Title: Jet substructure at the LHC

Date: Nov 05, 2010 02:30 PM

URL: http://pirsa.org/10110044

Abstract: The consequences of the fact that electroweak scale particles are often produced beyond threshold has been appreciated only recently. Decay products of boosted objects tend to be collimated and their final state radiation (FSR) might overlap. It has been shown that it can be advantageous to collect all FSR of a decaying resonance in a so-called 'fat jet' and apply subjet techniques to it to obtain a good mass reconstruction of the resonance and an improved background rejection. In my talk I would like to cover recent developments in this field and discuss applications to Higgs searches and top reconstruction within and beyond the Standard Model.

Jet substructure at the LHC

New Physics - new tools - new channels

Michael Spannowsky

University of Oregon

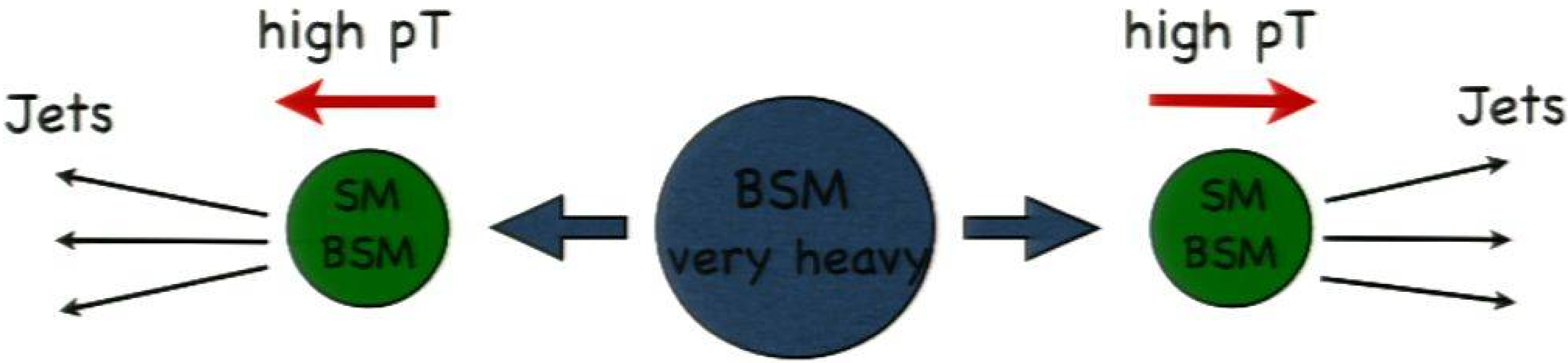
Jets are most frequently observed objects at the LHC

New energies long for new tools and techniques

Outline

- Which NP scenarios suitable for subjet techniques
- What are Jets, how to construct?
- Which subjet techniques are there
- Do subjet techniques really pay off?

I. naturally highly boosted signal:



- At LHC elw scale particles produced beyond threshold
- Jets highly collimated
- Jet-parton matching breaks down
- Decay products and FSR has to be collected in a fat jet
- Large UE contribution, jet grooming important

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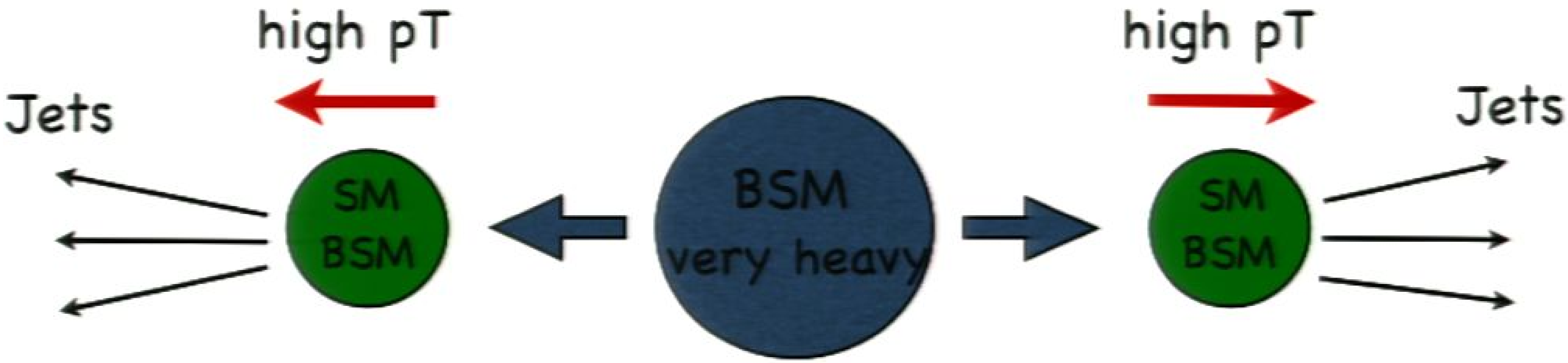

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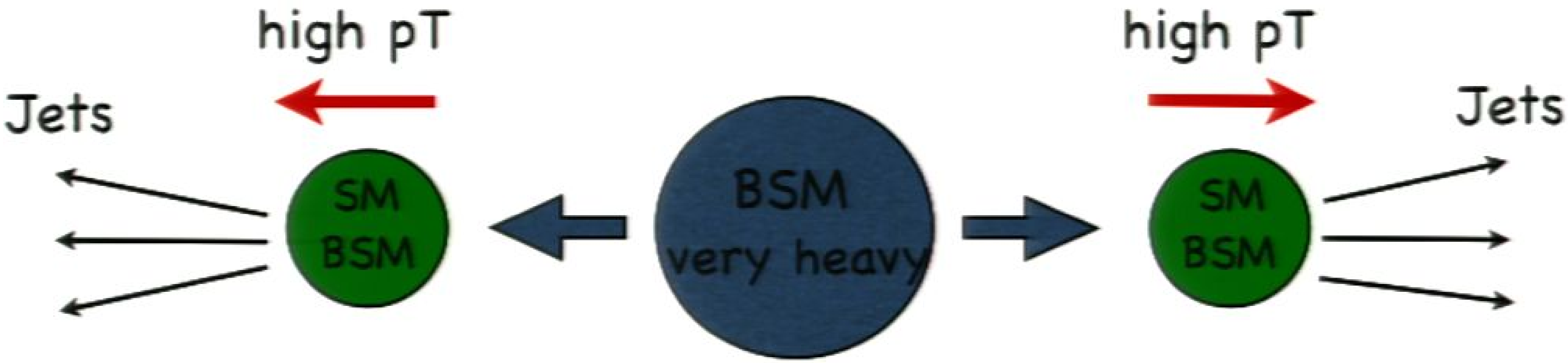

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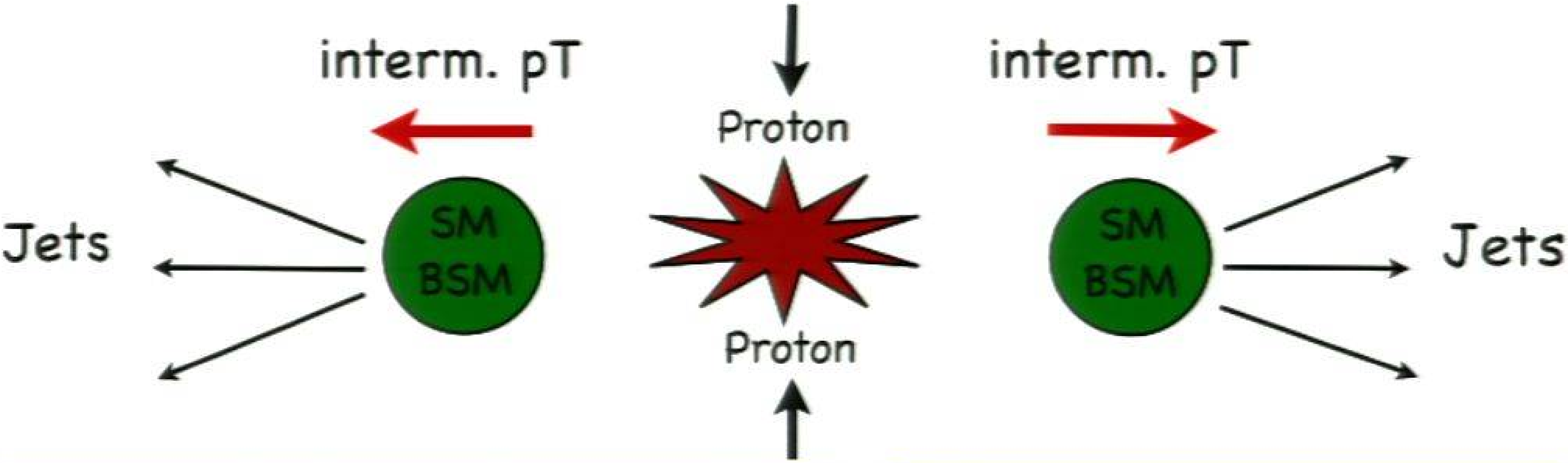

Advantages:

- Jet resolution
- b-tagging
- signal reconstruction efficiency
- lepton identification efficiency
- Reduced combinatorial problems

Disadvantages:

- Low cross section
- large ISR, UE, Pile-up contributions

need big jet cone
need jet grooming

[Thesis, Piacquadio] [ATL-PHYS-PUB-2009-088]

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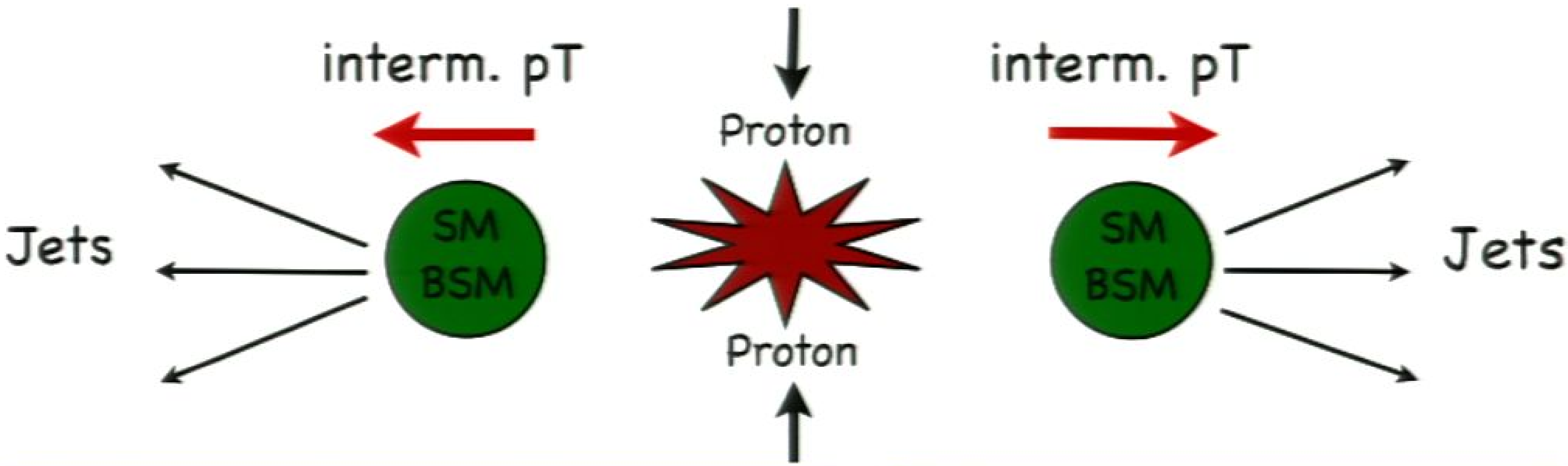

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My recent work on this subject

- Fat Jets for a Light Higgs (tth-channel) [Plehn, Salam, MS PRL 104 (2010)]
- Discovering the Higgs Boson in New Physics Events using Jet Substructure
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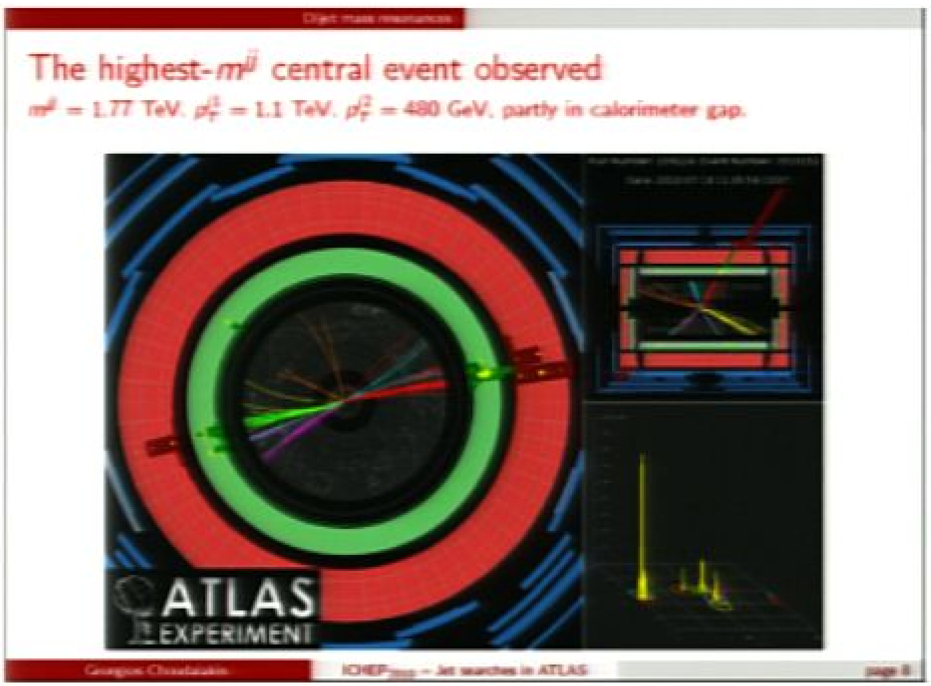
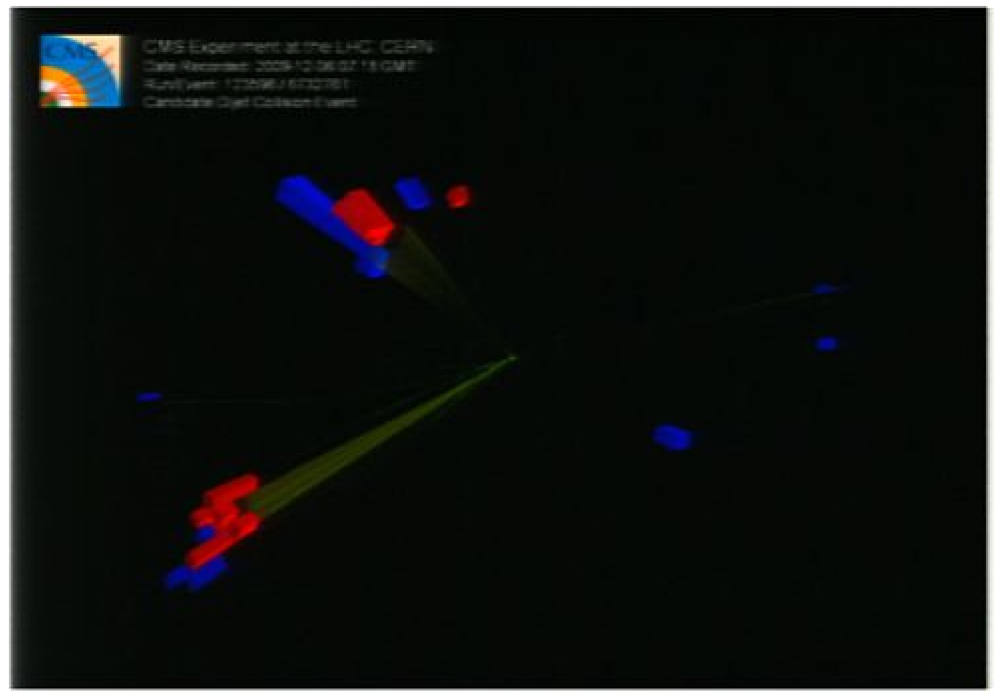
Graham

Backup?

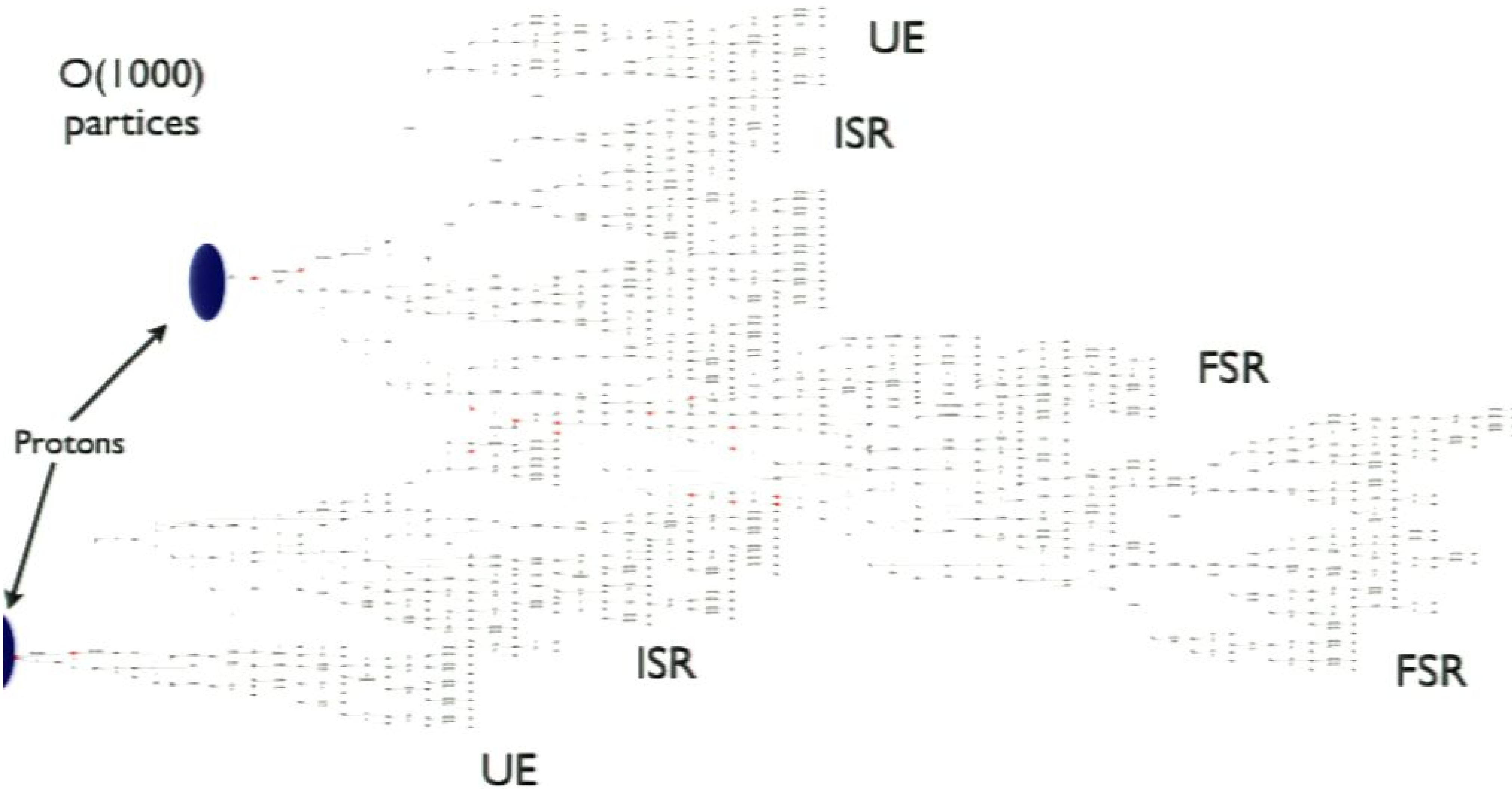
What is a Jet at the LHC?

Jet = collimated spray of hadronic "stuff" in the detector

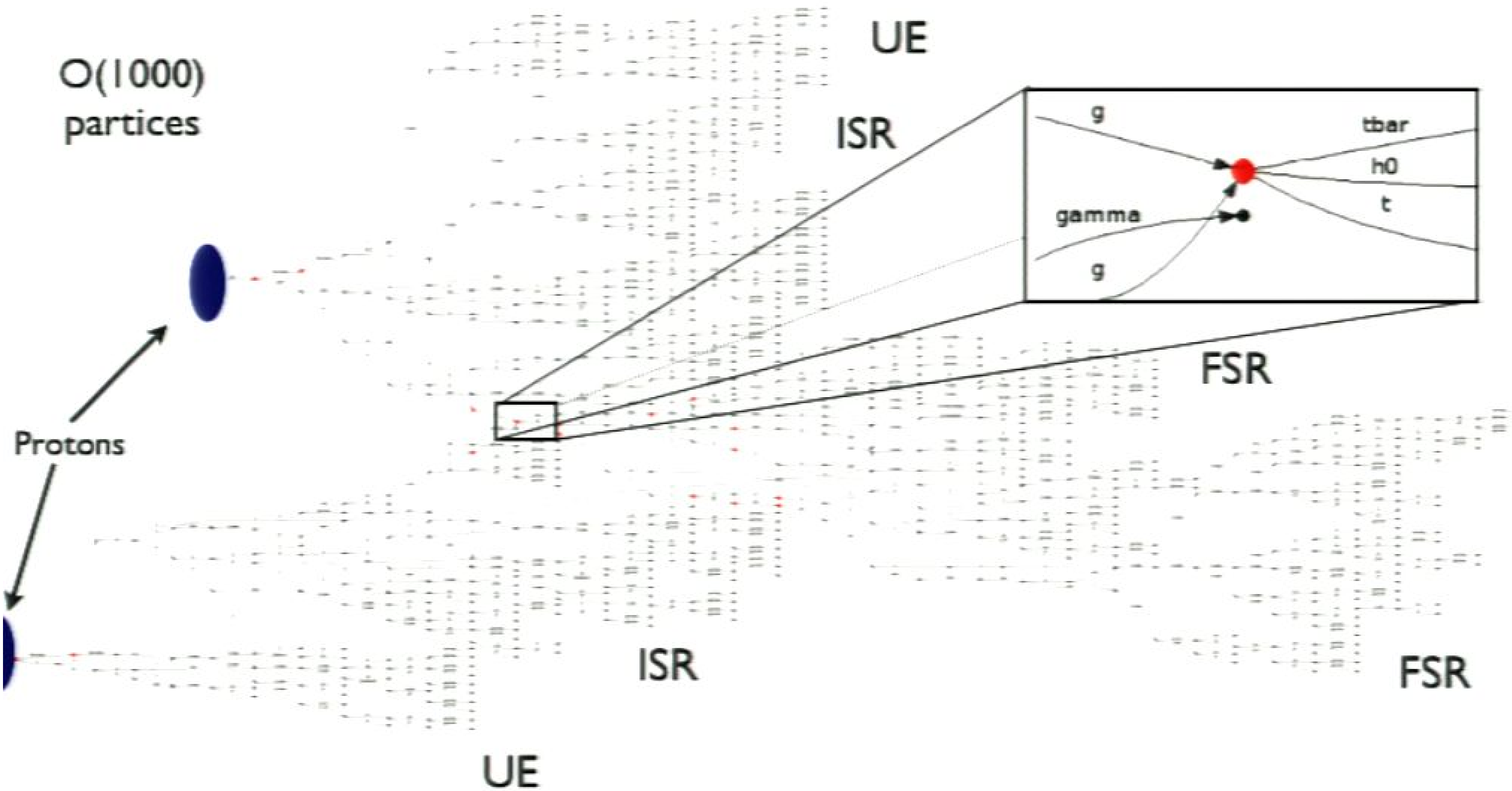




So what's the big deal?



Tedious for theorists and experimentalists



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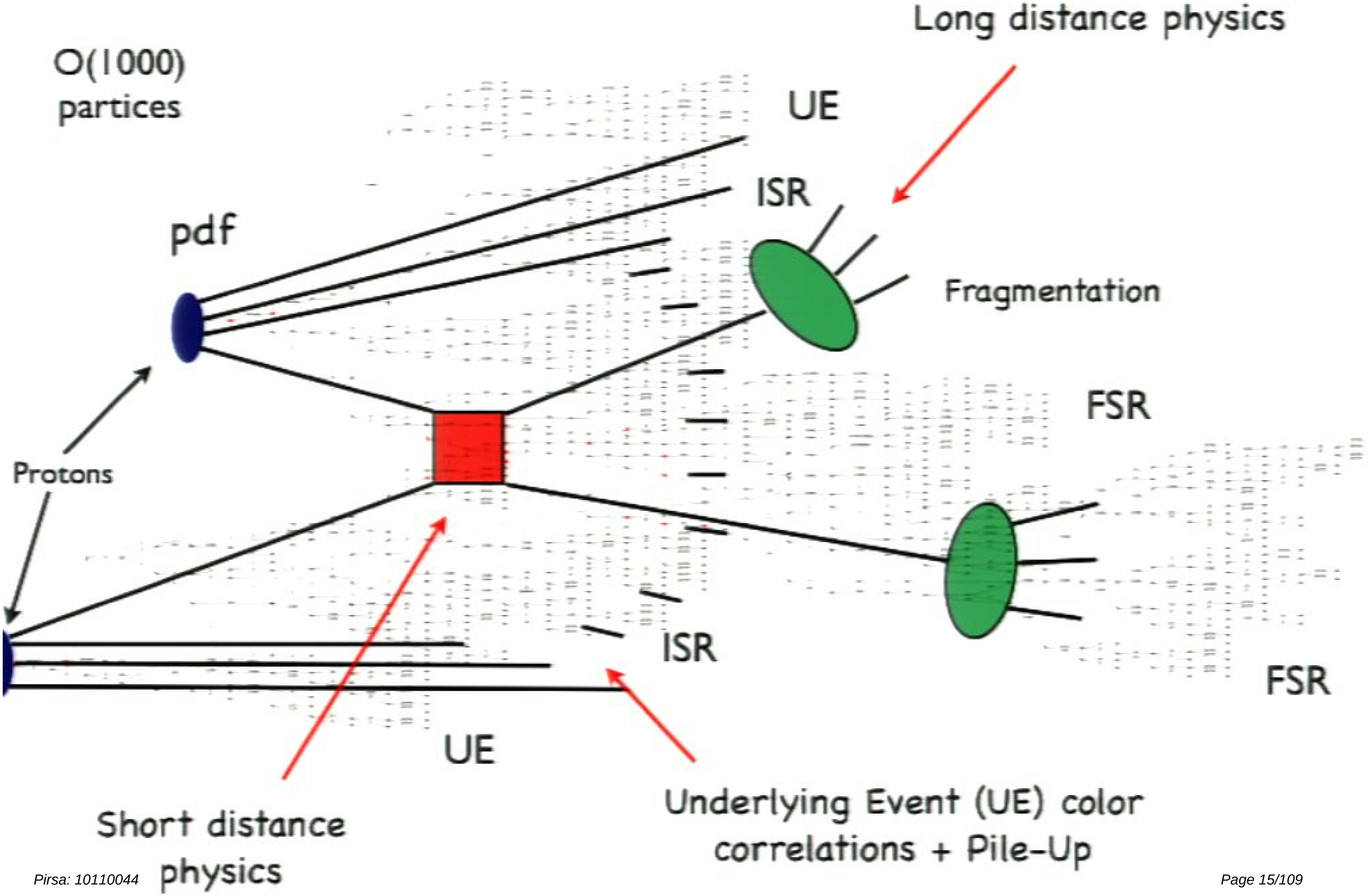
Long distance physics
O(1000)
partices
UE
ISR
pdf
Fragmentation
FSR
Protons
ISR
FSR
UE
Short distance
physics
Underlying Event (UE) color
correlations + Pile-Up

How to construct/define a Jet

Want mapping of hadronic final state to hard-interaction partons

Done by approx. collinear stuff (shower)

Jet issues:

"Splash in":
- Uncorrelated contributions of rest of collision (UE)
- Uncorrelated contributions of overlapping collsions (PU)

"Splash out":
- Showering - LL resumed, soft-coll. emissions
- Hadronization - nonpert. re-organization into color singlets

Higher order perturbative contributions - IR safety

- Should be IR-Safe ⟷ **KLN Theorem:** All soft and final state coll. IR singularities cancel against virtual IR singularities for suff. incl. observables

$$\sigma^{NLO} = \sum_{ab} \int d\Phi_{1+\mathrm{elw}} dx_1 dx_2 f_{a/P}(x_1, \mu_F^2) f_{b/P}(x_2, \mu_F^2)(\hat{\sigma}_{ab}^{\mathrm{LO}} + \hat{\sigma}_{ab}^{\mathrm{Virt}}(\mu_R^2, \mu_F^2))\mathcal{F}(\mathrm{p}_1)\Theta(\mathrm{cuts})$$
$$+ \sum_{ab} \int d\Phi_{2+\mathrm{elw}} dx_1 dx_2 f_{a/P}(x_1, \mu_F^2) f_{b/P}(x_2, \mu_F^2)\hat{\sigma}^{\mathrm{rem}} \mathcal{F}(p_1 + p_2)\Theta(\mathrm{cuts})$$

$$\lim_{p_1 \cdot p_2 \to 0} \mathcal{F}(p_1, p_2) = \mathcal{F}(p_1)$$

Jet definition not unambiguous: Which particles? How combined?

Cone algorithms: seeded vs unseeded

Sequential jet algorithms (e.g. kT, CA, anti-kT)

Recombination scheme, e.g. E-scheme

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Recombination scheme, e.g. E-scheme

- Sequential recombination, e.g. inclusive kT algorithm [S.D. Ellis & Soper, '93]

Distance measure
$$d_{ij} = \min(p_{Ti}^2, p_{Tj}^2)\frac{\Delta R_{ij}^2}{R^2}$$
$$d_{iB} = p_{Ti}^2$$

$$\Delta R_{ij}^2 = (y_i - y_j)^2 + (\phi_i - \phi_j)^2$$

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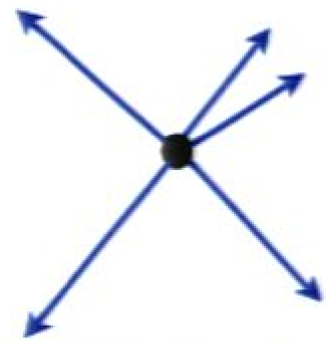
3. if iB call i a jet and remove from list of particles
4. repeat from 1. until no particles left



Minimum distance between jets is R

Only number of jets above pt cut is IR safe

Cambridge/Aachen alg. - distance measure: $d_{ij} = \frac{\Delta R_{ij}^2}{R^2}$ $d_{iB} = 1$

anti-kT alg. - distance measure: $d_{ij} = \min(p_{Ti}^{-2}, p_{Tj}^{-2})\frac{\Delta R_{ij}^2}{R^2}$ $d_{iB} = p_{Ti}^{-2}$

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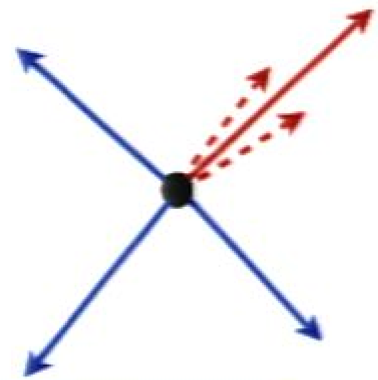

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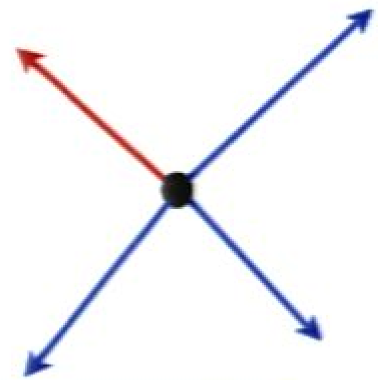

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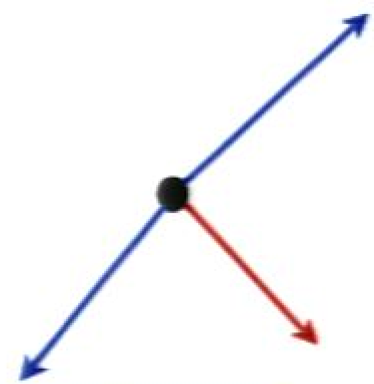

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Found 4 Jets

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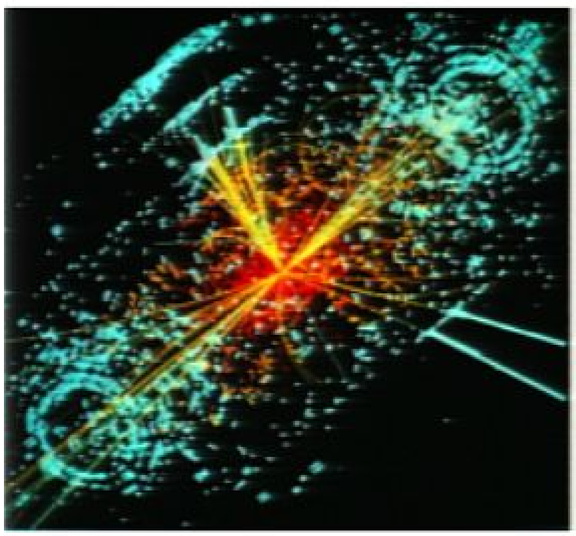
Sequential recombination algorithms

↓

Recombination history

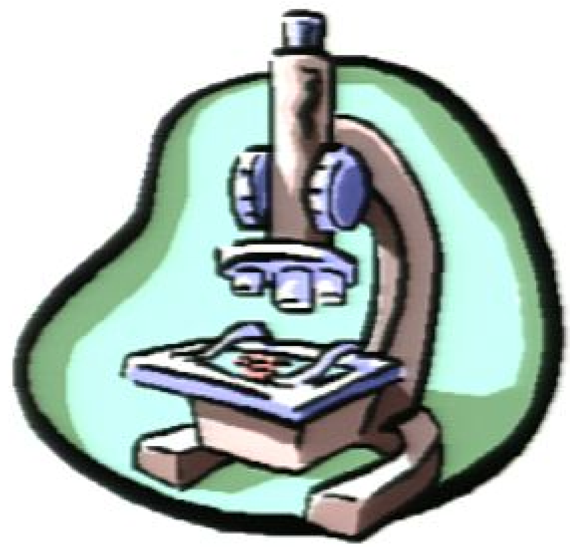
↓



Jet substructure

=

microscope for boosted resonance's properties



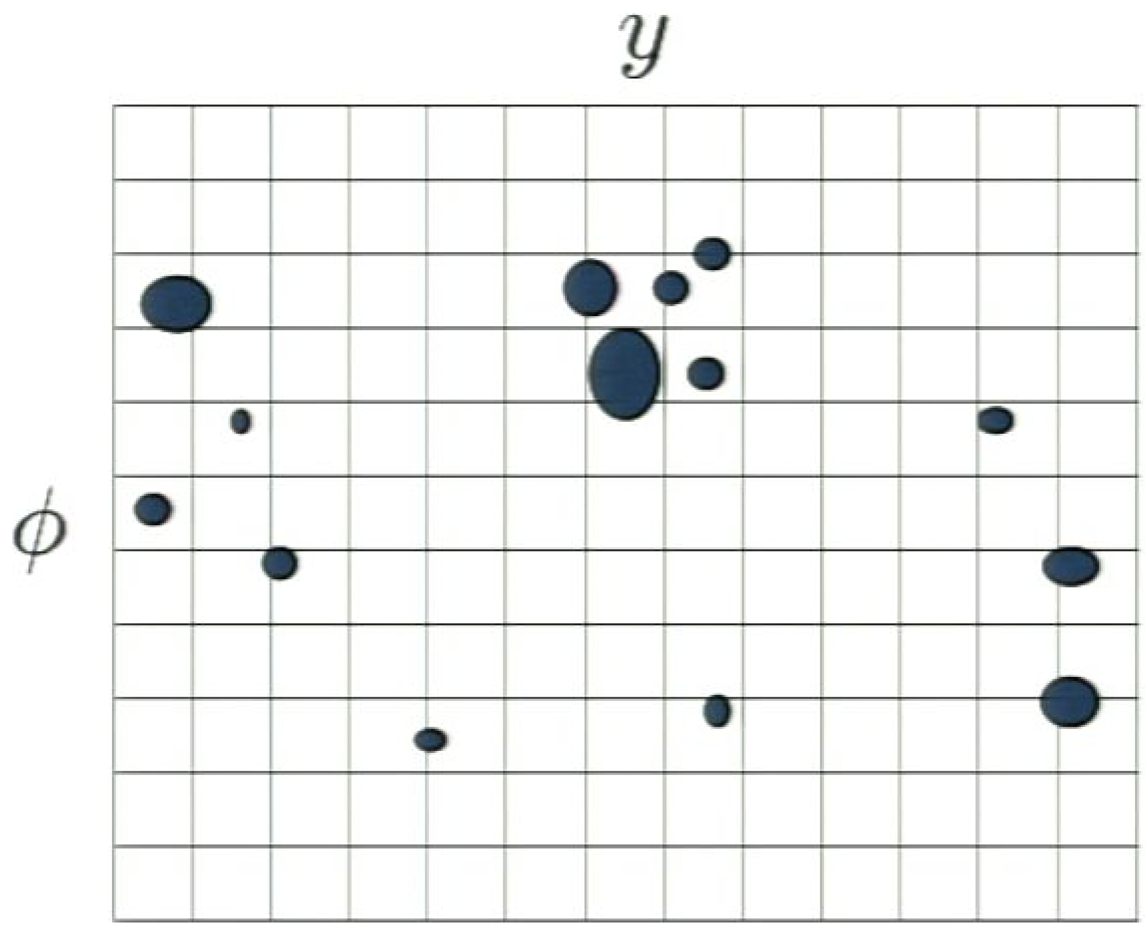
Tools for jet substructure

I. Subjet/grooming techniques

Filtering	[Butterworth et al. PRL 100 (2008)]
Pruning	[Ellis et al. PRD 80 (2009)]
Trimming	[Krohn et al. JHEP 1002 (2010)]

II. Techniques using jet energy flow

Jet/Event selection

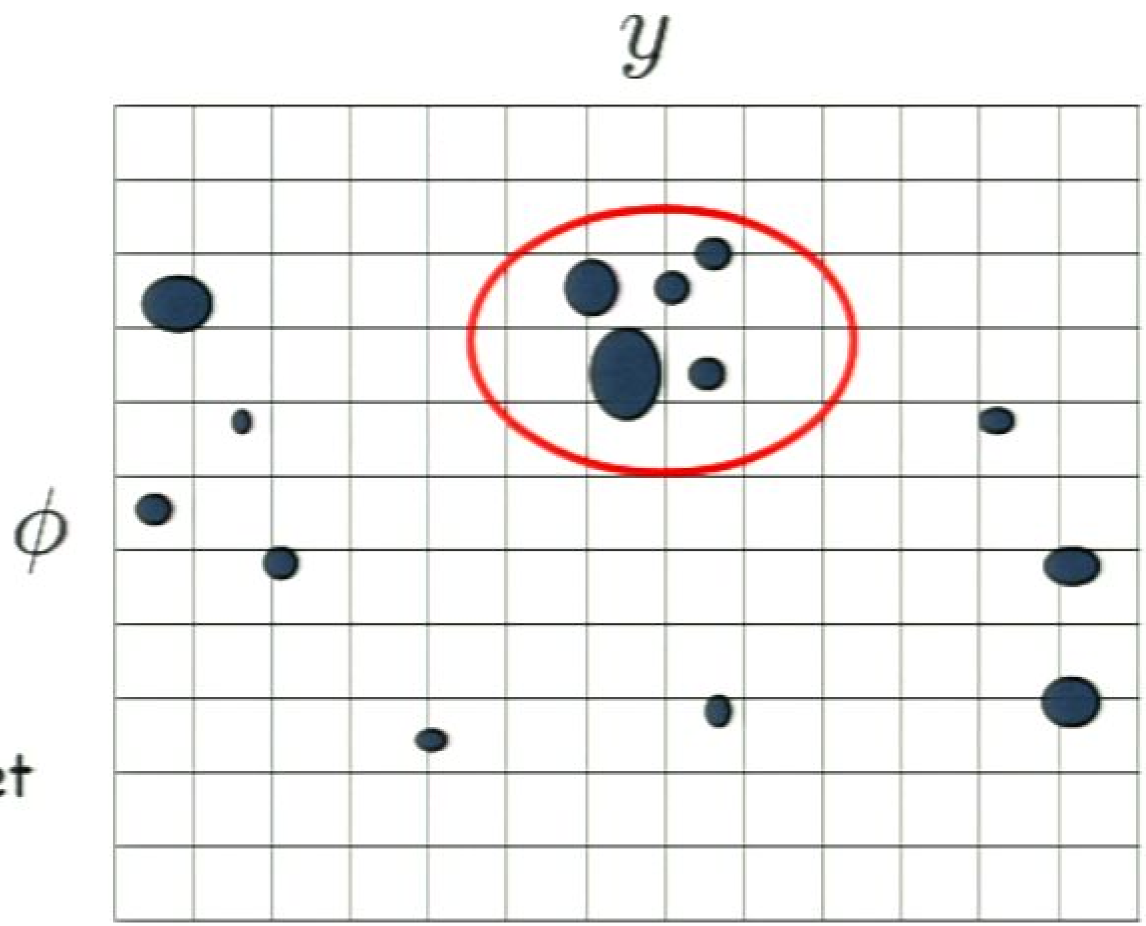


UE, ISR, Pile-up, hard interaction

Jet/Event selection

I. Locate hadronic energy deposit in detector by choosing initial jet finding algorithm, e.g. CA, R=1.2

II. Possible to impose jet selection cuts on fat jet



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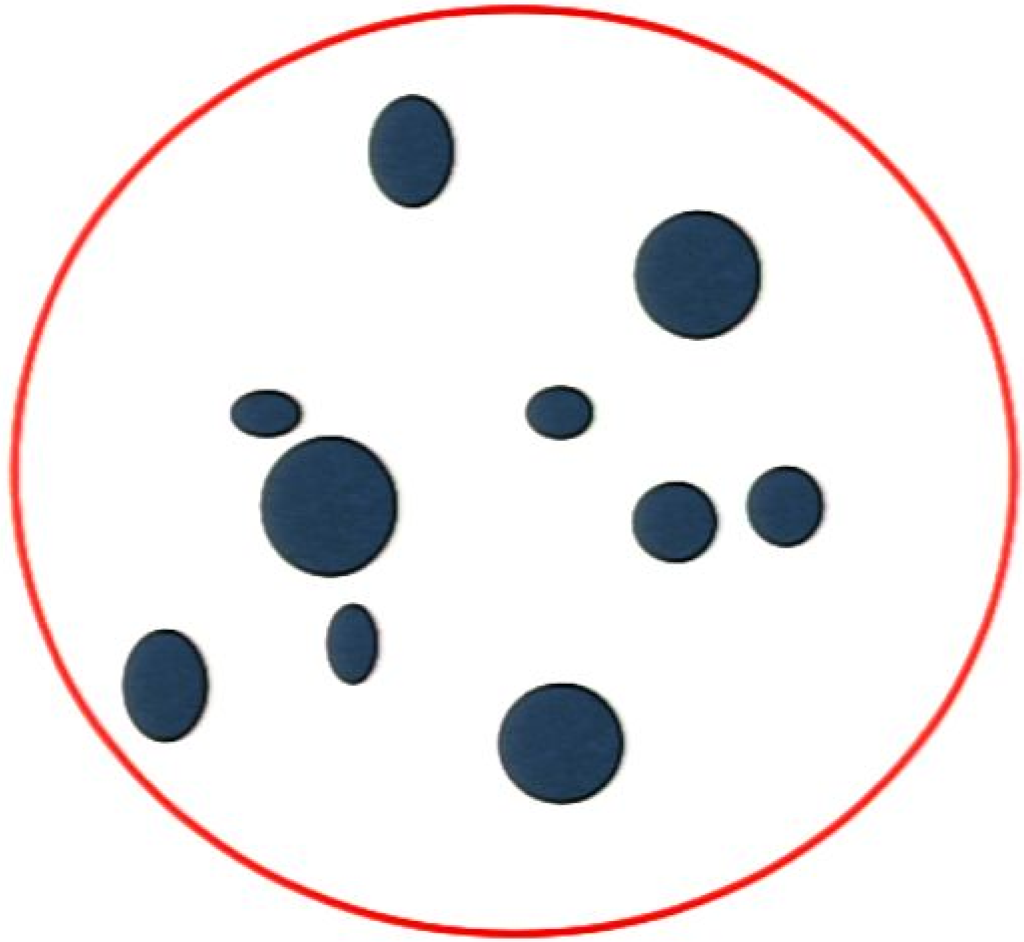
Filtering/Trimming

I. Recombine jet constituents with new alogrithm, eg CA, R=0.2

Filtering:
recombine n subjets

Trimming:
recombine subjets which fulfill $P_{T,j} > f \times \Lambda$



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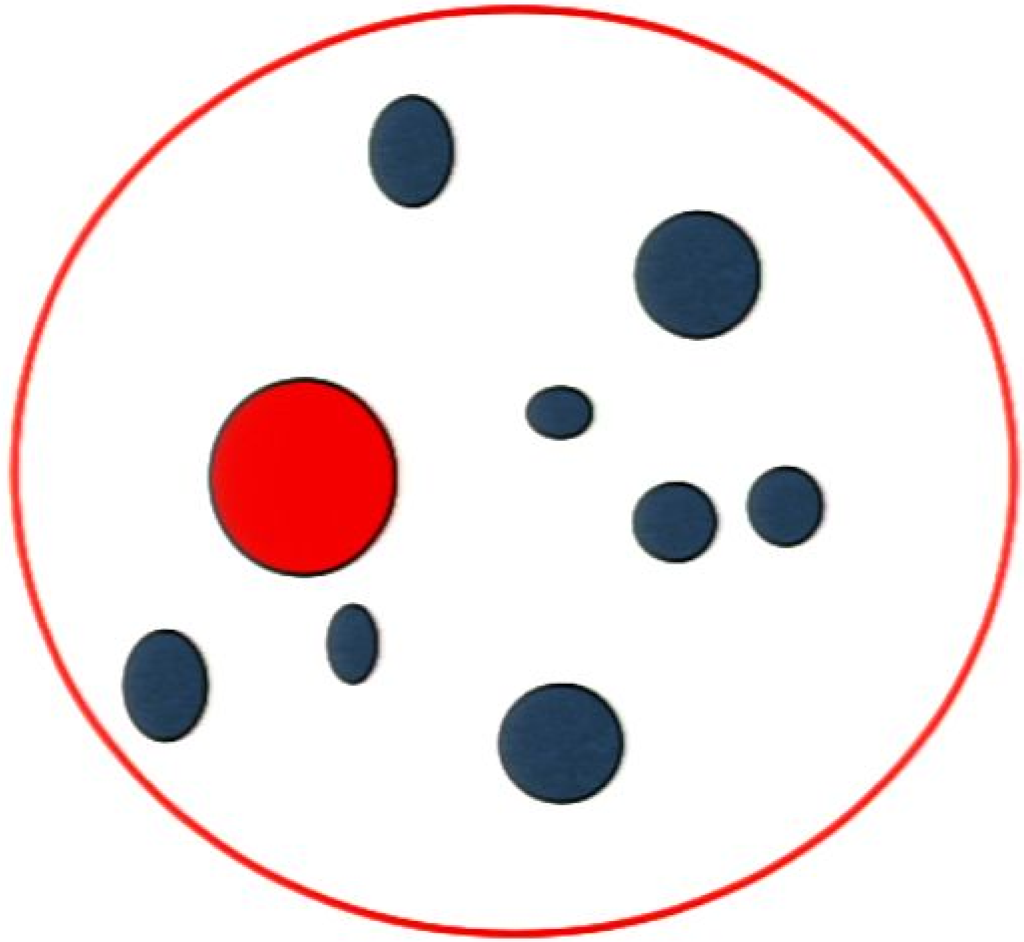

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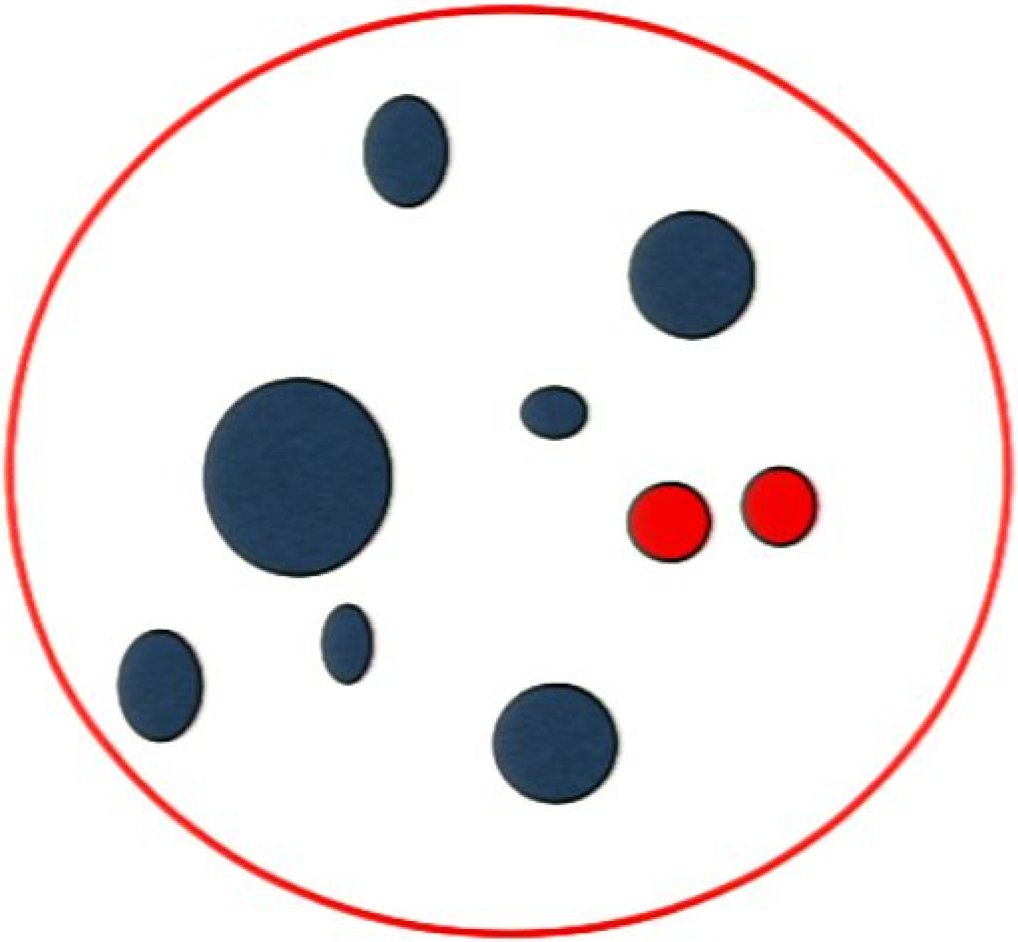

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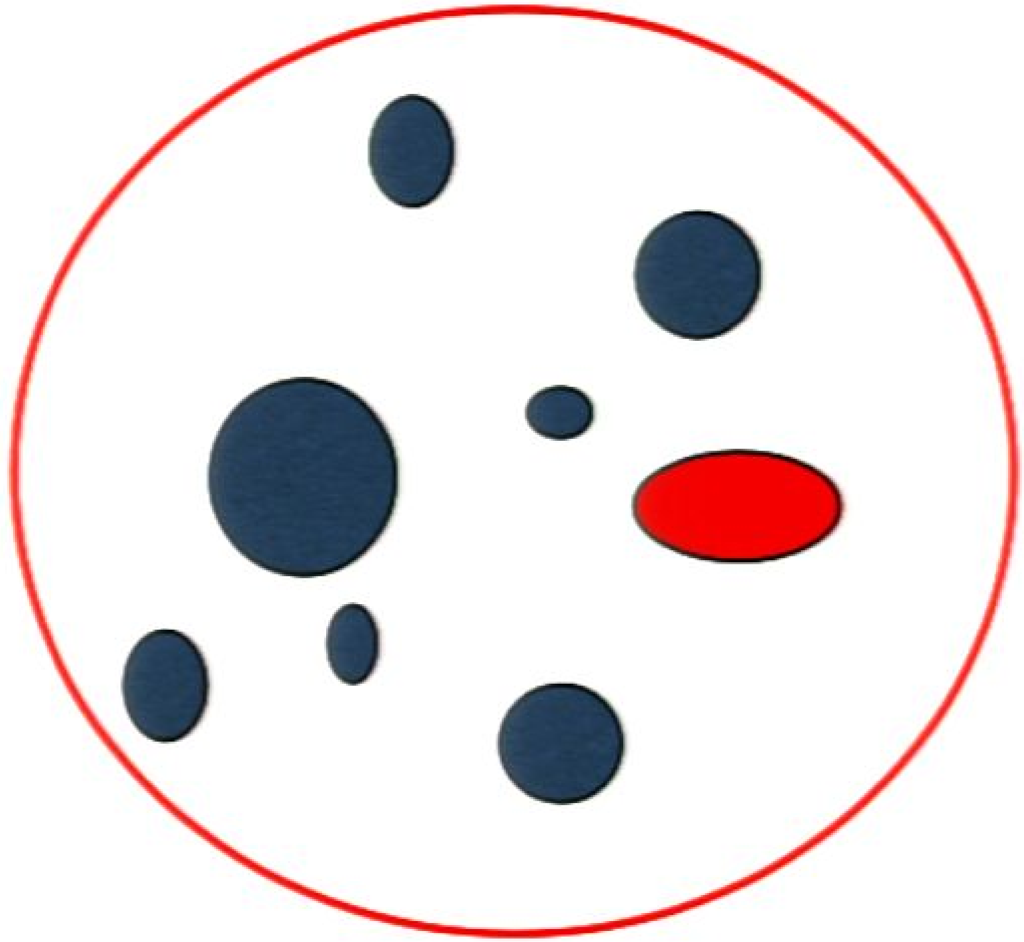

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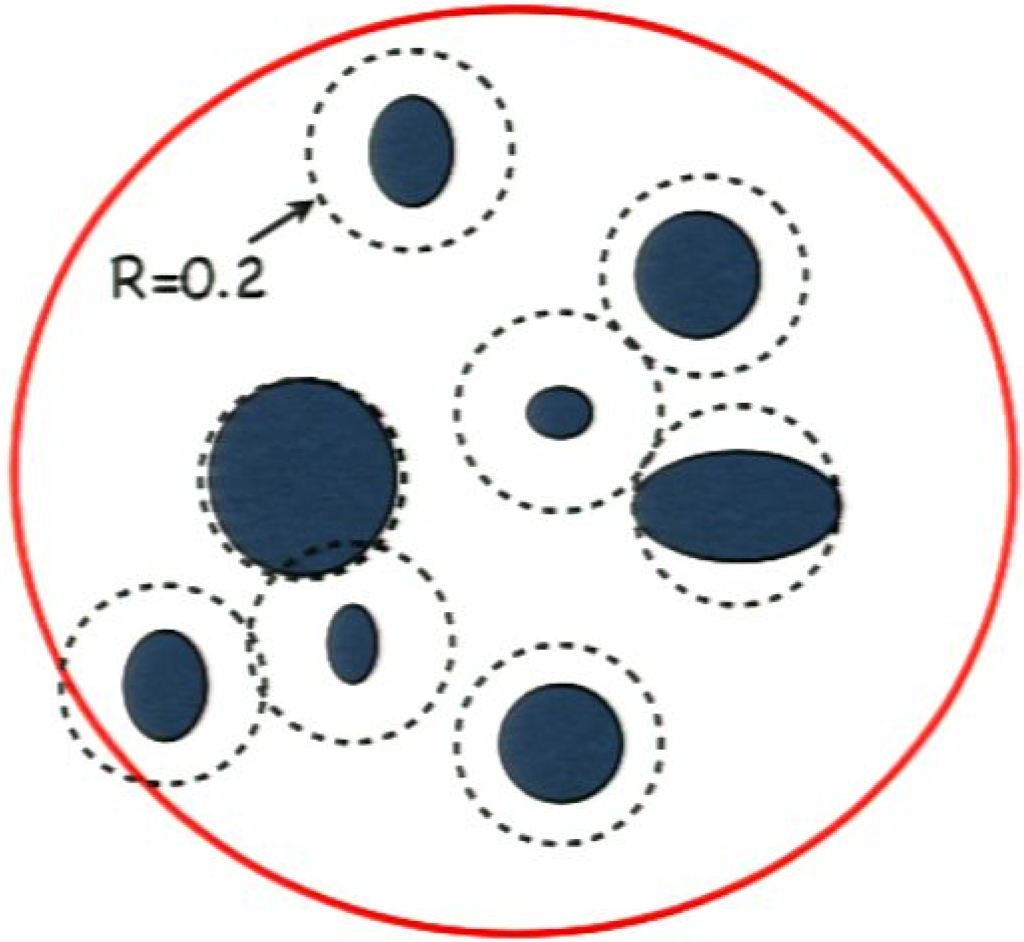

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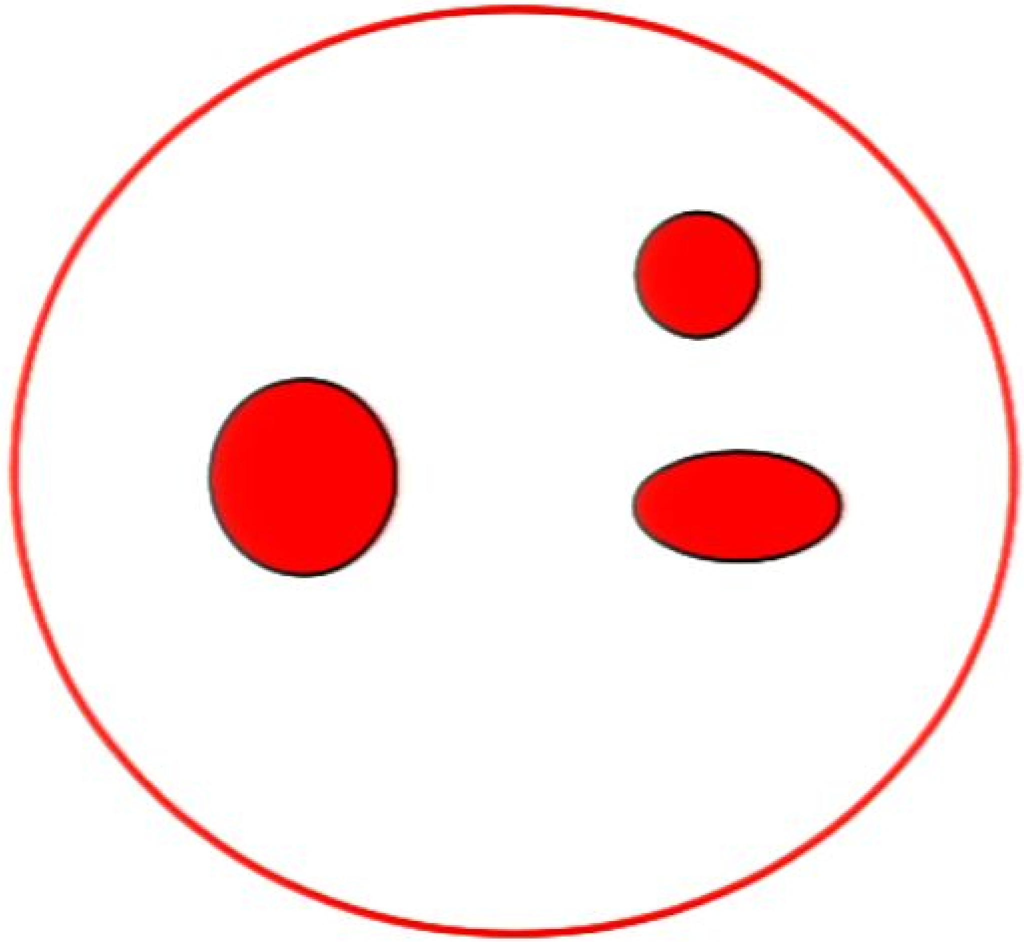

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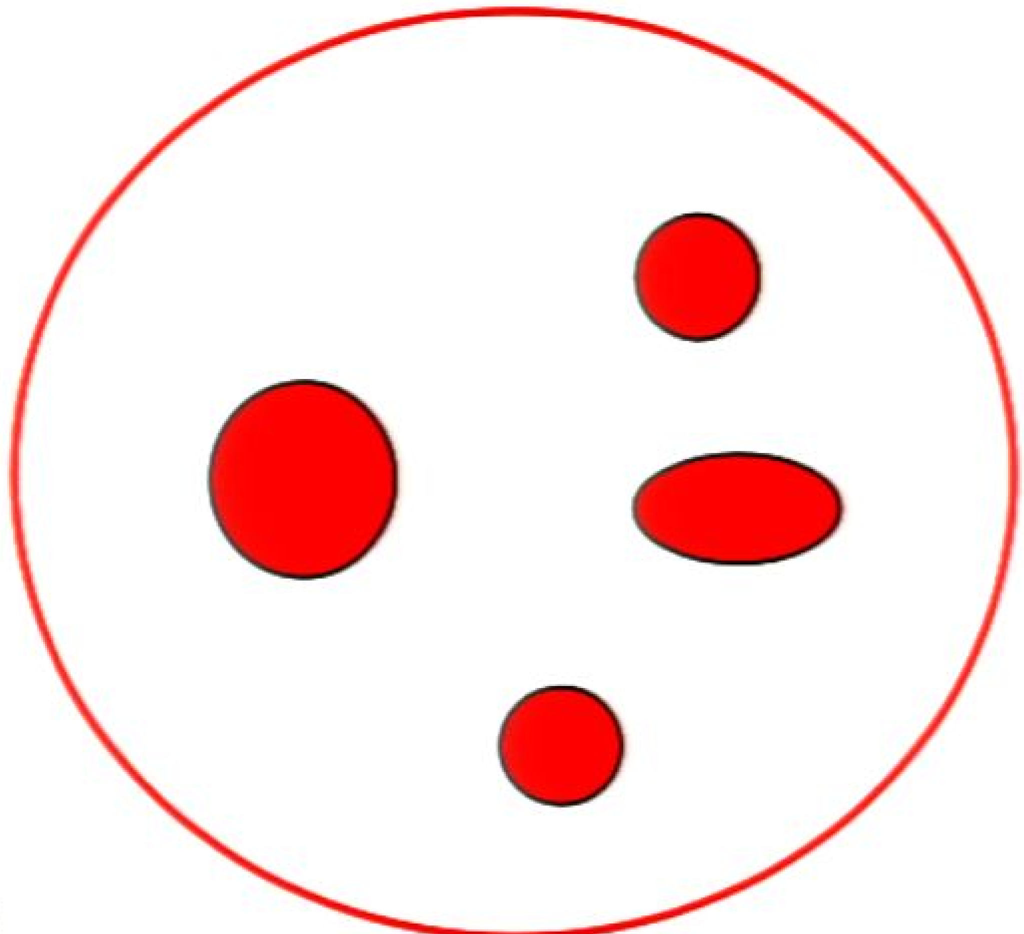

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fix choice (→ f) based on Jet property (→ Λ)

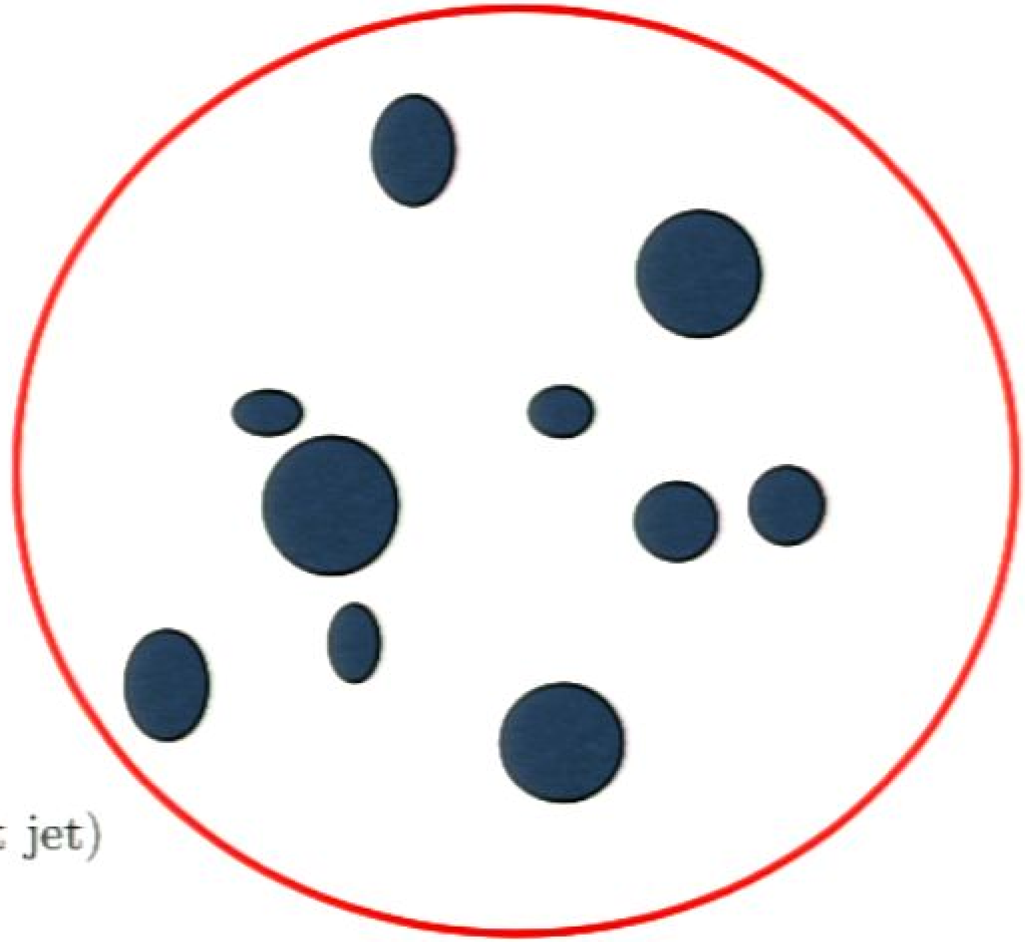
Pruning

Based on 2 conditions

If both hold true veto merging, eg. recombination is wide angle and asymmetric

$$z = \frac{\min(p_{T,i}, p_{T,j})}{|\vec{p}_{T,i} + \vec{p}_{T,j}|} < z_{\text{cut}}$$

$$\Delta R_{ij} > D_{\text{cut}} = M(\text{fat jet})/P_T(\text{fat jet})$$



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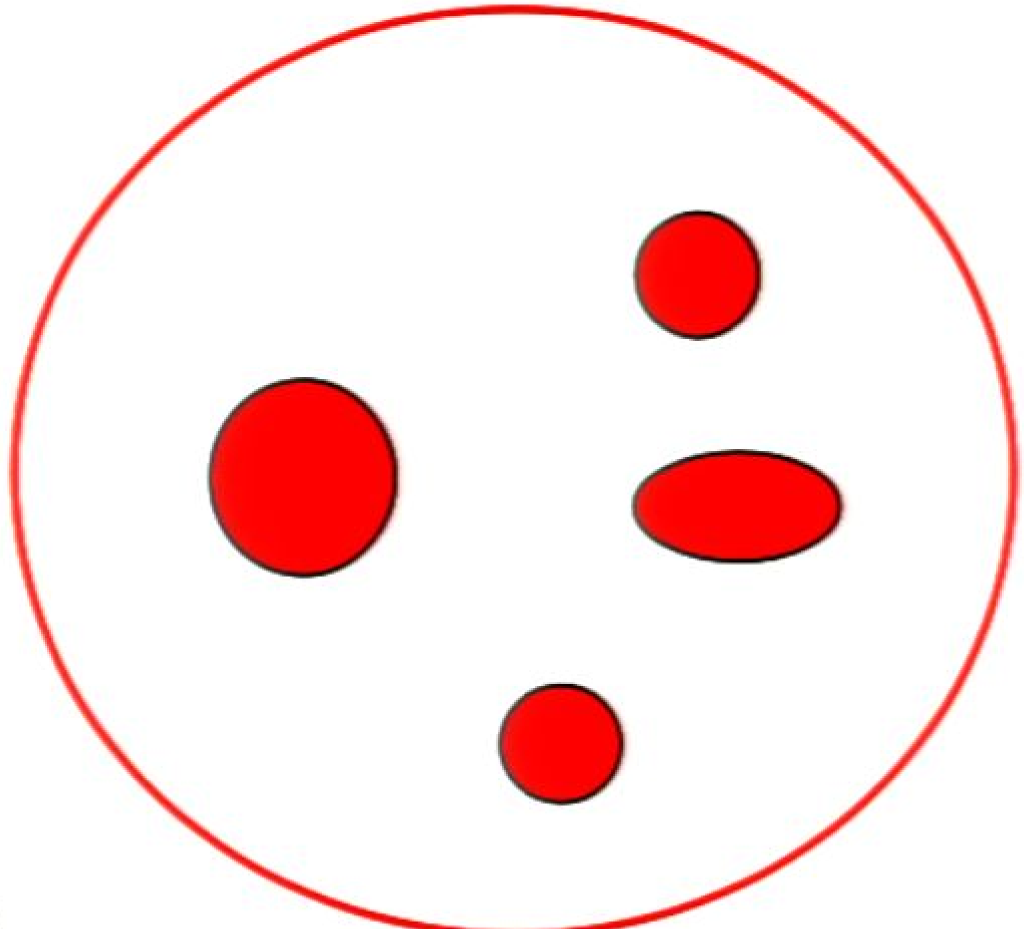

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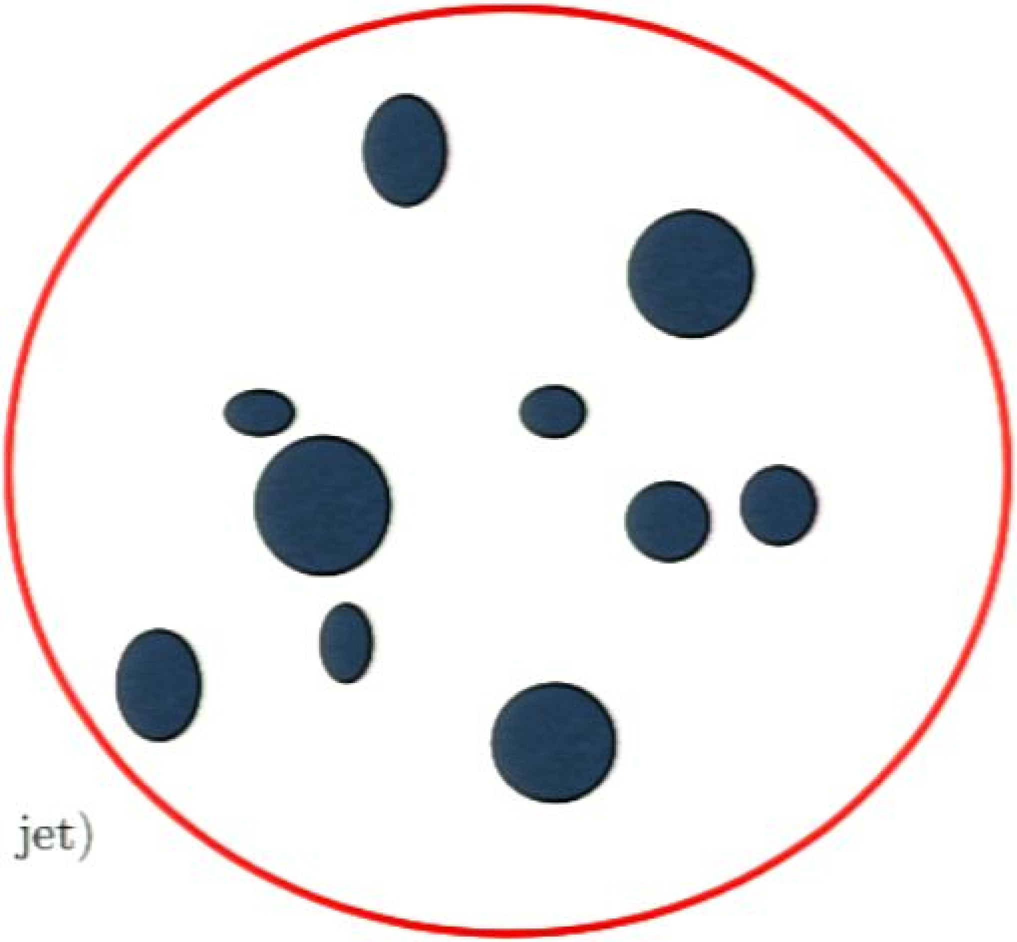

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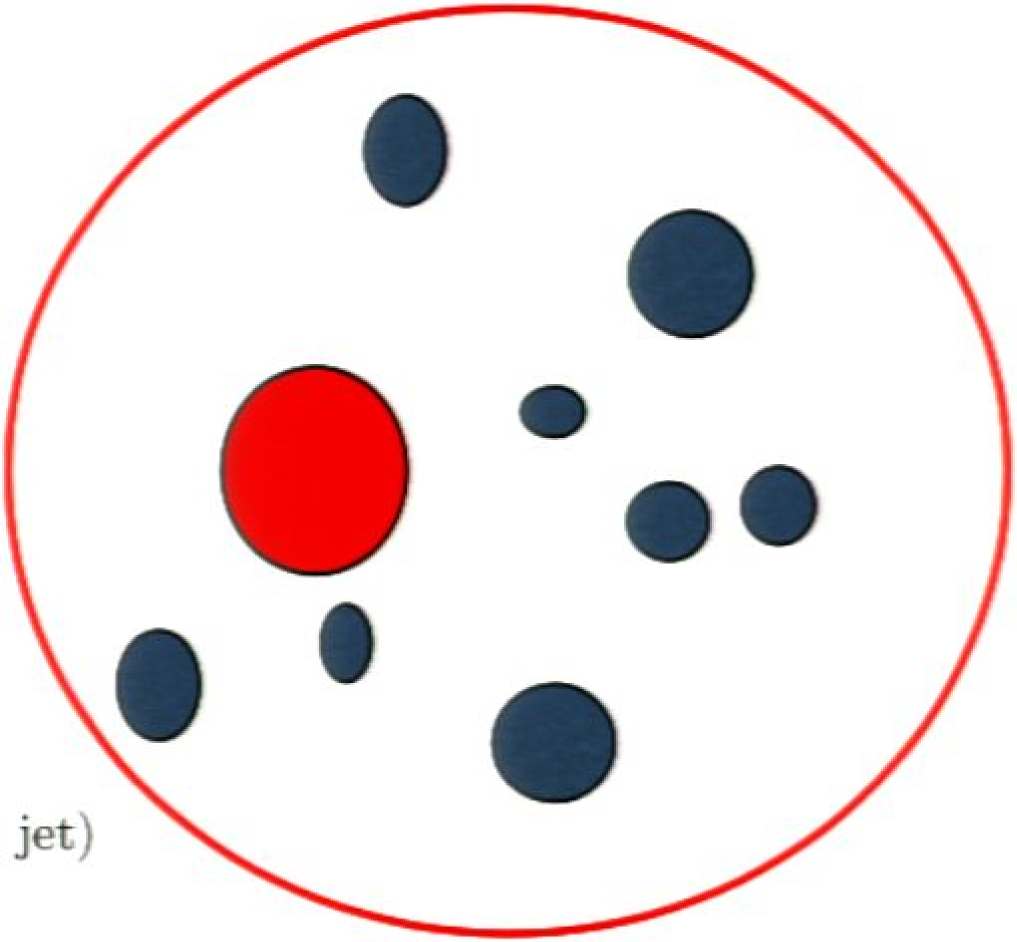

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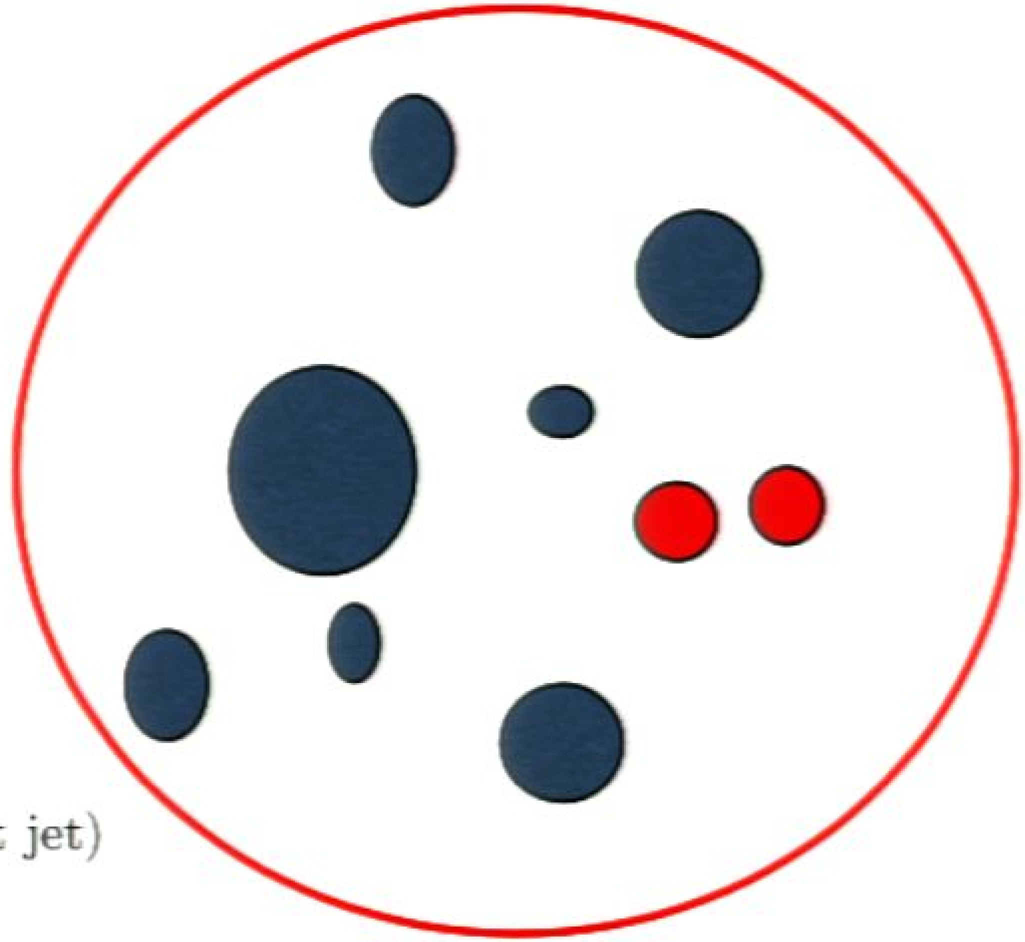

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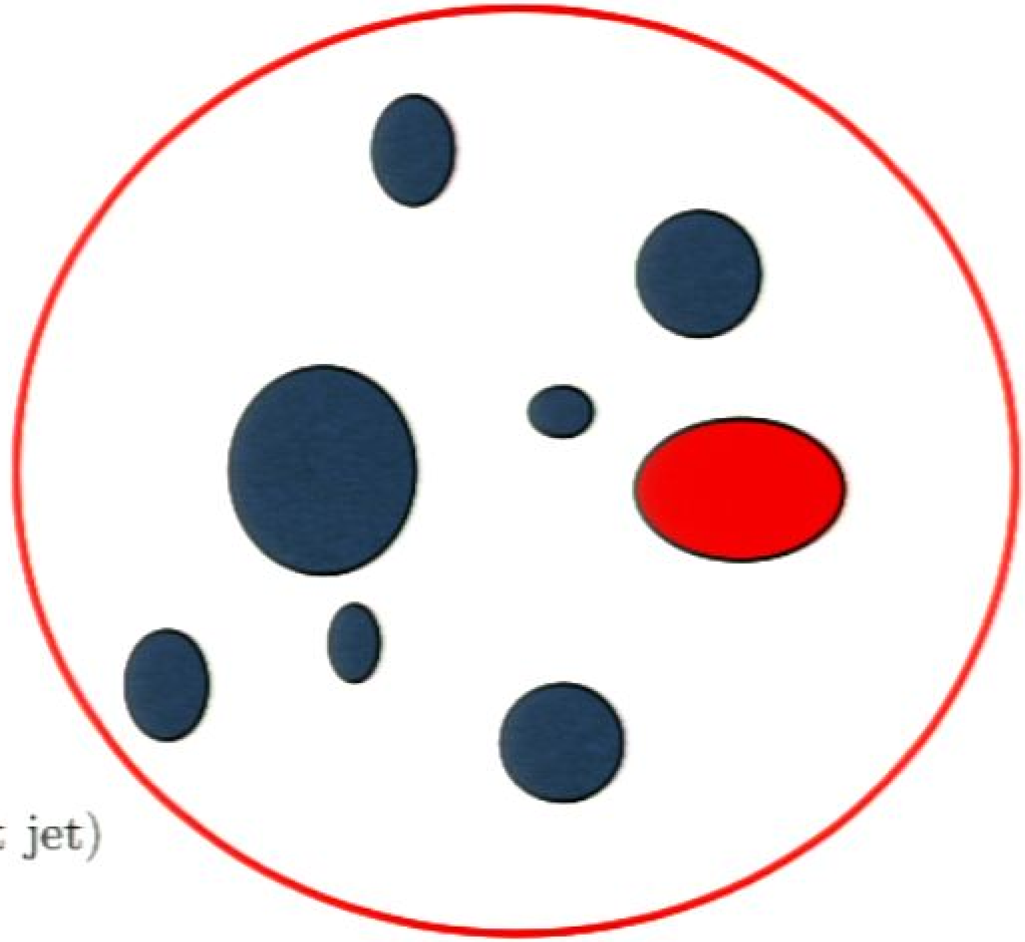
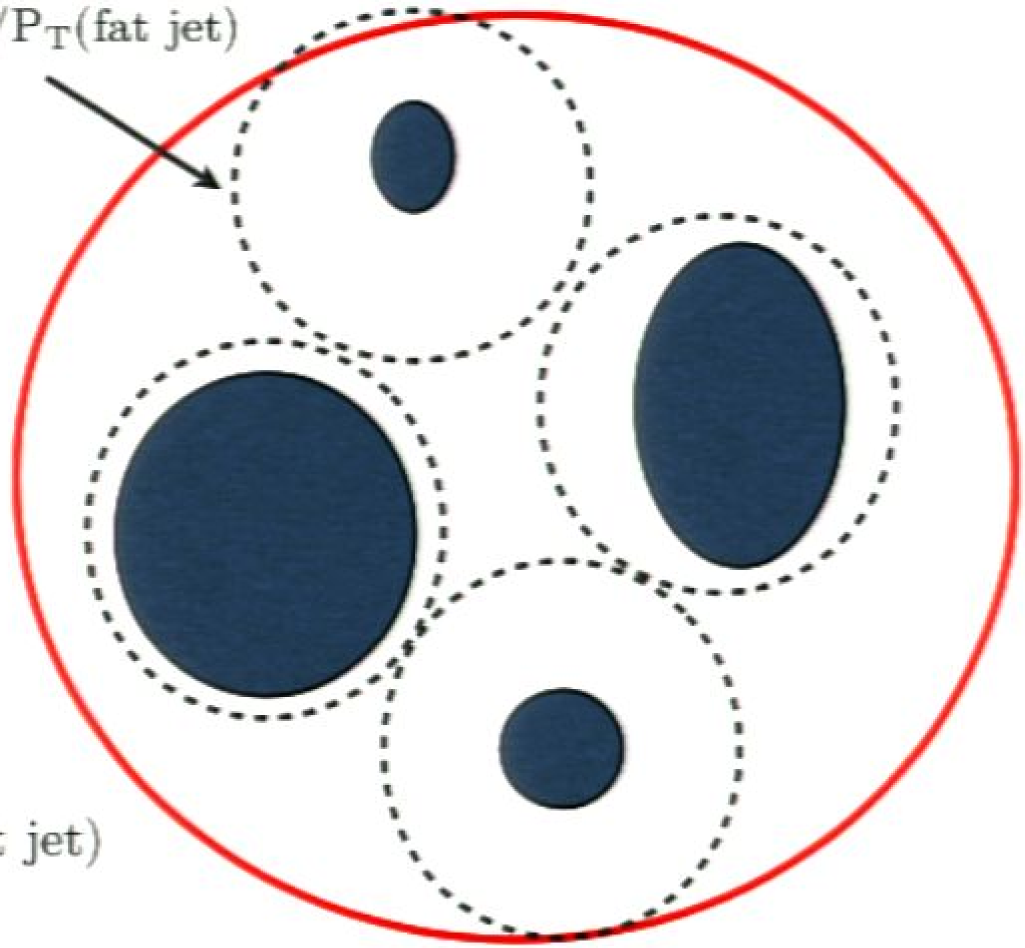


Pruning

$$R = M(\text{fat jet})/\text{P}_\text{T}(\text{fat jet})$$



Based on 2 conditions

If both hold true veto merging,
eg. recombination is wide angle and asymmetric

$$z = \frac{\min(p_{T,i}, p_{T,j})}{|\vec{p}_{T,i} + \vec{p}_{T,j}|} < z_{\text{cut}}$$

✓ $\Delta R_{ij} > D_{\text{cut}} = M(\text{fat jet})/P_T(\text{fat jet})$

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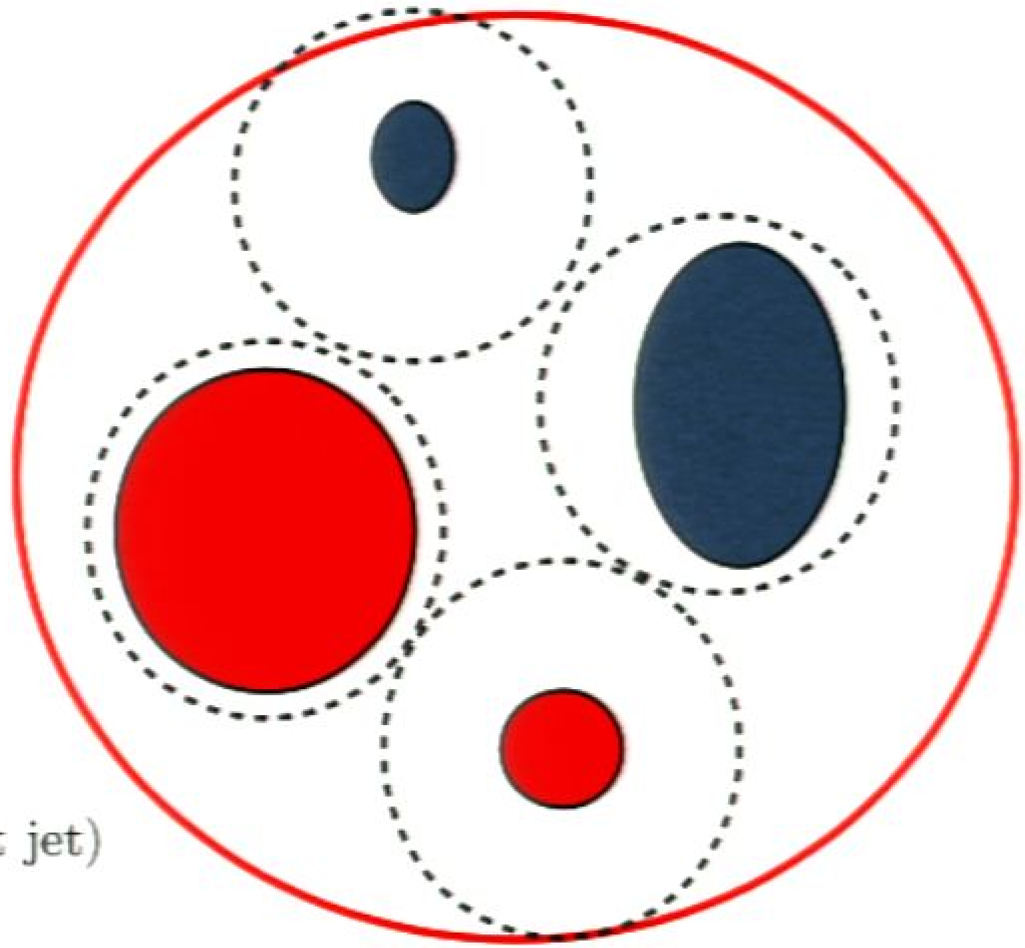

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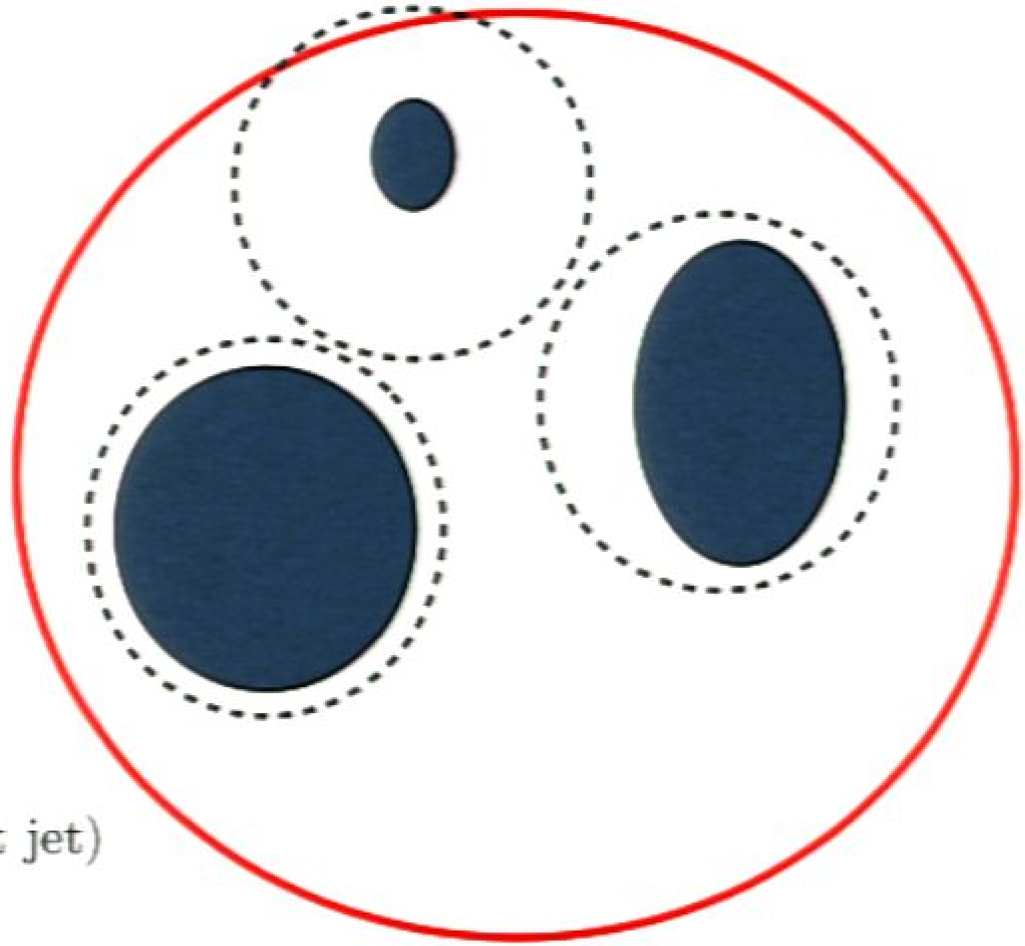

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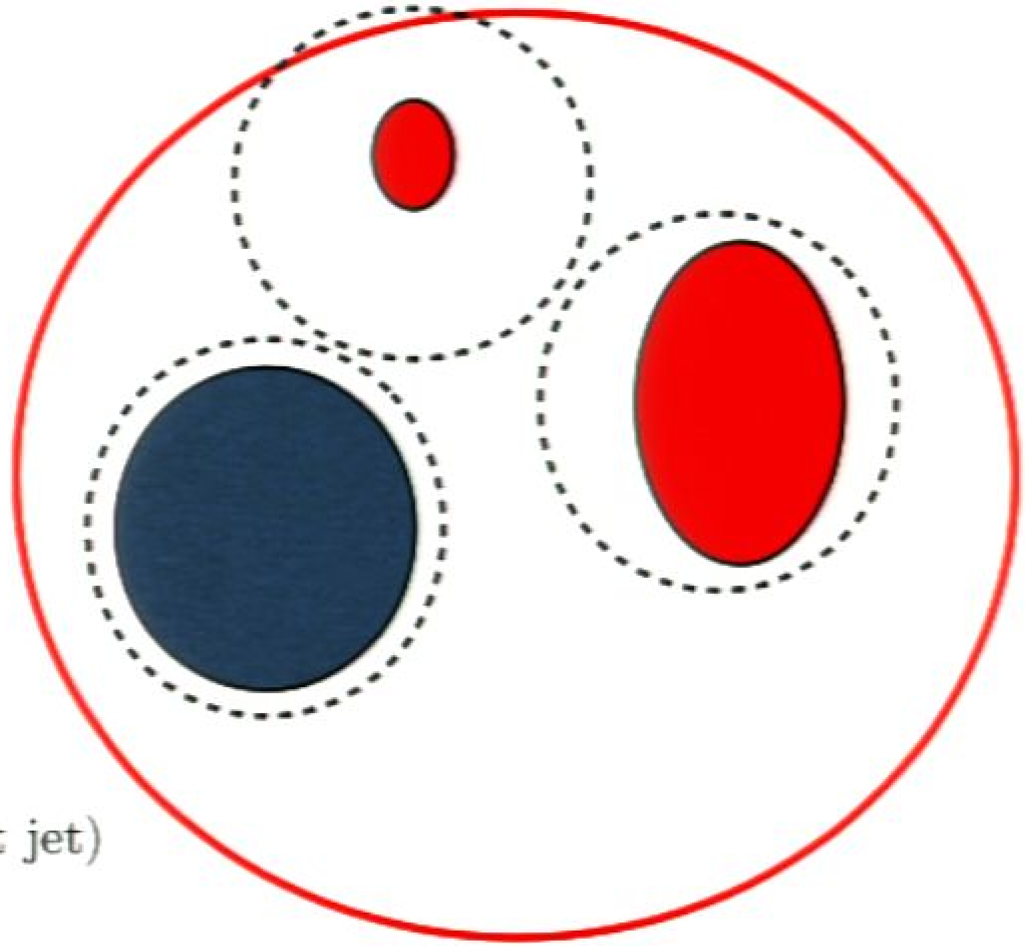

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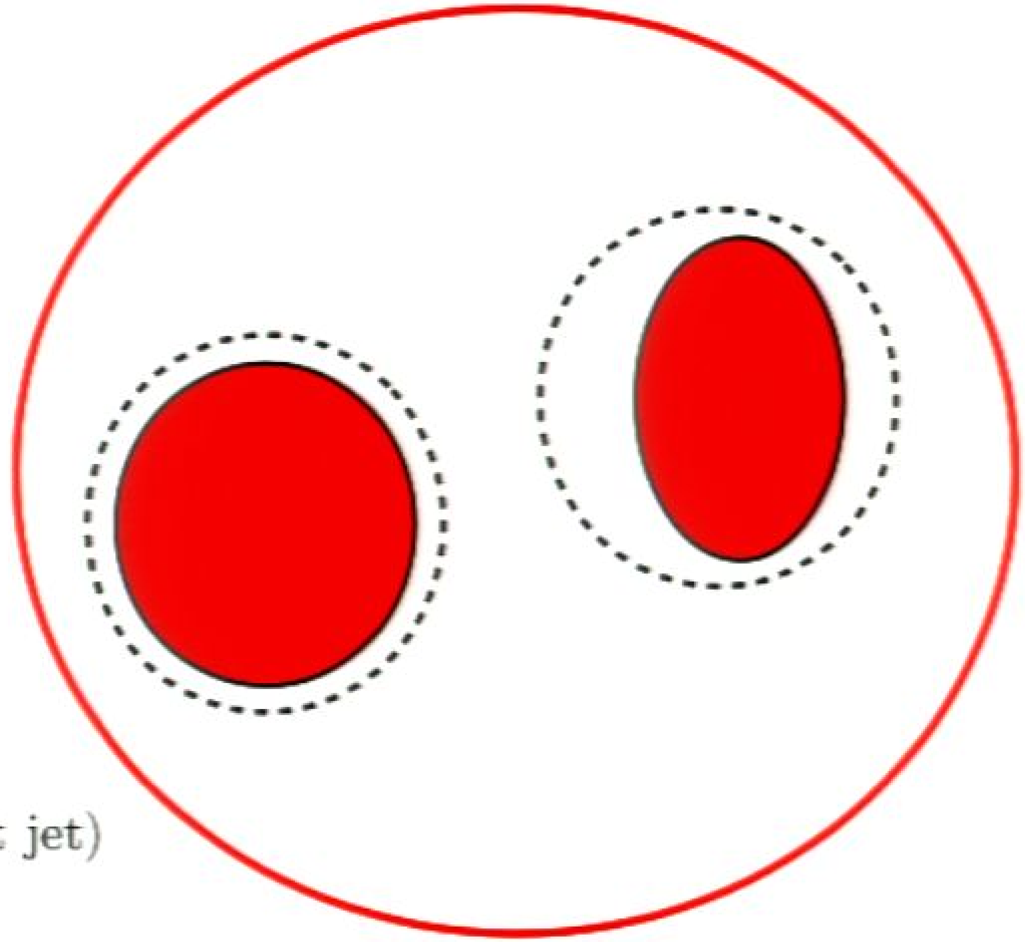

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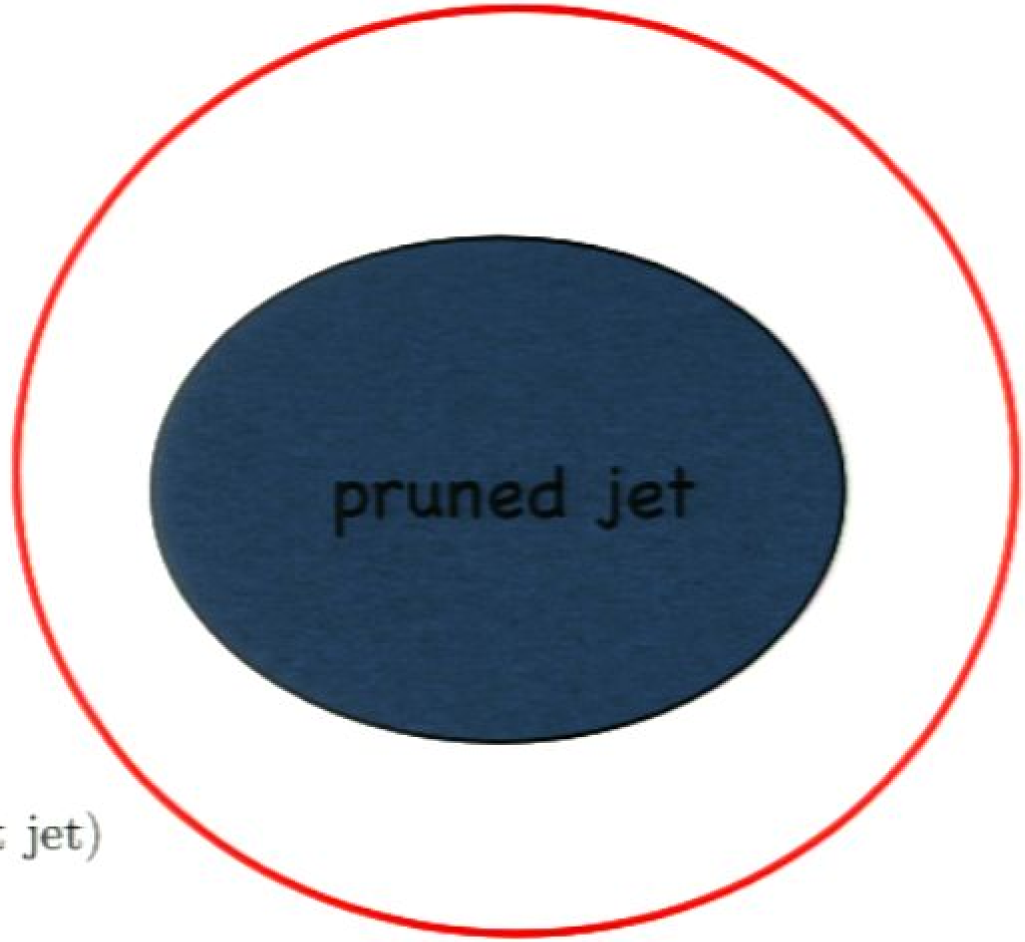


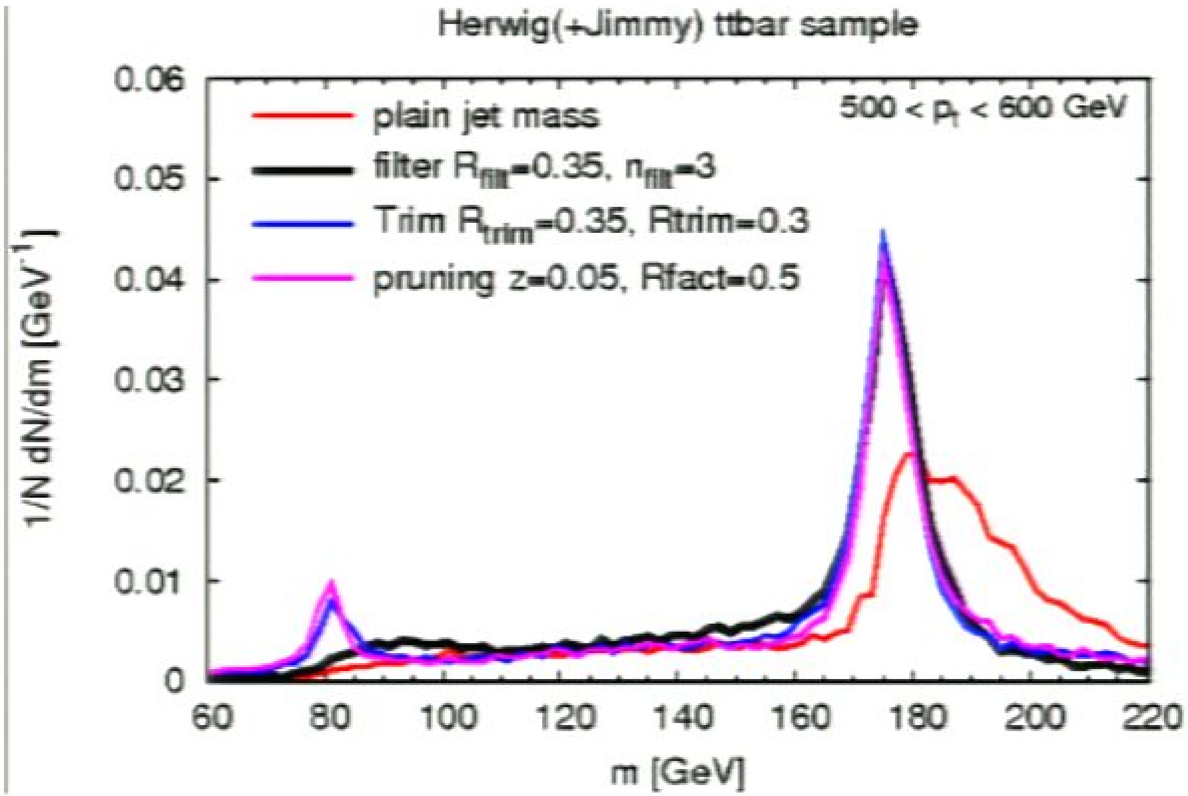
Comparison of the techniques

Pruning/Trimming can be generic tagging tools

Filtering needs input what to look for

For quantitative comparison:

https://atlaswiki.physics.ox.ac.uk/bin/view/Boost2010/PerformanceChecks



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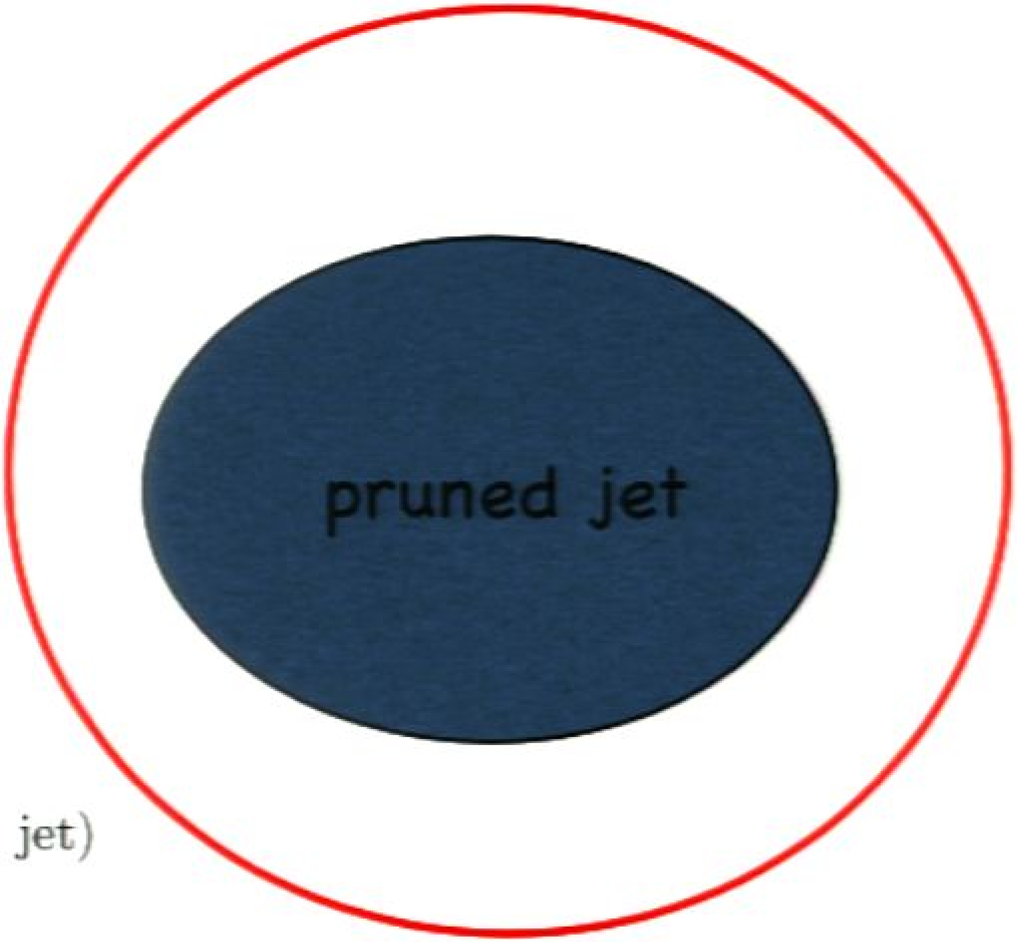

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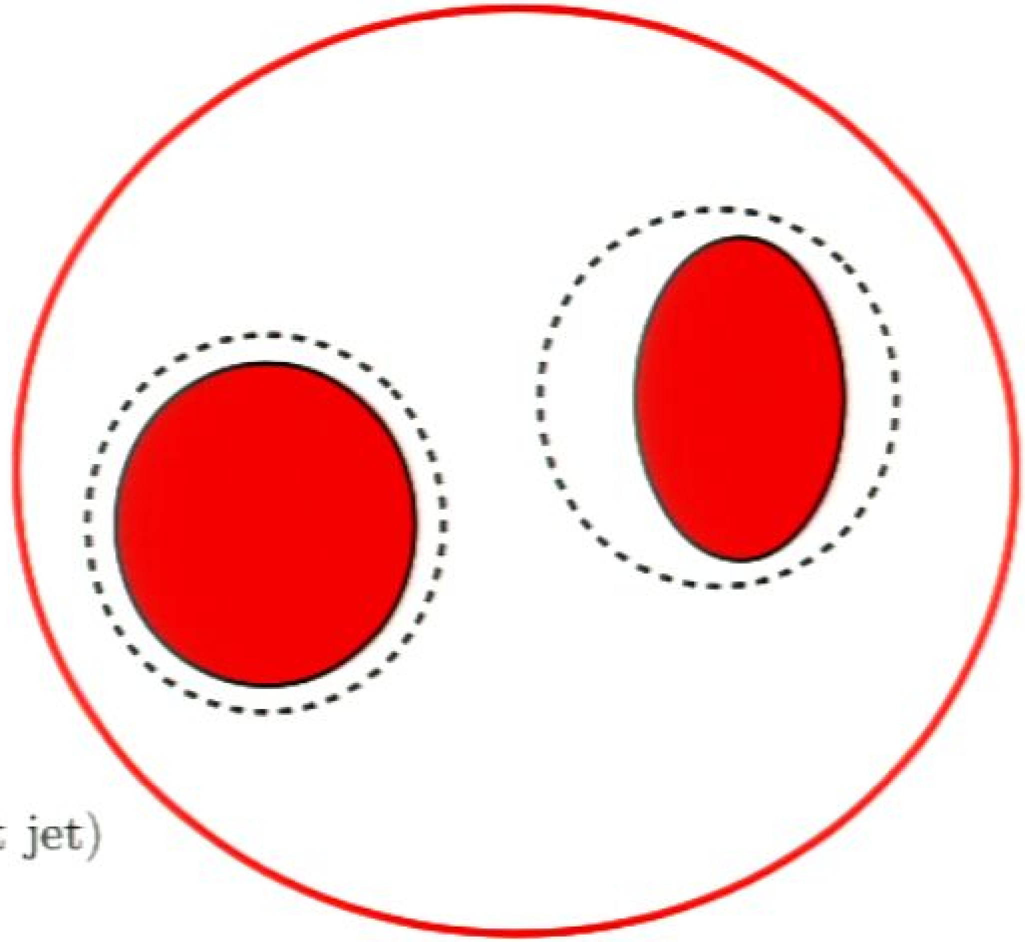

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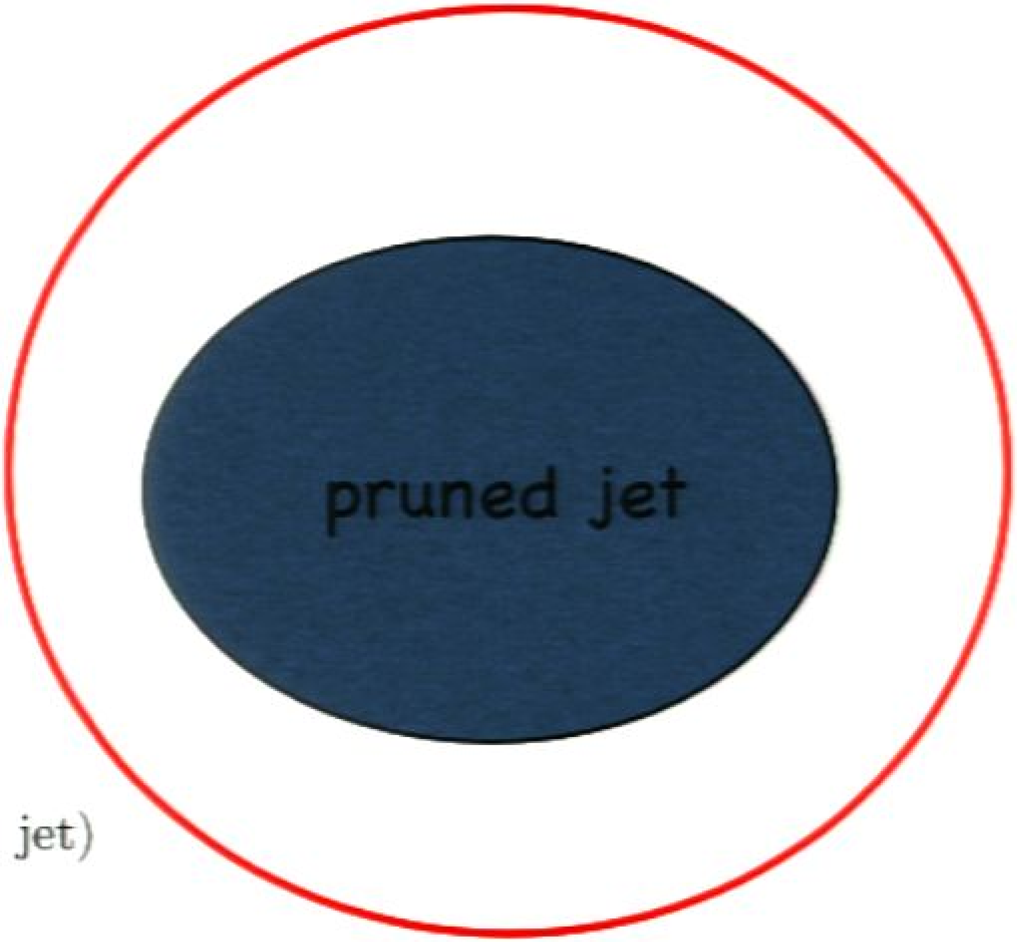

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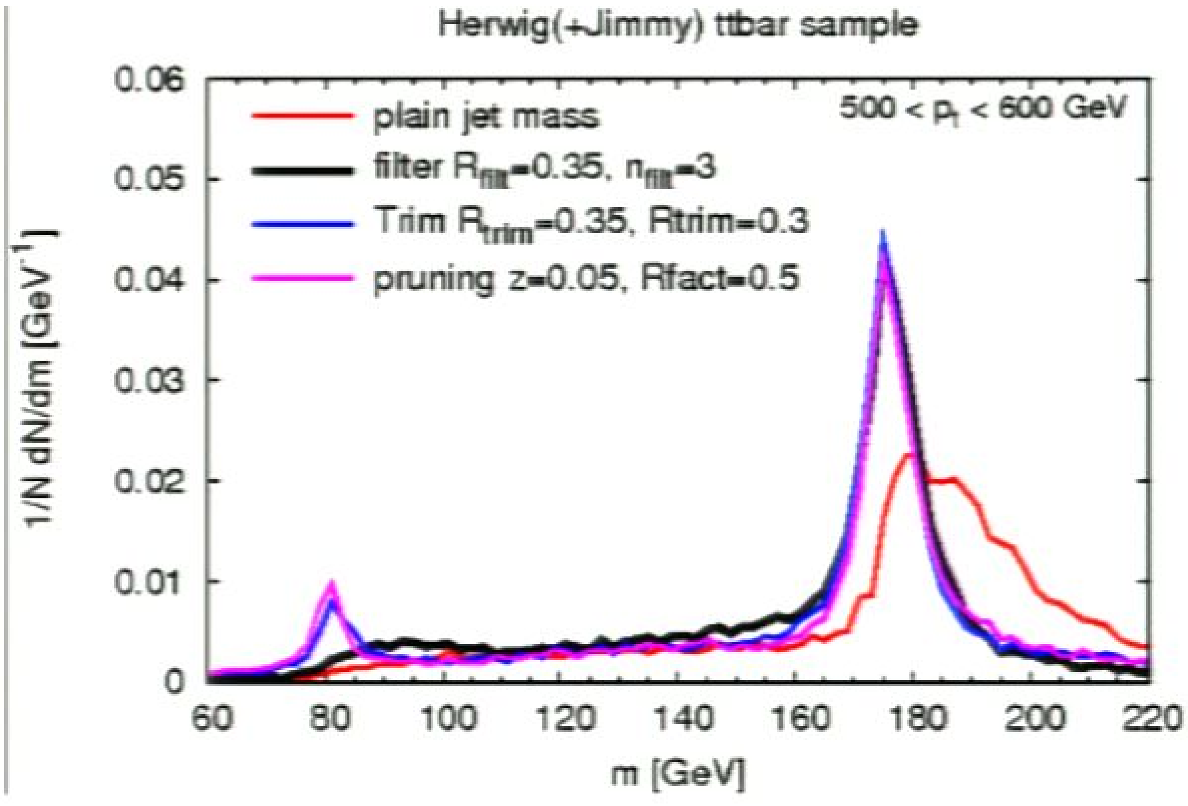
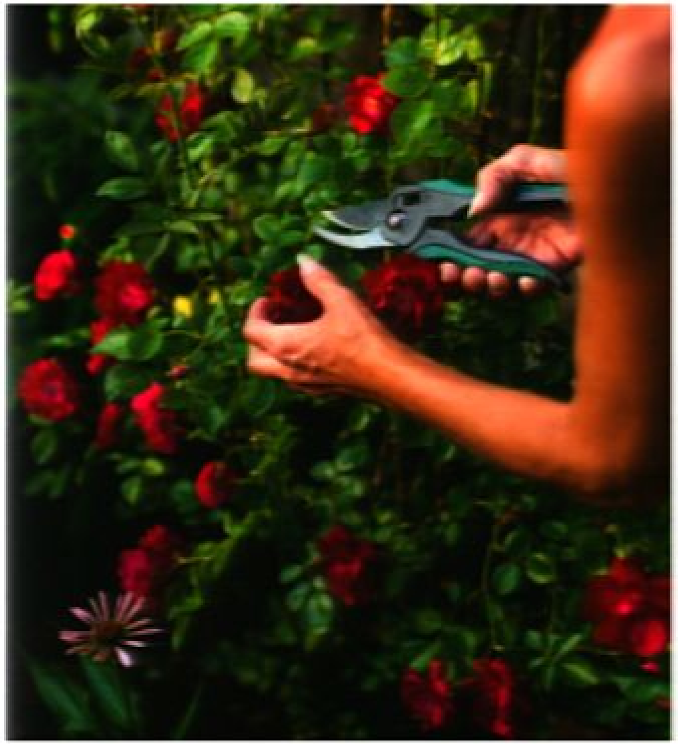
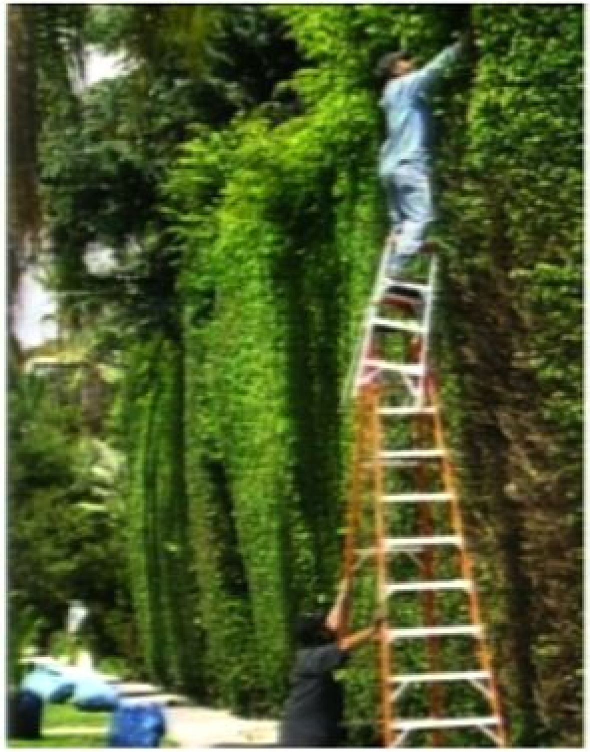


Application of jet grooming techniques to New Physics searches

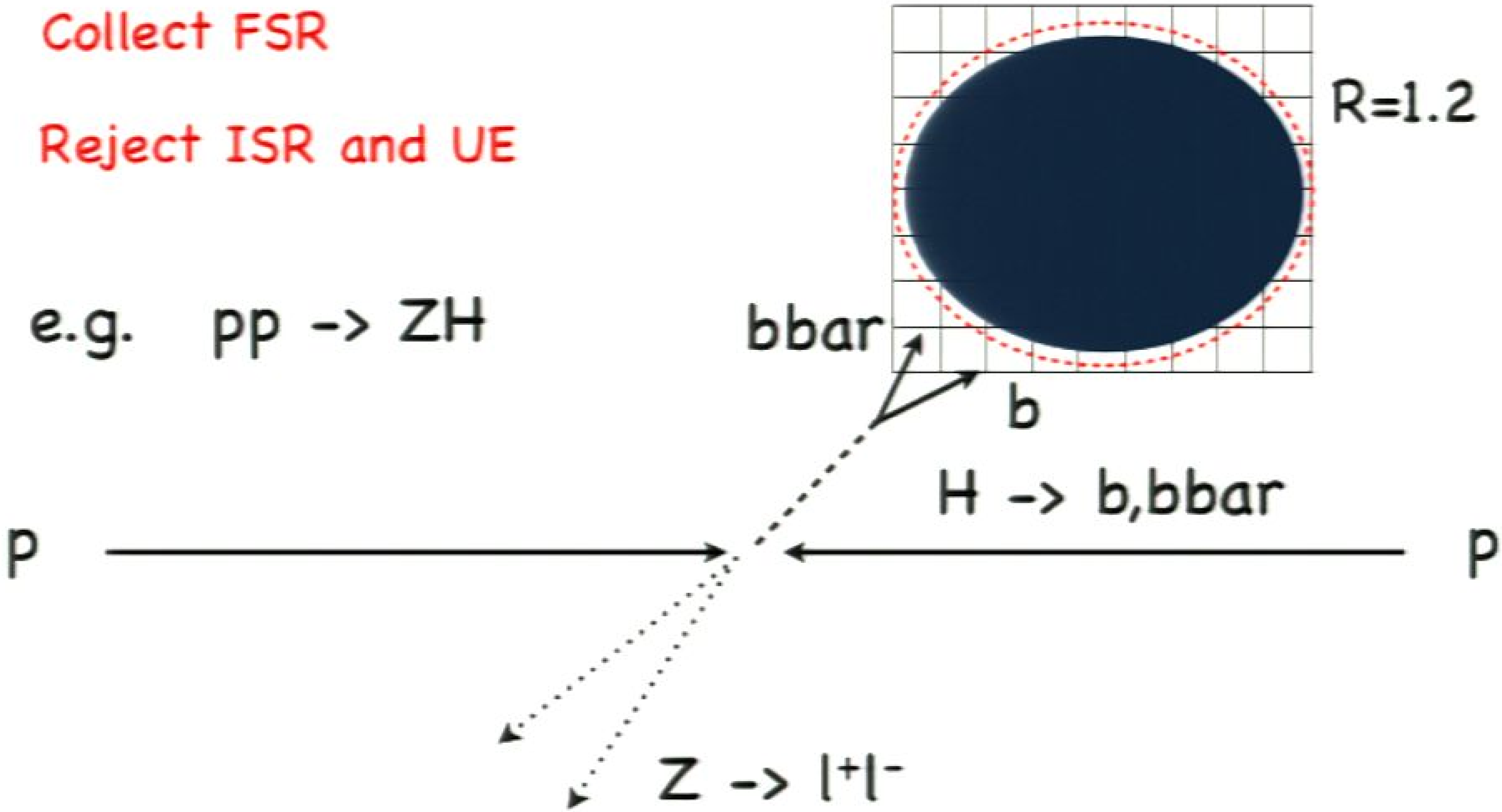

HV - Higgs discovery channel

[Butterworth, Davison, Rubin, Salam PRL 100 (2008)]

Collect FSR

Reject ISR and UE

e.g. pp -> ZH



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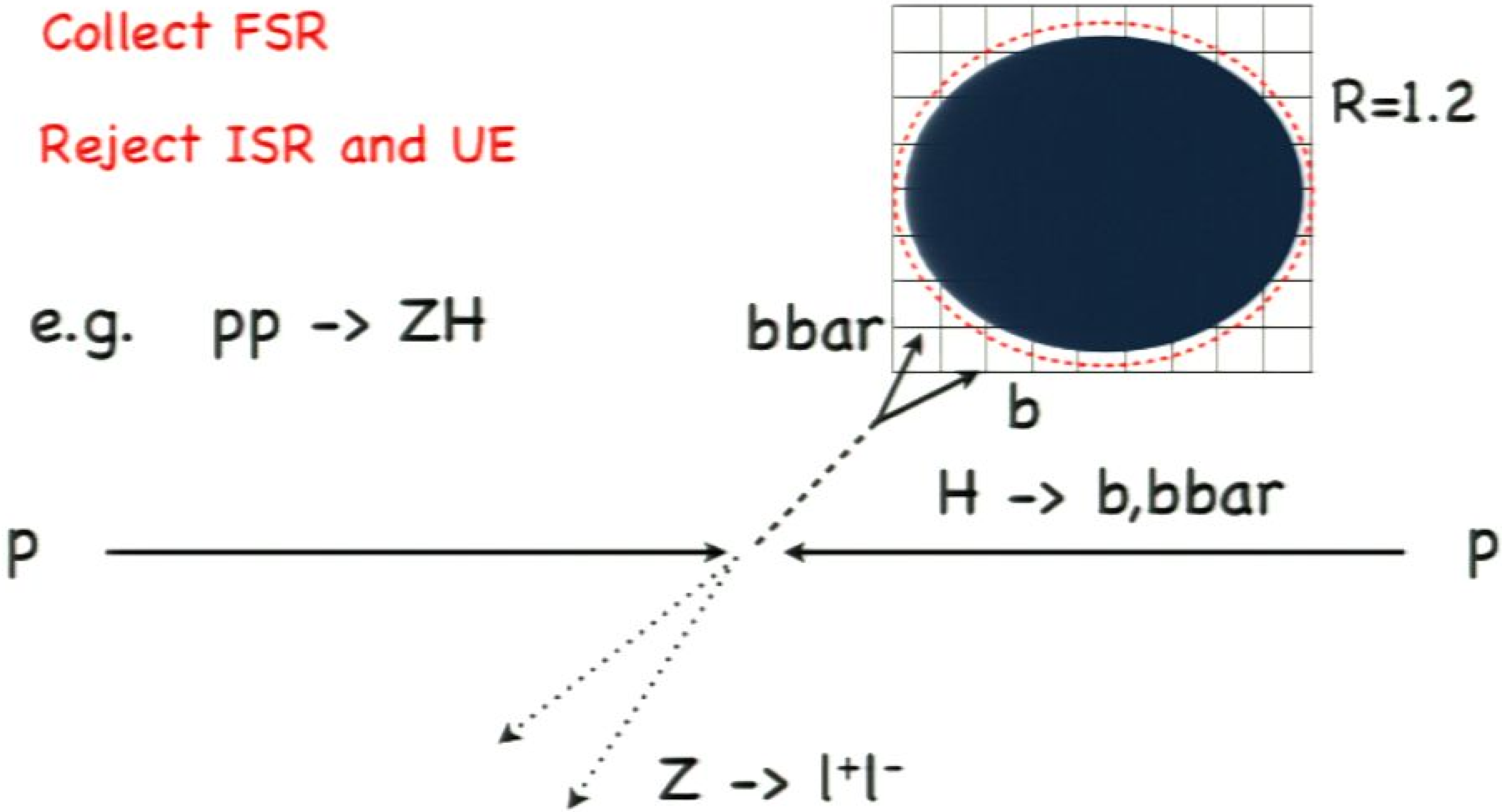


HV - Higgs discovery channel

[Butterworth, Davison, Rubin, Salam PRL 100 (2008)]

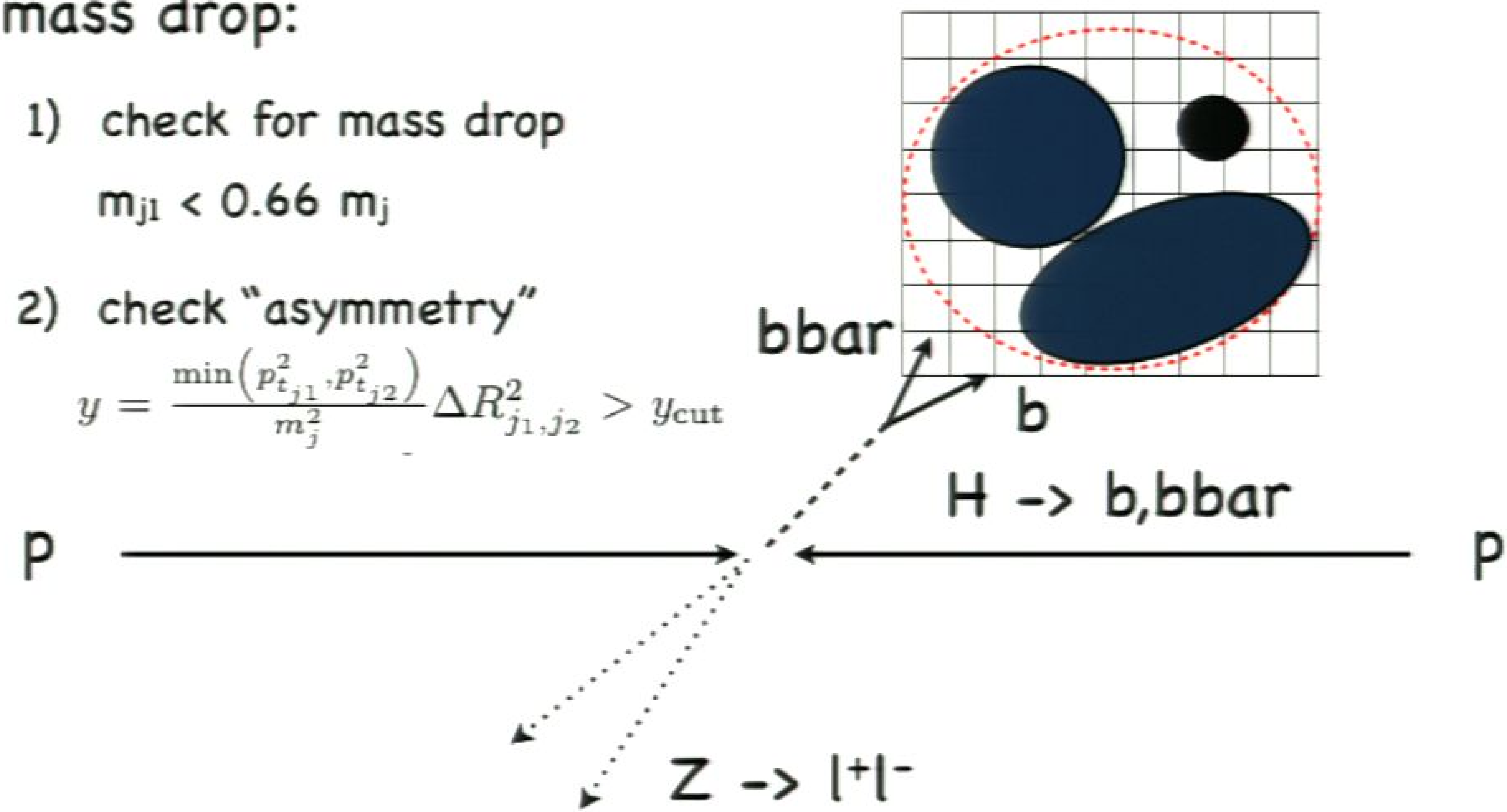
mass drop:

1) check for mass drop

   $m_{j1} < 0.66\, m_j$

2) check "asymmetry"

$$y = \frac{\min\left(p_{t_{j1}}^2, p_{t_{j2}}^2\right)}{m_j^2} \Delta R_{j_1,j_2}^2 > y_{\rm cut}$$

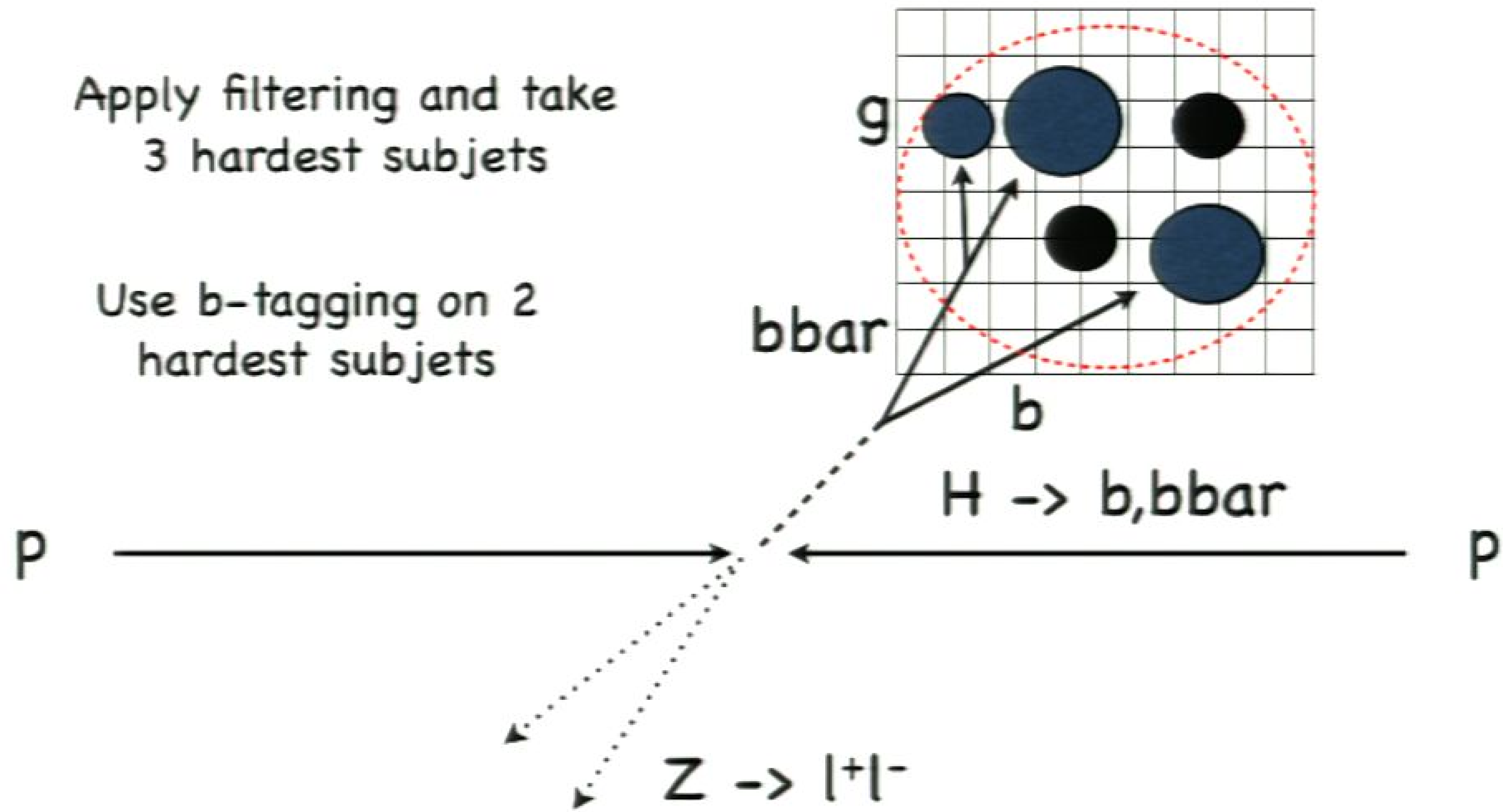


HV - Higgs discovery channel

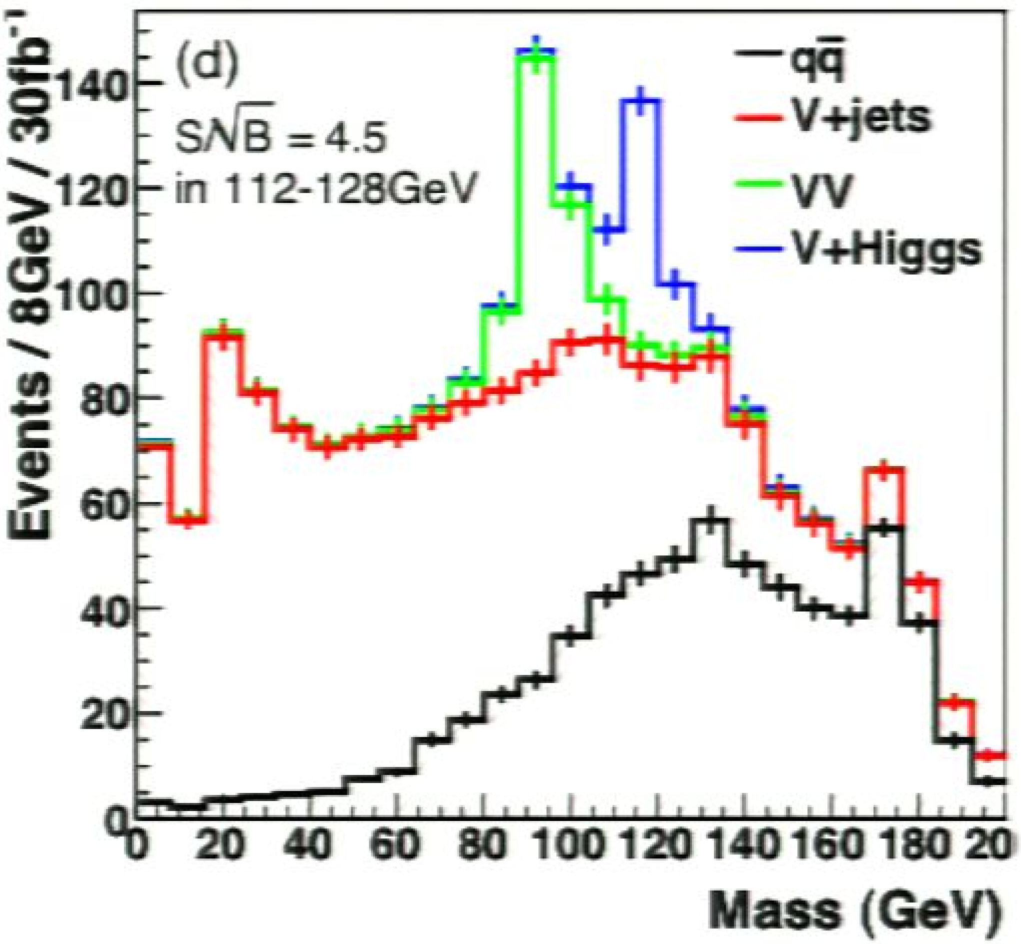
[Butterworth, Davison, Rubin, Salam PRL 100 (2008)]

Apply filtering and take 3 hardest subjets

Use b-tagging on 2 hardest subjets



BDRS Result



- LHC 14 TeV; 30 fb^{-1}
- HERWIG/JIMMY/Fastjet cross-checked with PYTHIA with "ATLAS tune"
- 60% b-tag; 2% mistag

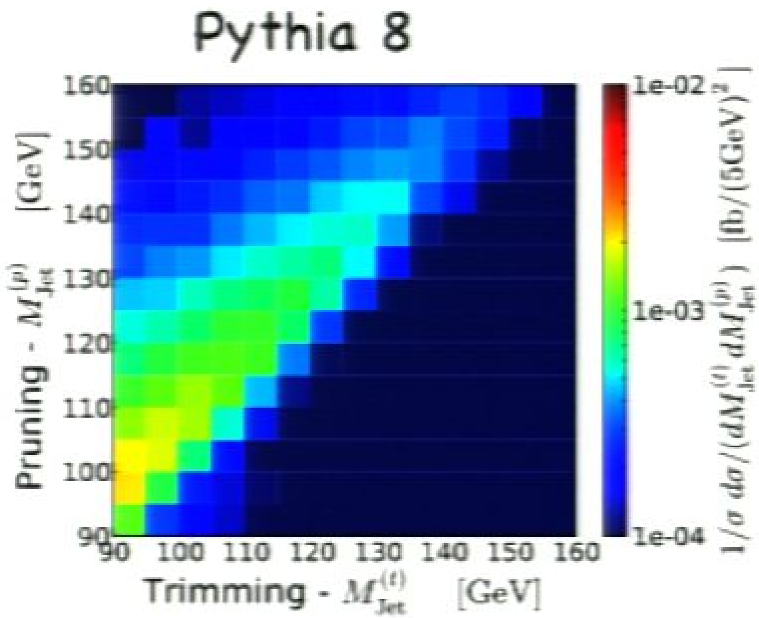
$S_{BDRS} \approx 4.2$ versus $S_{ATLAS} \approx 3.7$

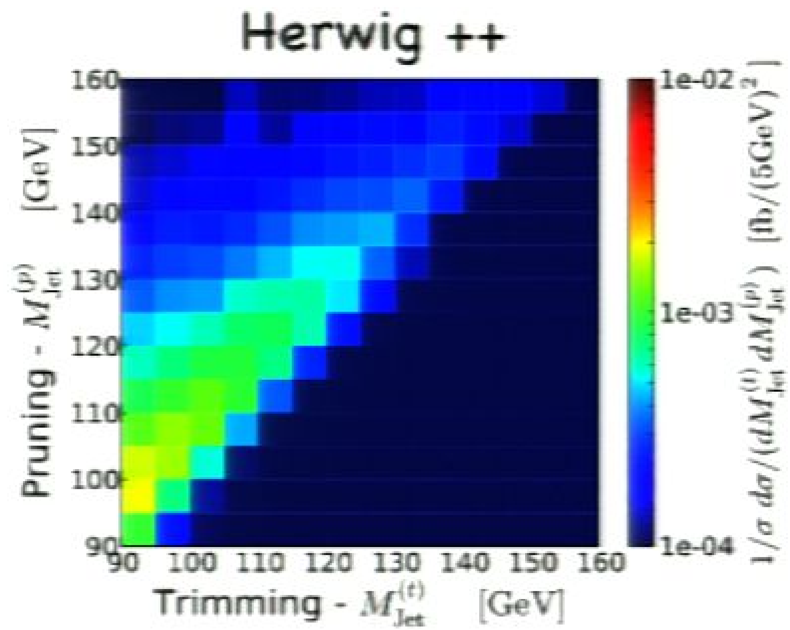
Grooming techniques work differently

Do they provide different information?

If yes,

combine them to gain more insights

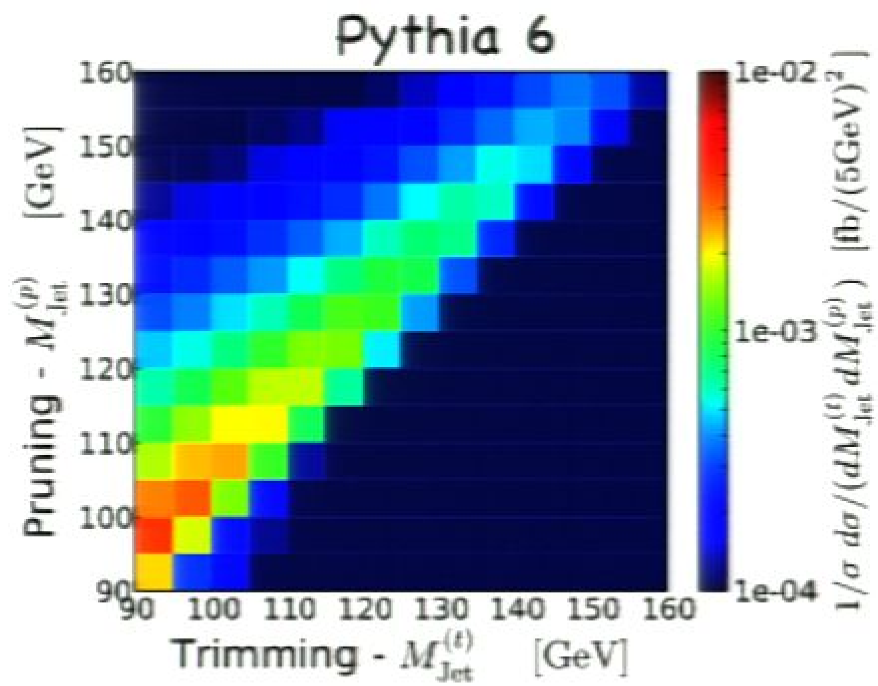




Dijet samples

hardest jet
pT > 150 GeV

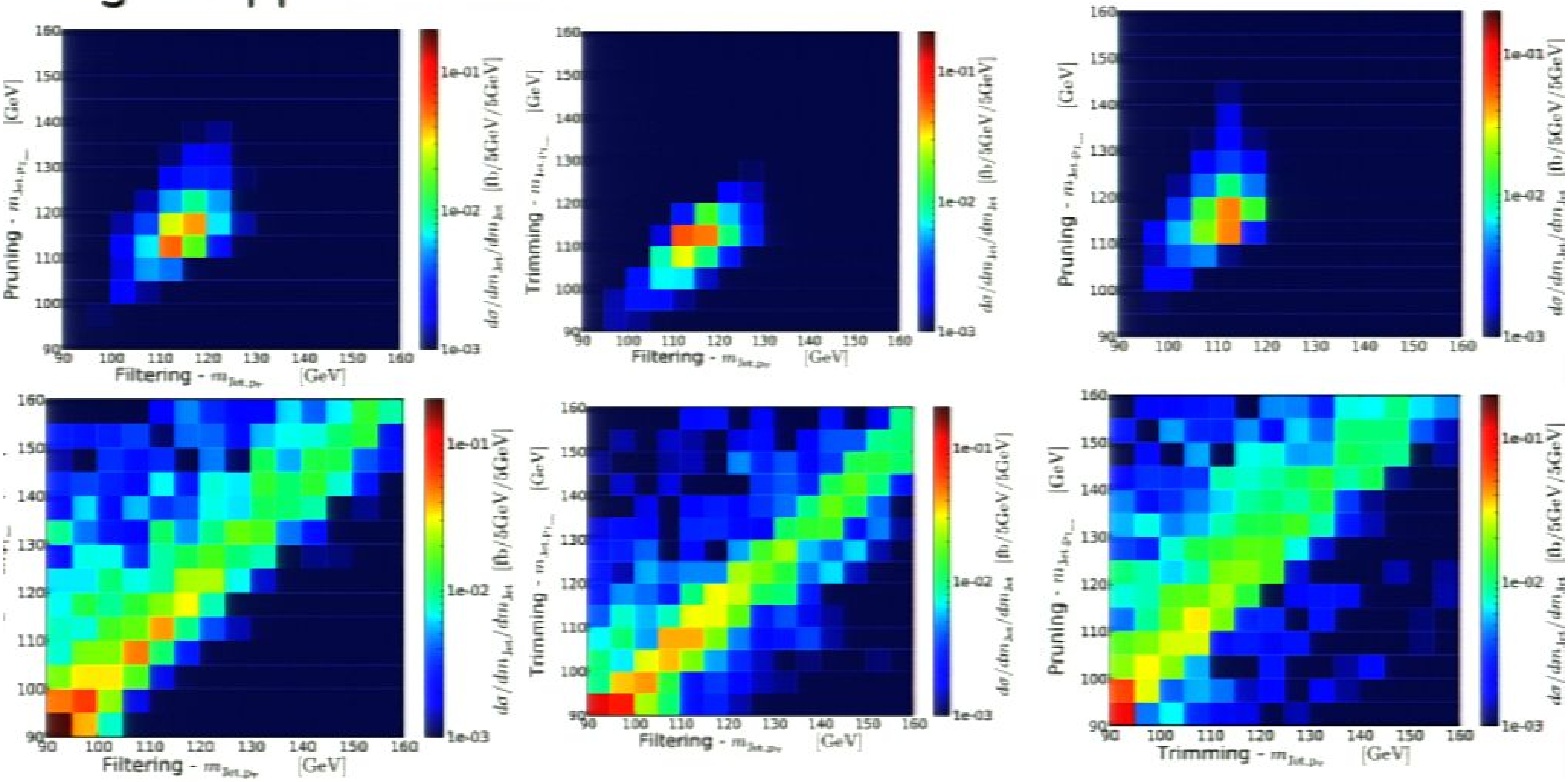
with granularity and
cell pT > 0.5 GeV



chosen:
R=1.2
Pruning (CA)
Trimming (aKT,KT)

Combine Mass-Drop/Filtering with Pruning and Trimming

signal: pp->HZ->bbll [Soper, MS JHEP 1008 (2010)]



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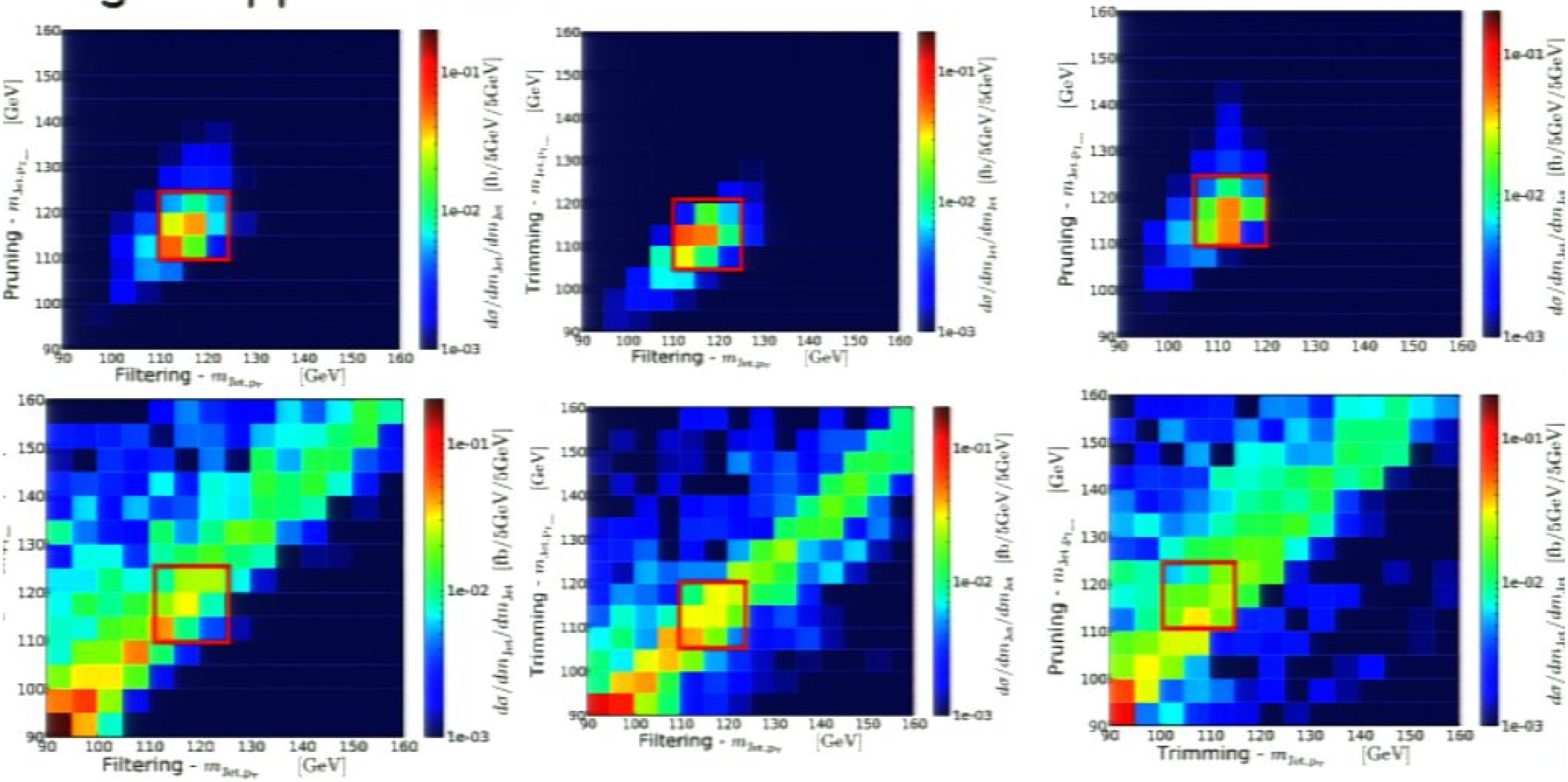
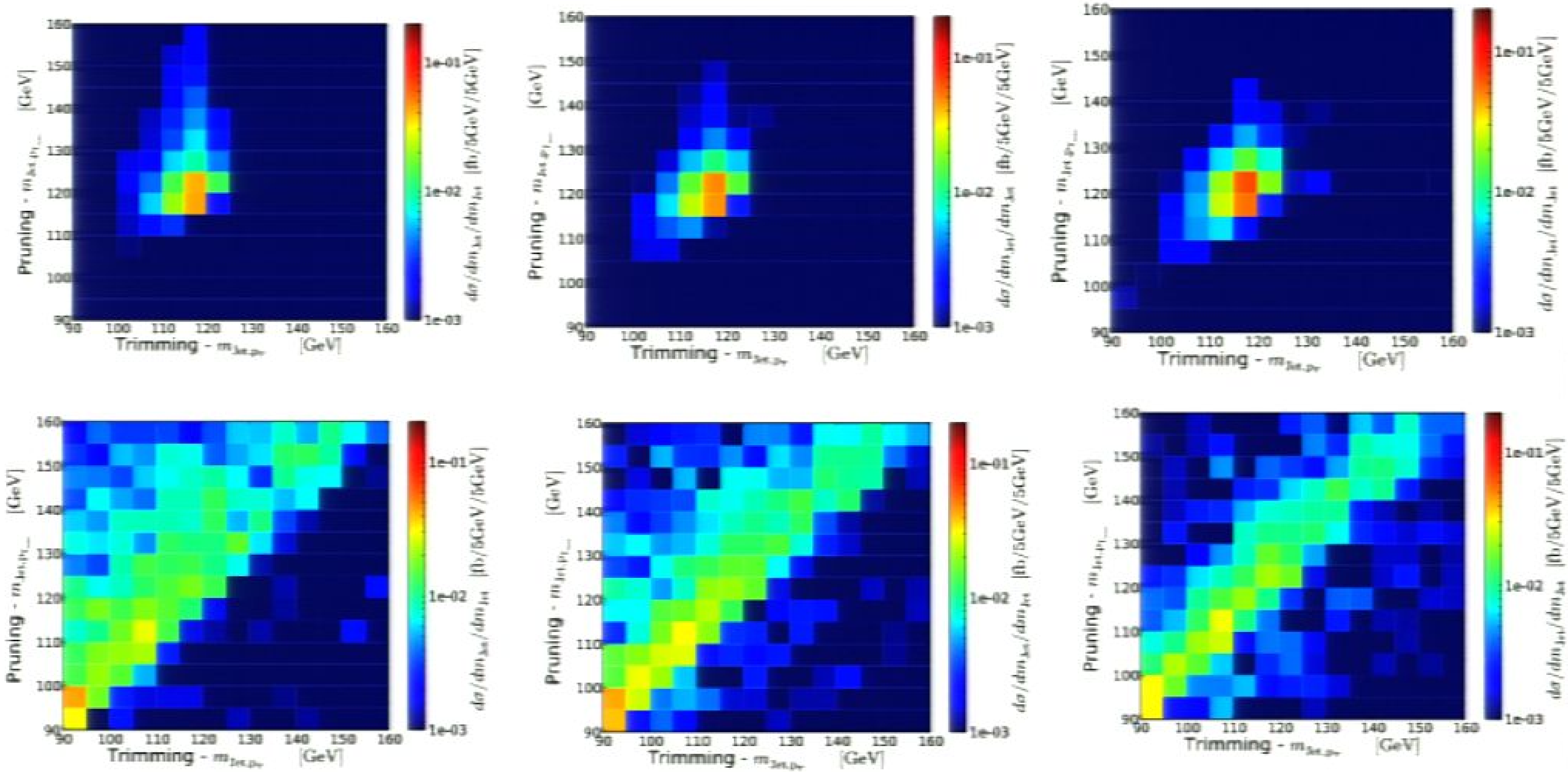


Pruning tuning:

Z=0.05 Z=0.1 Z=0.2



Exploitation of asymmetry

Cut based approach

Exp. Likelihood Ratio $$\langle \mathcal{L}(\{n\})\rangle_{\rm SB} = \sum_J \left[(s_J + b_J)\log\left(1+\frac{s_J}{b_J}\right) - s_J \right]$$

	$M_{\rm Jet}^{(f)} \in W_f$	$M_{\rm Jet}^{(f)} \in W_f$ $M_{\rm Jet}^{(t)} \in W_t$	$M_{\rm Jet}^{(f)} \in W_f$ $M_{\rm Jet}^{(p)} \in W_p$	$M_{\rm Jet}^{(p)} \in W_p$ $M_{\rm Jet}^{(t)} \in W_t$	$M_{\rm Jet}^{(p)} \in W_p$ $M_{\rm Jet}^{(t)} \in W_t$
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Backgrnd cross section [fb]	0.30	0.20	0.17	0.16	0.13
s/b	0.67	0.90	1.0	1.1	1.3
$s/\sqrt{b}$ $(\int dL = 30\ {\rm fb}^{-1})$	2.0	2.2	2.3	2.3	2.4
$\langle\mathcal{L}(n)\rangle_{\rm SB}$ $(\int dL = 30\ {\rm fb}^{-1})$	1.7	1.9	2.0	2.1	2.2

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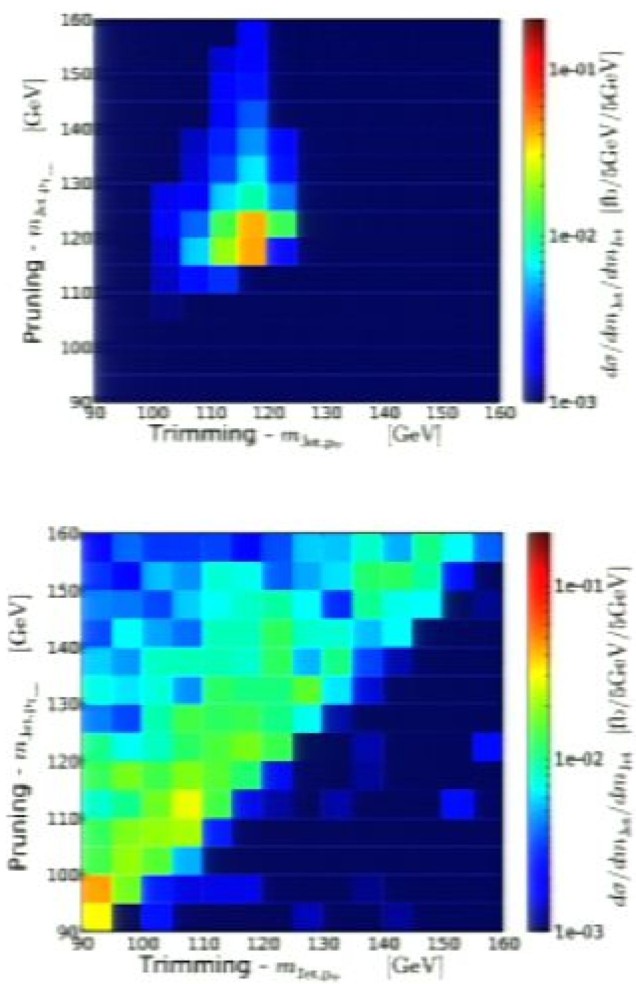

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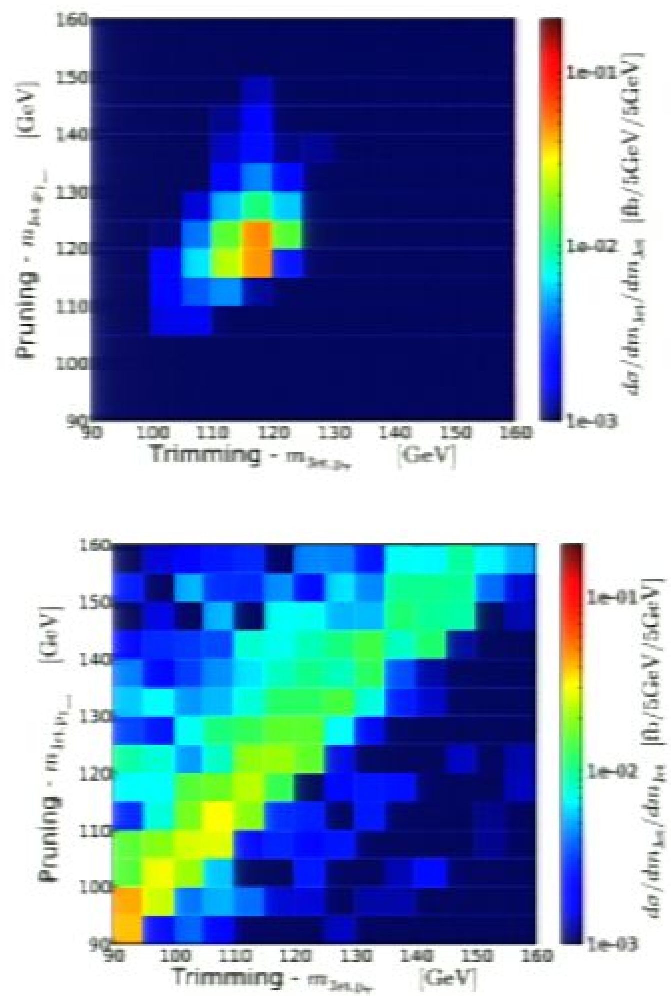
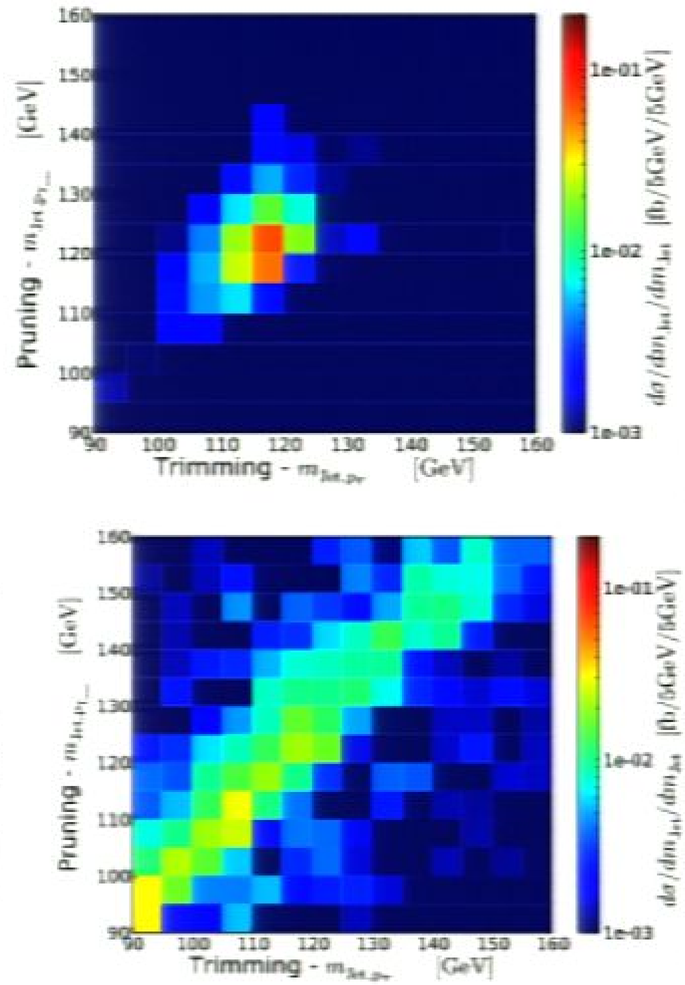


Z=0.2



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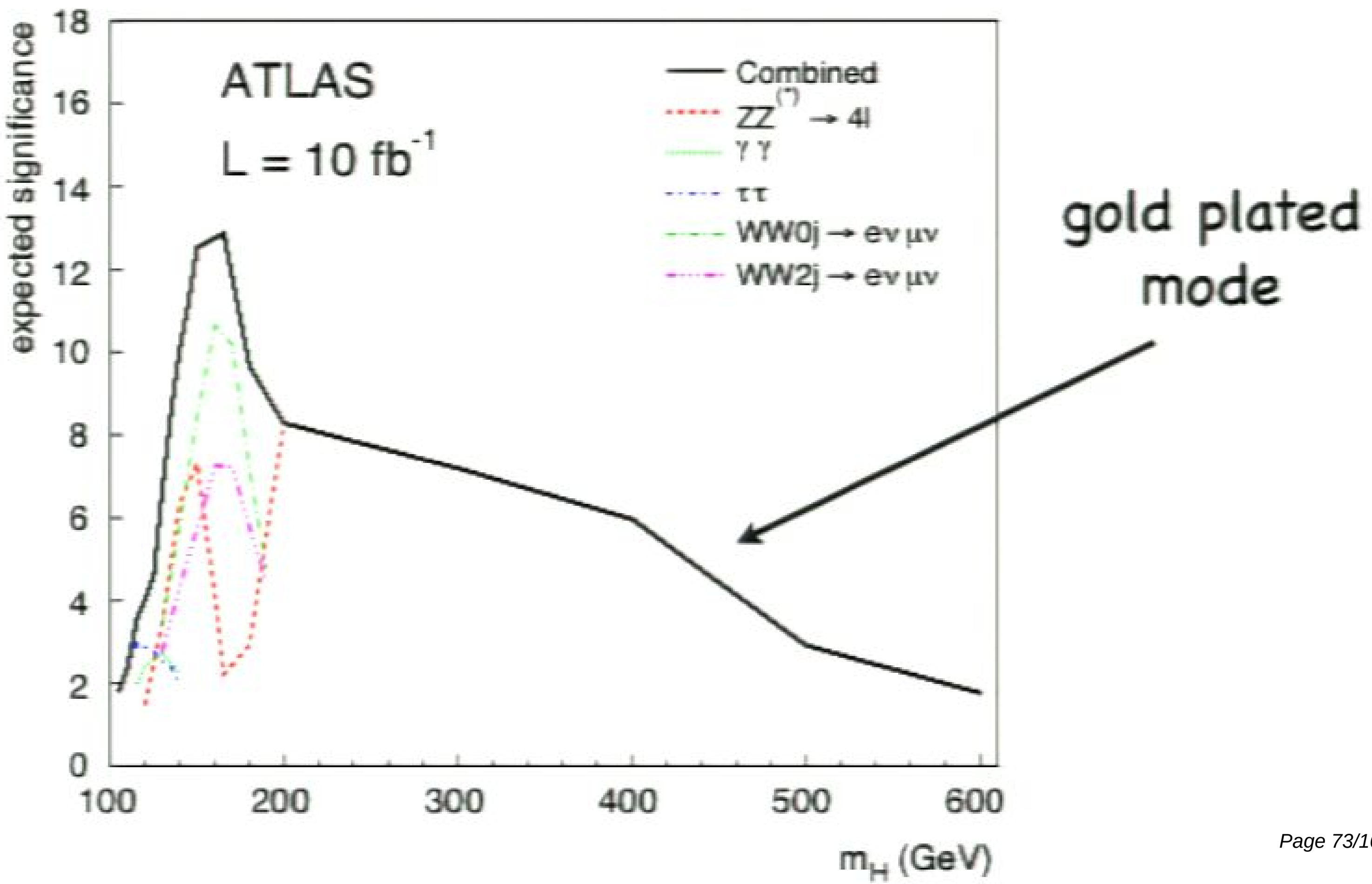
Heavy Higgs search in the 'forgotten channel'

[ATLAS TDR, 2008]



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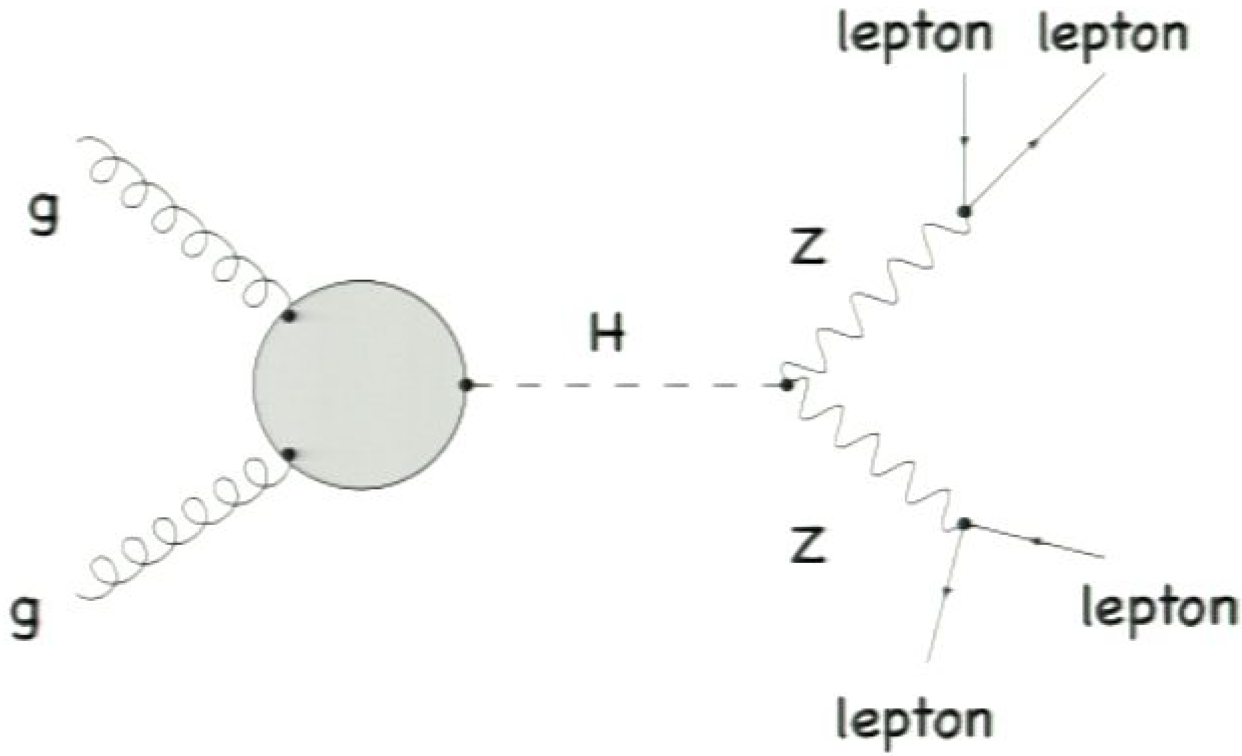

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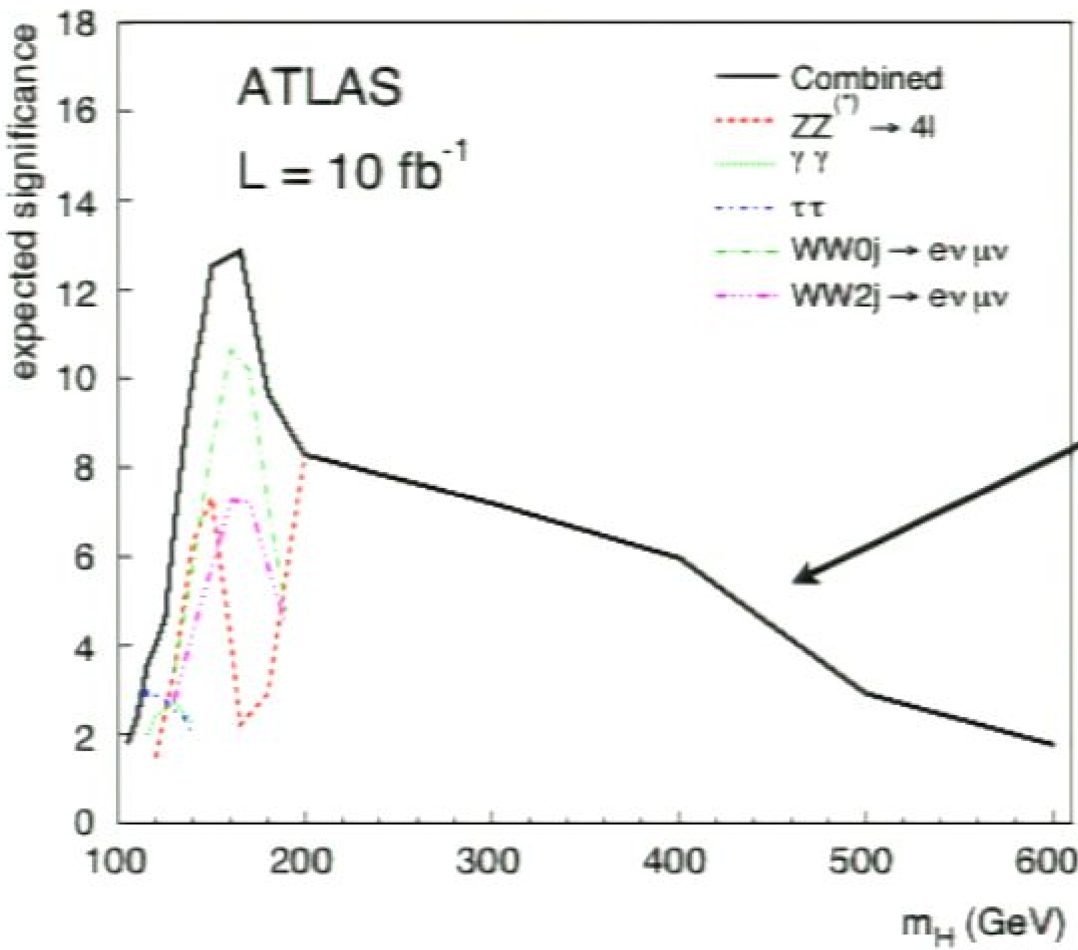

gold plated mode

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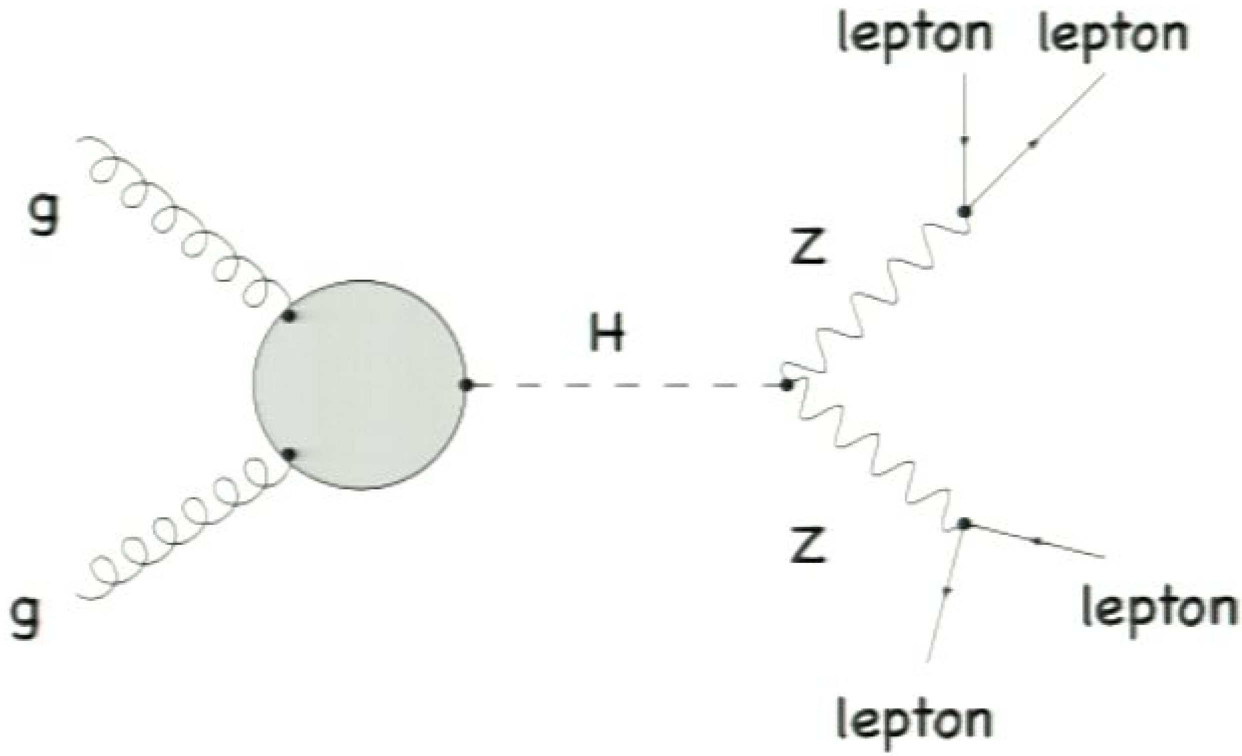

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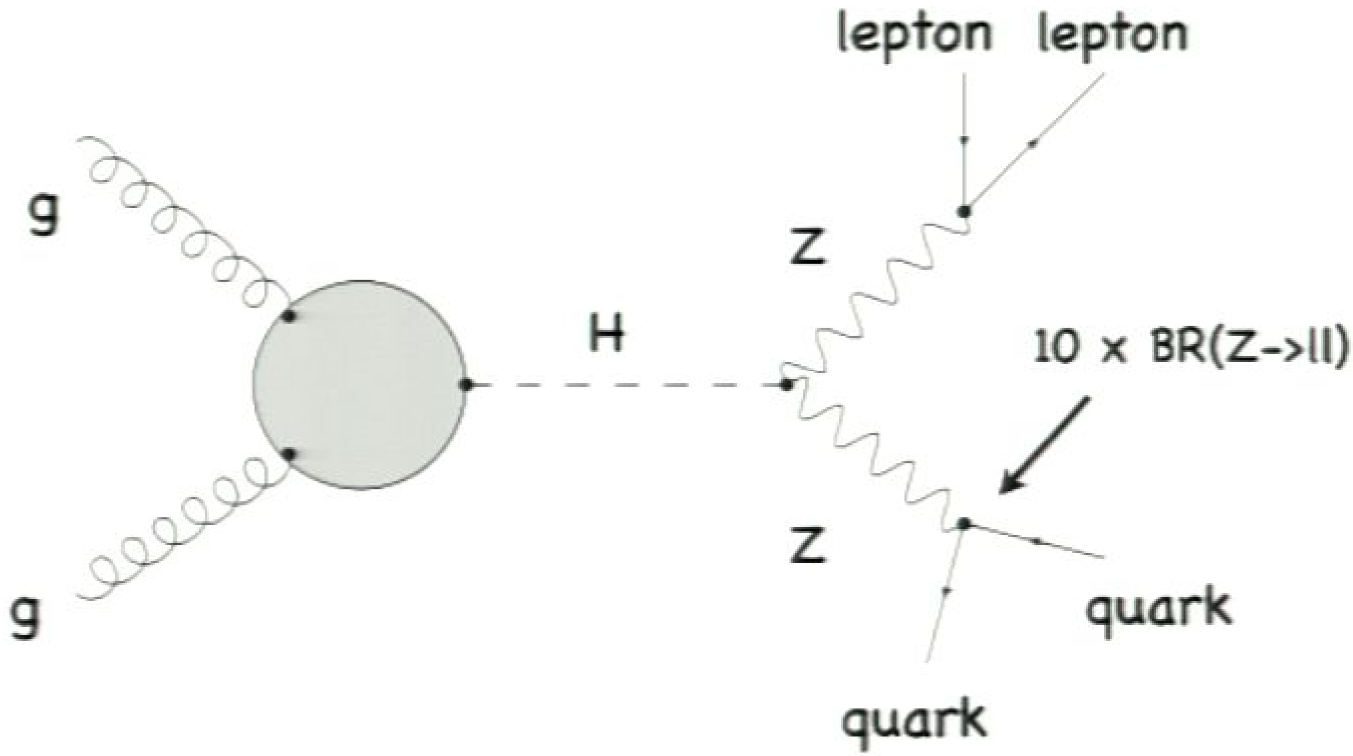
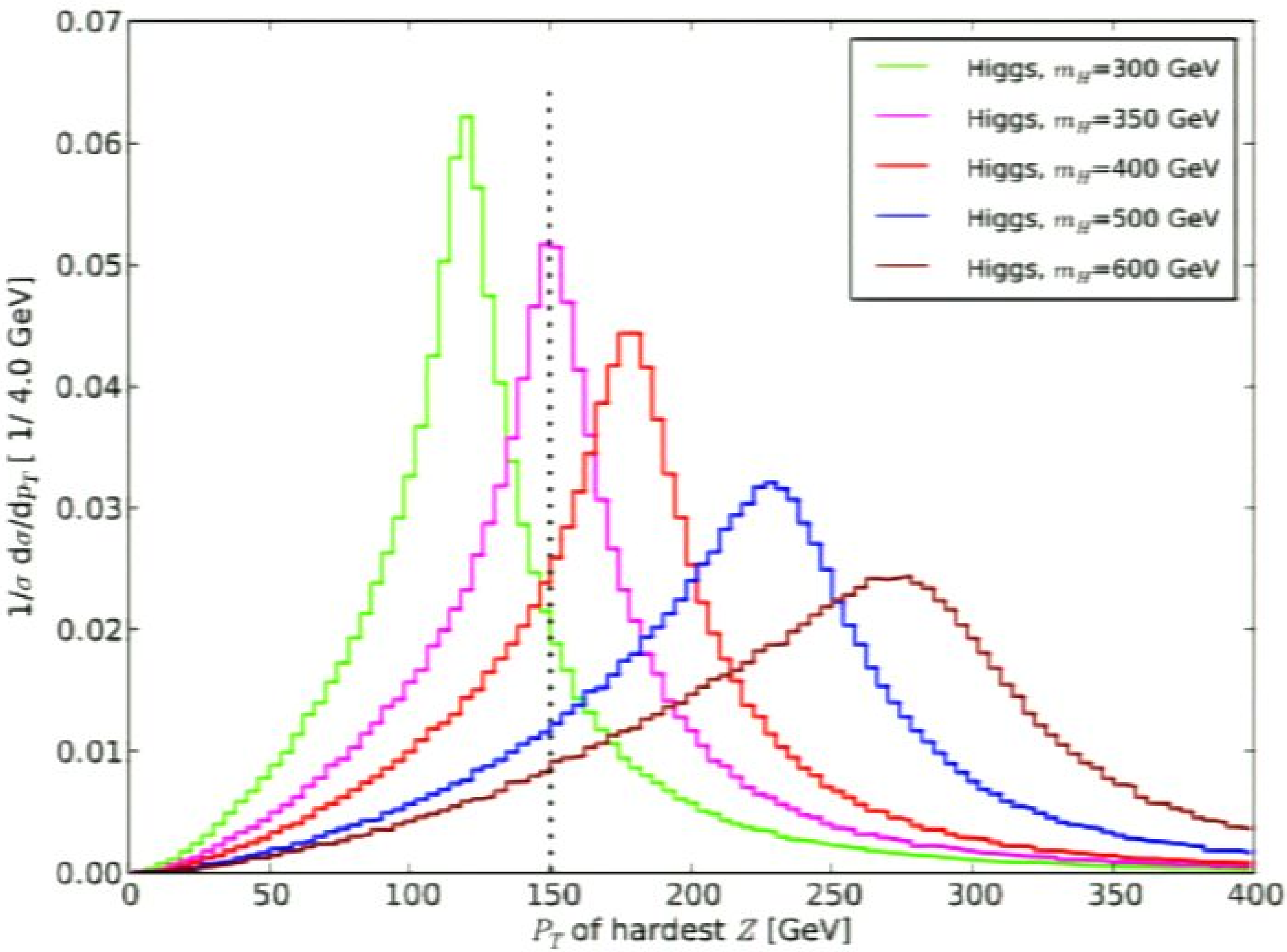


Heavy Higgs search in the 'forgotten channel'

Example for naturally boosted scenario



[Hackstein, MS 1008.2202]

Reconstruction in the 4 lepton gold plated mode:

- at least 4 isolated central muons
- 2 reconstructed Z bosons, requiring

$m_Z - 10\ \text{GeV} < m_{\mu\mu} < m_Z + 10\ \text{GeV}.$

Reconstruction in the semi-leptonic lljj mode:

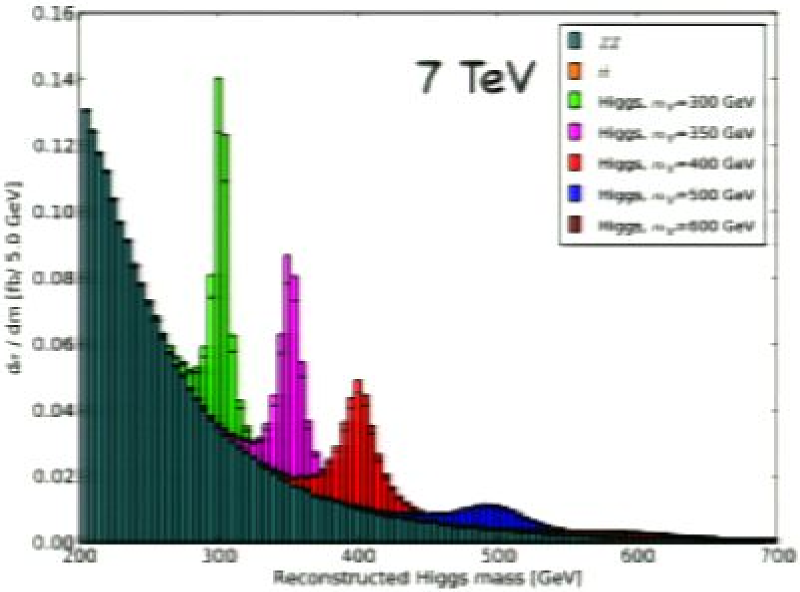
- Require fat jet (CA, R=1.2, pT>150 GeV)
- Leptonic Z reconstruction with two isolated central muons
- Hadronic Z reconstruction with filtering + mass drop
- Apply Pruning vs Trimming, requiring $m_Z^{\text{rec}} = m_Z \pm 10\ \text{GeV}.$

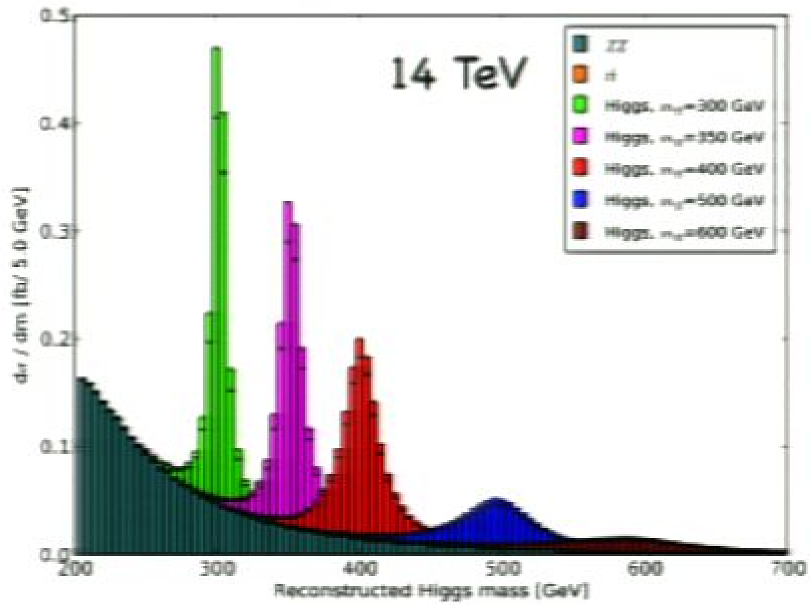
For calculation of significance take Higgs mass reconstruction with

$$(300 \pm 30,\ 350 \pm 50,\ 400 \pm 50,\ 500 \pm 70,\ 600 \pm 100)\ \text{GeV}$$

'Gold plated mode' is great, but suffers from few events

[Hackstein, MS 1008.2202]





	7 TeV				14 TeV			
m_H [GeV]	σ_S [fb]	σ_B [fb]	S/B	$S/\sqrt{B}_{10}$	σ_S [fb]	σ_B [fb]	S/B	$S/\sqrt{B}_{10}$
300	0.35	0.42	0.8	1.7	1.39	0.56	2.5	5.9
350	0.35	0.38	0.9	1.8	1.52	0.53	2.9	6.6
400	0.28	0.21	1.3	1.9	1.34	0.31	4.4	7.6
500	0.11	0.11	1.0	1.1	0.65	0.18	3.7	4.9
600	0.05	0.07	0.7	0.6	0.30	0.12	2.5	2.7

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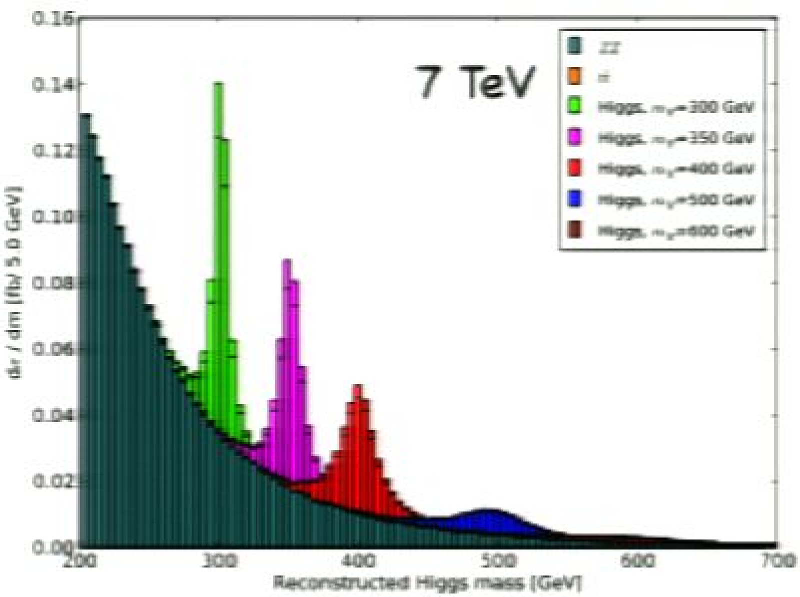

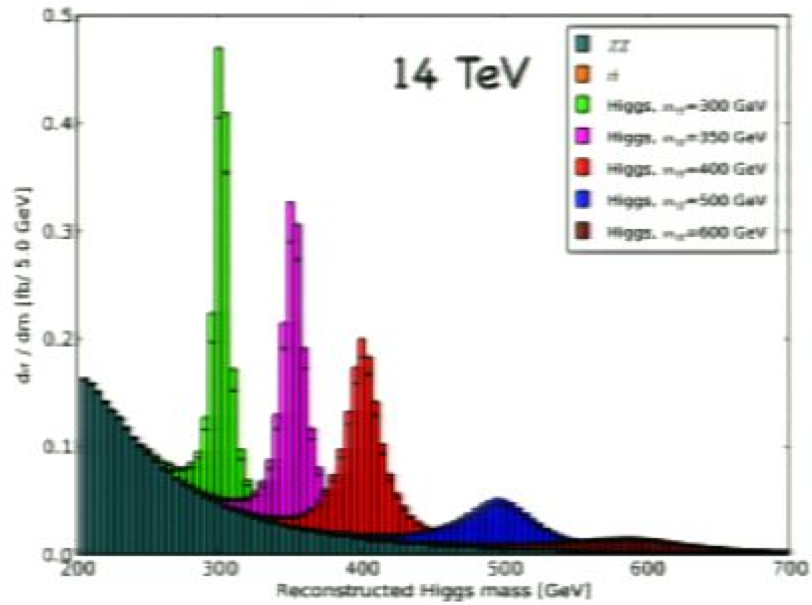

	7 TeV				14 TeV			
m_H [GeV]	σ_S [fb]	σ_B [fb]	S/B	$S/\sqrt{B}_{10}$	σ_S [fb]	σ_B [fb]	S/B	$S/\sqrt{B}_{10}$
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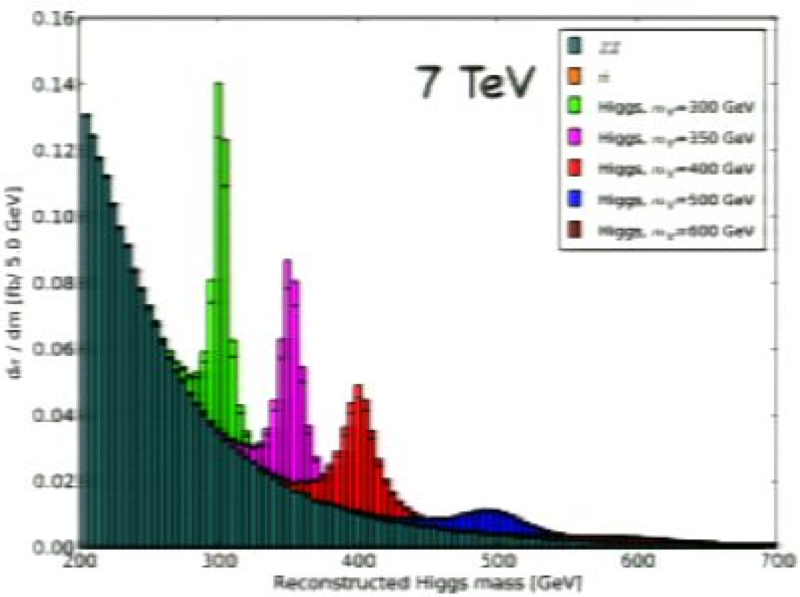

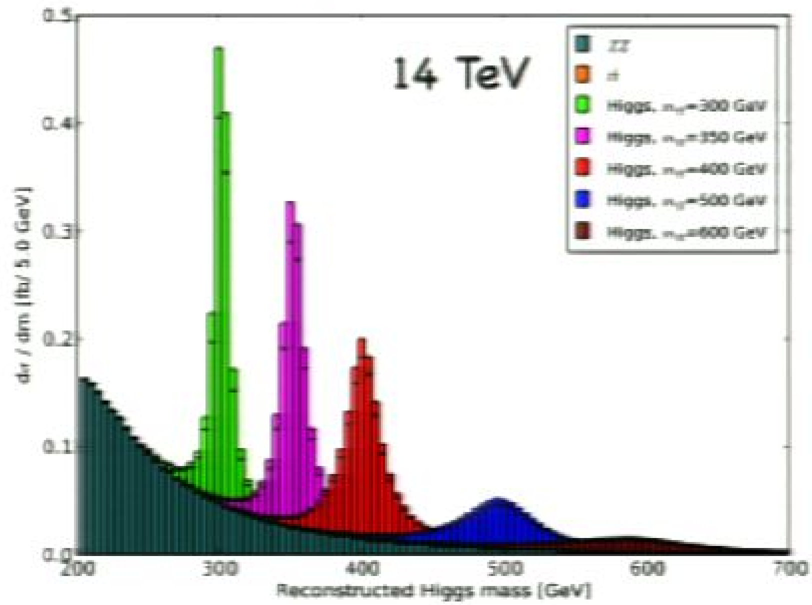

	7 TeV				14 TeV			
m_H [GeV]	σ_S [fb]	σ_B [fb]	S/B	$S/\sqrt{B}_{10}$	σ_S [fb]	σ_B [fb]	S/B	$S/\sqrt{B}_{10}$
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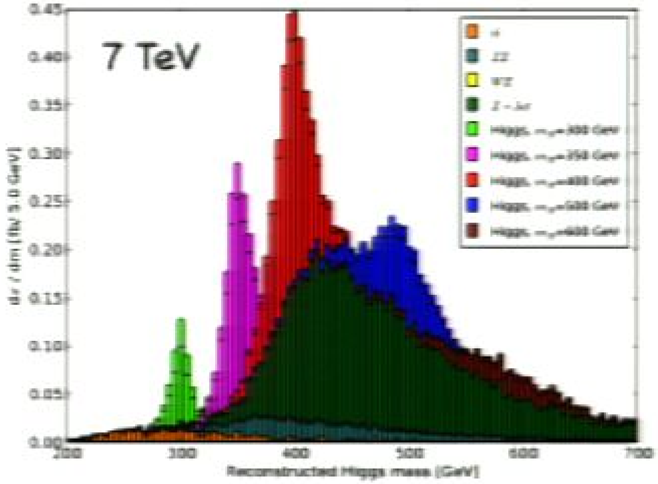
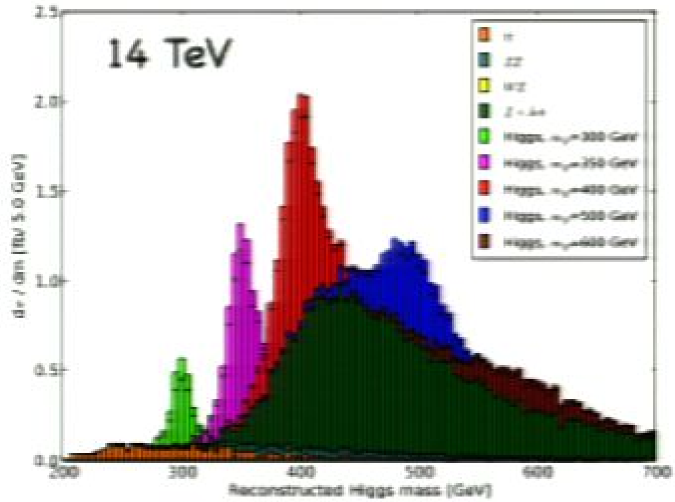
Semileptonic mode compensates worse S/B with more events





	m_H [GeV]	300		400		500		600	
	σ [fb]	σ_S	σ_B	σ_S	σ_B	σ_S	σ_B	σ_S	σ_B
7 TeV:	selection	3.37/0.89	907.3	8.89/0.97	907.3	4.91/0.70	907.3	2.19/0.46	907.3
	after analysis	0.29/0.12	0.39	2.02/0.24	3.97	1.11/0.18	3.33	0.46/0.12	1.97
	S/B	1.03		0.57		0.39		0.30	
	$S/\sqrt{B}_{10}$	2.0		3.6		2.2		1.3	
14 TeV:	selection	17.97/3.83	6200	46.18/4.64	6200	29.48/3.87	6200	15.08/2.90	6200
	after analysis	1.34/0.48	2.10	8.96/1.07	19.21	6.32/1.00	18.01	3.15/0.77	11.83
	S/B	0.87		0.52		0.41		0.33	
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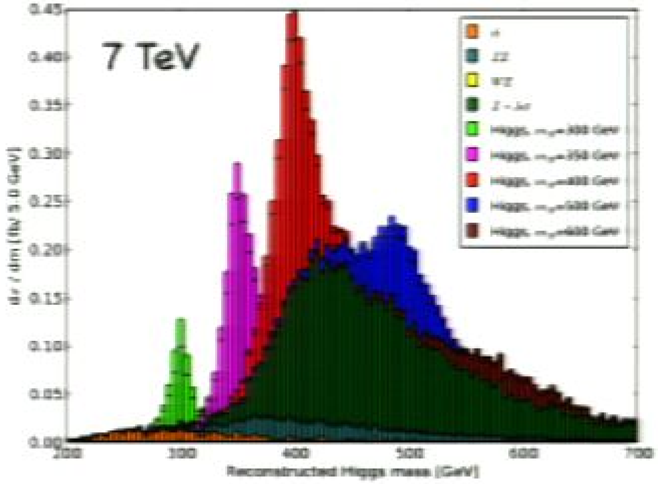

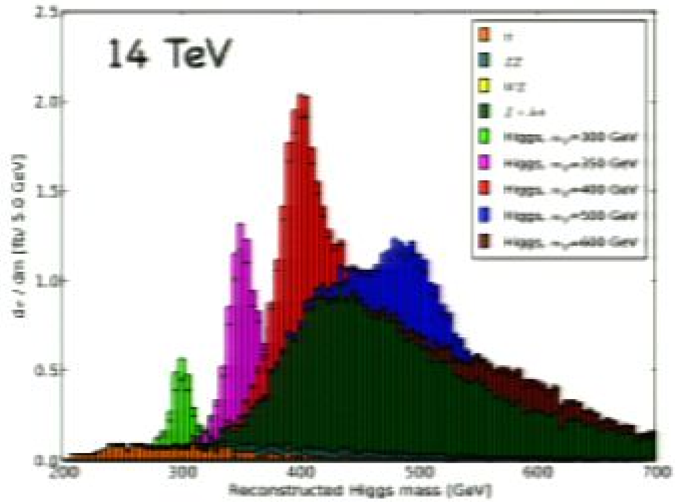

	m_H [GeV]	300		400		500		600	
	σ [fb]	σ_S	σ_B	σ_S	σ_B	σ_S	σ_B	σ_S	σ_B
7 TeV:	selection	3.37/0.89	907.3	8.89/0.97	907.3	4.91/0.70	907.3	2.19/0.46	907.3
	after analysis	0.29/0.12	0.39	2.02/0.24	3.97	1.11/0.18	3.33	0.46/0.12	1.97
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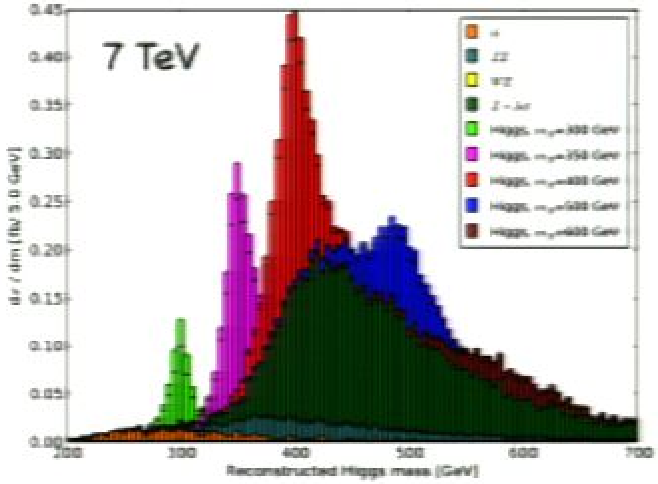

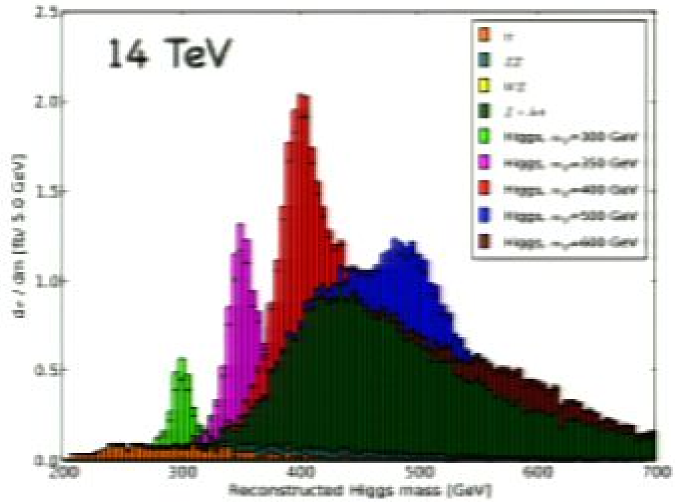

	m_H [GeV]	300		400		500		600	
	σ [fb]	σ_S	σ_B	σ_S	σ_B	σ_S	σ_B	σ_S	σ_B
7 TeV:	selection	3.37/0.89	907.3	8.89/0.97	907.3	4.91/0.70	907.3	2.19/0.46	907.3
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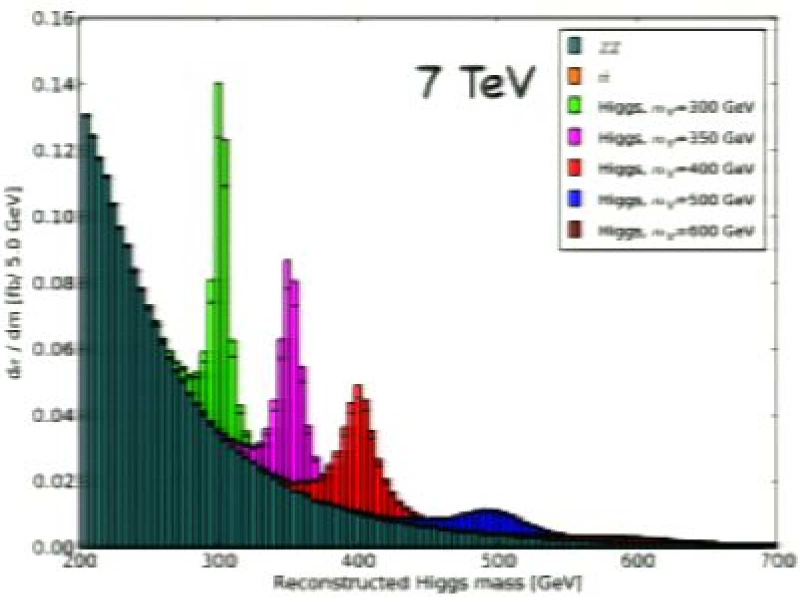

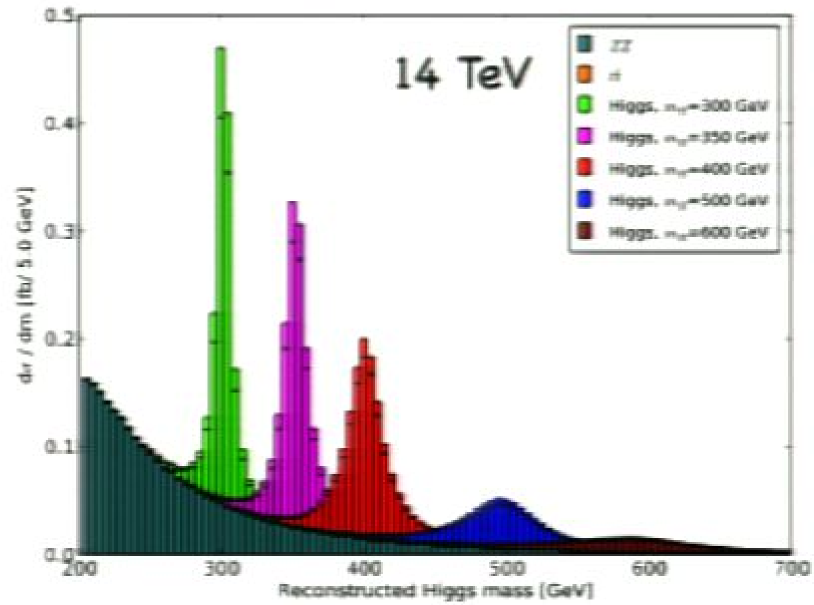

	7 TeV				14 TeV			
m_H [GeV]	σ_S [fb]	σ_B [fb]	S/B	$S/\sqrt{B}_{10}$	σ_S [fb]	σ_B [fb]	S/B	$S/\sqrt{B}_{10}$
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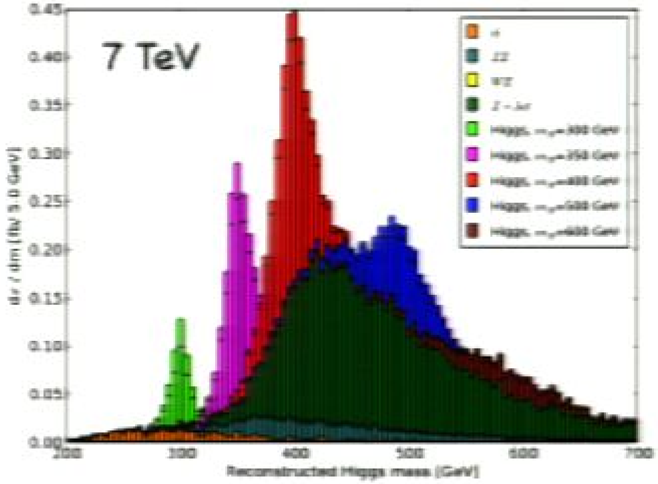

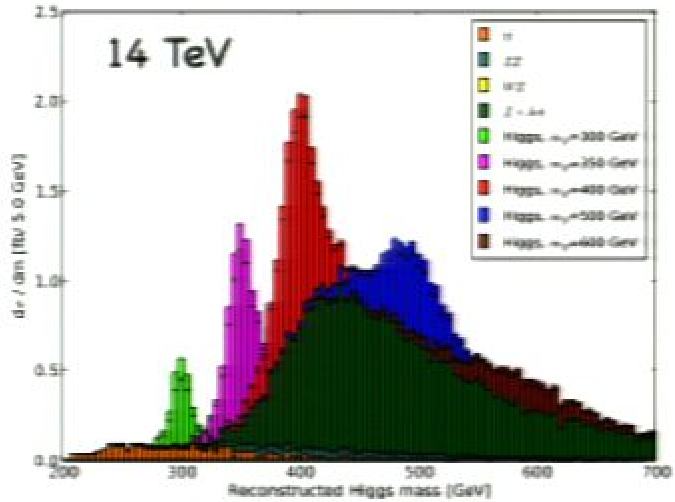

	m_H [GeV]	300		400		500		600	
	σ [fb]	σ_S	σ_B	σ_S	σ_B	σ_S	σ_B	σ_S	σ_B
7 TeV:	selection	3.37/0.89	907.3	8.89/0.97	907.3	4.91/0.70	907.3	2.19/0.46	907.3
	after analysis	0.29/0.12	0.39	2.02/0.24	3.97	1.11/0.18	3.33	0.46/0.12	1.97
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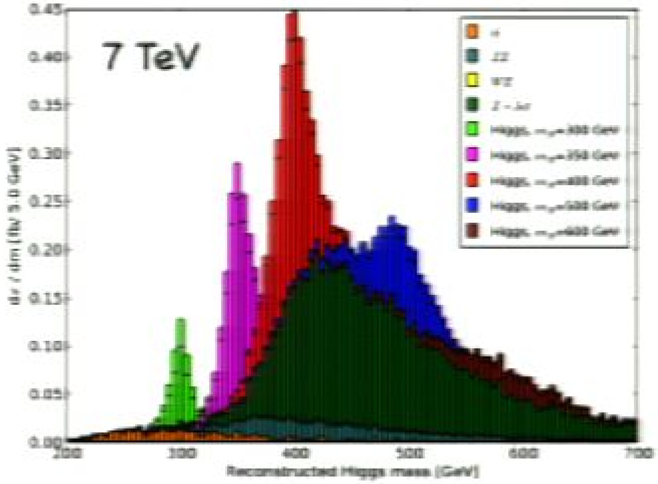

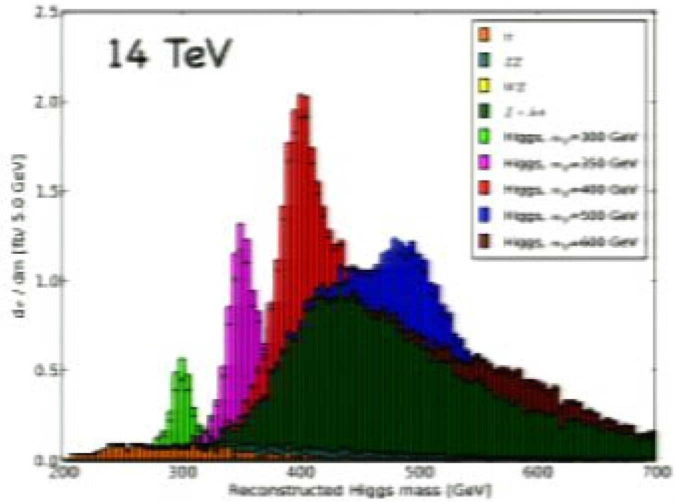

	m_H [GeV]	300		400		500		600	
	σ [fb]	σ_S	σ_B	σ_S	σ_B	σ_S	σ_B	σ_S	σ_B
7 TeV:	selection	3.37/0.89	907.3	8.89/0.97	907.3	4.91/0.70	907.3	2.19/0.46	907.3
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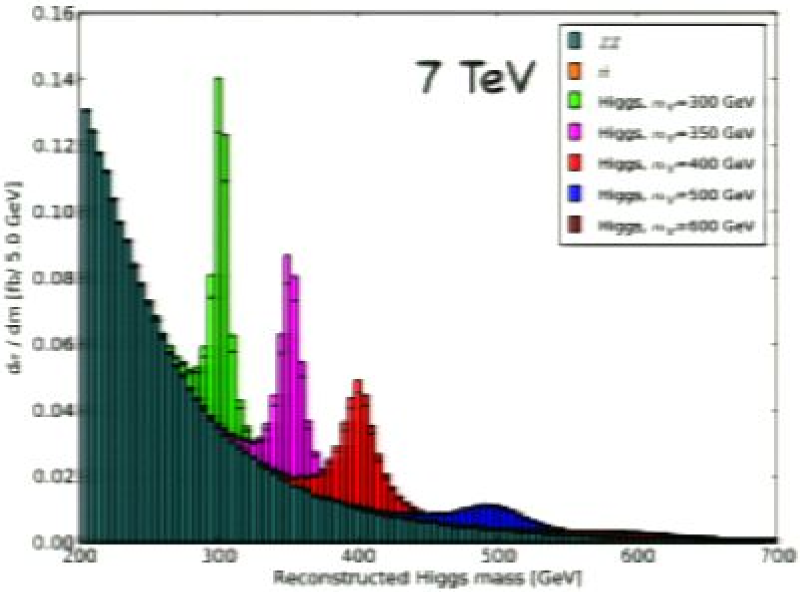

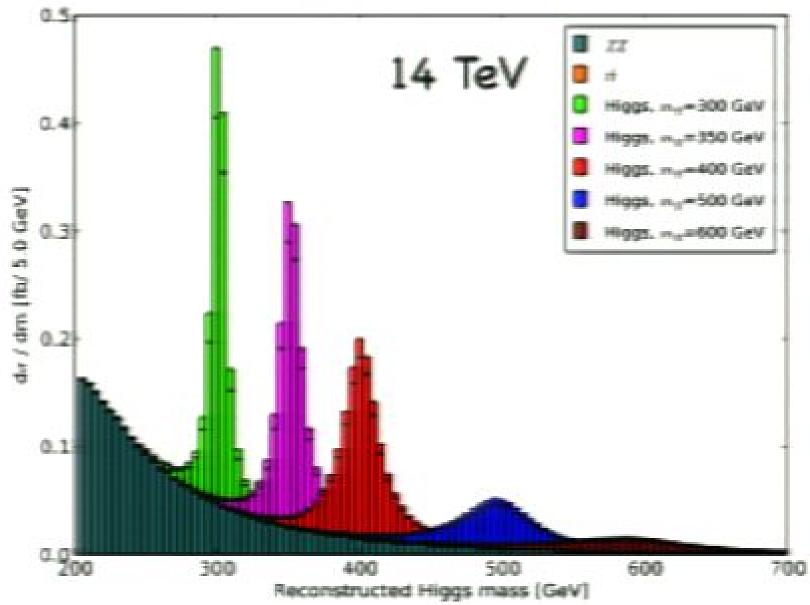

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[Hackstein, MS 1008.2202]

Reconstruction in the 4 lepton gold plated mode:

- at least 4 isolated central muons
- 2 reconstructed Z bosons, requiring

$$m_Z - 10\ \text{GeV} < m_{\mu\mu} < m_Z + 10\ \text{GeV}.$$

Reconstruction in the semi-leptonic lljj mode:

- Require fat jet (CA, R=1.2, pT>150 GeV)
- Leptonic Z reconstruction with two isolated central muons
- Hadronic Z reconstruction with filtering + mass drop
- Apply Pruning vs Trimming, requiring $m_Z^{\text{rec}} = m_Z \pm 10\ \text{GeV}.$

For calculation of significance take Higgs mass reconstruction with

$$(300 \pm 30,\ 350 \pm 50,\ 400 \pm 50,\ 500 \pm 70,\ 600 \pm 100)\ \text{GeV}$$

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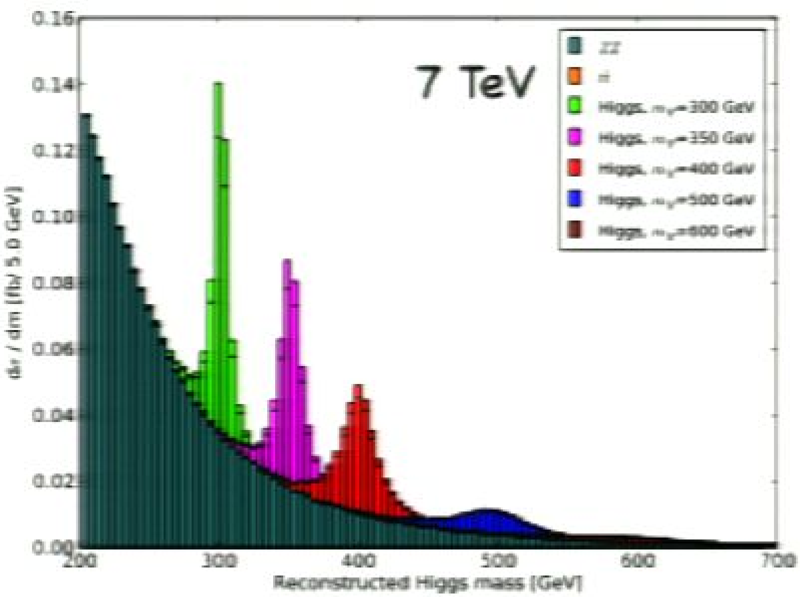

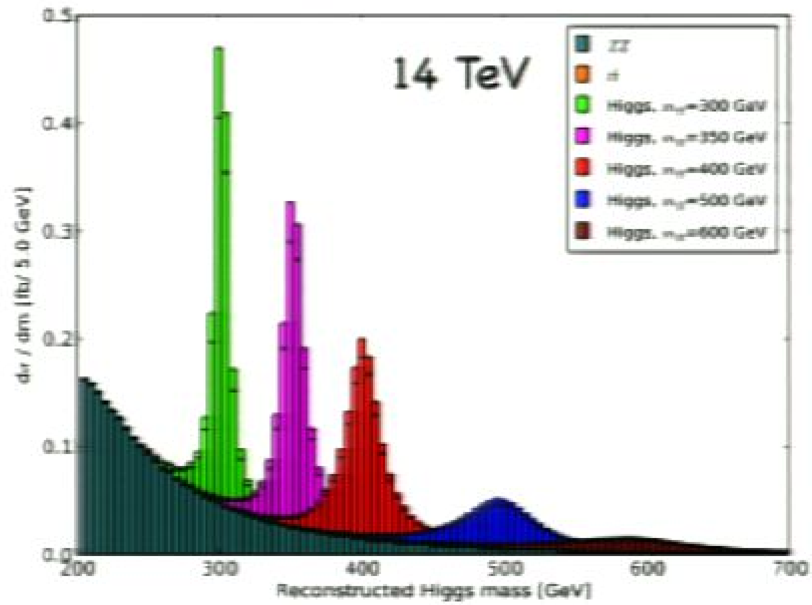

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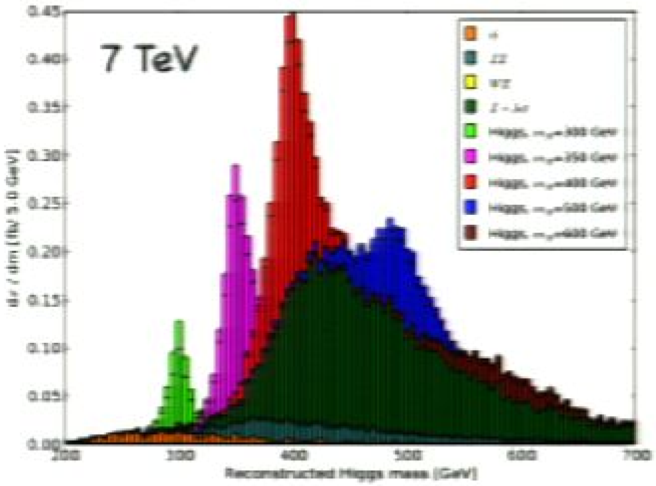

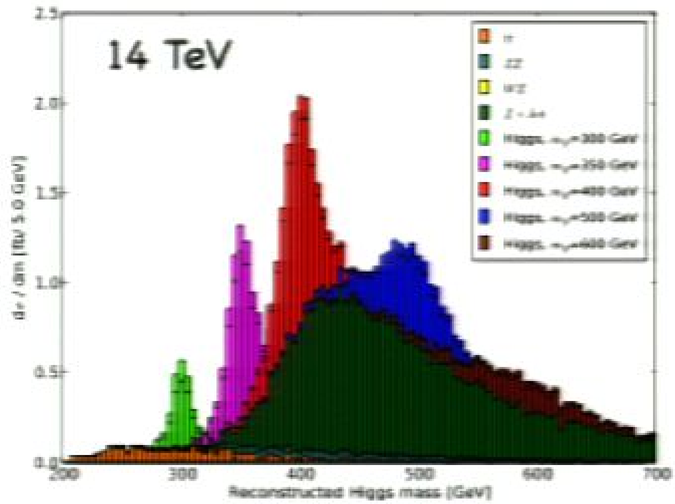

	m_H [GeV]	300		400		500		600	
	σ [fb]	σ_S	σ_B	σ_S	σ_B	σ_S	σ_B	σ_S	σ_B
7 TeV:	selection	3.37/0.89	907.3	8.89/0.97	907.3	4.91/0.70	907.3	2.19/0.46	907.3
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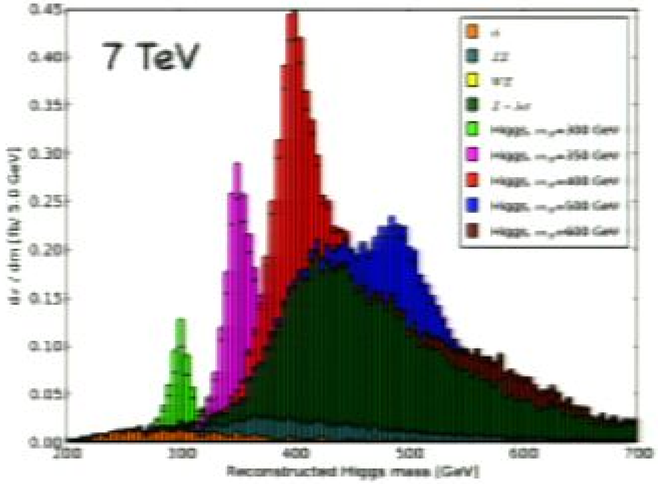

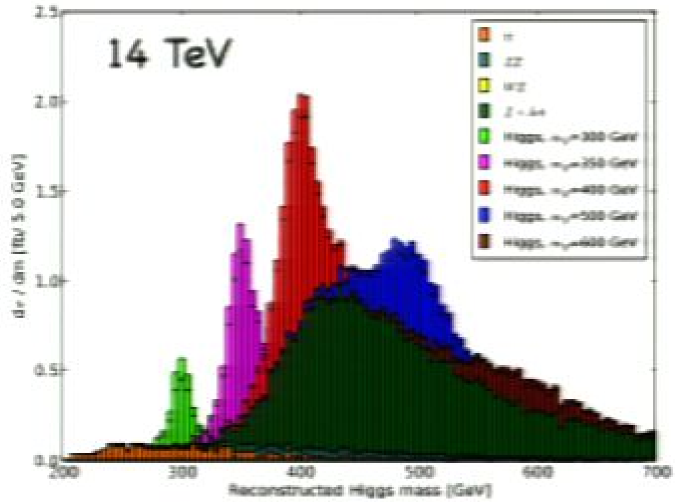

	m_H [GeV]	300		400		500		600	
	σ [fb]	σ_S	σ_B	σ_S	σ_B	σ_S	σ_B	σ_S	σ_B
7 TeV:	selection	3.37/0.89	907.3	8.89/0.97	907.3	4.91/0.70	907.3	2.19/0.46	907.3
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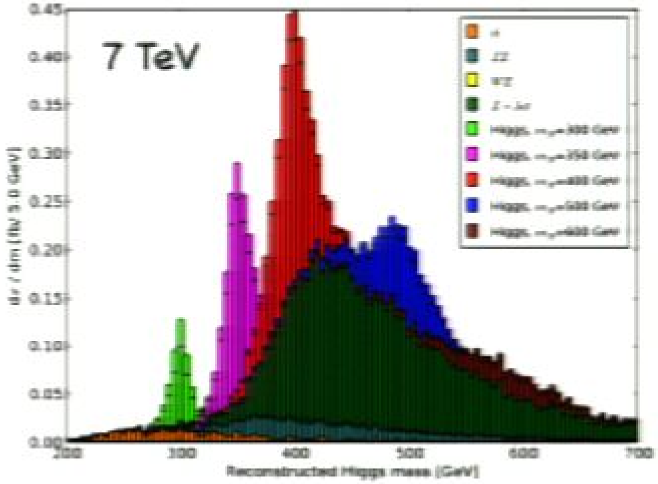

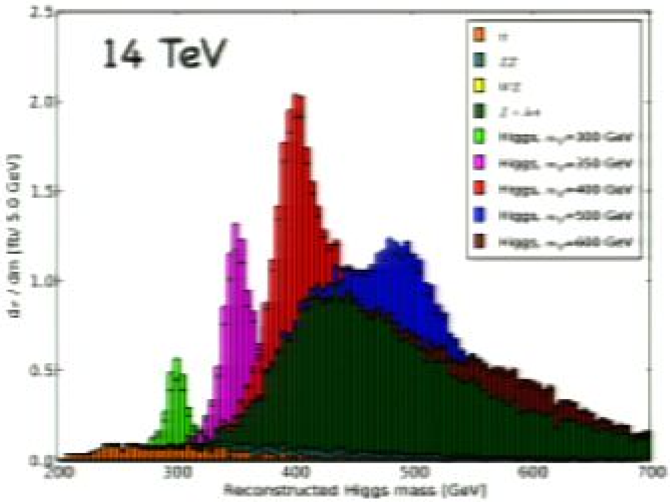

	m_H [GeV]	300		400		500		600	
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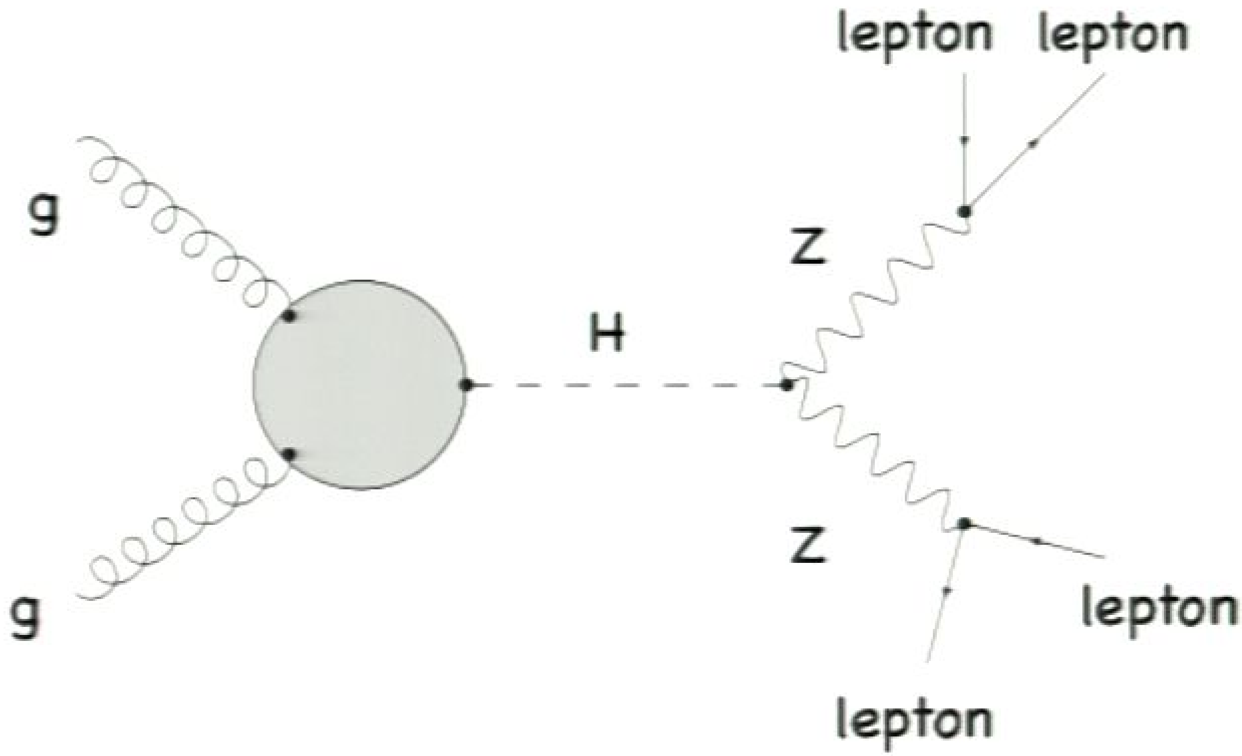
	$S/\sqrt{B}_{10}$	2.0		3.6		2.2		1.3	
14 TeV:	selection	17.97/3.83	6200	46.18/4.64	6200	29.48/3.87	6200	15.08/2.90	6200
	after analysis	1.34/0.48	2.10	8.96/1.07	19.21	6.32/1.00	18.01	3.15/0.77	11.83
	S/B	0.87		0.52		0.41		0.33	
	$S/\sqrt{B}_{10}$	4.0		7.2		5.5		3.6	

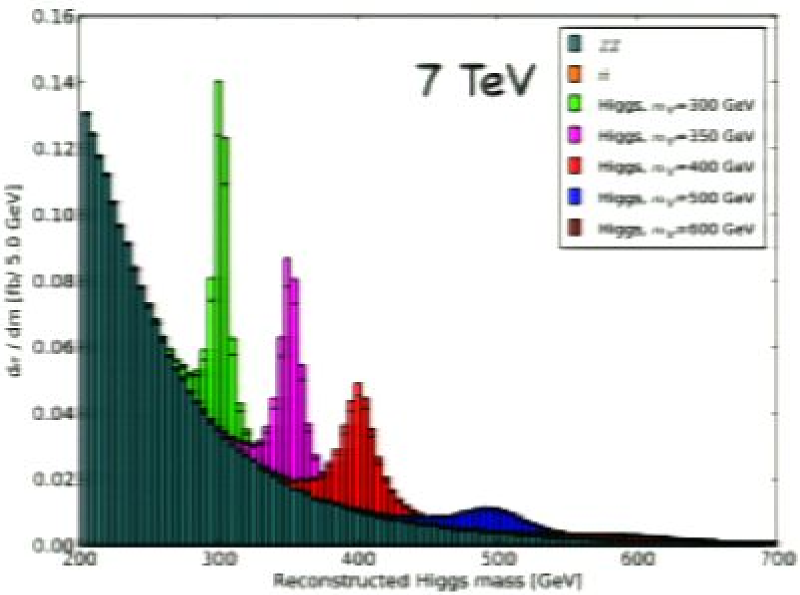
- Higher significance than 4l mode if LHC doesn't reach design energy
- 4Gen-Higgs can be detected/excluded with early data

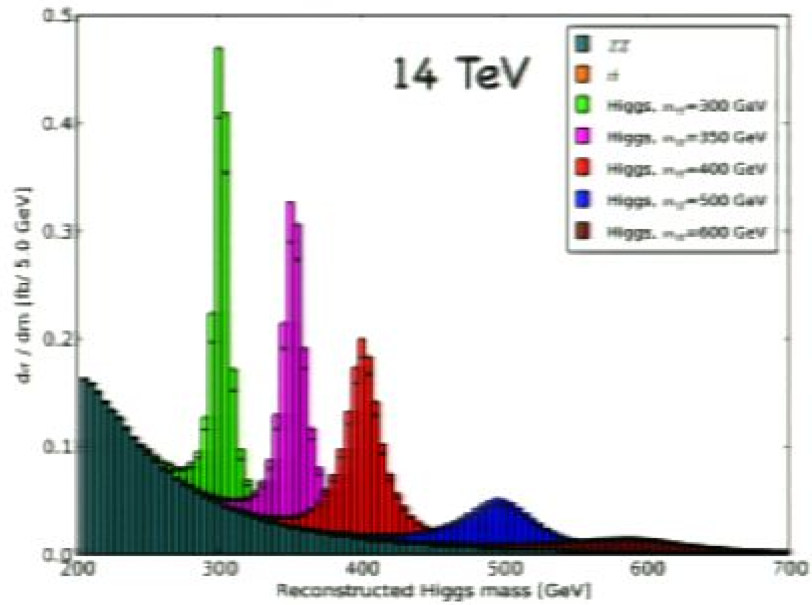
Heavy Higgs search in the 'forgotten channel'



'Gold plated mode' is great, but suffers from few events

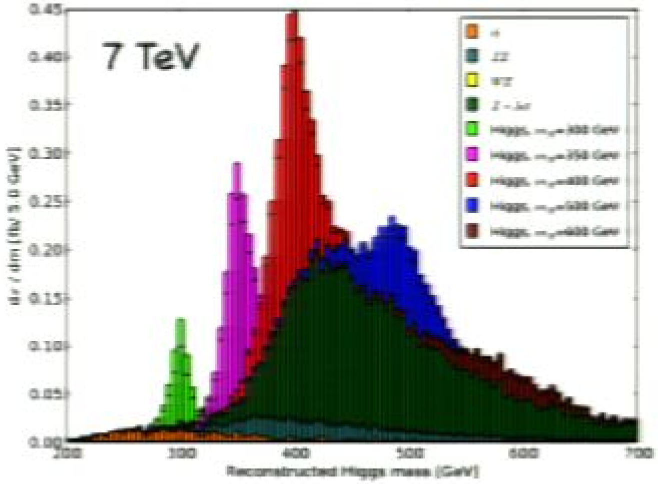
[Hackstein, MS 1008.2202]

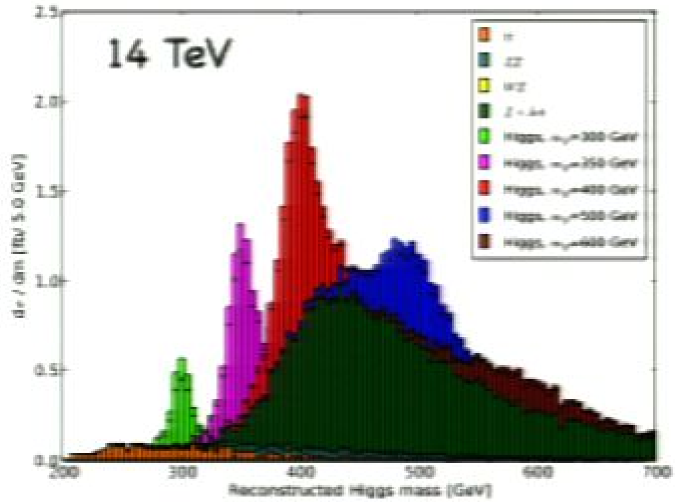




	7 TeV				14 TeV			
m_H [GeV]	σ_S [fb]	σ_B [fb]	S/B	$S/\sqrt{B}_{10}$	σ_S [fb]	σ_B [fb]	S/B	$S/\sqrt{B}_{10}$
300	0.35	0.42	0.8	1.7	1.39	0.56	2.5	5.9
350	0.35	0.38	0.9	1.8	1.52	0.53	2.9	6.6
400	0.28	0.21	1.3	1.9	1.34	0.31	4.4	7.6
500	0.11	0.11	1.0	1.1	0.65	0.18	3.7	4.9
600	0.05	0.07	0.7	0.6	0.30	0.12	2.5	2.7

Semileptonic mode compensates worse S/B with more events





	m_H [GeV]	300		400		500		600	
	σ [fb]	σ_S	σ_B	σ_S	σ_B	σ_S	σ_B	σ_S	σ_B
7 TeV:	selection	$3.37/0.89$	907.3	$8.89/0.97$	907.3	$4.91/0.70$	907.3	$2.19/0.46$	907.3
	after analysis	$0.29/0.12$	0.39	$2.02/0.24$	3.97	$1.11/0.18$	3.33	$0.46/0.12$	1.97
	S/B	1.03		0.57		0.39		0.30	
	$S/\sqrt{B}_{10}$	2.0		3.6		2.2		1.3	
14 TeV:	selection	$17.97/3.83$	6200	$46.18/4.64$	6200	$29.48/3.87$	6200	$15.08/2.90$	6200
	after analysis	$1.34/0.48$	2.10	$8.96/1.07$	19.21	$6.32/1.00$	18.01	$3.15/0.77$	11.83
	S/B	0.87		0.52		0.41		0.33	
	$S/\sqrt{B}_{10}$	4.0		7.2		5.5		3.6	

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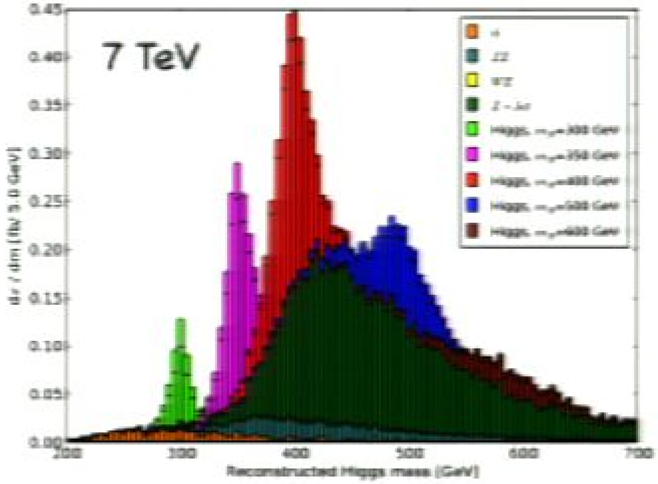

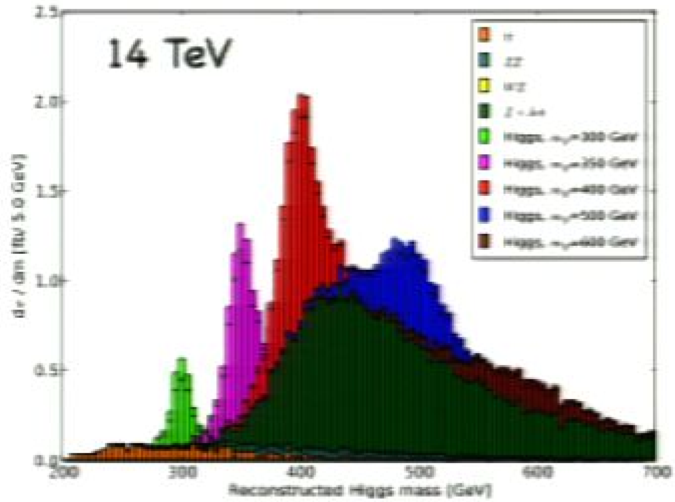

	m_H [GeV]	300		400		500		600	
	σ [fb]	σ_S	σ_B	σ_S	σ_B	σ_S	σ_B	σ_S	σ_B
7 TeV:	selection	3.37/0.89	907.3	8.89/0.97	907.3	4.91/0.70	907.3	2.19/0.46	907.3
	after analysis	0.29/0.12	0.39	2.02/0.24	3.97	1.11/0.18	3.33	0.46/0.12	1.97
	S/B	1.03		0.57		0.39		0.30	
	$S/\sqrt{B}_{10}$	2.0		3.6		2.2		1.3	
14 TeV:	selection	17.97/3.83	6200	46.18/4.64	6200	29.48/3.87	6200	15.08/2.90	6200
	after analysis	1.34/0.48	2.10	8.96/1.07	19.21	6.32/1.00	18.01	3.15/0.77	11.83
	S/B	0.87		0.52		0.41		0.33	
	$S/\sqrt{B}_{10}$	4.0		7.2		5.5		3.6	

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top tagging - a major application

Rough results for top quark with $p_t \sim 1$ TeV			
	"Extra"	eff.	fake
[from T&W]	just jet mass	50%	10%
Brooijmans '08	3,4 k_t subjets, d_{cut}	45%	5%
Thaler & Wang '08	2,3 k_t subjets, z_{cut} + various	40%	5%
Kaplan et al. '08	3,4 C/A subjets, $z_{cut} + \theta_h$	40%	1%
Ellis et al. '09	C/A pruning	10%	0.05%
ATLAS '09	3,4 k_t subjets, d_{cut} MC likelihood	90%	15%
Chekanov & P. '10	Jet shapes	60%	10%
Almeida et al. '08–'10	Template + shapes	13%	0.02%
Plehn et al. '09–'10	C/A MD, θ_h/Dalitz [busy evs, $p_t \sim 300$]	35%	2%

Will focus on Plehn et al = HEPTopTagger (Heidelberg-Eugene-Paris)

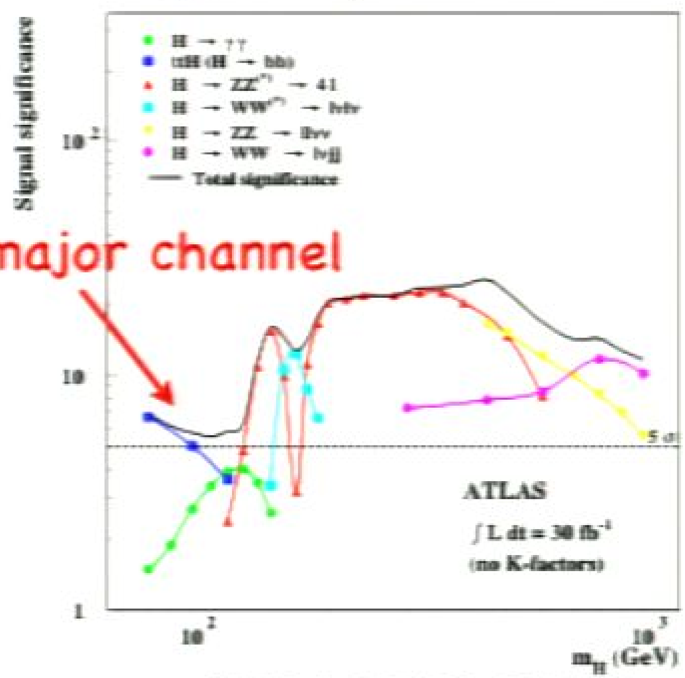
HEPTopTagger is being tested in ATLAS framework with good results

tth

as busy as it gets in the SM

Motivation:
- sizable cross-section
- Higgs discovery contribution in low mass range
- access to t- and b-Yukawa couplings

High expectations:



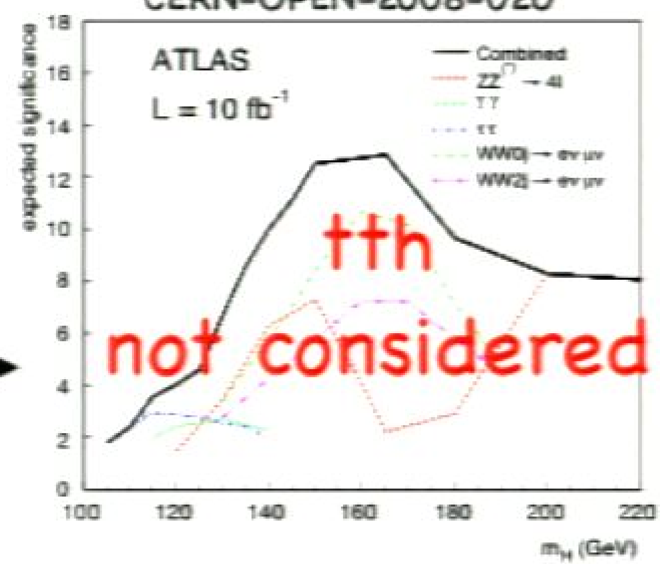
[ATLAS TDR 1999]

Cammin and Schumacher (ATLAS)

$S/B \simeq 1/9$

$S/\sqrt{B} \simeq 2.2$

Expected Performance of the ATLAS Experiment, CERN-OPEN-2008-020



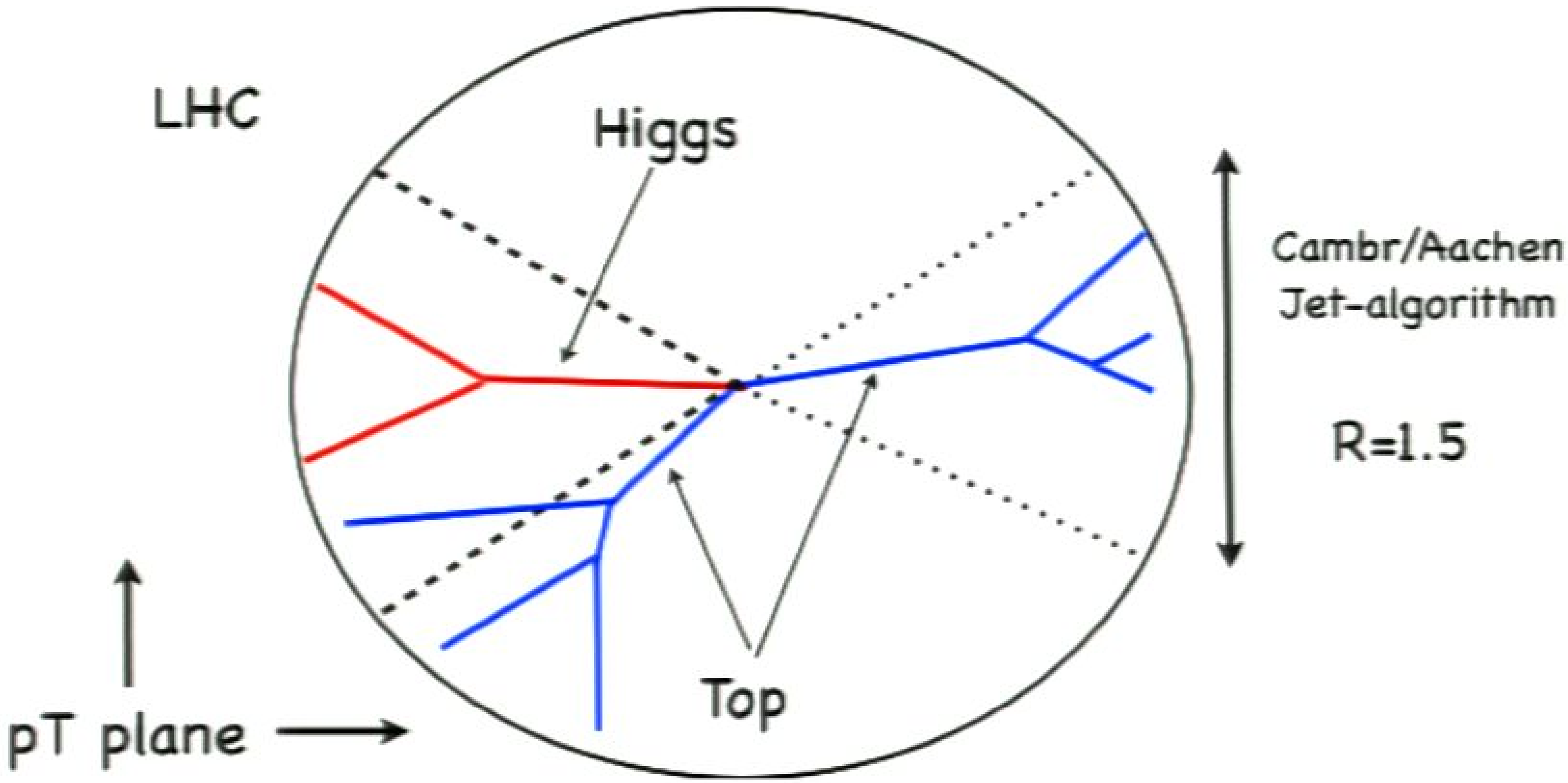
Problems in event reconstruction:

- (b-)jet multiplicity
- reconstruction efficiency

↔ Boost should help

but

need tagger for this environment



HEPTopTagger - a low-pT Tagger

(Plehn, Salam, MS, Takeuchi)

I. Find fat jets (C/A, R=1.5, pT>200 GeV)

II. Find hard substructure using mass drop criterion

Undo clustering, $m_{j_1} < 0.8\ m_j$ to keep j_1 and j_2

III. Filter and choose pairing

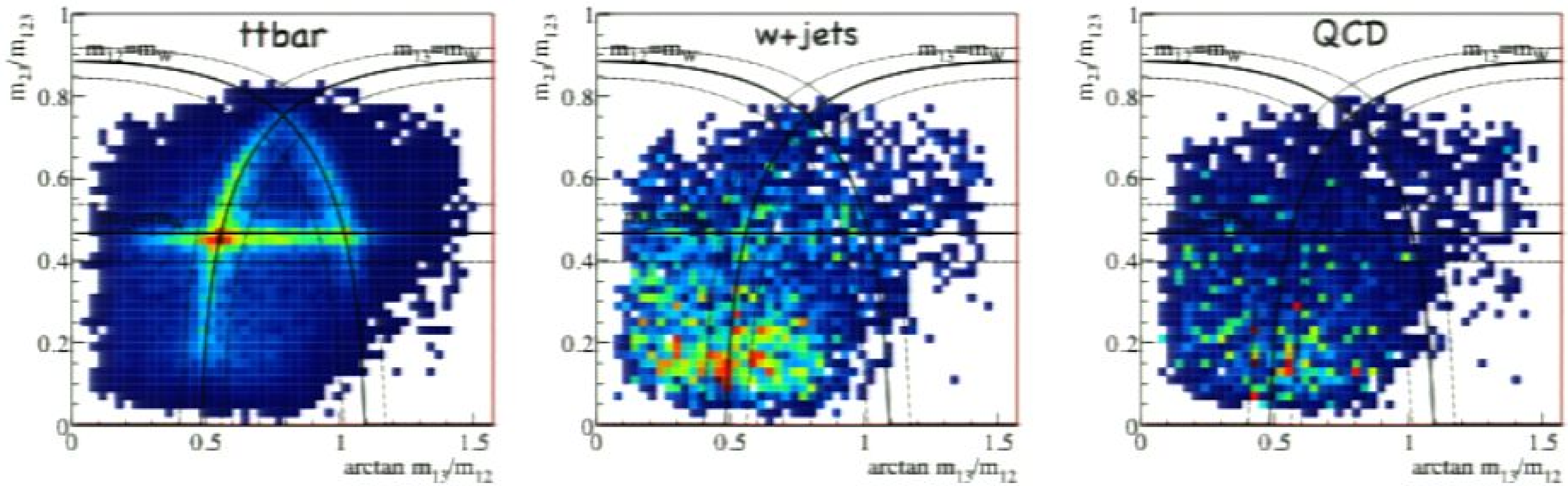
Take 3 hard objetcs, filter them, take 5 filered subjets, keep pairing with best top mass

top candidate $|m_{jjj} - 172.3\ \mathrm{GeV}| < 25\ \mathrm{GeV}$

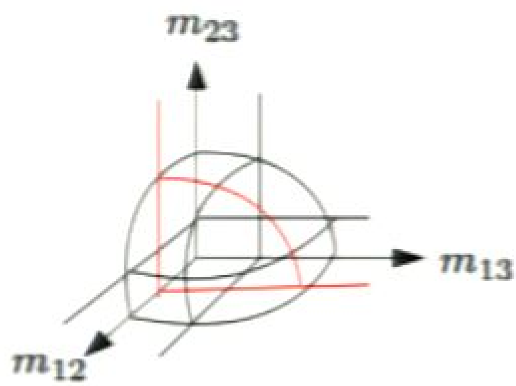
no b-tag, no W mass cut yet

IV. check mass ratios

Cluster top candidate into 3 subjets j_1, j_2, j_3



$$m_t^2 \equiv m_{123}^2 = (p_1+p_2+p_3)^2 = (p_1+p_2)^2 + (p_1+p_3)^2 + (p_2+p_3)^2 = m_{12}^2 + m_{13}^2 + m_{23}^2$$



$$R_{\min} < \frac{m_{23}}{m_{123}} < R_{\max} \quad \text{and} \quad 0.2 < \arctan\frac{m_{13}}{m_{12}} < 1.3$$

$$R_{\min}^2\left(1+\left(\frac{m_{13}}{m_{12}}\right)^2\right) < 1-\left(\frac{m_{23}}{m_{123}}\right)^2 < R_{\max}^2\left(1+\left(\frac{m_{13}}{m_{12}}\right)^2\right) \quad \text{and} \quad \frac{m_{23}}{m_{123}} > 0.3$$

$$R_{\min}^2\left(1+\left(\frac{m_{12}}{m_{13}}\right)^2\right) < 1-\left(\frac{m_{23}}{m_{123}}\right)^2 < R_{\max}^2\left(1+\left(\frac{m_{12}}{m_{13}}\right)^2\right) \quad \text{and} \quad \frac{m_{23}}{m_{123}} > 0.3$$

$$R_{\min} = 85\% \times m_W/m_t \qquad R_{\max} = 115\% \times m_W/m_t$$

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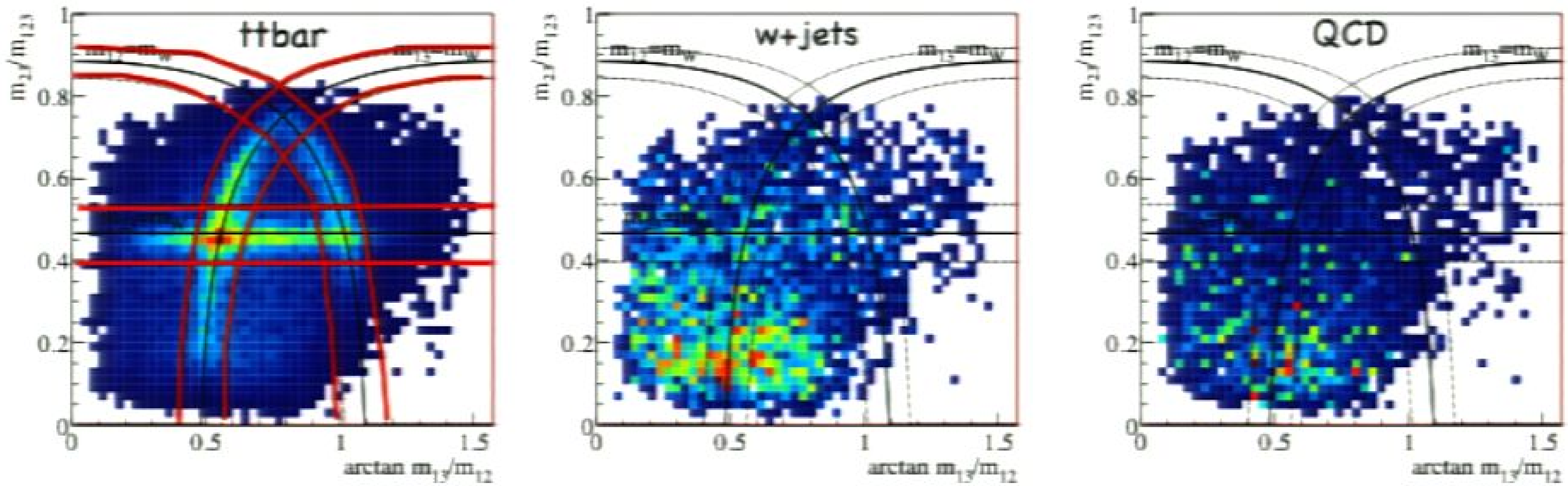
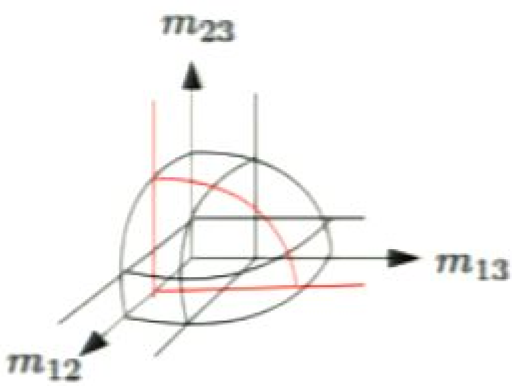
Cluster top candidate into 3 subjets j_1, j_2, j_3



$$m_t^2 \equiv m_{123}^2 = (p_1 + p_2 + p_3)^2 = (p_1 + p_2)^2 + (p_1 + p_3)^2 + (p_2 + p_3)^2 = m_{12}^2 + m_{13}^2 + m_{23}^2$$



$$R_{\min} < \frac{m_{23}}{m_{123}} < R_{\max} \quad \text{and} \quad 0.2 < \arctan\frac{m_{13}}{m_{12}} < 1.3$$

$$R_{\min}^2\left(1 + \left(\frac{m_{13}}{m_{12}}\right)^2\right) < 1 - \left(\frac{m_{23}}{m_{123}}\right)^2 < R_{\max}^2\left(1 + \left(\frac{m_{13}}{m_{12}}\right)^2\right) \quad \text{and} \quad \frac{m_{23}}{m_{123}} > 0.3$$

$$R_{\min}^2\left(1 + \left(\frac{m_{12}}{m_{13}}\right)^2\right) < 1 - \left(\frac{m_{23}}{m_{123}}\right)^2 < R_{\max}^2\left(1 + \left(\frac{m_{12}}{m_{13}}\right)^2\right) \quad \text{and} \quad \frac{m_{23}}{m_{123}} > 0.3$$

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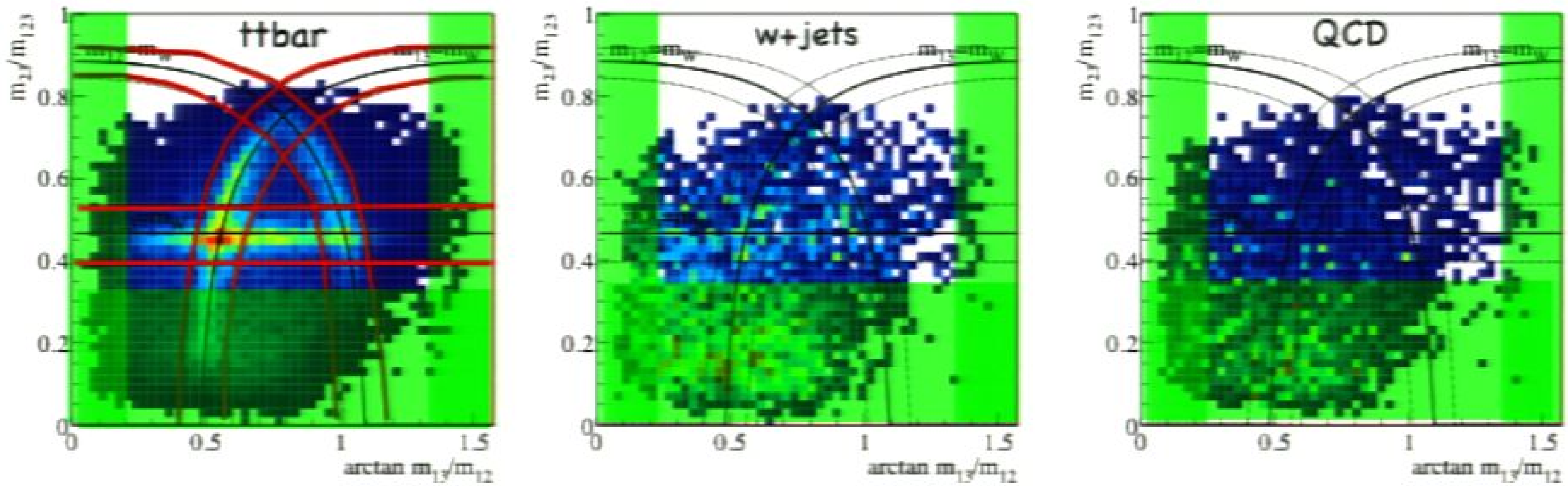

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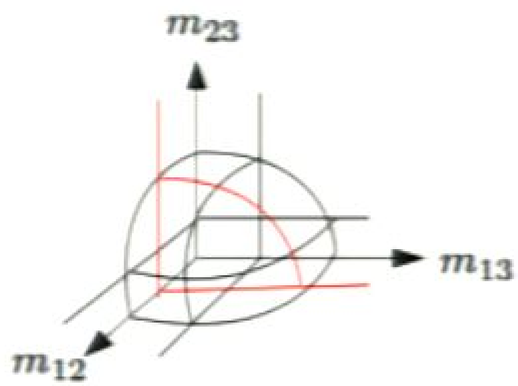

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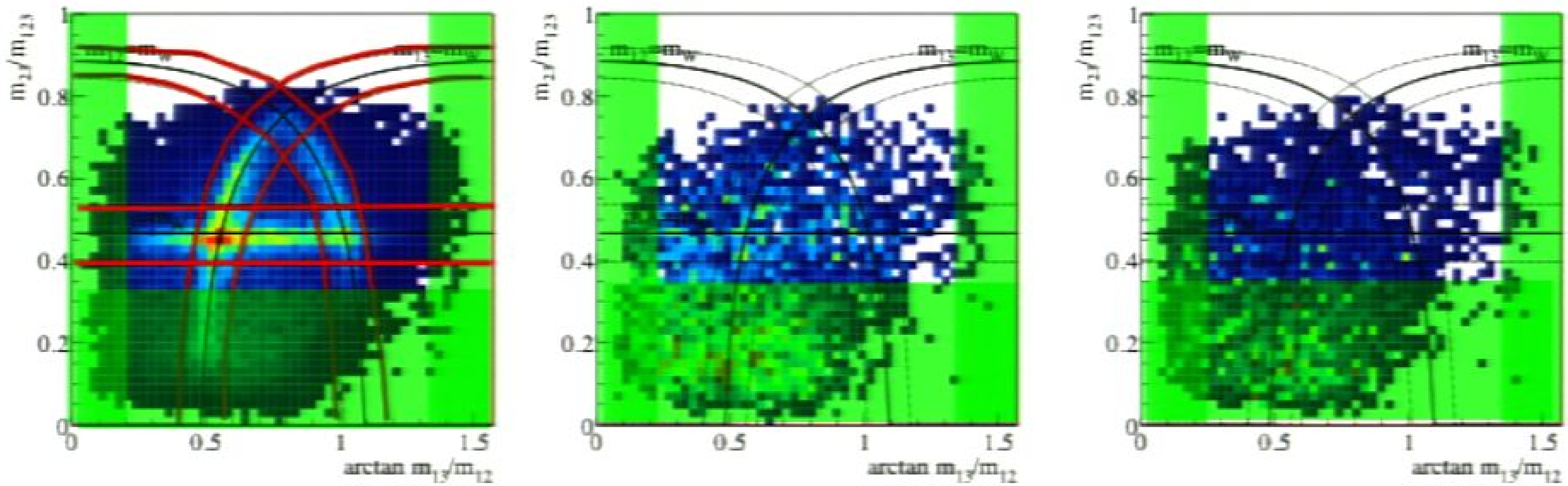
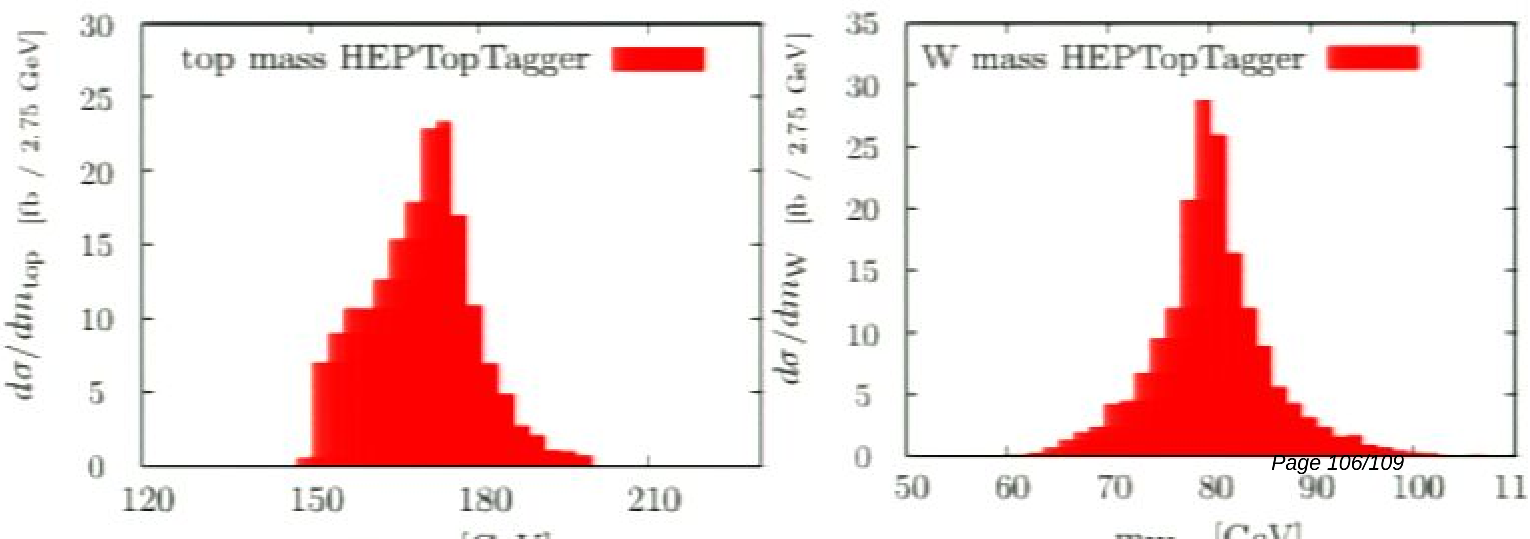
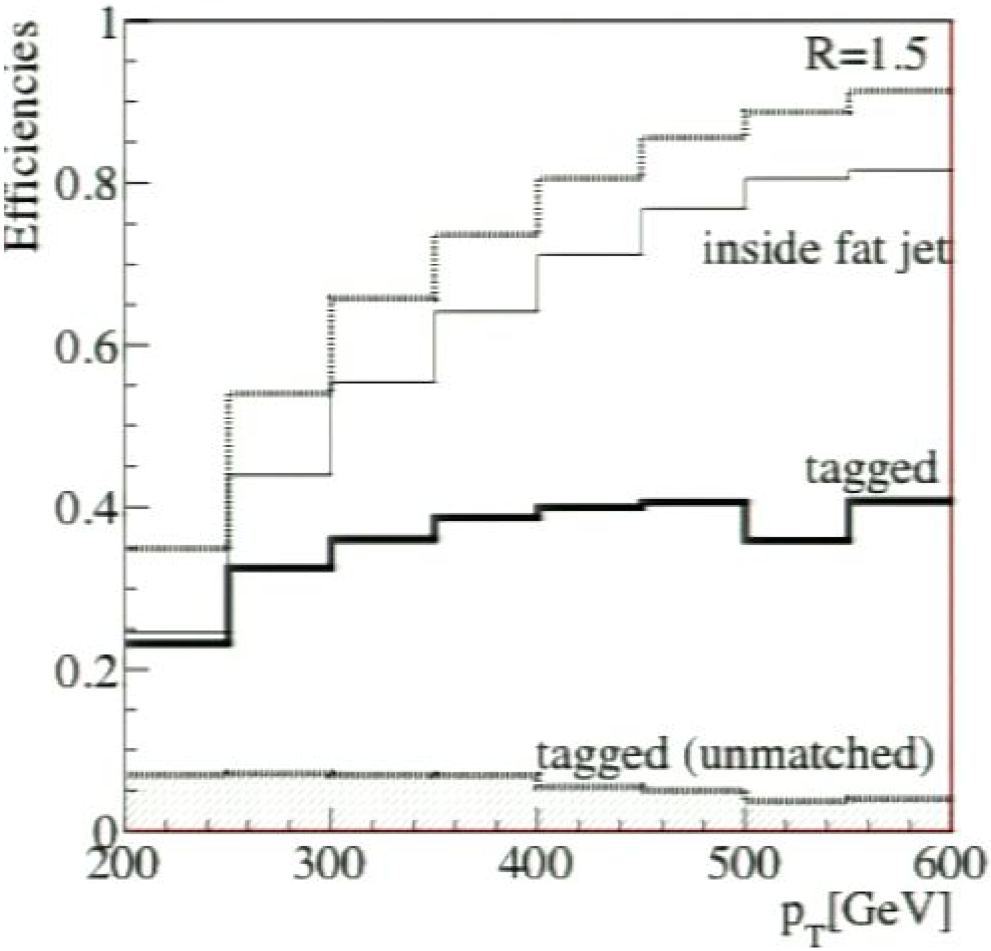


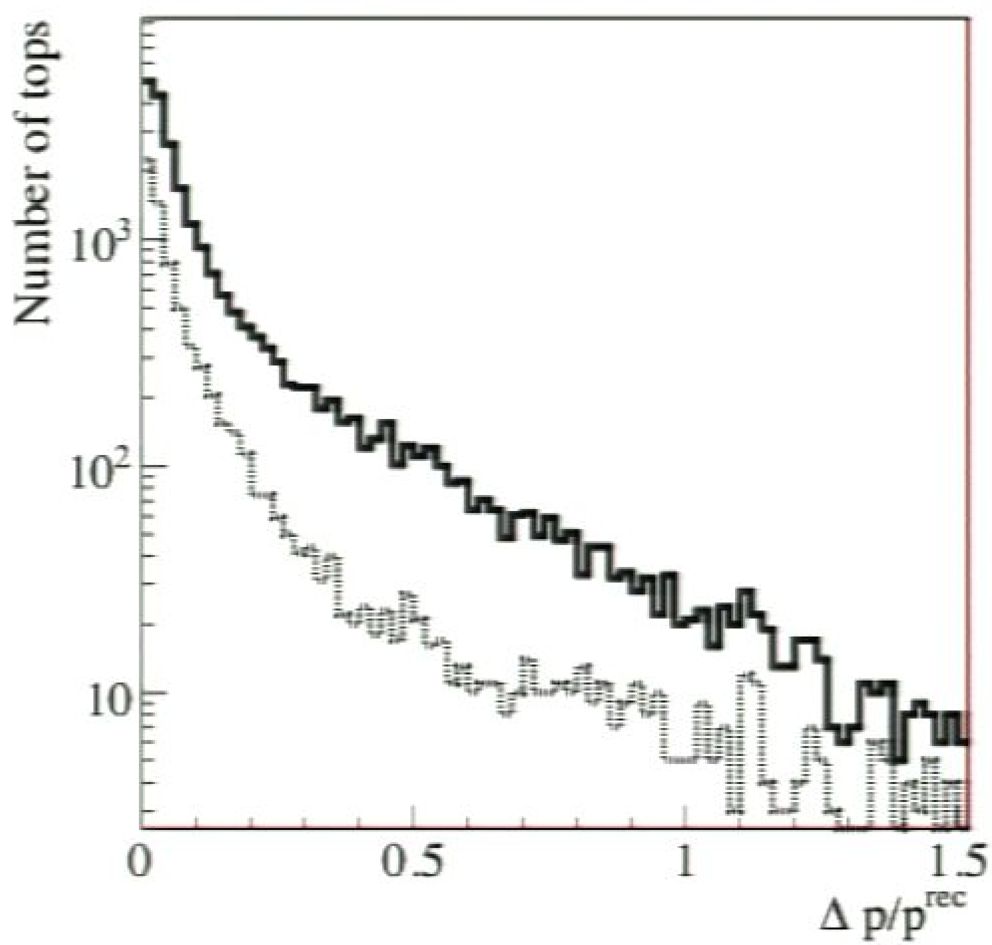
No fix pairing for W mass reconstruction

Only invariants for reconstruction

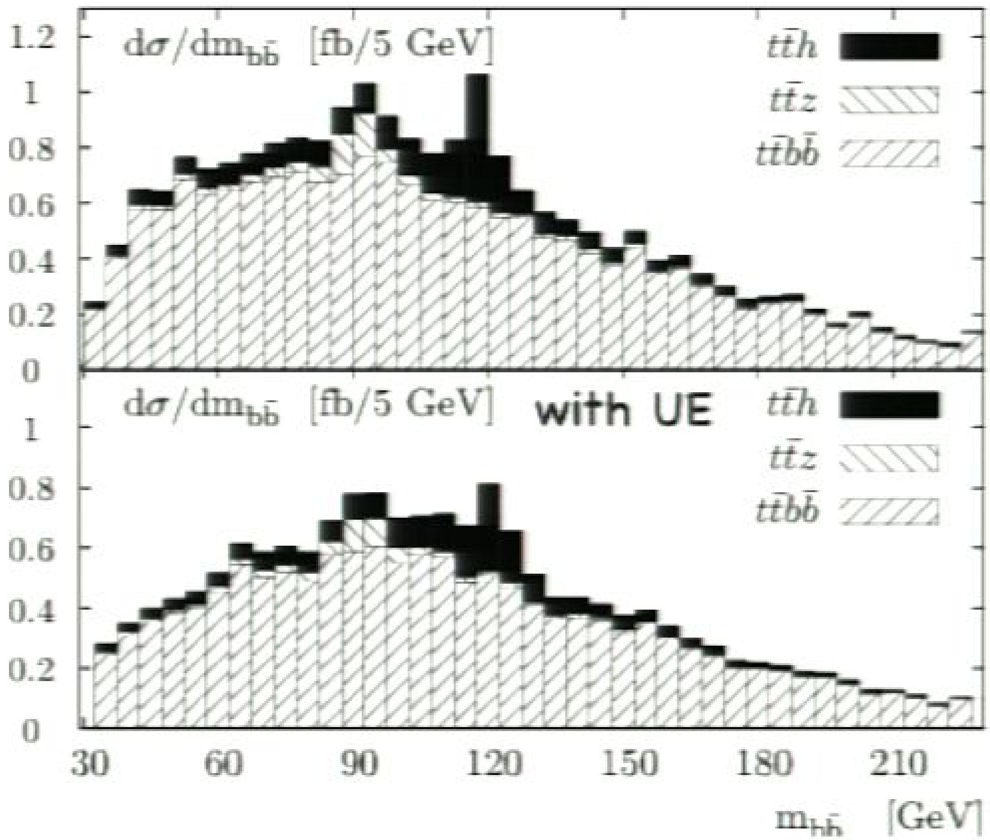


HEPTopTagger efficiencies for 14 TeV ttbar sample





Results for tth



- 5 sigma sign. with 100 1/fb
- Development of Higgs and top tagger for busy final state
- Improvement of S/B from 1/9 to 1/2

→ tth might contribute to Higgs discovery

→ tth might be a window to Higgs-top coupling

Conclusion

- Jet substructure yields huge potential to improve on NP searches
- On MC level improved reconstruction of resonances by removal of UE and Pile-up contributions
- Studies are promising, tools and taggers can be and should be tested with early data
- Where are the limitations of those tools?
- Can we access more inclusive phase space region?
- BOOST 2010: Proceedings will appear soon