Higgs self coupling

Djamel BOUMEDIENE, Pascal GAY
LPC Clermont-Ferrand

Outline

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- 2) λ_{hhh} measurement
- 3) Detector performance impact on λ_{hhh} measurement
  - ↳ **particle flow**
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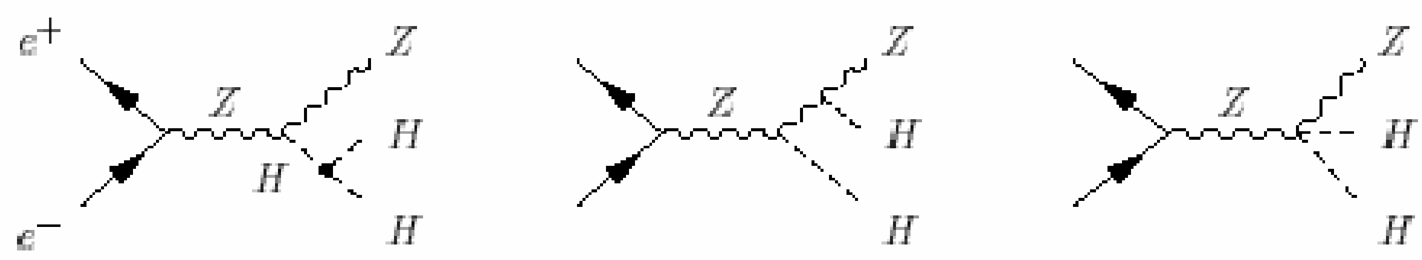
  - ↳ **c contamination**
- 4) Conclusion

Introduction



- Study realized for a center of mass energy of 500 GeV
- Additional backgrounds w.r.t published analysis
- m_H = 120 GeV, Br(H→bb) = 68%
- Signal cross section 0.18 pb
- $\Delta\lambda_{hhh}/\lambda_{hhh} \sim 1.75\ \Delta\sigma_{hhZ}/\sigma_{hhZ}$
- Presence of 6 jets, 8 jets events → overlap → importance of jet reconstruction (typical final state for ILC physics)

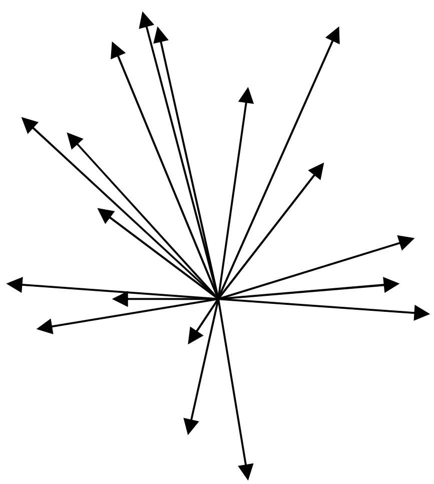
Typical analysis scheme

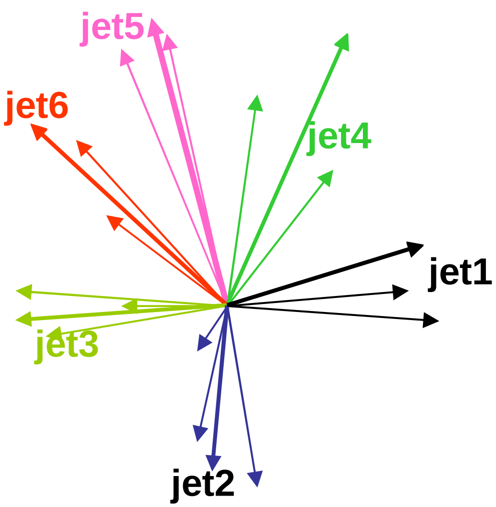
Energy deposits	Particles	Jets	di-jet masses

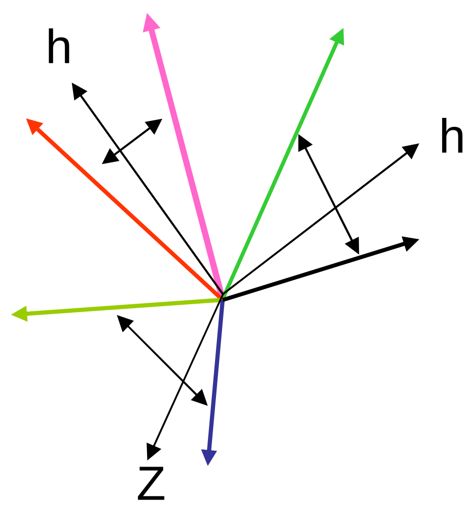
Particle Flow algorithms

Jet algorithms (Durham)

Jet pairing (based on di-jet masses)







Fast simulation choice

- Parametric fast simulation
  - ↳ **pflow $\Delta E/E = 30\%/\sqrt{E}$**
  - ↳ **typical b-tag efficiency = 90% (c contamination 35%)**

- Test of different detector performance through fast simulation with different parameters
  - ↳ **different pflow**
  - ↳ **different b-tag**

- It is too difficult to regenerate all the MC for different detector resolutions (geometries)
  - ↳ **how to simulate different particle flow in the full simulation**
  - ↳ **many parameters :**
    - ECAL
    - HCAL
    - ID Part
    - Confusion
    - …
  - ↳ **various sets of parameters may lead to the same particle flow resolution**

Parametric Fast simulation

detector simulation with a Parametric Monte Carlo

4 T magnetic field and $P_t^{min}(charged) > 0.5$GeV/c are reconstructed

VDET	$\theta \in [16°,164°]$
TPC	$\theta \in [12°,168°]$
Forward tracker	$\theta \in [5°,25°]$ and $[155°,175°]$
Forward μchambers	$\theta \in [5°,12°]$ and $[168°,175°]$

Table 2: Acceptances of the tracking system devices defined by their polar angle (θ).

Sub-detector Sub-detector	Angular acceptance	Energy Threshold	Energy resolution
ECAL	4.6°	1 GeV	$\Delta E/E = 10.2\%/\sqrt{E(GeV)}$
HCAL	4.6°	1 GeV	$\Delta E/E = 40.5\%/\sqrt{E(GeV)}$
LCAL	1.7-3.1°	30 GeV	$\Delta E/E = 10.\%/\sqrt{E(GeV)}$

Table 3: Characteristics of the calorimeters.

Angular acceptance down to 5° (TPC+Calo.)
2° Luminometer

- **jet b-tagging**
  - **based on combination of impact parameter in rz and rϕ views.**
  - **use b-tagging parametrisation from R. Hawkings (5μm, 5 layers)**

Monte Carlo simulation

To obtain a realistic result, the generated luminosity should be greater than the expected luminosity (drawback for a full simulation)

Processes	σ(pb)	N Generated	Generated luminosity (pb^{-1})	N expected (L = 500 pb^{-1})
hhZ	0,18441	15k	81340,49	**92,2**
Backgrounds	699	1820k		**332167**
tt	526,4	740k	1880,7	263200
ZZZ	1,051	40k	38059,0	525
tbtb	0,7	20k	28571,4	350
ZZ	45,12	50k	1108,2	22560
nntt	0,141327	20k	141515,8	70
wwz	35,3	130k	3682,7	17650
wtb	16,8	200k	2976,2	8400
eezz	0,287	10k	34843,2	143
nnww	3,627	30k	8271,3	1813
evzw	10,094	60k	5944,1	5047
nnzz	1,08257	20k	18474,6	541
ttZ	0,6975	20k	28673,8	541

Event reconstruction

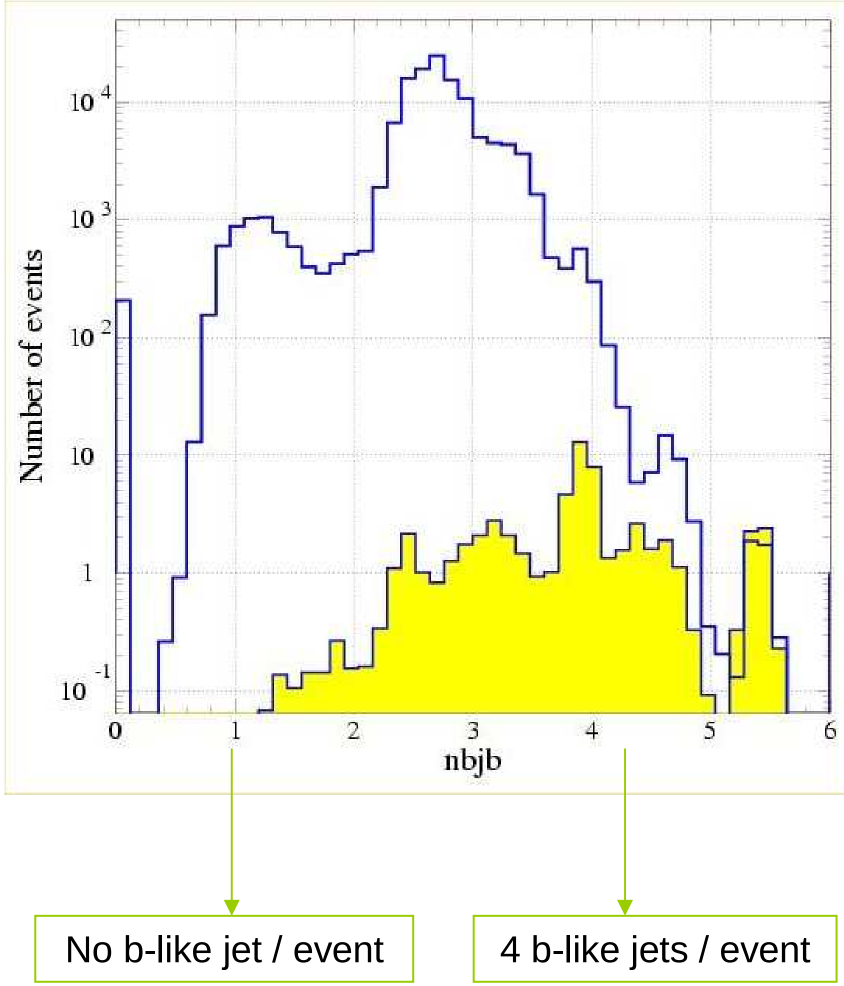
Signal : 3 channels

- ↳ **hhqq**
  - 6 jets
  - m_h & m_Z
- ↳ **hhνν**
  - 4 jets
  - missing energy
  - M_h
- ↳ **hhll**
  - 4 jets
  - 2 energetic leptons
  - m_Z & m_h

- Each event is reconstructed
  - ↳ **in 6 jets**
  - ↳ **in 4 jets**
  - ↳ **in 2 jets**
- Jet pairing based on di-jet masses associated to bosons
  - ↳ **Jets combined in pairs in order to test different final states**
  - ↳ **hhZ, hh(νν), ZZZ, ZZ, WWZ**
  - ↳ **For each event**
    - $\chi^2_{hhZ}=(m_{12}-m_h)^2/\sigma^2_h+(m_{34}-m_h)^2/\sigma^2_h +(m_{45}-m_Z)^2/\sigma^2_Z$
    - $\chi^2_{ZZ}=(m_{12}-m_h)^2/\sigma^2_Z+(m_{34}-m_Z)^2/\sigma^2_Z$
    - . . .

b - tagging

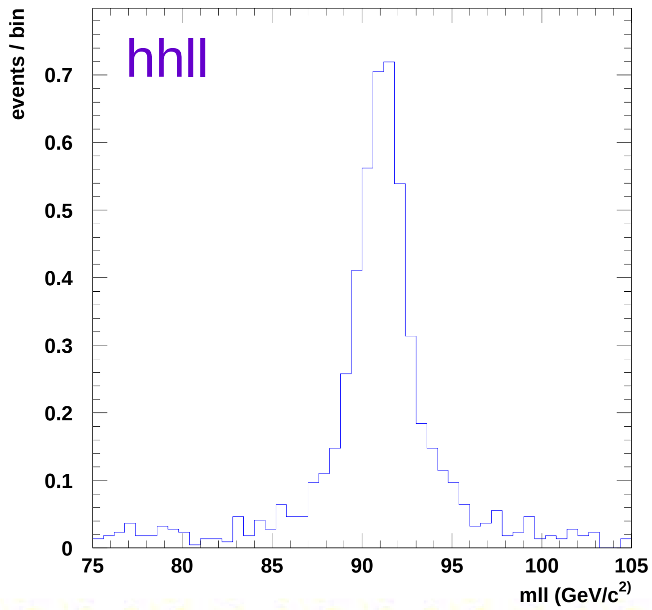
- Use the b flavor signature to reduce the background
- Global variable (crude approach)
    - ↳ **Estimator of # of « *b jets* » per event taking into account de c and uds contamination (parametrisation of a given VDET)**

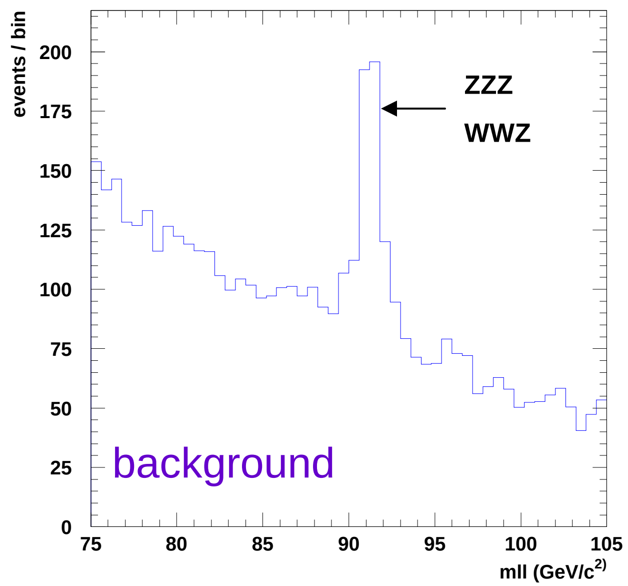


Event preselection

- Minimal b flavored content
  - ↳ Event by event basis
- Visible energy
- 2 isolated leptons in a mass window of 25 GeV around m_Z

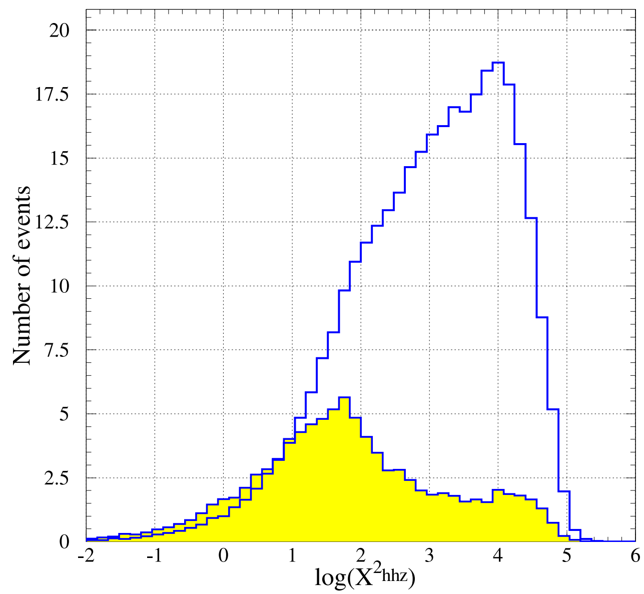
Selection	Evis	b content	2 Isoltd lept
hhqq	>370 GeV	> 3.6	No
hhνν	<370 GeV	>1.8	No
hhll	>370 GeV	>1.8	Yes





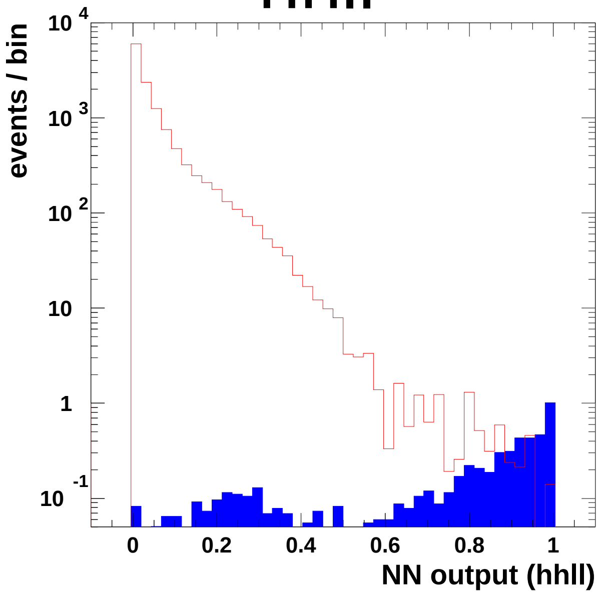
Event selection

- Multivariable Method
  - ↳ **Global inputs :**
    - Visible energy
    - Sphericity
  - ↳ **Reconstructed inputs :**
    - Number of jets (y_{cut})
    - χ^2_{hhZ} χ^2_{hh} $\chi^2_{2\text{-bosons}}$ $\chi^2_{3\text{-bosons}}$: hypothesis based on reconstructed masses

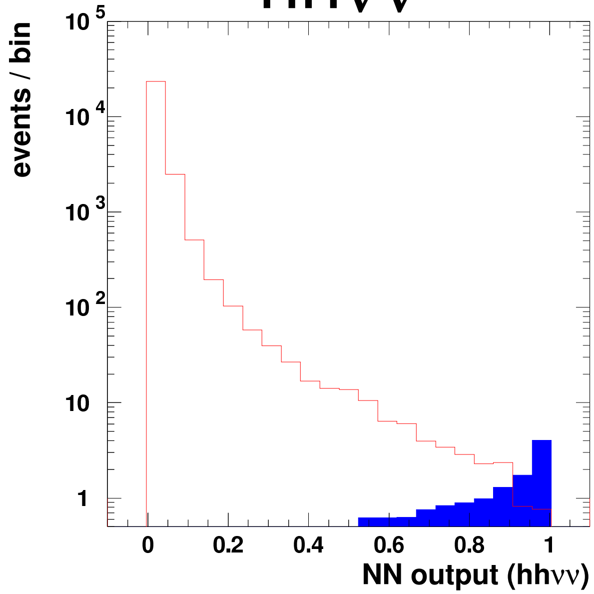


NN output

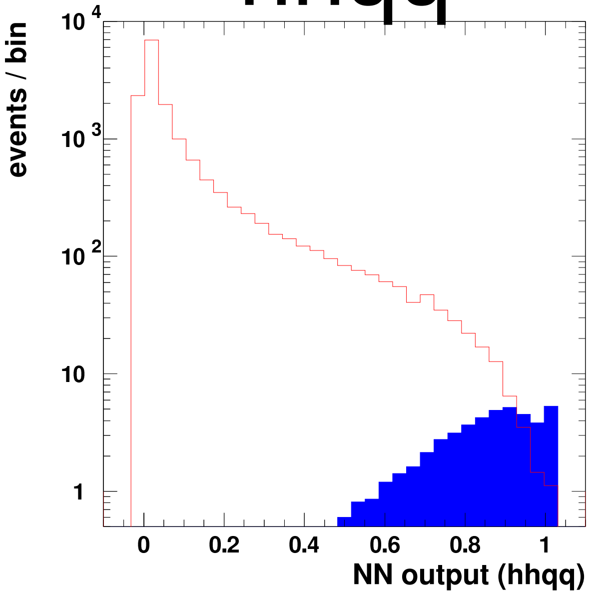
hhll



hhνν



hhqq



Expected number of events at $\mathcal{L}$ = 2 ab^{-1}

- Channel hhqq
  - **Signal : 67.3**
  - **Background : 93**
    - tt 9.2
    - tbtb 37.
    - ZZZ 16.4
    - ttZ 18.8
- Channel hh$\nu\nu$
  - **Signal : 20**
  - **Background : 14.6**
    - ZZ 2.4
    - tbtb 6.8
- Channel hhll
  - **Signal 10.3**
  - **Background : 26.8**

- **Significance = 6.6 σ**

Measurement of the cross section and of the hhh coupling

- σ_{hhZ} is measured using a maximum likelihood method and assuming a Poisson law distribution for the NN output x btag

- The 2 dimensional distribution is fitted :
  NN Output X b-tag

- The pseudo experiments method is used to evaluate the expected statistical error

- For ε_b=90% and pflow 30% : $\Delta\lambda_{hhh}/\lambda_{hhh}$ = 16%
  $\Delta\sigma_{hhh}/\sigma_{hhh}$ = 9 %
  (@ 500GeV L = 2ab^{-1})

- The observed contribution of the various channels to the measurement :
  - ↳ **hhqq 40%**
  - ↳ **hh$\nu\nu$ 25%**
  - ↳ **hhll 34%**

Jet charge can help ...

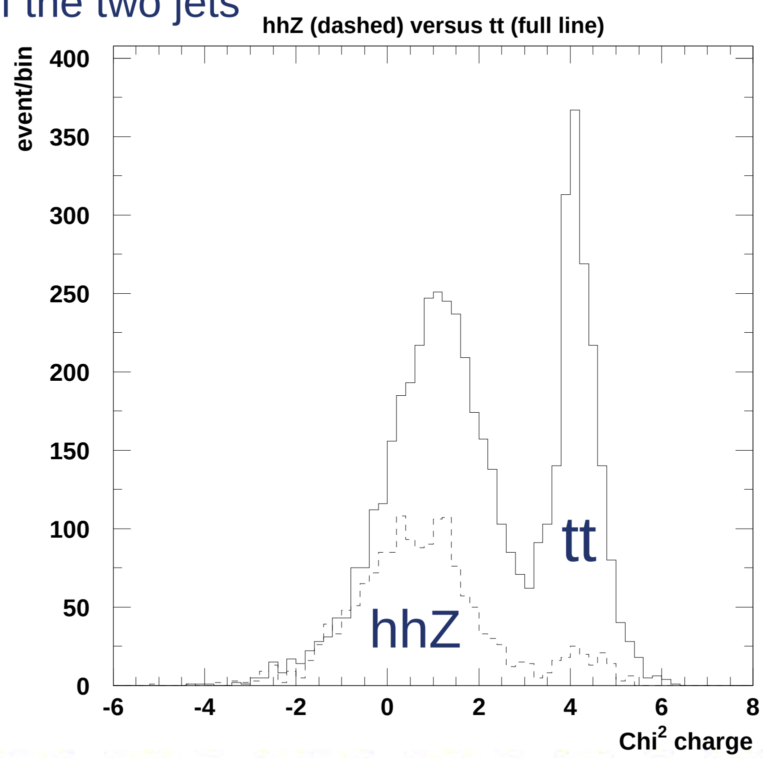
- Definition of the jet charge (Ch_j):
  - **For a jet j : $Ch_j = \Sigma\, q_i\, w_i \,/\, \Sigma\, w_i$**
    where q_i is the charge of the particle i
  - **$w_i = \sqrt{(p_i . e_j)}$**
    p_i is the particle's momentum, e_j the jet direction

- Boson charge = sum of the charges of the two jets

- For a given event, definition of a χ^2

$$\chi^2 = (Ch_{h1})^2/\sigma^2 + (Ch_{h2})^2/\sigma^2 + (Ch_Z)^2/\sigma^2$$

- It should improve the hhZ selection



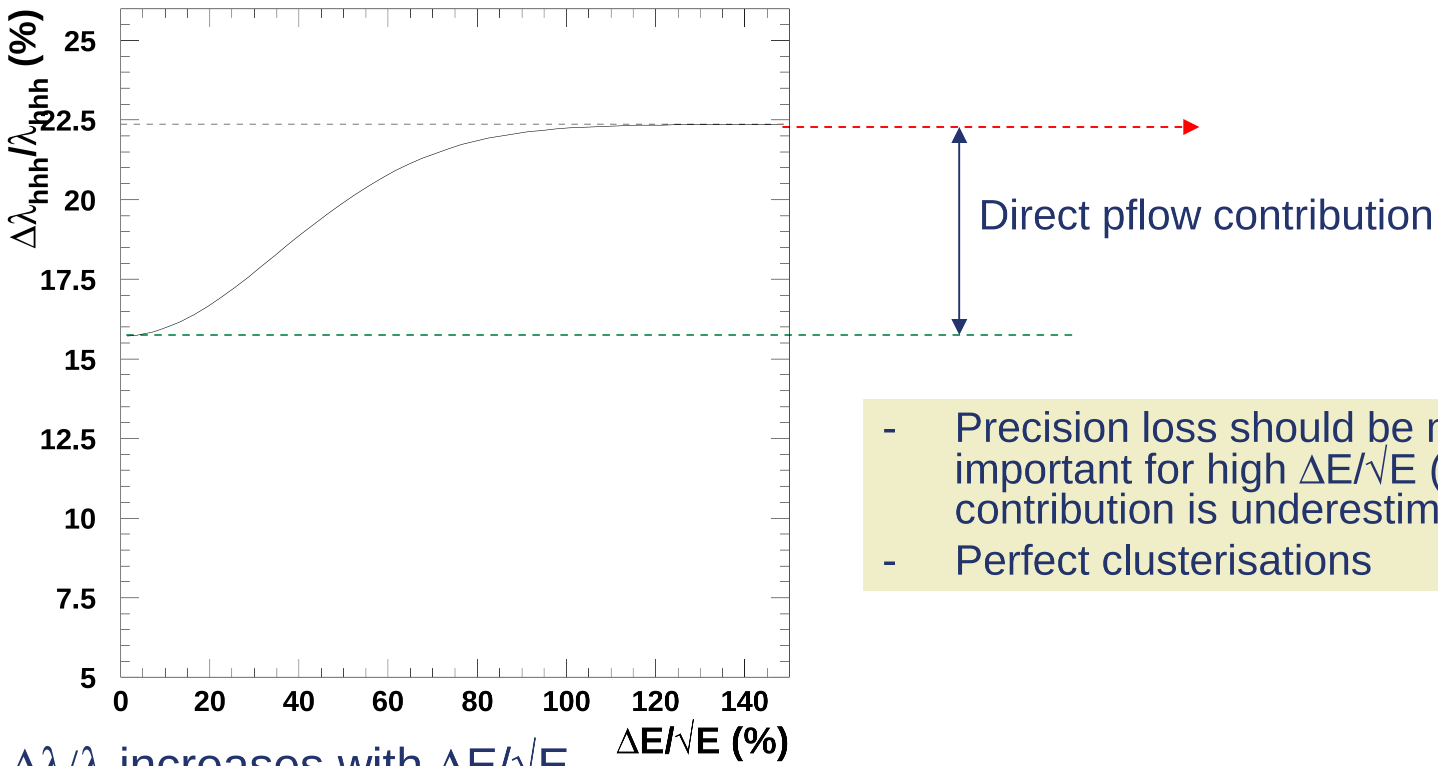
Impact of the detector performance

- Move from a realistic fast sim to a smearing of the visible energy of partons

- Simulation of different Particle flow resolutions
  - ↳ **Information at parton level**
    - Merge all the daughter (except ν's) of the quark in one object
    - BUT it cannot be done formally because of the string model
    - Method : clusterise of the daughters to form the parton direction
    - Smear the reconstructed parton to simulate the jets
    - An optimistic approach for bad particle flow resolutions
  - ↳ **Smearing of parton energy**
    - Range : 0%/√E → 130% /√E
      - ↳ perfect particle flow
  - ↳ **Jet pairing is changed (based on boson masses)**

- λ_{hhh} measurement
  - ↳ **For each detector hypothesis :**
    - New NN trained
    - Cuts fully optimized

$\Delta\lambda_{hhh}/\lambda_{hhh}$ *versus* $\Delta E/\sqrt{E}$



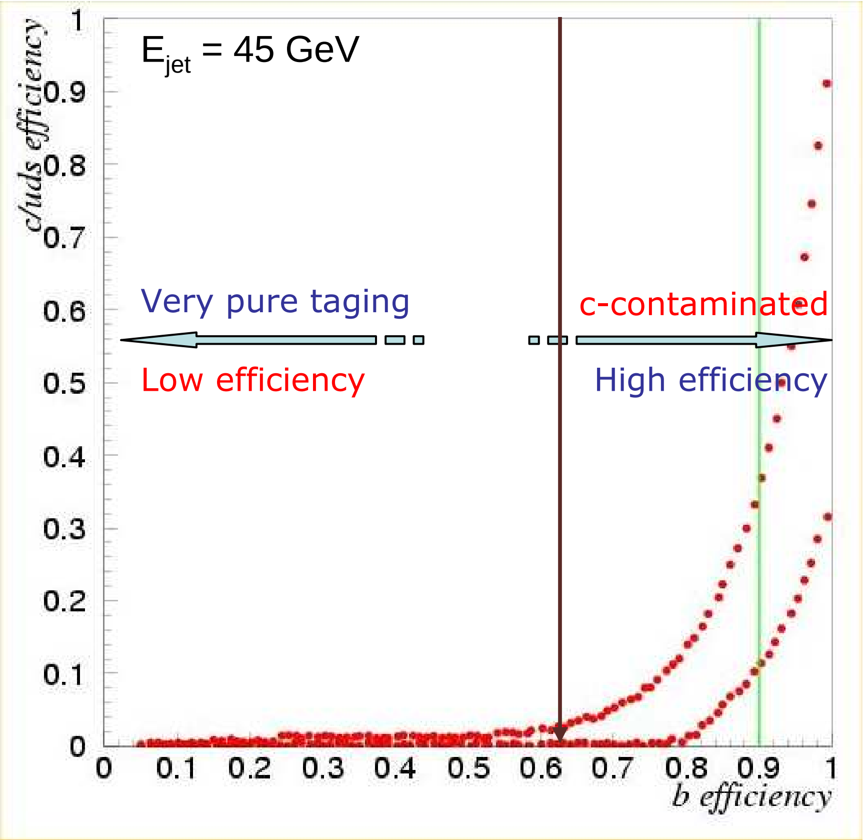
- Precision loss should be more important for high $\Delta E/\sqrt{E}$ (pflow contribution is underestimated)
- Perfect clusterisations

- $\Delta\lambda/\lambda$ increases with $\Delta E/\sqrt{E}$
  - ↳ **Gain when pflow are added = 22.5% → 16%**
- This reduction corresponds to a reduction in the required luminosity by a factor 2 : without the particle flow information 4 ab^{-1} are needed to reach 16% (optimistic)
- This result valid for a given b-tag/c-tag and for an non-optimized ε_b choice

b-tag choice

- For a given b-tag/c-tag parametrisation

  - ↳ **b-tag efficiency (ε_b) choice = analysis choice**
  - ↳ **efficiency ↔ purity (c contamination)**
  - ↳ **Which ε_b optimizes λ_{hhh} measurement ?**
  - ↳ **Previous working point :**
    - ε_b=90%
    - ε_c =35% (45GeV jet)



(Richard Hawkings parametrisation)

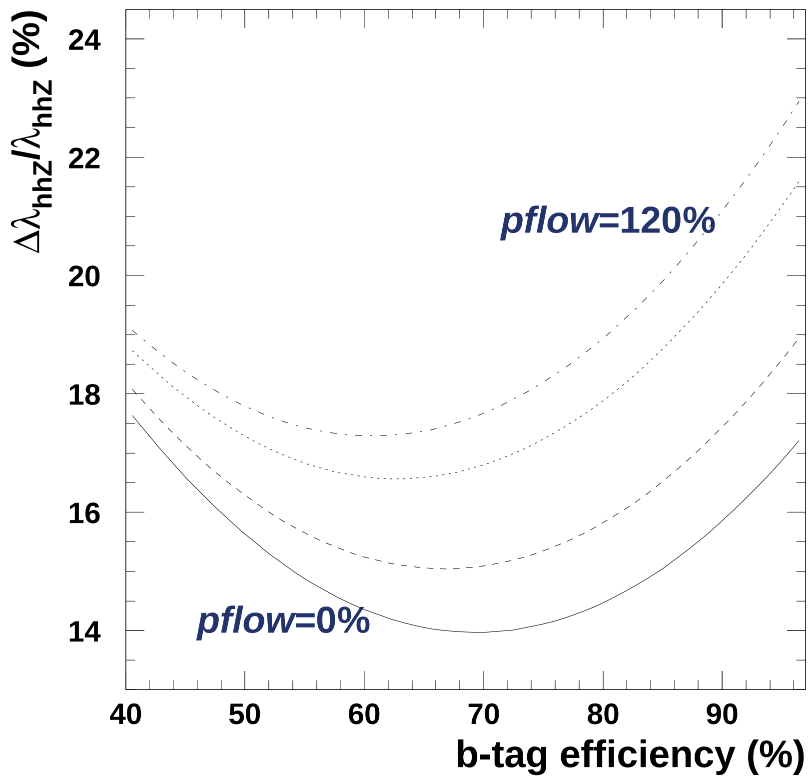
Tuned for back-to-back jets

Study of the detector performance

- Simulation of different b-tag efficiencies
  - ↳ **b-tag is defined statistically (from true jet flavor)**
  - ↳ **c-tag ↔ b-tag efficiencies respect the Hawkings parametrisation**
    - Tested range : 40% → 95%
    - For different pflow resolutions
- λ_{hhh} measurement
  - ↳ **For each pflow resolution :**
    - NN trained
    - Cuts optimized
    - 77 analyses are tested (for each combination pflow x btag)

$\Delta\lambda_{hhh}/\lambda_{hhh}$ versus b-tag efficiency

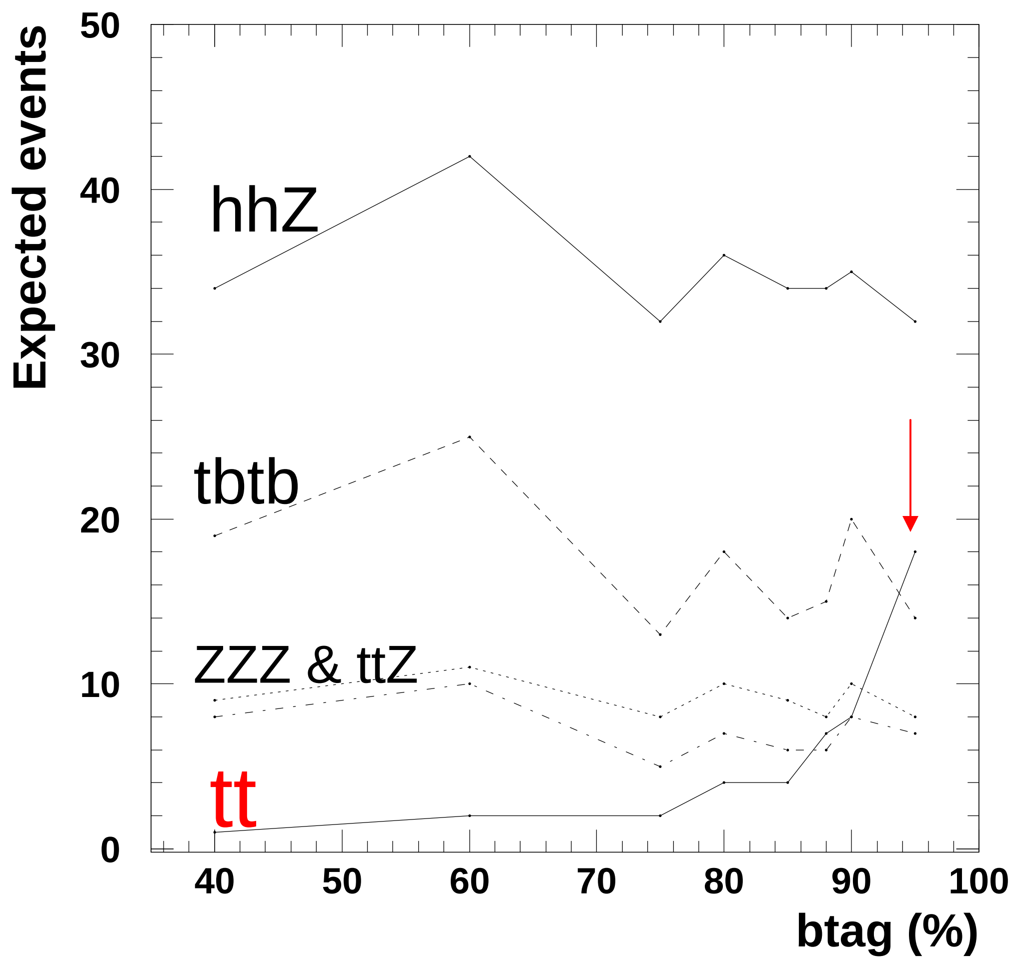
- Optimum @ ε_b ~ 65%
- ~ same resolutions for different pflow
- For *pflow* = 30%/√E
  - ↳ **A precision of 15% is reachable on λ_{hhh} with the optimal ε_b**



Background sensitivity to the b-tag choice

- Which background is most sensitive to b-tag choice ?
  - ↳ **tt**

- tt → WbWb → bbccss
  - ↳ **c-jets tagged as b-jets**
    ↔ bbbbqq like final state
    ↔ hhZ like final state
  - ↳ **bbbbqq is the hhZ flavor signature used in the selection**



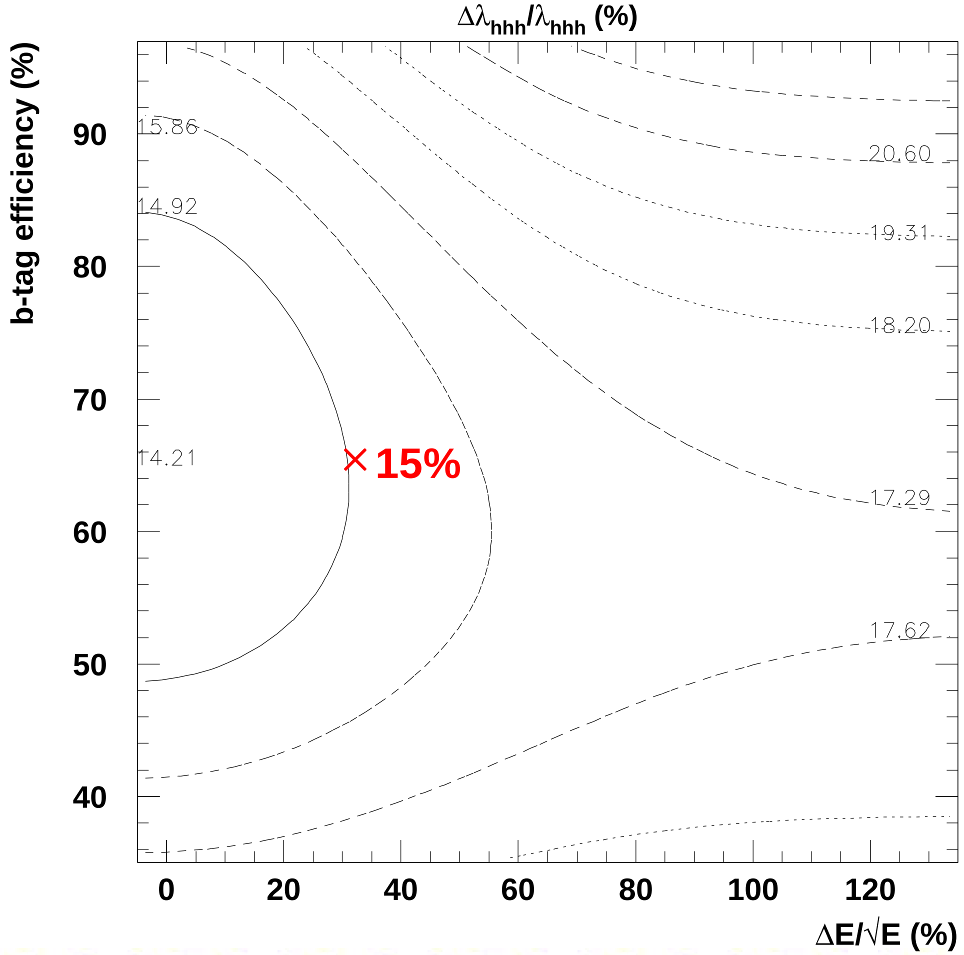
$\Delta\lambda_{hhh}/\lambda_{hhh}$ versus b-tag and pFlow

Expected statistical error (in %) for a luminosity of $2ab^{-1}$

For a given c-tag / b-tag parametrisation

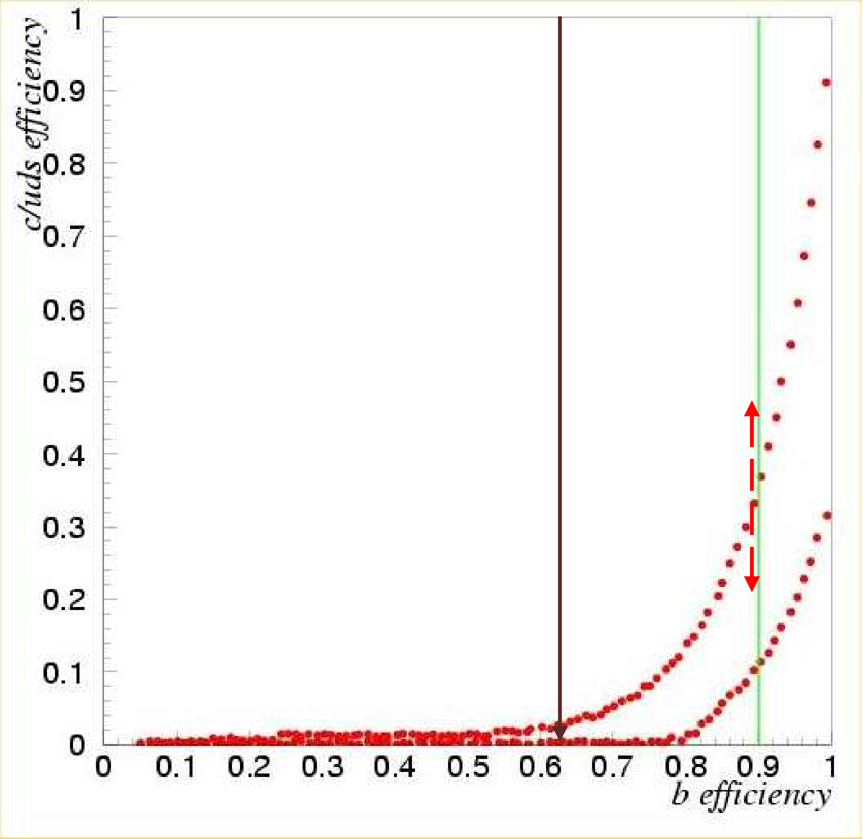
ε_c= 35%

ε_c~ 5%



- Best ε_b corresponds to
  - ↳ **ε_c < 5%**
  - ↳ **ε_{uds} negligible**
- What is the dependence of $\Delta\lambda_{hhh}/\lambda_{hhh}$ ↔ b-tag purity for a given efficiency (different b-tag/c-tag)

$\Delta\lambda_{hhh}/\lambda_{hhh}$ versus b-tag efficiency

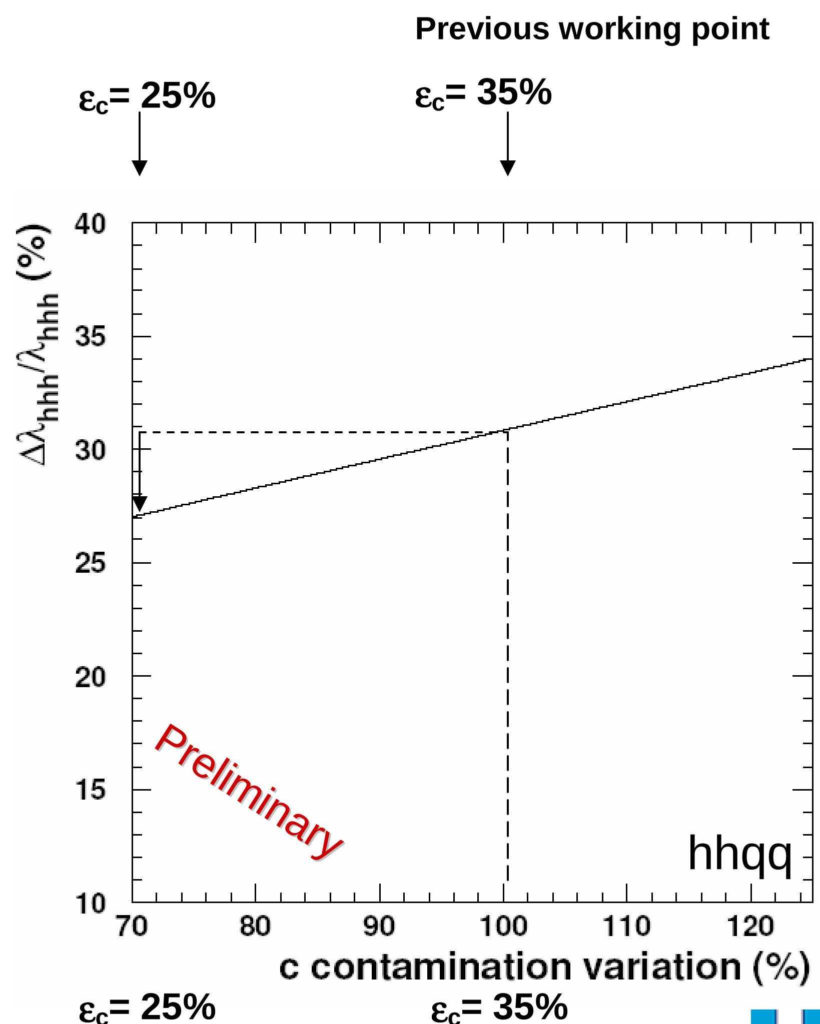


b-tag purity (c tagging)

- Tested on hhqq
- Using ε_b = 90%

- For a reduction of 30% of the c contamination (typically from 35% to 25% @ E_{jet}=45GeV)

  ↳ **$\Delta\lambda_{hhh}/\lambda_{hhh}$ is reduced by 12%**



Summary and Outlook

- The expected statistical precision on λ_{hhh} is evaluated to 15% with a typical detector configuration and for a luminosity of $2ab^{-1}$
- A particle flow of $30\%/\sqrt{E}$ reduces the necessary luminosity by at least a factor 2
- The b/c tag performance has an important effect and may be convoluted with Calorimeters
- The relation between clusterisation of the jets and pflow could be important and not completely treated yet.
- Obviously the analysis itself may be improved (e.g. by taking into account the jet charge)