Absolute energy calibration of FD by an electron linear accelerator for TA

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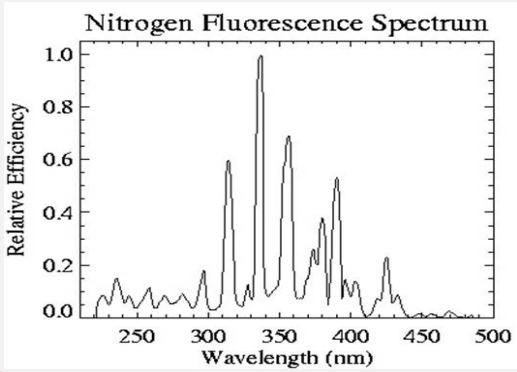
Energy Measurement with FD

Air Shower by Primary Cosmic Ray

①Fluorescence Light

Energy loss to Fluorescence photons

$\Delta E \rightarrow N_{photon}$

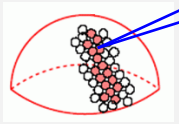


②Atmospheric Attenuation

Scattering and Absorption

N_{photon}

N'_{photon}



③Fluorescence Telescope

Photons to ADC count

$N'_{photon} \rightarrow N_{ADC}$

④Out of FoV, Missing Energy

Systematic Uncertainty of TAFD Energy Scale

Systematic errors

TA-FD Hybrid Analysis,
2010.March.JPS, presented by D.Ikeda

Item	Systematic error
Fluorescence yield	12%
Detector	10%
Atmosphere	11%
Primary particle mass	5%
MC correction	3%
Total	19%

Main Large Systematics

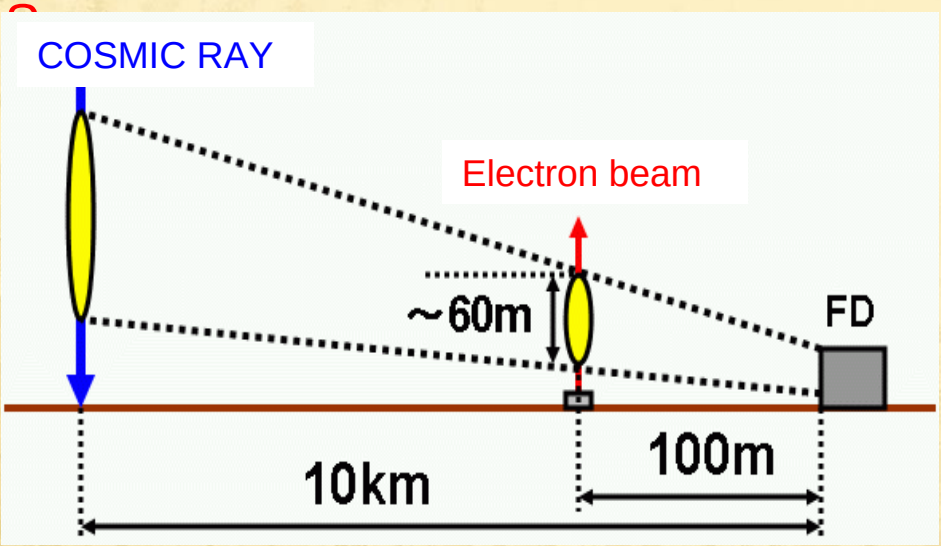
End-to-End Calibration Need !!

Electron Light Source (ELS)

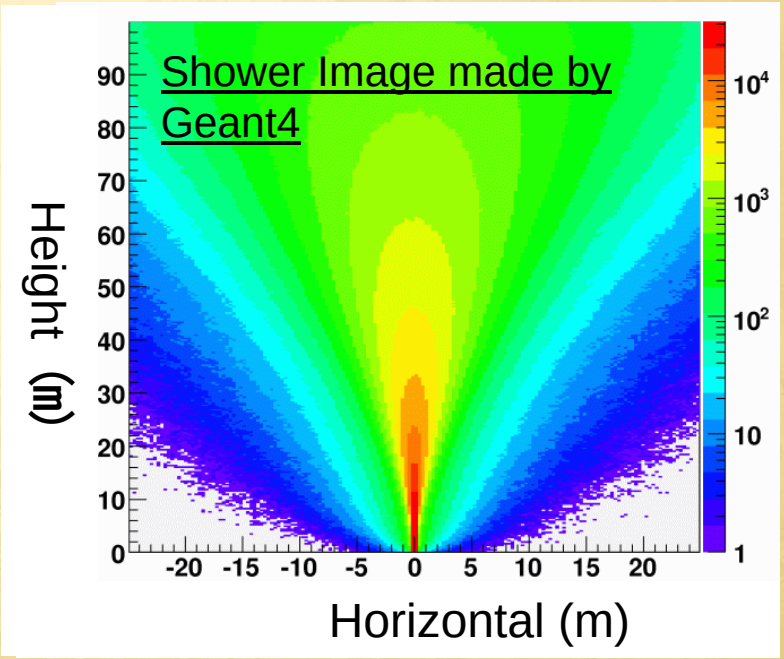
Energy Scale of Telescope Array (TA) experiment

= Decided by Electron Beam from LINAC(ELS) near FD site

Electron Light Source (ELS) = A unique absolute energy calibration



ELS is located at 100m far from FD



Known beam energy = We can estimate energy deposit in the air

We can calibrate all of FD calibration constant = End-to-End Calibration

The Specification of ELS

- Energy ：40MeV

  The electron energy in 10^{20}eV Air Shower
  （10MeV～1GeV）

- Position：100m far from FD

  Range of 40MeV electron～FoV of TA-FD

- Current：10^{9}e-/pulse

  10^{20}eV Air shower 10km far from FD

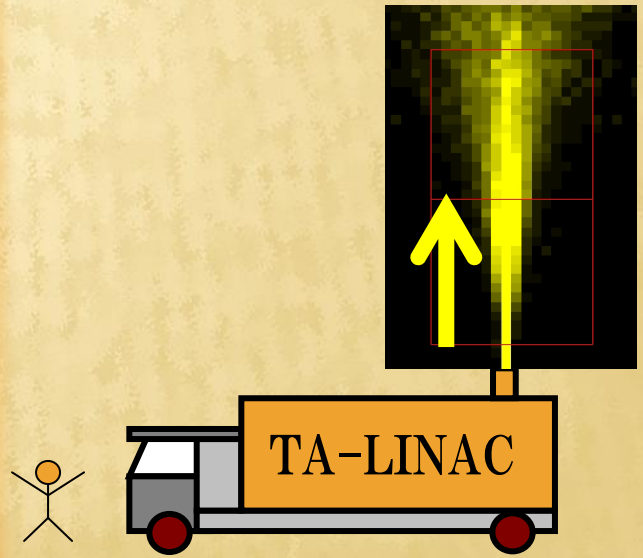
  →10^{16}eV @ 100m →10^{16}eV/4×10^{7}eV～10^{9}e-

- Pulse Width：1μsec

  Time scale of signal of air shower in ～1PMT

Development of ELS

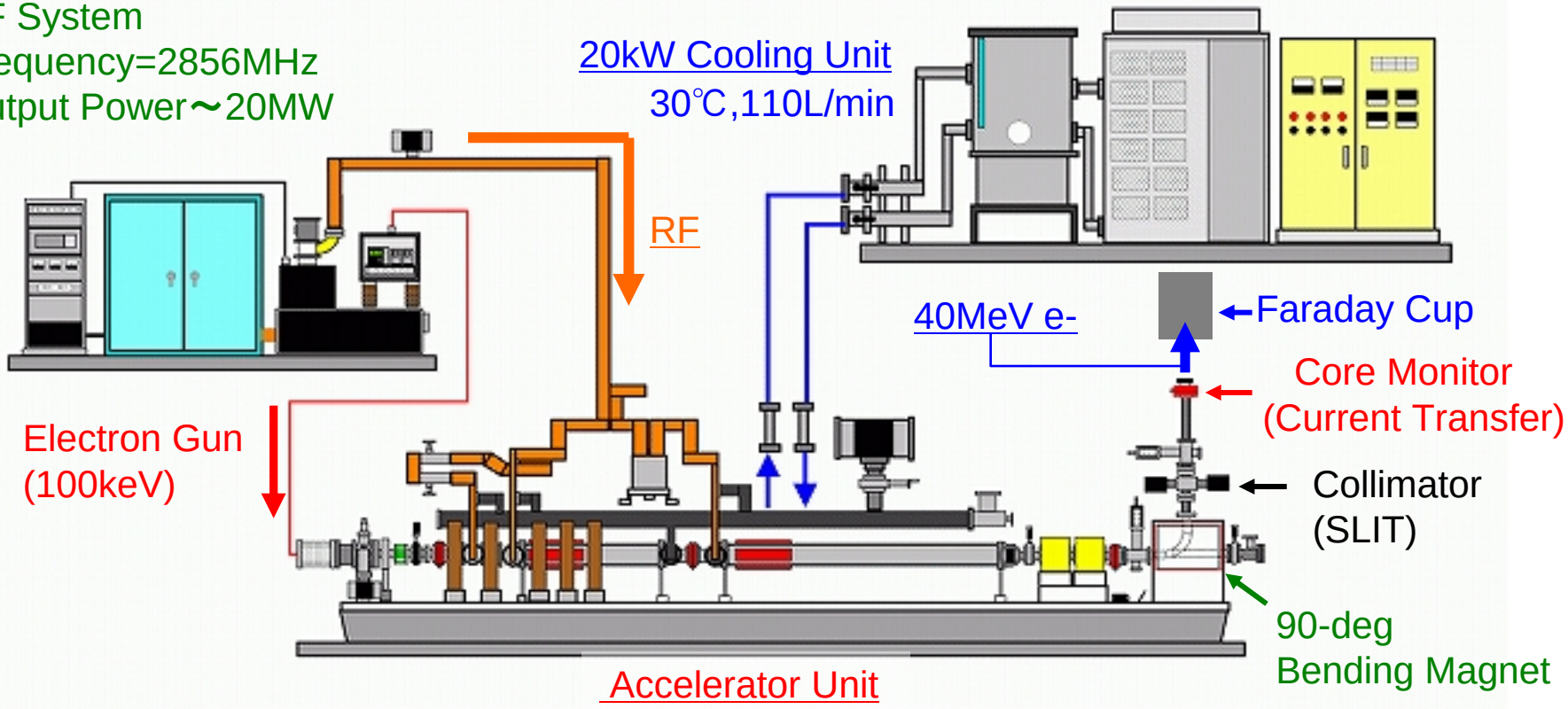
ELS was developed in KEK



Design of ELS

Use Non Frozen water : Propylene Glycol solution

RF System
Frequency=2856MHz
Output Power～20MW



Installation RF system and Accelerator Unit into the 40ft container

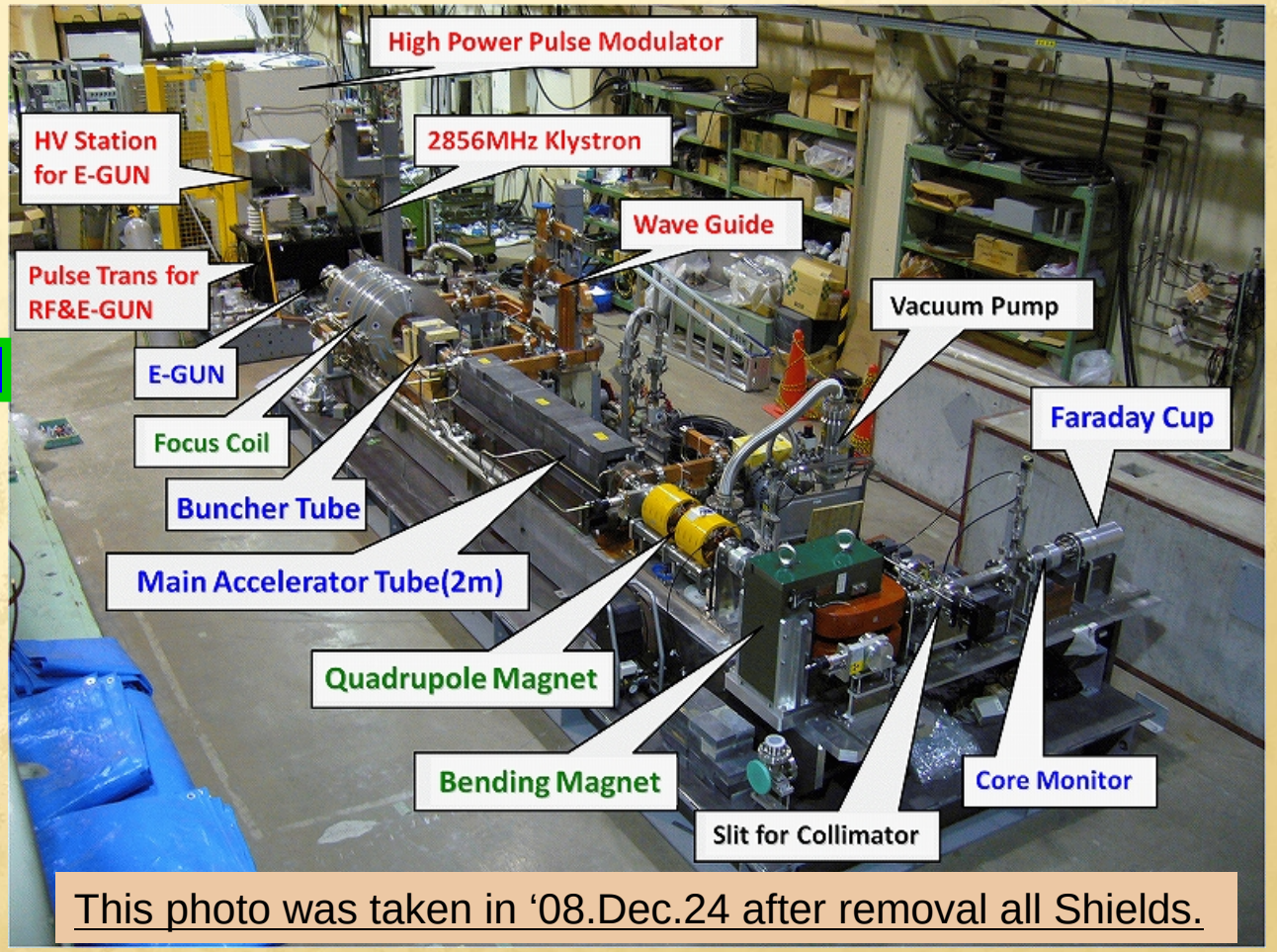
Cooling Unit into the 20ft container

Construction of ELS in KEK injector

-Construction Apr.2005 – Jan.2008
-Beam Operation '08.Feb.22th – Dec.10th

Beam Condition
- Repetition ~ 0.5Hz
- Energy ~ 40MeV
- Current
  10~250pC/pulse

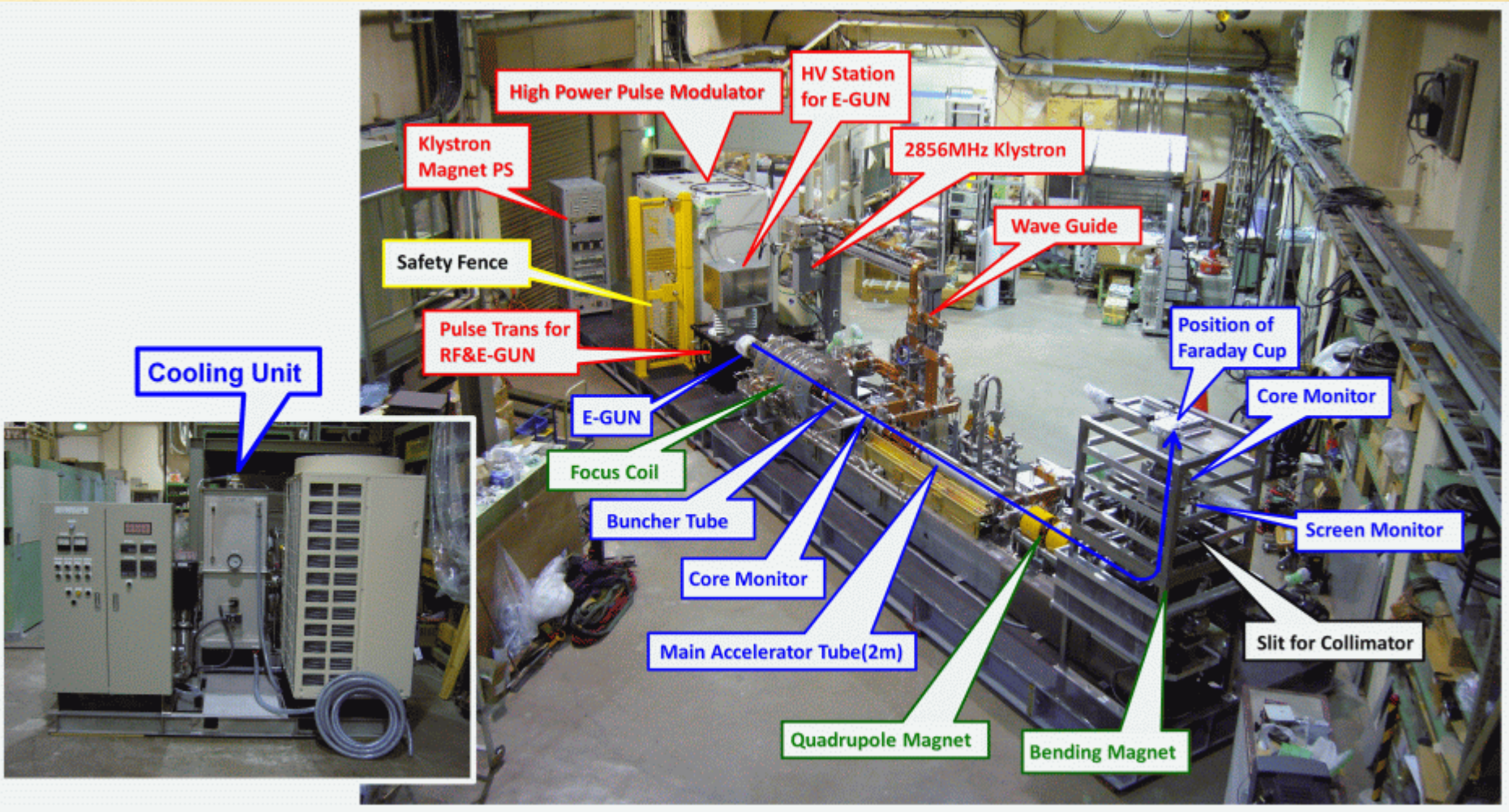
Built in
Shield room



This photo was taken in '08.Dec.24 after removal all Shields.

Final Figure of ELS at KEK

Final Reconstruction of ELS was completed in KEK, Feb.'09



Shipment of ELS KEK to U.S.

ELS was moved w/o disassembly

Route of transport

Yokohama

Long Beach (L.A)

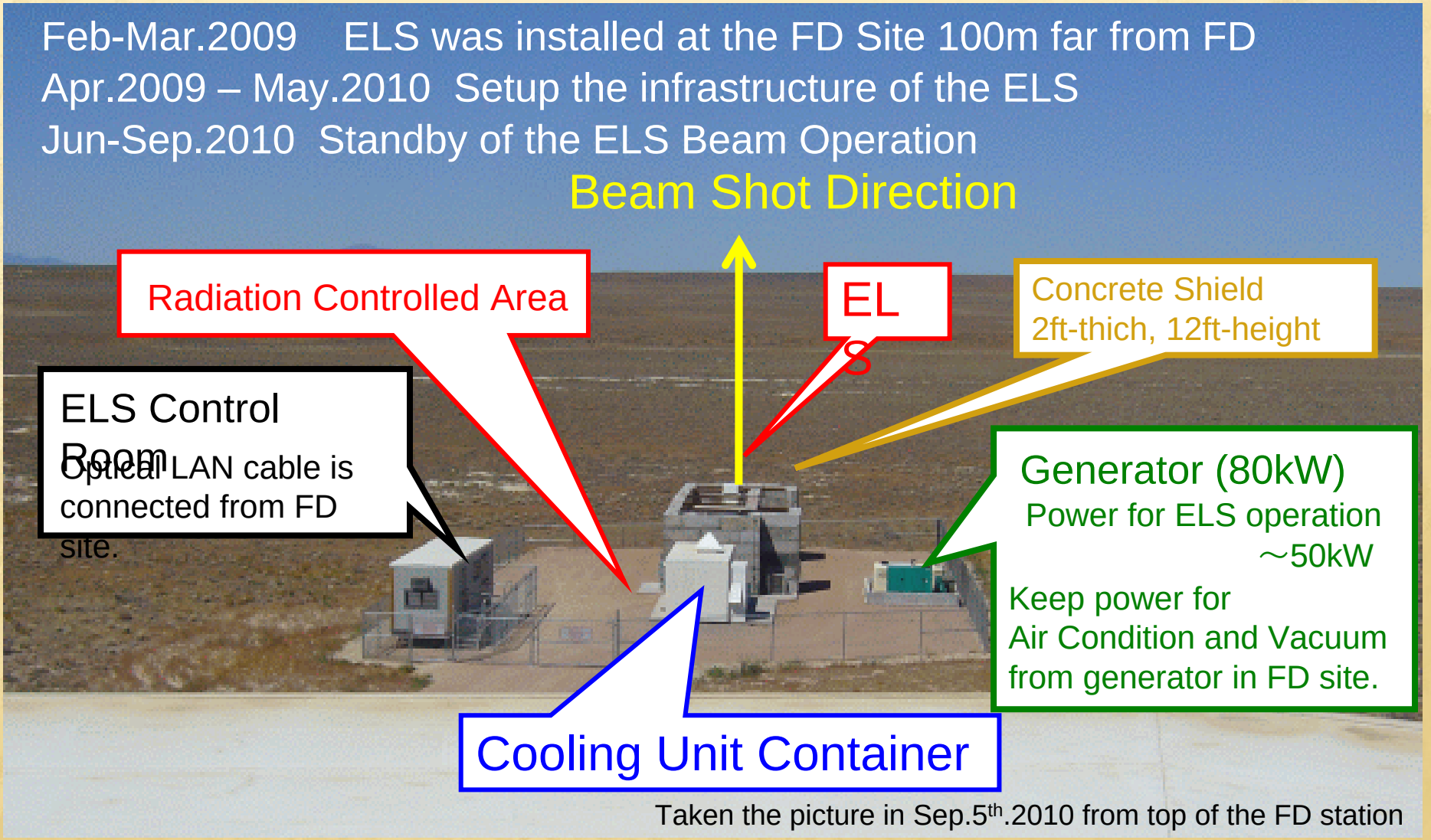
Google map

2009. Feb.23rd (Mon) Carried out from KEK
Mar.19th (Thu) Installation of ELS into FD site

ELS Standby in FD site

ELS Site at FD Site

Feb-Mar.2009 ELS was installed at the FD Site 100m far from FD
Apr.2009 – May.2010 Setup the infrastructure of the ELS
Jun-Sep.2010 Standby of the ELS Beam Operation



Taken the picture in Sep.5th.2010 from top of the FD station

ELS Radiation Safety

Administrator：University of Utah

Radiation Safety Officer (RSO)

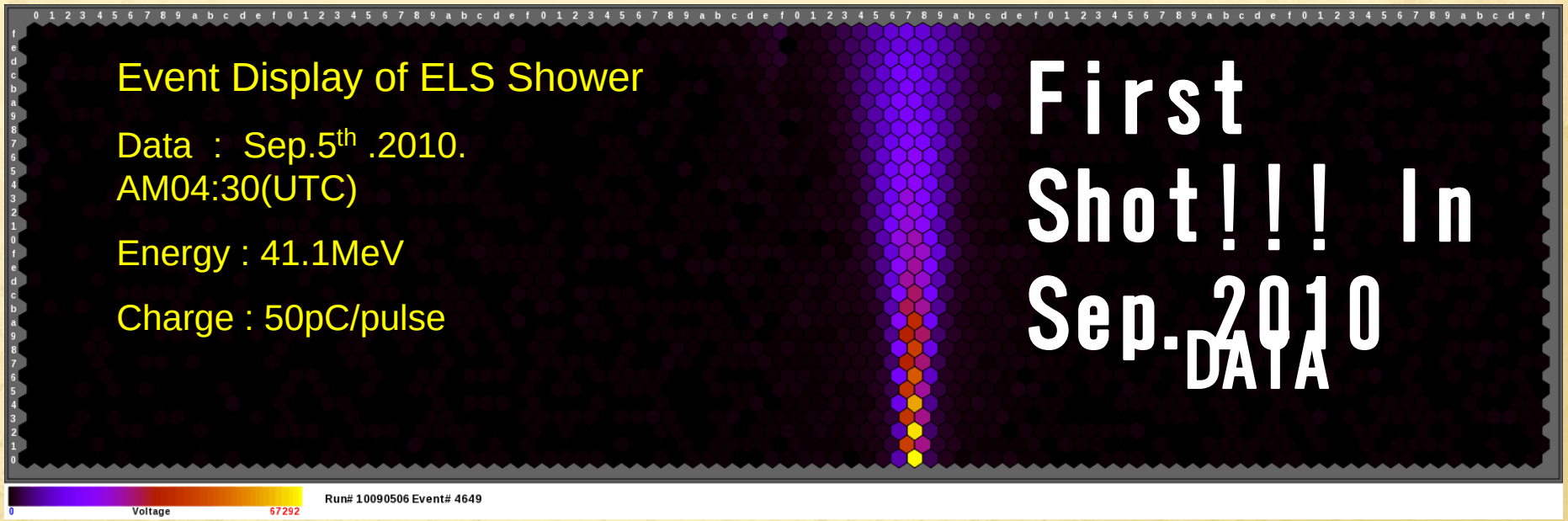
Responsible User(RU)

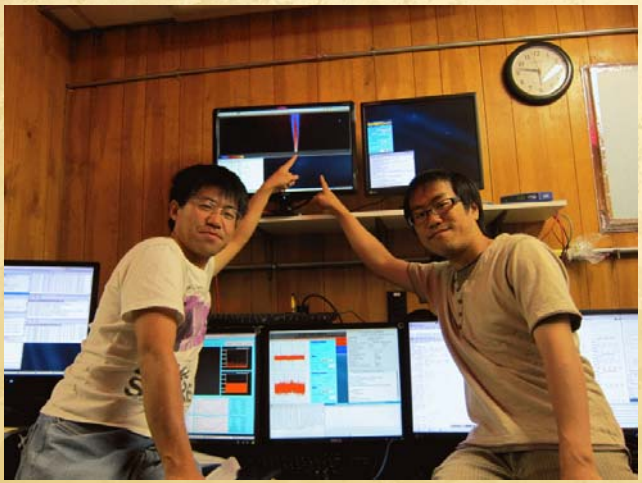
Onsite-Radiation Safety Officer (Onsite-RSO)

Onsite-Responsible User(Onsite-RU)

- Need ≧2 persons
  (Onsite-RSO ×1+Onsite-RU ×1)
- All people need license of Radiation worker

First Shot and Detection by FD





Beam Operation : Sep.2nd –4th

Beam shot into the Sky : Sep. 3rd and 4th

# of Shot into the Sky～1800 pulses

Output power = 41.4MeV×40～140pC/pulse×0.5Hz

Data Analysis

Energy Calibration w/ ELS

Energy Calibration =

Comparison of MC simulation and DATA

$$\frac{N_{p.e.}^{DATA}}{\qquad\qquad}$$

$$\sum_{i=1}^{256}\left(N_{p.e.}^{DATA}\right)_i$$

$$\left[\sum_{i=1}^{256}\left(N_{p.e.}^{MC}\right)_i\right]^{corr} = f_{calib}\times\sum_{i=1}^{256}\left(N_{p.e.}^{MC}\right)_i + c_{calib}$$

i=PMT#

Change the beam charge

$$\sum_{i=1}^{256}\left(N_{p.e.}^{MC}\right)_i$$

Correction factor, constant

Correction of MC used the correction factor and constant

Energy Calibration w/ ELS

Real Data

- ELS Data
  - Beam monitor (Time, Energy, Beam Current)
- FD Data
  - Shower data which is observed with FD
  - Environment condition (Temperature, Pressure, Humidity, ,,,)

Weather station at FD site

MC Data

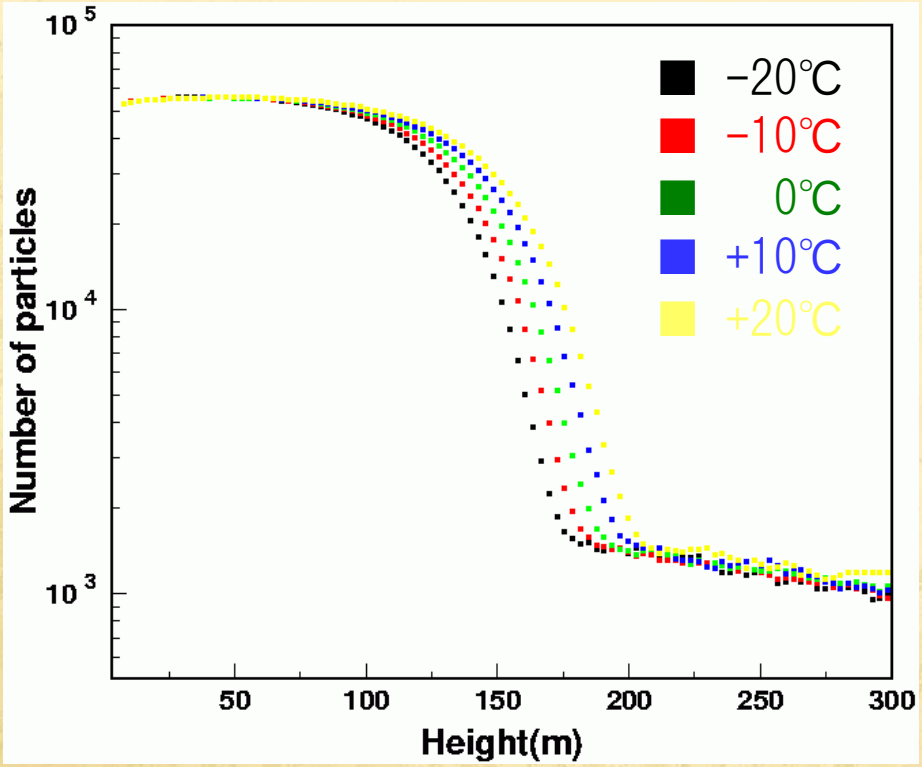
- Shower Simulation
  - Air shower simulation by using Geant4

We want to use more than two codes for double check of "Energy deposit" in the air.

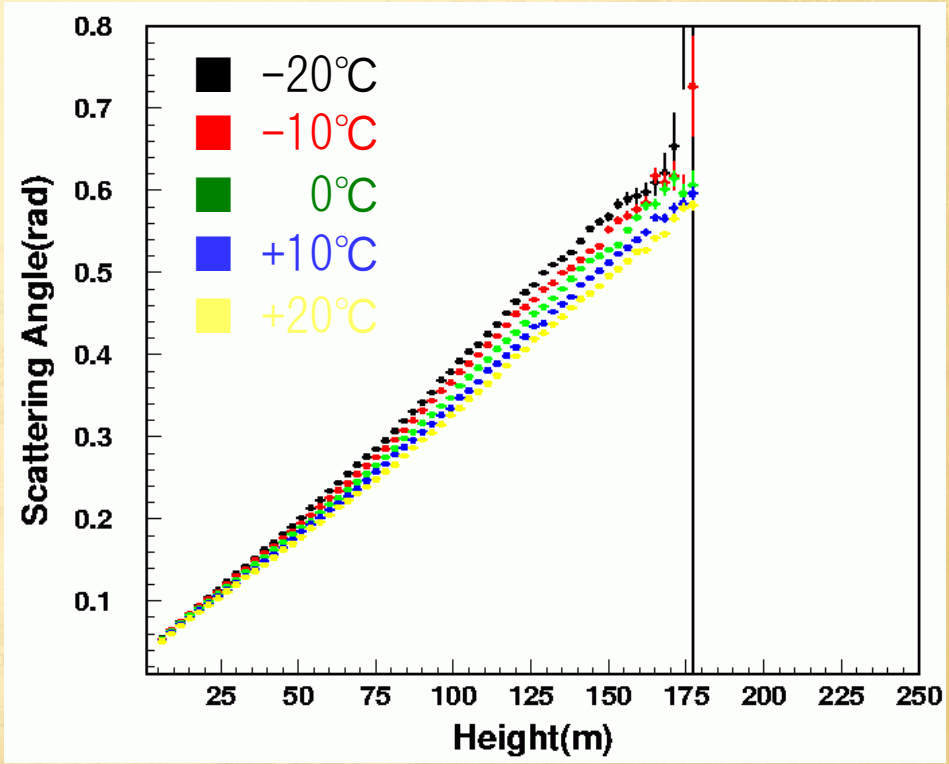
- FD Simulation

Performance the Air Shower

(1) Longitudinal distribution



(2) The scattering angle of primary electrons

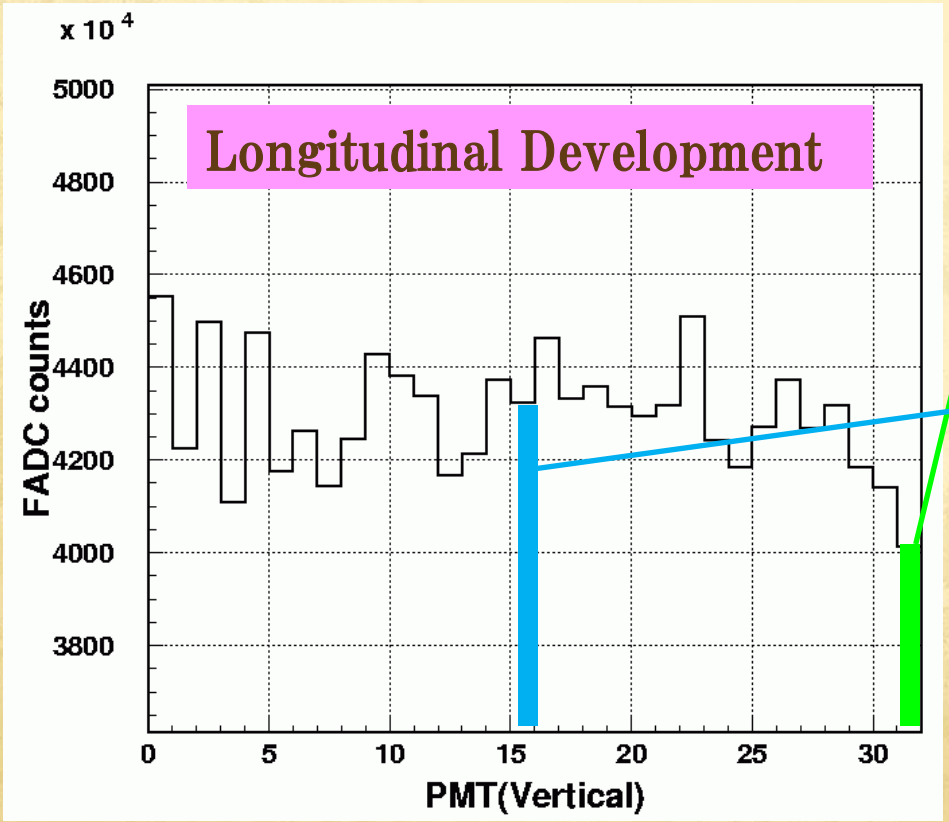


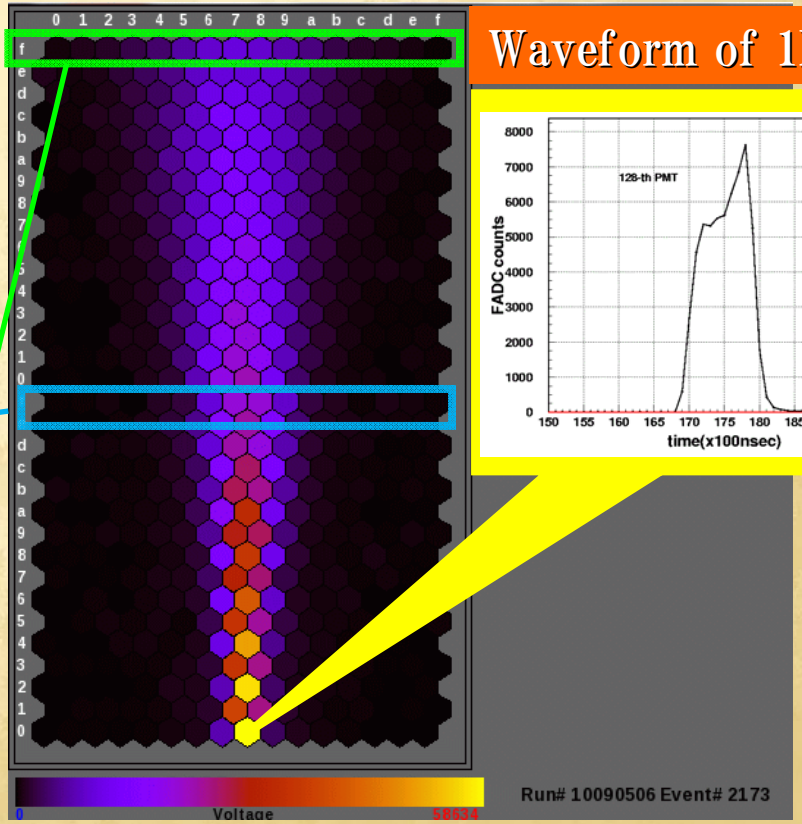
The distribution depends on temperature(density of air)

→This effect is small in the FoV (height：10m~70m)

Data Checking

Data set : Taken in Sep.5th (UTC)
checking now…





Systematics Improvement

■ Fluorescence Yield(12% → ～a few %)

In ideal, the systematic uncertainties becomes to be zero.

-The uncertainties of the spectrum remains ～a few % ?

■ Fluorescence Detector (10% → ～a few % ?)

In ideal, the systematic uncertainties becomes to be zero.

-The FDs which can not be calibrated by ELS will be calibrated by relative calibration with laser system～a few % ?

■ ELS(～4%)

- The uncertainty of output energy can be ignored.
  … in case of 40±2MeV → # of detected photons < 1% difference.

-The uncertainty of the beam charge = 4% (beam test in KEK)

Improved Systematics <10% →The total systematics ～10%+ α

Operation of ELS

- We will operate ELS for calibration every about 2 month

We want to calibrate FD in different air condition,
and study their dependence, and time variation.

But we need – Beam conditioning.
(next week … in Utah)
Beam direction, position monitor,
Energy, Current measurement…

– More Data Checking, and MC study.

Potential of ELS

- Standard energy calibration source for UHECR observation
  - Fluorescence experiment
    - Radio Detection
      - And your ideal …

Summary

Motivation of ELS (Electron Light Source)

Absolute Energy Calibration
(Calibrate all of calibration constants by one source)

= End-to-End Calibration

Status of ELS

Sep.2010 First Shot was Detected !!!!

On Going!!!

Started Energy calibration by ELS!!!!

- Shower simulation by using Geant4 → checking their performance.
- Data Analysis → checking.