# Signatures of the Inert Triplet Model from Vector Boson Fusion at a Muon Collider


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Based on arXiv: 2401.02697v2 [hep-ph]

## The Inert Triplet Model (ITM)

Extend the SM scalar sector with an $SU(2)$ triplet with $Y=0$

$$\mathcal{T} = \frac{1}{2}\begin{pmatrix} T^0 & \sqrt{2}T^+ \\ \sqrt{2}T^- & -T^0 \end{pmatrix}$$

odd under discrete $Z_2$ symmetry: remains inert.

After EWSB: at tree-level, $T^0$, $T^\pm$ are degenerate.
At one-loop: $M_{T^\pm} - M_{T^0} \sim 166\,\text{MeV}$ ⟶ $T^0$ is Dark Matter!
Compressed spectrum ⟶ displaced decay.

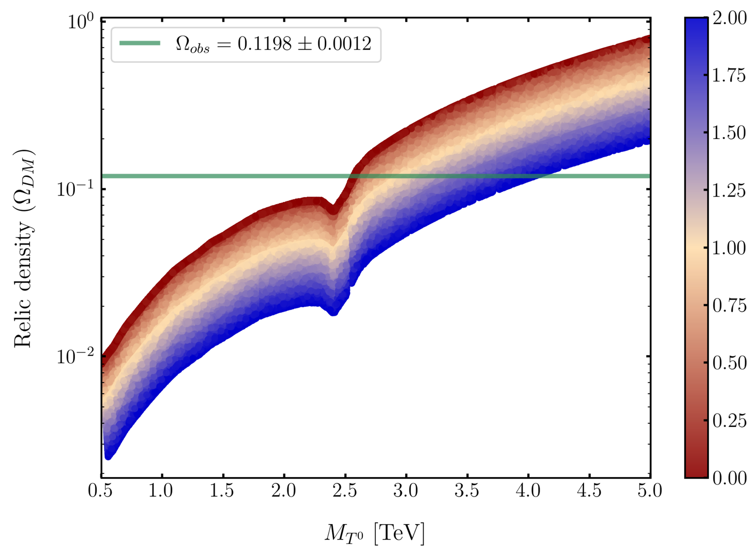
$$T^\pm \to T^0\pi^\pm \quad BR \sim 97.7\%,$$
$$T^\pm \to T^0 e^\pm \nu_e \quad BR \sim 2\%,$$
$$T^\pm \to T^0 \mu^\pm \nu_\mu \quad BR \sim 0.25\%,$$

proper lifetime ~ 0.19 ns
rest mass decay length ~ 5.7 cm

Cirelli et al, Nucl. Phys. B 753 (2006) 178-194

## Dark Matter and Benchmarks

relic density




collider benchmarks

| BP | $M_{T^0}$ [TeV] | $\lambda_{ht}$ | $\Omega_{DM}$ | $\Omega_{DM}/\Omega_{obs}$ |
|---|---|---|---|---|
| BP1 | 1.21 | 0.026 | 0.037 | 0.312 |
| BP2 | 1.68 | 0.0 | 0.063 | 0.525 |
| BP3 | 3.86 | 1.861 | 0.119 | 1.000 |

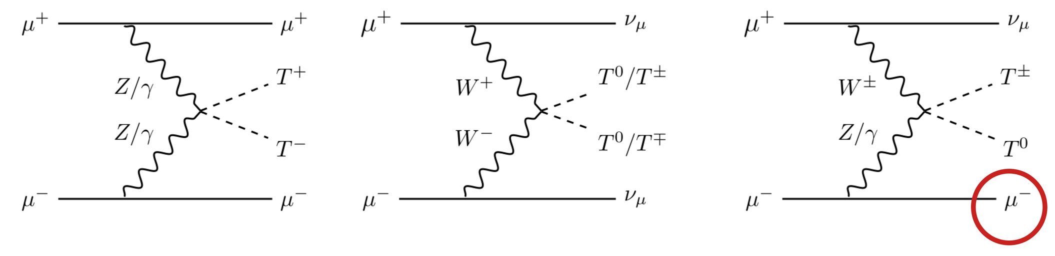
Masses between 1.9-3.8 TeV are excluded by Fermi-LAT data.

Collider reach studied independently, later.

## Why a Muon Collider?

TeV-scale inert scalar spectrum not efficiently produced at the LHC.
FCC has too much hadronic BG: we want to be hadronically quiet.
**Muon Collider (MuC):** all of the CM energy available for collision.
No ISR/FSR QCD hadronic BG: cleaner signals.
Ability to achieve much higher luminosities. ( 10/ab at 10 TeV! )
At high energies: essentially a vector boson fusion (VBF) machine.
⟶ Large VBF cross-sections for the ITM scalars!
Cons:
Accettura et al, *Towards a Muon Collider*, 2303.08533
Beam-induced BG (BIB): a sea of soft leptons, photons, pions...

## VBF at MuC

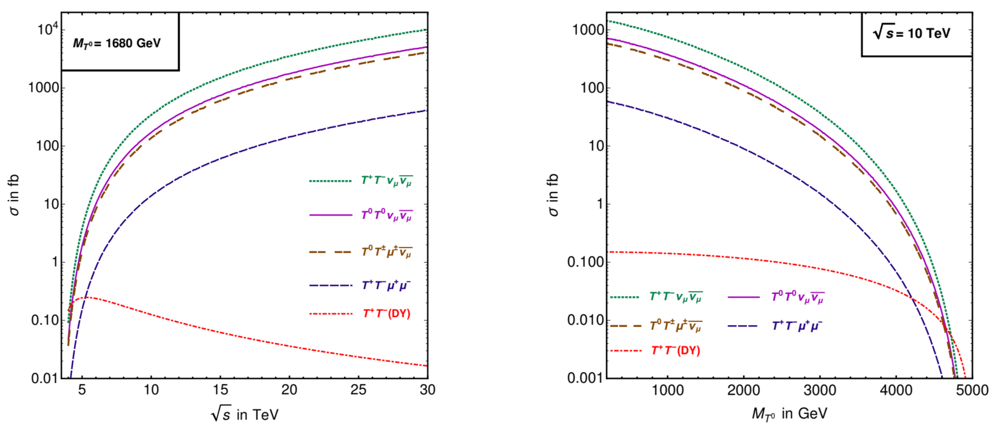


VBF wins over DY: grows $\propto \log^n(s/M_V^2)$

Forward Muons can trigger the VBF event.

BIB mitigation nozzles require main detector to have $|\eta| < 2.5$.
High-momentum Forward Muons pass through to dedicated detectors.

Spectator muons: high momentum, high pseudorapidity.
Large *TTVV*-type vertices: significant VBF production rate.




## Final states at MuC

Pions from $T^\pm$ decay are too soft to detect for heavier scalars: ⟶ disappearing charged tracks (DCT) for $T^\pm$.
Capdevilla et al, 2405.08858

Combined with detectable Forward Muons: four possible final states:

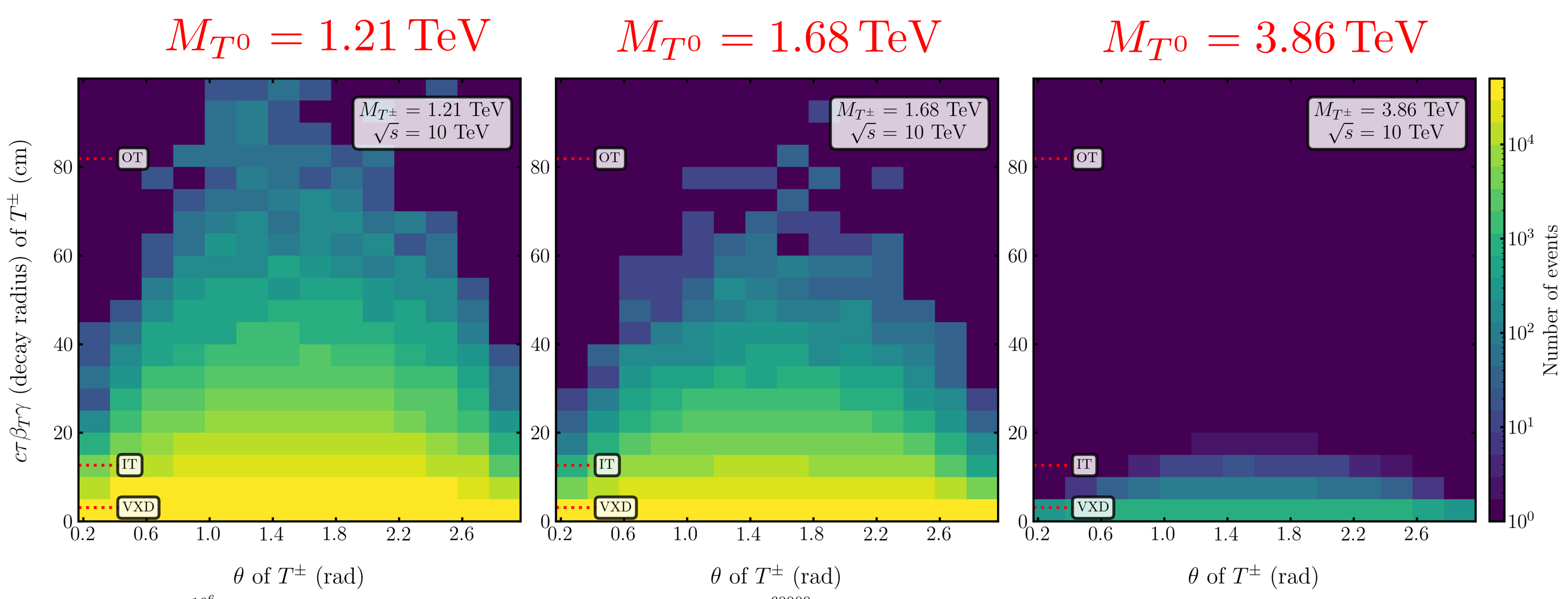
**FS1**: 1 DCT + 1 Forward muon + MET $\Longleftarrow T^\pm T^0 \mu^\pm \nu, \quad T^+T^-\mu^+\mu^-$;
**FS2**: 2 DCT + 2 Forward muons + MET $\Longleftarrow T^+T^-\mu^+\mu^-$;
**FS3**: 1 DCT + 2 Forward muons + MET $\Longleftarrow T^+T^-\mu^+\mu^-$;
**FS4**: 2 DCT + 1 Forward muon + MET $\Longleftarrow T^+T^-\mu^+\mu^-$.

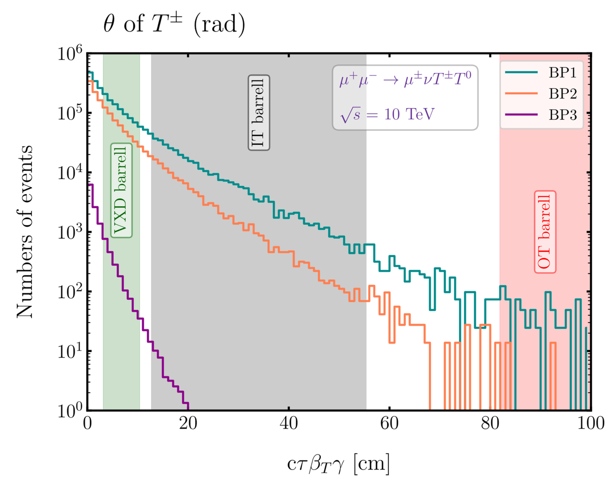
Veto out jets, leptons, calorimeter hits: No SM BG. only fake tracks from BIB.

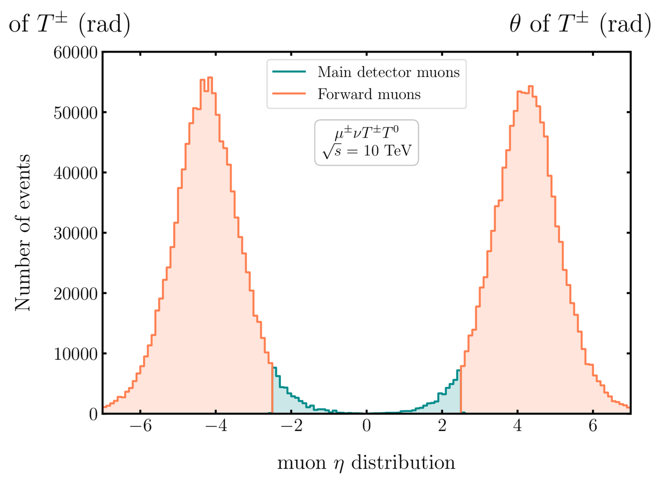
## Signal characteristics and selection

More BIB in endcaps + early tracker layers → less tracking efficiency

Efficiencies against BIB fake tracks calculated from explicit map provided in R. Capdevilla et al, JHEP 06 (2021) 133.



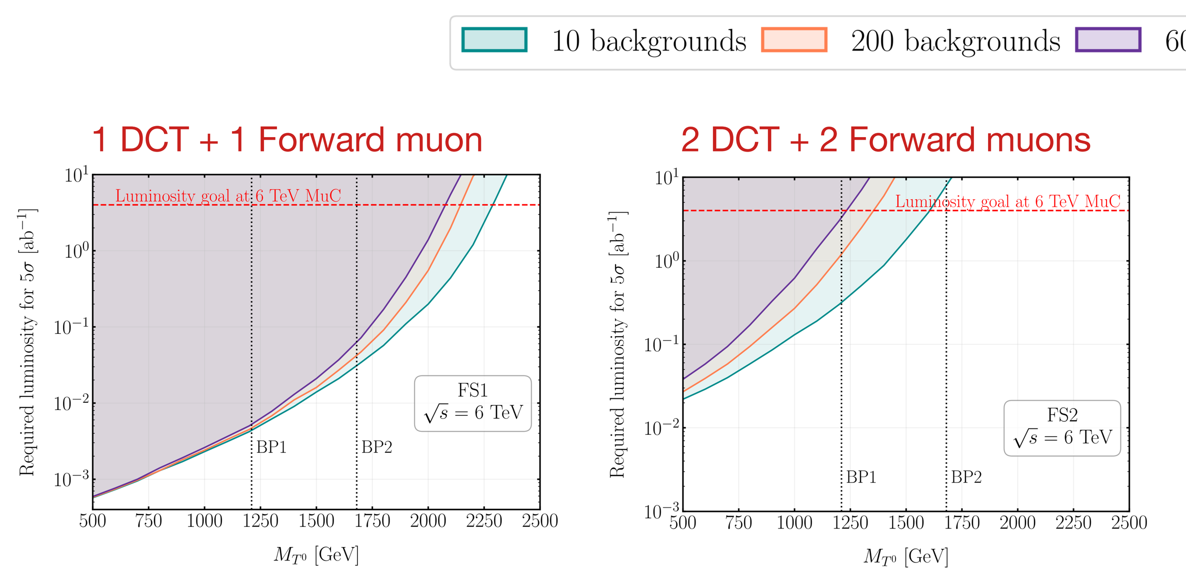




Plots at 10 TeV MuC with 10/ab luminosity

**Selection criteria for DCT:**
0.7 rad < $\theta$ < 2.44 rad (barrel)
5.1 cm < decay radius < 148.1 cm

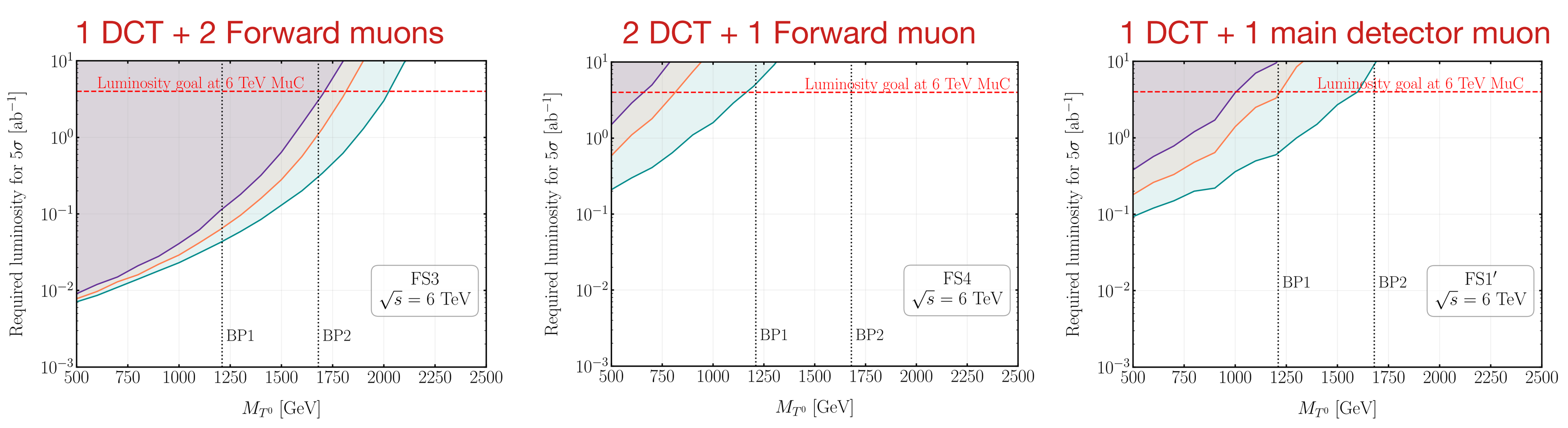
**Selection criteria for Forward $\mu^\pm$:**
$2.5 \leq |\eta| \leq 7.0$
$p_{\mu_F} \geq 300$ GeV.

## Discovery projection at 6 TeV MuC

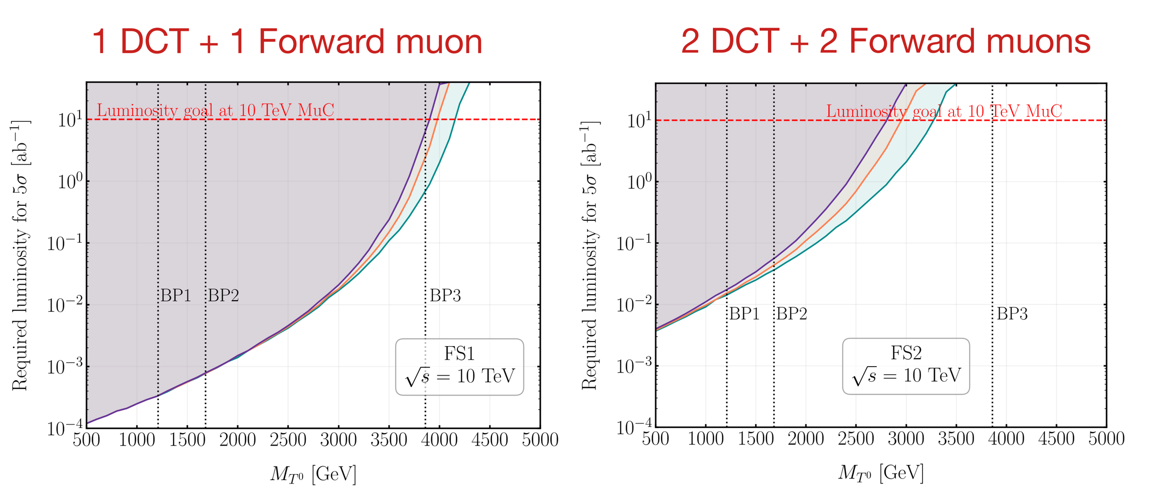



FS1 and FS3 can probe well beyond BP2 masses, with Forward muon tagging. BP3 is beyond kinematic reach.

Forward muon tagging enhances performance.

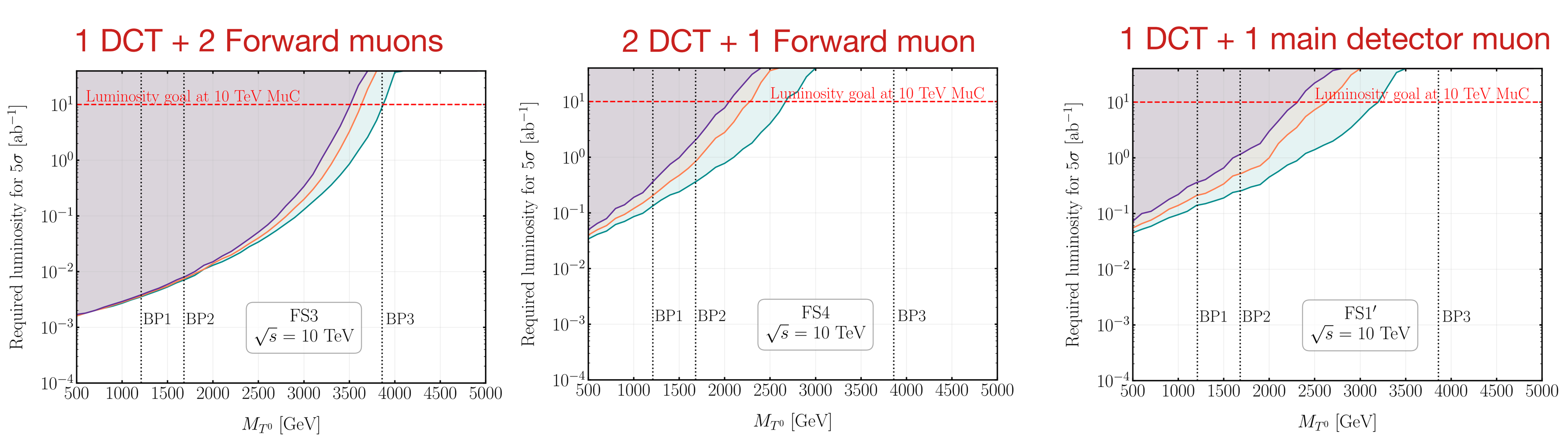



## Discovery projection at 10 TeV MuC




FS1 and FS3 can probe masses of all three BPs with the luminosity goal.

Maximum reach of 4.2 TeV (3.2 TeV) with (without) Forward muons.





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