Extreme Universe Space Observatory

Status of the JEM-EUSO project

H. Miyamoto, M. Teshima, R. Mirzoyan,
J. Ninkovic, T. Schweizer
Max-Planck-Institut für Physik

Contents

- Introduction
  - JEM-EUSO
  - Science objectives
  - Status
- Contribution of MPI
  - SiPM development and application study for JEM-EUSO advanced design
- Summary and Outlook

Extreme Universe Space Observatory

The JEM-EUSO Collaboration

12 countries, >60 institutes, ~170 members

USA
- NASA/MSFC
- Univ. of Alabama in Huntsville
- LBNL, UC Berkeley
- UCLA
- Vanderbilt Univ.
- Univ. of Arizona

Mexico
- Inst. de Ciencias Nucl., UNAM
- BUAP
- UMSNH

EU

France
- Observatoire de Paris, Univ. Denis Diderot
- LAL, IN2P3-CNRS

Italy
- Univ. of Florence
- CNR-INOA Firenze
- INAF-IASF, Palermo
- Univ. of Palermo
- INFN and Univ. of Rome "Tor Vergata"
- IFSI-To/INFN, Inst. Di Fisica dello Spazio Interplanetario, Torino
- Univ. of Torino
- Univ. gFederico Iih di Napoli
- INFN Napoles
- INFN-Frascati

Switzerland
- ETH

Spain
- Univ. of Alcaia

Germany
- MPI fuer Phys.
- Inst. of Astronomy and Astrophysics, Univ. of Tuebingen
- MPI Bonn
- Wuerzburg
- ECAP, Univ. of Erlangen-Nuremberg
- MPI of Quantum Optics
- LMU

Poland
- The Andrezej Soltan Inst. For Nucl. Studies
- Univ. of Podlasie Inst. of Math. And Phys.
- Jan Kochanowski Univ., Kielce, Inst. Of Phys.
- Jagiellonian Univ. Astro. Obs.
- SRC, Polish Academy of Sciences

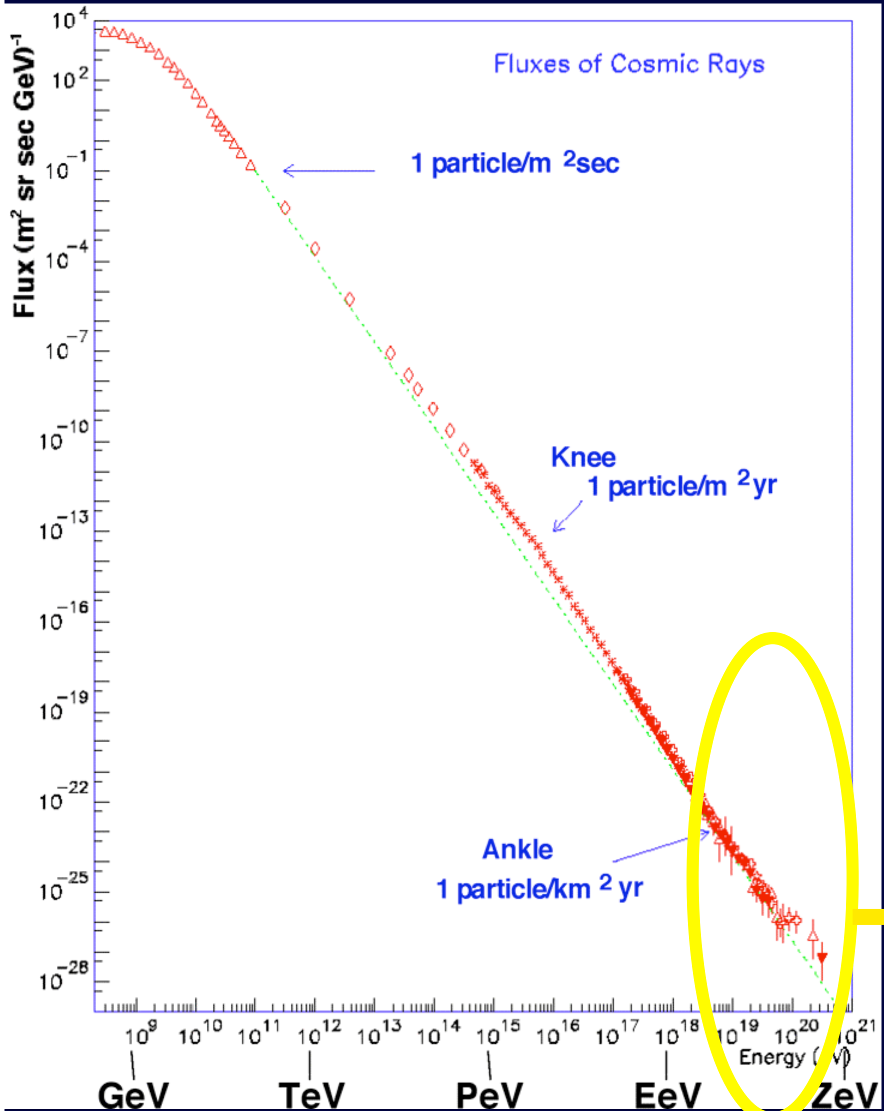
Slovakia
- Inst. Experimental Phys

Russia
- Skobeltsyn Inst. Of Nucl. Phys., Moscow Univ.
- Dubna, Joint Inst. For Nucl. Research

Republic of Korea
- Ehwa W. Univ.
- Yonsei Univ.
- Ajou Univ.
- Chonnam Univ.

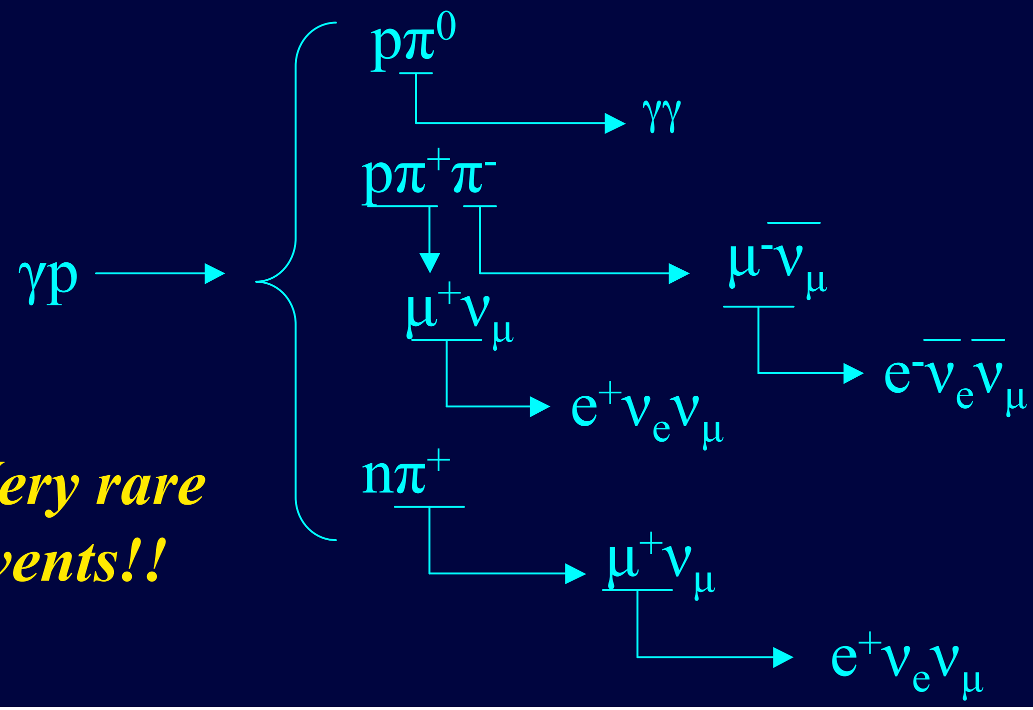
Japan
- RIKEN
- Konan Univ.
- Fuki Univ. of Tech.
- Aoyama Gakuin Univ.
- Saitama Univ.
- National Inst. of Radiological Sciences
- Univ. of Tokyo
- Tohoku Univ.
- ICRR
- KEK
- Chiba Univ.
- National Astro. Obs.
- JAXA
- Kanazawa Univ.
- Nagoya Univ.
- STEL, Nagoya Univ.
- Yukawa Inst.
- Kyoto Univ.
- Kobe Univ.
- Kinki Univ.
- Hiroshima Univ.
- Hokkaido Univ.
- Tokyo Inst. of Tech.

EHECRs
(GZK mechanism)



Very rare events!!

(Photopion Production)



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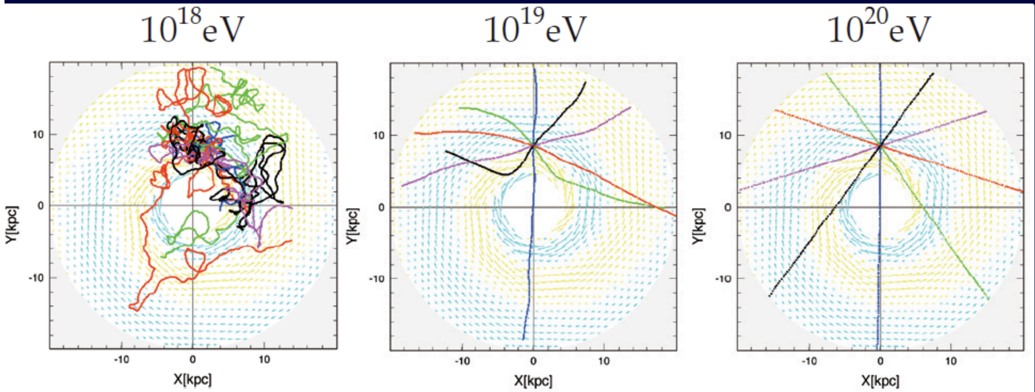
Science Objectives

~Main Objectives~

➤*Astronomy with EHECRs*



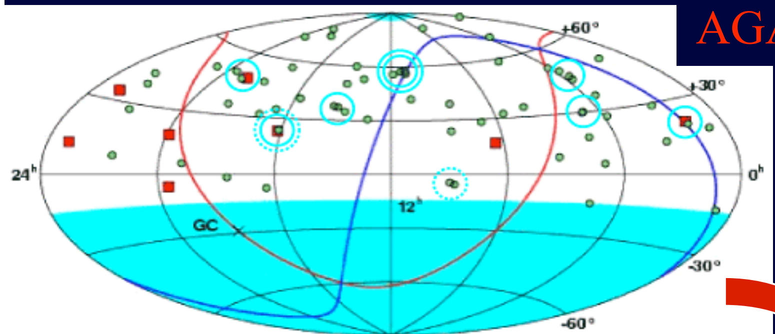
Simulation of the GMF

Full success criteria :

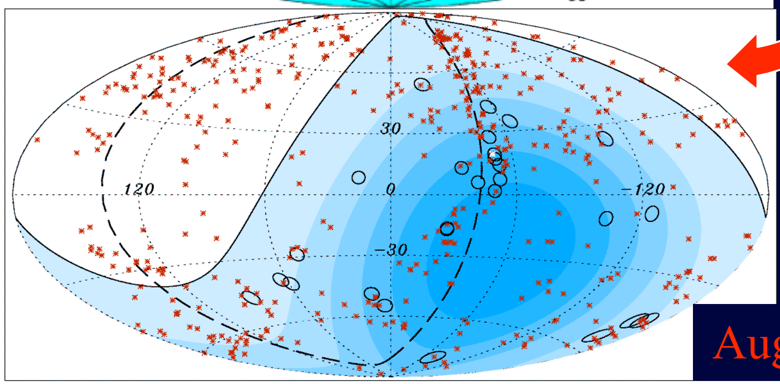
Detect more than 1,000 events > 7×10^{19} eV

- ➤EHECRs (>5×10^{19}eV) cannot come from > 100Mpc because of GZK cutoff
- ➤EHECRs are not deflected by galactic magnetic field (~nGauss) within 100Mpc
- ➤Possible EHE sources within 100Mpc are limited to GRBs or AGNs

AGASA

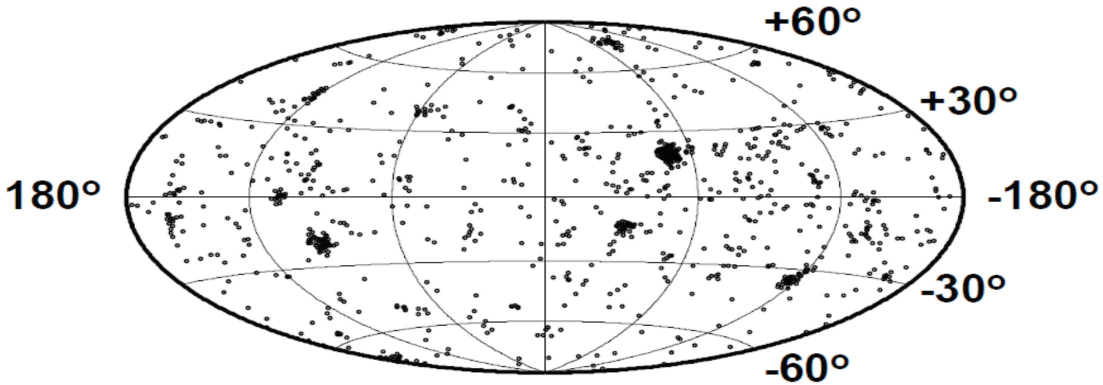


Auger



Forecast in case of 1,000 events

Brightness of particles ∝ X ray（AGN）

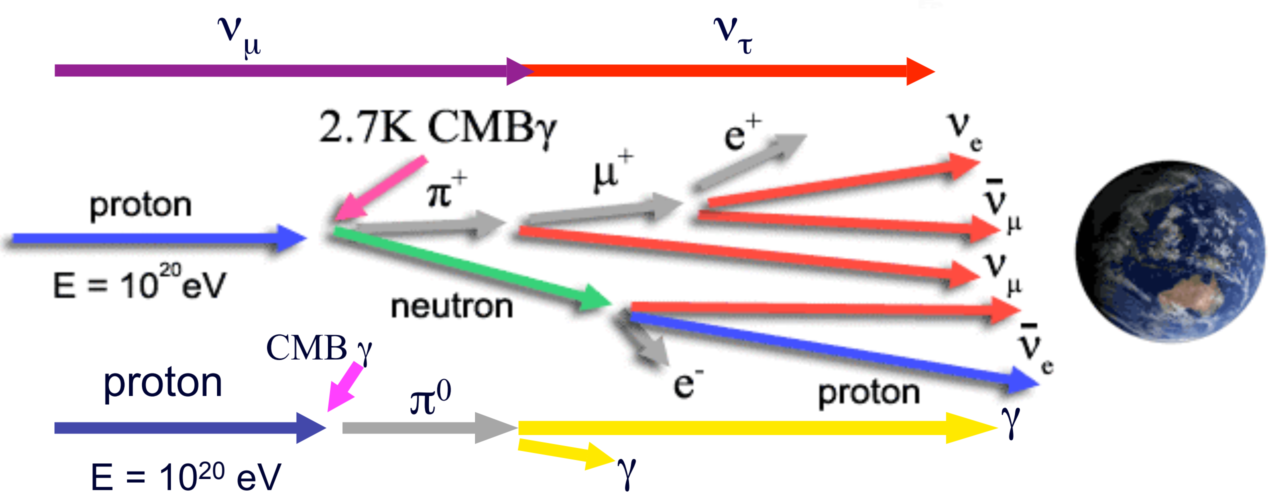


- **More than 1,000 events: E>7×10^{19}eV**
- **We expect to discover several dozens of clusters**
- **Can observe the whole sky**

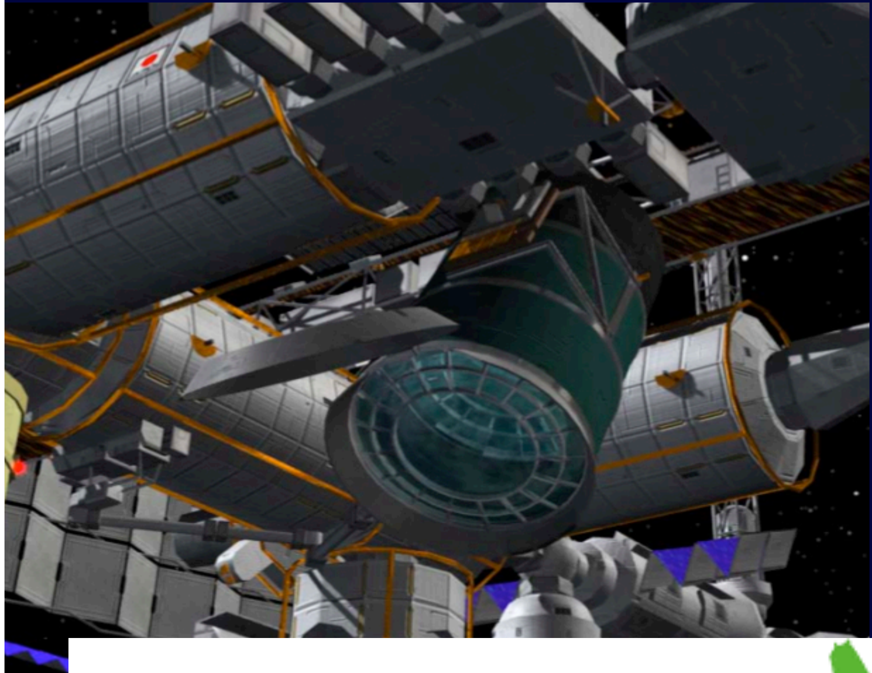
Science Objectives
~Exploratory Objectives~

➢*EHE Neutrinos/Gamma-Rays Search*
~no limitation of GZK cutoff

➢Neutrinos can travel without interaction from relativistic distance
➢EHE photons may also directly arrive at the earth (beyond the cutoff for the pair creation)



Extreme Universe Space Observatory

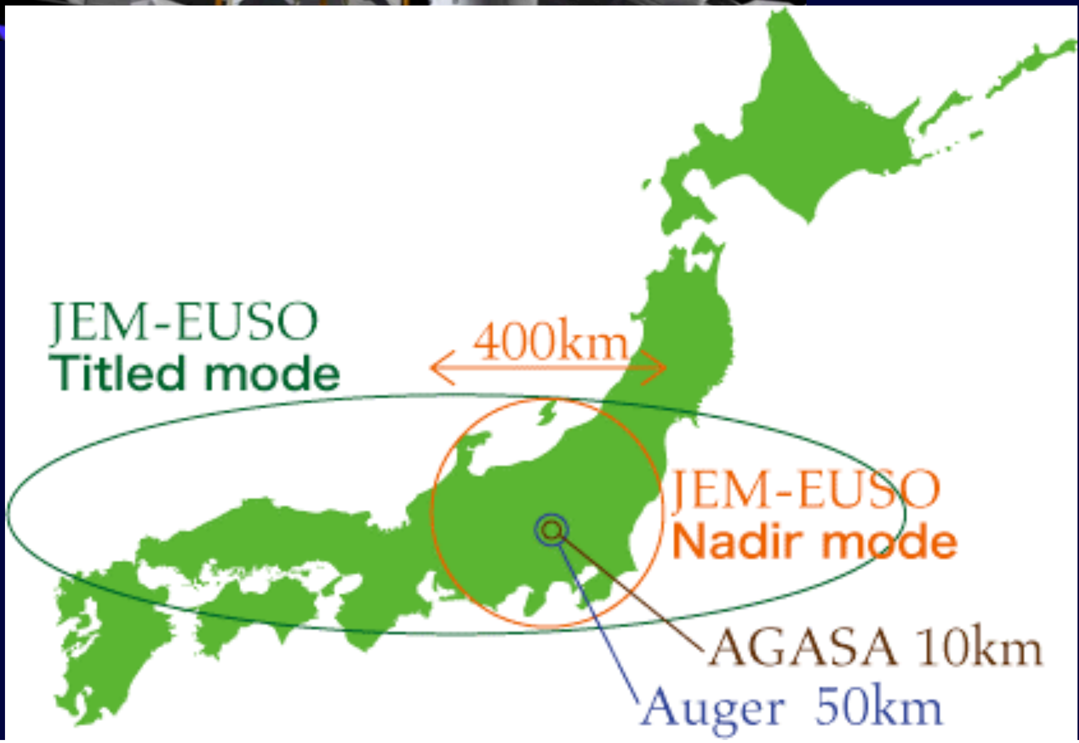


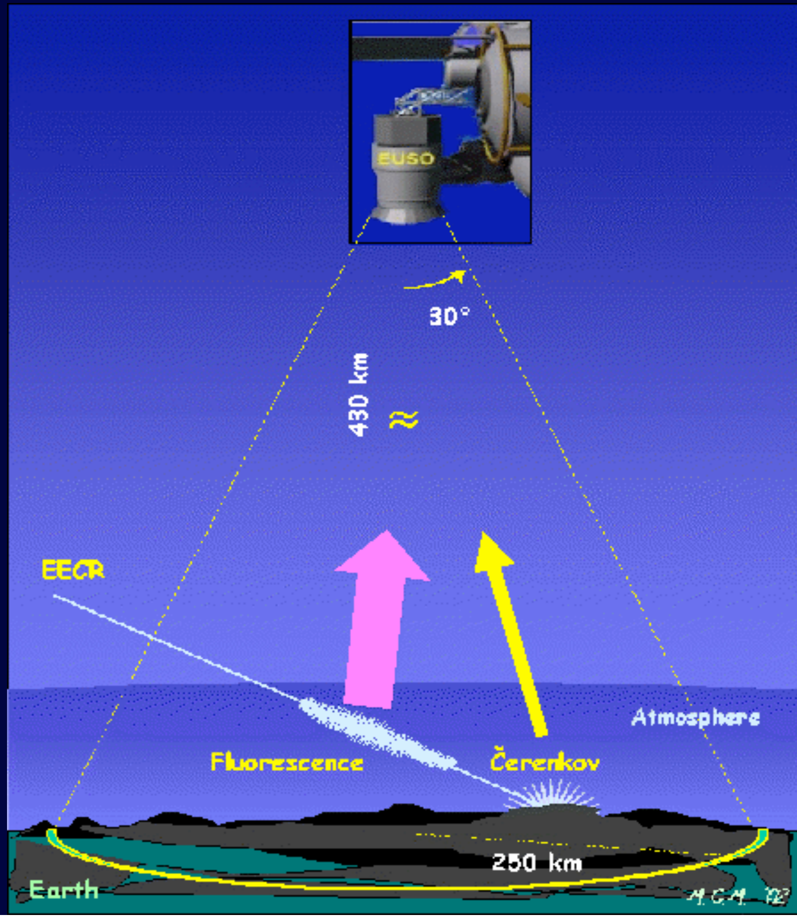
JEM-EUSO

~Astronomy with UHECRs~

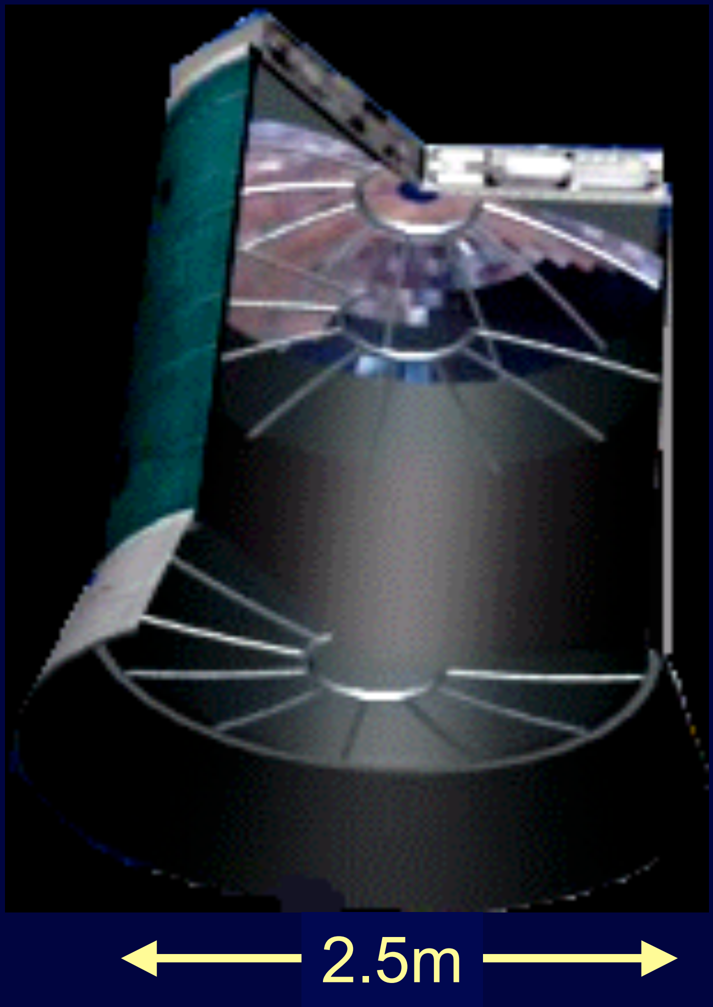
Aperture ~x30 Auger South (Instantaneous ~x150 Auger)

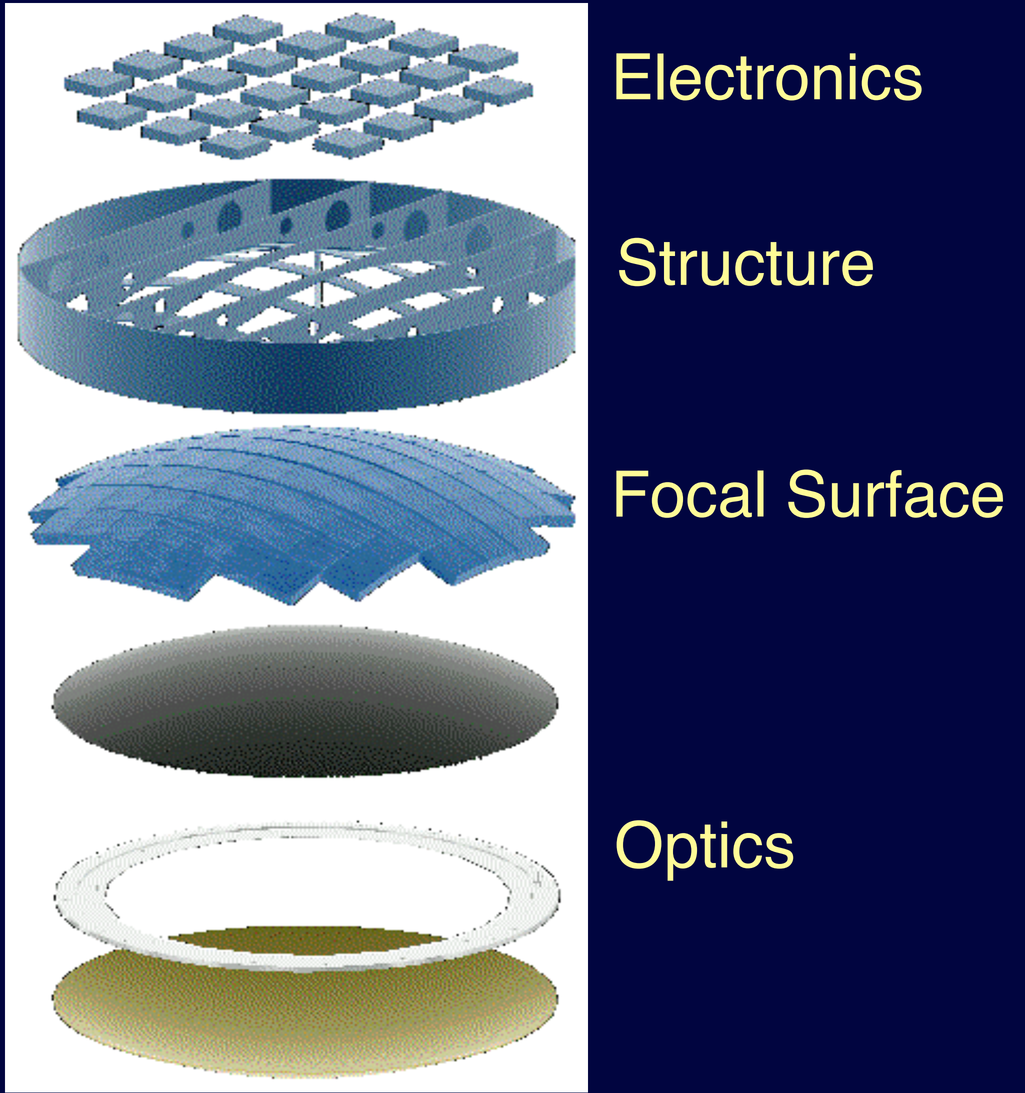
- *UHECRs 2x10^6 km^2 sr yr (tilt mode)*
- *UHE ν (tau) ~10 T-ton yr (Instantaneous 10,000 x IceCube!)*





JEM-EUSO Telescope Structure





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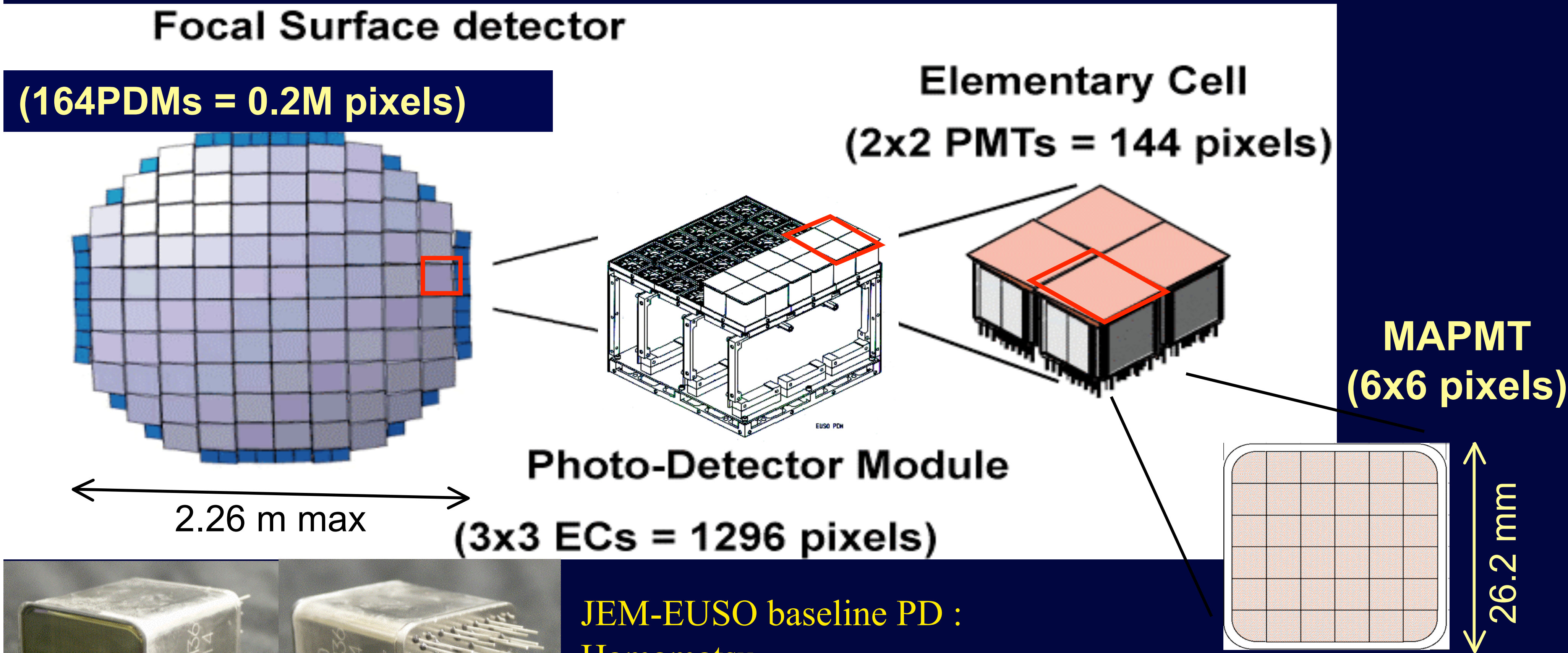
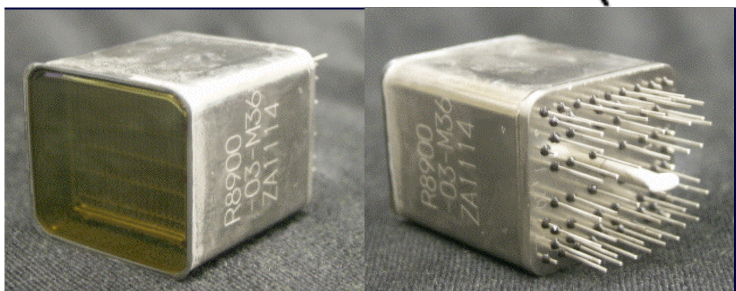
MPI für Physik

JEM-EUSO Focal Surface





JEM-EUSO baseline PD :
Hamamatsu
R8900U-08-M36-MOD
1 inch 36ch UBA MAPMT

Hiroko Miyamoto
MPI für Physik

Parameters of Instruments

Field of View	: ±30° (Nadir mode)
Aperture Diameter	: 2.5m
Optical bandwidth	: 330nm－400nm
Angular Resolution	: 0.1°
Pixel Size	: 4.5mm
Number of Pixels	: $\sim 2.0\times10^5$
Pixel Size at the ground	: 750m
Duty Cycle	: ~20%
Observational Area	: 1.9×10^5 km^2

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MPI für Physik

Parameters of Mission

- Time of Launch : year 2015
- Operation Period : 3 years (+2 years)
- Launching Rocket : H2B
- Transportation to ISS : un-pressurized Carrier of H2 Transfer Vehicle (HTV)
- Site to Attach : Japanese Experiment Module/Exposure Facility #2
- Height of the Orbit : ~430 km
- Inclination of the Orbit : 51.6°
- Mass : 1880 kg
- Power : 998 W (operative), 424 W (non-operative)
- Data Transfer Rate : 297 kbps

~Contribution of MPI~

Photodetectors for JEM-EUSO focal plain advanced design

For higher statistics and quality of rare events data, photosensors with higher photon detection efficiency is desirable (especially for tilt mode)…

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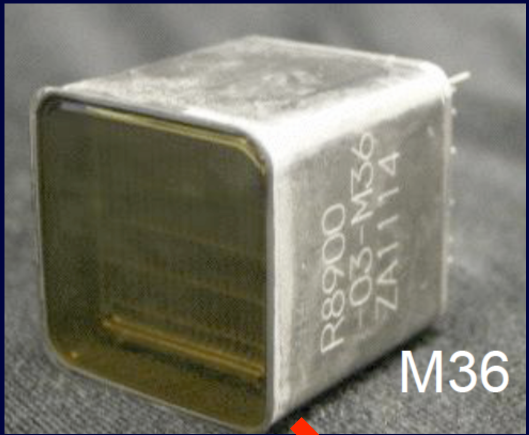
MPI für Physik

New MAPMT M64

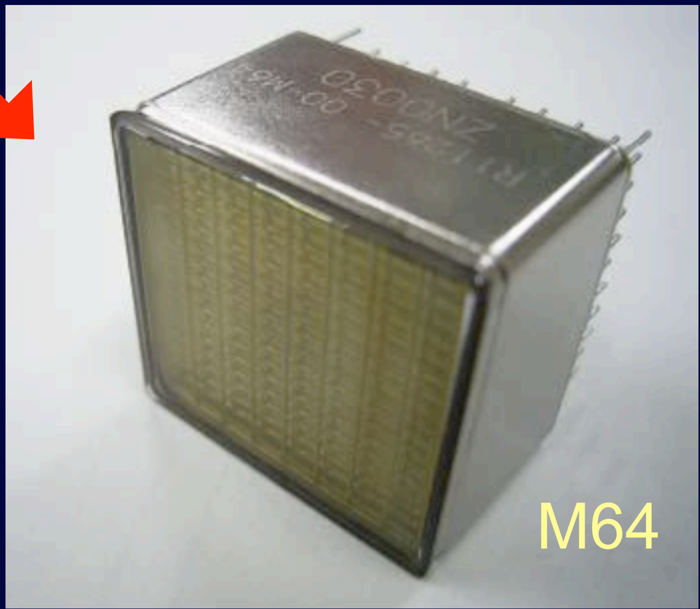
~JEM-EUSO advanced design PD (I)

R&D are ongoing in Japan

- High Quantum Efficiency (QE>40%)
- Higher Collection Efficency (CE~?)



New Hamamatsu UBA MAPMT M64



SiPM/G-APD/MPPC

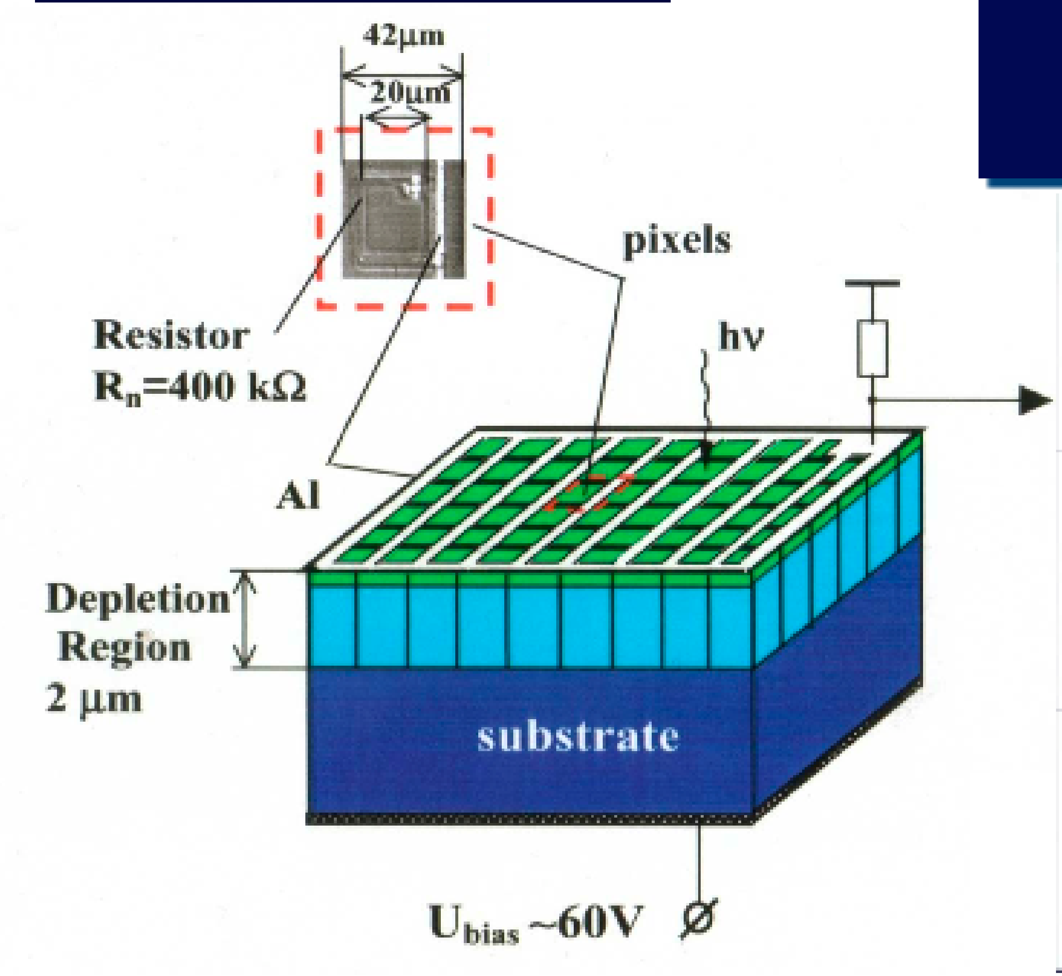
~JEM-EUSO advanced design PD (II)

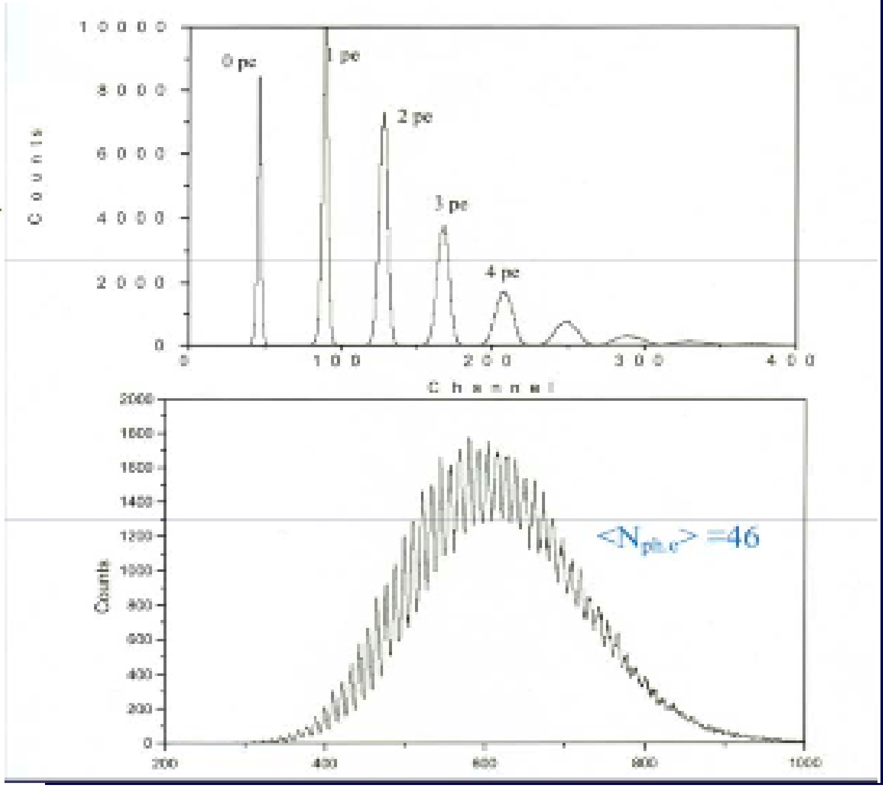
R&D are ongoing@MPI-HLL, MPI-MEPhI

SiPM for TESLA
by Dolgoshein et al. MEPhI

- Single PE measurement
- Gain ~10^6
- Ubias = 30~70
- P=50μW/mm^2
- Npixel 400~14400
- Insensitive to Magnetic field
- High Photon Detection Efficiency

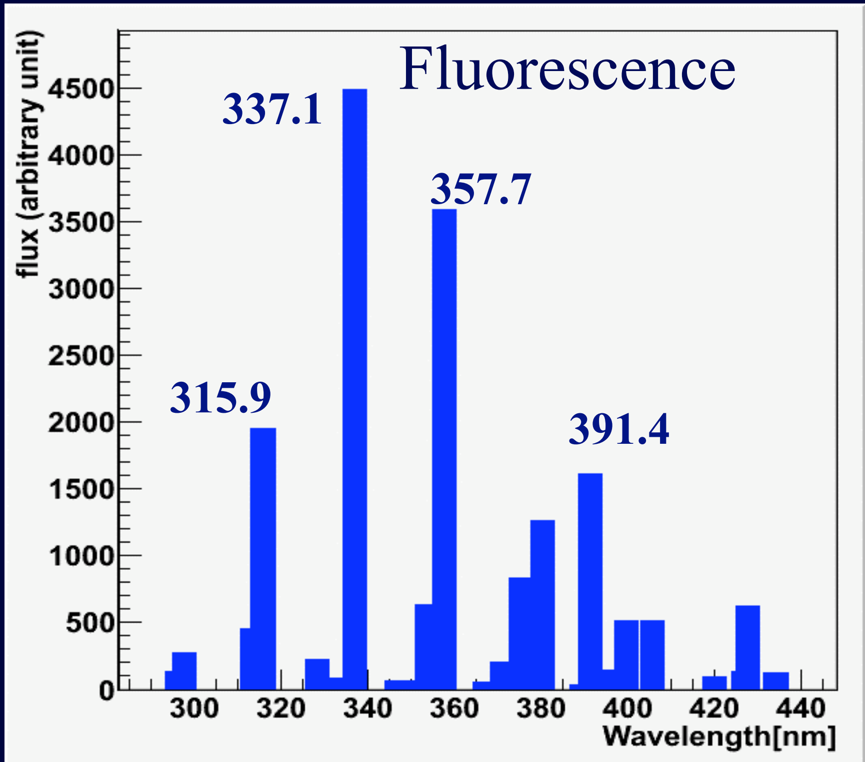
PDE = Fill factor x QE x Geiger eff.

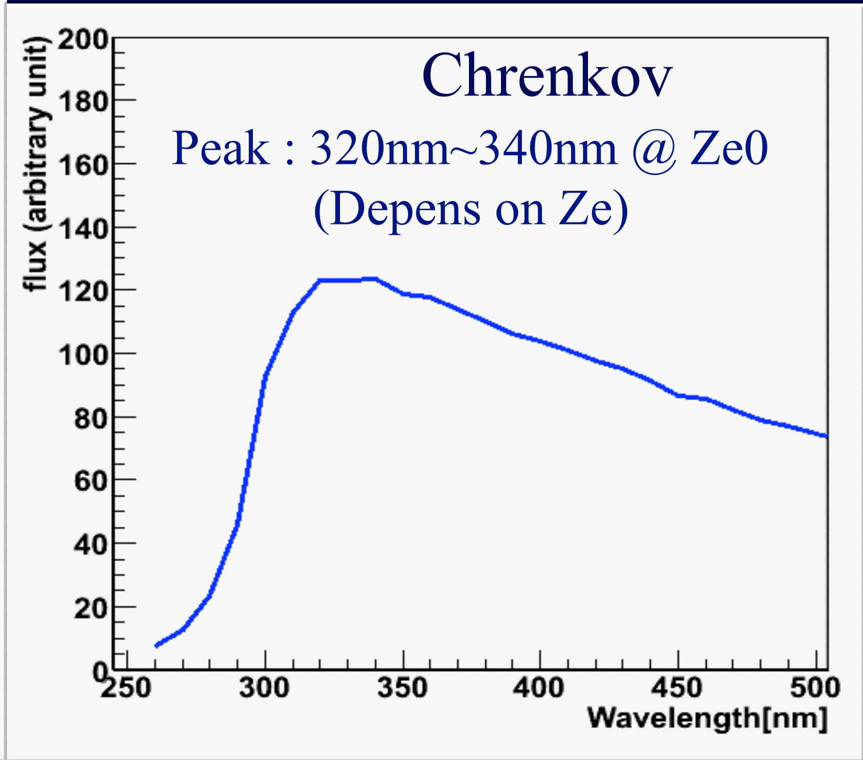




Toward the application of SiPM to JEM-EUSO

- PDE for UV region (Cherenkov, Fluorescence) is essential





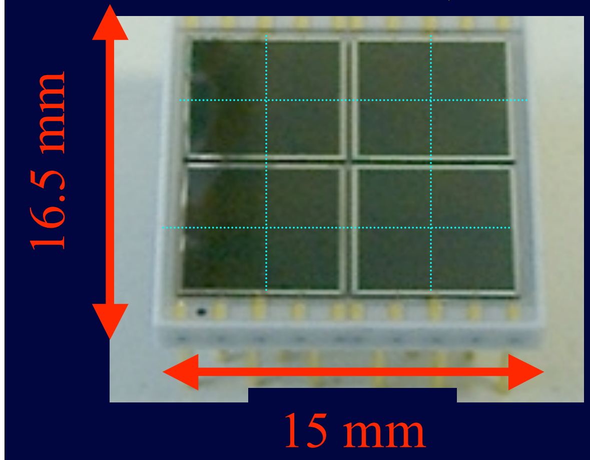
- Temperature dependence
  - Gain : breakdown voltage, over voltage
  - Dark rate
  - Space-qualified

UV sensitive SiPMs

(Candidates for JEM-EUSO advanced design)

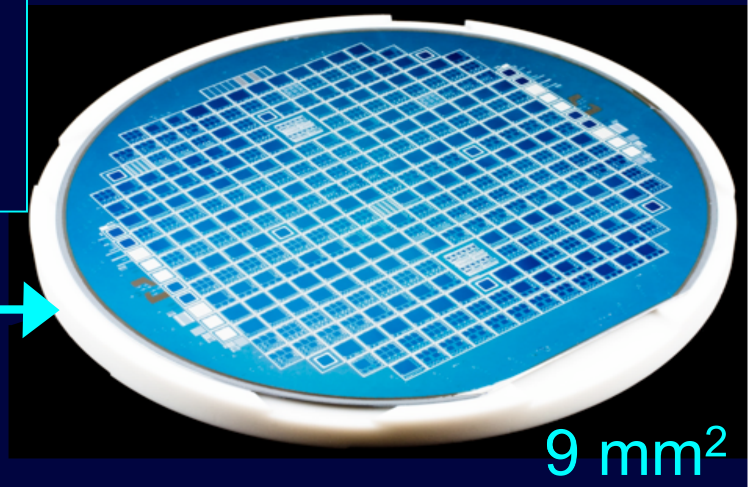
Hamamatsu (MPPC)

4x4 array of 9 mm² pixel device



- Commercial device
- Large detection area!
- Device is ready!
- Used for 256ch prototype camera
- Higher UV sensitive device developmen for JEM-EUSOt has began

MPI-HLL (SiMPL)

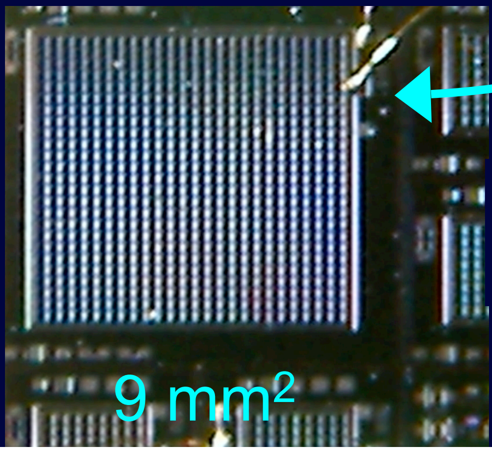


Aim PDE~61% in UV!!
Simple structure, low cost

See details in H. -G. Moeser talk for the project review on 14th!

Fundamental tests at wafer level are ongoing. Array modules will be ready next year!

MPI-MEPhI (Dolgoshein SiPM)



PDE>45%@350nm!!
Optical Crosstalk suppression!!

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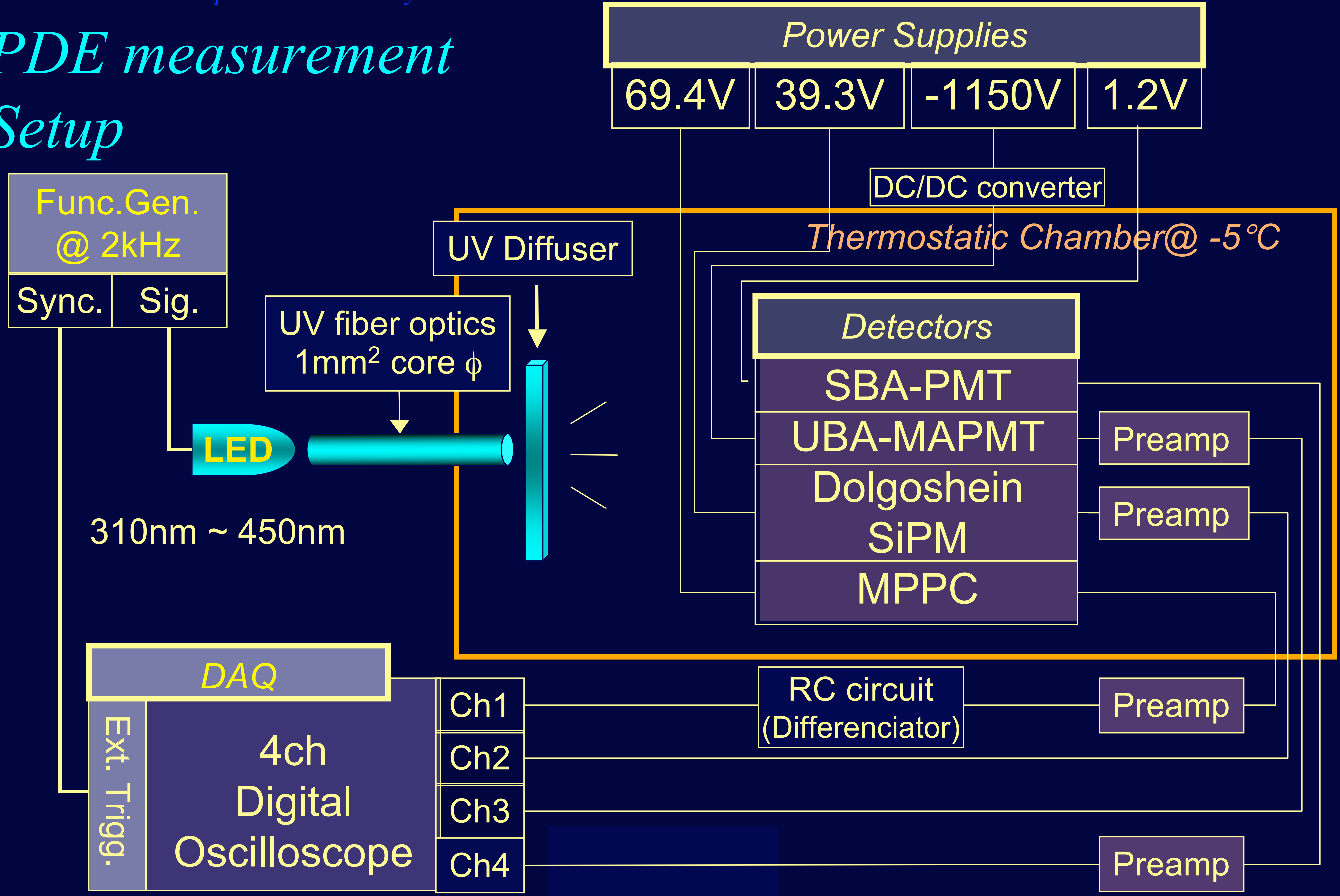
PDE measurement Setup



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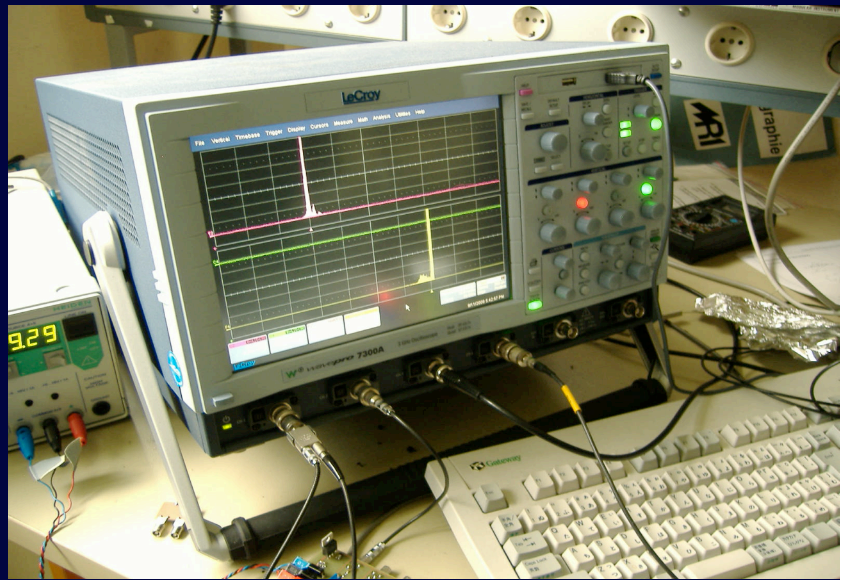
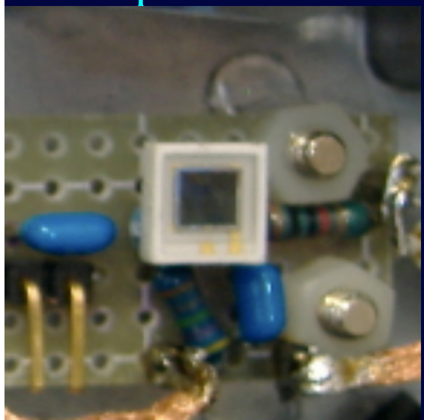
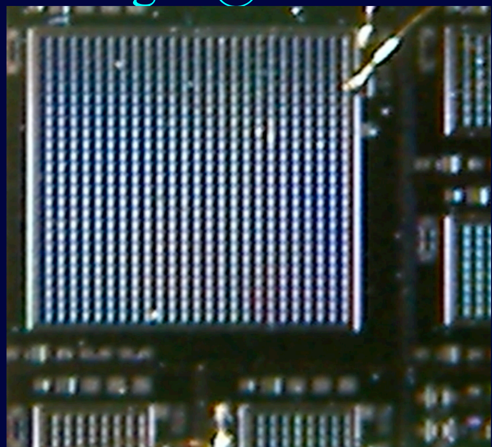
Devices

- LED (310 nm ~ 450nm)
- Agilent Function generator (33250A @ 2kHz)
- UV Tunable Laser (328nm @ 2kHz, full wavelength -> future work)
- Edmund Optics UV transparent fiber optics (0.22NA, 1mm core)
- UV Fused Silica diffuser
- Digital Oscilloscope (LeCroy WavePro 7300A 3GHz Dual 20GS/s)
- Temperature Box with Ar gas @ -5C

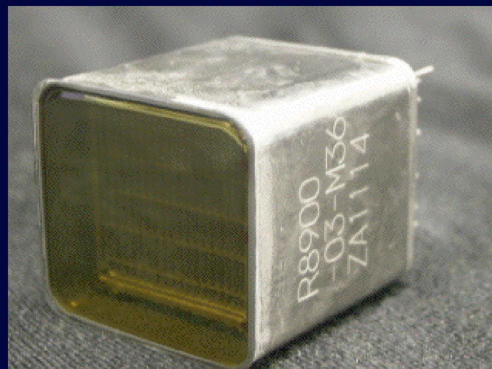




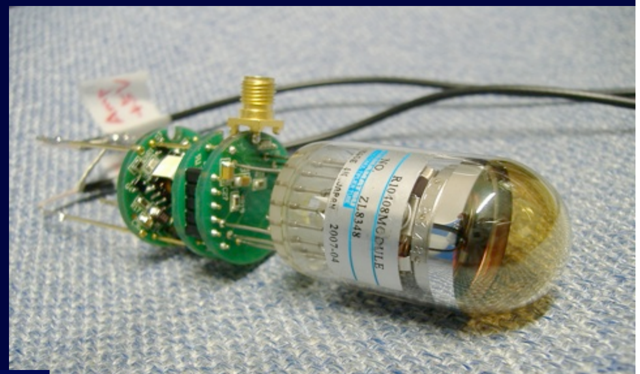
Hamamtsu
MPPC
$9mm^2$, 100U



Dolgoshein SiPM
$9mm^2$, 100U



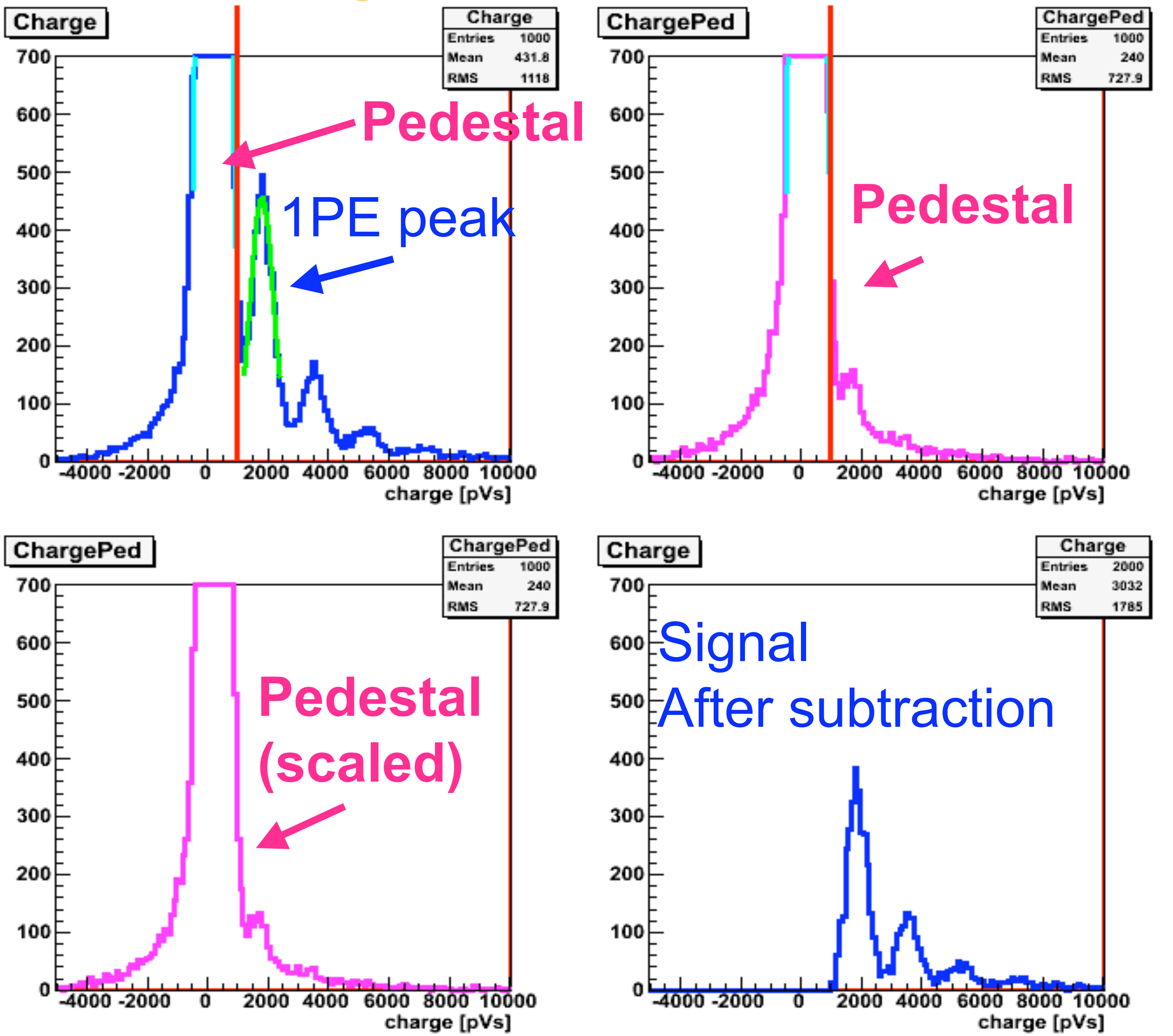
Hamamtsu
R8900U-08-M36-MOD
1 inch 36ch UBA
MAPMT
(with 3mm x 3mm slit)



Hamamtsu
R10408-MODULE
1 inch, SBA PMT
(Calibrated)
(with 3mm x 3mm slit)

Analysis : Counting method

ex. MPPC histogram



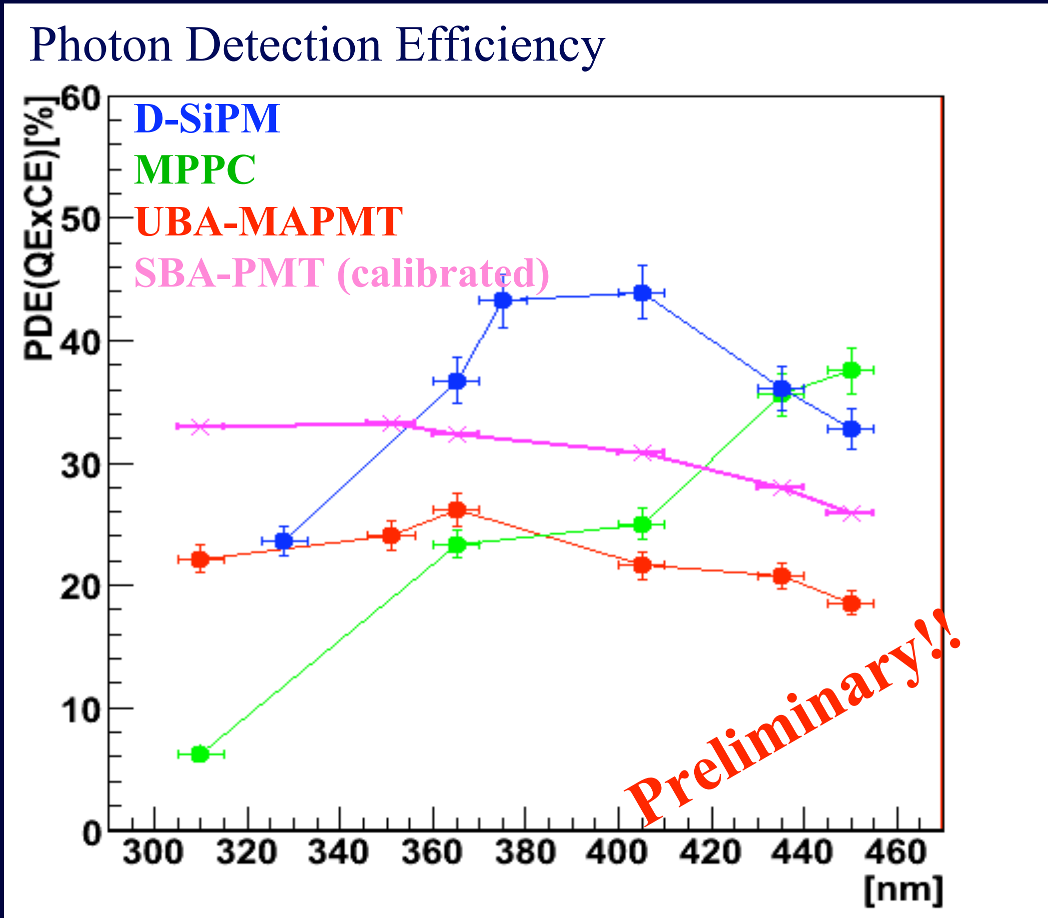
PE # calculate with Counting :

\# of scaled pedestal events

Using possibility of Poissonian

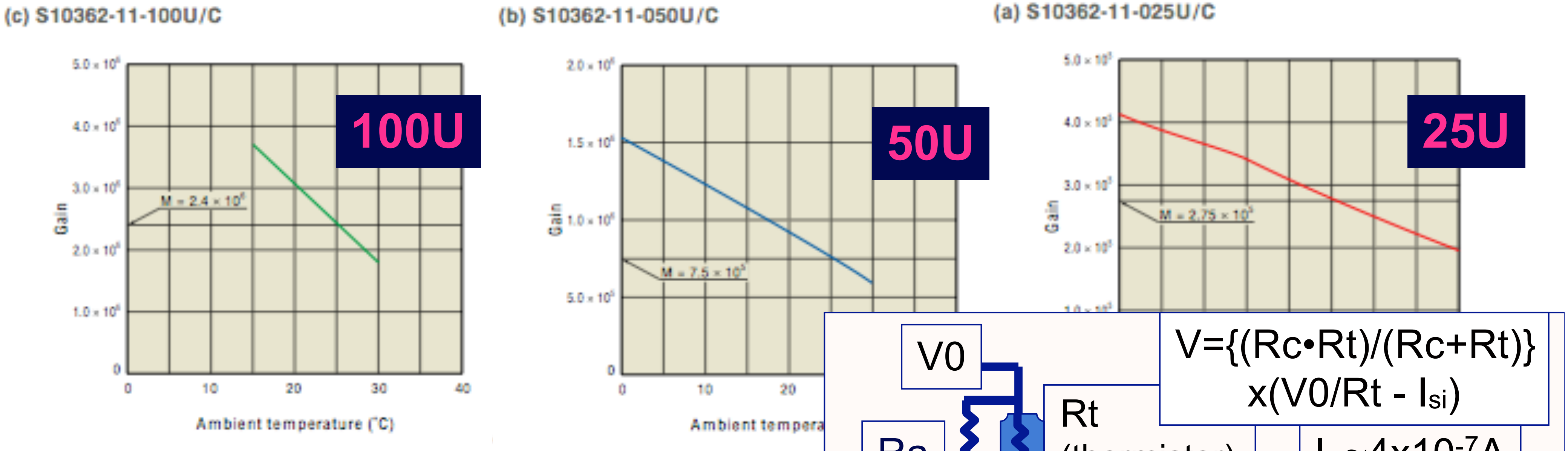
$P(\lambda>0)=-\ln(N_{ped}/N_{all})$

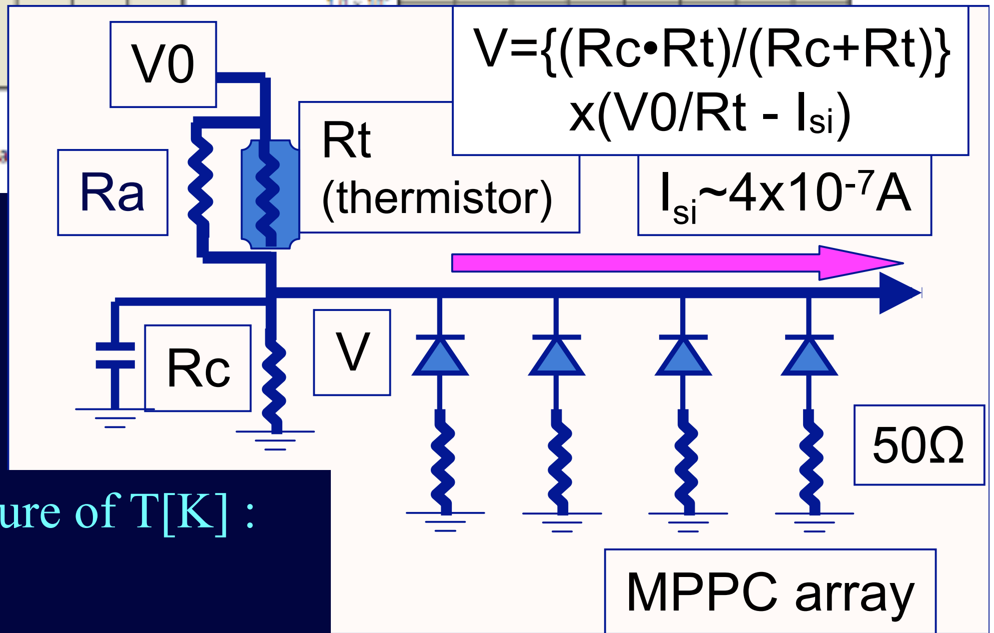
UV sensitive SiPMs
PDE measurement (@-5C)



- High sensitivity in UV region (300nm~400nm)
- Even higher sensitivity in longer wavelength in case of MPPC which is an advantage for Cherenkov events
- Still some systematic uncertainties.
- Temperature/Overvoltage dependence need to be verified.

Temperature Dependence of SiPM/MPPC Gain





by Hamamatsu Catalogue

3%~5%/ºC
@ const. bias voltage

Thermistor : Resistance of thermistor at temperature of T[K] :

$R = R0*\exp\{B(1/T-1/T0)\}$

B : (B value)

R0: resistance of thermistor @ temperature of T0[K]

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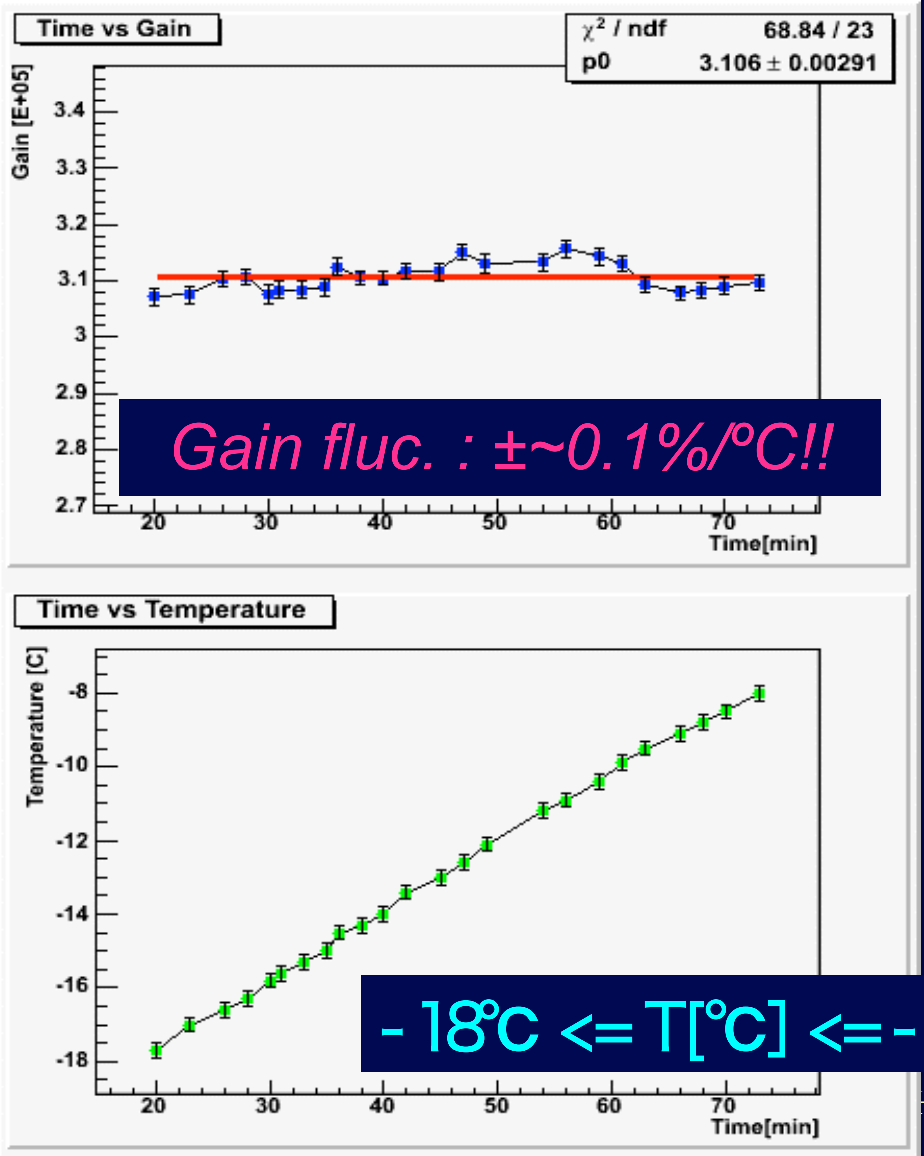
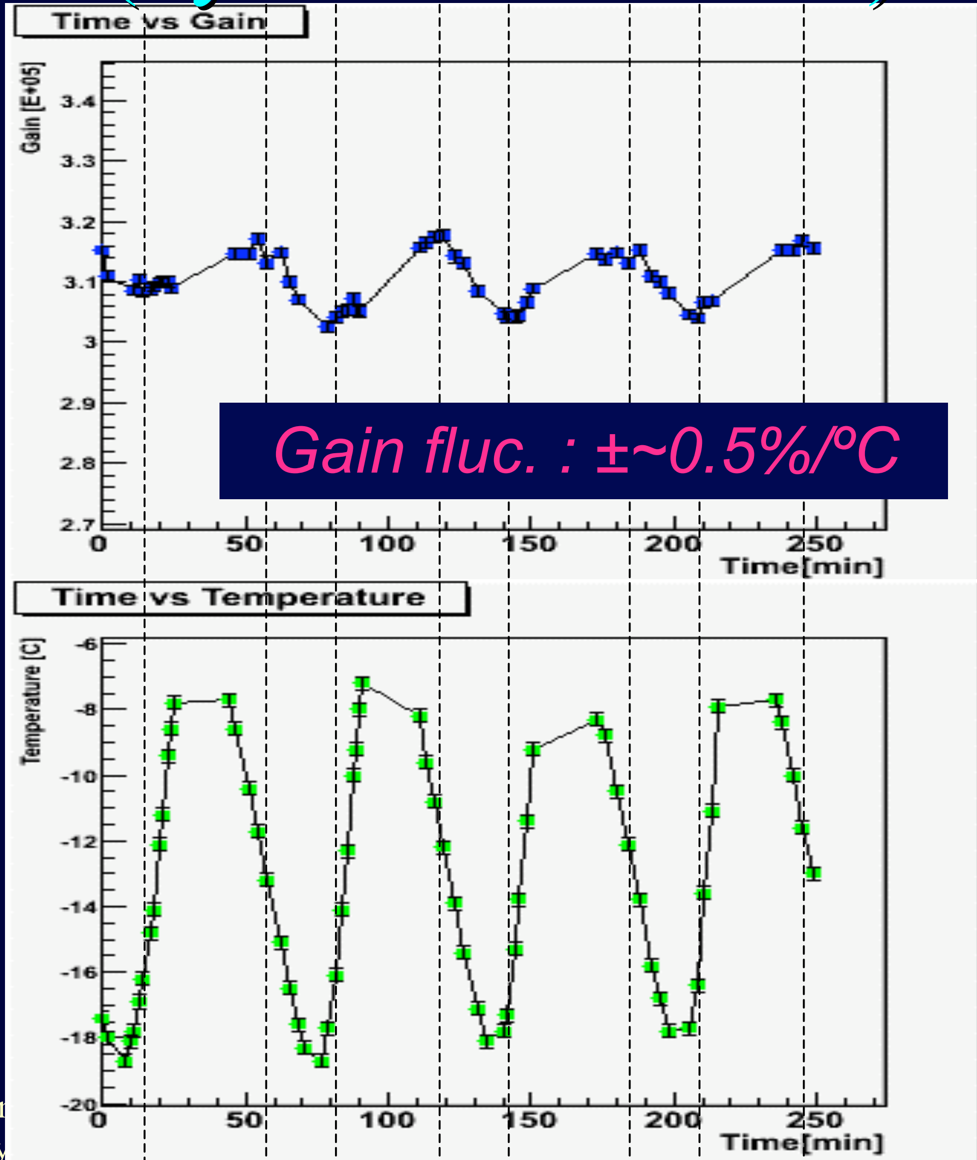
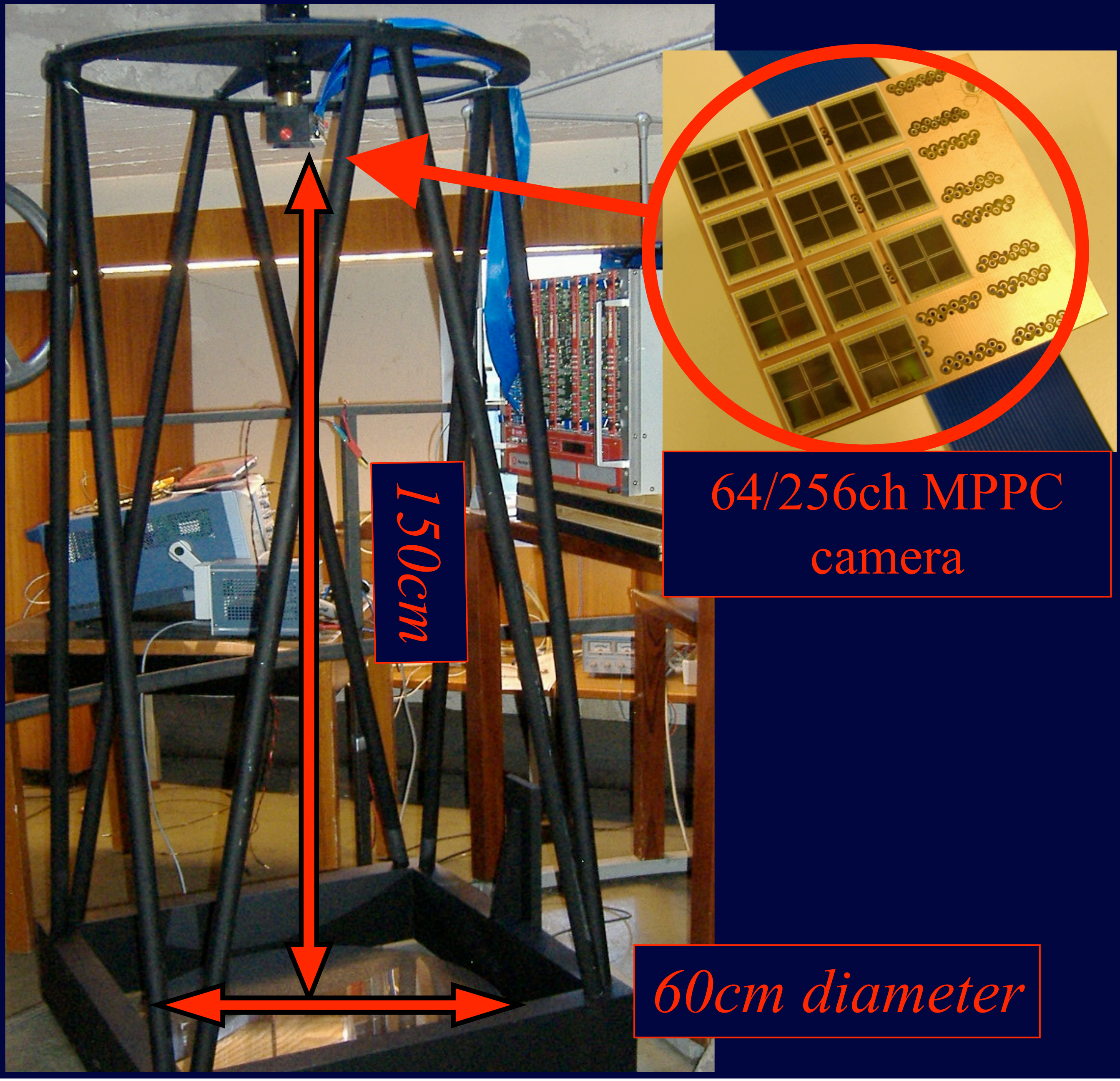
Gain vs Time (Static Measurement)



Gain vs Time (Dynamic measurement)

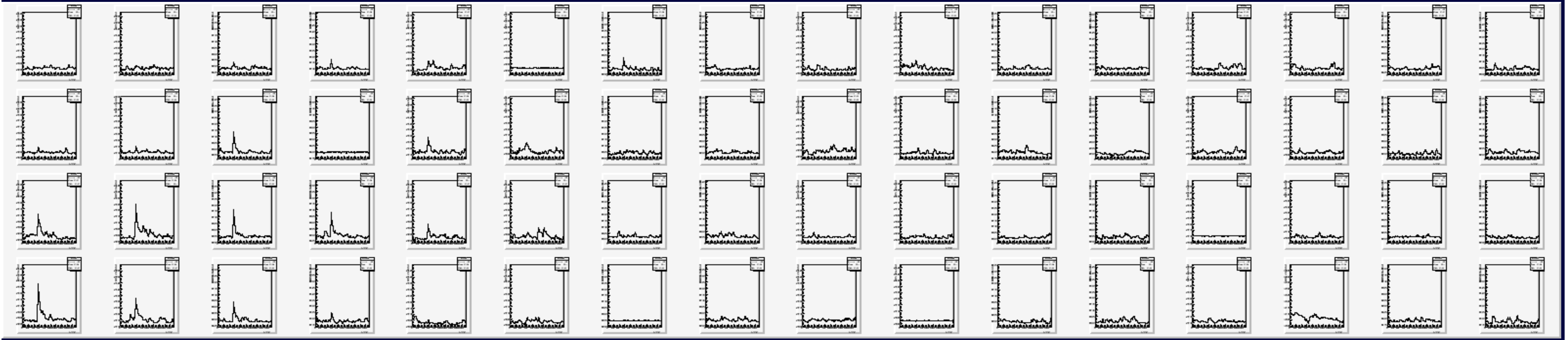


Prototype camera for a Cherenkov telescope

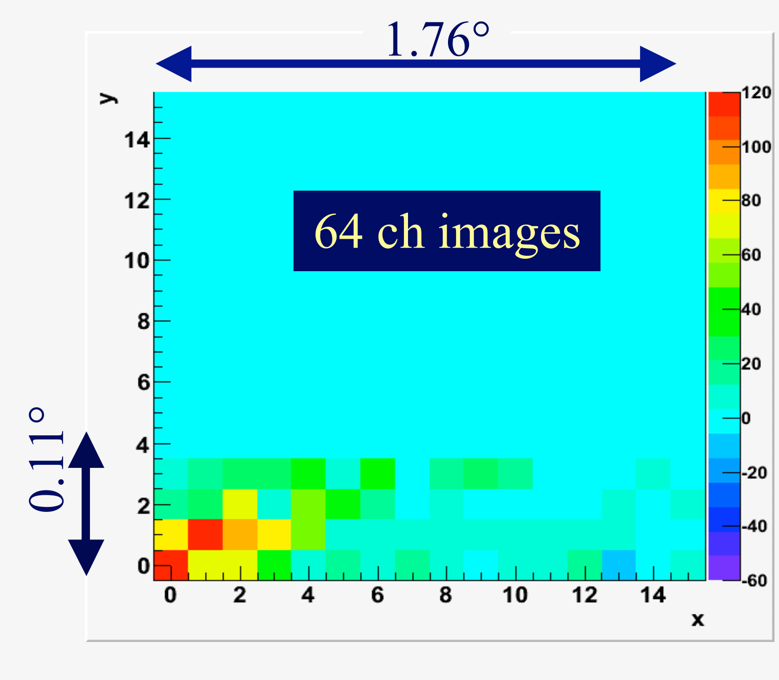


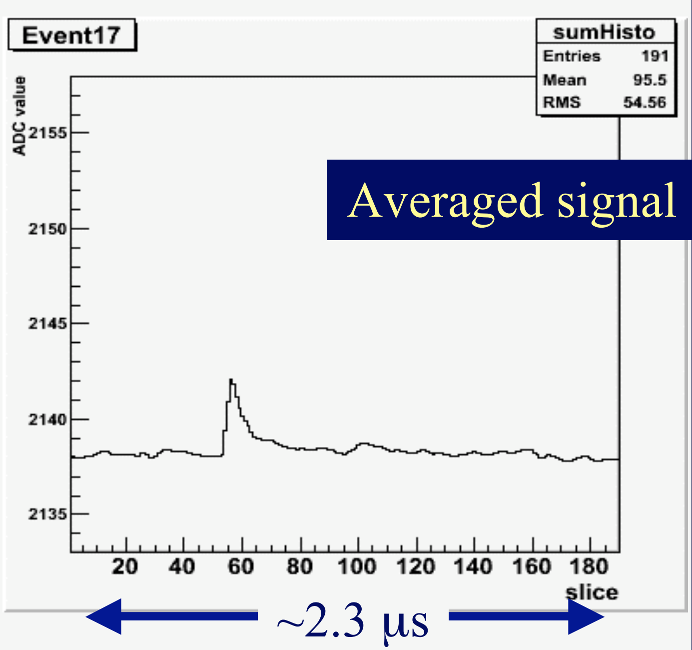
Cherenkov Events by the pure SiPM/MPPC camera!!

(in Munich downtown @ Room Temperature!)



64ch CAEN VME digitizer Waveforms



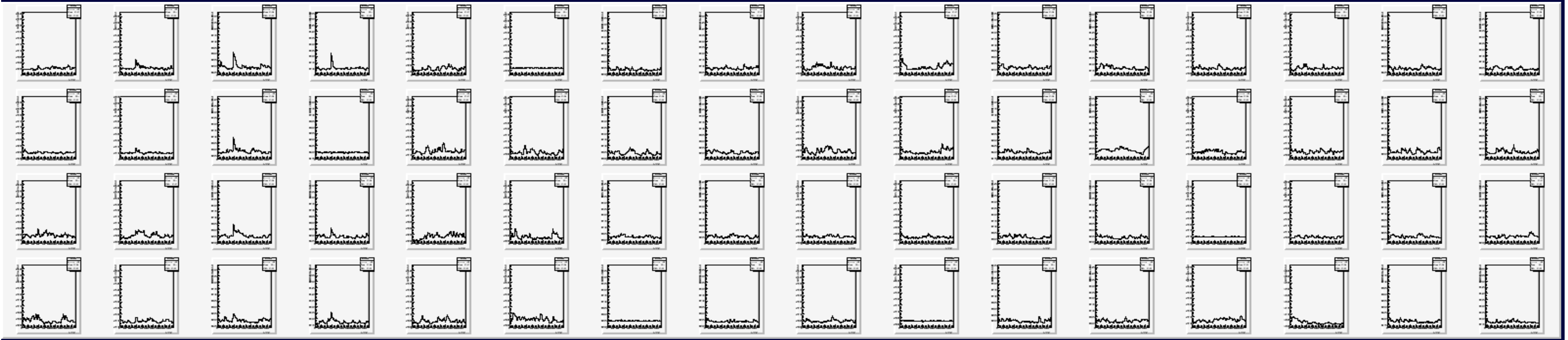


- ~8 events / hour
- ~20 PE level of trigger threshold
- 3 Next Neighbor software coincidence trigger
- Average ~700 PEs in an image (~100TeV)

Preliminary!!

Cherenkov Events by the pure SiPM/MPPC camera!!

(in Munich downtown @ Room Temperature!)



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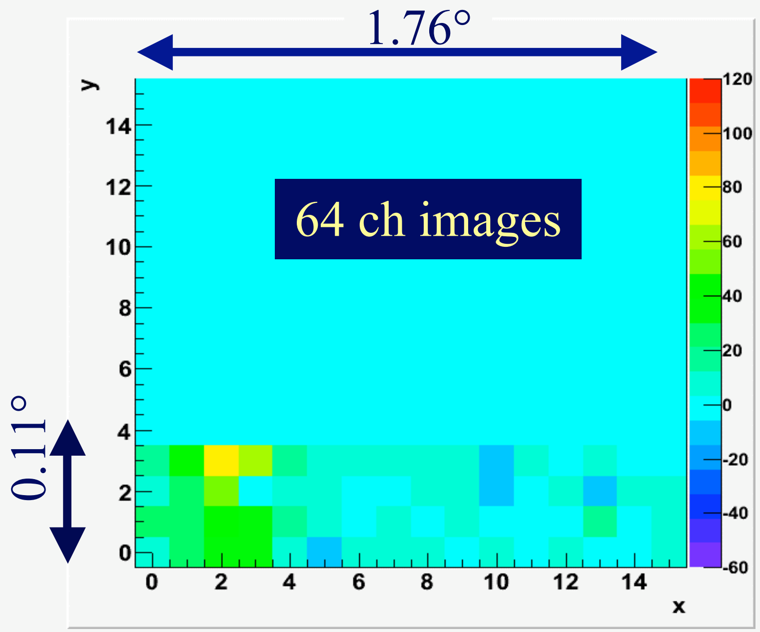

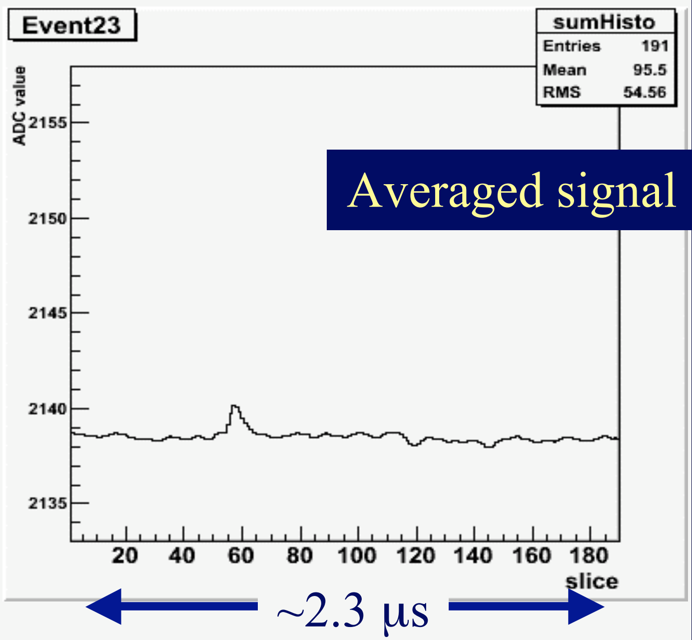

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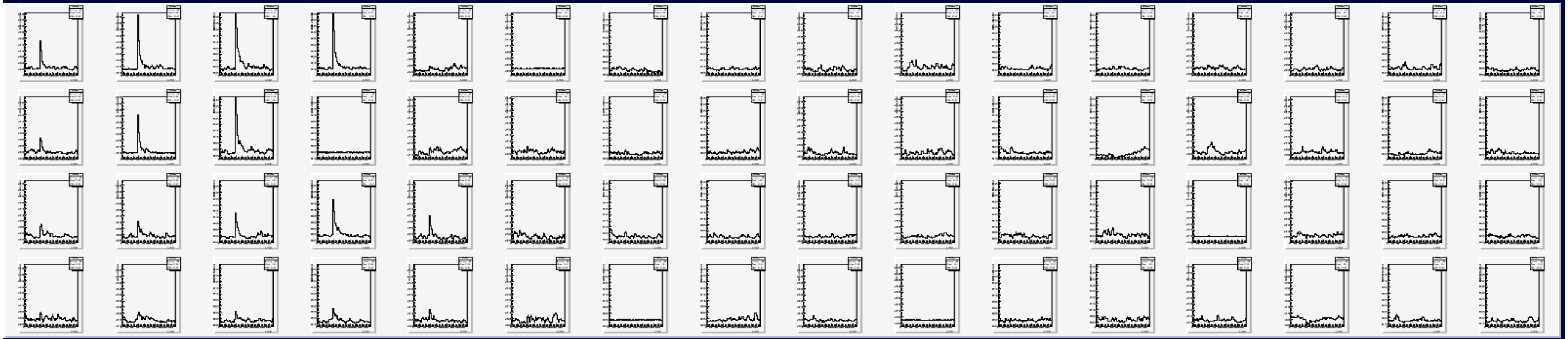

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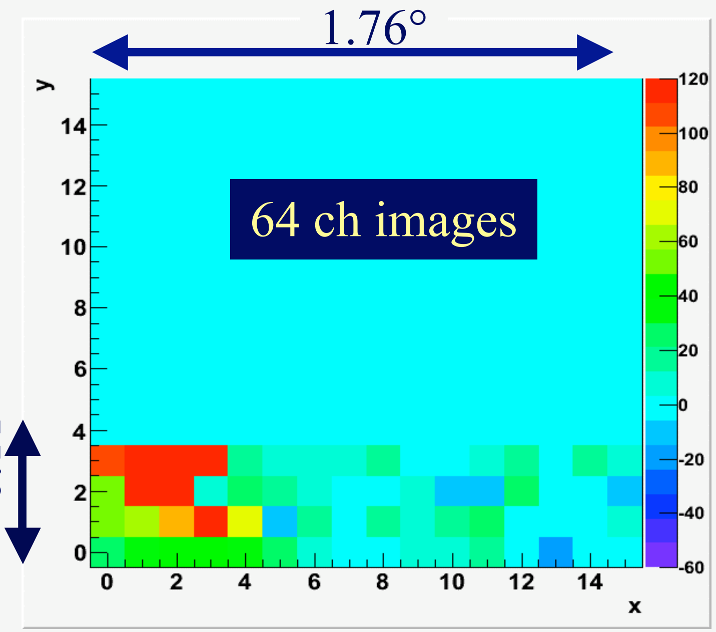

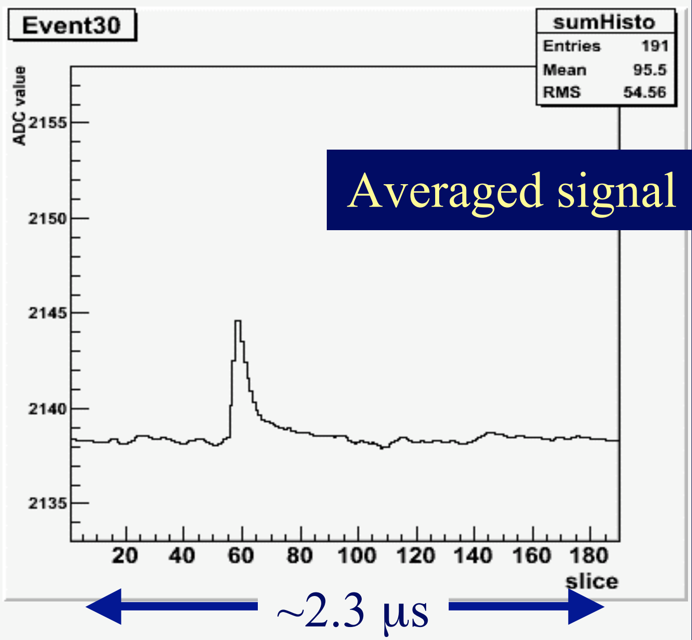

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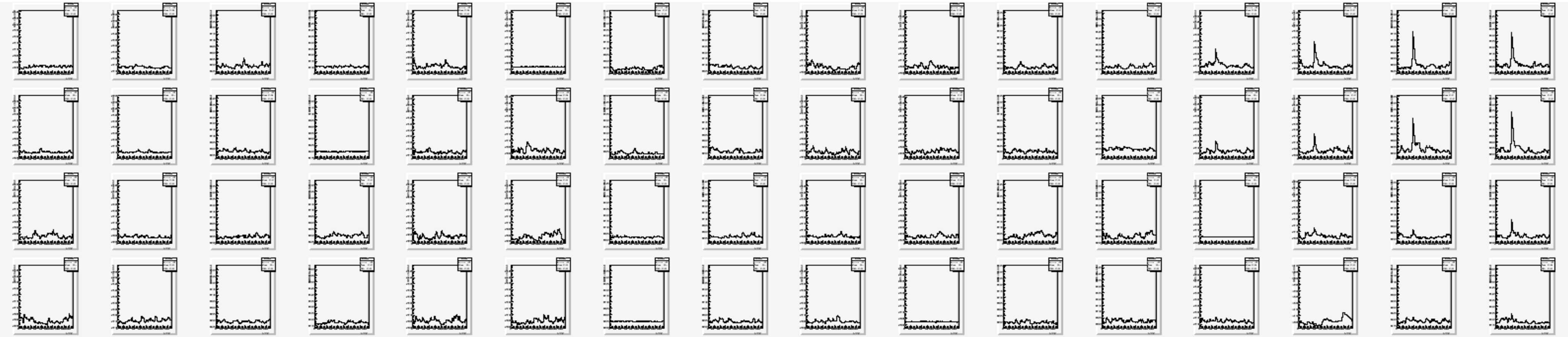
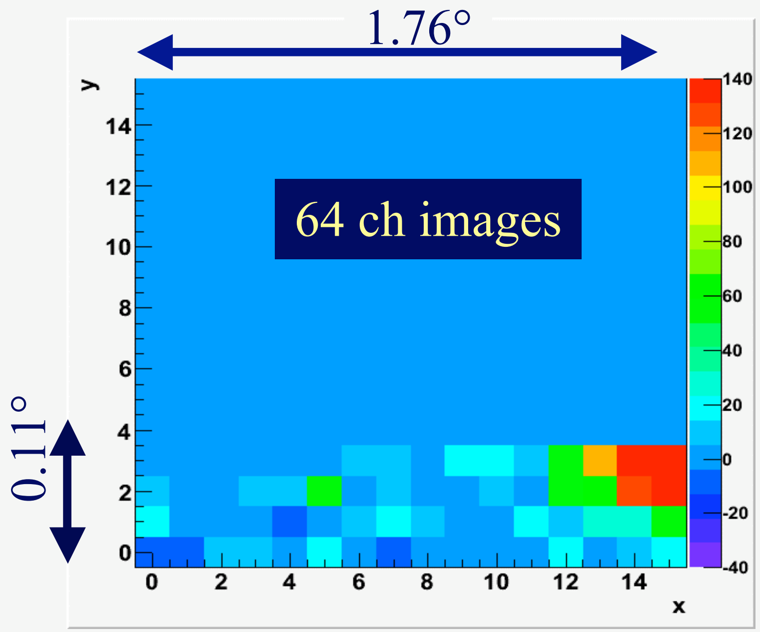
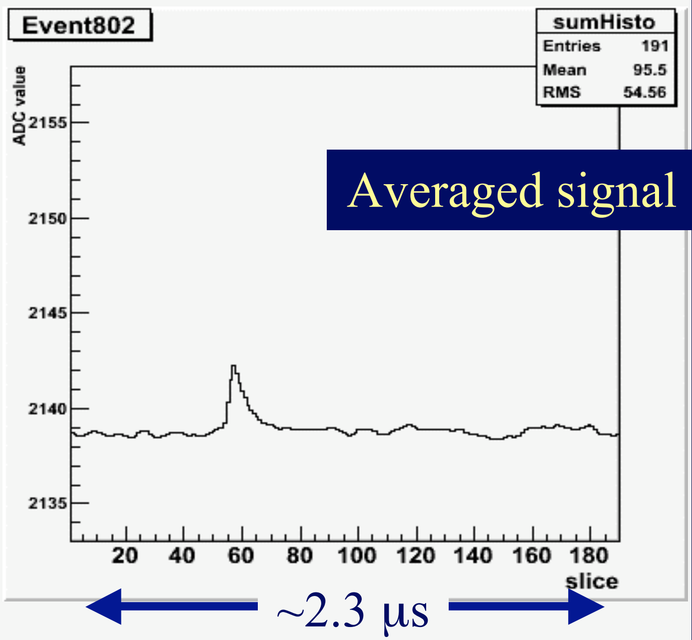


64ch CAEN VME digitizer Waveforms





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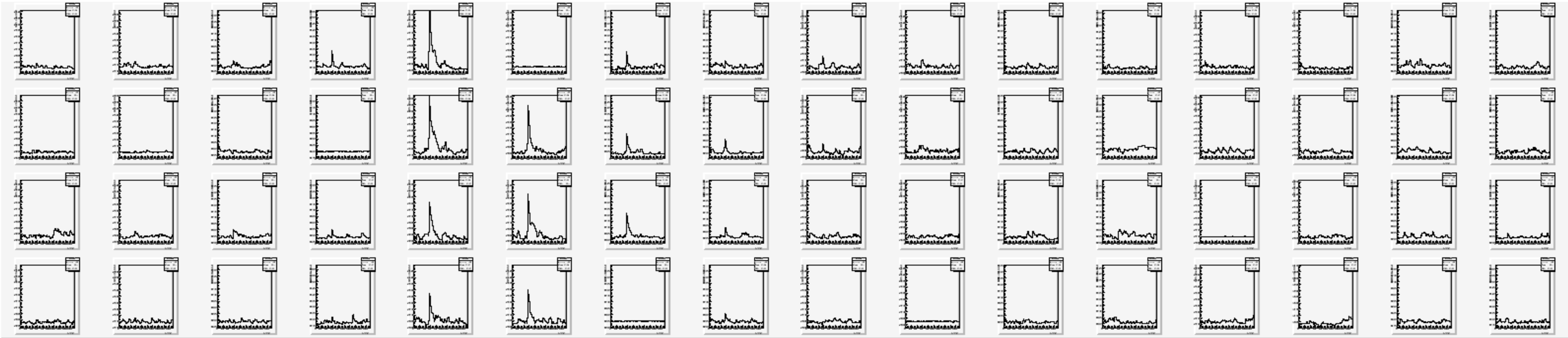
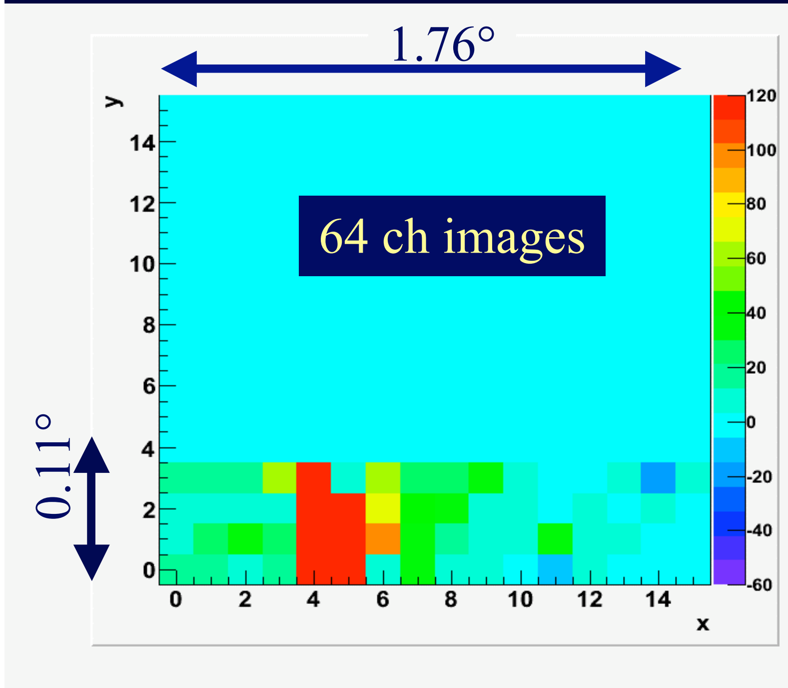
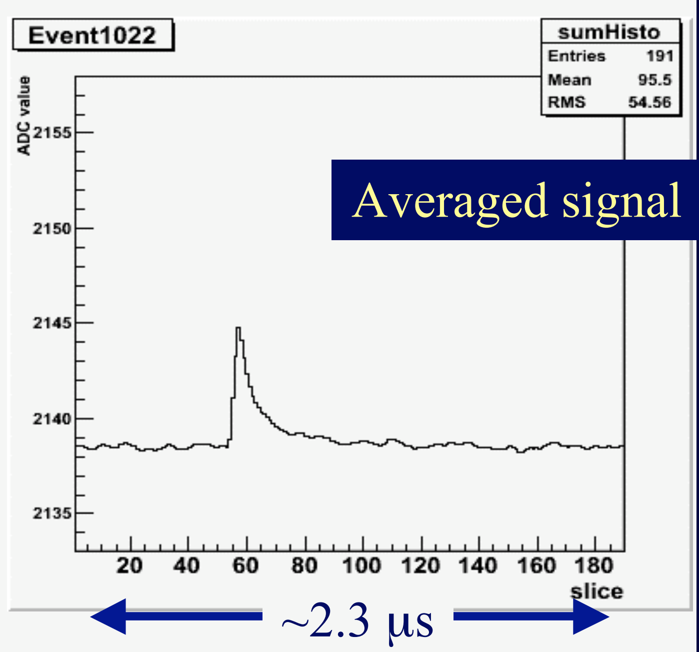


64ch CAEN VME digitizer Waveforms



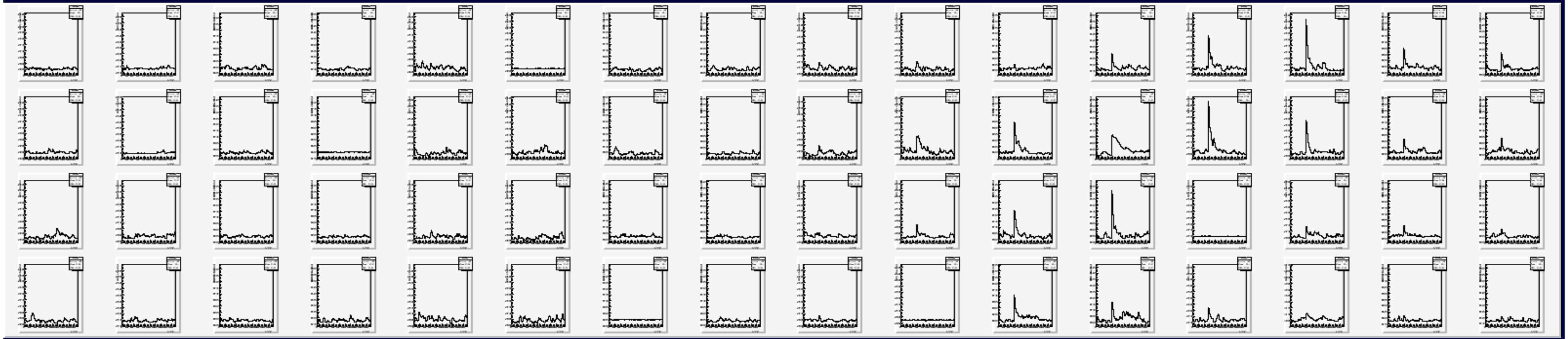


- ~8 events / hour
- ~20 PE level of trigger threshold
- 3 Next Neighbor software coincidence trigger
- Average ~700 PEs in an image (~100TeV)

Preliminary!!

Cherenkov Events by the pure SiPM/MPPC camera!!

(in Munich downtown @ Room Temperature!)



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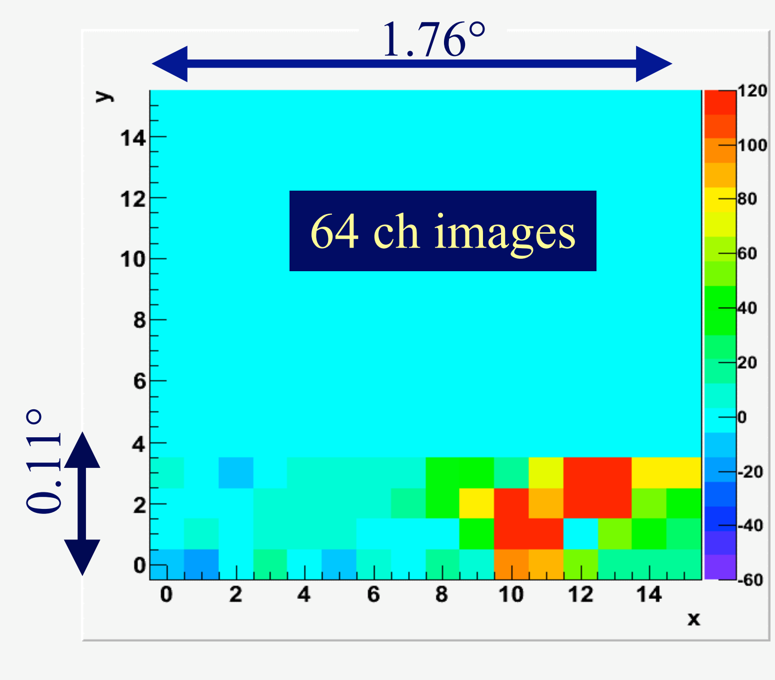

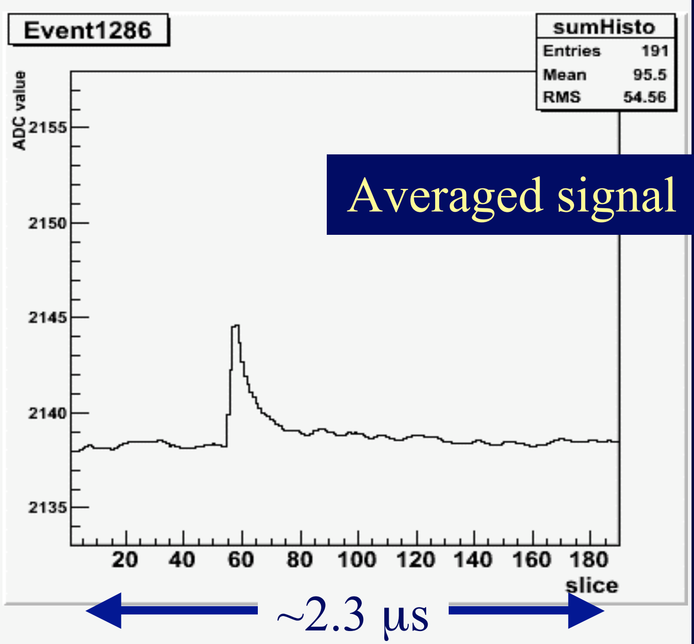

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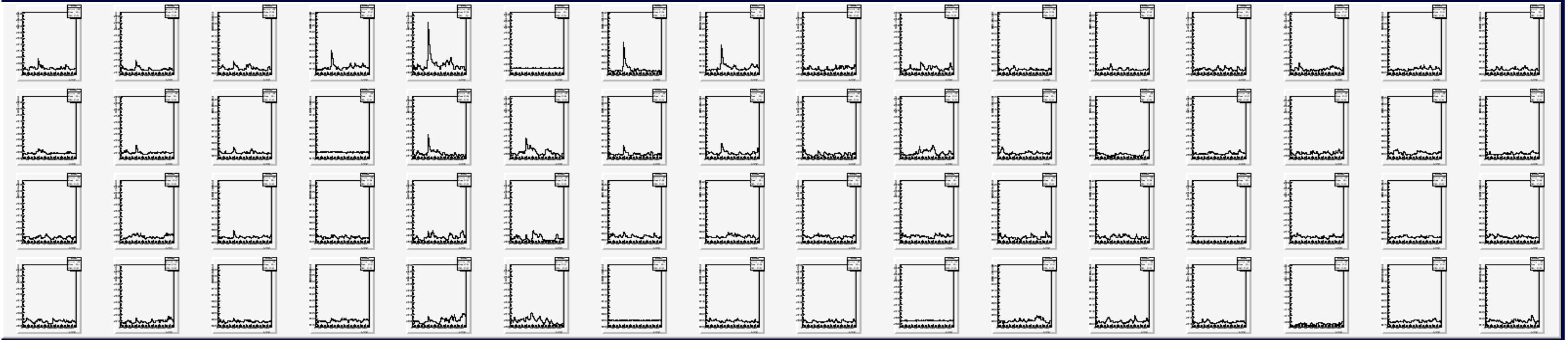

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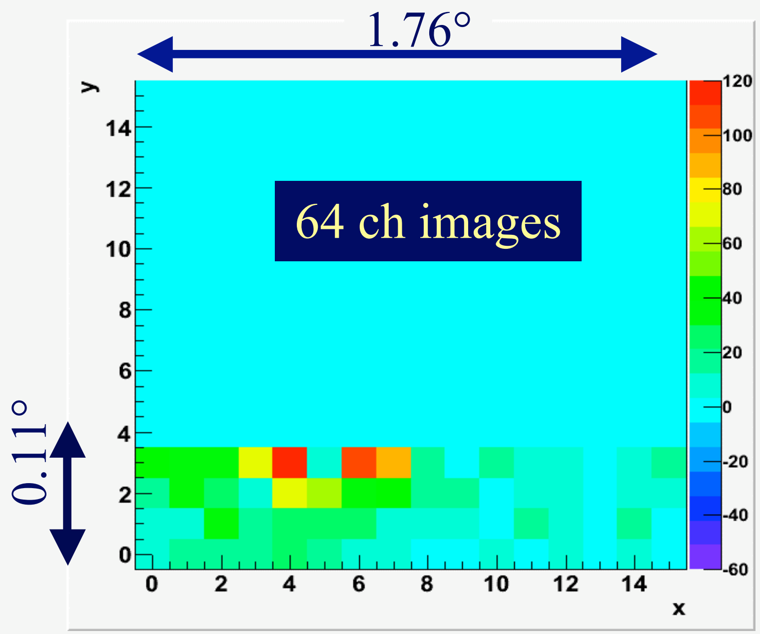

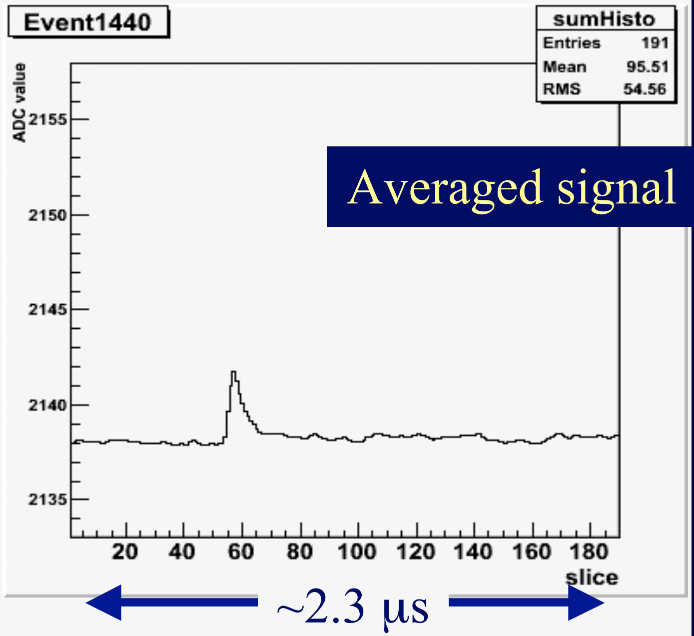

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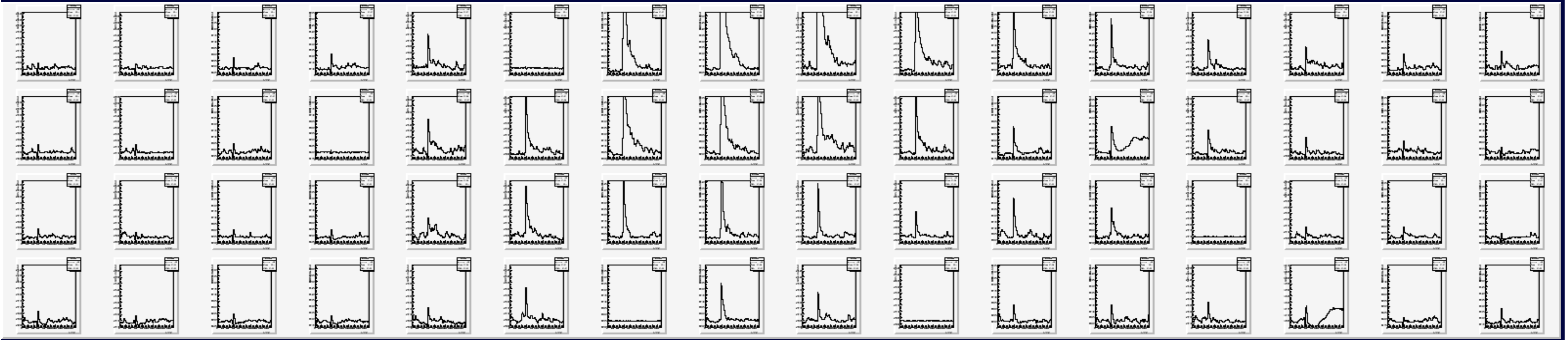

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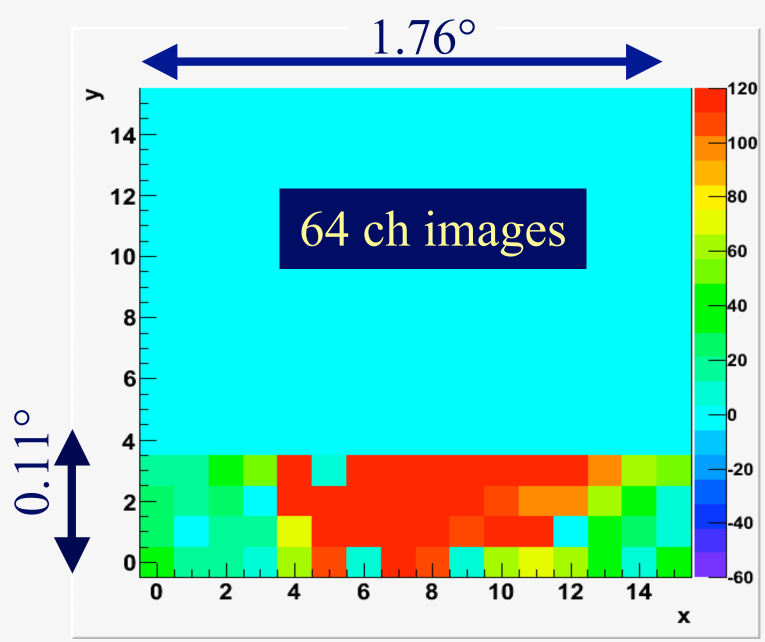

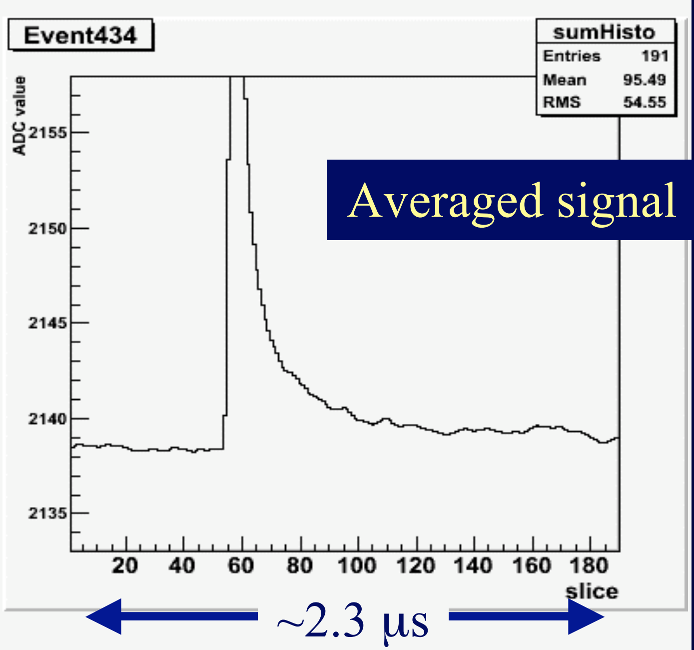

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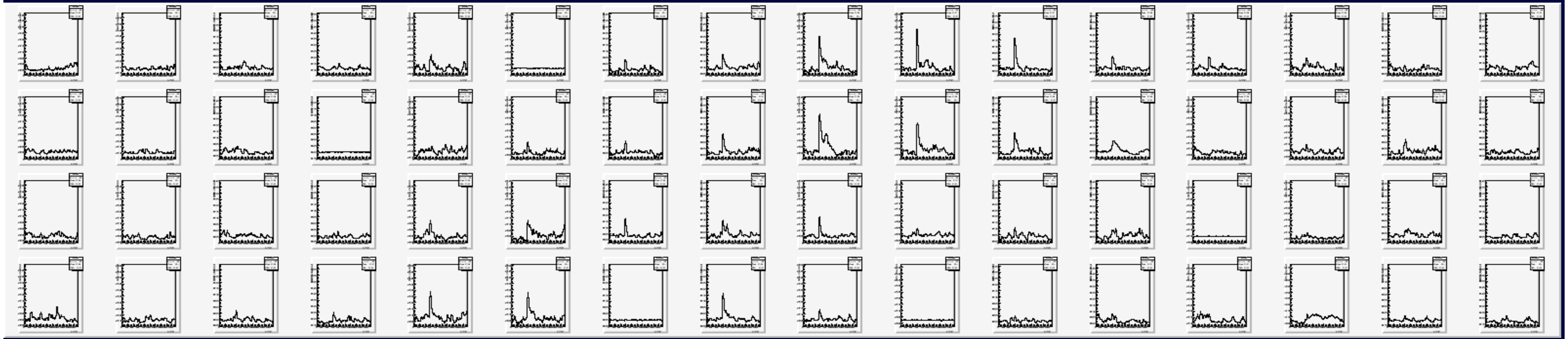
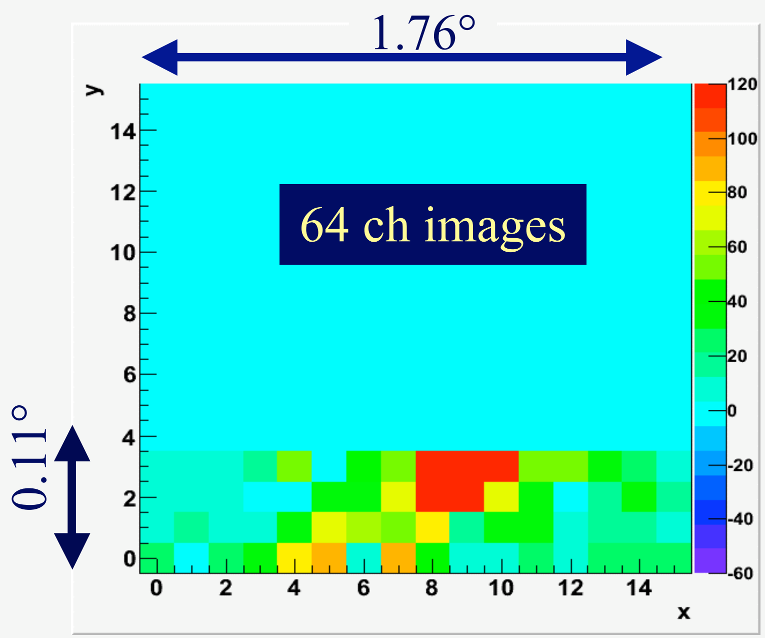
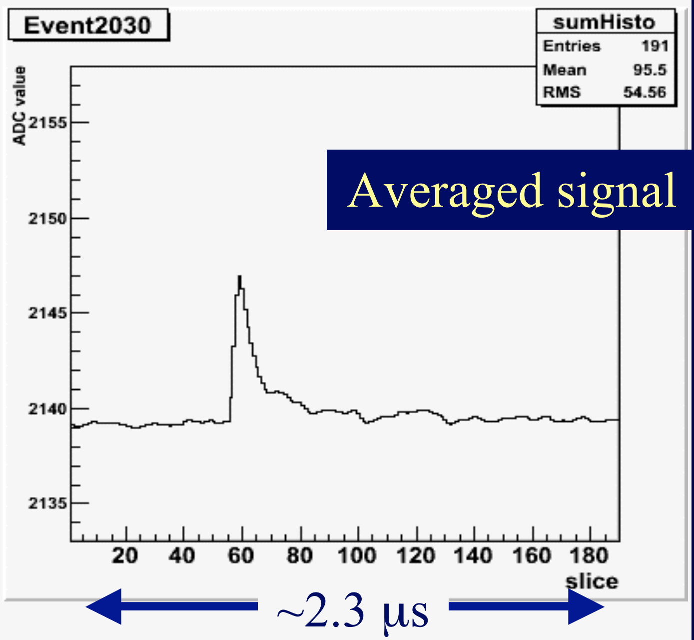


64ch CAEN VME digitizer Waveforms





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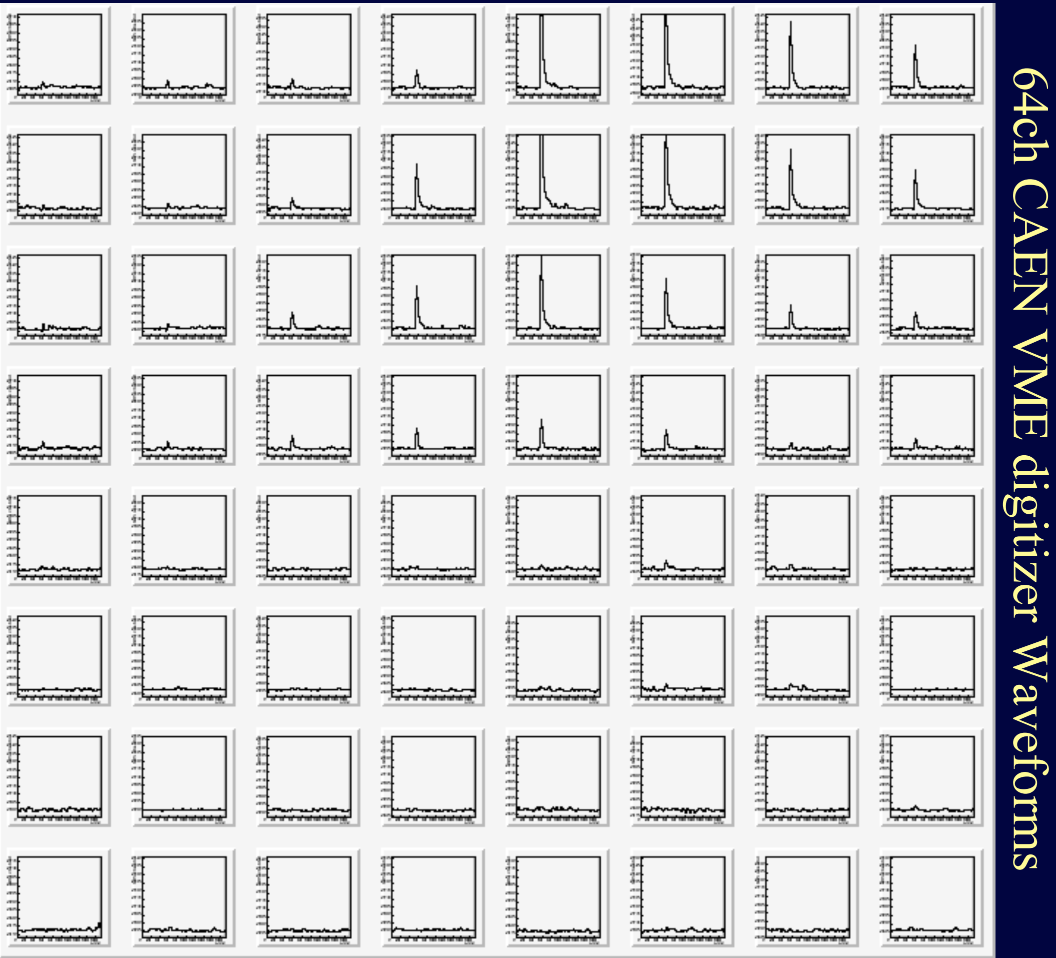

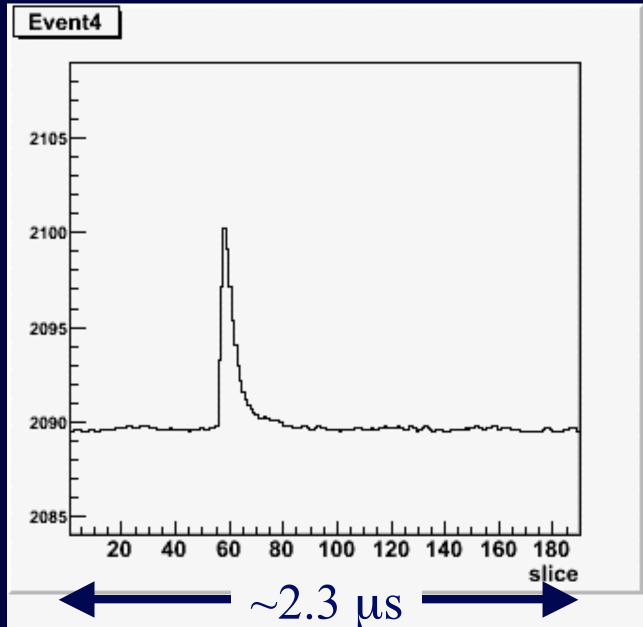

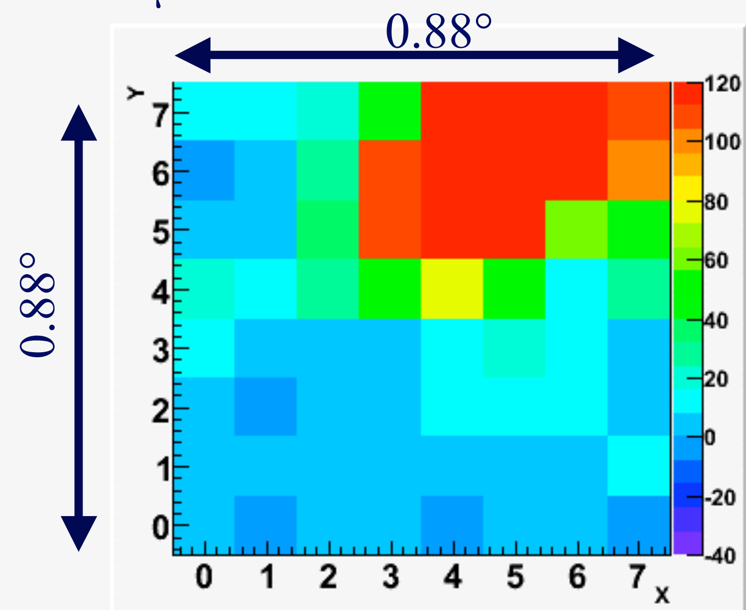

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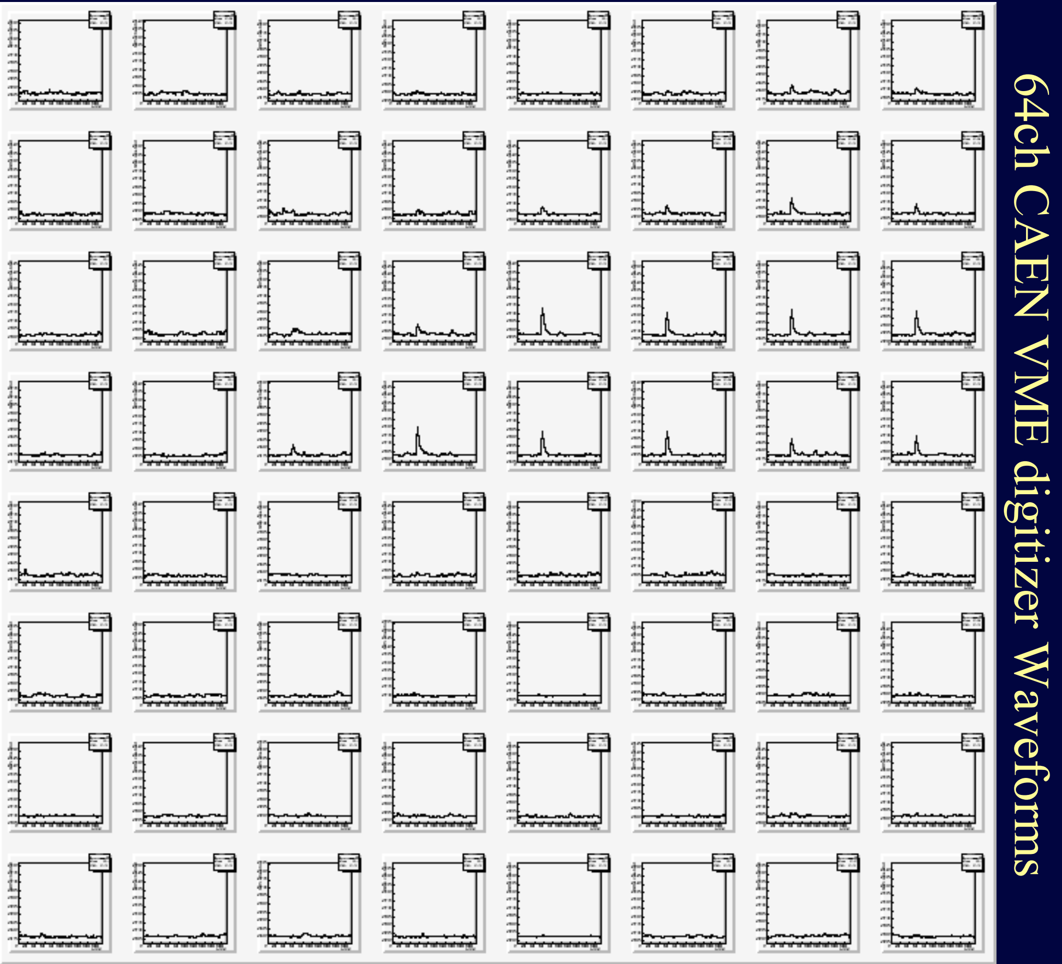

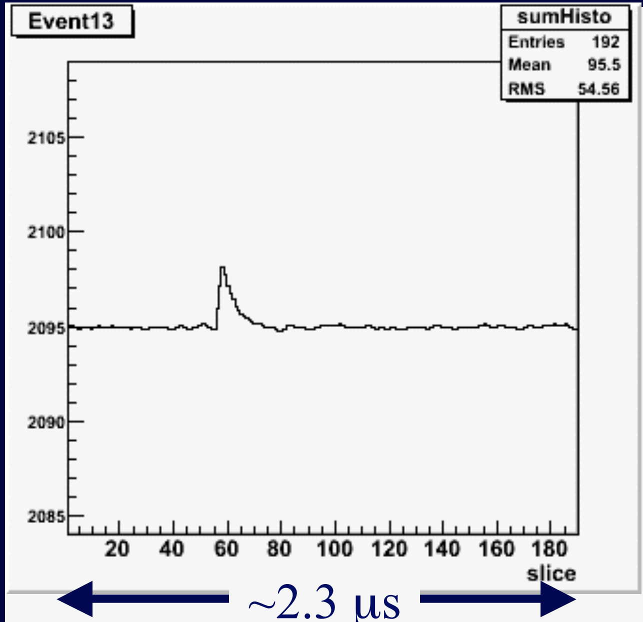

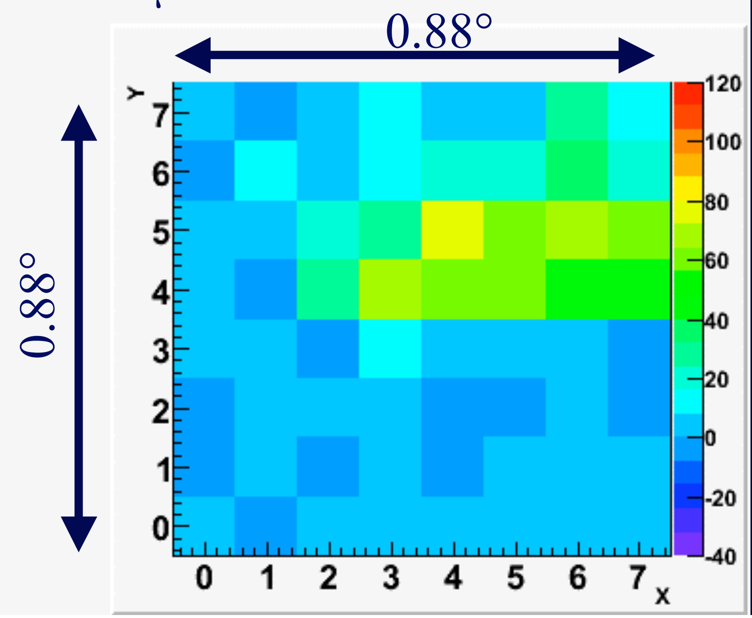

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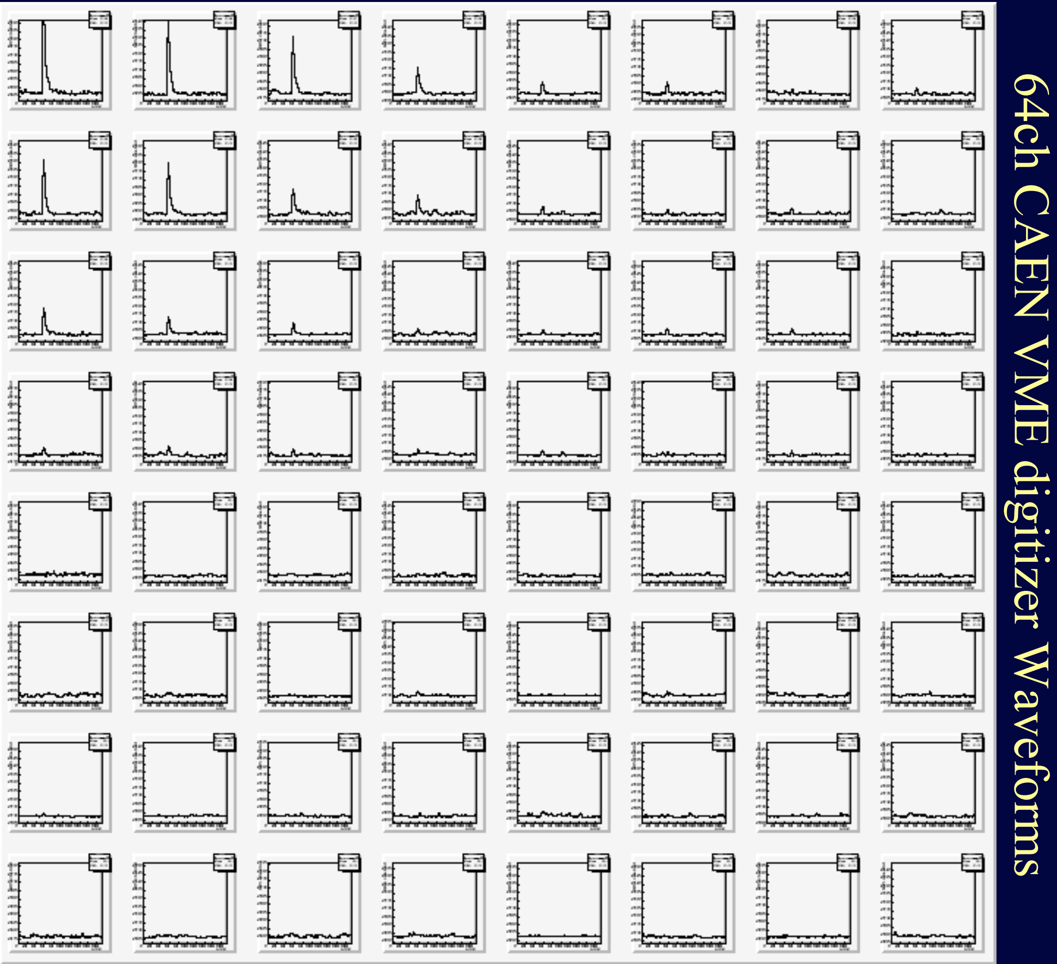

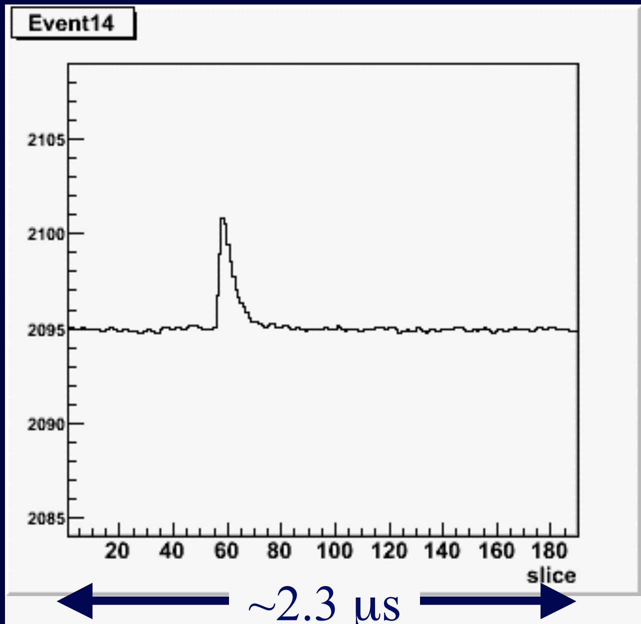

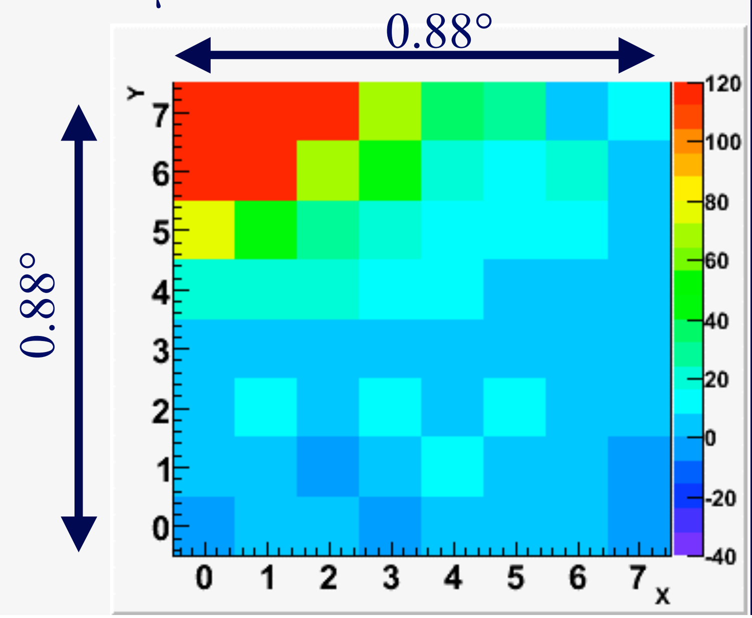

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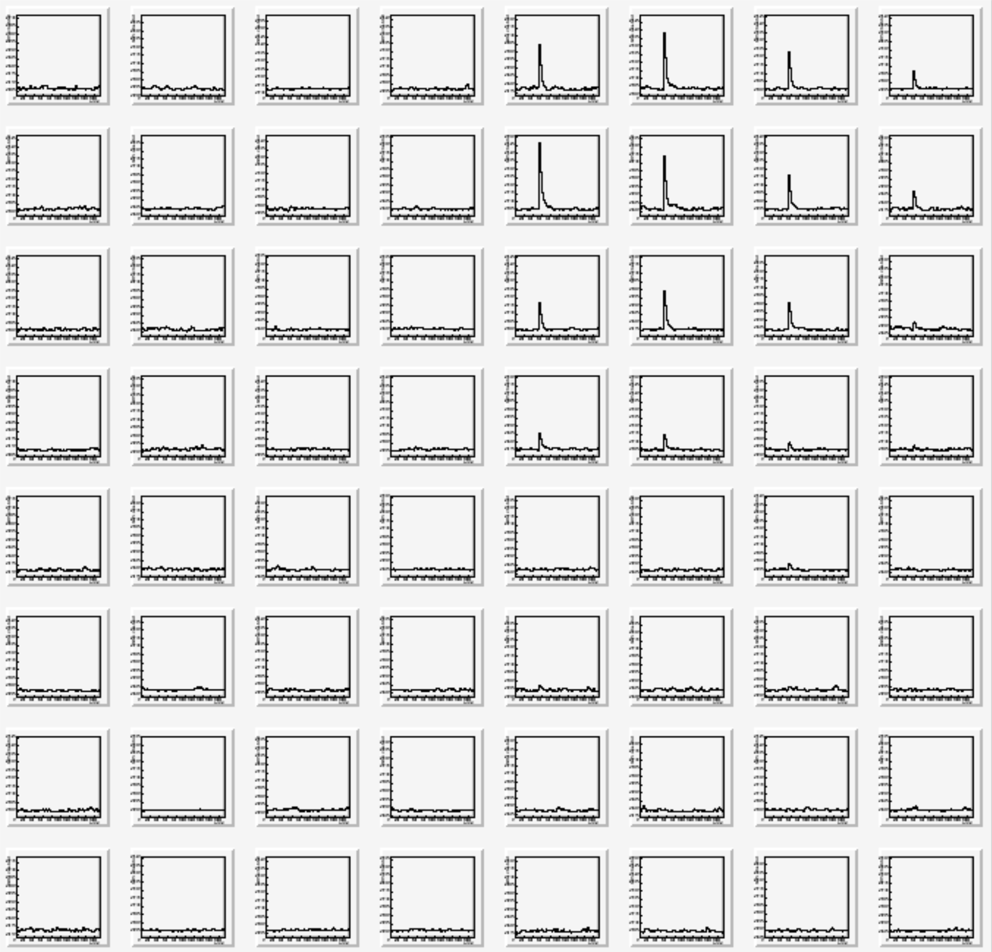
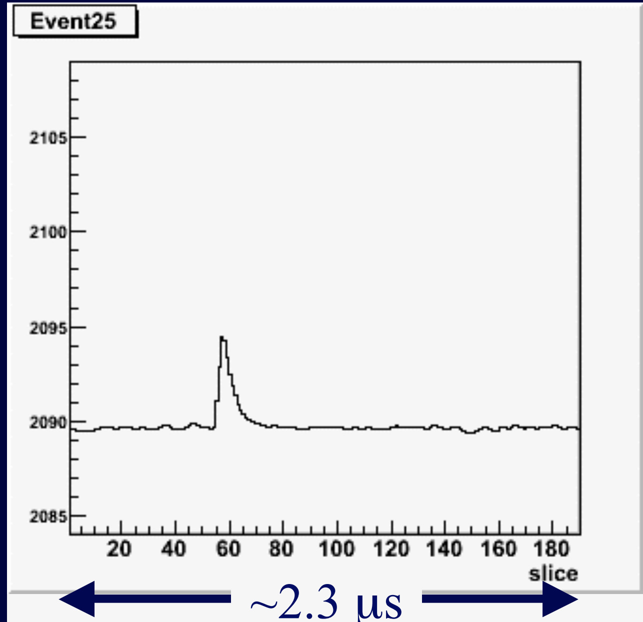
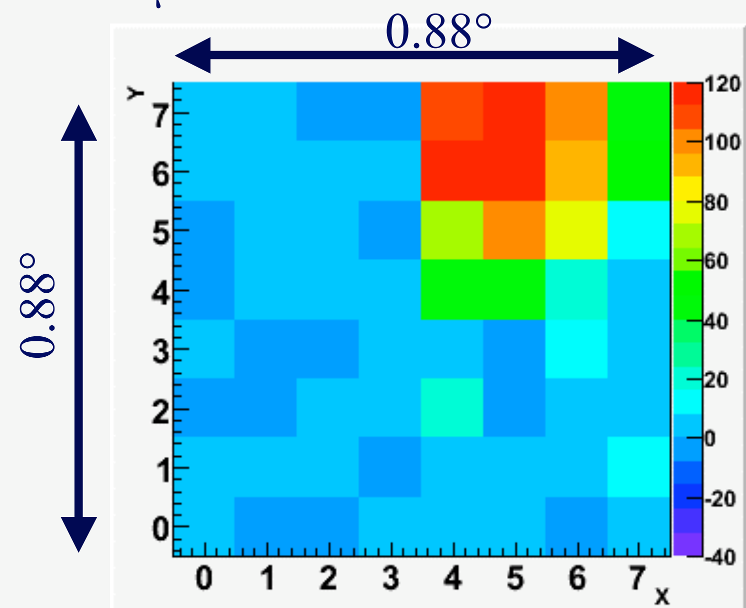

64ch CAEN VME digitizer Waveforms





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Preliminary!!

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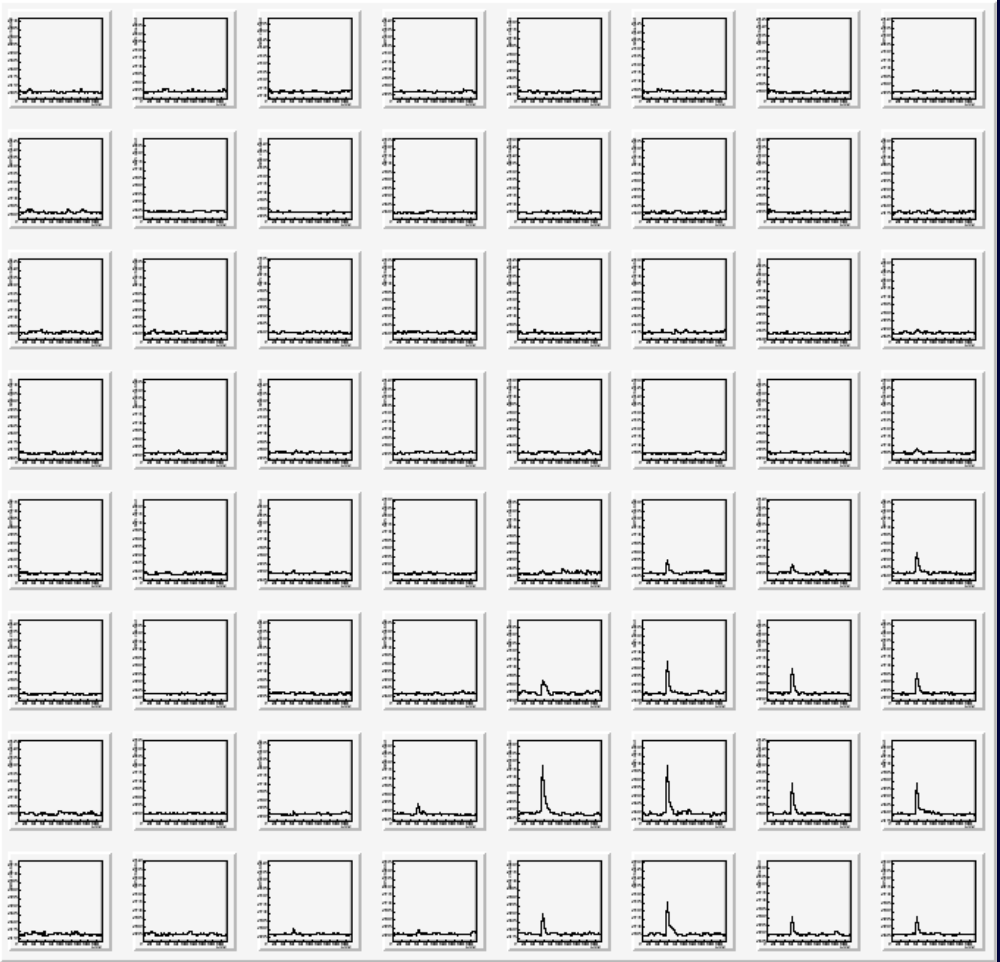
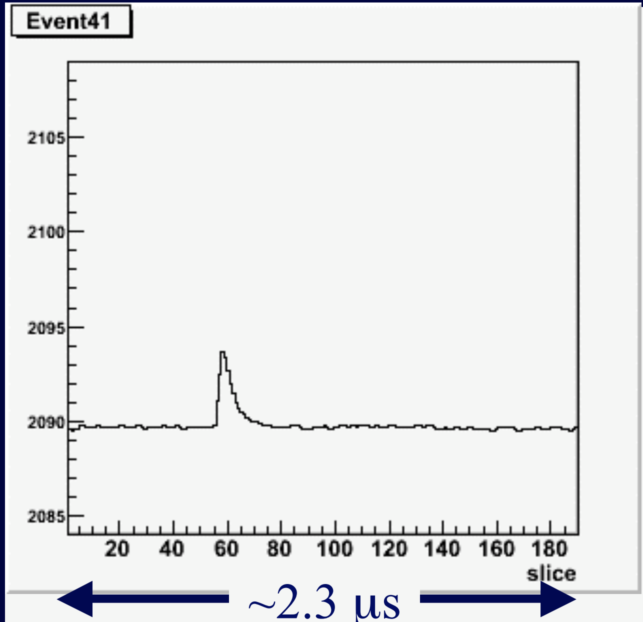
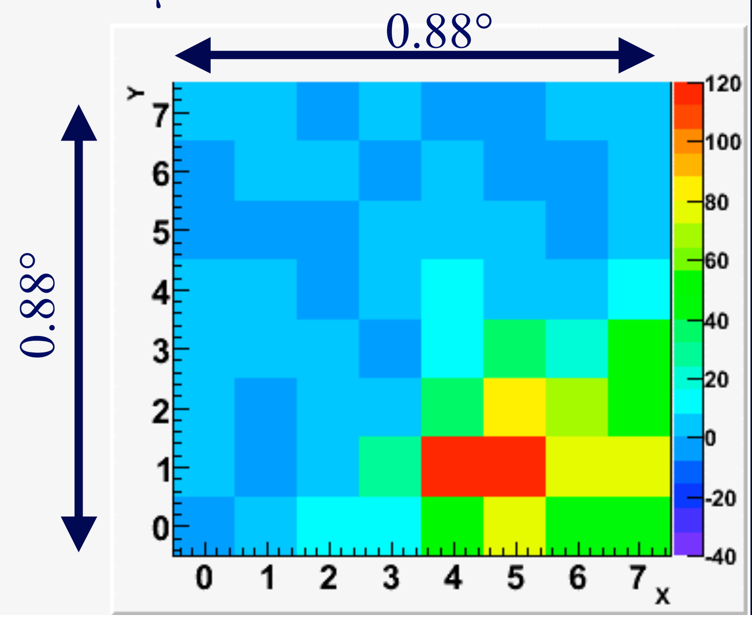
(in Munich downtown @ Room Temperature!)



64ch CAEN VME digitizer Waveforms





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- Average ~700 PEs in an image (~100TeV)

Preliminary!!

Summary I

- JEM-EUSO is the next generation wide FoV space-borne observatory, whose gigantic target volume enables EHECRs astronomy
- EUSO completed Phase-A from 2000 to 2004 in the ESA program and NASA MIDEX program
- JEM-EUSO has been selected by JAXA as a mission candidate for the second-phase utilization of JEM/EF on ISS for launch in 2015 for 5-yrs (or longer) exposure.
- Phase-A Study under JAXA (Japanese Space agency) is ongoing
- JEM-EUSO has exposure (with tilt) > 10^6 km^2 sr yr
  - *First Observatory of EHECRs from space!!*

Summary II & Outlook

Summary

- SiPM is promising for an ideal detector for JEM-EUSO
- Preliminary results of PDEs : PDE = ~45%@375nm (D-SiPM)
- Gain stability +- 0.1%/°C with a thermistor circuit.
- *64/256ch MPPC camera performance demonstrated*

  -> Cherenkov images by 1st practical pure SiPM/MPPC camera!

  @ Room Temperature, VERY BRIGHT and DUSTY Munich Sky

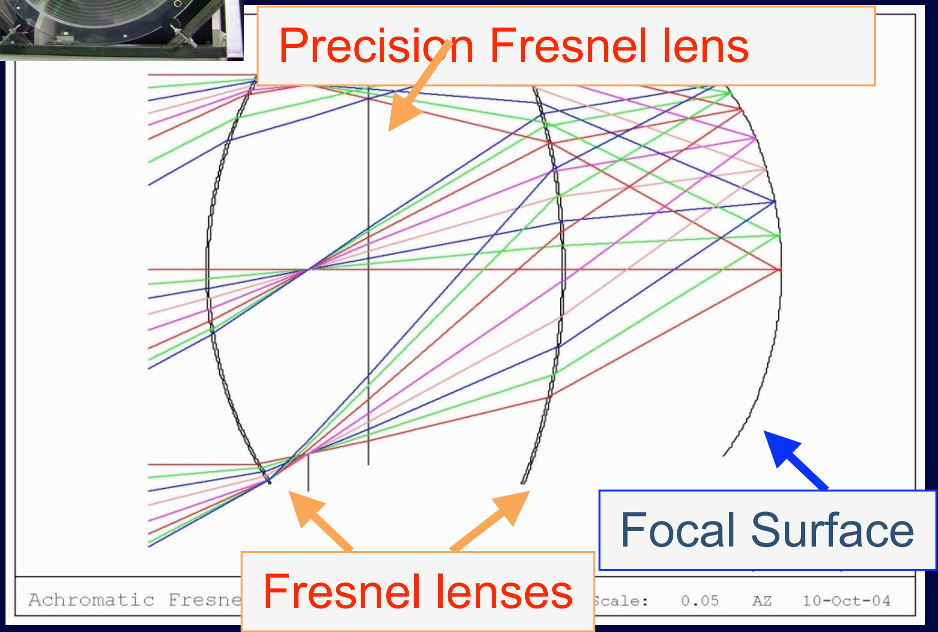
Outlook

- Develop a camera module for MAGIC-II telescope
- Space-qualified design and tests have to be done

Danke Schön!!

Hiroko Miyamoto
MPI für Physik

JEM-EUSO Optics

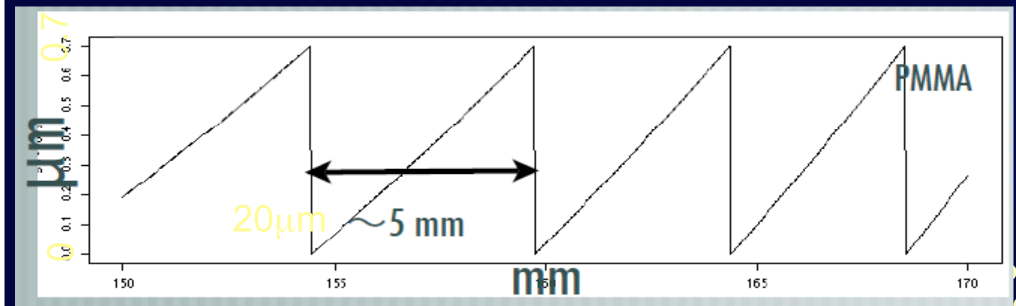


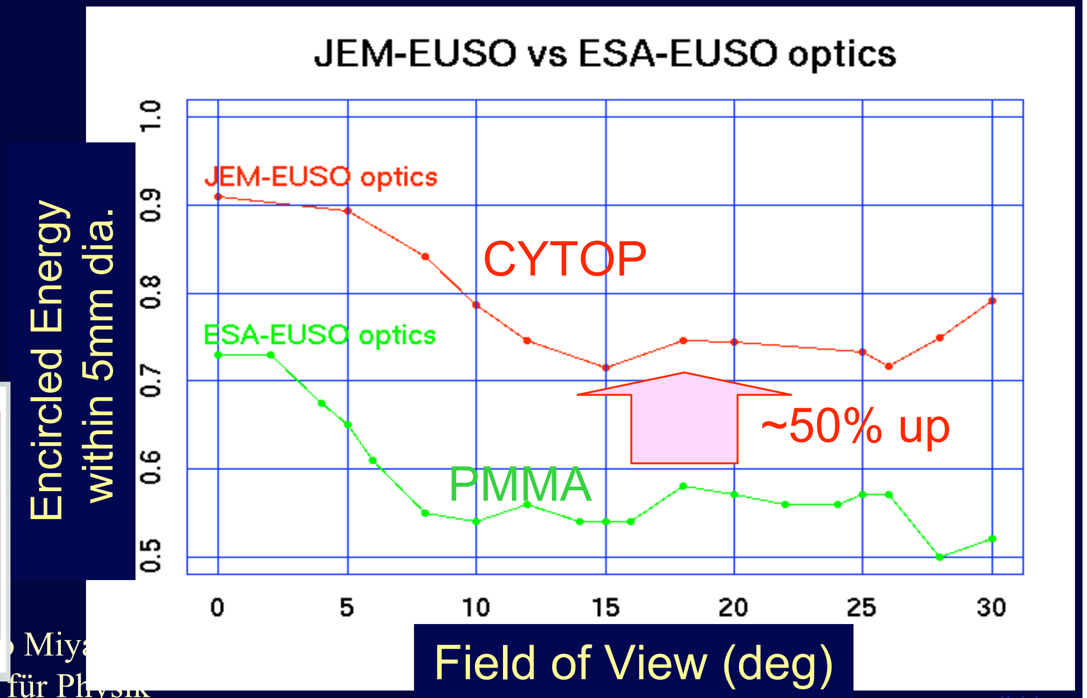
Precision optics cancels chromatic aberration

Optics Requirements

- FoV ± 30°
- Pupil entrance pupil ≥ 2 m
- F/# ≤ 1.0
- Spot dimension ~0.1° (5mmΦ)
- Spectral range 330nm-400 nm

Surface of the Precision Fresnel lens

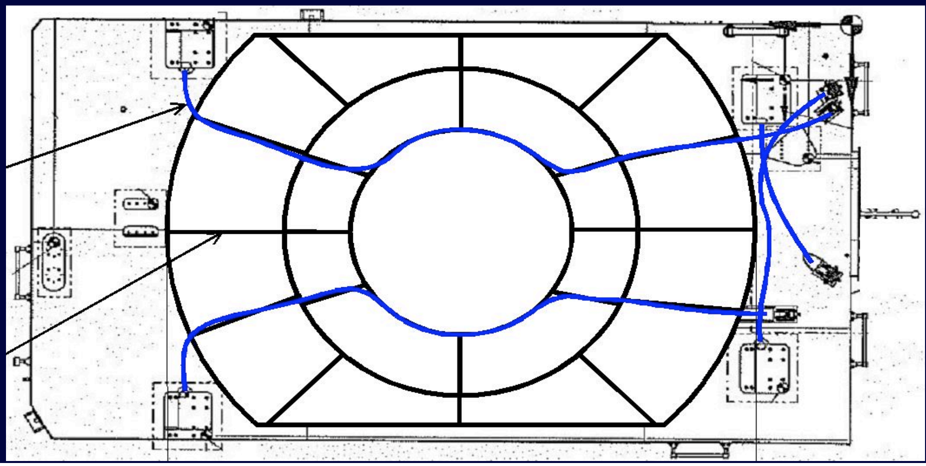


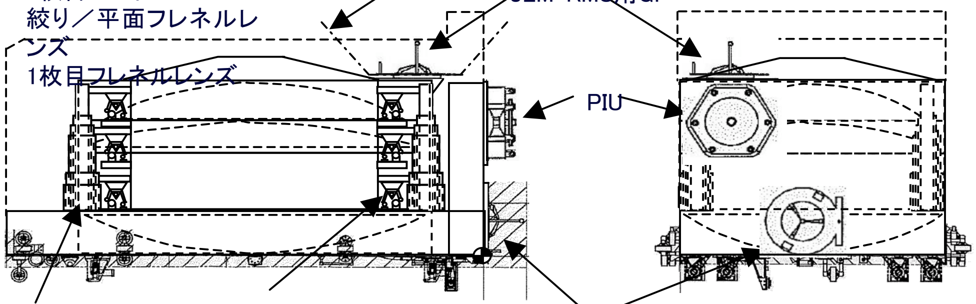


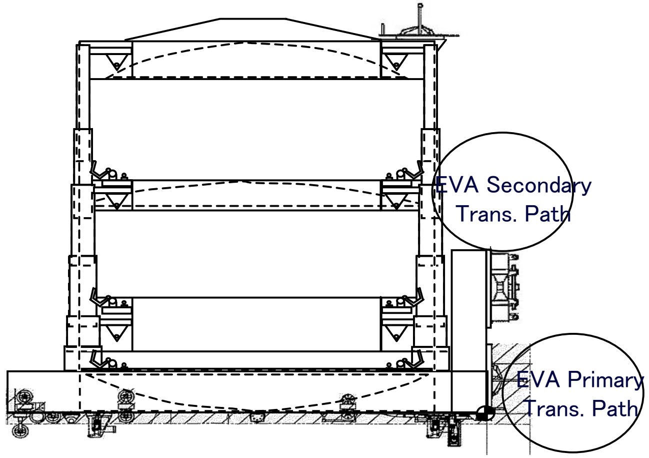
Extreme Universe Space Observatory

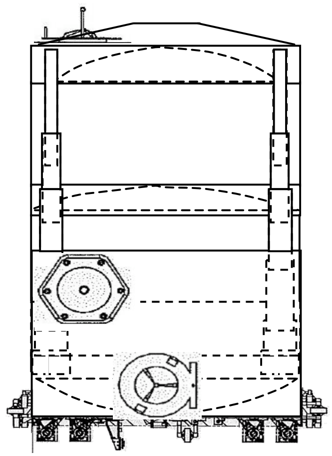
ACTIVITIES in Phase-A

Accommodation to HTV：Case-C







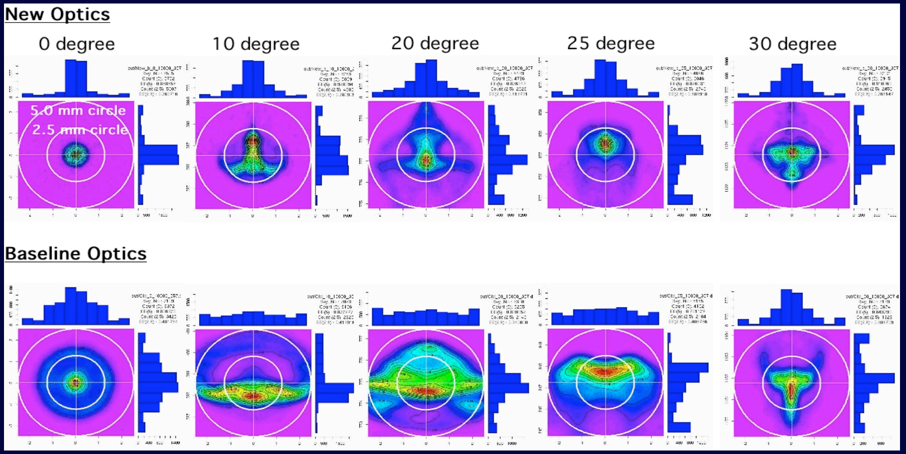


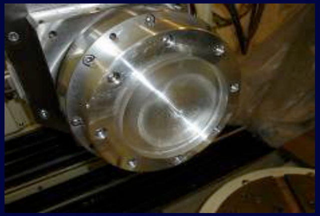
注)伸展機構の太さは強調して示してあり、EVA Secondary Trans. Pathとの干渉はないよう設計可能と考える。

ACTIVITIES in Phase-A

Advanced Design

- Re-Optimization of optics
  - Reduce spot size by factor of 2
- Test manufacturing of small pieces
  - Satisfy the specification
- Advanced Filter
  - Reduction of background light by factor of 2
- Finer Pixel
  - 4.4mm→3.3mm、2.5mm

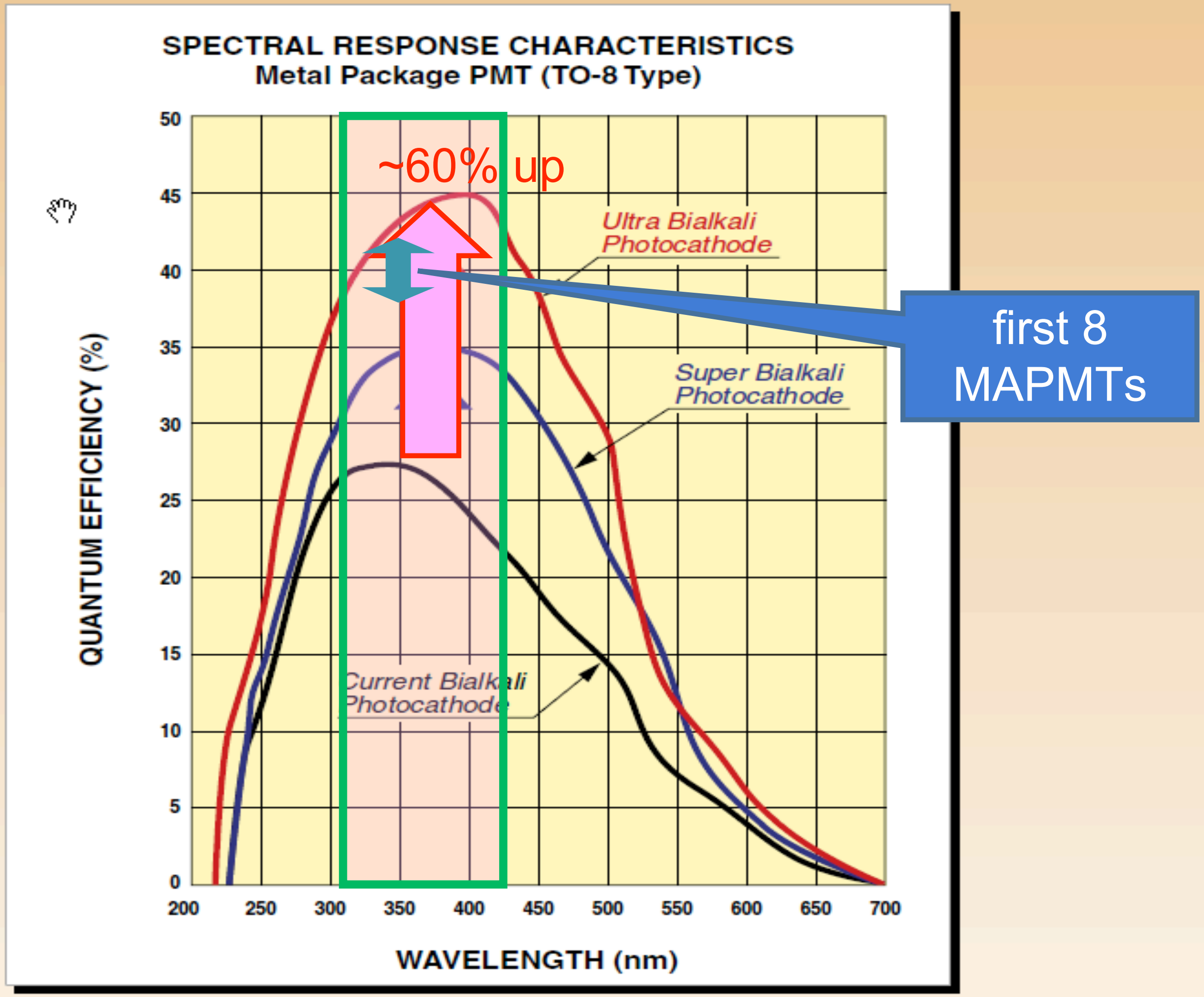




Front and Rear lenses: Surface roughness<15nm (RMS)

Precise lens: Height accuracy <±36nm , Surface roughness<16nm (RMS)

Ultra Bialkali Photocathode (UBA): QE 43% typ.
Super Bialkali Photocathode (SBA): QE 35% typ.

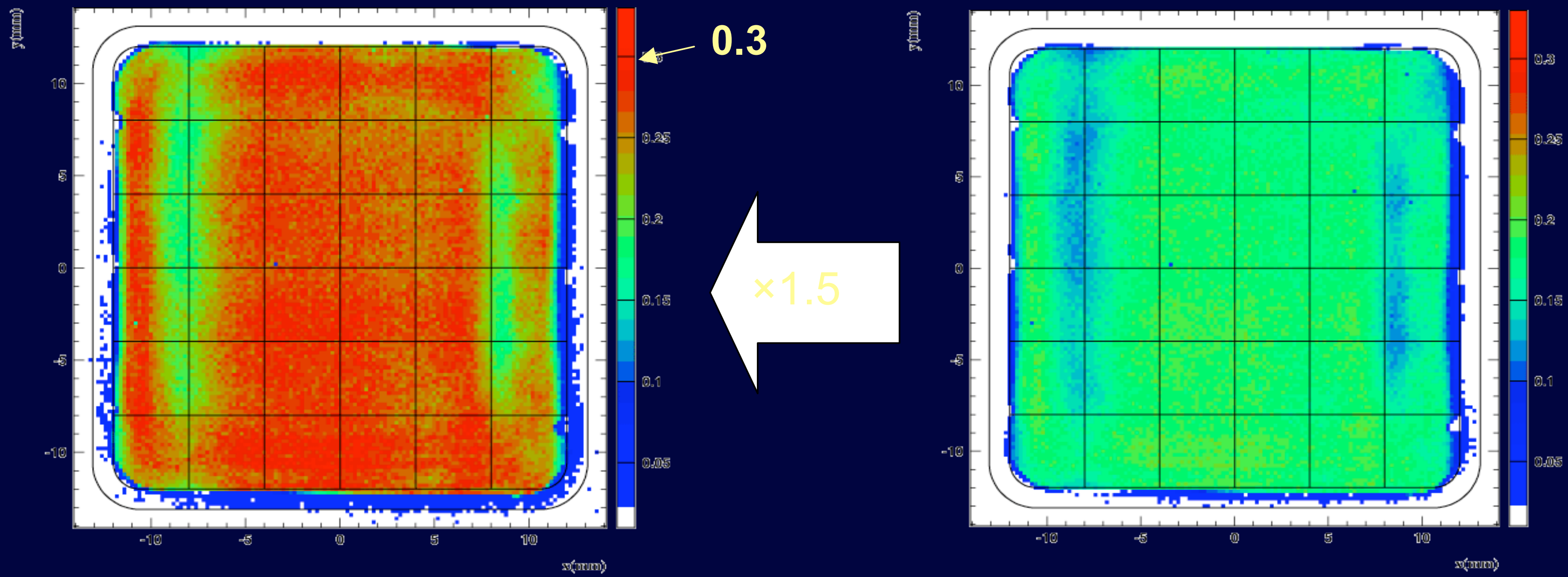


Hamamatsu Photonics

Photocathode	QE at peak wavelength		Type Availability
	Min.	Typ.	
Ultra Bialkali (UBA)	38 %	43 %	Metal Package PMT (TO-8 Type, □28 mm Type PMT)
Super Bialkali (SBA)	32 %	35 %	Metal Package PMT (TO-8 Type, □28 mm Type PMT) φ28 mm to φ76 mm Head-on PMT (Glass Bulb Type)

Hamamatsu Ultra Bialkali photocathode

Detection efficiency



On-board calibration

Light Source (3 color LED's)

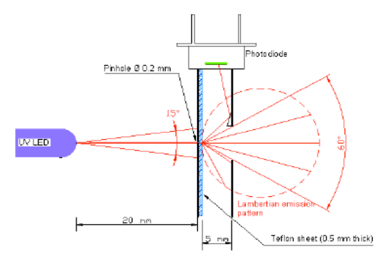


Figure 5.5.2.2-1 *Sketch of the source arrangement to get a point-like Lambertian UV source.*

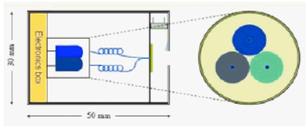


Figure 5.5.2.2-2 *Schematic drawing of the source arrangement for a multi-wavelength UV radiation source. The accommodation of 3 LEDs emitting at different wavelengths is shown in the front view on the right.*

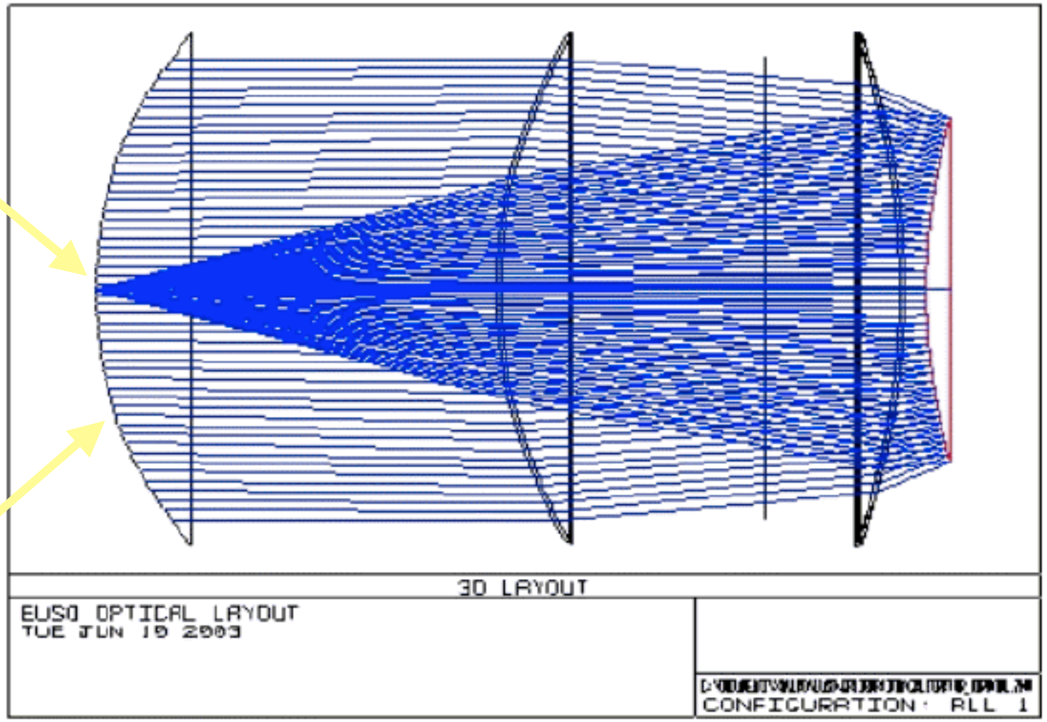


Figure 5.5.2.1-1 *Ray tracing of the EUSO Telescope with a point-like Lambertian source placed at the centre of the FS and a diffuse reflector at the rear side of the lid. After the diffuse reflection, the light enters the EUSO Telescope and illuminates the FS. The light intensity and uniformity at the diffuse reflector is monitored by seven PMTs embedded in the reflector and lid.*

Simulated Light Intensity on FS

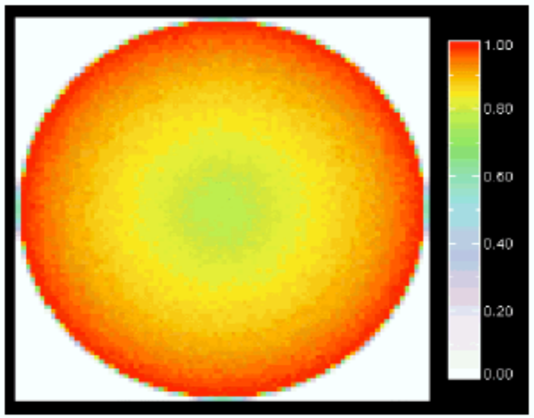
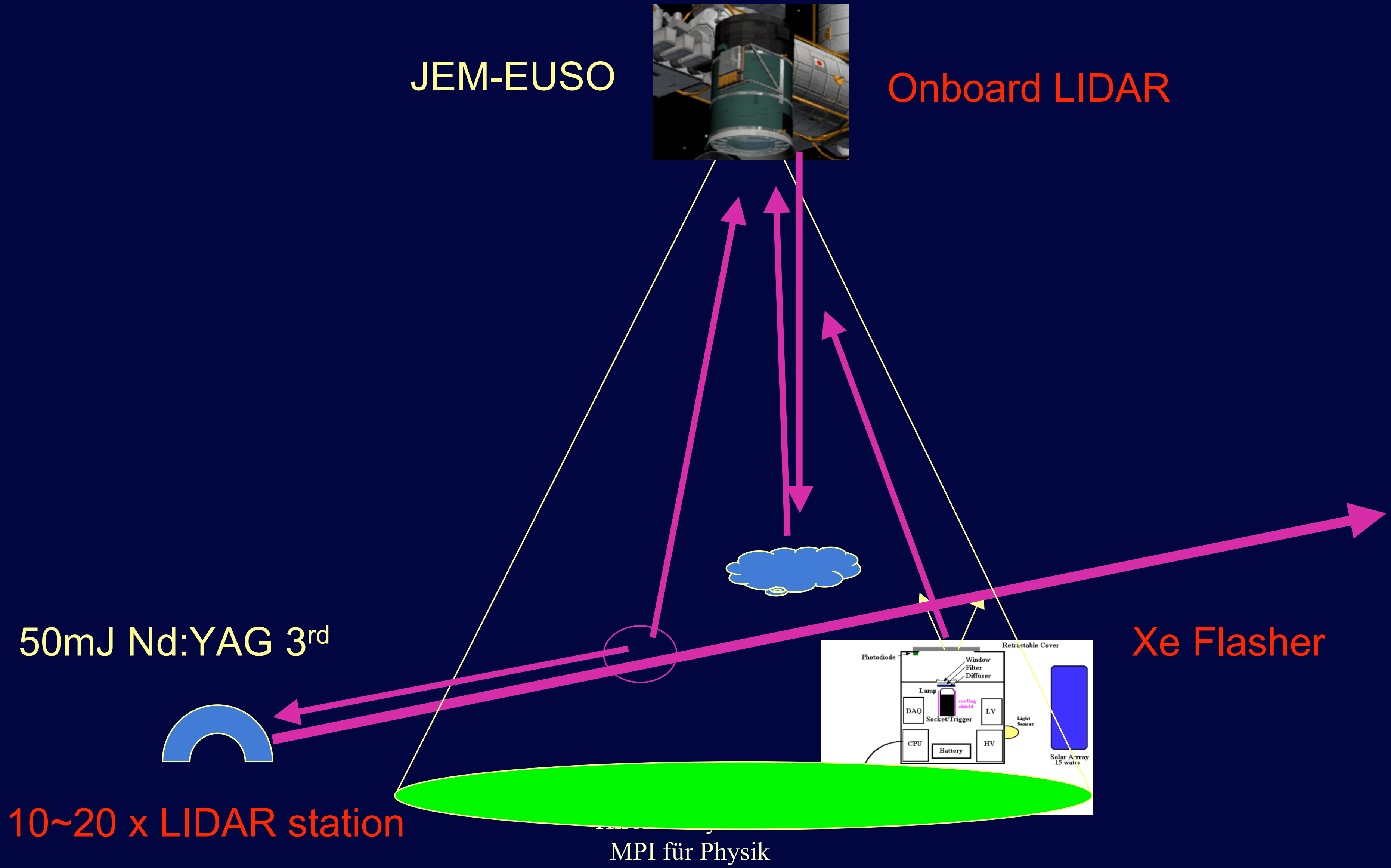


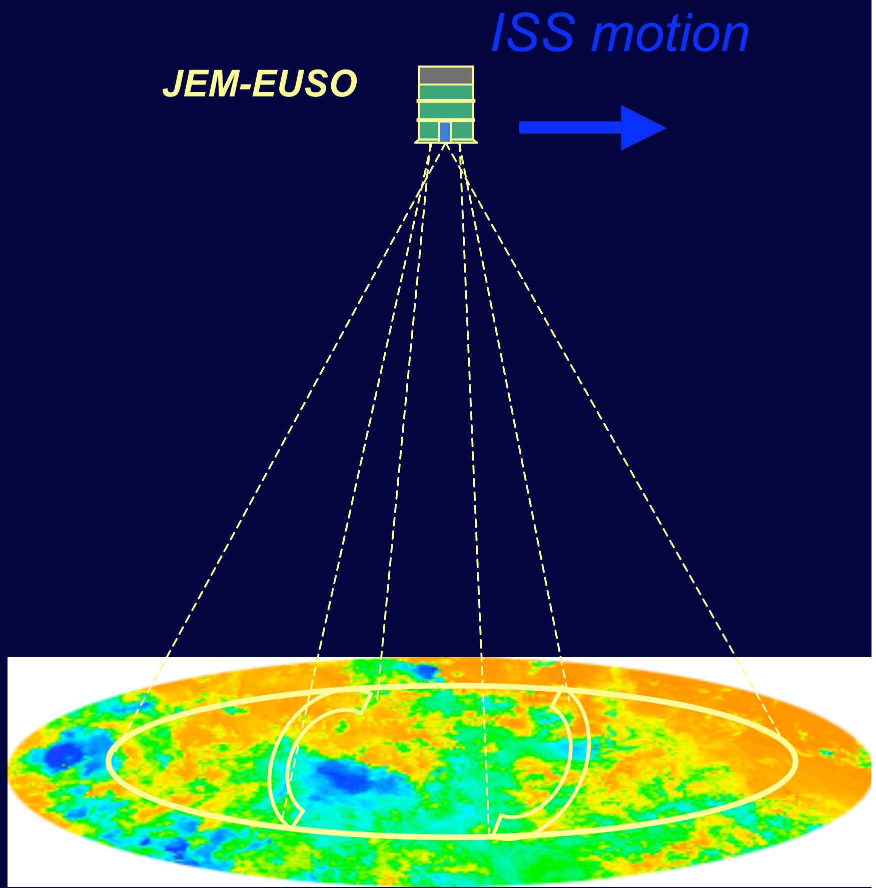
Figure 5.5.2.1-2 *Intensity distribution of the radiation arriving on the FS using a radiation source arranged on the FS.*

Hiroko Miyamoto
MPI für Physik

Calibration and Monitor by Onboard LIDAR, Ground LIDAR & Xe flasher



Atmospheric Monitoring System



- **IR Camera**

  Imaging observation of cloud temperature inside FOV of JEM-EUSO

- **Lidar**

  Ranging observation using UV laser

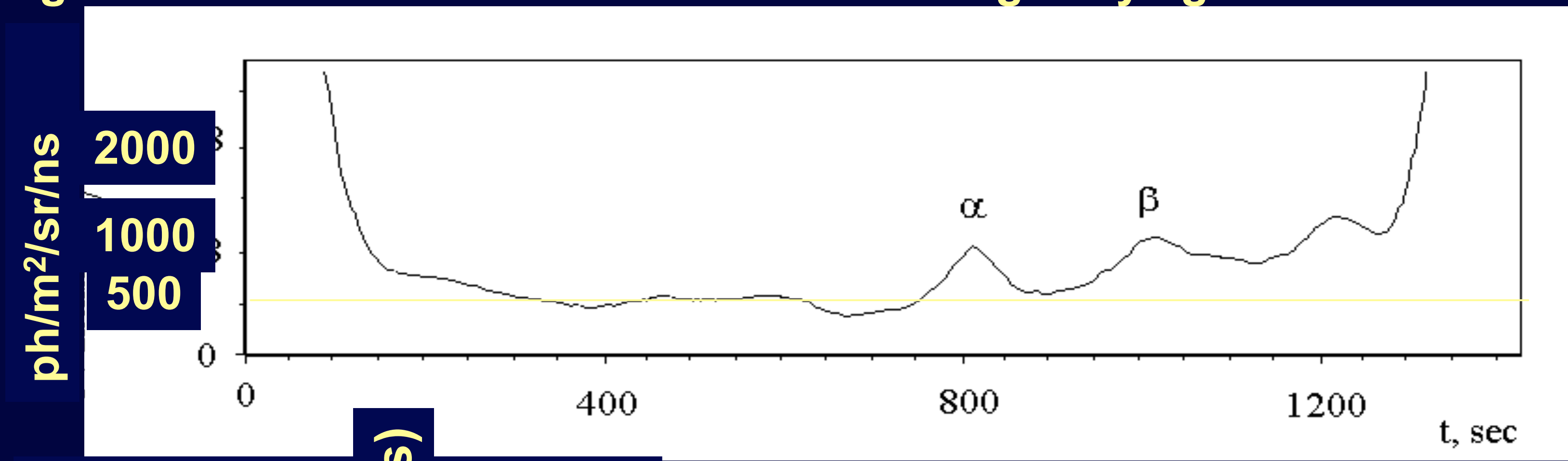
- **JEM-EUSO "slow-data"**

  Continuous background photon counting

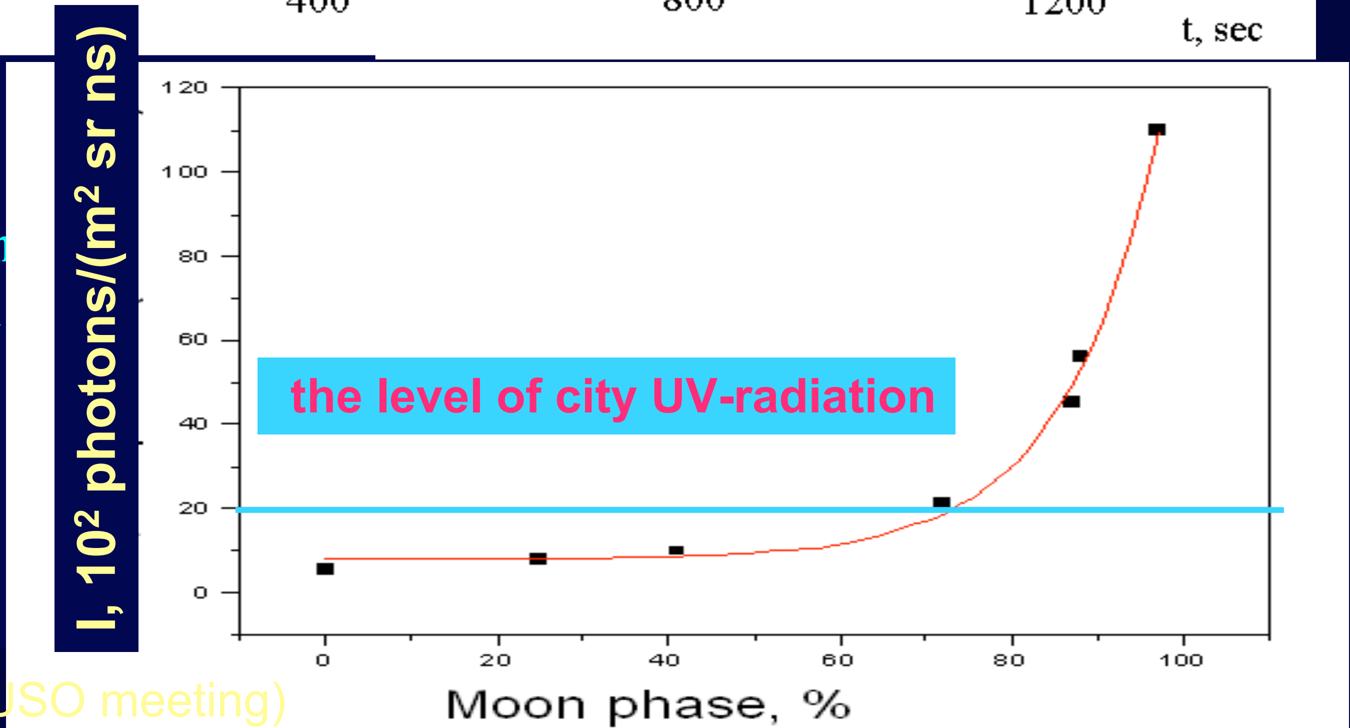
- *Cloud amount, cloud top altitude*: (IR cam., Lidar, slow-data)
- *Airglow*: (slow-data)
- *Calibration of telescope*: (Lidar)

Night glow background – Tatiana measurements

UV light intensity, measured by the "Tatiana" detector- moonless night side of the Earth. Peaks are from the large city lights.



The dependence of average UV-radiation intensity from Moon phase



(Klimov, 1st Int. JEM-EUSO meeting)

Expected Number of Events
5 years

	$>7\times10^{19}$ eV	$>1\times10^{20}$eV
2.6mφside cut Case-C	1850	450
Advanced Design Case-D	3600	680

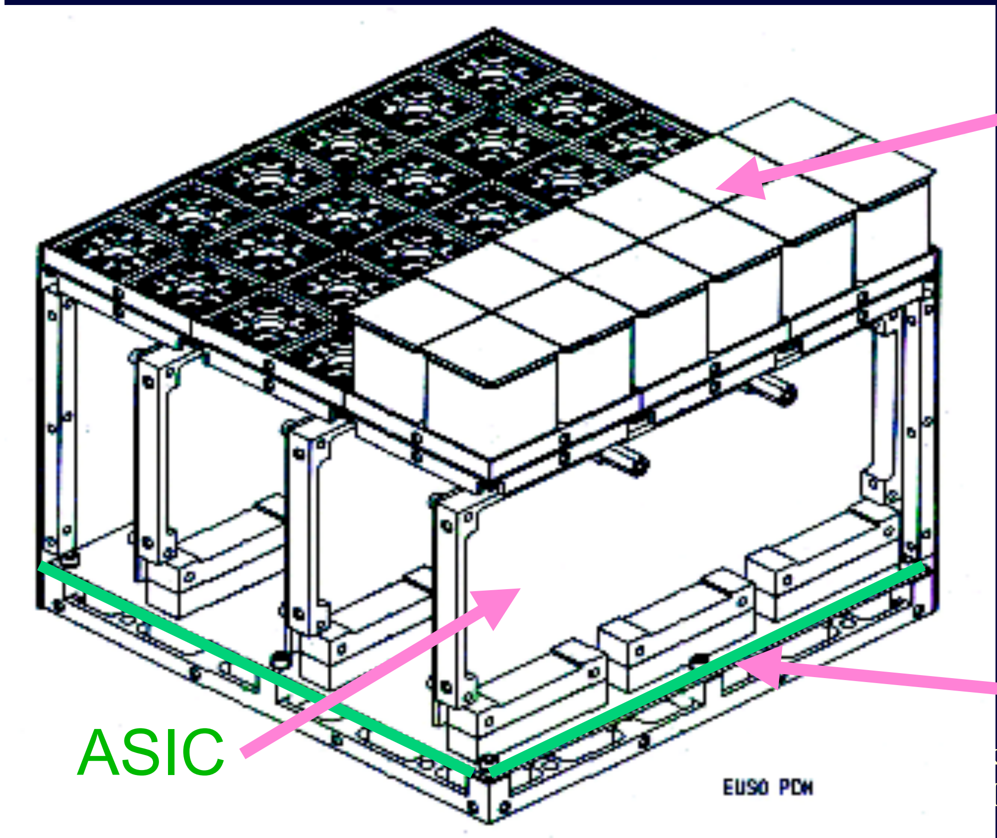
Photo Detector Module (PDM)

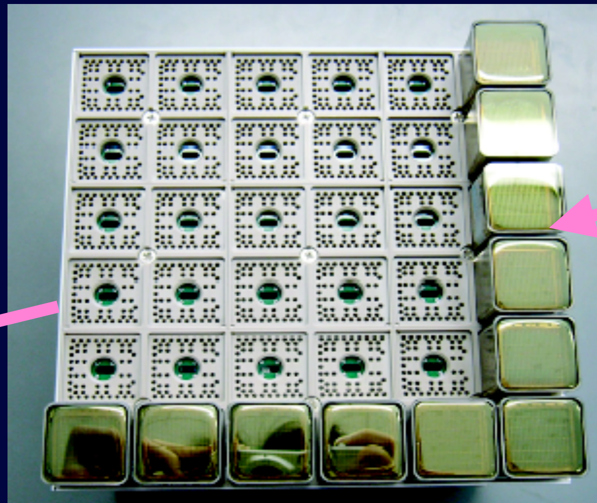
- ９ Elementary Cell (EC) , １ HV module, ９ HV divider

✓ Structure analysis / Vibration test

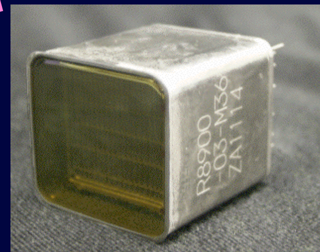
✓ Radiation test

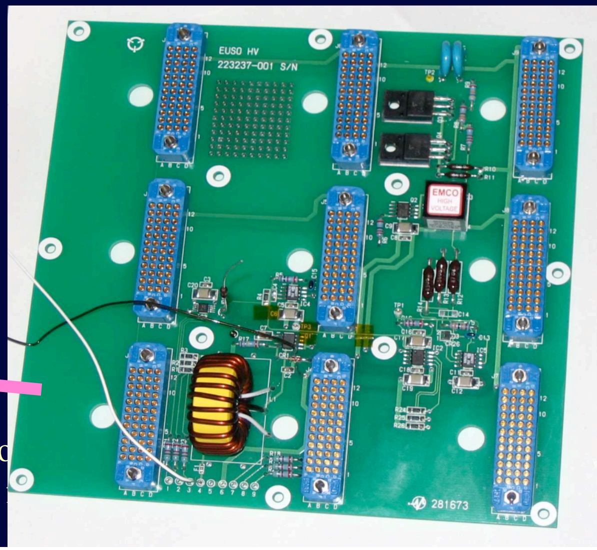
✓ Light protection circuit





MAPMT
36PMTx36ch



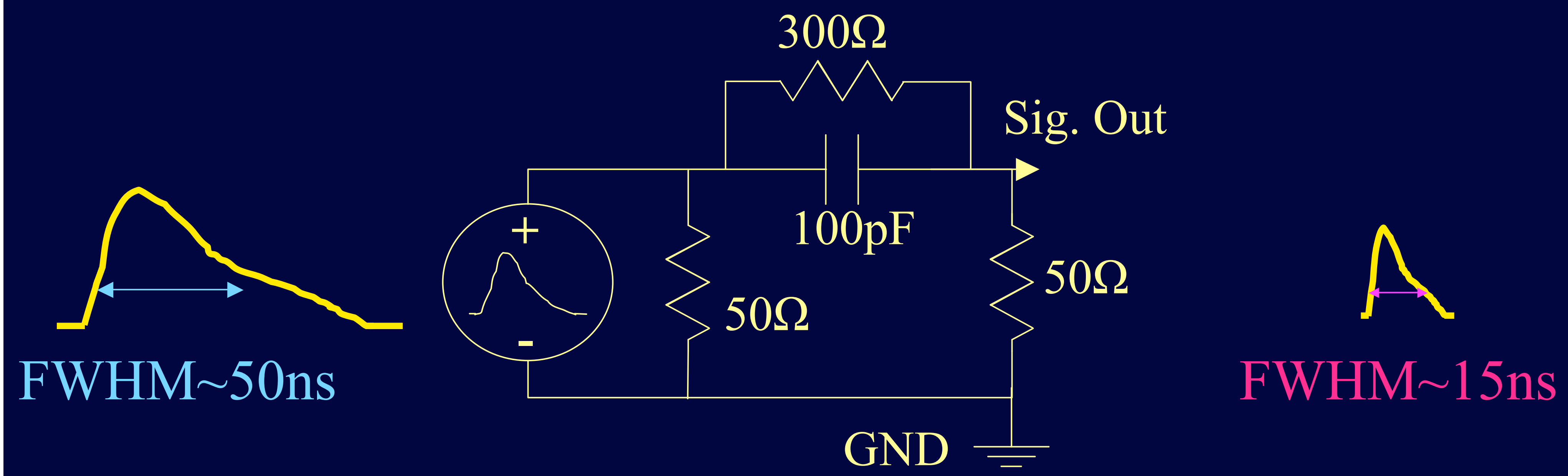


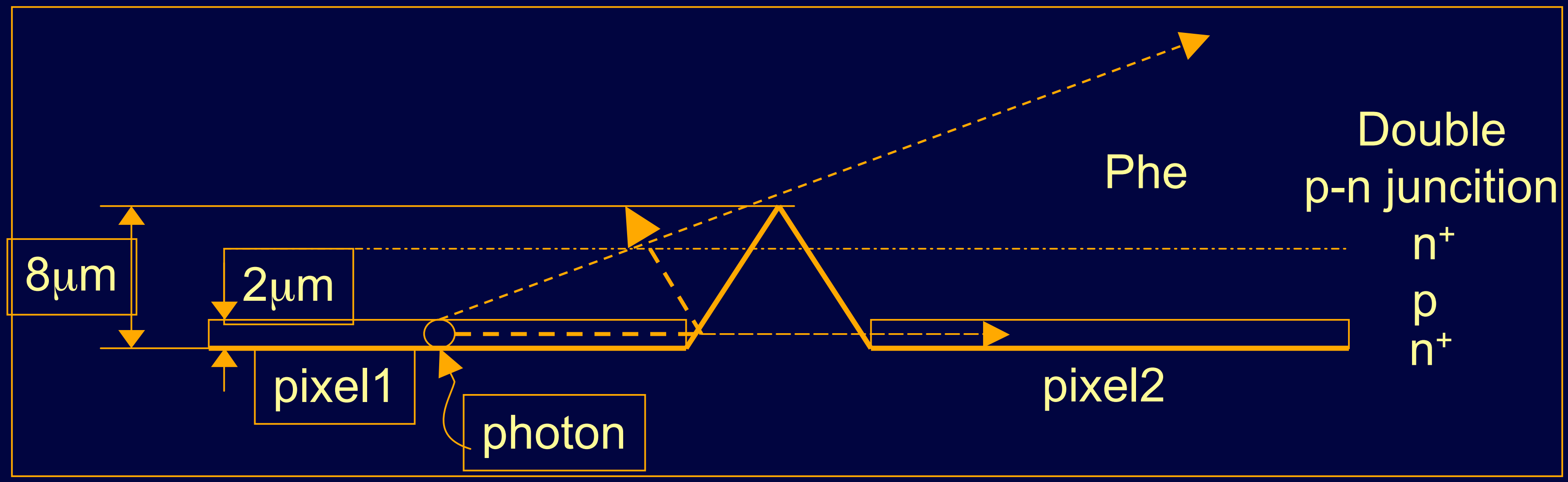
HV board

Toward the application(III)

RC circuit (Differentiator, optional)

SiPM (especially Hamamatsu MPPC) has a very wide pulses (MPPC: ~50ns, D-SiPM:~6ns, SiMPL: ~5ns-10ns (depends on pitch and gap) of FWHM)

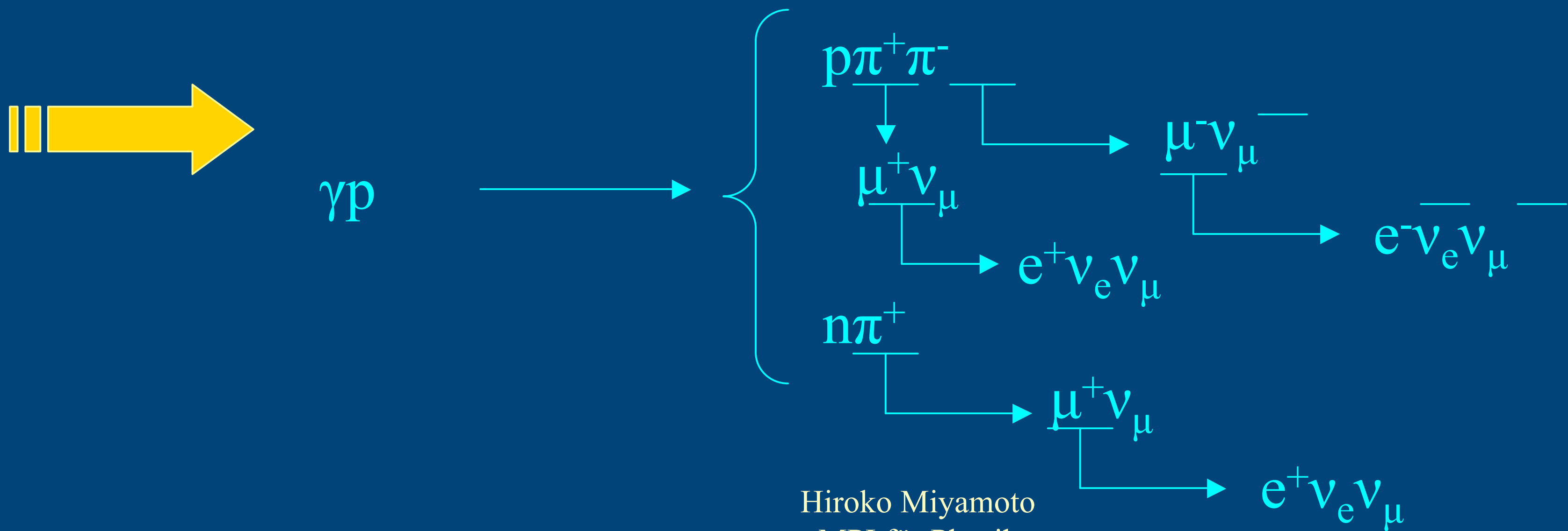



Phe
Double
p-n juncition
n+
p
n+
8μm
2μm
pixel1
photon
pixel2

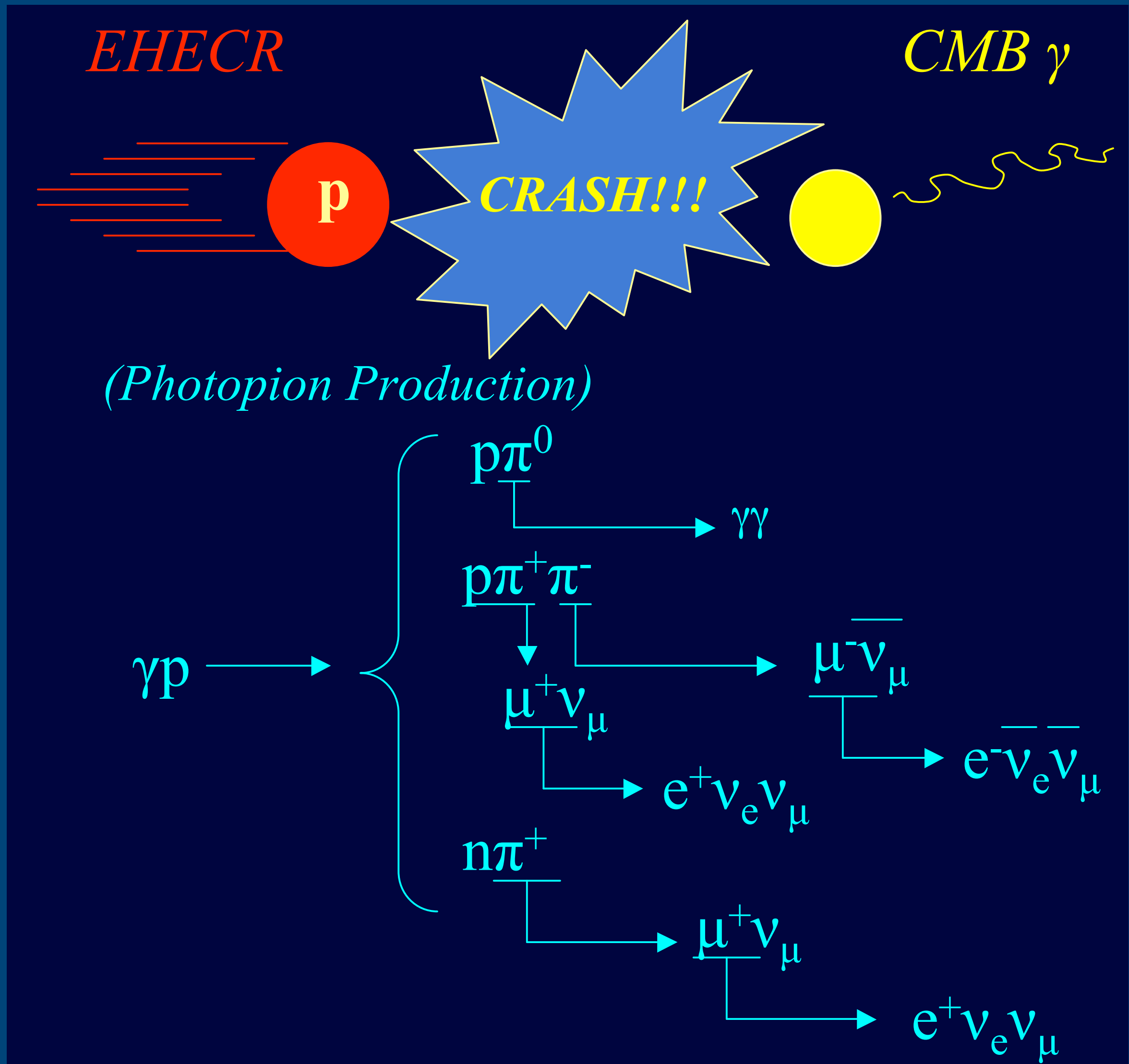
search for EHE neutrinos..

-- GZK Mechanism --

(Photopion Production)

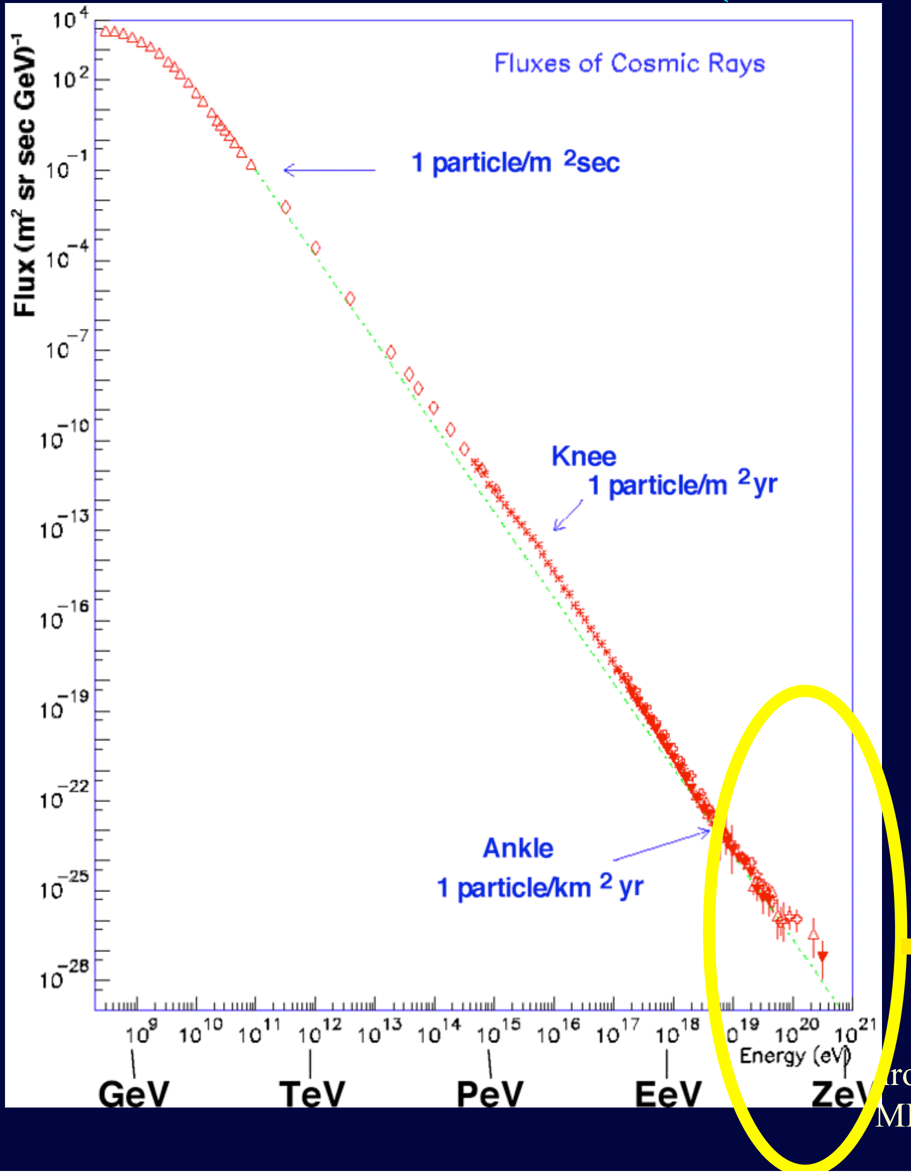


Hiroko Miyamoto
MPI für Physik


EHECR
p
CRASH!!!
CMB γ
(Photopion Production)
γp
$p\pi^0$
$\gamma\gamma$
$p\pi^+\pi^-$
$\mu^+\nu_\mu$
$\mu^-\bar{\nu}_\mu$
$e^+\nu_e\nu_\mu$
$e^-\bar{\nu}_e\bar{\nu}_\mu$
$n\pi^+$
$\mu^+\nu_\mu$
$e^+\nu_e\nu_\mu$

Extreme Universe Space Observatory

Cosmic ray acceleration
(GZK mechanism)



- Identify sources using the arrival direction and study acceleration mechanisms.
- Clarify the trans-GZK intensity profile of distant sources and the systematic survey of nearby sources.
- Separation of gamma rays and neutrinos from nucleons and nuclei, which allows testing of the Super-Heavy-Particle (SHP) models that assume long-lived particles produced in the early era of the universe.

Very rare events!!