Primary Cosmic Ray Observation by Emulsion Chamber

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Primary Cosmic Ray Observations by Emulsion Chambers

RUNJOB experiment

S. Kuramata
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@ Nagoya, Mar. 9, '02

RUNJOB

RUssia Nippon JOint Balloon experiment

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Russia

1: Department of Physics, Moscow State University
2: D.V.Skoveltsyn Institute of Nuclear Physics, Moscow State University
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4: Institute for Nuclear Research, Russian Academy of Science
5: Volsk Expeditionary Base of Lebedev Physical Institute

Japan

6: Faculty of Engineering, Aomori University
7: Department of Physics, Aoyama Gakuin University
8: Faculty of Science and Technology, Hirosaki University
9: School of Medicine, Hirosaki University
10: National Institute of Infomatics
11: Syonan Institute of Technology
12: Department of Management, Urawa College
13: Institute of Space and Astronautical Science

objectives

energy spectra

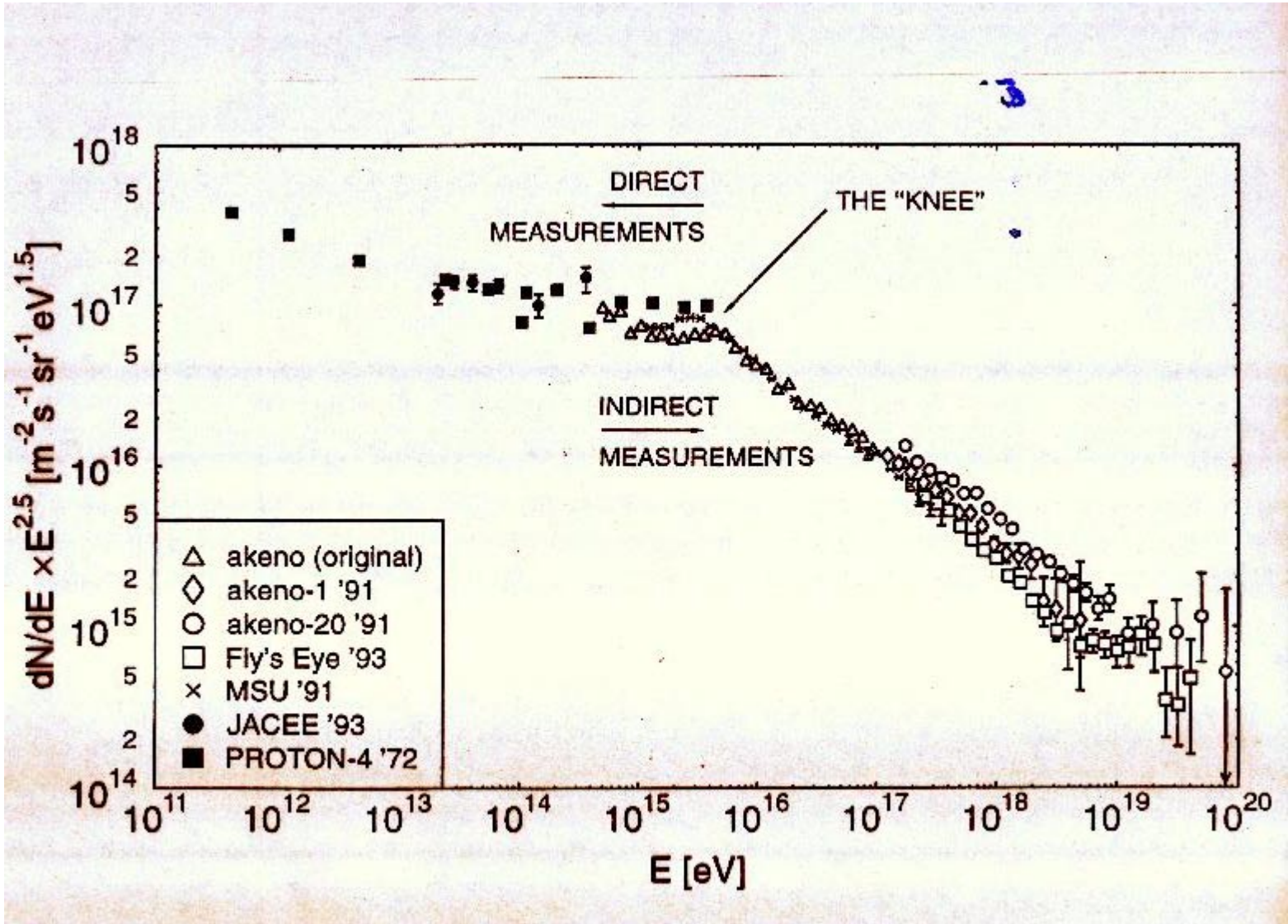
of primary cosmic rays

up to *100 TeV / particle

a clue to "knee"

↑ He ···· Fe

nuclear components


DIRECT
MEASUREMENTS
THE "KNEE"
INDIRECT
MEASUREMENTS
akeno (original)
akeno-1 '91
akeno-20 '91
Fly's Eye '93
MSU '91
JACEE '93
PROTON-4 '72
dN/dE ×E^2.5 [m^-2 s^-1 sr^-1 eV^1.5]
E [eV]

limit of acceleration ?

extra component ?

Direct Observation

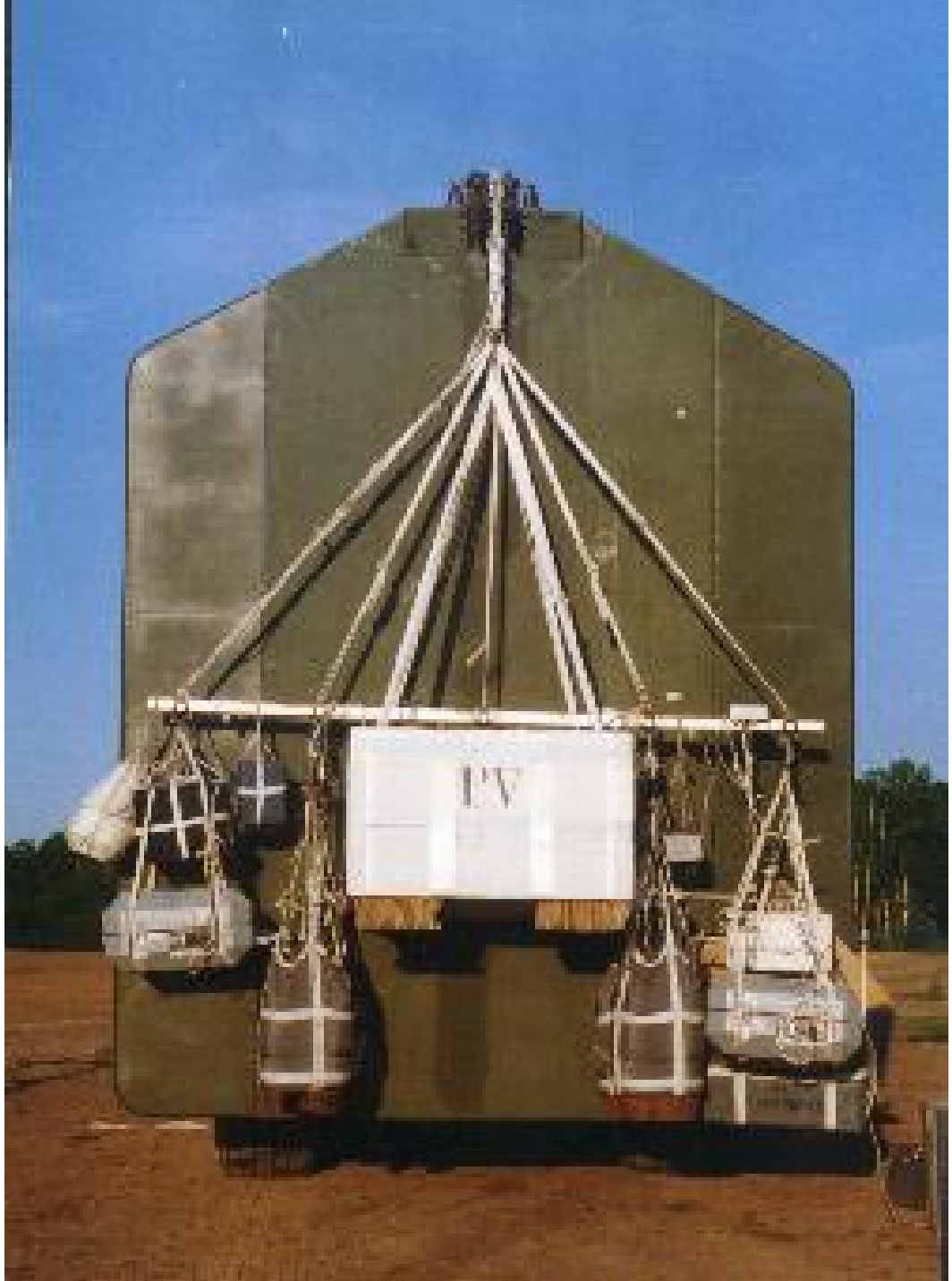
at the top of atmosphere

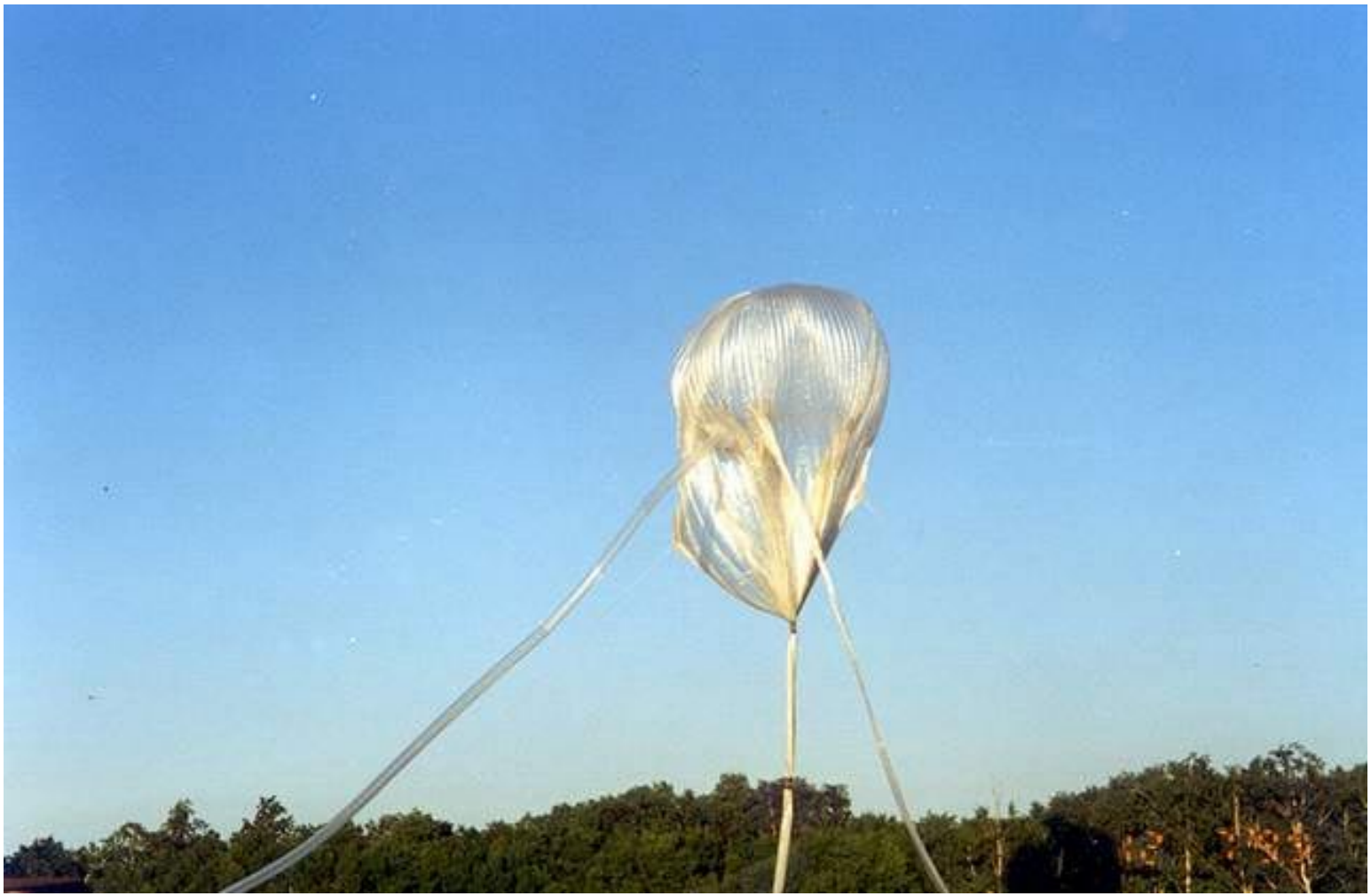
to top of the atmosphere

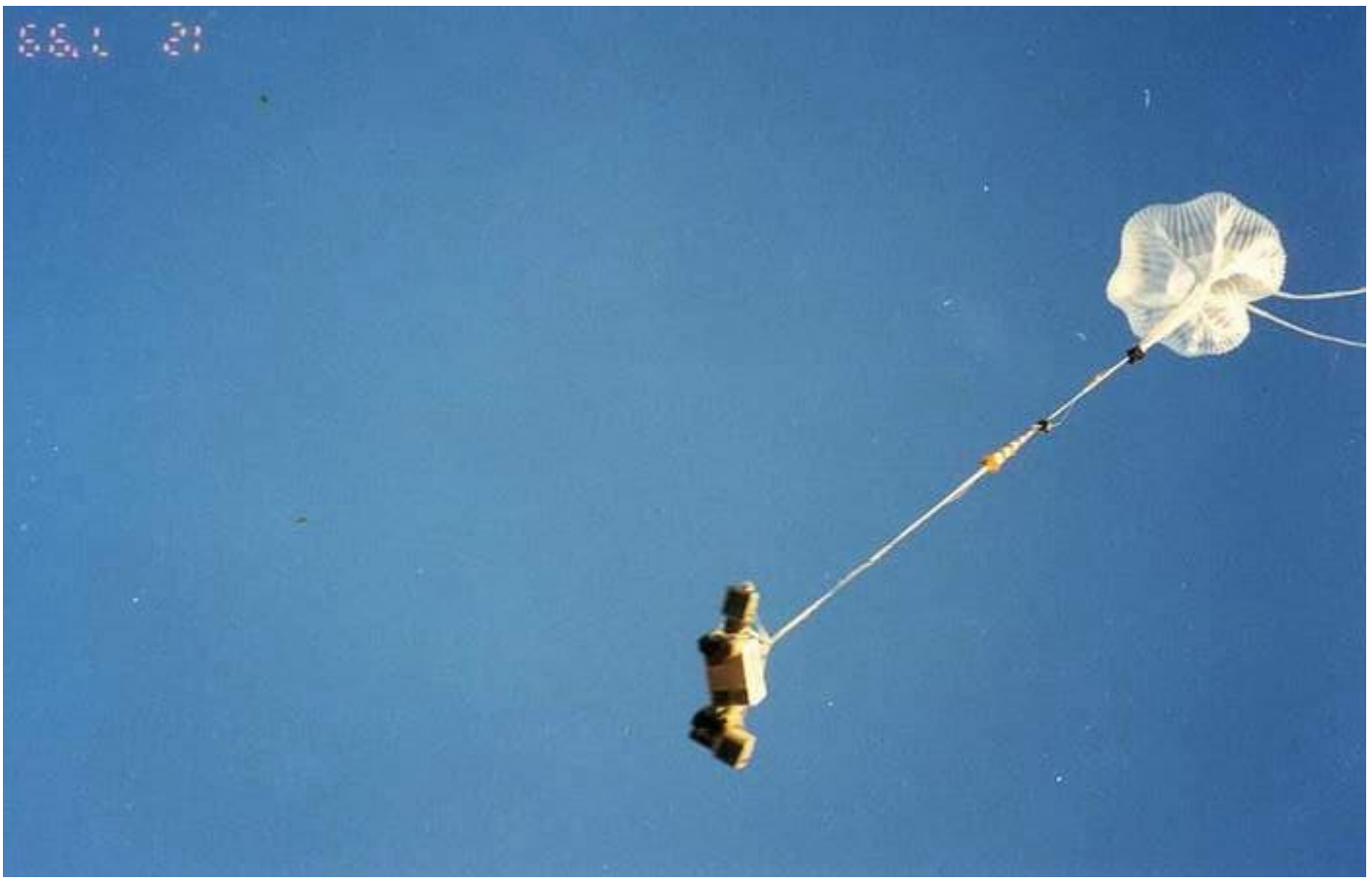
Balloon Envelope	180,000	m^3
	650	kg
Ballast	800	kg
Parachute	180	kg
Control evite	220	kg
	1 850	kg

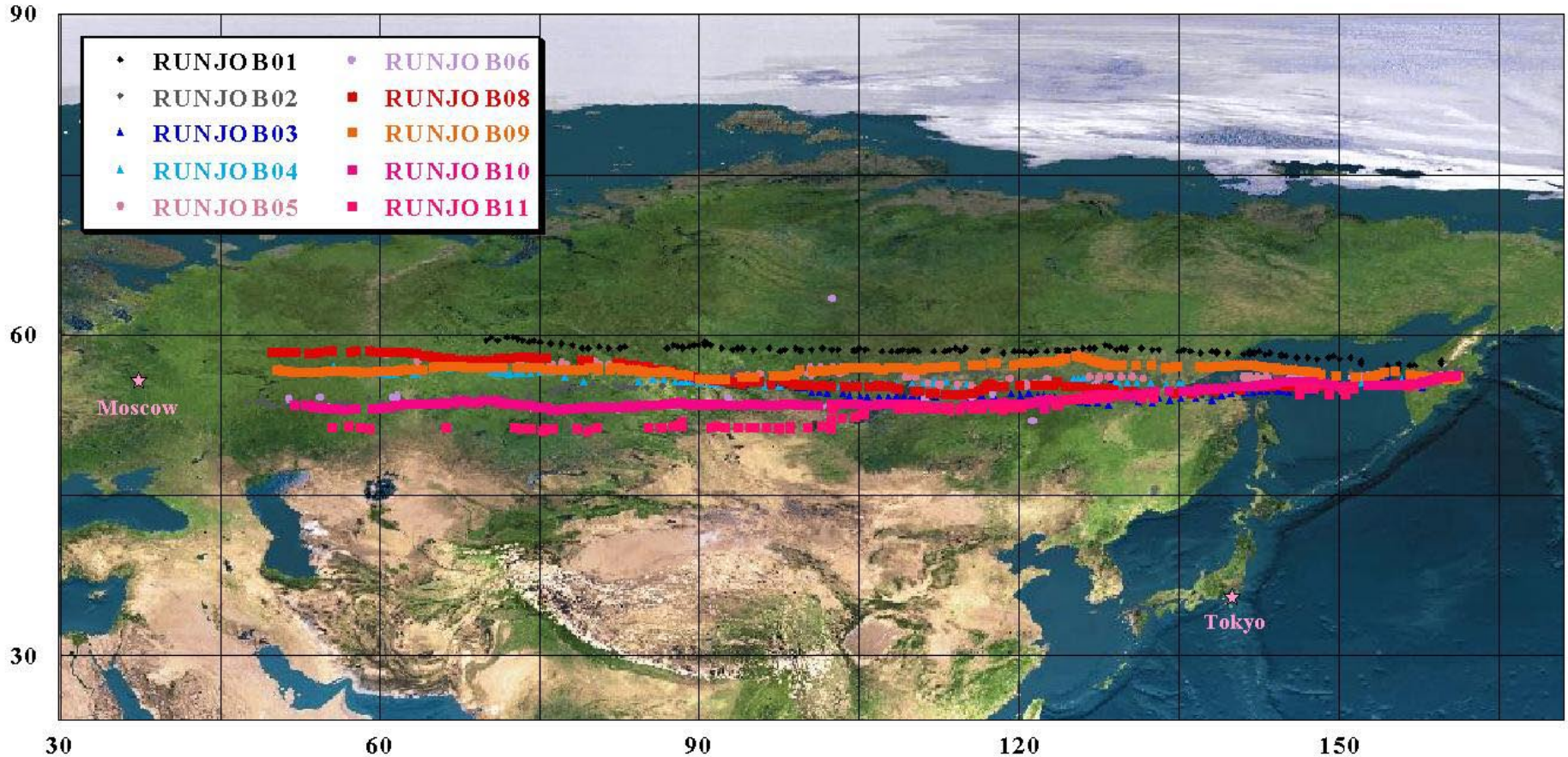
PI 230 ~ 270 kg

~ 2 tons


IV




66.L 21


RUNJOB01
RUNJOB02
RUNJOB03
RUNJOB04
RUNJOB05
RUNJOB06
RUNJOB08
RUNJOB09
RUNJOB10
RUNJOB11
Moscow
Tokyo
90
60
30
30
60
90
120
150

Summary of Flight

	1995		1996		1997		
Flight Number	1	2	3	4	5	6	7
Exposure time[hour]	130.0	167.0	134.0	147.5	139.5	139.5	FALSE
altitude[g/cm^2]	10.0	9.6	9.8	10.2	10.5	10.7	
Chamber area [m^2]	0.4	0.4	0.4	0.4	0.4	0.4	
Chamber weight [kg]	230.0	230.0	260.0	254.0	260.0	260.0	

	1999			
Flight Number	8	9	10	11
Exposure time[hour]	141.0	145.0	148.0	146.0
altitude[g/cm^2]	9.5	9.2	9.2	9.0
Chamber area [m^2]	0.4	0.4	0.4	0.4
Chamber weight [kg]	227.0	227.0	227.0	227.0

Total exposure factor = 575 [m^{2}hour] (259[m^{2}hour] analysed)

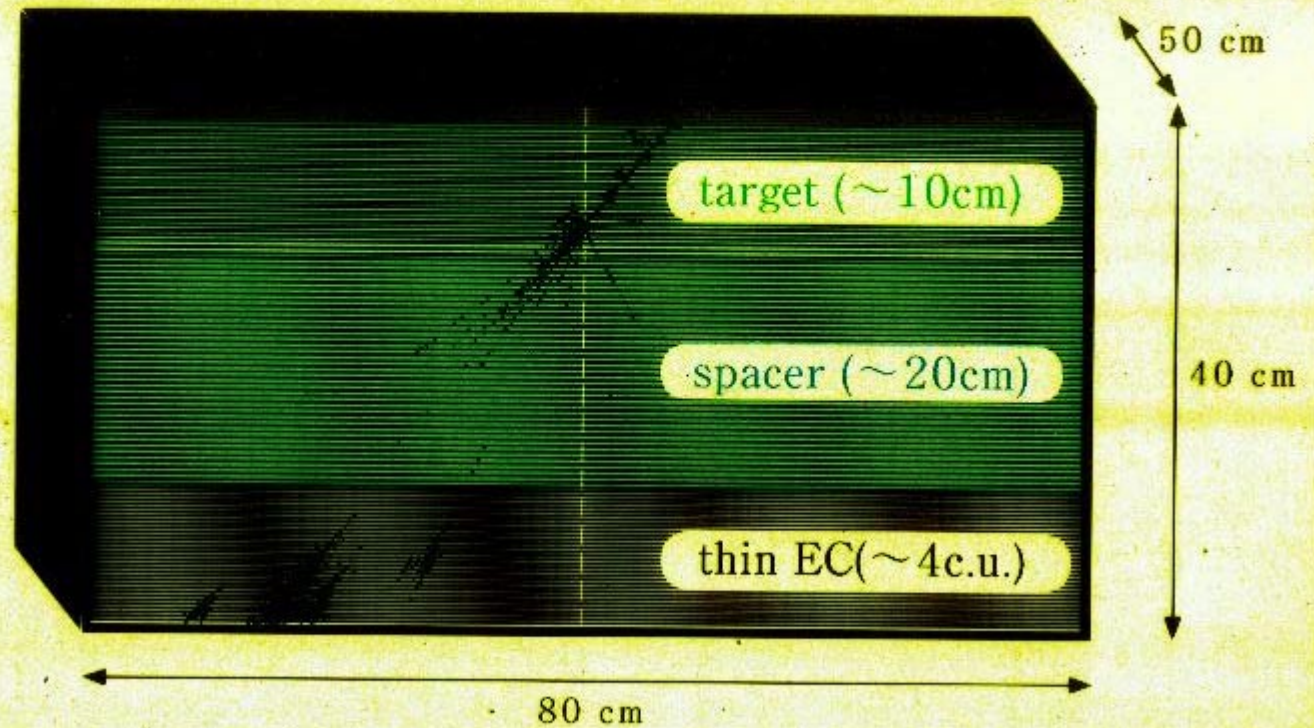
JACEE: 1436 [m^{2}hour] (644[m^{2}hour] analysed)

limited weight

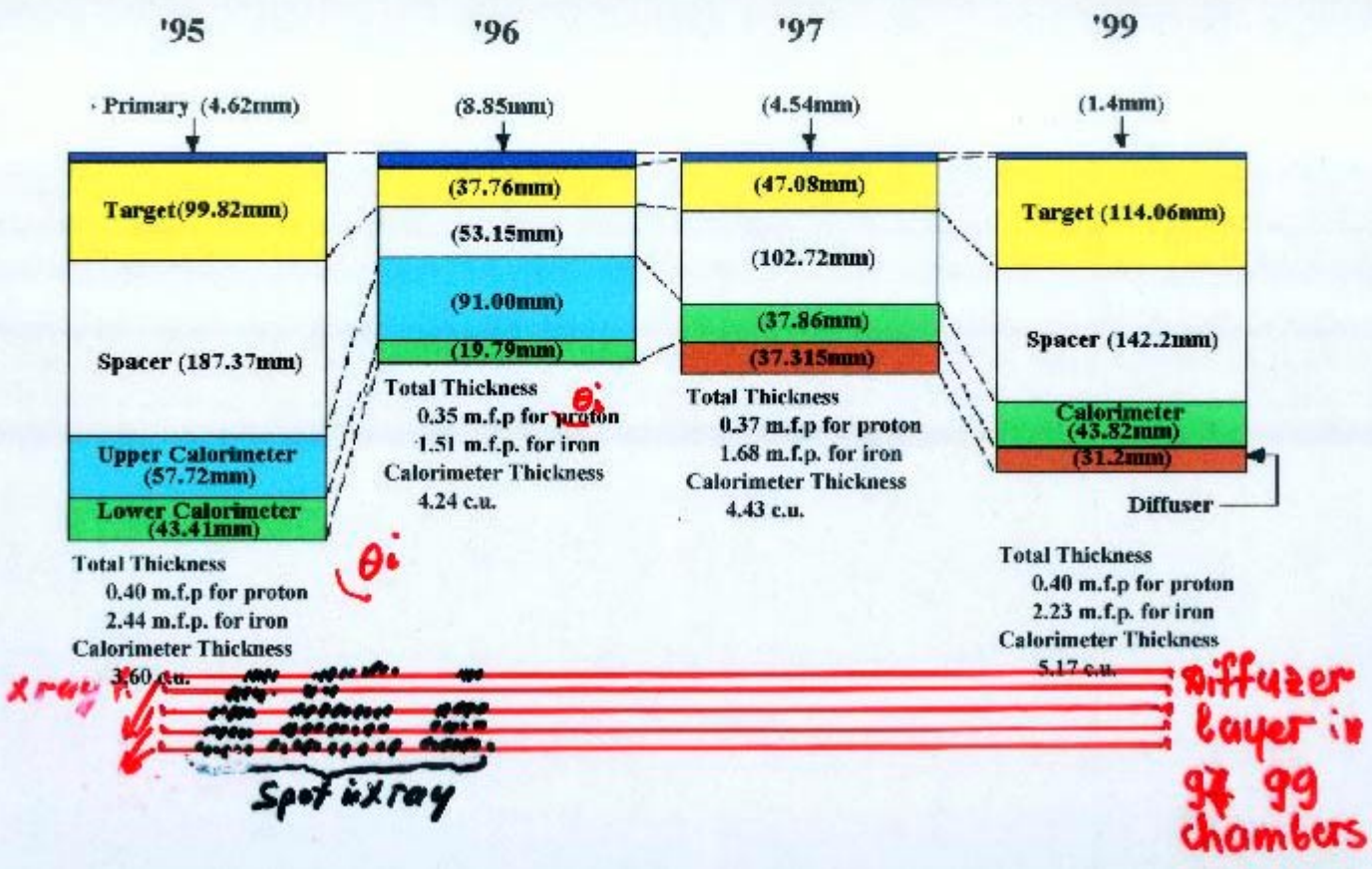
for detectors

thin emulsion chambers

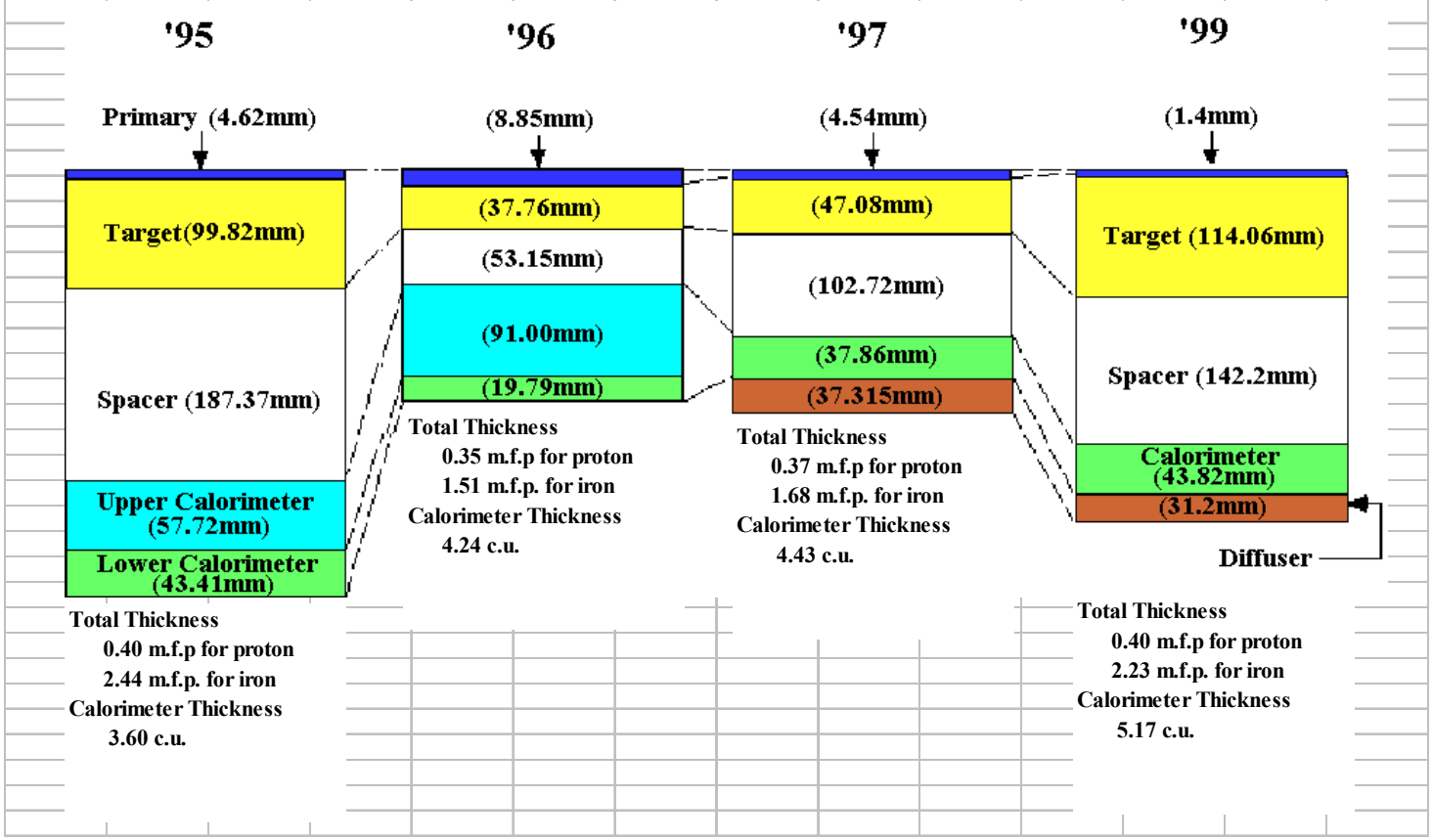
RUNJOB-chamber '95



History of Chamber Structure



History of Chamber Structure



Analysis Procedures

- Scanning X-ray films in calorimeter
- Scanning Nuclear Emulsion plates
- Tracing up to interaction points
- Measuring emission angles
- Identifying primary track

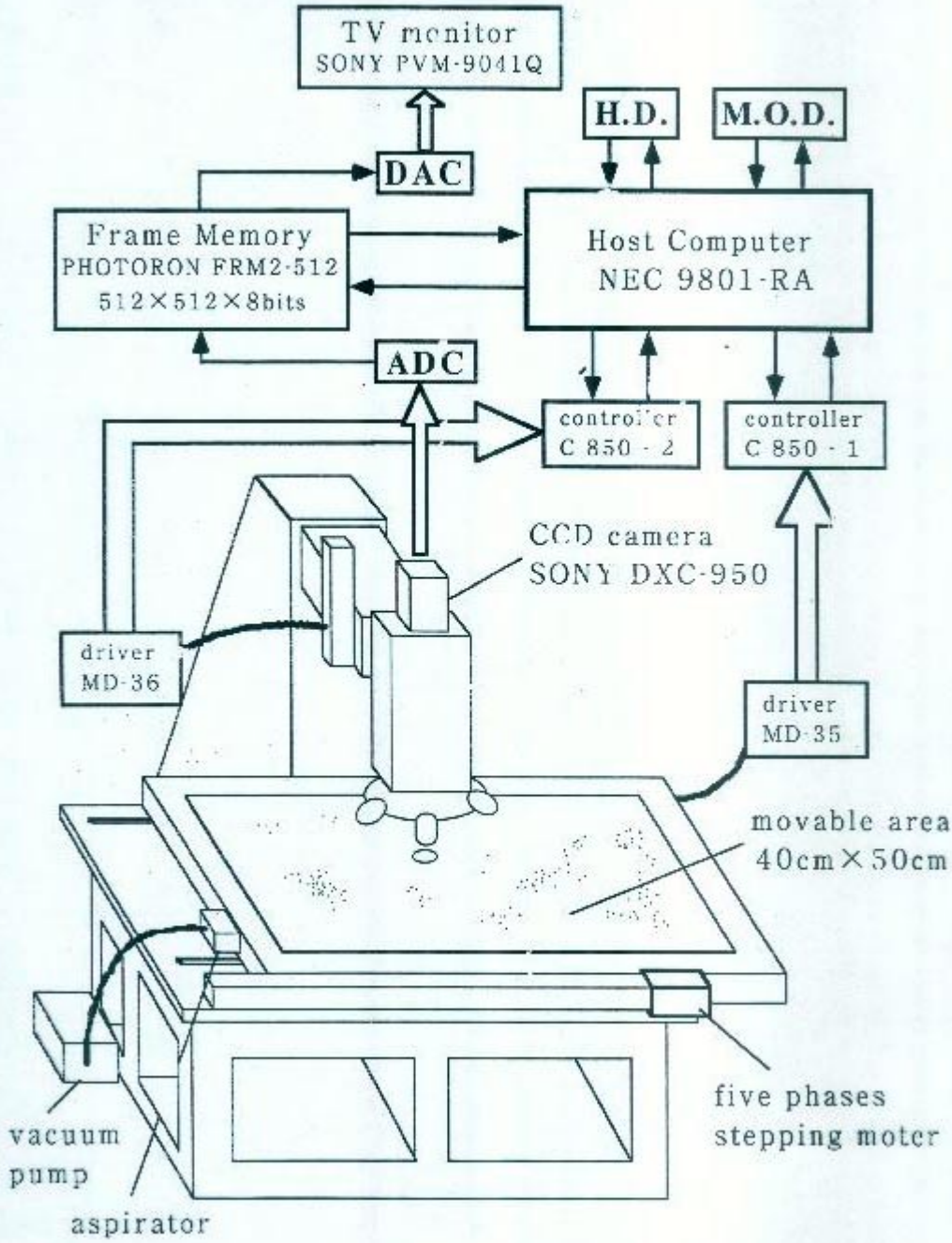

TV monitor
SONY PVM-9041Q
H.D.
M.O.D.
DAC
Frame Memory
PHOTORON FRM2-512
512×512×8bits
Host Computer
NEC 9801-RA
ADC
controller
C 850 - 2
controller
C 850 - 1
CCD camera
SONY DXC-950
driver
MD-36
driver
MD-35
movable area
40cm×50cm
five phases
stepping moter
vacuum
pump
aspirator

Fig. 4

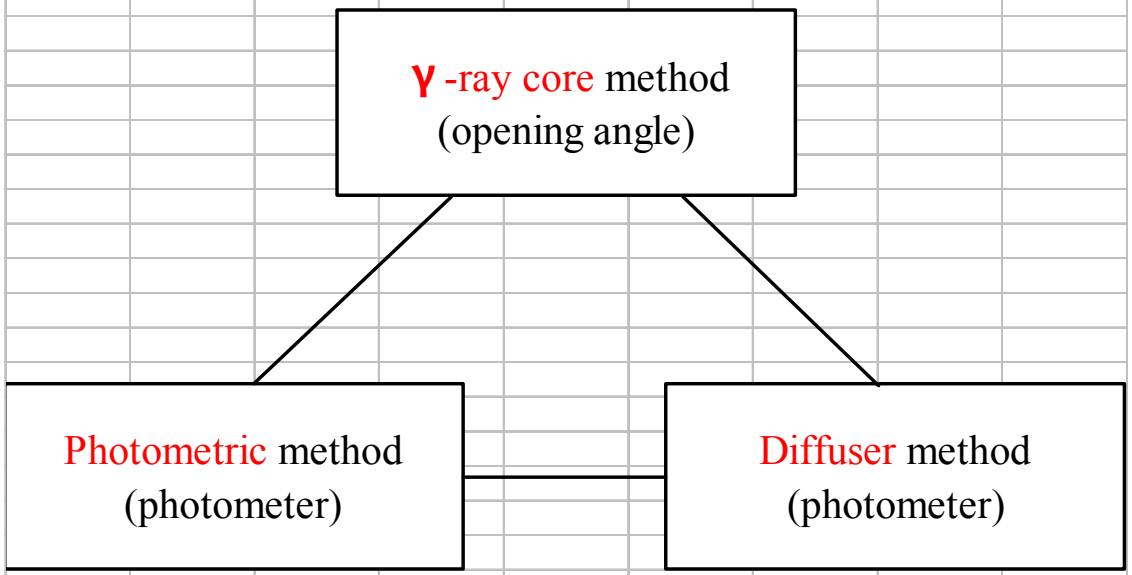
energy determination

charge determination

→ energy spectra

of nucleus components

Energy Determination of RUNJOB



- **γ -ray core method :**
  applied to events of
  target-jet without shower maximum
- **photometric method :**
  applied to events of
  detected shower maximum
- **Diffuser method :**
  applied to events of
  not detected shower maximum
  (since 1997 chamber)

γ-ray core method

$$E = \sum p_i$$

$$\simeq \sum \frac{\langle p_T \rangle}{\theta_i}$$

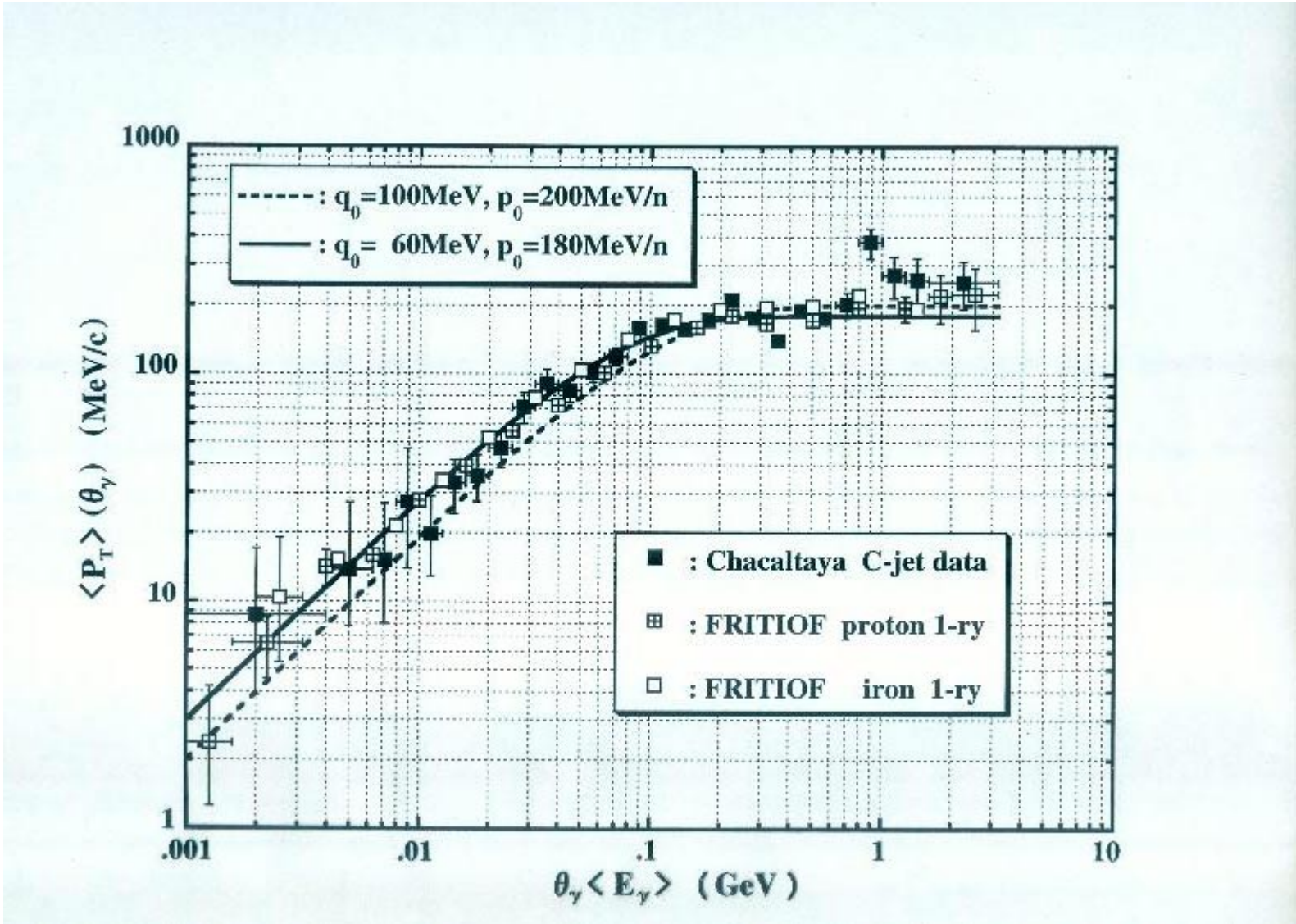
But $\langle p_T \rangle$ is <u>not</u> constant.

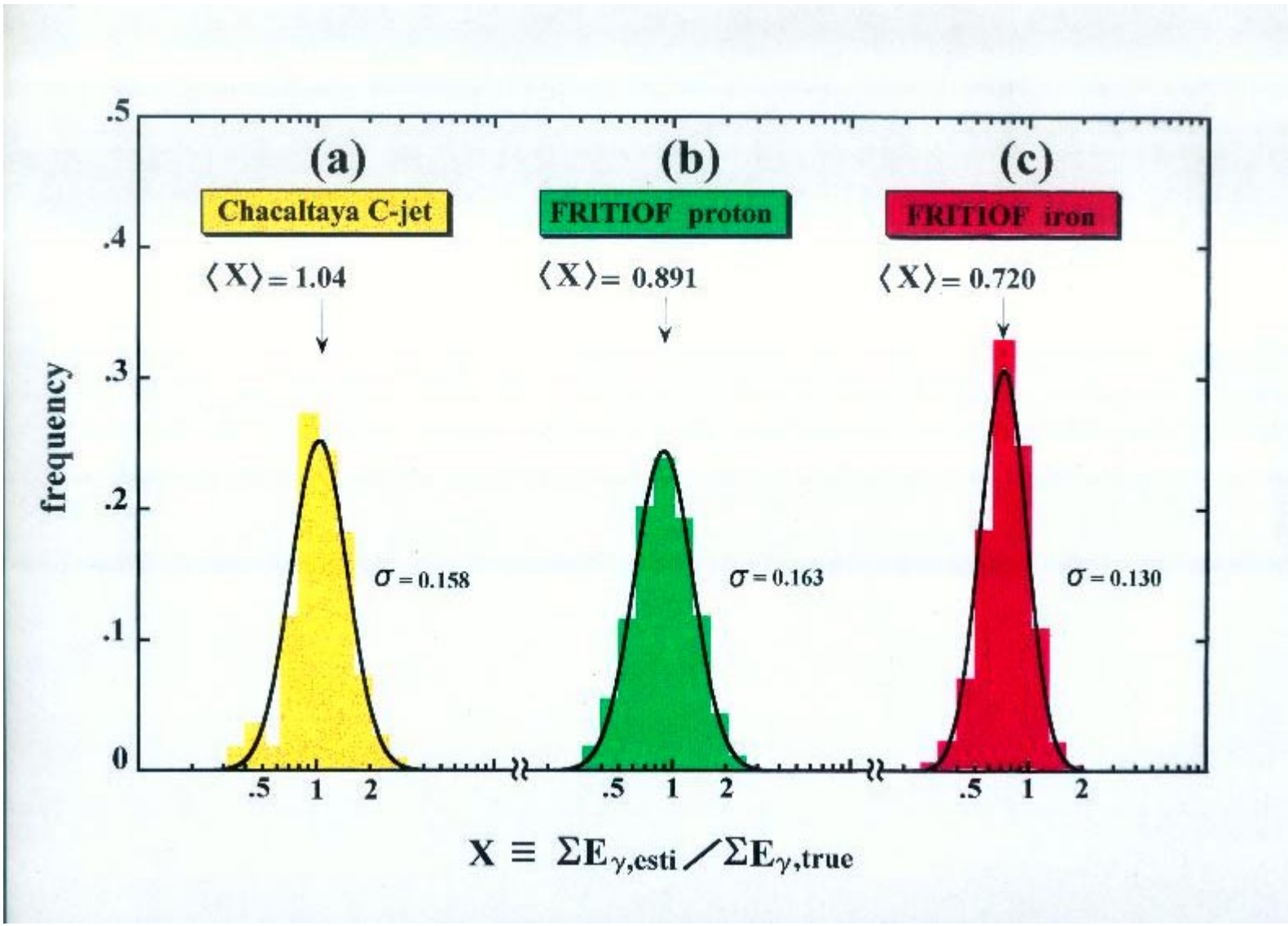
in forward region

$$\sum E_\gamma \simeq \sum_{i=1}^{n} \frac{\langle p_T \rangle(\theta_i)}{\theta_i}$$

$$\langle p_T \rangle(\theta) = p_0 \left[1 - e^{-\frac{\theta \sum E_\gamma}{8.n}} \right]$$

solve for $\sum E_\gamma$

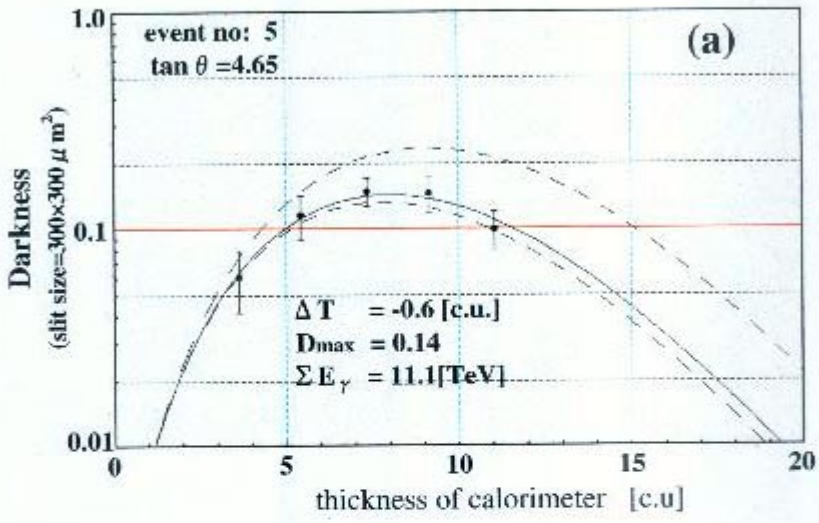

1000
100
10
1
.001
.01
.1
1
10
$\langle P_T \rangle (\theta_\gamma)$ (MeV/c)
$\theta_\gamma \langle E_\gamma \rangle$ (GeV)
------ : q_0=100MeV, p_0=200MeV/n
——— : q_0= 60MeV, p_0=180MeV/n
■ : Chacaltaya C-jet data
⊞ : FRITIOF proton 1-ry
□ : FRITIOF iron 1-ry

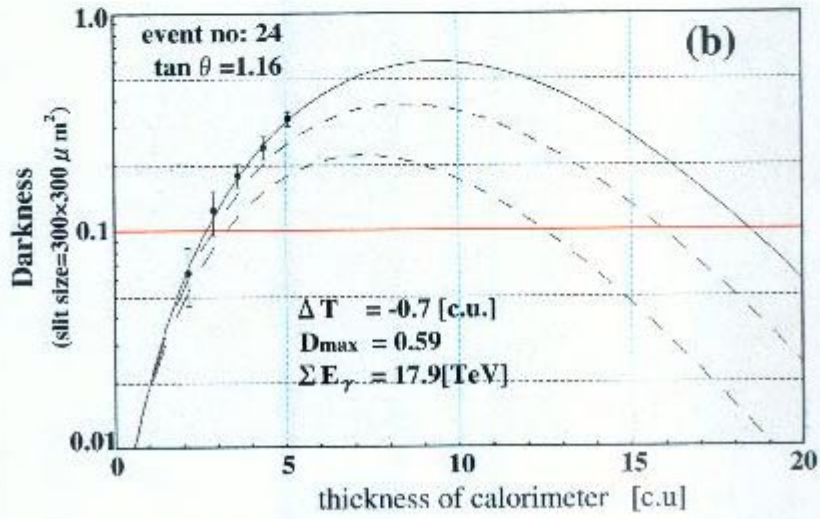

(a)
Chacaltaya C-jet
⟨X⟩ = 1.04
σ = 0.158
(b)
FRITIOF proton
⟨X⟩ = 0.891
σ = 0.163
(c)
FRITIOF iron
⟨X⟩ = 0.720
σ = 0.130
frequency
.5
.4
.3
.2
.1
0
.5 1 2
.5 1 2
.5 1 2
X ≡ ΣE γ,esti / ΣE γ,true

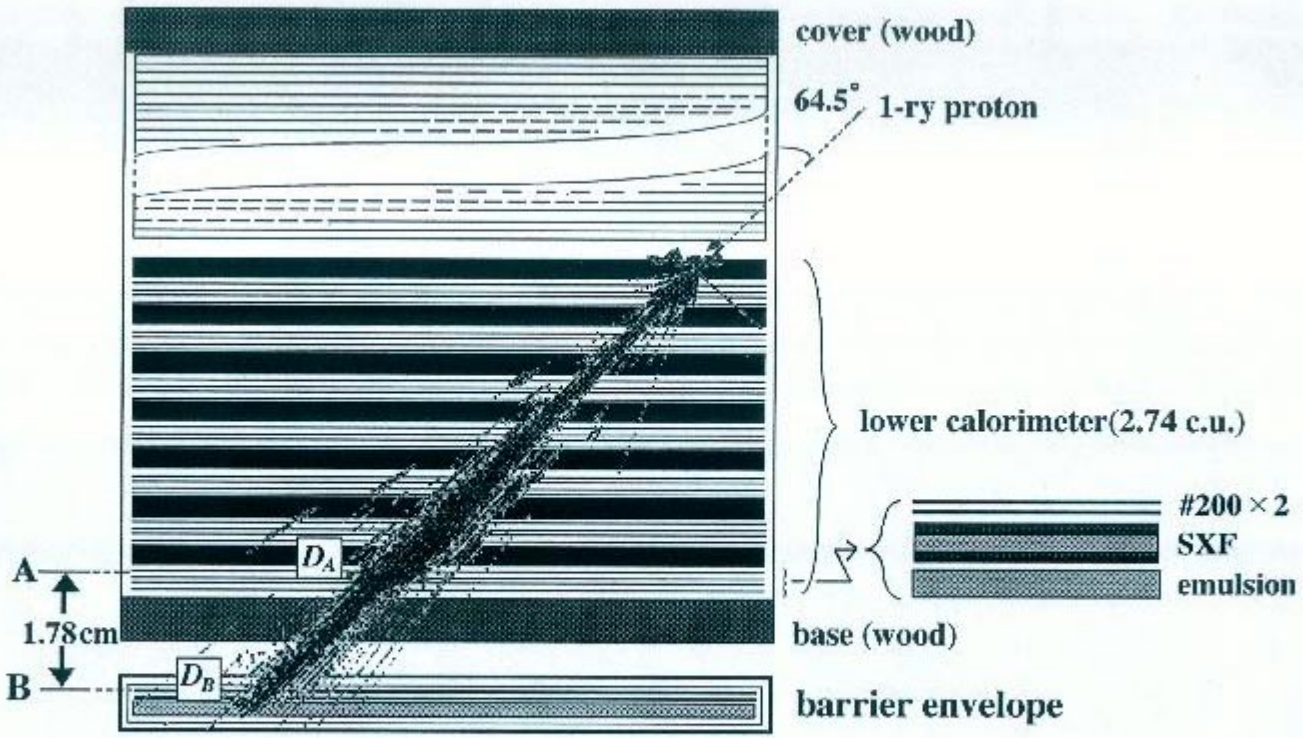
photometric method

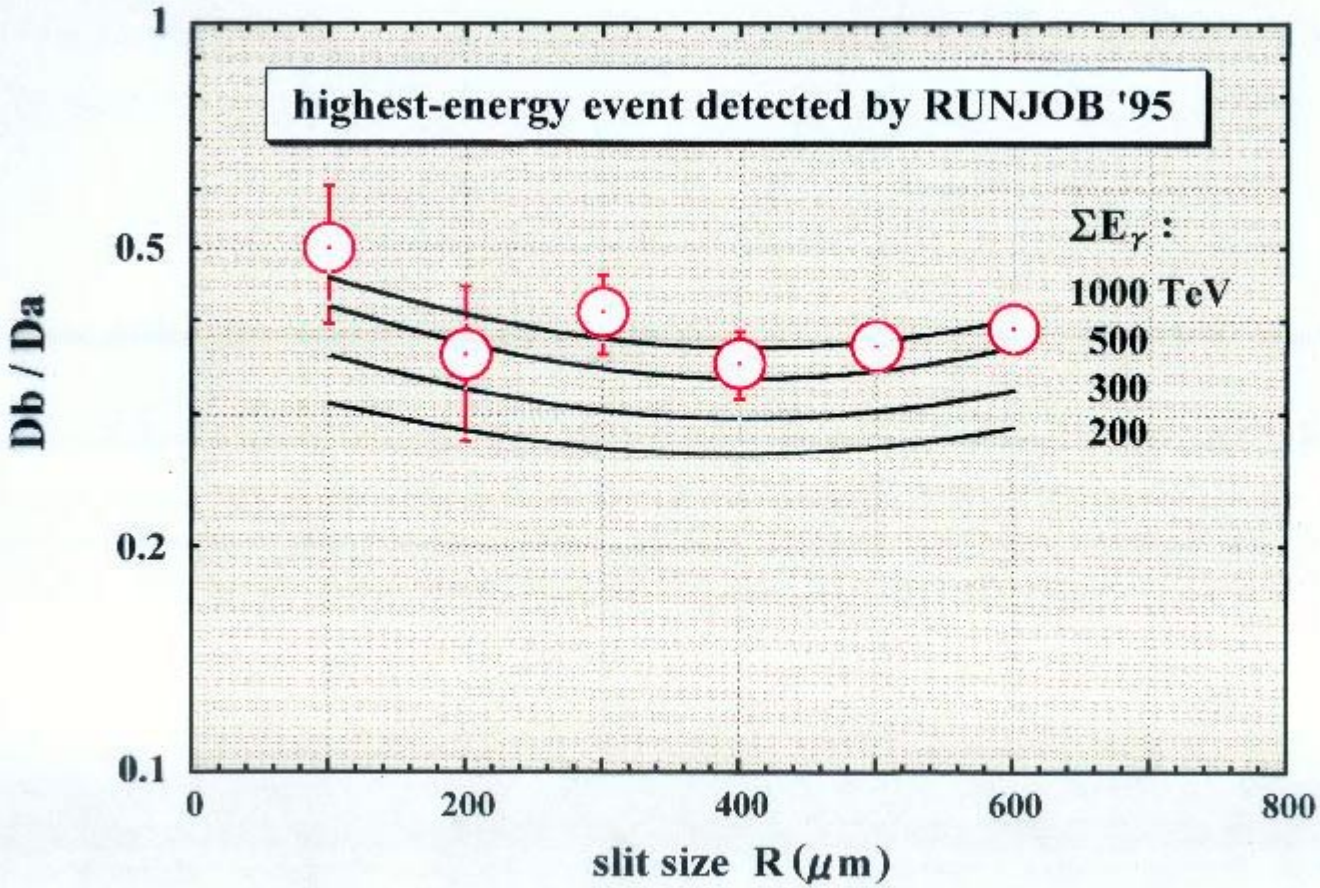
- photo meter
- scanner

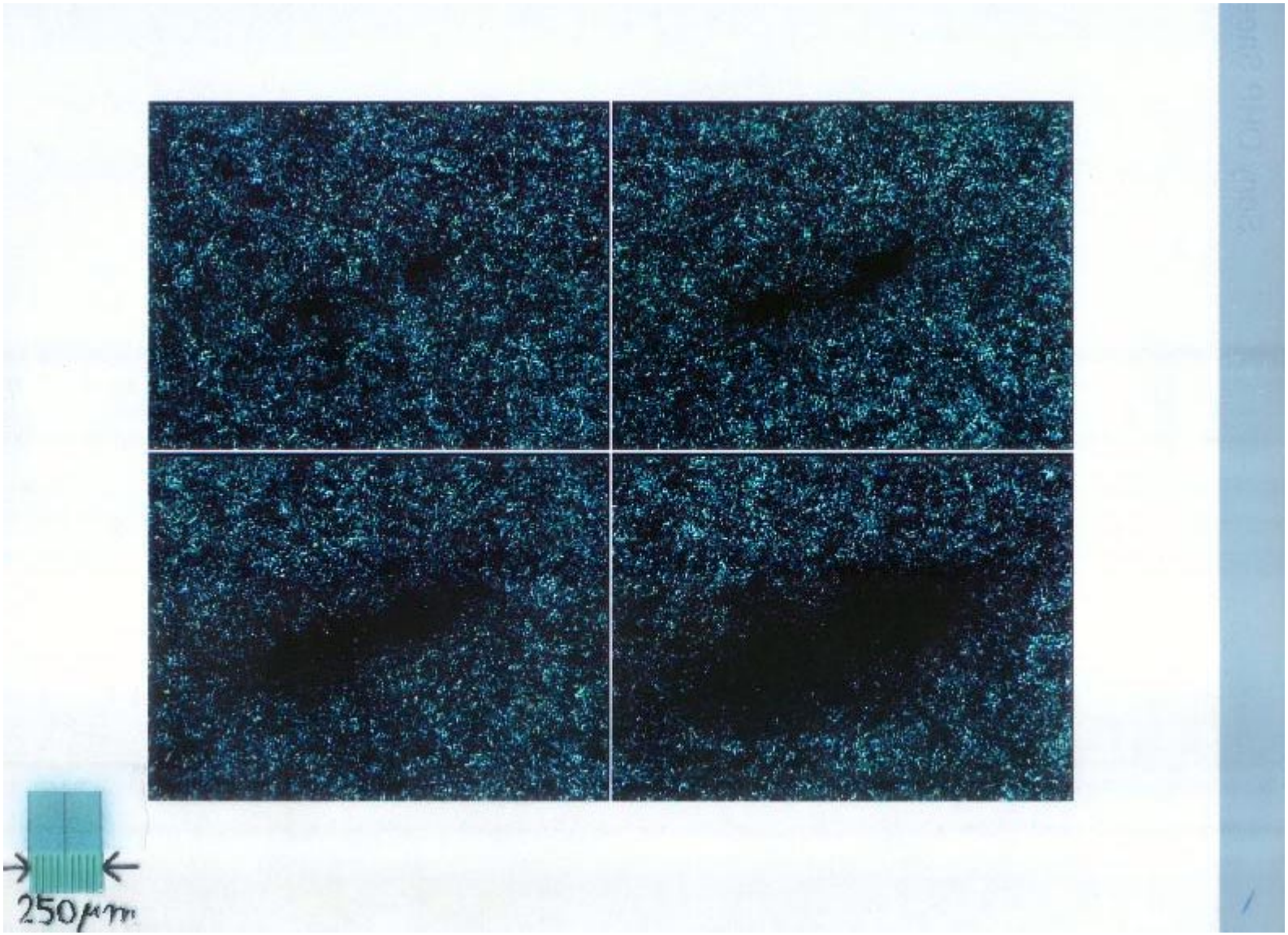
Transition curve fitting for energy determination

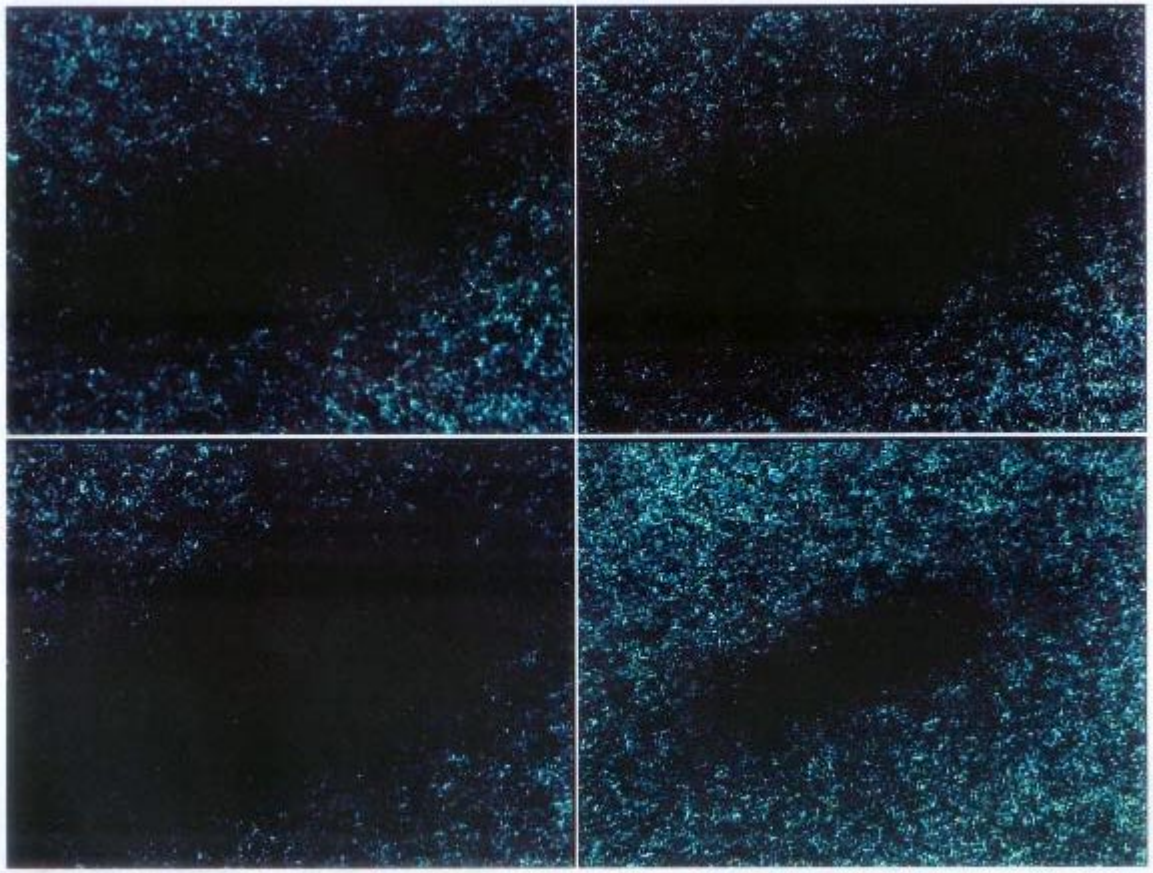


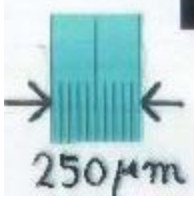


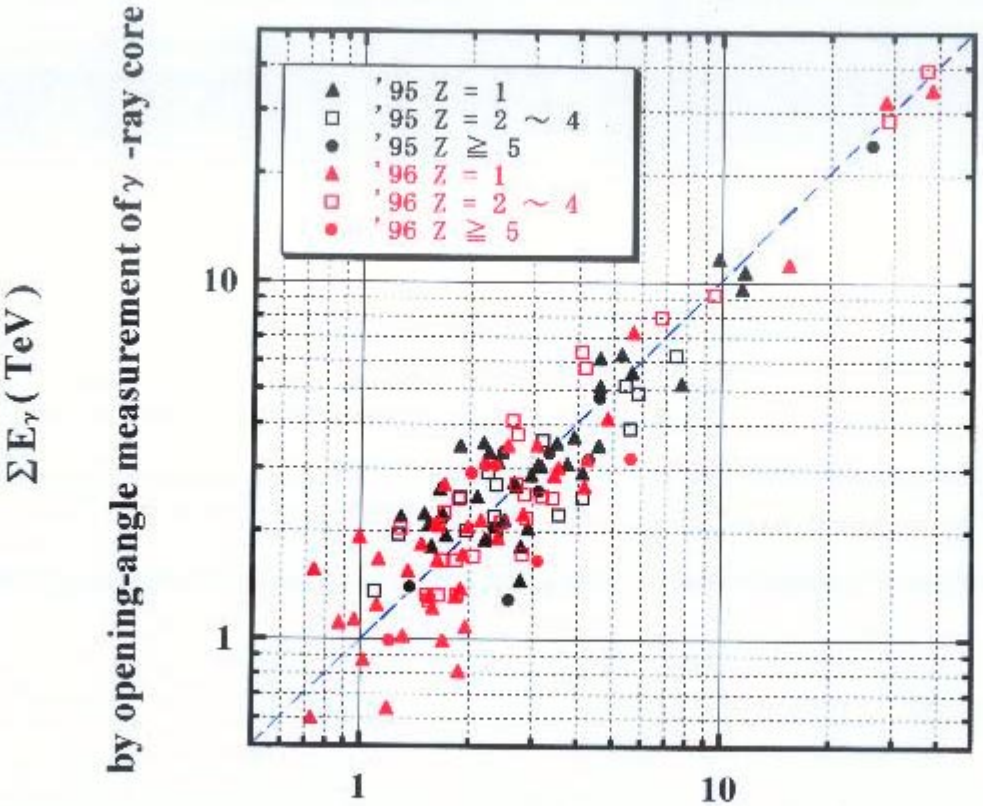

cover (wood)
64.5°
1-ry proton
lower calorimeter(2.74 c.u.)
#200 × 2
SXF
emulsion
A
1.78cm
B
D_A
D_B
base (wood)
barrier envelope


highest-energy event detected by RUNJOB '95
ΣE$_\gamma$:
1000 TeV
500
300
200
Db / Da
1
0.5
0.2
0.1
0
200
400
600
800
slit size R (μm)


250μm



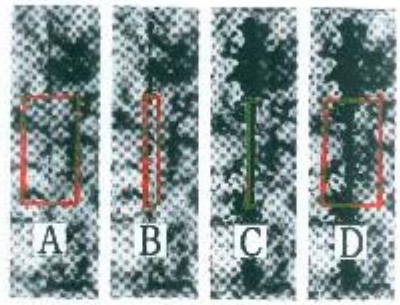

250μm



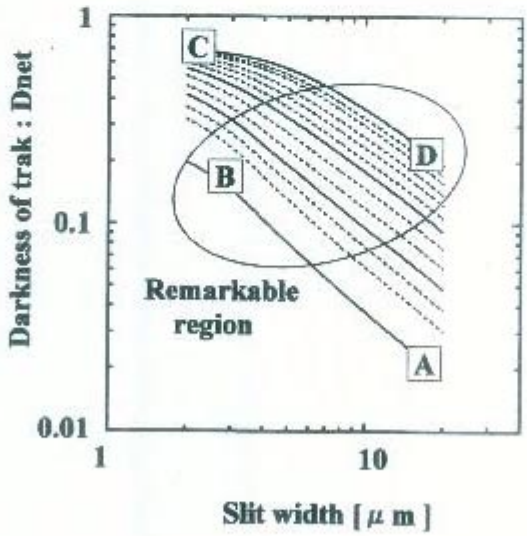
ΣE_γ (TeV)
by opening-angle measurement of γ -ray core

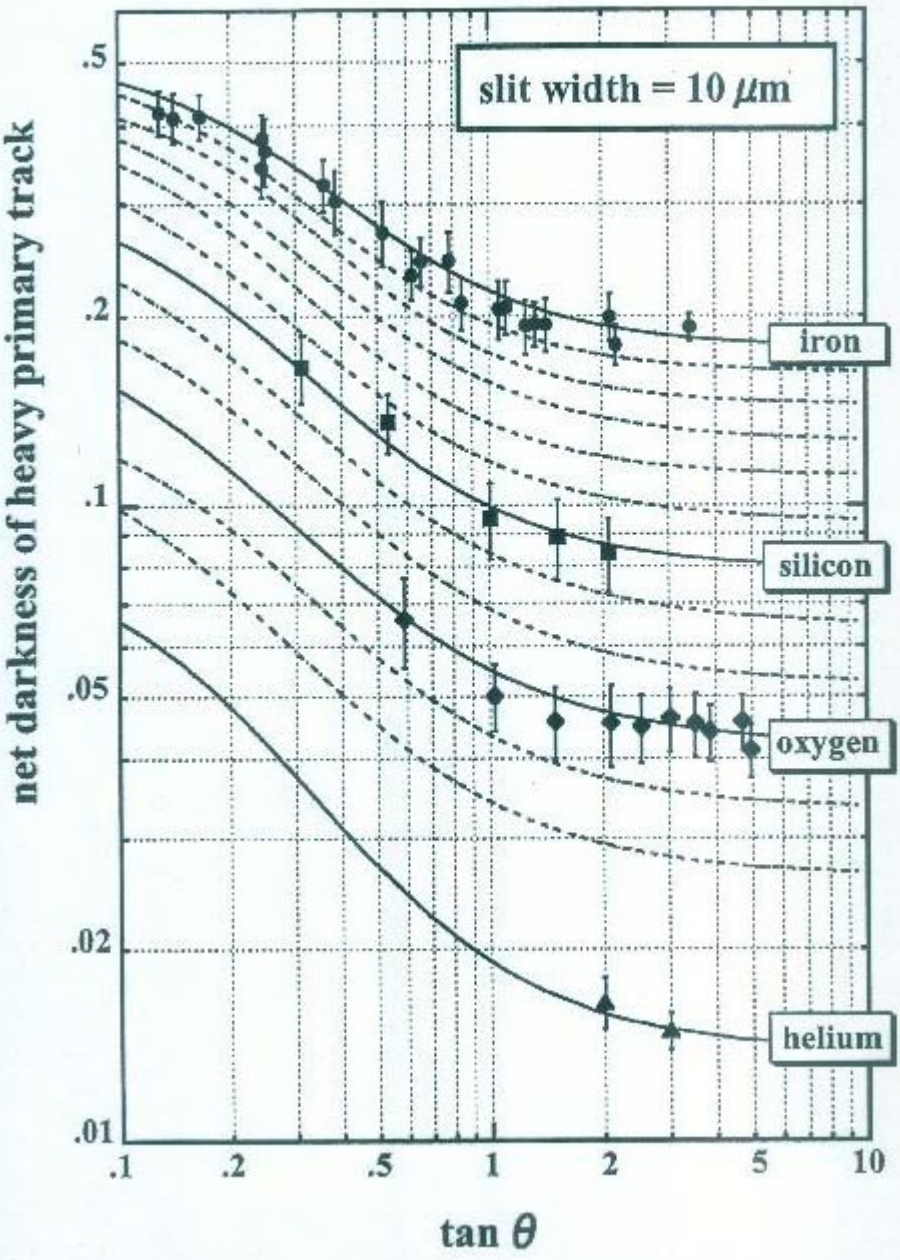
ΣE_γ (TeV)
by photometric measurement of spot-darkness

Charge Measurement



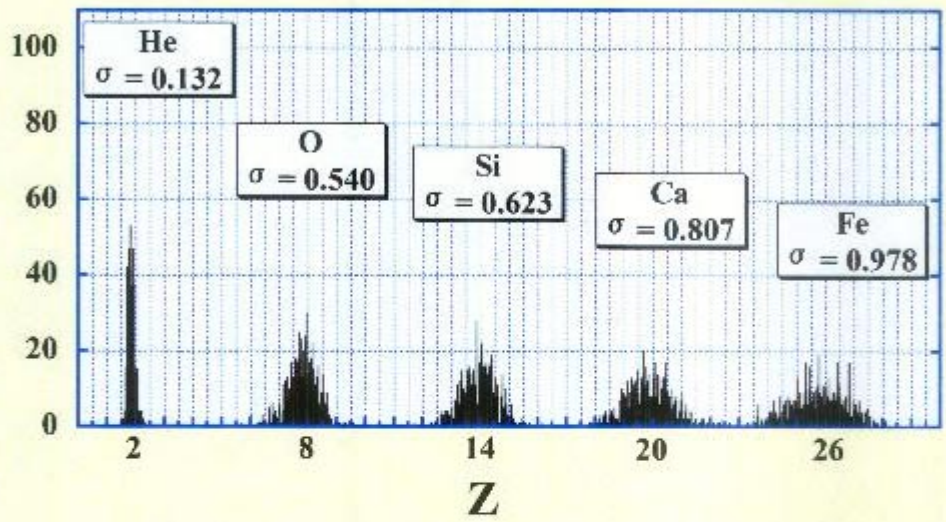
He Fe



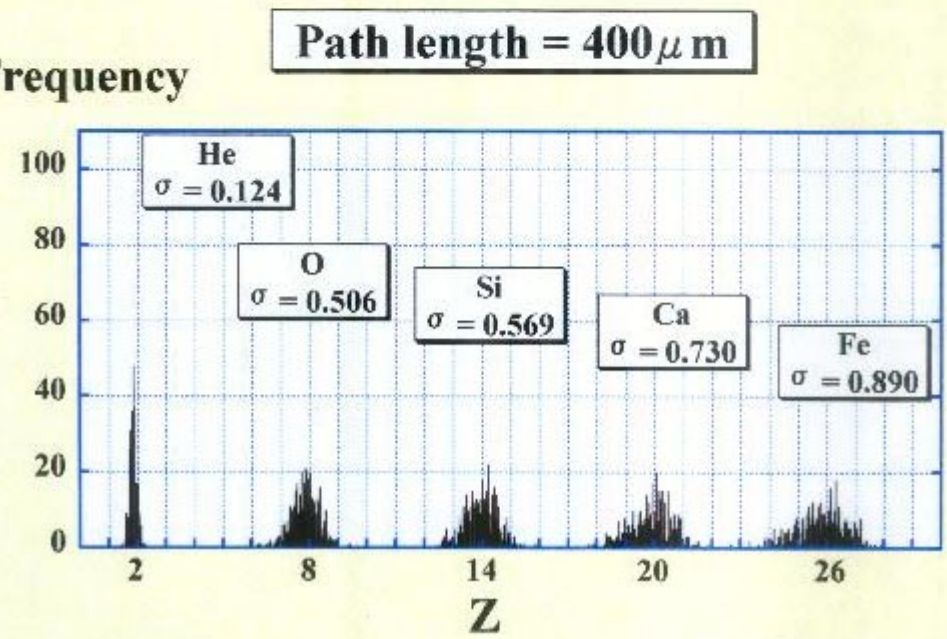

slit width = 10 μm
iron
silicon
oxygen
helium
net darkness of heavy primary track
.5
.2
.1
.05
.02
.01
.1
.2
.5
1
2
5
10
tan θ

Charge Resolution

Path length = 300 μm

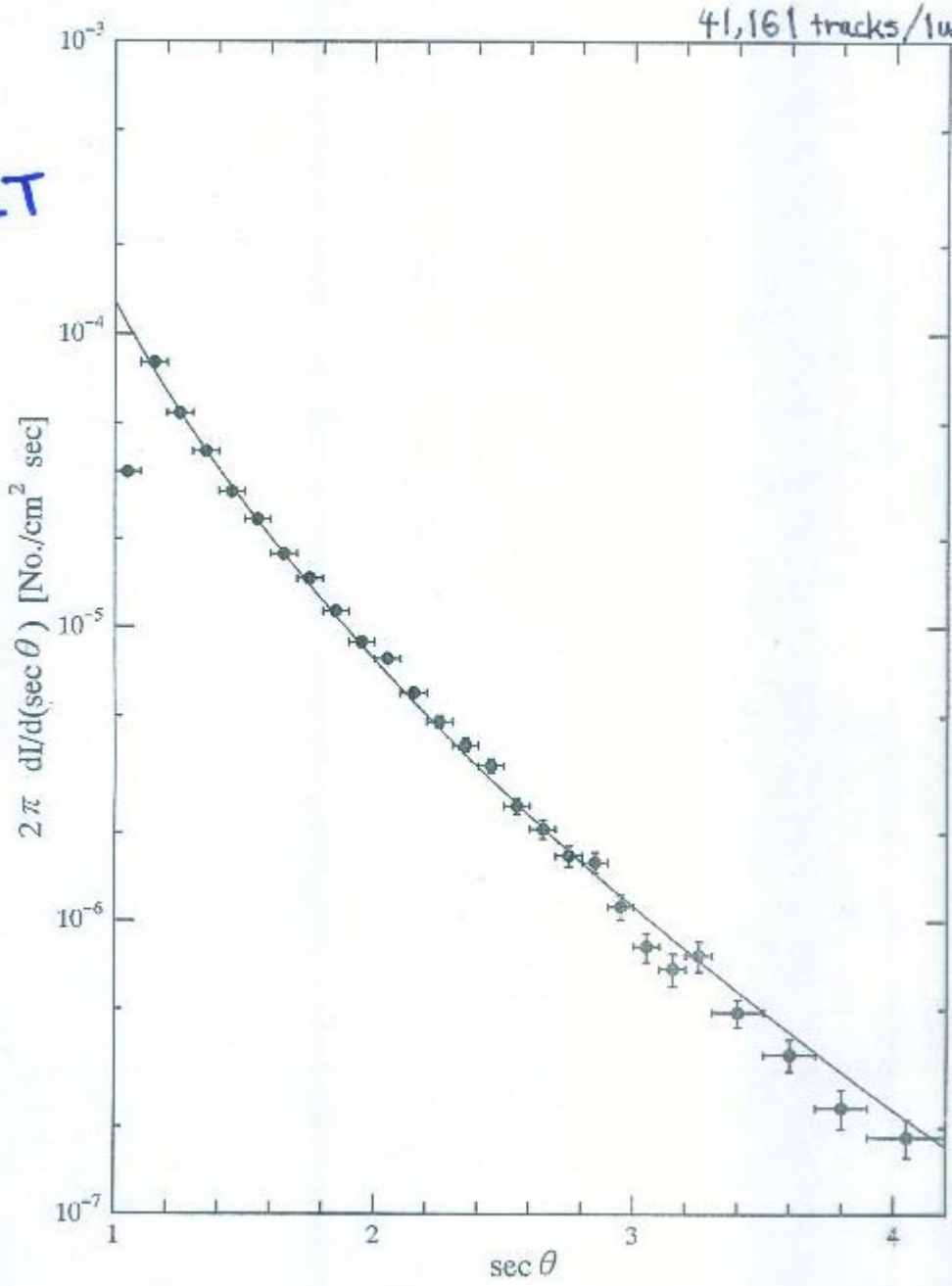


Path length = 400 μm



Zenith Angle Distribution for Fe primary

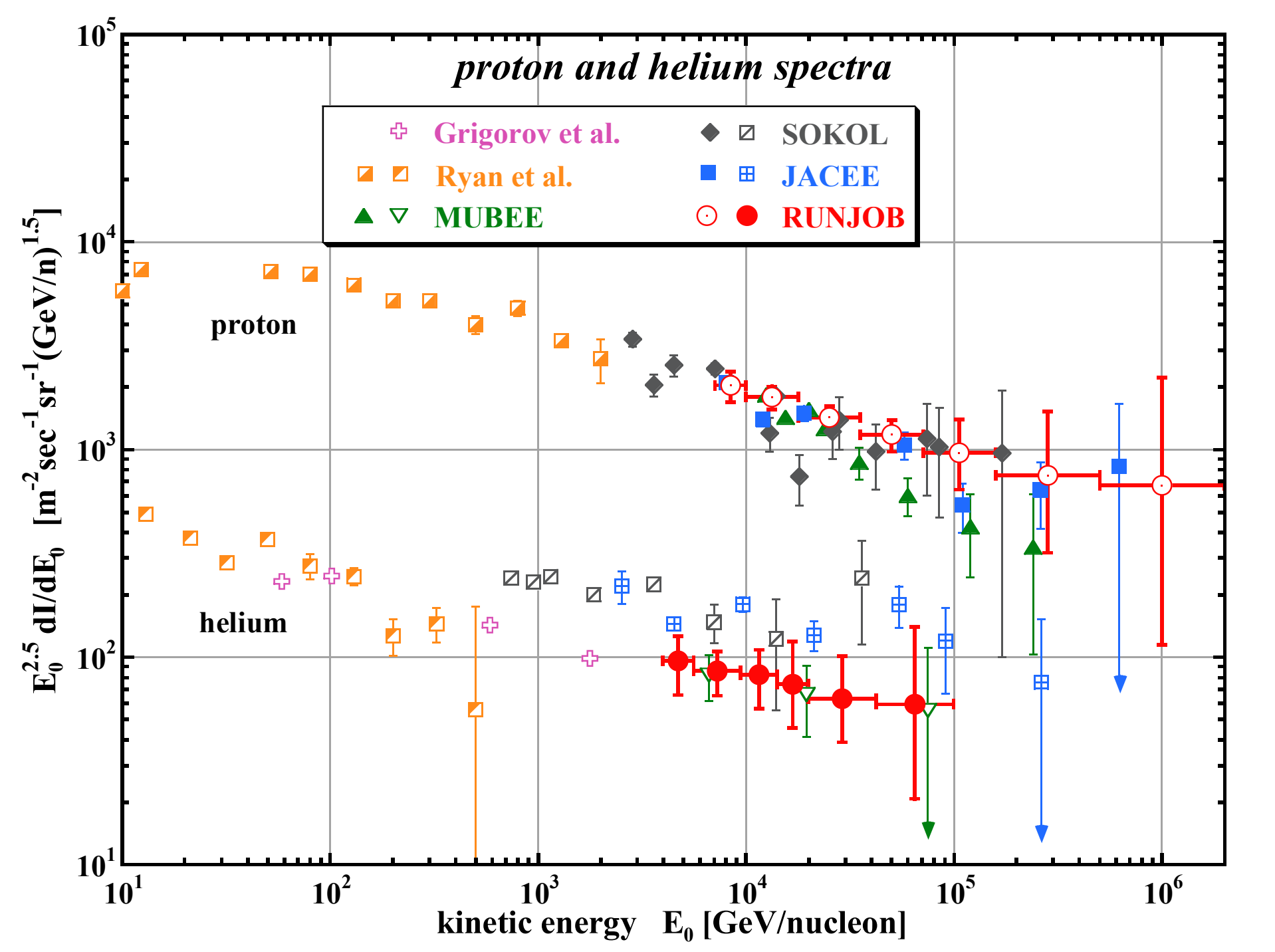
41,161 tracks/1unit

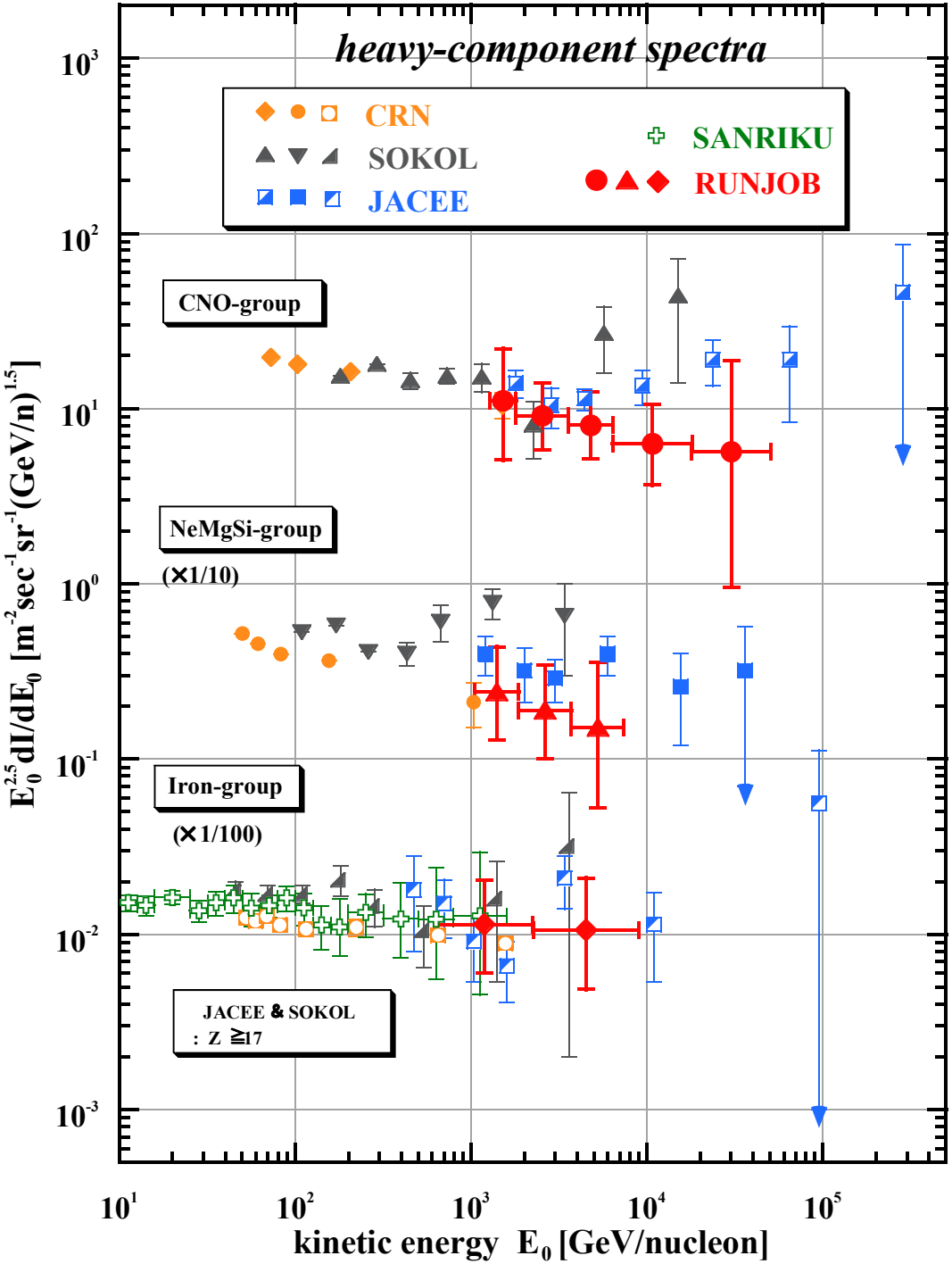


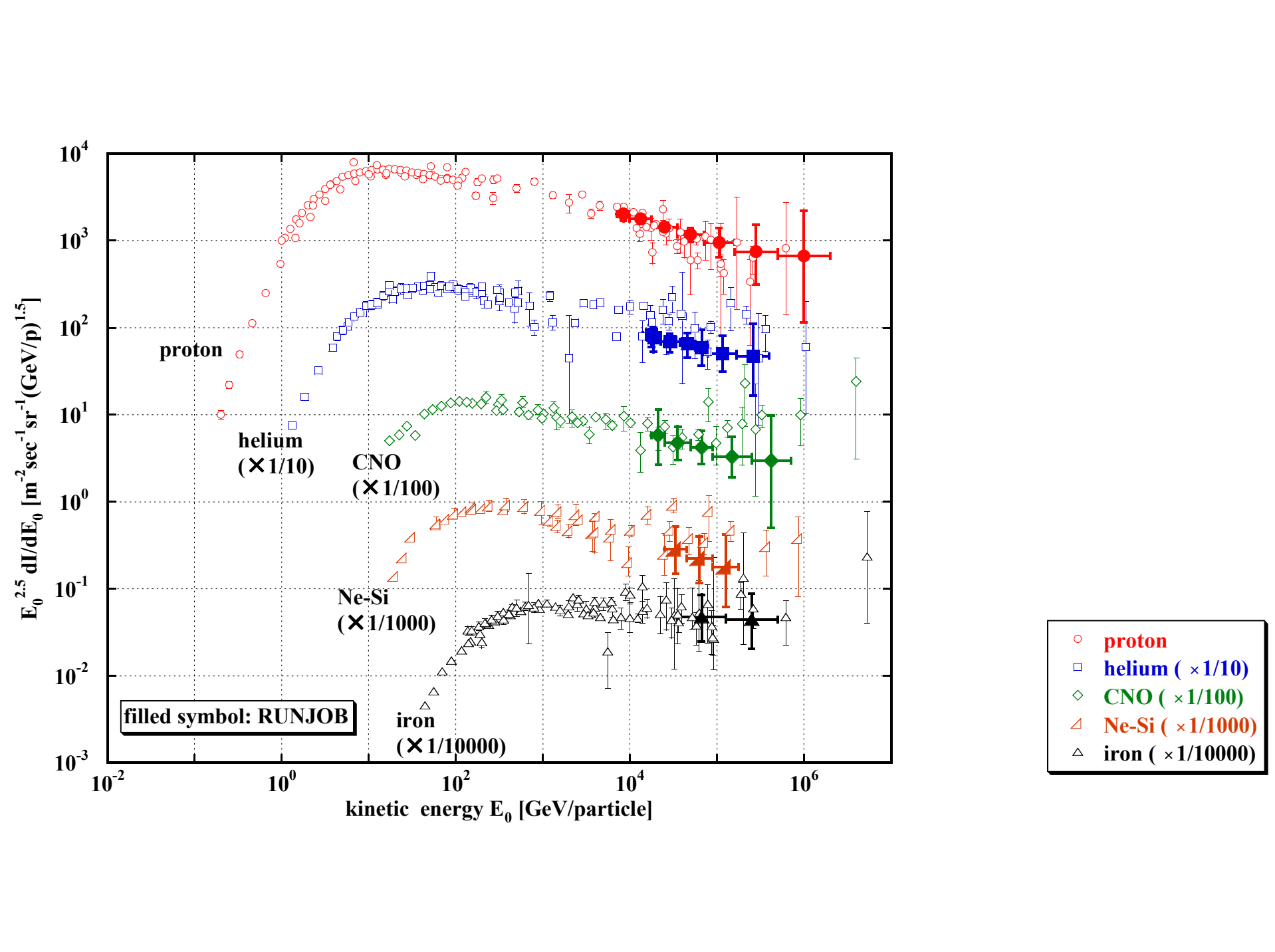
SΩT

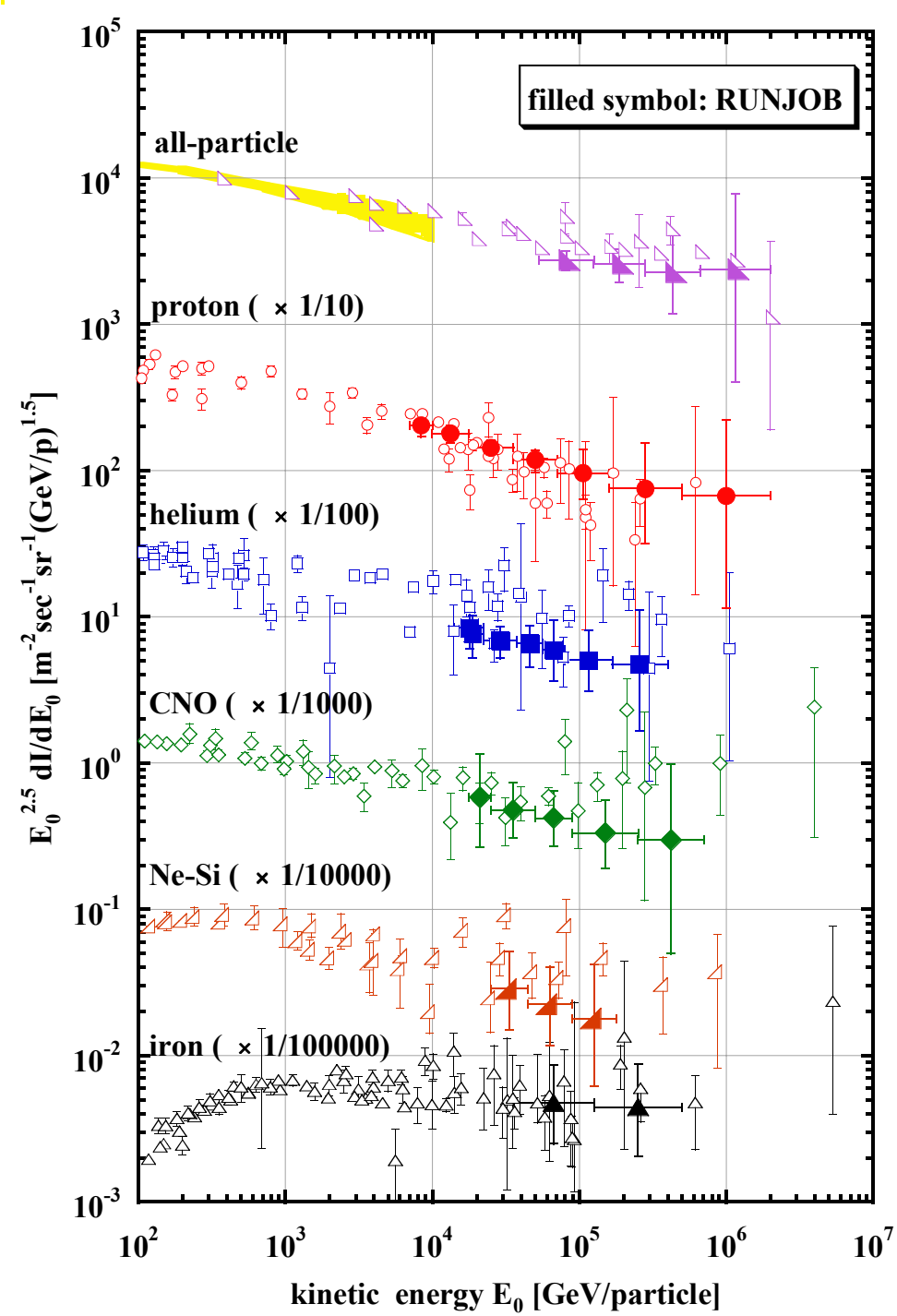
60°

90°

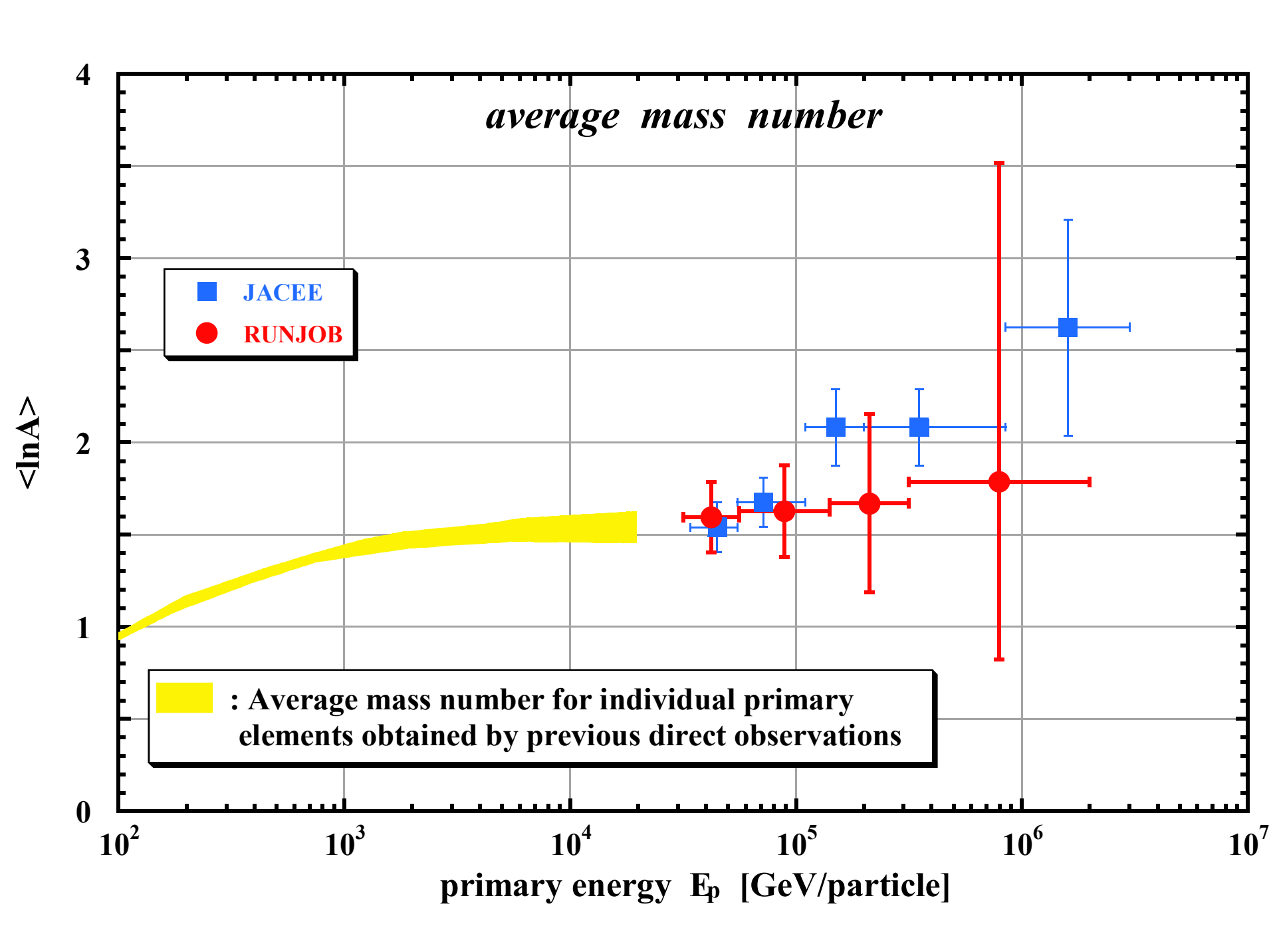

proton and helium spectra
Grigorov et al.
Ryan et al.
MUBEE
SOKOL
JACEE
RUNJOB
proton
helium
$E_0^{2.5}\, dI/dE_0$ [$m^{-2} sec^{-1} sr^{-1} (GeV/n)^{1.5}$]
kinetic energy E_0 [GeV/nucleon]
10^1
10^2
10^3
10^4
10^5
10^6


heavy-component spectra
CRN
SOKOL
JACEE
SANRIKU
RUNJOB
CNO-group
NeMgSi-group
(×1/10)
Iron-group
(×1/100)
JACEE & SOKOL
: Z ≧17
$E_0^{2.5} dI/dE_0$ [$m^{-2}sec^{-1}sr^{-1}(GeV/n)^{1.5}$]
kinetic energy E_0 [GeV/nucleon]
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^1
10^2
10^3
10^4
10^5


$E_0^{2.5}$ dI/dE$_0$ [m^{-2}sec^{-1}sr^{-1}(GeV/p)$^{1.5}$]
kinetic energy E$_0$ [GeV/particle]
proton
helium
(×1/10)
CNO
(×1/100)
Ne-Si
(×1/1000)
iron
(×1/10000)
filled symbol: RUNJOB
proton
helium (×1/10)
CNO (×1/100)
Ne-Si (×1/1000)
iron (×1/10000)



proton (1/10)
helium (1/100)
CNO (1/1000)
Ne-Si (1/10000)
iron (1/100000)
all particle


average mass number
JACEE
RUNJOB
: Average mass number for individual primary elements obtained by previous direct observations
<lnA>
primary energy Ep [GeV/particle]
0
1
2
3
4
10^2
10^3
10^4
10^5
10^6
10^7

Leaky Box Model

propagation in Galaxy

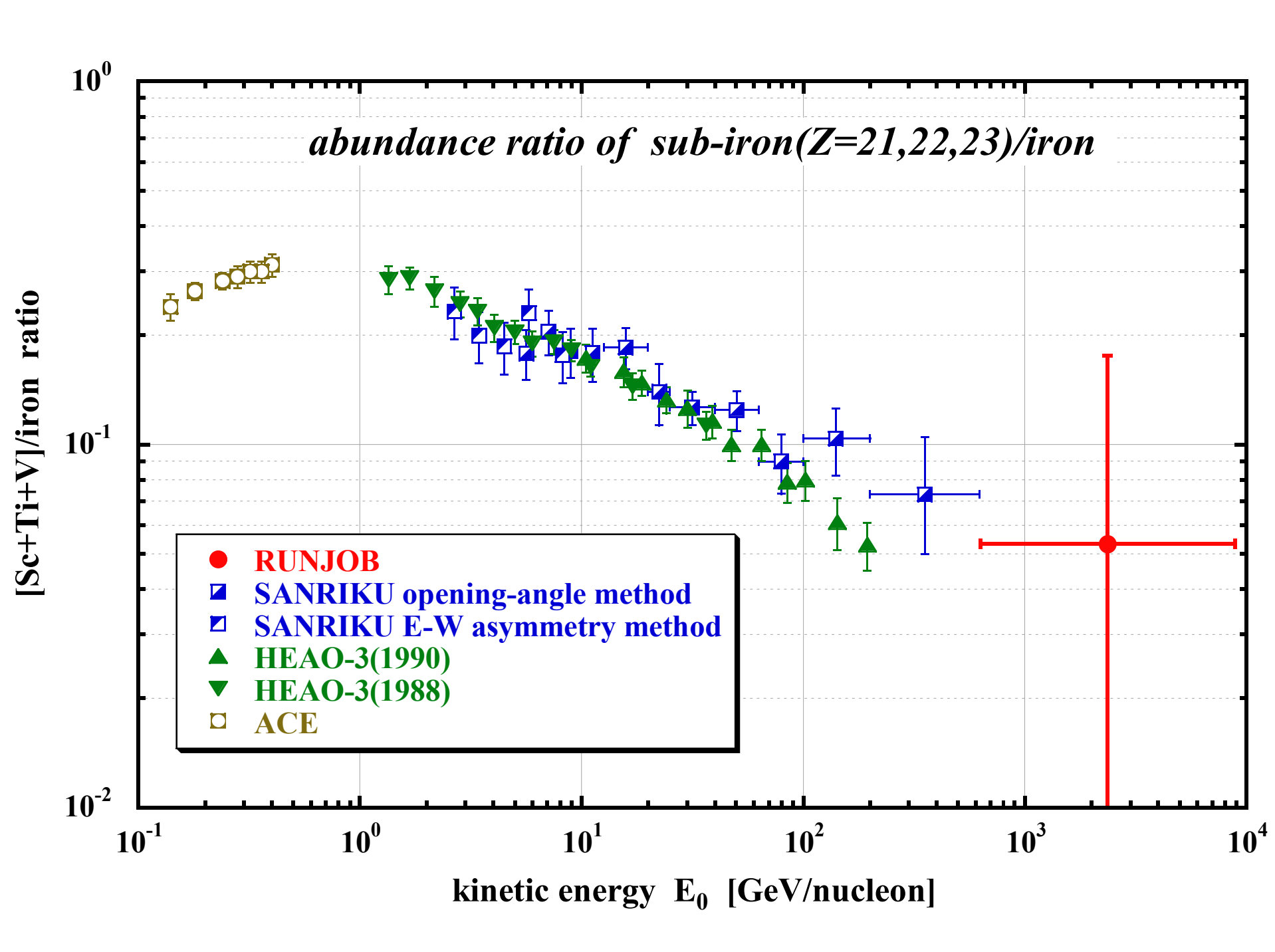
$$\left(\frac{1}{\lambda_{int}} + \frac{1}{\lambda_{esc}}\right) J_i = \frac{Q_i}{\rho} + \sum_{j>i} \frac{1}{\lambda_{ji}} J_j$$

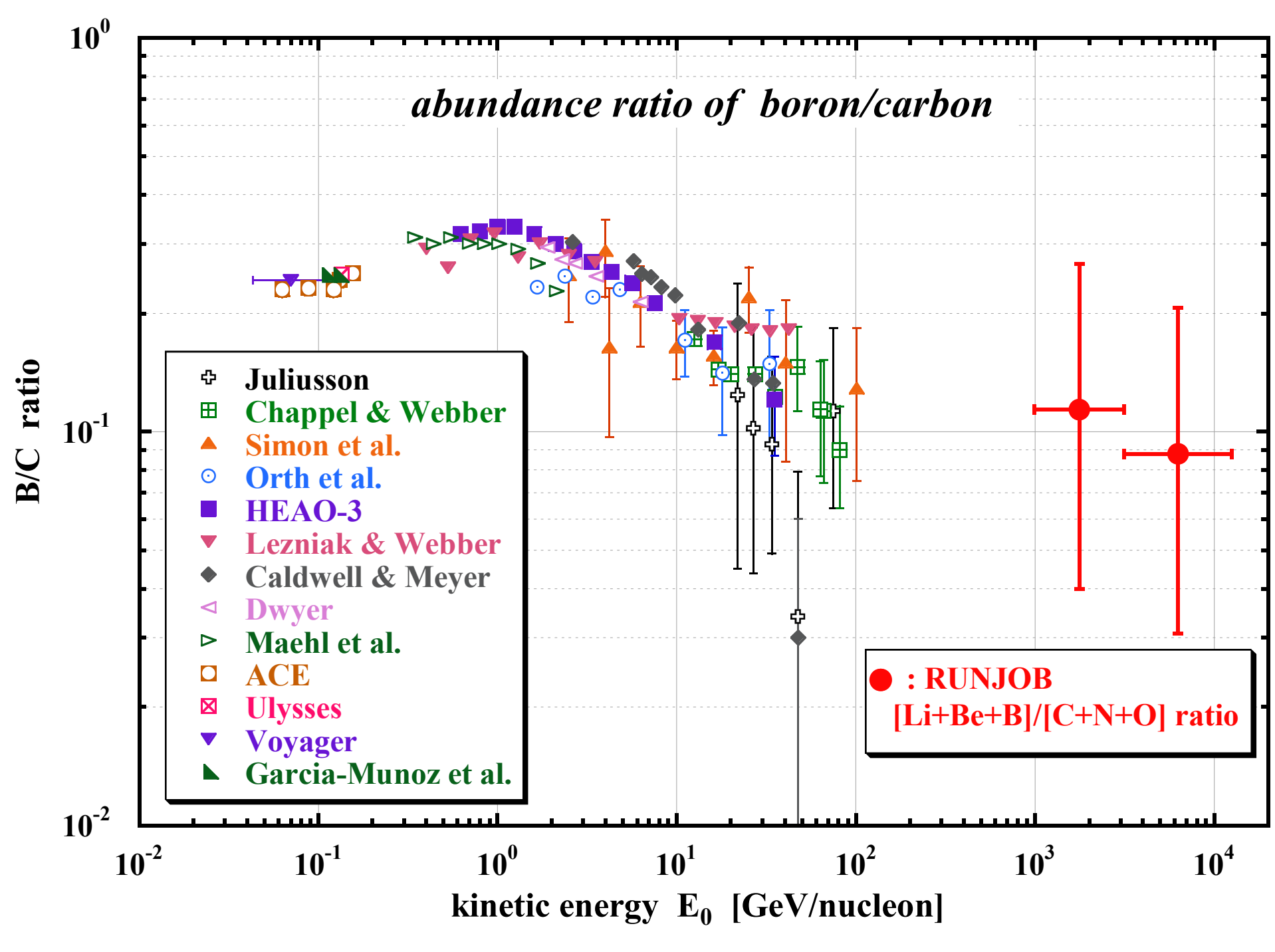
interaction | escape | source | fragment

λ_{int} almost energy independent

λ_{esc} rigidity dependent

$$R = \frac{pc}{Ze}$$


abundance ratio of sub-iron(Z=21,22,23)/iron
[Sc+Ti+V]/iron ratio
kinetic energy E0 [GeV/nucleon]
RUNJOB
SANRIKU opening-angle method
SANRIKU E-W asymmetry method
HEAO-3(1990)
HEAO-3(1988)
ACE


abundance ratio of boron/carbon
B/C ratio
kinetic energy E_0 [GeV/nucleon]
Juliusson
Chappel & Webber
Simon et al.
Orth et al.
HEAO-3
Lezniak & Webber
Caldwell & Meyer
Dwyer
Maehl et al.
ACE
Ulysses
Voyager
Garcia-Munoz et al.
● : RUNJOB
[Li+Be+B]/[C+N+O] ratio

propagation

interstellar space

galactic magnetic field

What is next ?

Higher energy

satellite

space station

Detailed analysis

in lower energies

- direct observation of source spectra

Our latest publication

Astroparticle Physics **16**(2001)13-46

The pdf file of the above will be sent upon the request to

kuramata@cc.hirosaki-u.ac.jp