Intelligent Detector Design

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Individual Particle Reconstruction

- The aim is to reconstruct individual particles in the detector with high efficiency and purity.
- Recognizing individual showers in the calorimeter is the key to achieving high di-jet mass resolution.
- High segmentation favored over compensation.
- Loss of intrinsic calorimeter energy resolution is more than offset by the gain in measuring charged particle momenta.
- Use this approach to design complete detector with best overall performance/price.

Absorber Requirements

-> Need a dense calorimeter with optimal separation between the starting depth of EM and Hadronic showers. If λ_I/X_0 is large, then the *longitudinal separation* between starting points of EM and Hadronic showers is large

-> For electromagnetic showers in a dense calorimeter, the transverse size is small

-> small r_M (Moliere radius)

-> If the transverse segmentation is of size r_M or smaller, get optimal *transverse separation* of electromagnetic clusters.

Dense, Non-magnetic

Material	λ_I (cm)	X_0 (cm)	λ_I/X_0
W	9.59	0.35	27.40
Au	9.74	0.34	28.65
Pt	8.84	0.305	28.98
Pb	17.09	0.56	30.52
U	10.50	0.32	32.81

. . . use these for ECAL

Less Dense, Non-magnetic

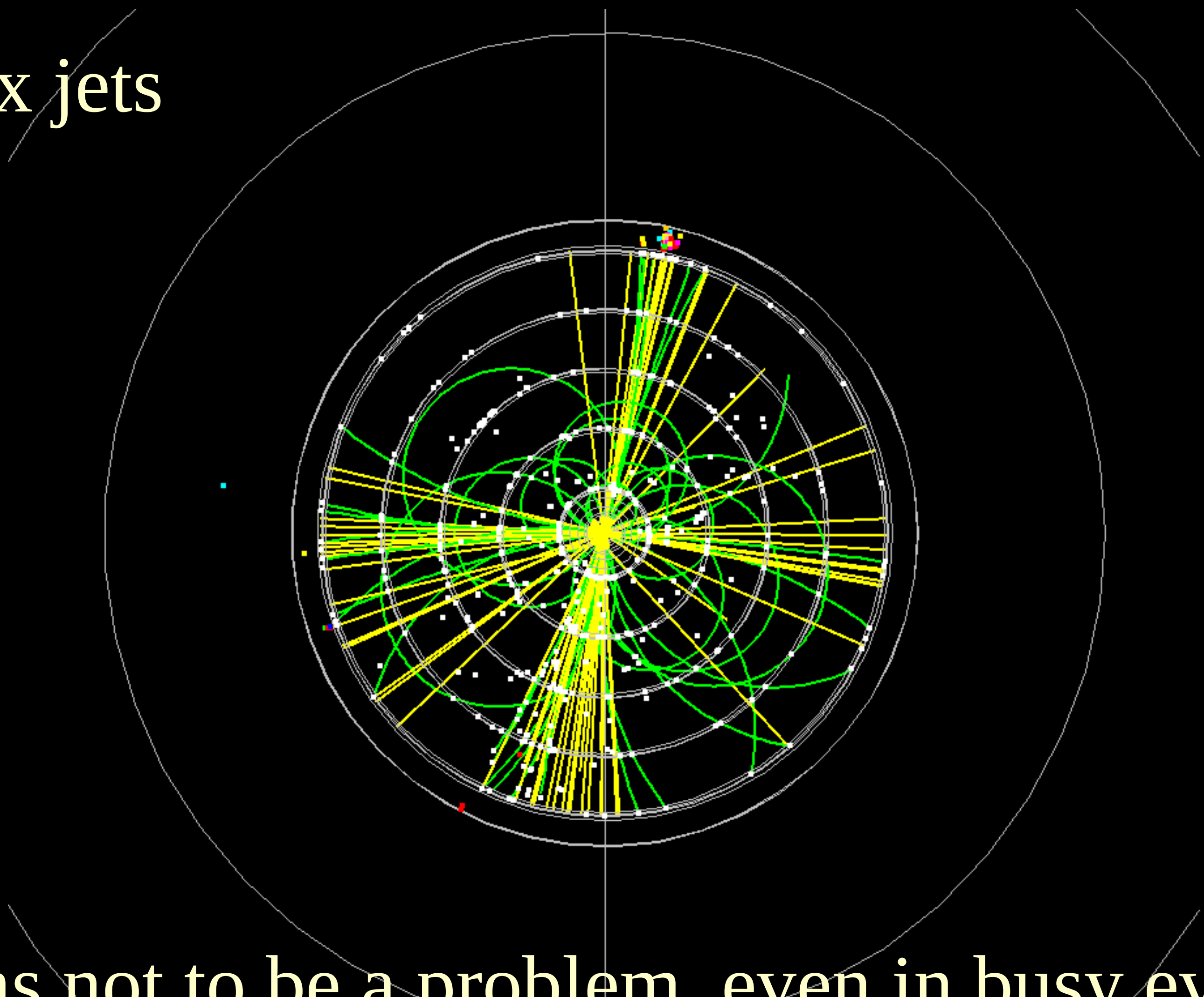
Material	λ_I (cm)	X_0 (cm)	λ_I/X_0
Fe (SS)	16.76	1.76	9.52
Cu	15.06	1.43	10.53

Calorimeter Segmentation

- Highly segmented calorimeters constructed of materials which induce compact shower size are necessary.
- Si-W default for electromagnetic calorimeter.
- Tungsten also being investigated for HCal
  - more compact design reduces cost of coil
- Need high segmentation to minimize the number of cells receiving energy deposits from more than one initial particle.

Occupancy Event Display

tt →six jets



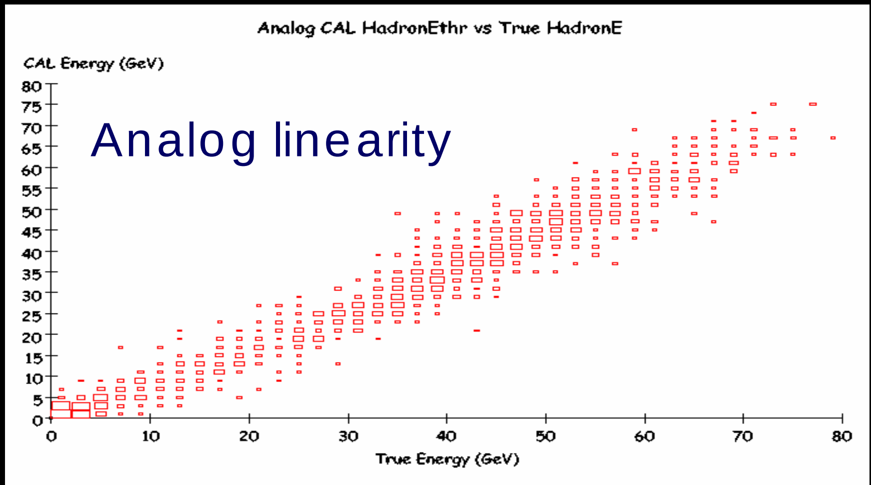
- Seems not to be a problem, even in busy events.

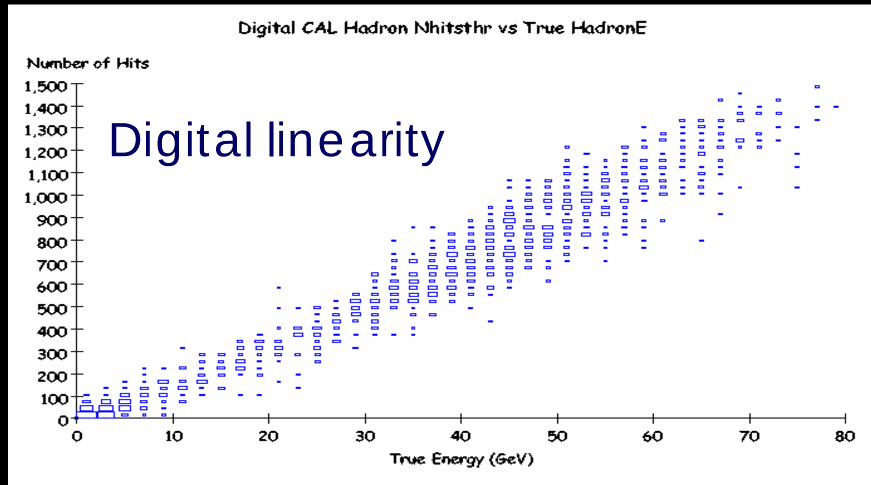
Digital HCAL?

GEANT 4 Simulation of Si Detector (5 GeV π^+)

-> sum of ECAL and HCAL analog signals - Analog

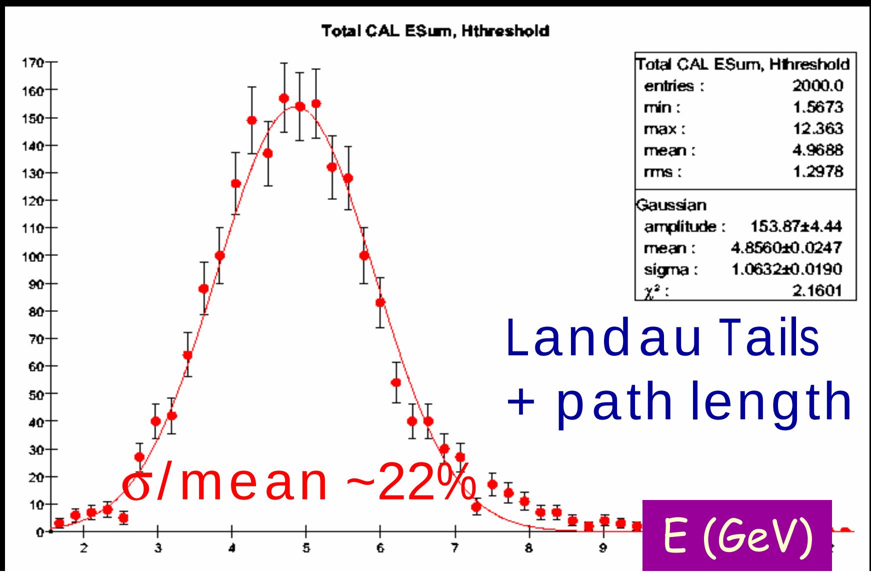
-> number of hits with 1/3 mip threshold in HCAL - Digital

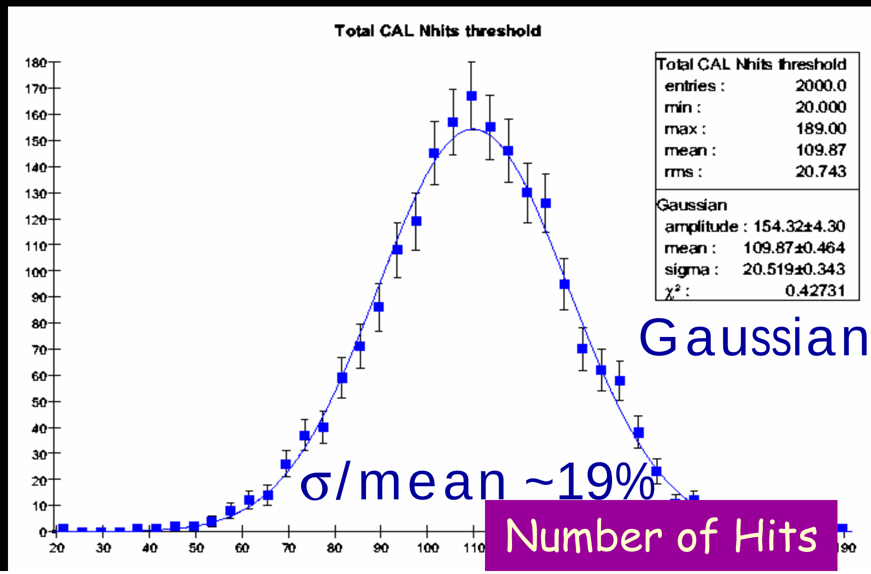


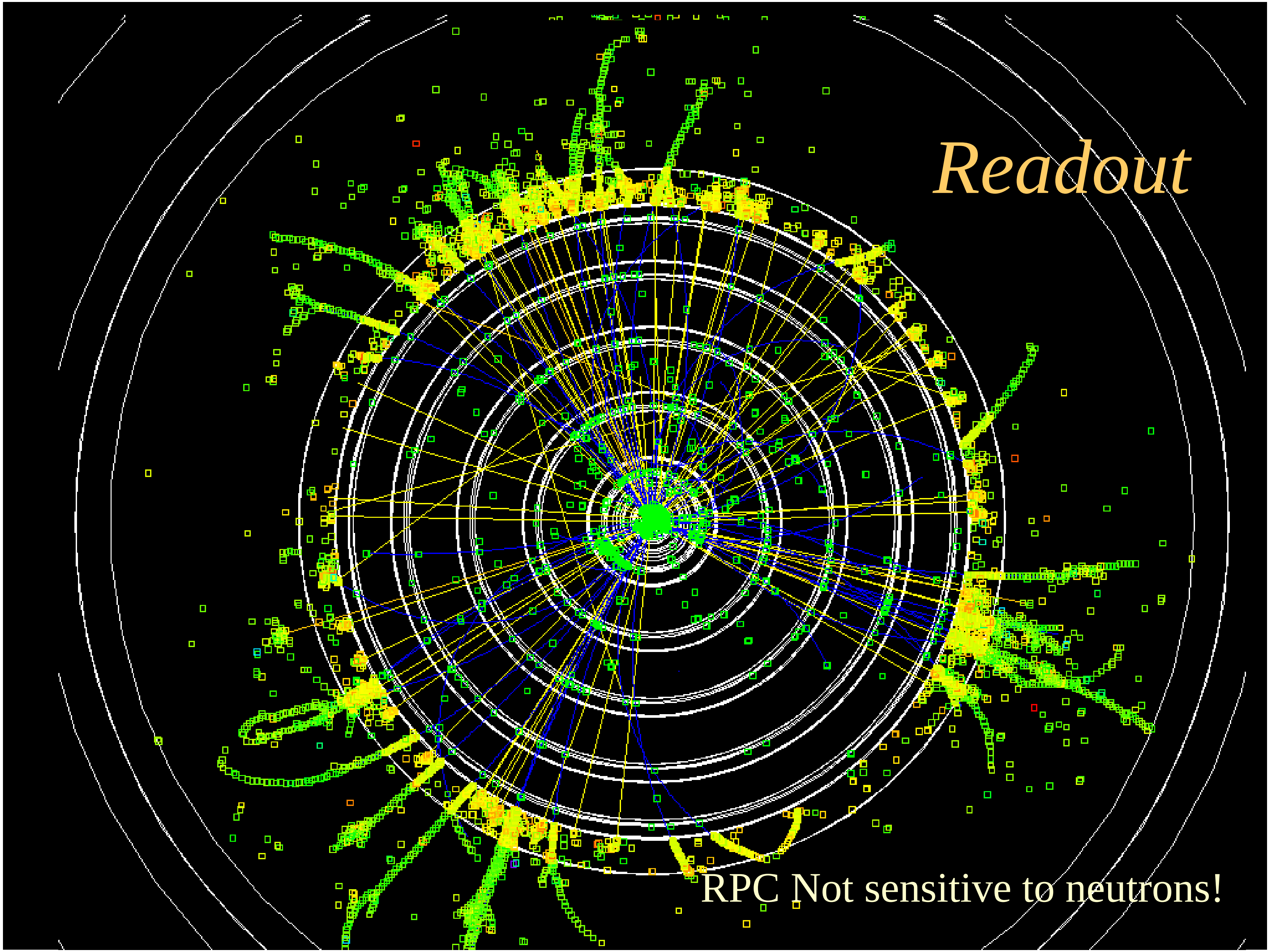


Analog

Digital






Readout
RPC Not sensitive to neutrons!

Detector models

- Calorimeters drive the whole detector design!
- Using Si-W as default electromagnetic calorimeter.
- Investigating several hadronic calorimeter designs

Absorbers	Readouts
Steel	RPC
Tungsten	Scintillator
Lead	GEM

- Varying inner radius of barrel, aspect ratio to endcap, strength of B Field, readout segmentation.

Reconstruction Strategy

- *Track-linked mip segments (ANL)*
  - find mip hits on extrapolated tracks, determine layer of first interaction based solely on cell density (no clustering of hits) ($\rightarrow \mu$ candidates)
- *Photon Finder (SLAC)*
  - use analytic longitudinal H-matrix fit to layer E profile with ECAL clusters as input ($\rightarrow \gamma, \pi^0, e^{+/-}$ candidates)
- *Track-linked EM and HAD clusters (ANL, SLAC)*
  - substitute for Cal objects (mips + ECAL shower clusters + HCAL shower clusters), reconstruct linked mip segments + clusters iterated in E/p
  - Analog or digital techniques in HCAL ($\rightarrow \pi^{+/-}$ candidates)
- Neutral Finder algorithm (SLAC, ANL)
  - cluster remaining CAL cells, merge, cut fragments ($\rightarrow$ n, K^0_L candidates)
- Jet algorithm
  - Reconstructed Particles used as input to jet algorithm, further analysis

Z Pole Analysis

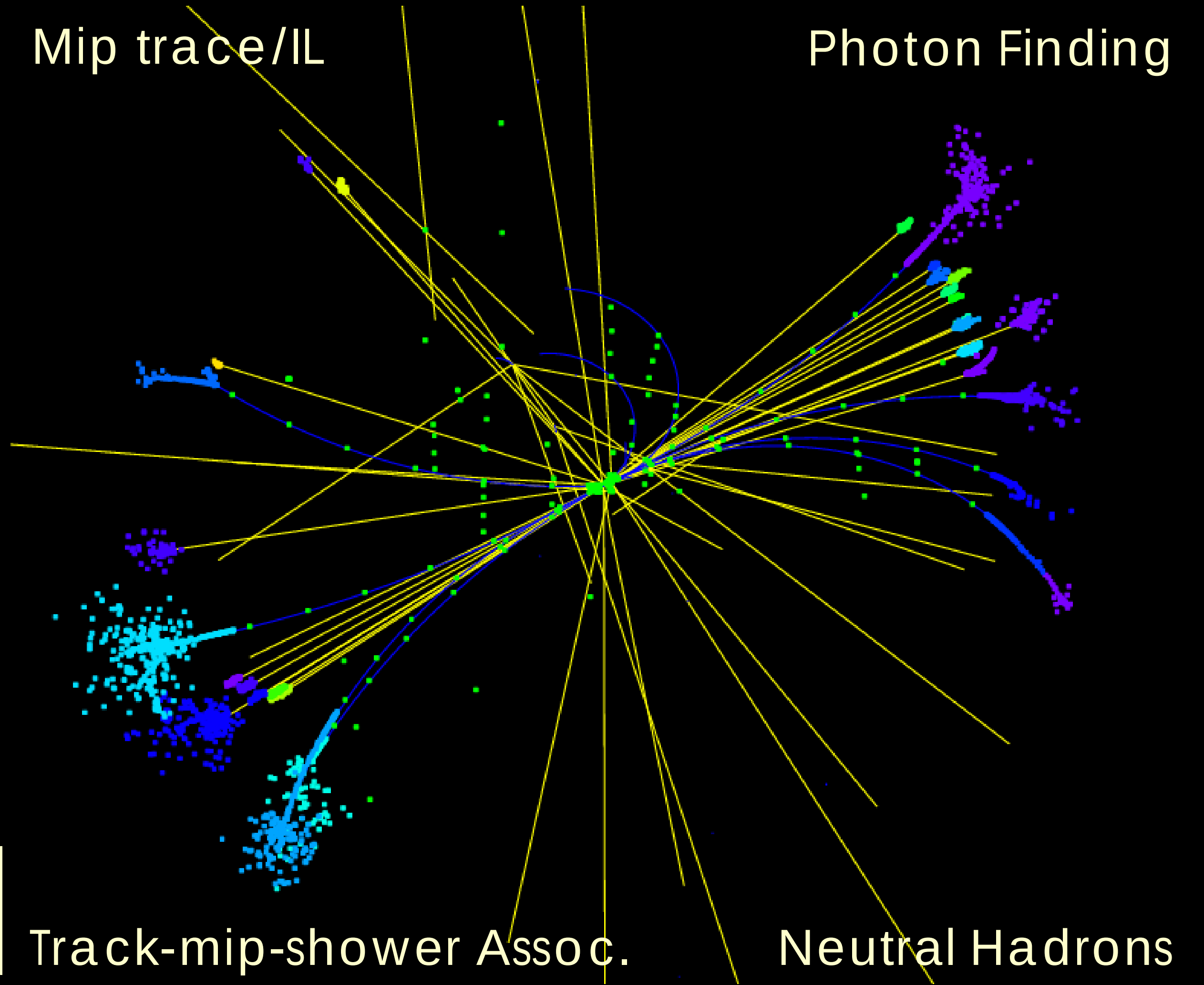
- Generate Z$\rightarrow$ qq events at 91GeV.
- Simple events, easy to analyze.
- Can compare analysis results with SLC/LEP.
- Can easily sum up event energy in ZPole events.
  - Width of resulting distribution is direct measure of resolution, since events generated at 91GeV.
- Run jet-finder on Reconstructed Particle four vectors, calculate dijet invariant mass.

Reconstruction Demonstration

6.6 GeV γ
1.9 GeV γ
1.6 GeV γ
3.2 GeV γ
0.1 GeV γ
0.9 GeV γ
0.2 GeV γ
0.3 GeV γ
0.7 GeV γ

4.2 GeV K+
4.9 GeV p
6.9 GeV π-
3.2 GeV π-

8.3 GeV $\bar{n}$
2.5 GeV K_L^0



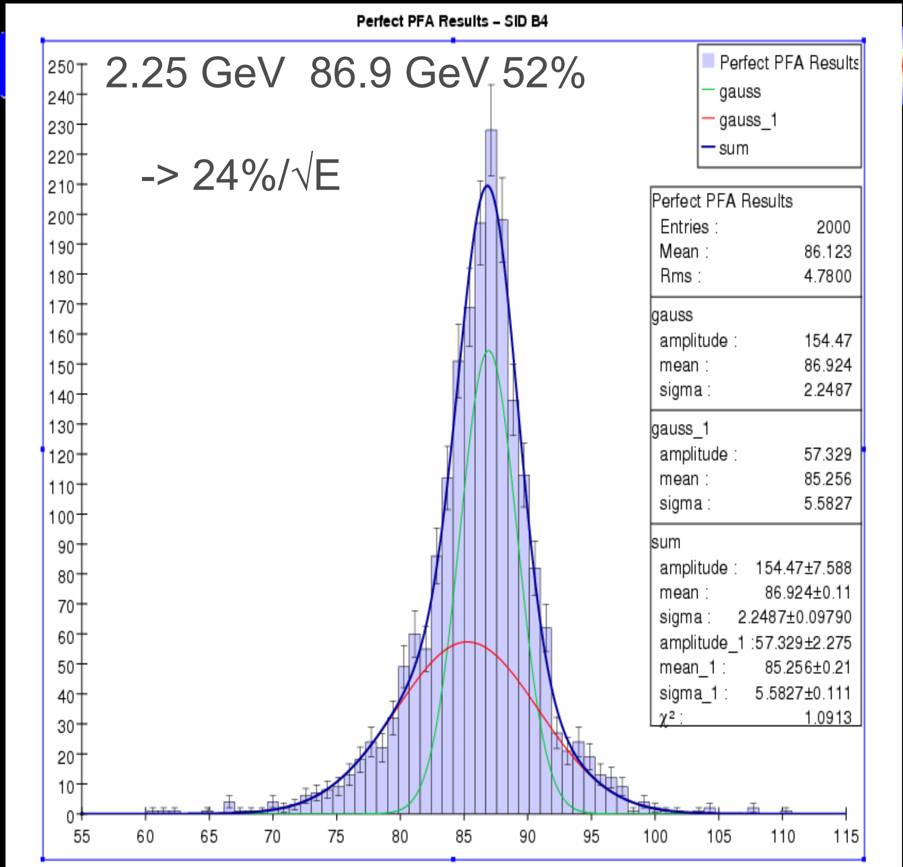
1.9 GeV γ
3.7 GeV γ
3.0 GeV γ
5.5 GeV γ
1.0 GeV γ
2.4 GeV γ
1.3 GeV γ
0.8 GeV γ
3.3 GeV γ
1.5 GeV γ

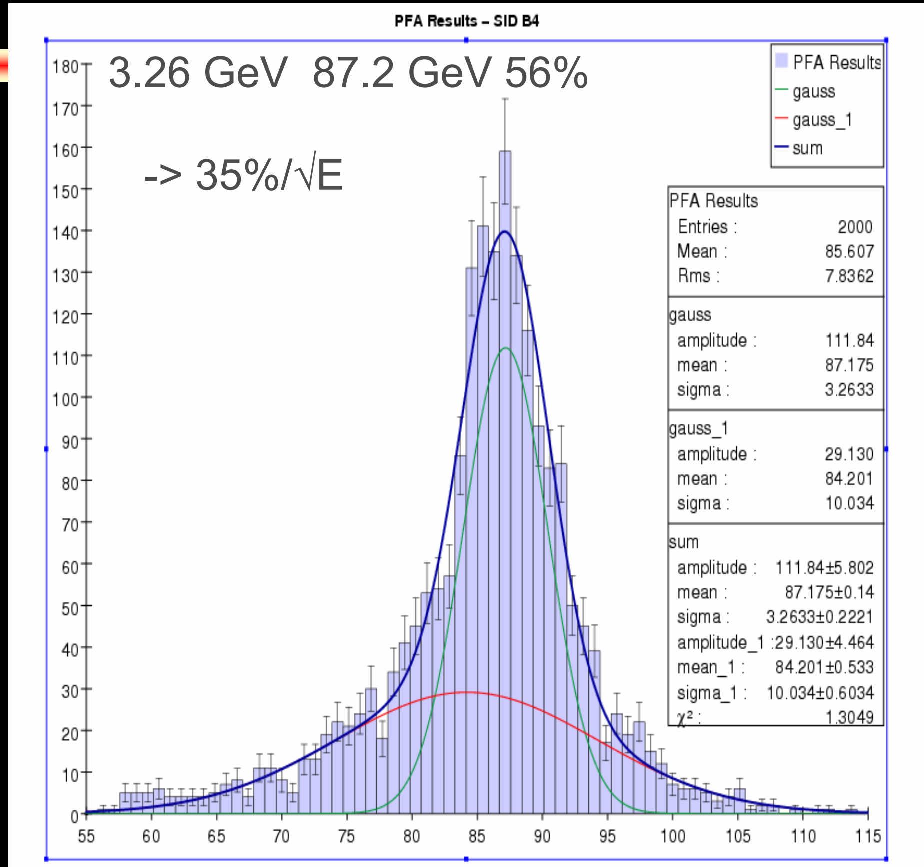
1.9 GeV π-
2.4 GeV π-
4.0 GeV π-
5.9 GeV π+

1.5 GeV $\bar{n}$
2.8 GeV n

Overall Performance : PFA ~33%/$\sqrt{E}$ central fit

Detector Comparisons, B Field



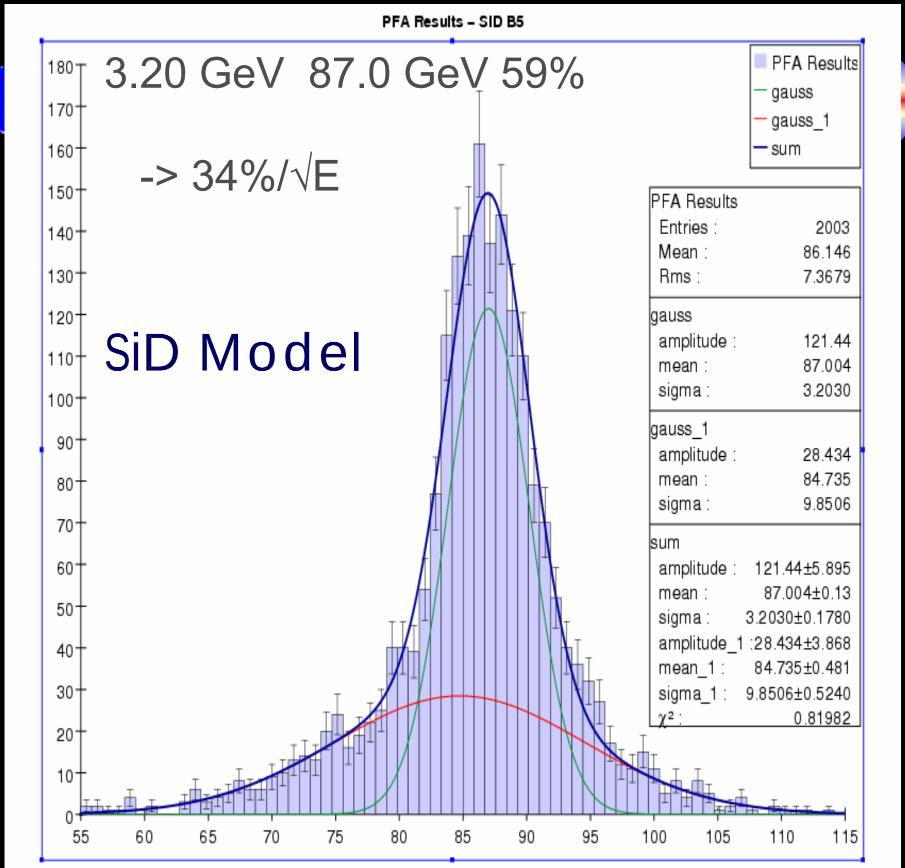


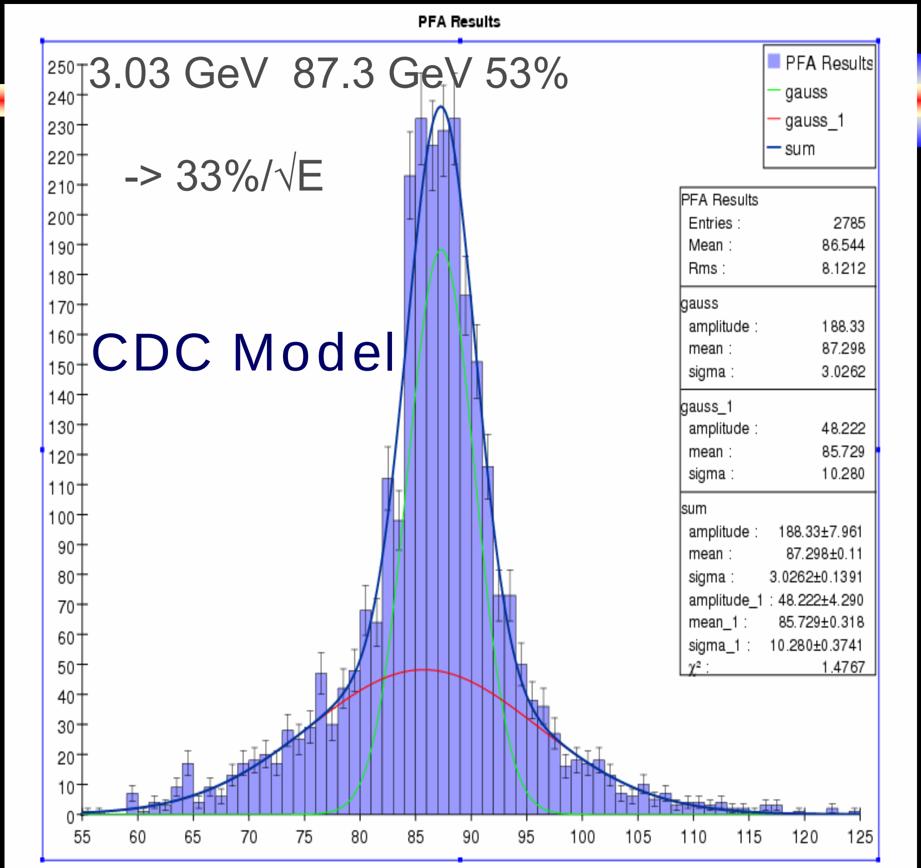
SiD SS/RPC - 5 T field
Perfect PFA σ = 2.6 GeV
PFA σ = 3.2 GeV
Average confusion = 1.9 GeV

SiD SS/RPC - 4 T field
Perfect PFA σ = 2.3 GeV
PFA σ = 3.3 GeV
Average confusion = 2.4 GeV

→ Better performance in larger B-field

Detector Optimization





SiD -> CDC 150

- ECAL IR increased from 125 cm to 150 cm
- 6 layers of Si Strip tracking
- HCAL reduced by 22 cm (SS/RPC -> W/Scintillator)
- Magnet IR only 1 inch bigger!
- Improved PFA performance w/o increasing magnet bore

Reconstruction Framework

- Analysis shown here done within the general ALCPG simulation & reconstruction environment.
- Framework exists for the full reconstruction chain which allows modular implementation of most aspects of the analysis.
- Interfaces allow different clustering algorithms to be swapped in and alternate strategies to be studied.
- Goals is to facilitate cooperative development and reduce time & effort between having an idea and seeing the results.

Testing Samples

- Testing reconstruction on simple events. Study finding efficiency, fake rates and measurement resolutions (E, p, mass) using:
- Single Fundamental Particles
  - $e^{+/-}$, γ, $\pi^{+/-}$, $\mu^{+/-}$
- Simple Composite Single Particles
  - π^0, K^0, ρ, Σ, τ, ψ
- Complex Composite Single particles
  - Z, W
- Physics Events

Canonical Samples (Physics)

- $WW\nu\bar{\nu}$ and $ZZ\nu\bar{\nu}$ at 500 and 1000 GeV cms
  - Stresses jet mass resolution.
  - $VV\nu\bar{\nu}$ removes temptation to include beam constraint.
- $t\bar{t}$, $t\bar{t}h$ at 500GeV
  - Stresses pattern recognition and flavor tagging in busy environment.
- Zh at 500GeV
  - Recoil mass tests tracking resolution.
  - Branching ratios stress flavor tagging eff./purity.
- $\tau^+\tau^-$ exercises τ ID and τ polarization (SUSY, P_{higgs})

Summary

- Individual Particle Reconstruction algorithms being developed with minimal coupling to specific detector designs.
- Photon and muon reconstruction fairly mature.
- Emphasis on track-following for charged hadrons.
- Canonical data samples identified and will be used to characterize detector response.
- Systematic investigation of σ_{jet} as a function of $B^n R^m a^p l^q$ (B-field, Cal radius, Cal cell area, Cal longitudinal segmentation), material and readout technology being undertaken.

Conclusions

- Unambiguous separation of charged and neutral hadron showers is the crux of this approach to detector design.
  - hadron showers *NOT* well described analytically, fluctuations dominate # of hits, shape
  - also investigating highly-segmented compensating calorimeter designs.
- Calorimeters designed for optimal 3-D shower reconstruction :
  - granularity << shower transverse size
  - segmentation << shower longitudinal size
- Critically dependent on correct simulation of hadronic showers
  - Investing a lot of time and effort understanding & debugging Geant4 models.
  - Timely test-beam results crucial to demonstration of feasibility.
- Full Simulations + Reconstruction $\rightarrow$ ILC detector design
  - Unique approach to calorimeter design
  - Ambitious and aggressive approach, strong desire to do it right.
  - Flexible simulation & reconstruction package allows fast variation of parameters.

Additional Information

- ILC Detector Simulation http://www.lcsim.org
- ILC Forum http://forum.linearcollider.org
- Wiki http://confluence.slac.stanford.edu/display/ilc/
- JAS3 http://jas.freehep.org/jas3
- WIRED4 http://wired.freehep.org
- AIDA http://aida.freehep.org