THE 'MULTIPLICIY JUMP!' – FINDING B'S IN MULTI-TEV JETS W/O TRACKS

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ARXIV:1701.06832

ALSO: 2016 J.PHYS. G: NUCL. PART. PHYS. 43 085001

OUTLINE

Why do we want to tag b-jets?

Explain the "multiplicity jump" technique (aka – Todd's crazy idea)

The "invented" parameter F_i

Pile-up and luminous region

Using an Artificial Neural Net (ANN)

- (It's not "deep" enough to be a DNN)
- Learning a little from "deep learning"

Future prospects @ ATLAS

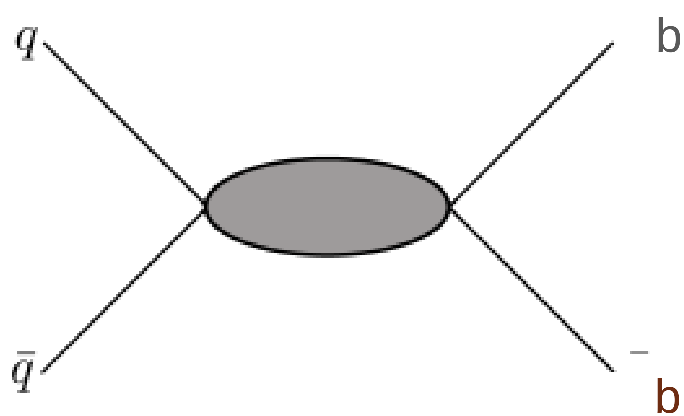
B HADRON'S IN JETS? WHY BOTHER -

Dijet Searches

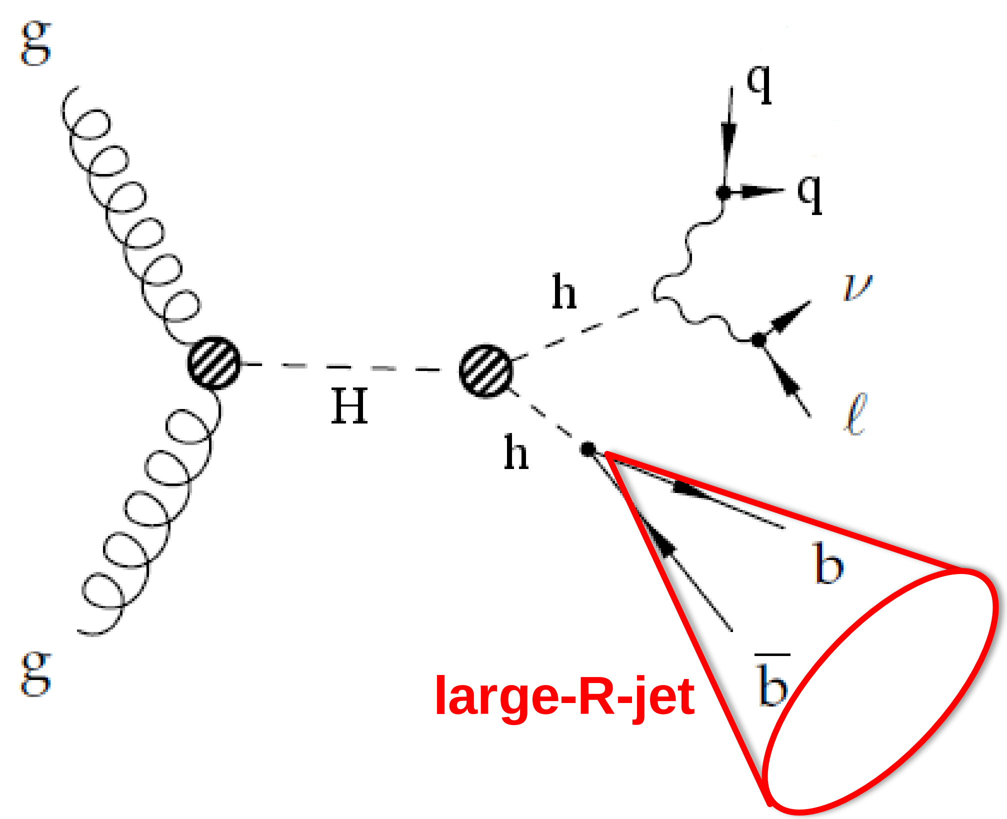
UNIVERSITY OF OXFORD

Goal: Search for non-resonant new physics using angular distribution of dijet events

e.g. Contact Interaction (CI)



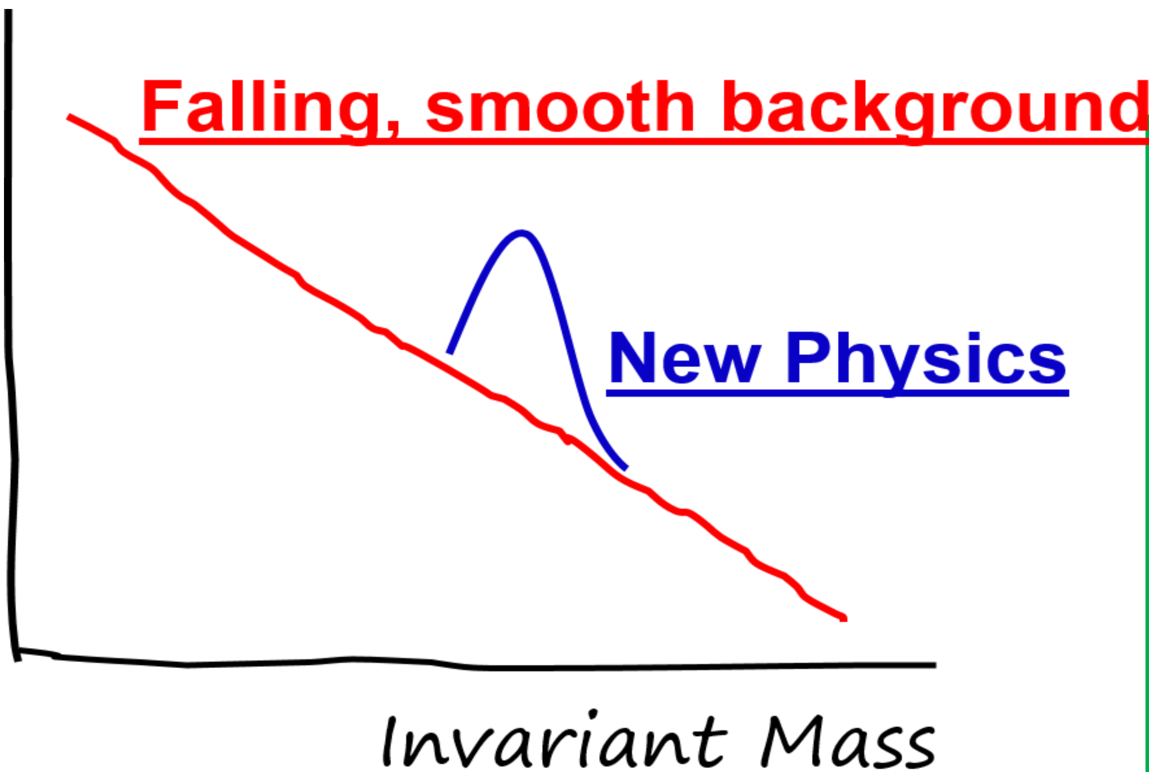
1-lepton final state
hh → bb + WW* → bb + lvqq

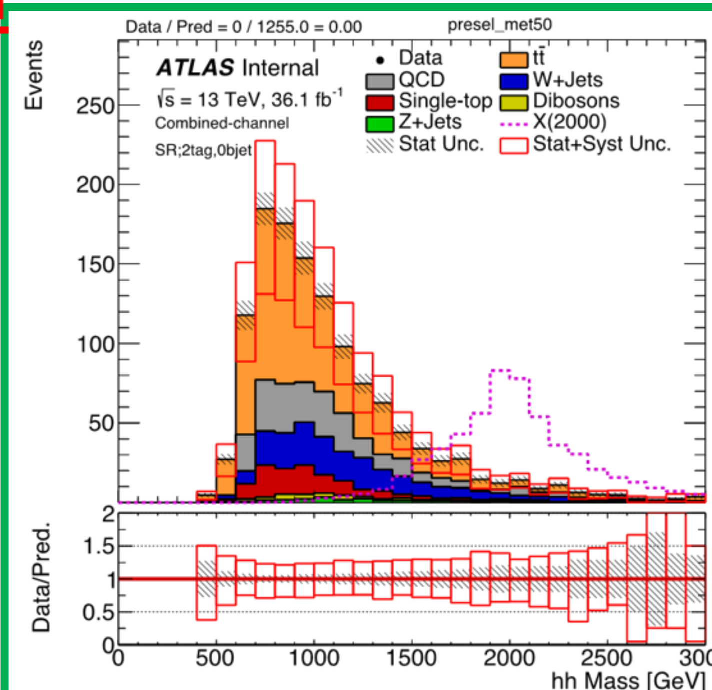


Boosted analysis

h → bb reconstruction with large-R jet.

BASIC POINT OF SEARCHES

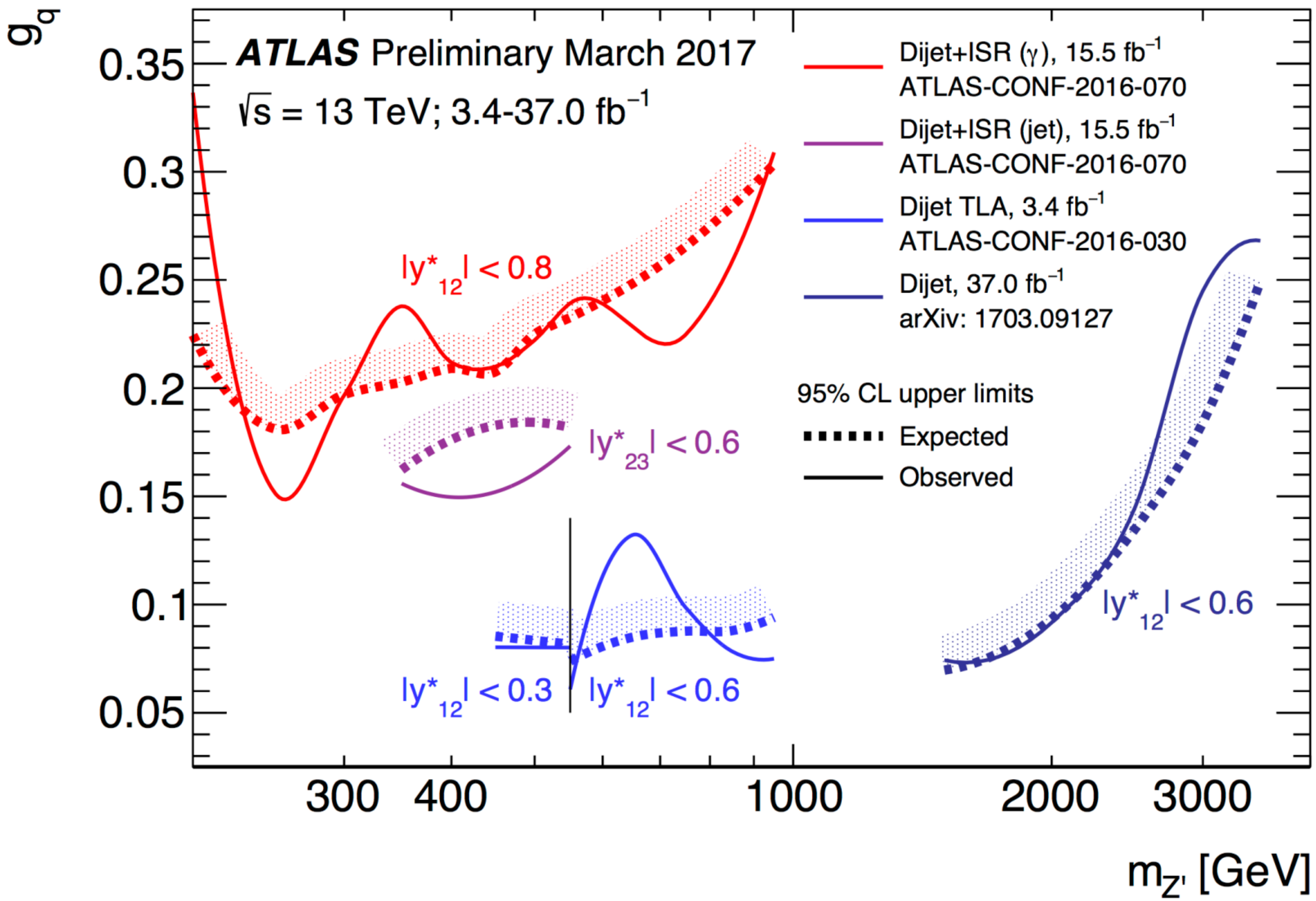


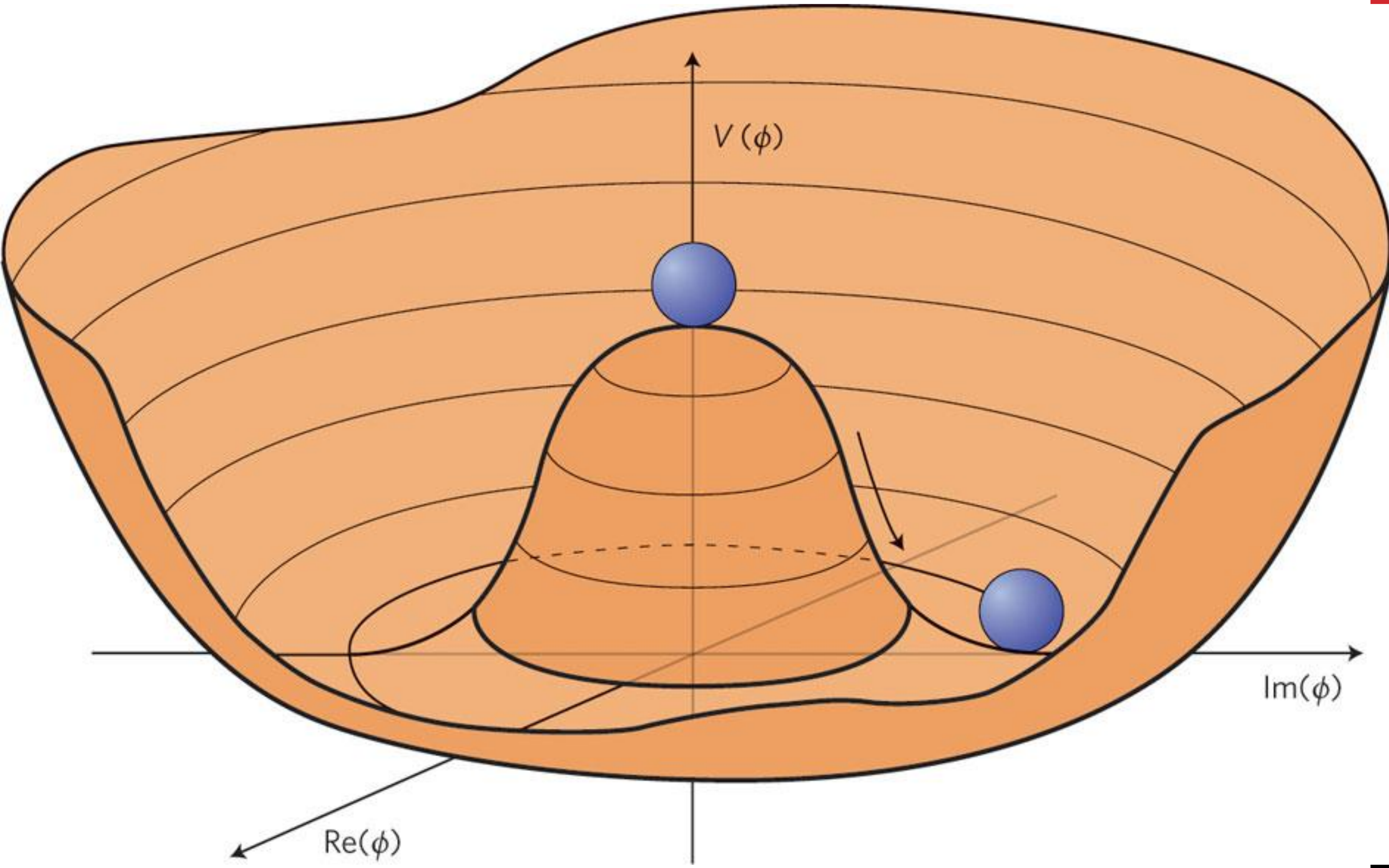


Search for an excess in m(hh)

DIJETS
ATLAS SEARCH - 2016

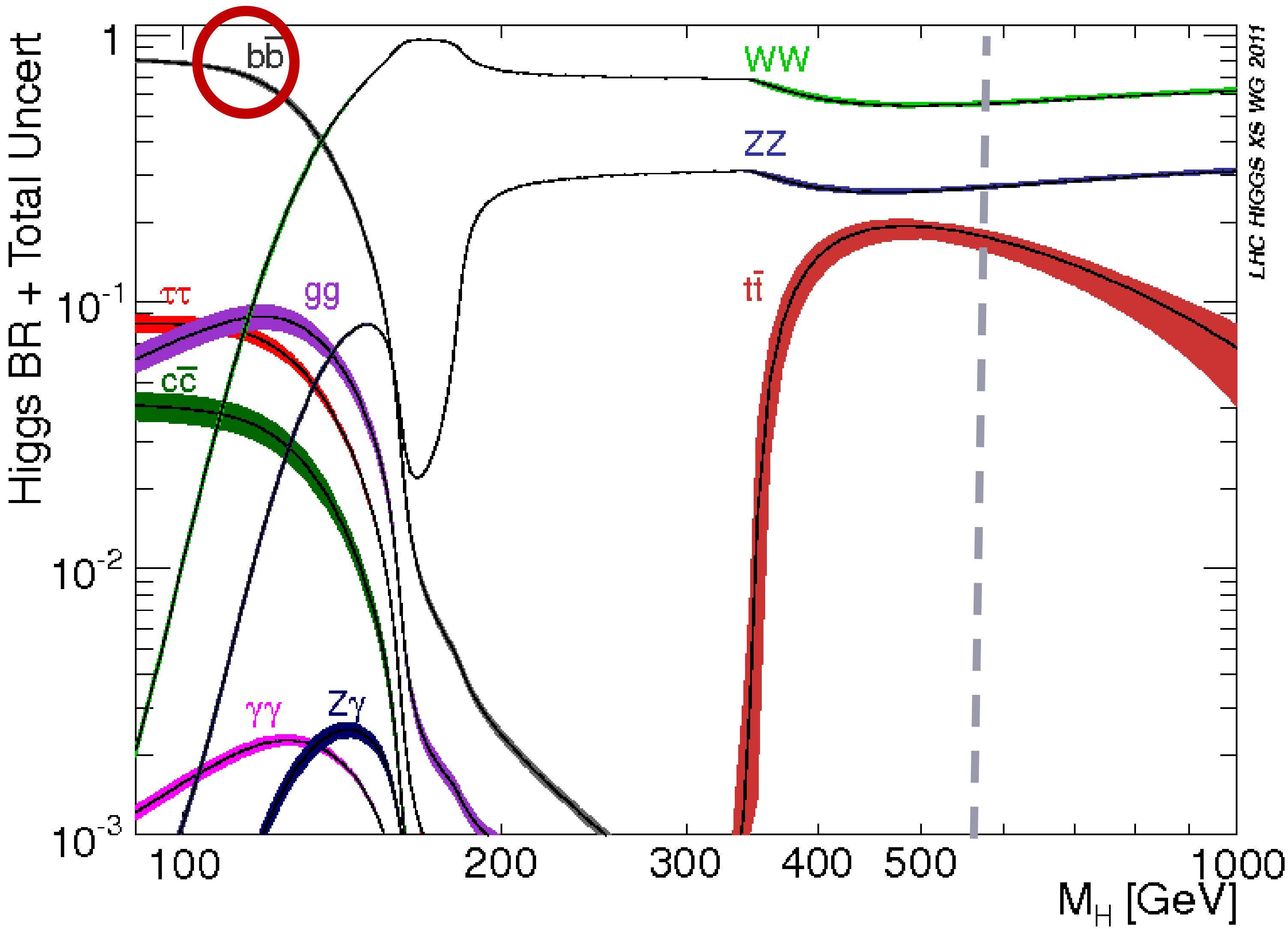
want to b-tag these jets





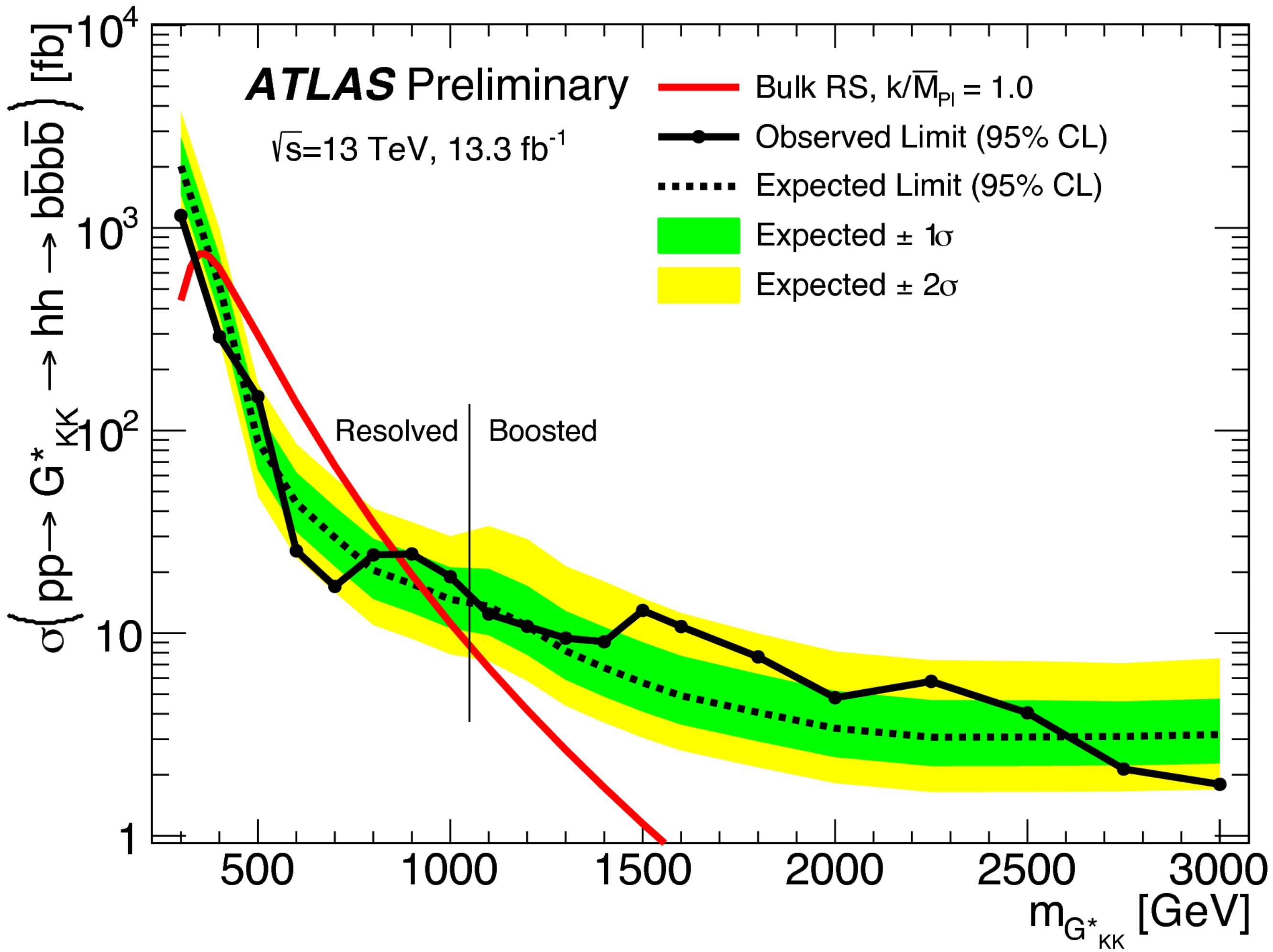
Taken from *Nature Physics* **7**, 2–3 (2011);

H→BB
80% BRANCHING RATIO

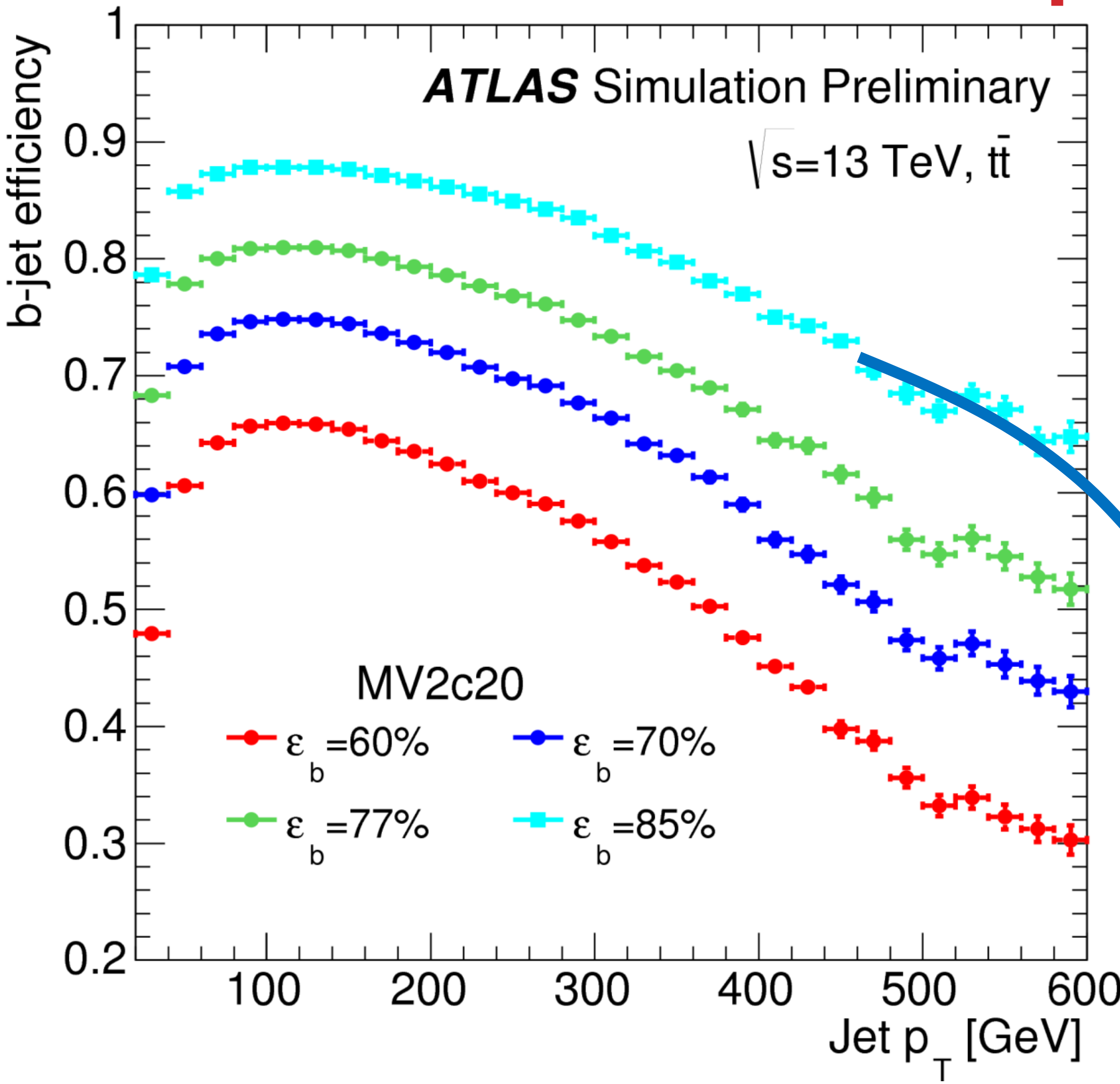


HIGGS HUNTING EXAMPLE
HH → 4B'S

ATLAS-CONF-2016-049



PROBLEM: TAG HIGH P_T B-JET



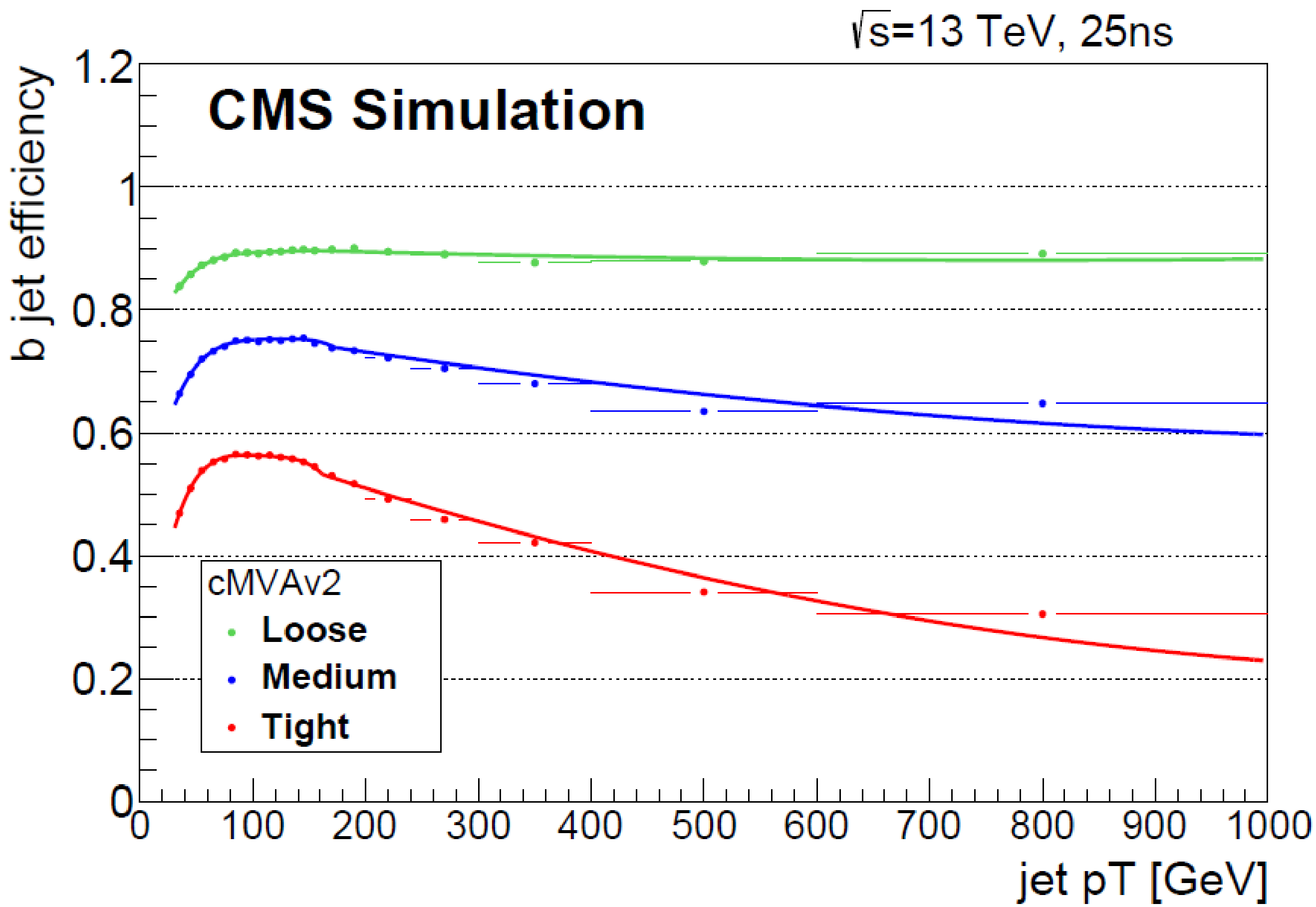
Aux. Fig. 4a → Pub. Note
ATL-PHYS-PUB-2015-022

Next: Why it happens

PROBLEM: TAG HIGH P_T B-JET

Much great work happening

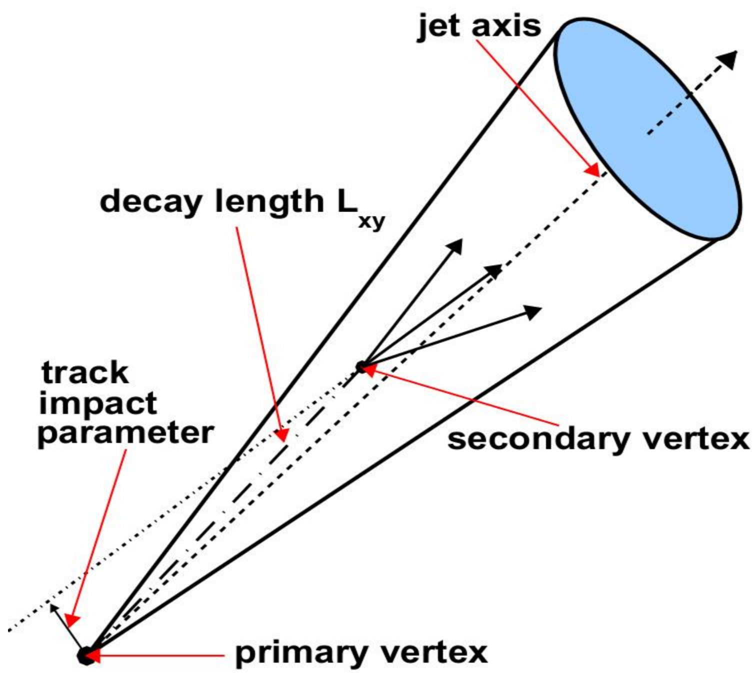
From CMS btag note
[CMS PAS BTV-15-001]



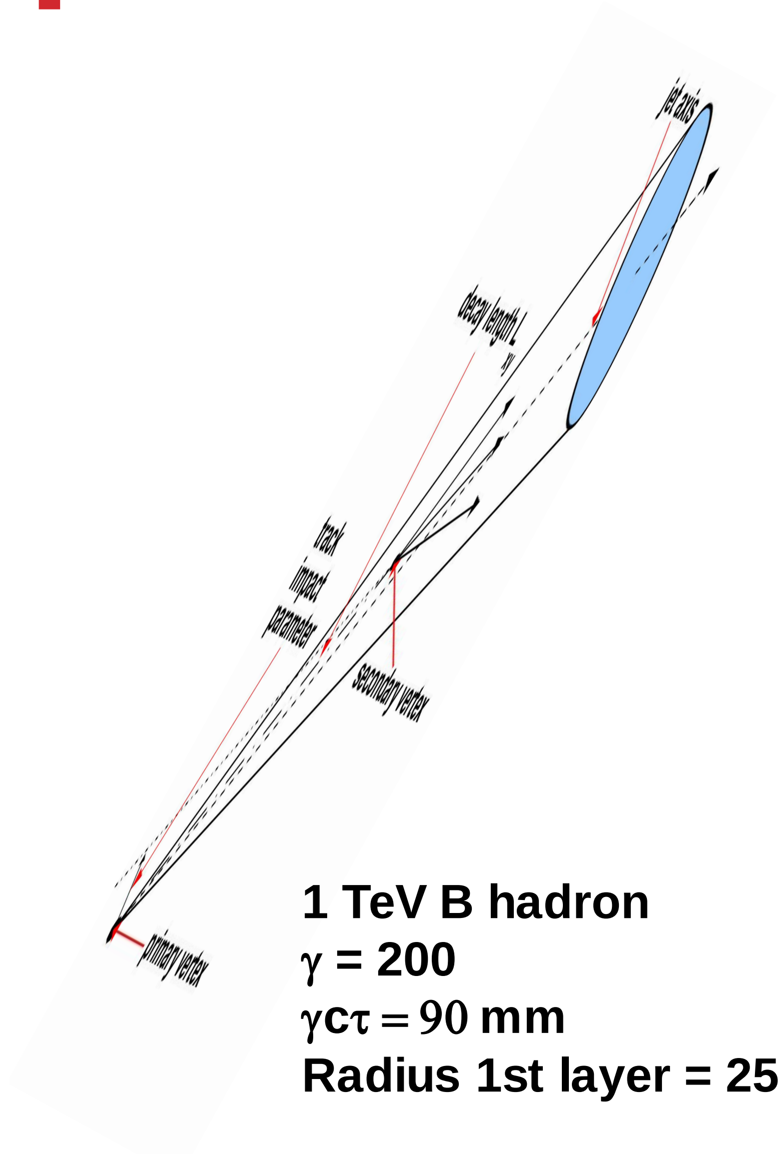
Why it happens

B-TAGGERS FIGHT RELATIVITY

Small cone sizes are prevalent.
$\Delta R \approx 0.04$ for a B in a 500+ GeV Jet.

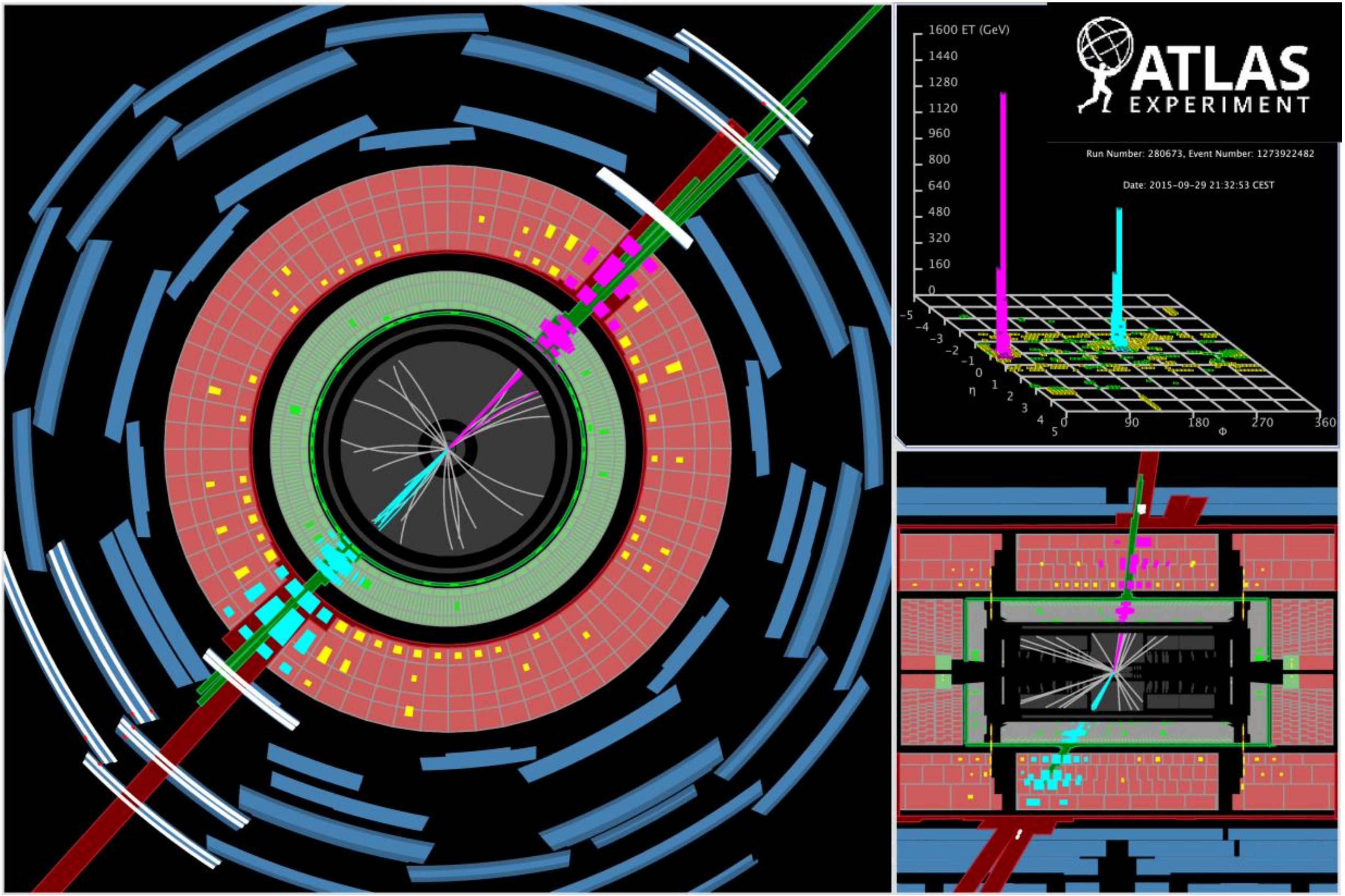


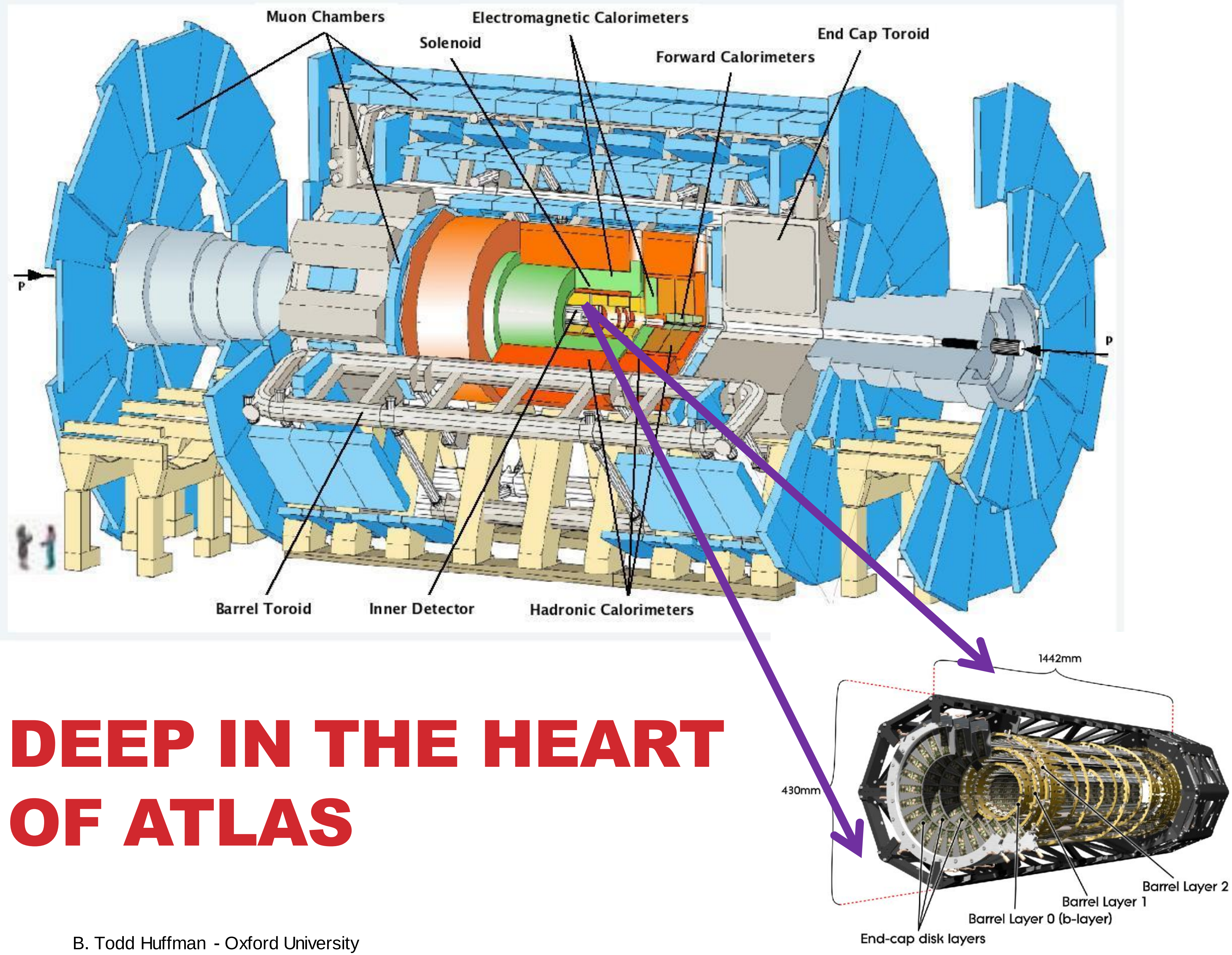
200 GeV B hadron
$\gamma = 40$
$\gamma c\tau = 18$ mm



1 TeV B hadron
$\gamma = 200$
$\gamma c\tau = 90$ mm
Radius 1st layer = 25 mm

>2.5 TEV JETS SEEN!





DEEP IN THE HEART OF ATLAS

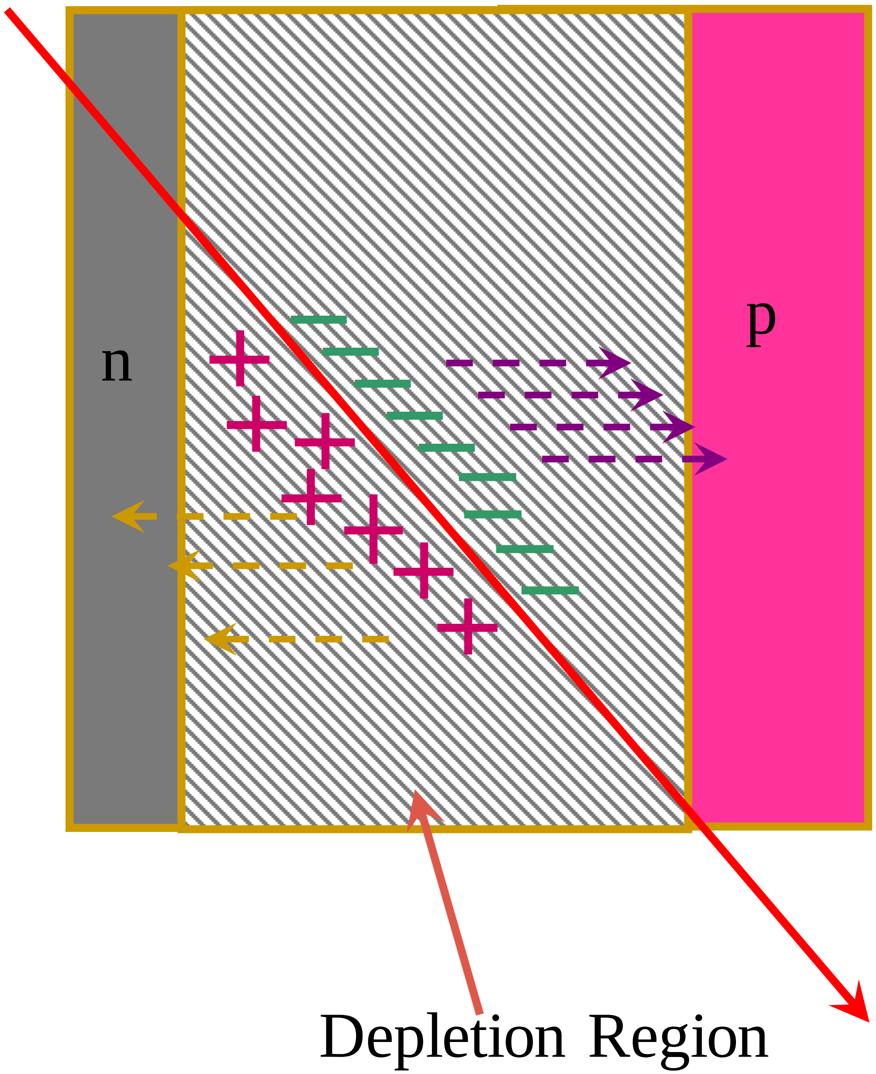
SILICON VERTEX DETECTOR

Silicon Detectors

- Reversed biased diodes
- Crank the reverse voltage up until they are fully depleted

Charged Particle liberates electron-hole pairs

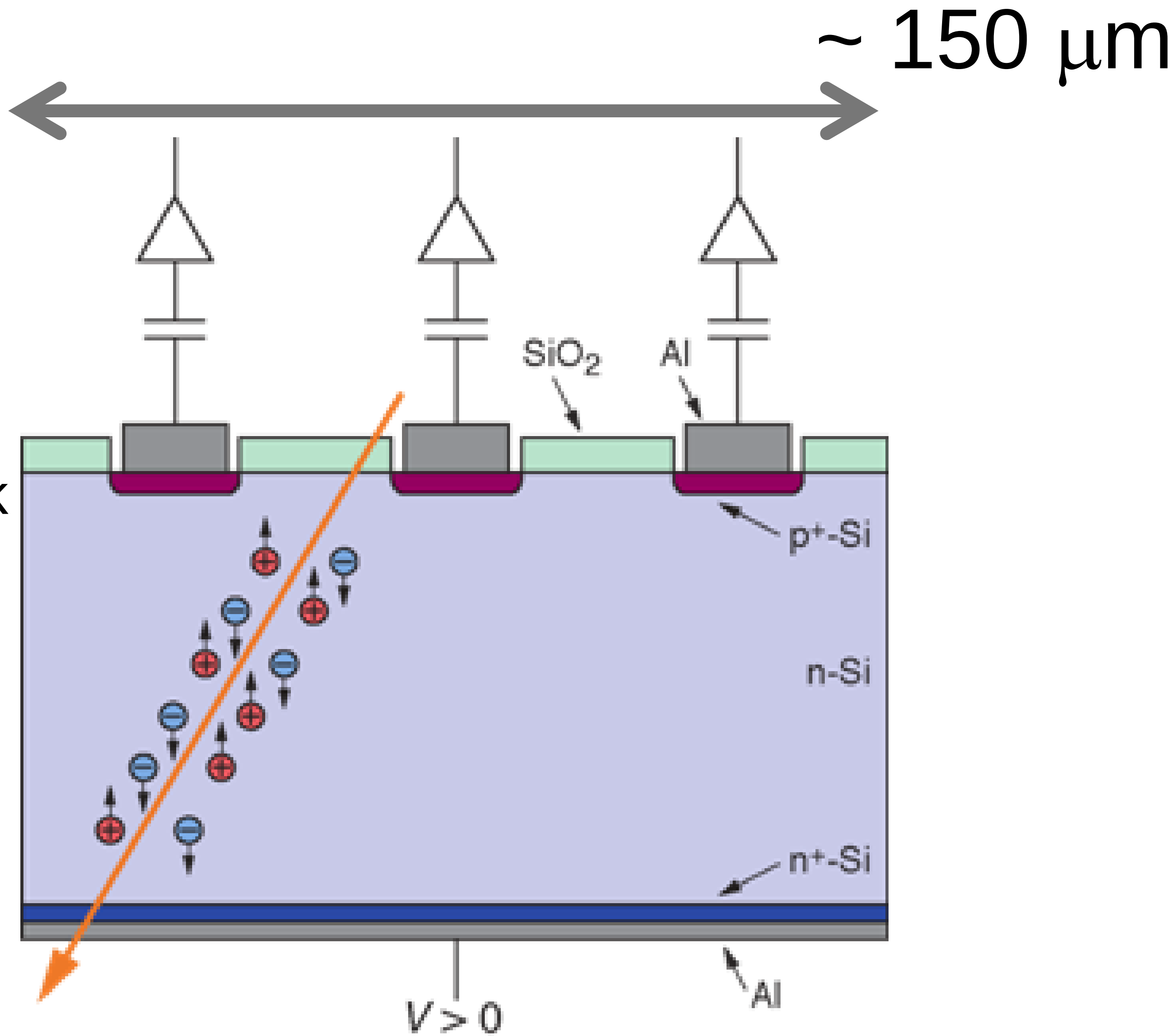
- Small pulse of current
- *Amplify it and record the hit.*

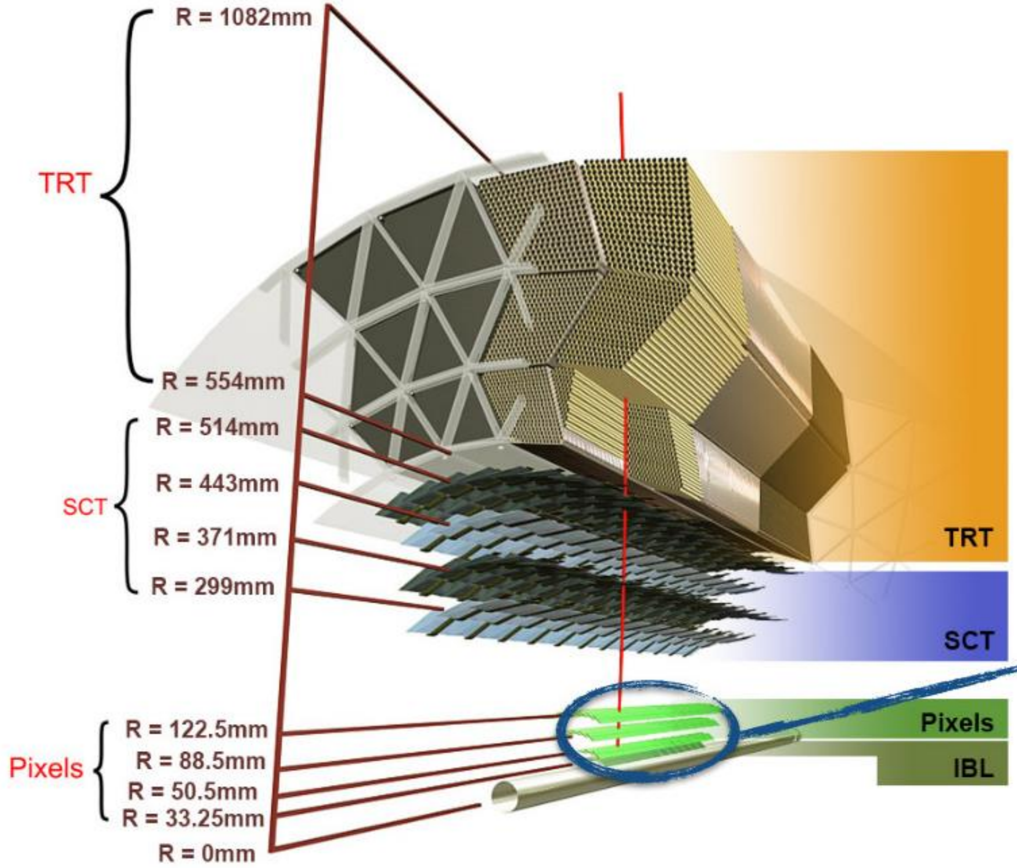


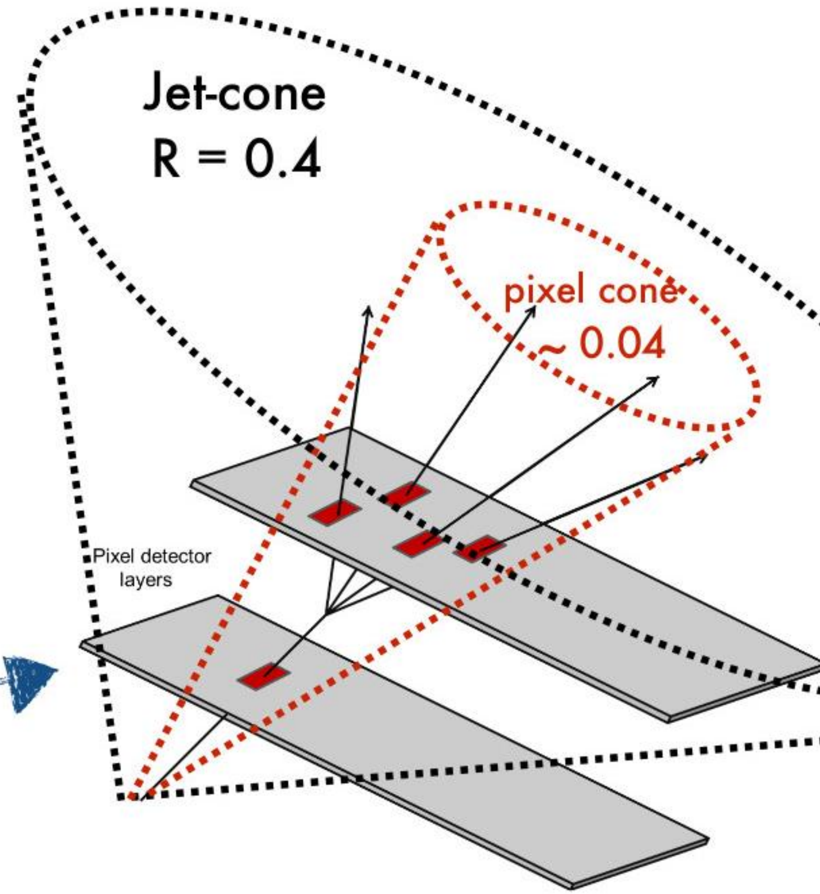
PIXEL DETECTOR

Many thousands of tiny sensors

50 μm x 250 μm and 300 μm thick







Building the discriminant

$$f_j = \frac{N_{j+1} - N_j}{N_j}$$

$$Jump = Max(j_1, j_2, j_3)$$

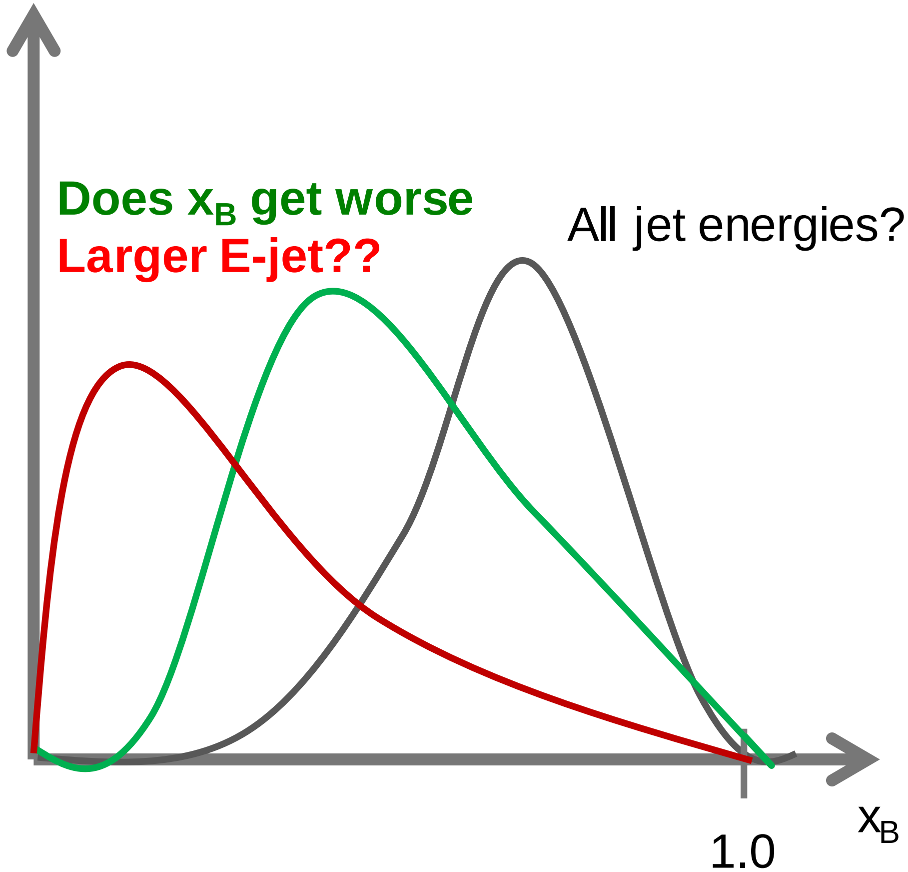
http://iopscience.iop.org/article/10.1088/0954-3899/43/8/085001/pdf

https://arxiv.org/pdf/1701.06832.pdf

ENERGY-FRACTION OF B HADRONS? DOES IT DEPEND ON JET ENERGY?

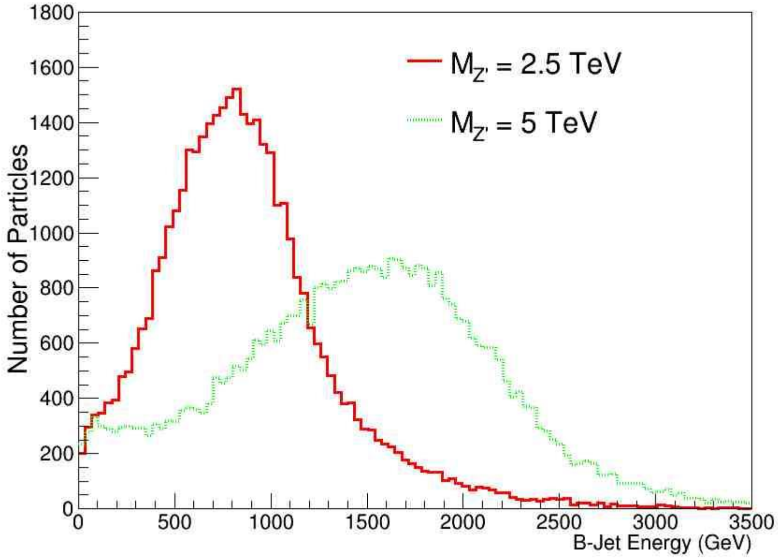
Energy fraction of B hadrons as Jet energy increases

- x_B Logarithmic?
- x_B Non-linear?
- x_B Constant?
- If Jet energy → more tracks
  - Helps taggers



Let's at least find out what simulations say!

B HADRON ENERGY FRACTION (PYTHIA+FASTJET)

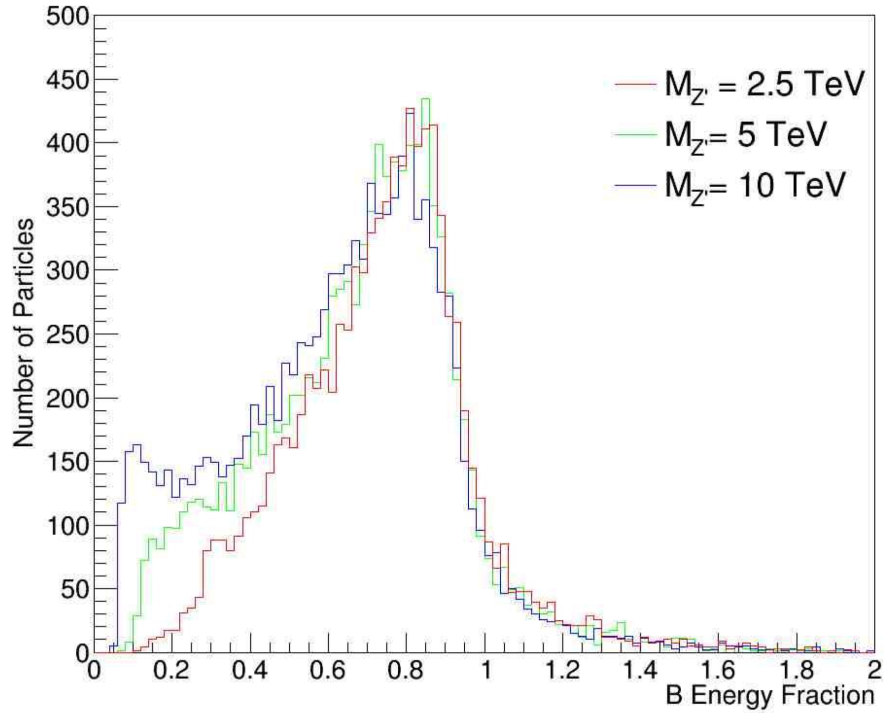


The energy of B hadrons in our simulation

So as Jet energy increases, the problems of B-taggers will get worse.

And more B hadrons will decay inside the detector volume.

However; Fraction of Jet energy each B hadron has does not strongly depend on energy of the jet.



SIMULATION DETAILS

Generator level simulation → Pythia 8

- pp collider with $\sqrt{s}$ = 13 TeV
- Generate hard QCD; P_T > 700 GeV
- Use EvtGen to get B hadron decays correct

Jet simulation → FastJet 3

- Anti-k_T algorithm for forming jets
- Can set jet cone size
  - We've used R = 0.2

Semi-Toy Detector simulation → GEANT4

- Volume → Cylinder 1.4 m radius filled with air, 2T mag. Field
- Silicon layers
  - Active at radii 25, 50, 88, and 122 mm
    - "Pixels" 50 x 400 x 300 μm (ϕ x z x r)
    - ***inner layer 50 x 250 x 300 μm → IBL-like***
  - *Passive cylinders 2.5 mm thick → X_0=2.5% per layer*

ΔHIT FRACTION → F_I

We *define* a quantity we call "Hit-difference Ratio" or "Hit-ratio" for short → "f_i".

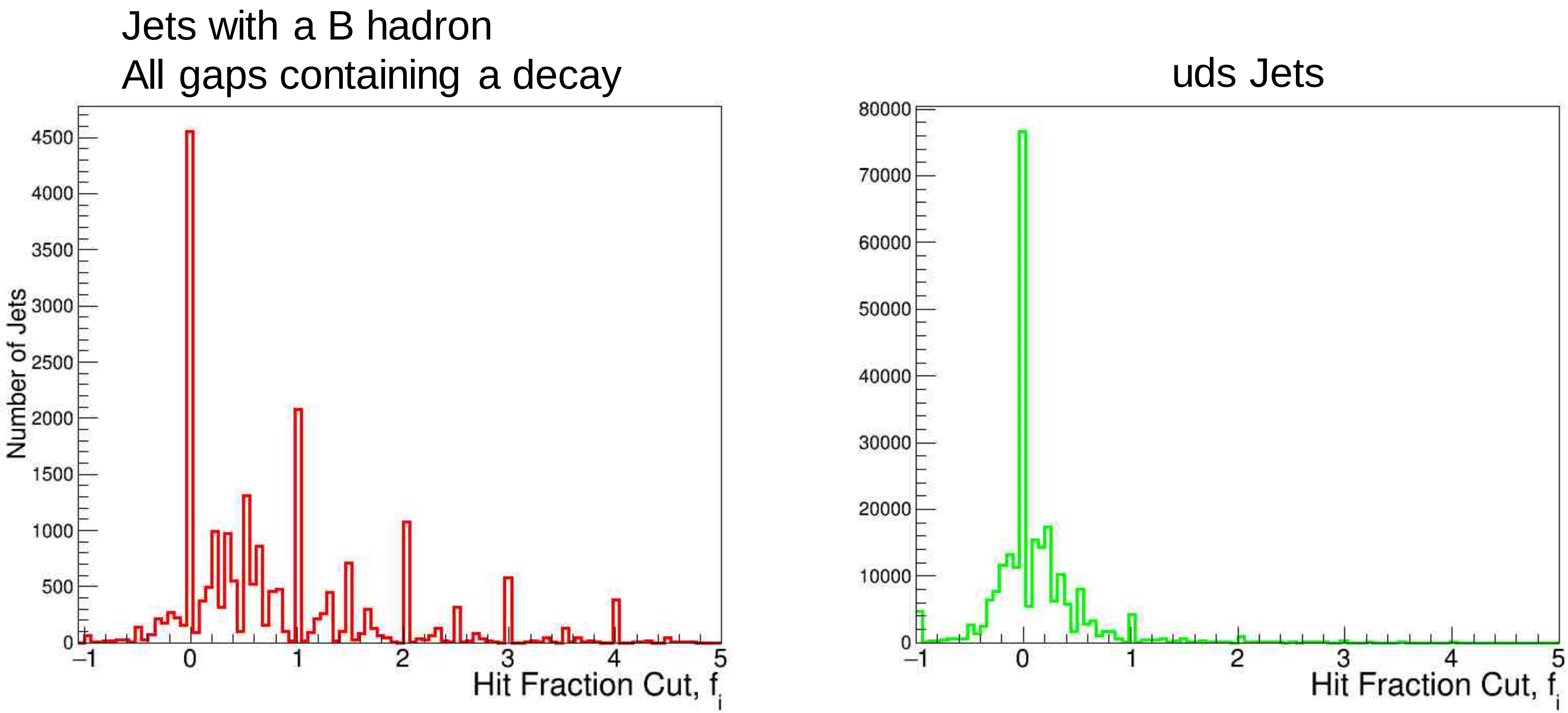
- Use cone $\Delta R < 0.04$ around jet axis.

from i^th layer: $\mathbf{f_i} = (\#hits_{i+1} - \#hits_i)/\#hits_i$

  - **Can only have positive or zero hits, so:**
  - $\mathbf{f_i}$ is bounded from below by -1. & unbounded from above.

- Have a look at the $\mathbf{f_i}$ distribution.
  - Note: This sample → 0.5 to 2.5 TeV jets.

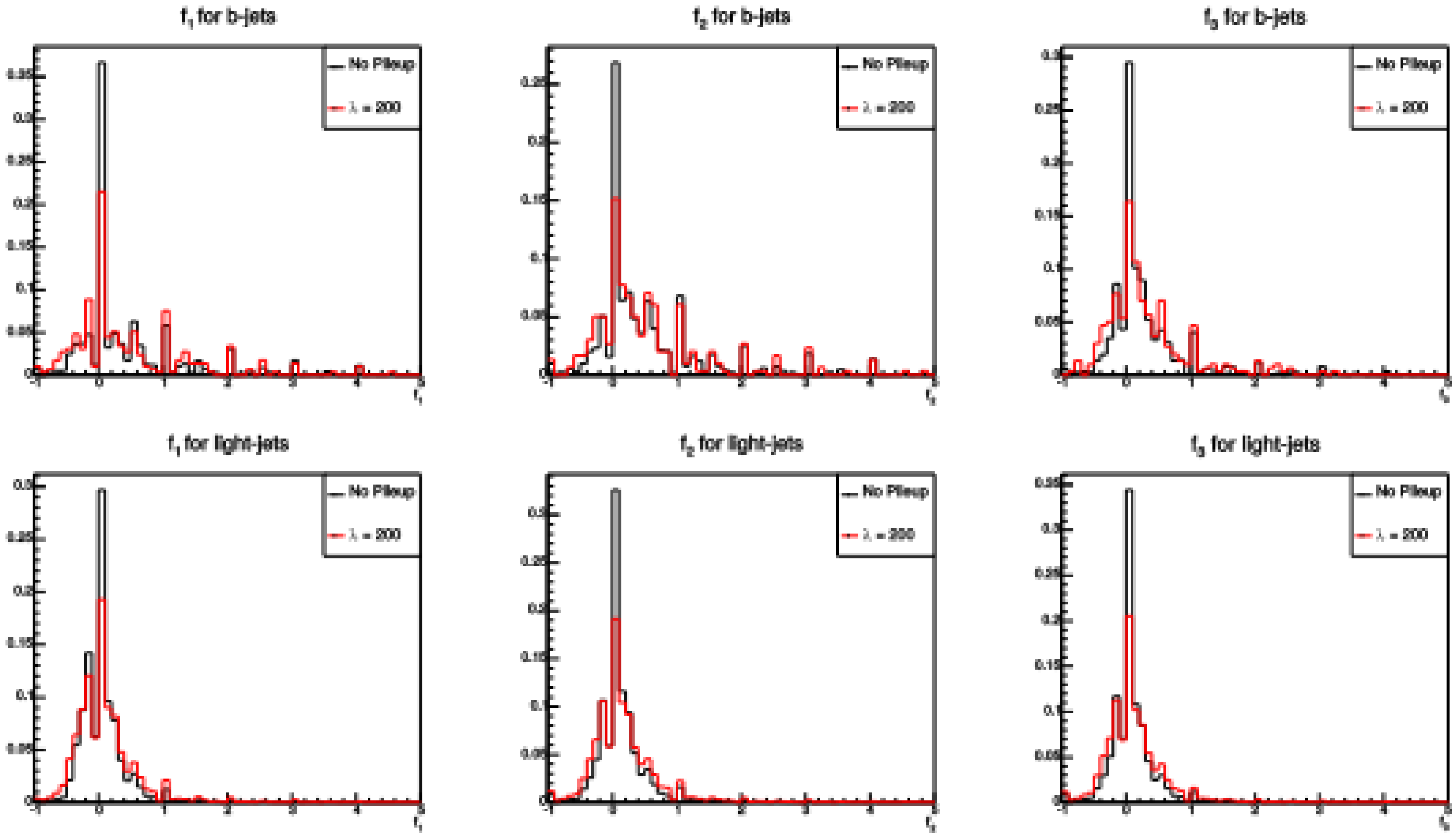
ΔHIT FRACTION = F_I



Simulation Z'→u,d,s,c, and b quarks only.
This looked promising → next use it as a cut variable

Pileup - f_i

How does pileup affect our f_i?



Pileup - Conclusion

- Tagger insensitive to increased pileup (tested to pileup with $\lambda = 200$),
  - little change in $f_i > 0$
- Makes sense - most pileup does not result in hits in $R<0.04$ between layers.

NOTE: All plots now have pileup with $\lambda = 45$.

APPLYING ΔHIT$_F$ CUT

Start at f_i= -1.0 (i.e. no cut at all)

- And Start increasing the cut.

At each cut value, Plot (Number of Events passing cut)/(number of starting events)

NOTE! Only count B hadron jets where B decayed inside the layers!

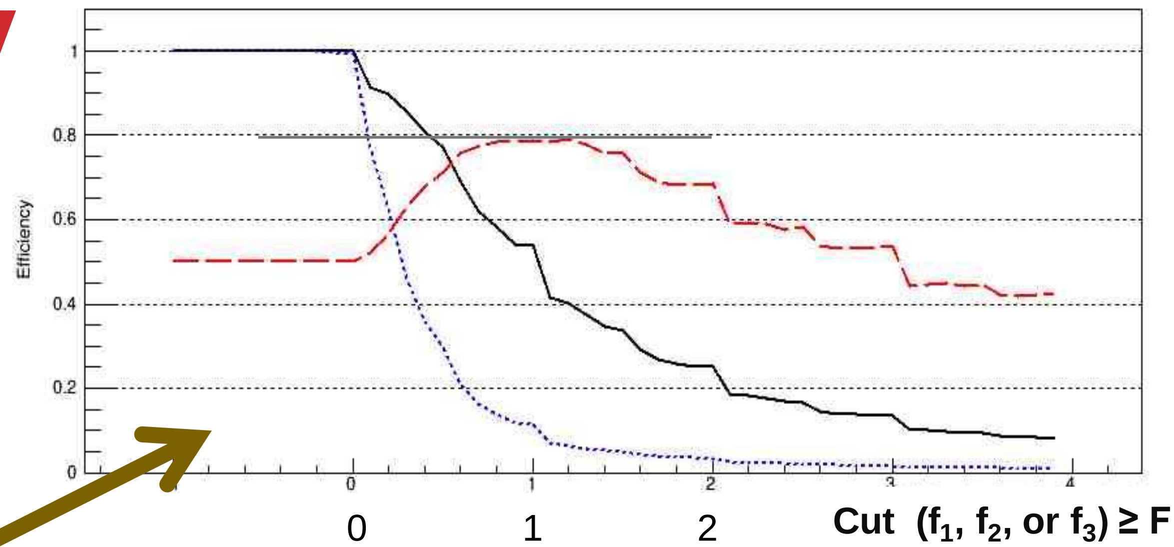
"ALL Layers" plot is logical OR of individual layers

- if any one of the ΔHit$_f$ between any pair of layers passes the cut, the event passes.

F_I EFFICIENCY AND PURITY - LAYERS 1234 $M_{Z'}$ = 2.5 TEV

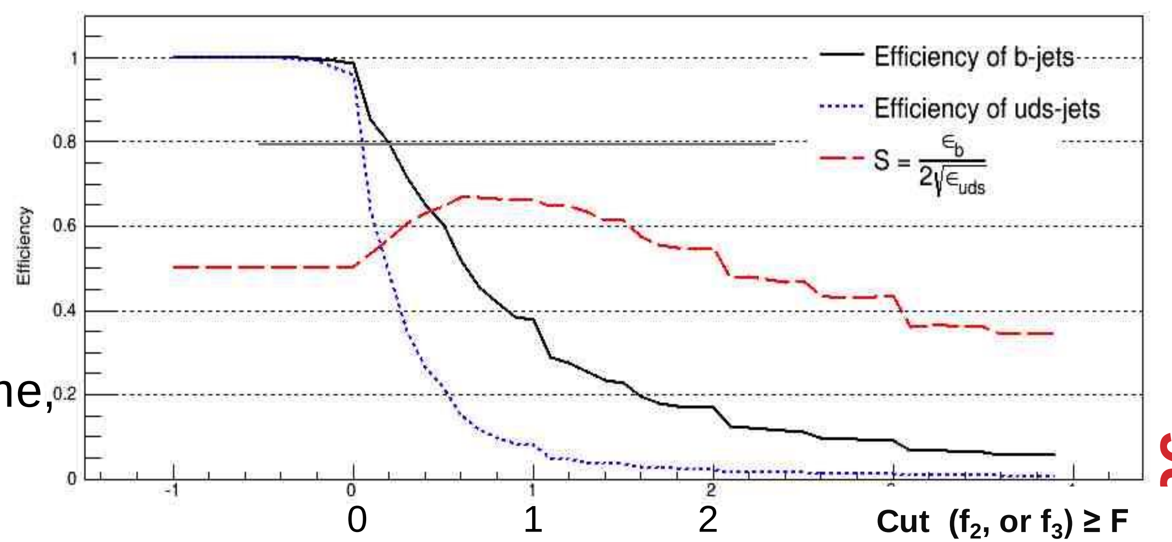
$f_i \geq F=1$

Layers:
1-2 or
2-3 or
3-4



Choose this one!!

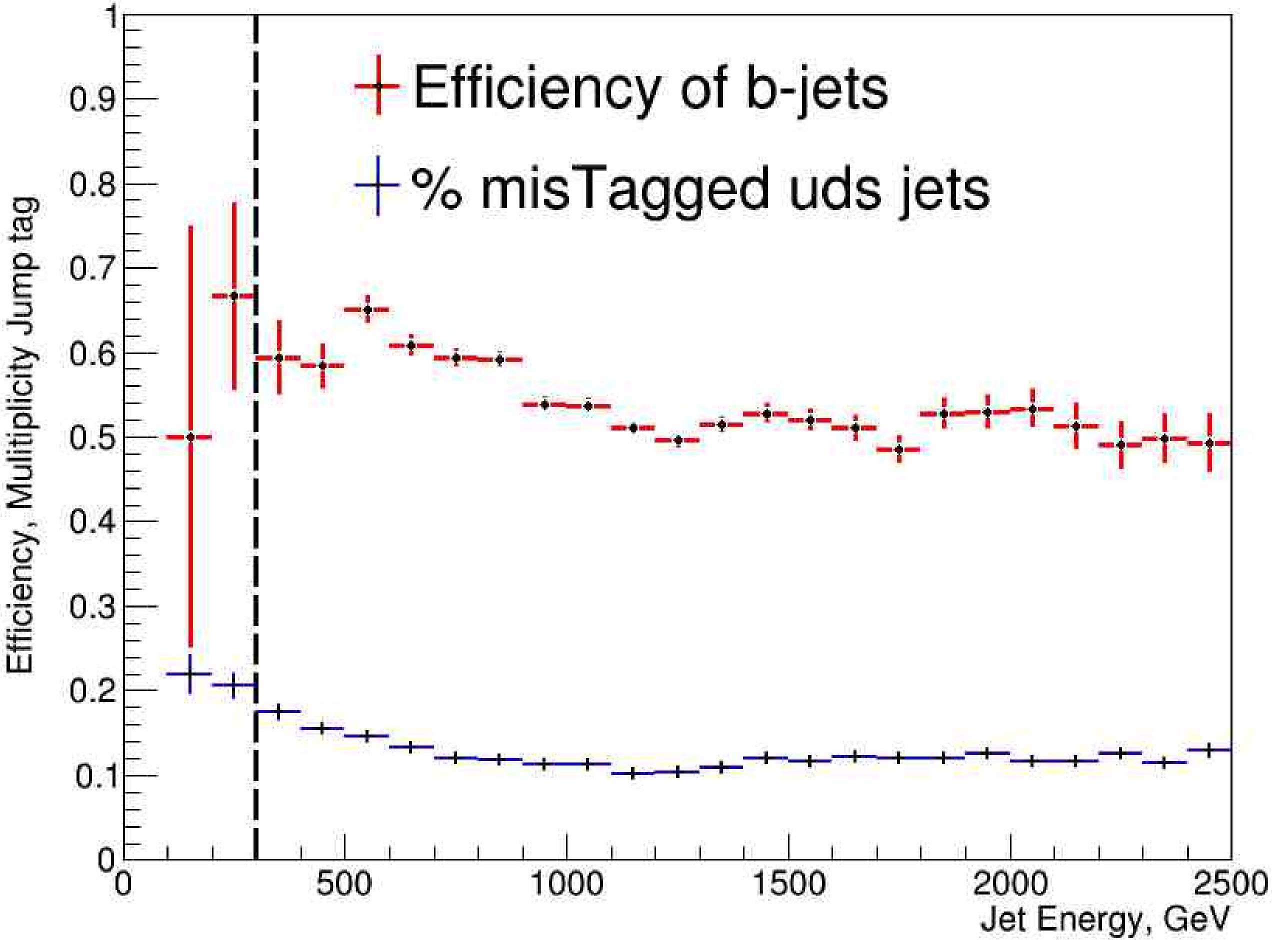
Layers:
2-3 or
3-4



Fiducial region → Whole volume, So can compare.

EFFICIENCY VS. JET ENERGY

Some uds separation – efficient for high Pt jets



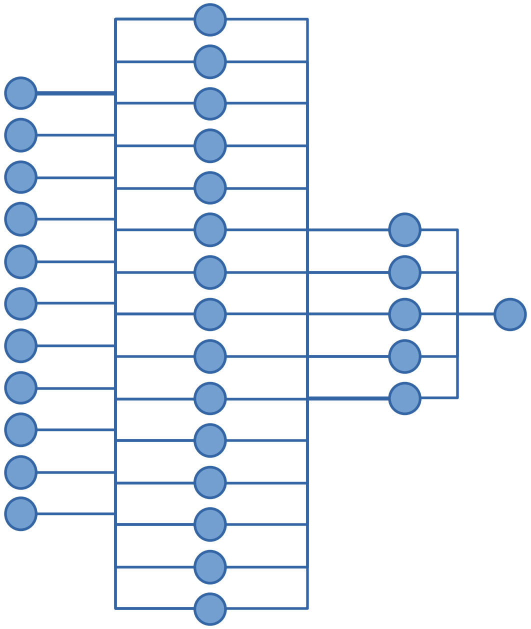
ARTIFICIAL NEURAL NETWORK

Building the ANN

ROC analysis showed that 8-layer ANN was as effective as a 2-layer ANN → not really a “deep learning” problem, Reducible, small feature set.
Fewer node layers means less chance of overfitting.
Used TMVA for a “standard HEP” packaged ANN.
Activation function was tanh(x).

Input Layer:

- Raw hits in each layer
- Multiplicites f_1, f_2, f_3
- max(f_1, f_2, f_3)
- Jet Energy, p_T and mass



2 Hidden layers:
16 and 5 neurons wide.

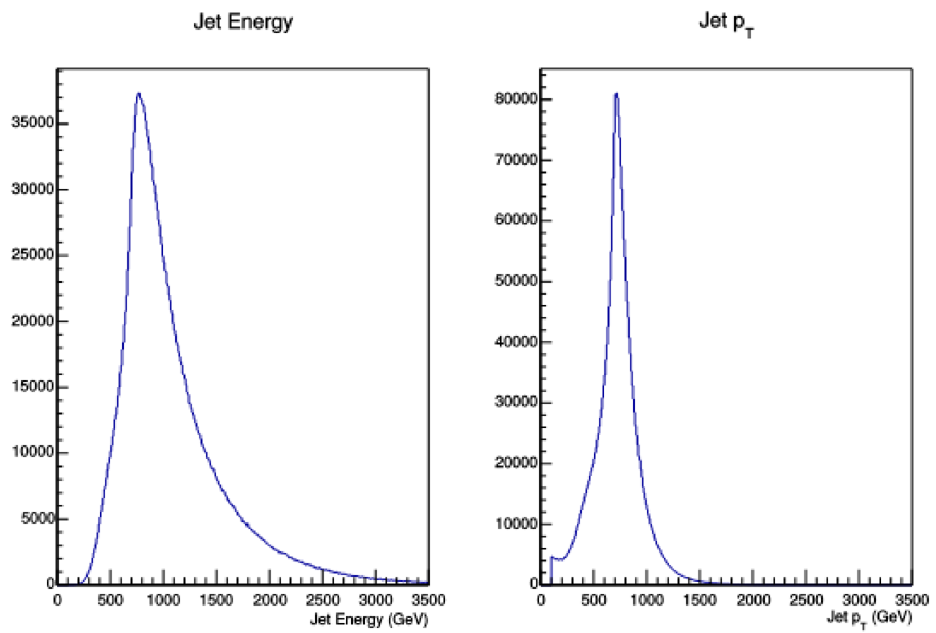
(Smaller second hidden layer helps prevent overfitting).

Architecture → educated guessing.
Too many combinations to evaluate

Training Sample

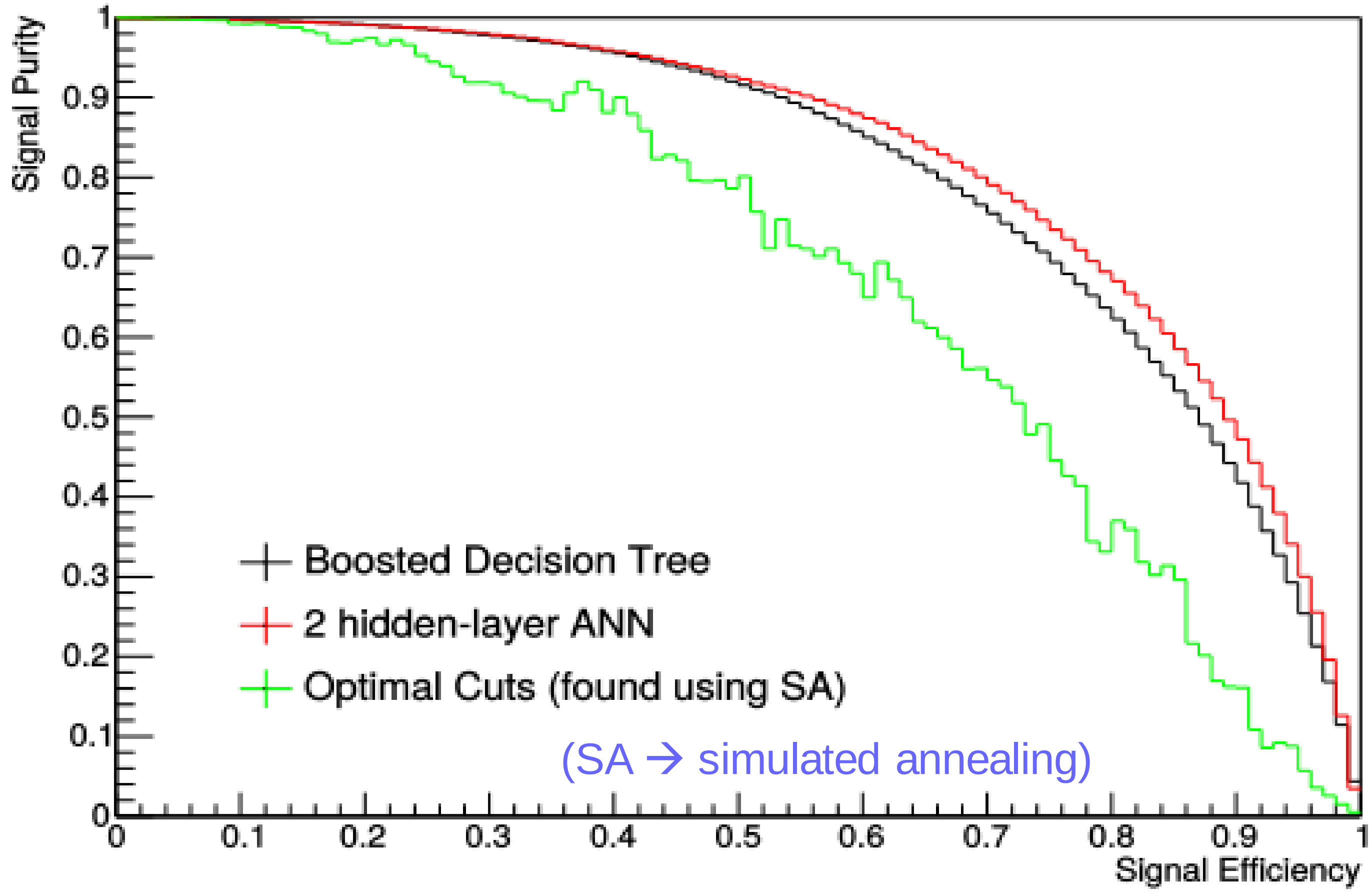
- Training sample had min p_T of interaction at 700GeV.
- 1 million general hard QCD events (anything goes), 300,000 hard QCD events resulting in B-hadron production.

Testing is then done on an independent hard QCD sample.



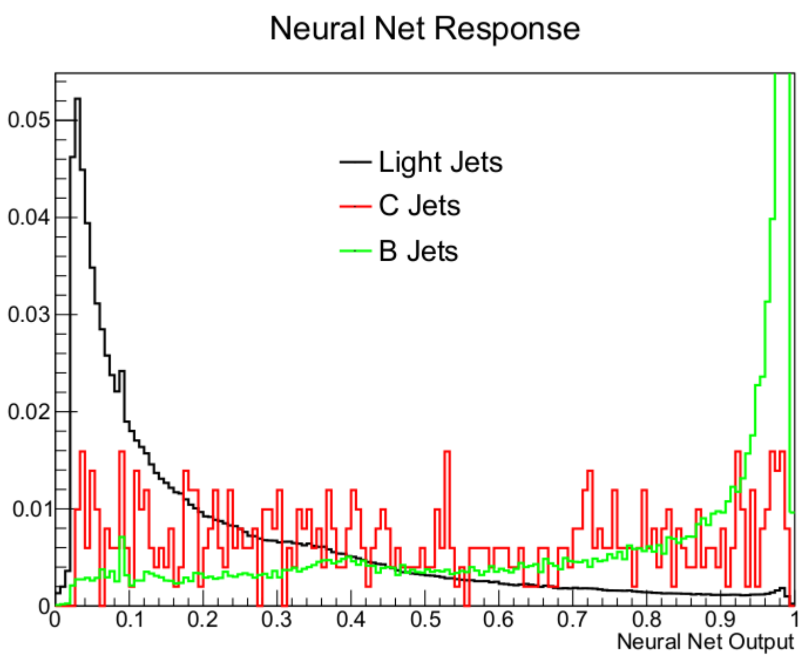
Choosing a ML technique

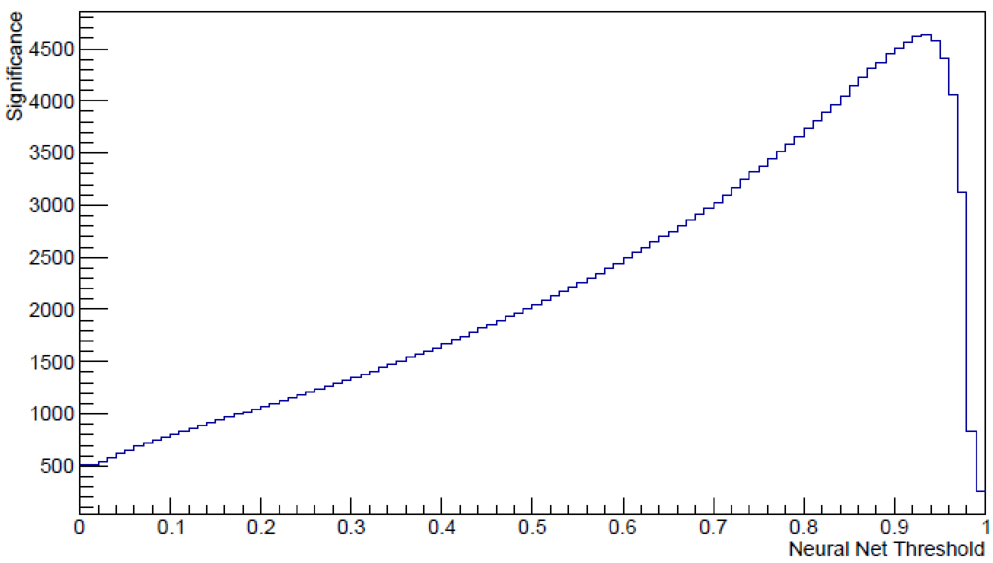
- Each ML technique has a distinct set of advantages/disadvantages.
- ROC curve (Signal Purity vs. Signal Efficiency)



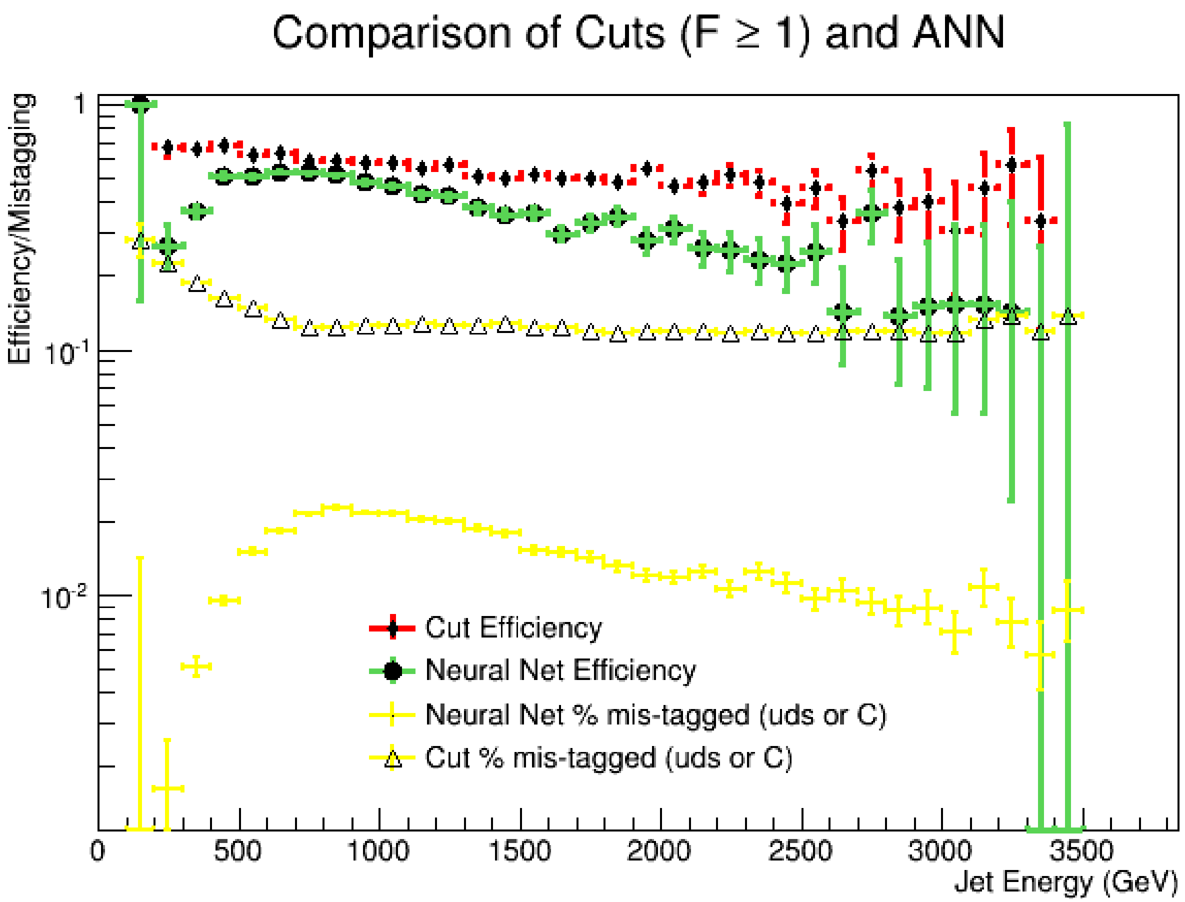
ANN TEST MC RESULTS

Significance = $\varepsilon_b / \sqrt{\varepsilon_{uds}}$

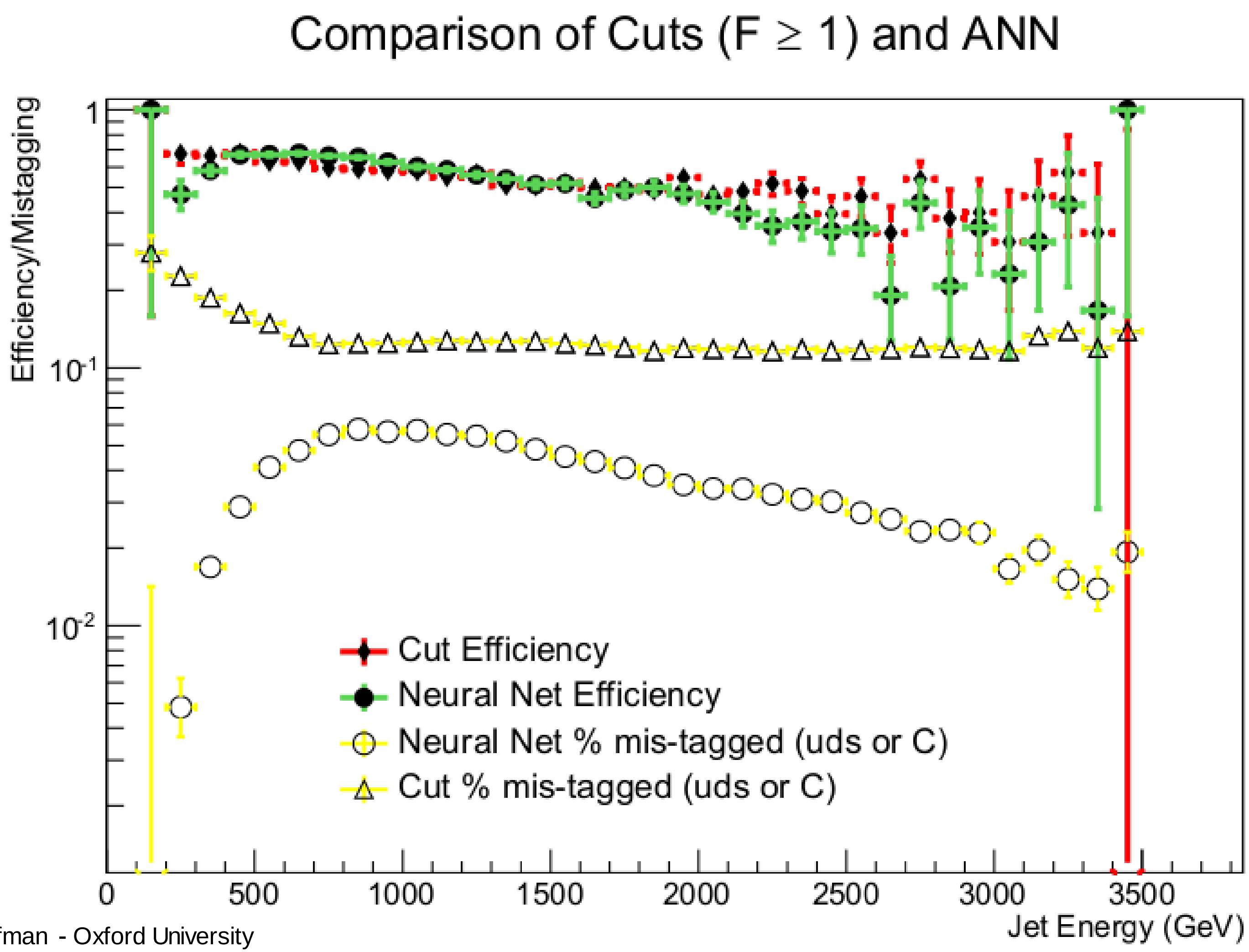




WITH → ANN OUTPUT>0.9

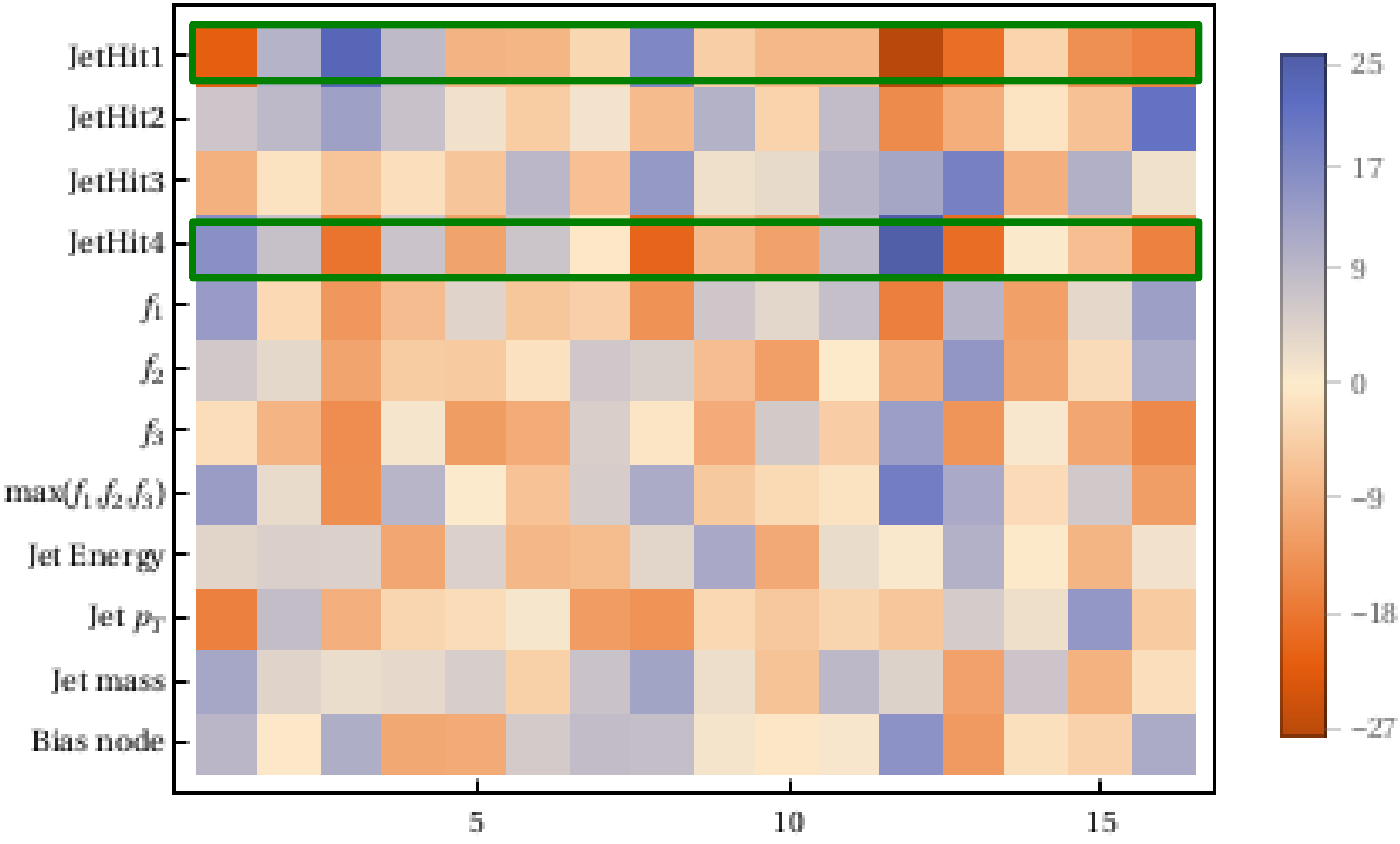


WITH → ANN OUTPUT>0.75



HEAT MAP

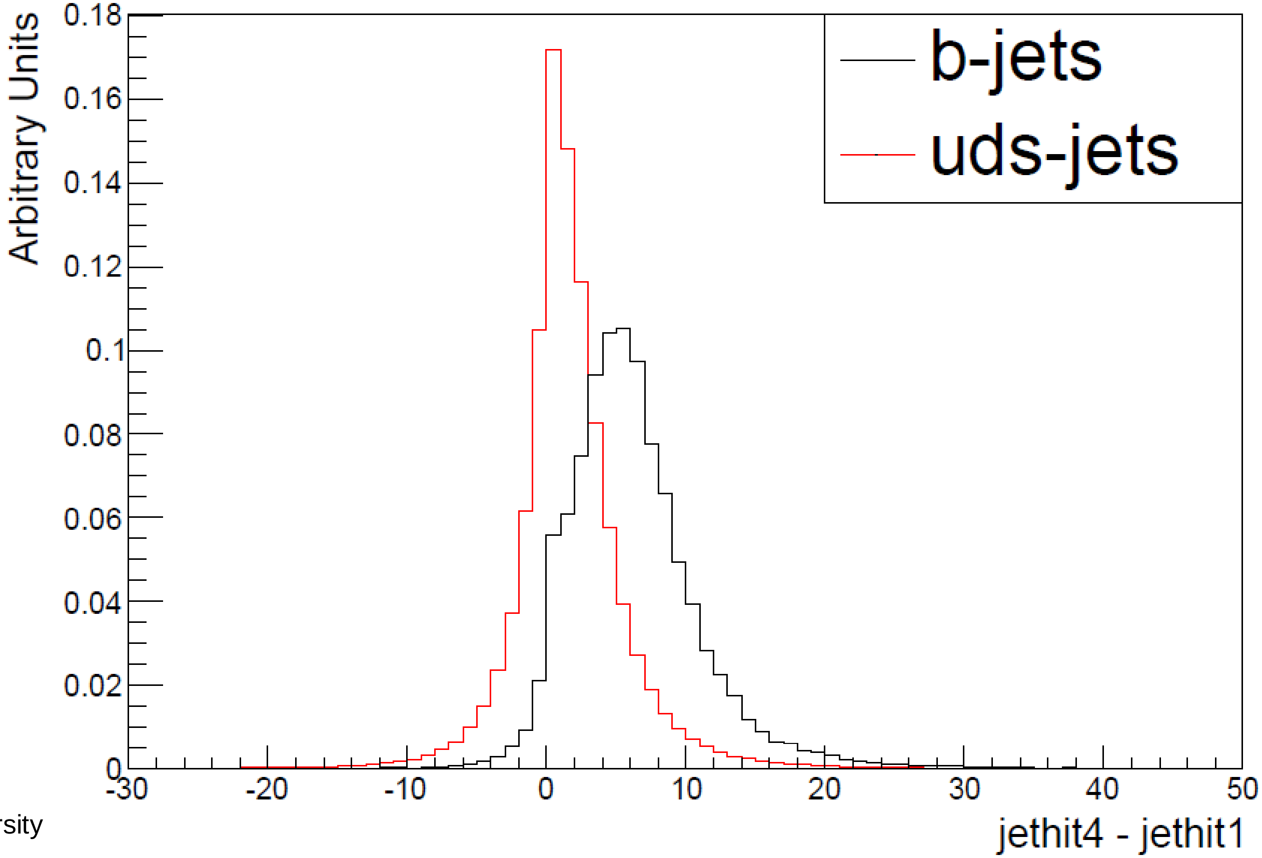
Neural Net seems to find Nhit4 – Nhit1 → good discriminator



ANN INSPIRED

Straight hit difference between layer 4 and layer 1.

Definite advantage can be seen.

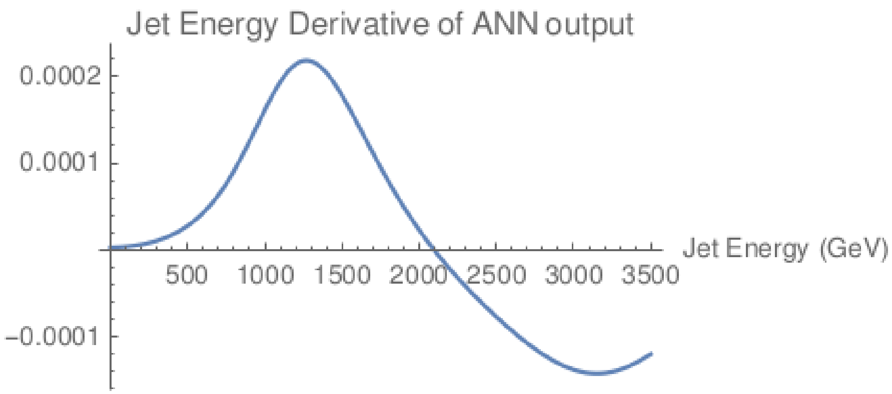


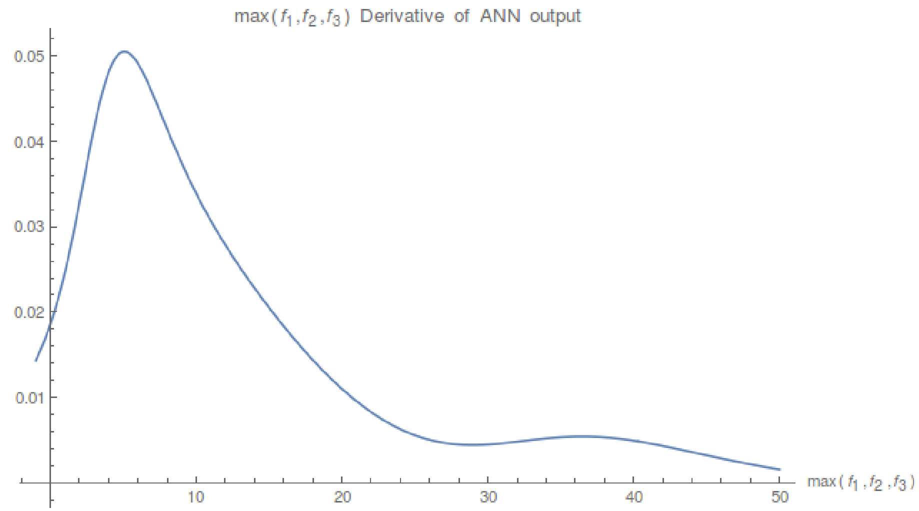
ANN OUTPUT DEPENDENCE
(EXAMPLES)

NN is just a complicated function $h(x_j)$ – Look at $\Delta h/\Delta x_j$

MAX(F)

JET ENERGY





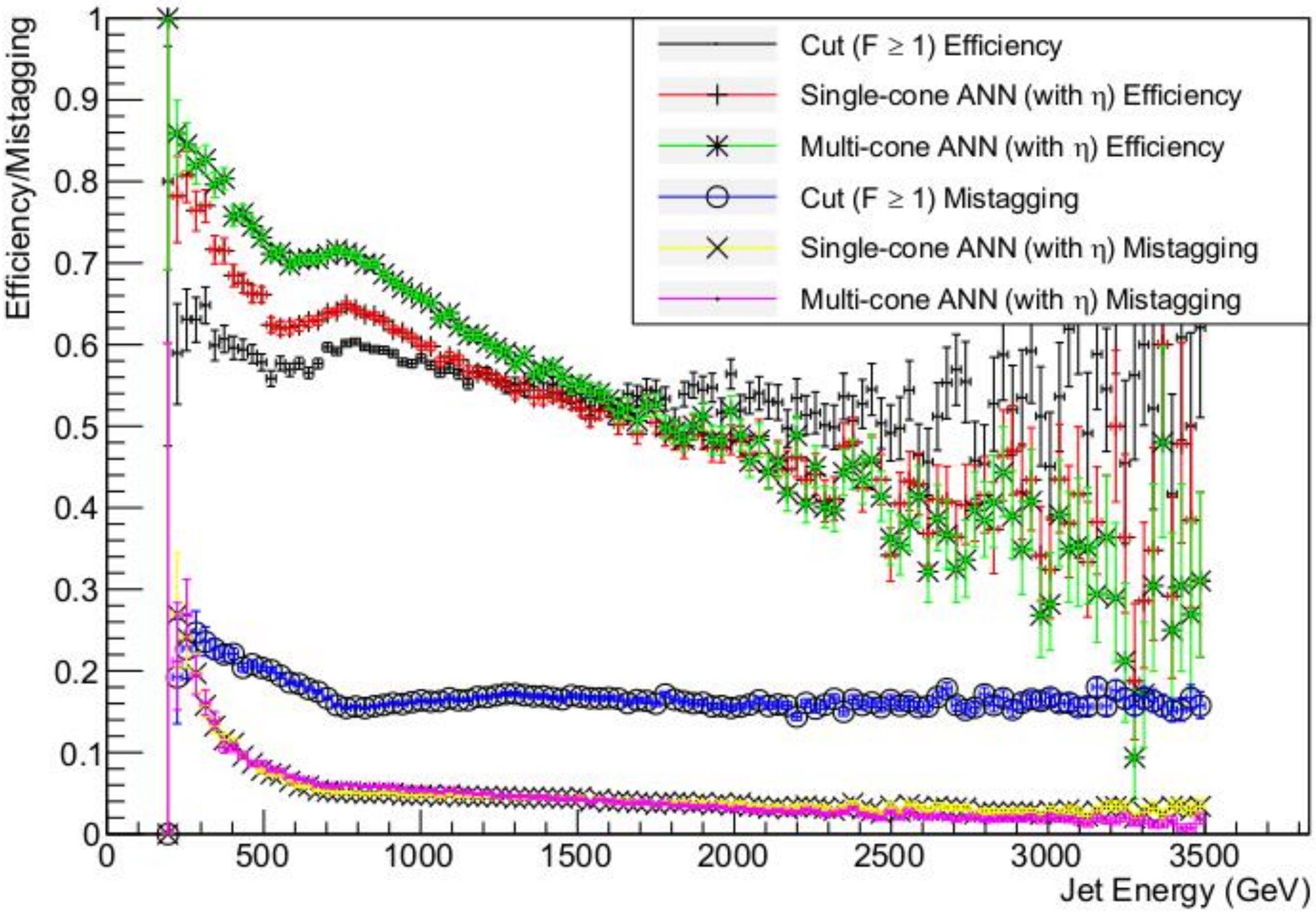
Trained NN output is ~100 times more sensitive to Max(F) than to Jet Energy

Conclude: The Machine is focused on the “right” types of quantities.

LAST THING – MULTIPLE CONE SIZES

Include more B hadron decay products @ lower Energy

ΔR<0.04, ΔR<0.1 and ΔR<0.2 added
Each with own set of inputs



Training sample Shape dependence?

CONCLUSIONS

Using Mulitvariate techniques significantly improves rejection of uds jets.

Results robust to pile-up

Multiplicity Jump technique more immune to searchlight effect and highly boosted B hadrons.

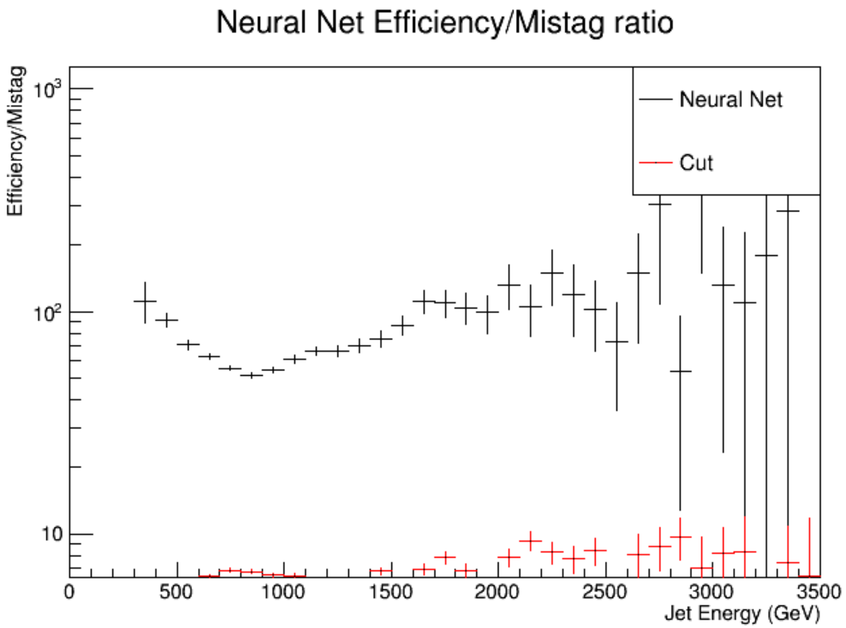
If continues to show promise, could be added to existing taggers to enhance efficiency at TeV scale jet energies.

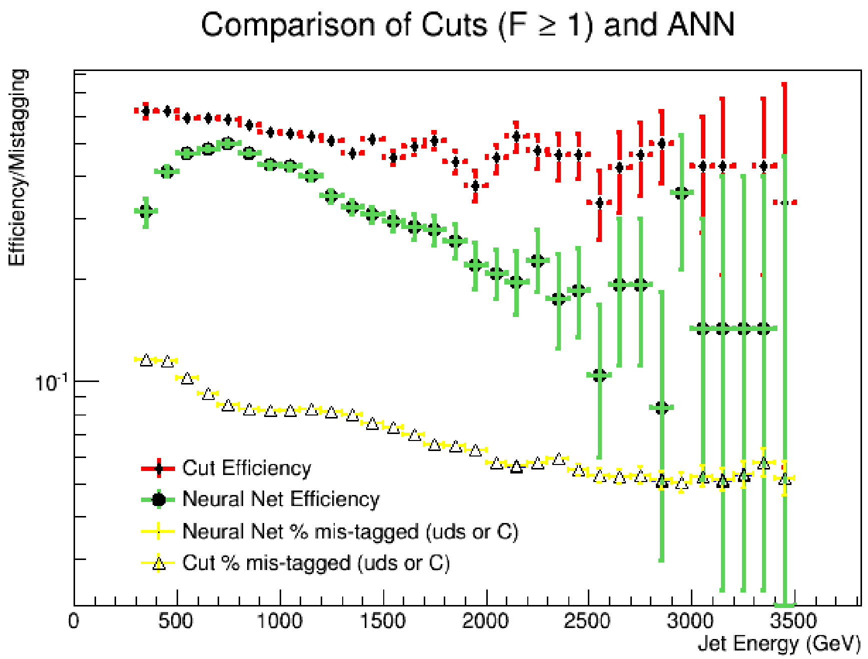
Experiments (ATLAS, CMS) are looking into the technique with full simulations → Clear next step.

HAND OFF TO ATLAS & CMS!!

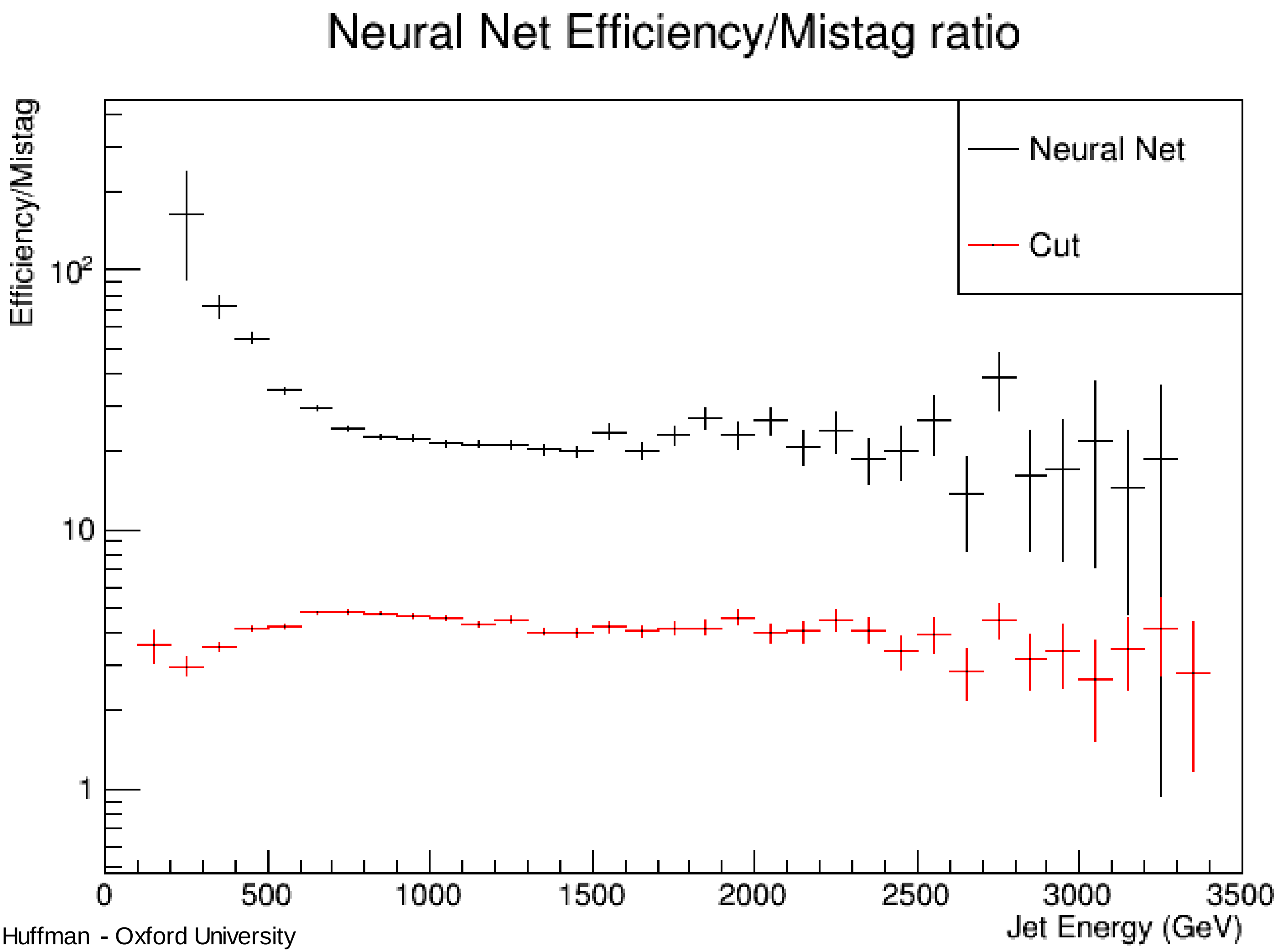
THANK YOU! (BACKUP SLIDES)

DEAD MATERIAL REMOVED – NO EARLY SHOWERS





ANN - STRAIGHT CUT COMPARISON

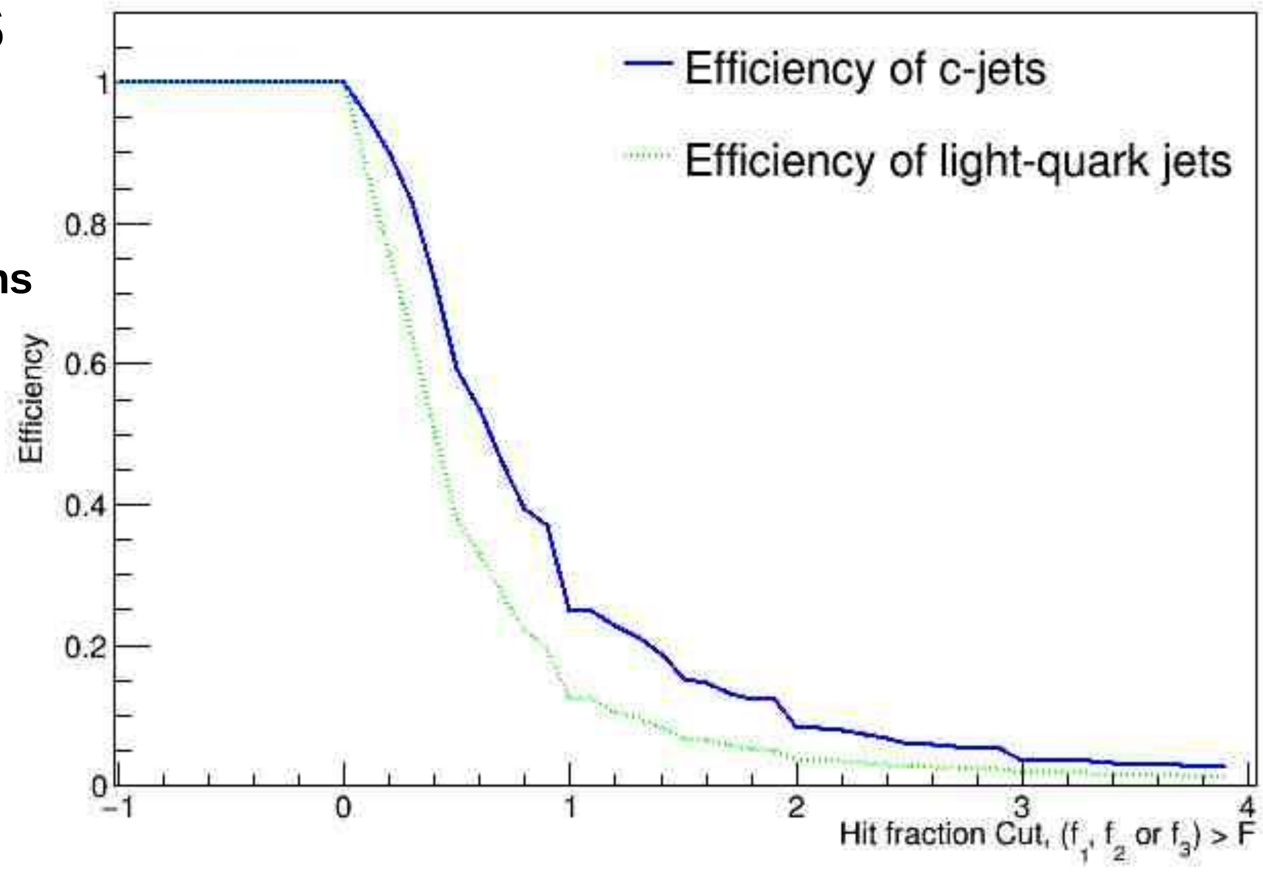


MAX(F_1,F_2,F_3) > ΔHIT

Completeness Charm jets

2.5 TeV

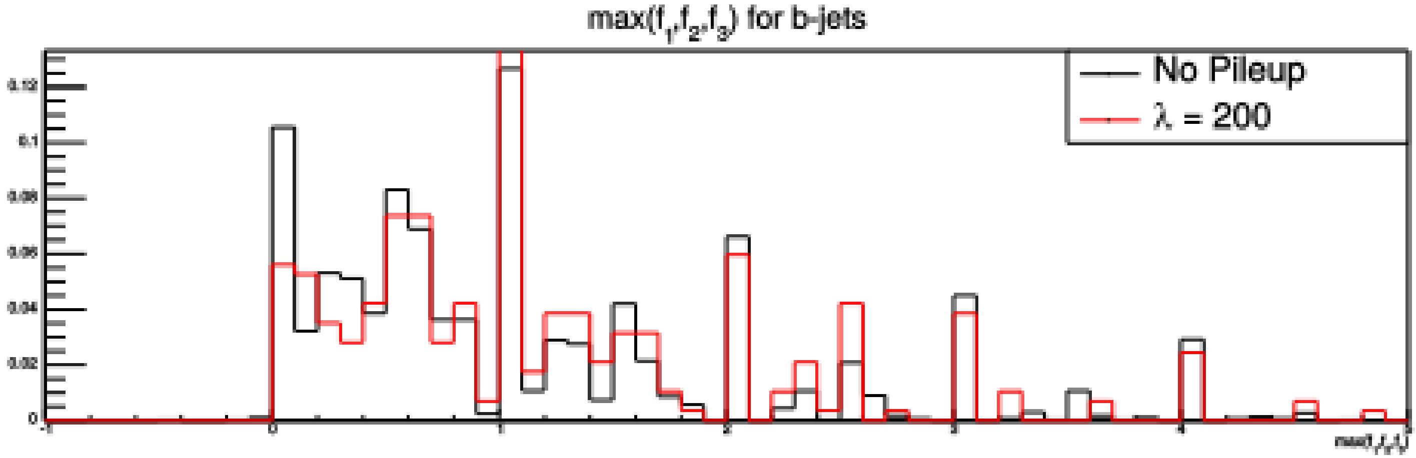
Same set of conditions

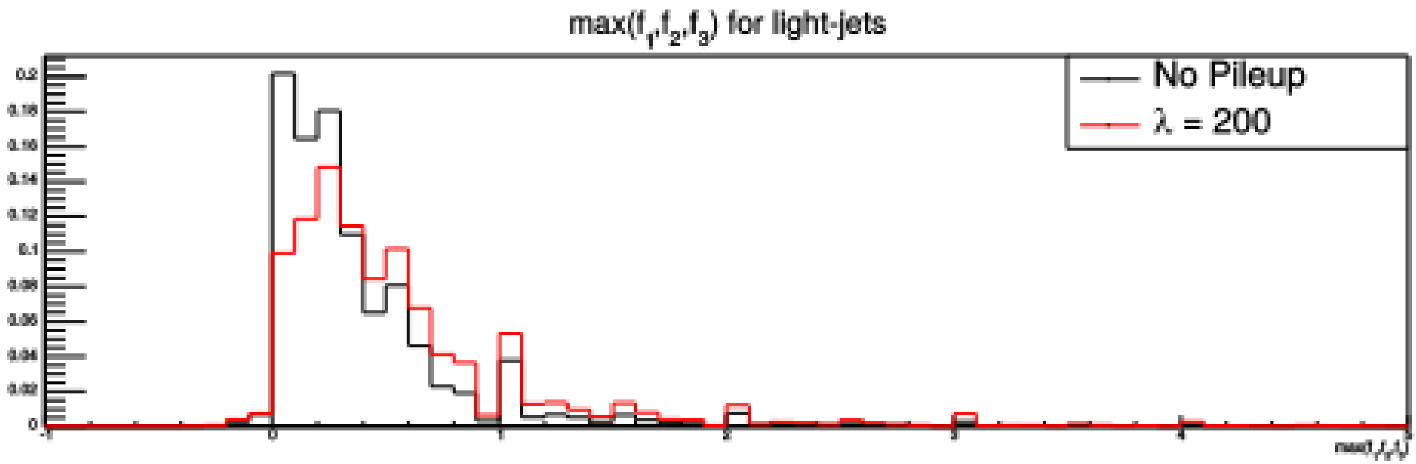


Upgrading the simulation

Making sure it works in a more realistic scenario

Pileup – max(f_1,f_2,f_3)



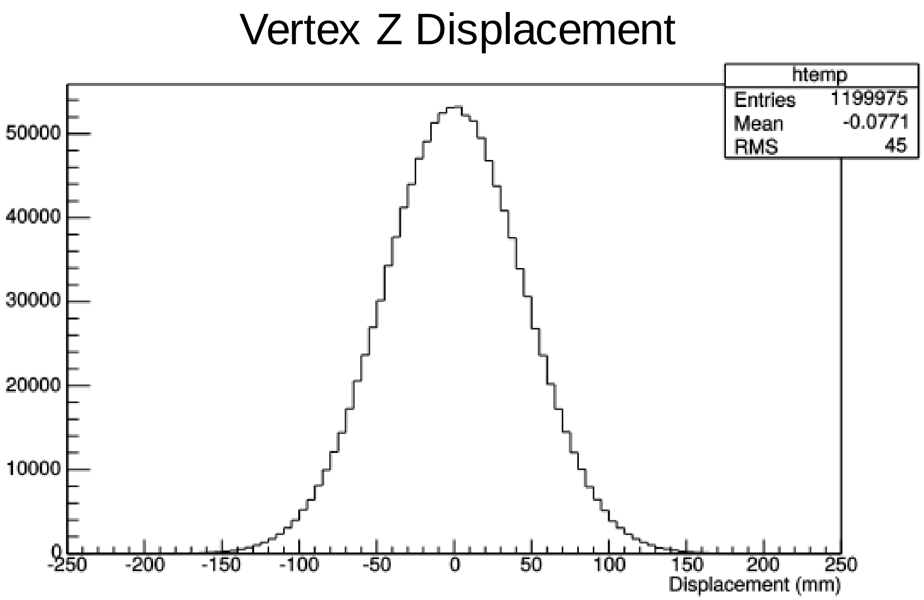


Luminous Region

Events do not always occur at (0,0,0) – modify GEANT4 sim to account for this.
ATLAS has σ_z= 45mm

New Problem – Jet vectors no longer from (0,0,0), have to be careful when selecting pixels.

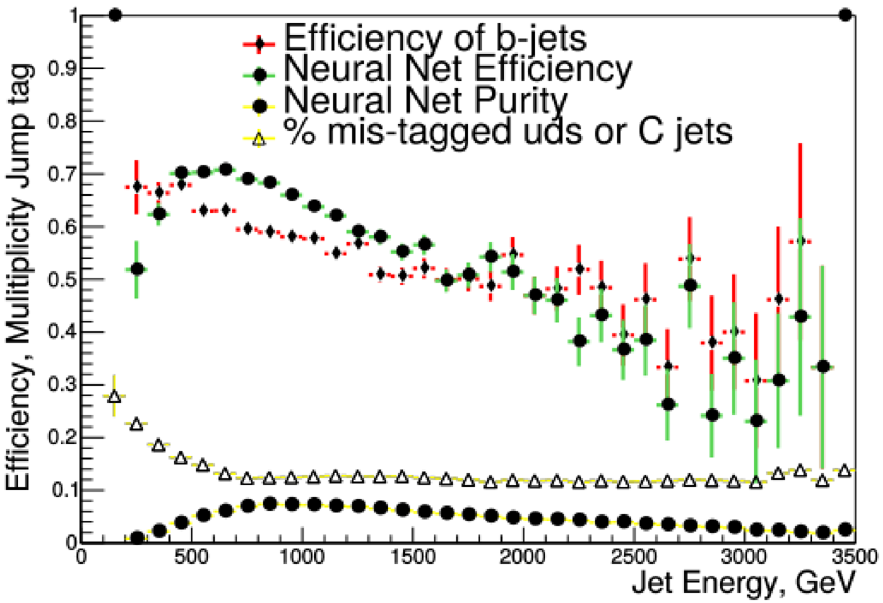
Easily resolved by finding the event primary vertex. Once this is done, luminous region vs origin makes no difference to the quality of the tagger.

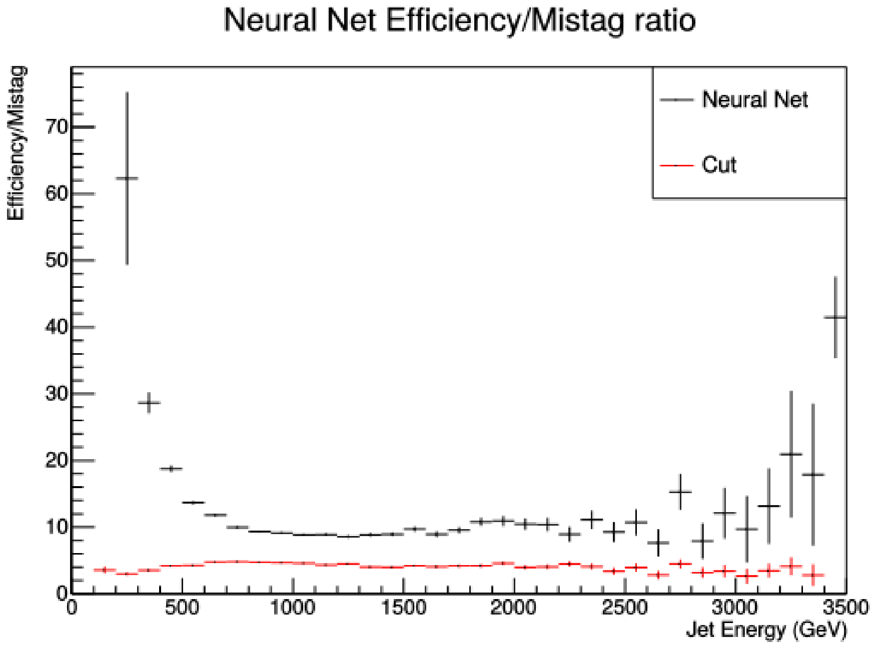


Upgrading the Tagger

We know it works… Let's make it work better!

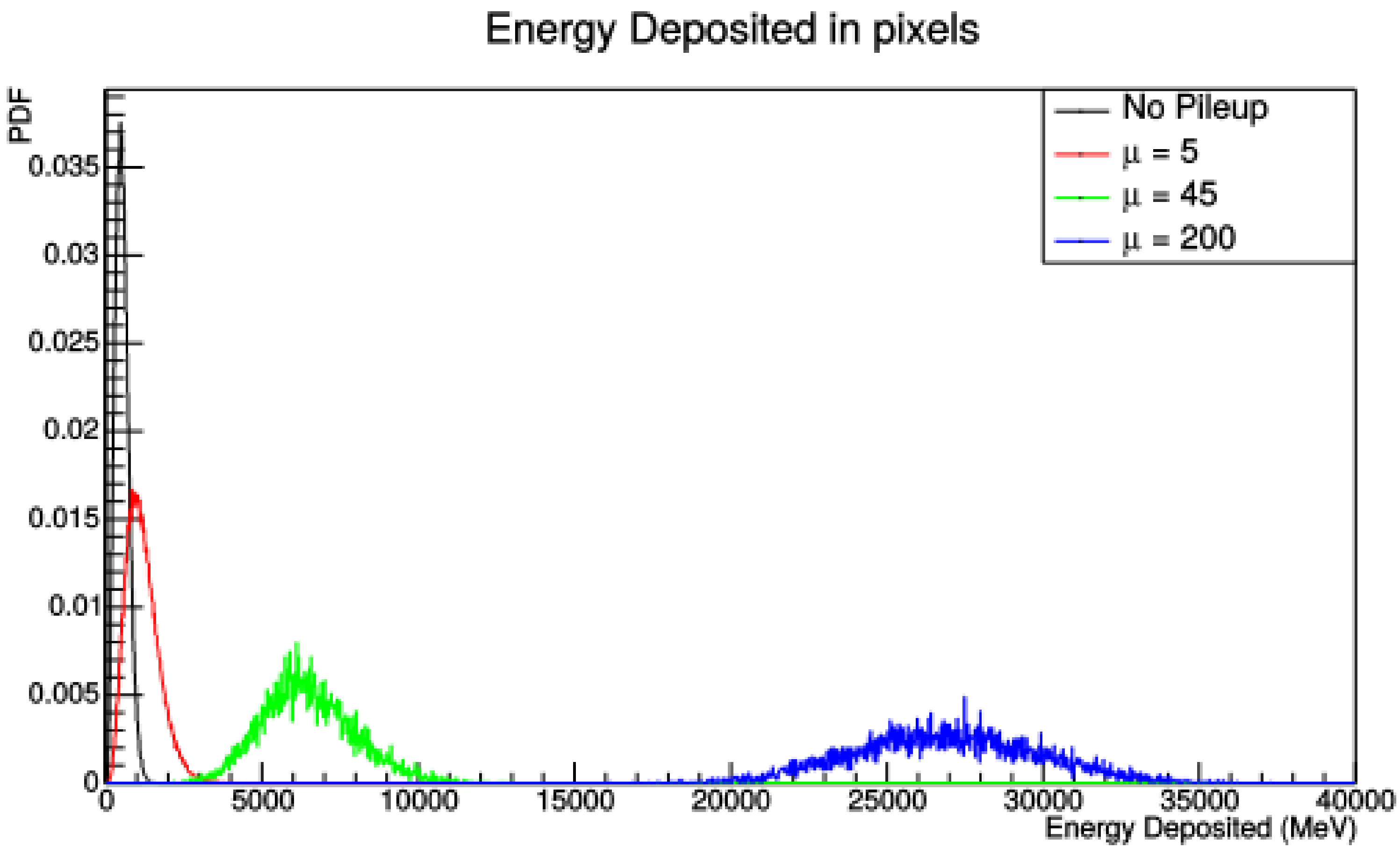
How does it do?





Neural Net Wins!!

Extra Slides


Energy Deposited in pixels
PDF
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
5000
10000
15000
20000
25000
30000
35000
40000
Energy Deposited (MeV)
No Pileup
μ = 5
μ = 45
μ = 200