PGS

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Fast Simulator Workshop
CERN, June 11, 2012

Contributors

PGS is the work of many people!

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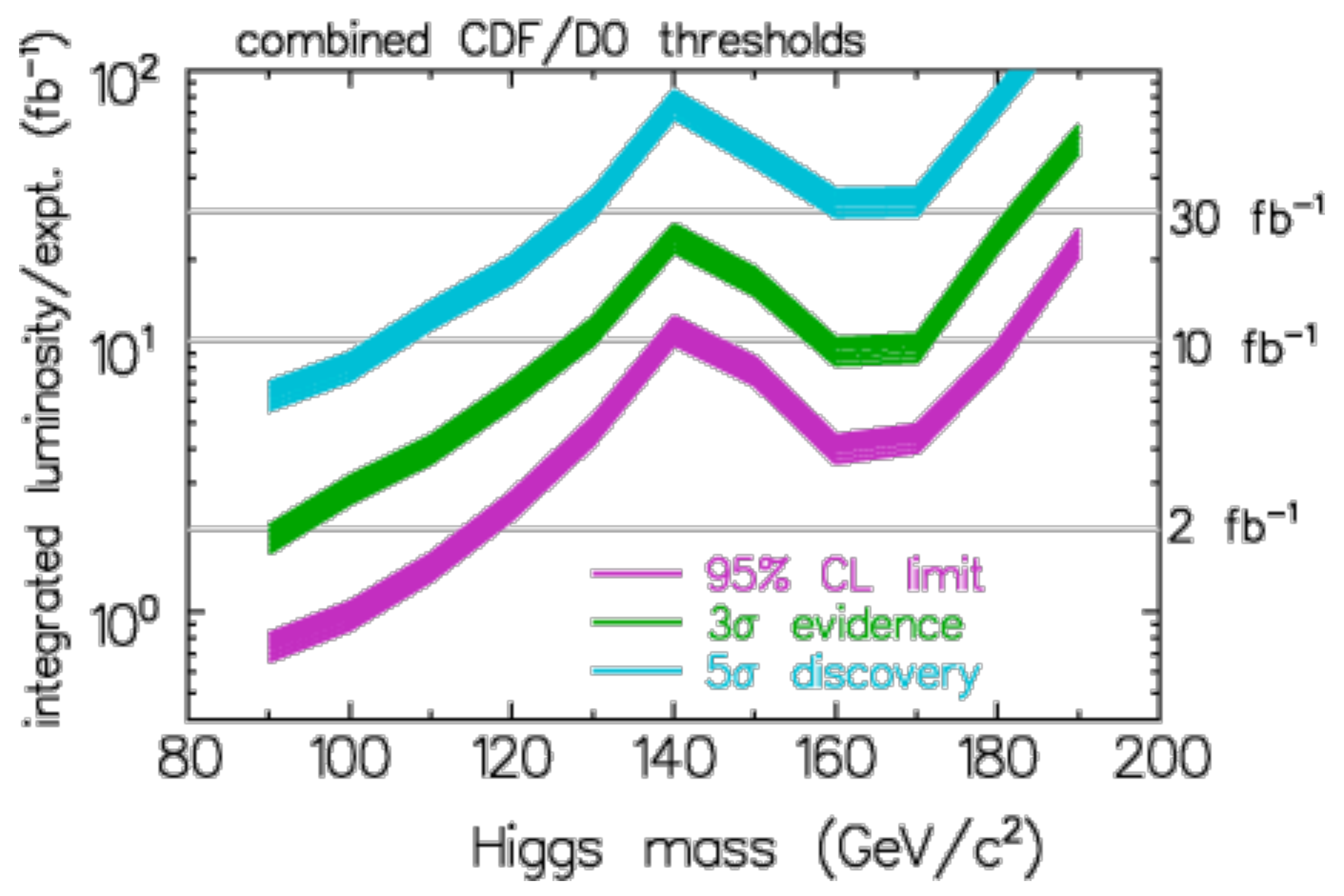
Special thanks to Matt Strassler, Matt Bowen, Nima Arkani-Hamed and Liantao Wang for furthering the use and development of PGS.

Origin of PGS

- March 1998: kickoff of the Tevatron Run 2 SUSY/Higgs Workshop
- no Run 2 CDF/D0 simulations available then
- developed "SHW" simulation as average of CDF/D0
- published SHW Higgs report: hep-ph/0010338 →
- fairly accurate for Tevatron Higgs reach!
- SHW -> PGS for Snowmass 2001
- has been used for VLHC, LHC, LC, Tevatron comparisons, especially by theorists

Tevatron SM Higgs: SHW



Famous result from the 1998 Tevatron Run 2 Susy/Higgs Workshop: from SHW simulation!

Origin of PGS

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PGS Design Goals

- interface to standard physics process generators (PYTHIA, HERWIG, ISAJET, ALPGEN, ...)
- perform very basic detector simulation with
    - tracks
    - calorimeter deposits
    - muon ID
- reconstruct physics “objects”: γ, e, μ, τ, jet (b), MET from tracks and calorimeter clusters
- parametrize where needed
- BE FAST!

PGS Simulation Features

	PGS?
• detector acceptance	yes
• detector efficiency	yes
• detector resolution	yes
• secondary interactions	
- nuclear interactions	no
- brehmsstrahlung	no
- pair production	no
- multiple scattering	no
• multiple interactions (pileup)	no
• event reconstruction effects	yes

Flow of PGS

event generation (PYTHIA, HERWIG, ...)

STDHEP common blocks

event simulation, object reconstruction

user analysis

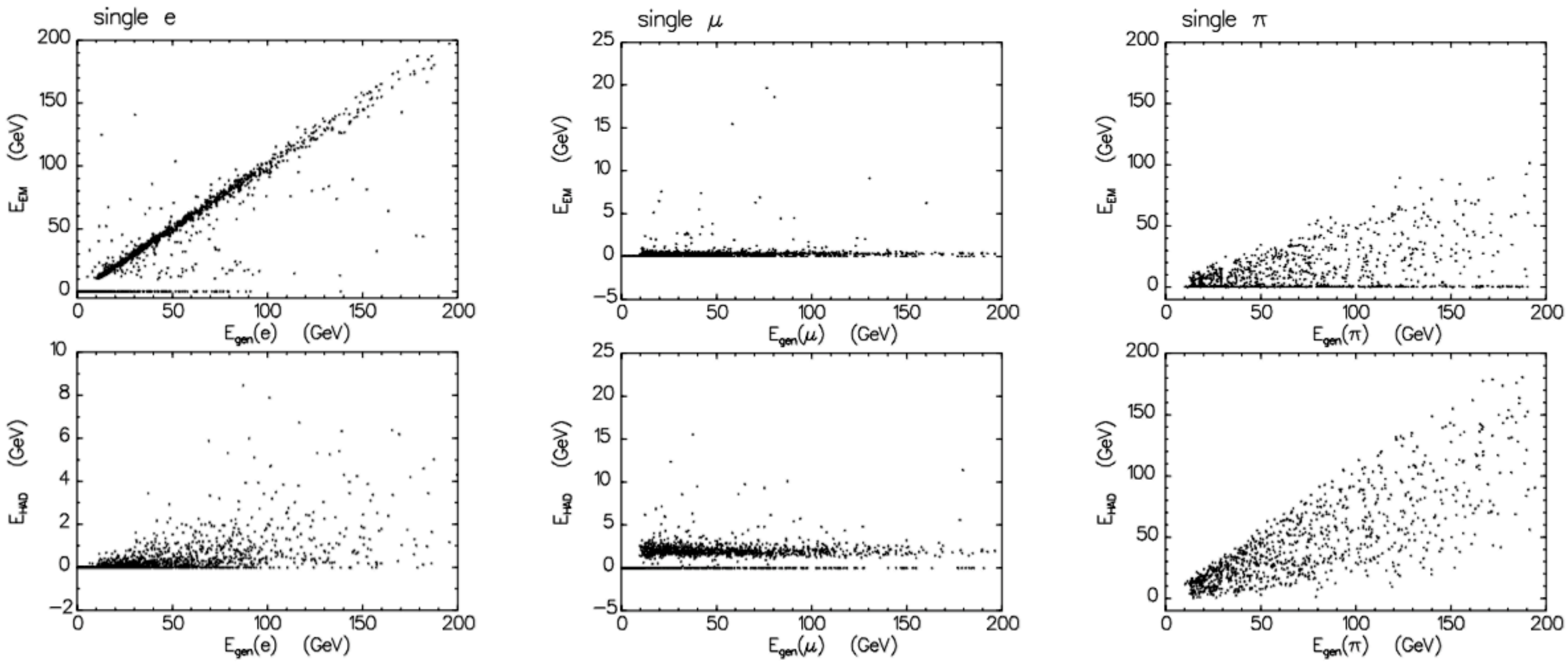
user output

PGS Detector Simulation

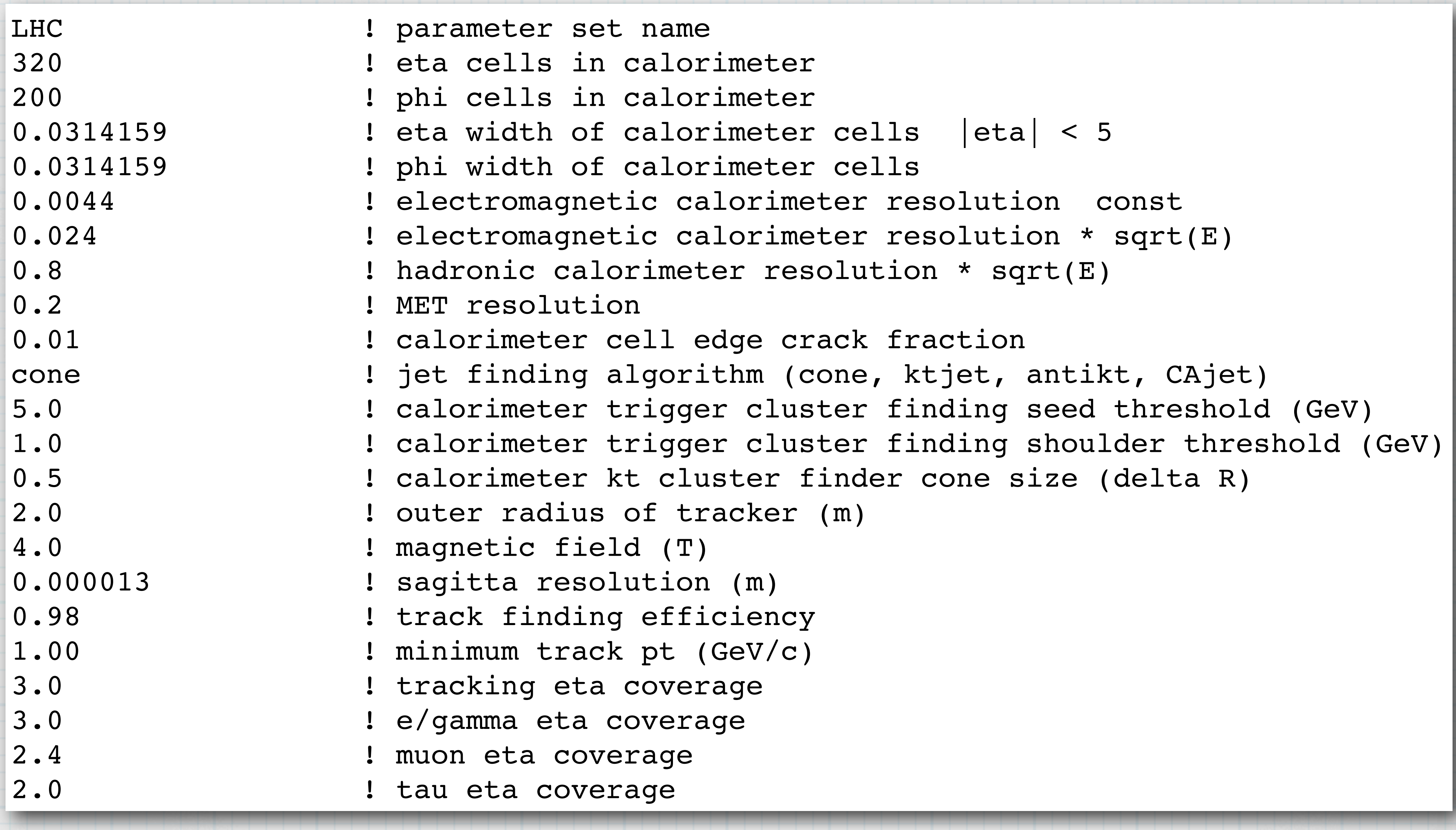
- loop through all final-state particles
- if charged, make charged track (straight...)
- calorimeter deposits:
    - gamma/electron: mostly electromagnetic
    - hadron: mostly hadronic
    - muon: minimum ionizing
- calorimeter is idealized, segmented in eta/phi
- resolutions are controllable parameters

PGS Event Simulation

- plots of electromagnetic, hadronic, muonic energy deposits as implemented in PGS:



PGS Parameters



```
LHC                    ! parameter set name
320                    ! eta cells in calorimeter
200                    ! phi cells in calorimeter
0.0314159              ! eta width of calorimeter cells  |eta| < 5
0.0314159              ! phi width of calorimeter cells
0.0044                 ! electromagnetic calorimeter resolution  const
0.024                  ! electromagnetic calorimeter resolution * sqrt(E)
0.8                    ! hadronic calorimeter resolution * sqrt(E)
0.2                    ! MET resolution
0.01                   ! calorimeter cell edge crack fraction
cone                   ! jet finding algorithm (cone, ktjet, antikt, CAjet)
5.0                    ! calorimeter trigger cluster finding seed threshold (GeV)
1.0                    ! calorimeter trigger cluster finding shoulder threshold (GeV)
0.5                    ! calorimeter kt cluster finder cone size (delta R)
2.0                    ! outer radius of tracker (m)
4.0                    ! magnetic field (T)
0.000013               ! sagitta resolution (m)
0.98                   ! track finding efficiency
1.00                   ! minimum track pt (GeV/c)
3.0                    ! tracking eta coverage
3.0                    ! e/gamma eta coverage
2.4                    ! muon eta coverage
2.0                    ! tau eta coverage
```

User is free to change these...at his or her own risk!

PGS Resolutions

- tracking (B field, radius, sagitta)
  - ✓ calculate sagitta, smear, get p_T
  - ✓ includes possibility of charge confusion
- em calorimetry

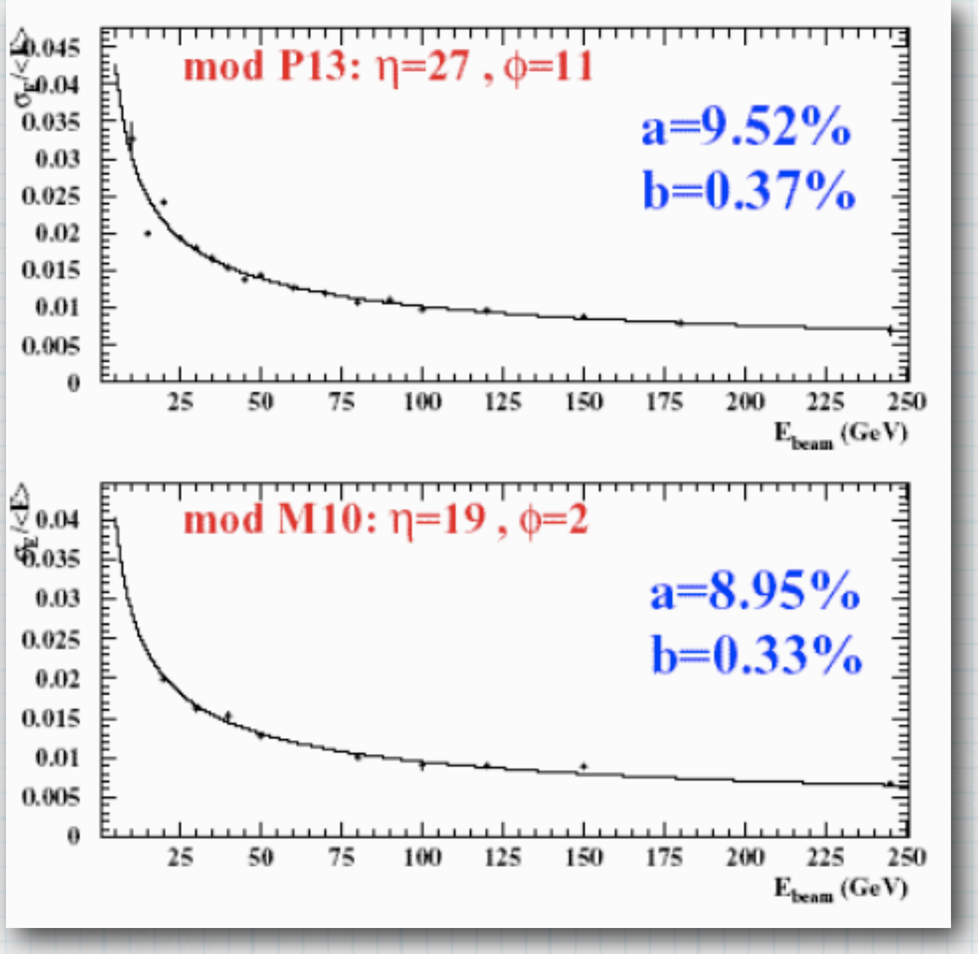
$$\Delta E/E = a + b/\sqrt{E}$$

- hadron calorimetry

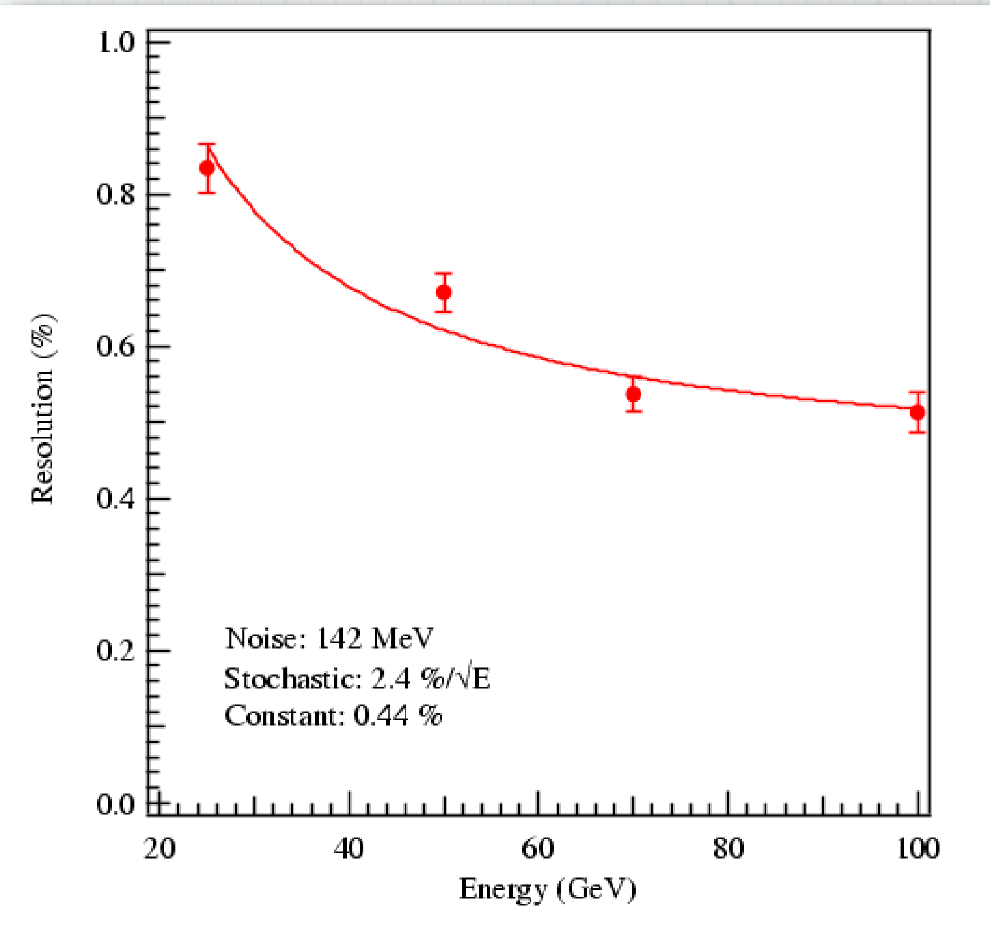
$$\Delta E/E = b/\sqrt{E}$$

ATLAS/CMS Calorimetry

ATLAS



CMS



This is from test beams - does not tell the whole story!

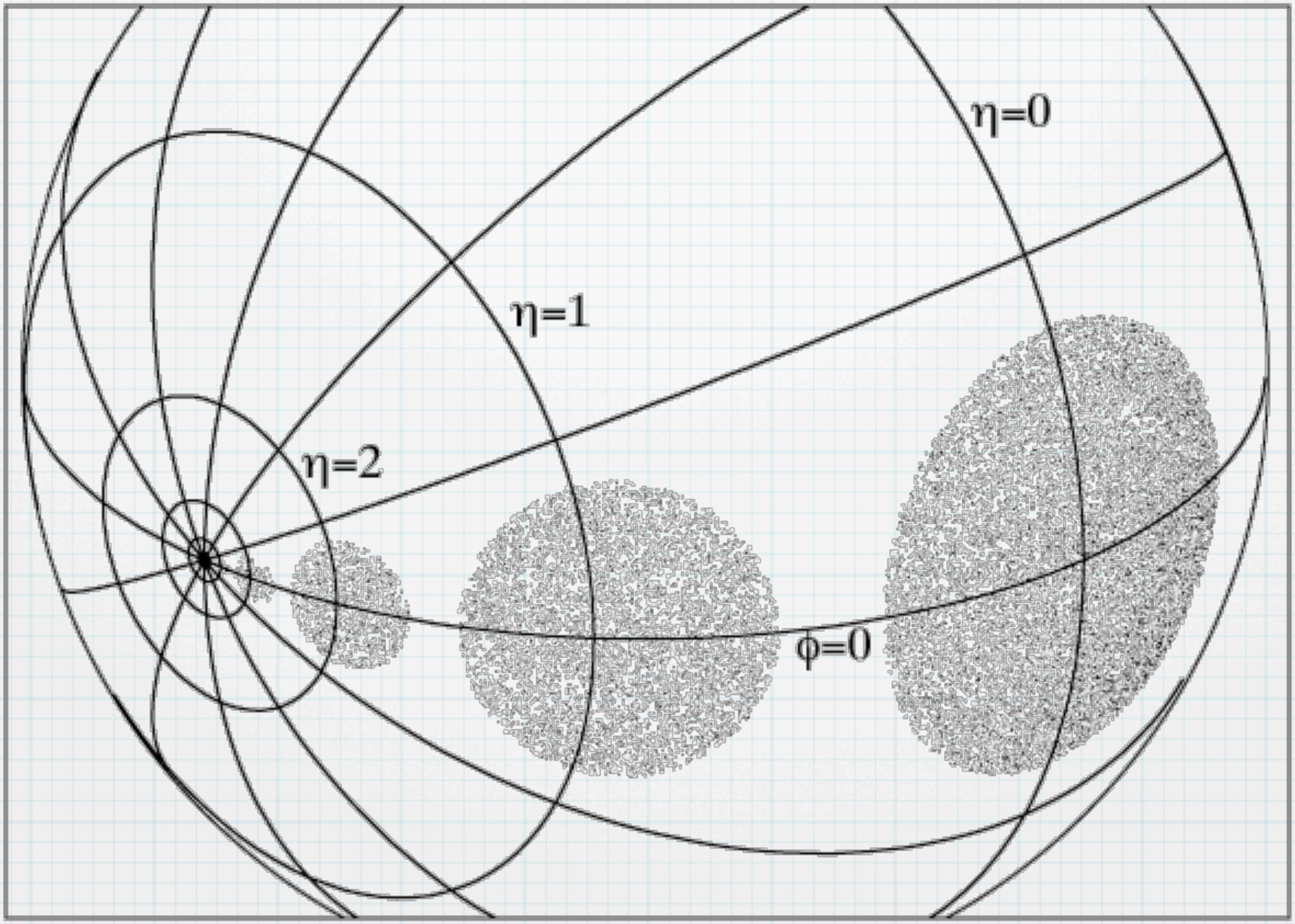
PGS Jet Finding

- after second LHC Olympics, request was made to use kt jet algorithm rather than the "JETCLU"-like cone algorithm formerly used
- both were available: top-down cone jets used for trigger objects, and bottom-up kt jets used for physics jet objects
- kt/anti-kt/CAjet jet finding done with FastJet-like algorithm (N lnN scaling)
- BUG in 090401 release of PGS, corrected as of April 2012 for version 120404 (thanks to Jay Wacker and Anson Hook for finding this!)

PGS Jet Finding

- only calorimeter tower energies used to reconstruct PGS jets! (no track info used)
- jet algorithms differ in the tails of various distributions
- funny-shaped jets (e.g. with g radiation) will always be a difficulty
- is ΔR even the right measure of separation?
- ΔR is z-boost invariant but the solid angle subtended by cones of constant ΔR varies dramatically with pseudorapidity

We plot here random points lying within ΔR of 0.4 from several reference points:



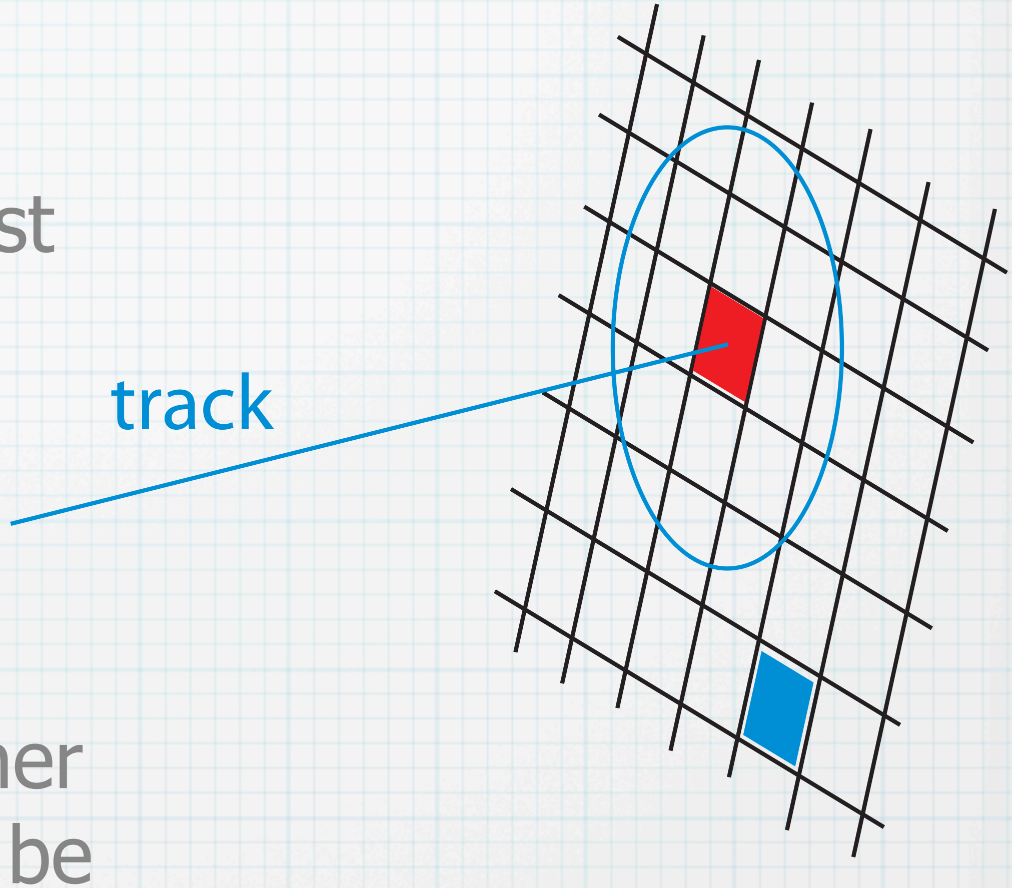
ΔR used for jet finding/merging, isolation, ... is it what we want in all cases?

PGS Electrons/Photons

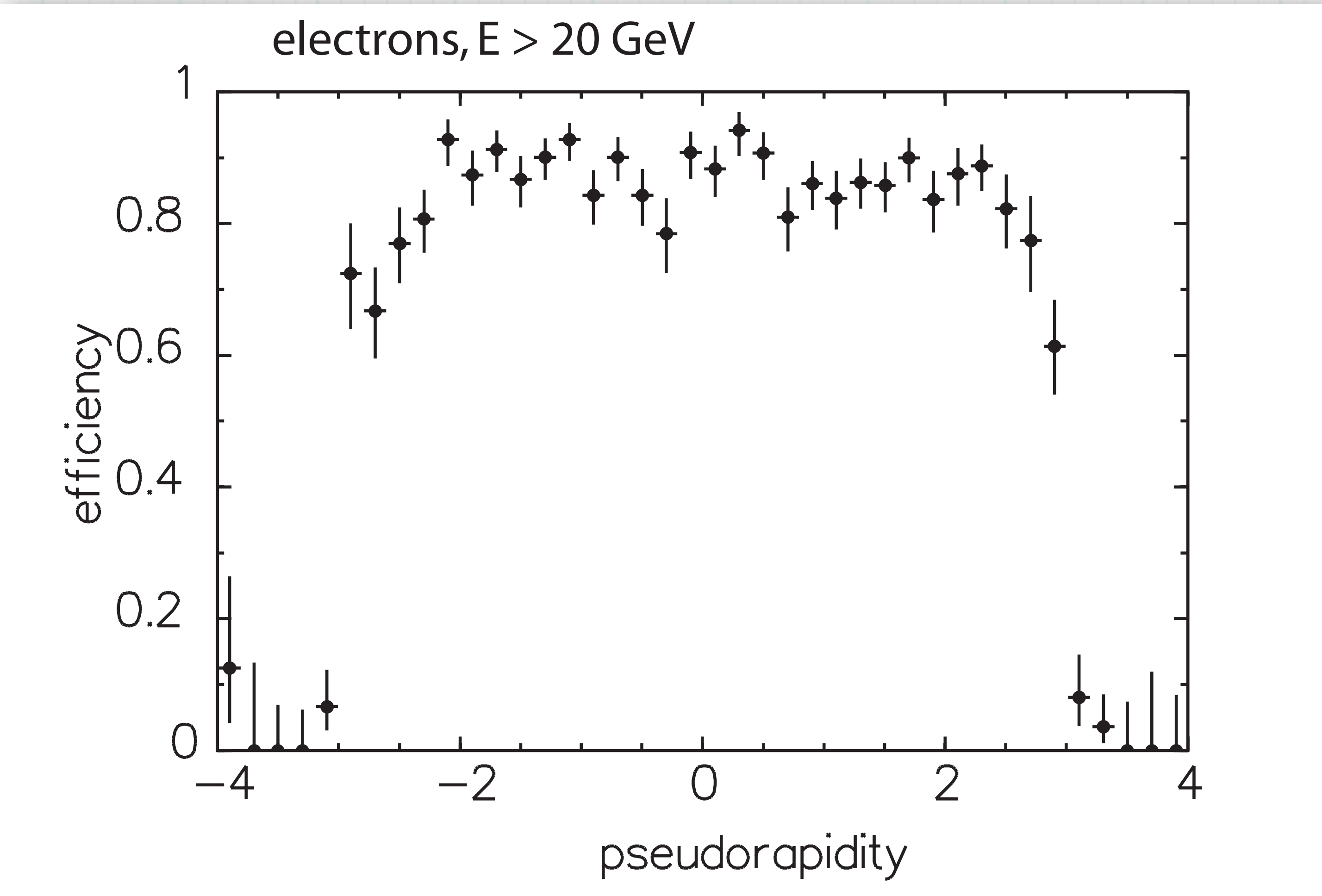
- in real life electromagnetic showers are narrow; hadronic showers are wide
- in PGS there is no lateral shower spread: the energy of each particle goes in one tower
- we simply rely on the fact that the energy is deposited in the em section of the calorimeter
- start with clusters and apply e.m. fraction cuts, match with track
- apply calorimeter isolation cut (3x3 region)

PGS Electrons/Photons

- look at em fraction of cluster (single tower most likely)
- see if there is a track; no track ⇒ photon
- require sum of p_T of other tracks in ΔR cone of 0.4 be less than 5 GeV
- require sum of energy in 3x3 collar region < 0.1 E



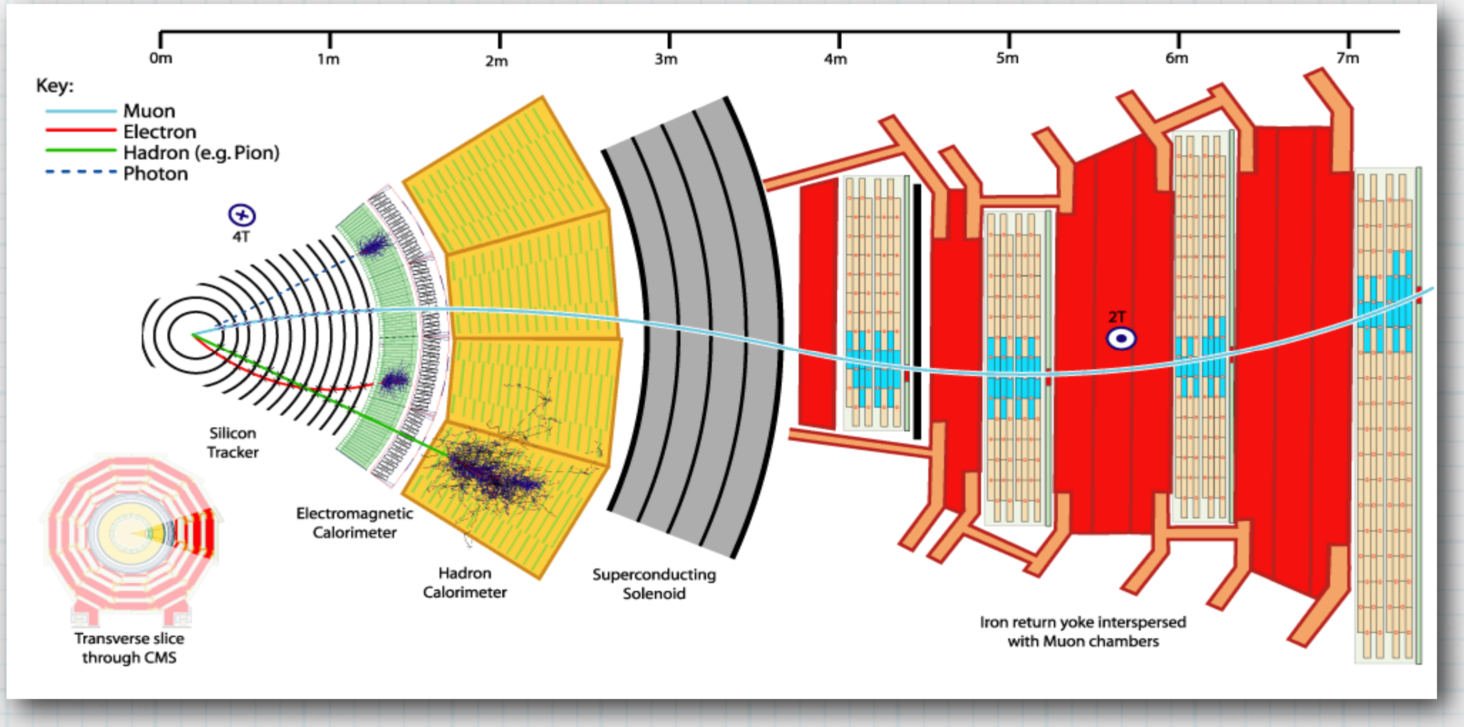
PGS electron efficiency



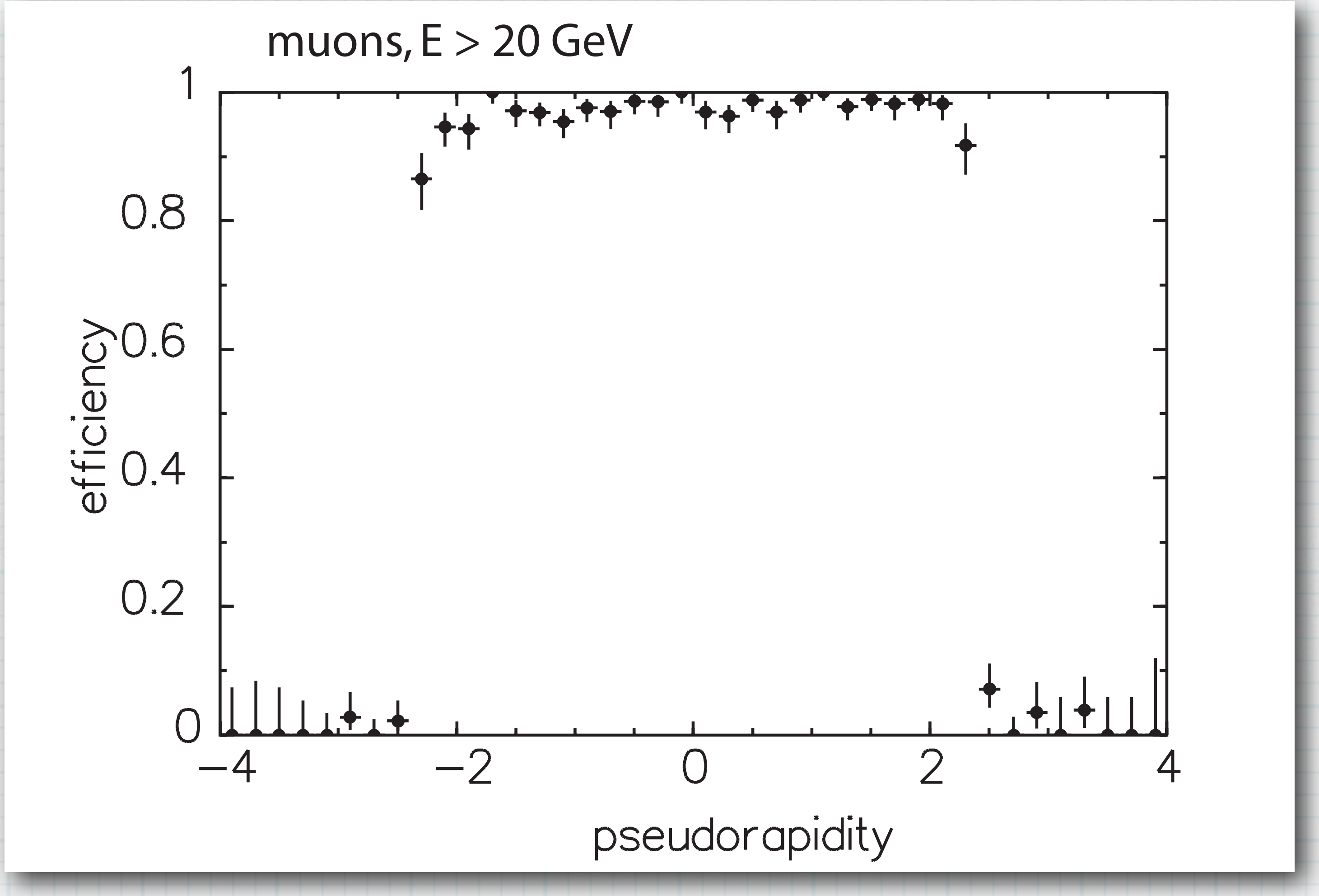
- efficiency about 87% out to $|\eta| = 3$

PGS Muons

- ATLAS/CMS muon systems are highly efficient/redundant!
- We provide a parametrized efficiency function but we do <u>not</u> apply it by default (more relevant to CDF)
- Also, we do not apply a muon isolation cut by default, and leave that to the user (applied in the olympics executable)



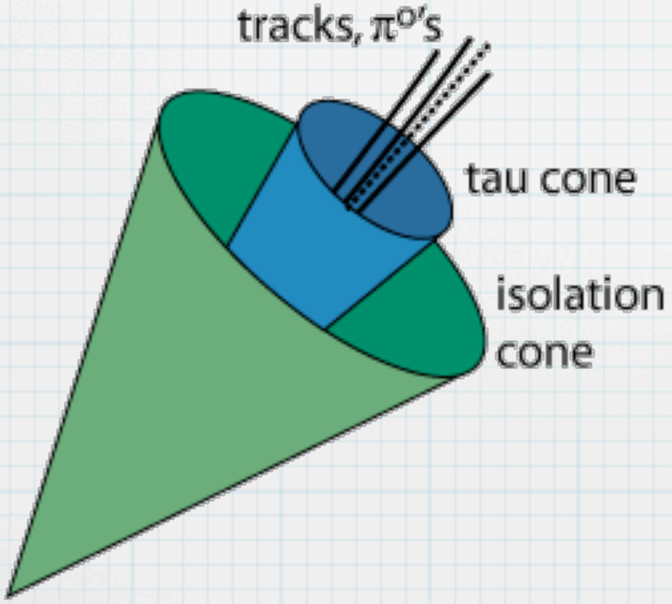
PGS muon efficiency

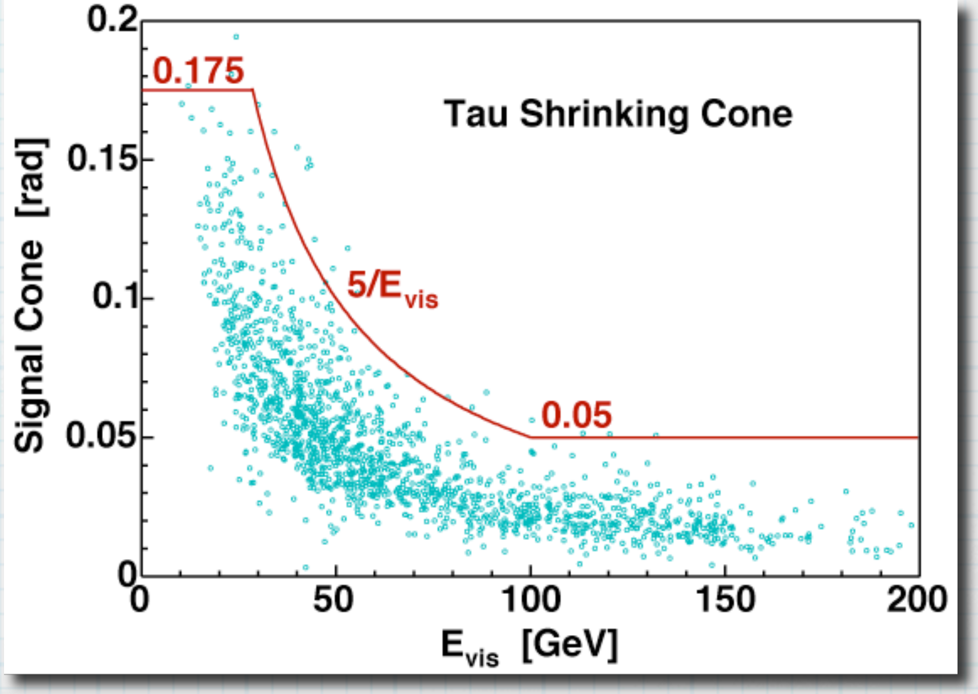


- efficiency about 97% out to |η| = 3

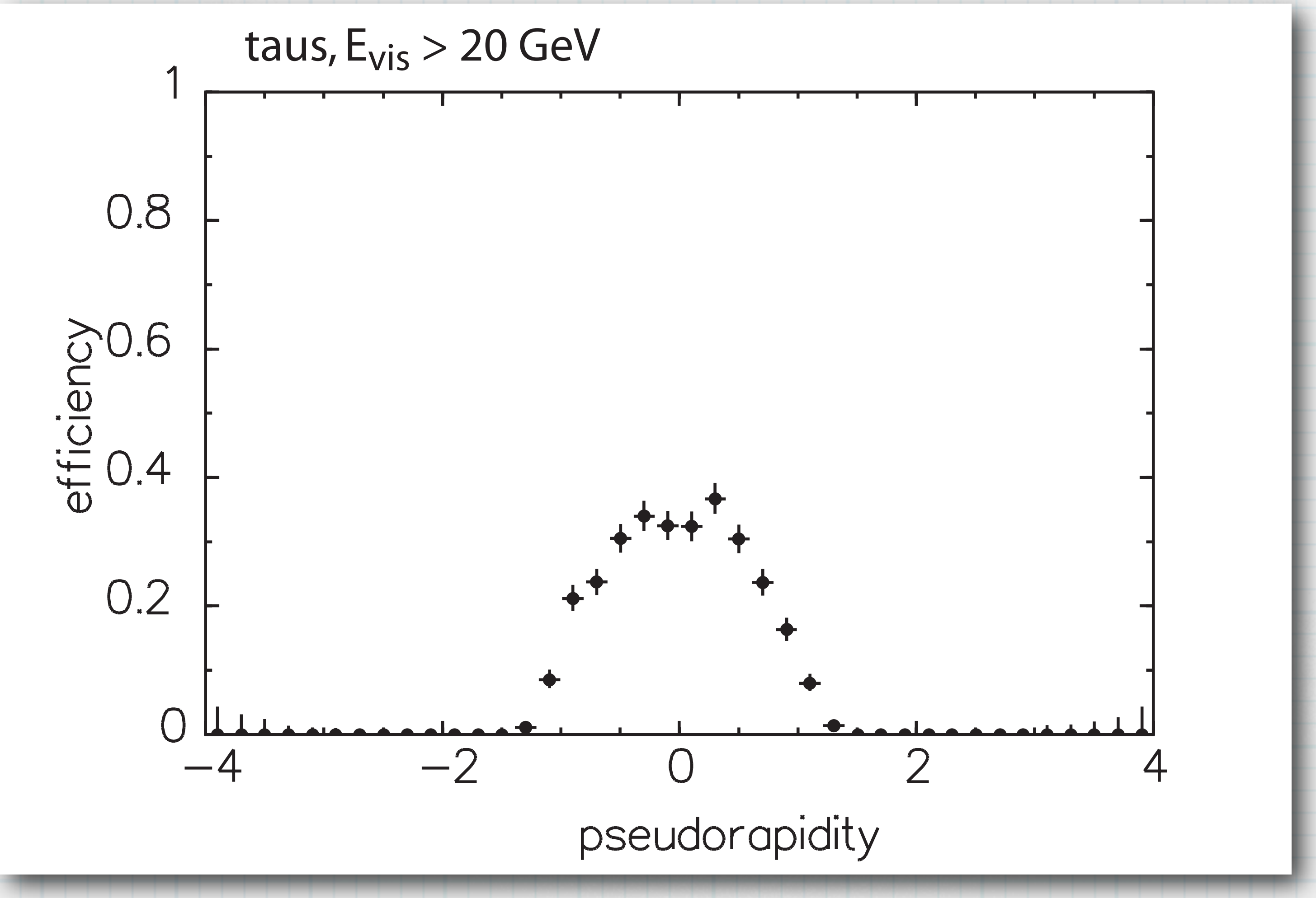
PGS Tau Reconstruction

- traditional standard approach at hadron colliders: cone-based algorithm
- use CDF-style "shrinking cone" surrounding high-p_T seed track
- we "fake" the π^0 reconstruction





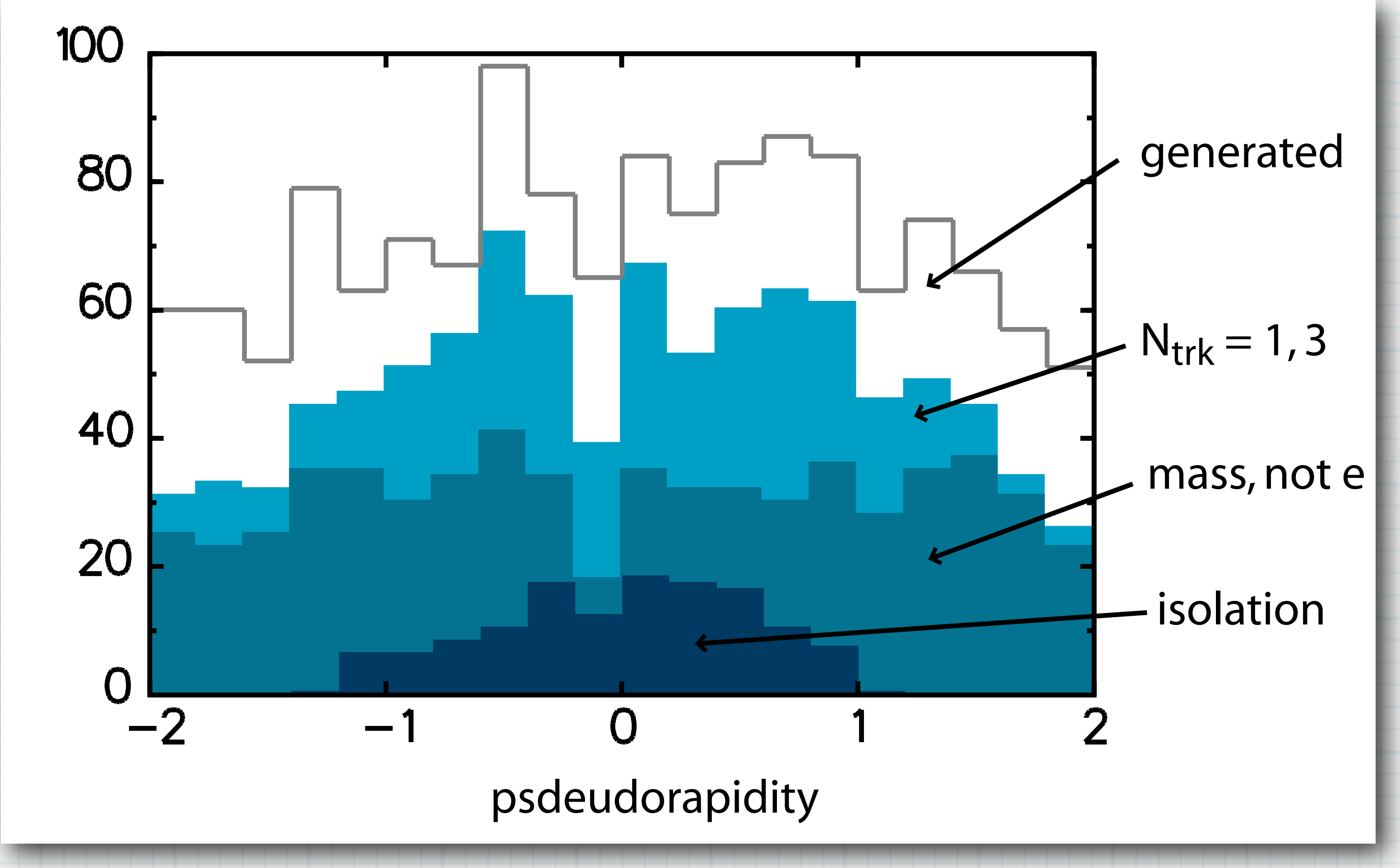
PGS tau efficiency



- efficiency much smaller than electrons, falls of rapidly at high pseudorapidity

PGS tau efficiency

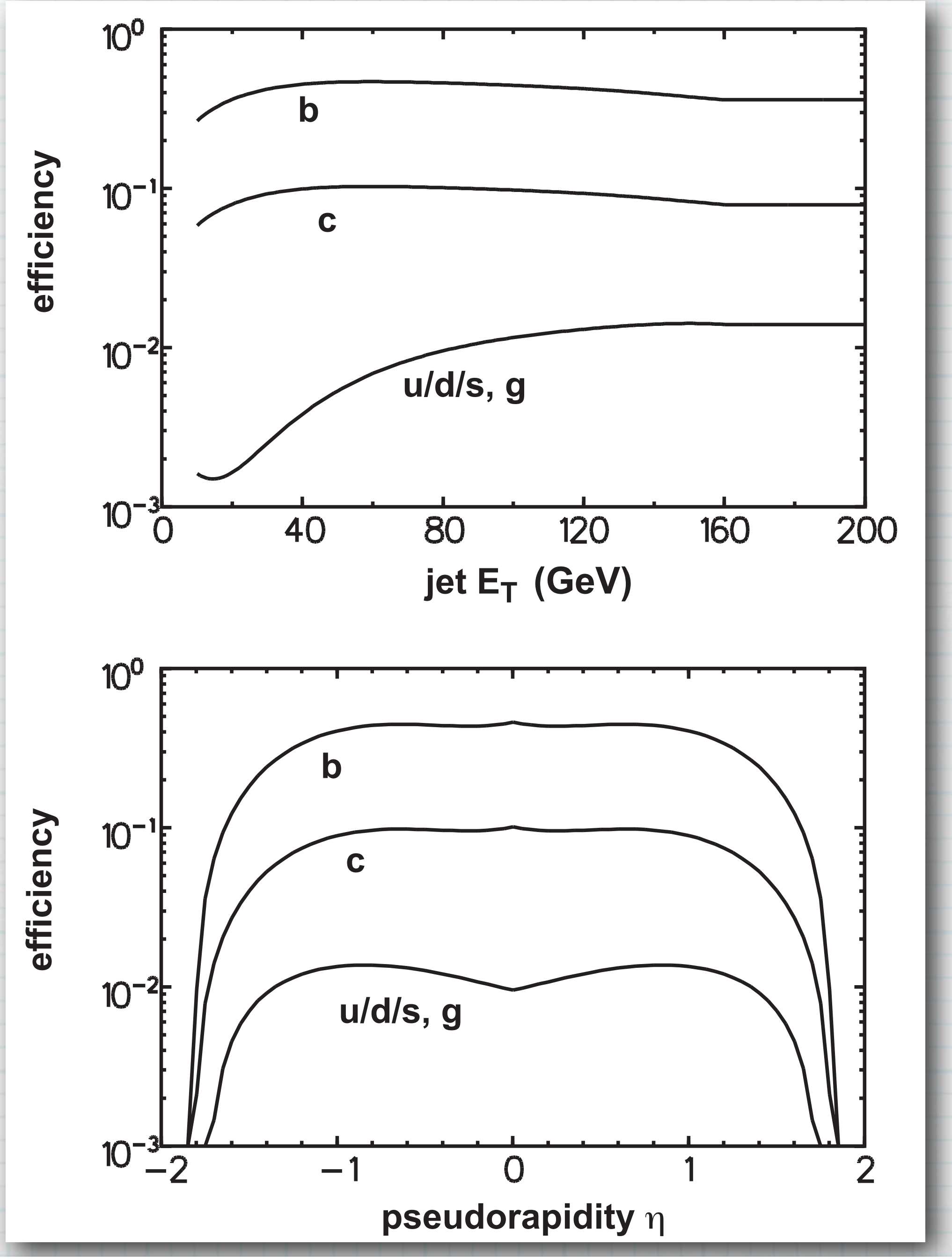
- can we understand which cut is hurting us?



- could be modernized (NN approach)

PGS b-tagging

- parametrize b-tagging efficiency as a function of jet ET, eta
- use MC truth to tell "true jet type"
- this parametrization based on CDF Run 2
- not too far from actual LHC experience...but needs updating



Uniqueness

- a given calorimeter energy (kt jet) cluster can give rise to
  - photon or electron
  - tau
  - jet
- must have algorithm to decide which it is!
- cannot call it two different things!

Uniqueness

- we define physics object precedence:

  γ > e > τ > jet

- if object is already identified as an electron it cannot be a tau or a jet; tau cannot be jet
- jet is "catch-all" class
- muons are all "unique"
- we do this using 3D angle of 10°
- as of PGS 4, provide "unique" flag for each object

PGS Trigger Objects

- PGS provides crude “trigger objects” formed from cone algorithm cluster and tracks:
    - gamma: em deposit, no track
    - electron: em deposit with track
    - muon: straight 98% on all muons that make tracks
    - tau: subset of tau cuts
    - jet: any cluster
- not realistic for LHC

PGS Input/Output

- PGS was designed to call PYTHIA/HERWIG/ISAJET to generate events and simulate on the fly
- PGS can read STDHEP binary files (XDR)
- PGS can read LHE files, run PYTHIA
- Output format is up to the user; Root is not the default, but technically possible
- LHC Olympics: ASCII output format became widely used (LHCO files)

Example Olympics Output

```
 #  typ      eta    phi      pt    jmas  ntrk  btag   had/em  dum1  dum2
                          0            1   3585
 1    4   -1.312  3.143  104.54   21.59  19.0   0.0     1.22   0.0   0.0
 2    4   -1.233  0.957   85.10   15.90  11.0   0.0     5.78   0.0   0.0
 3    4   -2.939  1.139   38.38   26.74  20.0   0.0    63.11   0.0   0.0
 4    4    3.226  5.123   37.37   34.33   8.0   0.0     1.10   0.0   0.0
 5    4   -3.718  4.691   21.52    1.55  17.0   0.0     1.35   0.0   0.0
 6    4    0.211  5.752   12.75   15.57   0.0   0.0     1.03   0.0   0.0
 7    4    1.008  3.038   12.60    4.18   3.0   0.0     1.73   0.0   0.0
 8    4   -2.106  4.275    7.93    2.75  19.0   0.0     3.32   0.0   0.0
 9    6    0.000  6.008   15.64    0.00   0.0   0.0     0.00   0.0   0.0
                          0            2   3599
 1    2   -1.317  3.638    3.36    0.11  -1.0   6.0    11.41   0.0   0.0
 2    2   -1.388  1.845   12.23    0.11   1.0  10.0     0.10   0.0   0.0
 3    4   -0.044  5.646   79.40  335.20   0.0   0.0     1.63   0.0   0.0
 4    4   -0.341  1.677   56.31   32.28   8.0   0.0     5.10   0.0   0.0
 5    4   -3.391  5.279   55.44   30.84  20.0   0.0     1.11   0.0   0.0
 6    4   -1.242  3.464   36.02   34.93   9.0   0.0     2.23   0.0   0.0
 7    4    3.875  2.981   23.08   25.33  12.0   0.0     1.78   0.0   0.0
 8    4   -2.934  0.093   11.33    2.15  21.0   0.0     6.17   0.0   0.0
 9    4   -1.584  4.694   11.12    2.39  18.0   0.0     5.91   0.0   0.0
10    4   -1.716  1.913    9.09    2.20  12.0   0.0     0.90   0.0   0.0
                           0            3   3585
 1    4    0.523  0.059  225.21   48.39  19.0   0.0     3.19   0.0   0.0
 2    4    1.336  3.220  228.44    3.75  10.0   0.0    10.04   0.0   0.0
 3    4    2.918  0.007   62.64  123.09  13.0   0.0     1.53   0.0   0.0
```

Future of PGS

- Should PGS have a future?
  - it’s Fortran
  - no transition to PYTHIA 8
  - not well documented (the code is, though!)

- Work is needed most on b-tagging, tau ID

Why was PGS successful?

- self-contained, simple distribution
- PGS worked out of the box
- supported on Linux, OS X
- final “product” was short list of physics objects that users could easily analyze
- simulation was quite crude but reproduced the main effects: acceptance, resolution, and efficiency
- very fast (100 Hz on ttbar events on Core i7)

Getting PGS

- PGS web page:

http://physics.ucdavis.edu/~conway/research/software/pgs/pgs4-general.htm

- PGS users mailing list:
    - send email to PGS_users@fnal
    - leave subject blank
    - put “subscribe” in first line of message