BESS result of primary cosmic ray flux

BESS Collaboration

Tomoyuki Sanuki
(Univ. of Tokyo)

June 12, 1998

Dear Colleagues,

To my regret,
I am unable to attend the symposium
due to sudden severe pain
on my back.
I am terribly sorry for this.
I wish you successful symposium.

Shyji Ohto

June 12. 1998.

BESS Collaboration

- *University of Tokyo*
  K.Abe, T.Agoh, K.Anraku, Y.Asaoka, M.Fujikawa, M.Imori,T.Maeno, N.Matsui, H.Matsunaga, M.Motoki, S.Orito*, T.Saeki,T.Sanuki, Y.Shikaze, T.Sonoda, I.Ueda and K.Yoshimura

- *NASA Goddard Space Flight Center (NASA/GSFC)*
  J.F.Ormes*, J.Mitchell, A.Moiseev, D.Righter, R.Streitmatter

- *High Energy Accelerator Research Organization (KEK)*
  Y.Makida, J.Suzuki, K.Tanaka, Y.Yamamoto† and T.Yoshida§

- *New Mexico State University (NMSU)*
  B.Kimbell and S.Stochaj

- *Kobe University*
  K.Kawagoe, H.Matsumoto, T.Mitsui, M.Nozaki and M.Sasaki

- *University of Maryland*
  F.B.McDonald and E.S.Seo

- *Institute of Space and Astronautical Science (ISAS)*
  J.Nishimura, N.Yajima and T.Yamagami

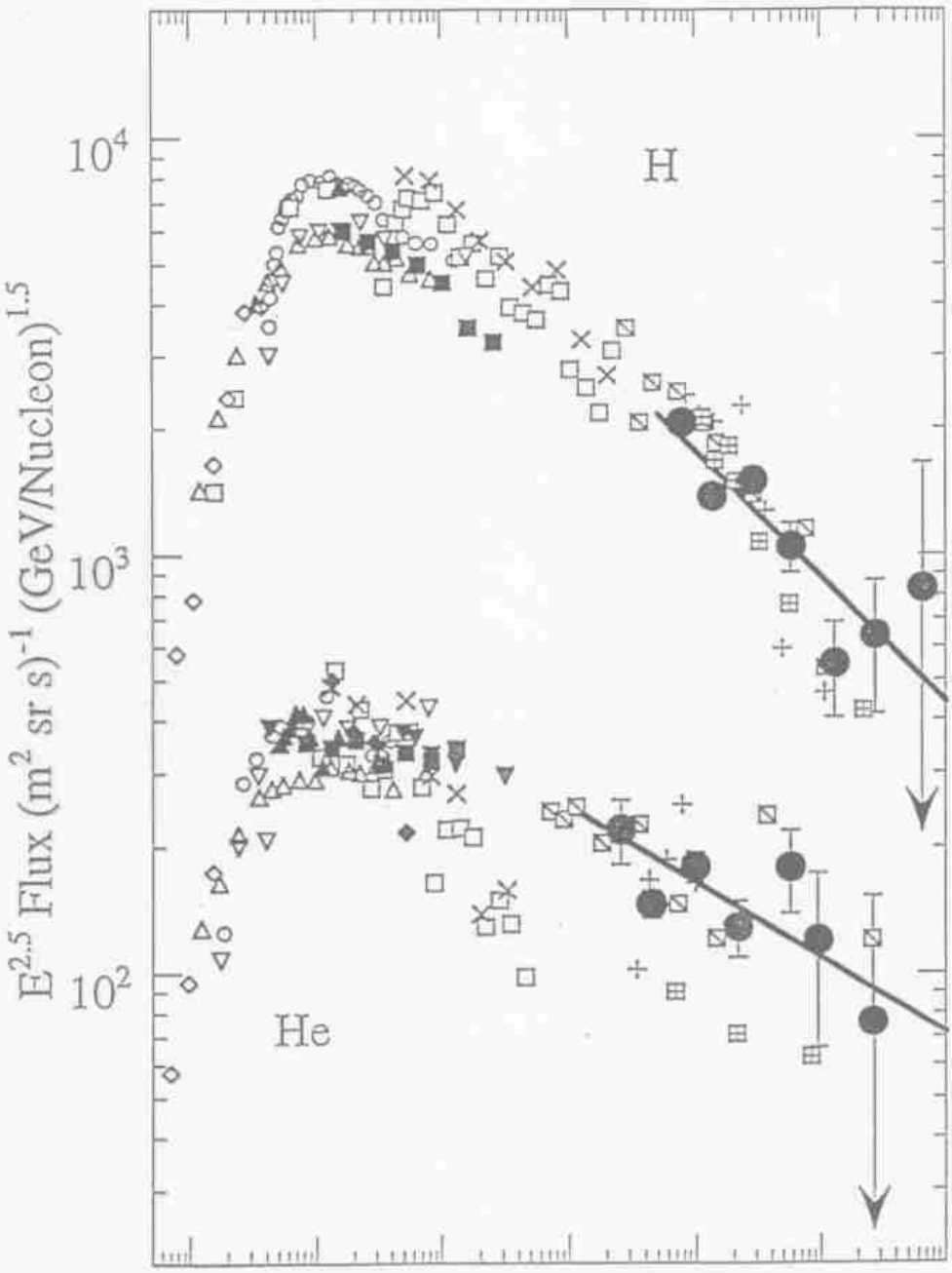
** Principal Investigators*
† Project Manager
§ Assisting Project Manager

CONTENTS

I. Introduction

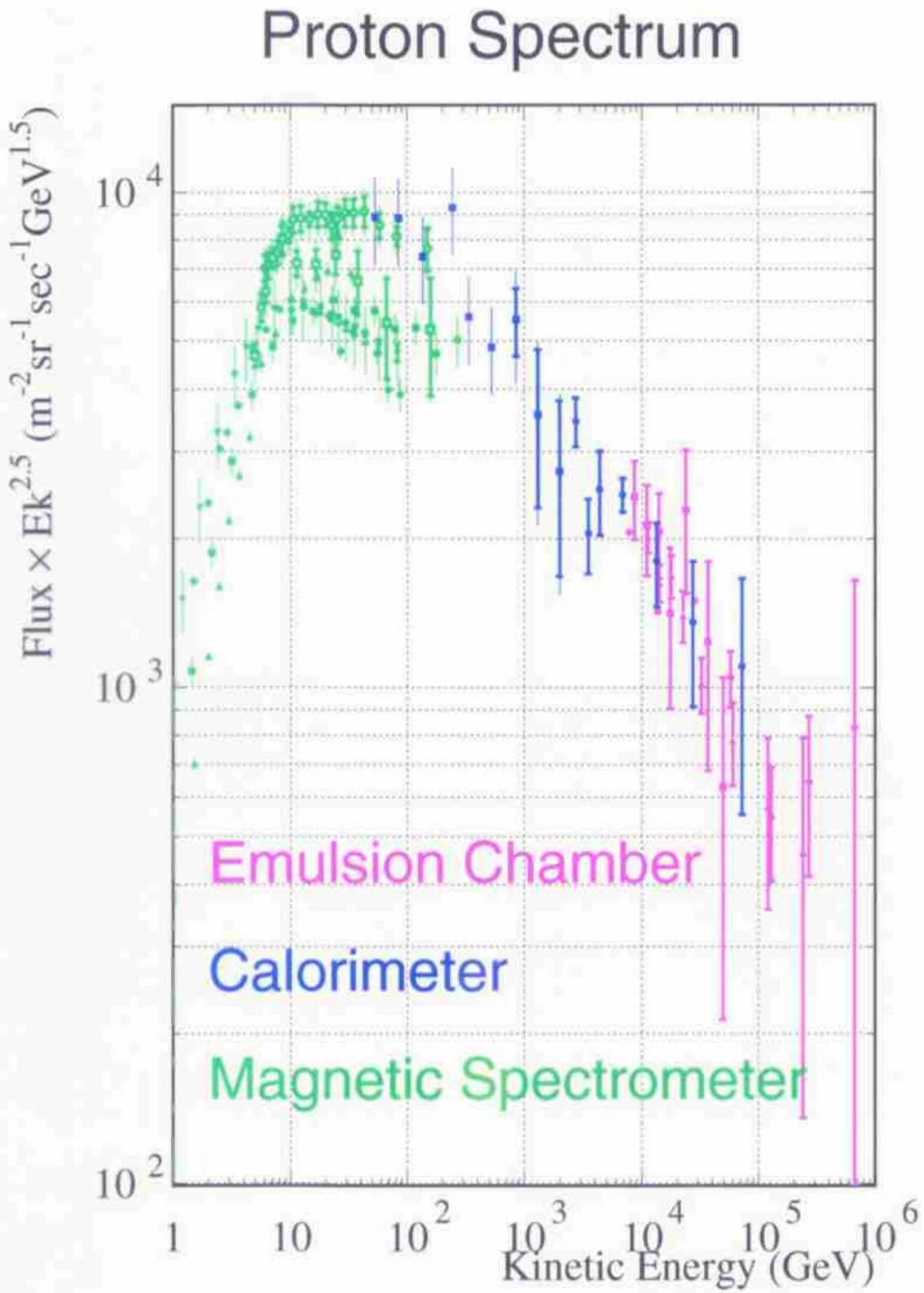
K. Asakimori et al
ICRC 1997

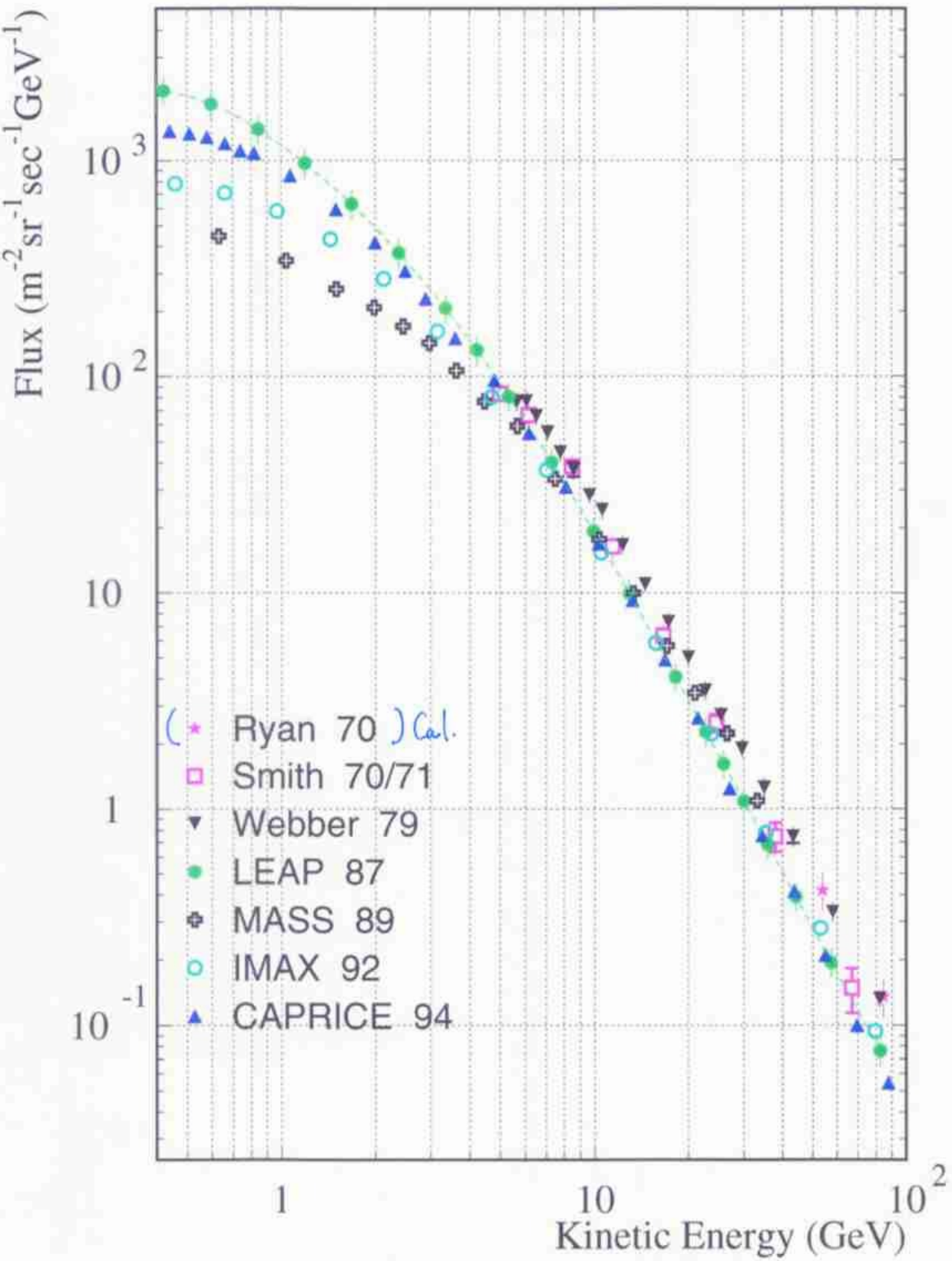
~ Previous Experiments ~



- many experiments
- by many groups

Fig. 3. Differential spectra dN/dE showing present results (●) together with earlier results from Freier and Waddington (1968, ◊), Anand et al. (1968, ▲), Ryan et al. (1972, ×), Verma et al. (1972, ♦), Ramaty et al. (1973, □), Smith et al. (1973, ▽), Badhwar et al. (1977, o), Seo et al. (1991, △), Dwyer et al. (1993, ▼), Ichimura et al. (1993, +), Ivanenko et al. (1993, ⊠), Zatsepin et al. (1993, ⊞), and Swordy et al. (1995, ■).

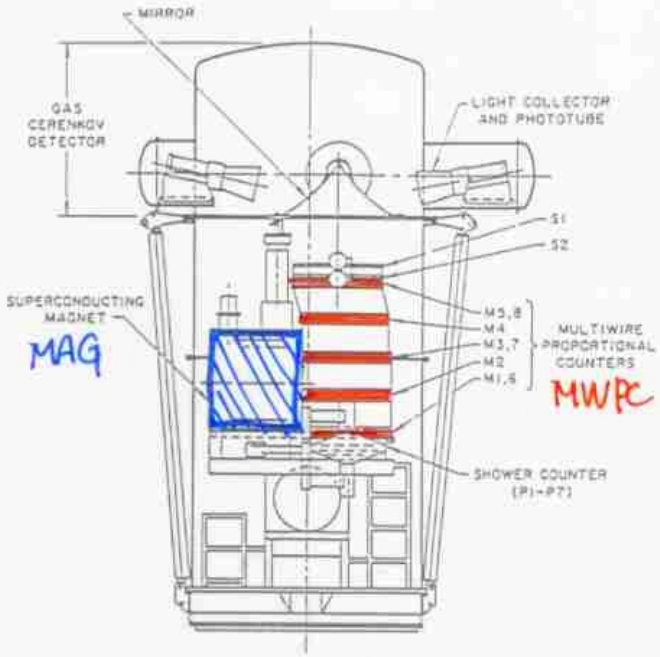

Proton Spectrum
Flux × Ek^2.5 (m^-2 sr^-1 sec^-1 GeV^1.5)
10^4
10^3
10^2
Emulsion Chamber
Calorimeter
Magnetic Spectrometer
1
10
10^2
10^3
10^4
10^5
10^6
Kinetic Energy (GeV)


Flux ($m^{-2}sr^{-1}sec^{-1}GeV^{-1}$)
10^3
10^2
10
1
10^{-1}
Ryan 70) Cal.
Smith 70/71
Webber 79
LEAP 87
MASS 89
IMAX 92
CAPRICE 94
1
10
10^2
Kinetic Energy (GeV)

ⓓ NMSU (Golden's) spectrometer

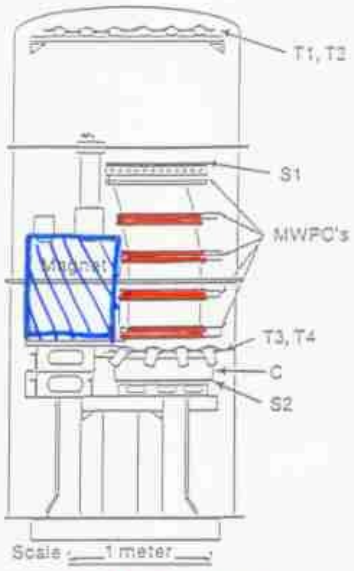
MAGNET + MWPC (x8) & DC (x2)

only IMAX, CAPRICE



Webber '79

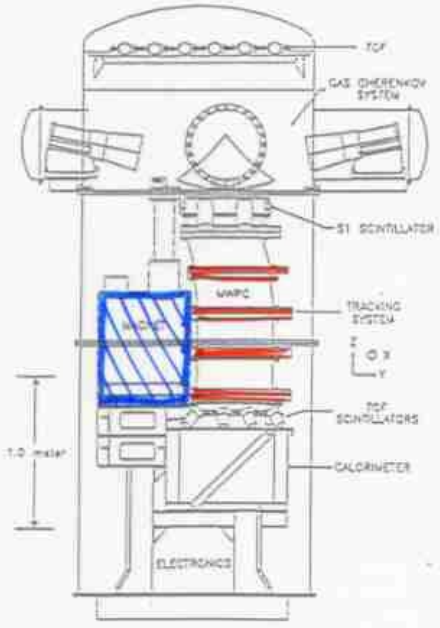
8



LEAP 87

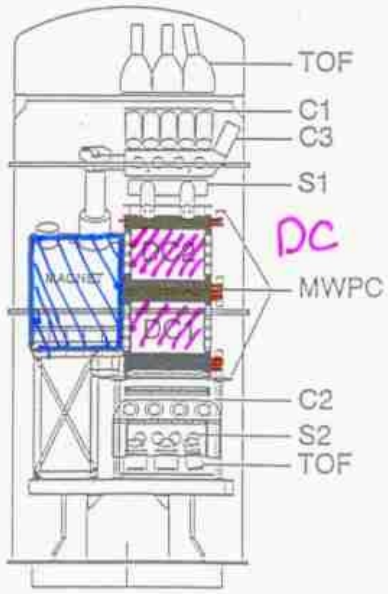
8

#measurement points (bending)



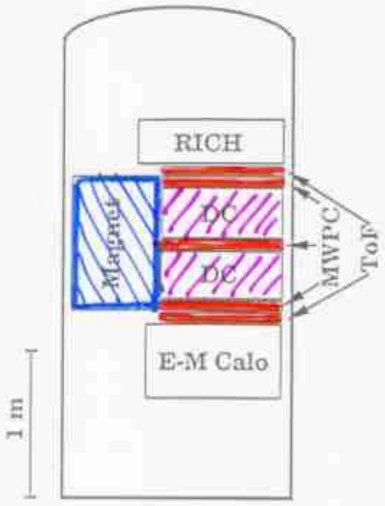
MASS89

8



IMAX92

20

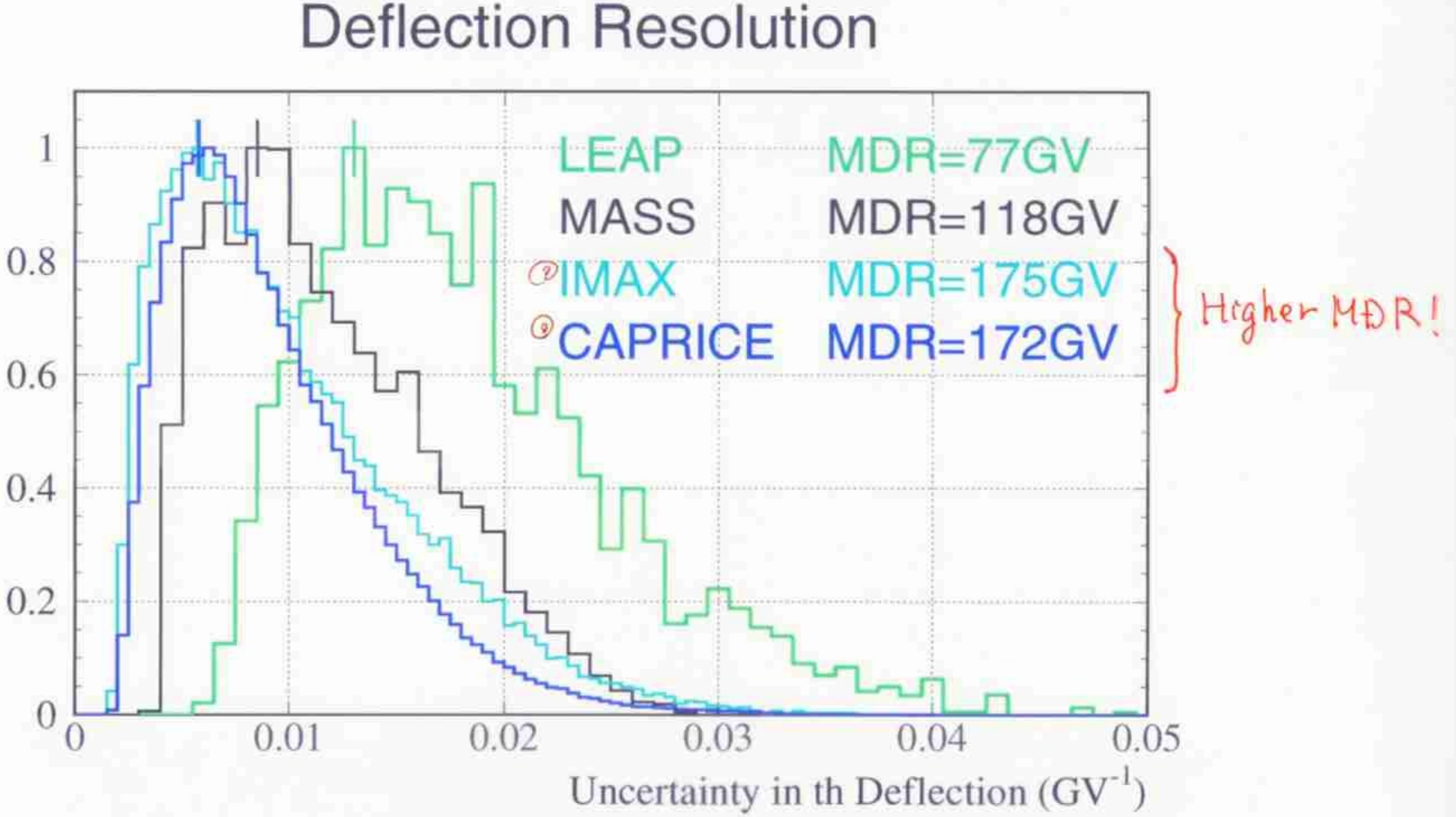


CAPRICE94

20

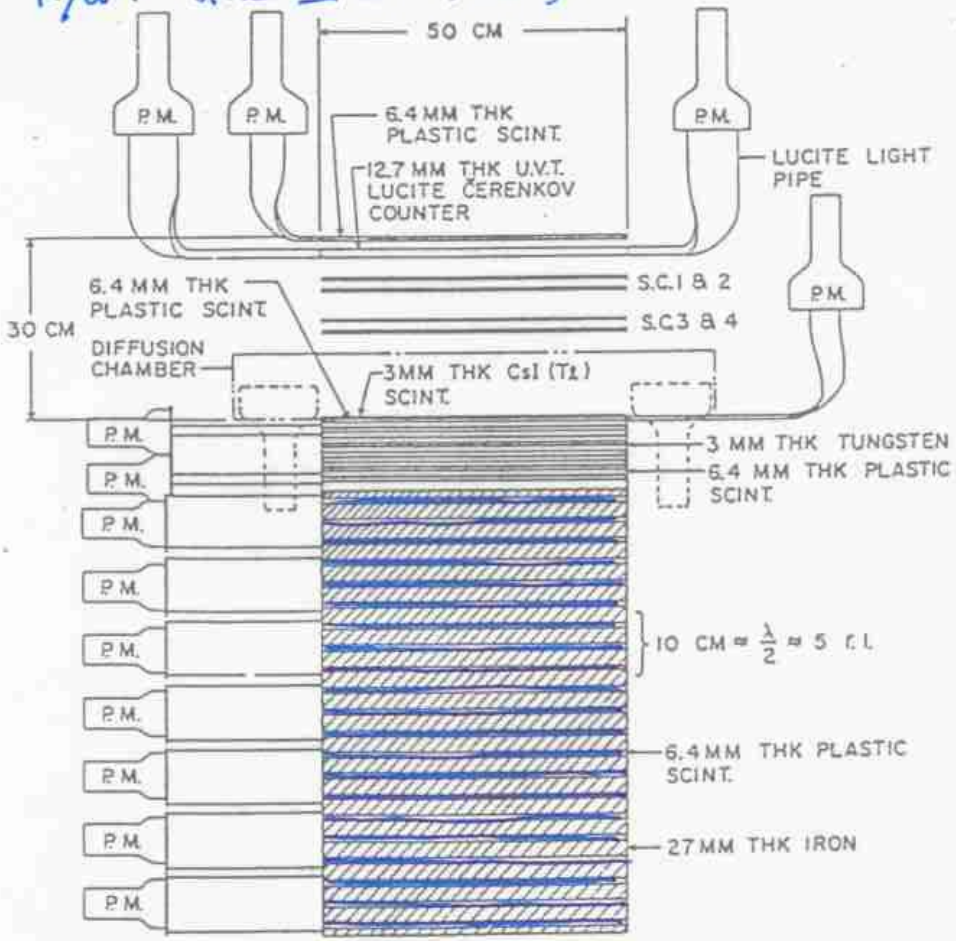
DCs improved MDR (Maximun Detactable Rigidyty)

Rigidity = P/Q



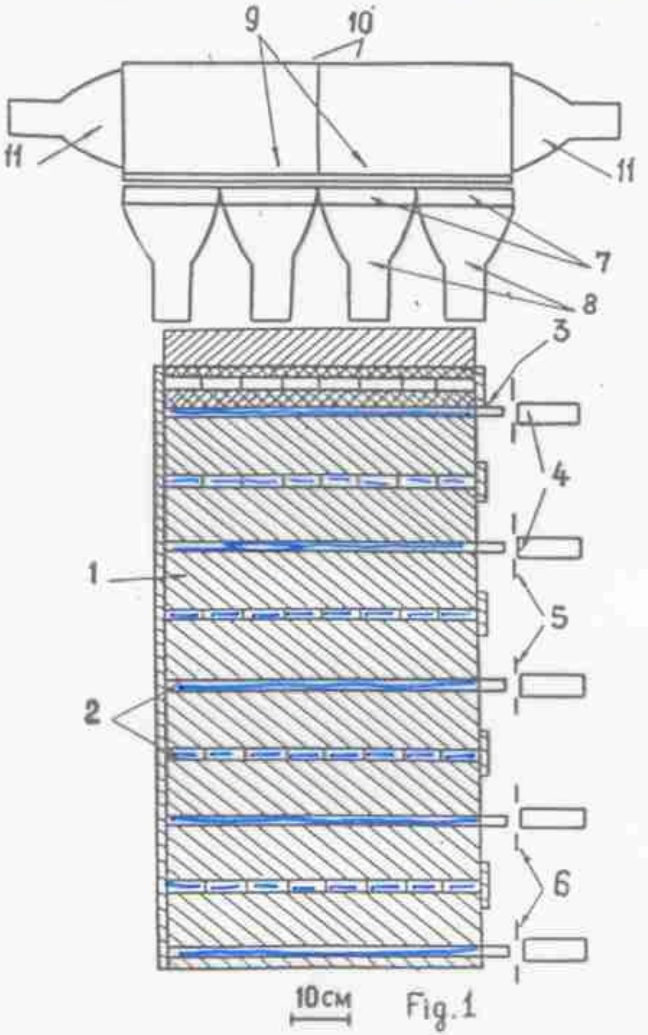
⊘ Calorimeter

Ryan (PRL 10 (1992) 985)



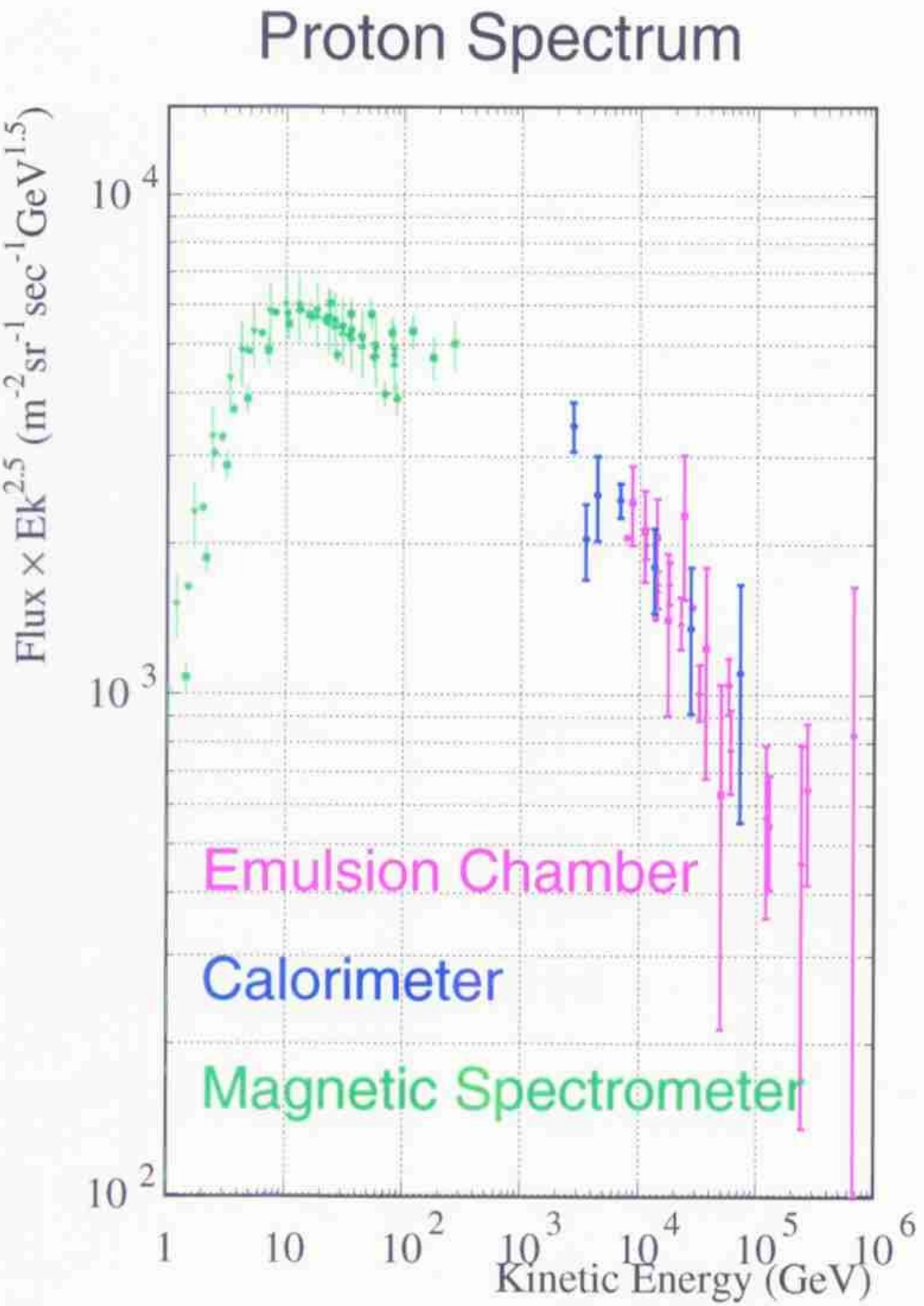
Extra hit can NOT be seen

⊘ SOKOL (ICRC 8 (1981) 49)



"Imaging" counter

rough (60 X 60 mm²) Resolution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Flux × Ek^2.5 (m^-2 sr^-1 sec^-1 GeV^1.5)
10^4
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Magnetic Spectrometer
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10^2
10^3
10^4
10^5
10^6
Kinetic Energy (GeV)

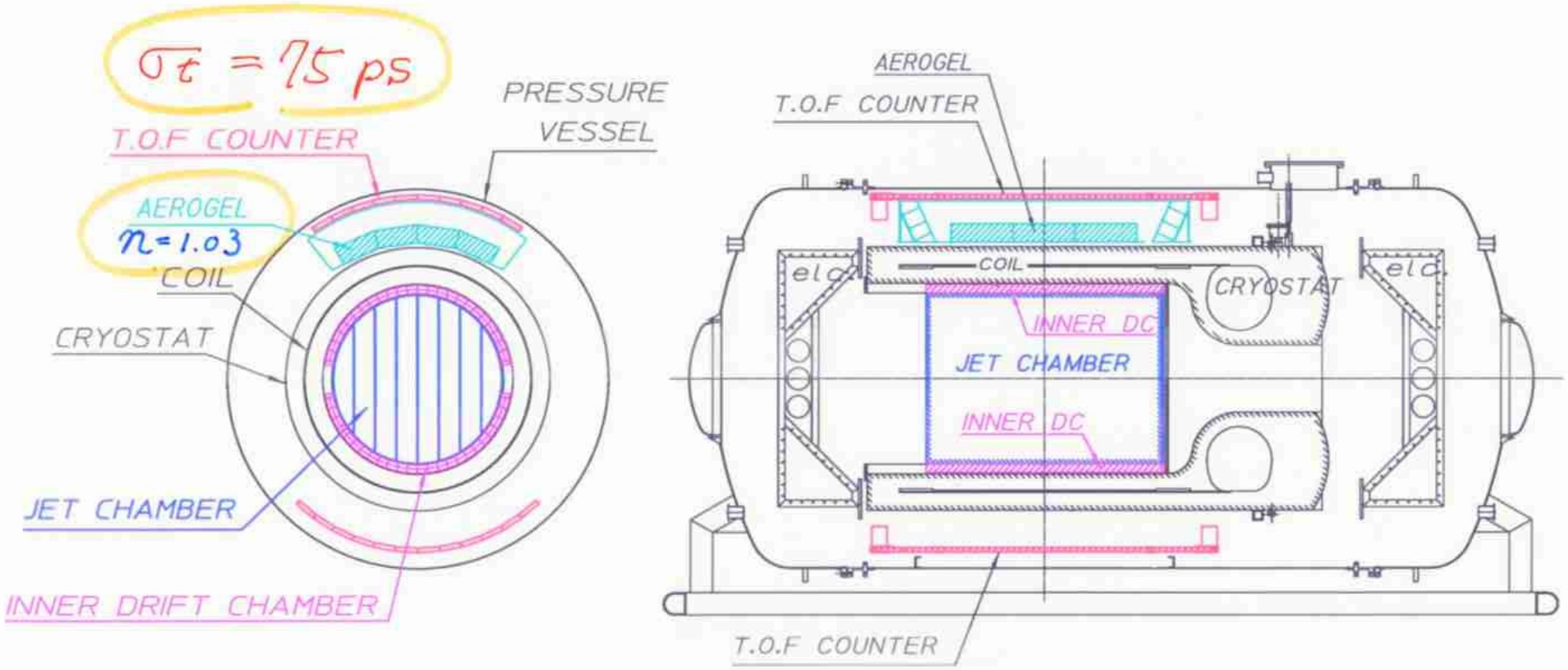
II. BESS Spectrometer

Balloon-Borne Experiment

with a

Superconducting Magnet Spectrometer

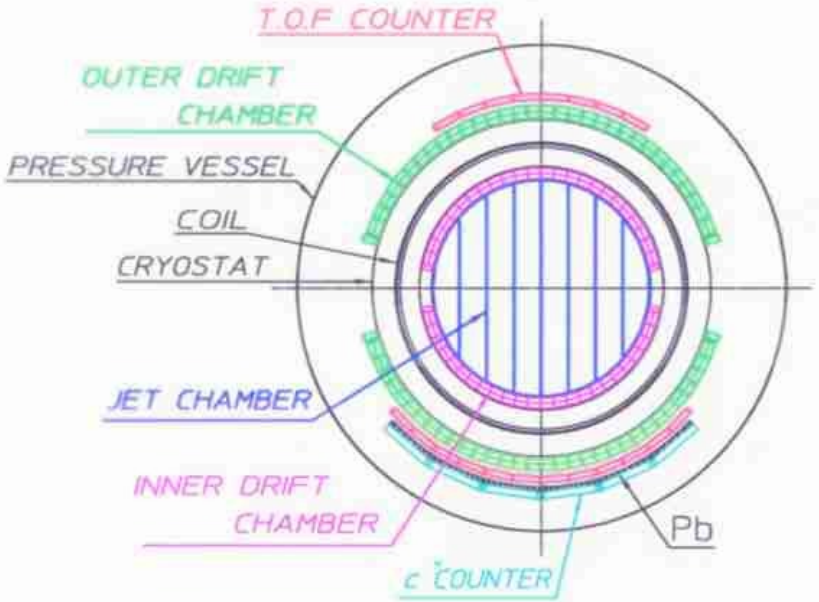
BESS 97

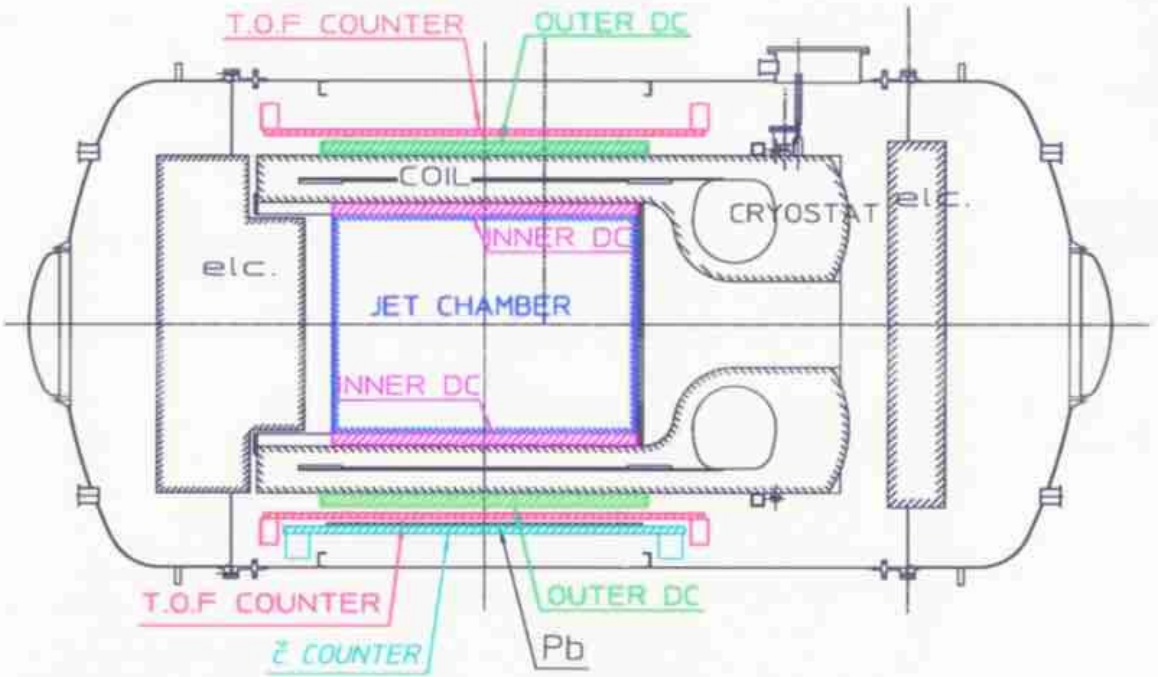

σt = 75 ps
PRESSURE VESSEL
T.O.F COUNTER
AEROGEL
n = 1.03
COIL
CRYOSTAT
JET CHAMBER
INNER DRIFT CHAMBER
AEROGEL
T.O.F COUNTER
COIL
CRYOSTAT
INNER DC
JET CHAMBER
INNER DC
T.O.F COUNTER
0
0.5m
1m

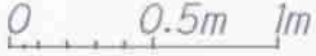
BESS 95

- cylindrical shape → large $S\Omega$ →
- up to 24 + 4 + 4 = 32 points / track recorded →
  (JET) (IDC) (ODC)
  28 for BESS97 (w/o ODC)

$\sigma_t = 110\,ps$

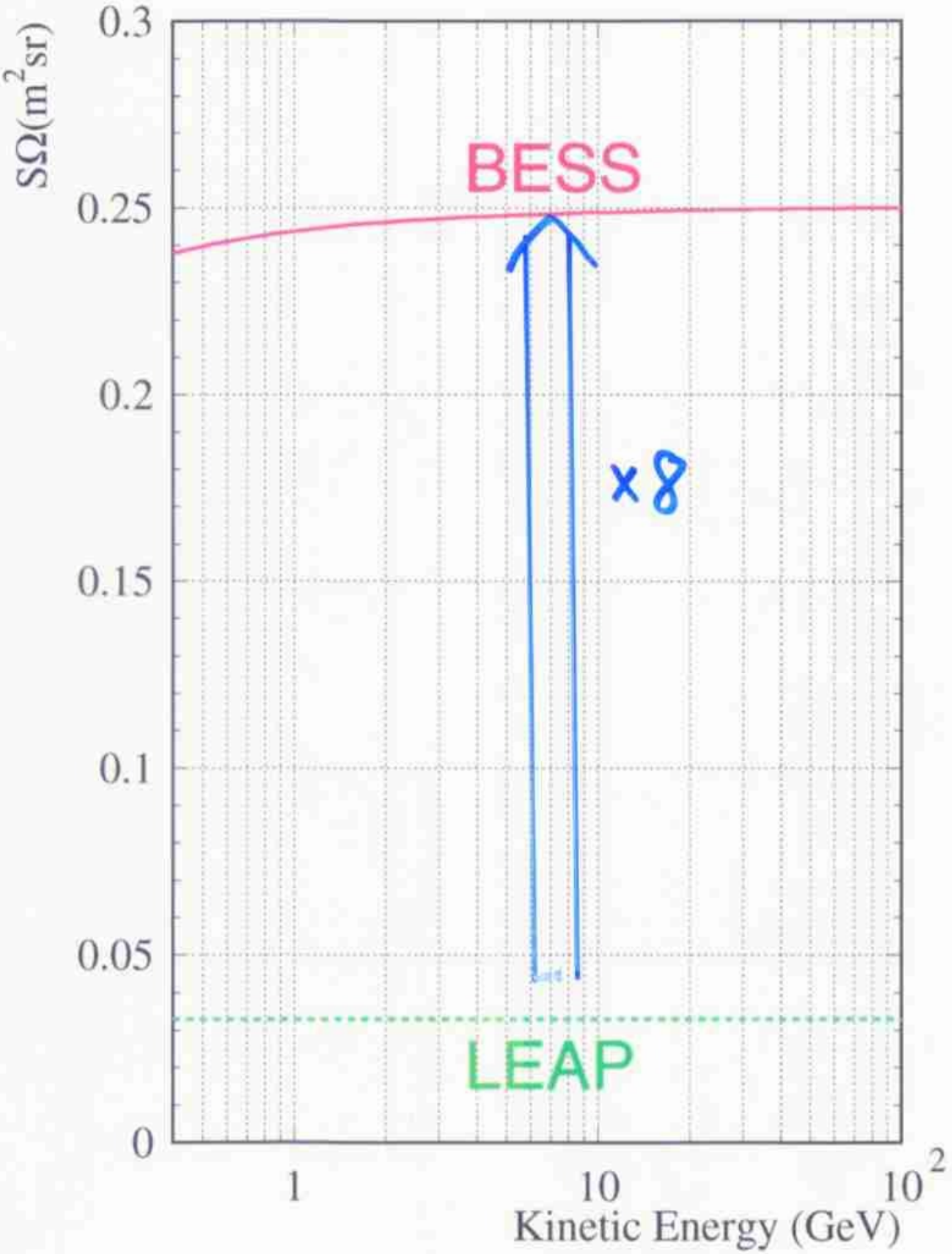






- thin Superconducting Solenoidal Magnet ($0.2X_0$) →
  uniform 1 T B field 0.8m ϕ x 1m

Geometrical Acceptance



BESS | Event # : 843087 | Trigger : 00250011 | Event timing
Exp # : 9 | Run # : 22 | 012:41:31.5263

/scratch/bess/exp9/run22/dat/dat404_1.dat

BESS 0.45GV

Rigidity: .448GV
beta: .951
path1:1352.4mm

Kappa: .340E-03
Phi0 : .474E+01
D0 : .179E+02
Z0 : -.614E+02
DZDS : -.134E+00
RGDT: .441GV
dRGDT: .001GV

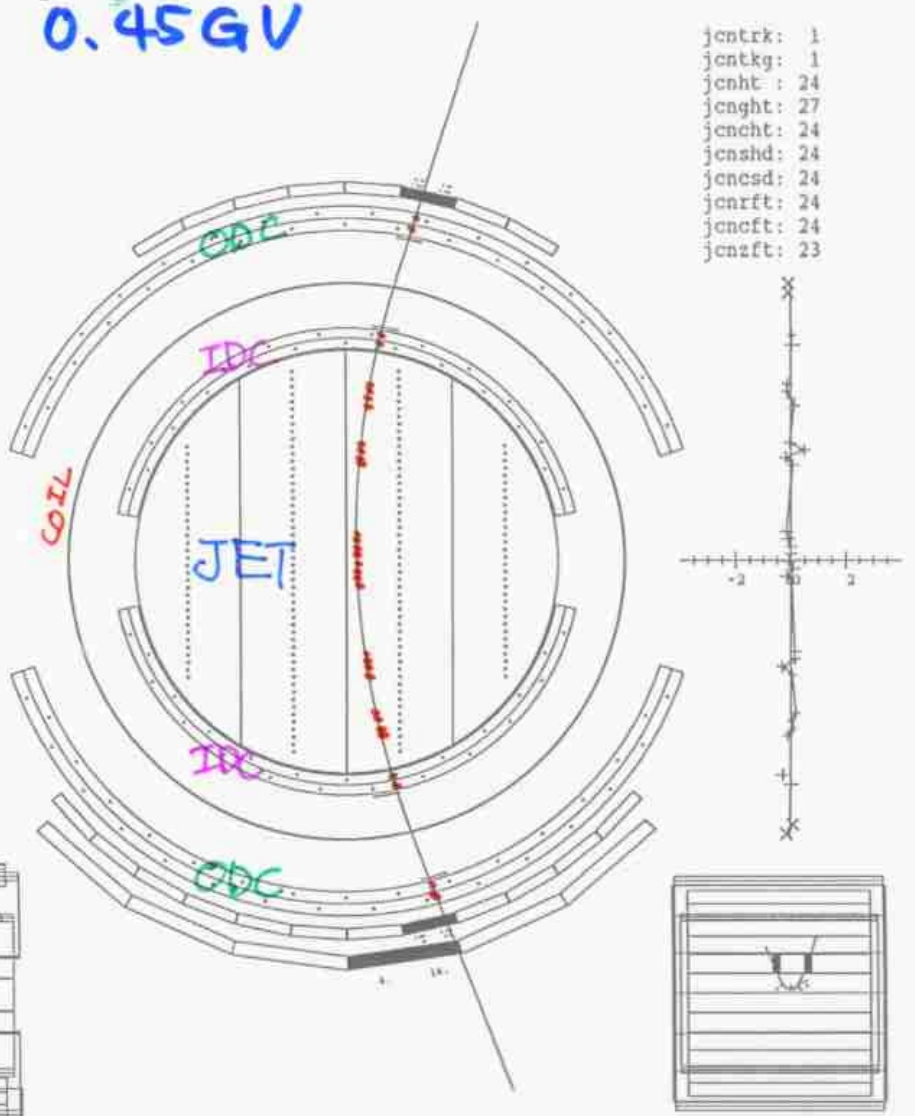
chisq1: .69
chisq2: 2.75
chisqj: .77

dE/dxU: 1.38
dE/dxL: 1.04
dE/dxJ: 1.62

masstf: .02GeV
massde: .16GeV

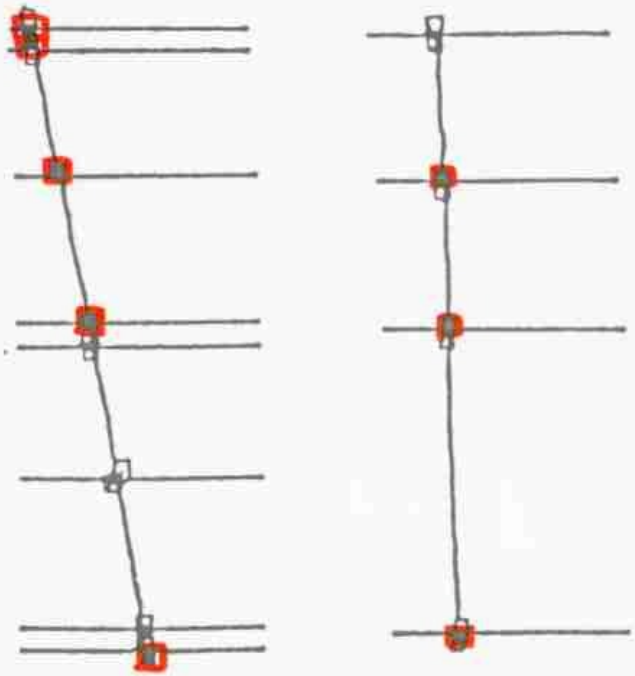
ntof U: 1
ntof L: 1
tofdzU:-13.9mm
tofdzL: 4.8mm
timeU: -3.43ns
timeL: 1.31ns
tofazU: -.131
tofazL: .109

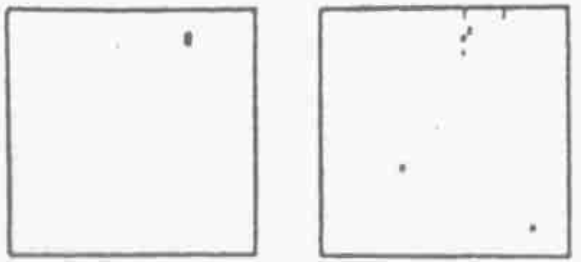
jcntrk: 1
jcntkg: 1
jcnht : 24
jcnght: 27
jcncht: 24
jcnshd: 24
jcncsd: 24
jcnrft: 24
jcncft: 24
jcnzft: 23



more reliable Rigidity measurement

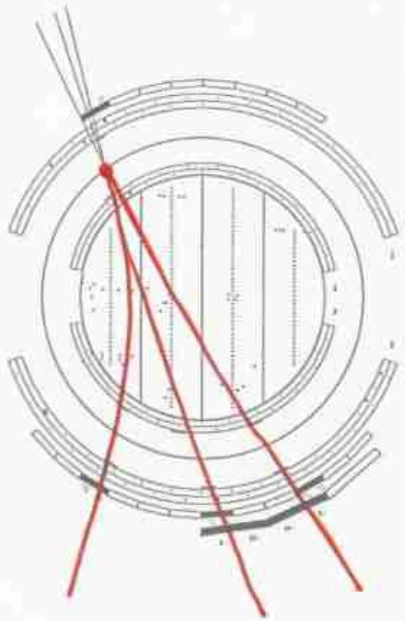
MASS -0.20GV



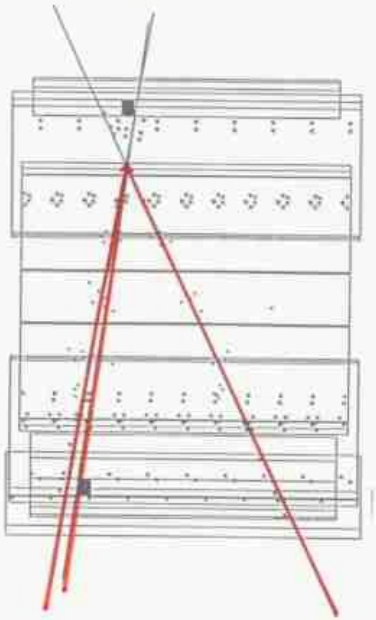


X-VIEW Y-VIEW

from front



side



bottom

interactions can be easily recognized

→ minimize backgrounds

sys. error

BESS Event # : 843087 Exp # : 9 Trigger : 00250011 Run # : 22 Event timing 012:41:33.5263

/scratch/bess/exp9/run22/dst/dst404_1.dat

Rigidity: .448GV
beta: .951
pathl:1352.4mm

Kappa: .340E-03
Phi0 : .474E+01
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Z0 : -.614E+02
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RGDT: .441GV
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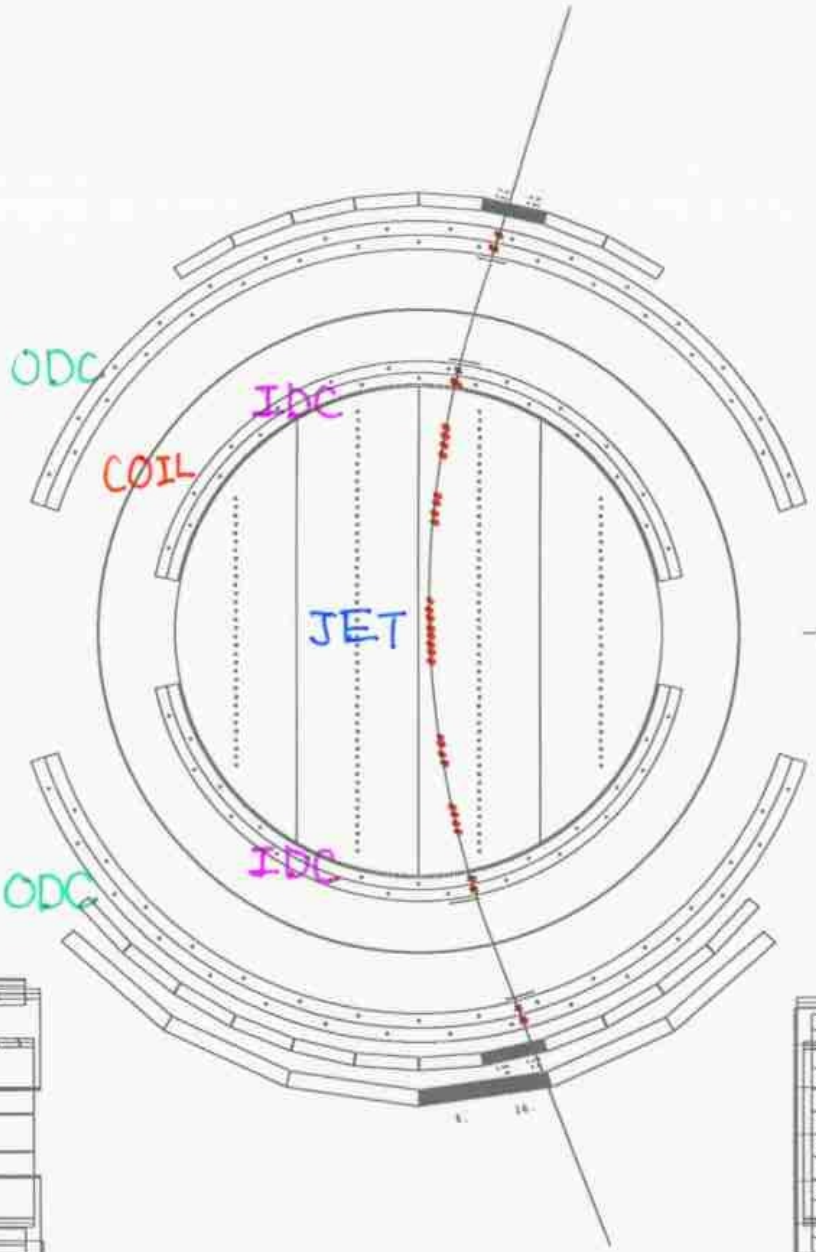
chisq1: .69
chisq2: 2.75
chisqj: .77

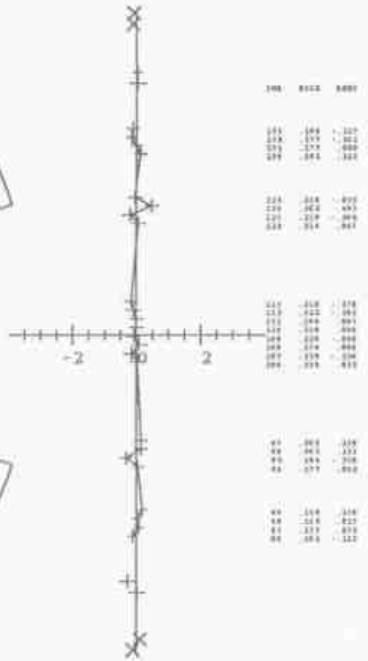
dE/dxU: 1.38
dE/dxL: 1.04
dE/dxJ: 1.62

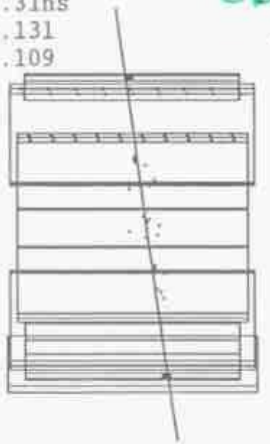
masstf: .02GeV
massde: .16GeV

ntof U: 1
ntof L: 1
tofdzU:-13.9mm
tofdzL: 4.8mm
timeU: -3.43ns
timeL: 1.31ns
tofazU: -.131
tofazL: .109



jcntrk: 1
jcntkg: 1
jcnht : 24
jcnght: 27
jcncht: 24
jcnshd: 24
jcncsd: 24
jcnrft: 24
jcncft: 24
jcnzft: 23





BESS
0.448GV

redundant track
up to 32points measured
$\sigma \sim 200\mu m$

⇓

Absolute Rigidity

BESS

Event # : 843087
Exp # : 9

Trigger : 00250011
Run # : 22

Event timing
012:41:33.5263

/scratch/bess/exp9/run22/dst/dst404_1.dat

Rigidity: .448GV
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tofdzL: 4.8mm
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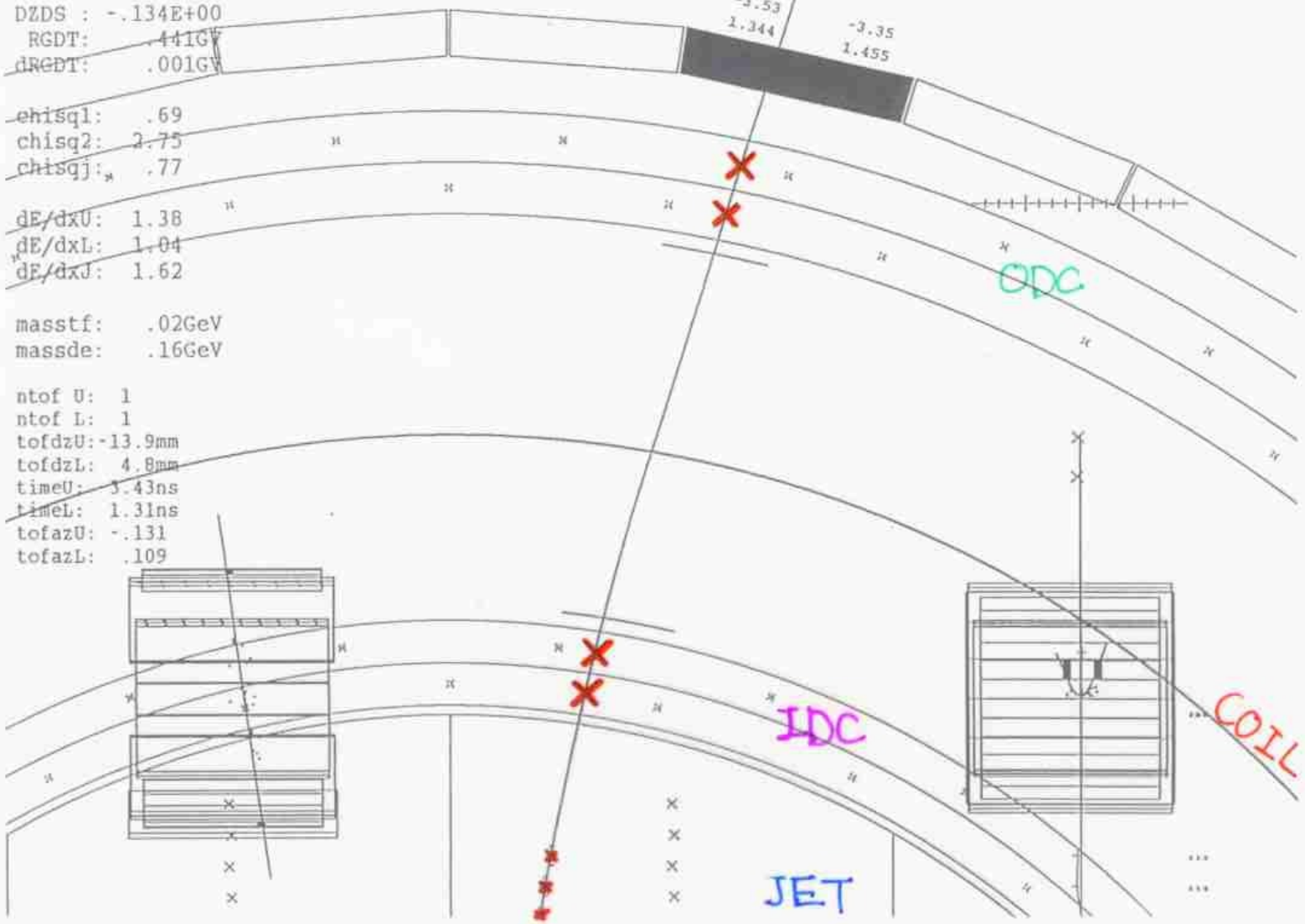
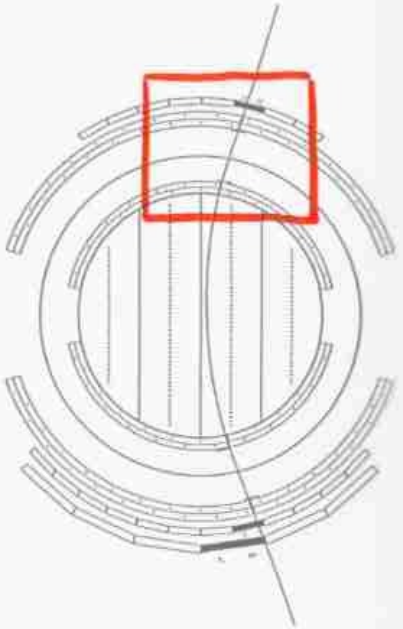
timeL: 1.31ns
tofazU: -.131
tofazL: .109

jcntrk: 1
jcntkg: 1
jcnht : 24
jcnght: 27
jcncht: 24
jcnshd: 24
jcncsd: 24
jcnrft: 24
jcncft: 24
jcnzft: 23





BESS

Event # : 843087
Exp # : 9

Trigger : 00250011
Run # : 22

Event timing
012:41:33.5263

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Rigidity: .448GV
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ntof U: 1
ntof L: 1
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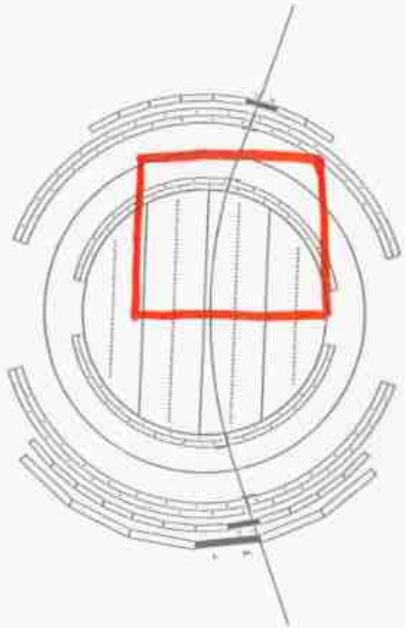
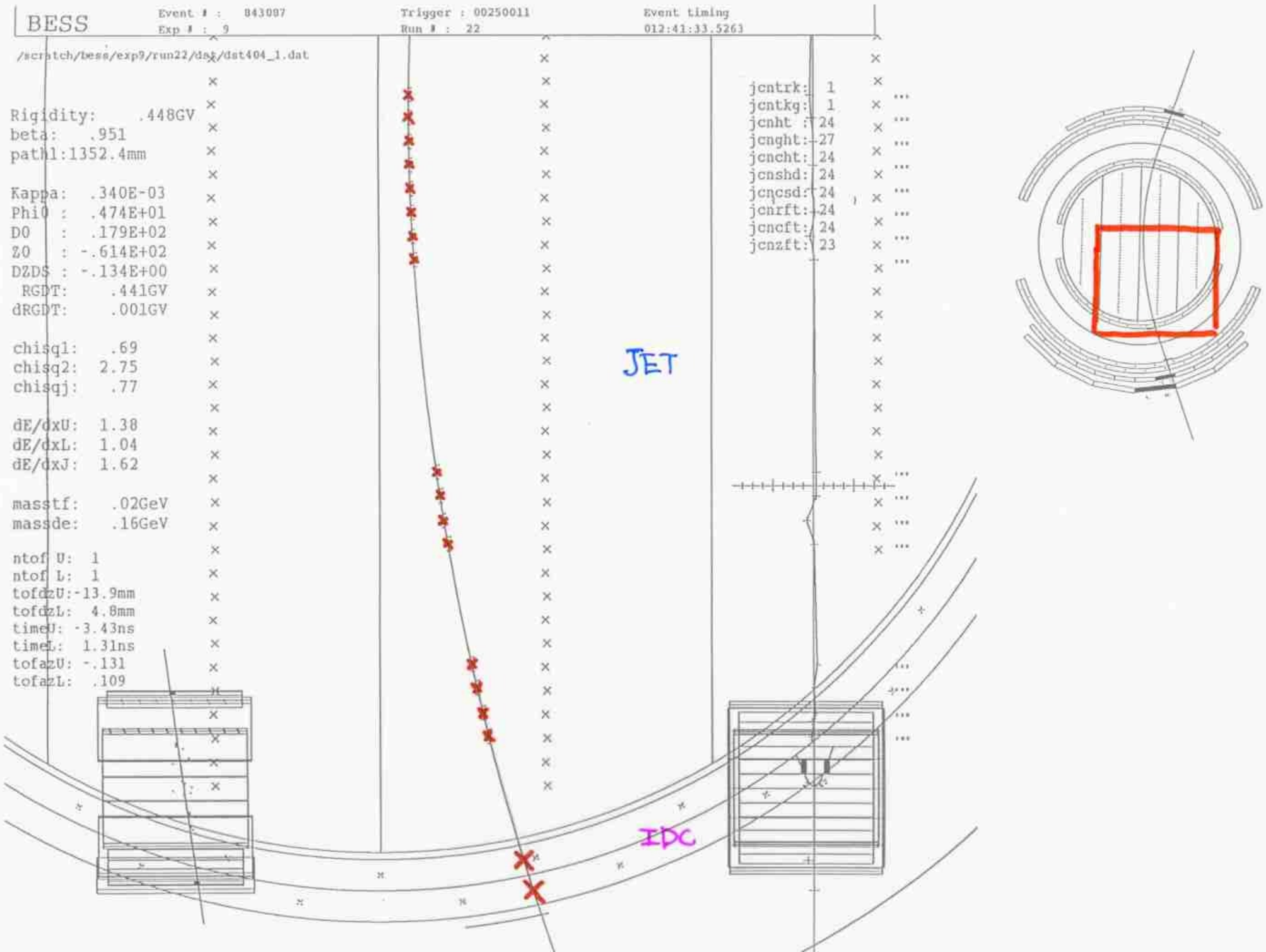
tofazL: .109

jcntrk: 1
jcntkg: 1
jcnht : 24
jcnght: 27
jcncht: 24
jcnshd: 34
jcncsd: 24
jcnrft: 24
jcncft: 24
jcnzft: 23

IDC

JET

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jcnght: 27
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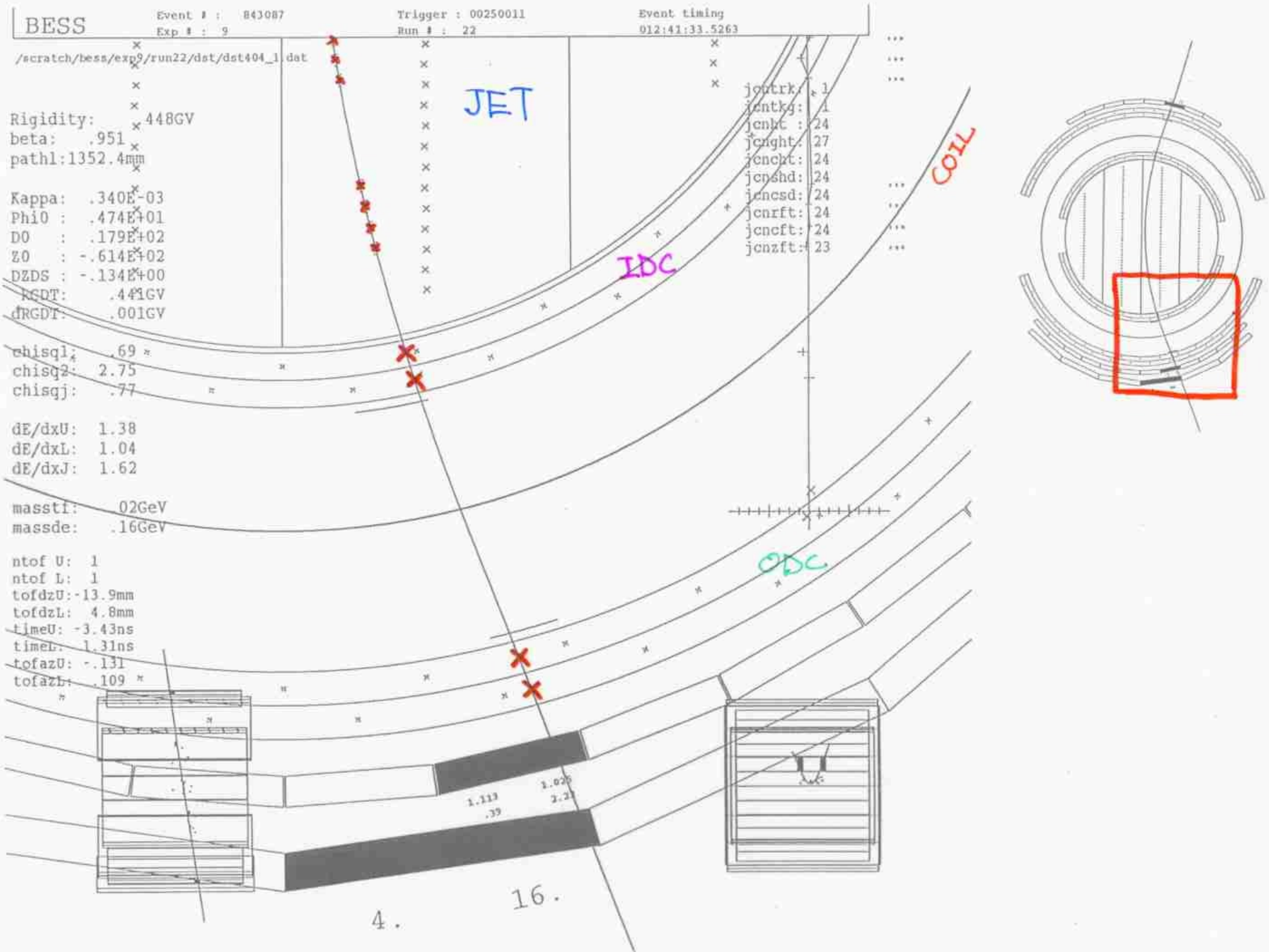
jcnshd: 24
jcncsd: 24
jcnrft: 24
jcncft: 24
jcnzft: 23
JET
IDC


BESS
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Exp # : 9
Trigger : 00250011
Run # : 22
Event timing
012:41:33.5263
/scratch/bess/exp9/run22/dst/dst404_1.dat
JET
IDC
ODC
COIL
Rigidity: .448GV
beta: .951
pathl:1352.4mm
Kappa: .340E-03
Phi0 : .474E+01
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tofazL: .109
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jcntkg: 1
jcnht : 24
jcnght: 27
jcncht: 24
jcnshd: 24
jcncsd: 24
jcnrft: 24
jcncft: 24
jcnzft: 23
1.113
.39
1.026
2.21

BESS

Event # : 123169
Exp # : 9

Trigger : 00250011
Run # : 17

Event timing
001:20:26.8432

/scratch/bess/exp9/run17/dst/dst404_1.dat

BESS
240GV

Rigidity: 239.917GV
beta: 1.035
pathl:1375.0mm

Kappa: .648E-06
Phi0 : .505E+01
D0 : -.545E+02
Z0 : .374E+02
DZDS : .245E+00
RGDT: 231.383GV
dRGDT: 189.299GV

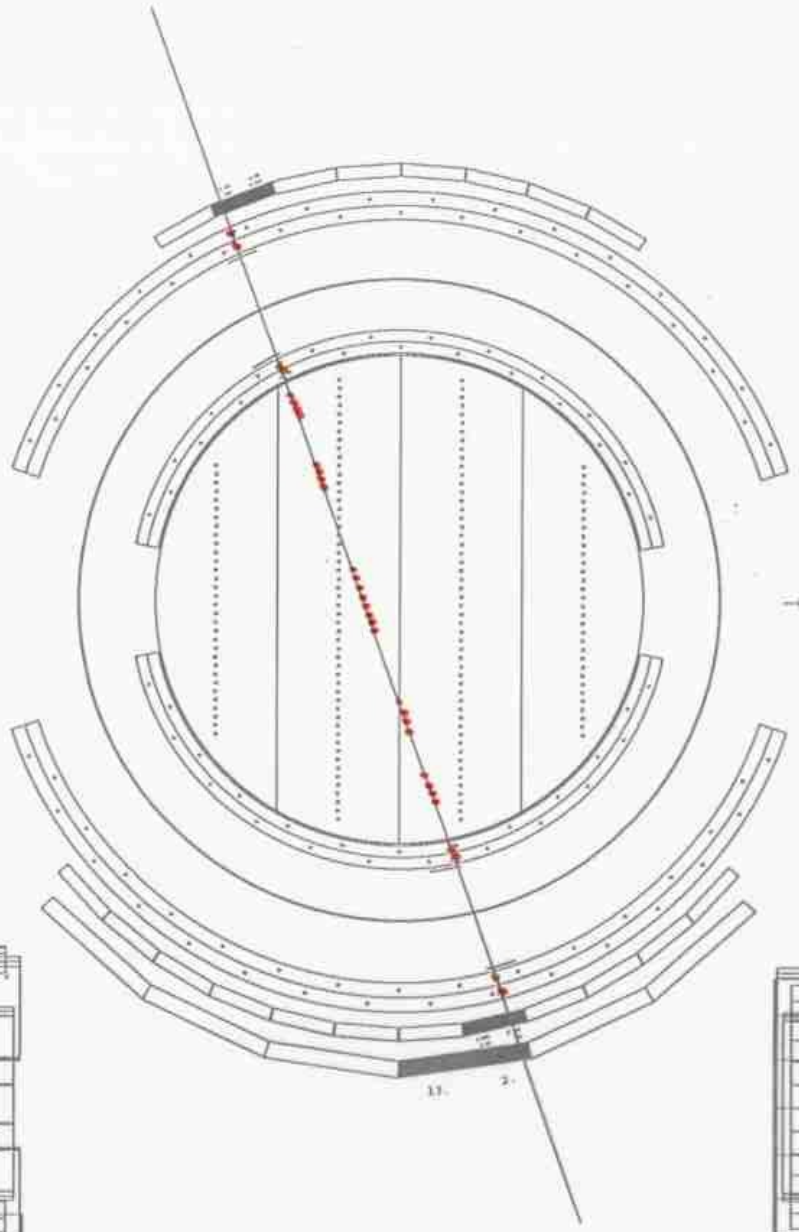
chisq1: .69
chisq2: 4.25
chisqj: .80

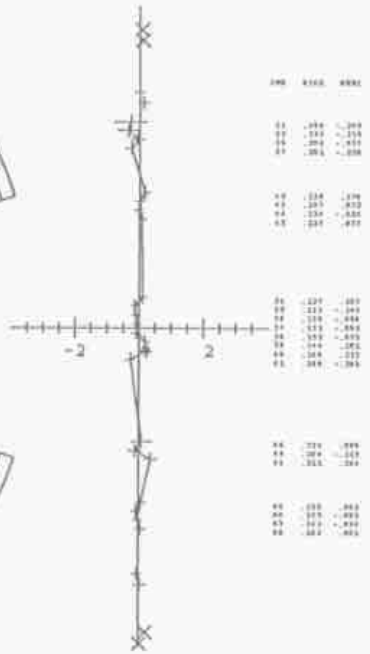
dE/dxU: .96
dE/dxL: 1.07
dE/dxJ: 1.51

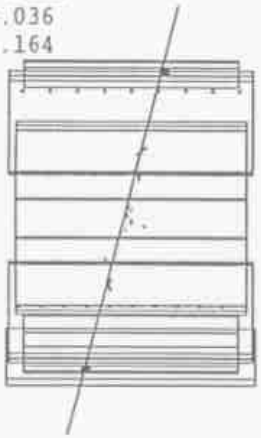
masstf:******GeV
massde:******GeV

ntof U: 1
ntof L: 1
tofdzU:-17.8mm
tofdzL: -1.2mm
timeU: -3.50ns
timeL: .93ns
tofazU: -.036
tofazL: -.164

jcntrk: 1
jcntkg: 1
jcnht : 23
jcnght: 37
jcncht: 23
jcnshd: 24
jcncsd: 24
jcnrft: 23
jcncft: 23
jcnzft: 22







BESS Event # : 123169 Exp # : 9 Trigger : 00250011 Run # : 17 Event timing 001:20:26.8432

/scratch/bess/exp9/run17/dst/dst404_1.dat

Rigidity: 239.917GV
beta: 1.035
path1:1375.0mm

Kappa: .648E-06
Phi0 : .505E+01
D0 : -.545E+02
Z0 : .374E+02
DZDS : .245E+00
RGDT: 231.383GV
dRGDT: 189.299GV

chisq1: .69
chisq2: 4.25
chisqj: .80

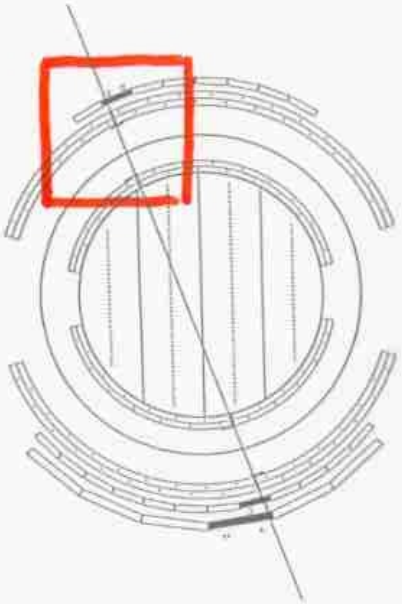
dE/dxU: .96
dE/dxL: 1.07
dE/dxJ: 1.51

masstf:******GeV
massde:******GeV

ntof U: 1
ntof L: 1
tofdzU:-17.6mm
tofdzL: -1.2mm
timeU: -3.50ns
timeL: .93ns
tofazU: -.036
tofazL: -.164

jcntrk: 1
jcntkg: 1
jcnhU : 23
jcngh : 37
jcnch : 23
jcnshd: 24
jcncsd: 24
jcnrft: 23
jcncft: 23
jcnzft: 22

-2.59
.865
-4.38
1.055

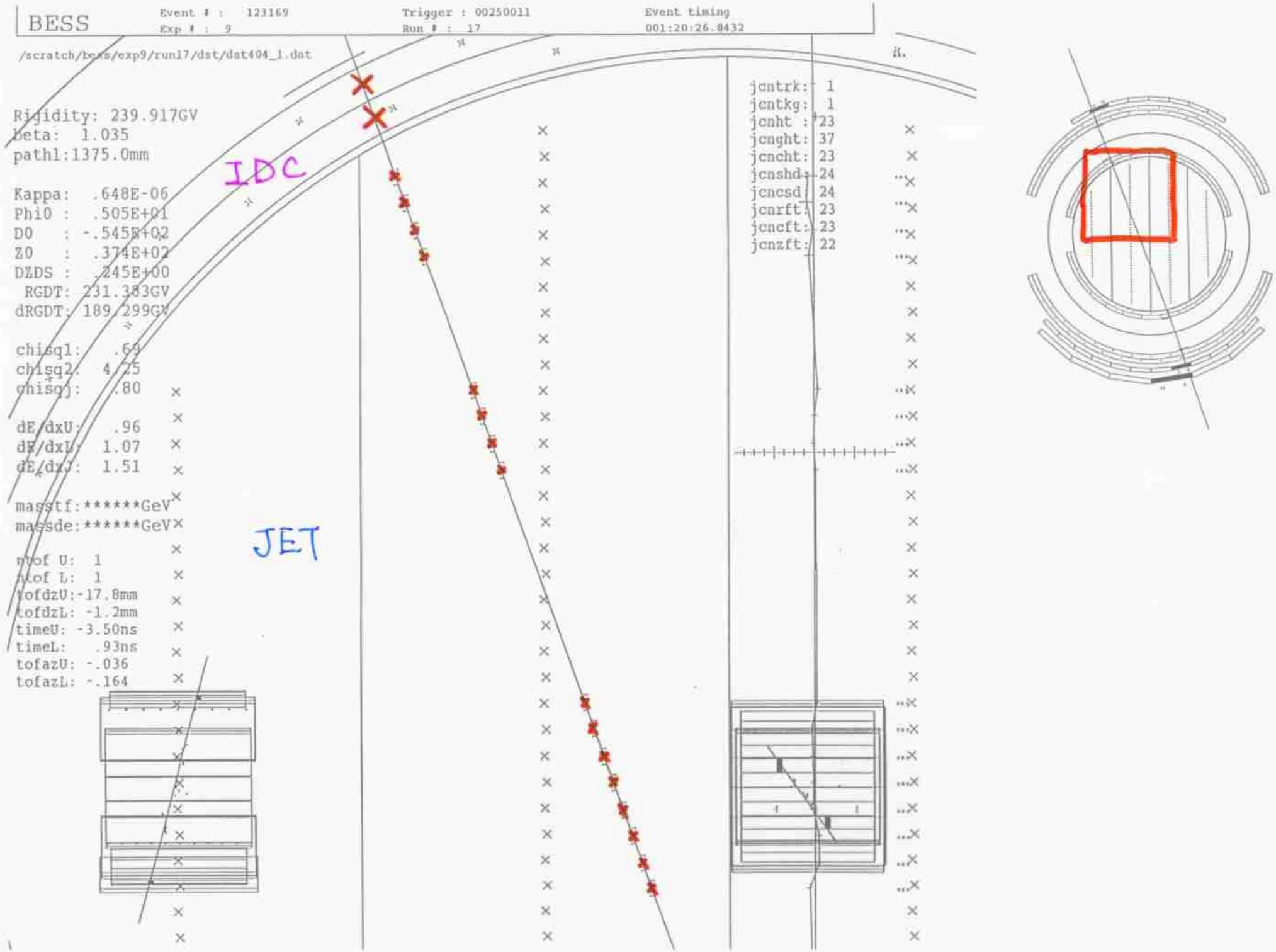


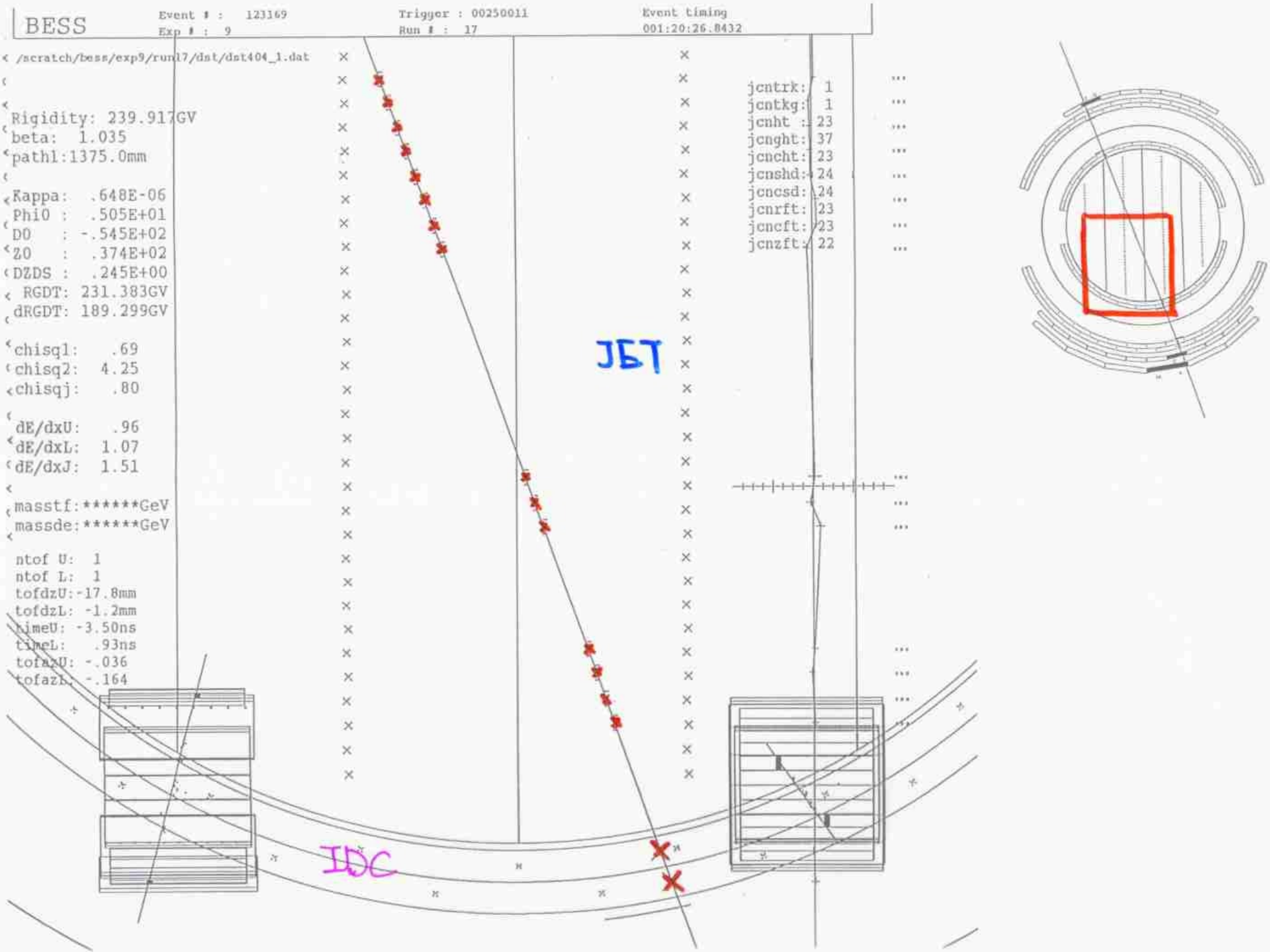
ODC

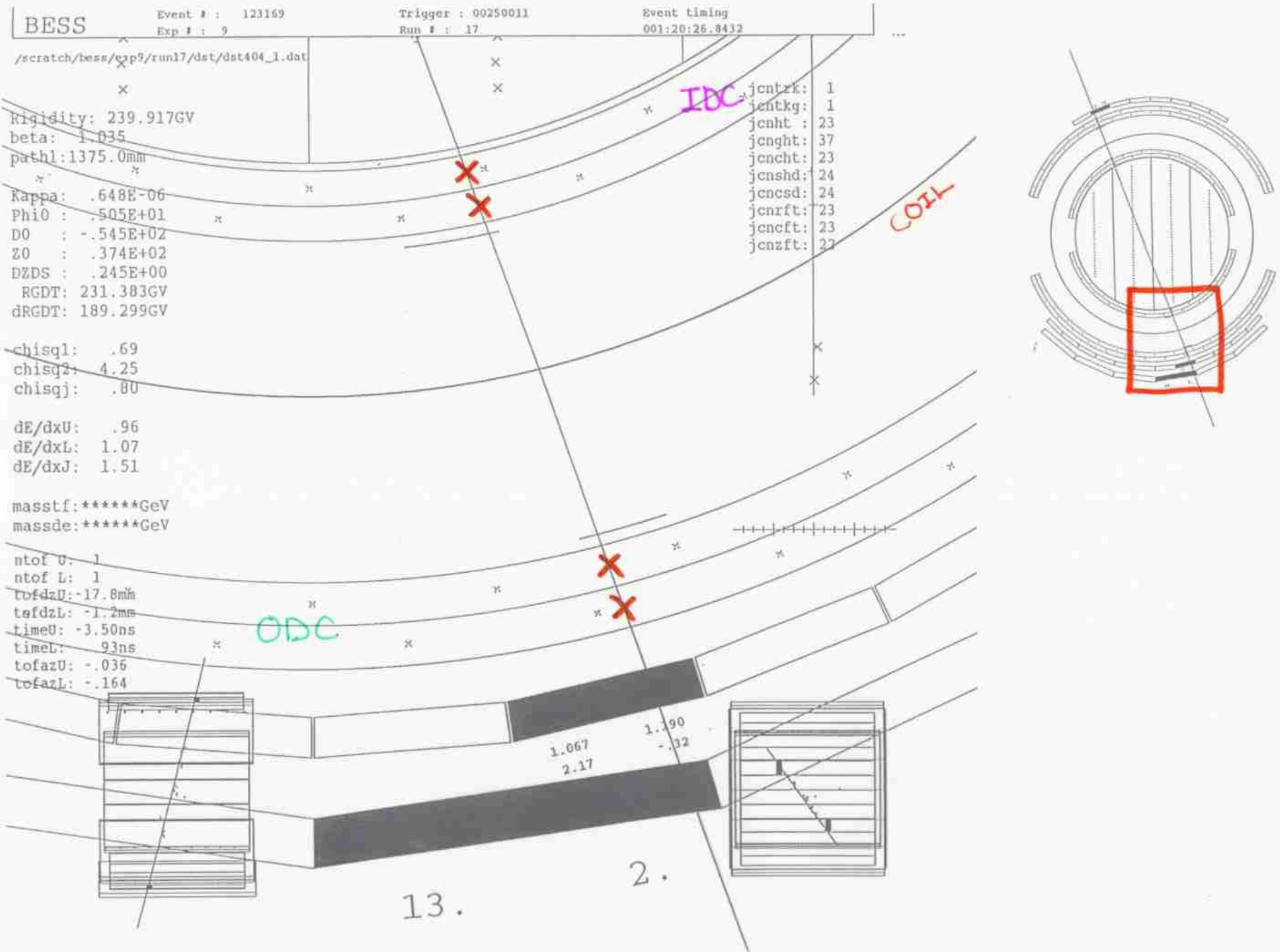
COIL

IDC

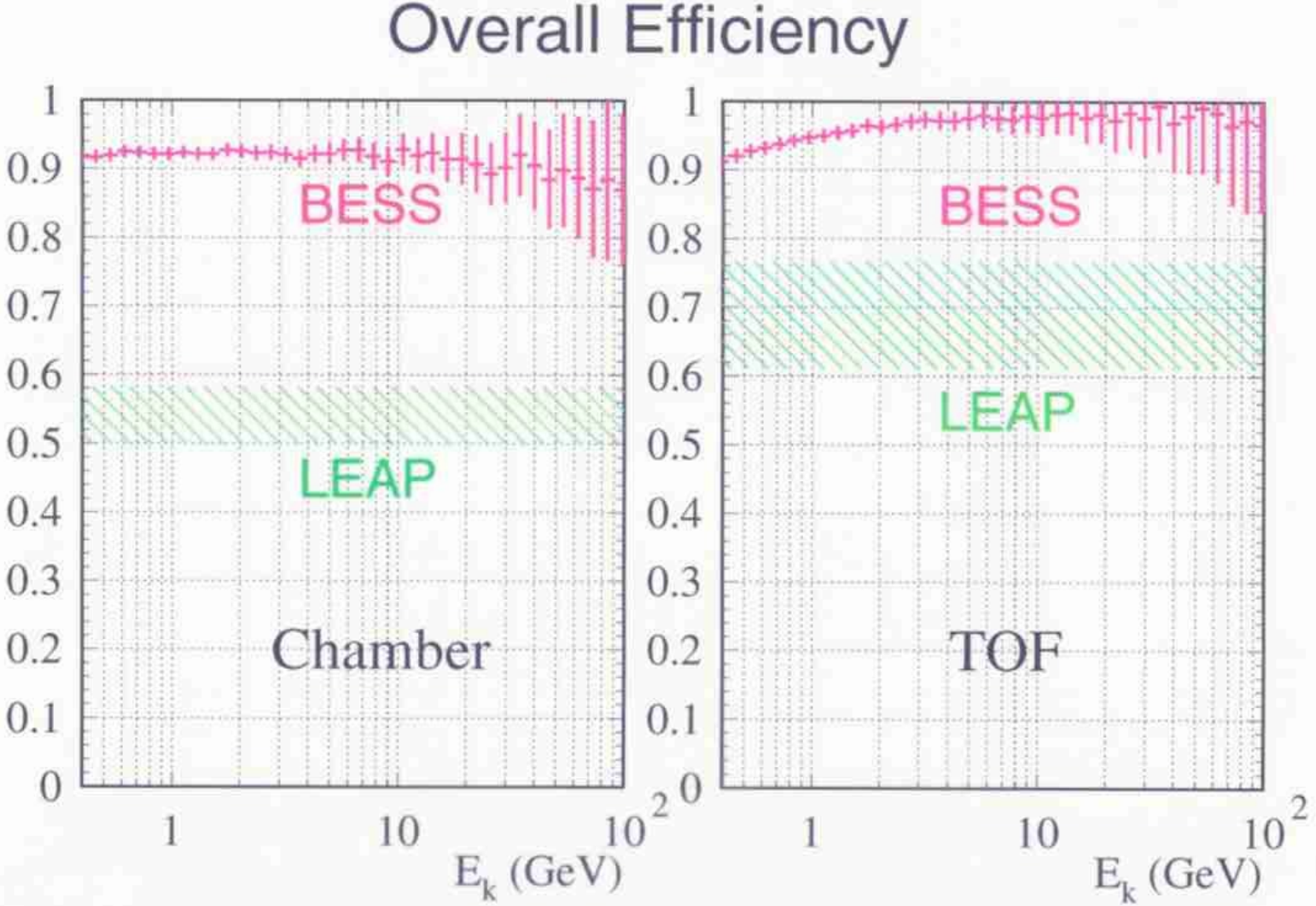
JET


BESS
Event # : 123169
Exp # : 9
Trigger : 00250011
Run # : 17
Event timing
001:20:26.8432
/scratch/bess/exp9/run17/dst/dst404_1.dat
Rigidity: 239.917GV
beta: 1.035
pathl:1375.0mm
Kappa: .648E-06
Phi0 : .505E+01
D0 : -.545E+02
Z0 : .374E+02
DZDS : .245E+00
RGDT: 231.383GV
dRGDT: 189.299GV
chisq1: .69
chisq2: 4.25
chisqj: .80
dE/dxU: .96
dE/dxL: 1.07
dE/dxJ: 1.51
masstf:******GeV
massde:******GeV
nuof U: 1
nlof L: 1
tofdzU:-17.8mm
tofdzL: -1.2mm
timeU: -3.50ns
timeL: .93ns
tofazU: -.036
tofazL: -.164
jcntrk: 1
jcntkg: 1
jcnht : 23
jcnght: 37
jcncht: 23
jcnshd: 24
jcncsd: 24
jcnrft: 23
jcncft: 23
jcnzft: 22
IDC
JET


BESS
Event # : 123169
Exp # : 9
Trigger : 00250011
Run # : 17
Event timing
001:20:26.8432
< /scratch/bess/exp9/run17/dst/dst404_1.dat
Rigidity: 239.917GV
beta: 1.035
path1:1375.0mm
Kappa: .648E-06
Phi0 : .505E+01
D0 : -.545E+02
Z0 : .374E+02
DZDS : .245E+00
RGDT: 231.383GV
dRGDT: 189.299GV
chisq1: .69
chisq2: 4.25
chisqj: .80
dE/dxU: .96
dE/dxL: 1.07
dE/dxJ: 1.51
masstf:******GeV
massde:******GeV
ntof U: 1
ntof L: 1
tofdzU:-17.8mm
tofdzL: -1.2mm
timeU: -3.50ns
timeL: .93ns
tofazU: -.036
tofazL: -.164
jcntrk: 1
jcntkg: 1
jcnht : 23
jcnght: 37
jcncht: 23
jcnshd: 24
jcncsd: 24
jcnrft: 23
jcncft: 23
jcnzft: 22
JET
IDC


BESS
Event # : 123169
Exp # : 9
Trigger : 00250011
Run # : 17
Event timing
001:20:26.8432
/scratch/bess/exp9/run17/dst/dst404_1.dat
Rigidity: 239.917GV
beta: 1.035
pathl:1375.0mm
Kappa: .648E-06
Phi0 : .505E+01
D0 : -.545E+02
Z0 : .374E+02
DZDS : .245E+00
RGDT: 231.383GV
dRGDT: 189.299GV
chisq1: .69
chisq2: 4.25
chisqj: .80
dE/dxU: .96
dE/dxL: 1.07
dE/dxJ: 1.51
masstf:******GeV
massde:******GeV
ntof U: 1
ntof L: 1
tofdzU:-17.8mm
tofdzL: -1.2mm
timeU: -3.50ns
timeL: 93ns
tofazU: -.036
tofazL: -.164
IDC
jcntrk: 1
jcntkg: 1
jcnht : 23
jcnght: 37
jcncht: 23
jcnshd: 24
jcncsd: 24
jcnrft: 23
jcncft: 23
jcnzft: 23
COIL
ODC
1.067
2.17
1.190
-.32
13.
2.

High Efficiency ~90%



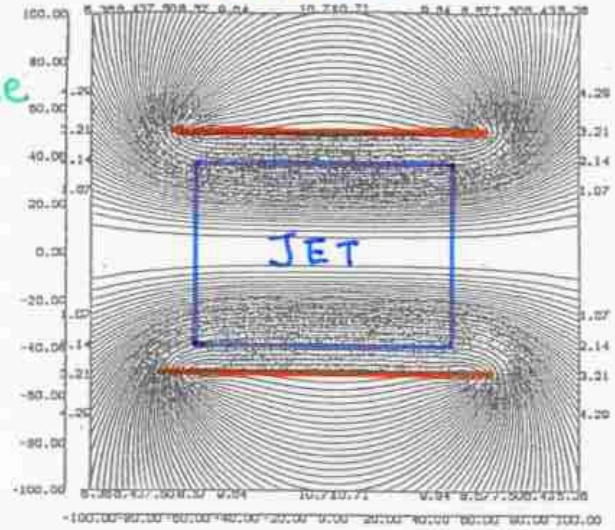
Seo et al
ApJ 378
763 (1991)

→ Small Sys. Error!

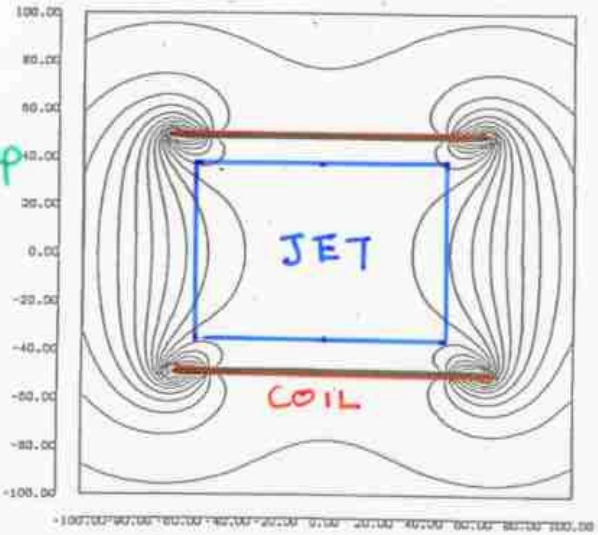
Uniform B

BESS

Flux Line

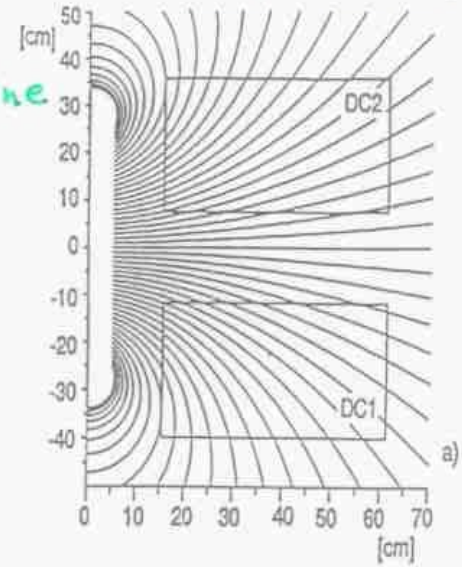


Field Counter Map

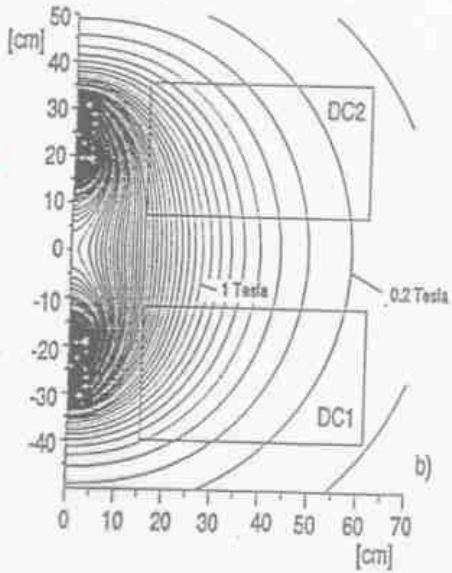


LEAP, MASS, IMAX, CAPRICE

Flux Line

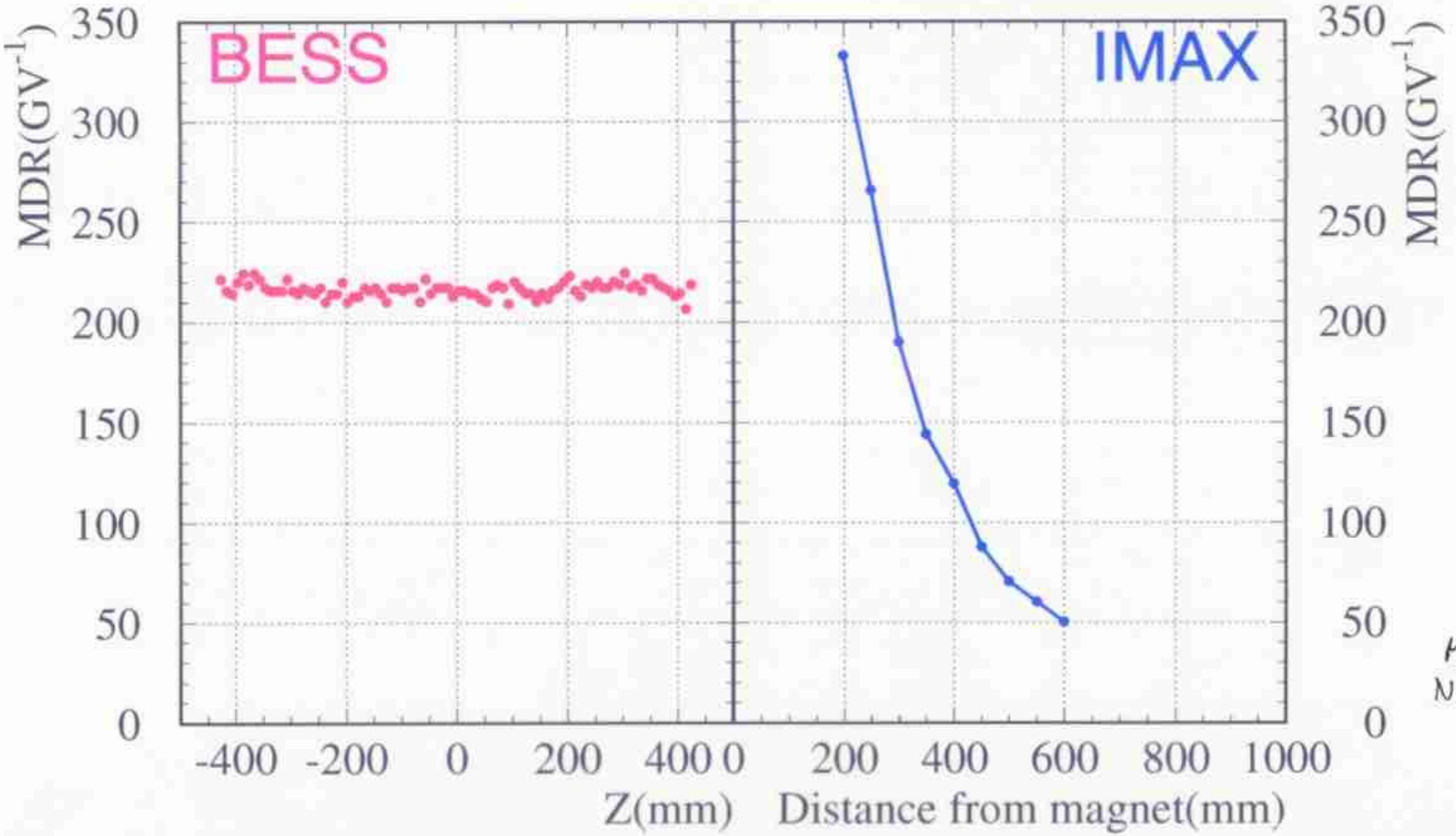


Field Counter Map



M Hof ~~abel~~
NIM A345
561 C1994)

MDR (determined during fitting process)



M. Hof et al.
NIM A 345
561 (1994

uniform

positron dependent

BESS

- Simple Cylindrical Geometry
- Uniform B

  Easy to determine $S\Omega$

- Long track
- 32 points (@ max) measurement

  Easy to determine absolute Rigidity

  Easy to see interacted or not

- High Efficiency

$\Rightarrow$ Small Systematic Error

Magnet ON
7 17 98

B82A7 #28
'97#

/scratchdisc1_03/exp14/run19/da601.hbook1

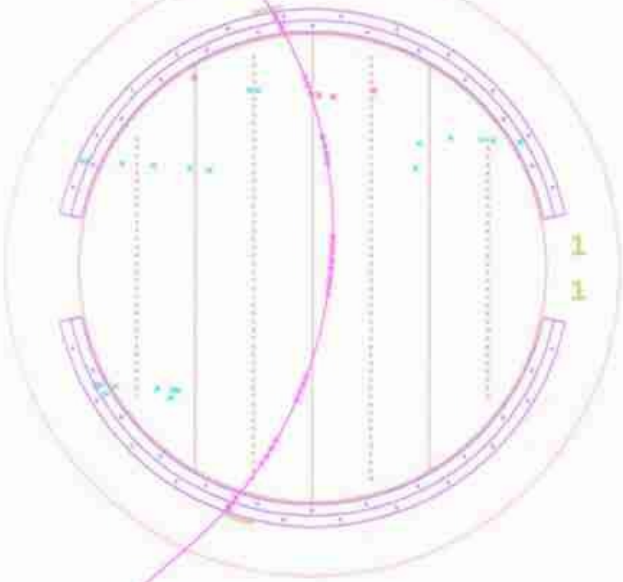
Run 19 Event No: 813158 Trigger : 00000101 Event timing
CAMAC : 140 FADC : 912 449:02:33.6203

TOF : 0001
CHARGE : 00000000
NTRACK : 0
MASTER : 000000010000

1

Ntk: 1

TID : 1
β^{-1} : 1.211
RGDT: -.206GV
Nht/Nud:23/24= .96
N_{fit}:23 N_{fit}:20
χ^2_{rz}: 3.05 χ^2_r : .67



F : 00000001
T 47 G 30 N 0

1
1

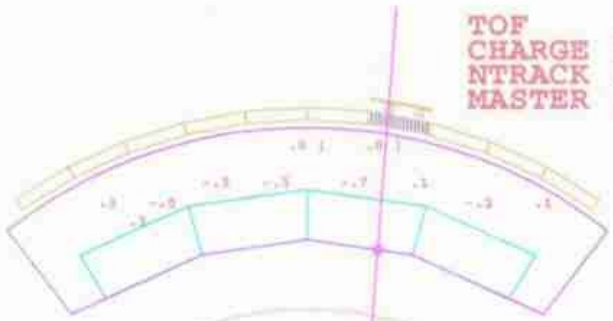
TID: 1
dE/dX_0: 2.190
dE/dX_1: 1.527
dE/dX_2: 1.271

1

/scratch/bess_03/exp14/run21/dst601.hbook2

Run 21 Event No: 1264399 Trigger : 00000101 Event timing
CAMAC : 132 FADC : 904 451:31:53.4353

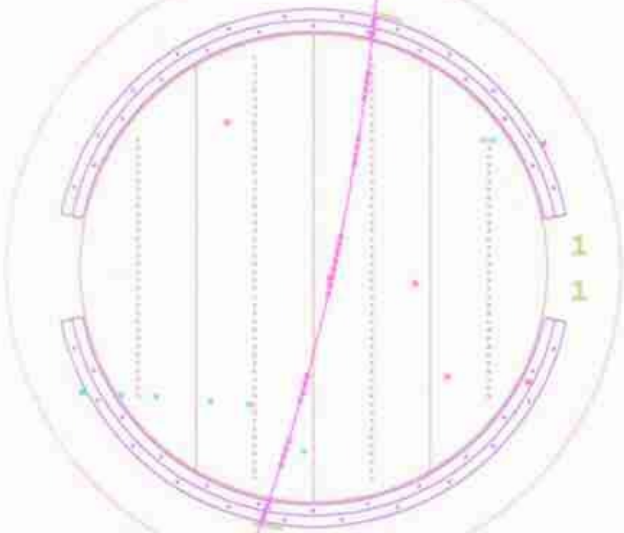
TOF : 0001
CHARGE : 00000000
NTRACK : 0
MASTER : 000000010000



1

Ntk: 1

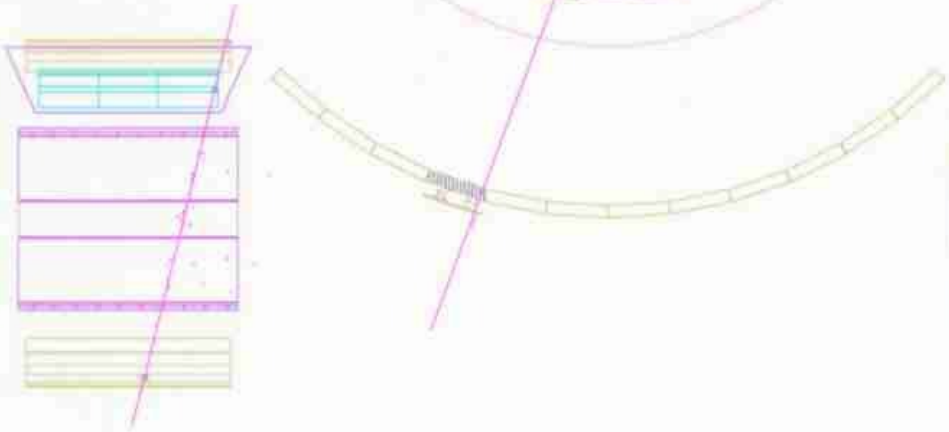
TID : 1
β^{-1} : 1.324
RGDT: -1.090GV
Nht/Nad:24/24=1.00
N_{ztic}:24 N_{xtic}:20
χ^2_{my}: .90 χ^2_x : .85



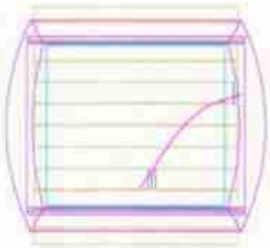
F : 00000001
T 42 G 27 N 0

1
1

TID: 1
dE/dX_0: 1.566
dE/dX_1: 1.553
dE/dX_y: 1.349



1



/scratch/bes_03/exp14/rm14/dst601.hbook2

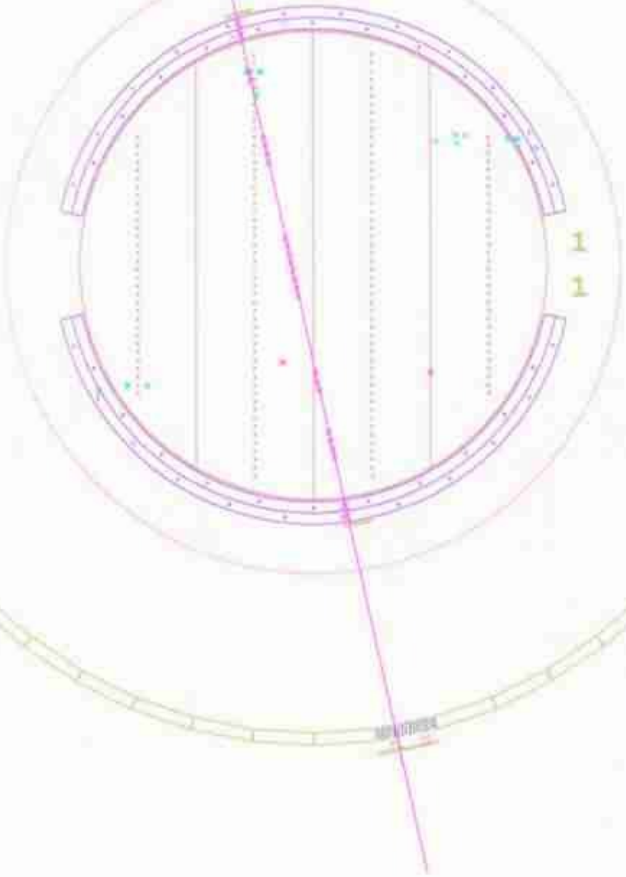
Run 14 Event No: 3500293 Trigger : 00000101 Event timing
CAMAC : 134 FADC : 928 445:01:42.5528

TOF : 0001
CHARGE : 00000000
NTRACK : 0
MASTER : 000000010000

1

Ntk: 1

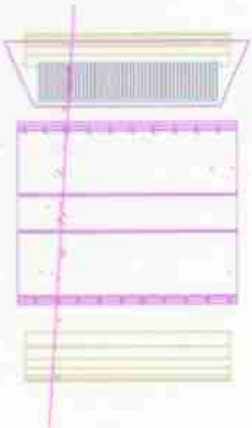
TID : 1
β^{-1} : 1.001
RIDT: 50.945GV
Nht/Nwd:23/24= .96
$N_{r\phi ix}$:21 N_{ztix}:15
$\chi^2_{r\phi}$: .58 χ^2_z : .79



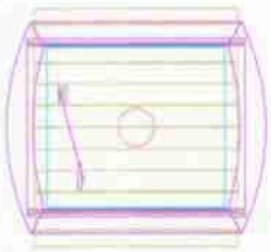
F : 00100000
T 0 G 0 N 0

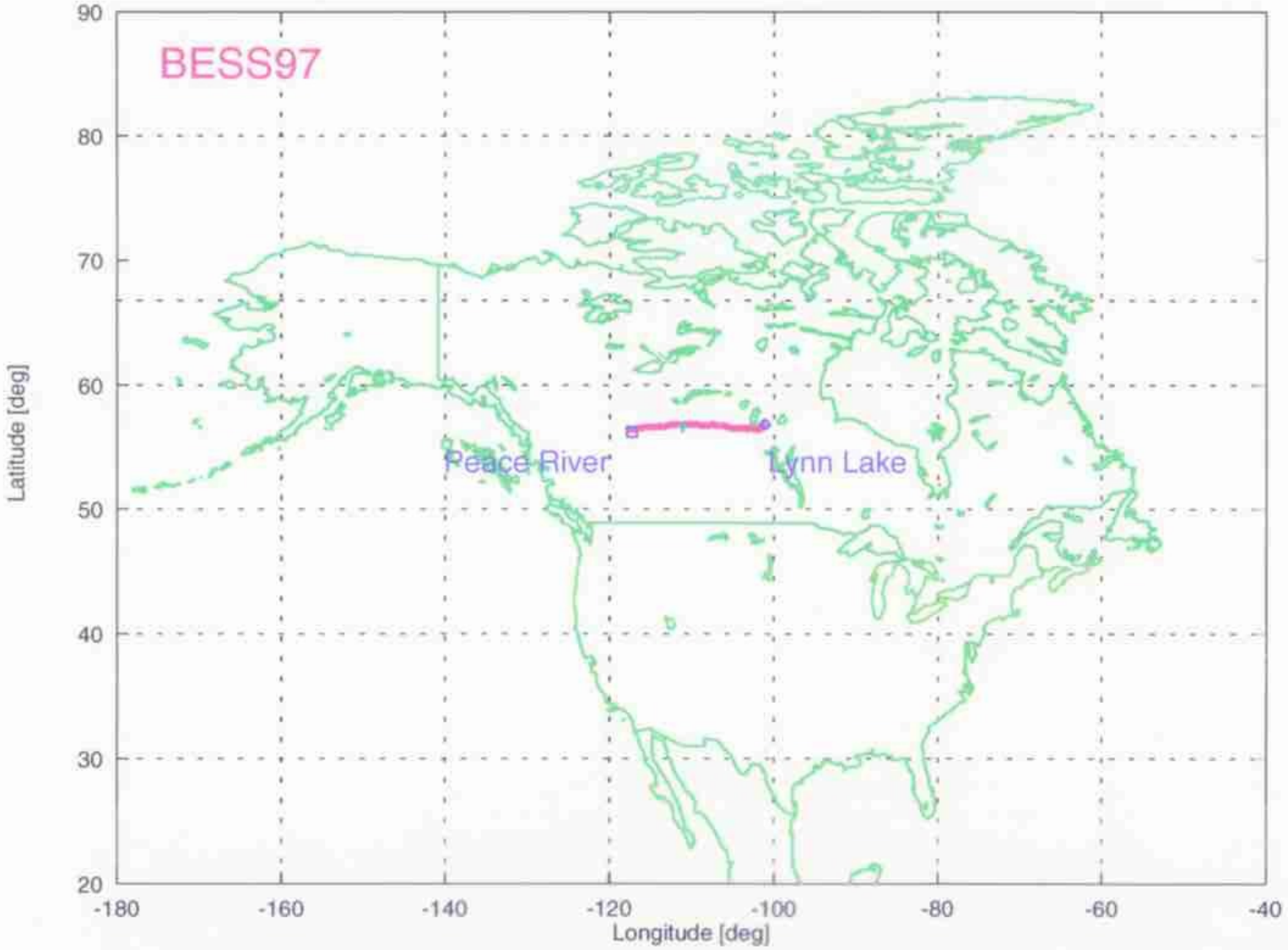
1
1

TID: 1
dE/dX_0: .982
dE/dX_1: 1.158
dE/dX_2: 1.465



1




BESS97
Peace River
Lynn Lake
Latitude [deg]
Longitude [deg]
90
80
70
60
50
40
30
20
-180
-160
-140
-120
-100
-80
-60
-40

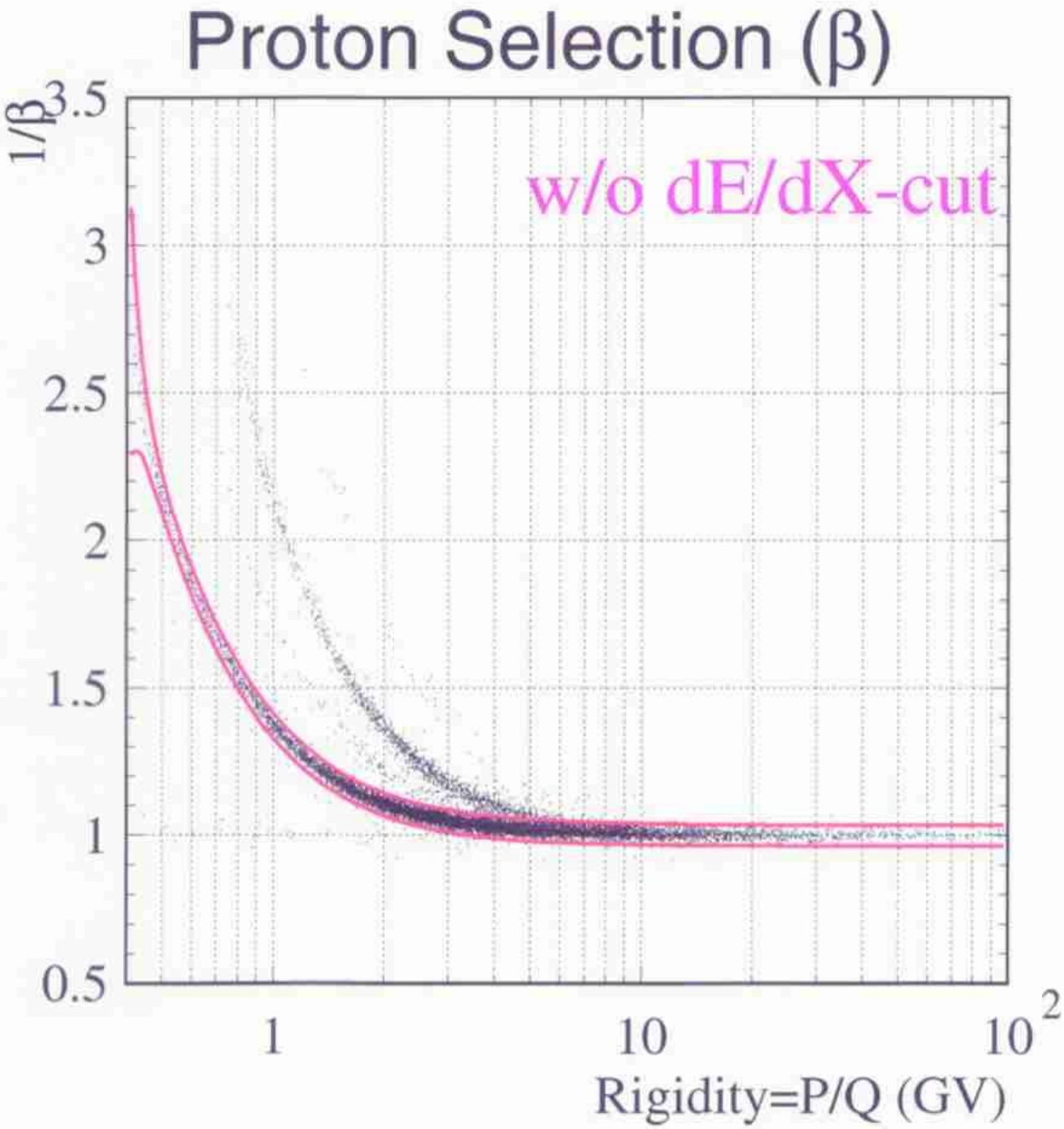
Ⅲ. Analysis (p BESS97)

① Select Single track events

② Track / TOF Quality Cut
- Check overall consistency

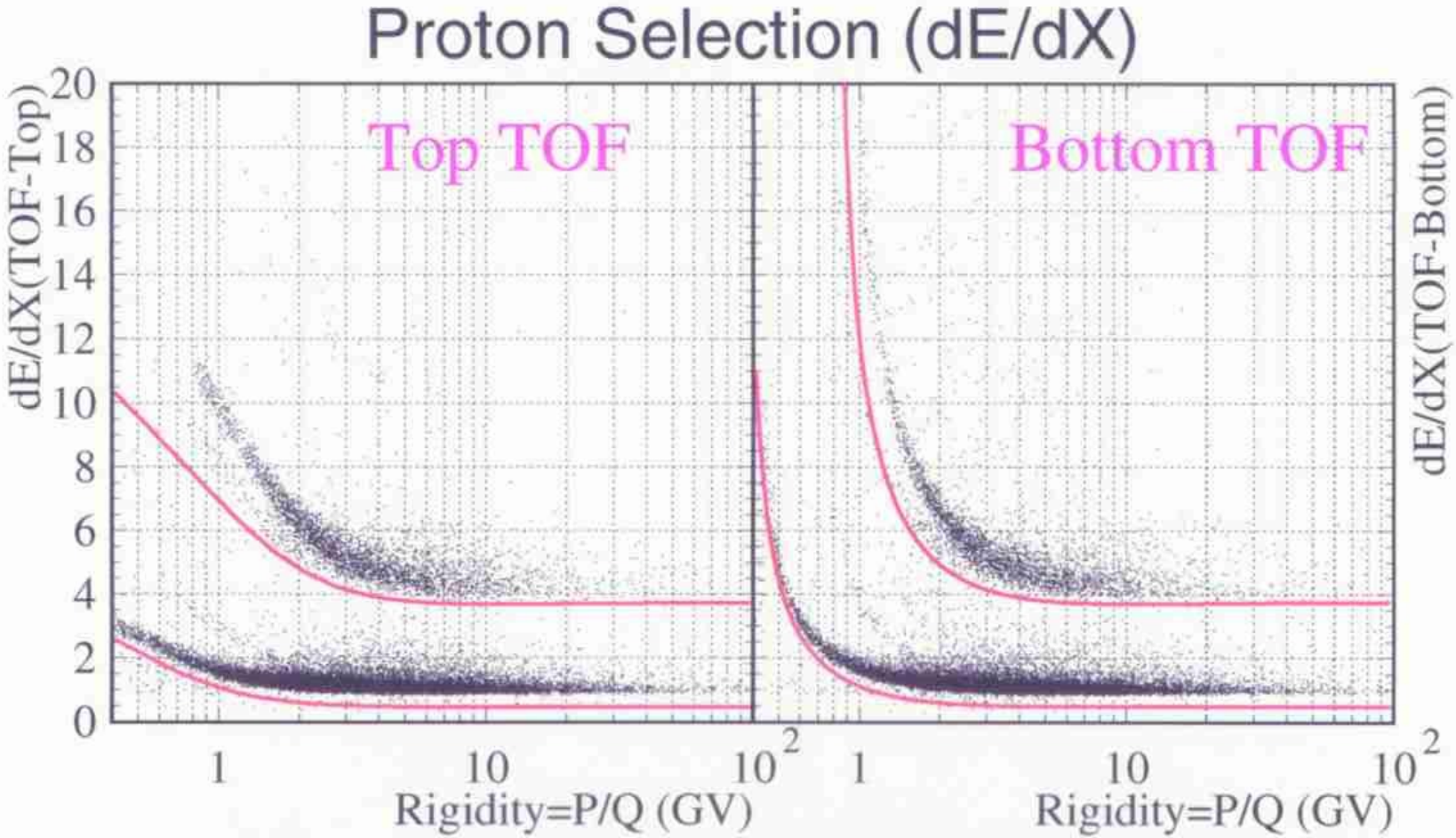
③ Proton Selection
- dE/dx, β

④ Corrections

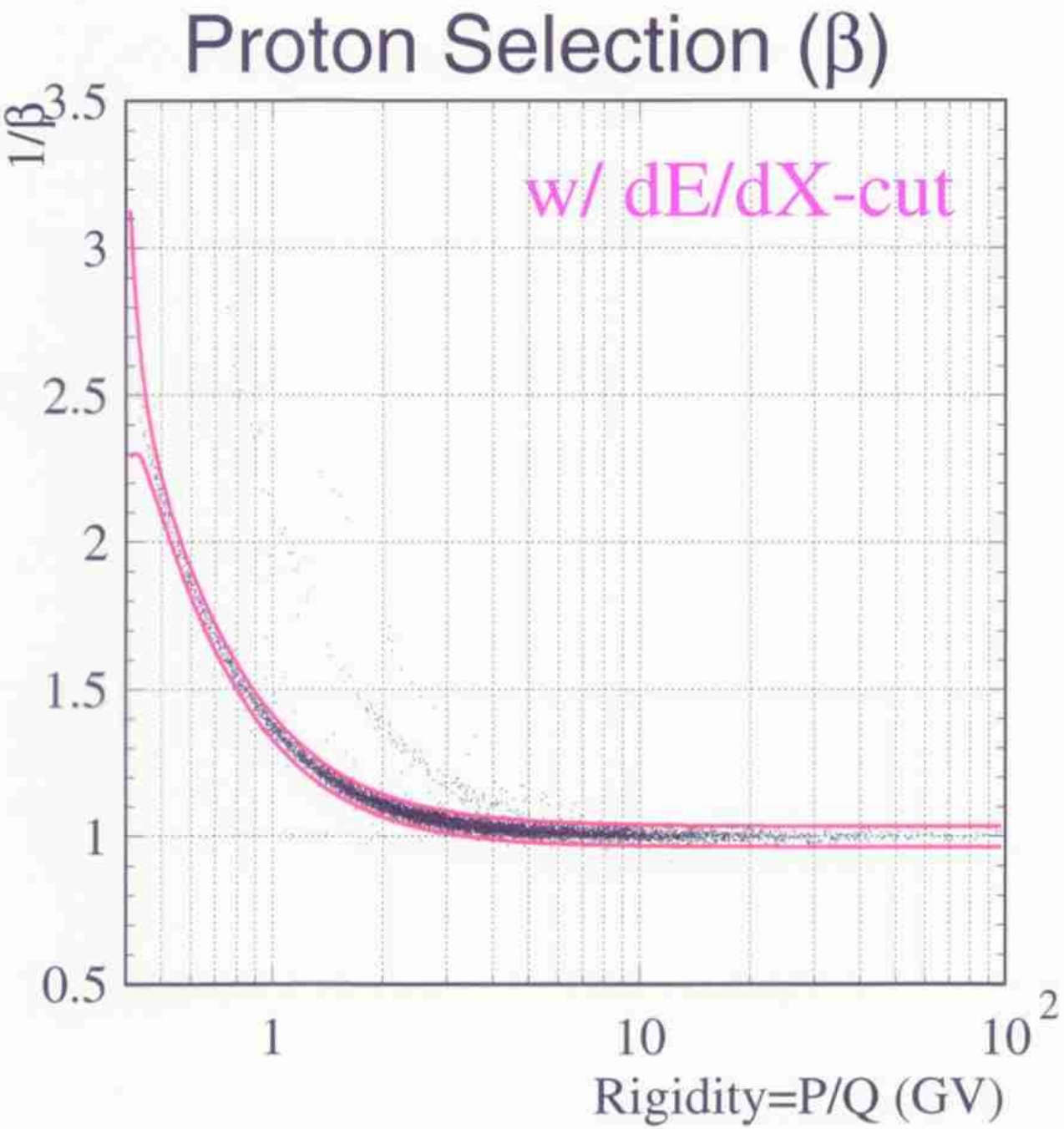

Proton Selection (β)
1/β
3.5
3
2.5
2
1.5
1
0.5
w/o dE/dX-cut
1
10
10^2
Rigidity=P/Q (GV)

3.89σ

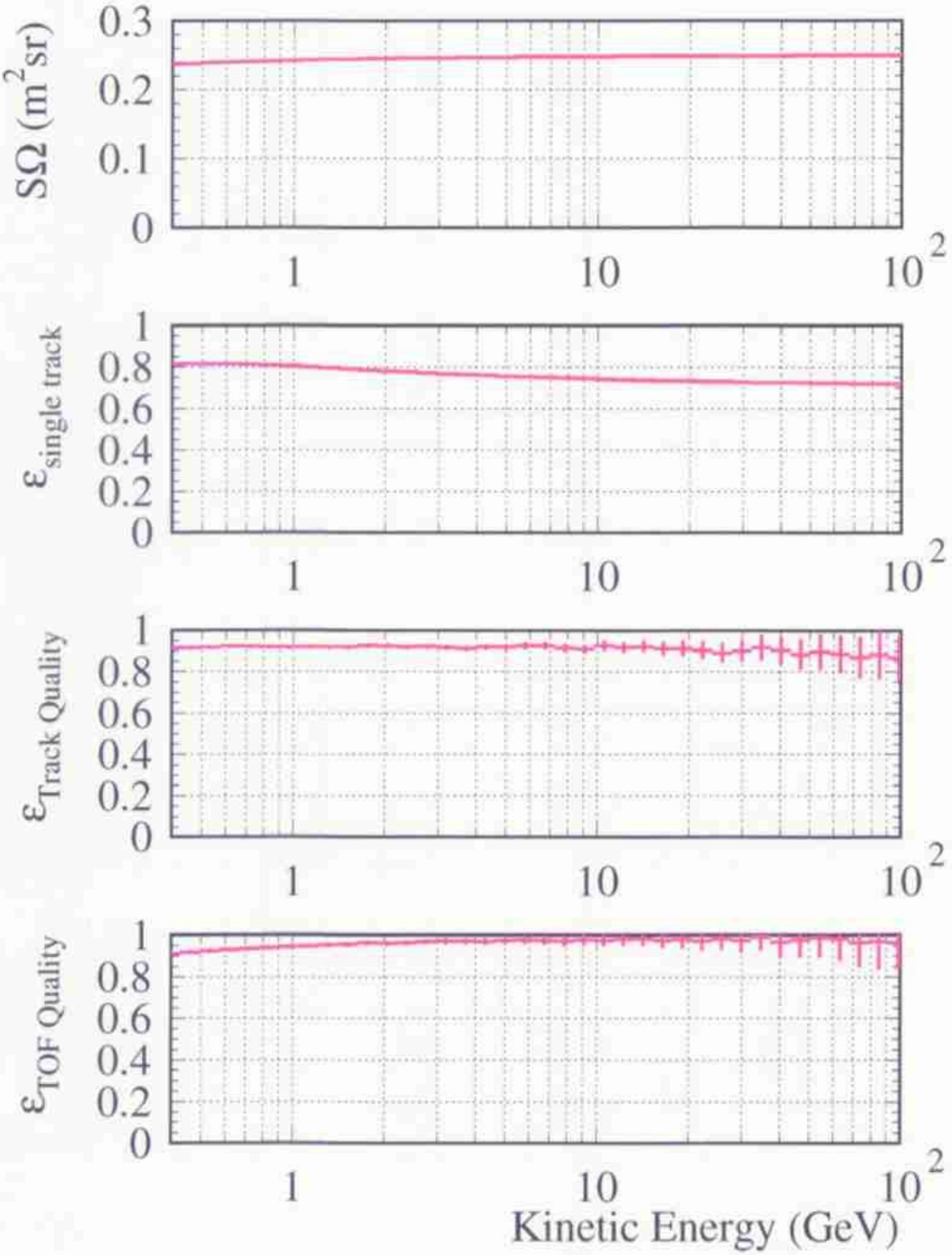
ε ~ 100%

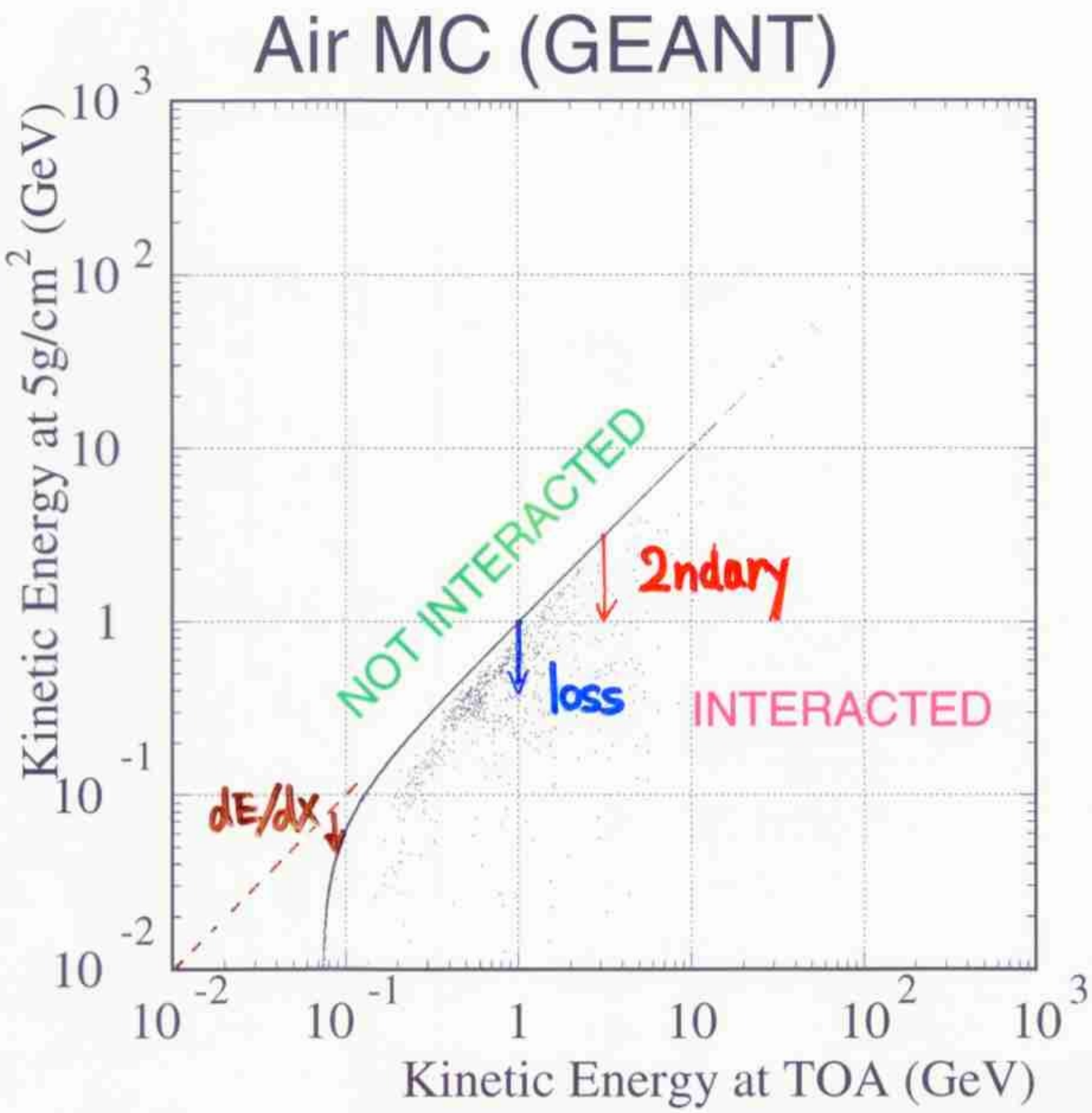


$\varepsilon \sim 95\%$


Proton Selection (β)
1/β
3.5
3
2.5
2
1.5
1
0.5
w/ dE/dX-cut
1
10
10^2
Rigidity=P/Q (GV)

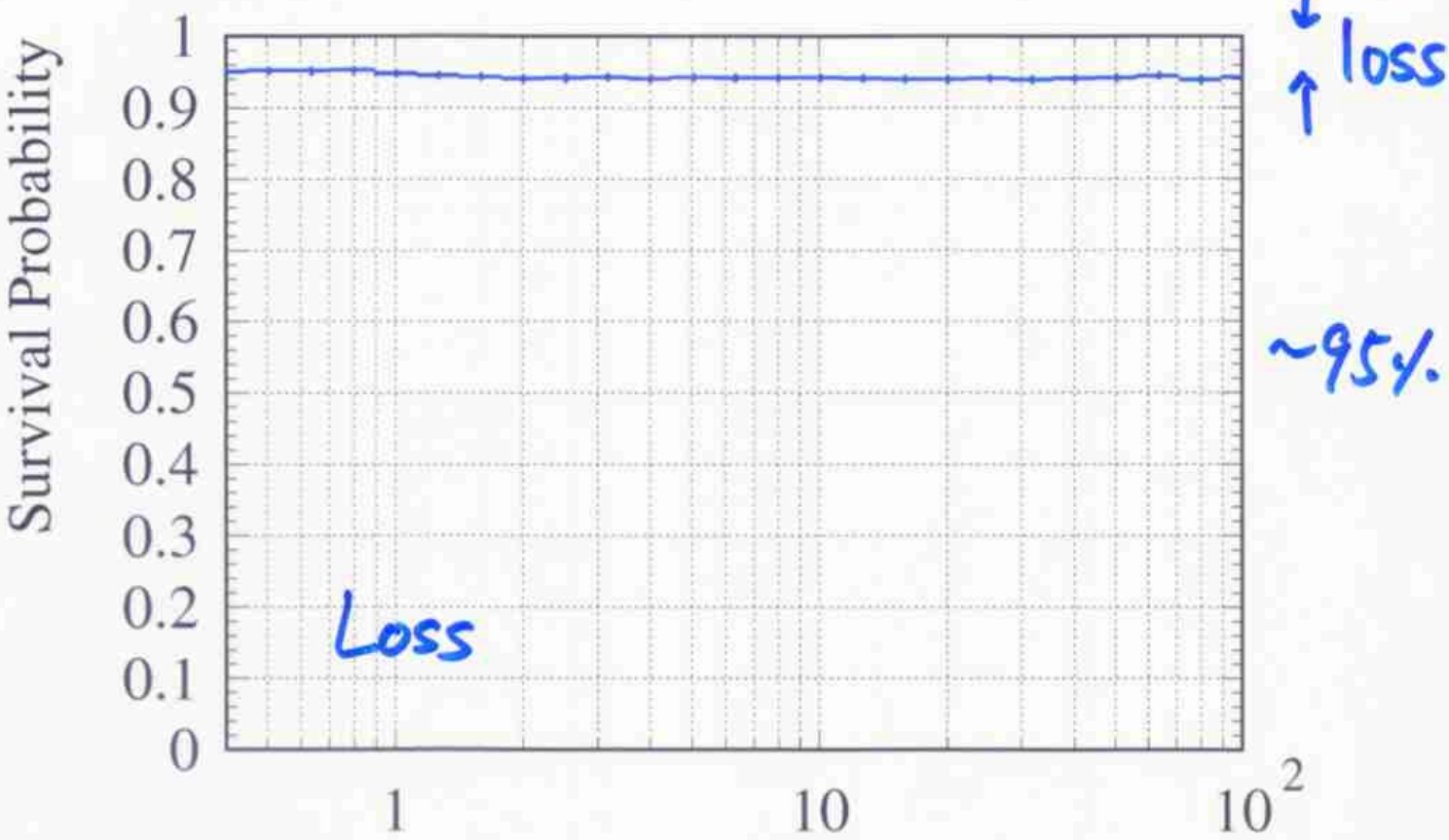
Corrections





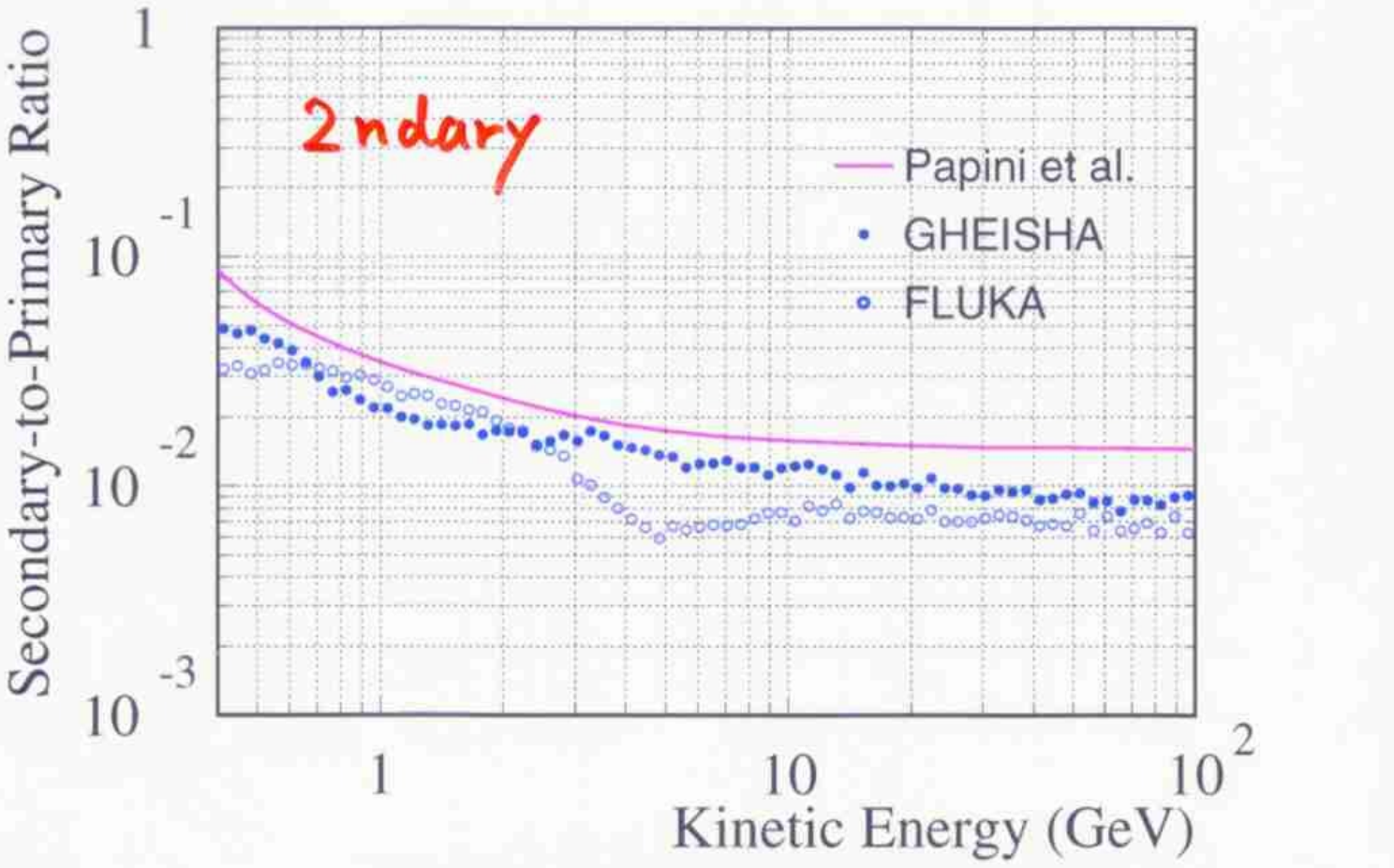
dE/dX : Calculated for each event

Air MC (GEANT)



↓ loss
↑

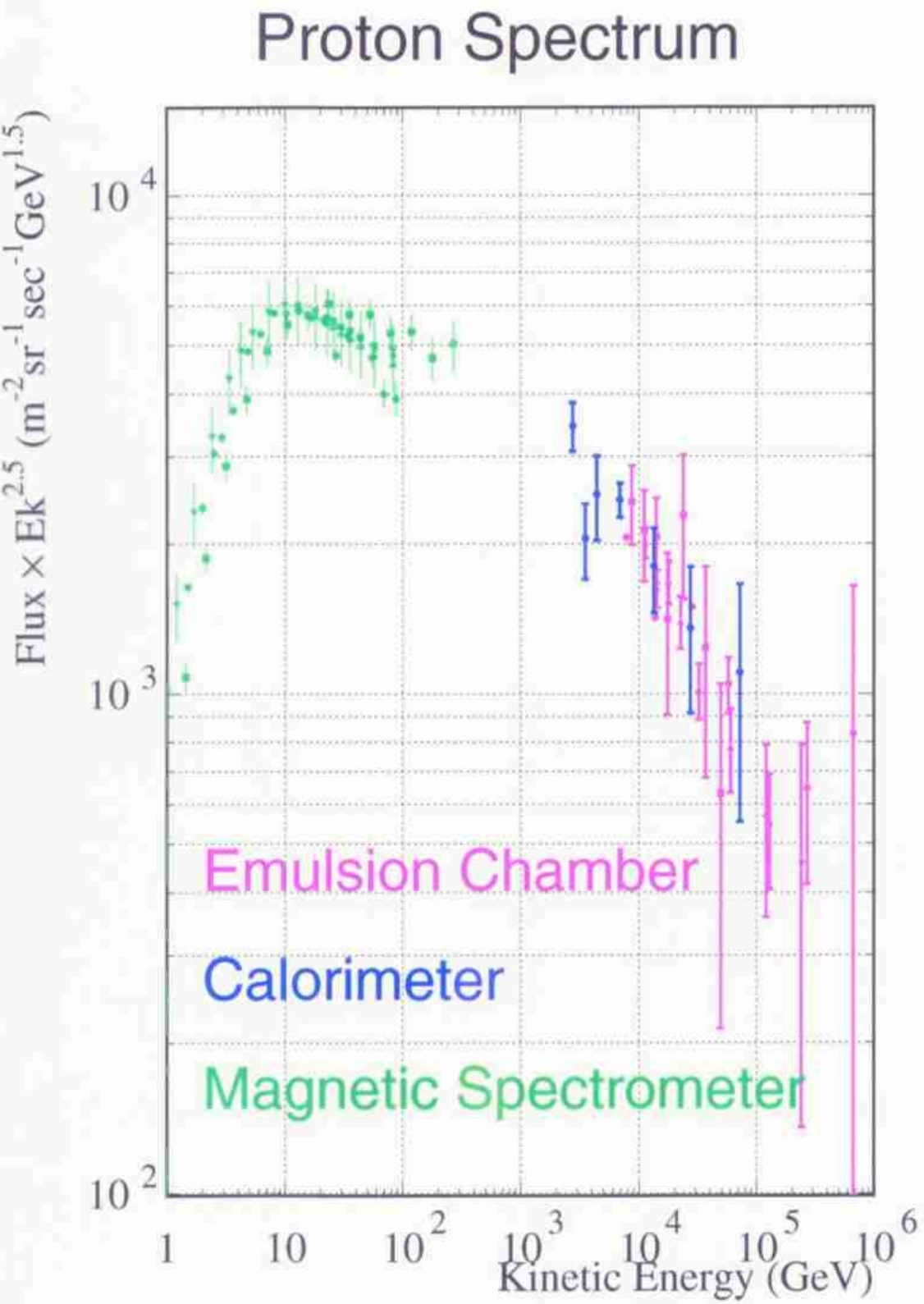
~95%

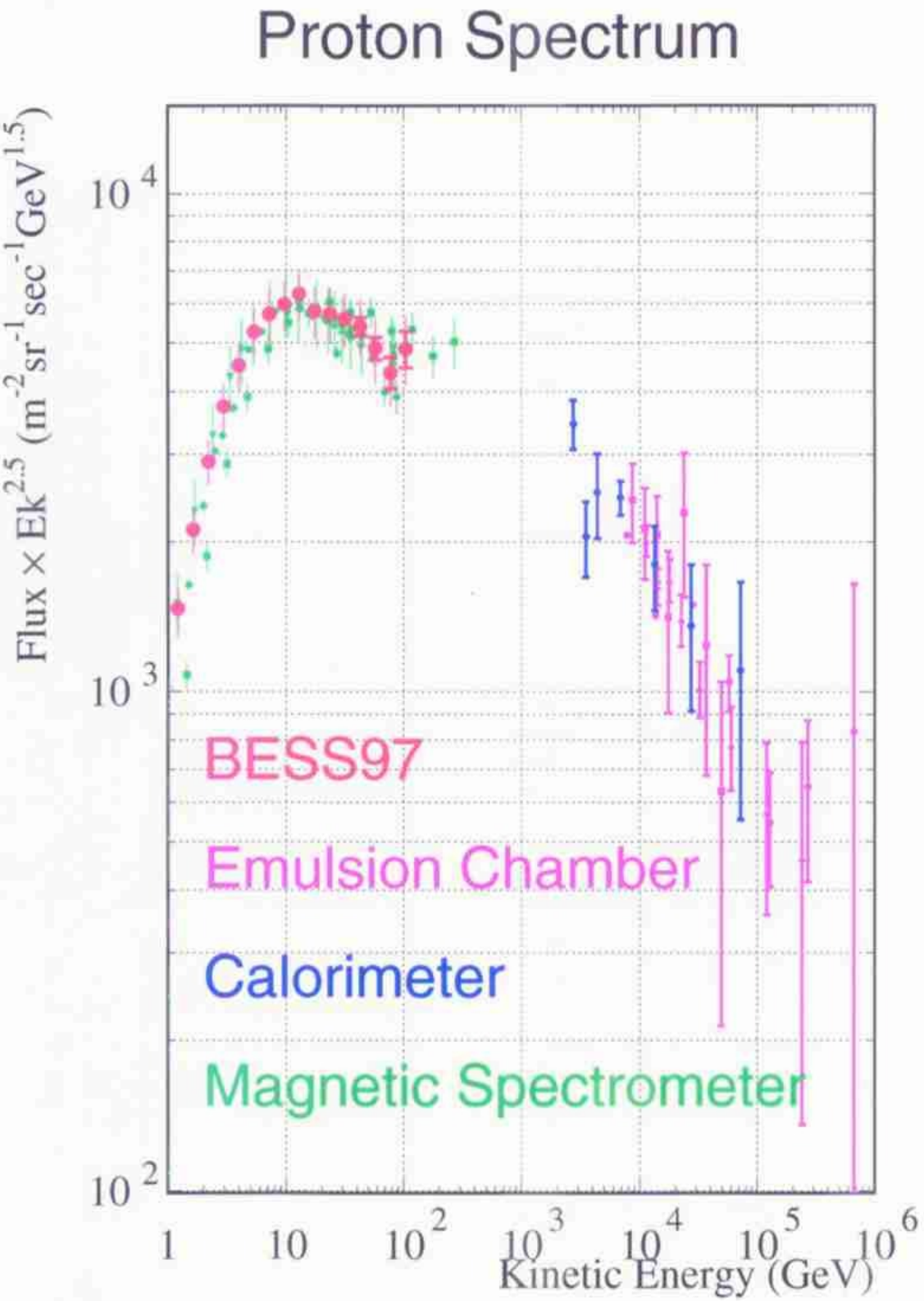


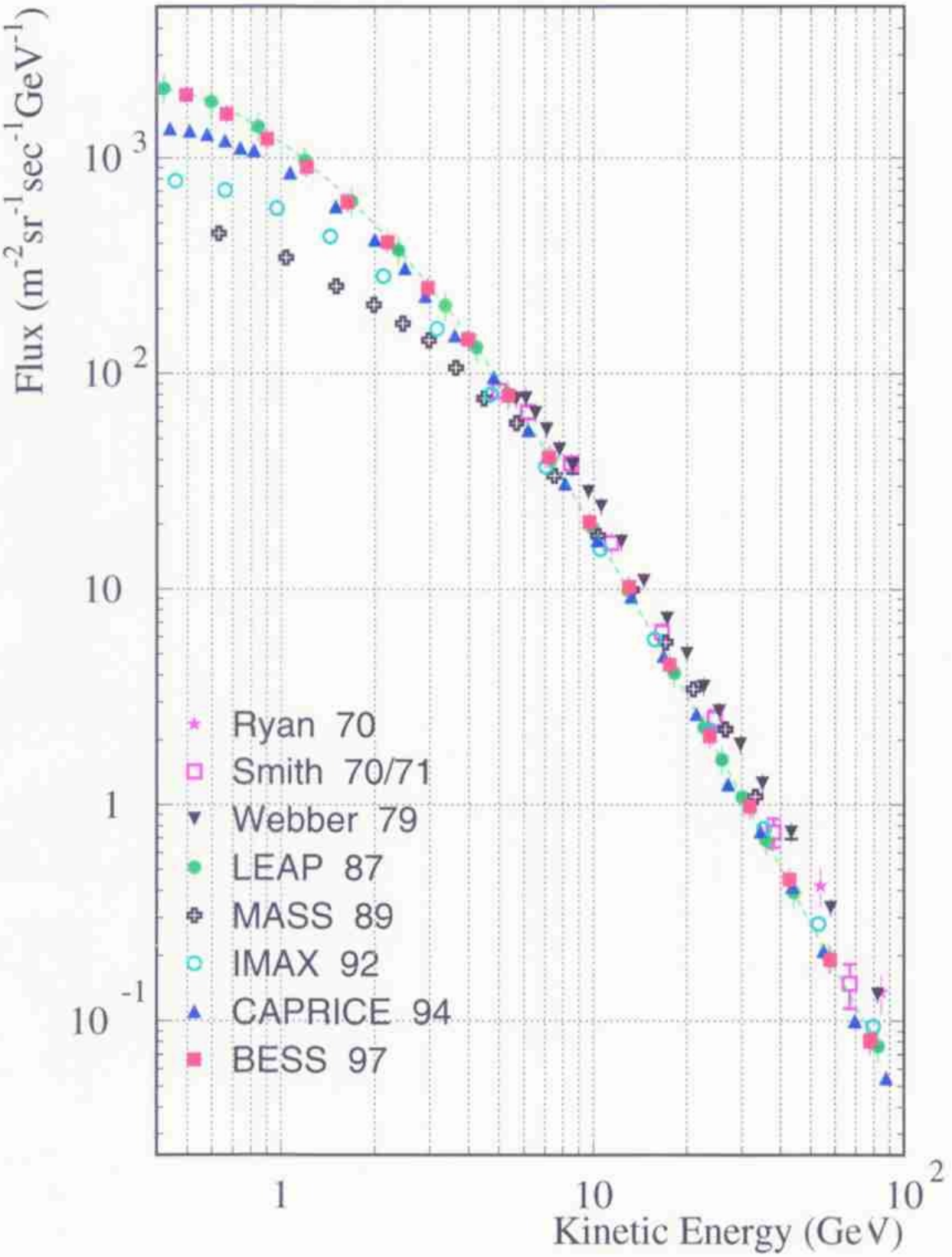
→ P flux @ ToA

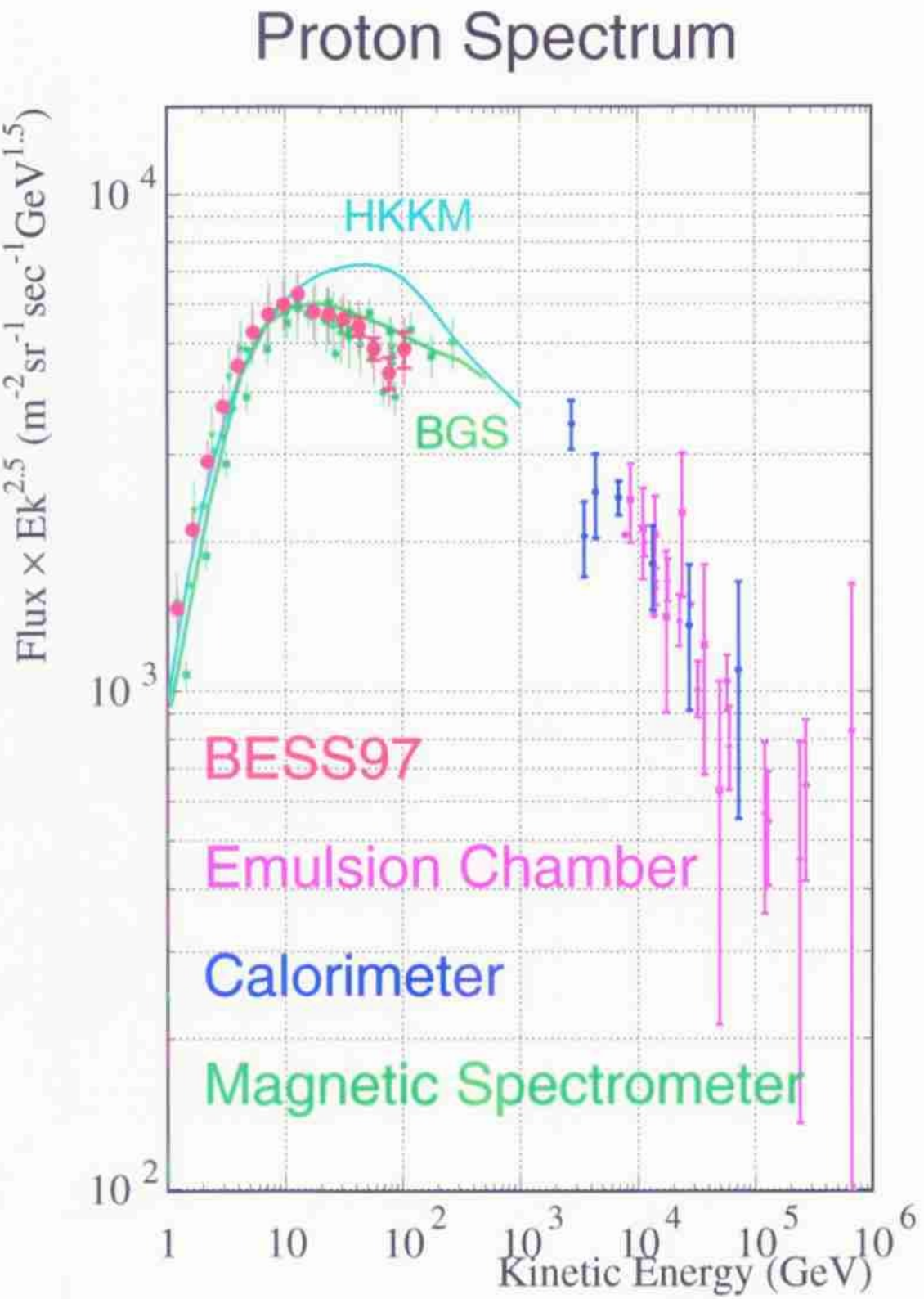
IV Results

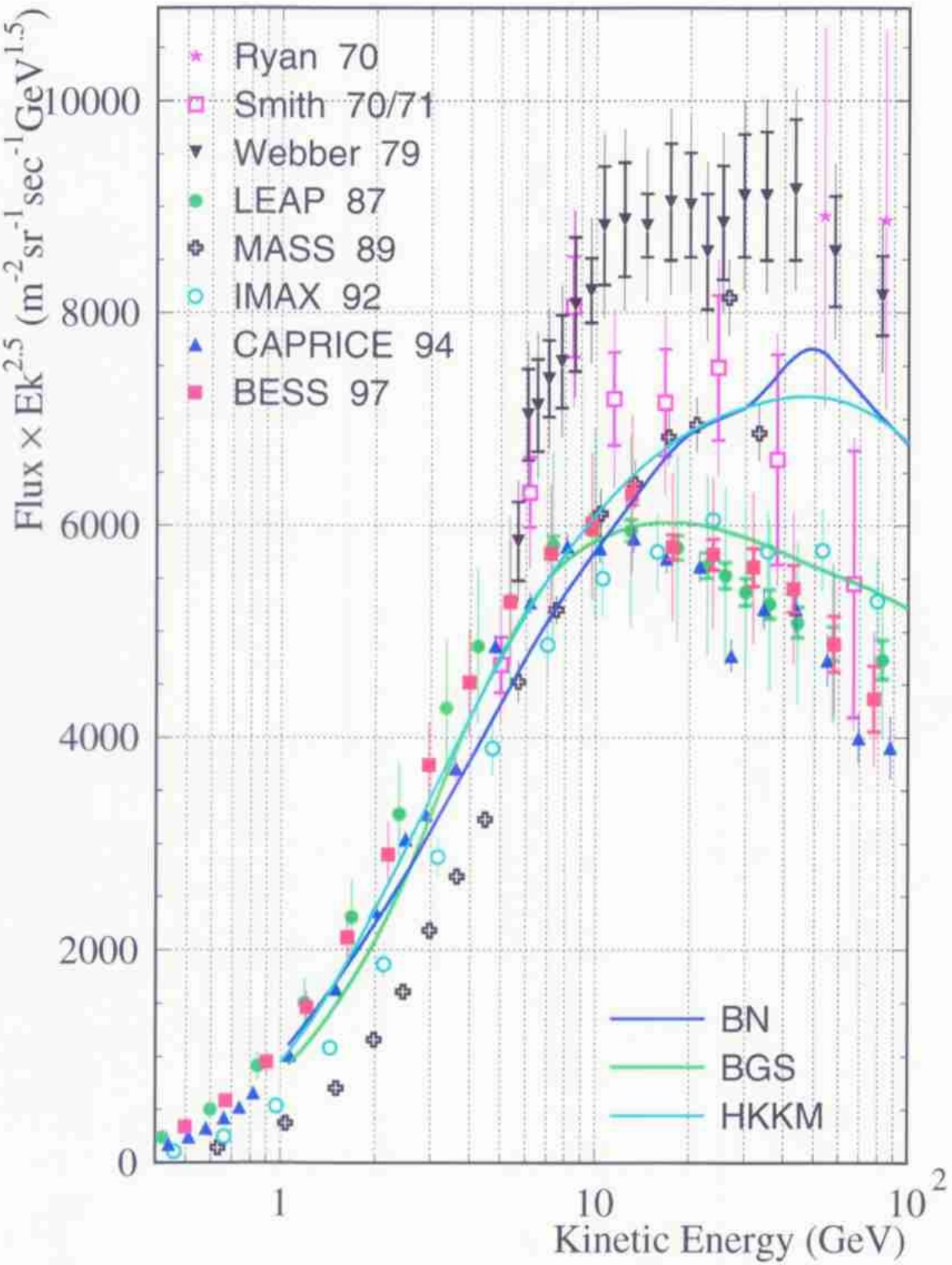
review

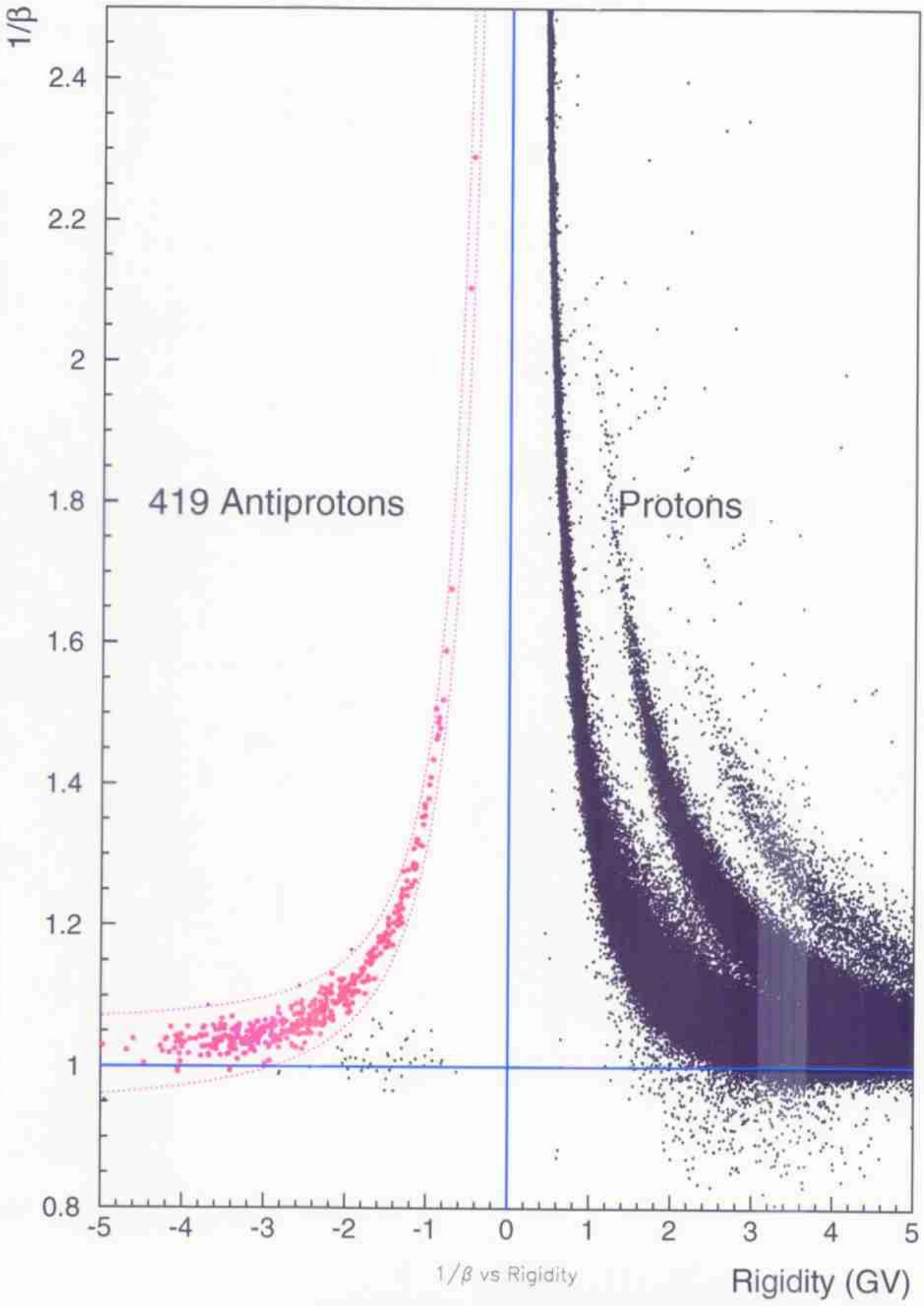

Proton Spectrum
Flux × Ek^2.5 (m^-2 sr^-1 sec^-1 GeV^1.5)
10^4
10^3
10^2
Emulsion Chamber
Calorimeter
Magnetic Spectrometer
1
10
10^2
10^3
10^4
10^5
10^6
Kinetic Energy (GeV)


Proton Spectrum
Flux × Ek^2.5 (m^-2 sr^-1 sec^-1 GeV^1.5)
10^4
10^3
10^2
BESS97
Emulsion Chamber
Calorimeter
Magnetic Spectrometer
1
10
10^2
10^3
10^4
10^5
10^6
Kinetic Energy (GeV)


Flux ($m^{-2}sr^{-1}sec^{-1}GeV^{-1}$)
10^3
10^2
10
1
10^{-1}
Ryan 70
Smith 70/71
Webber 79
LEAP 87
MASS 89
IMAX 92
CAPRICE 94
BESS 97
1
10
10^2
Kinetic Energy (GeV)


Proton Spectrum
Flux × Ek^2.5 (m^-2 sr^-1 sec^-1 GeV^1.5)
10^4
10^3
10^2
HKKM
BGS
BESS97
Emulsion Chamber
Calorimeter
Magnetic Spectrometer
1
10
10^2
10^3
10^4
10^5
10^6
Kinetic Energy (GeV)


Ryan 70
Smith 70/71
Webber 79
LEAP 87
MASS 89
IMAX 92
CAPRICE 94
BESS 97
BN
BGS
HKKM
Flux × Ek^2.5 (m^-2 sr^-1 sec^-1 GeV^1.5)
Kinetic Energy (GeV)
0
2000
4000
6000
8000
10000
1
10
10^2


1/β
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
-5
-4
-3
-2
-1
0
1
2
3
4
5
419 Antiprotons
Protons
1/β vs Rigidity
Rigidity (GV)

ν Ground μ

A Precise Measurement of the Flux of Atmospheric Muons at Sea-Level

Cut off Rigidity:
11.2GV (Tsukuba,JAPAN)
0.4GV (Lynn Lake,CANADA)

BESS collaboration

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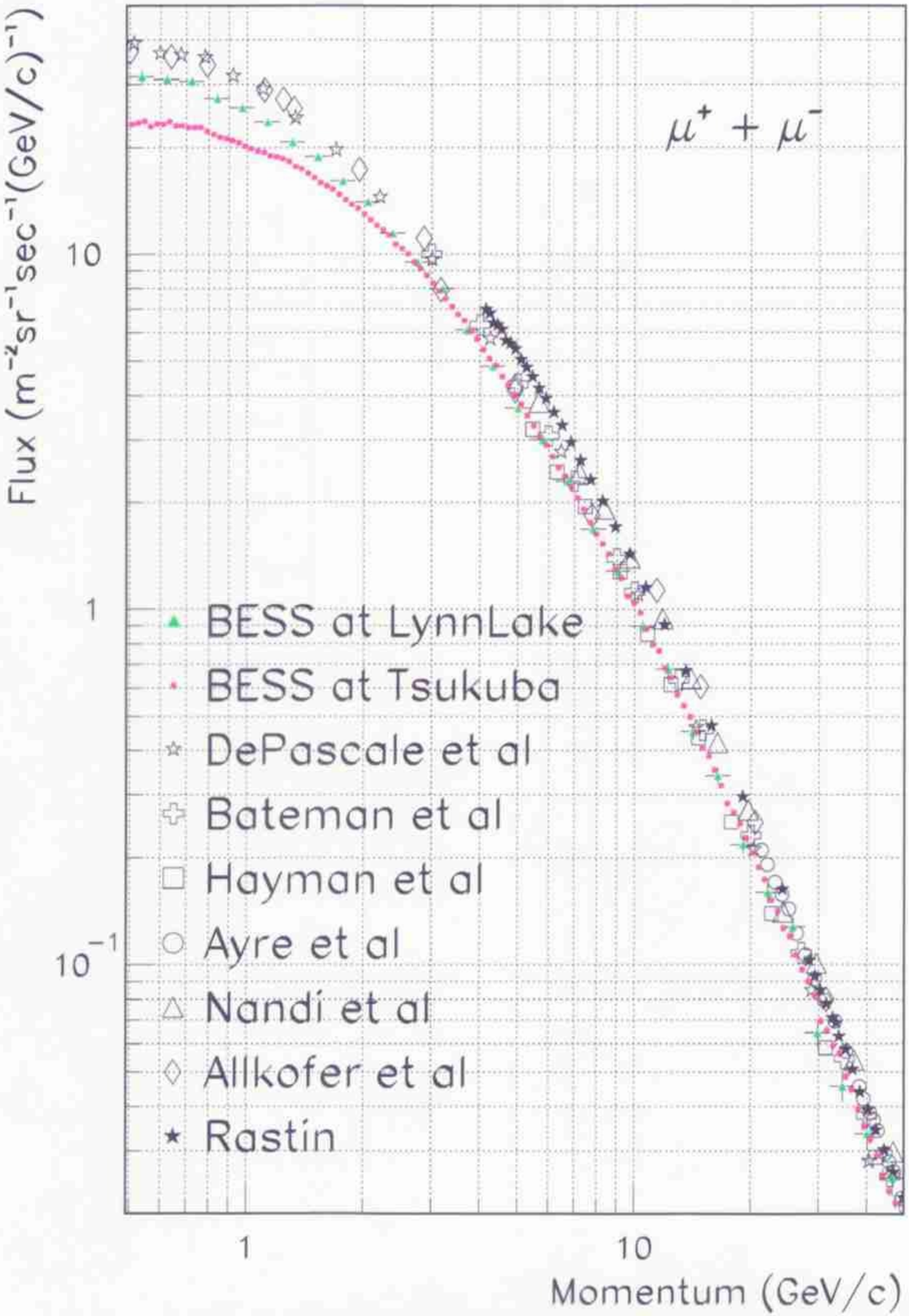
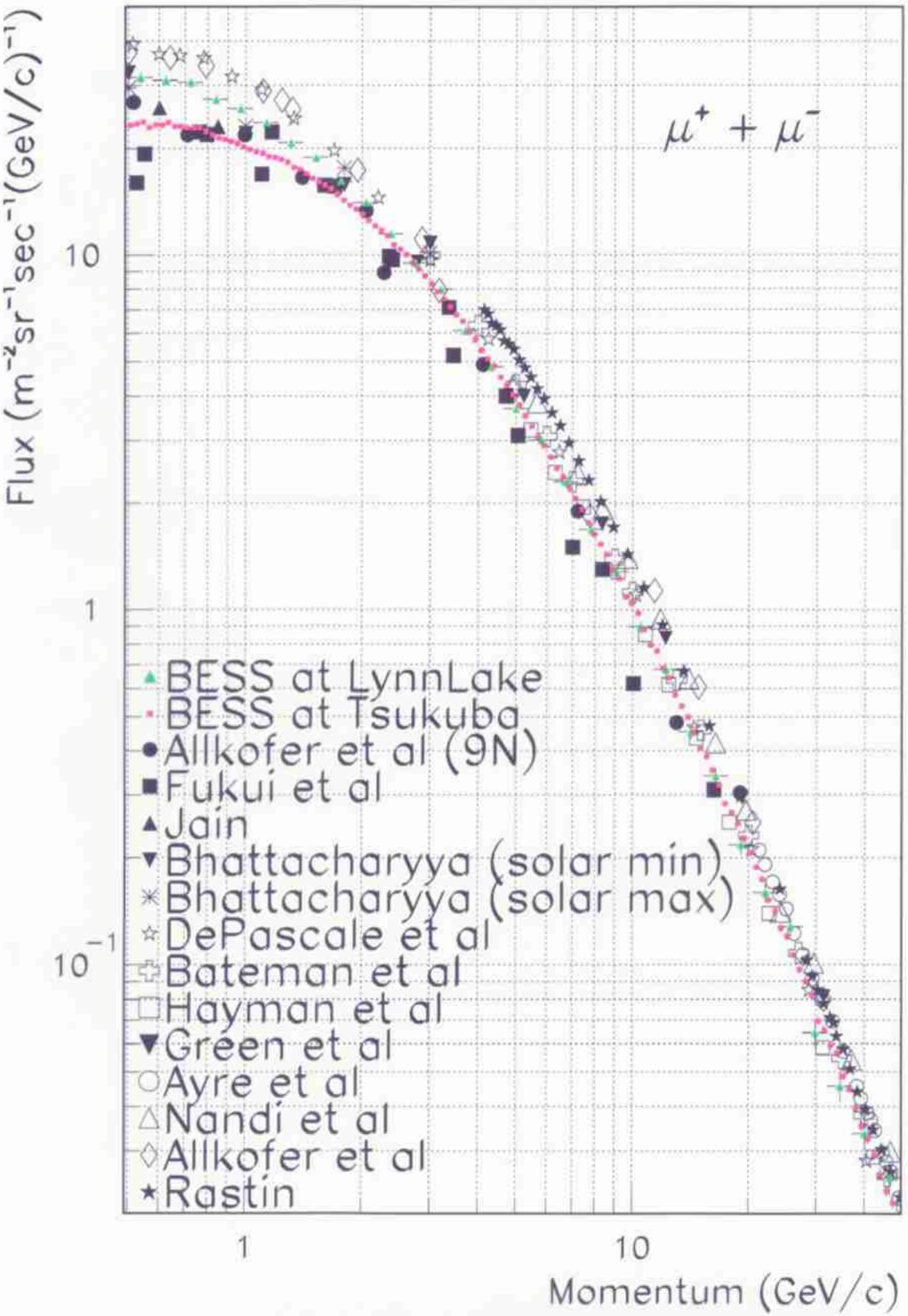
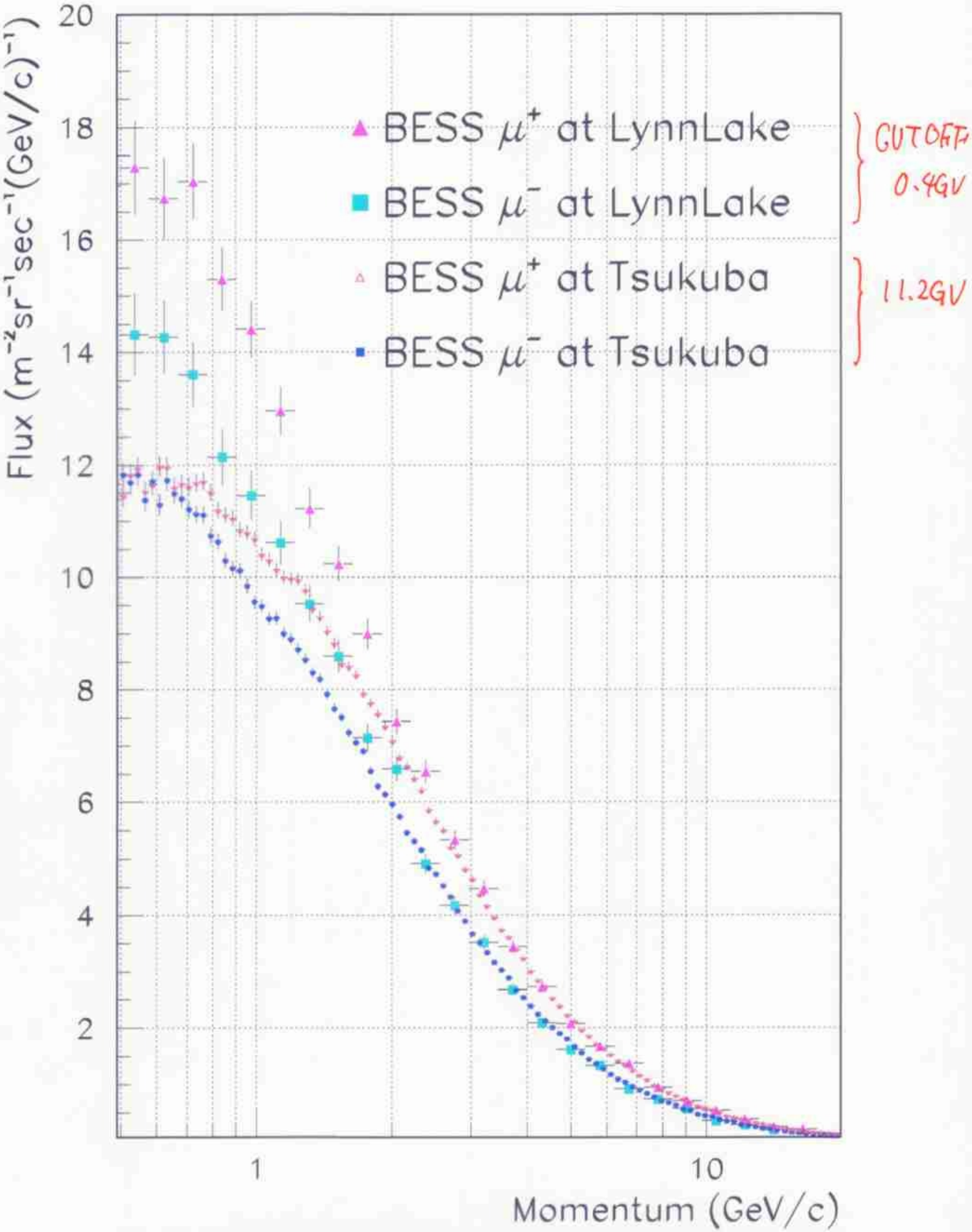
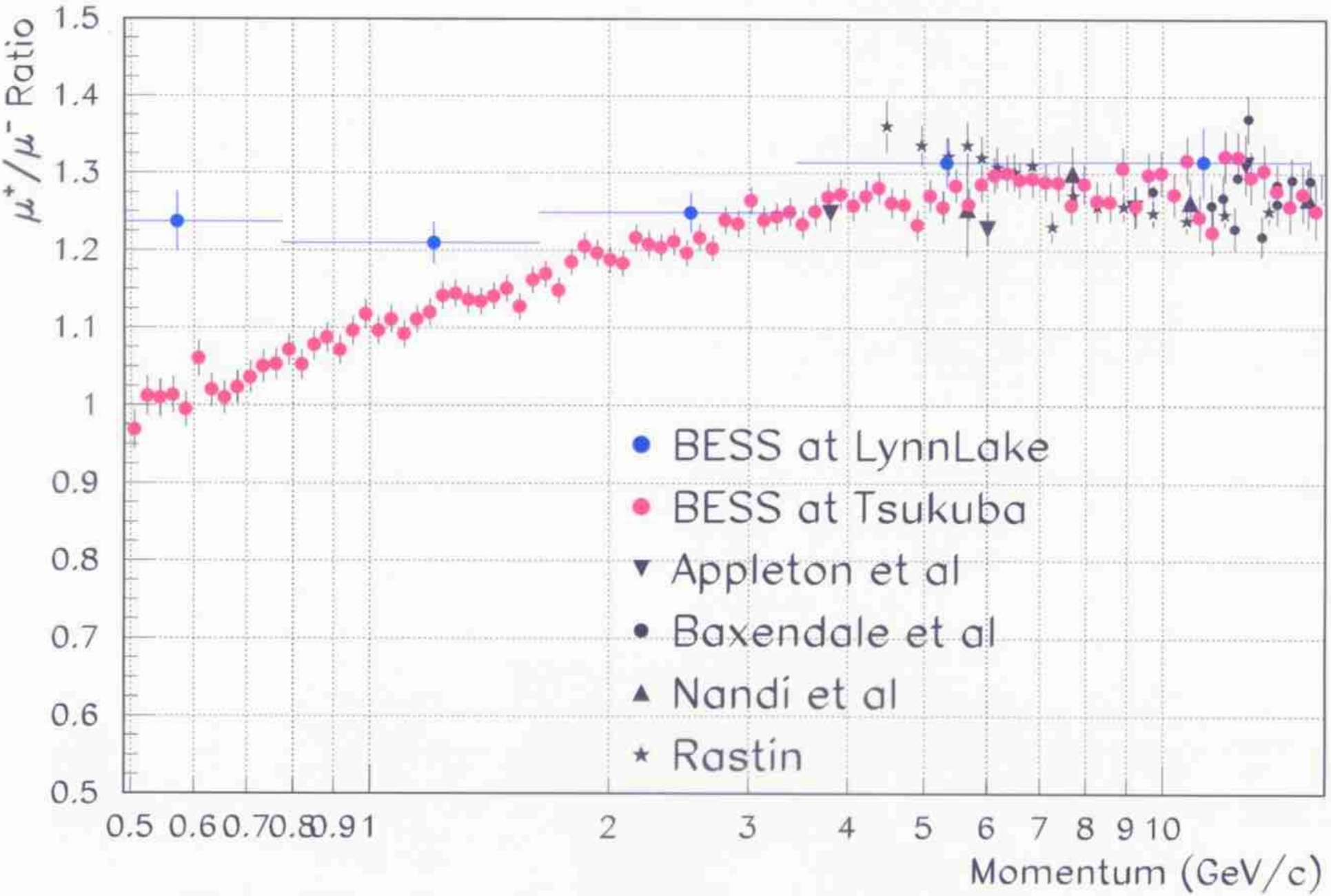
1998 June 12


$\mu^+ + \mu^-$
BESS at LynnLake
BESS at Tsukuba
DePascale et al
Bateman et al
Hayman et al
Ayre et al
Nandi et al
Allkofer et al
Rastin
Flux ($m^{-2}sr^{-1}sec^{-1}(GeV/c)^{-1}$)
Momentum (GeV/c)
10
1
10^{-1}
1
10


Flux ($m^{-2}sr^{-1}sec^{-1}(GeV/c)^{-1}$)
$\mu^+ + \mu^-$
10
1
10^{-1}
BESS at LynnLake
BESS at Tsukuba
Allkofer et al (9N)
Fukui et al
Jain
Bhattacharyya (solar min)
Bhattacharyya (solar max)
DePascale et al
Bateman et al
Hayman et al
Green et al
Ayre et al
Nandi et al
Allkofer et al
Rastin
1
10
Momentum (GeV/c)


Muon Flux
Flux ($m^{-2}sr^{-1}sec^{-1}(GeV/c)^{-1}$)
20
18
16
14
12
10
8
6
4
2
1
10
Momentum (GeV/c)
BESS μ^+ at LynnLake
BESS μ^- at LynnLake
BESS μ^+ at Tsukuba
BESS μ^- at Tsukuba
CUTOFF
0.4GV
11.2GV


μ^+/μ^- Ratio
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.5 0.6 0.7 0.8 0.9 1
2
3
4
5
6
7
8
9 10
Momentum (GeV/c)
BESS at LynnLake
BESS at Tsukuba
Appleton et al
Baxendale et al
Nandi et al
Rastin

Systematic Error

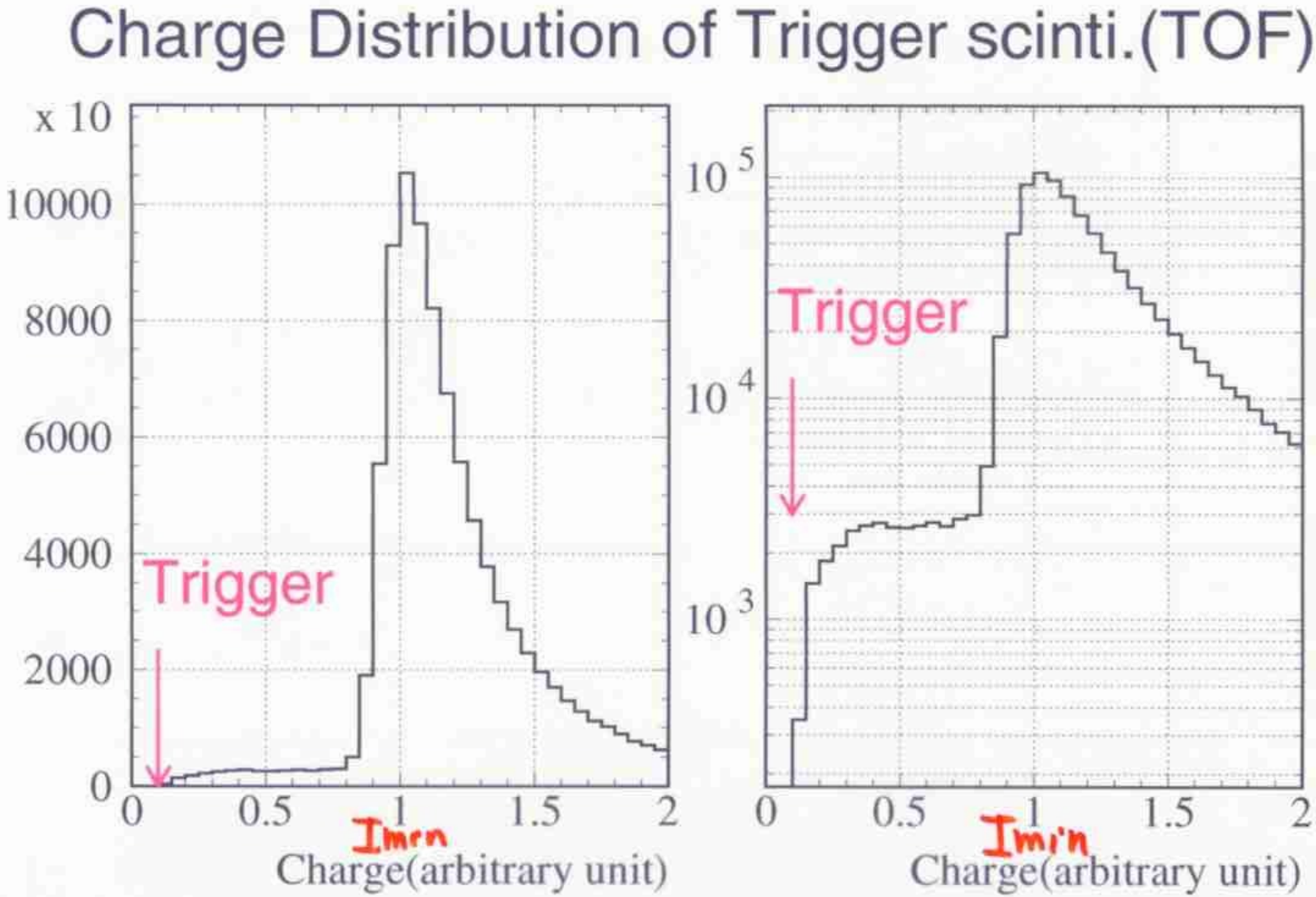
Possible Source

1. Trigger Efficiency

2. Live Time

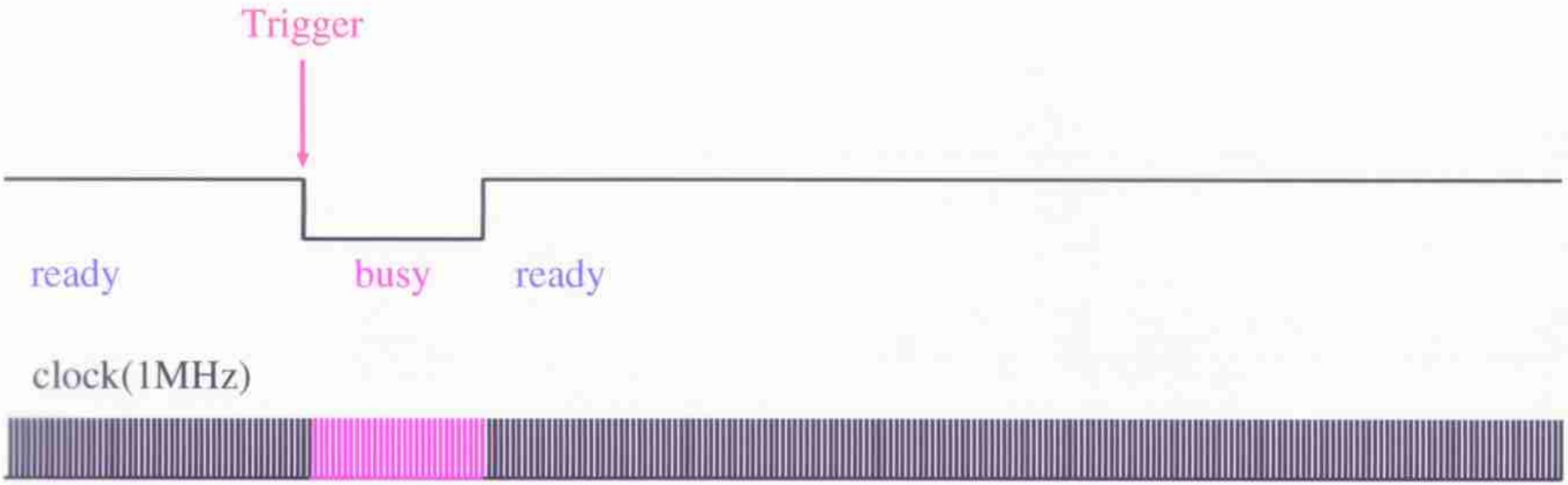
3. Geometrical Acceptance ($S\Omega$)

1. Trigger Efficiency



Trigger threshold is low enough

2. Live Time ; precisely measured



BESS97 ε = live time / real time = 87.2 %

'95 μ ε = 94.9 %

cf. cross-check

dead time

- fast clear 30μsec X 2kHz = 6 %
- data gathering 200μsec X 300Hz = 6 %

ε = 88 %

Live Time is measured exactly

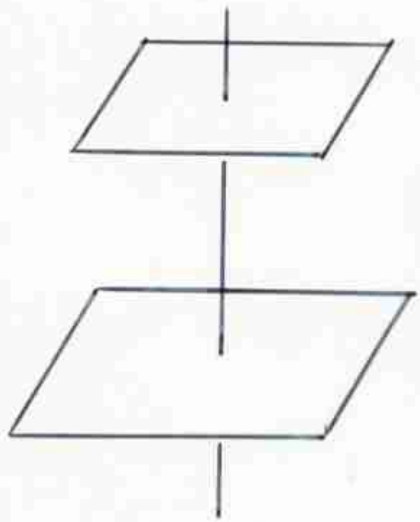
3. Geometrical Acceptance ($S\Omega$)

Check

Similar to BESS

but

Simple geometry



(a) Analytical (J.D. Sullivan, NIM 95 (1971) 5)

$$S\Omega = 0.433871 \quad m^2 sr$$

(b) M.C.

$$S\Omega = 0.434578 \quad m^2 sr$$

Agree within 0.16%

Our M.C. has NO Bug