Using Integral Dispersion Relations to Extend the LHC Reach for New Physics

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Overview

1. Brief derivation of IDRs
2. TOTEM experiment
3. Three ways of modeling new physics
4. Results: measurable effects

Some necessary formulas

1. Cauchy's integral formula

$$f(z') = \frac{1}{2\pi i} \oint_{\partial A} \frac{f(z)}{z - z'} dz$$

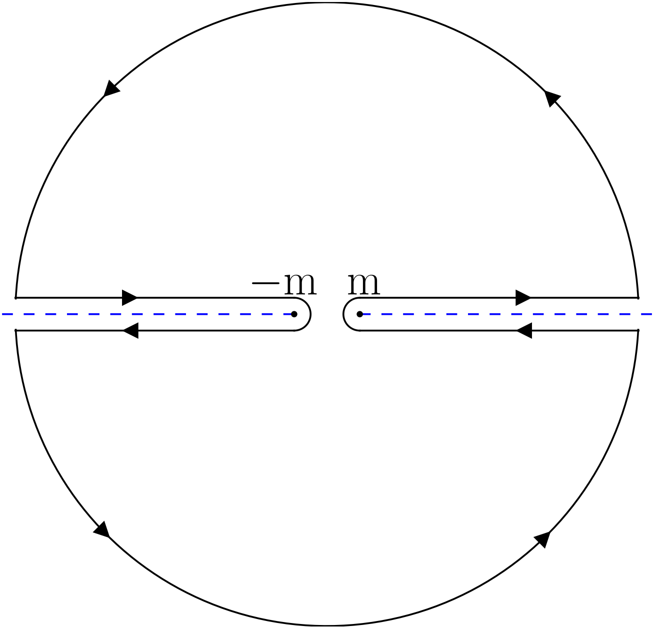
2. The optical theorem

$$\sigma_{tot} = \frac{4\pi}{p} \Im f(\theta = 0)$$

3. Definitions

$$\rho(E) \equiv \frac{\Re f(E, t=0)}{\Im f(E, t=0)} \qquad E \equiv \frac{s-u}{4m}$$

Integration contour



Integral Dispersion Relations

$$\rho_{pp}(E)\sigma_{pp}(E) = \frac{4\pi}{p}\Re f(0) + \frac{E}{p\pi}\mathcal{P}\int_m^\infty dE'\,\frac{p'}{E'}\left[\frac{\sigma_{pp}(E')}{E'-E} - \frac{\sigma_{p\bar{p}}(E')}{E'+E}\right]$$

IDR $\Rightarrow$ model dependent calculation of ρ.

Comparing ρ

$$16\pi \left.\frac{d\sigma}{dt}\right|_{t=0} = (\rho^2 + 1)\sigma_{tot}^2$$

$\Rightarrow$ model independent calculation of ρ.

SM parametrization

1. Froissart bound says $\sigma \leq C \log^2(E/E_0)$ asymptotically for some constants
2. Pomeranchuk theorem (c_4) says that $\sigma_{pp} - \sigma_{p\bar{p}} \to 0$ as $E \to \infty$
3. Standard parametrization:

$$\sigma_{pp,p\bar{p}}(E) = c_0 + c_1 \log(E/m) + c_2 \log^2(E/m) + \\ + c_3(E/m)^{-\frac{1}{2}} \pm c_4(E/m)^{\alpha-1}$$

Experiment

1. TOTEM: $\rho = 0.145$ at $\sqrt{s} = 7$ TeV (large errors)
2. SM Prediction: $\rho = 0.1345$ at $\sqrt{s} = 7$ TeV
3. "Signal": $(\rho - \rho_{\rm SM})/\rho_{\rm SM} = 0.0781$ (a 0.1σ "signal")

SM *pp* cross section and three simple modifications

We want to retain the $\log^2 s$ growth asymptotically

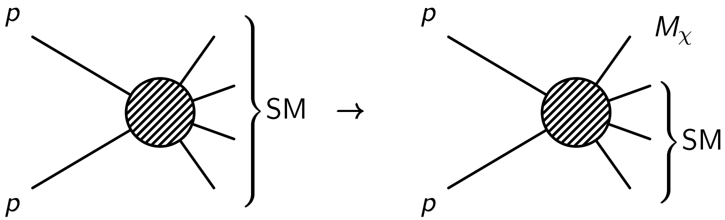
$$\sigma(s) = \sigma_{SM}(s)[1 + h_i(s)]\,.$$

The first modification is a simple step function:

$$h_1(s) = d\Theta(s - s_{thr})\,.$$

More physical modifications to the *pp* cross section

SUSY contributions are too small $\mathcal{O}(10^{-9})$.
RPV SUSY could provide a much larger effect.



More physical modifications to the *pp* cross section

We reduce the cross section by a phase space ratio given by

$$\sqrt{\frac{\lambda(\hat{s}, M_\chi^2, 0)}{\lambda(\hat{s}, 0, 0)}} = 1 - \frac{M_\chi^2}{\hat{s}}$$

We integrate this in terms of the parton distribution functions giving a modification of

$$h_2(s, M_\chi) = z \sum_{i,j} \int_{x_1 x_2 > M_\chi^2/s} dx_1 dx_2 \times f_i(x_1, M_\chi) f_j(x_2, M_\chi) x_1 x_2 \left(1 - \frac{M_\chi^2}{\hat{s}}\right)$$

Where $z = \sigma_{inel}/\sigma_{tot} \sim 0.7$.

Yet another *pp* cross section modification

We cut final states into two blocks by pseudorapidity and we let M_X be the mass of the more massive one. Let $\xi \equiv M_X^2/s$.

$$\frac{d\sigma}{d\xi} = \frac{1+\xi}{\xi^{1+\epsilon}} \qquad \epsilon \sim 0.08$$

To modify the *pp* cross section the integration bounds change.

$$h_3(s) = z\frac{1-2\epsilon+(\epsilon-1)\xi_\chi^{-\epsilon}+\epsilon\xi_\chi^{1-\epsilon}}{1-2\epsilon+(\epsilon-1)\xi_p^{-\epsilon}+\epsilon\xi_p^{1-\epsilon}}\Theta(1-\xi_\chi)$$

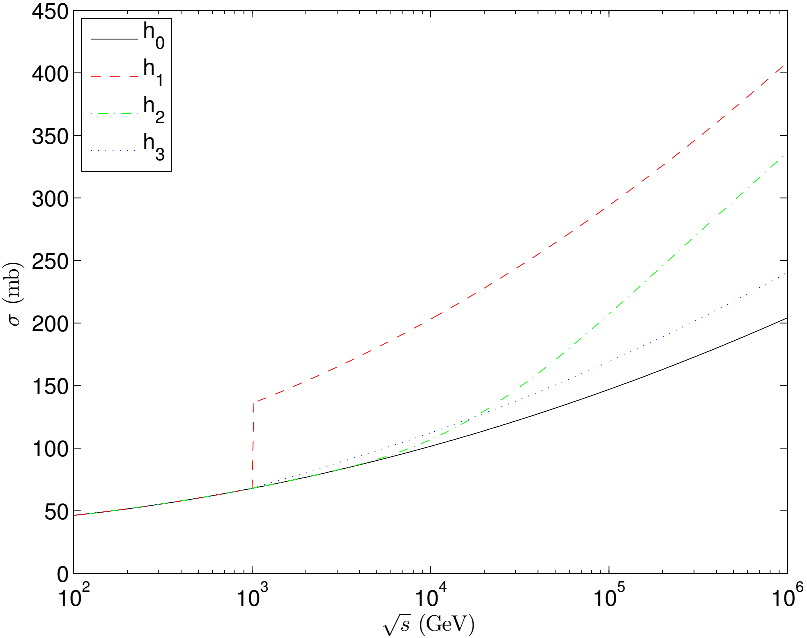
Exotic models

Other exotic models may give rise to significant σ_{pp} increases:

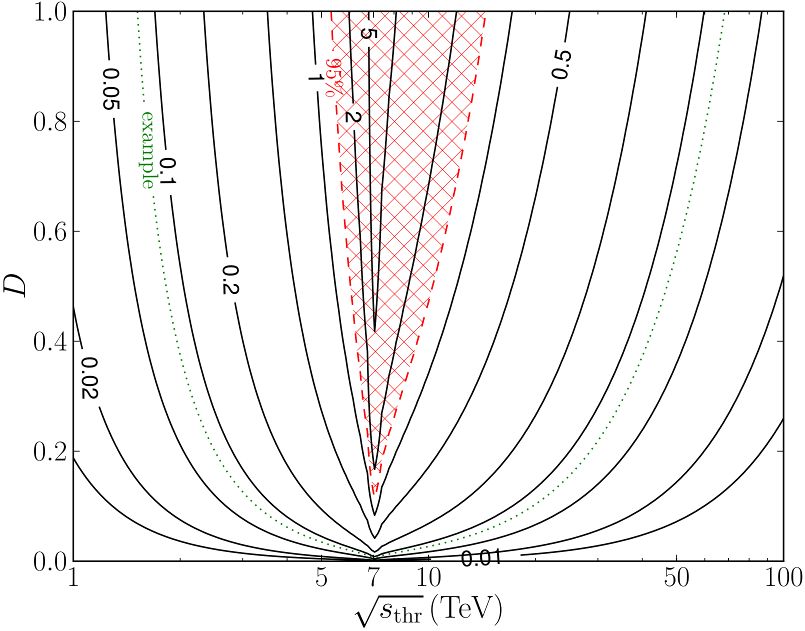
1. Kaluza-Klein modes
2. Weak scale gravity

These can be generally described as a step function, h_1, at the relevant energy with the magnitude of the step large - up to a factor of ten.

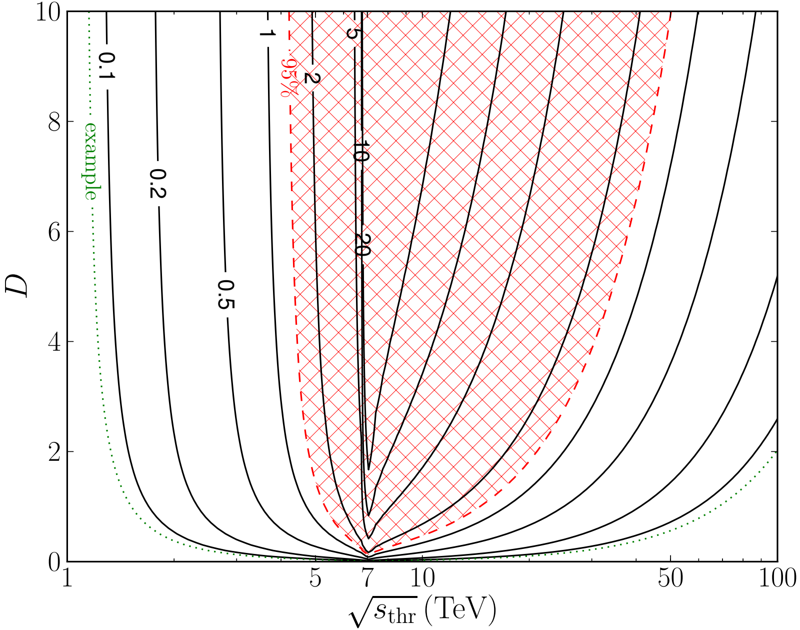
pp cross section modifications



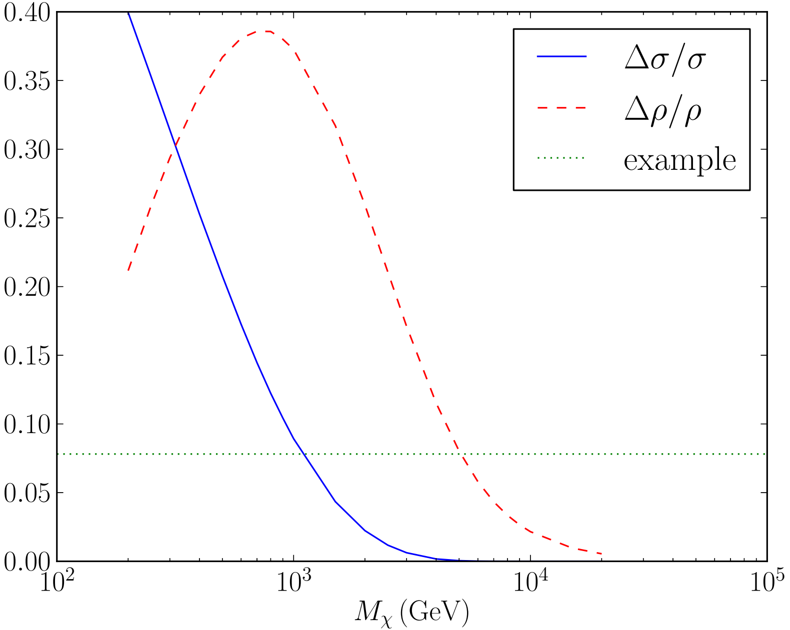
Results: h_1 step function



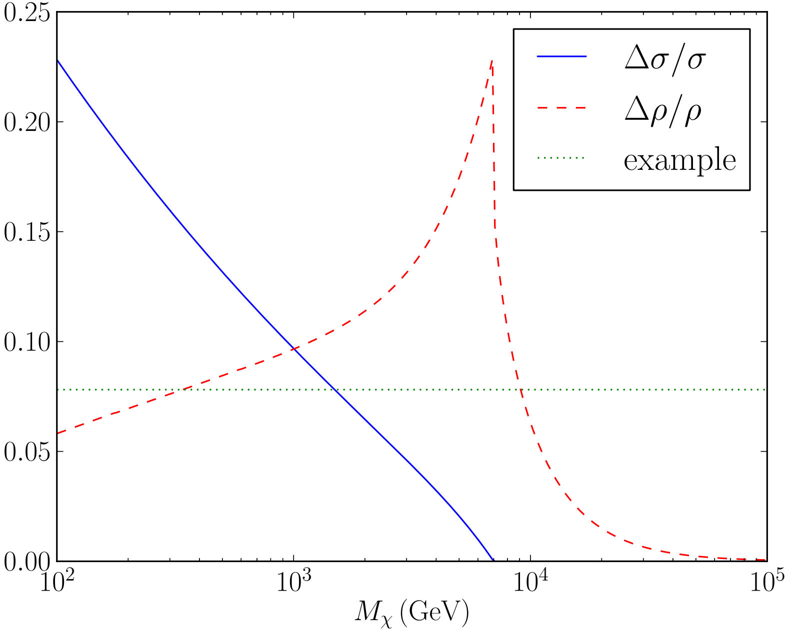
Results: h_1 step function to large d



Results: h_2 perturbative approach



Results: h_3 non-perturbative approach



Discussion and conlusions

1. IDRs can be used to detect large changes in σ_{pp}.
2. Perturbative models do not allow for large enough modifications.
3. A non-perturbative approach is more successful in a narrow region.

Other work (in progress): UHECR anisotropy

UHECR $\Rightarrow E_{CR} \gtrsim 50$ EeV $= 5 \times 10^{19}$ eV.
Things we don't know:

1. Composition: If UHECR are p, Fe, something inbetween.
2. Acceleration: How the flux we see is accelerated in astrophysical phenomena.
3. Sources: Where exactly do they come from.
4. Magnetic fields: How much UHECRs are bent inbetween galaxies and in our own galaxy.
5. Extensive air showers: How the showers propagate in the atmosphere.

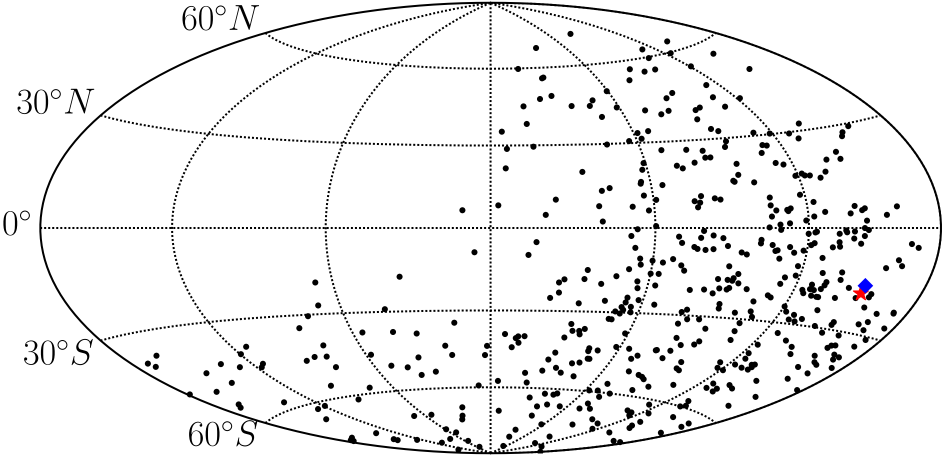
Backup: Non-perturbative cross section reproduces Froissart bound when properly expanded

We noted that the cross section function that goes into the modification h_3 rises like $\log^2 s$ in the appropriate limit:

$$\sigma \propto 1 - \xi_p - \log \xi_p + \left(1 - \xi_p + \xi_p \log \xi_p + \frac{1}{2} \log^2 \xi_p\right) \epsilon + \mathcal{O}(\epsilon^2)$$

with higher order ϵ terms resulting in higher orders of $\log s$ following the above pattern.

Other work (in progress): UHECR anisotropy



Other work (in progress): UHECR anisotropy

1. Several partial-sky experiments look at the sky: HiRes (Utah) and Pierre Auger Observatory (Argentina).
2. There is no (significant) evidence of anisotropy from these experiments.
3. Reconstructing anisotropies with partial-sky coverage is non-trivial.
4. One (of several) proposed new experiments is EUSO on the ISS to provide near uniform full-sky coverage.

Other work (in progress): UHECR anisotropy

Parameterize anisotropies in spherical harmonics and the power spectrum,

$$I(\Omega) = \sum_{\ell=0}^{\infty} \sum_{m=-\ell}^{\ell} a_\ell^m Y_\ell^m(\Omega)$$

$$C_\ell = \frac{1}{2\ell+1} \sum_{m=-\ell}^{\ell} |a_\ell^m|^2$$

See 1401.5757 (conference proceedings) for an introduction to our approaches.