PGS 4 and the LHC Olympics

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1. Detector Effects and Simulation
2. LHC Detectors
3. Design of PGS
4. PGS Physics Object Reconstruction
5. Triggers in PGS
6. Future Development

Contributors

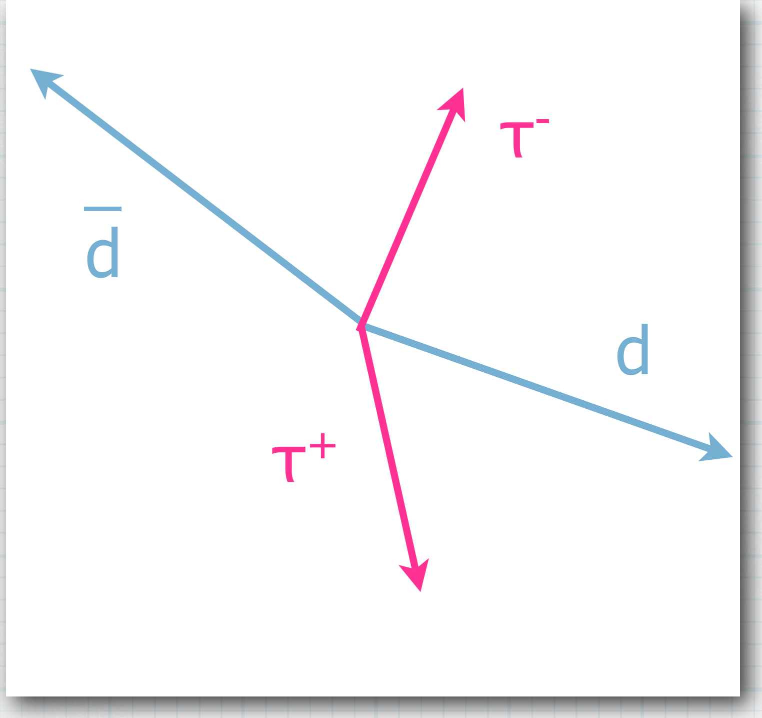
PGS is the work of many people!

John Conway (UC Davis), Ray Culbertson (FNAL), Regina Demina (U. Rochester), Ben Kilminster (Ohio State), Mark Kruse (Duke), Steve Mrenna (FNAL), Jason Nielsen (LBNL), Maria Roco (now at Lucent), Aaron Pierce and Jesse Thaler (Harvard), Natalia Toro (Harvard), Chris Tully (Princeton).

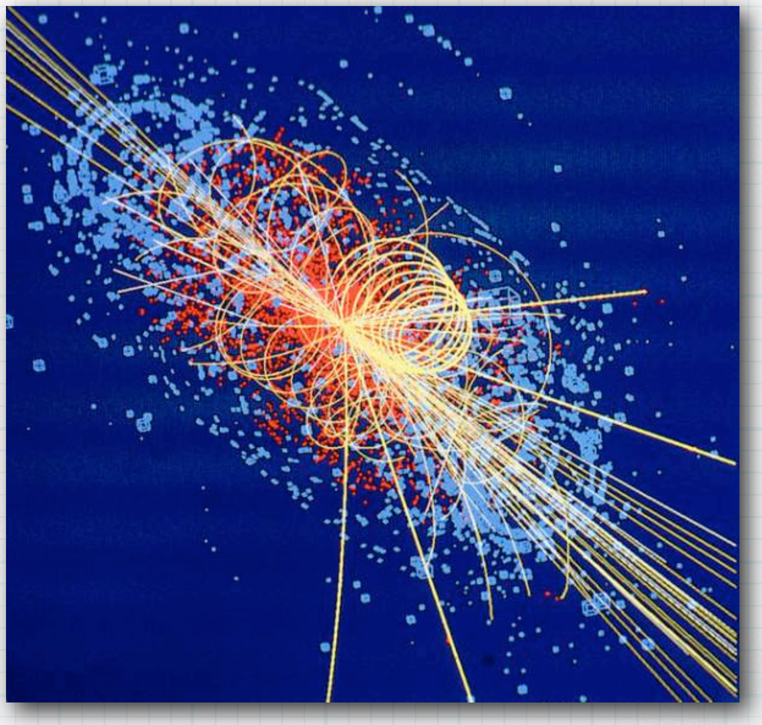
Special thanks to Matt Strassler, Matt Bowen, Nima Arkani-Hamed and Liantao Wang for furthering the use and development of PGS.

Detector Effects and Simulation

Ideally a high energy physics detector would tell us the four momenta of all outgoing particles in a hard collision:



what we want

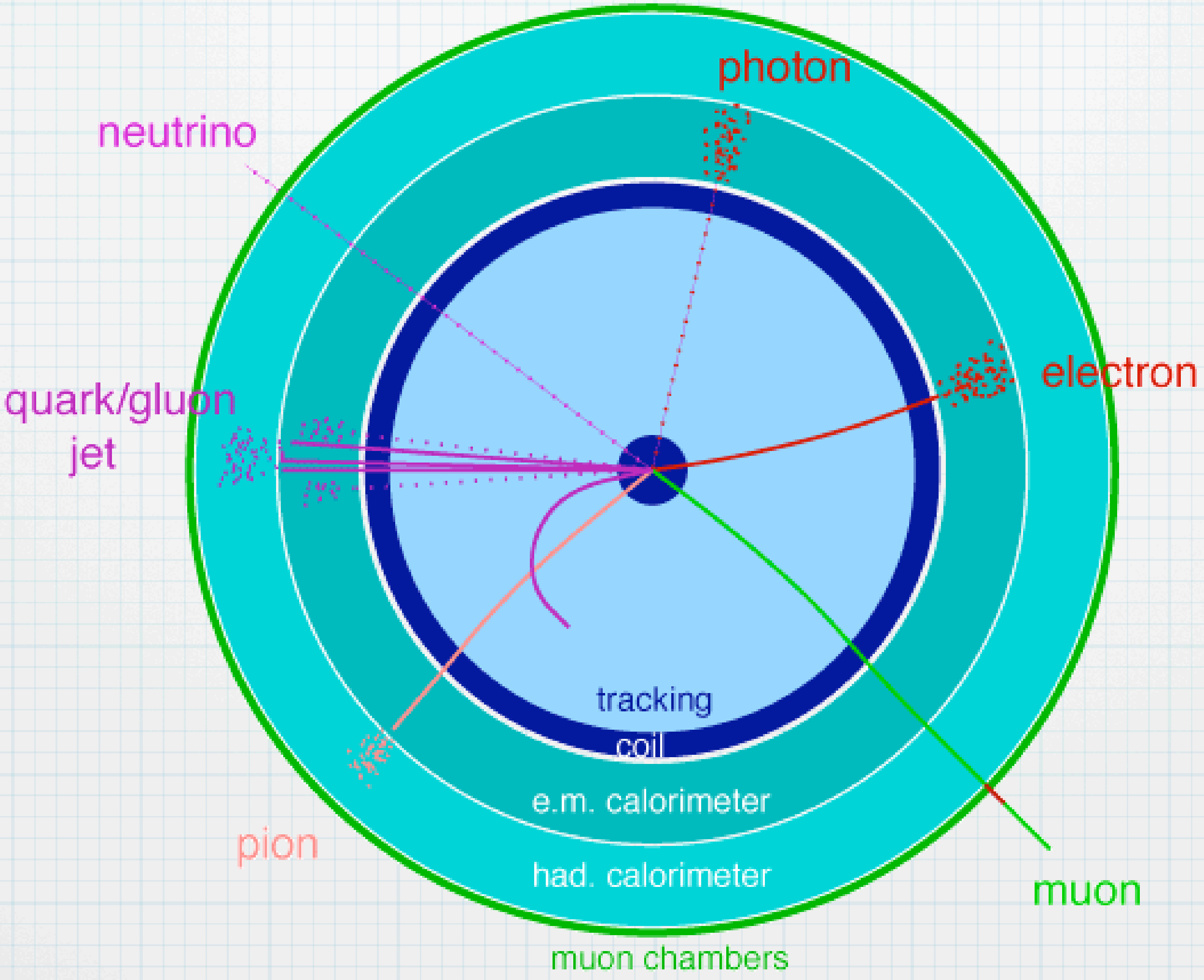


what we get

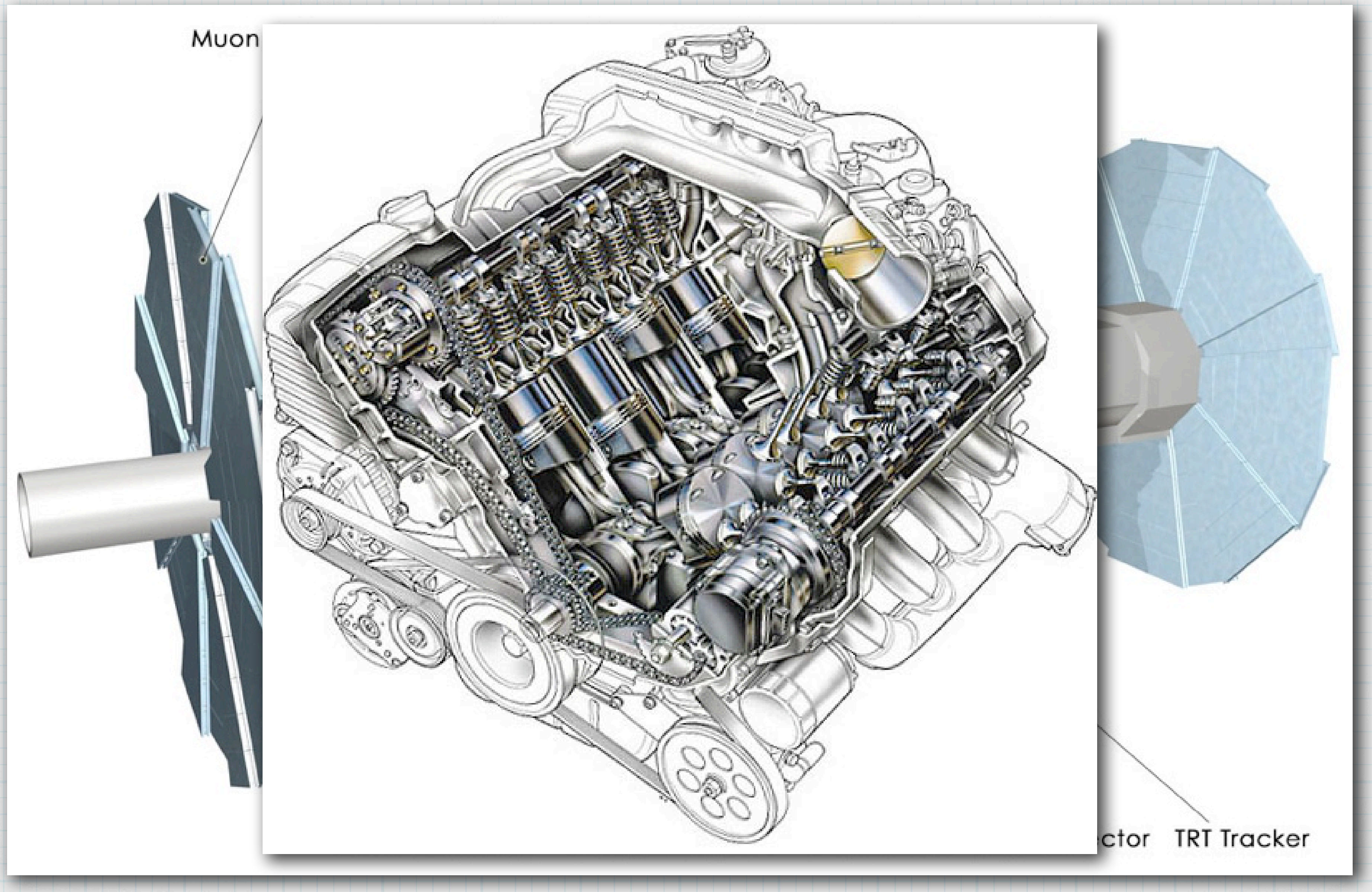
Detector Simulation: Goals

- detector acceptance
- detector efficiency
- detector resolution
- secondary interactions
  - nuclear interactions
  - brehmsstrahlung
  - pair production
  - multiple scattering
- multiple interactions (pileup)
- event reconstruction effects

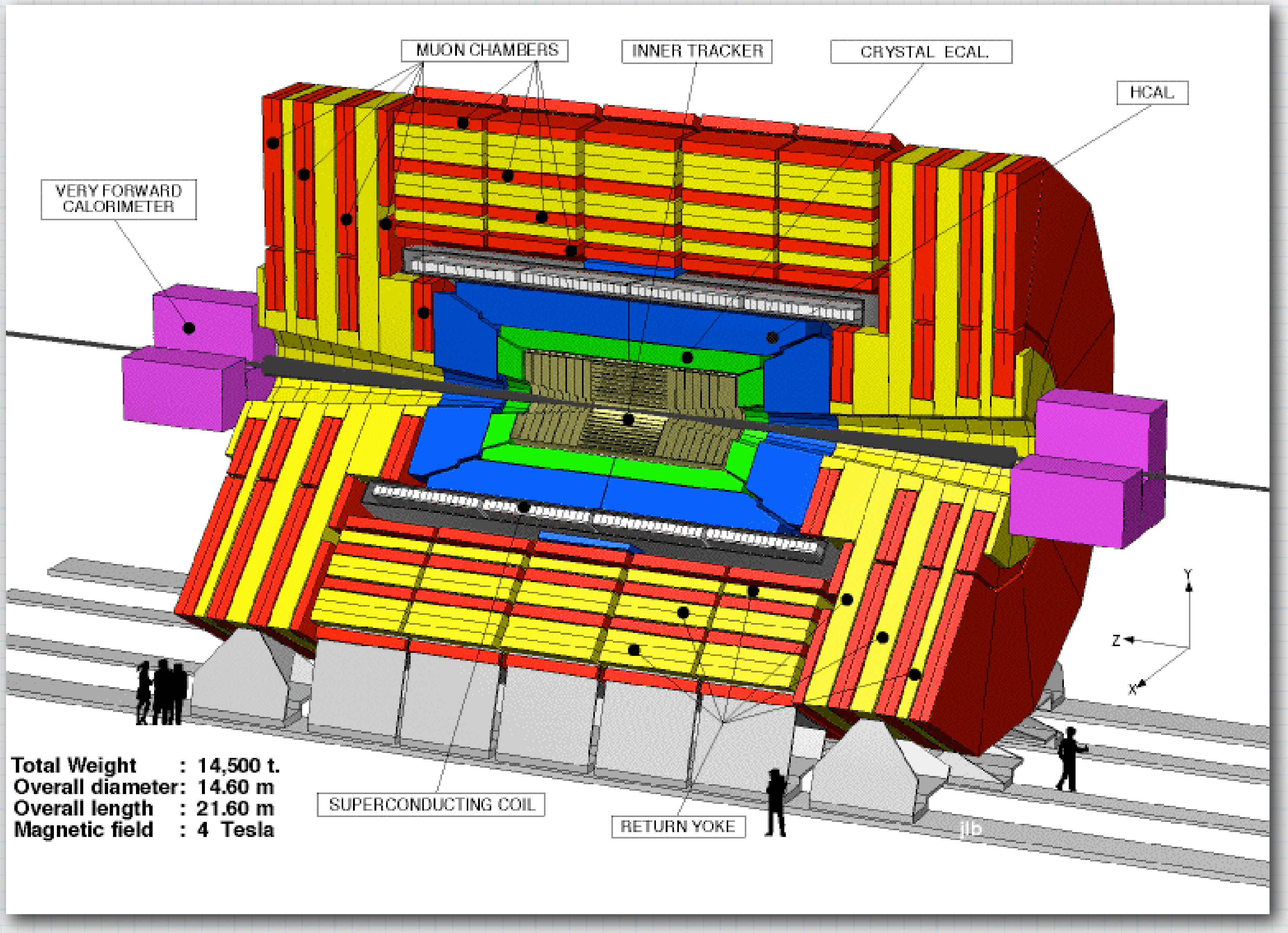
Generic HEP Detectors



ATLAS



CMS



Total Weight : 14,500 t.
Overall diameter: 14.60 m
Overall length : 21.60 m
Magnetic field : 4 Tesla

CMS and ATLAS

- similar, yet different approaches to LHC problem

	ATLAS	CMS
vertexing	Si pixels	Si pixels
tracking	Si strips/gas	Si strips
em cal	liquid Ar	$PbWO_4$
had cal	steel/scint.	brass/scint.
muon	RPCs/drift	RPCs/drift

GEANT

- the gold standard in high energy physics detector simulation software
- treats detector as “slabs” of particular material
- simulates in detail energy deposition from ionization, showering
- simulates all secondary interactions
- problem: takes minutes of CPU per event!

PGS Design

- 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/calorimeter
- parametrize where needed

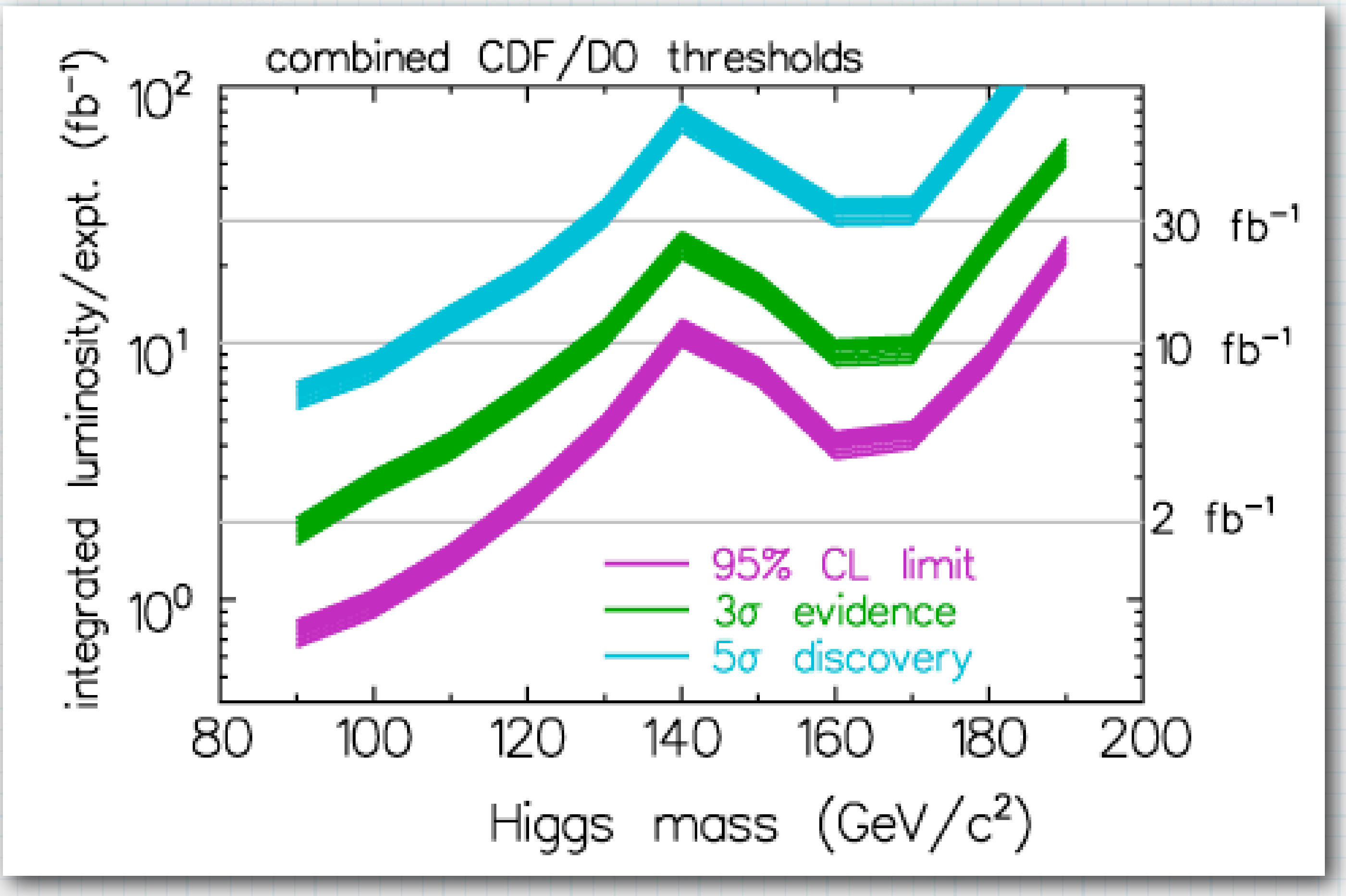
Detector Simulation Goals

	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

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
- still a reliable resource for Tevatron Higgs reach!
- SHW -> PGS for Snowmass 2001
- 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!

Flow of PGS

event generation (PYTHIA, HERWIG, ...)

STDHEP common blocks

event simulation, object reconstruction

user analysis

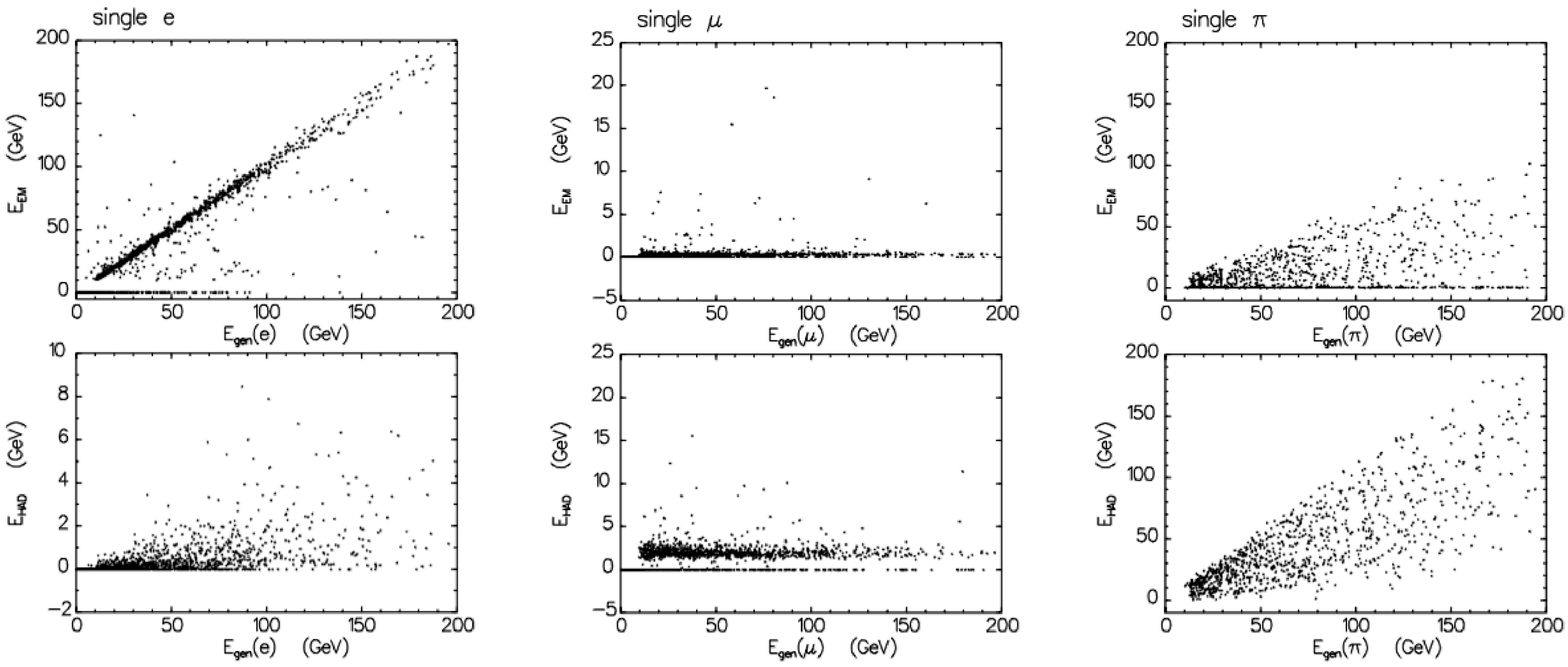
user output

PGS Detector Simulation

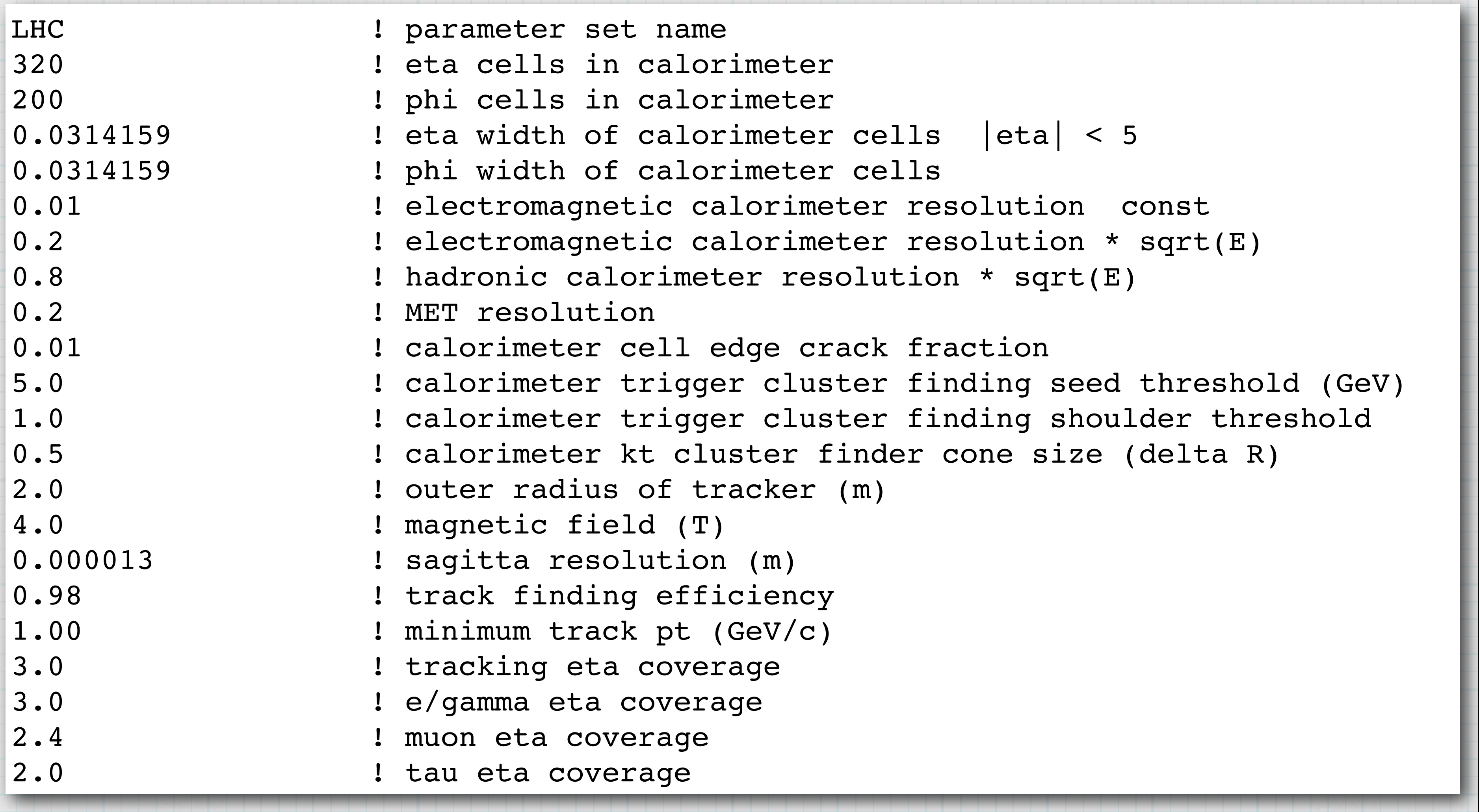
- loop through all final-state particles
- if charged, make charged track (straight...)
- calorimeter deposits:
    - gamma/electron: mostly electromagnetic
    - hadron: mostly hadronic
    - muon: minimum ionizing
- calorimeter is idealized, segmented in eta/phi
- resolutions are controllable parameters

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
0.01                ! electromagnetic calorimeter resolution  const
0.2                 ! electromagnetic calorimeter resolution * sqrt(E)
0.8                 ! hadronic calorimeter resolution * sqrt(E)
0.2                 ! MET resolution
0.01                ! calorimeter cell edge crack fraction
5.0                 ! calorimeter trigger cluster finding seed threshold (GeV)
1.0                 ! calorimeter trigger cluster finding shoulder threshold
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

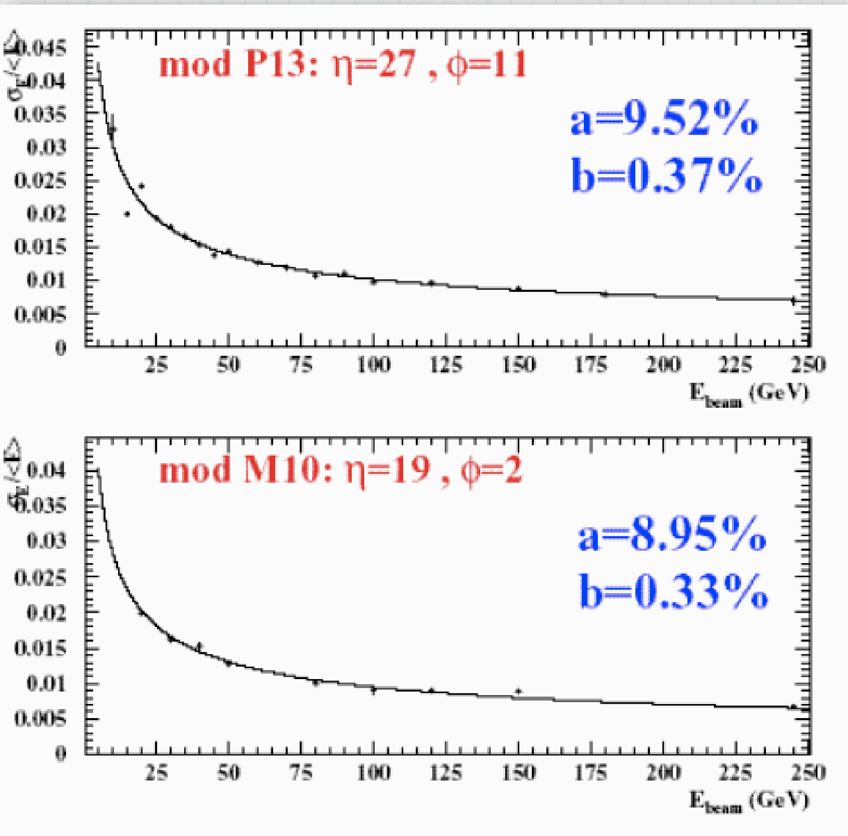
$$\Delta E/E = a + b/\sqrt{E}$$

- hadron calorimetry

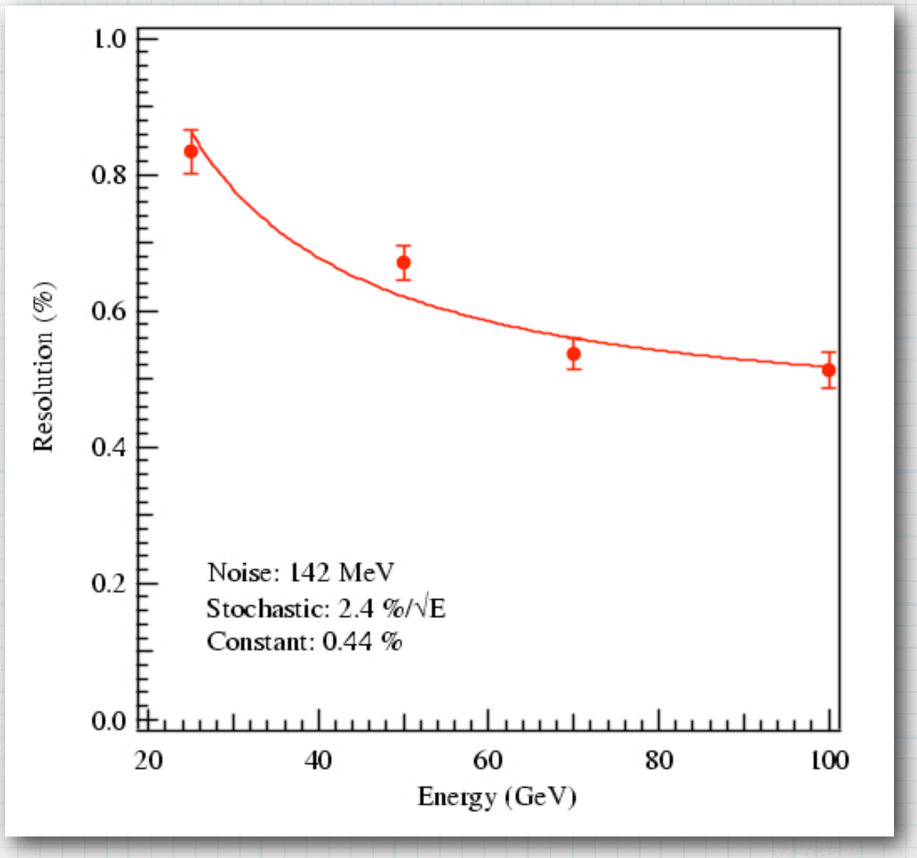
$$\Delta E/E = b/\sqrt{E}$$

ATLAS/CMS Calorimetry

ATLAS



CMS



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

PGS e.m. resolution

- presently in PGS (up to 060823):

$$\Delta E/E = 0.01 + 0.20/\sqrt{E}$$

- should be more like this:

$$\Delta E/E = 0.005 + 0.05/\sqrt{E}$$

PGS Jet Finding

- after second LHC Olympics, request was made to use kt jet algorithm rather than the "JETCLU"-like cone algorithm formerly used
- ended up doing both: top-down cone jets used for trigger objects, and bottom-up kt jets used for physics jet objects
- in next version of PGS will make this a user-settable switch
- studying the performance in the mean time...

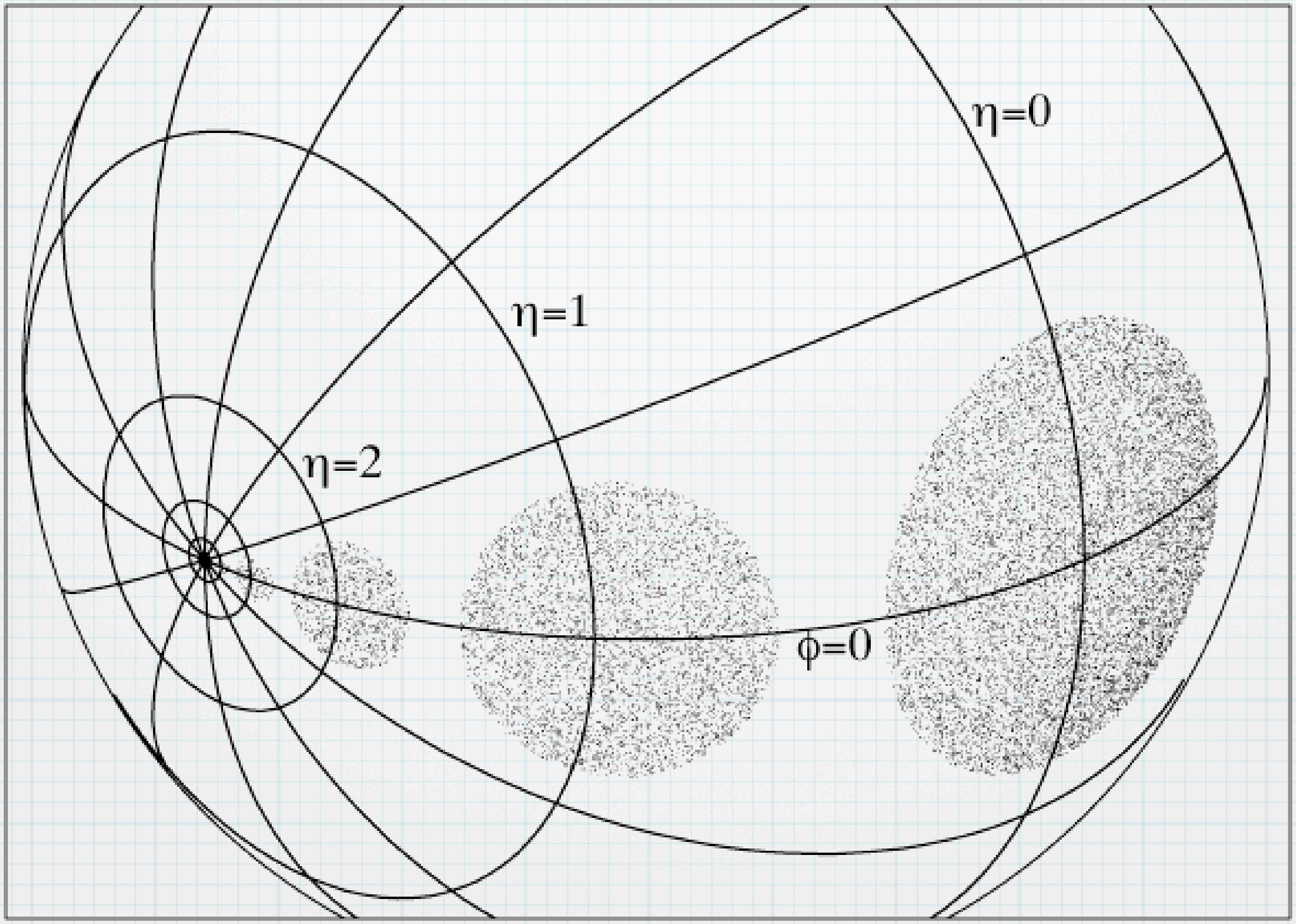
PGS Jet Finding

- “top-down” (cone): find highest ET tower, then add to it nearby towers above some threshold, lying within a pre-set cone size (ΔR_0); repeat until remaining highest ET tower is below some threshold
- “bottom-up” (kt jet): treat all towers (em+had) as “particles”; find all particle-particle distances $\min(k_{Ti}^2, k_{Tj}^2)\Delta R_{ij}^2/\Delta R_0^2$ and particle-”beam” distances k_{Ti}^2 and if the overall minimum is an ij, merge them; repeat until no merge-able pairs remain

PGS Jet Finding

- the two algorithms differ in the tails of various distributions
- kt jet clusters all energy above threshold; may not be desirable
- 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 I claim jets of a given energy have the same shape in space at any pseudorapidity...

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

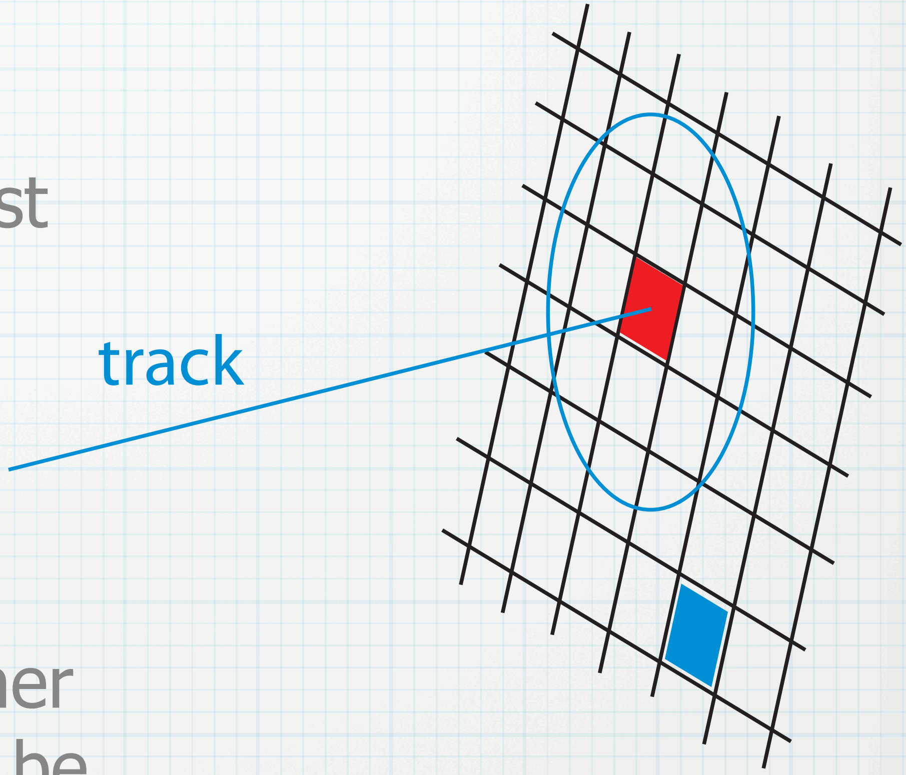


ΔR used for jet finding/merging, isolation, ... is it what we want in all cases?

PGS Electrons/Photons

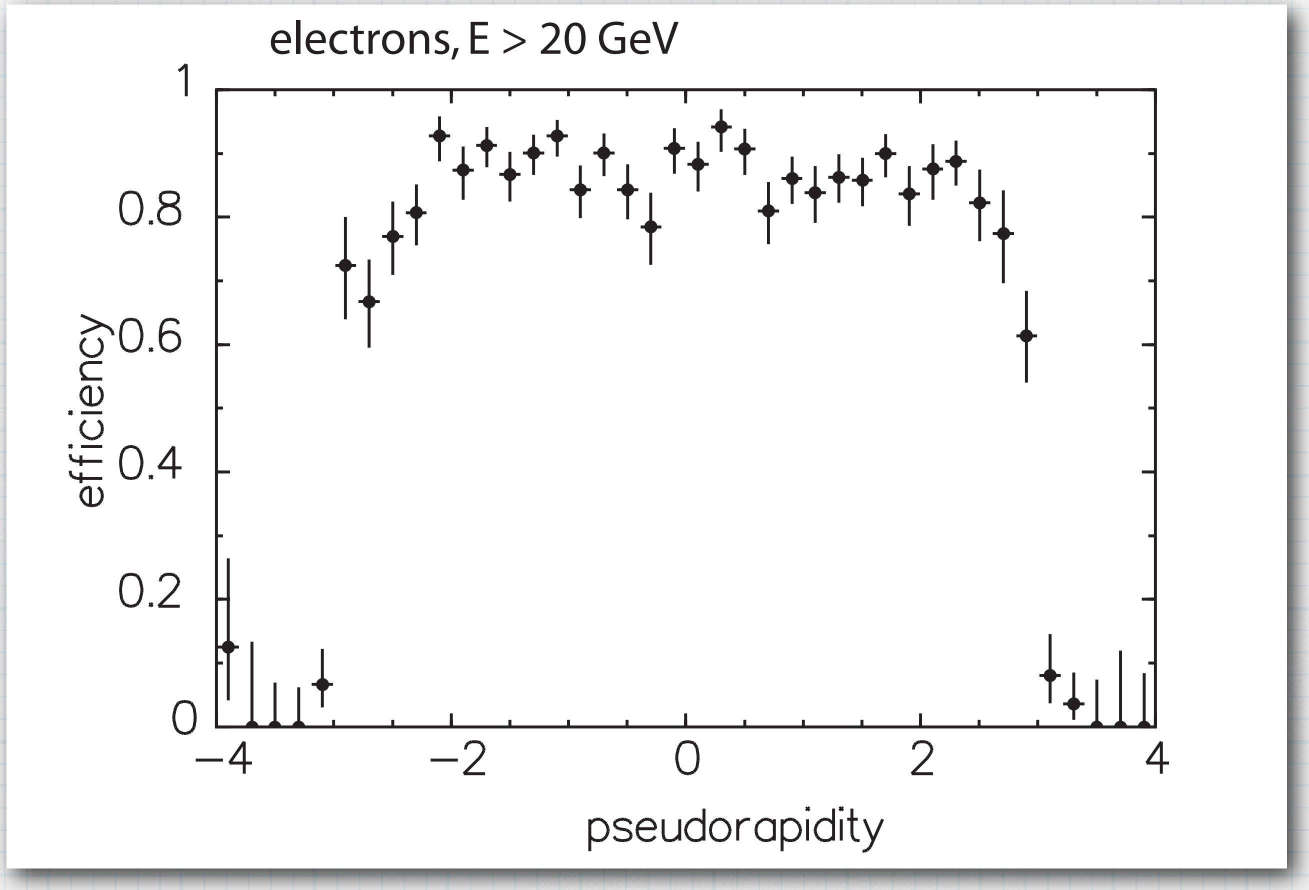
- in real life electromagnetic showers are narrow; hadronic showers are wide
- in PGS, alas, there is no lateral spread
- we simply rely on the fact that the energy is deposited in the em section of the calorimeter
- start with clusters (kt jet alg.) and apply em fraction cuts, match with track
- apply 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

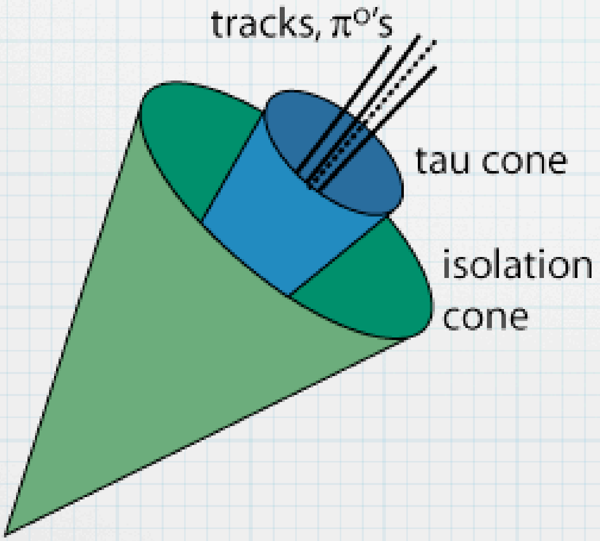
PGS electron efficiency

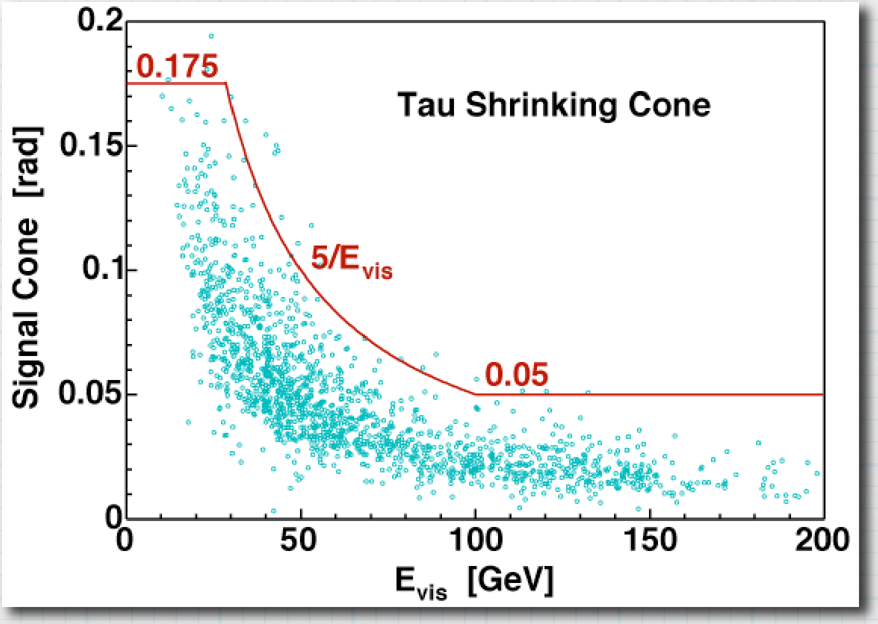


- efficiency about 87% out to |η| = 3

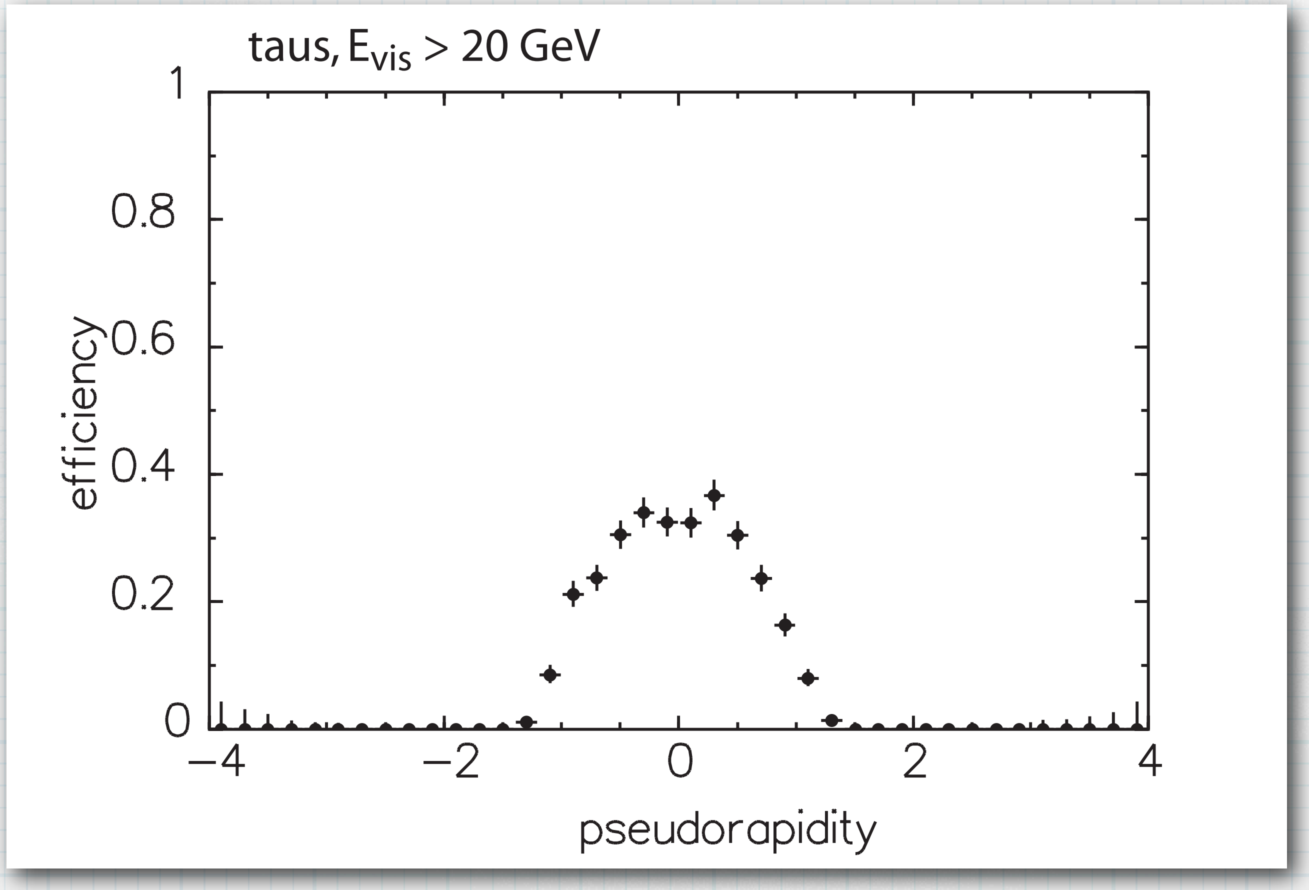
PGS Tau Reconstruction

- 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





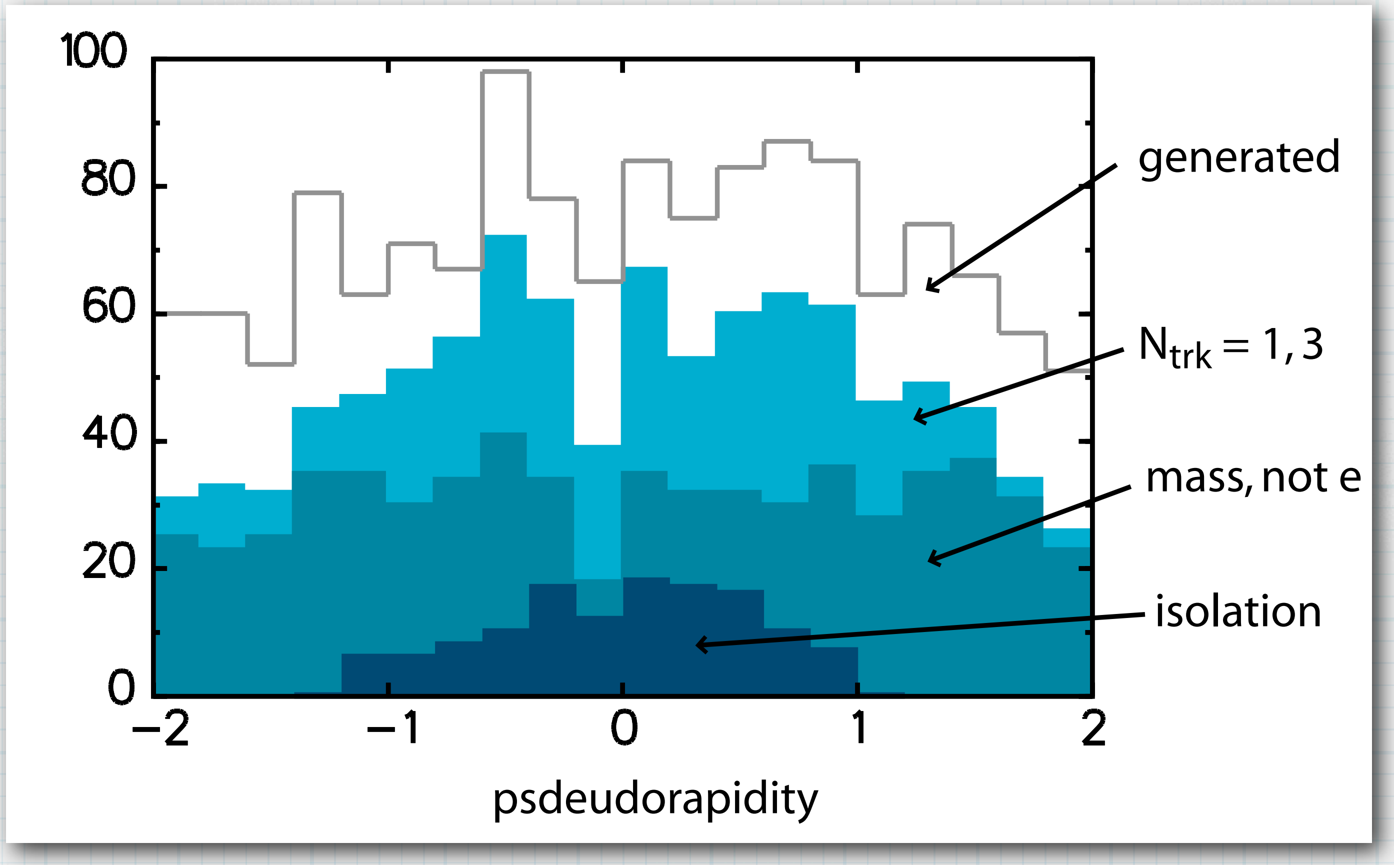
PGS tau efficiency



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

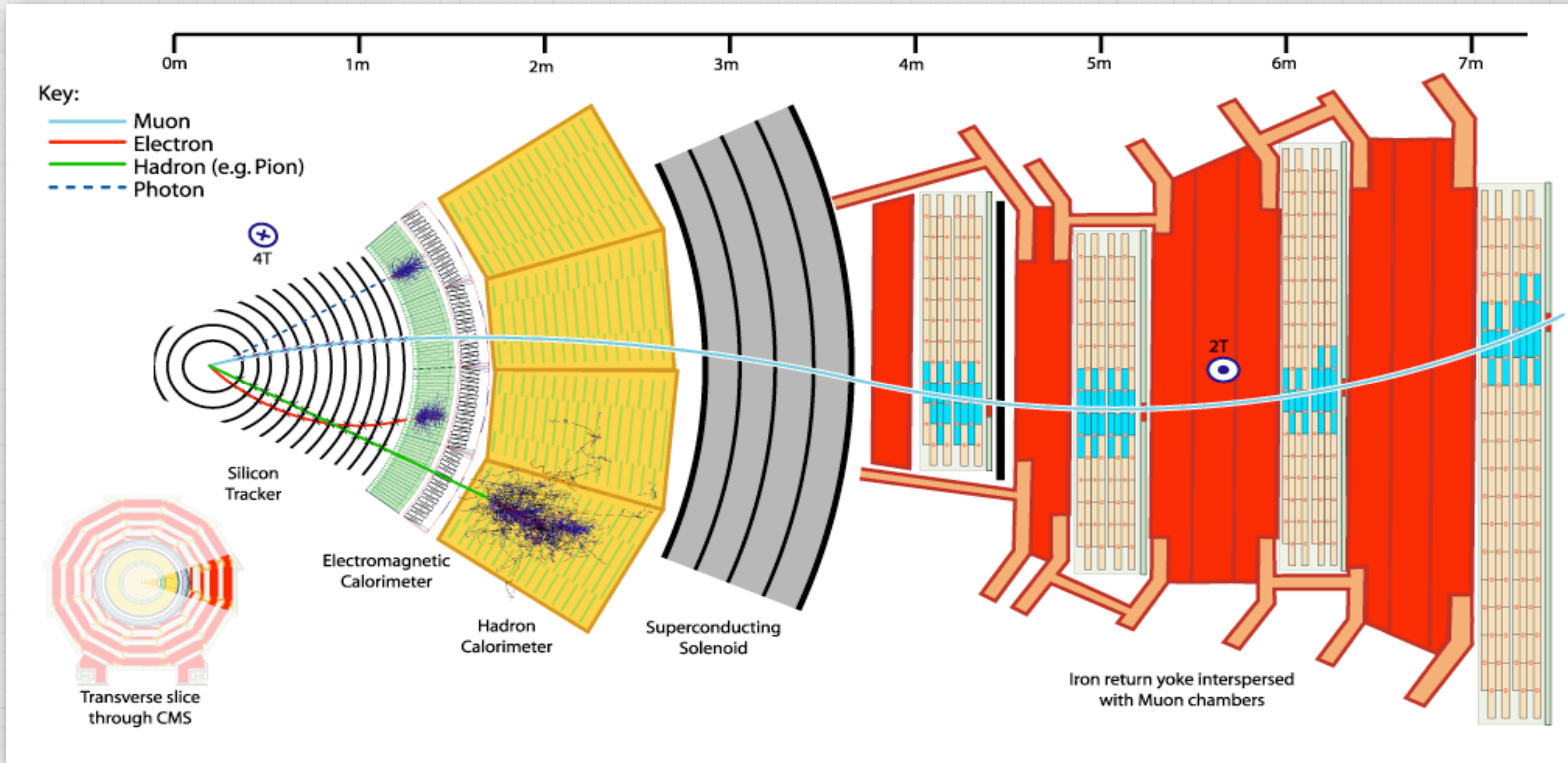
PGS tau efficiency

- can we understand which cut is hurting us?

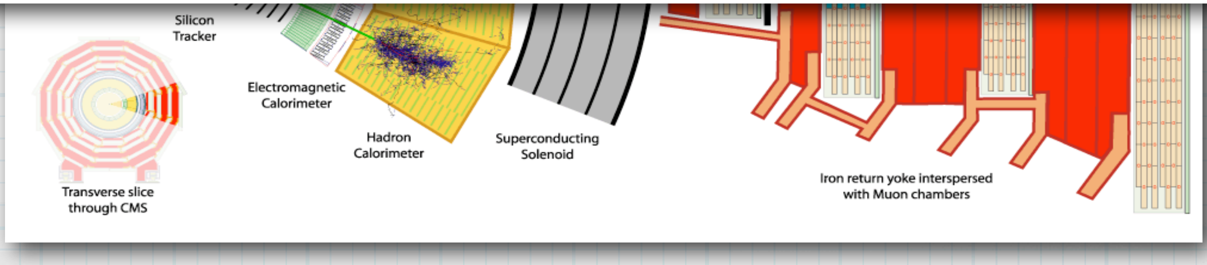


- need to work on this!!

PGS Muons

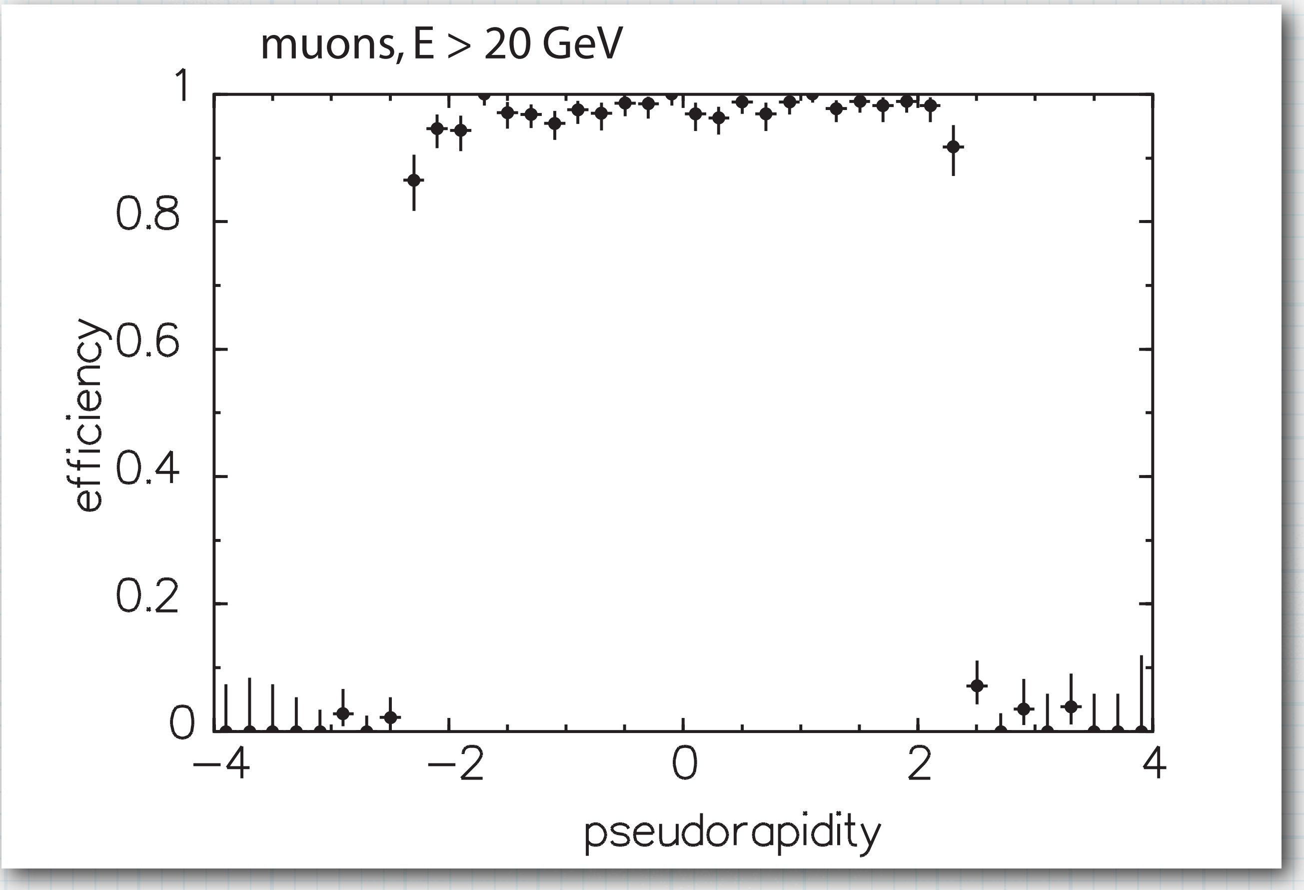


0m
1m
2m
3m
4m
5m
6m
7m
Key:
Muon
Electron
Hadron (e.g. Pion)
Photon
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
Transverse slice through CMS



Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
Transverse slice through CMS

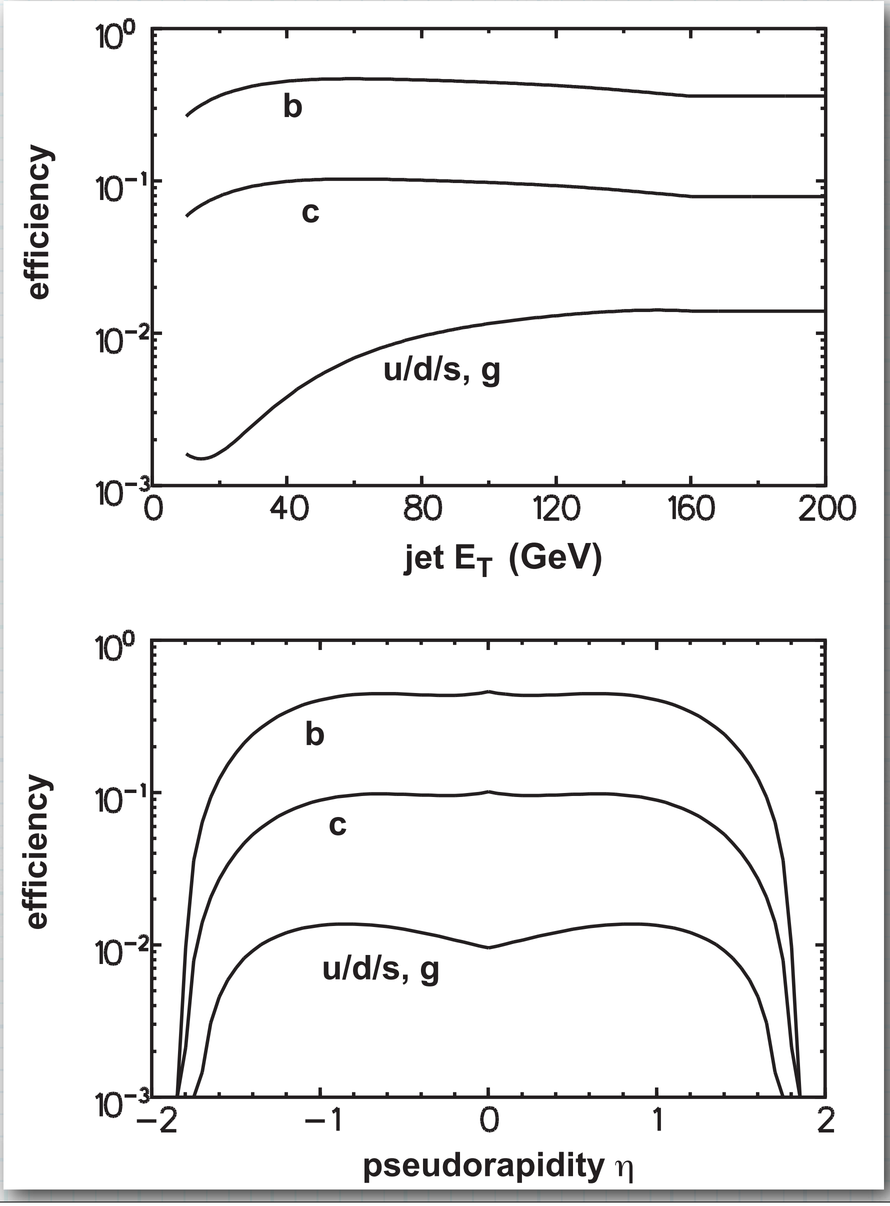
PGS muon efficiency



- efficiency about 97% out to $|\eta| = 3$

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
- probably not too far from eventual LHC experience...



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:

$$\gamma > e > \tau > \text{jet}$$

- 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^o
- enforced as of PGS 4; provide "unique" flag for each object

PGS for LHC Olympics

- goal of LHC Olympics: simulate the experience of analyzing physics “results” for new physics
- wanted fast (if rudimentary) simulation; PGS fit the bill
- created ASCII file output to store (unique) physics object list with eta, phi, pt, etc.
- for Third LHC Olympics, extended file format to include muon isolation, trigger information
- better-packaged, more-reliable distribution of PGS

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
- these are <u>not</u> used in the LHC Olympics!

LHC Olympics Trigger

- LHC Olympics trigger uses PGS physics objects, not PGS trigger objects
- Chris Tully and Herman Verlinde wrote an LHC-like trigger "table" including single leptons or photons, single jets, MET, lepton+jets, lepton+jets, jets+MET, dileptons, ...
- very complete table!
- divided into "Level 1" (low threshold) and "Level 2" (high threshold)
- record trigger "word" in LHC Olympics output

LHC Olympics Trigger

- some example triggers/thresholds:

trigger	L1 thresh	L2 thresh
inc. lepton	30	180
lepton+jet	20/100	130/200
dilepton	10/10	60/60
MET	90	200
jet + MET	180/80	300/125
lepton+tau	15/45	45/60
inc. jet	400	1000

OUCH !!

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
```

If this was easy it wouldn’t be so hard.

- Yogi Berra

Bugs

- an inevitable fact of life in large computer programs!
- a good introduction to experimental life...
- the PGS 3 → PGS 4 transition was very ambitious
- I had the help of several beta-testers, especially Jesse and Aaron (thanks!)
- we did not catch all of them for the June release...crap!

PGS 4 bug in k_T jet

- first spotted by Kyle Armour at U. Wash. on August 13
- effect: after some number of ttbar events using olympics executable, nothing but muons and jets in output ??
- seven hours of debugging later I discovered a situation in which PGS could overwrite its own code and/or data
- transcribing kT jets to cluster list failed to respect the maximum number of entries in the list
- case at hand: changed number of cal. towers

PGS 4 bug in k_T jet

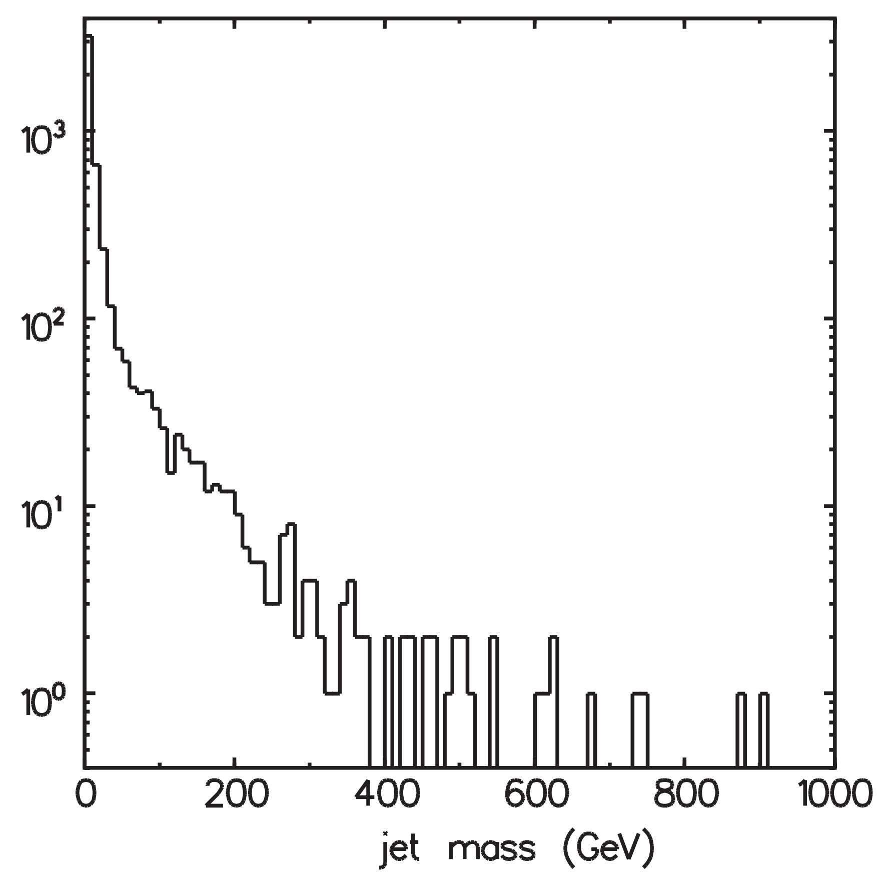
- immediately repaired problem in 060814 release
- put warning on web page
- alerted Jesse, Matt, Herman
- possible effects are difficult to predict!
- why had we not seen it before??
- are olympics files affected? (must be...)

Other PGS 4 bugs?

- At this point there are only unknown bugs in PGS 4.
- Small bug found this week in cluster width calculation (not generally used)
- Note: there were bugs found in PGS 3 in the process of upgrading to PGS 4
- These were mostly harmless or rare...but a pain nevertheless.

“Fat” jets?

- Matt/Kyle found an event in the ttbar sample “out of the box” with a jet having very large ET and mass, but no tracks
- do we expect such things?



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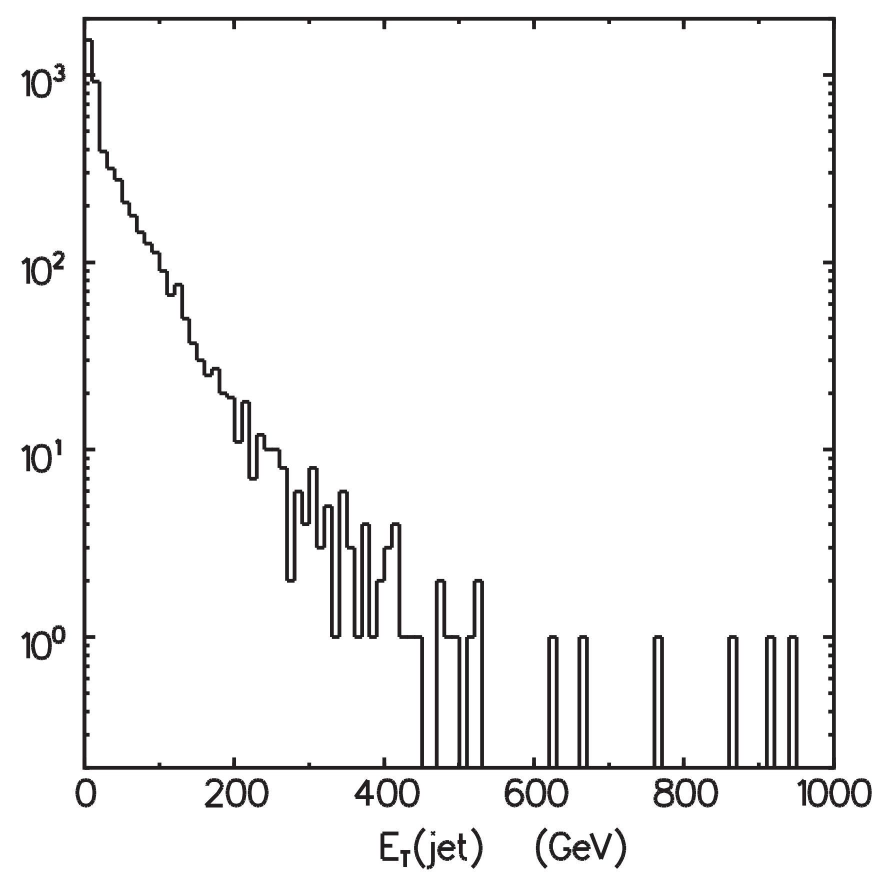

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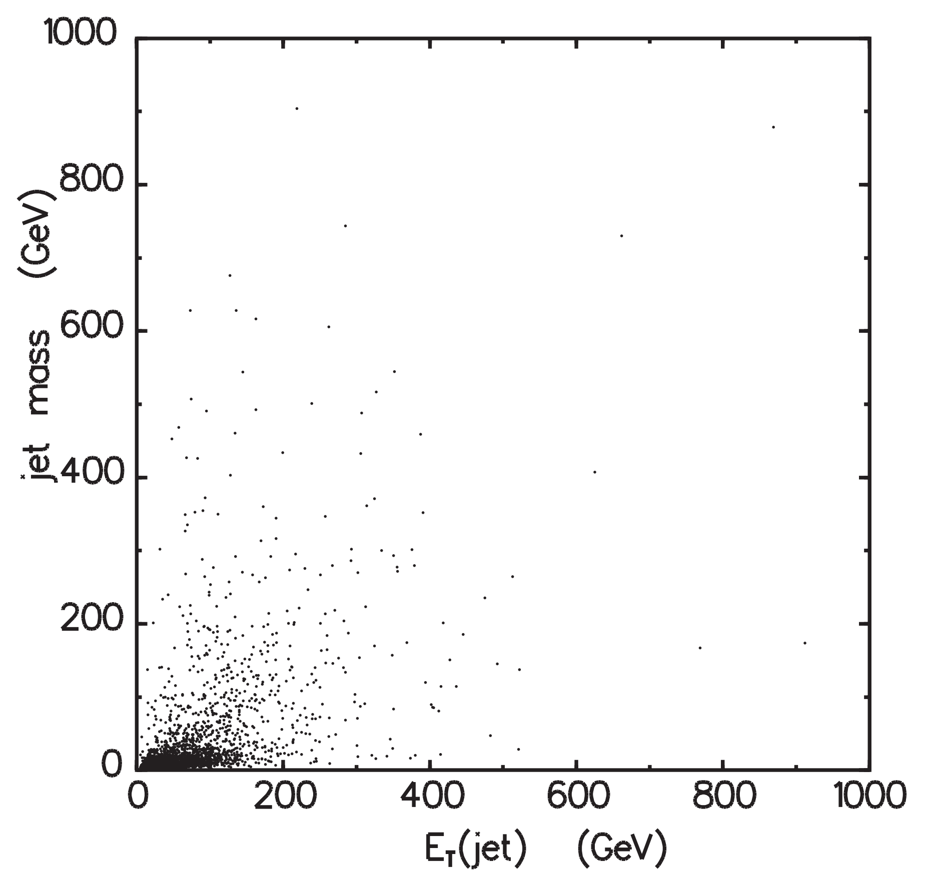

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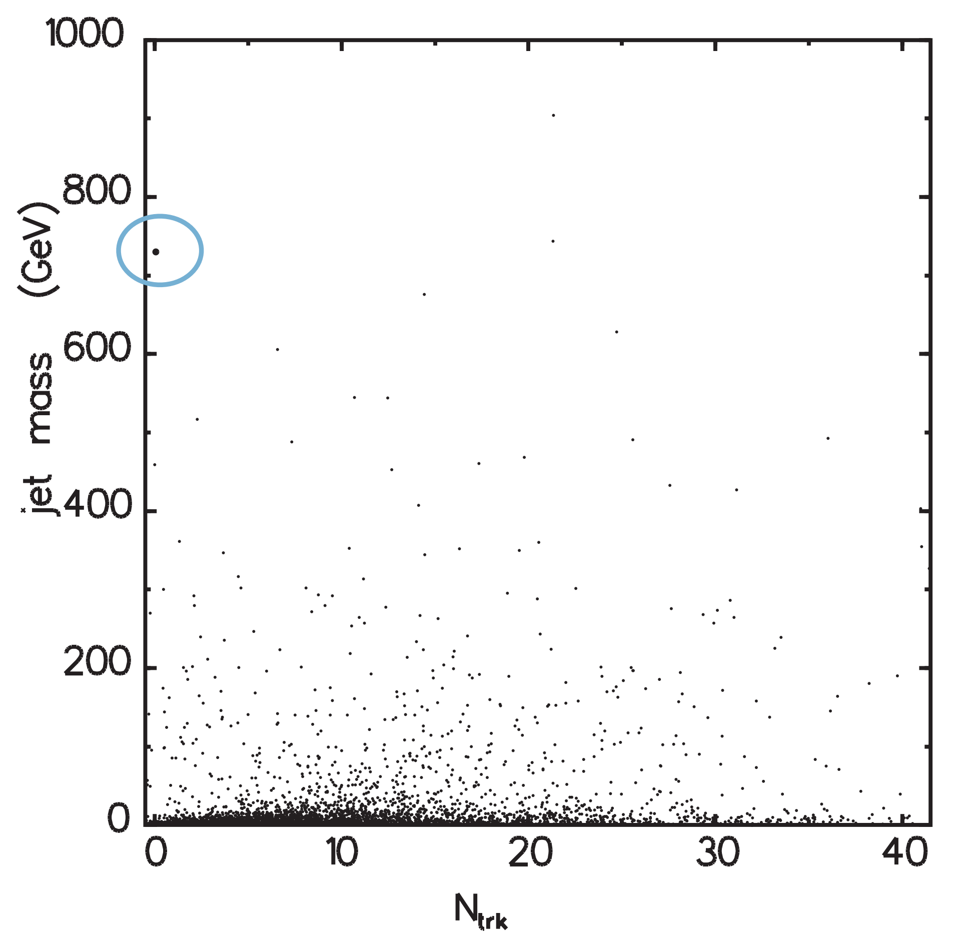

seems like it may be part of a continuum...strange...

Summary

- major new revision of PGS 4 with
  - enforced object cuts/uniqueness
  - kt jet finding as default
  - more realistic track p_T resolution
  - more realistic b tag efficiency
  - realistic electromagnetic resolution
  - support for PYTHIA, HERWIG, ALPGEN...
  - no dependency on CERNLIB