Test of non-commutative QED

in $e^+e^- \to \gamma\gamma$ at LEP

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- What is NCQED ?
- NCQED in $e^+e^- \to \gamma\gamma$
- What we (don't) see in the OPAL data

Non-commutative geometry

$$[x_\mu, x_\nu] = i\theta_{\mu\nu}$$

- $\theta_{\mu\nu}$: antisymmetric, constant, frame independent ∼length^2=1/energy^2∼ $1/\Lambda^2$.

  Analog of Planck constant h in ordinary Quantum Mechanics. $[x_\mu, p_\nu] = ih\delta_{\mu\nu}$

- In string theory, noncommutative geometry may arise through quantisation of string in the presence of background fields. (Connes, Douglas, Schwarz, Seiberg, Witten,..)

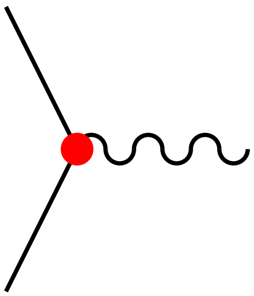
- Λ is perhaps ∼ the Planck scale.
- Λ might be at TeV scale ⇐ large extra dimension, D-brane, ... : TeV scale gravity

- Possible experimental signatures ?

Non-commutative QED

Non-commutative quantum field theory is not well known.

Non-commutative QED exists (NCQED). Renormalizable, U(1) gauge symmetry, ...

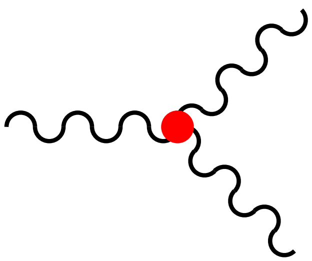


- **eeγ vertex contains a kinematic phase :** $e^{\frac{i}{2}p^\mu \theta_{\mu\nu} p^\nu}$

  Dependence on momenta and $\theta_{\mu\nu}$**.**

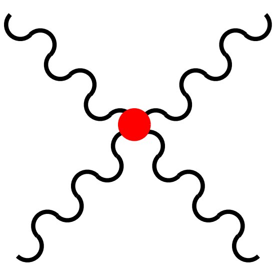
  $\longrightarrow$ **Unique direction.**

  Violaton of Lorentz invariance.



- **Nonabelian-like 3γ, 4γ self couplings,**

  also dependent on $p^\mu \theta_{\mu\nu} p^\nu$



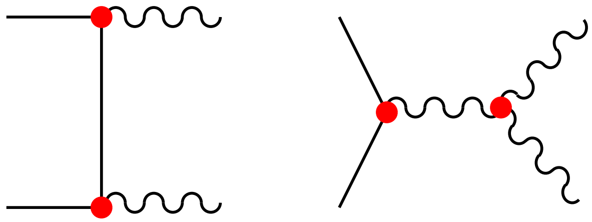
- **Relevant high energy processes:**

  $\gamma \mathrm{e} \to \gamma \mathrm{e}$, $\gamma\gamma \to \gamma\gamma$, $\mathrm{e}^+\mathrm{e}^- \to \gamma\gamma$,.....

- **Low energy experiments :**

  limits from Lamb shift, Aharonov-Bohm effect, clock comparisons, ...

$e^+e^- \to \gamma\gamma$ in NCQED



$e^+e^- \to \gamma\gamma$ is sensitive only to $\theta_{0i} = \frac{1}{\Lambda_{NC}^2} c_{0i}\ (i = 1, 3)$

space-time noncommutativity.

c_{0i} : Unit space vector pointing to the 'unique direction'

Λ_{NC} : Energy scale of non-commutativity

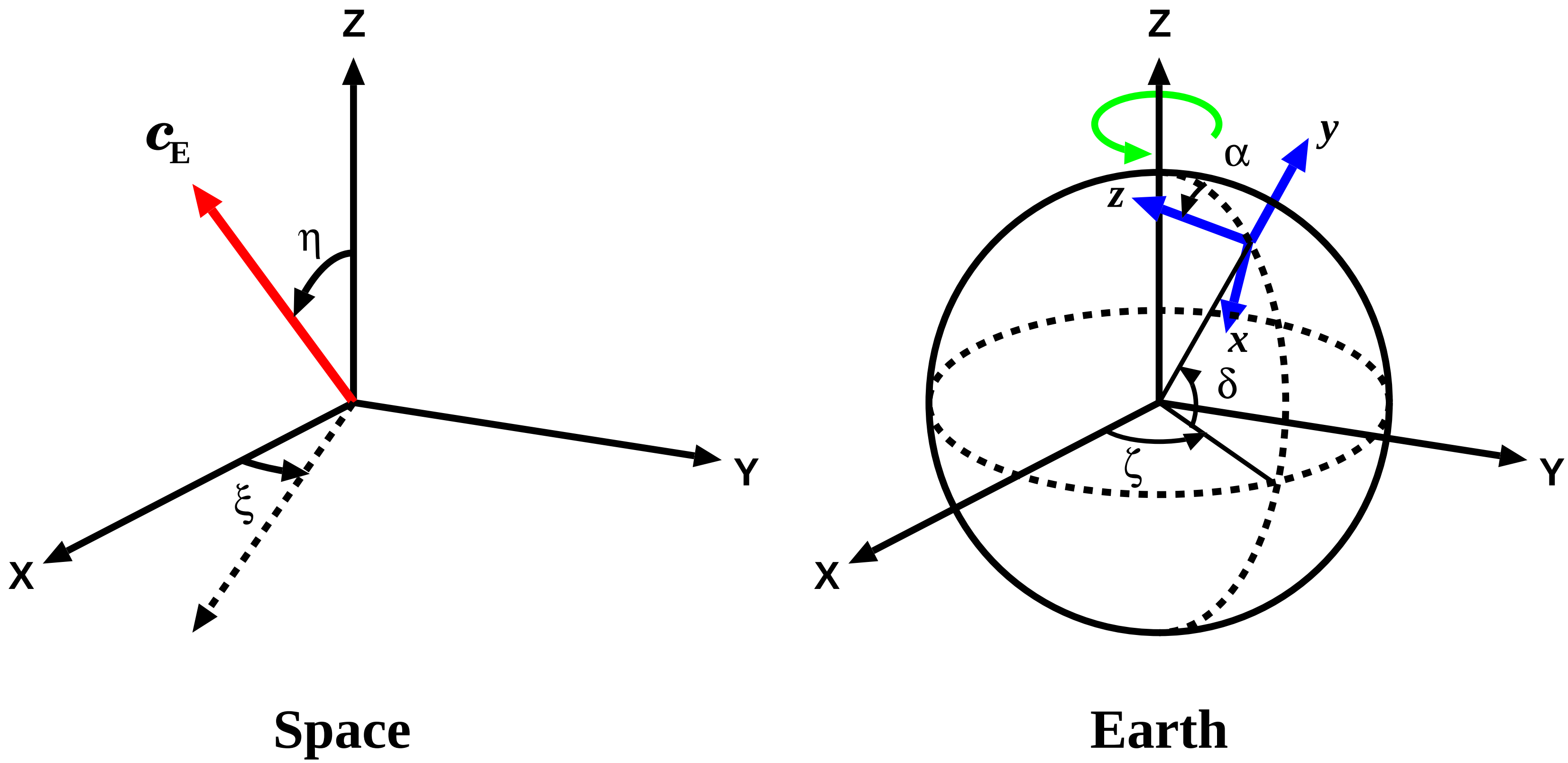
Differential cross-section for $e^+e^- \to \gamma\gamma$ (in the c.m. frame of e^+e^- collision) :

$$\frac{d\sigma}{d\cos\theta d\phi} = \frac{\alpha^2}{s}\frac{1+\cos^2\theta}{1-\cos^2\theta}(1 - \sin^2\theta \sin^2\Delta_{NC})$$

$$\Delta_{NC} = \frac{s}{4\Lambda_{NC}^2}(c_{01}\sin\theta\cos\phi + c_{02}\sin\theta\sin\phi + c_{03}\cos\theta)$$

Dependence on ϕ as well as θ.

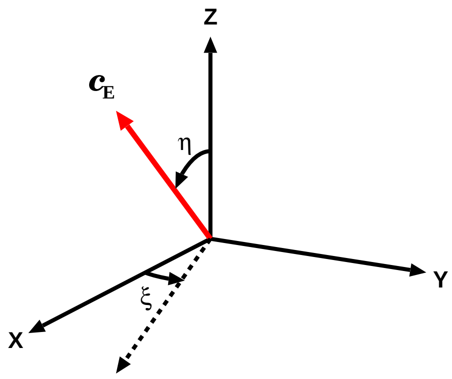
Definition of coordinate system



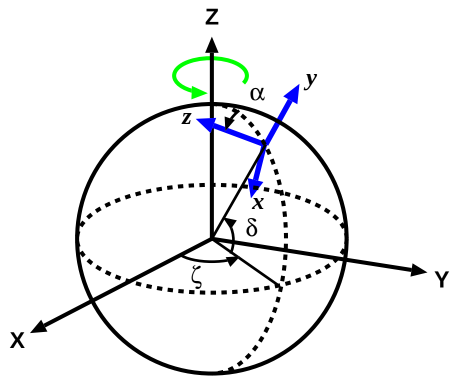
- The unit vector c_E is perhaps sitting on some large scale structure in space e.g. the rest frame of the cosmic microwave background.

- Experiment on the earth is changing its orientation as the earth rotates.

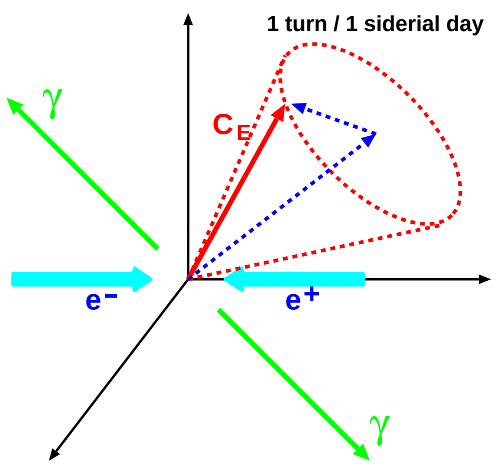
Transformation of coordinate system



Space



Earth



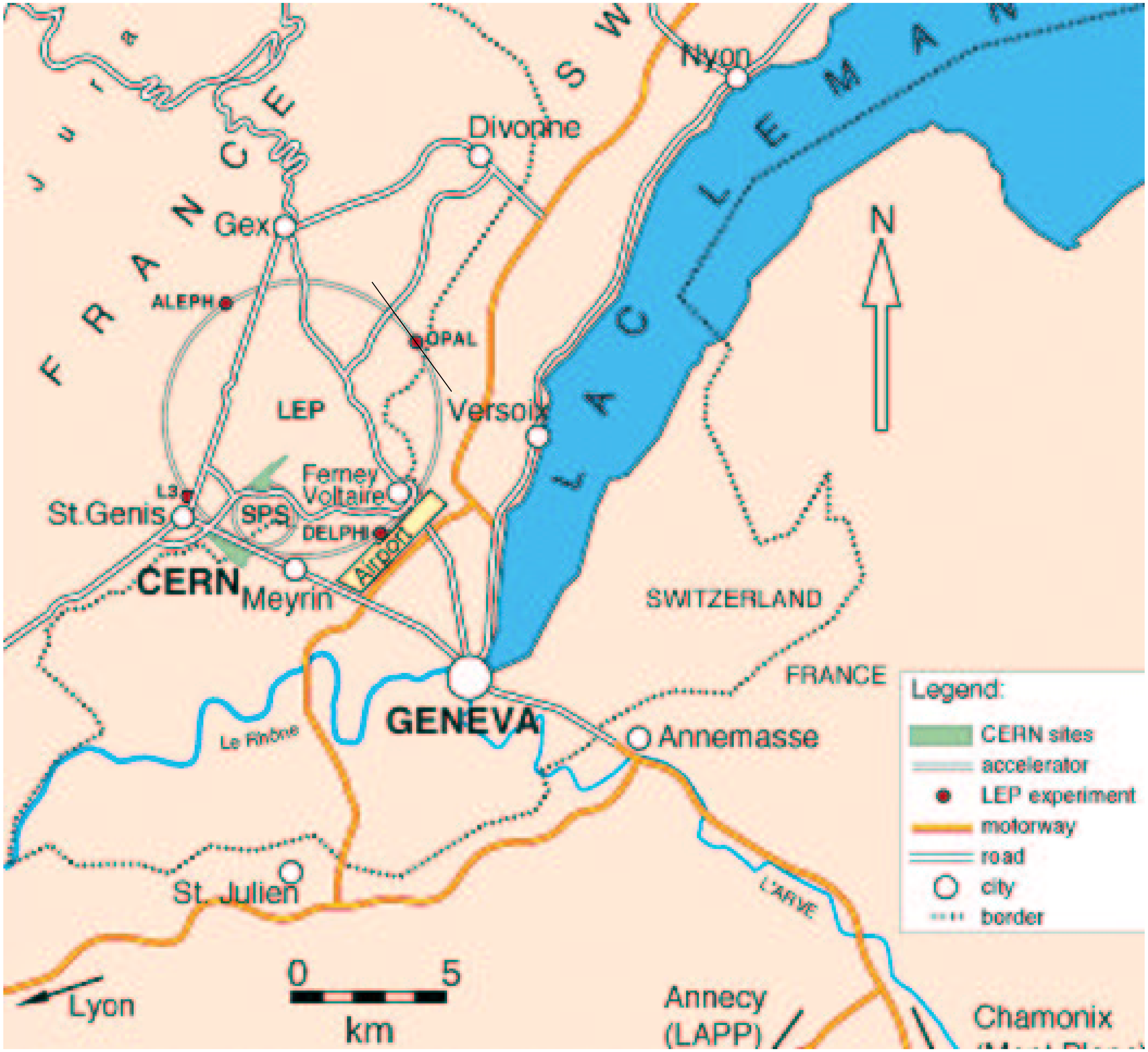
$$\boldsymbol{c_E} = \begin{pmatrix} s_\alpha s_\delta \\ c_\delta \\ -c_\alpha s_\delta \end{pmatrix} s_\eta \cdot \cos(\zeta - \xi) + \begin{pmatrix} c_\alpha \\ 0 \\ s_\alpha \end{pmatrix} s_\eta \cdot \sin(\zeta - \xi) + \begin{pmatrix} -s_\alpha c_\delta \\ s_\delta \\ c_\alpha c_\delta \end{pmatrix} c_\eta$$

$\zeta = \omega t, \;\; \omega = 2\pi / T_{sd}$ (T_{sd} = sidereal day)

Two components of c_E : constant term and terms varying with time.

when η=0 (parallel to the rotation axis of the earth), c_E is stationary.

Location and orientation of OPAL experiment



$$\delta = 46.29^\circ$$
$$\alpha = 33.60^\circ$$

OPAL data

OPAL $e^+e^- \to \gamma\gamma$ sample

- $\sqrt{s}$=181 - 209 GeV
- Collected in 1997-2000
- $\mathcal{L}$=672 pb^{-1}
- 5235 events $|\cos\theta| < 0.93$

$$\frac{d\sigma}{d\cos\theta d\phi}(\Lambda, \eta, \xi\,; \zeta = \omega t)$$

Consider 3 cross-sections

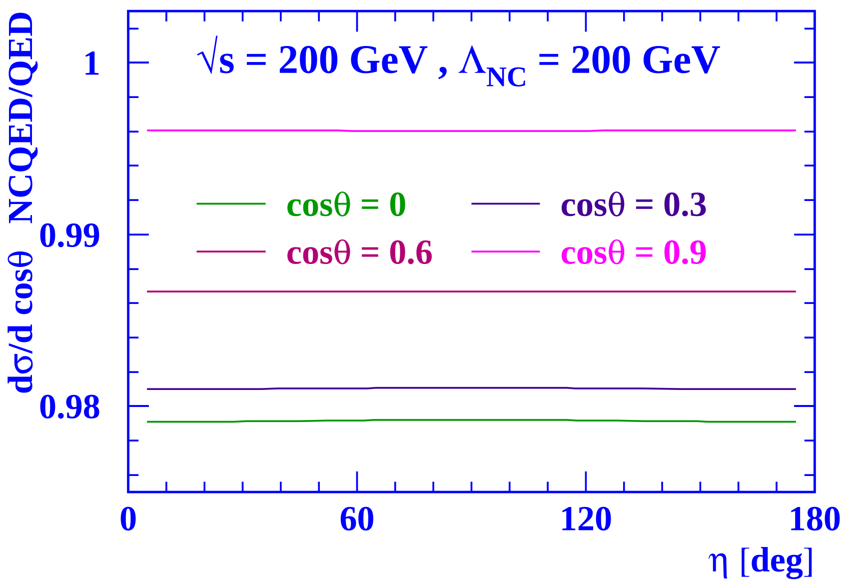
- $\frac{d\sigma}{d\cos\theta}$: ϕ integrated, time averaged
- $\frac{d\sigma}{d\phi}$: $\cos\theta$ integrated, time averaged
- $\sigma(t)$: $\cos\theta$ integrated (0.0-0.6), ϕ integreged

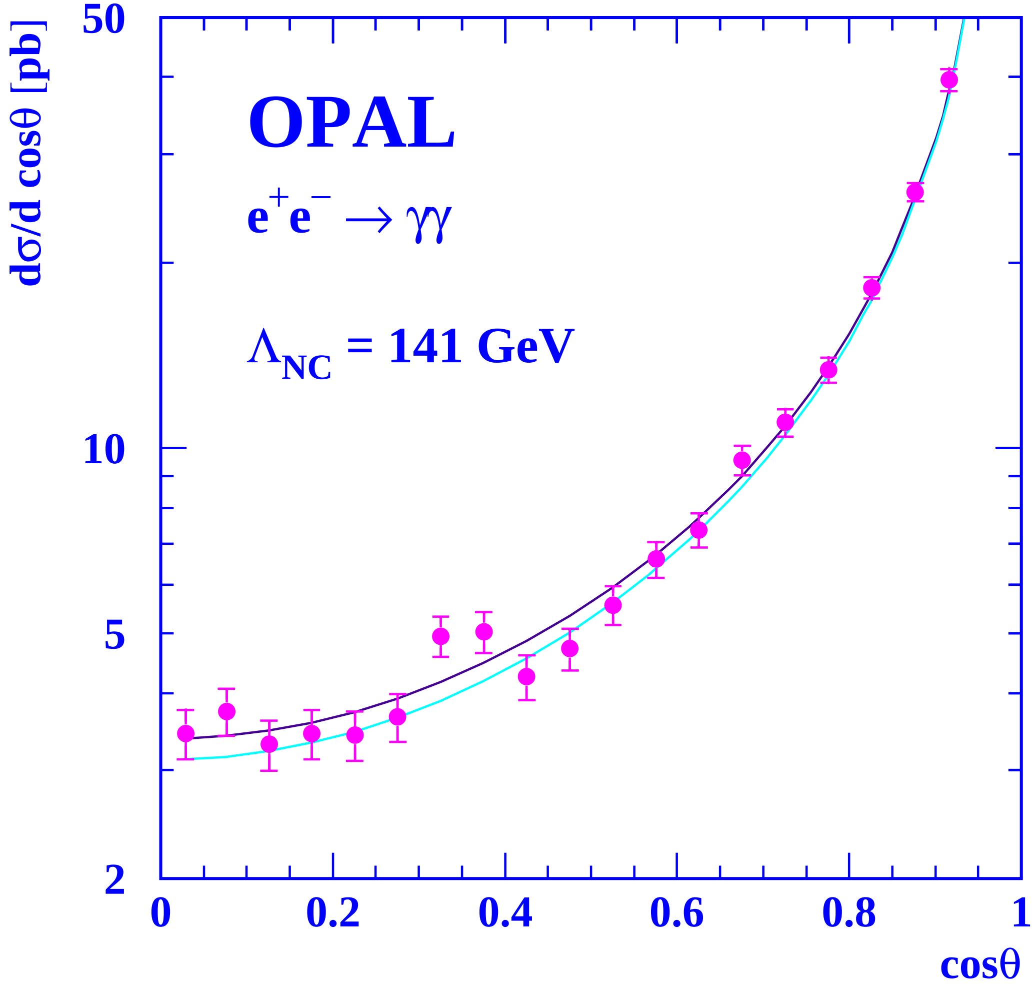
Time averaged, ϕ integrated $\cos\theta$ distribution

Accidentally, for the OPAL orientation,

Very small η dependence

Depends $\approx$only on Λ_{NC}





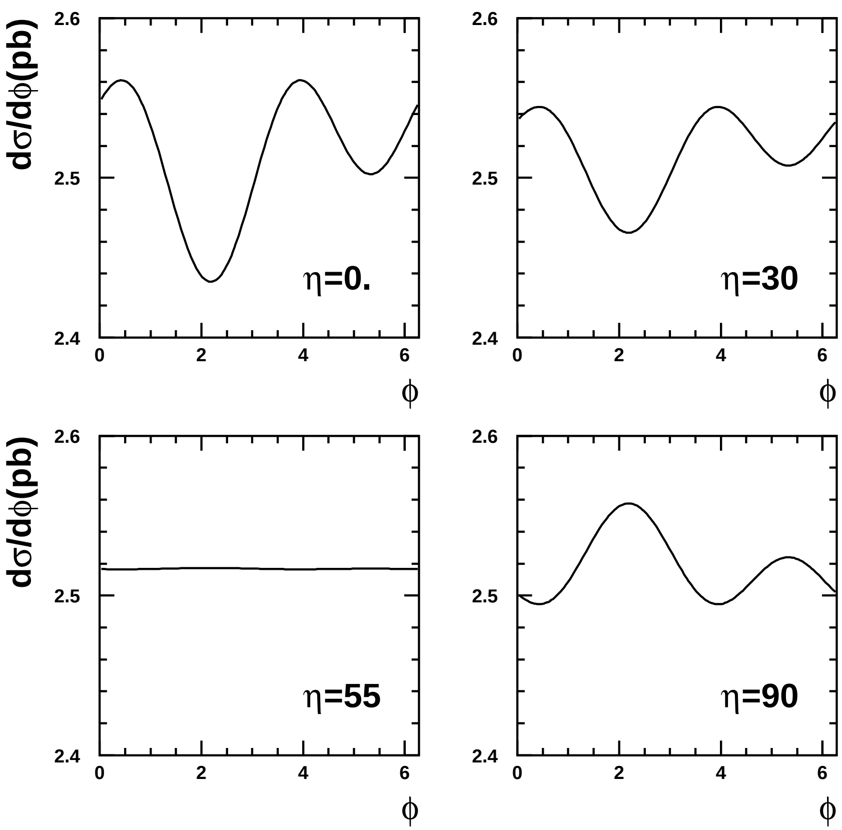
$\Lambda_{NC} > 141$ GeV at 95% CL

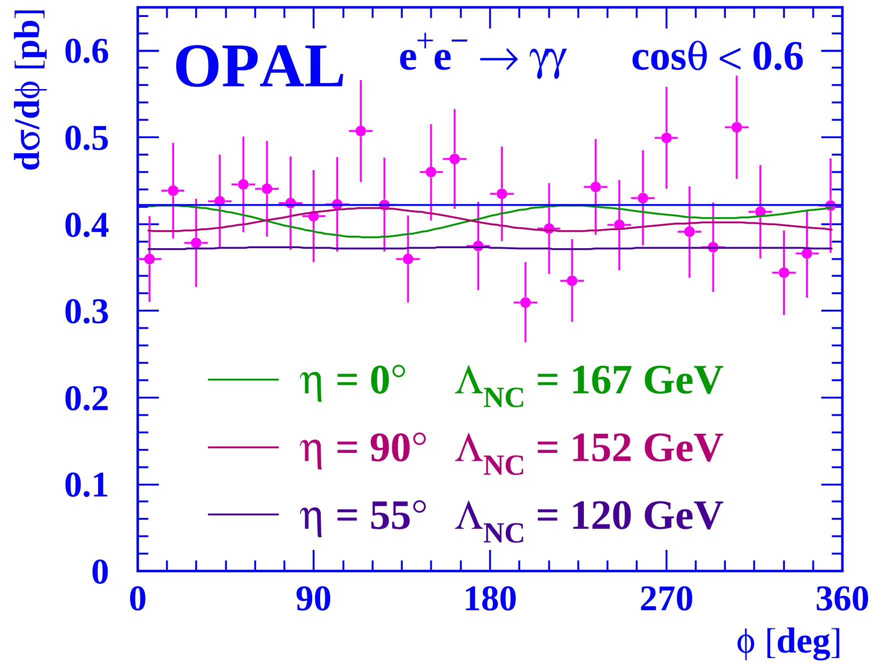
Independent of η

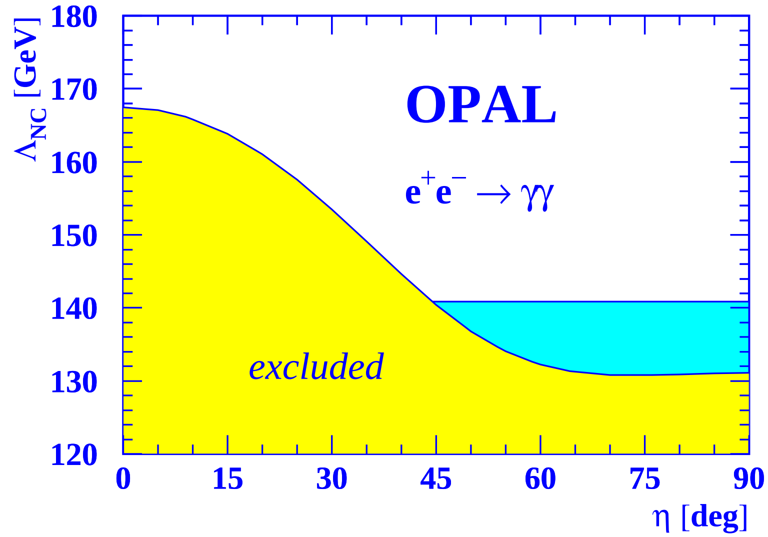
Time averaged, $\cos\theta$ integrated ϕ distribution

ϕ structure, depending on η

Amplitude depends on Λ



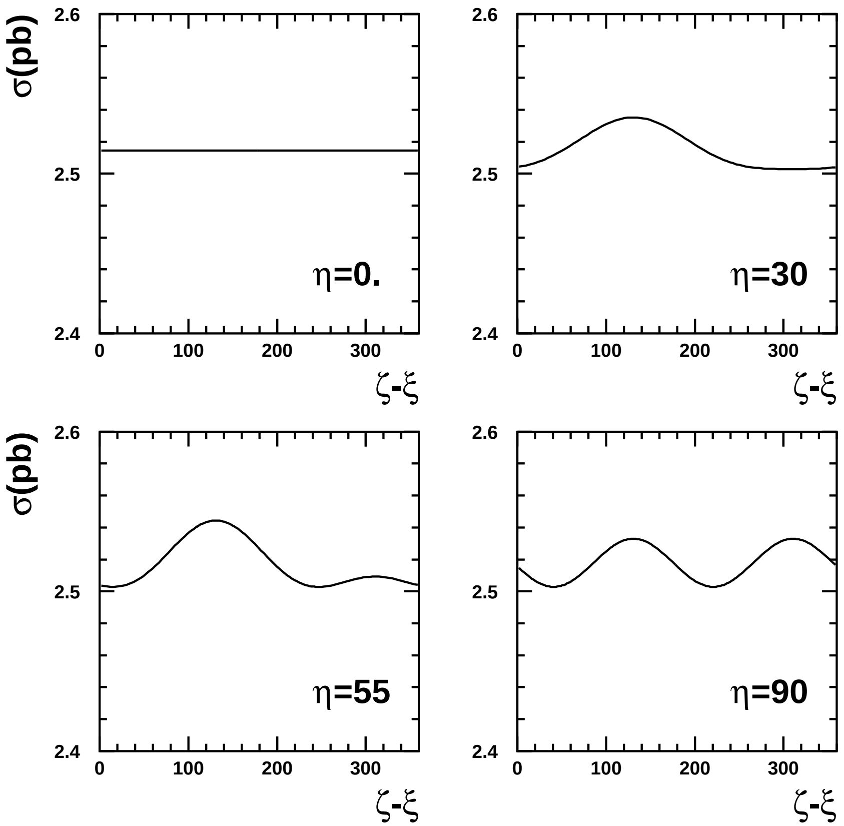




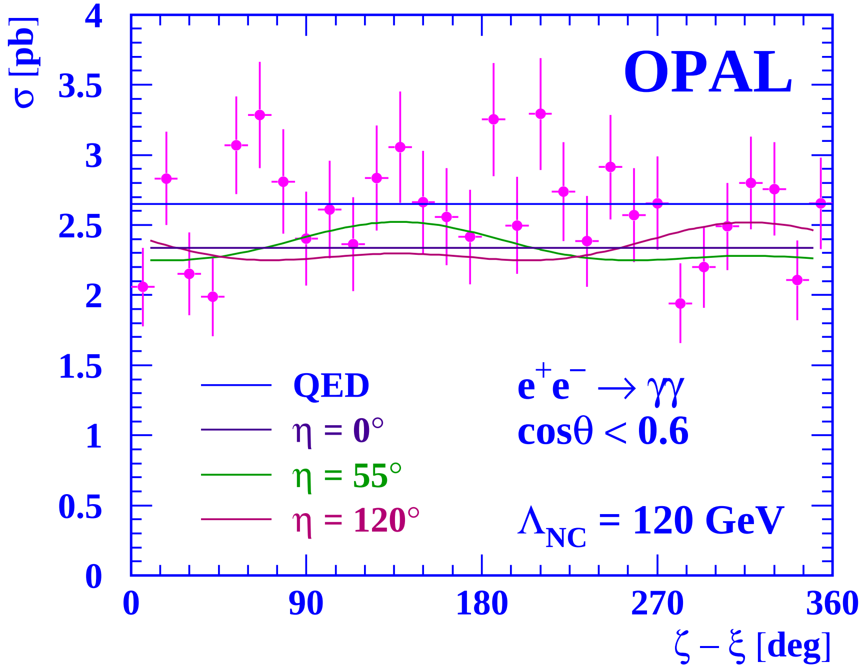
Time dependence of total cross-section

Sidereal daily structure of cross-section

If observed ⇒ infer ξ



Observed cross-section vs $(\zeta - \xi)$ (time):



χ^2/dof = 39.9/30

for constant QED cross-section

Conclusion

- Studied NCQED in $e^+e^- \to \gamma\gamma$ with OPAL data at LEP
- taking into account earth rotation. The unique direction specfied by η and ξ.
- Limit on $\Lambda_{NC} > 141$ GeV at 95% CL, independent of η from $\frac{d\sigma}{d\cos\theta}$.
- η dependent limit on Λ_{NC} from $\frac{d\sigma}{d\phi}$. $\Lambda_{NC} > 167$ GeV at $\eta = 0^\circ$.
- The first limit on NCQED from e^+e^- collider. (CERN-EP-2003-010, hep-ex/0303035)
- Study at higher energy linear collider $\Rightarrow$ Λ_{NC} to TeV.