Full simulation of FCNC top decays $t \to ch$ at 380 GeV

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Outline

Motivation

In the Standard Model, FCNC top decays are strongly suppressed (GIM mechanism + CMK suppression):

$$\begin{aligned} BR(t \to c\,\gamma) &\sim 5 \cdot 10^{-14} \\ BR(t \to c\,Z) &\sim 1 \cdot 10^{-14} \\ BR(t \to c\,g) &\sim 5 \cdot 10^{-12} \\ BR(t \to c\,h) &\sim 3 \cdot 10^{-15} \end{aligned}$$

Significant enhancement possible in many "new physics" scenarios, due to modified couplings or loop contributions of new particles

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Significant enhancement possible in many "new physics" scenarios, due to modified couplings or loop contributions of new particles

Decay $t \to c\,H$ considered:

- enhancement up to $10^{-5} - 10^{-2}$ possible
- test of Higgs boson couplings
- well constrained kinematics
- seems to be most difficult for LHC

Event selection: $t\bar{t}$ final state

"Signal" top: $t \to ch_1$ + higgs decay to $b\bar{b} \Rightarrow 2$ b tags

"Spectator" top: SM top decay $\Rightarrow 1$ b tag

Considered final states (resulting from $W^{\pm}$ decay channels):

- semileptonic: 4 jets + lepton + missing p_t
- fully hadronic: 6 jets, no leptons, no missing p_t

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Event selection cuts for $\sqrt{s} = 380$ GeV, $50\%/\sqrt{E}$ jet energy resolution

Semileptonic:

- Missing $p_t > 20$ GeV
- Single lepton with $p_t > 15$ GeV
- 4 jets with $p_t > 15$ GeV
- 3 jets b-tagged

Fully hadronic:

- Missing $p_t < 10$ GeV
- No lepton with $p_t > 10$ GeV
- 6 jets with $p_t > 15$ GeV
- 3 jets b-tagged

Signal selection

After pre-selection cuts, compare two hypothesis:

- signal hypothesis hadronic final state

$$\chi^2_{sig} = \left(\frac{M_{bqq} - m_t}{\sigma_t}\right)^2 + \left(\frac{M_{qq} - m_W}{\sigma_W}\right)^2 + \left(\frac{M_{bbq} - m_t}{\sigma_t}\right)^2 + \left(\frac{M_{bb} - m_h}{\sigma_h}\right)^2$$

- background hypothesis ($t\bar{t}$ hadronic decays)

$$\chi^2_{bg} = \left(\frac{M_{bqq} - m_t}{\sigma_t}\right)^2 + \left(\frac{M_{qq} - m_W}{\sigma_W}\right)^2 + \left(\frac{M_{bbq} - m_t}{\sigma_t}\right)^2 + \left(\frac{M_{bq} - m_W}{\sigma_W}\right)^2$$

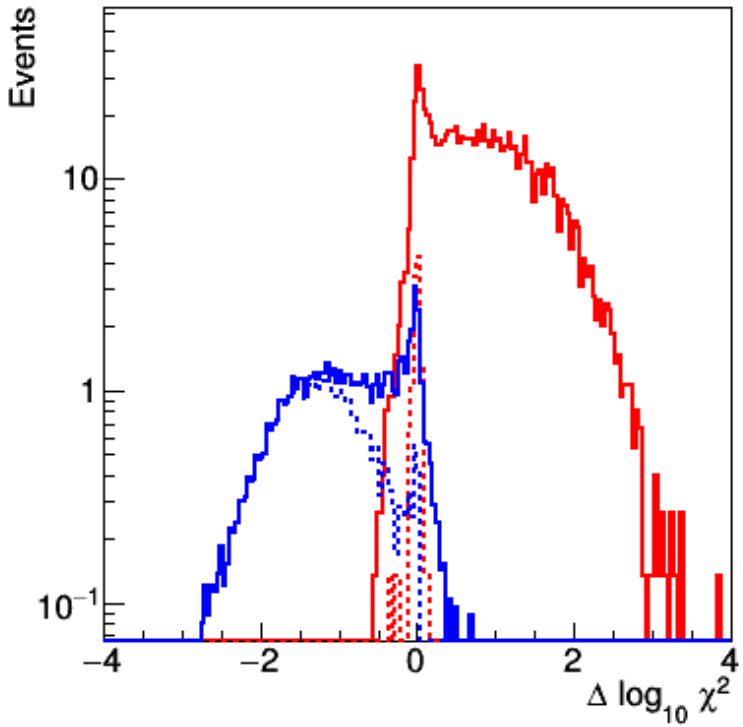
Independent search for best background and signal combinations
Difference in the last term only: h vs W mass discrimination crucial!

Signal selection

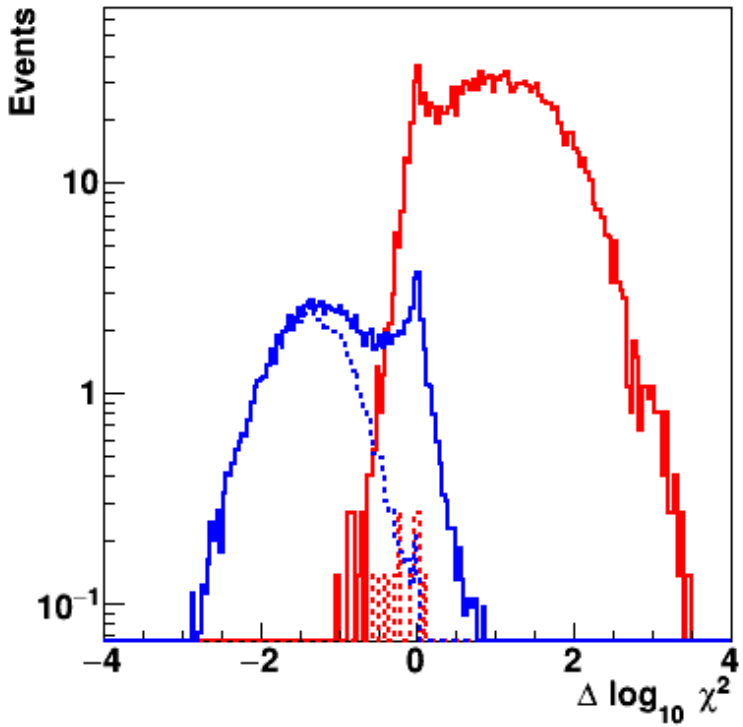
Difference of $\log_{10}\chi^2$ for two hypothesis, for signal and background events

Before (solid) and after (dashed) other selection cuts

Semi-leptonic events



Fully hadronic events



380 GeV, jet energy resolution 30%, 70% b-tagging efficiency

Background rejection strongly depends on the detector performance

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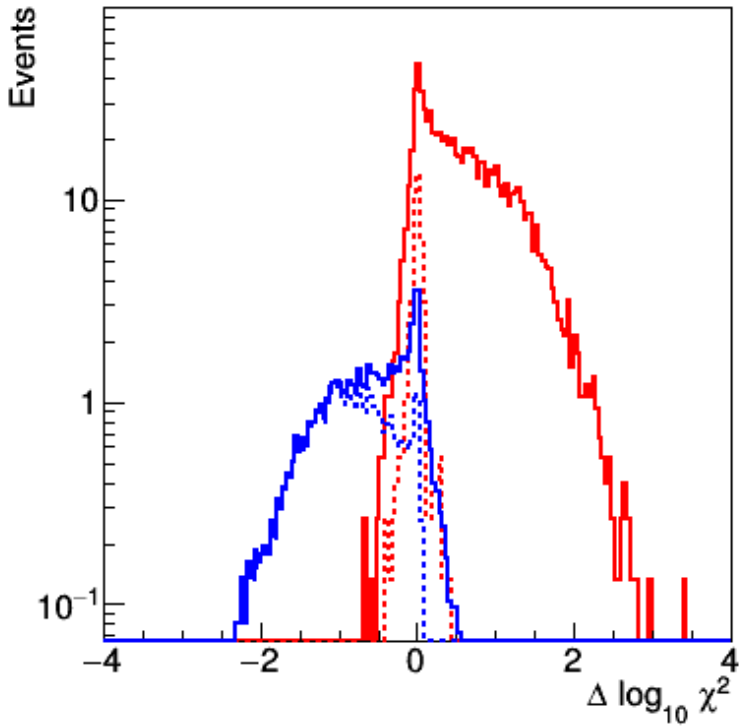

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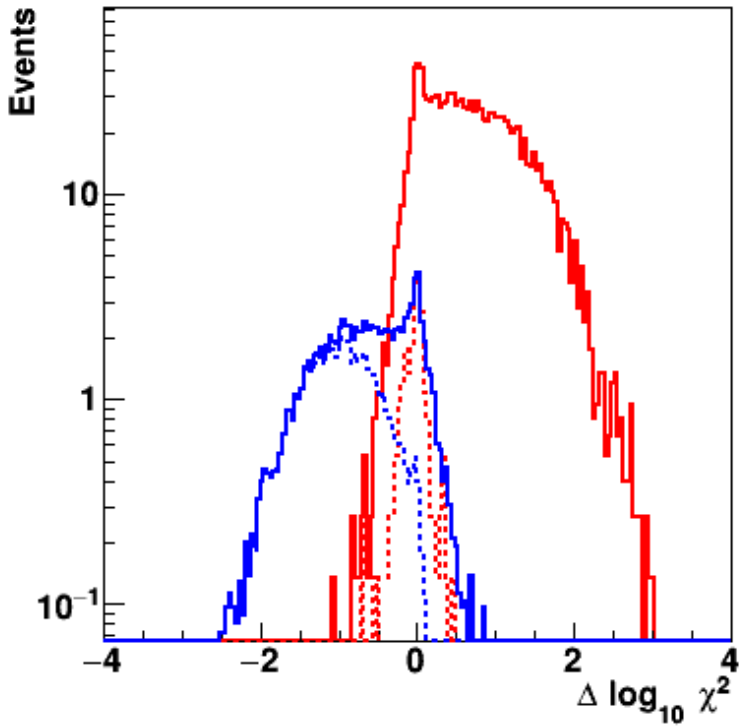

380 GeV, jet energy resolution 50%, 70% b-tagging efficiency

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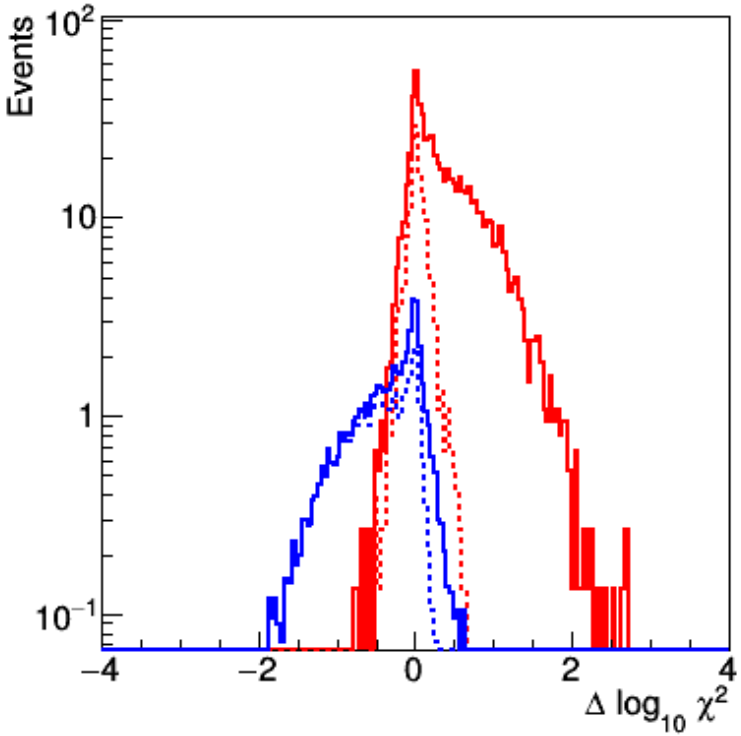

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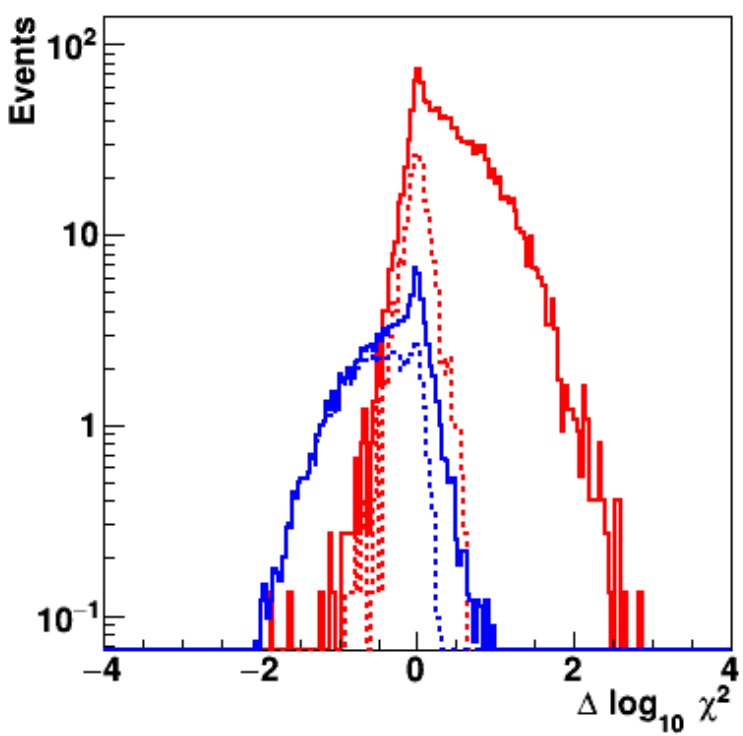
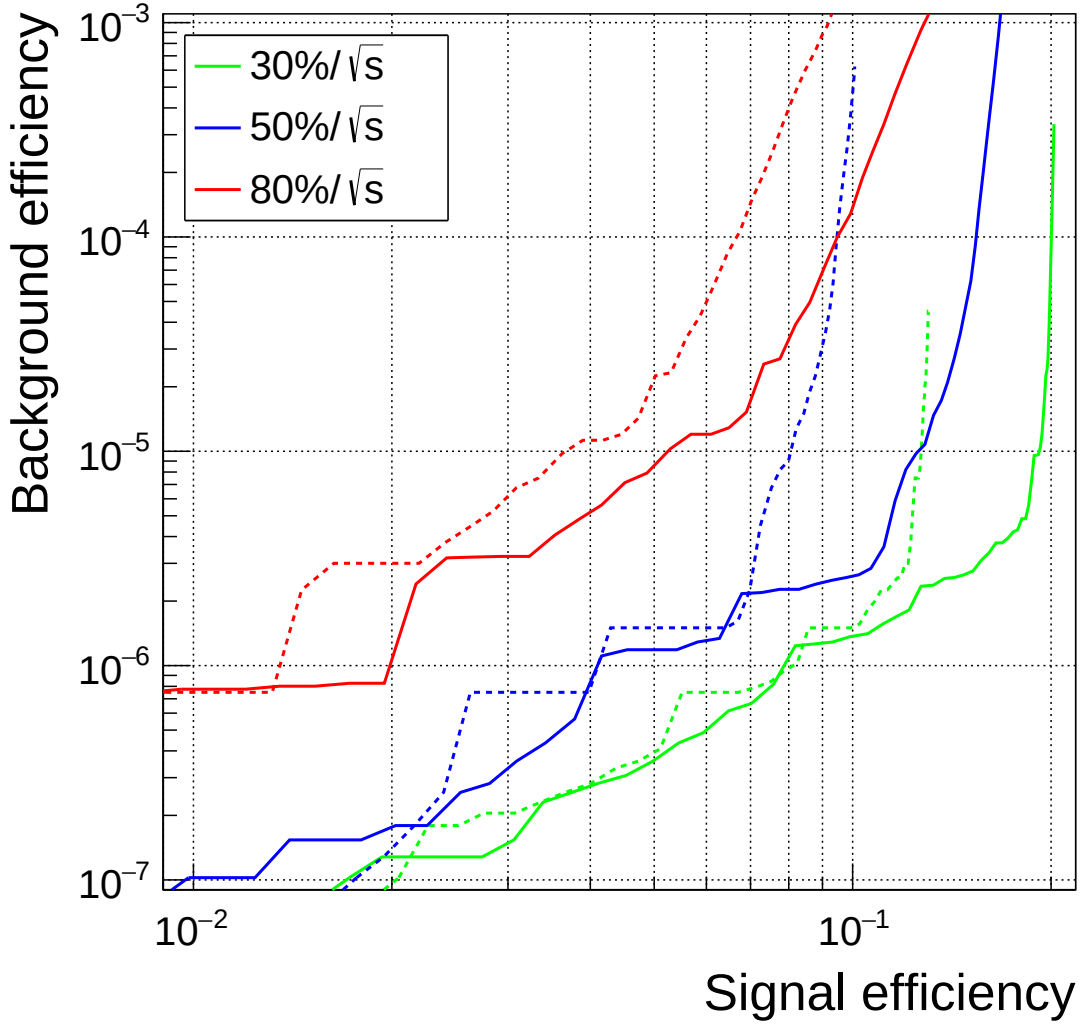


380 GeV, jet energy resolution 80%, 70% *b*-tagging efficiency

Background rejection strongly depends on the detector performance

Selection efficiencies

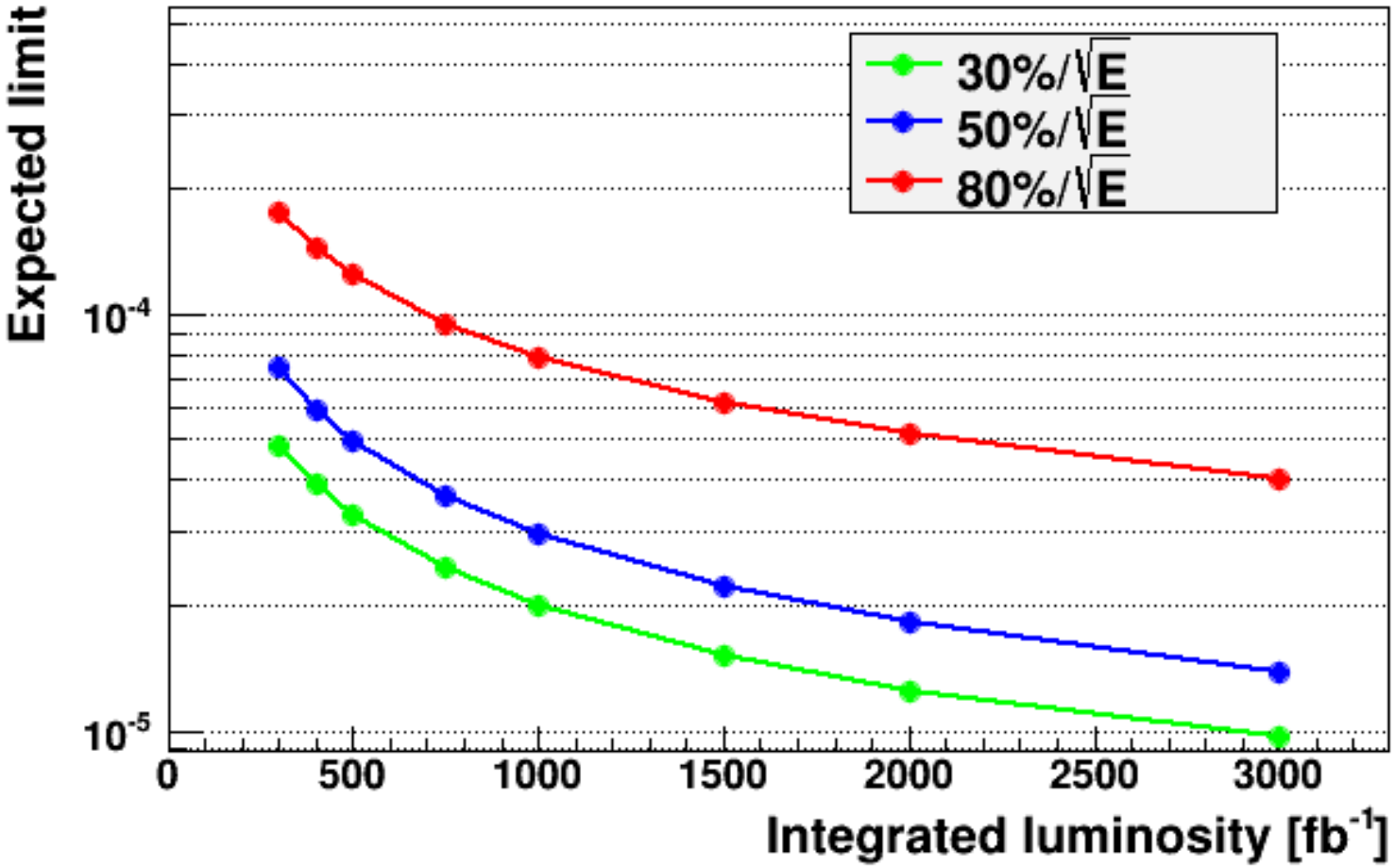
380 GeV, different jet energy resolutions



full lines: combined (semi-leptonic+hadronic) analysis, dashed lines: hadronic decays only

Expected limits on $BR(t \to ch) \times BR(h \to b\bar{b})$

Collision energy 380 GeV, different jet energy resolutions



Full simulation

Signal sample

10'000 events generated with WHIZARD 2.2.8

- THDMIII model from SARAH, tuned for BR($t \to ch$) = 10^{-3}
- generated processes: $e^+e^- \longrightarrow t\bar{c}h$ and $e^+e^- \longrightarrow ch\bar{t}$
- beam spectra from file (350 GeV scaled to 380 GeV)
- quark masses and PYTHIA settings adjusted to CLIC CDR
- no polarization (problem in SARAH-WHIZARD interface)
- colinear ISR only (no p_t for ISR photons generated)

Standard event processing with CLIC_ILD_CDR500 configuration

many thanks to Philipp Roloff

Background samples

Standard Monte Carlo samples for top reconstruction studies
Only small, selected samples of dduyyu, yycyyu, sscbbc,
yyveyx, yyvlyx and yyvelv (5'000 events each).

Full simulation

Event analysis many thanks to Ignacio Garcia

DST files processed with MARLIN 01.16 (ilcDIRAC):

- Using SelectedPandoraPFANewPFOs as input collection compare to PandoraPFANewPFOs, LooseSelectedPandoraPFANewPFOs, TightSelectedPandoraPFANewPFOs
- IsolatedLeptonFinder
- Initial jet clustering (inclusive k_t) for gamma-gamma removal
  optional, does not really matters for VLC jets
- LCFI+ primary and secondary vertex finder
- LCFI+ jet finding, vertex corrections and flavour taging

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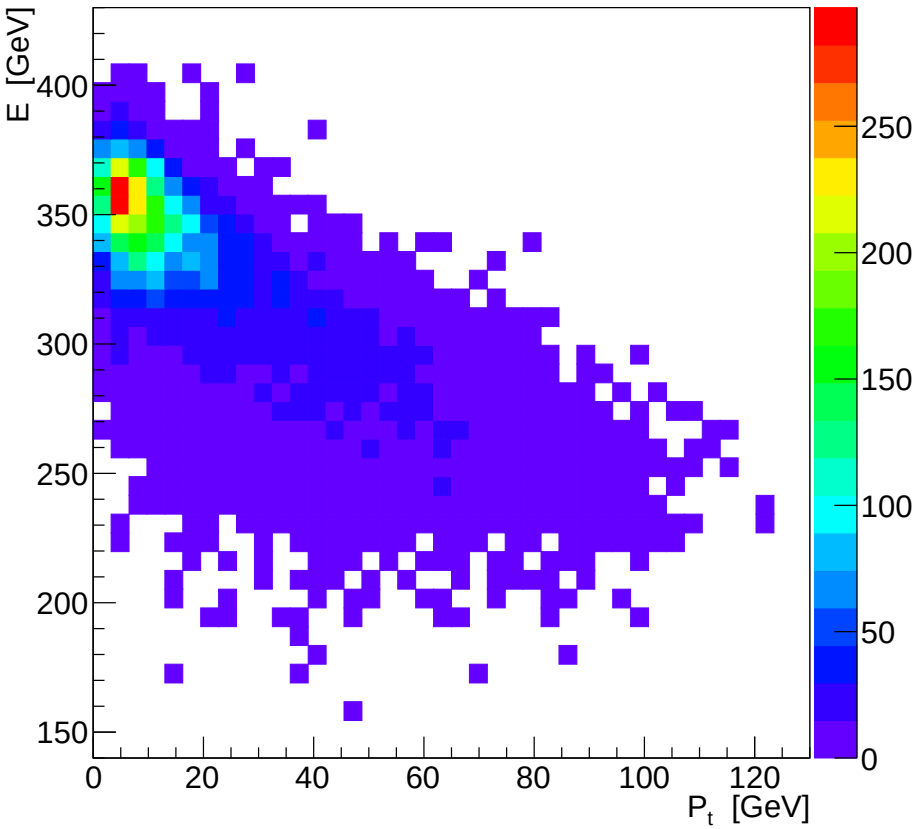
Final analysis in root:

- event pre-selection cuts
- jet finding with Valencia algorithm, LCFI+ matching
- kinematic fit
- final selection cuts

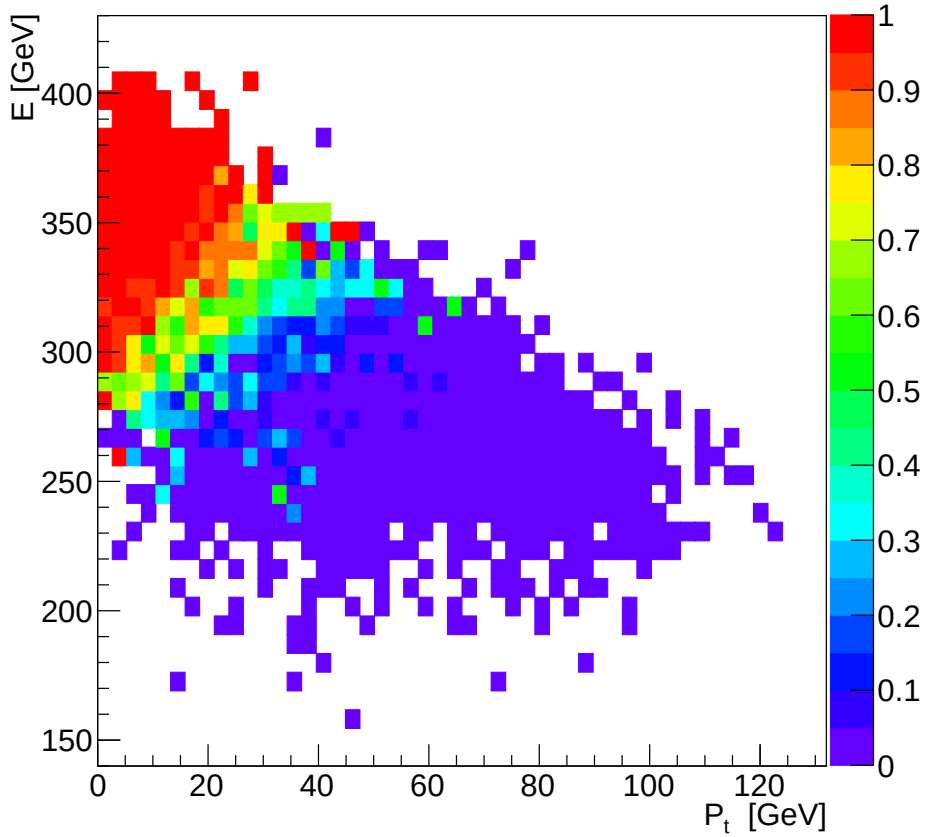
Hadronic event selection

Selection of hadronic top decays based on reconstructed $E - 2p_t$,
instead of the standard p_t cut

Event distribution



Hadronic event fraction



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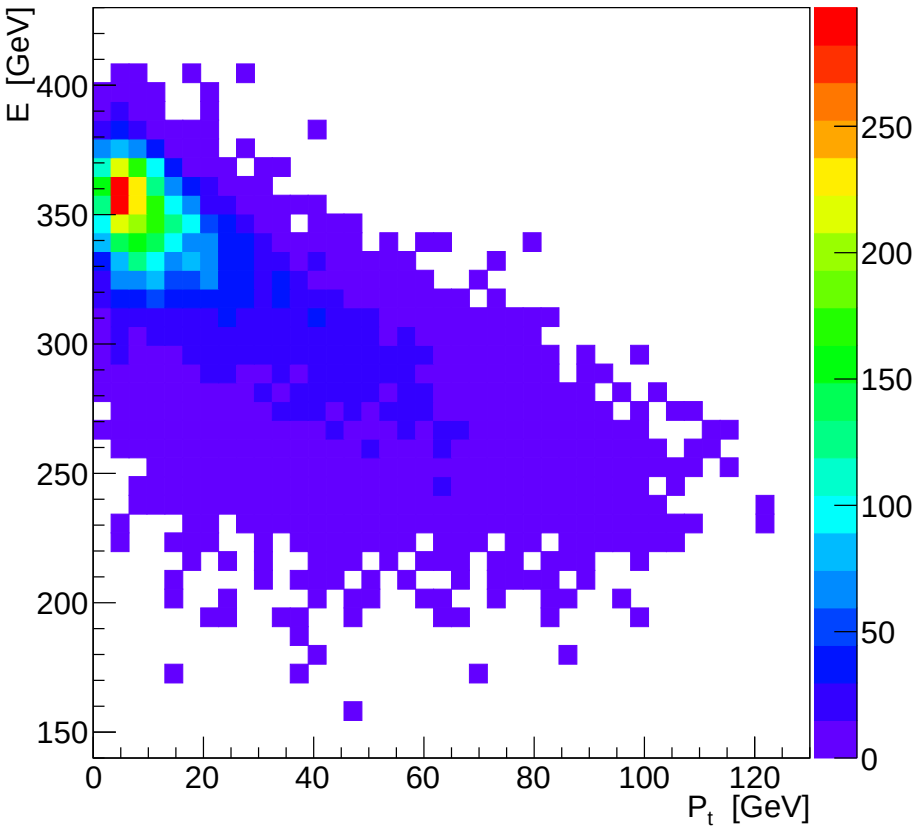

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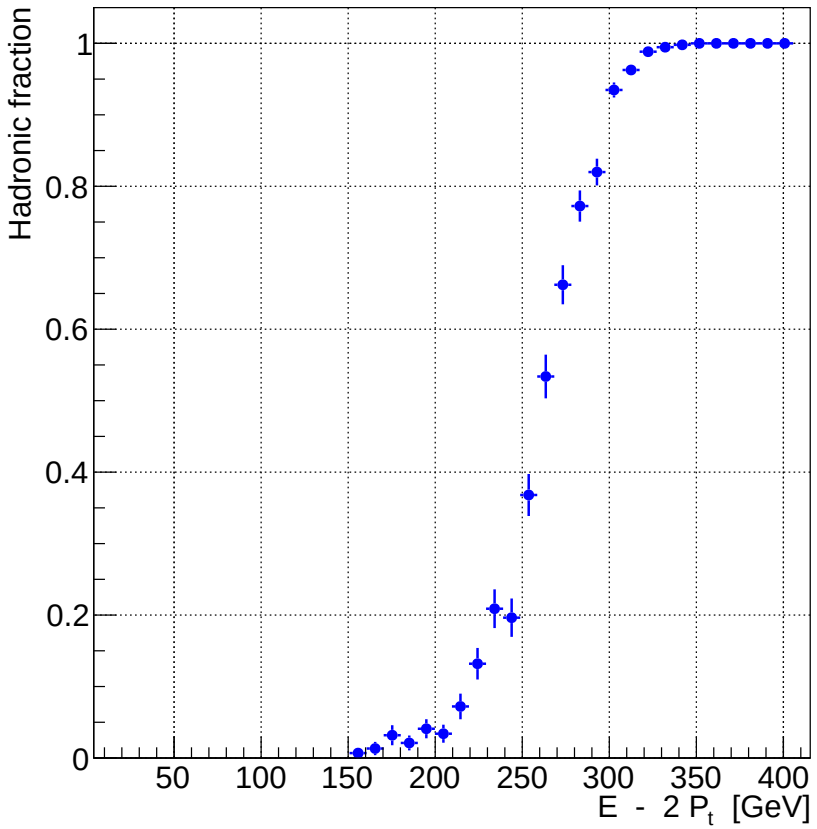
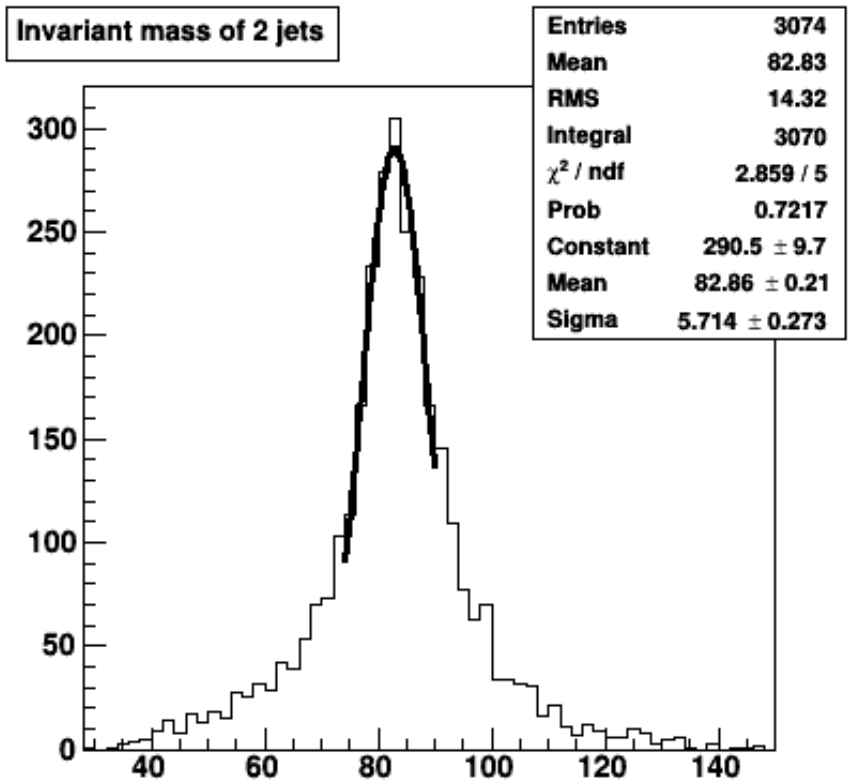


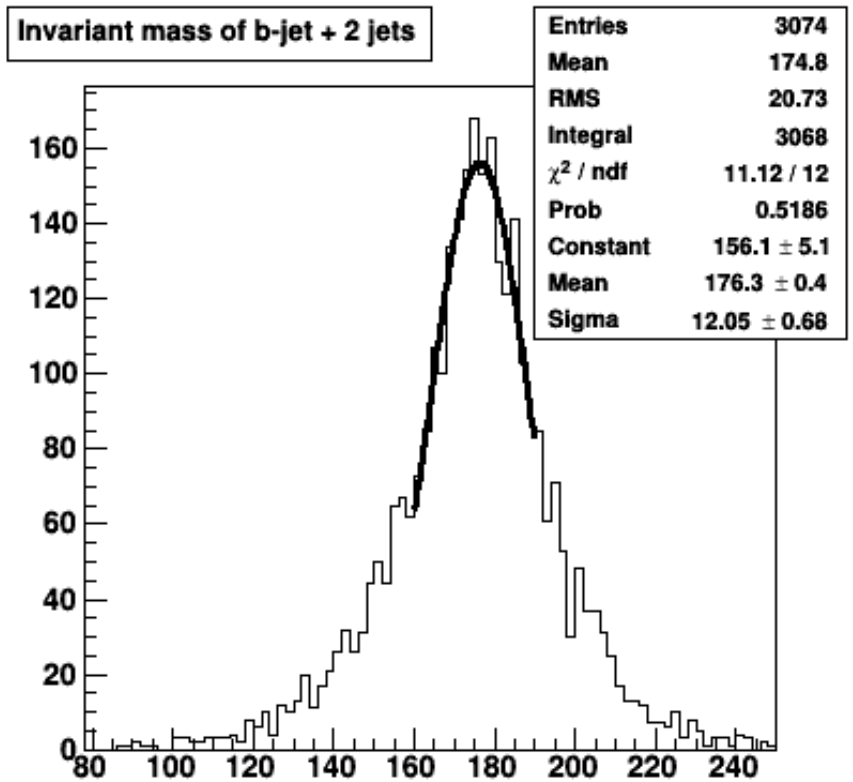
Mass resolution

Reconstructed mass distributions for signal events (VLC jets)

W boson



"spectator" top



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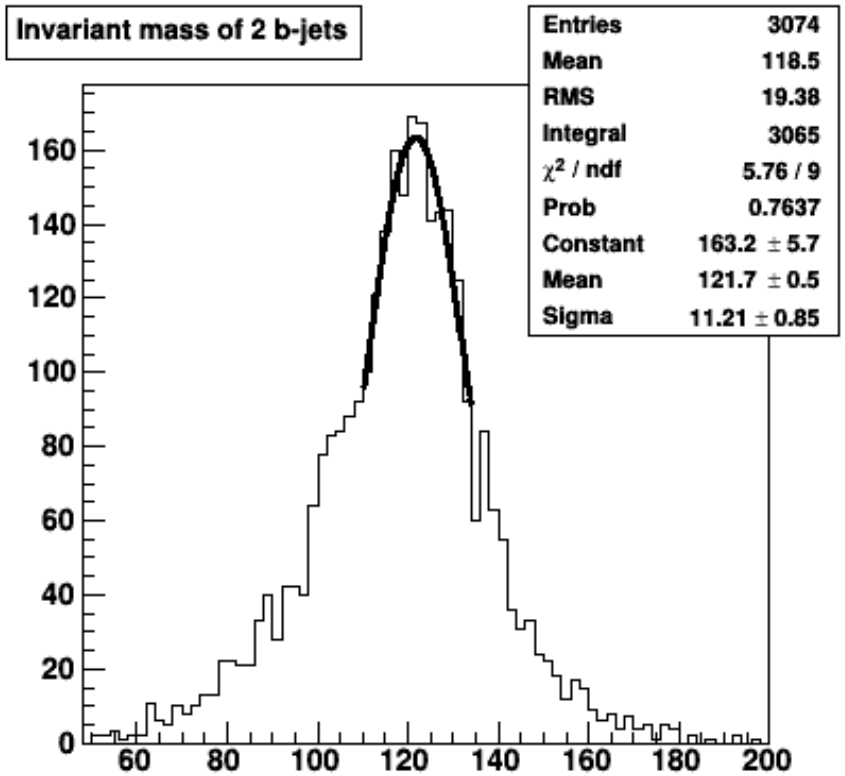
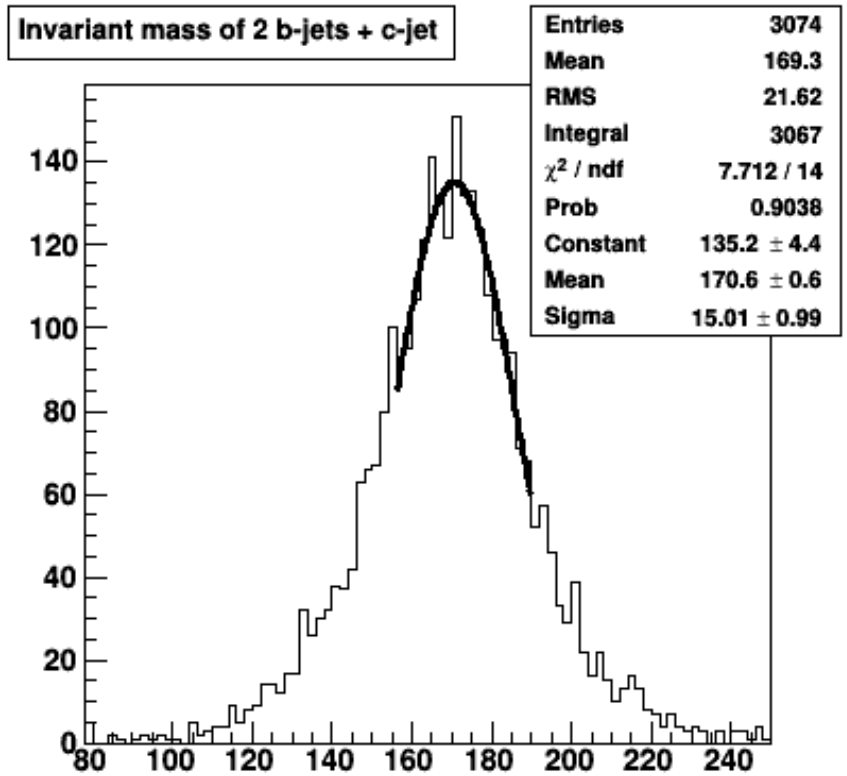
Higgs



"signal" top

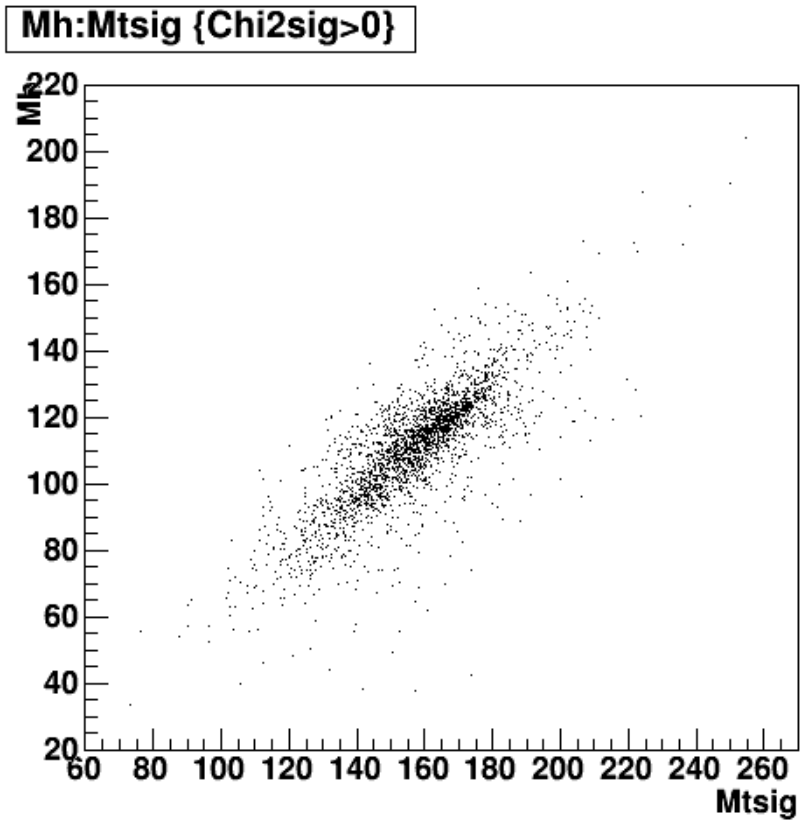


Poor mass reconstruction. Influence of overlay or problem with b-jets?

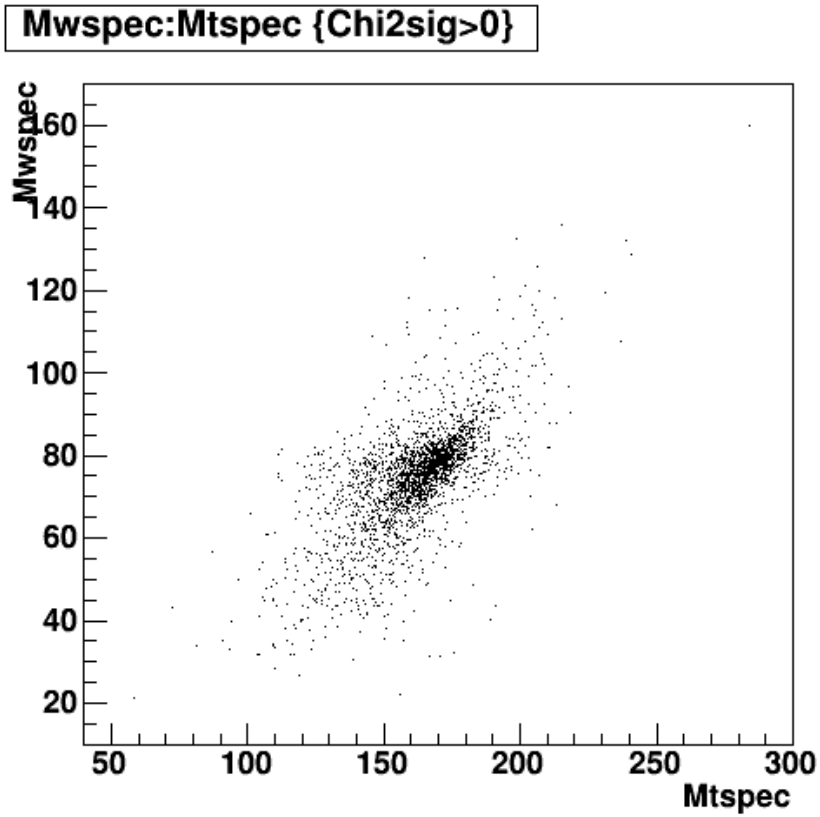
Mass correlation

Significant correlation observed between reconstructed masses of

Higgs and "signal" top



W boson and "spectator" top

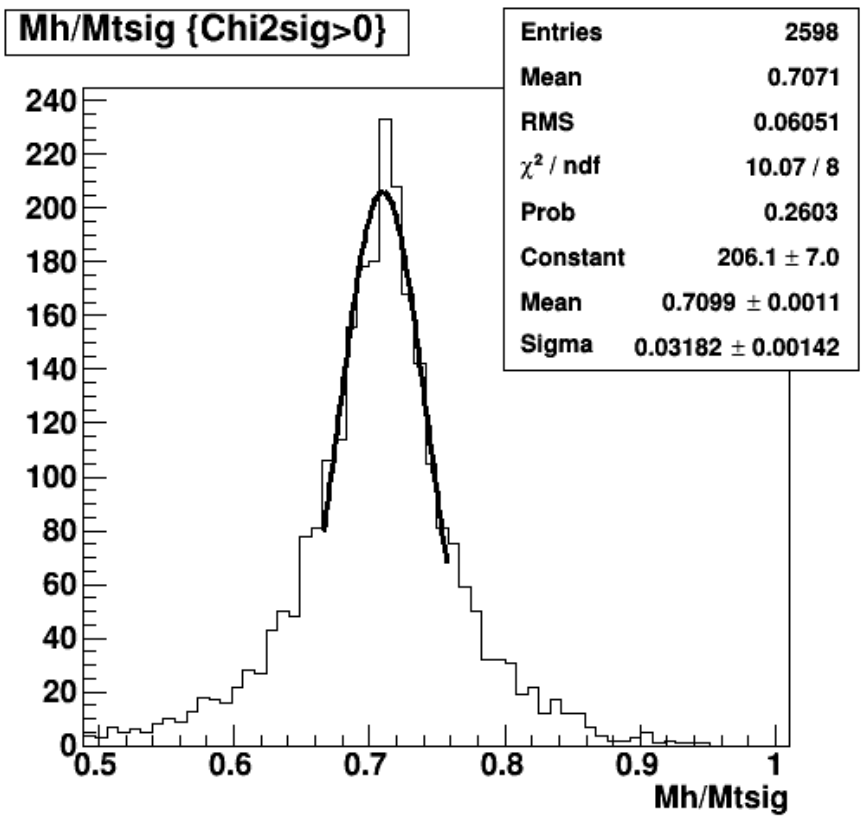


$\Rightarrow$ should be taken into account in event selection

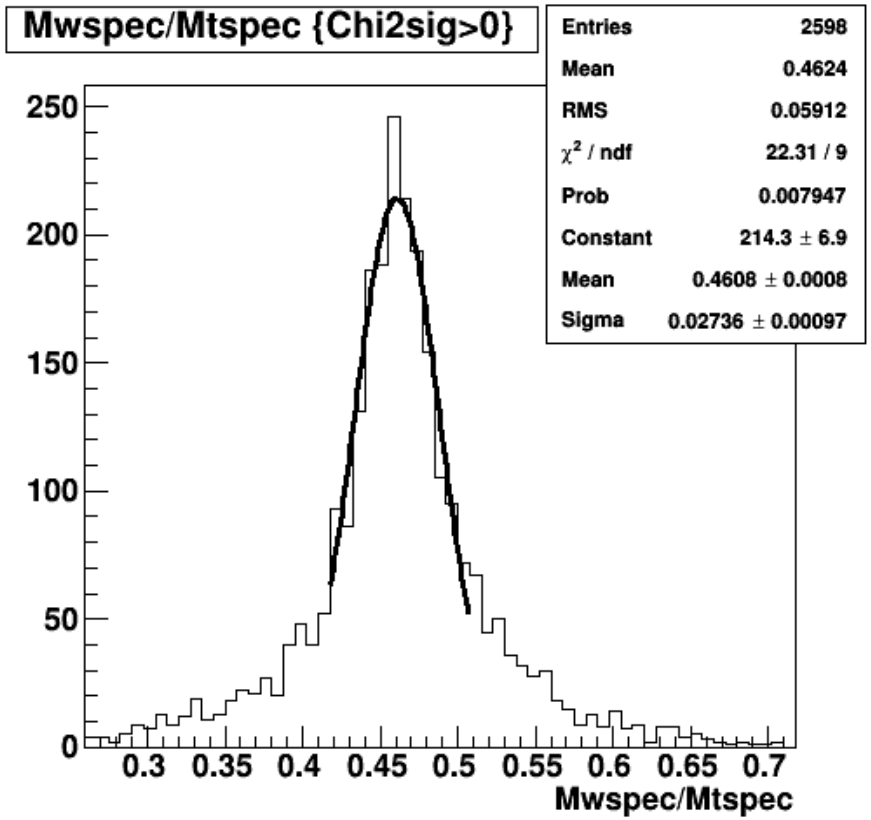
Mass ratio

Daughter to parent mass ratio measured much better

Higgs to "signal" top



W boson to "spectator" top

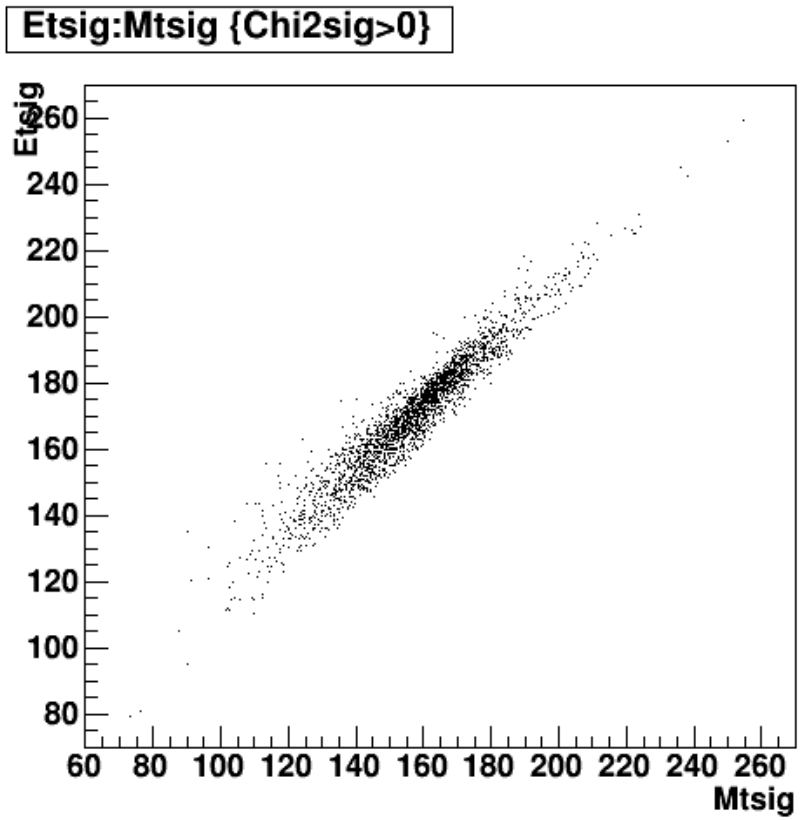


good agreement with expected values (0.72 and 0.46)

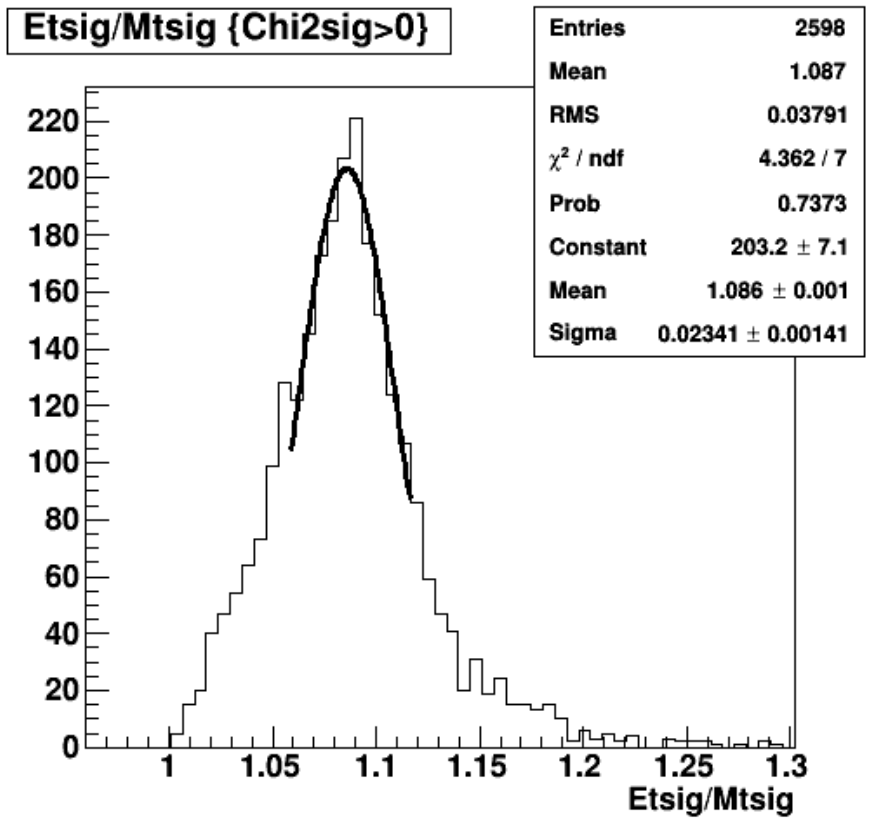
Top boost

"signal" top mass highly correlated with reconstructed energy

Energy vs mass



Energy to mass ratio



$\Rightarrow$ can be added as additional kinematic constraint

New χ^2 definition

- signal hypothesis hadronic final state

$$\chi^2_{sig} = \left(\frac{M_{bqq} - m_t}{\sigma_t}\right)^2 + \left(\frac{M_{bbc} - m_t}{\sigma_t}\right)^2 + \left(\frac{\frac{E_{bqq}}{M_{bqq}} - \gamma_t}{\sigma_\gamma}\right)^2 + \left(\frac{\frac{E_{bbc}}{M_{bbc}} - \gamma_t}{\sigma_\gamma}\right)^2 + \left(\frac{\frac{M_{qq}}{M_{bqq}} - \frac{m_W}{m_t}}{\sigma_{R_W}}\right)^2 + \left(\frac{\frac{M_{bb}}{M_{bbc}} - \frac{m_h}{m_t}}{\sigma_{R_h}}\right)^2$$

- similar for background hypothesis ($t\bar{t}$ hadronic decays)

$$\chi^2_{bg} = \ldots + \left(\frac{\frac{M_{qq}}{M_{bqq}} - \frac{m_W}{m_t}}{\sigma_{R_W}}\right)^2 + \left(\frac{\frac{M_{bq}}{M_{bqq}} - \frac{m_W}{m_t}}{\sigma_{R_W}}\right)^2$$

Selection

Preselection (before kinematic fit)

- cut on $E - 2p_t > 280$ GeV
- isolated lepton veto
- 6 jets reconstructed
- jet $p_t > 10$ GeV and $\cos\theta < 0.95$
- ≥ 3 jets with b-tag value above threshold (eg. 0.3)

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Final selection (after selecting best signal hypothesis)

- cut on product of b-tag values (eg. 0.85)
- cut on χ^2_{sig}/χ^2_{bg}
- cut on reconstructed Higgs mass

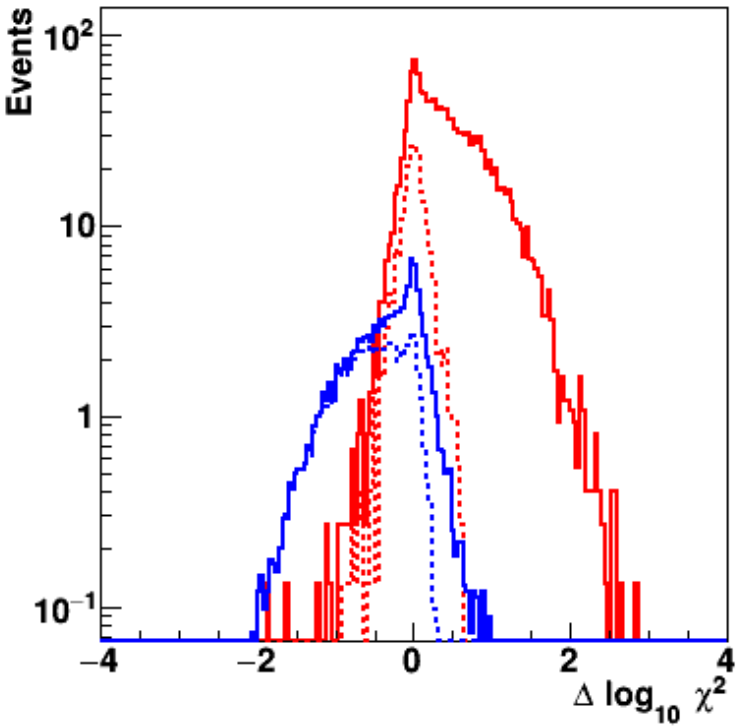
Results

Small background samples considered - results very preliminary !
Still, some conclusions possible...

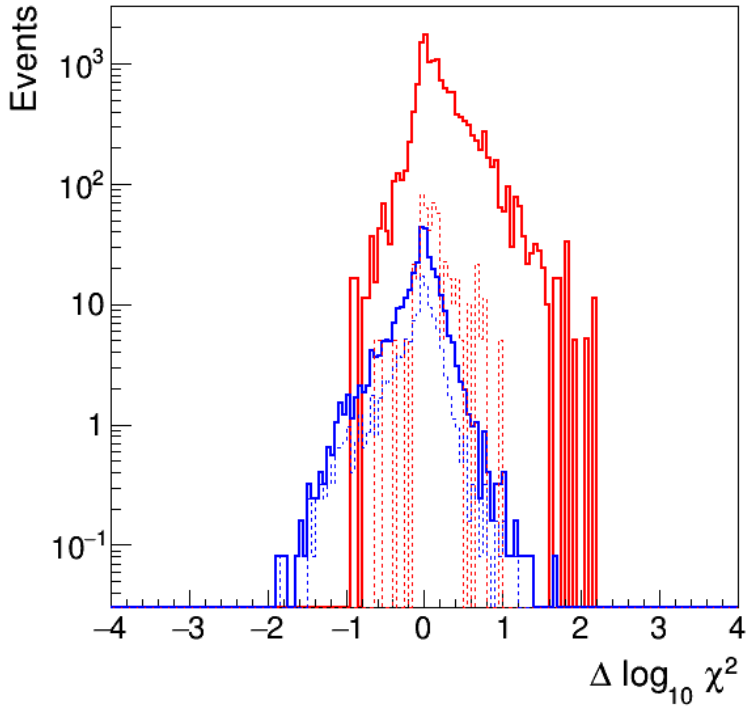
Comparison of hypothesis

Difference of $\log_{10}\chi^2$ for two hypothesis, for signal and background events
Before (solid) and after (dashed) other selection cuts

Parton level, $80\%/\sqrt{E}$



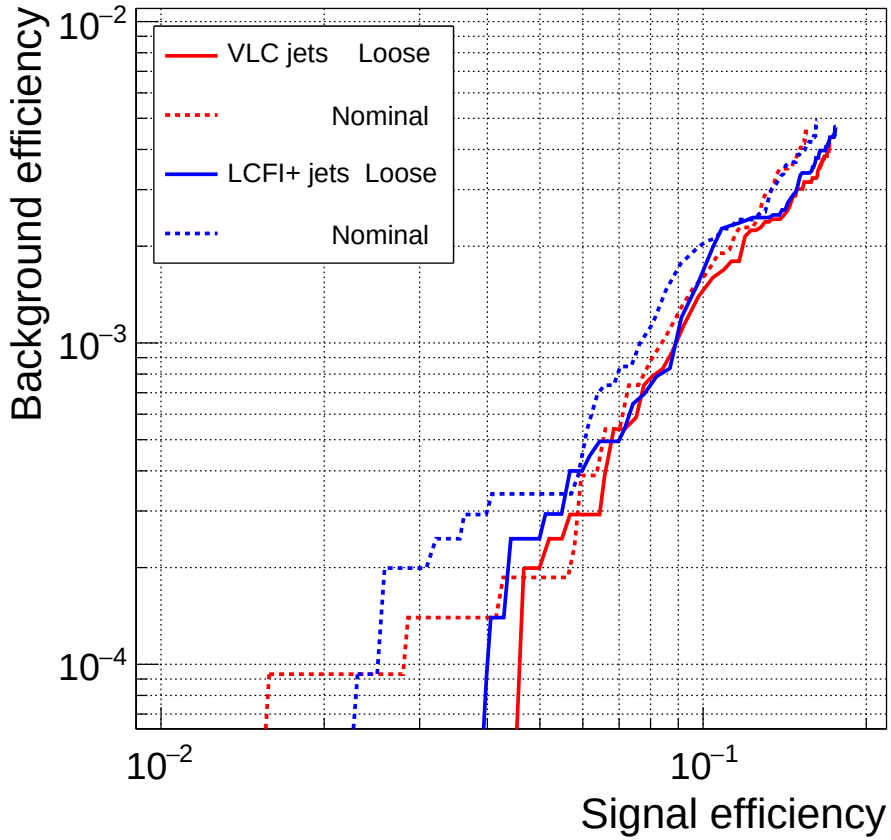
Full simulation



Selection efficiency

Influence of the jet algorithm used

Pre-selection b-tag cut at 0.3, final selection at 0.85

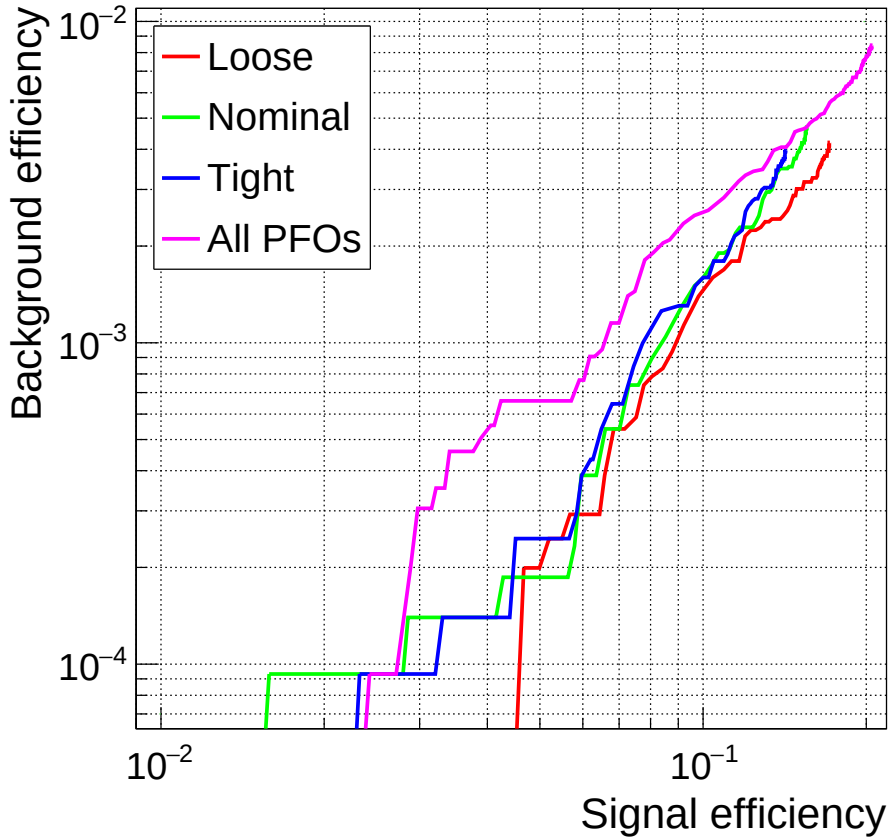


$\Rightarrow$ VLC clearly better in kinematic reconstruction

Selection efficiency

Influence of the selected PFO collection

Pre-selection b-tag cut at 0.3, final selection at 0.85

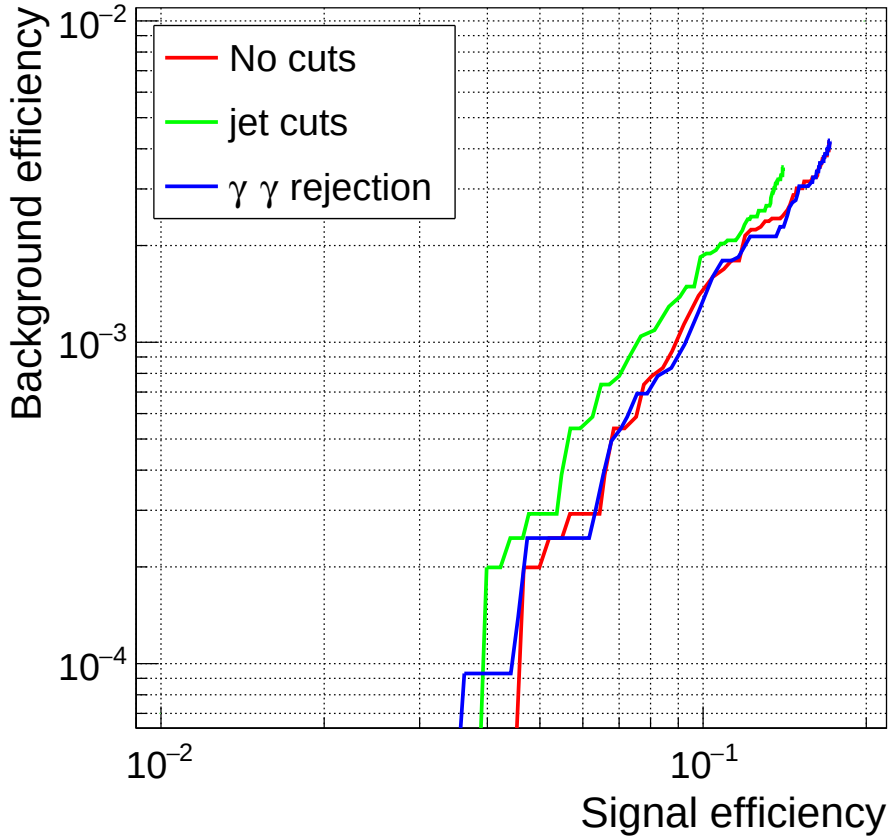


$\Rightarrow$ loose cluster selection works best

Selection efficiency

Influence of the additional jet cuts

Pre-selection b-tag cut at 0.3, final selection at 0.85

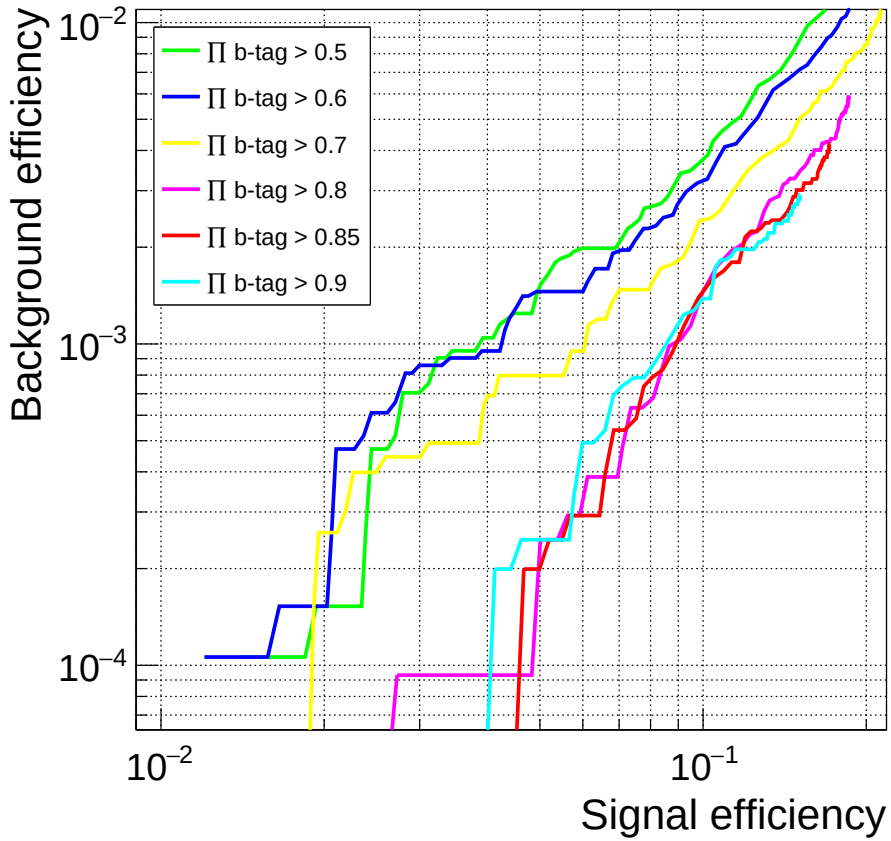


$\Rightarrow$ no significant improvement (need more statistics)

Selection efficiency

Influence of the final cut on the product of b-tag values

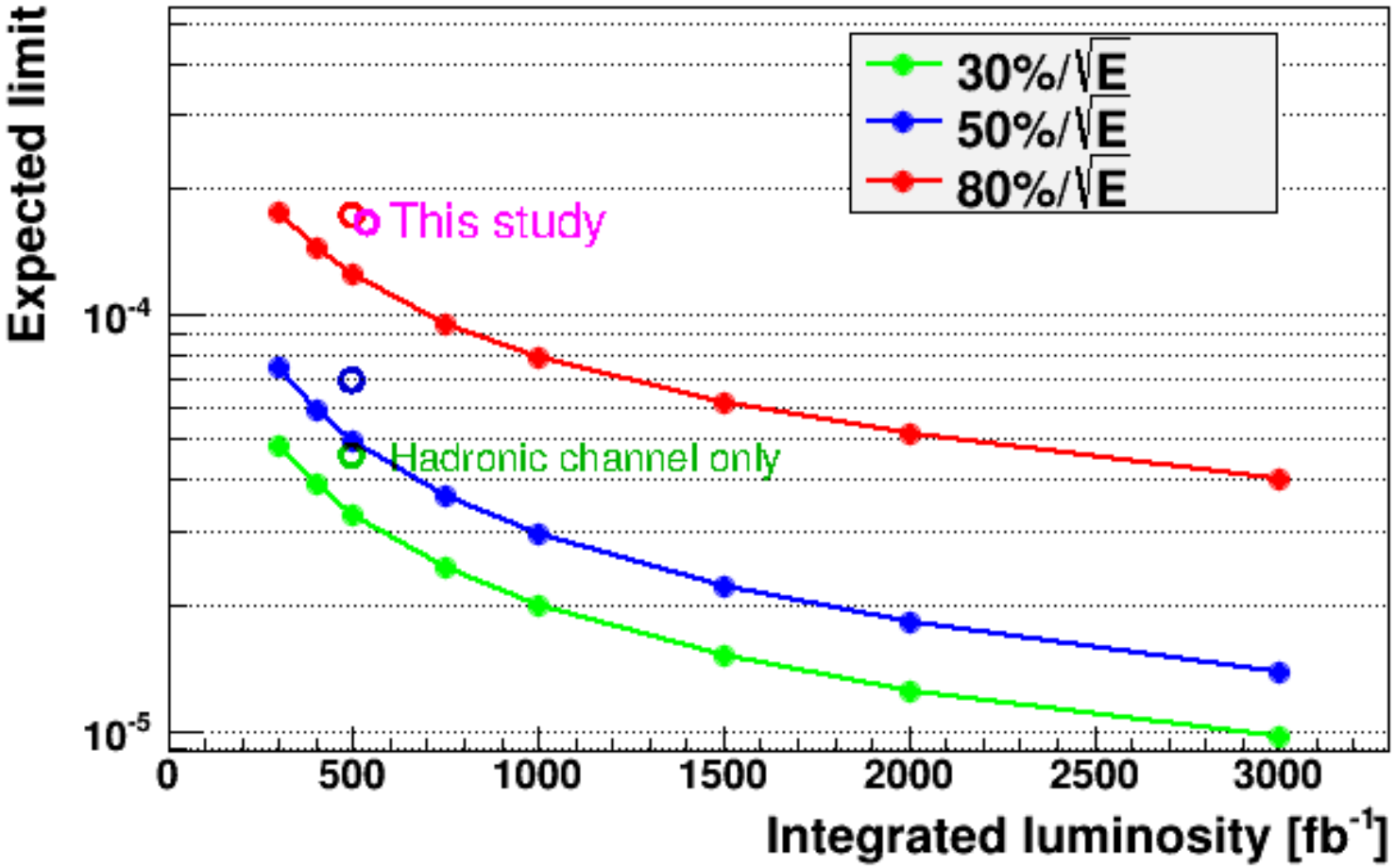
Pre-selection b-tag cut at 0.3



$\Rightarrow$ no improvement beyond selection cut of 0.80-0.85

Expected limits on $BR(t \to ch) \times BR(h \to b\bar{b})$

Collision energy 380 GeV, different jet energy resolutions



Conclusions

FCNC top decays $t \to ch$

Preliminary results from full simulation at 380 GeV presented

Focus on optimizing kinematic reconstruction in the hadronic channel

Resulting limits similar to "worst case" scenario... $(\sigma_E \sim 80\%/\sqrt{E})$

Need to understand the poor mass resolution

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Possible ways to improve

- use c-tag information
- optimize LCFI+ performance
- proper b-tagging for VLC jets
- include semi-leptonic channel
- increase background statistics for better optimization, limit estimate
- try to use MVA

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Better reconstruction possible at higher energies, but statistics decreases...

Backup slides

Parton Level study

Two Higgs Doublet Model (2HDM) type III used as a test scenario. Implemented in SARAH $\Rightarrow$ WHIZARD 2 thanks to Florian Staub, many thanks also due to Juergen Reuter and Wolfgang Kilian...

WHIZARD 2.2.5 used to generate signal and background samples.

Test configuration of the model:

- $m_{h_1} = 125$ GeV
- $\mathrm{BR}(t \to ch_1) = 10^{-3}$
- $\mathrm{BR}(h \to b\bar{b}) = 100\%$

Generated samples:

- $e^+e^- \longrightarrow t\bar{t}$ (2HDM/SM)
- $e^+e^- \longrightarrow ch_1\bar{t},\ t\bar{c}h_1$ (2HDM)
- $e^+e^- \longrightarrow cb\bar{b}\bar{t},\ t\bar{c}b\bar{b}$ (SM)

Assume that main background to FCNC decays comes from standard decay channels, including $t \to bW^+$ followed by $W^+ \to c\bar{b}$

All events generated with CIRCE1 spectra + ISR. No polarization.
Only t, W and h defined to be unstable. No hadronization/decays.
No generator-level cuts imposed.

Very simplified detector description

- detector acceptance for leptons: $|\cos\theta_l| < 0.995$
- detector acceptance for jets: $|\cos\theta_j| < 0.975$
- jet energy smearing:

$$\sigma_E = \begin{cases} \frac{S}{\sqrt{E}} & \text{for} \quad E < 100\,GeV \\ \frac{S}{\sqrt{100\ GeV}} & E > 100\,GeV \end{cases}$$

with S = 30%, 50% and 80% [GeV$^{1/2}$]

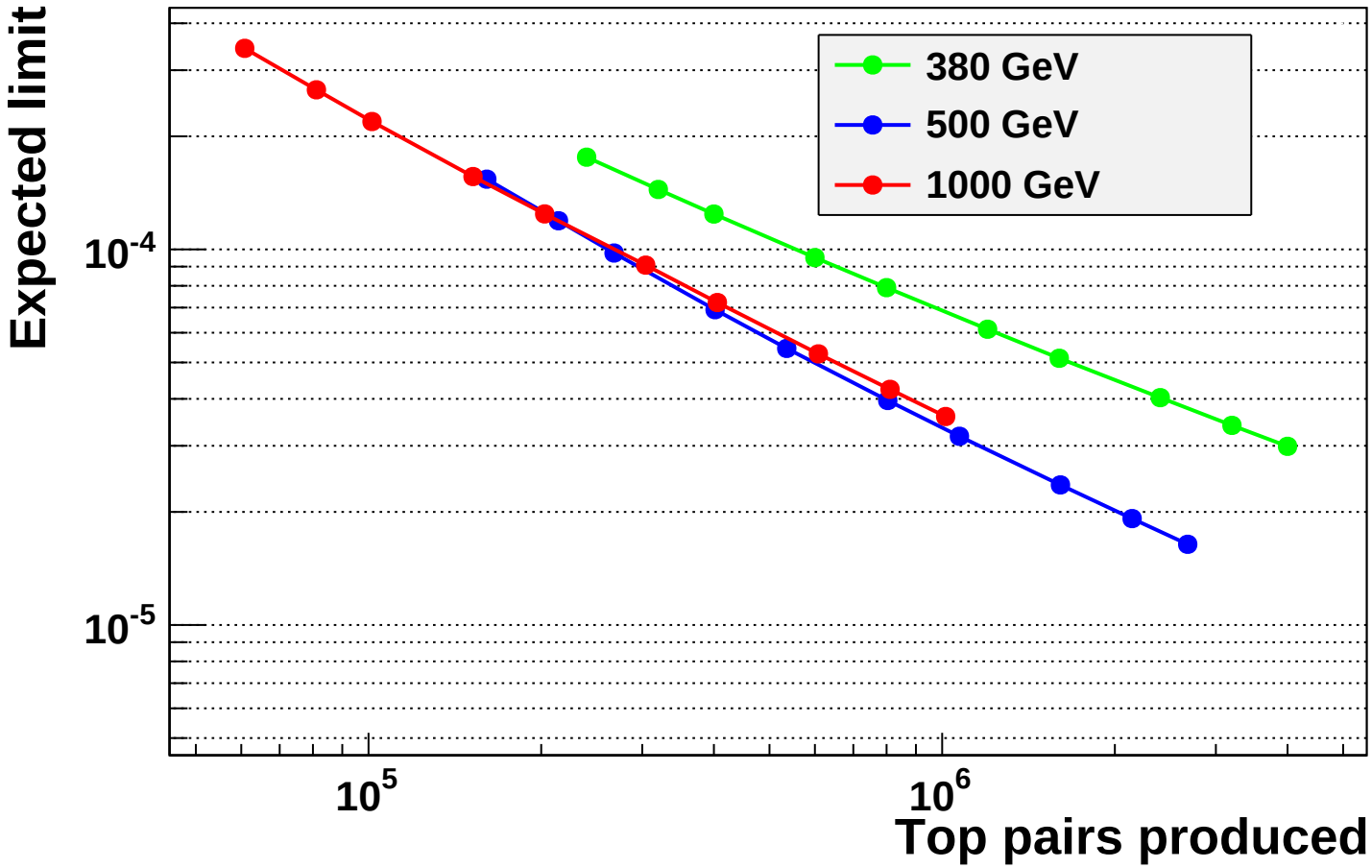
- b tagging (misstagging) efficiencies: (as expected for LCFI+)

Scenario	b	c	uds
Ideal	100%	0%	0%
A	90%	30%	4%
B	80%	8%	0.8%
C	70%	2%	0.2%
D	60%	0.4%	0.08%

Parton Level study

Expected limits on $BR(t \to ch) \times BR(h \to b\bar{b})$

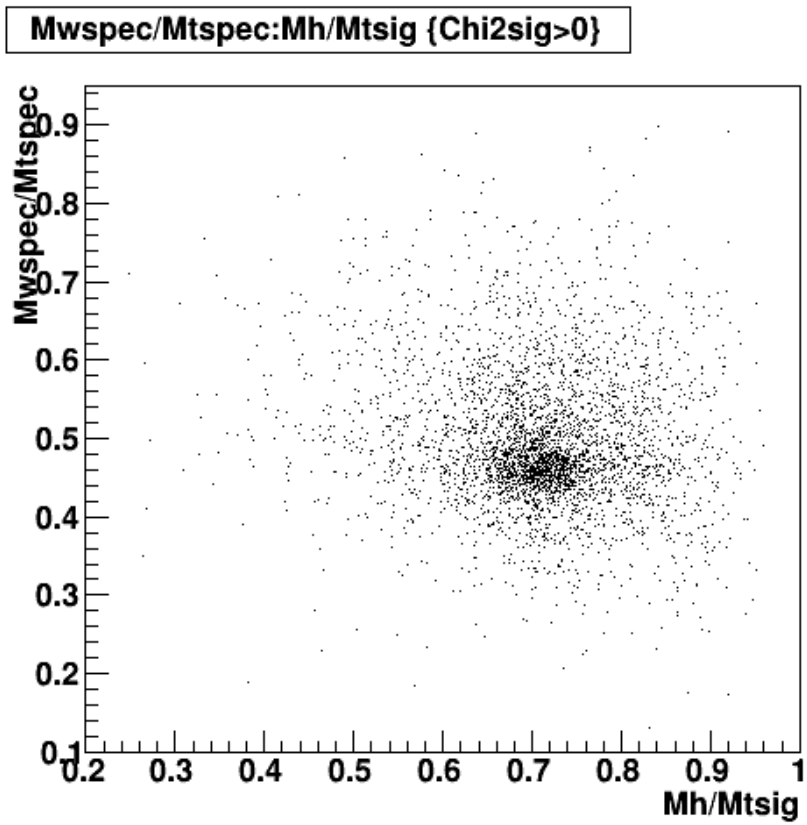
Jet energy resolution 80%



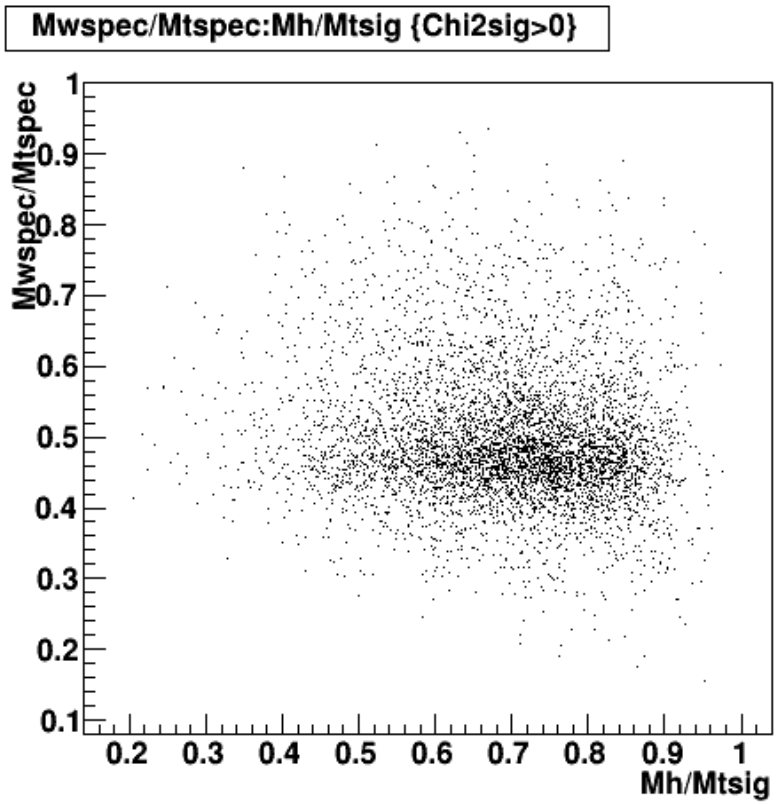
Mass ratio correlation

Correlation of W boson mass ratio and Higgs mass ratio to parent top

signal events



background (hadronic $t\bar{t}$)

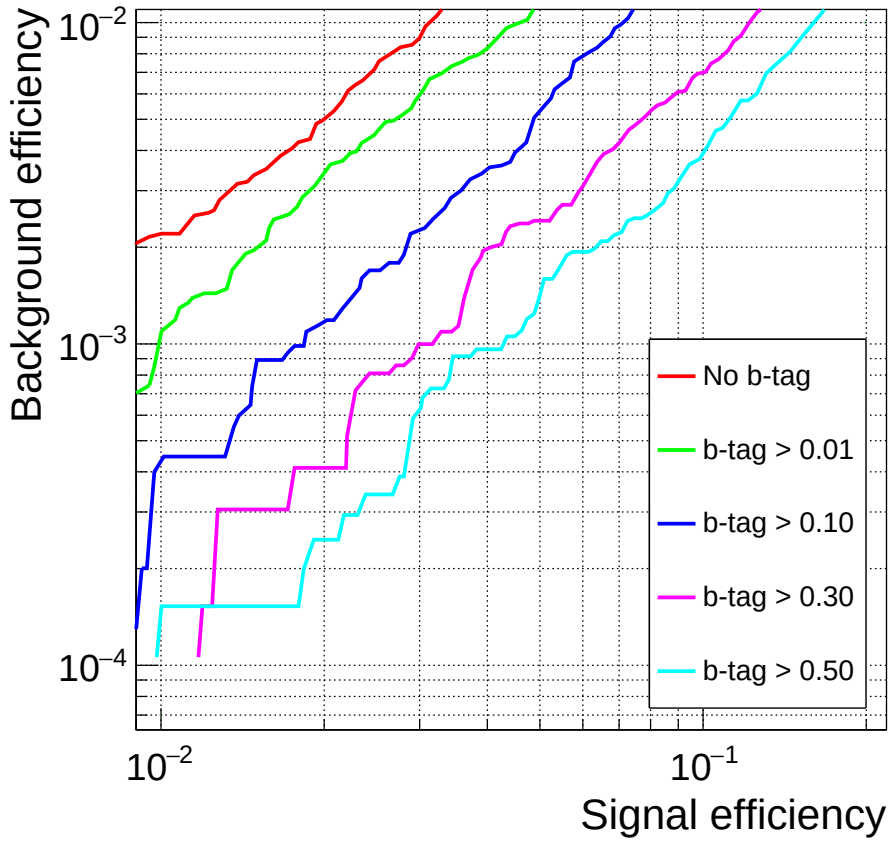


$\Rightarrow$ signal separation possible, but hard due to non-gaussian tails

Selection efficiency

Influence of the pre-selection b-tag on the signal vs background separation

Without final b-tag cut

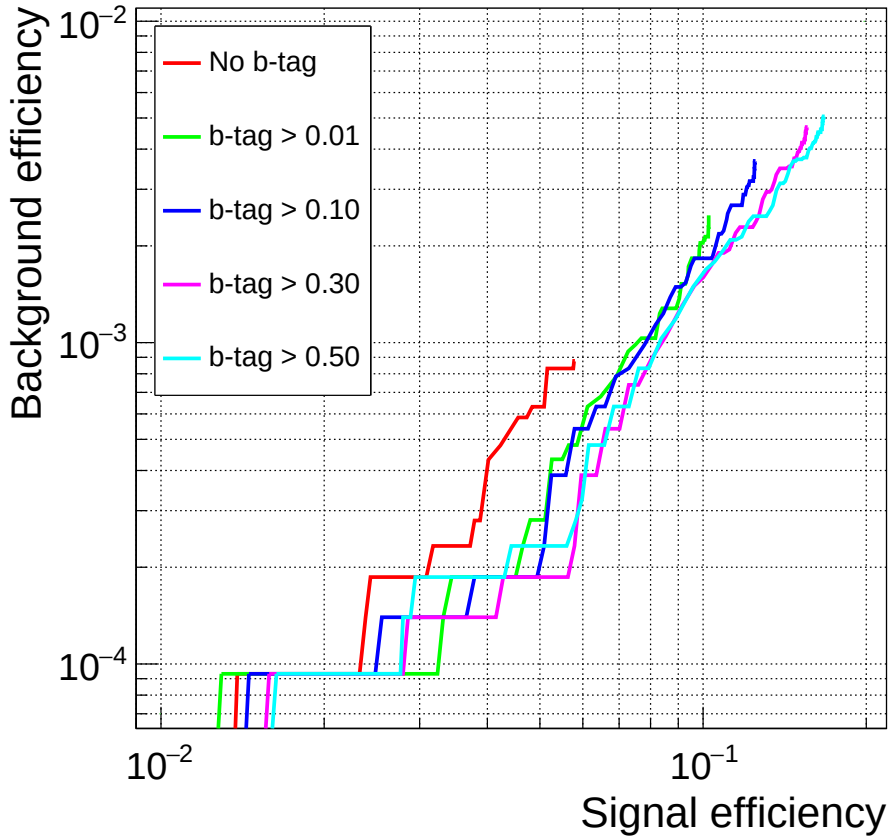


$\Rightarrow$ no improvement beyond pre-selection cut of 0.3

Selection efficiency

Influence of the pre-selection b-tag on the signal vs background separation

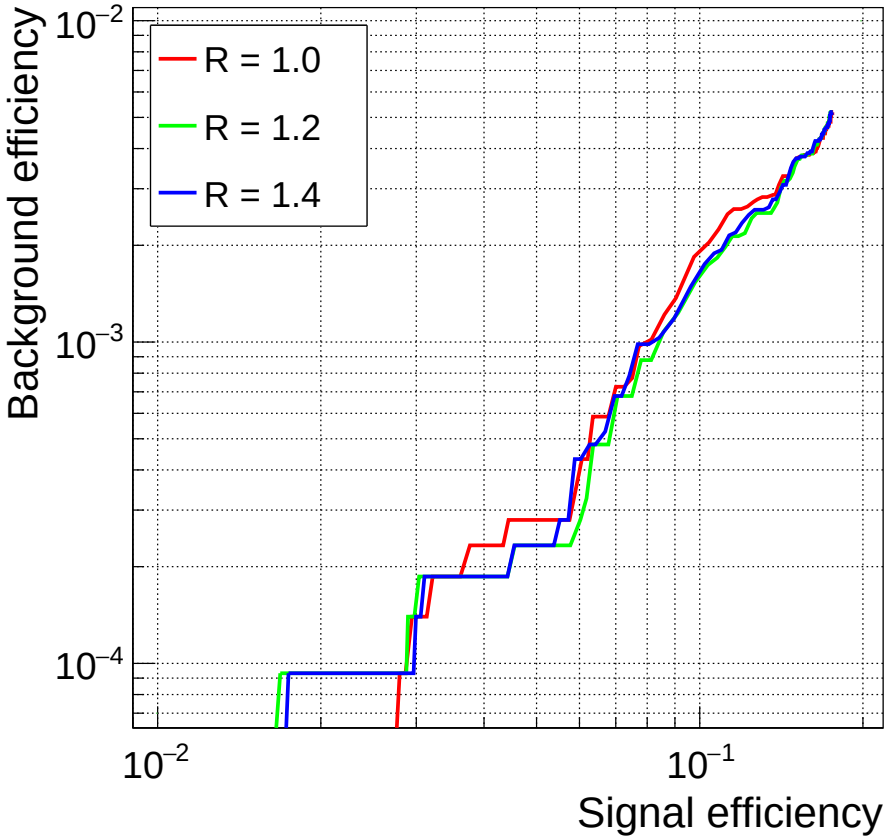
Final selection: $\prod b_i > 0.85$

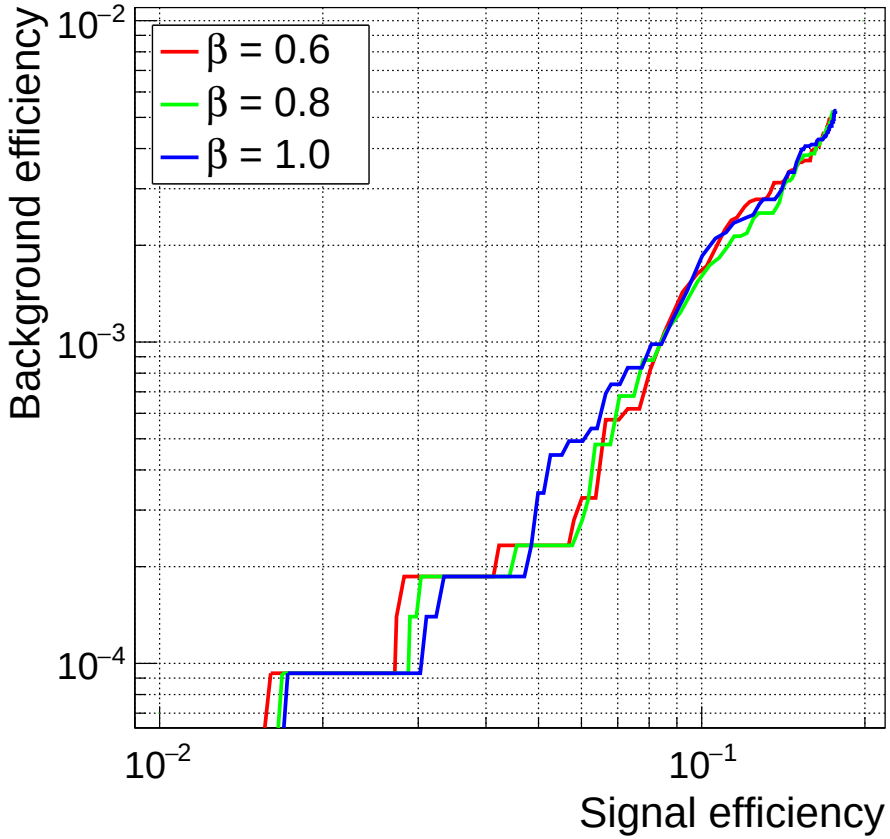


$\Rightarrow$ no improvement beyond pre-selection cut of 0.3

Selection efficiency

Checking VLC algorithm parameters





$\Rightarrow$ suggested settings ($R = 1.2$, $\beta = \gamma = 0.8$) seem to be optimal