Explanation of the ATLAS Z-peaked excess in the NMSSM

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Cooperate with

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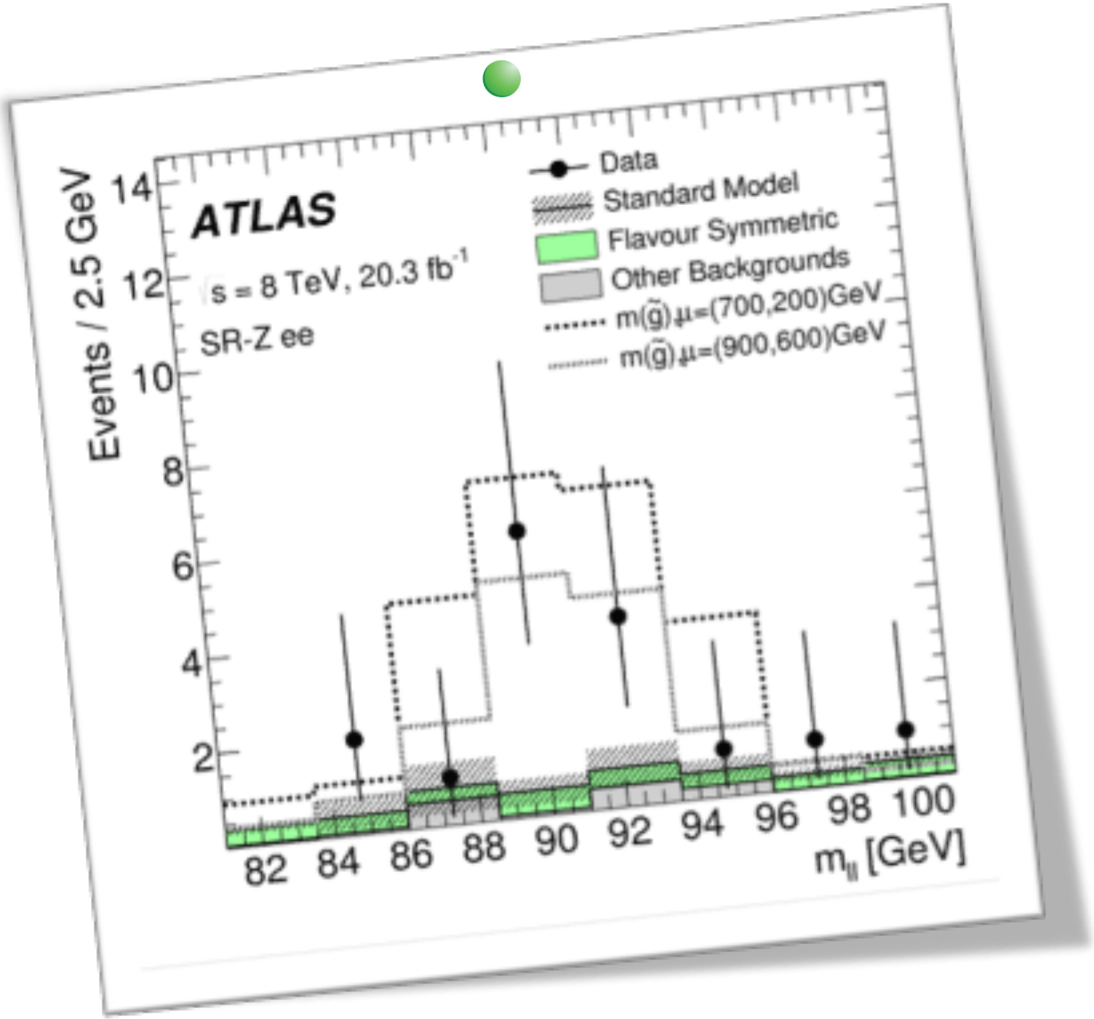
Liangliang Shang



- I Monte Carlo simulation
  - 1. Why do we need to do MC simulation?
  - 2. How to do MC simulation in collider physics?
  - 3. Which kind of work can MC simulation do?

- II Example: Explanation of the ATLAS Z-peaked excess in the NMSSM
  - 1. Brief introduction of SUSY
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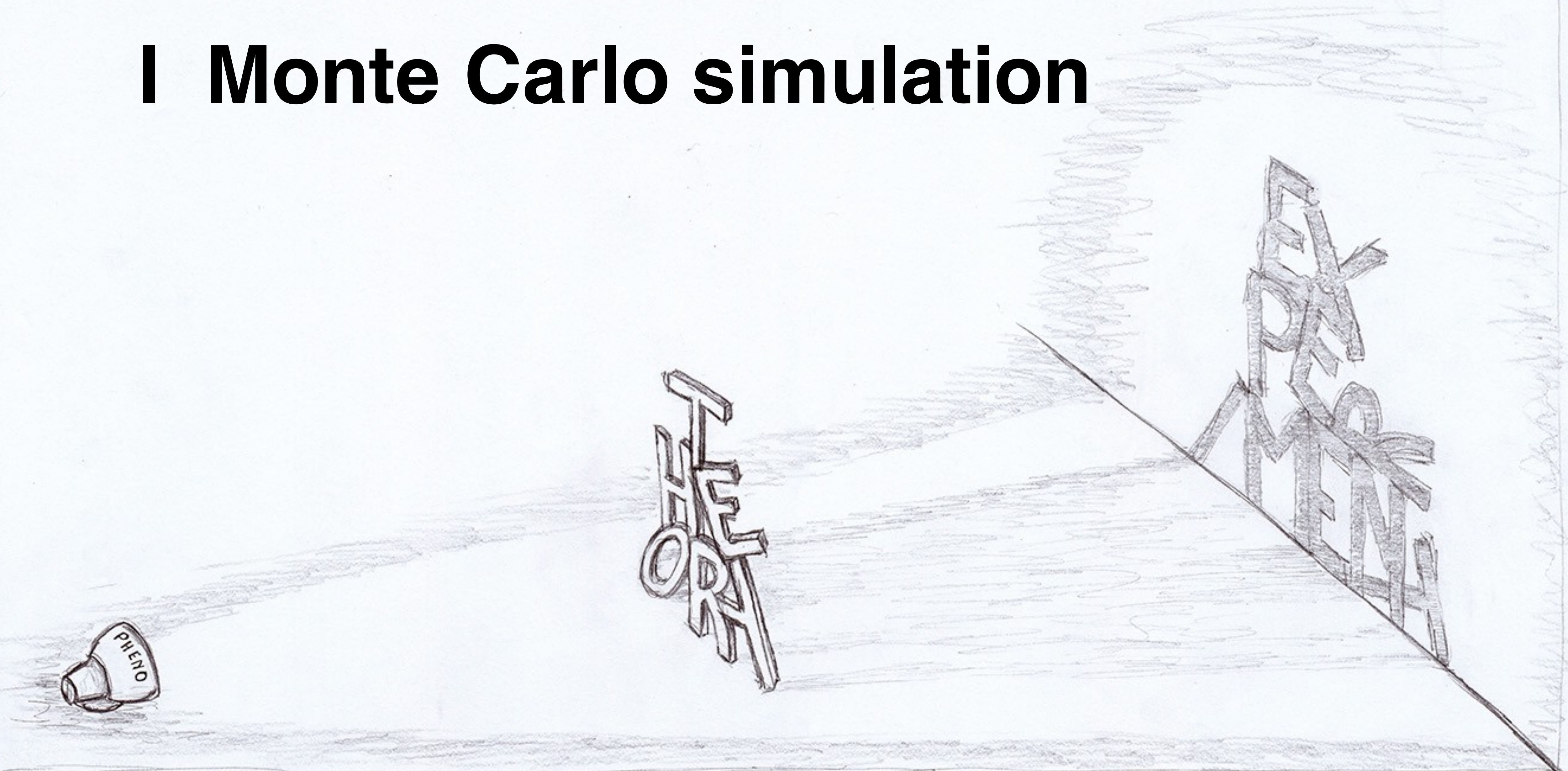
  - 3. The explanation of the Z-peaked excess

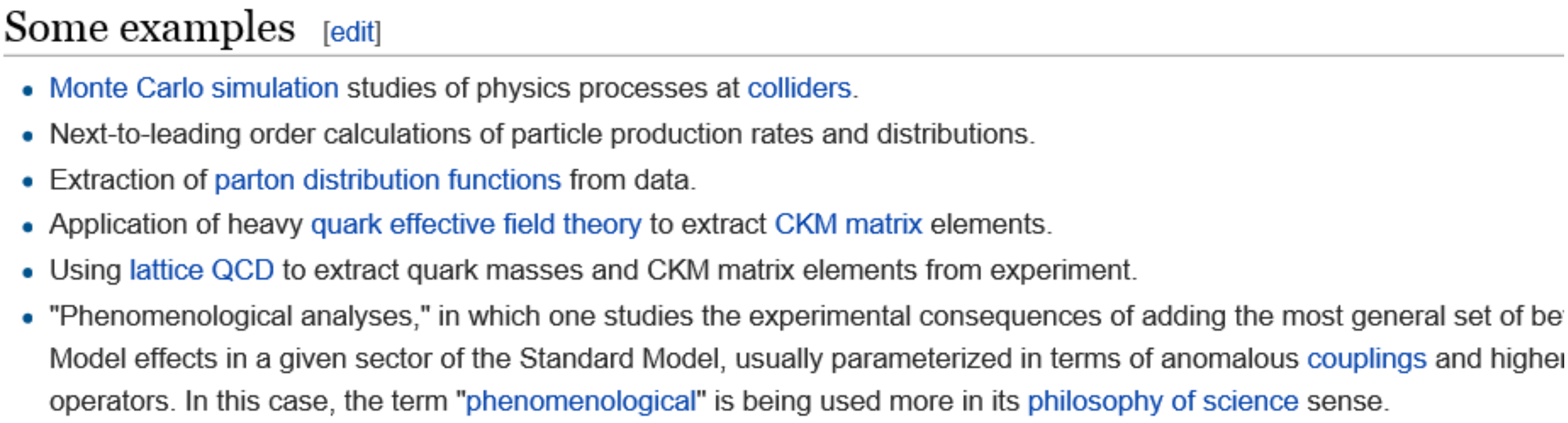
- III Conclusion

I Monte Carlo simulation



1.Why do we need to do MC simulation?

Particle physics phenomenology is the part of theoretical particle physics that deals with the application of theoretical physics to high-energy particle physics experiments.

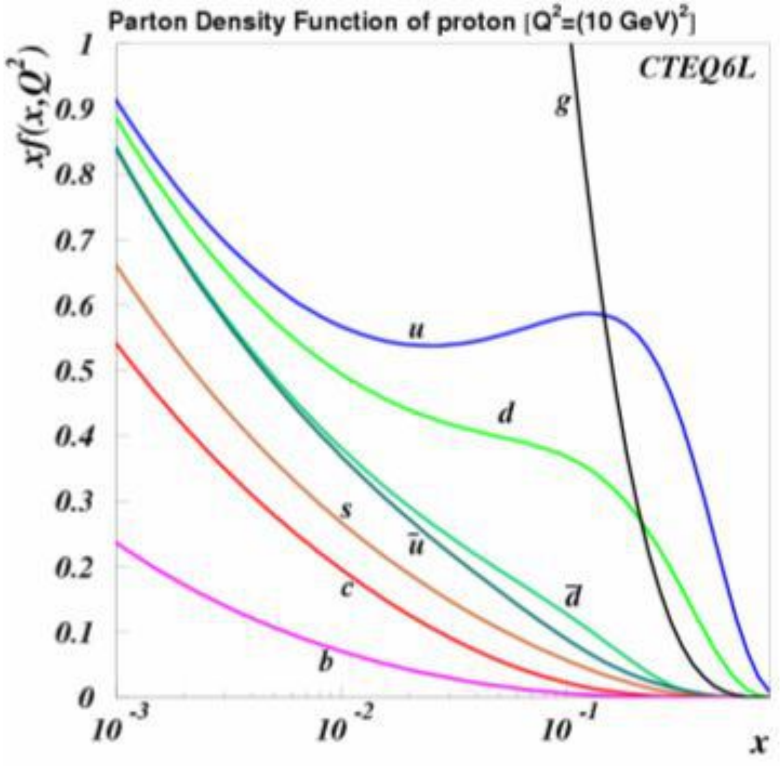


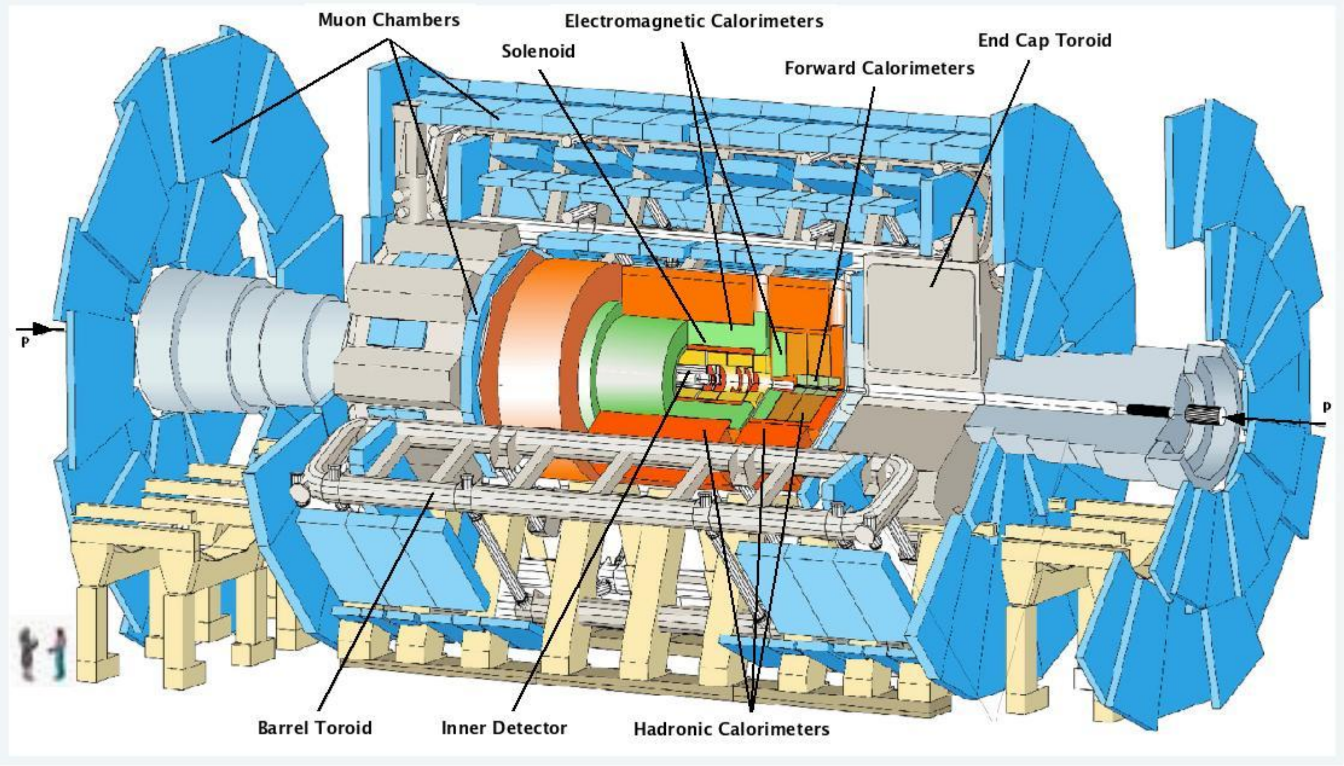
Some examples [edit]

- Monte Carlo simulation studies of physics processes at colliders.
- Next-to-leading order calculations of particle production rates and distributions.
- Extraction of parton distribution functions from data.
- Application of heavy quark effective field theory to extract CKM matrix elements.
- Using lattice QCD to extract quark masses and CKM matrix elements from experiment.
- "Phenomenological analyses," in which one studies the experimental consequences of adding the most general set of be Model effects in a given sector of the Standard Model, usually parameterized in terms of anomalous couplings and highe operators. In this case, the term "phenomenological" is being used more in its philosophy of science sense.

1.Why do we need to do MC simulation?

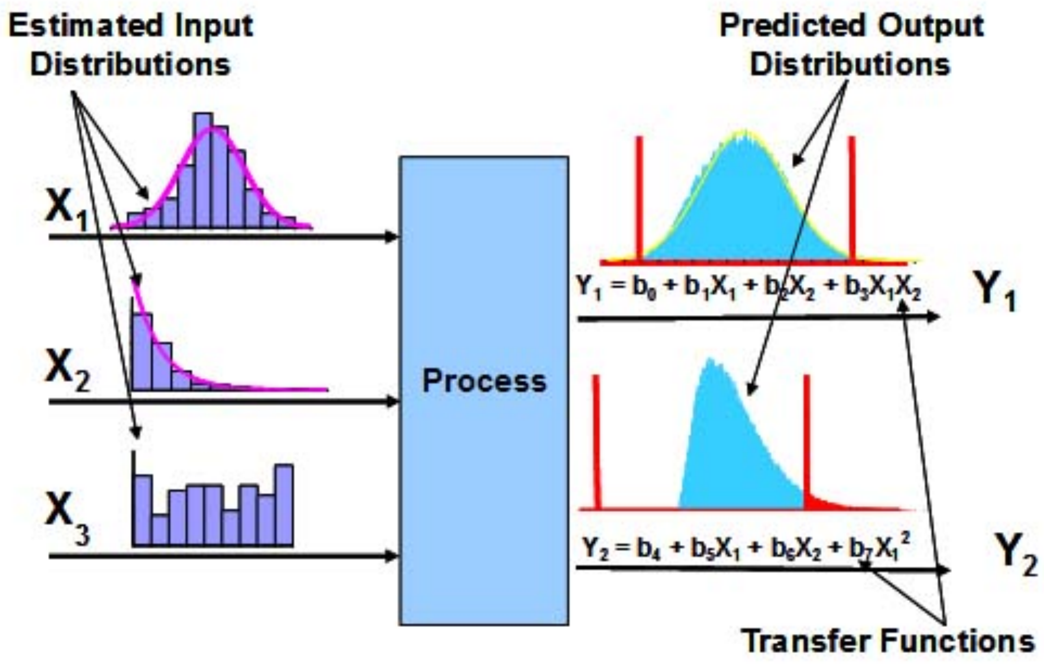
- Theory $\longrightarrow \dot{N} = \sigma L \longrightarrow$ Experiment



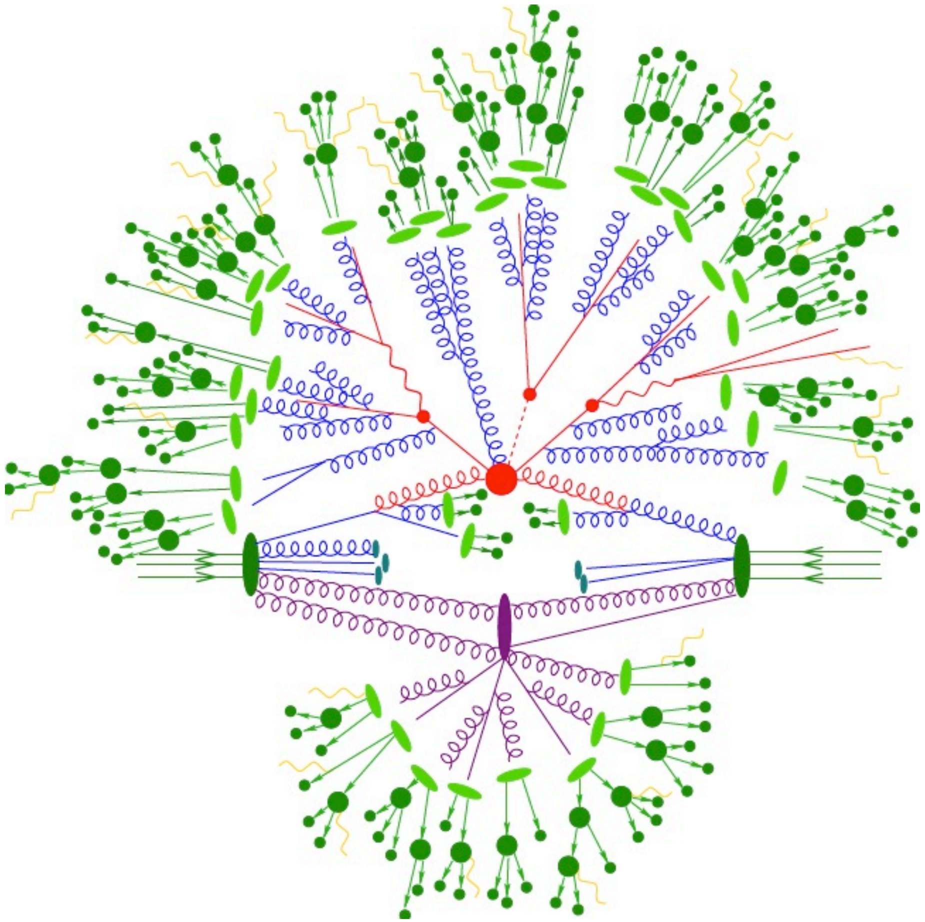


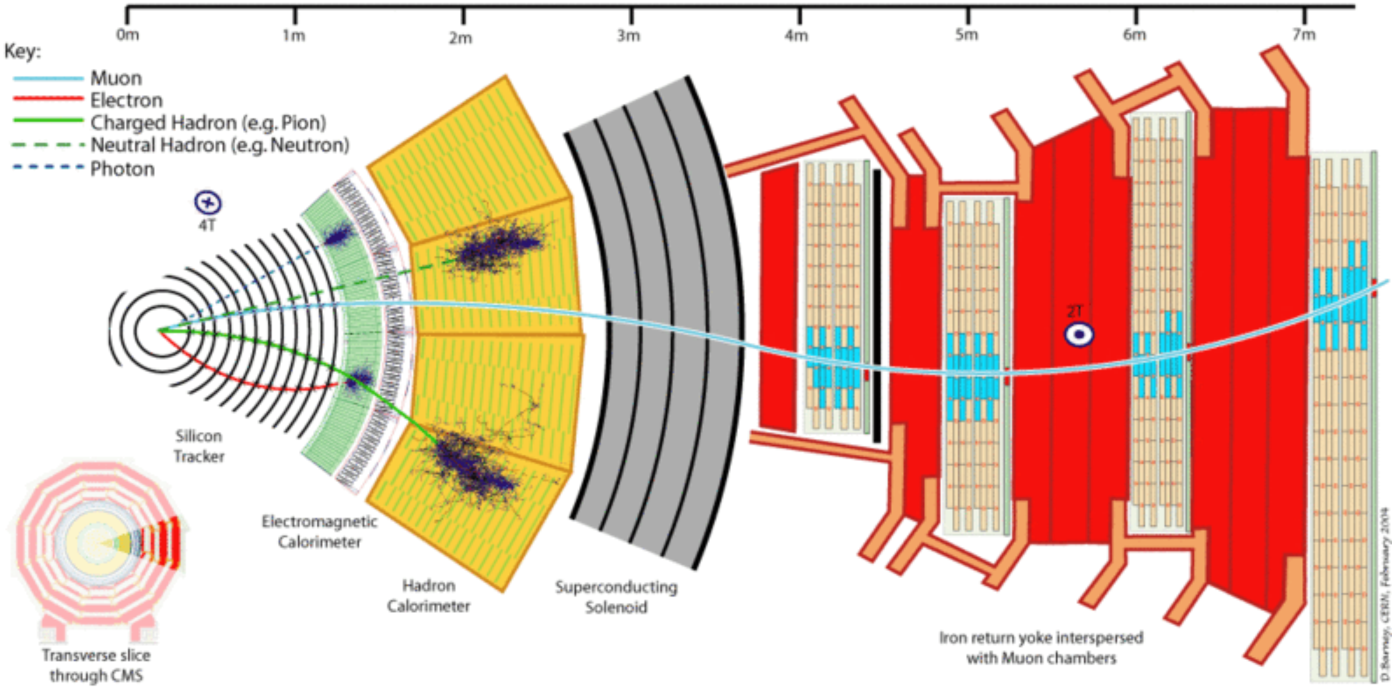
1.Why do we need to do MC simulation?

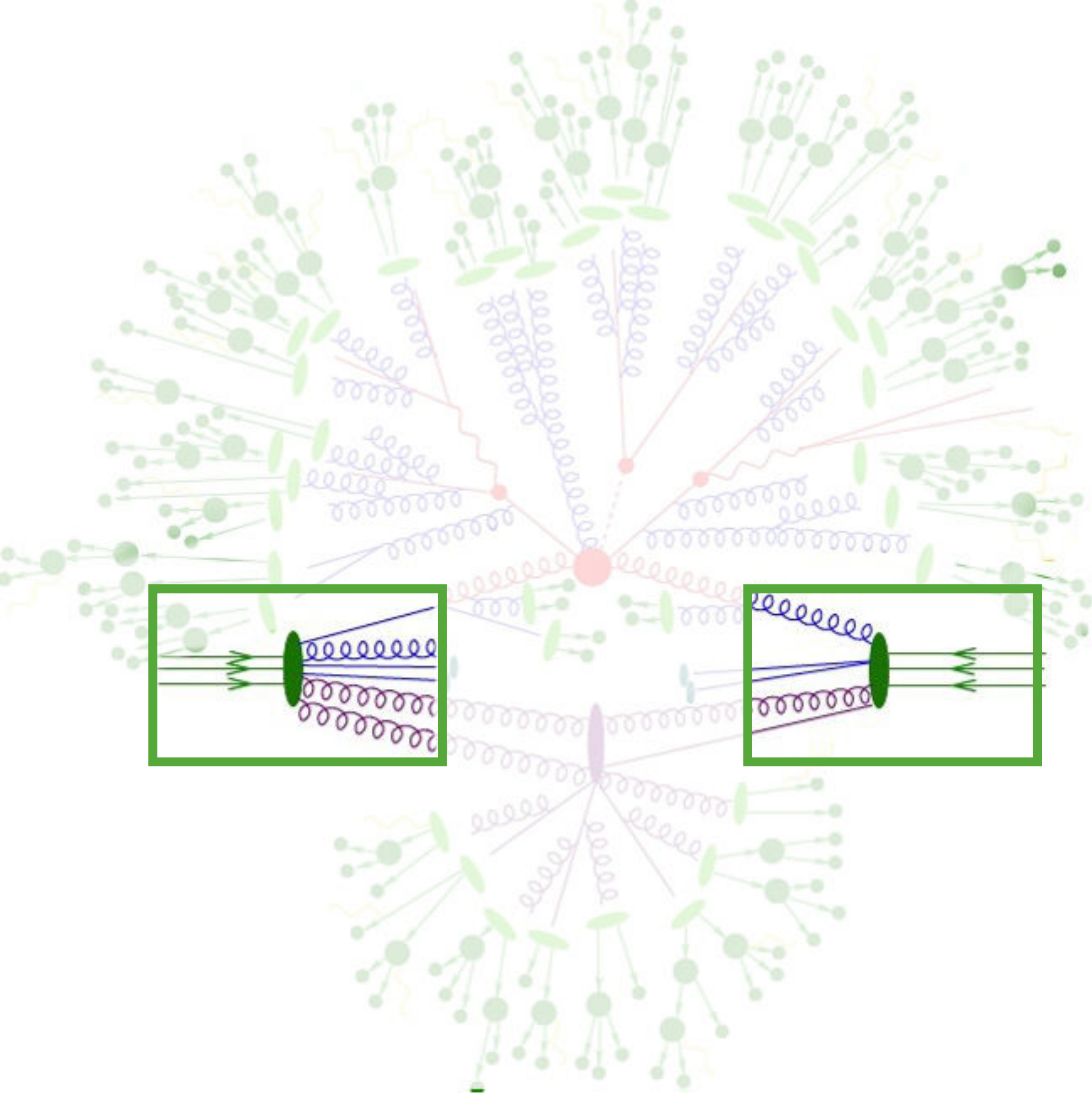
- Monte Carlo methods (or Monte Carlo experiments) are a broad class of computational algorithms that rely on repeated random sampling to obtain numerical results. Monte Carlo methods are mainly used in three distinct problem classes: optimization, numerical integration, and generating draws from a probability distribution.



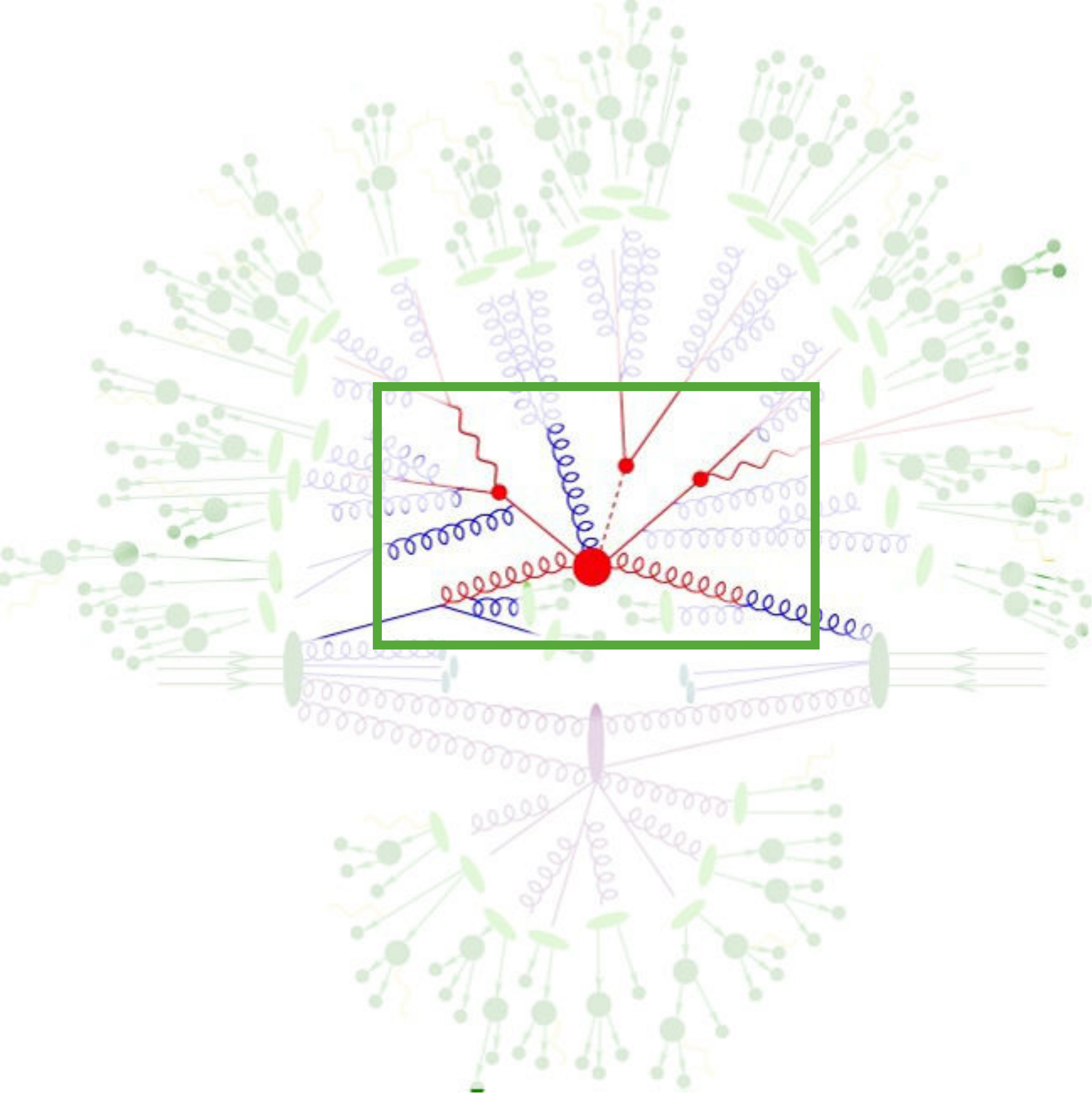
2.How to do MC simulation in collider physics?







- a. PDF
  - CTEQ6L1
- b. Hard scattering
  - MadGraph/MadEvent, SHERPA, …
- c. Parton Shower
- Hadronization
  - PYTHIA
- d. Detector
  - Delphes, PGS, GEANT4, …
    - FastJet



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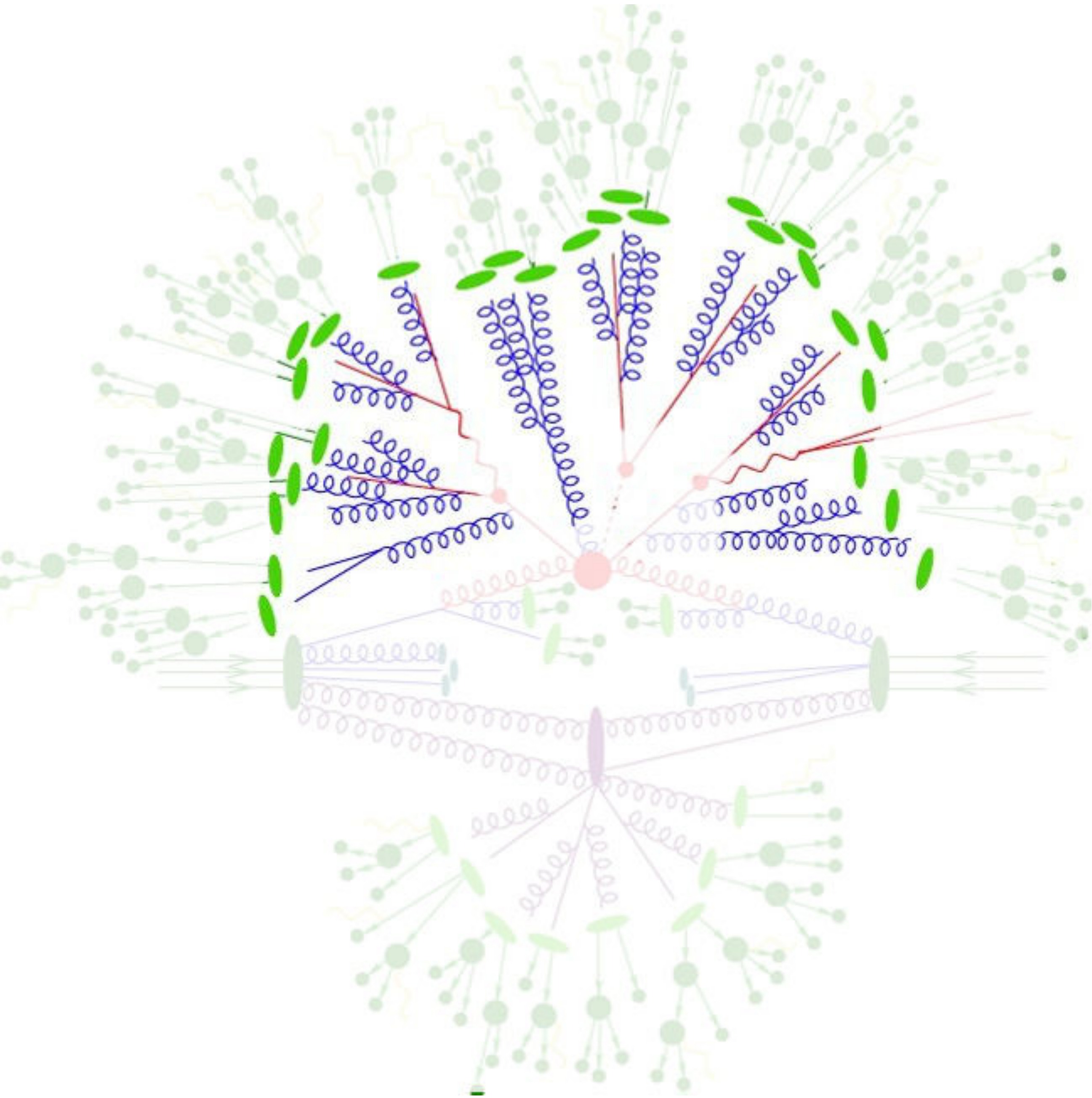

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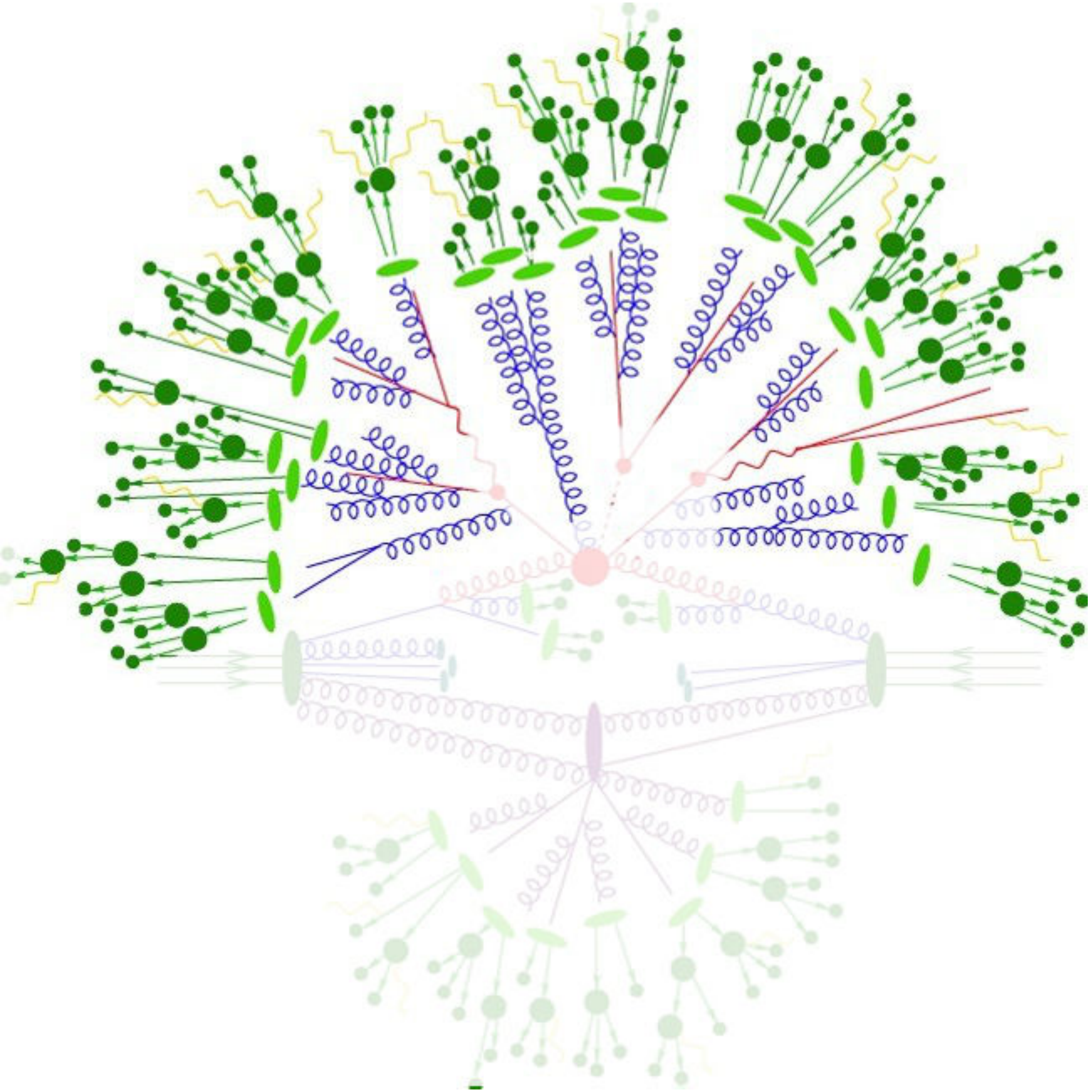

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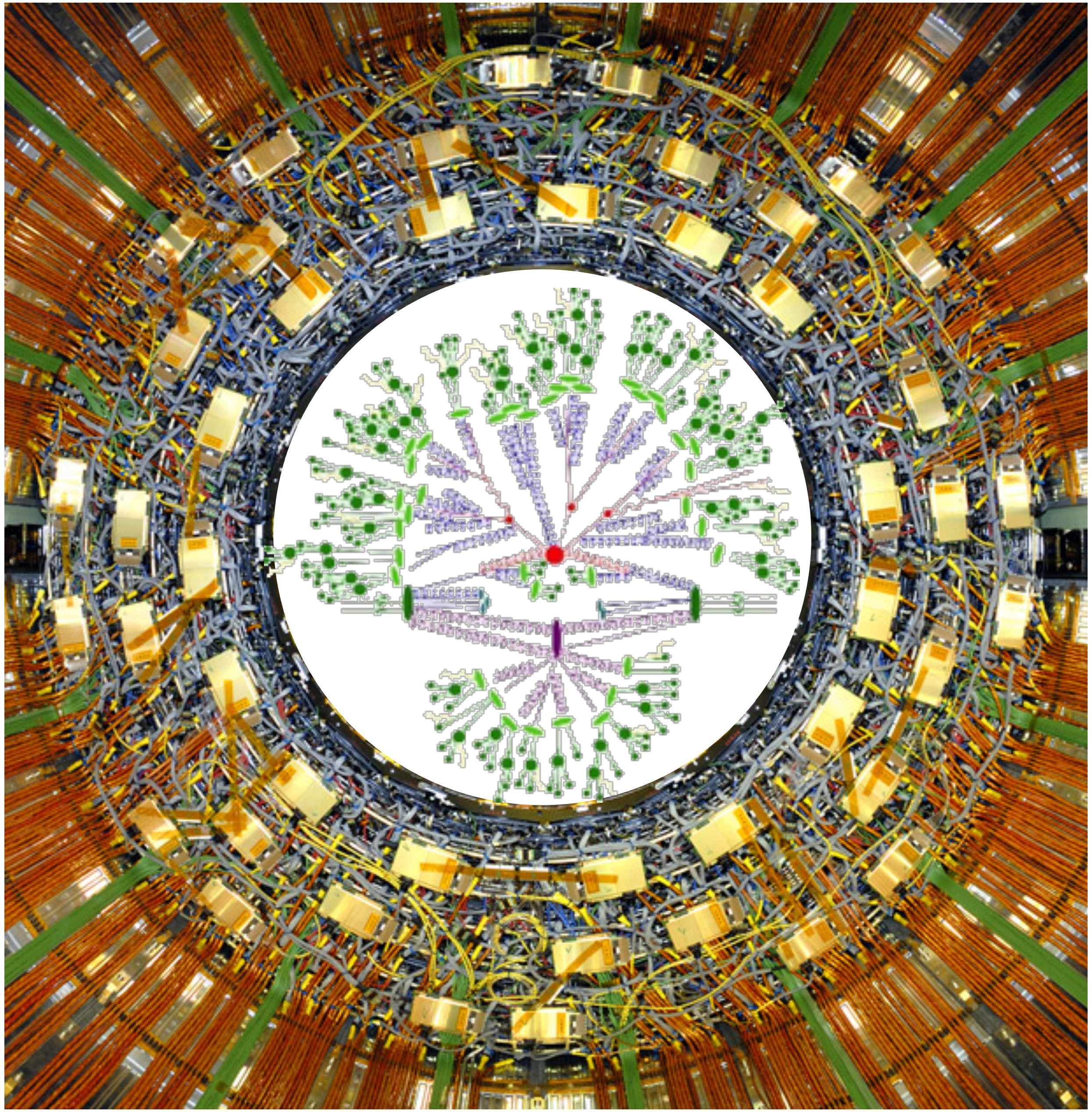

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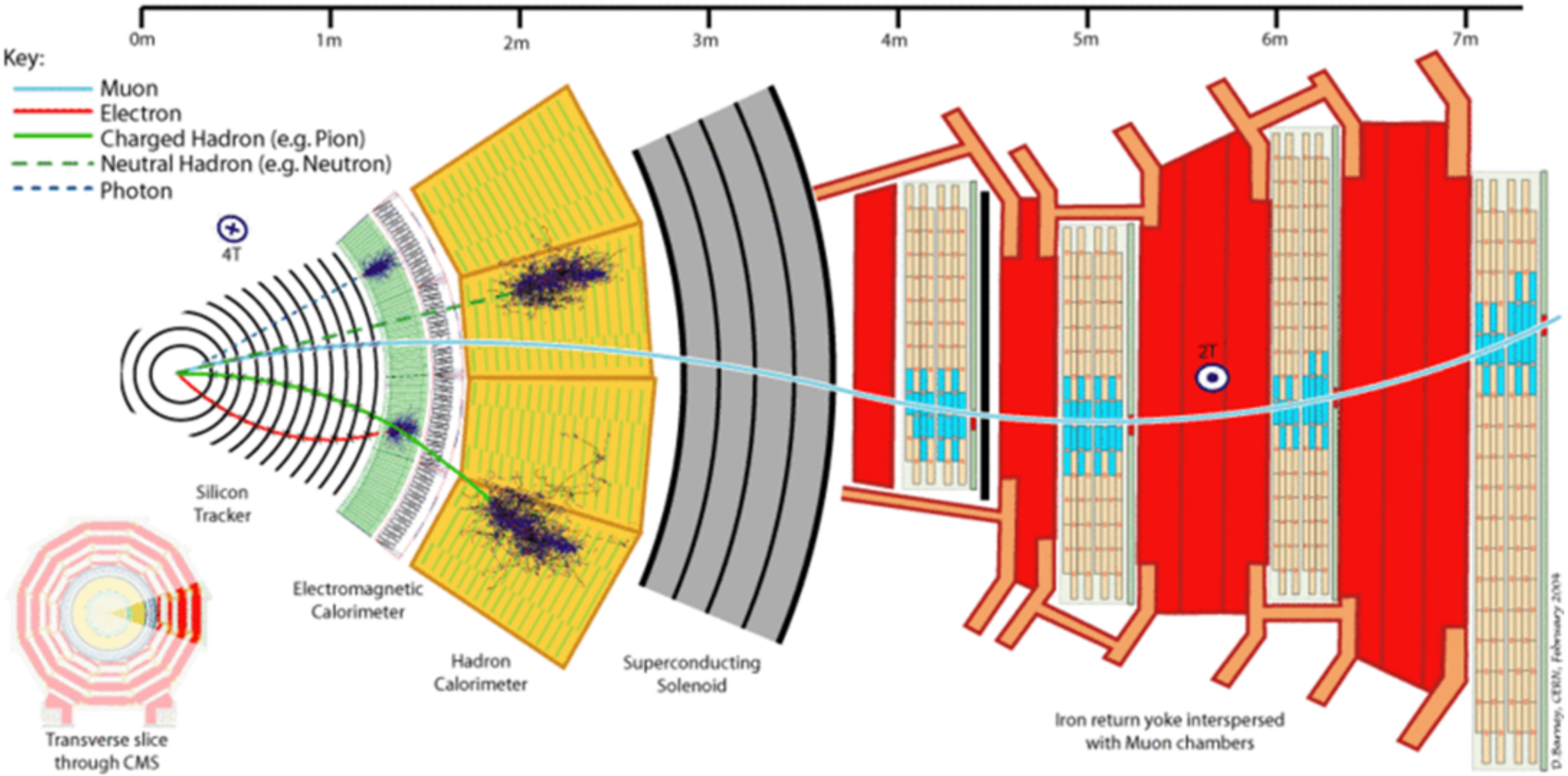
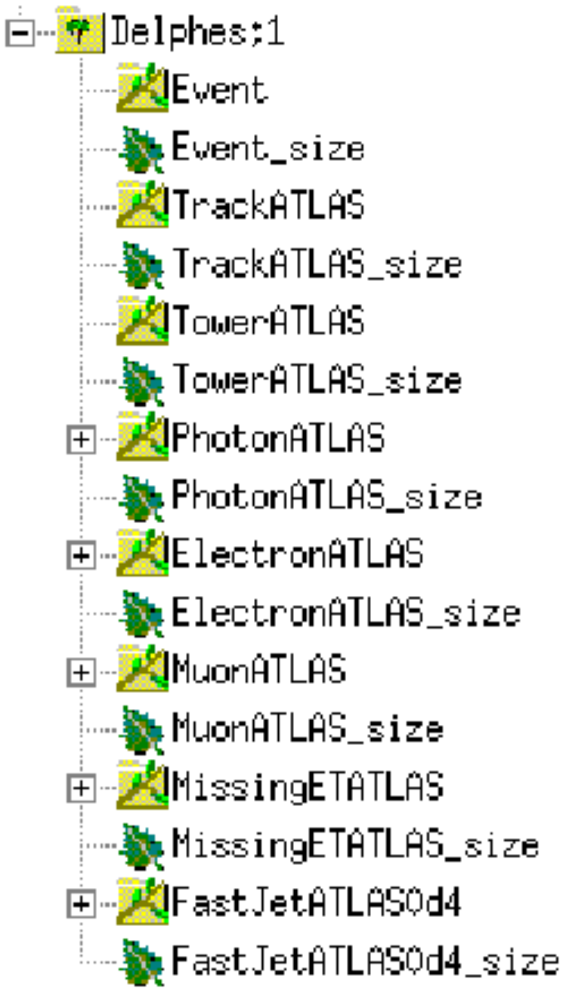


2.How to do MC simulation in collider physics?



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⊟ Delphes;1
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    Event_size
    TrackATLAS
    TrackATLAS_size
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    TowerATLAS_size
  ⊞ PhotonATLAS
    PhotonATLAS_size
  ⊞ ElectronATLAS
    ElectronATLAS_size
  ⊞ MuonATLAS
    MuonATLAS_size
  ⊞ MissingETATLAS
    MissingETATLAS_size
  ⊞ FastJetATLAS0d4
    FastJetATLAS0d4_size
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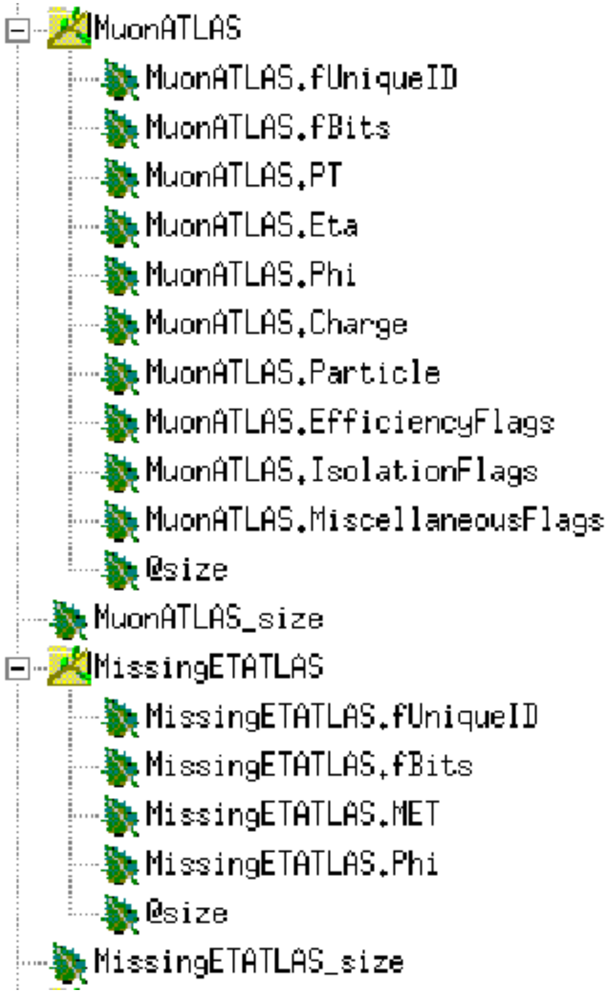

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    MuonATLAS.fBits
    MuonATLAS.PT
    MuonATLAS.Eta
    MuonATLAS.Phi
    MuonATLAS.Charge
    MuonATLAS.Particle
    MuonATLAS.EfficiencyFlags
    MuonATLAS.IsolationFlags
    MuonATLAS.MiscellaneousFlags
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  MuonATLAS_size
⊟ MissingETATLAS
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    MissingETATLAS.Phi
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  MissingETATLAS_size
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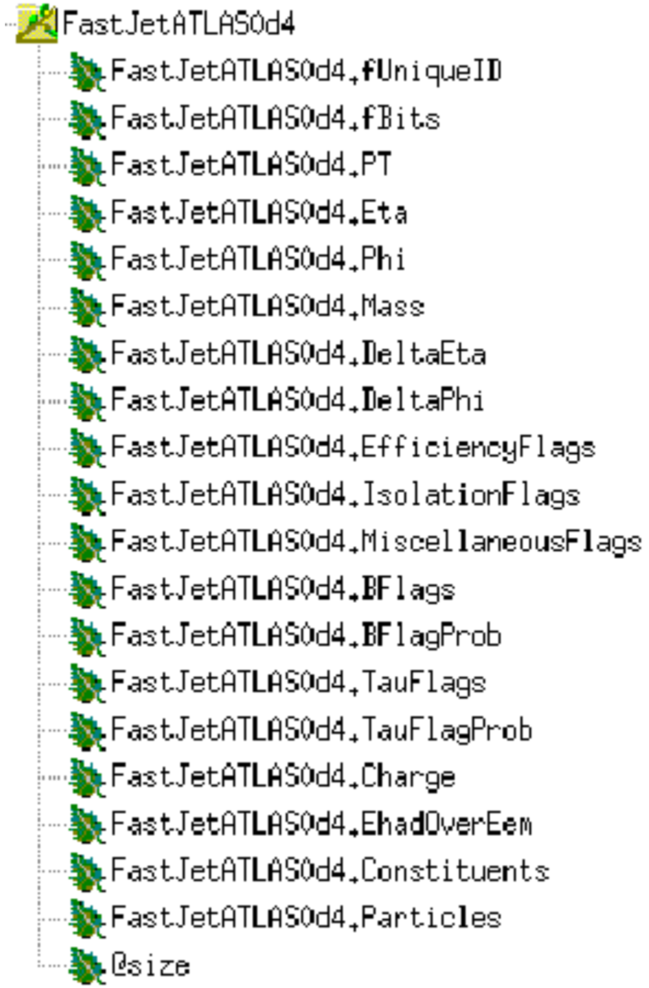

```
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    FastJetATLAS0d4.fUniqueID
    FastJetATLAS0d4.fBits
    FastJetATLAS0d4.PT
    FastJetATLAS0d4.Eta
    FastJetATLAS0d4.Phi
    FastJetATLAS0d4.Mass
    FastJetATLAS0d4.DeltaEta
    FastJetATLAS0d4.DeltaPhi
    FastJetATLAS0d4.EfficiencyFlags
    FastJetATLAS0d4.IsolationFlags
    FastJetATLAS0d4.MiscellaneousFlags
    FastJetATLAS0d4.BFlags
    FastJetATLAS0d4.BFlagProb
    FastJetATLAS0d4.TauFlags
    FastJetATLAS0d4.TauFlagProb
    FastJetATLAS0d4.Charge
    FastJetATLAS0d4.EhadOverEem
    FastJetATLAS0d4.Constituents
    FastJetATLAS0d4.Particles
    @size
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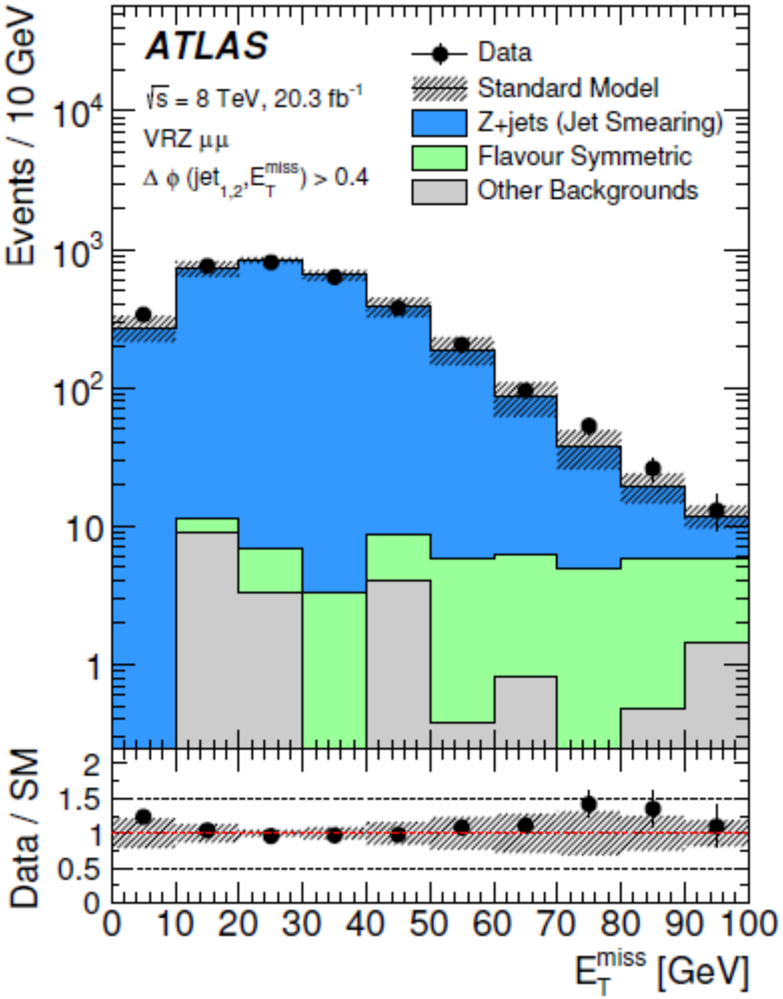
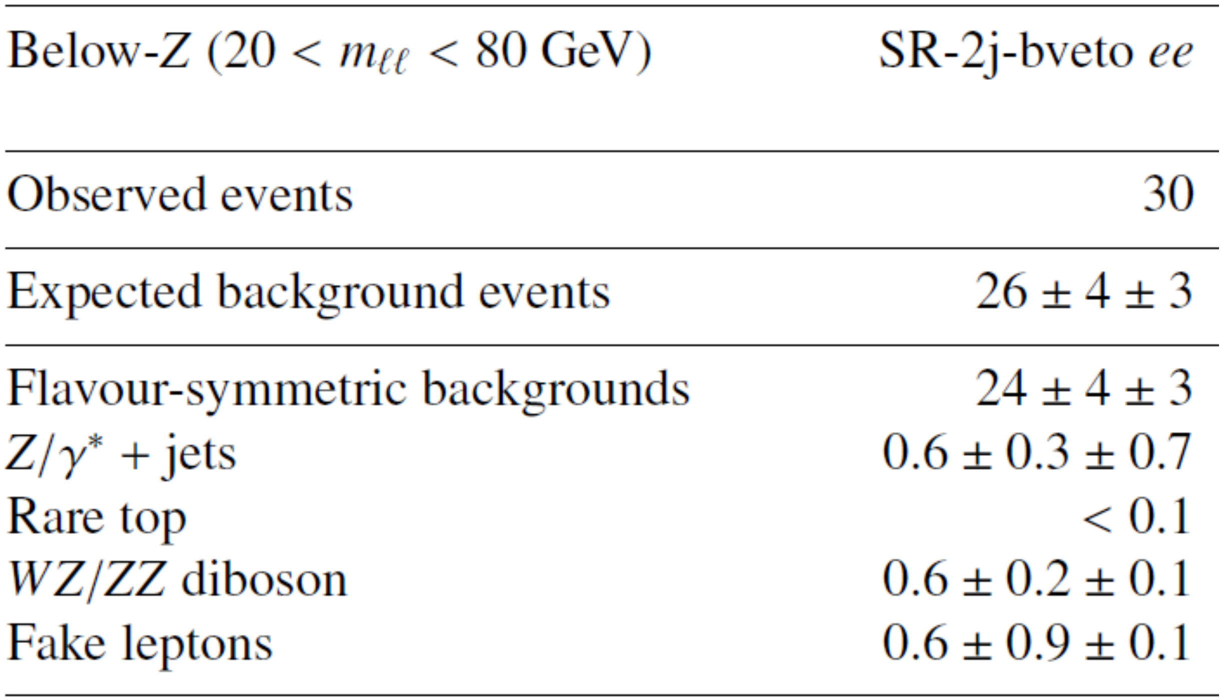
2.How to do MC simulation in collider physics?





Below-Z ($20 < m_{\ell\ell} < 80$ GeV)	SR-2j-bveto ee
Observed events	30
Expected background events	26 ± 4 ± 3
Flavour-symmetric backgrounds	24 ± 4 ± 3
$Z/\gamma^* +$ jets	0.6 ± 0.3 ± 0.7
Rare top	< 0.1
WZ/ZZ diboson	0.6 ± 0.2 ± 0.1
Fake leptons	0.6 ± 0.9 ± 0.1

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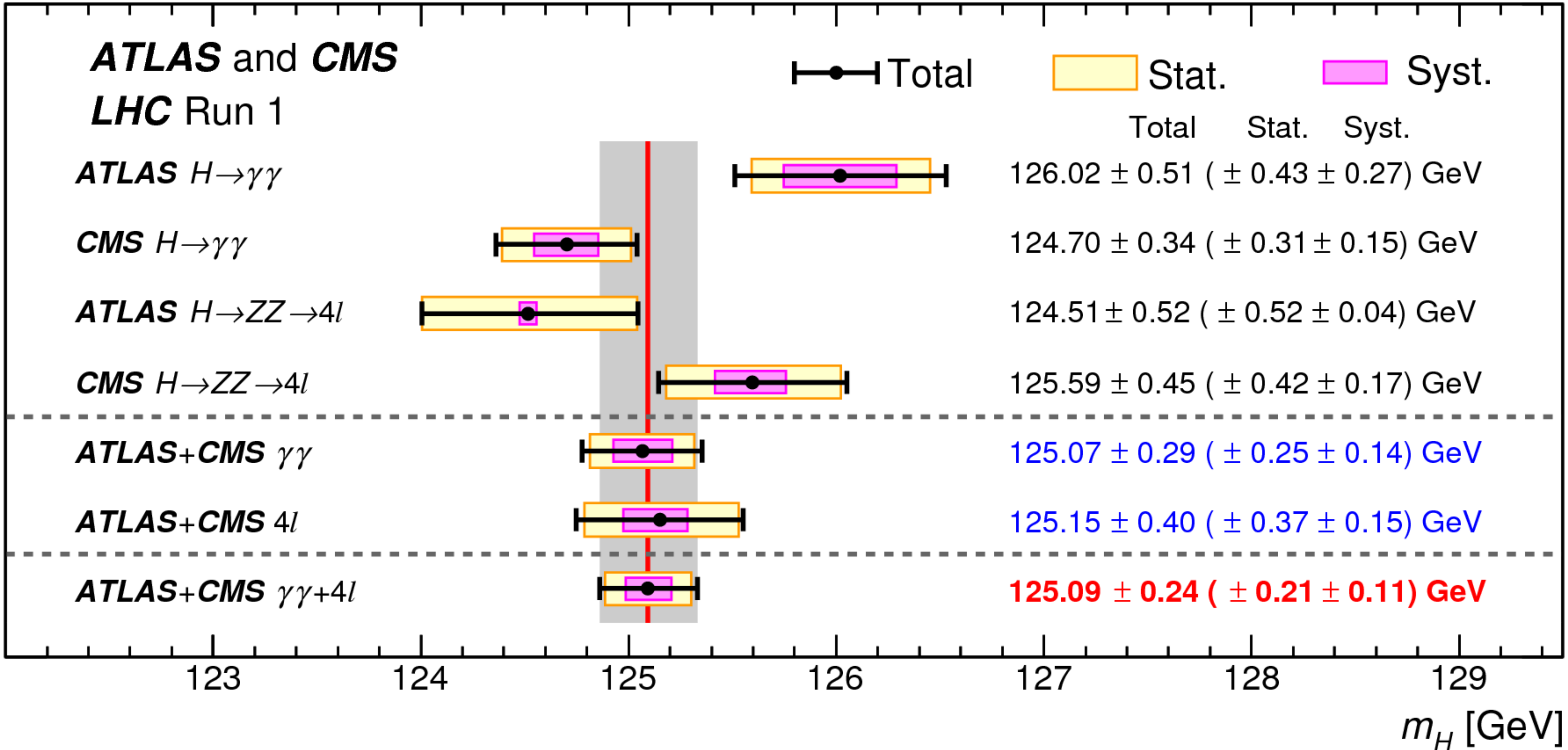
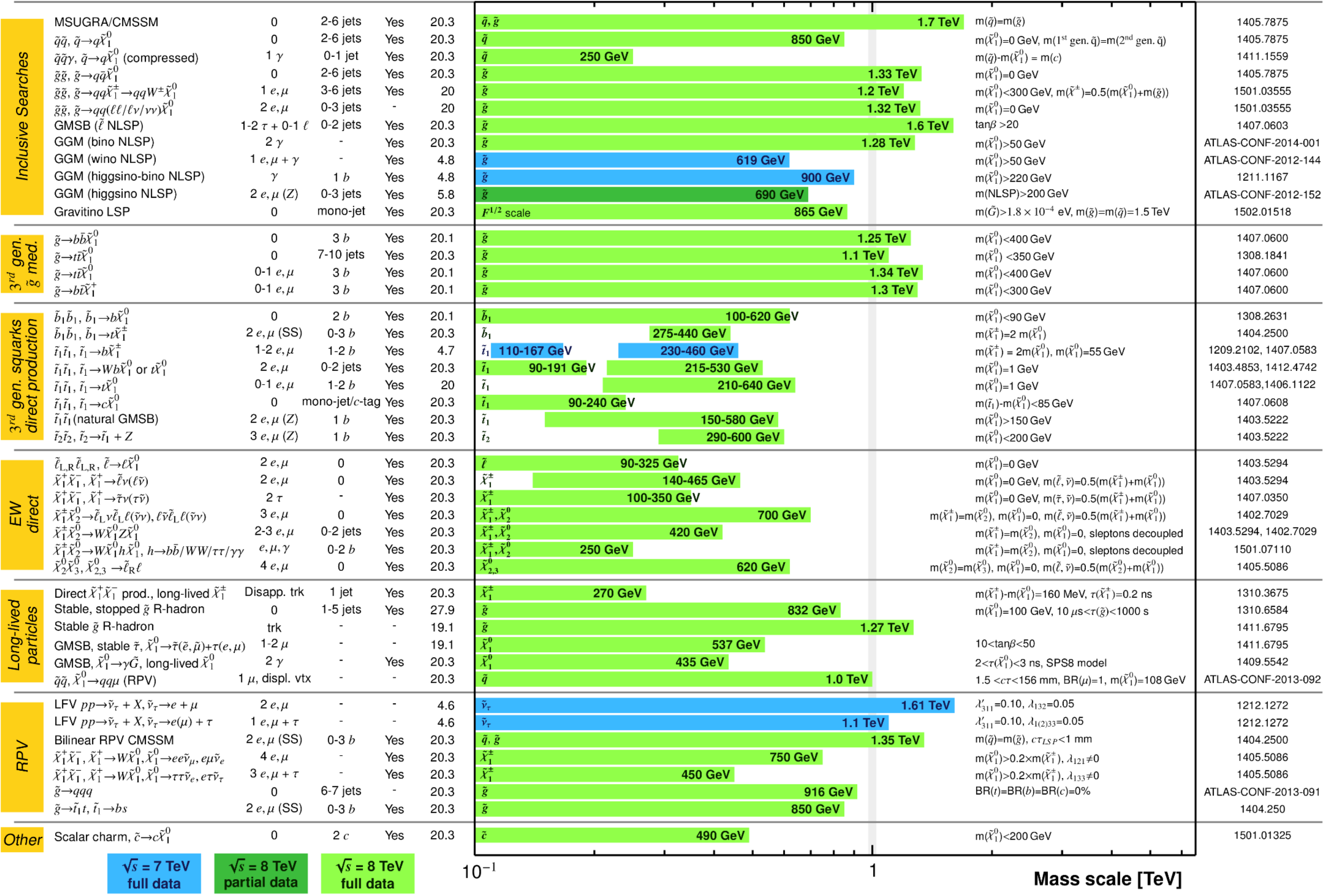


ATLAS SUSY Searches* - 95% CL Lower Limits

Status: Feb 2015

ATLAS Preliminary

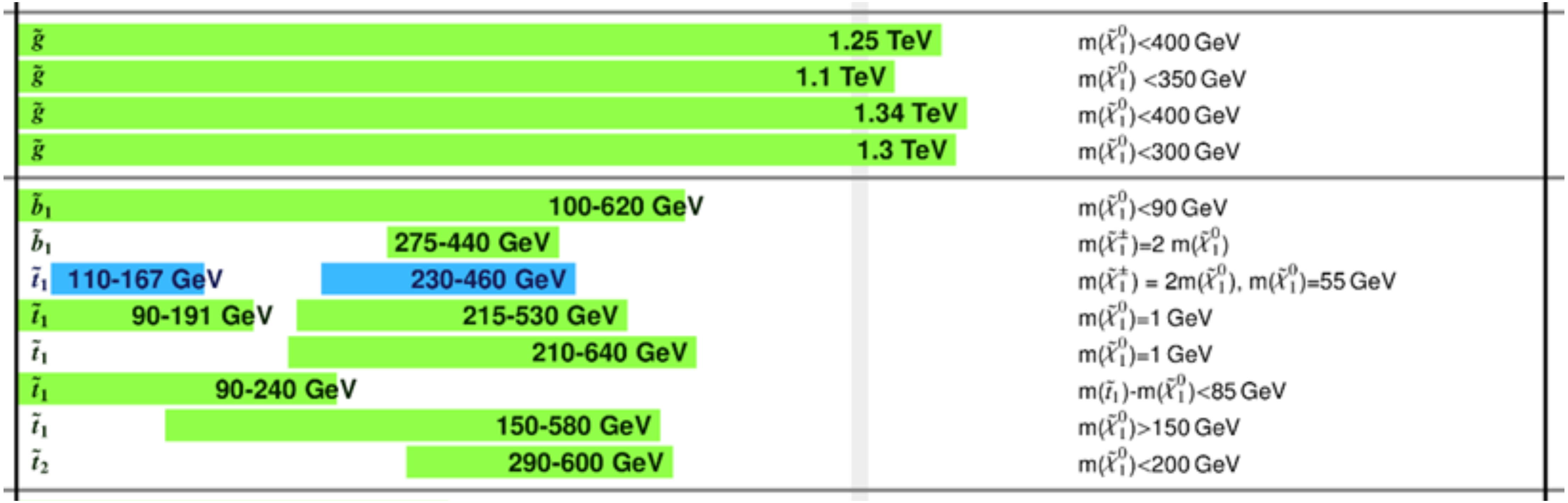
$\sqrt{s}$ = 7, 8 TeV



	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt[\mathrm{fb}^{-1}]$	Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.7 TeV	m($\tilde{q}$)=m($\tilde{g}$)	1405.7875
	$\tilde{q}\tilde{q}$, $\tilde{q}\rightarrow q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$ 850 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m(1st gen. q̃)=m(2nd gen. q̃)	1405.7875
	$\tilde{q}\tilde{q}\gamma$, $\tilde{q}\rightarrow q\tilde{\chi}_1^0$ (compressed)	1 γ	0-1 jet	Yes	20.3	$\tilde{q}$ 250 GeV	m($\tilde{q}$)-m($\tilde{\chi}_1^0$) = m(c)	1411.1559
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$ 1.33 TeV	m($\tilde{\chi}_1^0$)=0 GeV	1405.7875
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow qq\tilde{\chi}_1^{\pm}\rightarrow qqW^{\pm}\tilde{\chi}_1^0$	1 e, μ	3-6 jets	Yes	20	$\tilde{g}$ 1.2 TeV	m($\tilde{\chi}_1^0$)<300 GeV, m($\tilde{\chi}^{\pm}$)=0.5(m($\tilde{\chi}_1^0$)+m($\tilde{g}$))	1501.03555
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e, μ	0-3 jets	-	20	$\tilde{g}$ 1.32 TeV	m($\tilde{\chi}_1^0$)=0 GeV	1501.03555
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	20.3	$\tilde{g}$ 1.6 TeV	tanβ >20	1407.0603
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde{g}$ 1.28 TeV	m($\tilde{\chi}_1^0$)>50 GeV	ATLAS-CONF-2014-001
	GGM (wino NLSP)	1 $e, \mu + \gamma$	-	Yes	4.8	$\tilde{g}$ 619 GeV	m($\tilde{\chi}_1^0$)>50 GeV	ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	4.8	$\tilde{g}$ 900 GeV	m($\tilde{\chi}_1^0$)>220 GeV	1211.1167
	GGM (higgsino NLSP)	2 e, μ (Z)	0-3 jets	Yes	5.8	$\tilde{g}$ 690 GeV	m(NLSP)>200 GeV	ATLAS-CONF-2012-152
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale 865 GeV	m($\tilde{G}$)>1.8×10^{-4} eV, m($\tilde{g}$)=m($\tilde{q}$)=1.5 TeV	1502.01518
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\rightarrow b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$ 1.25 TeV	m($\tilde{\chi}_1^0$)<400 GeV	1407.0600
	$\tilde{g}\rightarrow t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.1 TeV	m($\tilde{\chi}_1^0$) <350 GeV	1308.1841
	$\tilde{g}\rightarrow t\bar{t}\tilde{\chi}_1^0$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$ 1.34 TeV	m($\tilde{\chi}_1^0$)<400 GeV	1407.0600
	$\tilde{g}\rightarrow b\bar{t}\tilde{\chi}_1^+$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$ 1.3 TeV	m($\tilde{\chi}_1^0$)<300 GeV	1407.0600
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\rightarrow b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{b}_1$ 100-620 GeV	m($\tilde{\chi}_1^0$)<90 GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\rightarrow t\tilde{\chi}_1^{\pm}$	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{b}_1$ 275-440 GeV	m($\tilde{\chi}_1^{\pm}$)=2 m($\tilde{\chi}_1^0$)	1404.2500
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\rightarrow b\tilde{\chi}_1^{\pm}$	1-2 e, μ	1-2 b	Yes	4.7	$\tilde{t}_1$ 110-167 GeV 230-460 GeV	m($\tilde{\chi}_1^{\pm}$) = 2m($\tilde{\chi}_1^0$), m($\tilde{\chi}_1^0$)=55 GeV	1209.2102, 1407.0583
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\rightarrow Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	2 e, μ	0-2 jets	Yes	20.3	$\tilde{t}_1$ 90-191 GeV 215-530 GeV	m($\tilde{\chi}_1^0$)=1 GeV	1403.4853, 1412.4742
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\rightarrow t\tilde{\chi}_1^0$	0-1 e, μ	1-2 b	Yes	20	$\tilde{t}_1$ 210-640 GeV	m($\tilde{\chi}_1^0$)=1 GeV	1407.0583,1406.1122
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\rightarrow c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$ 90-240 GeV	m($\tilde{t}_1$)-m($\tilde{\chi}_1^0$)<85 GeV	1407.0608
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e, μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$ 150-580 GeV	m($\tilde{\chi}_1^0$)>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\rightarrow\tilde{t}_1 + Z$	3 e, μ (Z)	1 b	Yes	20.3	$\tilde{t}_2$ 290-600 GeV	m($\tilde{\chi}_1^0$)<200 GeV	1403.5222
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\rightarrow\ell\tilde{\chi}_1^0$	2 e, μ	0	Yes	20.3	$\tilde{\ell}$ 90-325 GeV	m($\tilde{\chi}_1^0$)=0 GeV	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\rightarrow\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e, μ	0	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 140-465 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m($\tilde{\ell}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_1^{\pm}$)+m($\tilde{\chi}_1^0$))	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\rightarrow\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 100-350 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m($\tilde{\tau}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_1^{\pm}$)+m($\tilde{\chi}_1^0$))	1407.0350
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e, μ	0	Yes	20.3	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ 700 GeV	m($\tilde{\chi}_1^{\pm}$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_1^{\pm}$)+m($\tilde{\chi}_1^0$))	1402.7029
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	2-3 e, μ	0-2 jets	Yes	20.3	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ 420 GeV	m($\tilde{\chi}_1^{\pm}$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, sleptons decoupled	1403.5294, 1402.7029
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow W\tilde{\chi}_1^0 h\tilde{\chi}_1^0$, $h\rightarrow b\bar{b}/WW/\tau\tau/\gamma\gamma$	e, μ, γ	0-2 b	Yes	20.3	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ 250 GeV	m($\tilde{\chi}_1^{\pm}$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, sleptons decoupled	1501.07110
	$\tilde{\chi}_2^0\tilde{\chi}_3^0$, $\tilde{\chi}_{2,3}^0\rightarrow\tilde{\ell}_R\ell$	4 e, μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$ 620 GeV	m($\tilde{\chi}_2^0$)=m($\tilde{\chi}_3^0$), m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_2^0$)+m($\tilde{\chi}_1^0$))	1405.5086
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^{\pm}$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 270 GeV	m($\tilde{\chi}_1^{\pm}$)-m($\tilde{\chi}_1^0$)=160 MeV, τ($\tilde{\chi}_1^{\pm}$)=0.2 ns	1310.3675
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$ 832 GeV	m($\tilde{\chi}_1^0$)=100 GeV, 10 μs<τ($\tilde{g}$)<1000 s	1310.6584
	Stable $\tilde{g}$ R-hadron	trk	-	-	19.1	$\tilde{g}$ 1.27 TeV		1411.6795
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0\rightarrow\tilde{\tau}(\tilde{e}, \tilde{\mu})+\tau(e, \mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}_1^0$ 537 GeV	10<tanβ<50	1411.6795
	GMSB, $\tilde{\chi}_1^0\rightarrow\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	$\tilde{\chi}_1^0$ 435 GeV	2<τ($\tilde{\chi}_1^0$)<3 ns, SPS8 model	1409.5542
	$\tilde{q}\tilde{q}$, $\tilde{\chi}_1^0\rightarrow qq\mu$ (RPV)	1 μ, displ. vtx	-	-	20.3	$\tilde{q}$ 1.0 TeV	1.5 <$c\tau$<156 mm, BR(μ)=1, m($\tilde{\chi}_1^0$)=108 GeV	ATLAS-CONF-2013-092
RPV	LFV $pp\rightarrow\tilde{\nu}_\tau + X, \tilde{\nu}_\tau\rightarrow e + \mu$	2 e, μ	-	-	4.6	$\tilde{\nu}_\tau$ 1.61 TeV	λ'_{311}=0.10, λ_{132}=0.05	1212.1272
	LFV $pp\rightarrow\tilde{\nu}_\tau + X, \tilde{\nu}_\tau\rightarrow e(\mu) + \tau$	1 $e, \mu + \tau$	-	-	4.6	$\tilde{\nu}_\tau$ 1.1 TeV	λ'_{311}=0.10, $\lambda_{1(2)33}$=0.05	1212.1272
	Bilinear RPV CMSSM	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.35 TeV	m($\tilde{q}$)=m($\tilde{g}$), $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\rightarrow W\tilde{\chi}_1^0, \tilde{\chi}_1^0\rightarrow ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e, μ	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 750 GeV	m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^{\pm}$), $\lambda_{121}\neq0$	1405.5086
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\rightarrow W\tilde{\chi}_1^0, \tilde{\chi}_1^0\rightarrow\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 $e, \mu + \tau$	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 450 GeV	m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^{\pm}$), $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\rightarrow qqq$	0	6-7 jets	-	20.3	$\tilde{g}$ 916 GeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2013-091
	$\tilde{g}\rightarrow\tilde{t}_1 t$, $\tilde{t}_1\rightarrow bs$	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{g}$ 850 GeV		1404.250
Other	Scalar charm, $\tilde{c}\rightarrow c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	$\tilde{c}$ 490 GeV	m($\tilde{\chi}_1^0$)<200 GeV	1501.01325

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

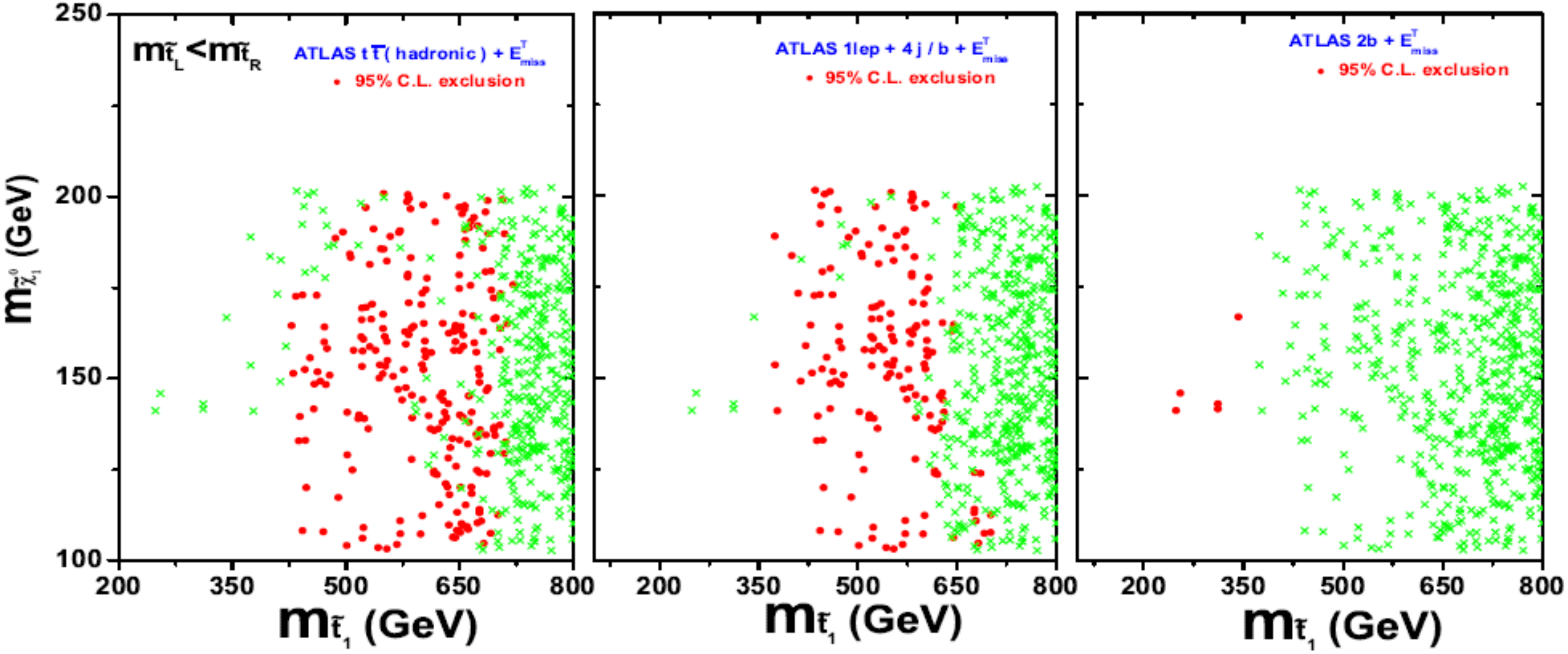
Why do **we** need to do MC simulation?



$\tilde{g}$	1.25 TeV	$m(\tilde{\chi}_1^0)$<400 GeV
$\tilde{g}$	1.1 TeV	$m(\tilde{\chi}_1^0)$ <350 GeV
$\tilde{g}$	1.34 TeV	$m(\tilde{\chi}_1^0)$<400 GeV
$\tilde{g}$	1.3 TeV	$m(\tilde{\chi}_1^0)$<300 GeV
$\tilde{b}_1$	100-620 GeV	$m(\tilde{\chi}_1^0)$<90 GeV
$\tilde{b}_1$	275-440 GeV	$m(\tilde{\chi}_1^\pm)$=2 $m(\tilde{\chi}_1^0)$
$\tilde{t}_1$	110-167 GeV 230-460 GeV	$m(\tilde{\chi}_1^\pm)$ = 2$m(\tilde{\chi}_1^0)$, $m(\tilde{\chi}_1^0)$=55 GeV
$\tilde{t}_1$	90-191 GeV 215-530 GeV	$m(\tilde{\chi}_1^0)$=1 GeV
$\tilde{t}_1$	210-640 GeV	$m(\tilde{\chi}_1^0)$=1 GeV
$\tilde{t}_1$	90-240 GeV	$m(\tilde{t}_1)$-$m(\tilde{\chi}_1^0)$<85 GeV
$\tilde{t}_1$	150-580 GeV	$m(\tilde{\chi}_1^0)$>150 GeV
$\tilde{t}_2$	290-600 GeV	$m(\tilde{\chi}_1^0)$<200 GeV

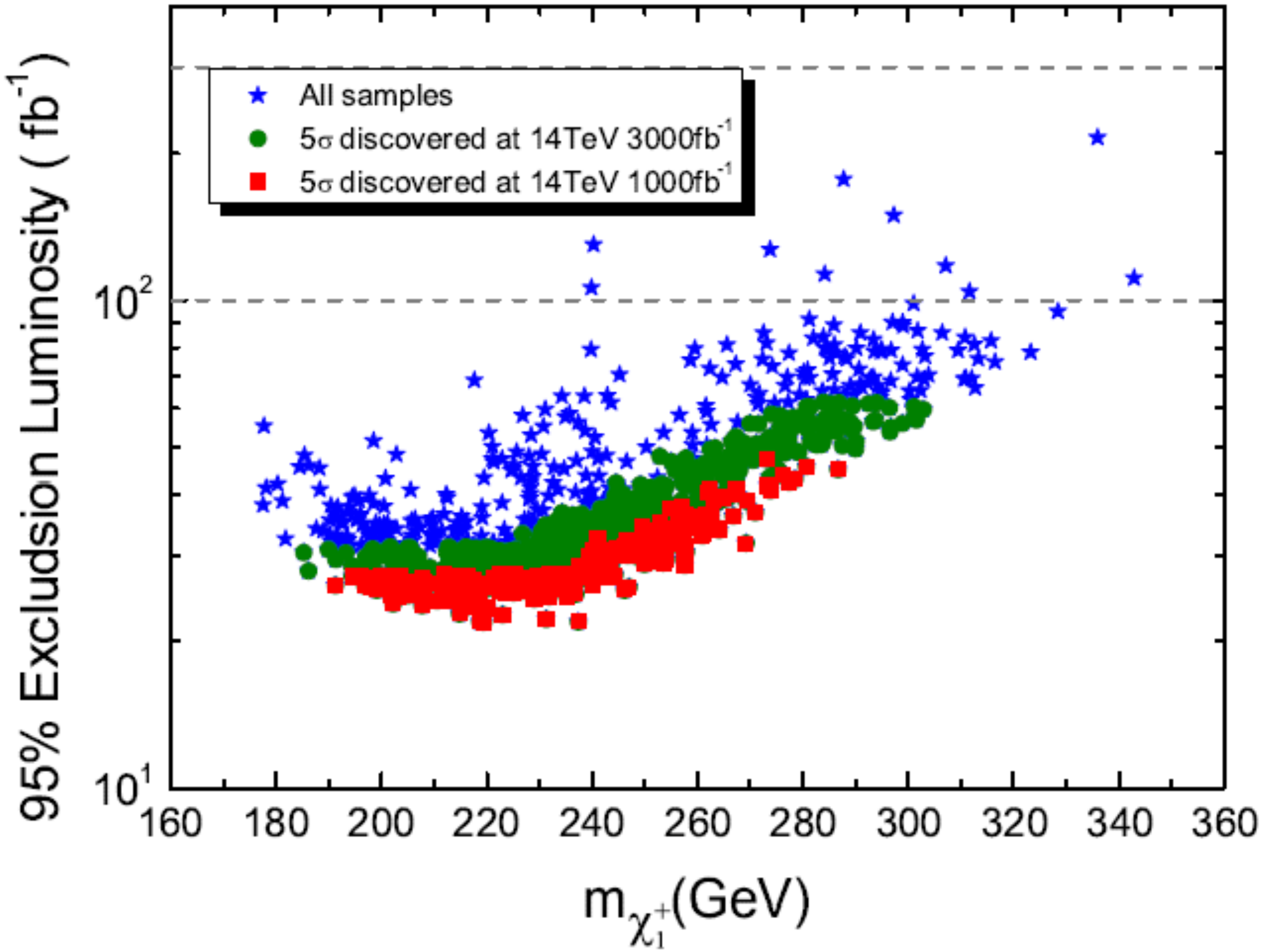
3. Which kind of work can MC simulation do?

arXiv:1308.5307



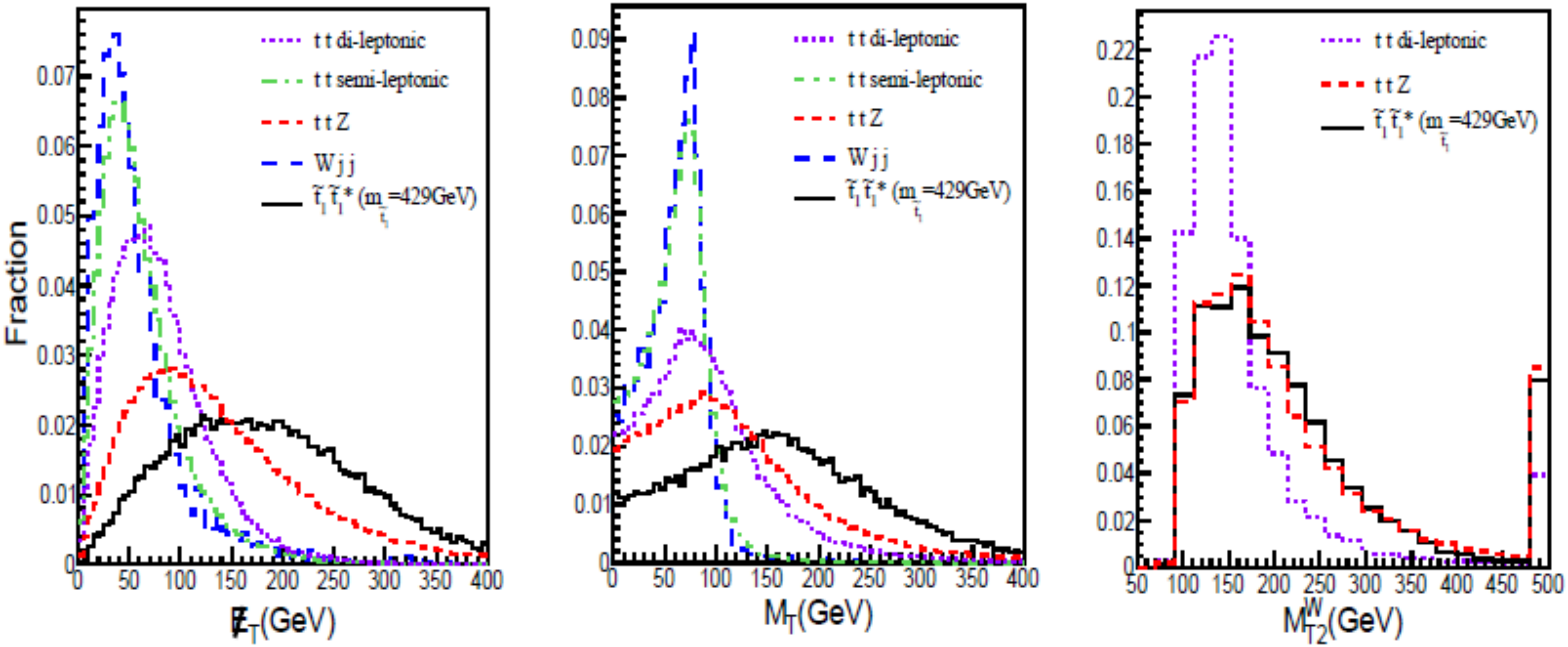
3. Which kind of work can MC simulation do?

arXiv:1410.3239

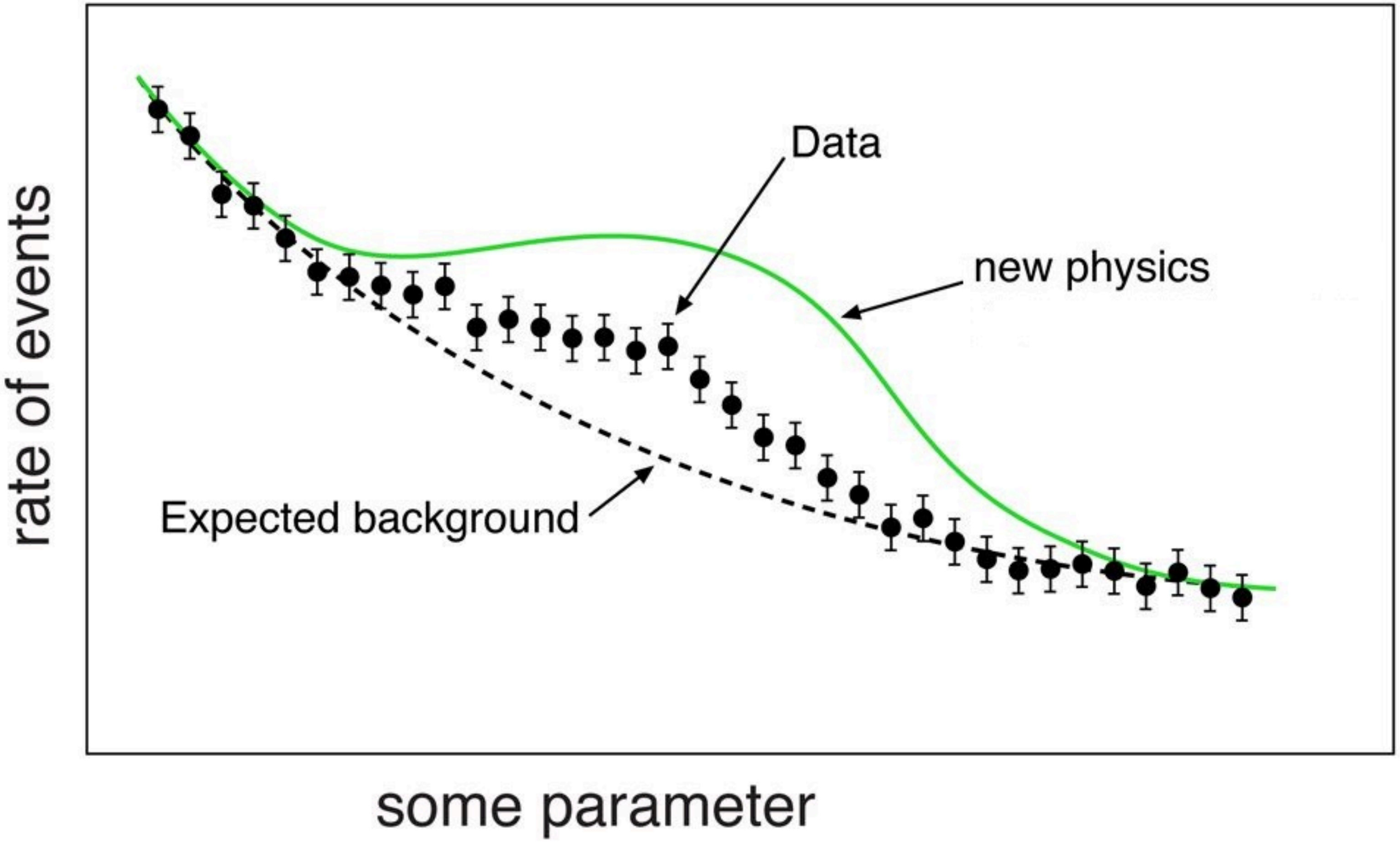


3. Which kind of work can MC simulation do?

arXiv:1206.3865



3. Which kind of work can MC simulation do?

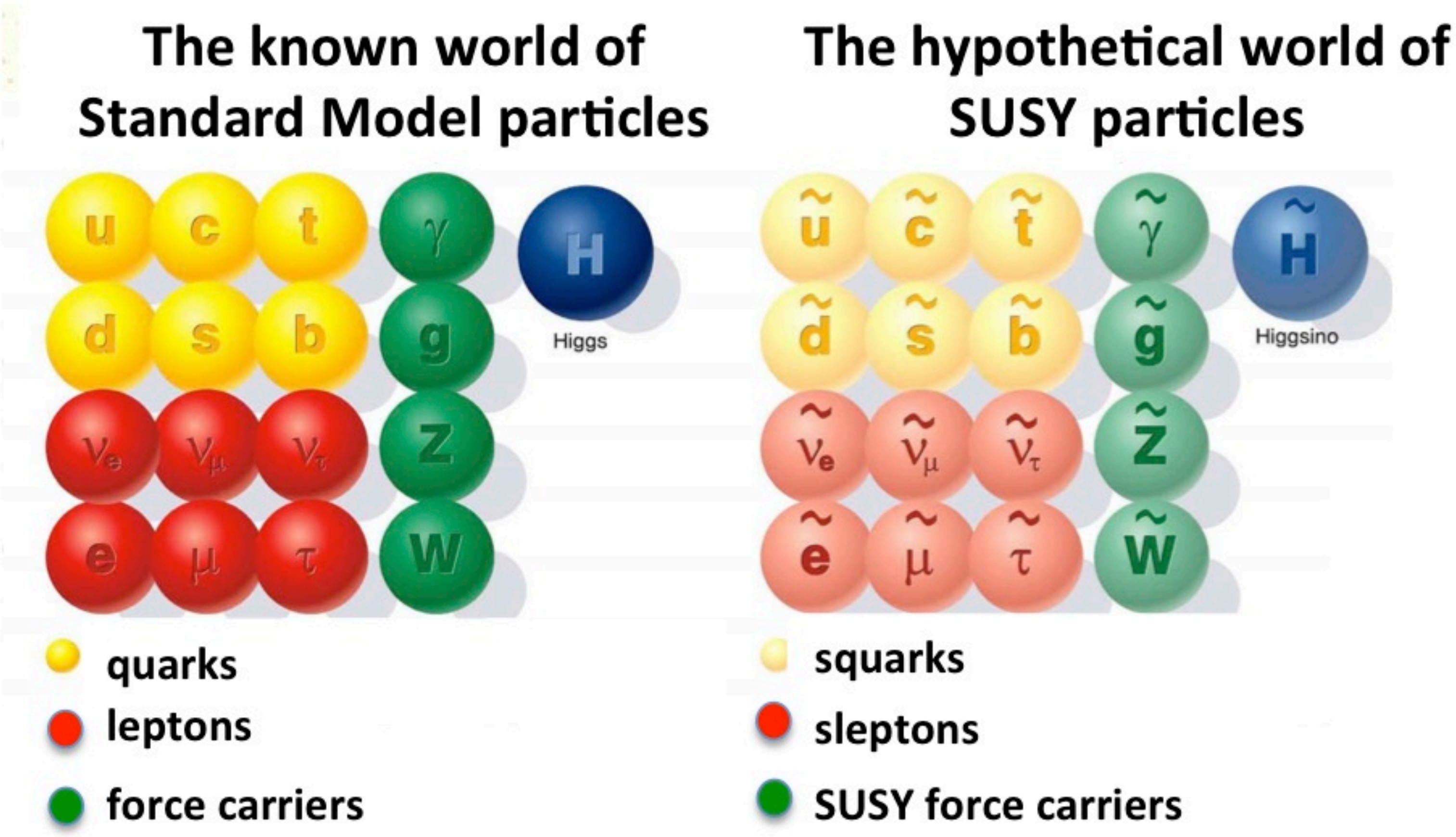


II Example

Explanation of th
ATLAS Z-peaked
excess in the NM

arXiv: 1504.07869

1. Brief introduction of SUSY



$$(\tilde{B}, \widetilde{W}, \ \widetilde{H}_u, \widetilde{H}_d)$$

$$\downarrow$$

$$(\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0)$$

NMSSM

$$W_{NMSSM} = W_{MSSM} + \lambda \hat{S} \hat{H}_u \cdot \hat{H}_d + \xi_F \hat{S} + \frac{1}{2}\mu' \hat{S}^2 + \frac{\kappa}{3}\hat{S}^3$$

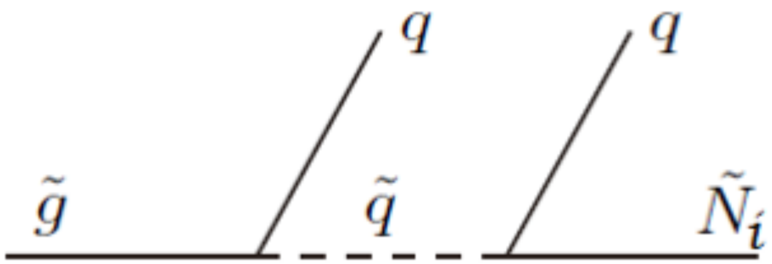
$$\mathcal{M} = \begin{pmatrix} M_1 & 0 & \frac{ev_u}{\sqrt{2}c_w} & -\frac{ev_d}{\sqrt{2}c_w} & 0 \\ 0 & M_2 & -\frac{ev_u}{\sqrt{2}s_w} & \frac{ev_d}{\sqrt{2}s_w} & 0 \\ \frac{ev_u}{\sqrt{2}c_w} & -\frac{ev_u}{\sqrt{2}s_w} & 0 & -\mu_{eff} & -\lambda v_d \\ -\frac{ev_d}{\sqrt{2}c_w} & \frac{ev_d}{\sqrt{2}s_w} & -\mu_{eff} & 0 & -\lambda v_u \\ 0 & 0 & -\lambda v_d & -\lambda v_u & 2\kappa s + \mu' \end{pmatrix}$$

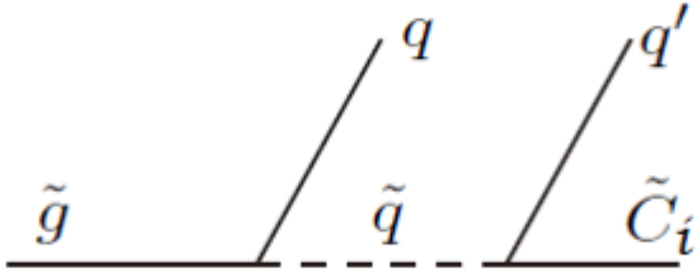
$$(\tilde{B}, \widetilde{W}, \widetilde{H}_u, \widetilde{H}_d, \tilde{S})$$

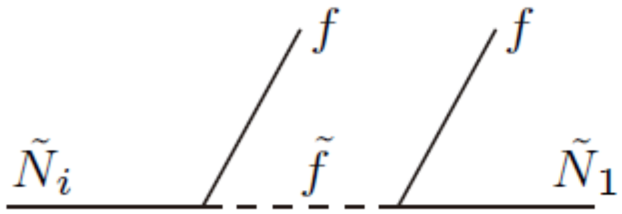
$$\downarrow$$

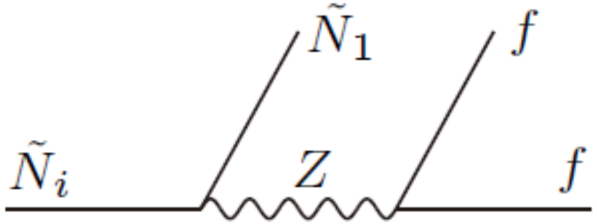
$$(\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0, \tilde{\chi}_5^0)$$

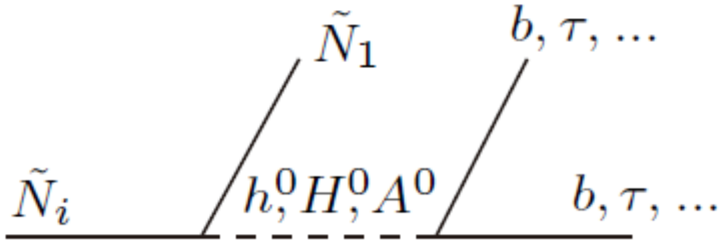
Sparticle Decay

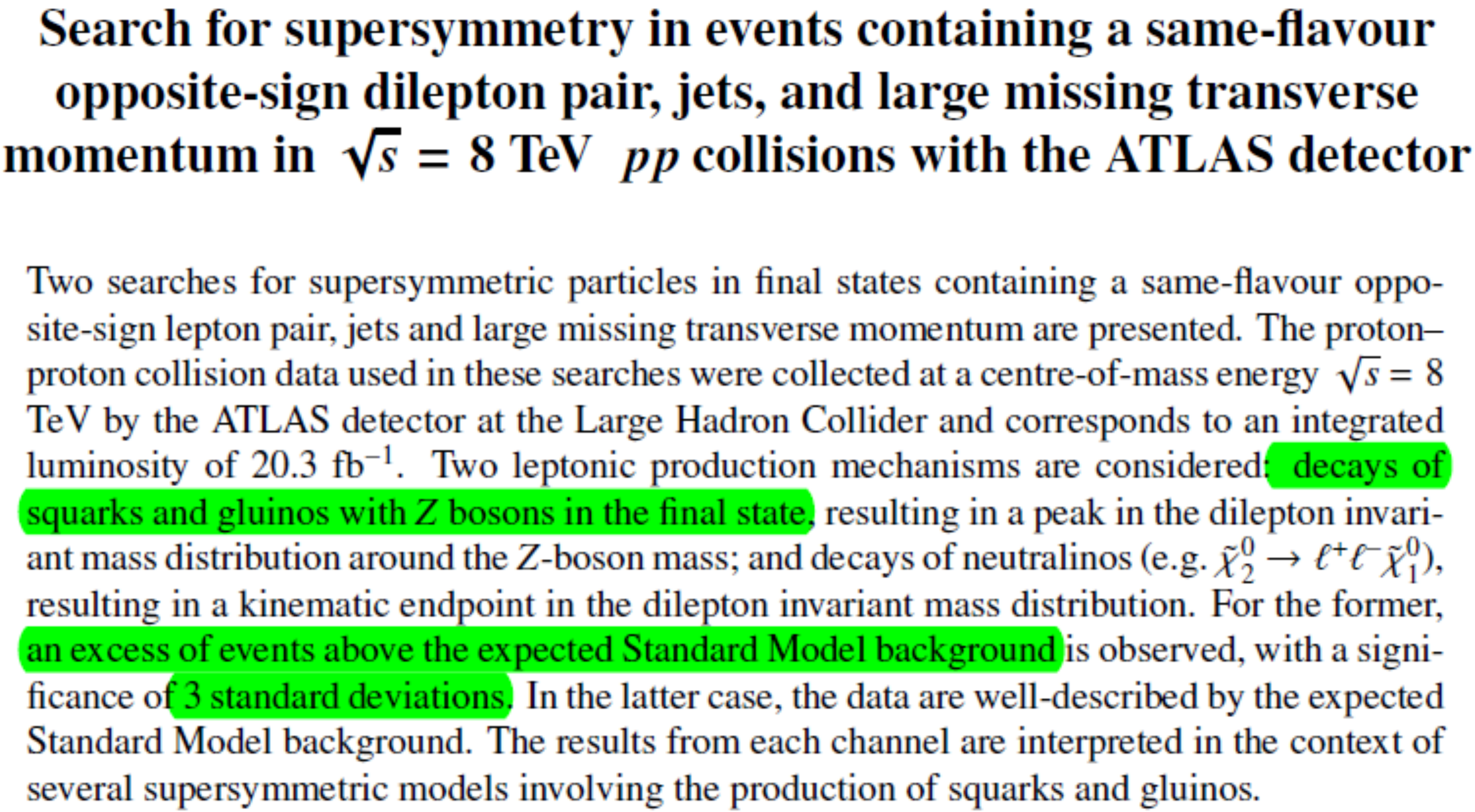












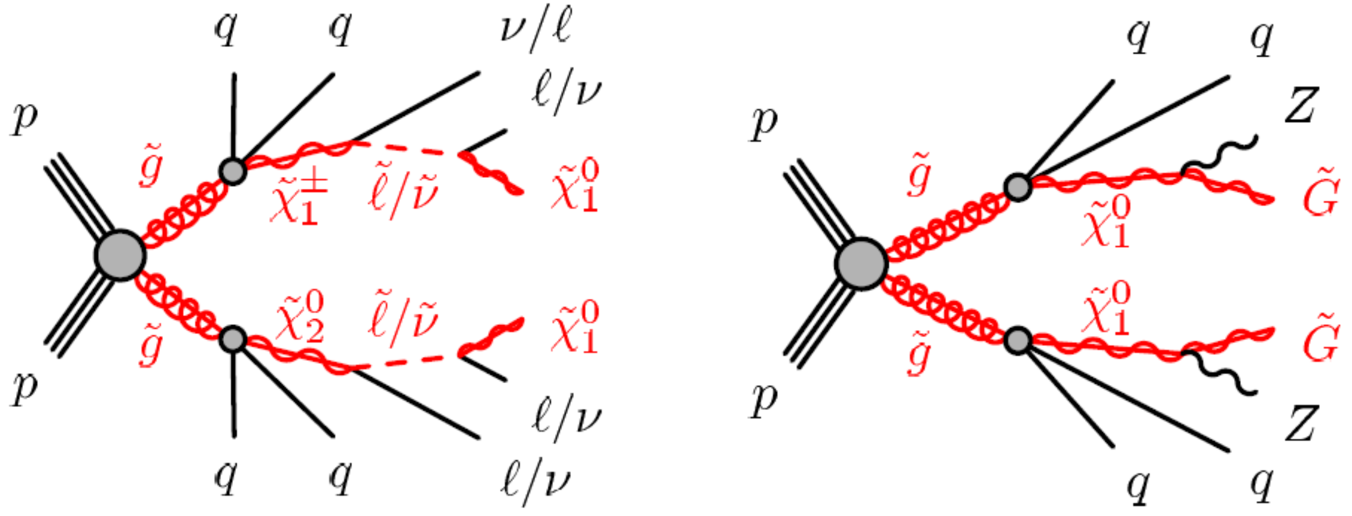
Search for supersymmetry in events containing a same-flavour opposite-sign dilepton pair, jets, and large missing transverse momentum in $\sqrt{s} = 8$ TeV pp collisions with the ATLAS detector

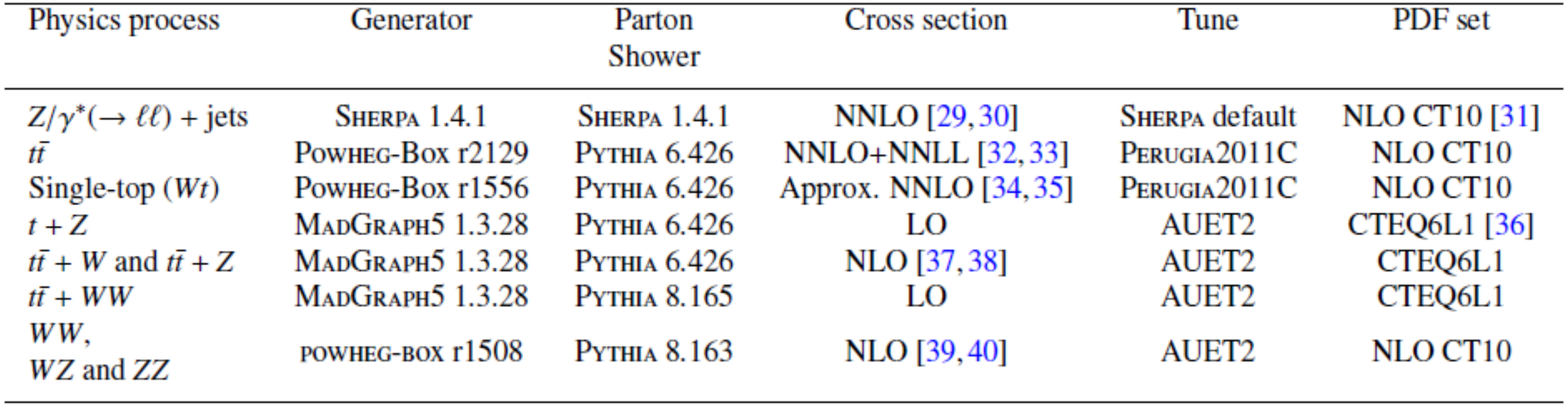
Two searches for supersymmetric particles in final states containing a same-flavour opposite-sign lepton pair, jets and large missing transverse momentum are presented. The proton–proton collision data used in these searches were collected at a centre-of-mass energy $\sqrt{s} = 8$ TeV by the ATLAS detector at the Large Hadron Collider and corresponds to an integrated luminosity of 20.3 fb^{-1}. Two leptonic production mechanisms are considered: decays of squarks and gluinos with Z bosons in the final state, resulting in a peak in the dilepton invariant mass distribution around the Z-boson mass; and decays of neutralinos (e.g. $\tilde{\chi}_2^0 \to \ell^+\ell^-\tilde{\chi}_1^0$), resulting in a kinematic endpoint in the dilepton invariant mass distribution. For the former, an excess of events above the expected Standard Model background is observed, with a significance of 3 standard deviations. In the latter case, the data are well-described by the expected Standard Model background. The results from each channel are interpreted in the context of several supersymmetric models involving the production of squarks and gluinos.

arXiv:1503.03290

1. The ATLAS report

general gauge mediation models





Physics process	Generator	Parton Shower	Cross section	Tune	PDF set
$Z/\gamma^*(\rightarrow \ell\ell)$ + jets	Sherpa 1.4.1	Sherpa 1.4.1	NNLO [29,30]	Sherpa default	NLO CT10 [31]
$t\bar{t}$	Powheg-Box r2129	Pythia 6.426	NNLO+NNLL [32,33]	Perugia2011C	NLO CT10
Single-top (Wt)	Powheg-Box r1556	Pythia 6.426	Approx. NNLO [34,35]	Perugia2011C	NLO CT10
$t + Z$	MadGraph5 1.3.28	Pythia 6.426	LO	AUET2	CTEQ6L1 [36]
$t\bar{t} + W$ and $t\bar{t} + Z$	MadGraph5 1.3.28	Pythia 6.426	NLO [37,38]	AUET2	CTEQ6L1
$t\bar{t} + WW$	MadGraph5 1.3.28	Pythia 8.165	LO	AUET2	CTEQ6L1
WW, WZ and ZZ	powheg-box r1508	Pythia 8.163	NLO [39,40]	AUET2	NLO CT10

Electron candidates are reconstructed using energy clusters in the electromagnetic calorimeter matched to ID tracks. Electrons used in this analysis are assigned either “baseline” or “signal” status. Baseline electrons are required to have transverse energy $E_\mathrm{T} > 10$ GeV, satisfy the “medium” criteria described in Ref. [64] and reside within $|\eta| < 2.47$ and not in the range $1.37 < |\eta| < 1.52$. Signal electrons are further

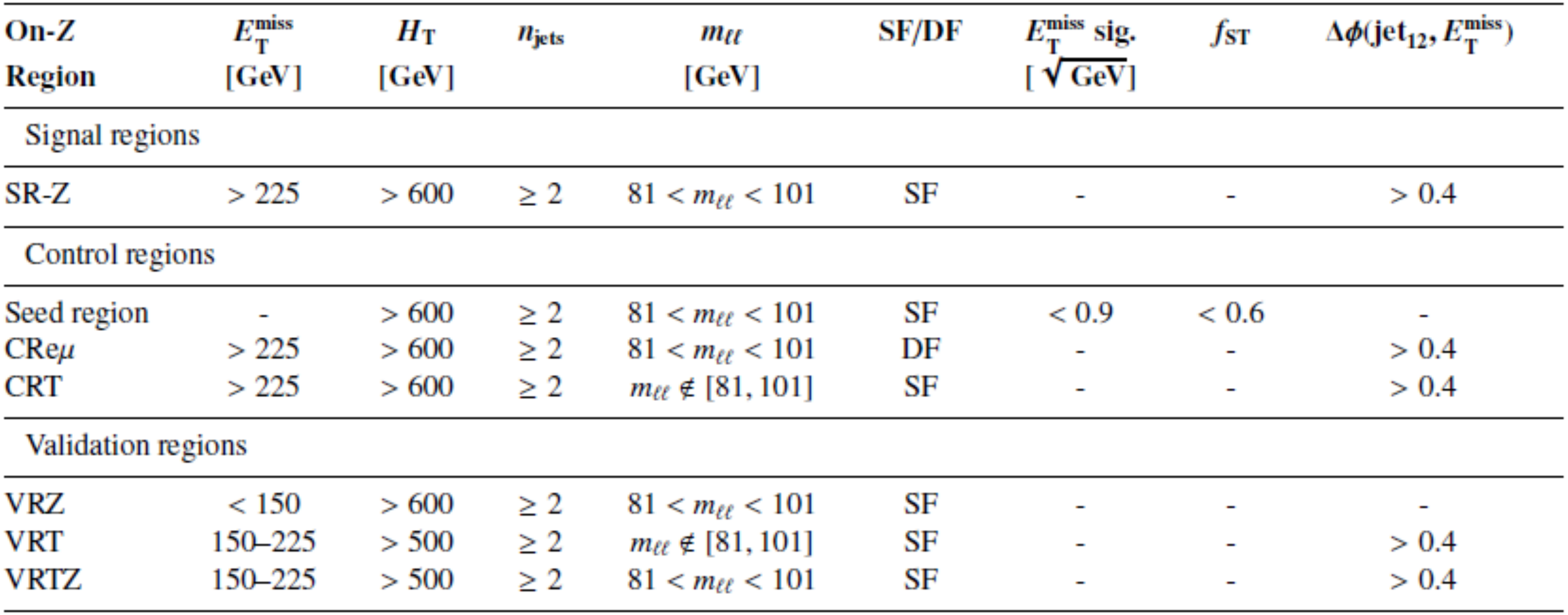
Baseline muons are reconstructed from either ID tracks matched to muon segments or combined tracks formed from the ID and muon spectrometer [65]. They are required to be of good quality, as described in Ref. [66], and to satisfy $p_\mathrm{T} > 10$ GeV and $|\eta| < 2.4$. Signal muons are further required to be isolated,

Jets are reconstructed from topological clusters in the calorimeter using the anti-k_t algorithm [67] with a distance parameter of 0.4. Each cluster is categorised as being electromagnetic or hadronic in origin

between response in data and MC simulation. Baseline jets are selected with $p_\mathrm{T} > 20$ GeV. Events in which these jets do not pass specific jet quality requirements are rejected so as to remove events affected by detector noise and non-collision backgrounds [72, 73]. Signal jets are required to satisfy $p_\mathrm{T} > 35$ GeV and $|\eta| < 2.5$. To avoid the inclusion of jets resulting from pile-up, jets with $p_\mathrm{T} < 50$ GeV within $|\eta| < 2.4$

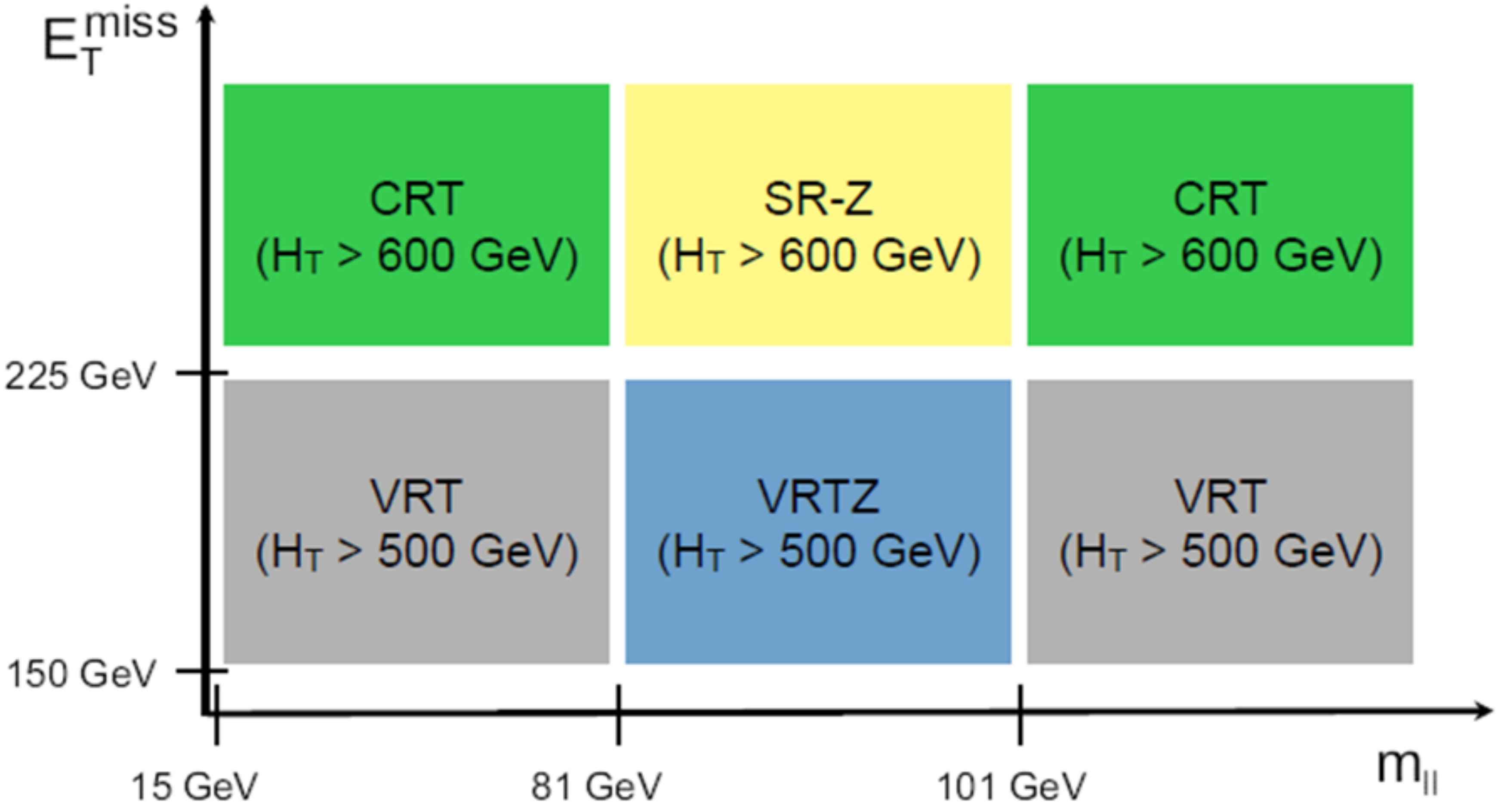
of associated tracks and any reconstructed secondary vertices. For this analysis, the working point corresponding to a 60 % efficiency for tagging b-jets in simulated $t\bar{t}$ events is used, resulting in a charm quark

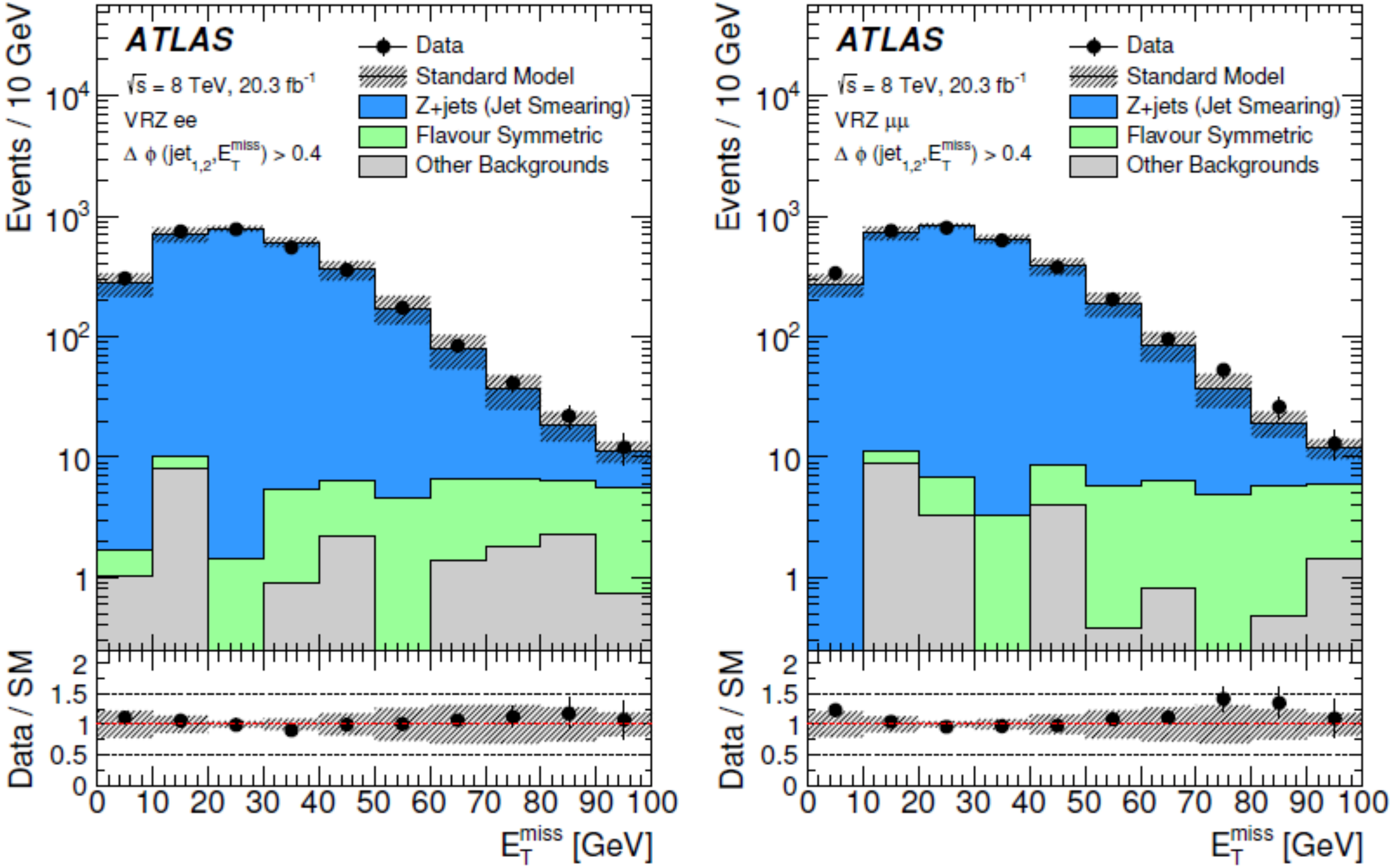
Event selection



On-Z **Region**	$E_{\mathrm{T}}^{\mathrm{miss}}$ **[GeV]**	H_{T} **[GeV]**	n_{jets}	$m_{\ell\ell}$ **[GeV]**	**SF/DF**	$E_{\mathrm{T}}^{\mathrm{miss}}$ **sig.** $[\sqrt{\mathrm{GeV}}]$	f_{ST}	$\Delta\phi(\mathrm{jet}_{12}, E_{\mathrm{T}}^{\mathrm{miss}})$
Signal regions								
SR-Z	> 225	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	-	-	> 0.4
Control regions								
Seed region	-	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	< 0.9	< 0.6	-
CReμ	> 225	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	DF	-	-	> 0.4
CRT	> 225	> 600	≥ 2	$m_{\ell\ell} \notin [81, 101]$	SF	-	-	> 0.4
Validation regions								
VRZ	< 150	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	-	-	-
VRT	150–225	> 500	≥ 2	$m_{\ell\ell} \notin [81, 101]$	SF	-	-	> 0.4
VRTZ	150–225	> 500	≥ 2	$81 < m_{\ell\ell} < 101$	SF	-	-	> 0.4

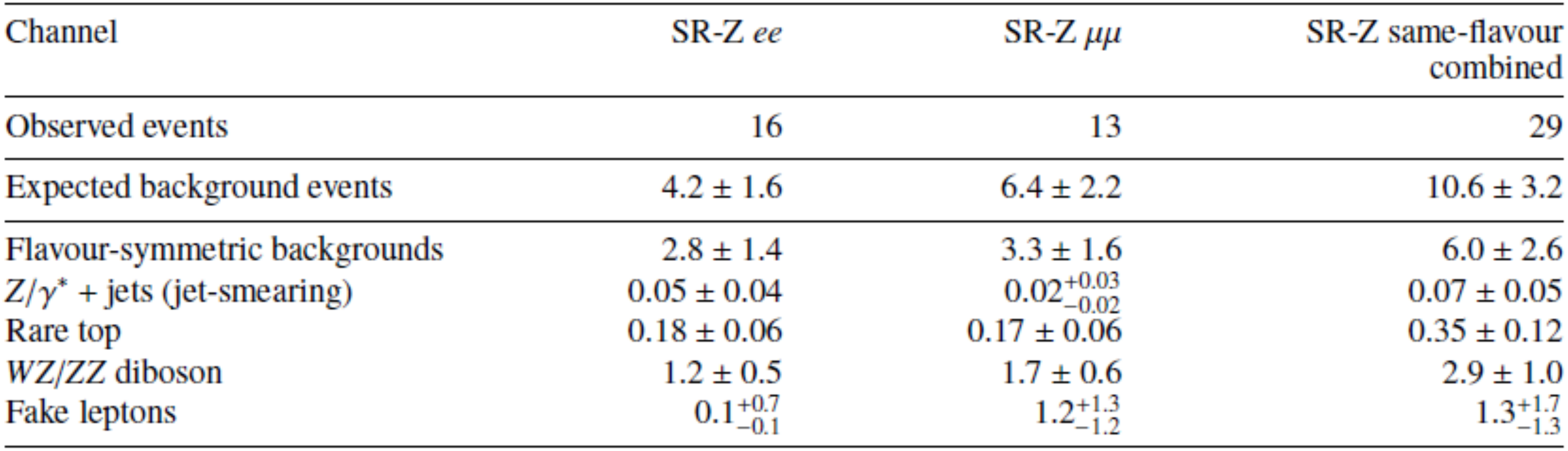
Event selection



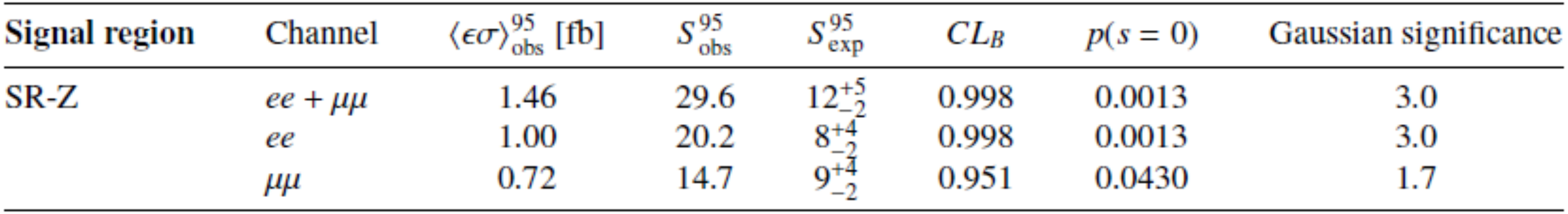


The jet smearing method using the data-corrected jet response function is validated in VRZ, comparing smeared pseudo-data to data. The resulting E_T^{miss} distributions show agreement within uncertainties

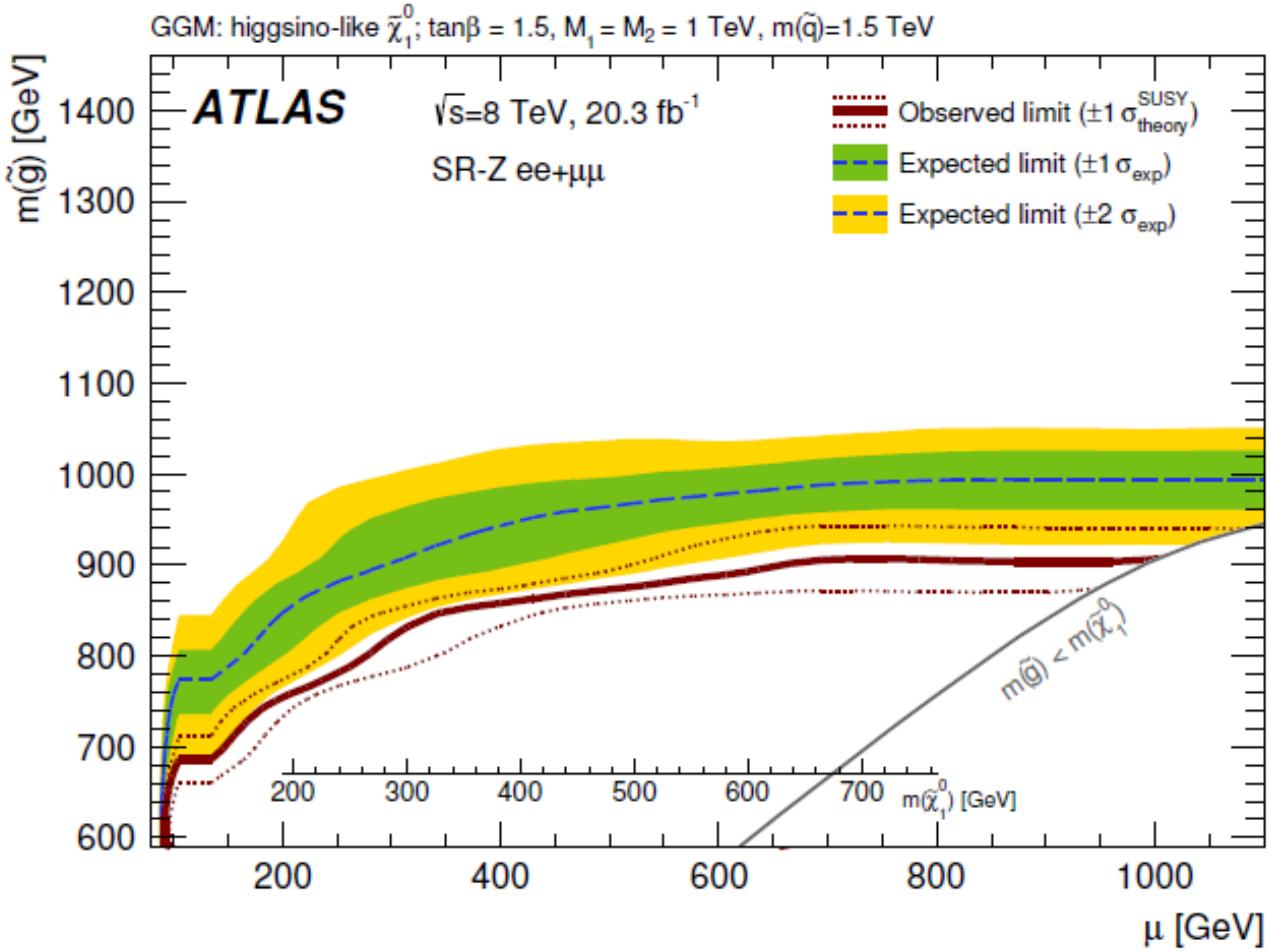
Result



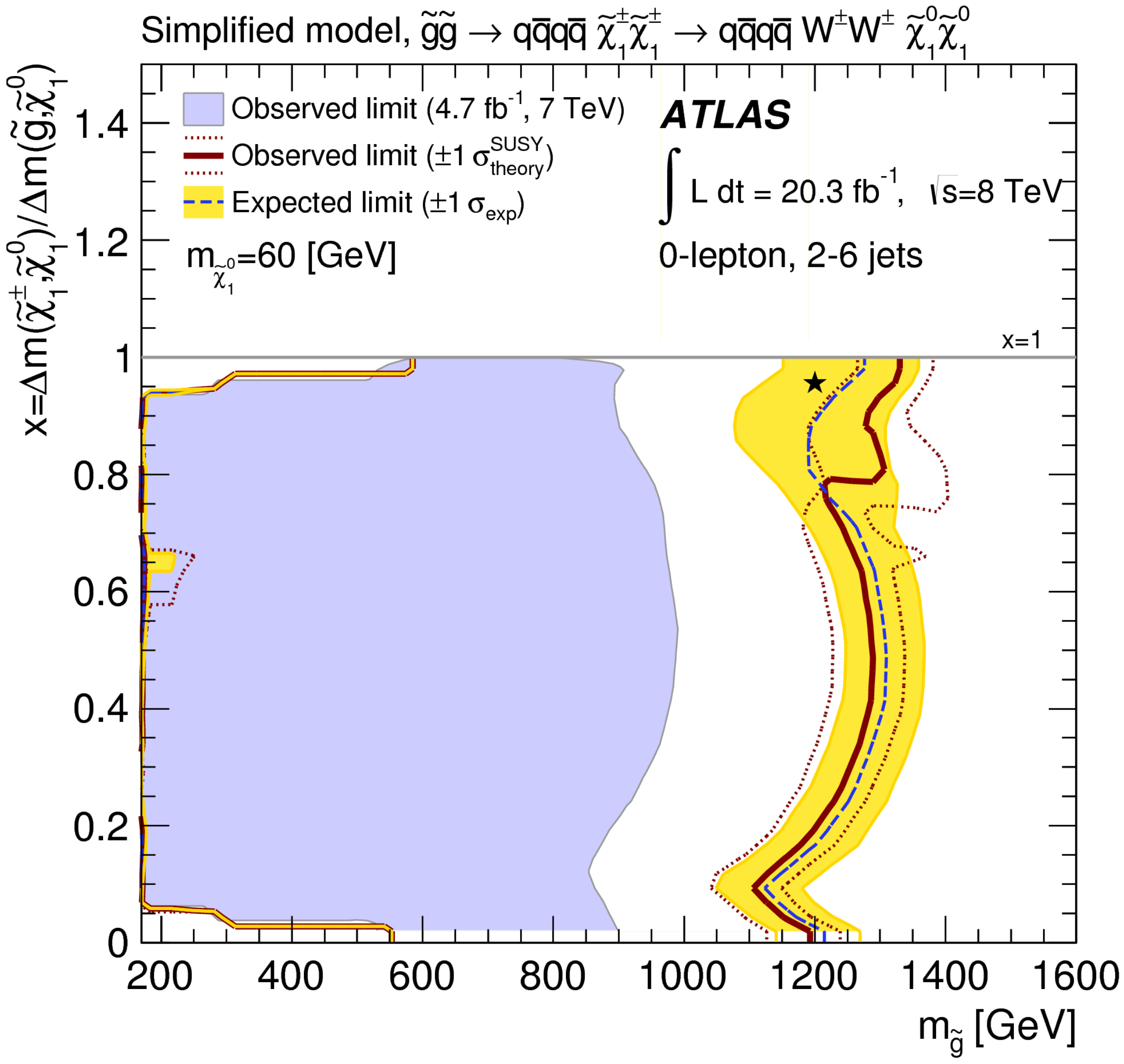
Channel	SR-Z *ee*	SR-Z $\mu\mu$	SR-Z same-flavour combined
Observed events	16	13	29
Expected background events	4.2 ± 1.6	6.4 ± 2.2	10.6 ± 3.2
Flavour-symmetric backgrounds	2.8 ± 1.4	3.3 ± 1.6	6.0 ± 2.6
Z/γ^{*} + jets (jet-smearing)	0.05 ± 0.04	$0.02^{+0.03}_{-0.02}$	0.07 ± 0.05
Rare top	0.18 ± 0.06	0.17 ± 0.06	0.35 ± 0.12
WZ/*ZZ* diboson	1.2 ± 0.5	1.7 ± 0.6	2.9 ± 1.0
Fake leptons	$0.1^{+0.7}_{-0.1}$	$1.2^{+1.3}_{-1.2}$	$1.3^{+1.7}_{-1.3}$

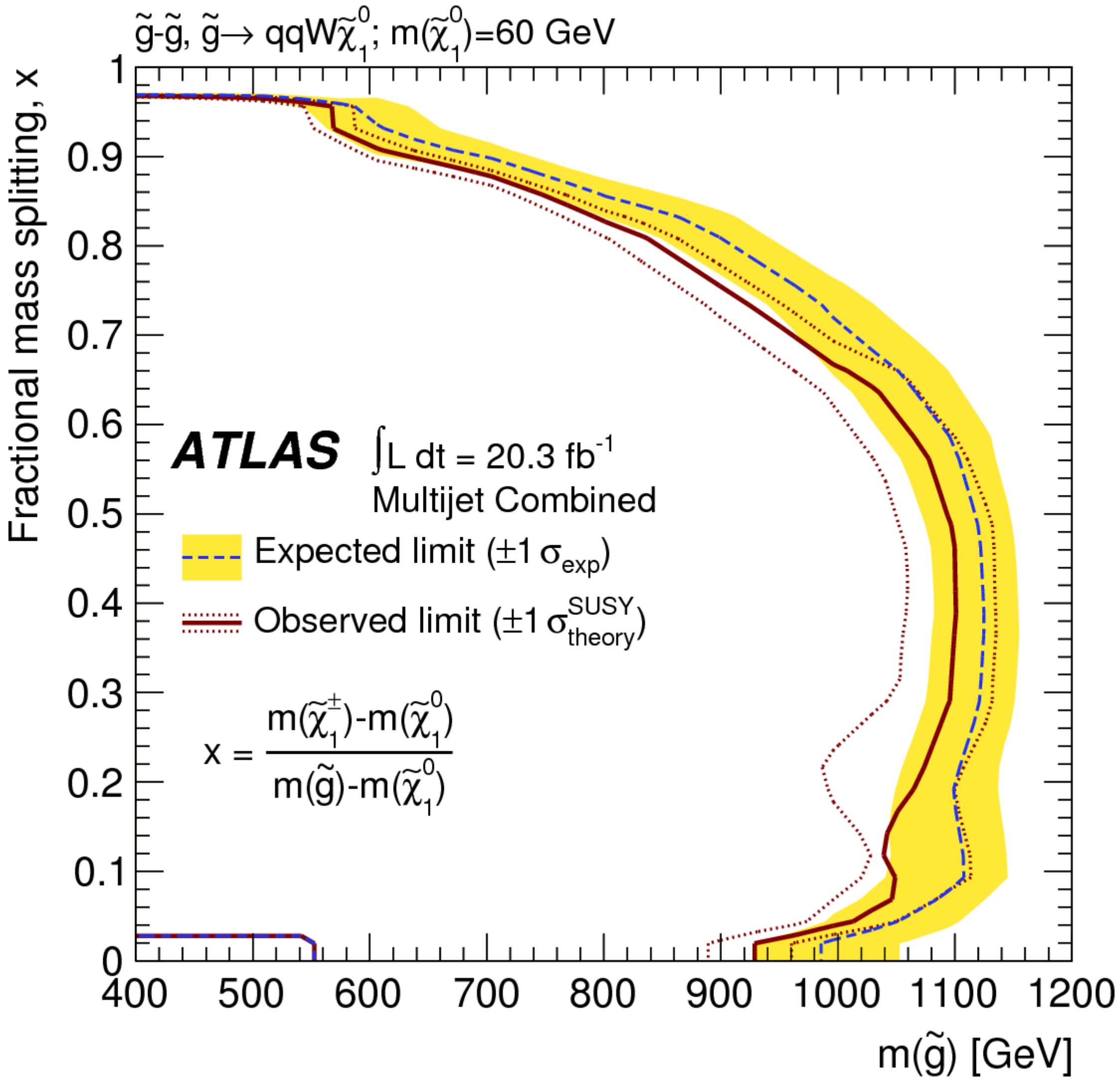


Signal region	Channel	$\langle\epsilon\sigma\rangle^{95}_{\text{obs}}$ [fb]	S^{95}_{obs}	S^{95}_{exp}	CL_B	$p(s=0)$	Gaussian significance
SR-Z	$ee+\mu\mu$	1.46	29.6	12^{+5}_{-2}	0.998	0.0013	3.0
	ee	1.00	20.2	8^{+4}_{-2}	0.998	0.0013	3.0
	$\mu\mu$	0.72	14.7	9^{+4}_{-2}	0.951	0.0430	1.7

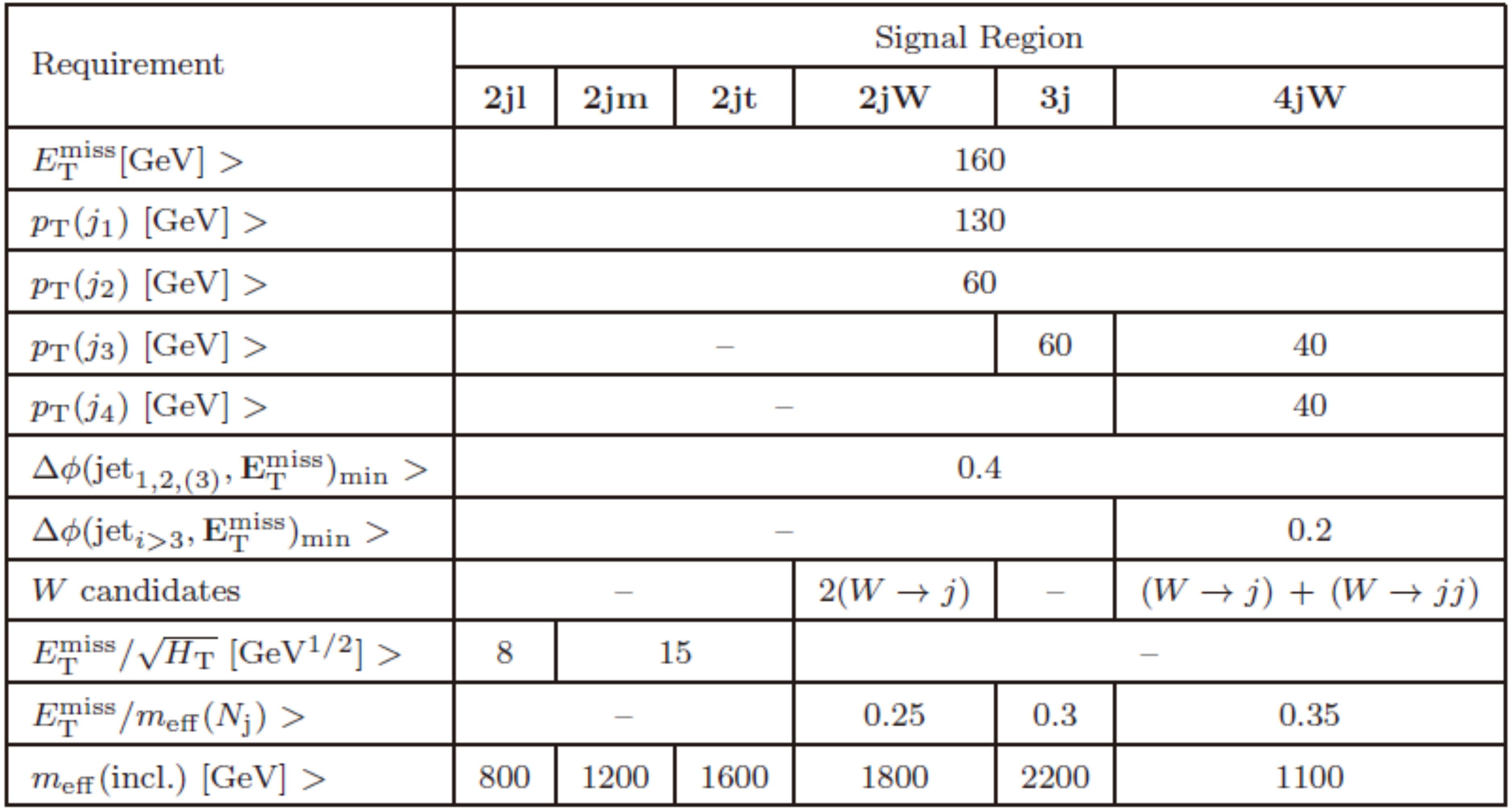

GGM: higgsino-like $\tilde{\chi}_1^0$; tanβ = 1.5, $M_1 = M_2$ = 1 TeV, m($\tilde{q}$)=1.5 TeV
ATLAS
$\sqrt{s}$=8 TeV, 20.3 fb^{-1}
SR-Z ee+μμ
Observed limit (±1 $\sigma_{\rm theory}^{\rm SUSY}$)
Expected limit (±1 $\sigma_{\rm exp}$)
Expected limit (±2 $\sigma_{\rm exp}$)
m($\tilde{g}$) [GeV]
1400
1300
1200
1100
1000
900
800
700
600
200
400
600
800
1000
μ [GeV]
200
300
400
500
600
700
m($\tilde{\chi}_1^0$) [GeV]
m($\tilde{g}$) < m($\tilde{\chi}_1^0$)

3. Explanation



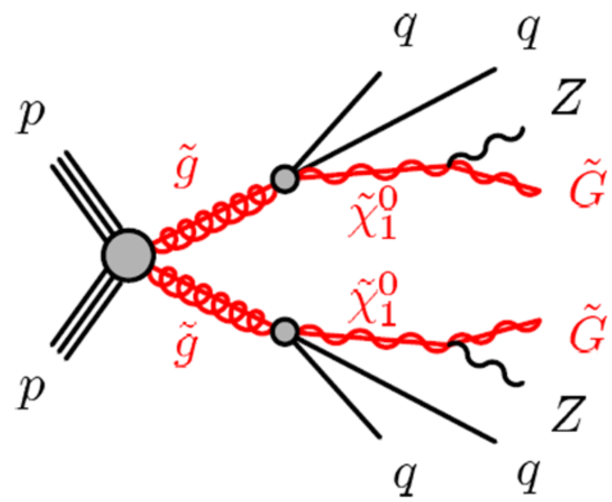


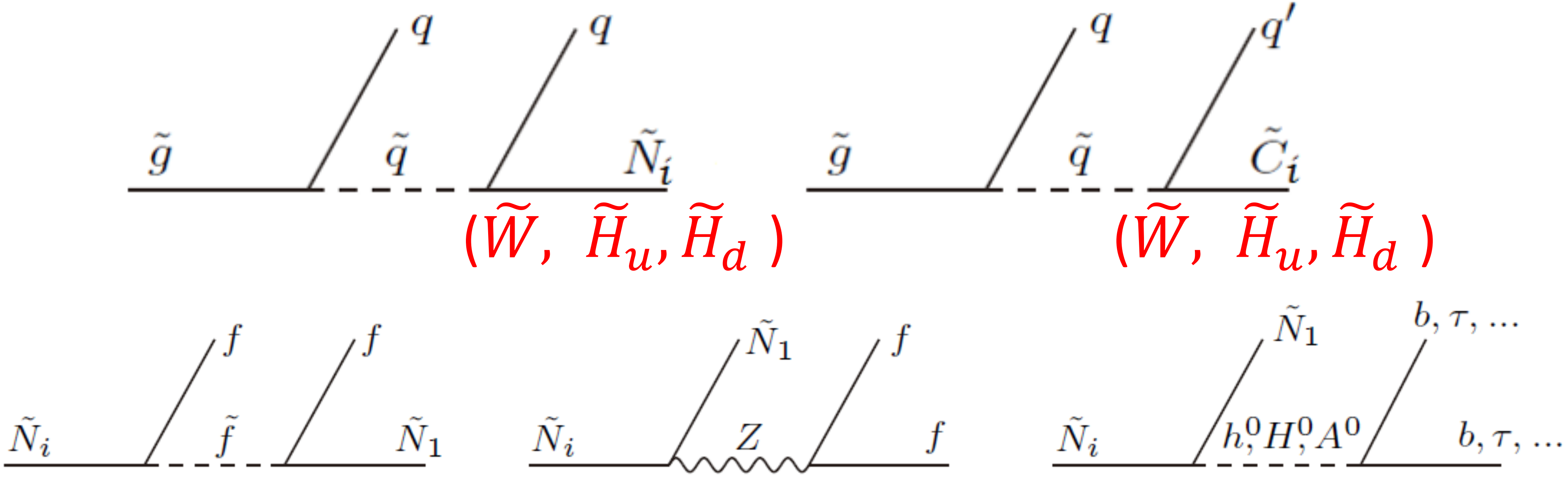
0 lepton, 2~6 jets



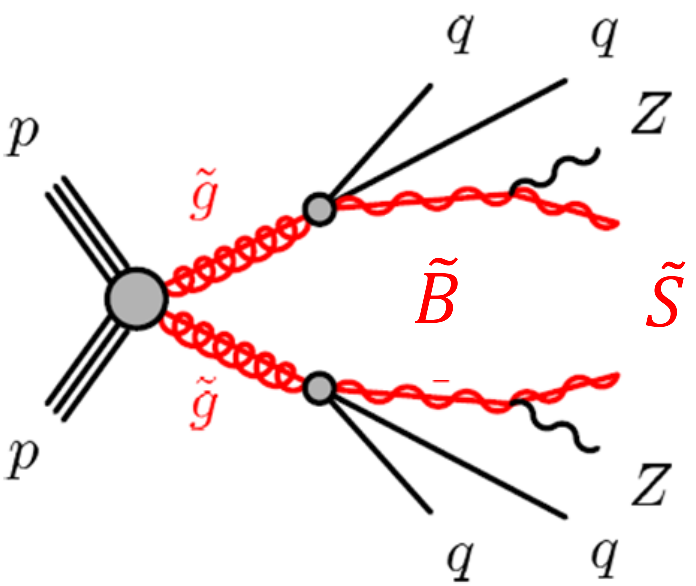
Requirement	Signal Region					
	2jl	**2jm**	**2jt**	**2jW**	**3j**	**4jW**
$E_{\mathrm{T}}^{\mathrm{miss}}$[GeV] $>$	160					
$p_{\mathrm{T}}(j_1)$ [GeV] $>$	130					
$p_{\mathrm{T}}(j_2)$ [GeV] $>$	60					
$p_{\mathrm{T}}(j_3)$ [GeV] $>$	–				60	40
$p_{\mathrm{T}}(j_4)$ [GeV] $>$	–					40
$\Delta\phi(\mathrm{jet}_{1,2,(3)}, \mathbf{E}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}} >$	0.4					
$\Delta\phi(\mathrm{jet}_{i>3}, \mathbf{E}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}} >$	–					0.2
W candidates	–			$2(W \rightarrow j)$	–	$(W \rightarrow j) + (W \rightarrow jj)$
$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$ [GeV$^{1/2}$] $>$	8	15		–		
$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}(N_{\mathrm{j}}) >$	–			0.25	0.3	0.35
m_{eff}(incl.) [GeV] $>$	800	1200	1600	1800	2200	1100

3. Explanation





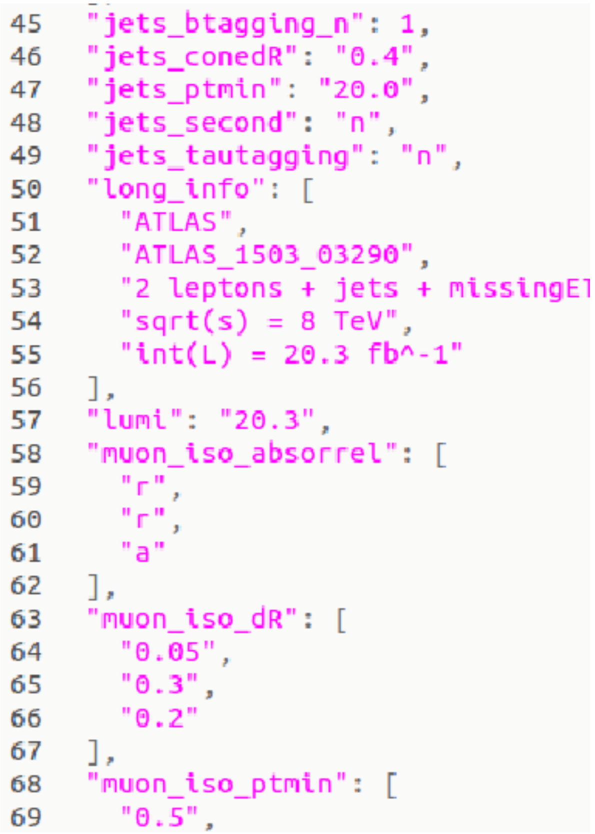
NMSSM



$$\begin{aligned}\mathcal{L}_{\tilde\chi^0} = {} & \tilde{u}_L^* \bar{\tilde\chi}_j^0 \Big[\frac{-e}{\sqrt{2} s_w c_w}(\frac{1}{3} N_{1j} s_w + N_{2j} c_w) P_L - y_u N_{4j}^* P_R\Big] u \\ & + \tilde{d}_L^* \bar{\tilde\chi}_j^0 \Big[\frac{-e}{\sqrt{2} s_w c_w}(\frac{1}{3} N_{1j} s_w - N_{2j} c_w) P_L + y_d N_{3j}^* P_R\Big] d \\ & + \tilde{u}_R^* \bar{\tilde\chi}_j^0 \Big[\frac{2\sqrt{2} e}{3 c_w} N_{1j}^* P_R - y_u N_{4j} P_L\Big] u + \tilde{d}_R^* \bar{\tilde\chi}_j^0 \Big[\frac{-\sqrt{2} e}{3 c_w} N_{1j}^* P_R + y_d N_{3j} P_L\Big] d \\ & + \frac{e}{s_w c_w} Z_\mu \bar{\tilde\chi}_i^0 \gamma^\mu (\mathcal{O}_{ij}^L P_L + \mathcal{O}_{ij}^R P_R) \tilde\chi_j^0 + h_u \bar{\tilde\chi}_i^0 (\frac{\lambda}{\sqrt{2}} \Pi_{ij}^{45} - \frac{g_1}{2} \Pi_{ij}^{13} + \frac{g_2}{2} \Pi_{ij}^{23}) \tilde\chi_j^0 + \cdot (2.3)\end{aligned}$$

$N_{ij}\ (i,j = 1, \cdots, 5)$, $\mathcal{O}_{ij}^L = -\mathcal{O}_{ij}^{R*} = -\frac{1}{2} N_{i3} N_{j3}^* + \frac{1}{2} N_{i4} N_{j4}^*$,

CheckMATE



```
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  "jets_conedR": "0.4",
  "jets_ptmin": "20.0",
  "jets_second": "n",
  "jets_tautagging": "n",
  "long_info": [
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    "ATLAS_1503_03290",
    "2 leptons + jets + missingE
    "sqrt(s) = 8 TeV",
    "int(L) = 20.3 fb^-1"
  ],
  "lumi": "20.3",
  "muon_iso_absorrel": [
    "r",
    "r",
    "a"
  ],
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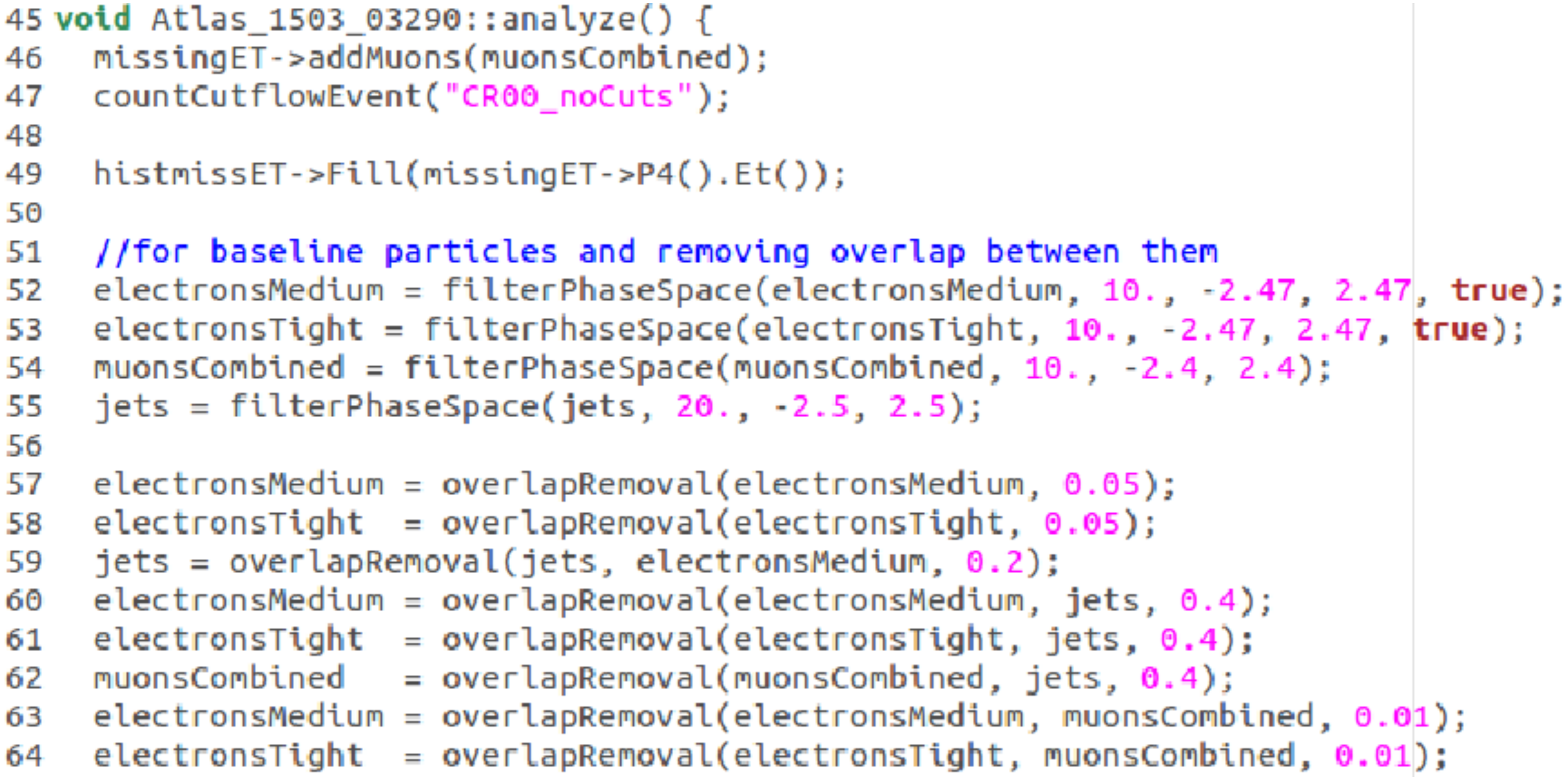
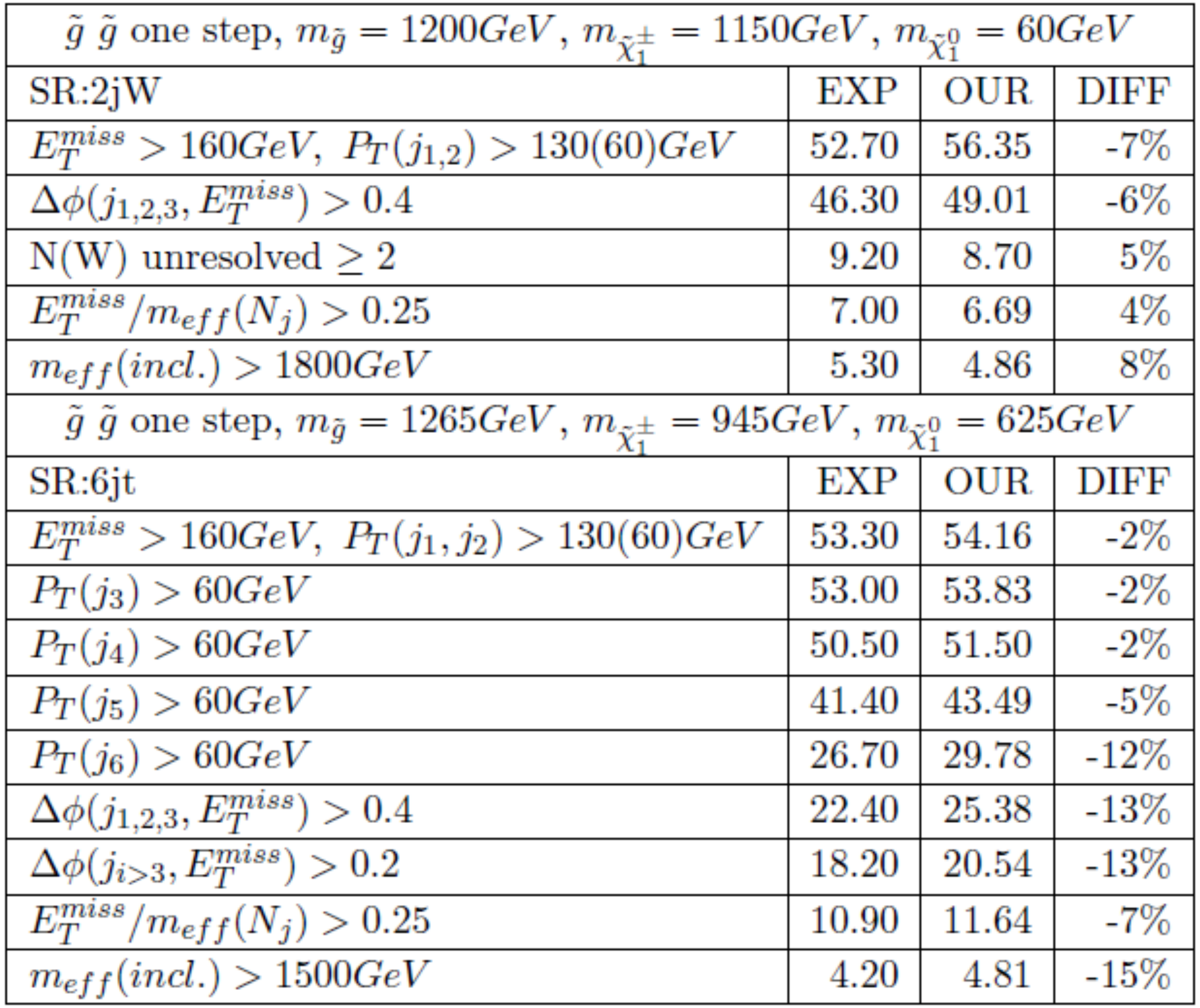


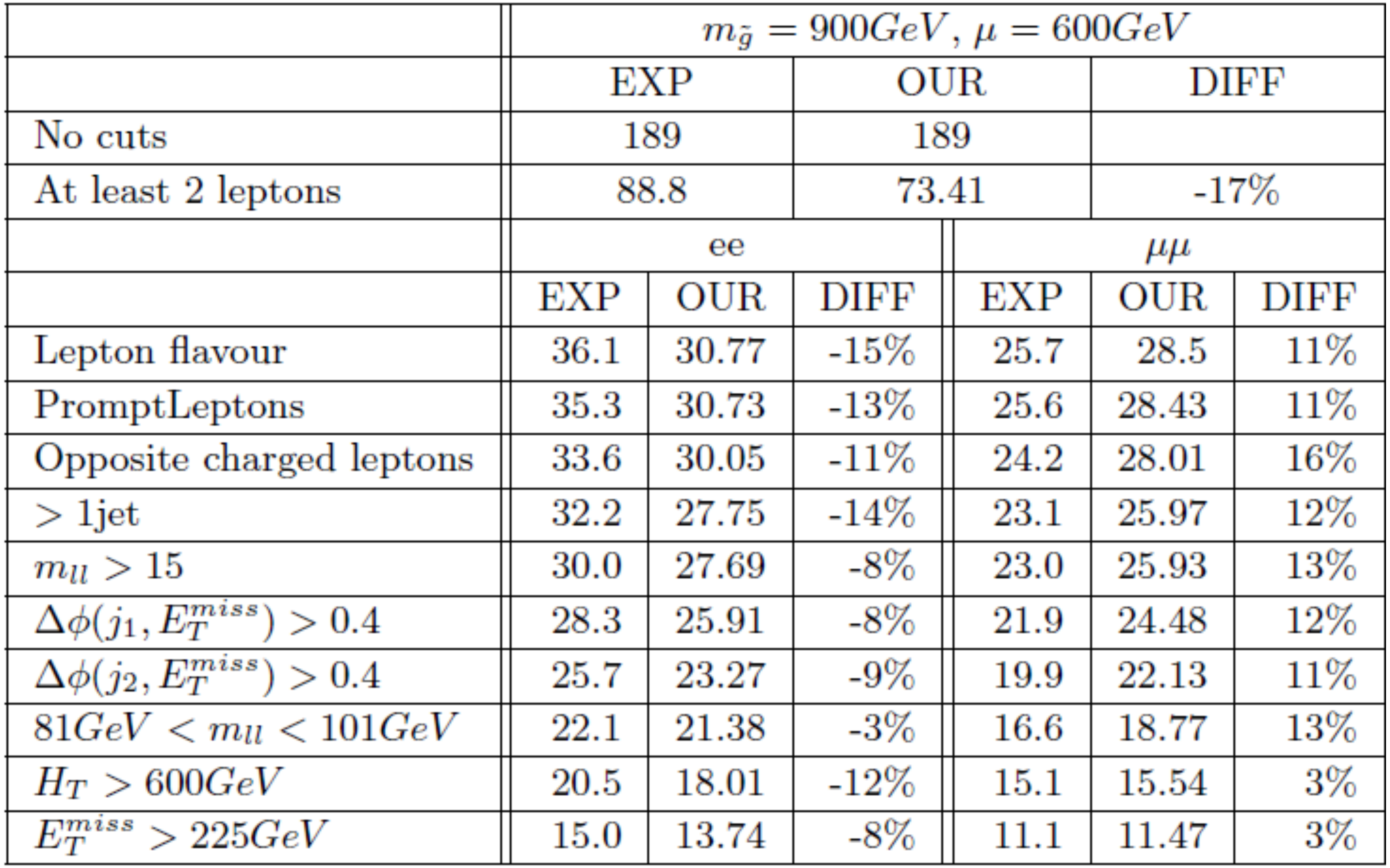
```
void Atlas_1503_03290::analyze() {
  missingET->addMuons(muonsCombined);
  countCutflowEvent("CR00_noCuts");

  histmissET->Fill(missingET->P4().Et());

  //for baseline particles and removing overlap between them
  electronsMedium = filterPhaseSpace(electronsMedium, 10., -2.47, 2.47, true);
  electronsTight = filterPhaseSpace(electronsTight, 10., -2.47, 2.47, true);
  muonsCombined = filterPhaseSpace(muonsCombined, 10., -2.4, 2.4);
  jets = filterPhaseSpace(jets, 20., -2.5, 2.5);

  electronsMedium = overlapRemoval(electronsMedium, 0.05);
  electronsTight  = overlapRemoval(electronsTight, 0.05);
  jets = overlapRemoval(jets, electronsMedium, 0.2);
  electronsMedium = overlapRemoval(electronsMedium, jets, 0.4);
  electronsTight  = overlapRemoval(electronsTight, jets, 0.4);
  muonsCombined   = overlapRemoval(muonsCombined, jets, 0.4);
  electronsMedium = overlapRemoval(electronsMedium, muonsCombined, 0.01);
  electronsTight  = overlapRemoval(electronsTight, muonsCombined, 0.01);
```

Validation

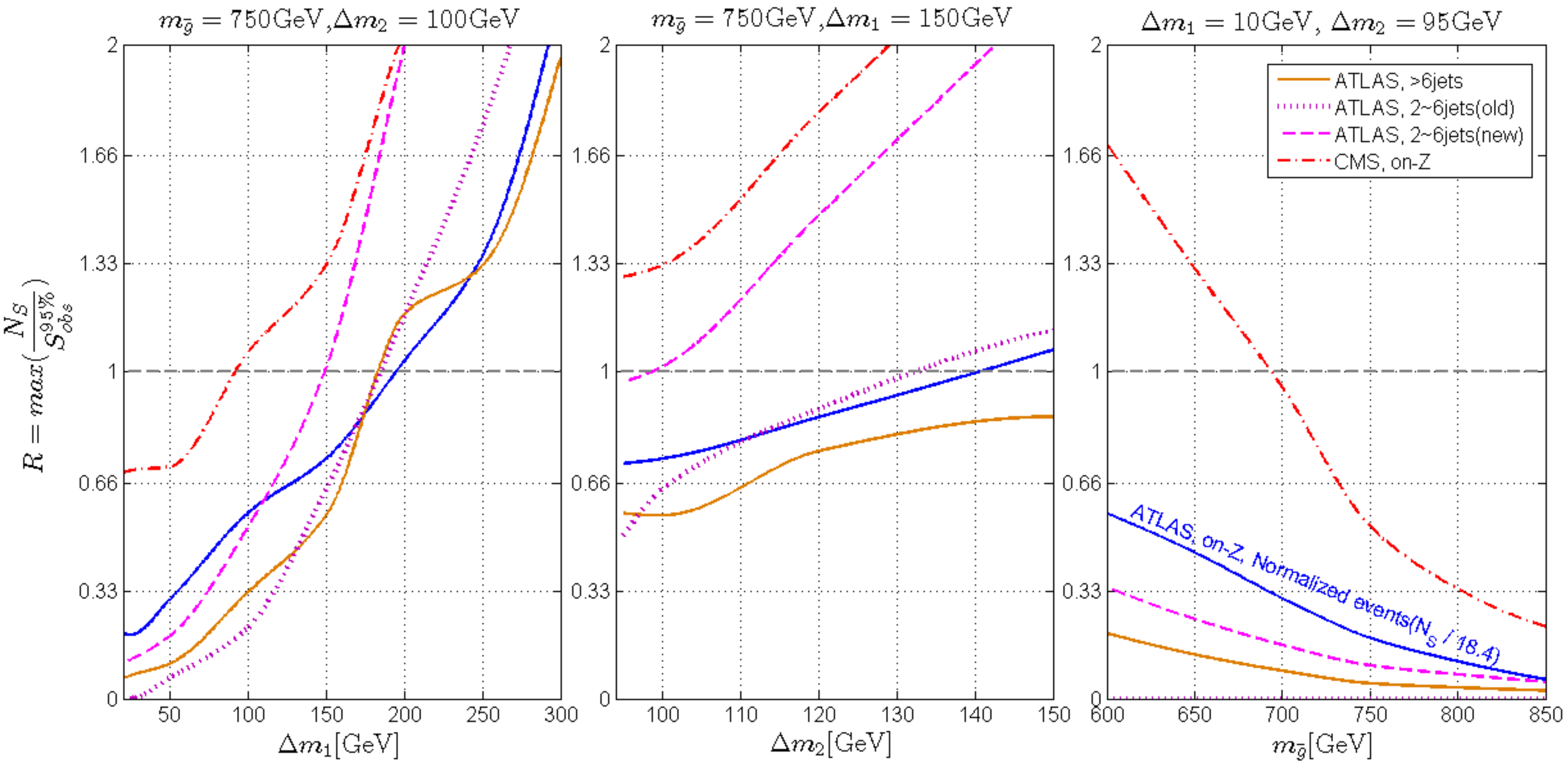


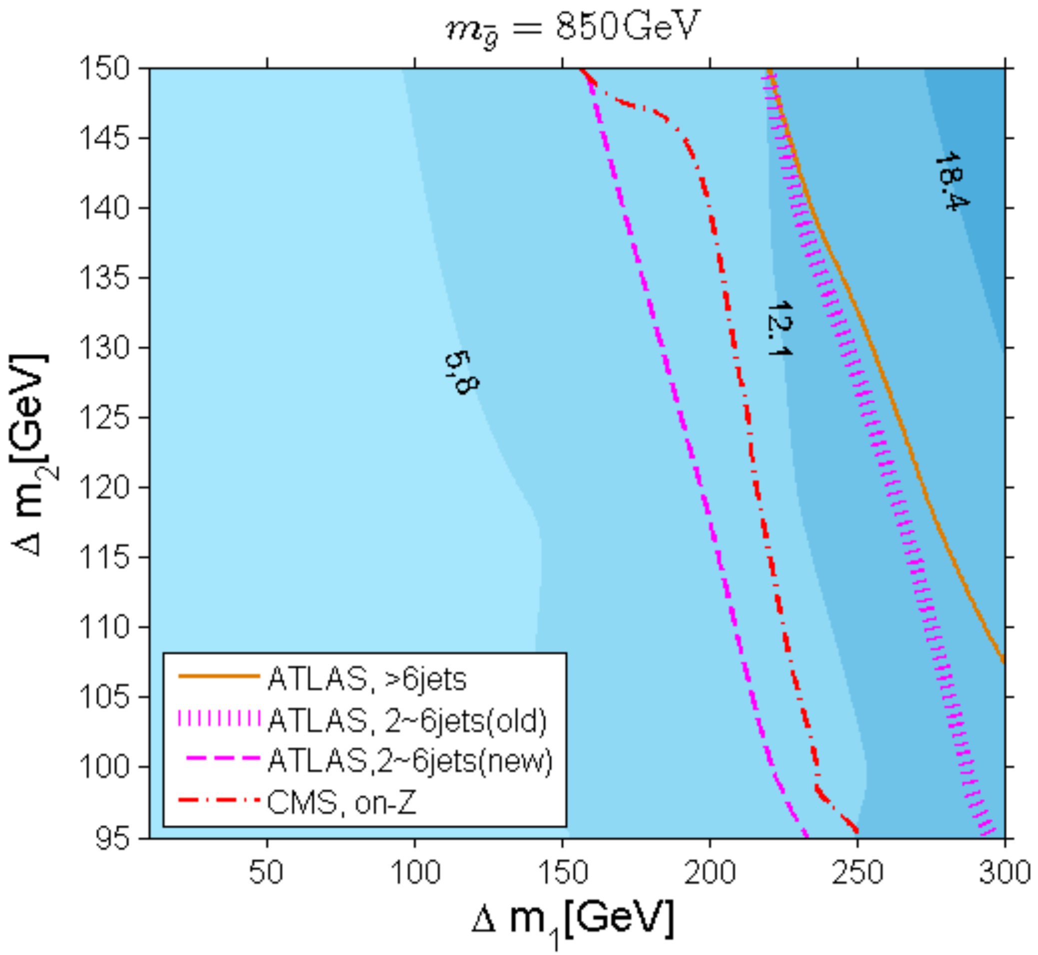
$\tilde{g}\,\tilde{g}$ one step, $m_{\tilde{g}} = 1200GeV$, $m_{\tilde{\chi}_1^\pm} = 1150GeV$, $m_{\tilde{\chi}_1^0} = 60GeV$			
SR:2jW	EXP	OUR	DIFF
$E_T^{miss} > 160GeV,\ P_T(j_{1,2}) > 130(60)GeV$	52.70	56.35	-7%
$\Delta\phi(j_{1,2,3}, E_T^{miss}) > 0.4$	46.30	49.01	-6%
N(W) unresolved ≥ 2	9.20	8.70	5%
$E_T^{miss}/m_{eff}(N_j) > 0.25$	7.00	6.69	4%
$m_{eff}(incl.) > 1800GeV$	5.30	4.86	8%
$\tilde{g}\,\tilde{g}$ one step, $m_{\tilde{g}} = 1265GeV$, $m_{\tilde{\chi}_1^\pm} = 945GeV$, $m_{\tilde{\chi}_1^0} = 625GeV$			
SR:6jt	EXP	OUR	DIFF
$E_T^{miss} > 160GeV,\ P_T(j_1, j_2) > 130(60)GeV$	53.30	54.16	-2%
$P_T(j_3) > 60GeV$	53.00	53.83	-2%
$P_T(j_4) > 60GeV$	50.50	51.50	-2%
$P_T(j_5) > 60GeV$	41.40	43.49	-5%
$P_T(j_6) > 60GeV$	26.70	29.78	-12%
$\Delta\phi(j_{1,2,3}, E_T^{miss}) > 0.4$	22.40	25.38	-13%
$\Delta\phi(j_{i>3}, E_T^{miss}) > 0.2$	18.20	20.54	-13%
$E_T^{miss}/m_{eff}(N_j) > 0.25$	10.90	11.64	-7%
$m_{eff}(incl.) > 1500GeV$	4.20	4.81	-15%

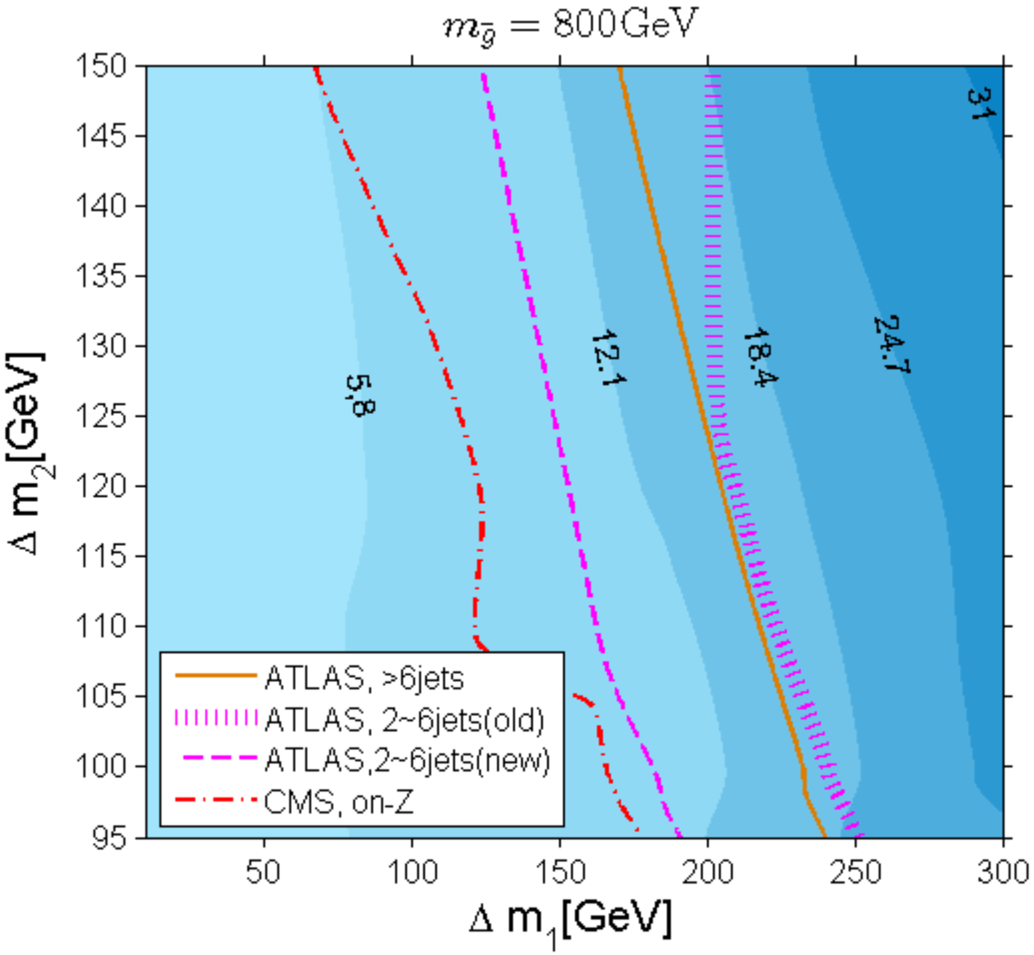
Validation

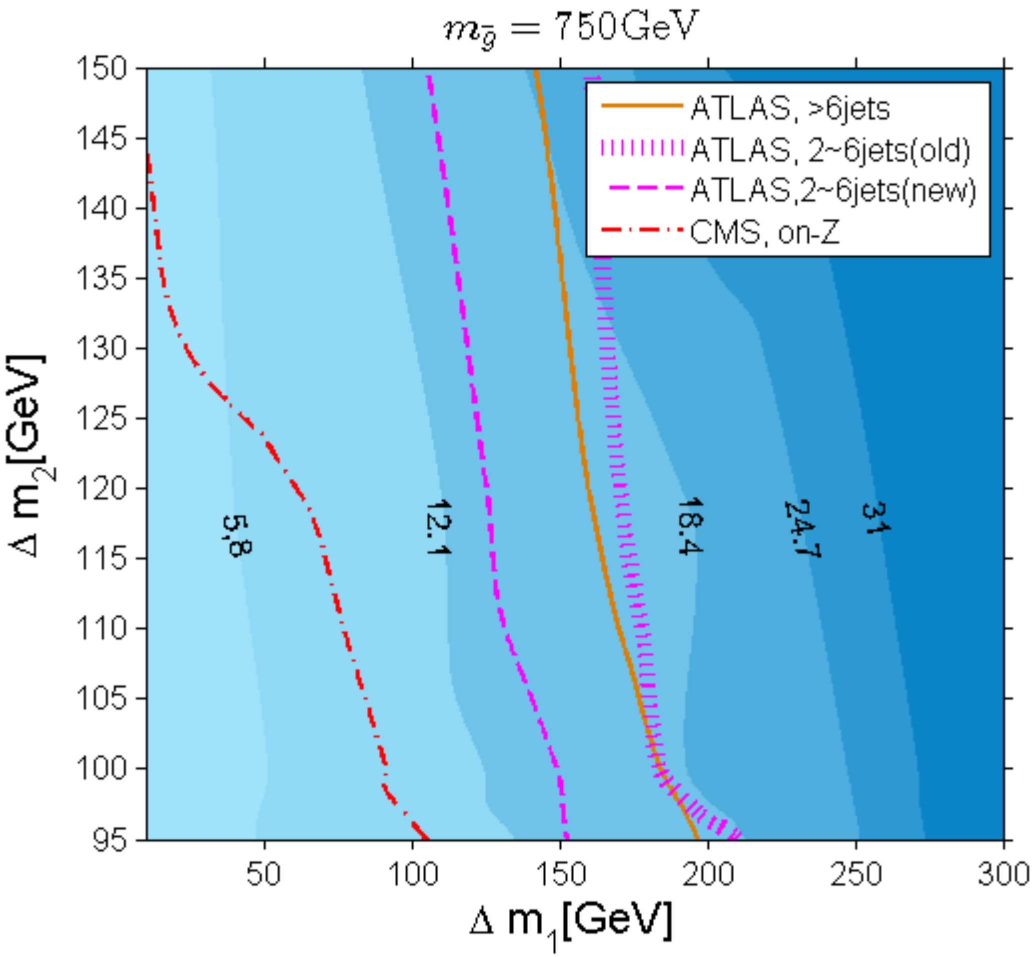


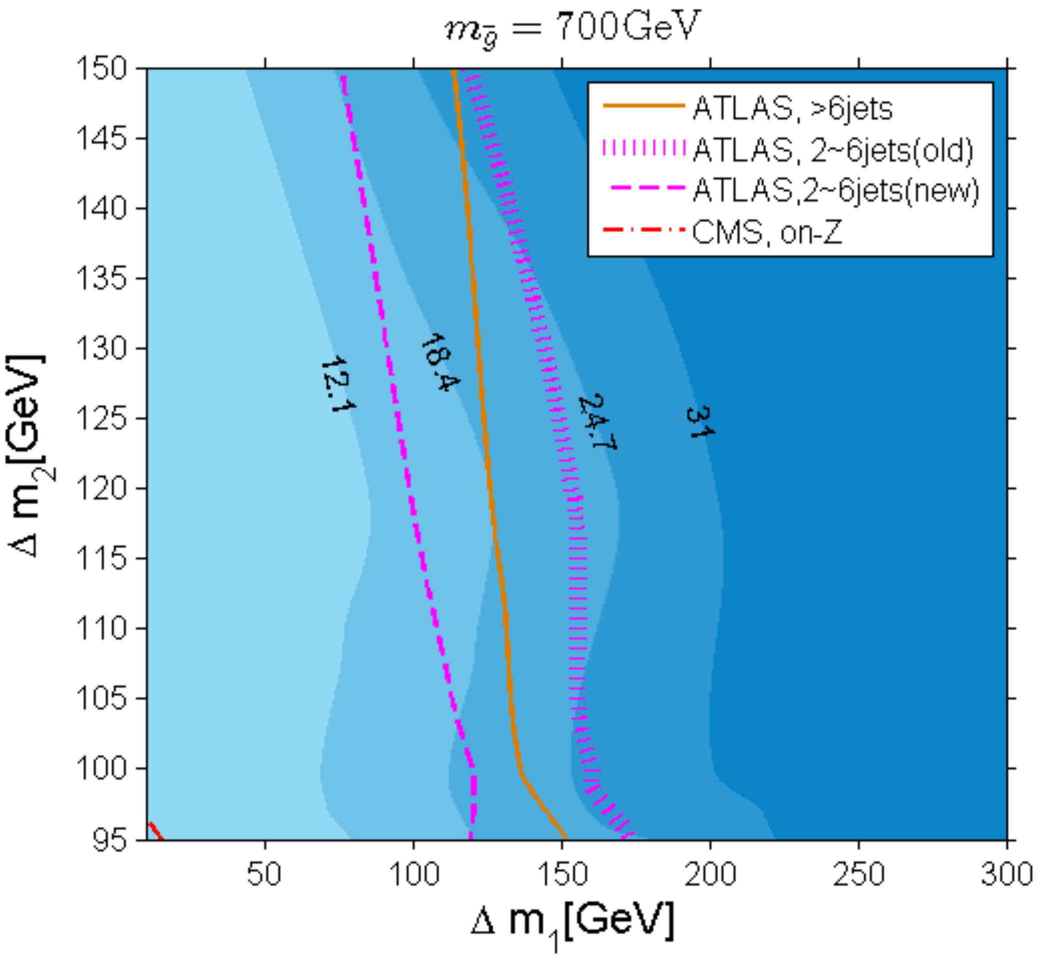
<table>
<tr><td></td><td colspan="6">$m_{\tilde{g}} = 900GeV, \mu = 600GeV$</td></tr>
<tr><td></td><td colspan="2">EXP</td><td colspan="2">OUR</td><td colspan="2">DIFF</td></tr>
<tr><td>No cuts</td><td colspan="2">189</td><td colspan="2">189</td><td colspan="2"></td></tr>
<tr><td>At least 2 leptons</td><td colspan="2">88.8</td><td colspan="2">73.41</td><td colspan="2">-17%</td></tr>
<tr><td></td><td colspan="3">ee</td><td colspan="3">$\mu\mu$</td></tr>
<tr><td></td><td>EXP</td><td>OUR</td><td>DIFF</td><td>EXP</td><td>OUR</td><td>DIFF</td></tr>
<tr><td>Lepton flavour</td><td>36.1</td><td>30.77</td><td>-15%</td><td>25.7</td><td>28.5</td><td>11%</td></tr>
<tr><td>PromptLeptons</td><td>35.3</td><td>30.73</td><td>-13%</td><td>25.6</td><td>28.43</td><td>11%</td></tr>
<tr><td>Opposite charged leptons</td><td>33.6</td><td>30.05</td><td>-11%</td><td>24.2</td><td>28.01</td><td>16%</td></tr>
<tr><td>> 1jet</td><td>32.2</td><td>27.75</td><td>-14%</td><td>23.1</td><td>25.97</td><td>12%</td></tr>
<tr><td>$m_{ll} > 15$</td><td>30.0</td><td>27.69</td><td>-8%</td><td>23.0</td><td>25.93</td><td>13%</td></tr>
<tr><td>$\Delta\phi(j_1, E_T^{miss}) > 0.4$</td><td>28.3</td><td>25.91</td><td>-8%</td><td>21.9</td><td>24.48</td><td>12%</td></tr>
<tr><td>$\Delta\phi(j_2, E_T^{miss}) > 0.4$</td><td>25.7</td><td>23.27</td><td>-9%</td><td>19.9</td><td>22.13</td><td>11%</td></tr>
<tr><td>$81GeV < m_{ll} < 101GeV$</td><td>22.1</td><td>21.38</td><td>-3%</td><td>16.6</td><td>18.77</td><td>13%</td></tr>
<tr><td>$H_T > 600GeV$</td><td>20.5</td><td>18.01</td><td>-12%</td><td>15.1</td><td>15.54</td><td>3%</td></tr>
<tr><td>$E_T^{miss} > 225GeV$</td><td>15.0</td><td>13.74</td><td>-8%</td><td>11.1</td><td>11.47</td><td>3%</td></tr>
</table>

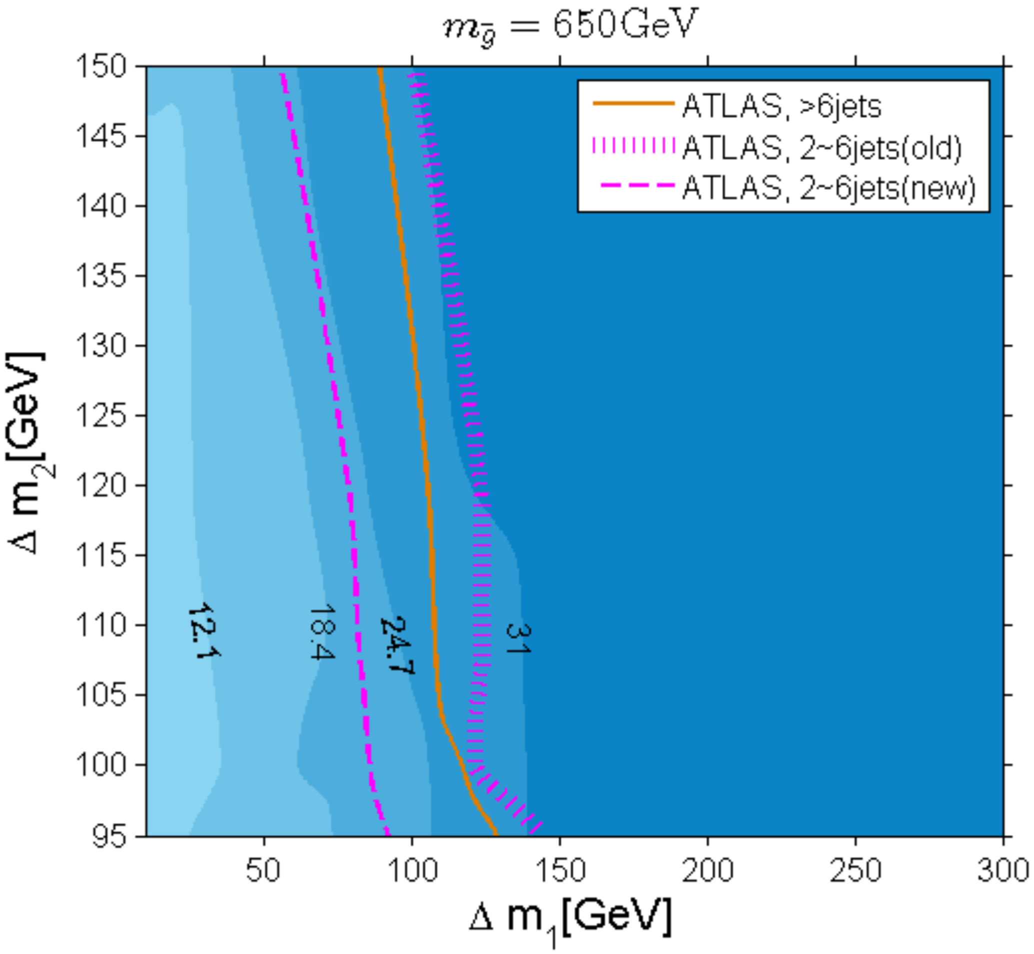

$m_{\tilde{g}} = 750\text{GeV}, \Delta m_2 = 100\text{GeV}$
$m_{\tilde{g}} = 750\text{GeV}, \Delta m_1 = 150\text{GeV}$
$\Delta m_1 = 10\text{GeV}, \ \Delta m_2 = 95\text{GeV}$
$R = max(\frac{N_S}{S_{obs}^{95\%}})$
0
0.33
0.66
1
1.33
1.66
2
50
100
150
200
250
300
$\Delta m_1[\text{GeV}]$
100
110
120
130
140
150
$\Delta m_2[\text{GeV}]$
600
650
700
750
800
850
$m_{\tilde{g}}[\text{GeV}]$
ATLAS, >6jets
ATLAS, 2~6jets(old)
ATLAS, 2~6jets(new)
CMS, on-Z
ATLAS, on-Z, Normalized events(N_S / 18.4)

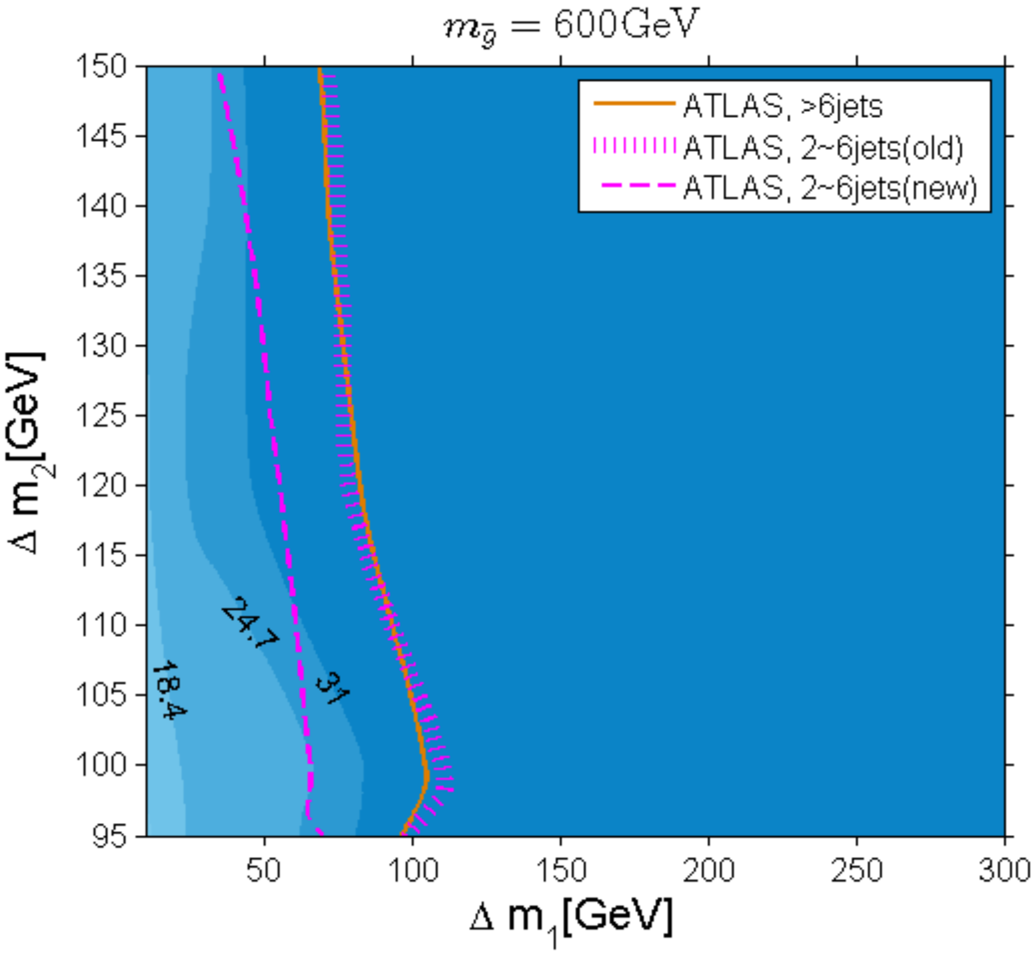

$m_{\bar{g}} = 850\mathrm{GeV}$
Δ m_2[GeV]
Δ m_1[GeV]
150
145
140
135
130
125
120
115
110
105
100
95
50
100
150
200
250
300
5,8
12.1
18.4
ATLAS, >6jets
ATLAS, 2~6jets(old)
ATLAS,2~6jets(new)
CMS, on-Z


$m_{\bar{g}} = 800\mathrm{GeV}$
Δ m_2[GeV]
Δ m_1[GeV]
150
145
140
135
130
125
120
115
110
105
100
95
50
100
150
200
250
300
5,8
12.1
18.4
24.7
31
ATLAS, >6jets
ATLAS, 2~6jets(old)
ATLAS,2~6jets(new)
CMS, on-Z


$m_{\tilde{g}} = 750\text{GeV}$
ATLAS, >6jets
ATLAS, 2~6jets(old)
ATLAS,2~6jets(new)
CMS, on-Z
5.8
12.1
18.4
24.7
31
Δ m$_2$[GeV]
Δ m$_1$[GeV]
150
145
140
135
130
125
120
115
110
105
100
95
50
100
150
200
250
300


$m_{\tilde{g}} = 700\text{GeV}$
ATLAS, >6jets
ATLAS, 2~6jets(old)
ATLAS,2~6jets(new)
CMS, on-Z
12.1
18.4
24.7
31
Δ m$_2$[GeV]
Δ m$_1$[GeV]
150
145
140
135
130
125
120
115
110
105
100
95
50
100
150
200
250
300


$m_{\bar{g}} = 650\text{GeV}$
ATLAS, >6jets
ATLAS, 2~6jets(old)
ATLAS, 2~6jets(new)
12.1
18.4
24.7
31
Δ m₂[GeV]
150
145
140
135
130
125
120
115
110
105
100
95
50
100
150
200
250
300
Δ m₁[GeV]


$m_{\bar{g}} = 600\text{GeV}$
ATLAS, >6jets
ATLAS, 2~6jets(old)
ATLAS, 2~6jets(new)
18.4
24.7
31
Δ m₂[GeV]
150
145
140
135
130
125
120
115
110
105
100
95
50
100
150
200
250
300
Δ m₁[GeV]

Result

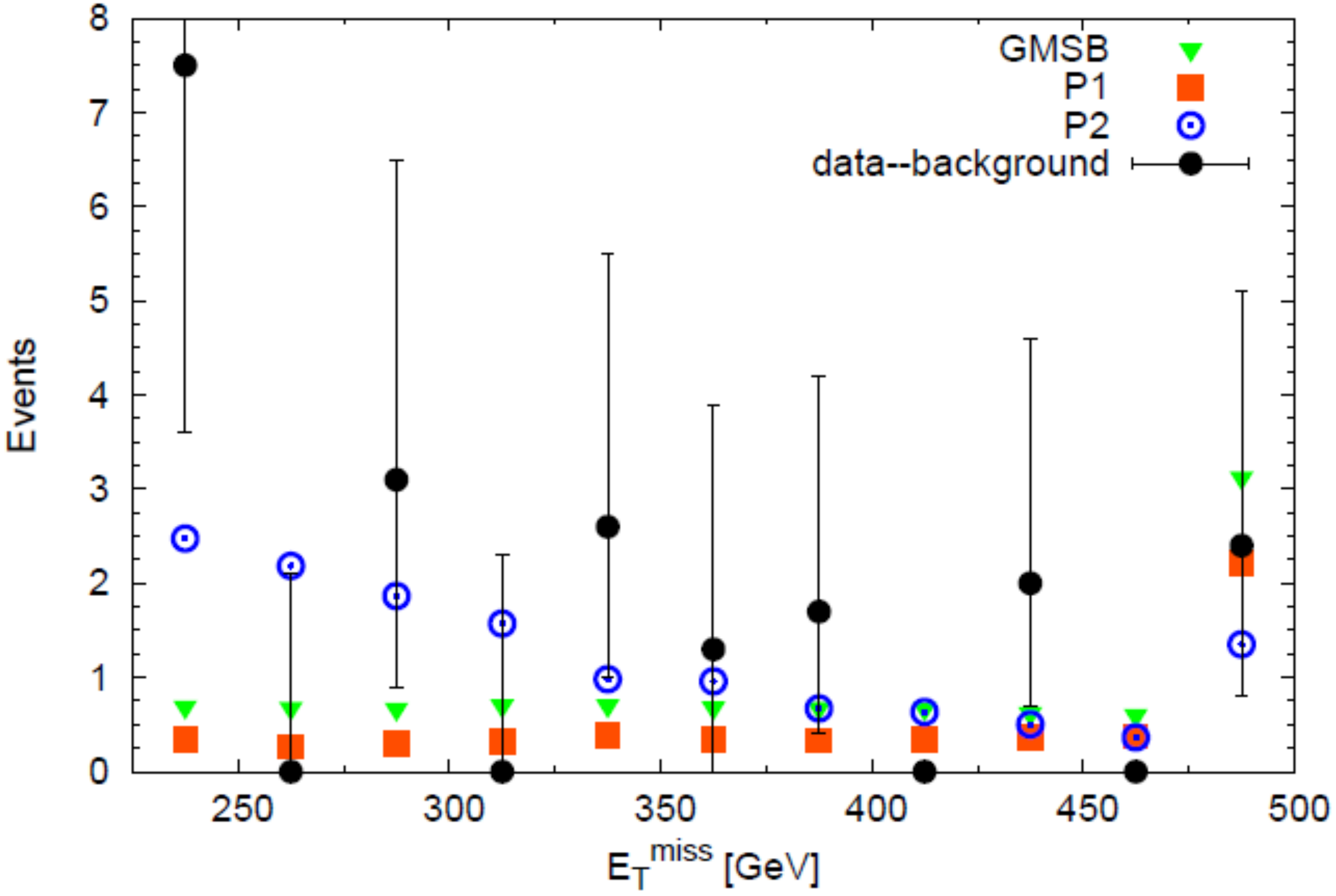
1. With out CMS limit, NMSSM can explain the ATLAS Z-peaked excess at 1σ within in optimal cases, such as $m_{\tilde{g}} = 650GeV, m_{\tilde{\chi}_2^0} = 565GeV, m_{\tilde{\chi}_1^0} = 465GeV$.

2. With CMS limit, NMSSM can explain the ATLAS Z-peaked excess at

   1.2σ away(11 Events).

Distribution

Ulrich Ellwanger, arXiv:1504.02244



Conclusion

- I Monte Carlo simulation
  - 1. Why do we need to do MC simulation?
    - An important way in phenomenology
  - 2. How to do MC simulation in collider physics?
    - MadGraph/MadEvent, Pythia, Delphes, Root, CheckMATE, …
  - 3. Which kind of work can MC simulation do?
    - Constant, Prediction, Improve, Explanation
- II Example: Explanation of the ATLAS Z-peaked excess in the NMSSM
  - 1. Brief introduction of SUSY
    - MSSM and NMSSM
  - 2. The ATLAS experimental report for Z-peaked excess
    - Process, identification, selection, results
  - 3. The explanation of the Z-peaked excess
    - $m_{\tilde{g}} = 650GeV, m_{\tilde{\chi}_2^0} = 565GeV, m_{\tilde{\chi}_1^0} = 465GeV$ can explain at 1σ

WE ARE JUST O THE WAY

Thank you.