Improvements in jet/flavor reconstruction and its application to Higgs Self Coupling analysis

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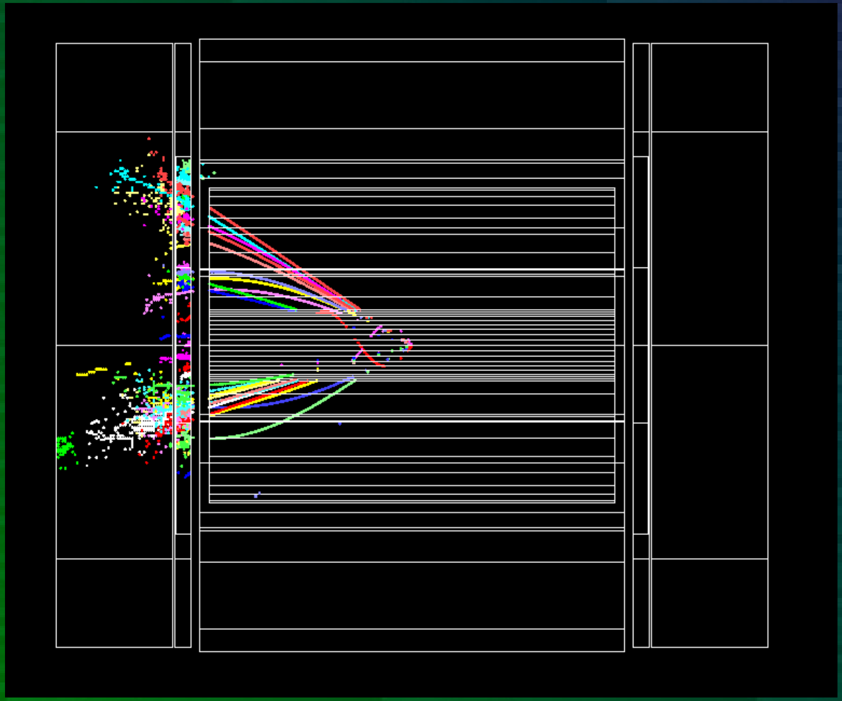
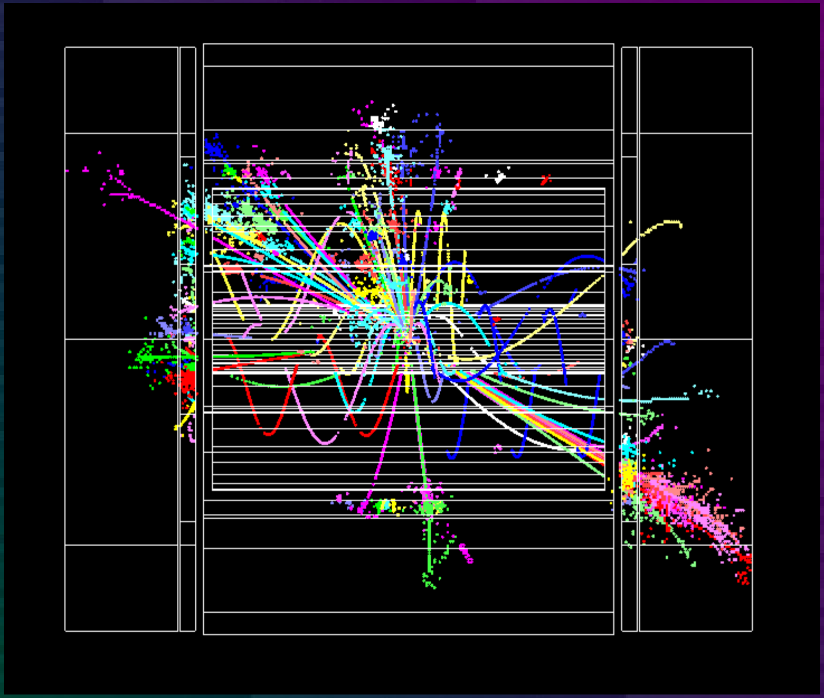
- Introduction
- Vertex finder
- Jet clustering
- Flavor tagging
- Application to ZHH & Summary

jets vs. performance drivers





2-4 jets:
 ZH, WW, ZZ etc.

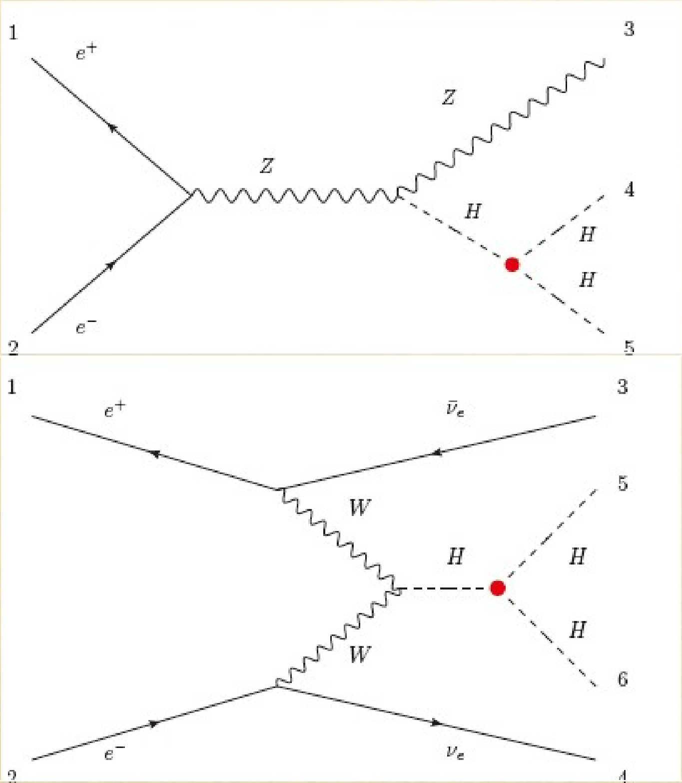
PFA
Pure flavor tagging

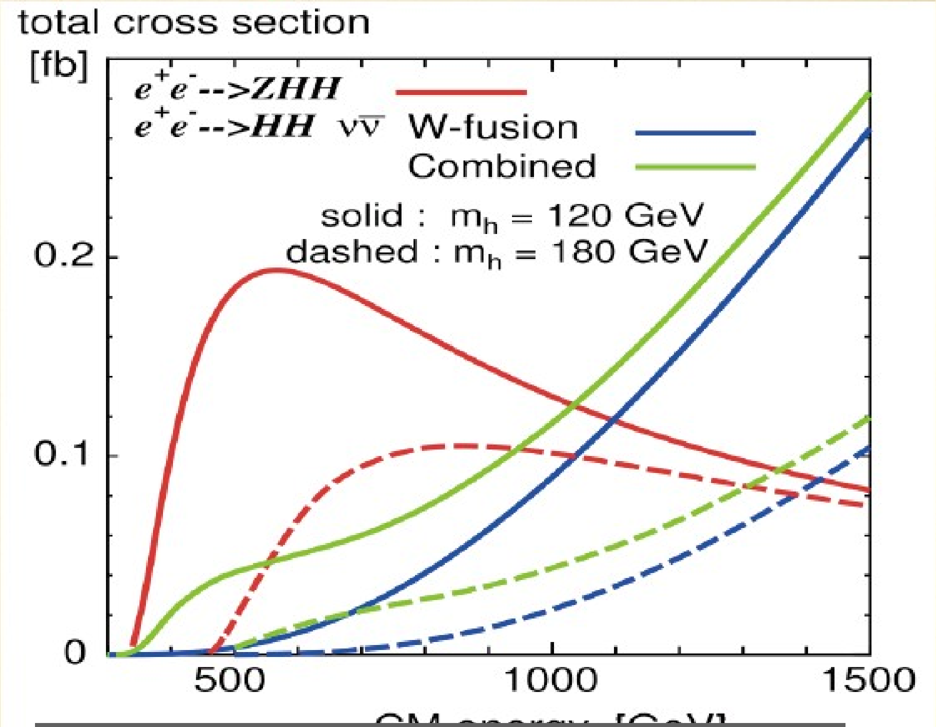
6-8 jets:
 ZHH, ttH, tt etc.

Jet clustering
Noise-resistant flavor tagging

Measurement of the trilinear Higgs self-coupling @ ILC

- double Higgs-strahlung (dominate at lower energy)
- WW fusion (dominate at higher energy)





σ = 0.2 fb:
Only 100 events in 500 fb^{-1}

ZHH BR & # events (m_H=120 GeV)

Decay mode	BR.	# events in 1 ab^{-1}
qqbbbb	32%	73
$\nu\nu$bbbb	9%	21
qqbbWW*->qqbbqqqq	6%	14
llbbbb	4%	10
qqbbWW*->qqbbqlν	3%	7
qqbbWW*->qqbblνqq	3%	7
others	43%	97
tt -> bbqqqq		~400,000

- assuming polarization (e^-: 80%, e^+: 30%)
- qqbbbb has > 30% branching ratio
- all others < 10%
- total cross section is 0.225fb – extremely small!

qqhh (with Z-like pair)

reduction table (probZ1+probZ2 > 0.9)

P(e-,e+)=(-0.8,+0.3) $E_{cm} = 500\text{GeV}, M_H = 120\text{GeV}$ $\int Ldt = 2\text{ab}^{-1}$

normalized	expected	MC	pre-selection	probZ1+probZ2>0.9	Evis>400 MissPt<60 ! (Plmax>20&&Econe>10)	MLP_bbbb>0.2	MLP_bbqqqq>-0.3	MLP_qqbbbb>-0.6	Bmax3>0.76 Bmax4>0.33
qqhh(qqbbbb)	313(138)	117173	82.0(65.1)	15.5(13.8)	13.9(13.0)	13.1(12.3)	12.7(11.9)	12.1(11.4)	8.50(8.15)
qqbbbb	192	59994	50.9	3.17	2.97	2.01	1.75	1.28	0.55
qqqqH(ZZH)	381	49702	45.8	6.58	5.72	5.11	4.80	4.14	2.70
bbcsdu	394548	710285	3016	29.7	29.1	22.3	14.9	13.5	1.38
bbuddu	199165	109200	374	10.5	7.92	5.37	5.37	5.37	0.28
bbcssc	197790	359084	4904	58.4	53.8	47.9	39.2	36.5	2.01
ttqq	2169	9999	170	10.0	5.08	4.83	4.70	4.49	1.85
bbbb	40824	198431	4722	598	494	2.83	2.20	1.80	1.27
lvbbqq	821199	797027	12216	230	33.2	6.18	6.18	4.39	0.07
BG			25509	951	636	100	82.2	73.7	11.7

qqhh (without Z-like pair) reduction table

$(probZ1+probZ2 < 0.9)$

P(e-,e+)=(-0.8,+0.3) $E_{cm} = 500\text{GeV}, M_H = 120\text{GeV}$ $\int Ldt = 2\text{ab}^{-1}$

normalized	expected	pre-selection	probZ1+probZ2<0.9	Plmax<20 || Econe>10	Evis>400 MissPt<60	MLP_bbbb>-0.2	MLP_bbqqqq>0.16	Bmax3>0.8 Bmax4>0.52
qqhh(qqbbbb)	313(138)	82.0(65.1)	66.4(51.3)	63.0(50.9)	57.6(48.7)	54.9(47.1)	33.1(29.1)	16.6(15.1)
qqbbbb	192	50.9	47.7	47.4	44.9	36.2	11.7	6.00
qqqqH(ZZH)	381	45.8	39.2	38.2	35.0	32.3	15.5	7.65
bbcsdu	394548	3016	2986	2973	2869	2581	469	42.2
bbuddu	199165	374	364	364	356	[illegible]	[illegible]	5.37
bbcssc	197790	4904	4845	4825	4616	[illegible]	[illegible]	39.6
ttqq	2169	170	159	107	79.4	78.4	42.8	13.7
bbbb	40824	4722	4124	4106	3368	70.1	18.2	9.12
lvbbqq	821199	12216	11986	8041	1641	297	49.4	4.34
BG		25509	24557	20509	13015	7555	1298	129

ttbar with mis-b-tag

put all together
(preliminary)

Polarization: (e-,e+)=(-0.8,0.3) $e^+ + e^- \rightarrow ZHH$ $M(H) = 120\text{GeV}$ $\int Ldt = 2\text{ab}^{-1}$

Energy (GeV)	Modes	signal	background	significance	
				excess (I)	measurement (II)
500	$ZHH \rightarrow (l\bar{l})(b\bar{b})(b\bar{b})$	6.4	6.7	2.1σ	1.7σ
500	$ZHH \rightarrow (\nu\bar{\nu})(b\bar{b})(b\bar{b})$	5.2	7.0	1.7σ	1.4σ
500	$ZHH \rightarrow (q\bar{q})(b\bar{b})(b\bar{b})$	8.5	11.7	2.2σ	1.9σ
		16.6	129	1.4σ	1.3σ

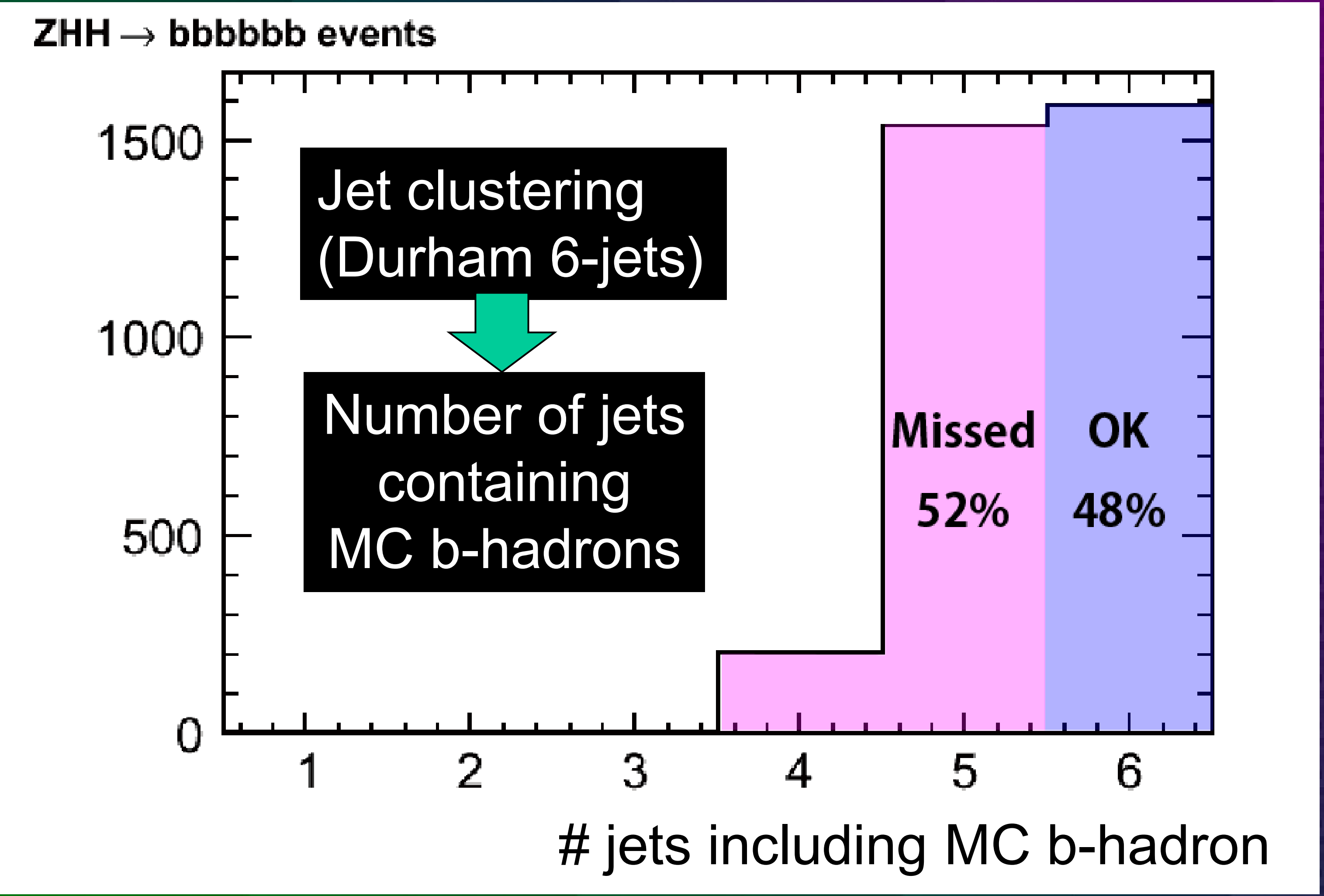
we are interested in:

A. the combined significance of ZHH excess.

B. the combined precision of measured ZHH cross section.

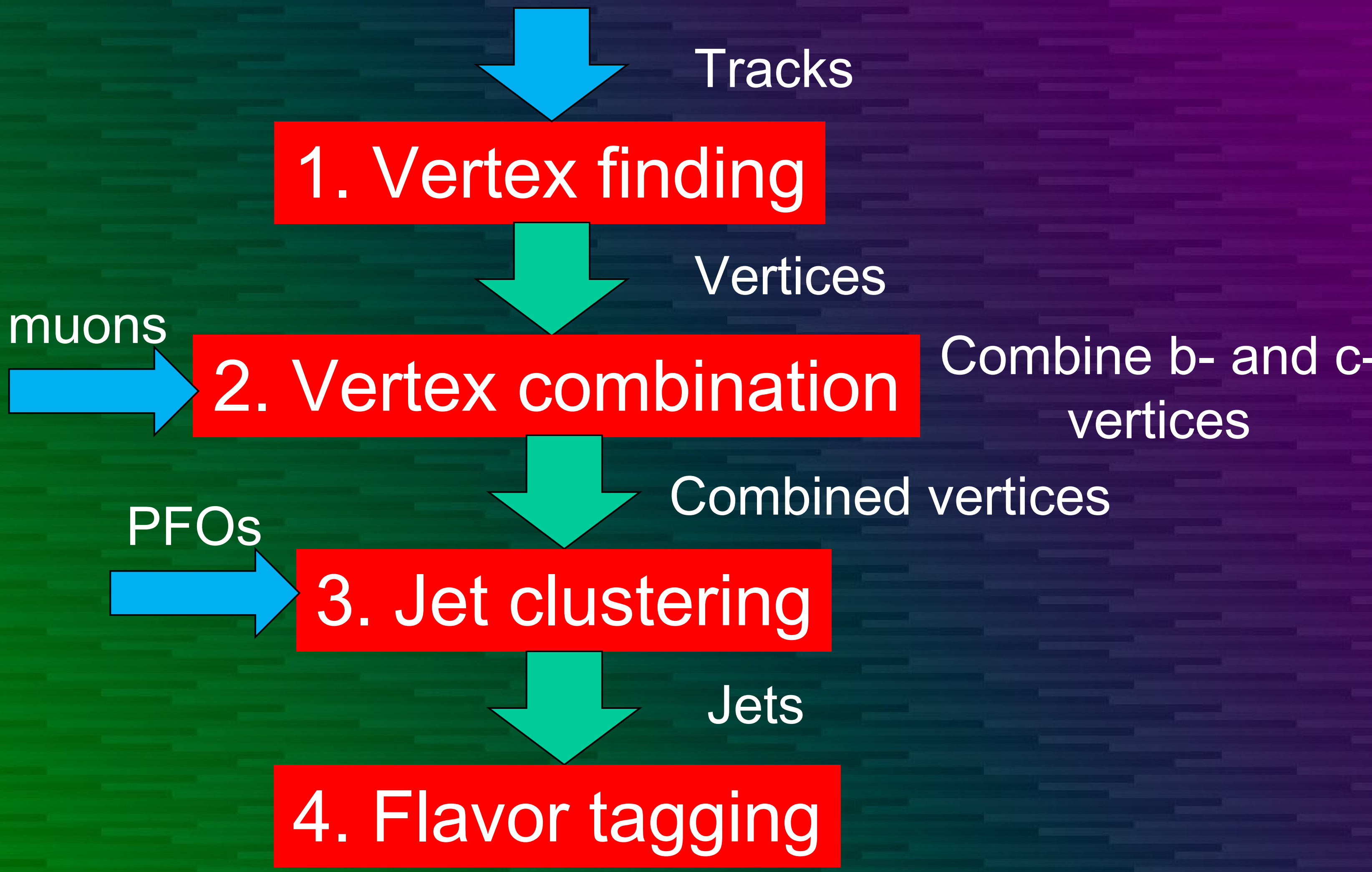
Overall signal excess: 3.9σ in 2 ab^{-1} -> not enough??

'# of b jets' in ZHH



# of b-jets is reduced due to mis-jet-clustering.

The new JC/FT procedure



finished!

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A new build-up vertex finder

LCFIVertex package already has ZVTOP vertex finder; but

ZVTOP needs jet directions
(purity significantly goes down without jet direction)

Original vertex finder

- Build-up method (pairing tracks -> association)
- Do not use jet direction
- Including mass-based vertex selection
- Targeted for higher purity
  (wrong vertices significantly affect jet clustering)

For implementation details, see ALCPG11 slides

Comparison of vertex finders

Vertex qualification (by MC)

- GOOD vertex:
  All tracks in the vertex originate from the same MC metastable particle (mainly b- or c- hadrons). Tracks from secondary and tertially vertices may be combined in the same GOOD vertex
- PURE vertex:
  All tracks in the vertex are from the same vertex (ie. secondary, tertially and more following vertices must be completely separated)

Performance: track view

qqhh, 500 GeV

Trks.	# tracks	ZVTOP (Durham 6-jets)			Build-up original		
		All	GOOD	PURE	All	GOOD	PURE
Primary	10231	160			54		
b	2037	1399	1344	857	1309	1303	919
c	2433	1653	1618	1181	1571	1562	1197
Others	587	159	45	34	46	18	13
All	**15288**	**3371**	**3007**	**2072**	**2980**	**2883**	**2129**

bbcssc, 500 GeV

Trks.	# tracks	ZVTOP (Durham 6-jets)			Build-up original		
		All	GOOD	PURE	All	GOOD	PURE
Primary	6980	76			14		
b	893	612	593	405	579	573	413
c	1627	1086	1052	878	1045	1035	874
Others	430	119	28	24	53	19	15
All	**9930**	**1893**	**1673**	**1307**	**1691**	**1627**	**1302**

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Concept of the jet clustering

Jet clustering with only 4-momenta information has a limitation

- Low-energy quark-jet reconstruction
  (inevitable for reconstructing 6/8-jet processes)
  => cannot be distinguished with hard-gluons
- Durham, Cambridge, Lund, … all similar performance

Vertex information is very powerful for jet clustering

- b/c hadrons are usually at the core of the color string
- good separation from gluon emission
  (g->bb, cc BR is small)

Vertex jet clustering!

Vertex combination & muons

Vertex finder

Build-up (original)

Secondary muons

Simple muon tagging:

- PFO w/ MUON hit > 50 MeV
- Impact parameter > 5 σ, < 5 mm
- ECAL, HCAL energy deposit
  (ECAL < 1.0 GeV,
  1.5 < HCAL < 5.0 GeV)

Seed of the jets

Combined vertex

Combination criteria:

- opening angle of two vertices to IP < 0.2 rad.
- opening angle of the vertex and muon direction to IP < 0.3 rad.

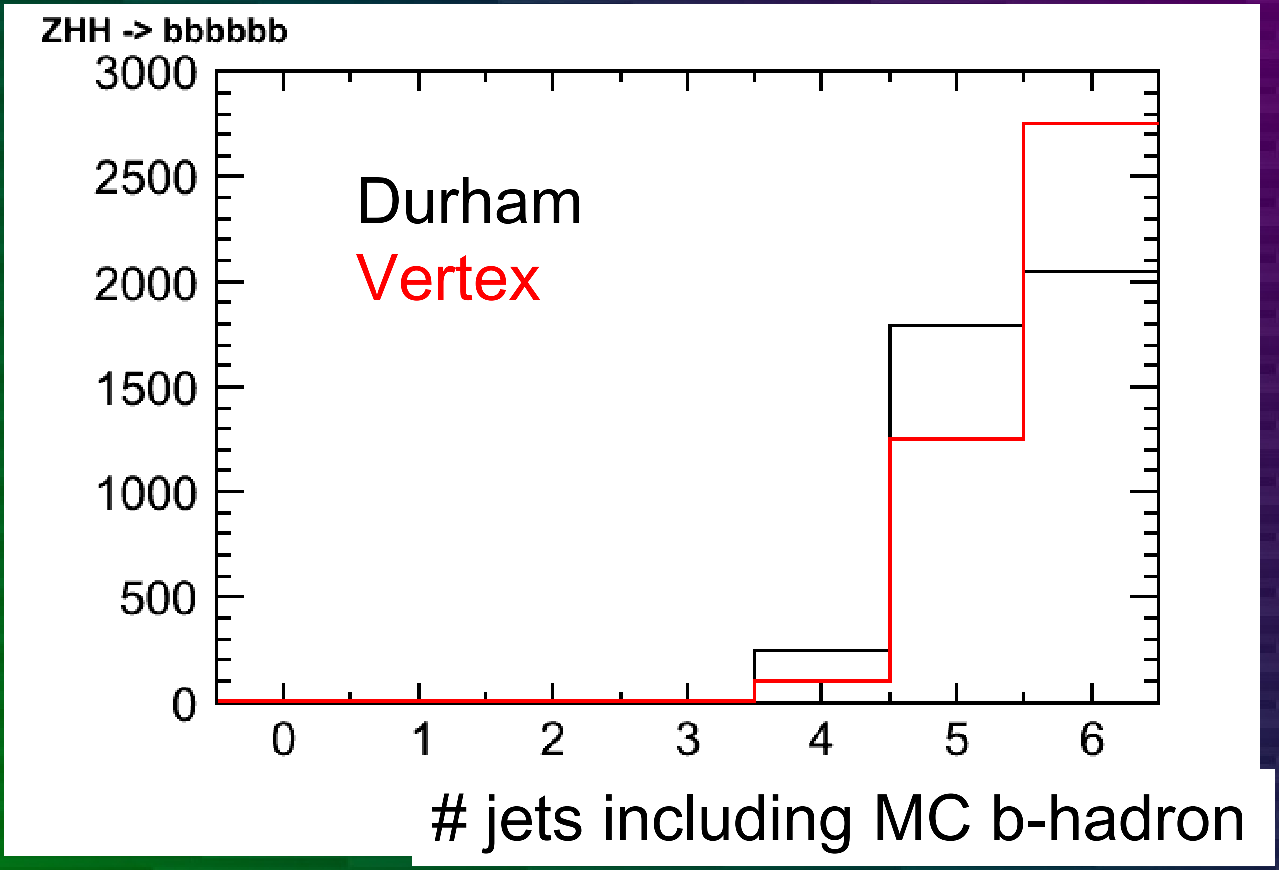
Jet clustering using vertices

1. Combined vertices are listed as 'jet core'
2. All particles within 0.2 rad. to the jet core are associated to the core
3. All associated jet cores and residual particles are associated with Durham y criteria

$$y = \frac{2\min(E_1, E_2)^2(1-\cos\theta_{ij})}{Q^2}$$

* Jet cores with vertices are never combined to each other (y value is set to +inf.)

b-hadron separation (6b process)

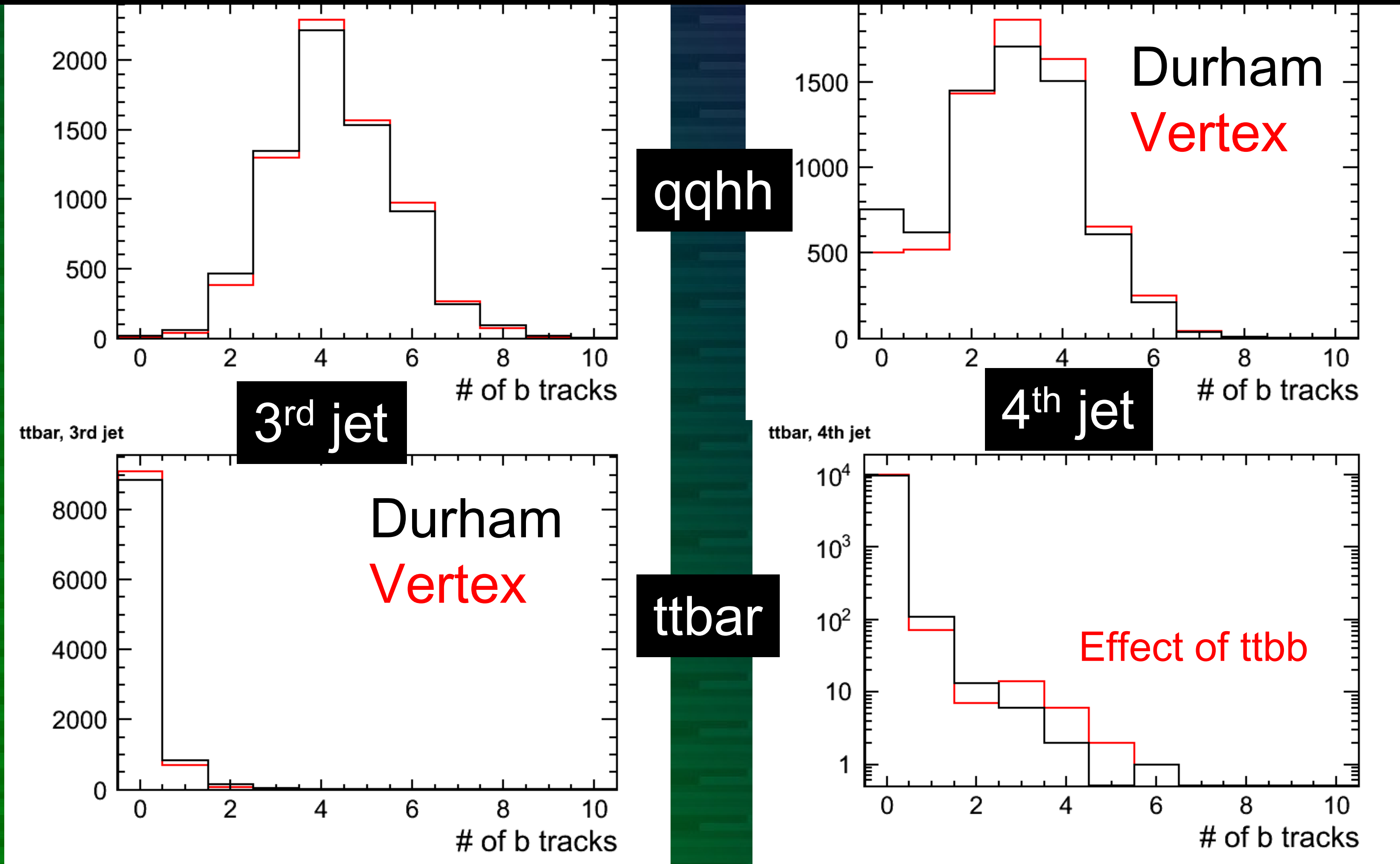


All jets including b – 52% -> 66%

Significant improvement! (already shown in ALCPG)

b-hadron tracks (qqhh vs bbcssc)

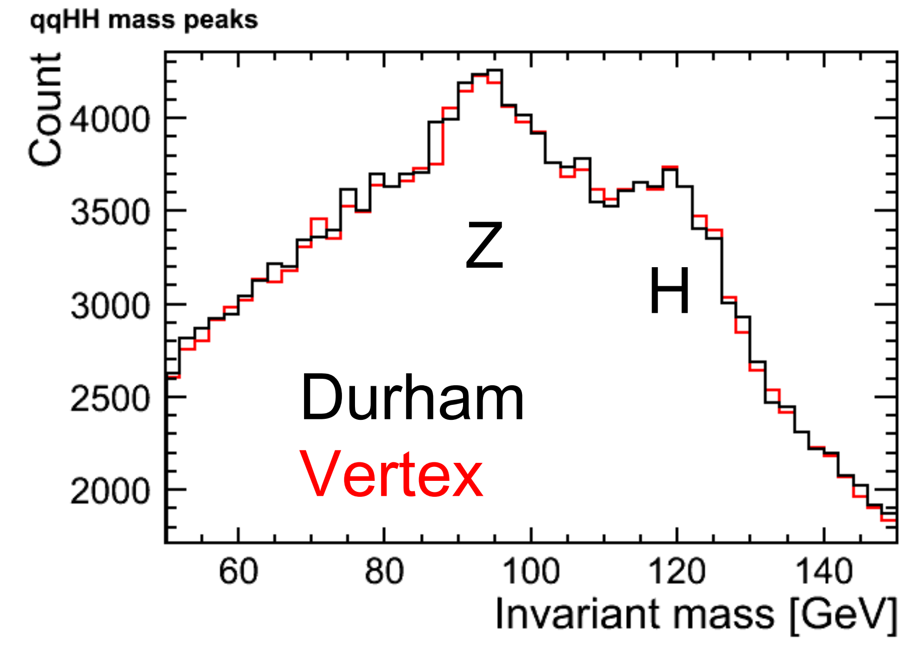
Jets are sorted by descending order of # of b-hadron tracks

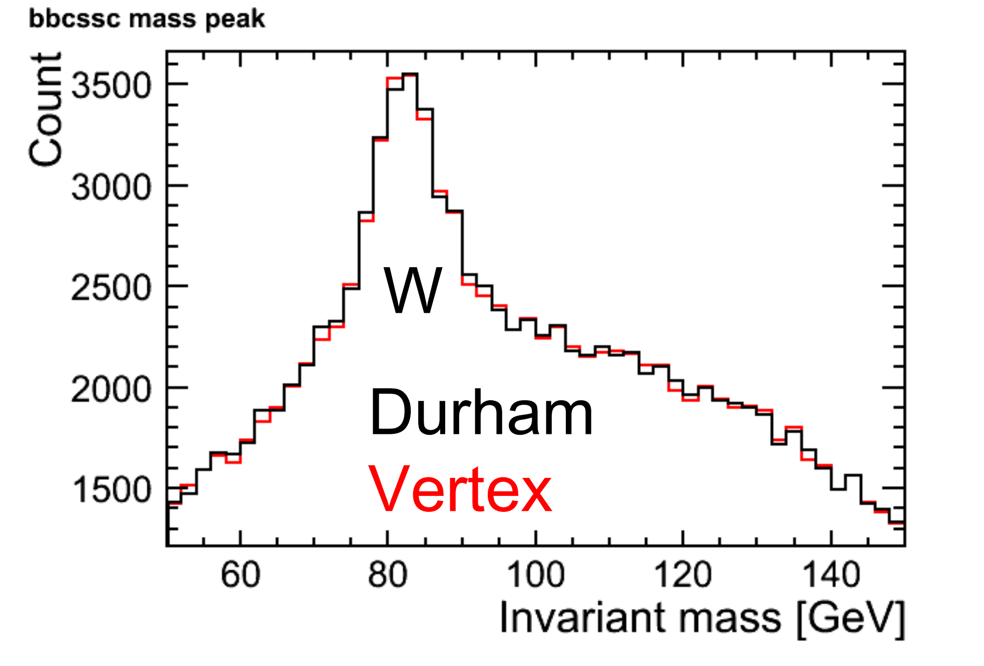


ttbar rejection improved

qqhh acceptance improved

Mass peak (reco)





All combinations are used
No significant difference

- Introduction
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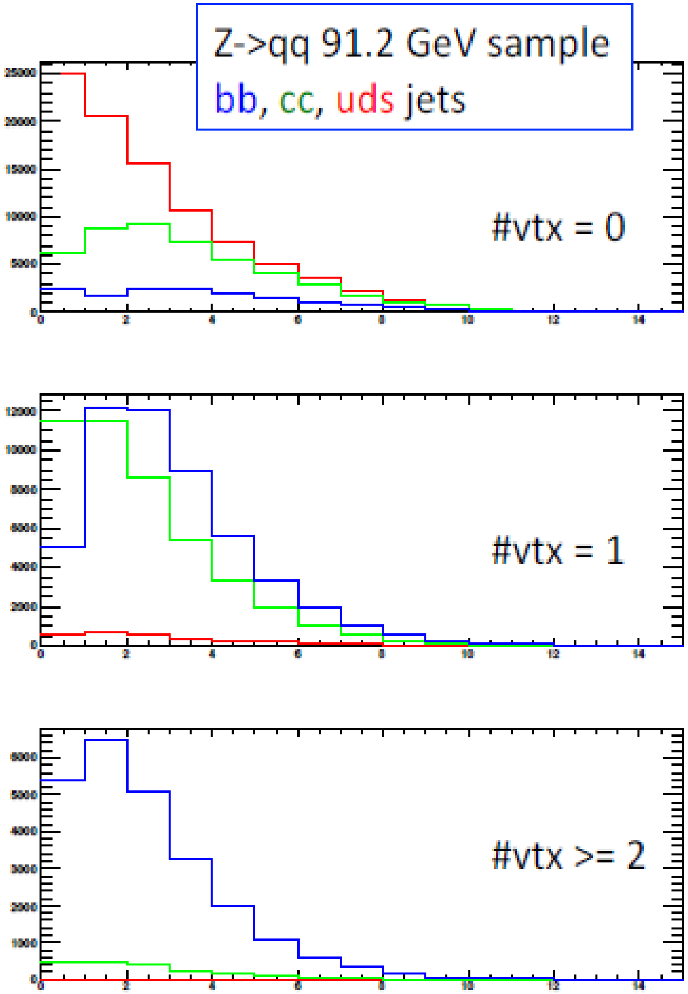
Update on the flavor tagging

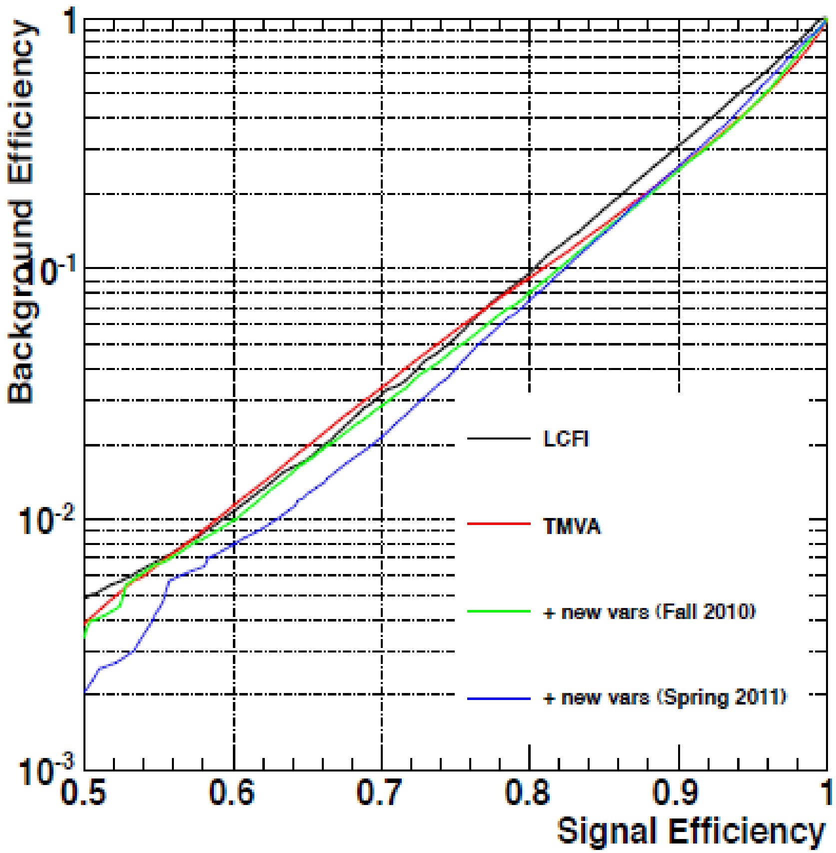
- Use of TMVA instead of home-maid ANN
- More input variables
  - boosted sphericity
  - vertex displacement/momentum angle
  - vertex mass (not pt corrected)
  - mass, momentum, decay distance, decay significance for the first and second (if found) vertices
  - distance, significance, and displacement/momentum angle between the first and second vertices

- See ALCPG11 slides for the details

flavor tagging



number of trks *not* used in primary or secondary vertex

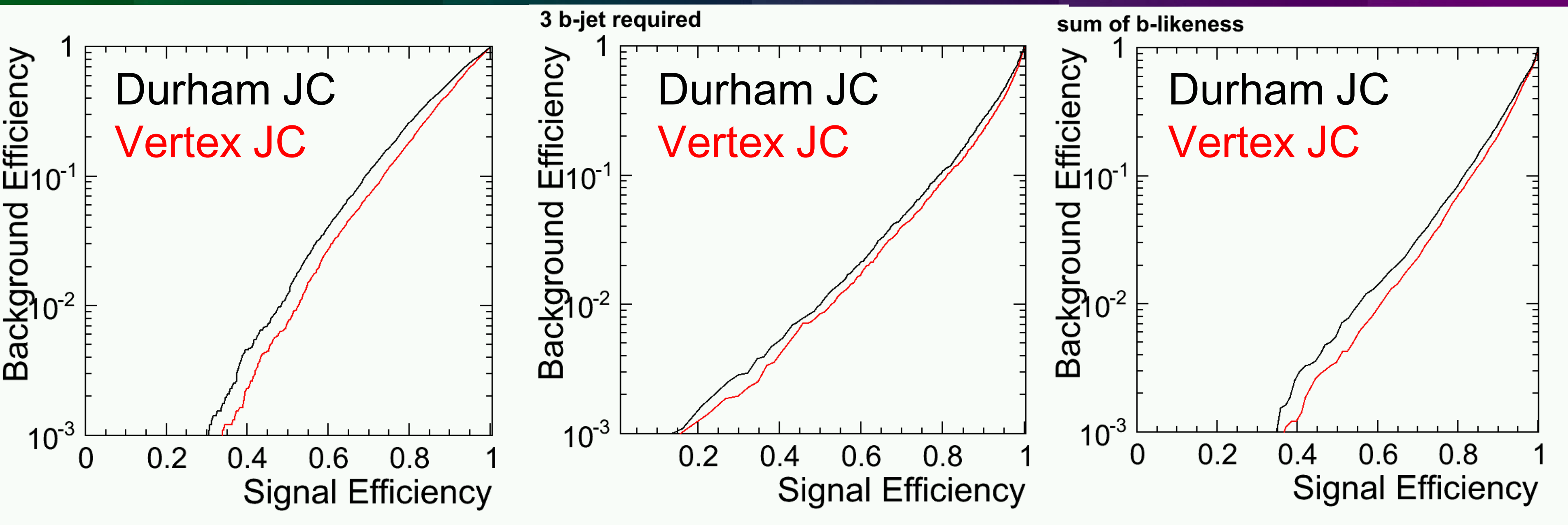


- we do much better in the high purity region
- this demonstrates that there is still information in the jet that we have not previously used
  - should be even better if we use track parameters & errors, e.g. joint probabilities with respect to secondary vertices

Separation of ttbar background

- qqhh (h->bb) : 4-6 b
  bbcssc (ttbar) : 2 b
- b-probability of 3rd & 4th jet is the separator
  Sum of b-prob. over 6-jets can be used as well
- High background rejection ratio needed
  - Cross section ratio: 1 : >1000 (!)
- Signal efficiency vs bg acceptance ratio
  - Obtained by varying threshold

Separation ZHH vs ttbar



4b required

3b required

Sum b-likeness

- Overall performance improvement seen (sep. high-purity rgn.)
- (this is old-LCFI results; new framework is about to be ready)

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ZHH/ttbar separation

- Separation variables
  - B-tag variable (tt: 2b, qqHH: >4b)
  - Masses (Z, H, W, top)
  - Angles (tt: t-channel dominant)
- Now concentrated on b-tag variables
  - Other cut optimization needs more statistics
- Requirements of b-likeness in 3rd & 4th jet
  - Cut at 50% signal efficiency
    - New: 3rd th = 0.9, 4th th = 0.465
    - Old: 3rd th = 0.88, 4th th = 0.405

Separation performance

Vertex jet clustering

	No cut	4th jet cut	3rd jet cut	3rd & 4th jet cut
qqHH (H -> bb)	8352 (73)	4233 (37)	4367 (38)	3163 (28)
bbcssc	9930 (100000)	95 (960)	113 (1140)	20 (201)

30% improvement!

Durham jet clustering

	No cut	4th jet cut	3rd jet cut	3rd jet cut
qqHH (H -> bb)	8352 (73)	4277 (37)	4382 (38)	3116 (27)
bbcssc	9930 (100000)	145 (1460)	137 (1380)	29 (292)

Summary

- Improvement of jet-clustering, vertex finder & flavor tagging is necessary for ZHH analysis
- Original vertex finder can make vertices without jet clustering, performance not so degraded (compared to old LCFI/ZVTOP)
- Jet clustering shows significant reduction of bbcssc background

Prospects

- To Do
  - Optimize flavor tagging for multi-jets
  - Tuning vertex finder (more) / lepton tagging
  - Full ZHH analysis
    - Need more backgrounds! (with new Mokka/ilcsoft)
  - Overlay beam background
  - Vertex finder: speed
  - Software cleanup & publication
    - Including cooperation with CLIC strategy