Studies of Higgs hadronic decay channels at CLIC

IMPRS Young Scientist Workshop at Ringberg Castle
18th July 2014
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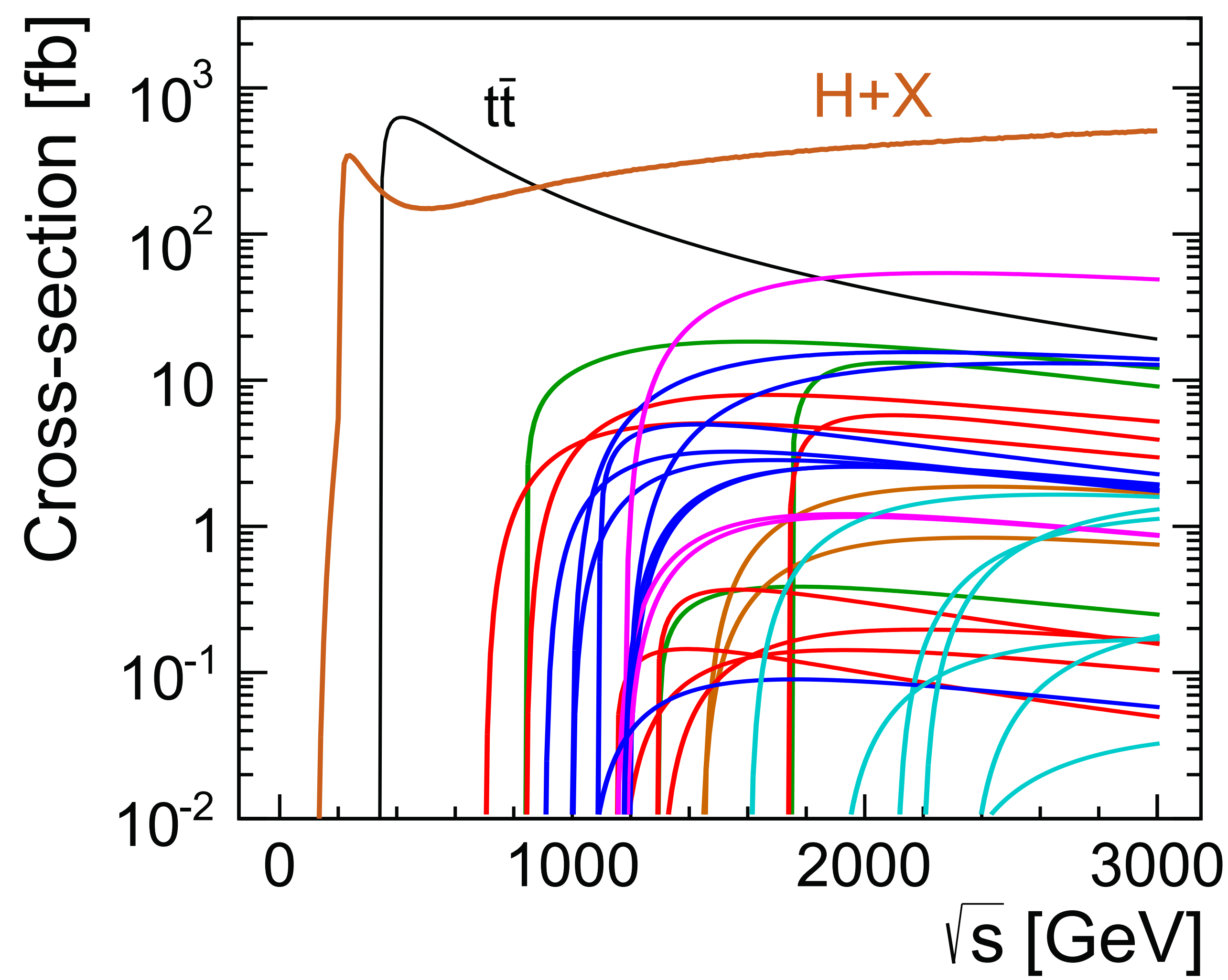
Outline

- Physics at e^+e^- colliders
- CLIC - collider and detectors
- BDT intermezzo
- Higgs branching ratio measurements
- Conclusions

Physics at e^+e^- colliders

- precision measurement of:
  - Higgs sector (couplings, mass, potential)
    - model independent H to Z coupling
  - top quark (mass, width)
  - EW sector

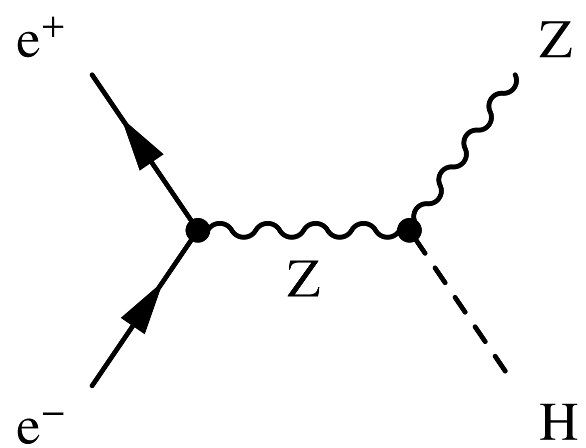
- Search for new physics:
  - direct reach up to $\frac{\sqrt{s}}{2}$
  - model-dependent indirect reach far beyond $\sqrt{s}$



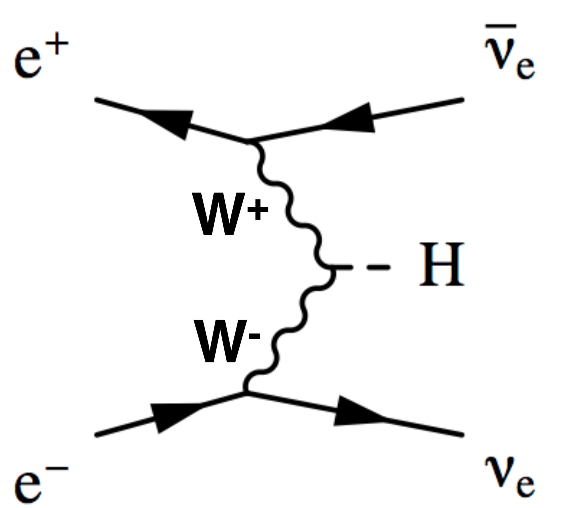
Higgs production in e^+e^- collisions

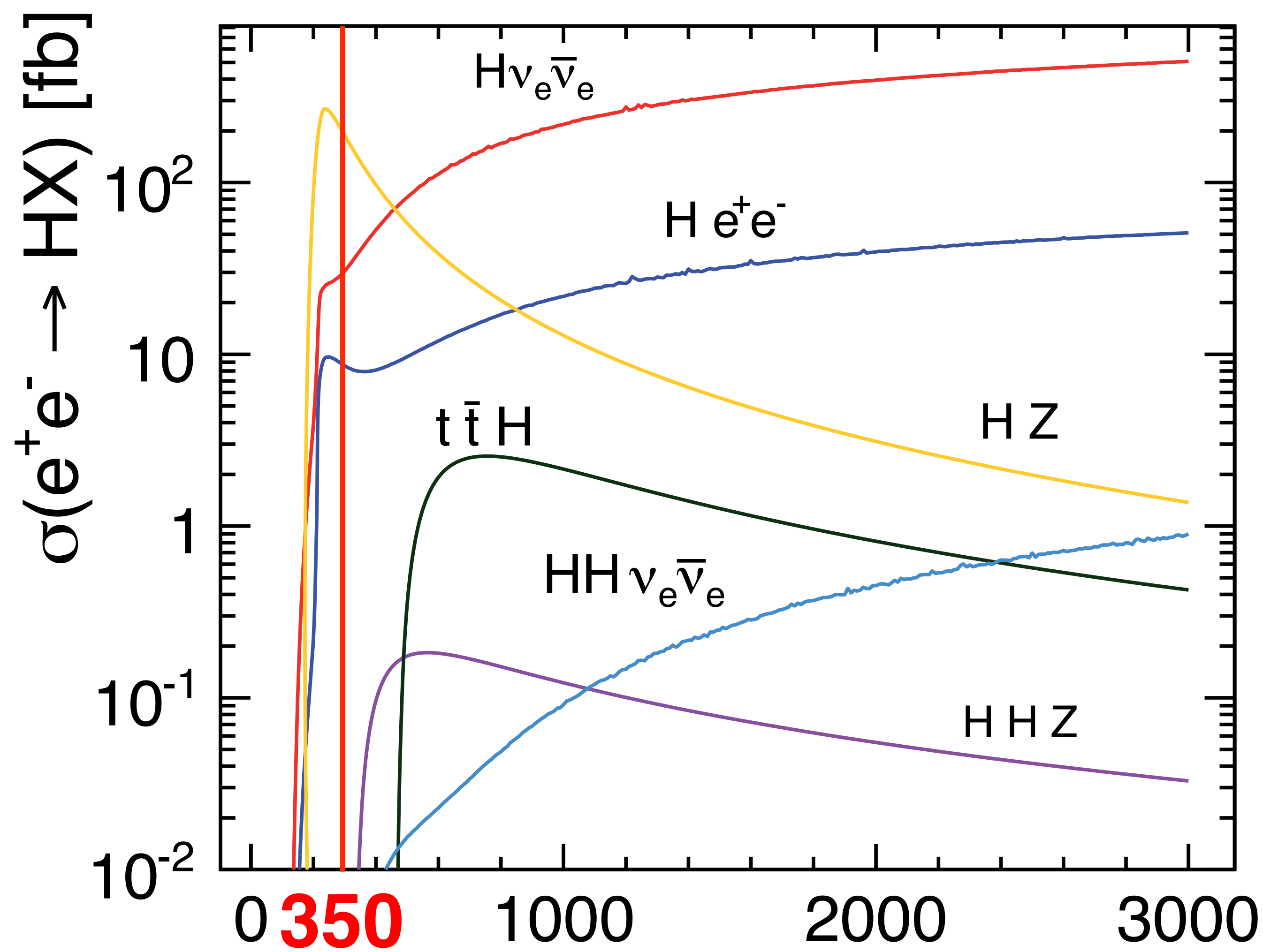
Main H production channels at 350 GeV:

- Higgs strahlung (allows model-independend Z to H coupling measurement)



- Vector Boson Fusion





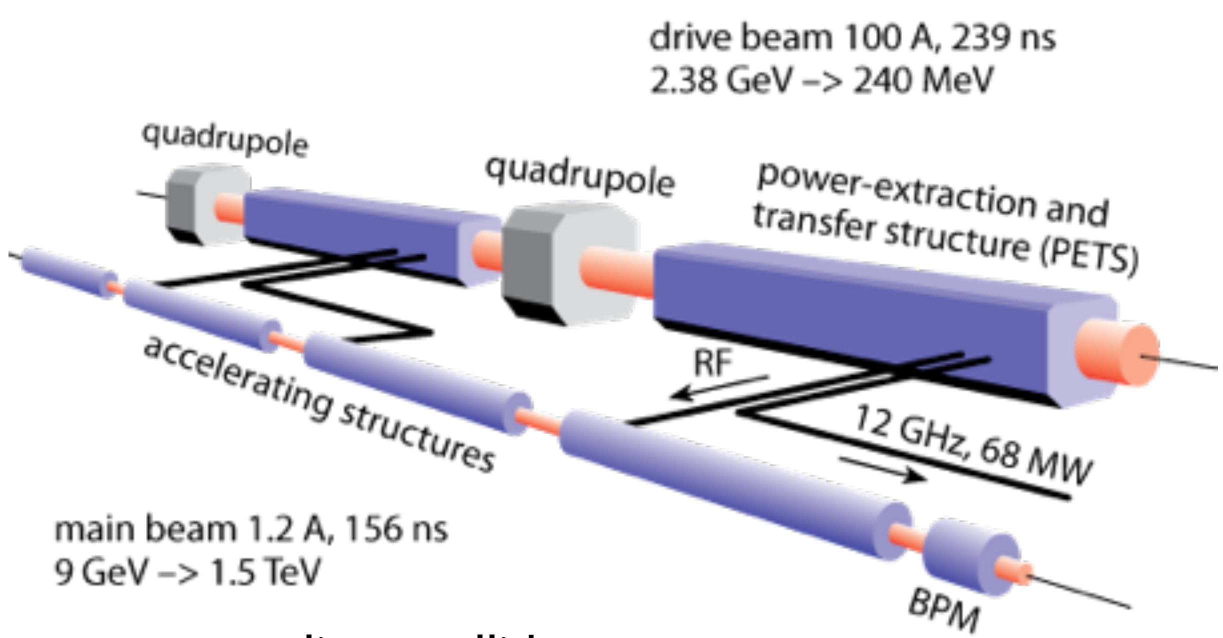
source: Frank Simon - arXiv:1211.7242

Linear Colliders - CLIC

- A lepton collider allows for precision measurements:
  - leptons → clean events, well defined initial state
  - linear → no synchrotron radiation energy losses
  - complementary to LHC

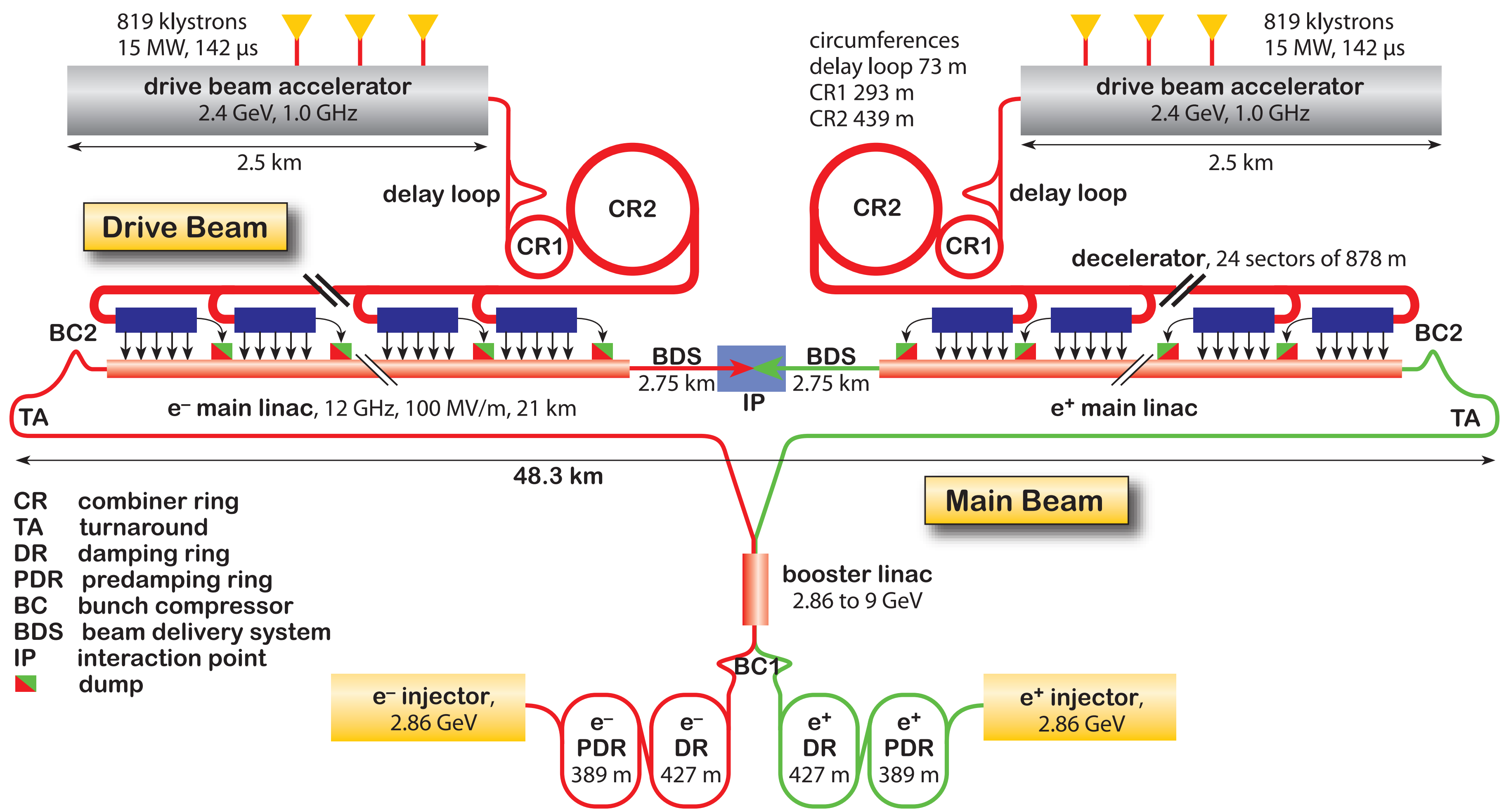
CLIC (Compact LInear Collider)

- 2-beam acceleration scheme
- 3 stages: 350 GeV, 1.4 & 3 TeV



source: linearcollider.org

Linear Colliders - CLIC II

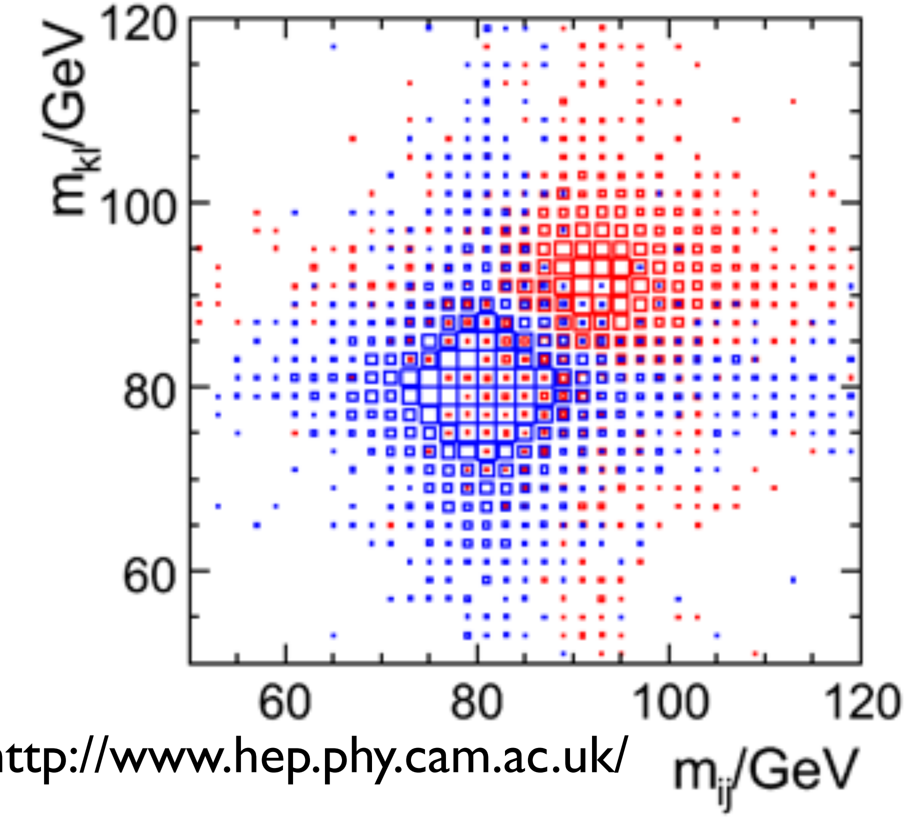


- Almost 50 km long!
- 2 beams: high intensity (~100A) low energy driver beam produces the 12 GHz RF power for a low intensity, high energy beam
- Goal is to achieve 100 MV/m

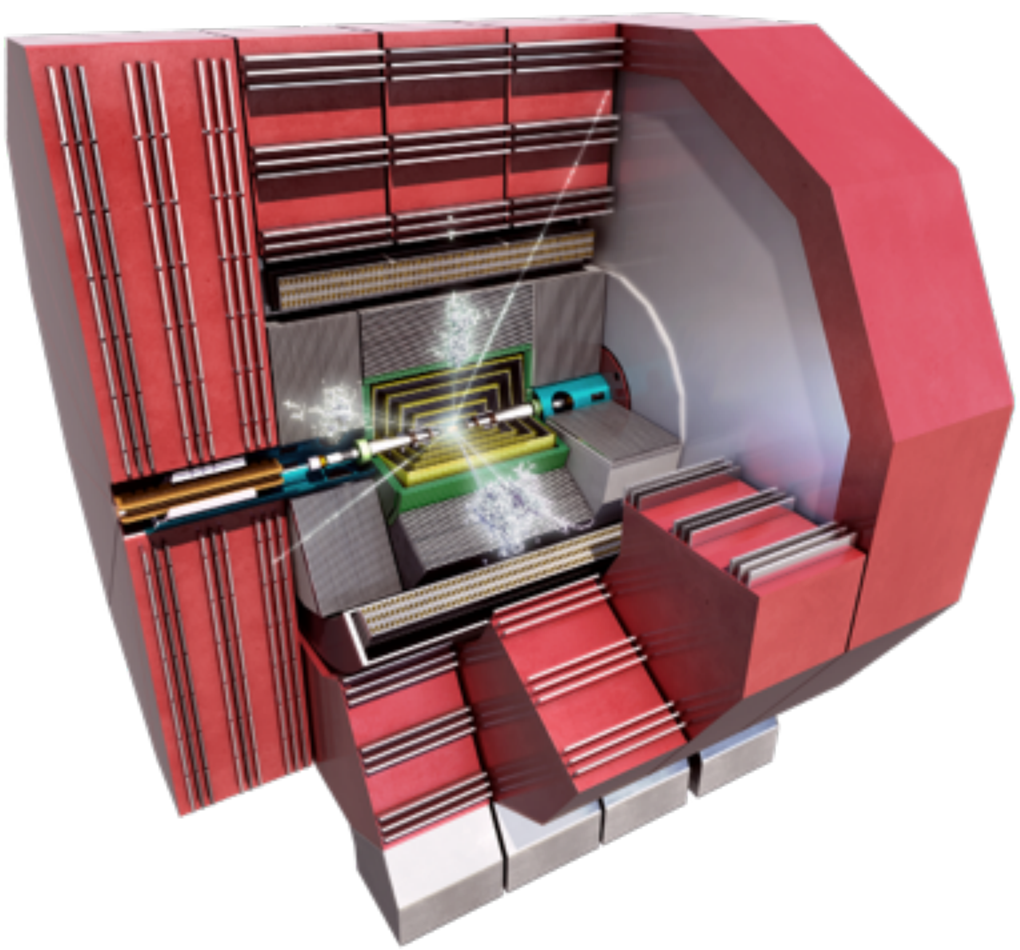
Detectors

GOALS

- High precision $Z \rightarrow \ell^+\ell^-$ reconstruction
- Separation of W and Z hadronic decays
- Measure Higgs couplings to fermions



source: http://www.hep.phy.cam.ac.uk/

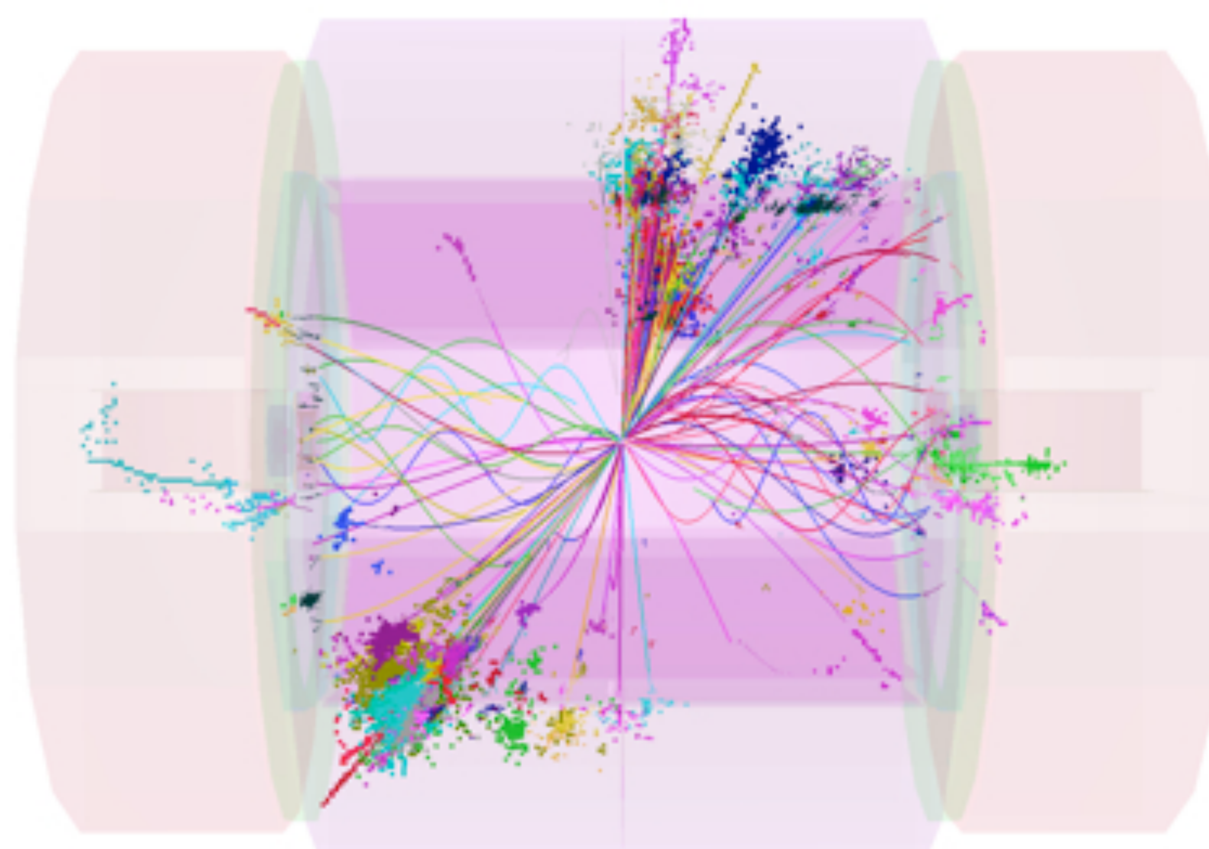


REQUIREMENTS

- Excellent tracking
- Highly granular calorimeters
- Very efficient b and c jet tagging
- Precise time stamping

Physics Benchmarks

- Simulation of a set of physics processes to quantify the response of a particular detector design
- Evaluate the physics potential of new accelerators
- Crucial to compare detectors before building them (or even prototypes)
- Can help to tune hardware parameters

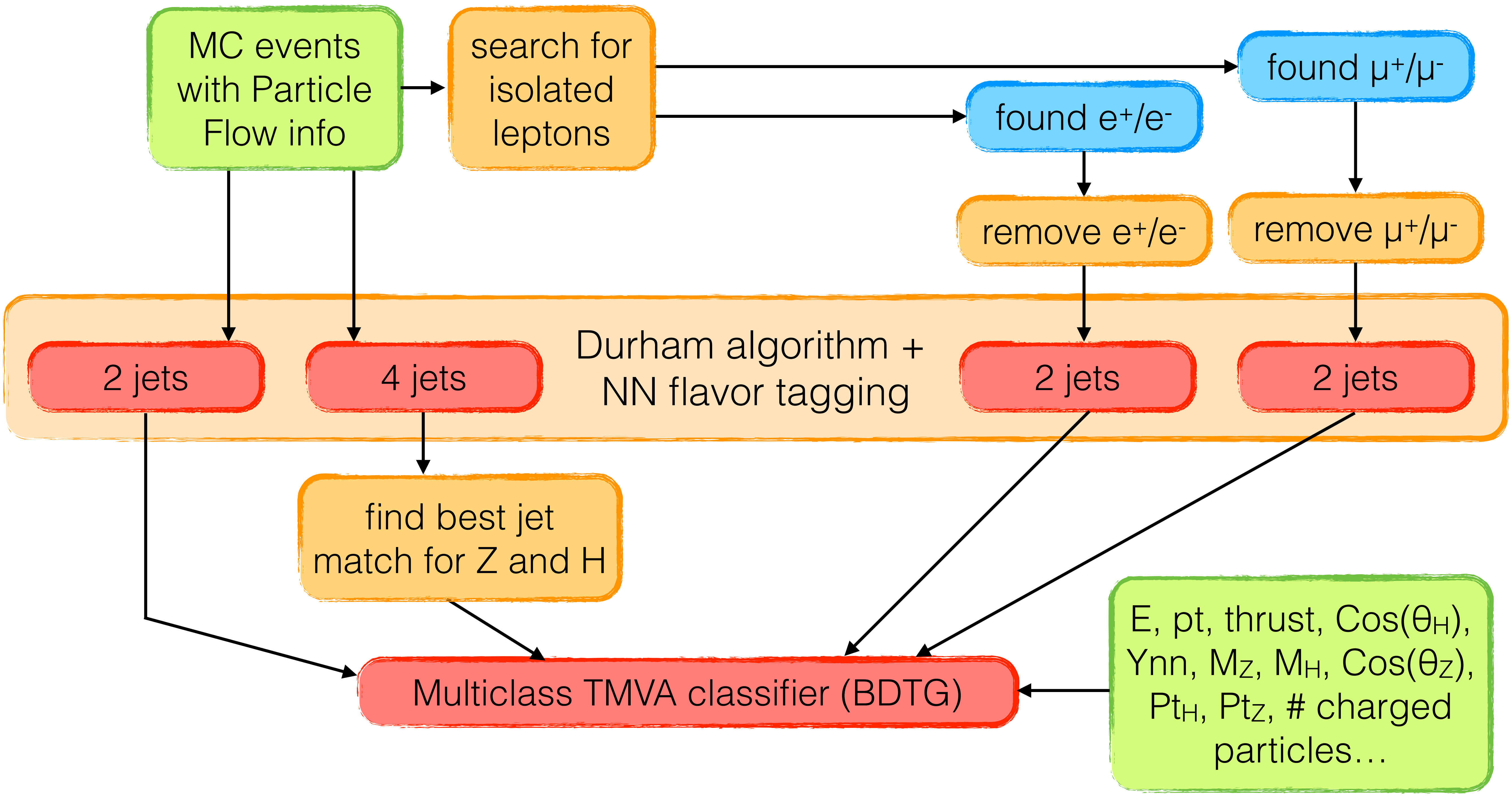


Higgs production at CLIC - 350 GeV

Channel	Xsection (fb)	# events for 500 fb^{-1}
Hvv (inclusive)	51.54	25,770
HZ, $Z \to e^+e^-$	4.92	2,460
HZ, $Z \to \mu^+\mu^-$	4.93	2,465
HZ, $Z \to$ jets	93.4	46,700

Background	Xsection (fb)	# events for 500 fb^{-1}
qqll	1,704	852,000
qqlv	5,914	2,957,000
qqvv	324.6	162,300
qqqq	5,847	2,923,500

Higgs event selection



Boosted Decision Trees Intermezzo

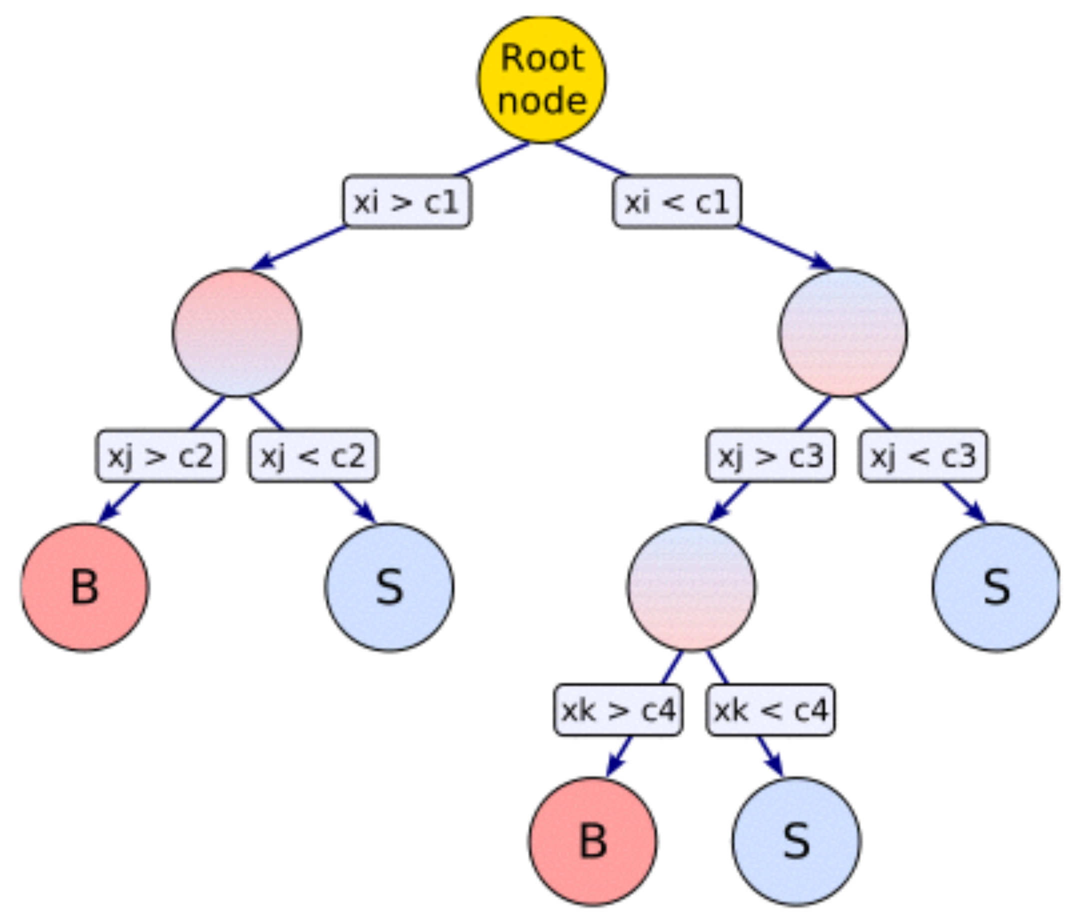
- Start with a MC sample of signal and background events
- Split the sample in 2 (train and test)
- Find the variable and the value that gives the best signal/background separation

$$P = \frac{\sum_s W_s}{\sum_s W_s + \sum_b W_b}$$

- Repeat on the children nodes

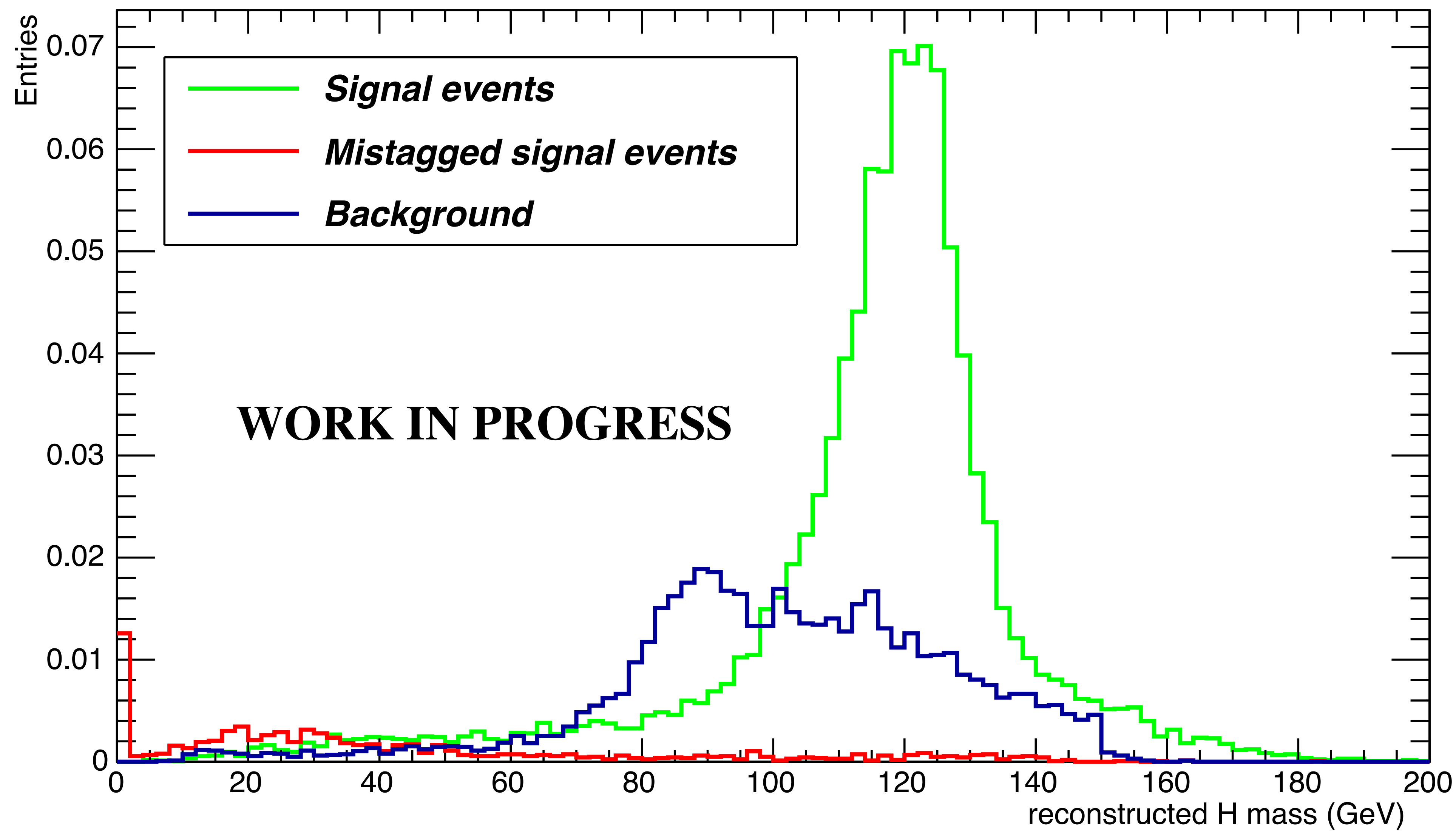
BOOSTING:

- Make new decision tree, previously misclassified events are weighted more



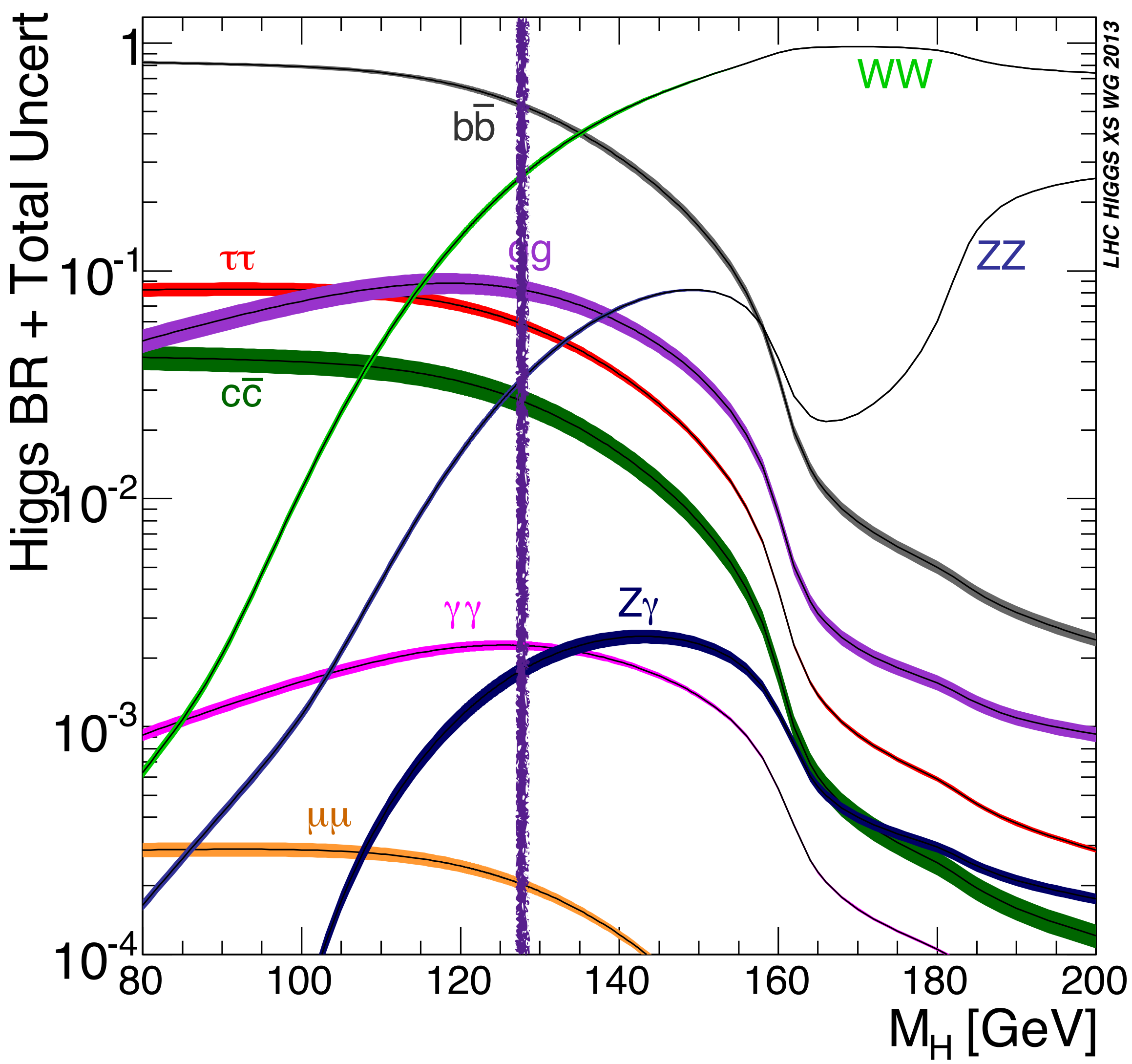
source: TMVA user guide

Higgs event selection - II



The BDT effectively suppresses the non Higgs background and properly separate the various signal final states

Higgs Branching Ratios



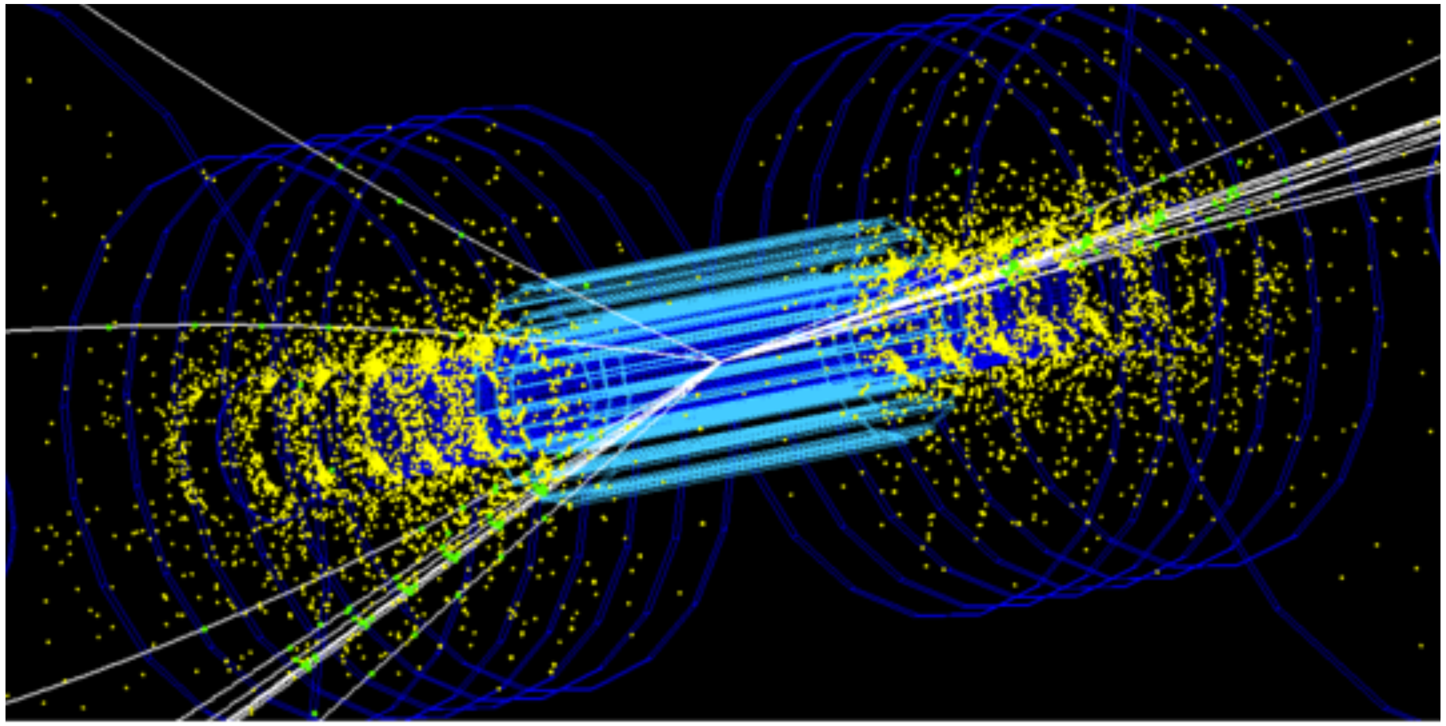
For 126 GeV Higgs boson

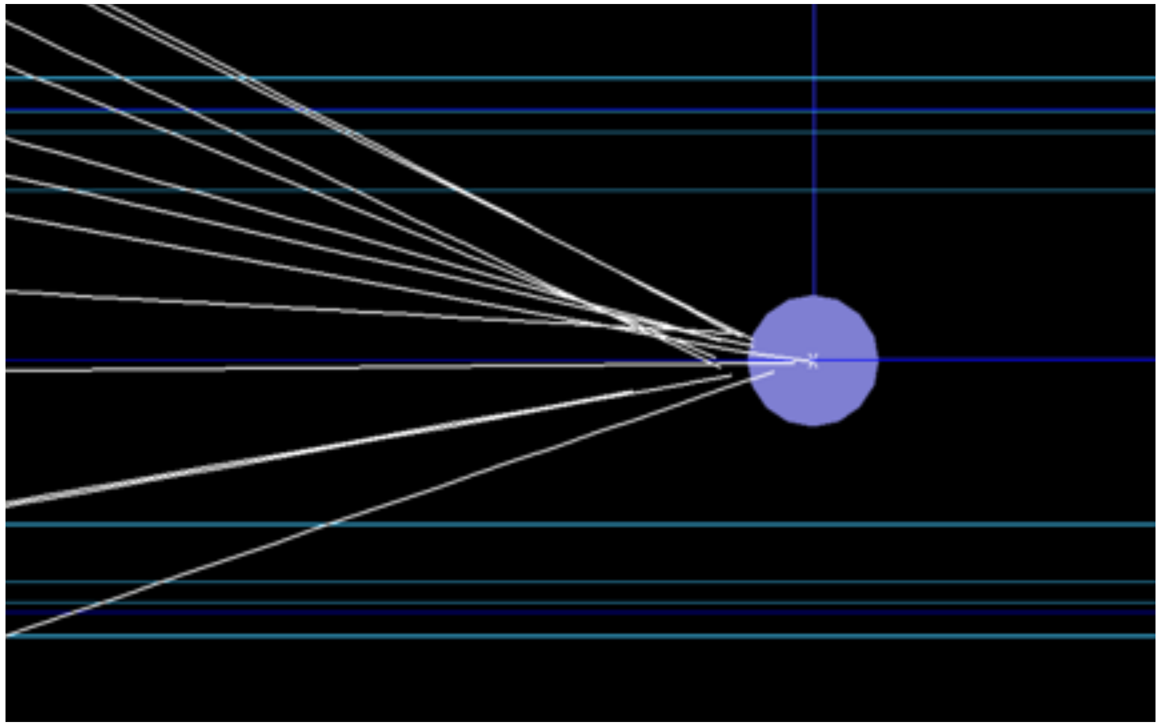
H →bb	56%
H →WW	23.3%
H →gg	8.5%
H →ττ	6.1%
H →ZZ	2.9%
H →cc	2.8%
H →γγ	0.23%
H → μμ	0.02%

Separate H → bb, H → cc and H → gg based on flavor tagging information

Flavor Tagging

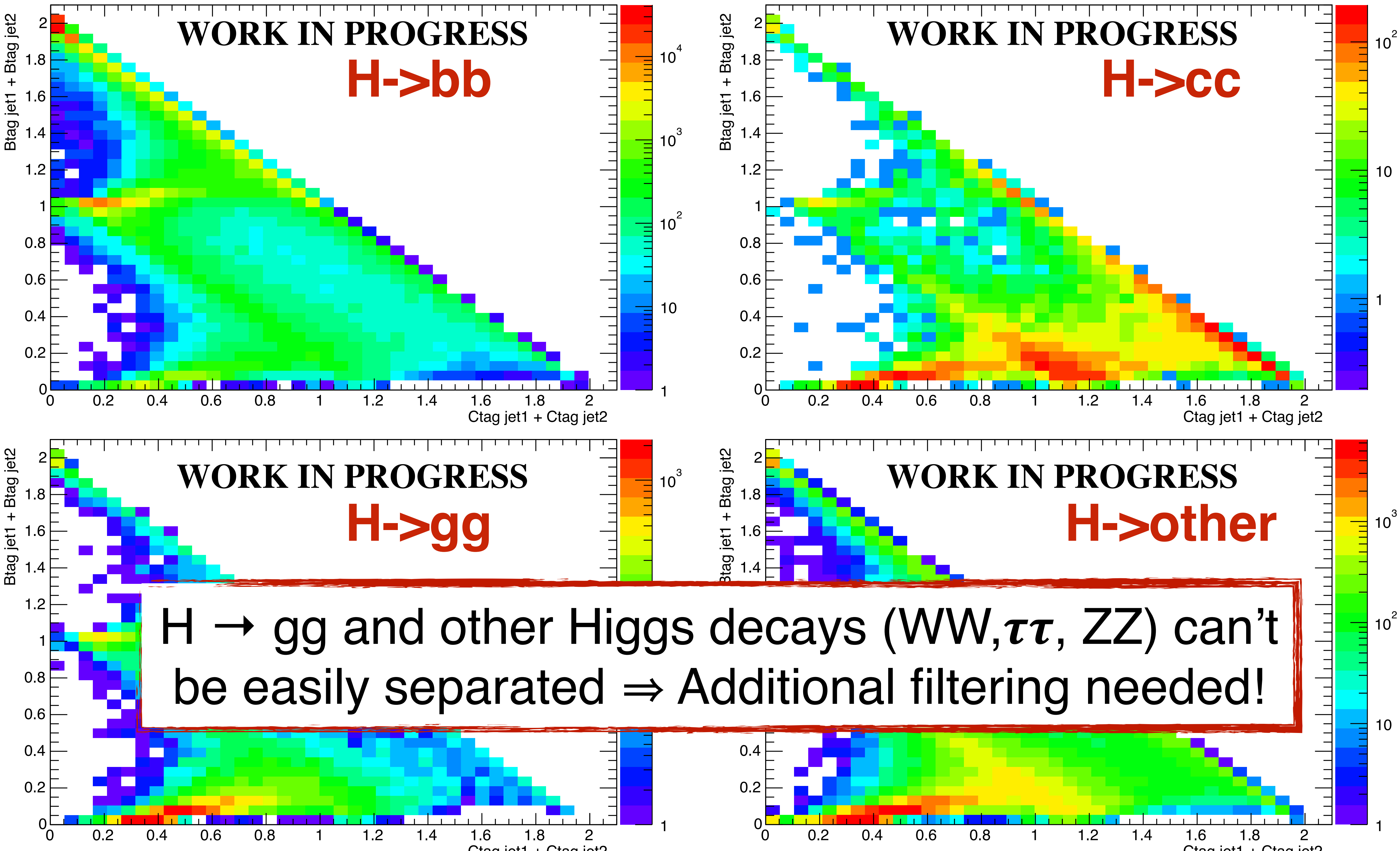
Precise vertex reconstruction allow to identify the interaction point and secondary vertices





Jet flavor tagging information come from these vertices (e.g. M and ***p*** for the leading hadron in the decay)

Higgs decay separation

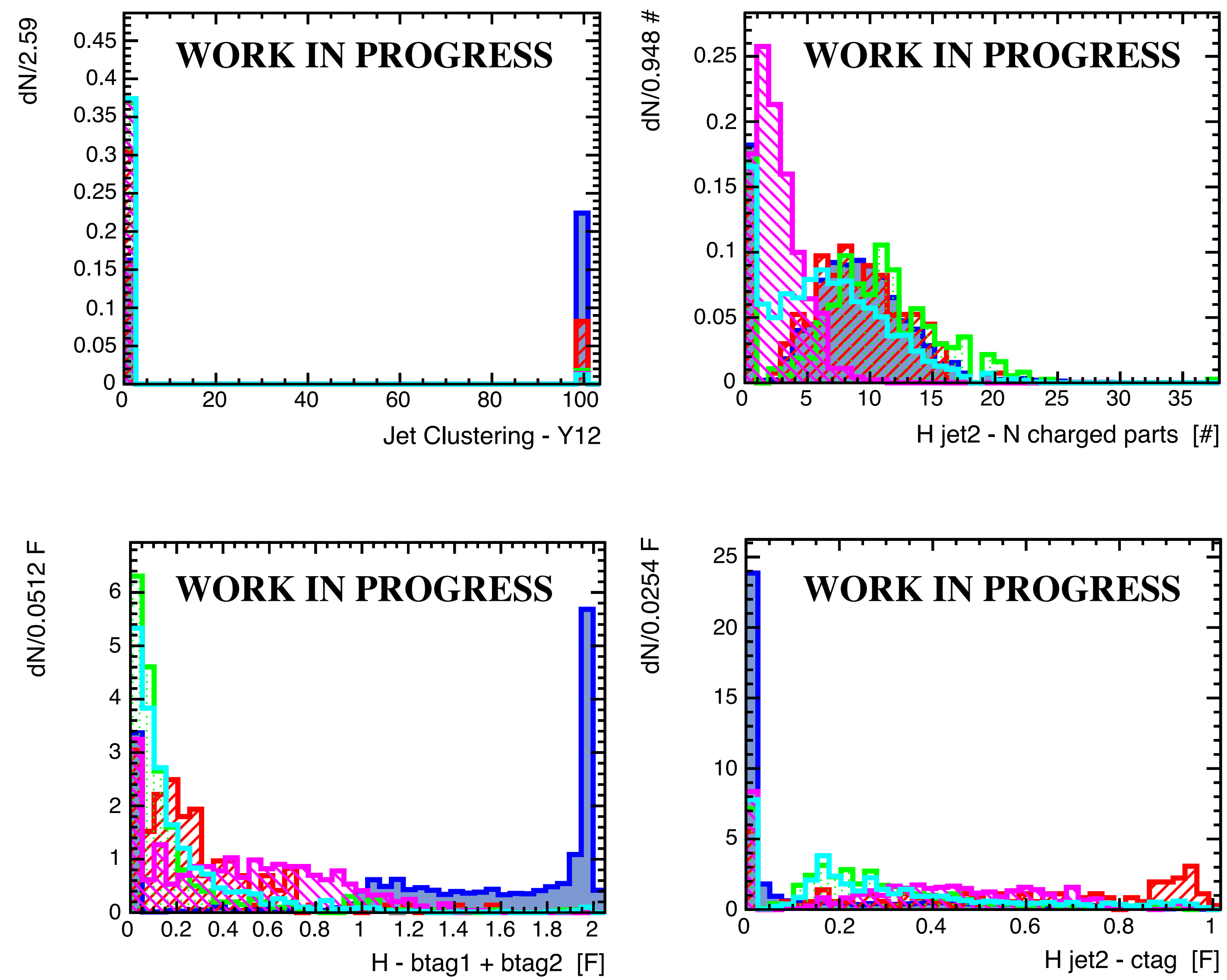


H → gg and other Higgs decays (WW,$\tau\tau$, ZZ) can't be easily separated ⇒ Additional filtering needed!

Higgs decay separation - II

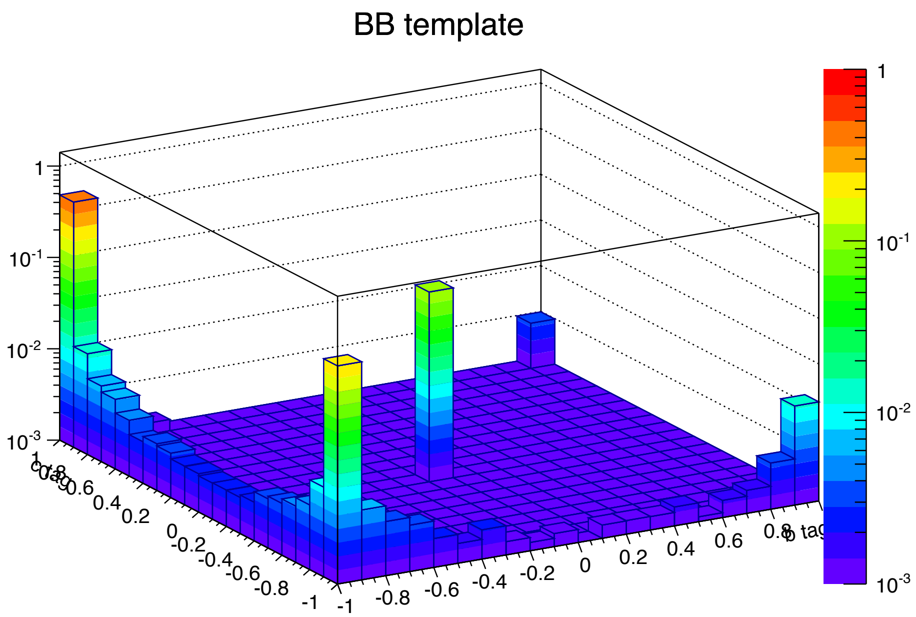
Additional TMVA (BDTG) filter on:

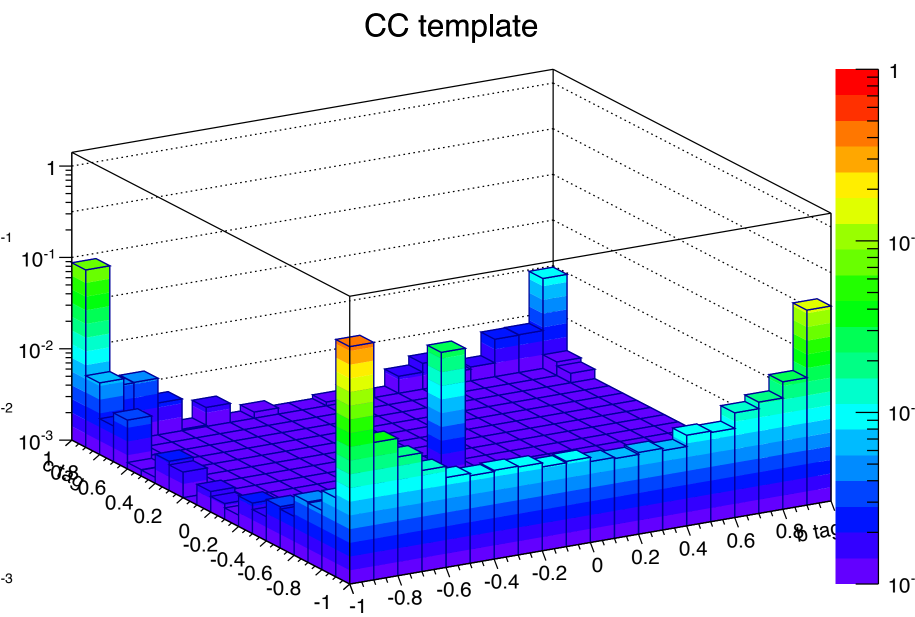
- Flavor tagging info
- number of particles in jet (discriminates tau jets)
- Higgs invariant mass (discriminates W leptonic decay - missing E)
- Ynn (discriminates H → WW → qqqq - more jets than what is clustered)

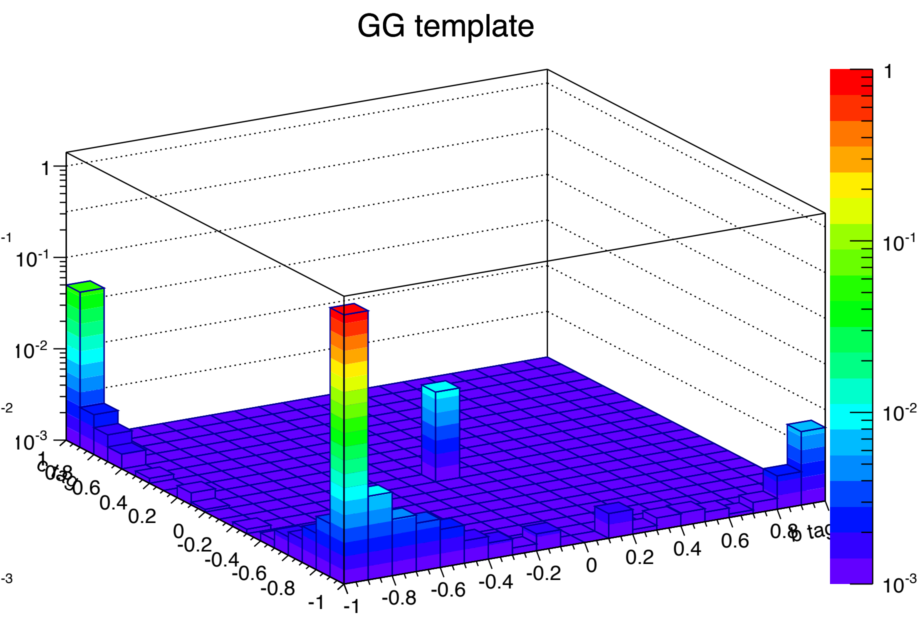


3 binary classifier give the probability to be an H→bb, H→cc or H→gg event

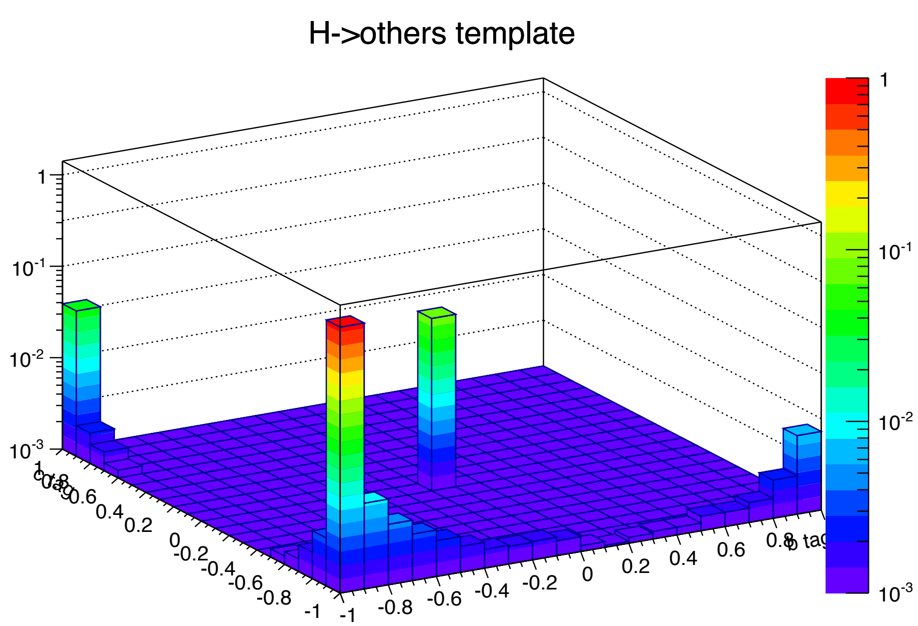
Templates

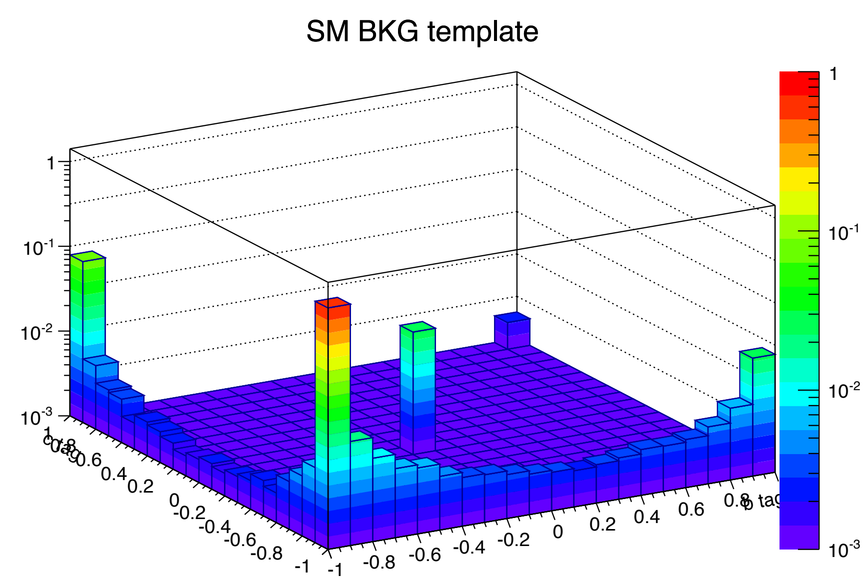






2D projection of 3D templates





Fitting the templates

- Binned maximum likelihood fit

- Assume Poissonian fluctuation for each data bin:

$$P_{ijk} = \frac{\mu^n e^{-\mu}}{n!}$$

  with n = number of data entries in bin ijk
  and $\mu = \sum w_m T_m$ for the same bin

- Then the Likelihood is the product of P_{ijk} in all bins

- Find the w_m that maximize this value

Putting all together

- To compare experimental results to theory, we want to obtain the Higgs couplings starting from the measurement of σ and σ x BR

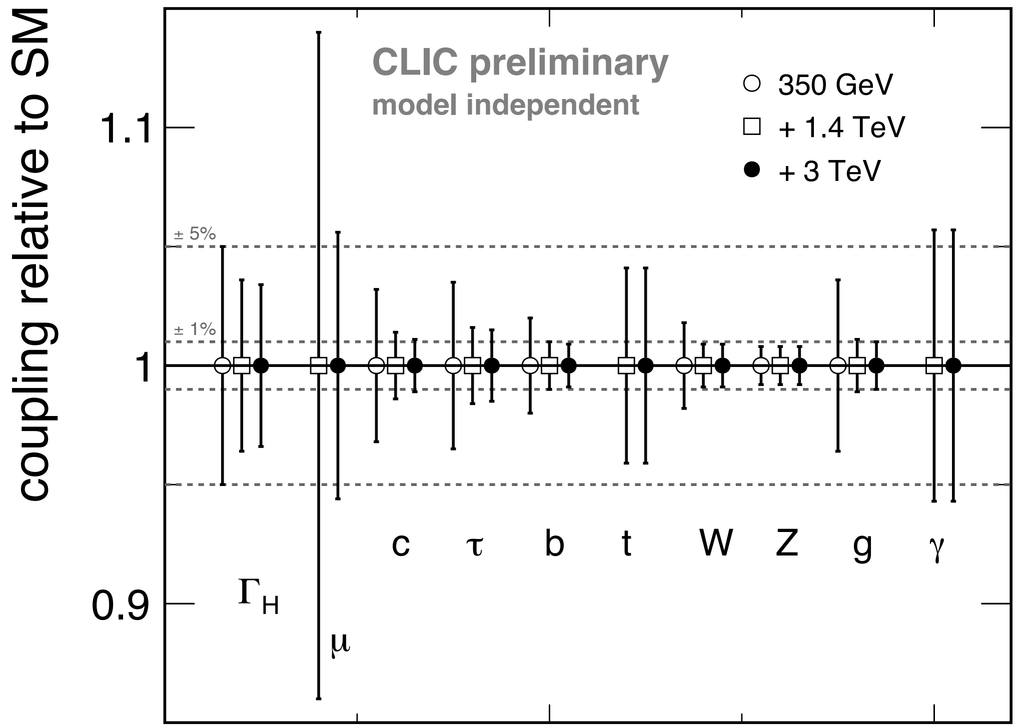
- Global fit including all the available measurement

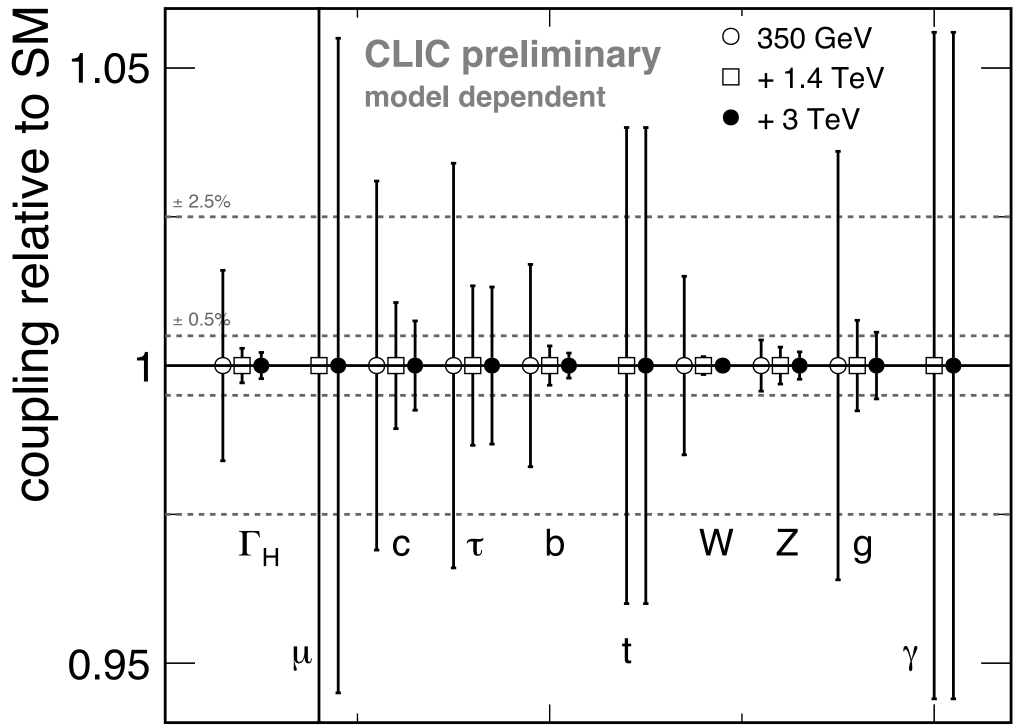
$$\chi^2 = \sum \frac{(C_i - 1)^2}{\Delta F_i^2}$$

where C_i depend on the couplings
(e.g. $C_{ZH,H\rightarrow bb} = \frac{g_{HZZ}^2 \, g_{Hbb}^2}{\Gamma^2}$)
and ΔF_i is the experimental precision

Global Fit

2 possible fit: model-independent and model-dependent





Model-independent:
total width Γ is a free parameter of the fit

CAN NOT BE DONE AT LHC!

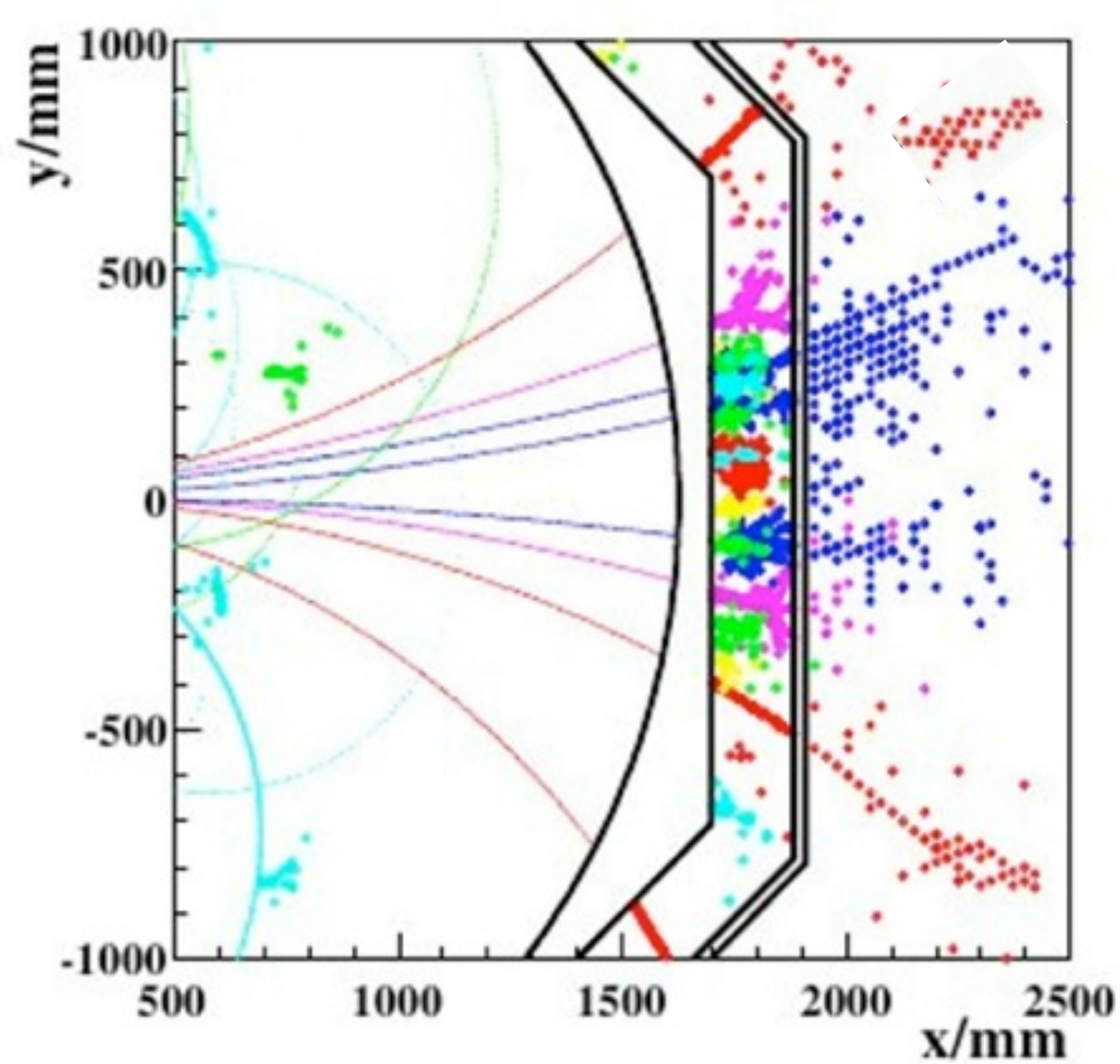
Model-dependent:
- assume SM only
- Total width described by few parameters that account for deviation with SM

Conclusions

- e^+e^- linear colliders are a key tool to explore the Higgs sector with precision measurements (complementary to LHC)
- A new generation of detectors with excellent jet energy resolution and tracking is being developed
- Model independent H to Z couplings can be measured with such machines
- Unique possibility in e^+e^- due to clean environment and precise vertexing
- Higgs hadronic decay is very interesting since $H \rightarrow cc$ and $H \rightarrow gg$ can't be measured at LHC (and $H \rightarrow bb$ is very difficult too)

BACKUP

Detectors - Particle Flow algorithms

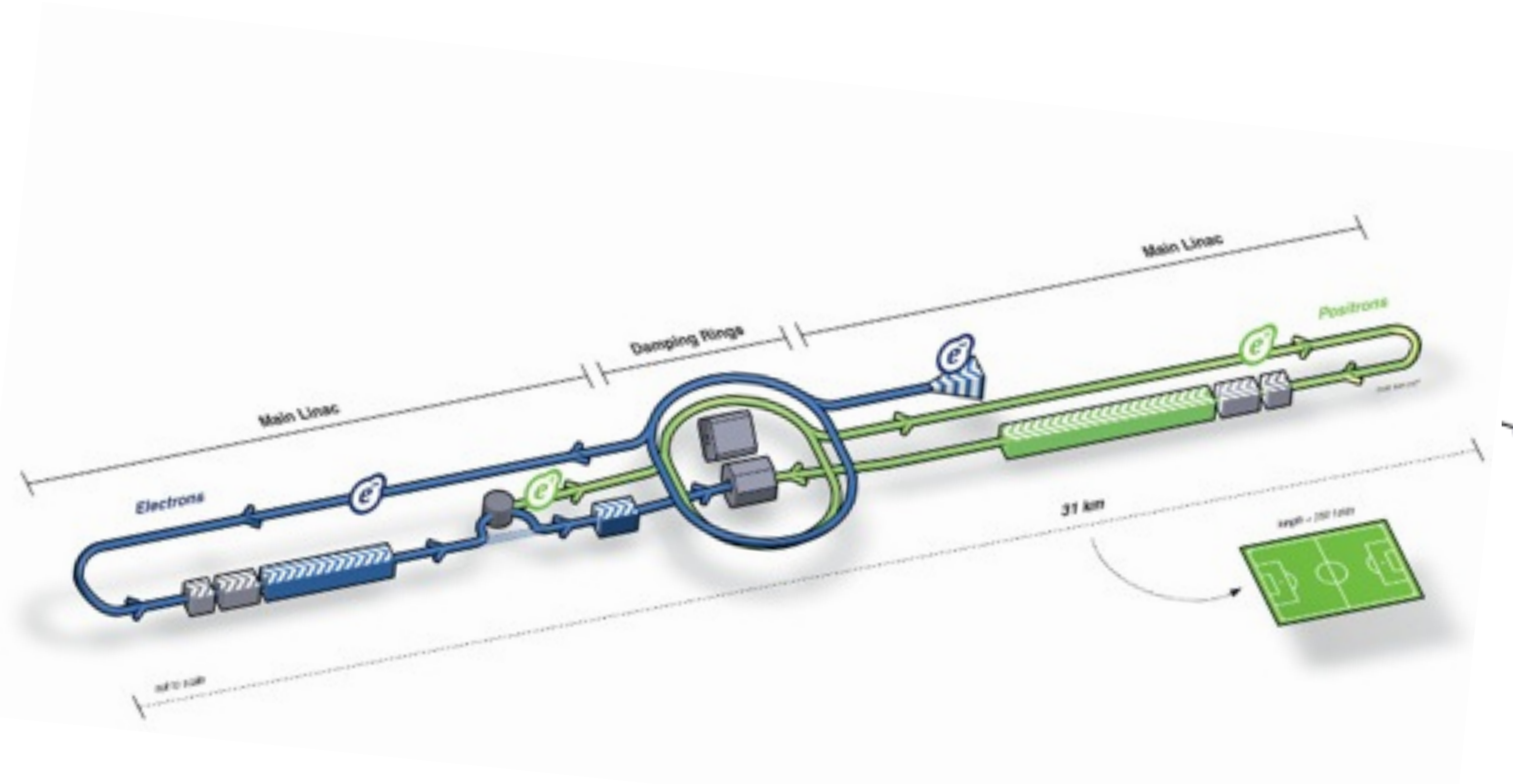


Track finder algorithm reconstruct charged particles tracks

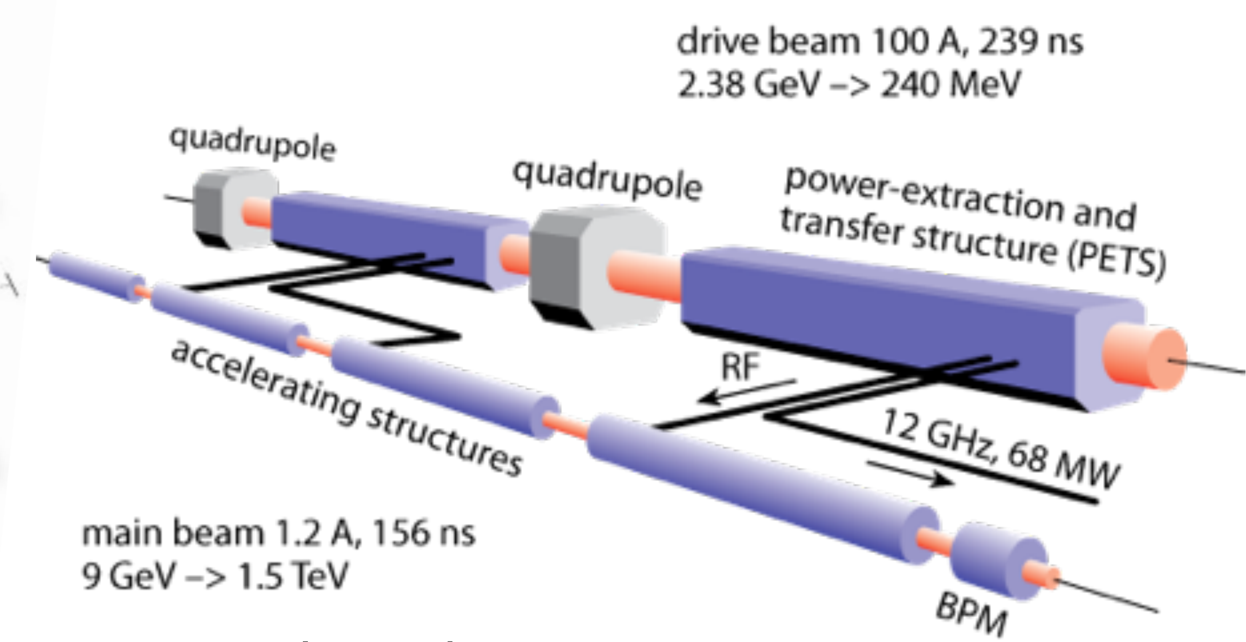
Raw data from the detector

Linear Collider Design Concepts

- A lepton collider allows for precision measurements (clean events, well defined initial state)
  - in the TeV range to complement LHC
  - linear to prevent synchrotron radiation energy losses
- Two machine concepts:
  - ILC: superconductive accelerator technology - ready to build
  - CLIC: two-beam accelerator for higher energies - still in development



source: linearcollider.org



source: clic-study.org