Di-photon production at the LHC at next-to-leading order in the Unparticle scenario

Anurag Tripathi

Harish-Chandra Research Institute
Allahabad, India

Collaborators

V. Ravindran (HRI)

P. Mathews (SINP)

M.C. Kumar (SINP)

The LHC Search

- The Higgs Boson
- Physics beyond the Standard Model

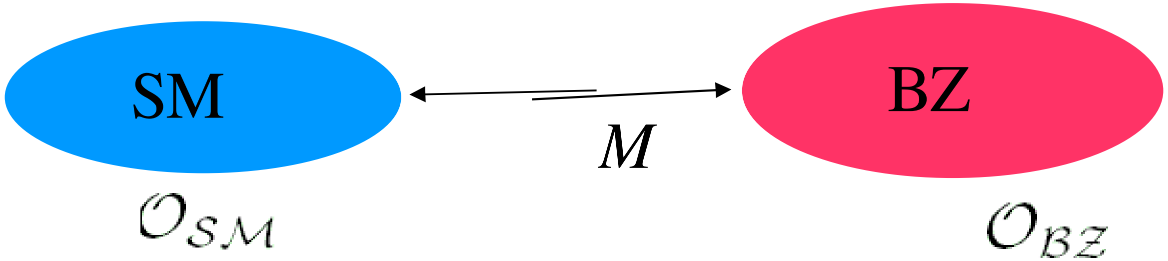
New Physics

- Super Symmetry
- Large extra-dimensions
- Unparticles
- Something more exotic

Unparticle Scenario

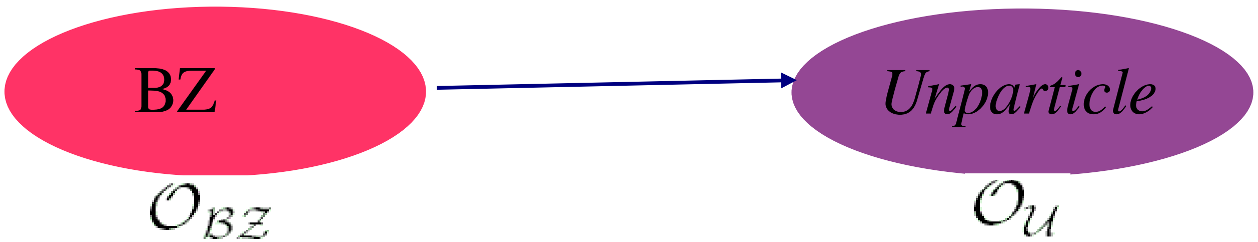
- Motivated by Banks and Zaks — *Nucl. Phys.* **B196** (1982) 189.
- Scheme by Georgi — Phys. Rev. Lett. **98** (2007) 221601.

At Very High Energy :



BZ sector has a nontrivial IR fixed point

Below $\Lambda_{\mathcal{U}}$ scale invariance emerges



Scale invariant degrees of freedom are termed as **unparticles.**

Effective field theory

Below M Below Λ_U

$$\frac{1}{M^k}\mathcal{O}_{SM}\mathcal{O}_{BZ} \xrightarrow{\text{matches to}} C_u \frac{\Lambda^{d_{BZ}-d_u}}{M^k}\mathcal{O}_{SM}\mathcal{O}_U$$

$$d_{BZ} \rightarrow \text{ mass dimension of } \mathcal{O}_{BZ}$$

$$d_u \rightarrow \text{ scaling dimension of } \mathcal{O}_U$$

Scale invariance fixes two point Green's functions

Detailed knowledge of BZ sector in NOT required

Spectral density

(scalar unparticle operator)

$$|\langle O|\mathcal{O}_U(0)|P\rangle|^2\rho(P^2) = A_{d_u}(\mathcal{O}_U)\theta(P^0)\theta(P^2)\underbrace{(P^2)^{d_u-2}}$$

Propagator

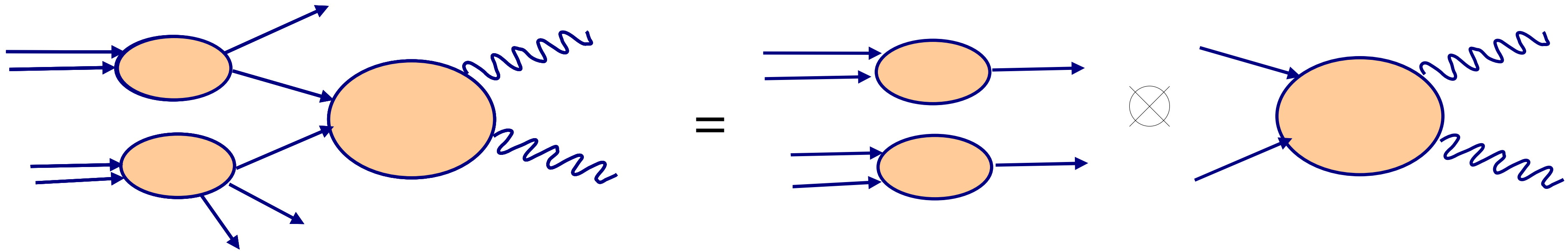
Georgi
Phys. Rev. Lett. **98** (2007) 221601.

$$\int d^4x e^{iP.x}\langle 0|T(\mathcal{O}_U(x)\mathcal{O}_U(0)|0\rangle$$

$$= \frac{A_{d_u}(\mathcal{O}_U)}{2\pi}\pi\frac{[e^{-i\pi}(P^2+i\epsilon)]^{d_u-2}}{sin(d_u\pi)}$$

Cheung et al
Phys. Rev. Lett. **98** (2007) 221601.

Direct di-photon production ($\gamma\gamma$) at The LHC



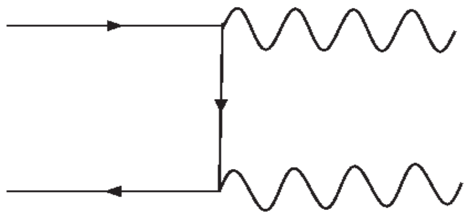
Hadronic cross section

Parton dist. functions
$f_{a/H}(x, \mu_F)$

Partonic cross section

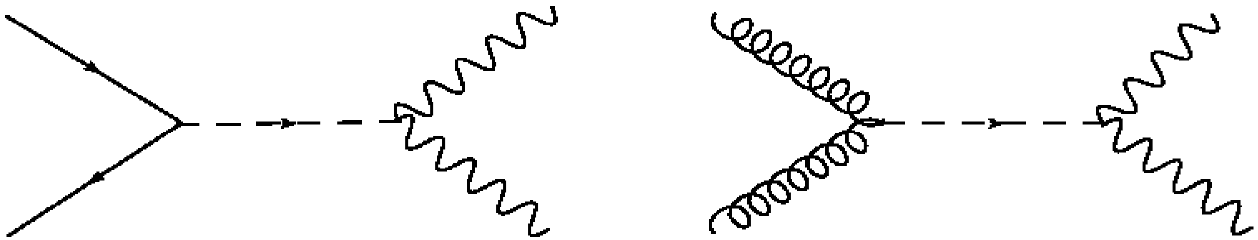
Leading order :

SM



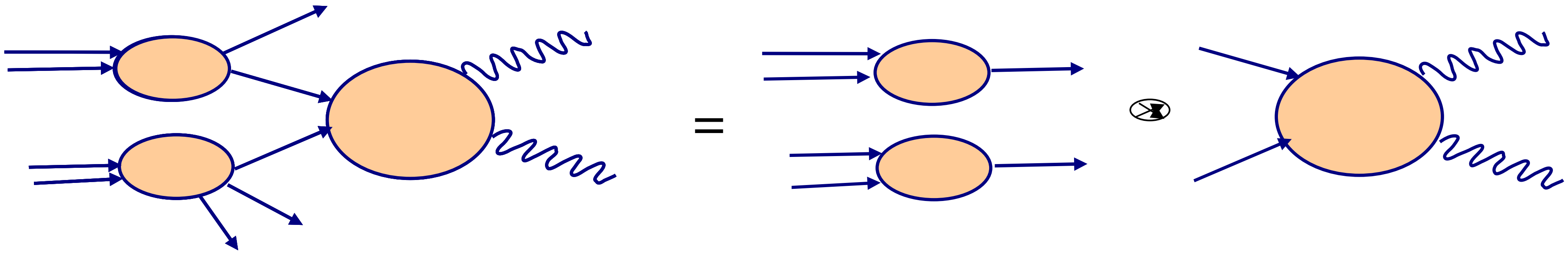
Interaction term: $\frac{\lambda_t}{\Lambda_{\mathcal{U}}^{d_{\mathcal{U}}}} T_{\mu\nu} \, O_{\mathcal{U}}^{\mu\nu}$

Unp



- Unparticles couple to all partons with same strength
- We consider only spin-2 unparticles
- Coupling through energy momentum tensor

Di-photon production: PP ---> gamma gamma



Hadronic cross section = Parton dist. functions $f_{a/H}(x, \mu_F)$ ⊗ Partonic cross section

$f_{a/H}(x, \mu_F)$ Depends on μ_F.

μ_F is arbitraty.

Cross section depends on μ_F

α_s is large

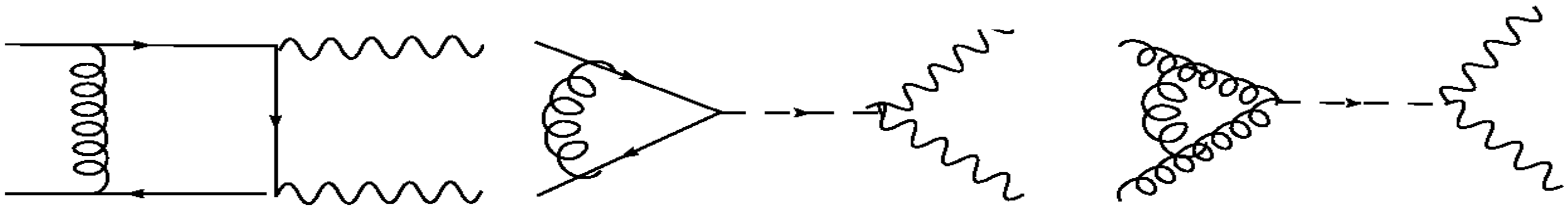
$\alpha_s(M_Z) = 0.118$

⇉ Higher order QCD corrections can be important

higher order cross section ⟶ μ_F dependence ↓

Next-to-leading order

Virtual corrections



Singularities from loop integrals

UV

Originate from high energy degrees of freedom

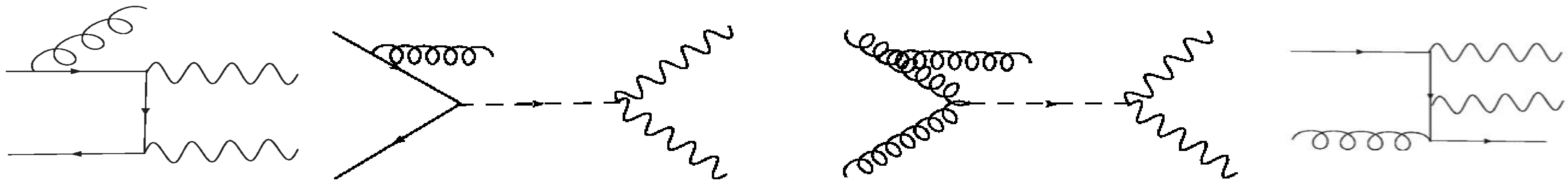
Soft

appears when the loop momentum goes to zero

Collinear

appears when the loop momentum becomes collinear
to quark or gluon lines.

Real emission



Singularities from phase space integrals

Soft

when gluon momentum goes to zero

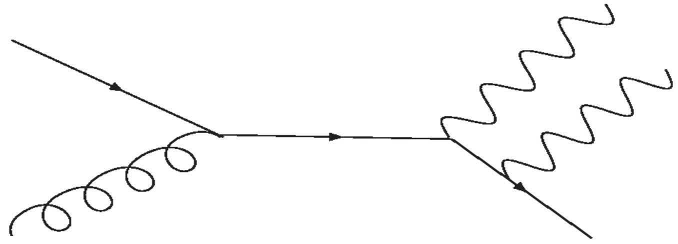
Collinear

when two massless partons become collinear

Soft singularities always cancel
between real and virtual contributions

Collinear singularities do not cancel completely
absorbed (factorized) in bare pdf's

Final state QED singularity



photon collinear to quark gives QED singularilty

can be absorbed into fragmentation functions,
however frag. functions are not known preceisely

Alternatively,
can be suppressed using smooth-cone-isolation,
also removes fragmentation photons

Smooth-cone isolation

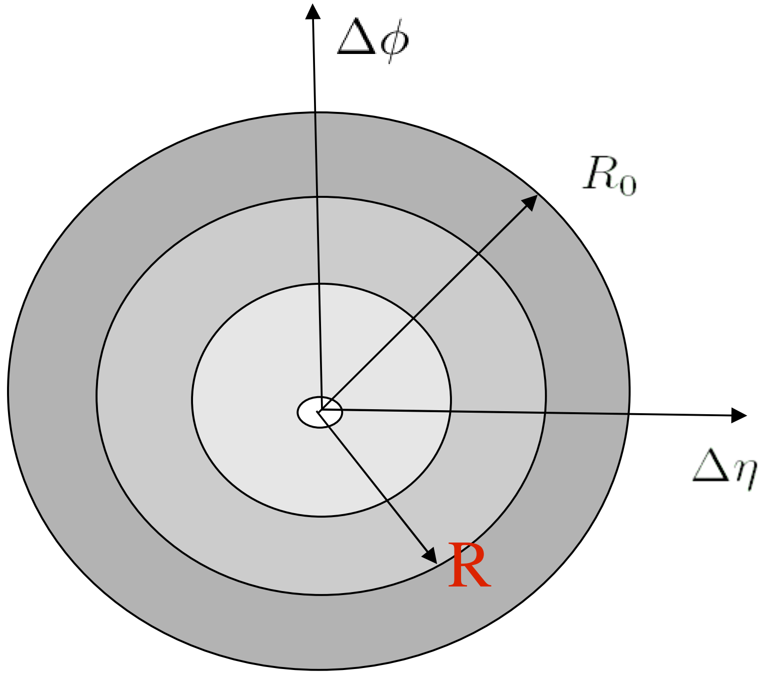
S. Frixione, Phys. Lett. B **429** (1998) 369.

$$R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

$$E_T(R) < E_T^{iso} \left(\frac{1 - cos R}{1 - cos R_0} \right)^2$$

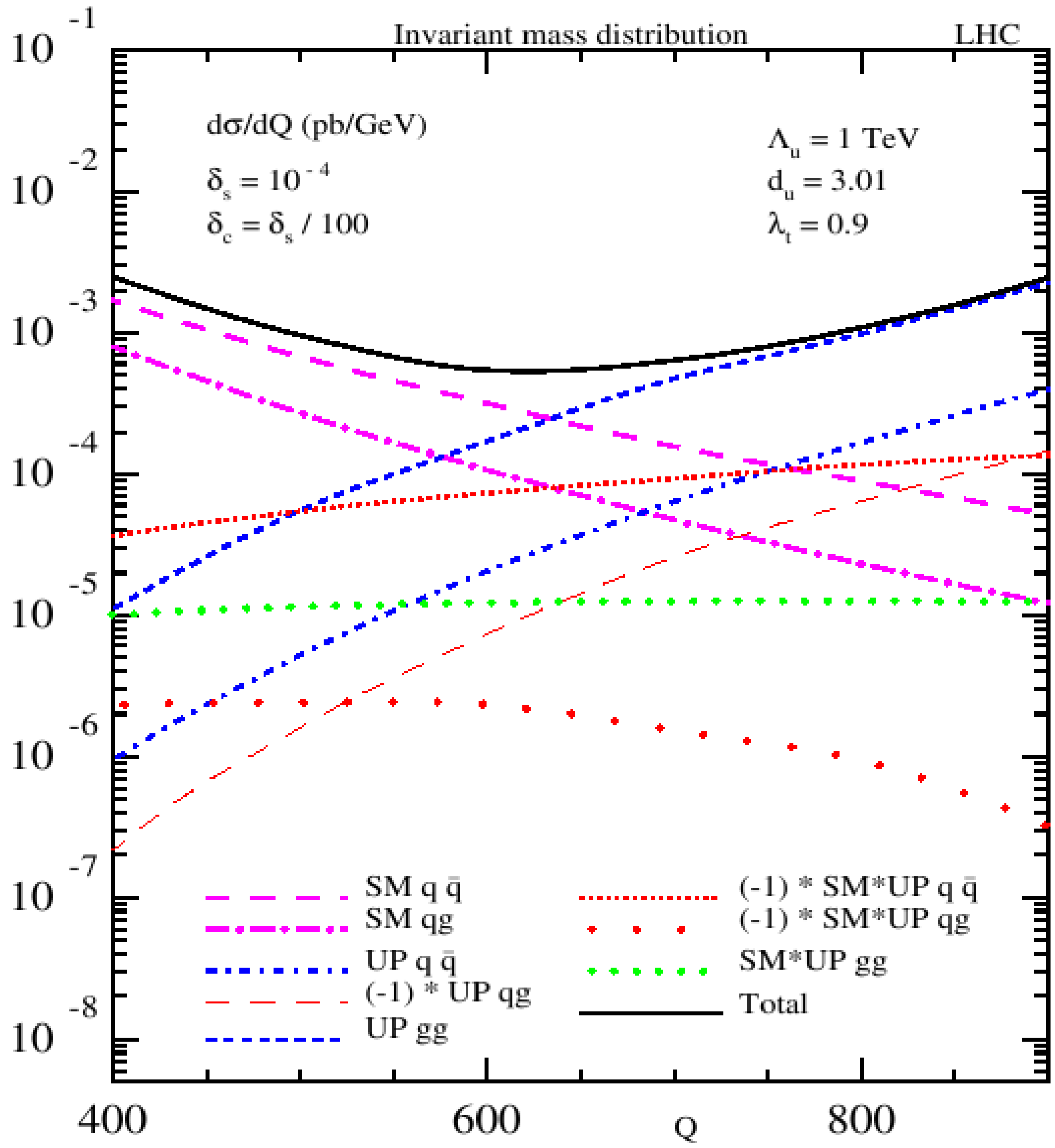
$$E_T^{iso} = 15 \; GeV$$

$$R_0 = 0.4$$



Other cuts (ATLAS)

$p_T^\gamma > 40$ (25) GeV for harder (softer) photon, $|\eta_\gamma| < 2.5$ for each photon.



Kumar et. al PRD 77: 079901,2008

Kumar et. al arXiv: 0804.4054

$$Q^2 = (p_{\gamma_1} + p_{\gamma_2})^2$$

Below 600 GeV SM is dominant.

Above 600 GeV *Unp.* contribution is dominant

PDF's
LO : CTEQ6L
NLO: CTEQ6M

Subprocesses contributions in SM and Unparticle model in the invariant mass distribution at NLO for $400 < Q < 900$ GeV.

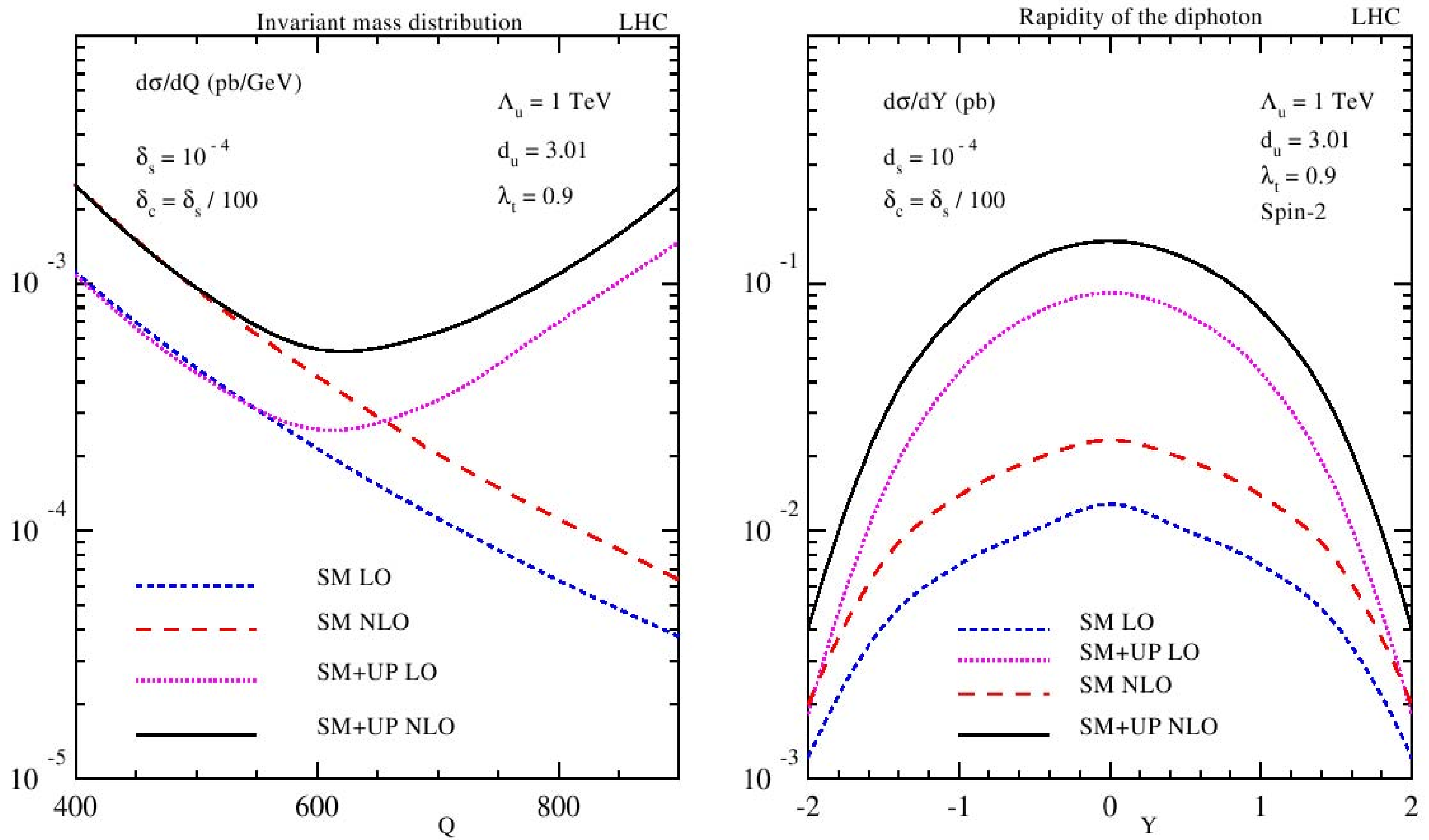


Figure 3: Plots showing invariant mass (left panel) and rapidity (right panel) distributions of the di-photon system with $d_{\mathcal{U}} = 3.01$, $\Lambda_{\mathcal{U}} = 1$ TeV and $\lambda_t = 0.9$. For rapidity distribution Q is integrated in the range 600 GeV $< Q < 0.9\Lambda_{\mathcal{U}}$.

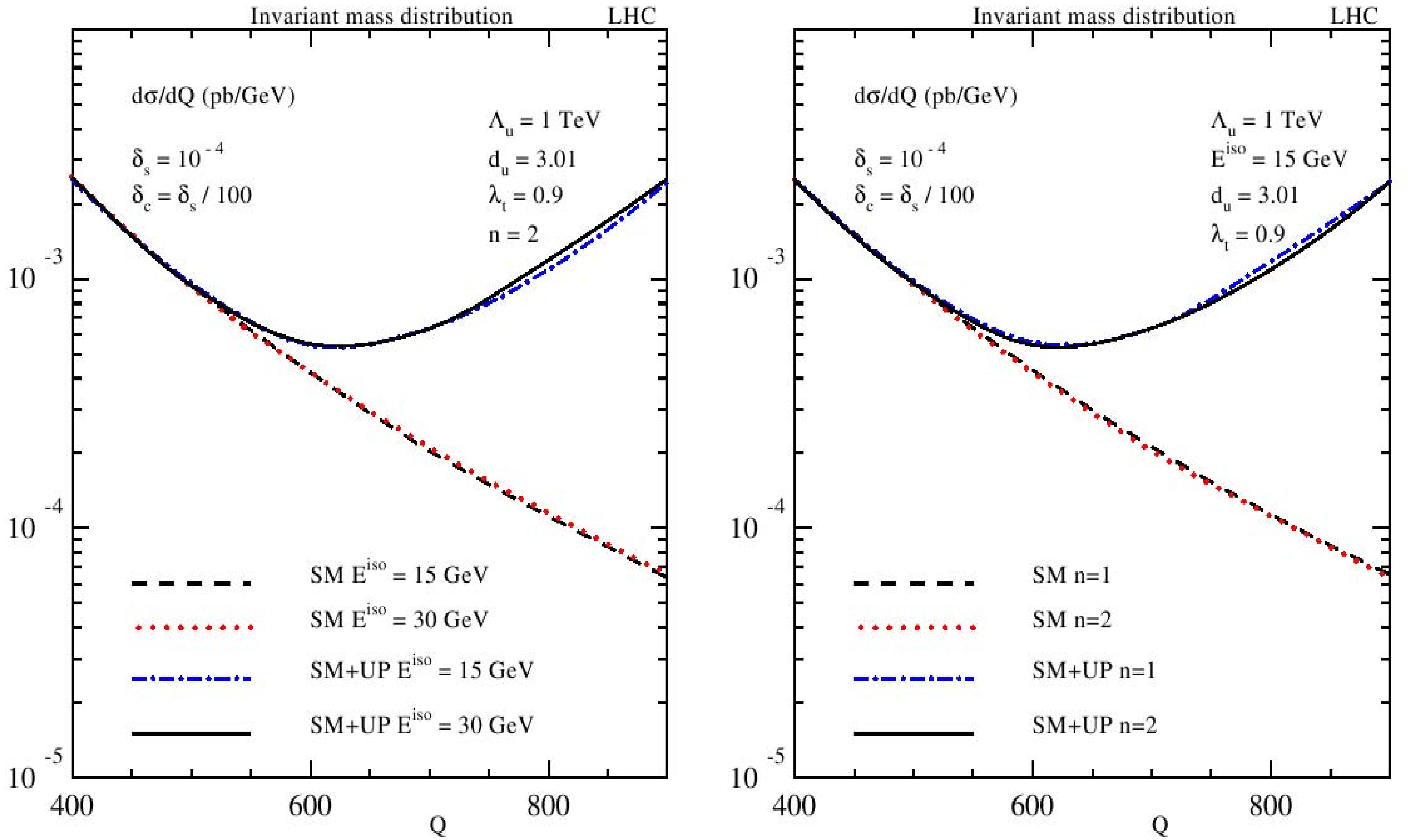


Figure 4: Dependence on isolation parameters E_T^{iso} (left) and n (right) is shown in invariant mass distribution for the range $400 < Q < 900$ GeV.

Conclusions

•Unparticles contribute significantly at higher energies to diphoton production

•Next-to-leading order contributions are large

•Cross-sections show very mild dependence on the smooth-cone isolation parameters

Thank You !