Special low-energy runs at FCC-ee: e^+e^- at $\sqrt{s}$ = 20–80 GeV

198th FCC-ee Accelerator Design Meeting

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QCD physics studies with low-$\sqrt{s}$ e^+e^- collisions at FCC-ee

(in preparation)

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FCC

QCD studies in ee(20–80 GeV) runs

- FCC-ee will enable ultra-precise QCD studies with 10^{12}, 10^{8}, 10^{6} hadronic Z,W Higgs, top decays, covering total hadronic (jet) energies: ≈80–365 (40–180) GeV

- Many QCD studies would benefit from having e^+e^- collisions with hard scale between $Q = m_\Upsilon \approx 10$ GeV and $Q = m_{W,Z} \approx 80$ GeV:
  - – Dialing relative size of hard (pQCD), shower (resummation), non-pQCD contribs.:

$$d\sigma \sim \mathrm{Hard}(Q_H, Q, m_Q) + \mathrm{Resum}(Q_H/Q, Q/m_Q, Q/\Lambda_{\mathrm{QCD}}) + \mathrm{NonPert}(\Lambda_{\mathrm{QCD}}/Q, m_Q/Q)$$

  - – High-precision QCD coupling $\alpha_s(Q)$ extractions over Q ≈ 10–80 GeV via: R-ratio, event shapes, jet rates, FFs evolution,…
  - – Multiple new precise QCD observables proposed in the last years to be studied with much better FCC-ee detectors:
    Event shapes variables: EE correlators, thrust/sphericity families, angularities,...
    Jet substructure, Lund Plane: tagging of parton flavour, spin, charge,…
    Non-pQCD models: Color reconnection, final-state interactions,...

- Limited existing e^+e^- data sets with $\mathcal{O}(10^5)$ evts between B factories and LEP-I:
  - – Fixed CM energy $\sqrt{s} \approx$ 12–64 GeV:
  - – ISR events at LEP $\sqrt{s'} \approx$ 30–85 GeV.

Accelerator	Energy range, GeV	Luminosity, pb^{-1}	Good multihadron events, $\times 10^3$
TRISTAN	50 – 64	900 [16]	≈ 110 [15]
PETRA	12 – 47	760 [14]	≈ 200 [14, 17]
PEP	29	315 [18]	144 [18]

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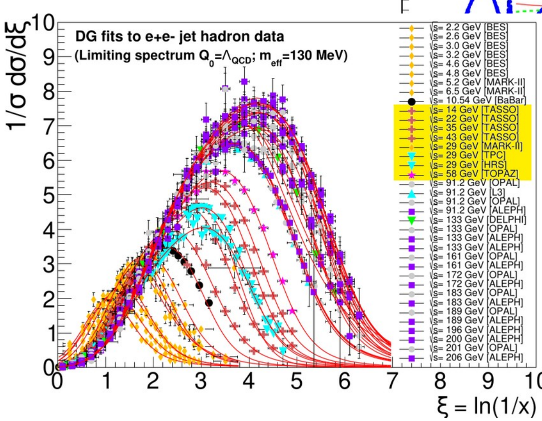

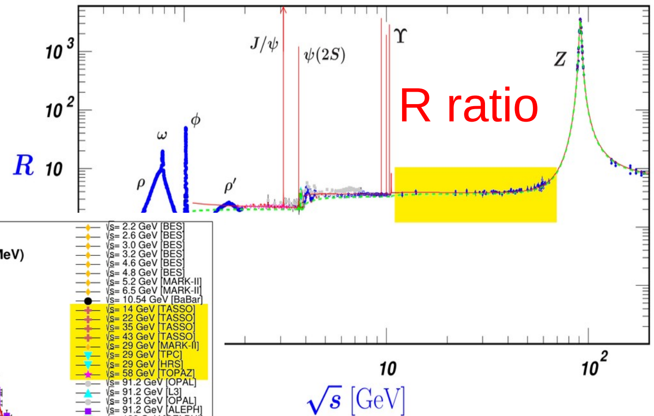

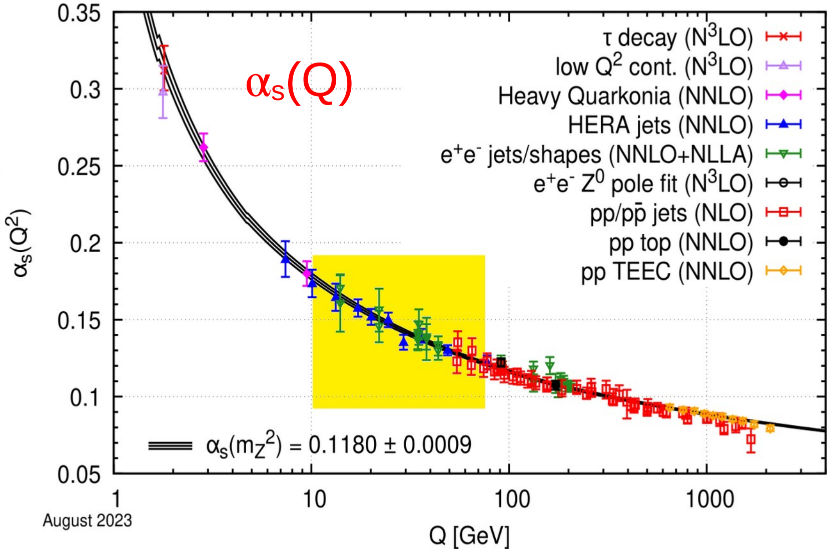

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Achieving ee(20–80 GeV) at FCC-ee

- There are two non-exclusive means to obtain low-$\sqrt{s}$ hadronic data at FCC-ee:

1) Run at fixed CM energies (above 40-GeV booster injection energy) over $\sqrt{s}$ = 40–80 GeV (assuming simple/plausible Z-pole setup plus $\mathcal{L} \propto \sqrt{s}$ scaling):

Table 2: Time needed to collect 10^9 hadronic events in dedicated runs at given CM energy assuming instant luminosity $\mathscr{L}$ is the same as at Z peak and is equal to $4.6\ \mathrm{pb}^{-1} s^{-1}$ and assuming scaling $\mathscr{L} \propto E$ [13].

Beam energy accuracy/precision within $\mathcal{O}$(0.1 GeV) should be enough

$\sqrt{s}$ (GeV)	Time (days) to collect 10^9 hadronic events	
	$\mathscr{L} = \mathscr{L}$(91 GeV)	$\mathscr{L} \propto E$
80	6	7
70	13	17
60	15	22
50	12	22
40	8	18

Max. ~1 month? needed (incl. ~1 week? setup time) to collect $\mathcal{O}(10^9)$ hadronic evts. per $\sqrt{s}$

2) Analyse ISR events over $\sqrt{s'} \approx$ 20–80 GeV profiting from huge $\mathcal{L}_{int}$ at Z-pole run:

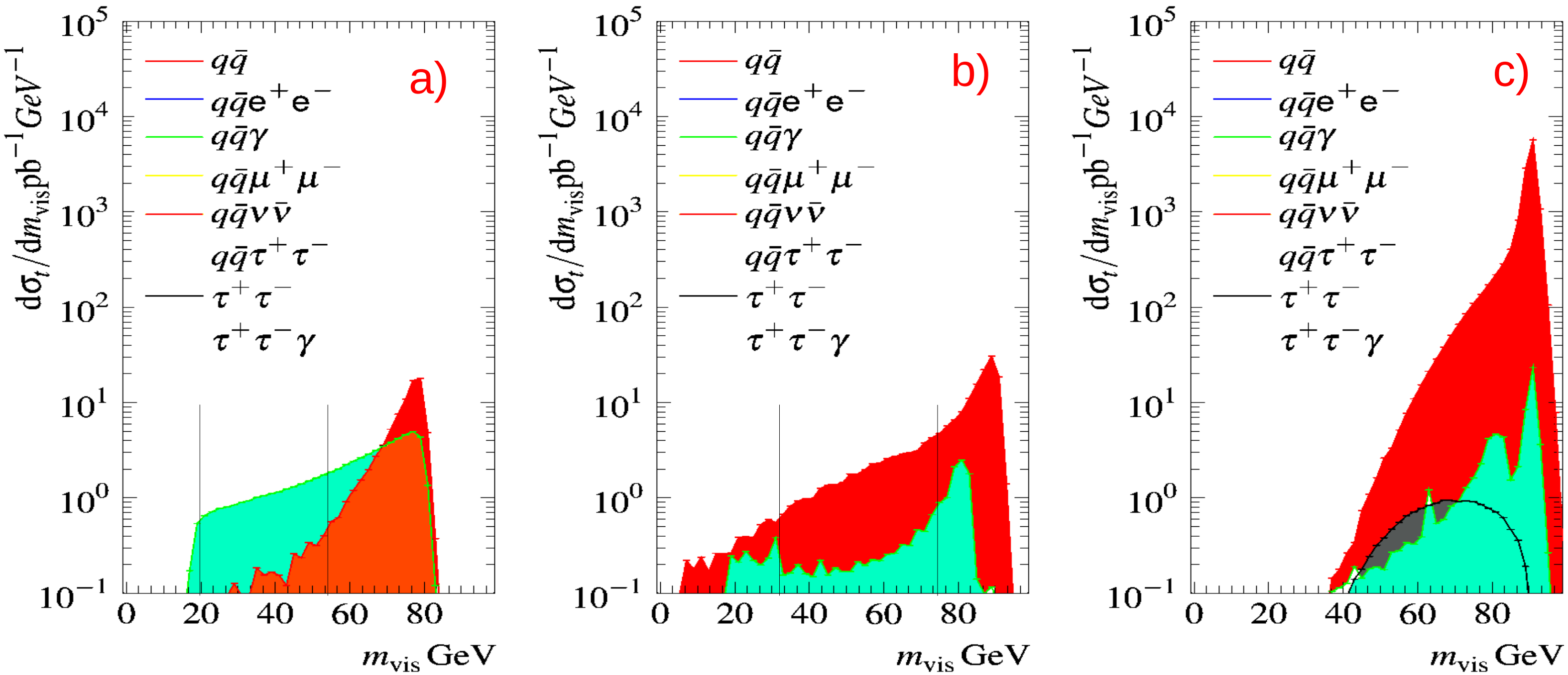
Table 1: Properties of the hadronic data samples collected from ISR/FSR by the L3 experiment [10] and estimated number of events that could be similarly obtained at FCC-ee with the expected 100 ab^{-1} at the Z pole.

Type	$\sqrt{s'}$ (GeV)	$\langle\sqrt{s'}\rangle$ (GeV)	Lumi (pb^{-1})	Selection Eff. (%)	Purity (%)	# Sel. Evts	FCC-ee, estimation
Reduced	30–50	41.4	142.4	48.3	68.4	1247	0.9×10^9
Centre-	50–60	55.3	142.4	41.0	78.0	1047	0.7×10^9
of-	60–70	65.4	142.4	35.2	86.0	1575	1.1×10^9
Mass	70–80	75.7	142.4	29.9	89.0	2938	2.1×10^9
Energy	80–84	82.3	142.4	27.4	90.5	2091	1.5×10^9
	84–86	85.1	142.4	27.5	87.0	1607	1.1×10^9
Z pole	91.2	91.2	8.3	98.5	99.8	248 100	3.1×10^{12}

$\mathcal{O}(10^9)$ ISR events per $\sqrt{s'}$ (scaling from LEP studies)

ISR events at the Z-pole run

- Selection methods of hadronic final-state (HFS) events in ISR $e^+e^- \to q\bar{q}(\gamma)$
  - a) Wide-angle high-E γ emitted from SR/ISR evts. Reconstruct HFS kinematics.
  - b) Collinear ISR γ lost inside beampipe. Reconstruct $\sqrt{s'}$ from vis. HFS kinematics.
  - c) $Z \to q\bar{q}$ with misreconstructed m_{vis}.
- Distributions of visible HFS mass for events passing the 3 selections *(Sherpa 3.0.1 events with IDEA detector DELPHES card):*



Selection a) provides ee → had+γ FSR/ISR evts with purity ≈ 90% over m_{vis} = 20–55 GeV

Selection b) provides ee → had+γ FSR/ISR evts with purity ≈ 90% over m_{vis} = 35–70 GeV

Summary: low-energy FCC-ee runs

- Summary:
  - There are unique and interesting QCD physics opportunities at FCC-ee with $\mathcal{O}(10^9)$ hadronic events over $\sqrt{s}$ = 20–80 GeV.
  - Dedicated runs with $\sqrt{s}$ = 40–80 GeV could take ~1 month per $\sqrt{s}$ point, but require real accelerator studies:

    Do you see any showstopper from the FCC-ee machine point-of-view for such runs?
    Is the $\mathcal{L} \propto \sqrt{s}$ scaling reasonable? Is it improvable?
    Is the 1-month (incl. beam setup) time reasonable?
    Can one "easily" define accelerator parameters for such collisions?
    …?
  - Studies are being developed to quantify what fraction of the physics accessible with such low-$\sqrt{s}$ runs can be realized exploiting ISR events from the high-luminosity Z-pole run (which would automatically scan the whole hadronic mass range: $\sqrt{s}$ = 20–60 GeV).
  - PS: We plan to submit a EU Strategy Particle Phys. Update document.

Backup slides