Update

Felipe

Sprace

Studies

- Standard Model
  - S. F. Novaes, (IFT-UNESP), Standard Model: An Introduction
- Dark Matter
  - Stefano Profumo, An Introduction to Particle Dark Matter
- The theory and phenomenology of QCD
  - P. Z. Skands, Introduction to QCD
- Jet
  - Gavin P. Salam, Towards Jetography
- Matching scheme
  - J. Alwall, et al, Comparative study of various algorithms for the merging of parton showers and matrix elements in hadronic collisions

Studies of minimal freeze-in models

- Studies of minimal freeze-in models
  - Disappearing Tracks.
  - Source: https://arxiv.org/abs/1811.05478
- Tools
  - Madgraph Studies UNDERWAY
  - ROOT Studies UNDERWAY
  - Pythia 8 Studies UNDERWAY
  - Delphes Studies UNDERWAY
- Reconstruction UNDERWAY
  - $pp \to F\overline{F} \to \mu s\overline{\mu}s$

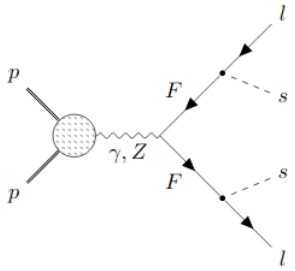
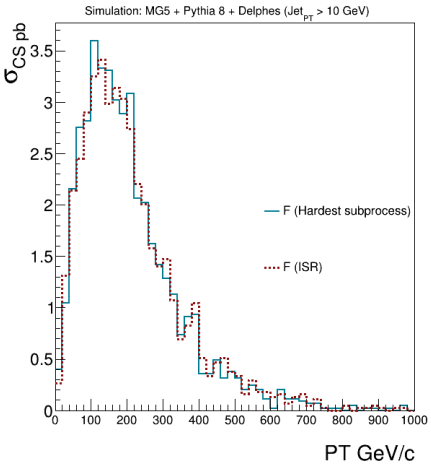


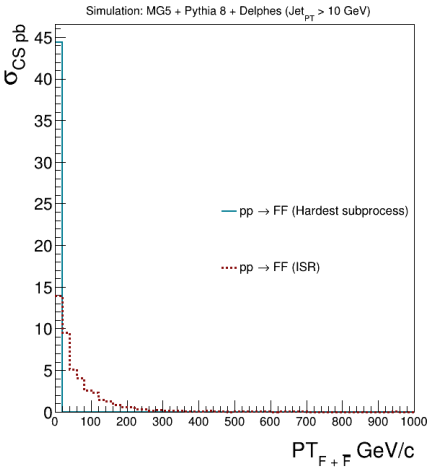
Figure: Decay process of F

Simulation

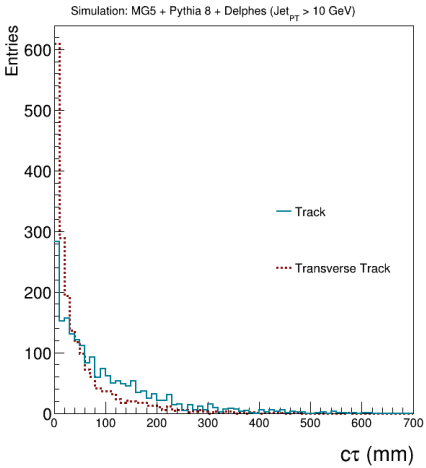
- Events Generation:
  - 10,000 generated events.
  - Generation: $pp \rightarrow F\overline{F}$, $F \rightarrow \mu s$ in 13 TeV.
  - Generation: $pp \rightarrow F\overline{F} + Jet$, $F \rightarrow \mu s$ in 13 TeV.
  - Generation: $pp \rightarrow F\overline{F}$ and $F\overline{F} + Jet$, $F \rightarrow \mu s$ in 13 TeV.
  - Select the Jet in each event with PT $\geq$ 10 GeV/c and 30 GeV/c.
- Goal:
  - Observe the shape of the graph.

Simulation


Simulation: MG5 + Pythia 8 + Delphes (Jet$_{PT}$ > 10 GeV)
σ_{CS} pb
F (Hardest subprocess)
F (ISR)
PT GeV/c


Simulation: MG5 + Pythia 8 + Delphes (Jet$_{PT}$ > 10 GeV)
σ_{CS} pb
pp → FF (Hardest subprocess)
pp → FF (ISR)
PT$_{F + \bar{F}}$ GeV/c

Simulation


Simulation: MG5 + Pythia 8 + Delphes (Jet$_{PT}$ > 10 GeV)
Entries
Track
Transverse Track
cτ (mm)

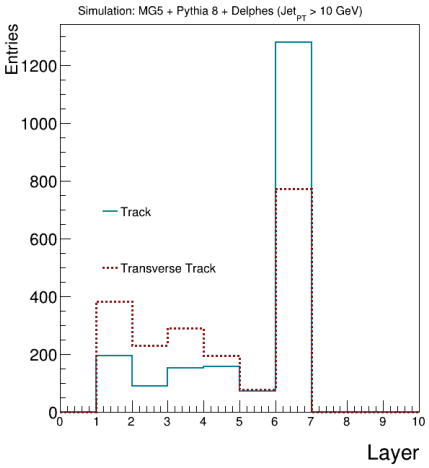
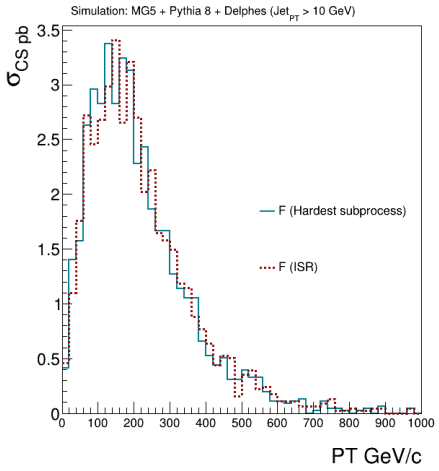
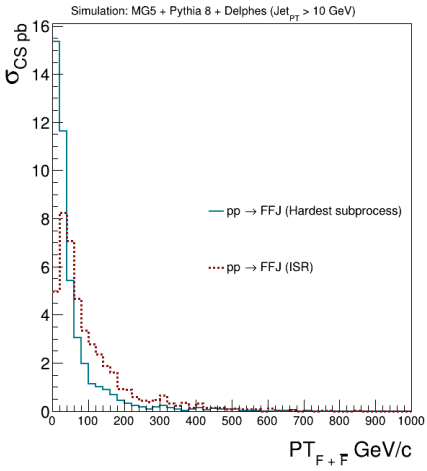

Simulation: MG5 + Pythia 8 + Delphes (Jet$_{PT}$ > 10 GeV)
Entries
Track
Transverse Track
Layer

Table: Generation

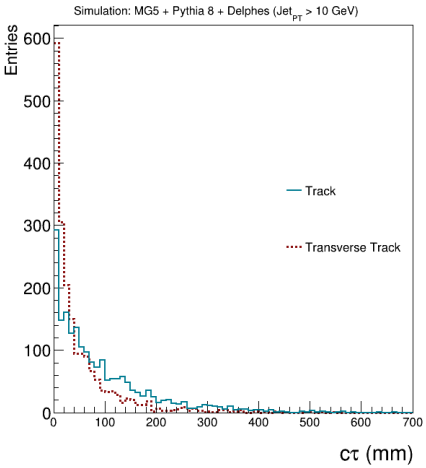
Process	Jet$_{PT}(GeV/c)$	Type	n$_{layer} = 4$	n$_{layer} = 5$	n$_{layer} \geq 6$
$pp \rightarrow F\overline{F}$	> 10	Track	8.1	3.6	65.8
$pp \rightarrow F\overline{F}$	> 10	T. Track	10	4	40

Simulation


Simulation: MG5 + Pythia 8 + Delphes (Jet$_{PT}$ > 10 GeV)
σ_{CS} pb
F (Hardest subprocess)
F (ISR)
PT GeV/c


Simulation: MG5 + Pythia 8 + Delphes (Jet$_{PT}$ > 10 GeV)
σ_{CS} pb
pp → FFJ (Hardest subprocess)
pp → FFJ (ISR)
PT$_{F+\bar{F}}$ GeV/c

Simulation


Simulation: MG5 + Pythia 8 + Delphes (Jet$_{PT}$ > 10 GeV)
Entries
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
Track
Transverse Track
cτ (mm)

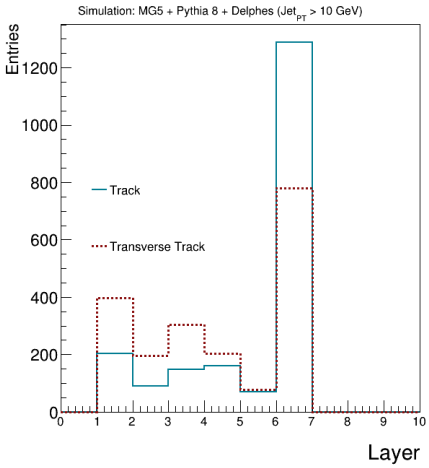
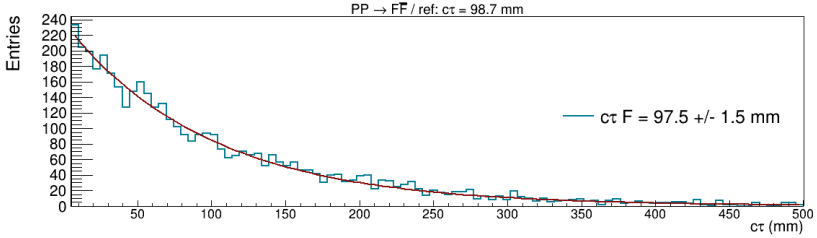
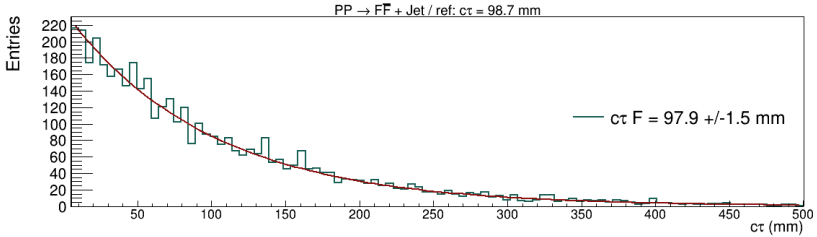

Simulation: MG5 + Pythia 8 + Delphes (Jet$_{PT}$ > 10 GeV)
Entries
1200
1000
800
600
400
200
0
0
1
2
3
4
5
6
7
8
9
10
Track
Transverse Track
Layer

Table: Generation

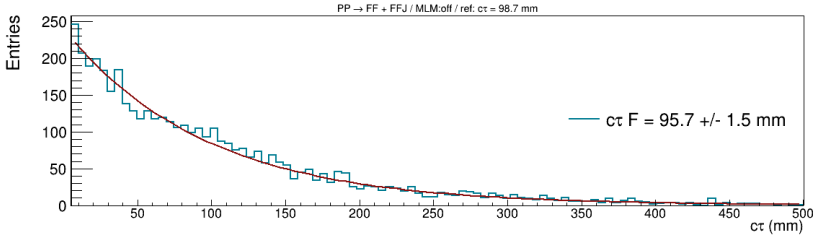
Process	Jet$_{PT}(GeV/c)$	Type	n$_{layer} = 4$	n$_{layer} = 5$	n$_{layer} \geq 6$
$pp \rightarrow F\overline{F}J$	> 10	Track	8.2	3.6	65.7
$pp \rightarrow F\overline{F}J$	> 10	T. Track	10.4	4	39.8

Simulation


PP → FF̄ / ref: cτ = 98.7 mm
Entries
cτ F = 97.5 +/- 1.5 mm
cτ (mm)


PP → FF̄ + Jet / ref: cτ = 98.7 mm
Entries
cτ F = 97.9 +/-1.5 mm
cτ (mm)

Simulation


PP → FF + FFJ / MLM:off / ref: cτ = 98.7 mm
Entries
cτ F = 95.7 +/- 1.5 mm
cτ (mm)

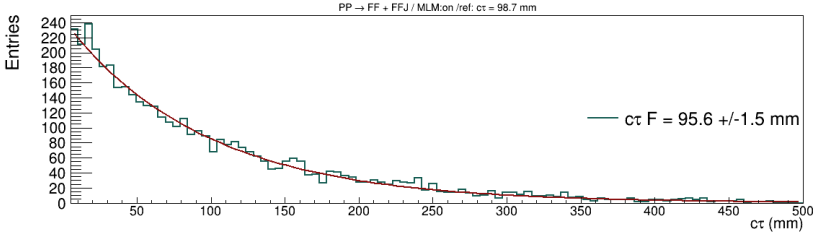

PP → FF + FFJ / MLM:on /ref: cτ = 98.7 mm
Entries
cτ F = 95.6 +/-1.5 mm
cτ (mm)

Figure 17: Illustration of the three signal regions defined in terms of n_{layers}, for the barrel region.

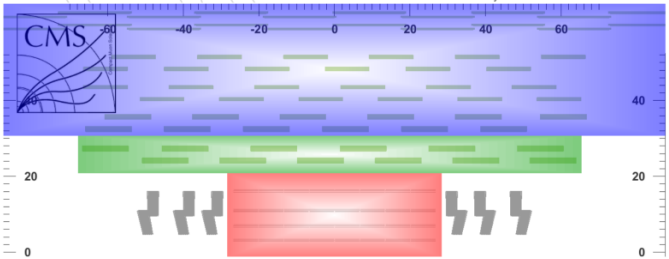


Figure: Source: http://dx.doi.org/10.1016/j.physletb.2020.135502

Table: Generation

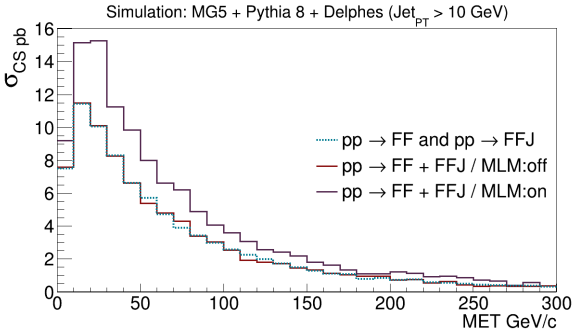
Process	Jet$_{PT}(GeV/c)$	MLM	n$_{layer} = 4$	n$_{layer} = 5$	n$_{layer} \geq 6$
$pp \to F\overline{F}$	> 10	-	66.4	60.2	57.2
$pp \to F\overline{F} + Jet$	> 10	-	66.0	59.6	56.8
$pp \to F\overline{F} + pp \to F\overline{F} + Jet$	> 10	On	66.0	59.6	56.5
$pp \to F\overline{F} + pp \to F\overline{F} + Jet$	> 10	Off	66.7	60.1	57.3
$pp \to F\overline{F}$	> 30	-	67.2	60.7	57.8
$pp \to F\overline{F} + Jet$	> 30	-	65.6	59.4	56.3
$pp \to F\overline{F} + pp \to F\overline{F} + Jet$	> 30	On	66.2	59.8	57.2
$pp \to F\overline{F} + pp \to F\overline{F} + Jet$	> 30	Off	66.3	59.3	56.6

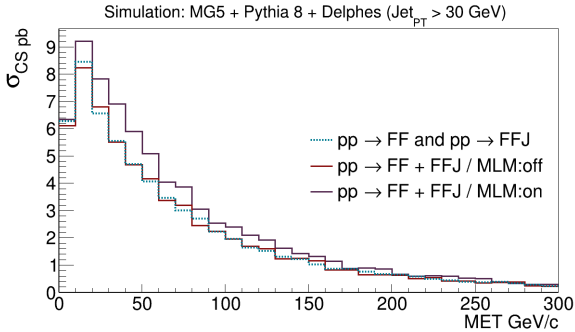
Table: Generation

Process	Jet$_{PT}(GeV/c)$	$\sigma_c s$	MLM
$pp \to F\overline{F}$	> 10	44.27	-
$pp \to F\overline{F} + Jet$	> 10	43.98	-
$pp \to F\overline{F}$ and $pp \to F\overline{F} + Jet$	> 10	124	On
$pp \to F\overline{F}$ and $pp \to F\overline{F} + Jet$	> 10	88.3	Off
$pp \to F\overline{F}$	> 30	44.34	-
$pp \to F\overline{F} + Jet$	> 30	21.6	-
$pp \to F\overline{F}$ and $pp \to F\overline{F} + Jet$	> 30	77.91	On
$pp \to F\overline{F}$ and $pp \to F\overline{F} + Jet$	> 30	65.95	Off

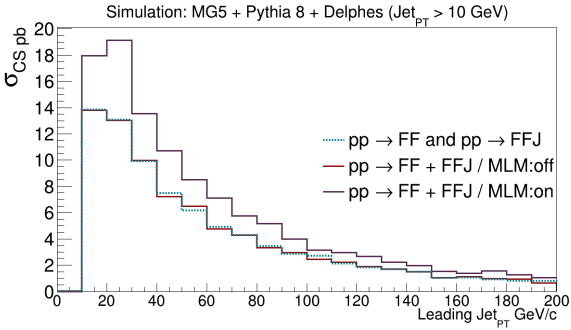
Backup

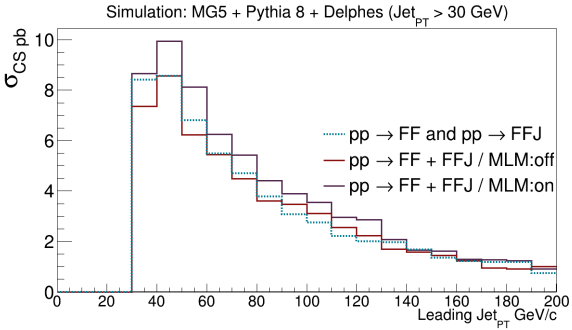
Simulation


Simulation: MG5 + Pythia 8 + Delphes (Jet$_{PT}$ > 10 GeV)
σ_{CS} pb
MET GeV/c
pp → FF and pp → FFJ
pp → FF + FFJ / MLM:off
pp → FF + FFJ / MLM:on

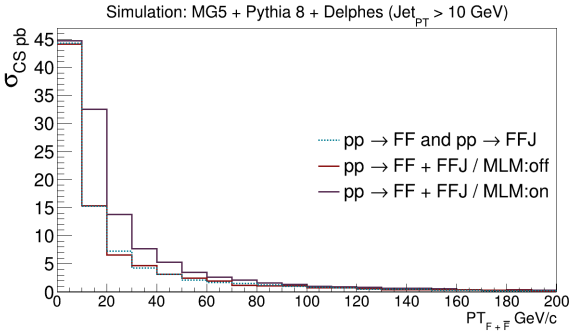

Simulation: MG5 + Pythia 8 + Delphes (Jet$_{PT}$ > 30 GeV)
σ_{CS} pb
MET GeV/c
pp → FF and pp → FFJ
pp → FF + FFJ / MLM:off
pp → FF + FFJ / MLM:on

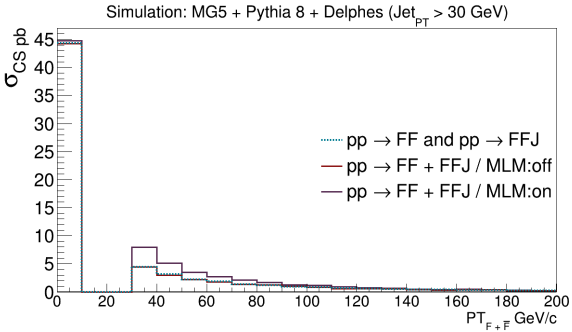
Simulation

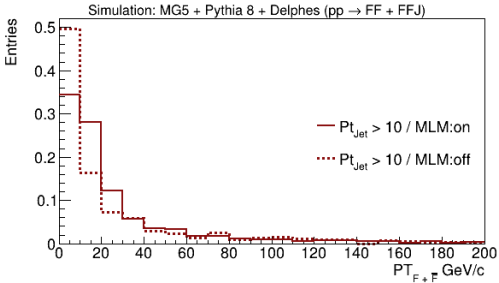

Simulation: MG5 + Pythia 8 + Delphes (Jet$_{PT}$ > 10 GeV)
σ_{CS} pb
pp → FF and pp → FFJ
pp → FF + FFJ / MLM:off
pp → FF + FFJ / MLM:on
Leading Jet$_{PT}$ GeV/c


Simulation: MG5 + Pythia 8 + Delphes (Jet$_{PT}$ > 30 GeV)
σ_{CS} pb
pp → FF and pp → FFJ
pp → FF + FFJ / MLM:off
pp → FF + FFJ / MLM:on
Leading Jet$_{PT}$ GeV/c

Simulation


Simulation: MG5 + Pythia 8 + Delphes (Jet$_{PT}$ > 10 GeV)
σ_{CS} pb
pp → FF and pp → FFJ
pp → FF + FFJ / MLM:off
pp → FF + FFJ / MLM:on
PT$_{F+\bar{F}}$ GeV/c


Simulation: MG5 + Pythia 8 + Delphes (Jet$_{PT}$ > 30 GeV)
σ_{CS} pb
pp → FF and pp → FFJ
pp → FF + FFJ / MLM:off
pp → FF + FFJ / MLM:on
PT$_{F+\bar{F}}$ GeV/c


Simulation: MG5 + Pythia 8 + Delphes (pp → FF + FFJ)
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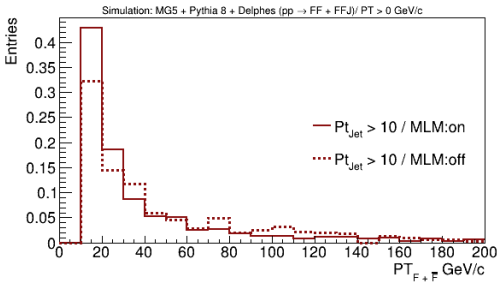
Pt_Jet > 10 / MLM:off
PT_F + F̄ GeV/c


Simulation: MG5 + Pythia 8 + Delphes (pp → FF + FFJ)/ PT > 0 GeV/c
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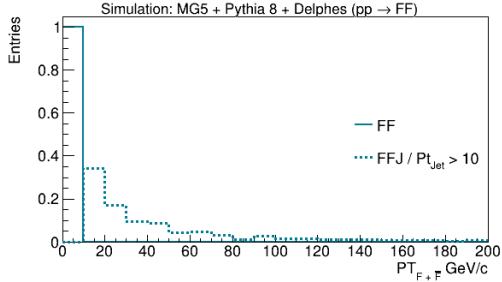
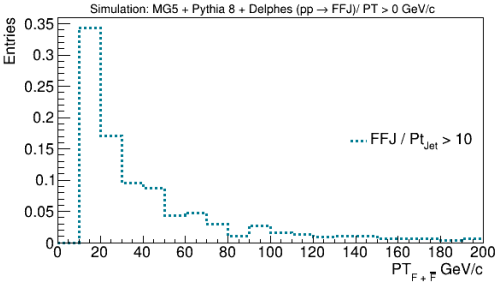
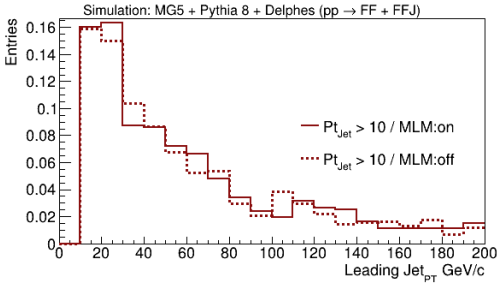
PT_F + F̄ GeV/c


Simulation: MG5 + Pythia 8 + Delphes (pp → FF)
Entries
FF
FFJ / Pt_Jet > 10
PT_F + F̄ GeV/c


Simulation: MG5 + Pythia 8 + Delphes (pp → FFJ)/ PT > 0 GeV/c
Entries
FFJ / Pt_Jet > 10
PT_F + F̄ GeV/c


Simulation: MG5 + Pythia 8 + Delphes (pp → FF + FFJ)
Entries
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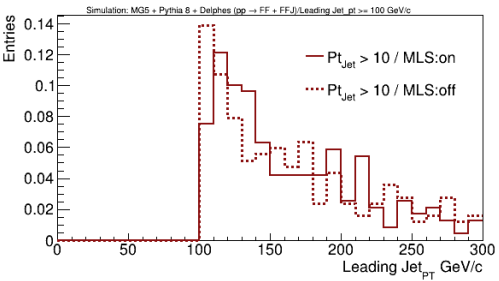
Leading Jet_PT GeV/c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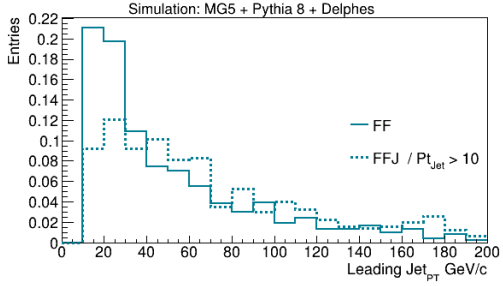
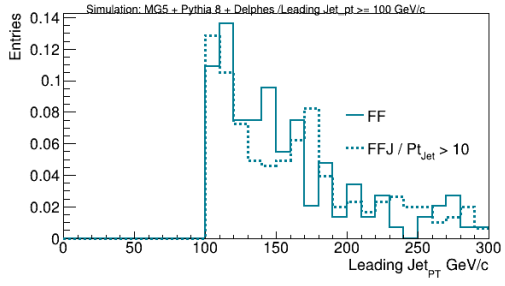
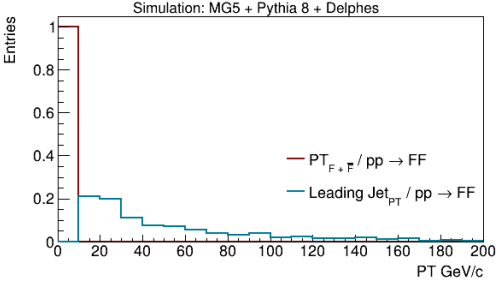
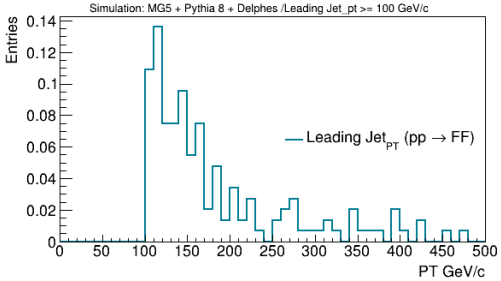
Pt_Jet > 10 / MLS:off
Leading Jet_PT GeV/c


Simulation: MG5 + Pythia 8 + Delphes
Entries
FF
FFJ / Pt_Jet > 10
Leading Jet_PT GeV/c


Simulation: MG5 + Pythia 8 + Delphes /Leading Jet_pt >= 100 GeV/c
Entries
FF
FFJ / Pt_Jet > 10
Leading Jet_PT GeV/c


Simulation: MG5 + Pythia 8 + Delphes
Entries
PT GeV/c
PT_{F + F̄} / pp → FF
Leading Jet_{PT} / pp → FF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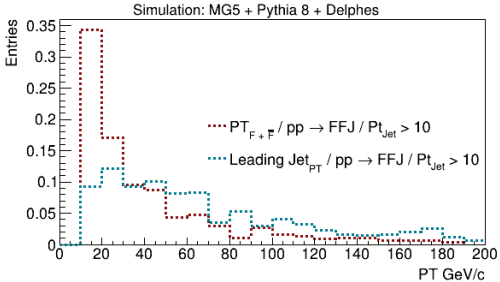
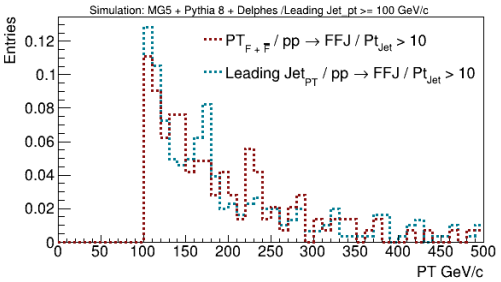
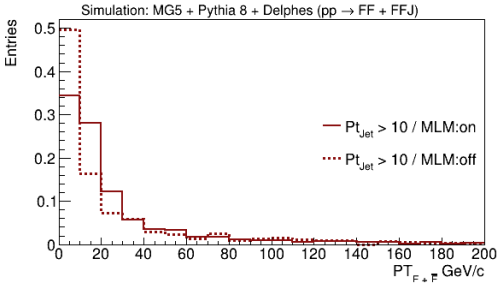
Entries
PT GeV/c
Leading Jet_{PT} (pp → FF)


Simulation: MG5 + Pythia 8 + Delphes
Entries
PT GeV/c
PT_{F + F̄} / pp → FFJ / Pt_{Jet} > 10
Leading Jet_{PT} / pp → FFJ / Pt_{Jet} > 10


Simulation: MG5 + Pythia 8 + Delphes /Leading Jet_pt >= 100 GeV/c
Entries
PT GeV/c
PT_{F + F̄} / pp → FFJ / Pt_{Jet} > 10
Leading Jet_{PT} / pp → FFJ / Pt_{Jet} > 10


Simulation: MG5 + Pythia 8 + Delphes (pp → FF + FFJ)
Entries
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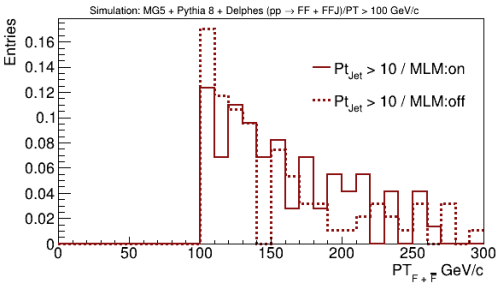
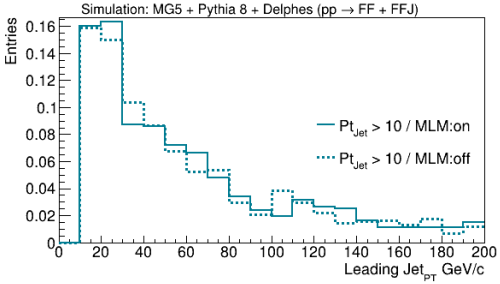
PT_F + F̄ GeV/c


Simulation: MG5 + Pythia 8 + Delphes (pp → FF + FFJ)/PT > 100 GeV/c
Entries
Pt_Jet > 10 / MLM:on
Pt_Jet > 10 / MLM:off
PT_F + F̄ GeV/c


Simulation: MG5 + Pythia 8 + Delphes (pp → FF + FFJ)
Entries
Pt_Jet > 10 / MLM:on
Pt_Jet > 10 / MLM:off
Leading Jet_PT GeV/c

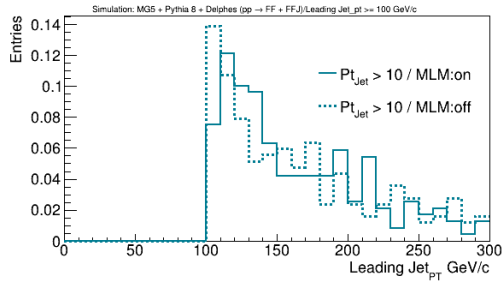

Simulation: MG5 + Pythia 8 + Delphes (pp → FF + FFJ)/Leading Jet_pt >= 100 GeV/c
Entries
Pt_Jet > 10 / MLM:on
Pt_Jet > 10 / MLM:off
Leading Jet_PT GeV/c

Table: Generation

Process	PT$_{Jet}(GeV/c)$	Events	$\sigma_c s$	MLM
$pp \to F\overline{F}$	> 10	836	44.51	-
$pp \to F\overline{F} + Jet$	> 10	975	43.83	On
$pp \to F\overline{F}$ and $pp \to F\overline{F} + Jet$	> 10	919	124.3	On
$pp \to F\overline{F}$ and $pp \to F\overline{F} + Jet$	> 10	913	88.77	Off

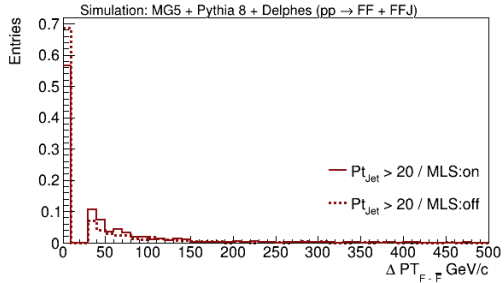
Result

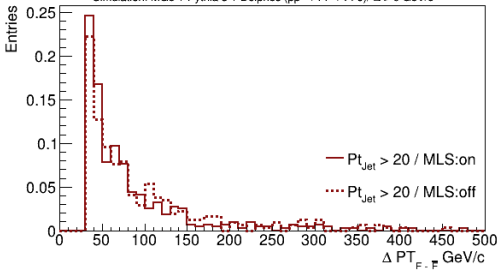
- The ratio between the processes of separate generations and the process of united generations with merging scheme is given by:

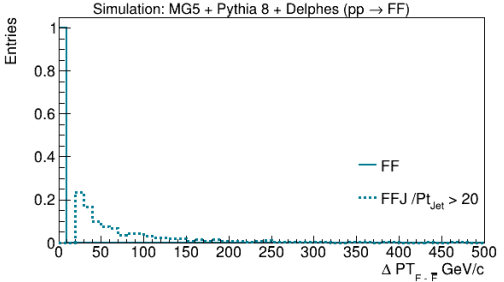
$$\frac{E_{FF} + E_{FFJ}}{E_{FF+FFJ}} = \frac{905}{919} \approx 0.98 \tag{1}$$

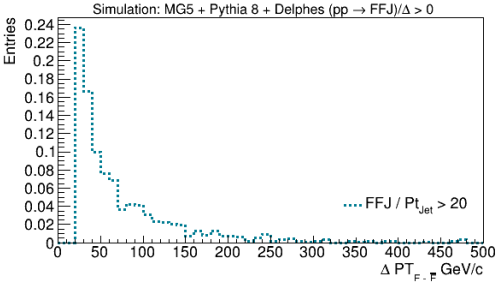
- Result
  - The ratio between the processes of separate generations and the process of united generations without merging scheme is given by:

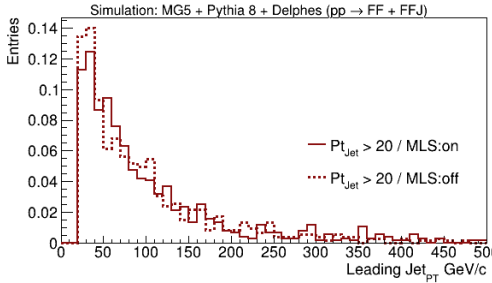
$$\frac{E_{FF} + E_{FFJ}}{E_{FF+FFJ}} = 1.0066 \tag{2}$$

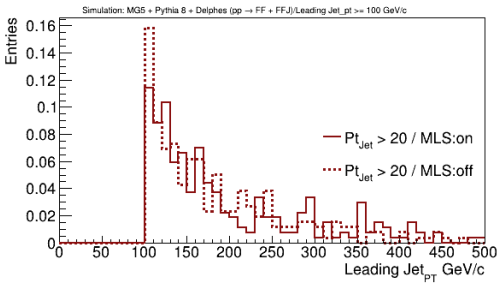

Simulation: MG5 + Pythia 8 + Delphes (pp → FF + FFJ)
Entries
Pt_Jet > 20 / MLS:on
Pt_Jet > 20 / MLS:off
Δ PT_F - F̄ GeV/c

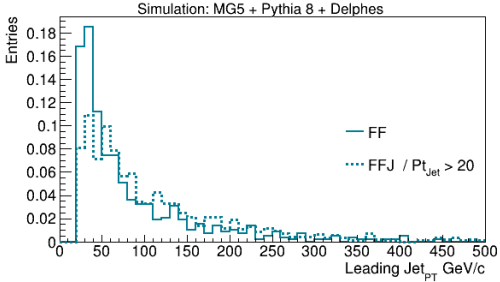

Simulation: MG5 + Pythia 8 + Delphes (pp → FF + FFJ)/ Δ > 0 GeV/c
Entries
Pt_Jet > 20 / MLS:on
Pt_Jet > 20 / MLS:off
Δ PT_F - F̄ GeV/c

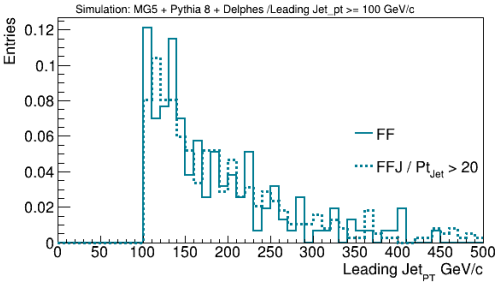

Simulation: MG5 + Pythia 8 + Delphes (pp → FF)
Entries
FF
FFJ /Pt_Jet > 20
Δ PT_F - F̄ GeV/c

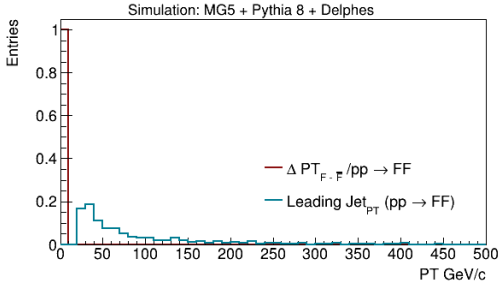

Simulation: MG5 + Pythia 8 + Delphes (pp → FFJ)/Δ > 0
Entries
FFJ / Pt_Jet > 20
Δ PT_F - F̄ GeV/c

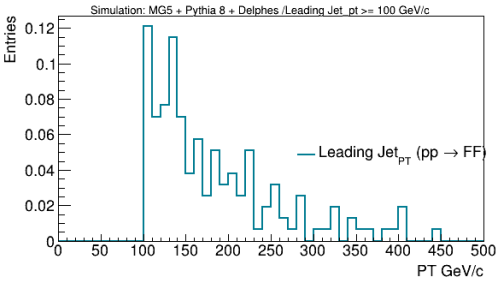

Simulation: MG5 + Pythia 8 + Delphes (pp → FF + FFJ)
Entries
Pt_Jet > 20 / MLS:on
Pt_Jet > 20 / MLS:off
Leading Jet_PT GeV/c

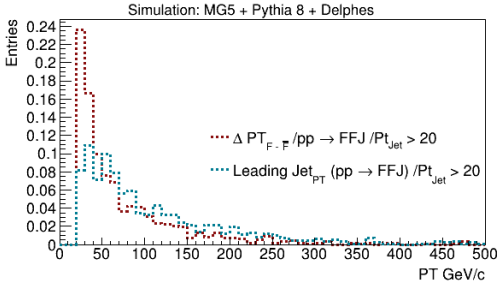

Simulation: MG5 + Pythia 8 + Delphes (pp → FF + FFJ)/Leading Jet_pt >= 100 GeV/c
Entries
Pt_Jet > 20 / MLS:on
Pt_Jet > 20 / MLS:off
Leading Jet_PT GeV/c

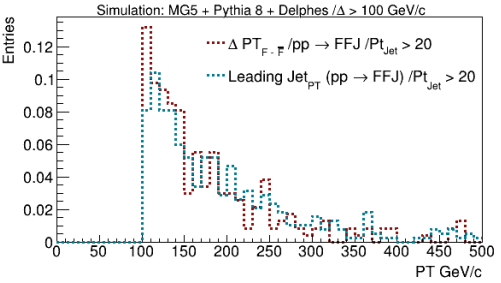

Simulation: MG5 + Pythia 8 + Delphes
Entries
FF
FFJ / Pt_Jet > 20
Leading Jet_PT GeV/c

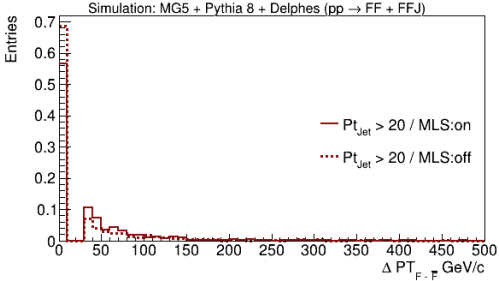

Simulation: MG5 + Pythia 8 + Delphes /Leading Jet_pt >= 100 GeV/c
Entries
FF
FFJ / Pt_Jet > 20
Leading Jet_PT GeV/c

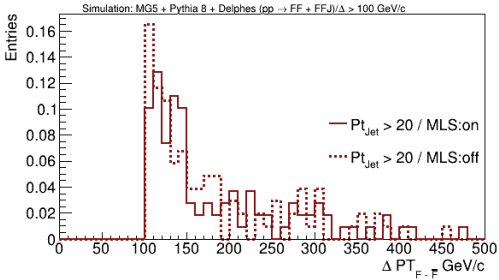

Simulation: MG5 + Pythia 8 + Delphes
Entries
PT GeV/c
Δ PT_{F - F̄} /pp → FF
Leading Jet_{PT} (pp → FF)

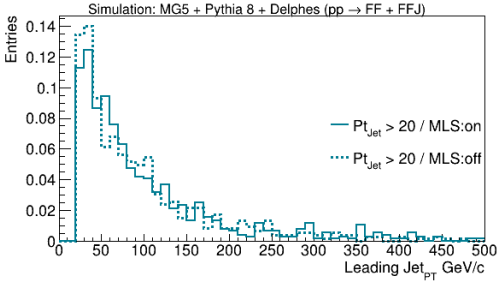

Simulation: MG5 + Pythia 8 + Delphes /Leading Jet_pt >= 100 GeV/c
Entries
PT GeV/c
Leading Jet_{PT} (pp → FF)


Simulation: MG5 + Pythia 8 + Delphes
Entries
PT GeV/c
Δ PT_{F - F̄} /pp → FFJ /Pt_{Jet} > 20
Leading Jet_{PT} (pp → FFJ) /Pt_{Jet} > 20


Simulation: MG5 + Pythia 8 + Delphes /Δ > 100 GeV/c
Entries
PT GeV/c
Δ PT_{F - F̄} /pp → FFJ /Pt_{Jet} > 20
Leading Jet_{PT} (pp → FFJ) /Pt_{Jet} > 20


Simulation: MG5 + Pythia 8 + Delphes (pp → FF + FFJ)
Entries
Pt_Jet > 20 / MLS:on
Pt_Jet > 20 / MLS:off
Δ PT_F - F̄ GeV/c


Simulation: MG5 + Pythia 8 + Delphes (pp → FF + FFJ)/Δ > 100 GeV/c
Entries
Pt_Jet > 20 / MLS:on
Pt_Jet > 20 / MLS:off
Δ PT_F - F̄ GeV/c


Simulation: MG5 + Pythia 8 + Delphes (pp → FF + FFJ)
Entries
Pt_Jet > 20 / MLS:on
Pt_Jet > 20 / MLS:off
Leading Jet_PT GeV/c

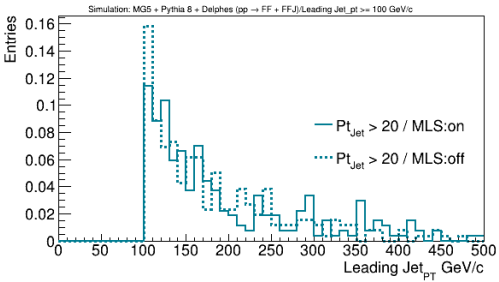
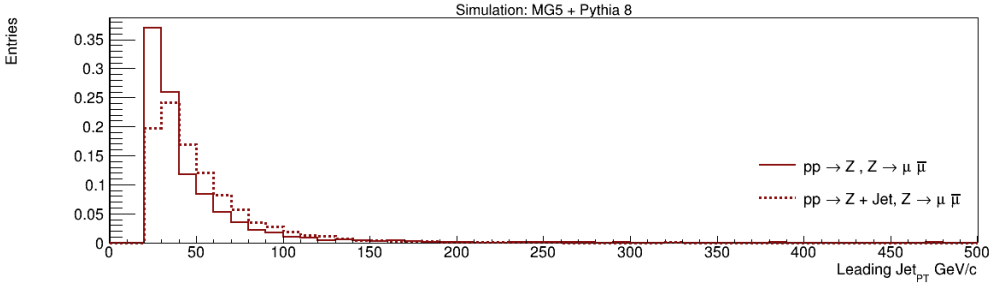

Simulation: MG5 + Pythia 8 + Delphes (pp → FF + FFJ)/Leading Jet_pt >= 100 GeV/c
Entries
Pt_Jet > 20 / MLS:on
Pt_Jet > 20 / MLS:off
Leading Jet_PT GeV/c

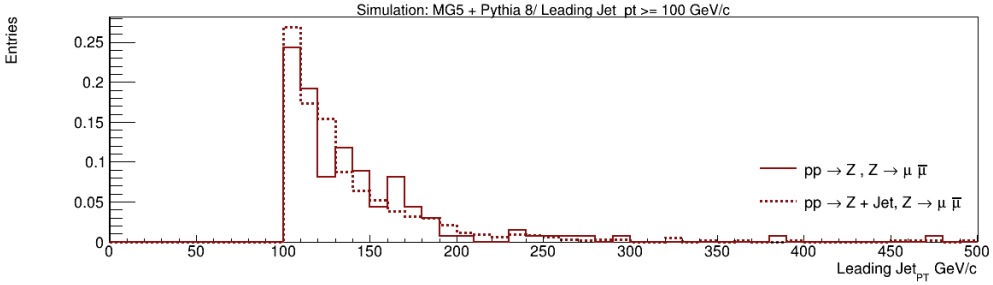
Table: Generation $pp \to F\overline{F}$ and $pp \to F\overline{F} + Jet$

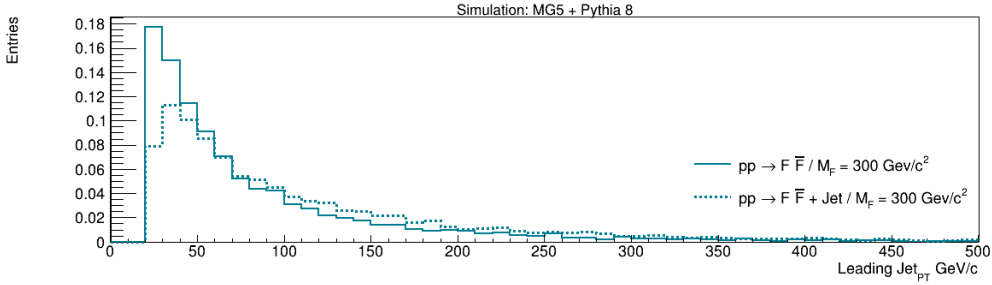
PT$_{Jet}(GeV/c)$	Events	$\sigma_c s$	MLM
$>$ 20	7769	77.64	On
$>$ 20	7348	65.83	Off
$>$ 90	7699	77.67	On
$>$ 90	7317	66.04	Off

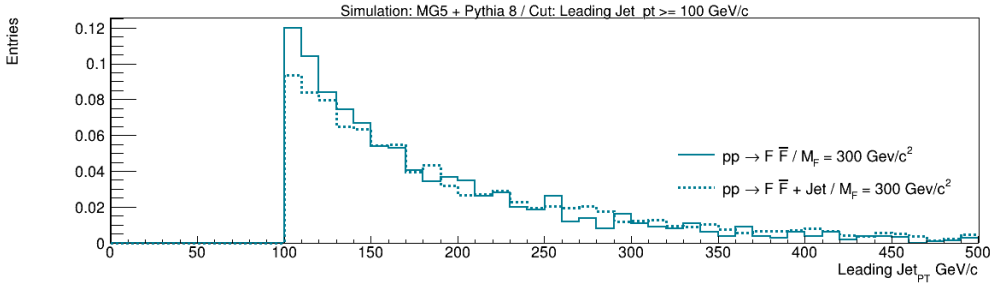
Table: Generation $pp \rightarrow F\overline{F} + Jet$

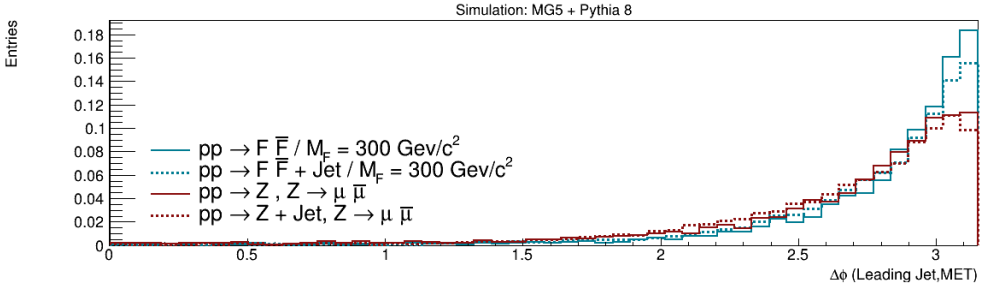
PT$_{Jet}(GeV/c)$	Events	$\sigma_c s$
$>$ 10	8559	43.79
$>$ 20	9436	28.79
$>$ 90	9999	7.58

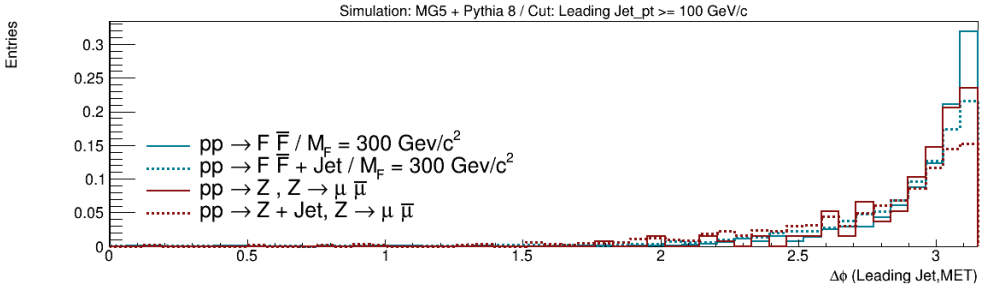

Simulation: MG5 + Pythia 8
Entries
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
50
100
150
200
250
300
350
400
450
500
Leading Jet$_{PT}$ GeV/c
pp → Z , Z → μ μ̄
pp → Z + Jet, Z → μ μ̄


Simulation: MG5 + Pythia 8/ Leading Jet pt >= 100 GeV/c
Entries
0.25
0.2
0.15
0.1
0.05
0
0
50
100
150
200
250
300
350
400
450
500
Leading Jet$_{PT}$ GeV/c
pp → Z , Z → μ μ̄
pp → Z + Jet, Z → μ μ̄

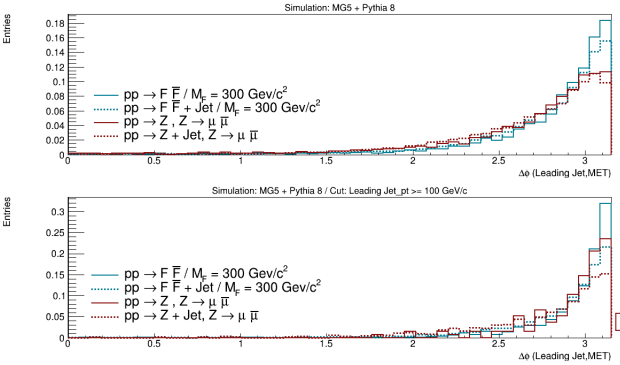

Simulation: MG5 + Pythia 8
Entries
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
50
100
150
200
250
300
350
400
450
500
Leading Jet$_{PT}$ GeV/c
pp → F $\overline{F}$ / M$_F$ = 300 Gev/c^2
pp → F $\overline{F}$ + Jet / M$_F$ = 300 Gev/c^2


Simulation: MG5 + Pythia 8 / Cut: Leading Jet pt >= 100 GeV/c
Entries
0.12
0.1
0.08
0.06
0.04
0.02
0
0
50
100
150
200
250
300
350
400
450
500
Leading Jet$_{PT}$ GeV/c
pp → F $\overline{F}$ / M$_F$ = 300 Gev/c^2
pp → F $\overline{F}$ + Jet / M$_F$ = 300 Gev/c^2


Simulation: MG5 + Pythia 8
Entries
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
0.5
1
1.5
2
2.5
3
pp → F F̄ / M_F = 300 Gev/c²
pp → F F̄ + Jet / M_F = 300 Gev/c²
pp → Z , Z → μ μ̄
pp → Z + Jet, Z → μ μ̄
Δϕ (Leading Jet,MET)


Simulation: MG5 + Pythia 8 / Cut: Leading Jet_pt >= 100 GeV/c
Entries
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3
pp → F F̄ / M_F = 300 Gev/c²
pp → F F̄ + Jet / M_F = 300 Gev/c²
pp → Z , Z → μ μ̄
pp → Z + Jet, Z → μ μ̄
Δϕ (Leading Jet,MET)

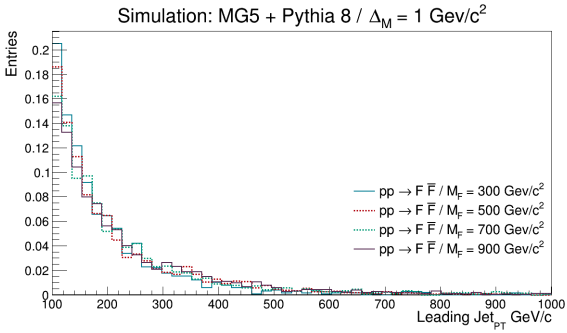
Simulation



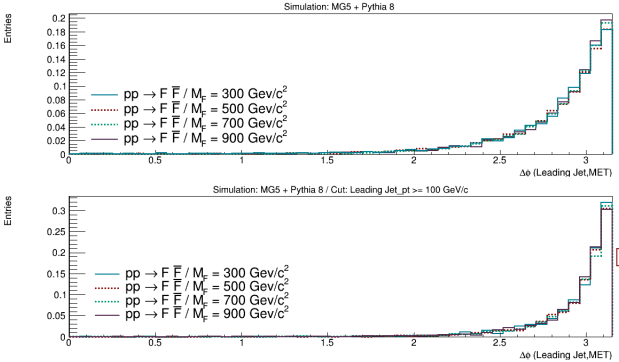
- Events Generation:
  - 10,000 generated events.
  - Generation: $pp \rightarrow F\overline{F}, F \rightarrow \mu s$ in 13 TeV.
  - Generation: $pp \rightarrow F\overline{F} + Jet$, $F \rightarrow \mu s$ in 13 TeV.
  - Generation: $pp \rightarrow Z \rightarrow \mu\overline{\mu}$ in 13 TeV.
  - Generation: $pp \rightarrow Z + Jet$, $Z \rightarrow \mu\overline{\mu}$ in 13 TeV.
  - Select the leading Jet in each event with PT $>=$ 100 GeV/c.
- Goal:
  - Observe the shape of the graph.

Simulation

- Events Generation:
  - 10,000 generated events.
  - Generation: $pp \rightarrow F\overline{F} \rightarrow \mu s \overline{\mu} \overline{s}$ in 13 TeV.
  - Select the leading Jet in each event with PT $>=$ 100 GeV/c.
  - Difference between mass of the F particle and the S particle is 1 GeV/c^2.
- Goal:
  - Observe the shape of the graph when increasing the mass of the FIMP.

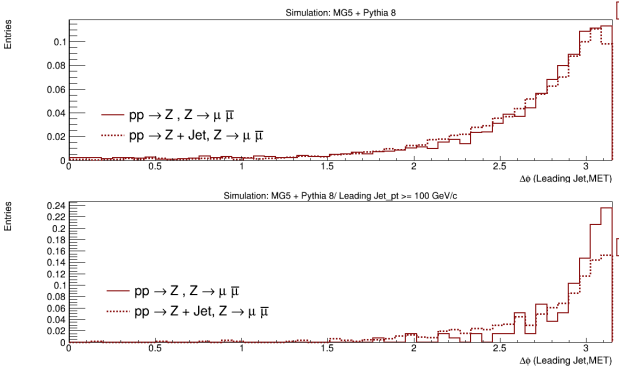


Simulation



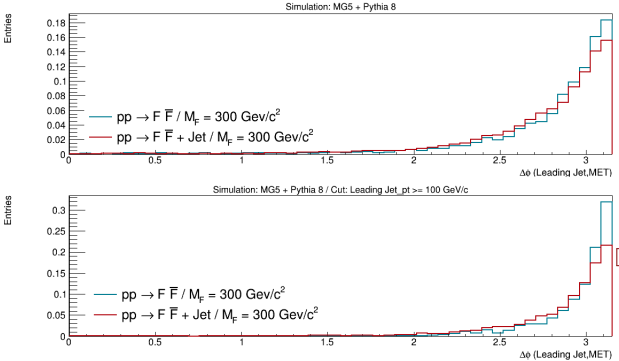
- Events Generation:
  - 10,000 generated events.
  - Generation: $pp \rightarrow F\overline{F} \rightarrow \mu s\overline{\mu}s$ in 13 TeV.
  - Select the leading Jet in each event with PT >= 100 GeV/c.
  - Difference between mass of the F particle and the S particle is 1 GeV/c^2.
- Goal:
  - Observe the shape of the graph when increasing the mass of the FIMP.

Simulation



- Events Generation:
  - 10,000 generated events.
  - Generation: $pp \rightarrow Z \rightarrow \mu\overline{\mu}$ in 13 TeV.
  - Generation: $pp \rightarrow Z + Jet$, $Z \rightarrow \mu\overline{\mu}$ in 13 TeV.
  - Select the leading Jet in each event with PT $>=$ 25 GeV/c or 100 GeV/c.
- Goal:
  - Observe the shape of the graph when Z and $Z + Jet$ are generated.

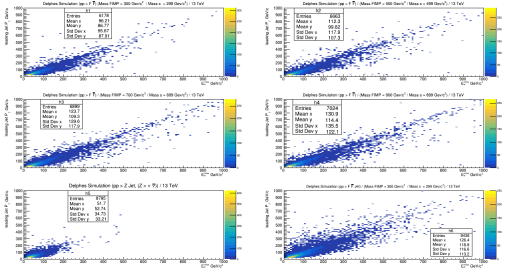
Simulation



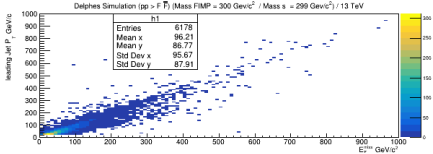
- Events Generation:
  - 10,000 generated events.
  - Generation: $pp \rightarrow F\overline{F}, F \rightarrow \mu s$ in 13 TeV.
  - Generation: pp $\rightarrow$ F $\overline{F} + Jet, F \rightarrow \mu\ s$ in 13 TeV.
  - Select the leading Jet in each event with PT $>=$ 100 GeV/c.
- Goal:
  - Observe the shape of the graph when $F\overline{F}$ and $F\overline{F} + Jet$ are generated.

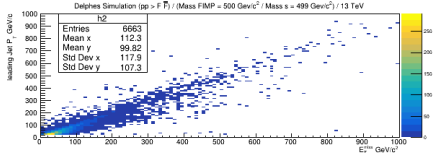
Simulation

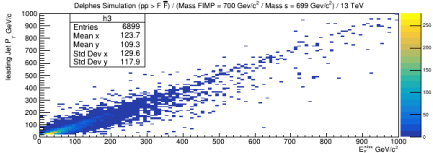
- Events Generation:
  - 10,000 generated events.
  - Generation: $pp \rightarrow F\overline{F}, F \rightarrow \mu s$ in 13 TeV.
  - Generation: $pp \rightarrow F\overline{F} + Jet,\ F \rightarrow \mu s$ in 13 TeV.
  - Generation: $pp \rightarrow Z \rightarrow \mu\overline{\mu}$ in 13 TeV.
  - Select the leading Jet in each event with PT $>=$ 25 GeV/c.
- Goal:
  - Observe the shape of the graph and check the proportionality relationship between PT and MET

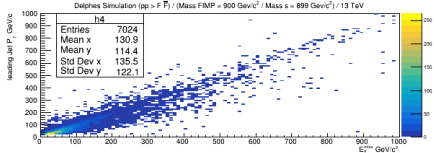


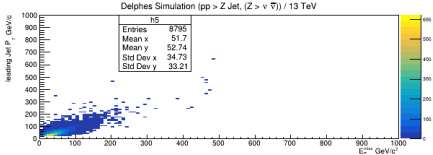
Simulation

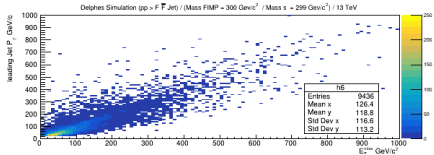

Delphes Simulation (pp > F $\bar{F}$) / (Mass FIMP = 300 Gev/c^2 / Mass s = 299 Gev/c^2) / 13 TeV
h1
Entries 6178
Mean x 96.21
Mean y 86.77
Std Dev x 95.67
Std Dev y 87.91
leading Jet P$_T$ GeV/c
E^{miss} GeV/c^2


Delphes Simulation (pp > F $\bar{F}$) / (Mass FIMP = 500 Gev/c^2 / Mass s = 499 Gev/c^2) / 13 TeV
h2
Entries 6663
Mean x 112.3
Mean y 99.82
Std Dev x 117.9
Std Dev y 107.3
leading Jet P$_T$ GeV/c
E^{miss} GeV/c^2

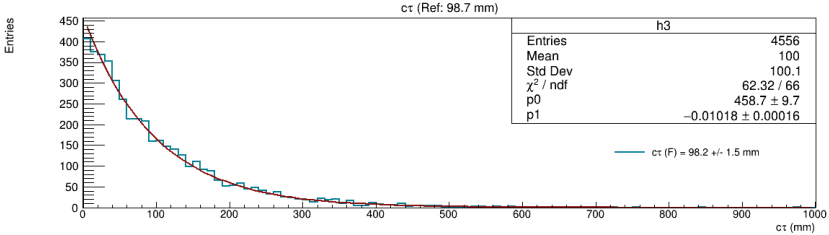

Delphes Simulation (pp > F $\bar{F}$) / (Mass FIMP = 700 Gev/c^2 / Mass s = 699 Gev/c^2) / 13 TeV
h3
Entries 6899
Mean x 123.7
Mean y 109.3
Std Dev x 129.6
Std Dev y 117.9
leading Jet P$_T$ GeV/c
E^{miss} GeV/c^2

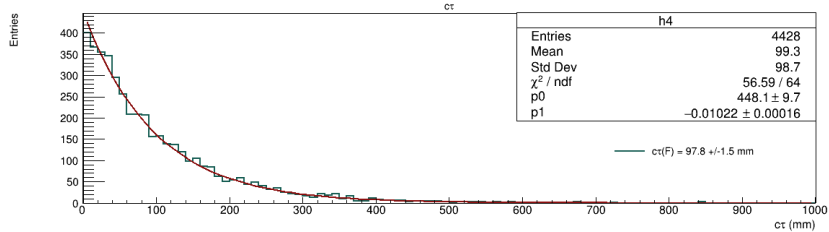

Delphes Simulation (pp > F $\bar{F}$) / (Mass FIMP = 900 Gev/c^2 / Mass s = 899 Gev/c^2) / 13 TeV
h4
Entries 7024
Mean x 130.9
Mean y 114.4
Std Dev x 135.5
Std Dev y 122.1
leading Jet P$_T$ GeV/c
E^{miss} GeV/c^2


Delphes Simulation (pp > Z Jet, (Z > ν $\bar{\nu}$)) / 13 TeV
h5
Entries 8795
Mean x 51.7
Mean y 52.74
Std Dev x 34.73
Std Dev y 33.21
leading Jet P$_T$ GeV/c
E^{miss} GeV/c^2


Delphes Simulation (pp > F $\bar{F}$ Jet) / (Mass FIMP = 300 Gev/c^2 / Mass s = 299 Gev/c^2) / 13 TeV
h6
Entries 9436
Mean x 126.4
Mean y 118.8
Std Dev x 116.6
Std Dev y 113.2
leading Jet P$_T$ GeV/c
E^{miss} GeV/c^2

Simulation


cτ (Ref: 98.7 mm)
Entries
h3
Entries 4556
Mean 100
Std Dev 100.1
χ² / ndf 62.32 / 66
p0 458.7 ± 9.7
p1 −0.01018 ± 0.00016
cτ (F) = 98.2 +/- 1.5 mm
cτ (mm)


cτ
Entries
h4
Entries 4428
Mean 99.3
Std Dev 98.7
χ² / ndf 56.59 / 64
p0 448.1 ± 9.7
p1 −0.01022 ± 0.00016
cτ(F) = 97.8 +/-1.5 mm
cτ (mm)

SPRACE