Across the Pond: Calorimeter R & D Studies

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on behalf of
the North American NLC Detector group

- Benchmarks
- Overview of the Detectors
- Studies of $t\bar{t}$ Events
- T912 HCAL Testbeam Results
- Outstanding Issues

Acknowledgements

- Many thanks to ...

  Edward Kistenev (BNL)
  Ray Frey (U of Oregon)
  Masako Iwasaki (U of Oregon)
  Teruki Kamon (Texas A & M)
  Tohru Takeshita (Shinshu U.)
  Yoshiaki Fujii (KEK)
  and all the members of the
  North American working groups
  on Linear Collider Calorimetry
  and Detector Simulation

- Essentially all the credit for the content belongs to them
  ......to me, belongs blame for any errors

Physics processes of merit for calorimetry

flavoured by some personal biases

- Reconstruction of W, Z in hadronic modes

  $e^+e^- \to H^0 Z^0$ with $Z^0 \to q\bar{q}$

  Essential for Higgs Physics (statistics)

- Photonic Higgs Modes

  $BR(H^0 \to \gamma\gamma)$ is a key NLC measurement

  Places stringent reqs. on EM resolution

- Separation of W and Z hadronic modes

  WW scattering may be a critical process

  $e^+e^- \to \nu\bar{\nu}WW$ vs $e^+e^- \to \nu\bar{\nu}ZZ$

  Angular resolution important for TGC

- Reconstruction of $t\bar{t}$ events

  6 jets 45%

  Lepton plus 4 jets 44%

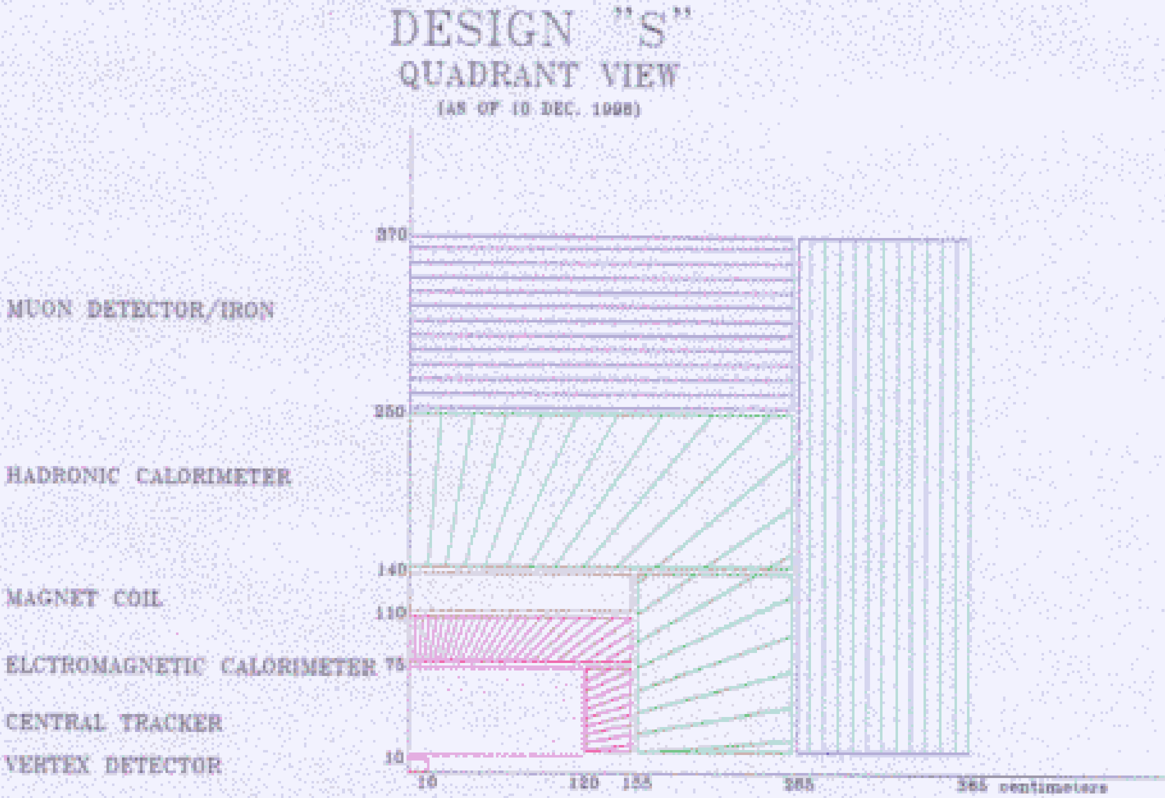
- Luminosity Measurement

  Determine $d\mathcal{L}(\sqrt{s_0})/d\sqrt{s_{\text{eff}}}$

  Use accolinearity of bhabha events

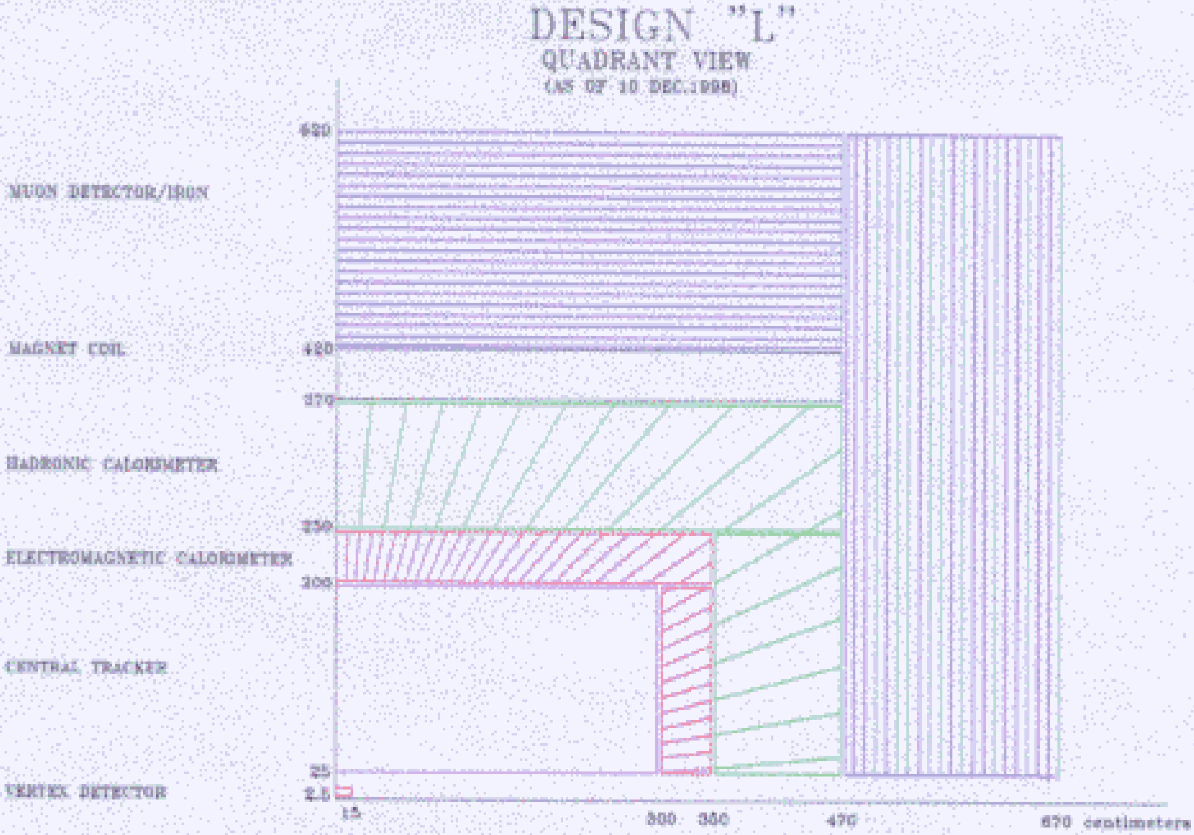
  Requires $\delta\theta_A \lesssim 1$ mrad

Small Detector Design



- Features: High B Field: 6 T
  Small Tracking Volume ($R_{\mathrm{ECAL}} = 75$ cm)
  Coil inside HCAL
- Highly Segmented Si-W EM calorimetry:
  $\sigma(E)/E = 0.12/\sqrt{E} \oplus 0.01$
  Silicon pad readout: 1.5 cm^2, 20 mrad × 20 mrad
  Total depth 25 X_0, 50 samples of $0.5X_0$
- Highly Segmented Cu-Scintillator HCAL
  $\sigma(E)/E = 0.50/\sqrt{E} \oplus 0.02$
  40 mrad × 40 mrad, 3 samplings

Large Detector Design



- Features: "Moderate" Field: 3 T

  Large Tracking Volume ($R_{\rm ECAL} = 200$ cm)

  Pb-Scint. EM and HCAL, Coil *outside* HCAL

- EM calorimetry (inspired by JLC design):

  $\sigma(E)/E = 0.15/\sqrt{E} \oplus 0.01$

  40 layers (4mm Pb + 1 mm scintillator)

  40 mrad $\times$ 40 mrad, 40 samplings

- Hadronic Calorimetry:

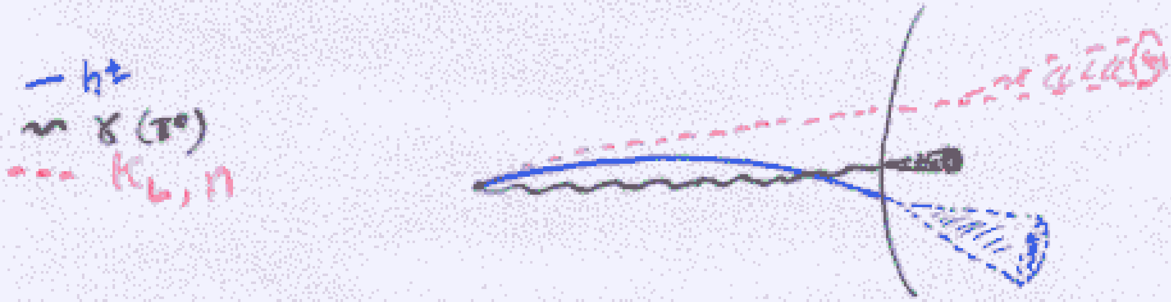
  $\sigma(E)/E = 0.40/\sqrt{E} \oplus 0.02$

  80 mrad $\times$ 80 mrad

Energy Flow Paradigm

- The lessons (paradigm?) of LEP

  Jet Energies will be determined using the Energy Flow Technique



- Key Issue: Charged/Neutral Separation

  Detector Segmentation: Longitudinal and Tranverse

  Radiator: X_0 and Moliere Radius

  Magnetic Field and Calorimeter Radius:

  Clustering Alogorithms (perhaps the least optimized aspect)

  Calorimeter Response: e/π, linearity

- Calorimeter Radius and Magnetic Field

  Track Sagitta goes as $B \times R^2$

  $\Rightarrow$ endup playing off physics vs. \$

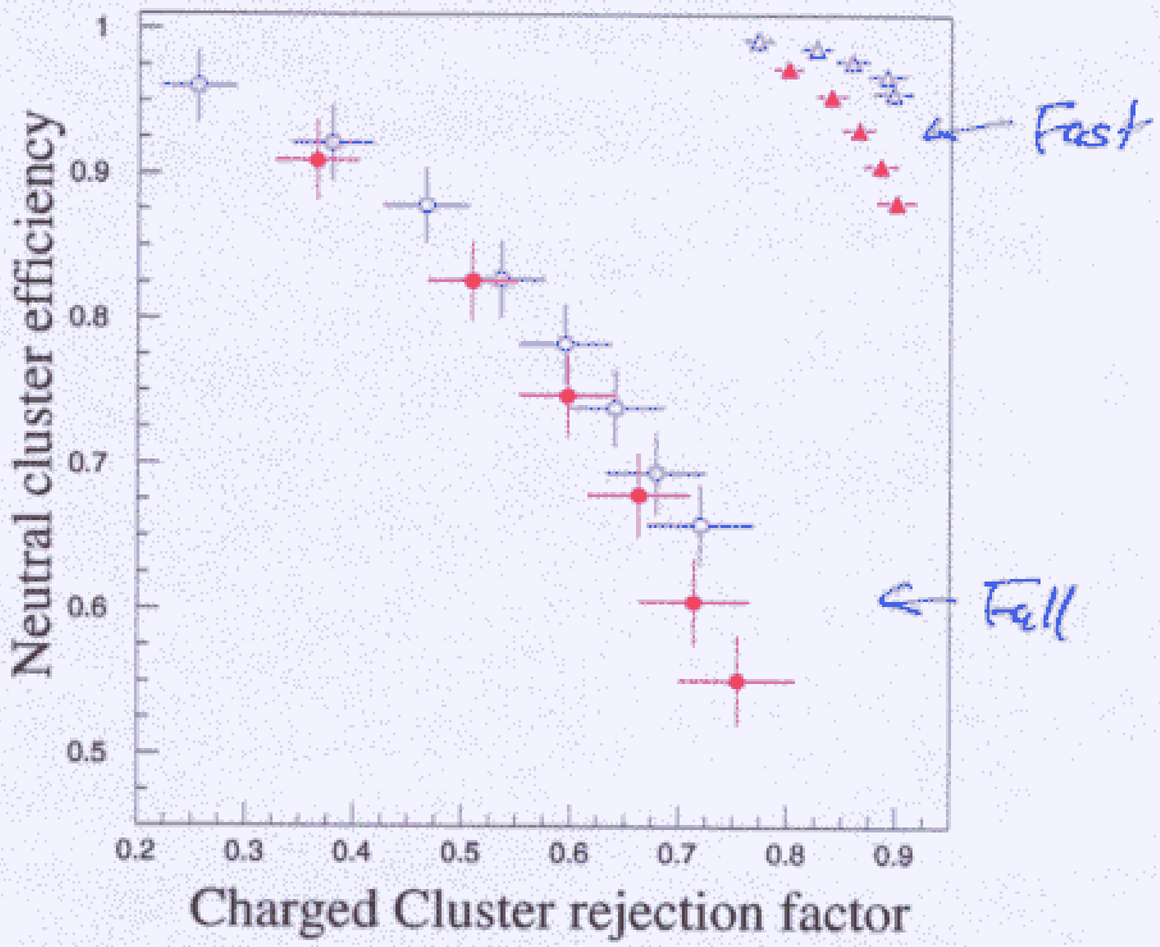
  Effect of Track Curl up?

  S Design: $p_T^{\text{min}} \sim 700$ MeV/c

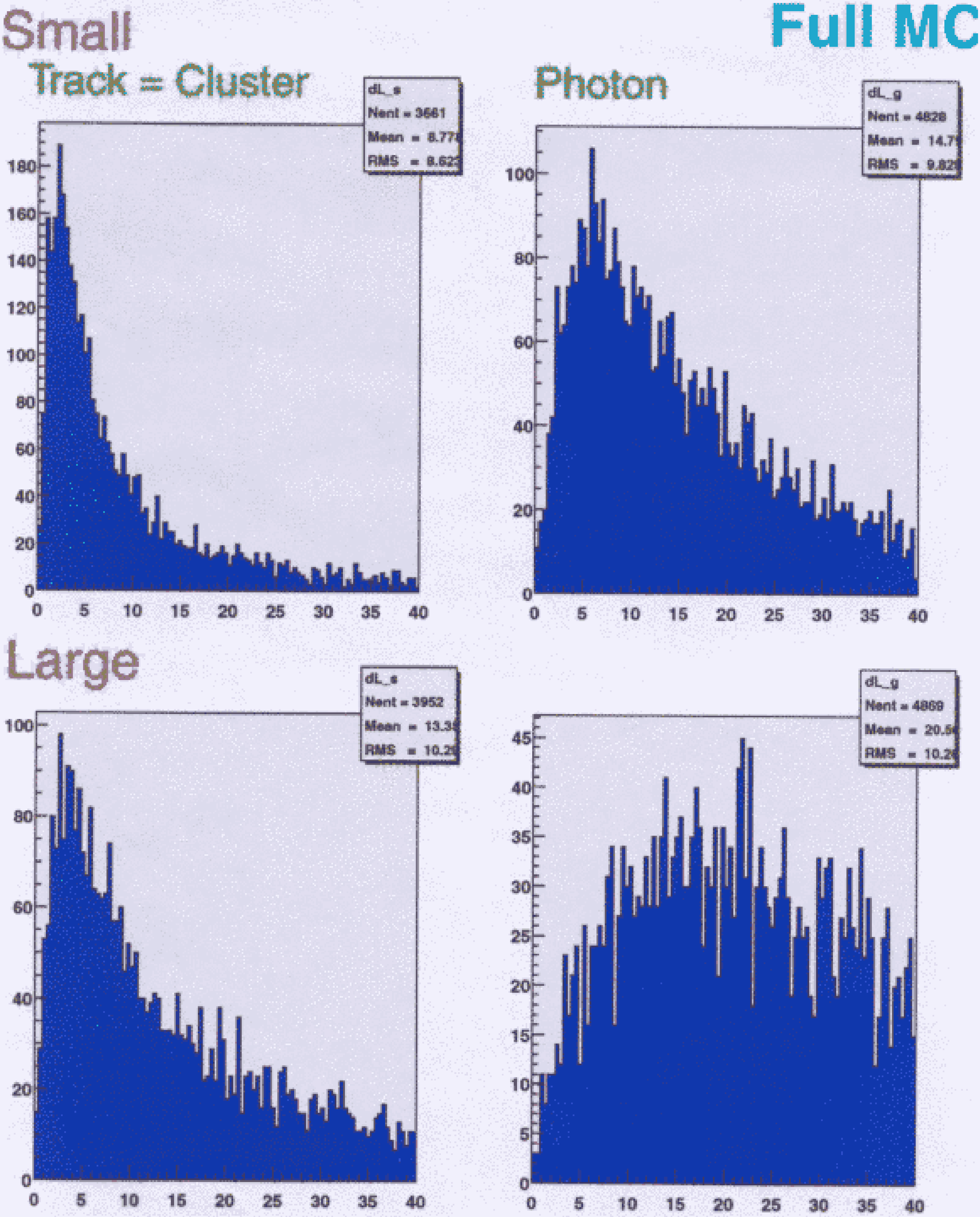
  L Design: $p_T^{\text{min}} \sim 900$ MeV/c

Study of $t\bar{t}$ events (M. Iwasaki)

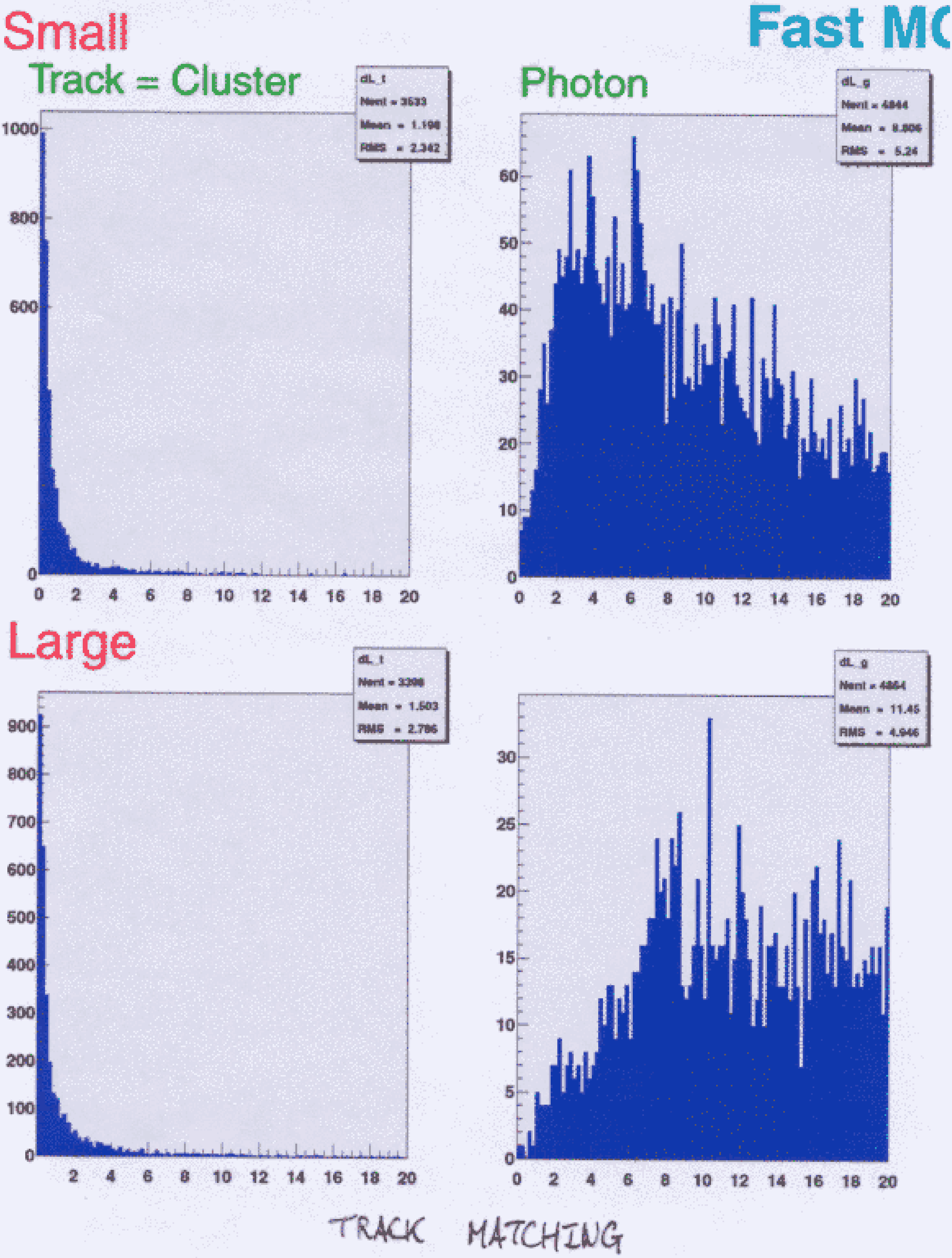
- Charged-Neutral Separation (slides)
  w/ Fast and Full MC for L and S detectors
- Effect of segmentation on reconstruction
  w/ Fast MC L and S detectors
- Figure of merit: Identification of Neutrals



Full MC



TRACK MATCHING



Small
Fast MC
Track = Cluster
dL_t
Nent = 3533
Mean = 1.198
RMS = 2.342
Photon
dL_g
Nent = 4844
Mean = 8.806
RMS = 5.24
Large
dL_t
Nent = 3298
Mean = 1.503
RMS = 2.796
dL_g
Nent = 4864
Mean = 11.45
RMS = 4.946
TRACK MATCHING

- Significant differences between Fast and Full
  Fast simulation does not properly handle transverse shower development
  Cluster position resolution is also improperly simulated

- Cluster Merging:
  Parameterize merging probability as function of transverse segmentation for Fast MC

	13 mrad	20 mrad	30 mrad
Small	2.7%	5.4%	10.0%
Large		5.1%	9.4%

- Now look at effect of granularity on $t\bar{t}$

- Relevent selection criteria

  W mass cut $|M_{jj} - M_W| < 12$ GeV

  Energy Fraction: $0.95 < x_{3jet} < 1.05$, $x_{3jet} \equiv \Sigma E^i_{jet}$

  Top mass cut $|M_{3jet} - M_t| < 10$ GeV

		13 mrad	20 mrad	30 mrad
Small	Eff (%)	79 ± 2.3	76 ± 2.3	74 ± 2.5
	σ_{mass}(GeV)	9.59 ± 0.18	9.66 ± 0.21	9.86 ± 0.86
	σ_θ(mrad)	63.9 ± 1.2	63.8 ± 1.3	71.4 ± 1.5
Large	Eff(%)		77 ± 2.3	75 ± 2.4
	σ_{mass}(GeV)		9.38 ± 0.17	9.96 ± 0.22
	σ_θ(mrad)		56.7 ± 1.3	60.1 ± 1.0

- Small Design:

  13 mrad vs 20 mrad difference is small

  30 mrad is clearly worse

- Large vs. Small

  Comparable mass resolution and efficiency

  L has better angular resolution

- Similar conclusions for $t\bar{t} \to$ lepton + 4 jets

- T912 U.S.-Japanese collaboration
  Study resolution, linearity and e/π response
  of a Pb-Scintillator Hadron Calorimeter
- Low Energy (≤ 4 GeV) test beam at KEK
  Vary lead thickness for fixed (2mm) scintillator
  Observed compensation at 9:2 volume ratio
  For $d_{Pb} = 8mm$ and $E_{beam} = 2 - 4$ GeV

$$\frac{\sigma}{E} = \frac{39.2\%}{\sqrt{E}} \oplus 5.3\%$$

(T. Suzuki *et al*, NIM A 432 (1999) 48)

- Same calorimeter placed in beam at FNAL in Fall 1999
  High Energy beams: 10-200 GeV
- Results will be used to tune Large Detector simulation

Fermilab

*T912 Collaboration

High-performance Calorimeter for Future Linear Colliders
(Test Beam @ Summer-Fall 1999)

		Institution
Spokesperson (Japan-side)	Tohru Takeshita	Shinshu Univ.
Spokesperson (US-side)	Teruki Kamon	Texas A&M Univ.
Members	Yoshiaki Fujii	KEK
	Jun'ichi Kanzaki	KEK
	Kiyotomo Kawagoe	Kobe Univ.
	Naoko Kanaya	Kobe Univ.
	Yoshiyuki Sugimoto	Kobe Univ.
	Akira Takeuchi	Kobe Univ.
	Fumiyoshi Kajino	Konan Univ.
	Keitaro Furukawa	Shinshu Univ.
	Shin-Hong Kim	Uinv. of Tsukuba
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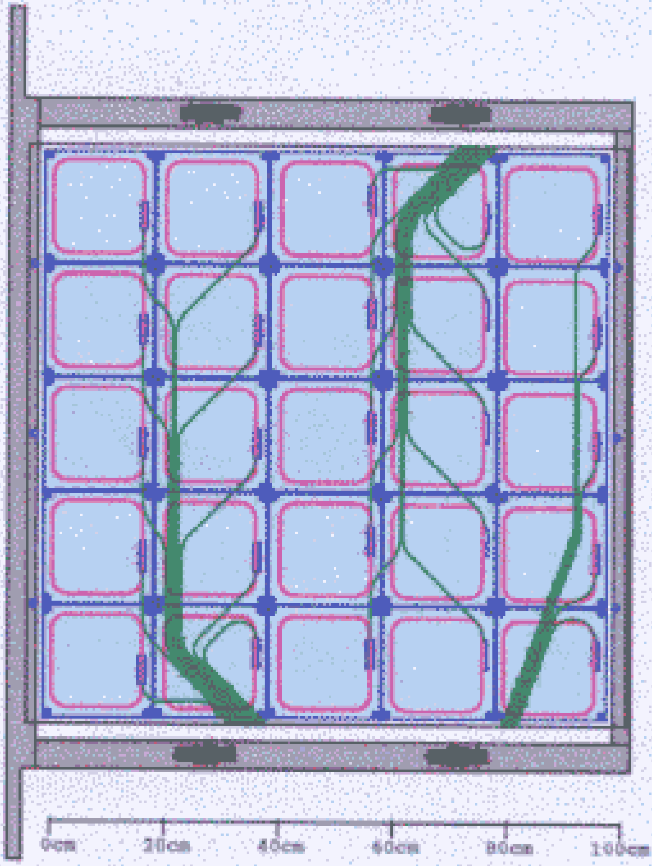
	Ryutaro Oishi	Uinv. of Tsukuba
	Atsuko Nakagawa	Uinv. of Tsukuba
	Tatsuro Ohta	Uinv. of Tsukuba
	Satoru Uozumi	Uinv. of Tsukuba
	James Done	Texas A&M Univ.



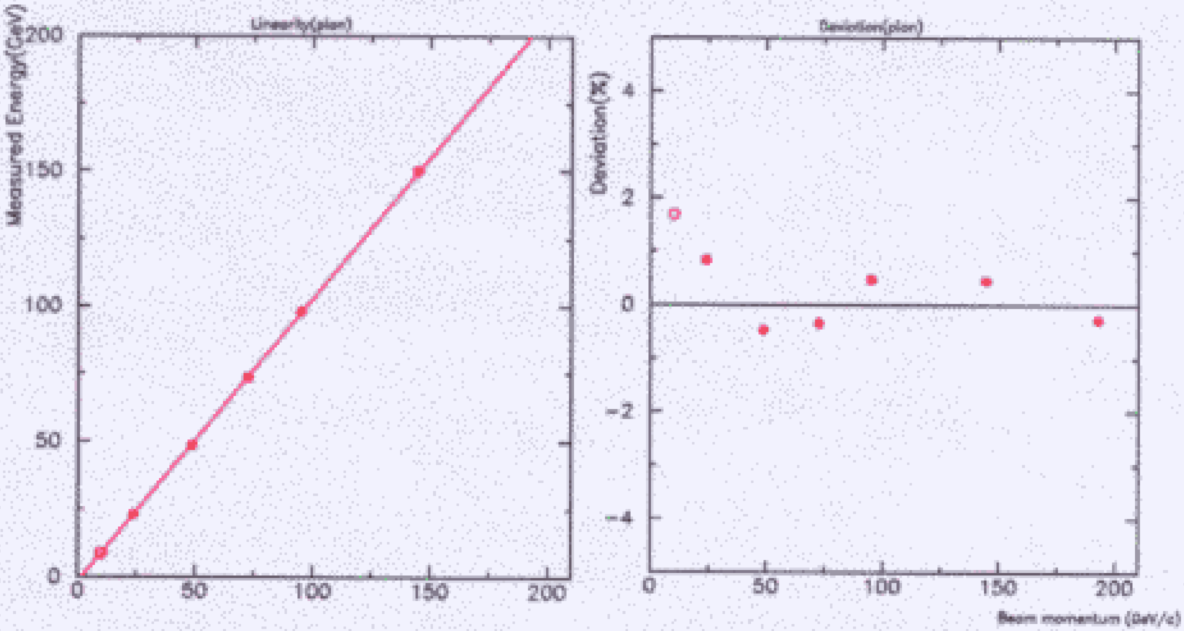
Tile-Fiber Calorimeter	
Thickness	4 λ
Samplings	80
Absorber: Pb	100 cm × 100 cm × 8 mm
Scintillator	20 cm × 20 cm × 2 mm
Segmentation	Transverse 25 (5 × 5)
	Longitudinal 4

T912 Preliminary Results

- Test Linearity of response for pions

  10, 25, 50, 100, 150, 200 GeV

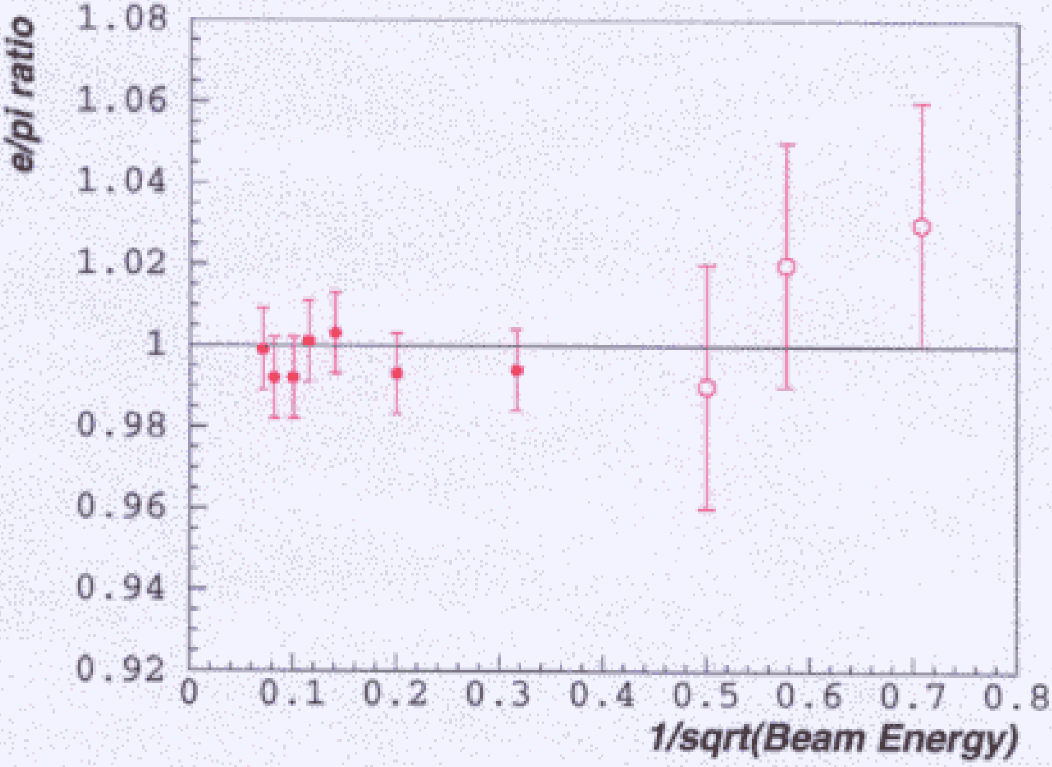
- Relative calibration with 50 GeV μ
- Absolute calibration with 50 GeV e & π



- Deviation within 1%

  N.B. Events with shower leakage vetoed

- e/π response ratio (KEK and FNAL)



- Fermilab testbeam w/ Tile-fiber
- KEK testbeam w/ Tile-fiber

- e/π ratio consistent with 1

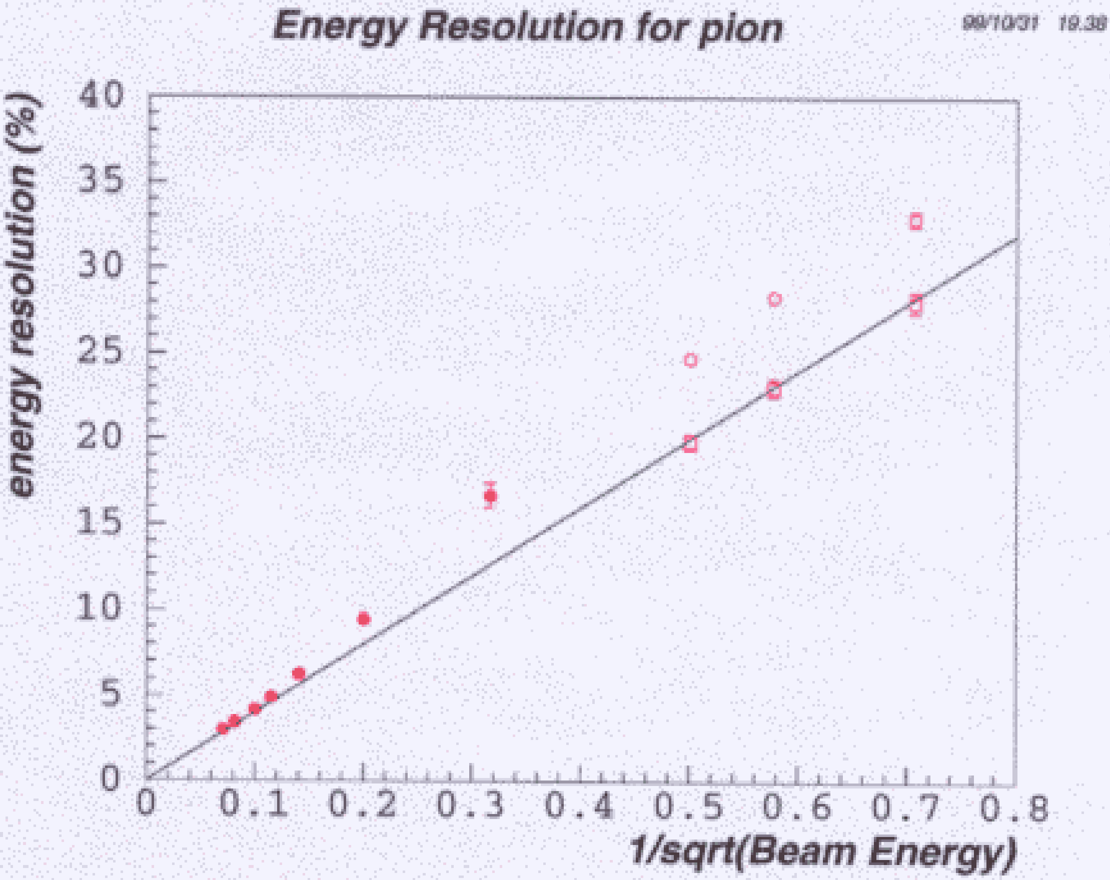
  $\Longrightarrow$ Compensation

  Note: Systematics not accounted for in comparison of KEK and FNAL results

T912 Preliminary Results

- Energy resolution for pions (Fermilab)

$$\frac{\sigma}{E} = \frac{44.1\%}{\sqrt{E}} \oplus 0.0\%$$

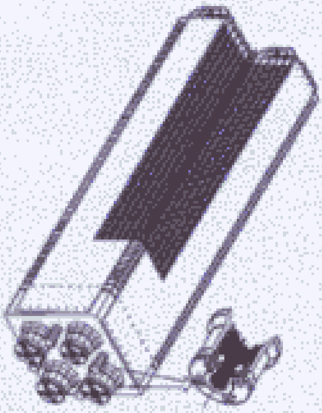


- Fermilab testbeam w/ Tile-fiber
- KEK testbeam w/ Tile-fiber
- KEK testbeam w/ Straight groove

- N.B. Events with shower leakage vetoed

  10 GeV point excluded from fit

PHENIX ECAL



- PHENIX EM calorimeter RHIC

  Depth: 18 X_0

  66 layers of 1.5 mm Pb and 4 mm Scintillator

  Optimized for Energy resolution $8\%/\sqrt{E} + 1.5\%$

  1 Longitudinal sampling, 15,552 channels

  Non-projective geometry, PMT read out

  108 super-modules of 0.46 m^2: Total 50 m^2

  Transverse tower size $5.52 \times 5.52\ cm^2$

- Cost: Approximately \$10 K per 0.46 m^2

  Built in Russia (lower production costs)

- Compare with L design ECAL dimensions

  Barrel: 87 m^2, Endcaps: 24.7 m^2 (for both)

- Si-W vs Metal-Scintillator

  Current efforts are optimizing

  for physics and not cost

- Some Si-W considerations (Ray Frey)

  Cost estimates for the NLC S-dectector

  As rule-of-thumb, roughly

  $d\$/dR \sim 1.0M\$$ */ cm R=inner radius*

  $d\$/dN \sim 1.6M\$$ */layer N=longitudinal samples*

  Significant cost!

  Does the physics require this?

- Some more considerations...

  Highly segmented metal-scintillator calorimetery

  appears to provide satisfactory performance

  Construction of **real** device will be challenging

  Projective geometry?

  Cracks? Uniformity? Support structure? ...

- Clearly, much more R&D is required