Towards

Detectors for Superboosted Jet Substructure at Future Circular Colliders

BOOST2016 [July 19, 2016]

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with
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Jesse Thaler (MIT), Caterina Vernieri (FNAL)

A NEW HIGH ENERGY COLLIDER WILL NECESSARILY NEED TO RECONSTRUCT BOOSTED HEAVY STANDARD MODEL OBJECTS

A LOT OF VERY HEALTHY DISCUSSION ABOUT THE CAPABILITIES OF AN HCAL TO TRANSVERSELY RESOLVE HADRONIC SHOWERS

(SEE TALKS AT BOOST15 BY GILAD PEREZ, SERGEI CHEKANOV)

OUTLINE:

WHAT CAN A CALORIMETER DO?

WHAT IS THE INTRINSIC CAPABILITY OF A CALORIMETER TO EXPLOIT SUBSTRUCTURE?

DO WE ACTUALLY NEED/WANT A CALORIMETER TO DO THOSE THINGS?

HOW MUCH INFORMATION (DISCRIMINATION POWER) DOES ONE LOSE BY THROWING OUT NEUTRAL (HADRON) INFORMATION?

BACK STORY

TRADITIONAL CALORIMETERS HAVE BEEN BUILT USING THE BASIC CONCEPT:

TRANSVERSE CALORIMETER CELL SIZE SHOULD BE ~X_0 (λ_0)

RECENT EXAMPLE: FROM HEP/PH:1506.02656 (BRESSLER,FLACKE,KATS,LEE,PEREZ)

$$\theta_{\rm had} \approx \frac{d_{\rm had}}{r_{\rm HCAL}}$$

REFERENCE ANGULAR SCALE FOR HADRONIC SHOWERS

$D_{\rm HAD}$ ~ λ (NUCLEAR INTERACTION LENGTH)

"HADRONIC MOLIERE RADIUS"

λ = 10, 11, 15, 17 CM FOR TUNGSTEN, URANIUM, COPPER, IRON

E.G., FOR A W $R_{\rm HCAL}$ = 1M, THIS MEANS THE ANGULAR SCALE IS $\theta_{\rm HAD}$ ~ 0.1

CONCLUSION: GIVE UP, USE TRACKS + γ TO BUILD OBSERVABLES

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CONCLUSION: GIVE UP, USE TRACKS + γ TO BUILD OBSERVABLES

HOW STRICT IS THIS ASSUMPTION? CAN WE DO MORE SOPHISTICATED THINGS?

STUDY PARAMETERS

WORK WITHIN THE BASIC NEEDS OF A 100 TEV COLLIDER

GOOD CONTAINMENT UP TO 20 TEV JETS NEED UP TO 12 λ FOR ECAL + HCAL

AFFECTS JET ENERGY RESOLUTION & LEAKAGE BIASES

GOOD LONGITUDINAL SEGMENTATION TARGET CONSTANT TERM OF 3%

AFFECTS JET ENERGY RESOLUTION

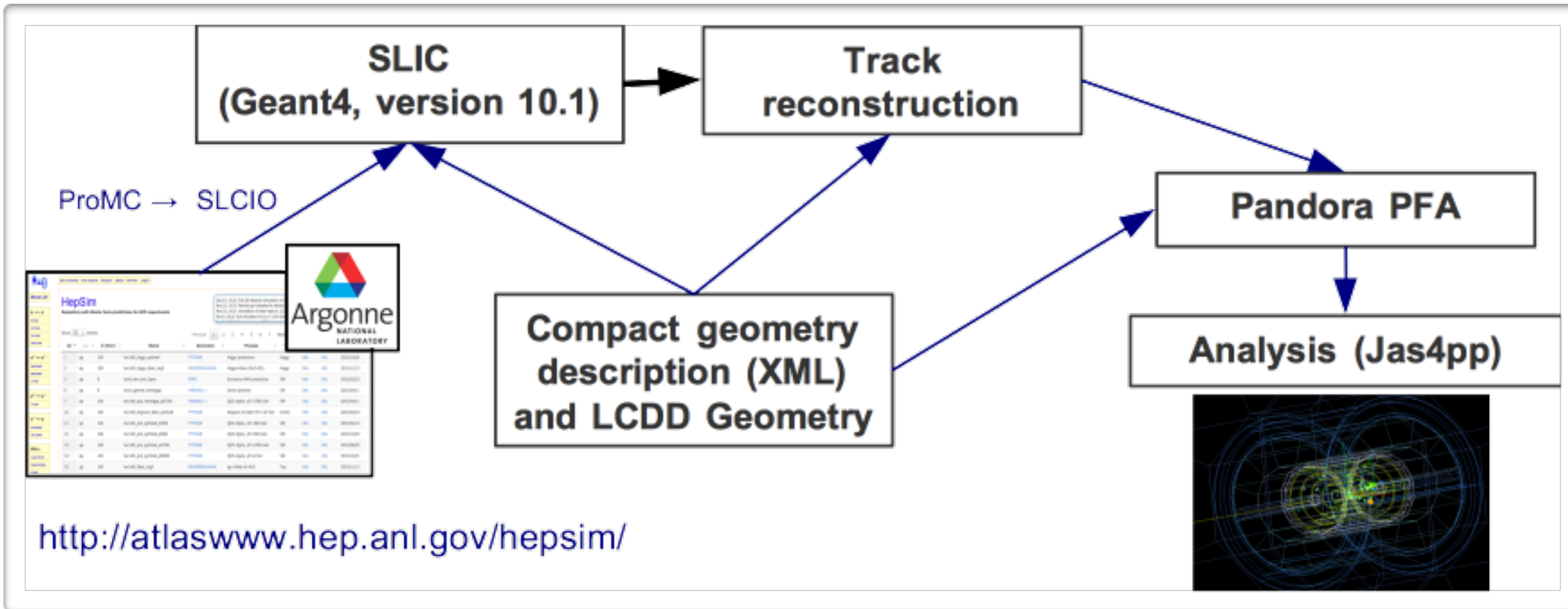
GOOD TRANSVERSE SEGMENTATION

FOR JET SUBSTRUCTURE, FOCUS OF THIS STUDY

REQUIRES STUDIES WITH FULL GEANT

REPURPOSE **SLIC** (SIMULATOR FOR THE LINEAR COLLIDER) OPTIMIZED FOR SID; USE FOR FCC PURPOSES

INTEGRATED WITH **HEPSIM** AND DEPLOYED ON THE **OSG (OPEN SCIENCE GRID)**



REQUIRES REAL INFRASTRUCTURE TO GENERATE HIGH ENERGY EVENTS IN FUTURE DETECTORS

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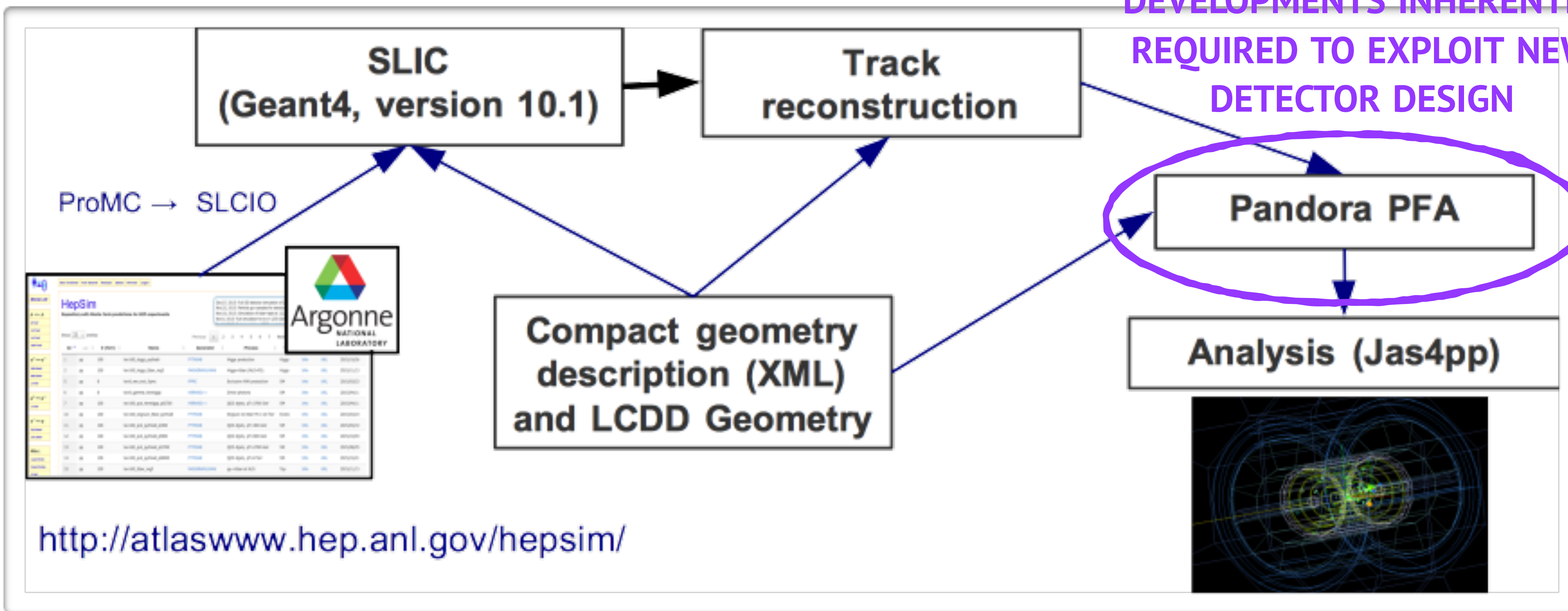
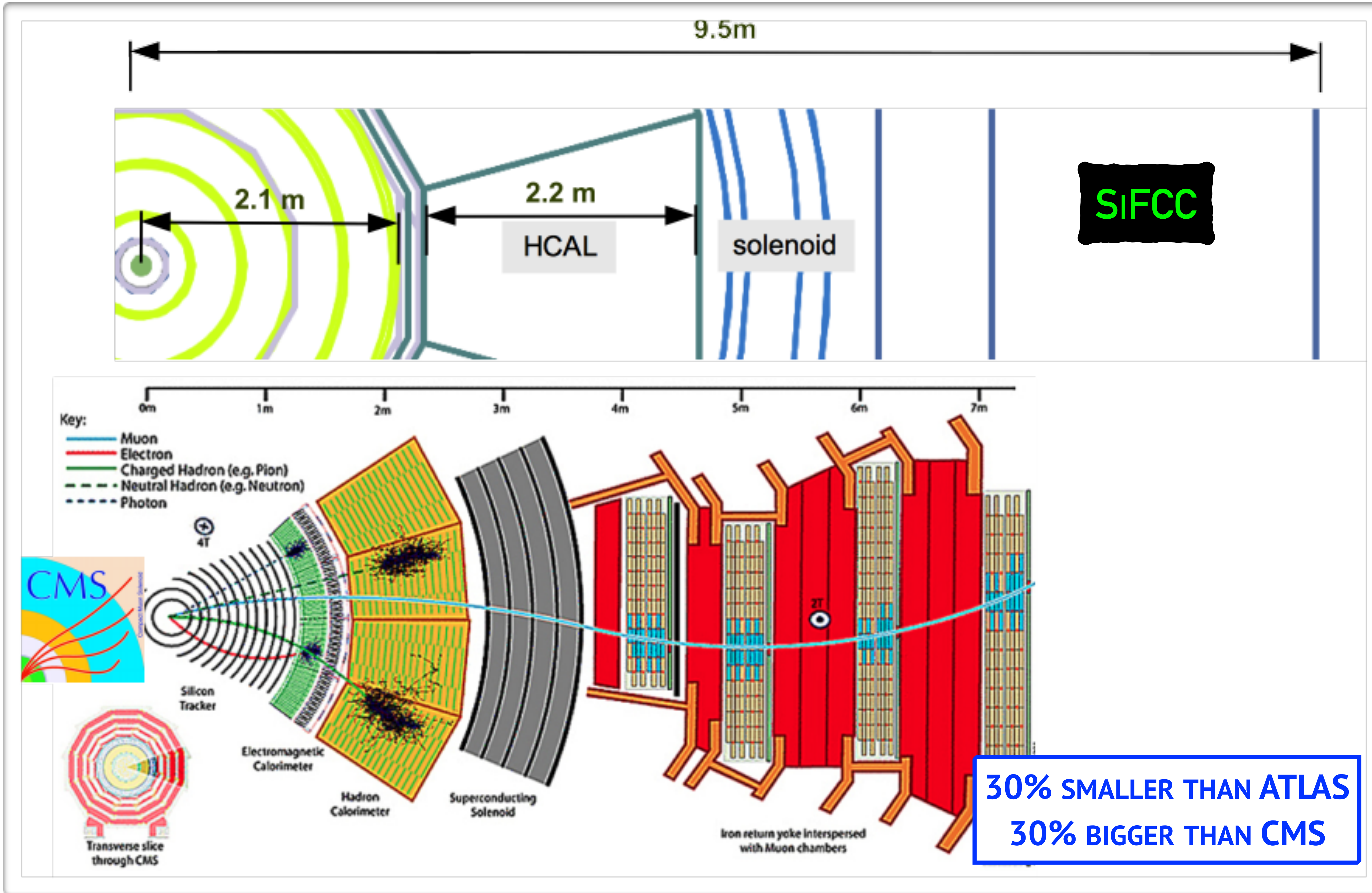
DEVELOPMENTS INHERENTLY REQUIRED TO EXPLOIT NEW DETECTOR DESIGN



REQUIRES REAL INFRASTRUCTURE TO GENERATE HIGH ENERGY EVENTS IN FUTURE DETECTORS

DETECTOR BASELINE

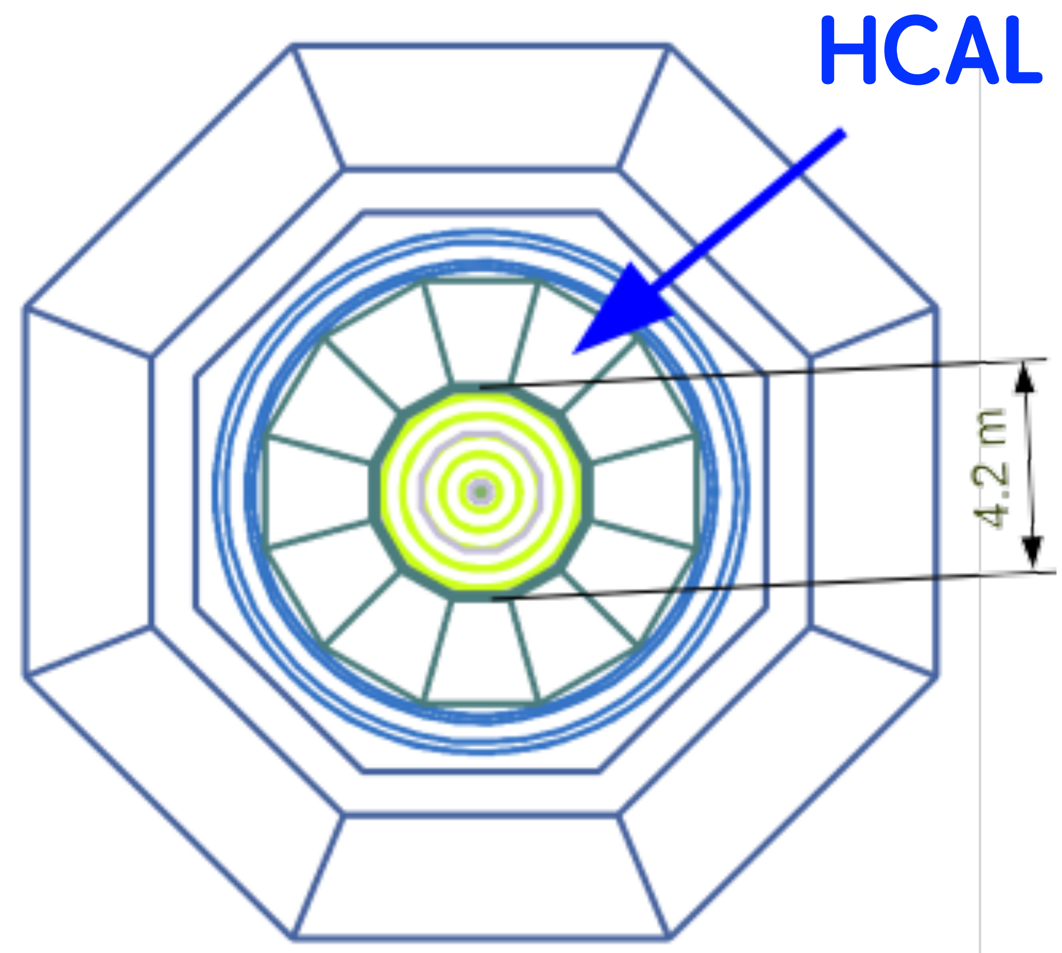


Detector Parameters

Baseline detector features

5T magnetic field

Pixel 20μm, outer 50μm pitch



Calorimeter (HGCal-like)

ECAL

32 layers Si-W sampling

~35 X_0 (~1λ), 2cm x 2cm cells

HCAL

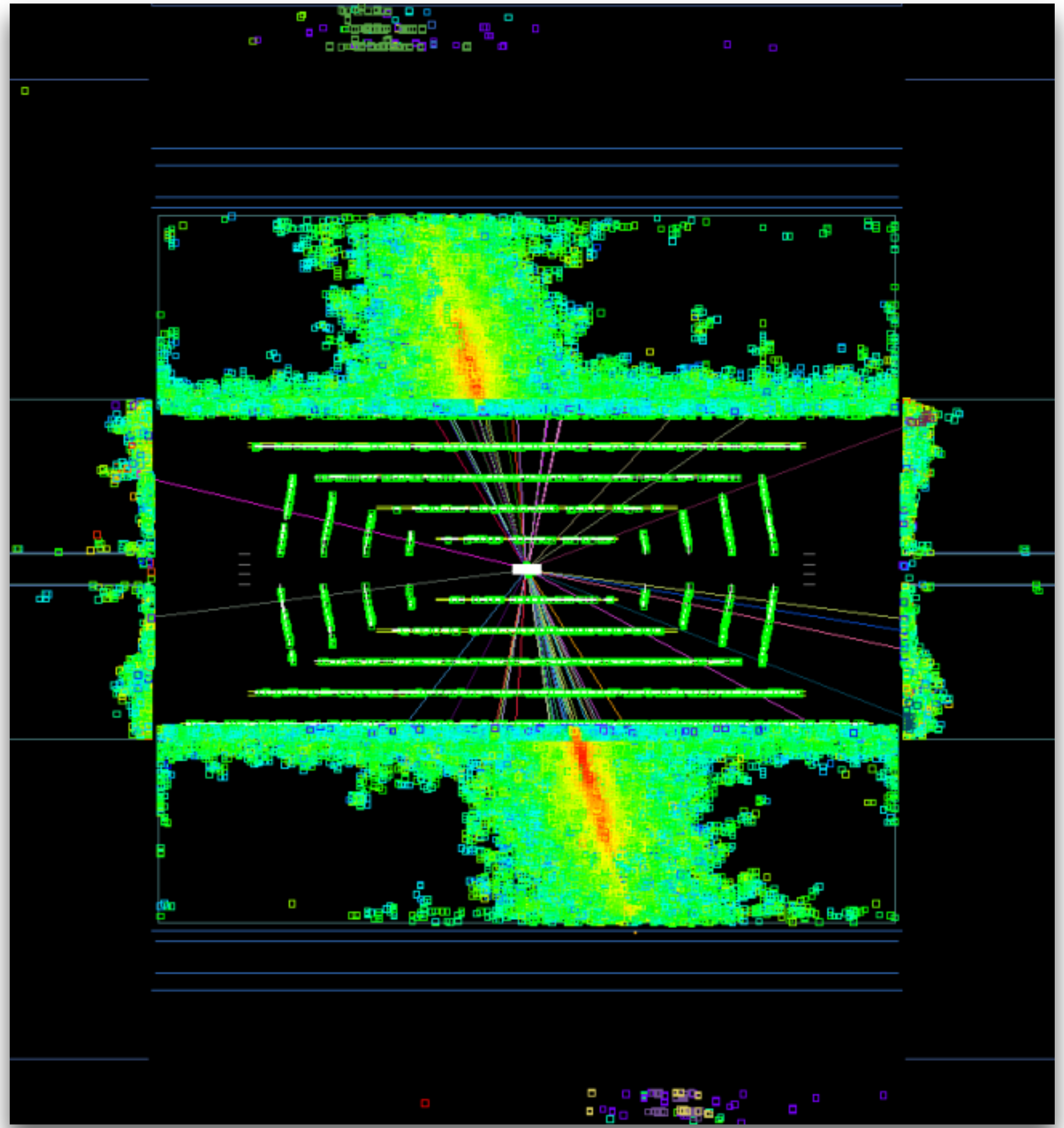
64 layers Fe-Scintillator sampling

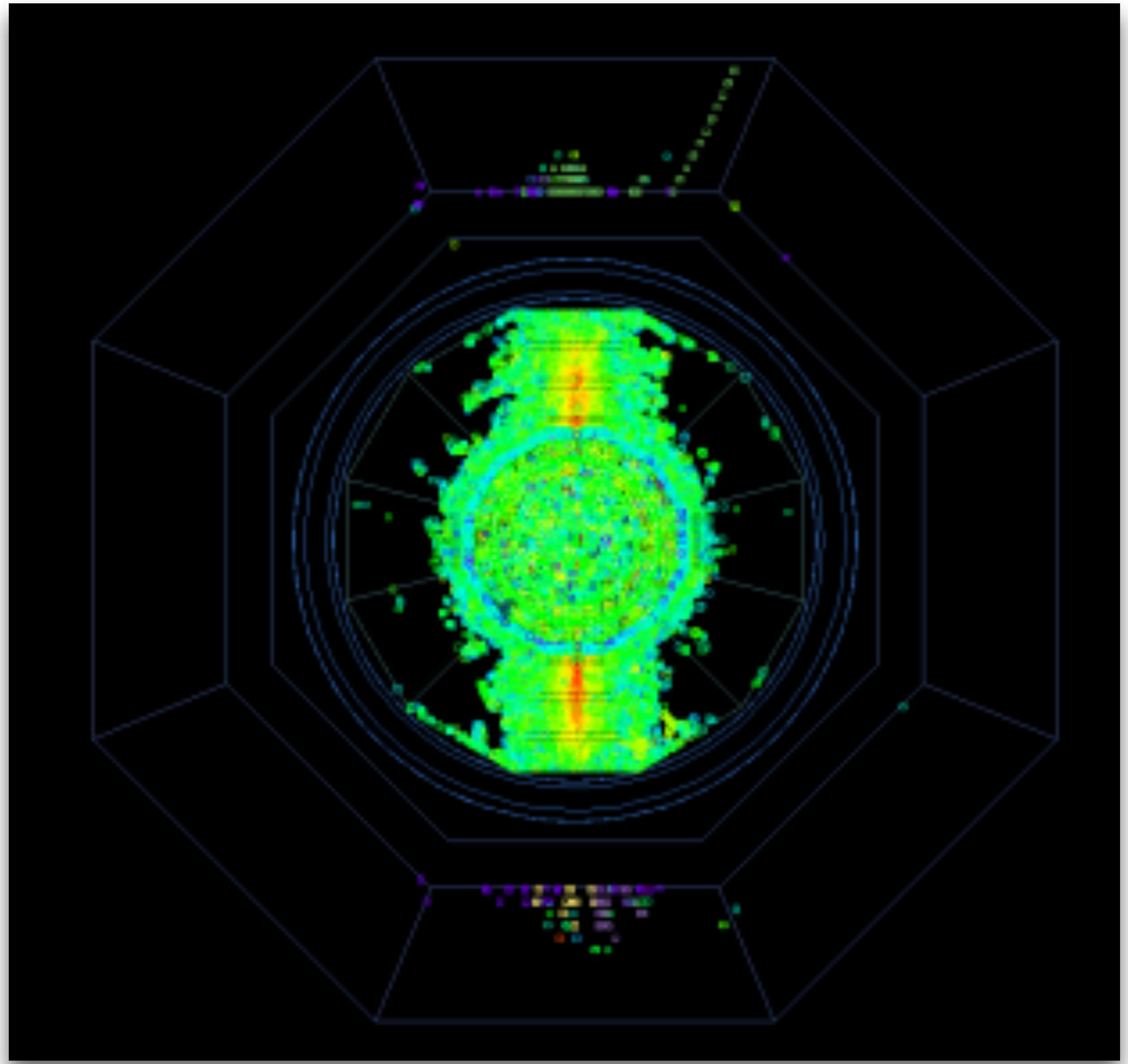
~11.3λ, 5cm x 5cm cells; Δη x Δφ ~ 0.022 x 0.022

finely longitudinally segmented (<< 1λ per layer)

EXAMPLE EVENT

EXAMPLE: Z'(40 TeV) TO WW



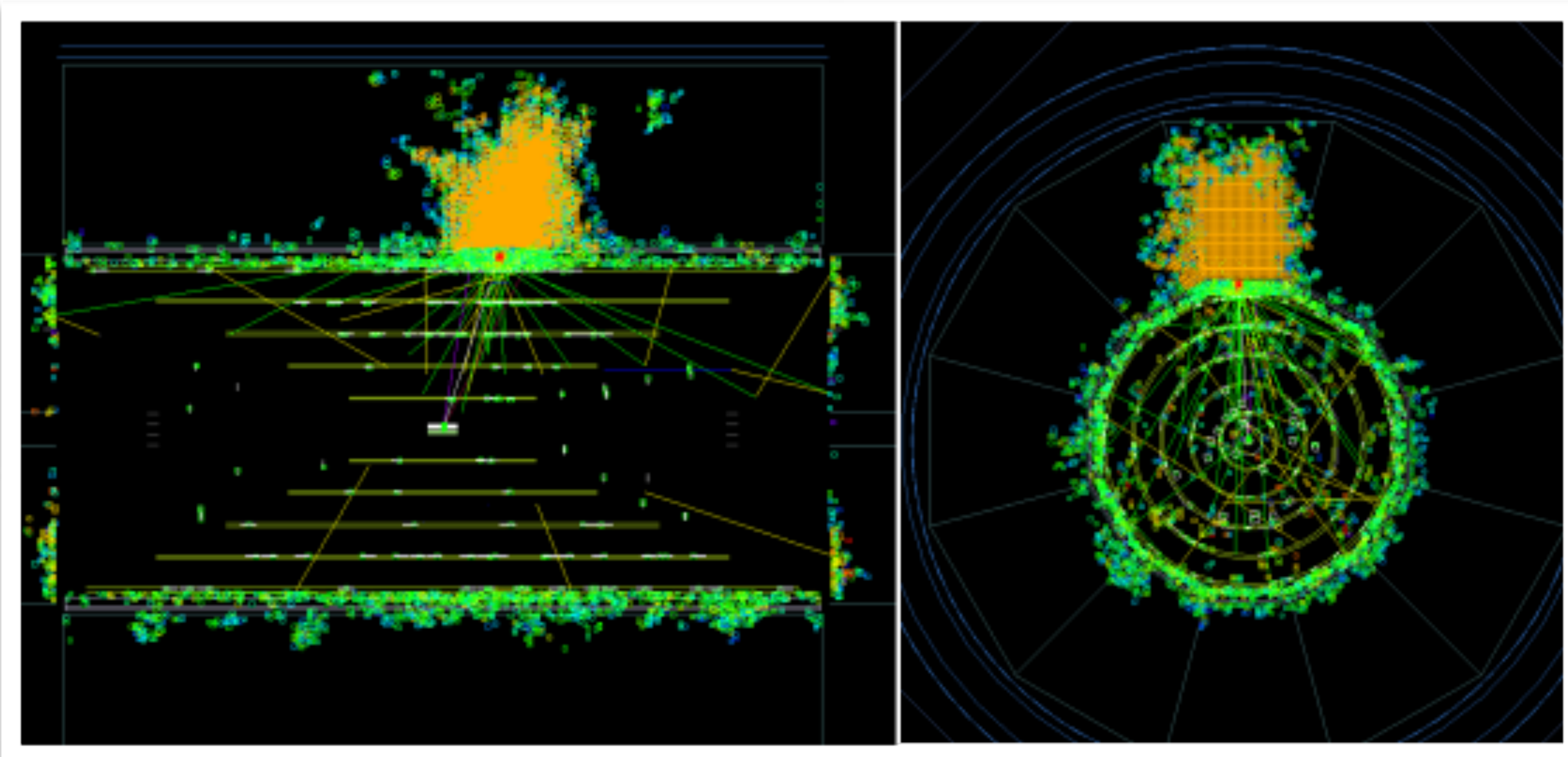


VERY BUSY, COMPLICATED EVENTS!

TO START UNDERSTANDING THINGS, GO TO SINGLE PARTICLE EVENTS...

EXAMPLE EVENT

EXAMPLE: 1 TEV SINGLE PION



7300 CALORIMETER HITS, 440 SITRACKER HITS

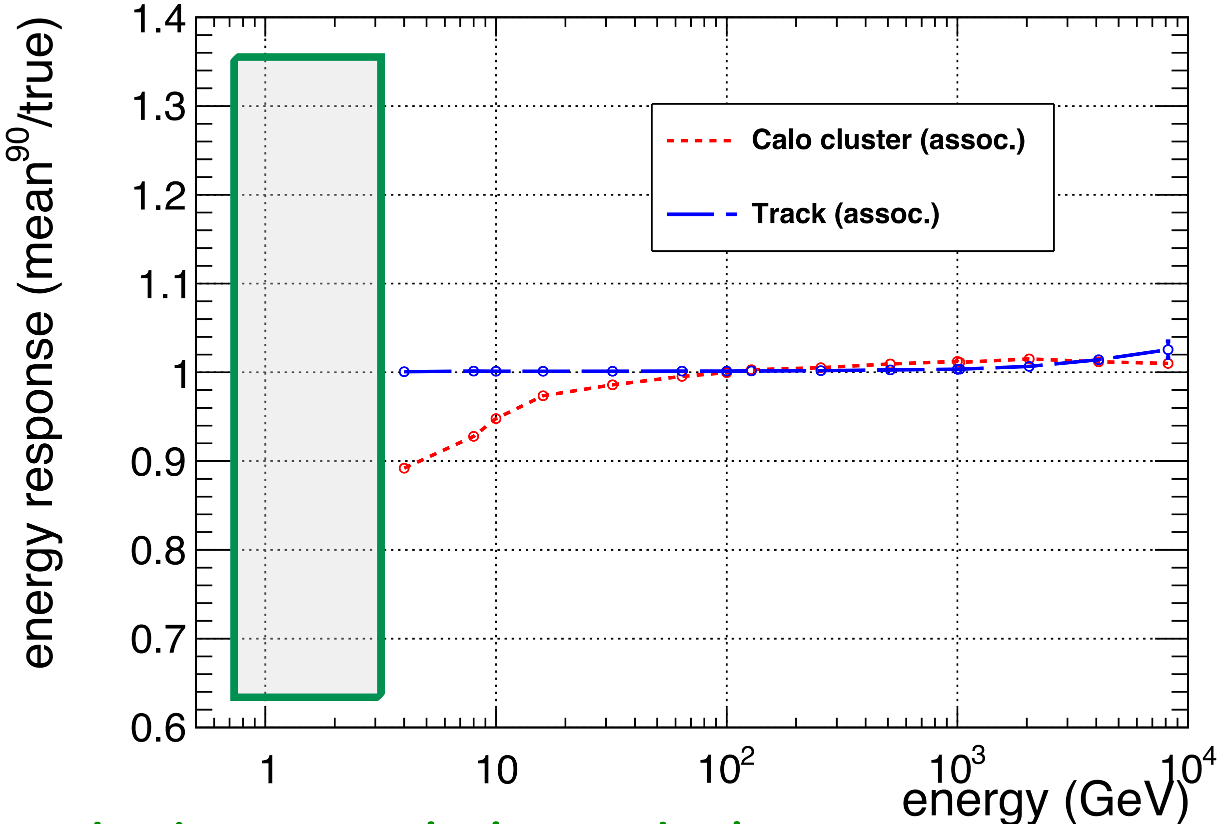
1 RECONSTRUCTED PFA (PI+) =998 GEV

1 RECONSTRUCTED CALOCLUSTER AT 1058 GEV

MANY BACK-SPLASH INTERACTIONS

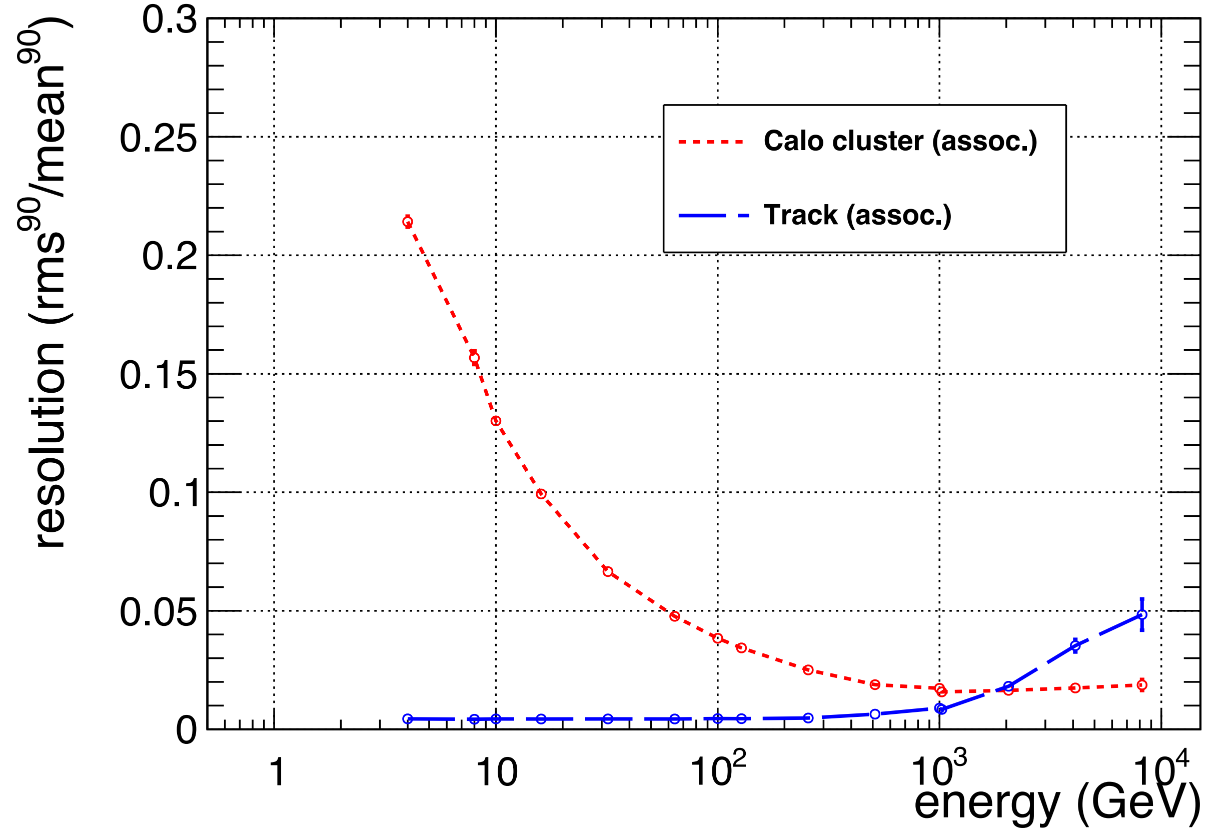
SINGLE PION PERFORMANCE

RESPONSE



Tracks do not reach the tracker!

RESOLUTION



BASIC PERFORMANCE OF ASSOCIATED TRACK AND CLUSTER TO PANDORA PFA OBJECT

NEED TO REVISIT CLUSTERING ALGORITHMS

BENCHMARK TARGET CALORIMETER PERFORMANCE:

~2% CONSTANT TERM, 40% SAMPLING TERM

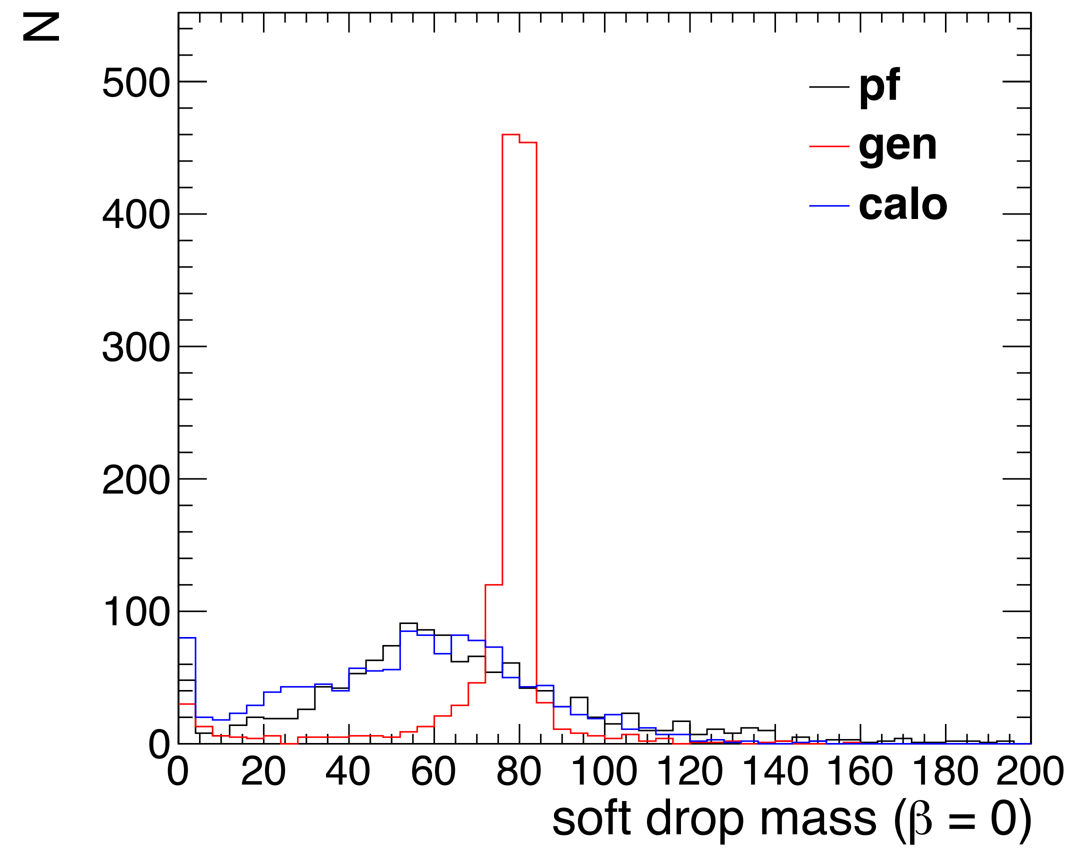
CROSS-OVER POINT OF TRACKER AND CALORIMETER RESOLUTION, ~ 2 TEV

TOWARDS AN INTRINSIC ANGULAR SCALE

GOING DIRECTLY TO JET PERFORMANCE CONVOLVES MANY DIFFERENT ISSUES.

ANGULAR SCALES, PARTICLE FLOW INTERNALS

Z' (10 TEV) TO WW EVENTS



WITH SINGLE PARTICLE VALIDATION, STUDY DOUBLE K^0_L SAMPLES

FIX $\eta = 0$, SLOWLY VARY K^0_L SEPARATION IN Φ

INTEGRATE SHOWER PROFILE IN Φ OVER MANY EVENTS TO DETERMINE AN INTRINSIC SCALE

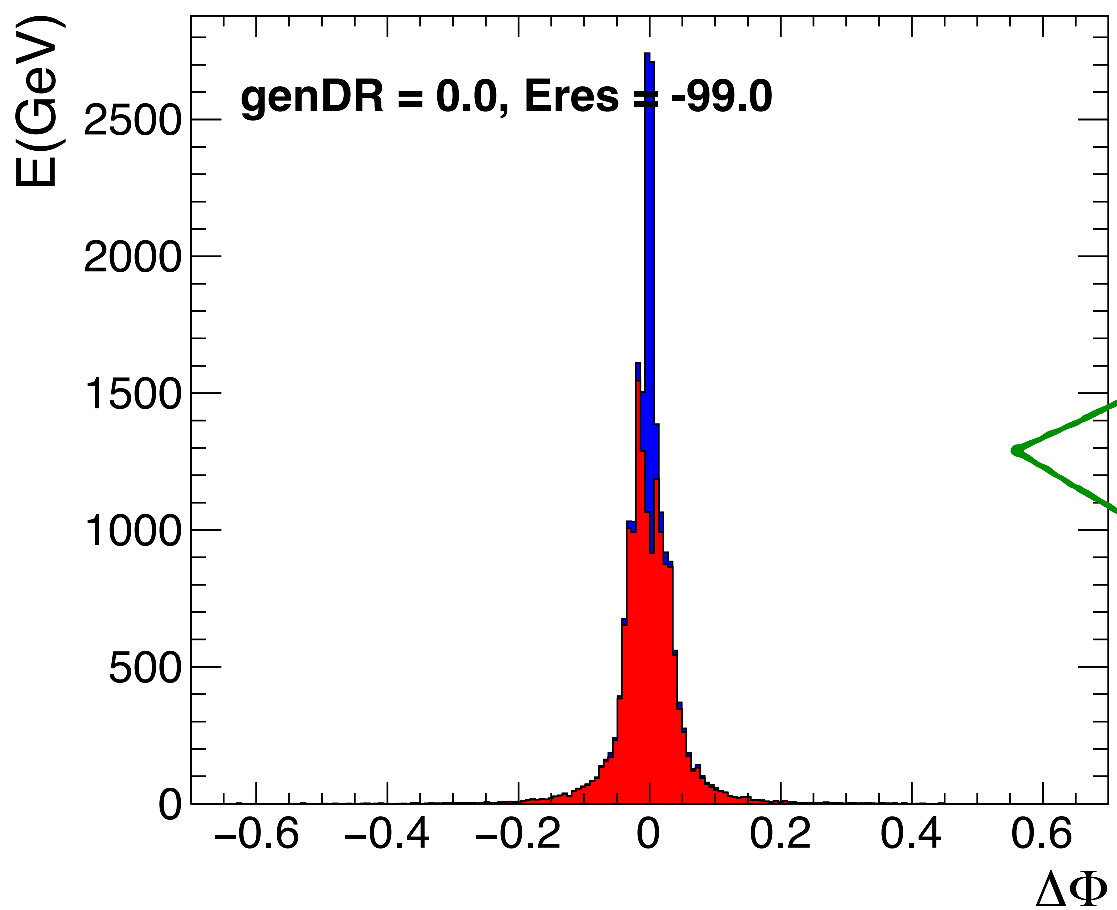
COMPARE 20CM X 20CM VS 5CM X 5CM HCAL CELLS

STUDY ONLY CALORIMETER HITS, NOT CLUSTERS (WHICH HAS PF ALGO DEPENDENCY)

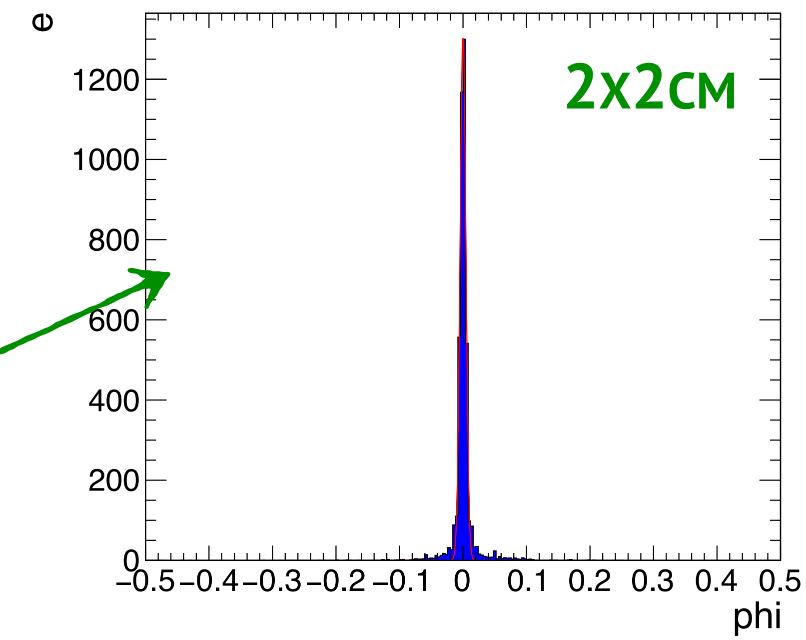
DOUBLE K^0_L - 20CM X 20CM - 100 GEV

ECAL
HCAL

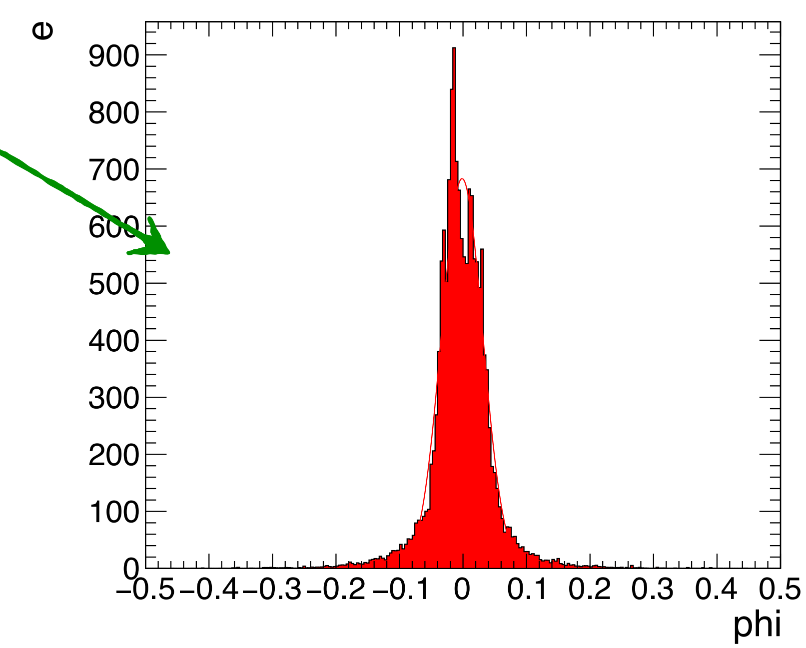
INTEGRATED OVER 50 EVENTS
2 K^0_L, ΔR = 0.0, 100 GEV EACH



$\sigma = 0.0045$



$\sigma = 0.032$



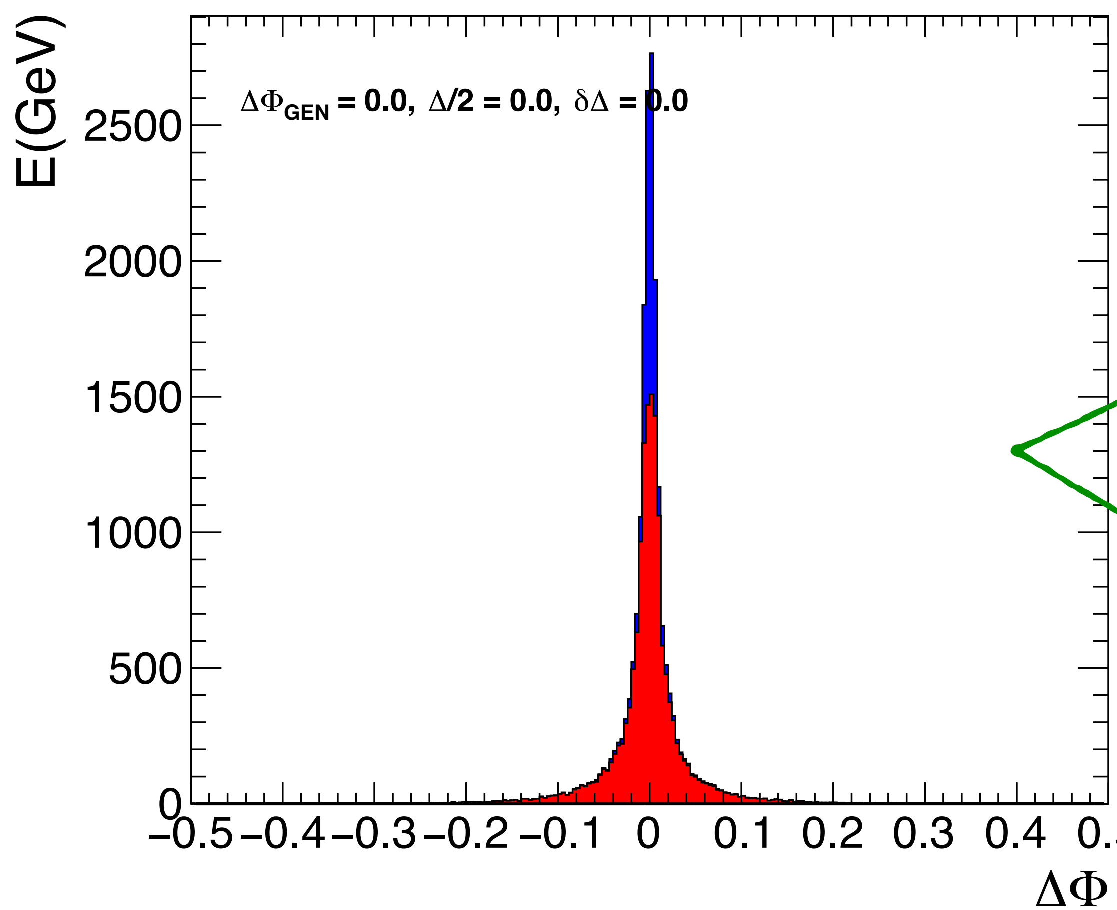
BE CAREFUL WITH THE CONCLUSIONS:
DIFFERENT COMPONENTS TO THE SHOWER, AND
DIFFERENT SHOWER POPULATIONS (E.G. SHOWERS
STARTING IN THE ECAL ~50% OF THE TIME)

DOUBLE K^0_L - 5CM X 5CM - 100 GEV

ECAL
HCAL

INTEGRATED OVER 50 EVENTS

2 K^0_L, ΔR = 0.0, 100 GEV EACH



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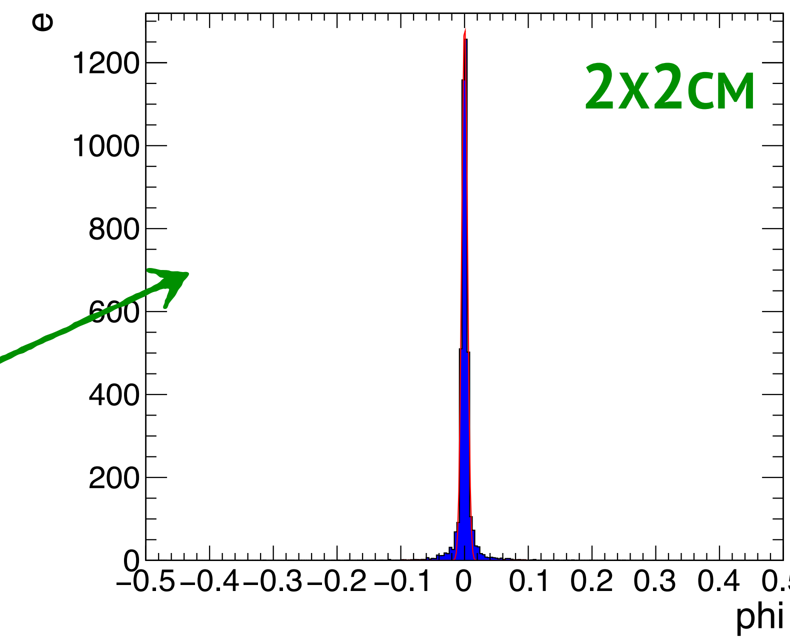
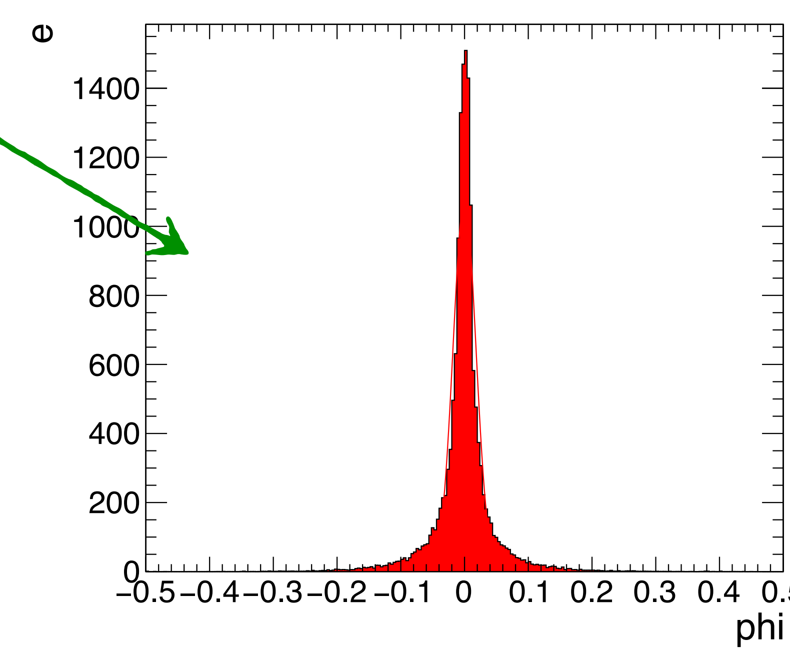


σ = 0.018



BE CAREFUL WITH THE CONCLUSIONS:

DIFFERENT COMPONENTS TO THE SHOWER, AND

DIFFERENT SHOWER POPULATIONS (E.G. SHOWERS

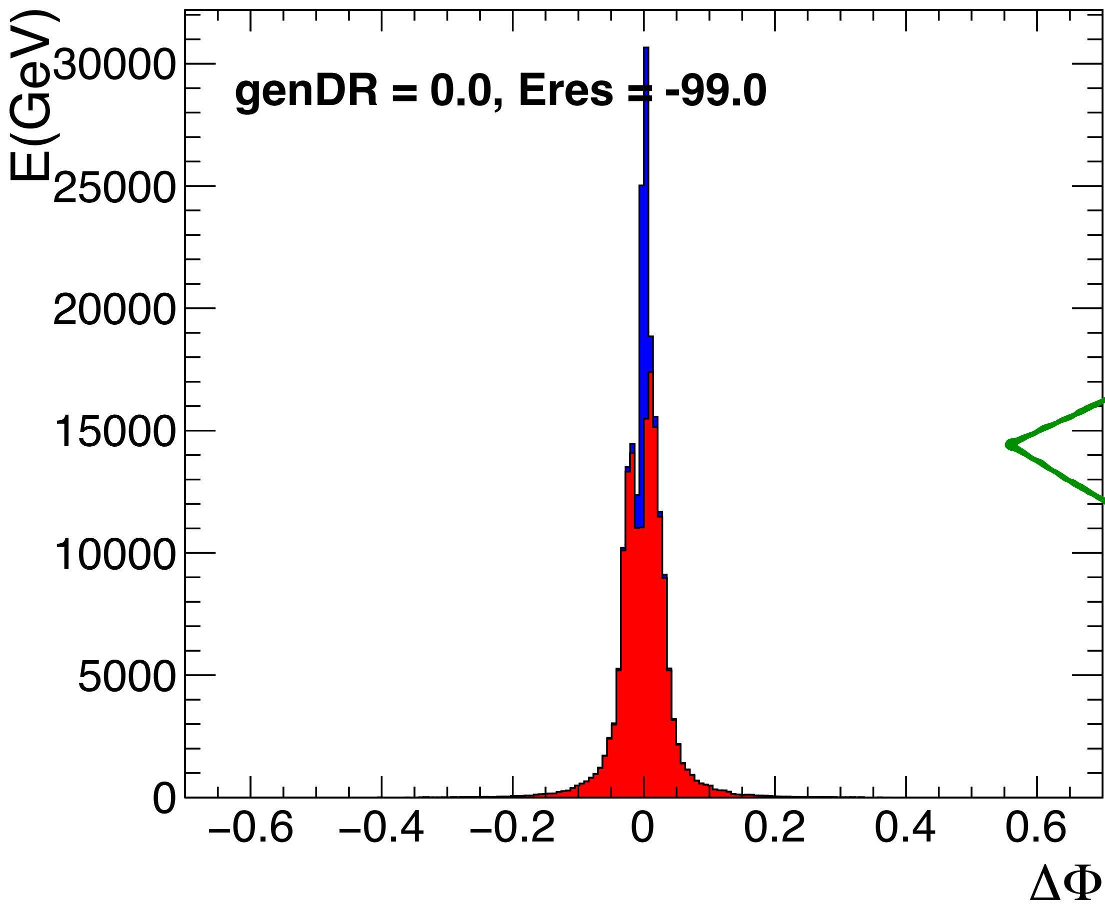
STARTING IN THE ECAL ~50% OF THE TIME)

DOUBLE K^0_L - 20CM X 20CM - 1000 GEV

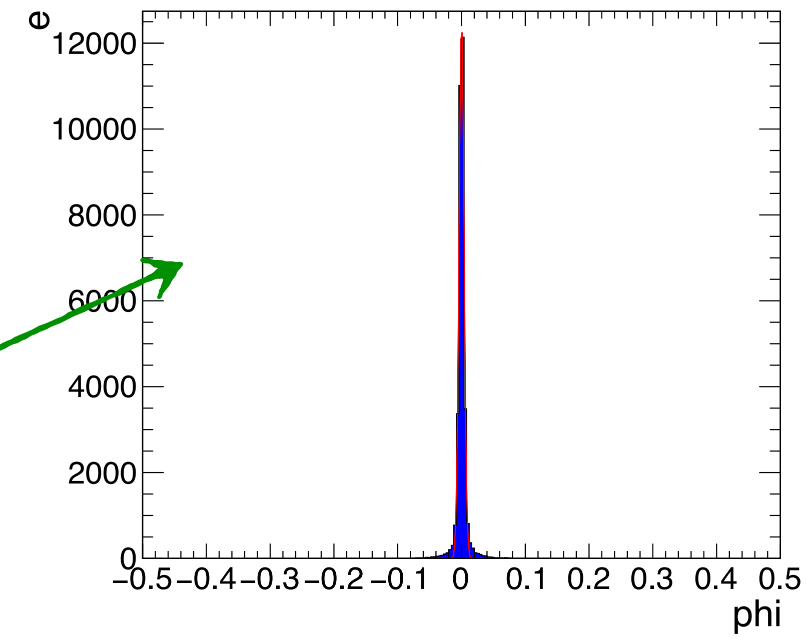
ECAL
HCAL

INTEGRATED OVER 50 EVENTS

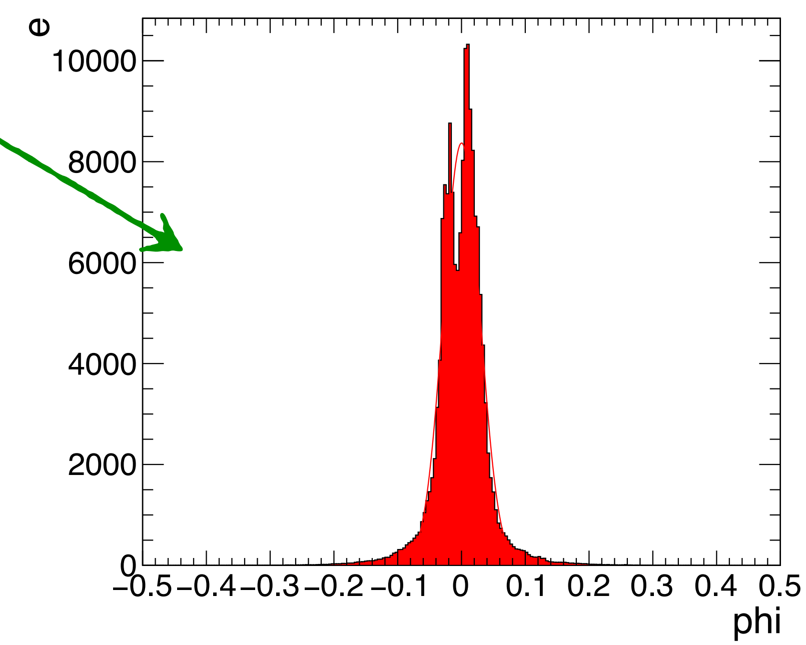
2 K^0_L, ΔR = 0.0, 1000 GEV EACH



σ = 0.0040



σ = 0.029



BE CAREFUL WITH THE CONCLUSIONS:

DIFFERENT COMPONENTS TO THE SHOWER, AND

DIFFERENT SHOWER POPULATIONS (E.G. SHOWERS

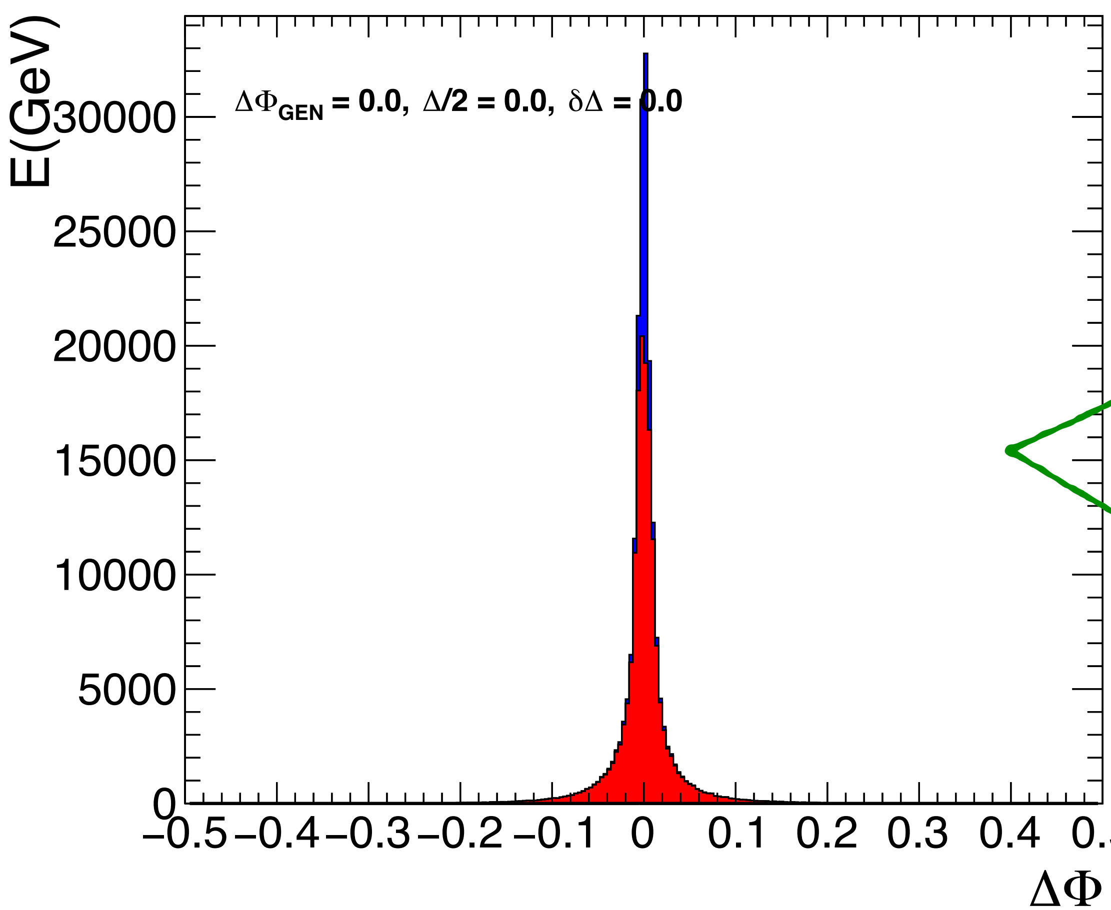
STARTING IN THE ECAL ~50% OF THE TIME)

Double K^0_L - 5cm x 5cm - 1000 GeV

ECAL
HCAL

Integrated over 50 events

2 K^0_L, ΔR = 0.0, 1000 GeV each



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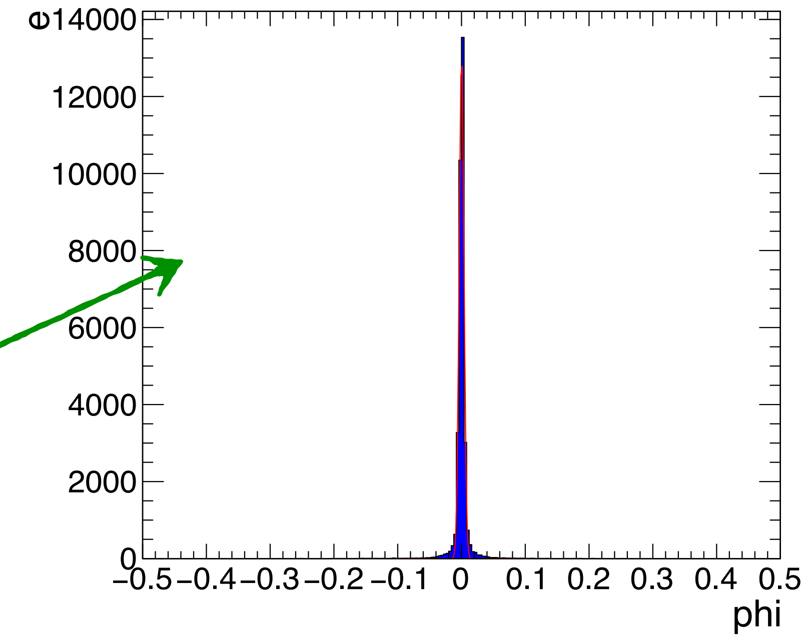
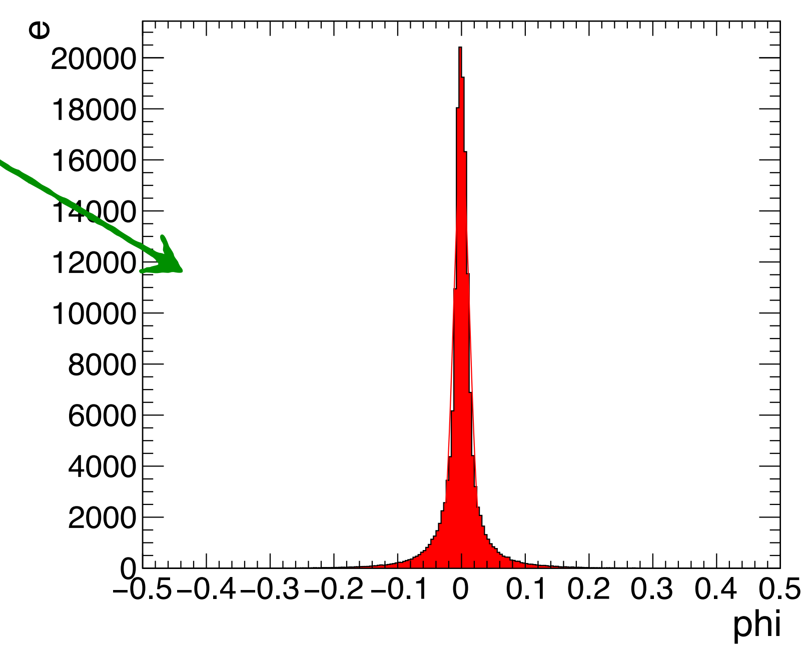


σ = 0.013



Be careful with the conclusions:

different components to the shower, and

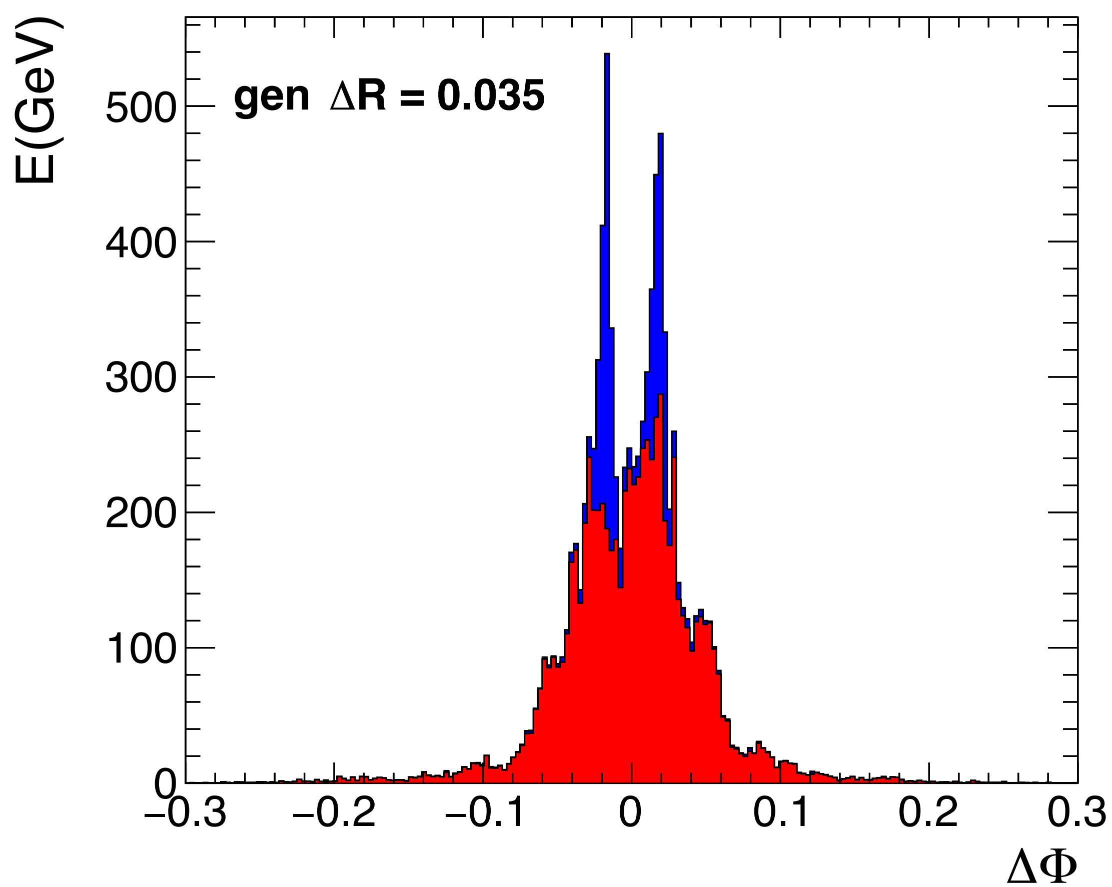
different shower populations (e.g. showers

starting in the ECAL ~50% of the time)

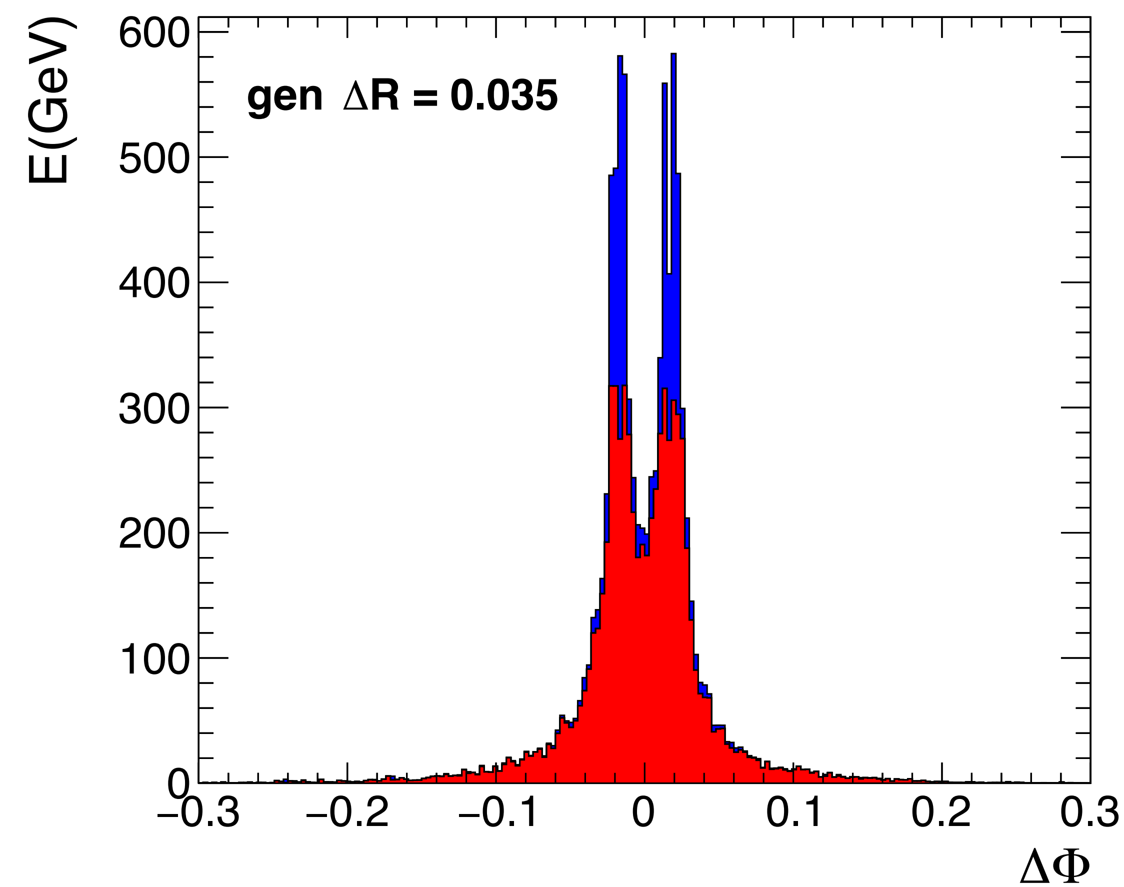
PULL THE K^0_L APART

PULL APART THE K^0_L TO SEE THE INTRINSIC ANGULAR SCALE

20x20



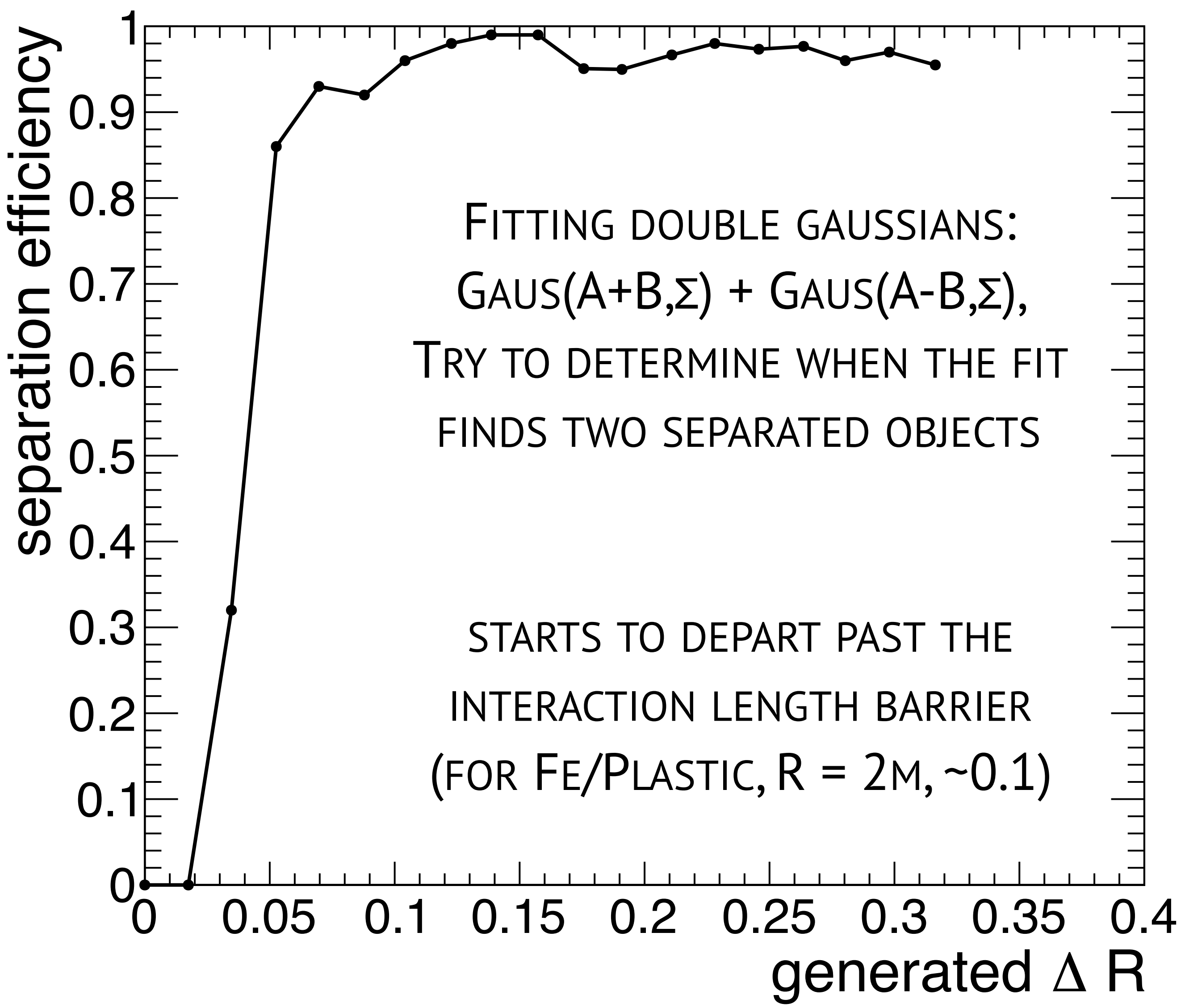
5x5



SO FAR LOOKING AT THINGS ON AVERAGE, BUT NEED TO UNDERSTAND HOW TO PULL THINGS APART ON AN EVENT-BY-EVENT BASIS

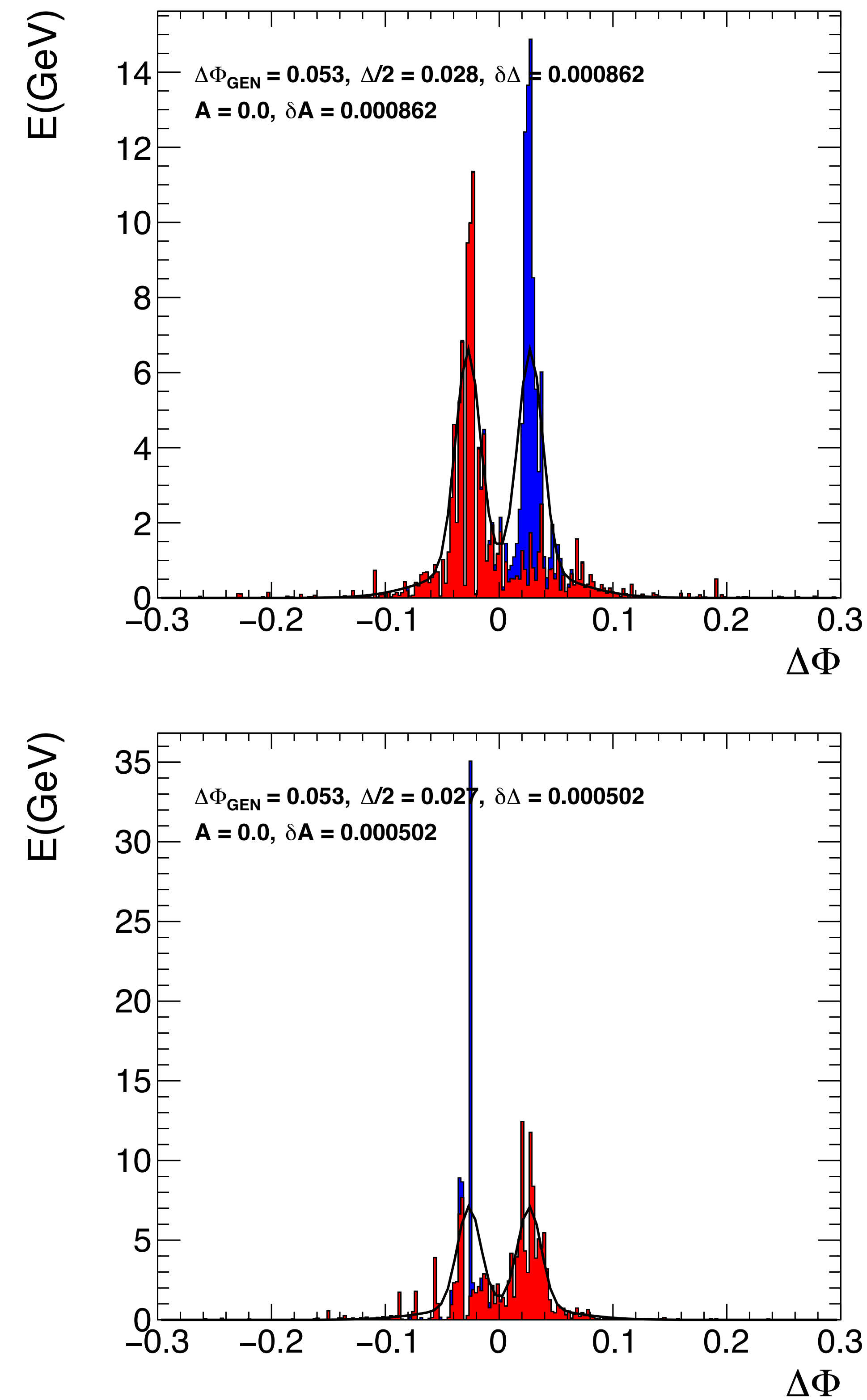
NAIVE CLUSTERING

IN THE ABSENCE OF A SOPHISTICATED CLUSTERING ALGORITHM
(UNDERSTANDING PANDORA PFA) MAKE NAIVE FIRST STAB...



FITTING DOUBLE GAUSSIANS:
GAUS(A+B,Σ) + GAUS(A-B,Σ),
TRY TO DETERMINE WHEN THE FIT
FINDS TWO SEPARATED OBJECTS

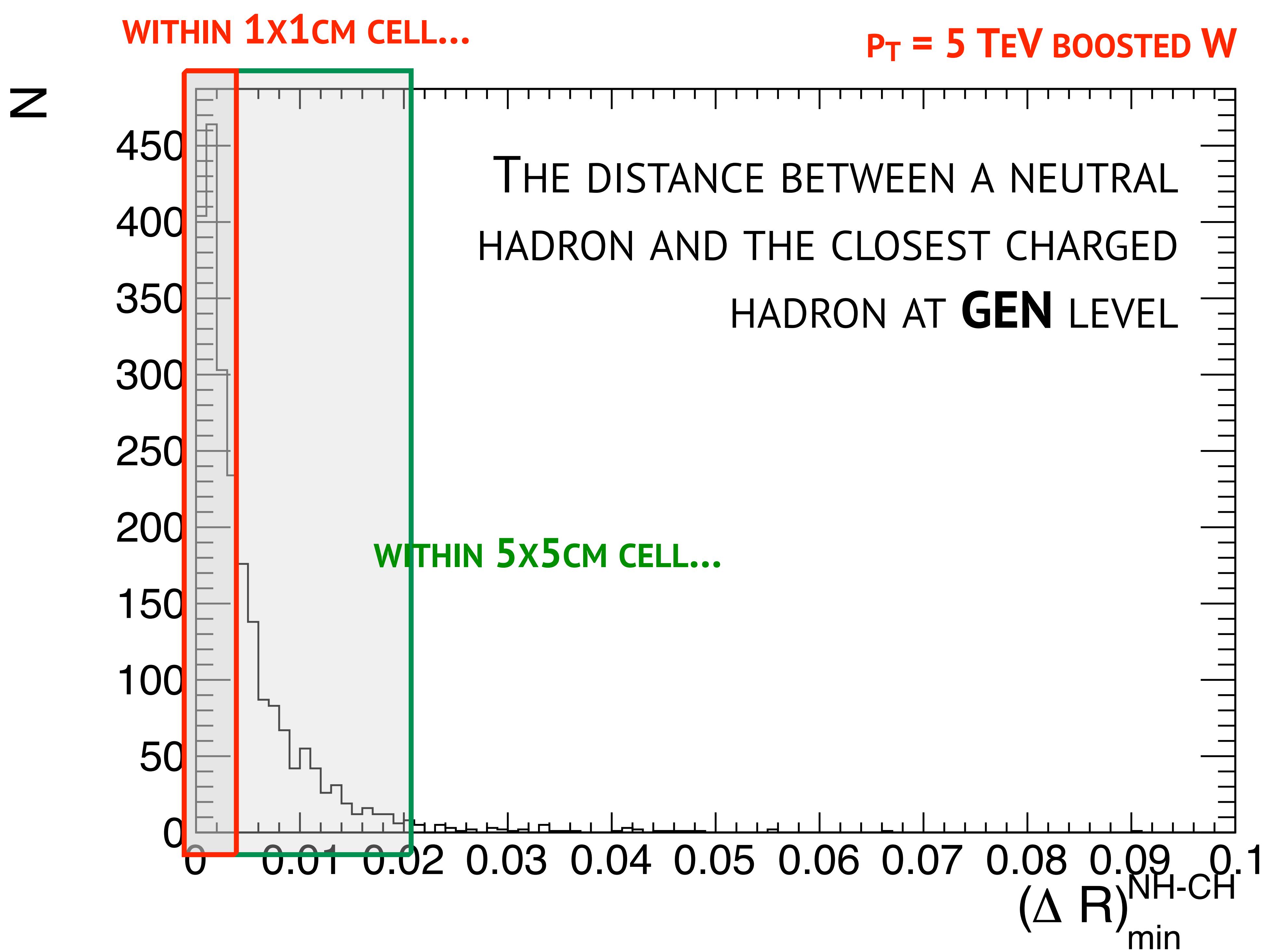
STARTS TO DEPART PAST THE
INTERACTION LENGTH BARRIER
(FOR FE/PLASTIC, R = 2M, ~0.1)



BIG CAVEATS ON NAIVETY, BUT DEFINITELY MORE
POWERFUL CLUSTERING METHODS CAN BE EXPLORED

NECESSARY ANGULAR RESOLUTION

WILL WE HAVE ENOUGH JUICE FOR A 5 TEV BOOSTED W? 20 TEV?



DISCUSSION

WORKING TOWARDS INTRINSIC HADRONIC ANGULAR SCALES

- NOT NECESSARILY DRIVEN BY NUCLEAR INTERACTION LENGTH
- NEED MORE SOPHISTICATED CLUSTERING METHODS, TO TAKE ADVANTAGE OF THE LONGITUDINAL SEGMENTATION

CAN "IMAGE" THE START OF THE SHOWER WITH HIGH LONGITUDINAL AND TRANSVERSELY GRANULAR DETECTORS

VERY INTERESTING TO UNDERSTAND THE INTERPLAY OF ANGULAR RESOLUTION ON LONGITUDINAL VERSUS TRANSVERSE GRANULARITY

INTRINSIC COUPLING BETWEEN GRANULARITY AND CLUSTERING ALGORITHM

LOOK AT ENERGY ASYMMETRIES, DIFFERENT PARTICLE SPECIES, AFFECT OF ABSORBER THICKNESS, ETC.

DO WE WANT/NEED SUCH A CALORIMETER?

Performance loss from partial information

Even if we could build a calorimeter to resolve hadronic showers at the $\Delta R < \sim 0.001$ level, is it worth it? [$$$$]

What do we gain?

What is the **true** discrimination power lost by throwing out the neutral hadron information?

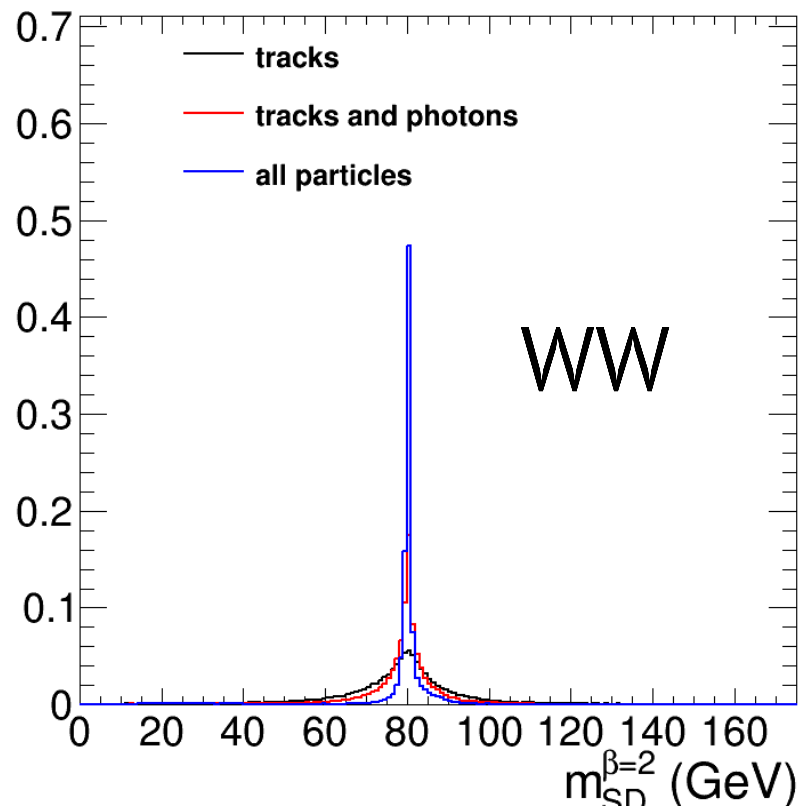
Study parameters:

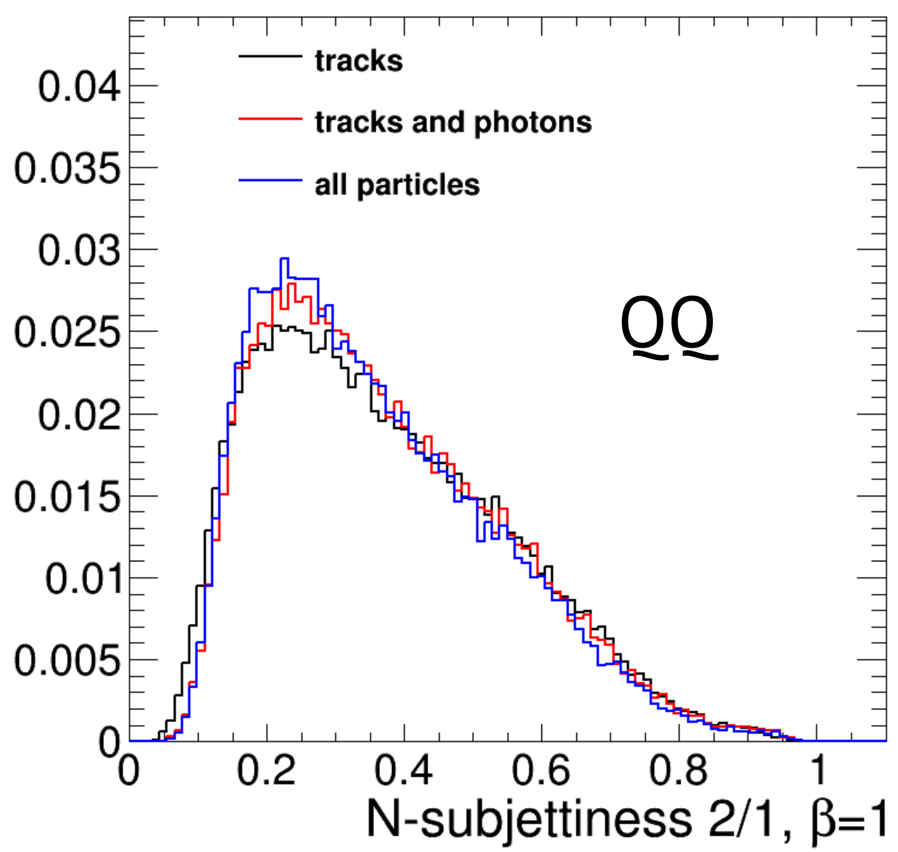
@Particle level, quantify how much performance degrades throwing out certain information

No smear/resolution: The **UPPER LIMIT** on performance difference

Geant studies will guide us further

Study inputs





Samples for comparison

Q,G,W,Z,T jets (p_T = 1,5 TeV)

Jet constituent Inputs:

TRACKS

TRACKS + γ

ALL PARTICLES

Substructure inputs

(a la BOOST13 report):

5 different groomed masses

N-subjettiness ($\tau_{1/2/3}$ ratios, β=1,2)

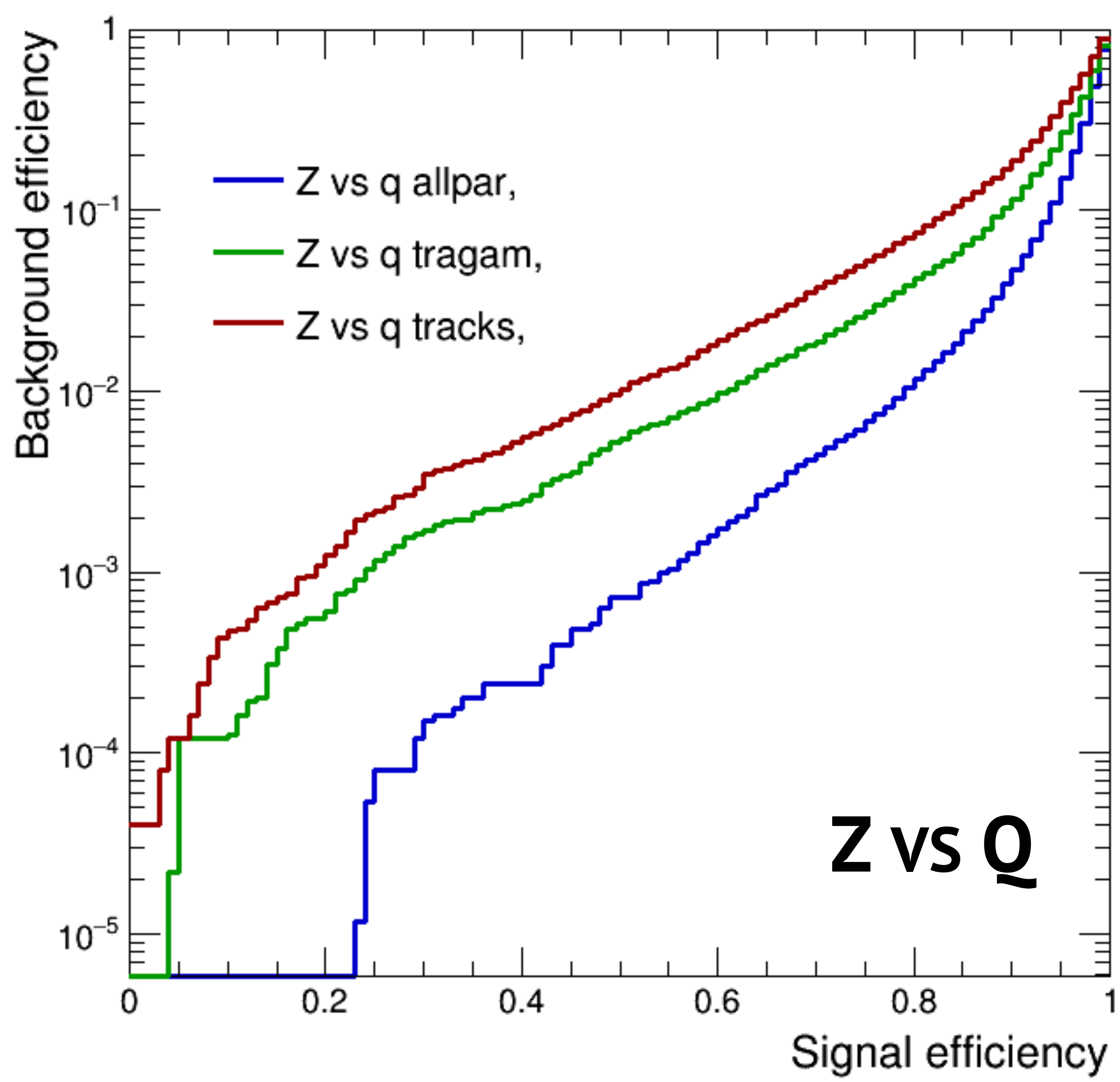
ECF ($C_{1/2}$ and $D_{1/2}$, β=1,2)

z log(z), multiplicity

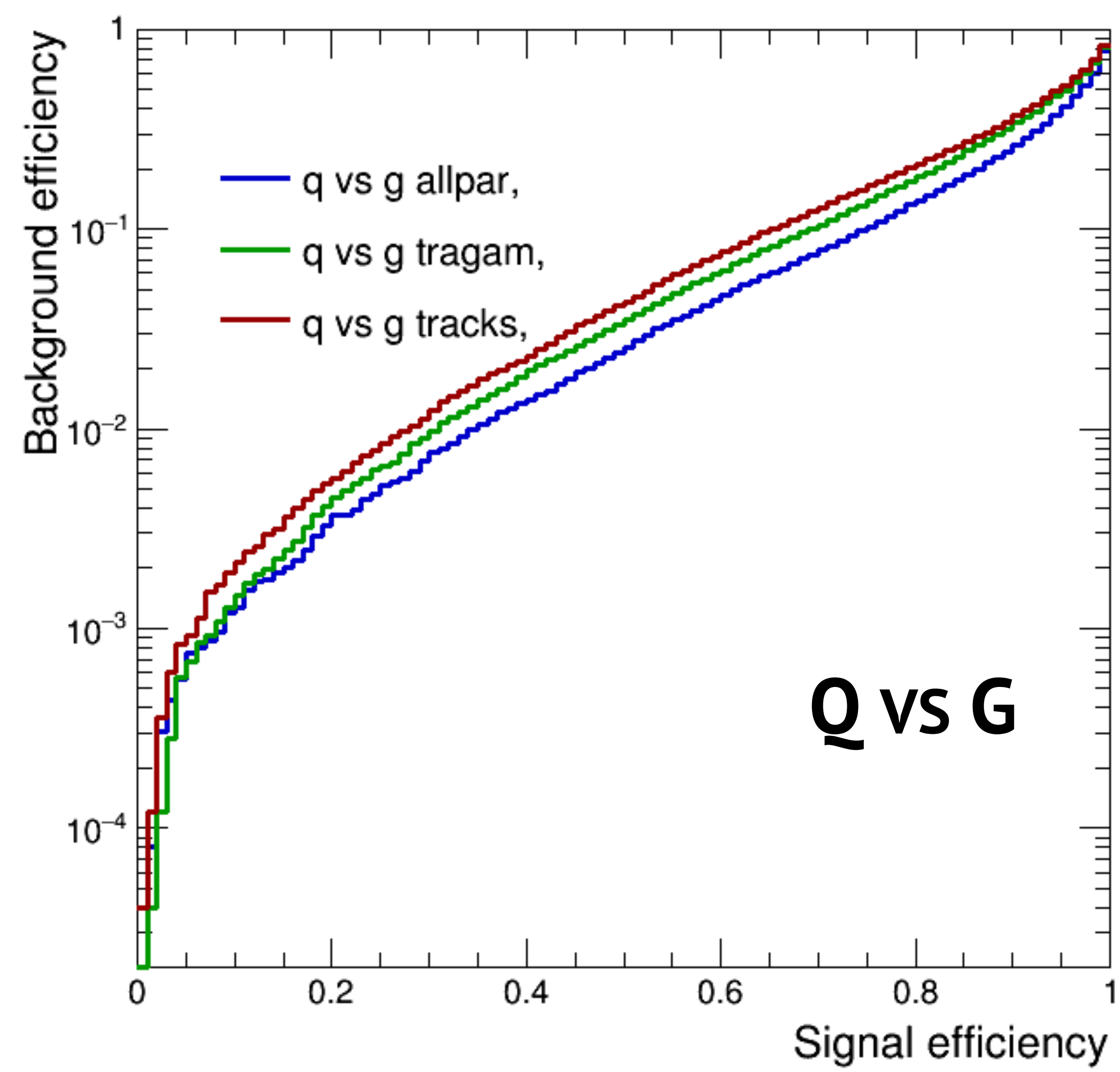
ROC DISCRIMINATION

QUANTIFYING THE INFORMATION LOSS...

EXAMPLE TRAININGS:

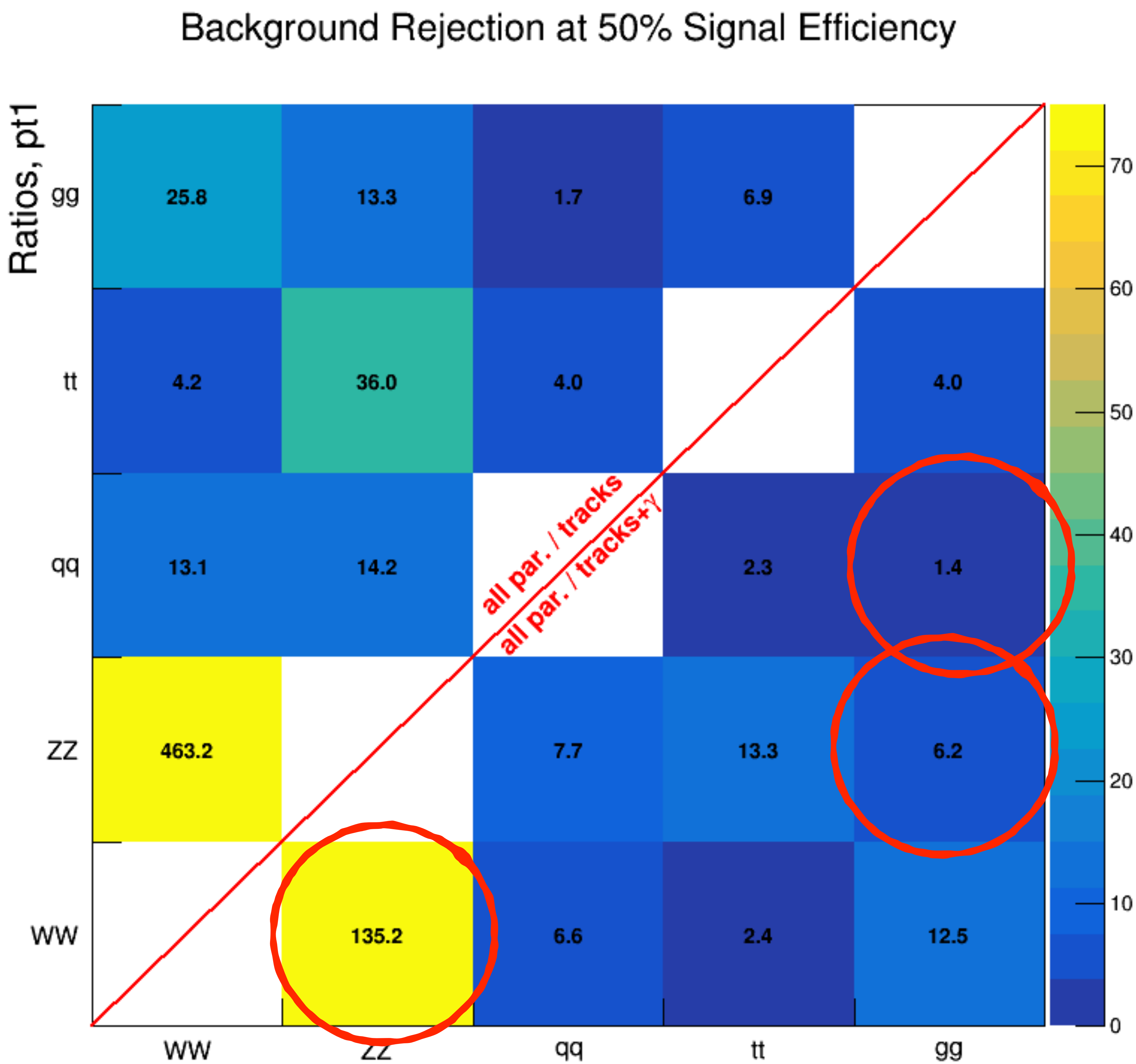


"MASS DRIVEN SEPARATION"

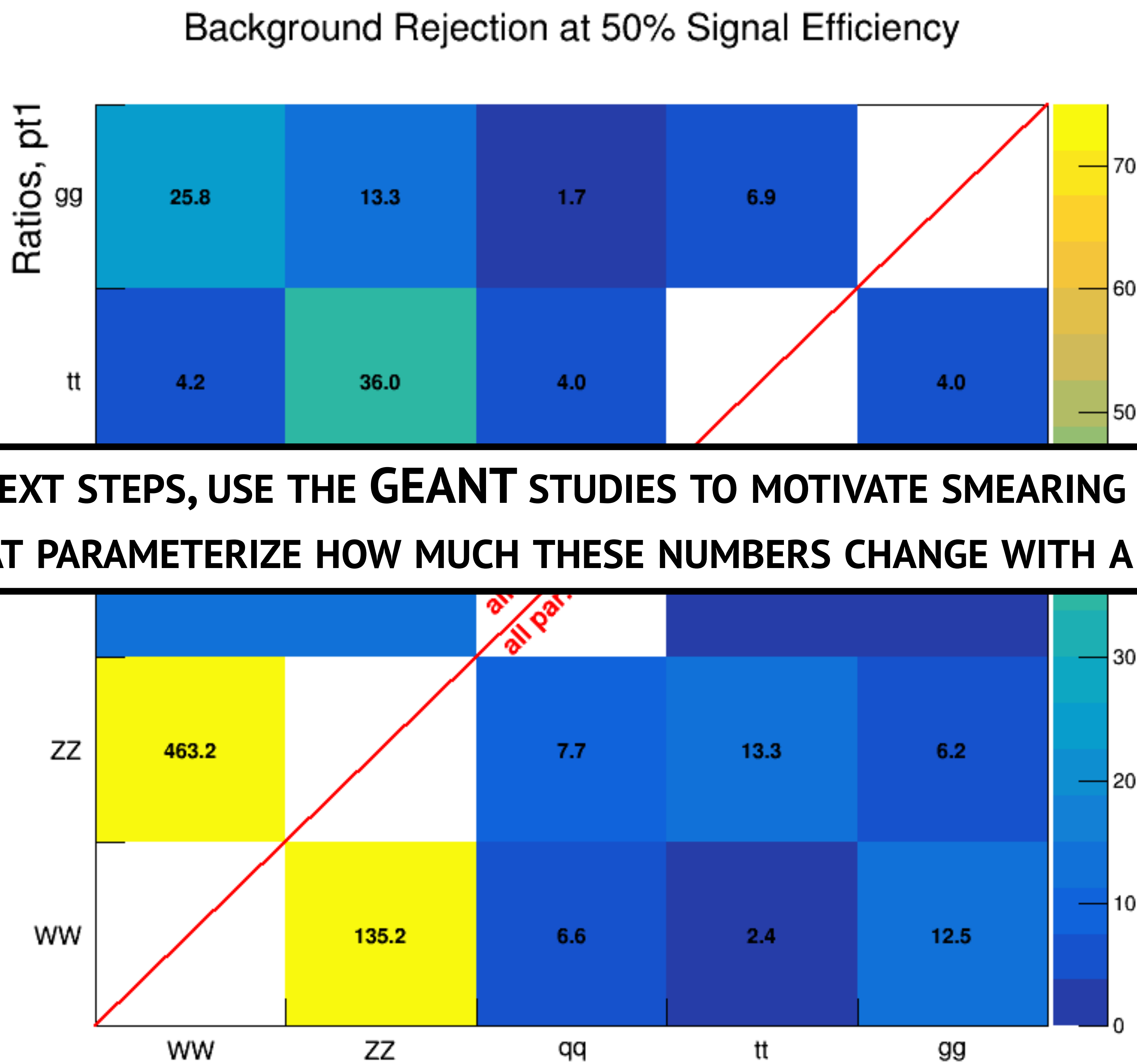


"SHAPE DRIVEN SEPARATION"

QUANTIFYING PERFORMANCE LOSS



QUANTIFYING PERFORMANCE LOSS



NEXT STEPS, USE THE GEANT STUDIES TO MOTIVATE SMEARING STUDIES THAT PARAMETERIZE HOW MUCH THESE NUMBERS CHANGE WITH A DETECTOR

SUMMARIZING

TAKING 2 APPROACHES TO UNDERSTANDING DETECTOR DESIGN FOR JET SUBSTRUCTURE IN THE SUPER-BOOSTED REGIME

LOW LEVEL GEANT STUDIES TO UNDERSTAND INTRINSIC GRANULARITY/ RESOLUTION LIMITATIONS

FIRST PROMISING RESULTS WHICH INDICATE ONE CAN USE CELL SIZES SMALLER THAN INTERACTION LENGHT

PARTICLE LEVEL STUDIES TO QUANTIFY PERFORMANCE LOSS FROM USING ONLY PARTIAL INFORMATION

FOR SHAPE BASED DISCRIMINATION, NOT MUCH PERFORMANCE LOSS THOUGH FOR MASS DISCRIMINATION, EFFECTS CAN BE PROHIBITIVE

A LONG AND DIFFICULT QUESTION TO FULLY ANSWER, BUT GAINING A DEEPER INTUITION; COLLABORATORS ALWAYS WELCOME!

ADDITIONAL