tt+DM Simplified Model Benchmarks

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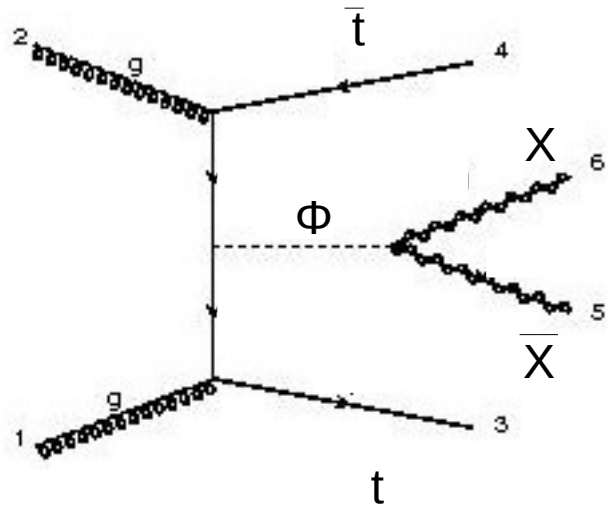
tt+DM Simplified Model

- Summary of efforts on spin-0 mediated ttbar+DM
  - Review of relevant kinematic regimes
  - Selection of common mediator/DM model points
- Simplified model
  - Scalar or pseudoscalar mediator (Φ)
  - Dirac fermion DM particle (χ)
  - Yukawa coupling of mediator to SM fermions
    - Universal $g_{SM} = g_{DM}$
  - Minimum width (Φ couples only SM fermions and χ)

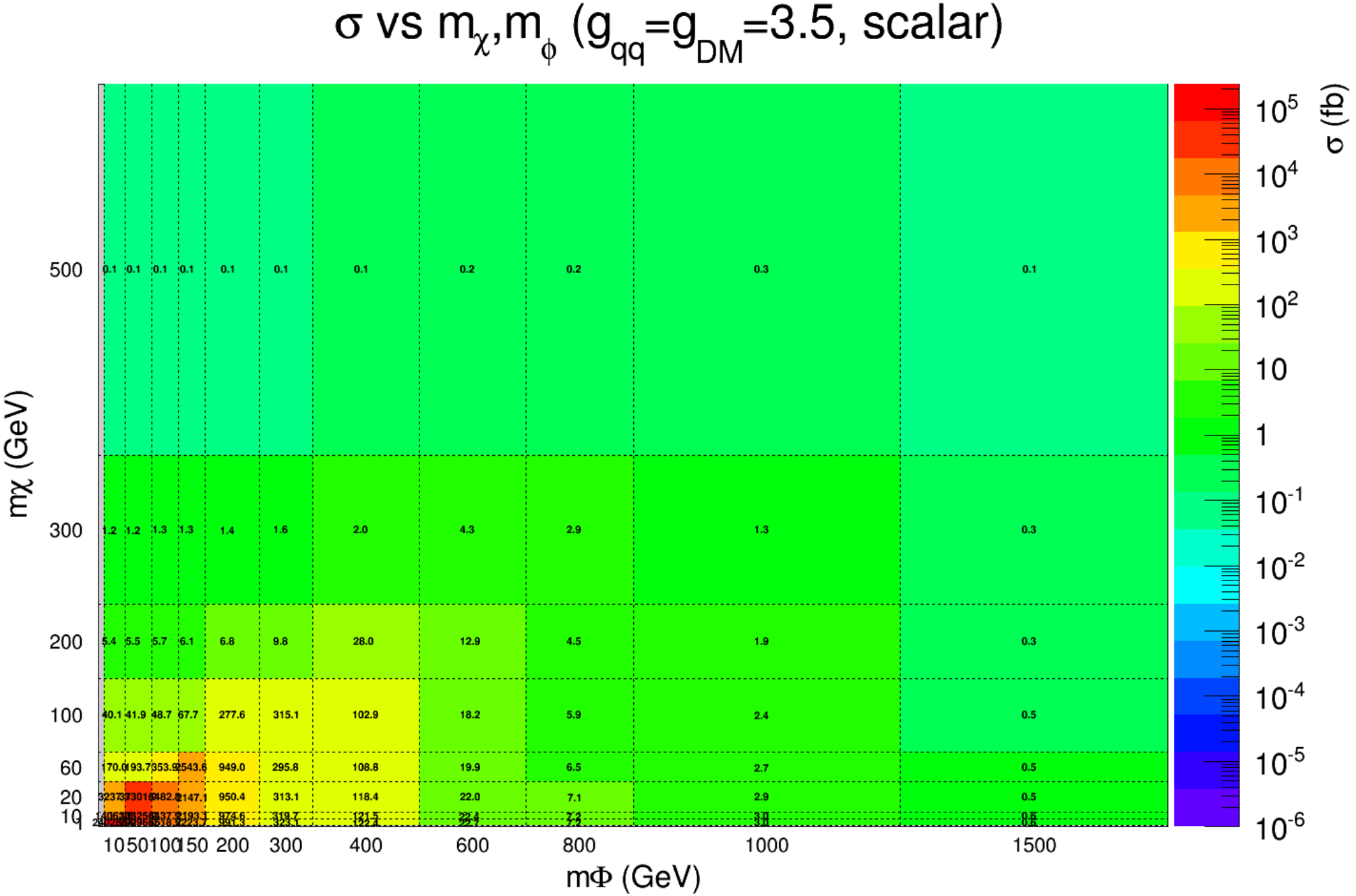


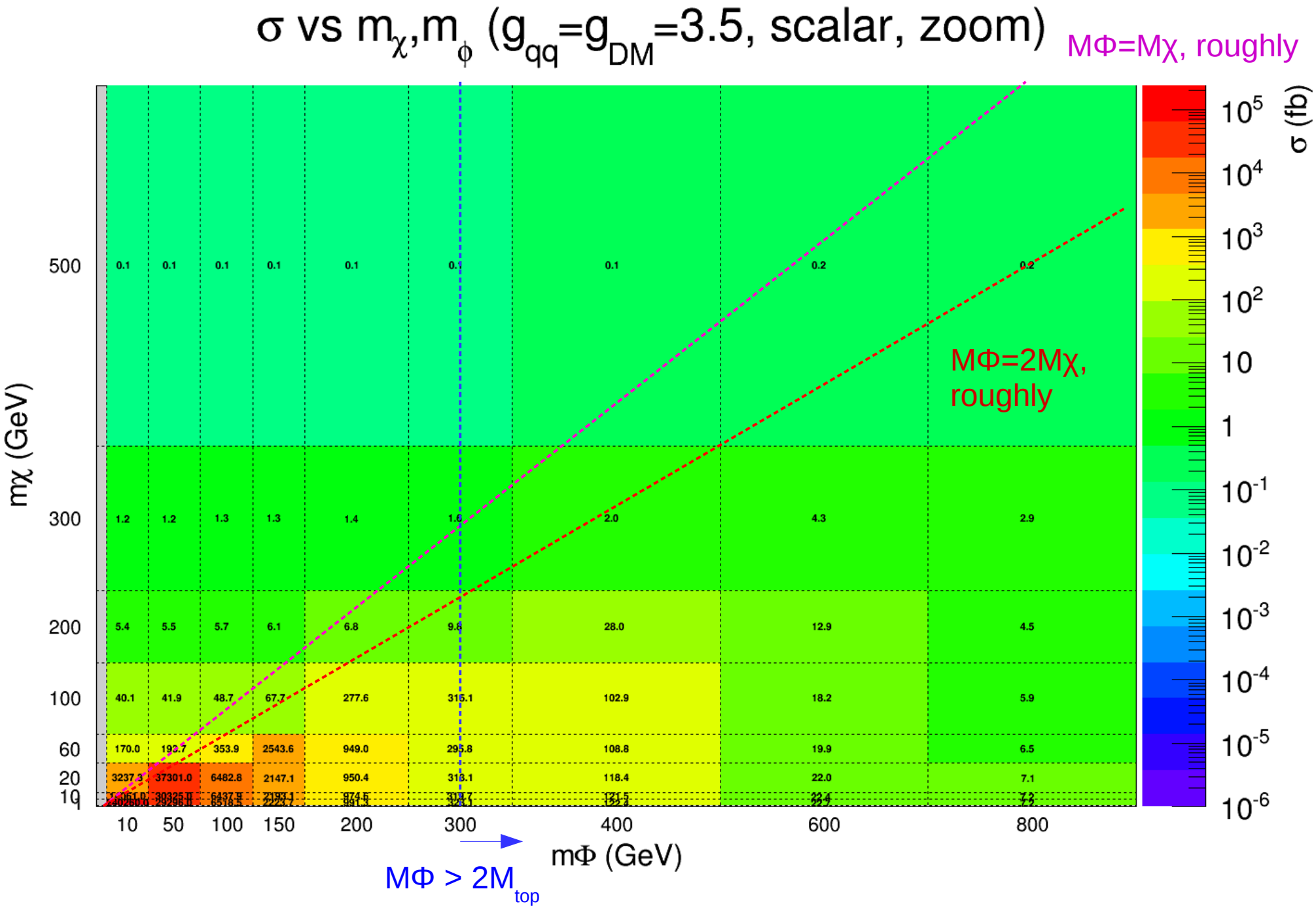
- Exploring with 2 separate MadGraph setups
  - Feynrules based (arXiv:1410:6497, M. Buckley et al.)
  - Minimally modified standard model (w/ in-model Φ width calculation)
  - Consistent σ, Γ to ~ 1%
    - Additional studies with models from T. Tait

Benchmark Studies

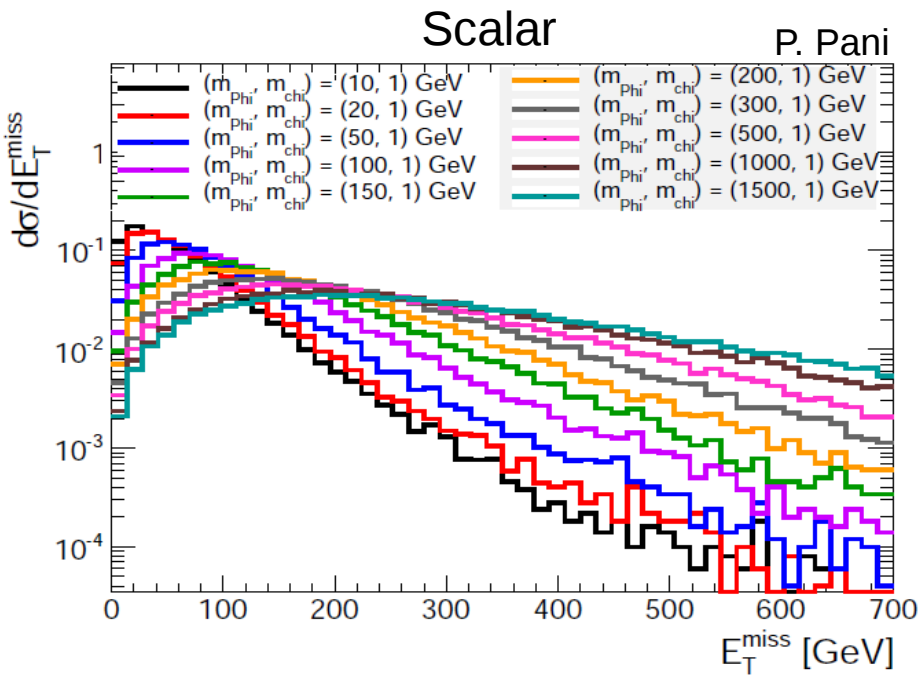
- Rich and varied kinematics for tt+DM
  - $M_{\Phi} > 2M_{top}$ (heavy mediator)
  - $M_{\Phi} > M_{\chi}$, $M_{\Phi} < 2M_{top}$ (sub-ttbar threshold, on-shell)
  - $M_{\Phi} < M_{\chi}$, $M_{\Phi} < 2M_{top}$ (sub-ttbar threshold, off-shell)
- Choose benchmarks to explore these regions while considering near-term sensitivity
  - *Heuristic* minimum sensitive cross section:
    - N_{obs}: Need O(1) events
    - L_{int}: year-1 = 30 fb-1
    - αε: O(1%)
    - $\sqrt{4\pi} > g > 0.1$
  - Lower by another o.o.m for safety/optimism

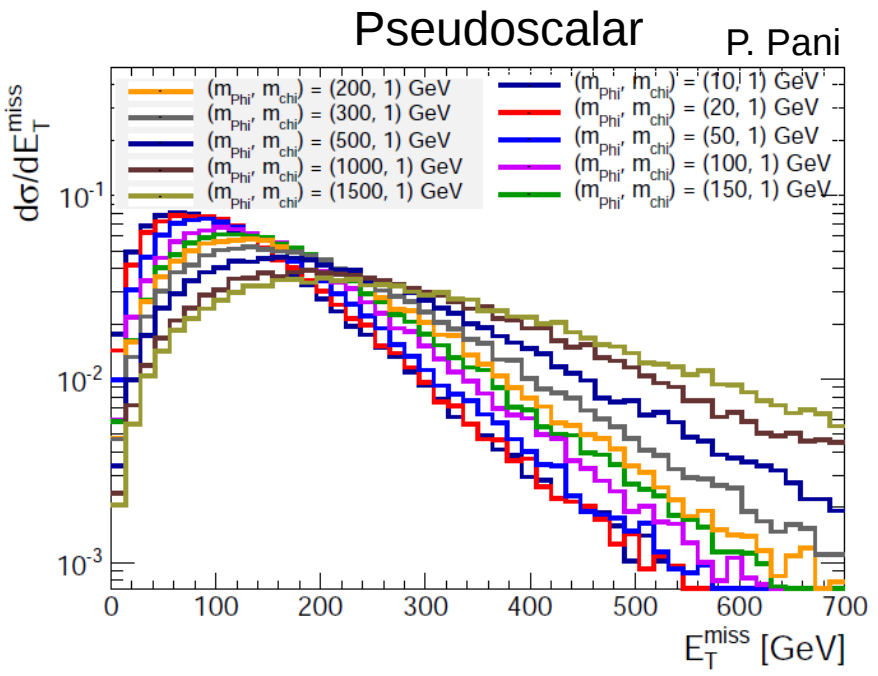
$$\sigma_{min} > 0.3 \text{ fb}$$


σ vs m_χ,m_φ (g_qq=g_DM=3.5, scalar)
mχ (GeV)
mΦ (GeV)
σ (fb)
500
300
200
100
60
20
10
1
50
150
400
600
800
1000
1500
0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.2 0.2 0.3 0.1
1.2 1.2 1.3 1.3 1.4 1.6 2.0 4.3 2.9 1.3 0.3
5.4 5.5 5.7 6.1 6.8 9.8 28.0 12.9 4.5 1.9 0.3
40.1 41.9 48.7 67.7 277.6 315.1 102.9 18.2 5.9 2.4 0.5
170.0 193.7 353.9 2543.6 949.0 295.8 106.8 19.9 6.5 2.7 0.5
950.4 313.1 118.4 22.0 7.1 2.9 0.5


σ vs mχ,mϕ (gqq=gDM=3.5, scalar, zoom)
MΦ=Mχ, roughly
MΦ=2Mχ, roughly
mχ (GeV)
mΦ (GeV)
σ (fb)
MΦ > 2Mtop
500
300
200
100
60
20
10
10
50
100
150
200
300
400
600
800
0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.2 0.2
1.2 1.2 1.3 1.3 1.4 1.6 2.0 4.3 2.9
5.4 5.5 5.7 6.1 6.8 9.6 28.0 12.9 4.5
40.1 41.9 48.7 67.7 277.6 315.1 102.9 18.2 5.9
170.0 193.7 353.9 2543.6 949.0 295.8 108.8 19.9 6.5
3237.3 37301.0 6482.8 2147.1 950.4 318.1 118.4 22.0 7.1

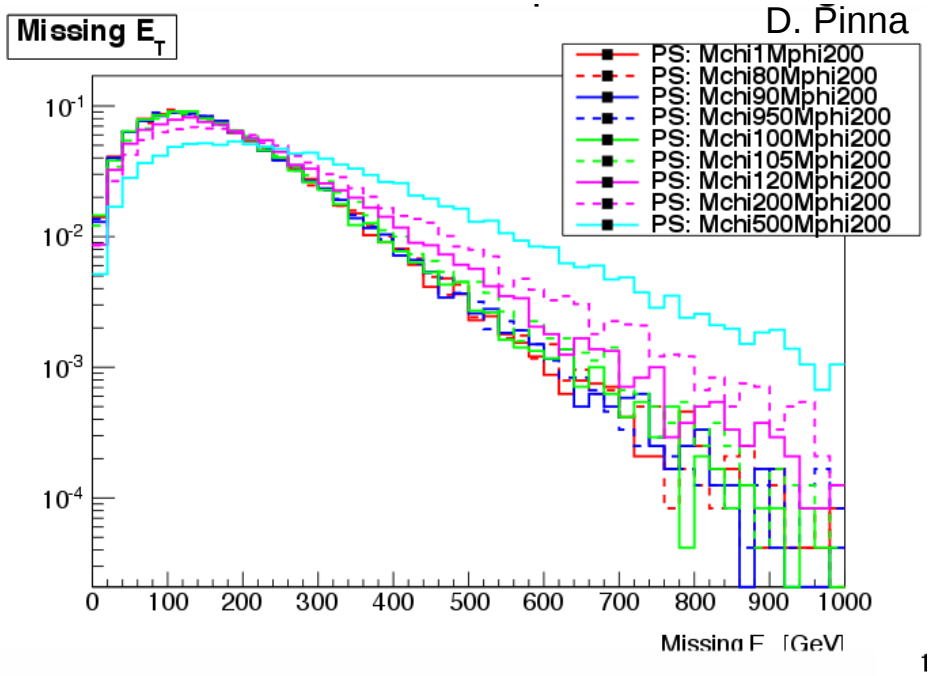
- Now explore kinematics within the sensitive region
  - Investigate impact of masses/coupling type/coupling strength
  - For off-shell & on-shell. Low, intermediate & high MΦ
- Largest kinematic differences found when scanning MΦ
  - MET broadens as MΦ grows (caveats at MΦ > 2 TeV, slide 9)
  - Plots below gen MET, elsewhere analogous $p_T(\chi\chi)$

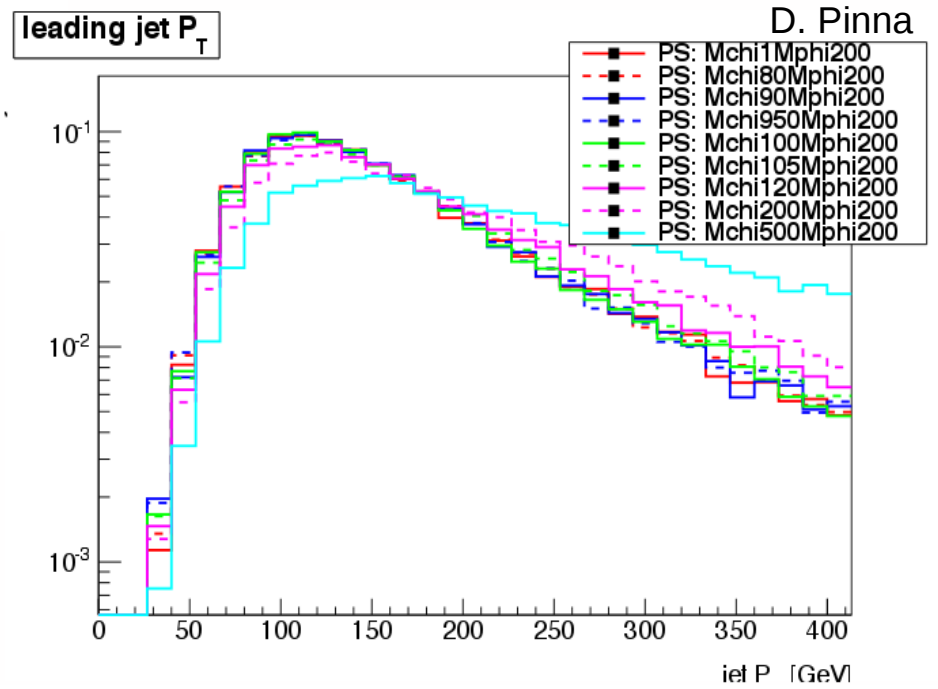




Scan over Mχ

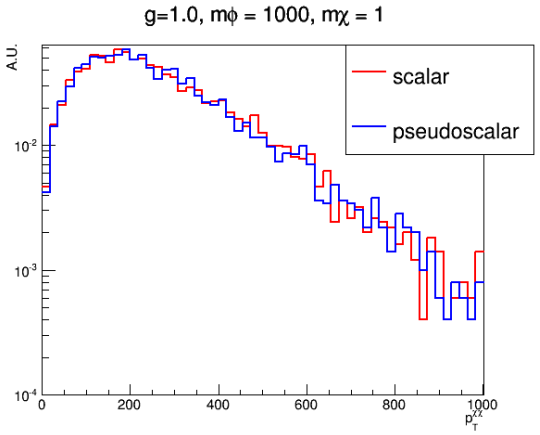
- No impact on kinematics when MΦ > 2Mχ
- Kinematics can be significantly altered when Φ is off-shell

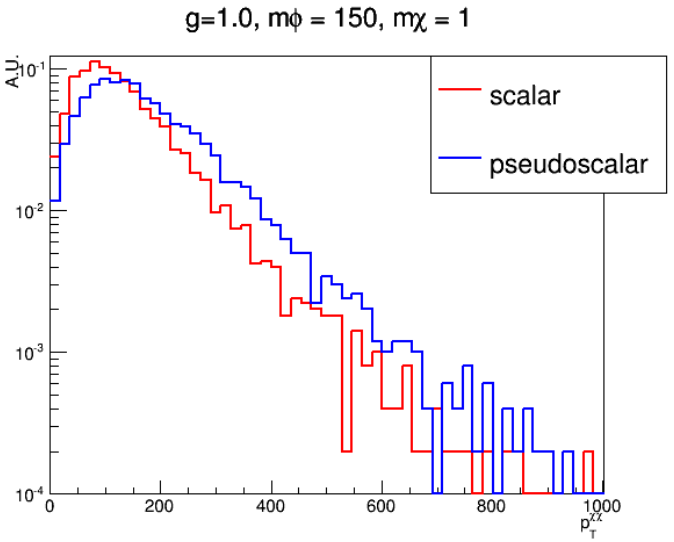


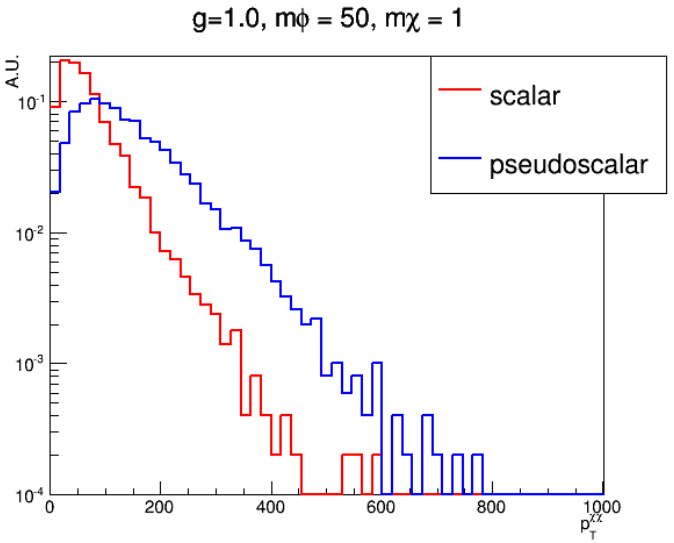


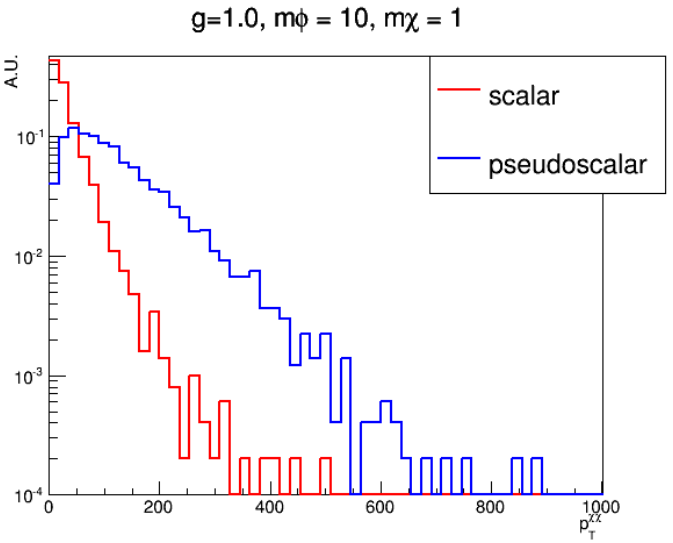
Coupling Type

- Cross sections differ across the MΦ spectrum
  - Due to exponent difference in the width
- Kinematics vs couplings
  - Little difference near/above ttbar threshold
  - However large impact below threshold
  - Differences widen as MΦ is decreased



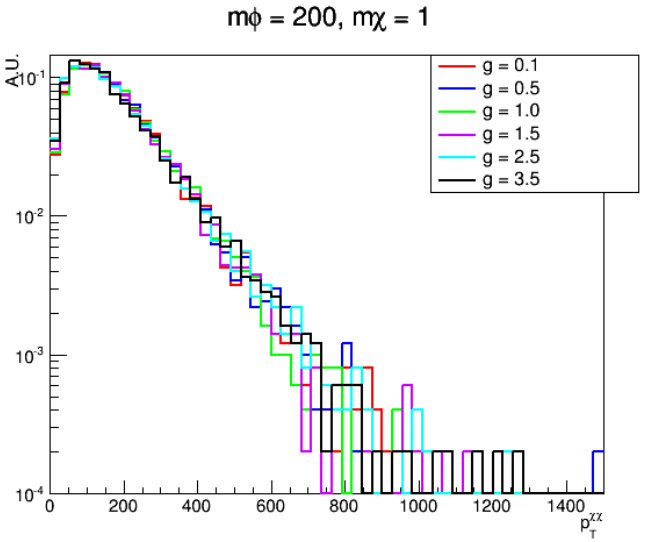


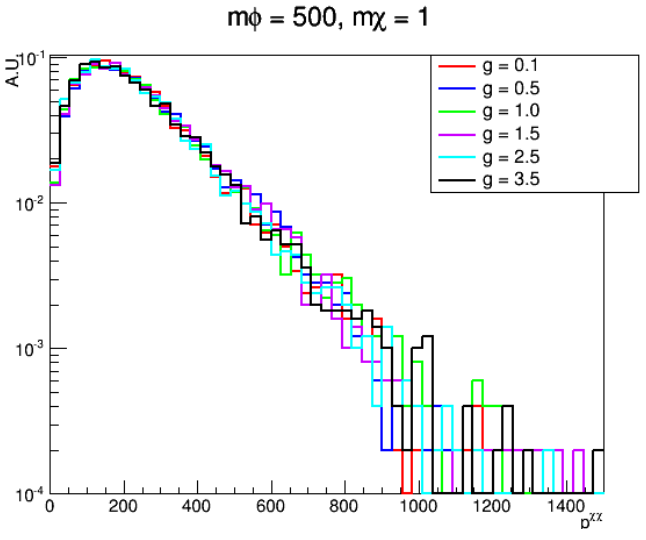


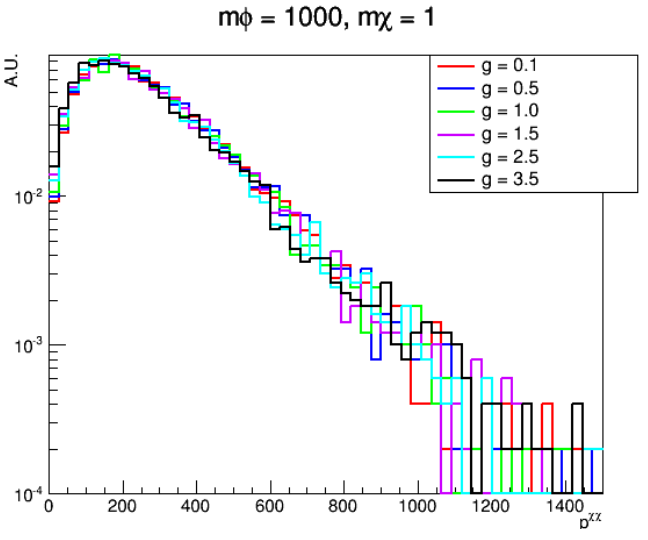


Coupling Strength

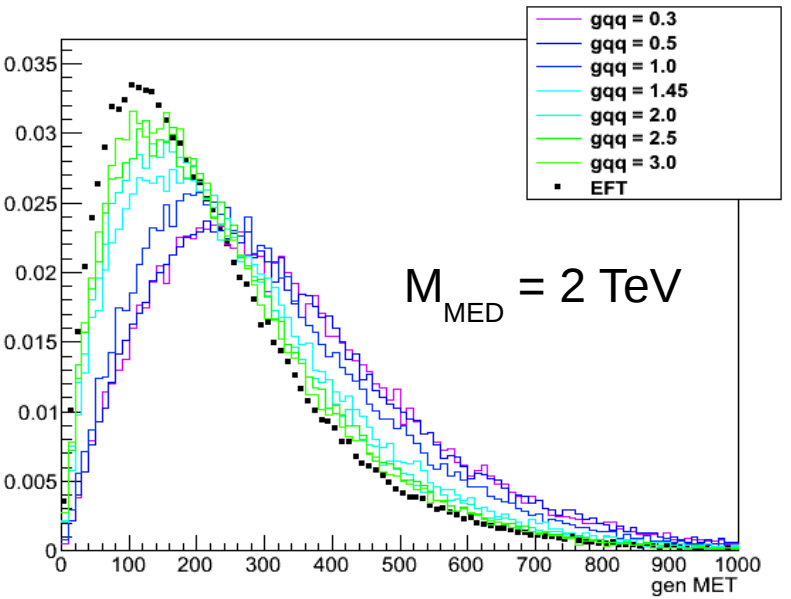
- On-shell: little difference in kinematics from couplings (ie: width) for the MΦ's we will be sensitive to in year-1







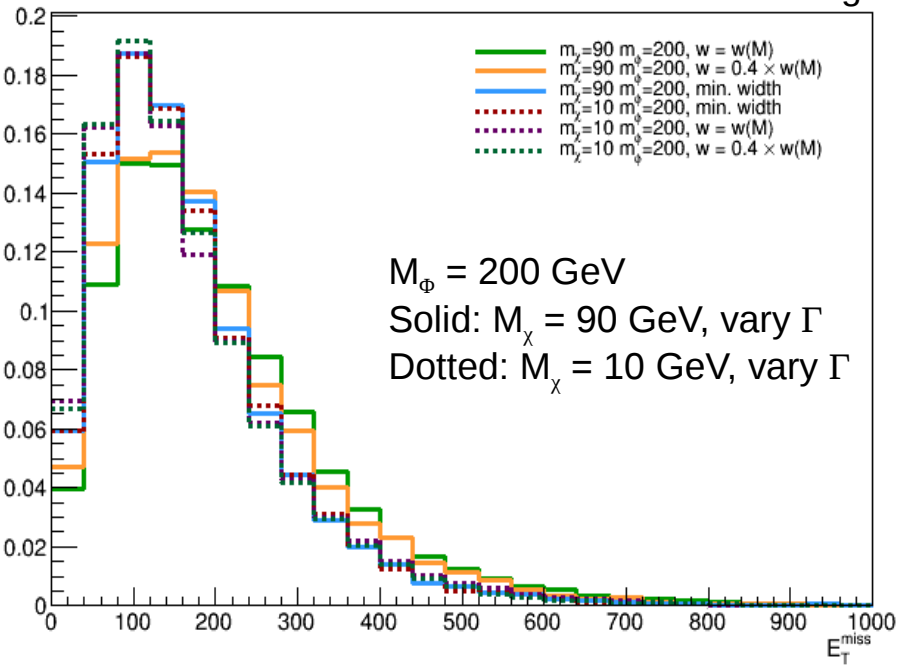
- NB: impact on kinematics becomes relevant with more data
  - Larger g → larger width
  - Large $s_{\chi\chi}$ pdf suppressed at large couplings
  - Broad MET distribution for small g



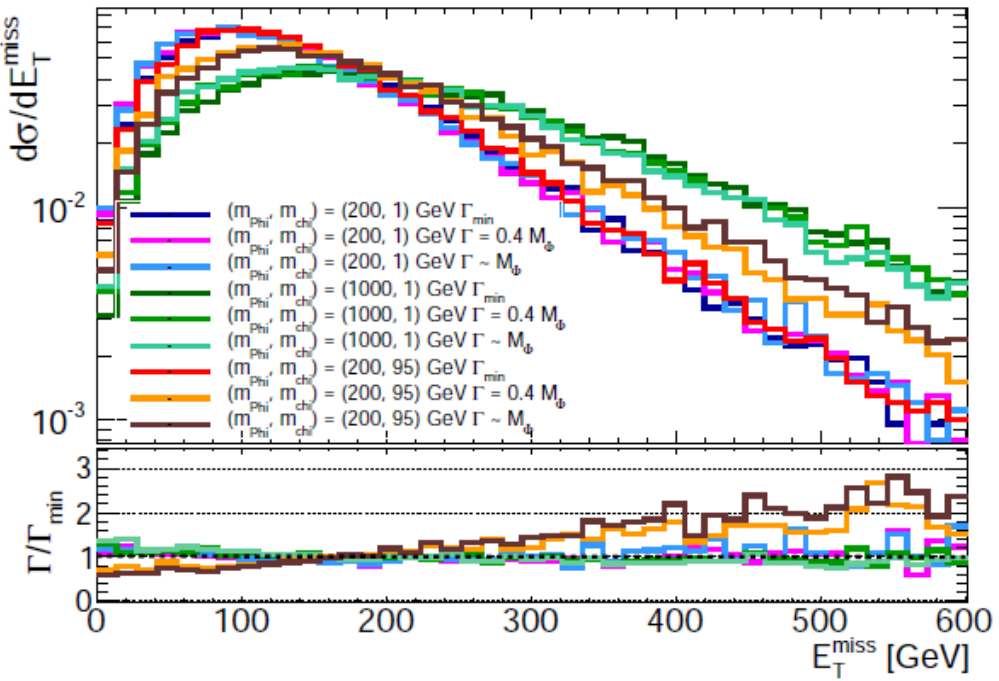
Coupling Strength (2)

- Couplings/width also impacts kinematics near resonance
  - Determines mixture of on/off shell kinematics

B. Penning



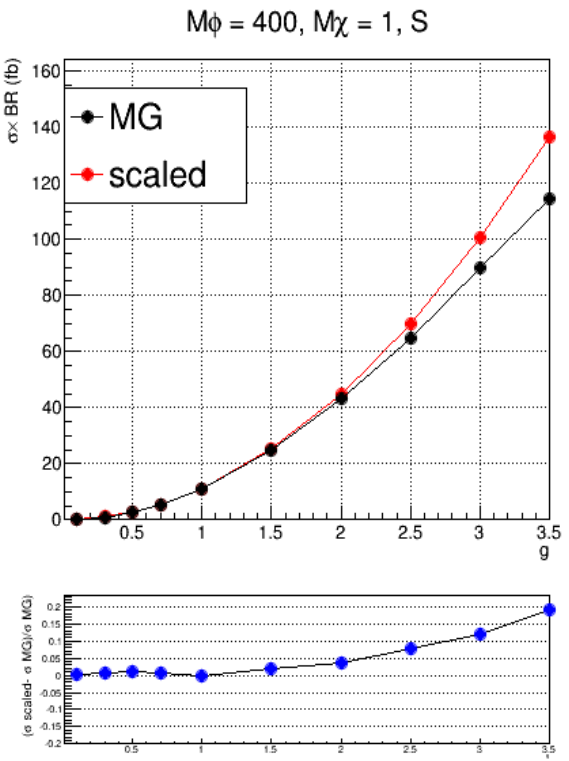
P. Pani

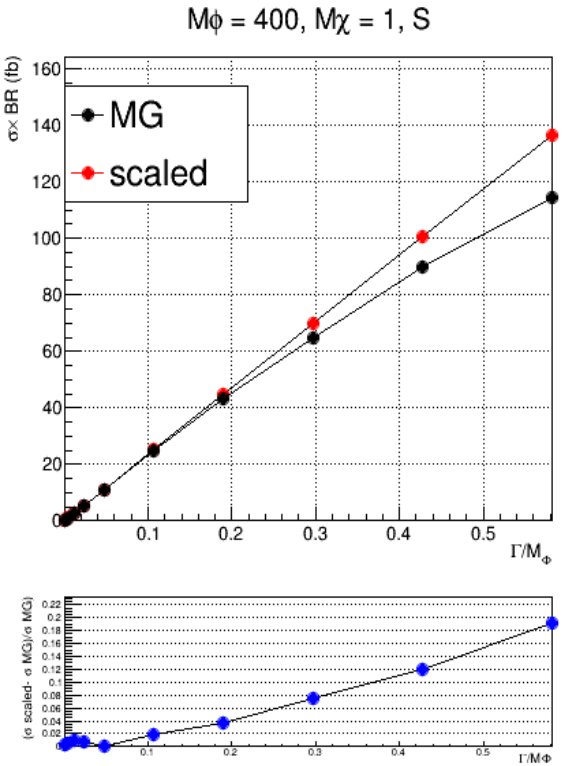


Coupling Strength (3)

- Impact on cross section
  - We chose $g_{SM}=g_{DM}=1$ for convenience
  - For small g, can simply scale g=1 benchmark cross section (g_B,σ_B)
    - $\sigma = \sigma_B\, g^4\, (\Gamma_B / \Gamma)$

- Departure from scaling due to finite width effects
  - Effect appears when $\Gamma/M_\Phi \sim 0.1$ ($g > 1$)
  - Effect grows with increasing M_Φ





Benchmarks

- Determine a set of MΦ,Mχ grid points to capture the relevant kinematics
- Additional inputs/constraints:
  - Sensitivity limit: MΦ < 1500 GeV
  - Off-shell: include MΦ = 2Mχ threshold and MΦ = Mχ diagonal
  - Small Mχ: consider sensitivity of current (10 GeV) and future (1 GeV) direct detection experiments

Same set of mass points for both scalar and pseudoscalar. 68 grid points total

M_χ (GeV)	M_Φ (GeV)
1	10, 20, 50, 100, 150, 200, 300, 500, 1000, 1500
10	10, 20, 50, 100, 150, 200, 300, 500, 1000, 1500
50	50, 100, 150, 300, 500, 1000, 1500
150	150, 500, 1000, 1500
500	500, 1000, 1500

This is simply a common set of benchmark points. Experiments can (will?) generate additional points.

Benchmark σ's & Γ's

- Additionally produce a table of cross sections for several value of coupling strengths
  - g = {0.1, 0.3, 0.7, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5}
  - Demonstrates the validity/limits of simple scaling
  - Useful set of pre-synchronized points for model interpretation
    - Must link to the MadGraph settings used for this to be useful

0.2.3 Table of Cross Sections

Coupling (g)	m_{Phi} [GeV]	m_{χ} [GeV]	Γ_{min} [GeV]	σ
0.1	10	1	0.00374318	0.207 ± 0.0006846
0.1	20	1	0.00784569	0.1121 ± 0.0003285
0.1	50	1	0.01987	0.03211 ± 0.0001005
0.1	100	1	0.0398141	0.007325 ± 2.416e-05
0.1	150	1	0.0597437	0.002396 ± 7.419e-06
0.1	200	1	0.0796724	0.001018 ± 3.398e-06
0.1	300	1	0.119549	0.0003394 ± 1.234e-06
0.1	500	1	0.310863	6.802e-05 ± 2.343e-07
0.1	1000	1	0.881329	5.817e-06 ± 2.356e-08
0.1	1500	1	1.40417	8.942e-07 ± 3.832e-09
0.1	10	10	6.3312	1.007e-05 ± 3.761e-08
0.1	20	10	7.01043	1.965e-05 ± 7.368e-08
0.1	50	10	0.0153395	0.03212 ± 0.0001037

Summary

- We've converged on a common grid of MΦ,Mχ points for the g=1 spin-0 mediated tt + χχ simplified model
  - Representative of the various kinematic scenarios relevant for the start of Run-2
  - Consistent with scalar/pseudoscalar points from monojet
- Additional cross section & width tabulation for g != 1.0
- Several iterations on the write-up already
  - Expect a final version for the editors in O(days)