A Study of Heavy Higgs Pair Production at 3 TeV

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LCWS2011
Granada, Spain, September 27, 2011

Consider two scenarios with heavy H^+ and A^0 at 3 TeV CLIC for the CDR

Scenario 1) (CDR H Benchmark)

MSSM model
with non-unified gaugino masses

M_1=780 GeV, M_2=940 GeV, M_3=540 GeV
m_0 = 303 GeV, A_0 = -750 GeV,
tan β = 24, μ>0

M_A = 902.6 GeV
M_H = 902.4 GeV
M_{H+} = 906.3 GeV

Scenario 2) (CDR χ Benchmark)

MSSM model

$m_{1/2}$=966 GeV, m_0 = 800 GeV,
A_0 = 0, tan β = 51, μ<0

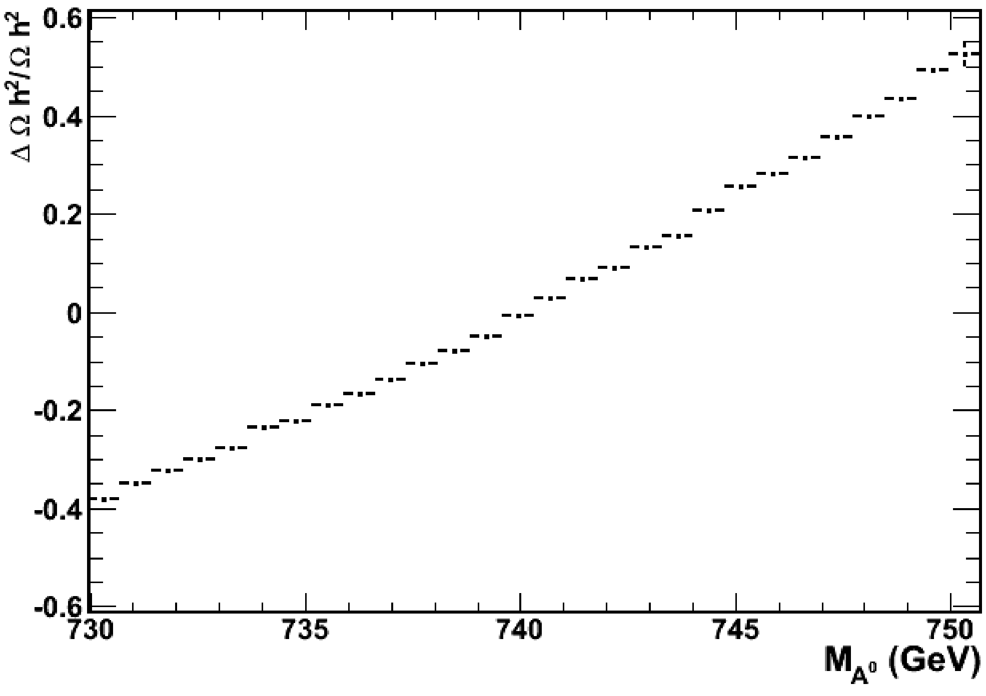
M_A = 742.8 GeV
M_H = 742.0 GeV
M_{H+} = 747.6 GeV

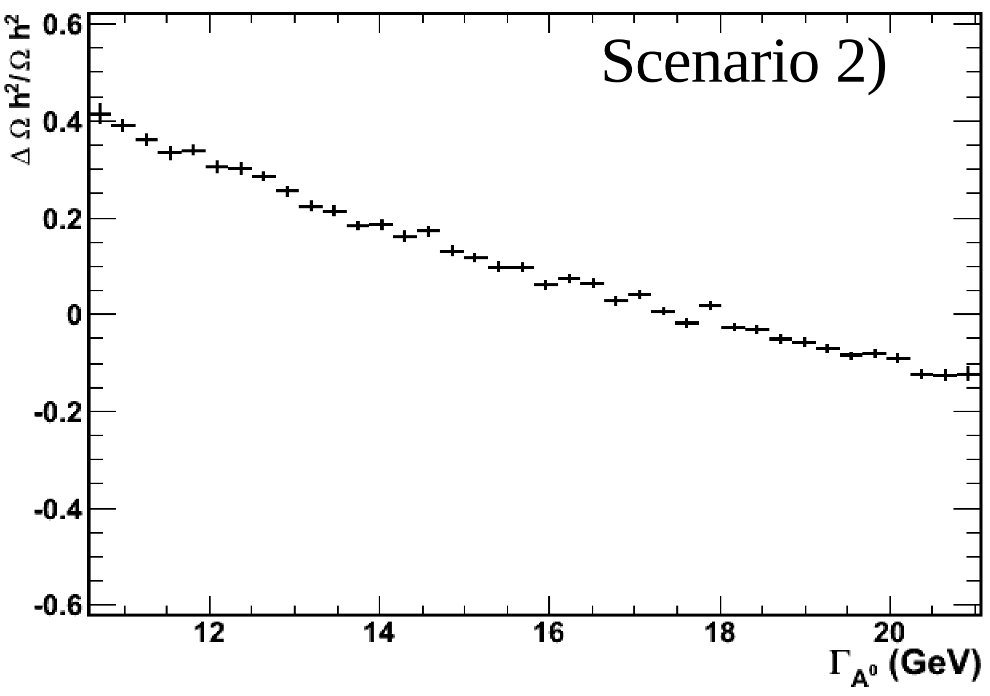
Determining Heavy Higgs Mass and Widths at CLIC: Accuracy Requirements from DM connection

(with A Arbey and N Mahmoudi)

Assess required accuracy on M_A and Γ_A by studying their contribution to uncertainty on extracting $\Omega_\chi h^2$ in large tan β scenarios;

16-parameter pMSSM scans using SuperIso Relic and cross-check with Micromegas;



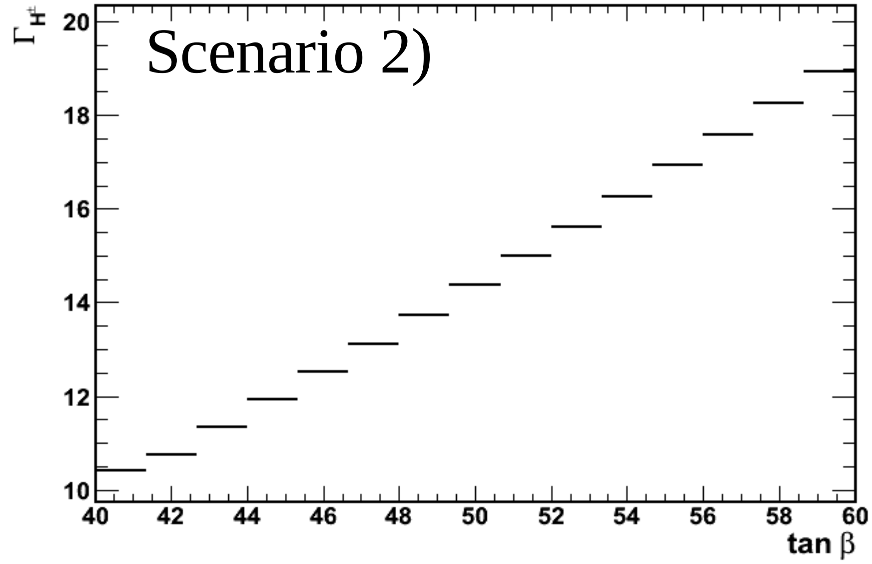


Determining Heavy Higgs Masses and Widths at CLIC: Accuracy Requirements from DM connection

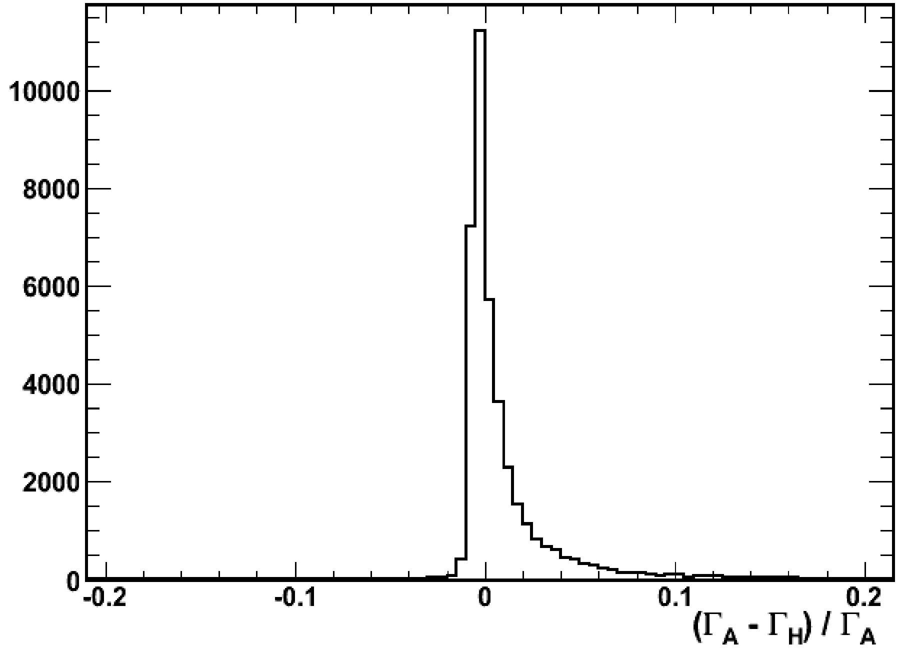
(with A Arbey and N Mahmoudi)

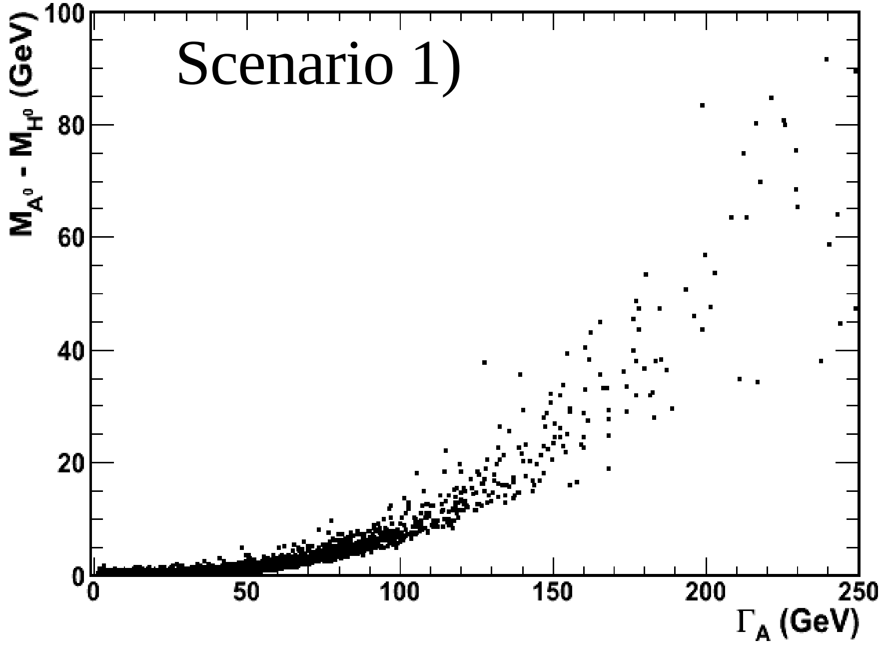
H^+ width measurement in $e^+e^- \rightarrow H^+H^-$ clean and effective way to constrain $\tan\beta$ and width of A^0 boson;

Over pMSSM phase space M_A-$M_H << \Gamma_A$ $\rightarrow$ justify equal mass constrainto extract Γ



FeynHiggs scan of pMSSM parameter space





Event Generation, Simulation and Reconstruction

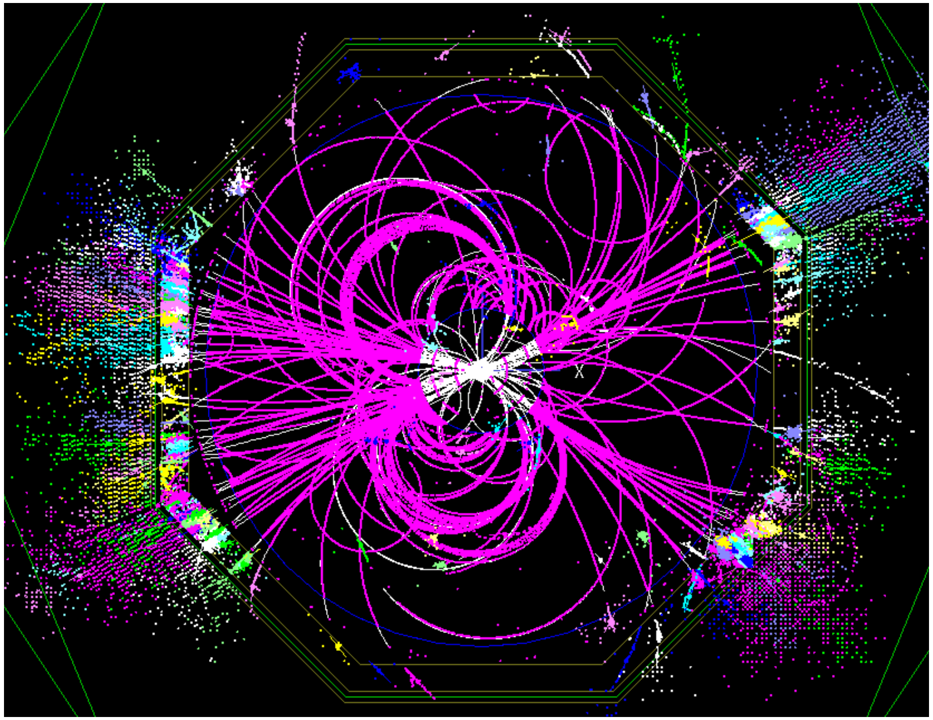
Signal generation with PYTHIA 6.215+ISASUGRA 7.67,

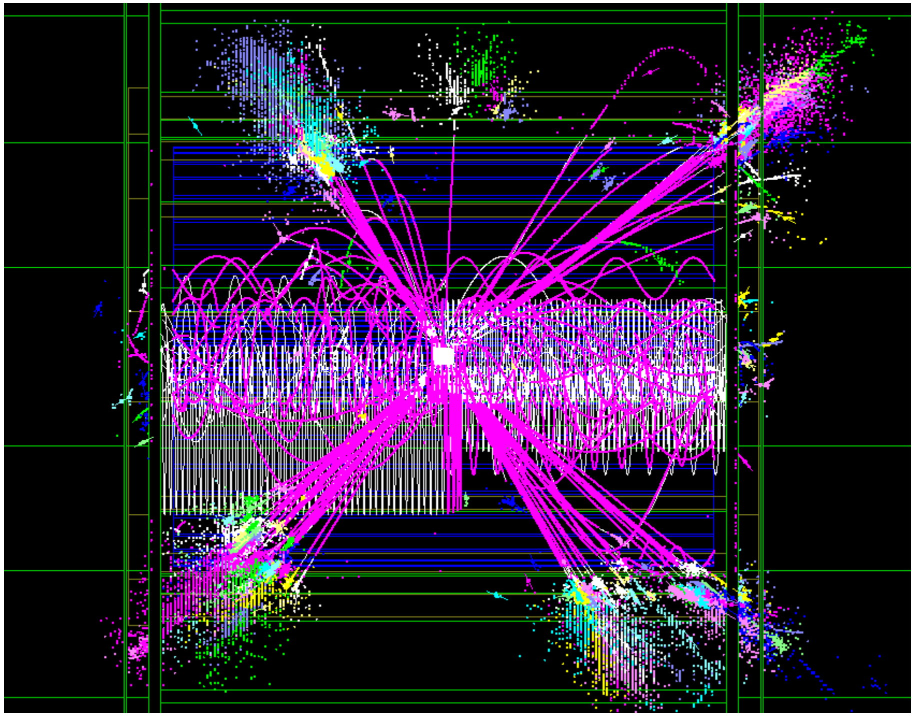
Full simulation with MOKKA using CLIC_ILD CDR detector model,
Centralised GRID production for CLIC CDR (thanks to JJ Blaising, S Poss);

Reconstruction with FASTJet jet clustering, b-tagging based on ZVTOP vars and port of DELPHI PUFITC kinematic fitter to Marlin;

Process	σ (fb)	Generator
H^0A^0	0.7 / 0.4	ISASUGRA 7.69+ PYTHIA 6.215
H^+H^-	1.6 / 1.1	ISASUGRA 7.69+ PYTHIA 6.215
Inclusive SUSY	84.9 / 77.1	ISASUGRA 7.69+ PYTHIA 6.215
W^+W^-	728.2	PYTHIA 6.215
Z^0Z^0	54.8	PYTHIA 6.215
$t\bar{t}$	30.2	PYTHIA 6.215
$b\bar{b}b\bar{b}$	5.8	WHIZARD
$W^+W^-Z^0$	32.8	CompHEP+ PYTHIA 6.215
$Z^0Z^0Z^0$	0.5	CompHEP+ PYTHIA 6.215

$e^+e^- \rightarrow H^0A^0 \rightarrow bbbb$





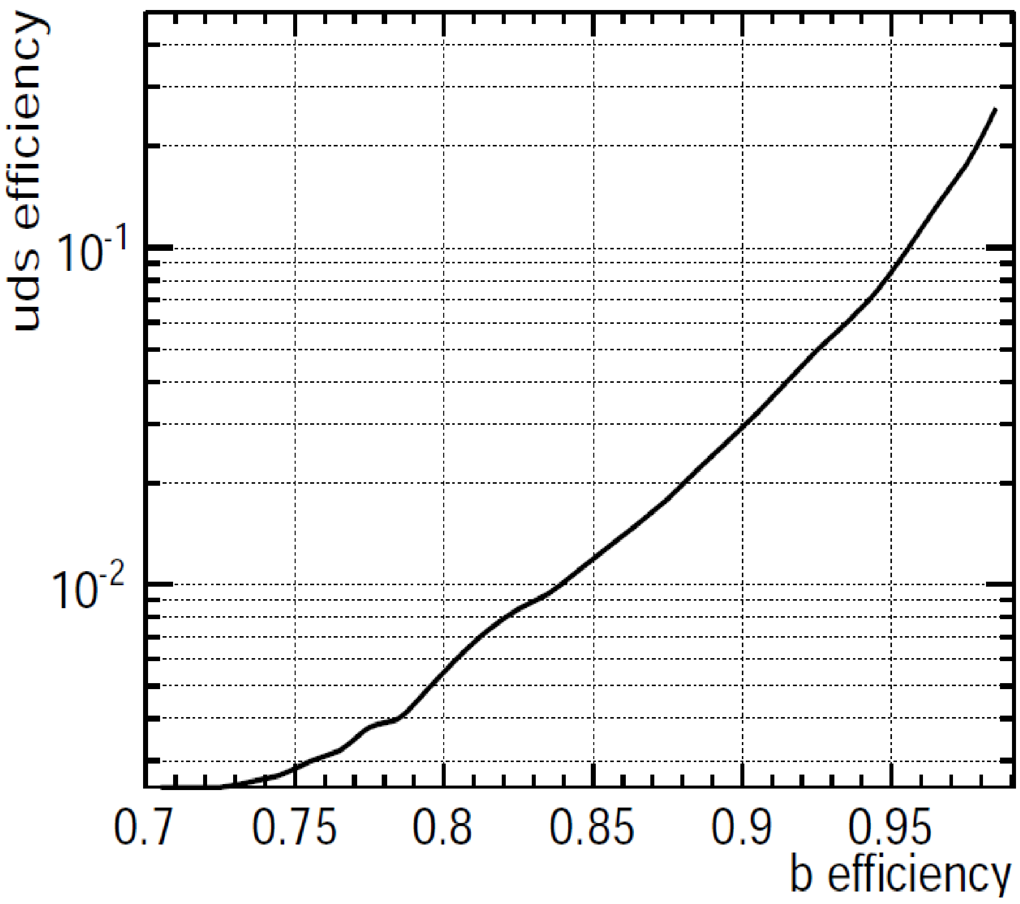
Based on analyses of MB, Hooberman & Kelley, PRD 78 (2008) 015021
and MB and P Ferrari, CERN-LCD-Note-2010-006.

H^0A^0 Signal Event Selection: b Tagging

Explicit b-tagging based on topological vertex reconstruction with ZVTOP-ZVRES;

b-tagging optimise for high efficiency by performing secondary particle search in jets with no reco secondary vertices;

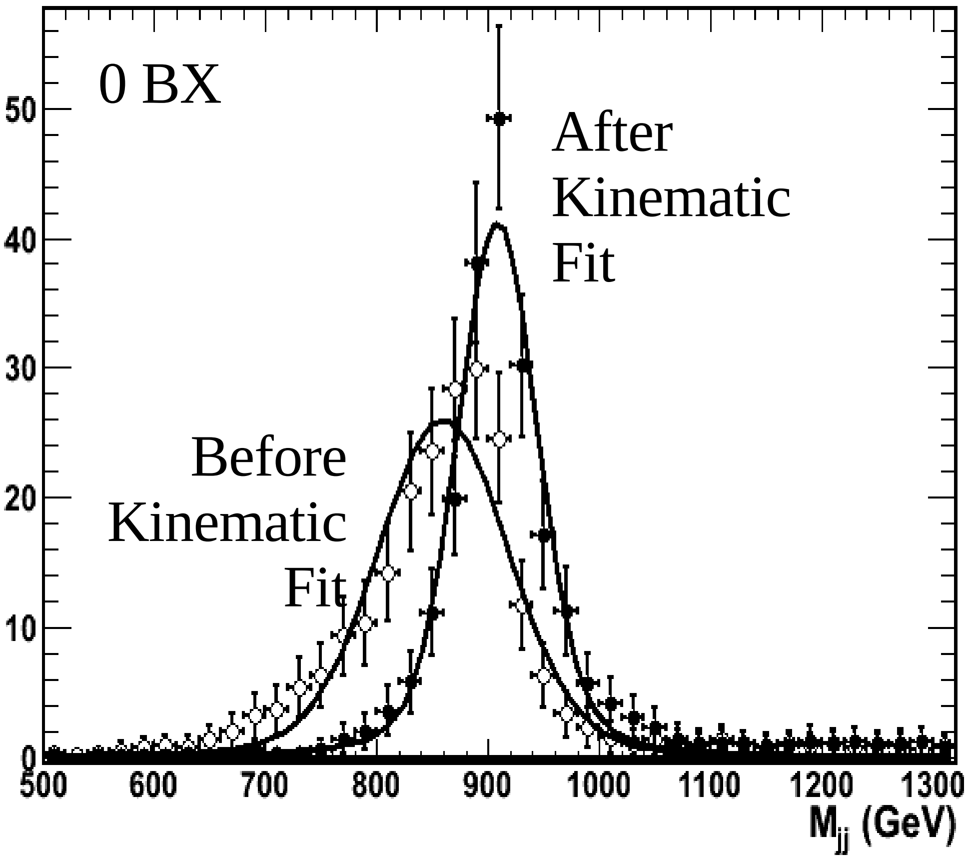
b-tag probability computed per jet using boosted decision tree strategy in TMVA package and then combined for di-jets and event.



Higgs Mass Reconstruction: Kinematic Fit

	$\Delta E_{jet}/E_{jet}$ RMS90	σ_M (GeV)
Raw (bb)	0.091	51.5
Raw (qq)	0.071	37.6
CKF Durham	0.075	27.9

Apply kinematic fit, accomodating beamstrahlung, to improve di-jet mass resolution (finite detector resolution, particle flow confusion, jet clustering confusion and s.l. B decays (+22% $\Delta E_{jet}/E_{jet}$)

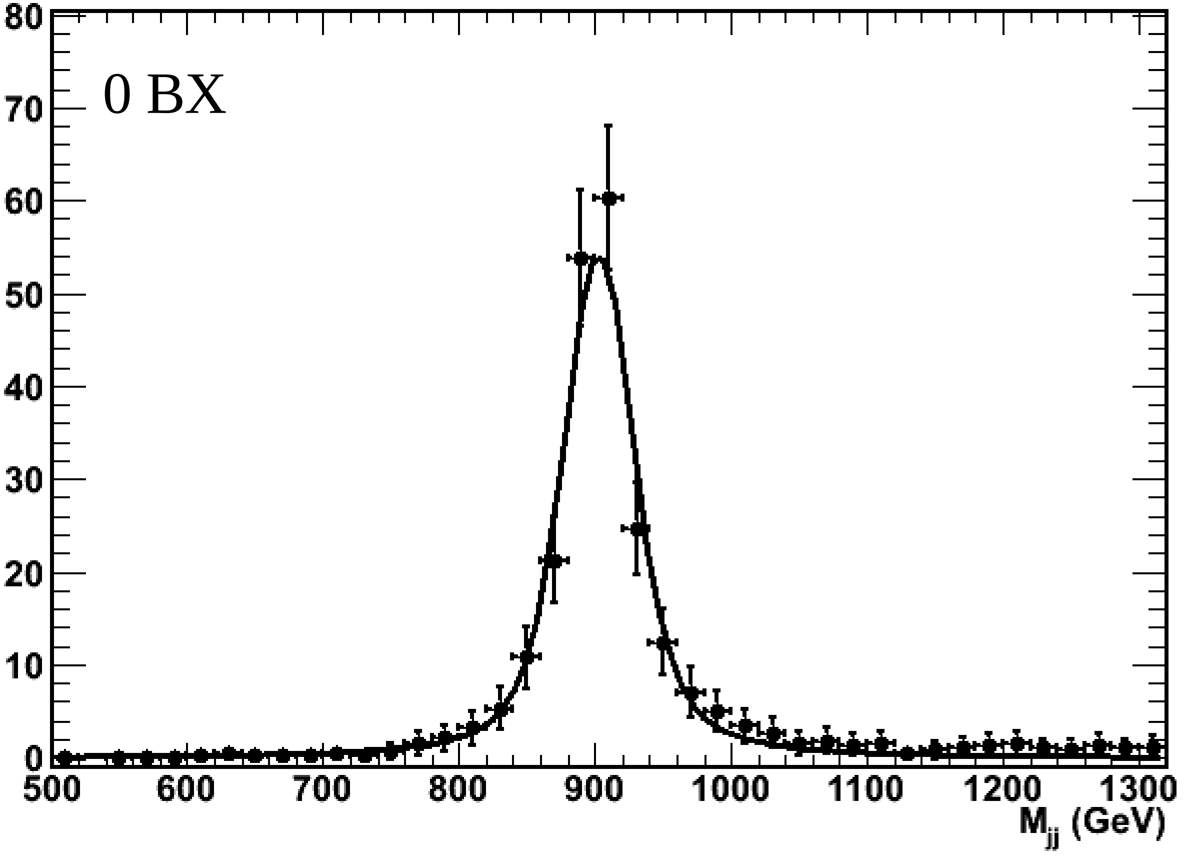


Model mass as convolution of BW(natural width Γ) and Gaussian (detector resolution σ_M), after kinematic fit Gaussian resolution improves by ~45% and accuracy on fitted mass by ~30%.

Scenario 1)
3-par Fit to Signal Only
M_A = (904.2+/-2.9 (stat)) GeV

Higgs Mass and Width Reconstruction: Kinematic Fit with Equal Mass Constrain

Apply kinematic fit imposing equal mass bosons



	Gauss Width	σM
CKF	27.9	2.9
CKFM	16.2	2.1

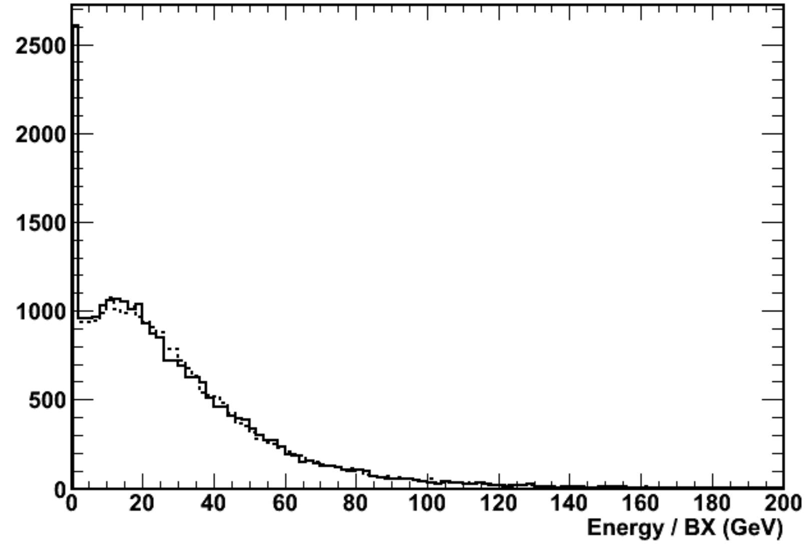
Scenario 1)
3-par Fit to Signal Only
M_A = (902.5+/-2.1 (stat)) GeV
Γ_A = (22.2+/-3.5) GeV

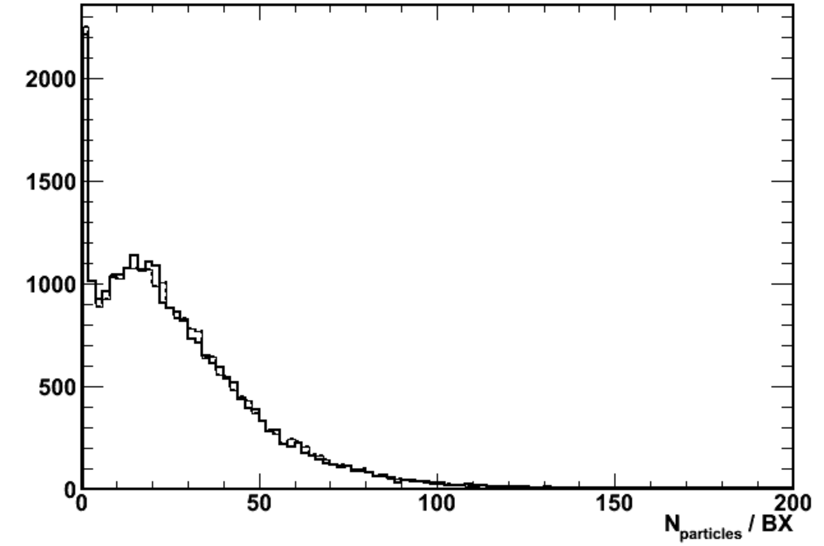
Higgs Mass Reconstruction
$\gamma\gamma \rightarrow$ hadron Background

Use semi-inclusive jet clustering: anti-kt algorithm of FastJet (implemented as Marlin processor) requiring 4 jets with E_{jet} > 150 GeV to avoid incorporating background hadrons into "physics" jets, rate of low energy jets can be used to monitor background;

Semi-inclusive jet clustering mitigates impact of $\gamma\gamma \rightarrow$ hadrons on the width and central value of the di-jet invariant mass. Kinematic fit also helps reducing contribution of $\gamma\gamma$ hadrons to jet energy.

Study effect of $\gamma\gamma$ bkg for 10ns time stamping with Loose, Std and Tight PFO selection





Higgs Mass Reconstruction
$\gamma\gamma \rightarrow$ hadron Background

Total Energy and Nb of Particles in Event

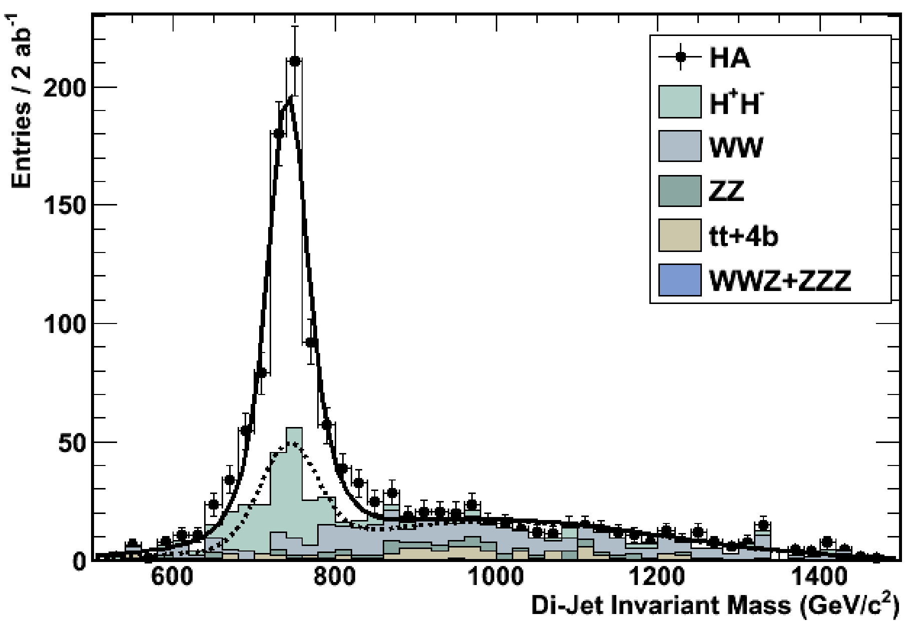
	0 BX (p_t>0.25)	10ns (p_t>0.95)	Loose (p_t>0.95)	Std (p_t>0.95)	Tight (p_t>0.95)
E_{tot} (GeV)	2575	3075	2690	2677	2609
N_{ptc}	161	212	183	184	156

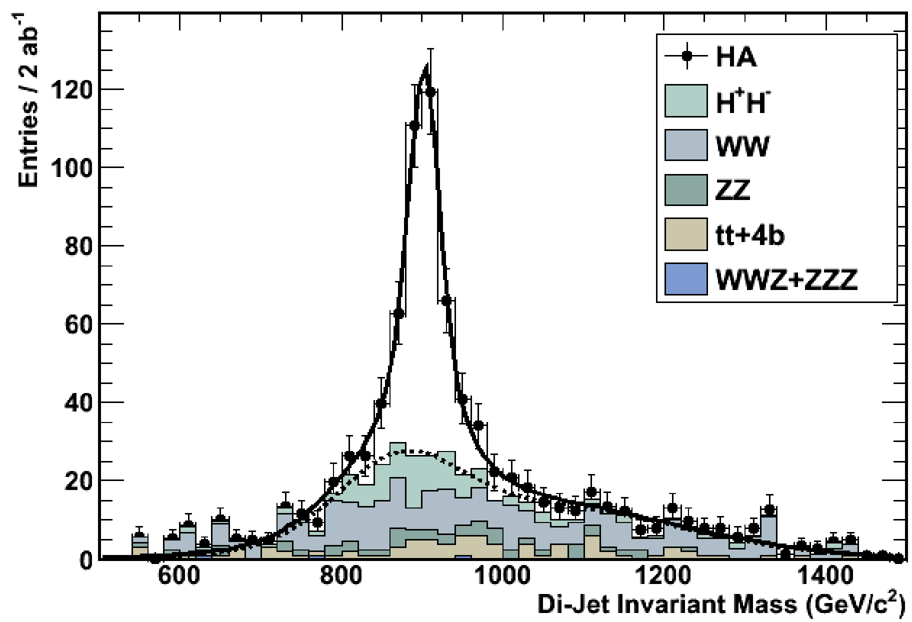
Gaussian di-Jet Invariant Mass Resolution

σ_M (GeV)	0 BX (p_t>0.25)	10ns (p_t>0.95)	Loose (p_t>0.95)	Std (p_t>0.95)	Tight (p_t>0.95)
Raw	51.5+/-5.7	130.1+/-14.5	76.7+/-8.8	73.2+/-8.1	65.0+/-6.0
CKF Durham	27.9+/-3.8	73.0+/-9.6	49.7+/-4.8	46.5+/-4.4	36.5+/-4.9
CKF anti-kt	30.8+/-4.9	39.2+/-6.2		36.6+/-4.3	

A^0 Mass and Width Reconstruction:

Kinematic Fit with Equal Mass Constrain, anti-kt semi-exclusive jet clustering





Signal + SM Bkg
6-par Fit
M_A = (742.7+/-1.4 (stat)) GeV
Γ_A = (21.7+/-3.3) GeV

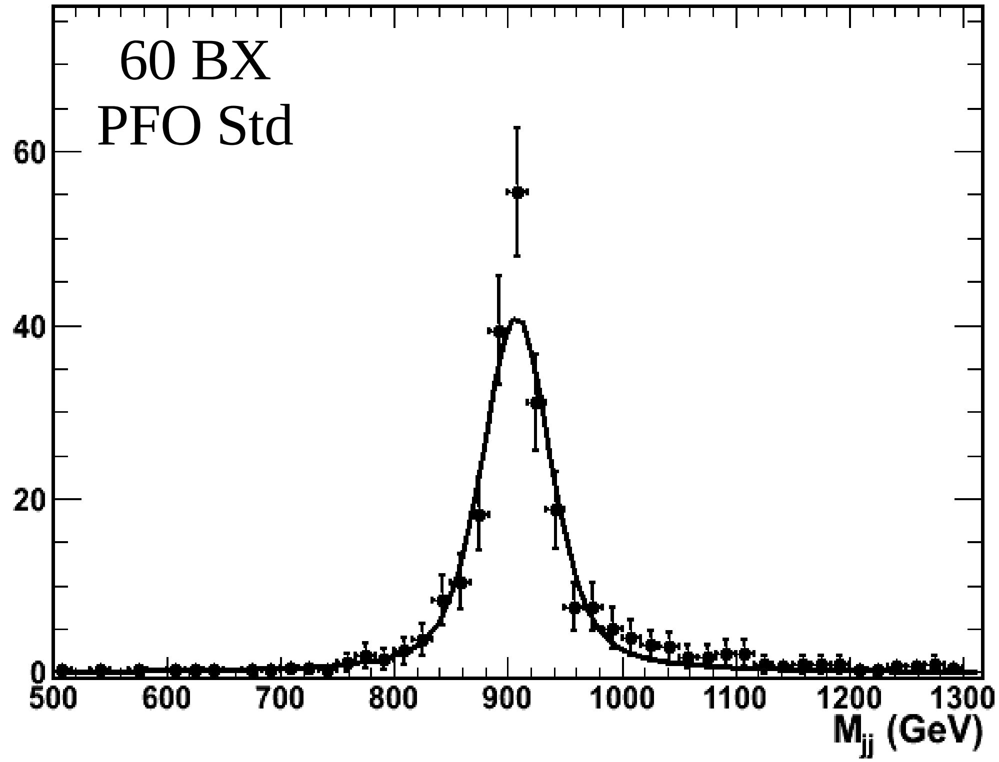
Signal + SM Bkg
6-par Fit
M_A = (902.1+/-1.9 (stat)) GeV
Γ_A = (21.4+/-5.0) GeV

Higgs Mass and Width Reconstruction: Kinematic Fit with Equal Mass Constrain + γγ

3-par Fit to Signal Only

Durham with PFO Std
M_A = (930.5+/-3.7 (stat)) GeV
Γ_A = (27.2+/-5.8) GeV

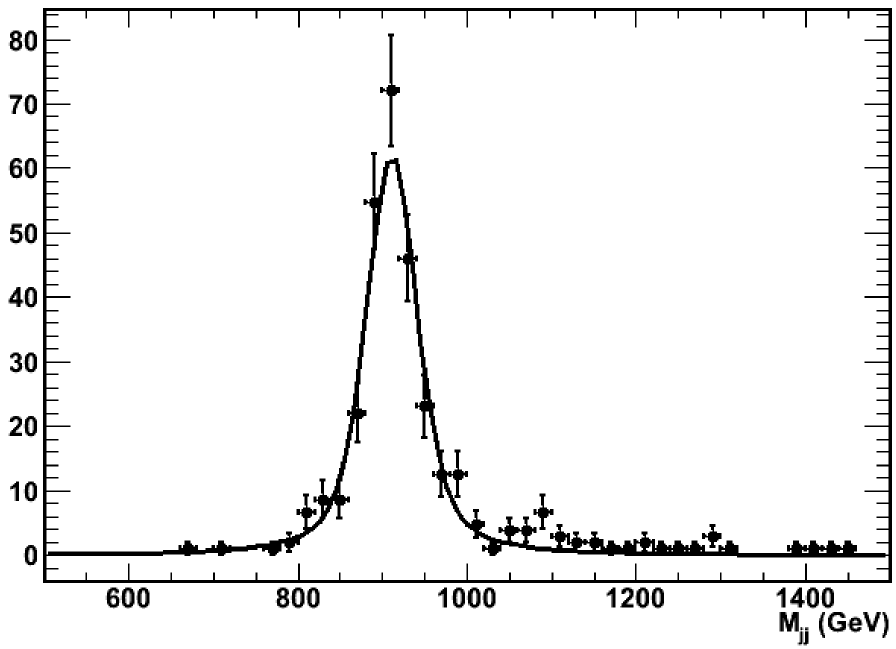
anti-kt with PFO Std
M_A = (905.4+/-2.4 (stat)) GeV
Γ_A = (23.4+/-4.0) GeV

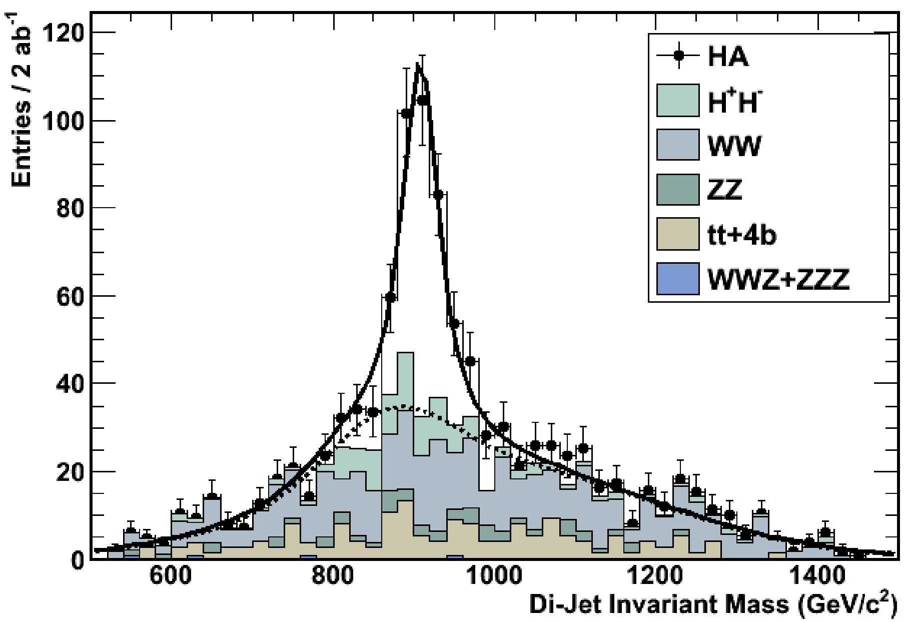


3-par Fit to Signal Only
anti-kt with PFO 10 ns
M_A = (906.3+/-4.1 (stat)) GeV
Γ_A = (28.6+/-5.2) GeV

A^0 Mass and Width Reconstruction:

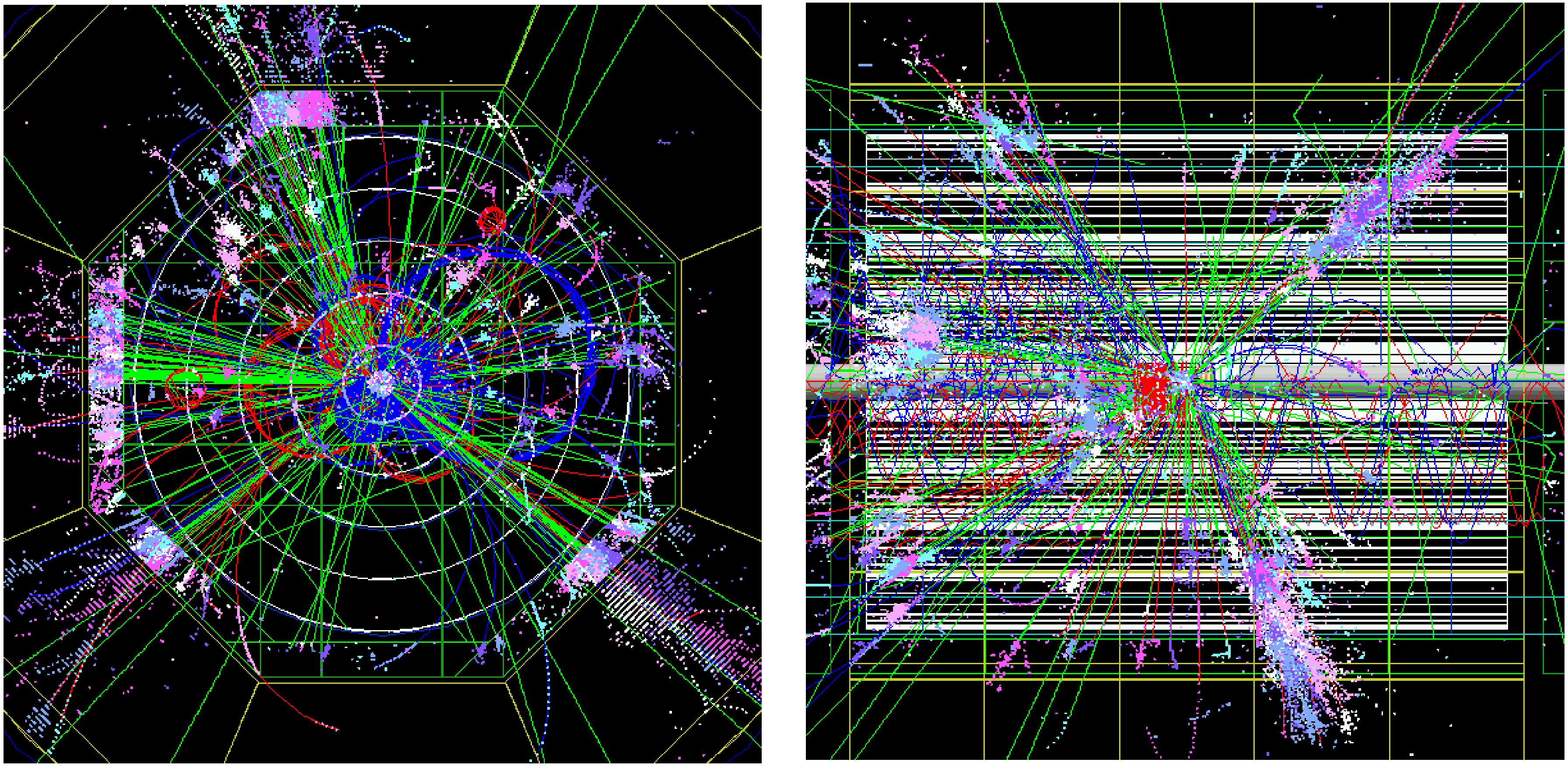
Kinematic Fit with Equal Mass Constrain,
anti-kt semi-exclusive jet clustering
with PFO Std selection in 10 ns





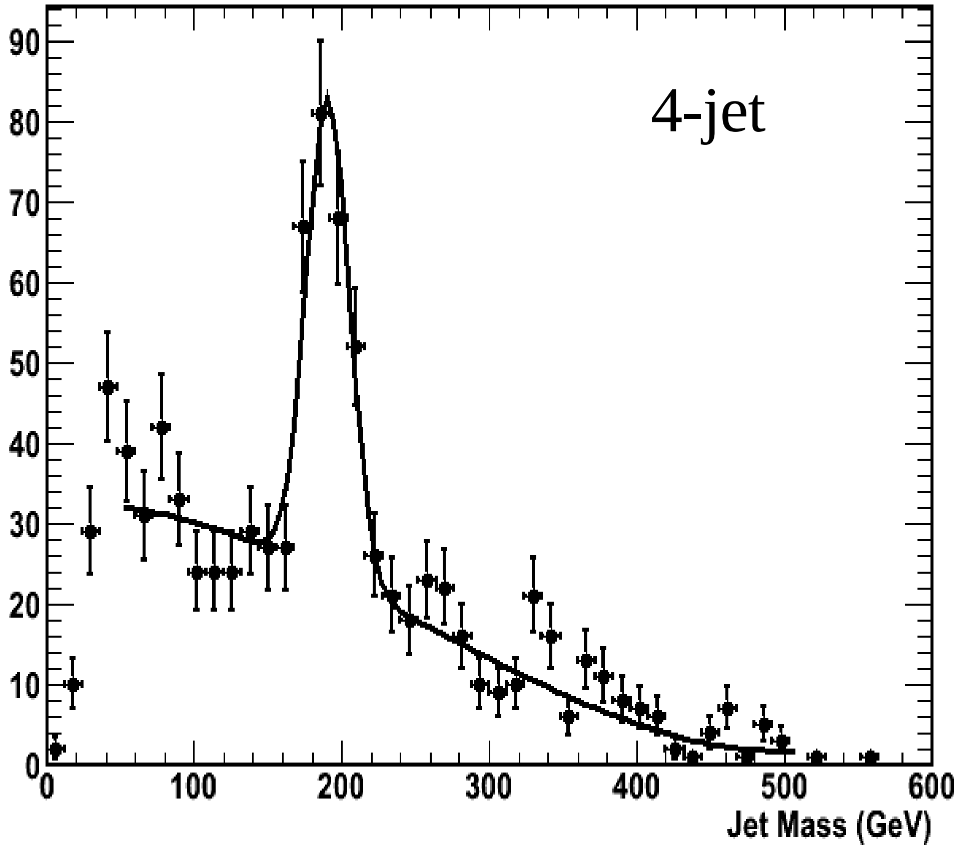
Signal + γγ Bkg	Signal + SM Bkg + γγ Bkg
3-par Fit	6-par Fit
M_A = (904.8+/-2.2 (stat)) GeV	M_A = (904.5+/-2.8 (stat)) GeV
Γ_A = (24.4+/-3.7) GeV	Γ_A = (20.6+/-6.3) GeV

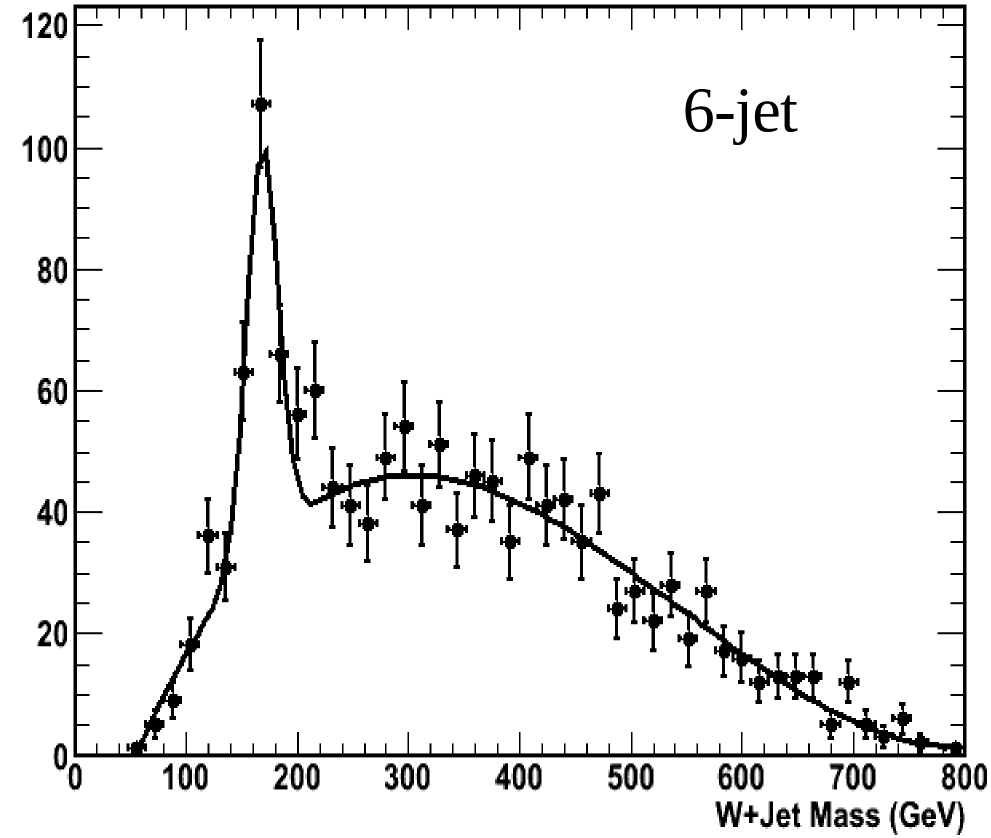
$e^+e^- \rightarrow H^+H^- \rightarrow tbtb$



Start from analysis of H^+H^- for CERN-2004-005 CLIC Physics Report
later extended and published as Coniavitis & Ferrari, PRD 75 (2007) 015004

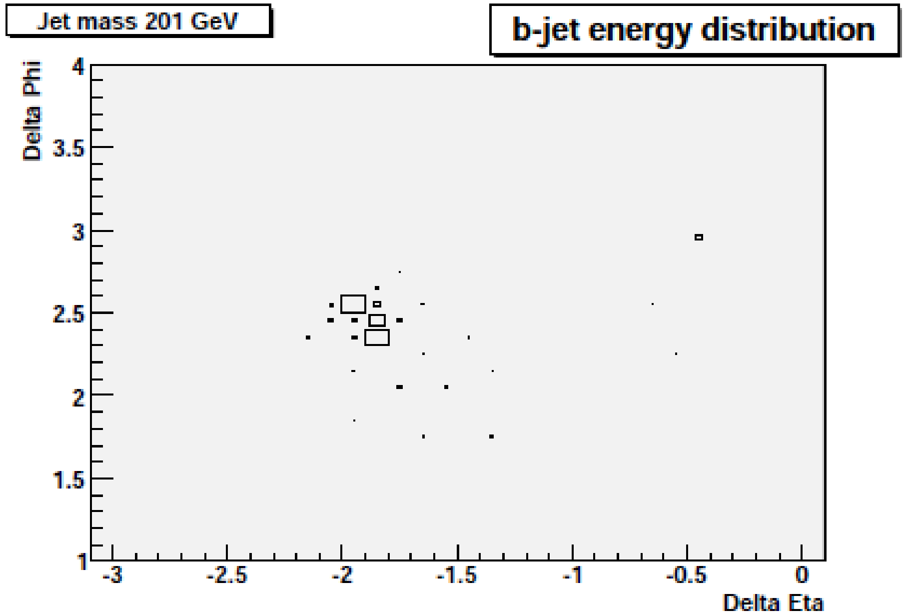
Top Reconstruction and Tagging

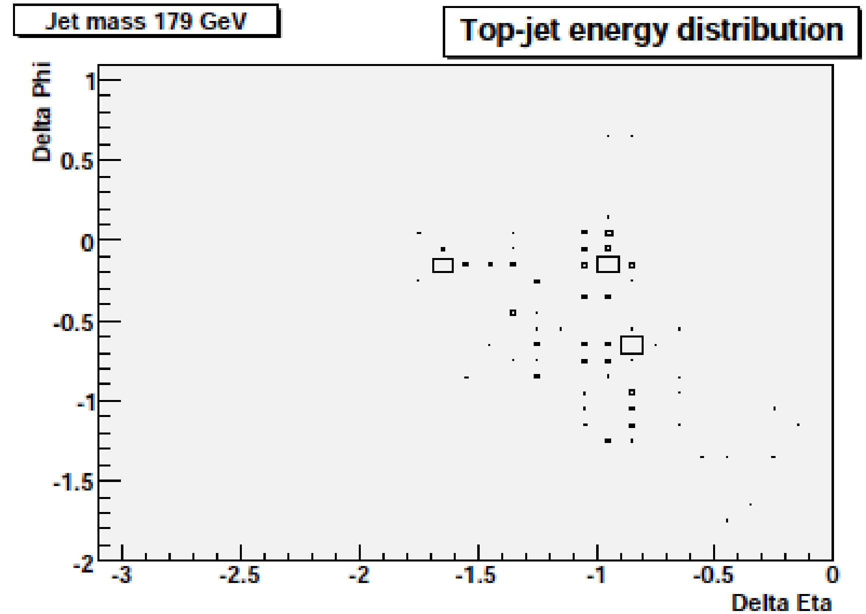




Two alternative reconstruction strategies:
- force event into 4-jet and look for two jets with largest mass (require mass of one or both to be compatible with M_{top});
- reconstruct $t \rightarrow b\, W \rightarrow b\, qq$ through 6 jet reconstruction (W b, W b, b b)

Jet sub-structure for Top tagging





Due to gluon radiation jet invariant mass not an effective observable to reject b jets, while jet structure is. Discriminate top “jets” from b from substructure of particle flow in jets from 4-jet reconstruction, rather than by exclusive 6- or 8-jet clustering;

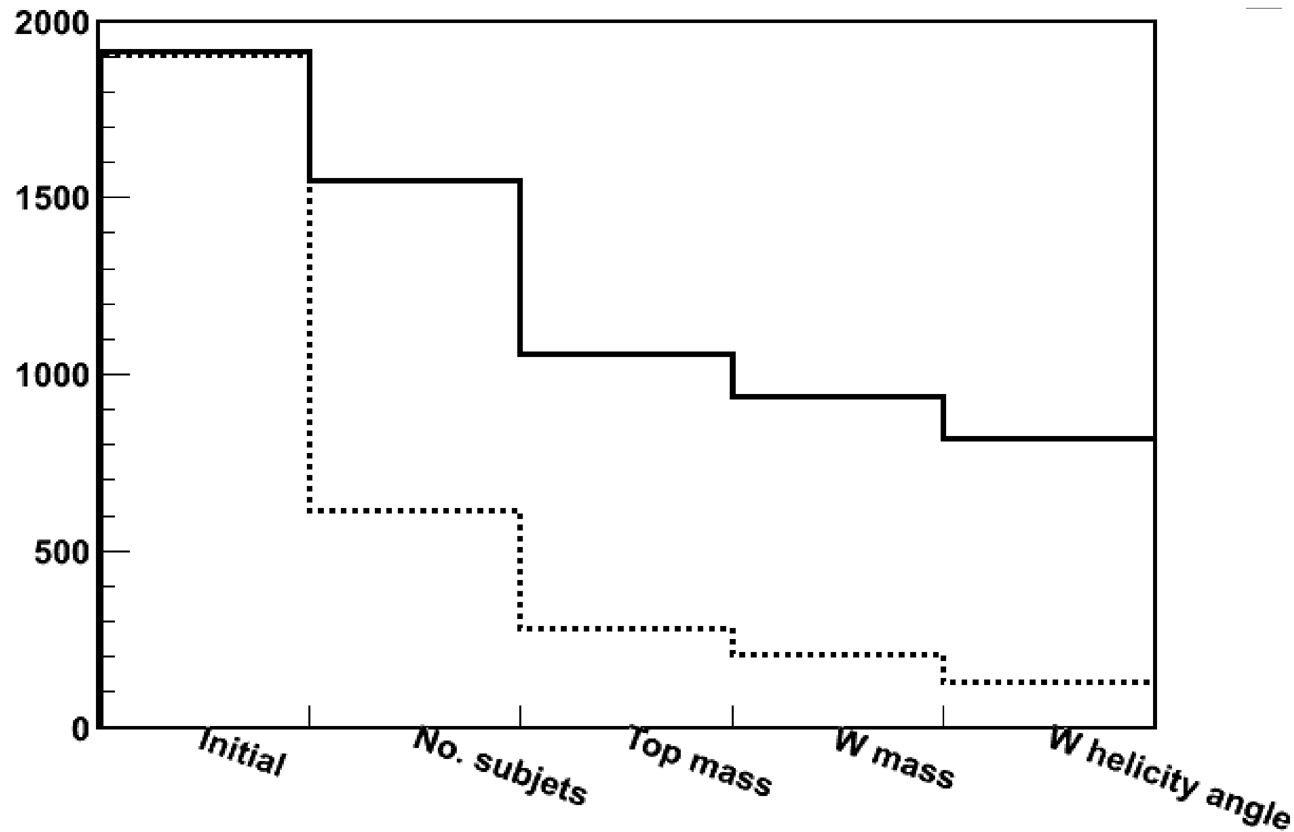
Technique already developed at LHC experiments (top tagging, Higgs analysis): Iterative jet de-clustering using FastJet anti-kt algorithm to obtain a sub-jet decomposition matching the expected numer of partons

Jet sub-structure for Top tagging

Compare performance of Jet sub-structure tagging to 6-jet reconstruction for top efficiency and b quark mis-identification using generator level H^+H^- events;

Jet sub-structure offers factor ~ 10 b quark rejection:

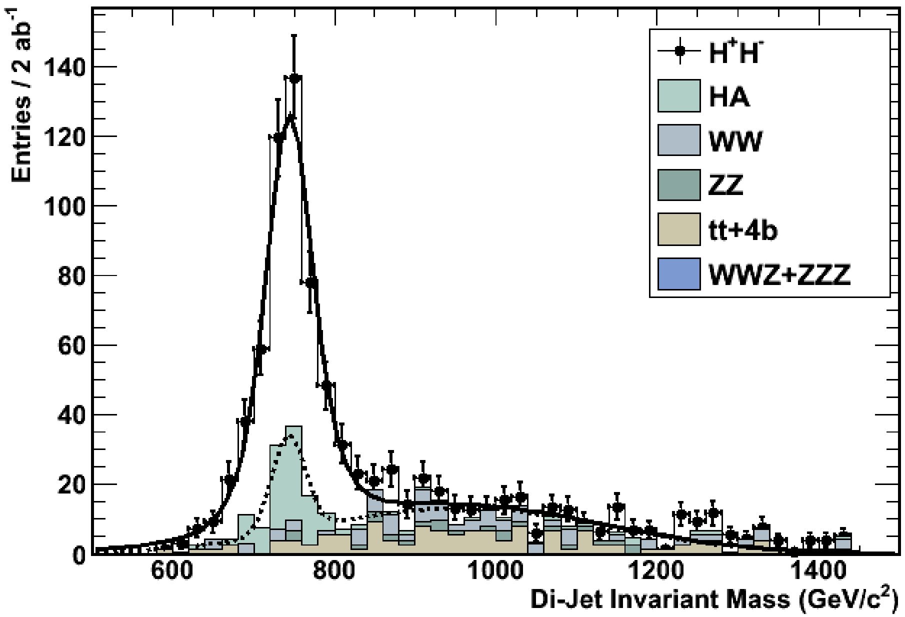
Strategy for CDR analysis: 4-jet clustering with FastJet anti-kt algorithm + top tagging using jet mass and jet sub-structure.

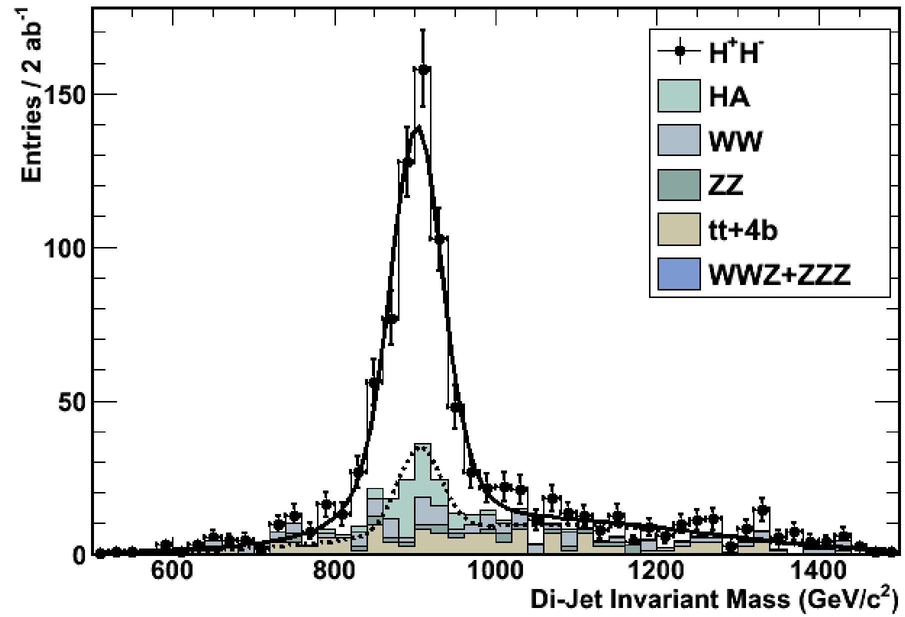


Perfomance	Jet Substructure	6-Jet
$\varepsilon(t \rightarrow t)$	0.37	0.42
$\varepsilon(b \rightarrow t)$	0.04	0.13

H^+ Mass and Width Reconstruction:

Kinematic Fit with Equal Mass Constrain,
anti-kt semi-exclusive jet clustering



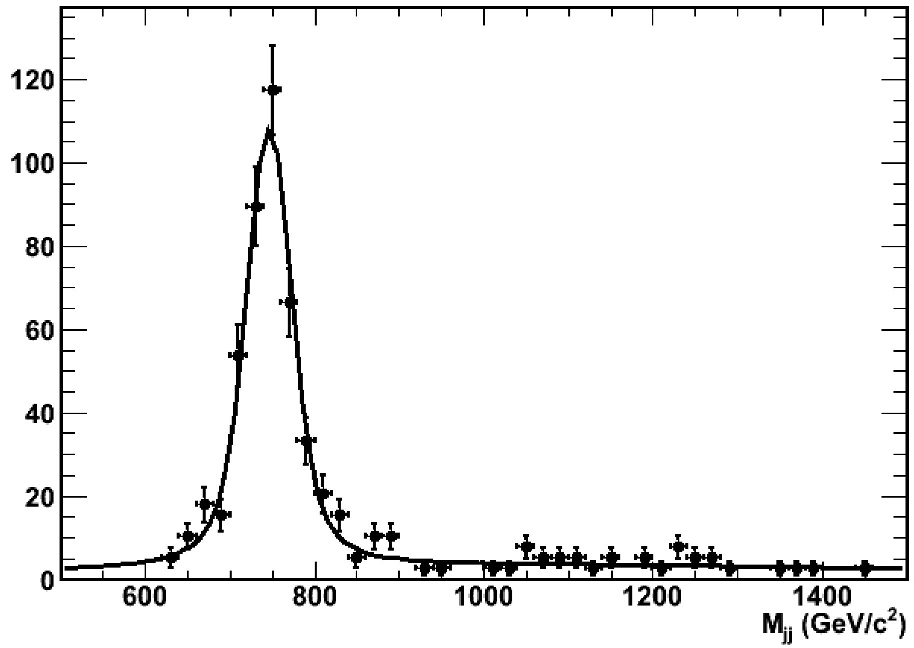


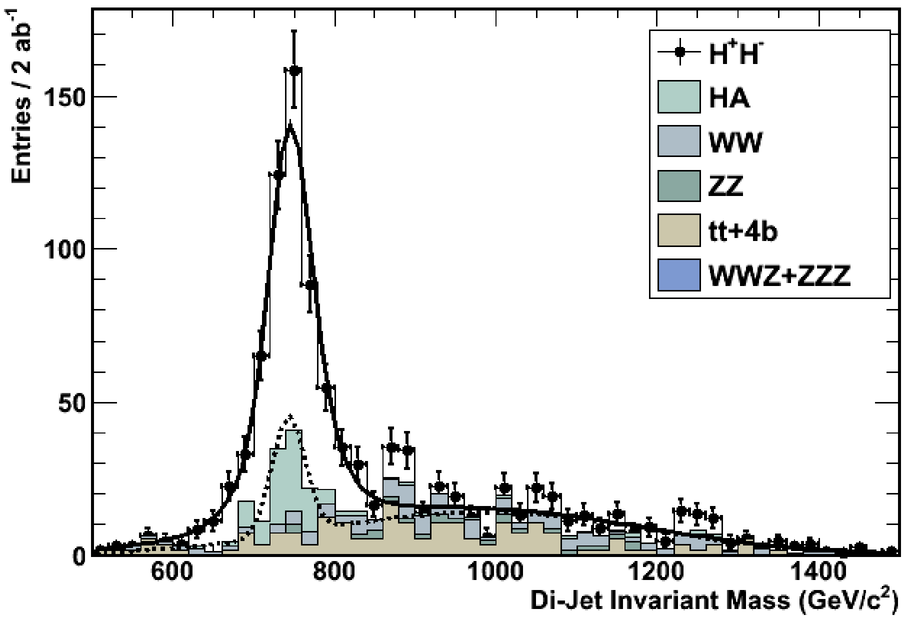
Signal + SM Bkg
6-par Fit
M_H = (744.3+/-2.0 (stat)) GeV
Γ_H = (17.0+/-4.7) GeV

Signal + SM Bkg
6-par Fit
M_A = (901.4+/-1.9 (stat)) GeV
Γ_A = (18.9+/-4.4) GeV

H^+ Mass and Width Reconstruction:

Kinematic Fit with Equal Mass Constrain, anti-kt semi-exclusive jet clustering with PFO Std selection in 10 ns





Signal +γγ Bkg	Signal + SM Bkg + γγ Bkg
3-par Fit	6-par Fit
M_H = (745.5+/-1.7 (stat)) GeV	M_A = (746.9+/-2.1 (stat)) GeV
Γ_H = (19.8+/-2.8) GeV	Γ_A = (21.4+/-4.9) GeV