The top mass at the ttbar threshold with CEPC

CEPC RefTDR weekly meeting

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on behalf of

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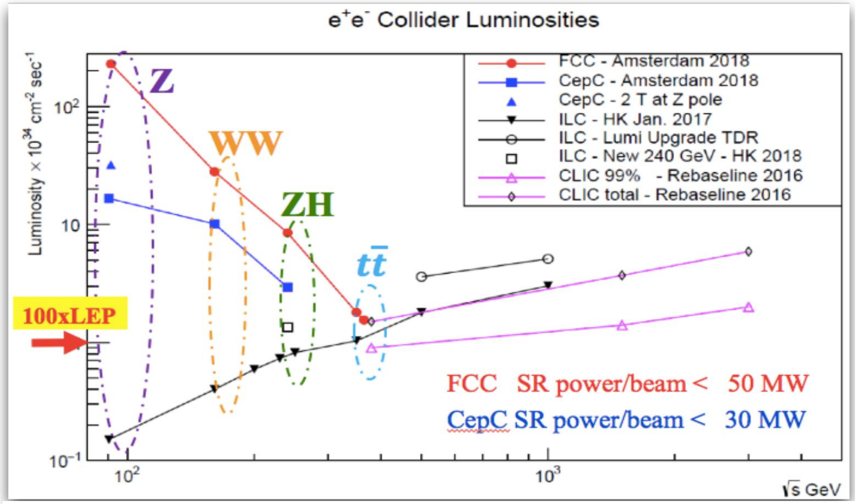
Reference: Eur. Phys. J. C (2023) 83:269, arXiv:2207.12177

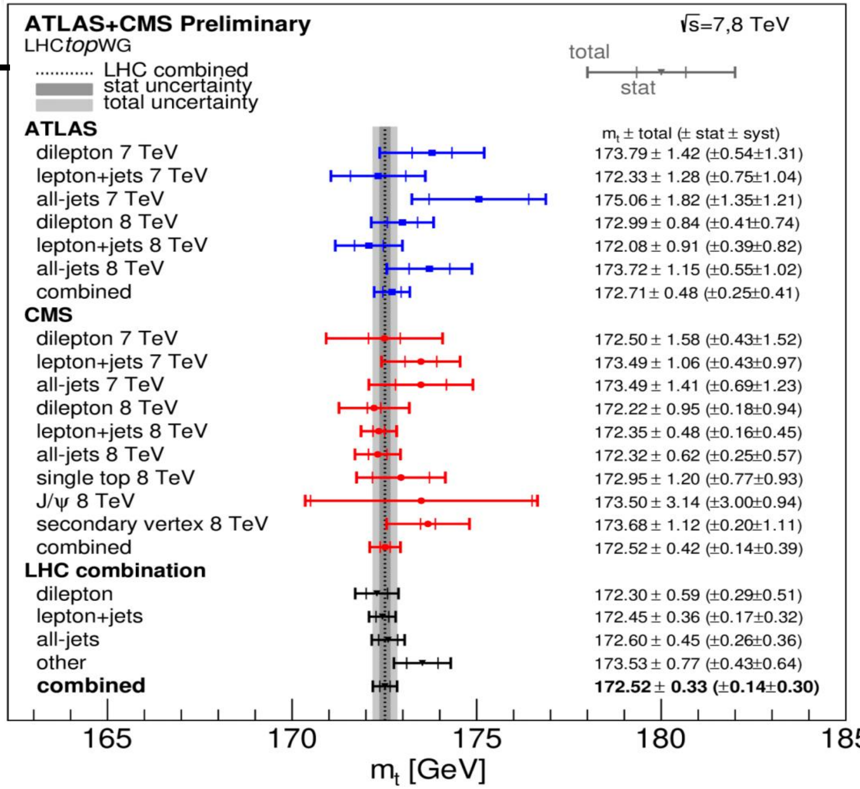
Introduction

- CEPC will be a versatile machine with many opportunities
  - Higgs factory @~240 GeV, Diboson factory @~160 GeV, Z factory @~90 GeV
- @~360 GeV it can also be a playground for
  - Top quark precision measurements
  - Higgs complementary measurements
  - BSM searches



Top quark mass measurements

- The top "pole" mass is measured using top reconstruction at hadron colliders
- Heavily relies on the performance of MET (the neutrino) and JER & JES
- ATLAS+CMS combined measurements (15) reached a level of uncertainties of 330 MeV dominated by systematic uncertainties
- Further improvements in precision are highly challenging due to the predominance of systematic uncertainties inherent to hadron collider environments.

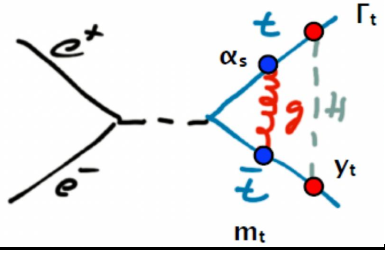


ATLAS-CONF-2023-066, CMS-PAS-TOP-22-001 for Run1

New results such as CMS Eur. Phys. J. C 83 (2023) 963 with 370 MeV using Run2

ttbar threshold scan

- ee-colliders enable both top reconstruction and ttbar threshold scan.
- The scan is made against $\sqrt{s}$ and cross-section is the direct observable
- This brings measurements of top mass and a couple of other parameters
  - Top width, Top Yukawa coupling, α_S



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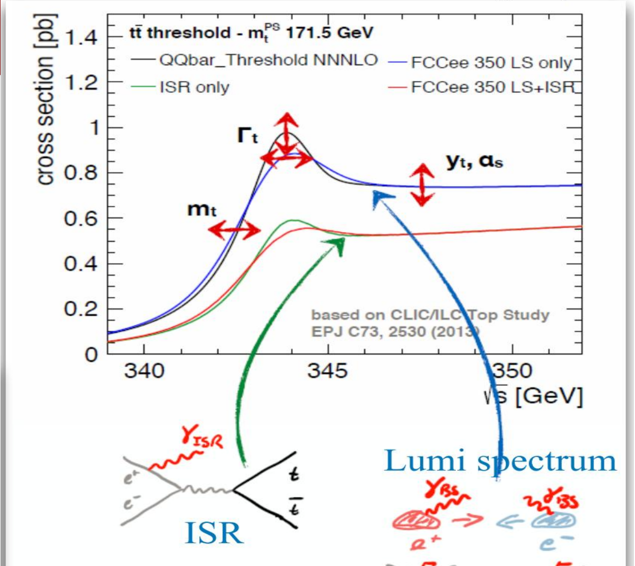


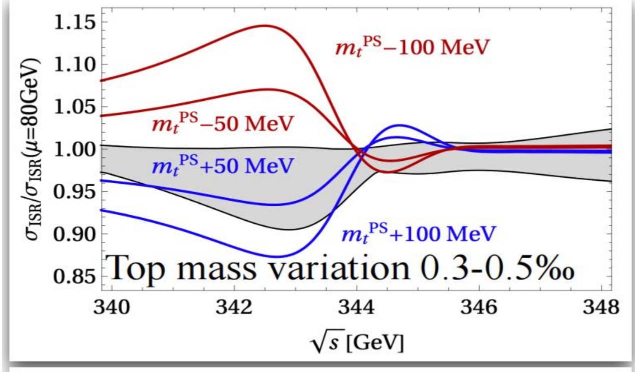
Alain Blondel

Our setup in [Eur. Phys. J. C (2023) 83:269](), [arXiv:2207.12177]()

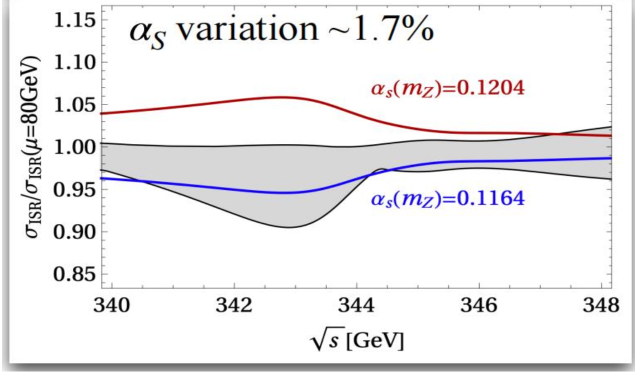
- Use the package "QQbar_threshold" to calculate cross-section near threshold in ee-colliders at N^{3}LO in resummed non-relativistic perturbation theory
  - The incorporation of Coulomb interactions between the quark and the antiquark results in a significant enhancement of the cross section.
  - To circumvent ambiguities arising from IR renormalons, the package employs the PS shift (PSS) mass scheme as the default approach.

$$\boxed{m_t^{\mathrm{PS}} = 171.5\,\mathrm{GeV}, \qquad \alpha_s(m_Z) = 0.1184}$$

  - ISR effects are also included in the package
- We integrate luminosity spectrum (LS) by a Gaussian function with the CEPC expected beam energy spread (~500 MeV) as a function of s



Top mass variation 0.3-0.5‰

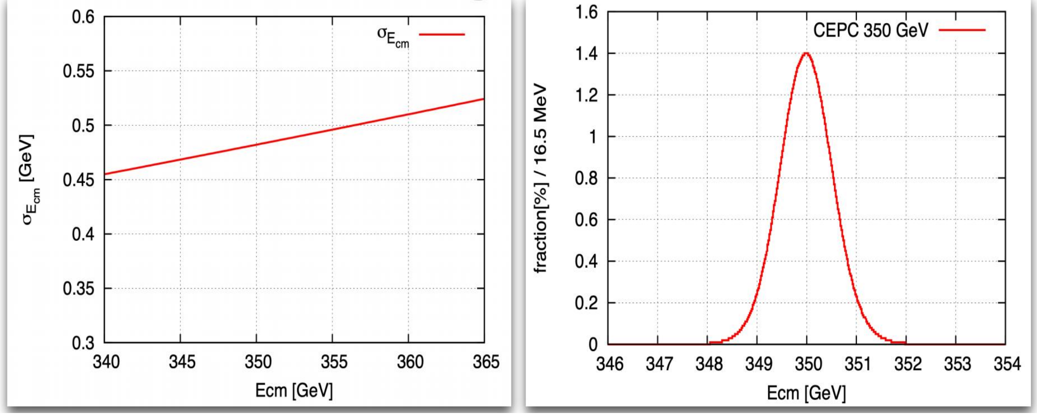


α_S variation ~1.7%

Luminosity Spectrum (LS) @ CEPC

- The beam energy resolution increases as a function of $\sqrt{s}$
- The LS is shown for $\sqrt{s} = 340\text{GeV}$ with a width of ~480 MeV
- Similar to the FCC-ee scenario

LS @ CEPC

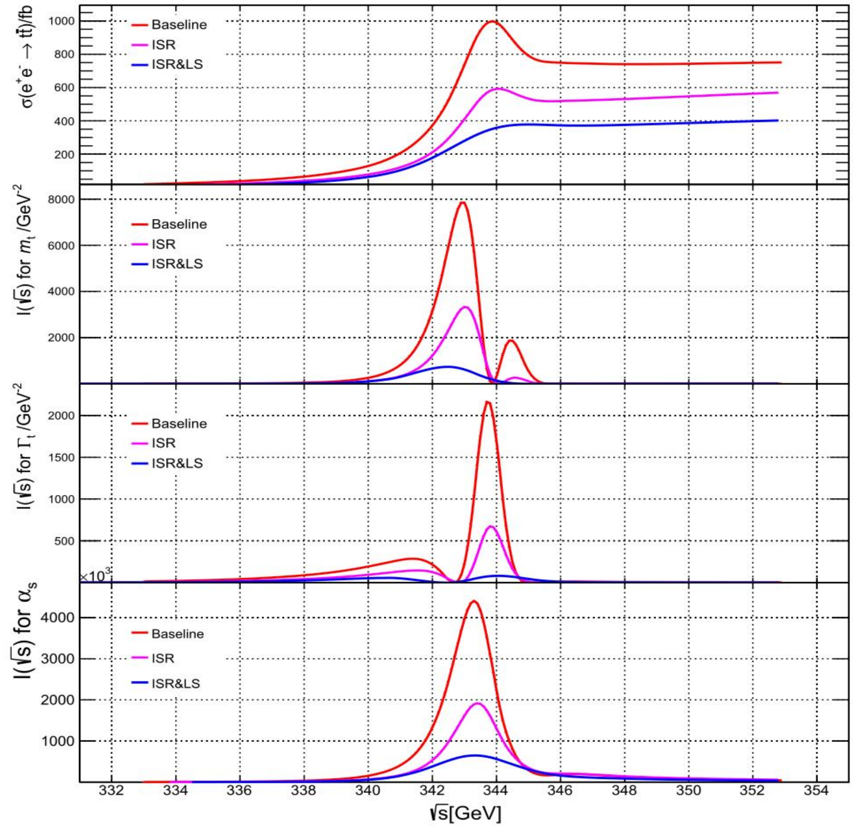


Which energy to collide with?

- Around the ttbar threshold, we need to identify the energy point(s) that contain(s) the most sensitivity
- Construct Fisher information to test the energy point(s)

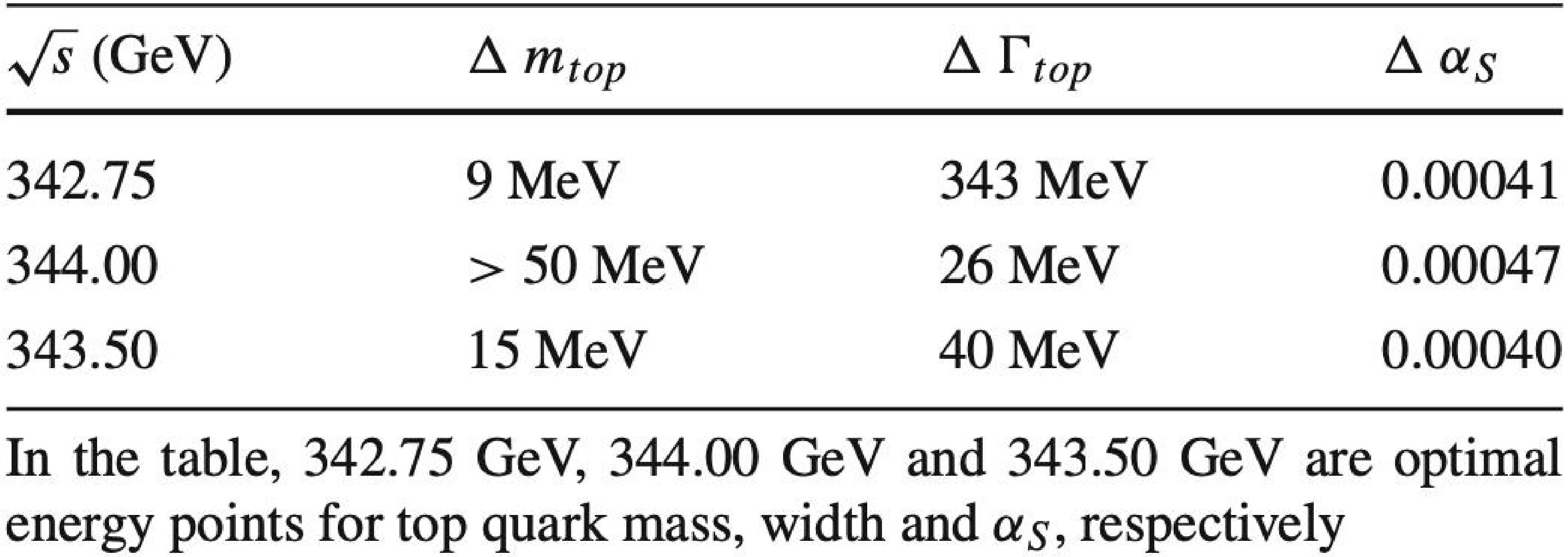
$$I(\sqrt{s}) = \int \left(\frac{\partial log(G(\sigma|\sigma_0(\sqrt{s},\theta), \sqrt{\sigma_0(\sqrt{s},\theta)}))}{\partial\theta}\right)^2 \times G(\sigma|\sigma_0(\sqrt{s},\theta), \sqrt{\sigma_0(\sqrt{s},\theta)})d\sigma.$$

- Larger amplitudes implies richer information and higher sensitivities



Statistical uncertainty of 1D scan

- Aiming at measuring one parameter at a time (1D), given limited total luminosity:
  - Only colliding at one optimal energy point would give the best sensitivity
  - This is tested with many different scenarios: one vs multiples energy points, un-even luminosity allocation etc.
- The precision of statistical-only one-parameter measurement using one optimal energy point @CEPC is calculated



$\sqrt{s}$ (GeV)	$\Delta\, m_{top}$	$\Delta\, \Gamma_{top}$	$\Delta\, \alpha_S$
342.75	9 MeV	343 MeV	0.00041
344.00	> 50 MeV	26 MeV	0.00047
343.50	15 MeV	40 MeV	0.00040

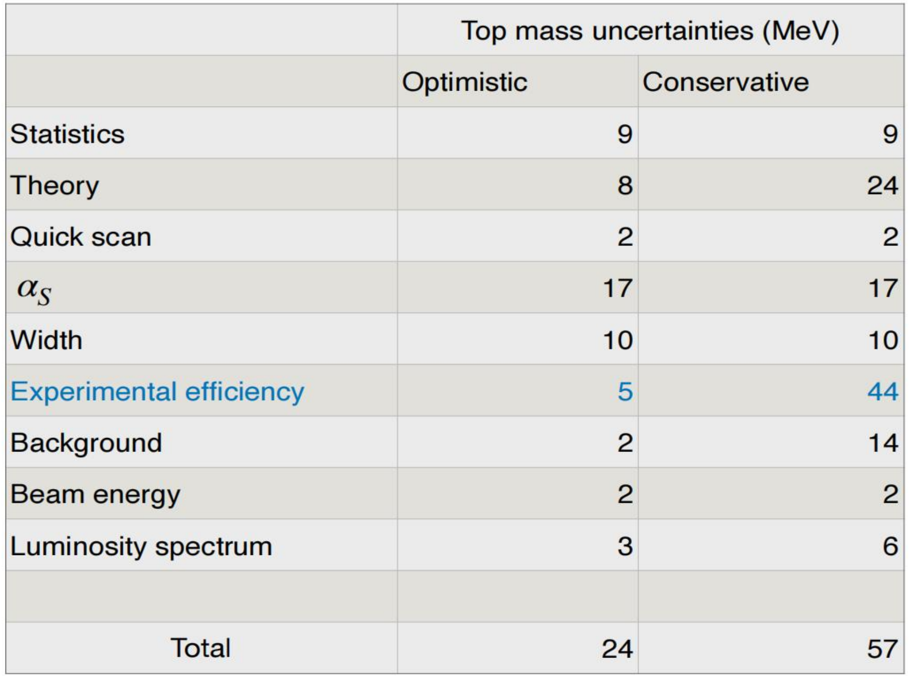
In the table, 342.75 GeV, 344.00 GeV and 343.50 GeV are optimal energy points for top quark mass, width and α_S, respectively

All are stats-only here

Eur. Phys. J. C (2023) 83:269, arXiv:2207.12177

Totally assumed Exprimental Uncertainty

- Experimental efficiency of the future detectors is yet to know(JER, JES, btagging-effciency...)
- Assume possible scenarios of uncertainties 0.5%, 1%, 3% and 5% that impacts signal rates directly
- This leads to top mass uncertainties of 5, 10, 27, 44 MeV, respectively



	Top mass uncertainties (MeV)	
	Optimistic	Conservative
Statistics	9	9
Theory	8	24
Quick scan	2	2
α_S	17	17
Width	10	10
Experimental efficiency	5	44
Background	2	14
Beam energy	2	2
Luminosity spectrum	3	6
Total	24	57

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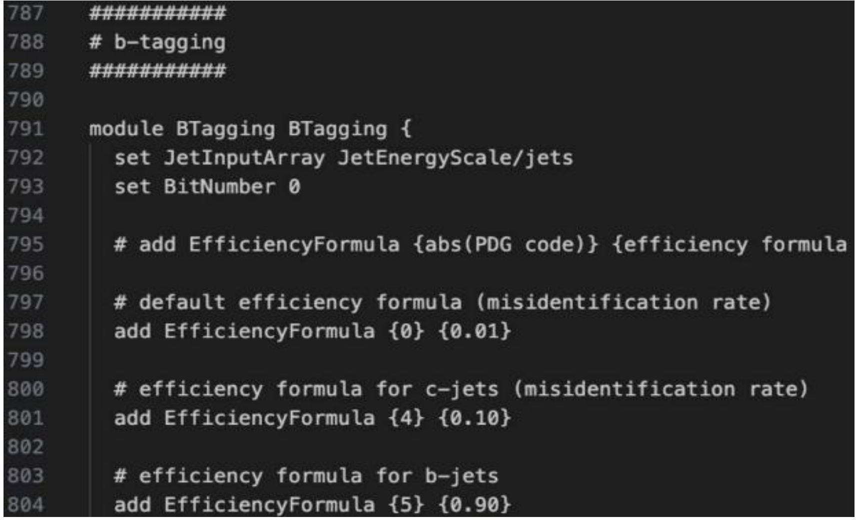
Collaborative Experimental Study with CEPC ttbar coupling group

- Using the detector simulation information provided by the CEPC refTDR physics group, we can more accurately assess experimental uncertainties
- Experimental uncertainty sources we care about most & truly need:
  - JES and its uncertainties
  - an excellent btagger and its uncertainties
  - JER and its impact on b-tagging

Primary Plan

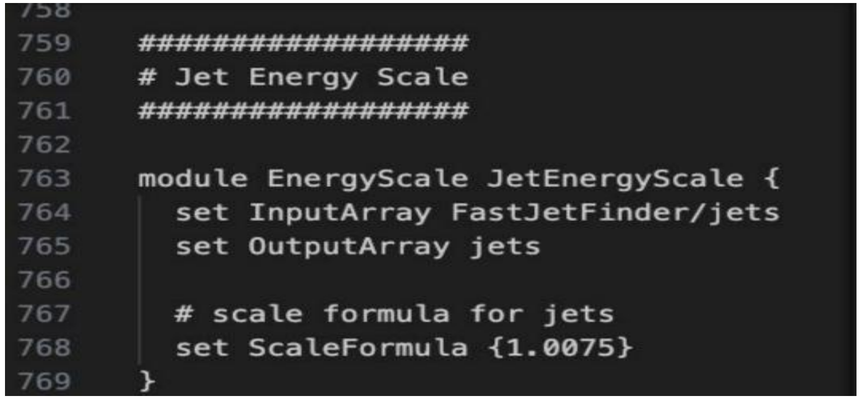
- Level 1: Complete the production of the ttbar signal sample.
- Level 2: Complete the production of the background sample.
- Approach:
  - Utilize CEPC_SW for sample generation as the primary option.
  - Prioritize the ttbar signal sample due to time constraints.



```
###########
# b-tagging
###########

module BTagging BTagging {
  set JetInputArray JetEnergyScale/jets
  set BitNumber 0

  # add EfficiencyFormula {abs(PDG code)} {efficiency formula

  # default efficiency formula (misidentification rate)
  add EfficiencyFormula {0} {0.01}

  # efficiency formula for c-jets (misidentification rate)
  add EfficiencyFormula {4} {0.10}

  # efficiency formula for b-jets
  add EfficiencyFormula {5} {0.90}
```

Backup Plan: Fast Simulation with Delphes

- If the primary plan faces delays or challenges, switch to fast simulation using Delphes.
- Key modifications to Delphes card:
  - Incorporate JES and its uncertainties.
  - Include JER and its uncertainties.
  - Add b-tagging efficiency curves and their uncertainties.

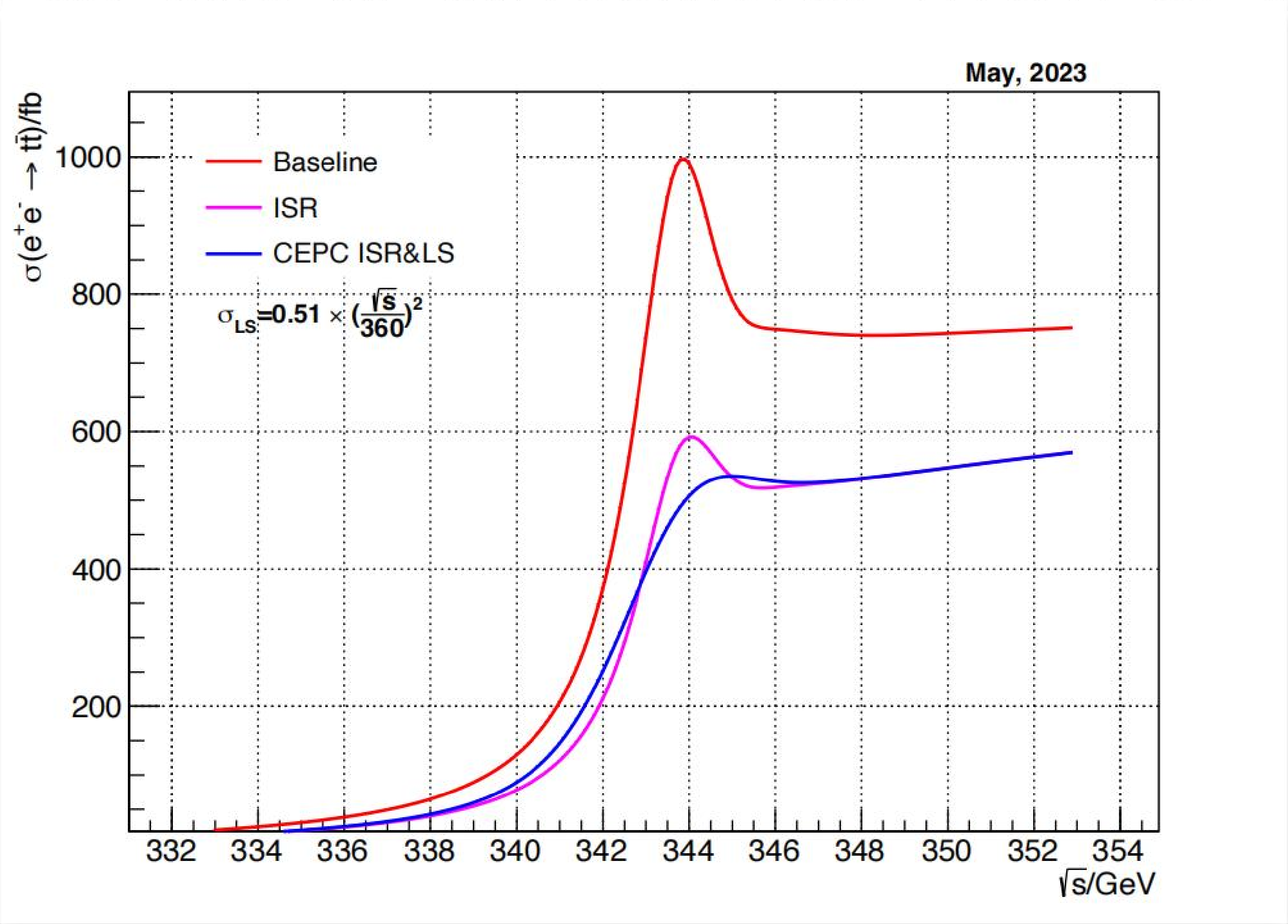


```
##################
# Jet Energy Scale
##################

module EnergyScale JetEnergyScale {
  set InputArray FastJetFinder/jets
  set OutputArray jets

  # scale formula for jets
  set ScaleFormula {1.0075}
}
```

delphes_card_CEPC.tcl

Back Up

XS at the $t\bar{t}$ threshold with CEPC



fast_sim framework

- **tcl card overview of delphes_CEPC ❓**

- **LO sample generate workflow ✅**
  - **Basic Process Overview**
  - **How to submit madevent jobs(.sh .py ...)**
  - **Issues**
  - **Allocation of sample jobs (Leyan, Yuming @ ihep.ac.cn)**

- **Outlook on Analysis framework ❓**

整个框架

MG5 pythia8 产生samples

这里可以做一个表 list

然后接入delphes_cepc

接着进入我们自己的分析框架

Top quark Mesurement @ CEPC

```
e- e+ > mu- mu+
e- e+ > q qbar
e- e+ > b b~
e- e+ > a z
e- e+ > w+ w-
e- e+ > z z
e- e+ > z w+ w-
e- e+ > z z z
```

```
e- e+ > t t~ QED<=99 QCD<=99, (t > w+ b QED<=99 QCD<=99, w+ > up_type_q
down_type_q QED<=99 QCD<=99), (t~ > w- b~ QED<=99 QCD<=99, w- > up_type_q
down_type_q QED<=99 QCD<=99)
```

```
e- e+ > t t~ QED<=99 QCD<=99, (t > w+ b QED<=99 QCD<=99, w+ >
up_type_q down_type_q QED<=99 QCD<=99), (t~ > w- b~ QED<=99
QCD<=99, w- > charged_lepton neutrino QED<=99 QCD<=99)
```

```
e- e+ > t t~ QED<=99 QCD<=99, (t > w+ b QED<=99 QCD<=99, w+ >
charged_lepton neutrino QED<=99 QCD<=99), (t~ > w- b~ QED<=99
QCD<=99, w- > up_type_q down_type_q QED<=99 QCD<=99)
```

```
e- e+ > t t~ QED<=99 QCD<=99, (t > w+ b QED<=99 QCD<=99, w+
charged_lepton neutrino QED<=99 QCD<=99), (t~ > w- b~ QED<=9
QCD<=99, w- > charged_lepton neutrino QED<=99 QCD<=99)
```

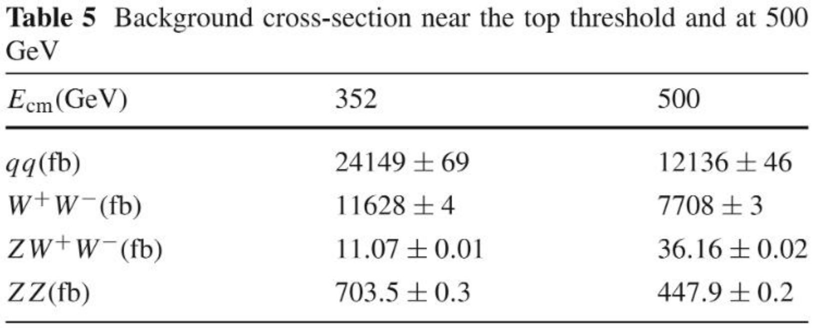
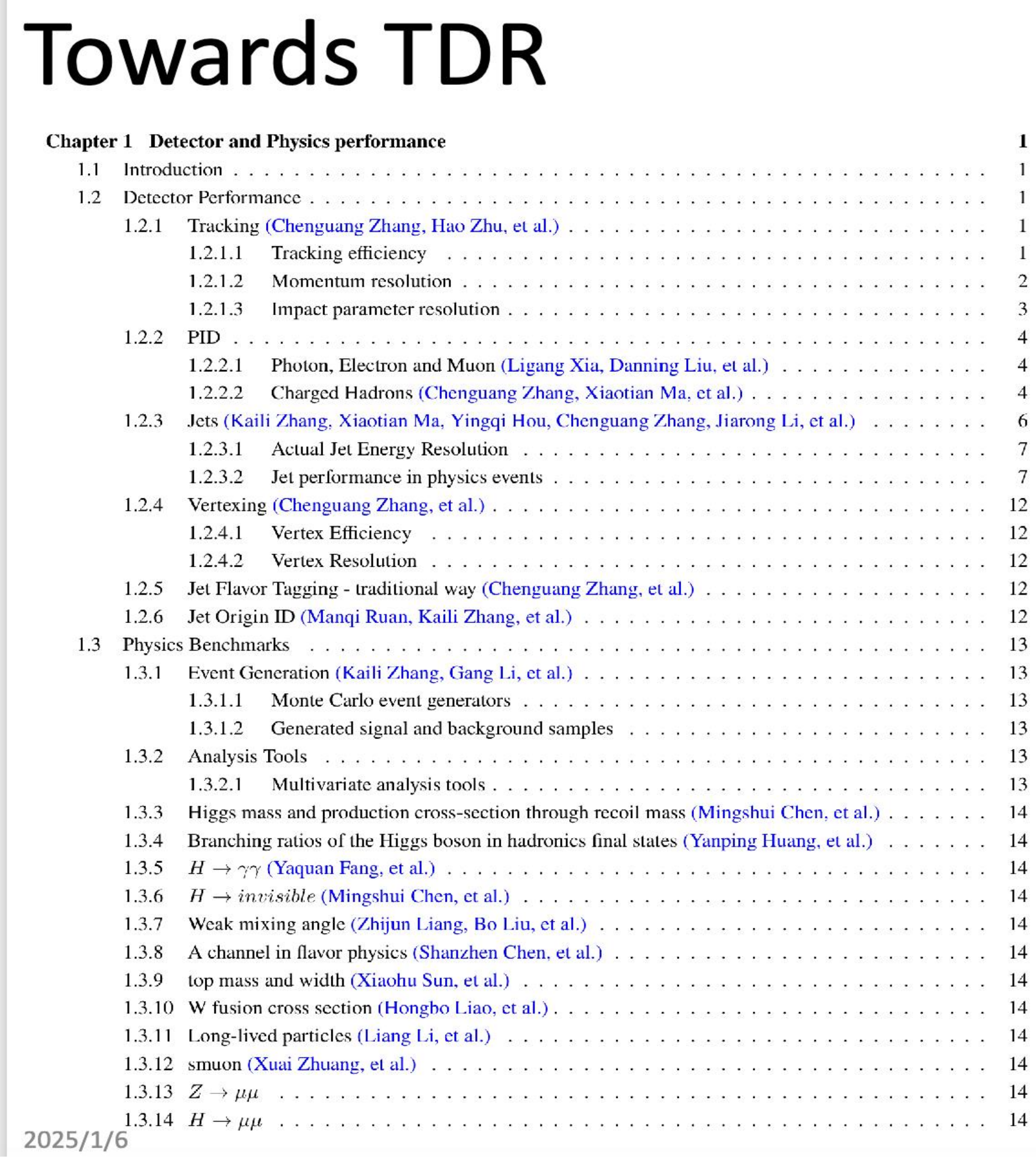


Table 5 Background cross-section near the top threshold and at 500 GeV

E_{cm}(GeV)	352	500
qq(fb)	24149 ± 69	12136 ± 46
W^+W^-(fb)	11628 ± 4	7708 ± 3
ZW^+W^-(fb)	11.07 ± 0.01	36.16 ± 0.02
ZZ(fb)	703.5 ± 0.3	447.9 ± 0.2

```
e- e+ > w+ t~ b $ t t~, (w+ > up_type_q down_type_q), (t~ > w- b~, w- > up_type_q down_type_q)
e- e+ > w+ t~ b $ t t~, (w+ > charged_lepton neutrino), (t~ > w- b~, w- > charged_lepton neutrino)
e- e+ > w+ t~ b $ t t~, (w+ > charged_lepton neutrino), (t~ > w- b~, w- > up_type_q down_type_q)
e- e+ > w+ t~ b $ t t~, (w+ > up_type_q down_type_q), (t~ > w- b~, w- > charged_lepton neutrino)
```

```
e- e+ > w- t b~ $ t t~, (w- > up_type_q down_type_q), (t > w+ b, w+ > up_type_q down_type_q)
e- e+ > w- t b~ $ t t~, (w- > charged_lepton neutrino), (t > w+ b, w+ > charged_lepton neutrino)
e- e+ > w- t b~ $ t t~, (w- > up_type_q down_type_q), (t > w+ b, w+ > charged_lepton neutrino)
e- e+ > w- t b~ $ t t~, (w- > charged_lepton neutrino), (t > w+ b, w+ > up_type_q down_type_q)
```



Towards TDR

2025/1/6