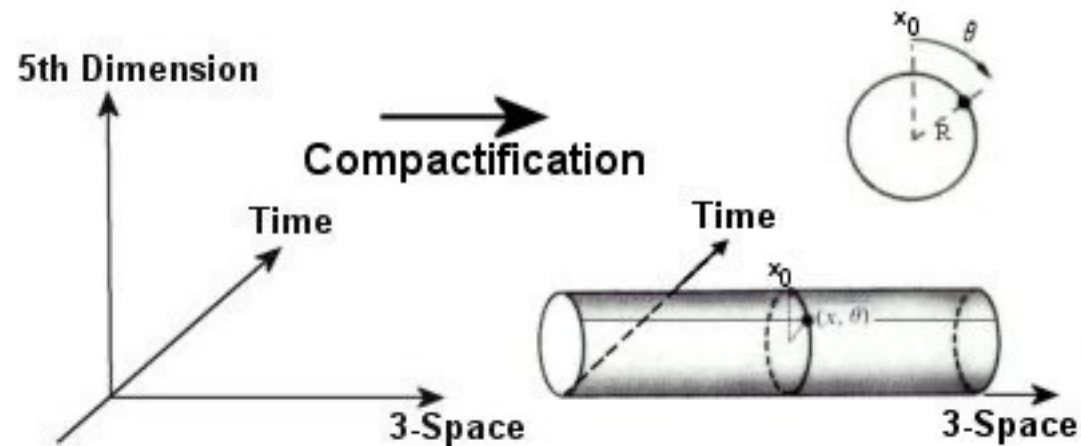


LHC Bounds on MUED After Run 2 a.k.a. *MUEDs and Where To Find Them*

Marvin M. Flores, Jong Soo Kim, Krzysztof Rolbiecki, Roberto Ruiz de Austri Bazan

Extending SM by adding dimensions

- Simplest case is 5D
- Novel features emerge when theory is reduced back to 4D



Minimal Universal Extra Dimensions

- With a massless 5D scalar field, our action becomes

$$\mathcal{S}_{5D} = \int d^5x \partial^M \varphi \partial_M \varphi$$

- Set the extra dimension $x^4 = y$, defining a circle with $y \equiv y + 2\pi r$
- Periodicity allows a Fourier expansion of the scalar fields

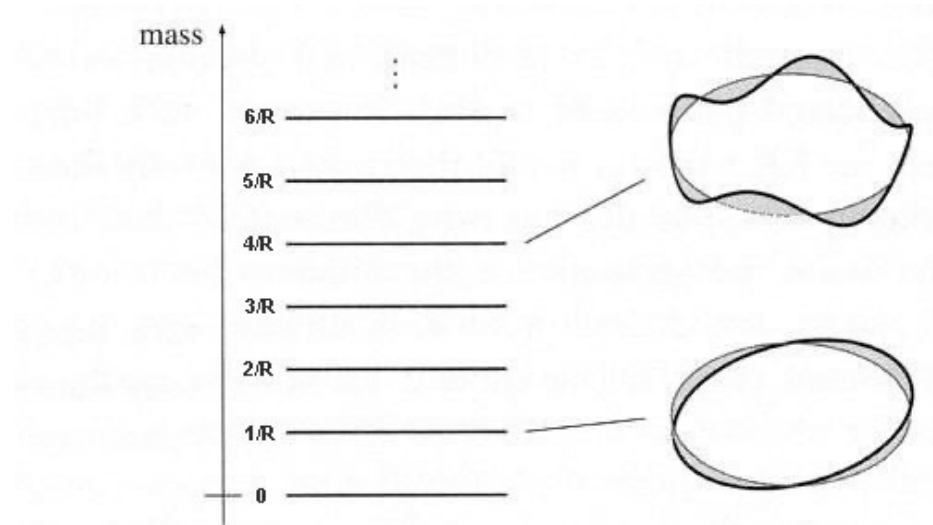
$$\varphi(x^\mu, y) = \sum_{n=-\infty}^{\infty} \varphi_n(x^\mu) \exp\left(\frac{iny}{r}\right)$$

- Leading to the equations of motion

$$\partial^M \partial_M \varphi = 0 \implies \sum_{n=-\infty}^{\infty} \left(\partial^\mu \partial_\mu - \frac{n^2}{r^2} \right) \varphi_n(x^\mu) \exp\left(\frac{iny}{r}\right) = 0$$

Kaluza-Klein Tower (a.k.a. KK Modes / KK Particles)

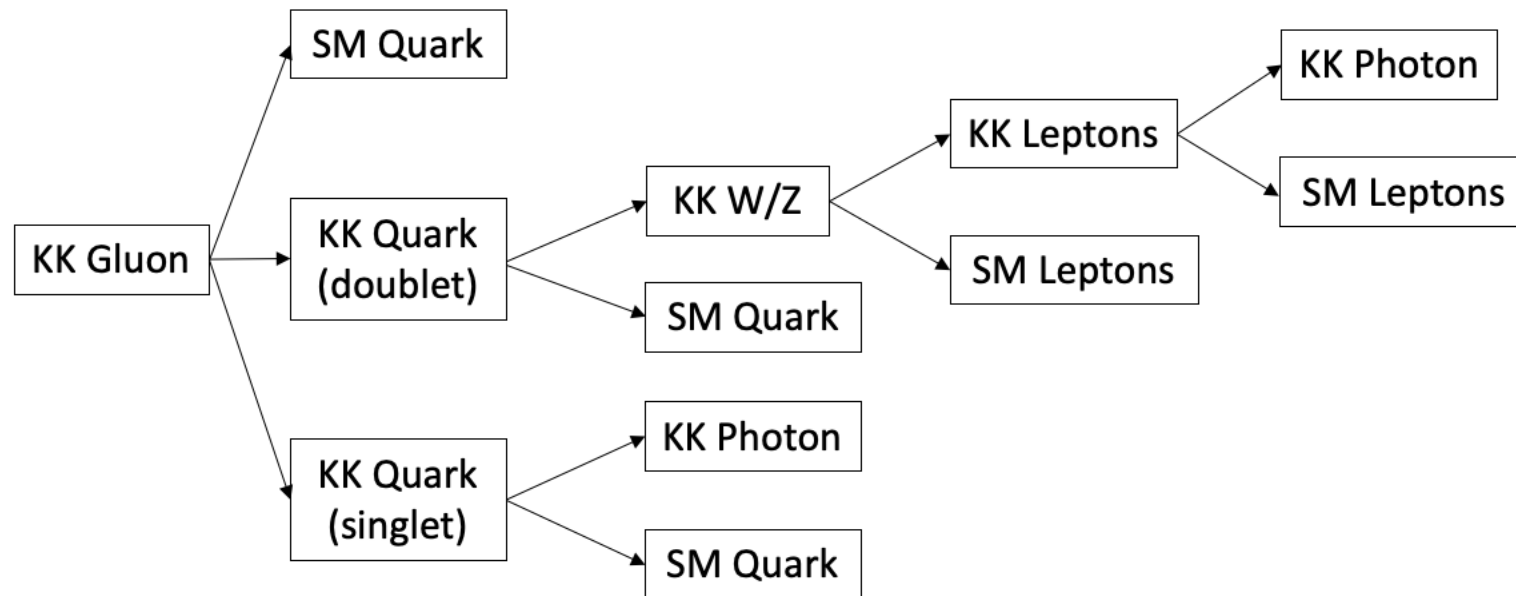
- $n = 0$ mode corresponds to SM



- Theory needs to be renormalizable so we need another parameter Λ , the cut-off scale
- Hence, MUED only has **two** parameters: R and Λ

Typical Decay Chain

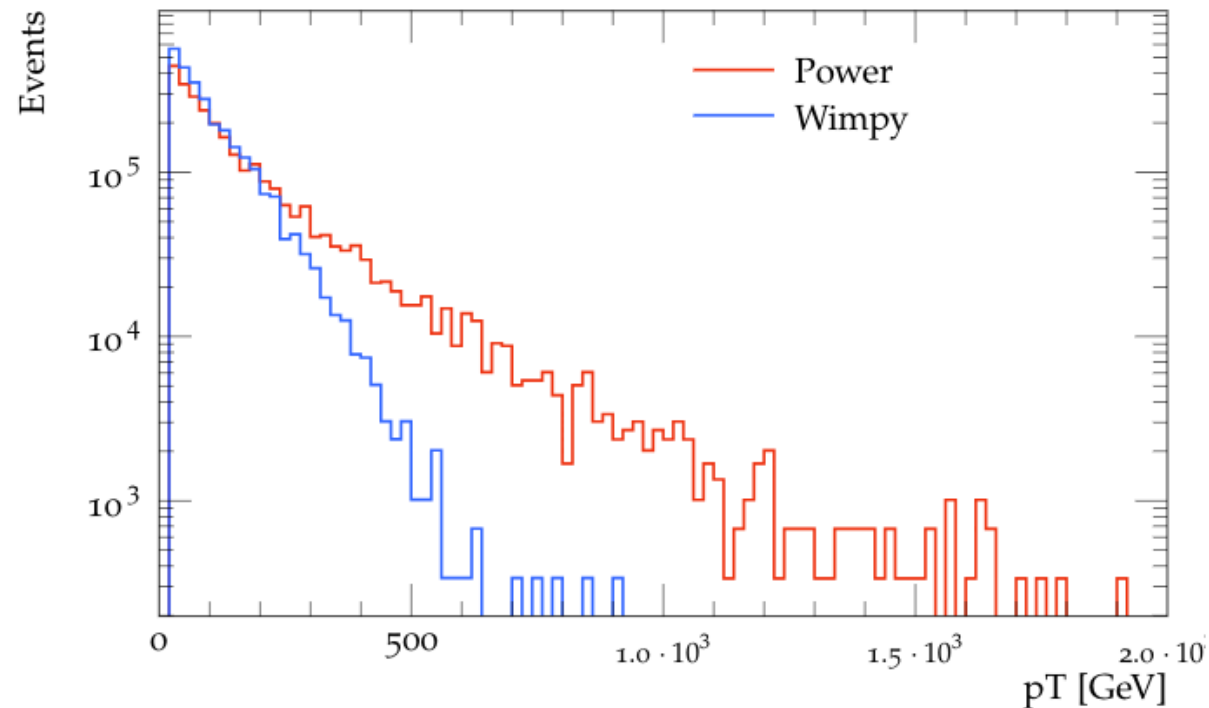
- Events usually have a relatively **large lepton multiplicity, multiple jets, and missing transverse momentum**
- Decay products will be relatively **soft** due to the relatively compressed spectrum



Previous Limits Use No Matching

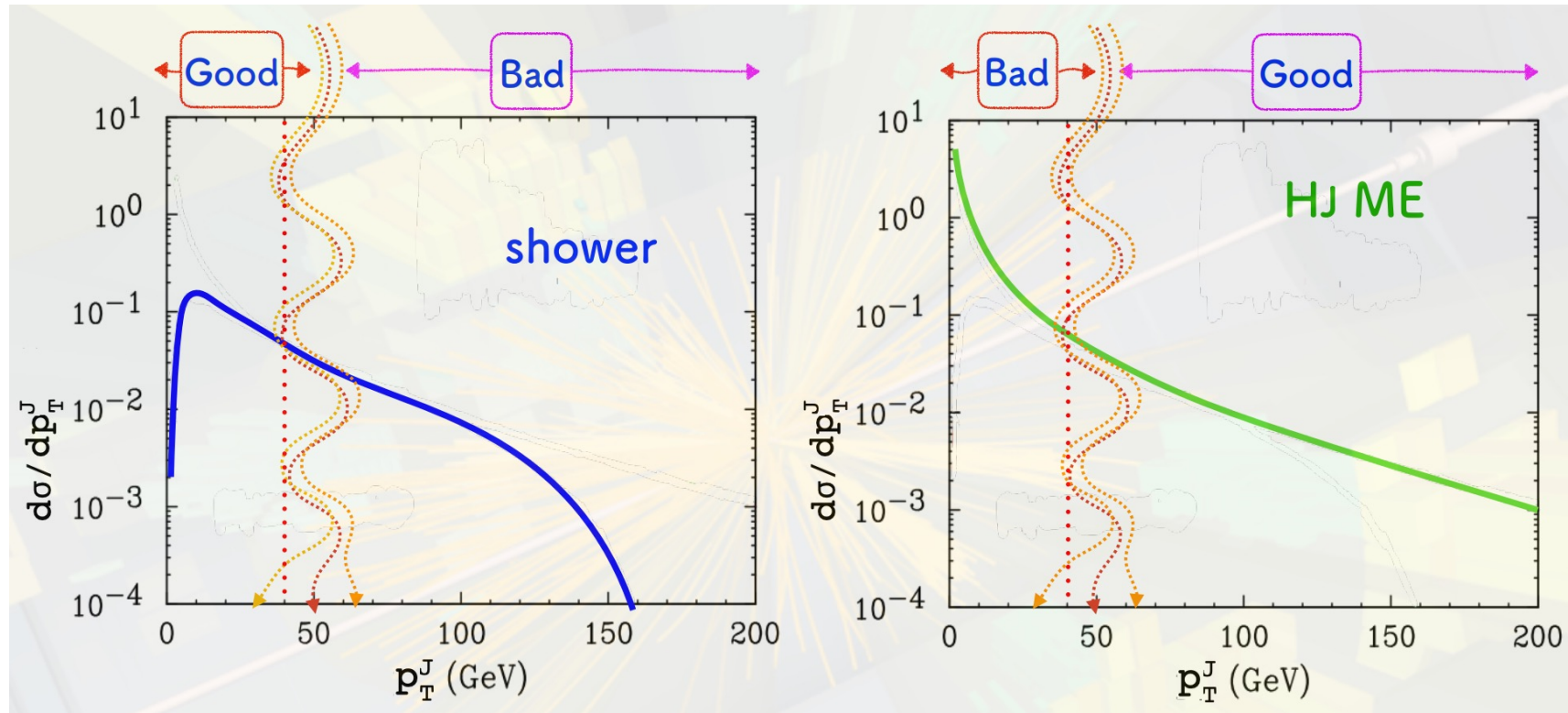
- “Wimpy” versus “Power” when matching is off

Leading Jet



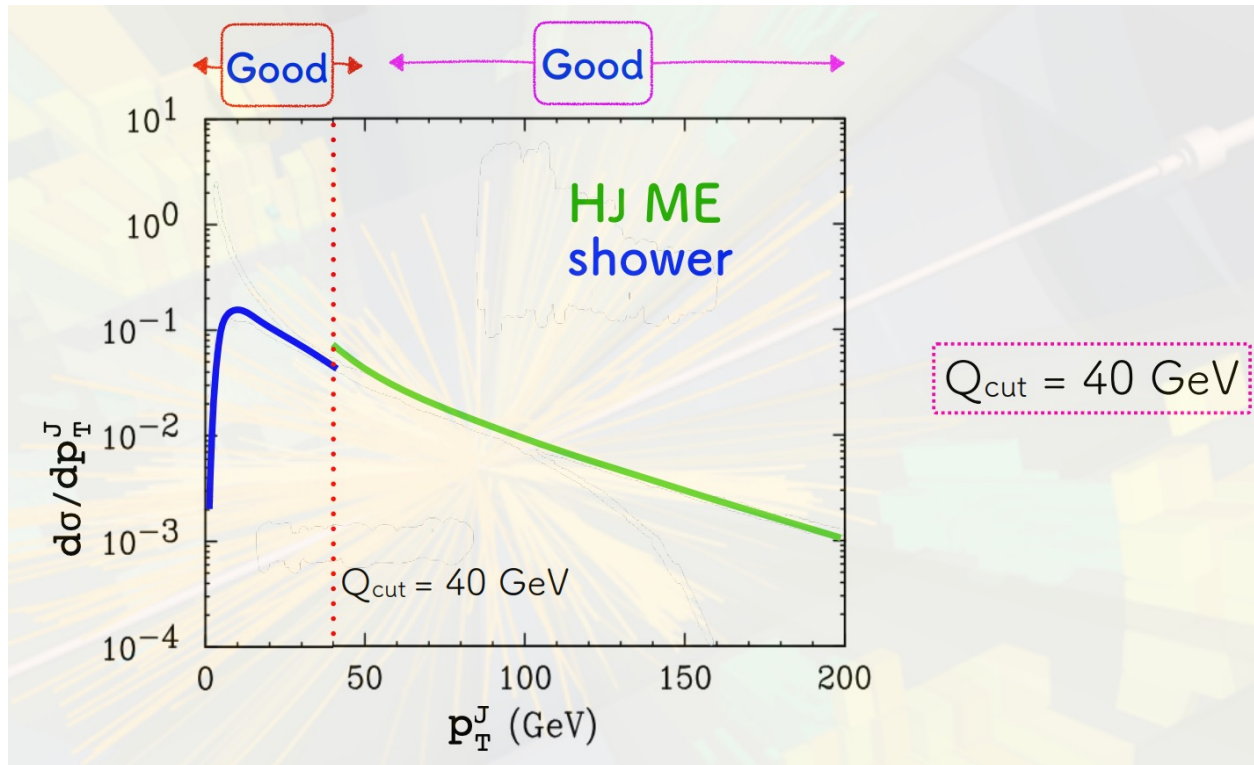
Matching

- Matrix Elements vs Parton Shower



Matching

- Matrix Elements vs Parton Shower

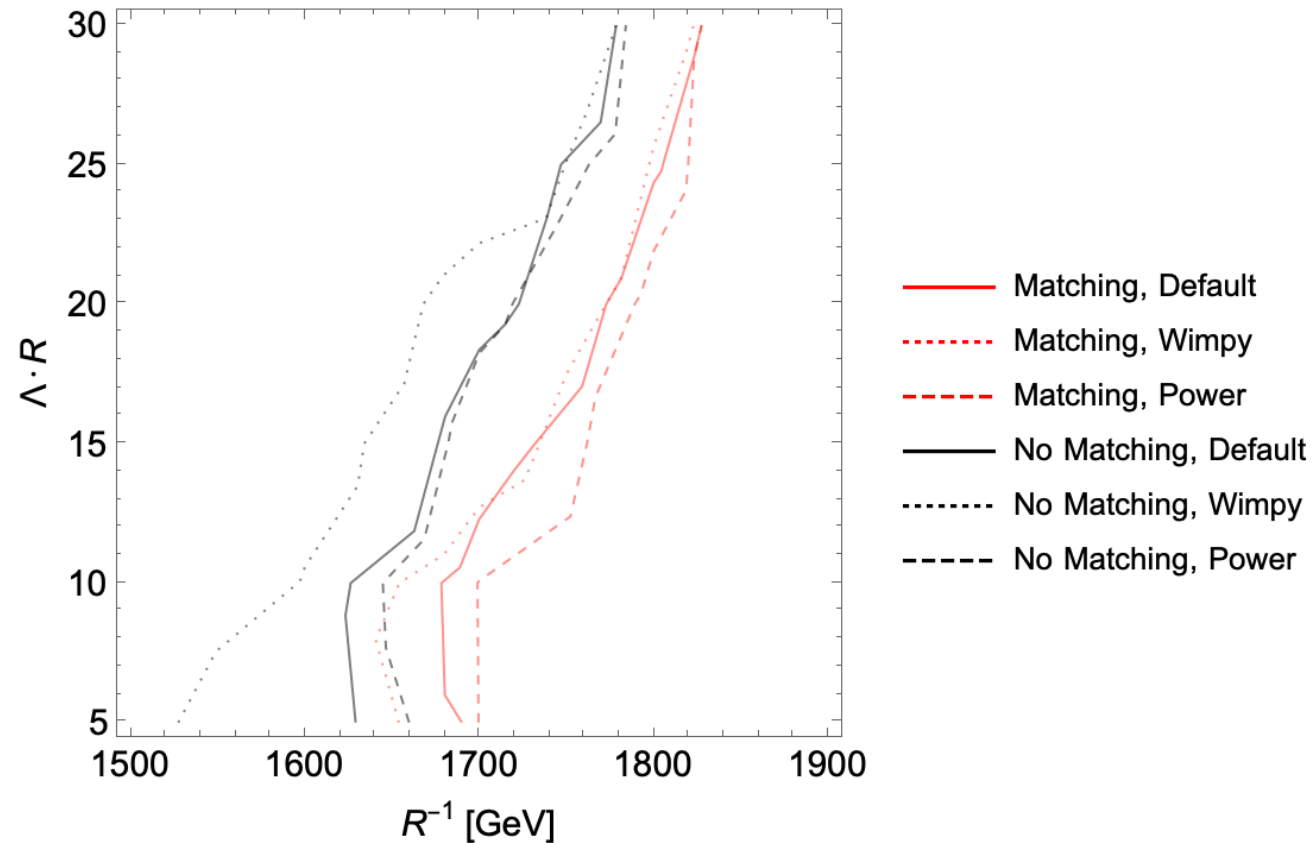


Updated Limits (with matching)

Check Models At Terascale Energies

<https://arxiv.org/pdf/1611.09856.pdf>

- We used **CheckMATE** to scan the relevant parameter space (against over 30 ATLAS/CMS searches)



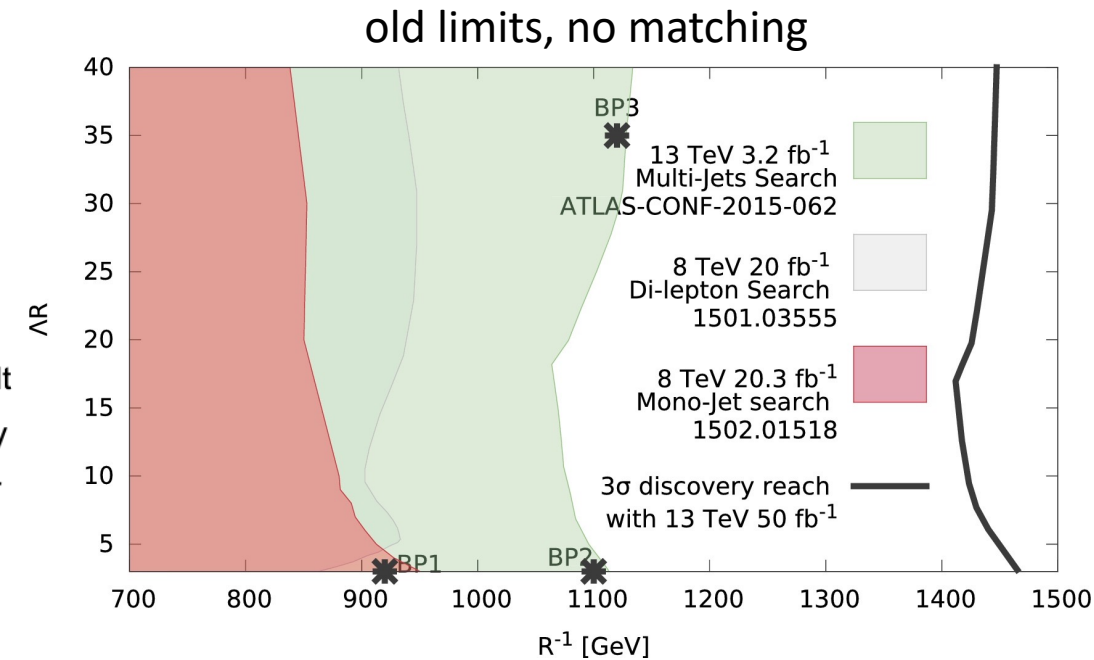
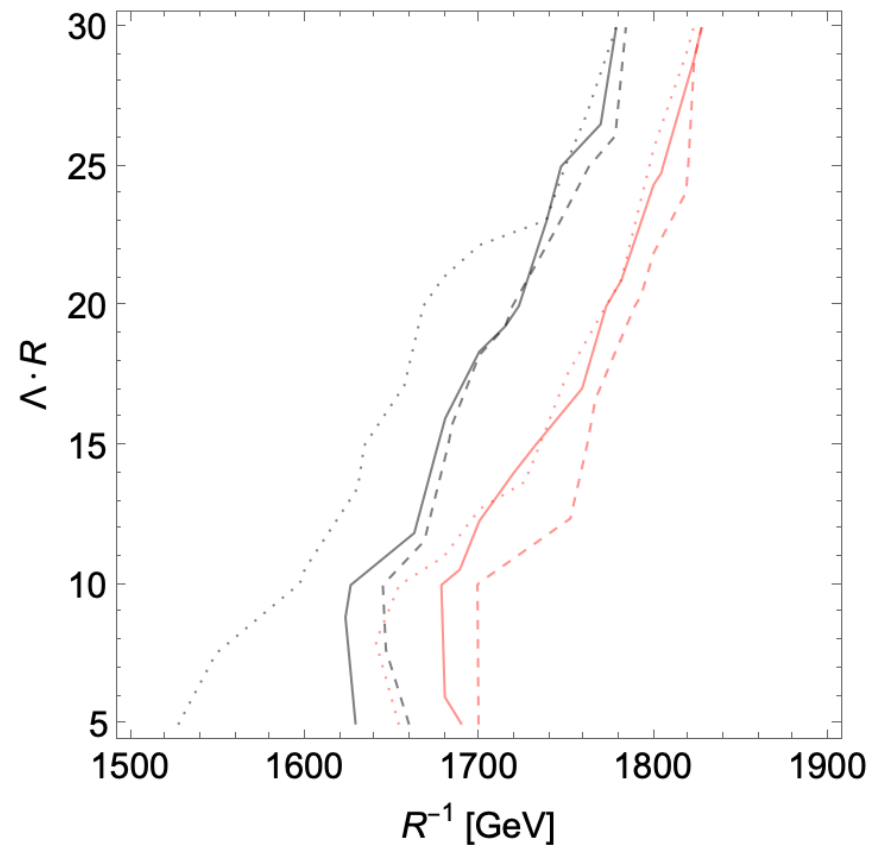
<https://arxiv.org/pdf/2110.00500.pdf>

Updated Limits (with matching)

Check Models At Terascale Energies

<https://arxiv.org/pdf/1611.09856.pdf>

- We used **CheckMATE** to scan the relevant parameter space (against over 30 ATLAS/CMS searches)

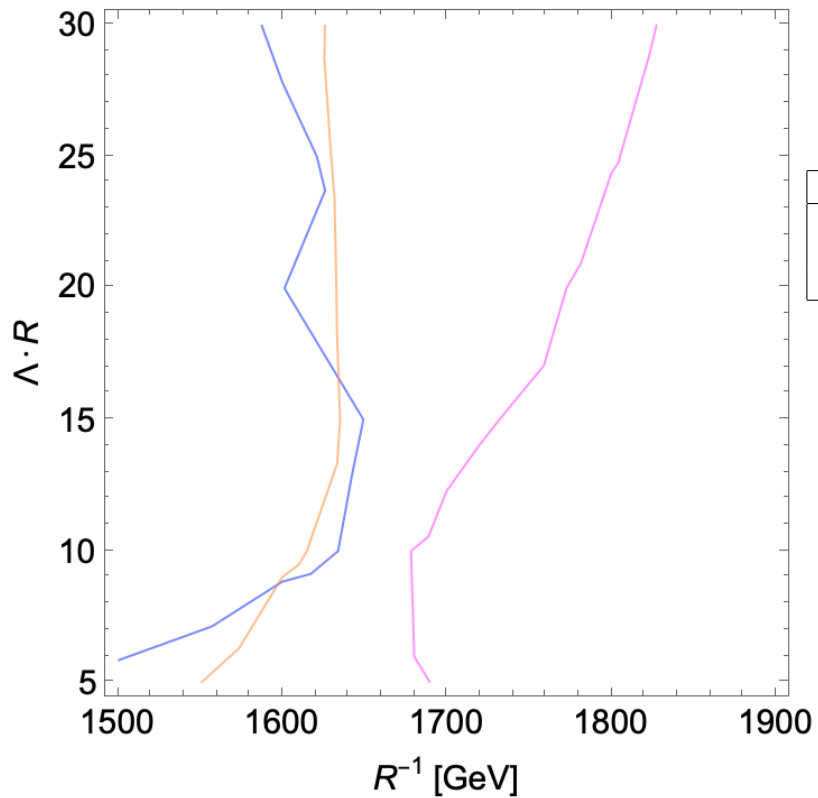


<https://arxiv.org/pdf/1606.04084.pdf>

<https://arxiv.org/pdf/2110.00500.pdf>

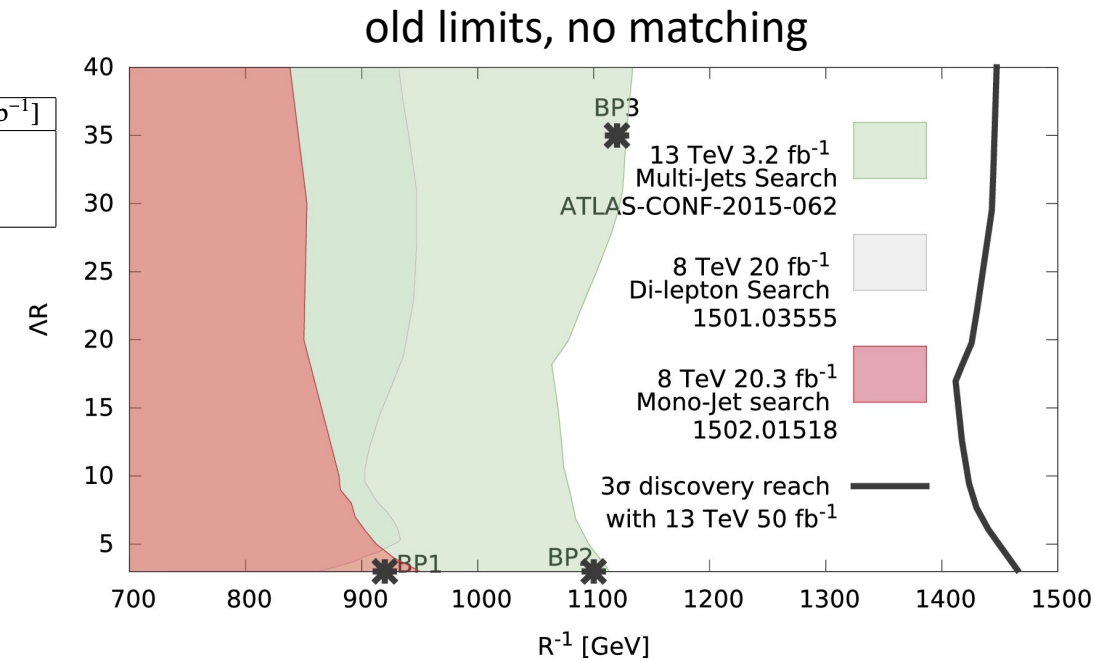
Updated Limits (with matching)

- Strongest is the mono-lepton search by ATLAS (<https://arxiv.org/pdf/2101.01629.pdf>)



Analysis	Final State	\mathcal{L} [fb^{-1}]
atlas_2101_01629 [44]	$1l + \text{jets} + \cancel{E}_T$	139
atlas_conf_2019_040 [43]	$\text{jets} + \cancel{E}_T$	139
cms_sus_16_039 [45]	$\text{leptons} + \cancel{E}_T$	35.9

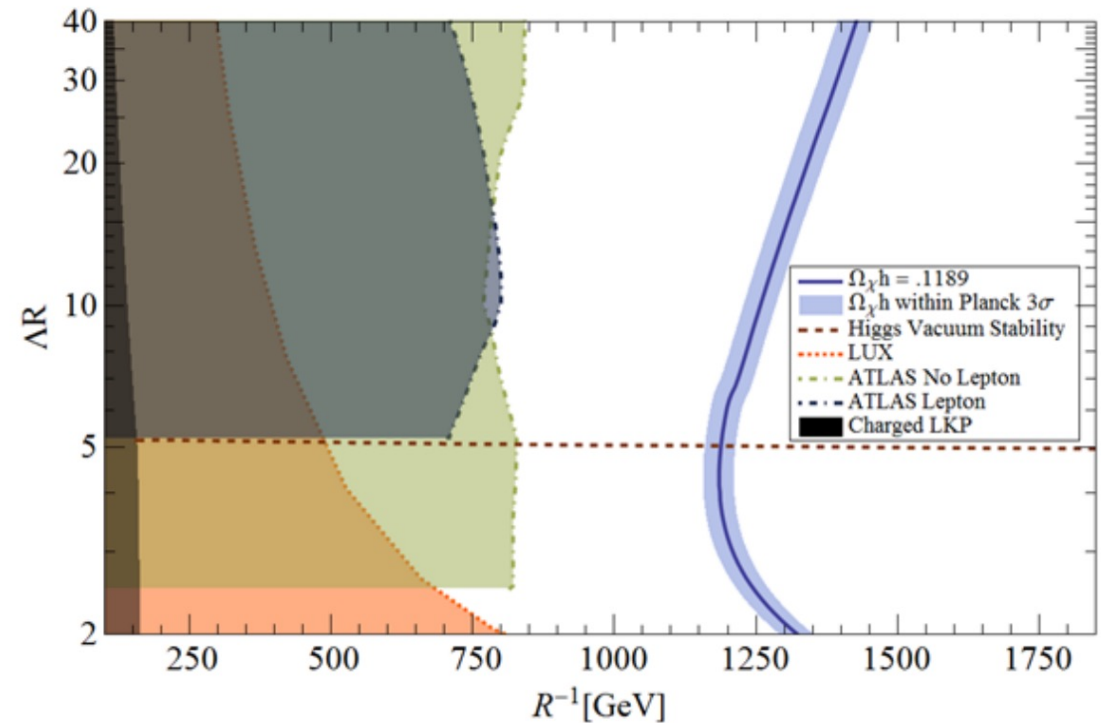
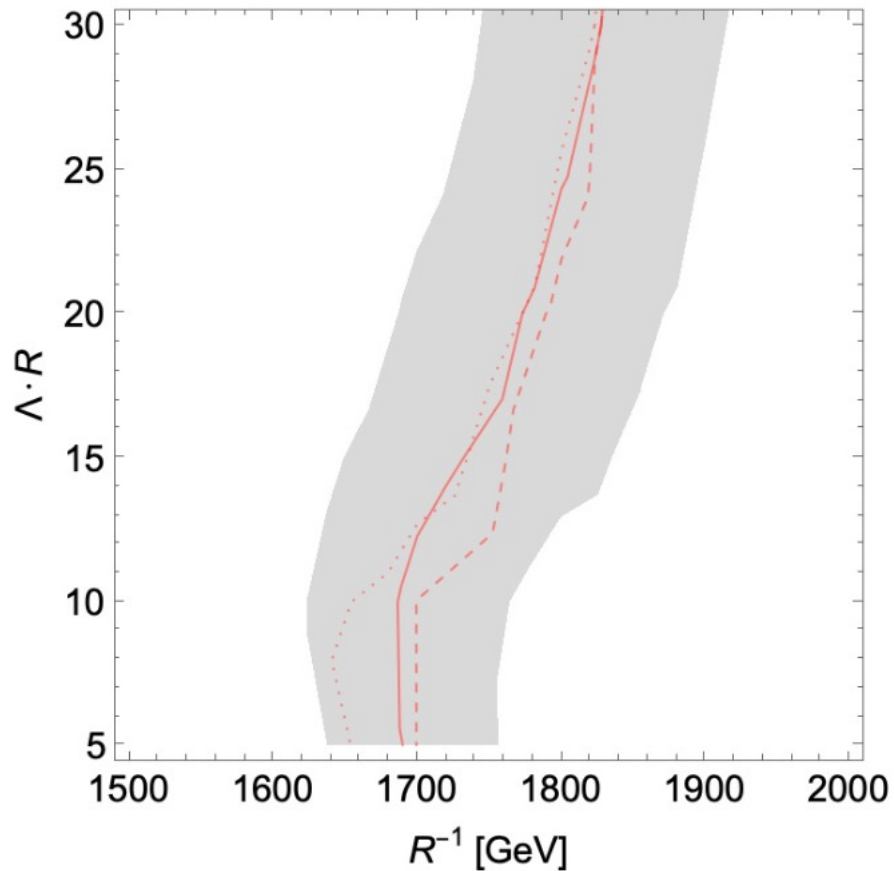
- cms_sus_16_039
- atlas_conf_2019_040
- atlas_2101_01629



<https://arxiv.org/pdf/1606.04084.pdf>

<https://arxiv.org/pdf/2110.00500.pdf>

Goodbye MUED? Limits from “two infinities”



values for $\Omega_\chi h$ between 0.1136 and 0.1238. All values of R^{-1} greater than the value traced by this line are forbidden as they lead to over-closure of the universe.

<https://arxiv.org/pdf/2110.00500.pdf>

<https://arxiv.org/pdf/1401.7050.pdf>

Thank you!!!