# Development of a new detector technology for fiber sampling calorimeters for EIC and STAR.

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# Motivation:

Develop ***simple*, *cost effective*, *flexible*** techniques to build ***compact*** sampling calorimeters with *good characteristics*.

***Simple*** – to the level that a typical university group can build it without heavy investments in “infrastructure”.
***Cost effective*** – fraction of the cost of crystals.

***Flexible*** – tuneable for particular experimental requirements.

# Idea:

Mix tungsten powder and scintillating fibers.

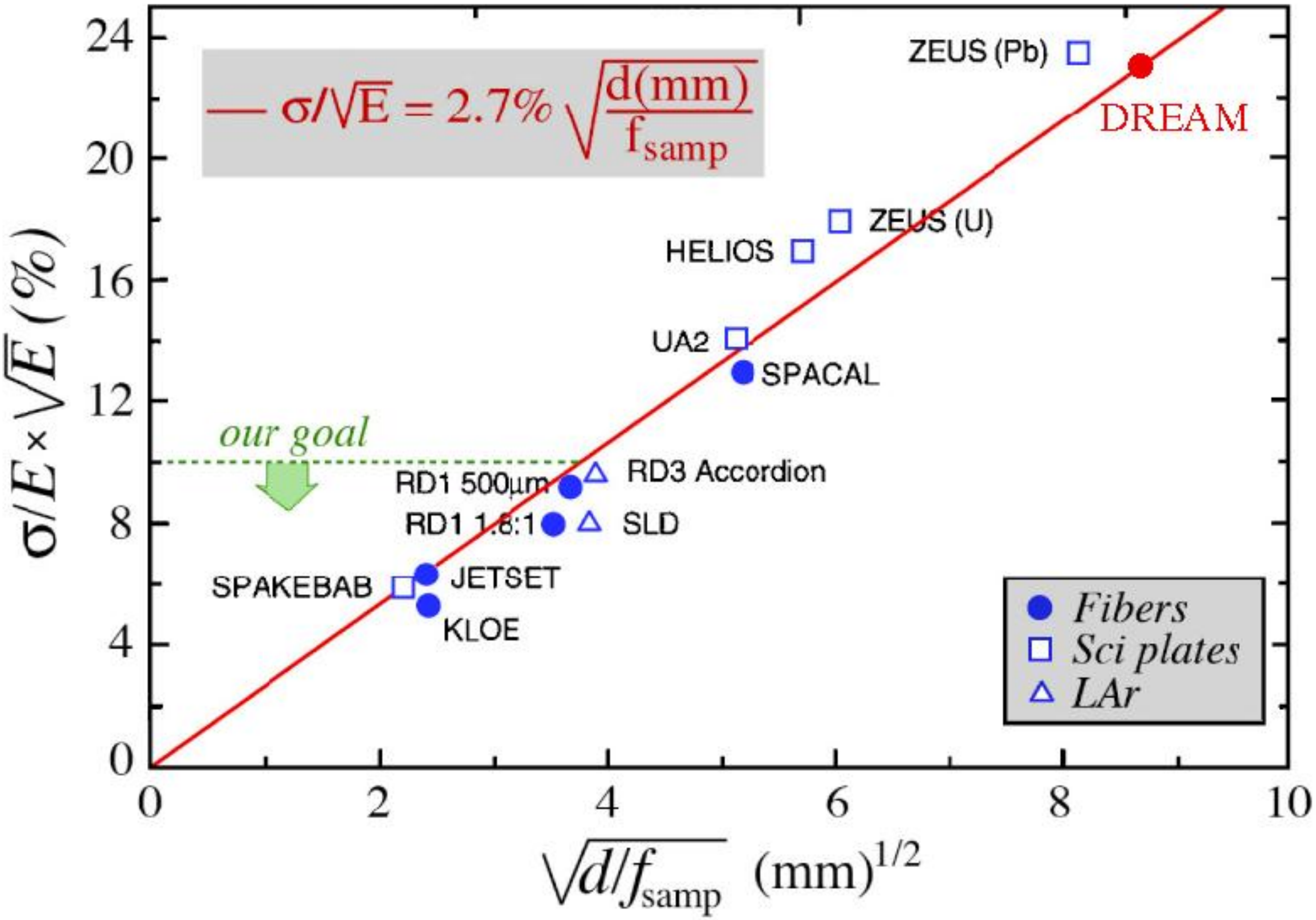
Why SciFi type?

# The properties of SciFi calorimeters which we like are:

“Speed of response, compensation, linearity, good energy resolution for electromagnetic and hadronic showers, uniformity of response as a function of impact point and angle, hermeticity, ease of lateral segmentation, spatial resolution, low noise, and sensitivity to minimum ionizing particles”

NIM A302(1991) 36-46 “Electron-pion discrimination with scintillating fiber calorimeter”

R.Wigmans , Calor 2010



**Fiber calorimeters have a very good record.**

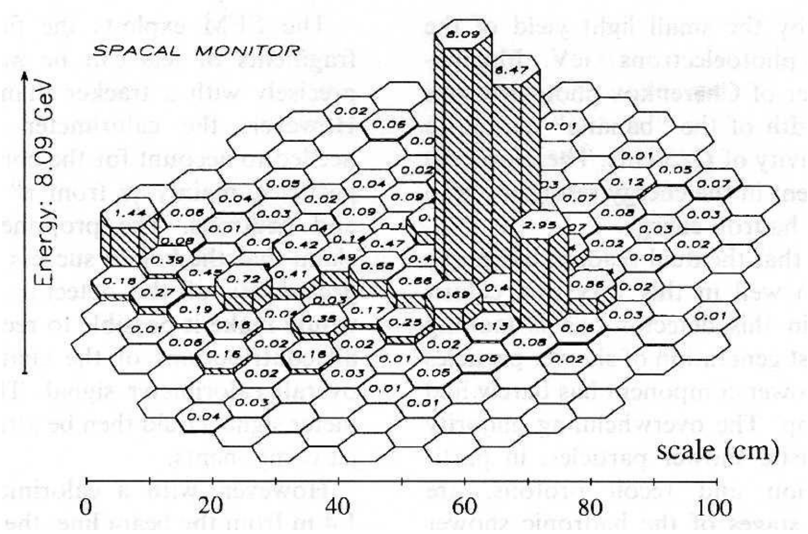
**SPACAL still holds the record for best hadronic resolution.**

**DREAM aims to set new standards in high resolution calorimetry.**

| ***Small d, Small Fs (A)*** | ***Small d, Large Fs (B)*** | ***Large d, Large Fs (C)*** |
|---|---|---|
| This is SciFi calorimeters. | This is “Shashlik” type. | Tile/Fiber type. |
| Key words:<br>Good energy , position resolution.<br>Fast, compact, hermetic.<br>Problems are;<br>Projectivity, high cost (1/10th of crystals).<br>Example (H1) | Key words:<br>Excellent energy resolution<br>Reasonably fast<br>Small dead areas<br>Problems are:<br>Low density, projectivity.<br>Moderate cost<br>Example (KOPIO/PANDA) | Key words:<br>Ok energy resolution<br>Reasonably fast<br>Very cost effective<br>Problems are:<br>Moderate density, large dead areas.<br>Example (STAR BEMC) |
| Rm 1.8 cm | 6 cm | 3 cm |
| X0 0.7 cm | 3.4 cm | 1.2 cm |
| Energy reso. ~ 10% /√(E) | 4%/√(E) | 15%/√(E) |
| Density ~ 10 g/cm^3 | 2.5 g.cm^3 | 6 g/cm^3 |
| Number of fiber/tower~ 600 (0.3 mm diameter, 0.8mm spacing) | 0.3 mm Pb/1.5 mm Sc<br>400 layers | 5mm Pb/ 5mm Sc<br>20 layers |

**We are proposing to develop new technology for (A) with the price tag comparable to the cost of tile/fiber type calorimeters.**

# SPACAL, as an example



NIM A305 (1991) 55-70

Parameters:

| | |
|---|---|
| Eff. Radiation Length | 7.5 mm |
| Eff. Rm | 25mm |
| Eff. Nucl. Int. Length | 21 cm |
| Density | 9.3g/cm^3 |
| Sampling Fraction | 2.3% |
| Depth | 10 Int. length |
| Width | 5 Int. length |
| Granularity (eff. Radius) | 39mm |

# SPACAL as an example.  A bit of propaganda...

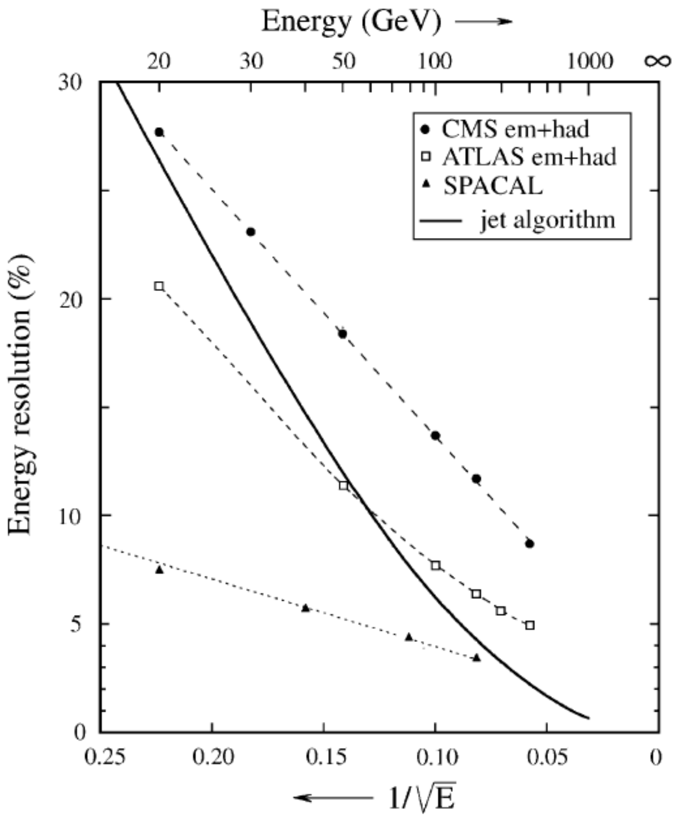


Fig. 1. The hadronic energy resolution of three calorimeter systems and the contribution of a jet-defining cone with $R = 0.3$ to the jet energy resolution, as a function of energy.

R.Wigmans, NIM A494 (2002) 277-287

**Compensation**

*Particle identification with calorimeters*

e/π separation using time structure signals

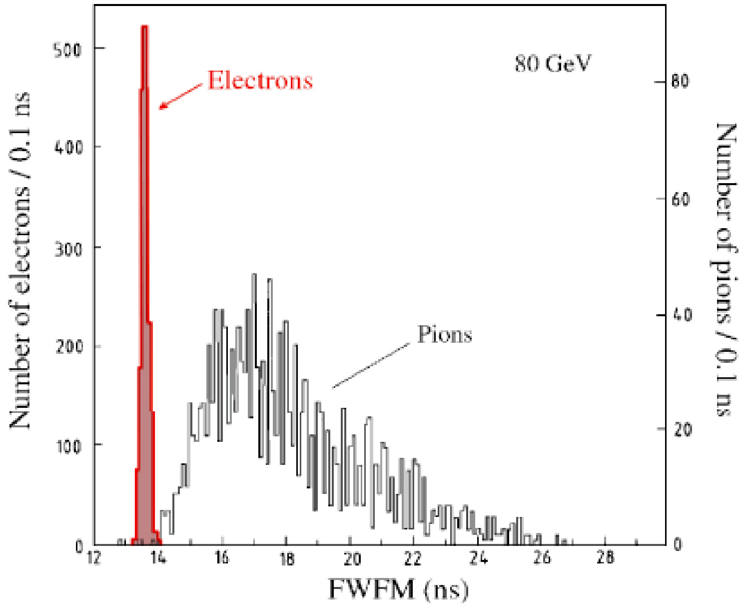


FIG. 7.33. The distribution of the full width at one-fifth maximum (FWFM) for 80 GeV electron and pion signals in SPACAL [Aco 91a].

D.Acosta et al., NIM A302 (1991) 36-46

SPACAL had fast (25ns) ‘electron’ trigger.
e/h rejection ~1000 at 80GeV, e efficiency ~90%

**Speed of response**

# "Localizing particles showering in a Spaghetti Calorimeter" NIM A305(1991) 55-70

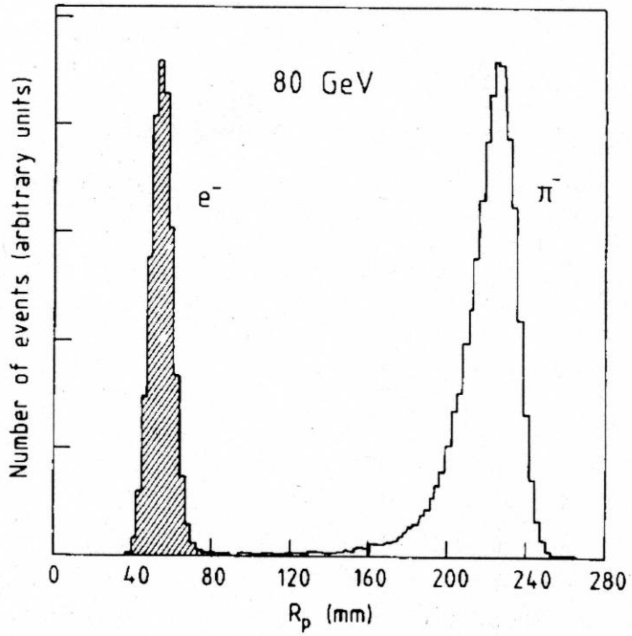


Fig. 27. Distribution of the effective width $R_p$ (see text) for electron and pion showers at 80 GeV and $\theta_z = 2°$.

e/h rejection is ~ 1000

**Ease of lateral segmentation and hermeticity.**

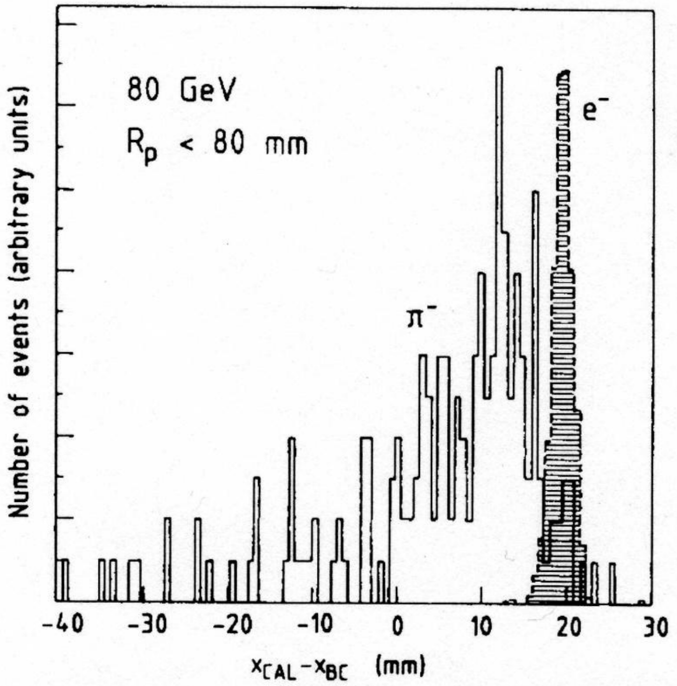


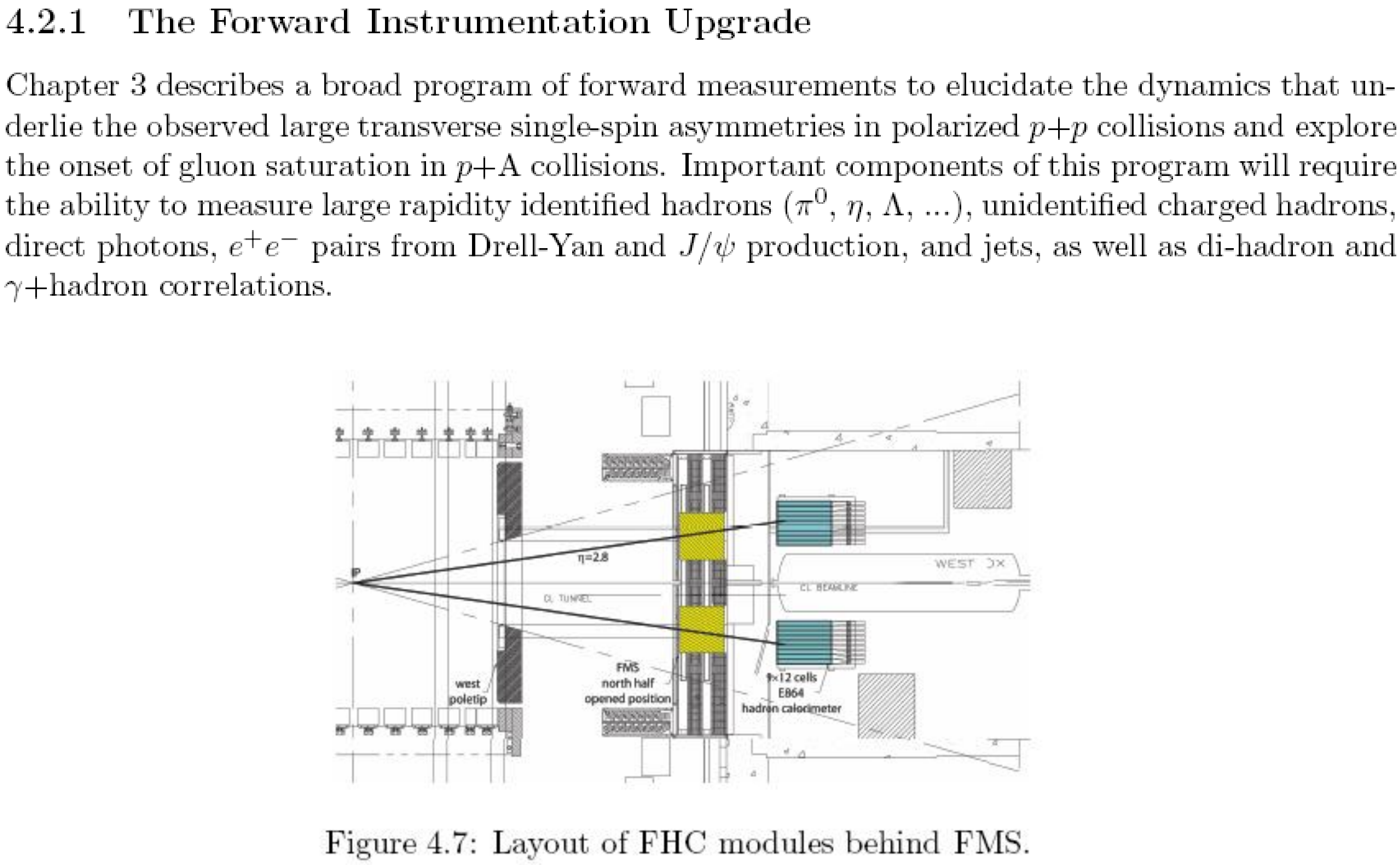
Fig. 28. Distribution of the displacement of the shower centre of gravity with respect to the particle impact point for electrons and for pions that produce showers that are laterally indistinguishable from electrons. Data for 80 GeV particles at $\theta_z = 2°$. The coordinates $x_{CAL} - x_{BC}$ have an offset (see ref. [11]).

e/h rejection is ~ 10000, e efficiency 98%

**Good position resolution and non-projectivity**

- Is an integrated detector similar to SPACAL, designed to detect both electromagnetic and hadronic particle showers, the right choice in the forward direction (STAR West Side, for example)?
- Assuming,  that the granularity can be made small enough (or in combination with an additional pre-shower) so as to distinguish between two ~50 GeV photons at ~1 cm distance.

# What is in STAR Decadal Plan:



### 4.2.1 The Forward Instrumentation Upgrade

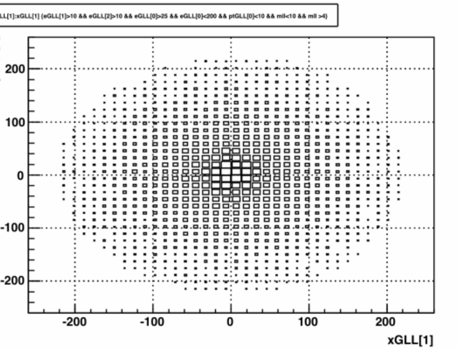
Chapter 3 describes a broad program of forward measurements to elucidate the dynamics that underlie the observed large transverse single-spin asymmetries in polarized $p$+$p$ collisions and explore the onset of gluon saturation in $p$+A collisions. Important components of this program will require the ability to measure large rapidity identified hadrons ($\pi^0$, $\eta$, $\Lambda$, ...), unidentified charged hadrons, direct photons, $e^+e^-$ pairs from Drell-Yan and $J/\psi$ production, and jets, as well as di-hadron and $\gamma$+hadron correlations.

Figure 4.7: Layout of FHC modules behind FMS.

Akio Ogawa, Iowa 2010

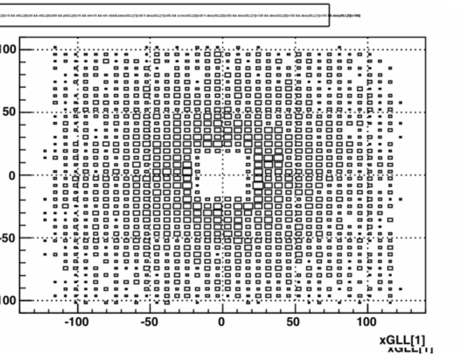
# DY signal

pythia6.222, p+p @ sqrts=500
DY process, 4M events/6.7E-05mb ~ 60/pb
e+/e- energy>10GeV & η>2
$x_F$>0.1 (25GeV)
4GeV < invariant mass < 10GeV



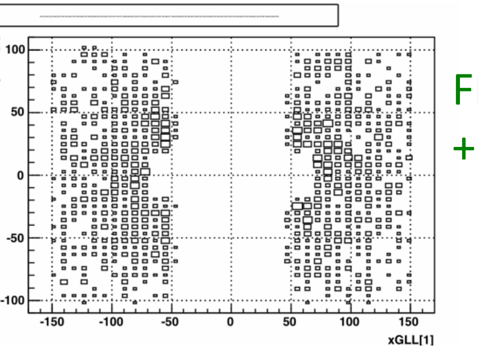
Everything η>2

**14799 events**



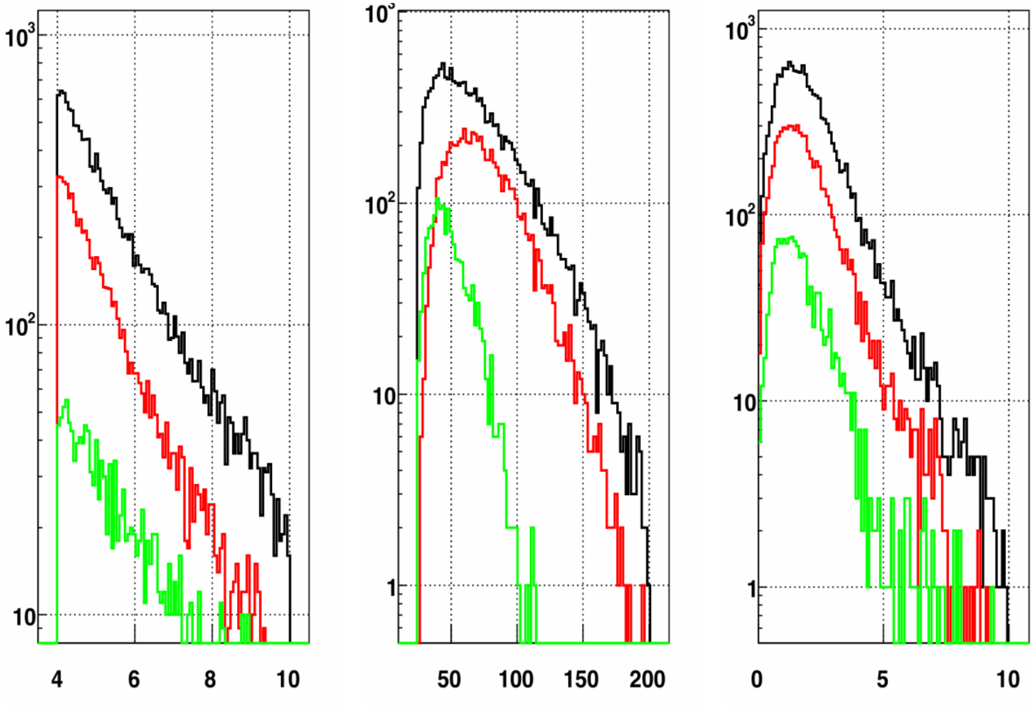
FMS closed
(FHC cannot
be placed due
To DX magnet)

**6512 events**



FMS open (x=50cm)
+ FHC (x=60cm)

**1436 events**
**(1/5 of the closed configuration)**



Inv Mass
E
$p_T$

# Preparing for ***eSTAR***

ToF: π , K identification,
$t_0$, electron

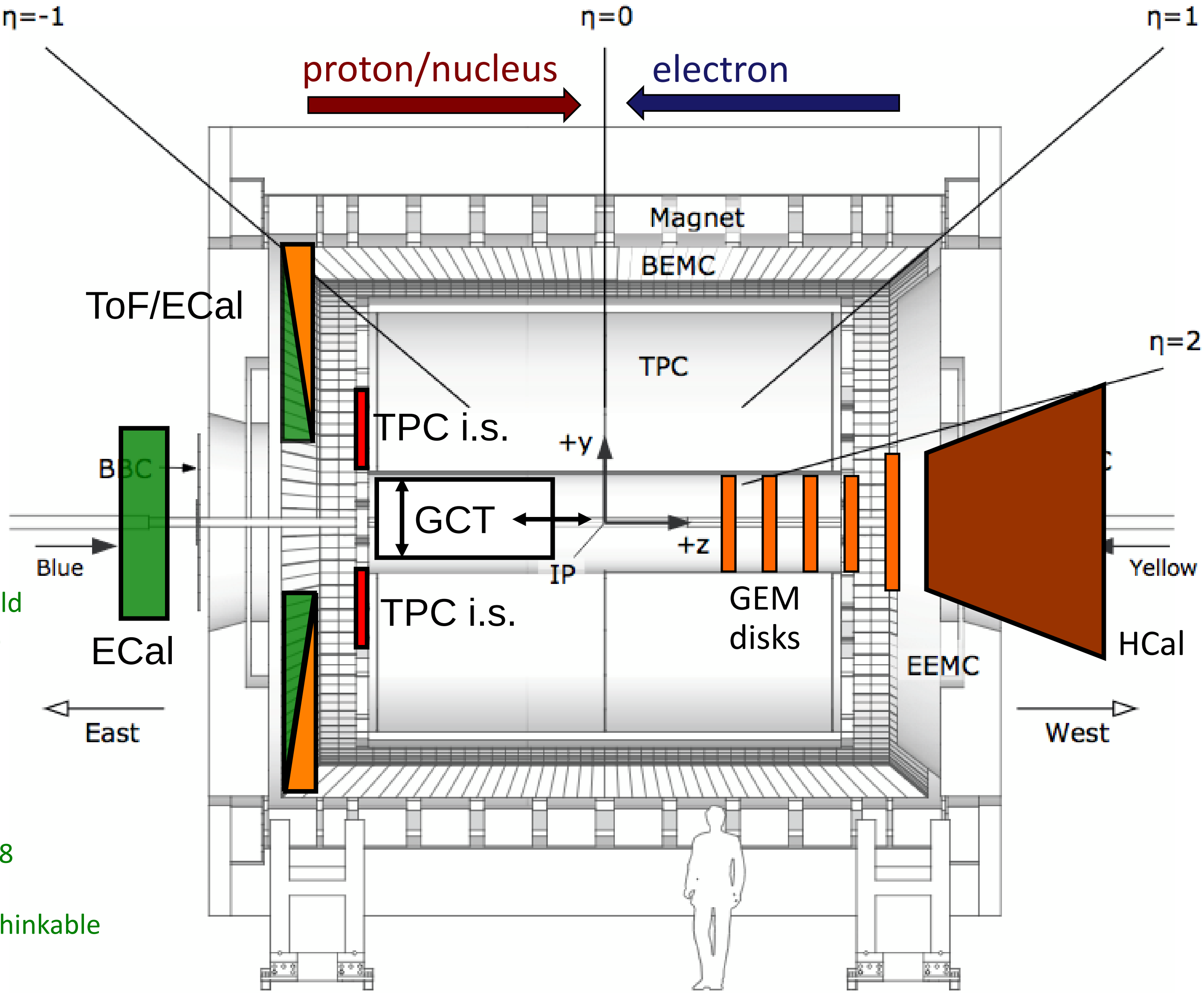
ECal: 5 GeV, 10 GeV, ...
electron beams

GCT: a compact tracker with enhanced electron capability;

- Seeks to combine high-threshold (gas) Cherenkov with TPC(-like) tracking
- Similarities with
  - Giomataris and Charpak NIM A310, 589
  - PHENIX HBD
  - Nemethy et al. NIM A328, 578
- will certainly involve R&D.
- Conventional alternatives are thinkable

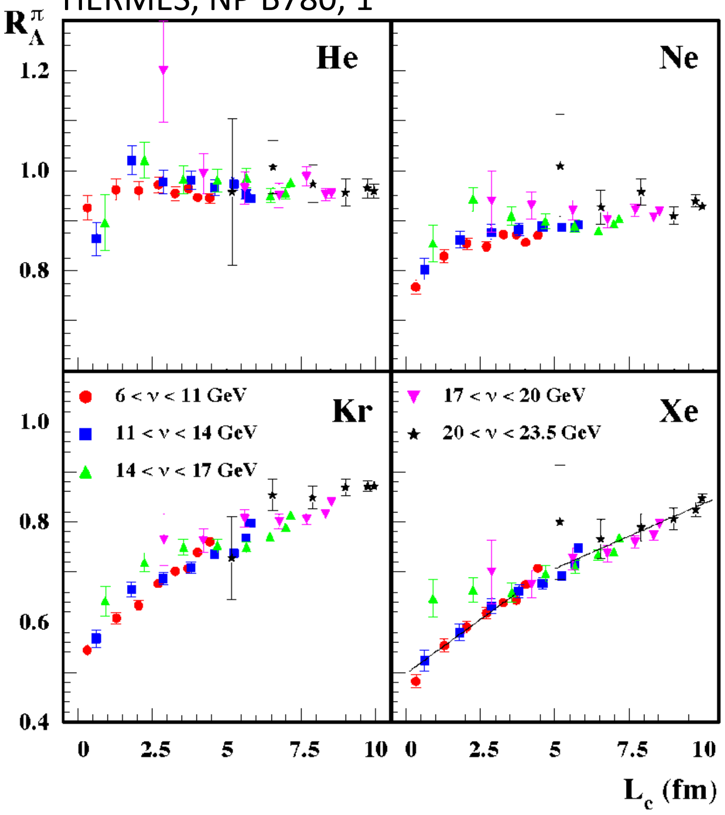
Simulations ahead:

**eSTAR** task force formed

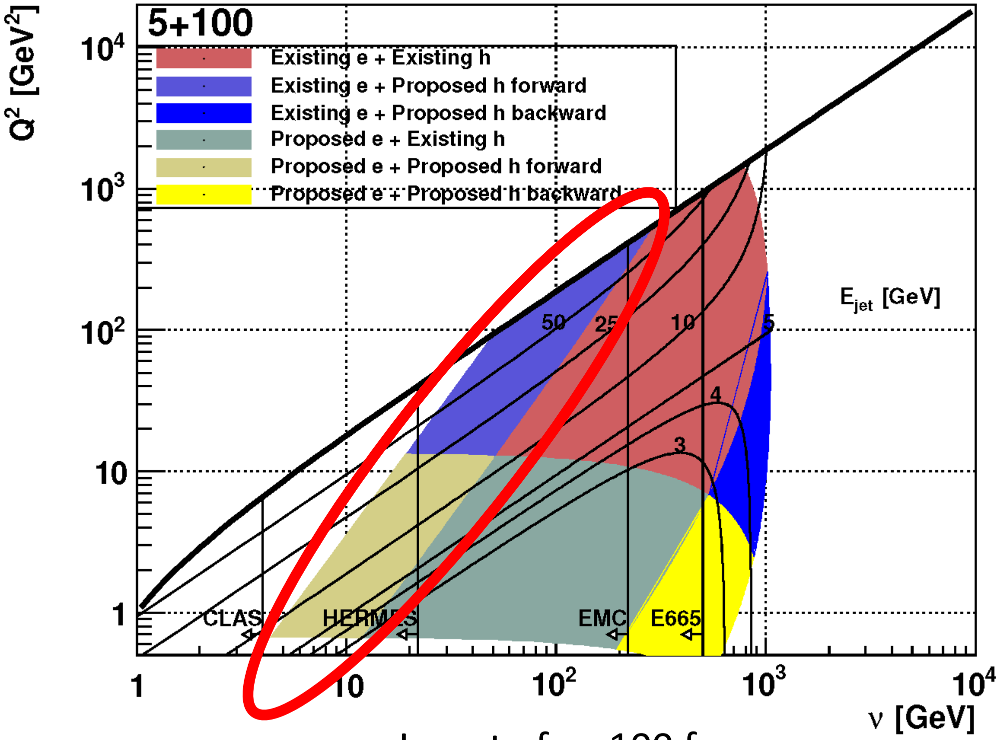


E. Sichtermann (LBNL)

# One ***eSTAR*** application: parton energy loss in cold QCD matter



HERMES, NP B780, 1

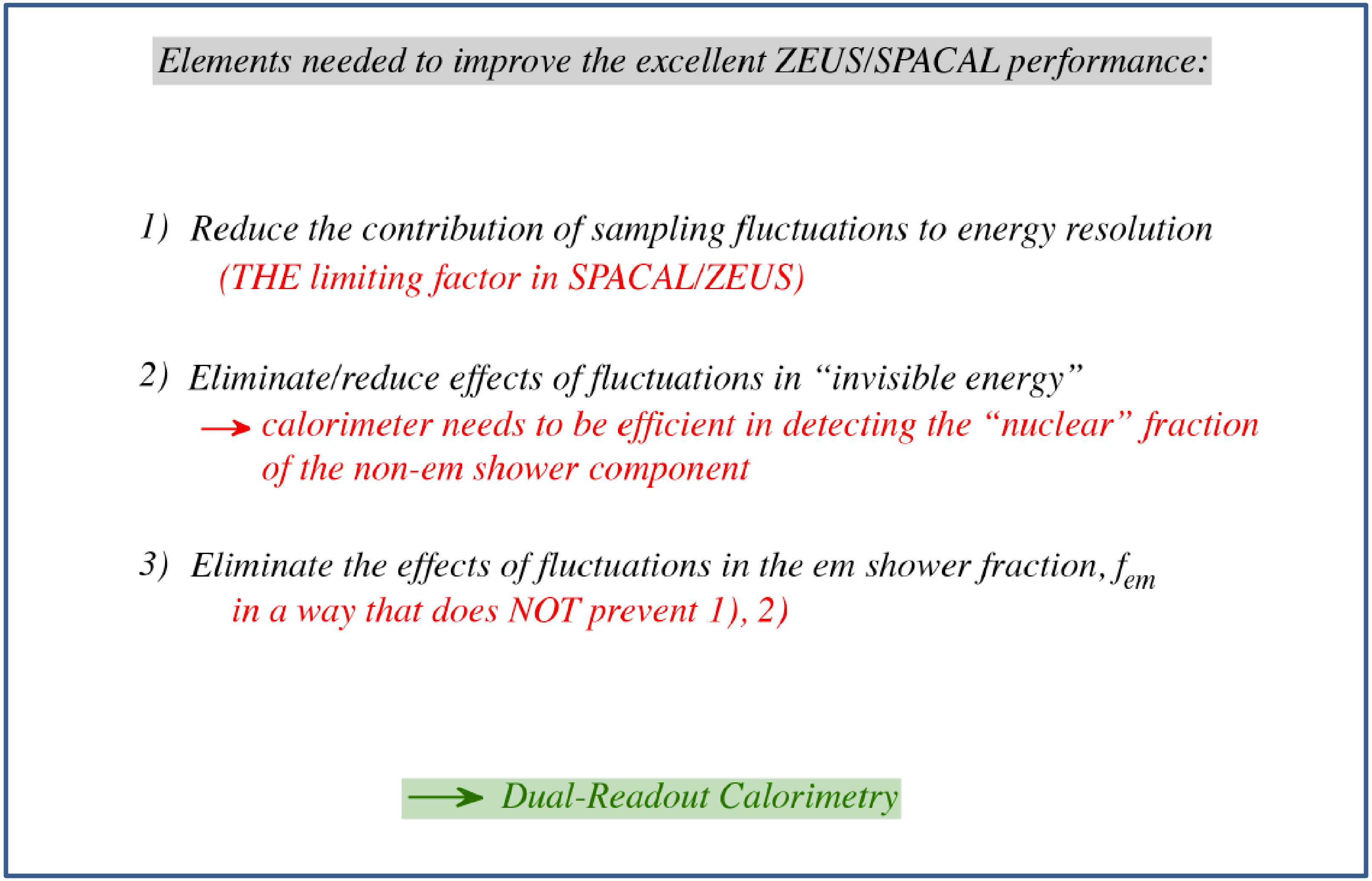


$L_c$ up to few 100 fm

- Complementary probe of the mechanism of partonic energy loss
- HERMES: hadrons can form partially inside the medium
  - Mixture of hadronic absorption and partonic energy loss
- eRHIC: light quarks form well outside the medium
- Forward hadron detection important to
  - Make contact with HERMES measurements
  - Extend acceptance to higher $Q^2$ for intermediate parton energies

# What problems should a new generic technology address?

**(slide from R.Wigmans talk on Calor2010)**



*Elements needed to improve the excellent ZEUS/SPACAL performance:*

1) *Reduce the contribution of sampling fluctuations to energy resolution*
   *(THE limiting factor in SPACAL/ZEUS)*

2) *Eliminate/reduce effects of fluctuations in "invisible energy"*
   → *calorimeter needs to be efficient in detecting the "nuclear" fraction of the non-em shower component*

3) *Eliminate the effects of fluctuations in the em shower fraction,* $f_{em}$
   *in a way that does NOT prevent 1), 2)*

→ *Dual-Readout Calorimetry*

Small Fs is the limiting factor for energy resolution for two best hadronic calorimeters.
Small Fs is required for compensation.

| | ZEUS $^{238}U$ | ZEUS Pb | SPACAL |
|---|---|---|---|
| $\sigma_p$ | 6%/√E | 10%/√E | 5%/√E |
| $\sigma_s$ | 31%/√E | 42%/√E | 27%/√E |
| $\sigma_i$ | 19%/√E | 11%/√E | 11%√E |
| $\sigma_h$ | 37%/√E | 44%/√E | 30%/√E |

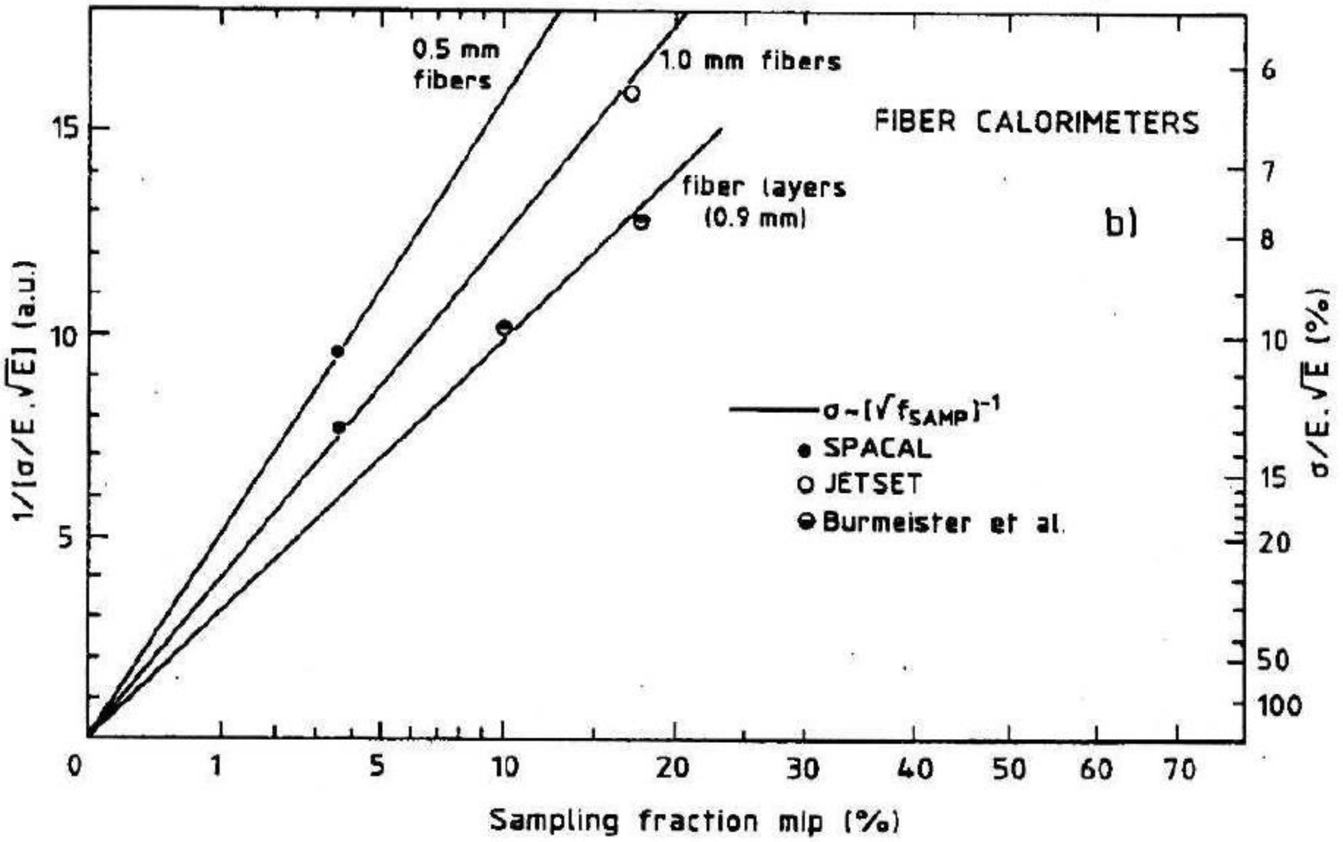
In our technique we can use both DREAM method and old compensation approach.

However, first we want to reduce sampling fluctuations and keep the sampling fraction low, i.e. preserve compensation and keep detector compact and simple.

DREAM method does not require compensation, but the limitation right now is the level of Cerenkov light (18 Phe/GeV, hope to get 100 Phe/GeV see Wigman's talk),
i.e. photostatistic may limit resolution.

# Small **Fs** and small **d** domain. Let's increase sampling frequency to reduce sampling fluctuations.

Taken from CERN Yellow report, CERN-95-02



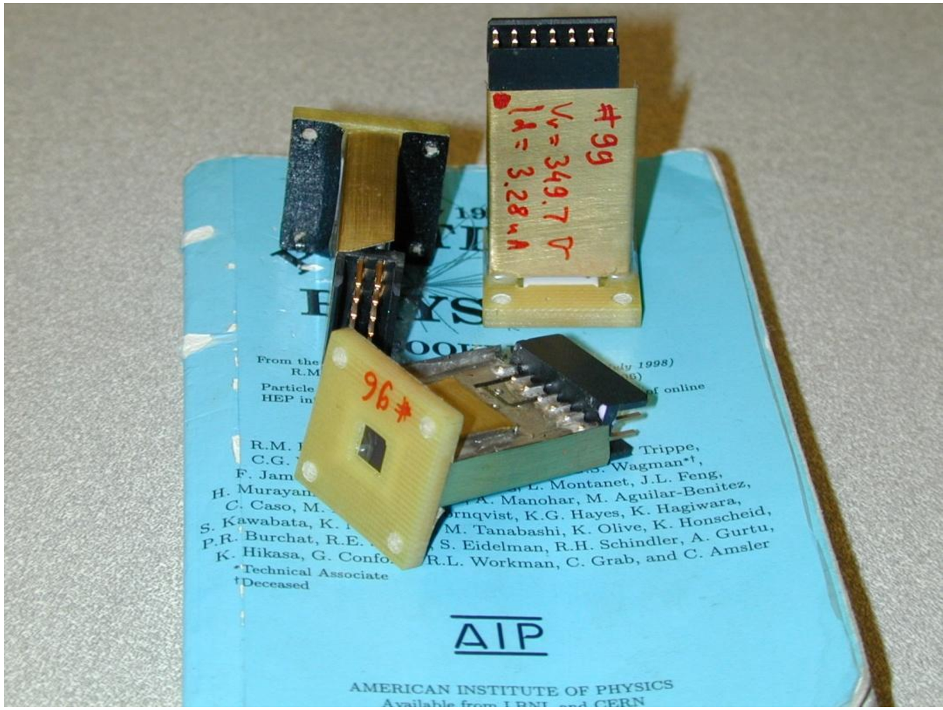
For fiber calorimeters for equal sampling fraction better resolution for smaller fiber diameter. But no one has built a large detector with fibers smaller than 0.5mm.

**New technique required to build SciFi calorimeters with extremely high sampling frequency.**

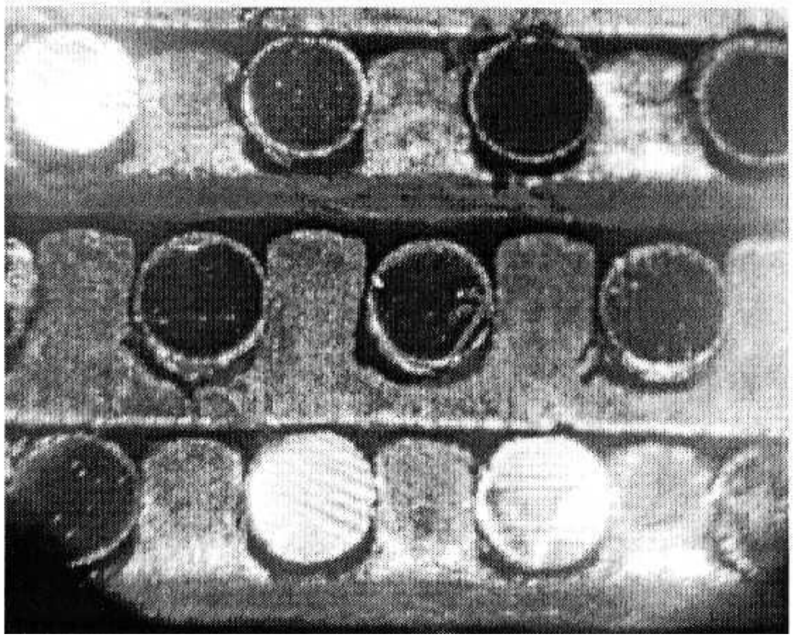
# Why do we want to keep **Fs** small? (Besides compensation)

Because we want detector to be compact with readout inside the magnet.

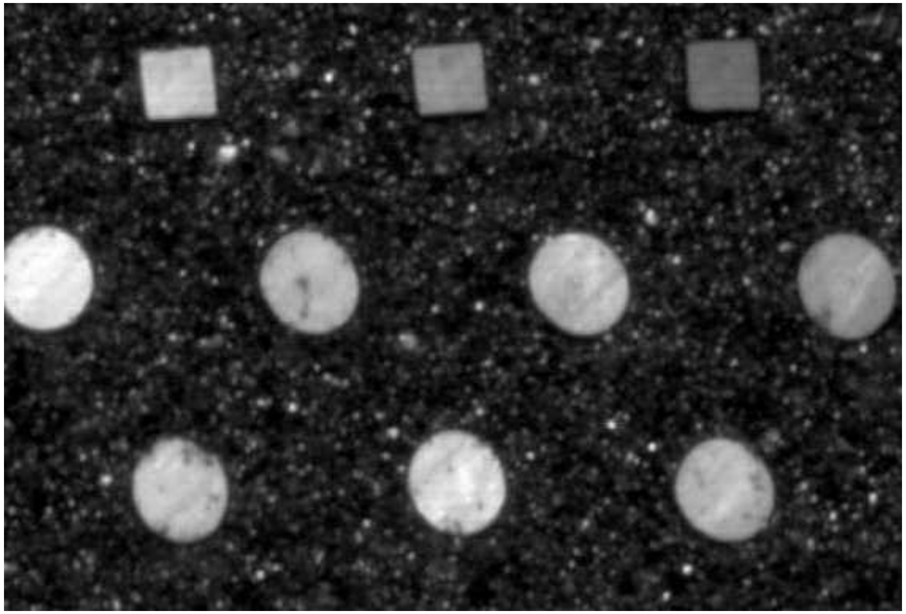
Readout this with something like that?



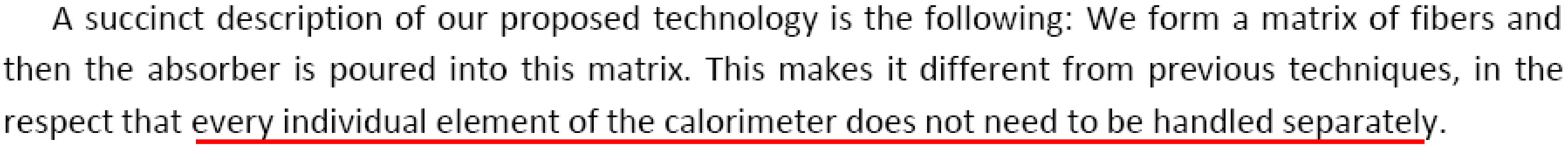
# We did small R&D back in 2003 /2004 in this direction.



**H1, 0.5 mm fibers 0.8mm spacing.**

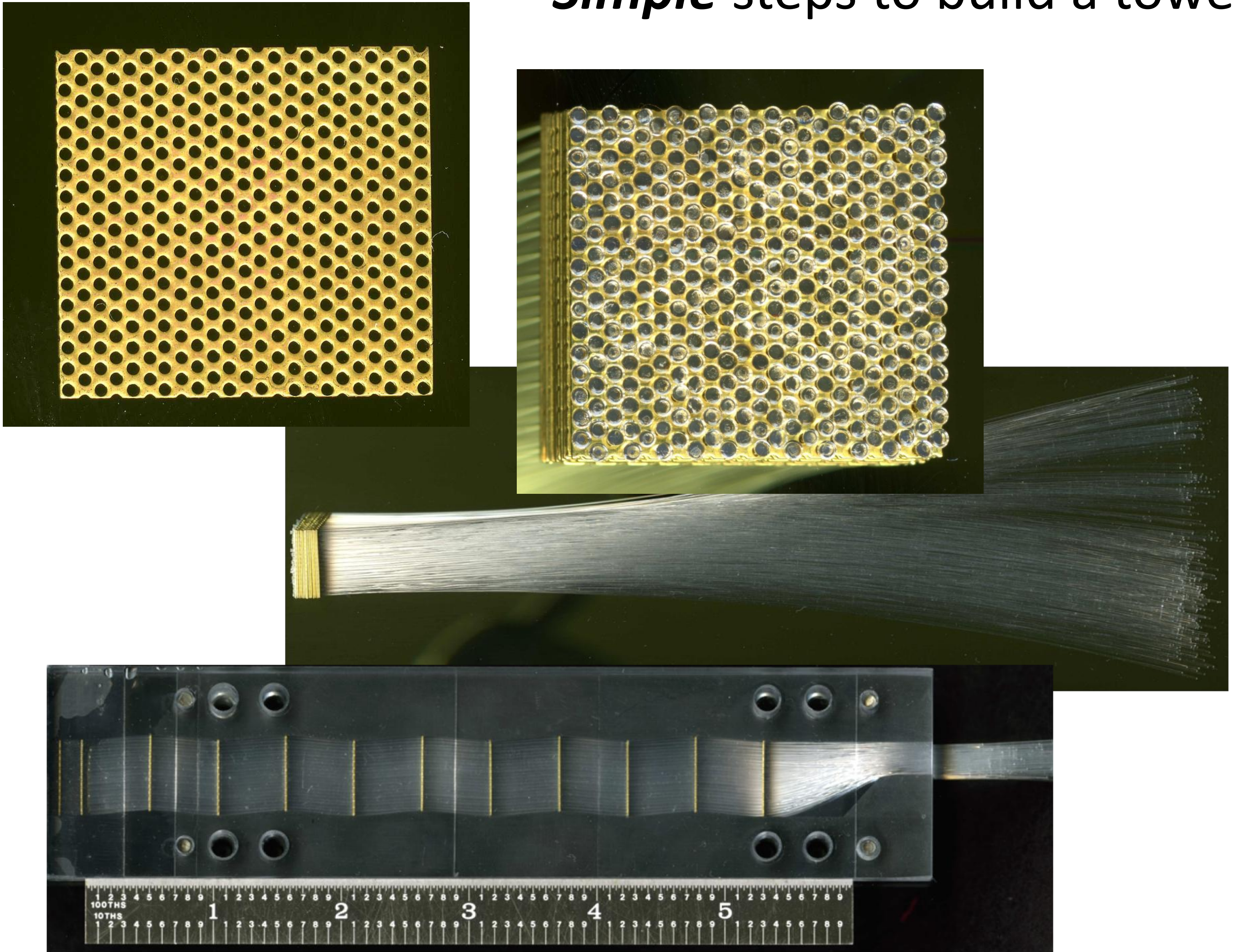


**UCLA mech. Prototype 0.25x0.25, 0.3 mm fibers 0.8 mm spacing**



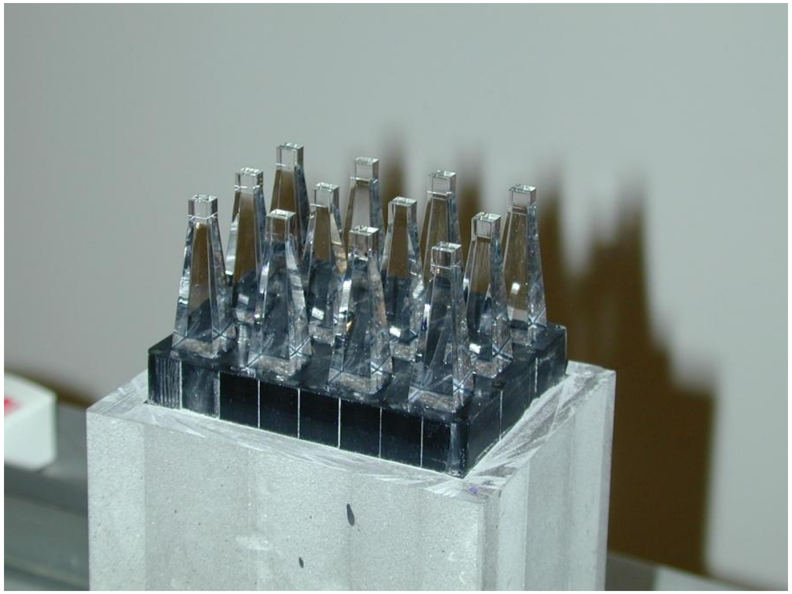
A succinct description of our proposed technology is the following: We form a matrix of fibers and then the absorber is poured into this matrix. This makes it different from previous techniques, in the respect that every individual element of the calorimeter does not need to be handled separately.

# *Simple* steps to build a tower.



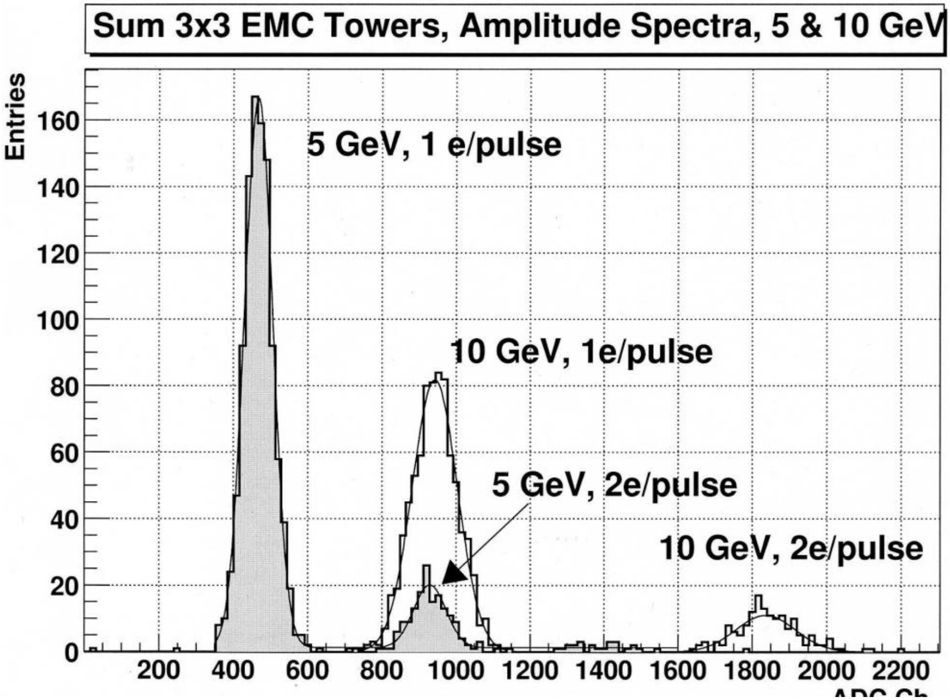
**We started with very simple "dry" version 4X4 matrix readout by APDs and mesh PMTs We tested it with the beam at SLAC in 2003, and found that it is too simple…**

**That forced us to think a bit more and change technique to "wet".**



**The second version "spacordion" has not been tested with the beam for a lots of different reasons…**

**The idea still needs to be proven!**

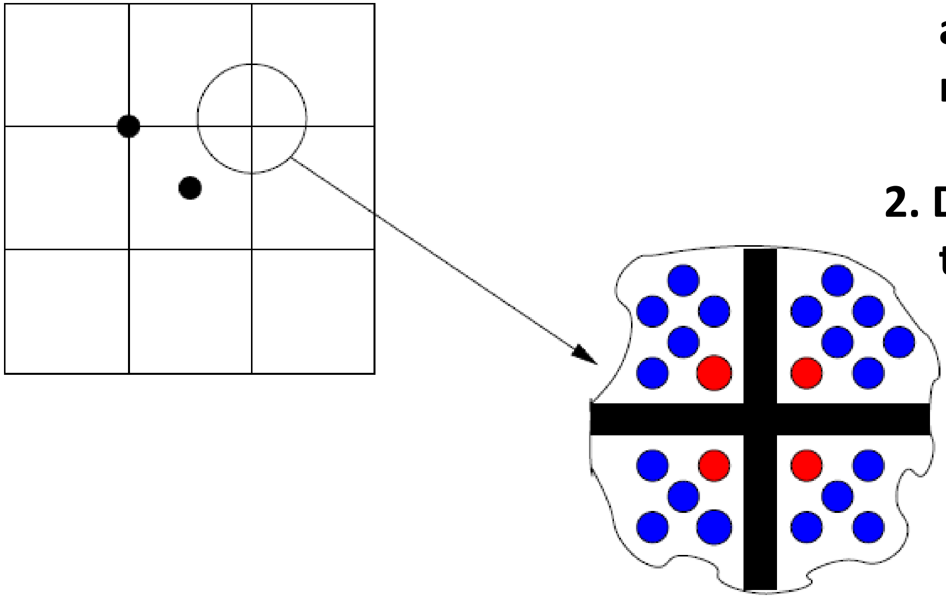


Dry prototype was very dense, almost like pure lead (10.3 g/cm3). It has 496 square 0.25mm x 0.25mm fibers inside a brass container with walls 62 um thick.

496 instead of 500 and 125 um brass in the corners explains largest variations in response during transverse scans (factor of two)

1. **Compactness requires very strict tolerances and homogeneity inside the towers to keep response uniform.**

2. **Dead materials and areas need to be eliminated.**

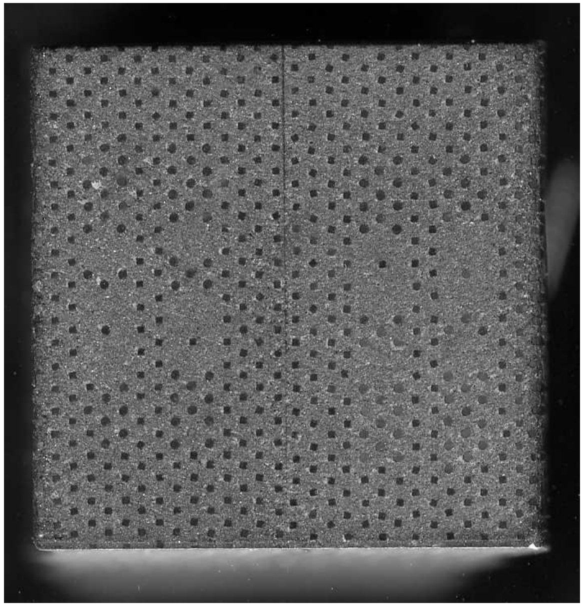


**Electromagnetic showers indeed very narrow!**

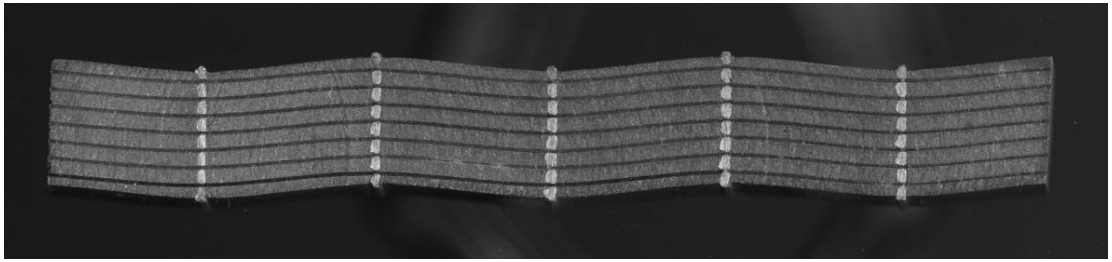
# To solve the problems with the first prototype:

1. **Add additional meshes to keep fibers in place along the towers.**
2. **Learned how to infuse epoxy into powder/fiber mixture.**
3. **Once we have meshes let's wiggle the fibers.**

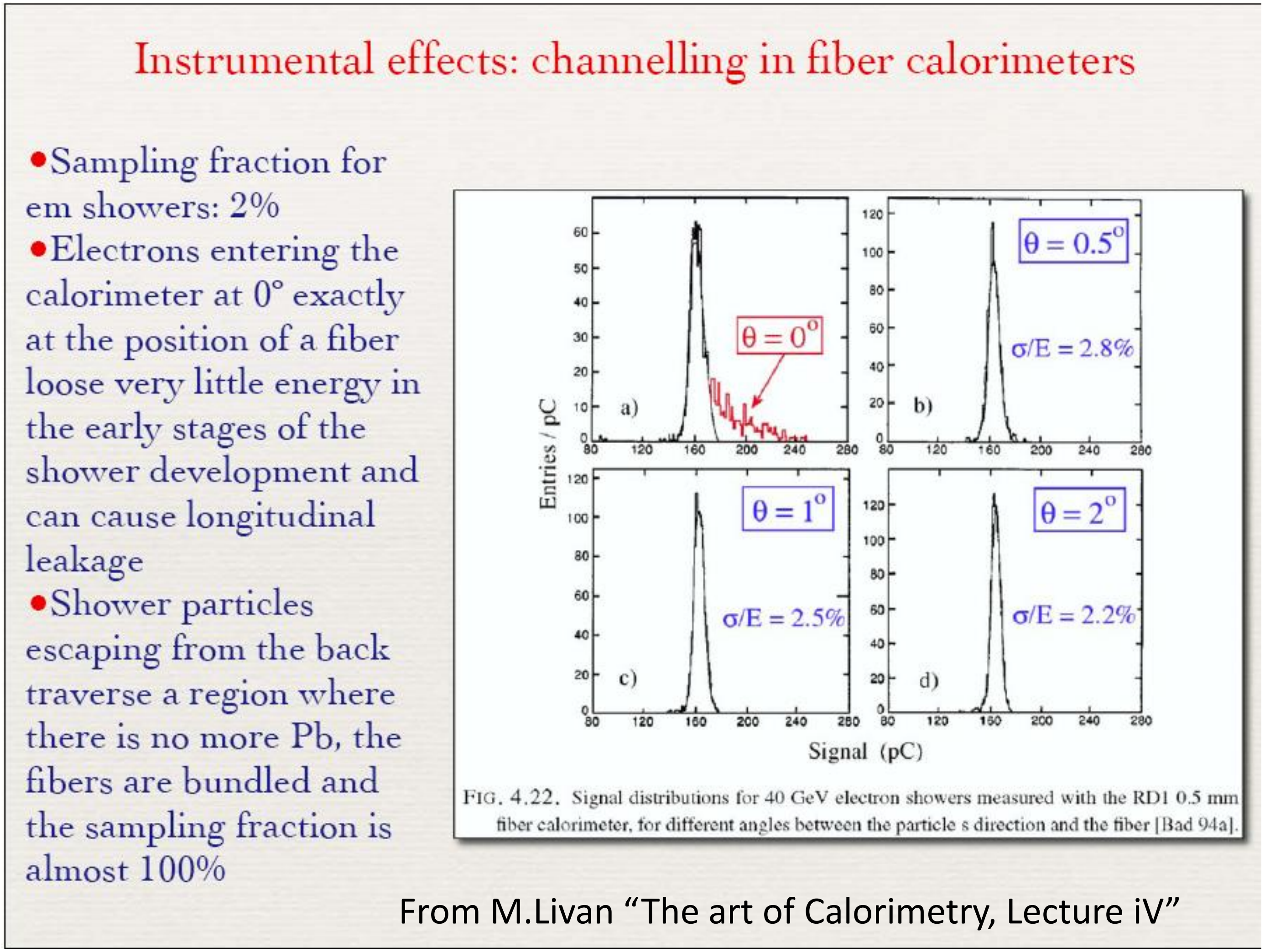
In the process of learning we built a few mechanical units which we sawed and shaved to see how uniform they were (found that the density was within 2% for a thickness of 2 cm). Two cm thickness is the maximum depth that we can infuse epoxy without pressure (i.e., suck the air out and let the epoxy flow into the assembly).



With this technique, probably not the simplest one, we believe we addressed all the problems we found with the first dry prototype.



Wiggle or not is a question. However for some applications where channeling is an issue this will help.



## Instrumental effects: channelling in fiber calorimeters

- Sampling fraction for em showers: 2%
- Electrons entering the calorimeter at 0° exactly at the position of a fiber loose very little energy in the early stages of the shower development and can cause longitudinal leakage
- Shower particles escaping from the back traverse a region where there is no more Pb, the fibers are bundled and the sampling fraction is almost 100%

FIG. 4.22. Signal distributions for 40 GeV electron showers measured with the RD1 0.5 mm fiber calorimeter, for different angles between the particle s direction and the fiber [Bad 94a].

From M.Livan "The art of Calorimetry, Lecture iV"

Plus:
Increased sampling frequency for given number of fibers.

More fibers will contribute to a signal, thus fiber-to-fiber variations will be diminished.

Minus: It is reasonably easy to wiggle 370 fibers of 0.33 mm diameter, mo than that will be a problem .

# “Proof of principle”

Build an electromagnetic calorimeter prototype (4x4matrix) using spacordion technique.

Targeted energy resolution ~10%/√E.

Tower size will be about 25mm x 25mm and $20X_0$ long.

Test this device with the beam. PMT readout.

# Beyond proof of principle…

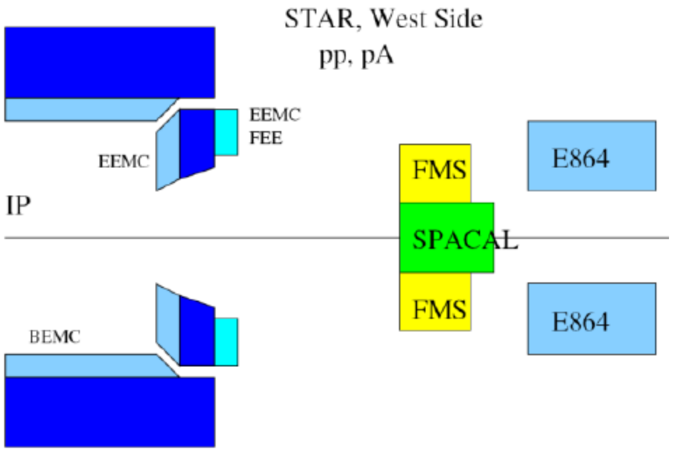
(Get an idea if very good em resolution can be achieved.)

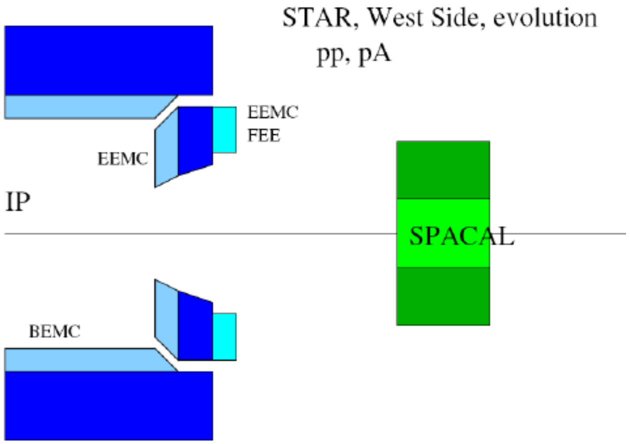
Build and test one tower with BCF20 fibers with increased sampling frequency and sampling fraction.

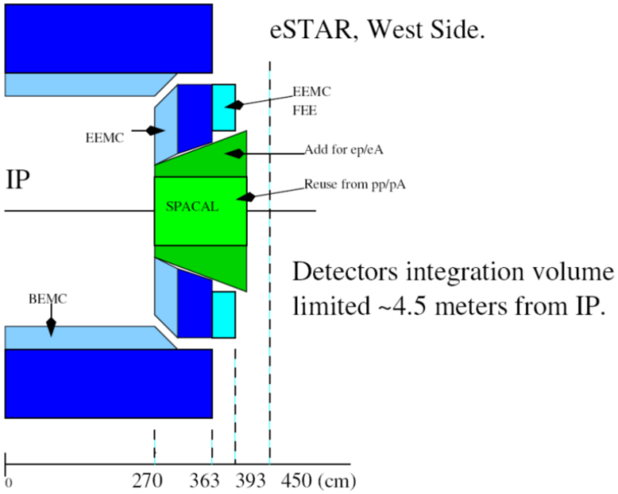
Fill it with BC517H LS instead of epoxy.

Compare it with a similar tower built with BCF12 fibers.

# SPACAL Type for STAR. ***Flexible*** Technique.


STAR, West Side
pp, pA


STAR, West Side, evolution
pp, pA


eSTAR, West Side.

Detectors integration volume limited ~4.5 meters from IP.

**Should consider:**

Available space

Magnetic Field

Radiation

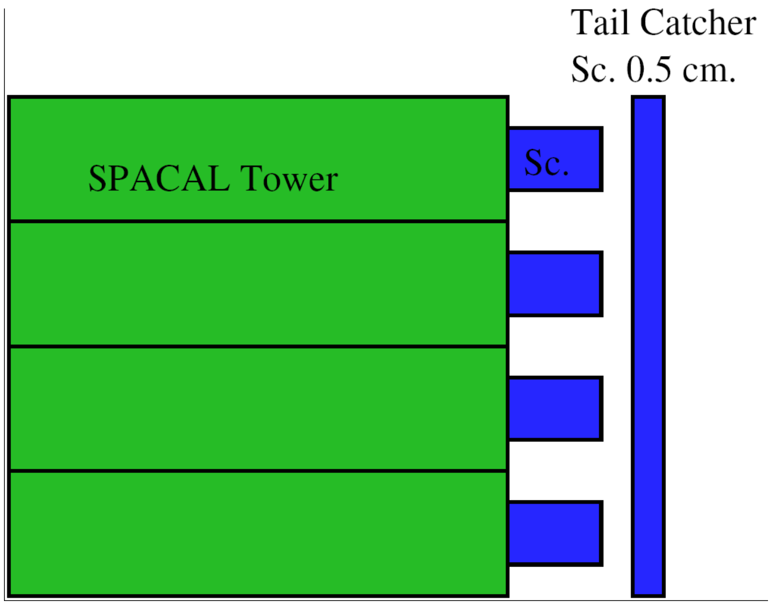
Installation/Integration?

# How to build it? Concept.

- Single container.
- Fill row by row with preassembled fibers.
- Fill row by row with dry powder.
- To reconfigure, drain the powder. Re-use fibers if possible (if they survive).

Lots of questions!

# GEANT4, MC current model.



Jay Dunkelberger (UCLA)

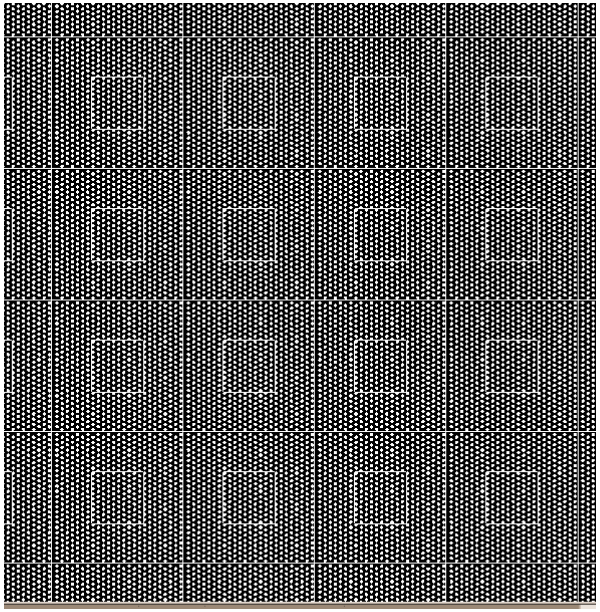
## Parameters:

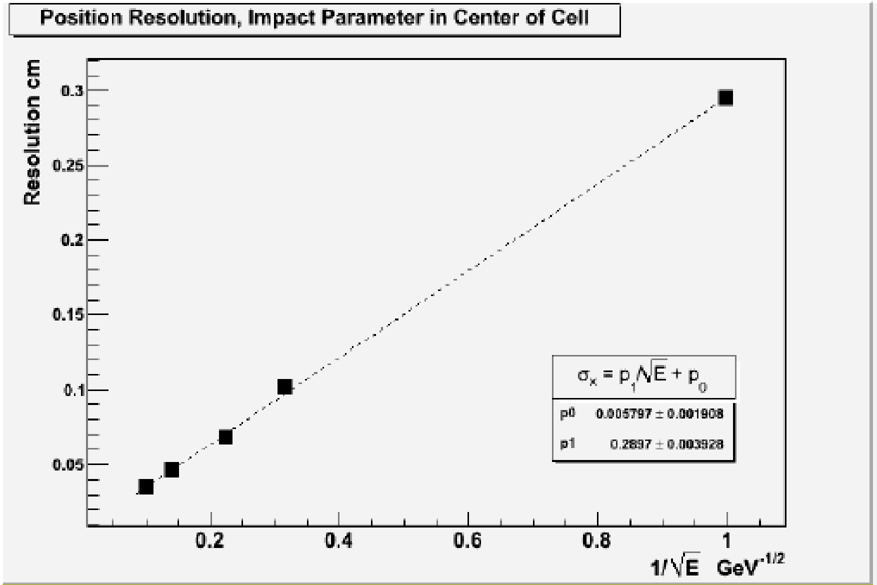
Total length, Granularity, Resolutions

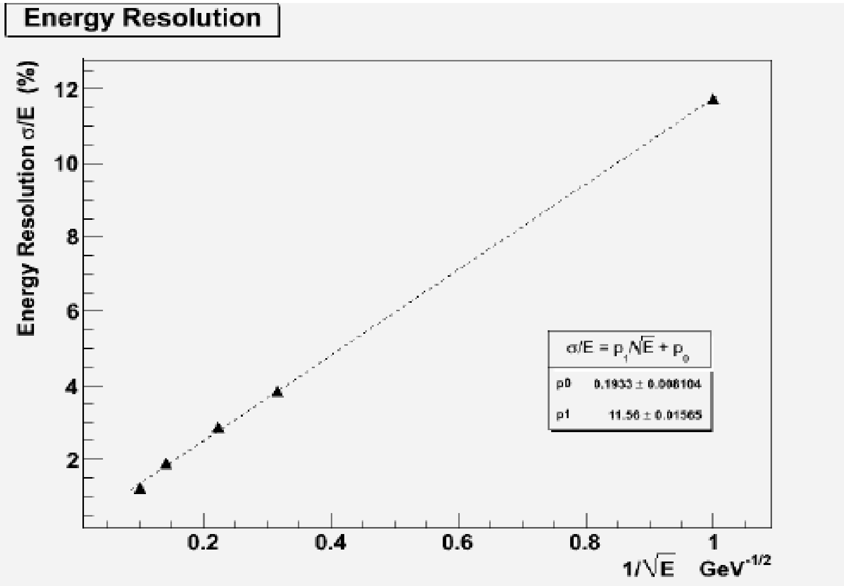
Fiber and absorber composition close to RD1,
Compensated HCAL. Fiber spacing 1 mm, fiber
Diameter 0.47 mm <- to match standard meshes.
Tower lateral dimensions 2.55 cm x 2.55 cm
715 fibers per tower. Length 1.3 m (~ 6 int. lengths)
400 towers in total.
Sc. block at the end of the tower to model fiber
bundles (2 cm x 1 cm x 1 cm).
Tail catcher granularity 4 x 4 towers.

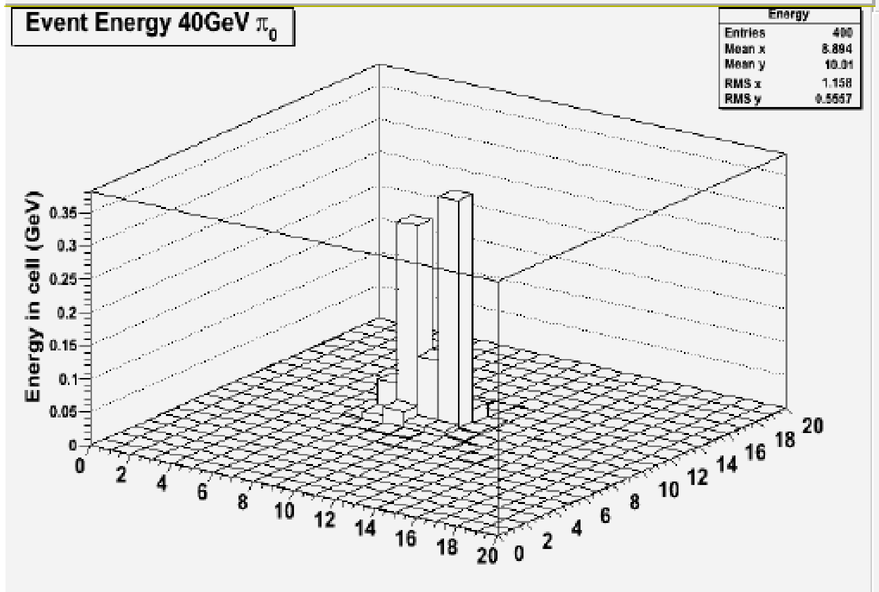
To do: cuts optimization, basics with em. showers (energy, position resolutions vs E). pi/gamma separation.

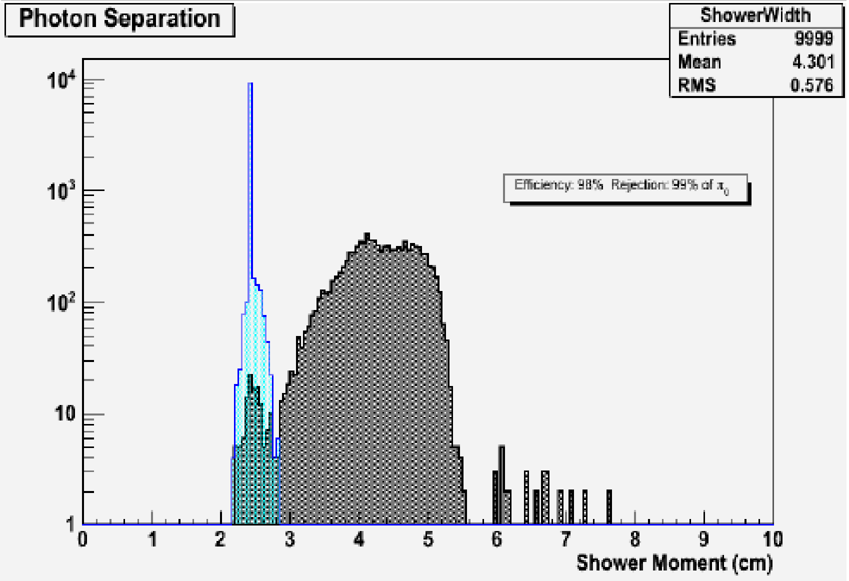
Later: hadronic showers. How well reproduces experimental results (compensation, etc…), then e/h rejection











Jay Dunkelberger (UCLA)

# From concept to something real…

Different construction method and fibers compared to EM prototype.

Fibers BCF 20. Readout with the same PMTs as EM prototype with additional K12 filter.

Want to test construction and assembly technique , the way it can be done in STAR. Preassemble fiber towers. For the test run, fill container with fibers and pour powder into it, without vibrating the container right at the test run setup (i.e., emulate as close as possible to how it can be done in STAR).

Get test results and compare with MC.

For year 1 R&D it will be sufficient to test this concept with electrons only.

# Summary:

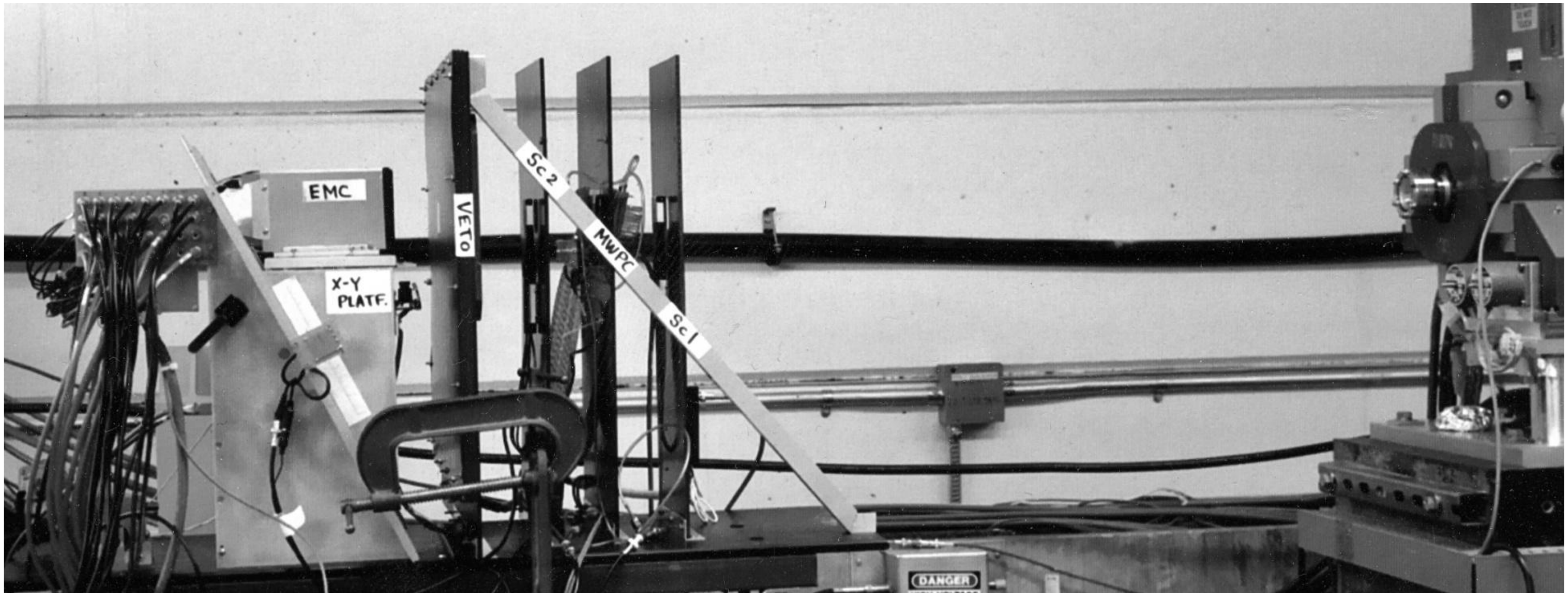
- In the first year of R&D we want to test new methods of construction of sampling calorimeters using our technique:
- Build and test with the beam 4x4 matrix of “spacordion” EM prototype.
- Build and test with the beam two EM towers with very fine sampling frequency.
- Build and test with the beam 4x4 matrix SPACAL type prototype. Compare with monte carlo.

# Budget Request.

| | |
|---|---|
| Tungsten powder, BCF12 scintillating fibers, epoxy and misc. mechanical components for 4x4 matrix “spacordion” EMC prototype. | \$10k |
| Tungsten powder, BCF20 scintillating fibers, epoxy and misc. mechanical components for 4x4 matrix SPACAL type combined EM+HAD small prototype. | \$30k |
| Upgrade for DAQ and test run equipment (electronics, test run counters, sc. hodoscopes, cables etc.) (includes 26% overhead)) | \$15k |
| Machine Shop | \$20k |
| Undergrad/Grad students labor (includes 26% overhead) | \$10k |
| Shipping (includes 26% overhead) | \$10k |
| Travel (5 people, 1 x 3 weeks) ( includes 26% overhead) | \$15k |
| Total direct cost | \$97k |
| Total indirect cost | \$13k |
| Total | \$110k |

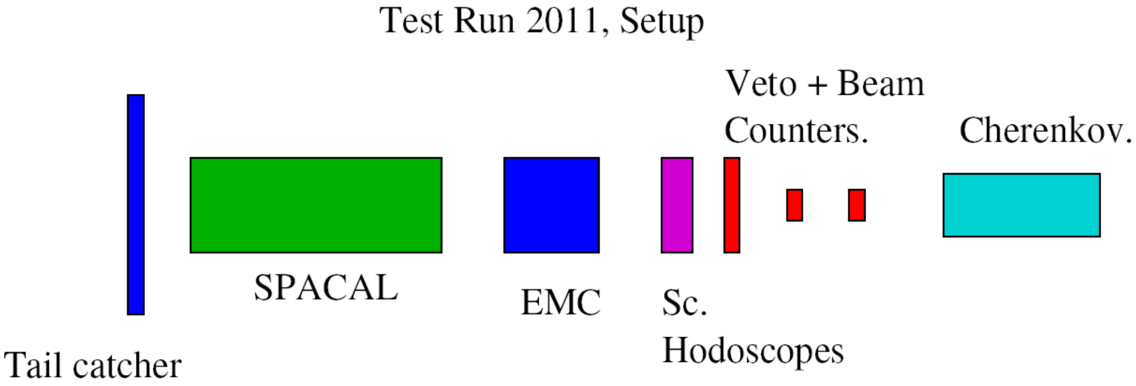
# Backup Slides.

# 'Everything should be kept as simple as possible, but no simpler.'



**Test setup at SLAC FFTB. Wanted to measure: resolution, linearity, uniformity.
For 36 hours of beam time, we spent most of them by scanning matrix across the face and along the towers, because almost immediately discovered that energy resolution is not what was expected (~30% off from 13%/sqrt(E)), but that wasn't the biggest problem…**

# To prove it work we need to build it and then test it with the beam.



Test Run 2011, Setup

EMC, “spacardeon type”, matrix 4 x4, readout with PMTs .
Some upgrades for test setup will be required. Want to replace
MWPC with Sc Hodoscope.

SPACAL for STAR will use different technique compare to EMC.  Not started yet.