ILD ANALYSIS & SOFTWARE MEETING - 8TH FEB

TOP QUARK MASS MEASUREMENT USING RADIATIVE EVENTS – STATUS AND OUTLOOK

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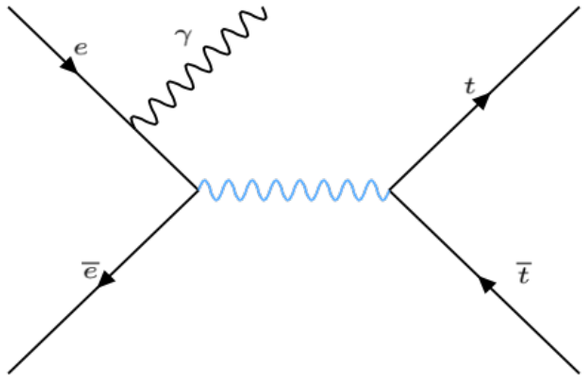
BRIEF RECAP:

OBSERVABLE & PARTON/ PARTICLE RESULTS

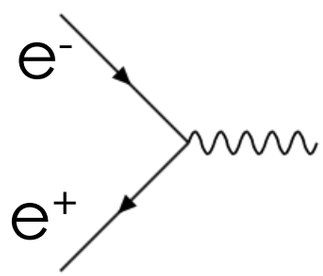
INTRODUCTION TO THE OBSERVABLE: ISR

- The idea is to measure the top-quark mass (m_t) measuring the differential cross section of the process $e^-e^+ \rightarrow$ ttbar γ_{ISR}



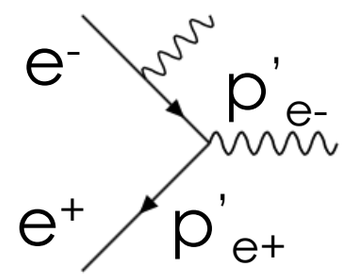
- The ttbar production cross section is sensitive to the center of mass energy and m_t

$$\sigma(e^+e^- \rightarrow t\bar{t}) = f(s, m_t)$$



$$s = (p_{e^-} + p_{e^+})^2$$

$$\sigma(e^+e^- \rightarrow t\bar{t}\gamma) = f(s', m_t)$$



$$s' = (p'_{e^-} + p'_{e^+})^2$$

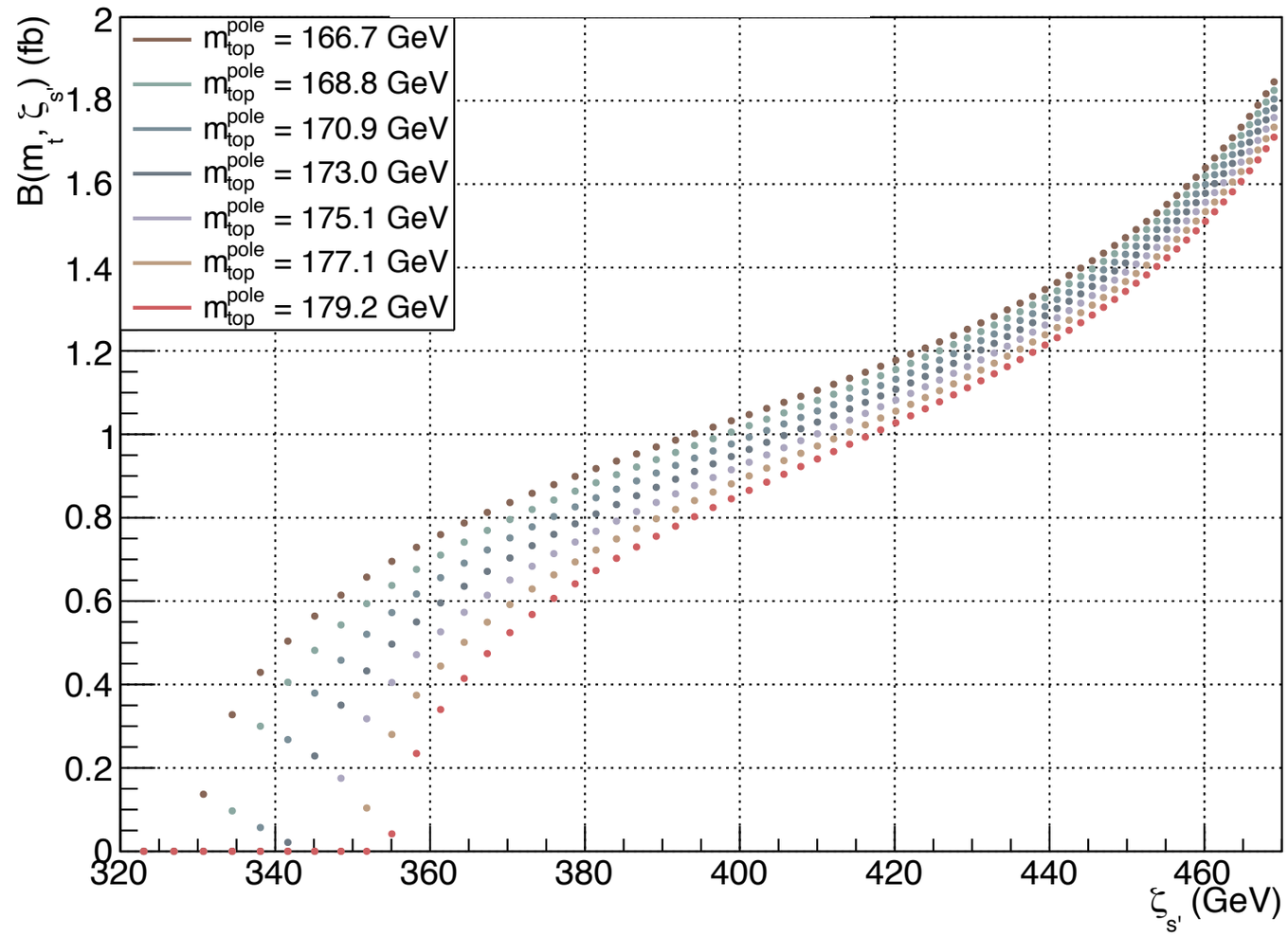
- The emitted γ_{ISR} reduce the available energy for the ttbar production
- Therefore the ttbar production cross section is sensible to the emitted ISR photon energy in the ttbar + γ_{ISR} production

INTRODUCTION TO THE OBSERVABLE: ISR (II)

- m_t can be measured by counting the ttbar events produced for a certain s′ (i.e ISR energy photon, which can be measured with high precision)

$$B(m_t, \zeta_{s'}) = \frac{d\sigma_{t\bar{t}\gamma}}{d\zeta_{s'}} \longrightarrow \zeta_{s'} = \sqrt{s'}$$

$$s' = s\left(1 - \frac{2E_\gamma}{\sqrt{s}}\right)$$

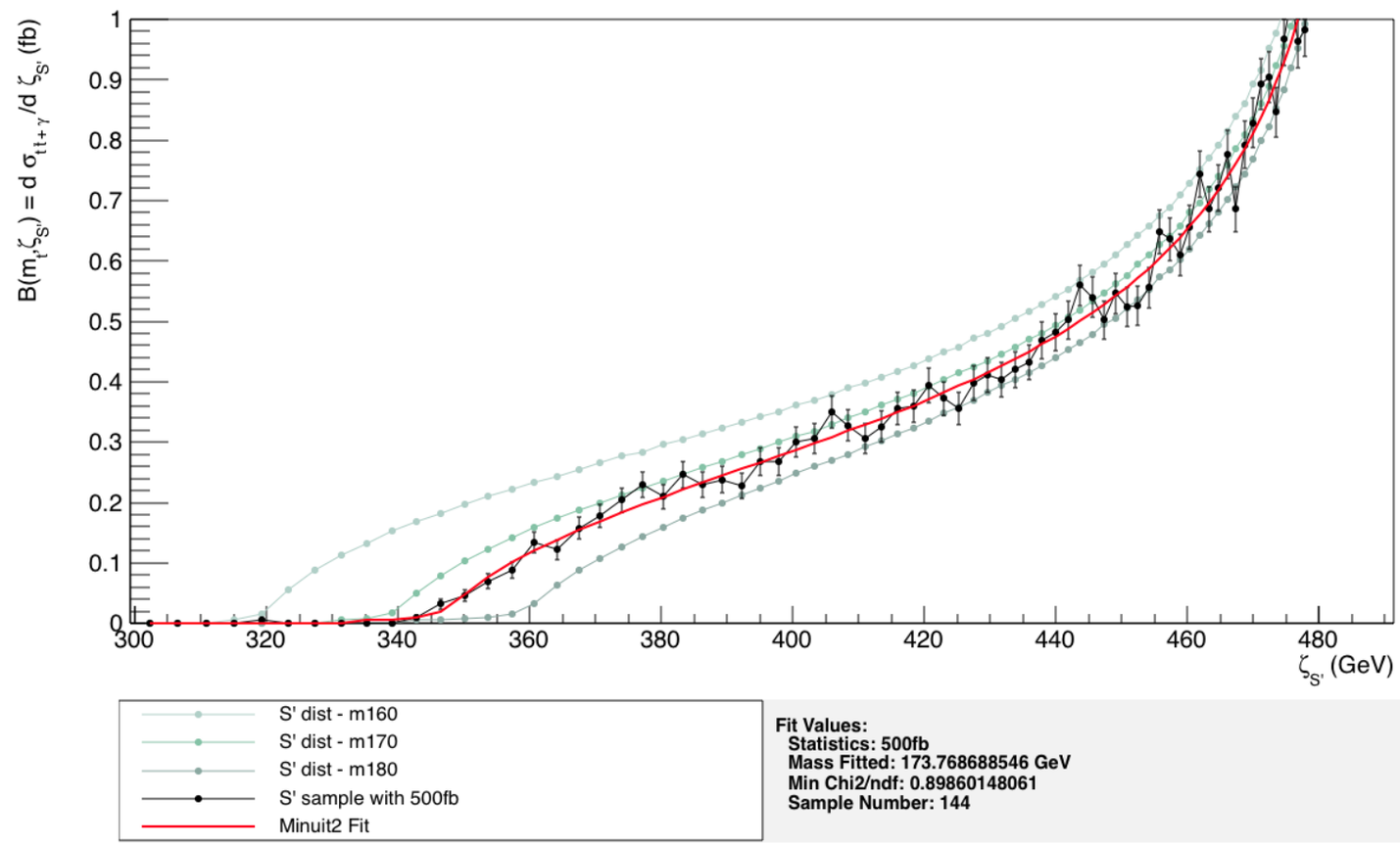


- Our observable $B(m_t, \zeta_{s'})$ is the differential cross section of the ttbar production as a function of $\zeta_{s'} = \sqrt{s'}$
- The observable is more sensitive to m_t near the top production threshold, and the dependence diminishes as $\zeta_{s'}$ grows

RESULTS AT PARTON LEVEL

PARTON LEVEL STUDY: PROCEDURE

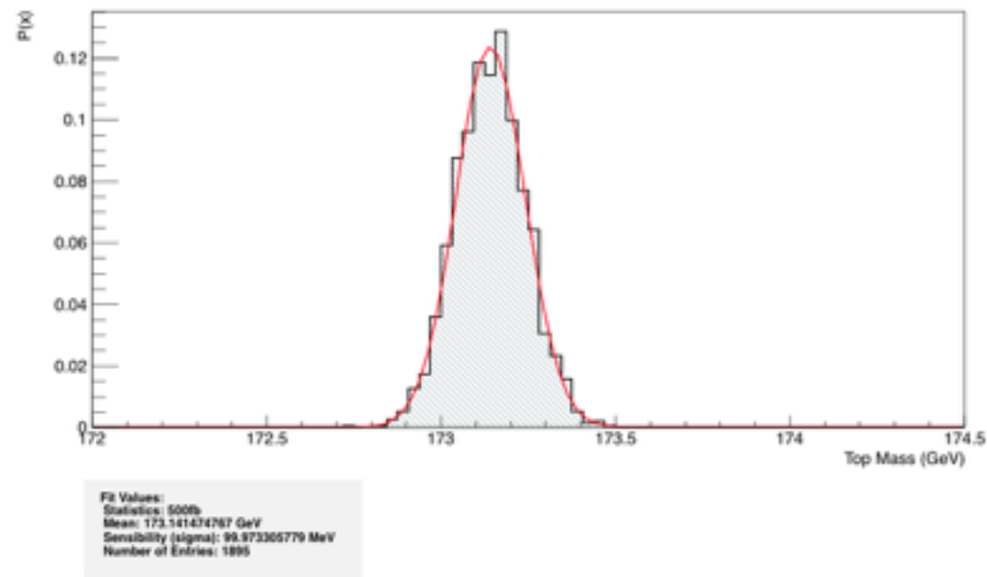
- A study to test the potential of the observable was produced using Pythia 8.1
- $e^-e^+ \rightarrow$ ttbar unpolarized events with ISR were produced at parton level
- From the energy spectrum of the ISR photons we obtained the observable curves



- For the study we produced reference curves (with high statistics) and datasets (for certain luminosities)
- A template fit of N (~100 - 500) datasets to the reference curves was performed in order to estimate the observable's sensitivity

PARTON LEVEL STUDY: RESULTS

- From these template fits the top quark mass is estimated as the mean of the distribution and its error as the standard deviation
- The input MC mass is m_t = 173.1 GeV



s = 500 GeV	Reconstructed mass	
Integrated Luminosity	m_t (GeV)	Δm_t (MeV)
500 fb^{-1}	173.158	155
1000 fb^{-1}	173.140	103
2600 fb^{-1}	173.133	61

RESULTS AT PARTICLE LEVEL

PARTICLE LEVEL STUDY: PROCEDURE

- To increase the realism of the study, photons are identified using selection criteria
- Only photons with polar angle $7° < \theta < 173°$ are considered, due to detector coverage
- As high-energy ISR emission is usually collinear to the emitter, a good portion of the statistics are lost

	380 GeV	500 GeV	1000 GeV
ISR lost	71%	74%	79%

- ISR photon are separated from photons originated in the decay chain of particles by imposing energy ($E_\gamma > E_0$) and isolation angle cuts ($\varphi > \varphi_0$)
- The following cuts are chosen:

Cut	380 GeV	500 GeV	1000 GeV
E_0	3	10	30
φ_0	8°	8°	4°

PARTICLE LEVEL: RESULTS

- Similarly to the parton study, the reference curves are constructed to perform template fits over N datasets (with m_t = 173.1 GeV), resulting in:

s (GeV)	Luminosity (fb^{-1})	m_t (GeV)	Δm_t (MeV)
380	500	173.141	100
500	500	173.327	294
500	4000	173.122	100
1000	1000	173.381	639
1000	3500	173.197	388

FULL SIMULATION STUDY: STATUS

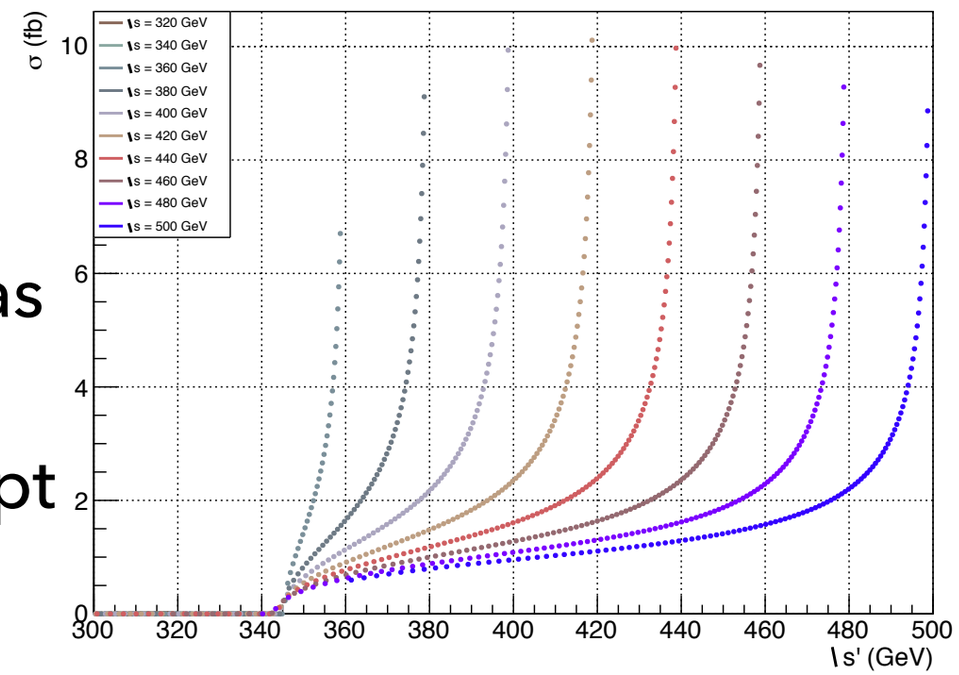
WORK IN PROGRESS: COMPREHENSIVE STUDY

- Given that the observable shows great potential a comprehensive study is being done
- A theoretical framework in a well defined mass scheme is being developed by A. H. Hoang and V. Mateu
- Studies to correct the effects of the luminosity spectrum smearing are being performed
- To accommodate detector effects full simulation DST samples of 6f_ttbar at ILD have been examined
- We are revisiting (and reoptimizing) the selection criteria for the photon-like PFOs in the full simulation sample

THEORETICAL MODEL

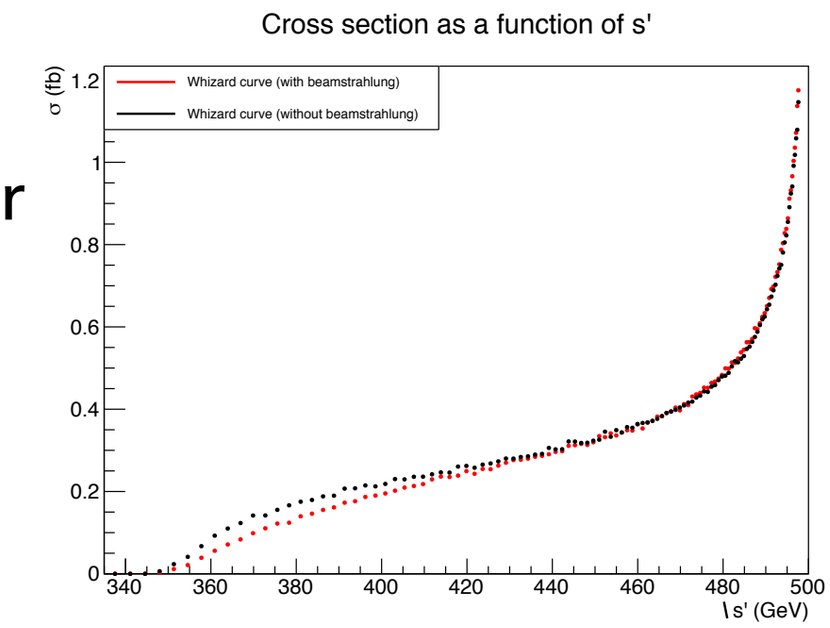
- A factorization theorem valid at $O(\alpha_{QED})$ and to all orders in α_s (beyond perturbation theory) has been stablished by A. H. Hoang and V. Mateu in which the observable can be calculated analytically:

$$B(m_t, \zeta_{s'}) = \sigma_{ISR}(s) * \sigma_{ttbar}(m_t, s')$$

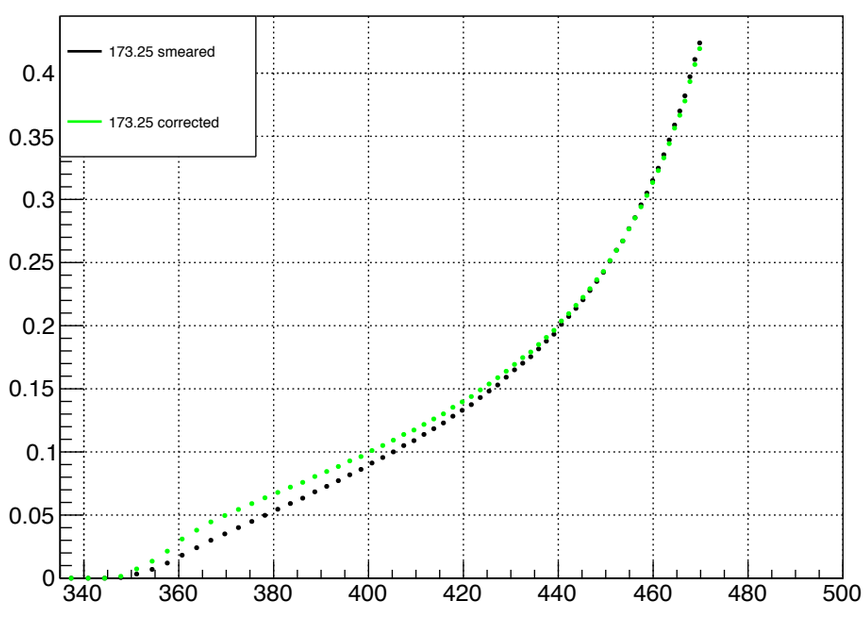


- A simple calculation taking the inclusive $e^-e^+ \rightarrow$ ttbar cross section at tree level has been successfully performed (cross-checked with Pythia) to prove the concept
- Work in progress:
  - Perform an analytic computation of the complete $e^-e^+ \rightarrow$ ttbar γ process to pin down how much ISR dominates over FSR plus ISR/FSR interference terms
  - Interface TOPPIK with the factorization theorem to explore the region of best mass sensitivity

LUMINOSITY SPECTRUM



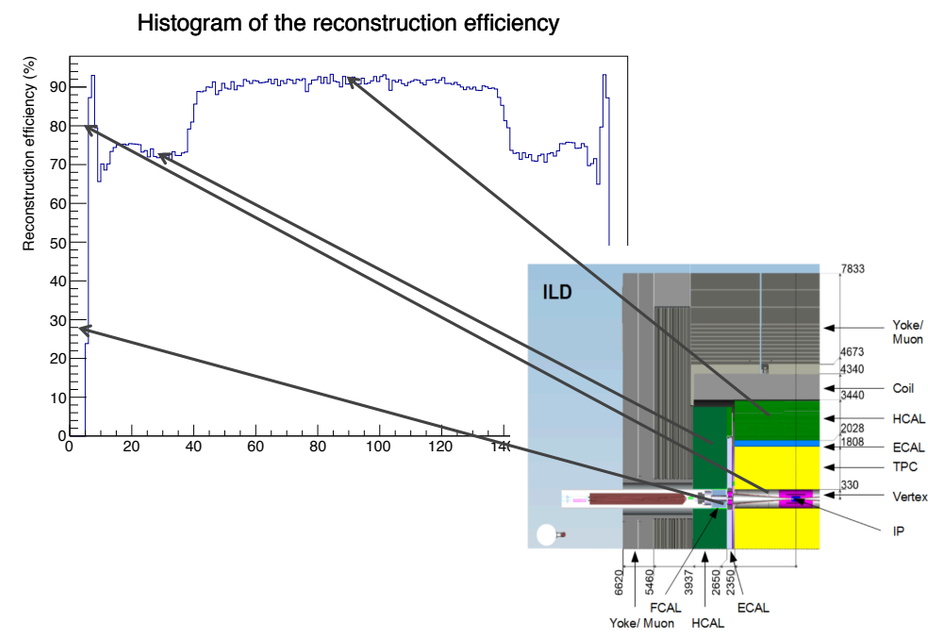
- In our previous studies we considered s known and fixed to nominal value, nonetheless, in linear accelerators the luminosity spectrum is smeared
- A temporal solution with a bin by bin correction is currently available
- When applying the correction to a dataset with beamstrahlung and m_t = 173.25 GeV and perform the template fit, the mass gets shifted by 30 MeVs (m_{FIT} = 173.279 GeV)

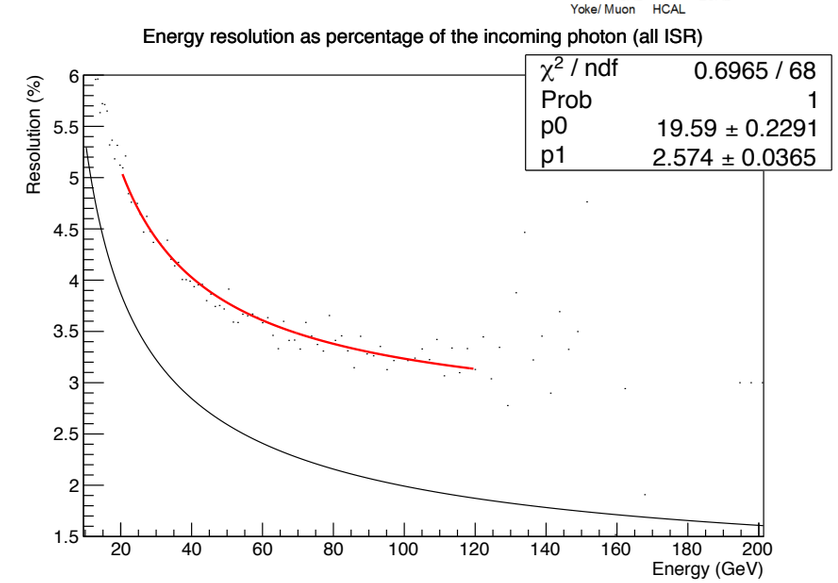


- Work in progress:
  - A more robust correction will be implemented by folding the luminosity spectrum with the theoretical calculation in the future
  - The propagation of the luminosity spectrum uncertainty to the correction has yet to be implemented

DETECTOR CONSIDERATIONS

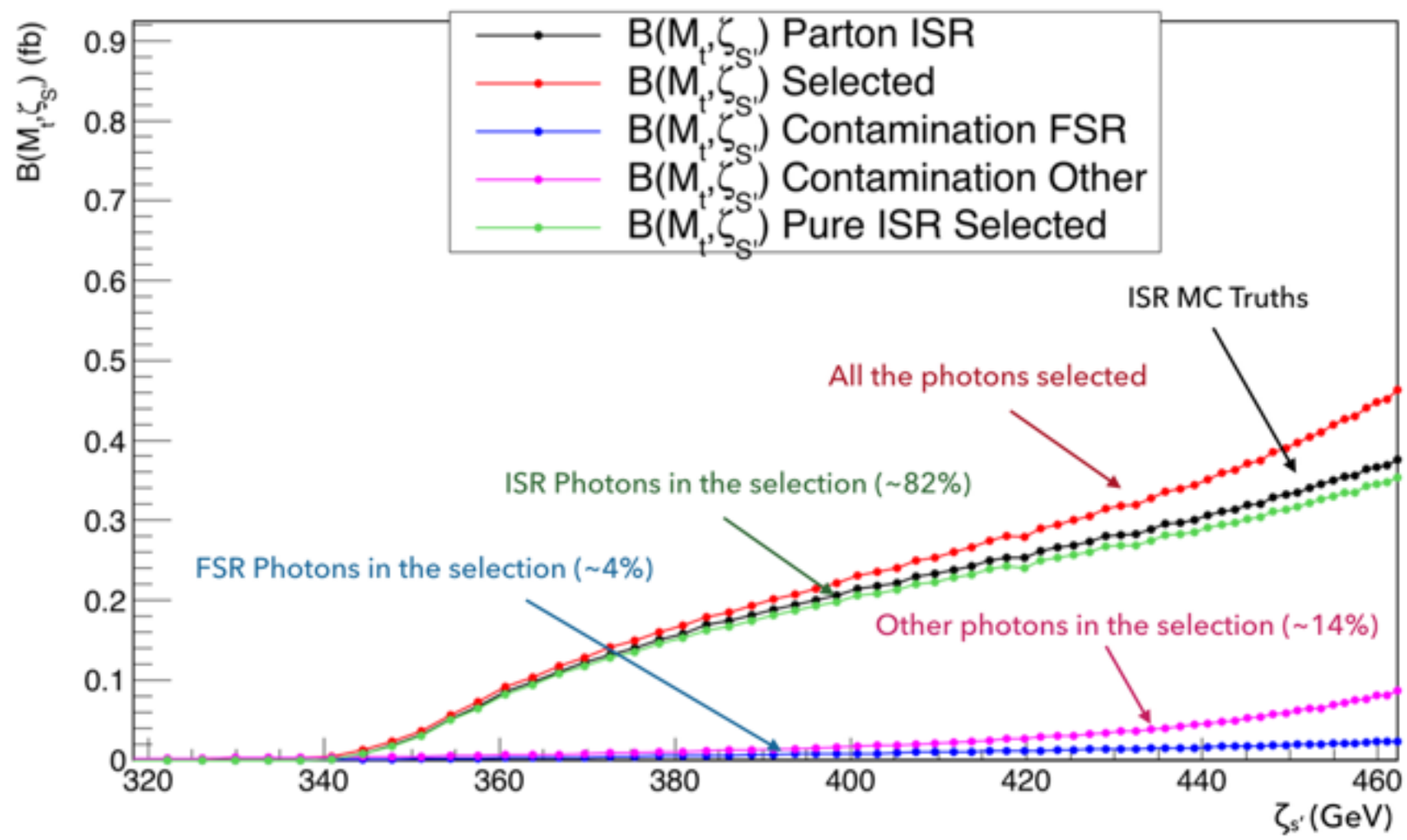
- To estimate detector effects we are studying 6f_ttbar DST samples decaying in semileptonic channels generated with ILCSoft v01-16-p05_500 (10.8 M events, available at the ILCdirac framework)
- Following the ISR MC truth photons in the simulation we find:
  - Detection efficiency is flat in energy (~80%), angularly ranging from 70% in the endcap to 90% in the petals and the barrel
  - Energy resolution found differ significantly to the nominal value of the ECAL
- These sub-optimal efficiencies and resolutions can be explained by the "scattering" of photons into multiple particles by PandoraPFO in these samples
- New samples with the improved PandoraPFO are needed in order to reevaluate the detector effects





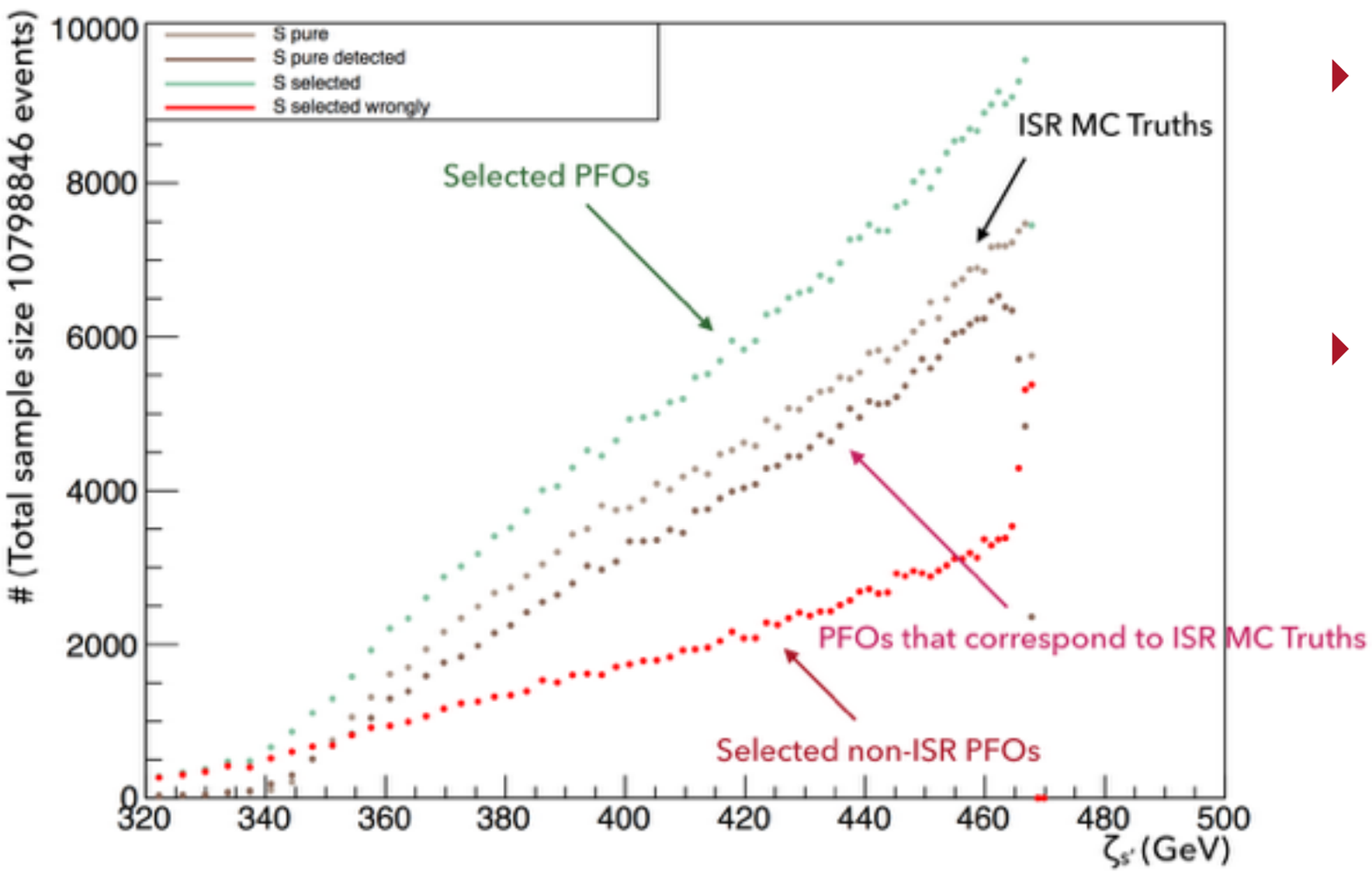
OPTIMIZING THE SELECTION: PARTICLE LEVEL

- In order to maximize the purity of the selection we studied the optimal selection of ISR photons
- As we expect the detector only to smear the energy resolution of the photons, we study the optimization the selection at particle level (Whizard 2.3.0)
- Finally, we select as ISR photon the most energetic photon-like PFO in the visible region (6° < θ < 174°) that has more than 30 GeV of energy and its isolated by at least 8°



APPLYING THE SELECTION ON THE FULL SIM.

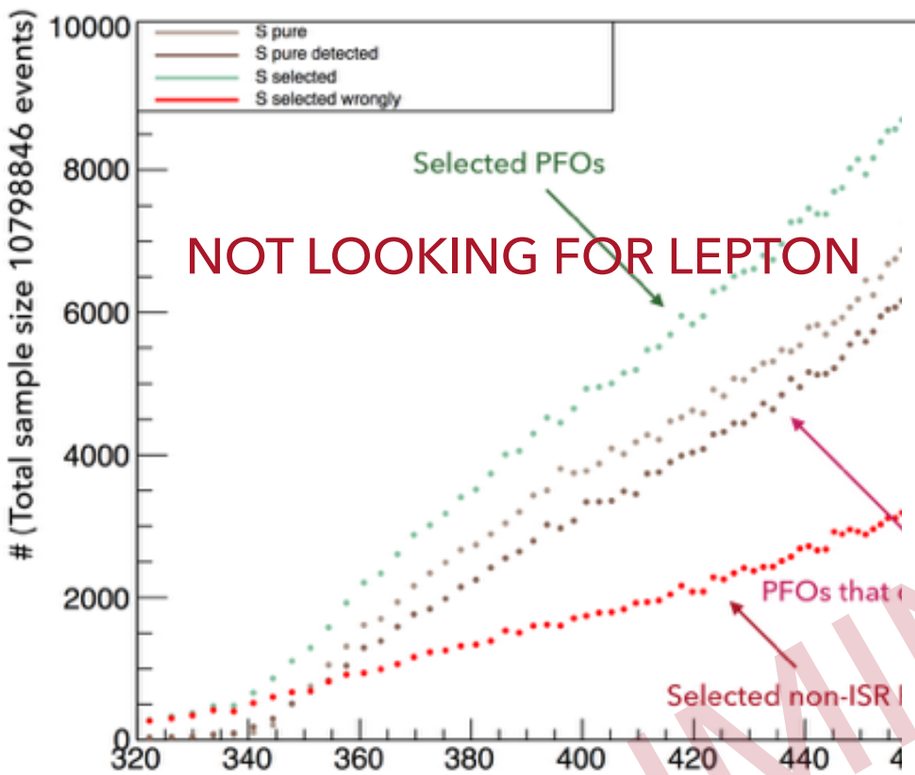
- As many other particles appear as a result of decays in the detectors, isolation angle is no longer a good observable to perform the selection cuts
- A scan to reoptimize the selection in the full simulation is performed, finding these cuts as optimal: $6° < \theta < 174°$, $E > 30$ GeV, $P_t < 120$ GeV, %E (< 2°) < 10%, %E (< 5°) < 10%, %E (< 10°) < 20%



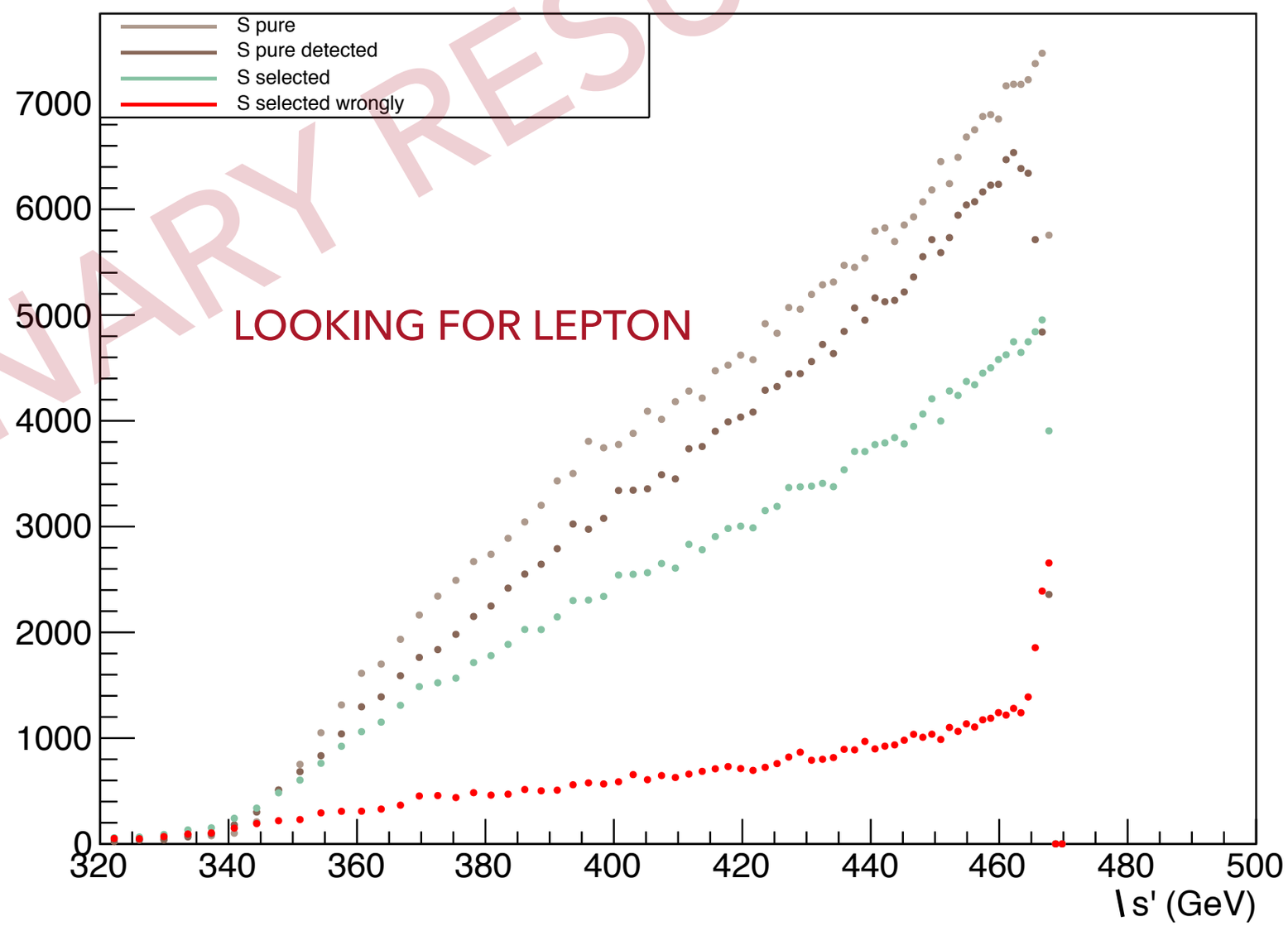
- With this selection we achieve efficiencies of ~92% and purities around ~60%
- A significant number of high energy photon-like PFOs not present in the WHIZARD simulations appear in the full simulation sample

SELECTION: PRELIMINARY RESULTS

- By looking for an isolated lepton as an extra criteria in the selection (as these are semileptonic decays), the background in our selection is highly reduced



Counts as a function of s'



- This could mean that some of the leptons are being reconstructed as photon-like PFO.

FULL SIMULATION STUDY: OUTLINE

NEXT STEPS

- Cluster the 6f_ttbar sample in 4-jets and B-tag them in order to reconstruct the ttbar pairs, and include the reconstruction process into the selection criteria
- Further investigate the high energy photon-like PFOs found in the full simulation sample: launch some ILCDirac jobs to track them down to their parton/particle level parents
- Reevaluate detector effects with the new full simulation samples when they become available

NEXT STEPS

- Take into account the uncertainty of the luminosity spectrum to properly eavluate the systematics due to the luminosity smearing
  - A new postdoc in our group (E. Fullana) is trying to reproduce the results from André Sailer thesis in order to produce estimators for the uncertainties at different energies
- Once the theoretical framework is ready to go:
  - Correct the luminosity spectrum smearing by folding it with the theoretical calculation, instead of using the bin by bin correction
  - Fit the full simulation data samples to the theoretical model to find a good estimator of what can be achievable in the actual experiment

SUMMARY

- As seen in the parton and particle level studies, we can obtain measurements in the order of 100-200 MeVs of statistical precision for the different phases of ILC/CLIC in the continuum
- By combining the ISR (photon) and FSR (extra jet) measurements we expect to have a final resolution of the top quark mass in the order of 100 MeVs
- A comprehensive full simulation study is under development:
  - Evaluating and correcting the systematics (selection criteria, luminosity spectrum smearing, theoretical uncertainties)
  - Impact of the detector: new samples with the newer PandoraPFA version are needed to reevaluate the impact of the detector
- In all these studies we assumed unpolarized beams, considering them will result in a good increase of the statistics

THANKS FOR YOUR ATTENTION