

Complementarity between dark matter and dark sectors

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Overview

- Dark QCD and dark matter
- Recasting for dark matter and dark showers

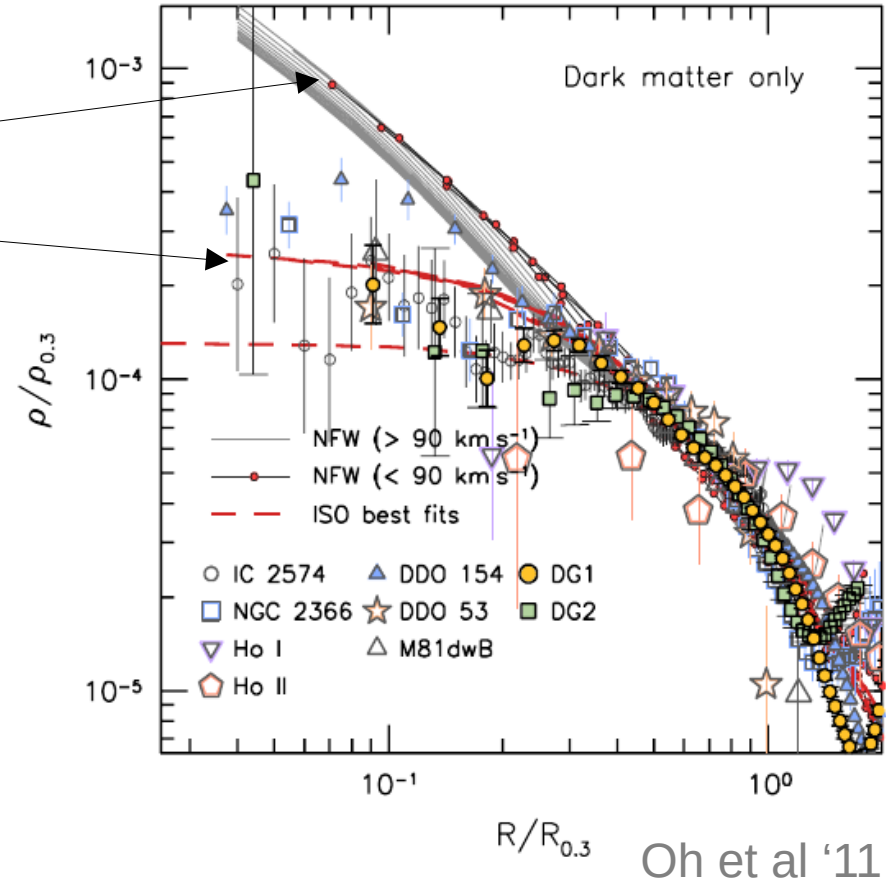
Cusp-Core problem

DM simulations predict(ed) cusps instead of the observed cores in galaxies

Need something to repel DM from the centre to reduce its density: one option is self interactions!

Spergel & Steinhardt '99

May also be relevant for 'too big to fail'



Self interactions

Typical galaxy has

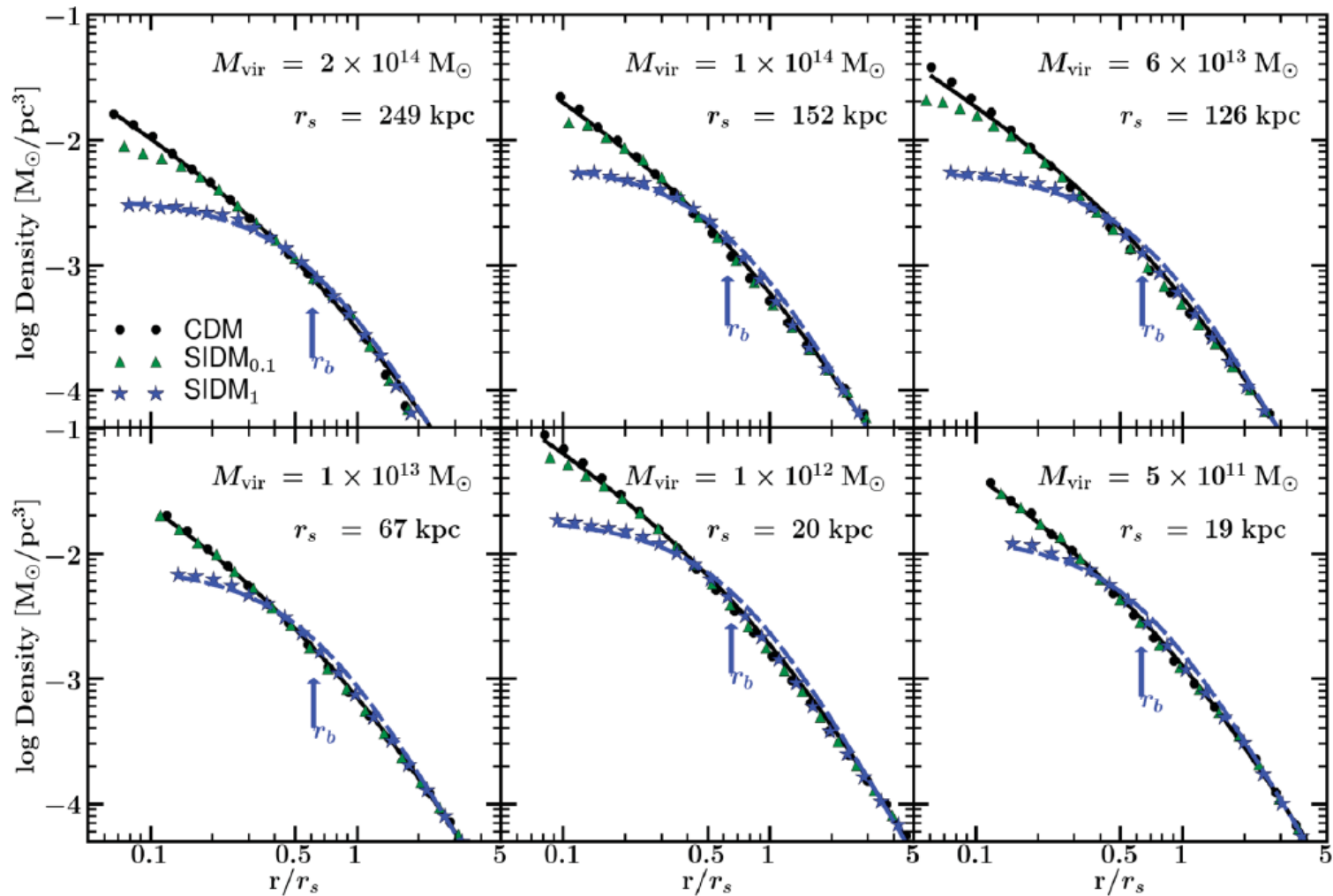
$$M \sim 10^{12} M_{\odot} \sim 10^{42} \text{kg} \quad r \sim 40 \text{ kpc} \sim 10^{23} \text{ cm}$$

If DM interacts once while crossing the galaxy:

$$\begin{aligned} \sigma n_{DM} r \sim 1 & \longrightarrow \sigma / m_{DM} \sim r / \rho_{DM} \sim r^2 / M \\ & \sim (\text{cm}^2) / g \\ & \sim (\Lambda_{QCD})^{-3} ! \end{aligned}$$

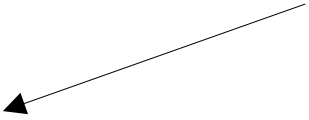
Simulations back
this up!

Rocha et al '12



Next challenge is to produce the DM: it should couple to the SM.

Standard examples: Z' kinetically mixing with hypercharge, scalar mediator


$$\mathcal{L} \supset \frac{\epsilon}{2} F_{\mu\nu} X^{\mu\nu} + g_X \bar{\psi}_{DM} \gamma^\mu \psi_{DM} X_\mu$$

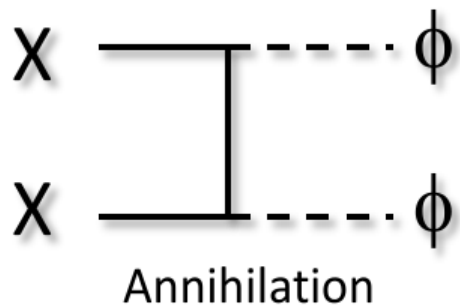

$$\mathcal{L} \supset g_X \bar{\psi}_{DM} \psi_{DM} \phi + \text{Higgs portal}$$

Various mechanisms have been considered:

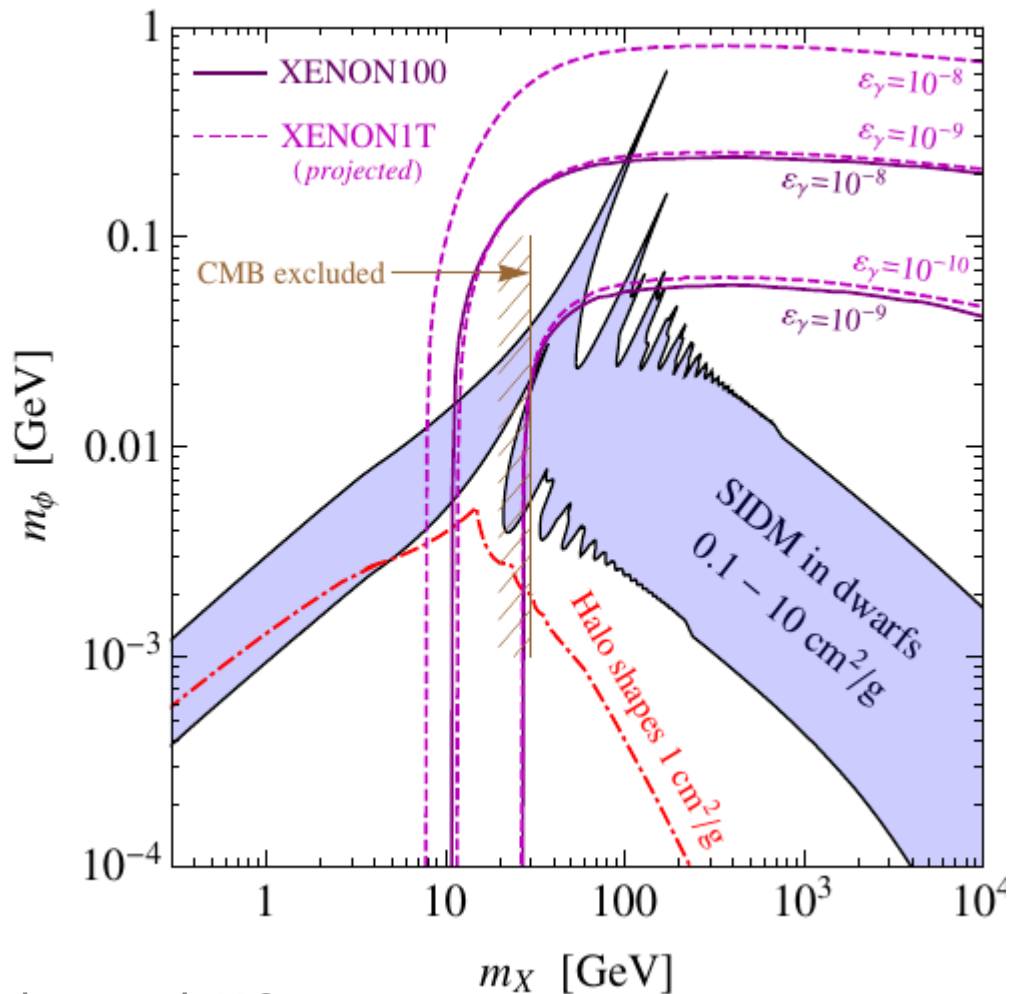
- Freeze-out
- Asymmetric DM
- SIMP miracle
- ...

Freeze-out seems to require tiny couplings to SM:

not much chance of collider complementarity since stable DM, no LLP



Symmetric SIDM with γ kinetic mixing

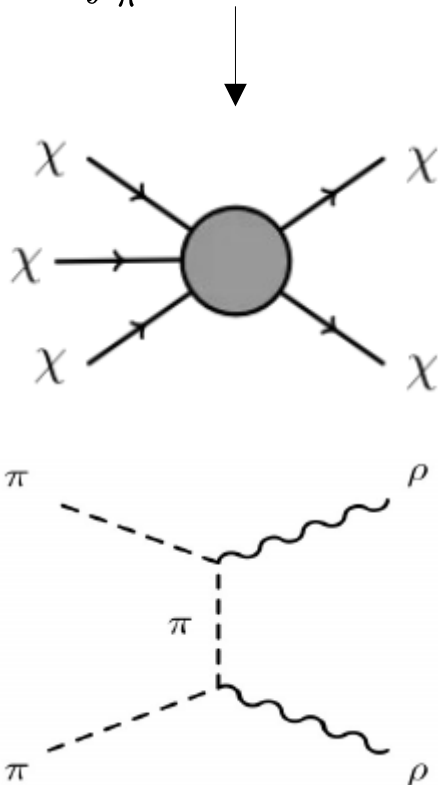


Freeze-out in dark sector

Dark QCD with dark pions has WZW term:

$$\mathcal{L} \supset \frac{2N_d}{15\pi^2 f_\pi^5} \epsilon^{\mu\nu\rho\sigma} \text{Tr}(\pi \partial_\mu \pi \partial_\nu \pi \partial_\rho \pi \partial_\sigma \pi)$$

Hochberg et al, 1411.3727

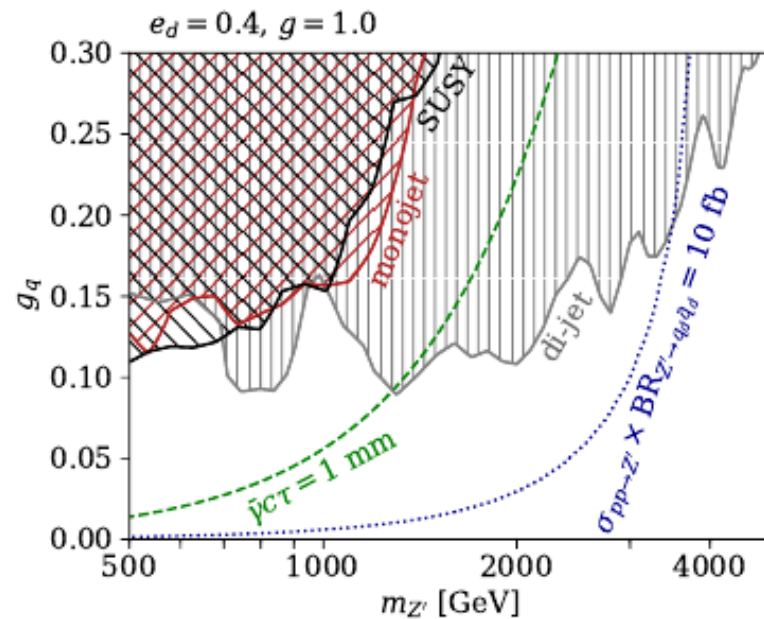
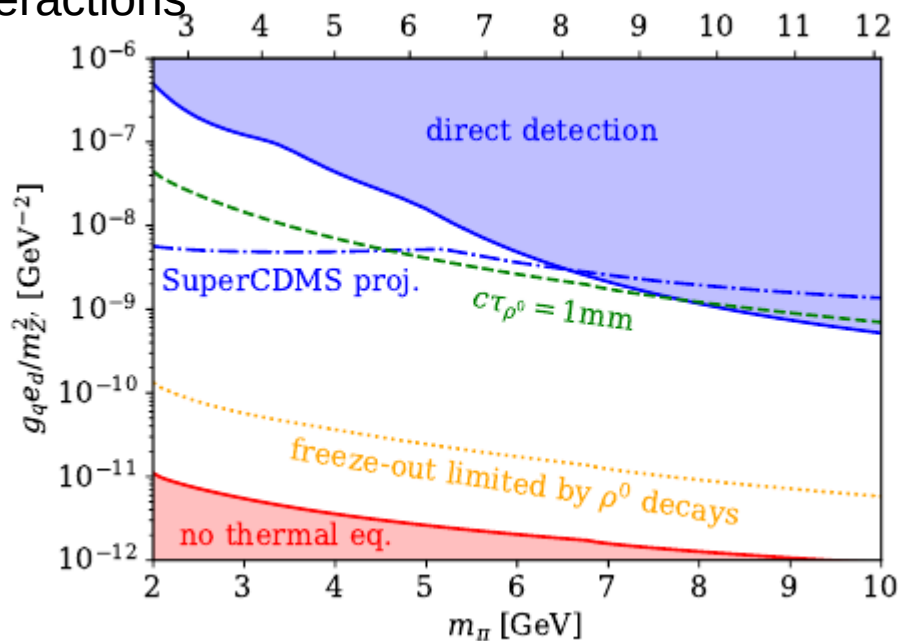
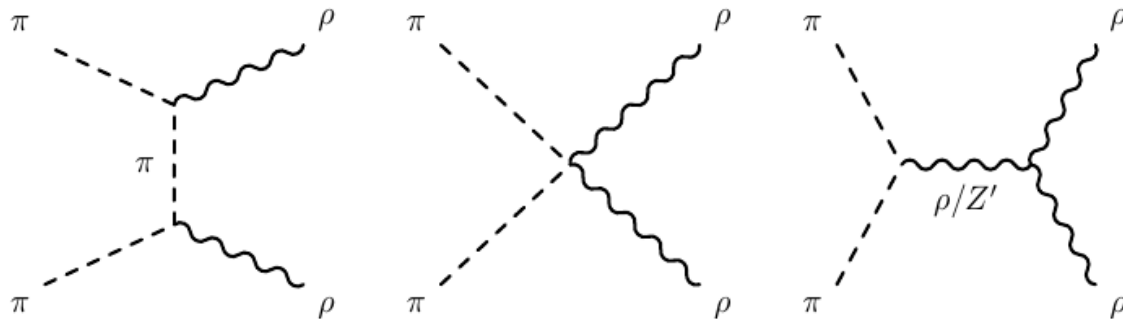


Or freeze-out using dark rhos:

Bernreuter, Kahlhoefer et al, 1907.04346

These are promising!

For dark rhos there is significant complementarity as can somewhat decouple the freeze-out from SM interactions



Bernreuter, Kahlhoefer et al, 1907.04346

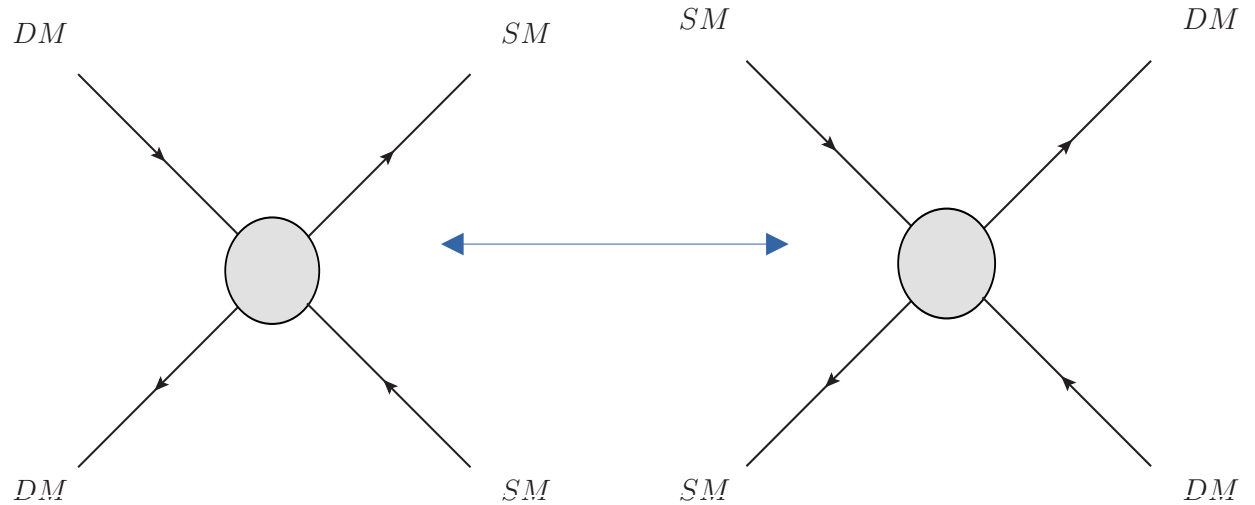
Dark DM challenges for theorists

Dark matter simulations:

- For WIMPs we have MicrOMEGAs (and also MadDM)
- Computing the dark matter density, direct detection etc for non-standard cosmologies/SIMPs has been done so far in piecemeal fashion
- In addition to actually understanding the strongly coupled models ...
- ... and relatively limited number of portal models.

Complementarity

With WIMPs have a standard picture of turning a diagram around to go from DM freezeout to colliders



For SIMPs and models with interactions in dark sector this link is no longer obvious: at very least, more parameters!

BUT we can continuously tune between visible/invisible sector by adjusting the mediator couplings: so monojet/dijets are complementary to emerging jets

Recasting

- The good news: have full run 2 monojet searches in MA5 for ATLAS and CMS
- BUT typically small mediator couplings lead to LLPs! These lead to obvious signatures!
- Such searches have typically been hard to recast:
 - They have been one of the frontiers in recasting and developing new LHC searches – large possibility of improvements in future!
 - MadAnalysis 5 has currently 3 LLP analyses + some ongoing (older and new)
 - CheckMATE has a similar number
 - There is an [LLP recasting github](#) with 5 older LLP analyses in
 - ... and that's it.

MDG, Priya
2106.08815

Araz, Fuks, MDG,
Utsch 2112.05163

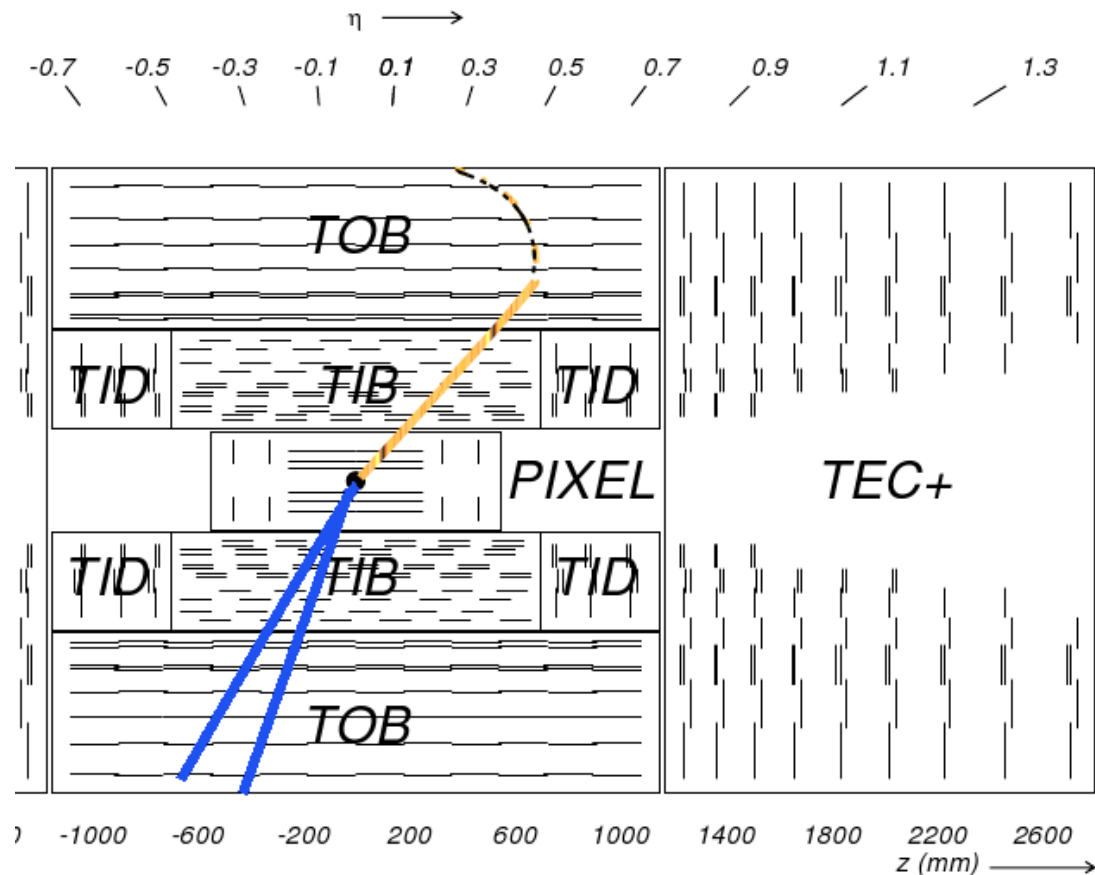
To give an example why:

CMS disappearing track search:

2004.05153 (EXO-19-010) and the older 1804.07321 (EXO-18-044)

101 fb^{-1}

38.4 fb^{-1}



Look for tracks that “disappear” in the tracker and after the pixel detector

i.e. one or more heavy charged particles that decay to something neutral and non-hadronic

Challenge: signal regions depended on how many tracker layers the track hit!

Had to invent a way to simulate this...

Equivalent ATLAS searches now give efficiencies (great!!) but how model dependent? And problems ...

Now we have two new challenges:

Emerging/dark/semi-visible jets

- Already just have to use efficiencies & smearing for JVT etc for visible jets
- What will the reco efficiencies for these be???

ML event selection

- Ongoing work with ATLAS group in Paris
- Community paper is being prepared on recommendations ... not limited to the subject of this workshop!

- There is a plan to add dark QCD analyses to MadAnalysis (thanks Sukanya ...)
- Collaboration with ATLAS groups in Paris and Grenoble on recasting Run 3 searches