CHARGED LEPTON FLAVOR VIOLATION E → TAU

HOW WELL CAN AN EIC DETECTOR BASED ON SPHENIX IDENTIFY TAU JETS?

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BSM/EW physics at EIC mini workshop

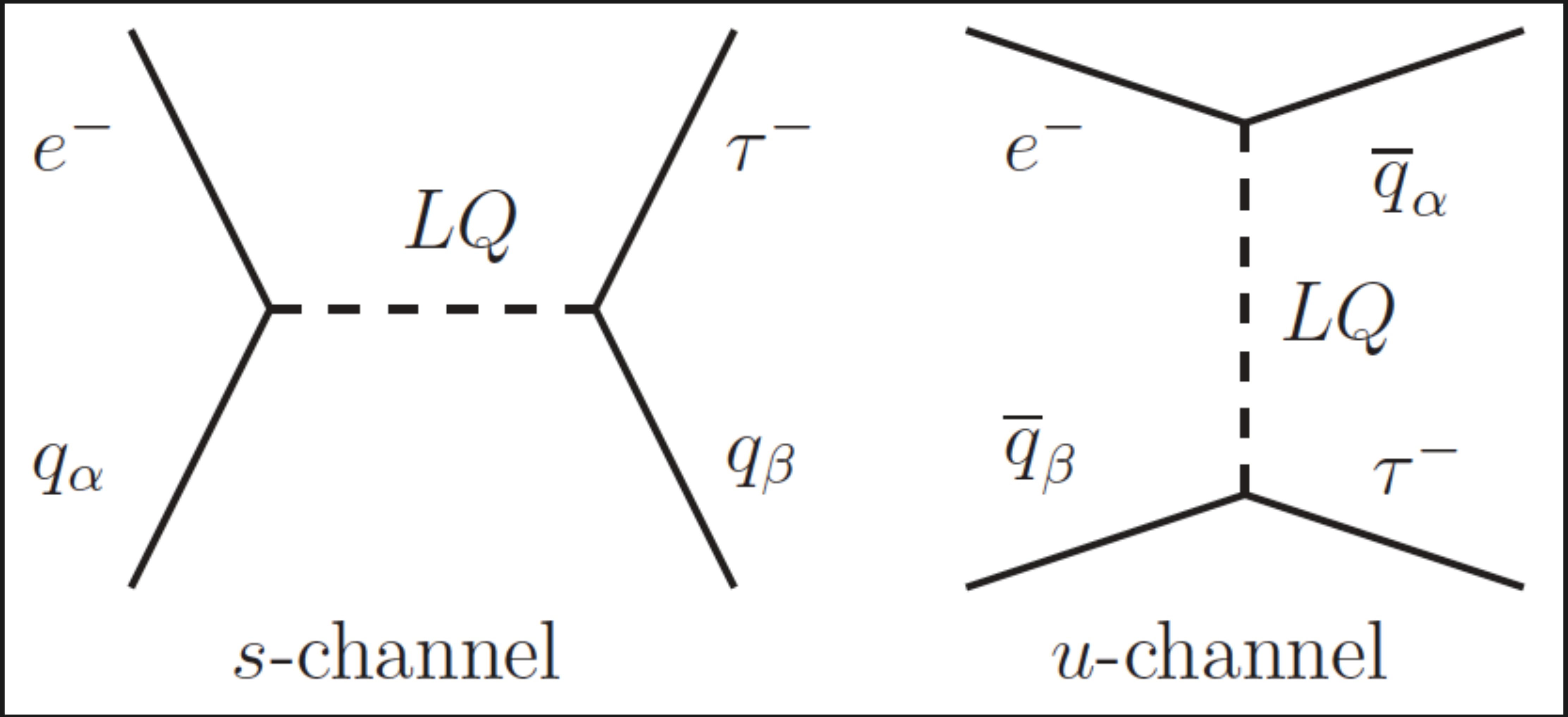
December 19th, 2017

Stony Brook University

E → TAU LFV AT EIC

- Limits in experimental searches for LFV(1,3) are significantly worse than those for LFV(1,2).
- Some BSM models specifically allow and enhance LFV(1,3) over LFV(1,2), for example:
  - Minimal Super-symmetric Seesaw model.
    J. Ellis et al, Phys. Rev. D66 115013 (2002)
  - SU(5) GUT with leptoquarks.
    I. Dorsner et al., Nucl. Phys. B723 53 (2005); P. Fileviez Perez et al., Nucl. Phys. B819 139 (2009)
- Study by Gonderinger & Musolf (2010): EIC with 10 fb^{-1} e-p at $\sqrt{s}$ = 90 GeV could improve leptoquark limits.
  - Assumes 100% detector and analysis efficiencies.
    M. Gonderinger & M. Ramsey Musolf, JHEP 1011 (045) (2010); D. Boer et al., arXiv:1108.1713
- It is a great feasibility study to test an EIC detector with.

LEPTOQUARK INTERACTIONS



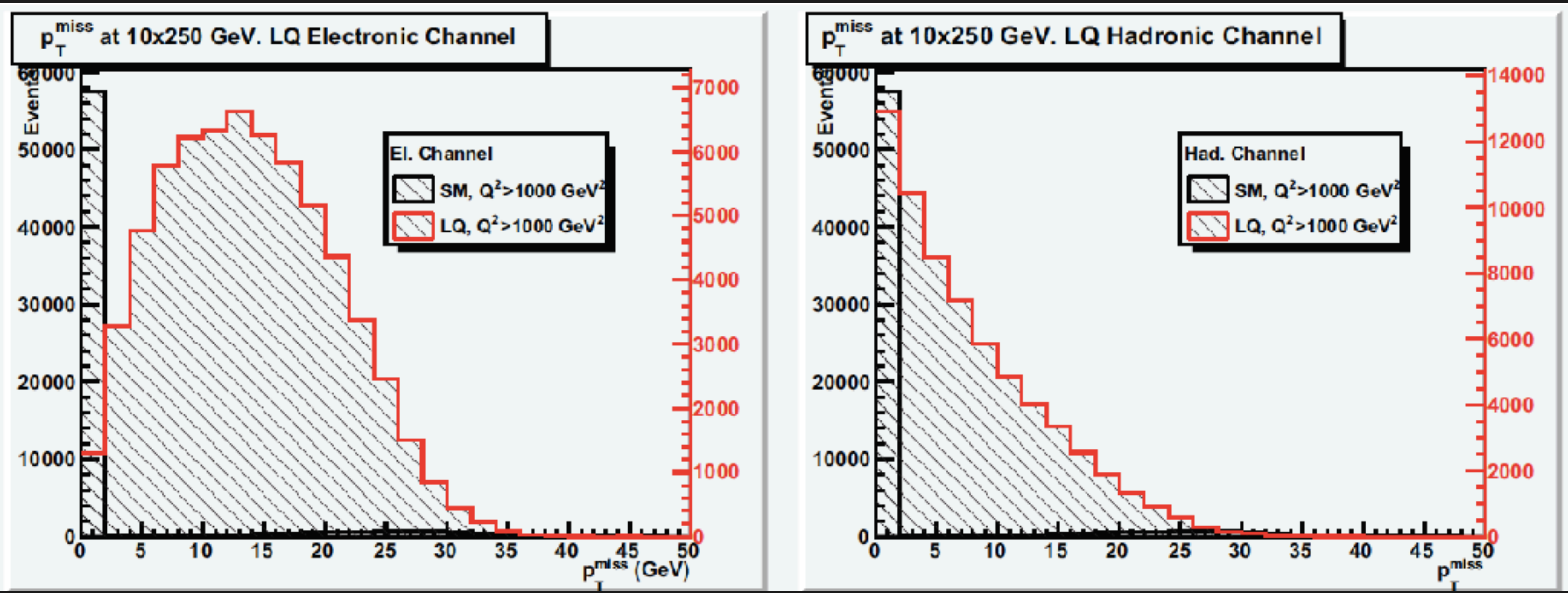
$\tau \rightarrow$ leptons with neutrinos (missing momentum) with different angular correlations in SM background and LQ events.

$\tau \rightarrow 3\pi$ characteristic decay signature (‘pencil jet’).

MISSING P_T SEPARATES LQ EVENTS FROM SM BACKGROUND

LQGENEP: Leptoquark generator for e-p processes using Buchmuller-Ruckl-Wyler model *(L. Bellagamba, Comp. Phys. Comm. 141, 83 (2001))*

Mass M_{LQ} = 200 GeV, coupling $\lambda_{11} = \lambda_{31} = 0.3$



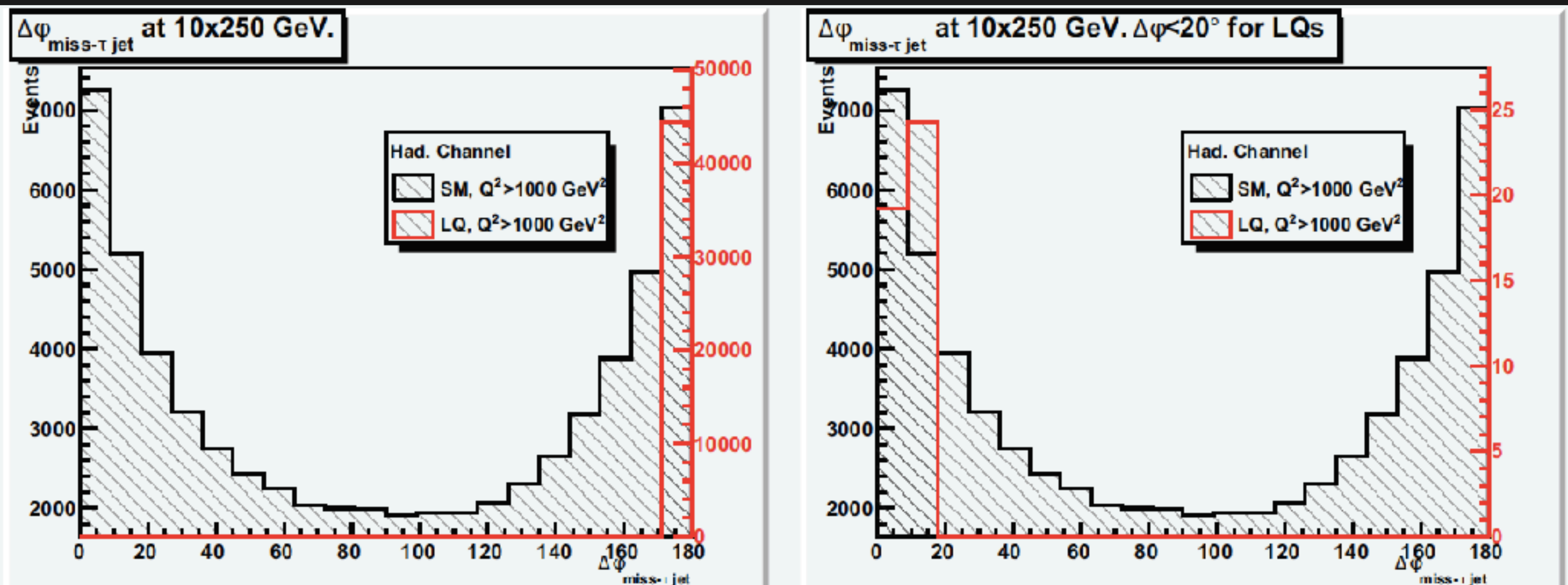
$$p_T^{miss} = \sqrt{(\Sigma P_{x,i})^2 + (\Sigma P_{y,i})^2}$$

D. Boer et al. arXiv:1108.1713

ACOPLANARITY SEPARATES LQ EVENTS FROM SM BACKGROUND

LQGENEP: Leptoquark generator for e-p processes using Buchmuller-Ruckl-Wyler model *(L. Bellagamba, Comp. Phys. Comm. 141, 83 (2001))*

Mass M_{LQ} = 200 GeV, coupling $\lambda_{11} = \lambda_{31} = 0.3$



D. Boer et al.
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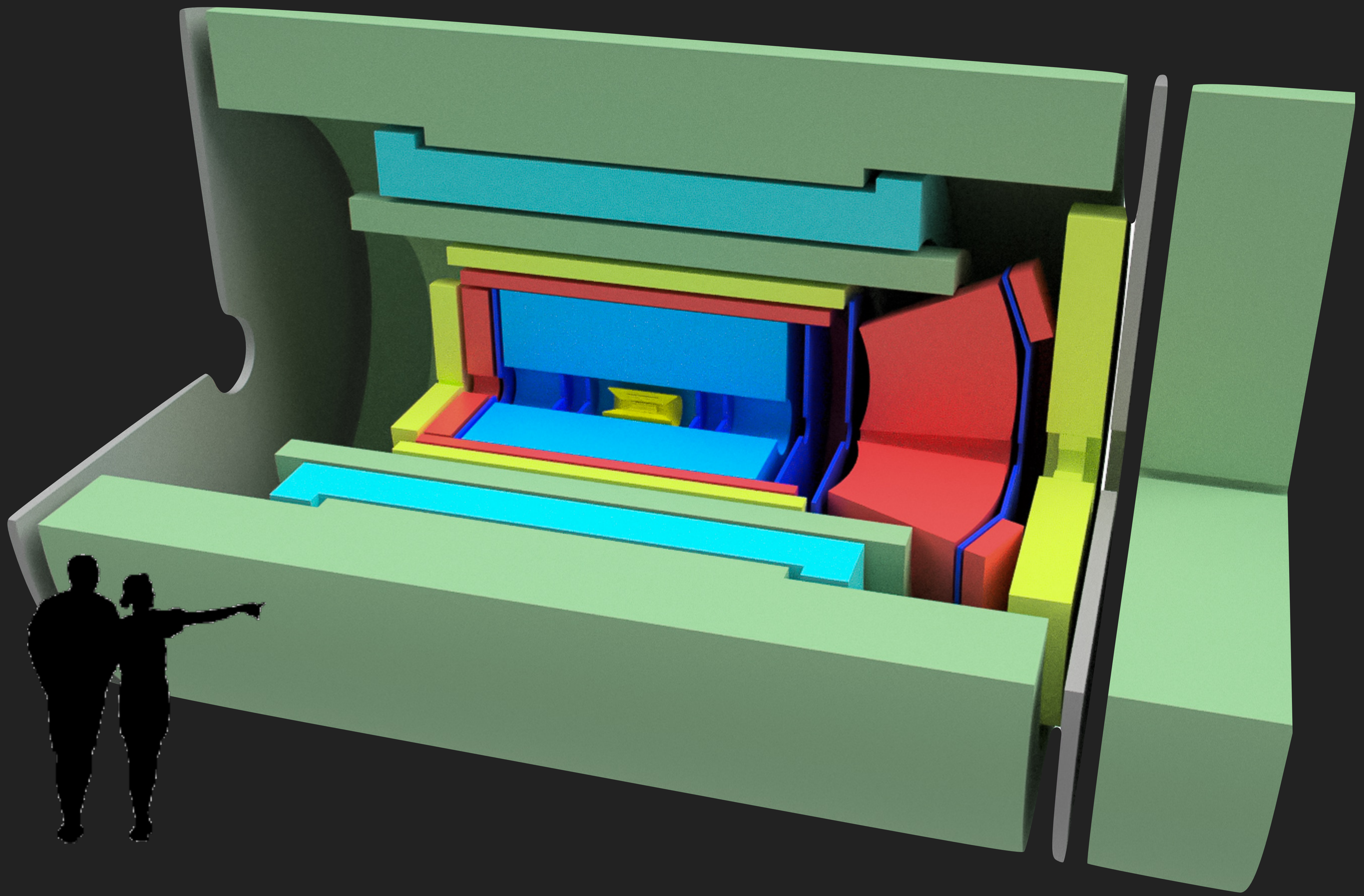
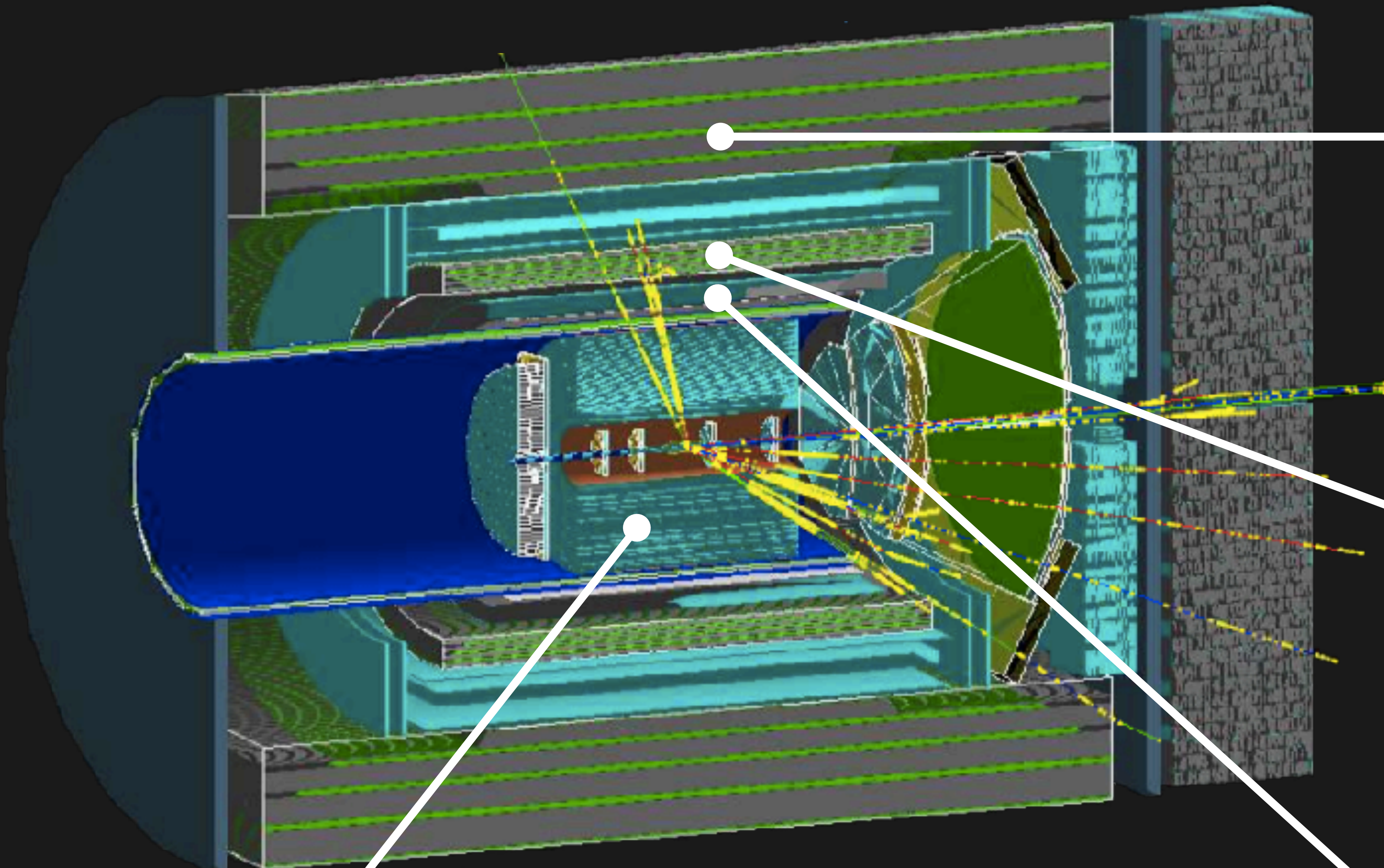


Solenoid
Flux return
Central tracking
Electromagnetic calorimeter
Forward tracking
Hadron calorimeter
Particle ID

FULL GEANT4 DETECTOR SIMULATION WITHIN THE FUN4ALL FRAMEWORK



HCAL: Fe + scintillator (0.1 x 0.1)

HCAL: Stainless steel + scintillator (0.1 x 0.1)

ECAL : W + scintillating fibre (0.025 x 0.025)

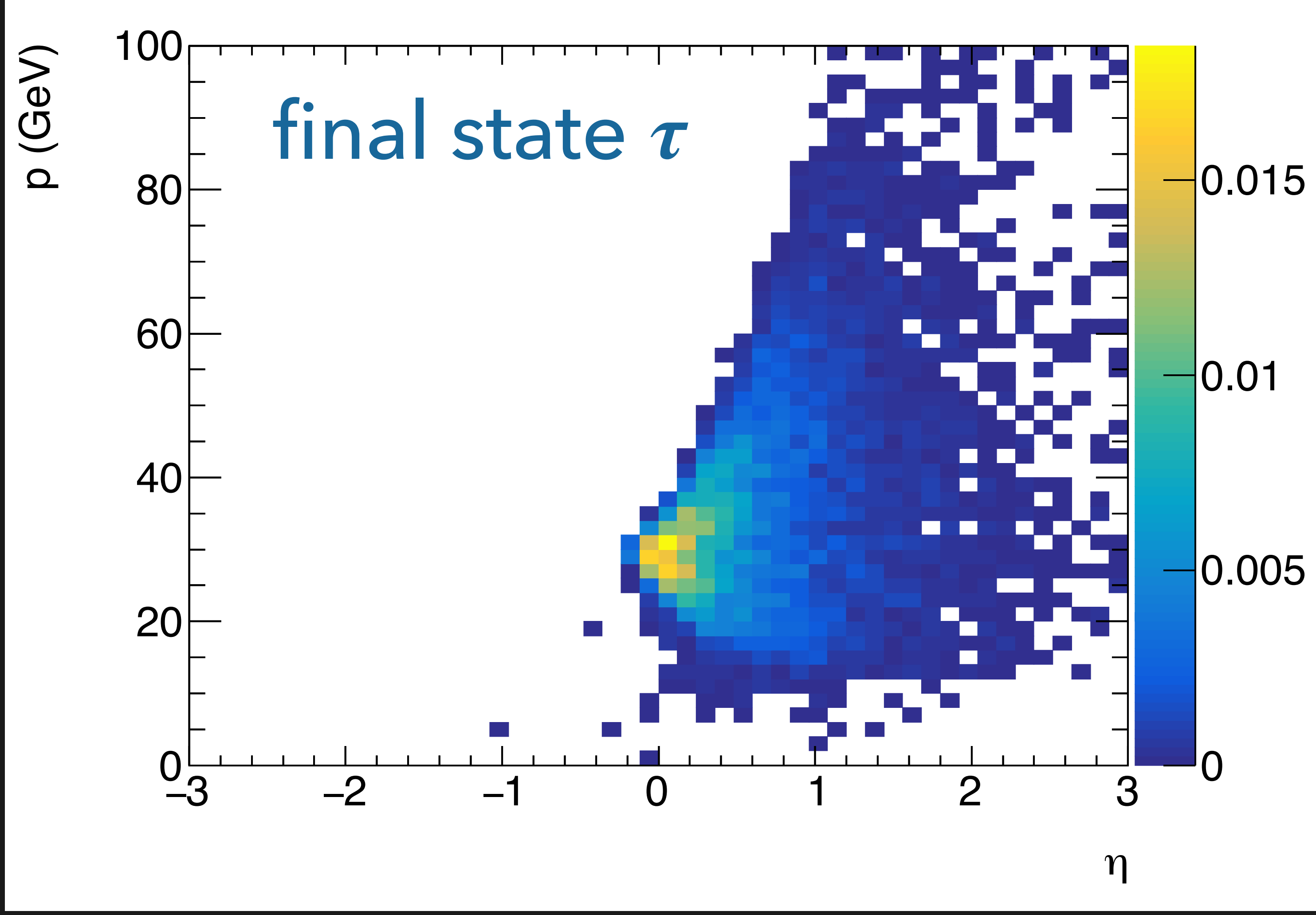
Continuous readout TPC

3-layer MAPS vertex detector

4-layer silicon-strip intermediate tracker

GENERATING MC EVENTS WITH LQGENEP

- Mass M_{LQ} = 1936.5 GeV
- Coupling $\lambda_{11} = \lambda_{31} = 0.3$
- d-quark in initial and final state (s-channel)
- τ is final state lepton
- e-p beam energies are 20 GeV x 250 GeV



events ($\tau \to 3\pi$): 8949

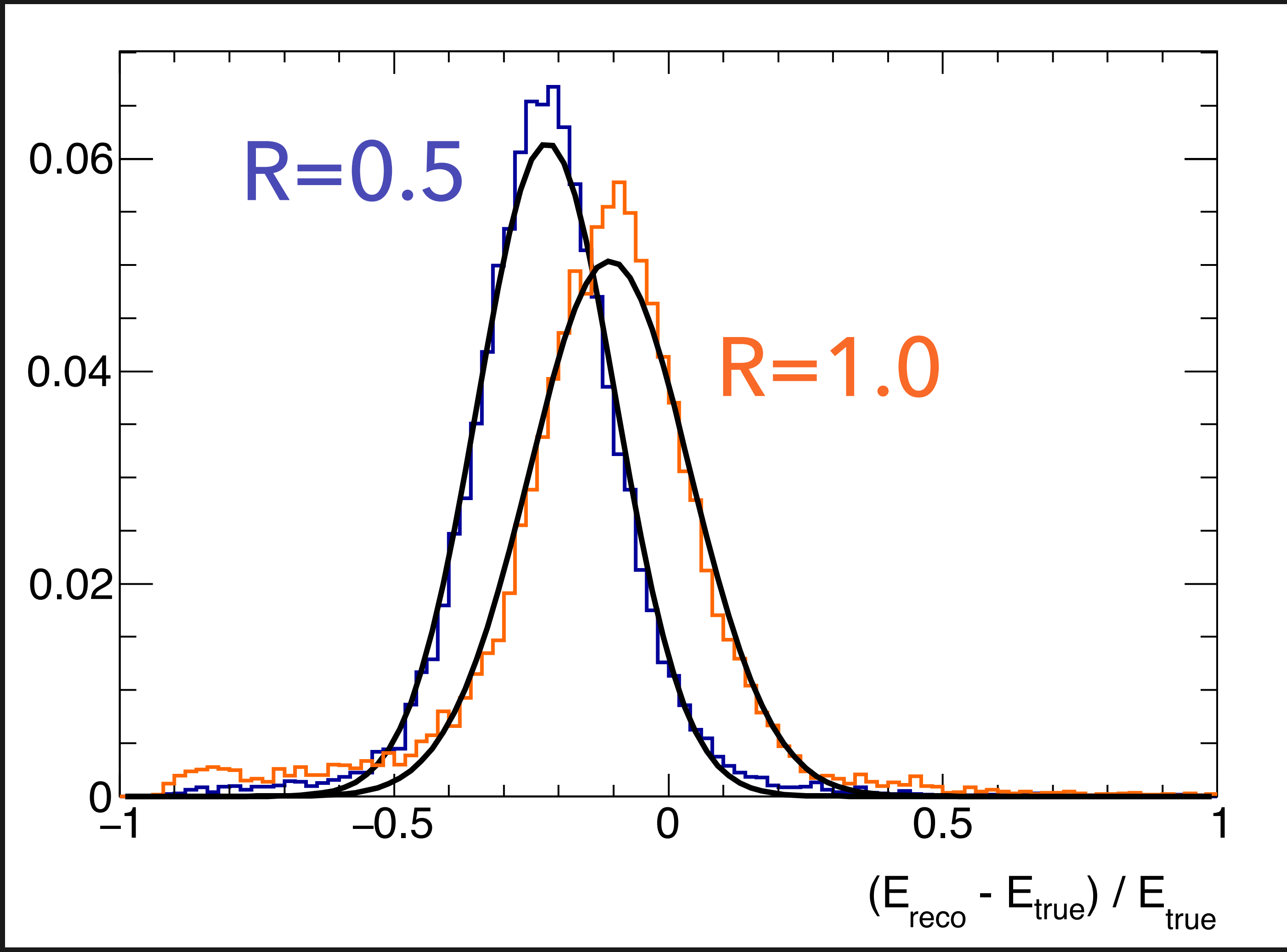
$-1.0 < \eta_\tau < 1.0$: 6920

MID-RAPIDITY JET RECONSTRUCTION

Jets are reconstructed using calorimeter tower and the FASTJET package anti-kT algorithm.

Jet selection:

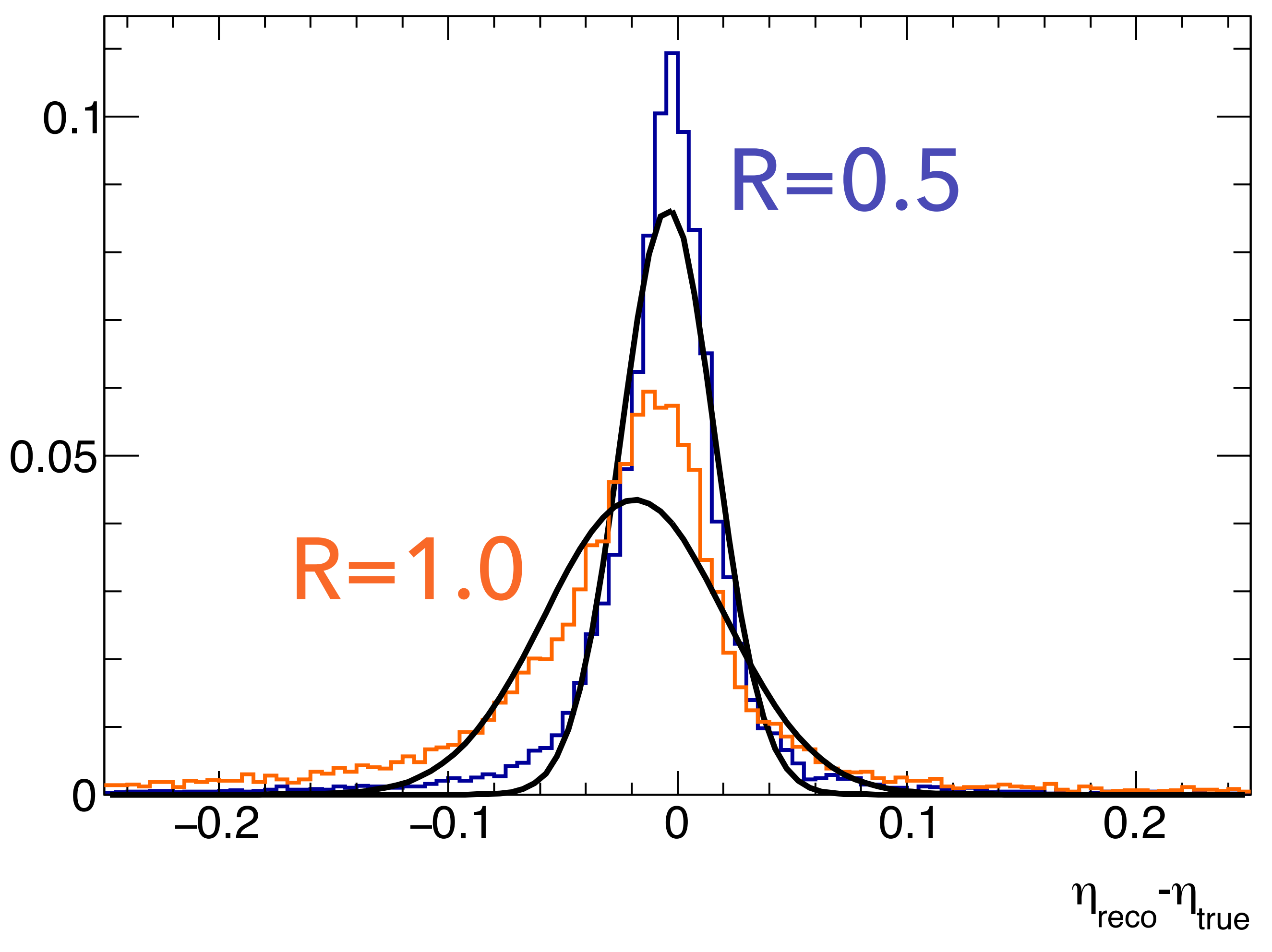
$p_T > 5$ & $-1 < \eta < 1$



R=0.5: $\mu = -0.22$, $\sigma = 0.13$

R=1.0: $\mu = -0.11$, $\sigma = 0.15$

MID-RAPIDITY JET RECONSTRUCTION

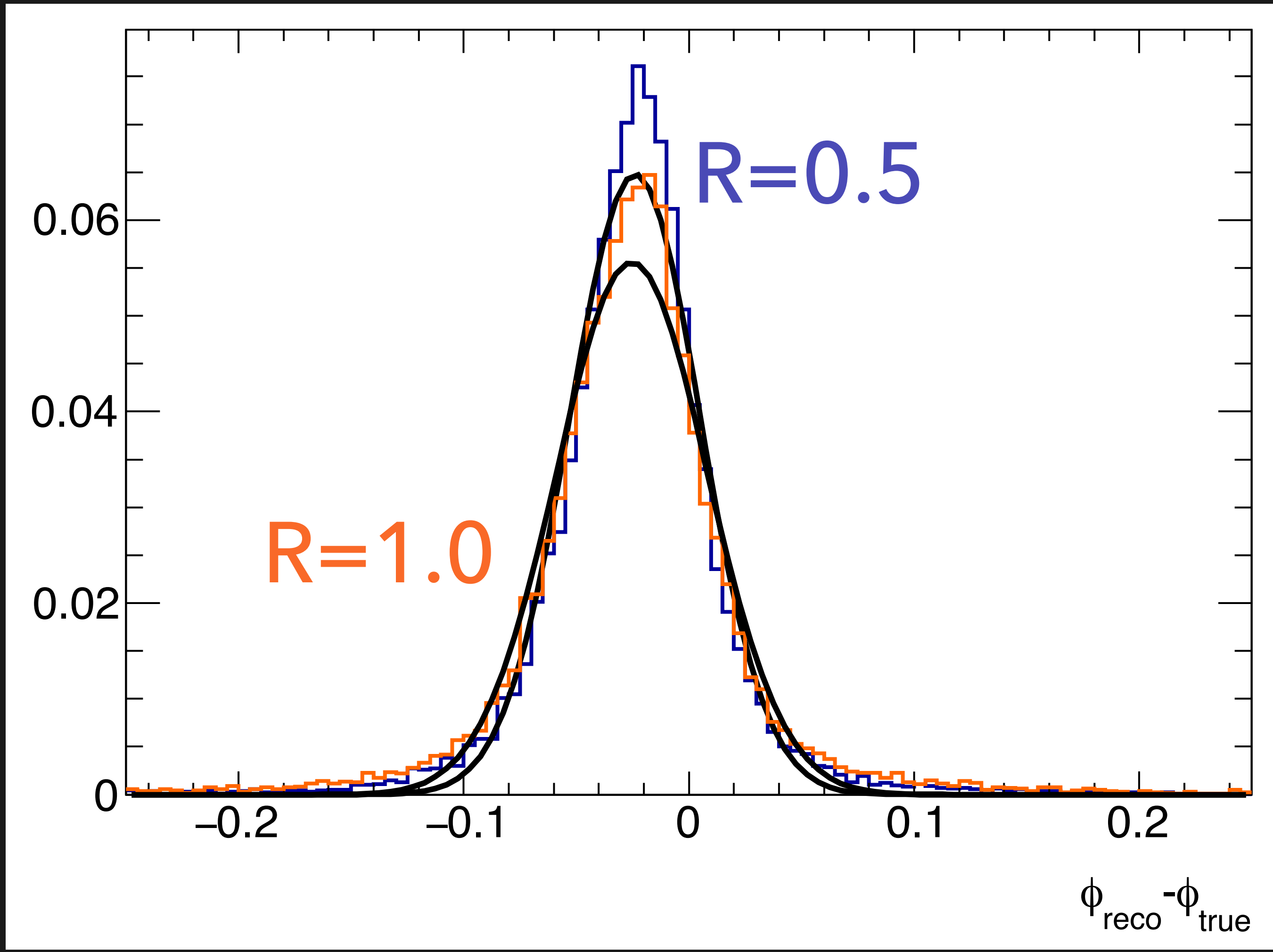


R=0.5: μ = 0.00, σ = 0.02

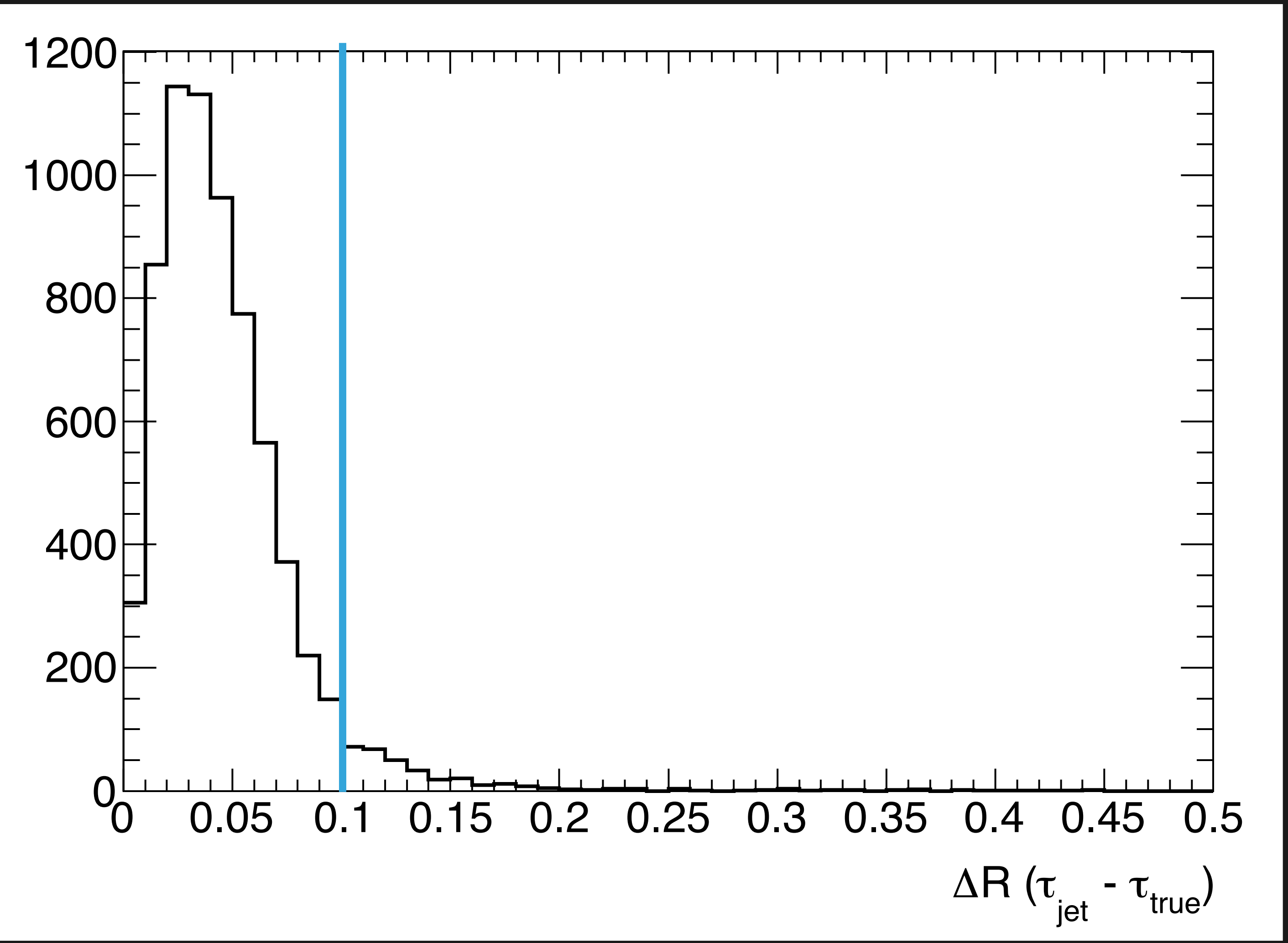
R=1.0: μ = -0.02, σ = 0.04

R=0.5: μ = -0.02, σ = 0.03

R=1.0: μ = -0.03, σ = 0.03



MID-RAPIDITY TAU RECONSTRUCTION



\# events ($\tau \rightarrow 3\pi$): 8949

$-1.0 < \eta_\tau < 1.0$: 6920 (77%)

6556 τ jets (73%) with

$p_T > 5$ GeV & $-1 < \eta < 1$

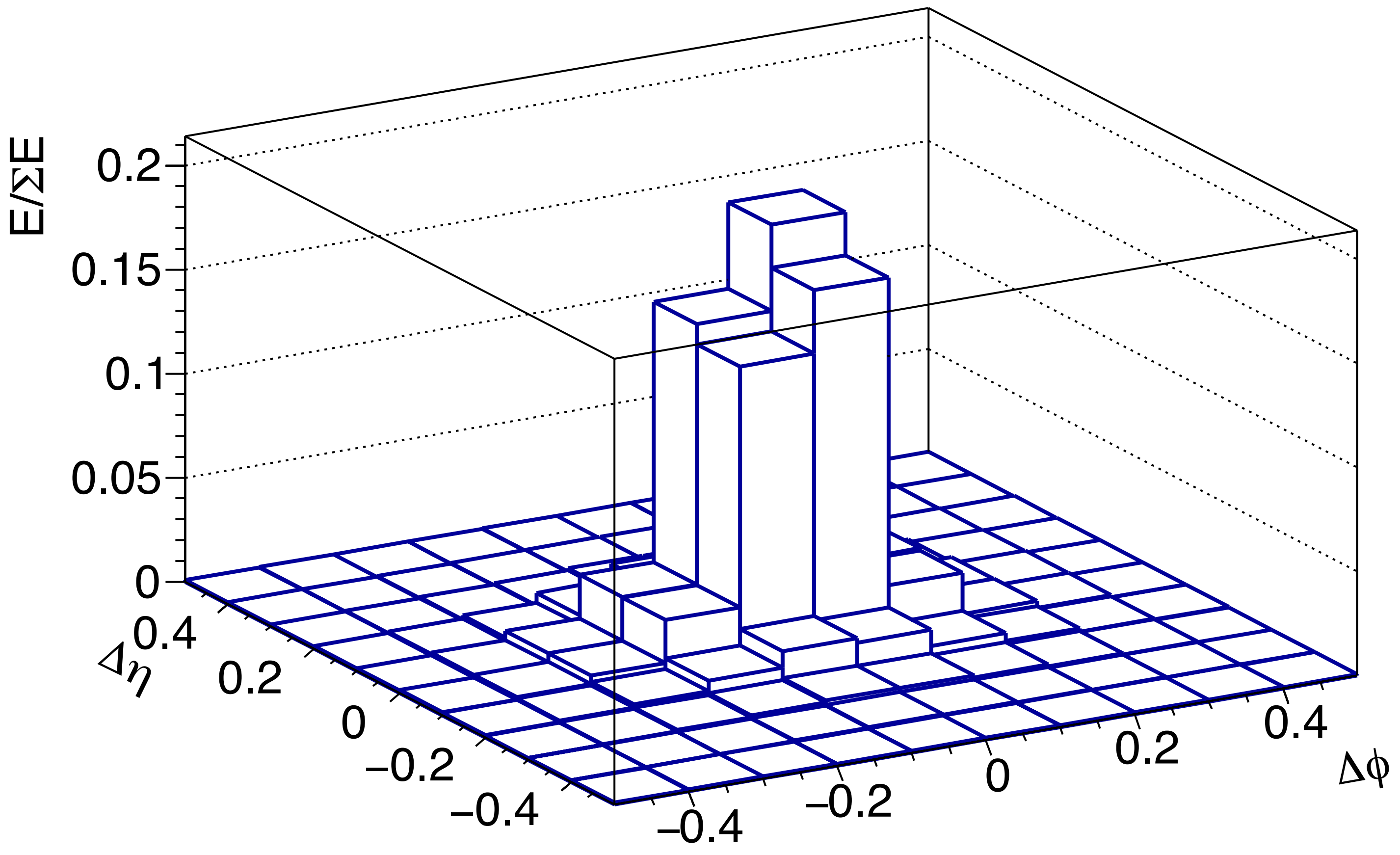
& $\Delta R < 0.1$

7807 non-τ jets with

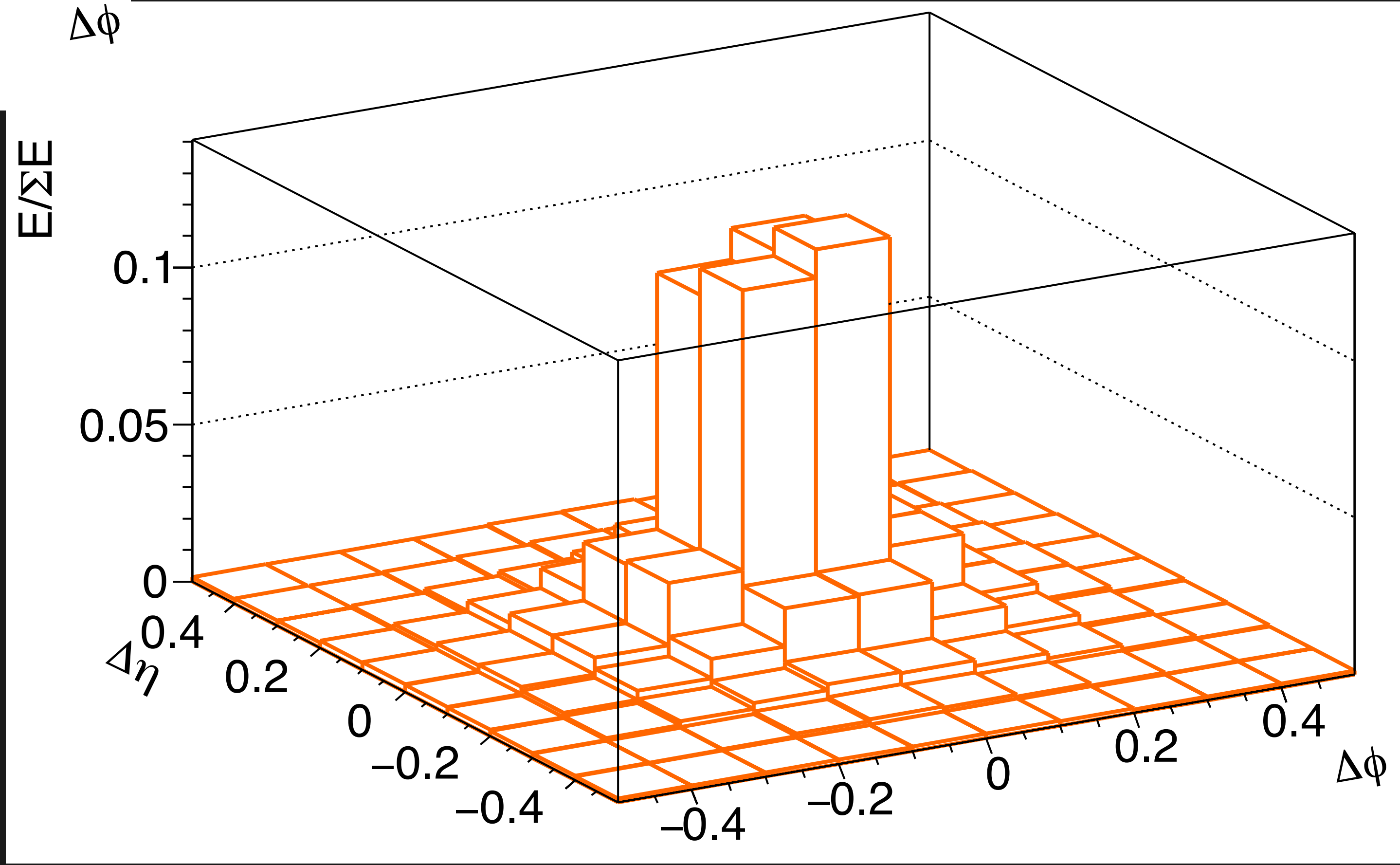
$p_T > 5$ GeV & $-1 < \eta < 1$

$$\Delta R = \sqrt{(\eta_{jet} - \eta_\tau)^2 + (\phi_{jet} - \phi_\tau)^2}$$

TAU AND PARTON JET SHAPES IN THE CALORIMETER

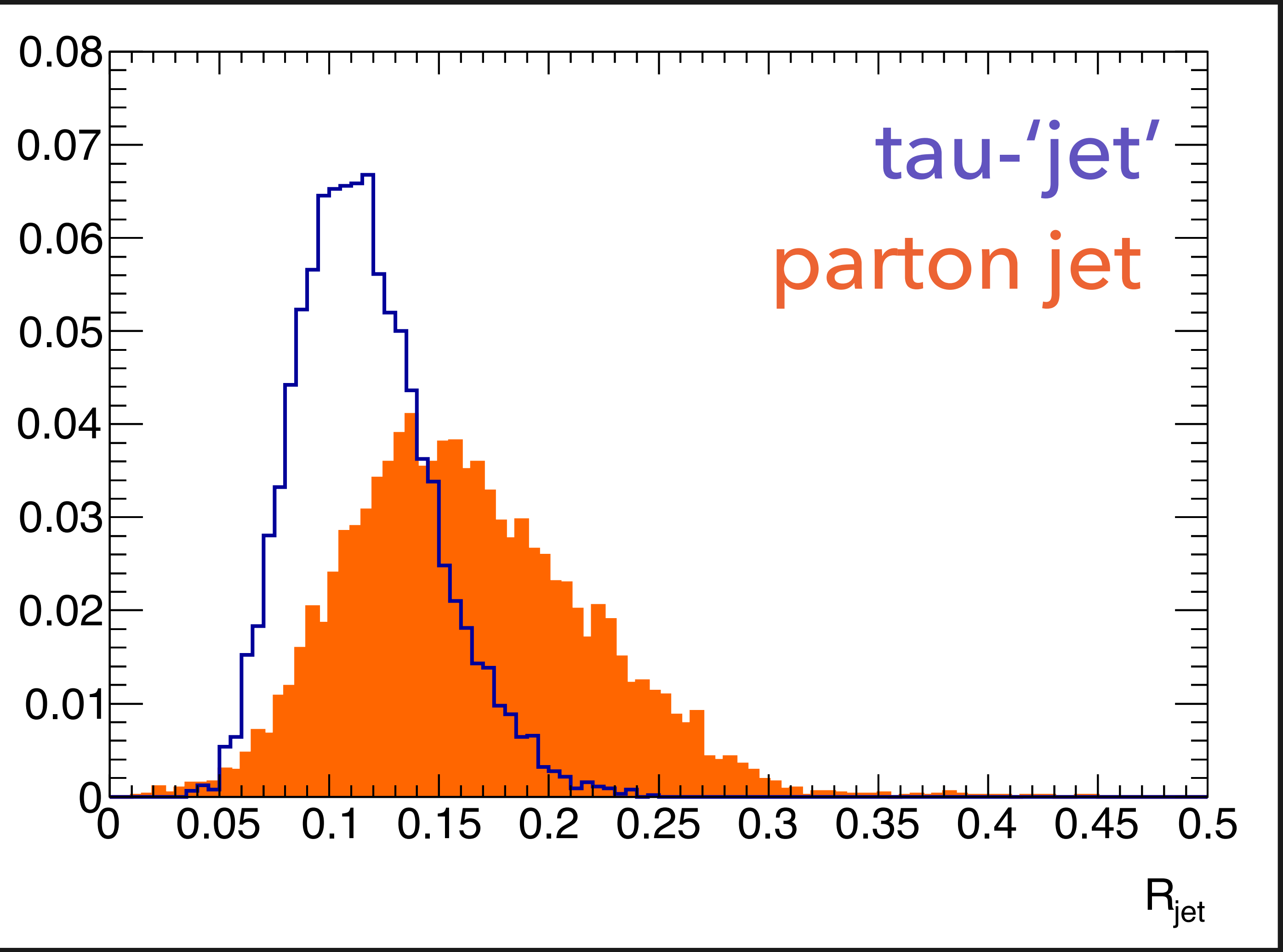


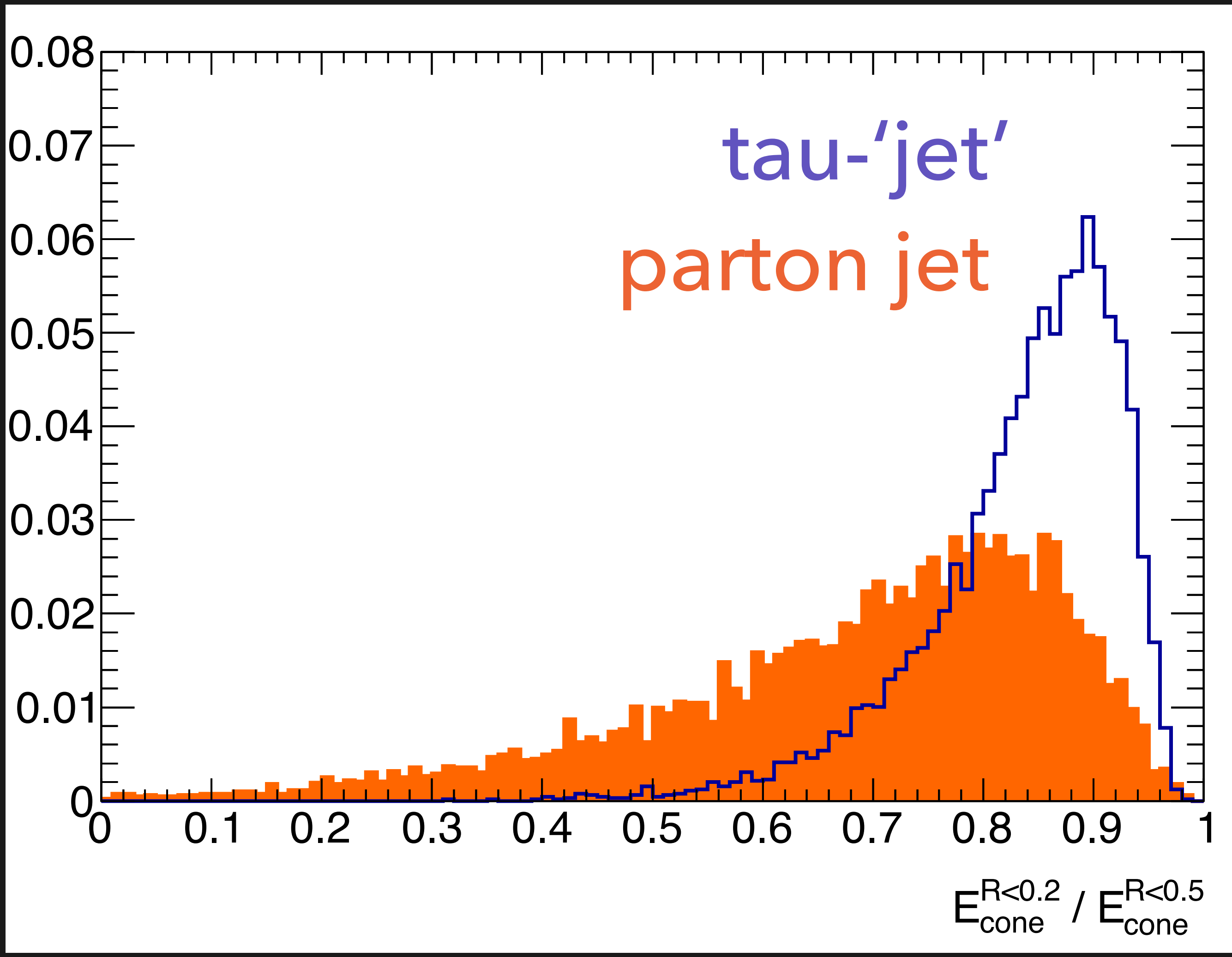
tau-'jet'



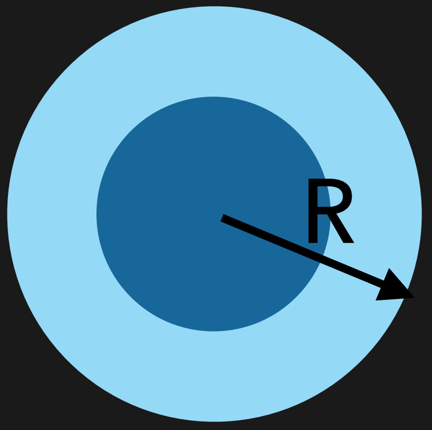
parton jet

OBSERVABLES TO CLASSIFY TAU AND PARTON JET SHAPES

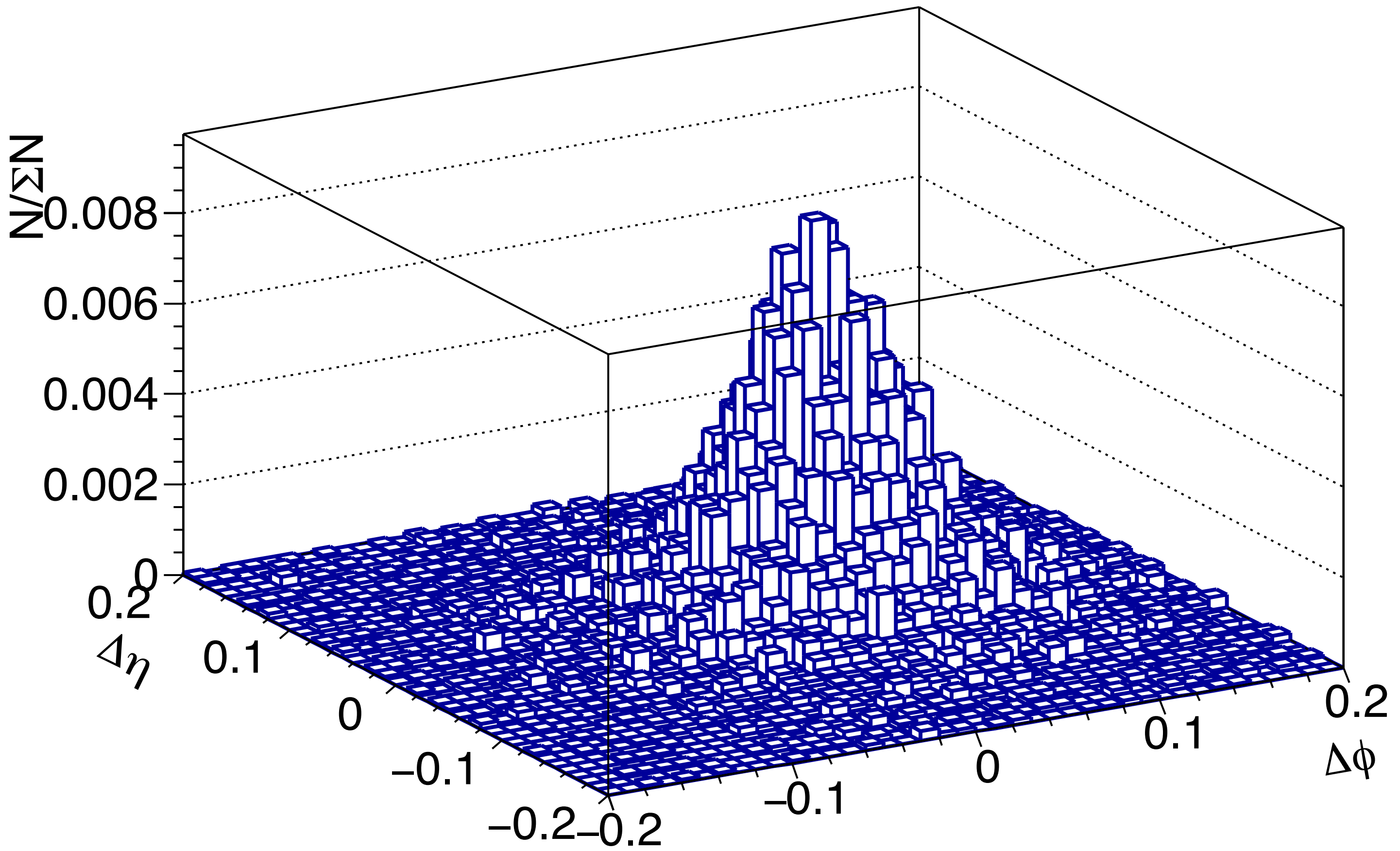




$$R_{jet} = \frac{\Sigma(E_{tower} \cdot R_{tower})}{\Sigma(E_{tower})}$$

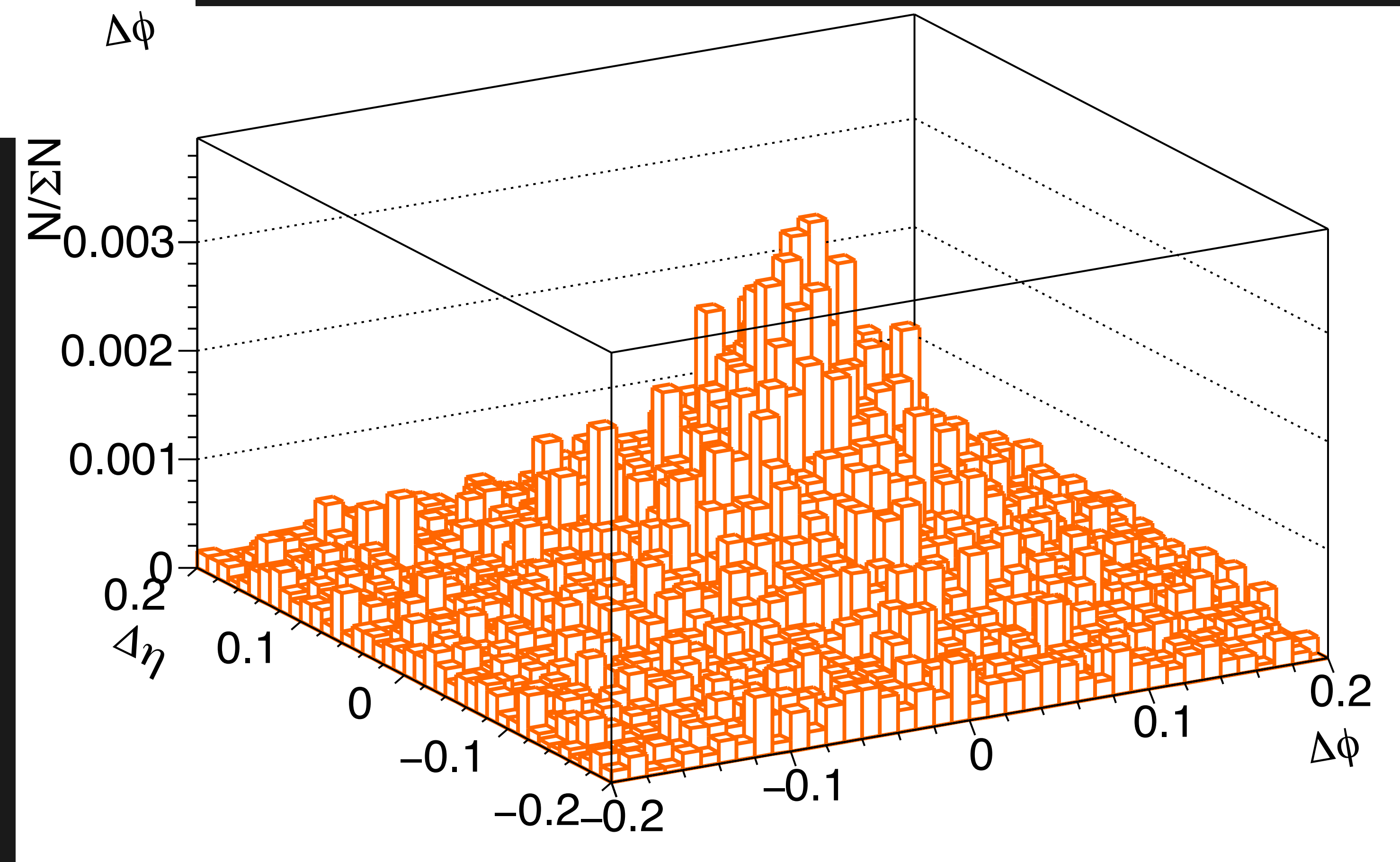


CHARGED TRACKS AROUND TAU AND PARTON JET AXES

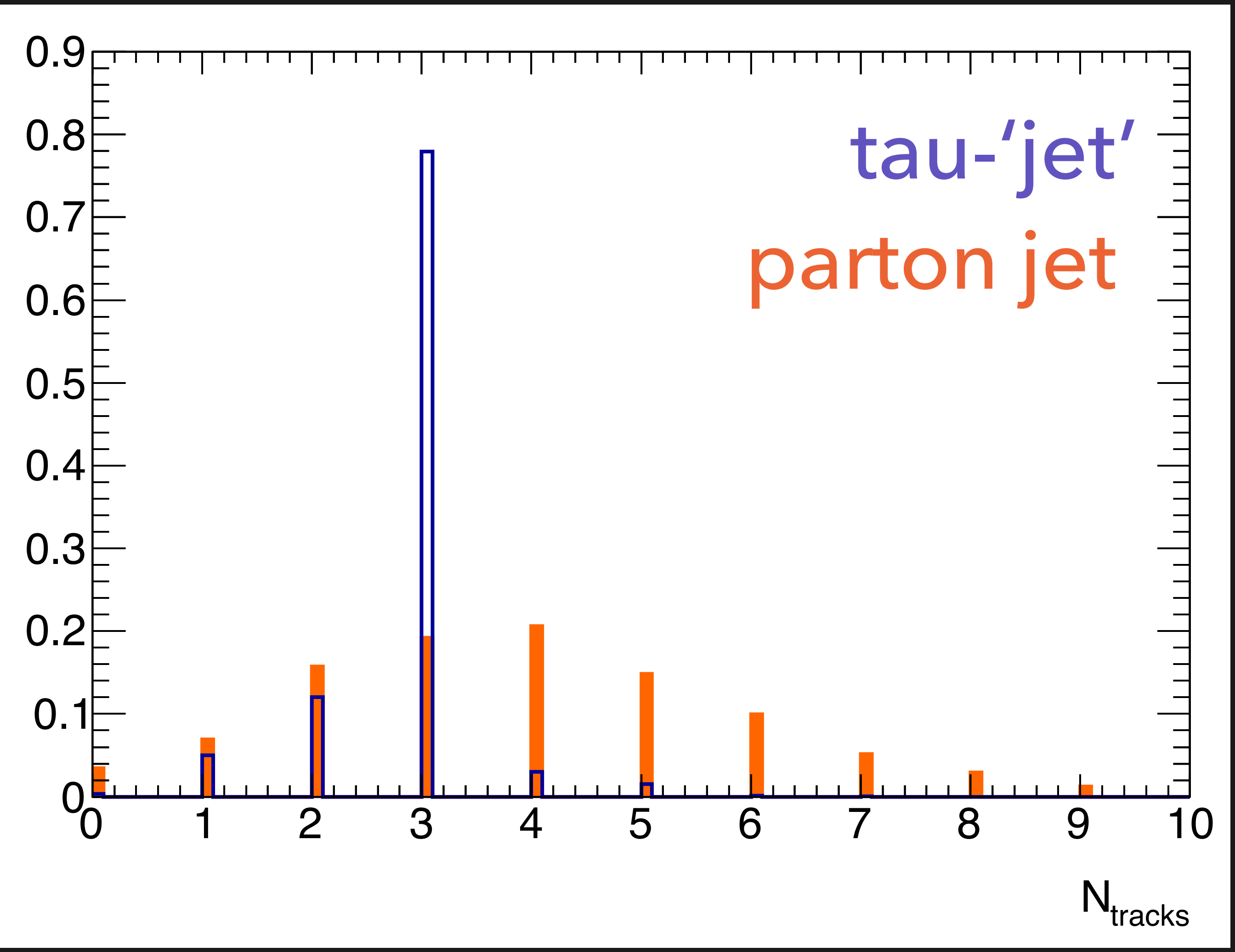


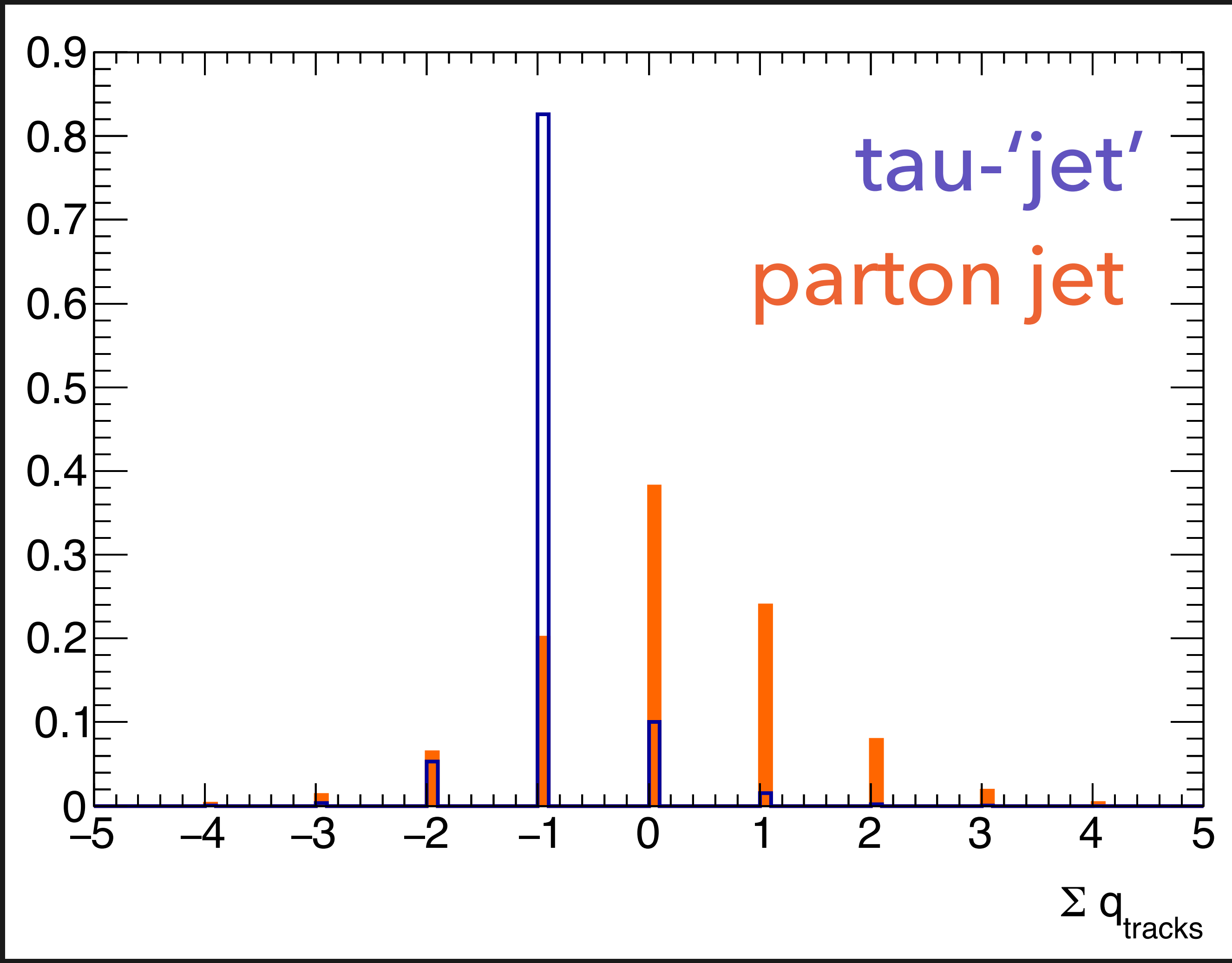
tracks near parton jet axis

tracks near tau-'jet' axis



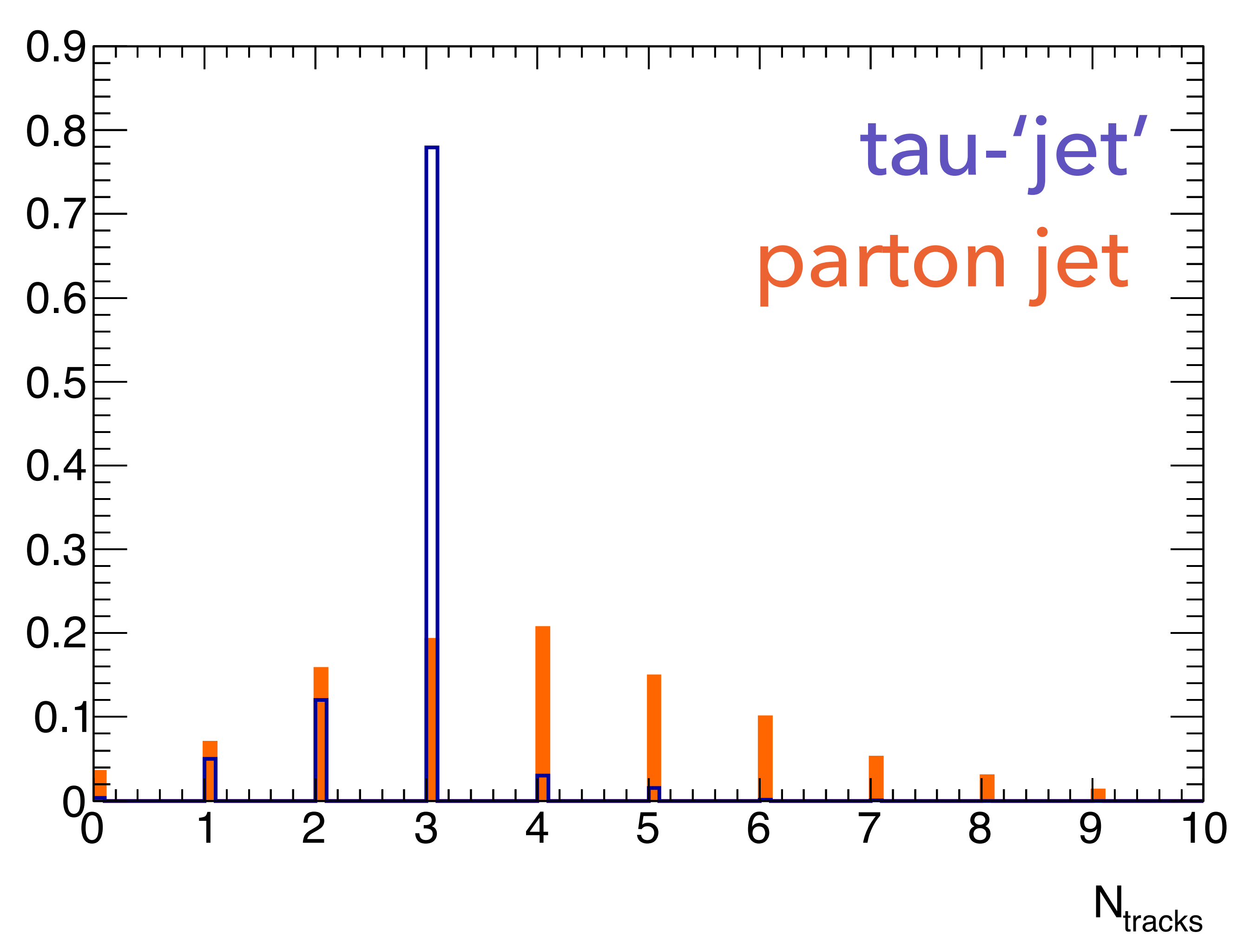
TRACK OBSERVABLES TO CLASSIFY TAU AND PARTON JETS

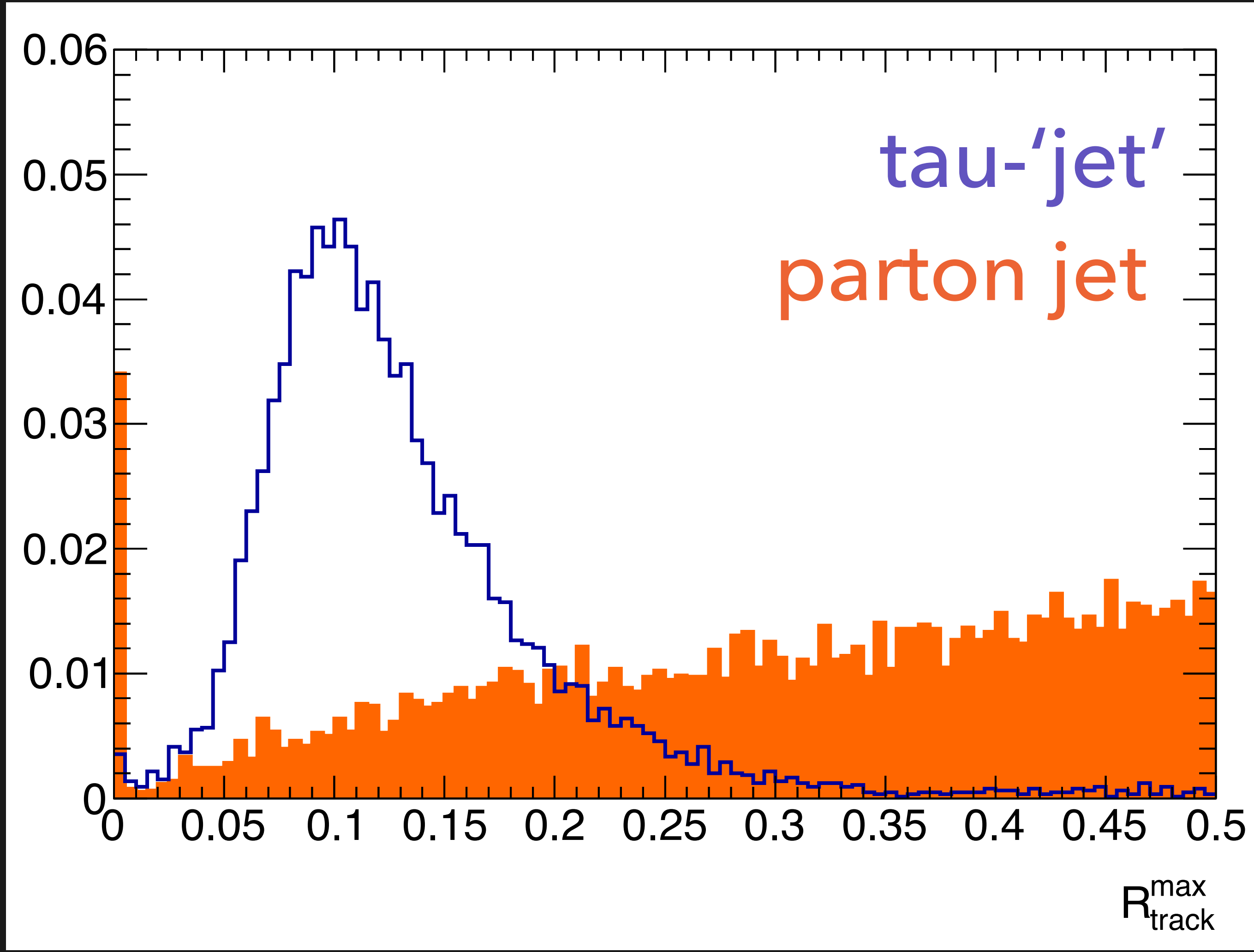




R=0.5 track search cone around jet axis

TRACK OBSERVABLES TO CLASSIFY TAU AND PARTON JETS





R=0.5 track search cone around jet axis

TAU JET CLASSIFICATION PERFORMANCE

LQGENEP events with $\tau \rightarrow 3\pi$ final states:

6556 τ jets and 7807 non-τ jets with $p_T > 5$ GeV & $-1 < \eta < 1$

Manual τ selection A:

$N_{tracks} = 3$ & $\Sigma q_{tracks} = -1$ & $R_{track}^{max} < 0.20$ & $R_{jet} < 0.15$

	Manual τ selection A
Identify τ as τ	0.601
Identify non-τ as τ	0.015

TAU JET CLASSIFICATION PERFORMANCE

LQGENEP events with $\tau \rightarrow 3\pi$ final states:

6556 τ jets and 7807 non-τ jets with $p_T > 5$ GeV & $-1 < \eta < 1$

Manual τ selection B:

$N_{tracks} = 3$ & $\Sigma q_{tracks} = -1$ & $R_{track}^{max} < 0.15$ & $R_{jet} < 0.15$

	Manual τ selection A	Manual τ selection B
Identify τ as τ	0.601	0.488
Identify non-τ as τ	0.015	0.010

TAU JET CLASSIFICATION PERFORMANCE

LQGENEP events with $\tau \rightarrow 3\pi$ final states:

6556 τ jets and 7807 non-τ jets with $p_T > 5$ GeV & $-1 < \eta < 1$

DecisionTreeClassifier from sklearn.tree with max_depth = 5, penalty (false positive) = 20, using N_{tracks}, Σq_{tracks} , R_{track}^{max}, R_{jet}

	Manual τ selection A	Manual τ selection B	DecisionTree Classifier
Identify τ as τ	0.601	0.488	0.576
Identify non-τ as τ	0.015	0.010	0.019

Charged Lepton Flavor Violation e → τ is a promising process to search for BSM physics at EIC:

- Potential to improve experimental limits for LFV(1,3) leptoquarks.
- sPHENIX based EIC detector can separate $\tau \to 3\pi$ 'jets' from parton jets at mid-rapidity with >60% true positive (at <2% false positive) efficiency.
- Full feasibility study continues (with SBU UG students):
  - Include forward tracker and calorimeter.
  - Use event topologies to identify leptoquark events.
  - Quantify EIC + detector impact on LFV(1,3) limits.