COMPACT LINEAR COLLIDER WORKSHOP

CLICWEEK2019 - CERN

TOP MASS MEASUREMENT THROUGH RADIATIVE EVENTS : STATUS AND UPDATES

SPEAKER : Esteban Fullana Torregrosa @ IFIC (UV-CSIC) on behalf of Pablo Gomis

WITH CONTRIBUTIONS FROM :

M. BORONAT*, J. FUSTER*, I. GARCÍA*, P. GOMIS*, A. H. HOANG°, V. MATEU+, M. PERELLÓ*, E. ROS*, A. SAILER#, M. A. VILLAREJO*, M. VOS*, A. WIDL°, P. ZEHETNER^#

* IFIC (UNIVERSITAT DE VALÈNCIA/CSIC)
+ UNIVERSIDAD DE SALAMANCA
° UNIVERSITÄT WIEN
^LMU
CERN

OUTLINE

TOP MASS MEASUREMENT THROUGH RADIATIVE EVENTS

- METHOD DESCRIPTION
- ESTIMATED UNCERTAINTITES
    - THEORETICAL UNCERTAINTY : SCALE VARIATION
        - THE LUMINOSITY SPECTRUM ROLE IN THE SCALE VARIATION
    - STATISCAL UNCERTAINTY (UPDATED FOR THE NEW LUMINOSITY SCHEDULE)
    - SYSTEMATIC UNCERTAINTY : PHOTON ENERGY SCALE
    - SYSTEMATIC UNCERTAINTY : IMPERFECT SIMULATION
    - SYSTEMATIC UNCERTAINTY : PROPAGATION OF THE LUMINOSITY SPECTRUM DETERMINATION

INTRODUCTION TO THE OBSERVABLE

Complementary to the threshold scan measurement, but also in a well defined mass scheme.

Using the 380GeV run (1ab^{-1} integrated luminosity)

Well establish technique:

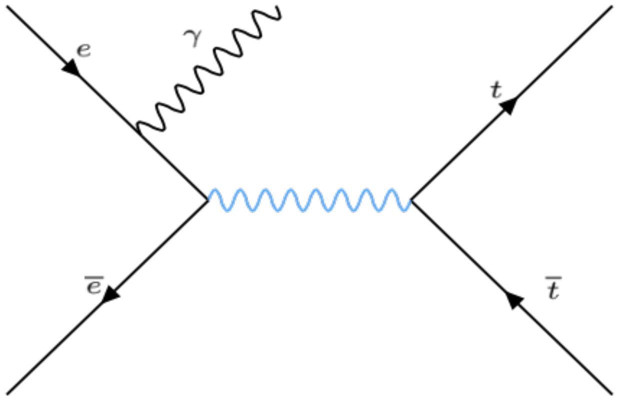
PROPOSED: **EUR. PHYS. J. C73 (2013) 2438**

USED BY ATLAS (@7TEV) : **JHEP 10 (2015) 121**

AND CMS (@8TEV): **CMS-PAS-TOP-13-006**

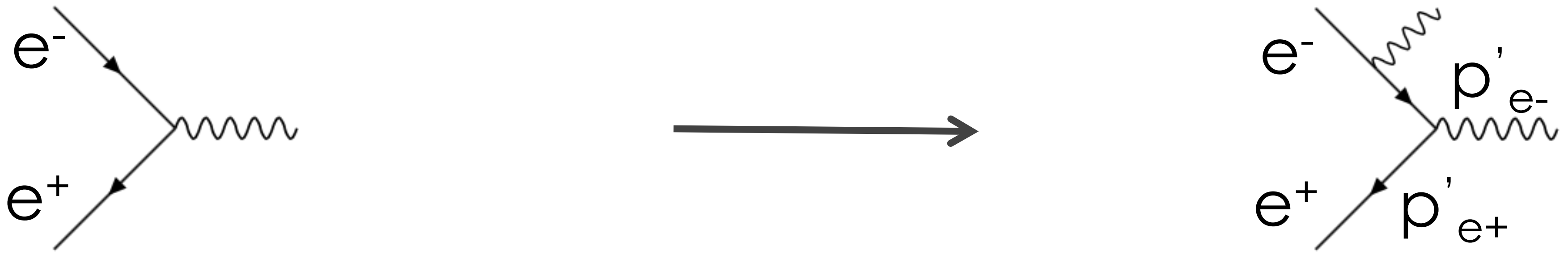
INTRODUCTION TO THE OBSERVABLE

- 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.

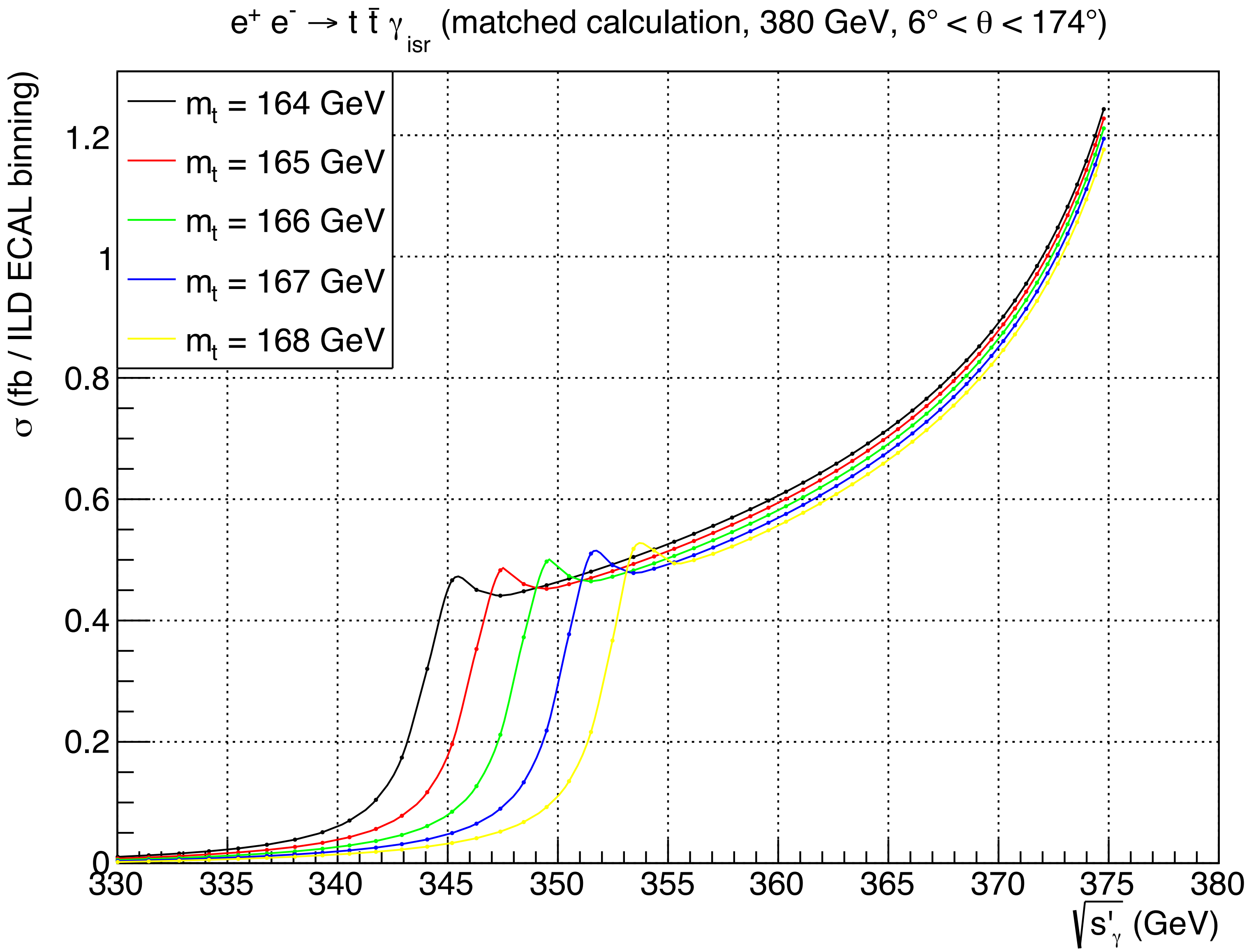
- Therefore the $t\,\bar{t}\,\gamma_{\mathrm{ISR}}$ production cross section is sensitive to the emitted ISR photon energy.

INTRODUCTION TO THE OBSERVABLE

- 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 is the differential cross section of the $t\,\bar{t}$ production as a function of $\sqrt{s'}$.



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

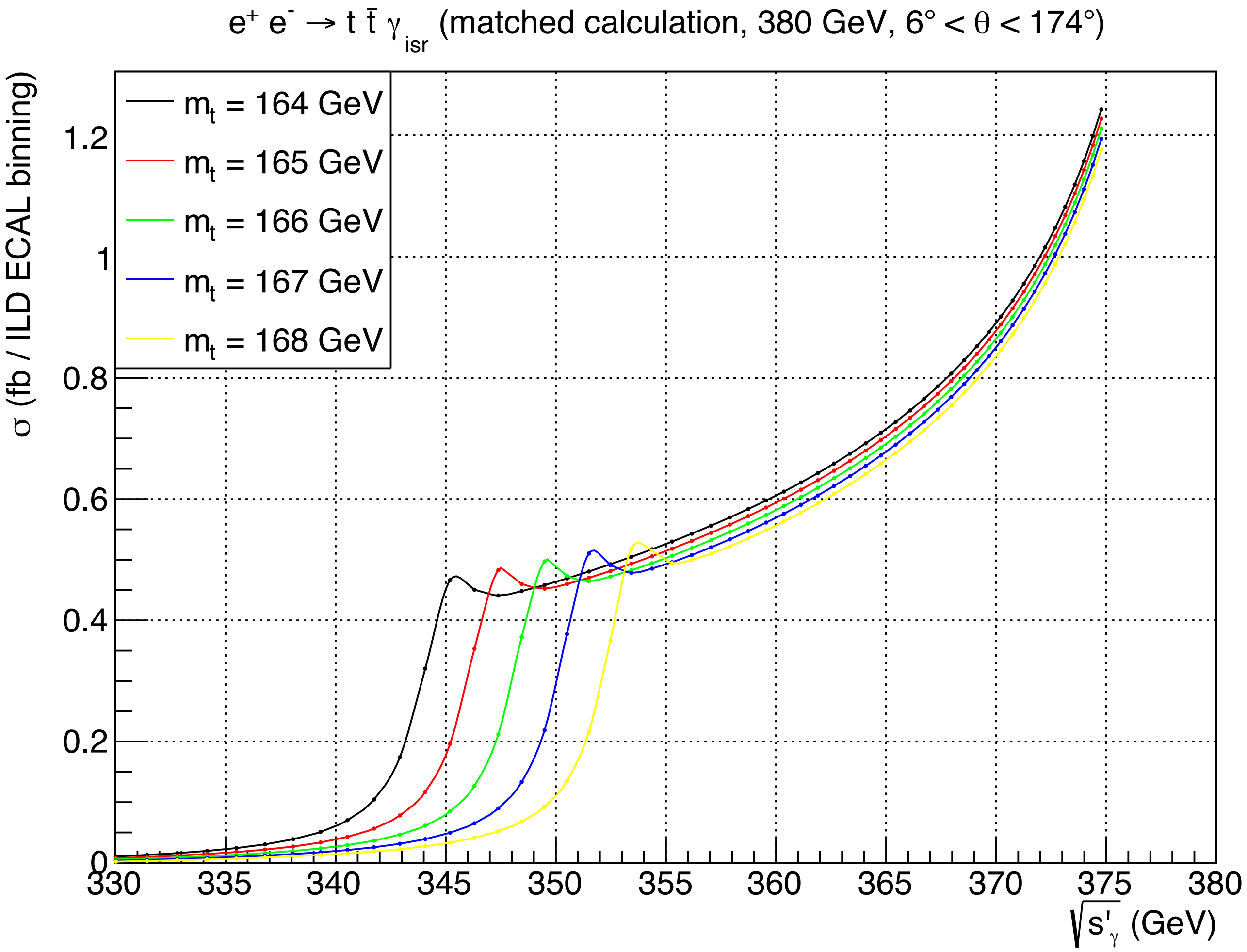
PABLO GOMIS

THEORETICAL MODEL: MATCHED CALCULATION

- A factorization theorem valid at O(α_{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:

$$\sigma_{t\bar{t}\gamma_{ISR}}(m_t, s') = \sigma_{ISR}(E_\gamma) * \sigma_{t\bar{t}}(m_t, s')$$

- The model convolves the ISR calculation with the threshold - continuum matched calculation by A. H. Hoang et al.
- 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 head-on collision, for a given top mass.



- For more information and details on the matched calculation:

ANGELIKA WIDL LCWS17 TALK

- The input mass can be chosen to be any short-distance mass scheme, in this case we chose the $\overline{\rm MS}$ scheme. For the calculation itself the 1S and MSR masses are used.

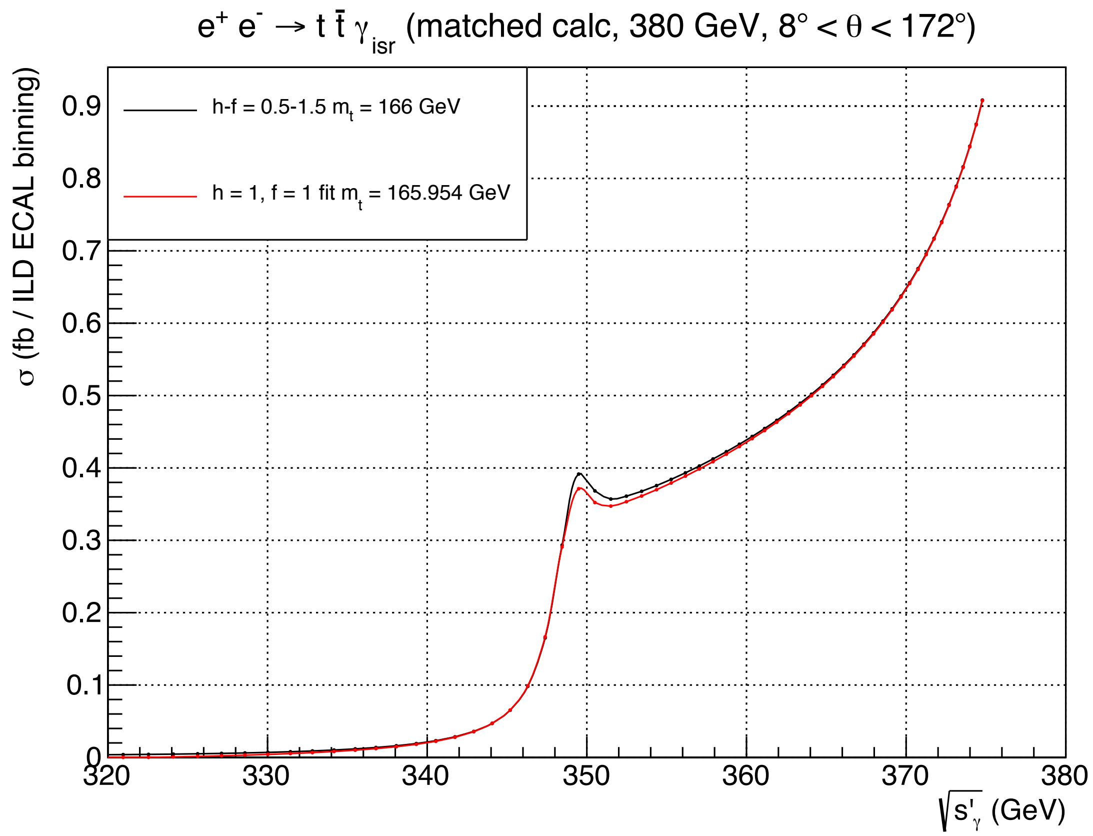
THEORETICAL MODEL UNCERTAINTY

- The main sources of uncertainty in the matched calculation come 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.

* results for 8° < θ < 172°

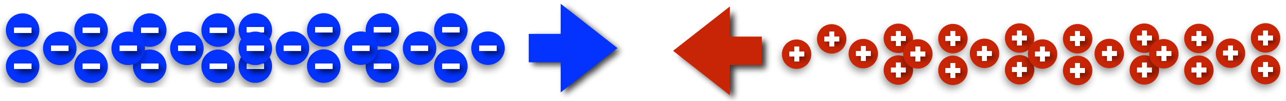
Proposed scale parameters variations (A. Hoang , M. Stahlhofen)									
h	1/2	1/2	1/2	1	1	1	2	2	2
f	2	3/2	1	1	$\sqrt{2}$	$\sqrt{(1/2)}$	1	3/4	1/2
Δm (MeV) @380 GeV	-44	-46	-43	0	-1	8	29	30	45
Δm (MeV) @500 GeV	-55	-58	-54	0	-2	12	32	34	51

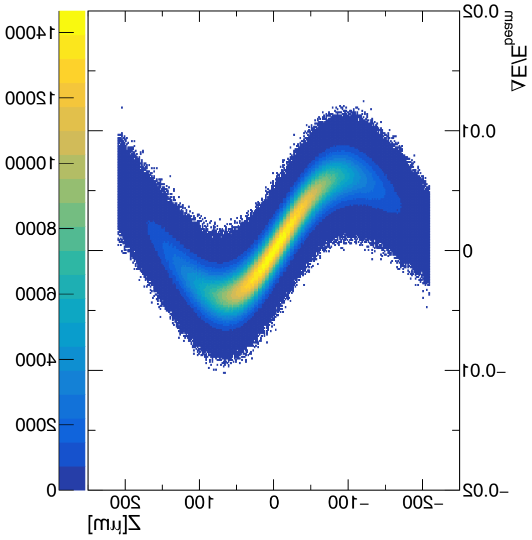
- We evaluate the theoretical uncertainty by fitting the model (at 380GeV, 500 fb^{-1}) with modified scales and a given top mass (166 GeV) to the same model with the nominal scales and with the top mass as a fit parameter.
- The fits lead to an estimation of **50 MeV (without the luminosity spectrum)**

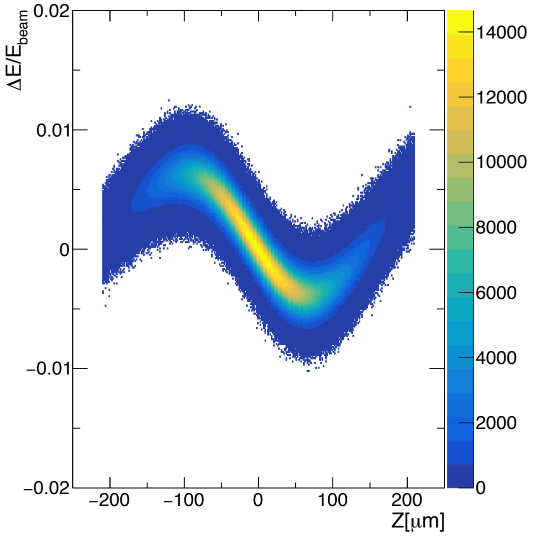


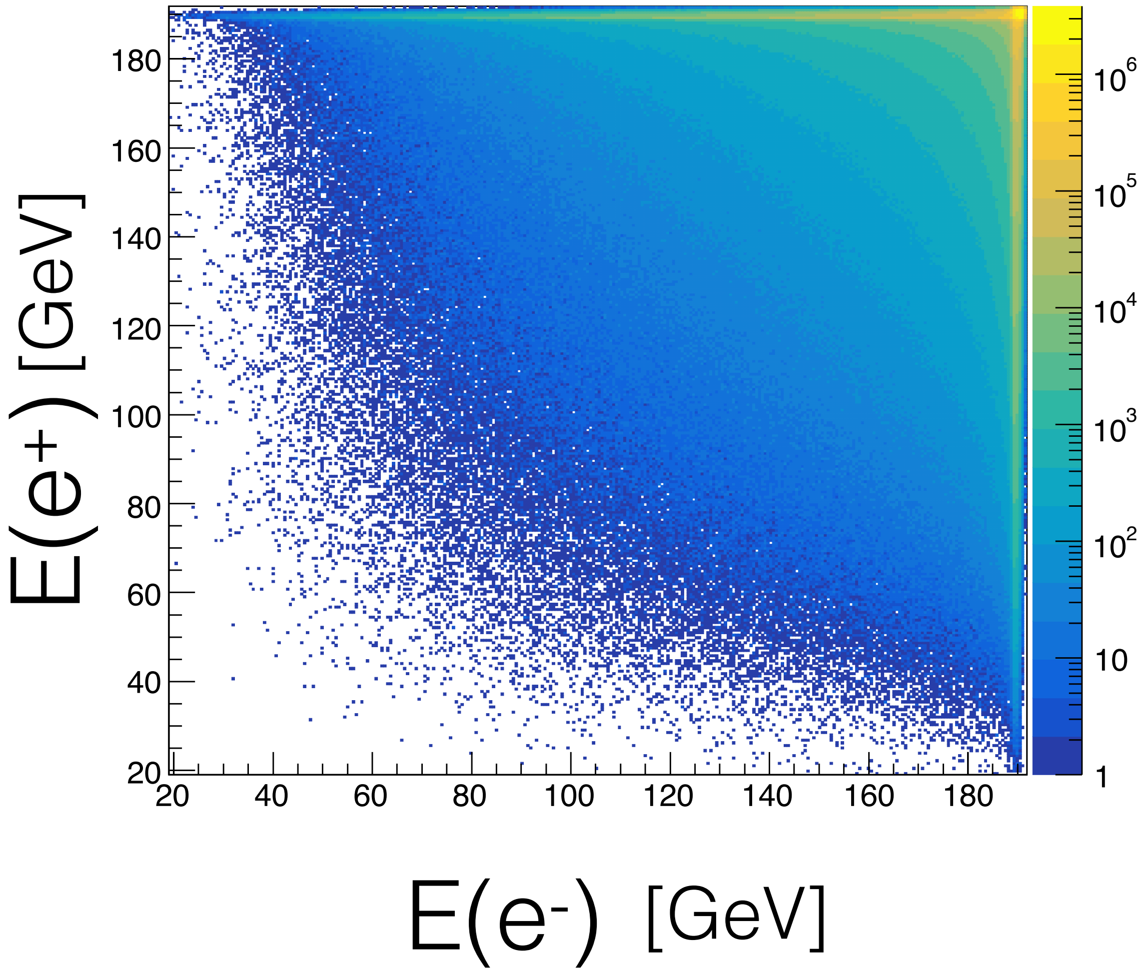
CLIC 380GEV LUMINOSITY SPECTRUM

(1) **beam energy spread** : energy distribution of the particles inside the bunch

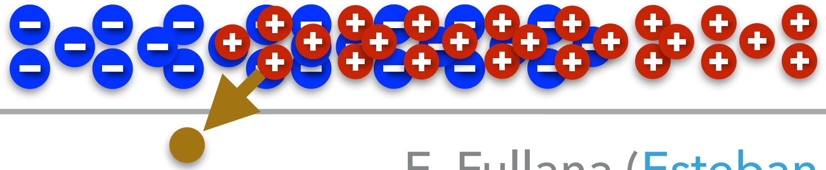








(2) **beamstrahlung**: radiation emitted due to the interaction with the em field of the opposite bunch



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f	2	3/2	1	1	√2	√(1/2)	1	3/4	1/2
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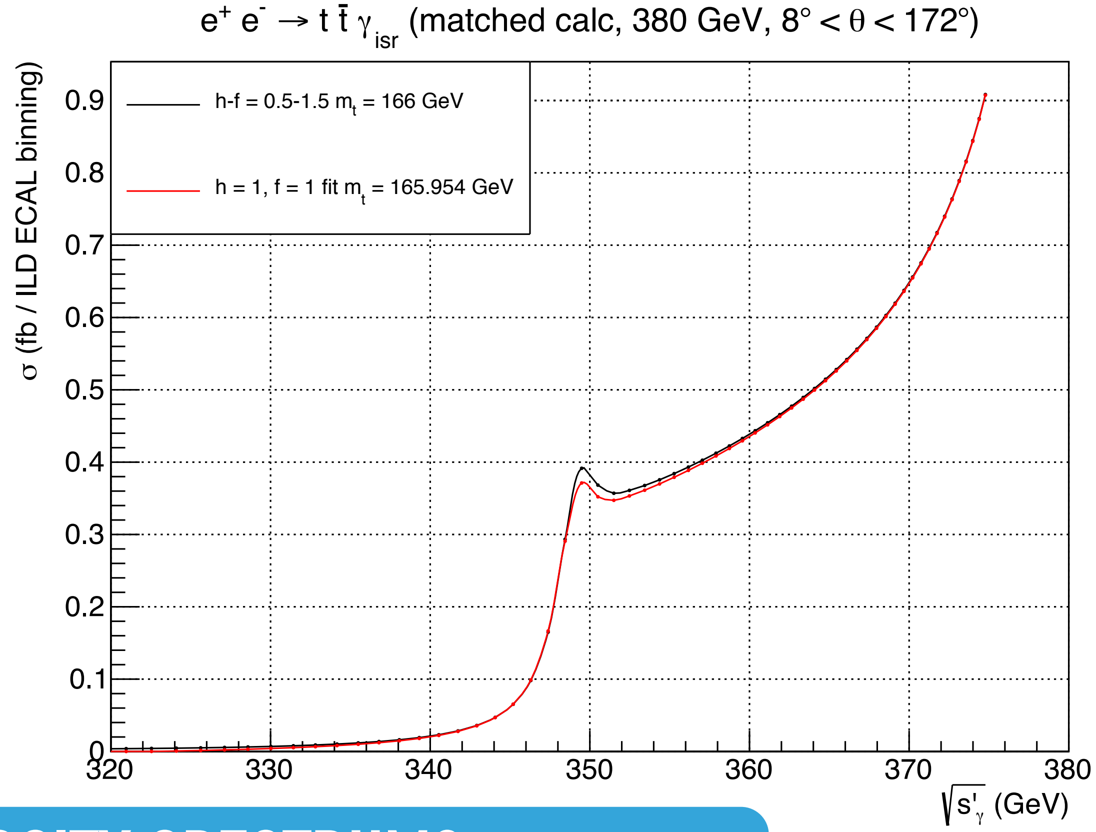

SO, HOW WE ACCOUNT FOR THE LUMINOSITY SPECTRUM?

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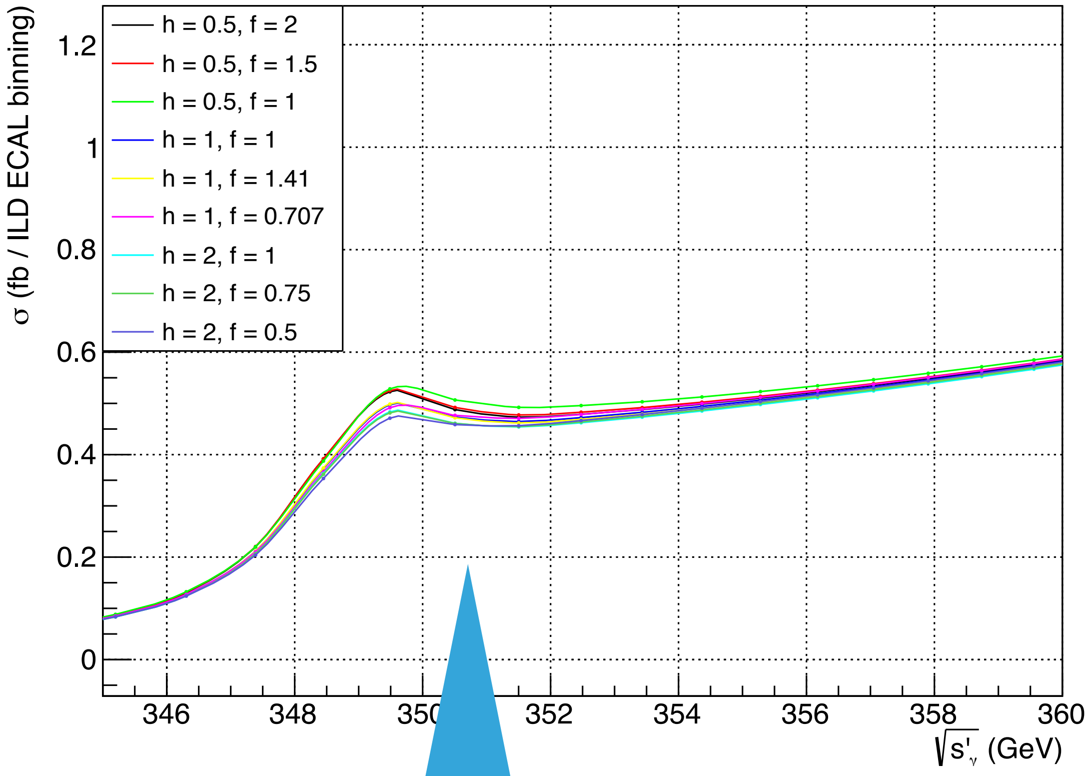
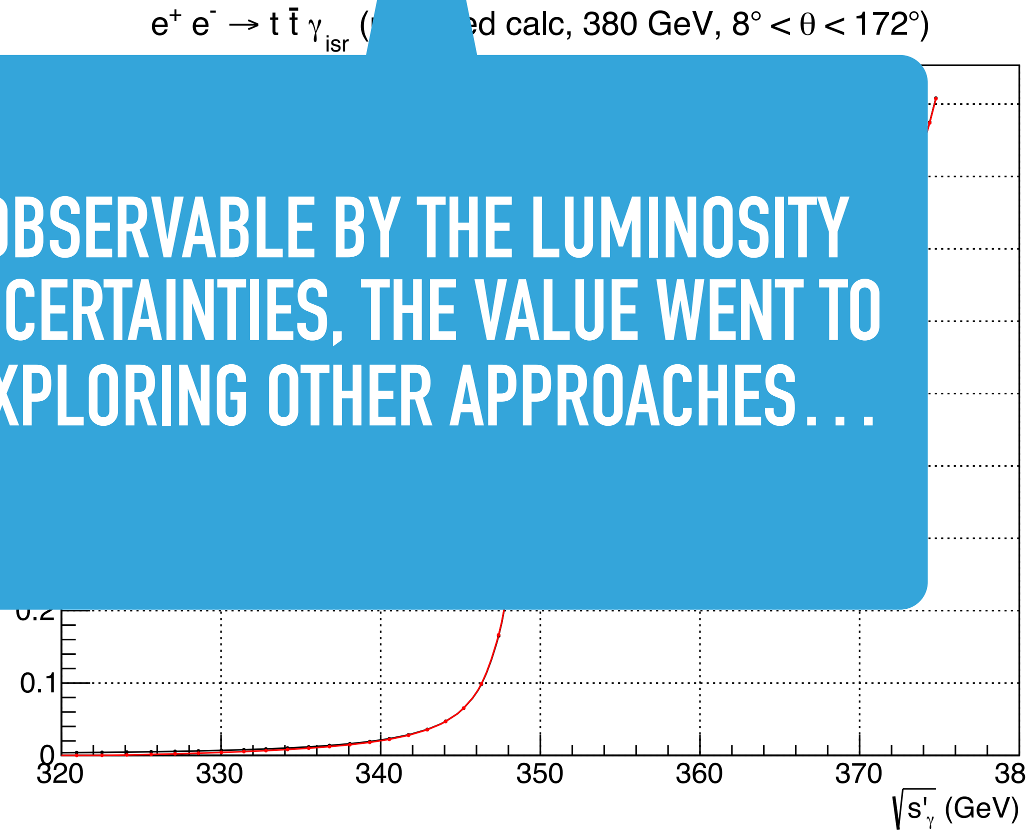


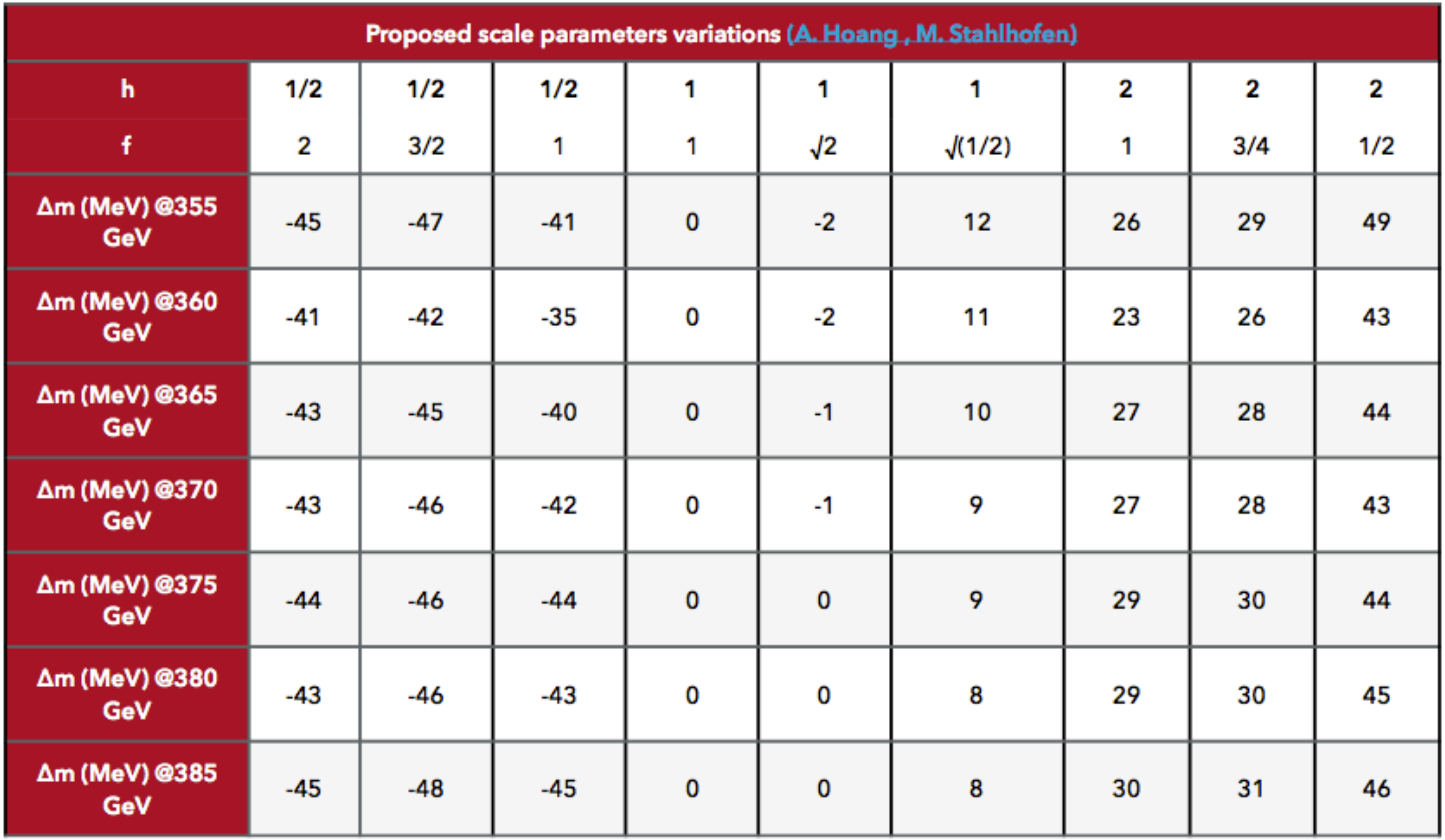


- We evalu
fitting the
modified
GeV) to t
scales an

THE FIRST ATTEMPT WAS TO WEIGHT THE OBSERVABLE BY THE LUMINOSITY SPECTRUM AND RECOMPUTE THE SCALE UNCERTAINTIES, THE VALUE WENT TO ABOUT 100MEV, BUT SINCE THEN WE ARE EXPLORING OTHER APPROACHES…

- The fits lead to an estimation of **50 MeV (without the luminosity spectrum)**

THEORETICAL MODEL UNCERTAINTY



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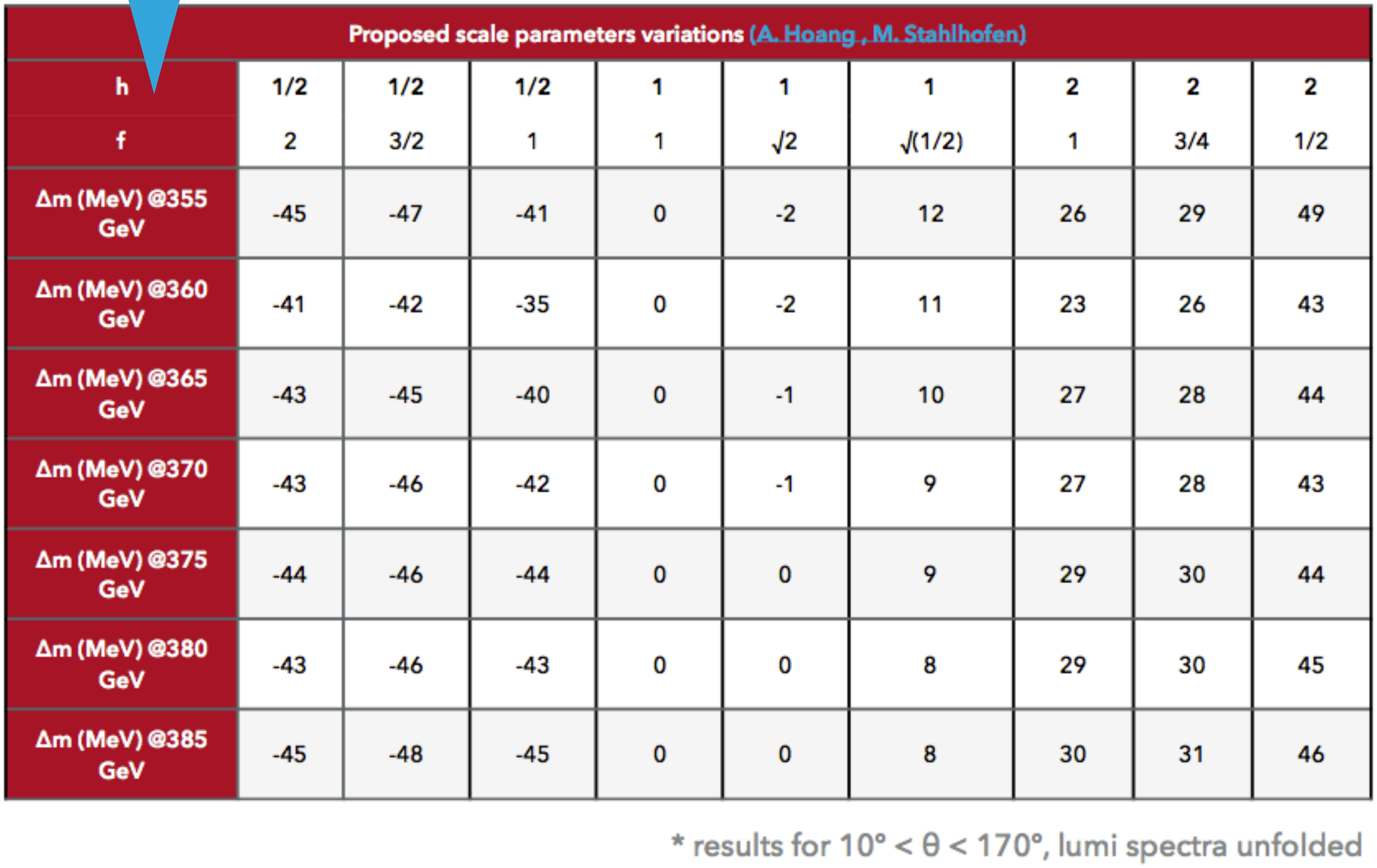
f	2	3/2	1	1	√2	√(1/2)	1	3/4	1/2
Δm (MeV) @355 GeV	-45	-47	-41	0	-2	12	26	29	49
Δm (MeV) @360 GeV	-41	-42	-35	0	-2	11	23	26	43
Δm (MeV) @365 GeV	-43	-45	-40	0	-1	10	27	28	44
Δm (MeV) @370 GeV	-43	-46	-42	0	-1	9	27	28	43
Δm (MeV) @375 GeV	-44	-46	-44	0	0	9	29	30	44
Δm (MeV) @380 GeV	-43	-46	-43	0	0	8	29	30	45
Δm (MeV) @385 GeV	-45	-48	-45	0	0	8	30	31	46

* results for 10° < θ < 170°, lumi spectra unfolded

THEORETICAL MODEL UNCERTAINTY

WE COMPUTE THE SCALE UNCERTAINTY AT EACH COLLISION ENERGY STARTING AT 355GEV TO 385GEV AT 5GEV INTERVALS, THE UNCERTAINTY IS CONSTANT AT ~50MEV



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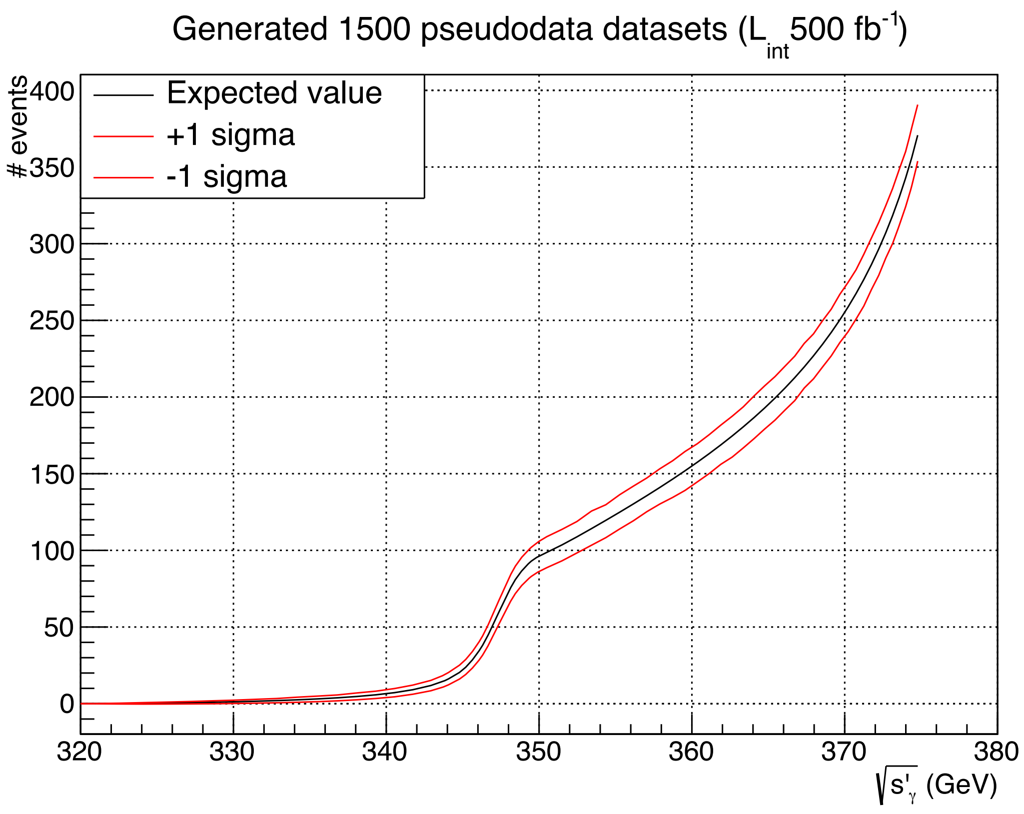
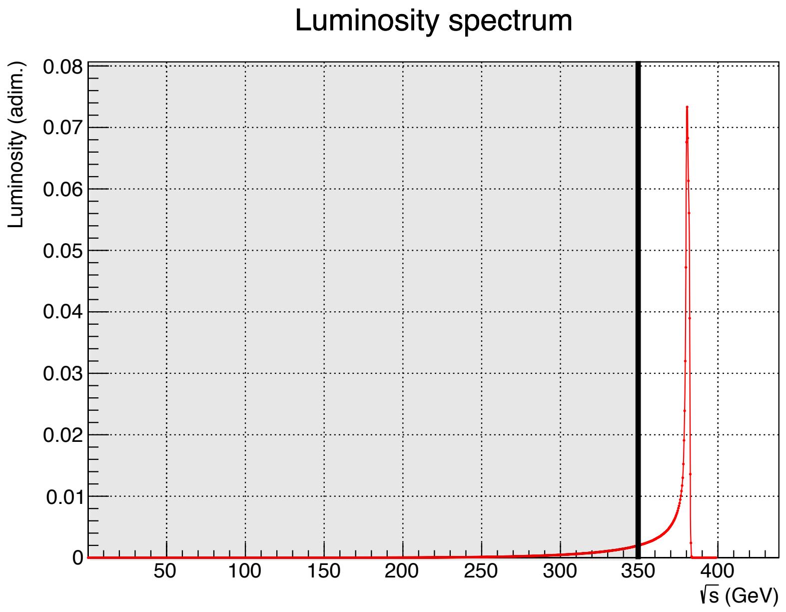
UNCERTAINTY ON THE TOP MASS (STATISTICS)

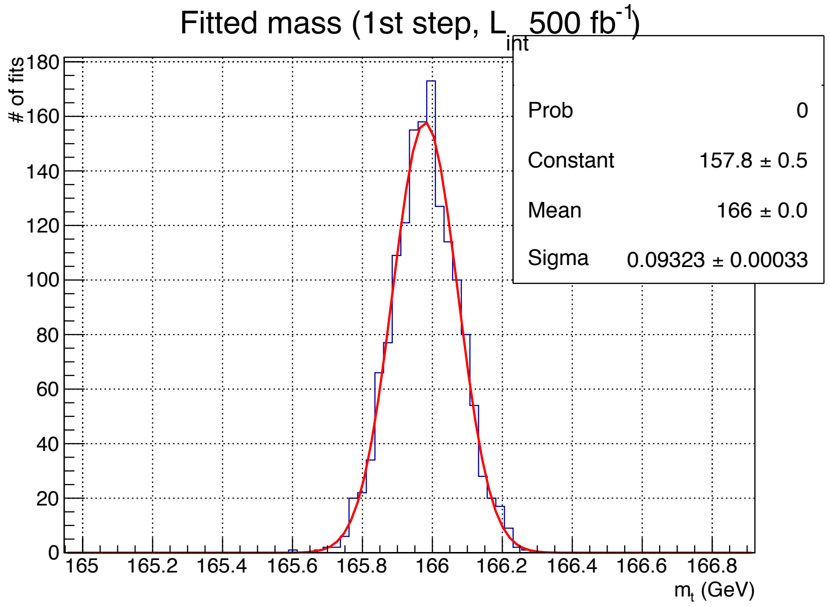
- Propagation of the statistical uncertainty into the top mass through pseudo experiments
- The Luminosity spectrum is propagated into the observable through a weighted sum
- Increment of ~30MeV when you include the Luminosity Spectrum in the observable



	6° < θ < 174°	8° < θ < 172°	10° < θ < 170°
CLIC Spectrum @ 500 fb^{-1}	75MeV (50MeV w/o)	93 MeV (60 MeV w/o.	104 MeV (65 MeV w/o. s.)

- Part of this loss in sensitivity is due to a loss of statistics (ttbar threshold acceptance). The other part, concerns the change in the shape due to bin migrations.
- Work in progress: by taking into account the correlations between these bins we expect to improve the sensitivity prospect.





PABLO GOMIS

UNCERTAINTY ON THE TOP MASS (STATISTICS)

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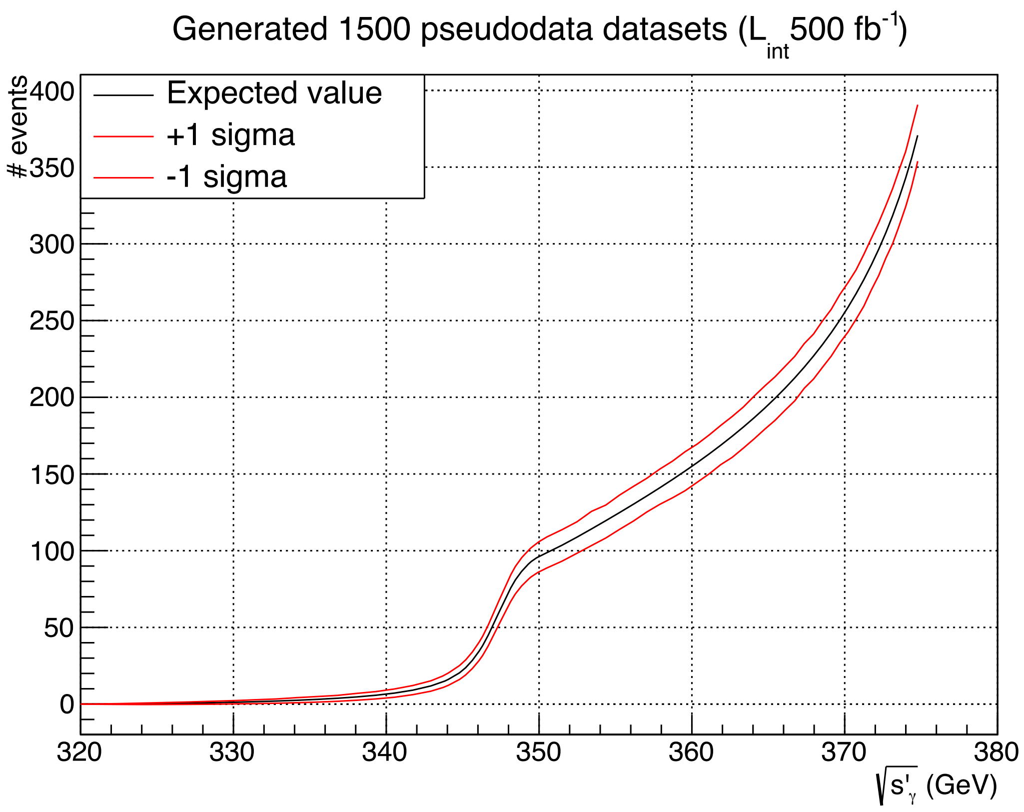

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UPDATED TO **71.3 MeV** WITH THE NEW LUMINOSITY SCHEDULE (TOTAL@380GeV 1 ab^{-1})

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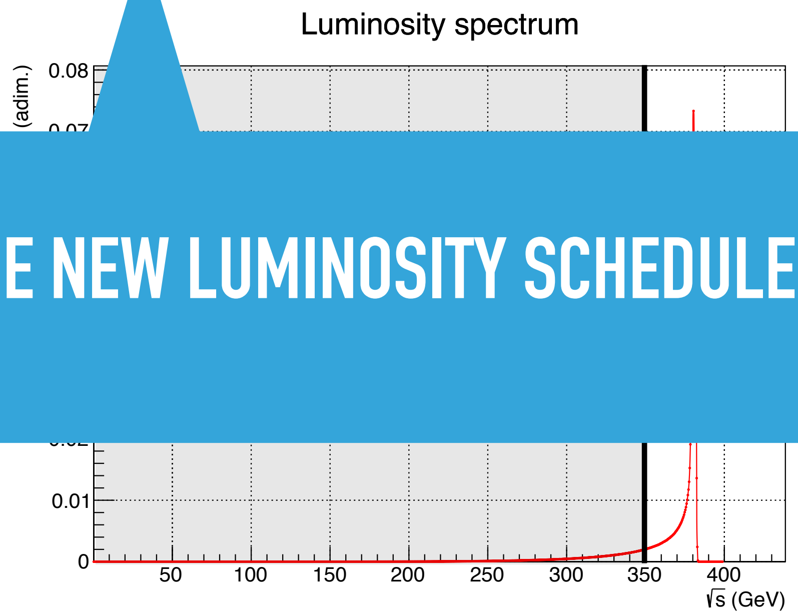
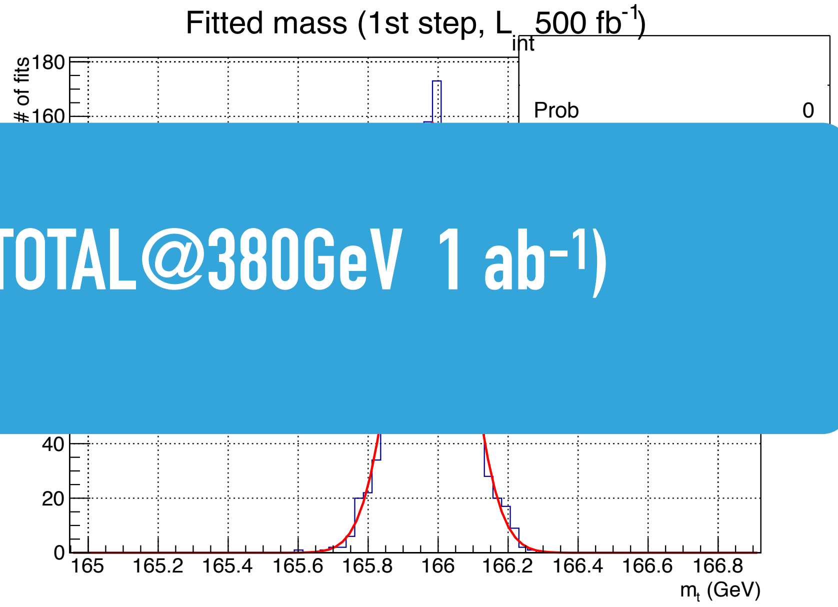
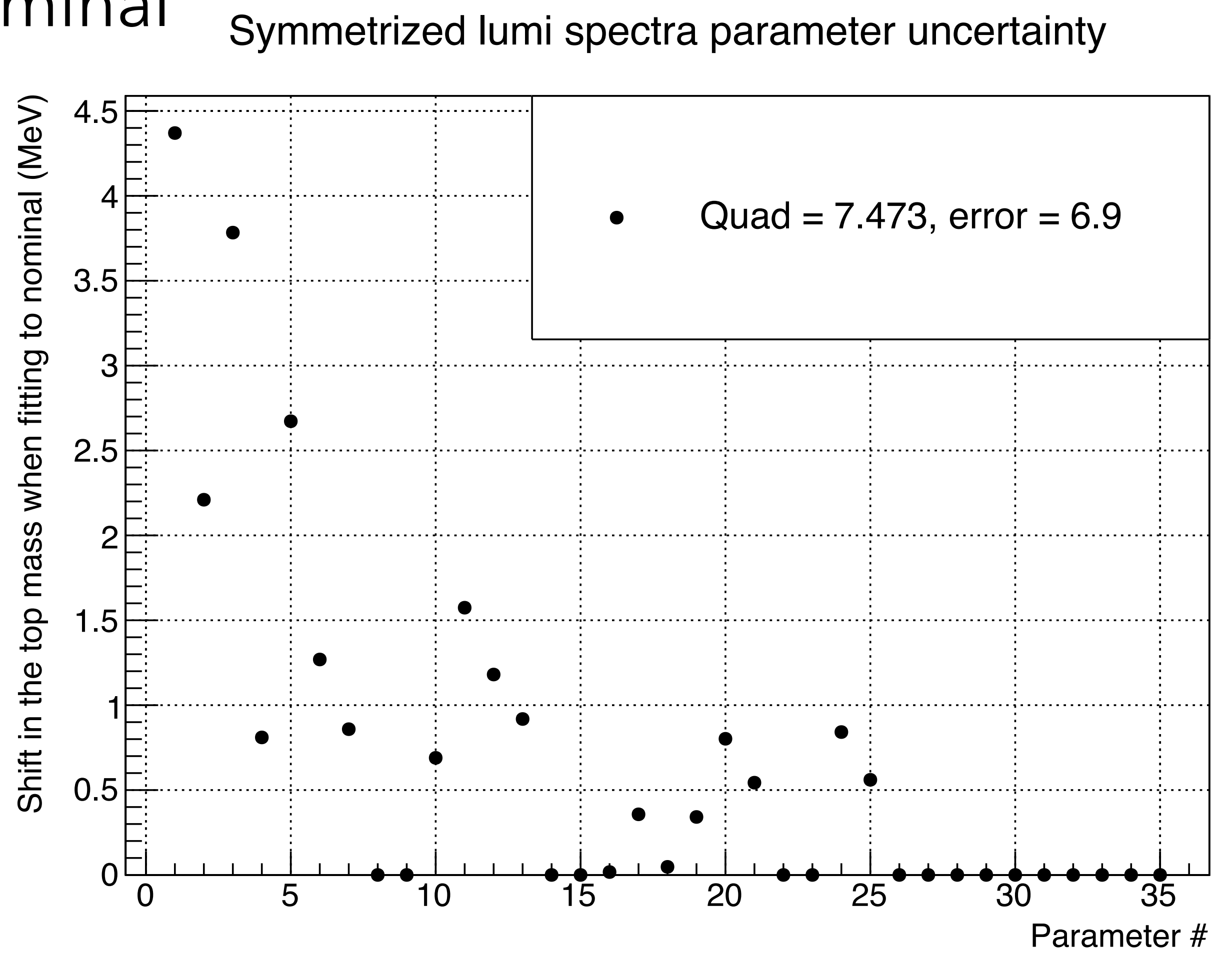




PROPAGATION OF THE UNCERTAINTY ON THE LUMINOSITY SPECTRUM INTO THE TOP MASS

- To estimate the effect of the luminosity spectrum uncertainty in our study we propagate the error from its 19 free parameters ()
- Using the 19 parameter errors from the luminosity spectrum reconstruction we generate 38 (19 parameters x 2 σ up, σ down) spectrums.
- We weight the spectrums with the observable and we fit it to the model weighted with the “nominal” reconstruction.
  - The propagated error for each parameter is taken as the symmetrisation (σ up, σ down) of the mass shifts obtained through the fits.
  - The total uncertainty is found by performing $E = \mathrm{sqrt}(E_p \ \mathrm{Cov} \ E_p{}^{T})$.
  - We find a total uncertainty of **7 MeV.**
- ~30M events were used in data and MC for this fit.

FOR THE DETERMINATION OF THE LUMI SPECTRUM GO HERE



PROPAGATION OF THE UNCERTAINTY ON THE LUMINOSITY SPECTRUM INTO THE TOP MASS

USING A RECONSTRUCTED LUMINOSITY SPECTRUM, BUT ASSUMING PERFECT SIMULATION OF THE DETECTOR (PABLO GOMIS STUDIES)

- To estimate the effect of the luminosity spectrum uncertainty in our study we propagate the error from its 19 free parameters ()
- Using the 19 parameter errors from the luminosity spectrum reconstruction we generate 38 (19 parameters x 2 σ up, σ down) spectrums.
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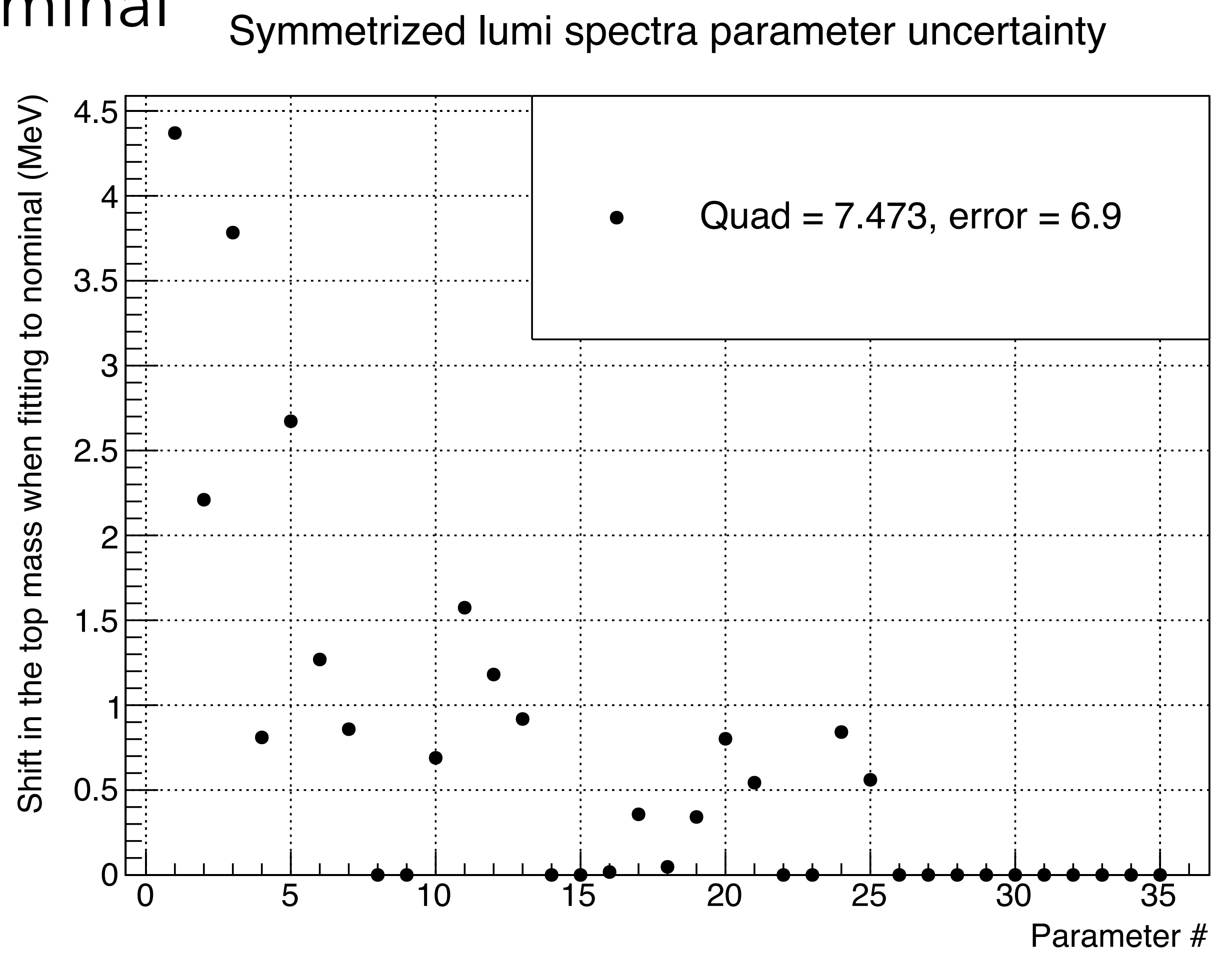
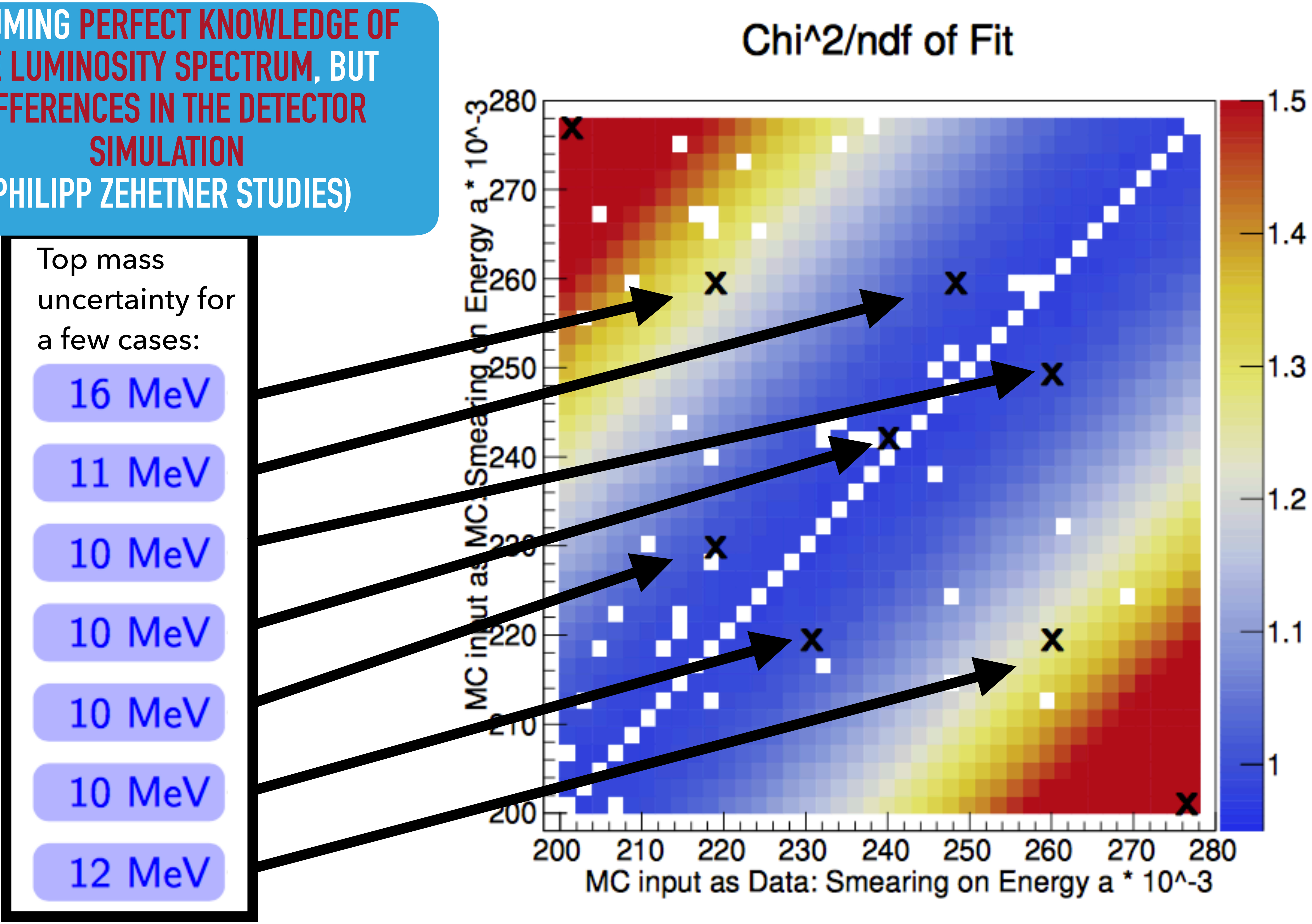


PROPAGATION OF THE UNCERTAINTY ON THE LUMINOSITY SPECTRUM INTO THE TOP MASS

P.ZEHETNER

ASSUMING PERFECT KNOWLEDGE OF THE LUMINOSITY SPECTRUM, BUT DIFFERENCES IN THE DETECTOR SIMULATION
(PHILIPP ZEHETNER STUDIES)

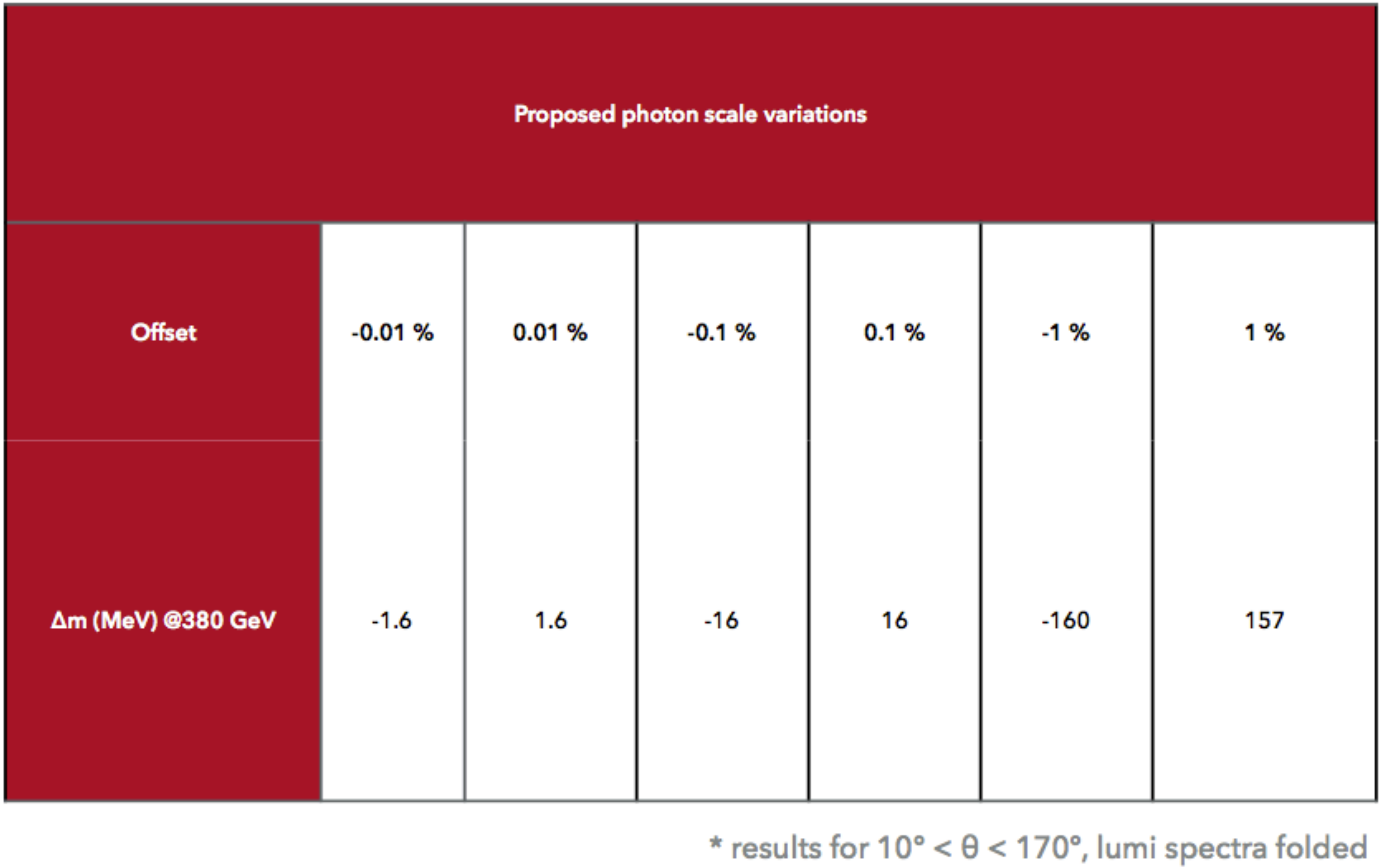


Top mass uncertainty for a few cases:

- 16 MeV
- 11 MeV
- 10 MeV
- 10 MeV
- 10 MeV
- 10 MeV
- 12 MeV

E. Fullana (Esteban.Fullana@ific.uv.es) @ CLICWEEK2019 - 24/01/2019

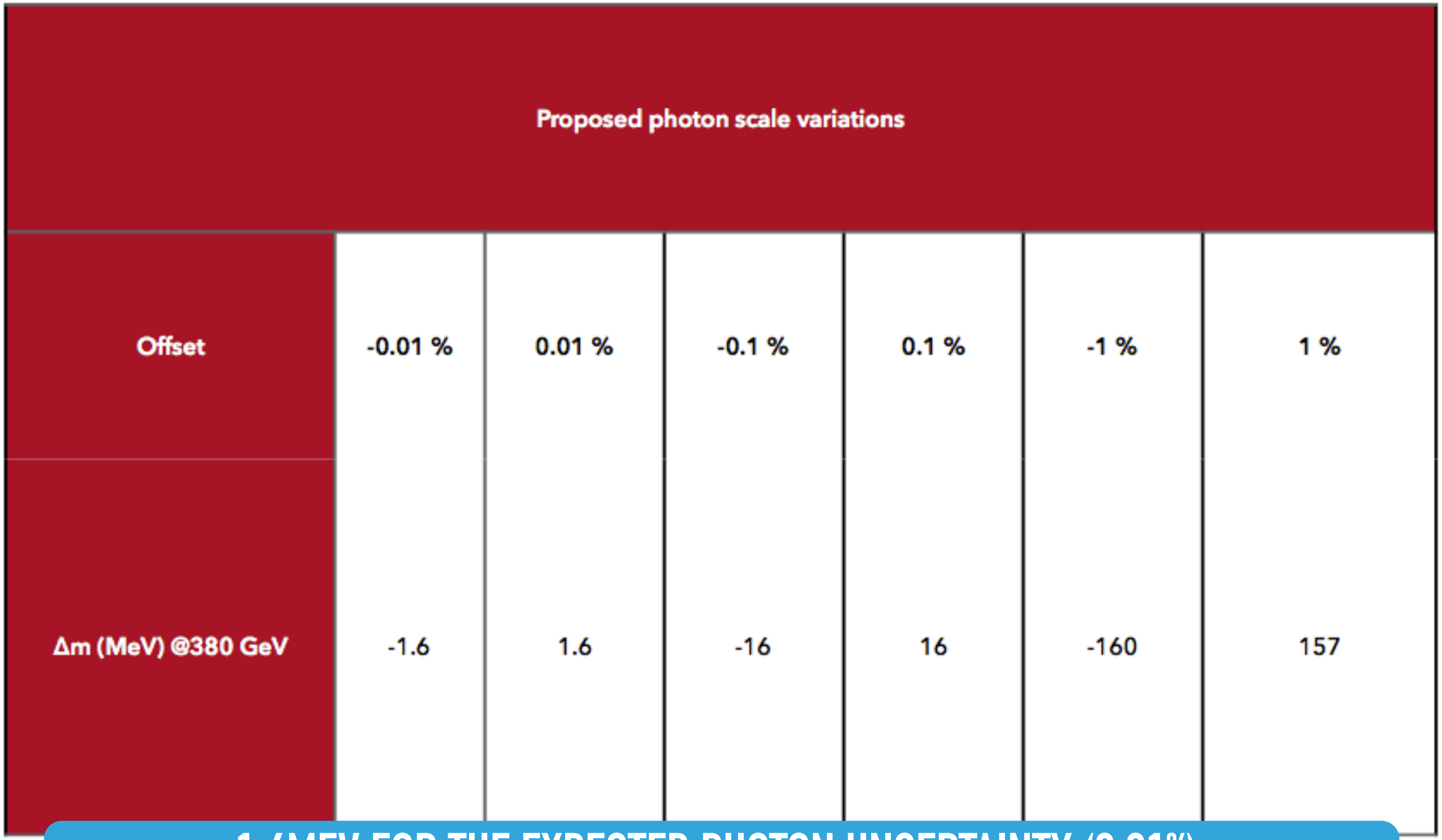
PHOTON ENERGY SCALE UNCERTAINTY



Proposed photon scale variations						
Offset	-0.01 %	0.01 %	-0.1 %	0.1 %	-1 %	1 %
Δm (MeV) @380 GeV	-1.6	1.6	-16	16	-160	157

* results for 10° < θ < 170°, lumi spectra folded

PHOTON ENERGY SCALE UNCERTAINTY



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Δm (MeV) @380 GeV	-1.6	1.6	-16	16	-160	157

1.6MEV FOR THE EXPECTED PHOTON UNCERTAINTY (0.01%), IT HAS TO BE 2 ORDERS OF MAGNITUD LARGER THAN THAT (~1%) TO BE SIGNIFICANT

CONCLUSIONS

- CLIC @ 380GeV can measure the top quark mass with an uncertainty :
  - Theoretical uncertainty : **100MeV➔50MeV** @380GeV.
  - Statistical uncertainty : **~70MeV@1ab^{-1}** (including the effect of the luminosity spectrum)
  - Systematics : Propagation of the uncertainty on the luminosity spectrum determination on the top mass: **<10MeV**
  - Systematics : Improper modelling of the simulation in the luminosity spectrum determination : **< 10MeV**
  - Systematics : Photon energy scale **~2 MeV**

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NEXT GOALS ARE:
WRITE THE PHD THESIS (PABLO)
WORK ON TECHNICS TO DECREASE THESE TWO UNCERTAINTIES (THE TEAM)
IMPROVE THE LUMINOSITY SPECTRUM DETERMINATION (ESTEBAN)

THANKS FOR YOUR ATTENTION!

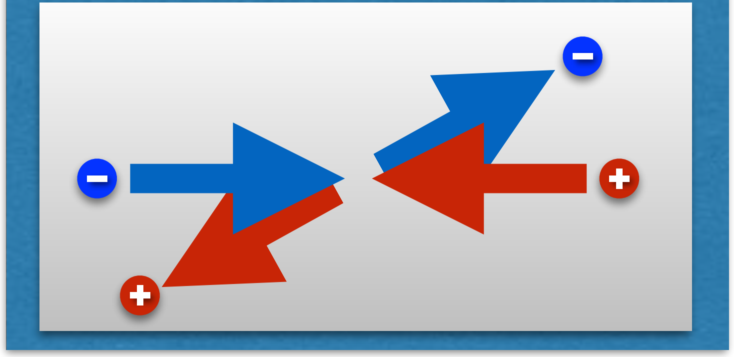
OUTLINE

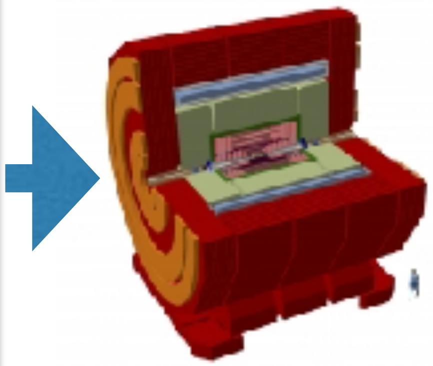
380 GEV CLIC LUMINOSITY SPECTRUM DETERMINATION AND IMPACT ON THE TOP MASS MEASUREMENT THROUGH RADIATIVE EVENTS

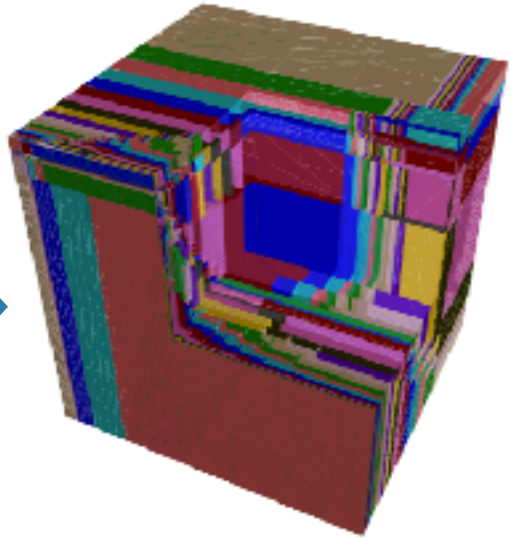
WHAT WE NEED TO MEASURE THE LUMI SPECTRA?

This strategy uses the reconstruction software from S.Poss and A. Sailer described here

Data : Bhabha Scattering events :





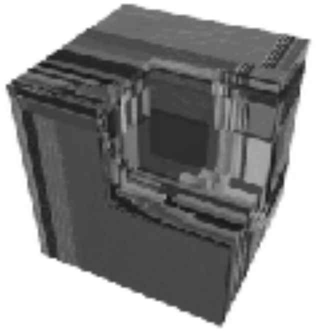


3D histogram :
E(e-)
E(e+)
Acollinearity (e+,e-)

Parametrized Model that generates pairs of energies of collided e- and e+

Bhabha scattering generator Montecarlo (BHWIDE)

Full Simulation of the detector



3D histogram :
E(e-)
E(e+)
Acollinearity (e+,e-)

Change the parameters to make the two 3D histograms as similar as possible

WHAT WE ~~NEED~~ HAVE TO “MEASURE” THE LUMI SPECTRA?

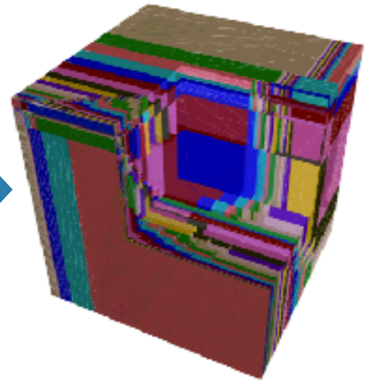
This strategy uses the reconstruction software from S.Poss and A. Sailer described here

Guinea Pig simulation provides pairs of energies of collided e- and e+

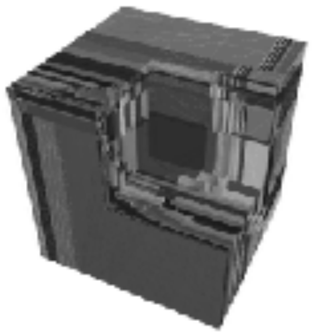
Parametrized Model that generates pairs of energies of collided e- and e+

Bhabha scattering generator Montecarlo (BHWIDE)

Smearing of the 4 momenta of the electron and positron.



3D histogram :
E(e-)
E(e+)
Acollinearity (e+,e-)

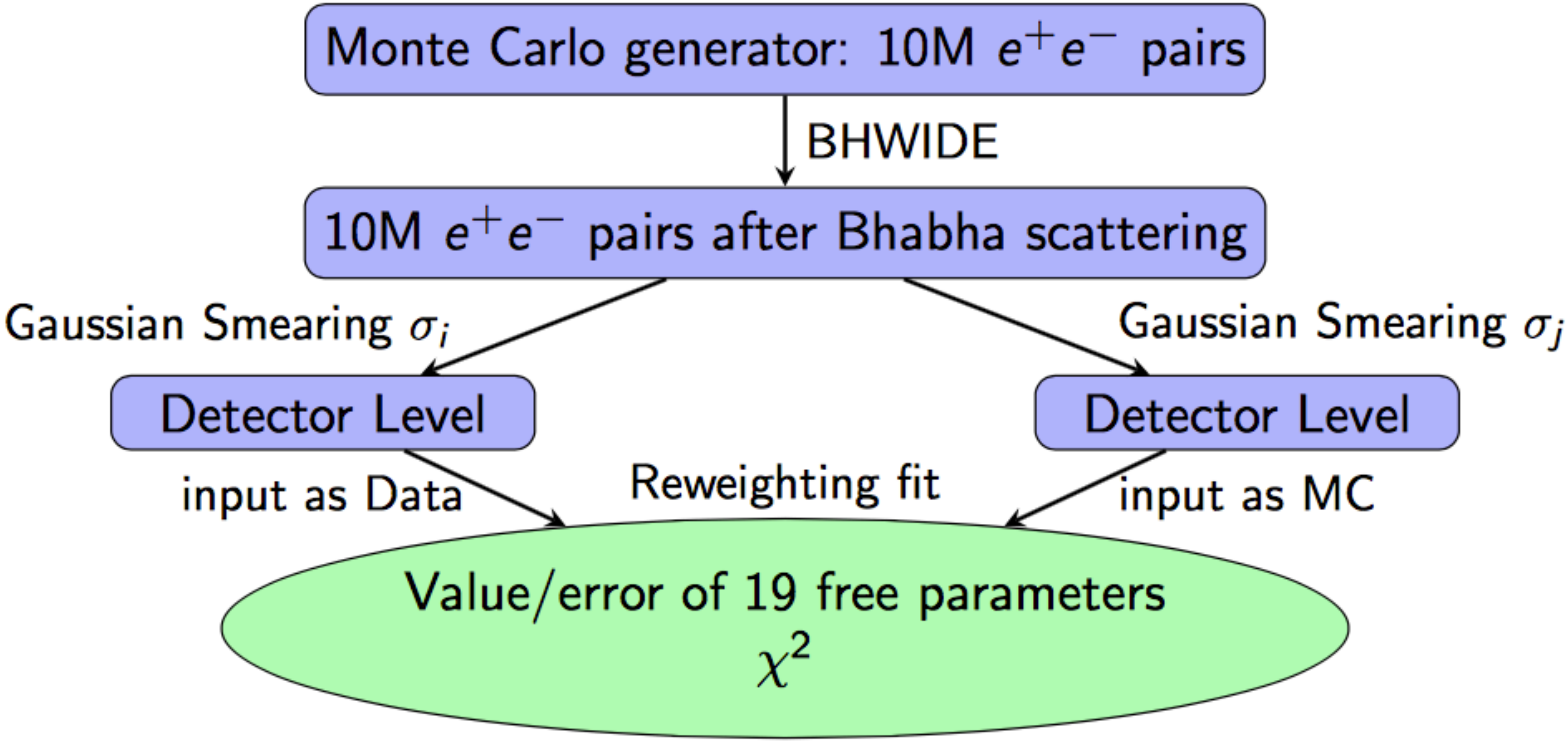


3D histogram :
E(e-)
E(e+)
Acollinearity (e+,e-)

Change the parameters to make the two 3D histograms as similar as possible

PROPAGATION OF THE UNCERTAINTY ON THE LUMINOSITY SPECTRUM INTO THE TOP MASS

ASSUMING PERFECT KNOWLEDGE OF THE LUMINOSITY SPECTRUM, BUT DIFFERENCES IN THE DETECTOR SIMULATION
(PHILIPP ZEHETNER STUDIES)



Monte Carlo generator: 10M e^+e^- pairs

BHWIDE

10M e^+e^- pairs after Bhabha scattering

Gaussian Smearing σ_i

Gaussian Smearing σ_j

Detector Level

Detector Level

input as Data

Reweighting fit

input as MC

Value/error of 19 free parameters

χ^2

PROPAGATION OF THE UNCERTAINTY ON THE LUMINOSITY SPECTRUM INTO THE TOP MASS

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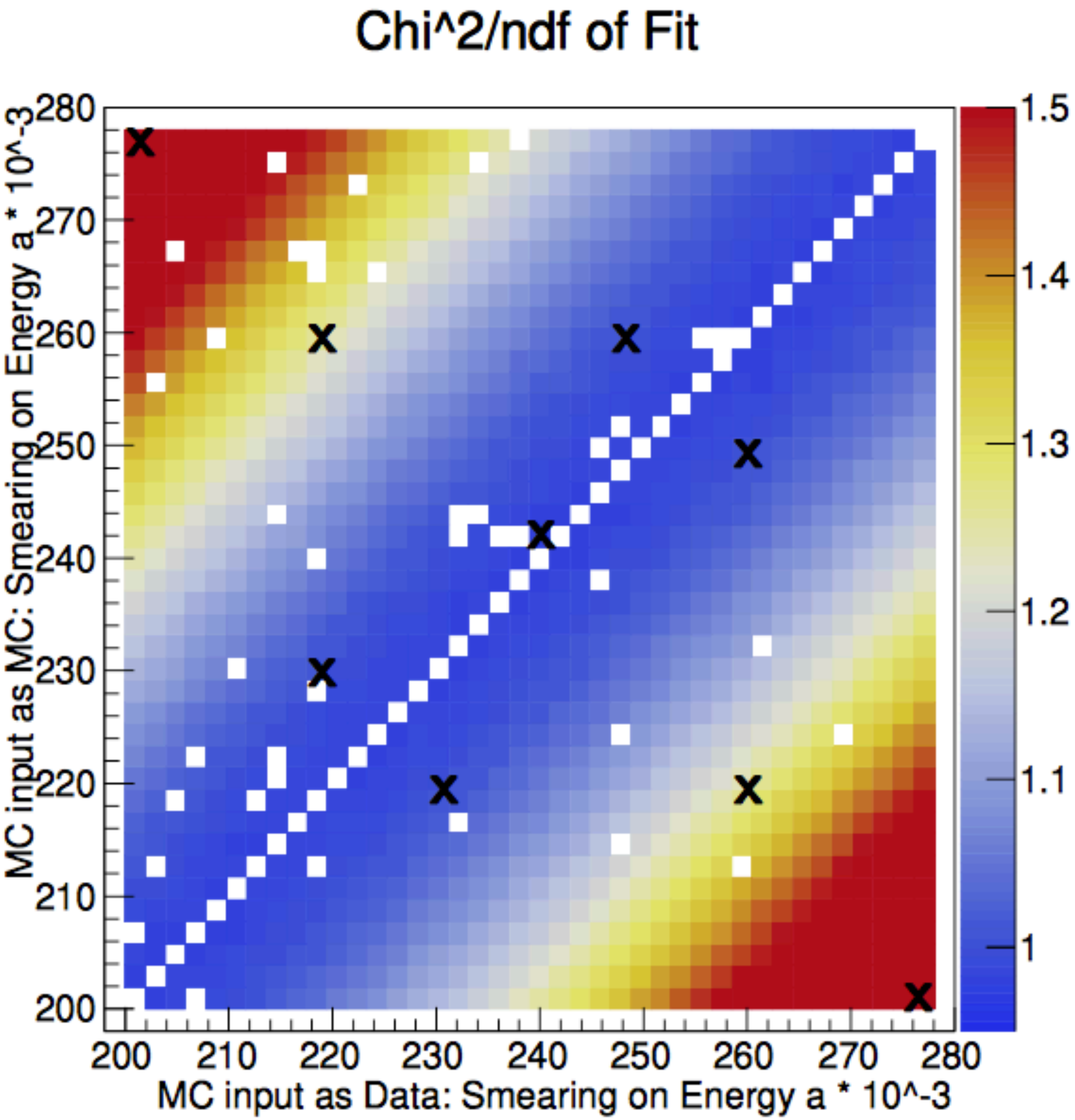

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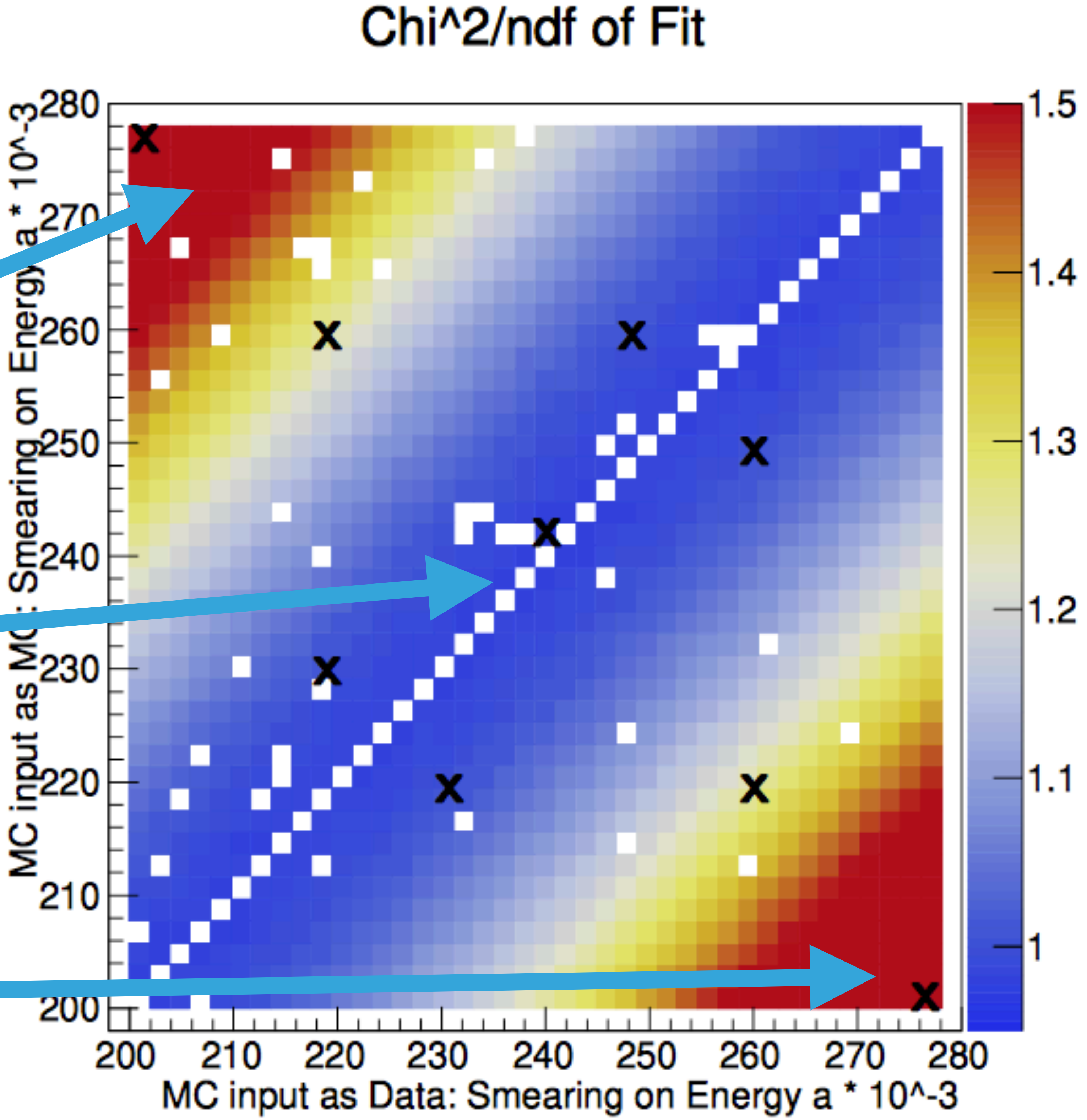


Area for better resolution on the detector than on the simulation

In the diagonal the simulation perfectly reproduces the detector resolution

Area for better resolution on the detector than on the simulation

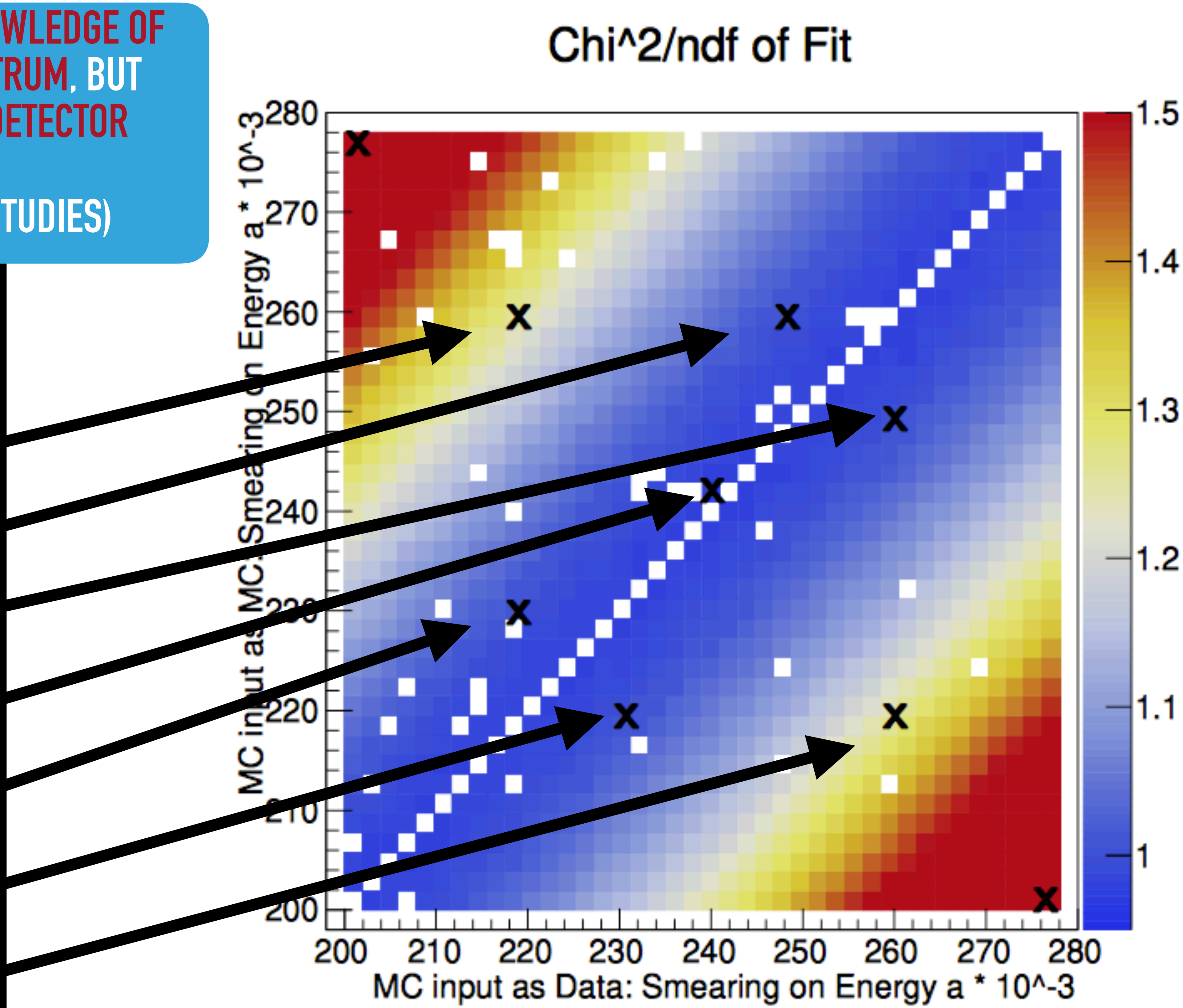
PROPAGATION OF THE UNCERTAINTY ON THE LUMINOSITY SPECTRUM INTO THE TOP MASS

P.ZEHETNER

ASSUMING PERFECT KNOWLEDGE OF THE LUMINOSITY SPECTRUM, BUT DIFFERENCES IN THE DETECTOR SIMULATION
(PHILIPP ZEHETNER STUDIES)

Top mass uncertainty for a few cases:

- 16 MeV
- 11 MeV
- 10 MeV
- 10 MeV
- 10 MeV
- 10 MeV
- 12 MeV



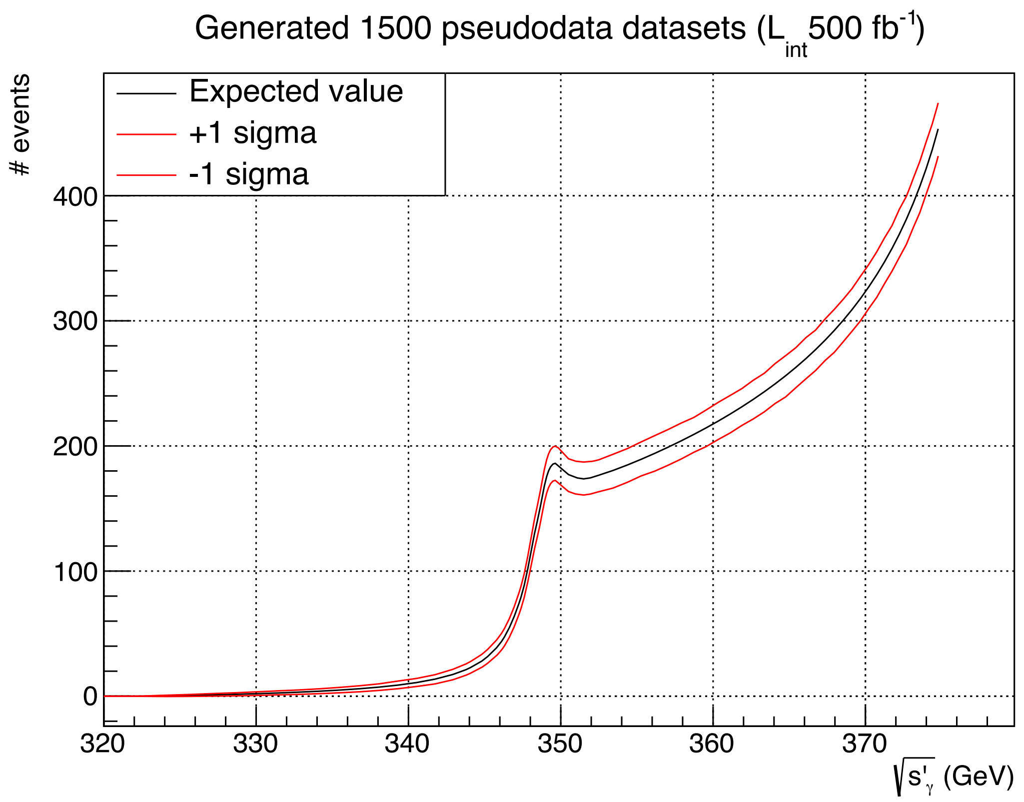
CONCLUSIONS

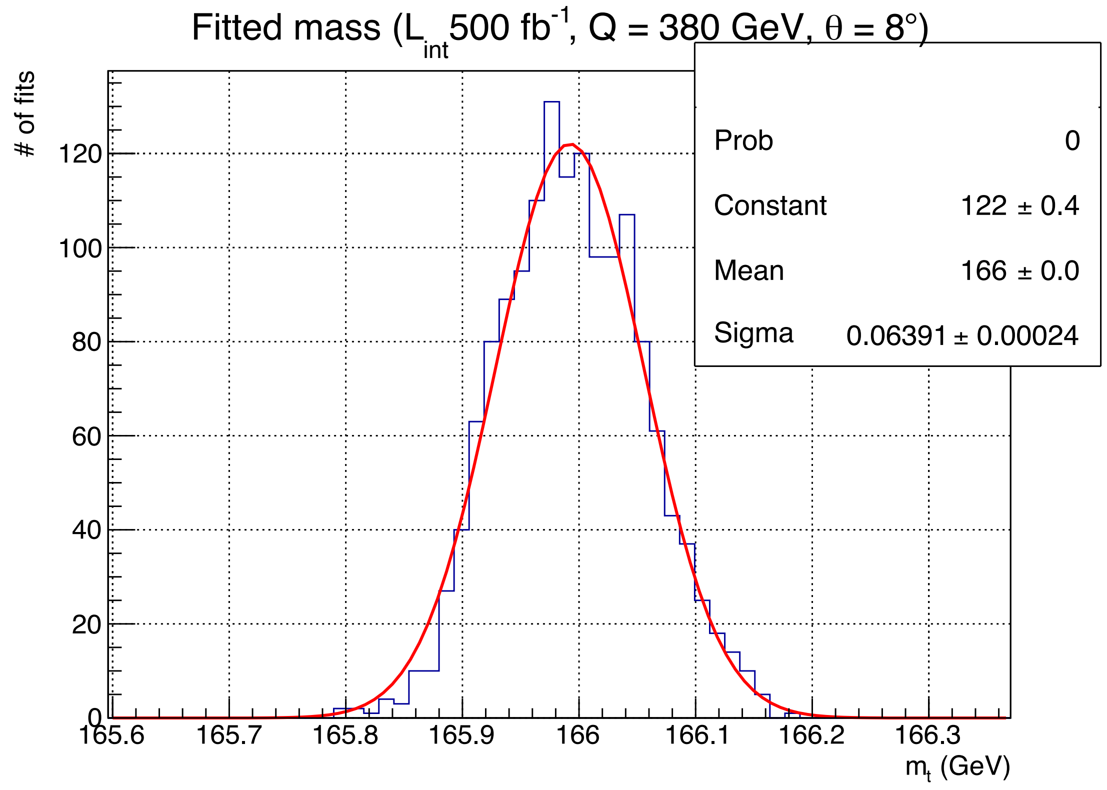
- CLIC @ 380GeV can measure the top quark mass with an uncertainty :
    - Theoretical uncertainty : between **50MeV to 100MeV** @380GeV. Goal is **50MeV** by improving the fit procedure.
    - Statistical uncertainty : ~100MeV@500fb^{-1}→**~70MeV@1ab^{-1}** (including the effect of the luminosity spectrum)
    - Propagation of the uncertainty on the luminosity spectrum determination on the top mass: **~10MeV**

END

SENSITIVITY TO THE TOP QUARK MASS

- In order to evaluate the sensitivity of the observable to the top mass we generate pseudo data of certain luminosities.
- We assume that the real number of events in that bin will follow a Poisson distribution with a mean equal to the multiplication of the cross section expected for each of the bins by the integrated luminosity.
- By generating thousands of datasets and fitting them to the theoretical model we obtain thousands of values for the mass, which then are used to fill a histogram.
- Then we fit the histogram to a gaussian and we estimate the precision for the mass measurement as its sigma.





SENSITIVITY TO THE TOP QUARK MASS (II)

Considering a detector coverage of 6° < θ < 174°

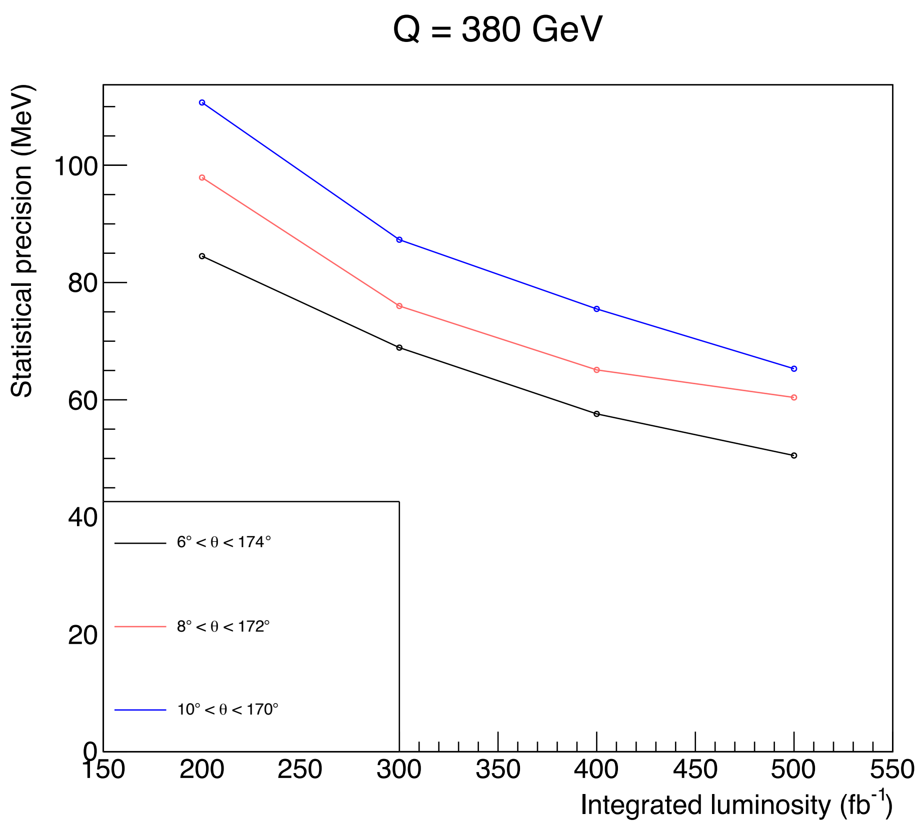
	200 fb^{-1}	500 fb^{-1}	1000 fb^{-1}	4000 fb^{-1}
σ_m (MeV) @380 GeV	85	50		
σ_m (MeV) @500 GeV	247	152	110	56

Considering a detector coverage of 8° < θ < 172°

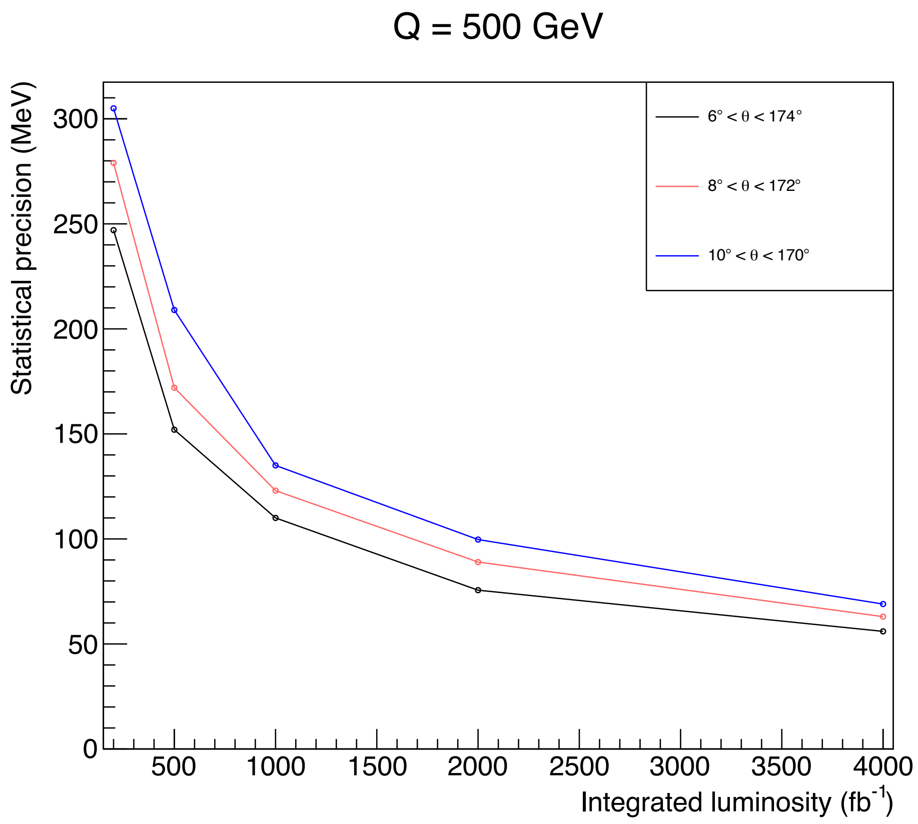
	200 fb^{-1}	500 fb^{-1}	1000 fb^{-1}	4000 fb^{-1}
σ_m (MeV) @380 GeV	98	60		
σ_m (MeV) @500 GeV	279	172	123	63

Considering a detector coverage of 10° < θ < 170°

	200 fb^{-1}	500 fb^{-1}	1000 fb^{-1}	4000 fb^{-1}
σ_m (MeV) @380 GeV	111	65		
σ_m (MeV) @500 GeV	305	209	135	69



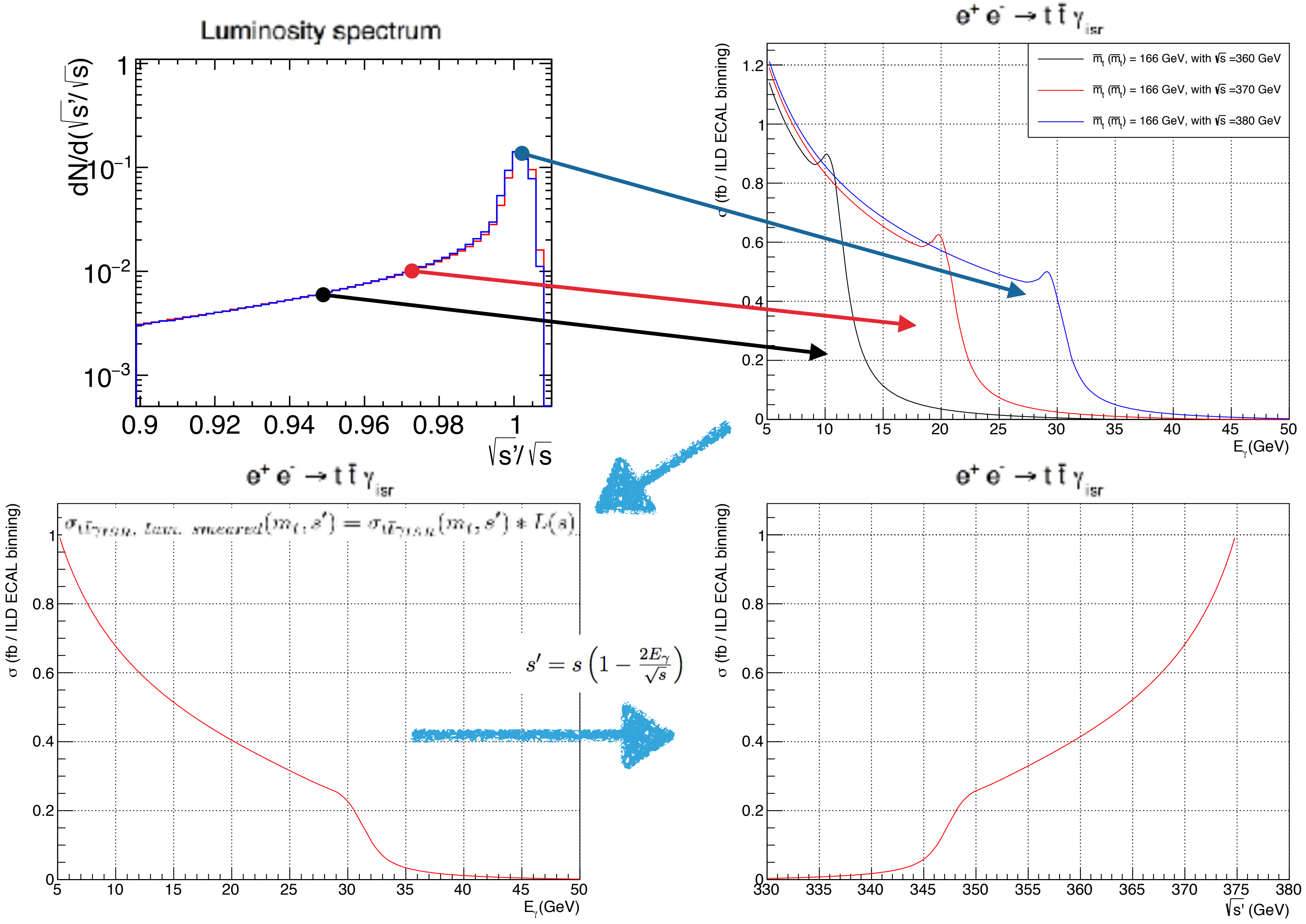
Q = 380 GeV



Q = 500 GeV

LUMINOSITY SPECTRUM WEIGHTING

- In the experiment, *s* isn't fixed to 380 GeV, but instead, it has a spectrum. To account for that, we fold our model with the luminosity spectrum.



$\sigma_{t\bar{t}\gamma_{ISR},\ lum.\ smeared}(m_t, s') = \sigma_{t\bar{t}\gamma_{ISR}}(m_t, s') * L(s)$

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

- We weight our observable distributions of a given Q with the luminosity spectrum.