SSC-SDE-12

SSC-SDC
SOLENOIDAL DETECTOR NOTES

MEETING ON SSC DETECTOR SIMULATION
SEPTEMBER 8, 1989

W.Greiman, D.Groom, D.Rotem, M.Shapiro, J.Siegrist, M.Strovink

Meeting on SSC Detector Simulation

LBL, Bldg 50b, Room 2222

9:00	Welcome	(S. Loken)
9:05	Overview of SSC Simulation Issues: Schedule, Requirements, etc	(M. Shapiro)
9:35	Discussion	
9:45	Overview of Issues in Software Management and Design	(W. Greiman)
10:15	Discussion	
10:30	Coffee Break	
11:00	Options for Specification of Detector Geometry:	
	- Overview/Geant (15 minutes)	(J. Siegrist)
	- CAD Products/Other commercial options?? (20 minutes)	(D. Rotem)
11:35	Discussion	
12:00	Lunch	
1:00	Options for Shower Simulations	
	- Overview/CDF Parameterization (20 minutes)	(M. Shapiro)
	- Wormsley et al Parameterization (15 minutes)	(M. Strovink)
	- Geisha/GFlash (30 minutes)	(D. Groom)
2:05	Discussion	
2:30	Discussion - Scope of Software Subsystem Proposal	(S. Loken)

M. Shapiro

Goals for this Meeting:

1. Begin to Specify Conceptual Design Requirements

2. Review current technology

3. Decide on short term strategy
   can we survive with present tools for letter of intent?

4. Begin planning for medium term

Issues:

1. User interface
2. Specification of Geometry
   - database?
   - code?
   - interaction with 1?
   - interaction with 3?
   - Speed, flexibility
3. Shower modeling
   - parameterizations?
   - full shower modeling?
   - Verification / documentation

Study of Pattern Recognition / Reconstruction

- Track finding hardware / algorithms
- cluster finding
- electron identification
- needs for detector segmentation

Must be able to include

- bremstrahlung
- Pair production
- event overlap
- noise
- electronics shaping

Simulation of raw hits required

Understanding Response + Resolution :
Detailed Simulation

eg: - Generation of response maps
- Evaluation + comparison of detector designs
- Fine tuning of calorimeter response

Again, different levels of detail needed
- global design issues
(eg: coil placement)
simplified geometry, parameterized showers

- crack regions - detailed design
. would eventually like to include struts, bolts, etc
. may need full shower simulation

* Tight coupling between design + simulation
- Modification of design → need for fast turn-around evaluation
- Need to respond to new information
  - CAD
  - test beam
- Need to share information
  - geographic
  - various subsystems

Physics Assessment : Modeling of Signals and Backgrounds

- rates vary by <u>many</u> orders of magnitude

  Full simulation of high rate processes not possible / desirable

  { Warning: never believe the <u>tails</u> of Monte Carlo distributions. No point in studying $> 10^5$ rejection factors with detailed simulation. Better off using physical intuition }

- for majority of applications, can use parameterized detector response

  eg: For a jet specify response + resolution (not necessarily gaussian) as a fn of η, ϕ, P_t ...

Note: this level of simulation can be implemented immediately

Warning: The assessment is only as good as the parameterization

Simulation Needs

Large range of tasks with very different requirements for speed, accuracy, level of detail

Need to Taylor simulation to specific problem while maintaing same framework

eg:
- user interface
- input from generators
  - ISAJET
  - Lund / Pythia
  - Herwig
  - Papageno ...
- method of specifyng geometry (although level of detail varies)
- method of invoking shower simulation (again varying levels of detail)
- form of output
  - raw data
  - tracks + clusters
  - electrons, jets, γ's ...

Let's look at some specific examples

Today's Envroment

large collaborations : several 100 to 1000

- wide geographic distribution
- large variation in skills, resources

take CDF + DΦ as prototypes :

- VAX for primary source code, code management
- Bitnet communication
- Distribution of code / databases via Decnet / bitnet servers

for now, code all in fortran

- can we use other language (s) for back bone?
- expect "users" to insist on Fortran for long time
- how to handle operating system dependence?

{ Need for unified online / offline approach }

Timescale

1. Letter of Intent due May 1990
   - Sept 25, 26 meeting at FNAL
   - Oct 1 subsystem proposals due
   - Oct 2-4 Dallas meeting
   {formation of collaborations}
   {specification of detector geometry | technology ? }

2. Proposals ~ Spring 1992
   - detailed engineering design
   - hardware + software specification
   - proto-types ?

3. Finished detectors 1998 - 2000 ?

Today, we will concentrate on short + medium term.

Short term: patch approach
medium term: . proto-type for future
. development of forward-looking tools

An Overview of SSC Simulation Issues

I Definition of Enviroment
- timescale
- sociology
- code development / communication

II Simulation Needs
- physics assessment
- algorithm + hardware design
- detailed detector design

III Issues for this meeting
- geometry
- shower simulation

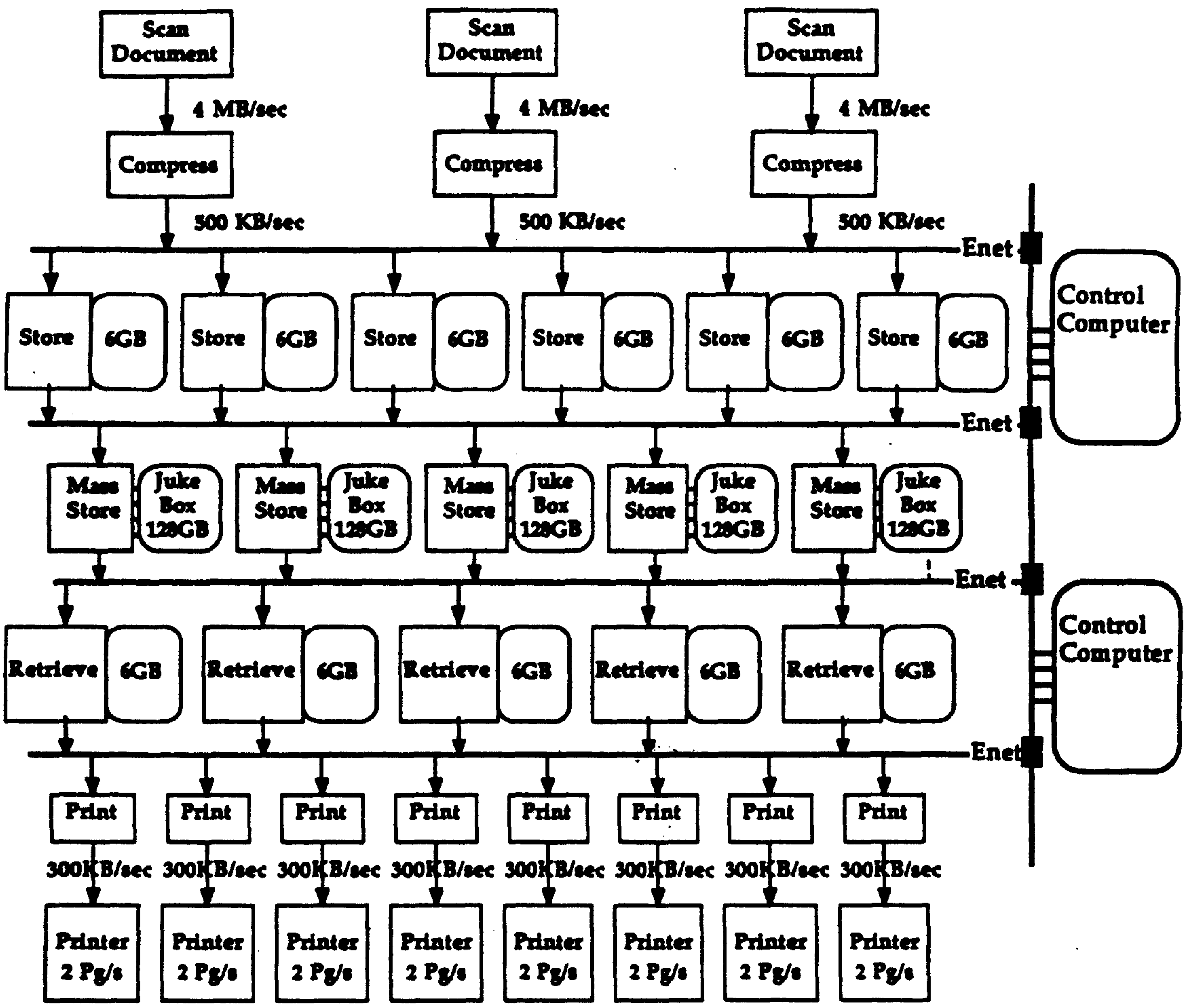
MANAGING A LARGE SOFTWARE DEVELOPMENT PROJECT

William H. Greiman
Lawrence Berkeley Laboraory

Presented at the SSC Controls Workshop

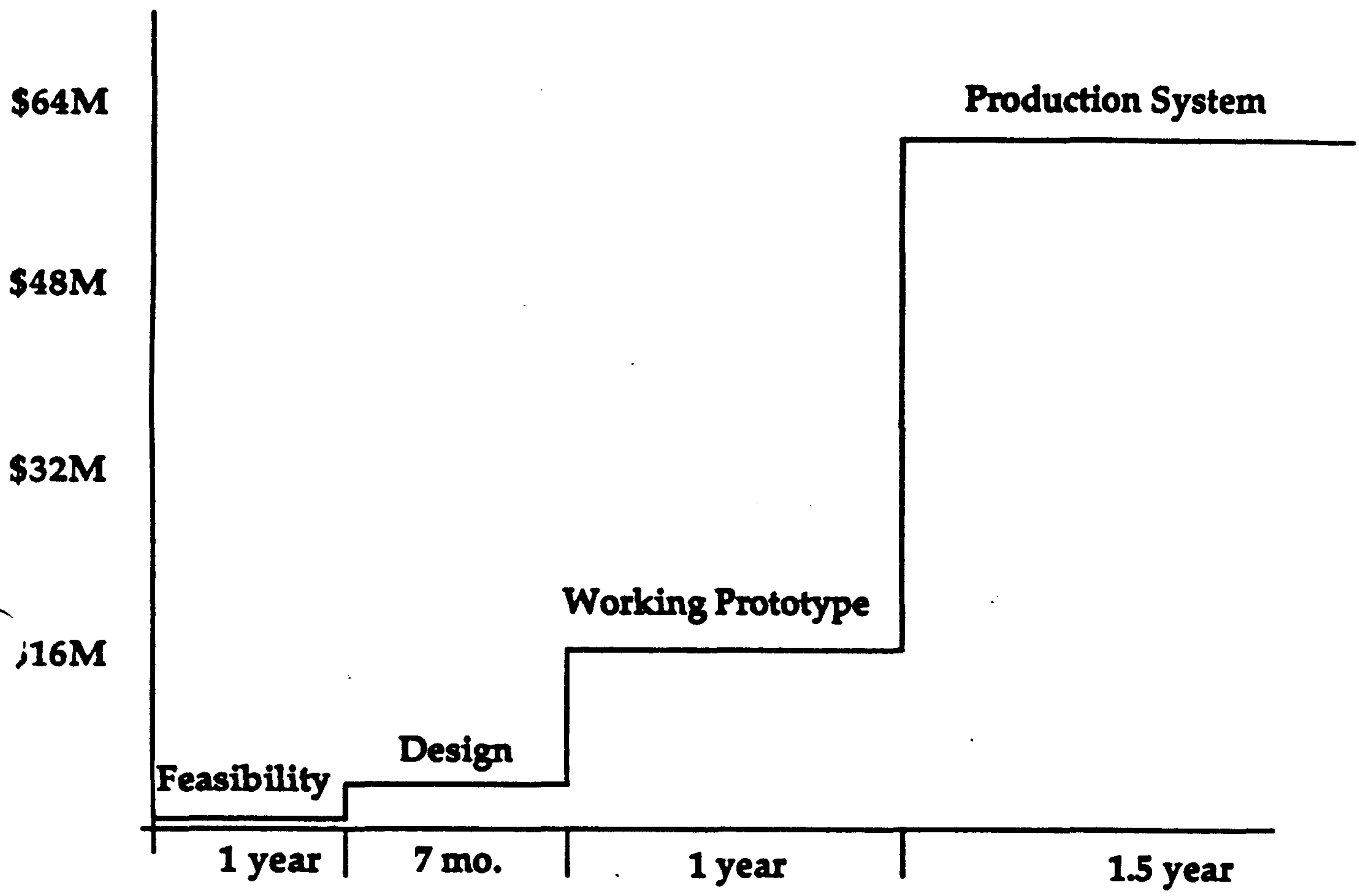
September 5-8, 1989

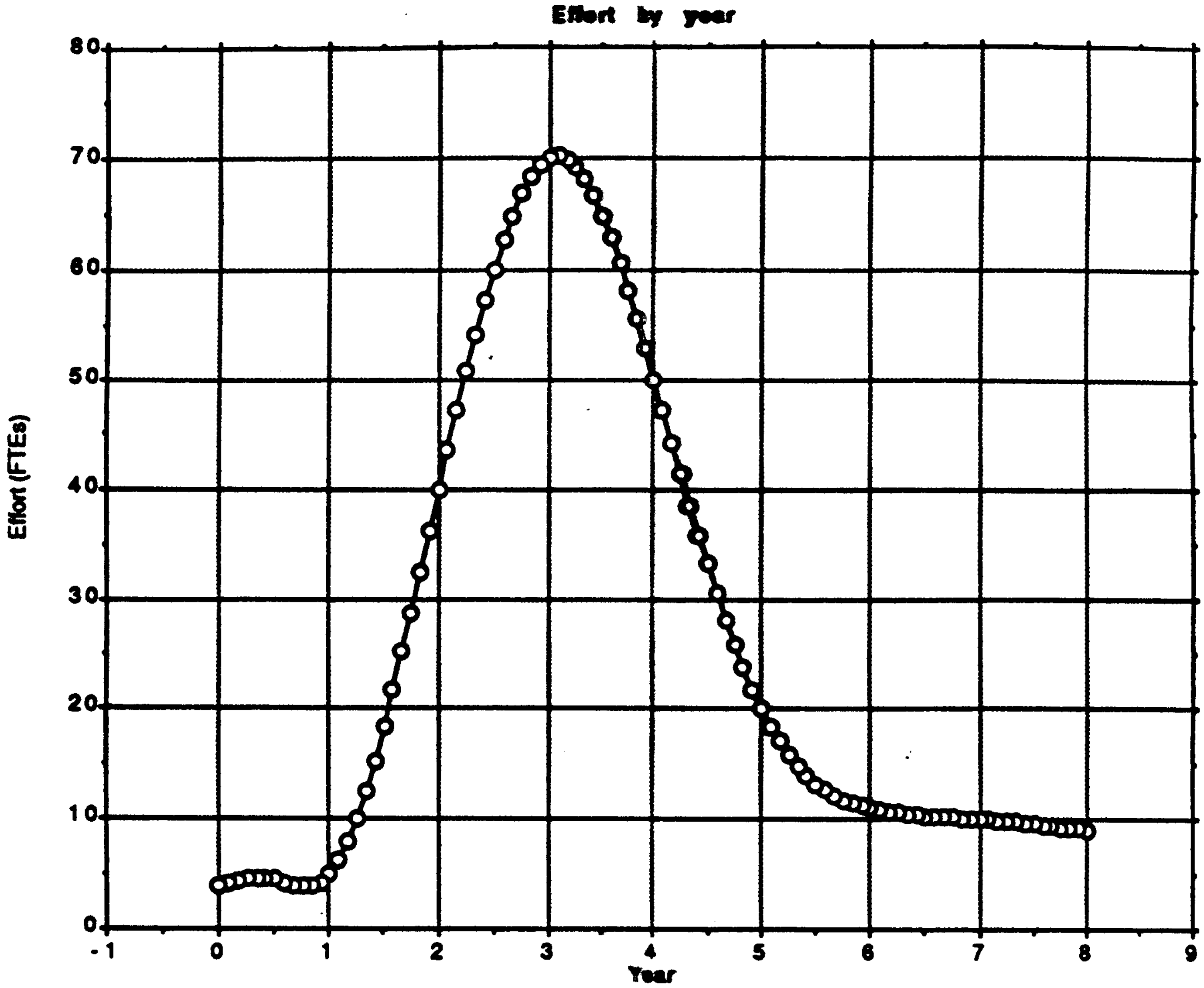
THE AMERICAN EXPRESS BILLING SYSTEM



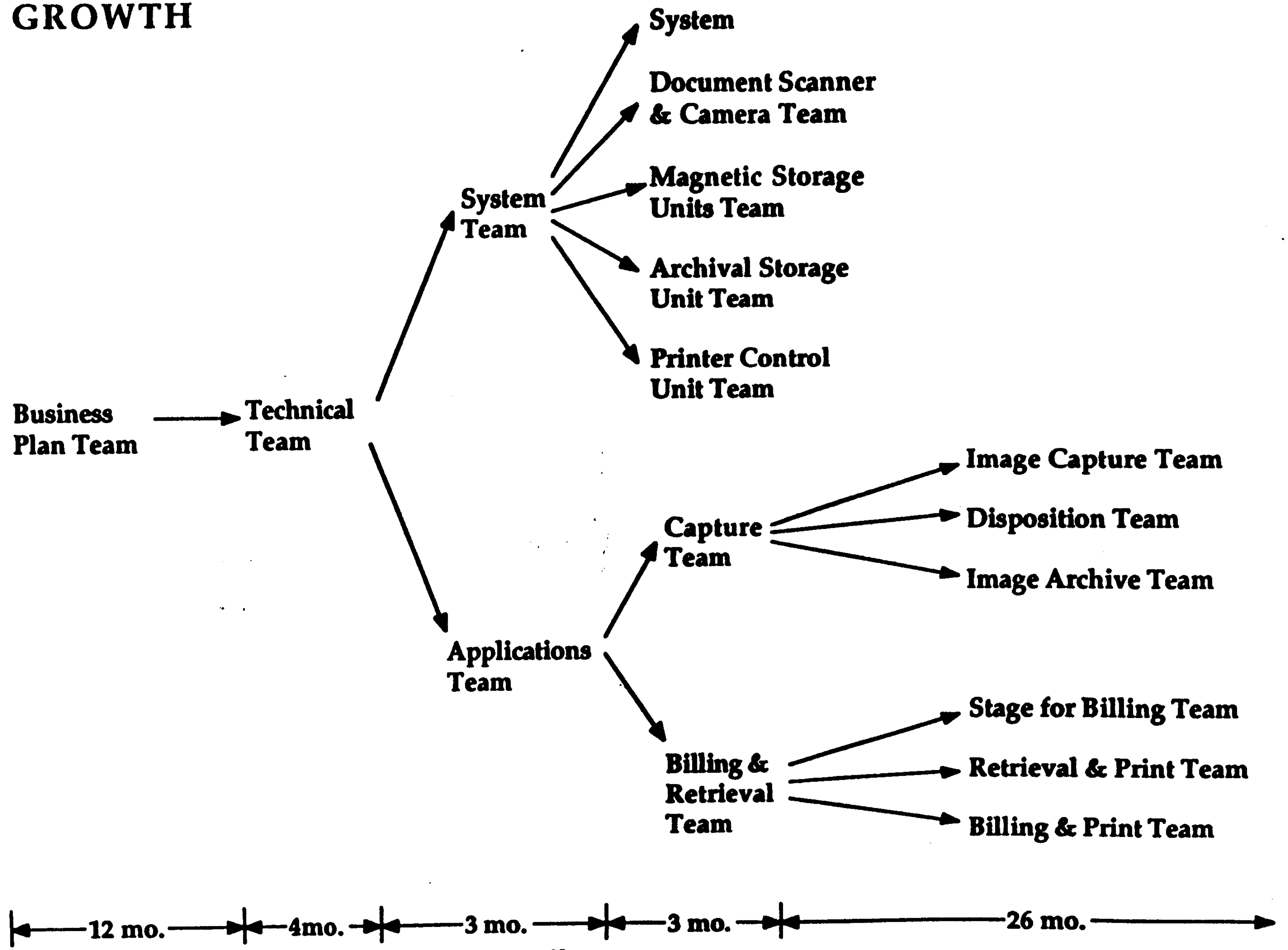
- Two sites - Phoenix, Ft. Lauderdale
- Fiber optic T1 link connection

MAJOR DECISION POINTS: (RISK CONTROL)



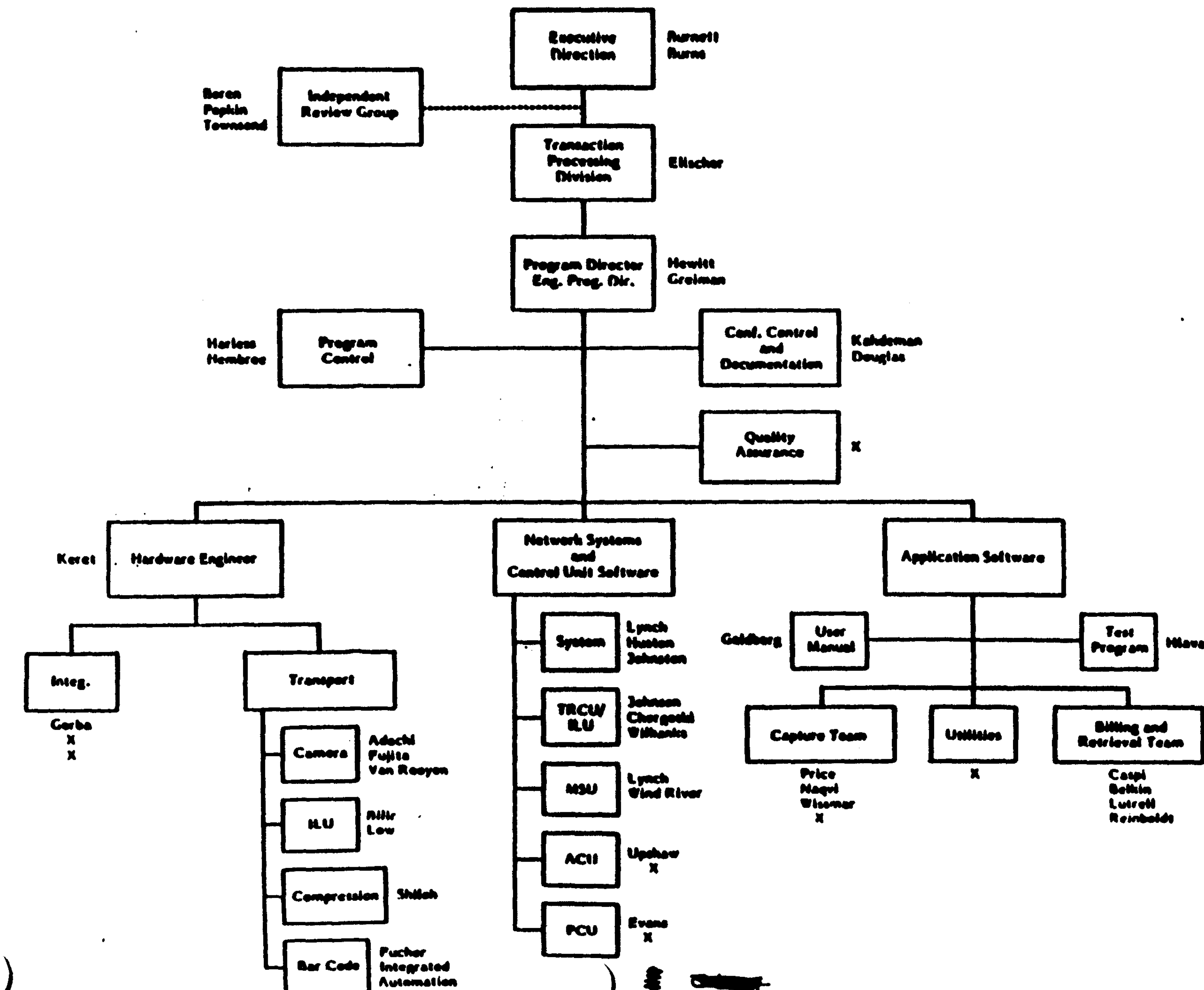

Effort by year
Effort (FTEs)
Year
80
70
60
50
40
30
20
10
0
-1
0
1
2
3
4
5
6
7
8
9

GROWTH



Business Plan Team
Technical Team
System Team
System
Document Scanner & Camera Team
Magnetic Storage Units Team
Archival Storage Unit Team
Printer Control Unit Team
Applications Team
Capture Team
Image Capture Team
Disposition Team
Image Archive Team
Billing & Retrieval Team
Stage for Billing Team
Retrieval & Print Team
Billing & Print Team
12 mo.
4mo.
3 mo.
3 mo.
26 mo.

ECCB Program Office



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PROJECT MATRICES:

	Project 1	Project 2	Project 3	...
Requirements				
Data model				
Data flow diagram				
State model				
Operator interface				
Reports generated				
Top level design				
Module design				
Test procedures				
User Manuals				
Operators guide				

↑ Life cycle

Examples:

- Schedule
- Work assignments
- Review dates
- Milestones

...

REVIEWS:

- **Weekly internal technical review of each team.**
- **Quarterly external technical review of entire project.**
- **Quarterly management review of entire project.**

WEEKLY INTERNAL TECHNICAL REVIEWS:

- Attended by team members plus engineering program director.
- Frequency is function of team performance (weekly is the average).
- Review results of previous action items.
- Evaluate progress toward milestones.
- Determine if resource adjustments are required.
- Determine if goal adjustments are required.
- Generate new action items.
- Generate summary for monthly management report.

QUARTERLY EXTERNAL TECHNICAL REVIEWS:

- **Dress rehearsal by internal review group.**
- **Attended by internal team leaders and upper management plus external technical and management reviewers.**
- **Document driven: distributed a week ahead of time.**
- **Tended to be reviews of requirements analysis, top level design, and testing/acceptance procedures.**
- **Generates list of issues and action items to be tracked.**

QUARTERLY MANAGEMENT REVIEWS:

- Attended by internal company president(s), VPs, and project senior management, as well as external company VPs, their assistants, and senior technical staff. (About 10 people.)

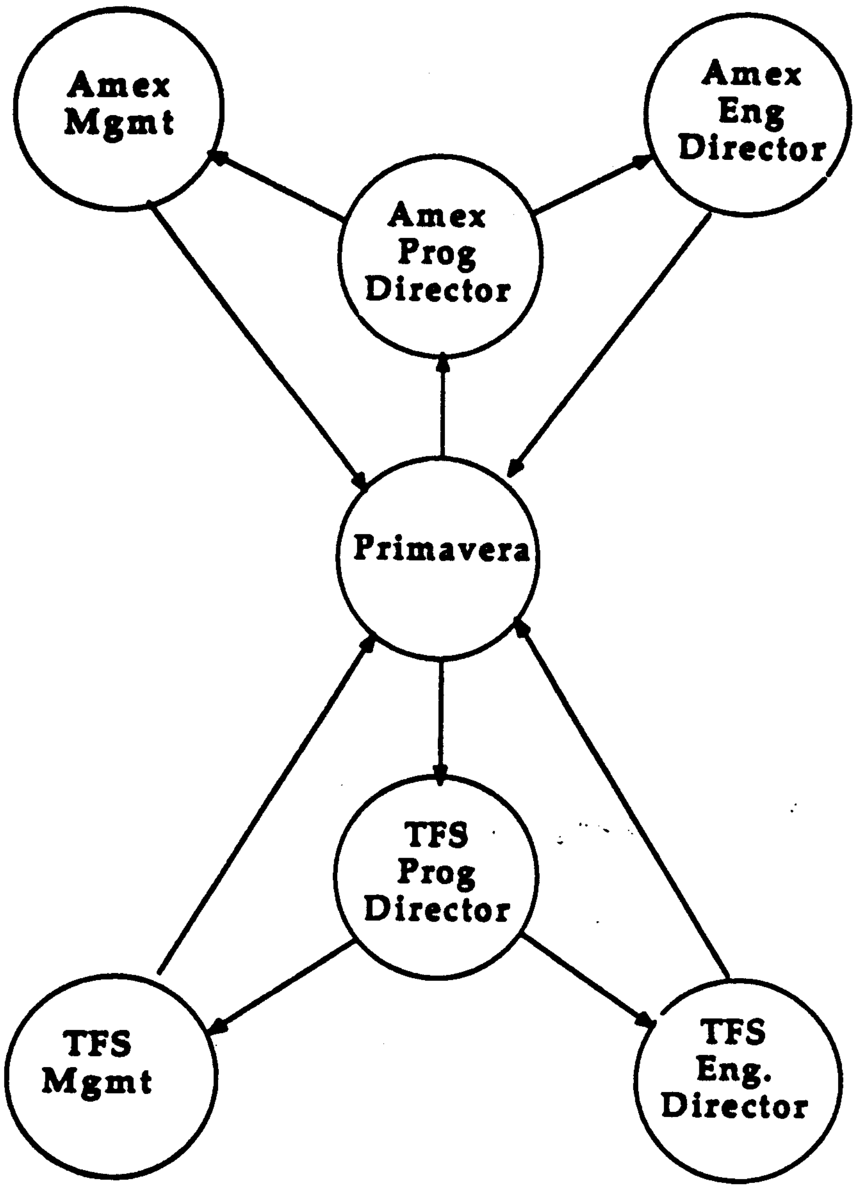
- Agenda determined by external reviewers.

- Examples include
  - milestone reviews
  - demonstrations
  - cost reviews
  - key technical issues
  - early go-ahead decisions

- Generates a list of issues and action items to be tracked.

PROJECT TRACKING SYSTEM:

- .5 FTE's to operate



STANDING DOCUMENTS:

- **Management Plan**
- **Functional Overview**
- **System Design Overview**
- **Software Development Plan**
- **Project Notebooks**
- **External Interface Definitions**
- **Test Plan, Requirements and Procedures**
- **Operators Guide**
- **Maintenance Guide**
- **Training Manuals**
- **Monthly Management Report**
- **Reference Material and Database**

DOCUMENT AND CONFIGURATION CONTROL TEAM:

- **3 FTE's [!]**

- **Based on Unix configuration control tools -**
  - **make**
  - **SCCS**
  - **awk**
  - **...**

SYSTEM INTEGRATION AND ACCEPTANCE TESTING TEAM (Quality Assurance):

- 3 FTE's TFS + 2 FTEs Amex
- Independent of development teams.
- Develop testing plans, requirements, and procedures.

SUBCONTRACTS:

Excelan	- Large Packet E-net
Informix	- Port to Intgtd. Solutions
Intgtd. Solutions	- VME/Unibus Adapter (Xerox)
Intgtd. Solutions	- Modify SCSI for optical drive
Xerox	- Add graphics features to 9700
Wind River	- Integrate VX works with Unix
Bank Tech. Intl.	- Two level 403B OCR
OSI	- Improved formatter for opt. disk
Intgtd Automtn	- Bar code read for special ink & code
Wind River	- Image storage on raw Unix disks
East Coast Co. ??	- Mech. mods. for paper registration

Able to use 20 contract programmers (6mo. - 1 yr.).

Normal subcontracts for fabricaton of PCBs, custom racks, etc..

CONCLUSIONS:

COSTS:

- Lots of hard work.
- ~ 10% *additional* overhead (mostly doc. mgmt.)

BENEFITS:

- Provides a picture of whole project in time.
- Protects the client's basic business.
- Protects the contractor's basic business.
- Allows organization structure to match work structure.
- Keeps project on time and on budget.
- Warns when resources should be reassigned.
- Ensures that products meet client's requirements.

8-SEP-89
Siegrist

GEOMETRY ISSUES

* Level of detail of the geometrical simulation should match detail of shower (detector) simulation (speed!)

* Should be easy to modify the geometry, preferably via interactive means

* Should be a 'clean' interface between geometry & detector simulation, so different levels of detail of simulation are flexibly introduced/modified (about code)

* A single framework for all levels of detail is preferred

* Drawing of geometry essential for checking results

* 'detector' interactions have to be included:
    - energy loss
    - γ conversions
    - decays in flight

      ⋮

* flexible user interface for:
    - changing geometry
    - running code
    - changing shower simulation

      ⋮

* documentation

* Appropriate catalog of basic shapes

* sensible interface to Monte Carlo generators (parton, particles)

How did WANG (etal) Implement
GEANT ?

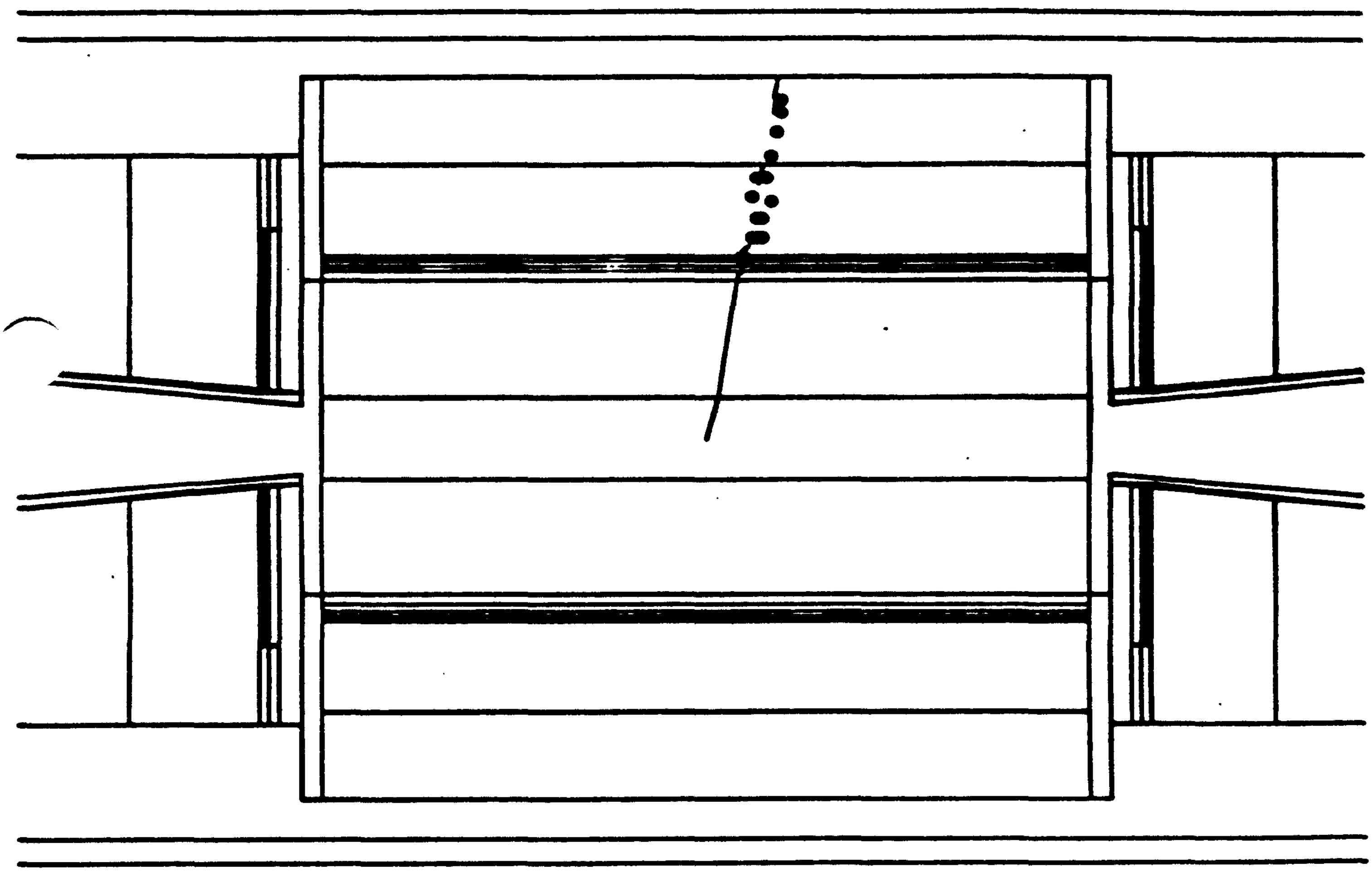
* particles come in thru ISAJET description, he moves them to GEANT

* (LSD) Detector geometry rather simply described, so program runs fast

* bin hits into towers After energy deposition => no towers in GEANT

* Drawing ....

Single π into 'LSD' . ;;



How Does GEANT (ala Wang) meet the requirements?

+	−
- Level of detail can be matched & modified	- 'Interface' is a piece of fortran, 'tuned' by hand (not clear automatic CAD output useful ...)
- Internal interface ≈ clean between geometry & shower simulation	- towers missing from list of shapes ...
- Drawing exists	- modification of geometry via interactive means will 'never' happen
- 'Detector' interactions included in a systematic way	- Drawing needs improvement - figures with content for debugging (Hooks there)
	- existing user interface poor/clumsy (not acceptable for wide Distribution)

— Documentation ...

Author(s) : F.Bruyant
Origin : GEANT3

Submitted: 01.10.84
Revised: 20.05.86

WANg's +

Simplified Program Flow Chart

```
MAIN (user)
|
|- GZEBRA  initialisation of ZEBRA system, dynamic core allocation
|- UGINIT  (user)
|    |
|    |- GINIT      initialisation of GEANT3 variables
|    |- GFFGO      interpretation of data cards
|    |- GZINIT     initialisation of ZEBRA core divisions and link areas
|    |- GPART      creation of the 'particle' data structure JPART
|    |- GMATE      creation of the 'material' data structure JMATE
|    |- 'user code'  description of the geometrical setup, of the sensitive detectors
|    |                 creation of data structures JVOLUM, JTMED, JROTM, JSETS
|    |- GPHYSI preparation of cross-section and energy loss tables for all used materials
|
|- GRUN  loop over events
|   ┌┐
|   |
|   |- GTRIGI   initialisation for event processing
|   |- GTRIG    event processing
|   |    |
|   |    |- GUKINE (user)  generation (or input) of event initial kinematics
|   |    |- GUTREV (user)
|   |    |      |- GTREVE (loop over tracks, including any secondaries generated)
|   |    |            |- GUTRAK (user)
|   |    |                  |- GTRACK  control tracking of current track
|   |    |                        |- GMEDIA  find current volume/tracking medium
|   |    |                        |- GTVOL   loop over successive media seen by the particle
|   |    |                              |- GTGAMA/GTELEC/.... tracking of particle according to type
|   |    |                                    |- GUSTEP (user) recording of hits in data structure JHITS
|   |    |                                                   and of space points in data structure JXYZ
|   |    |- GUDIGI  computation of digitisations and recording in data structure JDIGI
|   |    |- GUOUT   output of current event
|   |
|   └┘- GTRIGC  clearing of memory for next event
|
|- UGLAST  (user)
|    |
|    |- GLAST    standard GEANT3 termination.
|
stop
```

Overall Conclusions:

- Wang's Implementation of GEANT may meet most short & medium term needs.
- not going to get interactive detector modification a la CAD out of this.
- User interface obviously needs work
- Looks much better than, e.g., CDF framework

Short term:

- people other than the 'usual suspects' get some results with existing code
- figure out how to clean up user interface (mms, patchy, etc.) in some maintainable way

D. Rotem

Main Problems

- Communication between the designers of the system and the engineers building it.
  - ☐ Exchanging initial design information
  - ☐ Recording of changes made to the design by the engineers.
- Consistency checking of the design geometry
- Particle Tracking algorithms are slow
  - ☐ Data Structures which are convenient for designers are not always efficient for particle tracking.

Commercial CAD products (AUTOCAD)

Advantages:

- Offer interactive tools for drawing and generating a design database

- Come with a programming language (AUTOLISP) which allows modifications and enhancements of the package

Disadvantages:

- User Interface is Engineering oriented (Physicists don't like it)

- Data Structures generated are not geared towards particle tracking or ray tracing.

Ray tracing algorithms

- Perform some space subdivision algorithm

  ☐ Hierarchical Bounding Volumes

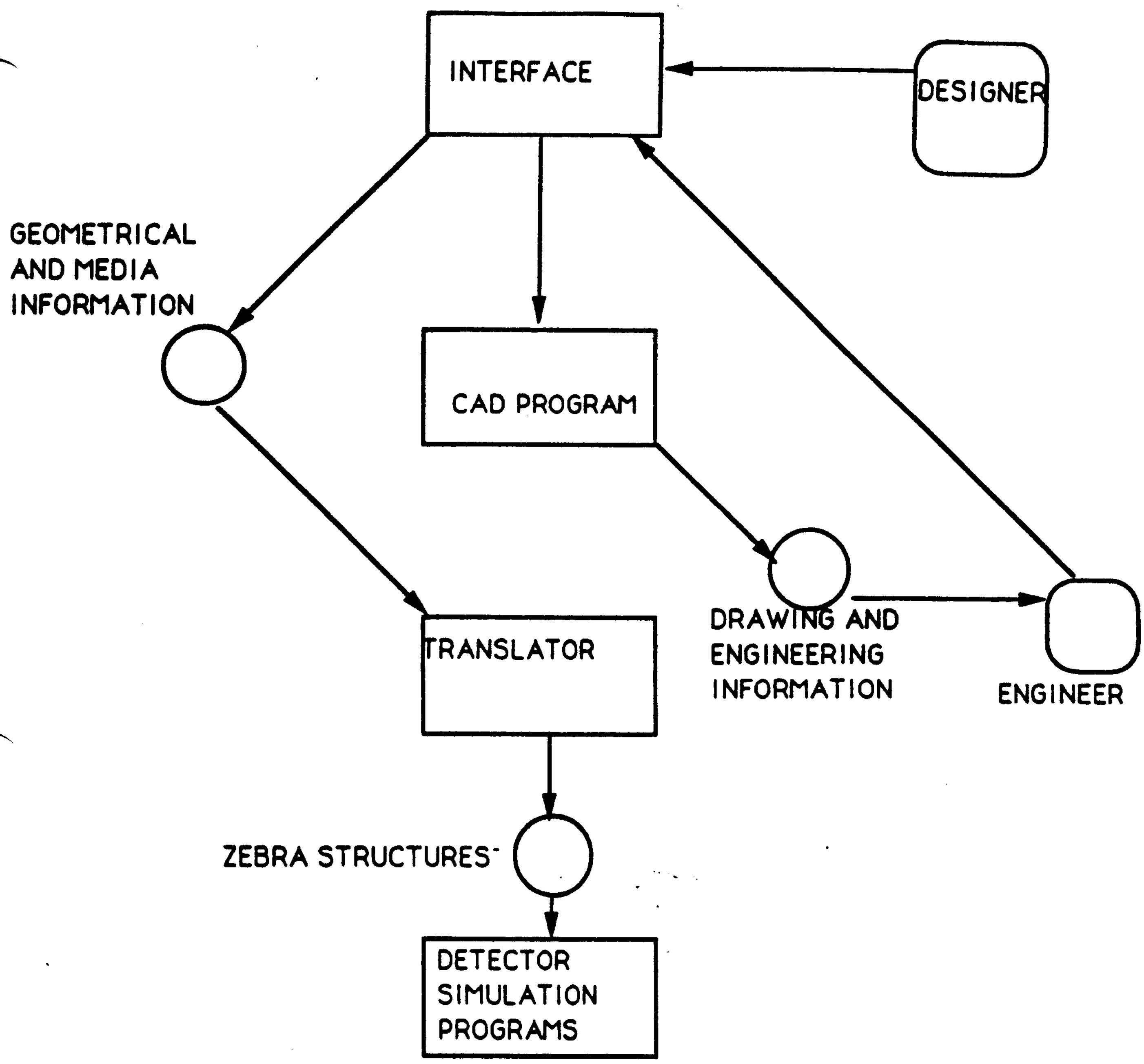
  ☐ Adaptive Grid Methods

  ☐ Hybrid Techniques combining adaptive subdivisions and bounding volumes [Glassner, 1988].

- Fast algorithms to move to neighbouring volumes

- Minimize expected number of object-ray intersection calculations

  Ratio of 1:50 between good and bad structures [Goldsmith et al. 87]


INTERFACE
DESIGNER
GEOMETRICAL AND MEDIA INFORMATION
CAD PROGRAM
DRAWING AND ENGINEERING INFORMATION
ENGINEER
TRANSLATOR
ZEBRA STRUCTURES
DETECTOR SIMULATION PROGRAMS

Proposed Solution

- Use a CAD system as a component in the system

Develop the following additional programs:

- An interface program tailored specifically for detector designs.

- A translator program from CAD structures into efficient structures for particle tracking.

- Adapt Ray tracing algorithms to the detector environment

Advantages

- Both designers and engineers will use the same system eliminating inconsistencies

- Design integrity checking can be performed automatically

- A detector design database will be created
  Keeping track of additional information, versions, bill of materials etc.

- Interface program simplifies the design task (Menus, Windows etc.)

- Translator can generate efficient data structures such as Oct-trees, Adaptive Grids etc.

M. Shapiro

CDF Shower Parameterizations

Philosophy same as Longo + Sestili, Bock et al, Womersley et al.

- ray tracing in detector (include B field)
- specify starting position of shower as Fn of # int. length, rad. length (use species + momentum dependent interaction x-section)
- parameterize transverse + longitudinal spread

What's different:

- parameterizations tuned to CDF test beam data
- fluctuations included.

Fast Simulation Geometry

QFL Geometry

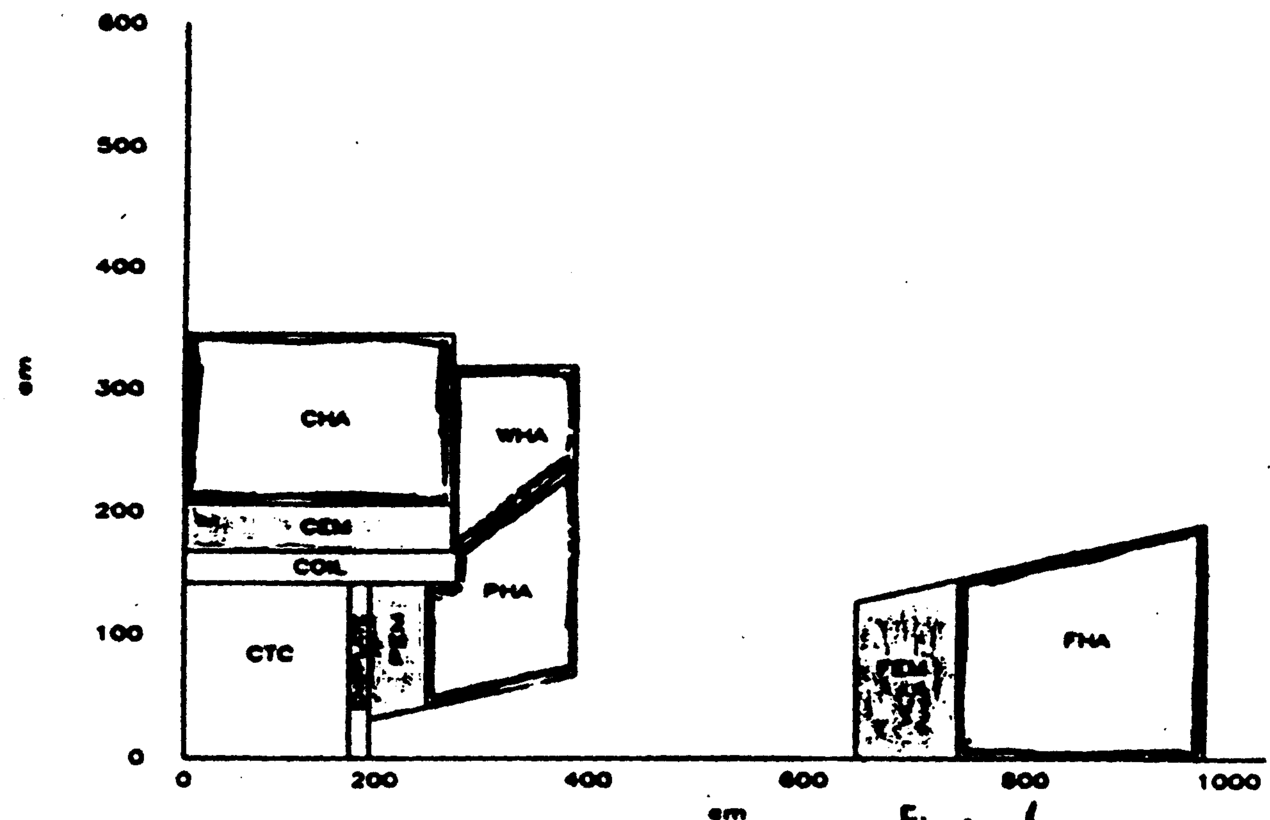
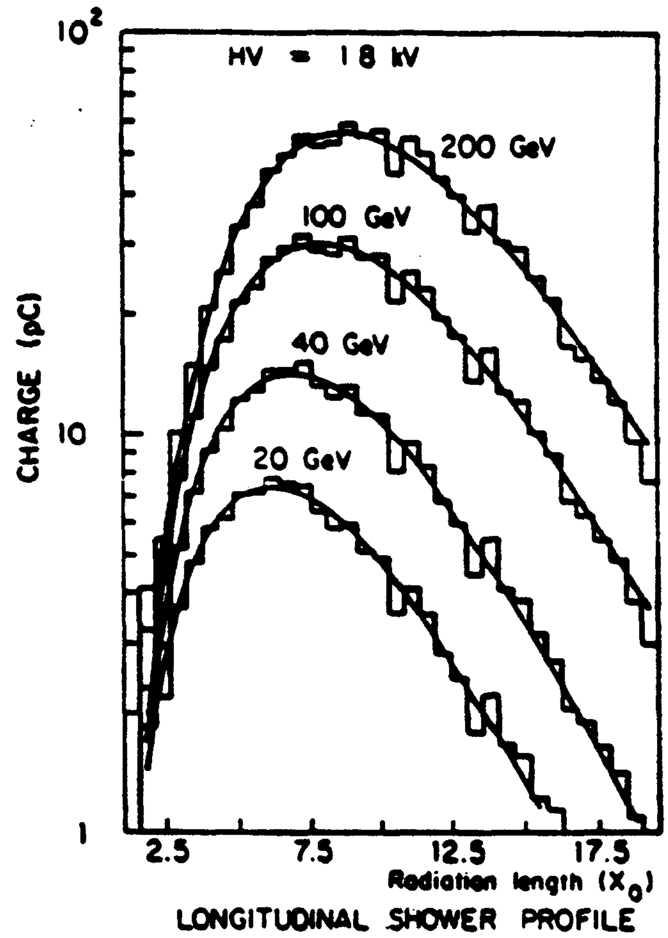


Figure 1

yellow = EM calorimeter
green = hadron calorimeter



Longitudinal profile of the electron induced shower measured by the anode wire planes.

Figure 3. Longitudinal profiles at various energies

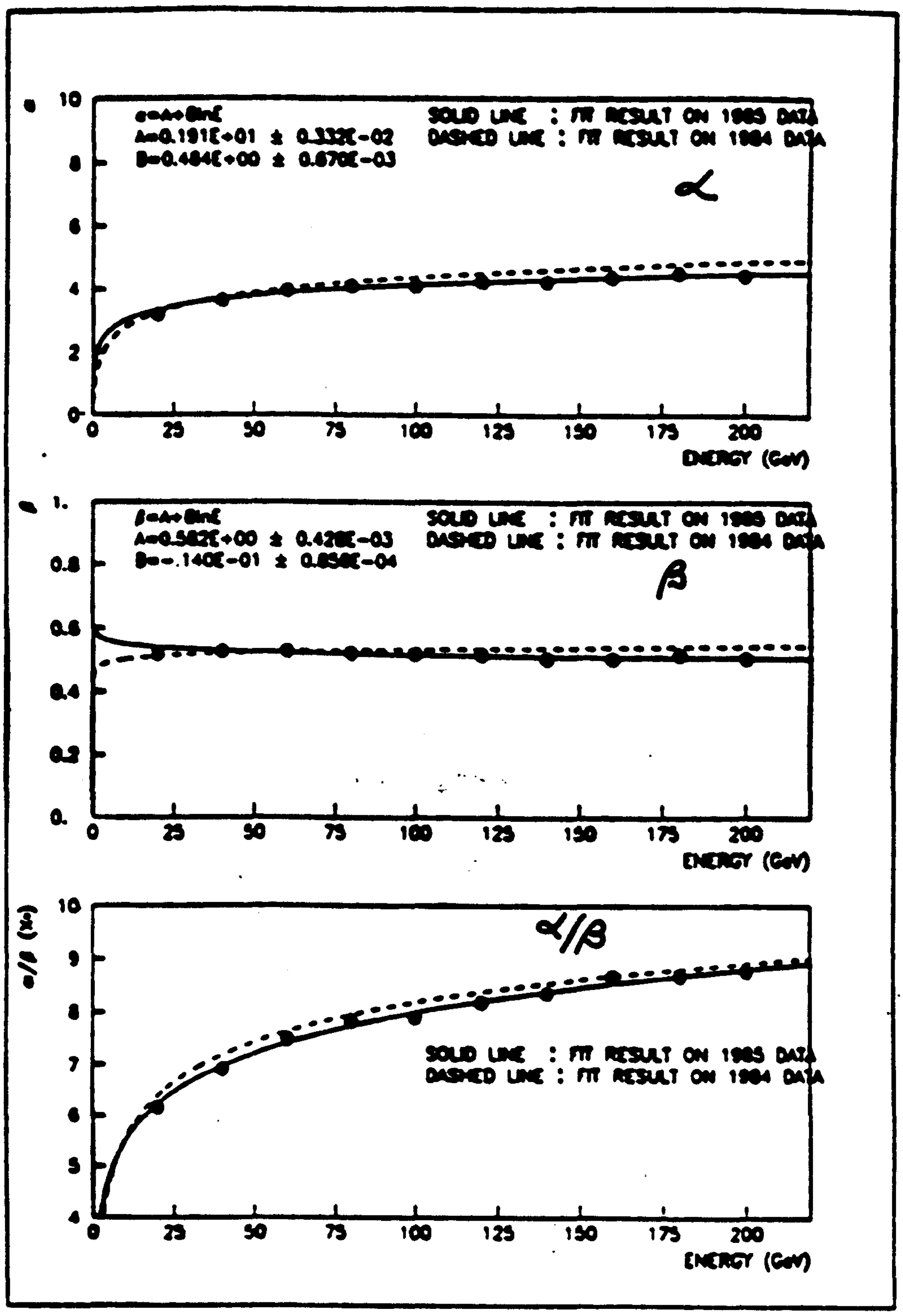


Figure 2. Energy dependence of shower parameters

Electromagnetic Showers:

use standard Form:

$$S(t) = K t^{\alpha} e^{-\beta t}$$

where

$$\alpha = 1.91 + 0.484 \ln E$$

$$\beta = 0.58 - 0.014 \ln E$$

these values have been measure in PEM
(Pb- MWPC ~ 18 r.l. thick)
readout every .5 r.l.

also, include fluctuations in α, β
(correlated parameters !!)

Hadron Showers: Much more complicated

Model as two components

"hadronic" depends on # interaction length

"electromagnetic" depends on # radiation lengths

Bock parameterization

$$\frac{dE}{ds} = k\left\{ \underbrace{W s^{\alpha-1} e^{-\beta s}}_{\text{electromagnetic}} + \underbrace{(1-W)\, t^{\gamma-1} e^{-\delta t}}_{\text{hadronic}} \right\}$$

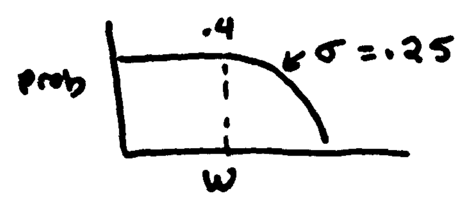
$\alpha = 1.0 + .036E \quad (E<10) \quad$ or $\quad .62 + .31\ln(E) \quad E>10$

$\beta \approx .22$

$\gamma = \alpha$

$\delta = .81 - .024 \ln(E)$

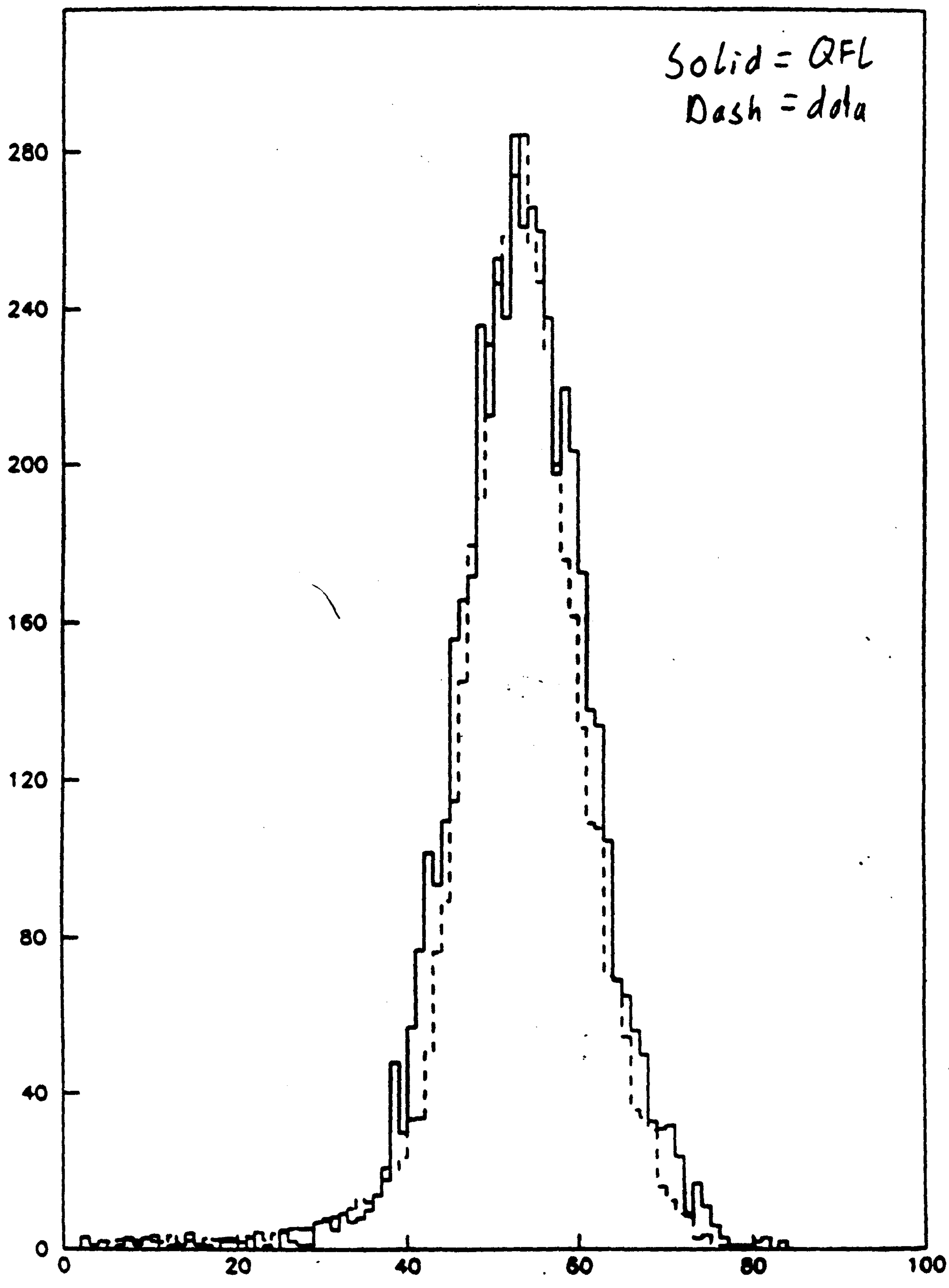
W is fluctuated



other parameters also allowed to fluctuate e/h : non-compensating calorimeter ⇒ different detector responses to $\pi^\pm$ + e^-

	w component	1-w component
EM	1.0	.4
Had	1.15	.9

also, hand tuning of low energy response + overall resolution.



NUMBER OF PIONS Figure 5

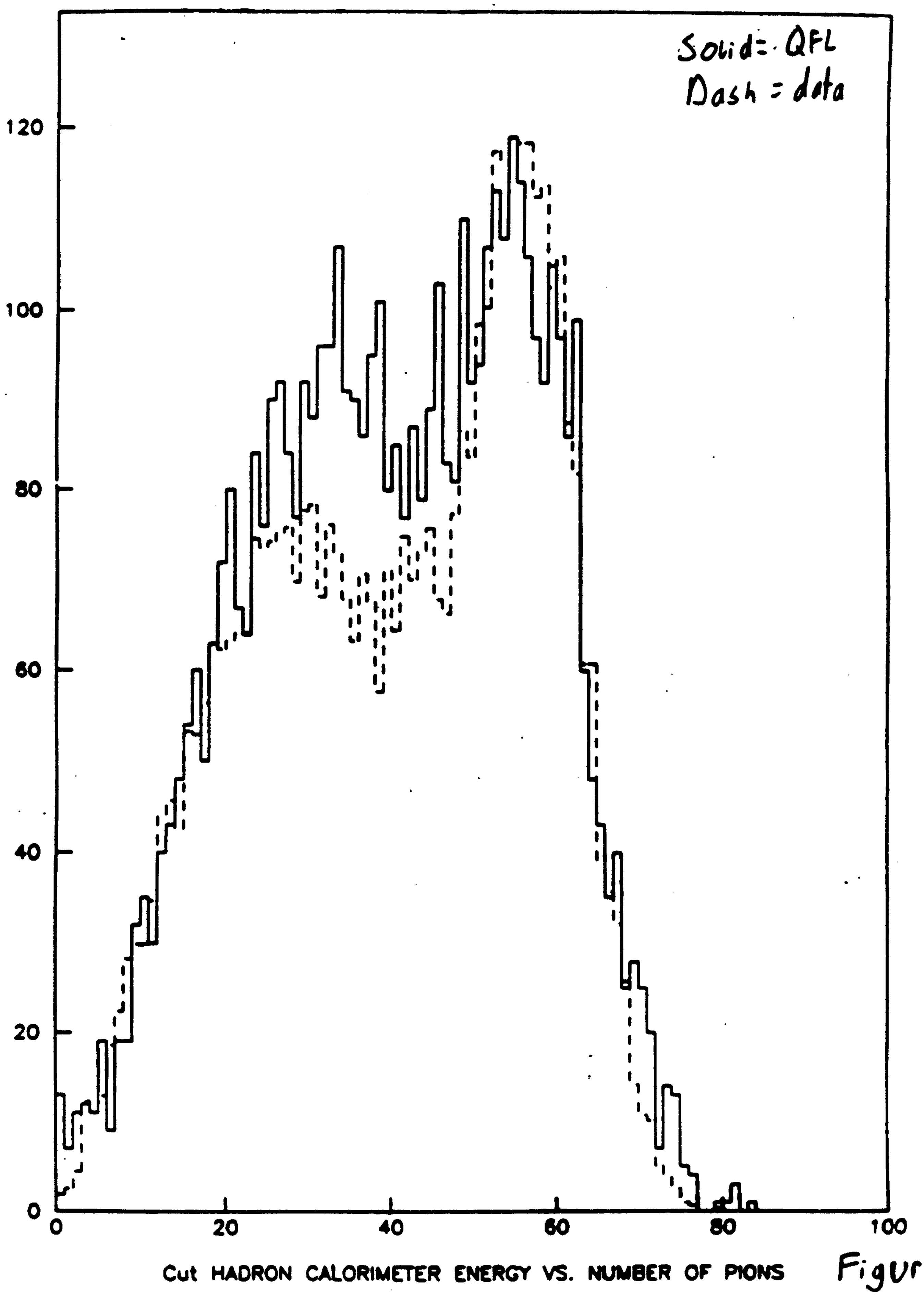
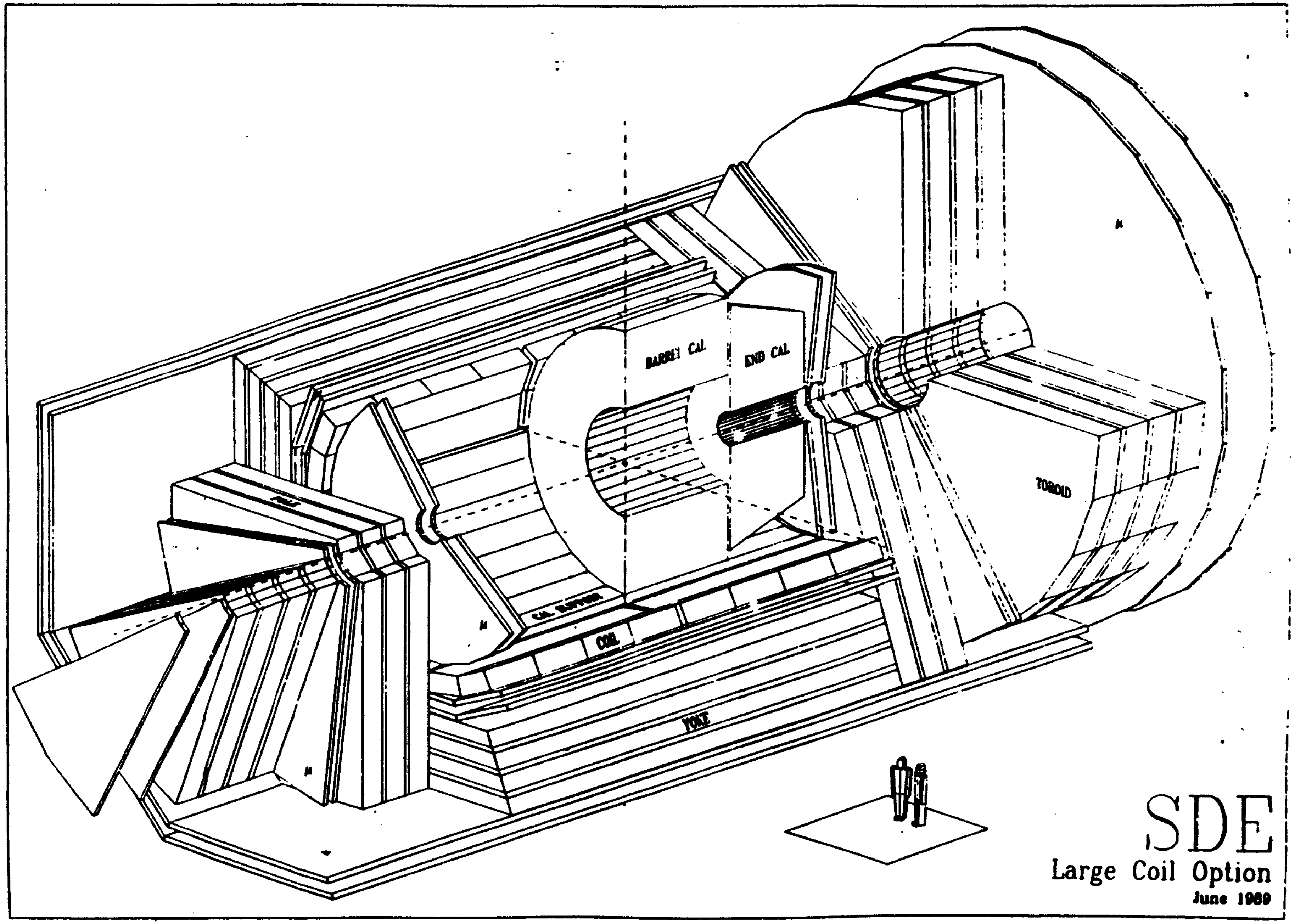

Solid = QFL
Dash = data
120
100
80
60
40
20
0
0
20
40
60
80
100
Cut HADRON CALORIMETER ENERGY VS. NUMBER OF PIONS

Figure 6

M. Strovink



SDE
Large Coil Option
June 1989

Auto LISP ?

full database access? YES

existing command to calculate intersection of line with 3D face? No (?)

Best bet :

{ DXF (drawing interchange file)
or
IGES (std. drawing format) }

plus another program.

EFFECT OF DEAD MATERIAL ON RESOLUTION

J. WOMERSLEY
DØ

FAST ESTIMATION BY:

1. EVALUATE MEAN ENERGY LOSS IN EACH LAYER (LIVE OR DEAD) USING STANDARD PARAMETRIZATIONS:

- EM $dE = k s^{a-1} e^{-bs} ds$
- HAD $dE = E\left\{ w \dfrac{x^{\alpha_E - 1} e^{-x}}{\Gamma(\alpha_E)} dx + (1-w) \dfrac{y^{\alpha_H - 1} e^{-y}}{\Gamma(\alpha_H)} dy \right\}$ $\quad x = \beta_E \dfrac{s - s_0}{X_0}$, $y = \beta_H \dfrac{s - s_0}{\lambda}$

(— T. HANSL-KOZANECKA)

2. EVALUATE RESOLUTION BY:

- $$\frac{\sigma}{\mu} = \left(\frac{S^2}{(\sqrt{E})^2} + C^2 + \sum_{\substack{\text{DEAD}\\ \text{LAYERS}}} \left(\frac{E_{LAYER}}{E_{INCIDENT}} \right)^2 \right)^{1/2}$$

— WHERE $S = 0.16$, $C = 0.003$ (EM)
$S = 0.49$, $C = 0.02$ (HAD) } DØ TEST BEAM

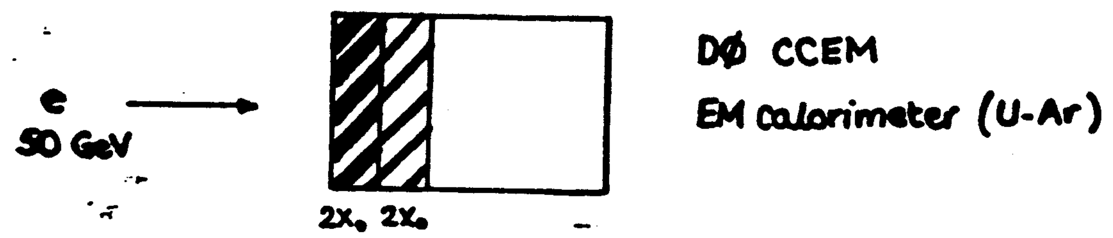
JUSTIFICATION:

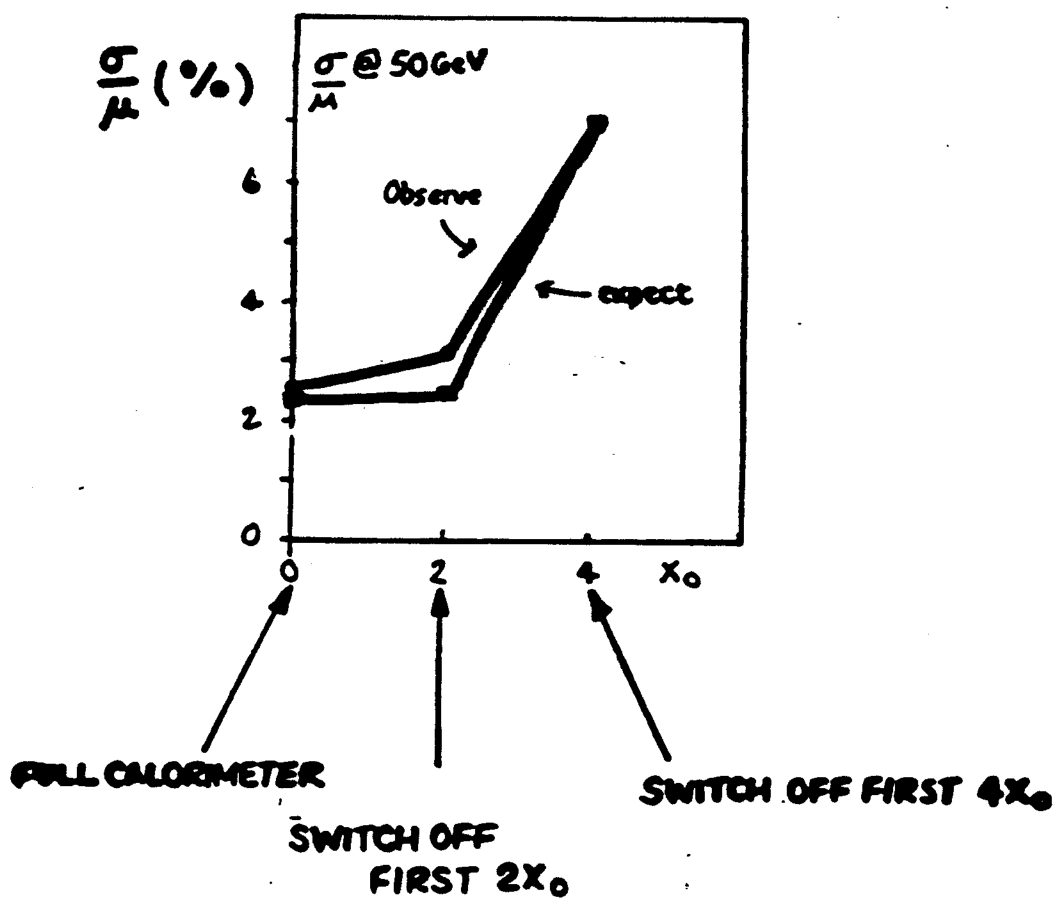
ENERGY IN A SMALL SLICE OF SHOWER TYPICALLY FLUCTUATES WITH AN RMS ≈ ITS MEAN (E.G. FURRY DISTRIBUTION IN EM SHOWER)

⇒ IF X % OF SHOWER ENERGY IS LOST INTO A DEAD LAYER, THE REMAINING ENERGY IS SUBJECT TO AN EXTRA X % FLUCTUATION

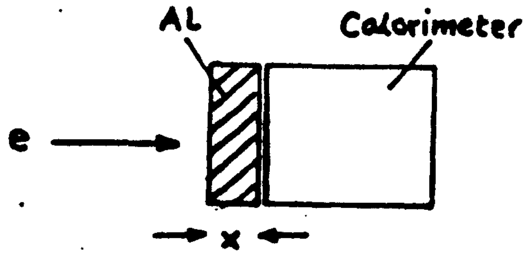
NOT EXPECTED TO BE EXACT, BUT SEEMS TO WORK WELL...

- REPRODUCES DØ EM CALORIMETER RESOLUTION WHEN UPSTREAM LAYERS SWITCHED OFF

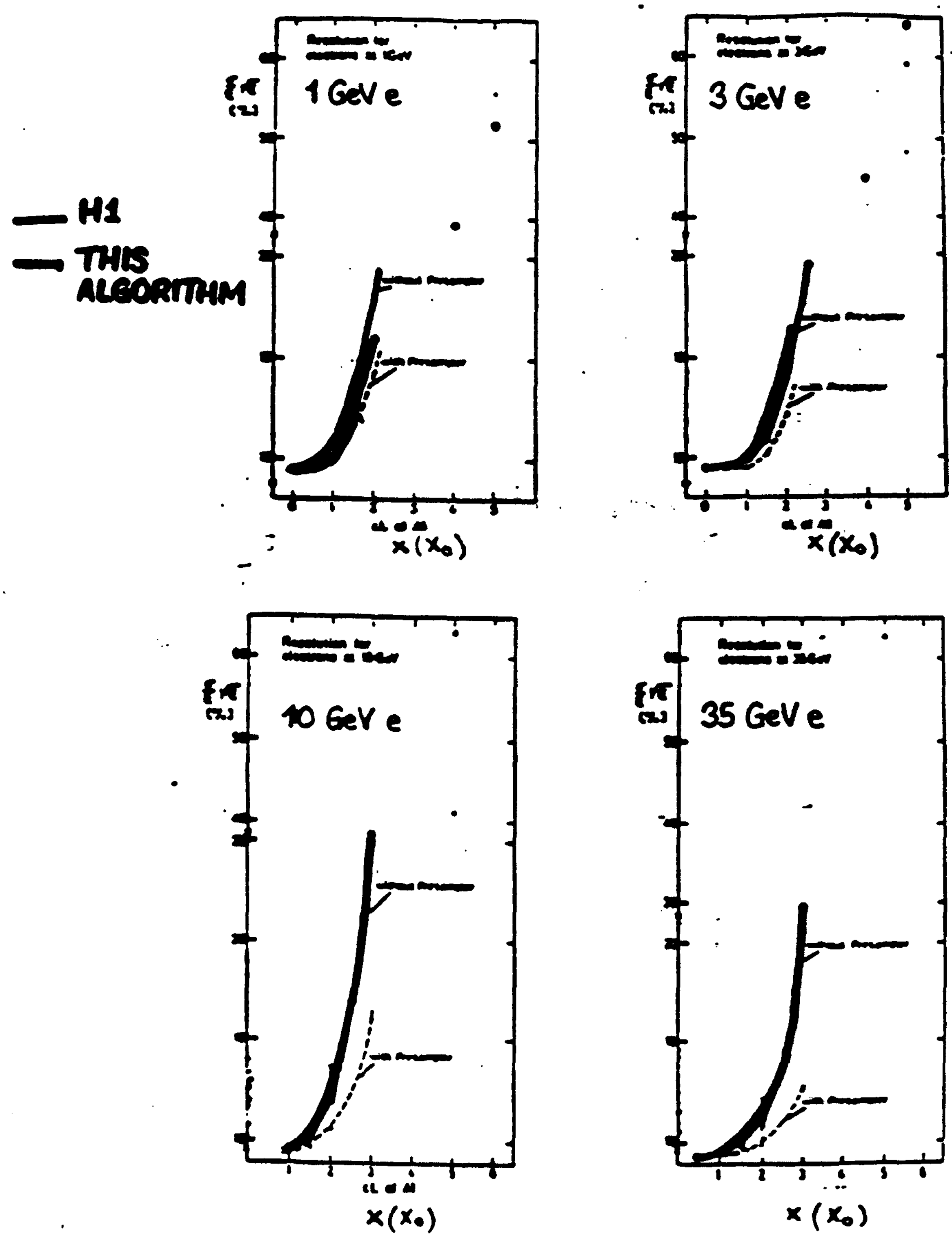




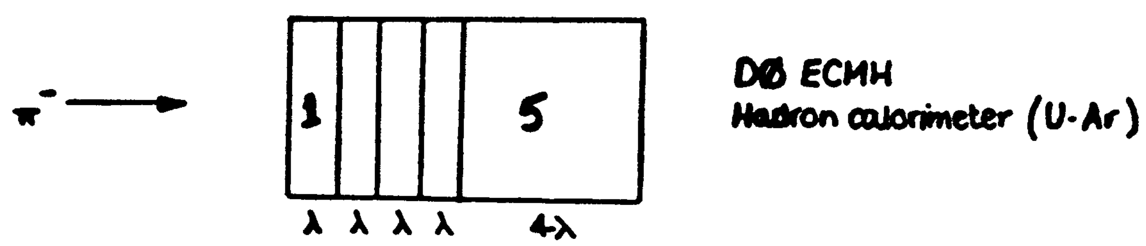
- REPRODUCES H1 RESULTS ON EFFECT OF ALUMINUM UPSTREAM OF CALORIMETER (use H1 rather than DØ EM resolution in this case)



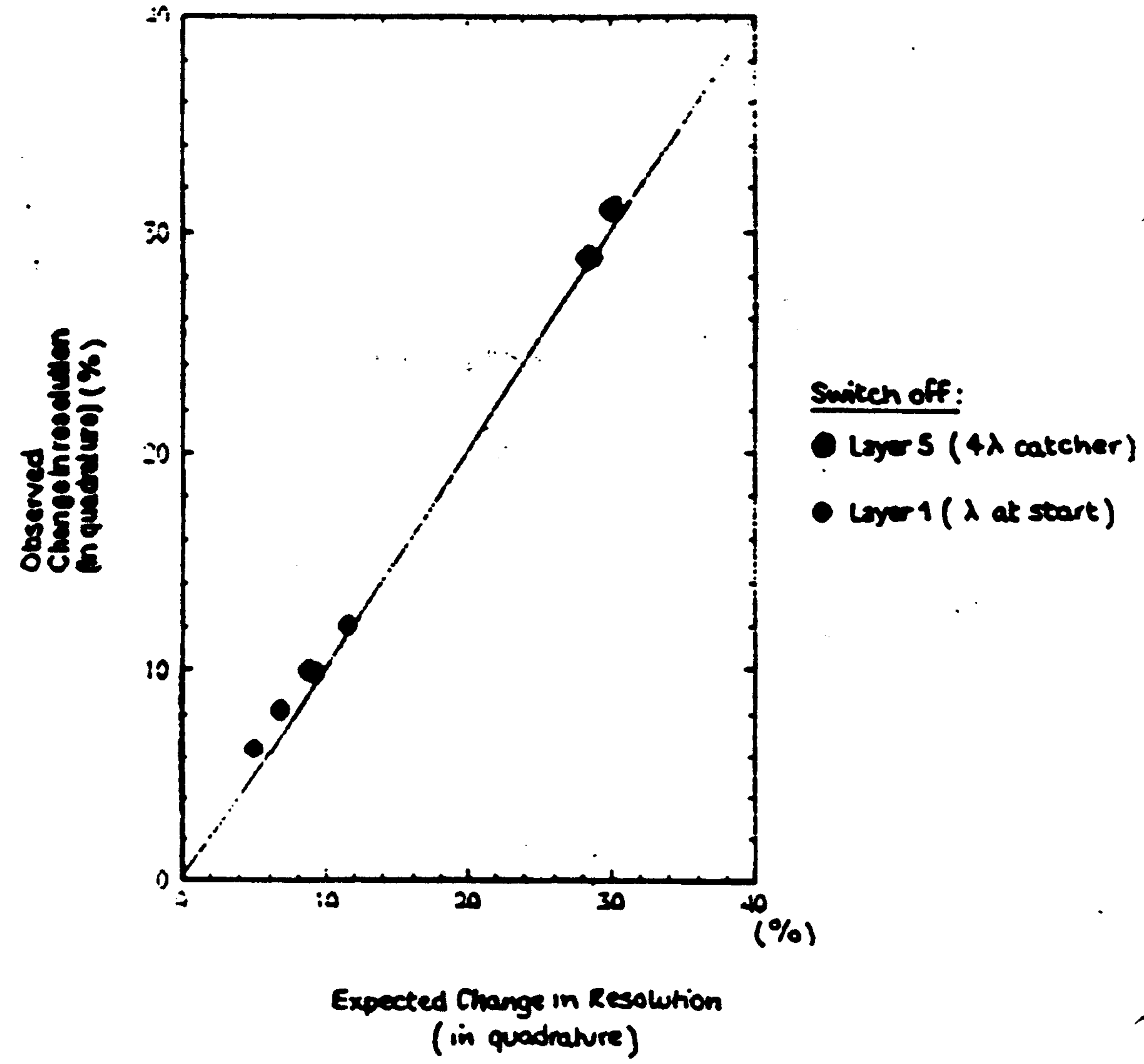
H1 Results
(G.Cozzika @ Boulder Workshop)



- REPRODUCES EFFECT OF SWITCHING OFF FIRST OR LAST LAYER OF DØ HADRON MODULE (25-150 GeV pions)



Effect of dead material energy on pion resolution



M. Strovink
3/14/89

Overall Conclusions

1. For the cryostats considered (Al, realistic walls, flat heads, no magnet coil inside) the effects of cracks and dead material between barrel and end units are serious for $e^{\pm}$ (without crack filler) and for $\pi^{\pm}$.

2. Without crack fillers, the "endcap" and "endplug" geometries are comparable; the "nose" is significantly worse.

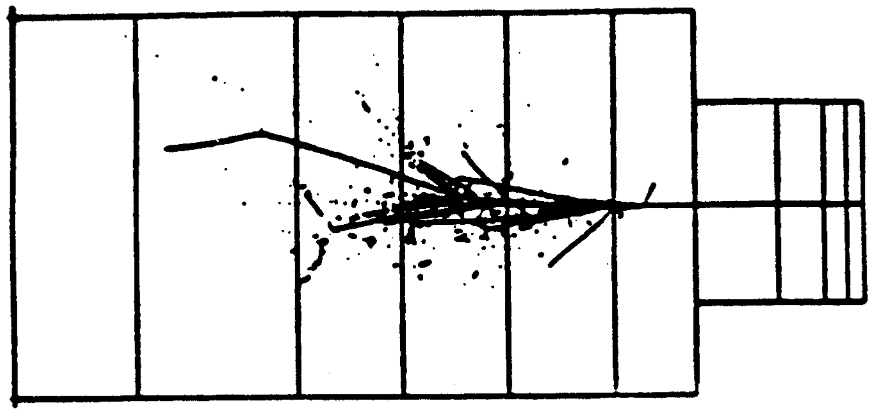
3. The crack filler, if used,

   - largely removes the barrel-end interface problem for $e^{\pm}$
   - gives moderate improvement for $\pi^{\pm}$
   - must be carefully designed and incorporated in the cryostat geometry from the outset.

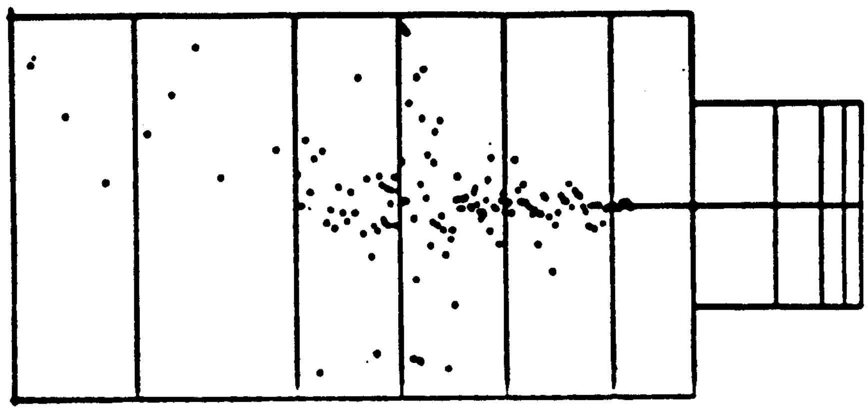
4. Many more hermeticity calculations must be done.

   - We don't necessarily need GEANT.
   - We do need a geometry program with a CAD interface.

GHEISHA8



GFLASH



...as seen by an ignorant skeptic

Don Groom
SSC/CDG (for the moment)
8 September 1989

1. GHEISHA8 (and a little 7)

— mainly by H. Fesefeldt, Aachen

— the GEANT default, as far as I know

References:

1. Report of the Task Force on Radiation Levels in the SSC Interaction Regions, SSC Central Design Group Report SSC-SR-1033 (June 1988). Appendix 16 contains a very short description by Fesefeldt, and gives the following references:
2. H. Fesefeldt, "The Physics of Hadronic Showers—Physics and Applications," RWTH Aachen PITHA 85/02 (1985).
3. H. Fesefeldt, "Low Energy Phenomena in Hadronic Showers," PITHA 87/20 and *Proc. Workshop on Detector Simulation for the SSC*, Argonne National Laboratory, Argonne IL, USA, August 24-28 (1987).

— and I couldn't locate references 2 and 3!

- GHEISHA is an inclusive hadronic cascade code
- Unlike HETC, FLUKA, etc., it follows particles down to very low energies (100 keV, if desired) without a "handoff" to another program
- It somehow handles nuclear physics without the enormous tables of cross sections that go with MORSE, ANISN, COG, etc. At the same time, it does distinguish between uranium and lead as far as fission goes.
- It handles three kinds of inelastic scattering
  - — Coherent high-energy hadron-nucleus scattering
  - — Incoherent high-energy hadron-nucleus scattering
  - — Low-energy nuclear interactions of the form

$$N + A \rightarrow N' + A' \ (+\gamma)$$

The incoherent processes are considered in three steps:

- The hadron interacts with one nucleon in the target (with Fermi momentum smear)
- An internuclear cascade develops
- The residual nucleus deexcites by evaporation (with fission competing in the case of uranium). A thermodynamic model describes evaporation, which is not distinguished from spallation

For h+A, fragmentation model assumed
→ for $E < 5$ GeV, partly replaced by 2-body resonance model

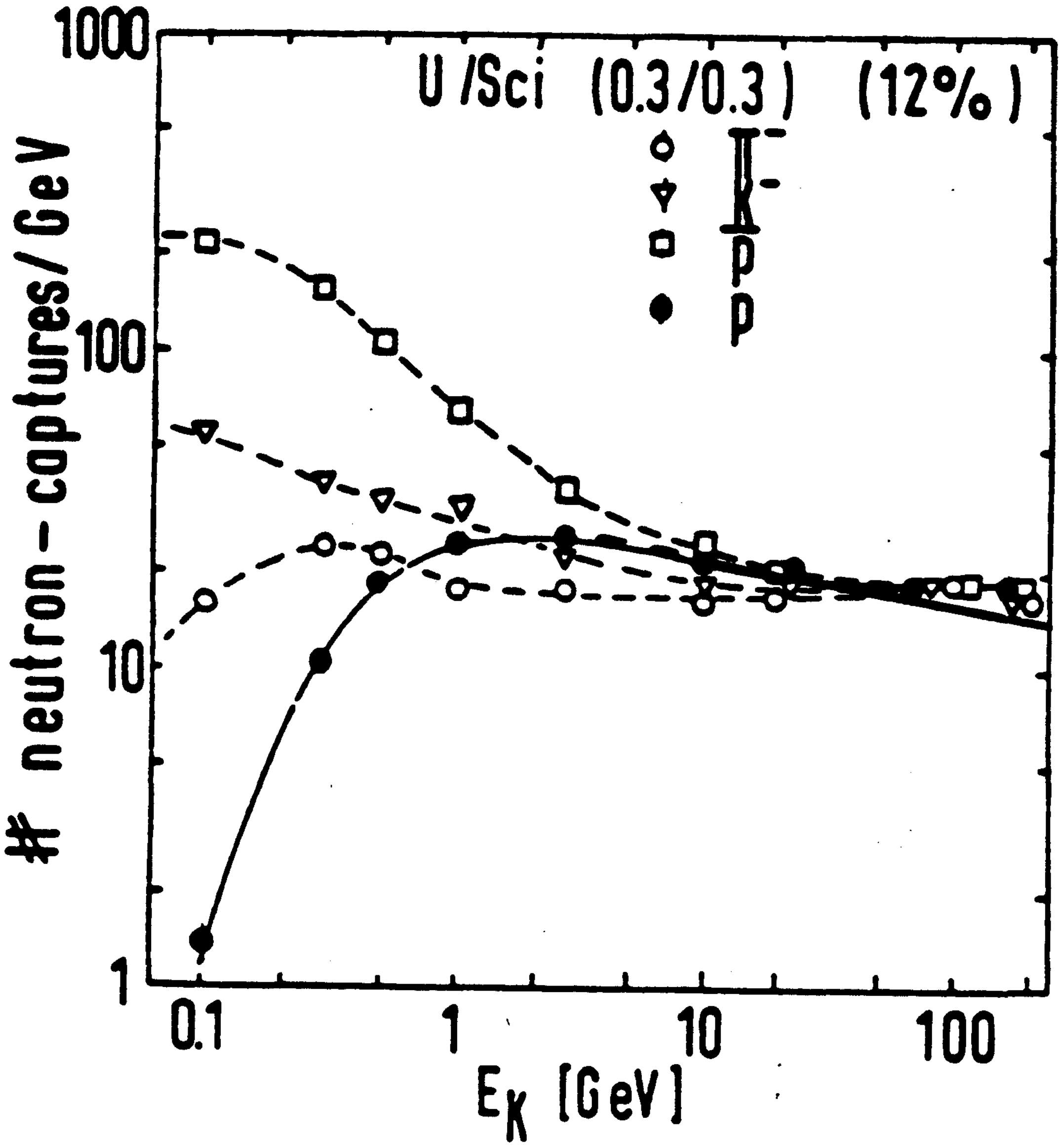
$A(N, N'(\gamma))A'$ dominates for $10\,\text{MeV} < E < 100\,\text{MeV}$;
at higher energies spallation turns on.

$\pi^{\pm}$ & K always produce spallation

<u>Neutrons</u>:

Production → moderation → capture

It's not clear that enough π^0's are created:



2. GFLASH

— Günter Grindhammer, M. Rudowicz, and S. Peters

— See SLAC–PUB–5072 (prepared for the Tuscaloosa proceedings)

It is well known that *average* cascade behavior can be described by a parameterized function of z and r (e.g. Bock *et al.*)

Ansatz:

An *individual* cascade can be described by the same function. To sufficient accuracy, it is the *parameters* which fluctuate from event to event.

Example: Electromagnetic cascades

Average well described by the Gamma distribution, so assume it applies to the ith cascade:

$$f_i(z) = \frac{x^{\alpha_i - 1} x^{-x}}{\Gamma(\alpha_i)}$$

where

$$x = \beta_i z$$

and x is measured in radiation lengths.

Procedure:

- Generate one shower at a given energy
- Evaluate α_i and β_i from the first two moments
- GOTO 1
- Calculate

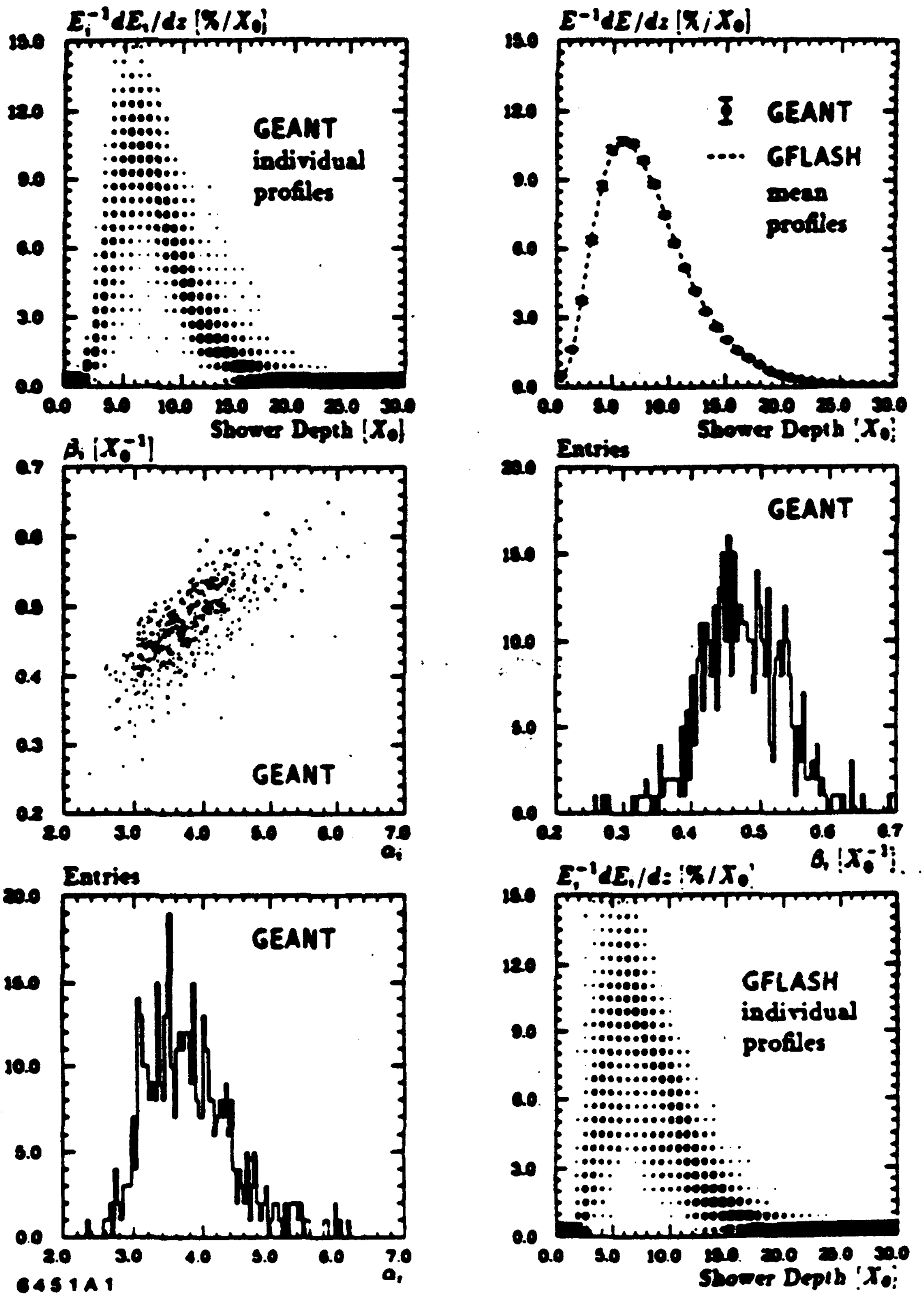
$$\mu_\alpha = \langle \alpha_i \rangle \qquad \sigma_\alpha^2 = \left\langle \alpha_i^2 \right\rangle - \langle \alpha_i \rangle^2$$

$$\mu_\beta = \langle \beta_i \rangle \qquad \sigma_\beta^2 = \left\langle \beta_i^2 \right\rangle - \langle \beta_i \rangle^2$$

  (Turns out marginal distributions are reasonably normal)
  and

$$\rho = \frac{\langle (\alpha_i - \langle \alpha_i \rangle)(\beta_i - \langle \beta_i \rangle) \rangle}{\sigma_\alpha \sigma_\beta}$$

  ($\rho \approx 0.73$ at all energies)
- Tabulate α, β, and ρ at enough energies to permit interpolation. (These data tables are created just once for a given calorimeter material)
- During simulation: Just choose (α_j, β_j) from normal distributions with means μ_α and μ_β, with correlation ρ.


GEANT
individual
profiles
Shower Depth [X_0]
GEANT
GFLASH
mean
profiles
Shower Depth [X_0]
GEANT
Entries
GEANT
Entries
GEANT
GFLASH
individual
profiles
Shower Depth [X_0]
6451A1

Radial distributions:

$$f(r) = \frac{2r\,R_{50}^2}{(r^2 + R_{50}^2)^2}$$

(e.m and hadronic)

r is in units of R_M (em) or λ_0 (had)

☞ Tabulate $\langle R_{50} \rangle$ as $f(E)$.

(R_{50} ~ log normal distributed).

Resolution:

For each z slice, put energy in "spots" chosen from $f(r)$.

Choose # from Poisson distribution, with λ fixed to give "right" resolution.

Timing

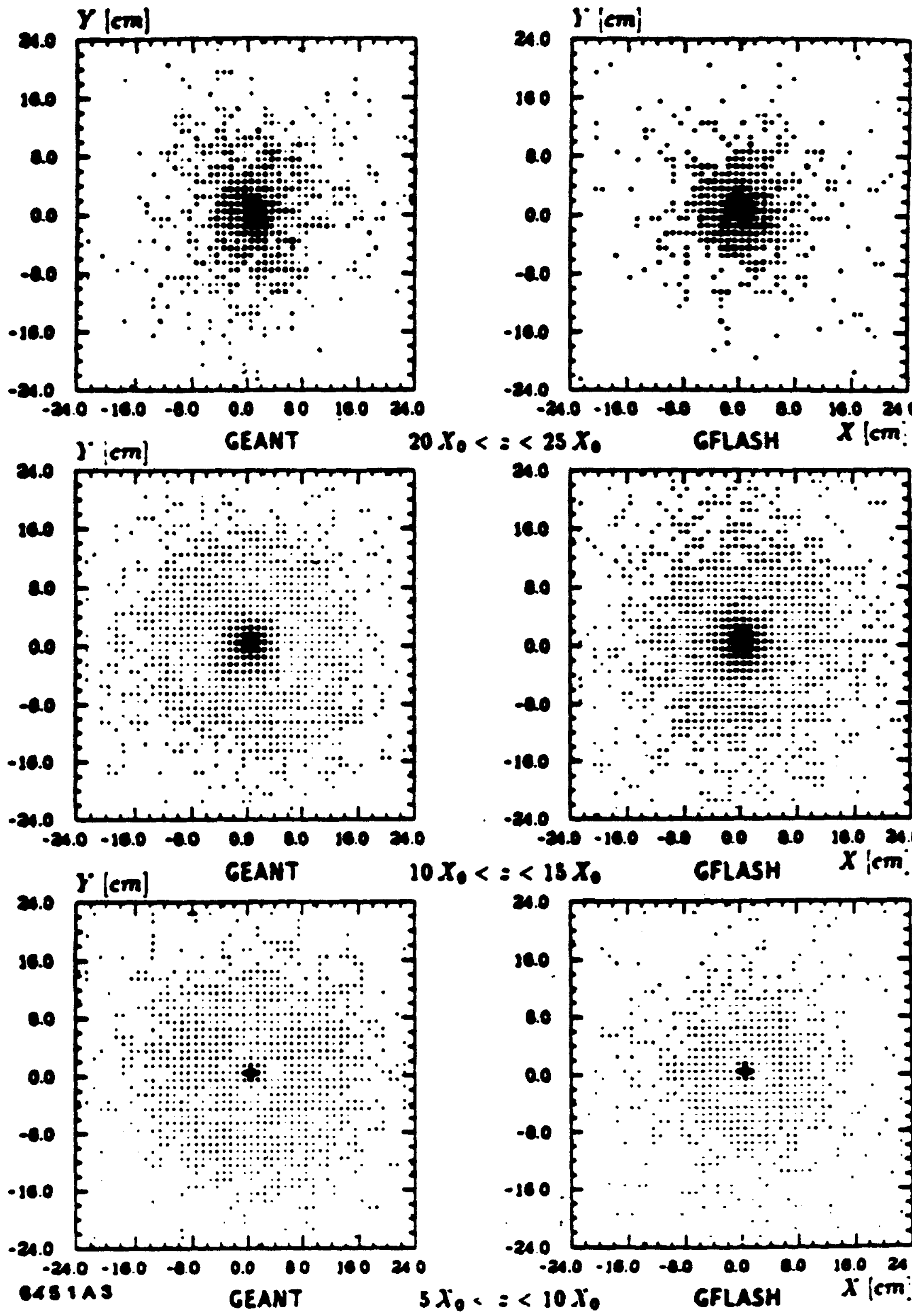
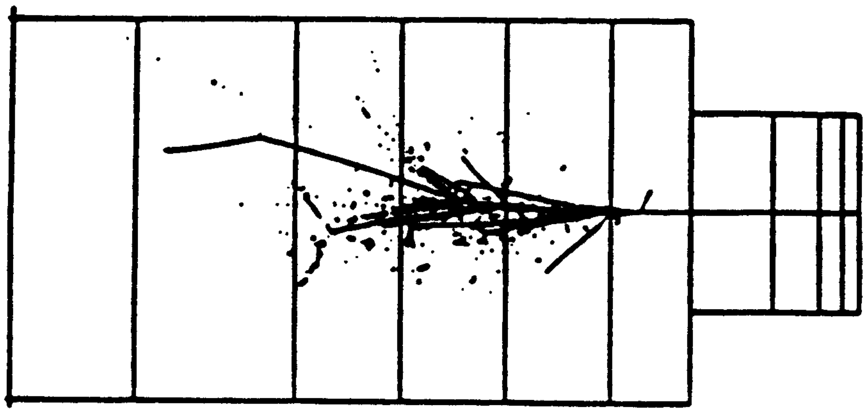
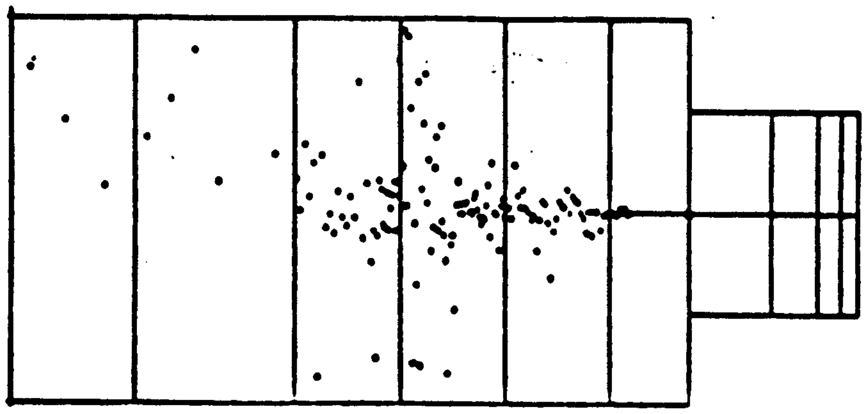


Figure 3: Lateral energy profile for 10 GeV e^- showers at different depth: GFLASH (left) and GEANT (right).

LA-U

H1 test calorimeter





Hadrons:

$$dE_{dep} = E_{dp}\left[c_h \mathcal{H}_r(x)\,dx + c_f \mathcal{F}_r(y)\,dy + c_l \mathcal{L}_r(z)\,dz\right]$$

(9 parameters)

– but do same thing!

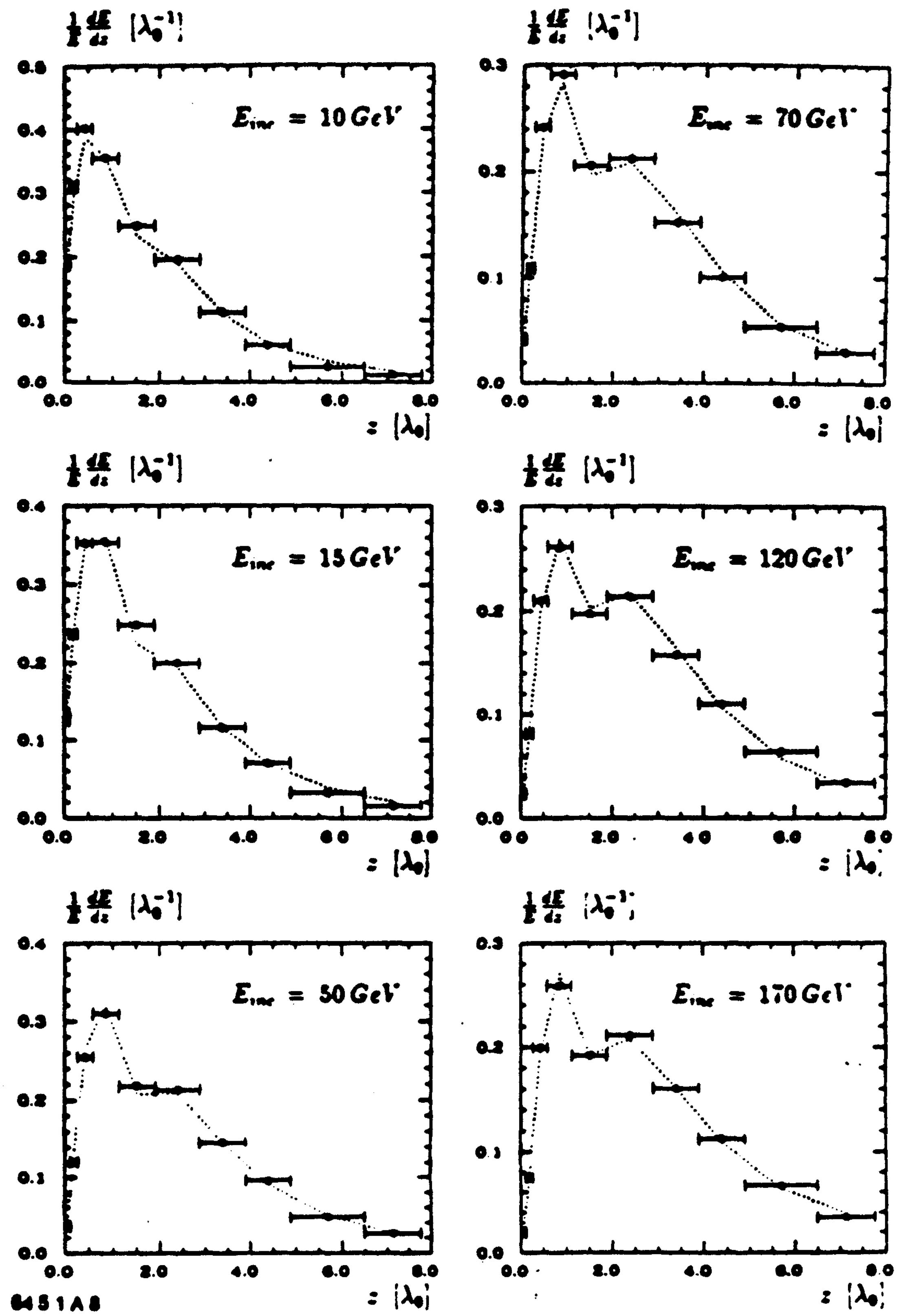


Figure 9: Mean longitudinal energy profile for π^- showers: experiment (o) and GFLASH (···).

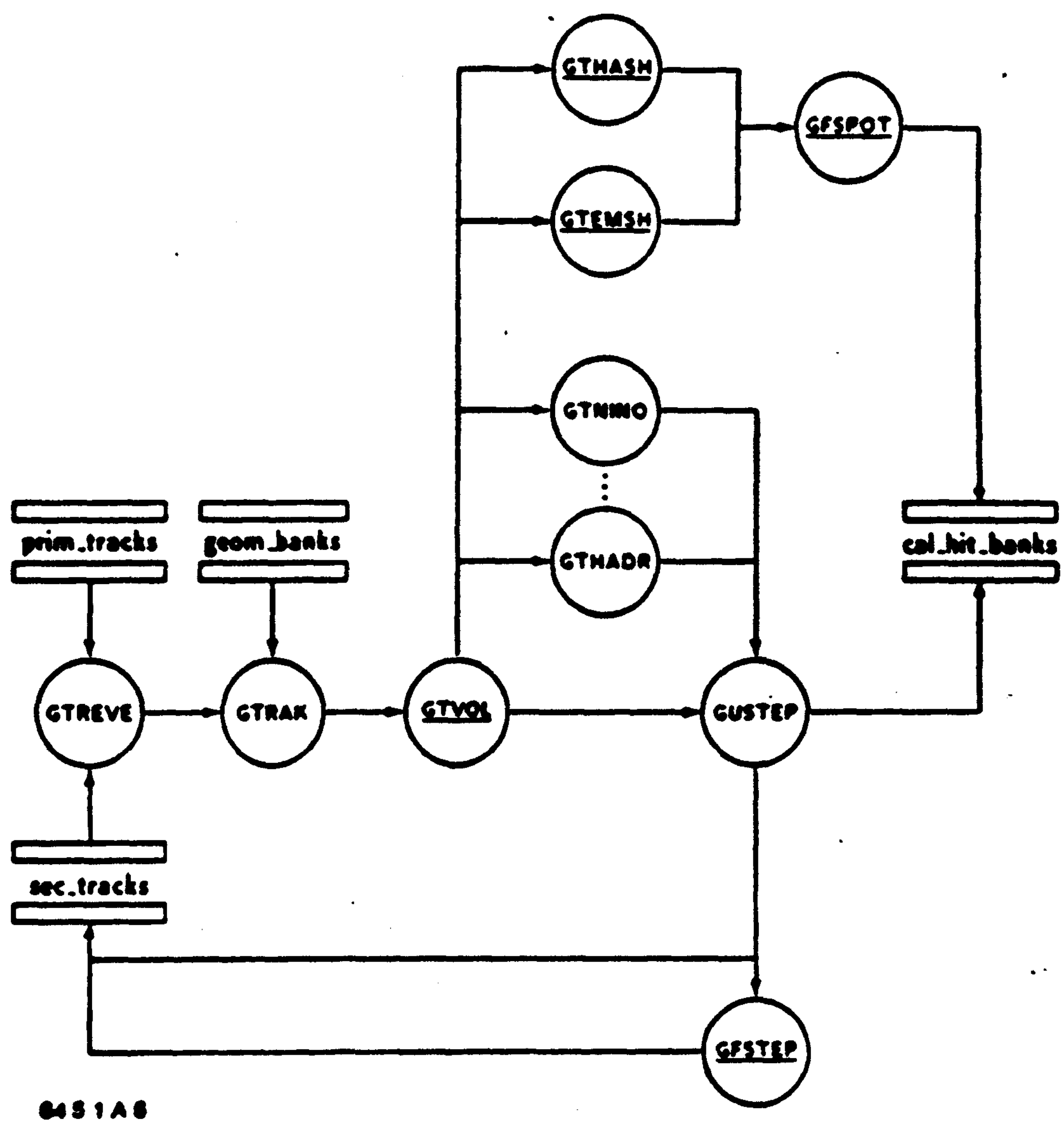


Figure 6: Schematic representation of the implementation of GFLASH in GEANT.

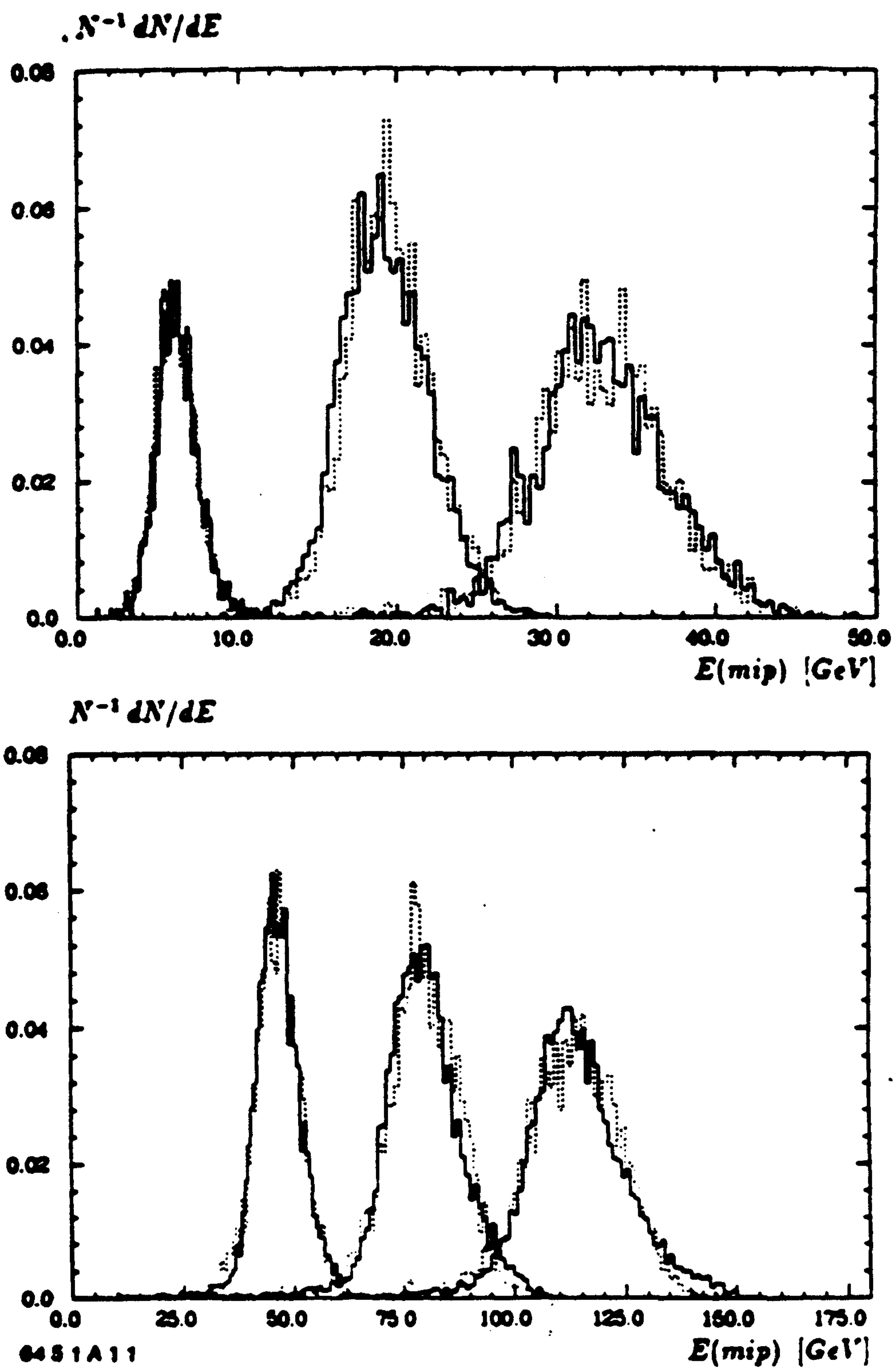


Figure 12: Energy distribution for π^- showers for beam energies 10, 30, 50 (top) and 70, 120, 170 GeV (bottom): experiment (—) and GFLASH (···).

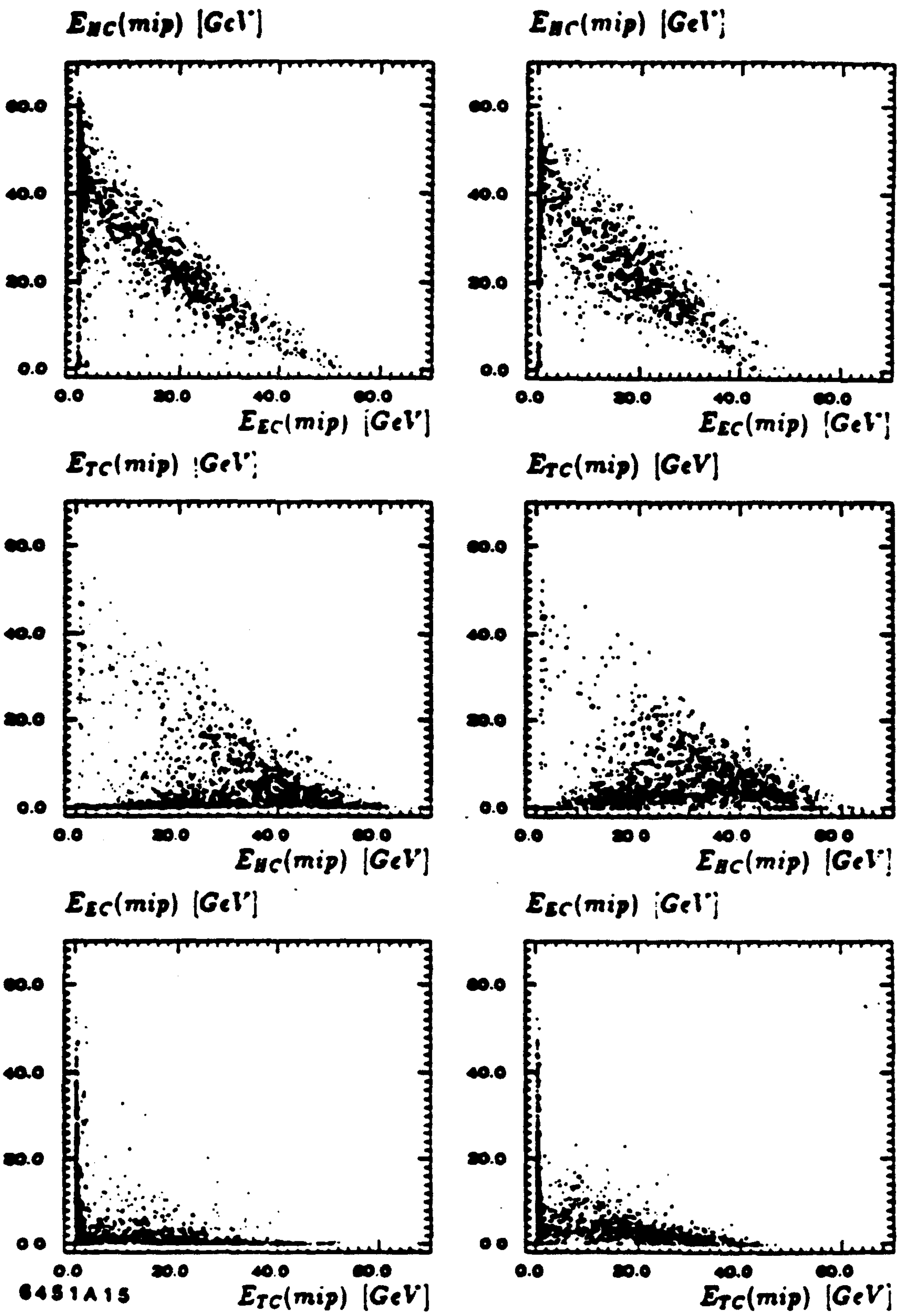


Figure 16: Energy correlations between different calorimeter modules for 70 GeV π^- showers: experiment (left) and GFLASH (right).