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Space anisotropy search at Colliders

Plan

- Introduction
- Model SME
- Lepton-Lepton colliders
- LHC, p-p colliders
- Summary

Space Anisotropy

- SM – isotropous and homogeneous space
- Noncommutative versions of the standard model *assumes space anisotropy* *arXiv:1006.1009v3 [hep-ph] 16 Jul 2010*
- SME by Alan Kostelezky Lorenz Violation *arXiv:0312310v2 [hep-th] 23 Marl 2004*
- Search for Lorentz and CPT violation using sidereal time dependence of neutrino flavor transitions over a short baseline, T2K

  https://arxiv.org/abs/1703.01361v2
- **Space Anisotropy Search at Colliders I. S. Karpikov, D.A. Tlisov, D.V. Kirpichnikov**

https://arxiv.org/abs/1612.02217

SME

$$S_{SME} = S_{SM} + S_{LV} + \ldots$$

$$L_{SM} = L_{lepton} + L_{quark} + L_{Yukawa} + L_{Higgs} + L_{gauge}$$

$$L^{CPT+}{}_{LV} = L^{CPT+}{}_{lepton} + L^{CPT+}{}_{quark} + L^{CPT+}{}_{Yukawa} + L^{CPT+}{}_{Higgs} + L^{CPT+}{}_{gauge}$$

$$L^{CPT-}{}_{LV} = L^{CPT-}{}_{lepton} + L^{CPT-}{}_{quark} + L^{CPT-}{}_{Higgs} + L^{CPT-}{}_{gauge}$$

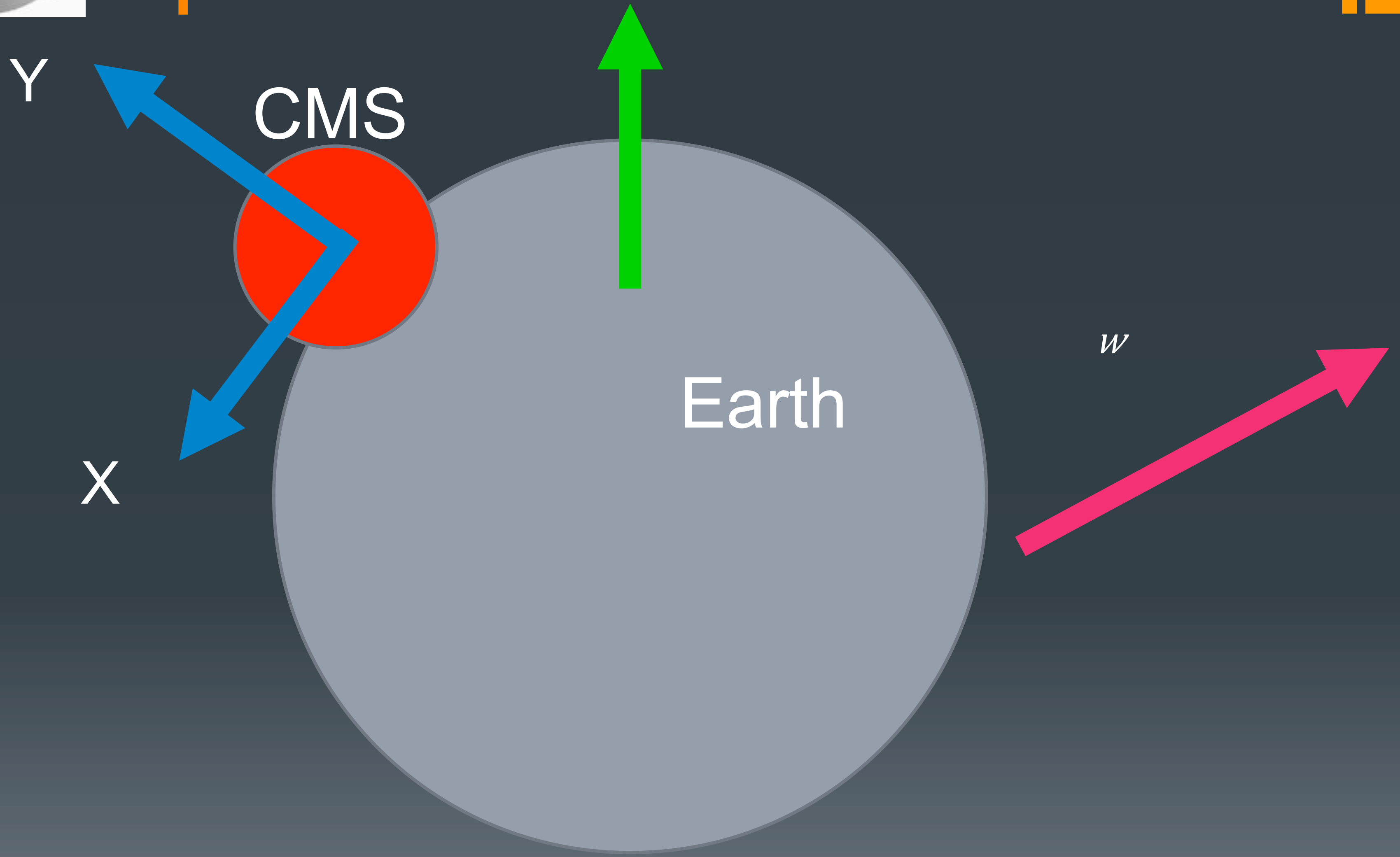
Current Limits

$$L^{CPT+}_{quark} = + (c_Q)_{\mu\nu AB}\,\bar{Q}_A\gamma^\mu\left(i\partial^\nu - \frac{g}{2}\tau^i W_i^\nu + \frac{g'}{6}B^\nu + \frac{g_s}{2}\lambda^a G_a^\nu\right)Q_B$$
$$+ (c_U)_{\mu\nu AB}\,\bar{U}_A\gamma^\mu\left(i\partial^\nu + \frac{2}{3}g' B^\nu + \frac{g_s}{2}\lambda^a G_a^\nu\right)U_B$$
$$+ (c_D)_{\mu\nu AB}\,\bar{D}_A\gamma^\mu\left(i\partial^\nu - \frac{1}{3}g' B^\nu + \frac{g_s}{2}\lambda^a G_a^\nu\right)D_B.$$

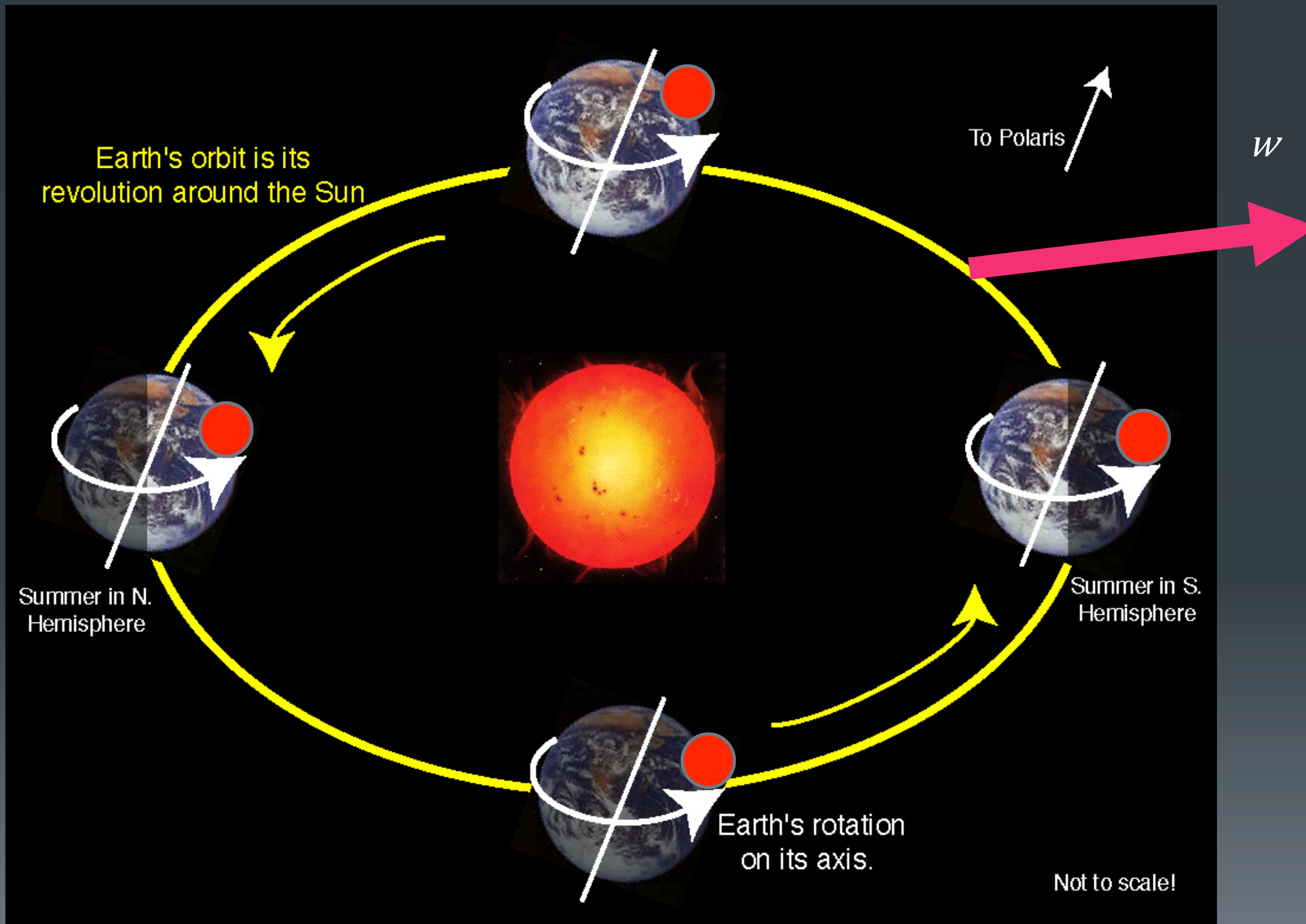
arXiv:0801.0287v8 [hep-ph] 19 Jan 2015

$(c_Q)_{XX33}$	$-0.12 \pm 0.11 \pm 0.02$	$t\bar{t}$ production
$(c_Q)_{YY33}$	$0.12 \pm 0.11 \pm 0.02$	"
$(c_Q)_{XY33}$	$-0.04 \pm 0.11 \pm 0.01$	"
$(c_Q)_{XZ33}$	$0.15 \pm 0.08 \pm 0.02$	"
$(c_Q)_{YZ33}$	$-0.03 \pm 0.08 \pm 0.01$	"
$(c_U)_{XX33}$	$0.1 \pm 0.09 \pm 0.02$	"
$(c_U)_{YY33}$	$-0.1 \pm 0.09 \pm 0.02$	"
$(c_U)_{XY33}$	$0.04 \pm 0.09 \pm 0.01$	"
$(c_U)_{XZ33}$	$-0.14 \pm 0.07 \pm 0.02$	"
$(c_U)_{YZ33}$	$0.01 \pm 0.07 \pm < 0.01$	"

Space Position



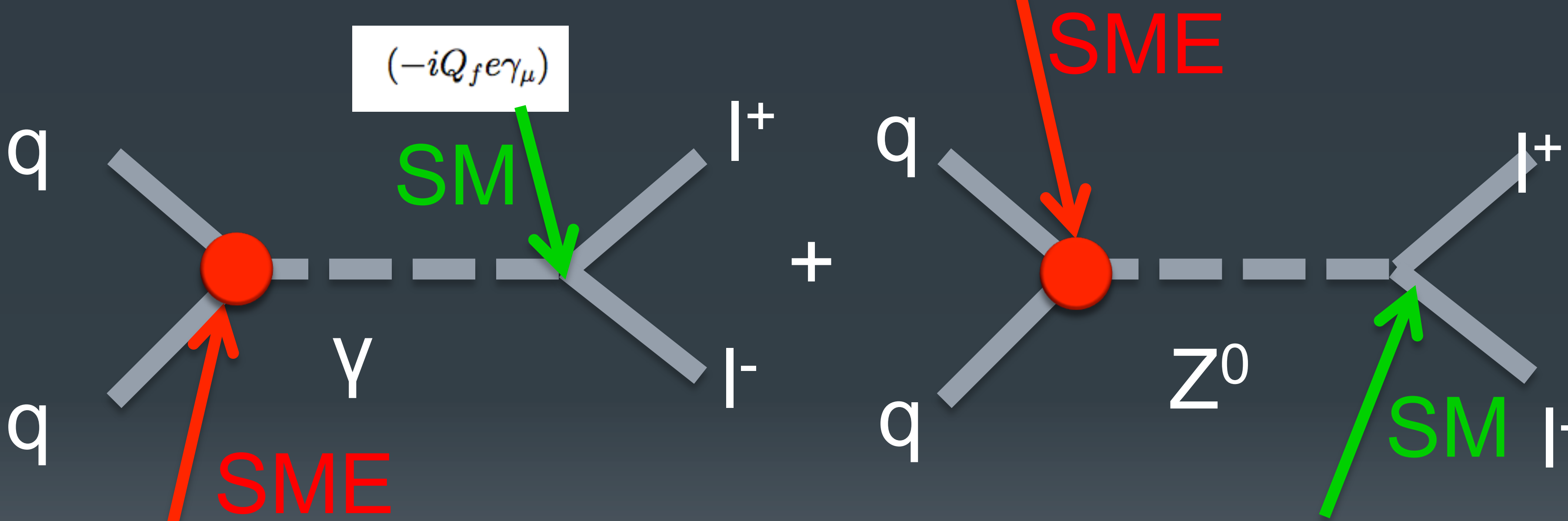
Earth rotation



SME Drell-Yan

$$\frac{(-ie)}{\sin 2\theta_W}\left(C^Q_{\mu\nu}C^q_L\frac{(1-\gamma_5)}{2}+C^U_{\mu\nu}C^q_R\frac{(1+\gamma_5)}{2}\right)\gamma^\mu$$

$$(-iQ_f e\gamma_\mu)$$



$$(-iQ_q e)\left(C^Q_{\mu\nu}\frac{(1-\gamma_5)}{2}+C^U_{\mu\nu}\frac{(1+\gamma_5)}{2}\right)\gamma^\mu$$

$$\frac{(-ie)}{\sin 2\theta_W}\left(C^f_L\frac{(1-\gamma_5)}{2}+C^q_R\frac{(1+\gamma_5)}{2}\right)\gamma^\mu$$

SME Drell-Yan

$$\frac{1}{4N_c}\sum_{s.c.}|\mathcal{M}|^2 \simeq \frac{1}{4N_c}\sum_{s.c.}|\mathcal{M}_\gamma + \mathcal{M}_Z|^2 + \frac{1}{4N_c}\sum_{s.c.}\left(2\mathcal{M}_\gamma^\dagger\delta\mathcal{M}_\gamma + 4\mathcal{M}_\gamma^\dagger\delta\mathcal{M}_Z + 2\mathcal{M}_Z^\dagger\delta\mathcal{M}_Z\right) \tag{4}$$

$$\frac{1}{4N_c}\sum_{s.c.}2\mathcal{M}_Z^\dagger\delta\mathcal{M}_Z = \frac{2}{N_c}\frac{e^4}{\sin^4 2\theta_W}\frac{1}{(s-M_Z^2)^2}\Big(\big(C_{\mu\nu}^Q(C_L^q)^2 + C_{\mu\nu}^U(C_R^q)^2\big)\big((C_L^l)^2+(C_R^l)^2\big)L_V^{\mu\nu} + \\ +\big(C_{\mu\nu}^Q(C_L^q)^2 - C_{\mu\nu}^U(C_R^q)^2\big)\big((C_L^l)^2 - (C_R^l)^2\big)L_A^{\mu\nu}\Big) \tag{5}$$

$$\frac{1}{4N_c}\sum_{s.c.}2\mathcal{M}_\gamma^\dagger\delta\mathcal{M}_Z = \frac{2}{N_c}\frac{e^2 Q_q Q_l}{\sin^2 2\theta_W}\frac{1}{s(s-M_Z^2)}\Big(\big(C_{\mu\nu}^Q C_L^q + C_{\mu\nu}^U C_R^q\big)\big(C_L^l + C_R^l\big)L_V^{\mu\nu} + \\ +\big(C_{\mu\nu}^Q C_L^q - C_{\mu\nu}^U C_R^q\big)\big(C_L^l - C_R^l\big)L_A^{\mu\nu}\Big) \tag{6}$$

$$\frac{1}{4N_c}\sum_{s.c.}2\mathcal{M}_\gamma^\dagger\delta\mathcal{M}_\gamma = \frac{2}{N_c}2\,Q_q^2 Q_l^2\frac{1}{s^2}\left(C_{\mu\nu}^Q + C_{\mu\nu}^U\right)L_V^{\mu\nu} \tag{7}$$

$$L_{\mu\nu}^A = (p_2k_1)(p_1k_2)g_{\mu\nu} - (p_2k_1)(k_{2\mu}p_{1\nu}) + (p_2k_2)(k_{1\mu}p_{1\nu}) - (p_2k_2)(k_1p_1)g_{\mu\nu} + \\ +(p_1k_1)(k_{2\mu}p_{2\nu}) - (p_1k_2)(k_{1\mu}p_{2\nu}) \tag{8}$$

$$L_{\mu\nu}^V = (p_1k_2)(k_{1\nu}p_{2\mu}) + (p_2k_2)(k_{1\nu}p_{1\mu}) + (p_1k_1)(k_{2\nu}p_{2\mu}) + (p_2k_1)(k_{2\nu}p_{1\mu}) - \\ -(p_1p_2)(k_{2\mu}k_{1\nu} + k_{1\mu}k_{2\nu}) - (k_1k_2)(p_{2\mu}p_{1\nu} + p_{1\mu}p_{2\nu}) \tag{9}$$

Cross section

$$\langle \delta | \mathcal{M} |^2_{\mathrm{SME}} (t) \rangle_t =$$

$$= \frac{1}{T_{\mathrm{sid}}} \int_0^{T_{\mathrm{sid}}} \delta |\mathcal{M}|^2_{\mathrm{SME}}(t) dt = C_{\mathrm{SME}} |M|^2_{\mathrm{SM}}$$

$$c^q_{IJ} = \begin{pmatrix} c^q_{XX} & c^q_{XY} & c^q_{XZ} \\ c^q_{YX} & c^q_{YY} & c^q_{YZ} \\ c^q_{ZX} & c^q_{ZY} & c^q_{ZZ} \end{pmatrix}$$

$$\sigma^{\mathrm{SME}}_{e^+e^- \to q\bar{q}} = \sigma^{\mathrm{SM}}_{e^+e^- \to q\bar{q}} \cdot (1 + C_{\mathrm{SME}})$$

$$C_{SME} = \frac{c_{ZZ}}{8}(1 + 3(\cos 2\alpha + \cos 2\chi - \cos 2\alpha \cos 2\chi)).$$

Cross section

$$\sigma^{SME}_{e^+e^-\to q\bar{q}} = \sigma^{SM}_{e^+e^-\to q\bar{q}} \cdot (1+\varepsilon(t))$$

$$c^q_{IJ} = \begin{pmatrix} c^q_{XX} & 0 & 0 \\ 0 & -c^q_{XX} & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$\varepsilon(t) = c^q_{XX}\left(\cos 2\omega t\{\cos^2\alpha\cos^2\chi - \sin^2\alpha + \cos^2\chi\} - \right.$$
$$\left. -\cos\chi\sin^2\alpha\sin 2\omega t\right).$$

ω = 2π/23 h 56 min 4.1 sec

LEP Data

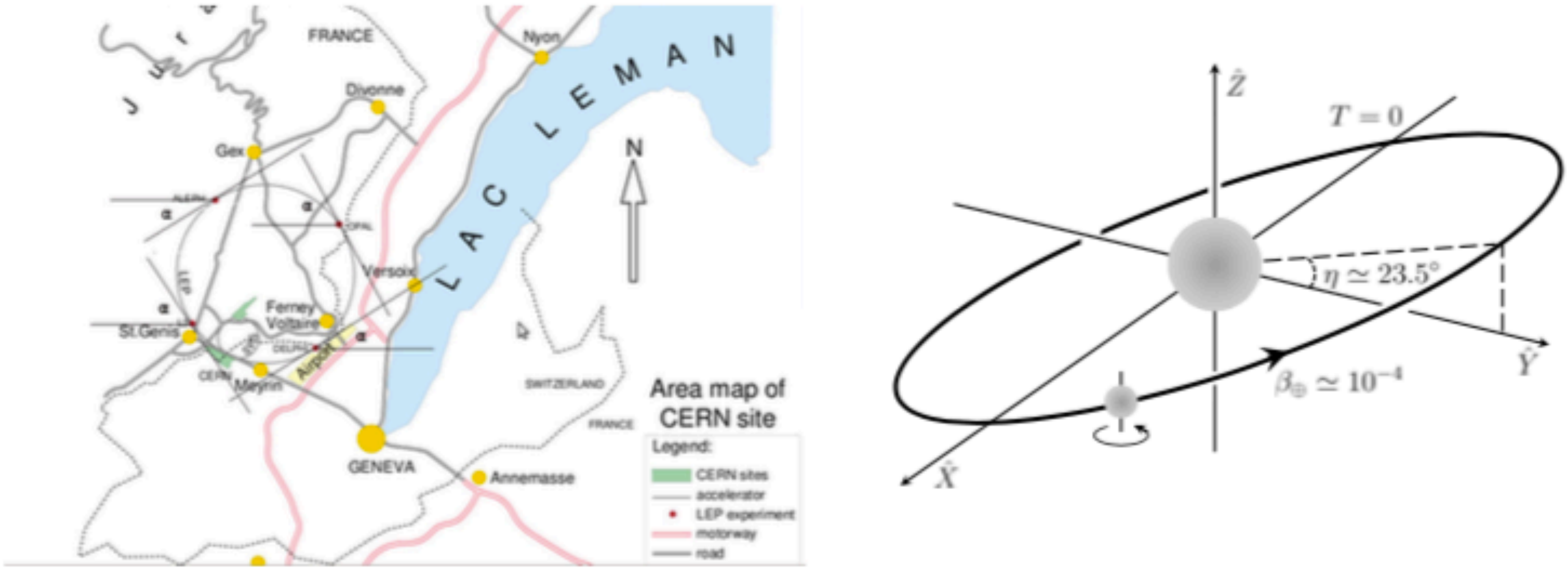


Figure 2: Left panel: orientation of the beam direction for ALEPH and OPAL detectors. Right panel: schematic illustration of the Sun-centered and Earth-based reference frames.

	ALEPH	OPAL	L3	DELPHI
Beam orientation (α)	33.92°	54.50°	55.60°	34.87°
Colatitude (χ)	43.77°	43.77°	43.77°	43.77°

LEP Data

	ALEPH	OPAL
$\Delta\sigma_{q\bar{q}}/\langle\sigma_{q\bar{q}}\rangle$	0.78%, Tab. 4 of Ref. [16]	1.21%, Tab. 5 of Ref. [18]
$\|c_{ZZ}\|$	< 0.027	< 0.036

Table 2: Conservative bounds on LV coupling of all quarks assuming $|c^u_{ZZ}| = |c^d_{ZZ}| = |c^s_{ZZ}| = |c^c_{ZZ}| = |c^b_{ZZ}| = |c_{ZZ}|$.

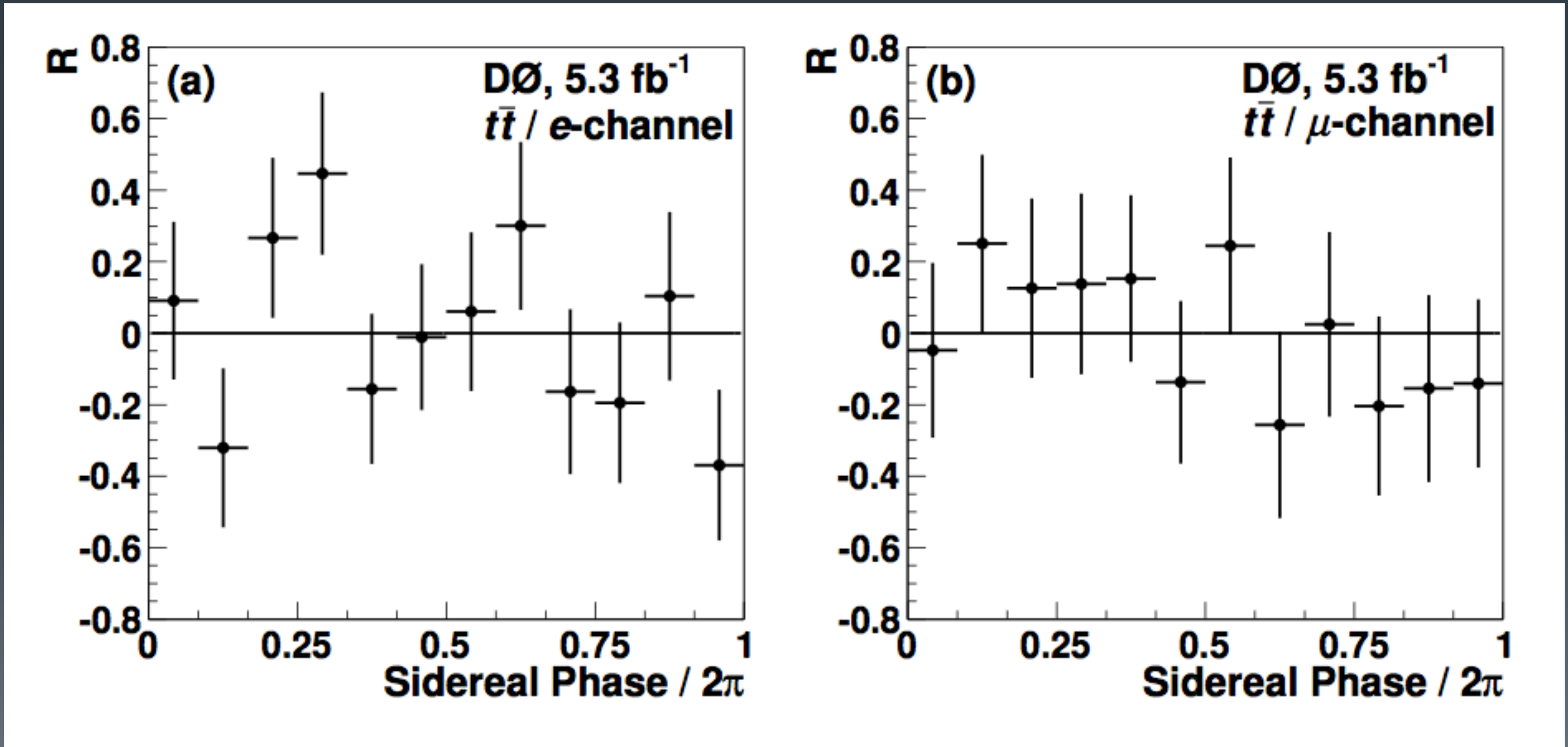
	ALEPH	OPAL
$\Delta\sigma_{q\bar{q}}/\langle\sigma_{q\bar{q}}\rangle$	0.78%, Tab. 4 of Ref. [16]	2.2% , Tab. 2 of Ref.[19]
$\Delta R_b/R_b$	9.2%, Sec. 7.1 of Ref. [16]	13.5%, Sec. 2.2 of Ref. [19]
$\Delta R_c/R_c$	10.8% Sec. 7.2 of Ref. [16]	-
$\|c^b_{ZZ}\|$	< 0.35	< 0.46
$\|c^c_{ZZ}\|$	< 0.4	-

Table 3: Conservative bounds on LV coupling of c- and b-quarks.

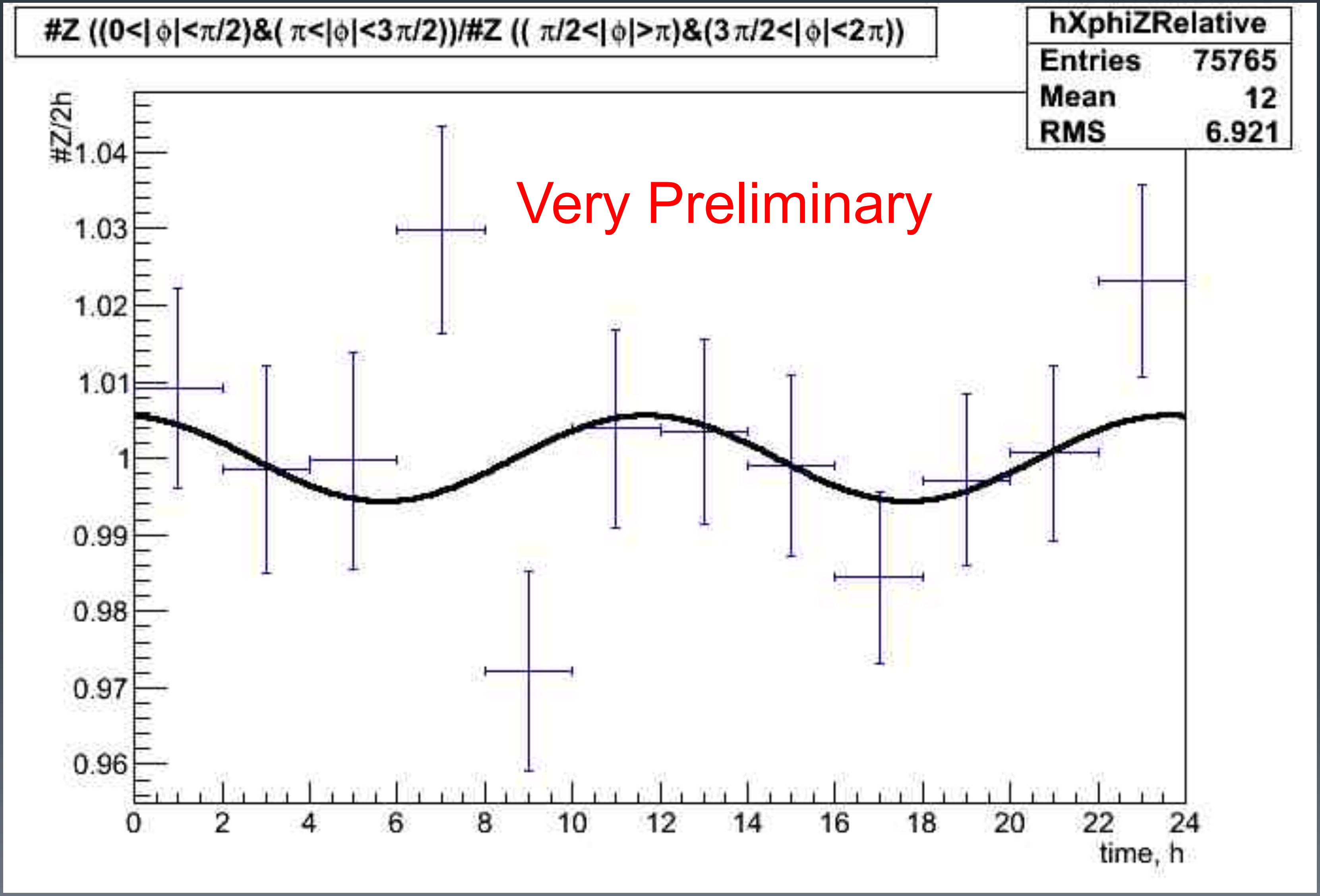
Current Limits

From Tevatron ttbar

arXiv:1203.6106v1 [hep-ex] 27 Mar 2012



CMS at 8 TeV


#Z ((0<|ϕ|<π/2)&(π<|ϕ|<3π/2))/#Z ((π/2<|ϕ|>π)&(3π/2<|ϕ|<2π))
hXphiZRelative
Entries 75765
Mean 12
RMS 6.921
Very Preliminary
#Z/2h
1.04
1.03
1.02
1.01
1
0.99
0.98
0.97
0.96
0
2
4
6
8
10
12
14
16
18
20
22
24
time, h

Outlook

- The LR Symmetry and Lorenz invariance are very interesting to check Space Anisotropy
- Limited parameters from LEP Data
- LHC can constrain parameters of SME with LV on level $\sim 10^{-6}$
- Future Lepton Colliders look beyond SM