Update on the $t \longrightarrow ch$ analysis

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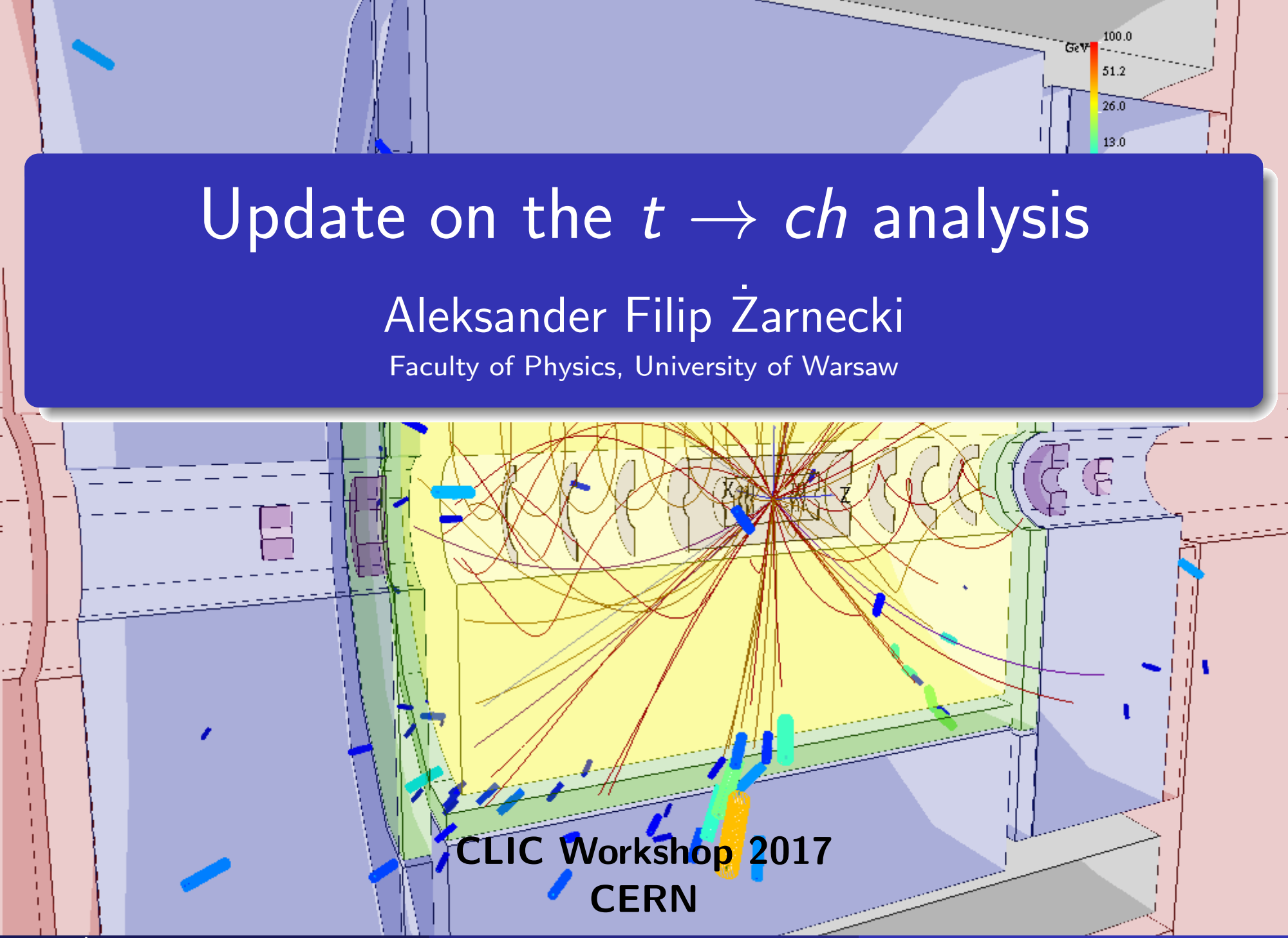

CLIC Workshop 2017

CERN

Motivation

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

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

Any signal is a direct signature of "new physics"...

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Any signal is a direct signature of "new physics"...

Decay $t \to c\,h$ is most interesting:

- well constrained kinematics
- test of Higgs boson couplings
- seems to be most difficult for LHC

Estimated HL-LHC reach:
(Snowmass 2013/ATLAS 2016)

$$BR(t \to qh) \sim 2 \cdot 10^{-4}$$

Two Higgs Doublet Model (2HDM) as a test scenario:

- one of simplest extensions of the SM
- $BR(t \to c\,h)$ up to 10^{-2} (tree level) and 10^{-4} (loop level)

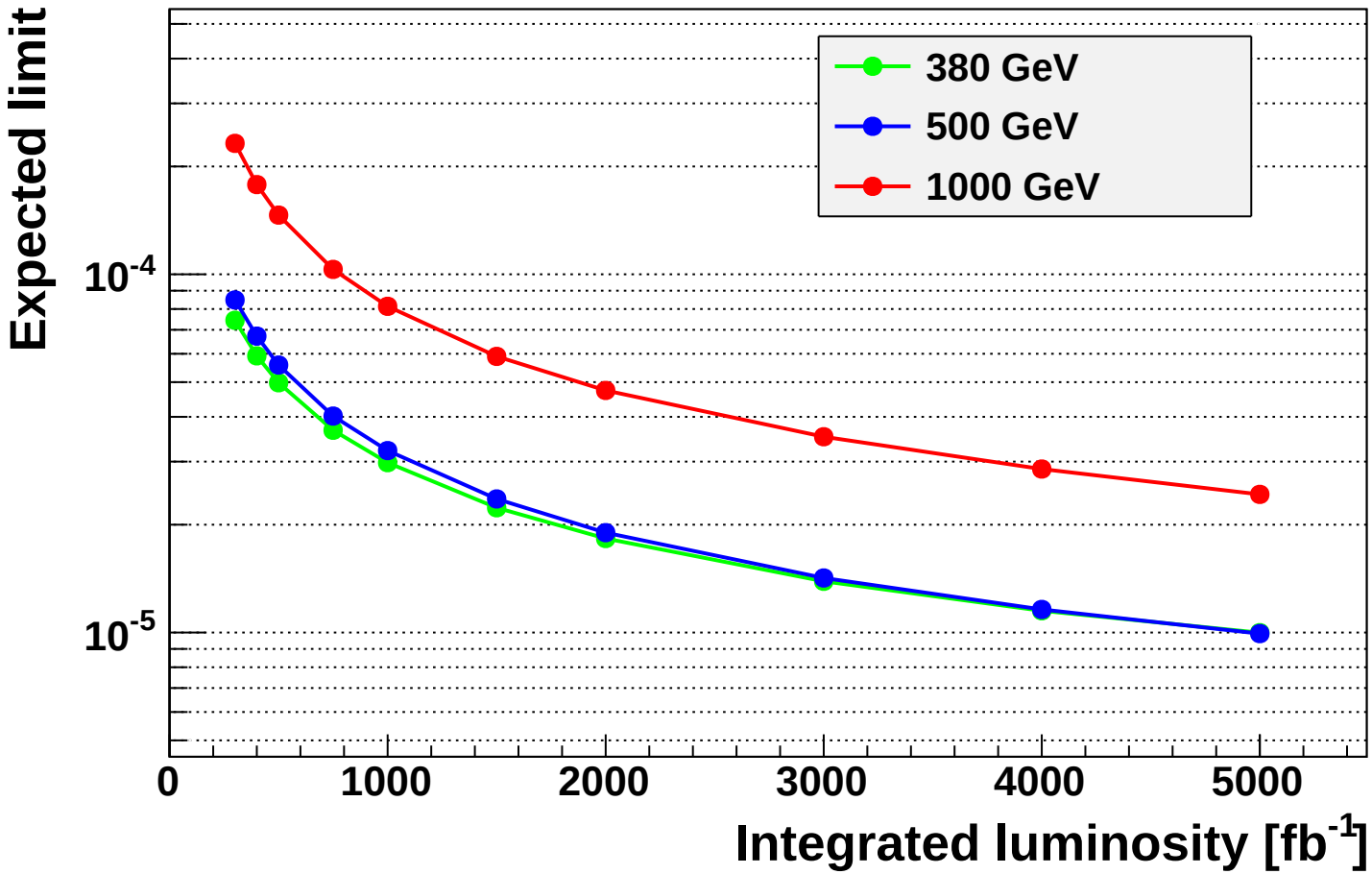
Motivation

Parton level study presented at TopLC'2015 [arXiv:1604.08122]

Promising results on the feasibility of the measurement

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

Assumed jet energy resolution $\sigma_E = 50\%/\sqrt{E}$ (5% above 100 GeV)



Full simulation

Dedicated samples generated with WHIZARD 2.2.8
Signal: SARAH implementation of 2HDM(III), BR($t \to ch_1$) = 10^{-3}

Beam spectra for CLIC taken from file (350 GeV scaled to 380 GeV)
Beam polarization of -80%/0% (for e^-/e^+)

Hadronization done in PYTHIA 6.427
quark masses and PYTHIA settings adjusted to CLIC CDR
Standard event processing with CLIC_ILD_CDR500 configuration

Samples considered in the presented study

- dedicated FCNC signal sample $e^+e^- \longrightarrow ch_1\bar{t},\ t\bar{c}h_1$
- test sample of SM background $e^+e^- \longrightarrow t\bar{t}$ for simulation validation
- full 6-fermion sample as produced for CLIC $t\bar{t}$ studies

Signal and background samples normalised to 500 fb^{-1}
Assumed $t\bar{t}$ cross section at 380 GeV: 820 fb

Event processing

DST files processed with MARLIN, ilcsoft v01-17-09 (ilcDIRAC)

- Using LooseSelectedPandoraPFANewPFOs as input collection
- LCFI+ primary and secondary vertex finder
- LCFI+ jet finding with Valencia algorithm
- LCFI+ vertex corrections and flavour taging
  default weights used (no tuning), but seem to work OK
- root TTree writing

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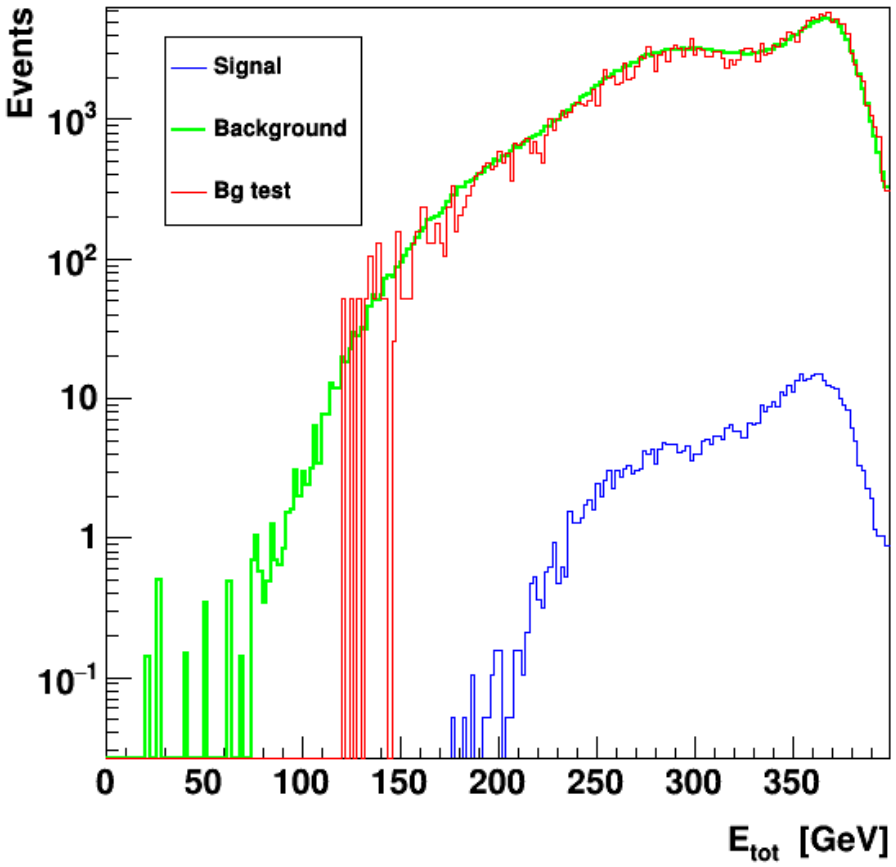
Final analysis in root:

- hadronic decay selection
- pre-selection cuts (loose cuts on flavour tagging)
- kinematic fit
- final selection (cuts or BDT)
  optimised for best BR limit

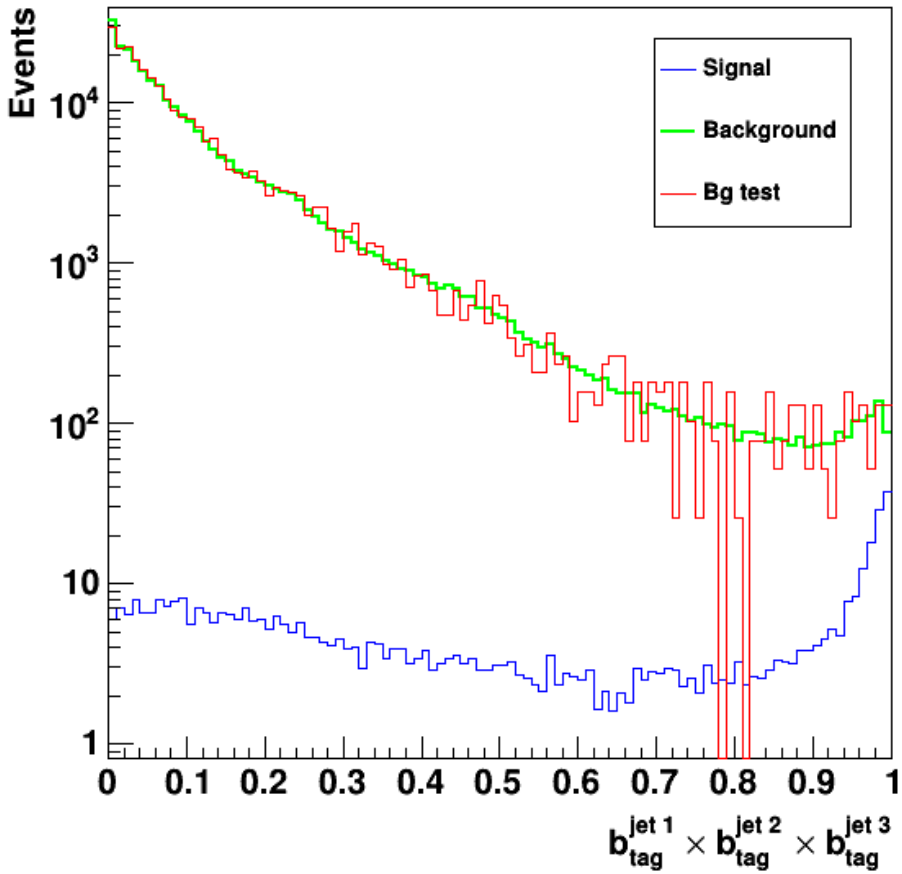
Control plots

Comparing signal sample with full background and test samples.

Total measured energy



Product of three highest *b*-tag value



LCWS'2016 results

Expected events in six-jet final state

For 500 fb^{-1}, assuming $BR(t \to ch) \times BR(h \to b\bar{b}) = 10^{-3}$ for signal

Analysis level / Selection cut	Expected events		Efficiency	
	$t\bar{t}$ (SM)	Signal	$t\bar{t}$ (SM)	Signal
All events	410'000	819	100%	100%
hadronic events	170'000	543	41.5%	66.3%
Before kinematic fit				
$E_{balance} < 100$ GeV	167'000	499	40.6%	60.9%
3 b jets tagged ($b_{tag} > 0.4$)	13'280	300	3.24%	36.6%
c jet tagged ($b_{tag}+c_{tag} > 0.4$)	9640	276	2.35%	33.8%
After kinematic fit				
Good fit ($\chi^2_{sig}<14$, $\Delta M_t<45$ GeV)	894	87	0.22%	10.7%
b-tag for higgs jets ($b_1 \times b_2 > 0.95$)	89.5	50.8	0.022%	6.2%
b and c tags ($b_3>0.9$, $c_4+b_4>0.75$)	10.7	34.1	$2.6 \cdot 10^{-5}$	4.2%
$\chi^2_{sig}/\chi^2_{bg} < 1.38$ (optimised for limit)	4.89	31.8	$1.2 \cdot 10^{-5}$	3.9%

LCWS'2016 results

Expected limits only hadronic channel considered !

Cuts were optimised for the best expected BR limit.

Final signal selection efficiency: 3.9% (5.9% of hadronic decays)
Background suppression: $1.2 \cdot 10^{-5}$

Expected 95% C.L. limit for 500 fb^{-1} at 380 GeV preliminary

$$BR(t \to ch) \times BR(h \to b\bar{b}) \quad < \quad 2.6 \cdot 10^{-4}$$

With luminosity of 1000 fb^{-1} at 380 GeV

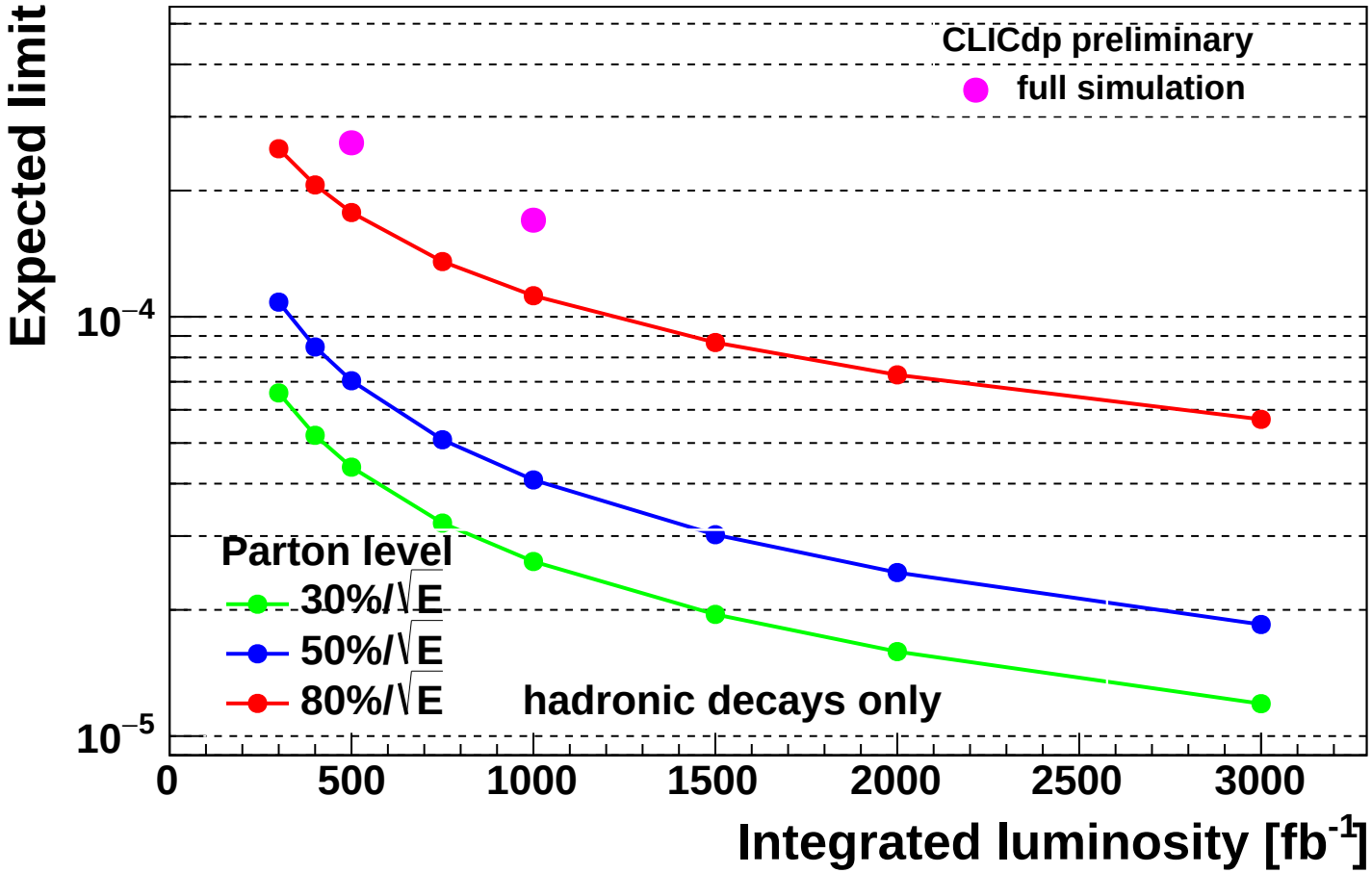
$$BR(t \to ch) \times BR(h \to b\bar{b}) \quad < \quad 1.7 \cdot 10^{-4}$$

assuming $t\bar{t}$ cross section at 380 GeV of 820 fb

see: `http://hep.fuw.edu.pl/u/zarnecki/talks/afz_lcws2016.pdf`

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

Comparison with parton level results, different jet energy resolutions

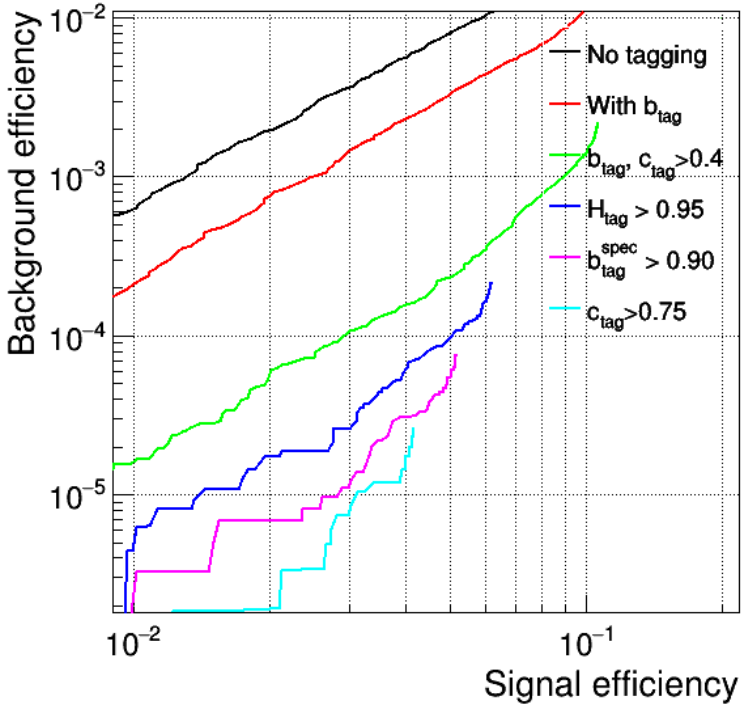


New: using BDT for final selection

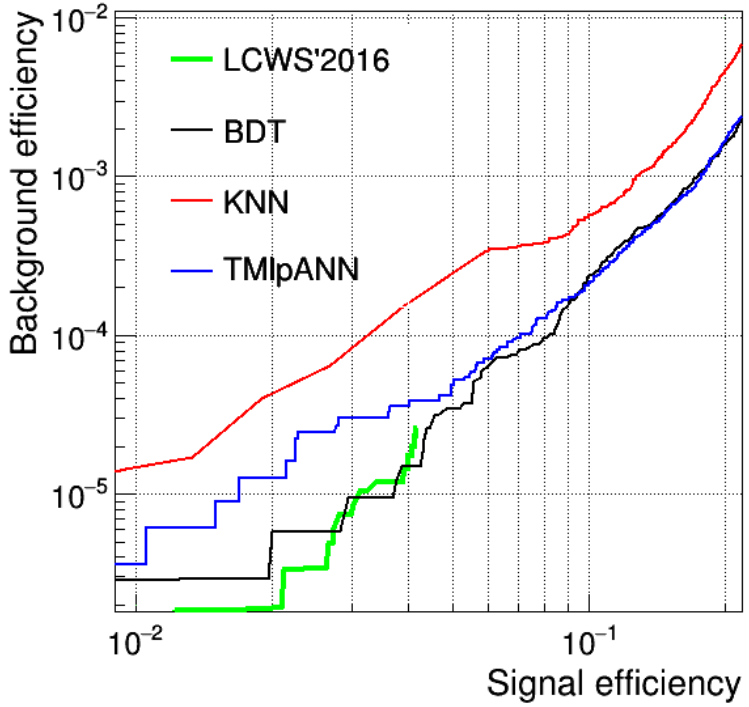
Background vs signal efficiency after the final selection cut

normalized to all decay channels

LCWS'16: cut on $\chi^2_{\rm sig}/\chi^2_{\rm bg}$



MVA: cut on the classifier response



⇒ BDT gives best selection

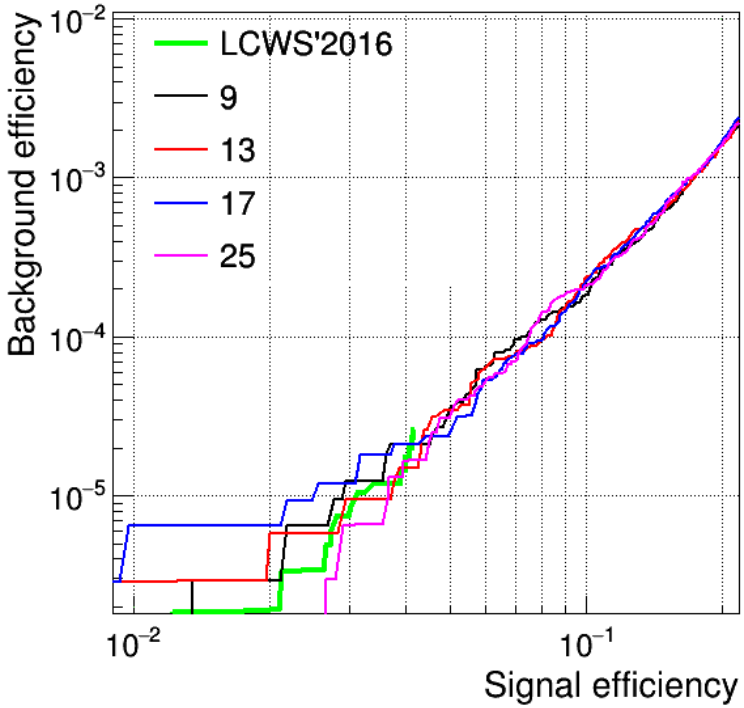
(compared to other MVA algorithms)

New: using BDT for final selection

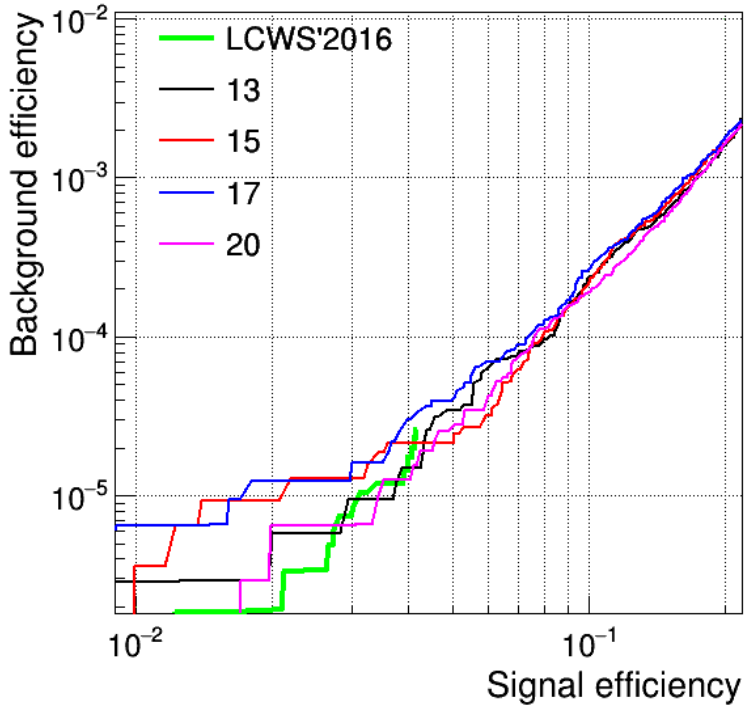
Background vs signal efficiency after the cut on BDT response
For different numbers (and choices) of variables used in BDT

number of variables indicated

Final state variables only



Including global event variables



$\Rightarrow$ best BDT result similar to LCWS'2016 (cut based approach)

Hard to get any significant improvement !?!

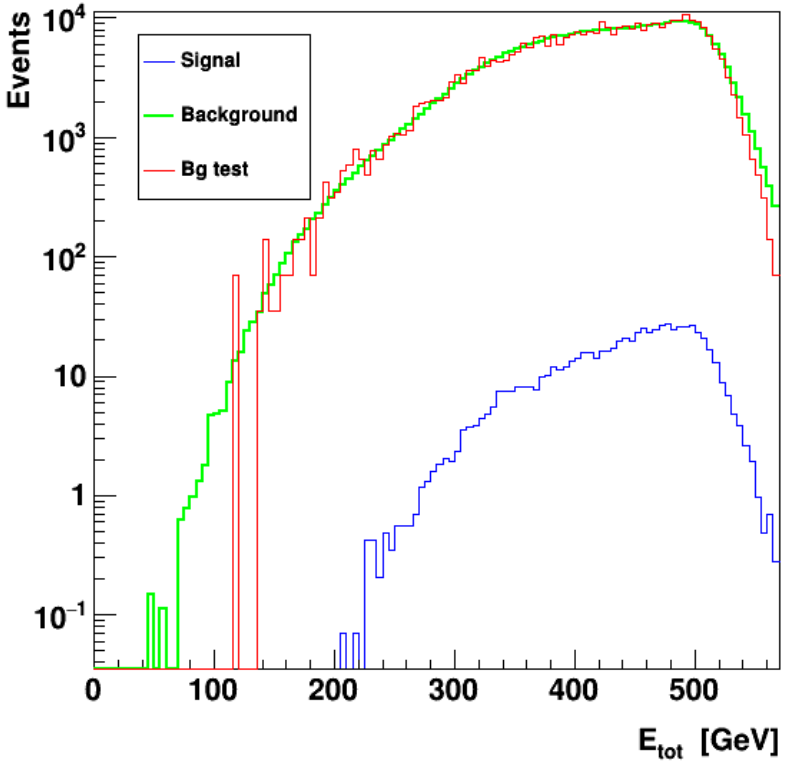
New: $\sqrt{s} = 500$ GeV

Dedicated signal and background samples generated and processed.
Full 6-fermion sample (negative polarisation) processed (1st step done).

Control plots

Comparing signal sample with full background and test samples.

Total measured energy



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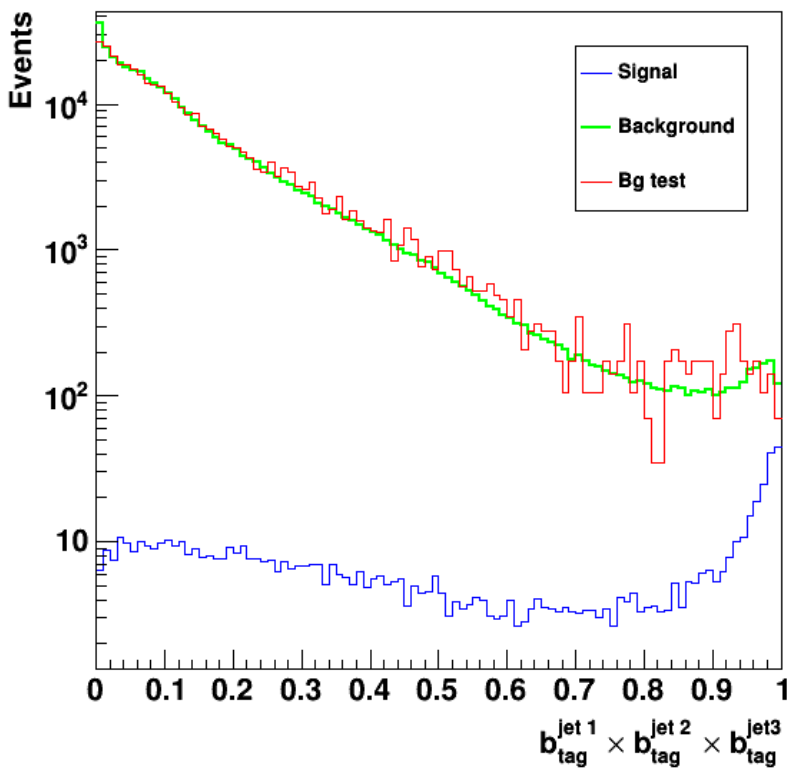
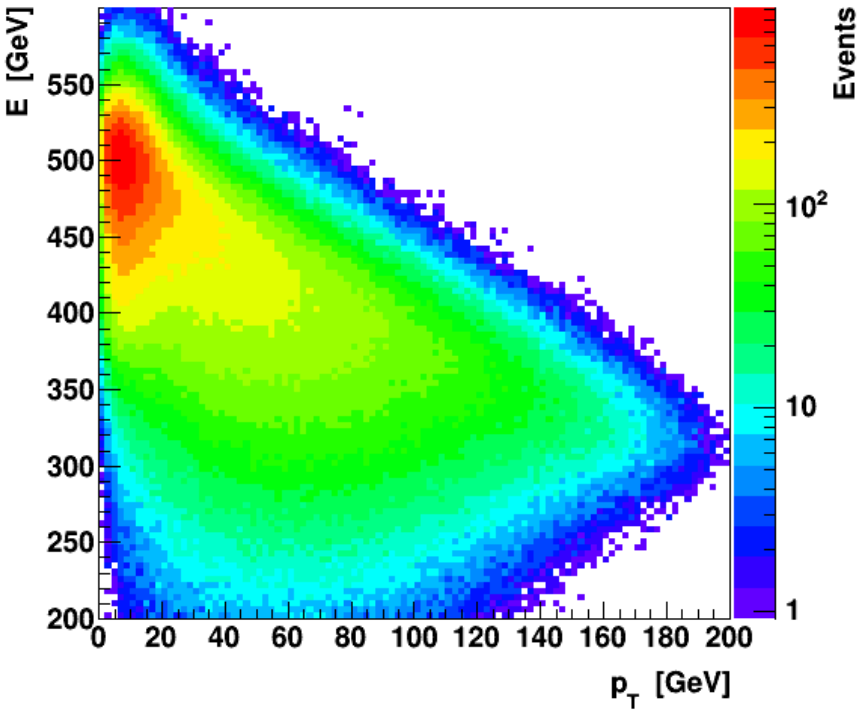


New: $\sqrt{s} = 500$ GeV

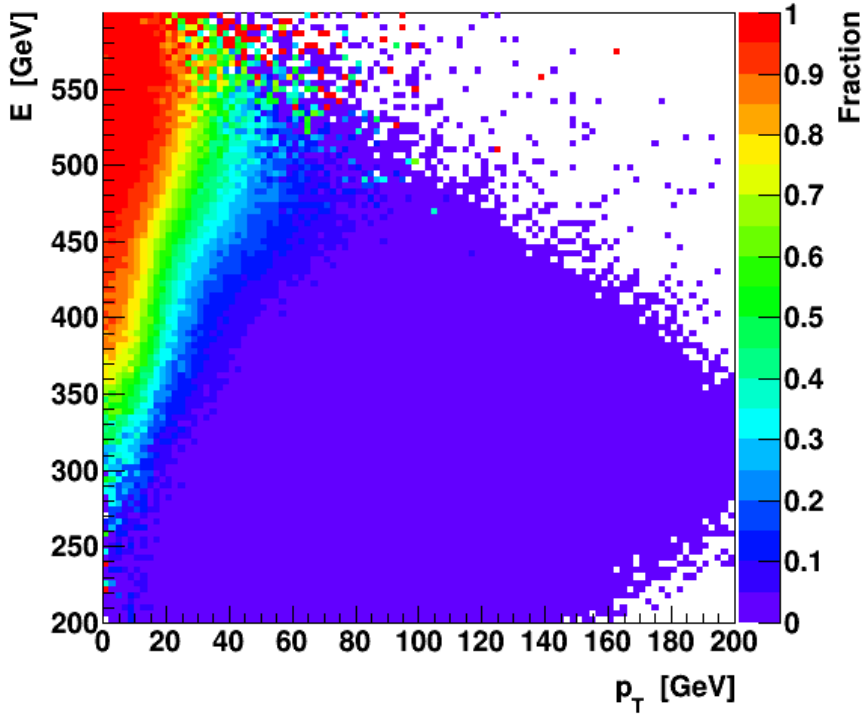
Pre-selection optimisation

Discrimination between hadronic and (semi-)leptonic events by looking at the correlation of transverse momentum and total energy

Background event distribution



Hadronic event fraction



Selection developed for 380 GeV (based on $E - 2\,p_z$) seems not optimal...

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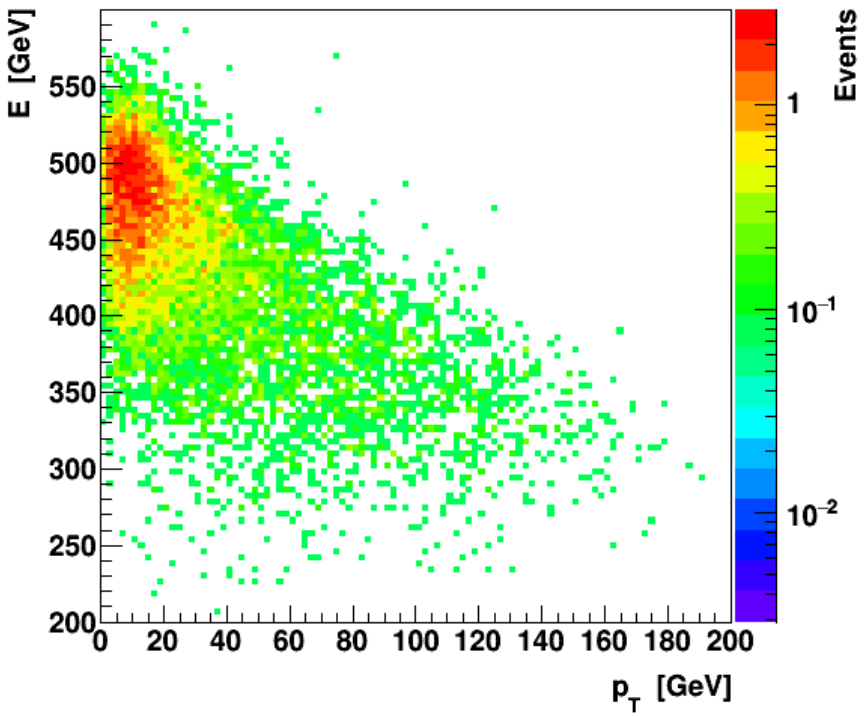
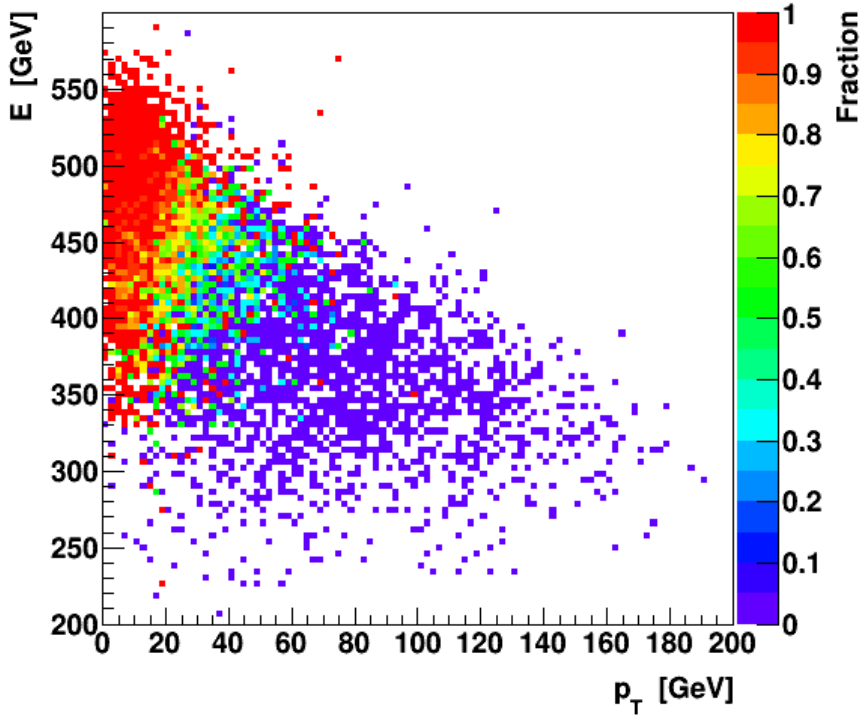


Hadronic event fraction



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Conclusions

FCNC top decays $t \to ch$

Preliminary results for 380 GeV presented at LCWS'2016.

Focus on optimizing kinematic reconstruction in the hadronic channel

Expected limit at 500 fb^{-1}

$$BR < 2.6 \cdot 10^{-4}$$

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Kinematic fit performance poorer than expected from parton level study

Background reduction primarily based on flavour tagging!

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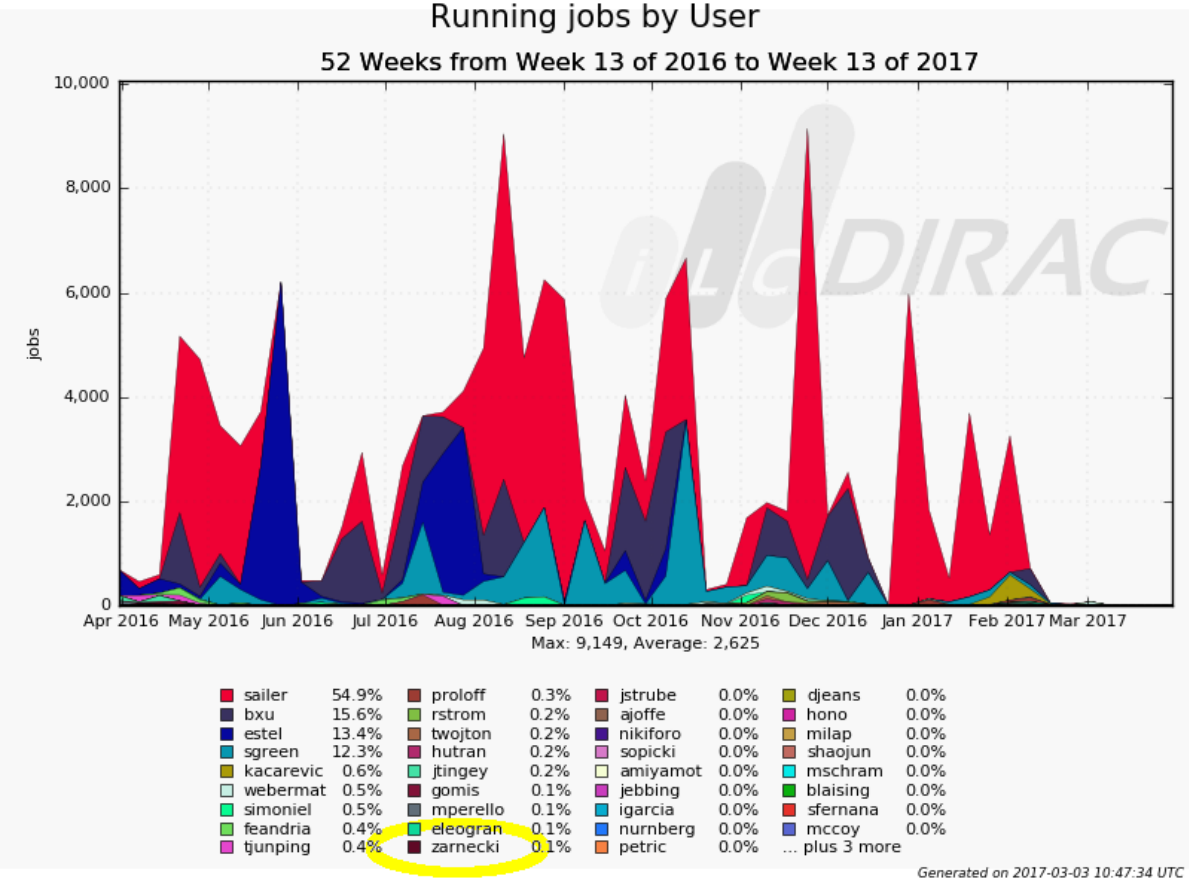
Analysis ongoing with main focus on:

- optimising final event selection with BDT
- extending the analysis to $\sqrt{s} = 500$ GeV
- semi-leptonic channel still waiting...

Thank you!

And many thanks to iLCDirac



from presentation by Jan Ebbing

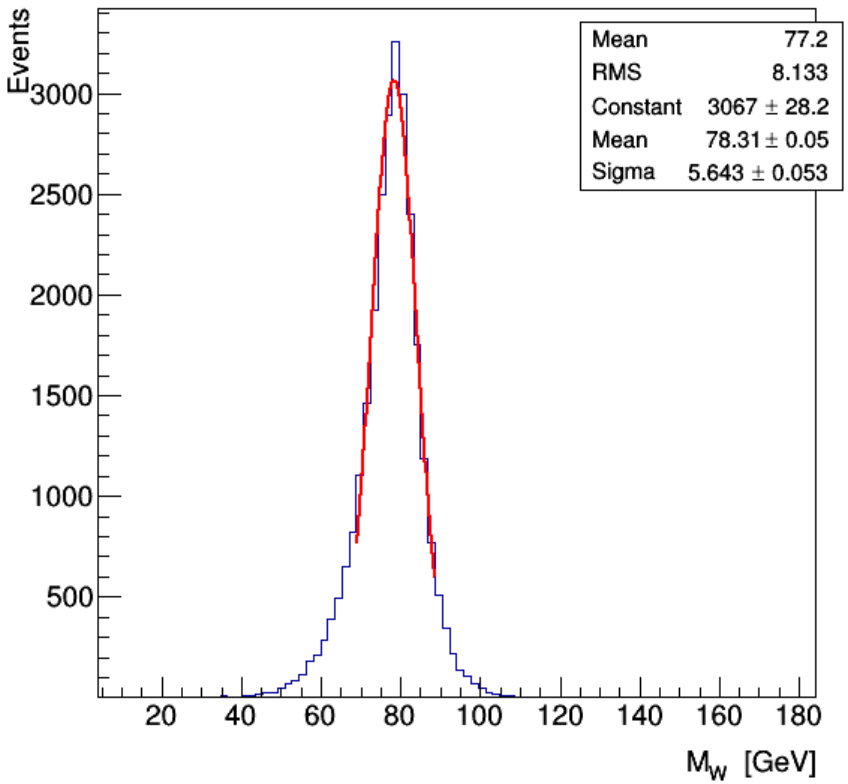
Backup slides

Mass resolution

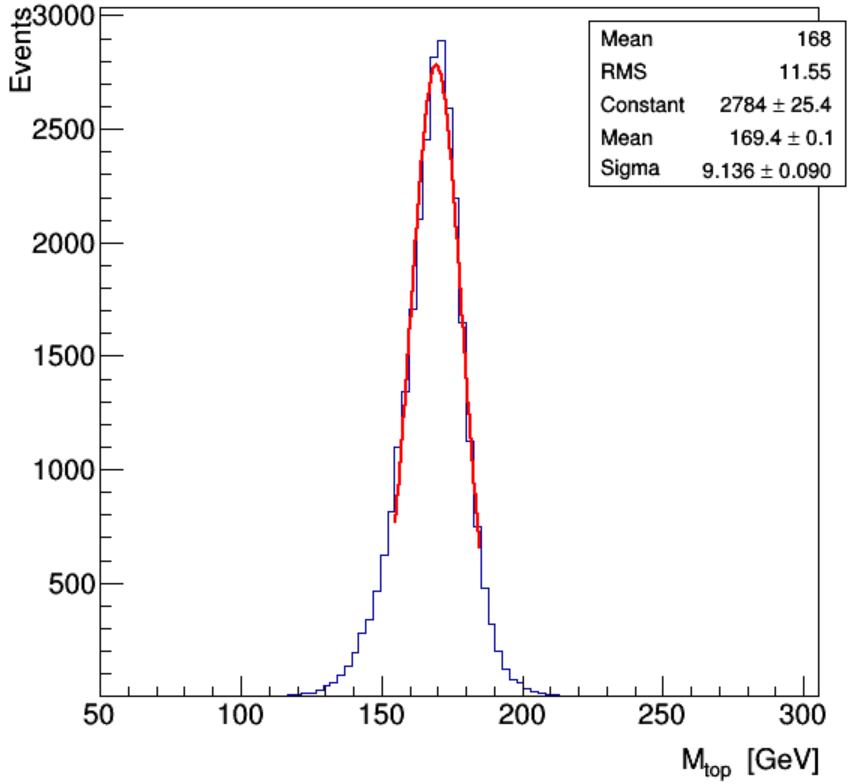
Reconstructed mass distributions for background events (Valencia jets)

For jet combination consistent with parton level configuration

W boson



Top quark



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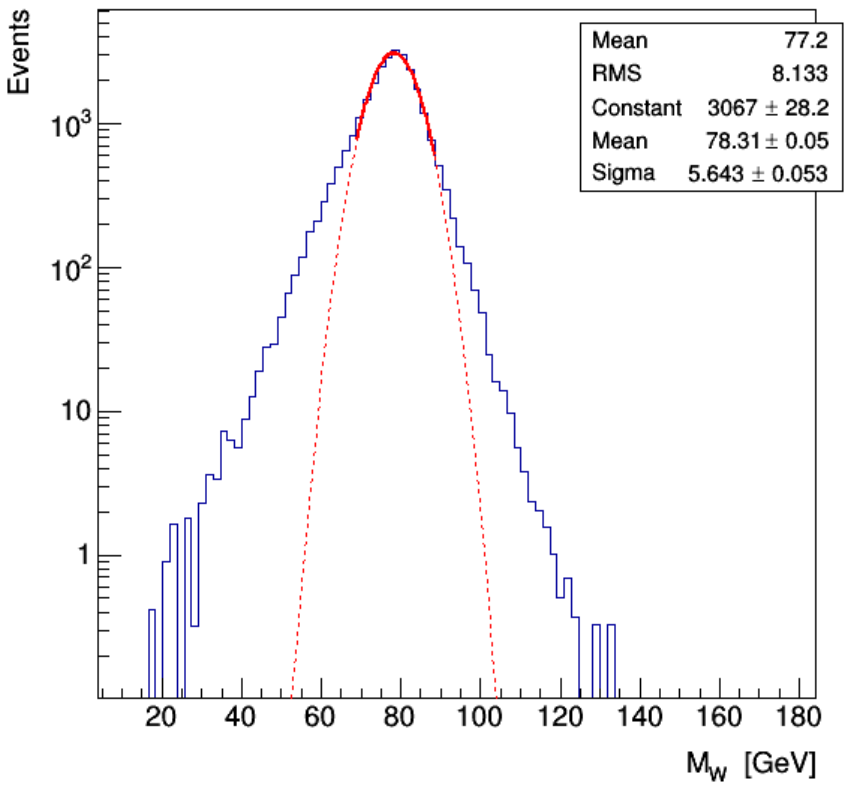

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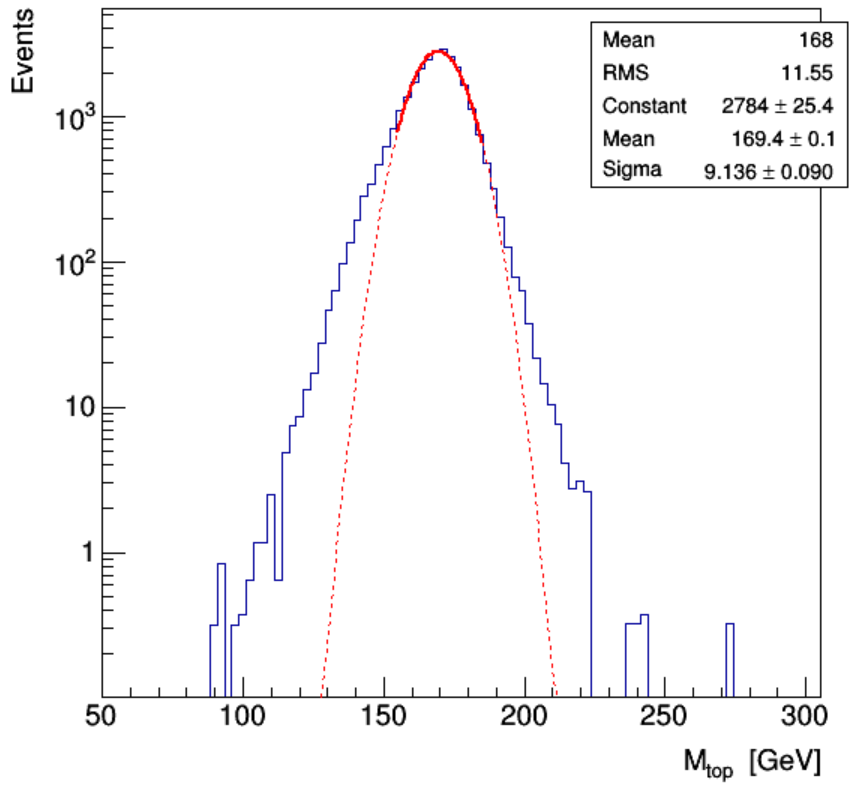
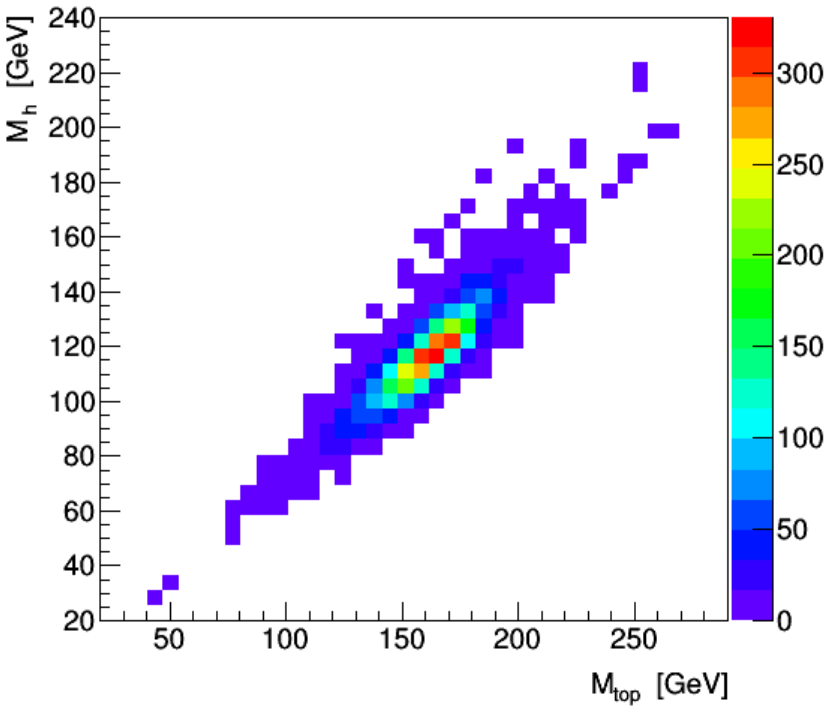


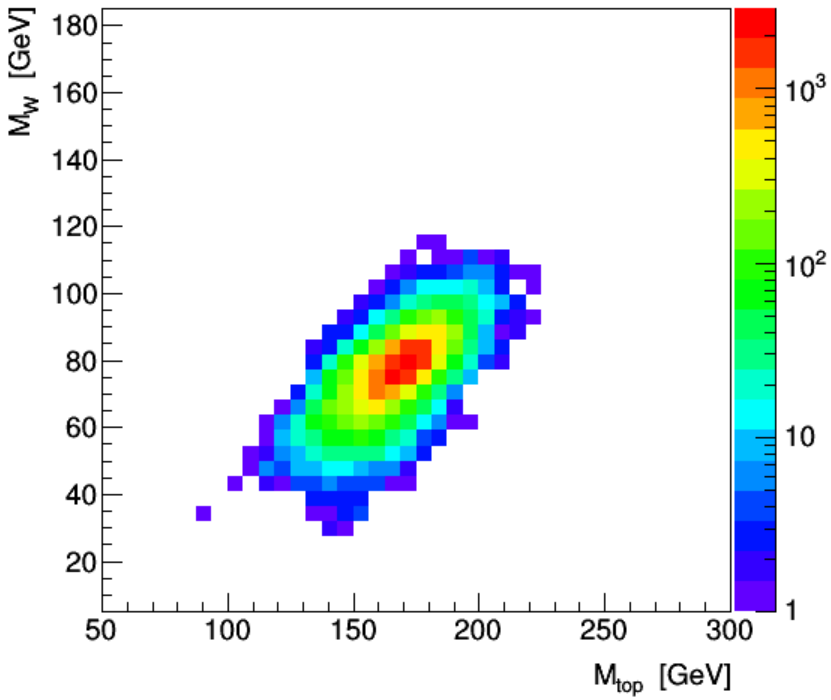
Mass correlation

Significant correlations observed between reconstructed masses of top (3 jets) and its decay product (2 jets)

Higgs and top (signal)



W boson and top (background)



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

New χ^2 definition

Using mass ratios to reduce influence of mass correlations:

- signal hypothesis — use also top boost as additional constrain

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

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

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

LCWS'2016 event selection

Preselection (before kinematic fit)

- cut on $E_{balance} < 100$ GeV
  no isolated lepton veto required
- 6 jets reconstructed in LCFI+
  no addition veto cuts required
- 3 jets with b-tag value above threshold of 0.4
- additional jet with b or c tag

Final selection cuts (after selecting best signal hypothesis)

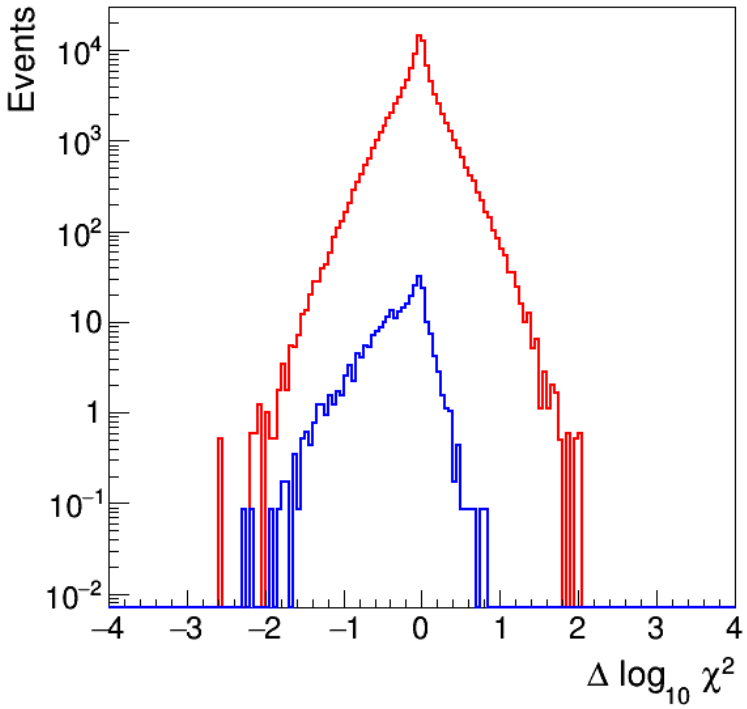
- quality of signal hypothesis (χ^2_{sig})
- the difference of reconstructed top masses (ΔM_{top})
- product of b-tag values for Higgs candidate
- b-tag value for b from spectator top
- sum of b-tag and c-tag values for c jet candidate
- χ^2_{sig}/χ^2_{bg} (final optimisation for best BR limit)

Signal-background discrimination

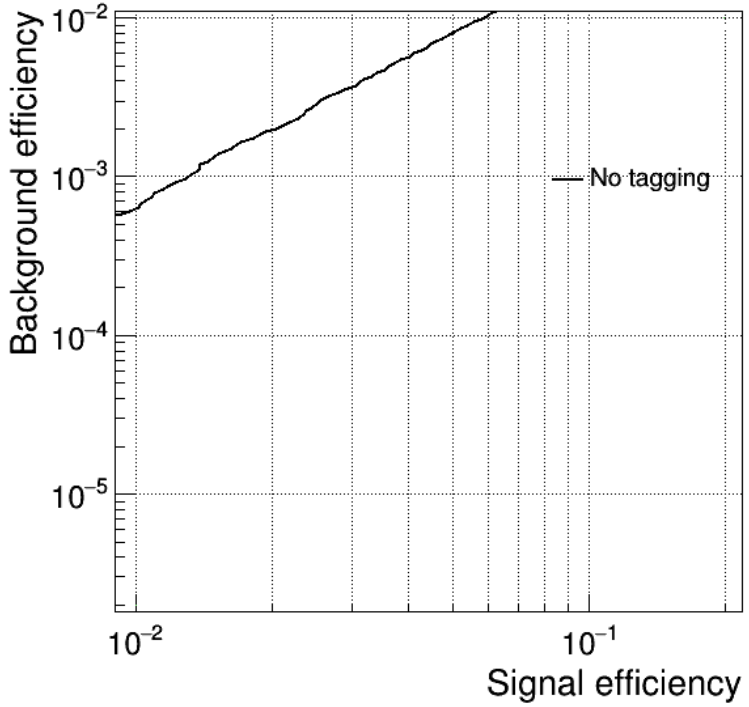
Based on the cut on the difference of $\log_{10}\chi^2$ for two hypothesis

Events with "good" fit of signal hypothesis ($\chi^2_{sig} < 14$, $|\Delta M_{top}| < 45$ GeV)

$\Delta \log_{10}\chi^2$ distribution for signal and background



Background vs signal efficiency after subsequent cuts



normalized to all decay channels

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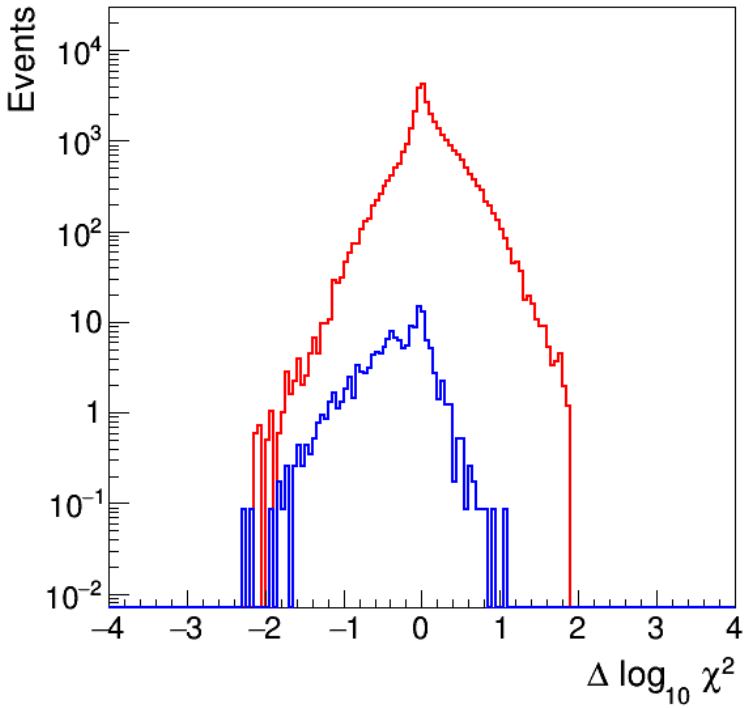

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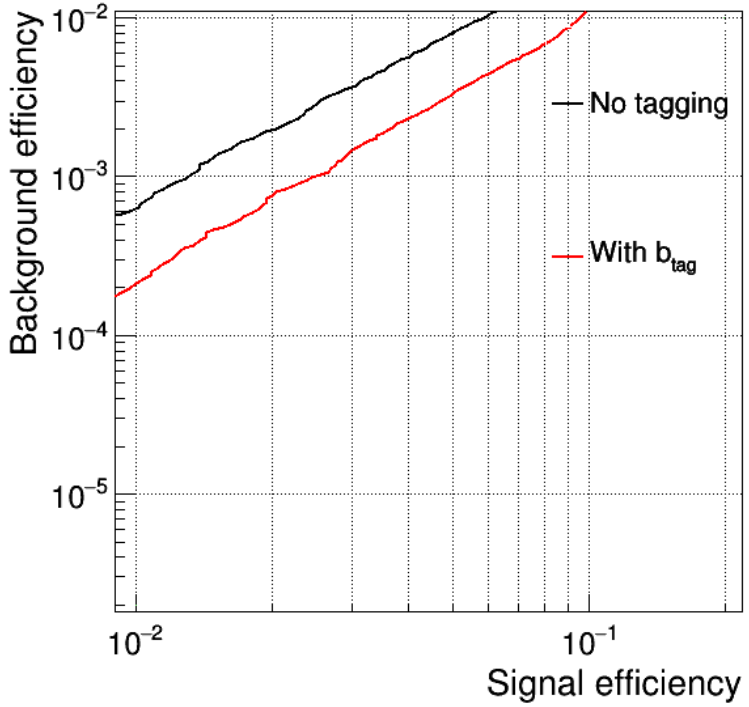

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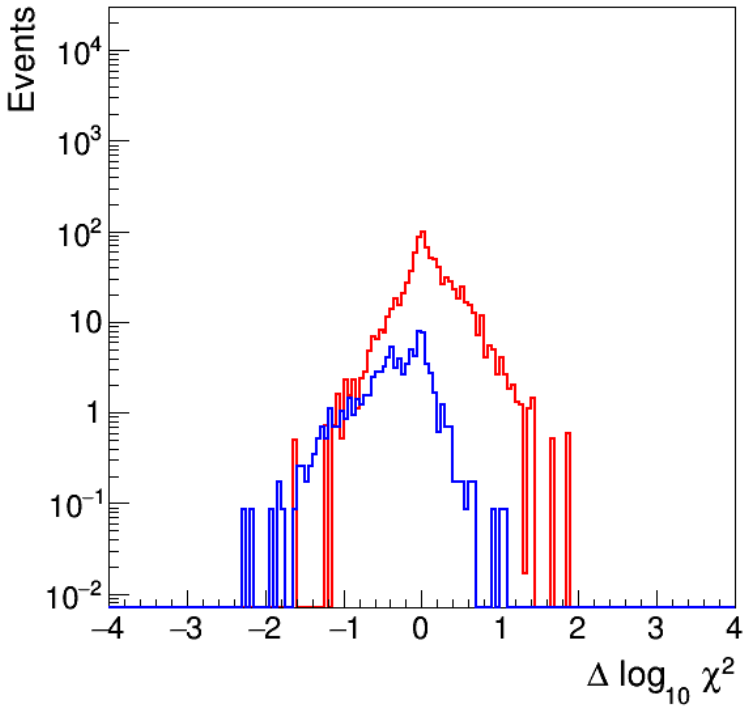

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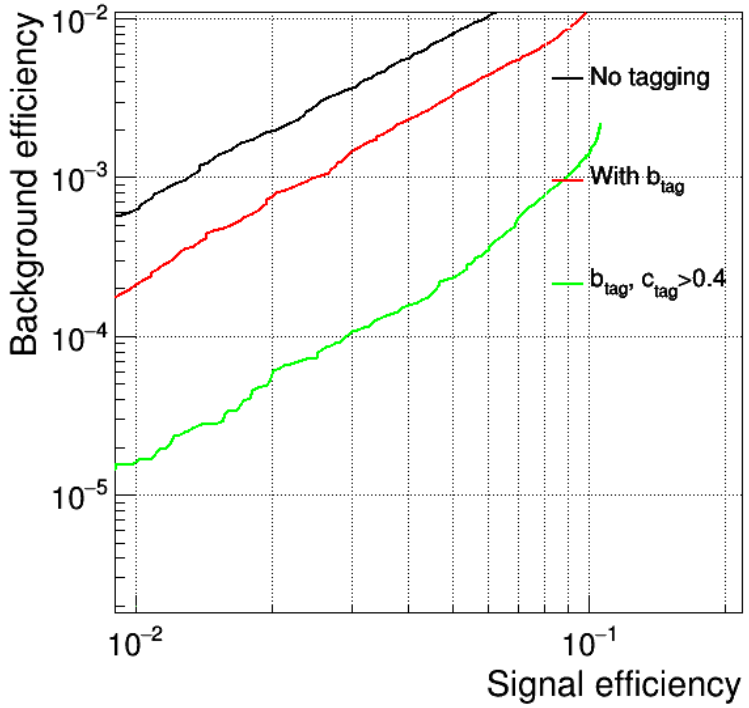

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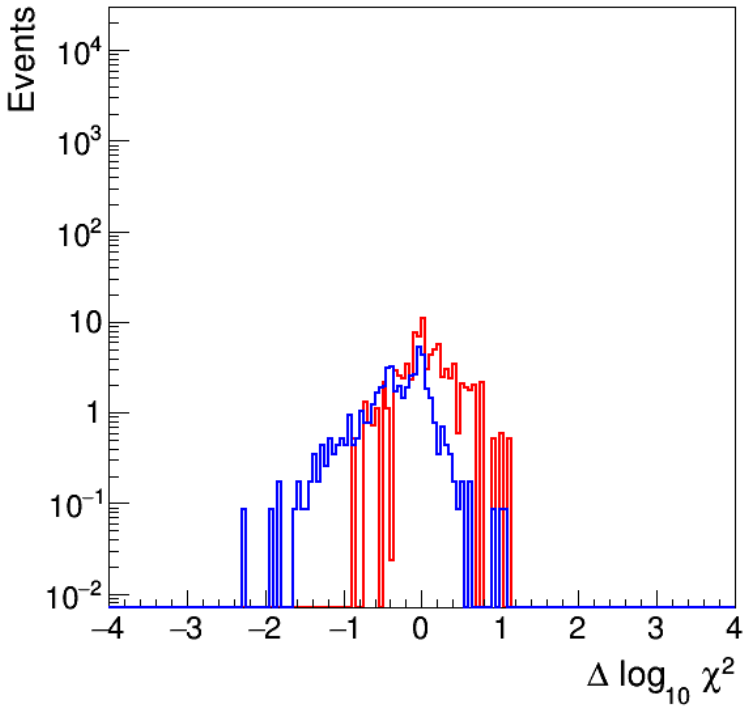

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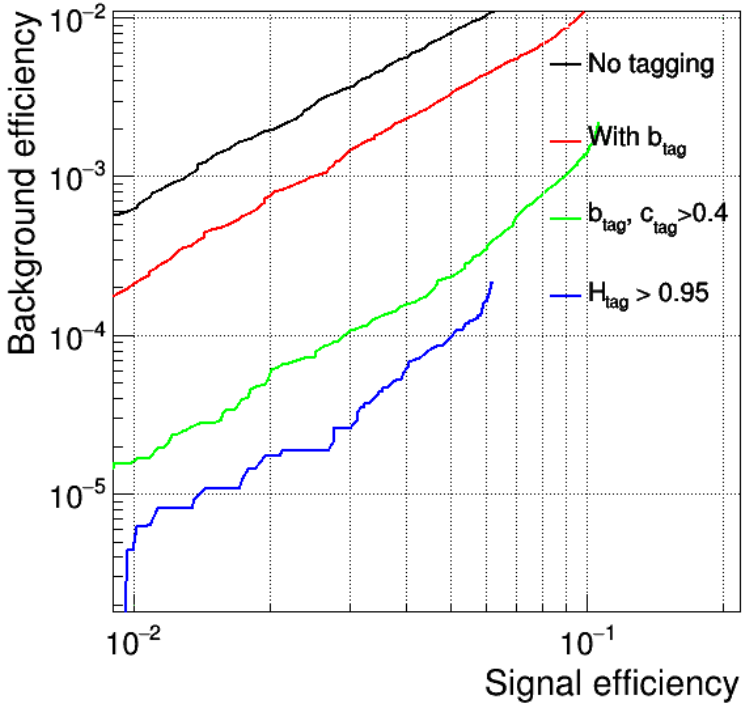

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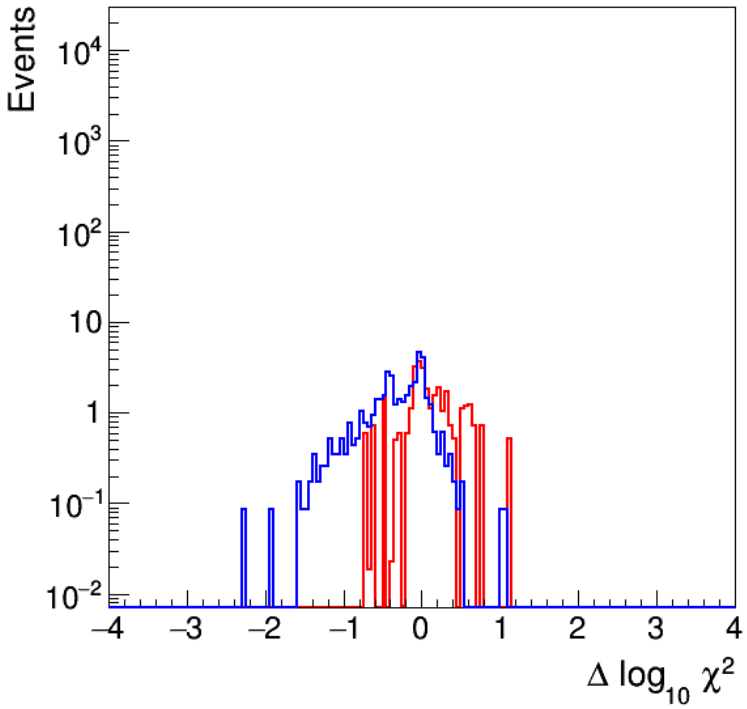

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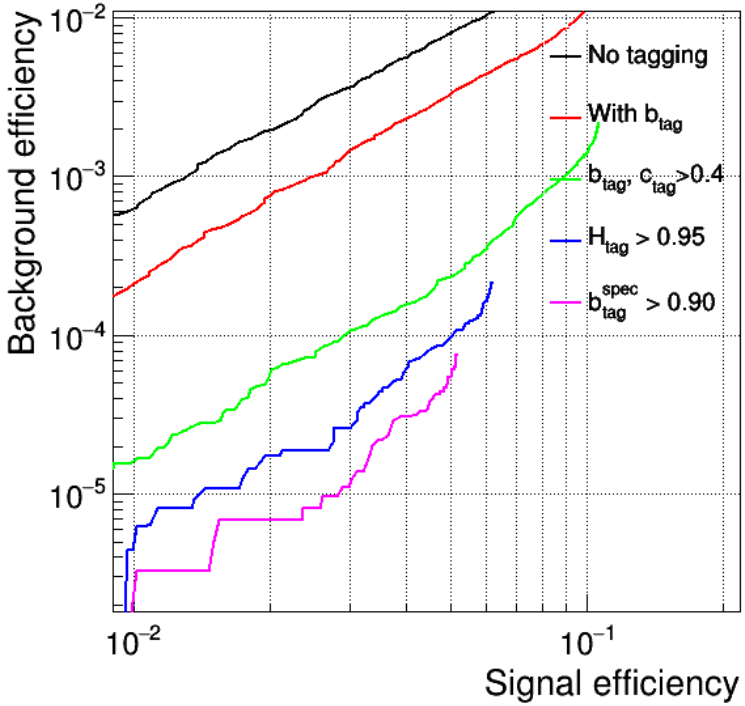

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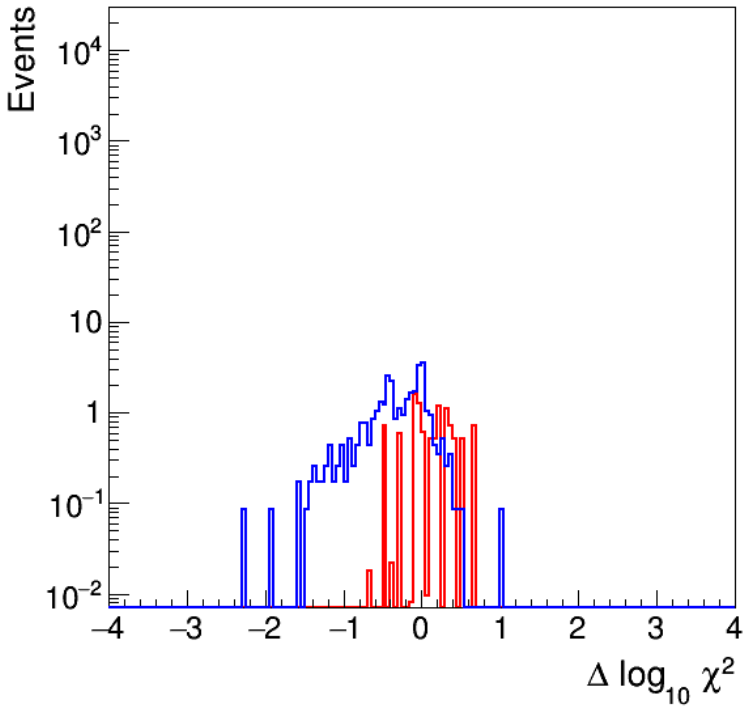

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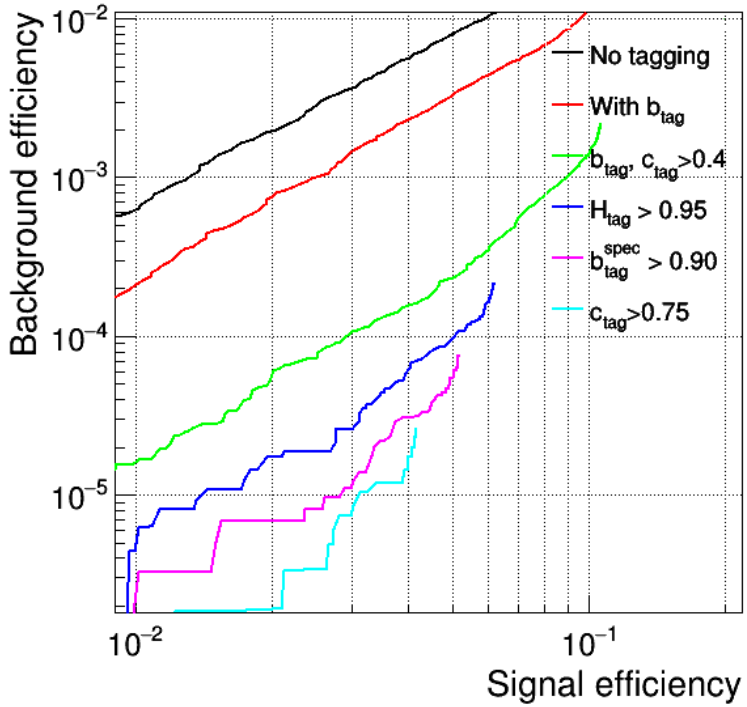

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