_g^\phi \frac{\phi}{\Lambda_\phi} G^a_{\mu\nu} G^{a\mu\nu}$$

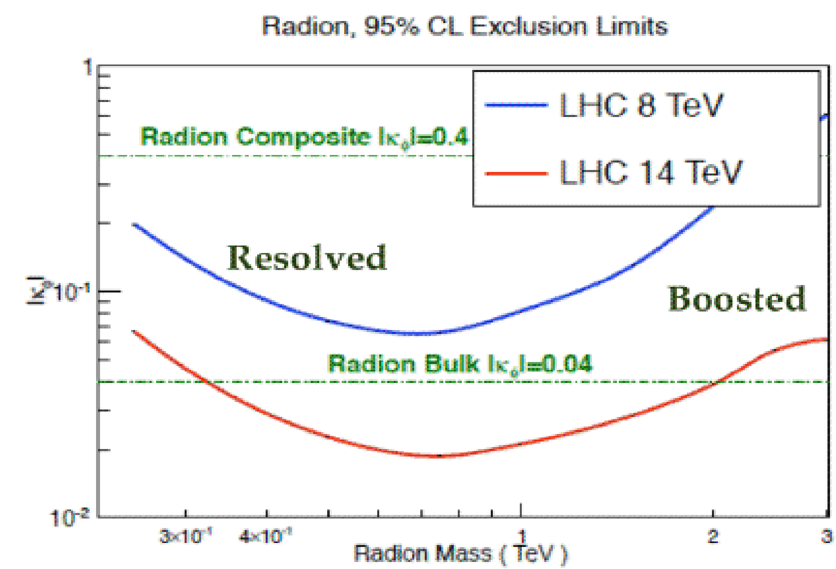
$$\kappa_g^\phi = -\frac{\alpha_s}{8\pi}\left(b_3 - \frac{1}{2}F_{1/2}\left(\frac{4m_t^2}{m_\phi^2}\right)\right) - \frac{1}{4kL}$$

radion Production			
Scenario	$\lvert\kappa_g^\phi\rvert$	Λ_ϕ	BR($\phi \to 2H$)
radion Bulk (R-Bulk)	$\lvert -\alpha_s b_3/8\pi - 1/4kL\rvert \sim 0.04$	2 TeV	1/4
radion Composite (R-Comp)	0.4	2 TeV	1/4
graviton Production			
Scenario	c_g	Λ_G	BR($G \to 2H$)
graviton RS1 (G-Brane)	1	2 TeV	1/4
graviton Bulk (G-Bulk)	$1/kL = 1/35$	2 TeV	1/4

Application to benchmark

- We use cross section values from LO calculations, using narrow width approximation
  - We check we reach similar signal efficiencies for Toy/Radion/Graviton
    - We see that to probe bulk graviton scenarios in this channel we have to wait for LHC14.
    - The same for radion scenarios, unless we have some unexpected effect that increases the cross section.





We do not apply strong angular cuts → multijet maybe is not the best channel for spin determination.

Conclusion and outlook

- We proved that with coherent analysis we can perform an mass independent event tagging in multijet channel keeping considerable signal efficiency and BKG rejection in a wide resonance mass range.
- We apply our strategy to resonant HH production @ LHC.
  - We also have b-tag.
  - We can exclude cross sections down to O(10 - 1) fb at 8 TeV, depending on the resonance mass (1 – 2 TeV).
- We also apply the results to specific WED model.
  - To probe bulk graviton scenarios in this channel we have to wait for LHC14.
  - Same for radion scenarios, unless we have some unexpected effect increases the cross section.
- The idea of scale invariant tagging can be applied to other hadronic channels, like top pair production.

Merci pour la attention!

The idea and the collaboration of this work was born one year ago, on this same Terascale conference, @ Clermont Ferrand

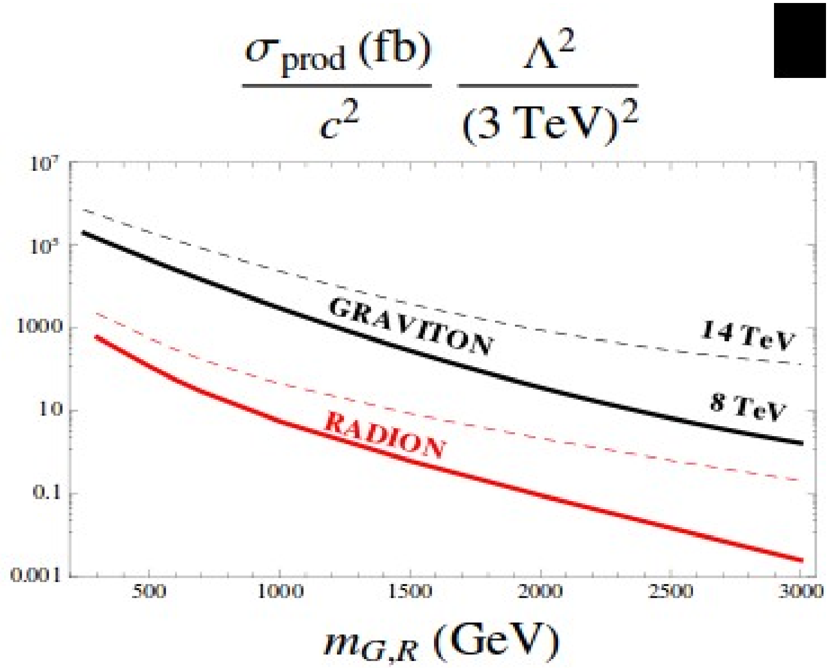
It was a a good birthday gift to present this work here!

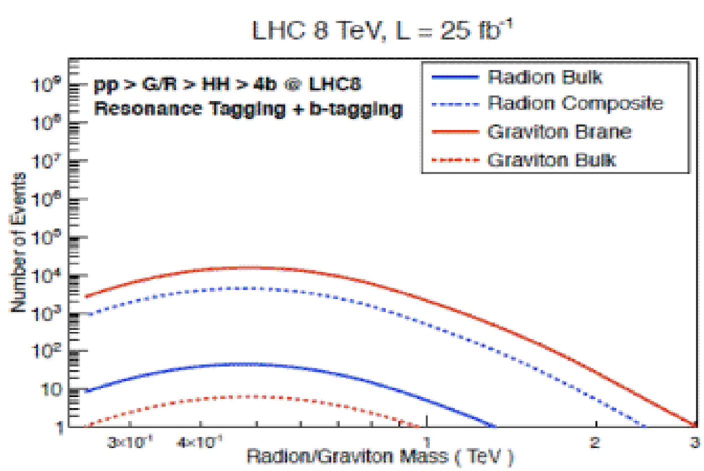
LHC multijet triggers and b-tagging

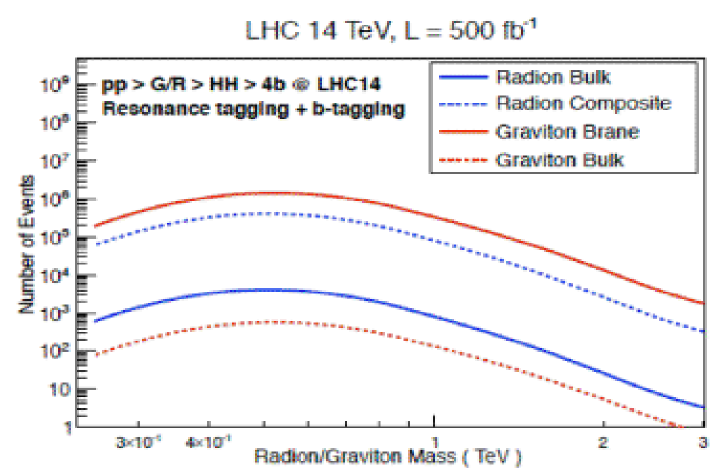
- Generic jets
  - We choose pT(b-quark) > 10 GeV, what corresponds to the pT(B meson > 5-6-7 GeV), the lowest "taggable" pT on how CMS and Atlas proceed.
  - This is not important for the signal where pT(b) >> 10 GeV (boosted) but for the estimate of the background.

- B-tagged triggers
  - Not so good for boosted case, since it looks for b-tag before any fat tag …

Application to benchmark



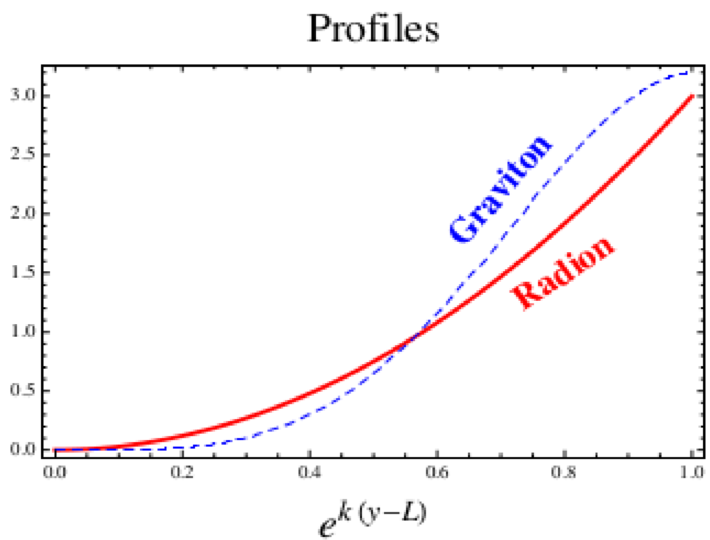




5D profiles and Graviton branching ratios

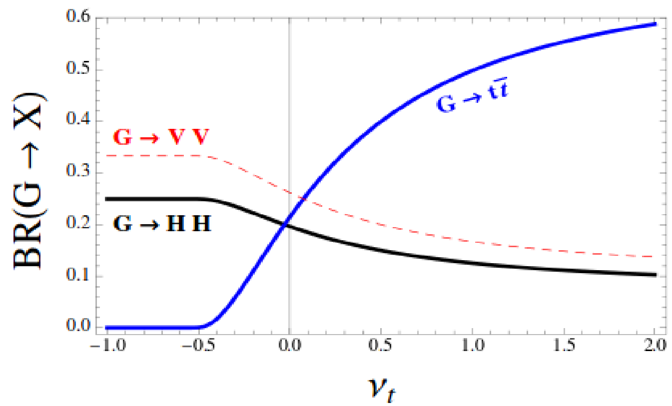
Light fermions

Higgs, Vector bosons, Top



UV brane

TeV brane



Comparison of the toy model and benchmark efficiencies level

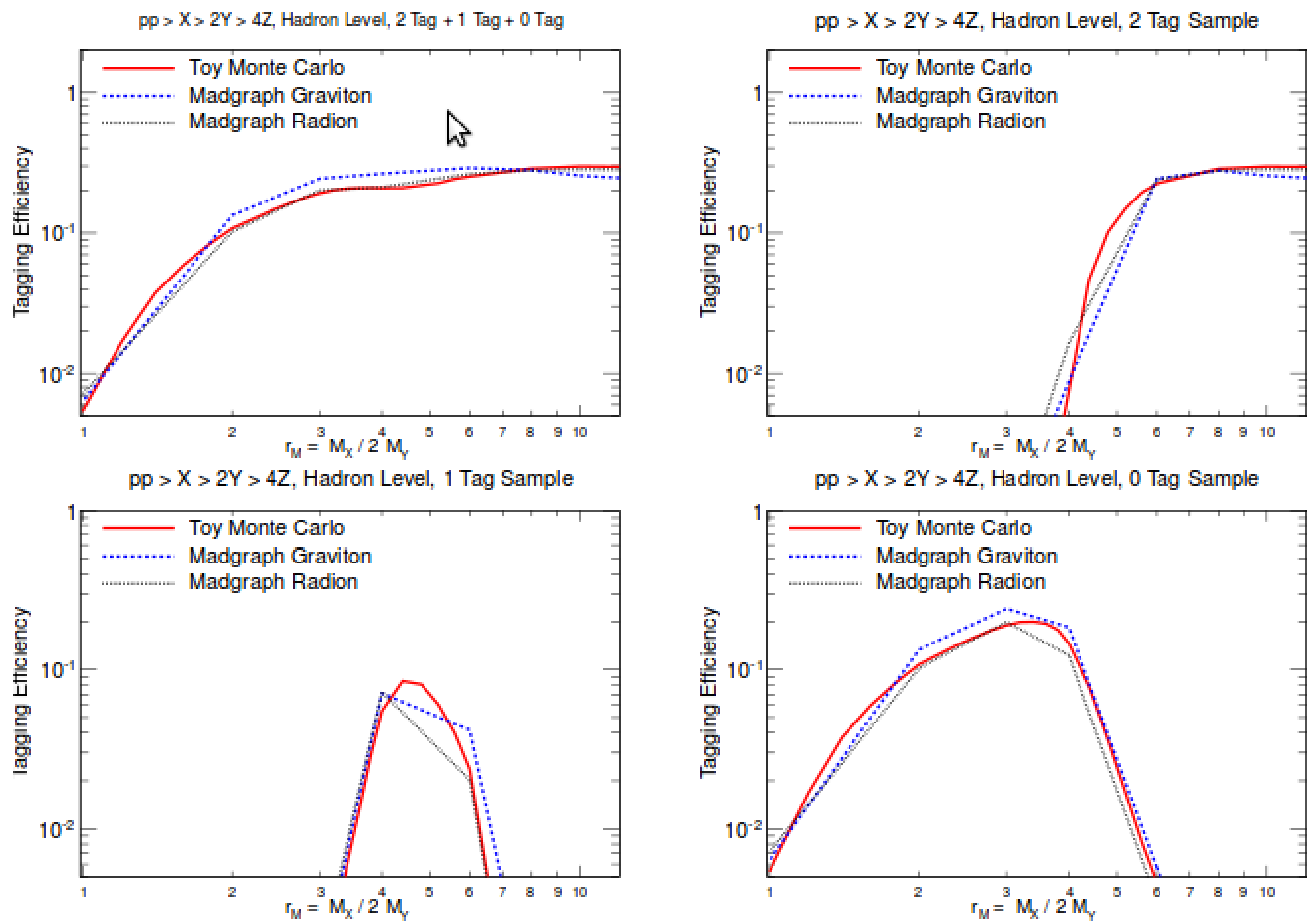
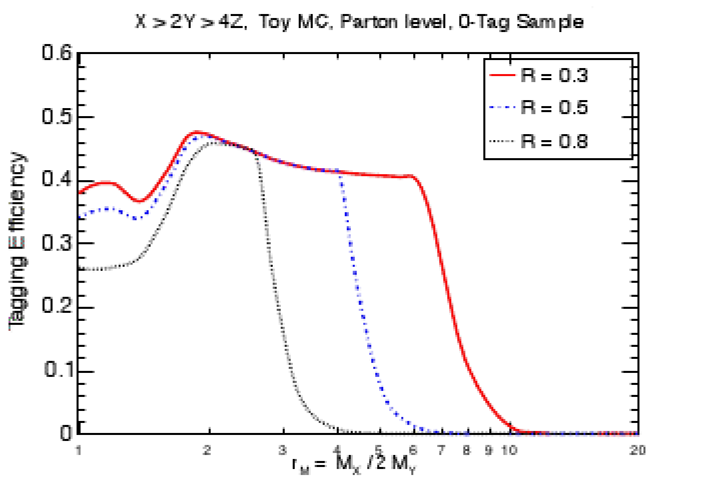
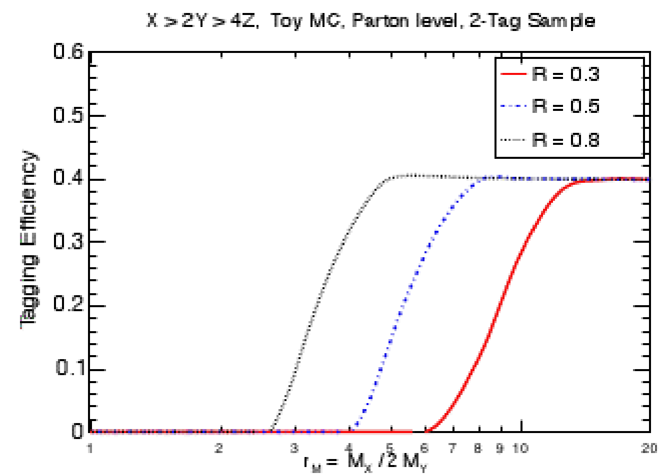


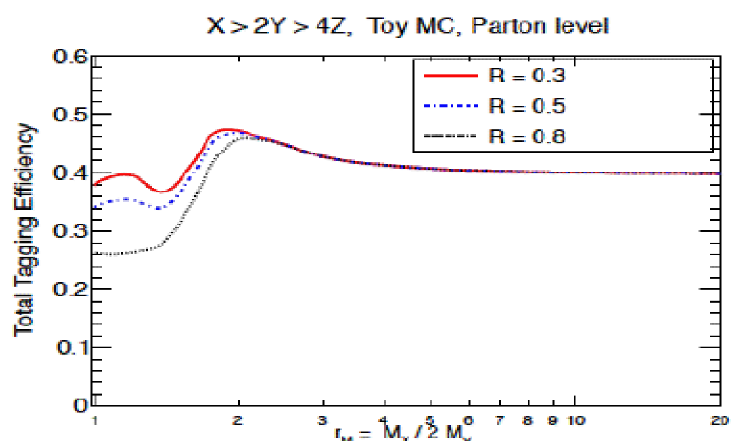
Figure 11: Comparison between the hadron-level tagging efficiencies, at the 8 TeV LHC, for the toy Monte Carlo events and the radion and graviton `MadGraph5` events. We show the total efficiencies and the breakup in different tagged samples, as a function of the boost factor r_M.

Tag populations on different jet radius definitions

- The event classification depends on the jet radius, the total efficiency tagging is sufficiently resilient although



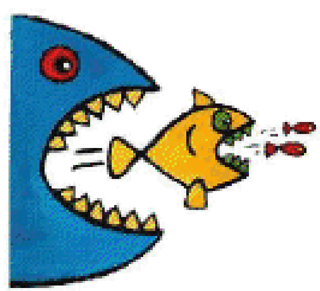


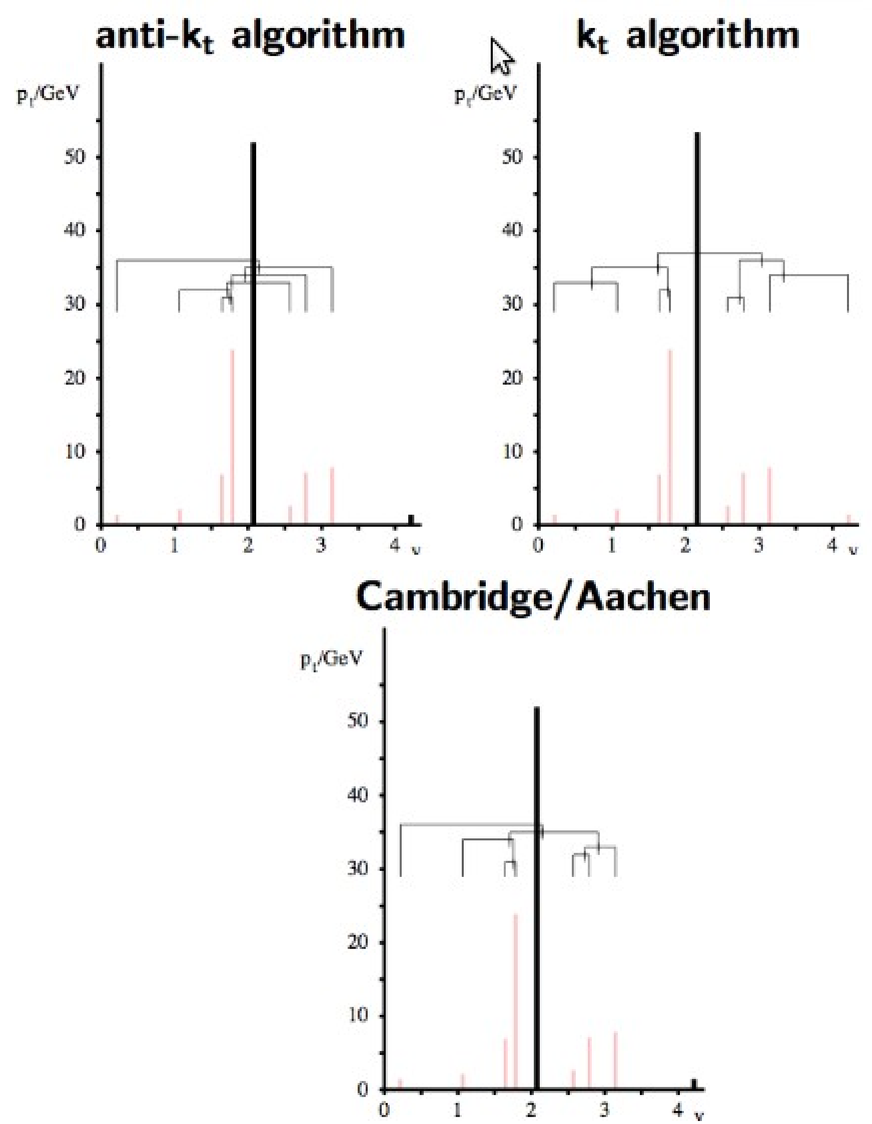


Jet Algorithms

$$d_{ij} = min(k_{ti}^n, k_{tj}^n)\Delta R_{ij}^2/R^2$$

N = 1: k_T – “Small fish eat first”
N = 0: CA - “Closest fish eat first“
N = -1: anti-k_T “Big fish eat first”



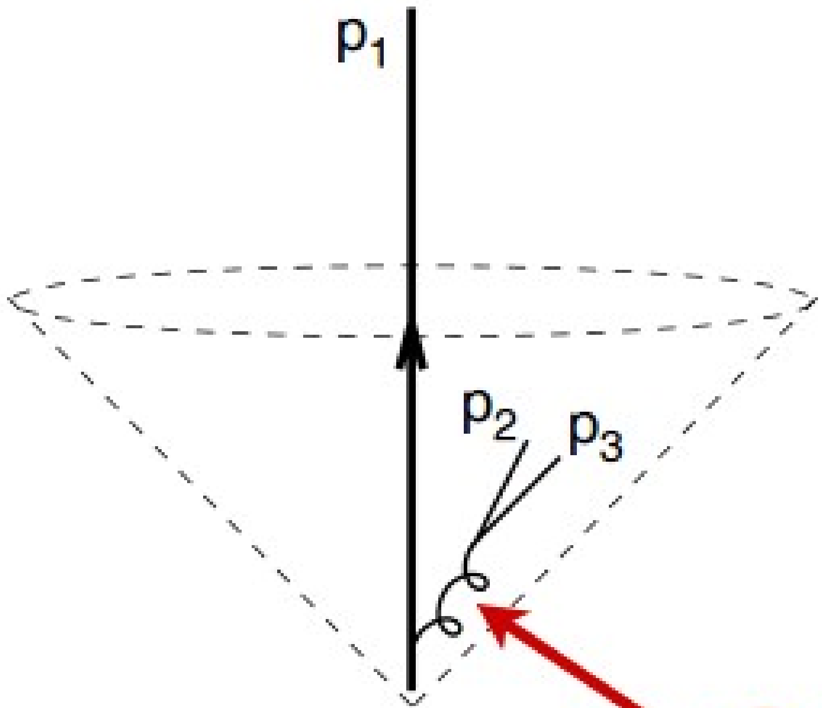


Stolen from
Maxime/Gavin

Mass drop tagger

1. Break the jet j into two subjets by undoing its last stage of clustering. Label the two subjets j_1, j_2 such that $m_{j_1} > m_{j_2}$.
2. If there was a significant mass drop, $m_{j_1} < \mu m_j$, and the splitting is not too asymmetric, $y = \min(p_{tj_1}^2, p_{tj_2}^2)\Delta R_{j_1 j_2}^2 / m_j^2 > y_{\text{cut}}$, then deem j to be the tagged jet.
3. Otherwise redefine j to be equal to j_1 and go back to step 1 (unless j consists of just a single particle, in which case the original jet is deemed untagged).

Stolen from Gavin

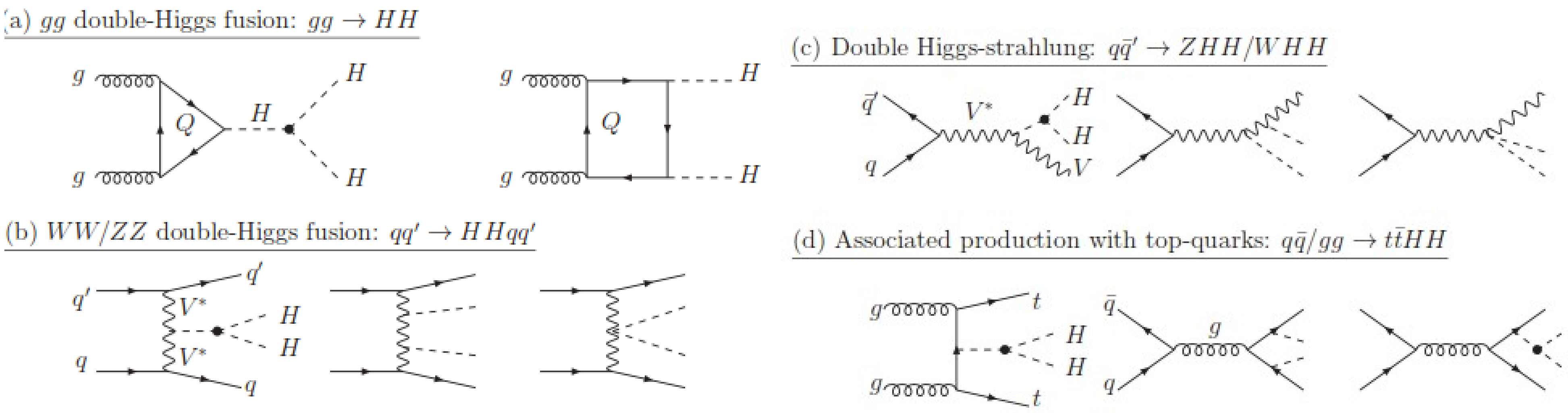


What MDT does wrong:

Can follow a soft branch ($p_2+p_3 < y_{cut}\ p_{jet}$) with "accidental" small mass, when the "right" answer was that the (massless) hard branch had no substructure

Subjet is soft, but has more substructure than hard subjet

HH SM signal



J. Baglio, A. Djouadi, R. Grober, M. M. Muhlleitner, J. Quevillon, M. Spira

arXiv:1212.5581 [hep-ph]

$\sqrt{s}$ [TeV]	$\sigma^{\rm NLO}_{gg\to HH}$ [fb]	$\sigma^{\rm NLO}_{qq'\to HHqq'}$ [fb]	$\sigma^{\rm NNLO}_{q\bar{q}'\to WHH}$ [fb]	$\sigma^{\rm NNLO}_{q\bar{q}\to ZHH}$ [fb]	$\sigma^{\rm LO}_{q\bar{q}/gg\to t\bar{t}HH}$ [fb]
8	8.16	0.49	0.21	0.14	0.22
14	33.89	2.01	0.57	0.42	1.09
33	207.29	12.05	1.99	1.68	8.37
100	1417.83	79.55	8.00	8.27	82.69

Table 1: The total Higgs pair production cross sections in the main channels at the LHC (in fb) for given c.m. energies (in TeV) with $M_H = 125$ GeV. The central scales which have been used are described in the text.