Unparticle Self-Interactions and Their Collider Implications

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[Feng,Rajaraman,HT, PRD77 (2008) 075007]

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Motivation

- Unparticles
  - Phenomenology of conformal field theories at colliders
- Unparticle self-interactions
  - Strong interactions calculable using CFT
  - No theoretical upper bounds on 3-point correlation function constant
- Spectacular signals at LHC e.g. $pp \to \gamma\gamma\gamma\gamma$
  - Negligible SM backgrounds
  - Rate not reduced with additional production of every high p_T particles

Unparticles

[Georgi '07]

- Hidden sector coupled to SM through $\frac{O_{\rm UV}\, O_{\rm SM}}{M^{d_{\rm UV}+n-4}}$
- Unparticle sector becomes conformal at Λ_U, coupling to SM preserves conformality in IR
- Operator $O_{\rm UV}$, dimension $d_{\rm UV} = 1, 2, ... \rightarrow$ operator O, dim. d
- Unparticle interactions
  - With SM fields: $\frac{e\, c_4^f}{\Lambda_4^d}\, OH\, \overline{f} f$, $\frac{e\, c_4^f}{\Lambda_4^d}\, \partial^\mu O\, \overline{f} \gamma_\mu f$, $\frac{c_4^F}{{\Lambda_4}^d}\, OF^2$, ...
  - With unparticles: $\langle 0|OOO|0\rangle$?

Unparticle 3-Point Correlation Function

Conformal invariacne fixes up to a constant

$$\langle 0|\, O(x)\, O(y)\, O^{\dagger}(0)\, |0\rangle \propto \left(\frac{1}{|x-y|}\right)^{d} \left(\frac{1}{|x|}\right)^{d} \left(\frac{1}{|y|}\right)^{d}$$

In momentum space

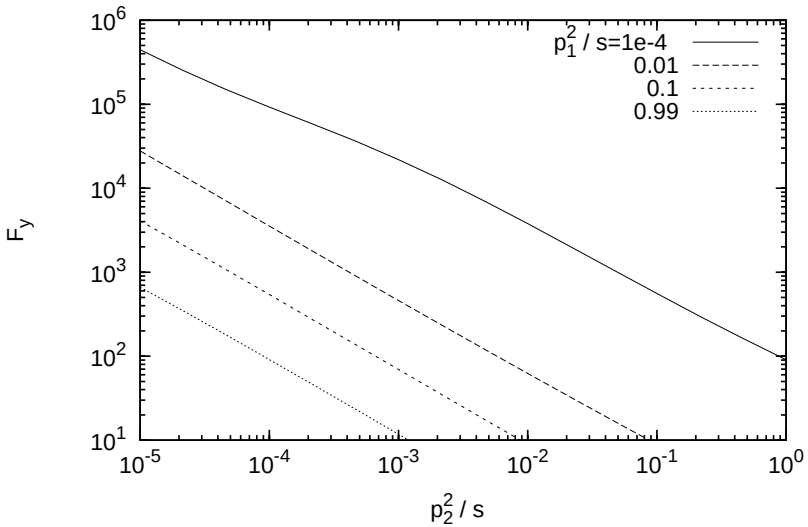
$$\langle 0|\, O(p_1)\, O(p_2)\, O^{\dagger}(p_1+p_2)|0\rangle =$$

$$C_d \int \frac{d^4q}{(2\pi)^4} \left[-q^2 - i\epsilon\right]^{\frac{d}{2}-2} \left[-(p_1-q)^2 - i\epsilon\right]^{\frac{d}{2}-2} \left[-(p_2+q)^2 - i\epsilon\right]^{\frac{d}{2}-2}$$

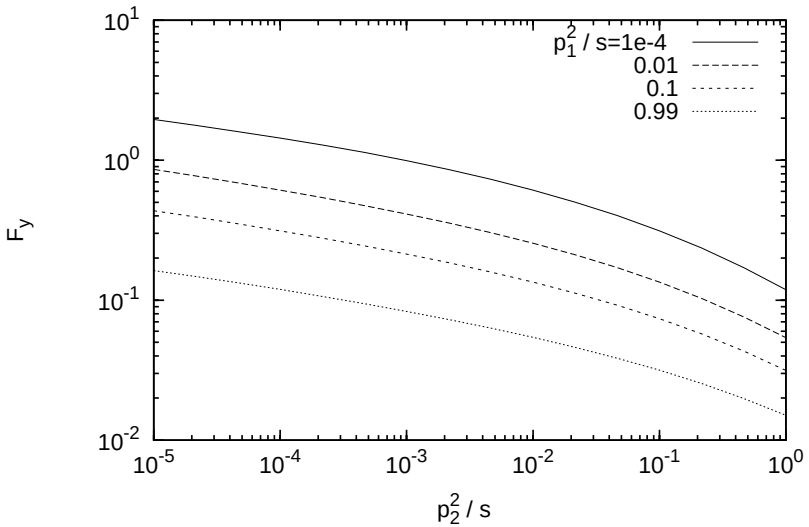
$$\propto C_d\, s^{\frac{3d}{2}-4}\, F_y\left(\frac{p_1^2}{(p_1+p_2)^2}, \frac{p_2^2}{(p_1+p_2)^2}; d\right)$$

Unparticle 3-Point Correlation Function (II)

$d = 1.1$

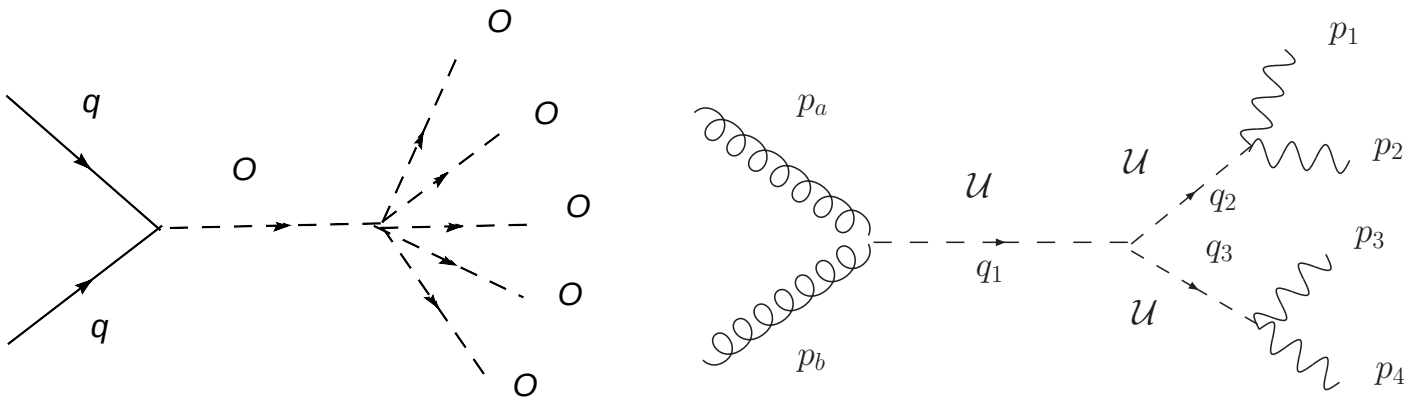


$d = 1.9$



Signatures from Multi Unparticle Interactions at LHC

- Multi-unparticle production unsuppressed
- Many possibilities for detection: $\gamma\gamma ZZ, \gamma\gamma\mu\mu, \gamma\gamma ee, \gamma\gamma\gamma\gamma, ...$



- Event rates $\propto C_d^2 \Lambda_4^{-6d}$, only constrained experimentally

Unparticle Four Photon Production Cross Section

- At parton level

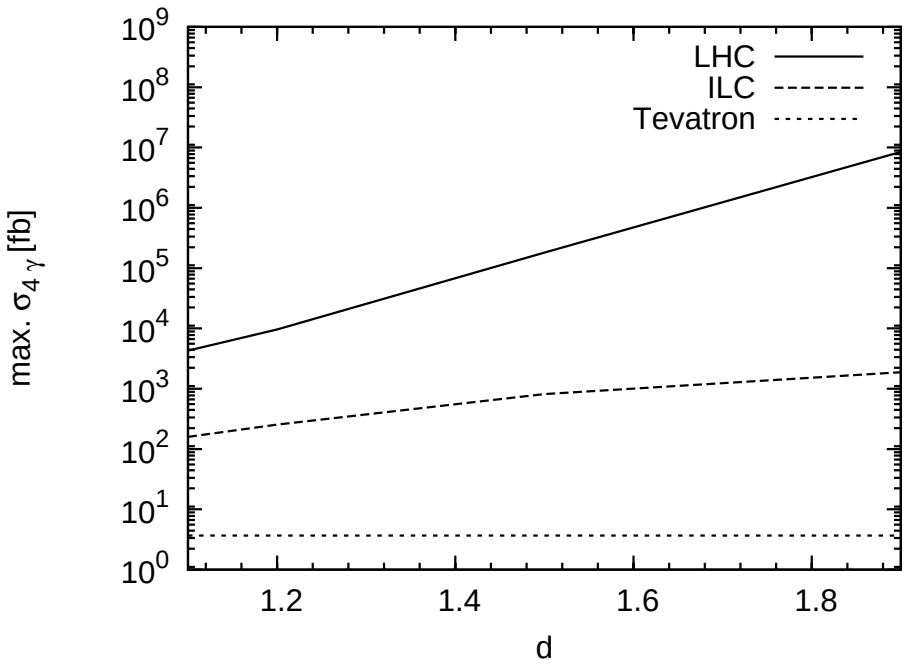
$$\hat{\sigma}_{gg\to 4\gamma}(\hat{s}) = f_d^g \, C_d^2 \left(\frac{\hat{s}}{\Lambda_4}^2\right)^{3d} \frac{1}{(\hat{s}/[\mathrm{GeV}^2]} \; [\mathrm{fb}]$$

$$\hat{\sigma}_{q\bar{q}\to 4\gamma}(\hat{s}) = f_d^q \, C_d^2 \left(\frac{\hat{s}}{\Lambda_4^2}\right)^{3d} \left(\frac{v^2}{s}\right) \frac{1}{(\hat{s}/[\mathrm{GeV}^2]} \; [\mathrm{fb}]$$

- D0 Collaboration search for fermiophobic Higgs in $3\gamma + X$
  - Kinematics: $|\eta_i| < 1.1$, $p_T^{1,2,3,4} > 30, 20, 15, 15$ GeV
  - SM background: diphoton production + ISR photons
- No excess events at Tevatron $\Rightarrow$ 95% CL upper bounds on

$$C_d^2 \left(\frac{1}{\Lambda_4 \; [\mathrm{TeV}]}\right)^{6d} \leq \frac{3.04}{0.83 \; \mathrm{fb}^{-1} \; \sigma_{4\gamma}^{\mathrm{ref}}}$$

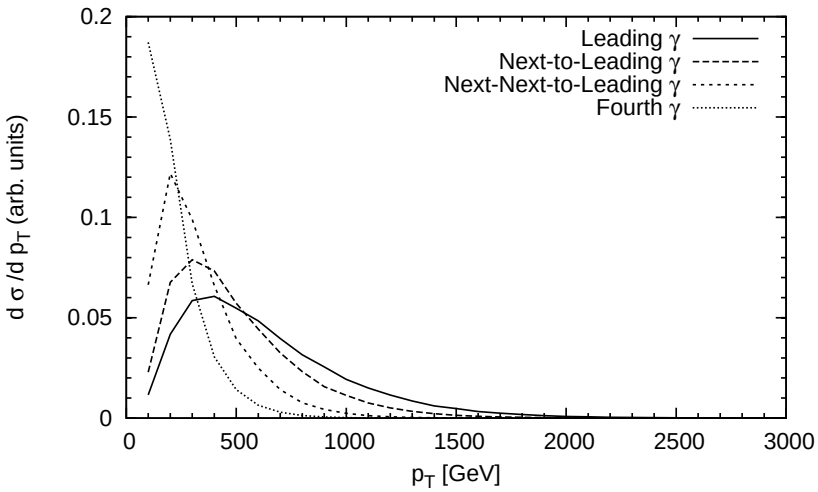
Maximal 4γ Cross Section at LHC and ILC



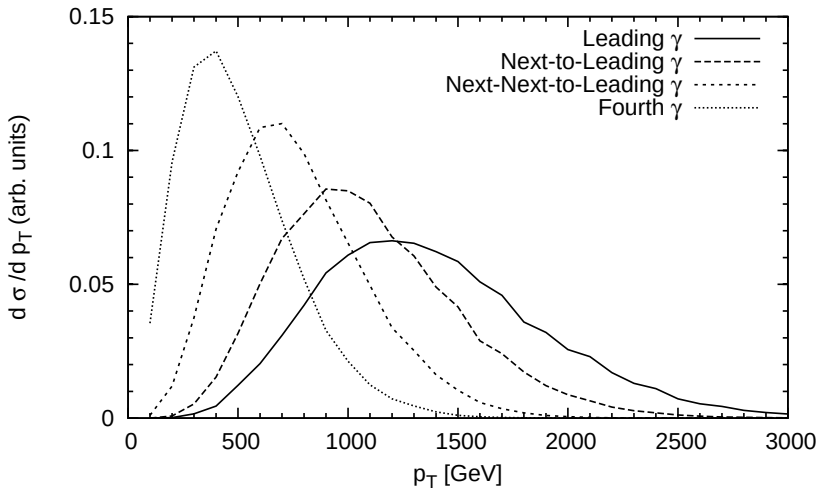
- From $0.83\ \mathrm{fb}^{-1} \cdot \sigma_{4\gamma}^{\mathrm{Tevatron}}\ [\mathrm{fb}] \leq 3.04$ events
- Independent of unknown unparticle scale Λ_4

MC Simulated p_T-Ordered Photon Spectrum at LHC

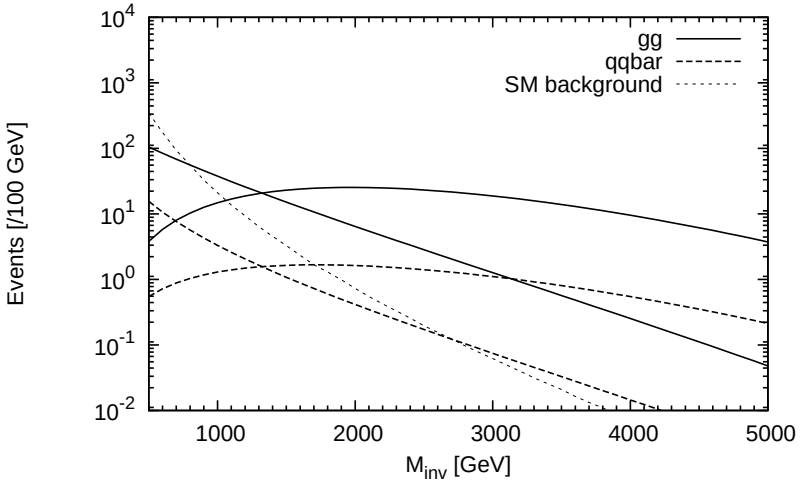
$d = 1.1$

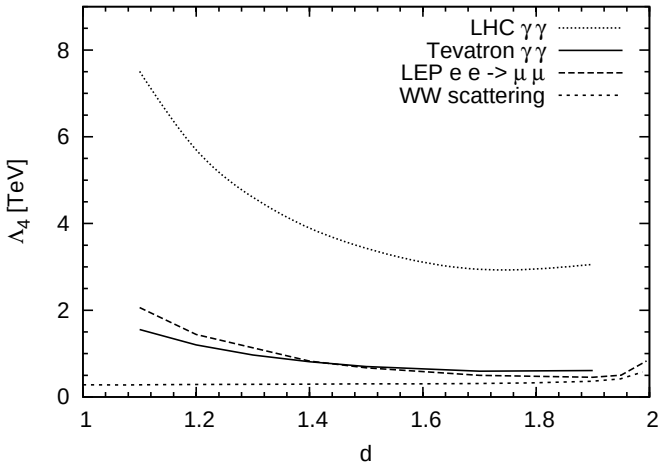


$d = 1.9$



Diphoton Production and Upper Bounds on Λ_4





[Feng,Rajaraman,Tu '07]

Summary

- Phenomenoligcal study of CFT at colliders
- Unparticle 3-point correlation function from conformal invariance
- Spectaculous events from multi-unparticle production
- Non-observation of high p_T four-photon events by D0 Collaboration at Tevatron $\Rightarrow$ maximum cross section at LHC and ILC