

Jet reconstruction in LHCb searching for Higgs-like particles

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Motivation

Jet reconstruction is important for searches of particles involving b-jets and displaced vertices since LHCb has a very good b-quark trigger and identification, and will be well calibrated with the large number of B mesons.

Jets reconstruction is used in:

- **Standard Model Higgs** of light mass going to $b\bar{b}$

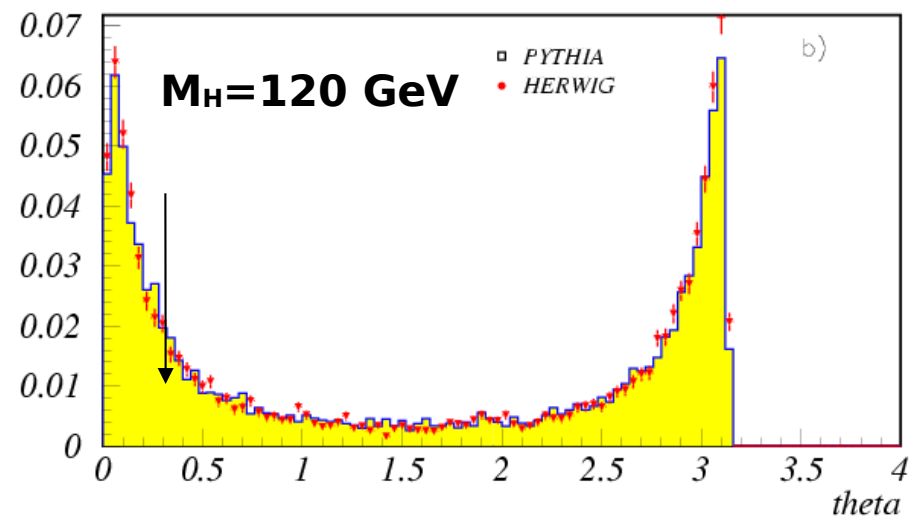
Precision EW fits give

$$M_H = 126^{+73}_{-48} \text{ GeV}$$

$$M_H < 219 \text{ GeV at 95\% C.L.}$$

- **Hidden Valley Models**
- **SUSY models with long lived neutralinos**

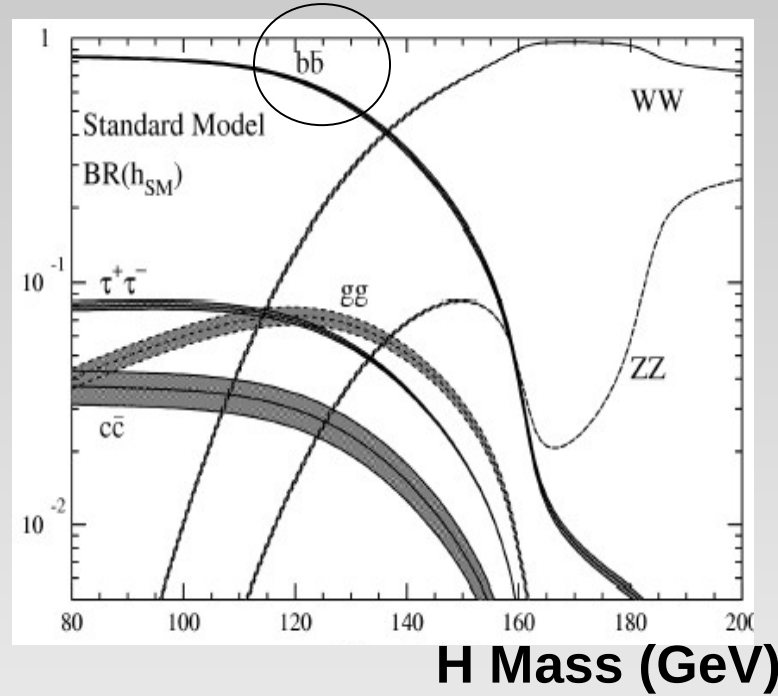
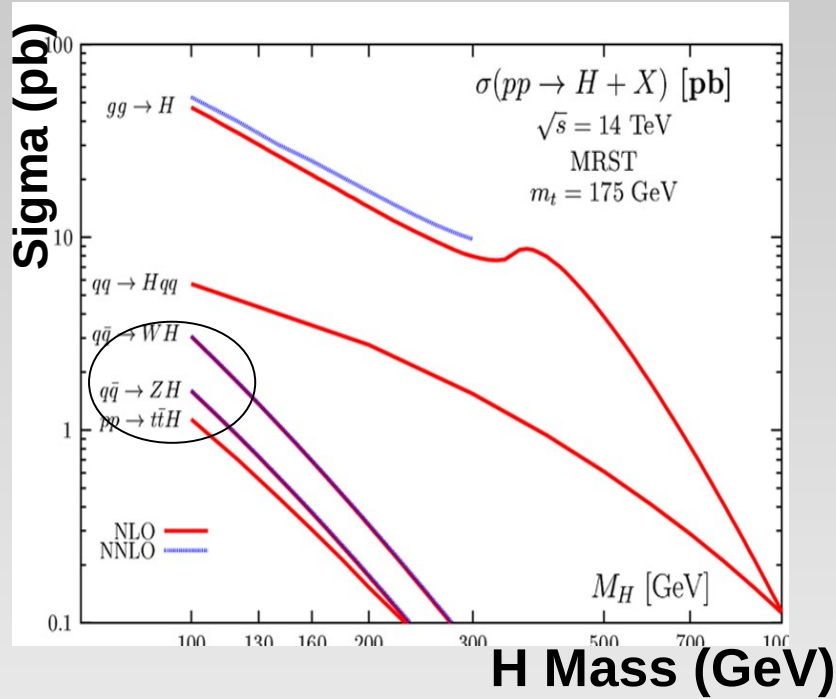
~30% SM Higgs events are in LHCb acceptance



This is a field of search which is outside the main LHCb scope, still the potentialities of the detector are worth being investigated

• Standard Model light Higgs

If one considers the associated Higgs production HW, HZ, for a SM Higgs:



$b\bar{b}$ dominant at low masses

SM predicts ~ 3 pb of HZ+HW at $M_H = 120$ GeV \rightarrow about 100 evts in one year LHCb data

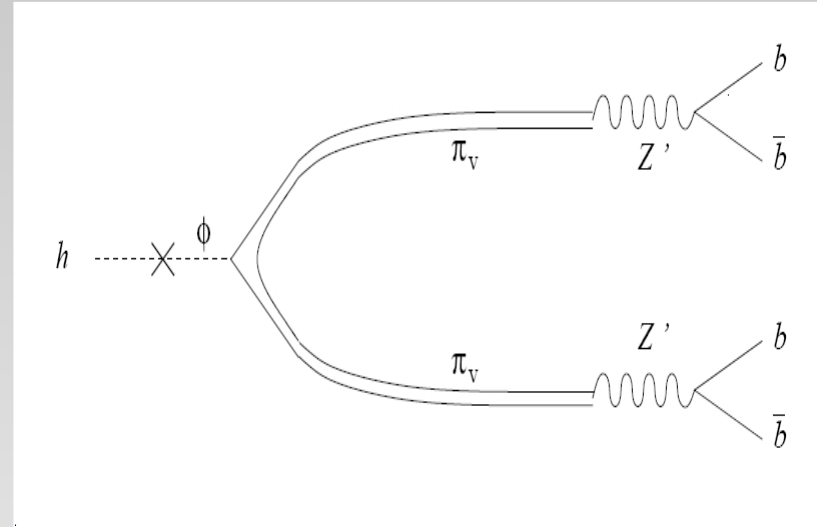
LHCb has good possibilities in triggering, reconstructing and tagging b-jets 😊

LHCb has a very restricted forward acceptance 😞

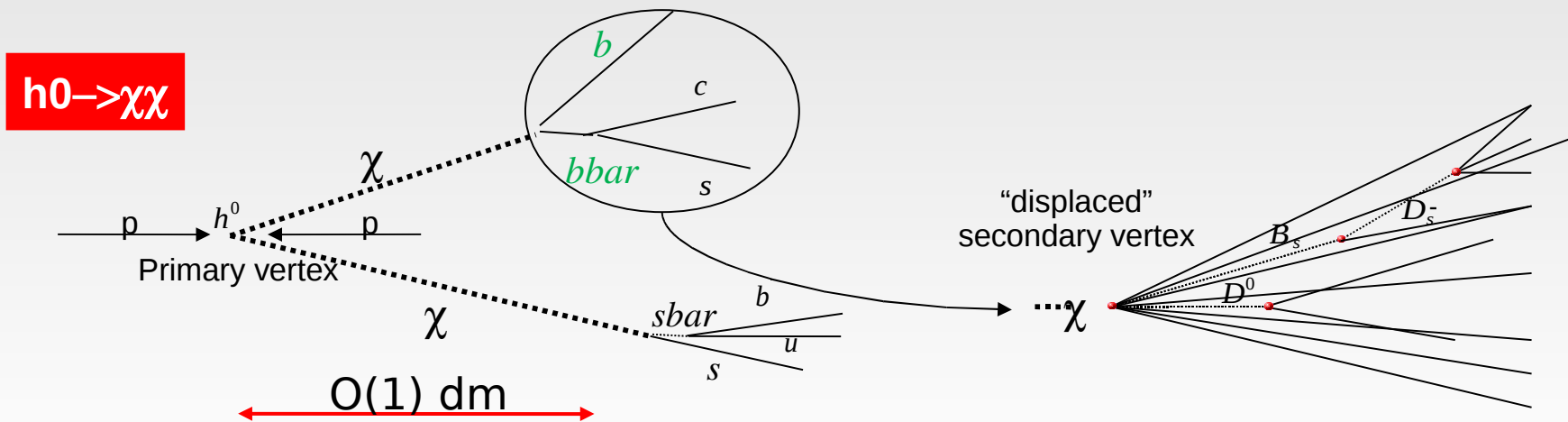
• Hidden Valley phenomenological models

Sectors with non-abelian gauge group which couple weakly to the standard model via higher dimension operators

- several, possibly long-lived, v-hadrons, with masses typically of the order v-confinement scale Λ_v
- some v-hadrons may be stable, providing dark matter candidates and missing energy signals, while others decay to neutral combinations of SM particles
- decay lifetimes can vary over many orders of magnitude producing displaced vertices in the detector



• MSSM with R-parity violation models (hep-ph/0607204)



LHCb Overview

Single arm spectrometer

$B\bar{B}$ production correlated and peaks in the forward-backward direction

Produced B mesons are highly boosted

Average B momentum ~ 80 GeV

Access to all B mesons with huge statistics

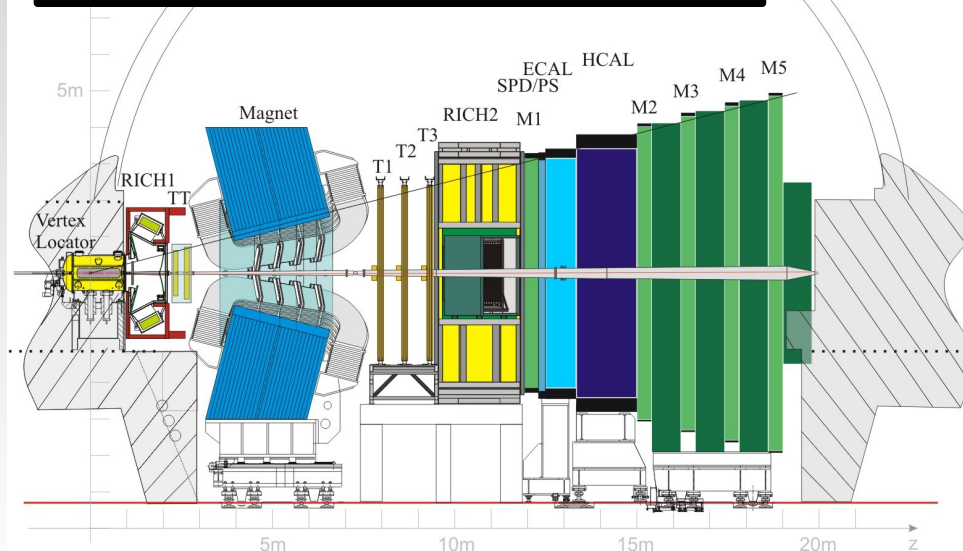
even though $LHCb_{lumi} = LHC_{lumi} / 50$
 10^{12} $b\bar{b}$ pairs per year

- ✓ LHCb is good to find secondary vertices
- ✓ LHCb is good to select “prompt” muons

Precision Vertexing:

- Primary vertex resolution
 $\sim 10\mu\text{m}$ transverse plane and
 $\sim 60\mu\text{m}$ in the longitudinal direction
- Impact parameter resolution
 $\sigma_{IP} = 14\mu\text{m} + 35\mu\text{m}/pT$

- Acceptance: 300 mrad
- Luminosity $2 \times 10^{32} \text{cm}^{-2} \text{s}^{-1}$

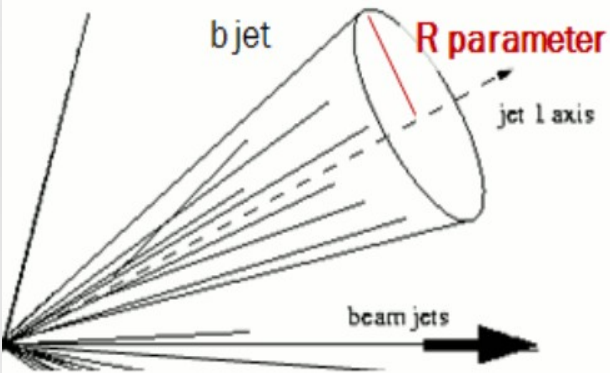


Muon ID: $\varepsilon = 89\%$ MisID=2.3%
Electron ID: $\varepsilon = 94\%$ MisID=0.7%

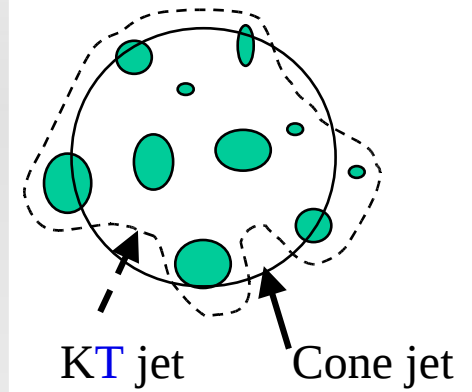
Jet algorithms

Nearness in angle
 ⇒ *Cone Algorithm*.

Nearness in relative
 transverse momentum
 ⇒ *Kt algorithm*.



$$R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$



Reconstruction

Matching tracks and
 electromagnetic clusters

Use track and calorimetric
 information to build
 4-MOMENTA

B-seed finding

Kt jet algorithm

Cone algorithm with
 B-seed

B-jet tagging

B-jets

B-jets

2 B-seeds from
 2-tracks
 secondary vertex

For R=0.5
 ~15 jets/event
 reconstructed

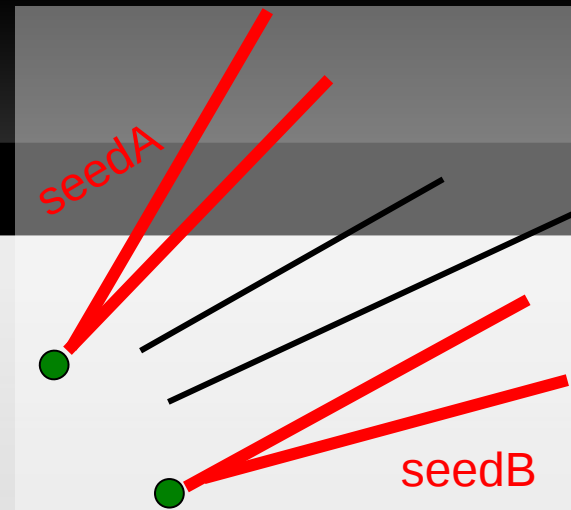
2 b-jets/event
 created

Ideally
 2 tagged
 jets/event

2-seed algo

Kt algo

LHCb Seed algorithm



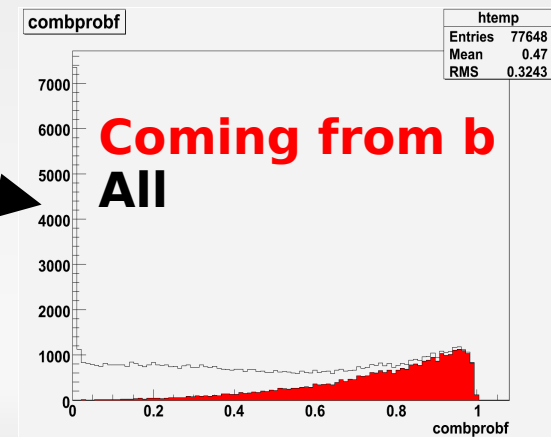
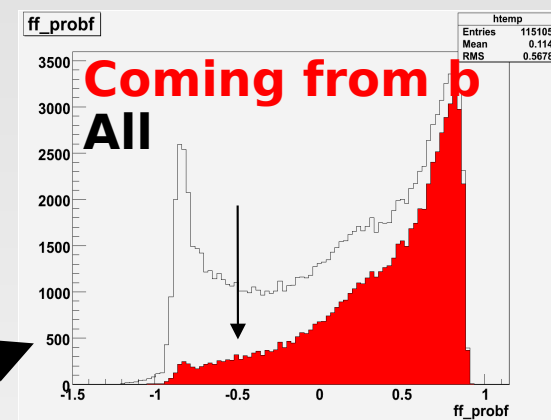
Track selection: build a 2-track vertex using cuts on

- χ^2 of tracking
- $P > 2$ GeV
- $IP/\sigma > 2.5, 2.8$ (wrt **Primary Vertex**)
- $P_t > 0.6, 0.8$
- K_S candidates are excluded in the mass window $M = [0.490; 0.505]$ GeV

Seeds selection. Select **seeds** on the base of a classifier using kinematic variables of tracks

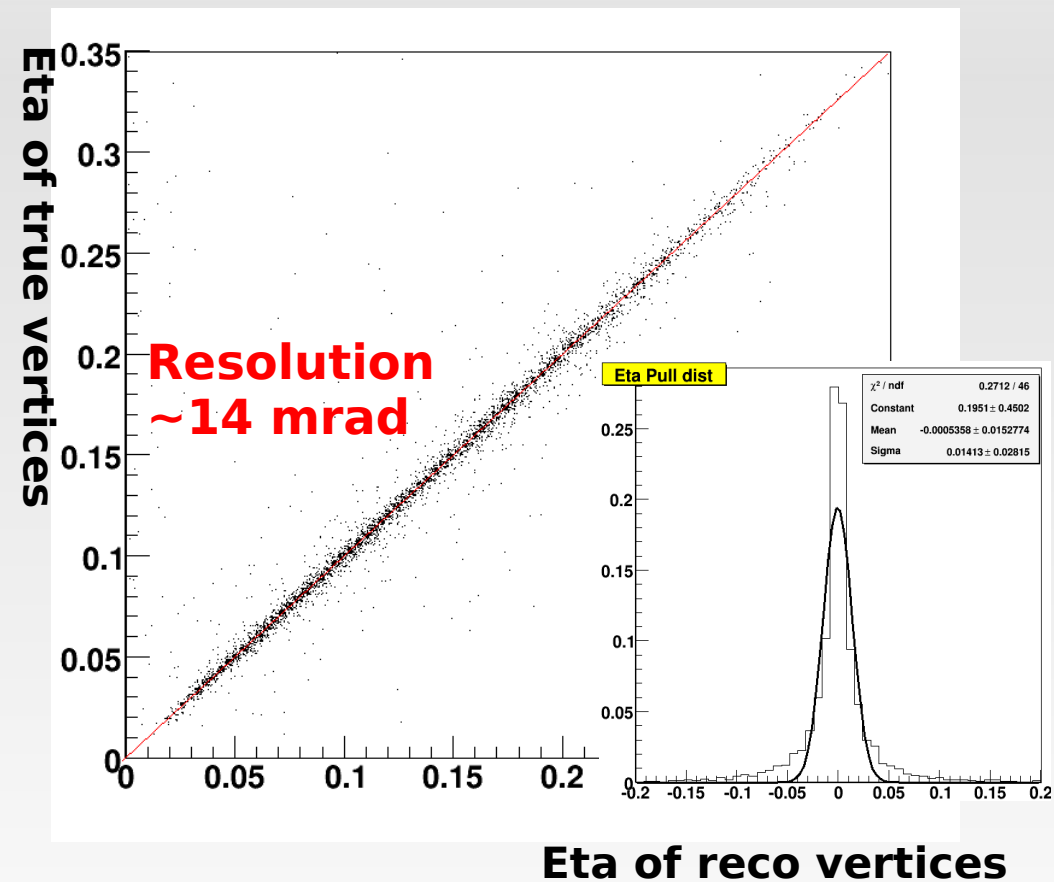
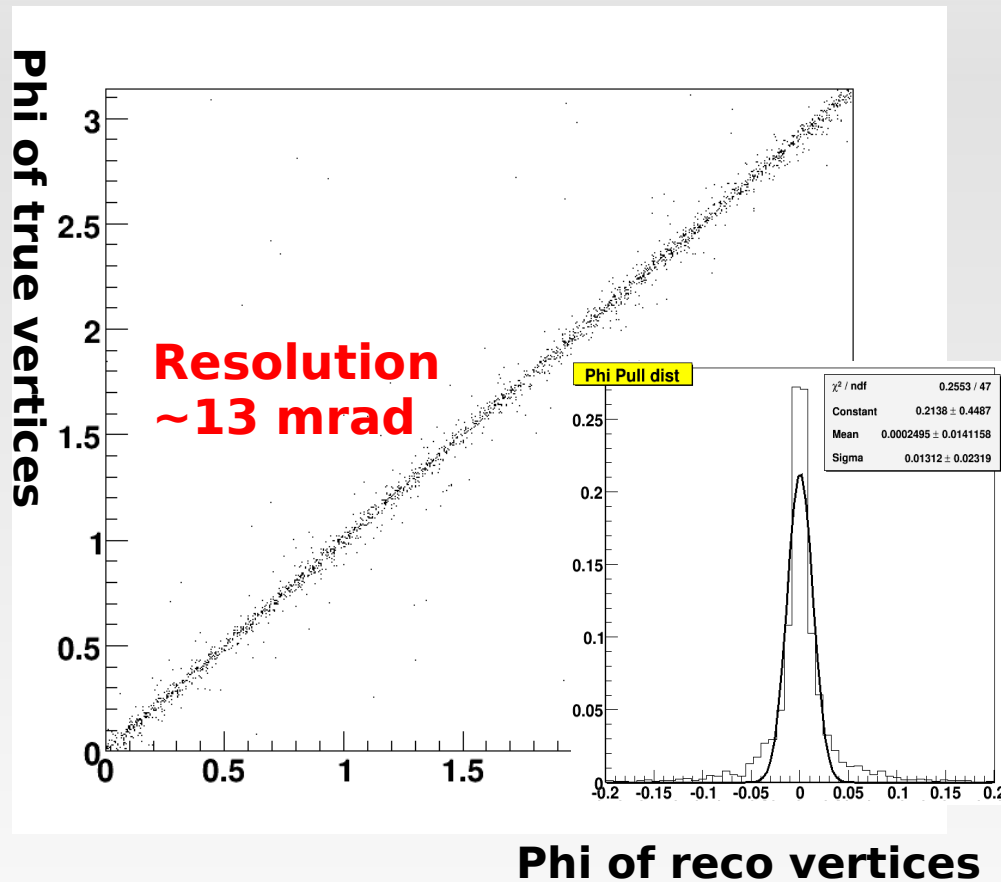
Double-seed selection. **Pairs of seeds** are passed to a second classifier, pick up the best seeds pair candidate according to classifier output.

Jets construction. Other particles are added to form a jet if particle belongs to a cone of $\Delta R = 0.7$



LHCb Seeds selection

HW, HZ Monte Carlo events generated with $M_H=120$ GeV and a lepton of $P_t > 10$ GeV within the acceptance



- ϕ and η correlation between reconstructed and true vertices
- No biases seen in the reconstructed jet direction

LHCb double-seed selection

Classifier output
for candidate
seed pairs in
the event



%	Prob>0.4
ϵ_{vis}	24.6
ϵ_{rec}	8.4
purity	72.3

numbers include trigger efficiency and muon/electron reconstruction

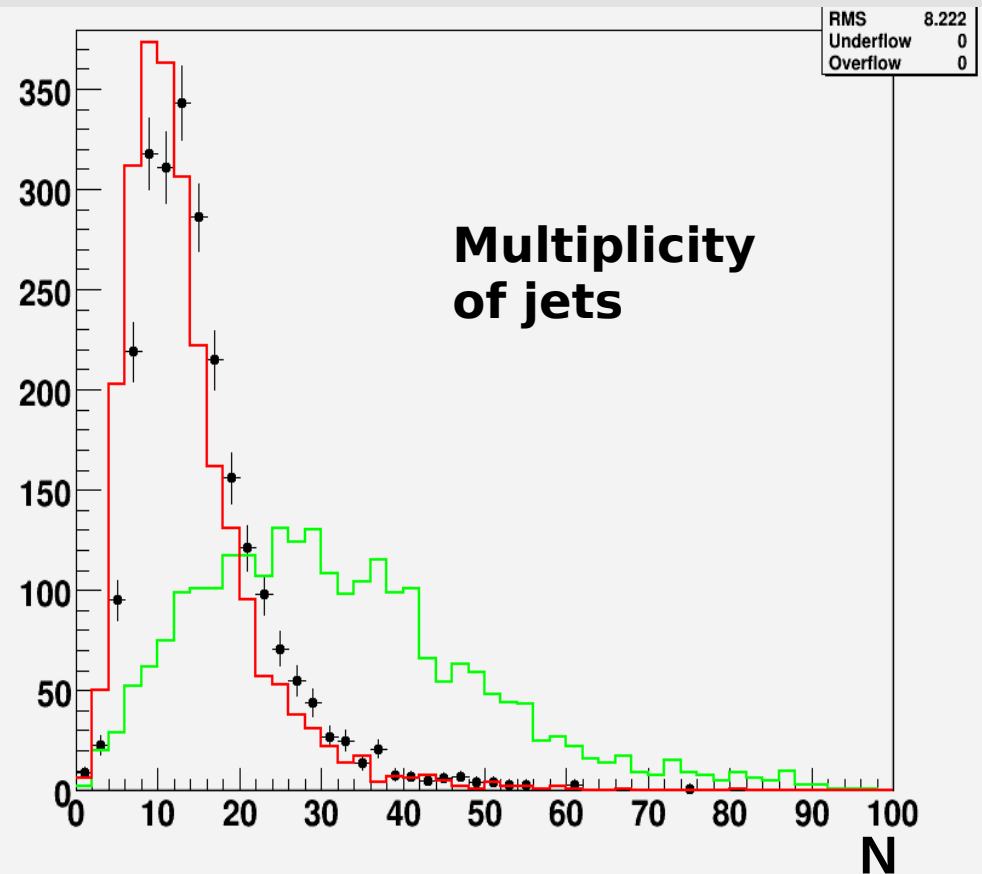
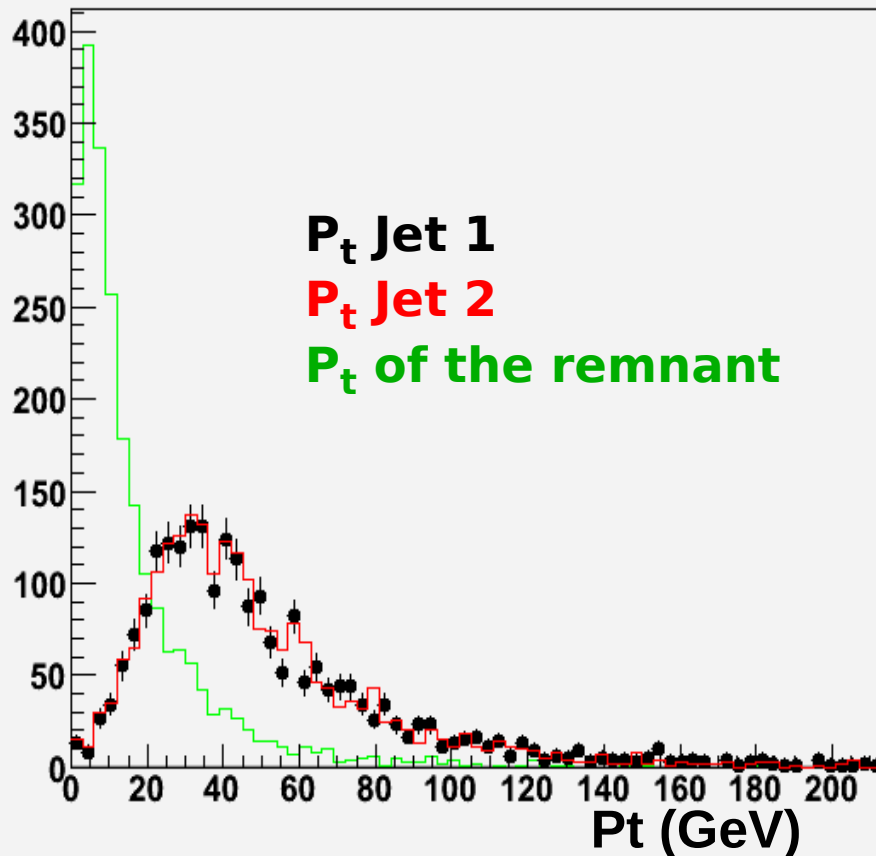
ϵ_{vis} : fraction of selected evts among visible true evts.
 ϵ_{rec} : fraction of evts that have a reco seeds combination over the total number of evts
purity: fraction of true seeds combination over the number of reco evts

Visible true evts: evts with 4 well reconstructed tracks (2 from each B, ~25% of the total of generated events).

Jets construction

HW, HZ Monte Carlo events generated with $M_H=120$ GeV and a lepton of $P_t > 10$ GeV within the acceptance

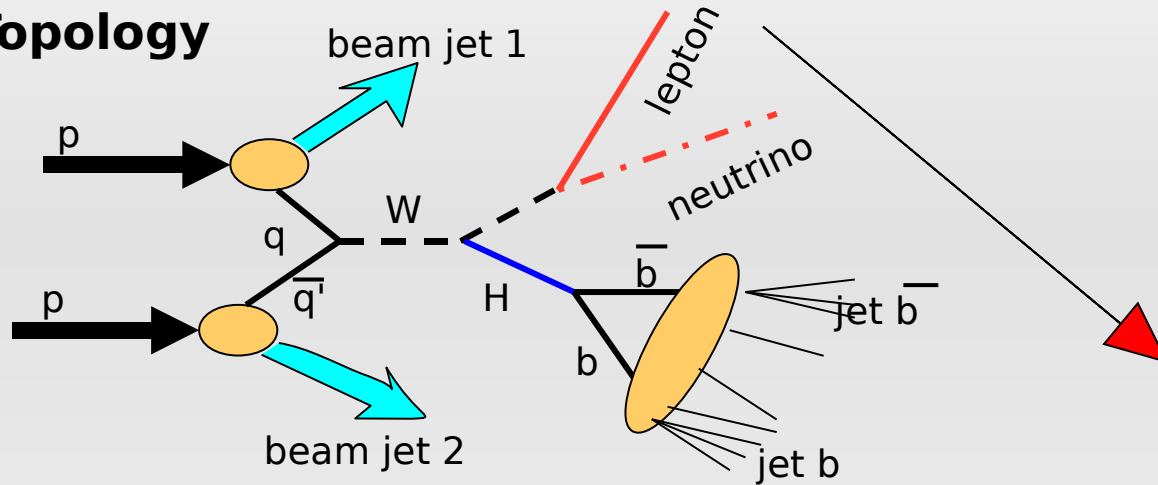
Once candidate pair of seeds is reconstructed, charged and neutral tracks are added to the cone of $\Delta R=0.7$ built around seeds directions



- High P_t lepton from W or Z boson is not included in jets

Light Higgs decay

Topology



- Selection: large P_t prompt lepton ($P_t > 10\text{GeV}$ | $IP/\sigma < 3$) to tag W,Z
- Reconstruction of 2 jets in LHCb acceptance

Sources of background [pb]

reducible background

$b\bar{b}$	$500 \cdot 10^6$
$t\bar{t}$	570
$\gamma^*/Z + \text{jets}$	10^4
W + jets	10^5

irreducible background

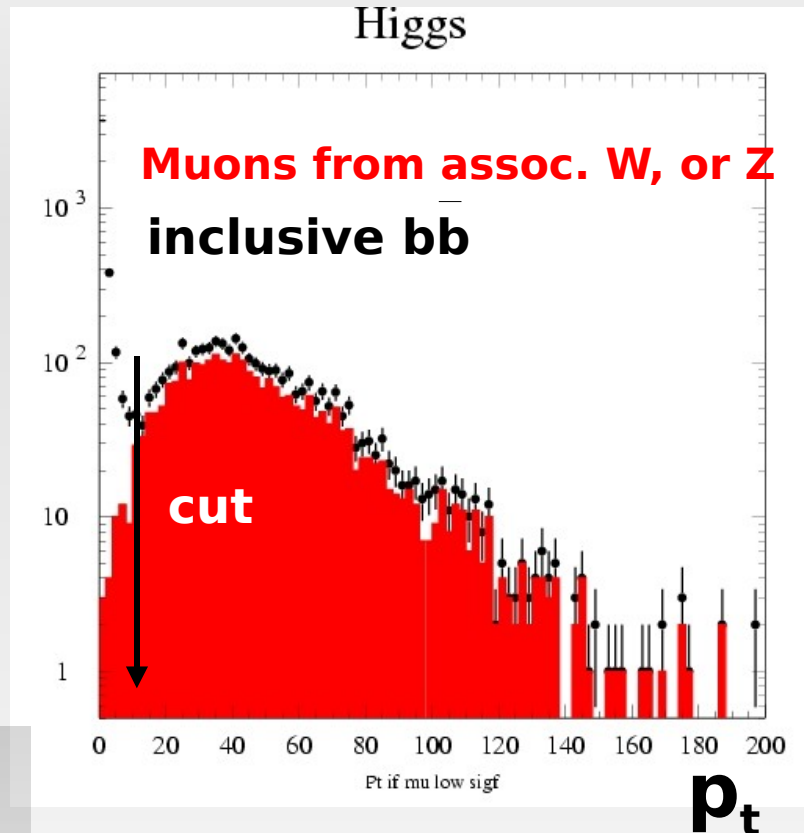
ZW	6.3
ZZ	2.5

weapon to fight it:

associated production
extra jet activity
b jet identification

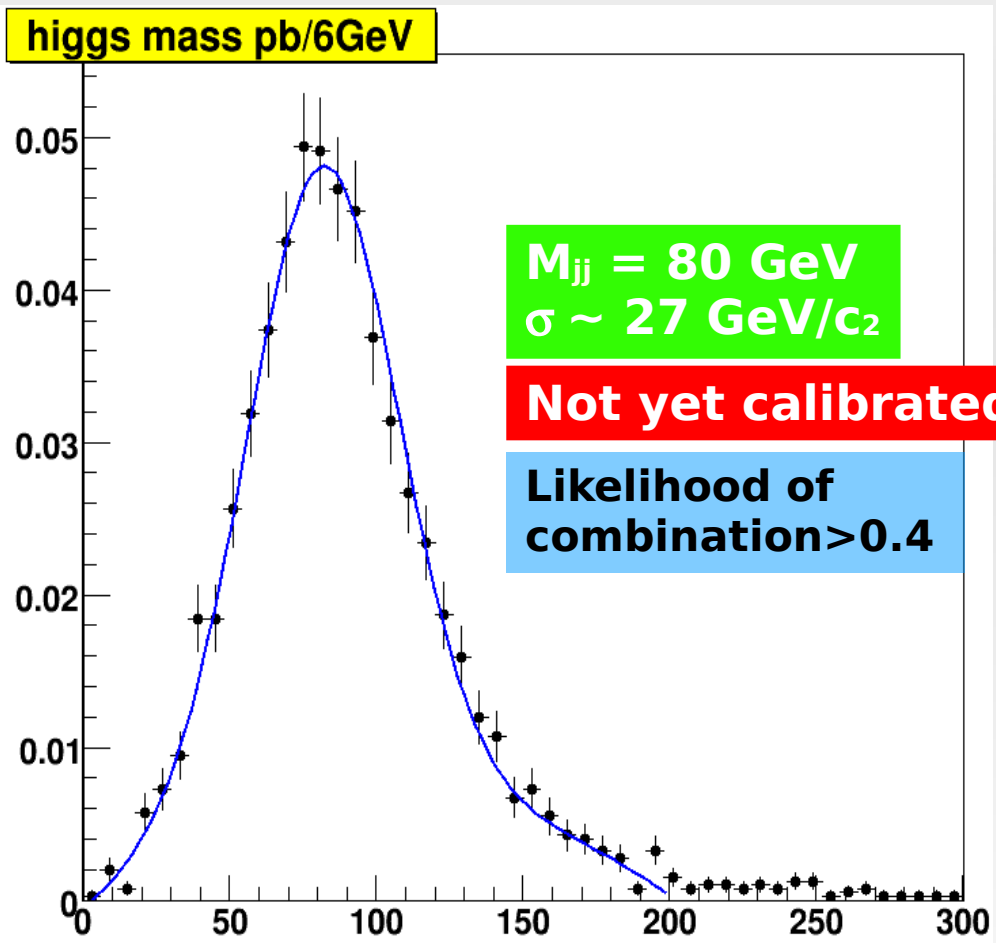
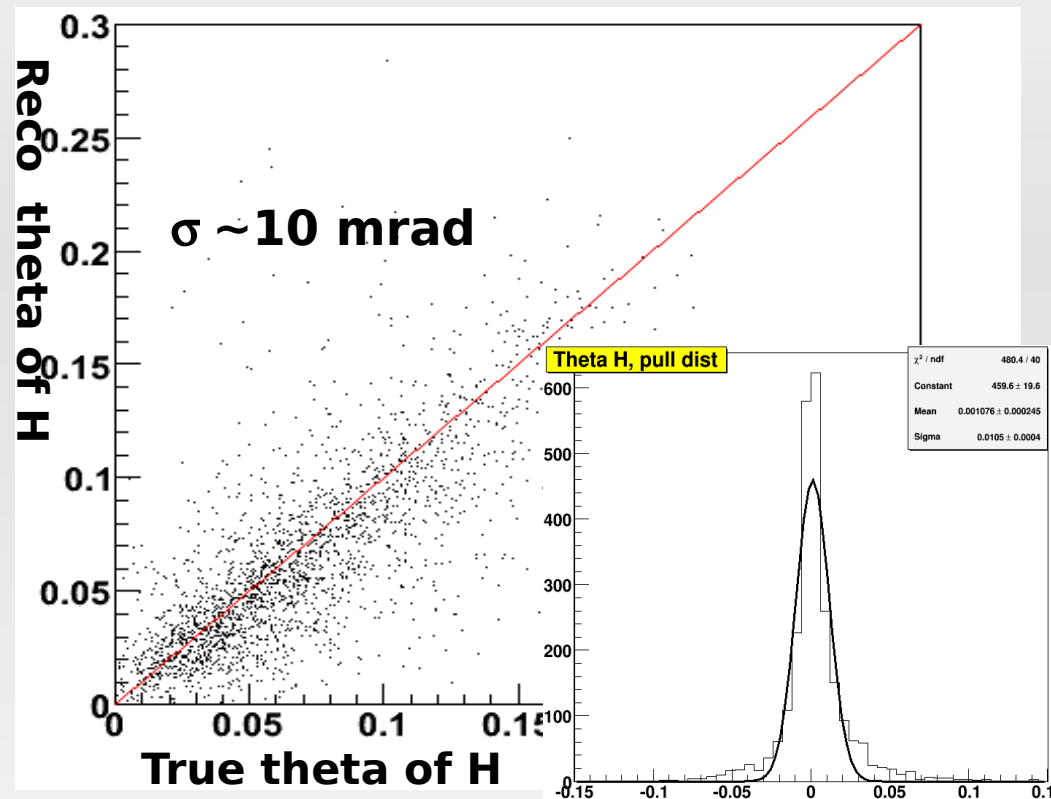
di-jet mass resolution

Discrete'08



Level 0 trigger 88% efficient to select HW e HZ events

Jets construction



Energy of Jets need to be calibrated. One can initially study it with MC and then use $Z \rightarrow b\bar{b}$ events

Detailed background studies in this approach are under way

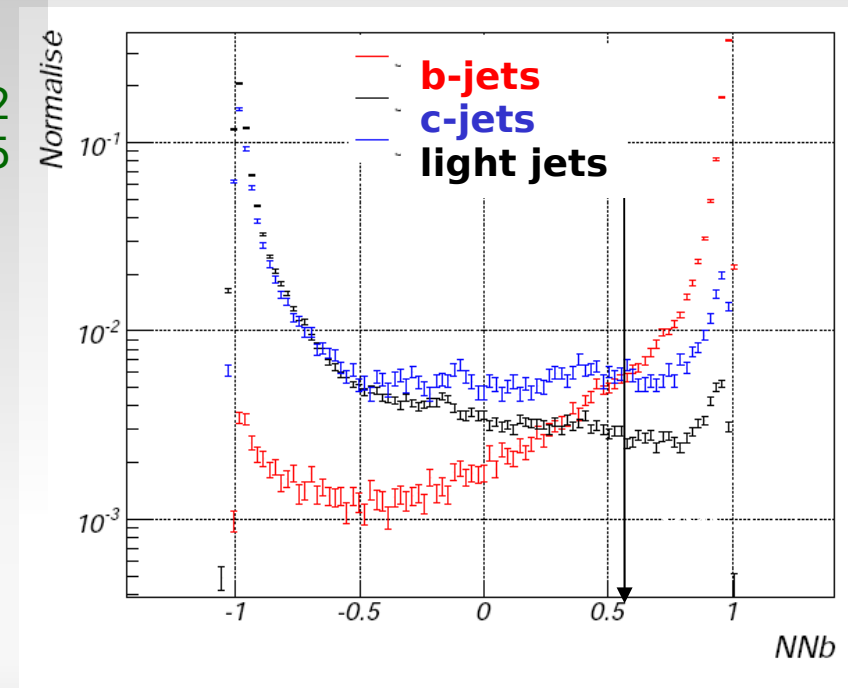
Kt algorithm

- Standard algorithm used by many experiments
- In LHCb Kt algorithm is used to make jets in the event with $\Delta R=0.75$
- Need to identify the b-jet

A jet then is defined as a b-jet if it has
at least 7 particles
at least 2 tracks with impact parameter significance >2
at least 1 tracks with impact parameter significance >5
energy of charged particles $> 3\%$ of the total energy
energy in a cone of $R=0.4$ around the jet axis $>70\%$
Ejet

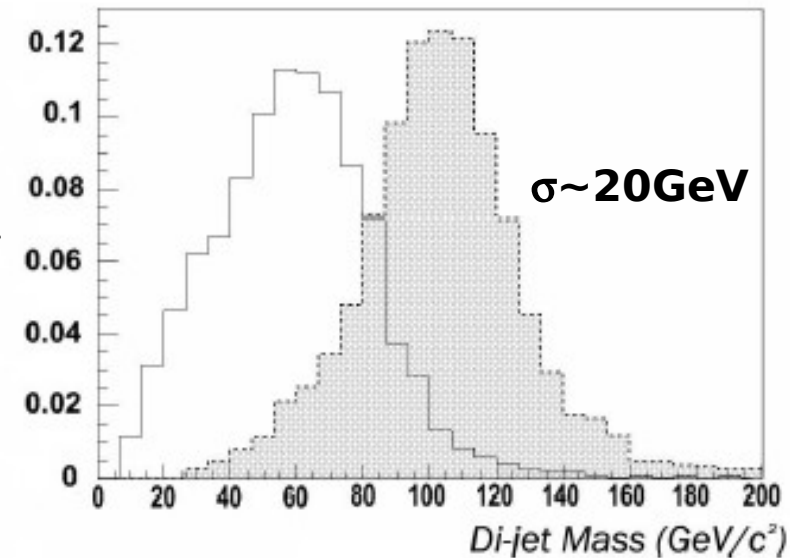
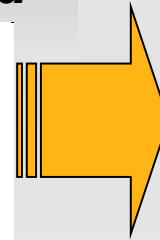
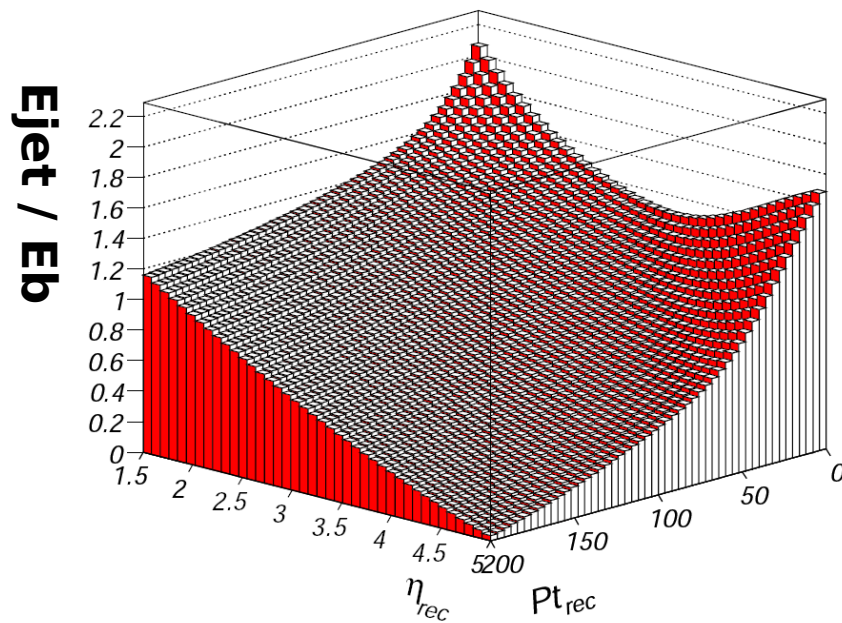
A neural net also trained to discriminate against
c-jets and light jets is also applied using kin. variables

Selection efficiency for b-jets 80%
with very good non-b jet rejection of 99.7%



Kt algorithm, jet calibration

If energy correction is used which takes into account the dependence of the rapidity and Pt of jet



Mass peak not centered on true mass (120 GeV) due to neutral hadrons and neutrino losses. Improvements are possible by adding HCAL information,

Dependence on the proportions of charged and neutral particles is to be looked at.

A better mass resolution is very important for improving the B/S ratio

- **Search for a SM Higgs**

Higgs of 120 GeV, associated production HW HZ,
Taking into account background sources like $t\bar{t}$, ZW, $Wb\bar{b}$, etc,
The expectation is about 15-20 reconstructed signal events
in one year of data taking (2/fb) with $S/\sqrt{B} = 0.34$

Need to suppress large $t\bar{t}$ contribution, work in progress.

- Development of jet algorithms is also useful for other searches involving exotic or heavy objects decaying into $b\bar{b}$ with finite lifetime
(e.g. Π_ν in Hidden Valley models, χ_0 neutralinos in SUSY models).
Interesting prospects for observation of New Physics, depending on the values of the model parameters.

Conclusions

- A dedicated approach based on displaced vertices for jet seeding has been developed. Jet calibration is mandatory to discriminate various sources of backgrounds.
- In LHCb it is a very challenging attempt to reconstruct a SM Higgs in the mass region up to ~ 135 GeV. At the moment the largely dominant background is $t\bar{t}$. Work is focused in trying to optimize background rejection.
- The high performance of LHCb in detecting secondary vertices and identify b-jets can be applied to any exotic particle decaying into 2 b quarks giving rise to high momentum jets in the high rapidity region.