



QCD & Gamma-Gamma Studies at FCC-ee

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OVERVIEW

Future electron-positron machines provide a rich testing ground not only for precision EW and BSM physics, but also offer important and unique physics opportunities through large numbers of photon-photon collisions and literally billions of hadronic final states. The FCC-ee working group WG5 joins people who want to explore the potential, with a view to informing a CERN Yellow Report on FCC-ee physics in 2017. **Participation is open to anyone** interested in studies of QCD and/or photon-photon physics at future ee colliders.

To join or subscribe: fcc-ee-qcd@cern.ch

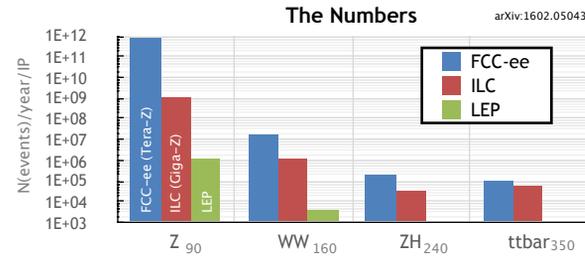
WORKSHOPS

A yearly workshop is organised to review the current state of the art, report on studies, and discuss potentials for new measurements. Registration and contributions are welcomed.

- **2016: Nov 21-22 (CERN):** Workshop on Jet Physics and Fragmentation from LHC to FCC-ee. (Registration soon on Indico.)
- **2015: Oct 12-13 (CERN):** Workshop on high-precision alphaS measurements from LHC to FCC-ee. *Proceedings: 1512.05194.*

PHYSICS GOALS

1. **Determine best achievable EXP & TH precision on α_s :** Z, W, t hadronic decays, widths, jet rates, event shapes,...
2. **Assess (B)SM photon-photon physics possibilities:** Higgs, anomal. quartic gauge couplings, anomal. top, t e.m. moments,...
3. **Exploit unique high-precision QCD physics opportunities in e+e-** (with a view to informing future pp colliders): Multi-jets, jet substructure, Q/G discrimination, parton-to-hadron fragmentation (q,g,c,b,(t)), colour (re)connections, constraints on anno-2030 MC models of QCD & EW phenomena, ...
4. **Set goals for sub-detector performance** (including fwd e± taggers for $\gamma\gamma$ physics, particle identification for fragmentation studies, jet resolution requirements for precision QCD, ...) and experimental-conditions so that syst. ~ stat. uncertainties.
5. **Define experimental/phenomenological software needs** to enable the measurements and precision interpretations.
6. **Help evaluating QCD impact on rest of FCC measurements.** Establish background event generators for QCD & $\gamma\gamma$ processes.



LOTS OF TOPICS FOR STUDY ACROSS ALL PHYSICS GOALS
ONLY A SMALL SELECTION / FEW EXAMPLES SHOWN HERE

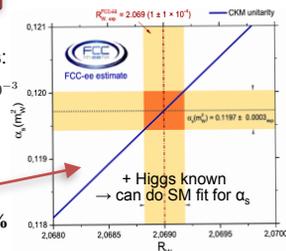
High-Precision α_s Determinations

The only free parameter in (massless) QCD. Least well known of all interaction couplings:

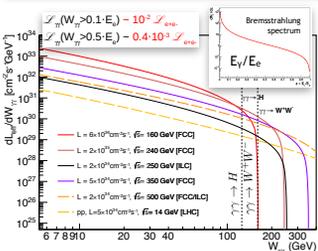
$$\delta\alpha \sim 10^{-10} \ll \delta G_F \sim 10^{-7} \ll \delta G_N \sim 10^{-5} \ll \delta\alpha_s \sim 10^{-3}$$

Impacts all pp cross sections, coloured BSM, GUTs (running), vacuum stability, ...

High-precision ee determinations from event shapes, jets, and hadronic Z & W decays (R ratio) → expect FCC-ee $\delta\alpha_s < 0.3\%$



Photon-Photon Physics Opportunities (QCD, BSM, & EW)



Higgs: $\gamma\gamma \rightarrow H \Rightarrow 100 \text{ H/ab}^{-1}$

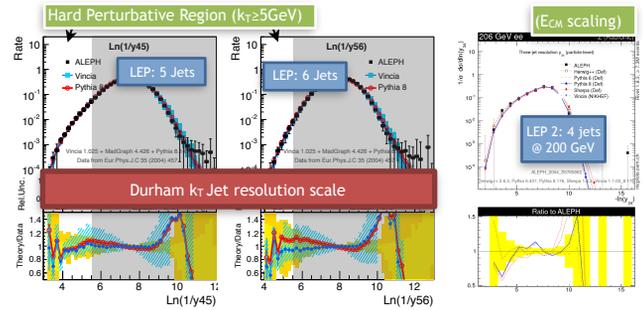
Can also produce $\pi, WW, \gamma\gamma$

QCD: $\sigma(\gamma\gamma \rightarrow \text{hadrons}) \sim \ln(s)$ vs $1/s$ for $e\bar{e} \rightarrow \text{hadrons}$
 $\Rightarrow \gamma\gamma$ rate higher at high s (even with $10^2\text{-}10^3 \text{ L}$ penalty)

Direct + VMD + "hadron"-induced + access to BFKL dynamics? (t-channel)

High-Precision QCD Multijets

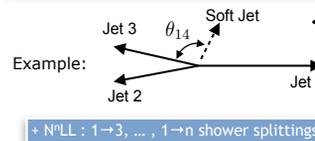
The region of multiple hard resolved jets occupies a small fraction of the total phase space in hadronic Z decays. Measurements at LEP had large (> 10%) uncertainties. With improved systematics, this interesting corner of phase space can be fully explored at an FCC-ee.



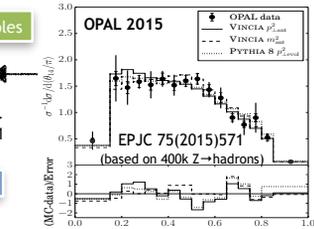
Coherence studies (& jet substructure); Colour (re)connections

Large numbers of multi-jet events (with good detector resolution) allow sensitive studies of coherence effects: multiple soft (but perturbative) emissions. + Observables targeting details of quark & gluon jet (sub)structure, going beyond the LL level. + Non-perturbative colour (re)connection effects → **precision jet structure**

Perturbative: QCD coherence for multipoles



Need high stats for multijets



Non-perturbative: coherent string/hadron formation & string interactions

