A study of the measurement of the tau-lepton anomalous magnetic moment in high energy lead-lead collisions at LHC

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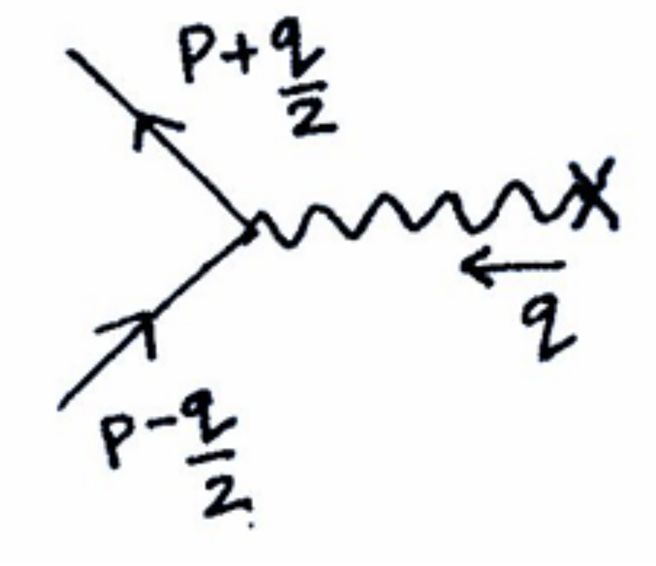
Outline

- Anomalous Magnetic Moment of the Tau Lepton
- Tau production at LHC with Pb-Pb collisions (nucleon-nucleon energy $\sqrt{s_{NN}} = 5.52\text{TeV}$)
- Analysis Strategy and results Phys. Rev. D 110, 052001 (2024)
  - Generation of standard model contribution + BSM and interference contributions (**different values of a_{tau}**)
  - Study of the sensitivity to atau using a multivariate approach and compare it with the ATLAS selection cuts analysis.
  - Comparison with LHC results of Run-2 data
    - Expect SM process to be low-mass, observation of $\gamma\gamma \rightarrow \tau\tau$ already performed in Heavy Ion (HI) collisions by both ATLAS [PRL 131 (2023) 151802] and CMS [PRL 131 (2023) 151803]



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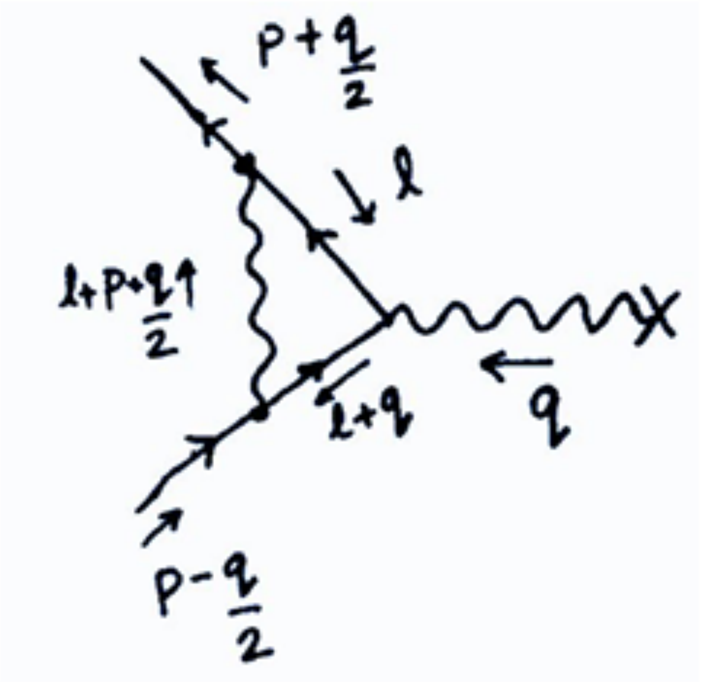

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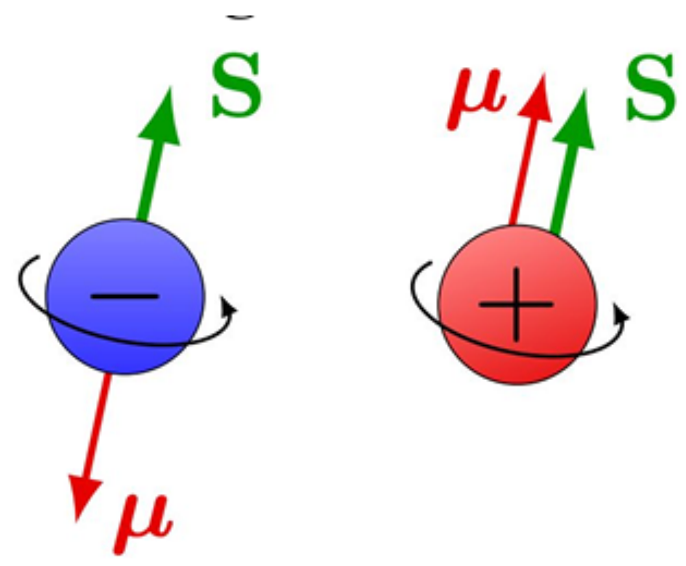
Magnetic Moment of Tau Lepton



$$\boldsymbol{\mu} = g\frac{e}{2m}\mathbf{S}$$

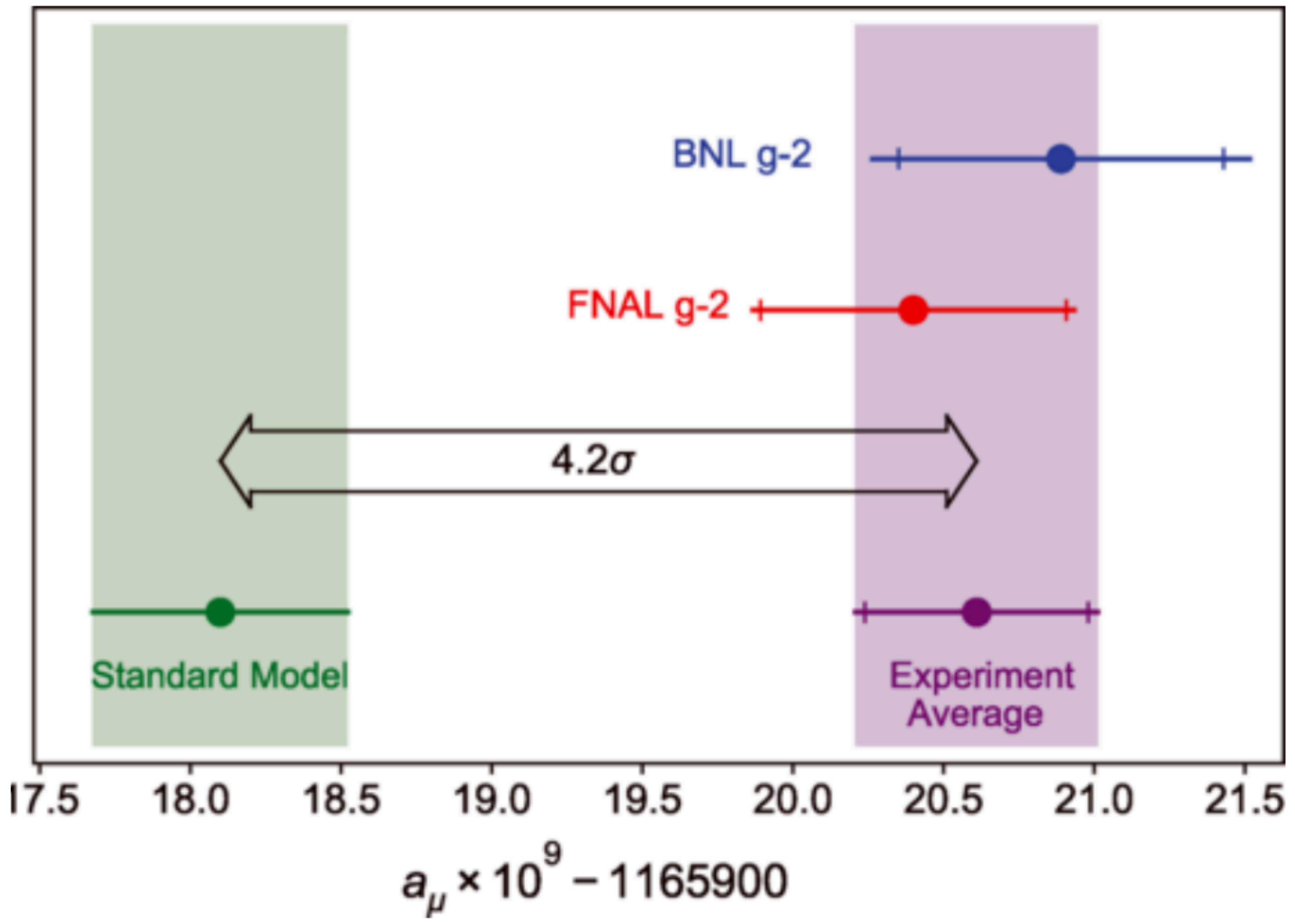
- Lepton spin, **S**, and magnetic moment, **μ**, linked through gyromagnetic factor, g
  - **Dirac equation predicts** $g = 2$
  - **Quantum corrections give rise to anomalous magnetic moments:**
    - $a_l = (g-2)/2$
- Electron and muon g-2 are some of the most precisely measured quantities in physics
  - Interesting tension between experiment and theory in muon g-2
- Tau g-2 evades precise measurement due to short tau lifetime
- **Standard Model prediction** (Mod. Phys. Lett. A 22 (2007) 159):

$a_\tau = 0.00117721 \pm 0.00000005$

- **Best experimental limits** on a_τ set by **DELPHI at LEP** (EPJ C 35 (2004) 159):

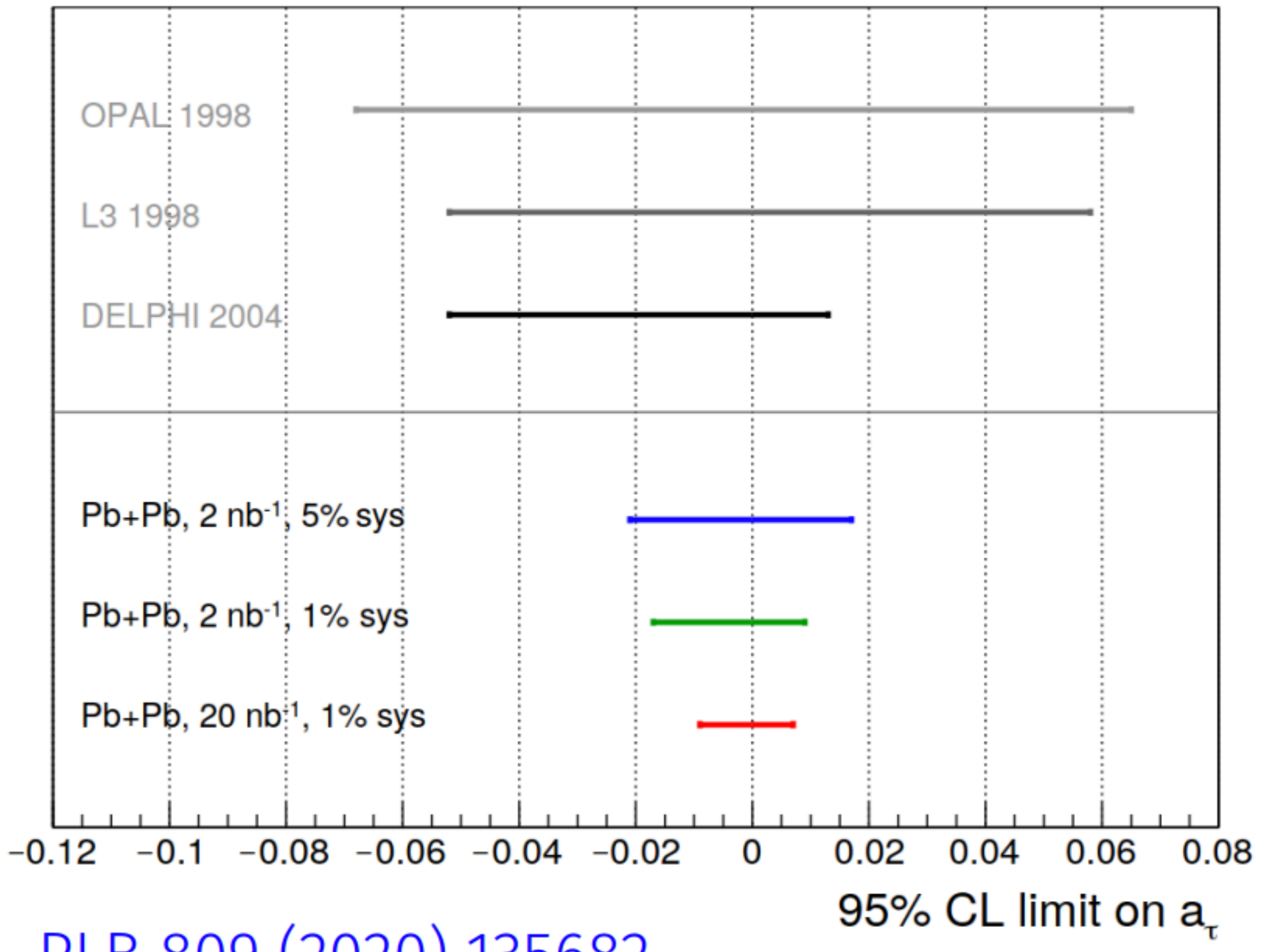
$-0.052 < a_\tau < 0.013$ (95% CL)

PhysRevLett.126.141801



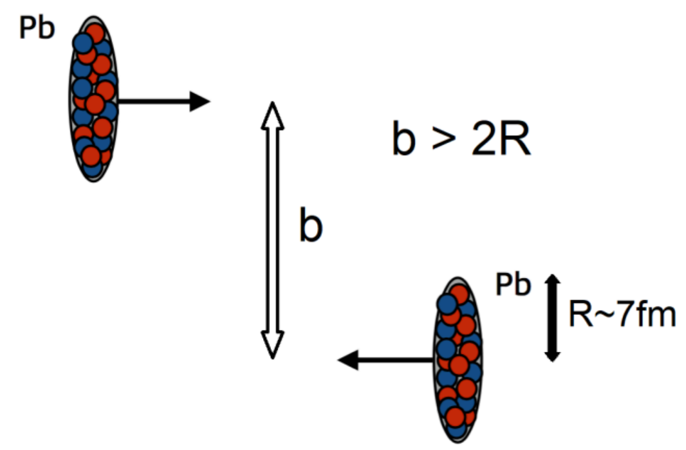
Motivation for a_{tau} measurement

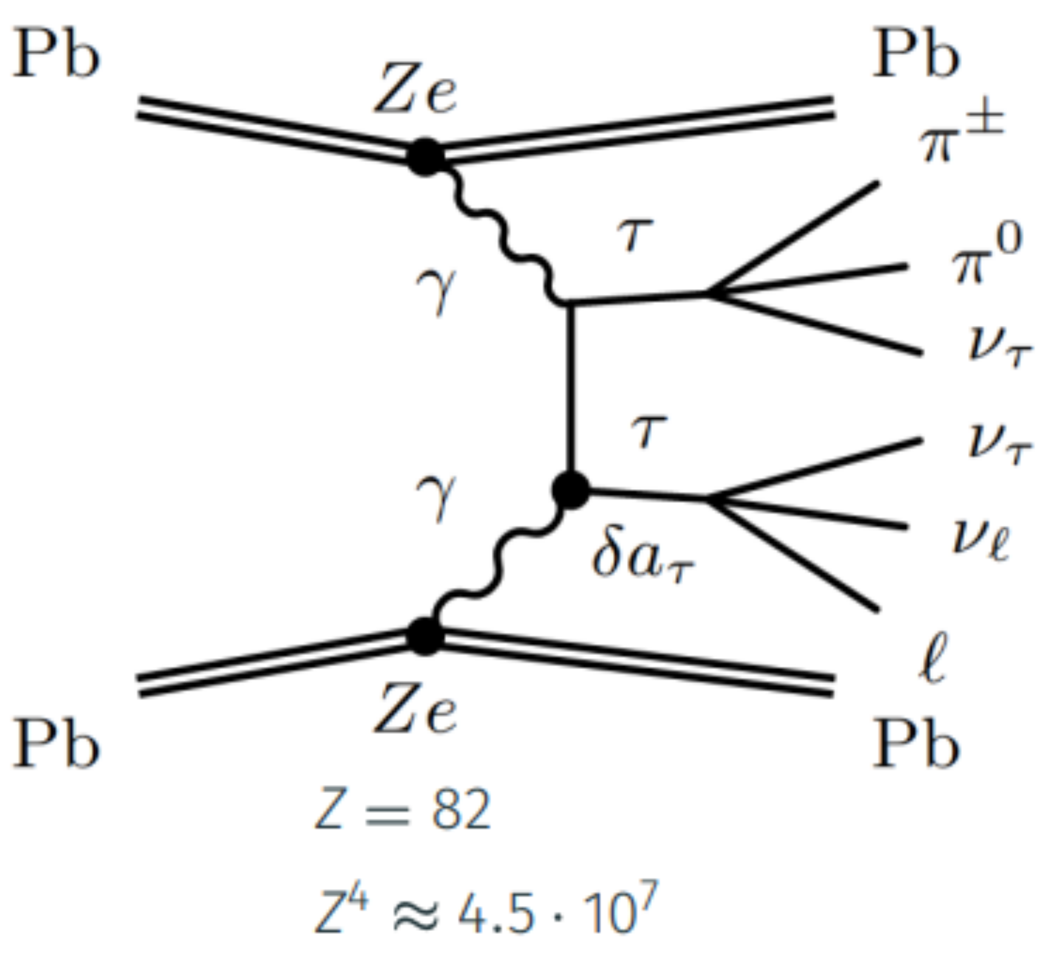
- Relevant for **precision measurement** of QED, electroweak, and QCD
- **Many BSM models predict modifications of a_τ:**
  - lepton compositeness where corrections are of $O(m_{lepton}/m_{constituent})$
  - SUSY models $O(\delta a_\tau \sim m^2_\tau/M^2_S)$
    - a_τ can be $m^2_\tau/m^2_\mu \approx 280$ times more sensitive to BSM than a_μ



PLB 809 (2020) 135682

- **Why Ultraperipheral Pb+Pb collisions at LHC?**
  - **Z^4 cross-section enhancement** balancing out lower luminosity
  - **essentially no pile-up** from hadronic interactions → exclusivity selections
  - **low trigger and reco object thresholds**





Constraining a_{tau} with LHC

- Analysis idea from:
  - L. Beresford, J. Liu, PRD 102 (2020) 113008
  - M. Dyndal, M. Schott, M. Klusek-Gawenda, A. Szczurek, PLB 809 (2020) 135682
- Constraints on a_τ from total $\gamma\gamma \rightarrow \tau\tau$ cross-section / yield and differential distributions (e.g. leading lepton p_T)
  - Main Background
    - $\gamma\gamma \rightarrow ll$
    - $\gamma\gamma \rightarrow qq$
    - photo-nuclear events

Work presented today

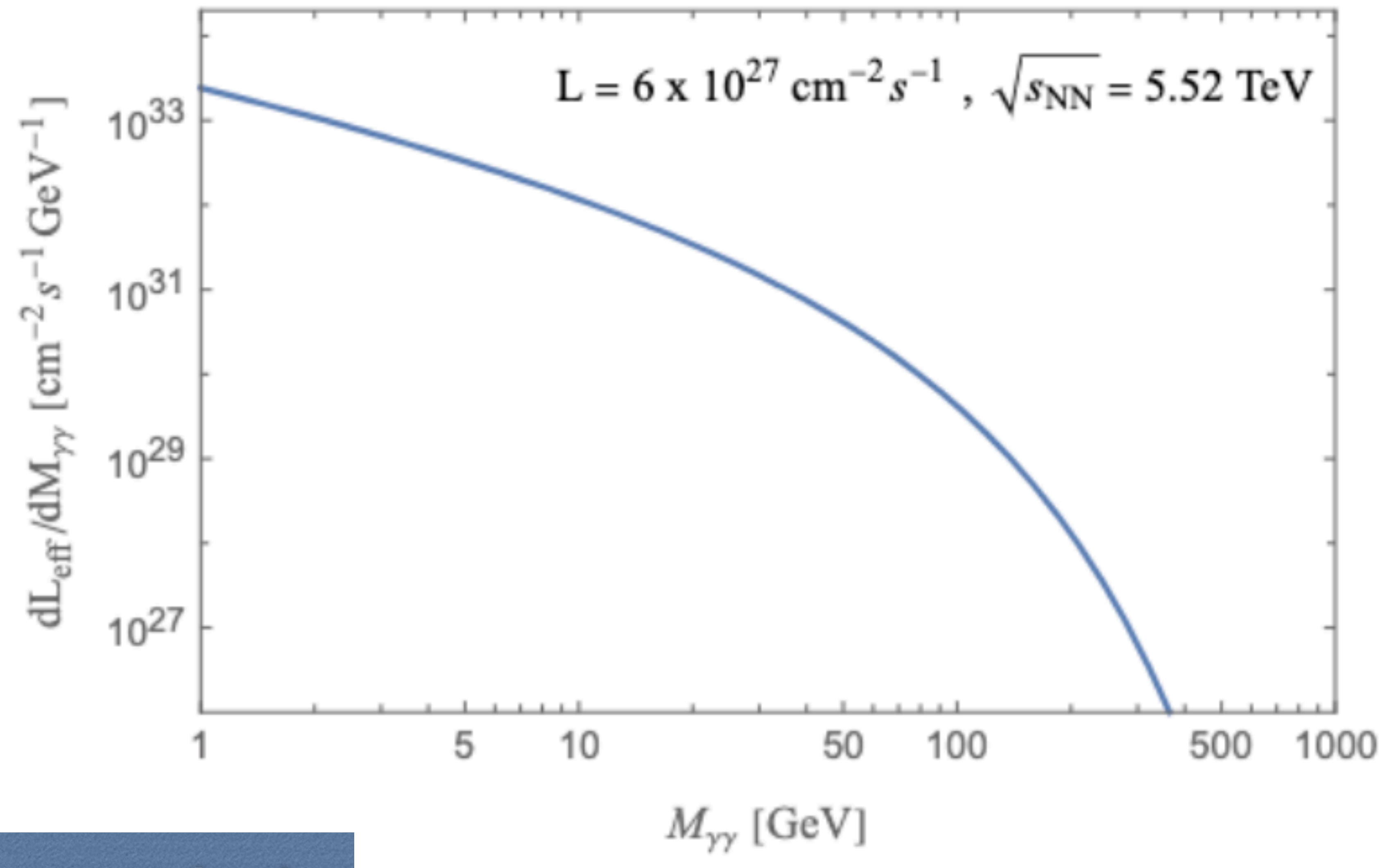
- Defined a dedicated Theory model
  - Generation, simulation and reconstruction of signal and background samples
- Signal and Control region definition common to other LHC analyses with heavy Ions
- Analysis Strategies:
  - Cut and Count approach by using the same cuts of ATLAS public Run2 data analysis **(SC)**
  - Multivariate Boost Decision Trees (BDTG) approach **(BDTG)**
  - Comparison of the two results and the ATLAS public results

The Theory Model

$$\mathcal{L}^{NP} = \frac{1}{2}\bar{\tau}_L \sigma^{\mu\nu}\left(a_\tau \frac{e}{2m_\tau} - i d_\tau \gamma_5\right)\tau_R F_{\mu\nu}$$

$$\sigma^{(Pb-Pb)}(\gamma\gamma \to \tau^+\tau^-) = \int dx_1 dx_2 N(x_1) N(x_2) \hat{\sigma}(\gamma\gamma \to \tau^+\tau^-)$$

- Tau−pair signal production is generated with an effective description in a UFO model (Universal FeynRules Output)
- Madgraph UFO model validated against theoretical analytical predictions (Landini and Jinwei Wang)
- Photon flux with EPA (equivalent photon approximation)
  - validated it against the results for the photon-photon luminosity quoted in 0909.3047 and the SM results in 1908.05180



Comparison with other models

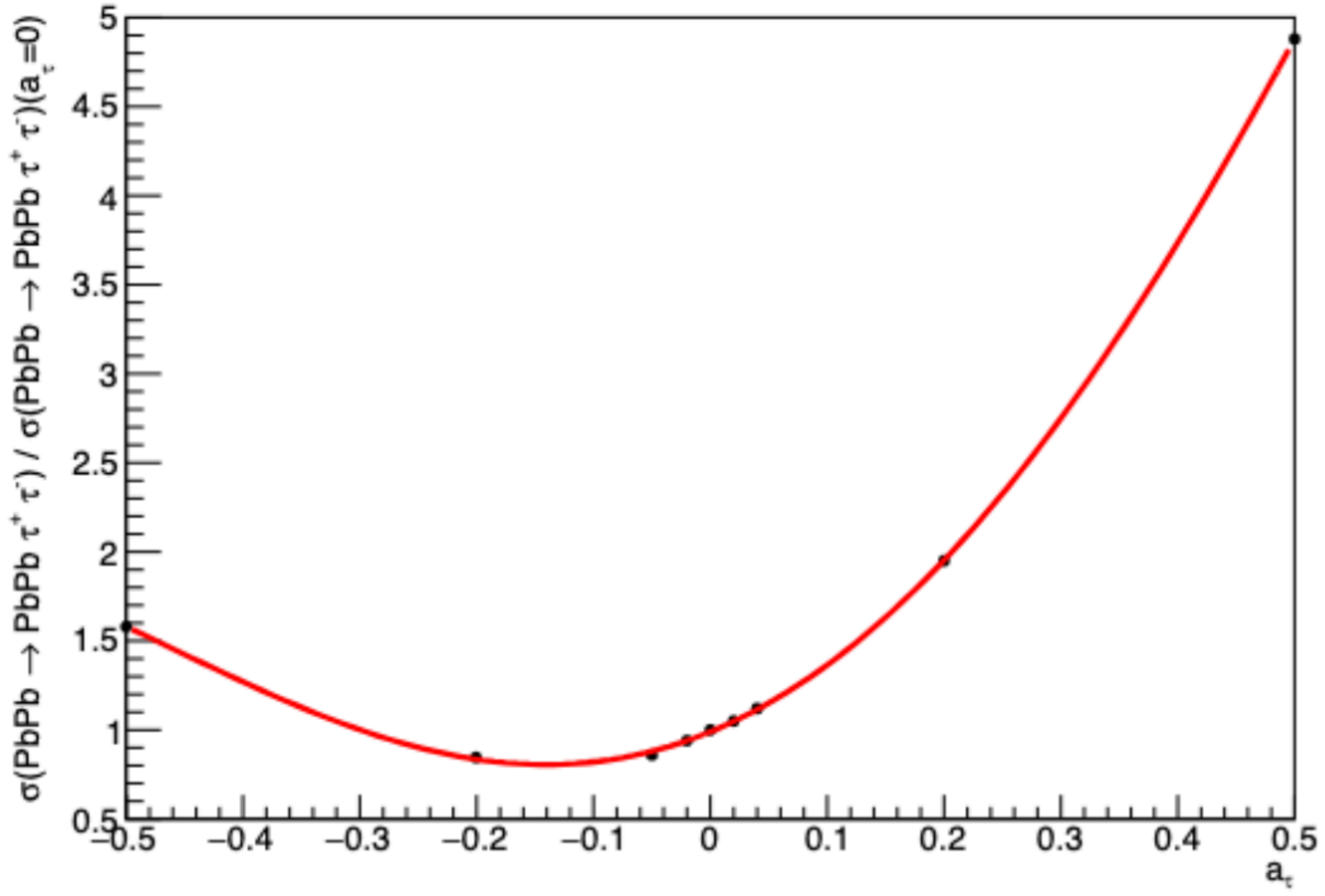
- L. Beresford, J. Liu, PRD 102 (2020) 113008
  - Same implementation of photon flux with Madgraph but different UFO model (SMEFT)
  - A factor 2 of difference (same factor found by Dyndal et al.)

- M. Dyndal, et al. PLB 809 (2020) 135682
  - Different photo flux and BSM implementation
  - Agreement within 10%

MonteCarlo Studies

- Generation of standard model contribution + BSM and interference contributions (**different values of a_{tau}**) by using MadGraph only (v3.3). The BSM contribution is added by using UFO Model. The τ decays, the hadronization and the shower processes are described with PYTHIA8
- Two Million of events per each sample
  - A generation preselection applied at leptons
    - $|\eta^{e/\mu}|<2.5$
    - $p_T^{\,lepton} > 1$ GeV
  - The Photon flux used includes photon from lead

Sample	Cross Section (pb)	events@2nb^{-1}
SM $(a_\tau = 0)$	$5.49 \times 10^8 \pm 1.7 \times 10^5$	1111111
SM+BSM $(a_\tau = +0.02)$	$5.79 \times 10^8 \pm 1.9 \times 10^5$	1176470
SM+BSM $(a_\tau = -0.02)$	$5.22 \times 10^8 \pm 1.8 \times 10^5$	1052631
SM+BSM $(a_\tau = -0.01)$	$5.35 \times 10^8 \pm 1.7 \times 10^5$	1081081
SM+BSM $(a_\tau = +0.01)$	$5.64 \times 10^8 \pm 1.8 \times 10^5$	1142857
SM+BSM $(a_\tau = -0.04)$	$4.99 \times 10^8 \pm 1.6 \times 10^5$	998000
SM+BSM $(a_\tau = +0.04)$	$6.12 \times 10^8 \pm 1.9 \times 10^5$	1212121
$\gamma\gamma \to e^-e^+$	$4.258 \times 10^8 \pm 1.8 \times 10^8$	869565
$\gamma\gamma \to \mu^-\mu^+$	$4.258 \times 10^8 \pm 1.8 \times 10^8$	869565
$\gamma\gamma \to bb$	$1.629 \times 10^6 \pm 2,3 \times 10^2$	3257
$\gamma\gamma \to cc$	$3.276 \times 10^6 \pm 1.3 \times 10^5$	6557
$\gamma\gamma \to jet(c,d,u)jet(c,d,u)$	$3.686 \times 10^6 \pm 1.5 \times 10^5$	7380



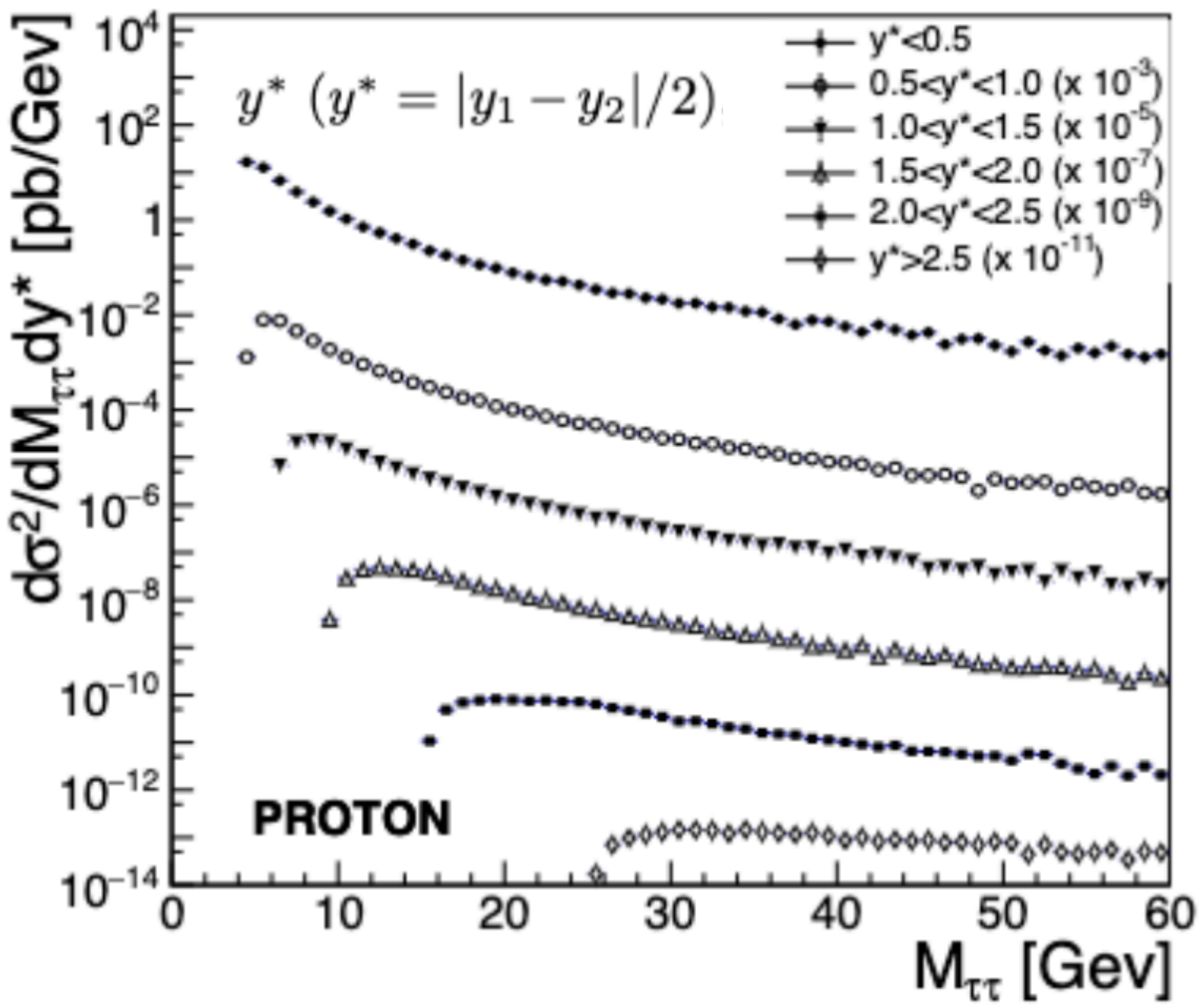
Ratio between the total nuclear cross sections for PbPb-> PbPb$\tau\tau$ production at the LHC energies as a function of a_{tau} and the cross section SM (a_{tau} = 0). At generation level a cut on lepton p_T >1 GeV is applied.

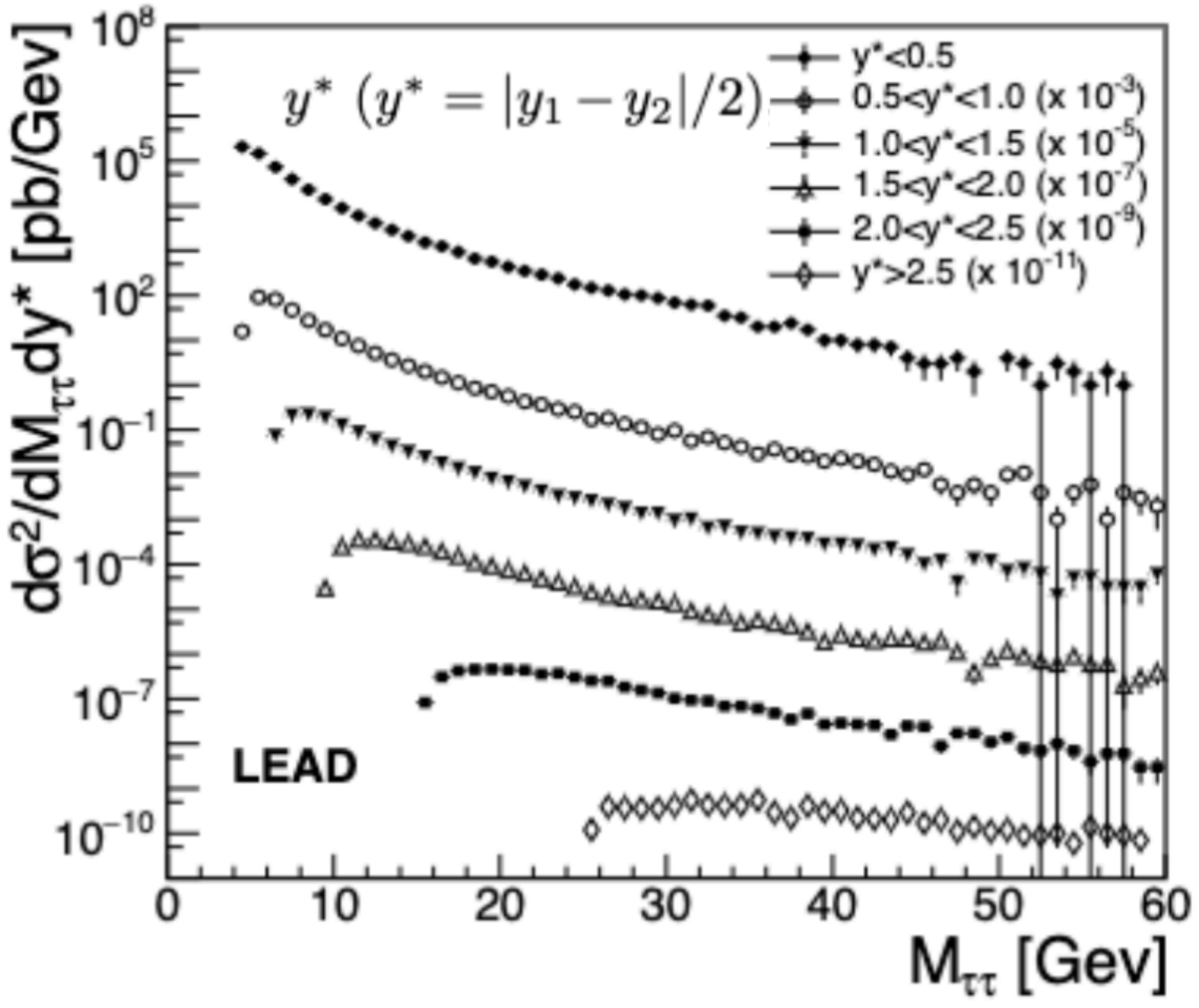
Photon Flux

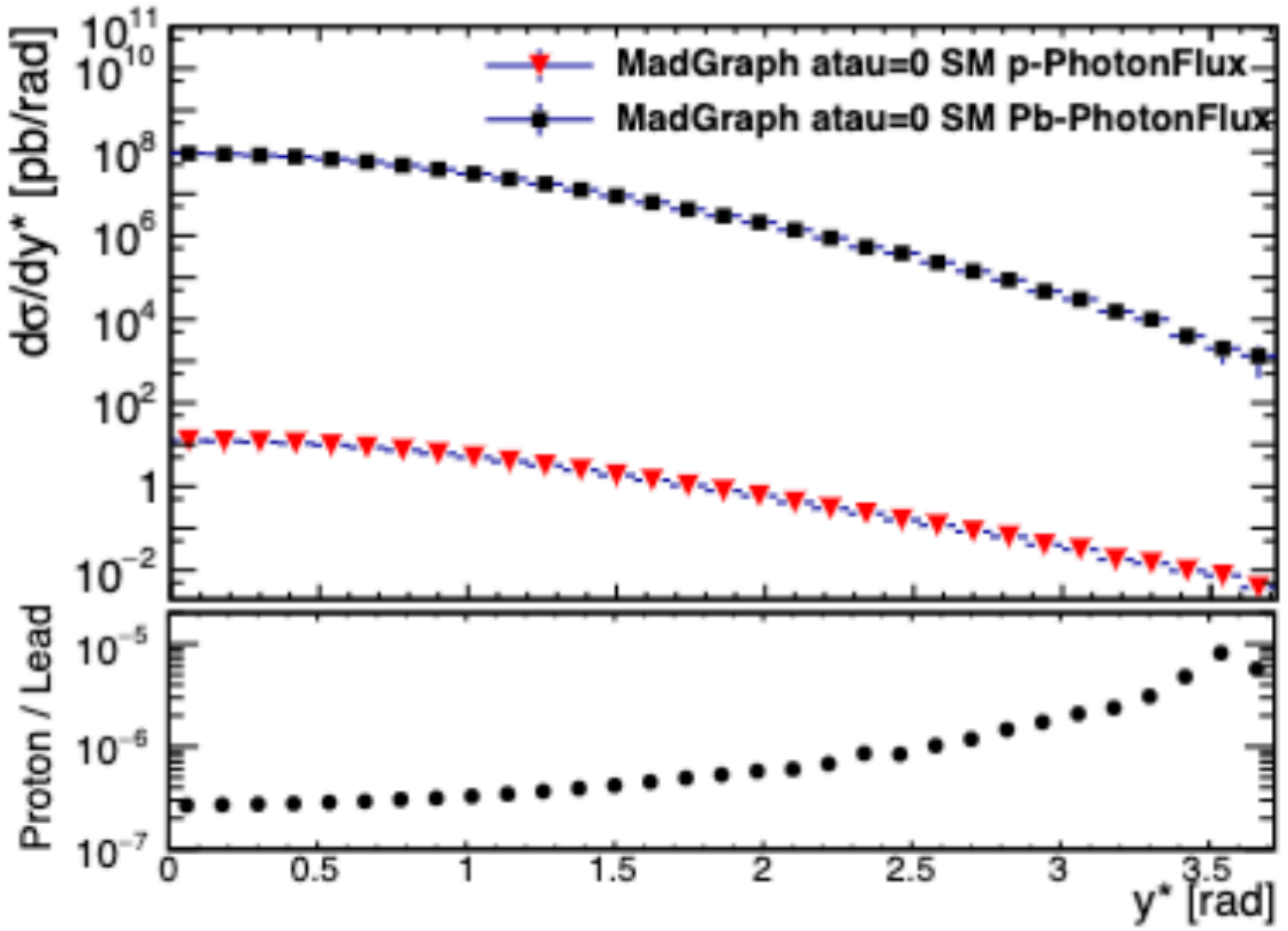
- We studied the differential cross section wrt P_T and rapidity/theta of the two taus to disentangle the two PDF. This is how MadGraph treats the Photon Flux:

$$\sigma^{(\mathrm{PbPb})}_{\gamma\gamma\to XX} = \int \mathrm{d}x_1 \mathrm{d}x_2\, n(x_1) n(x_2)\, \sigma_{\gamma\gamma\to XX}$$

- We compare the shapes (normalising the distribution to same area) and then we estimate the cross section depending of Y* and M(tau tau)

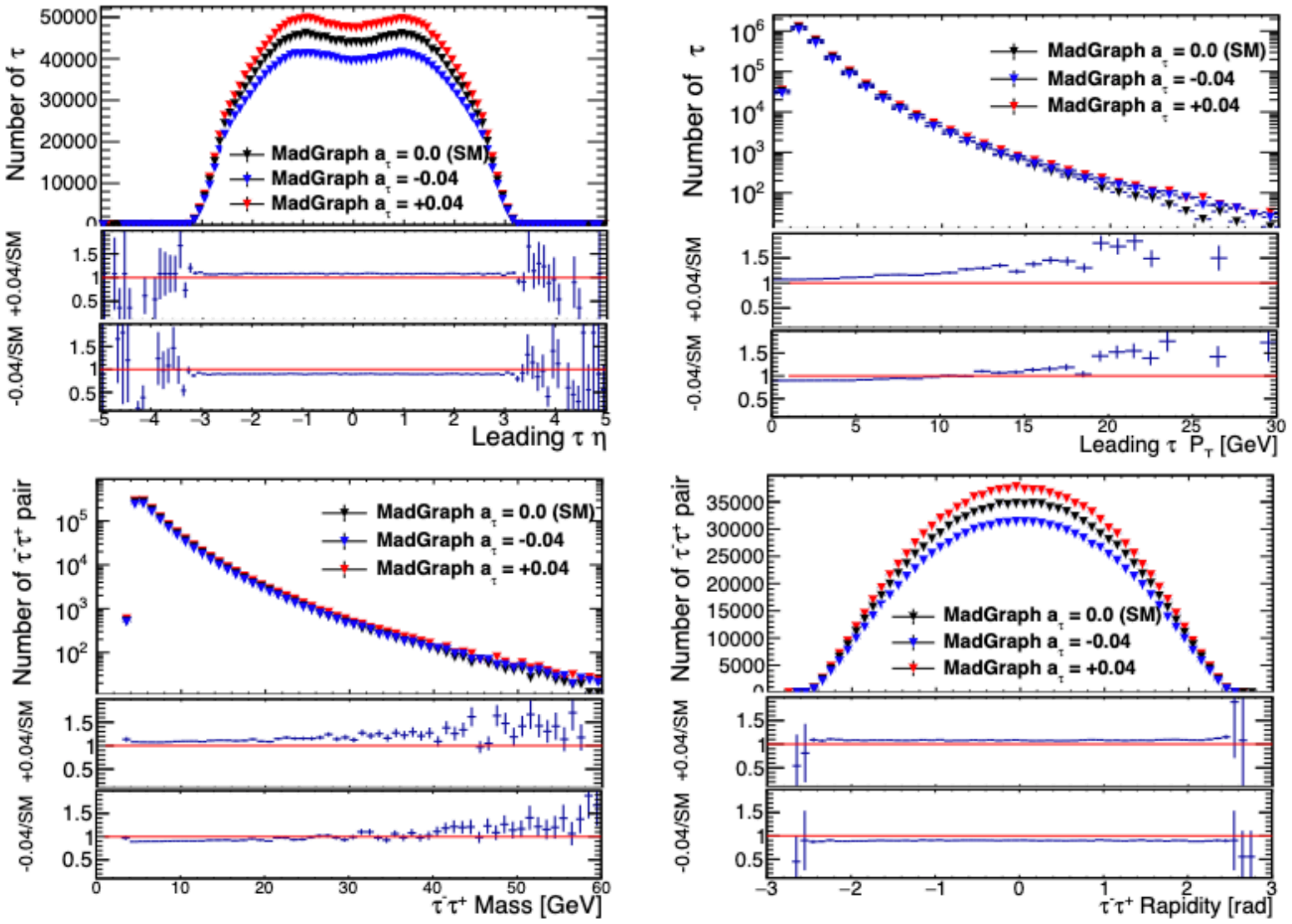






a_{tau} studies at generator level

- The effect of a_{tau} is investigated by looking at some tau and di-tau kinematical variables:
  - leading tau p_T and eta
  - di-tau invariant mass and rapidity of the di-tau system.
- Plots normalised to 2.0 nb^{-1}
- Here illustrated the differences between +0.04, -0.04 and the SM value set to 0



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Detector Simulation: Delphes

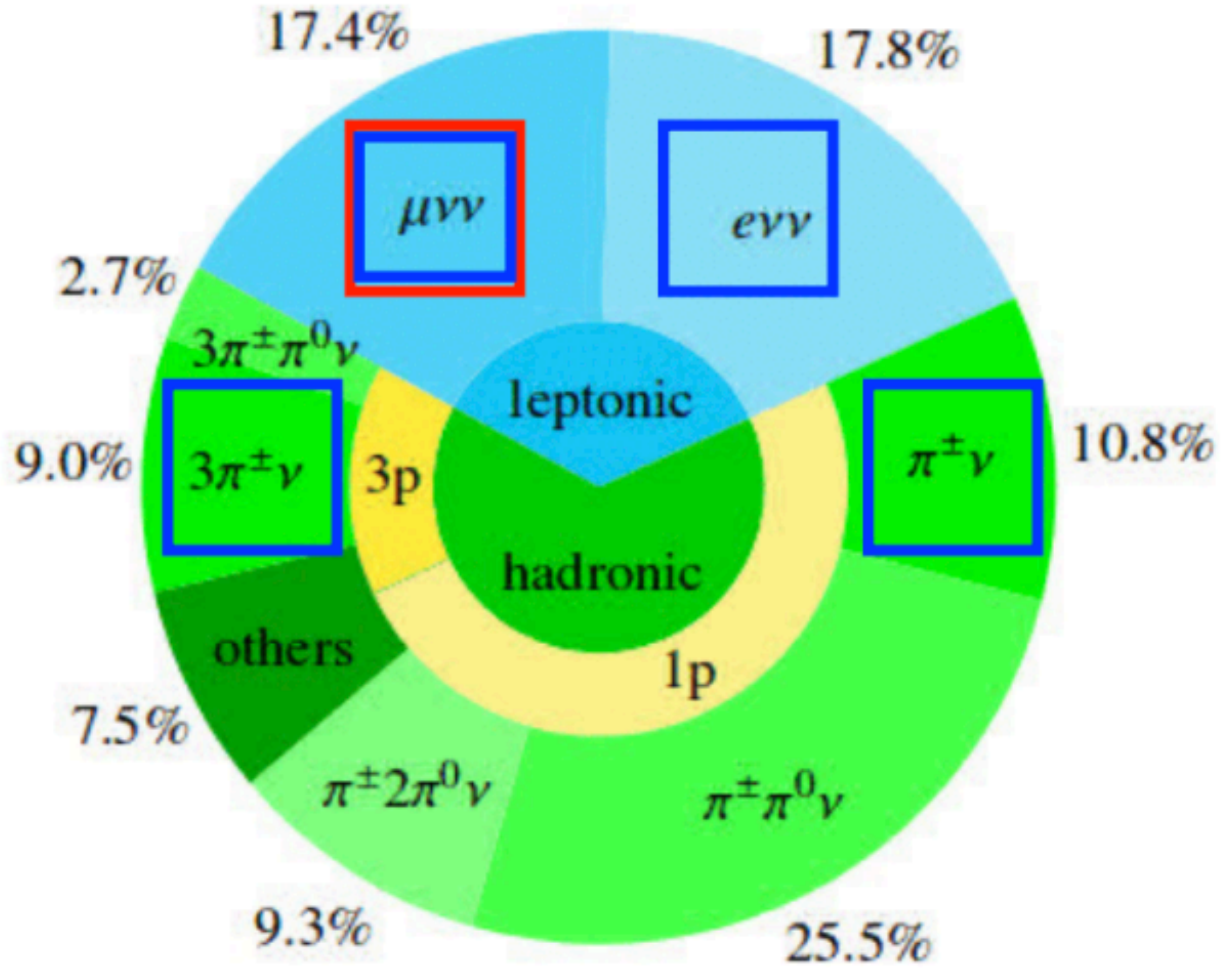
- Reconstruction Objects identified by DELPHES
  - Tracks, Muon, Electron,MissingET (Missing ET used as default calculation (calo tower calculation))
- Preselection in Lepton and Track Identification applied to all the objects.
  - **1 Lepton selection:**
    - $p_T^{e/\mu} > 4.5/3$ GeV, $|\eta^{e/\mu}| < 2.5/2.4$
  - **Tracks selection:**
    - $p_T^{track} > 0.5$ GeV, $|\eta^{track}| < 2.5$
    - Track not matched Lepton object ΔR(lepton-track)>0.02

Particle	η and p_T [GeV]	Efficiency [ϵ]
Electron	$\|\eta\| > 2.4$ and $p_T <= 4.5$	0.00
	$\|\eta\| <= 2.4$ and $4.5 > p_T < 30.0$	0.82
	$\|\eta\| <= 2.4$ and $30.0 > p_T < 40.0$	0.86
	$\|\eta\| <= 2.4$ and $40.0 > p_T <= 60.0$	0.88
	$\|\eta\| <= 2.4$ and $p_T > 60.0$	0.92
Muon	$p_T <= 3.5$ GeV	0.00
	$\|\eta\| <= 2.5$ and $3.5 > p_T < 4.0$	0.65
	$\|\eta\| <= 2.5$ and $4.0 > p_T < 5.0$	0.80
	$\|\eta\| <= 2.5$ and $p_T > 5.0$	0.95

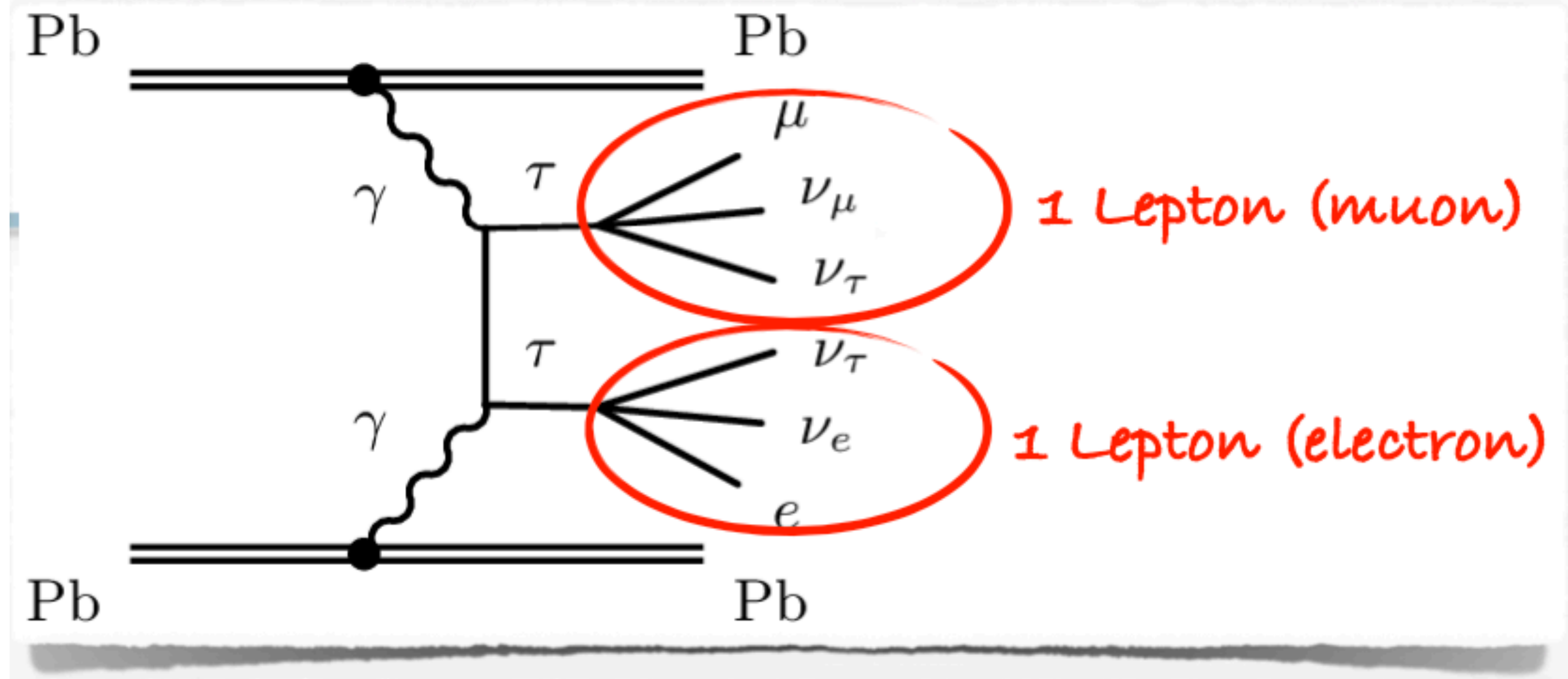
Preselection	Cuts
Electron Identification	$p_T > 4.5$ GeV, $\|\eta\| < 2.4$
Muon Identification	$p_T > 3.5$ GeV, $\|\eta\| < 2.5$
Track Identification	$p_T^{(track)} > 500$ MeV, $\|\eta^{(track)} > \| < 2.5$

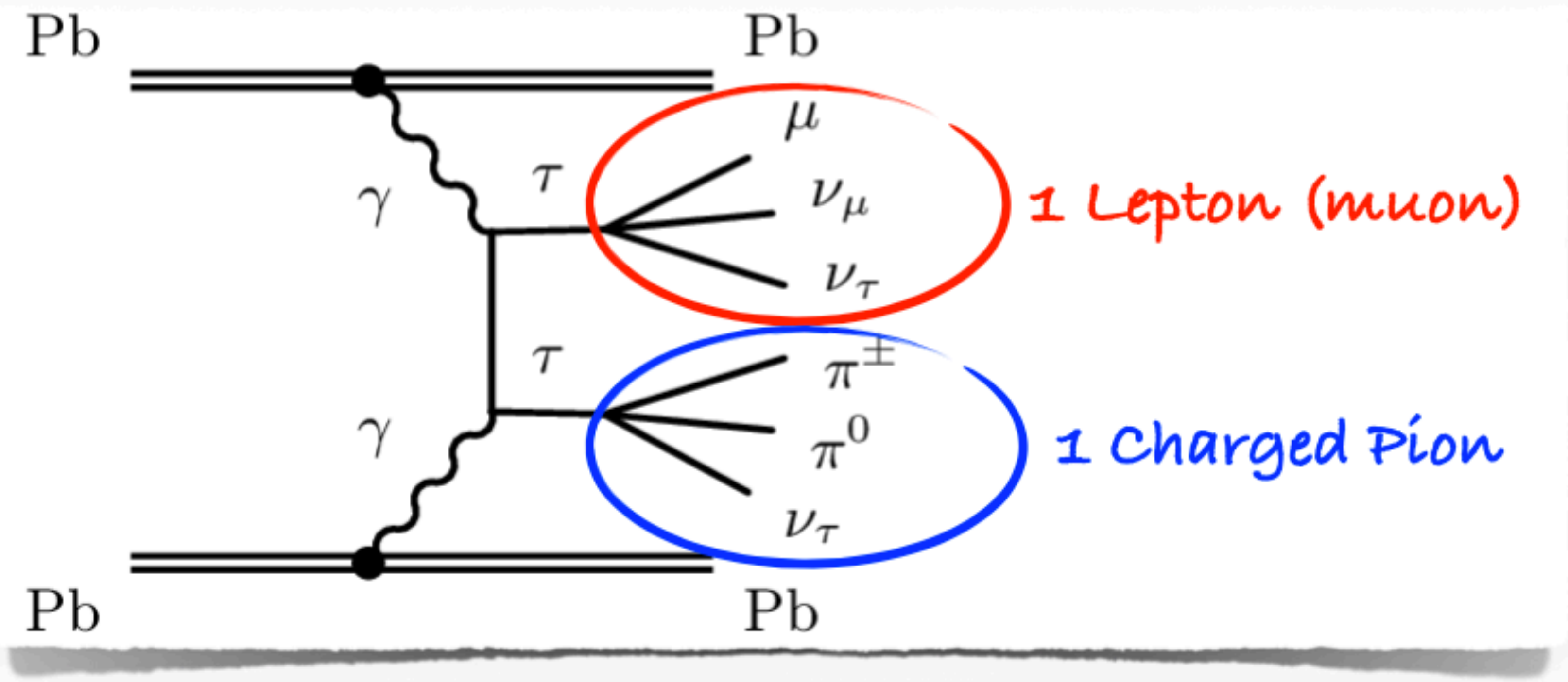
Tau Decays Topologies

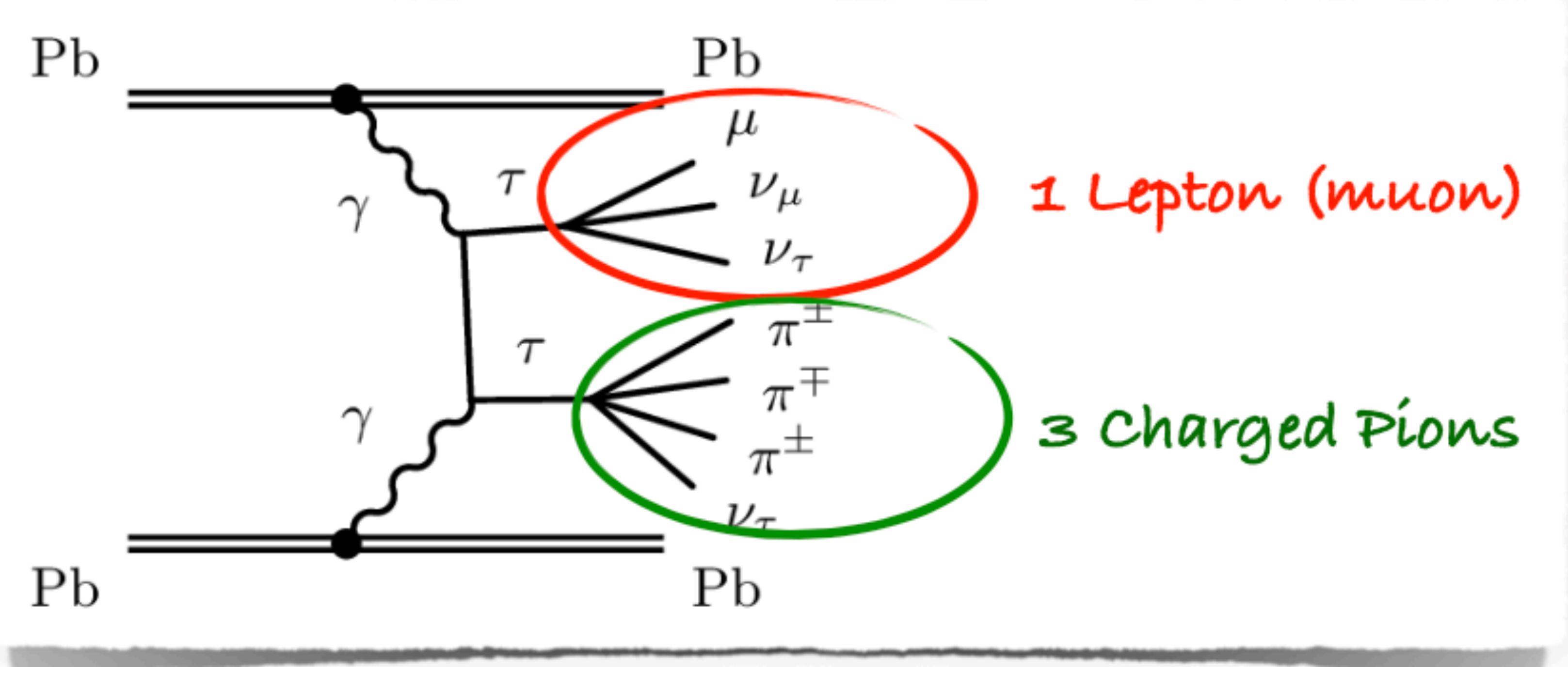
- Each tau can decay in hadrons or in leptons with different branching ratios (BRs).
  - **1 Lepton**
    - $\tau^{\pm} \rightarrow \nu_{\tau} + l^{\pm} + \nu_{l}\ (l = e, \mu)$
    - BR = 35%
  - **1 Charged Pion**
    - $\tau^{\pm} \rightarrow \nu_{\tau} + \pi^{\pm} + n\pi^{0}$
    - BR = 45.6%
  - **3 Charged Pions**
    - $\tau^{\pm} \rightarrow \nu_{\tau} + \pi^{\pm} + \pi^{\mp} + \pi^{\pm} + n\pi^{0}$
    - BR = 19.4%



- Categorise di-taus in two SR:
  - **1L1T (1Lepton+1Pion)**
  - **1L3T (1Lepton+3Pions)**
- **Control region 2MCR:** Events with 2 muons with invariant mass above 11 GeV to suppress quarkonia states and no additional tracks



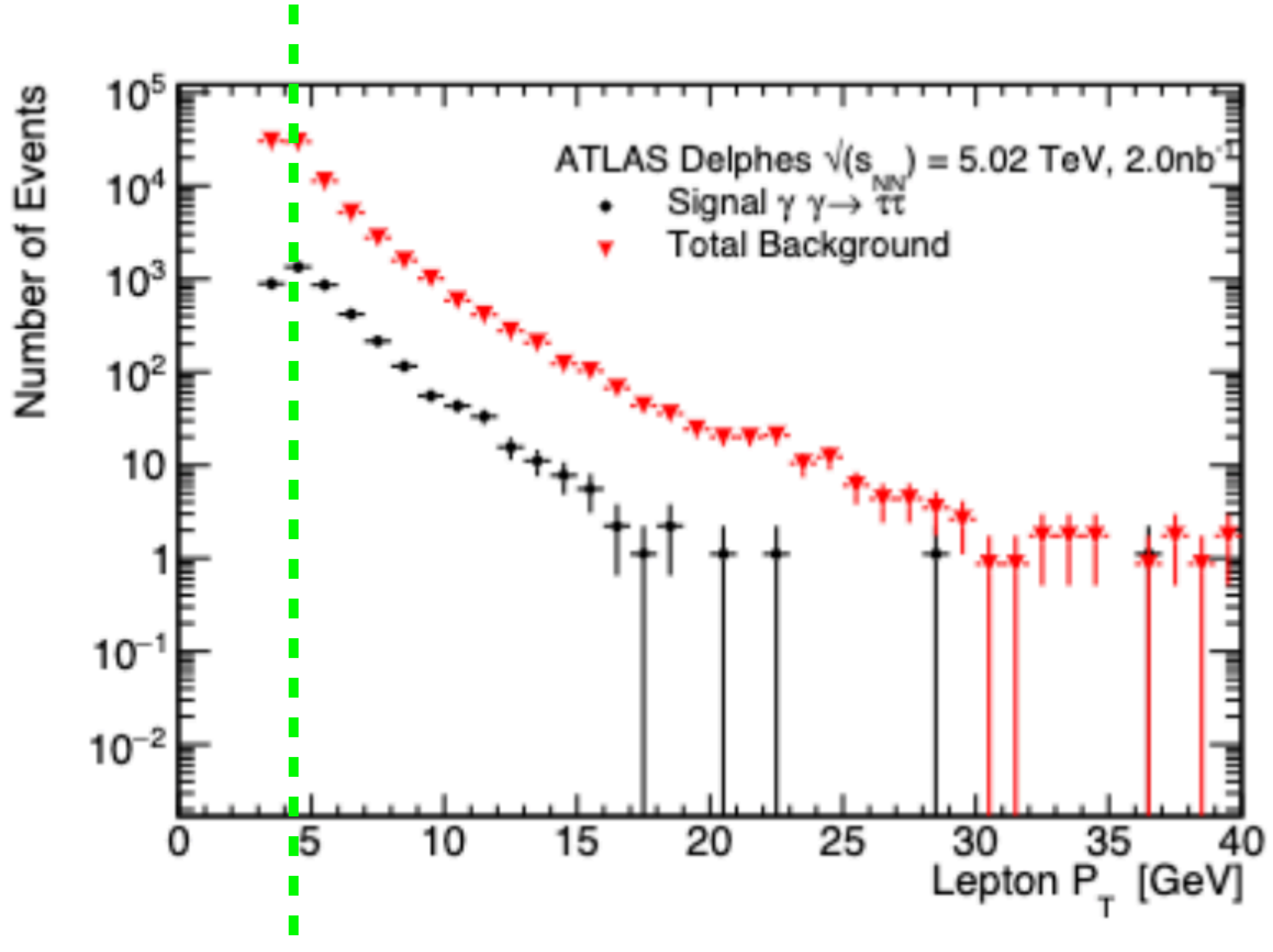


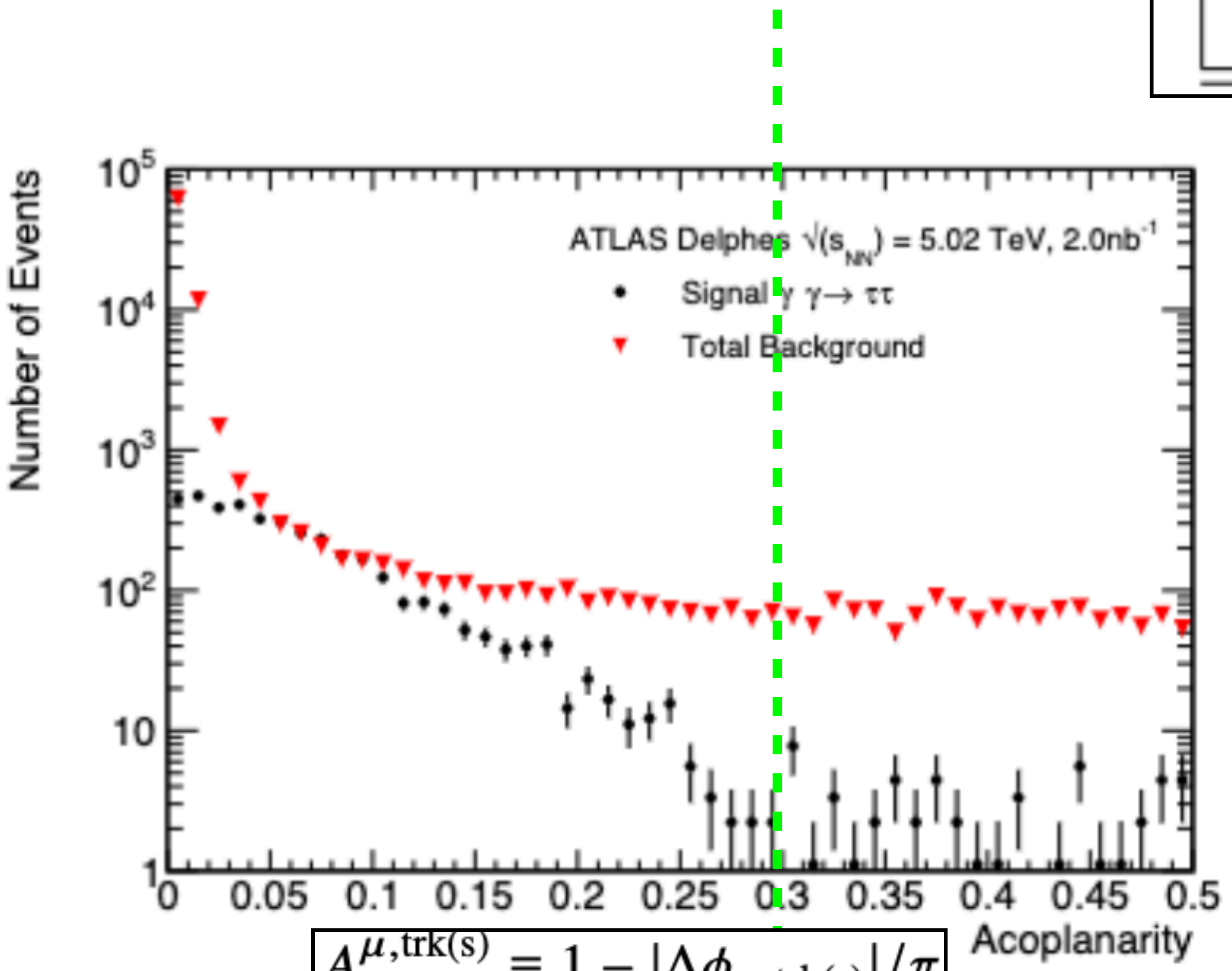


1 Lepton + One Track: SC

- **After the Preselection (1 Lepton and 1 Track)**
  - Total **Charge of track+ lepton equal to zero**
  - **Acoplanarity<0.4:** used in data analysis, reduce background from $\gamma\gamma \rightarrow \mu\mu$ and $\gamma\gamma \rightarrow ee$
  - **Muon p_T >4 GeV**: all the lepton with the same efficiency

Signal Region 1 Lepton and 1 Track (SR1L1T)
1 Lepton
1 Track
$\text{Charge}_{1L1T} = 0$
acoplanarity<0.4
p_T^{Muon} >4GeV





$$A_\phi^{\mu,\text{trk(s)}} \equiv 1 - |\Delta\phi_{\mu,\text{trk(s)}}|/\pi$$

SC Strategy

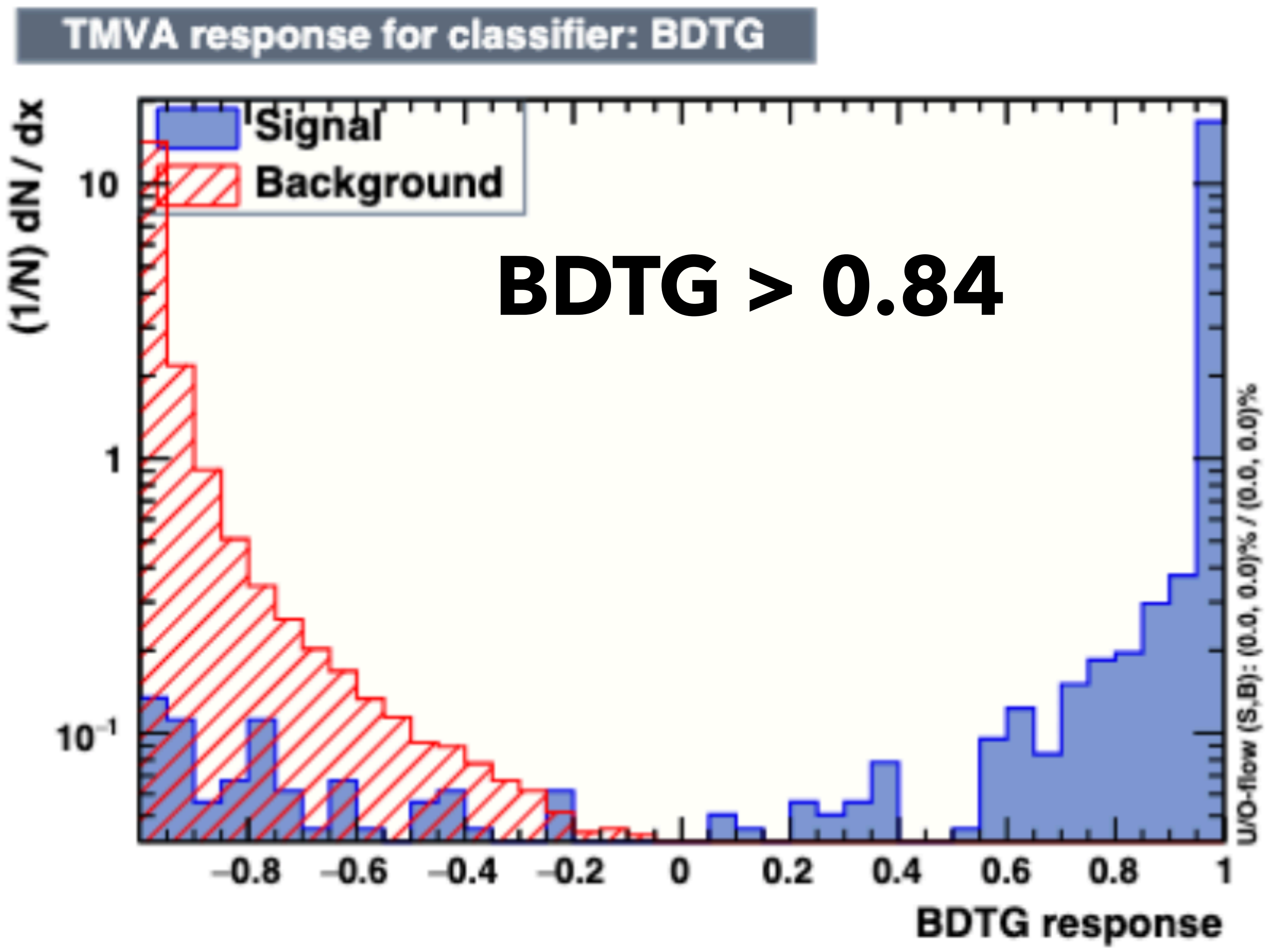
1) Standard Cuts SC (same cuts applied in ATLAS) but on Delphes samples

1 Lepton + One Track: BDTG

BDTG Strategy
1) Multivariate analysis with BDTG on Delphes samples

- **After the Preselection (requiring 1 Lepton and 1 Track) we apply a BDTG analysis using the following observable**

SR 1 Lepton and 1 Track SR1L1T
ϕ – MissingE$_T$
Track η
Lepton ϕ
Lepton η
Missing E_T
Acoplanarity
Track P_T
Invariant Mass (Lepton+Track)
Δ R (Lepton-Track)
Lepton P_T
$\Delta\phi$ (Lepton-track)
H_T $(\sum_i |\vec{p}_T(i)|)$

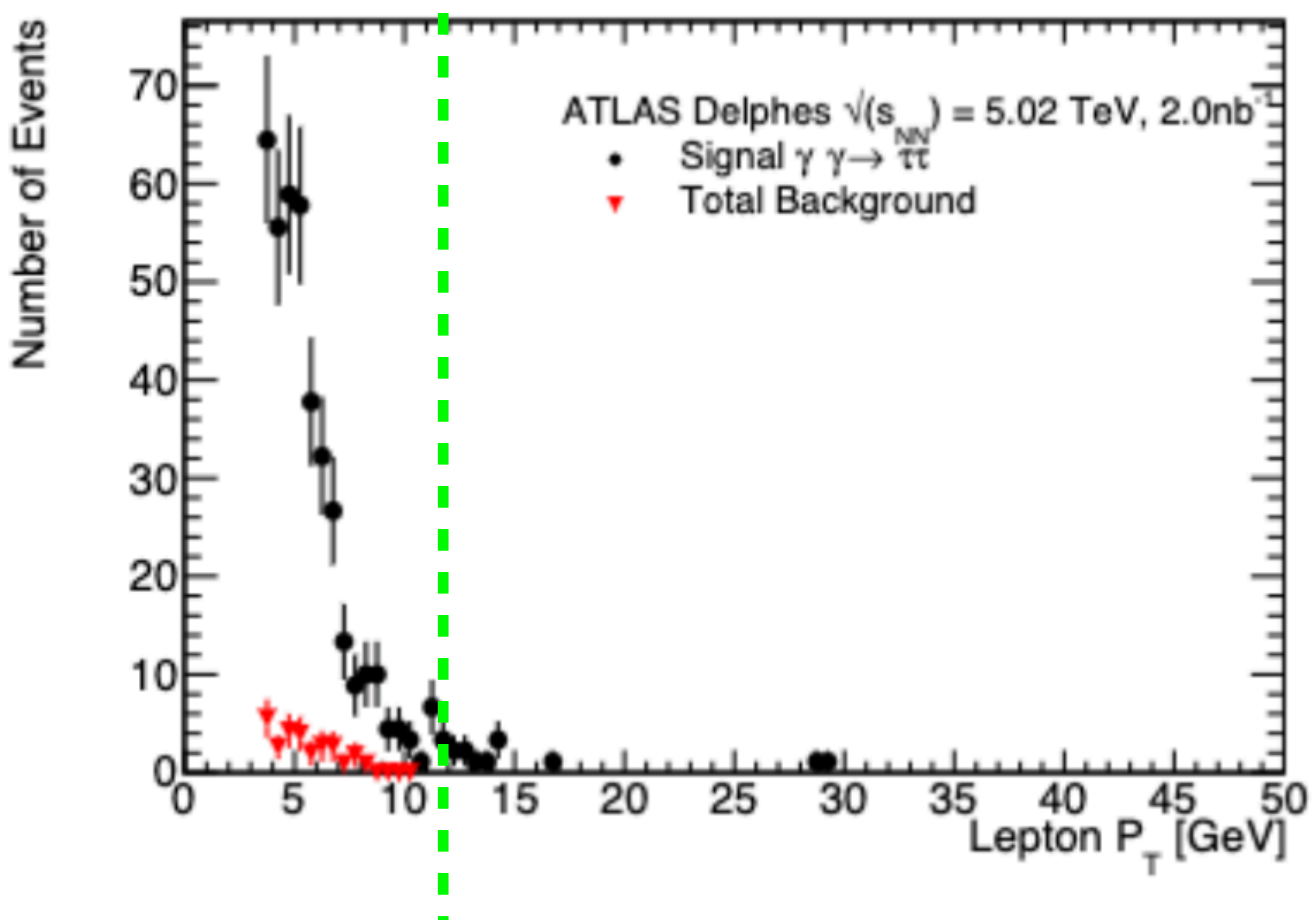


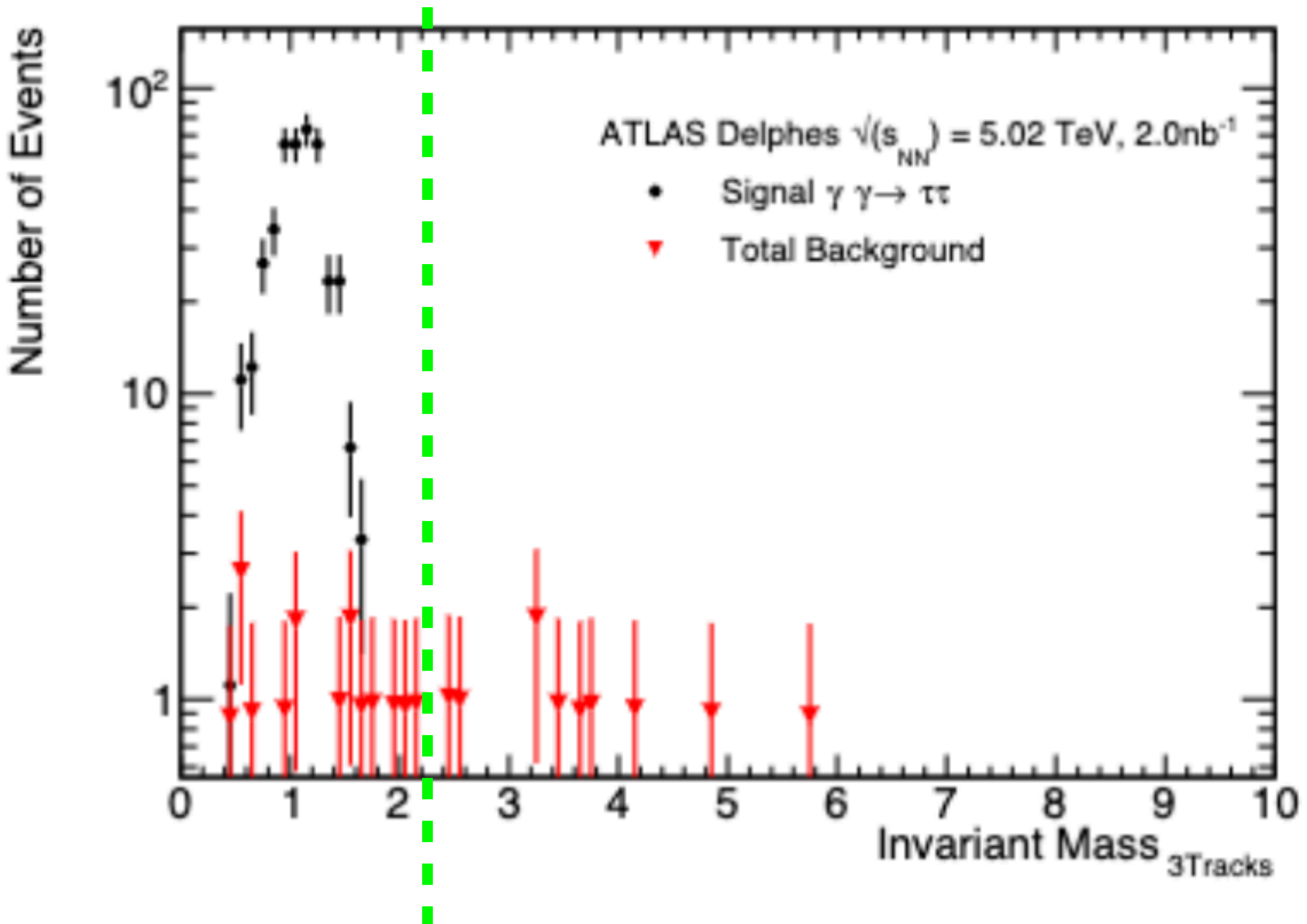
Best Significance S/sqrt(S+B)	SR 1L1T
27	Cut and Count up to muon p_T
58	BDTG >0.84

1 Lepton + Three Tracks: SC

- **After the Preselection (1 Lepton and 3 Tracks):**
  - **Total Charge of track+ lepton equal to zero**
  - **Mass (3Tracks)**: cut included in other analysis
  - **Acoplanarity<0.2**: used in data analysis, very similar to the Δϕ cut
  - **Muon p_T >4 GeV**: all the lepton with the same effi ciency

Signal Region 1 Lepton and 3 Track (SR1L3T)
1 Lepton
3 Tracks
$\text{Charge}_{1L3T} = 0$
$\text{Mass}_{3T} < 1.7\text{GeV}$
acoplanarity<0.2
$p_T^{Muon} > 4\text{GeV}$





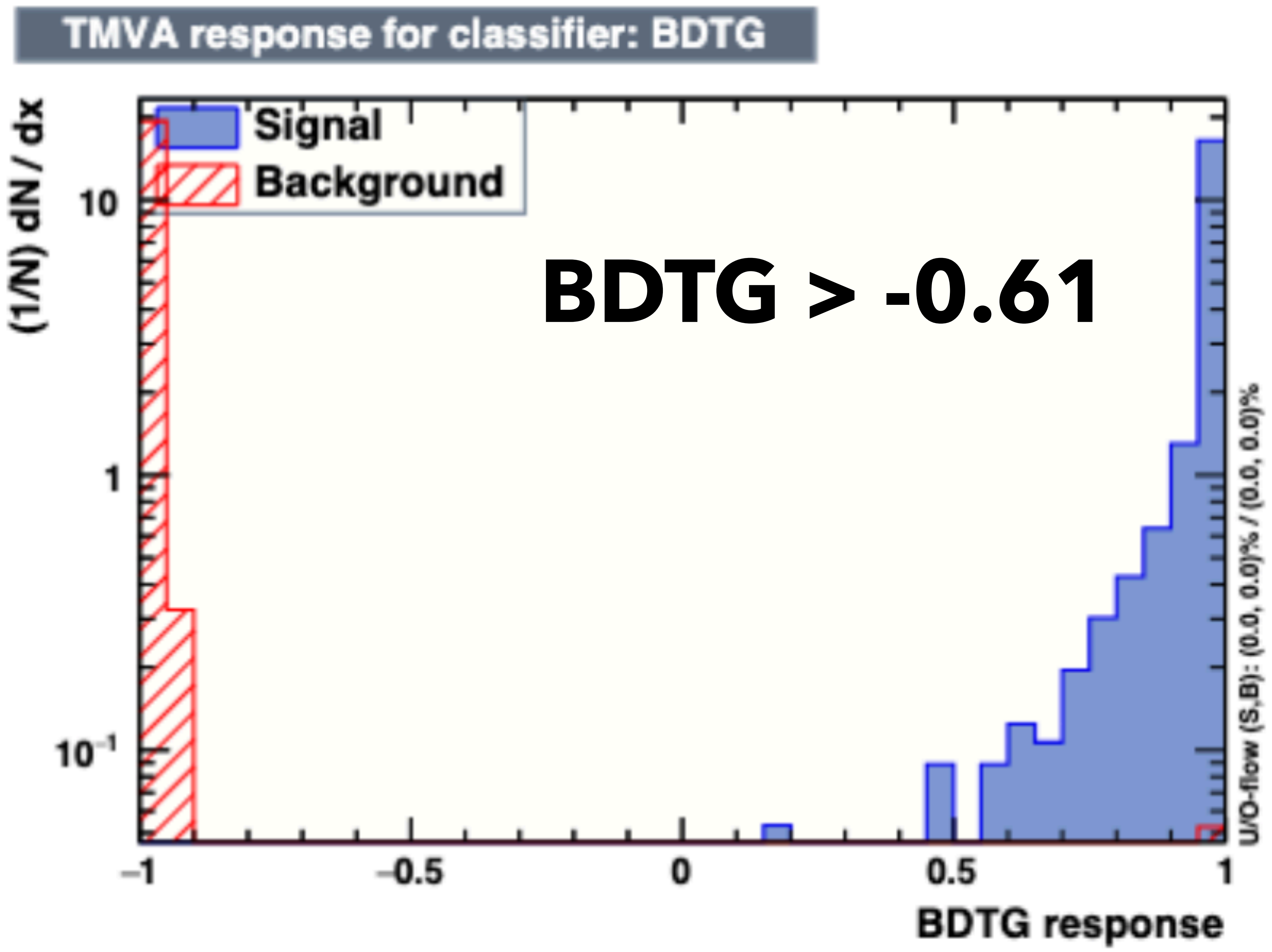
SC Strategy
1) Standard Cuts SC (same cuts applied in ATLAS) but on Delphes samples

1 Lepton + Three Tracks: BDTG

BDTG Strategy
1) Multivariate analysis with BDTG on Delphes samples

- After the Preselection (requiring 1 Lepton and 3 Tracks) we apply a BDTG analysis using the following observable

SR 1 Lepton and 3 Tracks SR1L3T
Sum p_T 3 tracks
Invariant Mass (Lepton+3Tracks)
Lepton P_T
Invariant Mass (3Tracks)
ΔR (Lepton-3tracks system)
$\Delta\phi$ (Lepton-3tracks system)
Missing E_T
ΔR (Lepton-Track)
Track P_T
$\Delta\phi$ (Lepton-track)
Acoplanarity
H_T $(\sum_i \vert\vec{p}_T(i)\vert)$

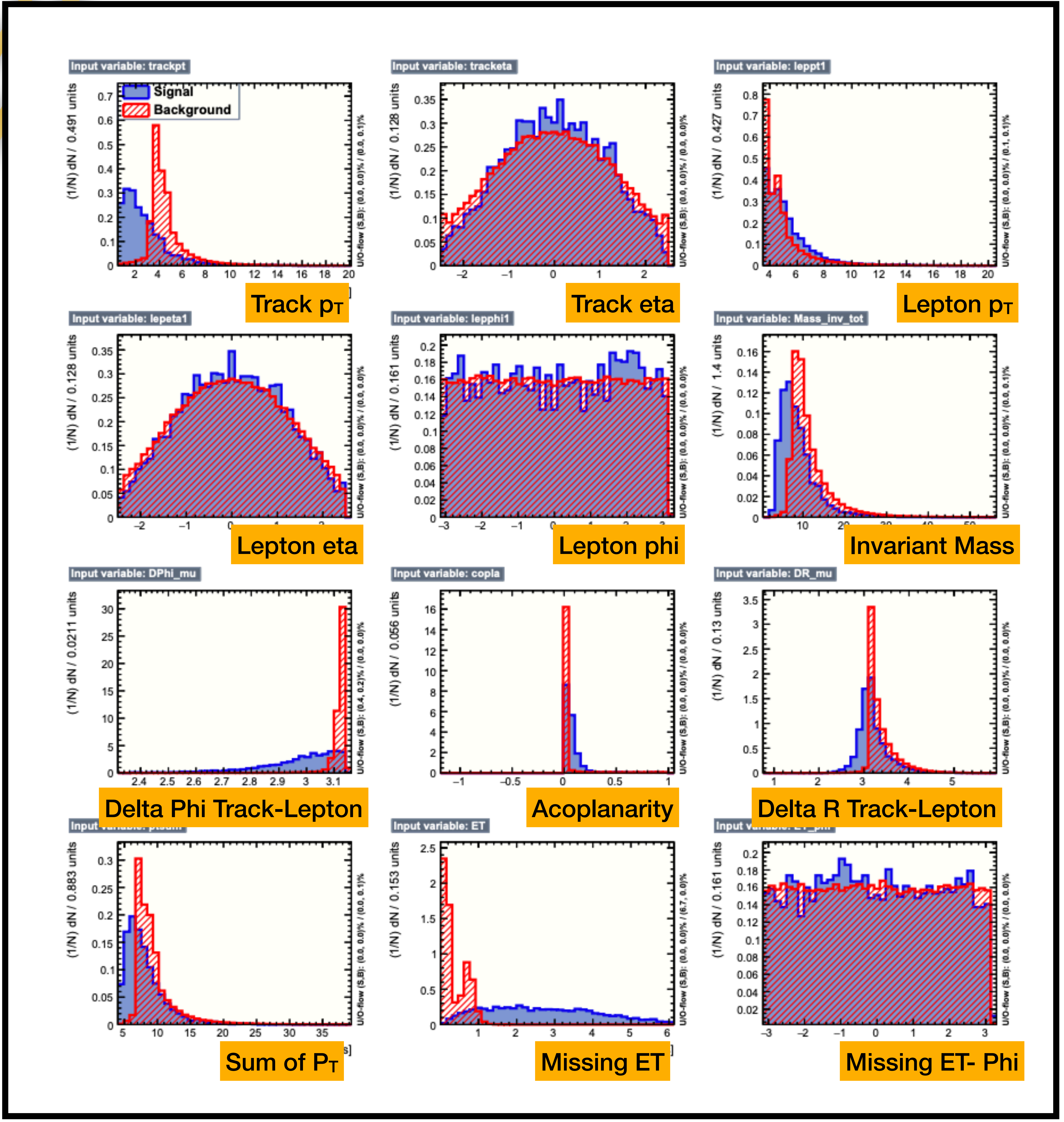


Best Significance S/sqrt(S+B)	SR 1L3T
18	Cut and Count up to muon p_T
20	BDTG >-0.61

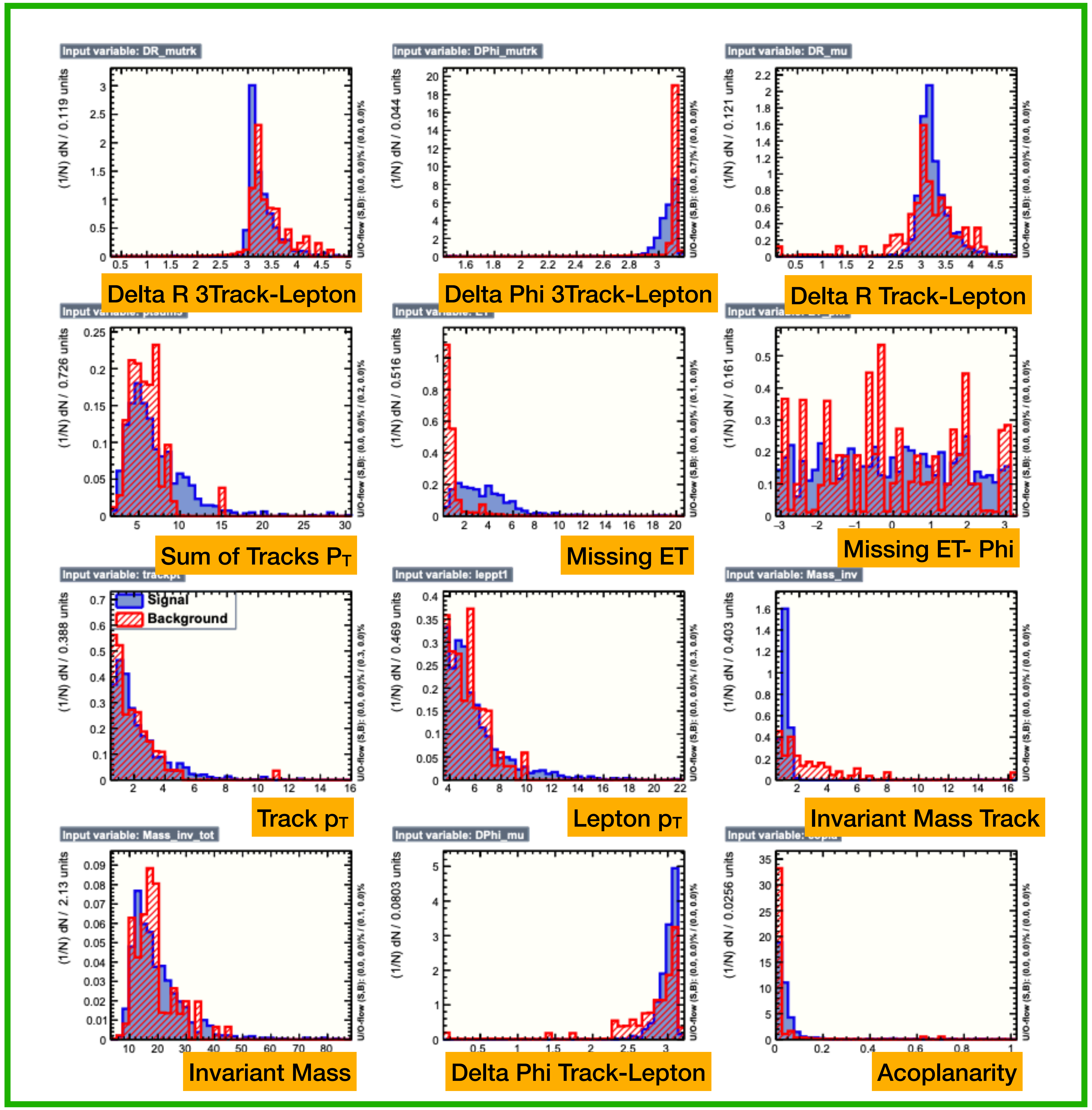
Background

Signal

1L1T



1L3T



Profile Likelihood Fit

- **The a_τ value is extracted using a profile likelihood fit** implemented with the TRExFitter package.
- Each **template for different a_τ** values from dedicated signal MC (no re-weight):
  - Lepton P_T distribution used for the fit normalised to 2.0 nb^{-1}
  - Asimov Data
- Separate fit setup used to extract the $\gamma\gamma \rightarrow \tau\tau$ signal strength ($\mu_{\tau\tau}$) under the assumption of $a_\tau = 0$.
- We performed a profile likelihood for the the SC and for the BDTG methods to highlight possible improvements.
- The systematic uncertainties included are on the luminosity, estimated to be 2% and an additional 10% to conservatively mimic the experimental conditions (uncorrelated for signal and background)
  - Use of control region: events with 2 muons with invariant mass above 11 GeV

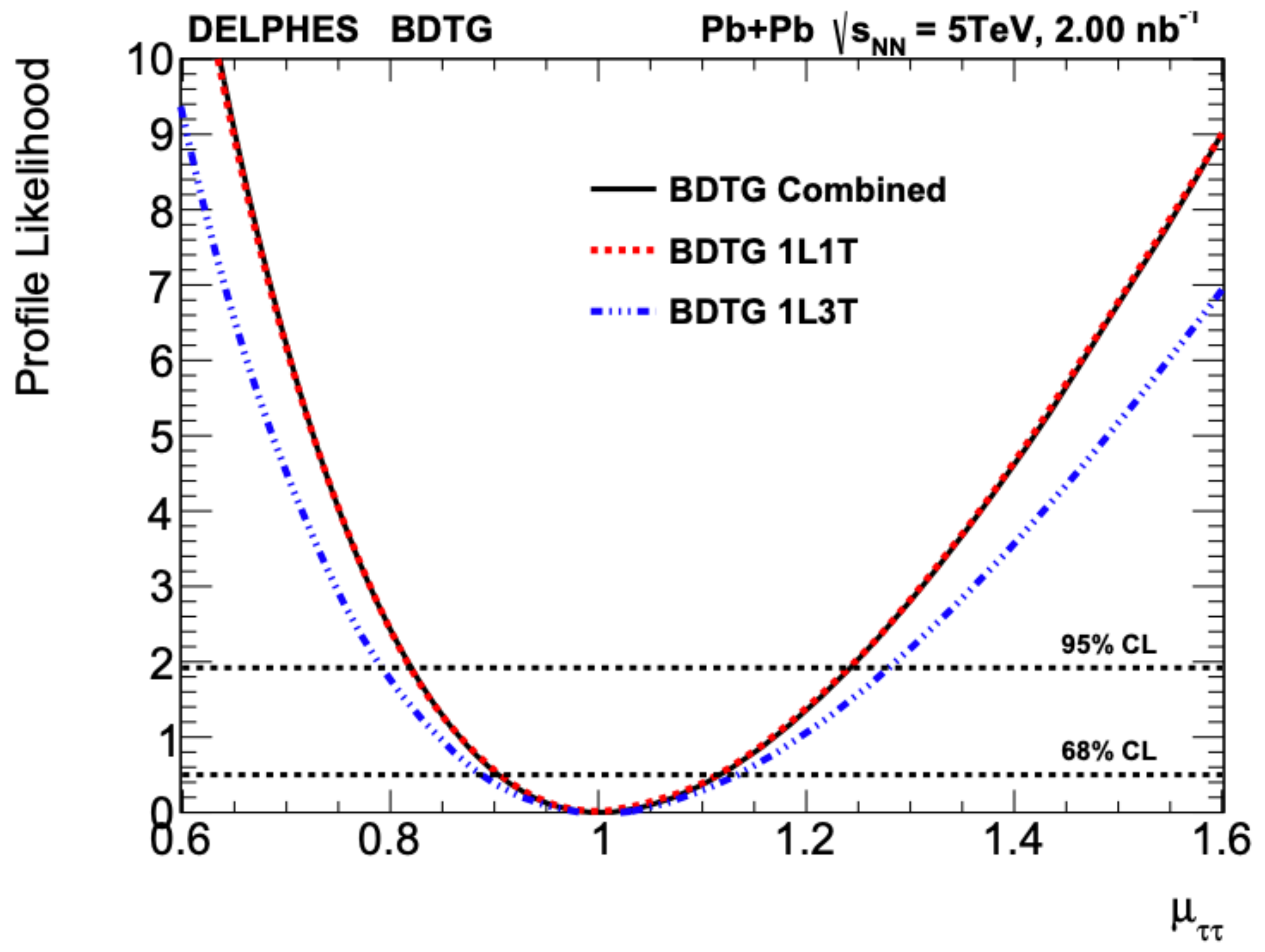
Results of Signal Strength

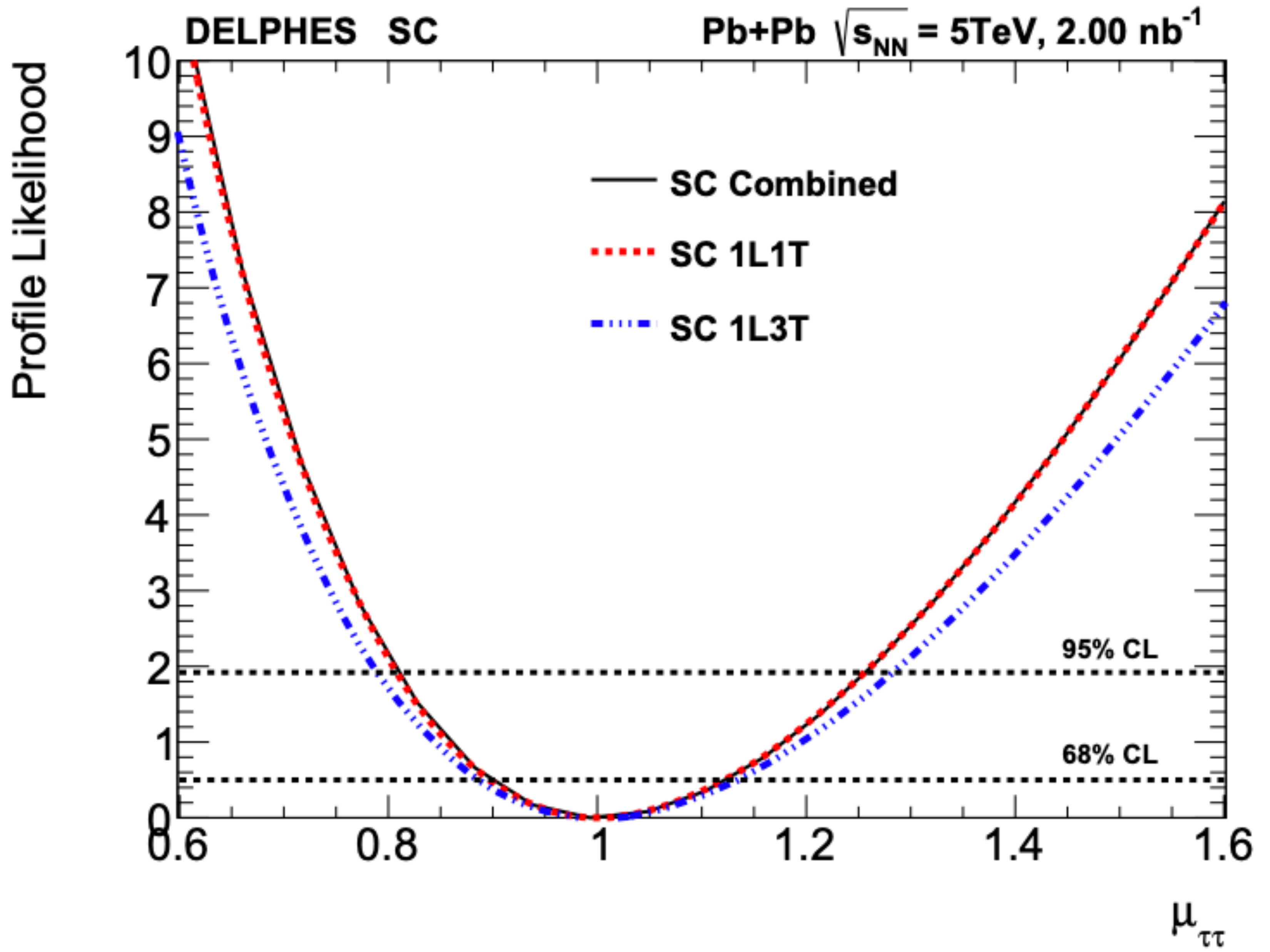
Profile likelihood scan of the signal strength parameter using Asimov Data and considering $a_\tau = 0$, for the two signal regions.

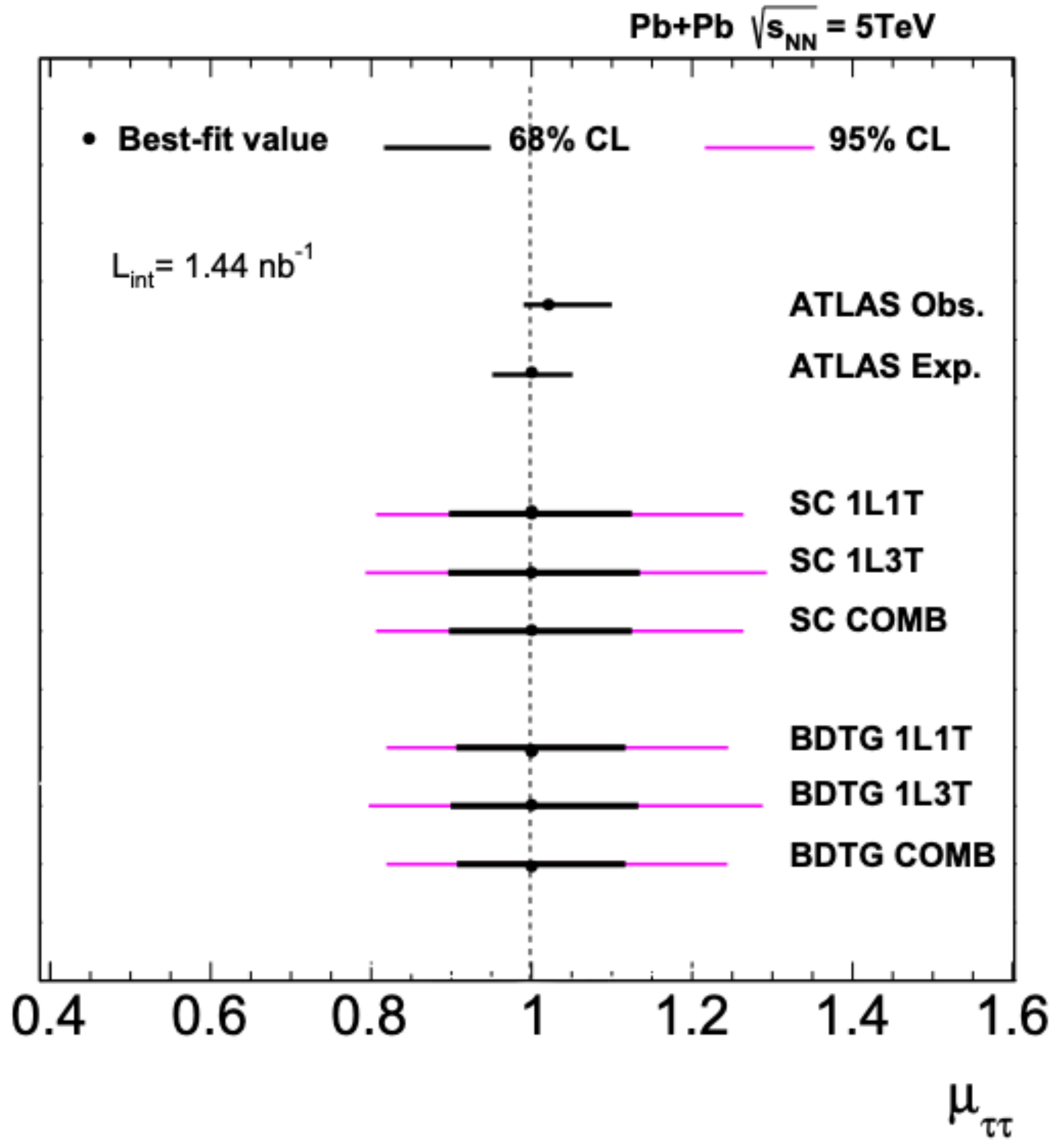
The normalisation systematic uncertainties included are: 2% to mimic the ATLAS luminosity uncertainties and an additional uncorrelated 10% for signal and background to overall mimic experimental conditions.

2.0nb^{-1}

95% CL	SR 1L1T	SR 1L3T	Combined
SC	$\mu_{\tau\tau} = 1\ ^{-0.189}_{+0.257}$	$\mu_{\tau\tau} = 1\ ^{-0.198}_{+0.282}$	$\mu_{\tau\tau} = 1\ ^{-0.189}_{+0.256}$
BDTG	$\mu_{\tau\tau} = 1\ ^{-0.179}_{+0.242}$	$\mu_{\tau\tau} = 1\ ^{-0.195}_{+0.277}$	$\mu_{\tau\tau} = 1\ ^{-0.179}_{+0.241}$





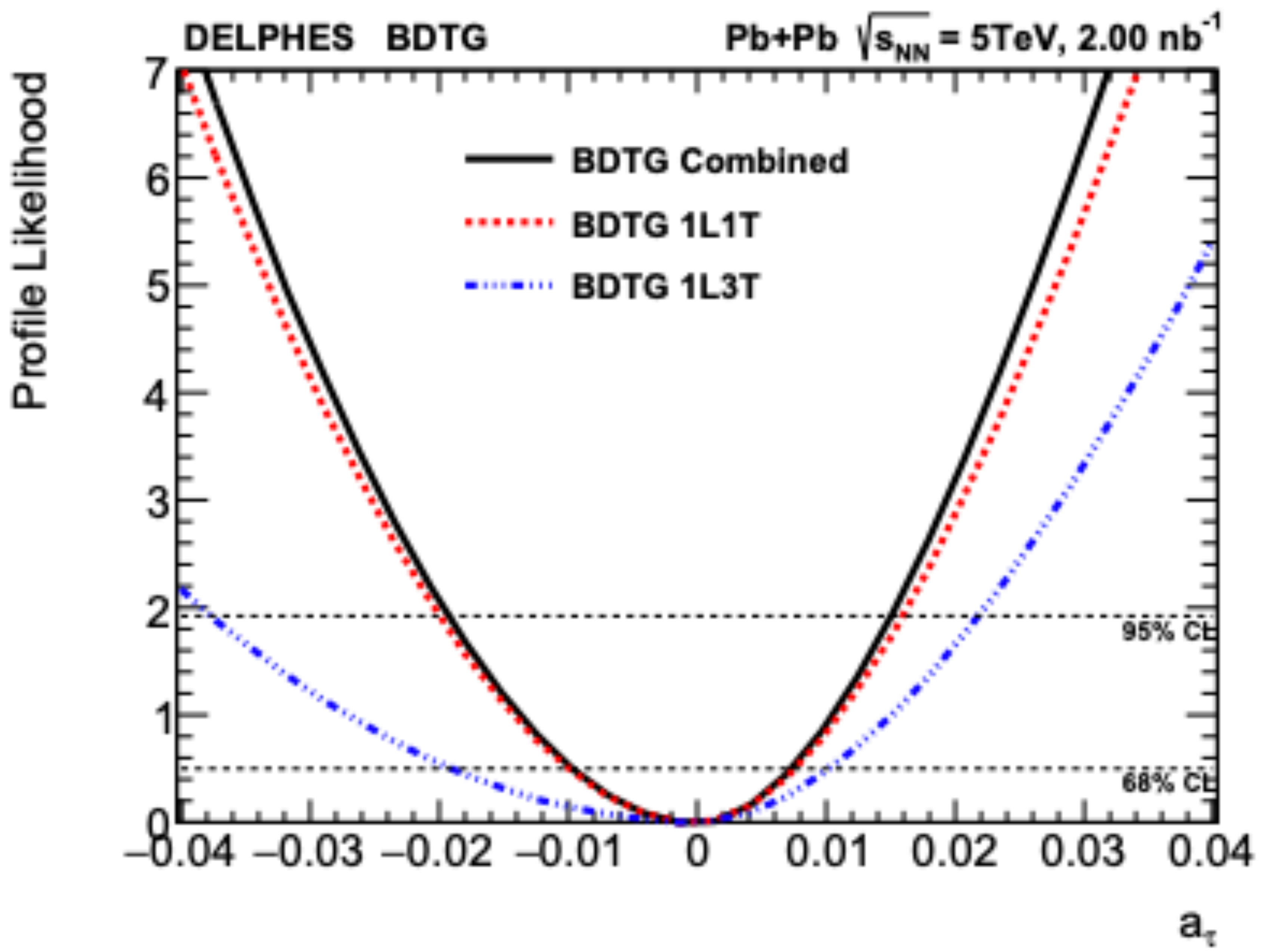


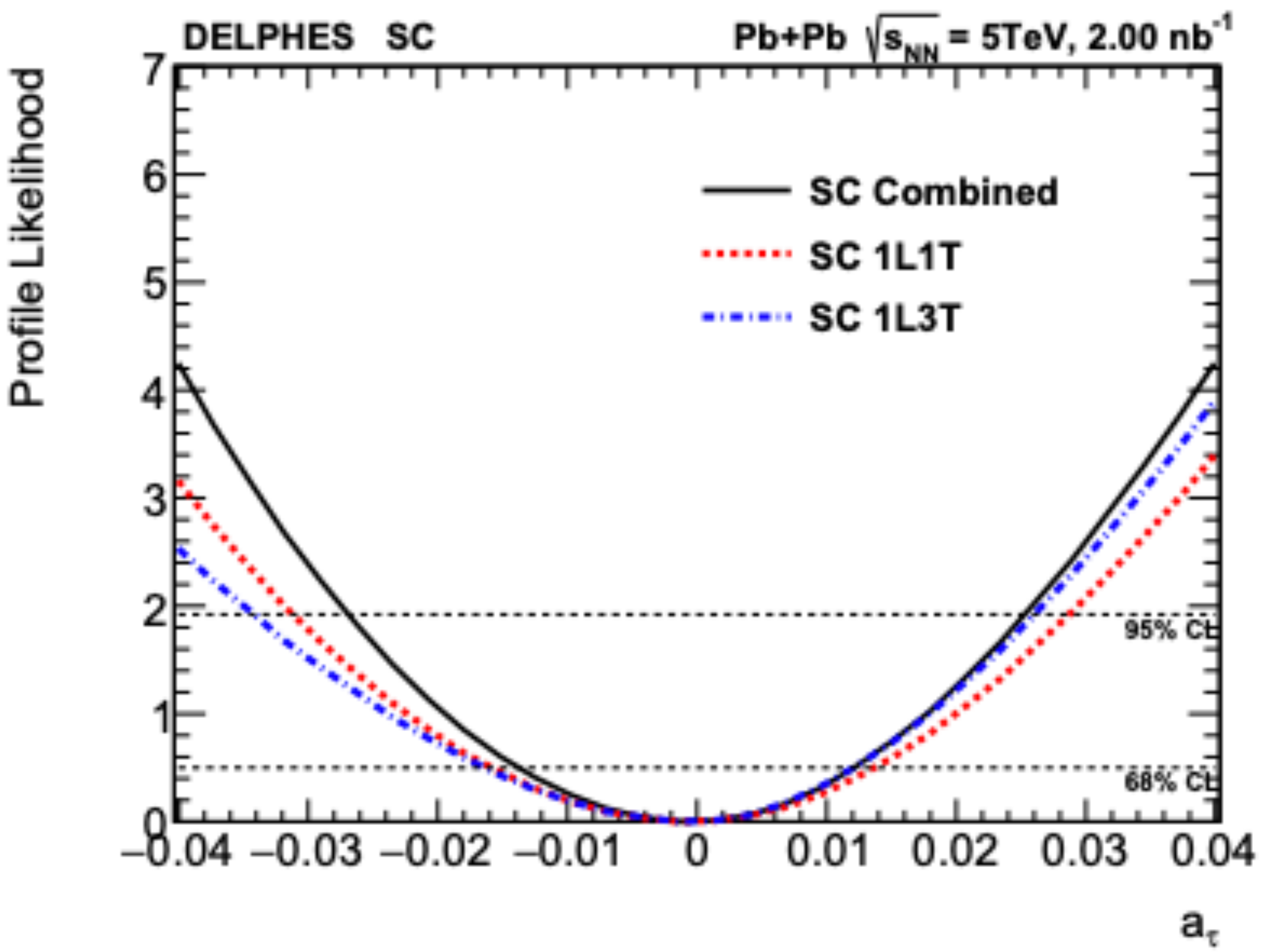
Results on a_{tau}

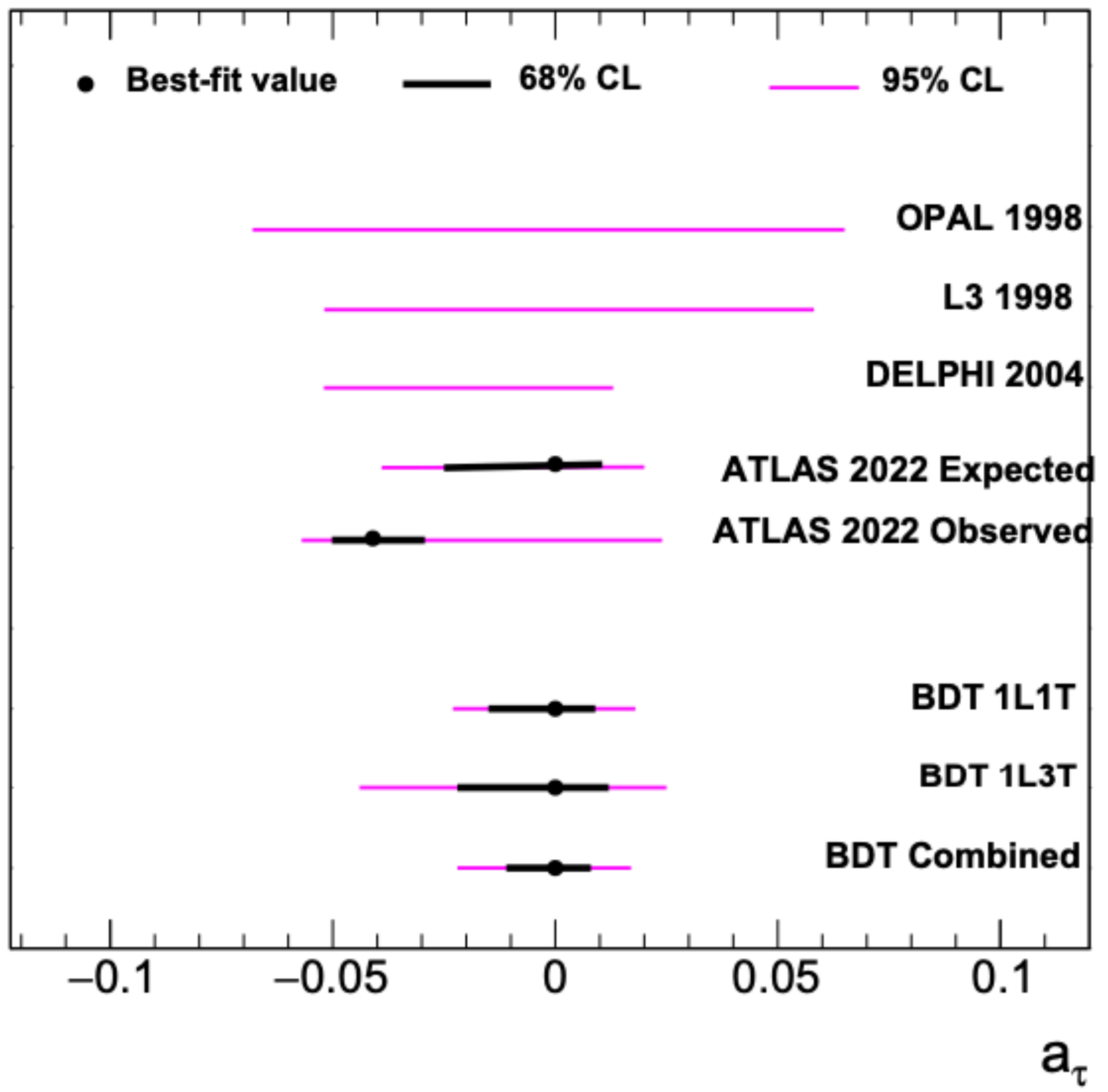
Profile likelihood scan of a_τ using Asimov Data for the two signal regions.
The normalisation systematic uncertainties included are: 2% to mimic the ATLAS luminosity uncertainties and an additional uncorrelated 10% for signal and background to overall mimic experimental conditions.

2.0nb^{-1}

95% CL	SR 1L1T	SR 1L3T	Combined
SC	$a_\tau = 0 ^{-0.031}_{+0.030}$	$a_\tau = 0 ^{-0.034}_{+0.026}$	$a_\tau = 0 ^{-0.027}_{+0.025}$
BDTG	$a_\tau = 0 ^{-0.020}_{+0.016}$	$a_\tau = 0 ^{-0.038}_{+0.022}$	$a_\tau = 0 ^{-0.019}_{+0.015}$







Conclusions

- A study on a_τ = (g−2)/ 2 using $\gamma\gamma \rightarrow \tau\tau$ events produced in ultraperipheral Pb+Pb collisions was presented. MC samples were generated by using MadGraph and Pythia8 and the ATLAS detector effects by using Delphes. Public in Phys. Rev. D 110, 052001 (2024)
  - All the samples have been produced and simulated (no weights used)
- A different approach of previous studies was adopted in term of :
  - Signal events produced by a_{tau} effective Lagrangian term in MadGraph
  - Analysis selection with multivariate method in both the SR
- The alternative theory method agrees with the other theory models.
- Additionally, the multivariate analysis shows a significant improvement with respect to the standard cut of about 35%.

For any questions and/or comments please mail me :
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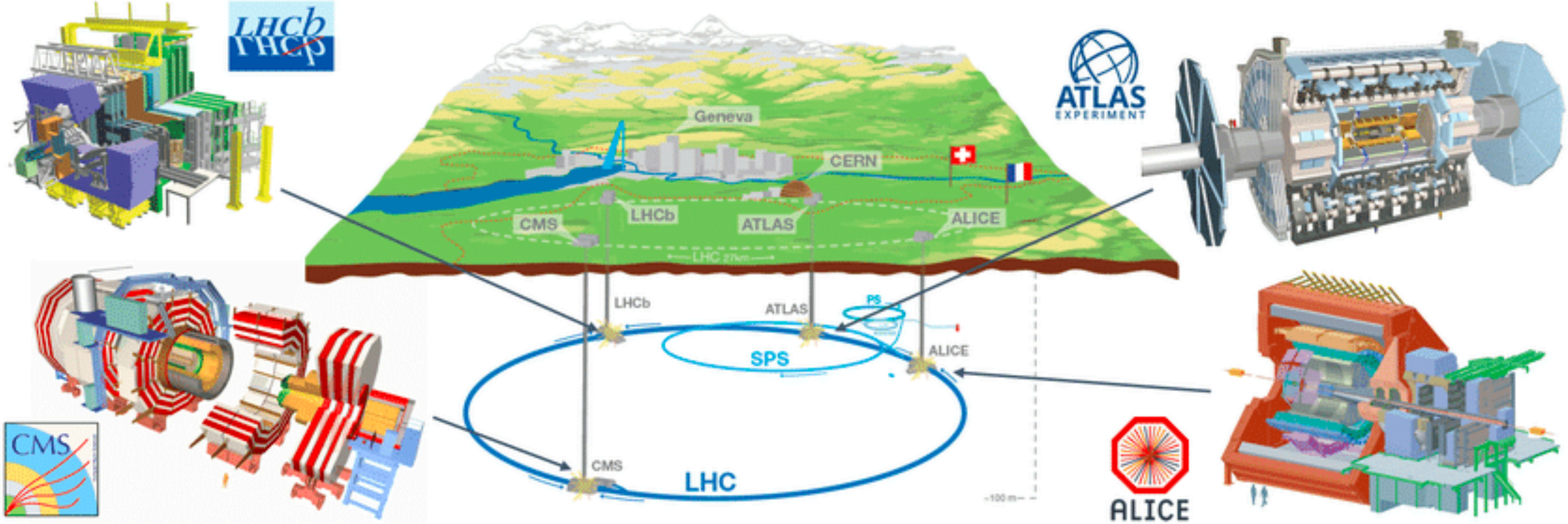
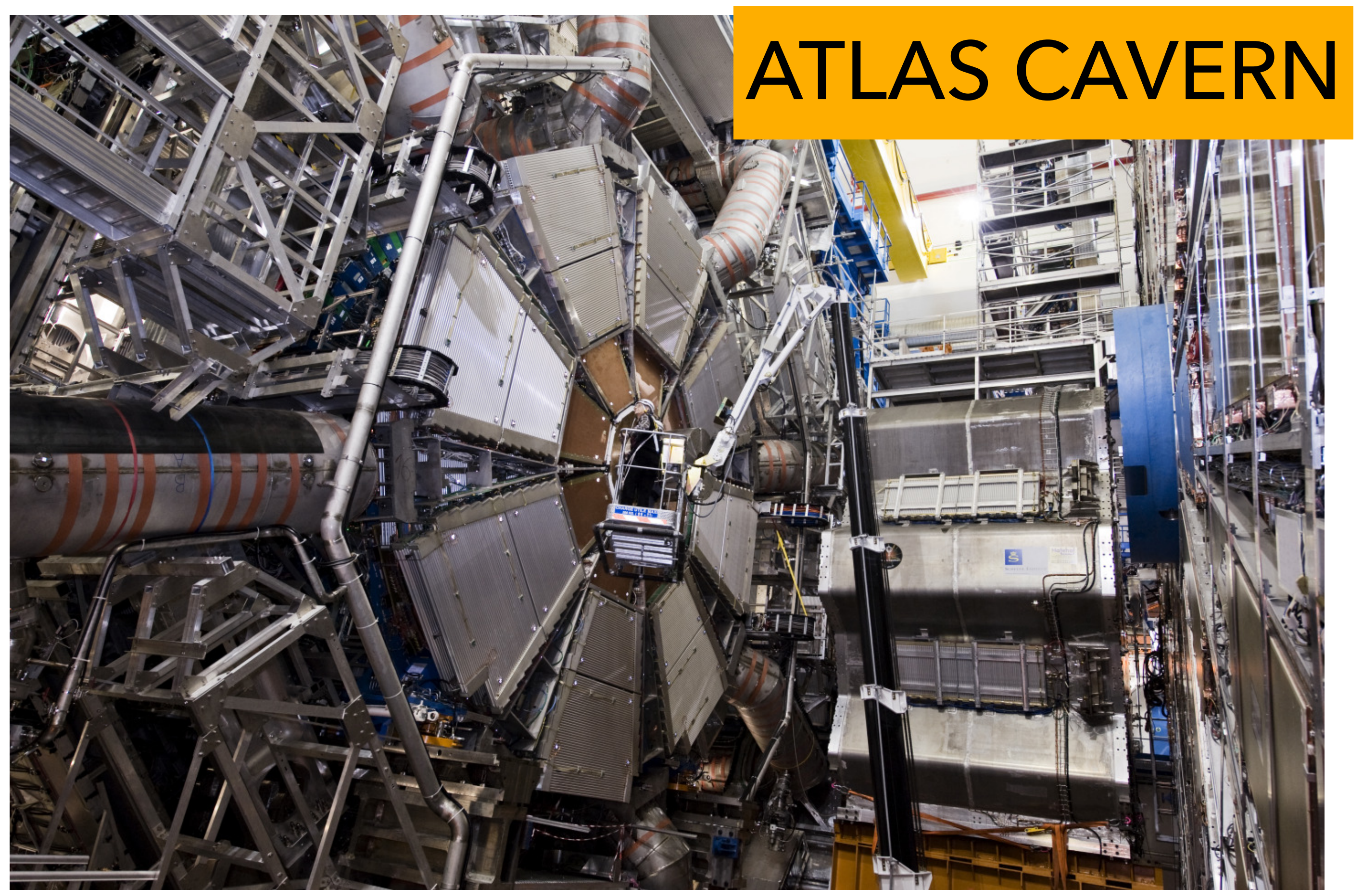
BackUp

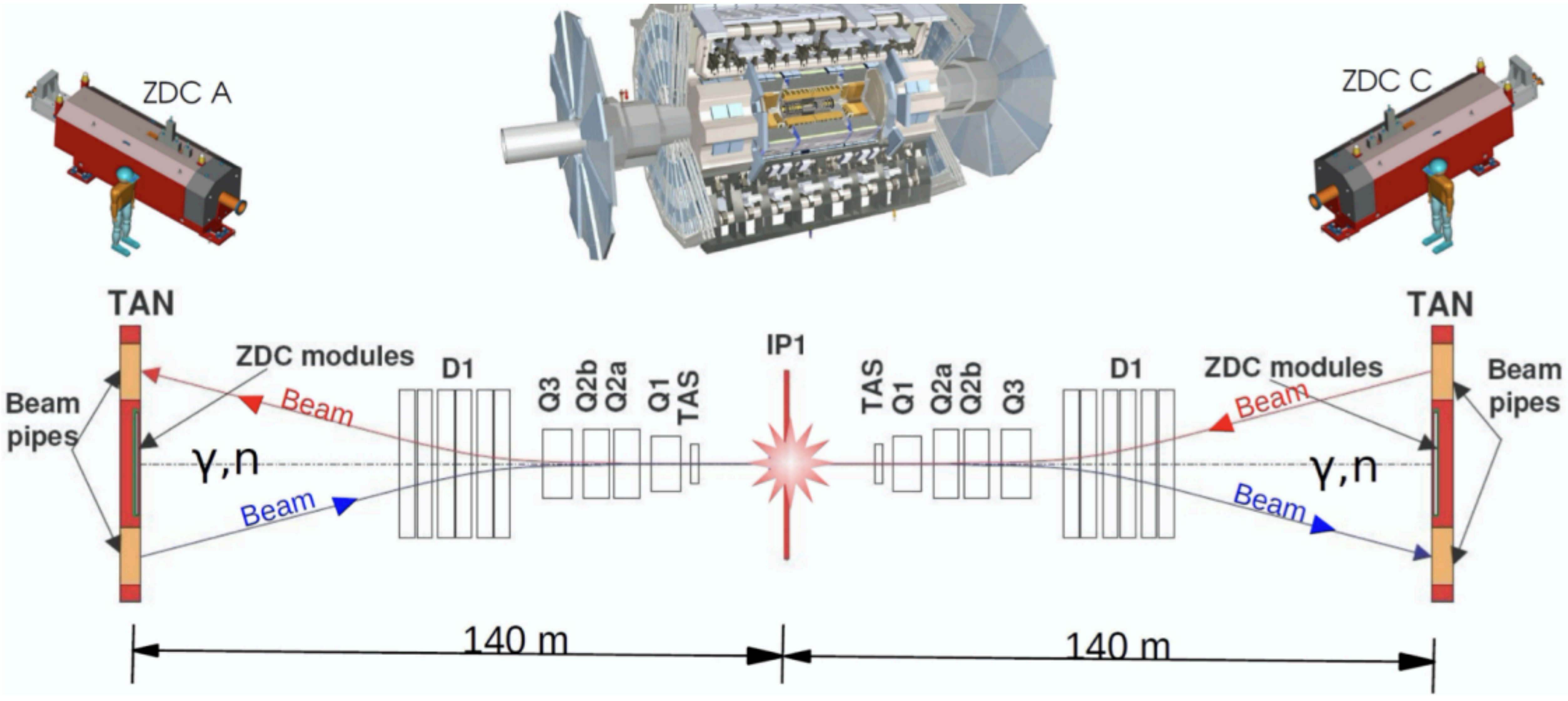
Experiments @ LHC

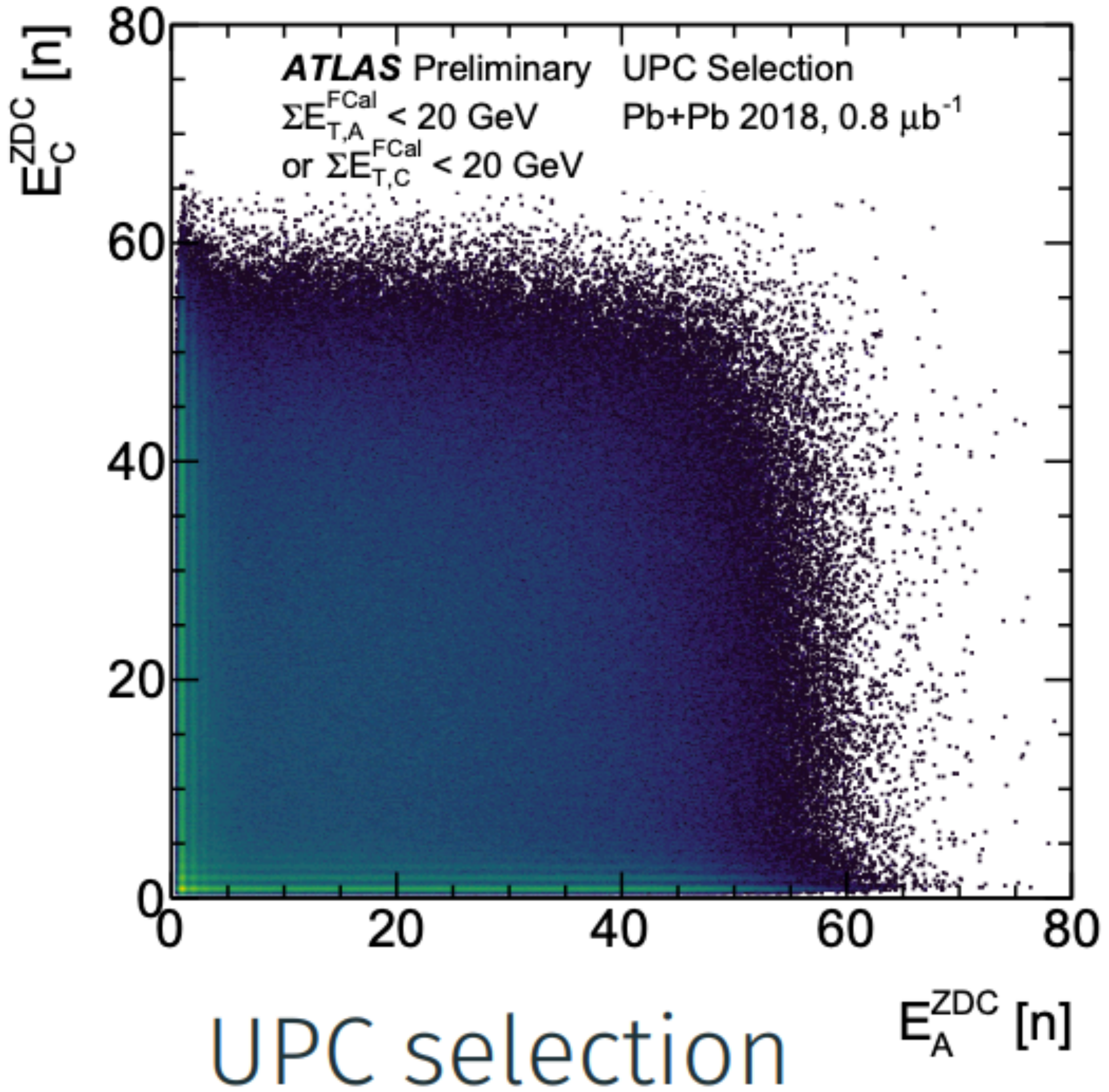




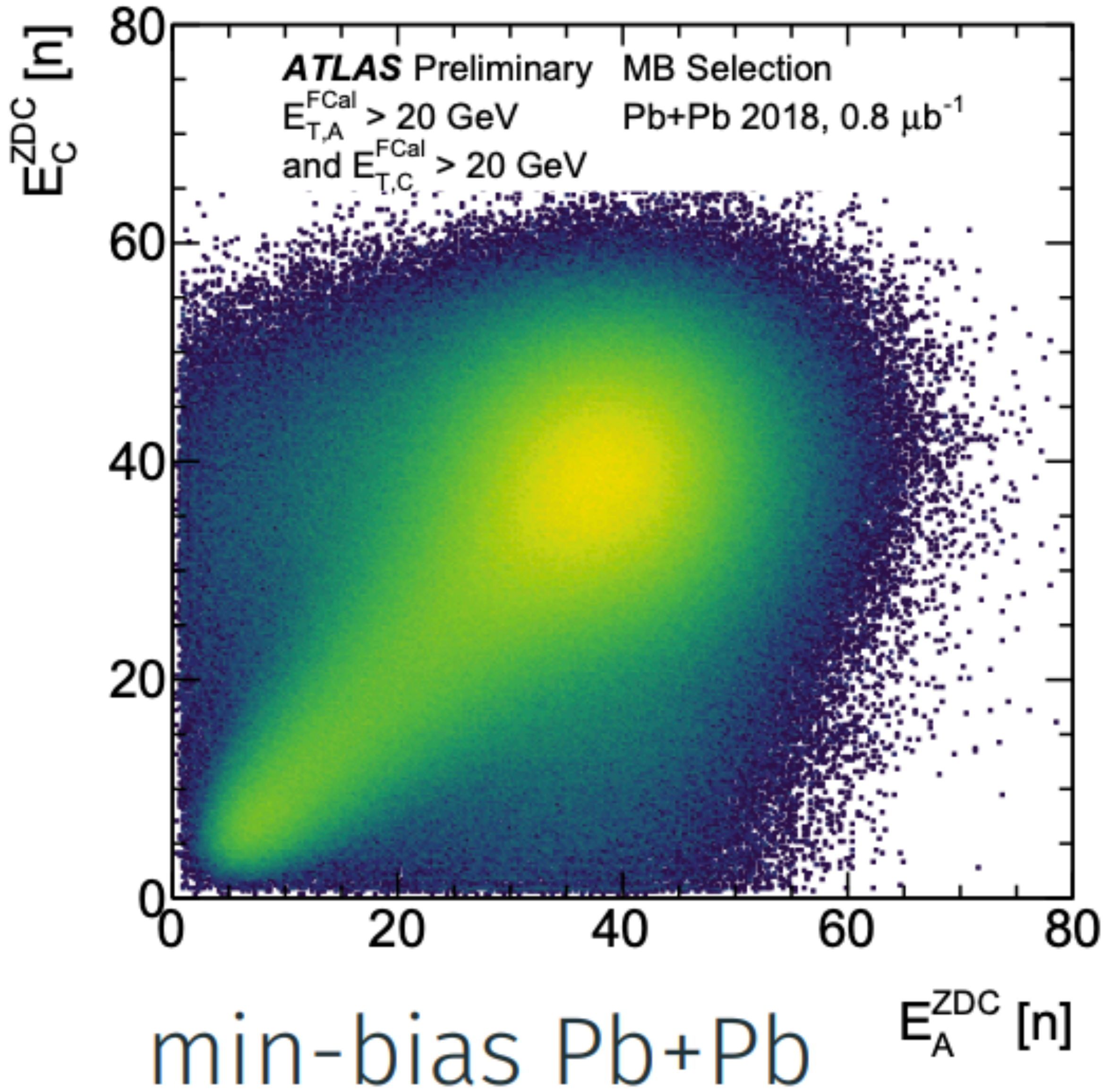
Zero Degree Calorimeter ZDC

- Energies of forward neutral particles (photons, **neutrons**) measured in two ZDC arms.
- Important for ATLAS heavy-ion program, e.g. helps to separate UPCs from inelastic Pb+Pb collisions.
- For $\gamma\gamma \to \tau\tau$ or $\gamma\gamma \to \ell\ell$ production expect $60-70\%$ of events to have no neutrons on either side (**0n0n topology**).
- ZDC is not simulated in MC, so ZDC selections can only be applied in data $\to$ **simulation reweighted to 0n0n topology**.





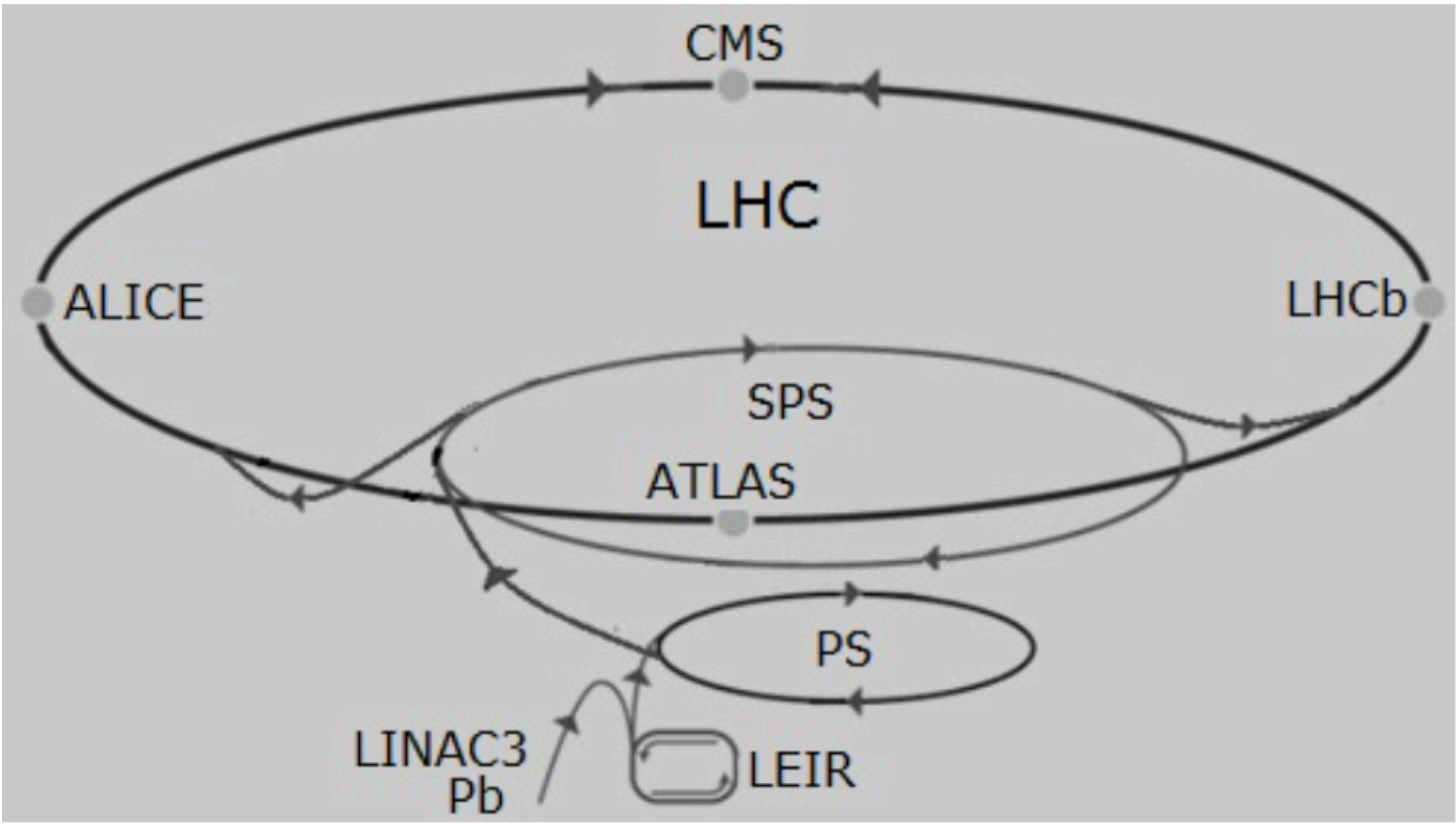
UPC selection



min-bias Pb+Pb

LHC with Lead Lead Collisions

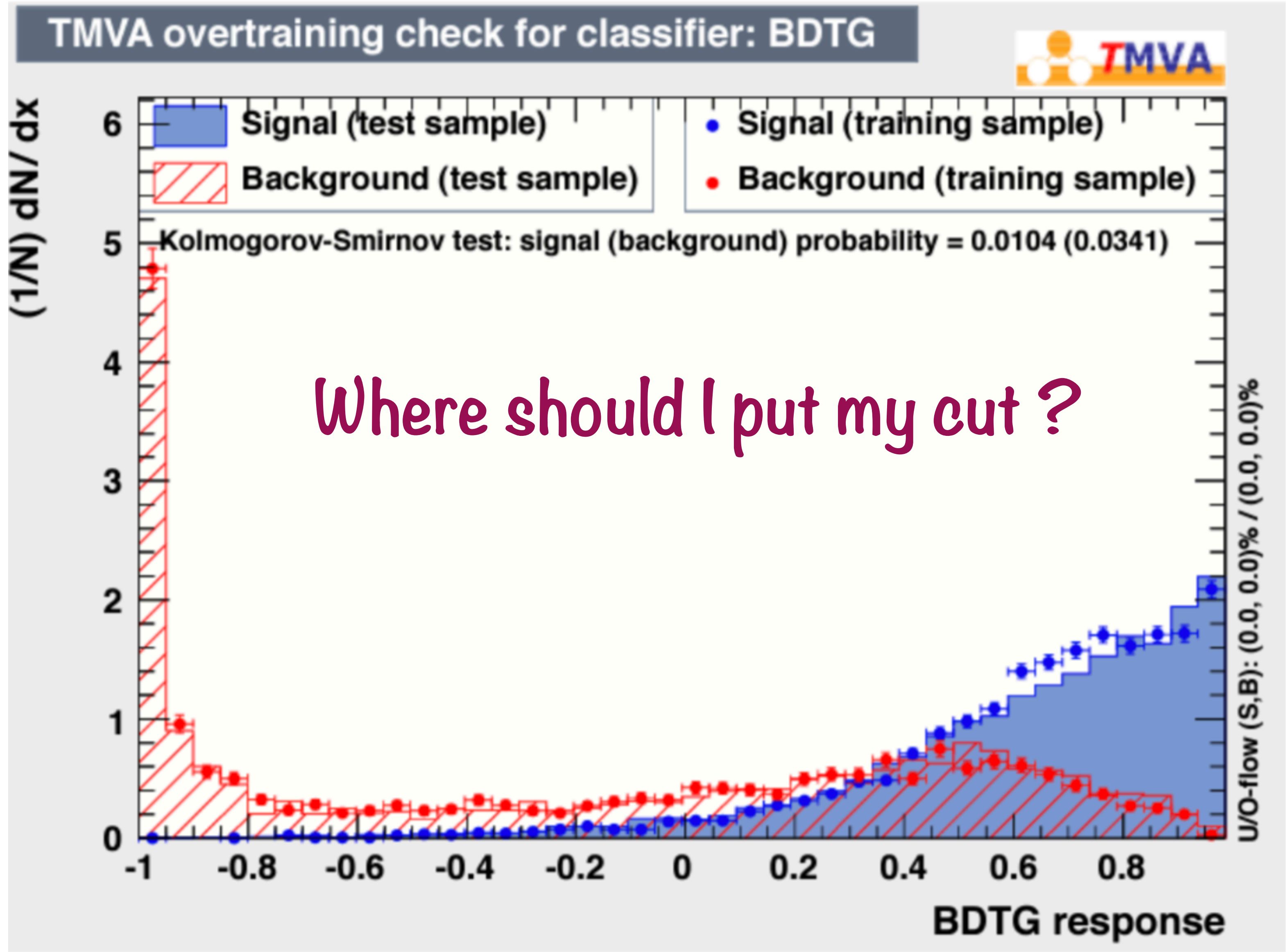
The ions first travel through a linear accelerator called **Linac3**, picking up a small amount of energy (4.5 MeV per nucleon). Next, the ions are accumulated and accelerated to 72 MeV per nucleon in the **Low Energy Ion Ring, or LEIR**. Then they move to **SPS**.

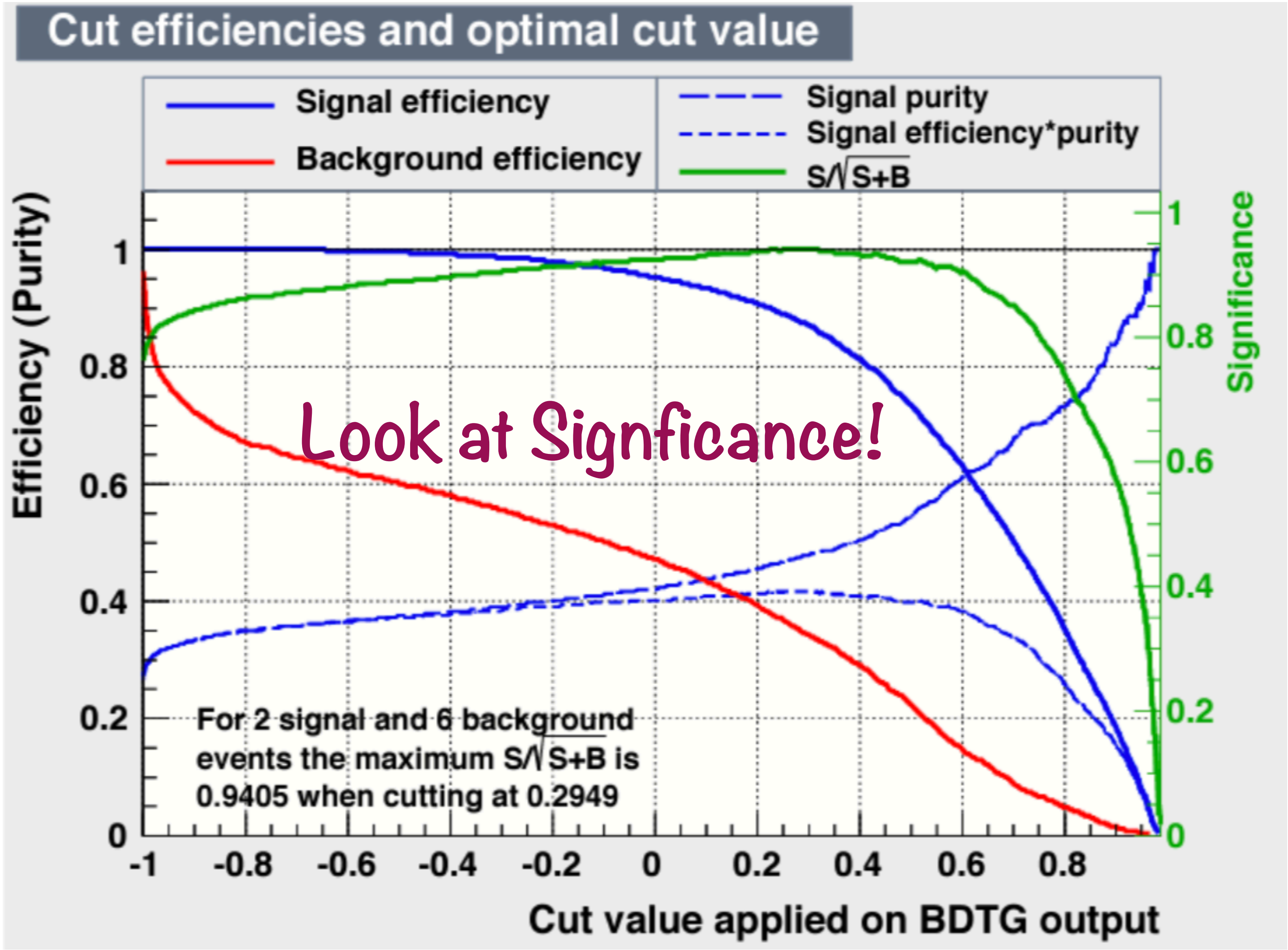


Each LHC ring will be filled in 10 min by almost 600 bunches, each of $7\times10_{7}$ lead ions. Central to the scheme is the Low Energy Ion Ring (LEIR), which transforms long pulses from Linac3 into highbrilliance bunches.

How do we optimise the selection?

- **Score Function: Significance** $S/\sqrt{(S+B)}$
  - Number of signal events S in a selected event sample is estimated by subtracting the estimated background B from the total number of events N:
    - S = N-B
- Statistical uncertainty in the signal estimate:
  - $S = \sqrt{N} = \sqrt{(S+B)}$
  - Poisson statistics
  - ignore systematic uncertainties, and consider B large enough
- goal: maximize significance
  - by keeping signal events
  - while suppressing background
- Additional score function based on likelihood test:
  - $\sqrt{2(S+B)ln(1+S/B)-2S}$





Analysis Strategy @ ATLAS

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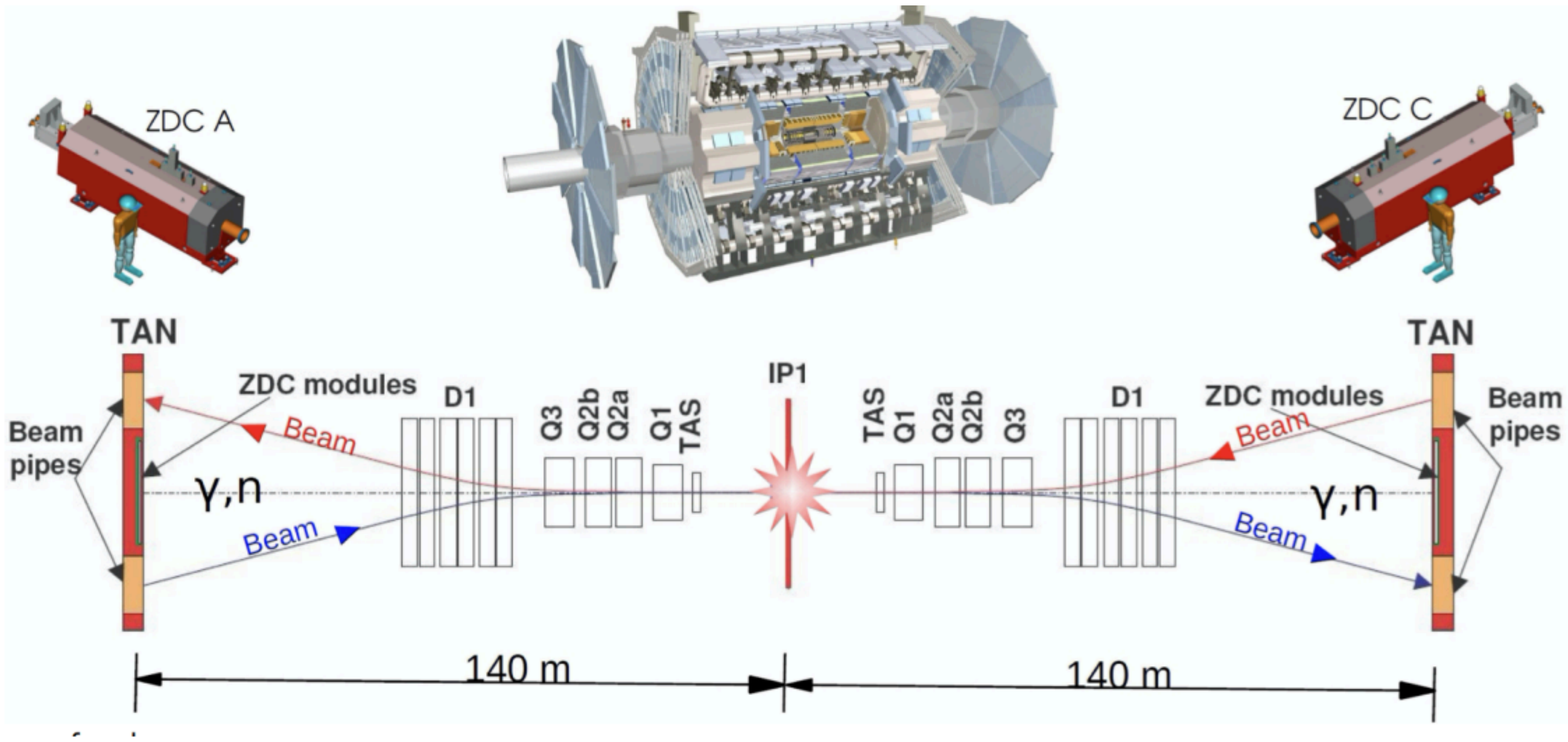
Analysis Strategy:

- 3 periods of heavy ion collisions during Run2
- Ultraperipheral Collisions (UPC) of PbPb at $\sqrt{s_{NN}} = 5.02$ TeV
  - Order of 1.44 nb^{-1} data sample
  - Elastic & diffractive
  - Small energy deposit in the forward detector system

Both ATLAS and CMS use muon to trigger the event.
Vetoing Forward activity to separate UPCs from inelastic Pb+Pb collisions

Zero Degree Calorimeter

- Constraints on a_τ from total $\gamma\gamma \to \tau\tau$ cross-section / yield and differential distributions (e.g. leading lepton p_T)
- Categorise di-τ events:
  - lepton + 1 track (ℓ/pion)
  - lepton + 3 tracks (3pions)
  - μ + e



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Analysis Strategy @ ATLAS

ATLAS

Event Preselection

- **Trigger:** HLT_mu4 + FCal-based forward gap + total E_T at L1 < 50 GeV
- E_{ZDC} <1TeV: reduce neutral particles in the forward region helps to separate UPCs from inelastic Pb+Pb collisions. Reduce photo-nuclear background

Region Selection

- Exclusivity selections: no tracks except signal leptons/tracks - no clusters unmatched to signal leptons/tracks
- Cuts on system p_T help to suppress $\gamma\gamma \to \mu\mu$ background in 1M1T SR

Observable	Preselection			
GRL	Pass			
$E_{ZDC}^{A,C}$	< 1 TeV			
Trigger	HLT_mu4_hi_upc_FgapAC3_L1MU4_VTE50 fired			
Region	1M1T SR	1M3T SR	1M1E SR	2M CR
$N_{\mu}^{baseline}$	= 1	= 1	—	—
N_{μ}^{sig}	= 1	= 1	= 1	2
N_{e}^{sig}	= 0	= 0	= 1	—
N_{trk} $\Delta R > 0.1$ from μ^{sig}	= 1	= 3	—	—
N_{trk} $\Delta R > 0.1$ from ℓ^{sig}	—	—	= 0	= 0
Unmatched clusters	= 0	= 0	—	—
$\sum$ charge	= 0	= 0	= 0	—
$p_T^{(\mu,trk)}$	> 1 GeV	—	—	—
$p_T^{(\mu,trk,\gamma)}$	> 1 GeV	—	—	—
$p_T^{(\mu,trk,cluster)}$	> 1 GeV	—	—	—
m_{trks}	—	< 1.7 GeV	—	—
$A_{\phi}^{\mu,trk(s)}$ (*)	< 0.4	< 0.2	—	—
$m_{\mu\mu}$	—	—	—	> 11 GeV

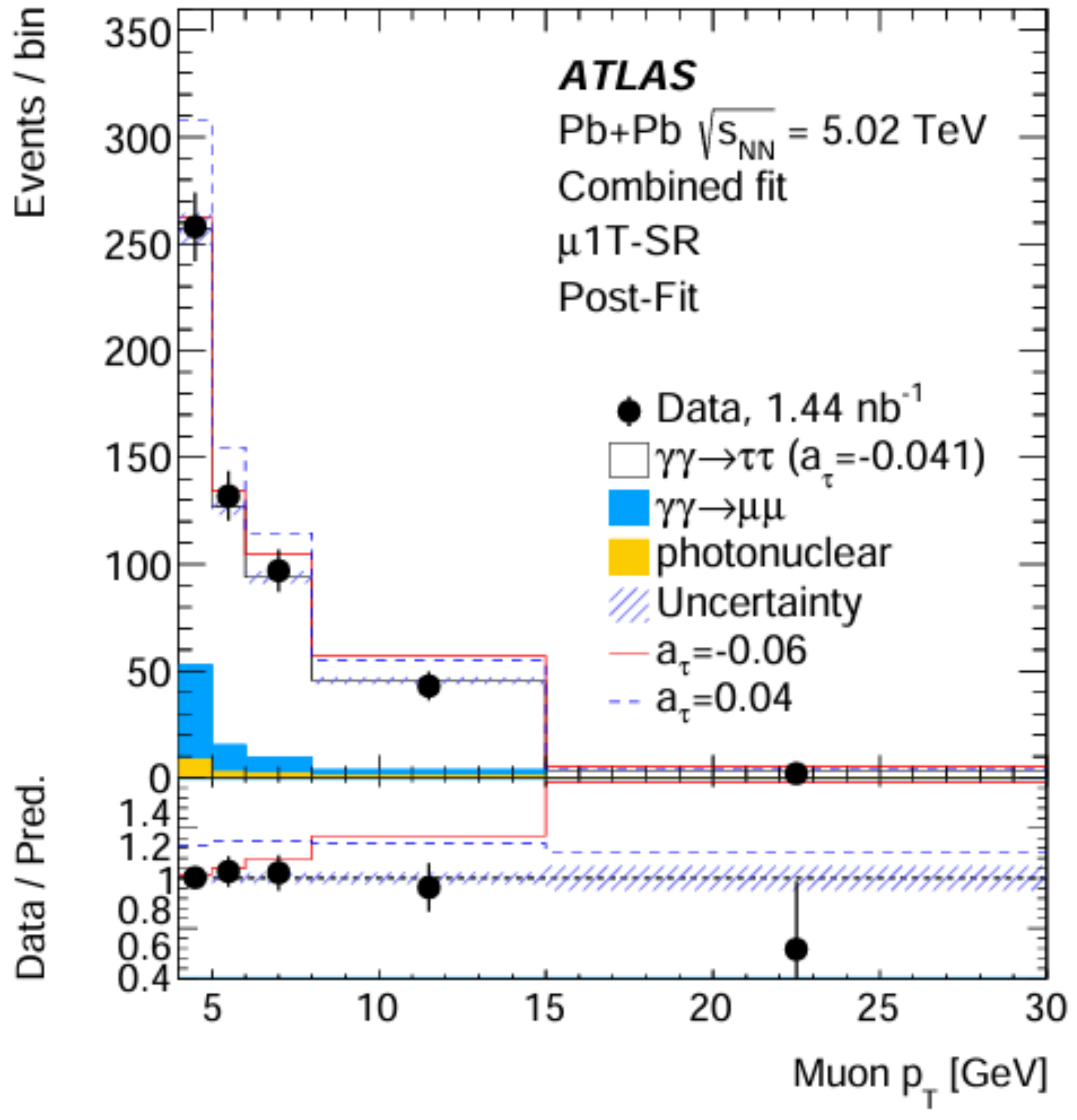
1Muon+1Track | 1Muon+3Tracks | 1Muon+1Electron

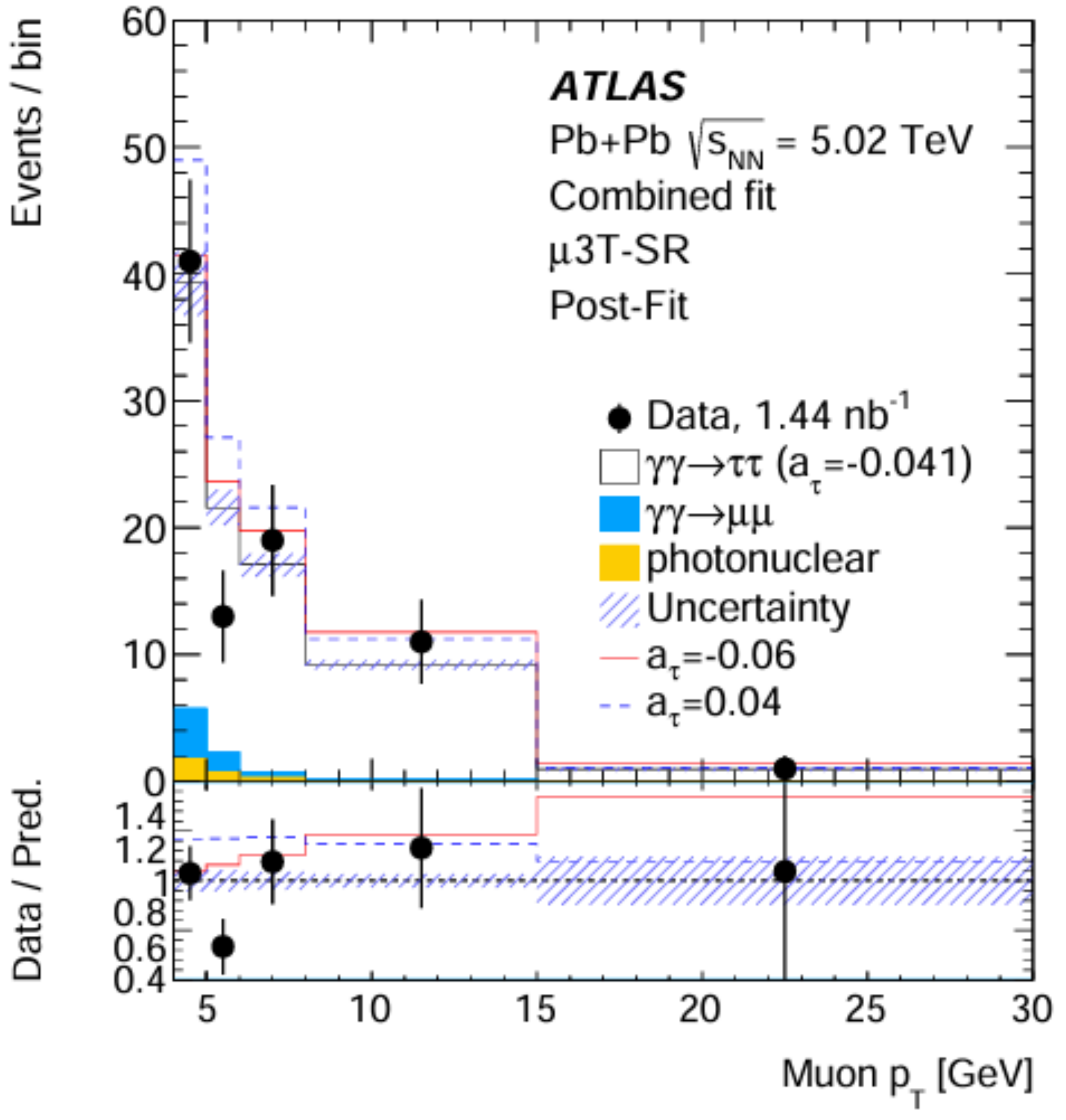
Region	Data	Signal $\gamma\gamma \to \tau\tau$	Background $\gamma\gamma \to \mu\mu(\gamma)$	Background $\gamma\gamma \to ee$	Background $\gamma\gamma \to$ jet	Background photonuclear
1M1T SR	532.0	497.1	70.2	0.0	0.1	13.5
1M3R SR	85.0	90.2	6.7	0.0	0.3	2.8
1M1E SR	39.0	35.2	2.8	0.0	0.0	0.0

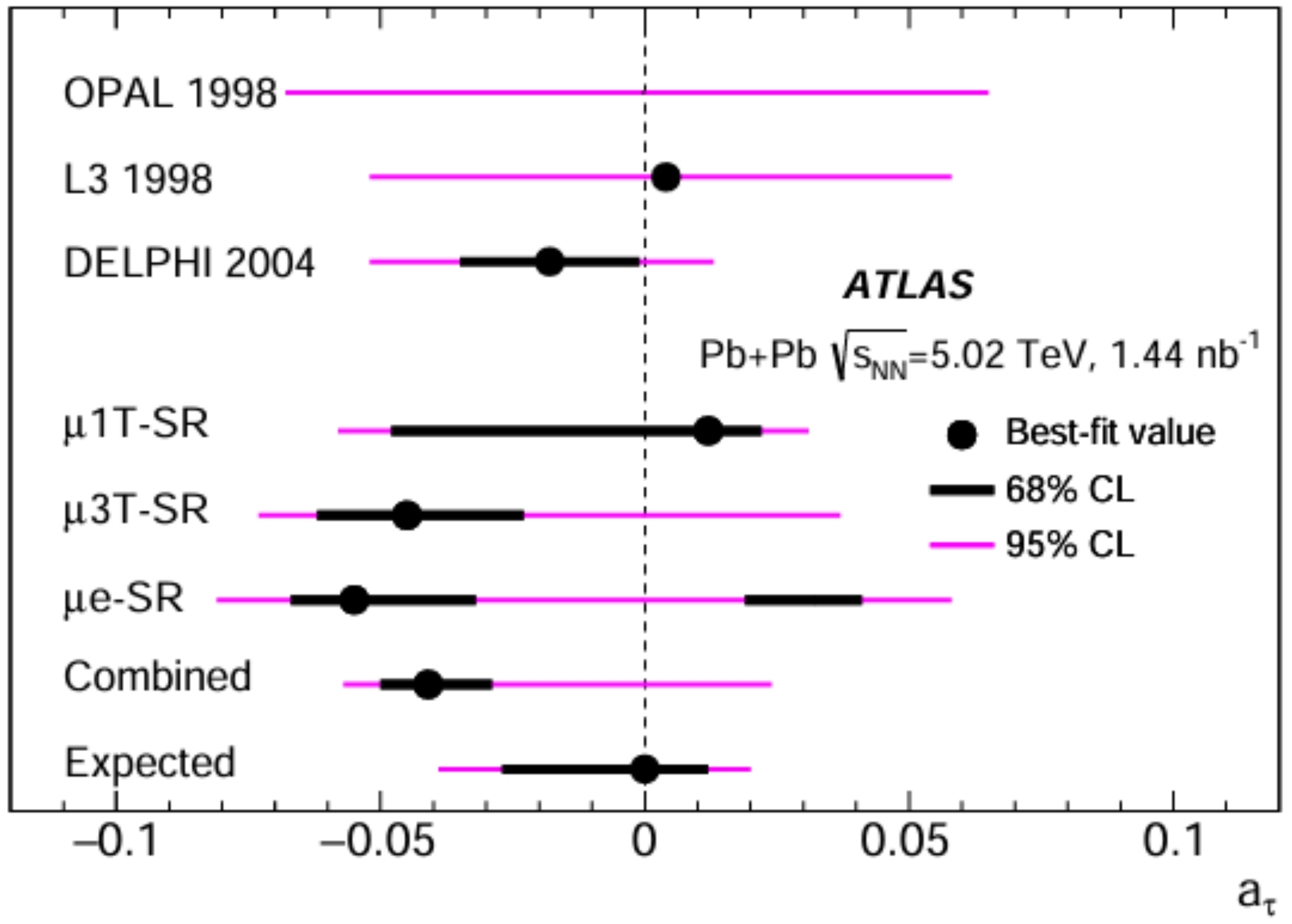
(*) $A_{\phi}^{\mu,trk(s)} \equiv 1 - |\Delta\phi_{\mu,trk(s)}|/\pi$

Results

- Muon transverse momentum used to extract the limits
  - Limits sets to anomalous magnetic momentum of tau
  - Limits set to signal strength $\mu_{\tau\tau} = 1.03^{+0.06}_{-0.05}$ (tot)







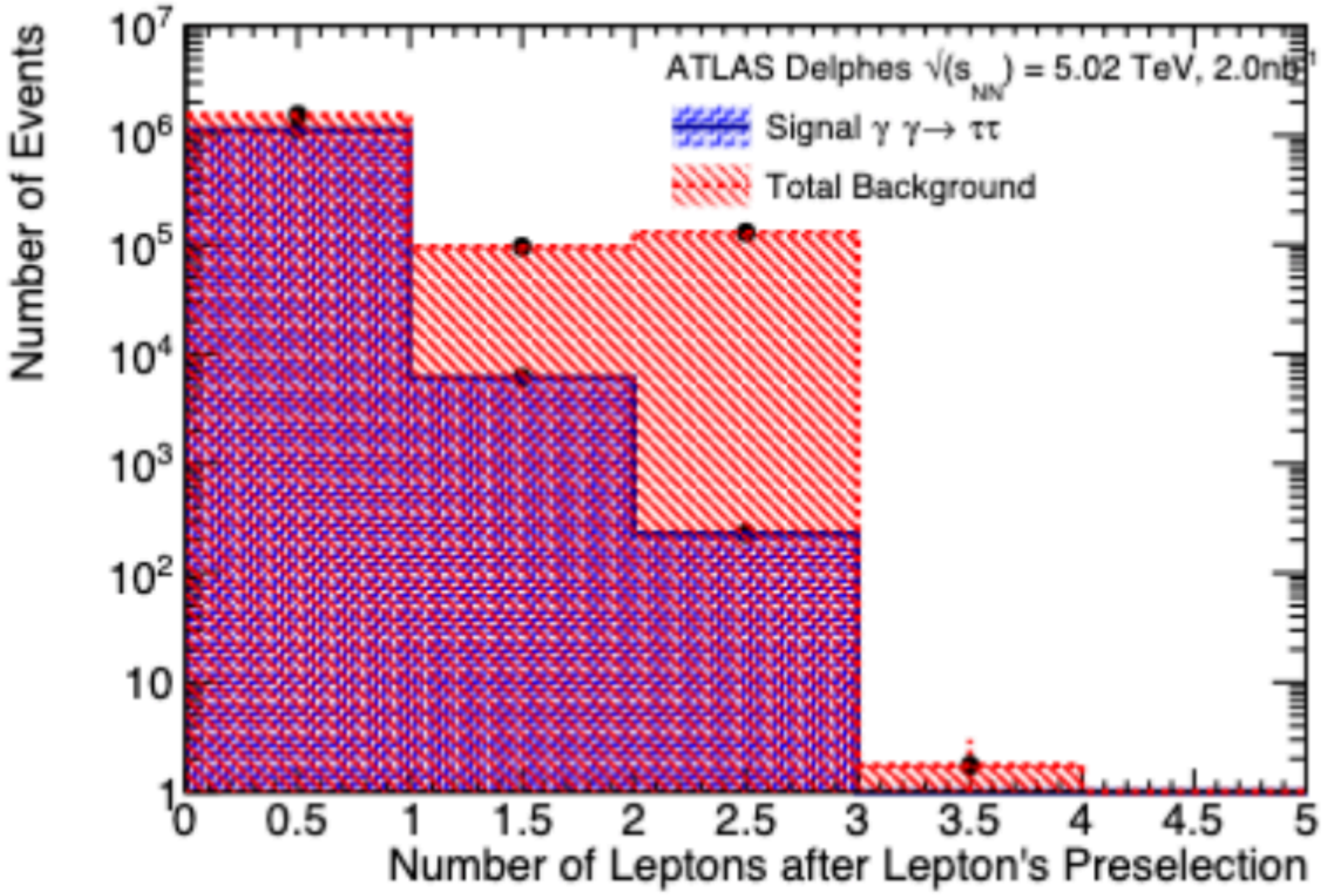
$-0.057 < a_\tau < 0.024$ at 95% CL.

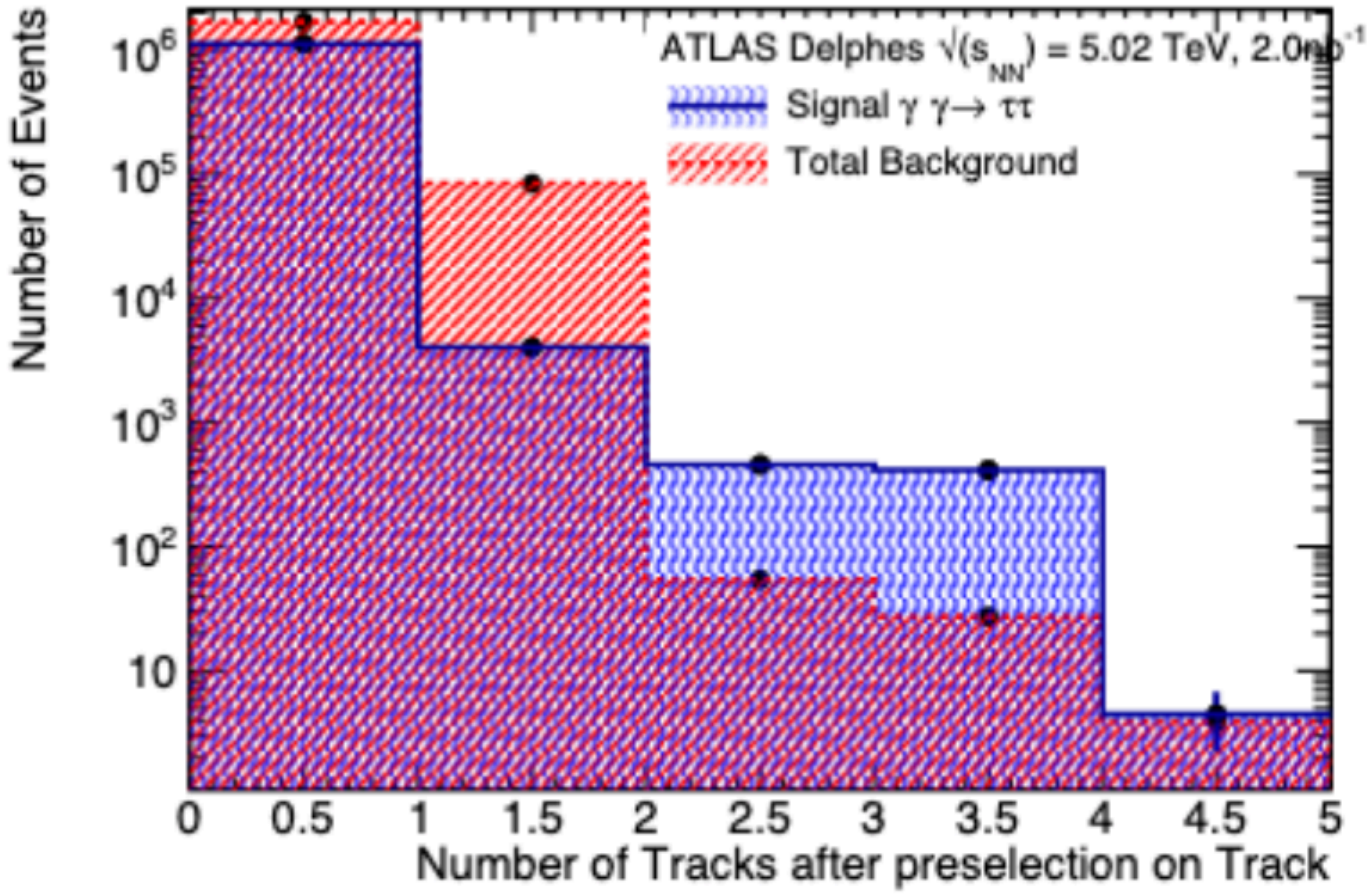
Signal Region Identification: Preselection

- Three Signal Regions (SRs) driven by tau decays:
  - **1 lepton + one track (1L1T)**
  - **1 lepton + three tracks (1L3T)**

Category Identification very similar to the one used in ATLAS full Analysis.

Two Strategies:
1) Standard Cuts SC (same cuts applied in ATLAS
2) BDTG Cuts



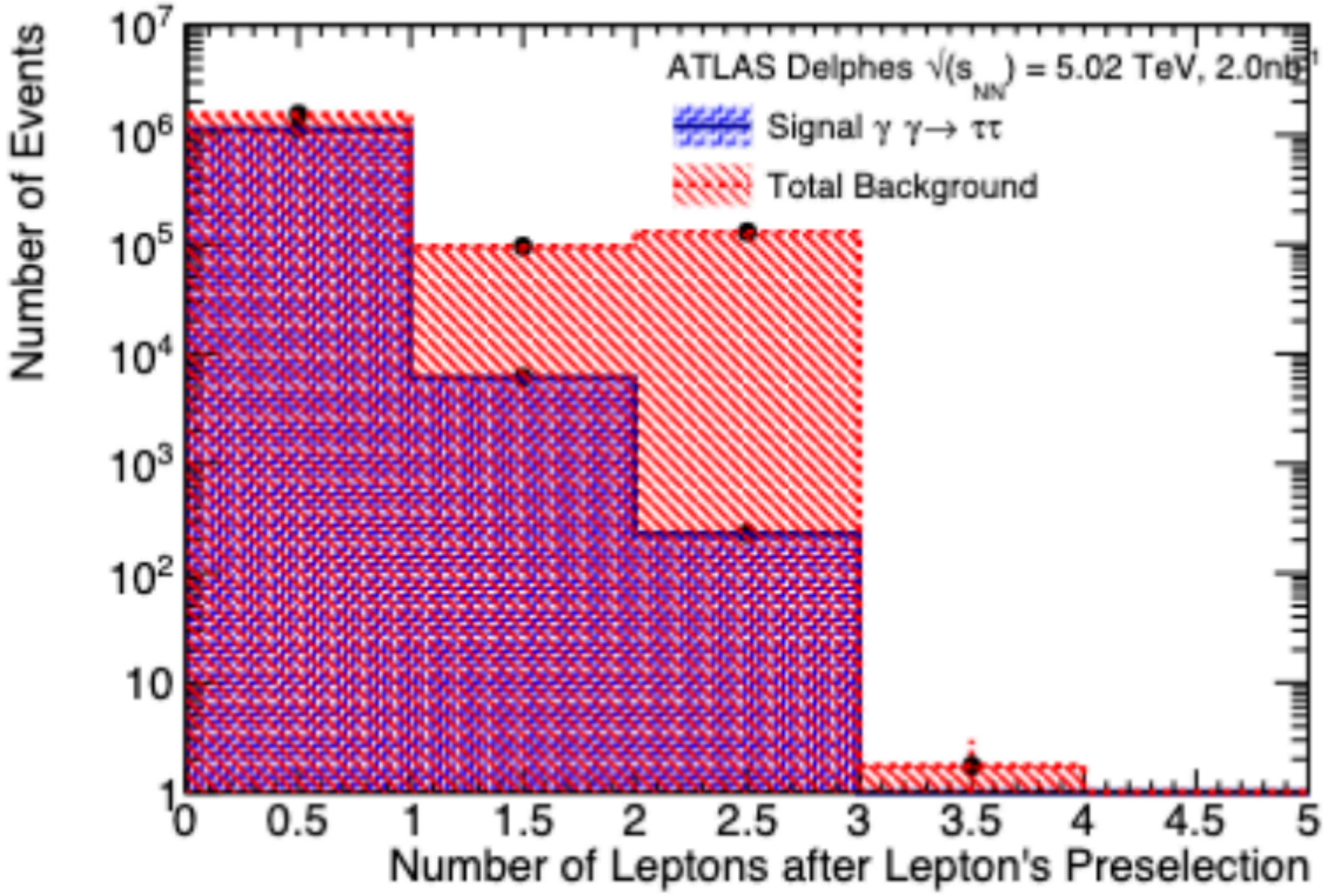


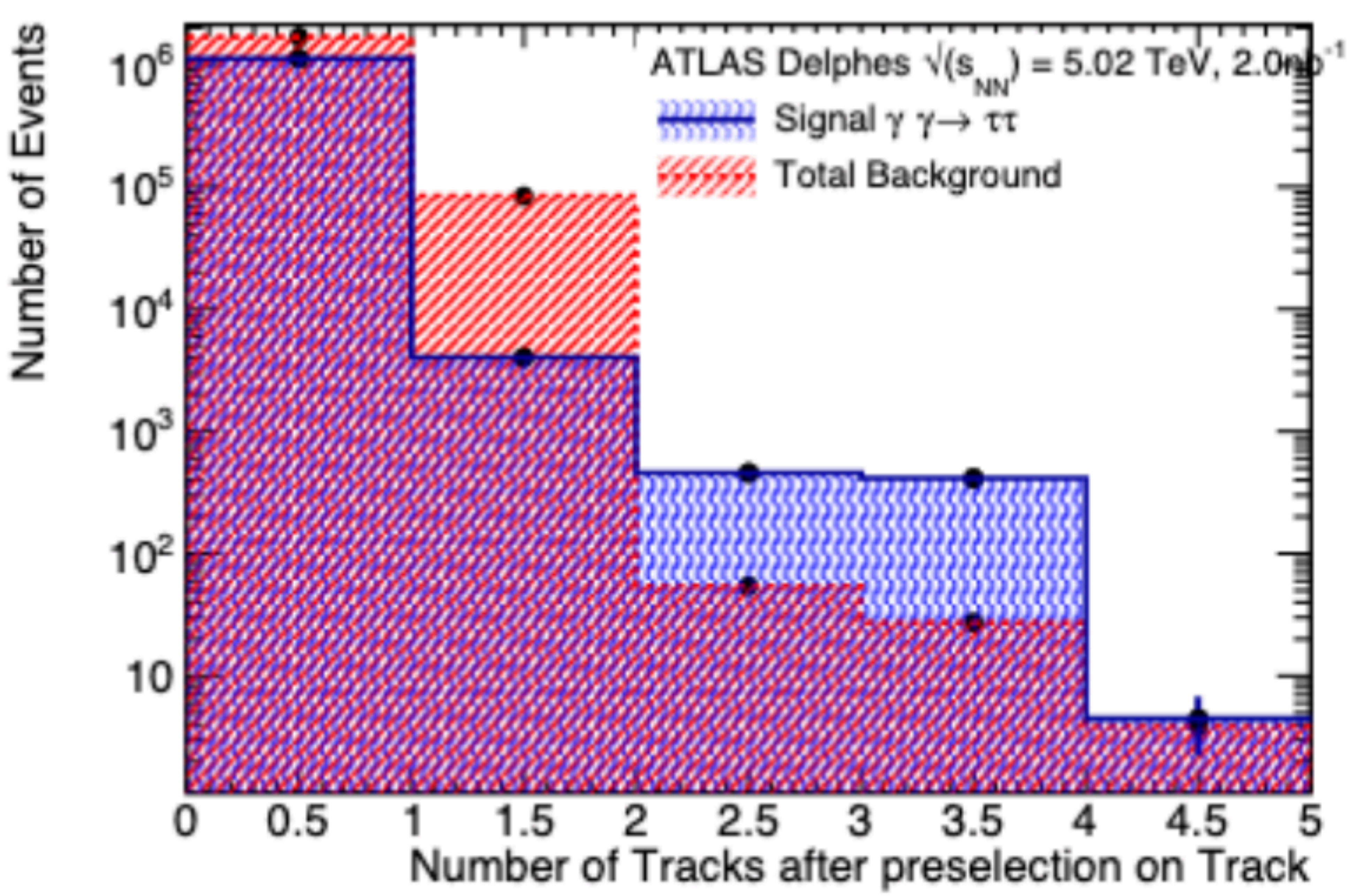
$$\mathcal{B}(\tau^{\pm} \to \ell^{\pm}\nu_{\ell}\nu_{\tau}) = 35\%,$$
$$\mathcal{B}(\tau^{\pm} \to \pi^{\pm}\nu_{\tau} + \text{neutral pions}) = 45.6\%,$$
$$\mathcal{B}(\tau^{\pm} \to \pi^{\pm}\pi^{\mp}\pi^{\pm}\nu_{\tau} + \text{neutral pions}) = 19.4\%.$$

Signal Region Identification

- Two Signal Regions (SRs) driven by tau decays:
  - **1 lepton + one track (1L1T)**
  - **1 lepton + three tracks (1L3T)**

Preselection	Cuts
Electron Identification	$p_T > 4.5$ GeV, $\lvert\eta\rvert < 2.4$
Muon Identification	$p_T > 3.5$ GeV, $\lvert\eta\rvert < 2.5$
Track Identification	$p_T^{(track)} > 500$ MeV, $\lvert\eta^{(\mathrm{track})}\rvert < 2.5$





Constraining atau with LHC

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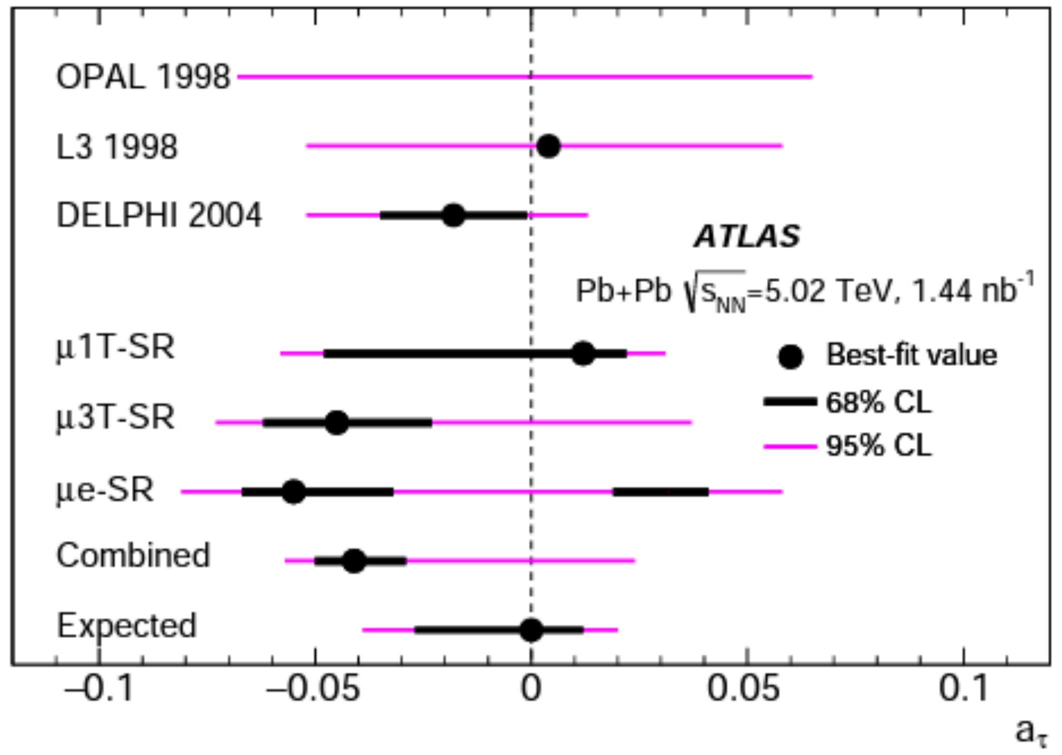
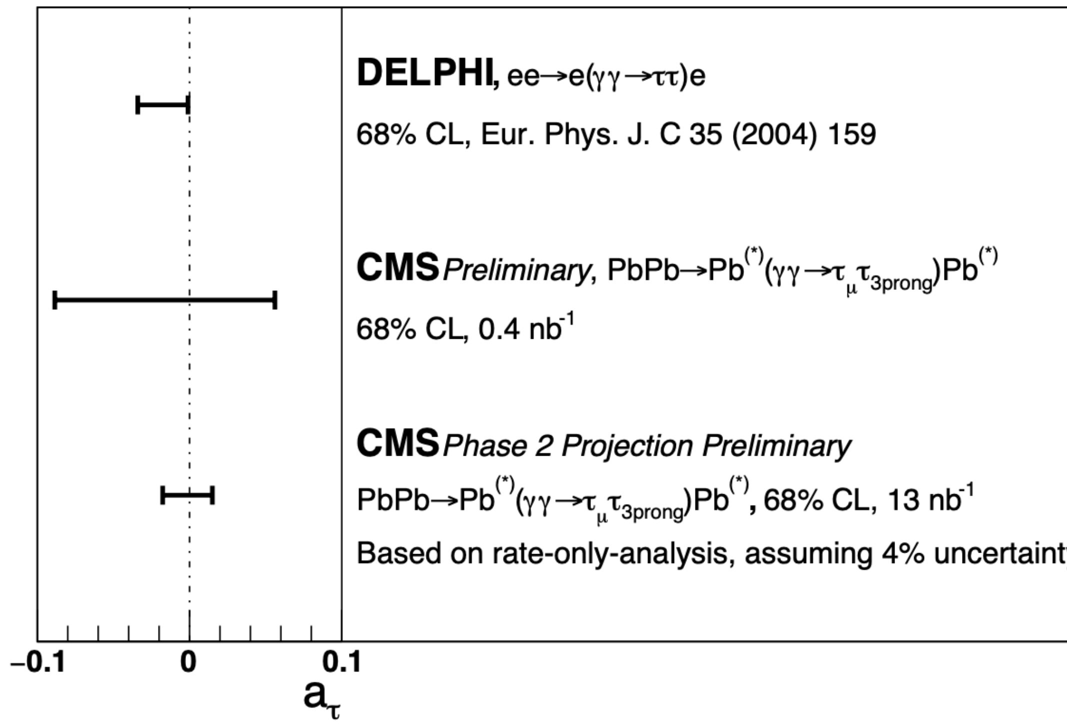
- ATLAS and CMS analyses aim to improve existing constraints on $a_\tau = (g-2)/2$ using $\gamma\gamma \to \tau\tau$ events produced in ultraperipheral Pb+Pb collisions.





- Analysis idea from:
  - L. Beresford, J. Liu, PRD 102 (2020) 113008
  - M. Dyndal, M. Schott, M. Klusek-Gawe… A. Szczurek, PLB 809 (2020) 135682
  - Main Background
    - $\gamma\gamma \to ll$
    - $\gamma\gamma \to qq$
    - photo-nuclear events

$\tau^\pm \to \nu_\tau + \ell^\pm + \nu_\ell \ (\ell = e,\ \mu)$	1 Lepton
$\tau^\pm \to \nu_\tau + \pi^\pm + n\pi^0$	1 Charged Pion
$\tau^\pm \to \nu_\tau + \pi^\pm + \pi^\mp + \pi^\pm + n\pi^0$	3 Charged Pions

$$\mathcal{B}(\tau^\pm \to \ell^\pm \nu_\ell \nu_\tau) = 35\%,$$
$$\mathcal{B}(\tau^\pm \to \pi^\pm \nu_\tau + \text{neutral pions}) = 45.6\%,$$
$$\mathcal{B}(\tau^\pm \to \pi^\pm \pi^\mp \pi^\pm \nu_\tau + \text{neutral pions}) = 19.4\%.$$

Complete cut flow: a_{tau}

Selection Cuts	a_τ -0.04	a_τ -0.02	a_τ -0.01	a_τ SM 0	a_τ +0.01	a_τ +0.02	a_τ +0.04
Total Event	1000000	1052631	1081081	1111111	1142857	1176470	1212121
Signal Region 1 Lepton and 1 Track (SR1L1T)							
1 Lepton	5828.5	5804.41	5766.66	6075.59	6113.13	6580.31	7057.2
1 Track	3917	3905.02	3923.1	4031.52	4091.79	4422.94	4804.2
$Charge_{1L1T} = 0$	3853	3845.06	3864.24	3967.14	4030.69	4349.44	4729.2
Acoplanarity<0.4	1757.5	1811.02	1773.9	1893.11	1872.31	2029.78	2149.2
P_T^{Muon} >4GeV	1320	1336.04	1318.14	1403.04	1374.4	1513.51	1596.6
E_T^{Miss} >1GeV	1220.5	1237.15	1213.92	1283.16	1259.63	1392.97	1480.2
Signal Region 1 Lepton and 3 Track (SR1L3T)							
1 Lepton	5828.5	5804.41	5766.66	6075.59	6113.13	6580.31	7057.2
3 Tracks	422	410.28	371.52	416.81	433.39	450.99	488.4
$Charge_{1L3T} = 0$	420.5	409.23	369.36	416.25	431.68	450.41	487.2
$Mass_{3T}$ <1.7GeV	420	403.97	365.58	413.48	426.54	449.23	484.8
Acoplanarity<0.2	403	383.98	345.06	390.72	403.13	420.42	459.6
P_T^{Muon} ¿4GeV	344	327.70	299.7	323.01	336.32	355.74	397.8

Complete Cut Flow

Selection	$\gamma\gamma \to \tau\tau$	$\gamma\gamma \to \mu\mu$	$\gamma\gamma \to ee$	$\gamma\gamma \to bb$	$\gamma\gamma \to cc$	$\gamma\gamma \to jj$
Total Event	1111111	869565	869565	3245.91	6557.38	7380.07
Signal Region 1 Lepton and 1 Track (SR1L1T)						
1 Lepton	6081.06	57964.6	35241.6	18.96	0.31	0.03
1 Track	4035.15	54400.6	27396.2	1.43	0.05	0
$Charge_{1L1T} = 0$	3970.71	54399.7	27395	0.88	0.02	0
Acoplanarity<0.4	1894.81	1193.53	435.71	0.52	0.003	0
P_T^{Muon} >4GeV	1404.3	746.75	435.71	0.31	0.003	0
Signal Region 1 Lepton and 3 Track (SR1L3T)						
1 Lepton	6081.06	57964.6	35241.6	18.96	0.31	0.03
3 Tracks	417.18	13.62	5.53	3.82	0.09	0.09
$Charge_{1L3T} = 0$	416.63	13.19	5.53	1.91	0.05	0
$Mass_{3T}$ <1.7GeV	413.85	5.96	2.55	0.40	0.01	0.01
Acoplanarity<0.2	391.07	5.96	1.70	0.35	0.01	0.01
P_T^{Muon} >4GeV	323.30	4.68	1.70	0.23	0.01	0.01

Photon Flux

$$\sigma^{(Pb-Pb)}(\gamma\gamma \to \tau^+\tau^-) = \int dx_1 dx_2 N(x_1) N(x_2) \hat{\sigma}(\gamma\gamma \to \tau^+\tau^-) \,,$$

$$N(x_i) = \frac{2Z^2\alpha}{x_i\pi}\{\bar{x}_i K_0(\bar{x}_i) K_1(\bar{x}_i) - \frac{\bar{x}_i{}^2}{2}[K_1^2(\bar{x}_i) - K_0^2(\bar{x}_i)]\} \quad (1)$$

$$x_i = E_i/E_{\rm beam}\,, \quad \bar{x}_i = x_i\, m_N b_{\rm min}/2\,,$$

where, for Pb, Z = 82, A = 208, the nucleon mass m_N = 0.9315 GeV, the nucleus radius $R_A \simeq 6.09 A^{1/3}$ GeV^{-1} ≃ 7 fm, bmin ≃ 2 R_A is the minimum impact parameter and K0(K1) are the modified Bessel functions of the second kind of the first (second) order.