# $t\bar{t}$ generation at FCCee

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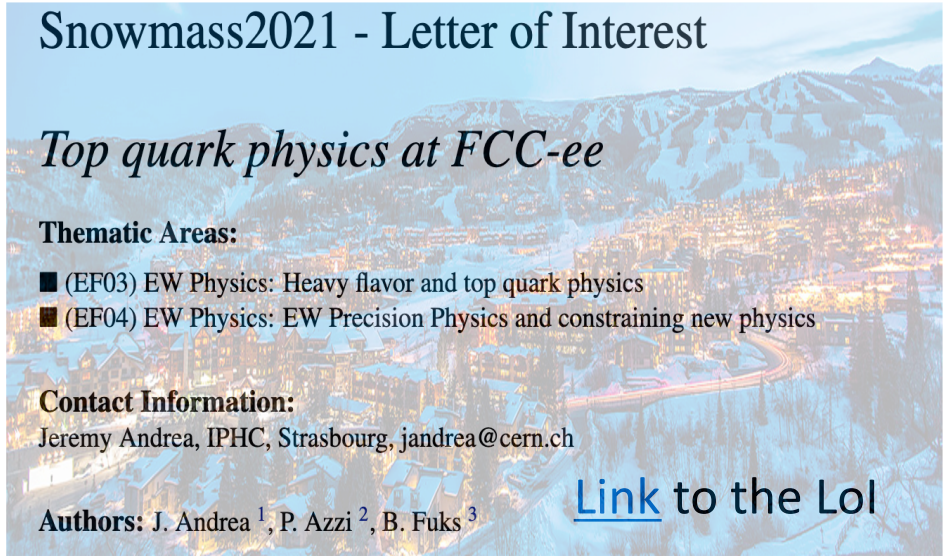
# Introduction

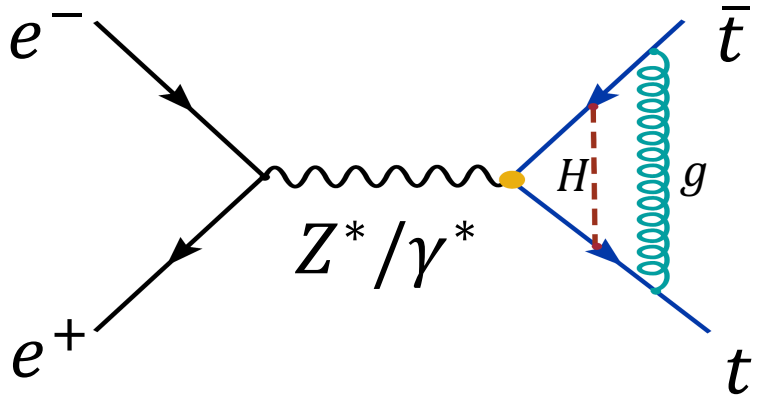
- Preparation of physics case studies (for Snowmass and beyond).
- Couple of presentations at Snowmass WG EF03 (link), and EF04 (link).
- Top@FCCee : growing community (collaboration with Copenhagen), but still critically lacking contributors.
- Environment that facilitates inclusion of new contributors :
  - Generation, analysis framework, object selection, events reconstructions etc.
  - Providing required tools for new comers.




- Past few months, focused on events generation, but other topics above can (and should) progress in parallel.
- In this presentation, some MC generators tested and compared. No final recipe !

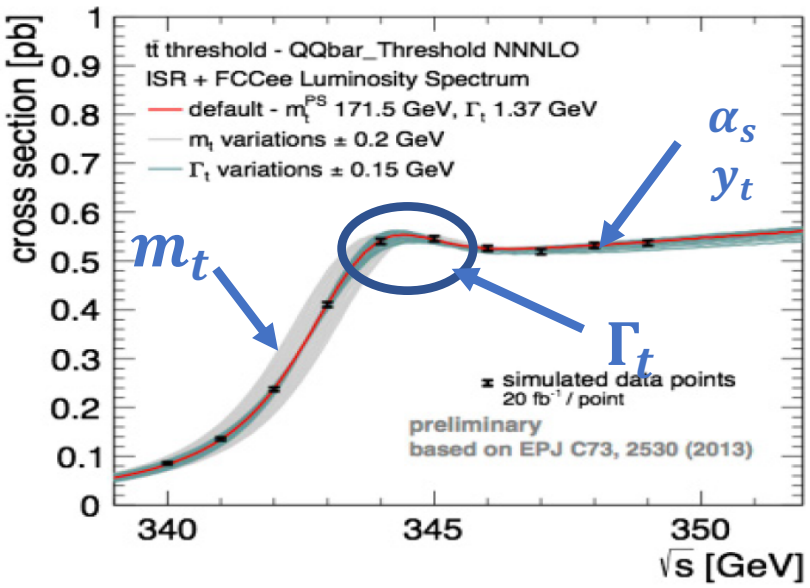
# Top quark physic at $e^+e^-$ colliders (in a nutshell)

- Physics program at lepton colliders <=> precision !
  - Low background,
  - excellent knowledge of the initial state,
  - detectors with very high precision.




- $t\bar{t}$ (differential) cross sections sensitive to :
  - **top quark mass $m_t$**, top quark width $\Gamma_t$,
  - Couplings to Z ($t\bar{t}Z$) and ($t\bar{t}\gamma$) couplings Higgs ($t\bar{t}H$), $y_t$
  - On $\alpha$ and $\alpha_s$.

CDR FCCee




- Top quark physics at $t\bar{t}$ threshold ($\sqrt{s}$ scan) :
  - measurements of mass and width, from event yields,
  - precision depends on the prediction of the theoretical function,
  - event yields => acceptance corrections depend on MC generator.

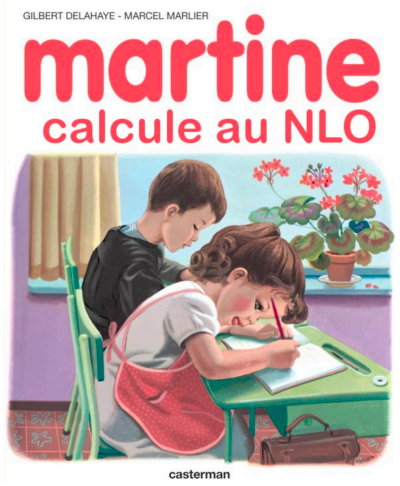
- Top quark physics above $t\bar{t}$ threshold.
  - measurements of $y_t$, top EWK couplings and searches for new physics,
  - signal modelling relies on MC simulation.

- Precise signal modelling is one of the keys to precision.
  - what is the effect of $\sqrt{s}$ on $t\bar{t}$ kinematics at threshold ?
  - cross section enhancement => impact on kinematics ?
  - generator systematics, dominate in several top analyses.

# Generators : aMC@NLO and Whizard

- "State-of-the-art" generator shopping list
  - maximum possible accuracy : NLO QCD+QED,
  - NLL+NLO matching ? Differential cross sections at threshold, effects of $\sqrt{s}$ on kinematics?
  - accounts for beam effects (discussed later),
  - at least 2 generators to perform comparisons,
  - two generators investigated here : Whizard and aMC@NLO.

- Both generators cover most of the required features (in a not-yet public release for aMC@NLO link) :
  - NLO accuracy, **Whizard** : QCD , **MadGraph** :QCD (QED under developments),
  - Initial State Radiation (ISR), **both,**
  - Beamstrahlung : **Whizard** : interface with GuineaPig/CIRCE. **MadGraph** : parametrization fitted to GuineaPig++.
  - Beam Energy Spread : **Whizard** : Gaussian smearing in case of FCCee, **Madgraph** : not available yet.




Whizard

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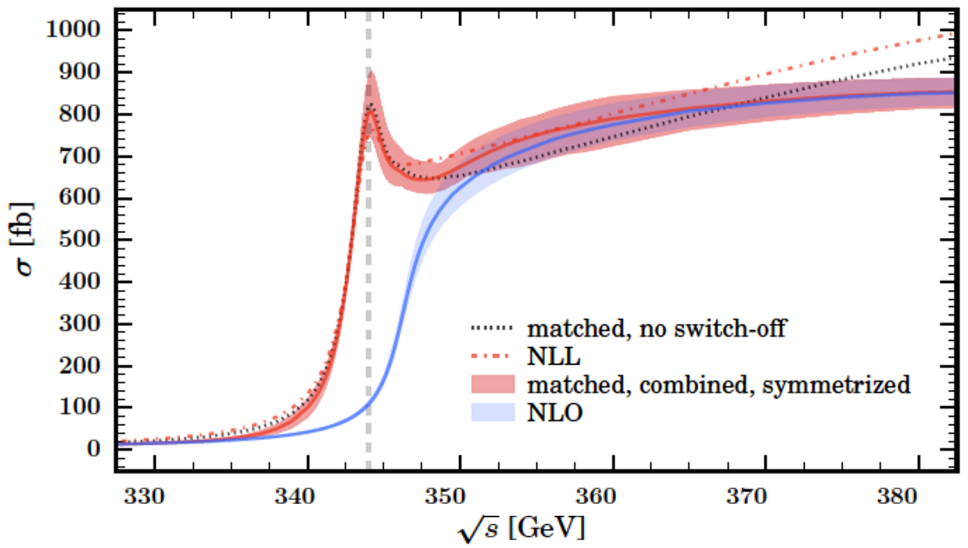
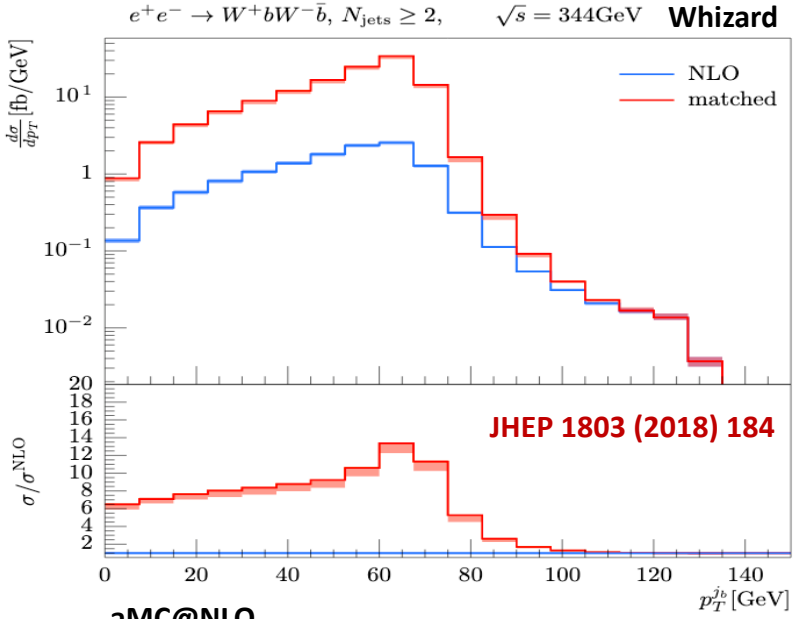



Whizard

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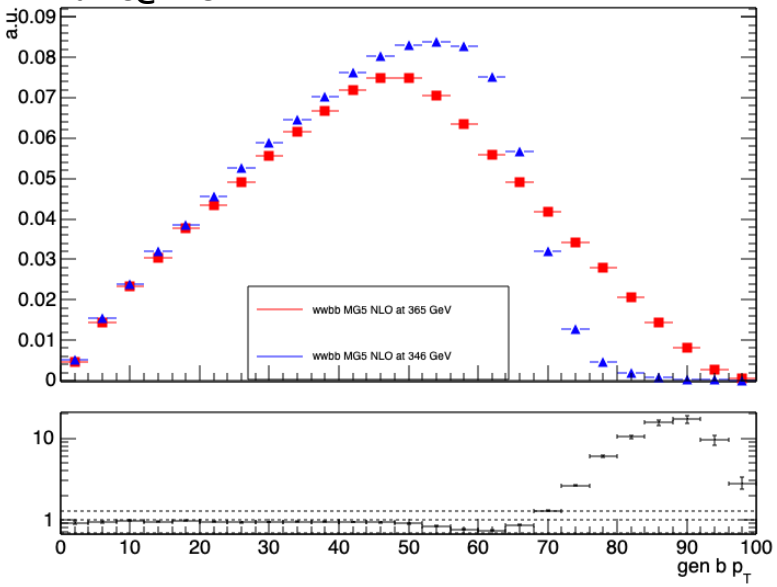
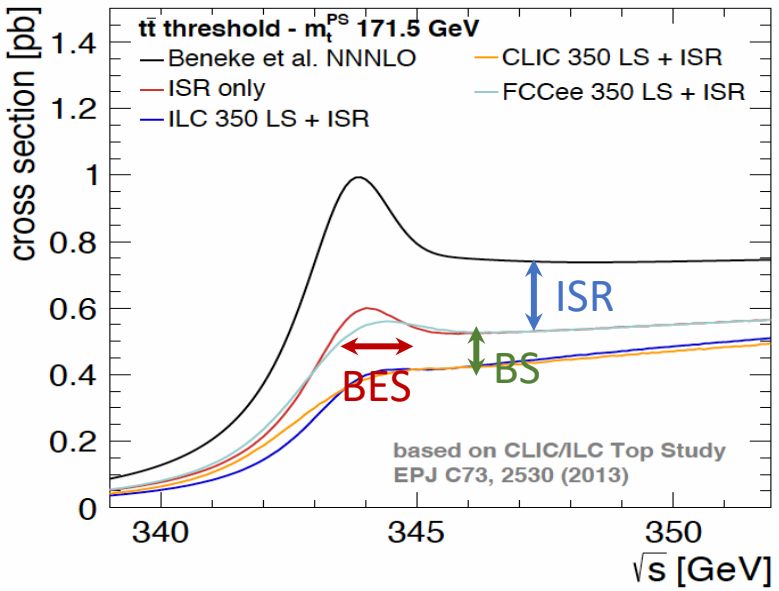
aMC@NLO

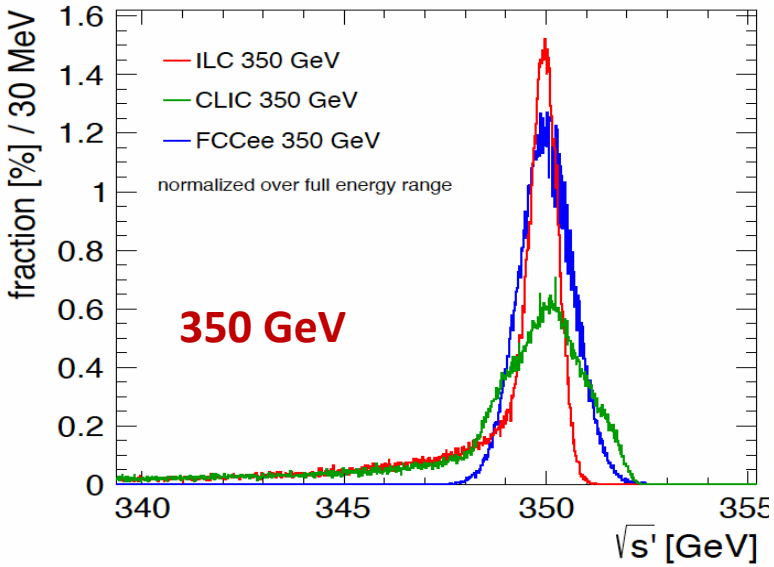


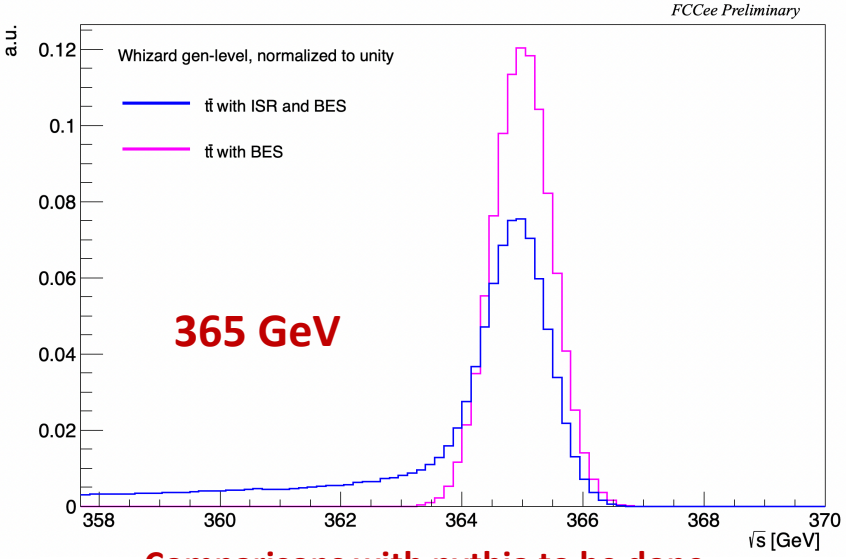
# Beam effects/ISR

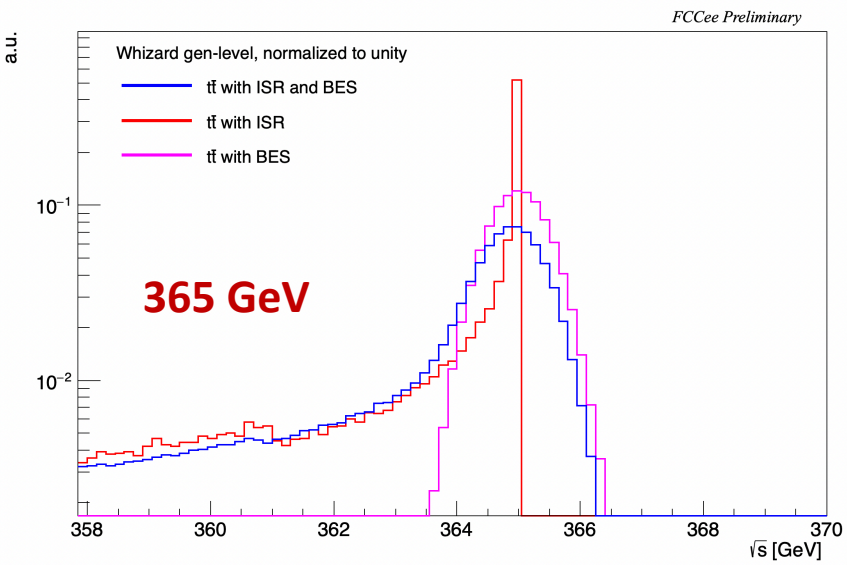
F.Simon, PoS (ICHEP 2016) 872




- ISR and beam effects on the threshold measurement :
  - ISR and Beam Backgrounds : reduce the energy in the $e^+e^-$ centre of mass => tails toward lower energies.
  - Beam Energy Spread (BES) : enlarges the $\sqrt{s}$ distribution. BES ~0.19% per beam.
- At FCCee BES : $\sqrt{s}$ distribution symmetric and gaussian with very good approximation.
- Whizard :
  - ISR implemented. Possible overlap with PS (pythia) to be understood.
  - BES : modelled by a gaussian.



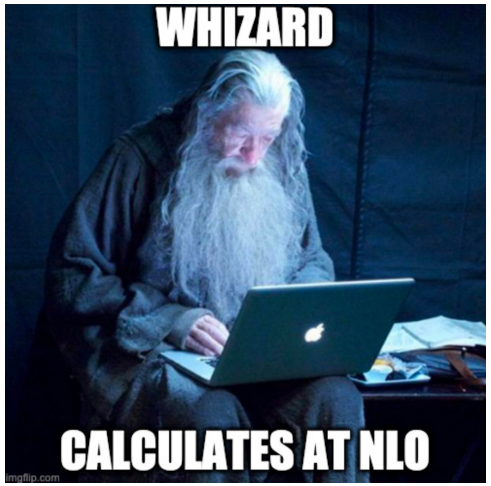



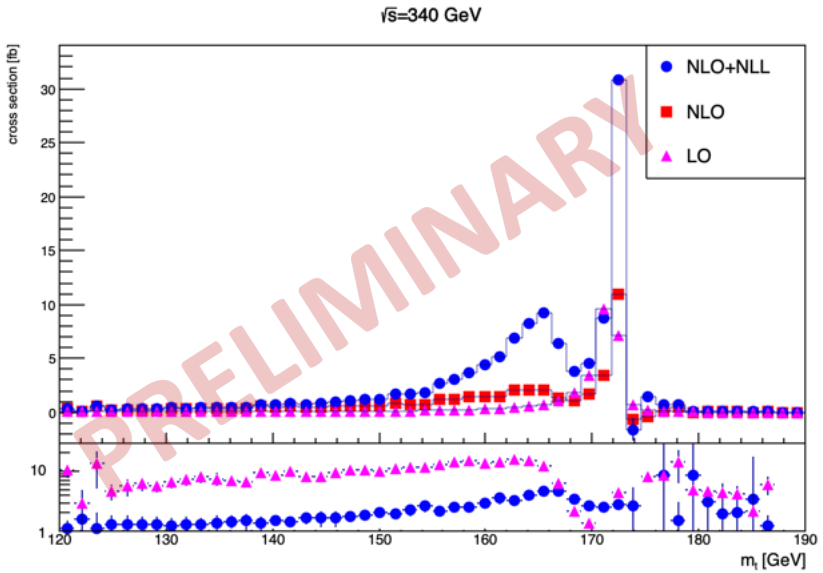



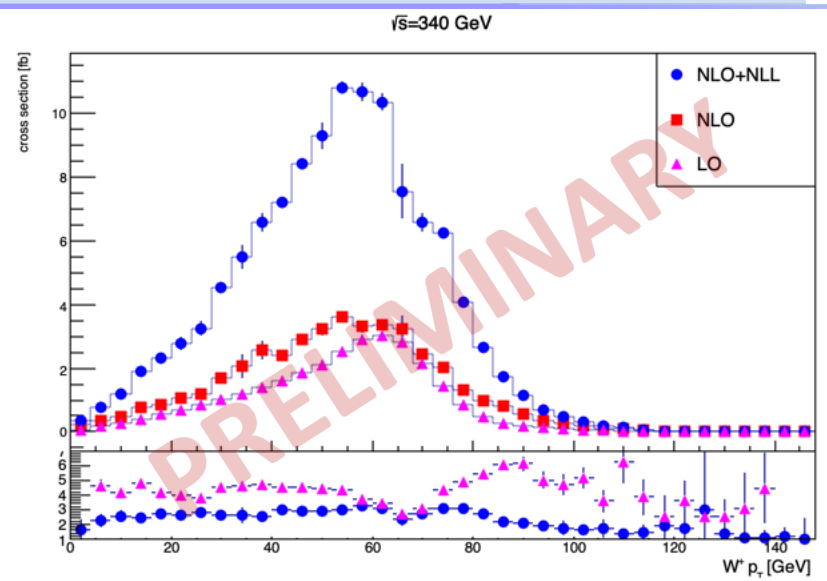

Comparisons with pythia to be done

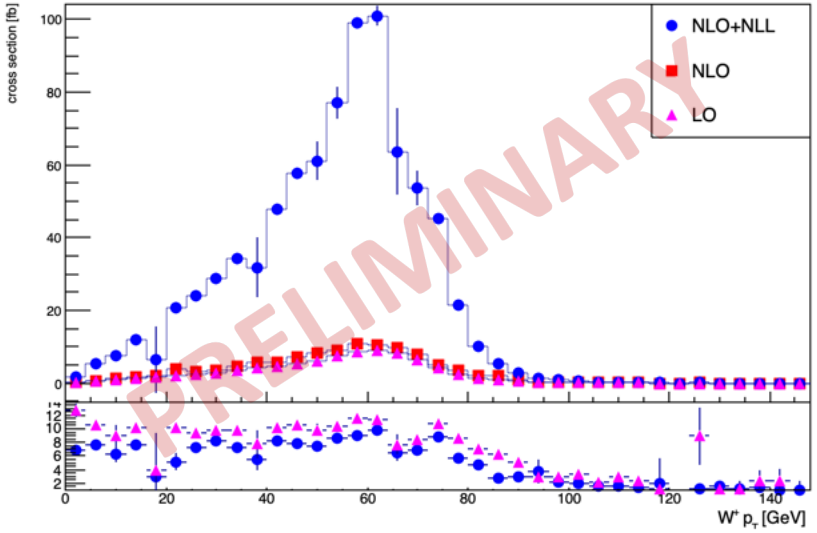
# Whizard at $t\bar{t}$ threshold

- Calculation of $t\bar{t}$ $(WWb\bar{b})$ (differential) cross sections at threshold.
  - NLO calculation performed with the SM model,
  - fixed order calculation : can not be used “as is” for event based analyses,
  - still gives precious information about changes of kinematics at threshold peak.
- Close collaboration with Whizard Authors **(many thanks to them)**.
- Results to be taken with a lot of care, but first results seem to show that acceptance should be similar when comparing matched and (N)LO.

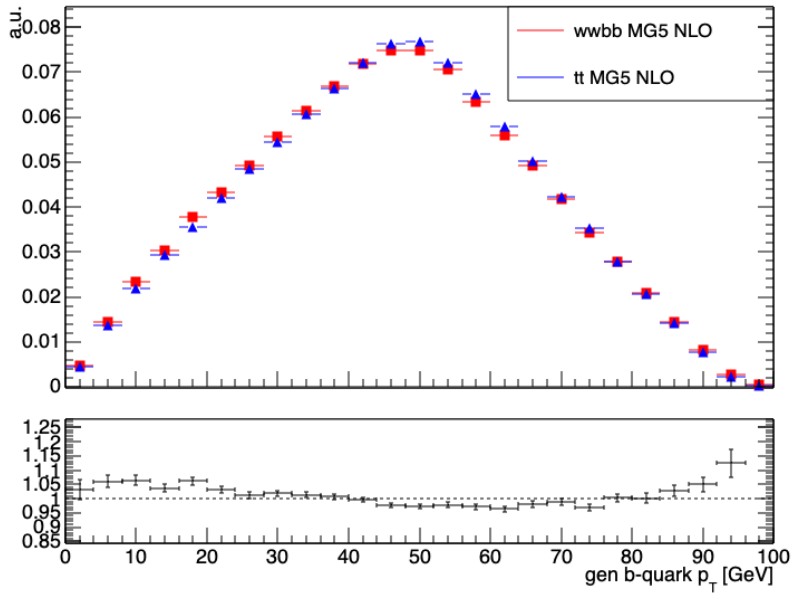


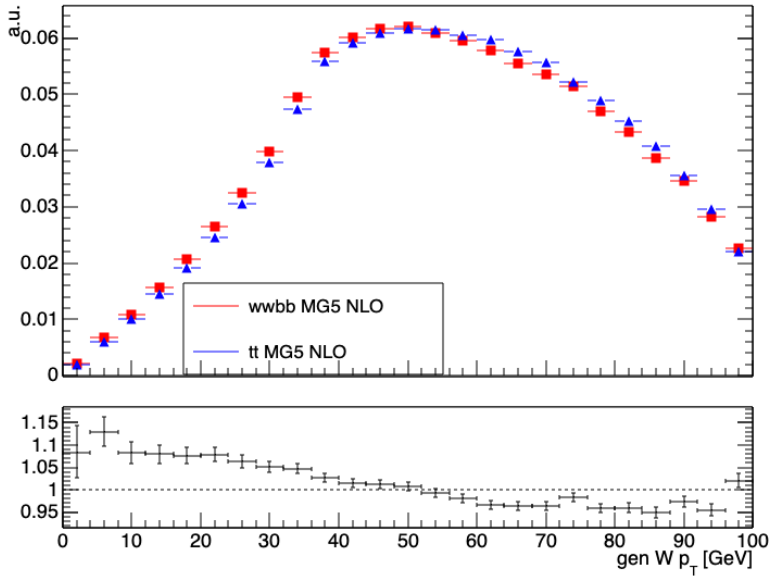



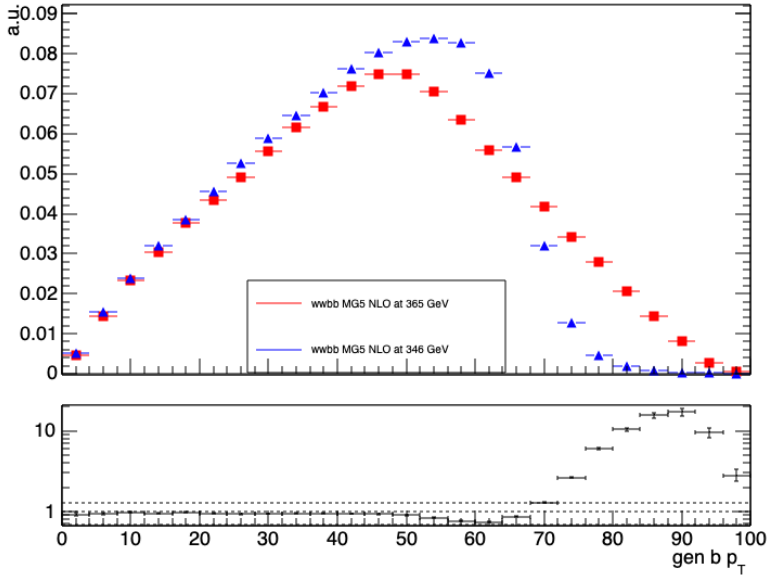



# Madgraph




- First tests also performed with MadGraph, generation at QCD NLO.
- Comparisons with $t\bar{t}$ and $W^+W^-b\bar{b}$ at 365 GeV.
- Kinematic 365 vs 346 GeV comparisons.
- New madgraph version coming (with BS, ISR). **Private versions shared with us for testing (many thanks !).** EWK NLO being worked on !




# Toward "stable" event generation configuration

- Whizard generator seems a reference so far at lepton colliders (for $t\bar{t}$ at least), but **comparisons with other generators is critical** (pyhtia, MG_aMC@NLO).

- Several approaches possible : LO, NLO,
  - $2 \to 2$ $(e^+e^- \to t\bar{t})$, only above threshold, Pythia for decays,
  - $2 \to 4$ $(e^+e^- \to W^+W^-b\bar{b})$, Pythia for decays,
  - $2 \to 6$ $\left(e^+e^- \to f\bar{f}'f\bar{f}'b\bar{b}\right)$, most complete, several process files (one per final states).

- Pythia used for PS and hadronization :
  - Pythia6 vs Pythia8,
  - Overlap between Pythia ISR (PS) and Whizard ISR ?

- Parameters to define :
  - model parameters (masses, couplings, scales),
  - Pythia parameters,
  - beam parameters and beam backgrounds (BS negligible at first ?)
  - How to deal with systematics …

- Get in touch with ILC/CLIC community to reproduce similar samples ?

# Events generation and selection

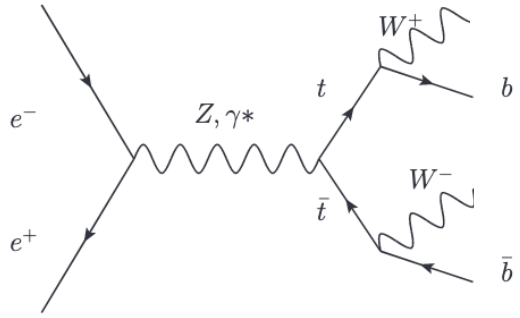
- First step of analysis implementation, above thresholds ($\sqrt{s}$=365 GeV).

- (Simple) events generation with whizard3 for the discussed results :
  - LO only, including BES and ISR,
  - Top, W and Z decayed with phytia6,
  - Pythia6 also used for Parton Shower (FSR only) and hadronization (Pythia8 can also be used),

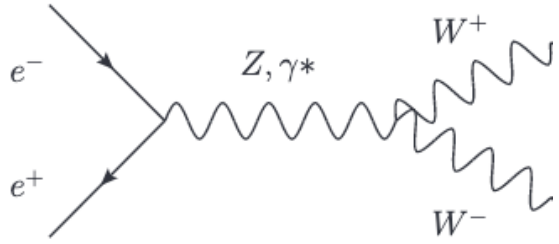
- Signal and backgrounds 2 → 2:
  - $e^+e^- \to t\bar{t}$,
  - $e^+e^- \to W^+W^-$, $e^+e^- \to ZZ$ and $e^+e^- \to Zh$
  - Rescaled to LO cross sections for backgrounds, NLO for signal.

- Much work needed toward final productions : expertise from ILC/CLIC on whizard usage would be extremely useful.
Next slide : ”naïve” whizard production tested with simple $t\bar{t}$ selection (l+jets). As also been tested with MadGraph.

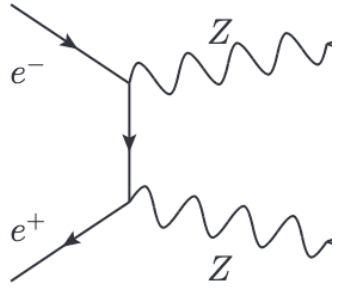
$e^+e^- \to t\bar{t}$



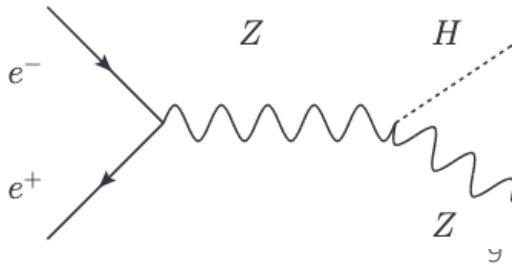

$e^+e^- \to W^+W^-$




$e^+e^- \to ZZ$



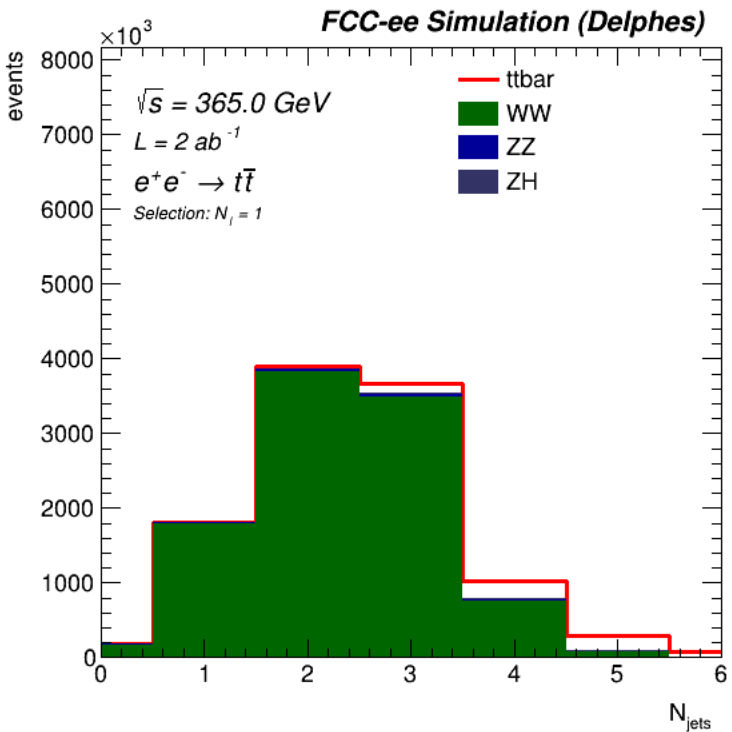

$e^+e^- \to Zh$

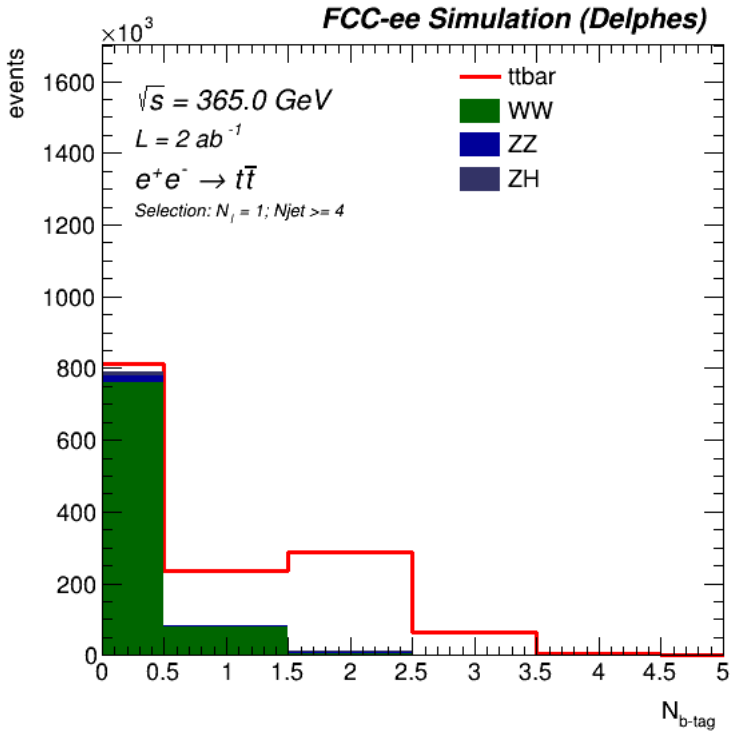


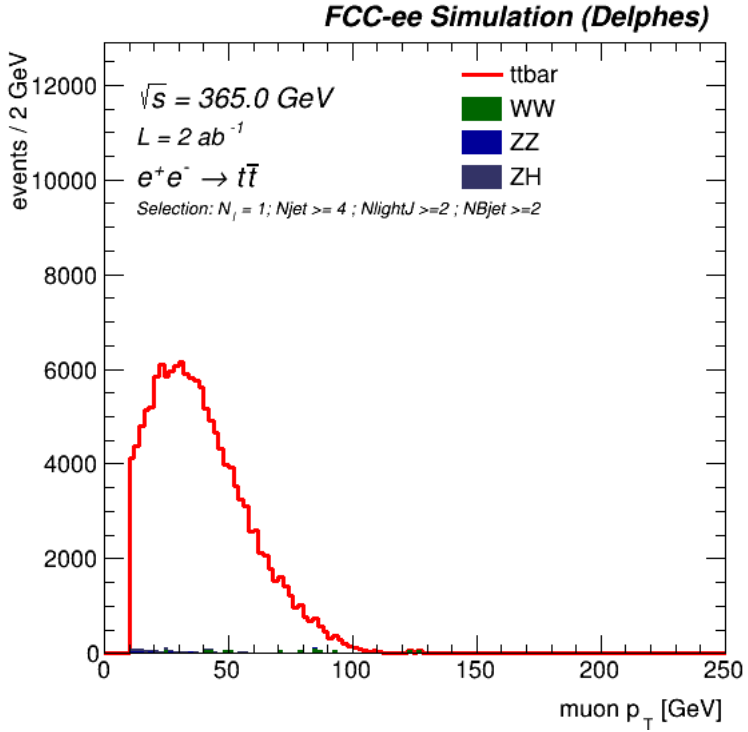
# Proto analysis

- Simple events selection (thanks to Clement for the help with the software).

- Baseline for future $t\bar{t}$ specific tools :
  - Baseline event selections, for each channel : **Required to preform MC validation,** various reconstruction algorithms to be tested, optimisation etc…
  - Event reconstruction : solve events reconstructions using the beam energy information, deal with combinatorics, Kin-fit to improve the resolution => Copenhagen group (Jorgen Beck, Julie Munch Torndal) and IPHC (JA, based on a method from Patrick Janot (thanks !!) ).



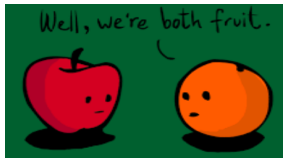



# Summary

- Precise and robust MC generators required for top quark physic.
  - At lepton colliders, NLO accuracy matters for QCD and EWK !
  - Other beam related effects should be included (BES, BS),
  - It seems that cross section enhancement at threshold does not affect the acceptance much.

- We should not rely on a single generator :
  - Comparisons critical for validation and understanding!
  - Comparisons relevant only if generators cover the same physics => ensure comparing apples to apples.
  - We need help from the theory community !




- In this presentation, preliminary studies have been performed with Whizard and Magraph,
  - More detailed and systematic studies/comparisons needed,
  - There might be other generators to test,

- Expertises in CLIC/ILC communities, **lets collaborate** !