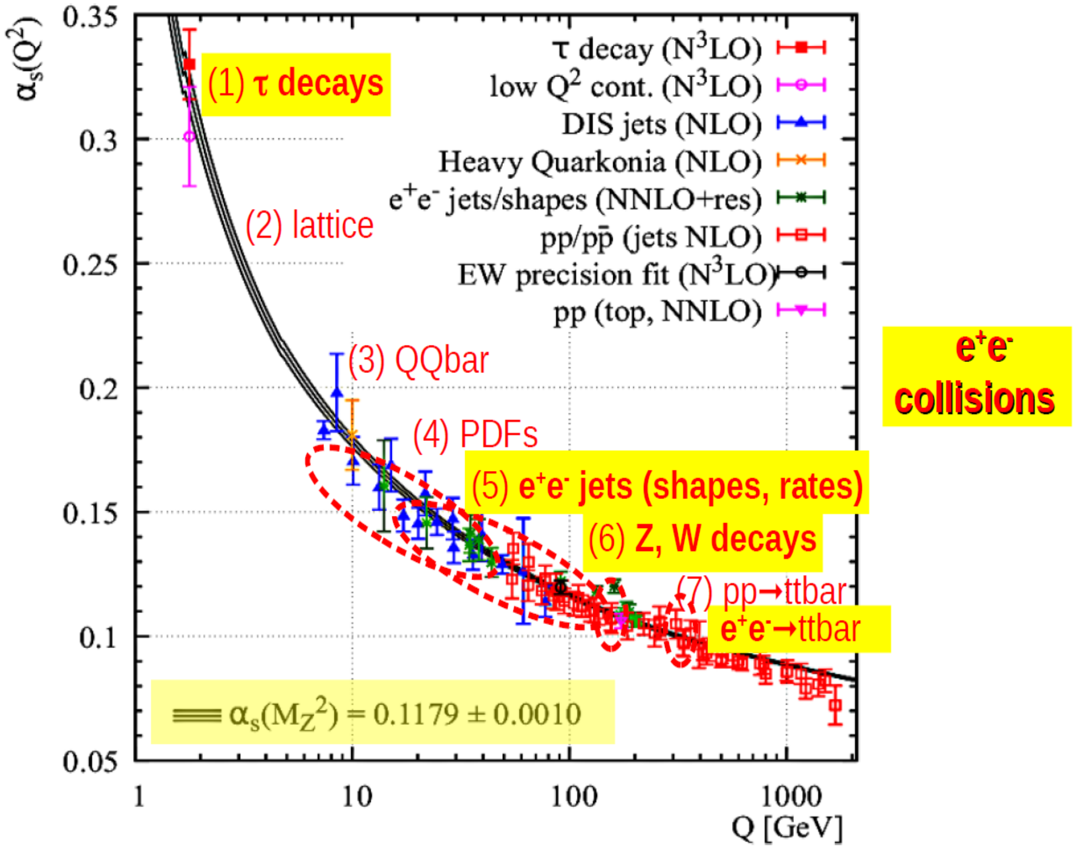
Perspectives for high-precision $\alpha_s(m_Z^2)$ determinations @ FCC-ee

Bogdan Malaescu, Luc Poggioli
LPNHE Paris

- Previous reports
- Goal
- Methods
- Preliminary results
- Next

Previous reports

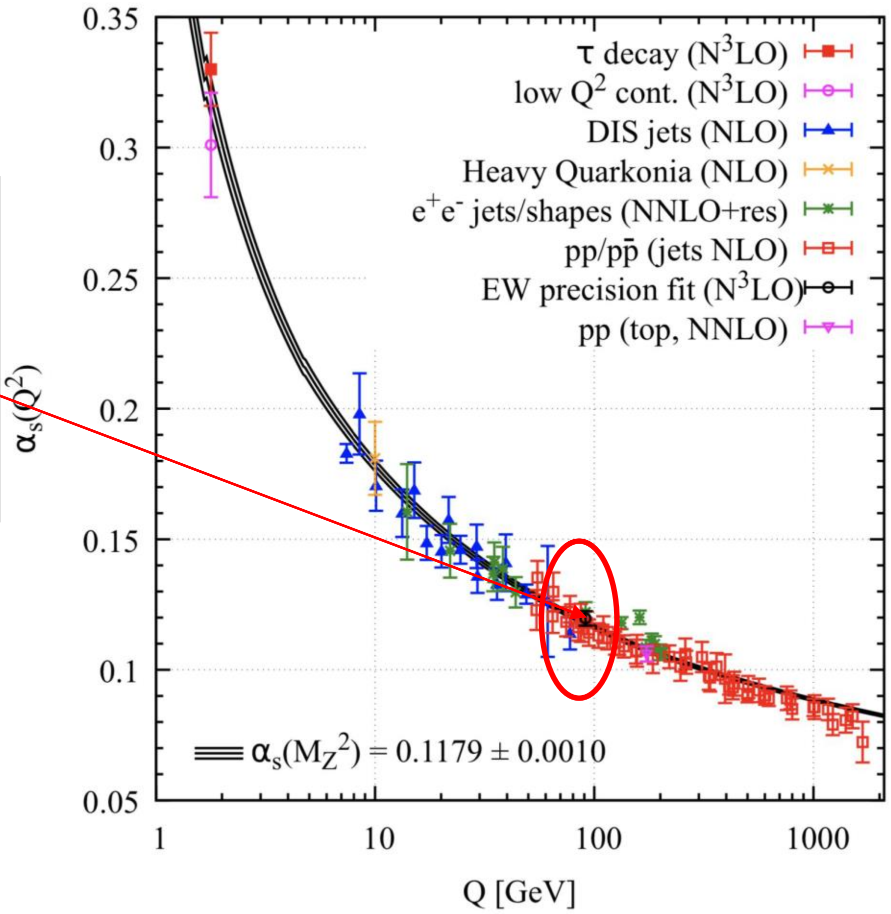
- D.d'Enterria "Ultimate α_s determination @ FCC-ee"
  - @ 1st FCC France Workshop 2020
  - Topic: α_s extractions from hadronic decays of τ, Z/W evt shapes, jet rates
- B. Malaescu, "Prospects for High Precision QCD Studies@ FCCee"
  - @ 2nd FCC France Workshop 2021
  - Topics:
    - α_s from *hadronic τ & Z decays*
    - α_s from (*ISR*) *jet production*
    - *Jet substructure* opportunities



α_S evaluation from *hadronic Z decays*

- Theoretical prediction available at N^{3}LO
  - Better convergence of perturbative series & less non-perturbative corrections wrt precise determination at lower scales (eg τ decays)

Used for "reference value"
Determinations at other energies evolved @ m_Z scale & then compared to test the RGE from QCD



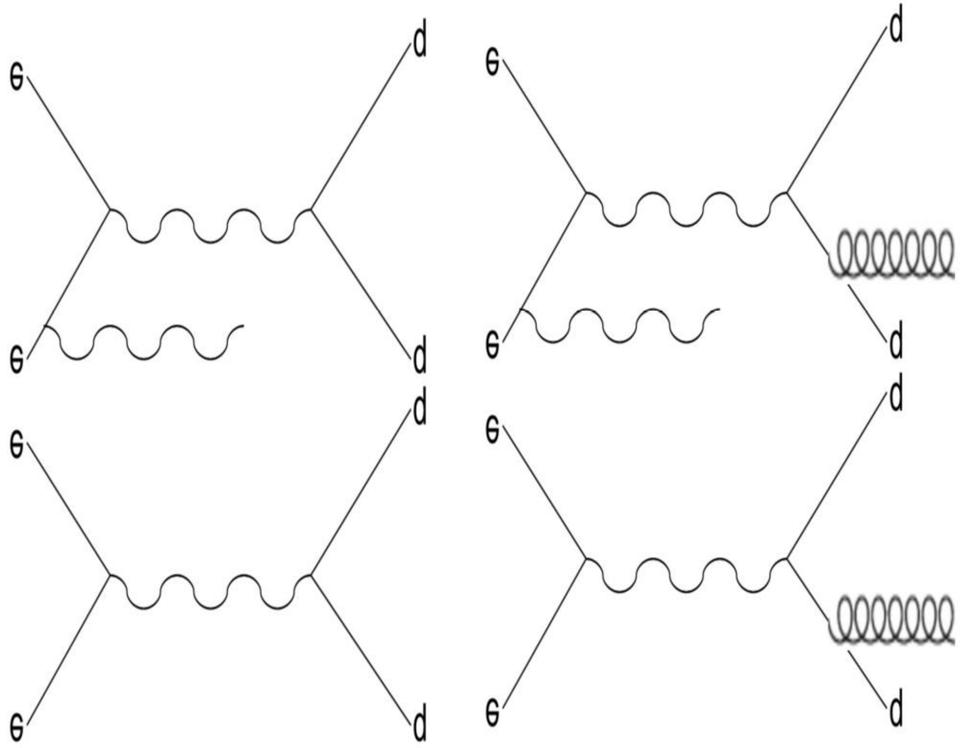
- → Need to study acceptance & reconstruction efficiency etc. -> *optimize detector design*

α_S evaluation from *(ISR) jet production*

- Sensitivity to α_S
  - eg from 3/2 jet ratios
  - Or jet rates wrt total hadronic xsec
- High luminosity -> large evts samples with collinear/large angle ISR γ
  - allows to scan $\sqrt{s'}$ with same detector & collider conditions
- Need to study
  - Jet and photon energy calibration and resolution
  - Acceptance & recons. efficiency -> *optimizing detector design*
  - Should be able to target $\delta\alpha_S / \alpha_S < 1\%$

N3LO + NNLL
(arXiv:1902.08158)

N2LO + NLLA
(arXiv:1205.3714)



Jet substructure opportunities (1)

- Algos/methods developed -> study jet substructure at LHC
  - -> Understand QCD effects inside jets, jet tagging, NP searches
- Precision studies possible also in clean FCC-ee environment
  - Impact on eg Calorimeter design
- Tool: Lund Jet Plane (LJP)
  - Principle
    - Angle & Momentum fraction of gluons emission wrt origin parton
    - q/g not available -> Use Proxy: Tracks/Calo
  - Goals
    - ATLAS: Improve x2 jet calibration uncertainties (dominate eg jet xsections)
    - ATLAS: Improve by ~30% discrimination between jets from q, g, H, W/Z
    - FCC-ee: Detectors optimization for LJP reco; α_S extraction & running test

ANR successful (ATLAS,FCC)

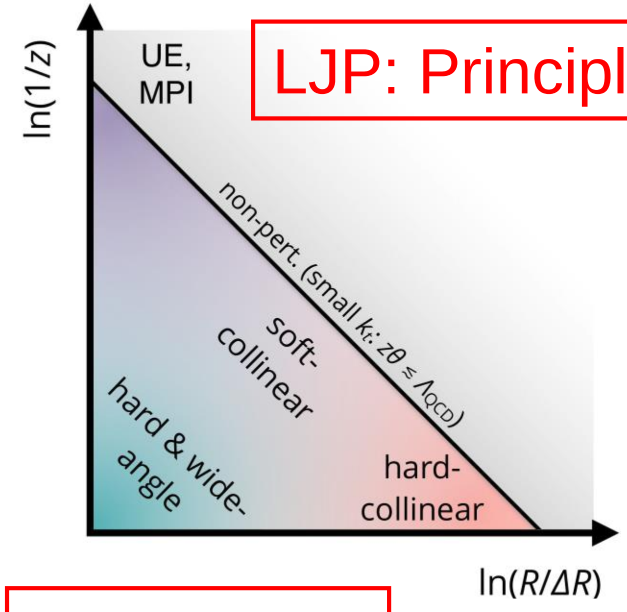
- -> 1 PostDoc for 3 years
- To start 01/03/2022

https://inspirehep.net/jobs/1972819

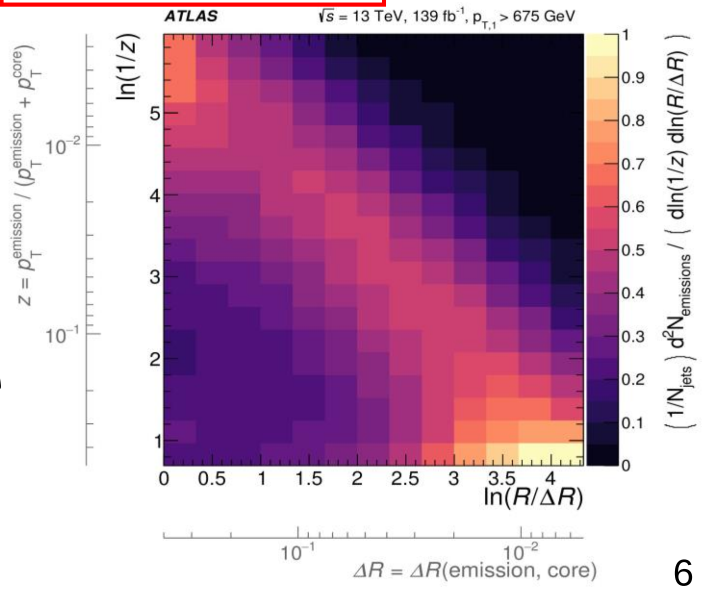
Jet substructure opportunities (2)

- Lund Jet Plane
  - Ln(1/z) vs Ln(R/ΔR)
  - Use Proto-jets then reclustering with ordering
- Directions
  - Analysis techniques
    - -> include calo info
    - Crucial impact on optimizing detector design
  - Determination of α_S
    - LJP -> Natural separation between pert./Non-pert.
    - Focus on perturbative region-> Precise α_S extraction
  - Jet classification w/modern techniques (ML)

LJP: Principle



LJP: ATLAS



First studies

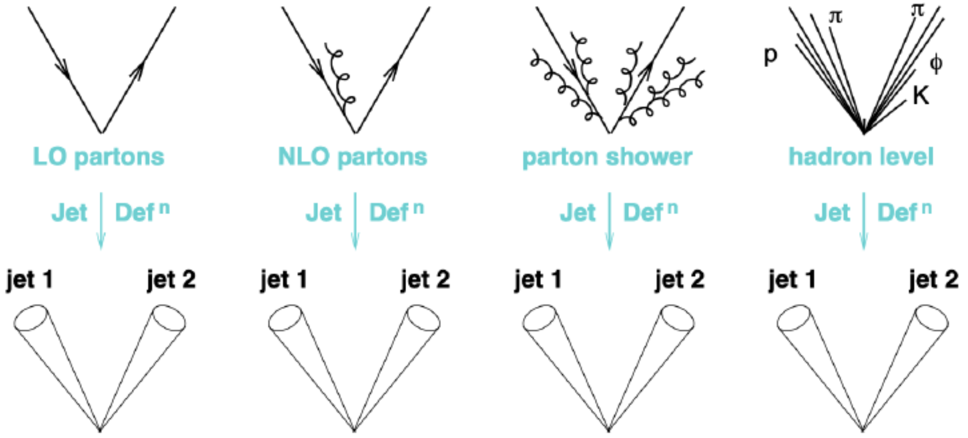
Performed in official FCCSW framework

Sukyung Kim (M2 intern, Spring 2021)

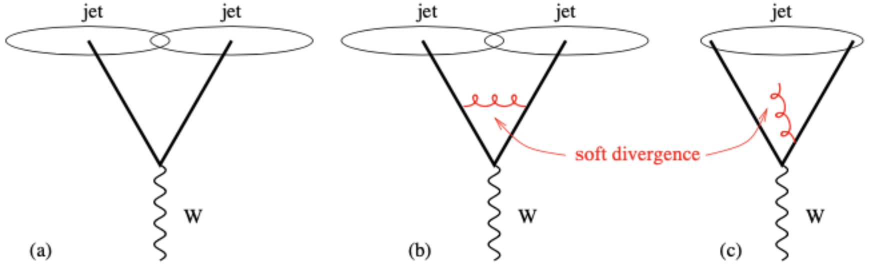
- Generation
  - Pythia e+e- -> Z -> qq at $s^{1/2} = m_Z$
  - Only generator available when starting the study but LO
  - > **Mimic Higher order & α_s values via FSR**
    - 'TimeShower:alphaSvalue' parameter
- Fast simulation: Delphes with IDEA simulation
- Analysis
  - Official python code (developed for top studies by Julie Torndal)
  - Integrates various jets reconstruction algorithms
  - Ad-hoc C++ code on .root files

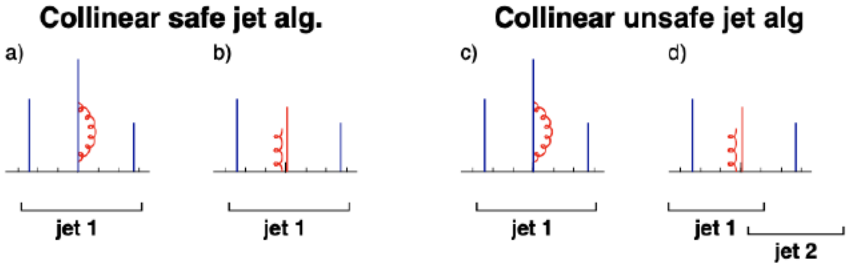
Jet Reconstruction

- Observable $R_{3/2}$: #evts w/ ≥ 3jets / #evts w/ ≥ 2 jets
  - Directly sensitive to α_S
- Principle
  - Jet algorithms



  - Properties





Infrared safety

Collinear safety

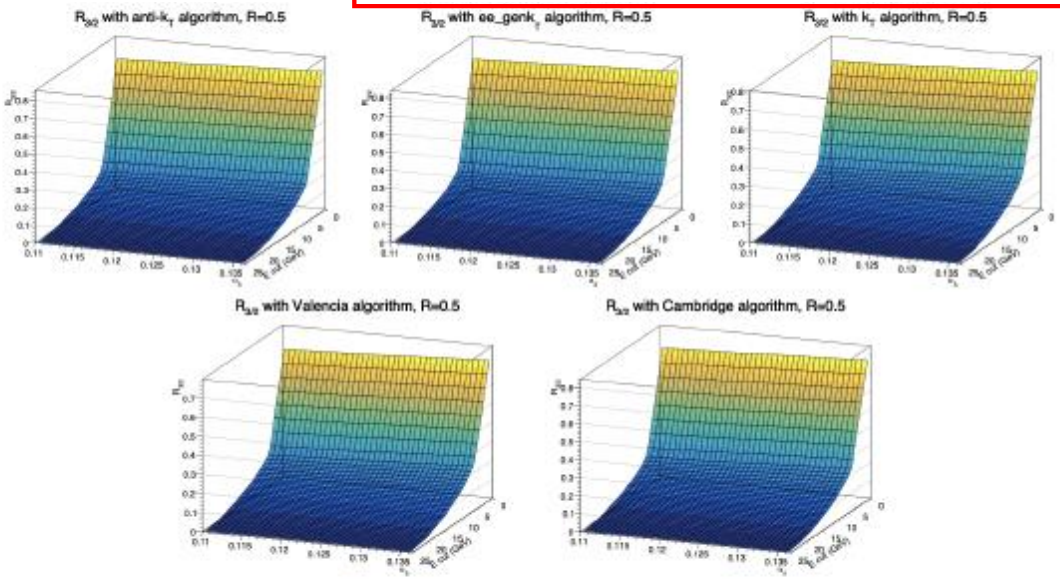
Jet algorithms: Examples

- Principle
  - Bottom-up algos -> repeatedly recombine closest pair of particles according to 'distance' measurements

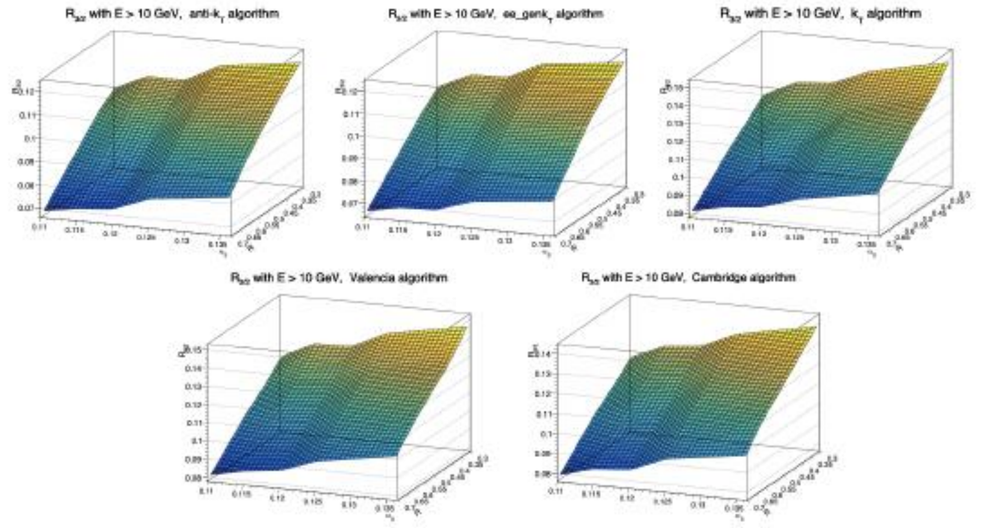
$$d_{ij} = min(p_{Ti}^{2p}, p_{Tj}^{2p}) \frac{\Delta R_{ij}^2}{R^2}$$

  - Examples
    - p=-1 anti-k_T ; p=1 k_T ; p=0 Cambridge-Aachen
- Start looking at systematics coming from jet algo choice

$R_{3/2}$ vs α_S & E^{jet}_{cut} for 5 jets algos



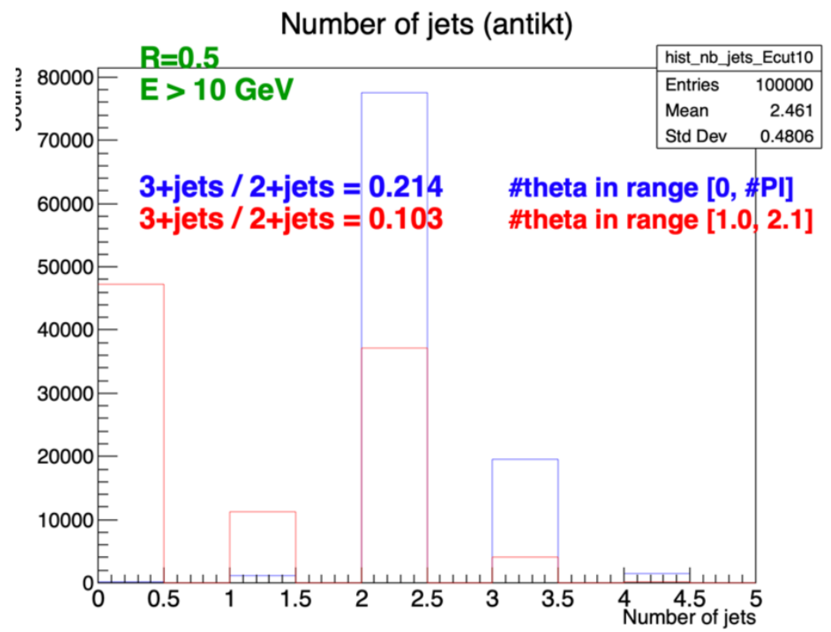
$R_{3/2}$ vs α_S & R for 5 jets algos



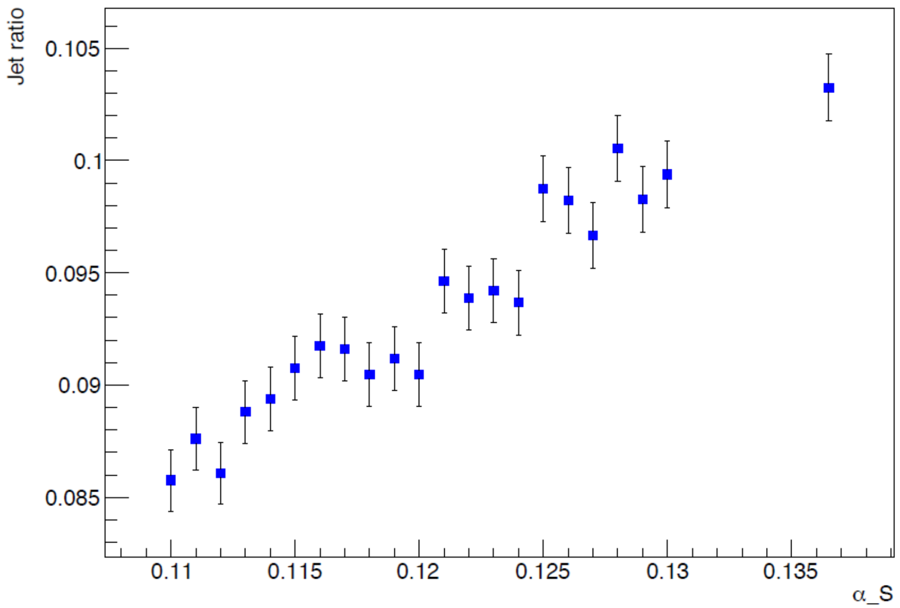
First preliminary results

- Look at
  - #jets w/ and w/ fiducial acceptance cuts & jet energy cut

#jets



$R_{3/2}$ wrt α_S



  - $R_{3/2}$ vs α_S (statistical error bars for 100k evts/ expected ~10^{12})
    - Clear correlation with 'structure', probably linked to generator choice

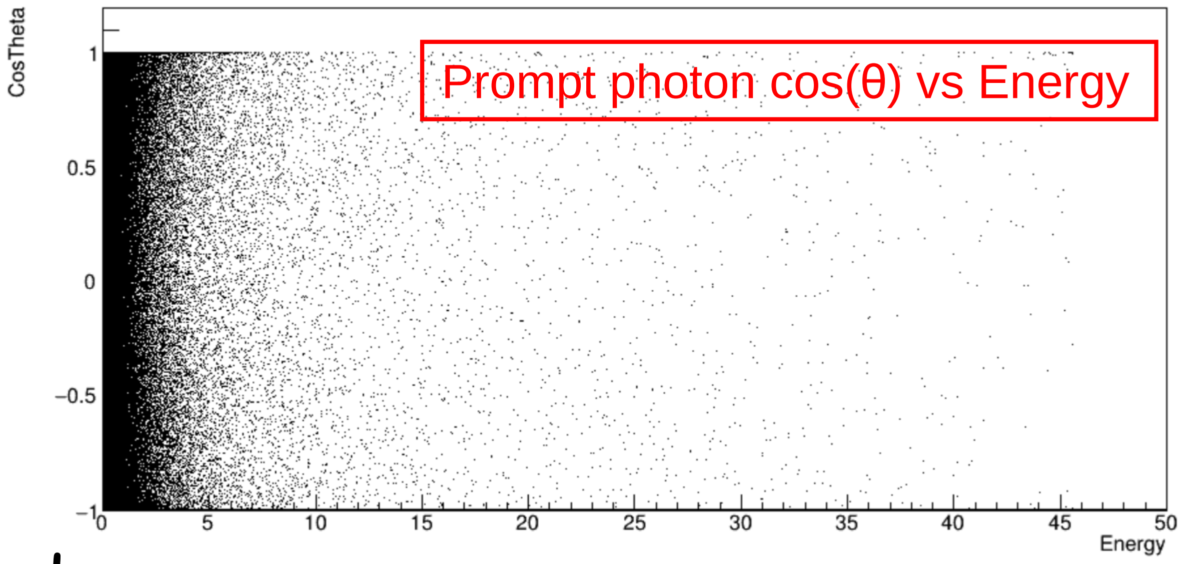
NLO generators: Status

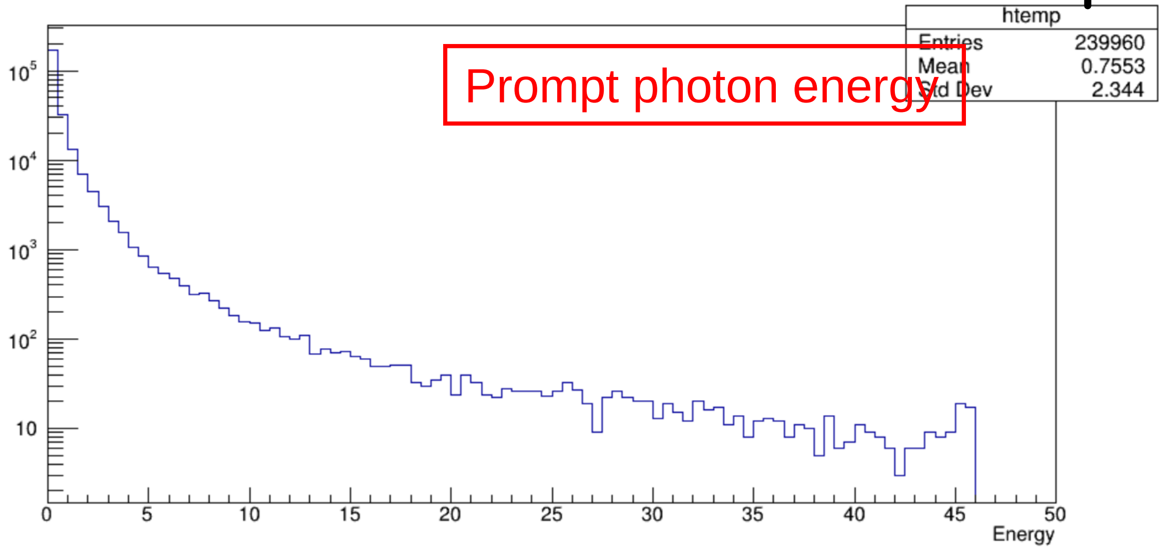
- Madgraph v3.1
  - Runs but not tested completely w/ Delphes interface
  - For ee Herwig and/or Sherpa recommended
- Herwig 7
  - Available as standalone. Difficult to use w/o full directory structure
  - Bootstrap method (i.e full install from scartch): Does not compile
- Sherpa 2.2.9
  - Full install from scratch OK
  - Interface with hadronization from Pythia does not work
    - LHE output format. Fails 'PYTHIA Error in ProcessLevel::checkColours: incorrect colour assignment'
    - HepMC output format. Needs to install hepMC-332 from scratch. Link fails

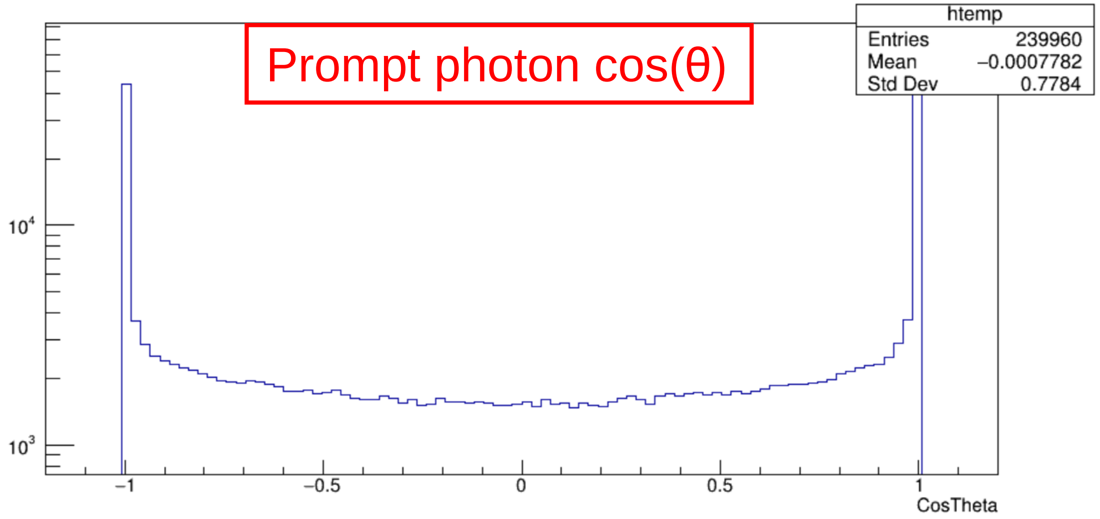
ISR: Use of KKMCee (1)

KKMCee V4.30

- Z -> qq evts @ Z pole
- Fragmentation OFF
- Output format .LHE
- Interfaced to Delphes + IDEA fast sim
- 100k evts sim'ted / ~10^{12} exp'ted



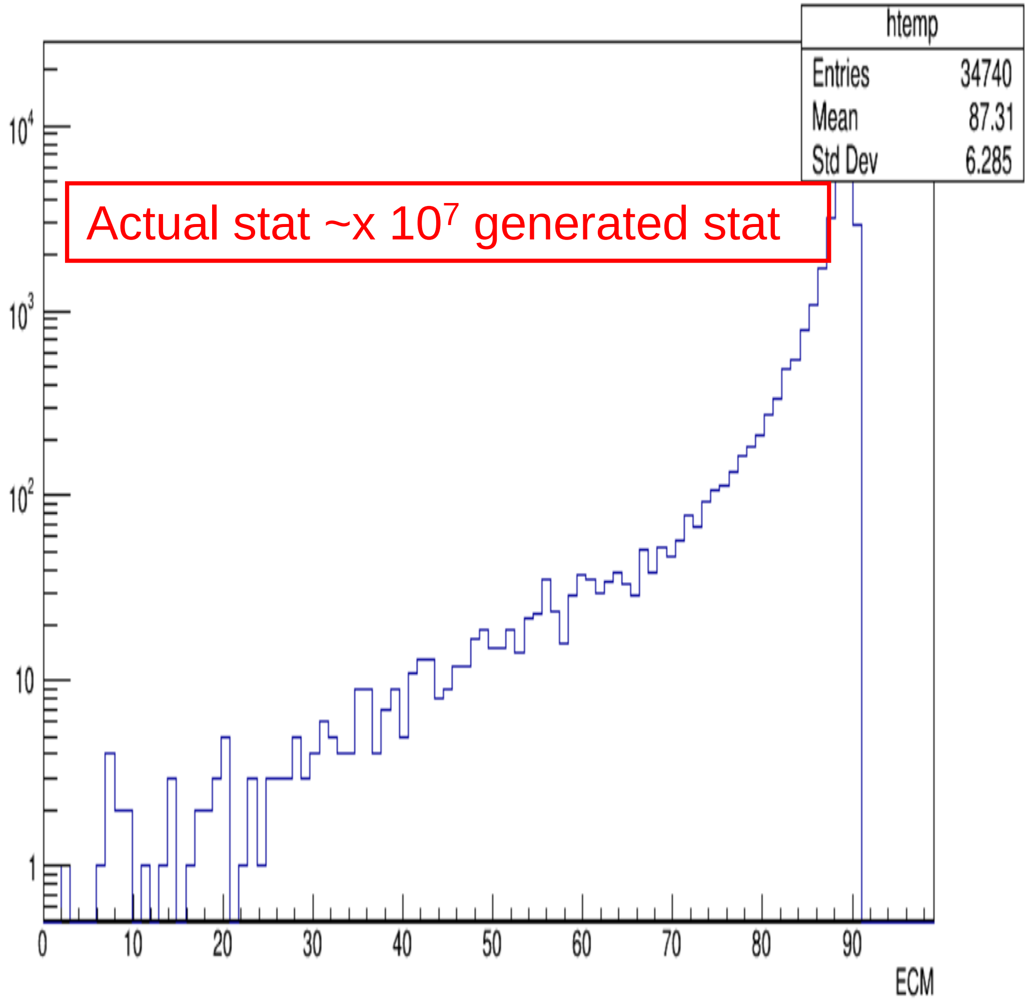




ISR: Use of KKMCEee (2)

Extremely preliminary results!!

- Photon selection (@4vector level)
  - E > 1 GeV & abs(θ) > 150mrad
- E_{CM} available via ISR
  - Most likely possible down to 10 GeV
- Next
  - More statistics
  - With 1 γ system overconstrained
  - ->Evaluate ECM from final jets only
  - To be studied
    - Impact of jet calibration
    - Impact of jet reconstruction



E_{CM} available

Next

- Jet ratio 3/2
  - Critical: Redo study with Higher orders generators
  - Quantify effects of parameters
    - Jet energy cut, jet algorithm used (type & parameters)
  - Evaluate detector parameters on α_S precision extraction
    - Granularity, energy resolution
- Running α_S with ISR
  - Reinforce first results from KKMCee
- Goal
  - Contribute to Snowmass white paper on QCD coupling α_S
  - Workshop in January https://indico.cern.ch/e/alphas2022