Study of t-Channel Production of Scalar LeptoQuarks at LHCb and Central Acceptance Detector

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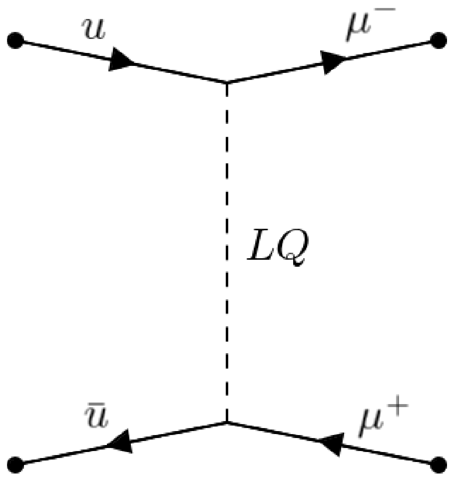
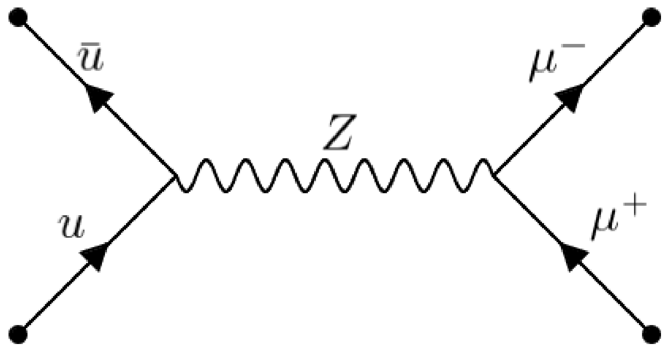
08/10/2023

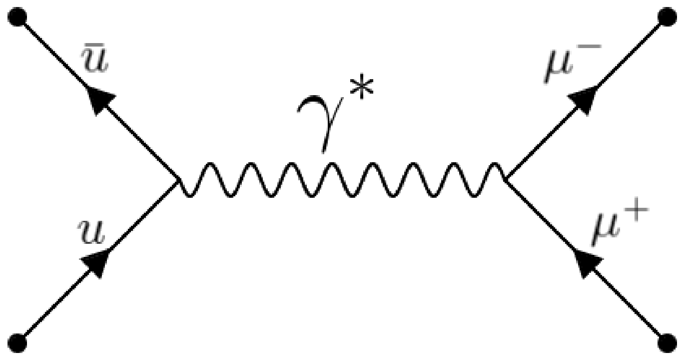
Background and Motivation

- **Scalar Leptoquark (SLQ): hypothetical beyond standard model particle that couples simultaneously to quarks and leptons**
- **Provides possible explanation for flavor anomalies detected at LHCb and other experiments**
- **Appear as propagator in Drell-Yan process – models with large couplings to heavy quarks link flavor anomalies with modifications in DY dilepton distributions**



t-channel SLQ production





SM s-channel Z boson, photon production

Method

- **Examine various simulated kinematic distributions for SM alone and then SM+SLQ model**
- **Compare the SM and SM+SLQ results for the Central Acceptance and LHCb detectors**
- **Make strategic cuts to enhance signal/background significance**
- **Significance estimator used is defined as:**

$$S = \frac{(SM + SLQ) - SM}{\sqrt{SM}}$$

SLQ Model

- **Used default parameters specified in SLQRules-UFO-CKM Madgraph model (default masses, default couplings set to unity)**
- **Simulated SM processes alone in Madgraph using default settings, then imported SLQ model and simulated SM and SLQ processes together**
- **Ran LO, fixed order simulation for both models (no showering effects included)**

SLQ Representation	Mass (GeV)
SU(2) triplet Φ_3	5000
SU(2) doublet Φ_2	3000
SU(2) doublet $\tilde{\Phi}_2$	3000
SU(2) singlet Φ_1	1000
SU(2) singlet $\tilde{\Phi}_1$	1000

Data Sets – LHCb, Central Acceptance

Generation Parameter	LHCb	Central Acceptance
Total # of events N	10^6	10^6
Collision Energy (TeV)	13.6	13.6
Luminosity L (fb^{-1})	50	500
Lepton pT (GeV)	> 10	> 10
Lepton Rapidity η	$2 < \eta < 5$	$-2.5 < \eta < 2.5$
$M_{\ell\ell}$ (GeV)	> 500	> 500

- **Simulation results normalized by normalization constant *c*:**

$$c = \frac{\sigma * L}{N}$$

Analysis

LHCb:

SM σ=1.39 (fb)

SM+SLQ σ=1.51 (fb)

$M_{\ell\ell}$ Cut	Fraction of SM Events	Fraction of SM+SLQ Events	Signal	Background
>600	$5.93*10^{-6}$	$6.64*10^{-6}$	0.70	5.94
>800	$4.76*10^{-7}$	$5.60*10^{-7}$	0.09	0.48
>1000	$3.66*10^{-8}$	$5.00*10^{-8}$	0.01	0.04

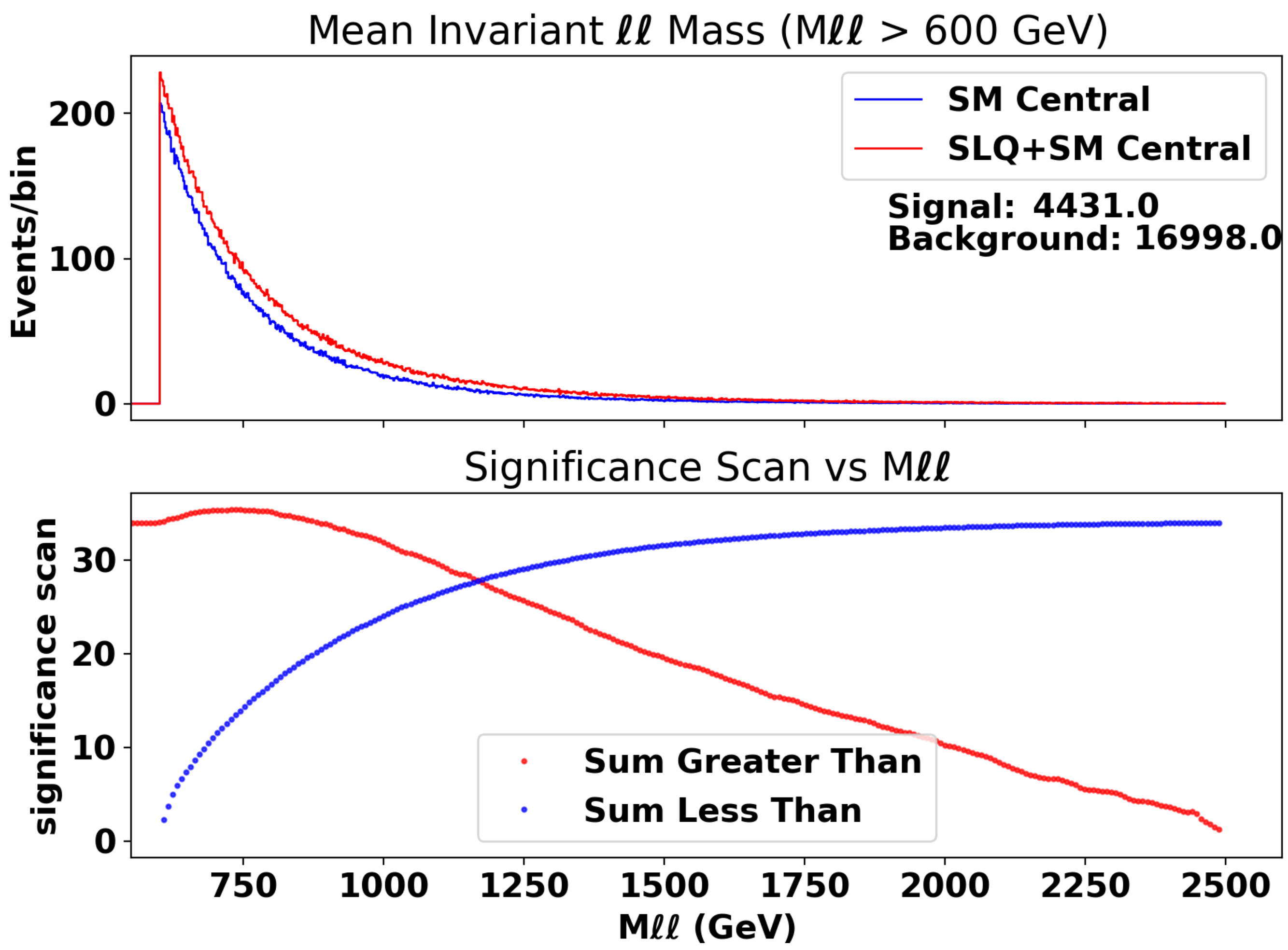
Central Acceptance:

SM σ=65.6 (fb)

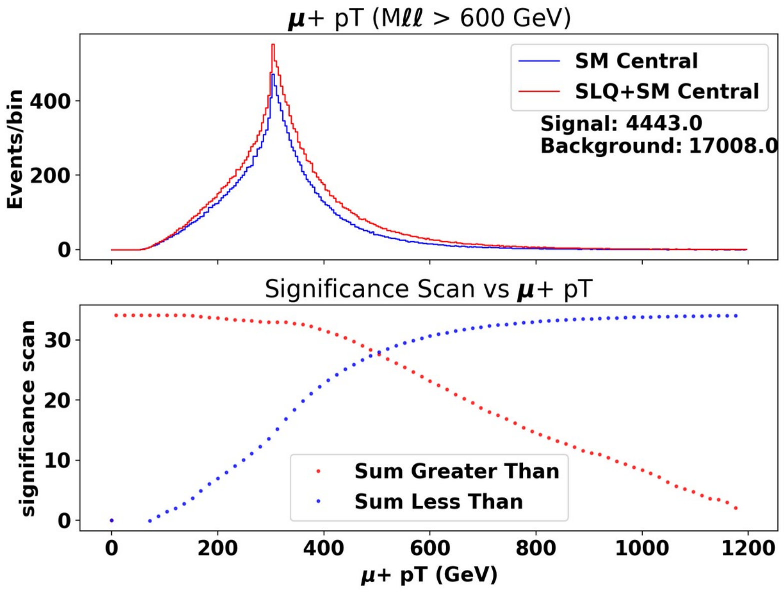
SM+SLQ σ=76.5 (fb)

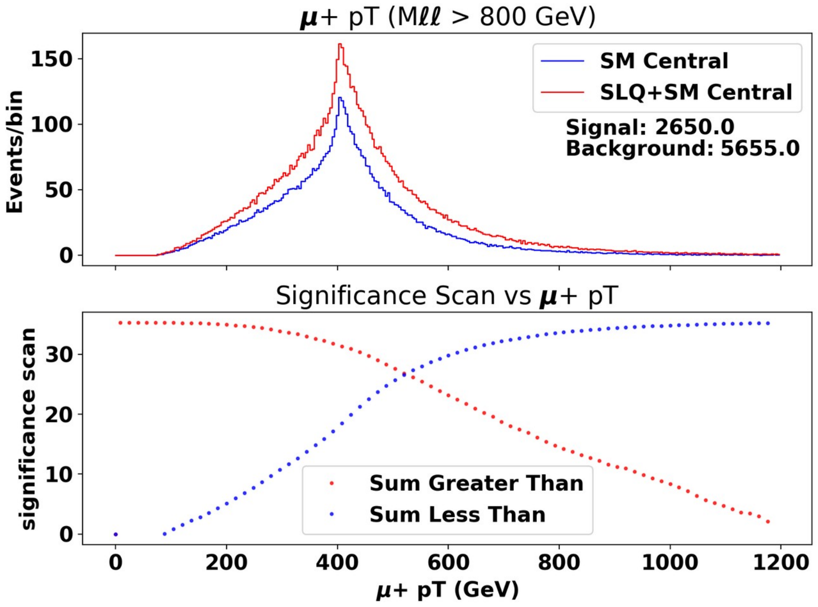
$M_{\ell\ell}$ Cut	Fraction of SM Events	Fraction of SM+SLQ Events	Signal	Background
>600	0.017	0.021	4,440	17,000
>800	0.006	0.008	2,660	5,660
>1000	0.002	0.004	1,520	2,240

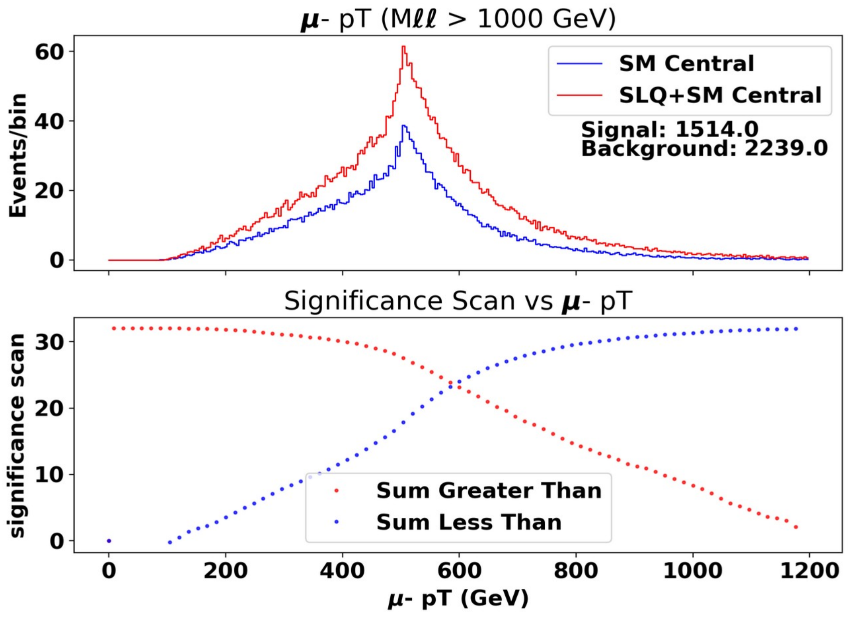
Central Acceptance Distributions - Mean Lepton Invariant Mass ($M_{\ell\ell}$)



Central Acceptance Distributions – pT, μ^+

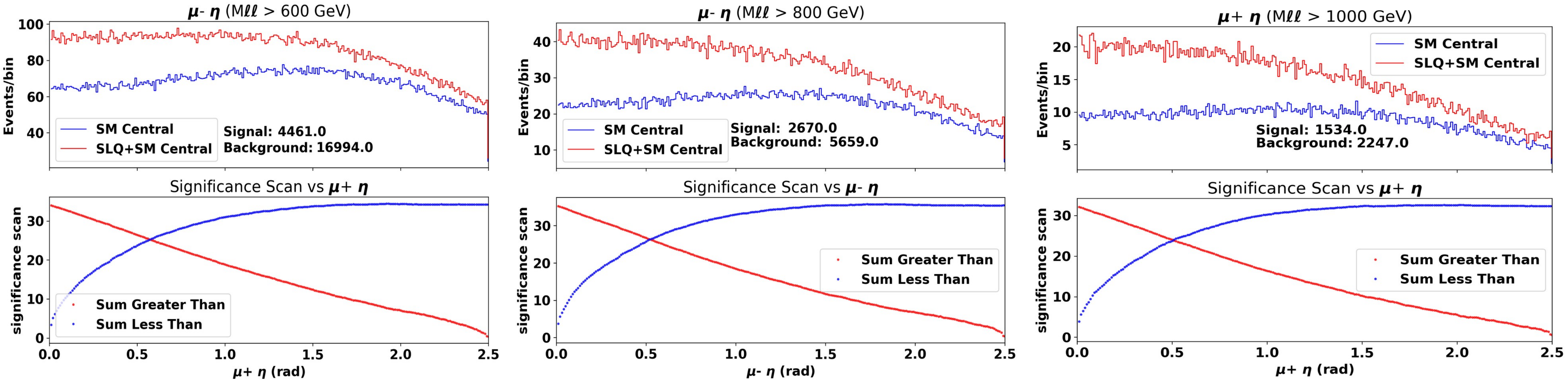




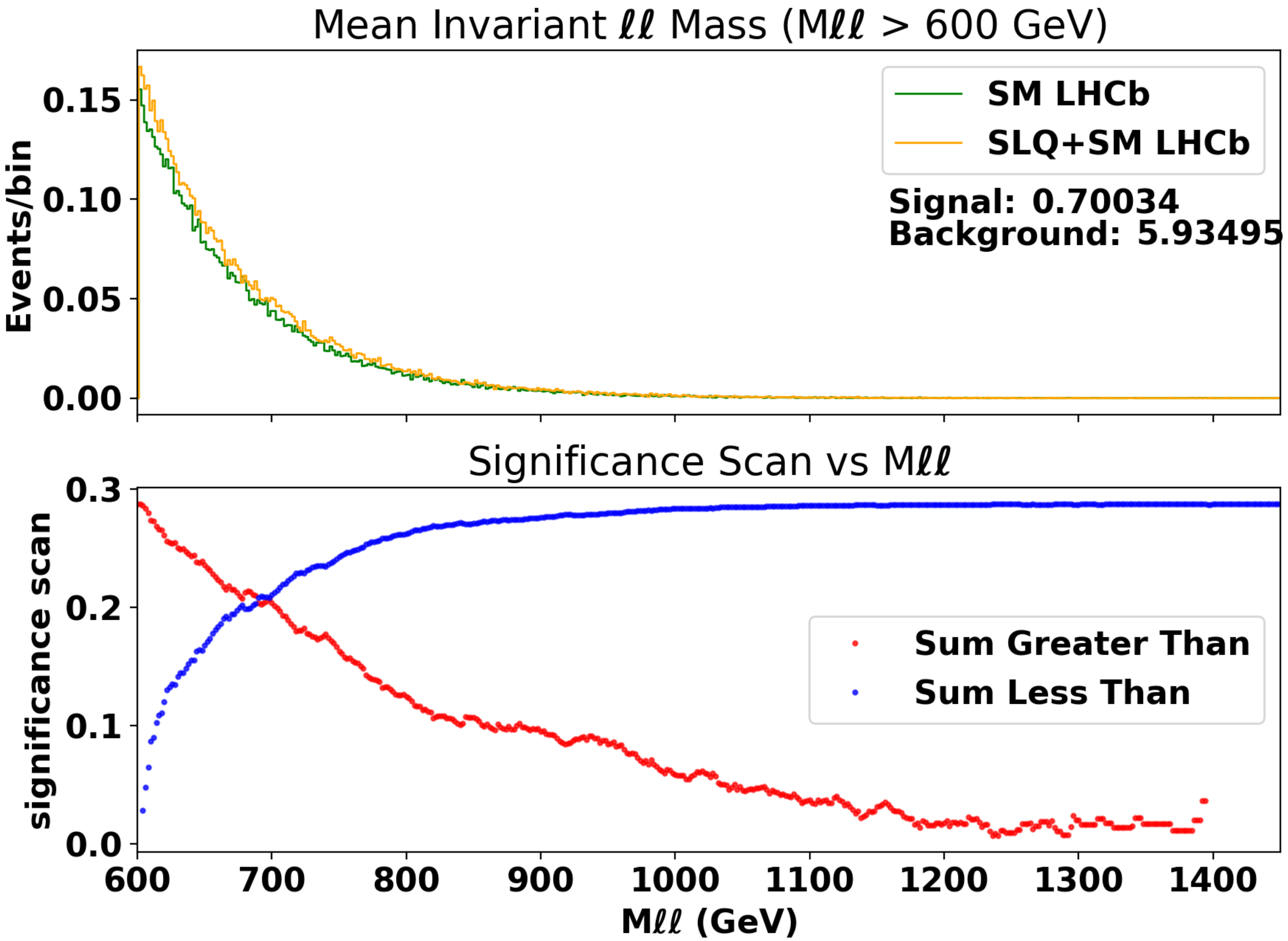


***lepton 1 and lepton 2 pT distributions are identical**

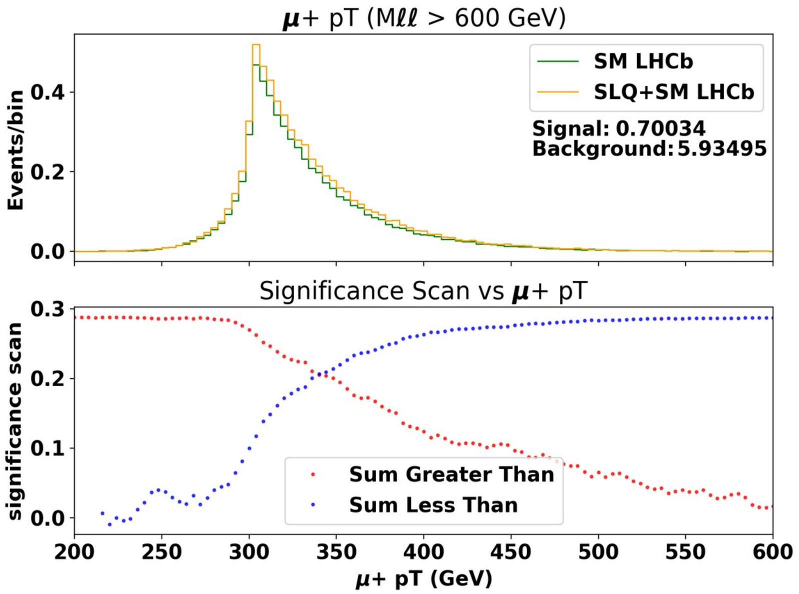
Central Acceptance Distributions – η, μ⁻ (absolute value)

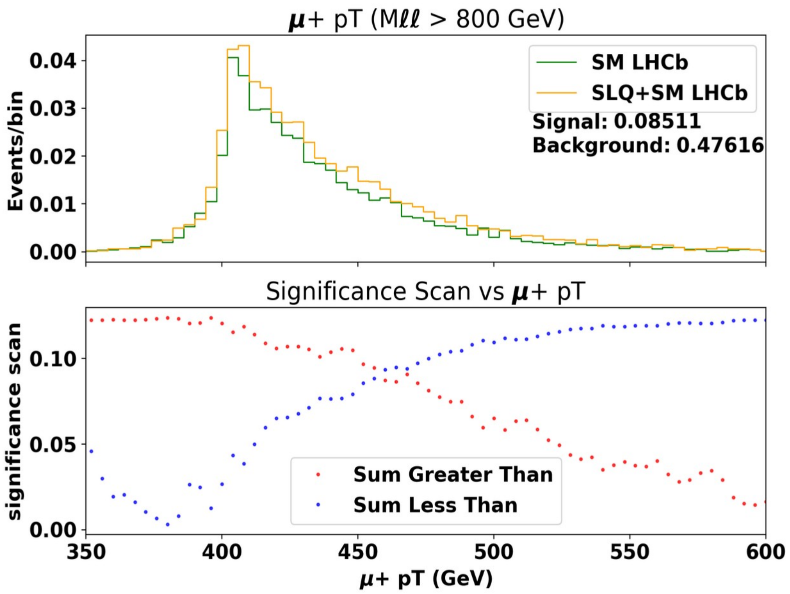


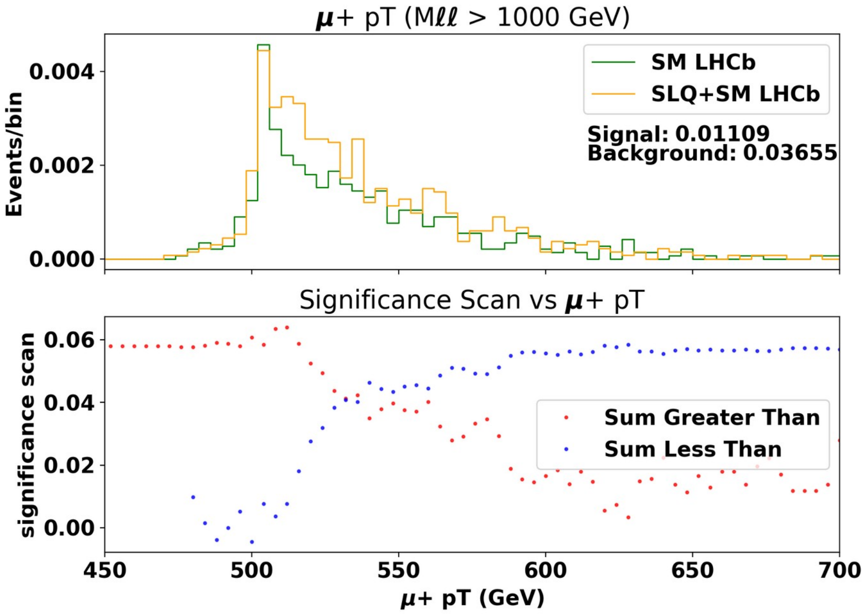
LHCb Distributions – $M_{\ell\ell}$



LHCb Distributions – pT, μ^+







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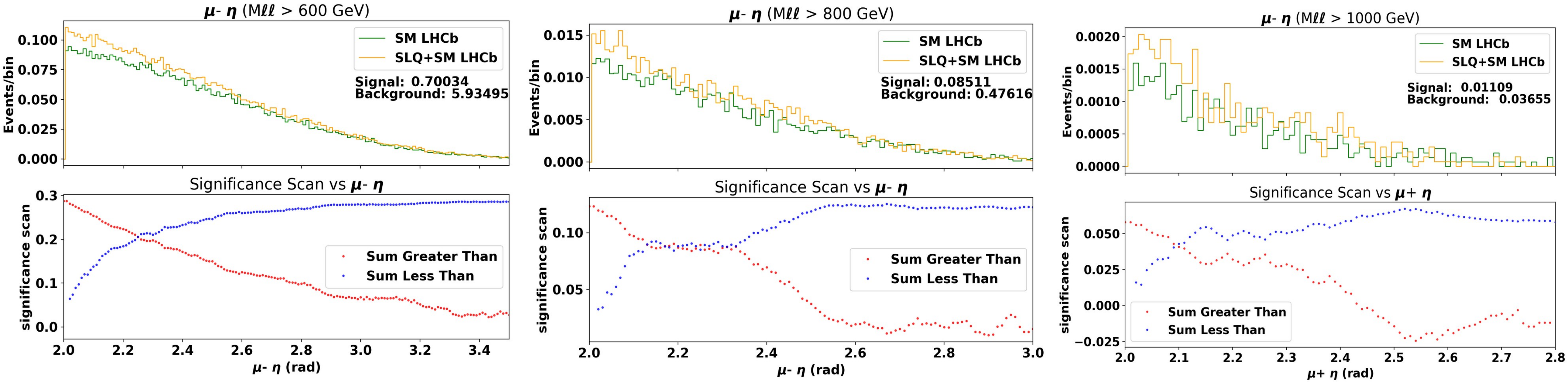
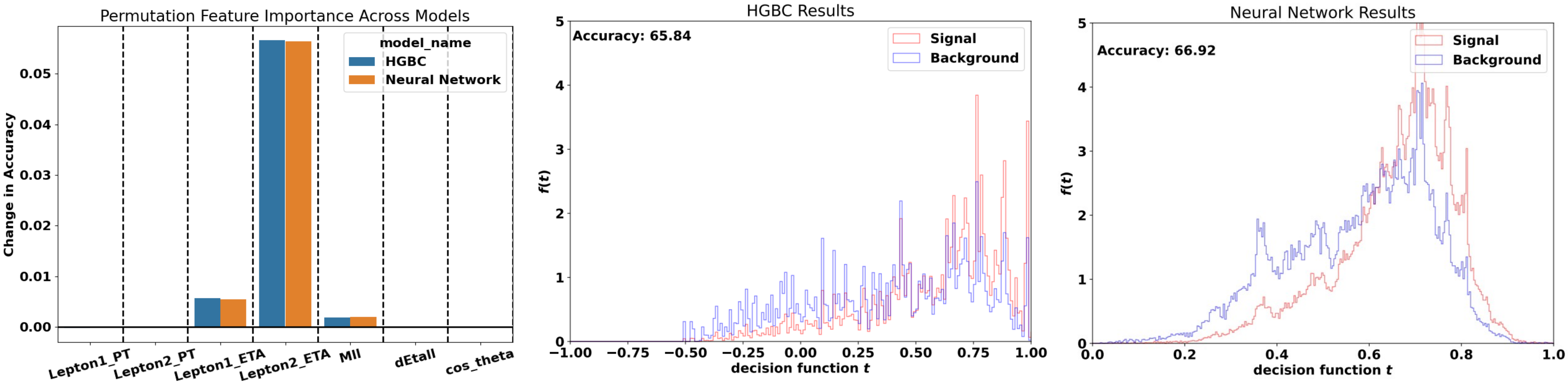
LHCb Distributions – η, μ-



Machine Learning Application

- To enhance signal/background separation, attempted ML classifier technique using the kinematic distributions as input
- Compared results from two types of classifiers: Histogram Gradient Boosting Classifier and a fully connected 5 hidden layer Neural Network Classifier
- Generated new sample set of SLQ events alone to train classifiers

Classifier Results (Preliminary) – Central Acceptance



Summary

- **Very low sensitivity to t-channel production of SLQs detected at LHCb, due to low luminosity and strict eta acceptance**
- **Much higher sensitivity found for central acceptance, higher luminosity detectors**
- **Machine learning classifiers can be used to increase signal/background signal deconvolution more than simple box cuts – further work to be done on optimizing algorithms and selecting appropriate cuts**

What I learned…

- **Using MadGraph and ROOT, improved python skills, first time using ML classification techniques**
- **The structure of a BSM analysis – how to choose what kind(s) of events to examine, how simulations are built and what we can use them for, choosing what data might be interesting to look at, and analyzing results to ensure they are consistent with expectations**

Questions?

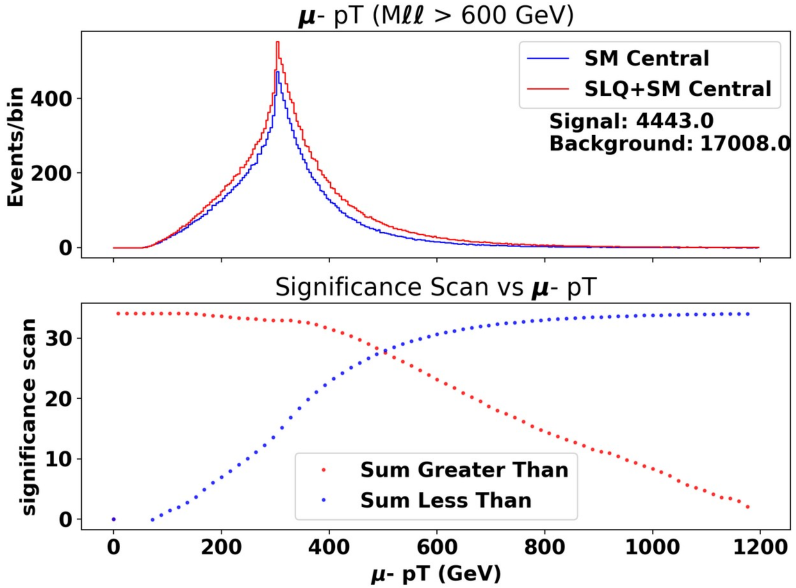
Thank you!

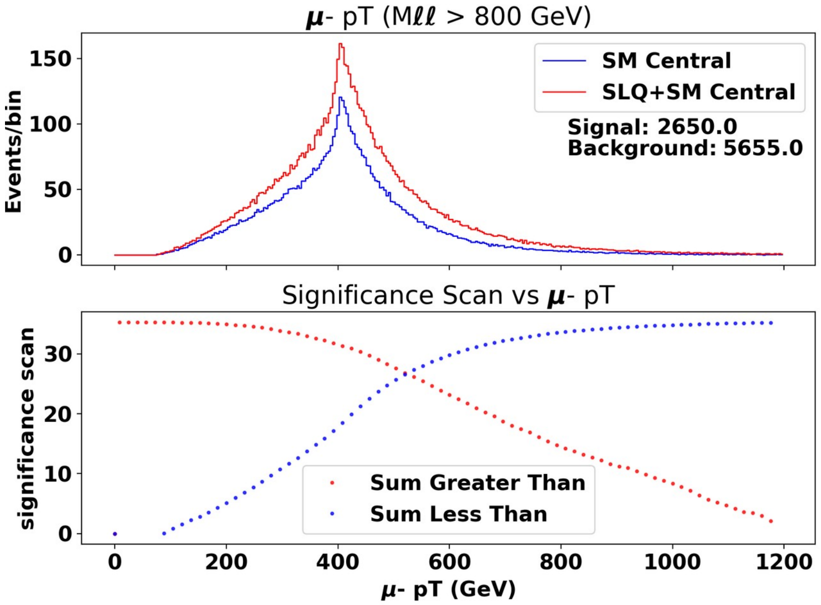
References

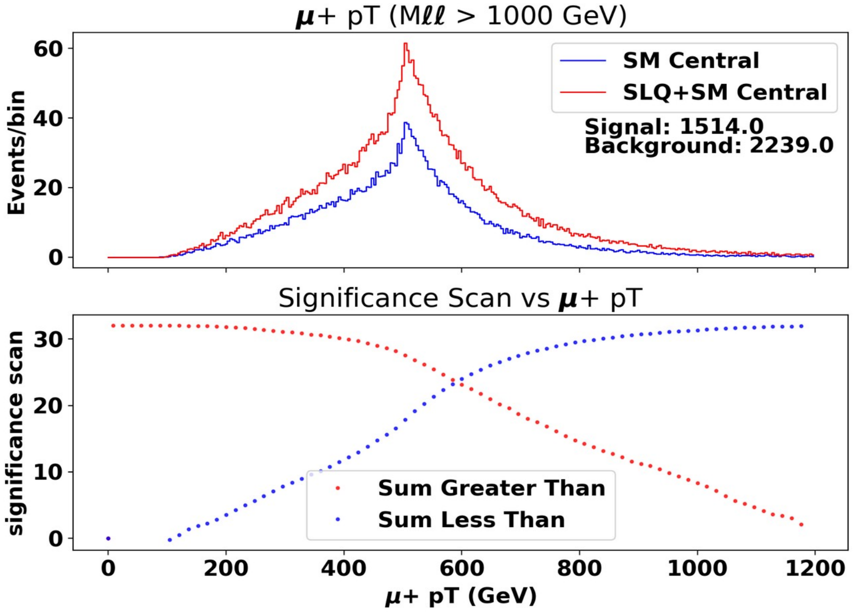
- Fajfer, S. (2018). Scalar leptoquarks: From GUT to B anomalies. EPJ Web Conf., 192 (2018) 00025.
- Wang, Y. (2022). Study of flavour-changing neutral current and charged current B meson decays [Doctoral thesis, Hua-Zhong Normal U]. CERN Theses.
- Haisch, U., Schnell, L., & Schulte, S. (2022). On Drell-Yan production of scalar leptoquarks coupling to heavy-quark flavours. Journal of High Energy Physics, 2022(11), 1-21.
- Crivellin, A., Schnell, L. Complete Lagrangian and Set of Feynman Rules for Scalar Leptoquarks. Computer Physics Communications, 271 (2022): 108188

Additional Slides

Central Acceptance Distributions – pT, μ-

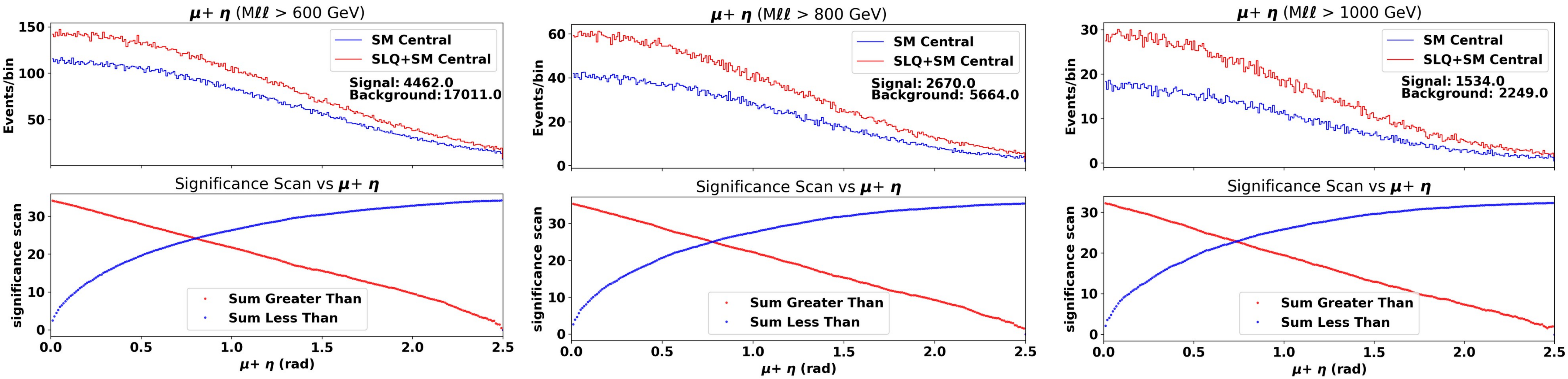




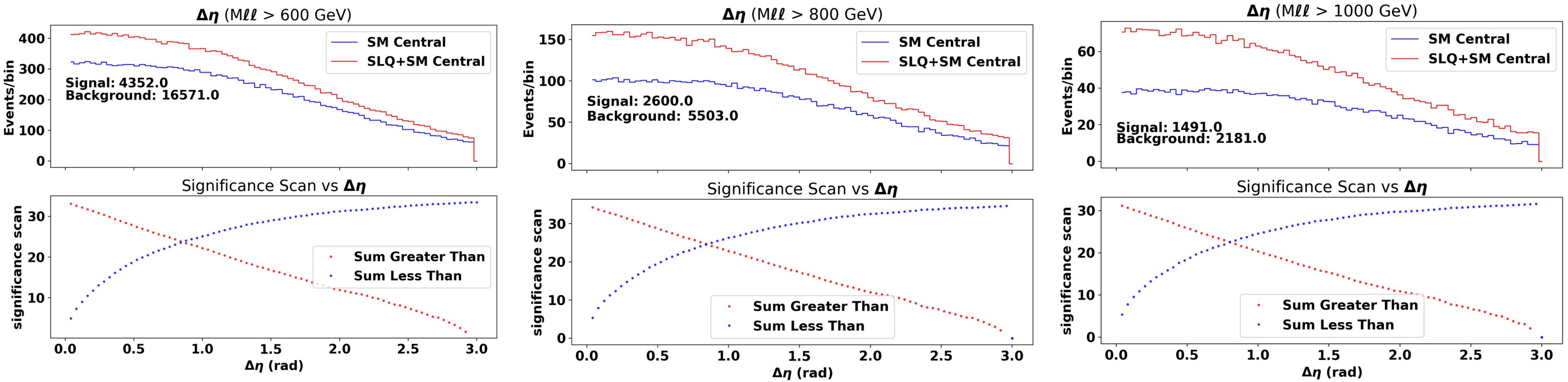


***lepton 1 and lepton 2 pT distributions are identical**

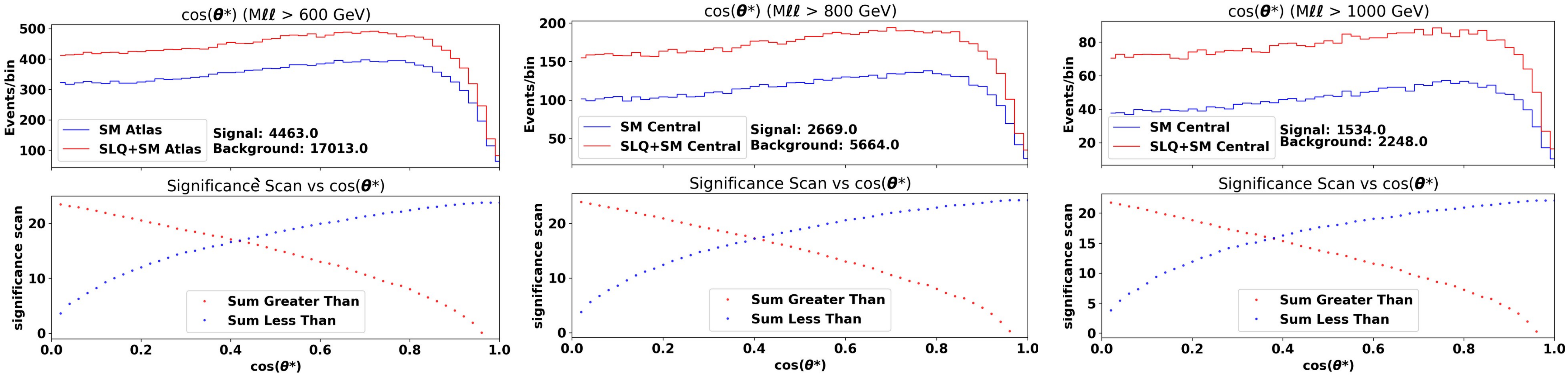
Central Acceptance Distributions – η, μ+ (absolute value)



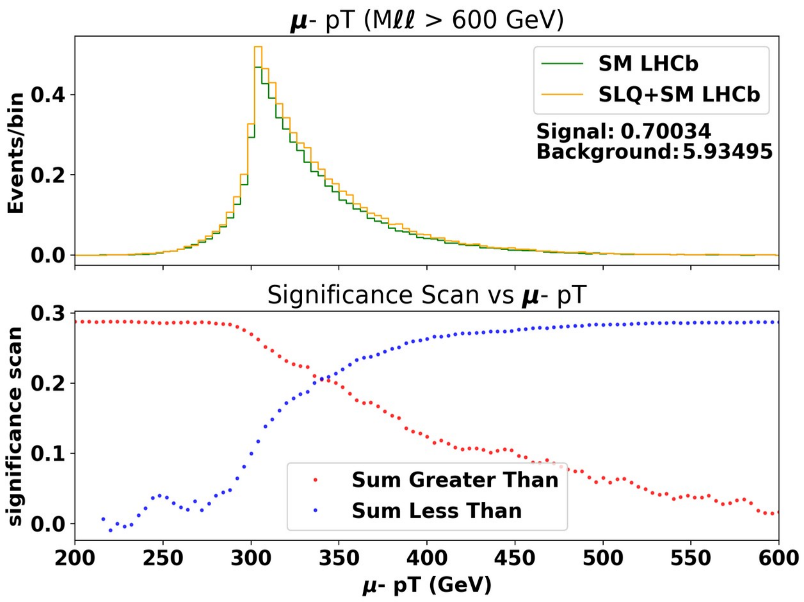
Central Acceptance Distributions – Δη (absolute value)

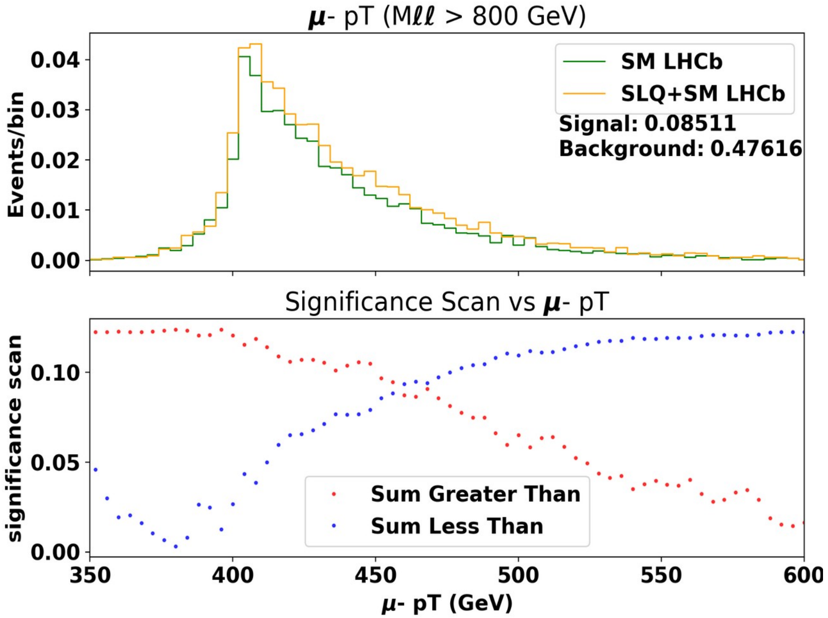


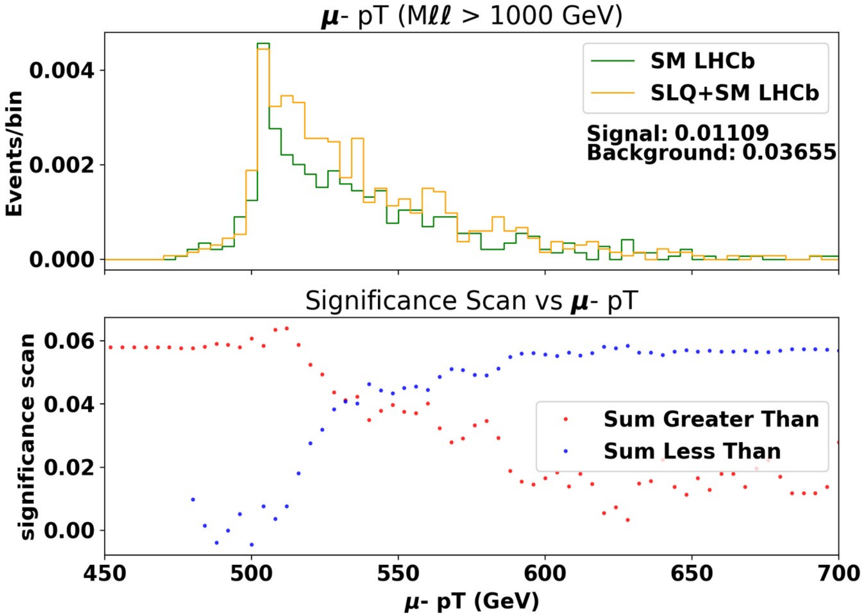
Central Acceptance Distributions – cos(θ*) (absolute value)



LHCb Distributions – pT, μ⁻







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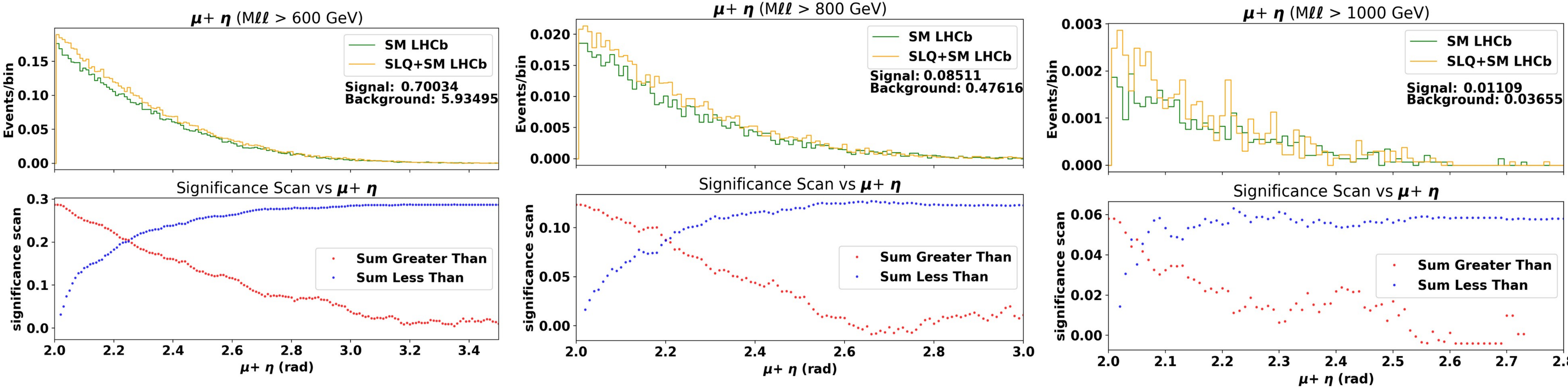
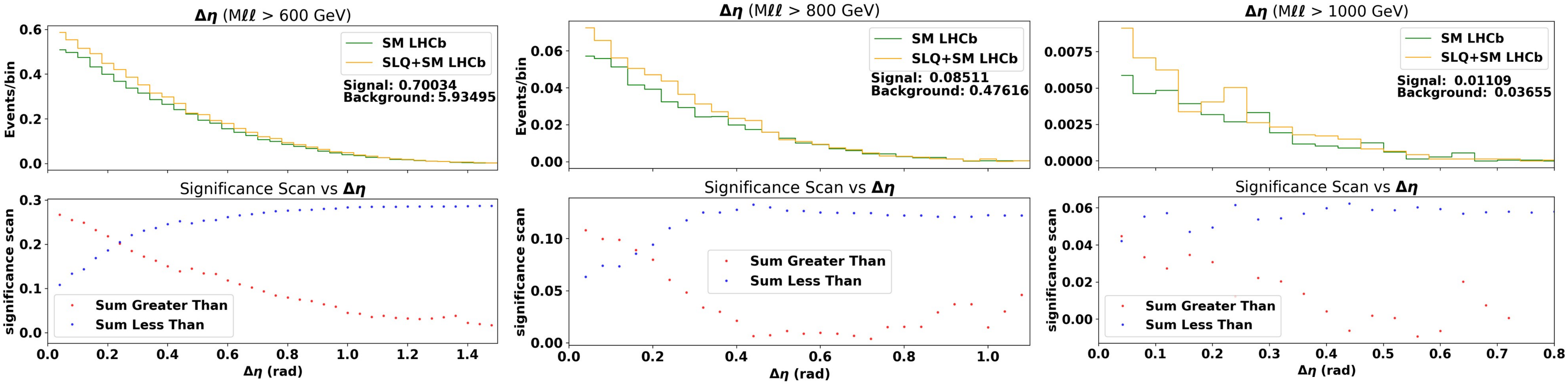
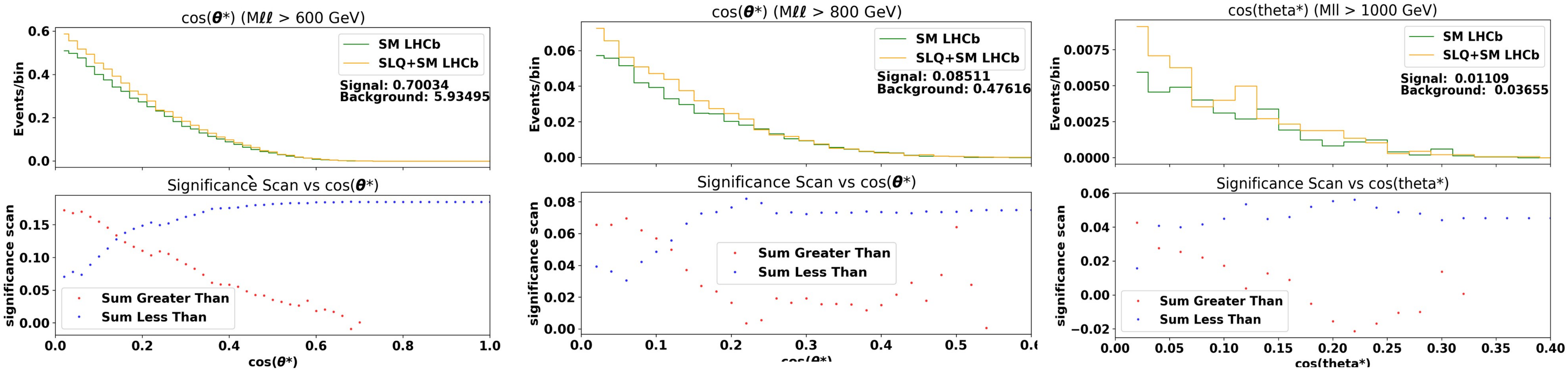
LHCb Distributions – η, μ+



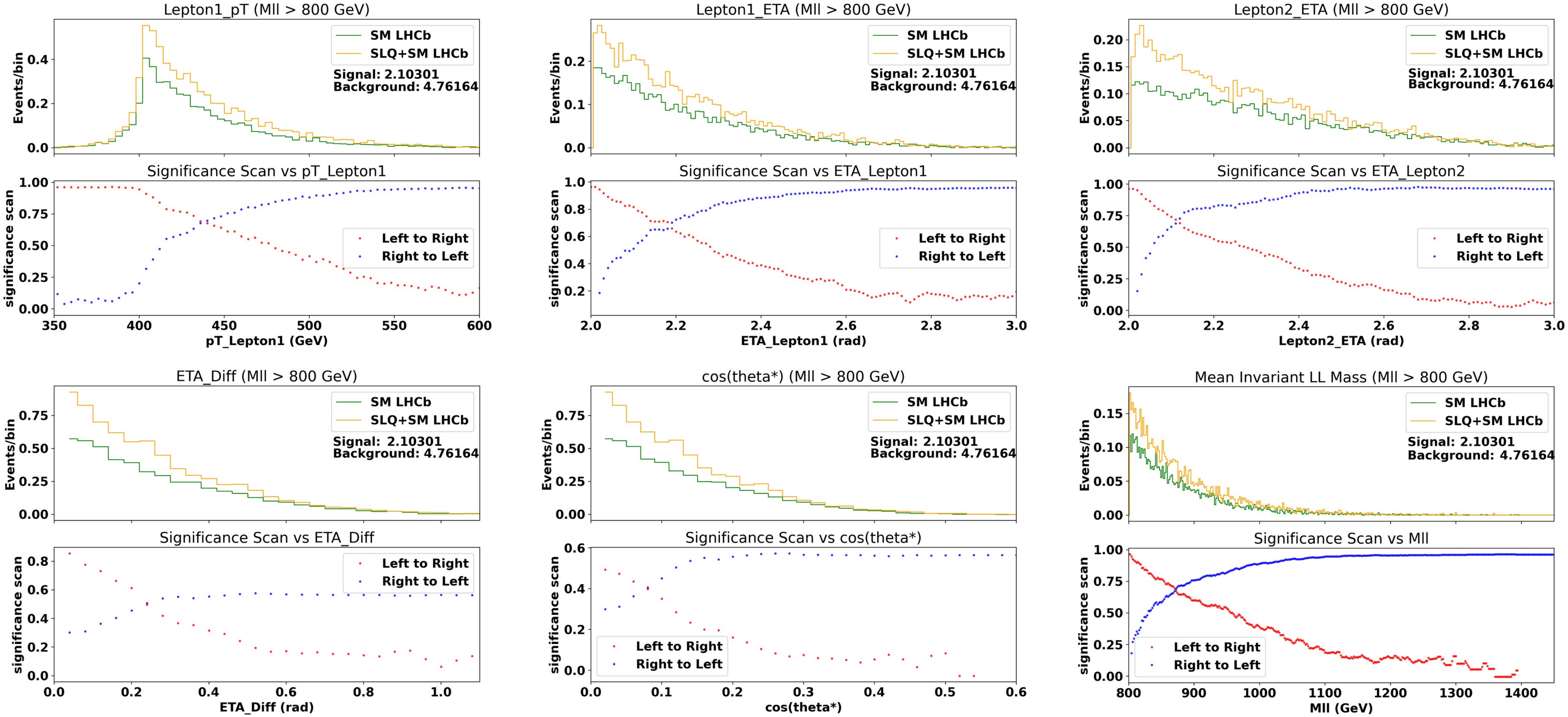
LHCb Distributions – Δη (absolute value)



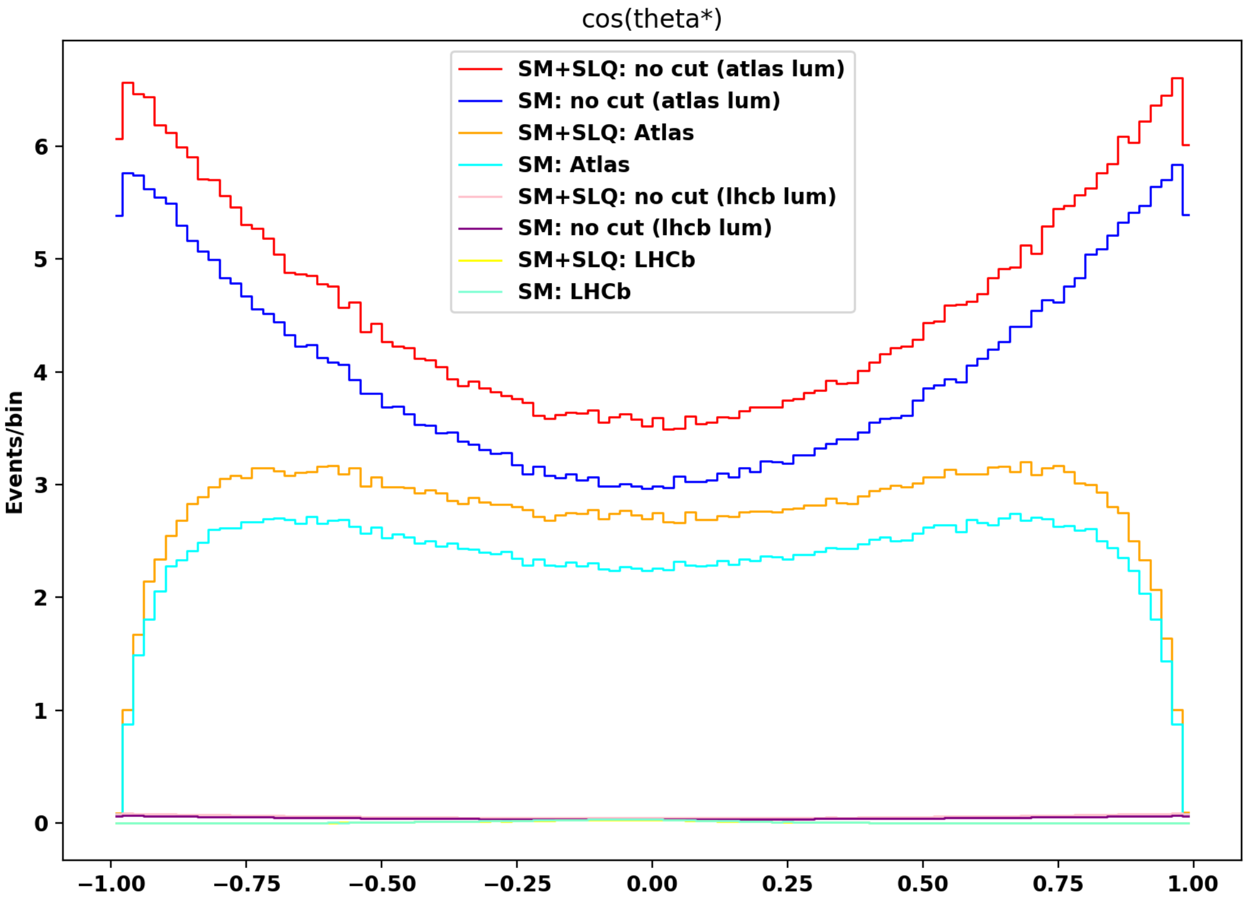
LHCb Distributions – cos(θ*) (absolute value)

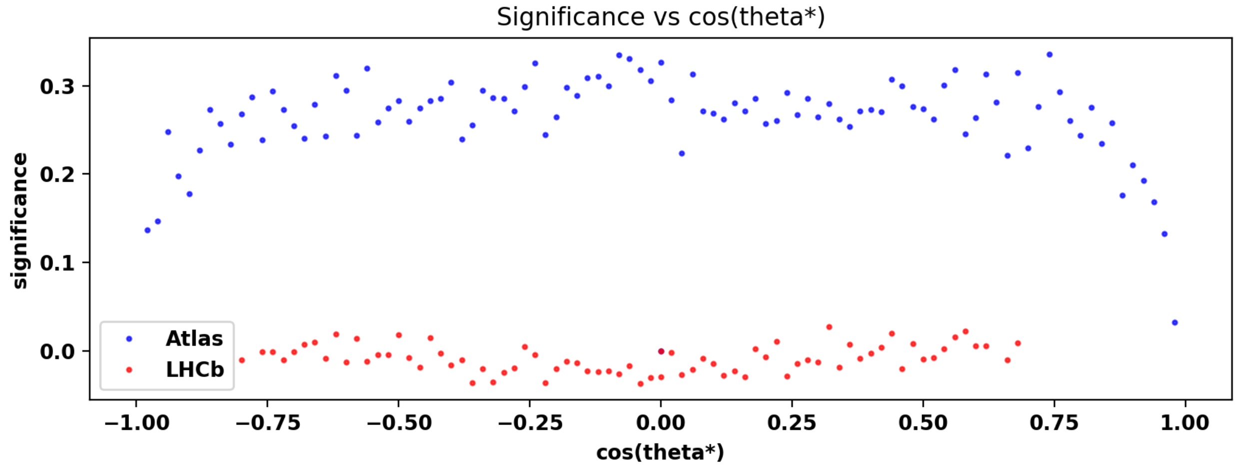


Kinematic Distributions – Half SLQ Masses, 2x L

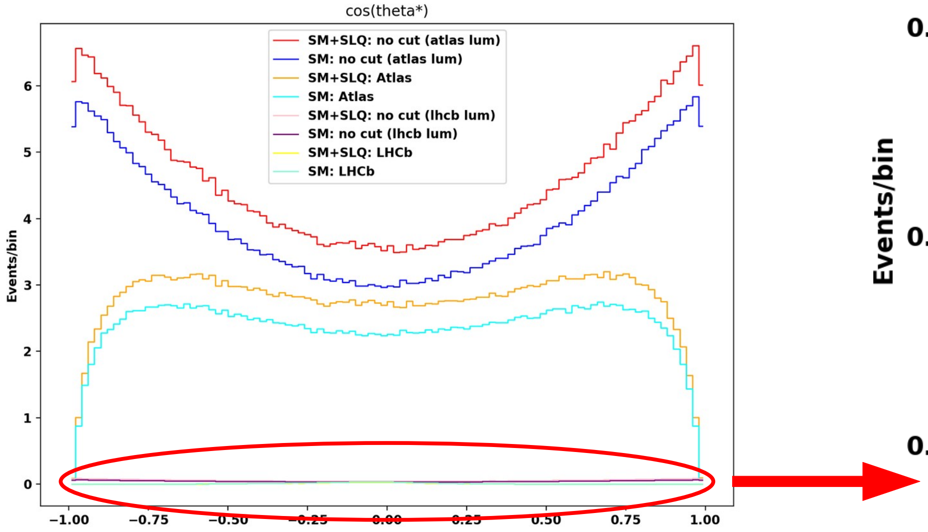


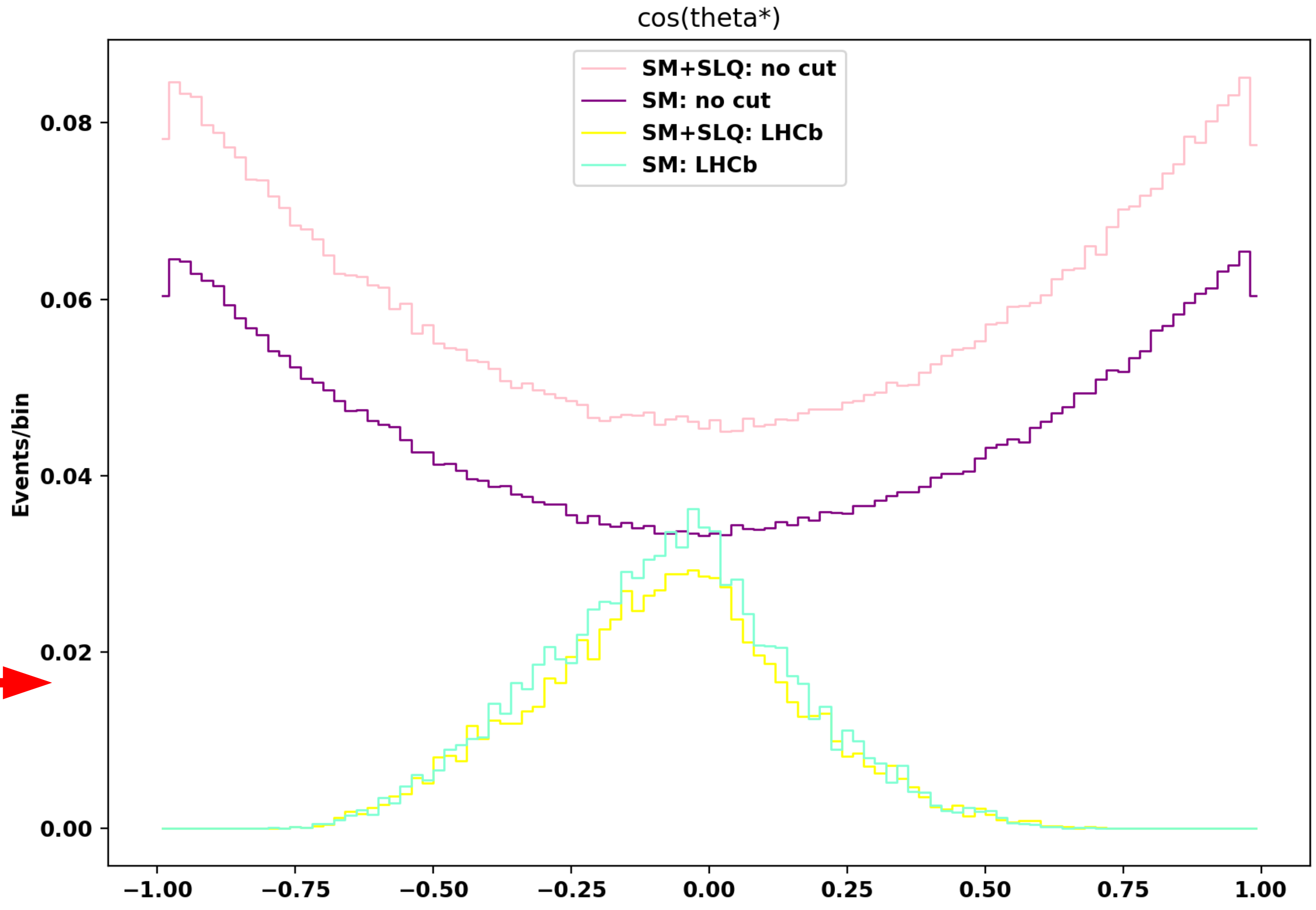
cos(ϴ*) And η Acceptance



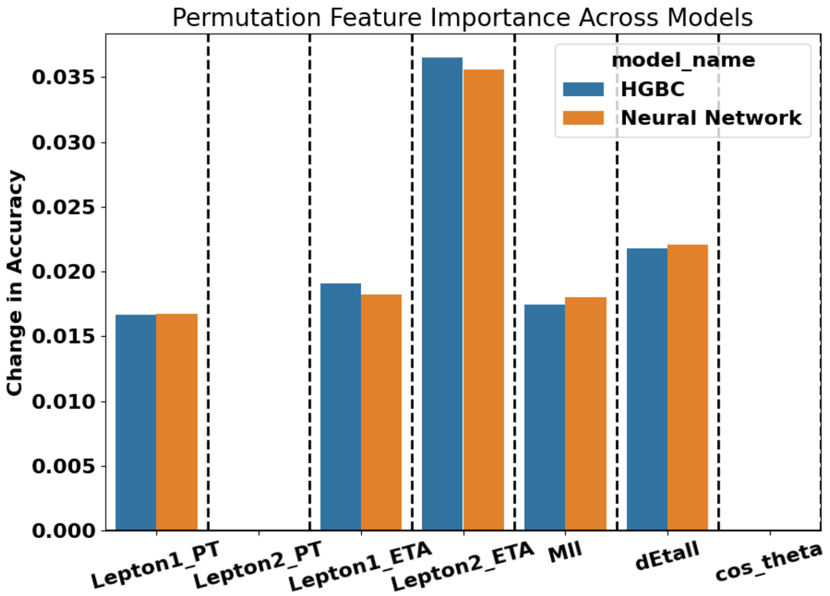


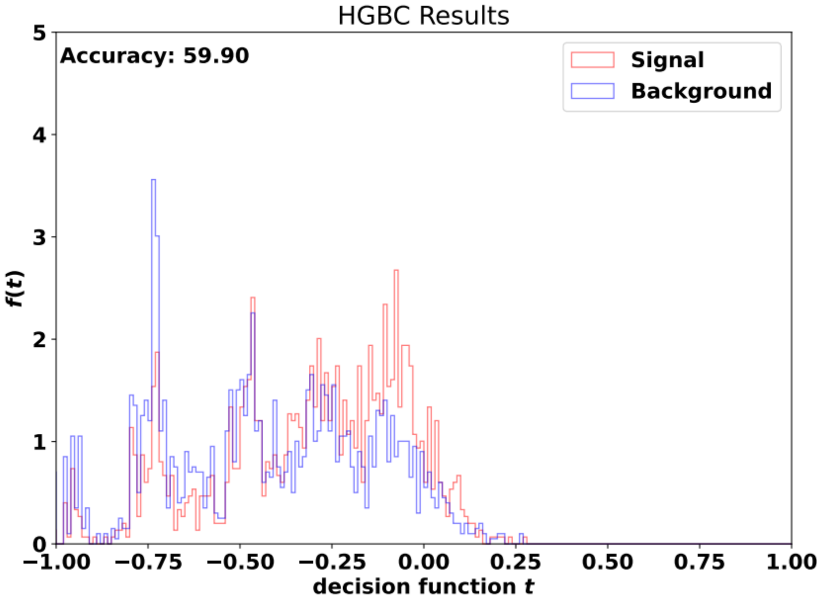
Additional Slides – cos(ϴ*) And η Acceptance

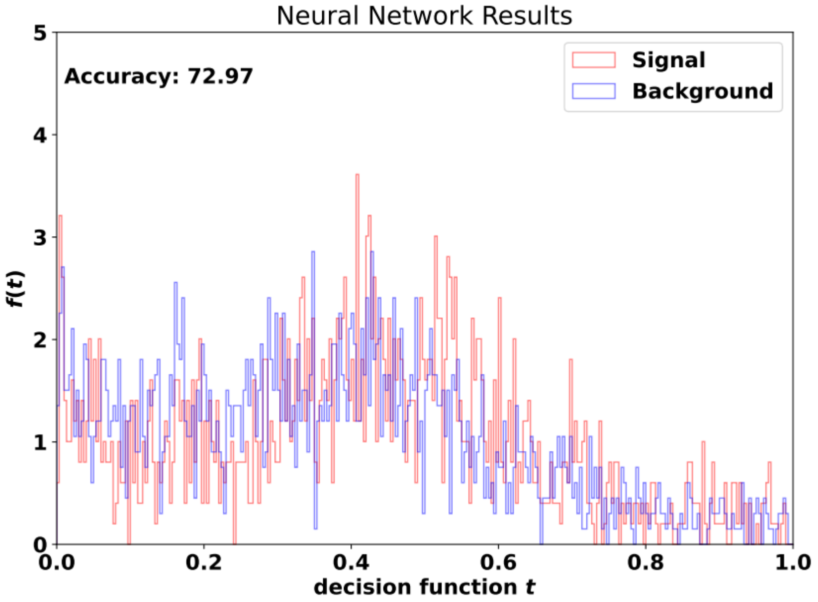




Classifier Results (Preliminary) – LHCb







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