Exploring the Electron + Track Signature to Measure Tau $g-2$

Summer Student Project

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Introduction

- Charged particles with spin have intrinsic magnetic moment
- For spin $1/2$ particles, magnetic moment is given by

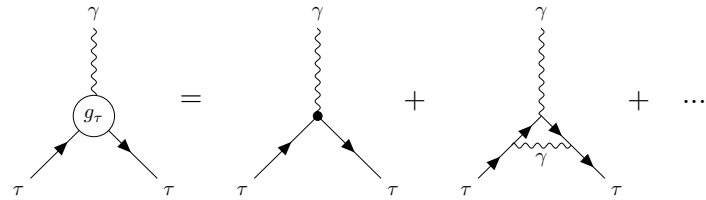
$$\vec{\mu} = g\frac{q}{2m}\vec{S}$$

- Proportionality factor g is called the g-factor
- Dirac equation predicts $g = 2$ for leptons

Anomalous Magnetic Moment

- Renormalisation in QFT leads to corrections to the g-factor
- Loop diagrams contribute to $\gamma\gamma\tau$-coupling
- The anomalous magnetic moment is defined as

$$a = \frac{g-2}{2}$$



Measurement of a_ℓ

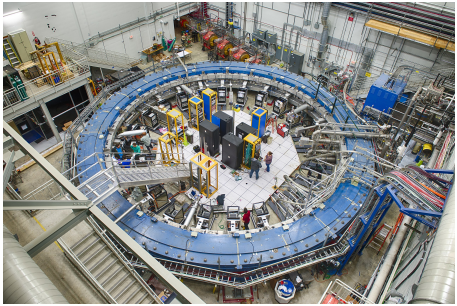
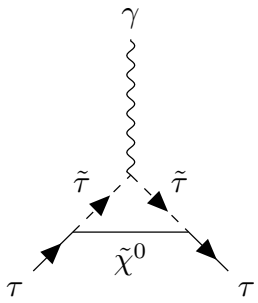


Figure: Fermilab g-2 ring [1]

- **Electron**:
  - Measured in particle trap
  - (one of the) most precisely measured value(s)
- **Muon**:
  - Measured in storage ring (spin precession)
  - Deviations between experiment and theory
  - Up to 5σ (depending on theory calculation)
- **Tau**:
  - 10^{-13}s lifetime
  - Extremely challenging experimentally
  - Measure in collider experiments

Why Measure a_τ?



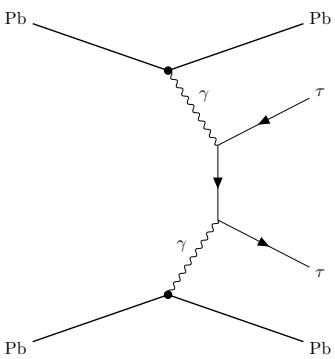
- Test SM γ-τ-coupling
- BSM physics might contribute to the anomalous magnetic moment
- Massive BSM particle contribution scales

$$\delta a_\ell = \frac{m_\ell^2}{M_S^2}$$

- Thus, τ is up to 280 times more sensitive than the muon
- Much less constrained [2]:

$$-0.052 < a_\tau < 0.013 \text{ 95\% CL}$$

Analysis Setup



- Aim: Probe τ-γ-coupling in PbPb collisions
- High electromagnetic field: photons fuse to $\tau\tau$ pair
- Cross-section enhanced by Z^4 compared to pp
- Target Ultra-peripheral collisions (UPC)
  - No hadronic activity
  - Clean event topology (no pile-up)
  - Ions (can) stay intact

Tau Decays

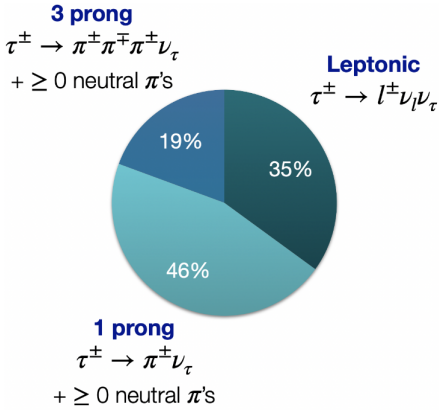


Figure: Tau decay branching ratios [3]

- Hadronic decays to pions
- Leptonic decays to electrons and muons
- Consider semi- and fully leptonic decays:
  - SR-$1\mu 1$T: 1 muon, 1 track
  - SR-$1\mu 3$T: 1 muon, 3 tracks
  - SR-$1\mu 1e$: 1 muon, 1 electron
  - SR-$1e1$T: 1 electron, 1 track
  - SR-$1e3$T: 1 electron, 3 tracks

Analysis Strategy

General Strategy:

- Define regions enriched with $\tau\tau$ events
- Define (2ℓ) control regions to constrain background
- Perform a_τ fit in the signal regions using templates of the signal process

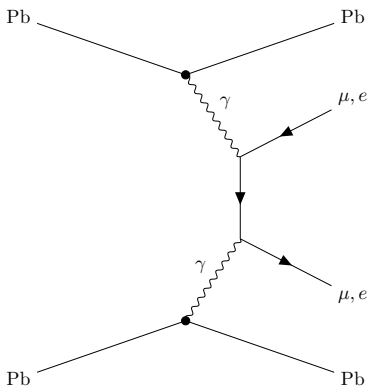
Run 3 Changes:

- Note: follows closely the analysis done by ATLAS for Run 2 [4]
- For now $\mathcal{L} = 1.67$ nb^{-1} in Run 3 compared to 1.44 nb^{-1} in Run 2
- But extends the analysis to include electron regions

Blinding:

- Shifting the signal sample cross-section randomly

Background Processes



- Very little background due to clean event topology
- Photonuclear background can be reduced in SRs
  - Rejected by zero-degree-calorimeter cut ($E_{\text{ZDC}} < 1$ TeV)
- Main (irreducible) background: PbPb $\rightarrow \mu\mu, ee$
- Charged leptons appear as tracks, mimicking τ decay

Event Selection

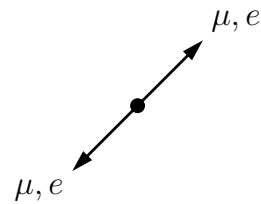
Reject $\gamma\gamma \to \ell\ell$ (balanced) events:

> Bkg.: Leptons are collinear

> Signal: Neutrinos dilute the collinearity of leptons

$\Rightarrow$ Require $p_T(\ell, \text{trk}) > 1$ GeV for SR-$1\ell 1$T

$\gamma\gamma \to \mu\mu, ee$

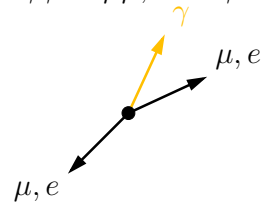


Reject $\gamma\gamma \to \ell\ell + \gamma$ (inbalanced) events:

> For FSR photons, leptons are not collinear

$\Rightarrow$ Require $p_T(\ell, \text{trk}, \gamma) > 1$ GeV for SR-$1\ell 1$T

$\gamma\gamma \to \mu\mu, ee + \gamma$



Summary of Regions

Region	Data 23	Pred	S	B	S/B	$S/\sqrt{S+B}$
CR-2μ	29085.0	29003.5	41.1	28962.4	0.0	0.2
CR-$2e$	23662.0	20529.3	14.0	20515.2	0.0	0.1
SR-1μ1T	942.0	1117.4	831.8	285.6	2.9	24.9
SR-$1e$1T	2279.0	1822.7	963.4	859.3	1.1	22.6

> Electrons leave tracks more often than muons

$\Rightarrow$ More $\gamma\gamma \to \ell\ell$ background in SR-$1e$1T

Summary of Regions

Region	Data 23	Pred	S	B	S/B	$S/\sqrt{S+B}$
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SR-1e1T	2279.0	1822.7	963.4	859.3	1.1	22.6
SR-1μ3T	135.0	127.8	122.8	5.0	24.5	10.9
SR-1e3T	392.0	233.2	192.3	40.9	4.7	12.6

> SR-1e3T has significant data excess

Summary of Regions

Region	Data 23	Pred	S	B	S/B	$S/\sqrt{S+B}$
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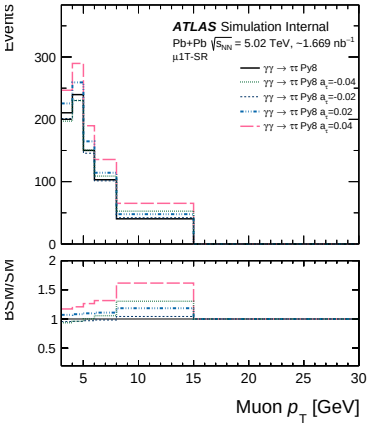
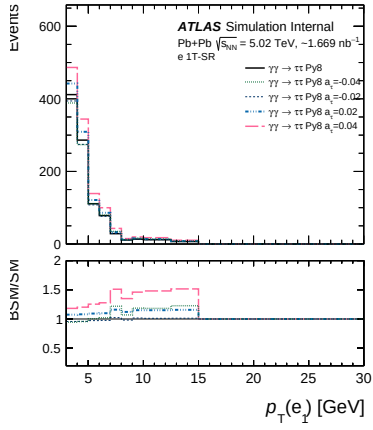
SR-1e3T	392.0	233.2	192.3	40.9	4.7	12.6
SR-1μ1e	85.0	63.6	54.9	8.7	6.3	6.9

Varied a_τ-Signal



- Samples with varied a_τ obtained by re-weighting signal sample
- Difference in shape and yield
- Muon p_T is sensitive to a_τ

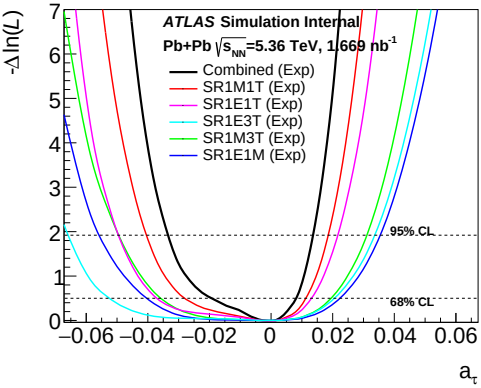
$\Rightarrow$ Used as observable in a_τ-fit



SR-1μ1T

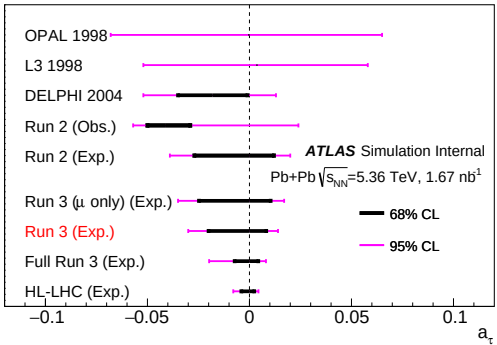
SR-1e1T

Likelihood Scans



- Most sensitive region: SR$1\mu 1$T
- Followed by SR$1e1$T and SR$1\mu 3$T
- Double peaked structure due to a_τ dependence of σ
- Note: only statistical uncertainties
- Statistical uncertainties are dominant

Expected Significance



- Improvement in expected sensitivity with increased luminosity
- Further improvement due to inclusion of electrons
- For HL-LHC, improvement by factor of 5 compared to LEP-results
- Not including a recent (06/2024) CMS result from pp collision [5]

Thank you!

Summary:

- a_τ is an important sensitive probe for BSM physics
- PbPb collisions provide a clean environment for this measurement
- With Run 3 data, the sensitivity is expected to improve by a factor of 3 compared to single best measurement

Contact

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References I

[1] Fermilab Visual Media Services. Muon g-2 experiment, 2017. URL https://vms.fnal.gov/asset/detail?recid=1950114. Accessed: 2024-08-26.

[2] DELPHI collaboration. Study of tau-pair production in photon-photon collisions at lep and limits on the anomalous electromagnetic moments of the tau lepton. The European Physical Journal C-Particles and Fields, 35(2):159–170, 2004.

[3] Lydia Audrey Beresford. Measuring tau g-2 using ATLAS Pb+Pb collisions. 2022. URL https://cds.cern.ch/record/2834319.

[4] G. Aad et al. Observation of the $\gamma\gamma \to \tau\tau$ process in Pb + Pb collisions and constraints on the τ-lepton anomalous magnetic moment with the atlas detector. Phys. Rev. Lett., 131:151802, Oct 2023. doi: 10.1103/PhysRevLett.131.151802. URL https://link.aps.org/doi/10.1103/PhysRevLett.131.151802.

References II

[5] CMS Collaboration. Observation of $\gamma\gamma \to \tau\tau$ in proton-proton collisions and limits on the anomalous electromagnetic moments of the τ lepton, 2024. URL https://arxiv.org/abs/2406.03975.

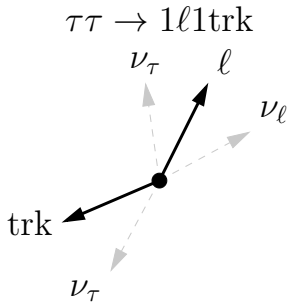
[6] ATLAS Collaboration. ATLAS Event Display: Tau-lepton pair produced in heavy-ion collisions. General Photo, 2022. URL https://cds.cern.ch/record/2806129.

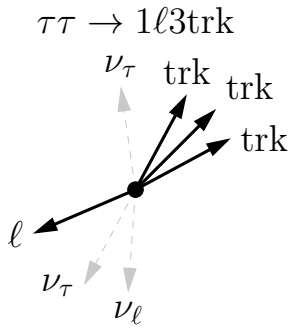
[7] ATLAS Collaboration. ATLAS event displays of lead-lead ion collisions in ATLAS detector during Run 3. General Photo, 2022. URL https://cds.cern.ch/record/2841509.

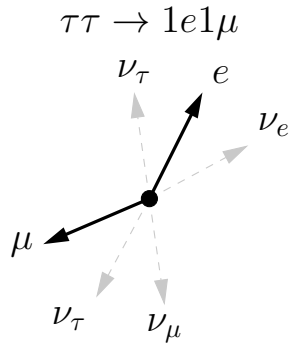
[8] Mateusz Dyndał, Mariola Kłusek-Gawenda, Antoni Szczurek, and Matthias Schott. Anomalous electromagnetic moments of τ lepton in $\gamma\gamma \to \tau^+\tau^-$ reaction in pb+pb collisions at the lhc. Physics Letters B, 809:135682, 2020. doi: https://doi.org/10.1016/j.physletb.2020.135682.

Backup

Signal Processes

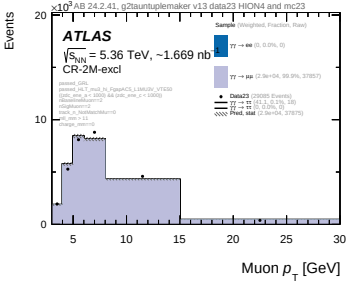




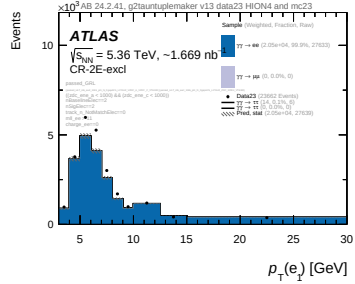


- Neutrions not visible in detector
- Tracks and leptons are not collinear

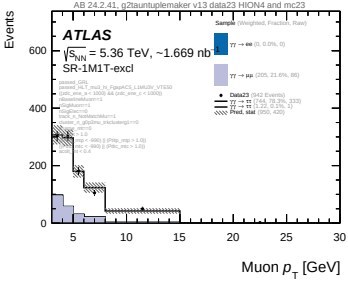
Control Regions



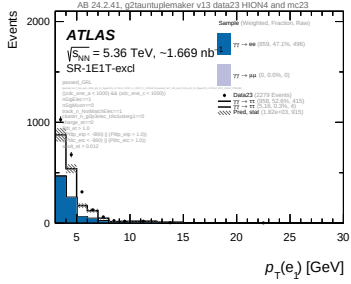
- Good agreement between data and prediction
- Normalisation not (yet) consistent for CR-$2e$



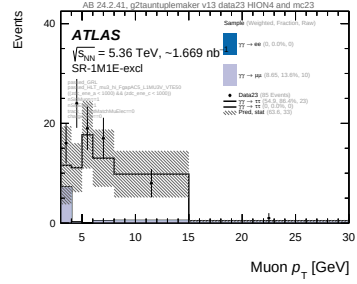
Signal Regions - 1 track, 1 electron



SR-1M1T



SR-$1e1T$

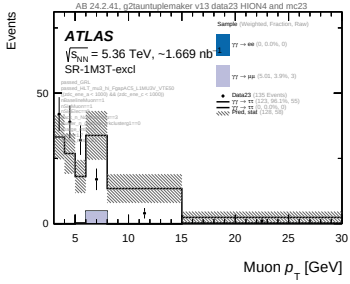


SR-$1\mu1e$

> Good agreement between data and prediction (note: Normalisation of $\gamma\gamma \to ee$)

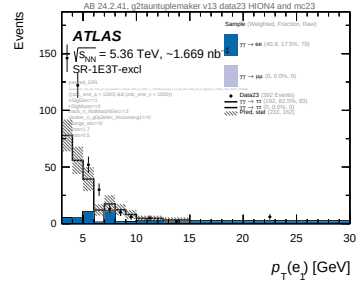
>

Signal Regions - 3 tracks



SR-$1\mu 3$T

- SR-$1e3$T: Excess in data in the low p_T region
- Most likely due to some unconsidered background



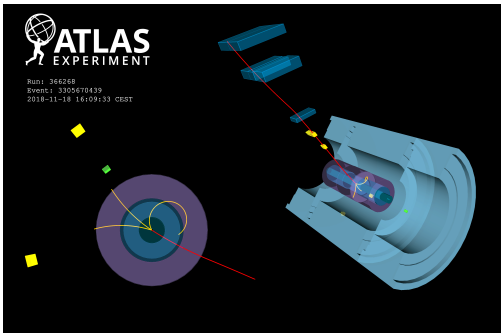
SR-$1e3$T

Event Selection

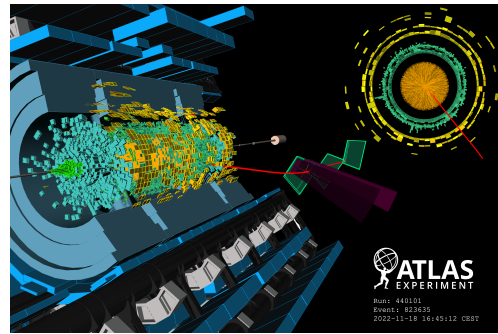
Observable	Preselection					
GRL	Pass					
$E_{\text{ZDC}}^{A,C}$	< 1 TeV					
Trigger	passed_HLT					
Region	**SR-1μ1T**	**SR-1e1T**	**SR-1μ3T**	**SR-1e3T**	**SR-1μ1e**	**CR-2μ**
$N_{\mu}^{\text{baseline}}$	=1	-	=1	-	-	-
N_{μ}^{sig}	=1	=0	=1	=0	=1	= 2
N_{e}^{sig}	=0	=1	=0	=1	=1	-
$N_{trk}(\Delta R > 0.1 \text{ from } \mu^{sig})$	=1	=1	=3	=3	-	-
$N_{trk}(\Delta R > 0.1 \text{ from } \ell^{sig})$	-	-	-	-	=0	=0
Unmatched clusters	=0	=0	=0	=0	-	-
$\sum$ charge	=0	=0	=0	=0	=0	-
$p_T^{(\mu,\text{trk})}$	> 1 GeV	> 1 GeV	-	-	-	
$p_T^{(\mu,\text{trk}),\gamma}$	> 1 GeV	> 1 GeV	-	-	-	
$p_T^{(\mu,\text{trk}),\text{cluster}}$	> 1 GeV	> 1 GeV	-	-	-	
m_{trks}	-	-	< 1.7 GeV	$\in [0.5 \text{ GeV}, 1.7 \text{ GeV}]$	-	-
$A^{\mu,\text{trk(s)}}$	< 0.4	> 0.012	< 0.2	-	-	-
$m_{\mu\mu}$	-	-	-	-	-	$> 11GeV$

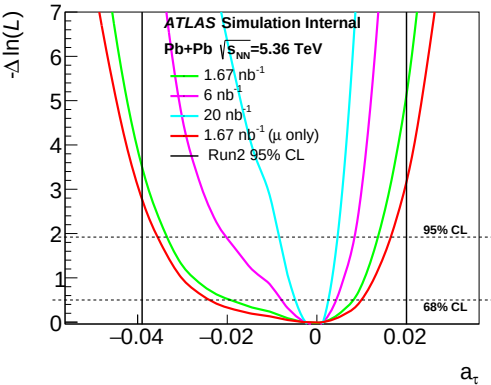
Ultra-Peripheral Collisions

UPC event [6]



Head on PbPb collision [7]





- Improvement in the expected sensitivity with increased luminosity
- Further improvement due to the inclusion of electrons

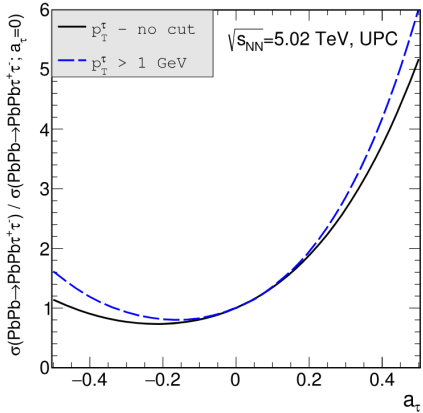
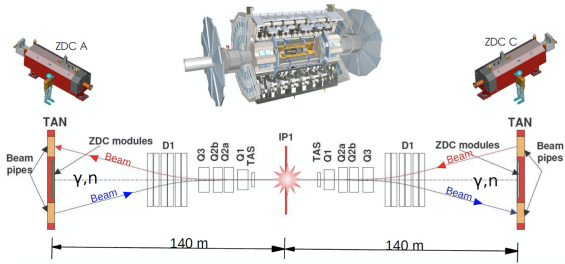


Figure: Figure taken from [8]

- Cross-section for τ production in PbPb collisions
- explains double peaked structure of a_τ likelihood
- Two a_τ values deliver the same yield
- The shape information breaks this symmetry

Zero Degree Calorimeter

- Detect neutral forward particles
- Used to select events with no hadronic



Goal and Strategy

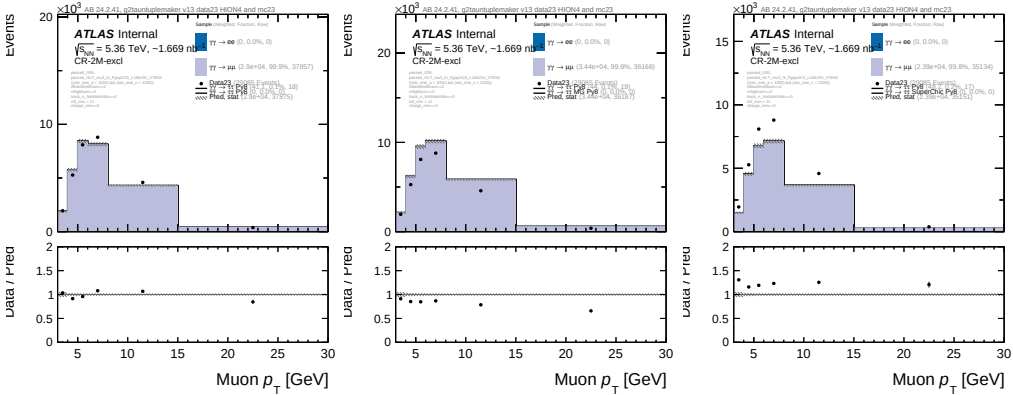
- Study muon CR and SRs using new 2023 data
- Using v13 of the ntuples
- Extend analysis to include electrons
- Definition of signal and control regions follows closely the muonic channels

Muon Regions Cutflow

Observable	Preselection			
GRL	Pass			
$E_{\text{ZDC}}^{A,C}$	< 1 TeV			
Trigger	passed_HLT_mu3_hi_FgapAC5_L1MU3V_VTE50			
Region	**SR-1μ1T**	**SR-1μ3T**	**SR-$1\mu1e$**	**CR-2μ**
$N_{\mu}^{\text{baseline}}$	=1	=1	-	-
N_{μ}^{sig}	=1	=1	=1	= 2
N_{e}^{sig}	=0	=0	=1	-
$N_{trk}(\Delta R > 0.1 \text{ from } \mu^{sig})$	=1	=3	-	-
$N_{trk}(\Delta R > 0.1 \text{ from } \ell^{sig})$	-	-	=0	=0
Unmatched clusters	=0	=0	-	-
$\sum$ charge	=0	=0	=0	-
$p_T^{(\mu,\text{trk})}$	> 1 GeV	-	-	-
$p_T^{(\mu,\text{trk}),\gamma}$	> 1 GeV	-	-	-
$p_T^{(\mu,\text{trk}),\text{cluster}}$	> 1 GeV	-	-	-
m_{trks}	-	< 1.7 GeV	-	-
$A^{\mu,\text{trk(s)}}$	< 0.4	< 0.2	-	-
$m_{\mu\mu}$	-	-	-	$> 11GeV$

Note: due to a new trigger require signal muon $p_T > 3$ GeV instead of 4 GeV.

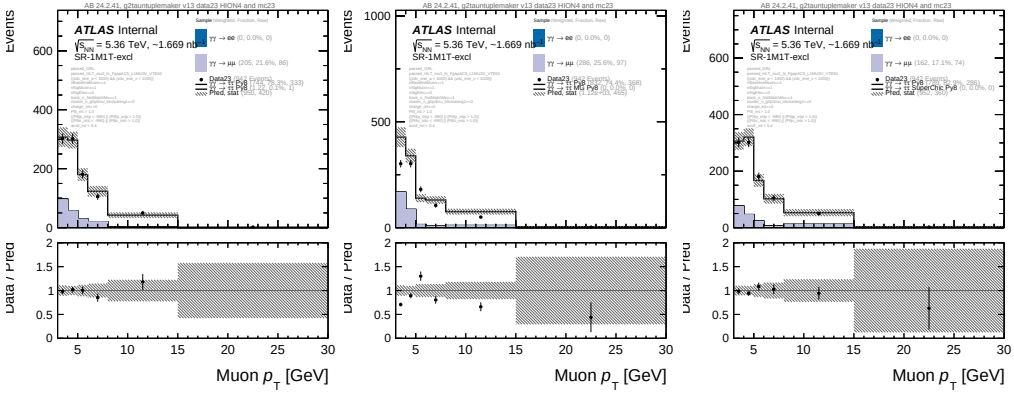
CR-2μ - $p_T(\mu_1)$



(a) STARLight (b) MadGraph (c) SuperChic

Figure: Distribution of $p_T(\mu_1)$ in CR-2μ

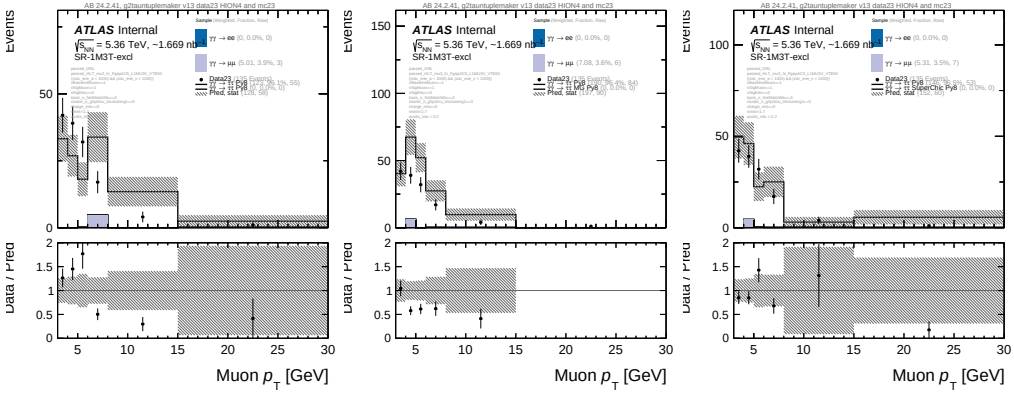
SR-$1\mu1$T - $p_T(\mu_1)$



(a) STARLight (b) MadGraph (c) SuperChic

Figure: Distribution of $p_T(\mu_1)$ in SR-$1\mu1$T

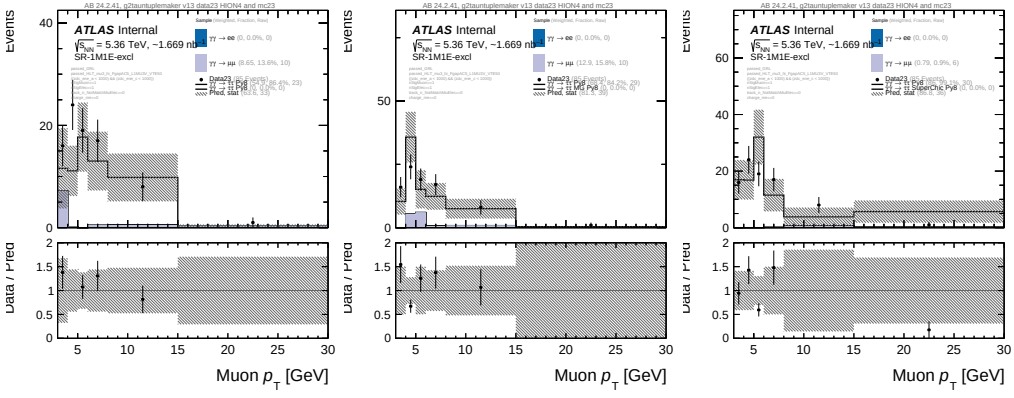
SR-$1\mu3$T - $p_T(\mu_1)$



(a) STARLight (b) MadGraph (c) SuperChic

Figure: Distribution of $p_T(\mu_1)$ in SR-$1\mu3$T

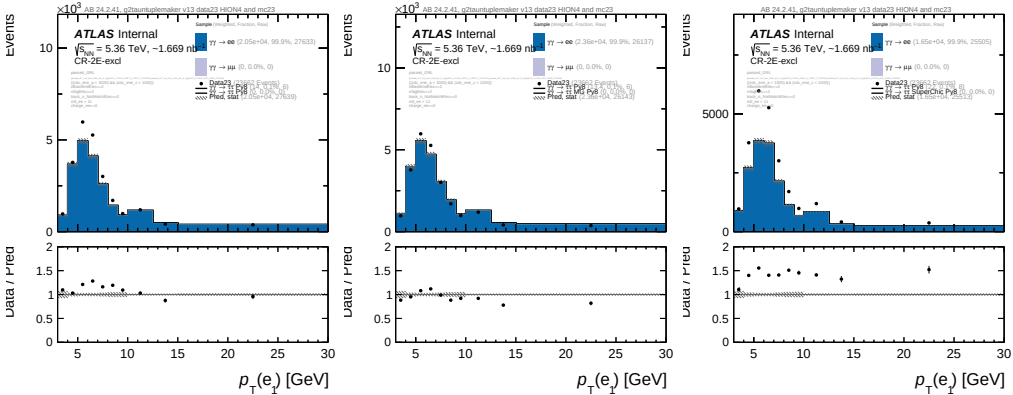
SR-$1\mu 1e$ - $p_T(\mu_1)$



(a) STARLight (b) MadGraph (c) SuperChic

Figure: Distribution of $p_T(\mu_1)$ in SR-$1\mu 1e$

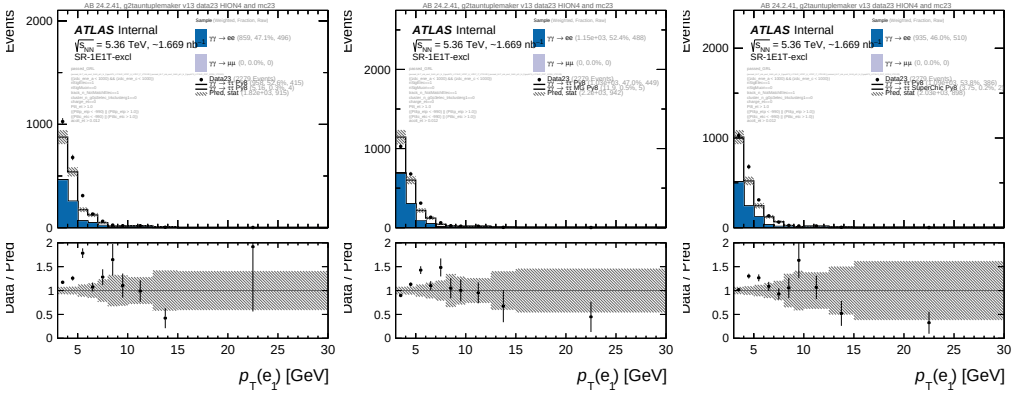
CR-$2e$ - $p_T(e_1)$



(a) STARLight (b) MadGraph (c) SuperChic

Figure: Distribution of $p_T(e_1)$ in CR-$2e$

SR-$1e1$T - $p_T(e_1)$



(a) STARLight (b) MadGraph (c) SuperChic

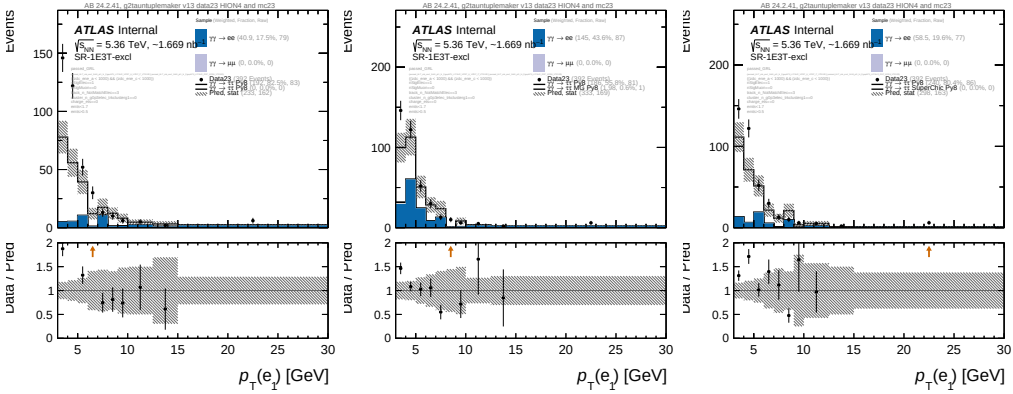
Figure: Distribution of $p_T(e_1)$ in SR-$1e1$T

Yields SR-$1e3$T

Region	Data 23	Pred	S	B	S/B	$S/\sqrt{S+B}$
SR-$1e3$T-MG	392.0	332.6	187.5	145.1	1.3	10.3
SR-$1e3$T-SL	392.0	233.2	192.3	40.9	4.7	12.6
SR-$1e3$T-SC	392.0	298.2	239.7	58.5	4.1	13.9

Table: AB 24.2.41, g2tauntuplemaker v13 data23 HION4 and mc23. Normalised to $\mathcal{L} = 1.669$ nb^{-1}.

SR-$1e3$T - $p_T(e_1)$



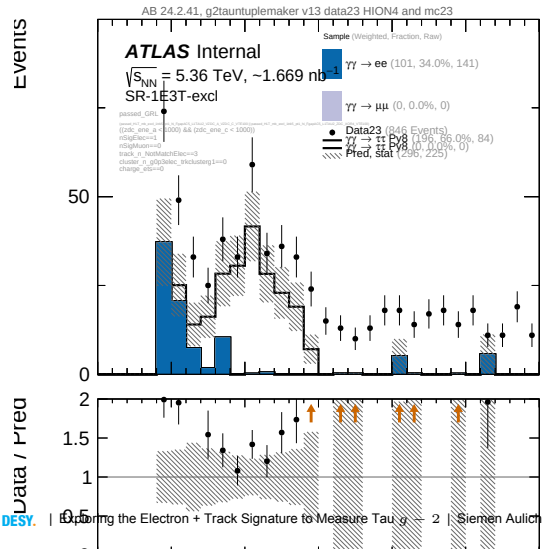
(a) STARLight (b) MadGraph (c) SuperChic

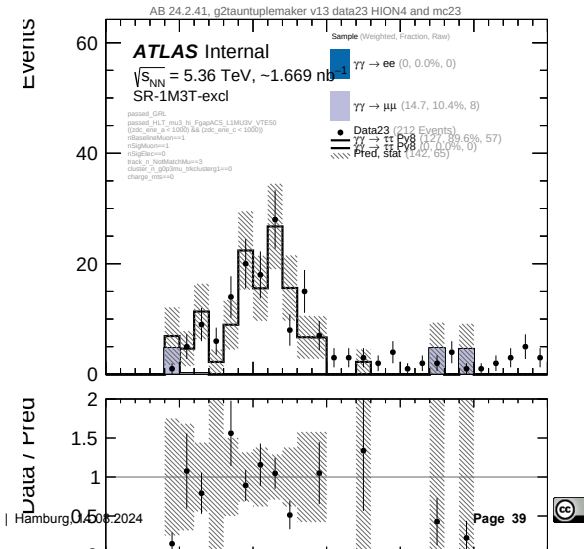
Figure: Distribution of $p_T(e_1)$ in SR-$1e3$T

Summary of Electron Regions

- Normalisation is off for STARLight and SuperChic: to be corrected by backgroud fitting
- Similar shape for $p_T(e_1)$ in all regions and generators
- Numbers in cutflow are similar for the different generators (see Appendix)

SR-1e3T - Excess





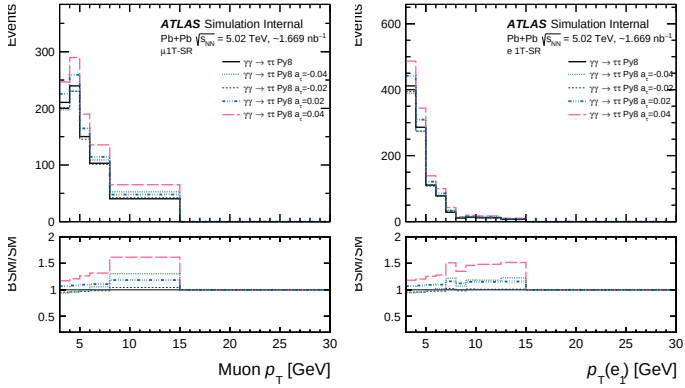
SR-$1e3$T Excess

- Data shows some continuum background
- Background estimation does not include this background
- Mostly cut away by m_{trks} cut, but might explain the excess in data
- Madgraph has significantly more (background) events in SR-$1e3$T (mostly at low m_{trks})
- Note: the samples were run with lower statistics, thus more fluctuations are expected

a_τ-Fit

- Extract a_τ from the p_T-distribution in the signal regions
- Perform a template fit using different a_τ values
- Compare the shapes of the p_T-distributions for different generators
- Note: the samples are using the Run 2 weights (e.g. $\sqrt{s} = 5.02$ TeV)

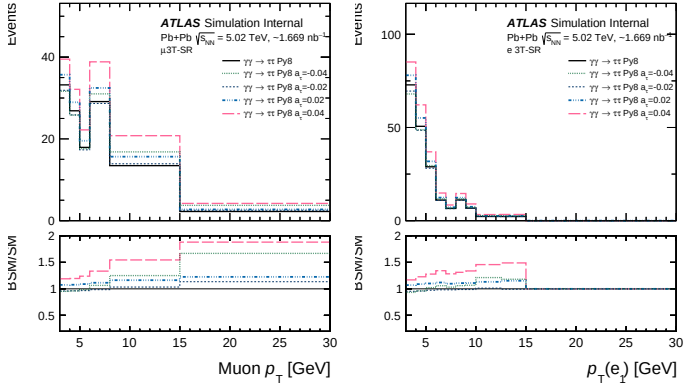
BSM a_τ: 1E/M1T - STARLight



(a) SR-1M1T (b) SR-$1e1$T

Figure: BSM p_T-distribution in SRs for different a_τ values.

BSM a_τ: 1E/M3T - STARLight



(a) SR-$1\mu3$T (b) SR-$1e3$T

Figure: BSM distribution in SRs for different a_τ values.

Cutflow CR-2μ - STARLight

Requirement	Data 23	$\gamma\gamma \to \tau\tau$	$\gamma\gamma \to ee$	$\gamma\gamma \to \mu\mu$	Pred	B	S/B	$S/\sqrt{S+B}$
pass GRL	1489893.0	69313.0	670874.1	494220.9	1234408.0	1165095.0	0.1	62.4
HLT mu3 trigger	401729.0	1802.6	0.7	79164.4	80967.7	79165.1	0.0	6.3
$E_{\text{ZDC}}^{A,C} < 1$ TeV	109394.0	1802.6	0.7	79164.4	80967.7	79165.1	0.0	6.3
$N_{\mu}^{\text{baseline}} = 2$	75971.0	145.9	0.0	71775.6	71921.4	71775.6	0.0	0.5
$N_{\mu}^{\text{sig}} = 2$	60486.0	70.3	0.0	58045.3	58115.7	58045.3	0.0	0.3
N_{trk} ($\Delta R > 0.1$ from μ) $= 0$	59347.0	70.3	0.0	57965.8	58036.2	57965.8	0.0	0.3
$m_{\mu\mu} > 11$ GeV	29086.0	41.1	0.0	28962.4	29003.5	28962.4	0.0	0.2
$\sum$ charge = 0	29085.0	41.1	0.0	28962.4	29003.5	28962.4	0.0	0.2

Table: AB 24.2.41, g2tauntuplemaker v13 data23 HION4 and mc23. Signal region CR-2M-excl. Normalised to $\mathcal{L} = 1.669$ nb^{-1}.

Cutflow CR-$2e$ - STARLight

Requirement	Data 23	$\gamma\gamma \to \tau\tau$	$\gamma\gamma \to ee$	$\gamma\gamma \to \mu\mu$	Pred	B	S/B	$S/\sqrt{S+B}$
pass GRL	1489893.0	69313.0	670874.1	494220.9	1234408.0	1165095.0	0.1	62.4
HLT e- trigger	1090600.0	11238.0	174453.3	57731.4	243422.7	232184.7	0.0	22.8
$E_{\text{ZDC}}^{A,C} < 1$ TeV	532051.0	11238.0	174453.3	57731.4	243422.7	232184.7	0.0	22.8
$N_e^{\text{baseline}} = 2$	101774.0	481.5	79256.2	2.3	79740.1	79258.6	0.0	1.7
$N_e^{\text{sig}} = 2$	53516.0	51.9	45400.1	0.4	45452.3	45400.5	0.0	0.2
N_{trk} ($\Delta R > 0.1$ from e) $= 0$	52553.0	45.3	45325.8	0.0	45371.1	45325.8	0.0	0.2
$m_{ee} > 11$ GeV	23724.0	14.0	20575.6	0.0	20589.6	20575.6	0.0	0.1
$\sum$ charge = 0	23662.0	14.0	20515.2	0.0	20529.3	20515.2	0.0	0.1

Table: AB 24.2.41, g2tauntuplemaker v13 data23 HION4 and mc23. Signal region CR-2E-excl. Normalised to $\mathcal{L} = 1.669$ nb^{-1}.

SR-$1\mu1$T - STARLight

Requirement	Data 23	$\gamma\gamma \to \tau\tau$	$\gamma\gamma \to ee$	$\gamma\gamma \to \mu\mu$	Pred	B	S/B	$S/\sqrt{S+B}$
pass GRL	1489893.0	69313.0	670874.1	494220.9	1234408.0	1165095.0	0.1	62.4
HLT mu3 trigger	401729.0	1802.6	0.7	79164.4	80967.7	79165.1	0.0	6.3
$E_{\text{ZDC}}^{A,C} < 1$ TeV	109394.0	1802.6	0.7	79164.4	80967.7	79165.1	0.0	6.3
$N_{\mu}^{\text{baseline}} = 1$	32615.0	1654.5	0.7	6767.5	8422.7	6768.2	0.2	18.0
$N_{\mu}^{\text{sig}} = 1$	27287.0	1532.1	0.7	5224.3	6757.1	5225.0	0.3	18.6
$N_{e}^{\text{sig}} = 0$	27094.0	1469.5	0.0	5216.4	6685.9	5216.4	0.3	18.0
N_{trk} ($\Delta R > 0.1$ from μ) $= 1$	6307.0	942.8	0.0	3890.1	4832.9	3890.1	0.2	13.6
Veto unmatched clusters	4688.0	912.5	0.0	3690.1	4602.5	3690.1	0.2	13.5
$\sum$ charge = 0	4645.0	894.6	0.0	3683.9	4578.6	3683.9	0.2	13.2
$p_{\text{T}}^{(\mu,\text{trk})} > 1$ GeV	1378.0	836.7	0.0	389.2	1226.0	389.2	2.1	23.9
$p_{\text{T}}^{(\mu,\text{trk},\gamma)} > 1$ GeV	1088.0	785.2	0.0	230.6	1015.9	230.6	3.4	24.6
$p_{\text{T}}^{(\mu,\text{trk,cluster})} > 1$ GeV	992.0	744.9	0.0	205.7	950.7	205.7	3.6	24.2
$A_{\phi}^{\mu,\text{trk}} < 0.4$	942.0	744.9	0.0	205.4	950.4	205.4	3.6	24.2

Table: AB 24.2.41, g2tauntuplemaker v13 data23 HION4 and mc23. Signal region SR-1M1T-excl. Normalised to $\mathcal{L} = 1.669$ nb^{-1}.

SR-$1\mu3$T - STARLight

Requirement	Data 23	$\gamma\gamma \to \tau\tau$	$\gamma\gamma \to ee$	$\gamma\gamma \to \mu\mu$	Pred	B	S/B	$S/\sqrt{S+B}$
pass GRL	1489893.0	69313.0	670874.1	494220.9	1234408.0	1165095.0	0.1	62.4
HLT mu3 trigger	401729.0	1802.6	0.7	79164.4	80967.7	79165.1	0.0	6.3
$E_{\text{ZDC}}^{A,C} < 1$ TeV	109394.0	1802.6	0.7	79164.4	80967.7	79165.1	0.0	6.3
$N_{\mu}^{\text{baseline}} = 1$	32615.0	1654.5	0.7	6767.5	8422.7	6768.2	0.2	18.0
$N_{\mu}^{\text{sig}} = 1$	27287.0	1532.1	0.7	5224.3	6757.1	5225.0	0.3	18.6
$N_{e}^{\text{sig}} = 0$	27094.0	1469.5	0.0	5216.4	6685.9	5216.4	0.3	18.0
N_{trk} ($\Delta R > 0.1$ from μ) $= 3$	852.0	135.2	0.0	15.3	150.5	15.3	8.8	11.0
Veto unmatched clusters	257.0	131.8	0.0	14.9	146.7	14.9	8.8	10.9
$\sum$ charge = 0	212.0	127.3	0.0	14.7	142.1	14.7	8.6	10.7
$m_{\text{trks}} < 1.7$ GeV	137.0	122.8	0.0	5.0	127.8	5.0	24.5	10.9
$A_{\phi}^{\mu,\text{trks}} < 0.2$	135.0	122.8	0.0	5.0	127.8	5.0	24.5	10.9

Table: AB 24.2.41, g2tauntuplemaker v13 data23 HION4 and mc23. Signal region SR-1M3T-excl. Normalised to $\mathcal{L} = 1.669$ nb^{-1}.

SR-$1e1$T - STARLight

Requirement	Data 23	$\gamma\gamma \to \tau\tau$	$\gamma\gamma \to ee$	$\gamma\gamma \to \mu\mu$	Pred	B	S/B	$S/\sqrt{S+B}$
pass GRL	1489893.0	69313.0	670874.1	494220.9	1234408.0	1165095.0	0.1	62.4
HLT e- trigger	1090600.0	11238.0	174453.3	57731.4	243422.7	232184.7	0.0	22.8
$E_{\text{ZDC}}^{A,C} < 1$ TeV	532051.0	11238.0	174453.3	57731.4	243422.7	232184.7	0.0	22.8
$N_e^{\text{sig}} = 1$	104838.0	2224.2	59807.0	16.9	62048.0	59823.9	0.0	8.9
$N_\mu^{\text{sig}} = 0$	104623.0	2129.5	59806.7	0.3	61936.5	59807.0	0.0	8.6
N_{trk} ($\Delta R > 0.1$ from e) $= 1$	54392.0	1386.4	47395.3	0.0	48781.7	47395.3	0.0	6.3
Cluster veto	49162.0	1338.4	45883.2	0.0	47221.6	45883.2	0.0	6.2
$\sum$ charge = 0	48688.0	1331.7	45524.6	0.0	46856.2	45524.6	0.0	6.2
$p_{\text{T}}^{(e,\text{trk})} > 1$ GeV	28818.0	1226.9	26870.8	0.0	28097.7	26870.8	0.0	7.3
$p_{\text{T}}^{(e,\text{trk},\gamma)} > 1$ GeV	22024.0	1157.5	19380.8	0.0	20538.3	19380.8	0.1	8.1
$p_{\text{T}}^{(e,\text{trk,cluster})} > 1$ GeV	19225.0	1096.6	16863.5	0.0	17960.1	16863.5	0.1	8.2
$A_\phi^{e,\text{trk}} > 0.012$	2279.0	963.4	859.3	0.0	1822.7	859.3	1.1	22.6

Table: AB 24.2.41, g2tauntuplemaker v13 data23 HION4 and mc23. Signal region SR-1E1T-excl. Normalised to $\mathcal{L} = 1.669$ nb^{-1}.

SR-$1e3$T - STARLight

Requirement	Data 23	$\gamma\gamma \to \tau\tau$	$\gamma\gamma \to ee$	$\gamma\gamma \to \mu\mu$	Pred	B	S/B	$S/\sqrt{S+B}$
pass GRL	1489893.0	69313.0	670874.1	494220.9	1234408.0	1165095.0	0.1	62.4
HLT e- trigger	1090600.0	11238.0	174453.3	57731.4	243422.7	232184.7	0.0	22.8
$E_{\text{ZDC}}^{A,C} < 1$ TeV	532051.0	11238.0	174453.3	57731.4	243422.7	232184.7	0.0	22.8
$N_e^{\text{sig}} = 1$	104838.0	2224.2	59807.0	16.9	62048.0	59823.9	0.0	8.9
$N_\mu^{\text{sig}} = 0$	104623.0	2129.5	59806.7	0.3	61936.5	59807.0	0.0	8.6
N_{trk} ($\Delta R > 0.1$ from e) $= 3$	3238.0	207.7	107.9	0.0	315.6	107.9	1.9	11.7
Cluster veto	1043.0	202.5	104.3	0.0	306.8	104.3	1.9	11.6
$\sum$ charge = 0	846.0	195.7	100.6	0.0	296.4	100.6	1.9	11.4
$m_{\text{trks}} < 1.7$ GeV	466.0	192.3	78.1	0.0	270.4	78.1	2.5	11.7
$m_{\text{trks}} > 0.5$ GeV	392.0	192.3	40.9	0.0	233.2	40.9	4.7	12.6

Table: AB 24.2.41, g2tauntuplemaker v13 data23 HION4 and mc23. Signal region SR-1E3T-excl. Normalised to $\mathcal{L} = 1.669$ nb^{-1}.