Single top and Matrix Element matching - Parton Shower

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Workshop on Top physics at the LC 2015
IFIC - Valencia (Spain), 30 June - 2 July

Outline

Single top production

- Single top vs *tt* production
- Impact on a experimental study at 500 GeV
- Impact in a study of top mass at threshold

Matrix Element-Parton Shower

- e^+e^- -> *tt* events at 500 GeV ILC
- MonteCarlo Samples
- WHIZARD MLM procedure and modelling

Conclusions

Single top

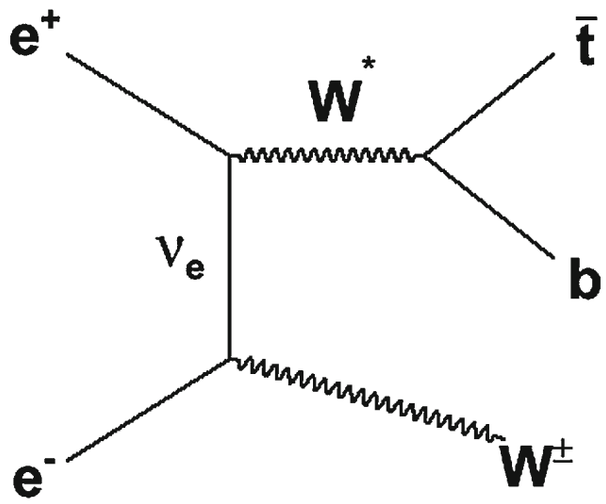
- This part of the talk is focused in the paper

  "Study of the single top production at high energy electron positron colliders"
  http://link.springer.com/article/10.1140%2Fepjc%2Fs10052-015-3453-2

- The **top quark has never been produced in e^+e^- machines**

- The study of **top quark properties** is therefore one of the most **exciting prospects** for a future linear collider

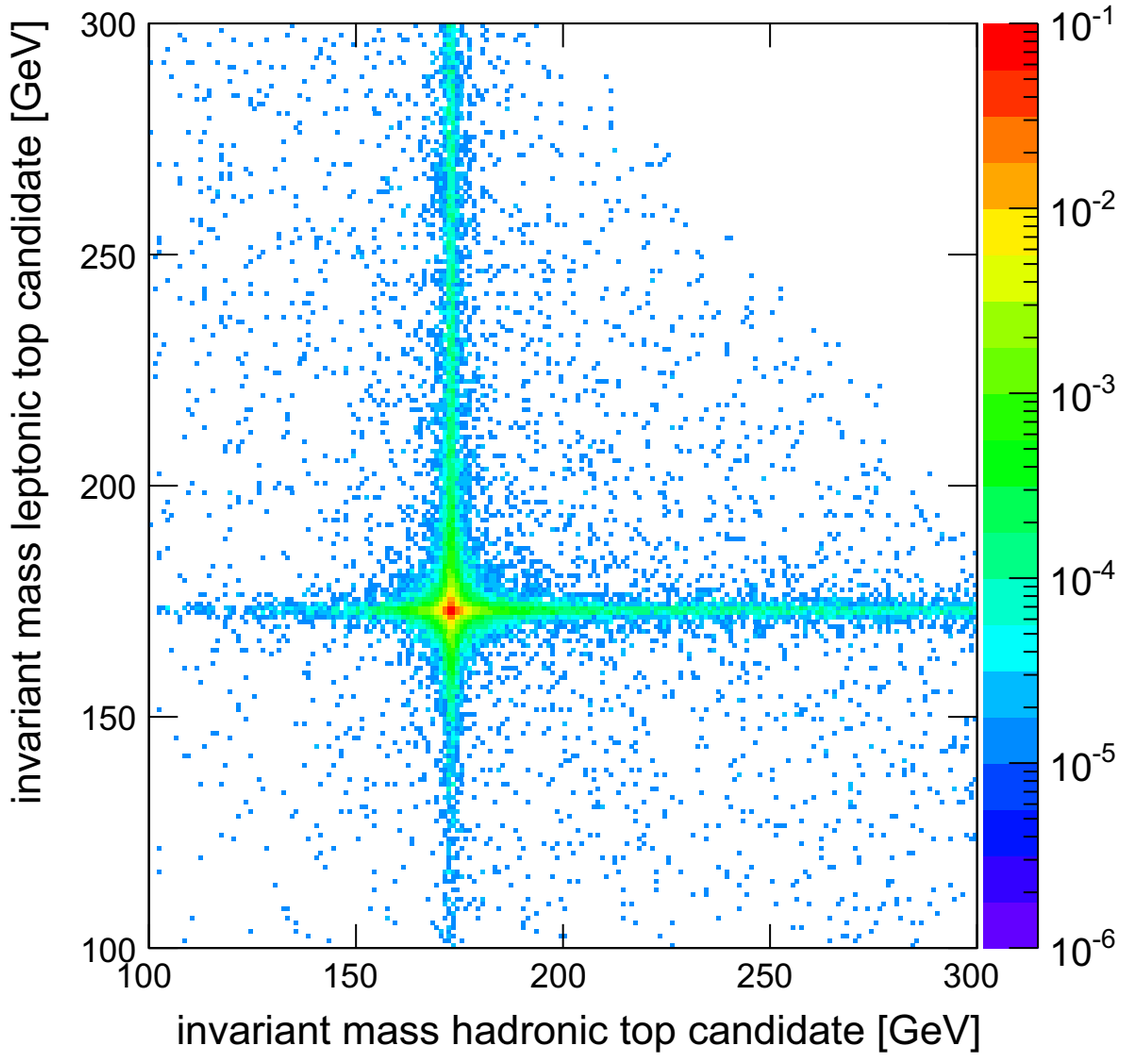
- **Single top production**, through $e^+e^- \to W^-t\bar{b}, W^+\bar{t}b$ **is abundant at e^+e^- colliders** that operate at $\sqrt{s} > 300$ GeV



- *In this work we investigate the impact of single top events in a few published analysis*

Distinguishing single top from $t\bar{t}$ production

- Question: **how can one distinguish single top events from $t\bar{t}$?**
- Answer: **No algorithm can ever separate them fully -> interference between the production diagrams**
- $e^+e^- \to t\bar{t} \to W^+bW^-\bar{b}$ events generated using **WHIZARD** at √s = 500 GeV including ISR and the Beam energy spread expected at the ILC



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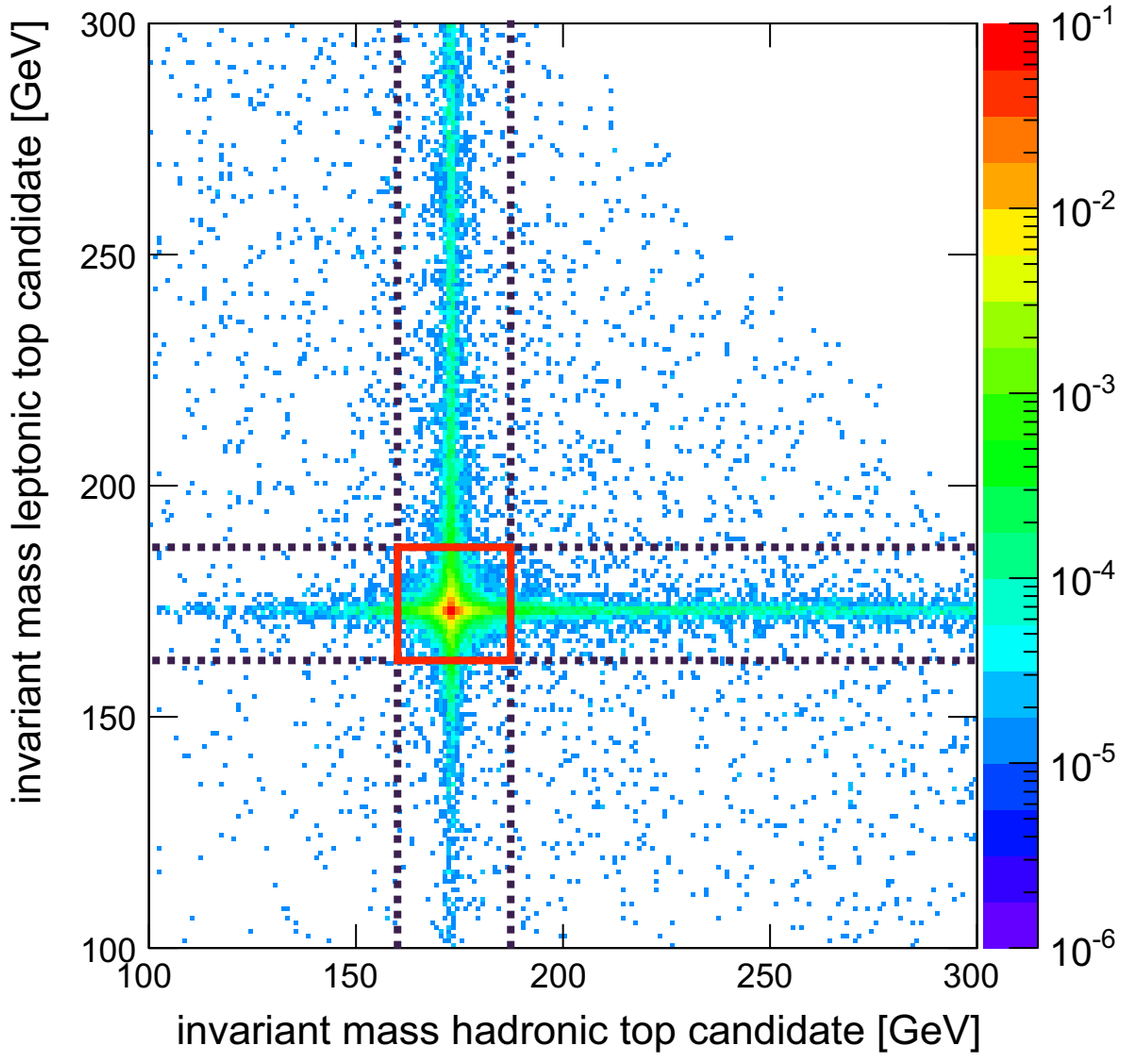
- So we consider a mass window to separate partially single and double-top events

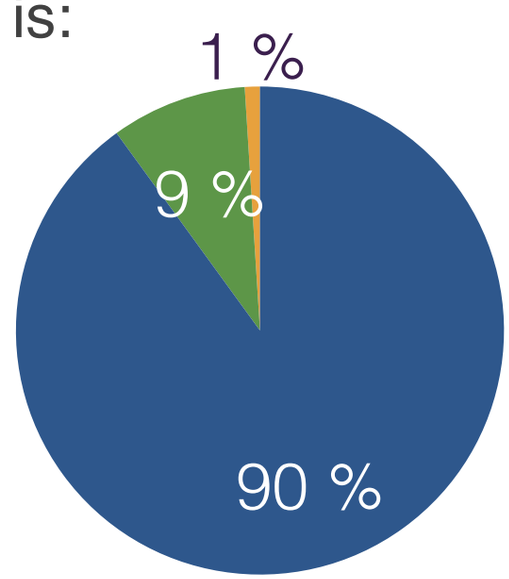


$$|m_{Wb} - m_t^{MC}| < 15 \text{ GeV}$$

Single top properties

- We have checked at truth level the composition of $e^+e^- \to t\bar{t} \to W^+bW^-\bar{b}$ samples, using the mass **window of 15 GeV,** and typically is:

	$e^-_L e^+_R$		$e^-_R e^+_L$
✓ ***tt* events:**	90,2%	→	94,3%
✓ **single top:**	8,9%	→	5,6%
✓ **non-top:**	0,9%	→	0,1%



1. The fraction of single-tops is non-negligible (5-10%)

2. Single top content depends on the beam polarisation (lower for $e^-_R e^+_L$) and the centre-of-mass energy (up to ~50%)

It may have a significant impact in the measurement of the top quark properties

Experimental study at √s = 500 GeV

IFIC/LAL study of ILC lepton+jets tt @ 500 GeV [arXiv:1307.8102]
Analysis based on the study of cross-sections and the asymmetries

Impact in the cross-section

Even in the best case ($e^-_R e^+_L$), the selected sample contains a **~5%** of single top after quality cuts -> **increase in the measured tt cross-section**

Impact in the forward-backward asymmetry

$e^-_L e^+_R$	*WbWb*	*ttbar*	*tWb*
ε_1(%)	**52,4**	**52,8**	**51,8**
ε_2 (%) $\chi2 < 15$	**36,7**	**38,3**	**26,8**
A_{FB}Reco $\chi2 < 15$	**0,32**	**0,34**	**0,04**

$\in_1$: kinematical and identification cuts

$\in_2$: $\chi2$ cut formed by the M_{top}, E_{beam} and E_b*

$$d^2 = \left(\frac{m_{cand.} - m_t}{\sigma_{m_t}}\right)^2 + \left(\frac{E_{cand.} - E_{beam}}{\sigma_{E_{cand.}}}\right)^2 + \left(\frac{p_b^* - 68}{\sigma_{p_b^*}}\right)^2.$$

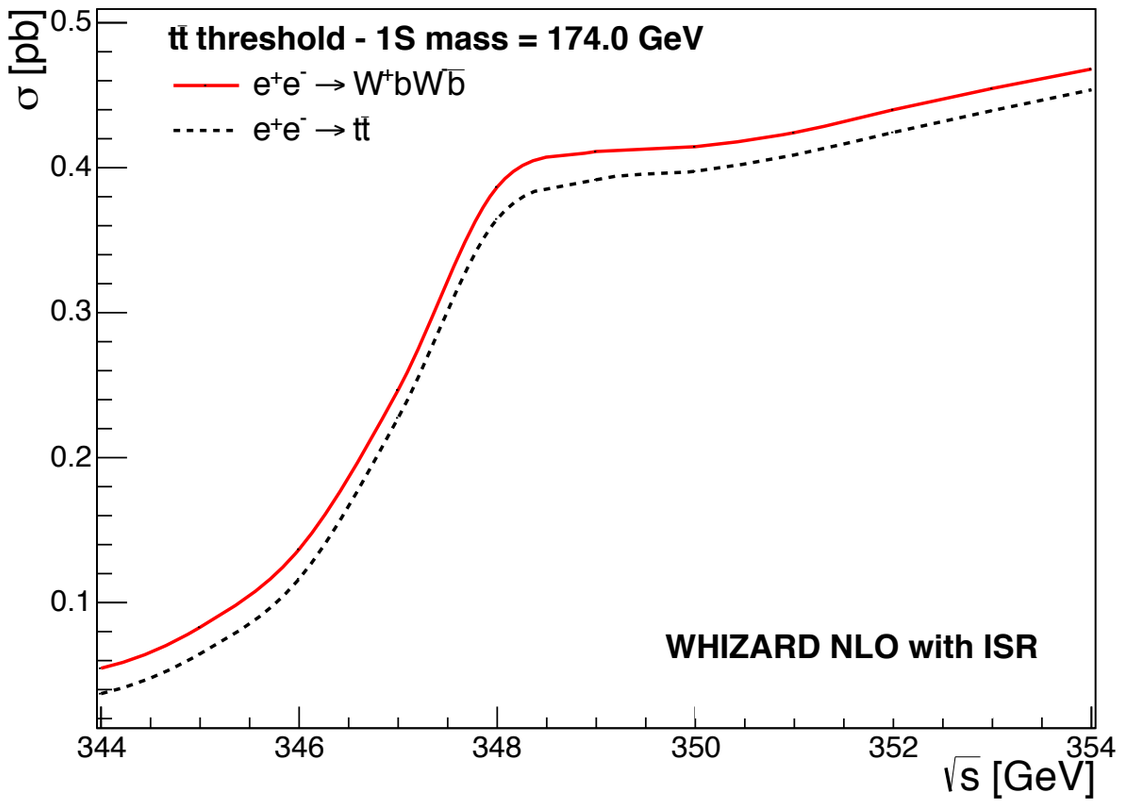
The **forward-backward asymmetry** is even more sensitive -> the measured value is **0.32 instead of the expected 0.34 (6% smaller)**

Analysis of top mass at threshold

- We also review the study [arXiv:1303.3758v3, Katja Seidel, Frank Simon et al.]

- **NLO** calculations for $W^+bW^-\bar{b}$ process in **WHIZARD 2.2.3** around the double-top production **threshold** (MC top mass 174 GeV)
- Content of single top and non-top events in the $W^+bW^-\bar{b}$

The tt cross-section may be obtained quite exactly by **shifting down** the W^+bW^-b cross-section by some **0.022 pb**

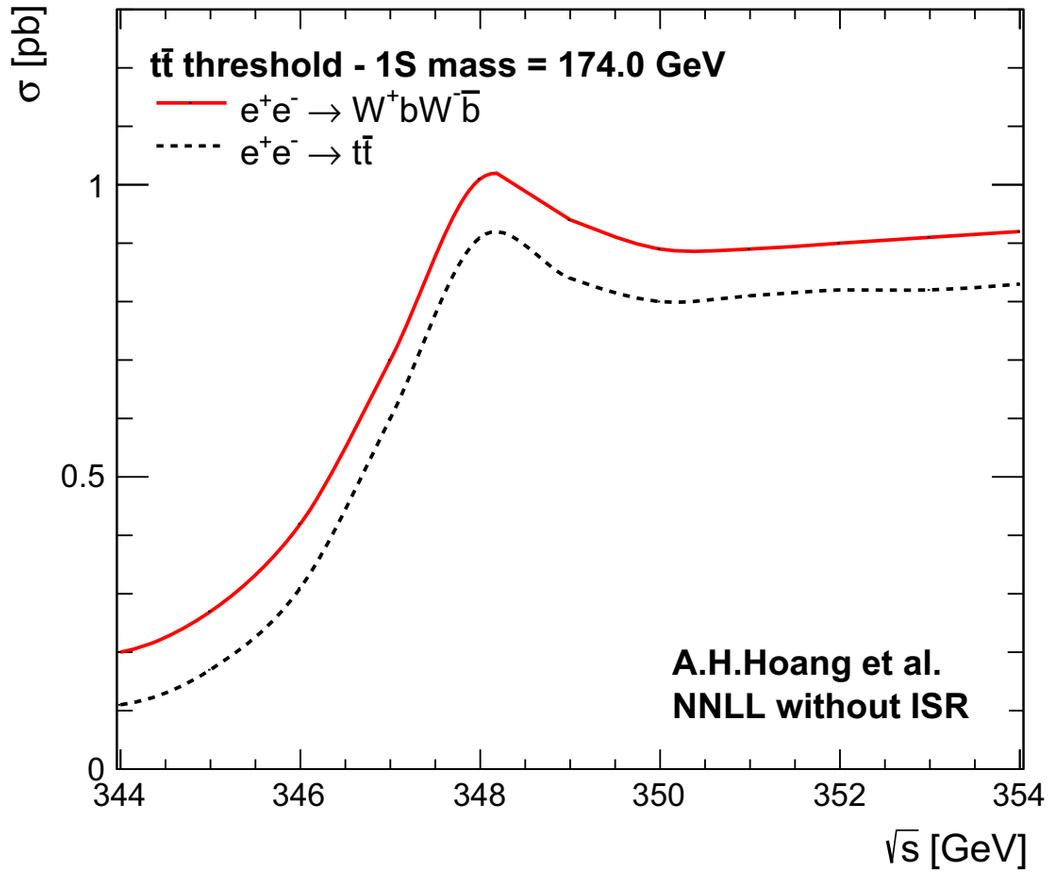


Analysis of top mass at threshold

- This result is also **supported by the NNLL** result in:
  A.H. Hoang, C.J. Reisser, P. Ruiz-Femenia, Phase space matching and finite lifetime effects for top-pair production close to threshold.

  Phys. Rev. D **82**, 014005 (2010). arXiv:1002.3223

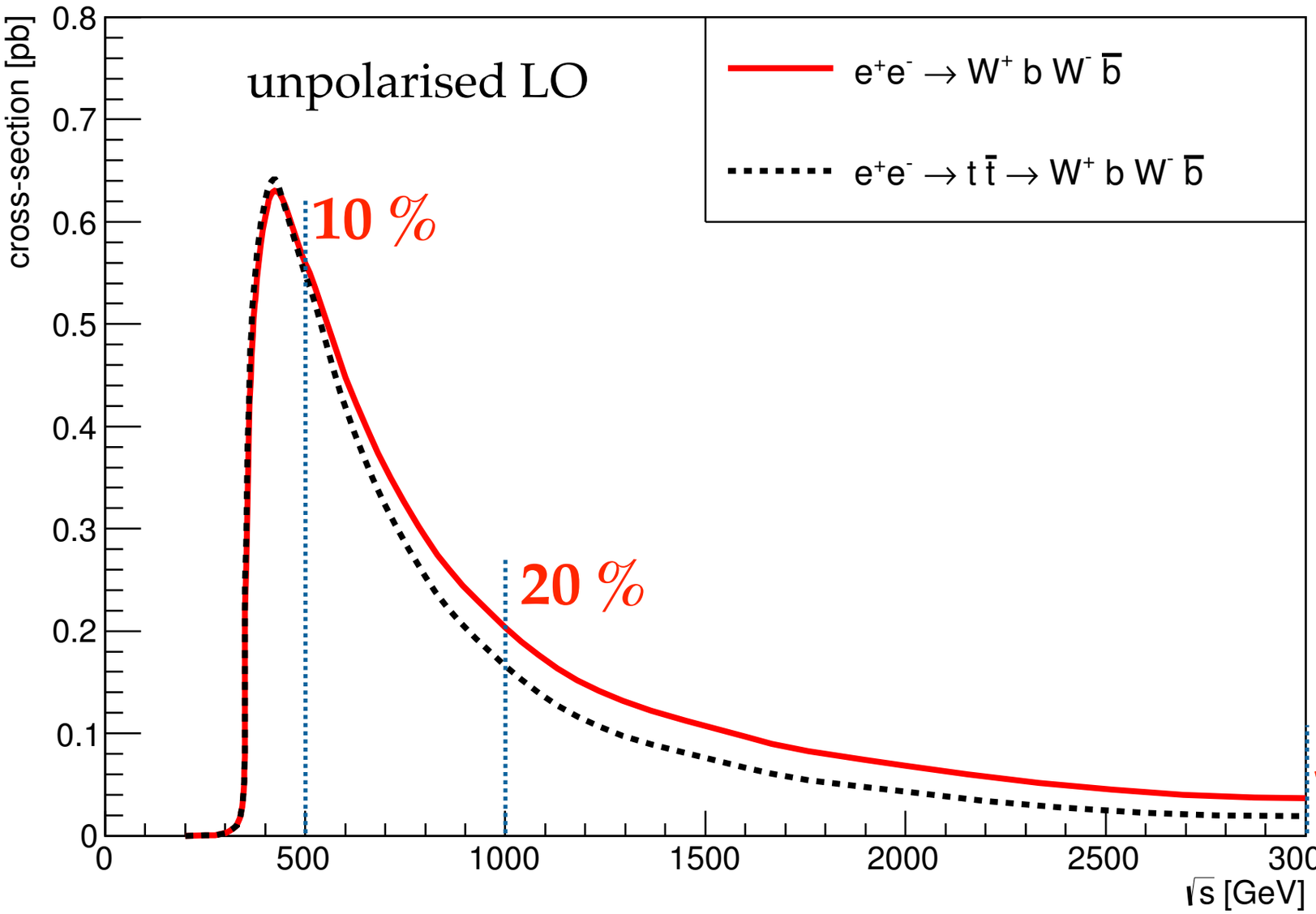
The tt cross-section may be obtained quite exactly by **shifting down** the W^+bW^-b cross-section by some **0.050 pb**



The presence of single top events modifies significantly the cross-section in the threshold region

Energy dependence

- The composition of $W^+bW^-\bar{b}$ is energy dependent



Generator tool:
WHIZARD 2.2

Unpolarised LO cross-sections

full 2->4 process
tt process

The rate for the e^+e^- -> tt drops at very large centre-of-mass energy, single top and non-top increase rapidly

Matrix Element Matching and Parton Shower

- **Compare** a number of **alternative schemes** to generate $e^+e^- \rightarrow t\bar{t}$ events at **500 GeV ILC**

- **WHIZARD 2.2.2**. includes an implementation of the **MLM matching** procedure

- **Modelling** uncertainties on the **cross-section** and $\mathbf{A_{FB}}$

- Validate the IFIC/LAL study of ILC lepton+jets tt @ 500 GeV performed with samples generated with the WHIZARD 1.95 without MLM Matching

MONTE CARLO SAMPLES

- **$t\bar{t}$+jets** events in the Matrix Element and matched to the Parton Shower with **3 additional jets** (maximum)

- **ISR** and **FSR** are included and beams are 100% polarised (R=+100%, L=-100%)

The generated samples are:

inclusive $e^+e^- \to t\bar{t}$

for both polarisations
$e^-_L e^+_R$ and $e^-_R e^+_L$

$e^+e^- \to t\bar{t} + t\bar{t}j + t\bar{t}jj + t\bar{t}jjj$

for different p_t of the additional jets
$(p_{t_{min}} > 10, 15, 20, 25\ \mathrm{GeV})$ for $e^-_L e^+_R$
$p_{t_{min}} > 10$ for $e^-_R e^+_L$

1 million of events per sample

- Then the events are passed to the **PYTHIA8** for the **parton shower** and the **hadronisation**

ANALYSIS CHAIN

- **Analysis is done using truth particles - No detector simulation**

1. **Semi-leptonic** events are selected keeping only **1-lepton events** $e^+e^- \to t\bar{t} \to l\nu qqb\bar{b}$

2. Stable particles are passed to **FastJet** -> Reconstruction of the 4 jets using **k_t algorithm with R = 1.5 exclusive clustering mode**

3. **b-tagging**: look for the **closest jets to the b and $\bar{b}$ Monte Carlo particles**.

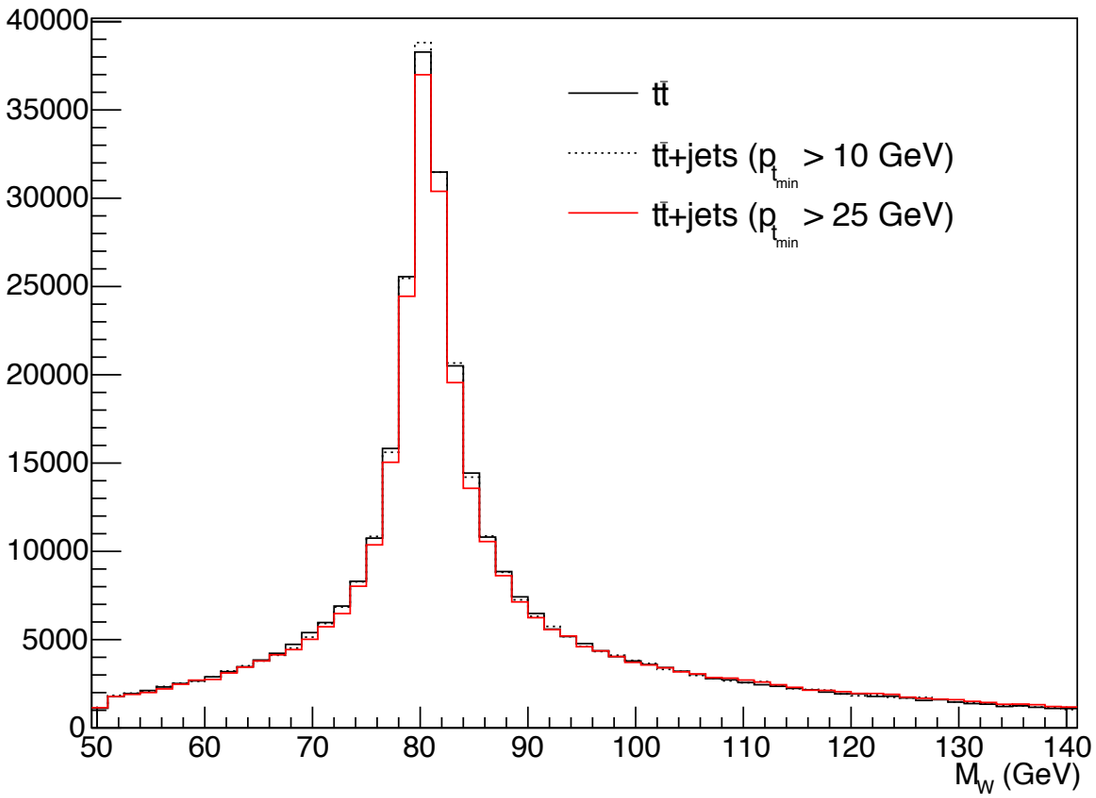
4. Top candidates are reconstructed using the χ^2 **method** (as always)

$$d^2 = \left(\frac{m_{cand.} - m_t}{\sigma_{m_t}}\right)^2 + \left(\frac{E_{cand.} - E_{beam}}{\sigma_{E_{cand.}}}\right)^2 + \left(\frac{p_b^* - 68}{\sigma_{p_b^*}}\right)^2 + \left(\frac{cos\theta_{bW} - 0.23}{\sigma_{cos\theta_{bW}}}\right)^2$$

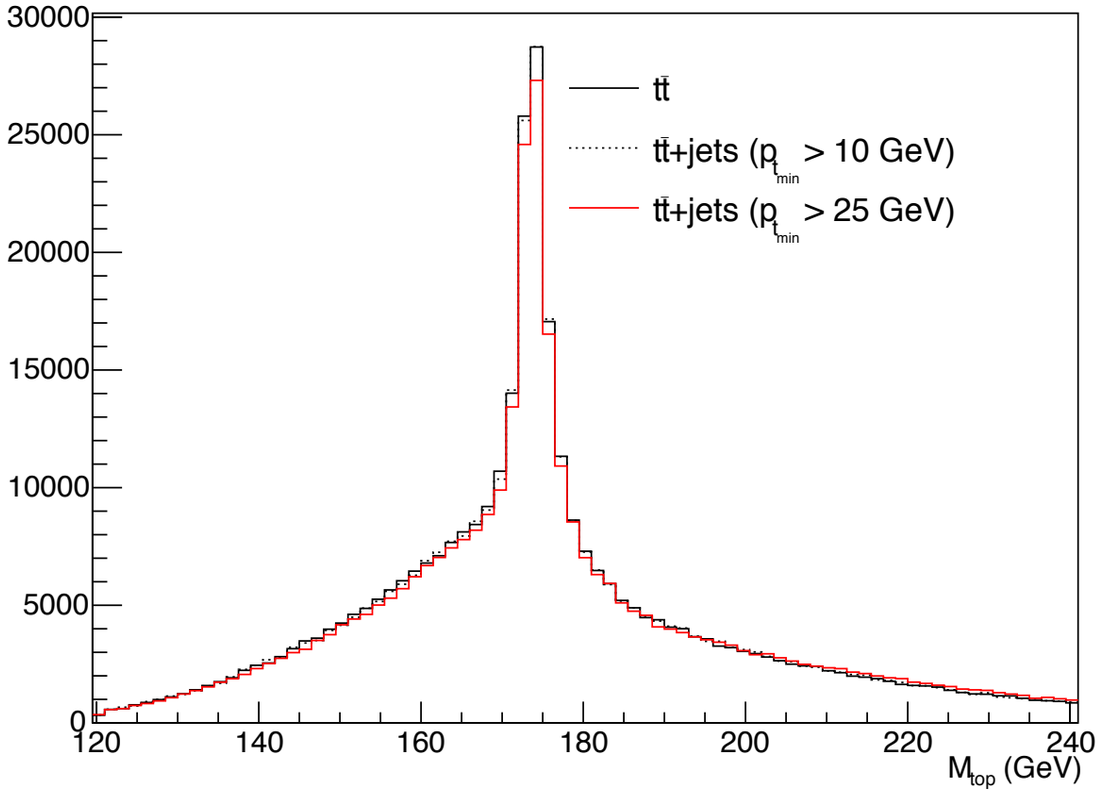
6. Similar cuts are applied.
   - **$180 < M_{had} < 420$ GeV**
   - **$50 < M_W < 120$ and $120 < M_{top} < 270$ GeV**

Maintaining the maximum similarity with the previous analysis

Validation and systematic uncertainties



Reconstructed W mass

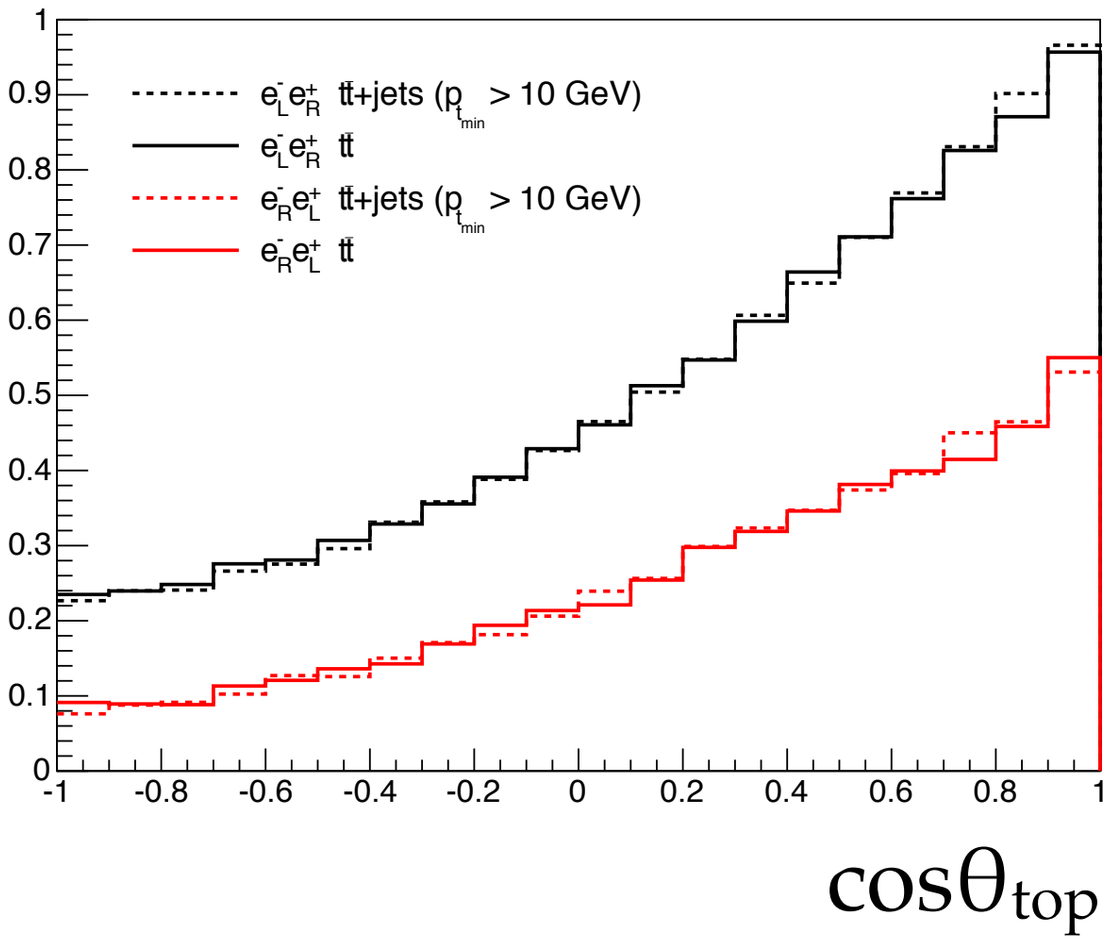


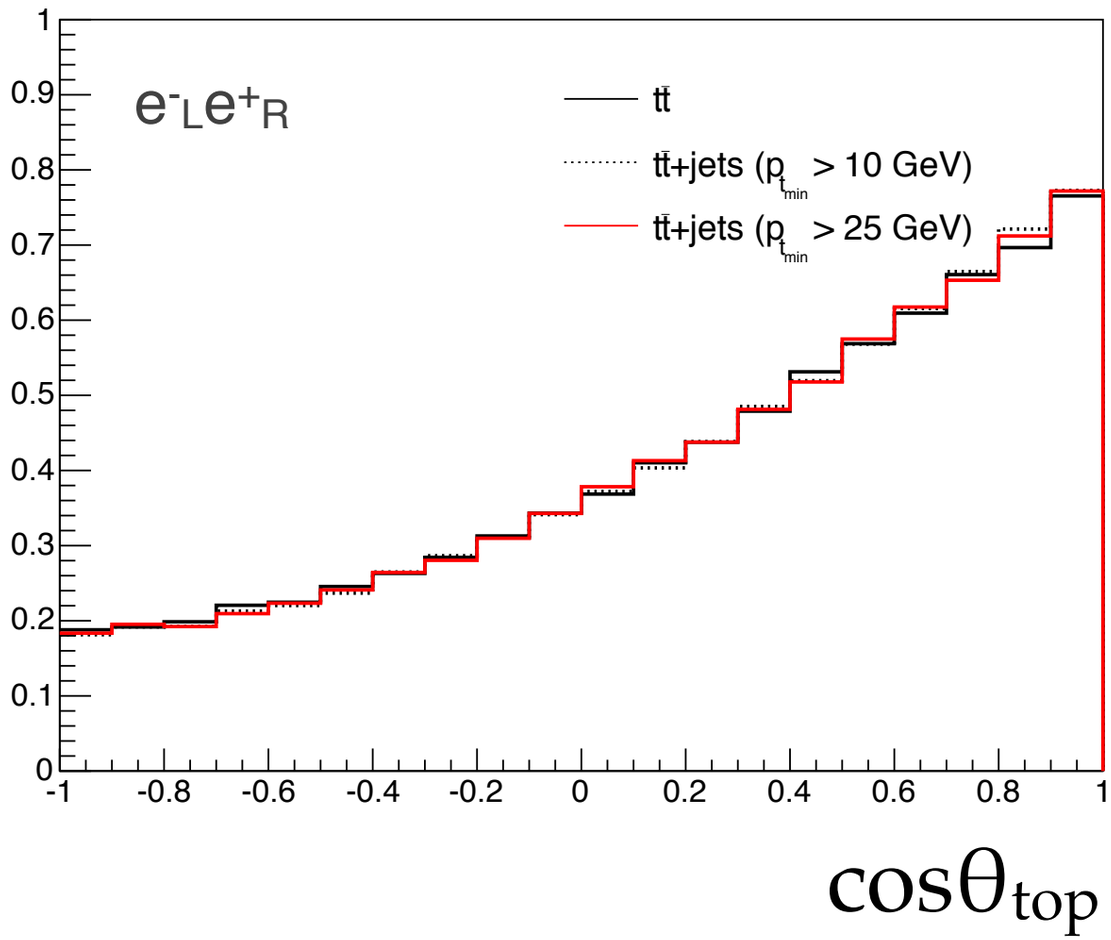
Reconstructed top mass

Mass distributions are practically not affected by the matched additional jets

Validation and systematic uncertainties

Forward-backward asymmetry





Differences between the matched and unmatched simulations are small

Therefore we can consider that the event generation with WHIZARD 1.95 is sufficiently accurate

Modelling uncertainties

Efficiencies of selection

$p_{t_{min}}$ (GeV)	Efficiency (%)	Efficiency $\chi^2 < 15$ (%)
10	87,1	36,7
15	86,9	36,3
20	86,9	36,4
25	86,7	35,7
unmatched $t\bar{t}$	86,8	36,7

After selection cuts

Quality cut

Uncertainty in the selection efficiency is 0.3%

The effect of the modelling is increased with the quality cut which goes to 1% for $\chi^2 < 15$

Forward-Backward Asymmetry

$p_{t_{min}}$ (GeV)	$(A^t_{FB})_{gen}$	A^t_{FB}	A^t_{FB} $\chi^2 < 15$
10	0,3944	0,3332	0,390
15	0,3963	0,3300	0,391
20	0,3917	0,3269	0,386
25	0,3925	0,3254	0,389
unmatched $t\bar{t}$	0,3895	0,3259	0,382

Statistical uncertainty ~0.5% on these numbers

Maximum variation (relative) about 2%

Conclusions

- **Single top** has a **significant impact** in the **measurement of the top quark properties** when in $e^+e^- \to t\bar{t}$ samples are analyzed
- **Single top** events **cannot be fully separated from** $t\bar{t}$ final states
- **We claim to calculate** $e^+e^- \to WbWb$ **to high orders (NLO, NNLO, etc…) instead** of $e^+e^- \to t\bar{t}$
- **Matrix Element matching** procedure has **not a large impact** in the cross-section and the A_{FB}

THANK YOU FOR YOUR ATTENTION

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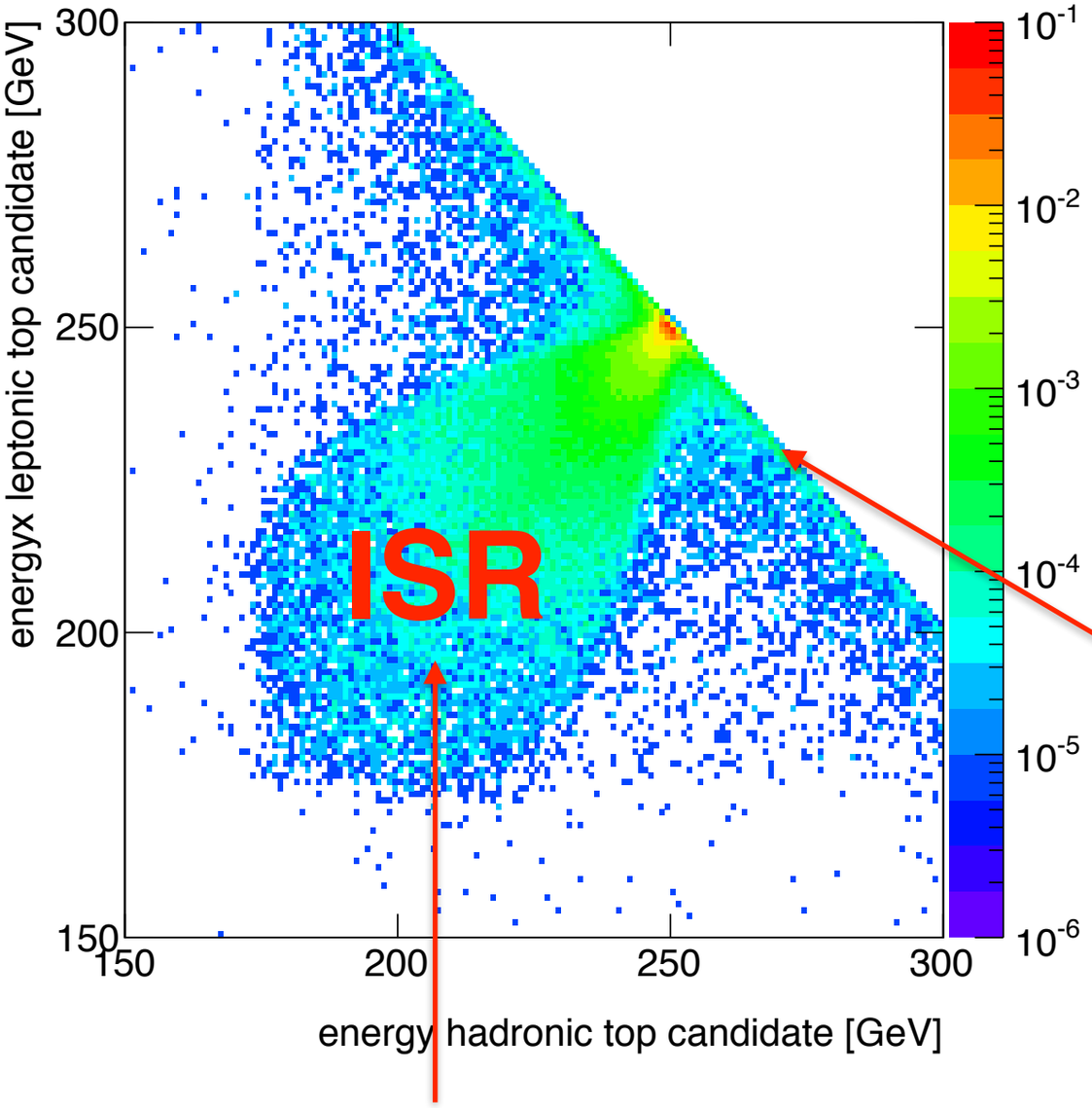
Distinguishing single top from $t\bar{t}$ production



$E_{lep}+E_{had}+E_{ISR} = \sqrt{s}$

- We also generated $e^+e^- \rightarrow W^+bW^-\bar{b}$ events with **WHIZARD** at √s = 500 GeV including ISR
- Only **semi-leptonic decays** are selected
- Significant fraction of events in the diagonal —> **Mostly single top events**

$E_{lep}+E_{had} = \sqrt{s}$

Potential criterium for the partial separation of single and double-top events