The Calorimetry for e^+e^- FLC
Summary of the session- D5

J-C BRIENT
LPNHE- Ecole Polytechnique

- Introduction
- Session summary
- Trends and perspectives

First informations

1 - The jet energy flow measurement is now intensively studied (about 50% of the talks)

2 - All the 3 regions attack this problem.

3 - Experts in reconstruction/Eflow begins to speak to experts in calor.design/hardware

Physics $\Longleftrightarrow$ **Eflow** $\Longleftrightarrow$ **Hardware**

Almost missing up to now

The quantitative test of a device must include the Eflow and **not only single particle results**

For one design $\Longrightarrow$ ΔM , ΔE_{jet}

- 2-b jets, WW , mass resolution (Higgs)
- WW/ZZ separation
- $\mathbf{t\bar{t}}$ final state (large number of jets) • • •

Presentation of the session

1. Pascal Gay (LPC-Clermont)
Eflow with granular calorimeter

2. Raymond Frey (Univ. Oregon)
Eflow jet reconstruction: Fast and full simulation studies

3. Yoshiaki Fujii (KEK)
Jet reconstruction studies

4. Vasiliy Morgunov (DESY)
HCAL reconstruction

5. Gary Bower (SLAC)
Calorimetry and jet reconstruction

6. Norman Graf (SLAC)
Clustering algorithm studies

7. Henri Videau (LPNHE-Ecole Polytechnique)
The W-Si electromagnetic calorimeter

8. Volker Korbel (DESY)
Tile hadronic calorimeter

9. Paolo Checchia (INFN-Padova)
The ECAL Shashlik design

10. Toru Takeshita (Univ. Shinshu)
Tile/Fiber hadron calorimeter performance

11. Kiyotomo Kawagoe (Univ. Kobe)
Performance of preshower/showermax detectors

EFLOW studies with ECFA/DESY TDR Calorimeter

ECAL A • W-Si sampling cal.

B • Shashlik

HCAL C • TiLE - INOX

D • Digital cal.

Report on EFLOW

on A - C Wsi - Tile

and A - D Wsi - Digital

Summary of the Eflow studies

1- Using a small granularity calorimeter

Cf. P.Gay

▷ relative contribution from energy resolution , reconstruction
$\Longrightarrow$ reconstruction is the major part

▷ Granular calorimeters (all pads are 1x1 cm) are very powerfull detectors for jets Eflow

- about 75% of the K0 are reconstructed at 3 cm from a charged track (about 99% at 20cm)
- about 90% of the photon are reconstructed at 3 cm from a charged track (about 99% at 10cm)

Full reconstruction with classical approach (clustering) gives already **about a factor 2 improvement** compared to LEP detectors

For jets, ΔE $\sim$ 40% $\sqrt{E}$

Prospect for improvment

Based on 3-D pattern and statistical approach, 30% $\sqrt{E}$ could be reached !!

P. Gay

FRAMEWORK

consists in ECAL and HCAL design and Jet reconstruction algorithm

- detectors

ECAL Si/W sampling calorimeter

Known principle

all requests fulfilled

$\Delta E_\gamma / E_\gamma \sim$ 12.0%$/\sqrt{E_\gamma}$

$1\text{x}1\text{cm}^2$ pad size

HCAL Digital calorimeter

sampling calorimeter (inox) with digital pad read-out

energy reconstructed from pad multiplicity (principle tested w/ ALEPH data)

$1\text{x}1\text{cm}^2$ pad size

- EFLOW algorithm

$$E_{jet} = \Sigma\, E_{ch} + \Sigma\, E_\gamma + \Sigma\, E_{neutralh}$$

Identification and reconstruction of all eflow objects

- Charged tracks from tracker system
- Photons from ECAL ⇒ photon reconstruction★
- Neutral hadrons (K_L, neutron) from ECAL & HCAL ⇒ neutral hadron reconstruction★

★ w/ rejection of debris from charged hadron interaction

Full Simulation ⊕ Reconstruction

Photon reconstruction

classical clustering algorithm

Lepton Identification

classical technique based on likelihood estimator

Neutral hadron reconstruction

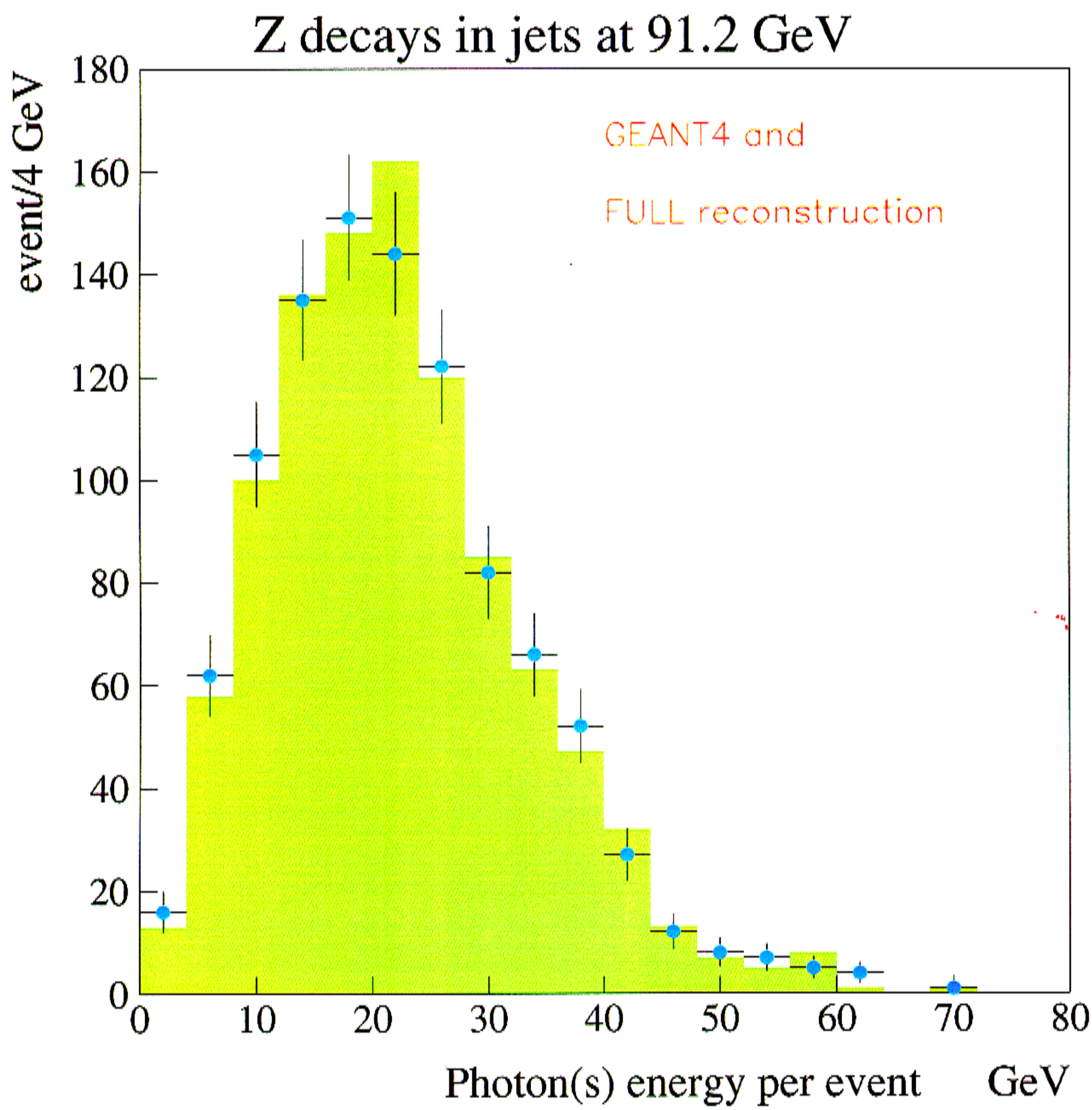
software of image processing for digital calorimeter - topological approach

⇛ **Jet reconstruction**

Refs
[Talks ECFA-DESY Workshop in Obernai]
[Talks ECFA-DESY Workshop in Padova]
[LC-note in preparation]

in more details ...

[redacted]



Z decays in jets at 91.2 GeV
event/4 GeV
180
160
140
120
100
80
60
40
20
0
GEANT4 and
FULL reconstruction
0
10
20
30
40
50
60
70
80
Photon(s) energy per event GeV

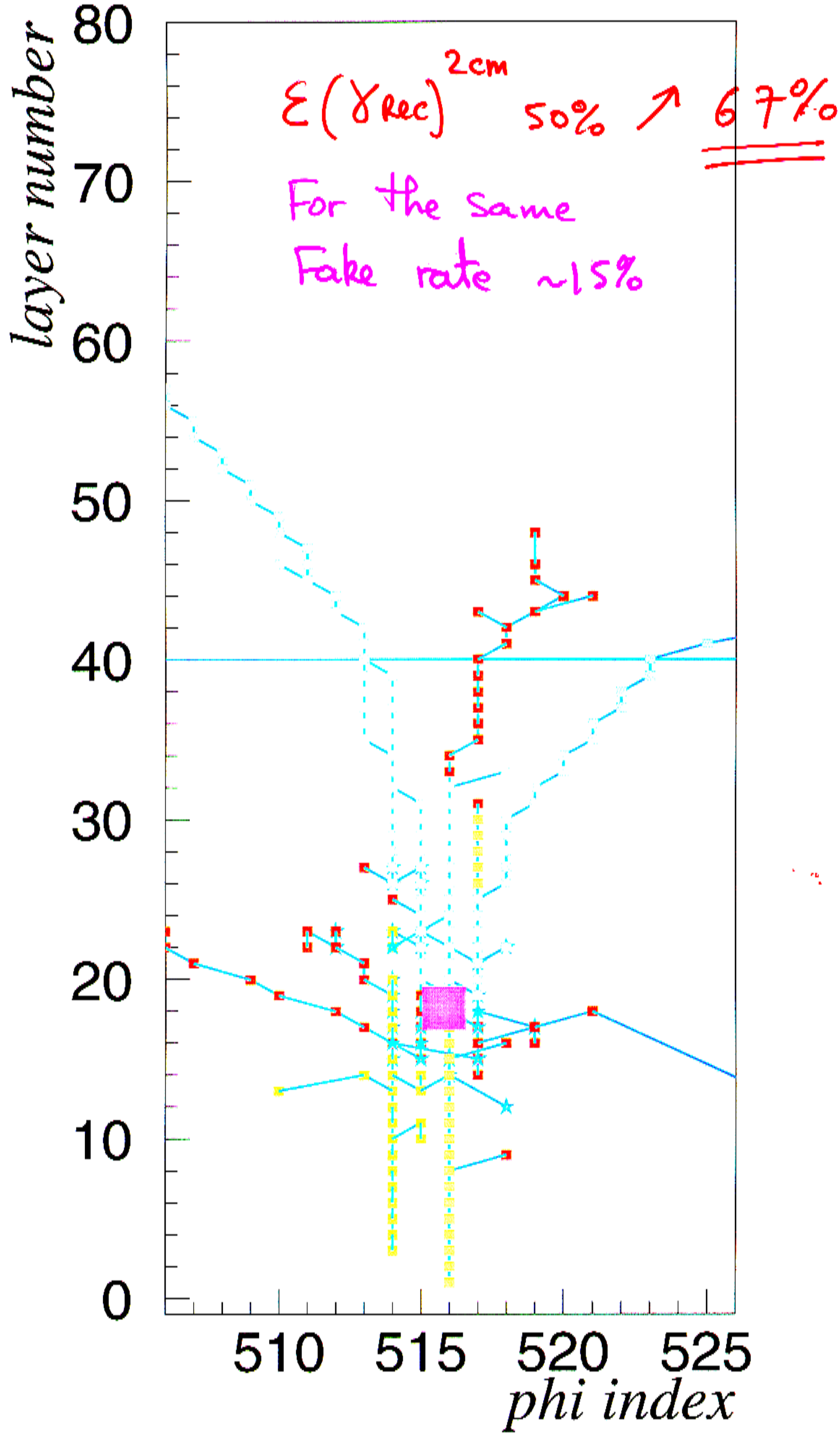
Lepton Id

- **Isolated tracks**

ID/particle	$e^{\pm}$	$\mu^{\pm}$	$h^{\pm}$
$e^{\pm(1)}$	**99.8%**	**0.**	$\sim$**5.**10^{-4}
$\mu^{\pm(2)}$	**0.**	**99.8%**	$\sim$**5.**10^{-3}
$h^{\pm}$	**0.2**	**0.2%**	**99.5%**

$^{(1)}$*Refs. cf LC-note on Eflow in preparation*

$^{(2)}$*Refs. cf talk in ECFA-Obernai*


$\varepsilon(\gamma_{Rec})^{2cm}$ 50% ↗ 67%
For the same
Fake rate ~15%
layer number
phi index
0
10
20
30
40
50
60
70
80
510
515
520
525

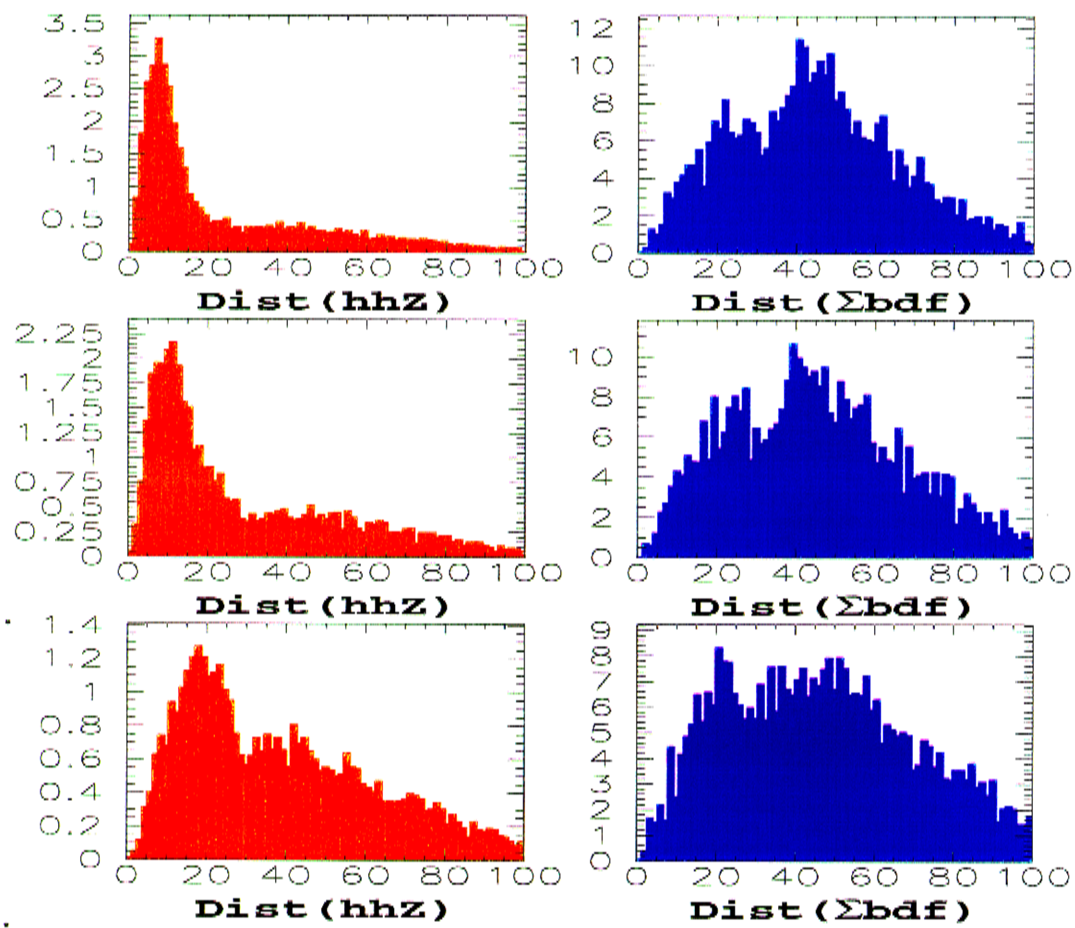
Summary of the Eflow studies

▷ Impact on Physics

P.Gay uses the measurement of the Higgs self-coupling to study the impact of the jets resolution.

$\boxed{\text{Running from 60\% to 30\% for the jet energy resolution}}$

- the background changes by a factor 6
- the precision on the cross section hhZ, by a factor 1.6



$30\%\ \sqrt{E}$

$40\%\ \sqrt{E}$

$60\%\ \sqrt{E}$

At least $40\%\ \sqrt{E}$ for jets energy resolution seems to be mandatory for this measurement

V. Morgunov

Work on reconstruction with calorimeter A-C (W-Si and Tile)

- First step → understand particle behavior in calorimeters
- Second step → establish a strategy for reconstruction.
- third step → DO IT

- parts of the program is OK
- parts under development

FULL Rec. very soon

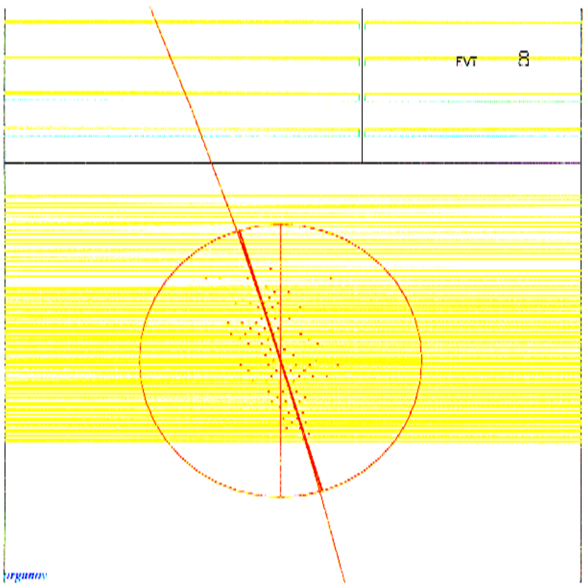
for fun, but also to see the calorimeter potentiel, $K^0_S \to \pi^0\pi^0 \to 4\gamma$

Programs

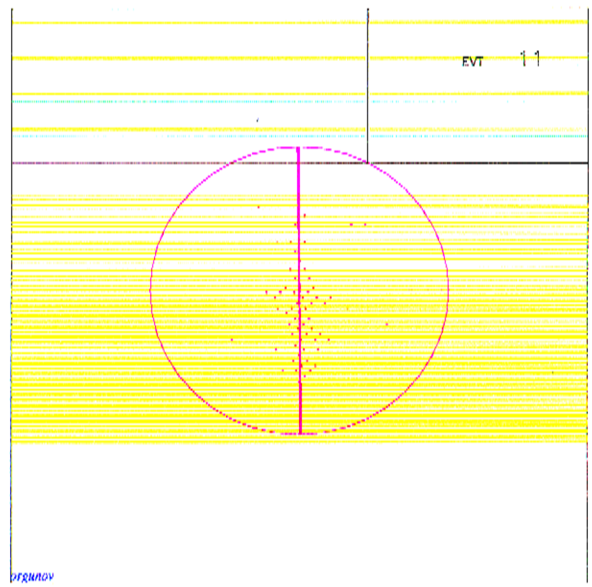
- HCAL barrel geometry with electronic cells structure – done
- HCAL barrel hit packing for the output – done
- HCAL barrel hit unpacking (reconstruction) to XYZ – GEANT mother coordinate system (program works inside GEANT environment and it uses GEANT geometry routines !) – done
- Super–Cluster and Cluster of hits search in ECAL and HCAL barrel – done
- Sub–Cluster search in HCAL to make energy weighting for better HCAL energy resolution – can be written
- Shower analysis – done
- Track finder in ECAL and HCAL – done
- Merge ECAL and HCAL to one pseudo–particle – will be written
- Merge calorimeter information with TPC information to replace charged particles parameters to TPC measured parameters and to find the neutral hadrons – will be written
- Event reconstruction and selection – will be written
- Event analysis (the simplest one) – done
- Code consists of about 15 K FORTRAN cards for now.
- CPU time for reconstruction of one $500GeV$ event is about 1 second.

Cluster shapes

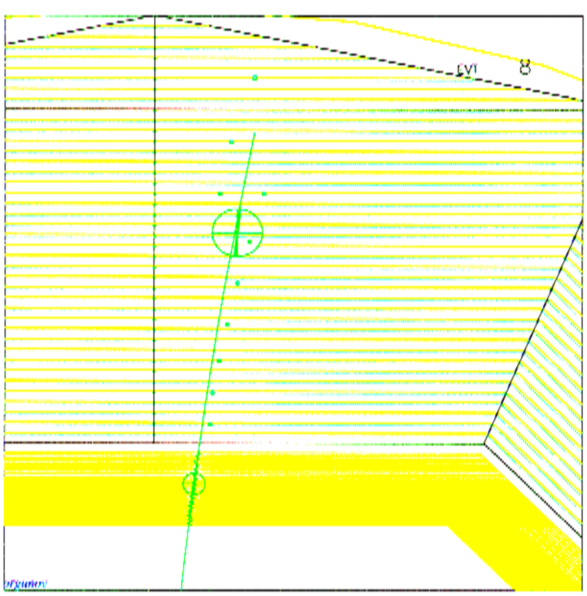
Electron



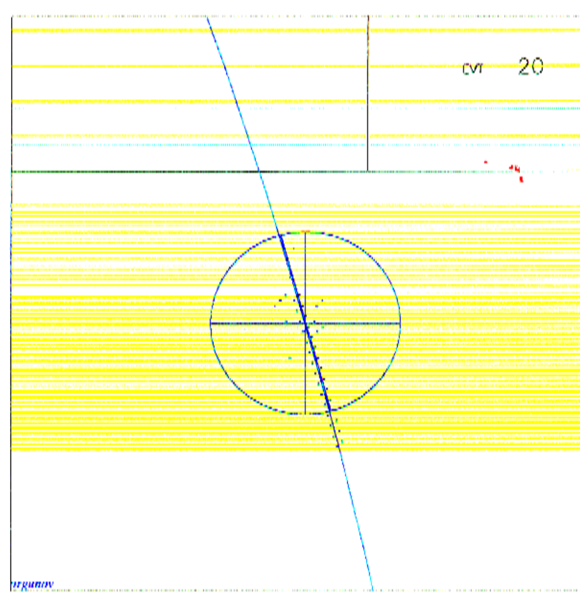
Gamma



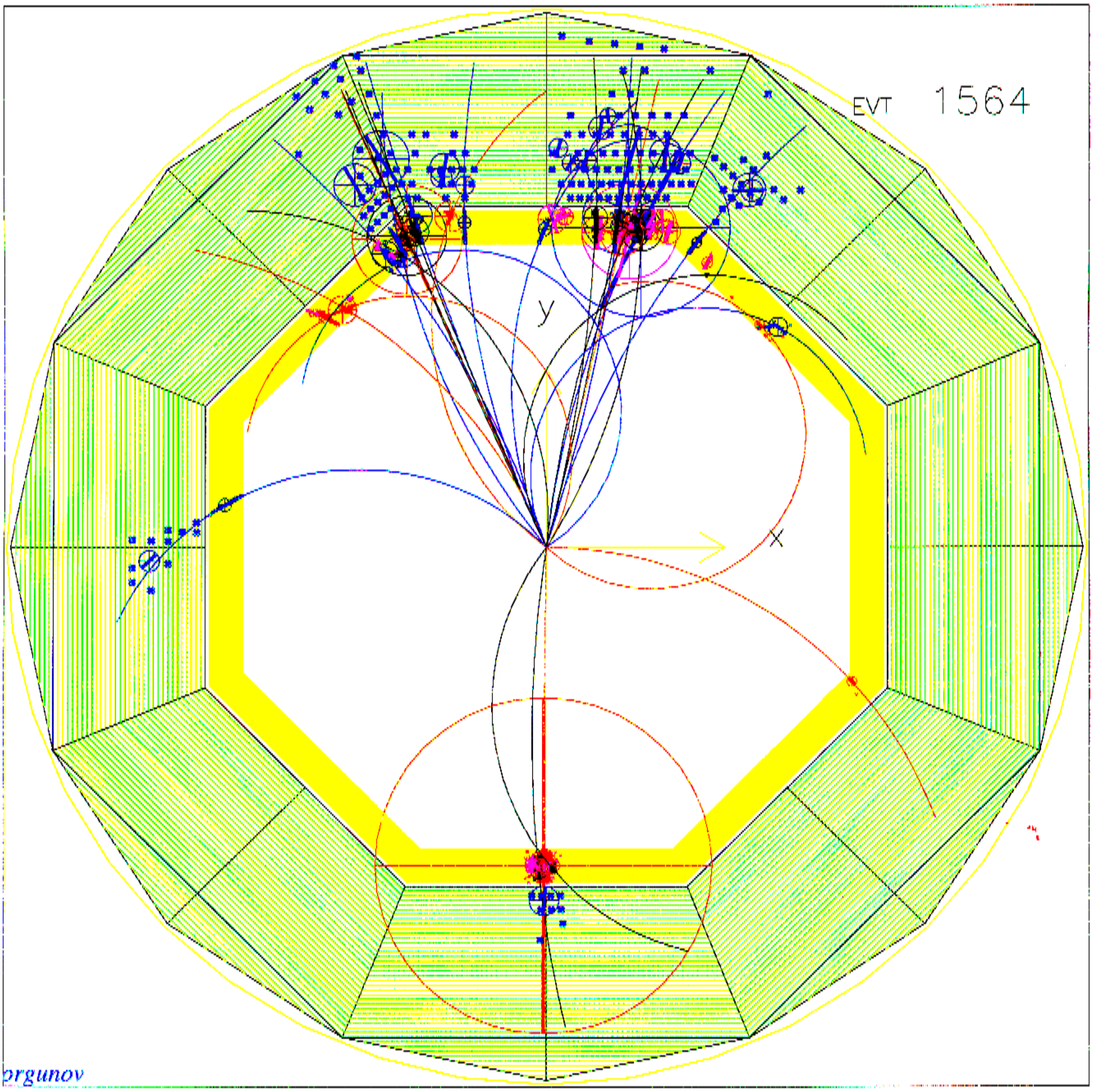
Muon



π meson

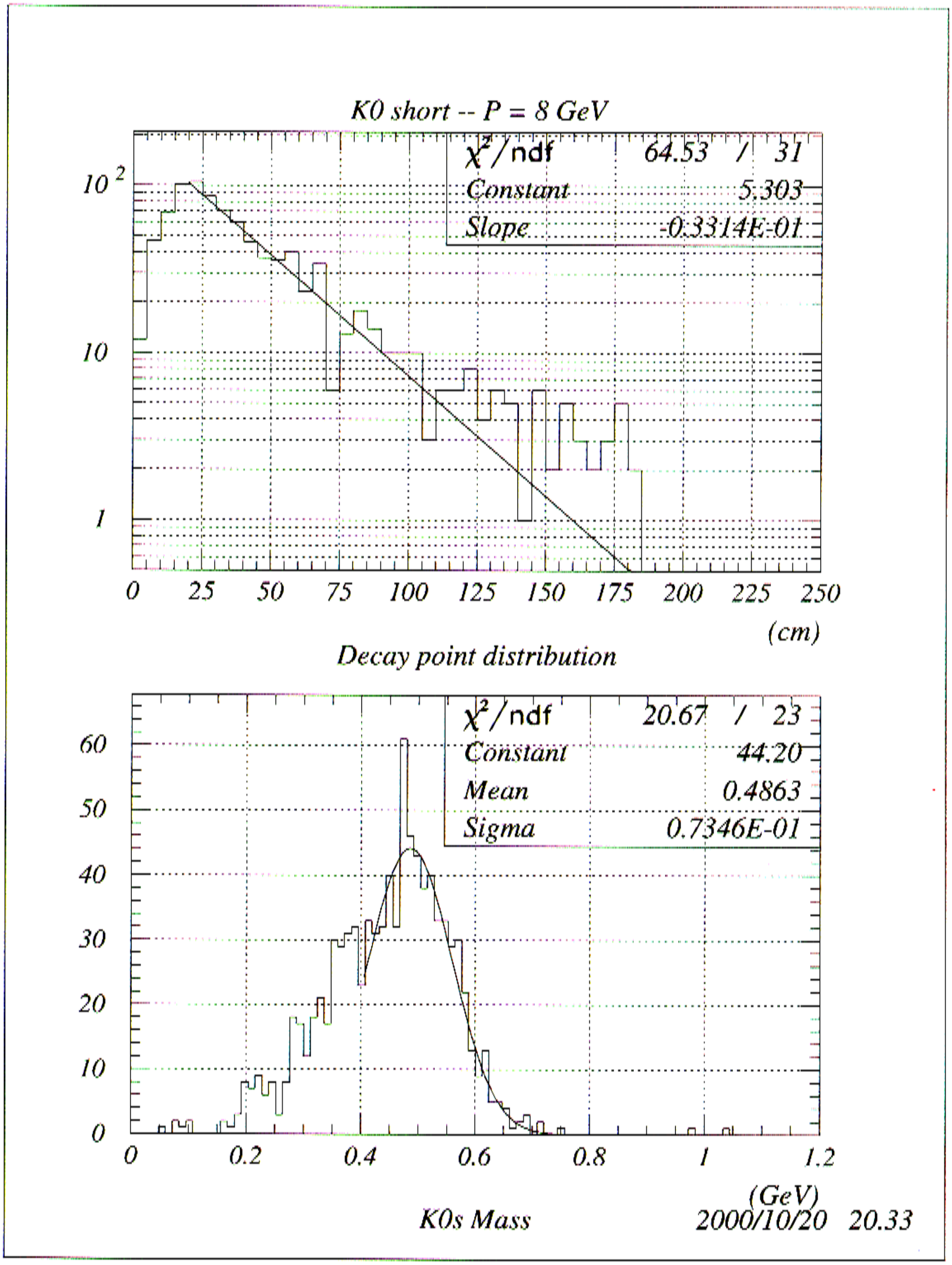


Event sample



Sometimes helix fit to IP allows to find hadron cluster that is at the unusual position, as it is shown at the left side of picture.

$K_s^0 \rightarrow \pi^0 \pi^0 \rightarrow \gamma\gamma\gamma\gamma$



– no kinematic constraint was used at this stage

R. Frey

LCD EFLOW STUDIES

- Keep flexibility on reconstruction in order to have same code for S/L (L2)

- Using Fast Simulation, try to quantify Eflow response for S and L detector

→ TCA based on dist. γ/track at the front face of calorimeter

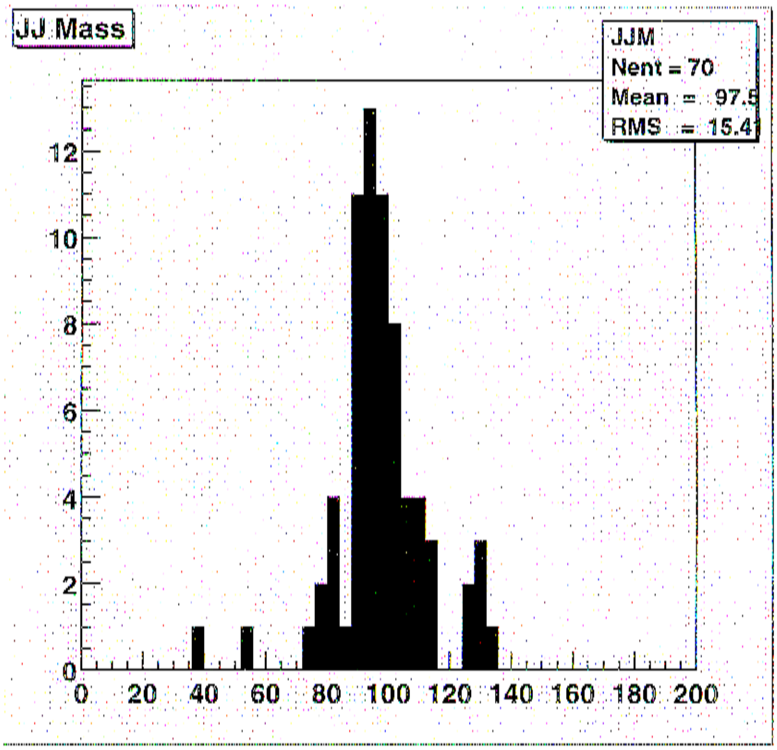
Some output of the study

- EFLOW (Tracks + neutral calor. obj.) is better than just calorimeter energy

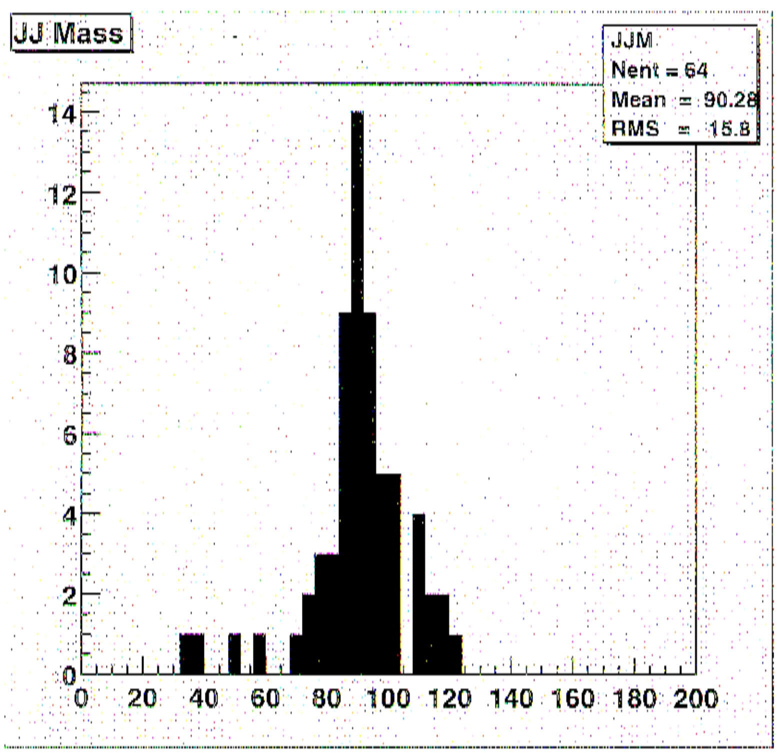
- L is better than S for what concern $\gamma/\pi^\pm$ separation

$e^+e^- \rightarrow ZZ \rightarrow$ Jets

- Energy Flow - Detector S; $d2D > 0.5$ cm, ($dE > 5$ GeV), no R cut:



- Energy Flow - Detector L; $d2D > 1.5$ cm, ($dE > 5$ GeV), no R cut::



Summary

- A start . . .
- Some optimization possible to nudge Fast Sim. EFlow $\rightarrow$ unsmeared 4-vector
- But clearly most important step is to use fully simulated MC and a realistic clustering algorithm
- Expect challenges with pattern recognition – Is it better than using cal.-only? Can one approach the Fast MC Sim. results?
- Important implications for detector cost and size
  - figure of merit is BR^2/R_m
  - Can one construct sufficiently fine granularity at modest R and cost ?

N. Graf

Fast Sim. could lead to
Wrong conclusion

↳ Reconstruction with
FULL SIM.

Is it possible to have
TCA "more or less"
independant of detector ?
(For granular calorimeter)

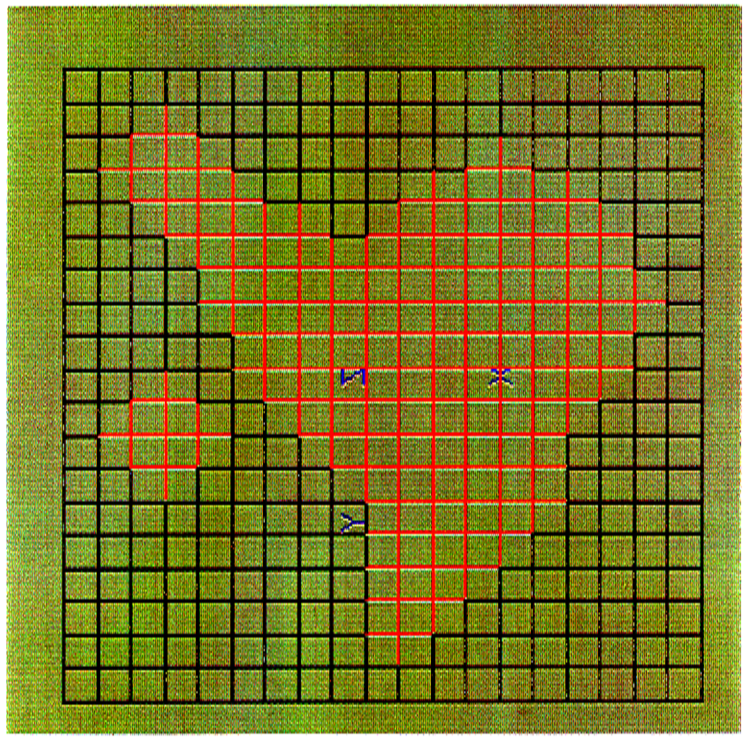
⇝ Clustering

⇝ Merging of clusters

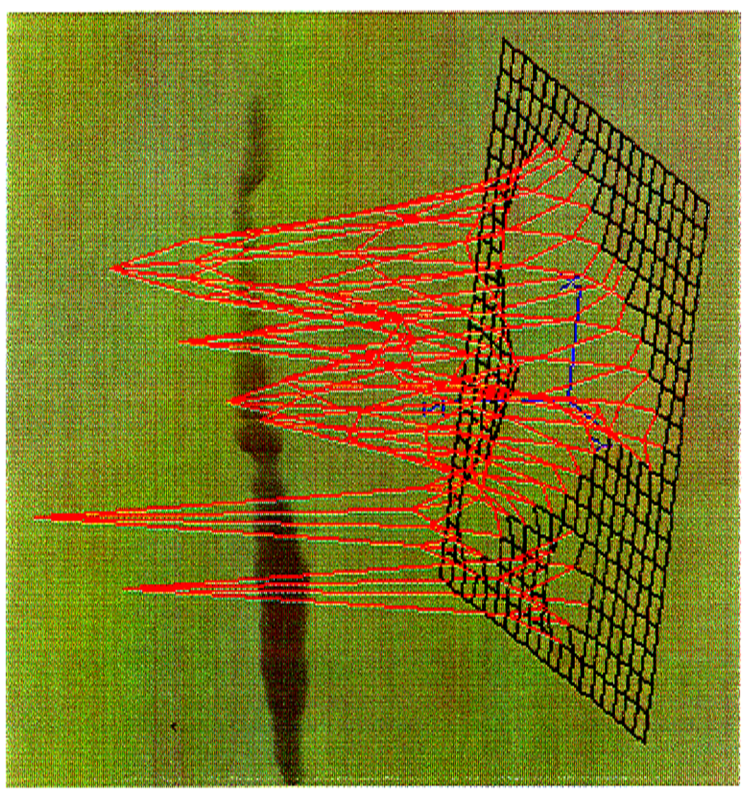
⇝ T. C. A.

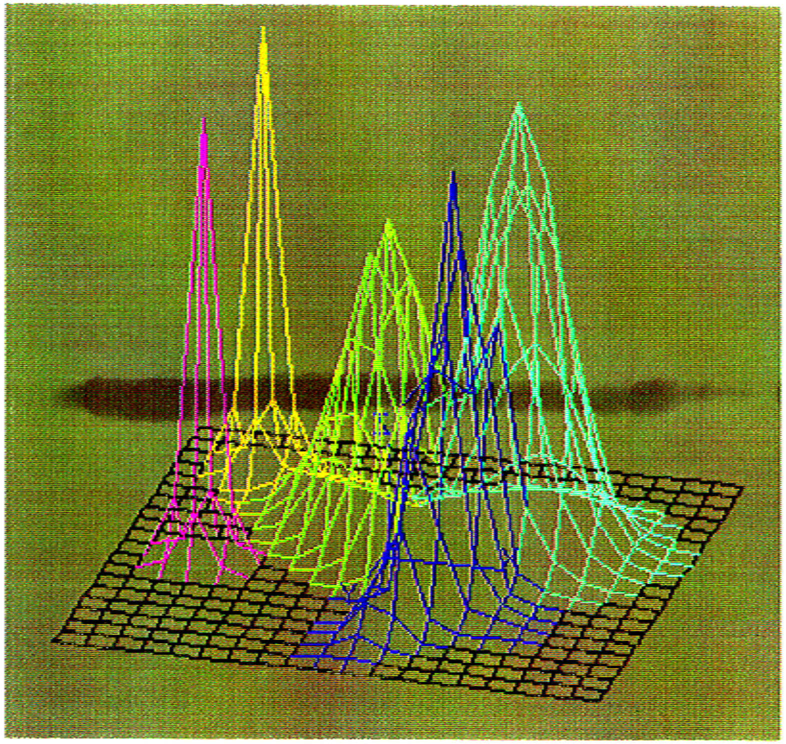
Looks promising

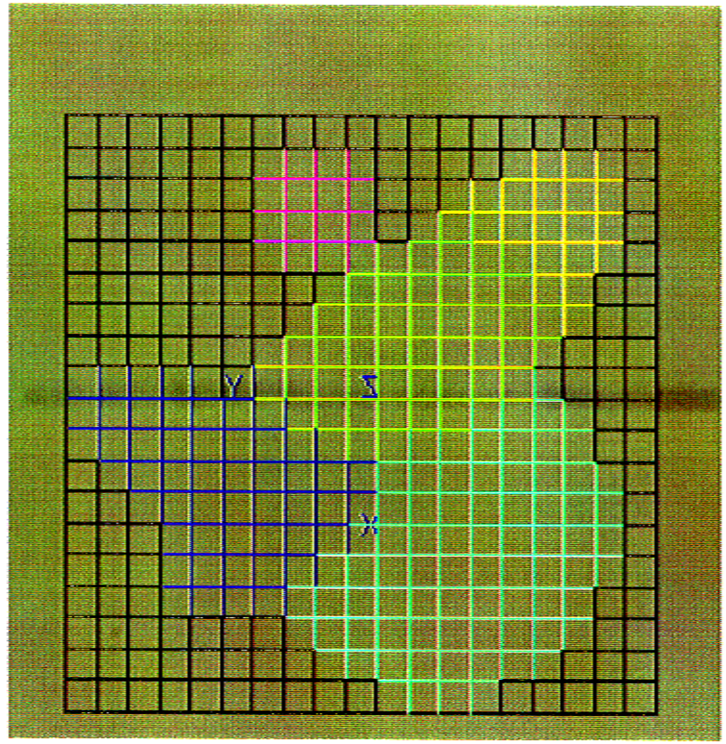
It would be a very
nice achievement



Z
X
Y






Y
Z
X

G. Bower

How to quantify the different EFLOW response (For each detector) but on physics rather than just ΔE_{jet} or ΔM_{JJ}

A set of jets final states

$q\bar{q}$ / ZZ / W^+W^- / ZH / $t\bar{t}$

Work on discriminant variables (Jets mult., $M_{Hemis.}$, particle rapidity, ...)

$\Downarrow$

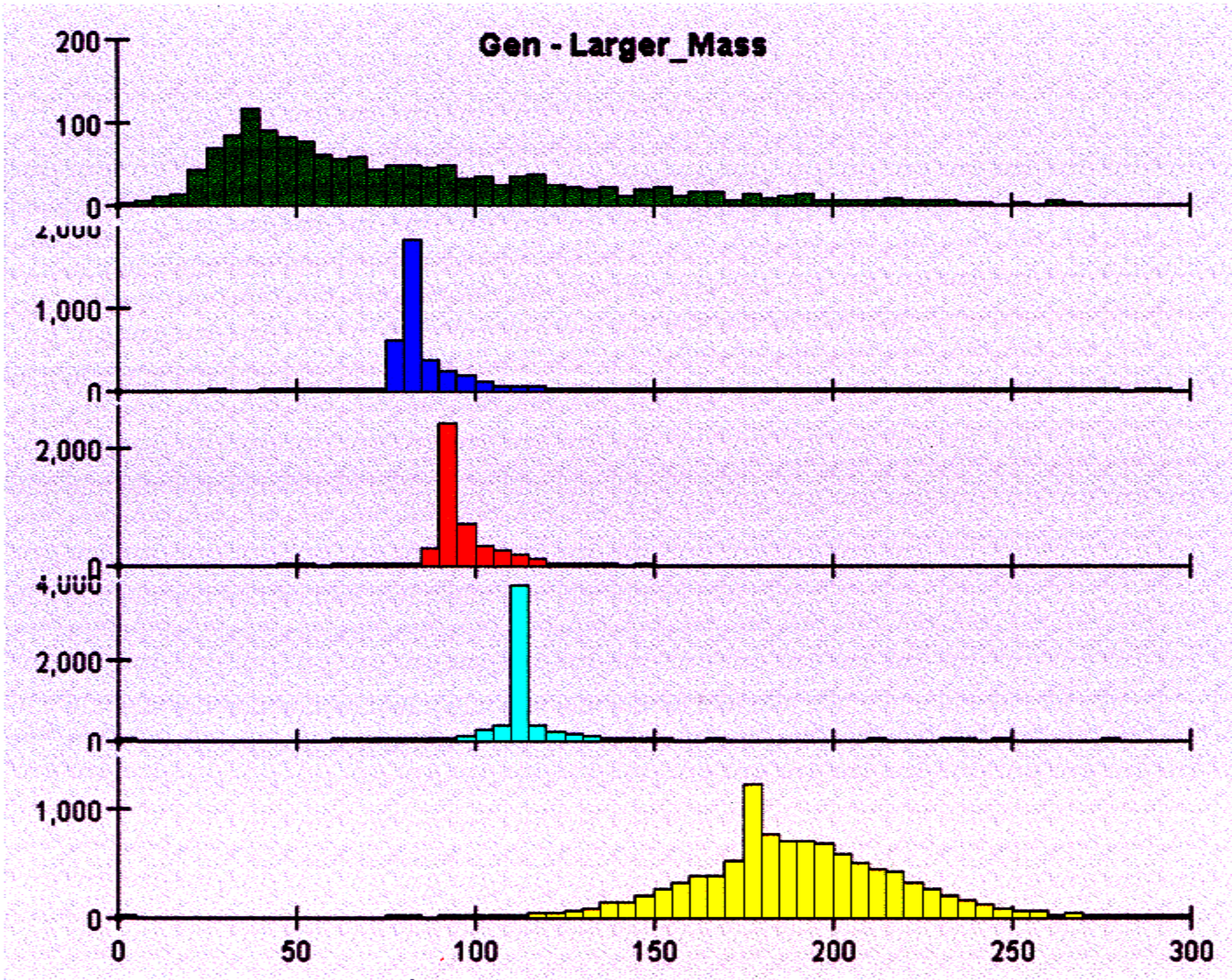
Neural Net

$\Downarrow$

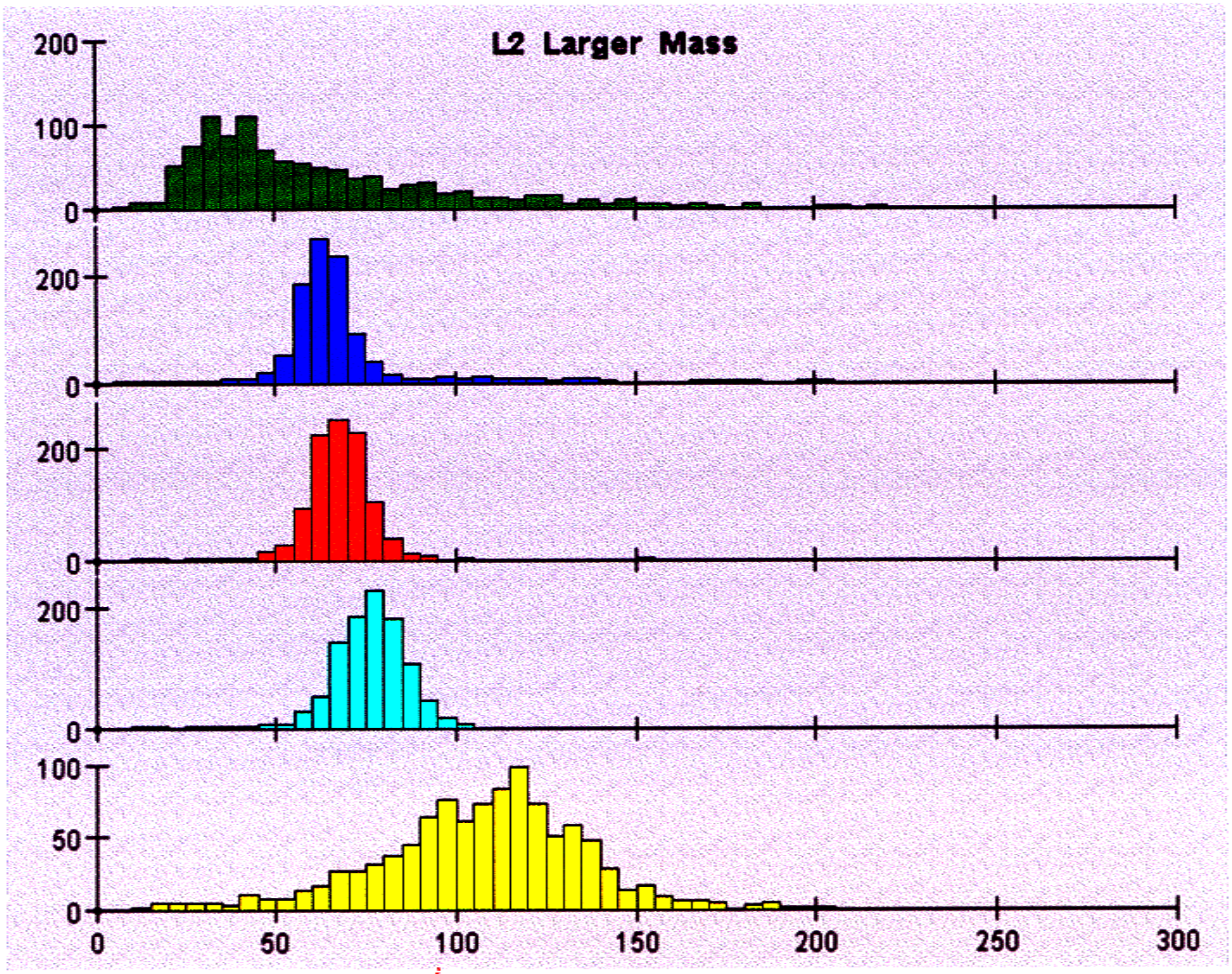
Tables $\rightarrow$

- For a given EFLOW $\oplus$ DETECTOR
  - $\rightarrow$ EFLOW object feed the NN
  - $\rightarrow$ produce a table

Larger Thrust Hemisphere Mass



Larger Thrust Hemisphere Mass



% Efficiency with NN

Level	Gen	Sim(L2)
qq	91	76
WW	90	66
ZZ	97	53
ZH	96	74
tt	100	86

Sorry: S2 and Small results to appear shortly.

Y. Fujii

JLC Eflow STUDIES

- The road of compensated calorimeters

- First study with 3T detector model

SLIDE

- Goal of the study

SLIDE

- Track Cluster Association

SLIDE

- "Jetty" multiparticles γ e π "jets" each 19 GeV

- No conclusion Yet

- My conclusion

"Fast Simulation does not mean Simple Simulation"

2. CAL design in the Simulator

Tile-fiber sampling calorimeter with hardware compensation ratio (EM=4:1,Had=8:2)

Design Energy Resolution (not input)

$\sigma_E/E = 15\%/\sqrt{E} \oplus 1\%$ for EM

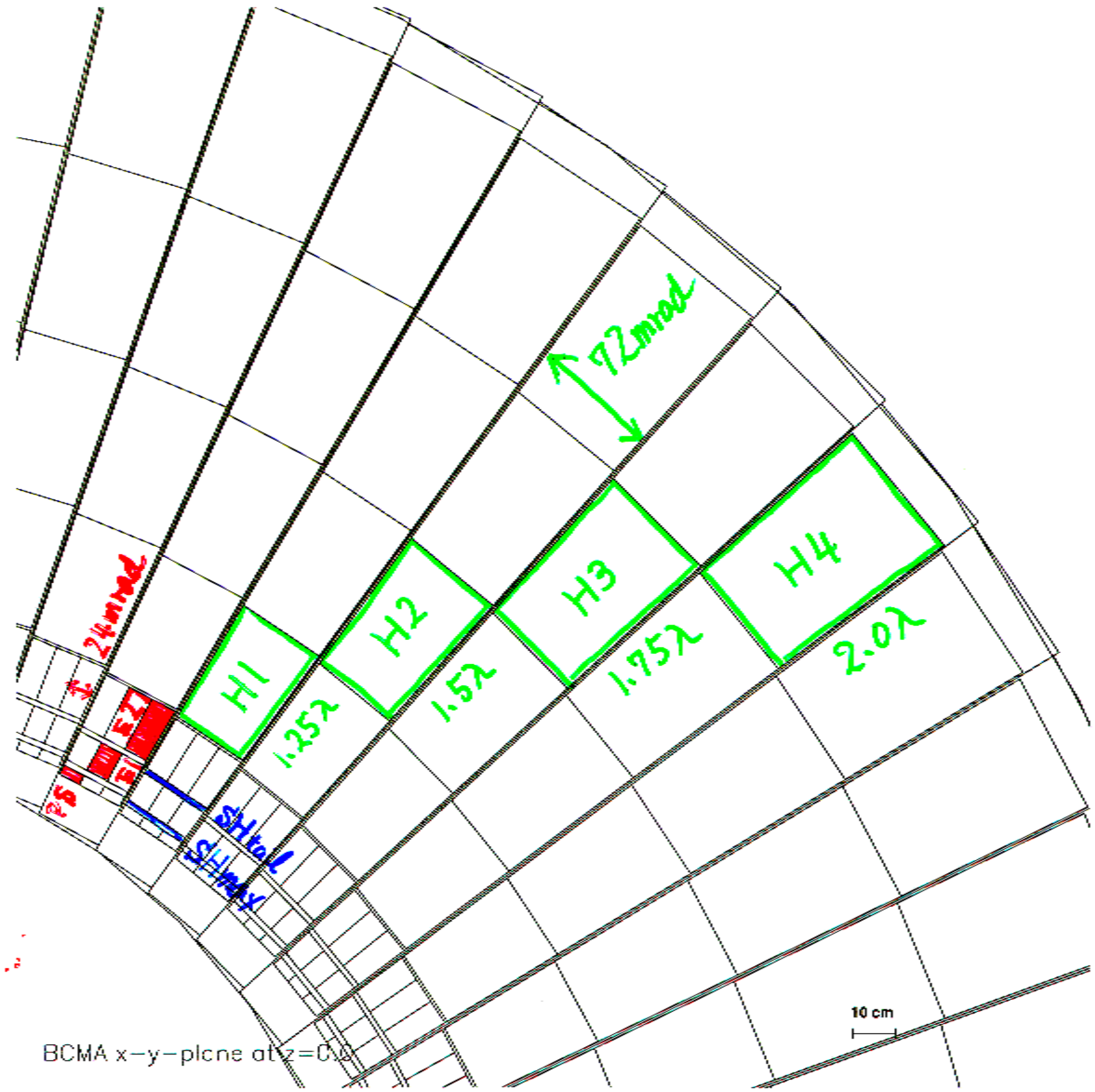
$\sigma_E/E = 40\%/\sqrt{E} \oplus 2\%$ for Hadron

Configuration

PreSH +SHmax + EM1 +SHtail + EM2 +HCAL1 +HCAL2 +HCAL3 +HCAL4

Transverse segment size

- EM ; 4cm x 4cm = 24mrad
- Had; 12cm x 12cm = 72mrad



3. Full Simulation Analysis

Event Samples to Study ;

- Single-Particle
- 'Jetty' multi-particles
- Jets from W decay

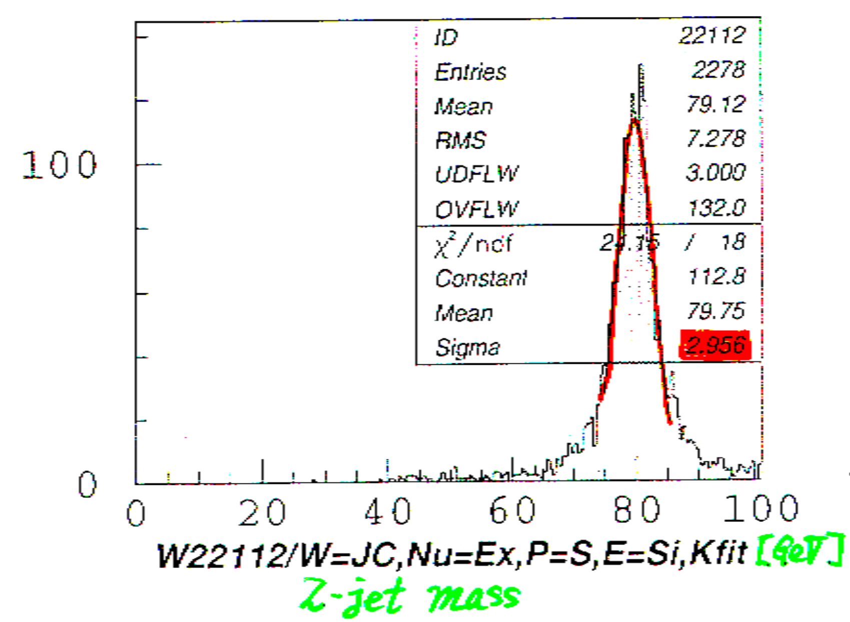
Reference = Quick-simulation analysis
for e+e- --> WW@400GeV
Reconstructed W width
3.0GeV with K-fit
3.3GeV w/o K-fit

Performances to Study ;

CAL response
- Energy Measurement Mapping
  Energy Resolition
- Tower-boundary Response

CAL clusters
- Energy Scale
- Energy Resolition
  Mass Resolution

CAT-Link
  Energy Scale
  Energy Resolition
- Mass Resolution
- Neutral Energy



3.2 Analysis Methods : The same algorism as the Quick-sim analysis.

1) Clustering

- EM clusters ; Only one particle in a cluster (Jade algorism)
- Hadron clusters ; Connected Island = Accecpt plural particles in a cluster

  (This gave better result than Jade-algorism for Quick-Simulation analysis.)

2) Cluster and Track Linking

a) Pick up an EM cluster in order of energy.

Find a charged track which position matches to it.

a-1) If energy matches ==> KILL this EM cluster.

a-2) If Ecluster > Ptrack ==> Photon overlapped. Subtract track energy and save.

a-3) If Ecluster < Ptrack ==> assume this is HADRON or mu, and

merge it to hadron cluster behind it, if there is such hadron cluster, or

leave it as it is is there is no such hadron cluster.

b) Pick up a hadron cluster in order of energy.

Find charged tracks (or a charged track) which position match to it.

b-1) If momentum-sum matches ==> KILL this hadron cluster.

b-2) If Ecluster > Ptrack ==> Neutral hadron overlap. Subtract track energy and save.

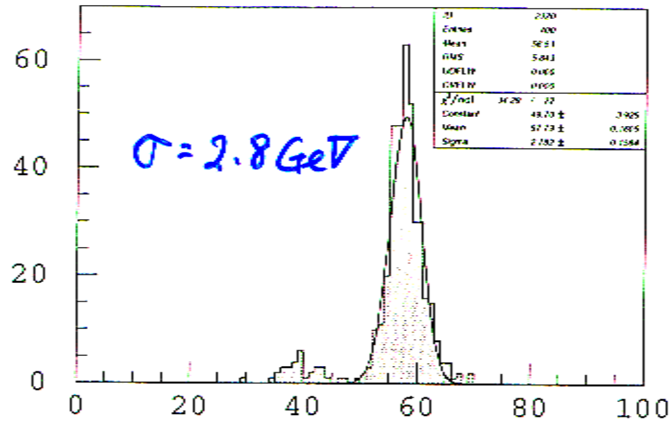
b-3) If Ecluster < Ptrack ==> could be muons or overlap of muon and neutral hadrons.

If Ecluster = Emip ==> This is muon. KILL this hadron cluster

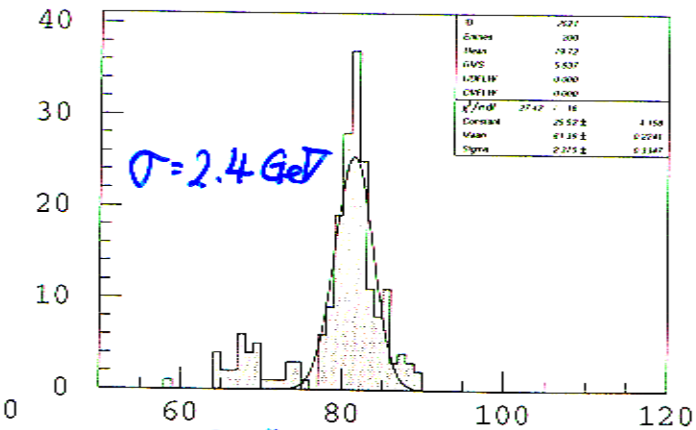
If Ecluster > Emip ==> Overlap of mu and neutral hadron. Subtract Emip and save.

Jet-Energy and 2-Jet mass obtained using Jade jet clustering

'Jetty' event analysis

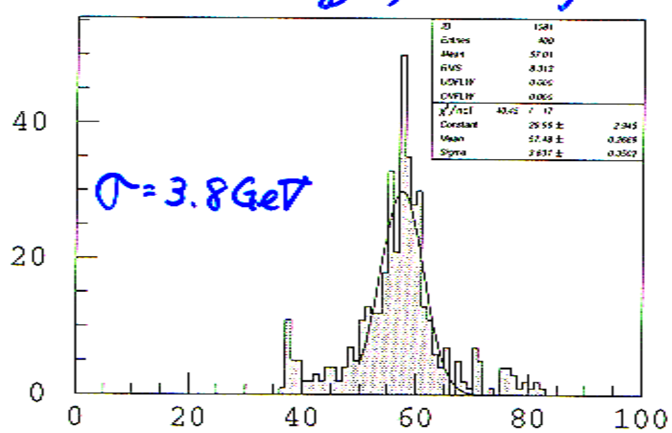


"Jet" Energy by CAL only

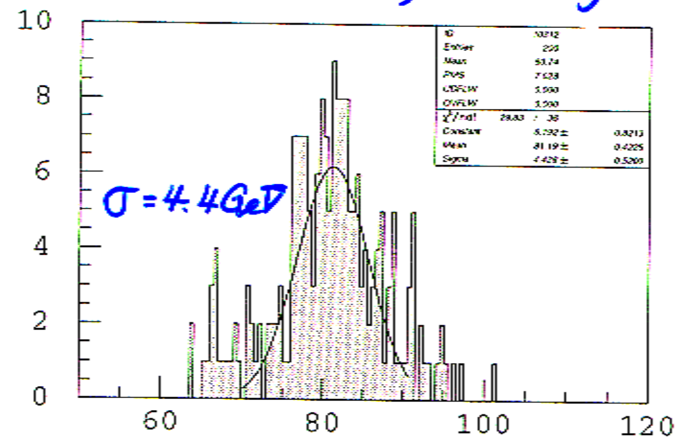


2-"Jet" mass by CAL only

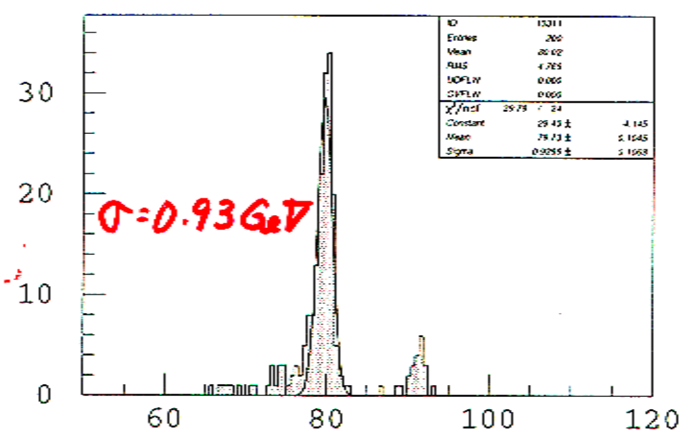
becomes WORSE !!



"Jet" Energy by CAT-Link



2-"Jet" mass by CAT-Link



2-"Jet" mass by CAT-Link when SMEARED ECAL is used.

CALORIMETER

DETECTOR

DESIGN

- Approach from analysis point of view
- Approach from Technology

TESLA-TDR detector design

The tungsten-silicon pads ECAL

Geometry: A "no-crack" design is proposed.

Mechanics: It is based on tungsten wrapped by carbon(?) fiber with alveoli for the active slabs (with Si pads)

Electronics : auto-trigger for each pad and BX, analogic zero supress, multigain preamps., and after multiplexing ~700 ADC's 10 bits with digital pipeline during the beam train.

Recons. software : See talks of P.Gay and V.Morgunov

A W–Si electromagnetic calorimeter for Higgs physics at a linear collider

Higgs Physics

Jet physics

Energy flow

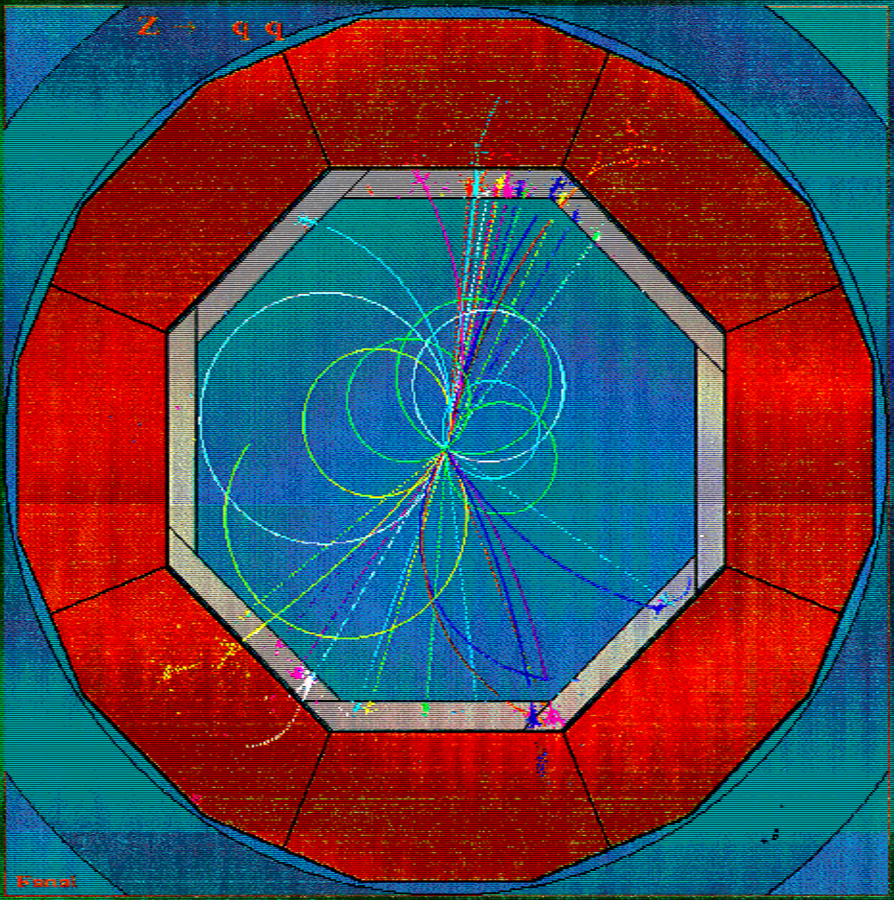
Hermeticity

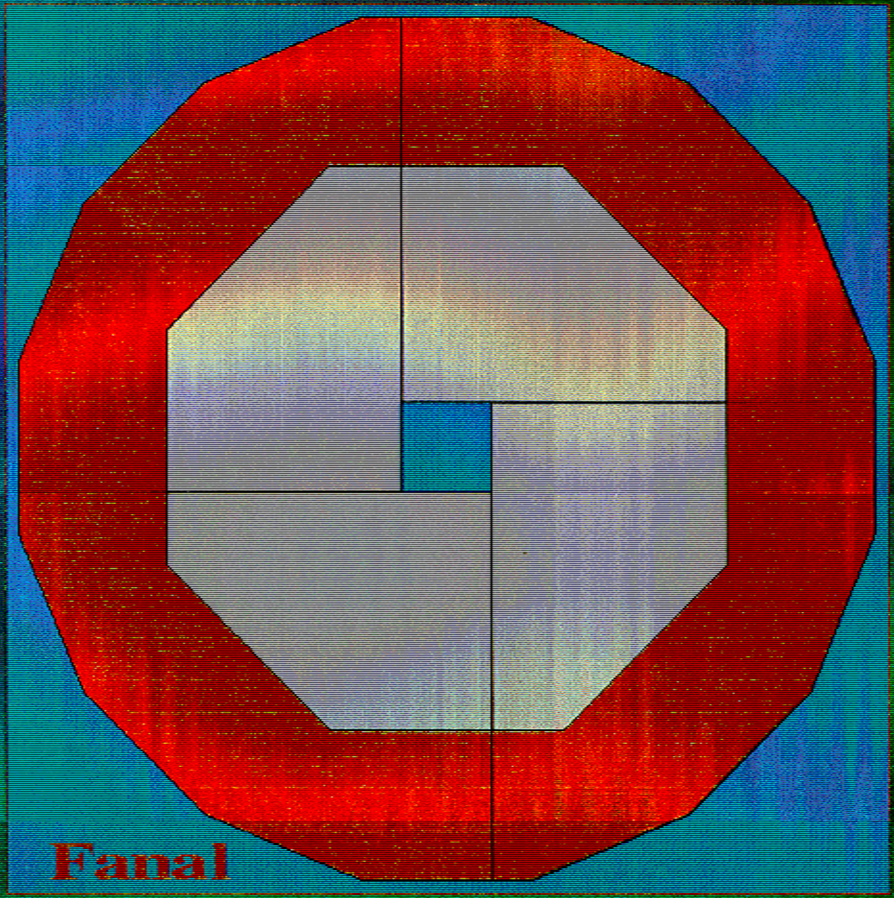
Granularity 3d

with few simple ideas

Mechanical design

The general geometry: an octogonal shape in the barrel
4 wedges in the end caps





Electronics and read out

large # of channels with small occupancy.

Dynamics from a fraction of a m.i.p. to max deposit in a cell by 500 GeV electron
$\Longrightarrow$ 15 bits

precision $\Longrightarrow$ 2 gains of 10 bits each

in Tesla quite some time to integrate signal (150 ns)
incoherent noise $\sim 1/10$ of a mip (tested)
coherent ?!

Functions amplify
cut locally at $\sim 2/3$ of a mip $\varepsilon = 97\%$
stamp bunch # address (analogically)
stores

Packaging a detector slabs contains about $2 \times 8 \times 140$ cells
to be treated in a tiny space by $(2) \times 8$ chips

Read-out a set of 40 detector slabs can be readout (through a token ring)
and digitized in few ms by one ADC $\Longrightarrow \sim 700$ 10bit ADC's + storage

a full train $\longrightarrow$ DAQ

Performances from a Geant 4 study (talk by P. Mora de Freitas)
(talk by P. Gay)

Photons

Efficiency and rate of fakes — see plots

Energy resolution $\sim 0.12/\sqrt{E}$ $\sim$ flat in angle

Position resolution $1/\sqrt{E} + 0.4$ mm

Angular resolution $60/\sqrt{E}$ mrad

Neutral hadrons → talk by P. Gay

Jets visible energy resolution $0.17/\sqrt{E}$ if no neutral hadrons

photon collection $\sim$ intrinsic resolution

$< 0.4/\sqrt{E}$ with hadrons ($\sim$ 2 times better than Aleph)

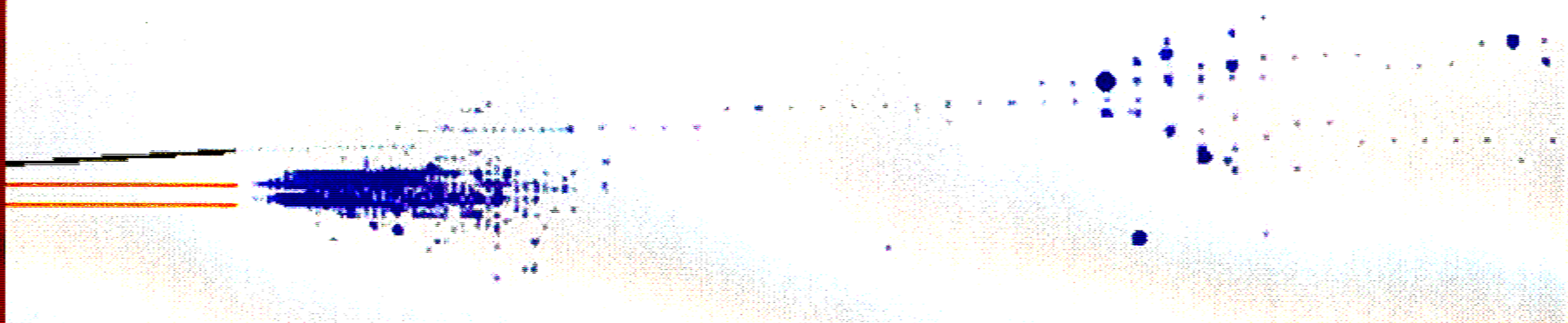
dominated by HCAL $\Longrightarrow$ work on pattern, resolution

Identification of isolated e and μ ($p > 2$ GeV) $\varepsilon = 99.8\%$ for contamination $< 10^{-3}$

~~work~~ going on for in jets

HV 6.8

" τ tagging is difficult"
" $\varepsilon_\tau \sim 0.5$"



" τ polarisation for $\tan\beta$"
" in τ decay"

300 GeV $\tau \to \nu_\tau \rho$

$\rho \to \pi^\pm \pi^0$

TESLA

A high granularity ECAL and HCAL

Cell size 1x1x0.5 cm^3

Back to bubble chambers?

Conclusions

We have a precise ECAL design for Higgs physics

It seems technically feasible with some delicate areas

- the detector slab or getting the signals out
- the front end electronics integration
- the industrialization of the Si processing to reduce cost.

being prototyped chip in 2001

It remains to be optimised, in particular in its layer structure

The software to exploit its capabilities is an interesting challenge
may bring a lot

The price, as of today (130 M€), is totally dominated by the silicon area.

Its probable evolution is under study - May bring a factor 3

Read the Tesla TDR when released.

V. Korbel

TILE HCAL
(TDR ECFA/DESY)

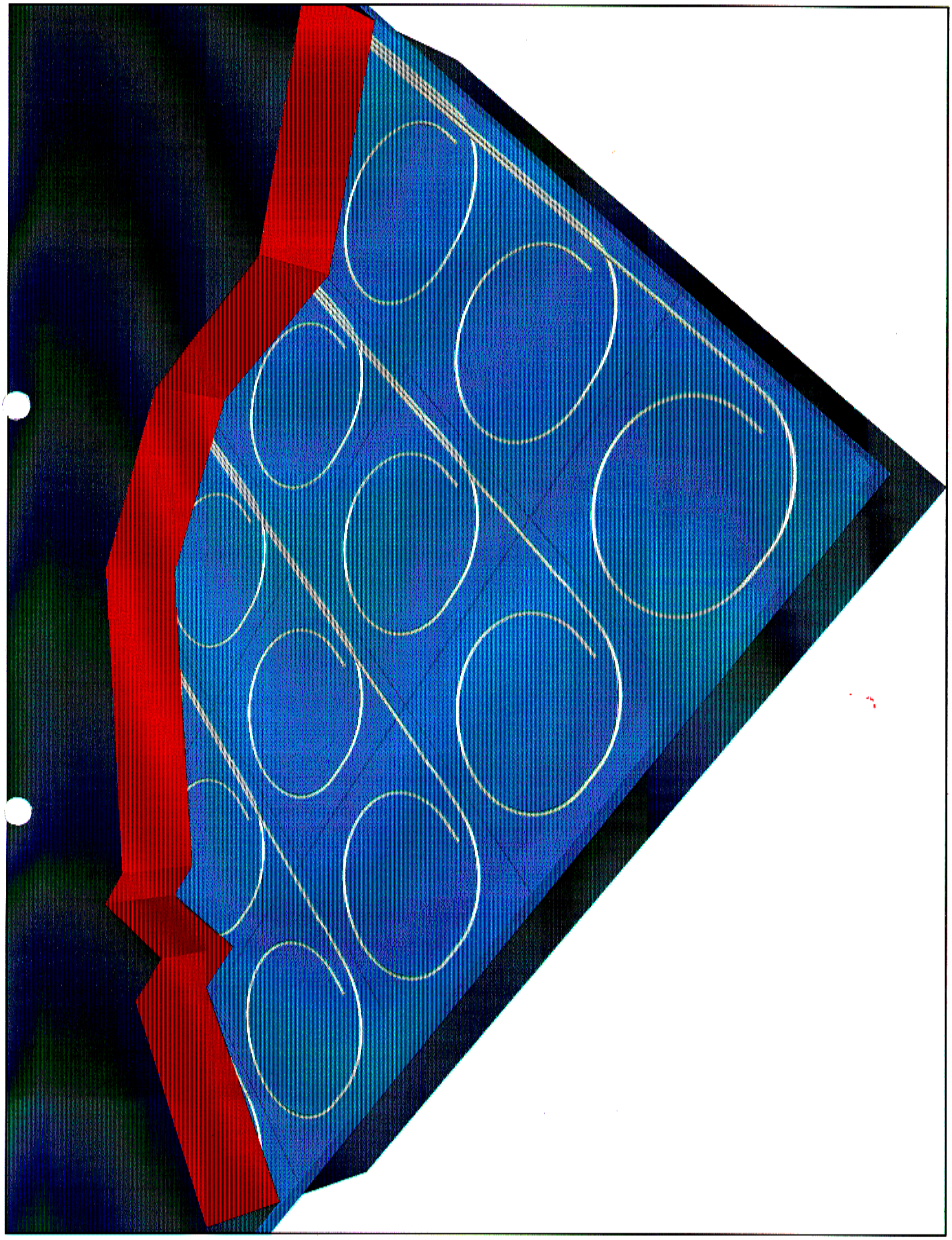
- TILE / INOX
  0.5 / 2 cm
- 5x5 cm TILE (entrance)
  to 20x20 cm (exit)
- 9 read-out layers

⇝ mechanics and design

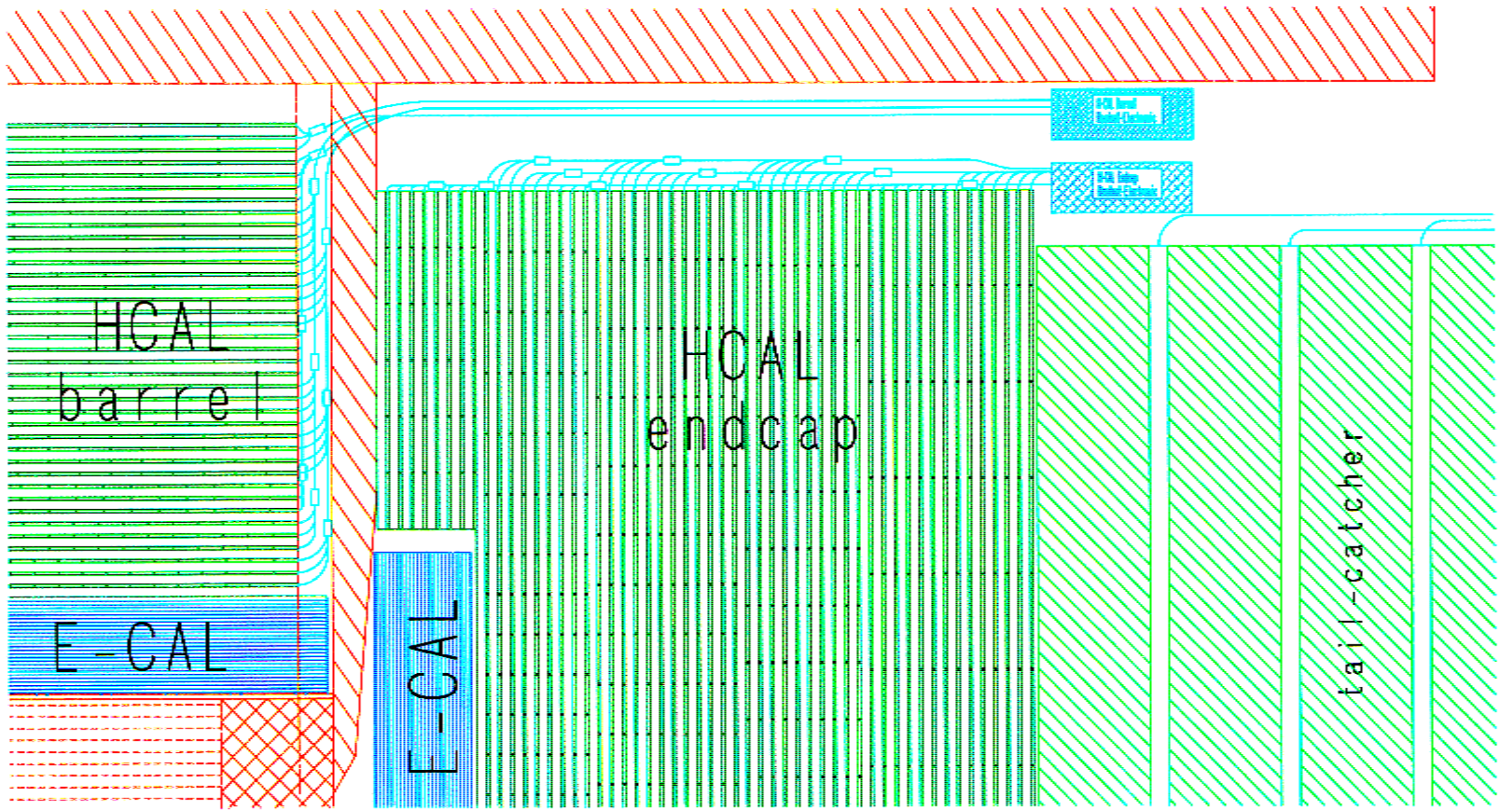
⇝ read-out and electronic

⇝ Installation with ECAL w-si

⇝ Future R&D, Test...



HCAL, readout



Electronic chain:

photodetectors

magnetic field, green light!

- APD
- MPD
- HPD
- VPD, VPT
- ?

preamplifier

low capacity (20-30 pF) APD's

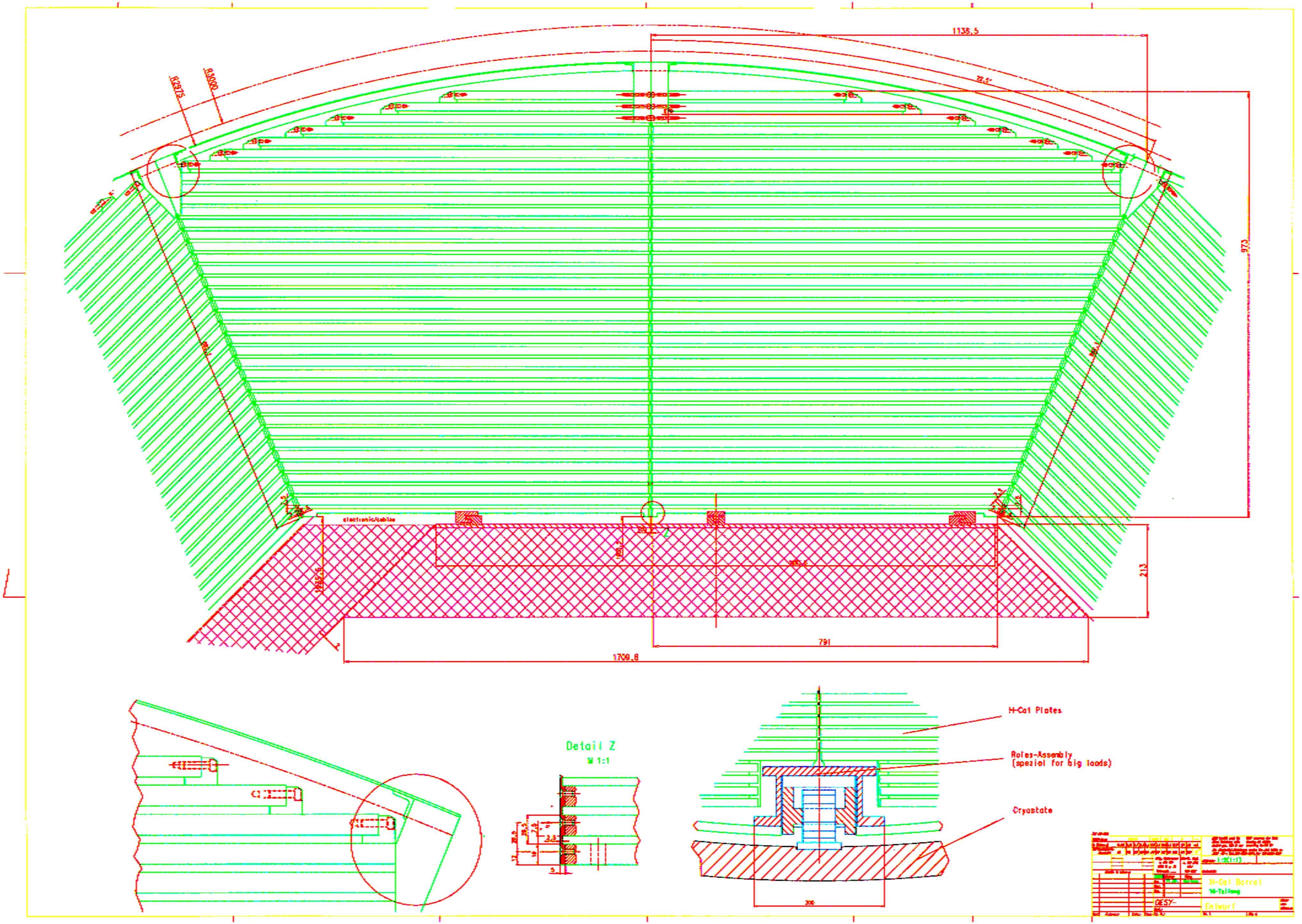
- noise < 1 MIP
- capacitive adaption
- shaping for good time measurement
- linearity
- time measurement
- additional shaper

FADC(40-100 MHz)

- 12 bit range, 3 thresholds
- Δt = +/- 2 nsec

see LC-Notes on all 3 topics

Untriggered contineous readout



1138,5
R3000
R2975
973
213
791
1709,8
electronic/cables
H-Cal Plates
Roles-Assembly
(speziel for big loads)
Cryostate
Detail Z
M 1:1
H-Cal Barrel
DESY-
Entwurf

R&D program for HCAL:

- find optimal
  - scintillator
  - wave length shifter fibre
  - reflector foil (mirror or diffractive reflection)
  - optical glue
  - clear fibre with long attenuation length
- optimize scintillator WLS light transition
  - shape of WLS fibre
  - contact of WLS fibre
  - reflectors (mirror /diffractive?)
- light transmission as function of bending radius
  - WLS fibre
  - clear fibre
- single or multiple cladding ofWLS and RO fibres
- noise minimizing: light tightness required for fibres
- tile mould casting or cutting on large boards?
- optimize fibre mixer in front of photodetector
- find appropriate:
  - photodetectors
  - preamps (to develop ?)
  - shaper (to develop ?)
  - FADC
- optimal degree of multiplexing?
- study stability of system (temp, HV, LV)
- establish good gain monitoring (LED, laser?)
- minimize noise >> observation of MIP's
- ensure radiation hardness of all components
- calibration studies with MIP's

R&D:
DESY
LPI Moskow
Tashkent
started

Barrel module prototype test >>>

P. Checcia

Shashlik design

→ SITGES : caleido 1

→ CALEIDO 2

2 segmentations in depth using scintillators with different time response

↓

TEST BEAM

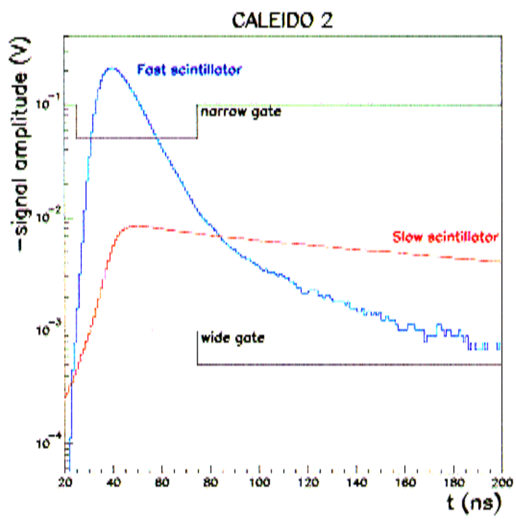
- Nice results on single particle

  * $\left(\frac{\Delta E}{E}\right)^{e.m.} \sim \frac{15\%}{\sqrt{E}}$

  * e/π separation

2 Scintillators with different time response

- First $5\ X_0$ with long τ scintillator
  same geometry, WLS fibers ....



- Slow scint.: BC444 from Bicron $\tau \sim 250$ ns
- e/γ: early shw.$\Rightarrow$ high E_{slow} and E_{fast}
  hadrons: late shw. $\Rightarrow$ small E_{slow}
- 9 counters (3×3) with (fast) PM's
  FEU-84-3 FEU-115M
- RO: narrow and wide gate (50 and 150 ns)
- Q_n and Q_w mix the two components

Shashlik

Testbeam Summary

First prototype:

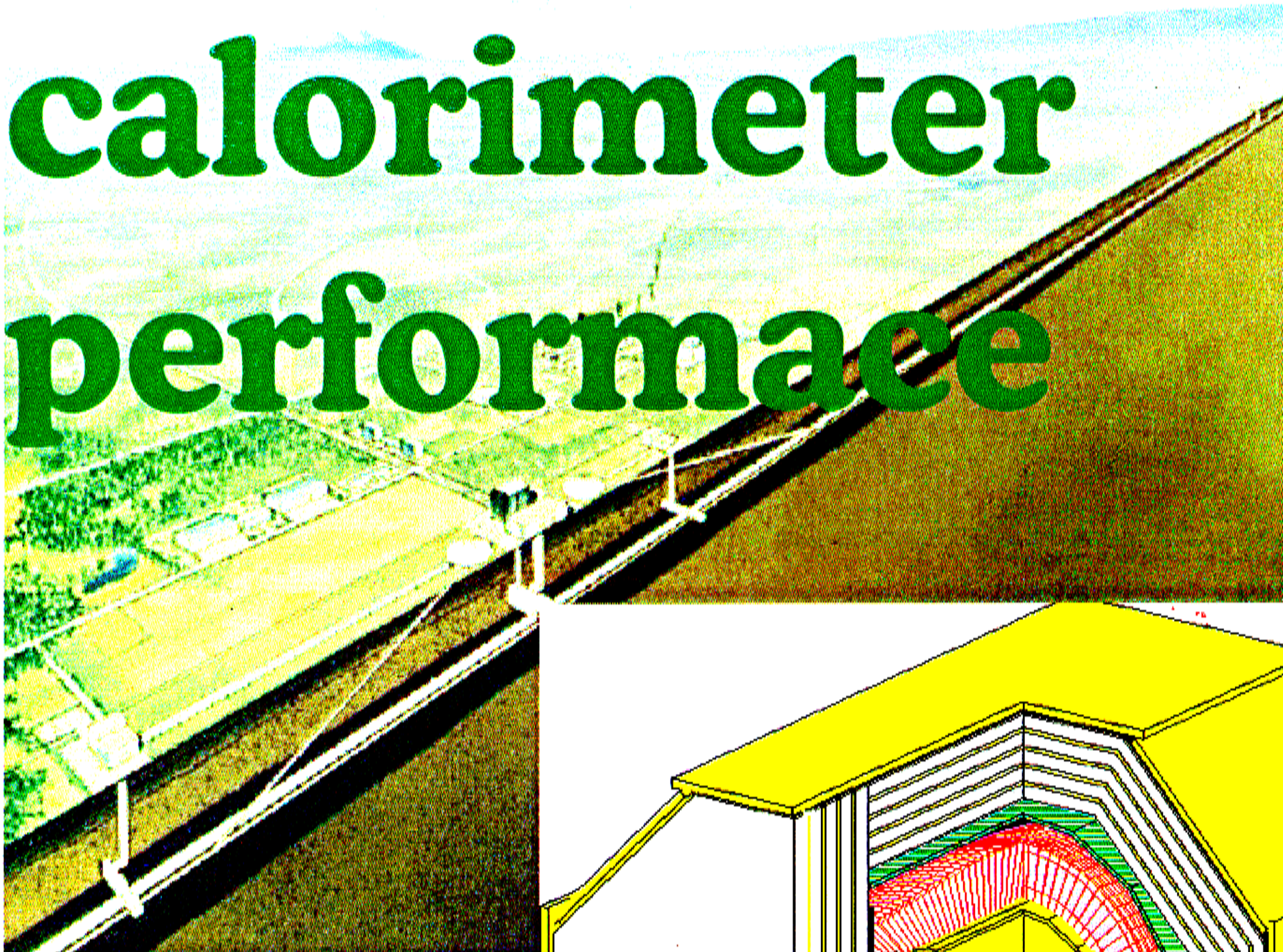
- Energy Resolution: $< \frac{10\%}{\sqrt{E}}$, $< 1\%$ c.t.
- e/π separation with lateral diode works:
  $< 5.0 \times 10^{-4}$ at 50 GeV
- Good Position Reconstruction
- No significative cracks

Second prototype:

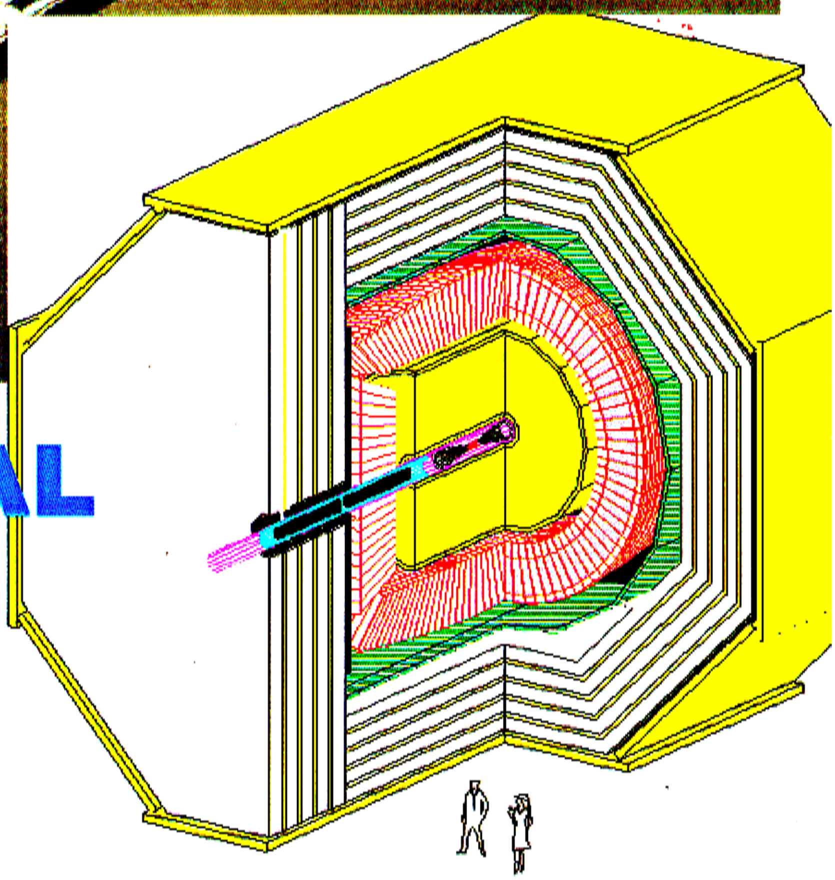
- Energy Resolution: $< \frac{15\%}{\sqrt{E}}$, $< 1\%$ c.t.
- e/π separation with 2 decay time scint. works:
  $< 6.0 \times 10^{-4}$ at 50 GeV
- See prototype 1...
- Possibility for more compact mechanics

Both prototypes meet requirements!

Tile/fiber hadron calorimeter performace



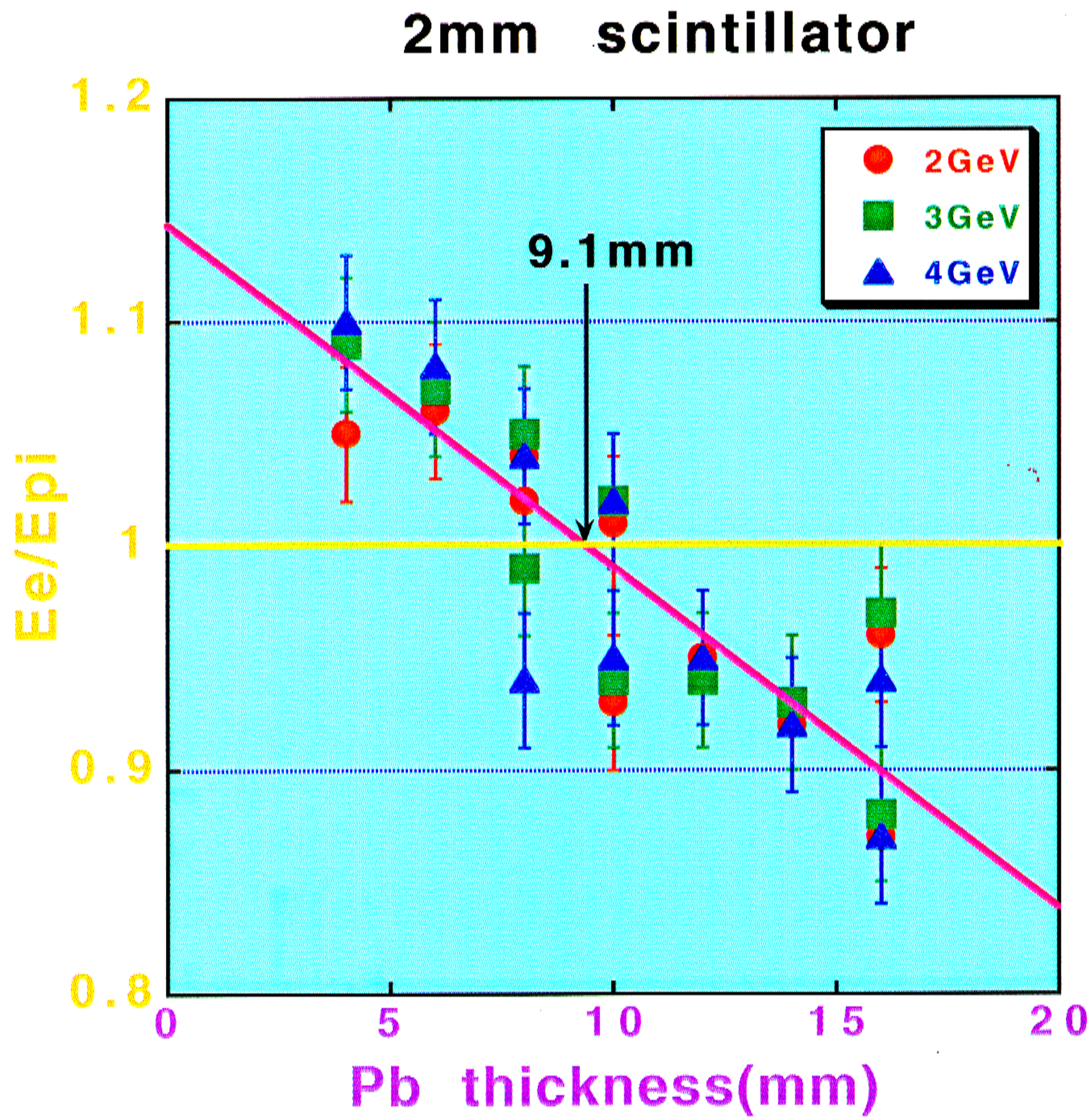
JLC-Hp CAL



Tohru
Takeshita
(Shinshu U)

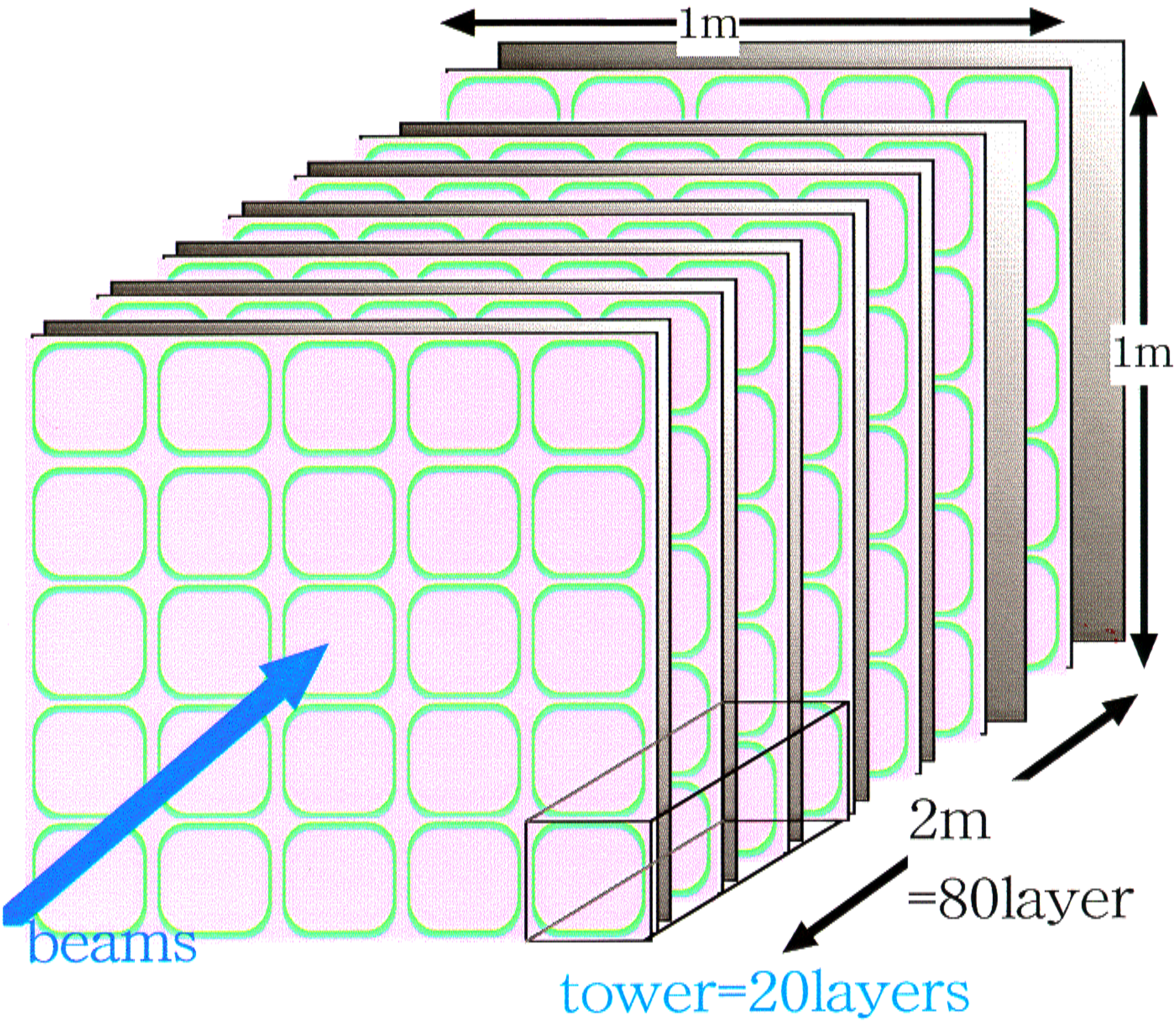
JLC-HCAL test module straight glooves

e/pi-ratio



JLC-HCAL test module

tile/fiber



5x5 towers X 4sectios

scinti.2mm+Pb8mm

$127X_0, 4.2\lambda_I$,9t

$+1.7\lambda_I$
+Straight groove CAL

TT-LCWS2000@Fermi

Tile/fiber hadron calorimeter performace

JLC-CAL

sandwitch Hp–CALs of Pb and plastic scintillator have been tested

energy resolution for 1-150GeV pions :

$\sigma/E = 46.6\%/\sqrt{E} \oplus 0.8\,\%$

e/p ratio for1-150GeV :

=1.0

need EM–fine sampling test

simulation

Shower position device in TILE ECAL

In order to have a better separation e/γ from hadron and a better position measurement

A preshower (PSD) and a Shower-maximum detector (SMD) are inserted in front of the TILE ECAL.→

- **PSD** 4.3 X0 , 6 layers of lead-scintillator sandwich and 2 read-out "layers"
- **SMD** 2 layers of scintillator strips with fibers
- Test beam at FNAL with 50, 75 and 100 GeV electrons, pions

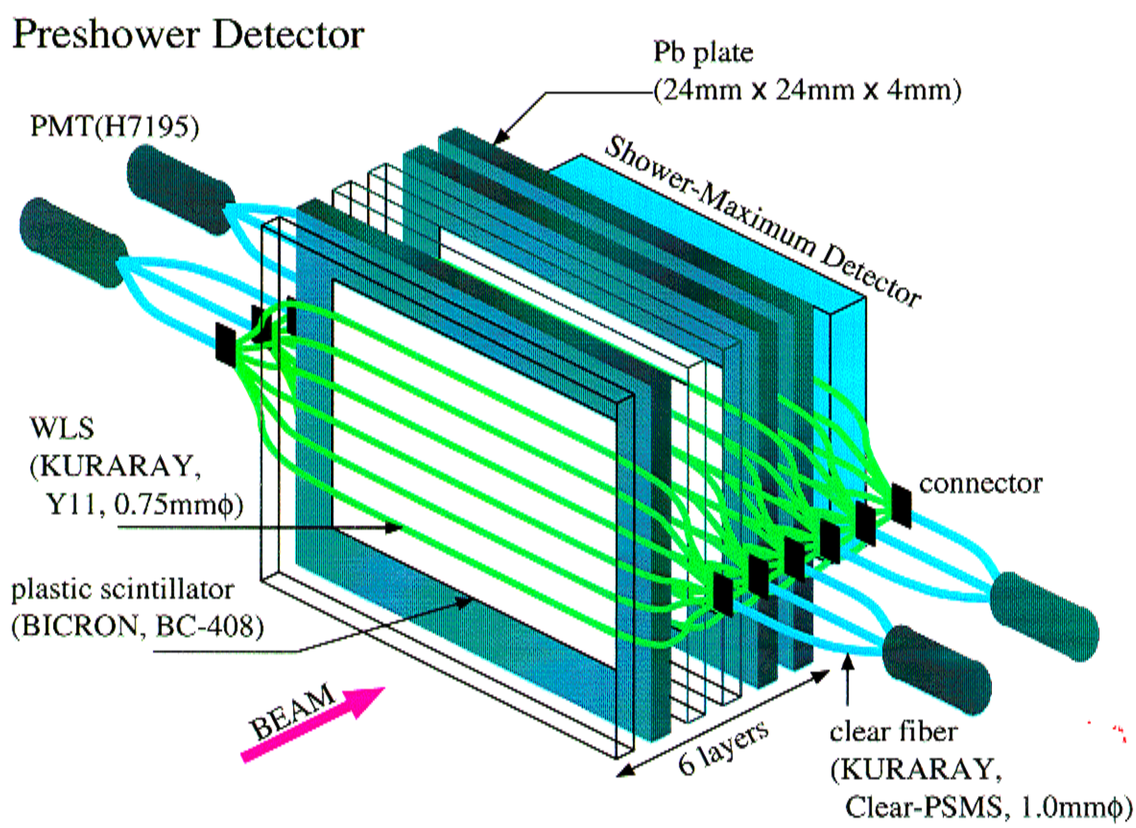
Test beam results

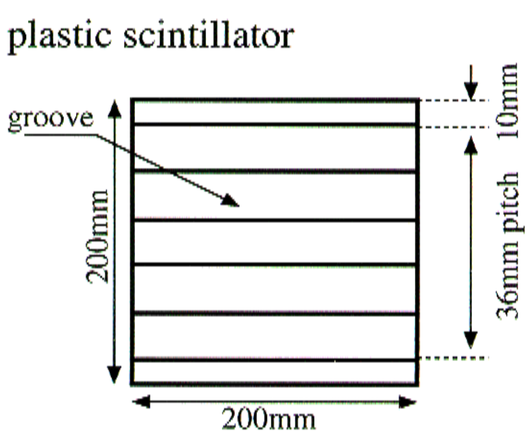
- For $\varepsilon_e = 98\%$, the pion contamination is $\varepsilon_\pi \sim$ few 10^{-3}
- Position resolution $\sigma_x = \frac{158.}{\sqrt{\mathrm{E(GeV)}}} + 0.5$ mm

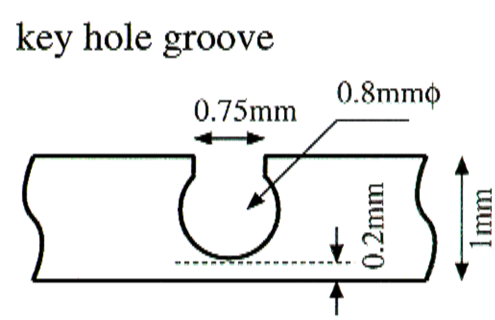
▷ **Low energy beam test**

▷ **What for jet environment ?**
which gain on TCA for instance ?

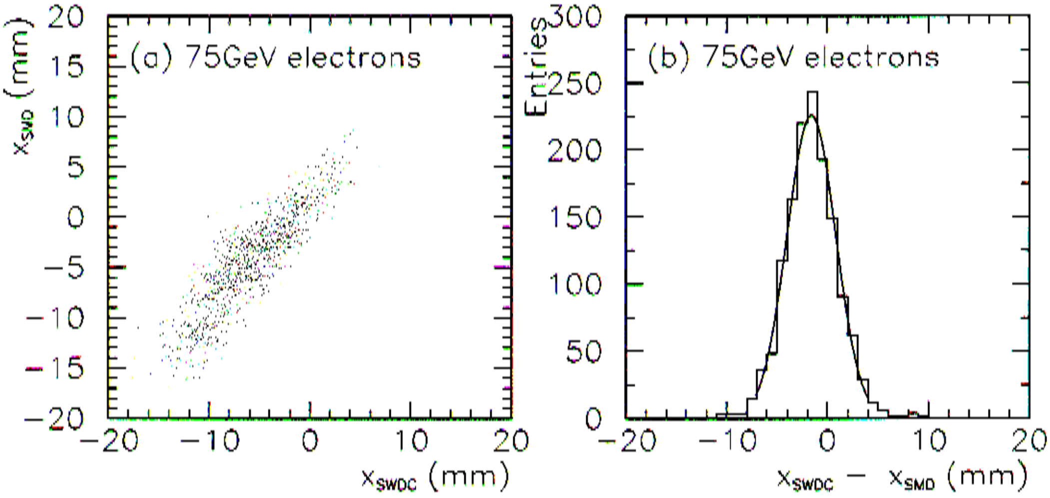
Preshower Detector (PSD)

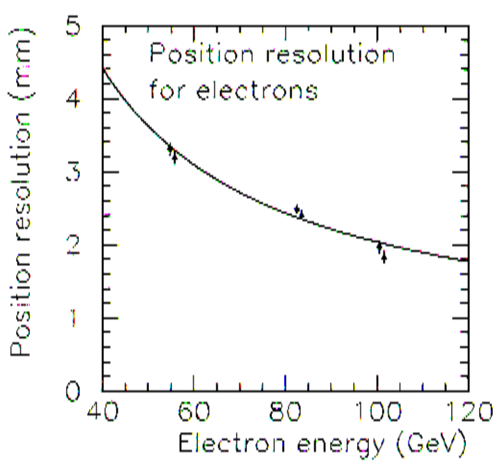






Position resolution





$$\sigma = \frac{(1.58 \pm 0.11) \times 10^2}{\sqrt{E}} + (0.46 \pm 0.14)\,\mathrm{mm}$$

Summary

- PSD/SMD prototype was tested with high energy beam (50 $\sim$ 100 GeV)
- Excellent e-ID capability for single particles

Method	r_π at ϵ_e=95% (75GeV)
R_{PS2}	14.0
N_{hit} in SMD	$\geq$ 11.3
S (spread)	30.2
D (depth)	719
S and R_{PS2}	487
D and R_{PS2}	1162
S and D	1162

- Reasonable position resolution for electrons

Future Prospect

- Performance test with low energy beam ?
- R&D of multi-pixel photo devices
- R&D of scinti-strip PSD / EMC to see 3-dim. EM shower development

My conclusion

(Pr. K. Fujii is waiting for)

- Eflow is a part of the calor. design
- Full simulation is recommanded to test any design
- $\lesssim 30\% / \sqrt{E}$ for JET is mandatory for the physics program of FLC

- 2 approaches for the calorimeter design

A • Compensated calorimeter

B • highly segmented calorimeter

At least one of the B design reach the

$$\sim \frac{30\%}{\sqrt{E_{jet}}}$$

And now

A lot of work remains on

- ΔE_{jet}, ΔM
- Cost estimate
- Technological challenges