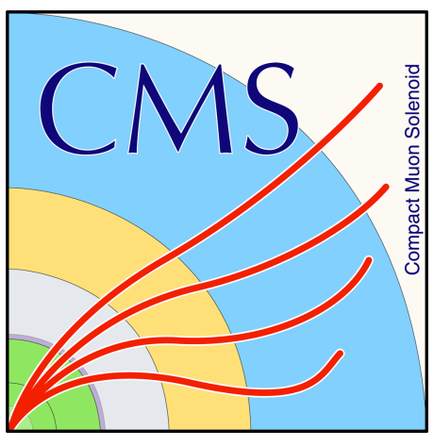
Searching for semivisible jets in CMS

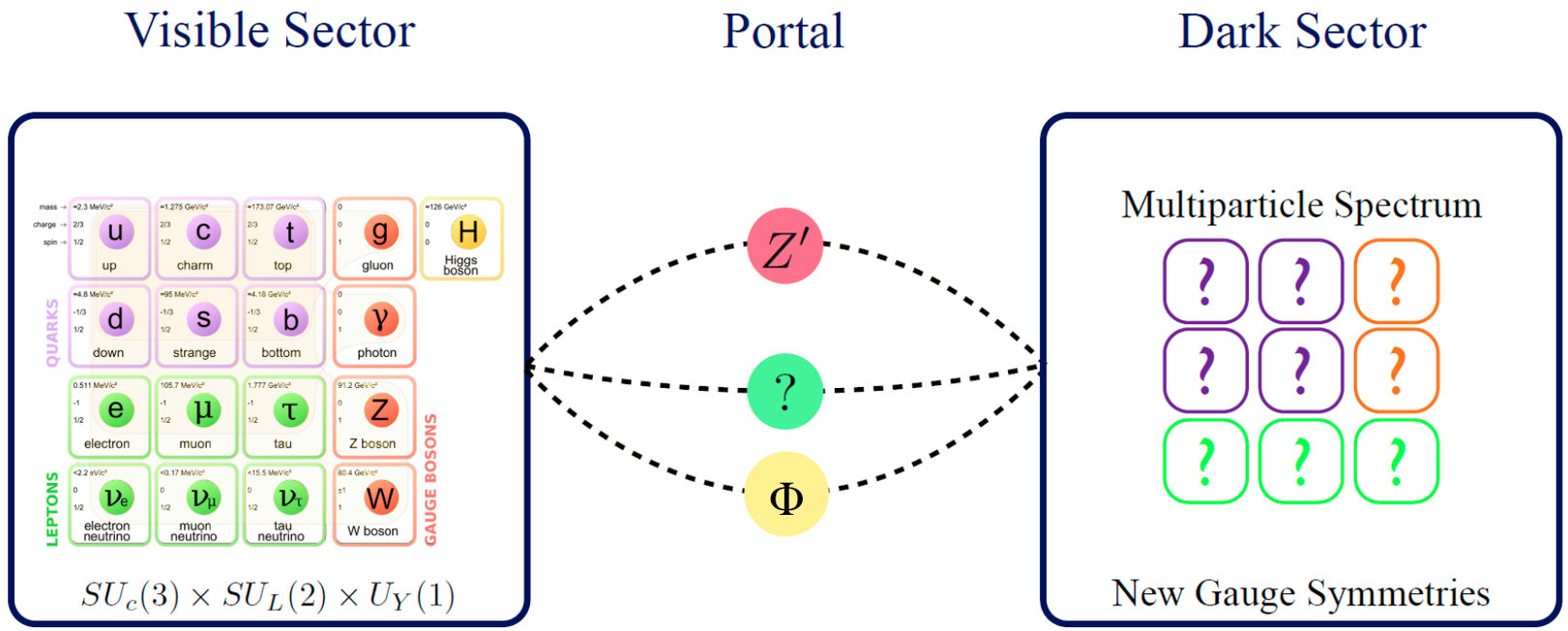
Thomas Klijnsma

On behalf of the CMS Collaboration

25 May 2022



About dark sectors

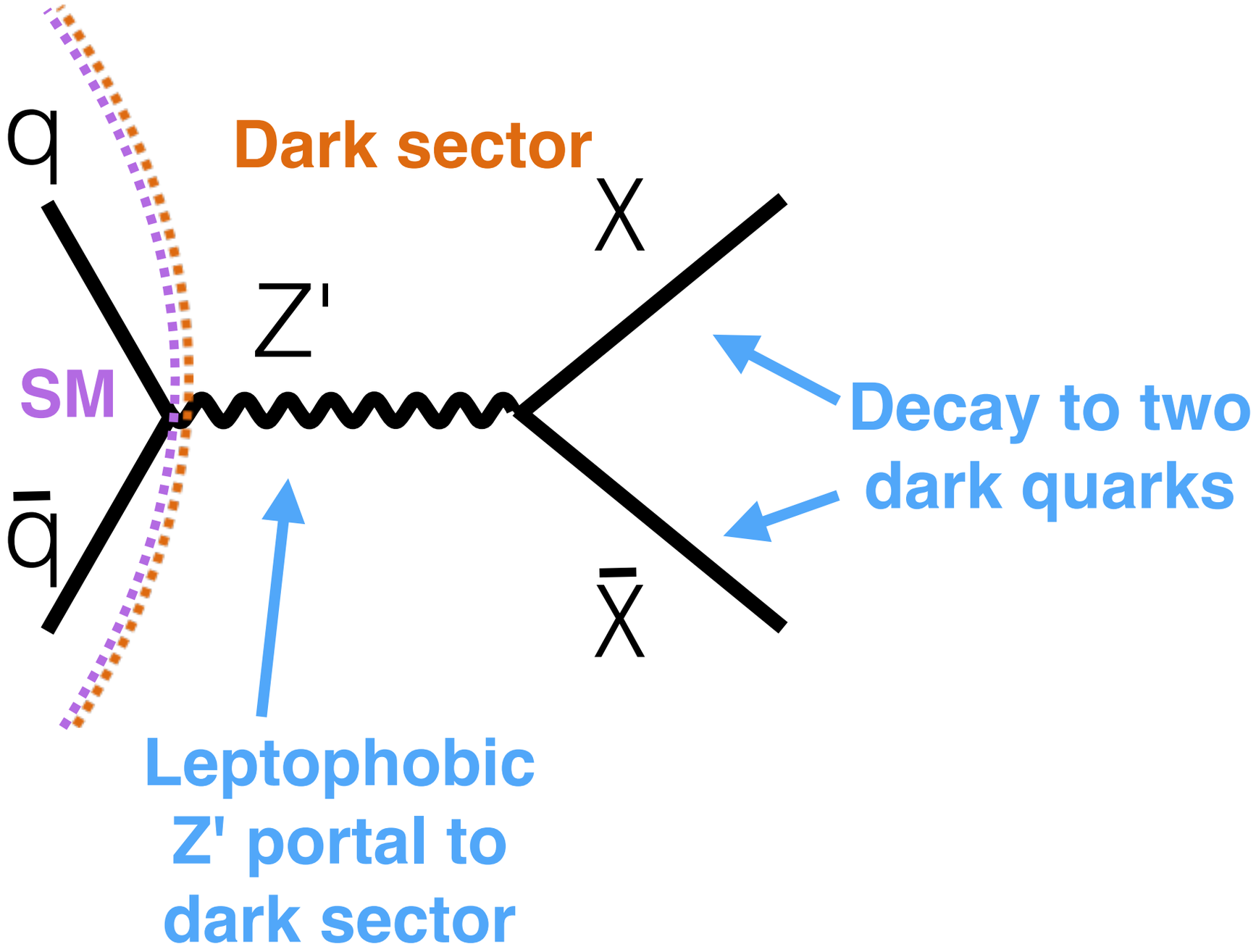


- What if dark matter is not a single particle?
- Dark sector models more complex, but then again, so is ordinary matter
- Alternative to WIMPs, detectable signatures
- **Signature may be hiding in already-taken data**
- This talk: **Semivisible jets** [1503.00009] (one of the many signatures)
  - CMS search accepted for publication: [CMS-EXO-19-020]

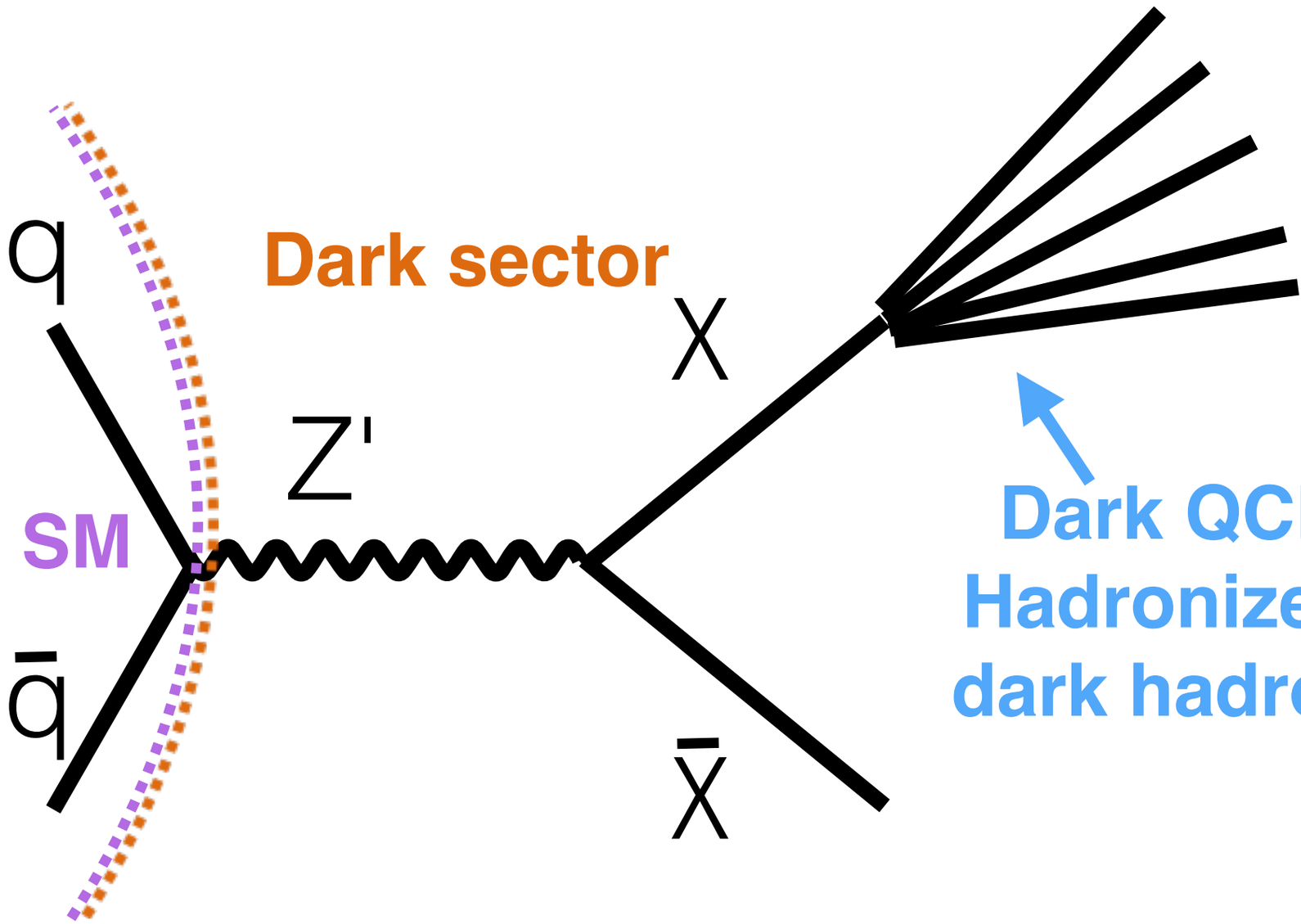
Outline

- What are semivisible jets?
- Why are they interesting to look for?
- Results on search for semivisible jets at CMS

Semivisible jets in a nutshell



Semivisible jets in a nutshell



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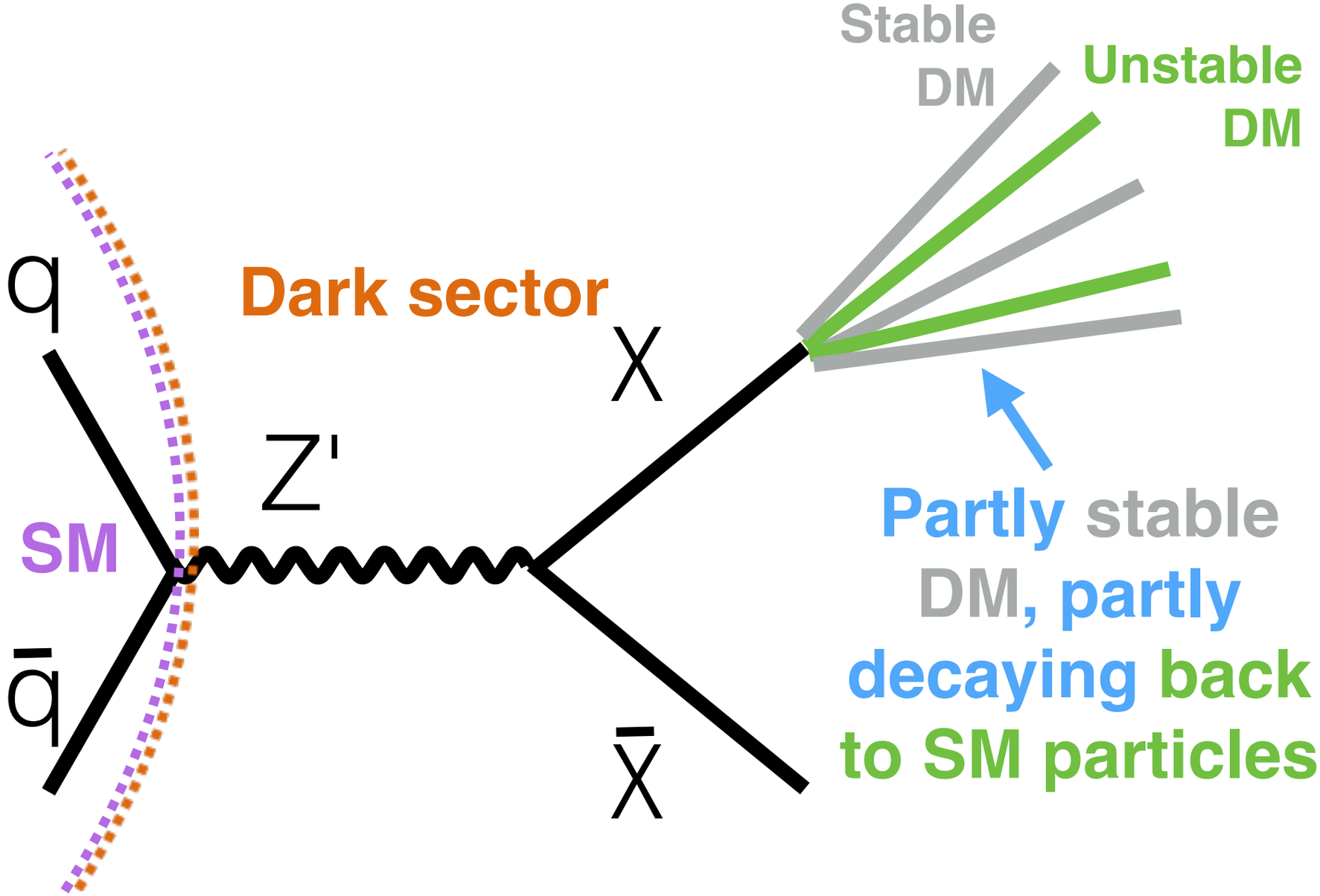
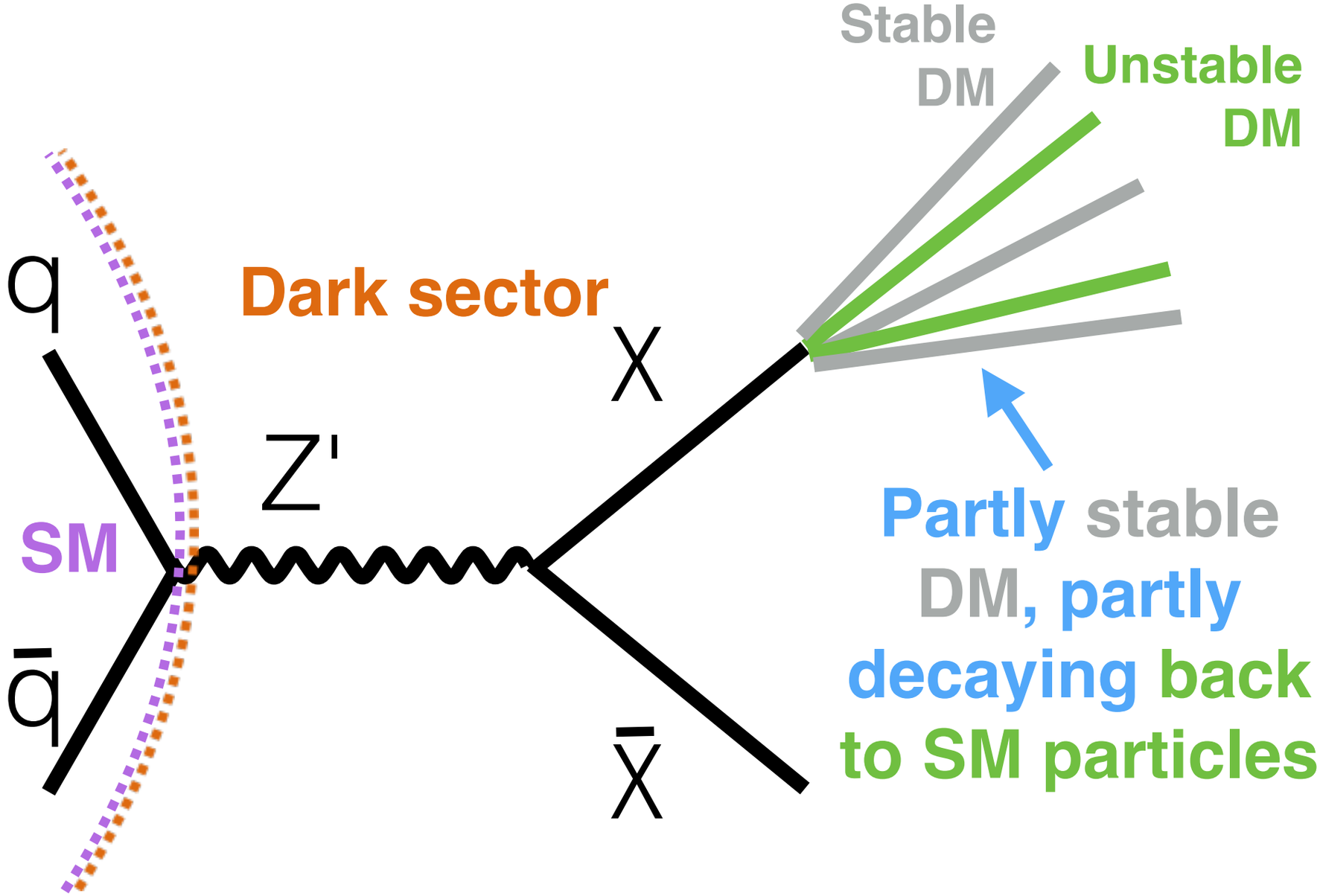


Semivisible jets in a nutshell



$$r_{inv} = \frac{\text{Number of stable dark hadrons}}{\text{Number of total dark hadrons}}$$

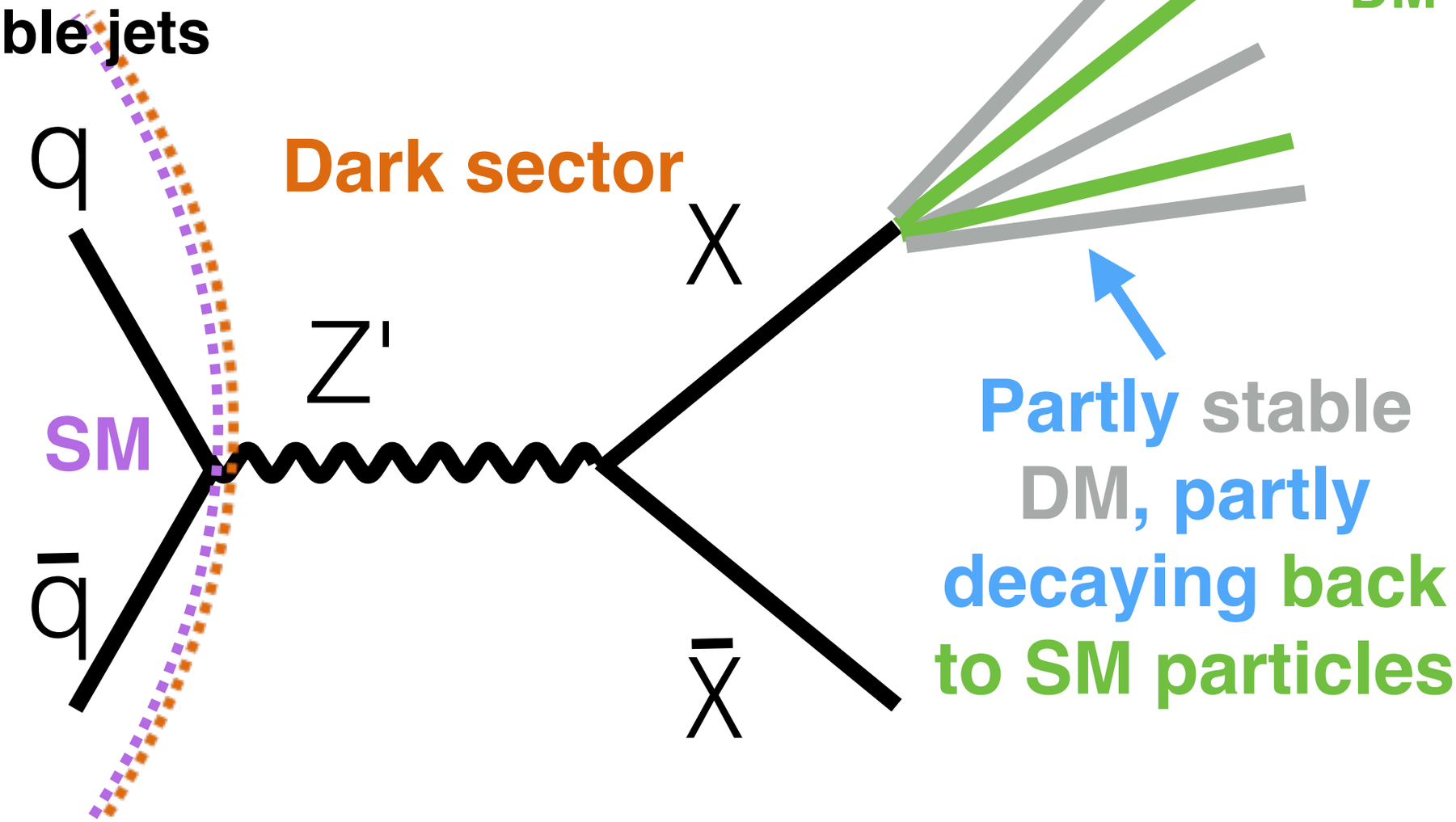
(stable + unstable)

Semivisible jets in a nutshell

r_{inv}=0: Completely reconstructed → **standard dijet search**

r_{inv}=1: Completely missed → **standard DM search**

0 < r_{inv} < 1: **semivisible jets**



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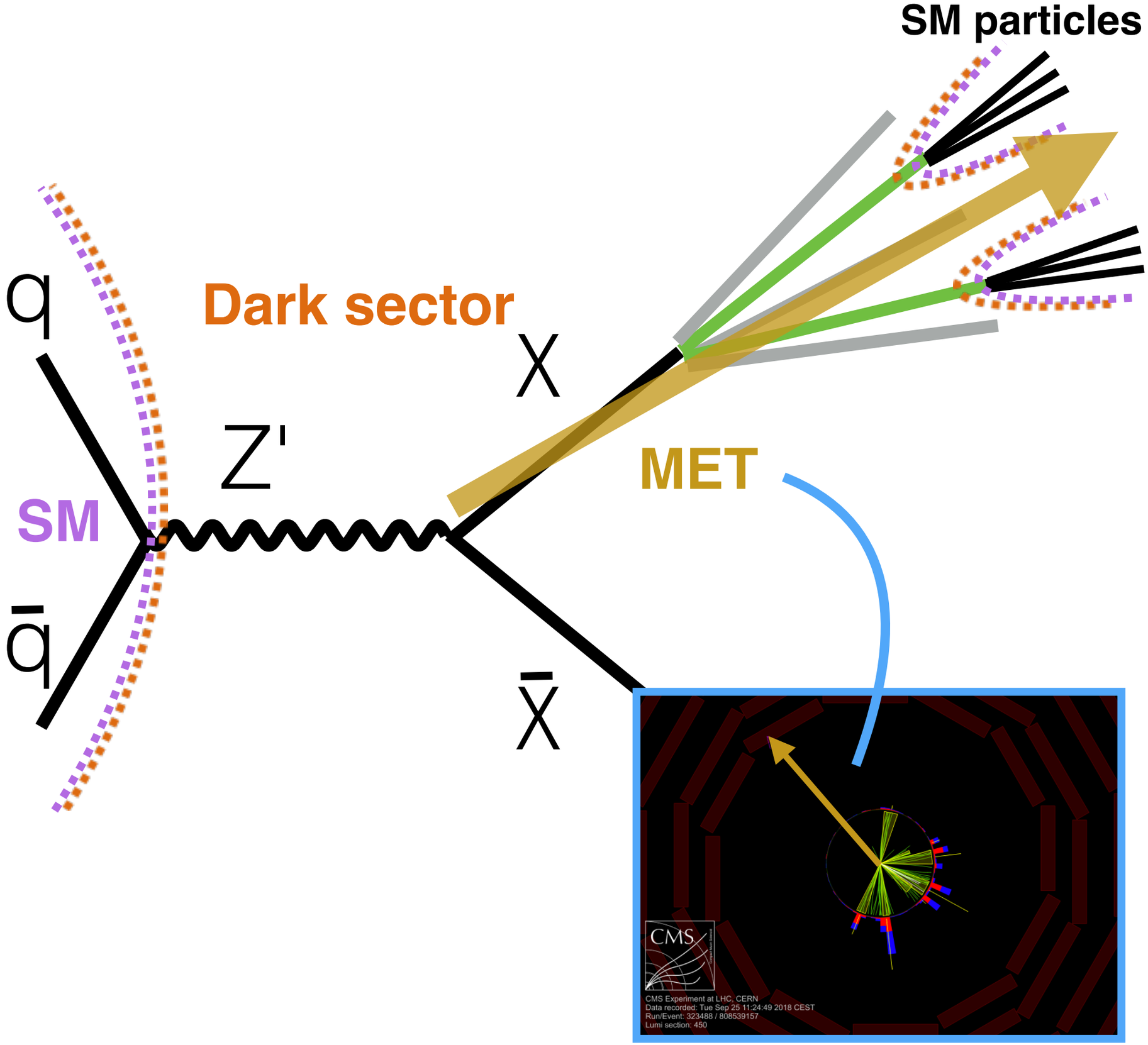
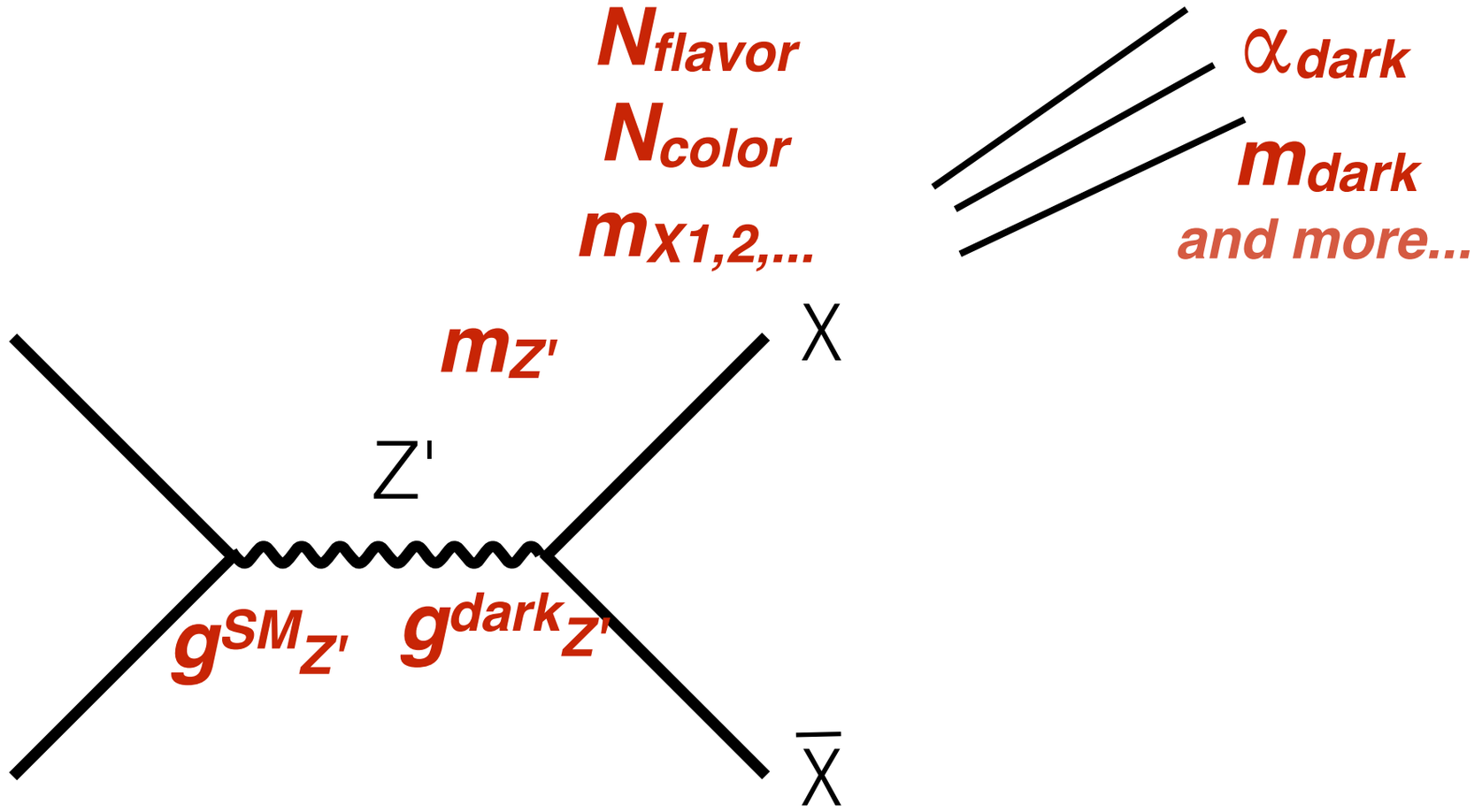
Semivisible jets in a nutshell



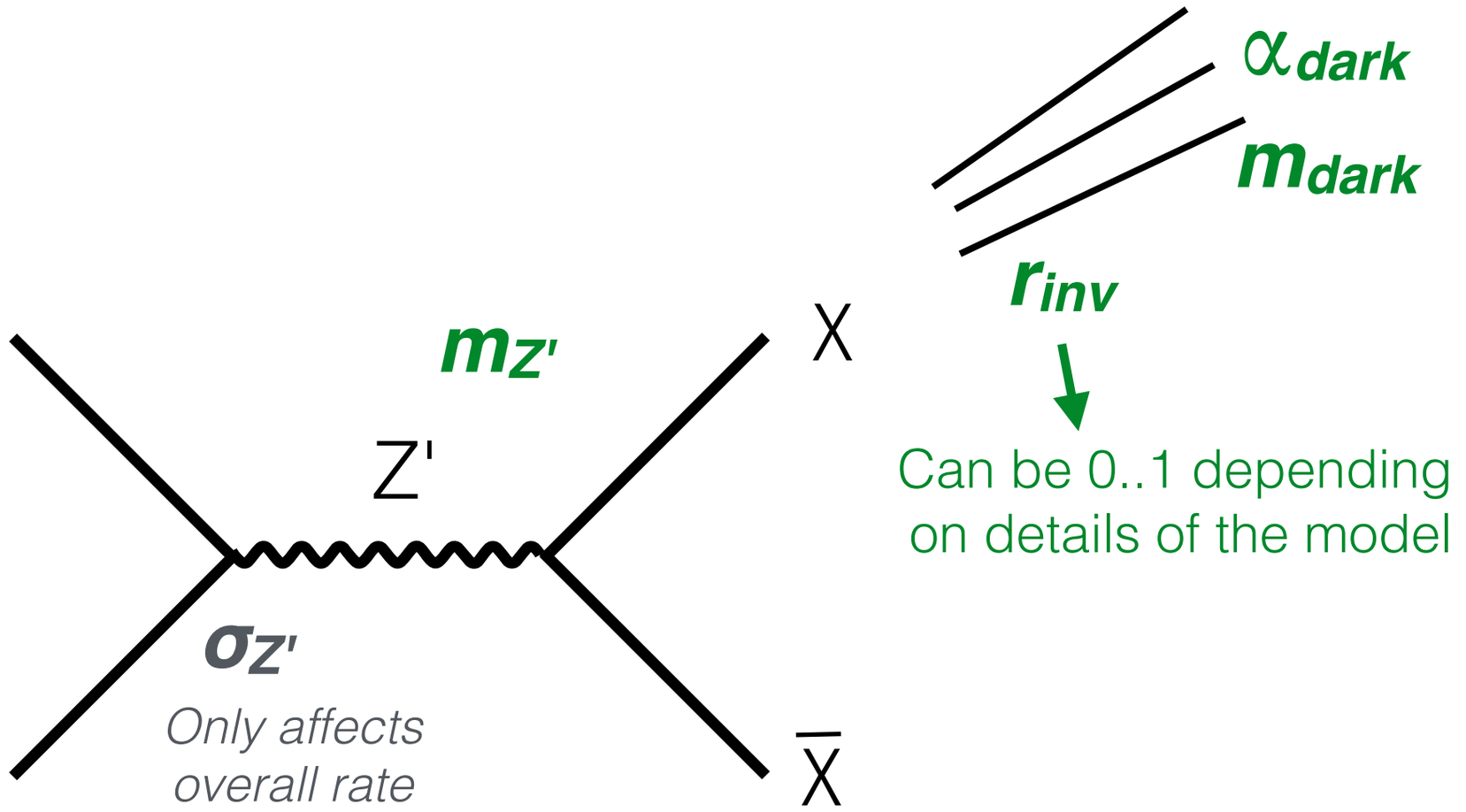
Model parameters

- Complete model parametrization can have many parameters
  - Some of these based on non-perturbative physics



Model parameters

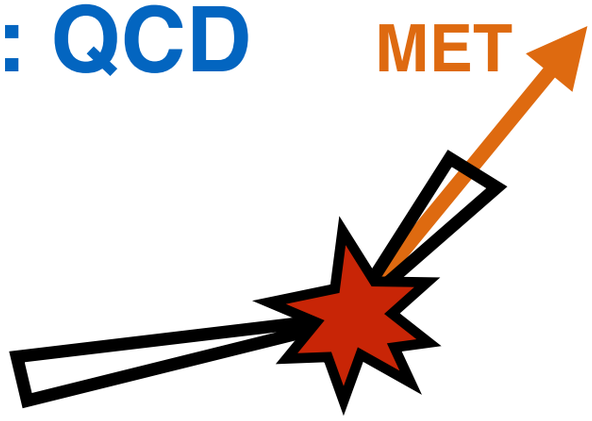
- Focus instead on **'effective' parameters** that have direct impact on jet observables and MET



- Dark hadrons decay promptly (no long lifetimes), dark QCD ($\Lambda_{dark} \ll m_{Z'}$), and no leptons in the dark hadron decays
  - Some alternative experimental signatures could be realized altering these details (displacement, leptons)

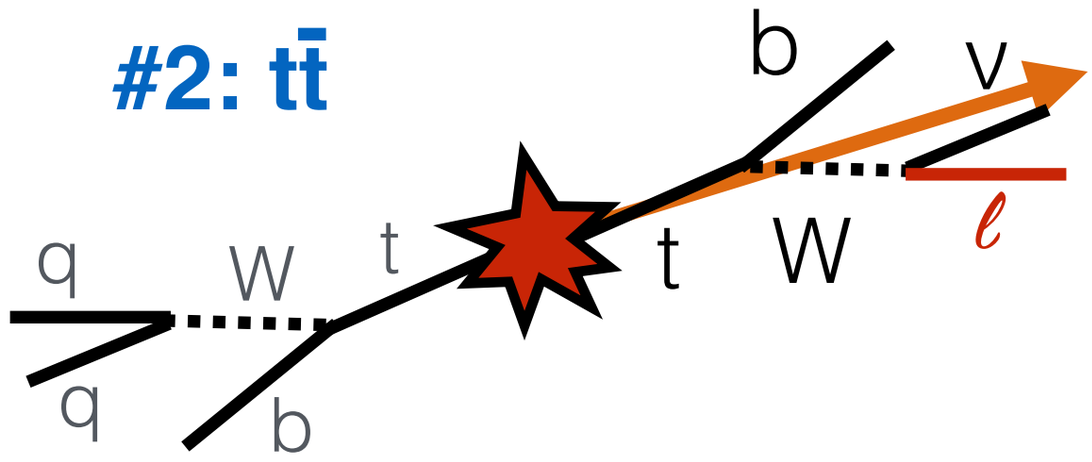
Backgrounds

#1: QCD



- **Dominant**; MET from misreconstruction

#2: $t\bar{t}$



- Mimics SVJ if lepton is missed

#3: W + jets

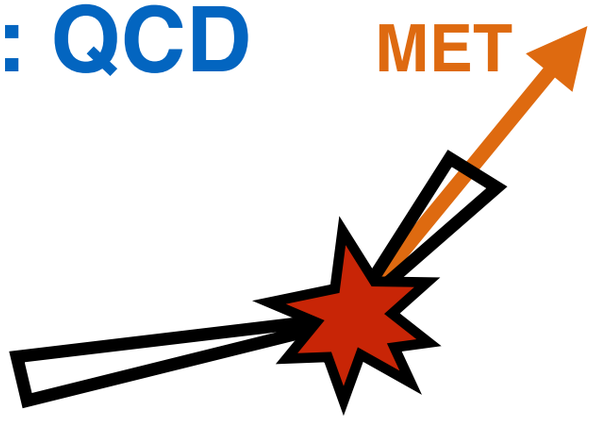
- MET from ν, missed lepton
- Not so likely to mimic SVJ but high σ

#4: Z + jets

- Least likely to have MET aligned with jet, but still noticeable background

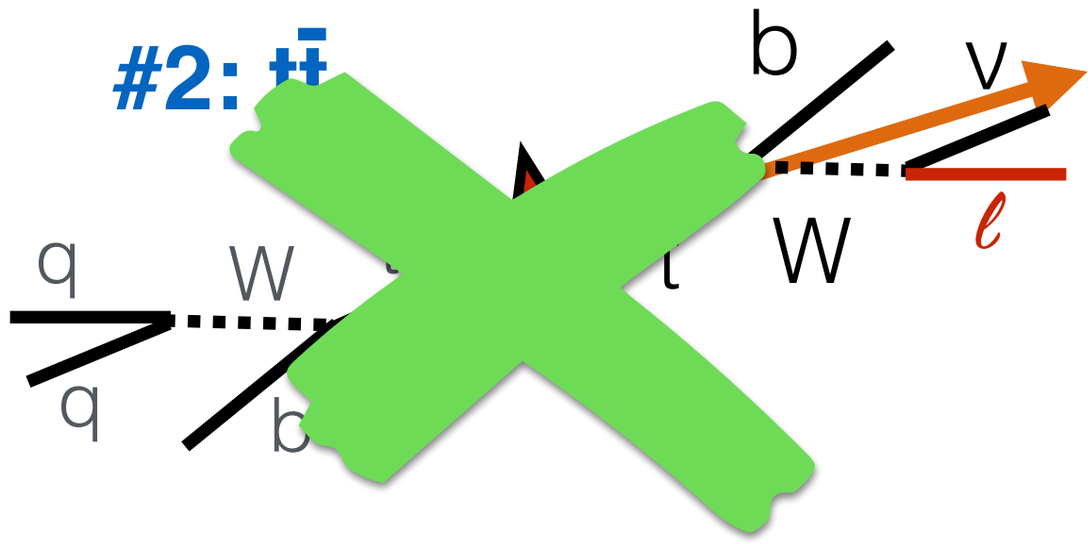
Backgrounds

#1: QCD



- **Dominant**; MET from misreconstruction

#2: $t\bar{t}$

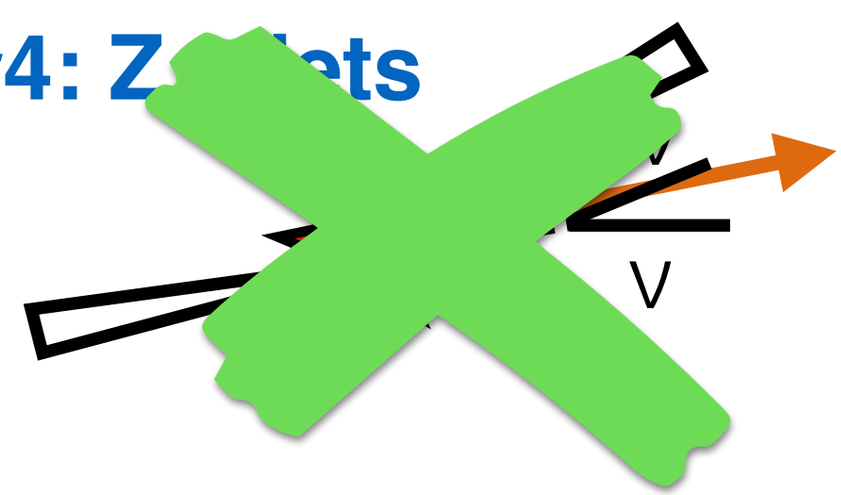


- Mimics SVJ if lepton is missed

#3: $t\bar{t}$ + jets

- MET from missed lepton
- Not so likely to mimic SVJ, but high σ
- **Veto leptons**
- **Require $\Delta\phi_{min}$ < threshold**
- Other less significant cuts

#4: Z + jets

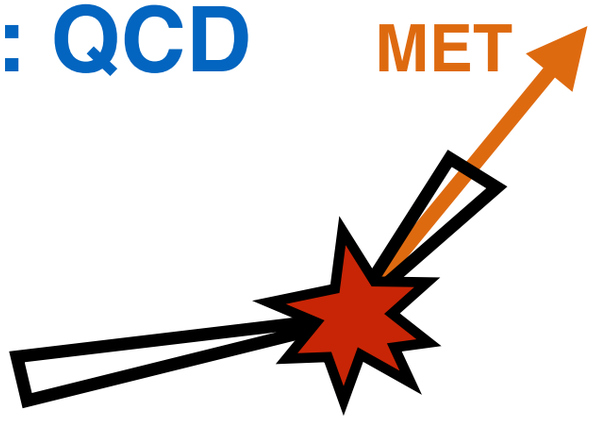


- Least likely to have MET aligned with jet, but still noticeable background

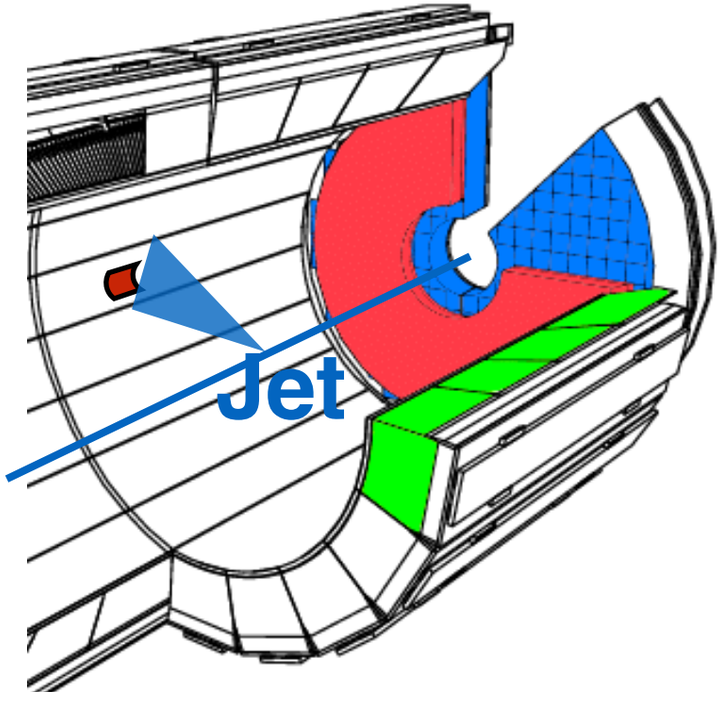
$\Delta\phi_{min} = \min(\Delta\phi(j_1, \text{MET}), \Delta\phi(j_2, \text{MET}))$

Backgrounds

#1: QCD



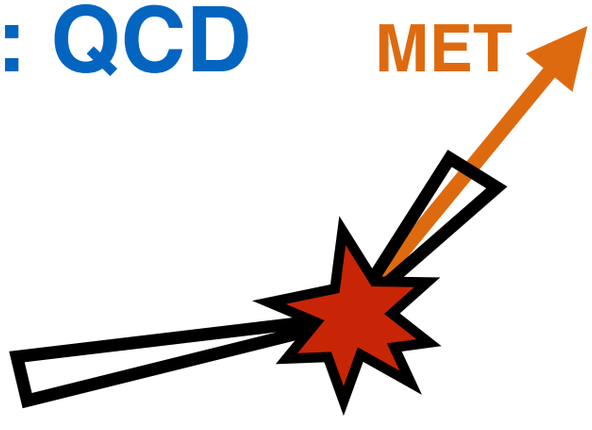
ECAL dead cell



- Mostly **instrumental MET**, i.e. failure to reconstruct the whole jet
- Example: ECAL dead cells
- Custom filter put in place to reject an additional 40% QCD

Backgrounds

#1: QCD



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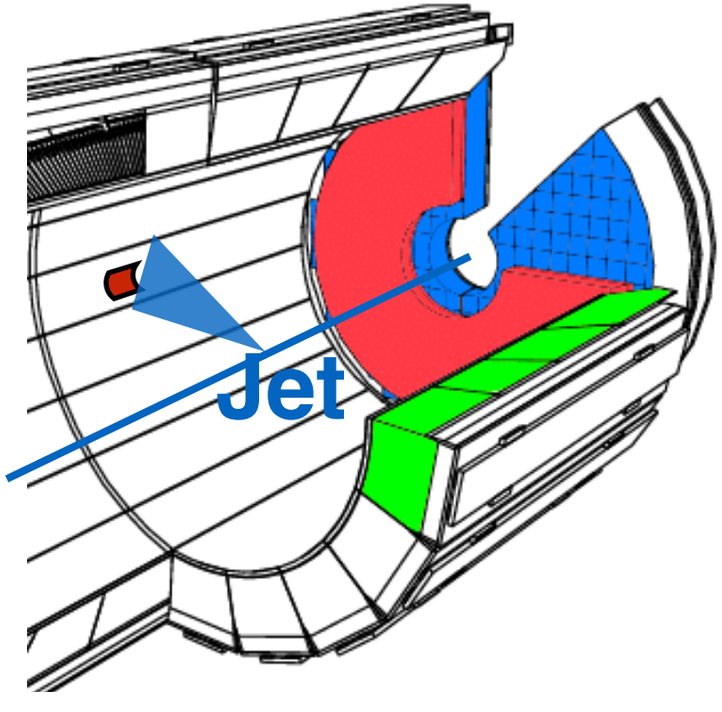
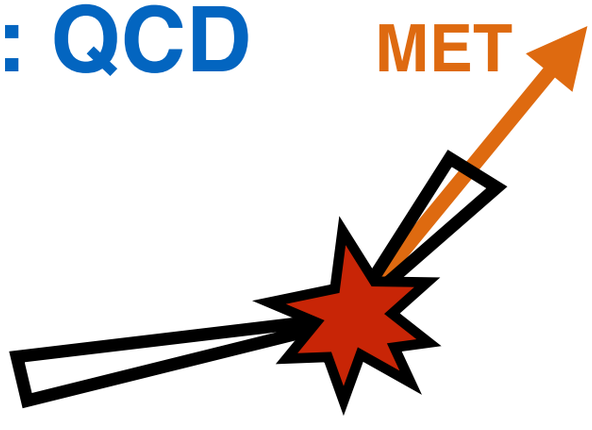


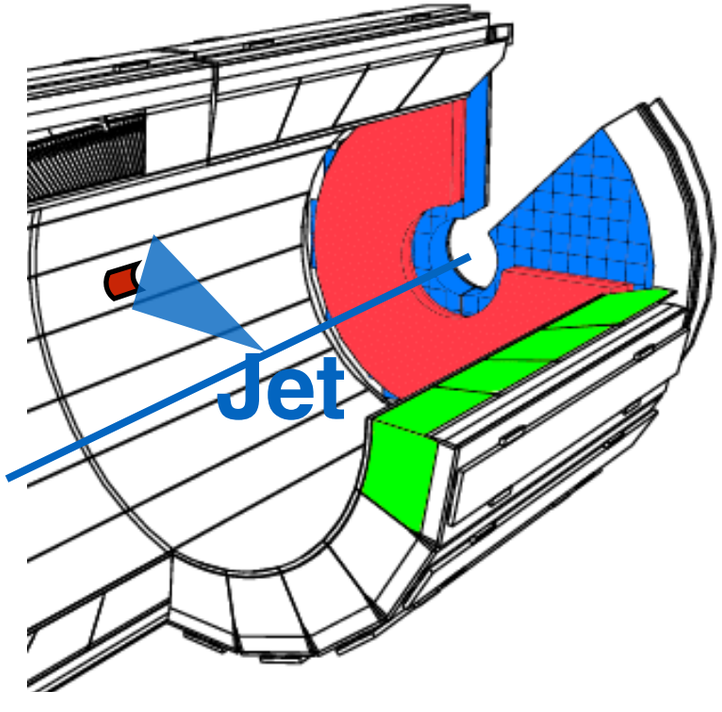
- Mostly **instrumental MET**, i.e. failure to reconstruct the whole jet
  - Example: ECAL dead cells
  - Custom filter put in place to reject an additional 40% QCD
- Main QCD rejection: require **R_T = MET/M_T > threshold**
  - Good QCD rejection without sculpting M_T distribution

Backgrounds

#1: QCD



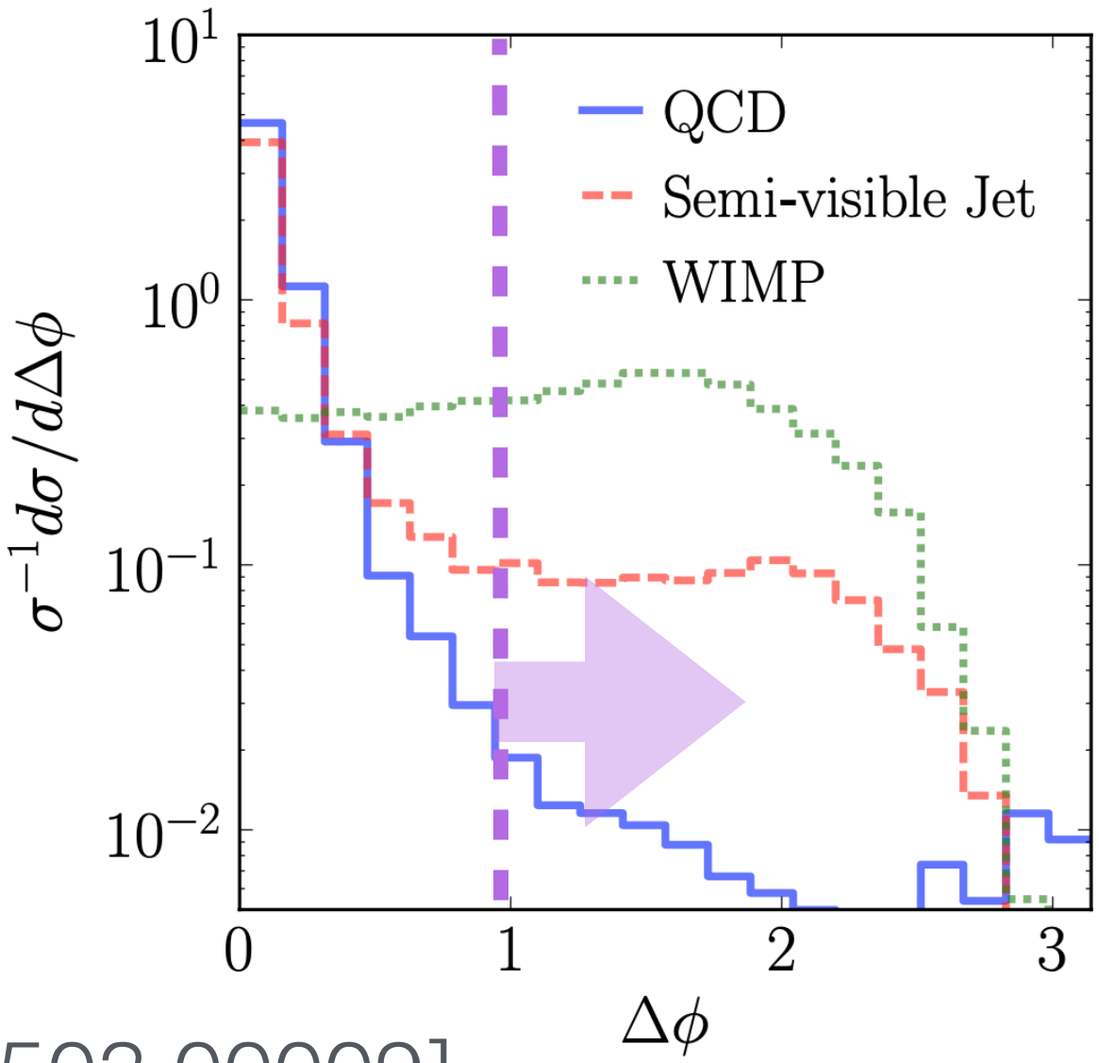
ECAL dead cell



- Mostly **instrumental MET**, i.e. failure to reconstruct the whole jet
  - Example: ECAL dead cells
  - Custom filter put in place to reject an additional 40% QCD
- Main QCD rejection: require **R_T = MET/M_T > threshold**
  - Good QCD rejection without sculpting M_T distribution
- Further reduction via a **BDT** based on jet variables
  - **Model dependent!**
  - Perform final fits **without BDT** too; weaker limits, but no model dependence

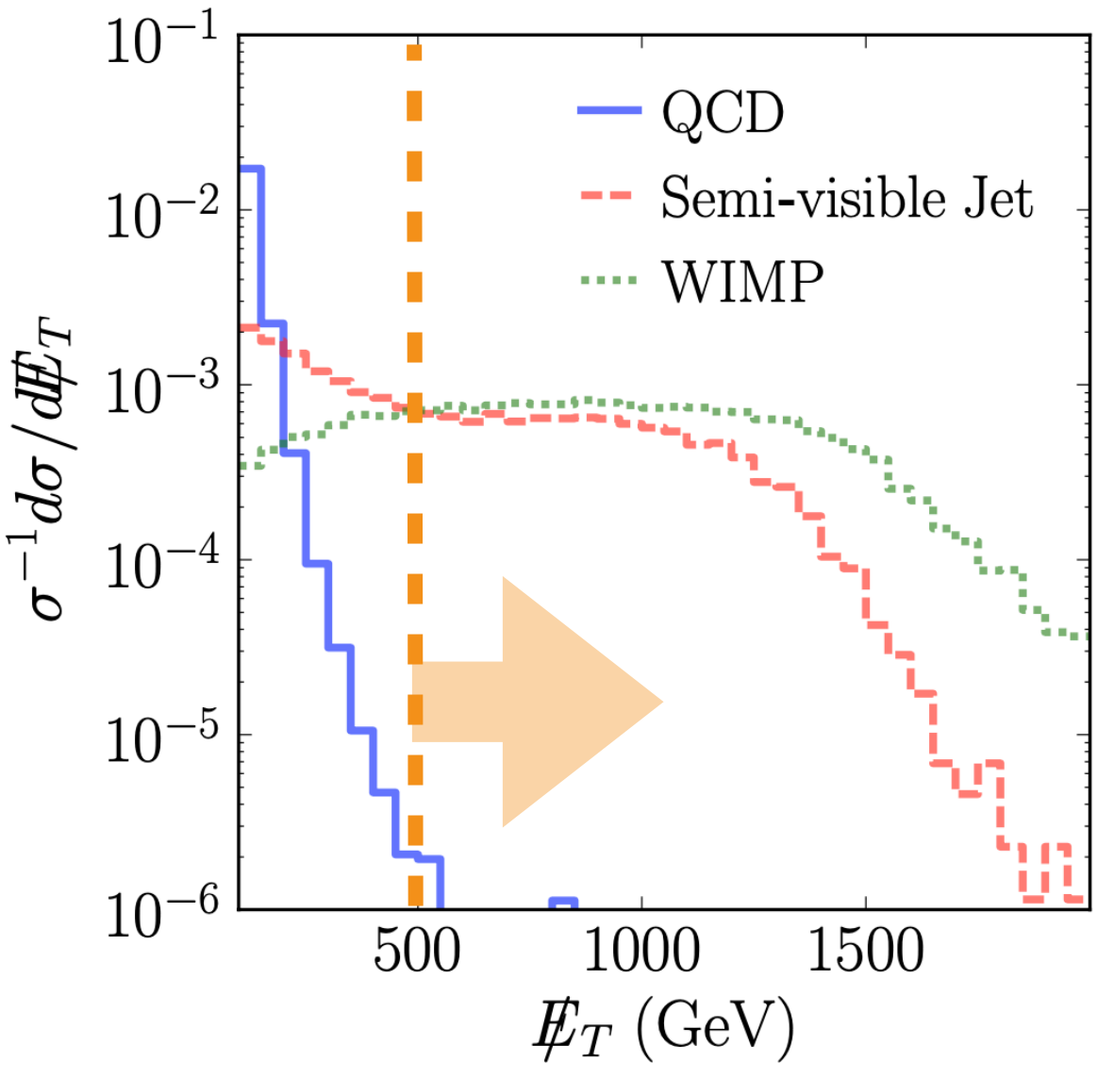
Phenomenology of SVJs

Δϕ cut very inefficient for SVJs



[1503.00009]

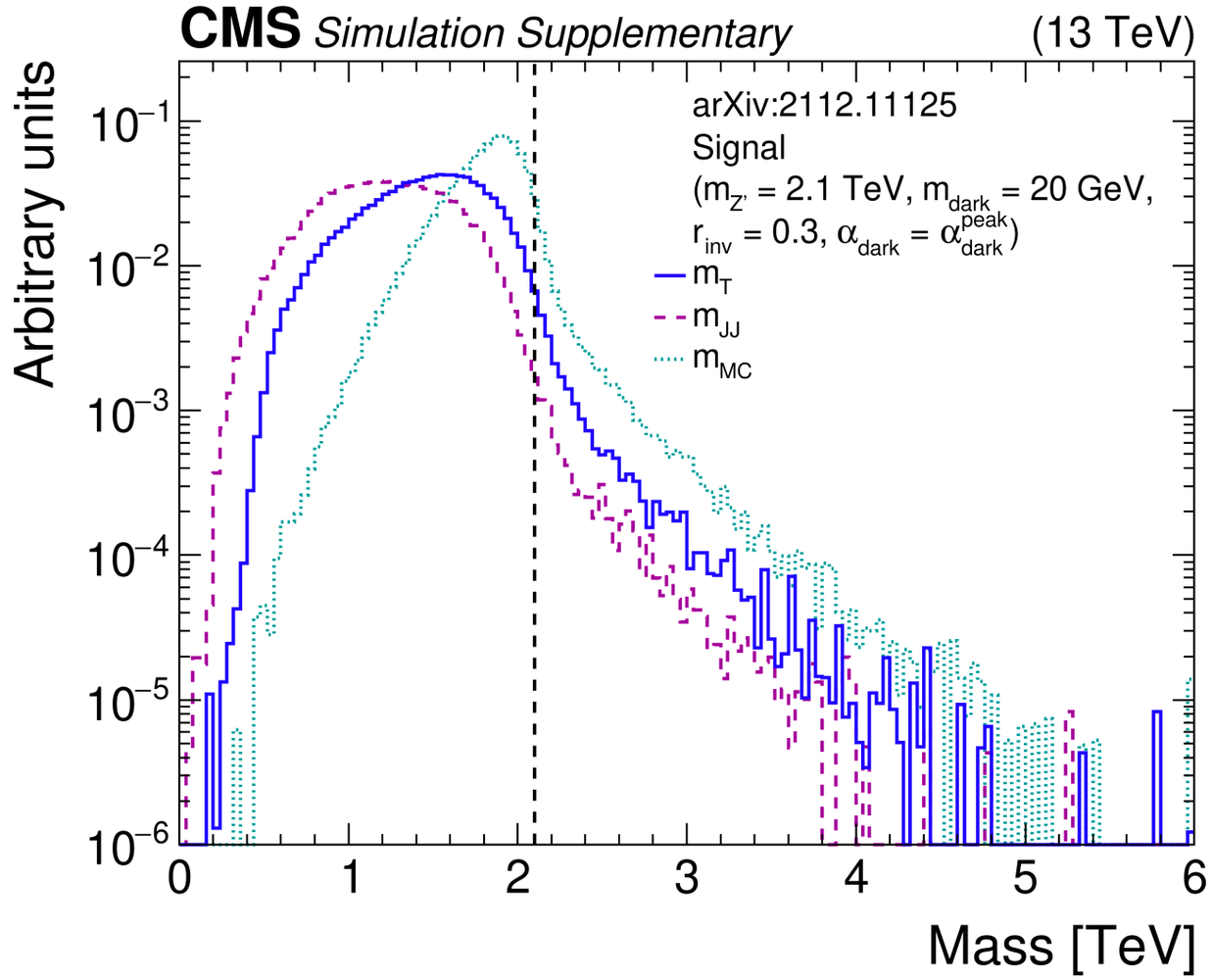
Cut on MET kills more than for WIMP case



- **Semivisible jet searches not covered by current searches**

Search strategy: Bump hunt

- High-mass Z' ($m_{Z'}$ > ~1000 GeV) leads to a **resonance** in the mass spectrum
- Searching in **M_T(JJ, MET):**



$$M_{\mathrm{T}}^2 = \left(\mathrm{MET} + \sqrt{p_{\mathrm{T,\,dijet}}^2 + m_{\mathrm{dijet}}^2}\right)^2 - (\mathrm{MET}_x + p_{x,\,\mathrm{dijet}})^2 - (\mathrm{MET}_y + p_{y,\,\mathrm{dijet}})^2$$

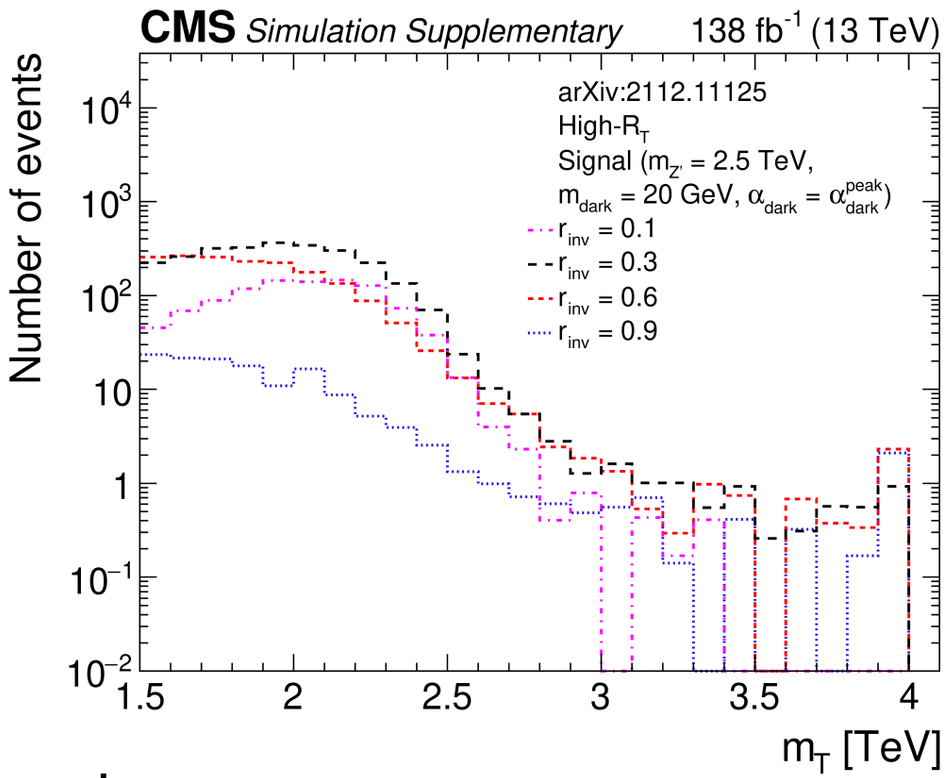
  - Kinematic **edge** @ $m_{Z'}$
  - Better resolution than m_{JJ}
- SM backgrounds smoothly falling

Signal regions

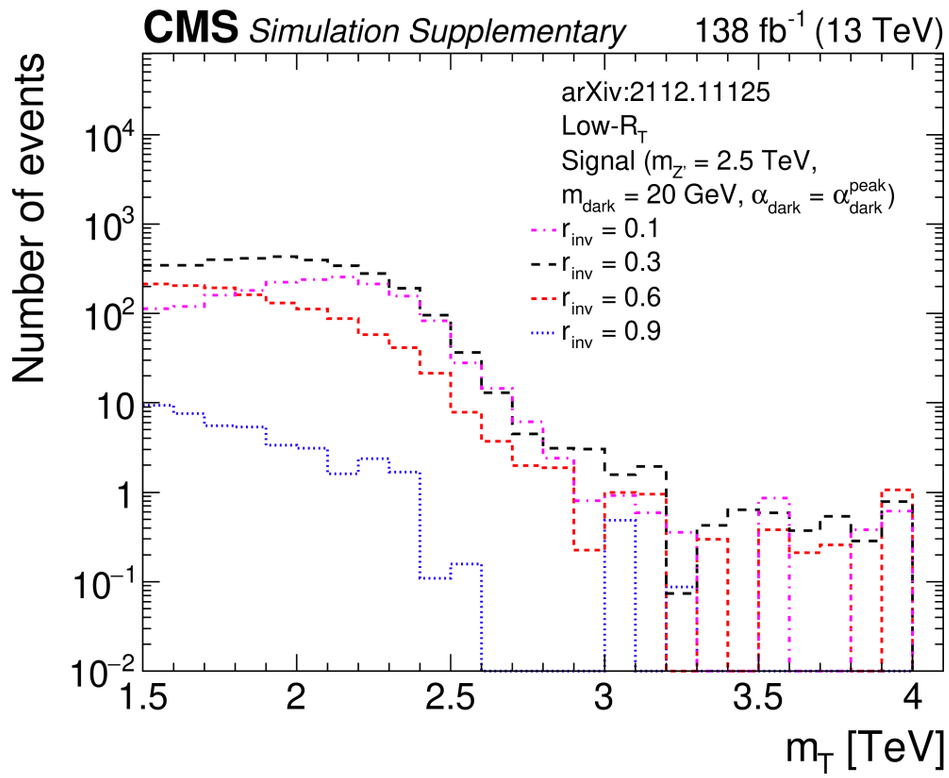
$R_T = MET/M_T$

- A low and high 'purity' regions are constructed to enhance sensitivity:

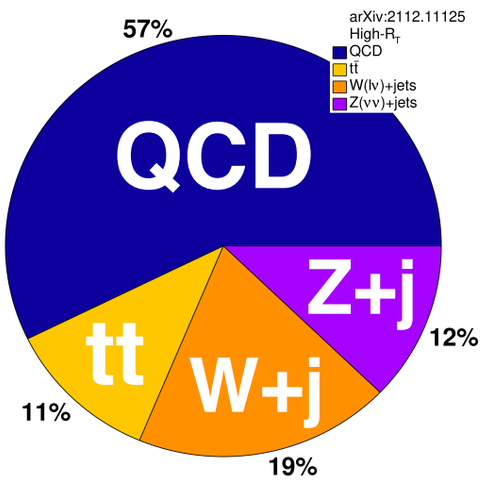
High: $R_T > .25$

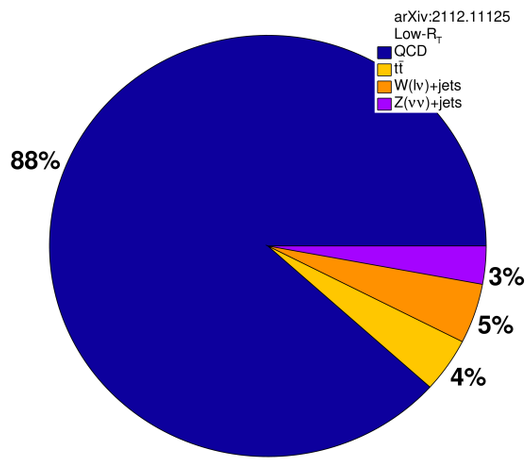


Low: $.15 < R_T < .25$



- Kinematic edge somewhat degraded in low purity region
- Pronounced effect of r_{inv} on M_T spectrum



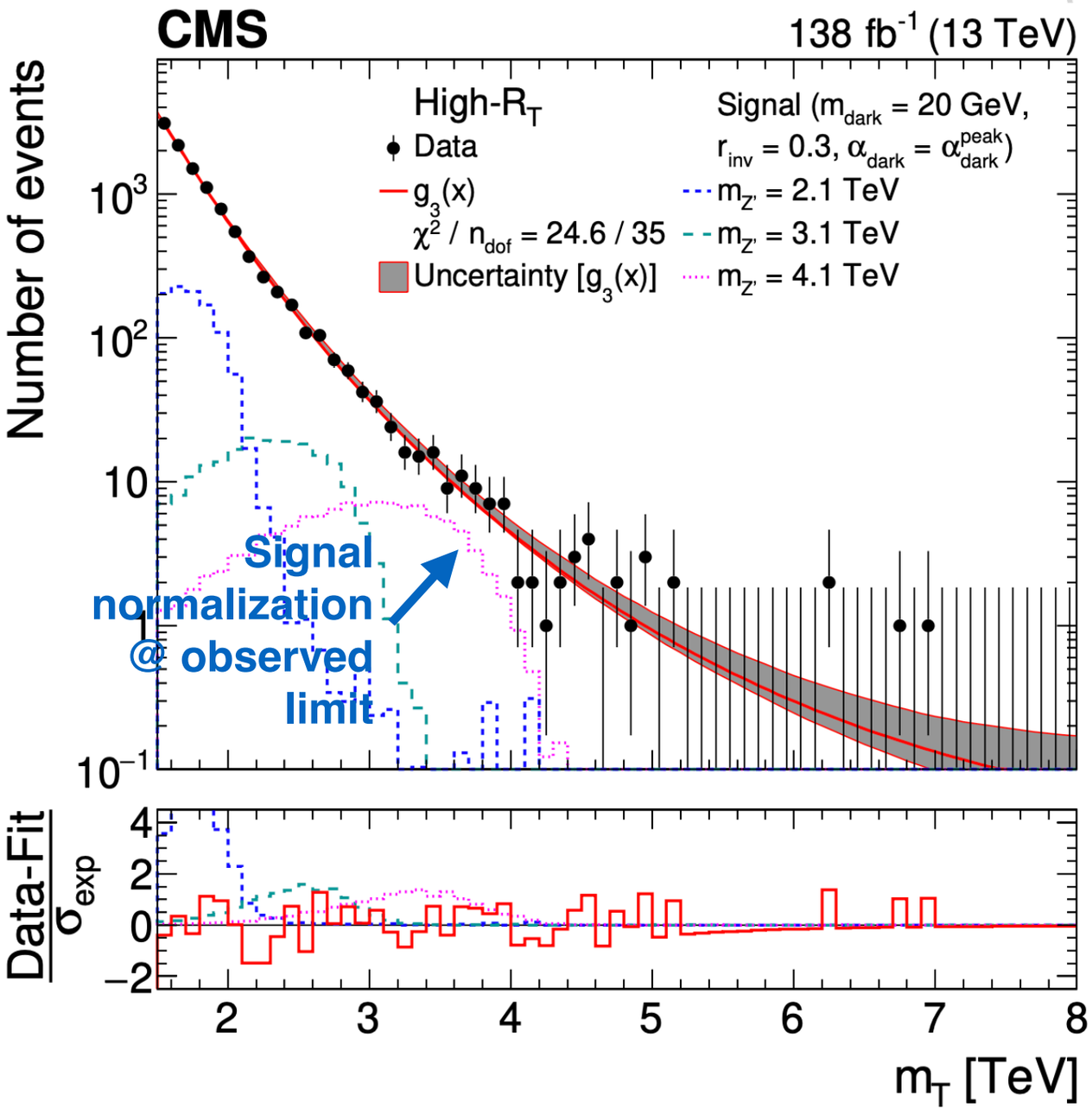


Results

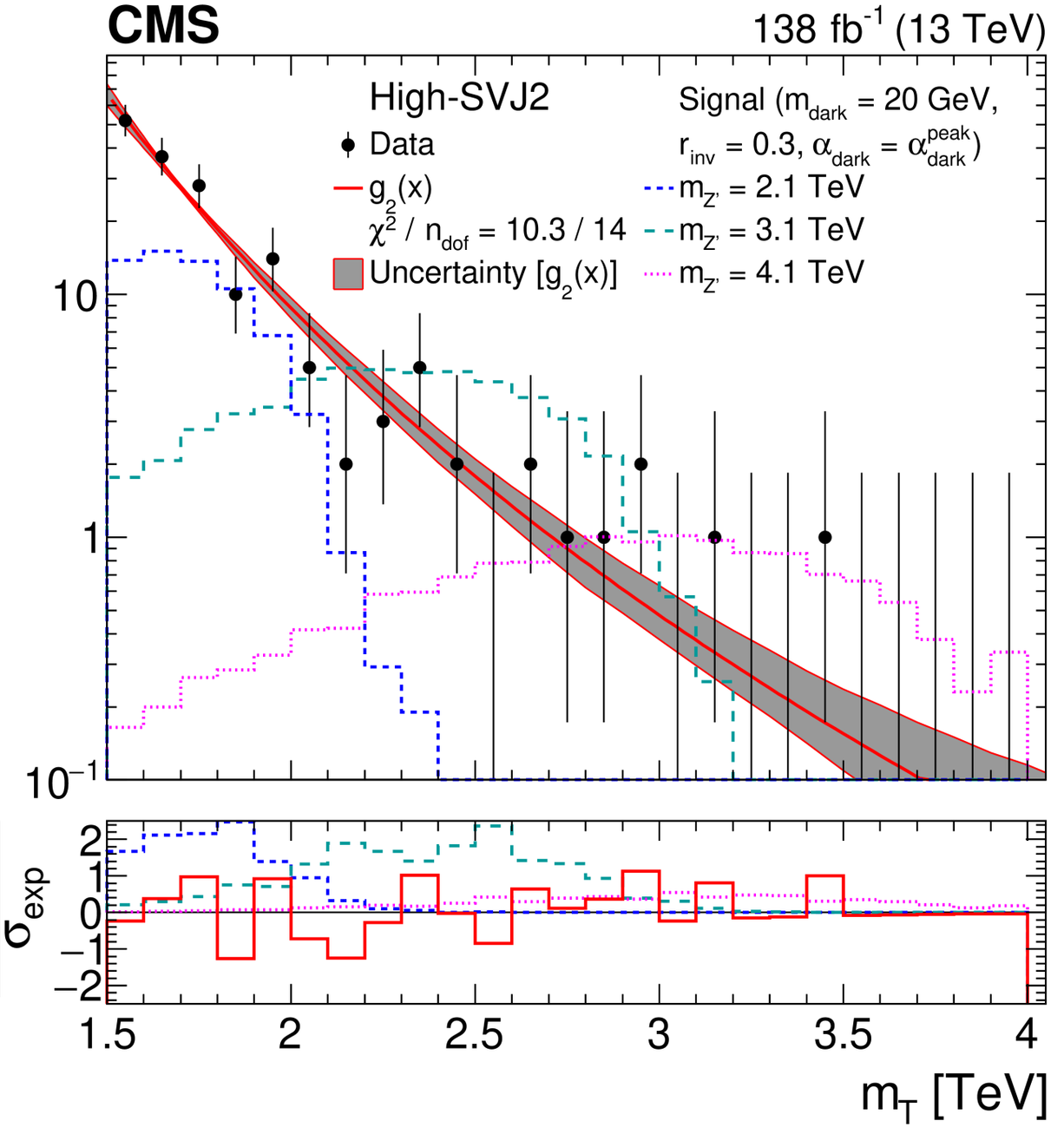
High purity region only: $R_T > .25$

- Background estimation relies on fit to data

No BDT

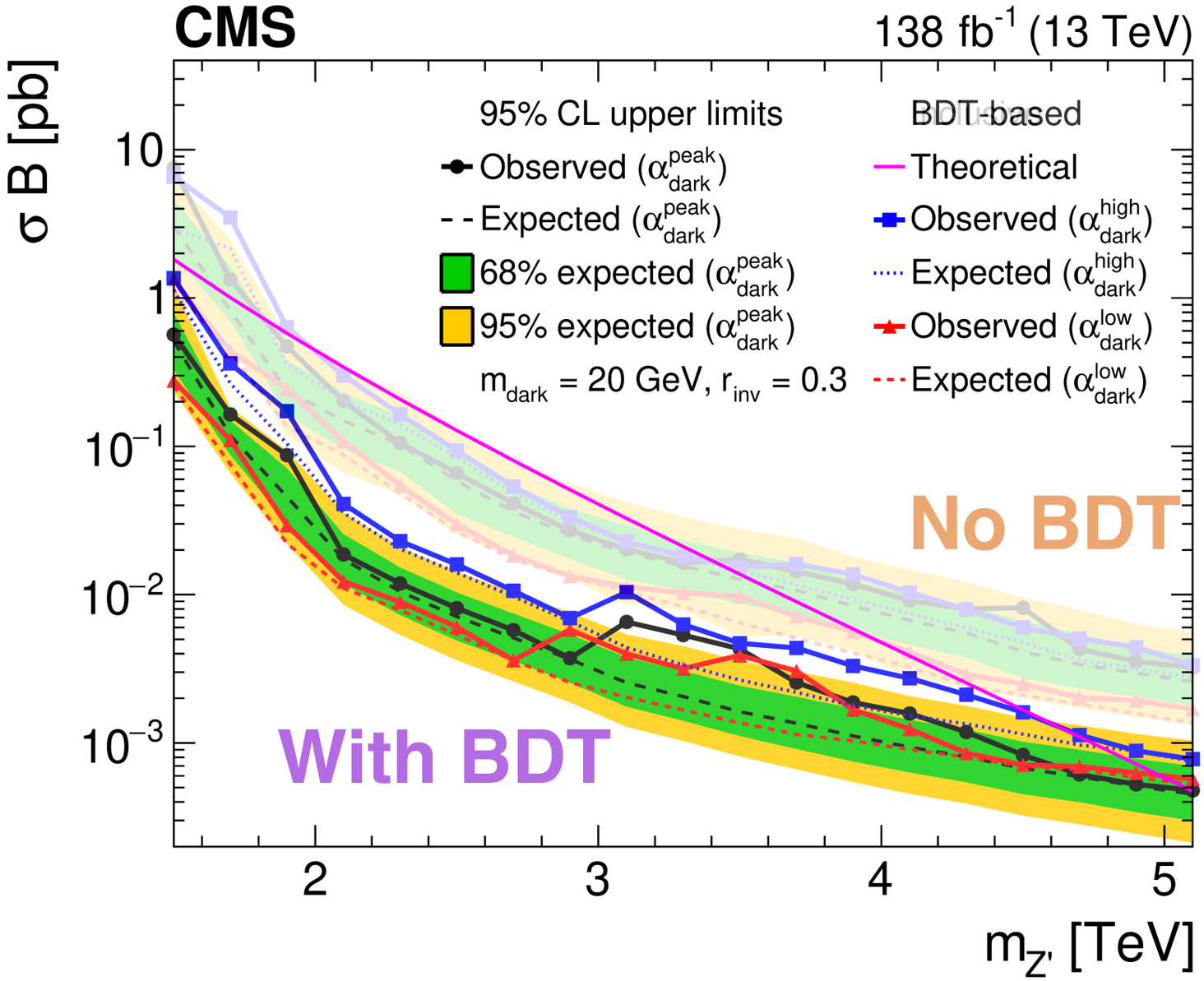


With BDT



- No significant deviations from data

Limits



No BDT

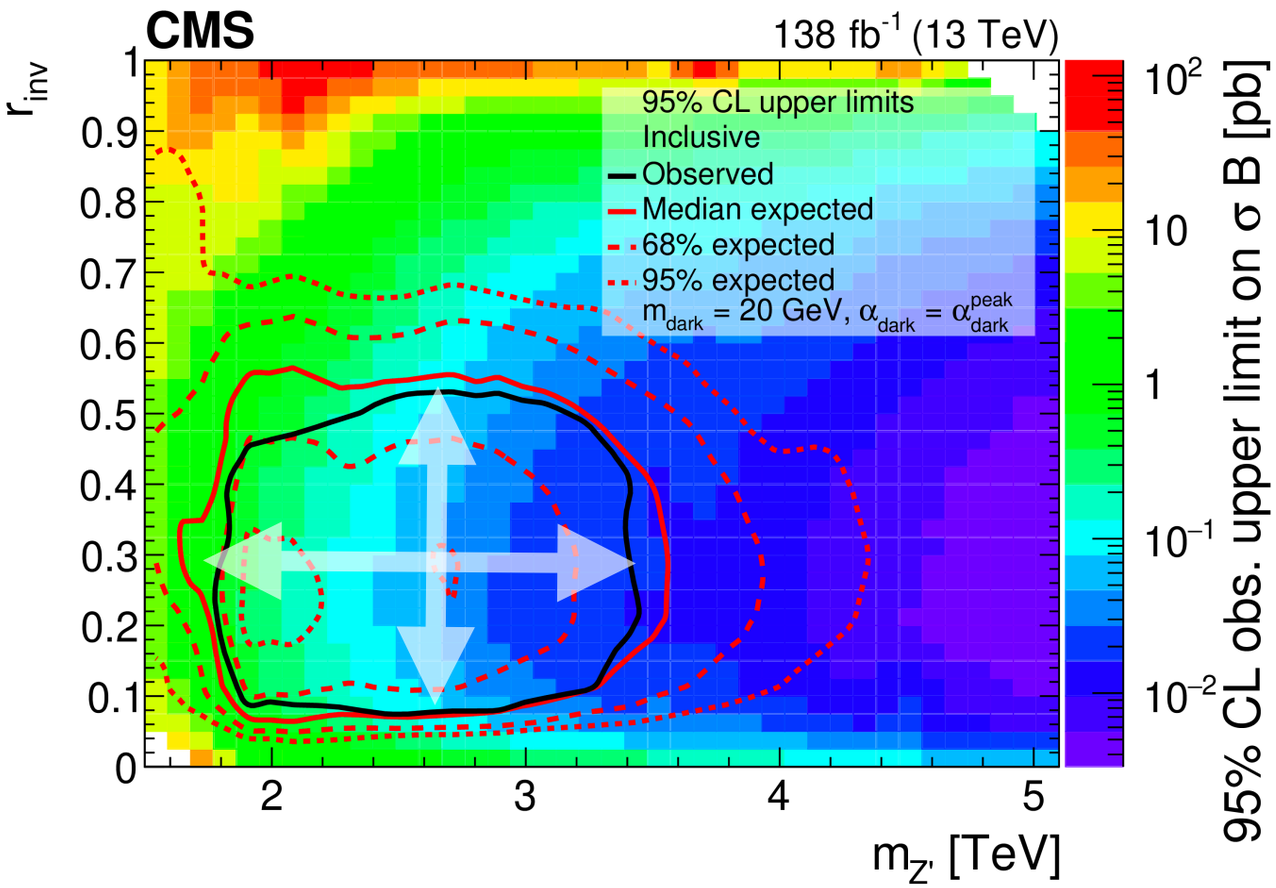
$1.5 < m_{Z'} < 4.0$ TeV (95% CL)

With BDT

$1.5 < m_{Z'} < 5.1$ TeV (95% CL)

Limits in ($m_{Z'}$, r_{inv})-plane

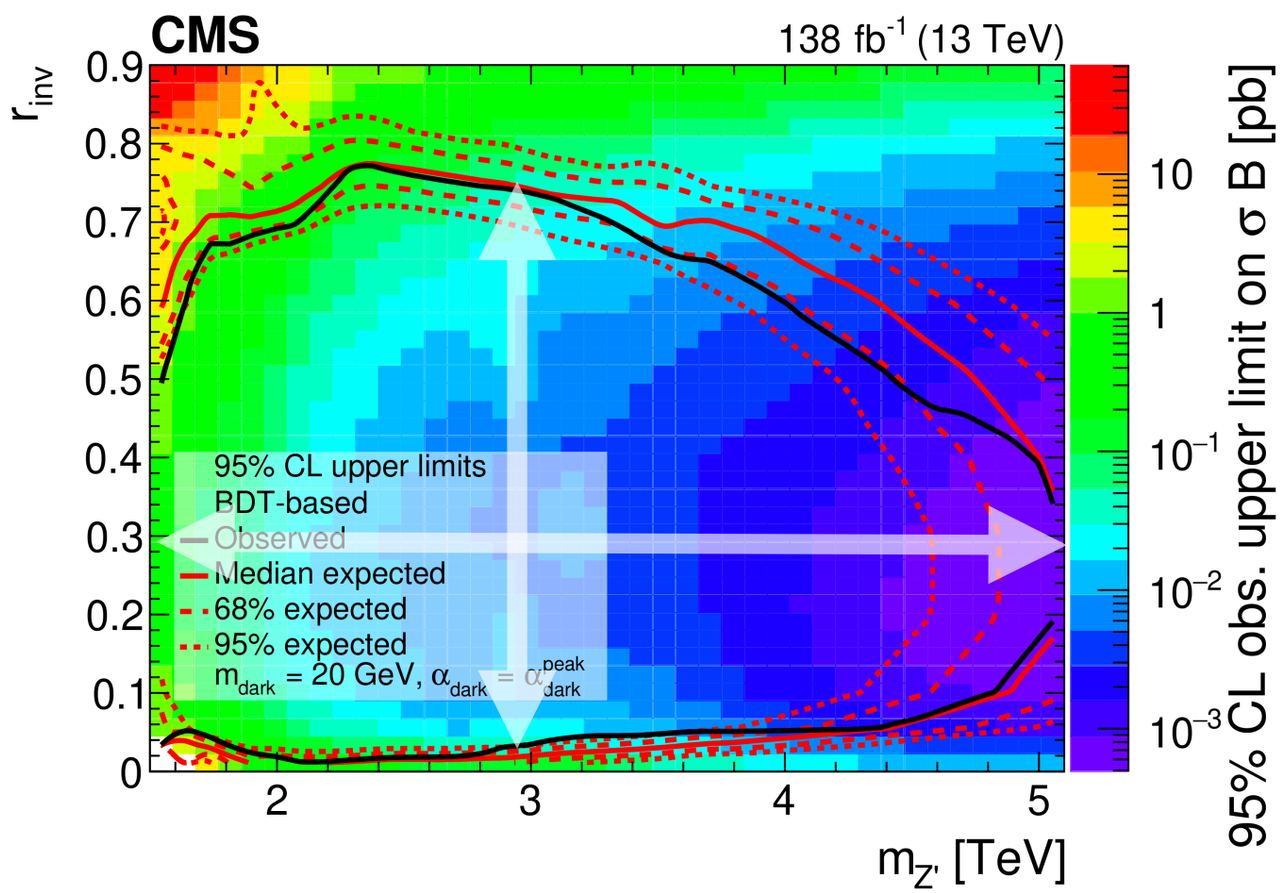
No BDT



$1.5 < m_{Z'} < 4.0$ TeV (95% CL)

$0.07 < r_{inv} < 0.53$ (95% CL)

With BDT



$1.5 < m_{Z'} < 5.1$ TeV (95% CL)

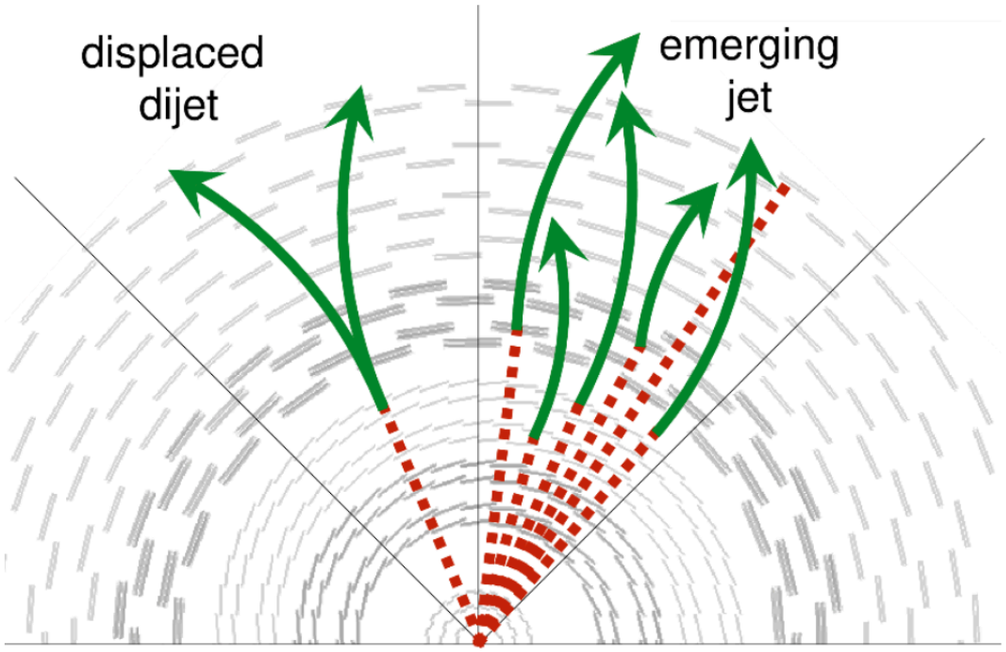
$0.01 < r_{inv} < 0.77$ (95% CL)

Other SVJ analyses in the pipeline

Emerging jets

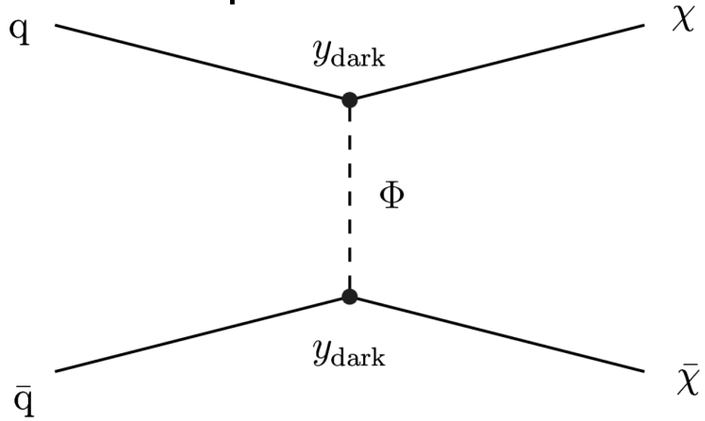
What if the dark hadrons have a non-negligible lifetime?

Published: [JHEP 02 (2019) 179]



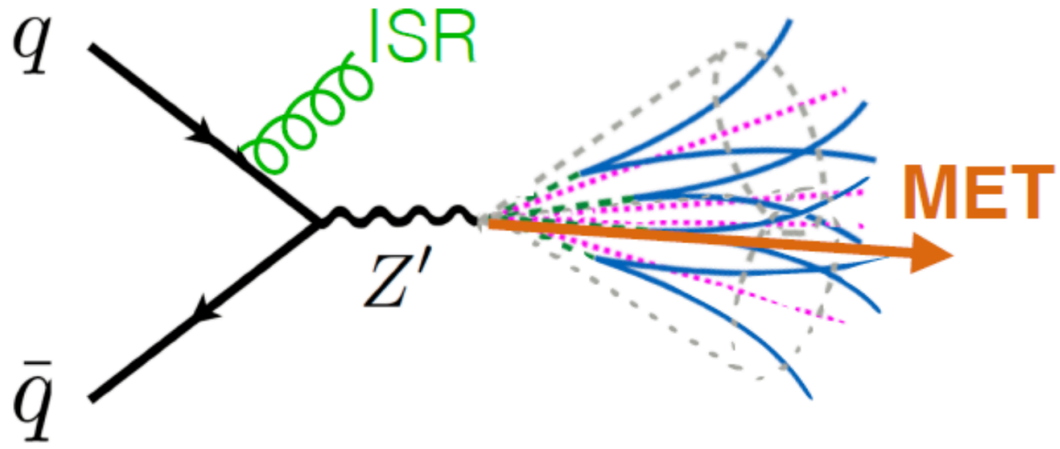
t-channel

Alternative production mode



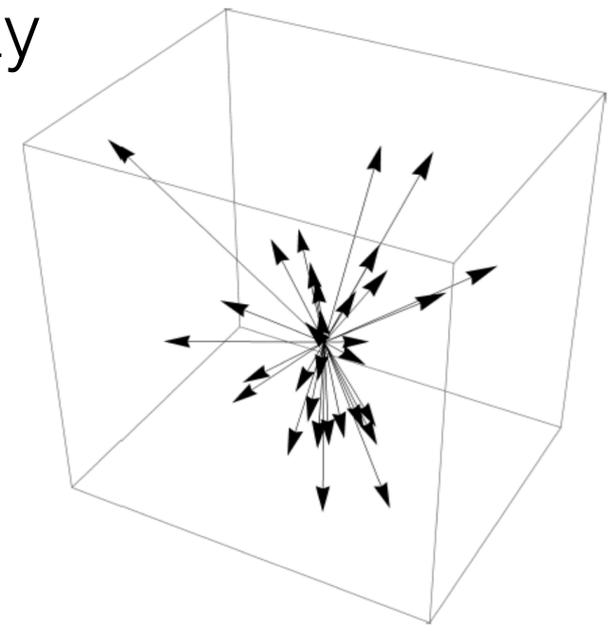
Boosted SVJs

What if $m_{Z'}$ is low and the Z' system is boosted?



Soft unclustered energy patterns (SUEPs)

Large 't Hooft coupling causing a spherical spray



Conclusion

- Dark sector models can have interesting new signatures in particle detectors
- Presented a search for semivisible jets in the CMS detector
  - First direct search for strongly-coupled composite dark matter at colliders
  - Both model independent and model specific results
- Many other interesting signatures possible - stay tuned!