Precision measurement of the Top quark mass at the FCC-ee

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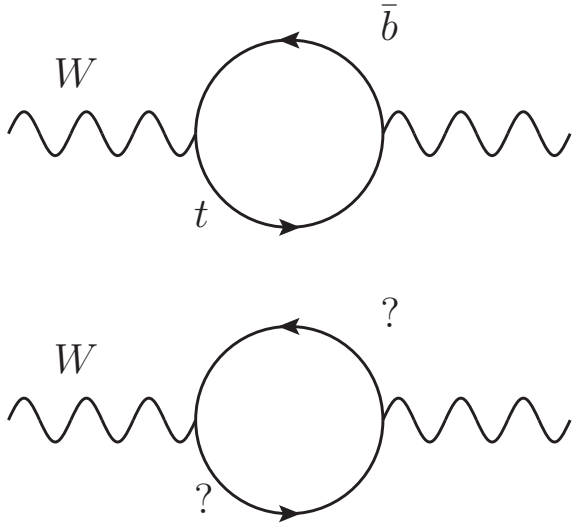
Precision Top quark physics

Why should we study the Top quark physics with high precision?

▶ The top quark is the heaviest particle in the SM

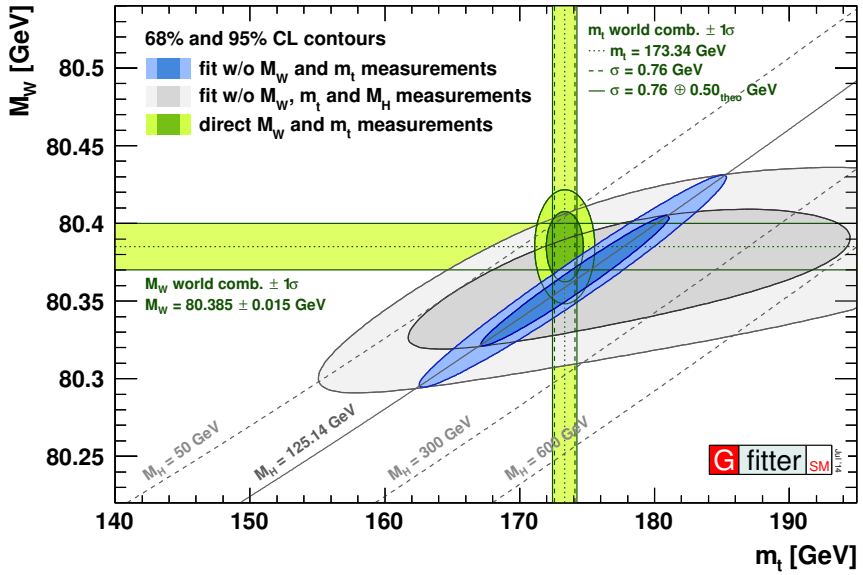
→ quantum corrections brought by the top quark are the most important ones



▶ Test the consistency of the SM

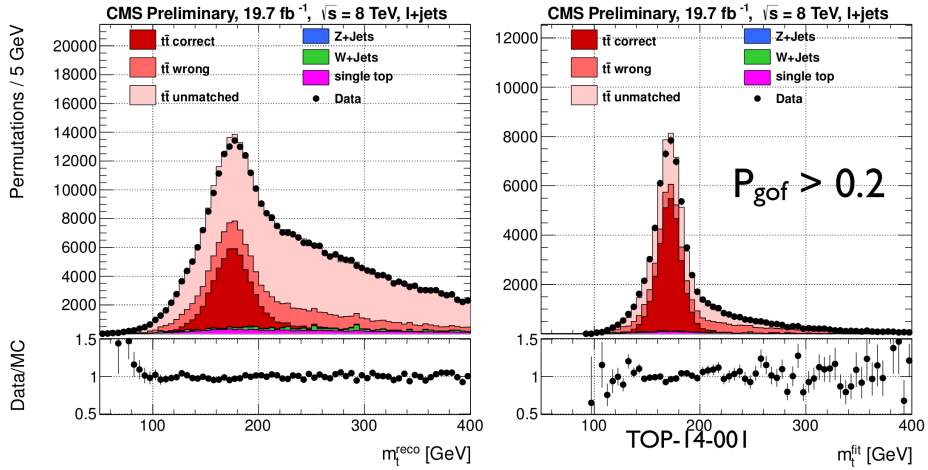
→ It's a way to discover new physics:

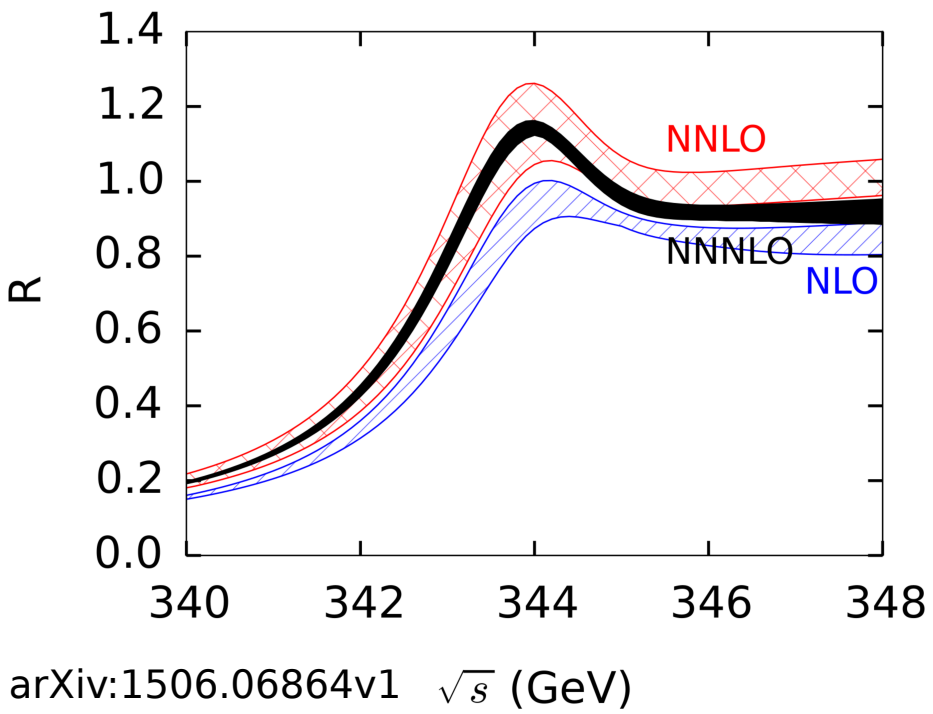
- inconsistency means new physics
- Explore energy scales that are larger than the TeV scale (explored with pp collision at the LHC)



Top quark mass: pp collider vs e^+e^- collider

- pp collision:
  - Reconstruct the invariant mass of the decay products
  - Fit with the MC
    $\rightarrow$ big systematic error: you are measuring the parameter of the simulation, whose relation to the top mass is complicated
  - Precision of $\simeq$ 500 MeV
- e^+e^- collision:
  - Scan the cross section as a function of the energy:
    $\rightarrow$ counting experiment!
  - Expected precision of $\simeq$ 10 MeV

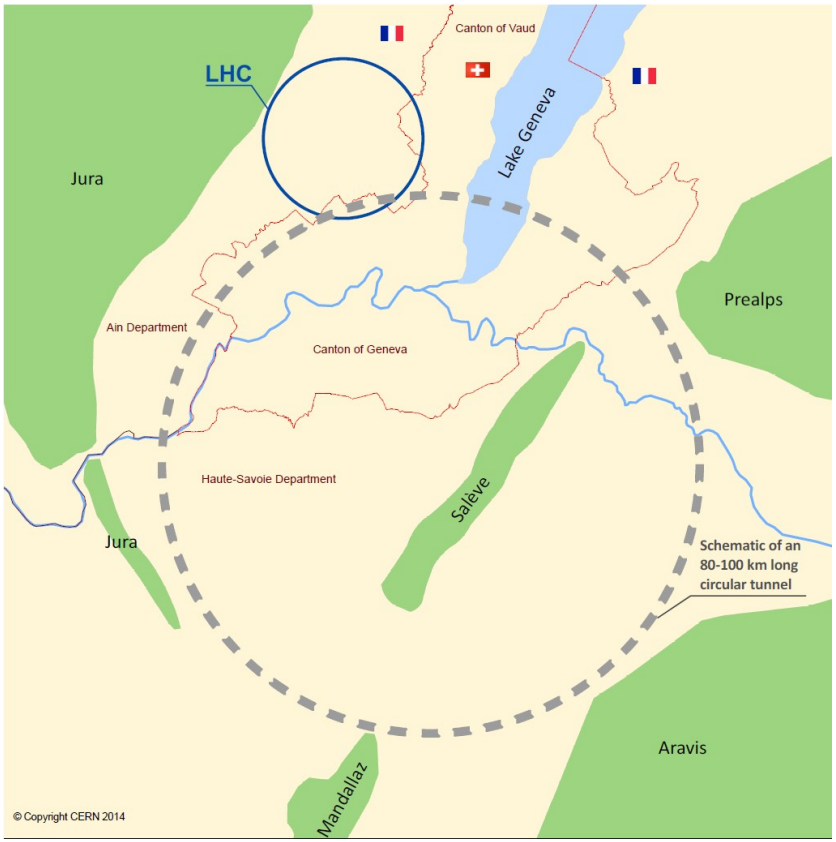




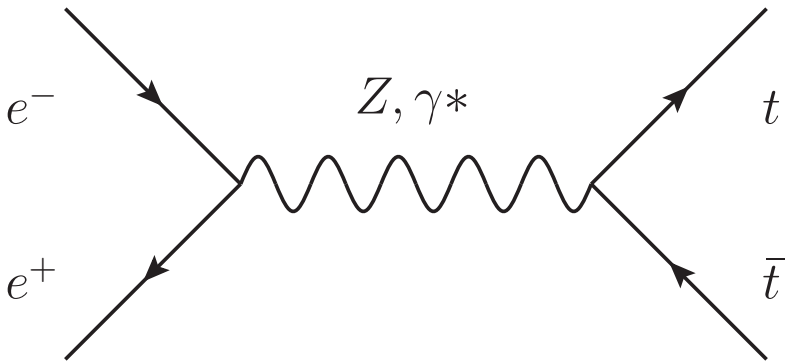
arXiv:1506.06864v1

FCC-ee and top physics

- Future circular collider:
  - High luminosity circular collider in a new 80-100 km ring in the CERN area
  - e^+e^- phase followed by a proton-proton phase



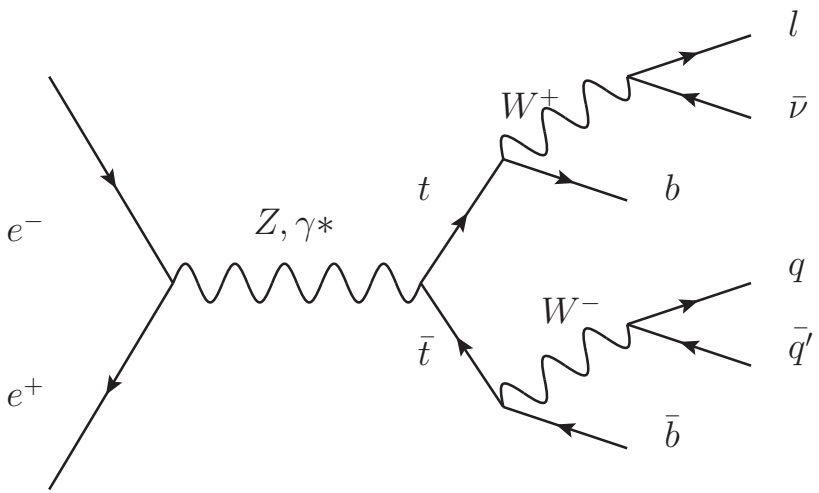
- FCC-ee top physics run:
  - $\sqrt{s} = 340 - 360$ GeV
  - L $= 0.7$ ab^{-1}/y
    $\rightarrow$ it's the first opportunity to study the top quark at an e^+e^- collider!



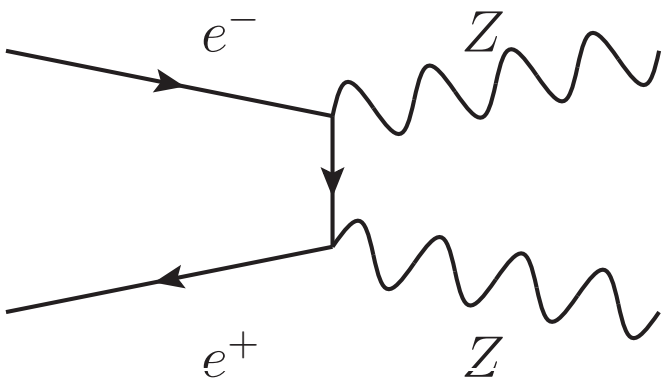
[1] See P. Janot summer student lectures, https://indico.cern.ch/event/520957

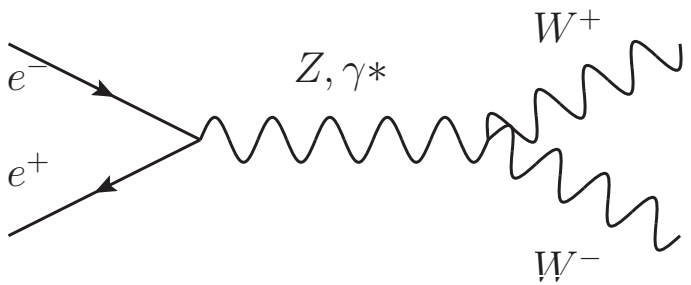
What do the $t\bar{t}$ (and background) events look like?

- Main features of the $t\bar{t}$ semileptonic decay channel:
  - One high energy isolated lepton
  - Missing 4-momentum (neutrino)
  - Four jets, two of which are **b-jets**
  - The invariant masses of the pairs have to be compatible with the W and the top masses



- The main background is produced by ZZ and WW events:





My project: MC analysis

Goal: which is the reachable precision on the top quark mass at the FCC-ee?

- Simulation
- Reconstruction, simulation of the effect of the detector
- Analysis:
  - Selecting the events and the background $\rightarrow$ efficiency and purity of the final sample
  - Fit the cross section to extract the **uncertainties** of the fit parameters
- Evaluate possible systematic uncertainties

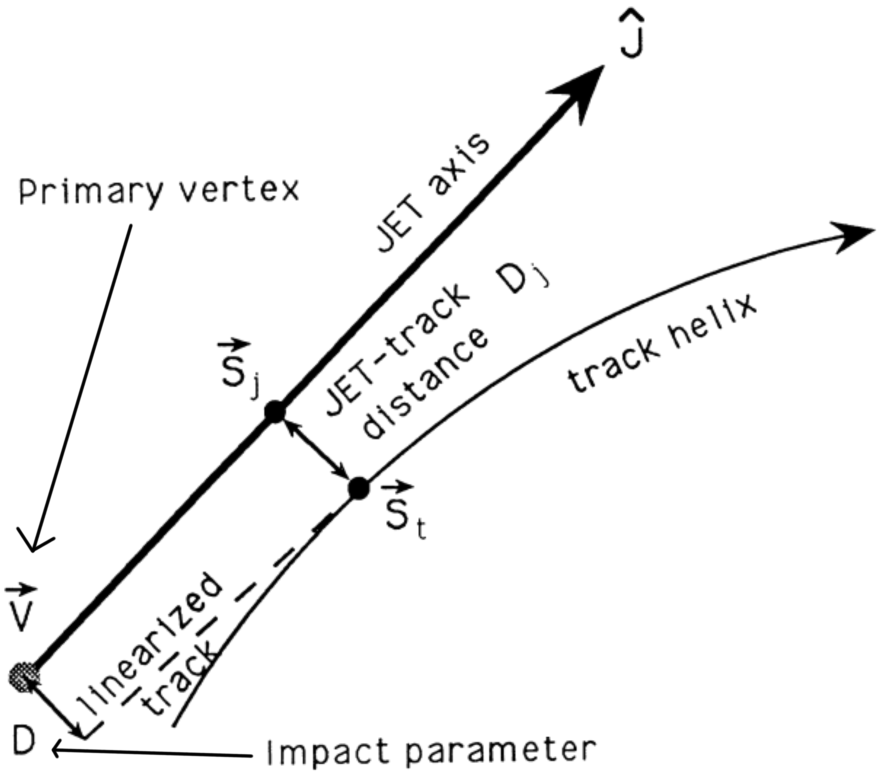
All the study is made within the FCC software framework
$\rightarrow$ so far I have been working mainly on the implementation of a b-tagging algorithm

How to do b-tagging

Basic idea: b-hadrons have long lifetime, so they usually decay far from the primary vertex

$\rightarrow$ Estimate the probability that a set of tracks comes from the primary vertex

- Calculate the impact parameter: basically it's the point of closest approach between a track and the primary vertex
- Calculate the probability that the **track** comes from the primary vertex
- Combine these probabilities to estimate the probability that the **jet** comes from the primary vertex



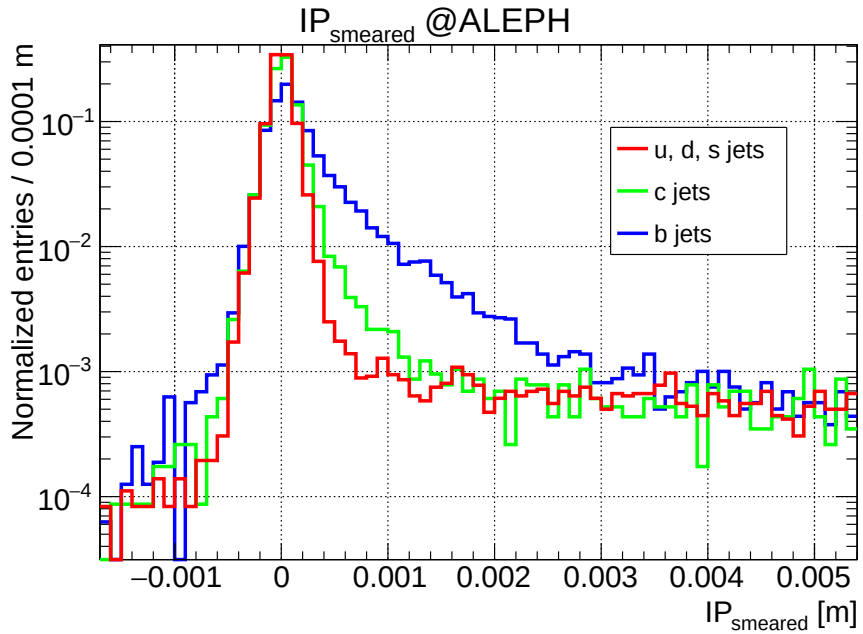
[2] For b-tagging see: D. Brown, M. Frank, *Tagging b hadrons using impact parameters, ALEPH note 92-135*

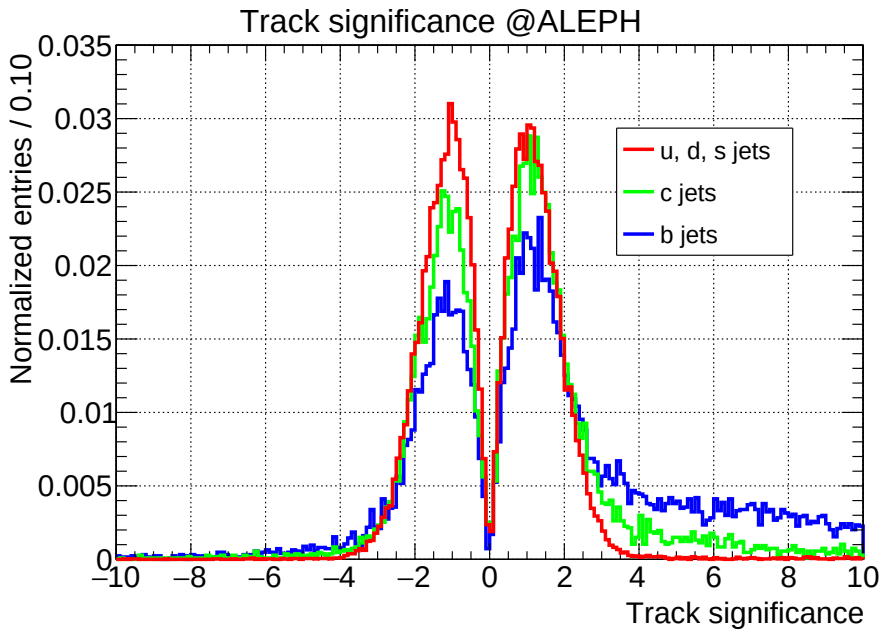
Implementing b-tagging in the FCC fast simulation

- Compute the IP with the MC track
- Apply a smearing, according to the parametrization of the resolution of your detector

$$\sigma_{ALEPH} = 25 \oplus \frac{95}{p}\mu\text{m}$$

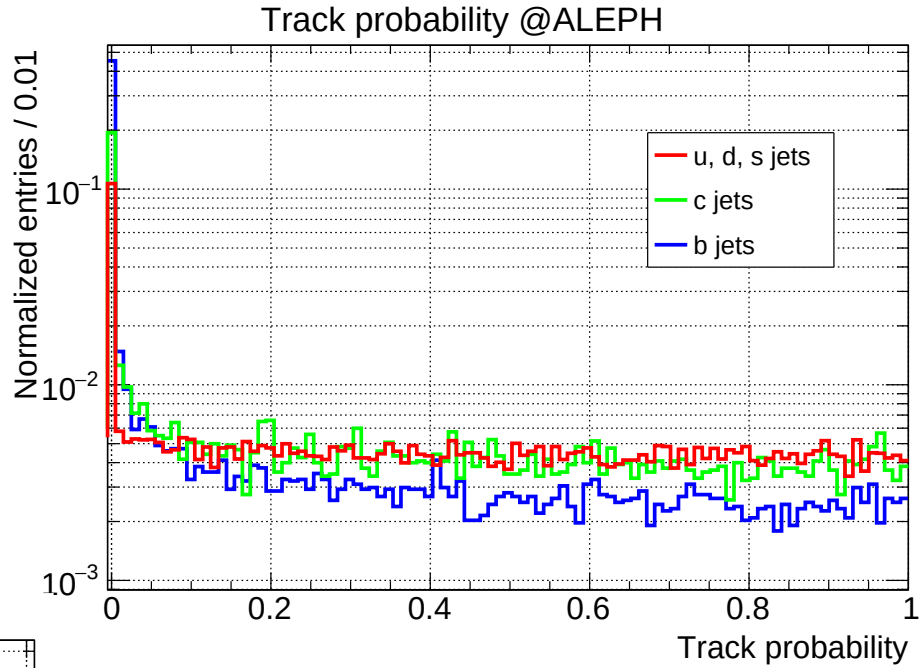
- Compute the track significance: $s = \frac{IP}{\sigma}$

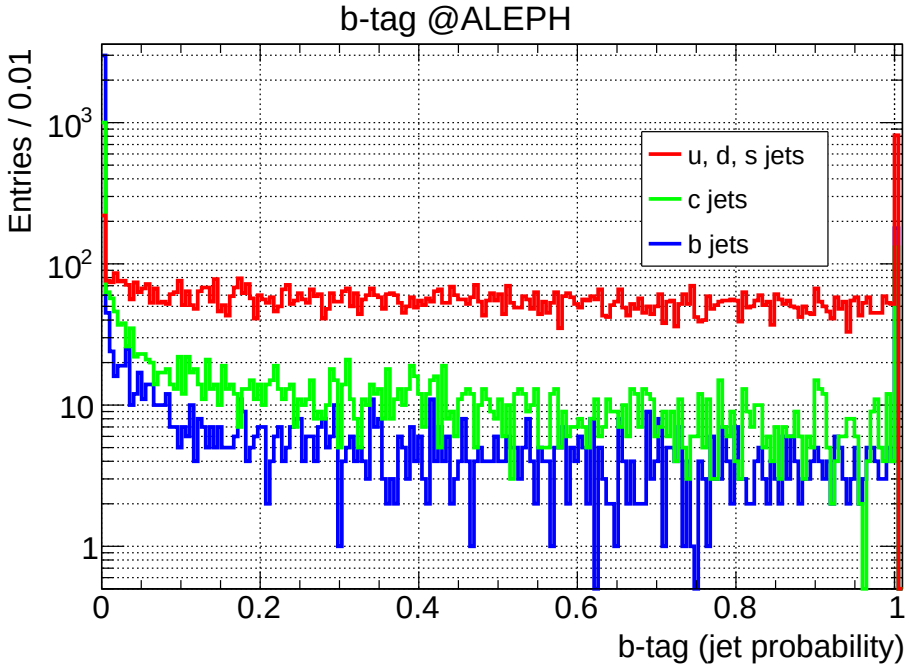




Track probability and jet probability

- Apply a track selection
- Probability that the track comes from the primary vertex: $P_t = e^{-\frac{s^2}{2}}$





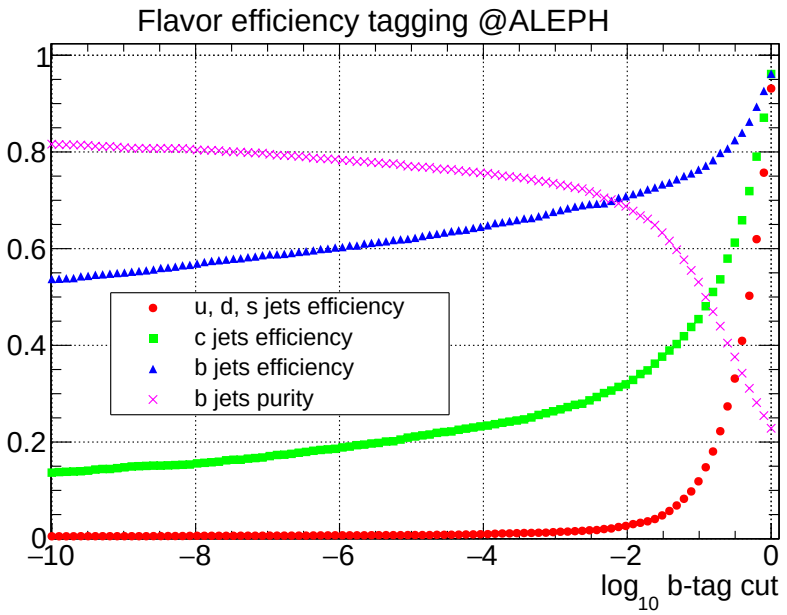
Combine the probability of the selected tracks inside a jet:

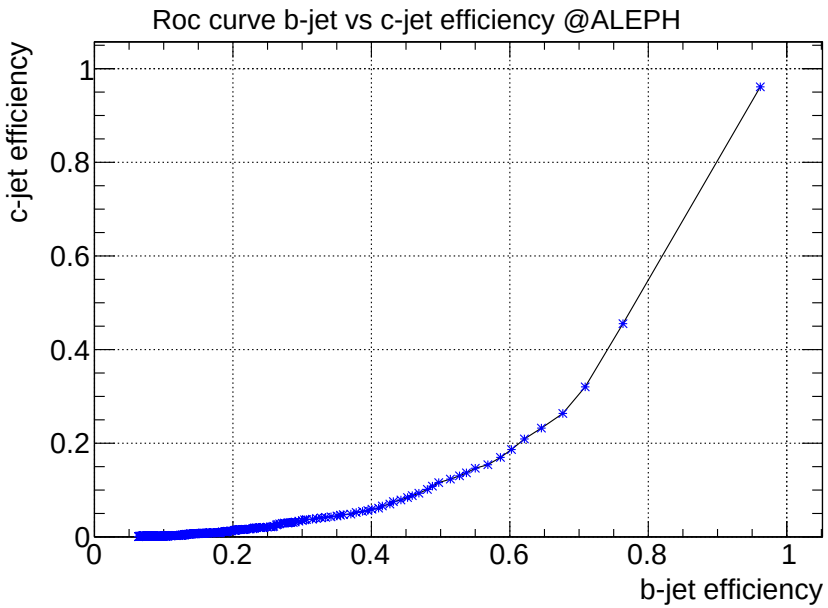
$$b_{tag} = P_{jet} = \pi \sum_{j=0}^{n-1} \frac{(-\log(\pi))^j}{j!}$$

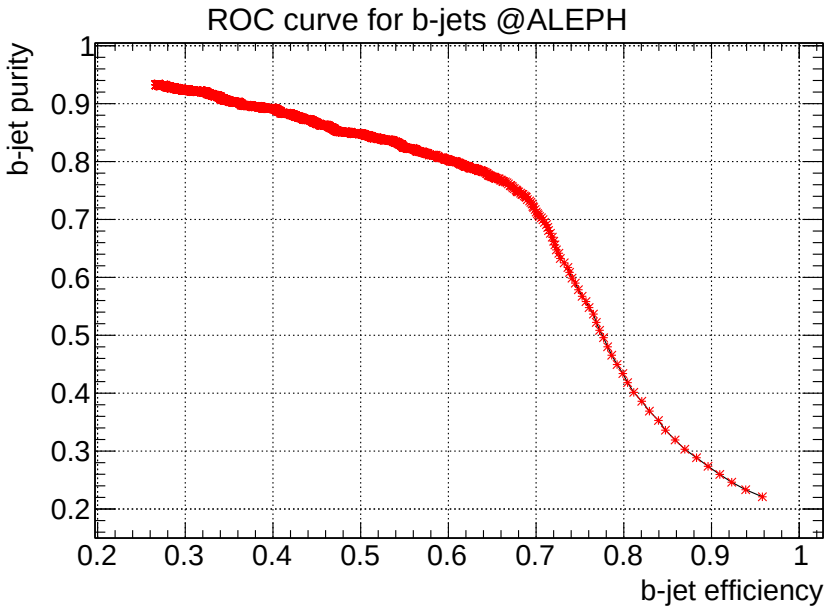
where $\pi = \prod_{i=1}^{n} P_t^i$

b-tagging efficiency

- Consider different cuts on the b-tagging variable
- Study efficiency and purity varying the cut
- the choice of the cut is analysis dependent







Conclusion and outlook

Summary

- Studying the Top quark physics is very important, both to test the consistency of the SM and to possibly discover new physics
- At FCC-ee it will be possible to measure the top-quark mass: with which precision?
- Only analytic estimates and extrapolations have been done so far, but now a MC study based on a fast simulation is in progress
- An algorithm to perform b-tagging has been implemented inside of the FCC fast simulation

Outlook

- Improve the performance by optimizing the track selection
- Use the algorithm in the MC analysis
- Study what resolution is required by a future detector to perform this measurement

Thanks for your attention

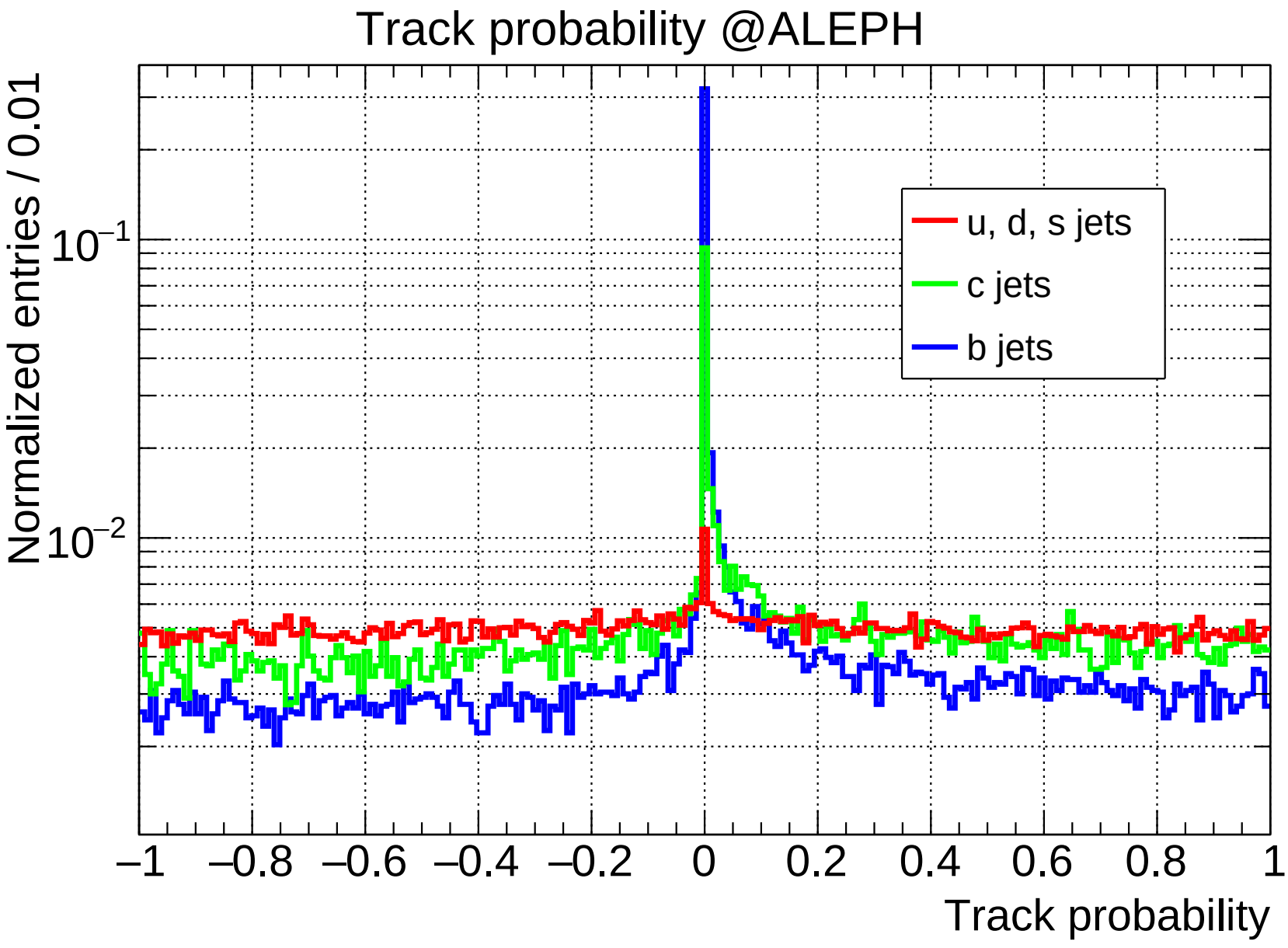
Any questions/suggestions?

Analysis steps

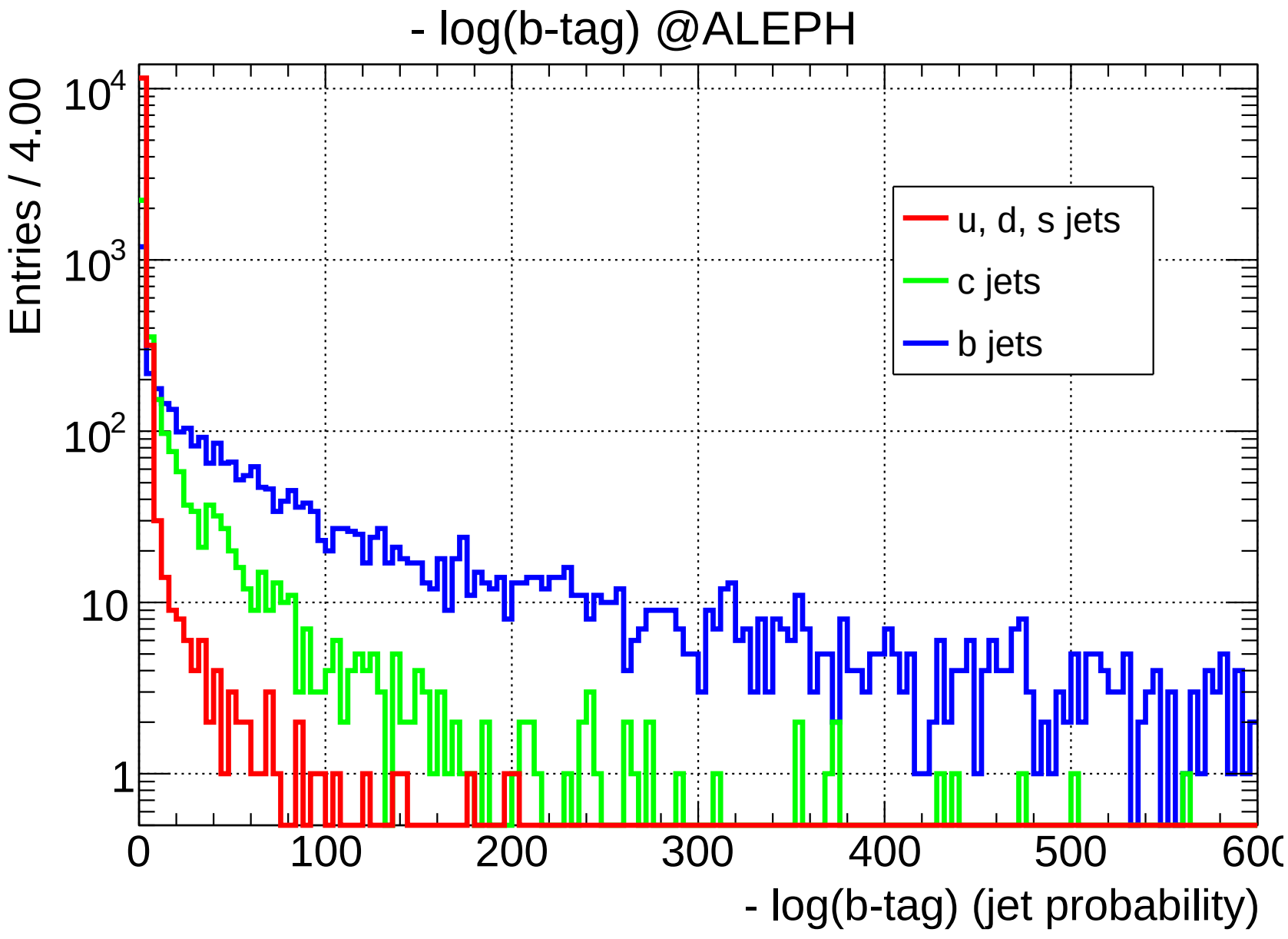
Goal: which is the reachable precision on the top quark mass at the FCC-ee?

- Simulation:
  - Generate signal and background samples according to the expected luminosity
  - You can use generators like Pythia8, Whizard*
- Reconstruction, simulation of the effect of the detector:
  - Full sim: simulate each interaction between particles and detector
  - Fast sim: the effect of the detector is modeled applying smearing and cuts on the particles according to the resolution, efficiency and acceptance
  - You can use software like Delphes, Papas* (particle flow based)
- Analysis:
  - Selecting the events and the background $\rightarrow$ efficiency and purity of the final sample
  - Fit the cross section to extract the **uncertainties** of the fit parameters
- Evaluate possible systematic uncertainties

Further details about track probability



-log(b-tag)


- log(b-tag) @ALEPH
Entries / 4.00
10^4
10^3
10^2
10
1
0
100
200
300
400
500
600
- log(b-tag) (jet probability)
u, d, s jets
c jets
b jets