INTERNATIONAL WORKSHOP ON FUTURE LINEAR COLLIDERS 2017

TOP QUARK MASS IN THE CONTINUUM

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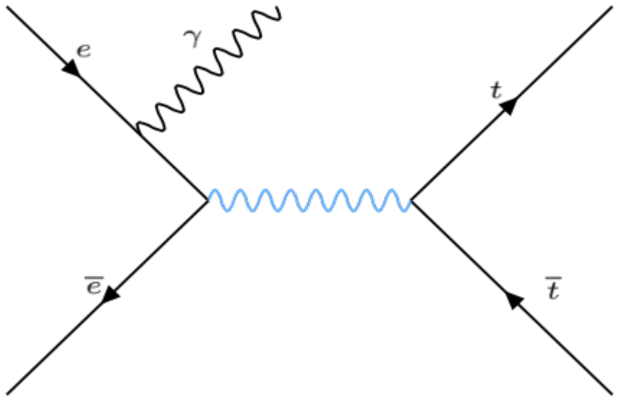
WITH MUCH APPRECIATED CONTRIBUTIONS FROM A. SAILER

MOTIVATION

- High-precision measurement of the top-quark mass in the continuum of an e^-e^+ linear collider.
- Sensitivity to the top-quark mass over a large range of production energies.
- Direct measure of the top-quark mass, complementary to the threshold measurement.
- Measurement of the top-quark mass in a well defined theoretical scheme.

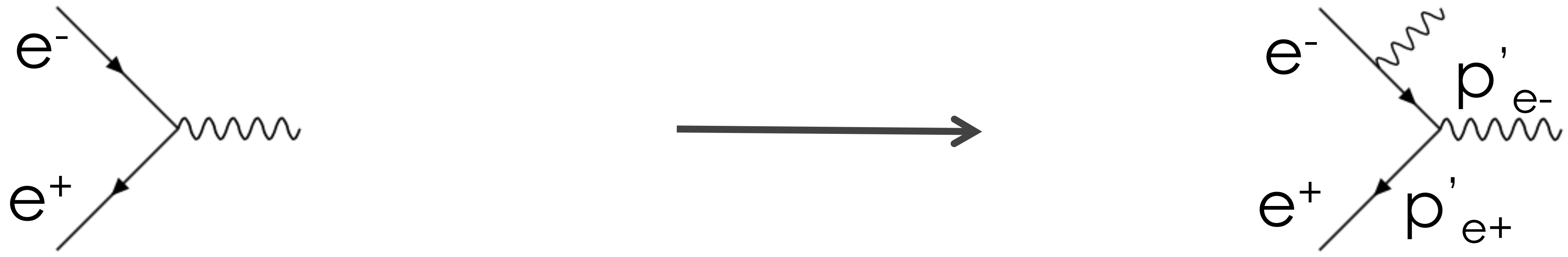
INTRODUCTION TO THE OBSERVABLE: ISR

- The idea is to measure the top-quark mass (m_t) measuring the differential cross section of the process $e^+e^- \rightarrow t\,\bar{t}\,\gamma_{\mathrm{ISR}}$.



- The $t\,\bar{t}$ production cross section is sensitive to the center of mass energy and m_t:

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



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

- The emitted γ_{ISR} reduces the available phase space for the $t\,\bar{t}$ production.

- Therefore the ttbar production cross section is sensitive to the emitted ISR photon energy in the $t\,\bar{t}\,\gamma_{\mathrm{ISR}}$ production.

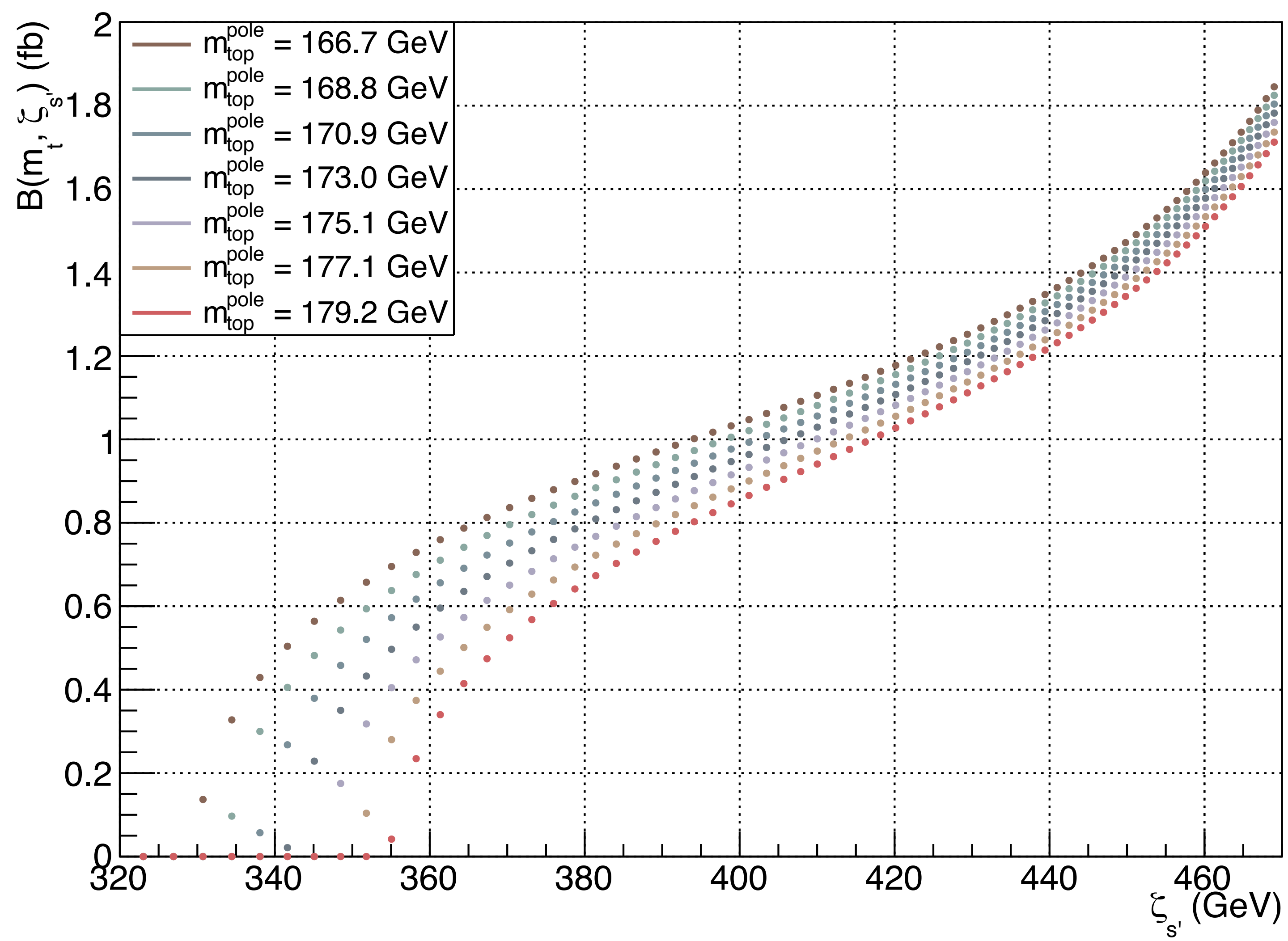
INTRODUCTION TO THE OBSERVABLE: ISR (II)

- m_t can be measured by counting the $t\bar{t}$ events produced for a certain s′ (i.e ISR energy photon):

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

- Our observable B(m_t, $\zeta_{s'}$) is the differential cross section of the $t\bar{t}$ production as a function of $\zeta_{s'} = \sqrt{s'}$.

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



- The observable is more sensitive to m_t near the top production threshold, and the dependence diminishes as $\zeta_{s'}$ grows.

PARTON AND PARTICLE LEVEL RESULTS

- Studies at parton and particle level were performed simulating $e^+e^- \to t\,\bar{t}\,\gamma_{\rm ISR}$ with Pythia 8.1.
- Template fits of 100-500 datasets to reference curves (high statistics datasets) were performed to estimate the observable sensitivity.

Parton level (s = 500 GeV)			
Luminosity (fb^{-1})	m_t (GeV)	Δm_t (MeV)	Δm_t (MeV, pol)
500	173.158	155	121
1000	173.140	103	80
2600	173.133	61	48

Particle level				
s (GeV)	Luminosity (fb^{-1})	m_t (GeV)	Δm_t (MeV)	Δm_t (MeV, pol)
380	500	173.141	100	78
500	500	173.327	294	229
500	4000	173.122	101	79
1000	1000	173.381	639	498
1000	3500	173.197	388	303

- For more information:

MARÇÀ BORONAT'S THESIS

PREVIOUS TALK AT TOP@LC 2016

- Stastical uncertainties of 100 - 200 MeV are within reach.

* pol ≡ extrapolated results for polarized beams p_{e-} = -80%, p_{e+} = +30% (64% bump in statistics)

WORK IN PROGRESS: COMPREHENSIVE STUDY

- Given that the observable shows great potential a comprehensive study is being done.
- Theoretical model uncertainty: a theoretical framework in a well defined mass scheme has been developed.
- Luminosity spectrum smearing: studies to reconstruct the luminosity spectrum (and estimate the error in the reconstruction) is being performed.
- Detector effects: full simulation DST samples of 6f_ttbar at ILD were examined in the past, and we are getting ready for the new samples that are on its way.

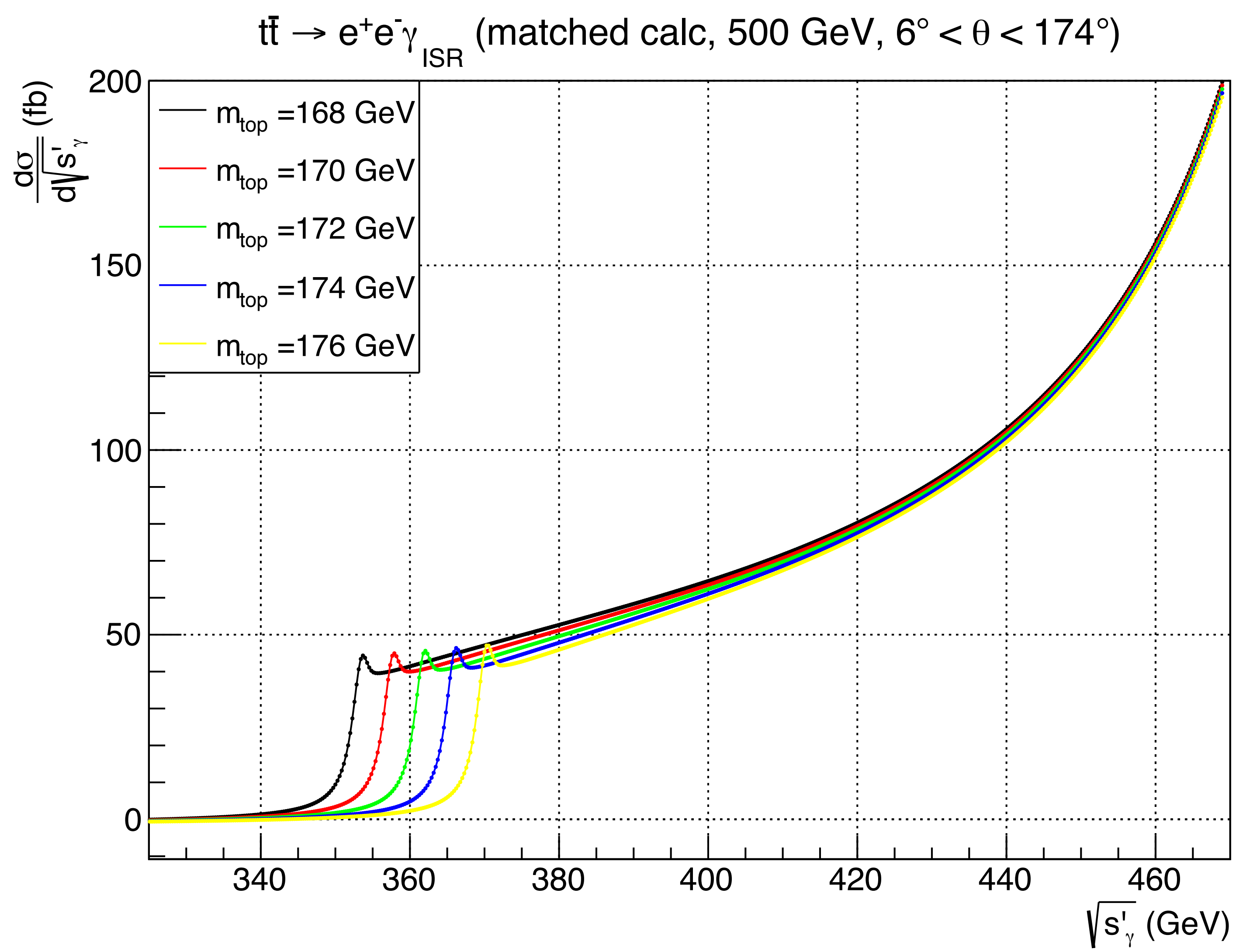
THEORETICAL MODEL: MATCHED CALCULATION

- 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:

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

- The model convolutes the ISR calculation with the threshold - continuum matched calculation presented by A. Widl.

- The model outputs the differential cross section of the $e^+e^- \to t\bar{t}\gamma_{\rm ISR}$ as a function of the photon energy and polar angle respect to the beampipe for a given top mass.



- For more information and details on the matched calculation:

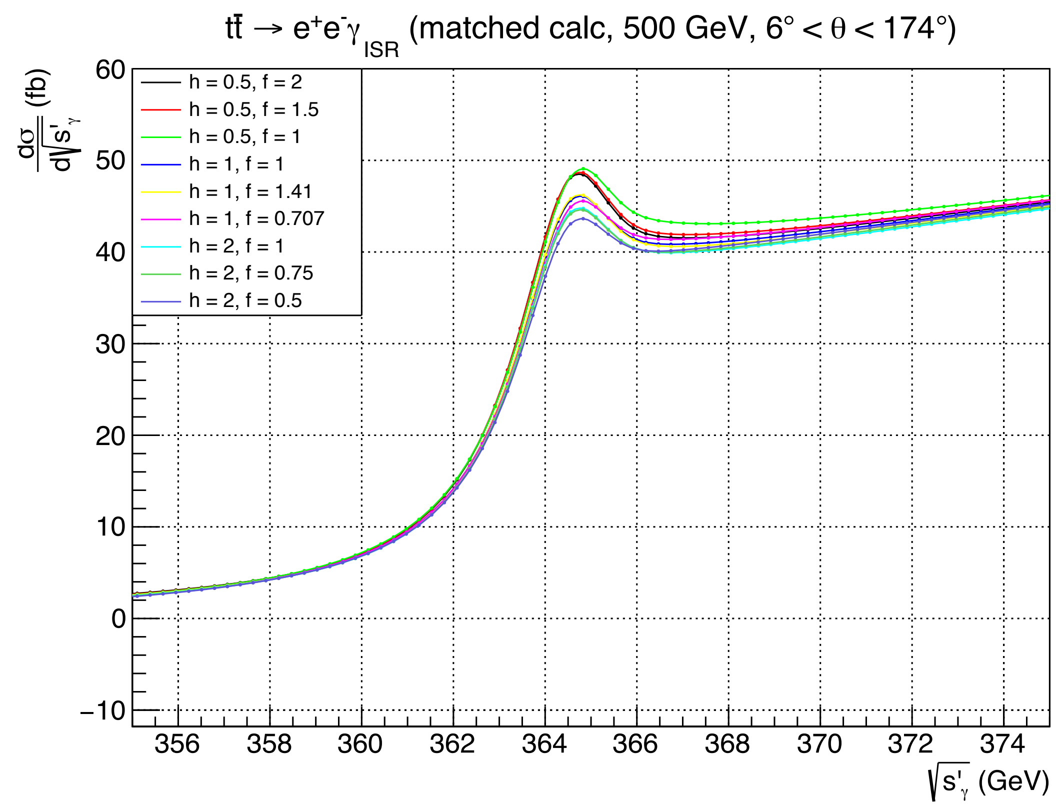
  ANGELIKA WIDL LCWS17 TALK

- The input for the top mass is in the form of $\overline{m}_t(\overline{m}_t)$. For the calculation itself the 1S and MSR masses are used.

THEORETICAL MODEL: UNCERTAINTY SOURCES

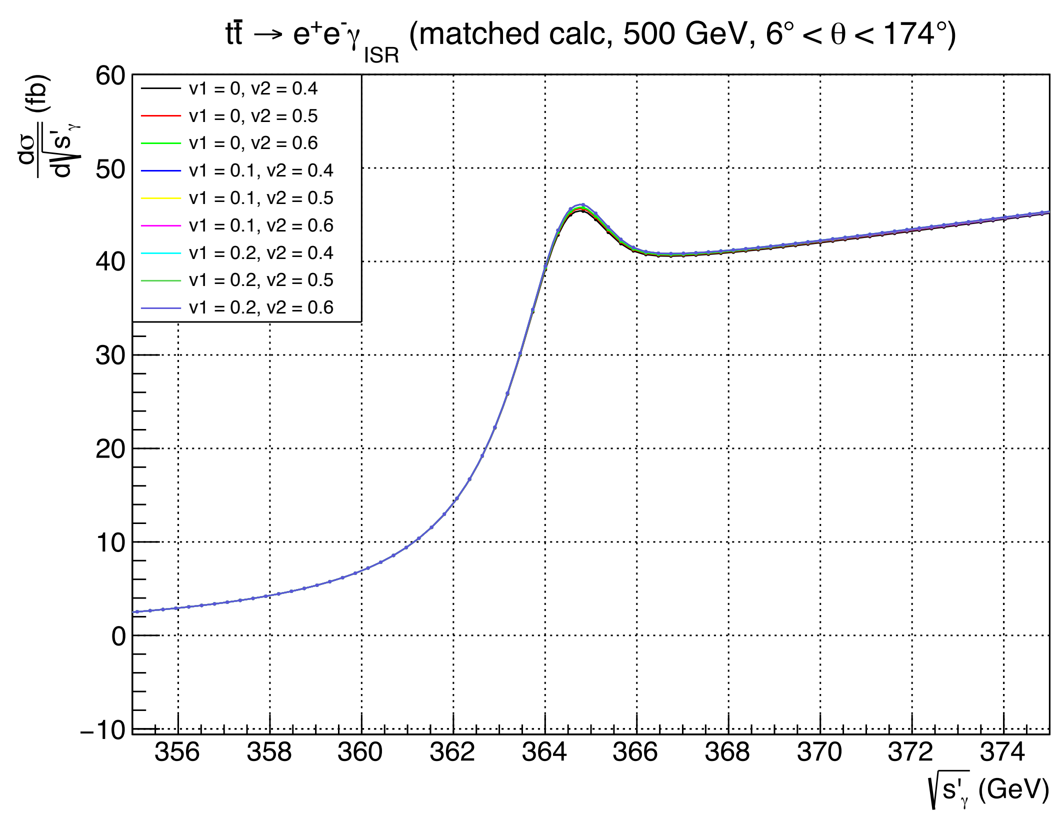
- The main sources of uncertainty in the matched calculation com from the hard, soft and ultra soft scales in the NRQCD calculation, which can be parametrized as a function of the h and f parameters.

Proposed scale parameters variations (A. Hoang , M. Stahlhofen)									
h	1/2	1/2	1/2	1	1	1	2	2	2
f	2	3/2	1	1	√2	√(1/2)	1	3/4	1/2

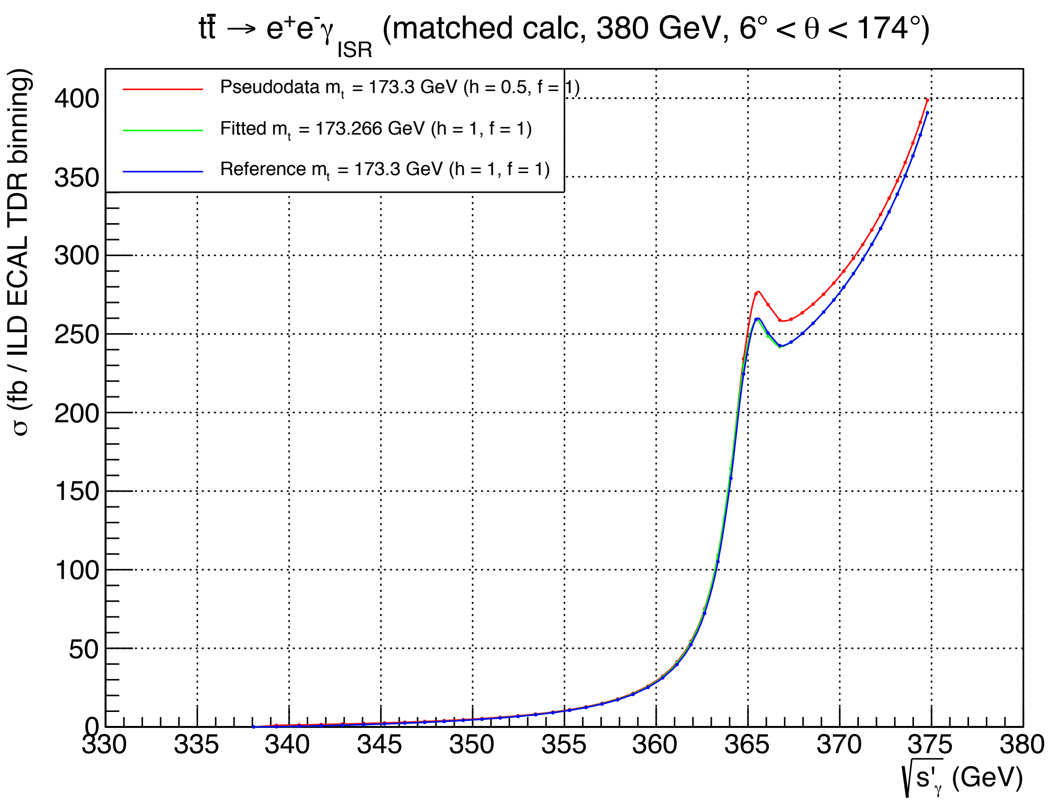


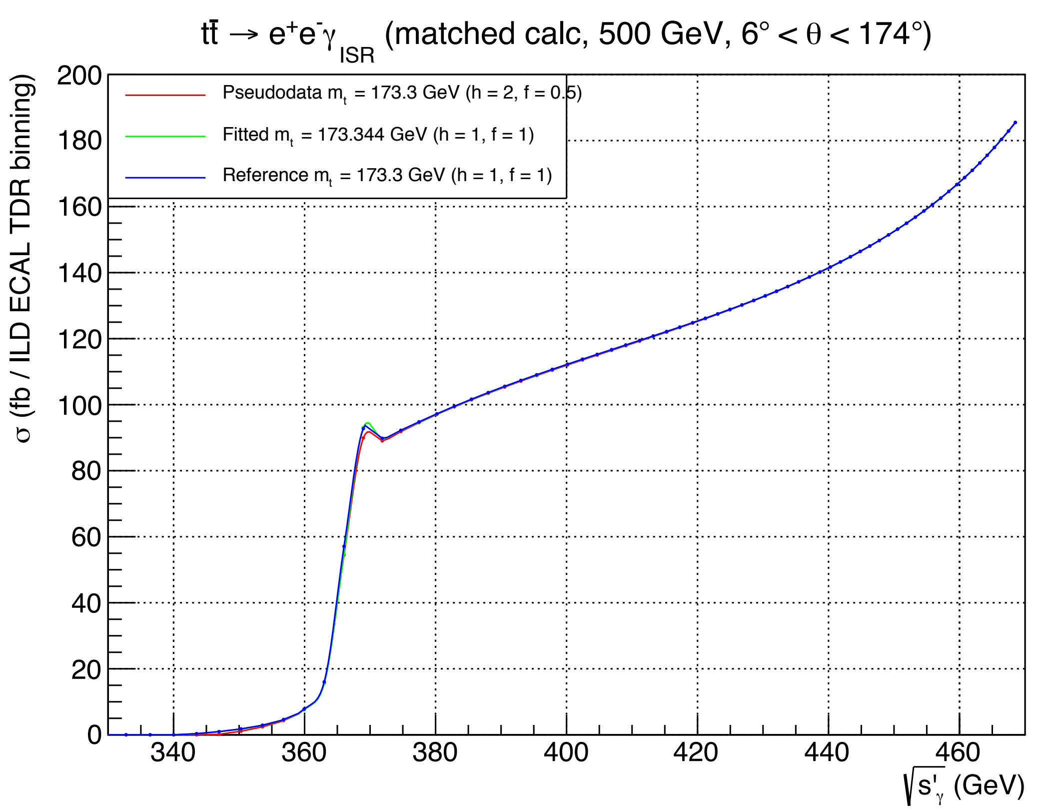
- Other potential source of uncertainty is the parameters of the switch-off function between the matched NRQCD and the fixed-order calculation: v1 and v2.

- By varying v1 between 0 and 0.2; and v2 between 0.4 and 0.6 we could see that the change on the distribution is negligible when compared with the scale changes.



THEORETICAL MODEL: FIRST ESTIMATIONS





- As a first approach to evaluating the theoretical uncertainty we perform a fit of the model with modified scales and a fixed top mass to the model with h=f=1 and the top mass as a parameter.

s (GeV)	h = 2, f = 1/2	h = 1/2, f = 1
380	173.347 GeV	173.266 GeV
500	173.344 GeV	173.268 GeV

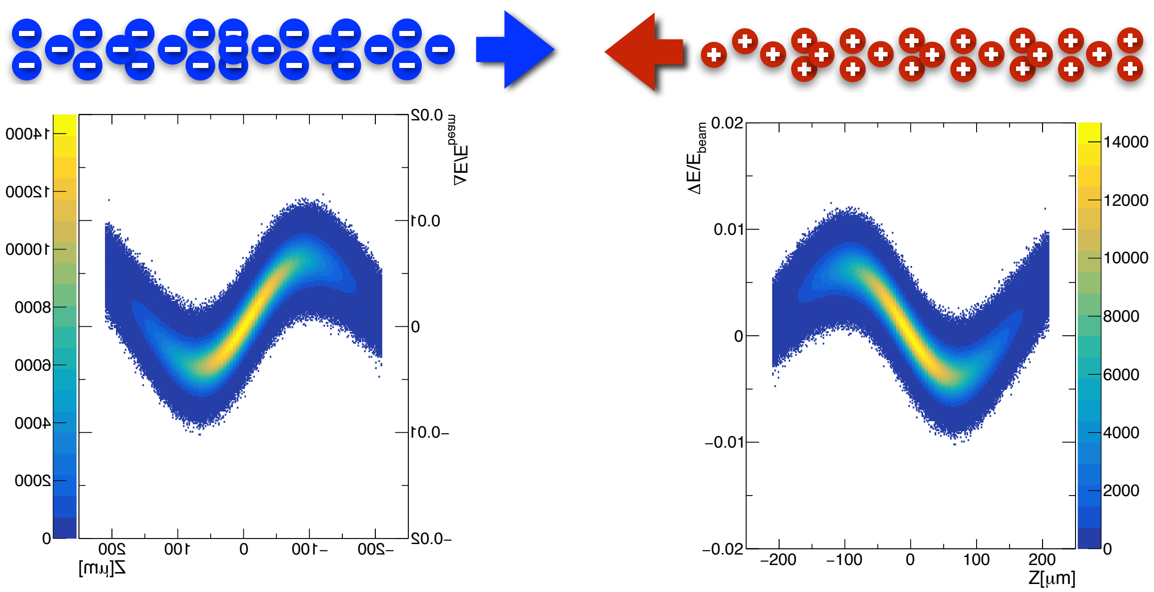
- As a first estimation we took (h, f) = (2, 1/2) and (1/2, 1) as they are the lower and upper limit to the scale variation envelope. The fits lead to a first estimation of ~50 MeV theoretical uncertainty for the model.

- Scales variations affect the distribution mostly in the magnitude of the threshold peak; whereas variations on the top mass move the distribution horizontally.

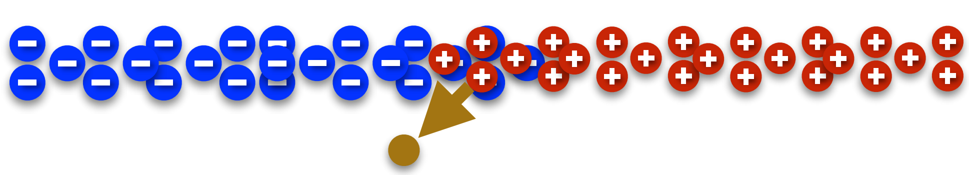
LUMINOSITY SPECTRUM SMEARING

- We considered s known and fixed to nominal value, nonetheless, the luminosity spectrum is actually smeared by:

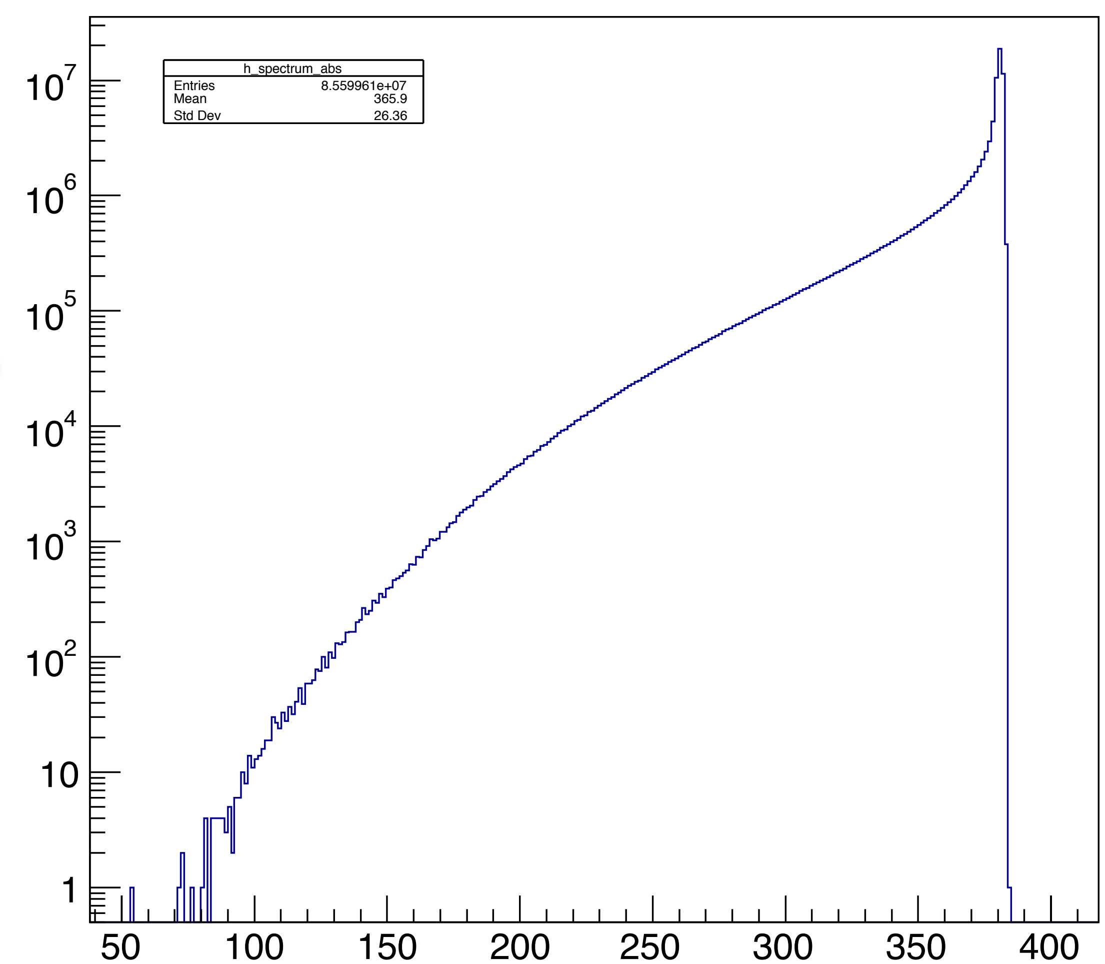
1. Beam energy spread: energy distribution of the particles inside the bunch.



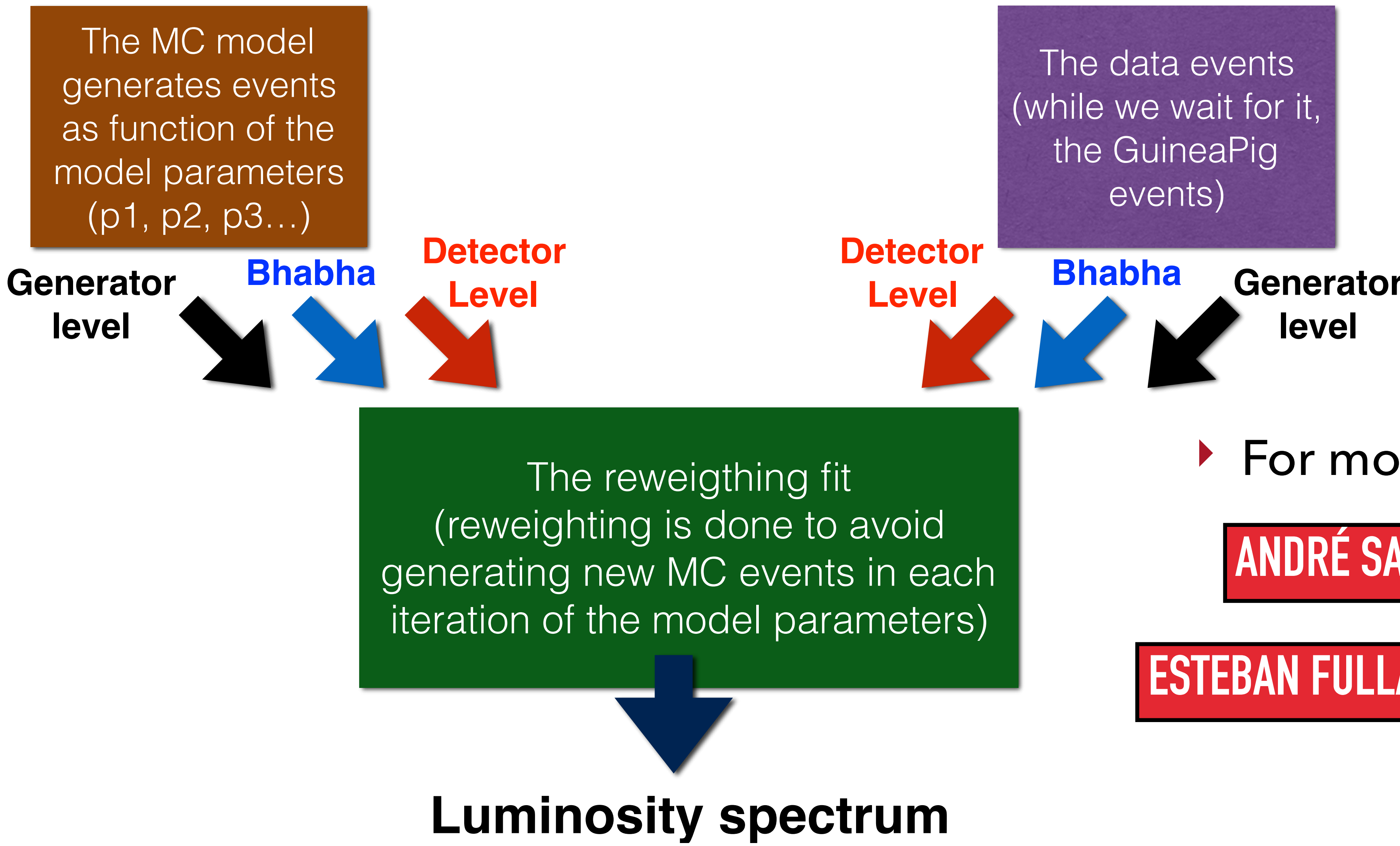
2. Beamstrahlung: radiation emitted due to the interaction with the em field of the opposite bunch.



Luminosity spectrum



MODELING THE LUMINOSITY SPECTRUM



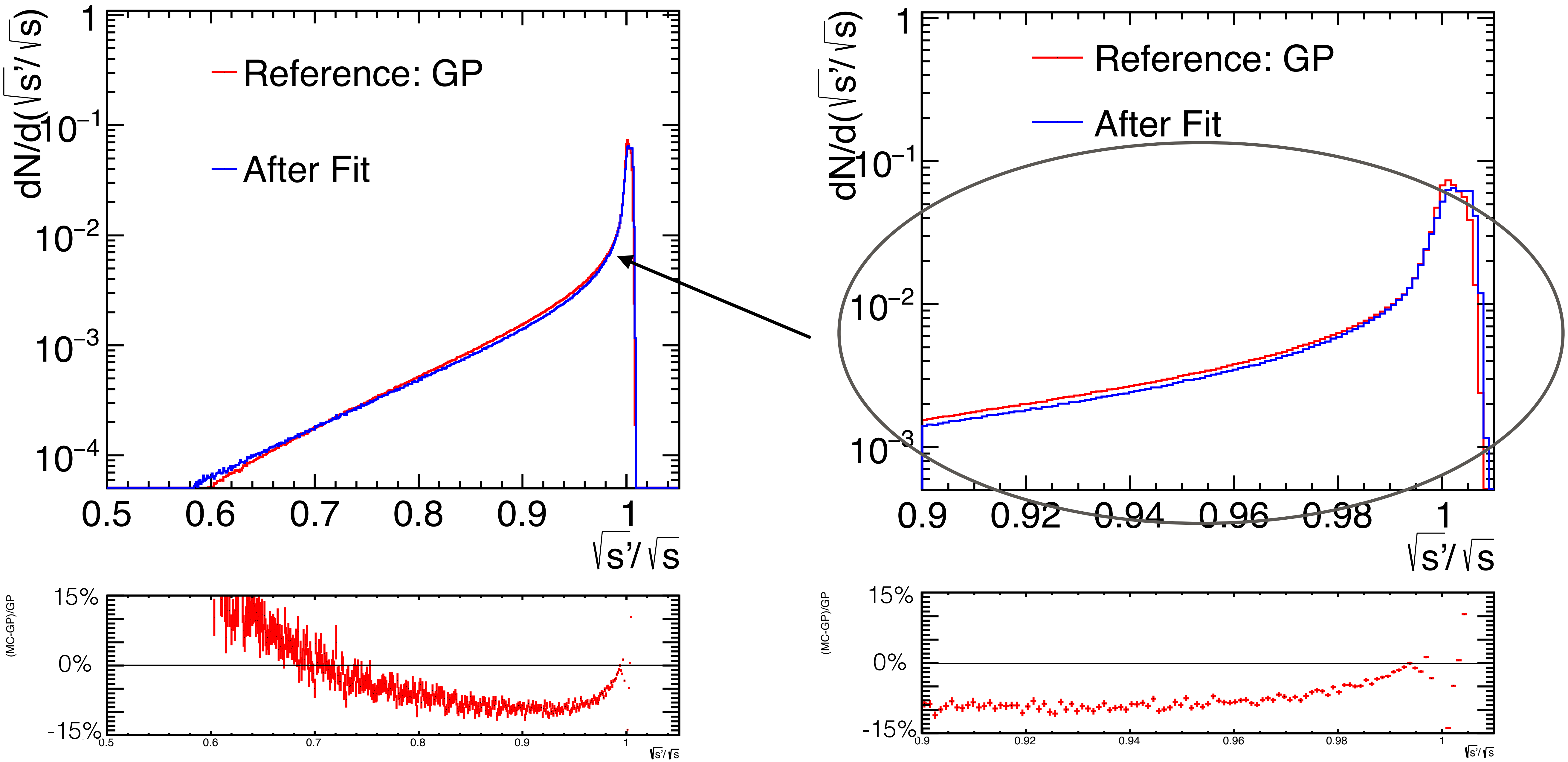
- For more information:

ANDRÉ SAILER'S PHD THESIS

ESTEBAN FULLANA TOP@LC 2017 TALK

- The model produces events consisting of pairs of beam energies and the corresponding probability to obtain a given event. This depends on the parameters that characterise de model.
- The minimum χ^2 between the distribution of the Model and the truth distribution corresponds to the optimal parameters values.
- Now studying the performance at three levels: generator, bhabhas and detector. With real data, the luminosity spectrum will be determined with bhabha events measured in the detector.

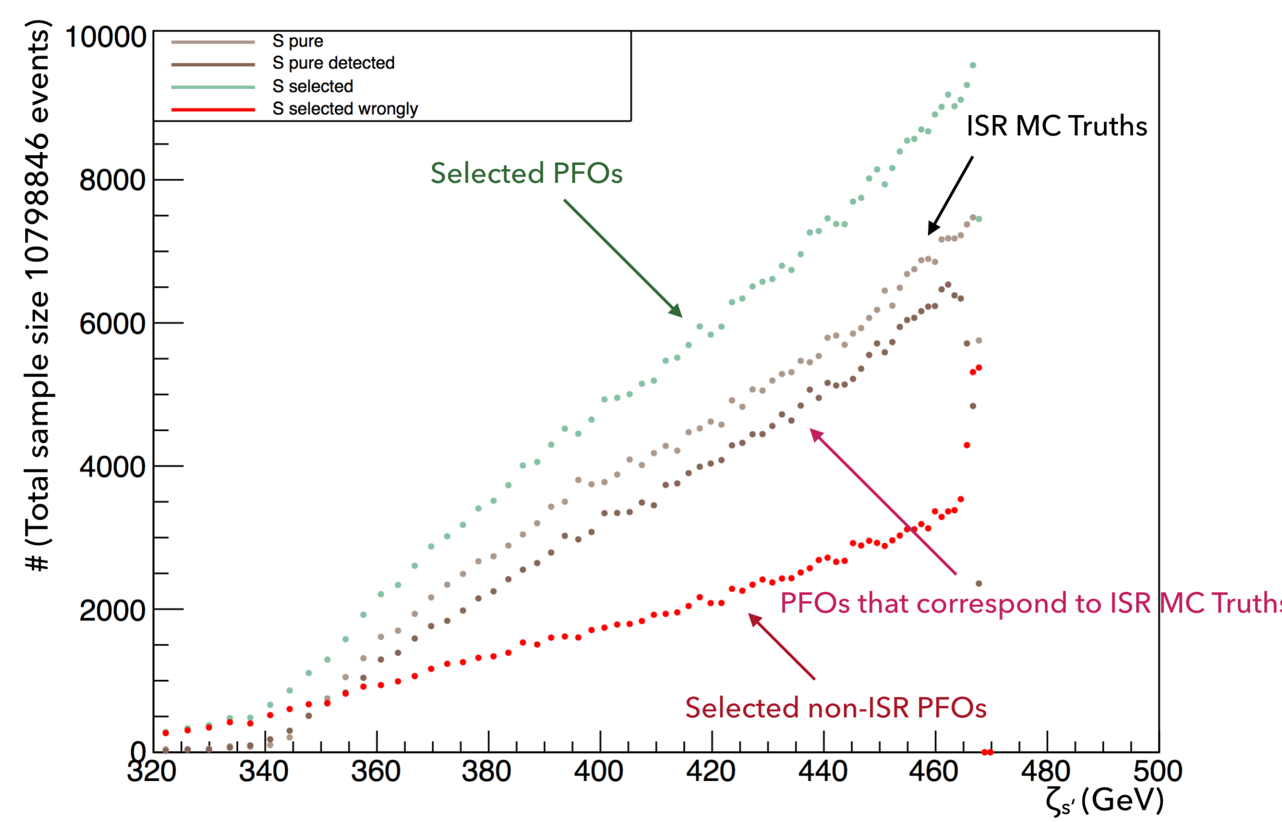
FIT RESULTS AT GENERATOR LEVEL



- At generator level the current fits show a residuals ~10% of the reference value for a CLIC 380 GeV scenario.
- We are currently working in the propagation of the uncertainty of the reconstructed spectrum to our observable.

DETECTOR CONSIDERATIONS

- To estimate detector effects we studied 6f_ttbar DST samples decaying in semileptonic channels generated with ILCSoft v01-16-p05_500 (10.8 M events, available at the ILCdirac framework).
- Sub-optimal efficiencies and resolutions for the photon detection were observed in this samples:
  - This can be explained by the "scattering" of photons into multiple particles by the older PandoraPFO algorithms used in these samples.
  - A reevaluation of the efficiency and resolution will be performed with the new samples.
- 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.
- A reoptimization of the selection cuts will be studied on the new samples.



NEXT STEPS

- Estimation and propagation of the uncertainty of the luminosity spectrum to our observable.
- Write up the current results and ongoing work, aiming to have a first draft for the end of the year.
- Reevaluate detector effects with the new full simulation samples.
- Reoptimize the selection cuts for the new samples:
  - Cluster the 6f_ttbar sample in 4-jets and B-tag them in order to reconstruct the ttbar pairs, including the reconstruction process into the selection criteria.

SUMMARY

- As seen in the parton and particle level studies, we can obtain measurements in the order of 80 MeVs (380 GeV, 500 fb^{-1}), 230 MeVs (500 GeV, 500 fb^{-1}) of statistical precision.
- Two major steps achieved:
  - Estimation of the theoretical uncertainty due to missing higher orders of ~50 MeVs.
  - Calculation of the luminosity spectrum (E. Fullana). Estimation of the uncertainty due to this effect to be evaluated soon.
- Ongoing evaluation of the most prevalent sources of systematics: selection criteria, inclusion of the FSR photons, background correction using the latest Whizard available.
- Production of a draft by late 2018 aiming to be included in the CLIC top physics paper.

THANKS FOR YOUR ATTENTION