WG5 detector requirements
QCD & γ-γ physics

2nd FCC-ee miniworkshop on detector requirements

CERN – 23th Nov. 2016

David d'Enterria (CERN)
Peter Skands (Monash)

WG5 activities & detector requirements

- 3 QCD working areas:
  QCD-1: High-precision strong coupling α_s measurement
  τ,Z,W hadronic decays, FFs, jet shapes & rates,...
  QCD-2: Parton radiation studies with (multi)jets
  g,q,Q rad., dead cone, jet substructure/shapes, jet charge,...
  QCD-3: High-precision parton-to-hadron (g,q, Q) FFs
  Baryon/strange production, colour reconnection, BE/spin corrs…

Generic detector requirements (consistent with flavour WG6?):
Good π,k,p PID (over limited acceptance?)
Low-p_T tracking (below ~100 MeV,r_{min}(2T)< 16 cm? Reduced B-field?)
Charm/bottom separation, very good subjet (calo/PF) resolution

- 3 photon-photon working areas:
  $\gamma\gamma$-1: QCD ($\sigma_{\gamma\gamma}$,VV, $F_{2\gamma}$) measurements + FCC-ee $\gamma\gamma\rightarrow$had. backgds.
  $\gamma\gamma$-2: Electroweak ($\gamma\gamma\rightarrow\gamma\gamma$, $\tau\tau$, WW, H,...) measurements
  $\gamma\gamma$-3: BSM (radion, dilaton, ...) measurements

Generic detector requirement: Forward $e^{\pm}$ taggers

QCD physics

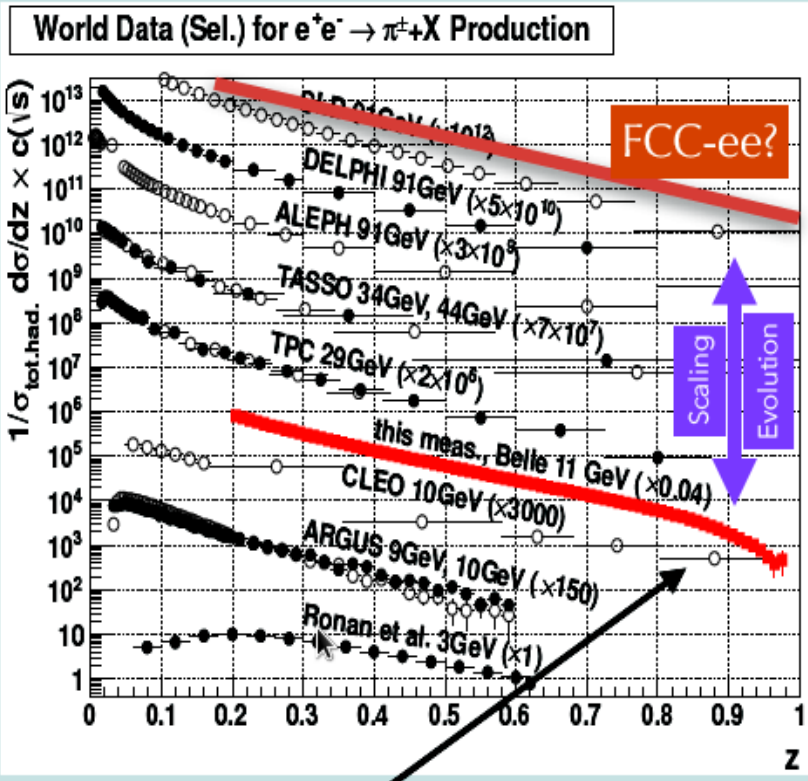
Summary workshop parton rad. & frag.

- Disclaimer: For many, this was their "first take" on FCC-ee. Fresh set of people thinking about the possibilities, but few came with prepared studies.
  → Few explicitly quantitative statements about detector requirements.
- Several themes emphasised repeatedly:
  - Particle Identification (particle spectra, correlations)
    Frag. Functions, Hadronisation Models (Jet composition ⟷ particle flow)
    Genuine non-perturbative effects revealed at scales ~ Λ_{QCD} ~ few hundred MeV
    Important to resolve soft tracks down to |p| ~ 70 MeV = $m_\pi/2$
    Good π/K down to |p|~100 MeV? (LEP had x_k measurements down to $|p_K|$~250 MeV)
    Leading-Particle (x→1) studies: hard protons, Kaons, pions? (→fake rates).
    + MC constraints & tuning, Colour Reconnections, Baryon and Strangeness Correlations, Bose-Einstein (π,K) and Fermi-Dirac (p,Λ) correlations, …
    Note: Fermi-Dirac radius puzzle. Fermi-Dirac correlations at LEP across multiple experiments & for both protons and Λ → 0.1 fm << r_p
  - Calo resolutions (& thresholds)
    Neutrals: Jet charge (colour reconnection constraints), gluon (vs q) jet discrimination
    Heavy-quark dead-cone effect: θ ~ m/E ~ 0.1 for b quarks, 0.03 for c quarks (at m_Z)

Parton-to-hadron fragmentation functions

[A.Vossen, FFs review]

- Precision of theory and experiment big advantage → Complementary to *pp* SIDIS
  - Evolution
  - Transverse momentum dependence in h+Jet Fragmentation
  - Gluon FFs
  - Smaller mass effects at low z
  - Flavor separation (polarization?)
- Flavor structure for FFs of Hyperons and other hadrons that are difficult to reconstruct in *pp* and SIDIS
- Heavy Quark FFs – Also from H decay?
- Larger multiplicities: Parity violating FF $\tilde{H}_1$: Local strong parity violating effects (next...)



Repeatedly emphasised gluon FF poorly constrained: Z→bbg , ZH(→gg): **good b-tagging**

High-N_{ch} performance

Particle ID

Higher ee energy (than Belle) → reach in z determined by reach in **low-|p| track reco**

Belle has FCC-ee like statistics at 10 GeV
High-z binning determined by **high-|p| track reco**

S. Moch (& others): field now moving towards NNLO accuracy: **per-cent level errors** (or better)

Parton showers

[P.Richardson, overview talk]

- In general good agreement for event shapes, jet rates etc.
- The description of meson spectra was generally good.
- However in all simulations baryon production has issues.
- At LEP II interest in colour reconnection between the W decay products and Bose-Einstein correlations.

Multi-jet events: kicked off matrix-element matching & merging

→ State of the art at LHC: multi-jet NLO merging

- For the first time in many years more work on the accuracy of the parton-shower algorithms.
- Needed as we go to higher accuracy for the matrix elements.
- $1/N_c$ (Plätzer, Sjödahl JHEP 1207 (2012) 042), (Nagy, Soper, JHEP 1507 (2015) 119)
- Subleading logs (Li, Skands, arXiv:1611.00013)
- This is the area where there is probably the greatest potential for improvement.
- If we can consistently improve the logarithmic accuracy.

(Precision) Jet Substructure → Resolution!

Quark vs gluon radiation

G. Soyez, K. Hamacher, G. Rauco, S. Tokar, Y. Sakaki

Handles to split degeneracies

H→gg vs Z→qq

Rely on good **H→gg vs H→bb** separation;
mandated by Higgs studies requirements anyway?

Z→bbg vs Z→qq(g)

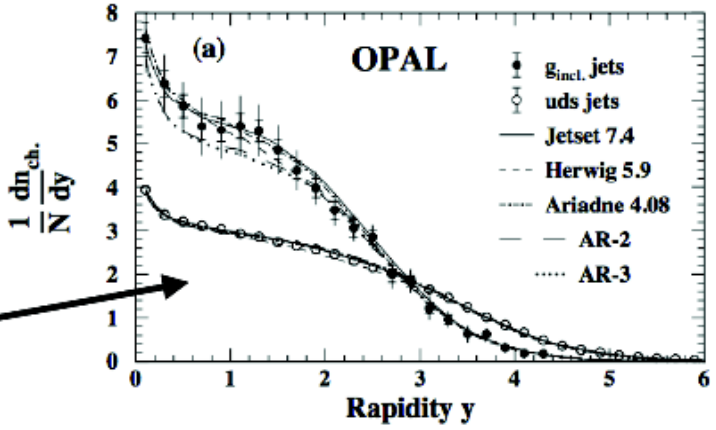
g in one hemisphere recoils against two b-jets in other hemisphere: **b tagging**

Vary jet radius: small-R → calo resolution

(R ~ 0.1 also useful for jet substructure)

Vary E_{CM} range : below m_Z : radiative events → **forward** boosted

(also useful for FFs & general scaling studies);
Scaling is **slow**, logarithmic → large lever arm



Octet neutralisation? (zero-charge gluon jet with rapidity gaps) → neutrals
Colour reconnections, glueballs, …

Leading baryons in g jets?
(discriminates between string/cluster models)
high-E baryons

Hamacher

- mitigate systematics/resolution by unfolding, control using E-dependence

- measurements mass-plots of resonances incl. (!) neutrals
- check baryons + resonances ($\Delta^{0,++}$, Λ, $\Lambda(1520)$, …)

Experimentally: need some particle id., high resolution e.m. calorimetry

Colour reconnection & correlations

T. Sjostrand, W. Metzger, S. Kluth, C. Bierlich

(also for m_{top})

At LEP 2: hot topic (by QCD standards): 'string drag' effect on W mass

Can turn around at FCC-ee; use semi-leptonic events to measure m_W → use m_W as constraint in fully hadronic WW to measure CR

Non-zero effect convincingly demonstrated at LEP, but without much detailed (differential) information

No-CR excluded at 99.5% CL.

Sjostrand

Has become even hotter topic at LHC

Much more colour flowing around; expect larger effects

(even more at FCC-pp!)

<pT> increases with N_{ch} (known since long)

ALICE @ ICHEP 2016: strangeness increases with N_{ch}

It appears jet universality is under heavy attack. Fundamental to our understanding (and modelling) of hadronisation

Many follow-up studies now underway at LHC.

High-stats ee needed to tell the other side of story

Low-momentum (identified) particles in high-multiplicity Z and WW events

Colour reconnection & correlations (2)

m_W, m_{top}, … and also Higgs CP-odd. Another reason to measure CR:

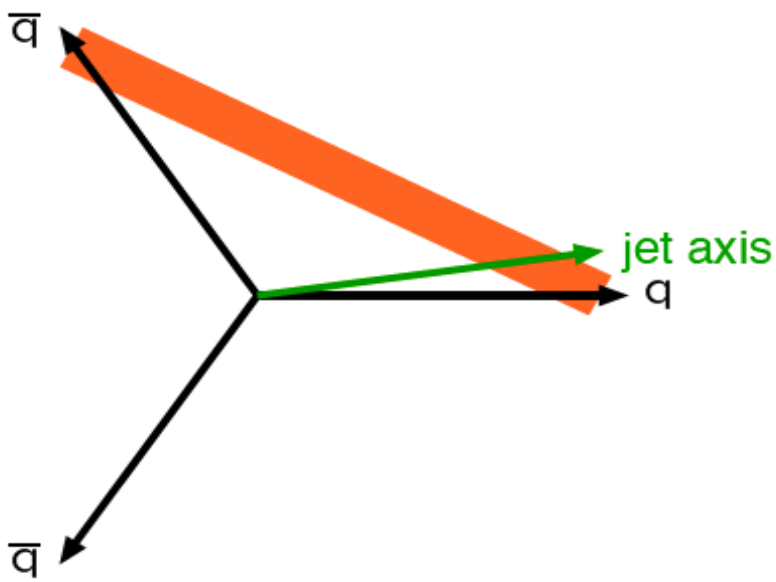
Is the 125 GeV Higgs a pure *CP*-even state? Any odd admixture?

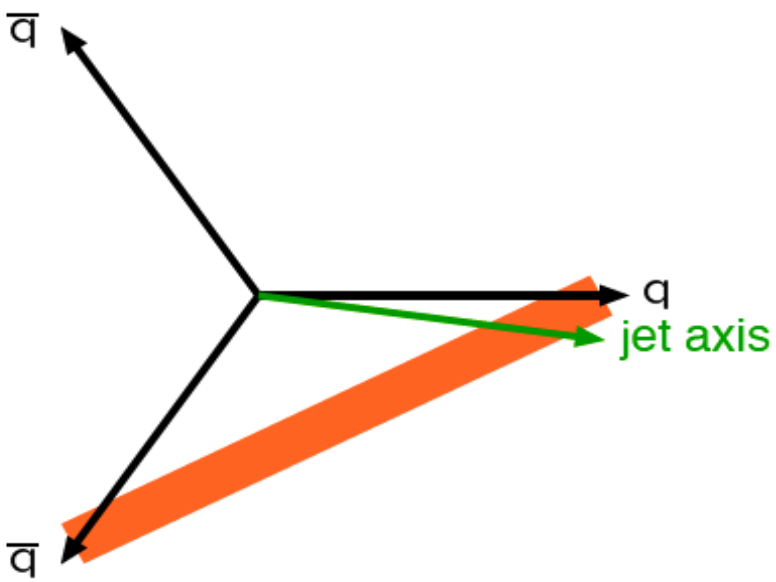
For LHC and future e^+e^- (& $\mu^+\mu^-$?) colliders to probe.

One possibility is $H^0 \to W^+W^- \to q_1\bar{q}_2q_3\bar{q}_4$.

Angular correlations put limits on odd admixture.

[T.Sjostrand]





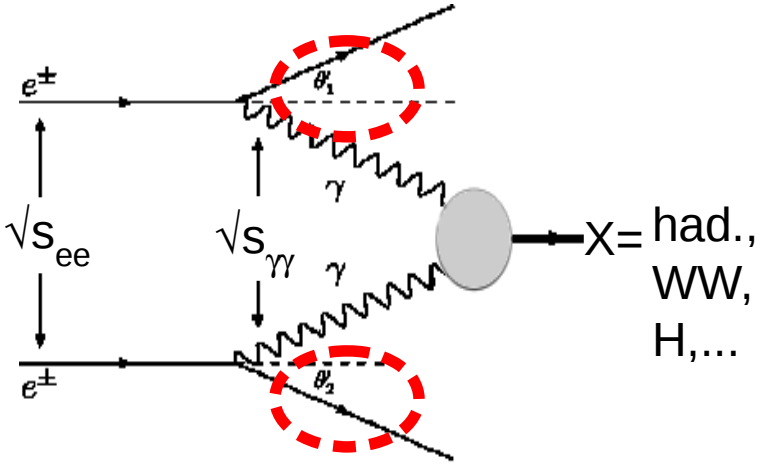
But: colour reconnection ⇒ shifted jet directions

⇒ shifted angular correlations.

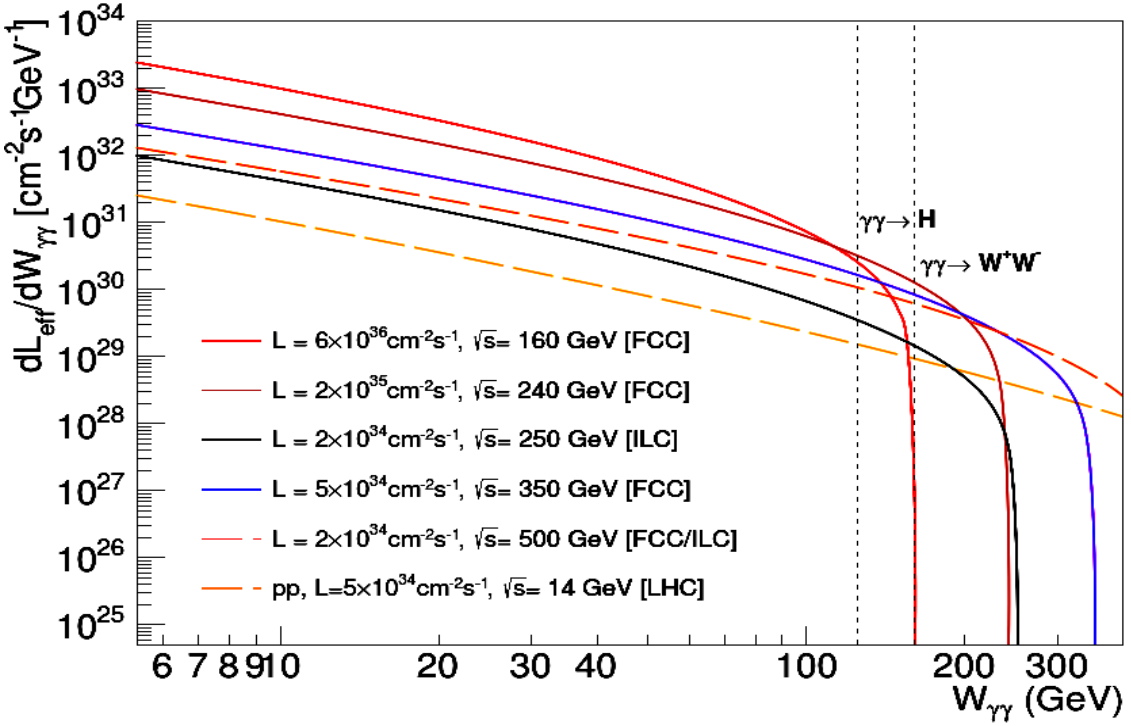
Photon-photon physics

Photon-photon physics

- Photon-photon collisions from equivalent Weizsäcker-Williams γ spectrum (EPA) of $e^{\pm}$ beams.
  Detectors at low θ angle needed to double-tag events.



- Competitive FCC-ee photon-photon luminosities up to $\sqrt{s_{\gamma\gamma}}$ ~ few 100 GeV



Photon-photon physics at FCC-e^+e^-

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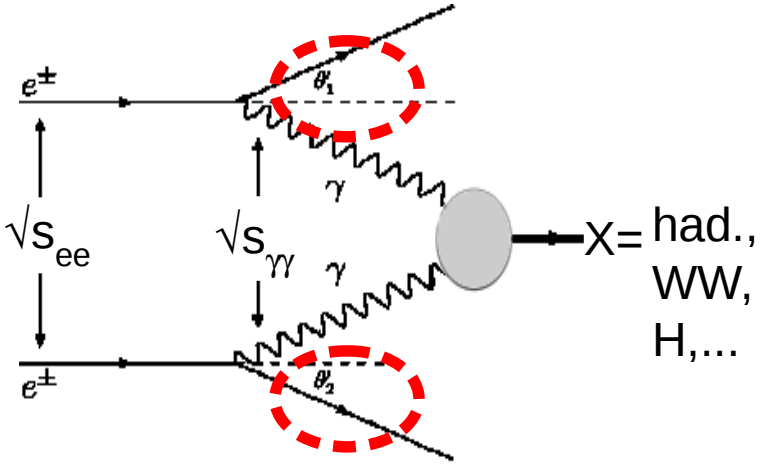
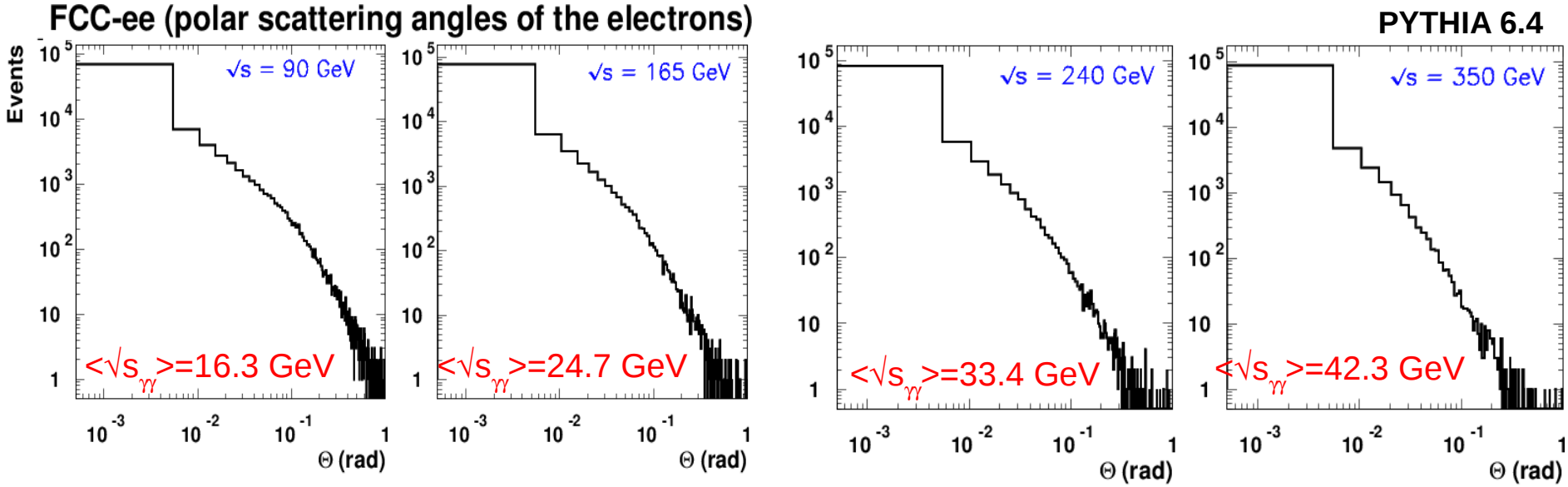


- Example: $F_{2\gamma}(x,Q^2)$ measurement via $\gamma\gamma \rightarrow$ hadrons [B.Krupa (Crakow)]



Angular distributions representative for other $\gamma\gamma$ processes at same $<\sqrt{s}_{\gamma\gamma}>$

Forward e± detectors (ILC/CLIC)

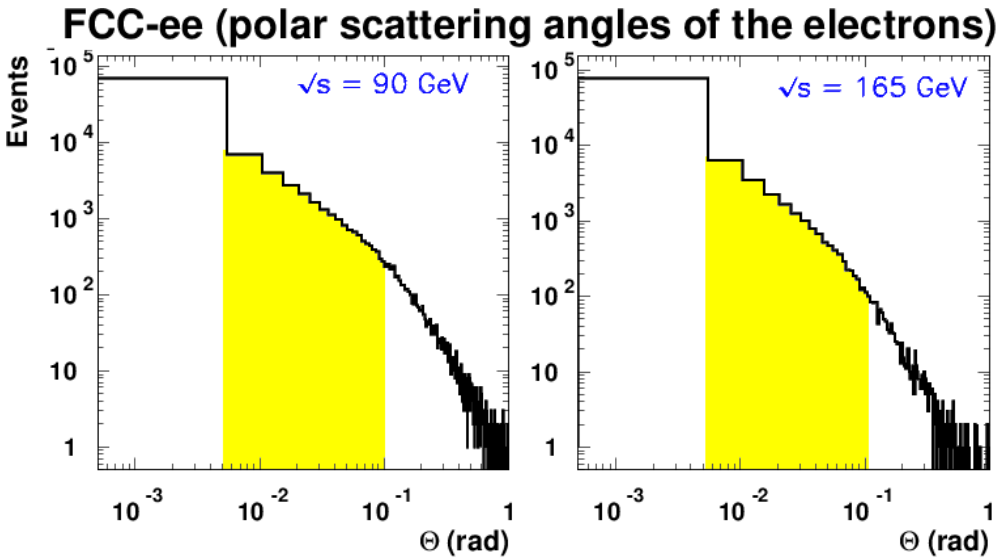
- ILC/CLIC fwd e± detectors coverage:

  ILC: LumiCal (31 – 78 mrad)
  BeamCal (5.8 – 43.5 mrad)

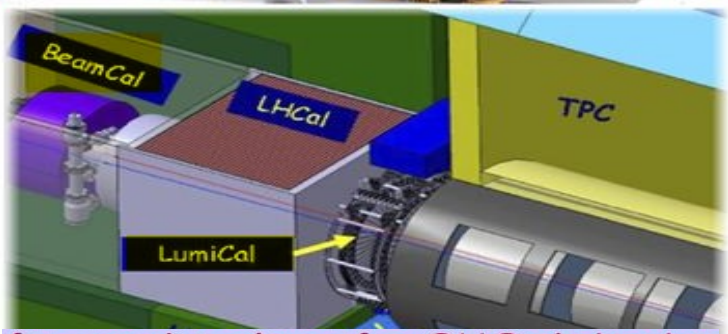
  CLIC: LumiCal (38 – 110 mrad)
  BeamCal (10 – 40 mrad)

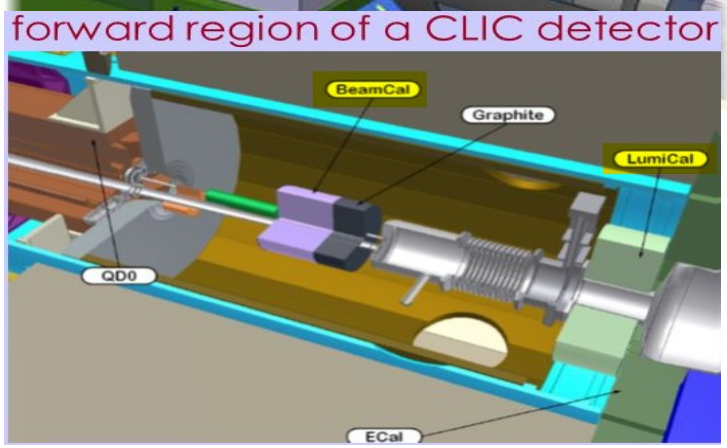
Can FCC-ee cover 5–100 mrad? Lower?

- Ex.: $F_{2\gamma}(x,Q^2)$ measurement via $\gamma\gamma \rightarrow$ hadrons

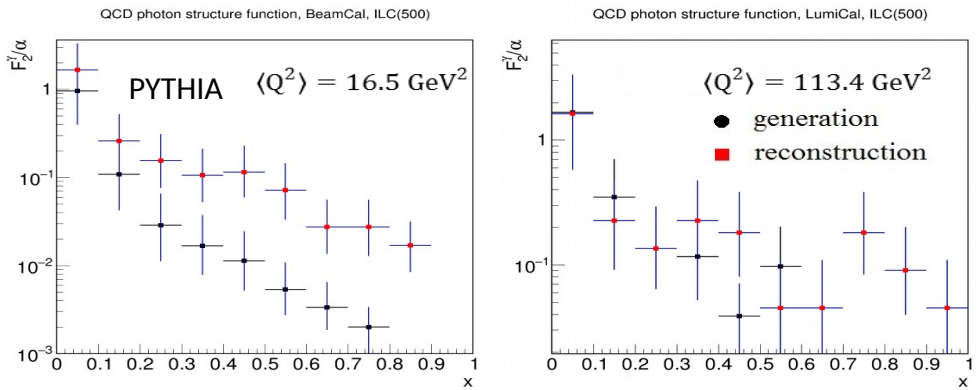


Double-tag accept: ~2.5% of $\gamma\gamma \rightarrow$ had. for $F_{2\gamma}(x,Q^2)$





Ex: Photon structure function $F^{\gamma}_2(x,Q^2)$



[B.Krupa (Crakow)]

Reconstructed F^{γ}_2 distributions for ILC(500 GeV) with scattered electrons tagged at LumiCal and BeamCal

(Only statistical uncertainties)

Estimated numbers of events per year

	sqrt(s) [GeV]	Luminosity [10^{34}cm^{-2}s^{-1}]	N(events)
ILC	500	2	1 x 10^7
	1000	4	3 x 10^7
CLIC	1500	3	2 x 10^7
	3000	6	1 x 10^8
FCC-ee	90	250	9 x 10^7
	160	41	3 x 10^7
	240	10	1 x 10^7
	350	3	5 x 10^6

arXiv:1601.06640v1 [hep-ex] 25 Jan 2016

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Backup slides

Particular questions to PWG5 from Gigi

1) Quantitative needs for PID (separation vs momentum).
   Is π/k separation sufficient? I would like to see something quantitative.

2) Is PID important for charm tagging ? Is π/k separation to
   10 GeV (?) important for charm tagging ?

3) How far from the vertex do you need k0's ?
   Is the wire chamber (r>50 cm) alone sufficient for K0 reconstruction
   and in general for displaced vertices?