VECTORS and SUBMICRON PRECISION:
REDUNDANCY and 3D STACKING IN SILICON PIXEL DETECTORS

Erik H.M. HEIJNE   IEAP/CTU Prague & CERN CH1211 Geneva 23

WIT2010, LBL Berkeley, 3-5 February 2010

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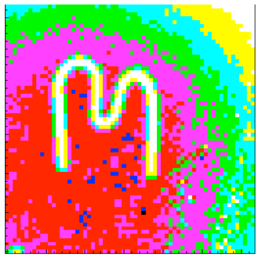
Richard PLACKETT, Lukas TLUSTOS and Winnie WONG
CERN CH 1211 Geneva 23

Daan BOLTJE, Jos VERMEULEN and Jan VISSCHERS
NIKHEF, Science Park, Amsterdam



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Si STACK in 3 DIMENSIONS

PATTERN RECOGNITION

SPACE VECTORS

DELTA RAY CORRUPTION

SUBMICRON PRECISION

MICRO → NANO ELECTRONICS

THIN DETECTOR LAYERS

BUT MANY MORE THAN USUAL

THIN DETECTOR LAYERS

55 um Si

BUT MANY MORE THAN USUAL

HIGHLY REDUNDANT DETECTOR

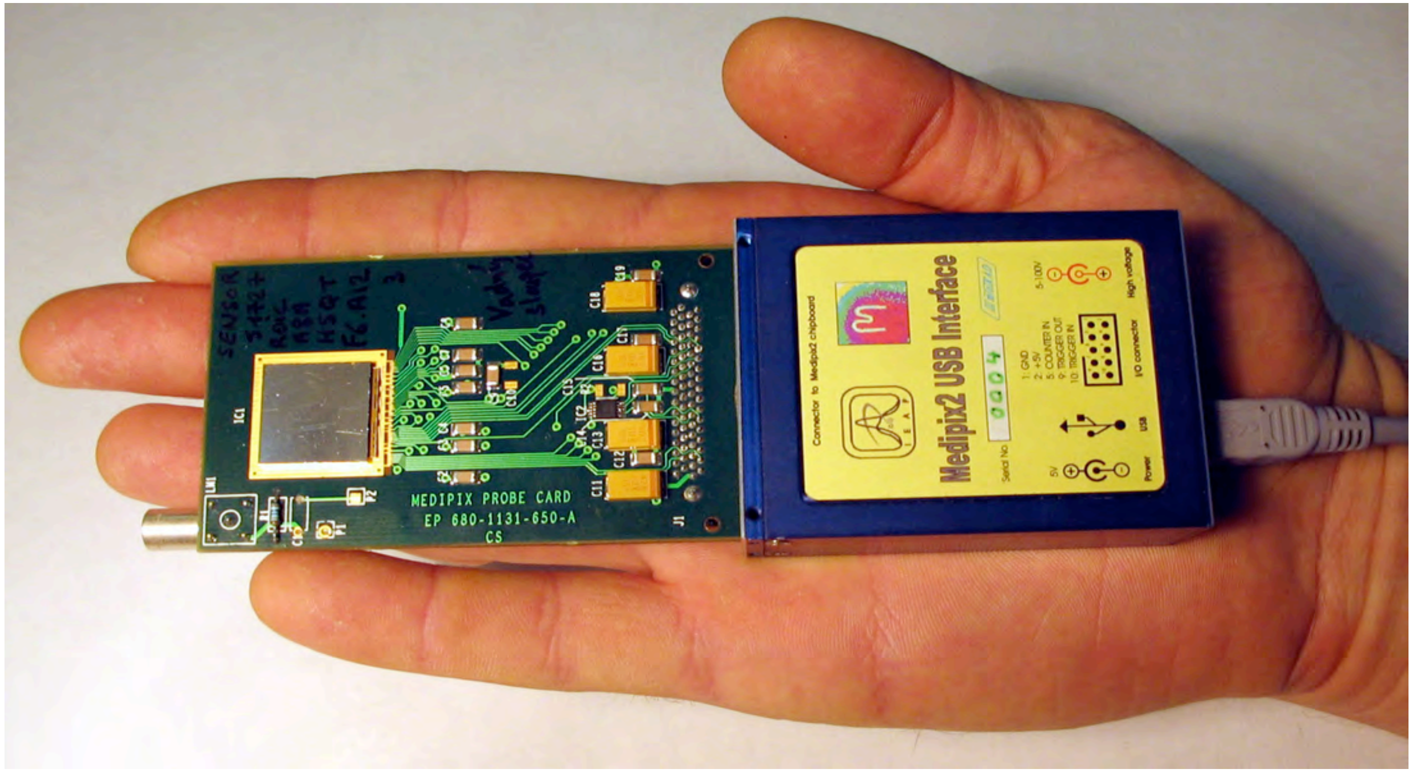
EXPLORATION of DIFFERENT APPROACH

VECTOR DETECTOR,
STACKING ELIMINATES AMBIGUITIES,
SUB-MICRON POSITION INFORMATION,
ENERGY INFORMATION & DELTA-RAY CORRUPTION

MEDIPIX / TIMEPIX USB

OPERATED and POWERED from PORTABLE COMPUTER

PIXELMAN SOFTWARE
PRAGUE IEAP - CTU



Erik HEIJNE IEAP/CTU & CERN PH Dep

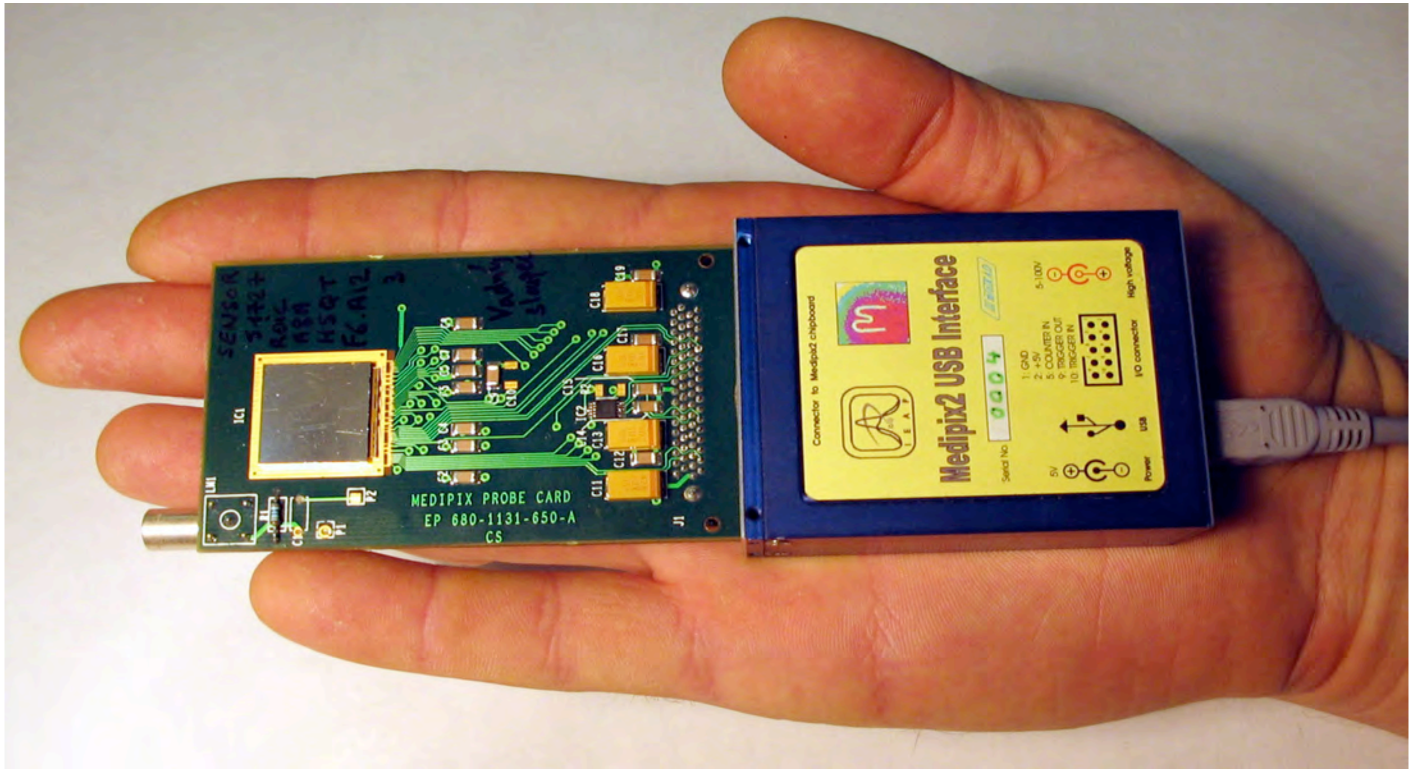
WIT2010 LBL, 3-5 February 2010

MEDIPIX / TIMEPIX USB

OPERATED and POWERED from PORTABLE COMPUTER

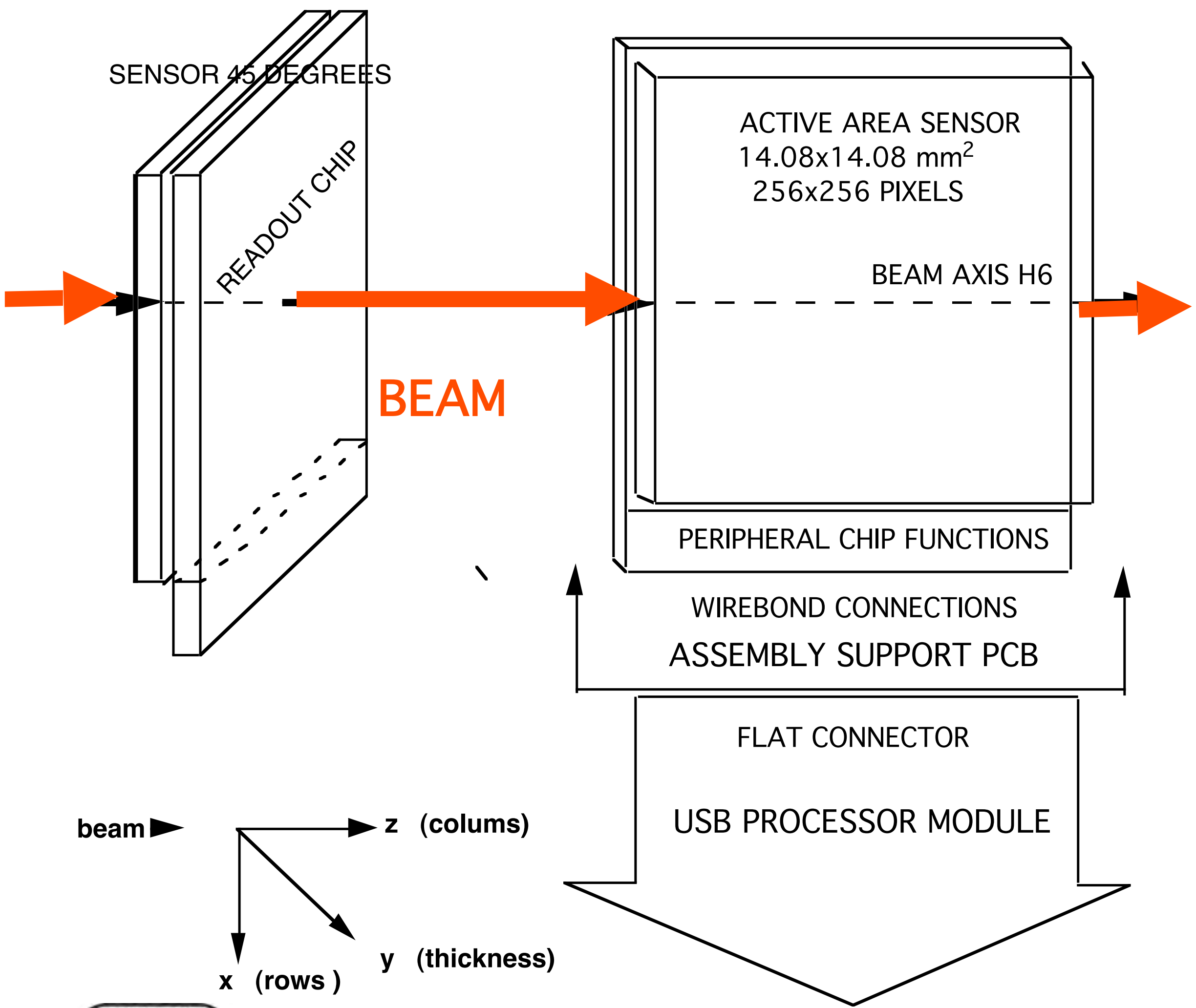
RECENT PLANS:
TALK by Xavi LLOPART

PIXELMAN SOFTWARE
PRAGUE IEAP - CTU

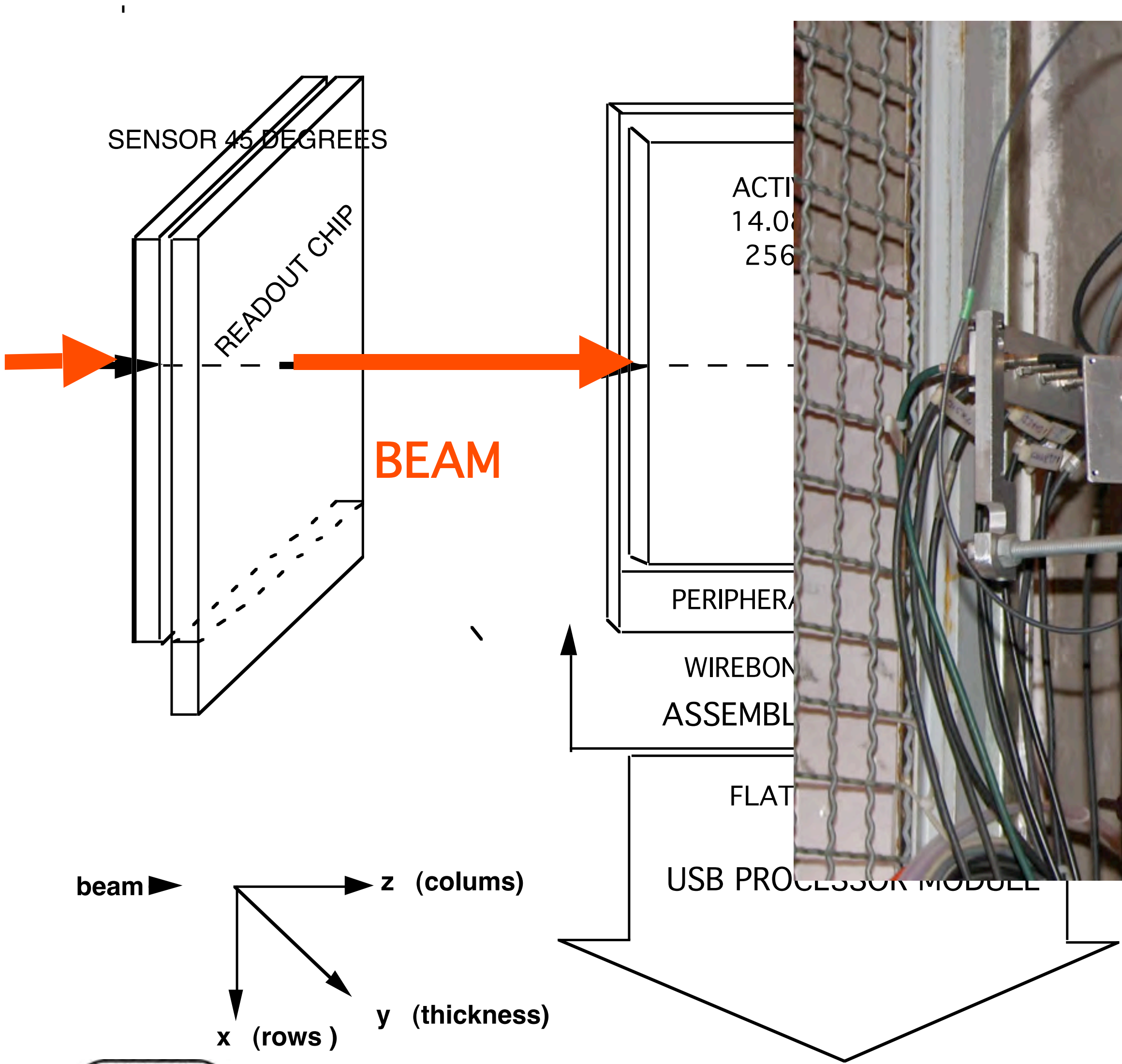


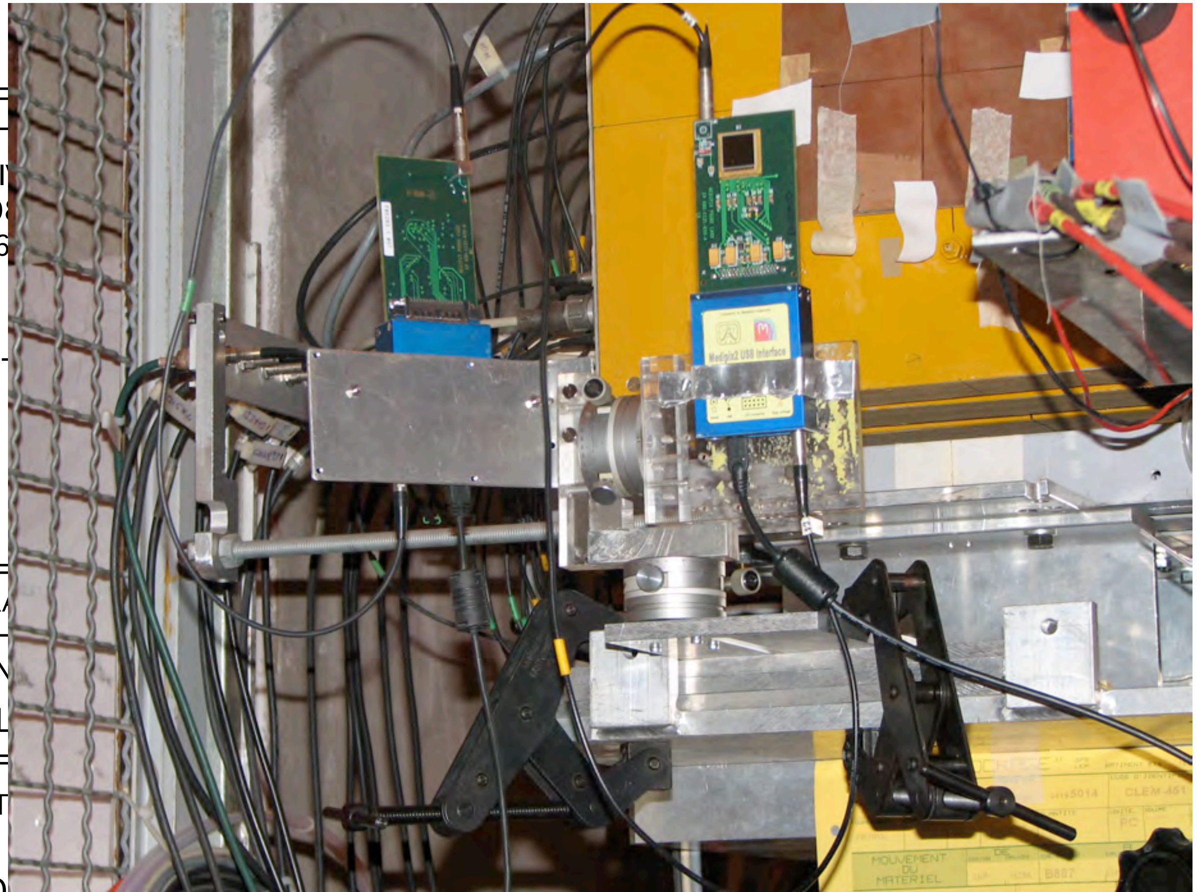
soon:
USB2
ETHERNET

SETUP in H6 BEAM CERN

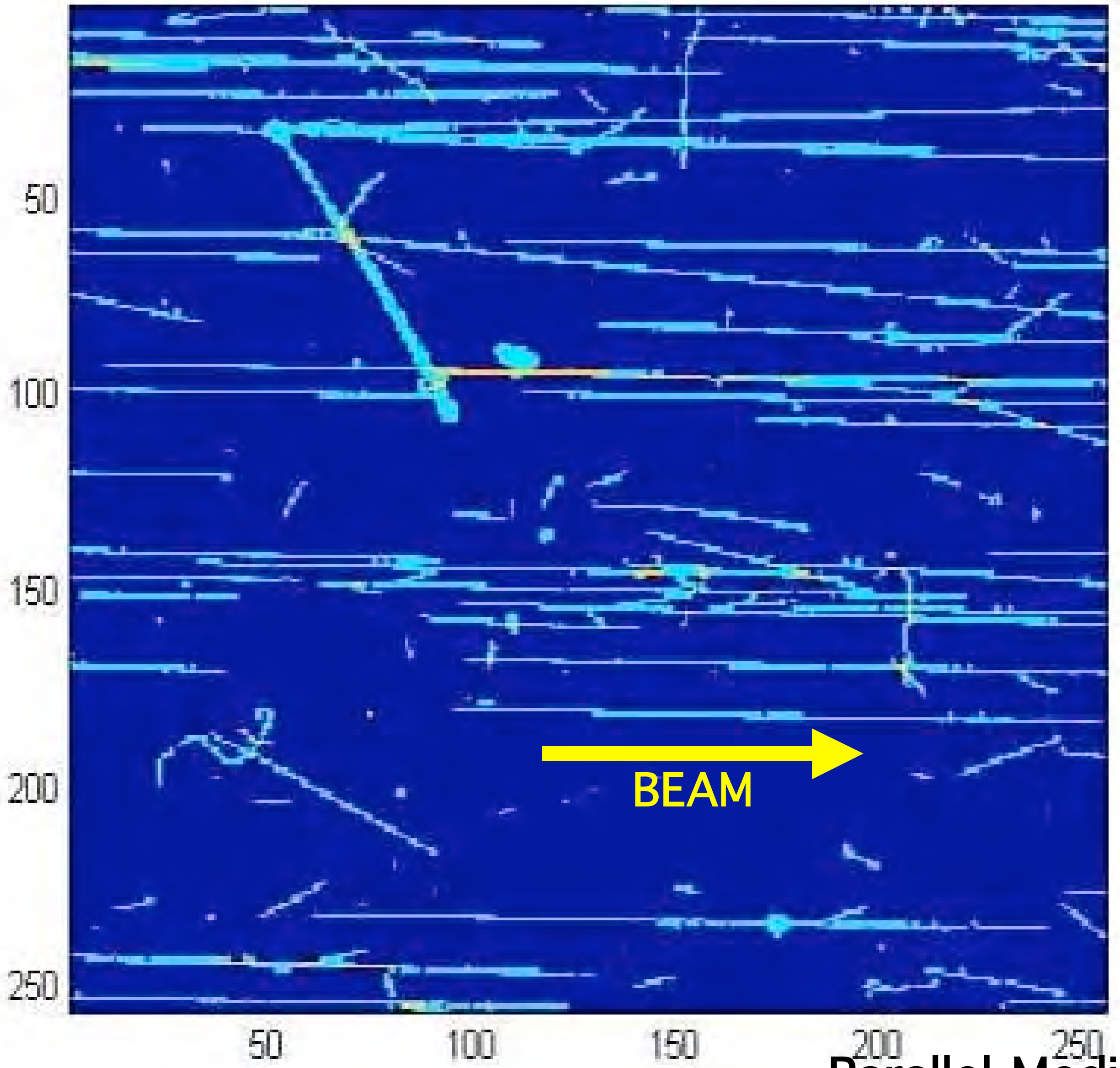


H6 BEAM CERN 120 GeV PIONS - MUONS





MEDIPIX as HEP PARTICLE DETECTOR 120 GeV PIONS



EXPOSURE 1 s

14.08 mm

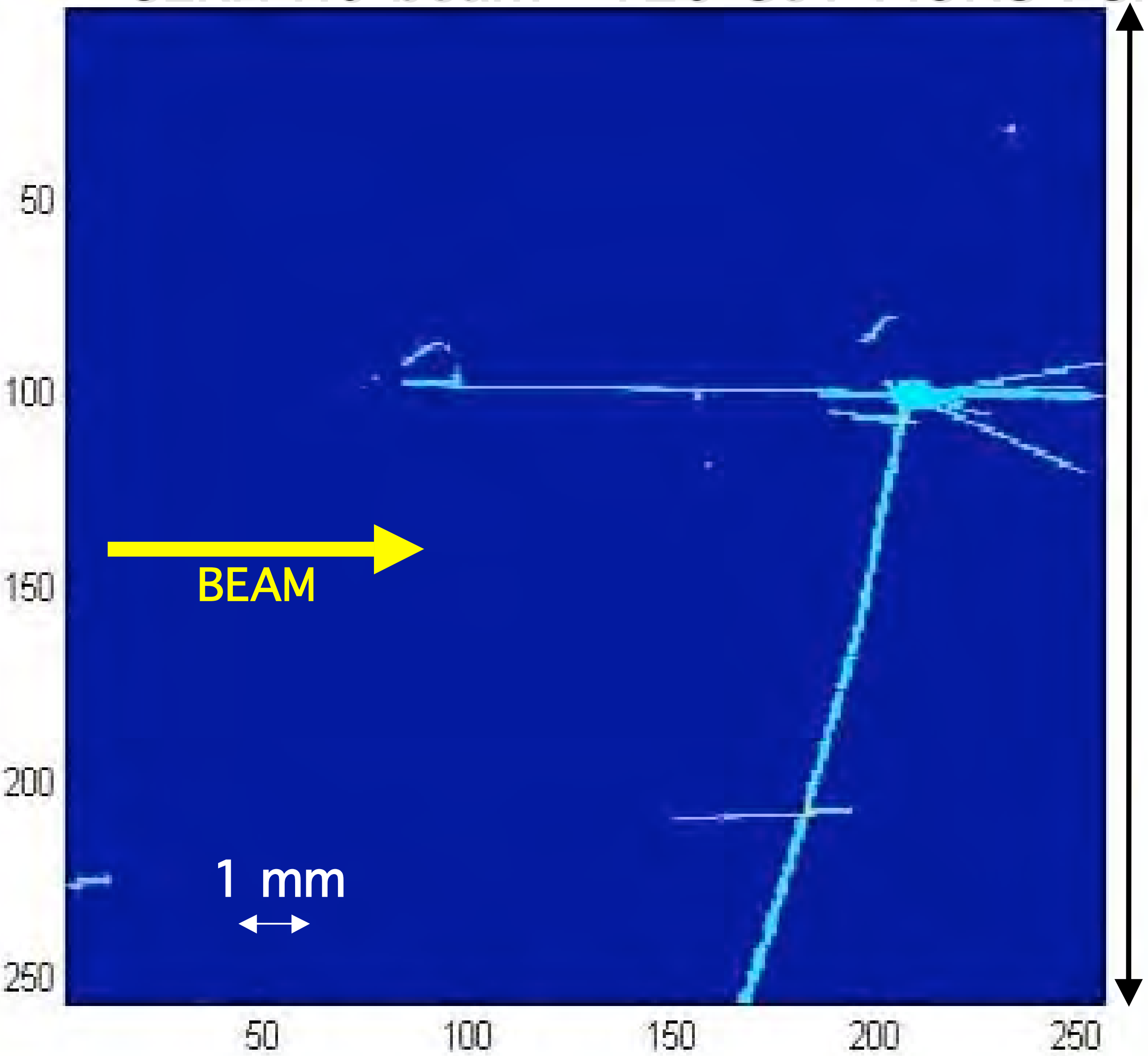
256 pixels

PARTICLE 'TRAILS'
~ PARALLEL

INTERACTIONS

Parallel Medipix2 P-02-0668

CERN H6 beam   120 GeV PIONS : Si EMULSION ?



SILICON PIXEL ASSEMBLY
256x256   55um pixels
EXPOSURE TIME 50 ms

BEAM HODOSCOPE
&
TARGET
&
DETECTOR

14.08 mm

256 pixels

Medipix2   FRAME P04-0356

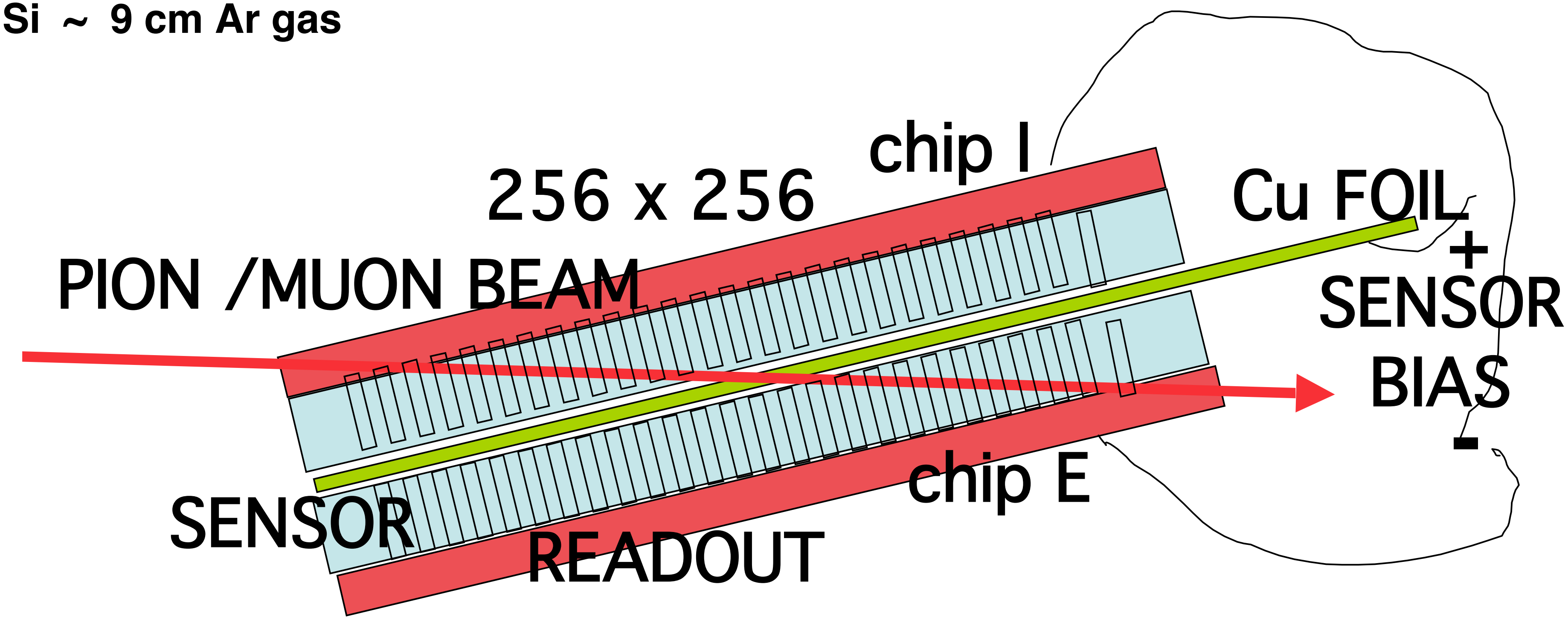
FRONT-BACK AMBIGUITY can be SOLVED BY STACKED SENSOR LAYERS

UNAMBIGUOUS 3D VECTORS INSTEAD of SPACE POINTS

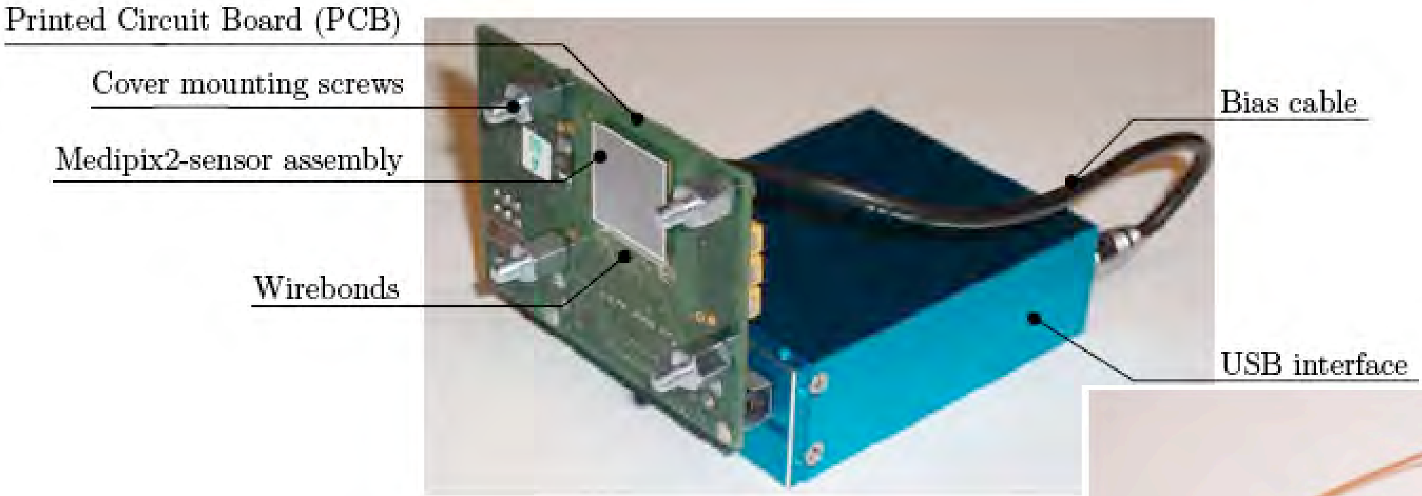
BEAM GRAZING THROUGH STACK

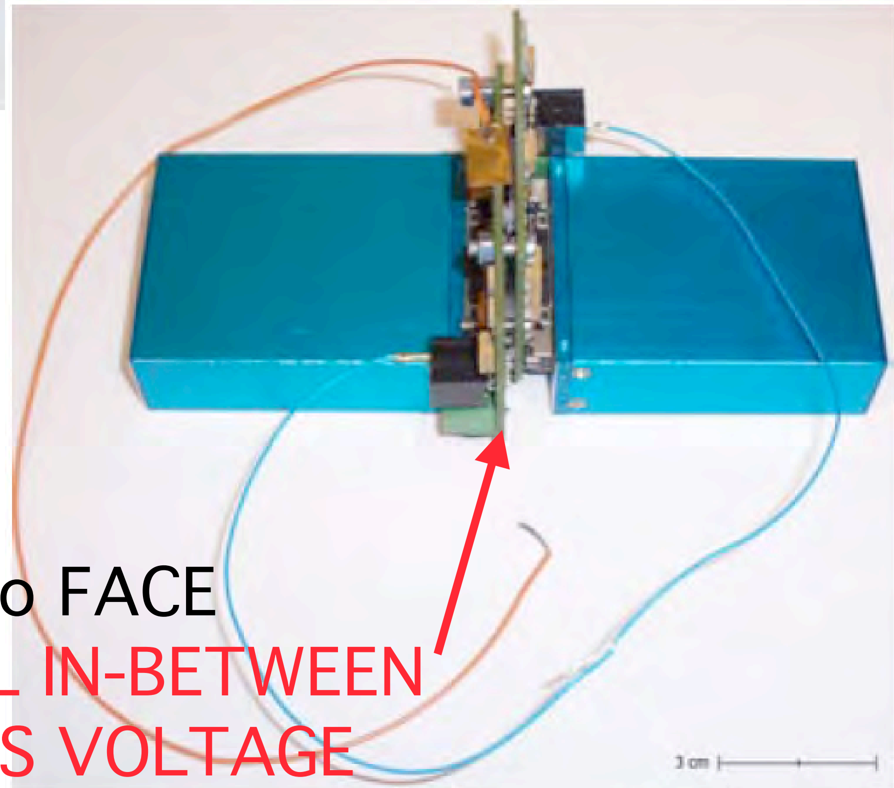
M.I.P. TYPICALLY DEPOSITS 200 - 300 eV per um Si
11- 16.5 keV in 55um PIXEL --> 3400 e-
COMPARE with 1mm Ar --> 1-10 e-

55um Si ~ 9 cm Ar gas



FIRST 2-PLANE MEDIPIX STACK





(a) The stacked prototype

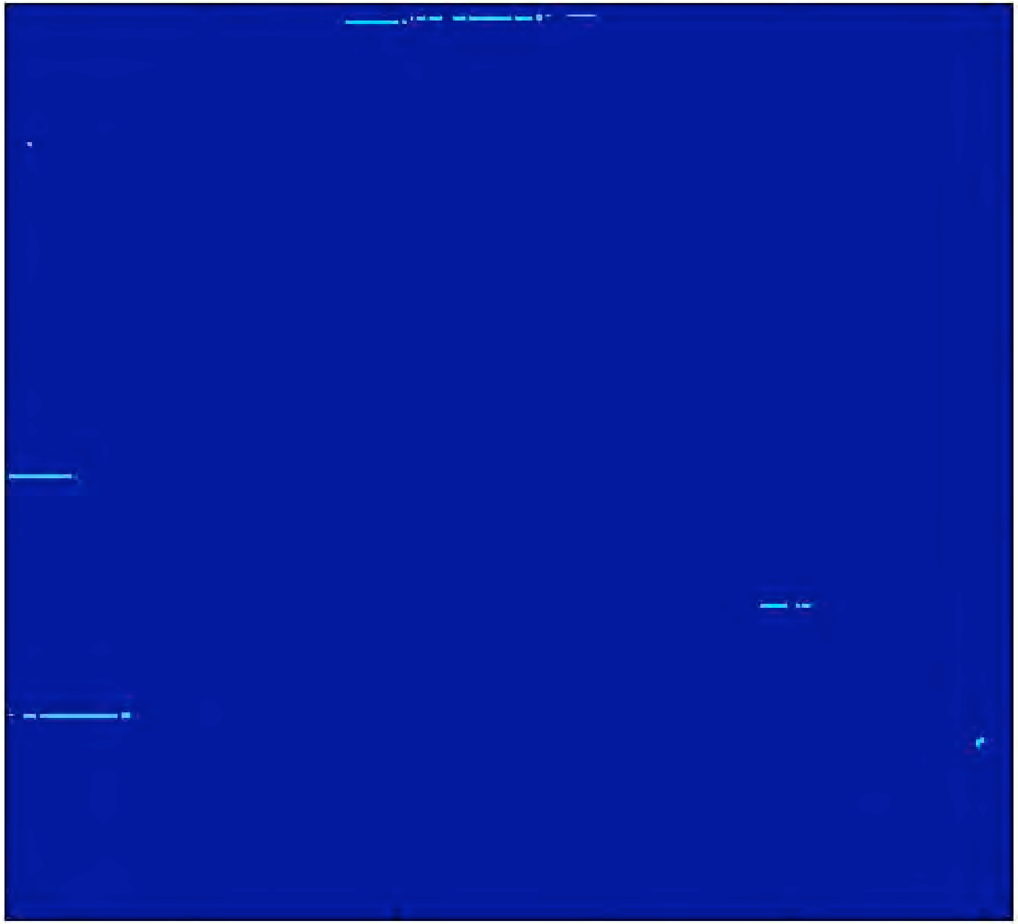
FACE-to FACE
Cu FOIL IN-BETWEEN
for BIAS VOLTAGE

JAN VISSCHERS
DAAN BOLTJE
NIKHEF

2 FRAMES BACK-to-BACK

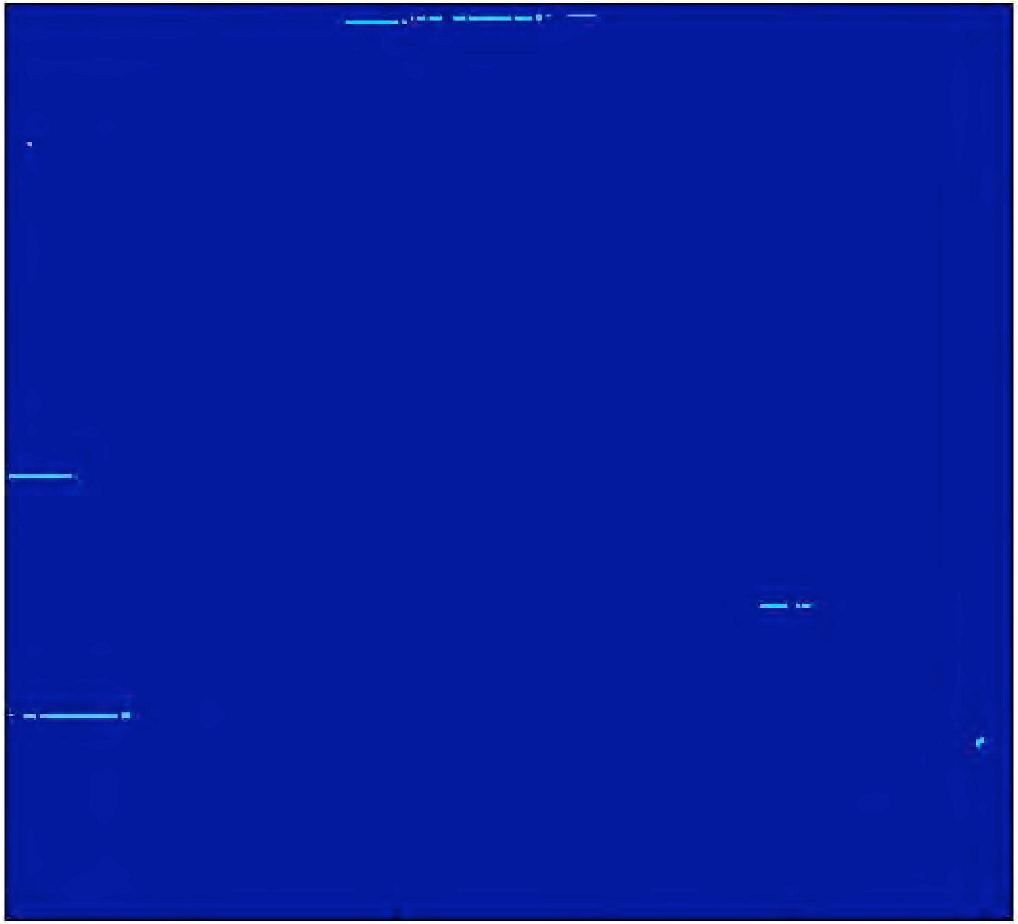
FRAME 218 4 MUONS

I

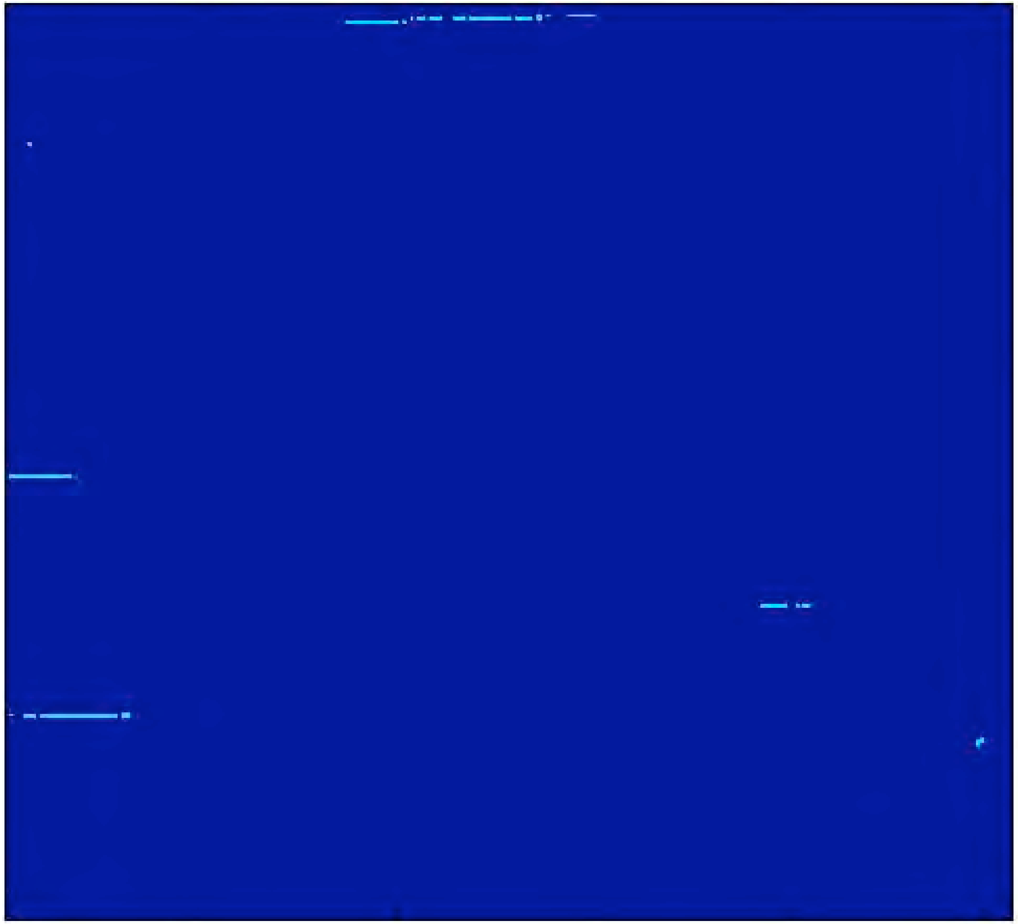


E

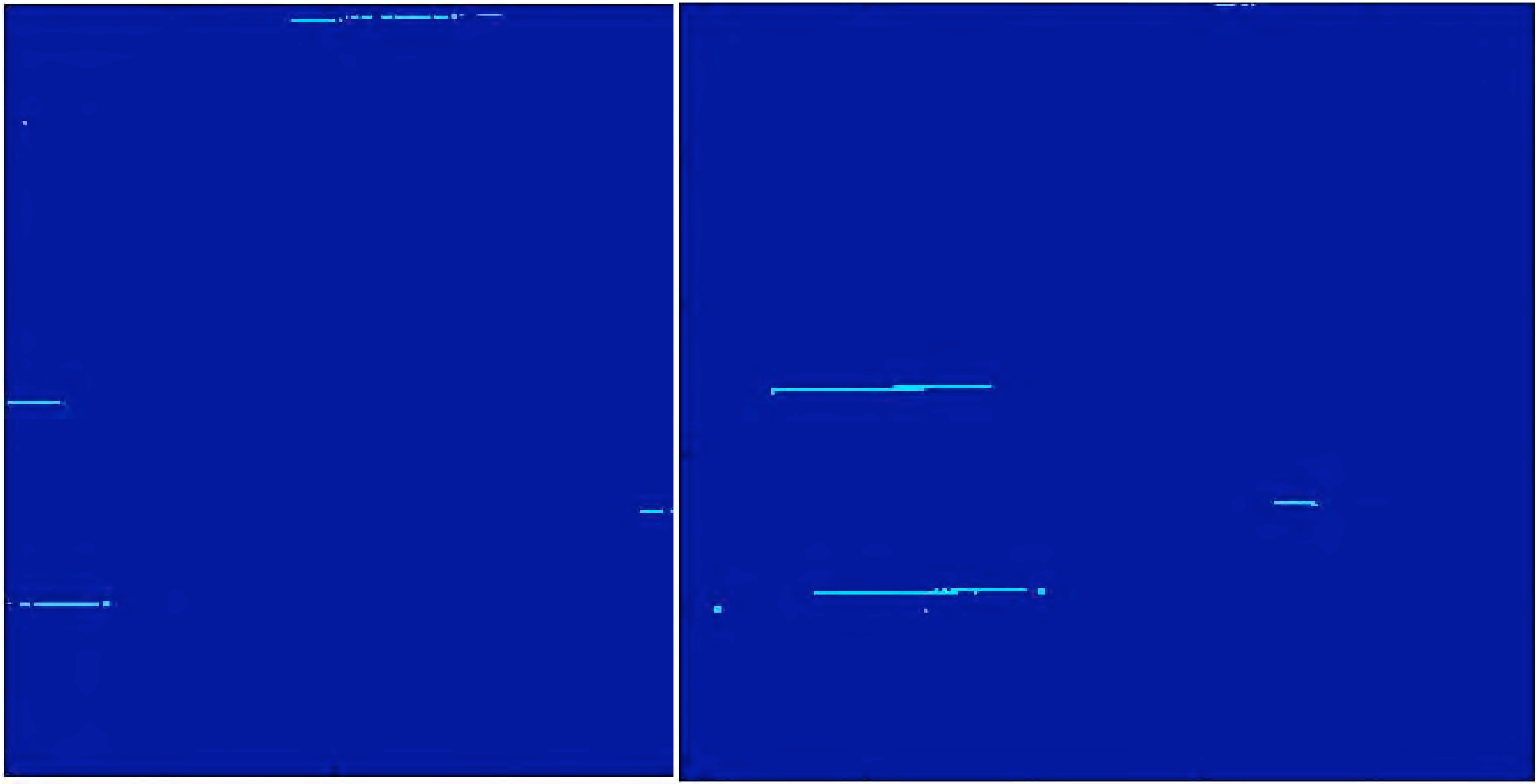
I FRAME 218 4 MUONS E flipped



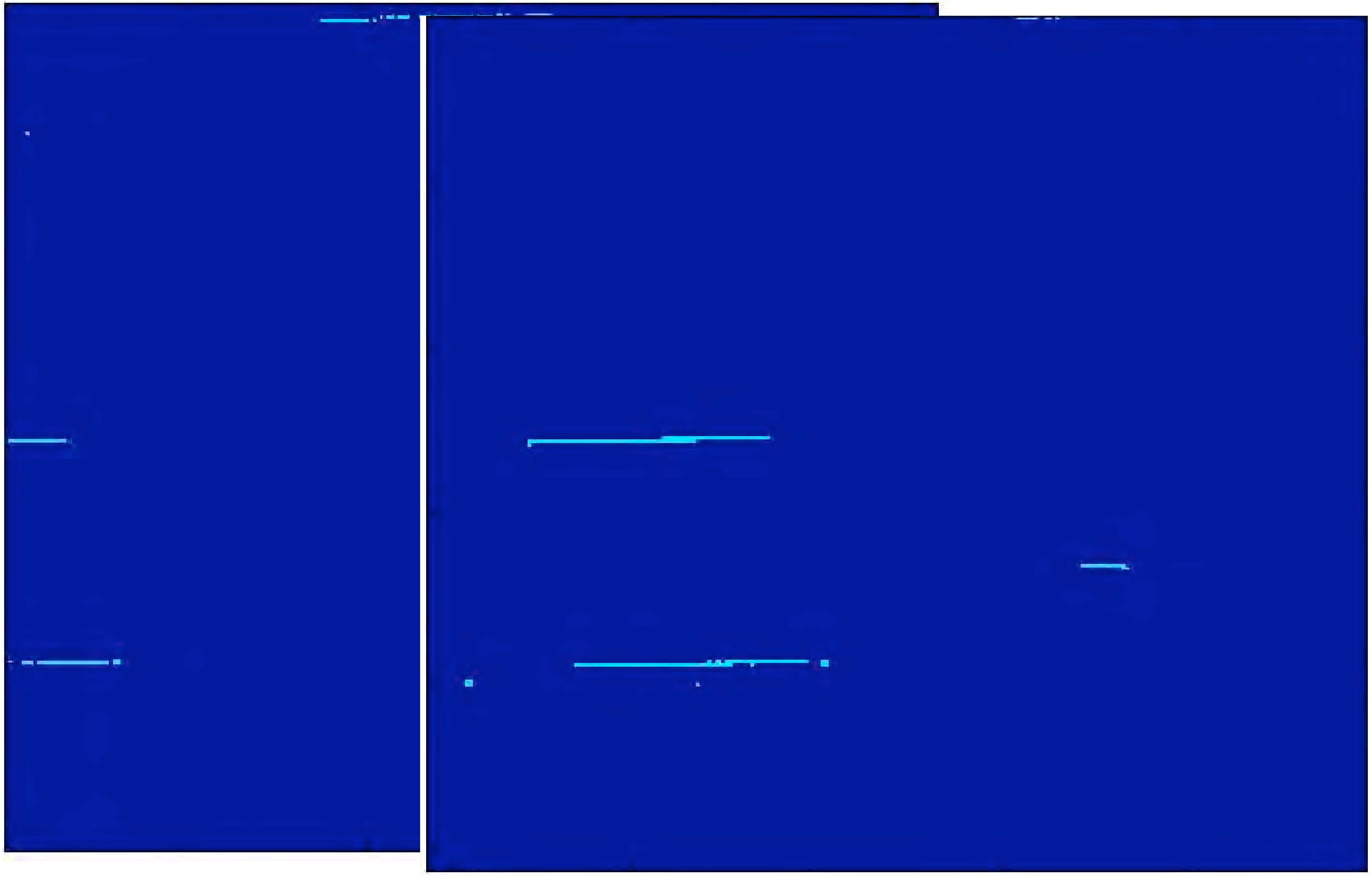
FRAME 218 4 MUONS



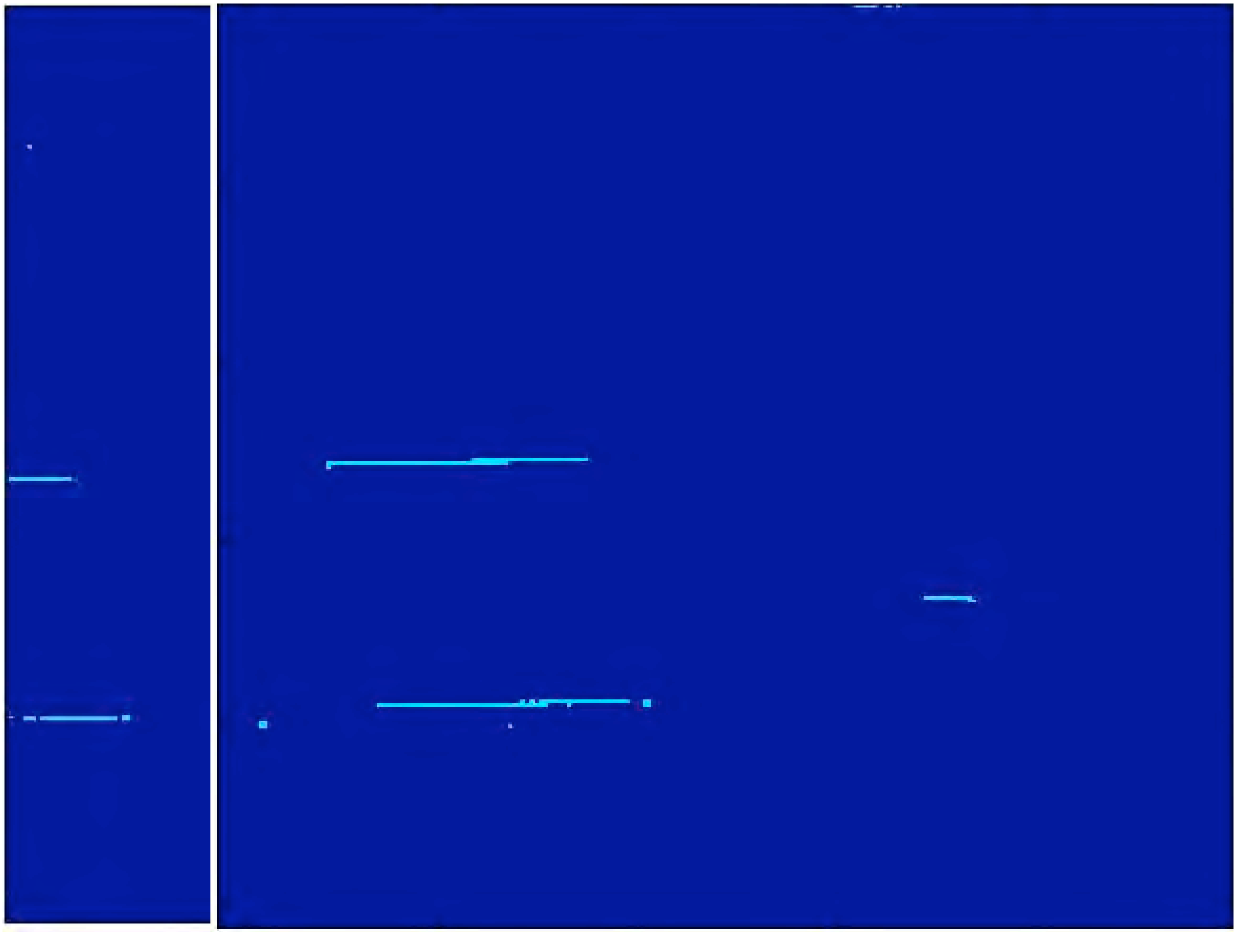
FRAME 218 4 MUONS



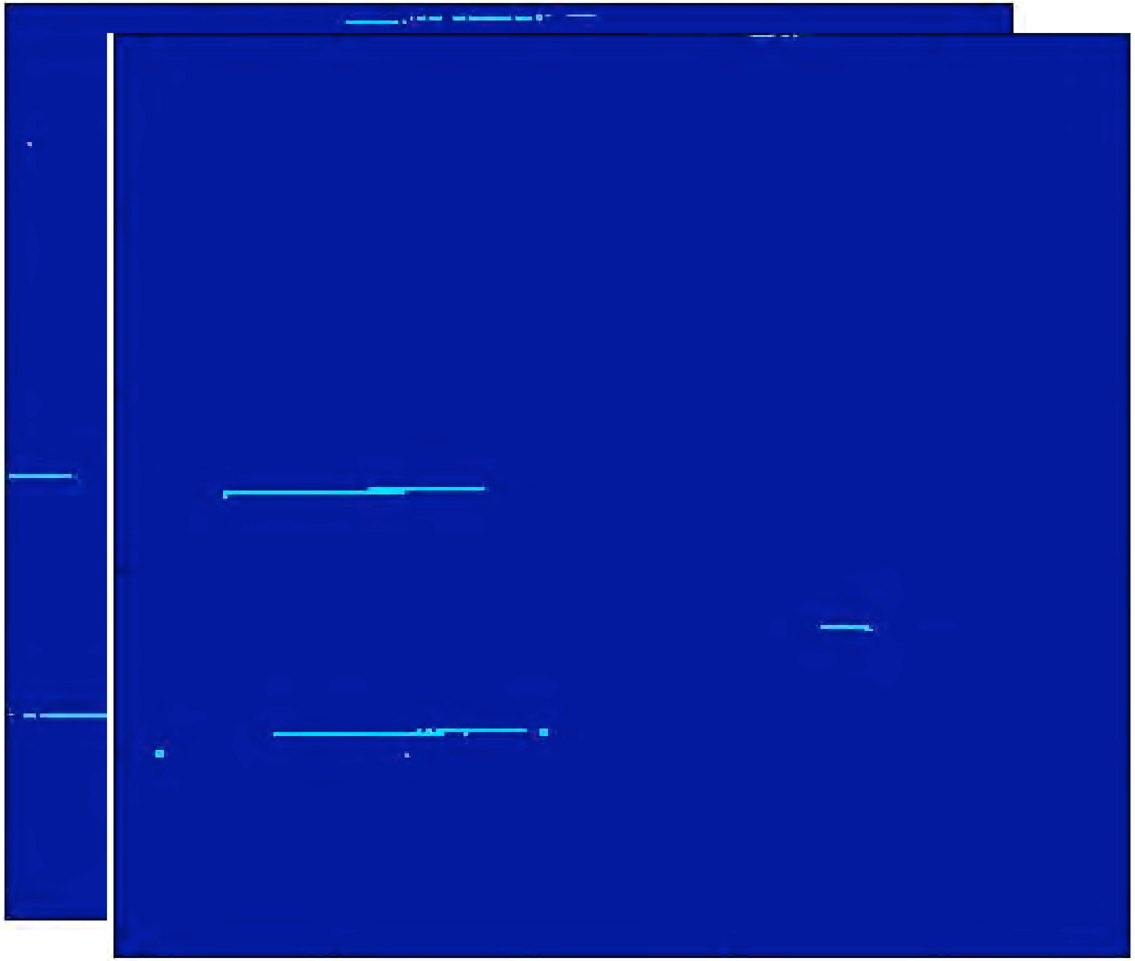
FRAME 218   4 MUONS



FRAME 218   4 MUONS



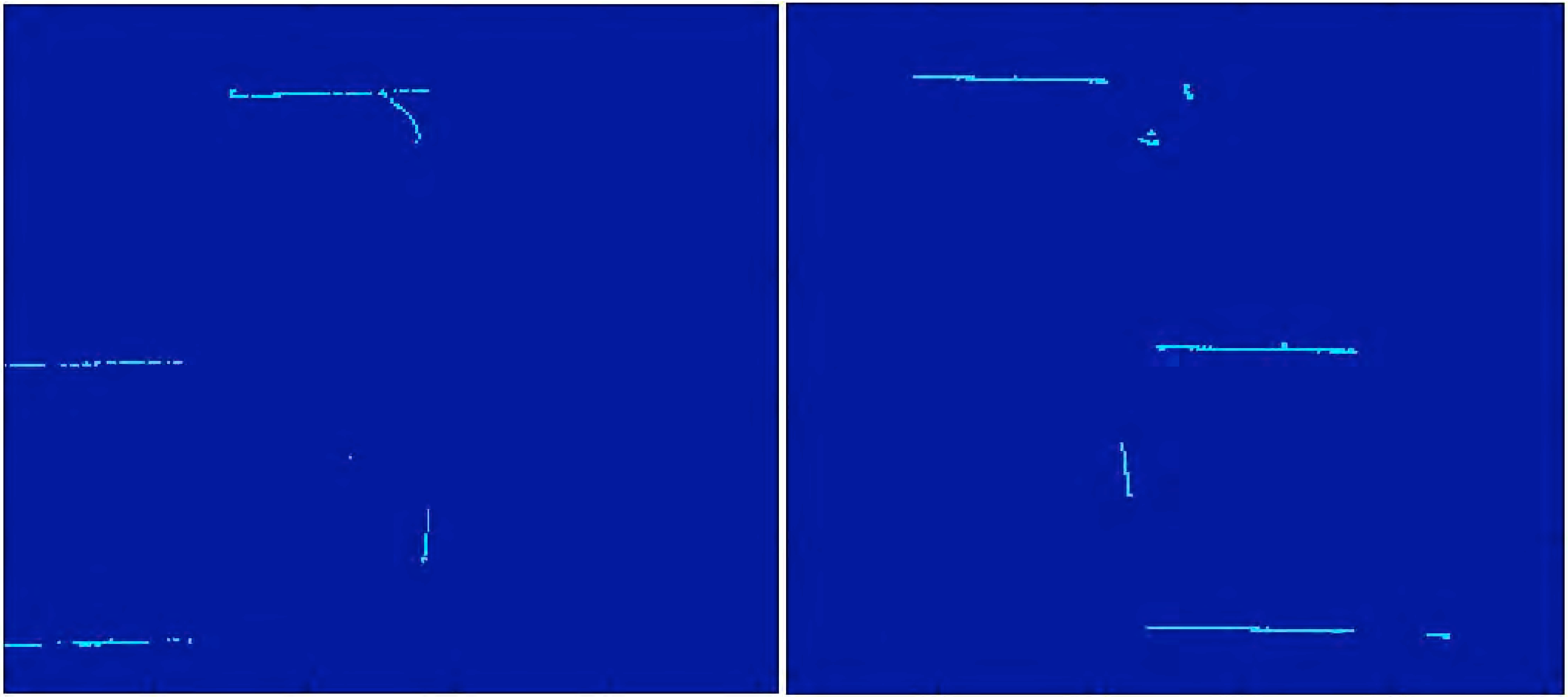
FRAME 218   4 MUONS



FRAME 218   4 MUONS

SUPERIMPOSED

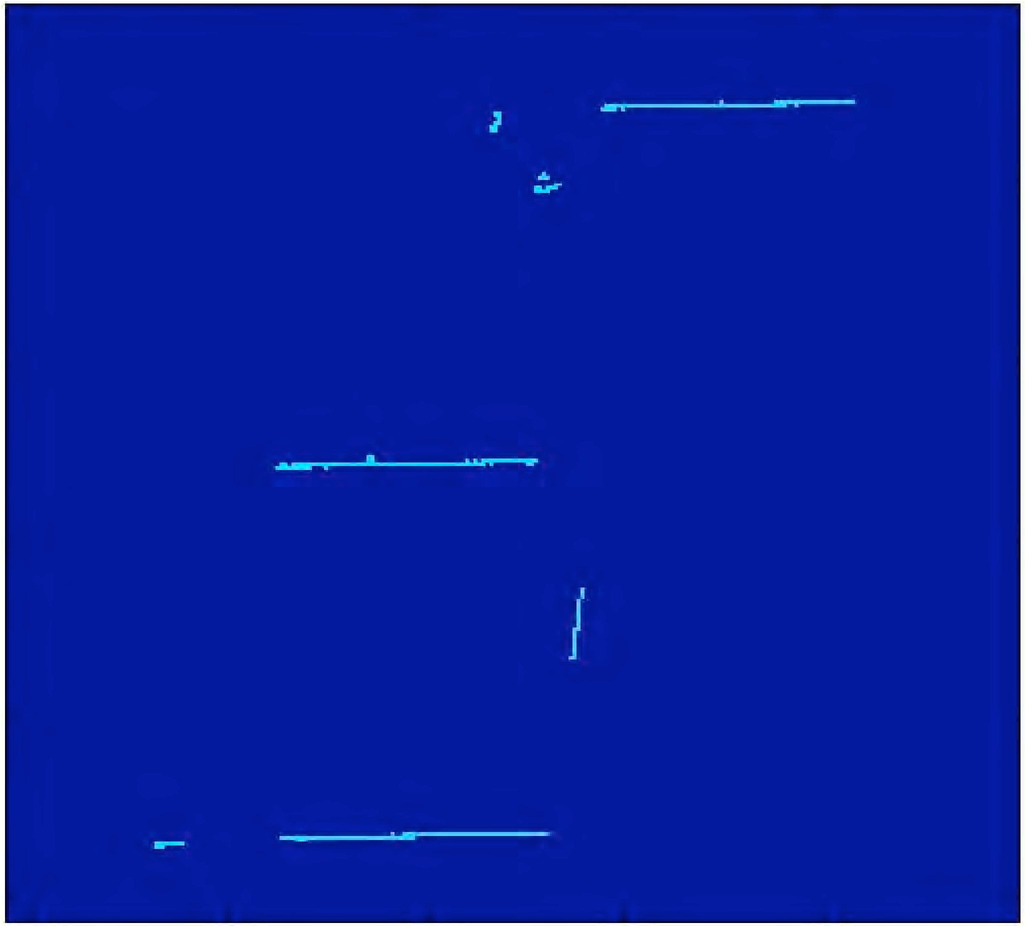
FRAME 223   3 beam 1 cosmic



I   E

FRAME 223   3 beam 1 cosmic

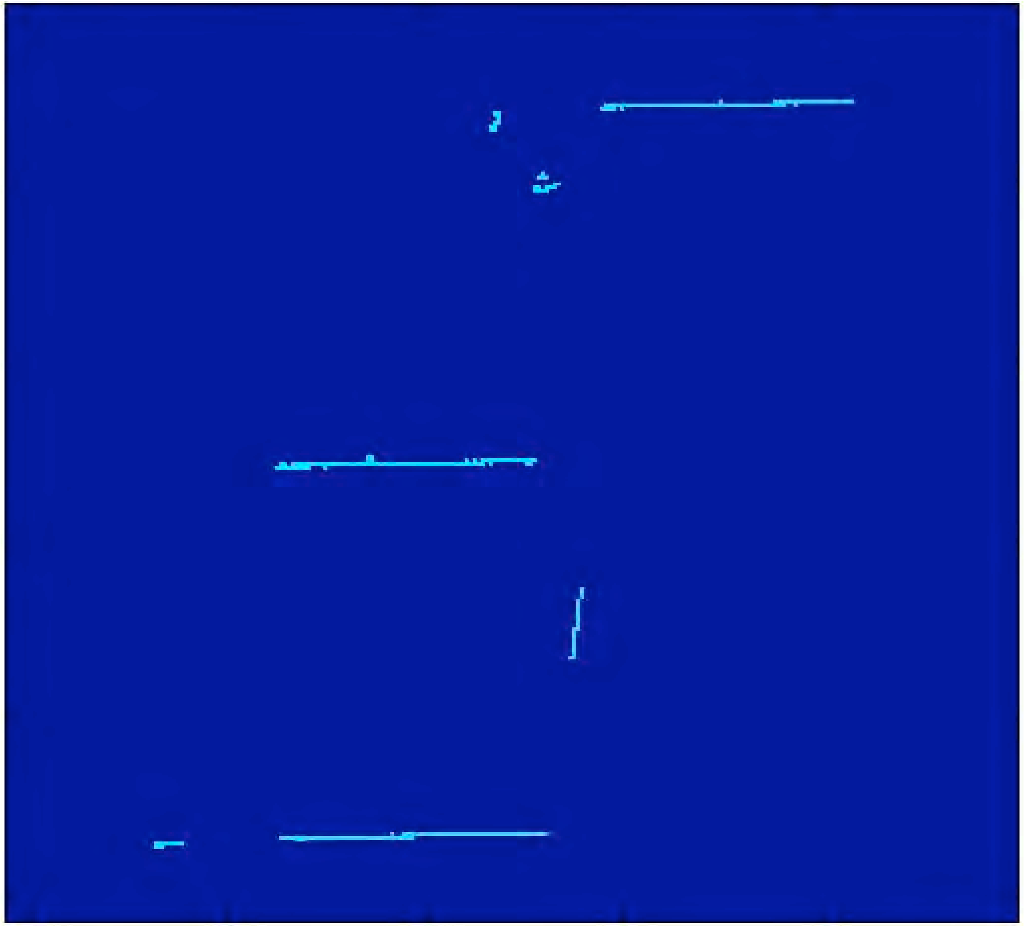
I



E flipped

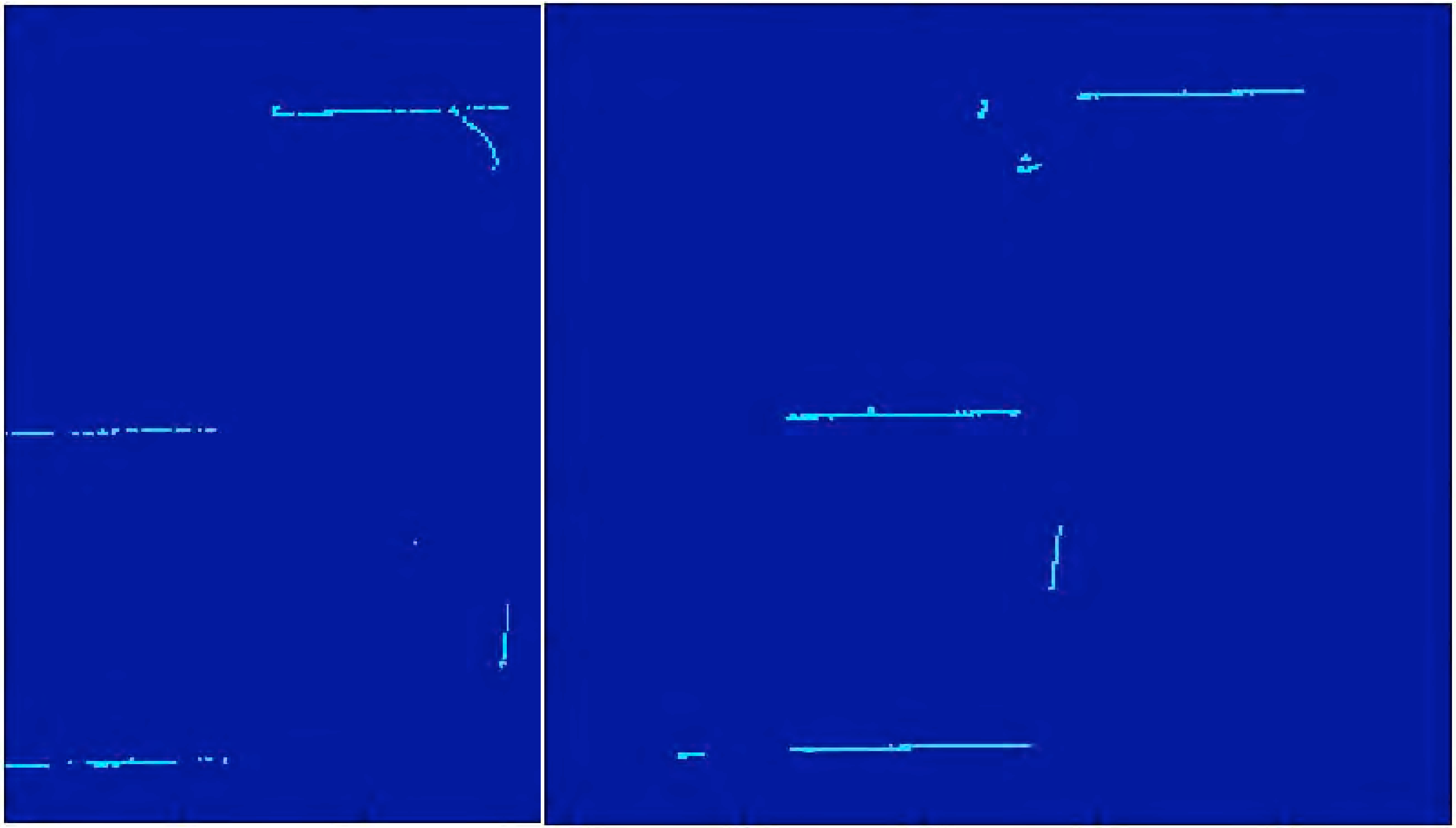
FRAME 223 3 beam 1 cosmic

I



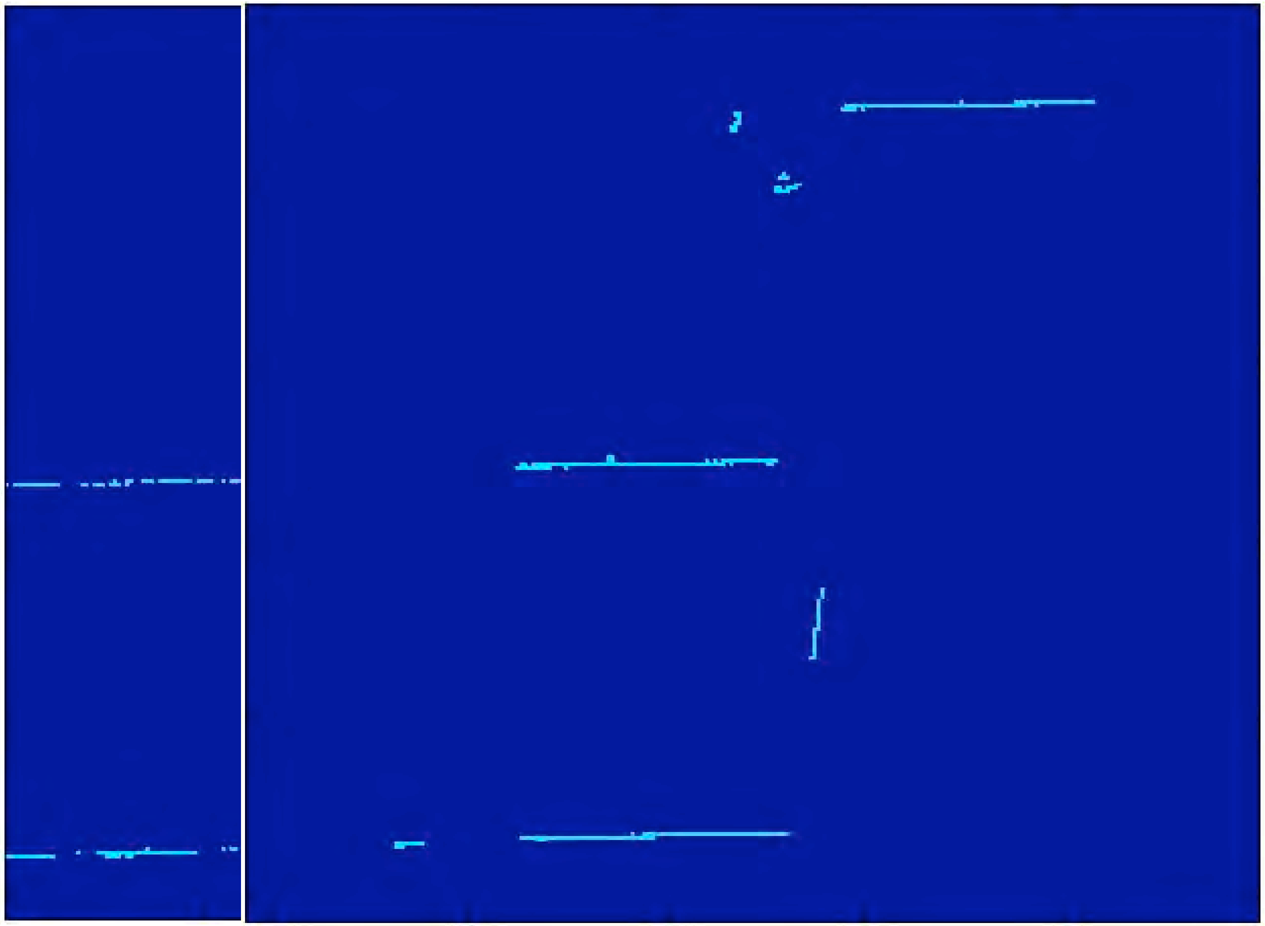
E flipped

FRAME 223   3 beam   1 cosmic



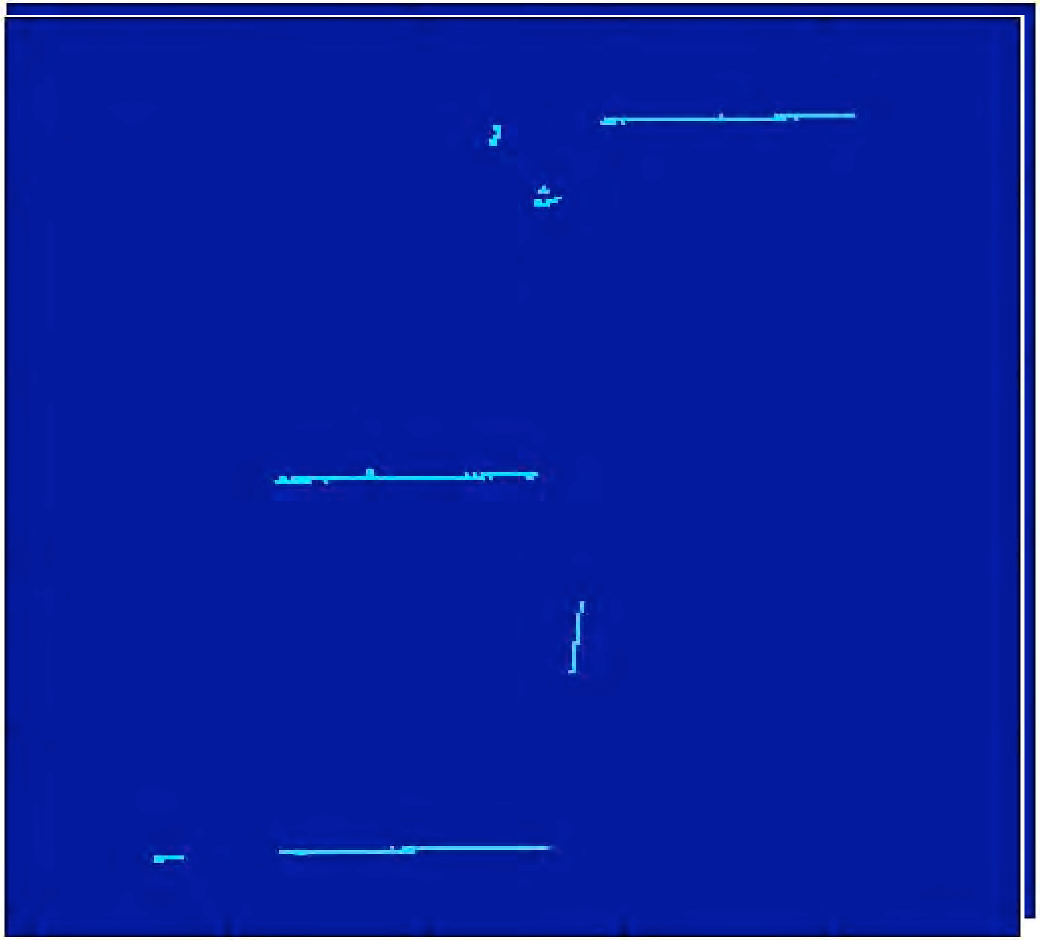
I   E flipped

FRAME 223 3 beam 1 cosmic



I E flipped

FRAME 223 3 beam 1 cosmic

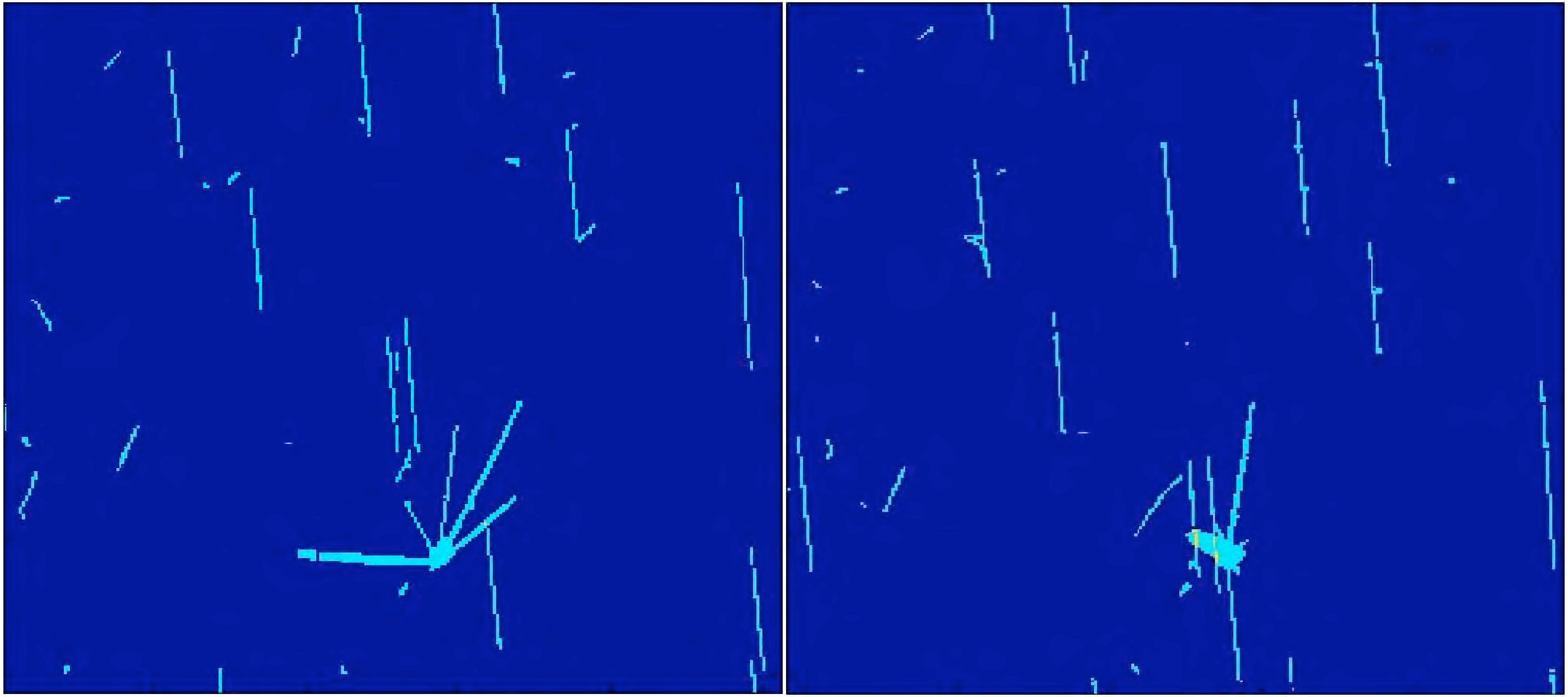


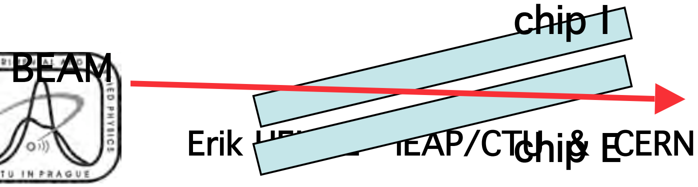
I

E flipped

INTERACTION in Cu FOIL

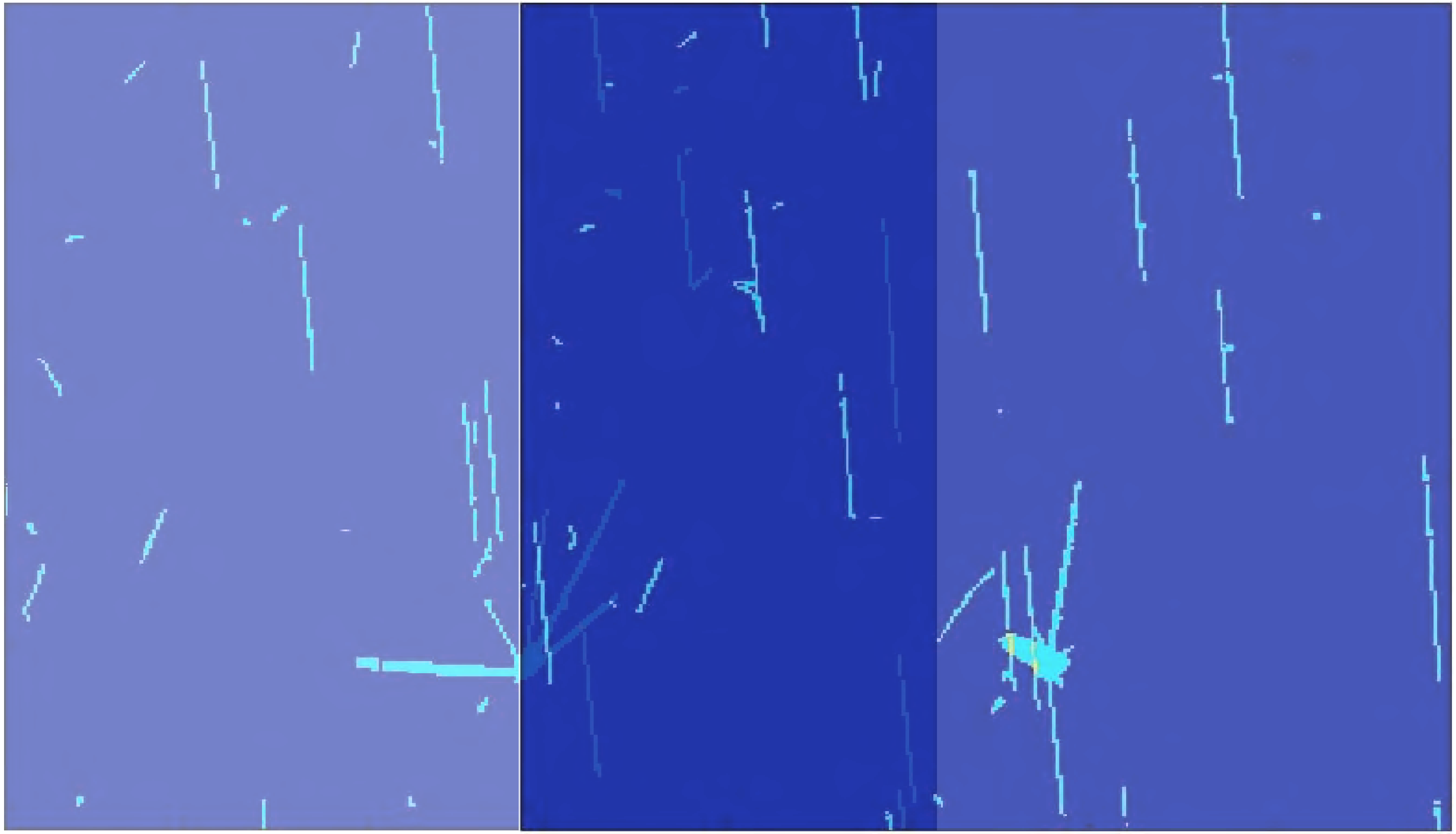
chip E FRAME Aug t 26 chip I





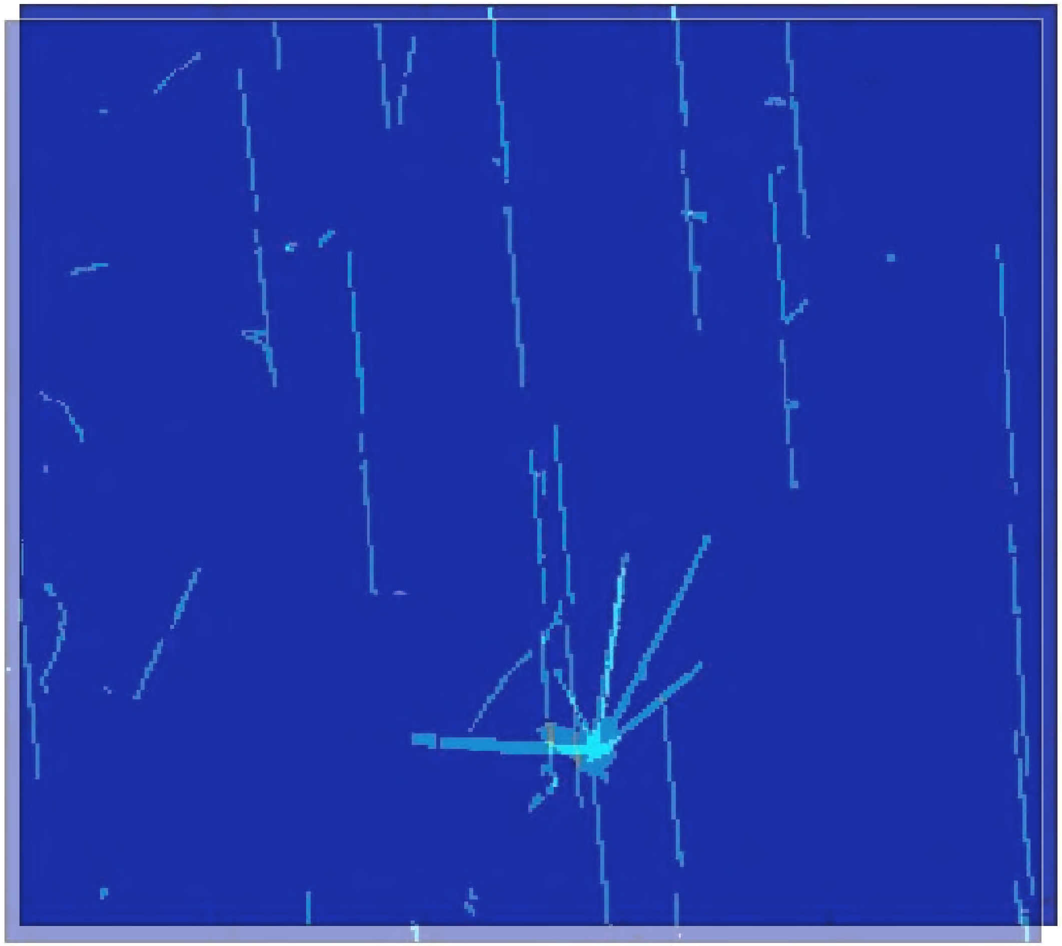
BEAM

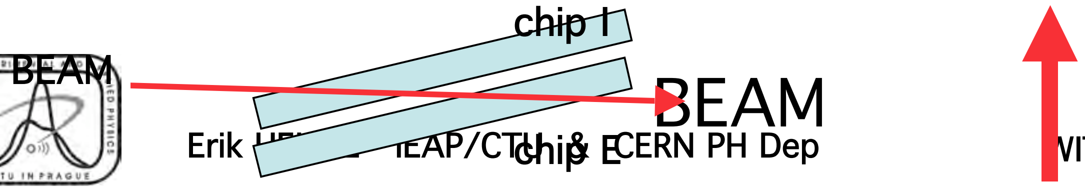
E FRAME Aug t 26 I



E FRAME Aug t 26 I

chip I & E superimposed





ANALOG PIXEL DATA

&

DELTA RAY CORRUPTION

ANALOG MEASUREMENTS with Si TIMEPIX

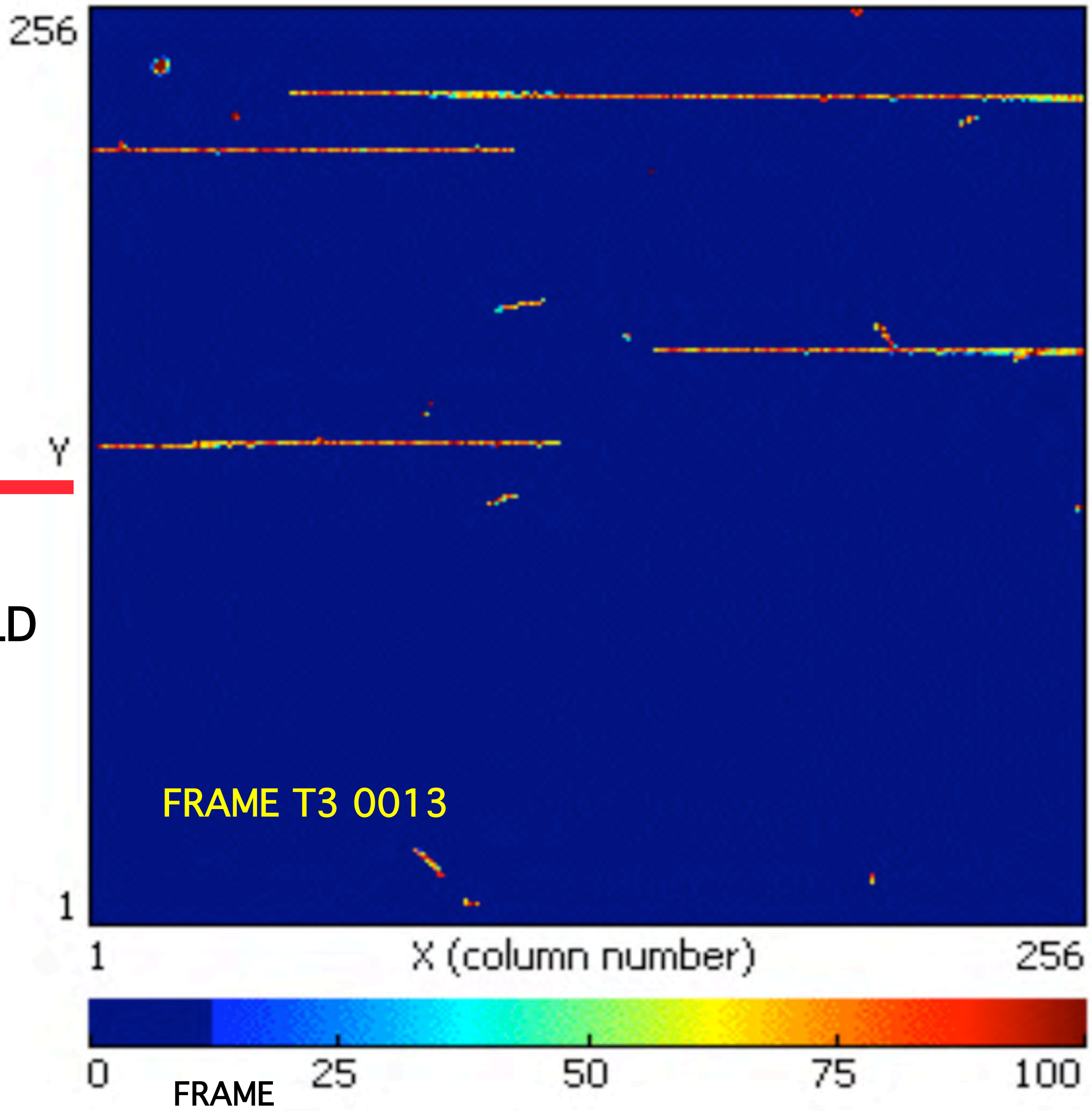
MUONS / PIONS
H6 in EHN1

June 2007

INCIDENT from RIGHT

BEAM

TIME-OVER-THRESHOLD
in # COUNTS
MIP PEAK ~ 65



JOHN IDARRAGA
DOMINIC GREIFFENBERG
ERIK HEIJNE

MEASUREMENTS with MIPs in Si TIMEPIX (2007)

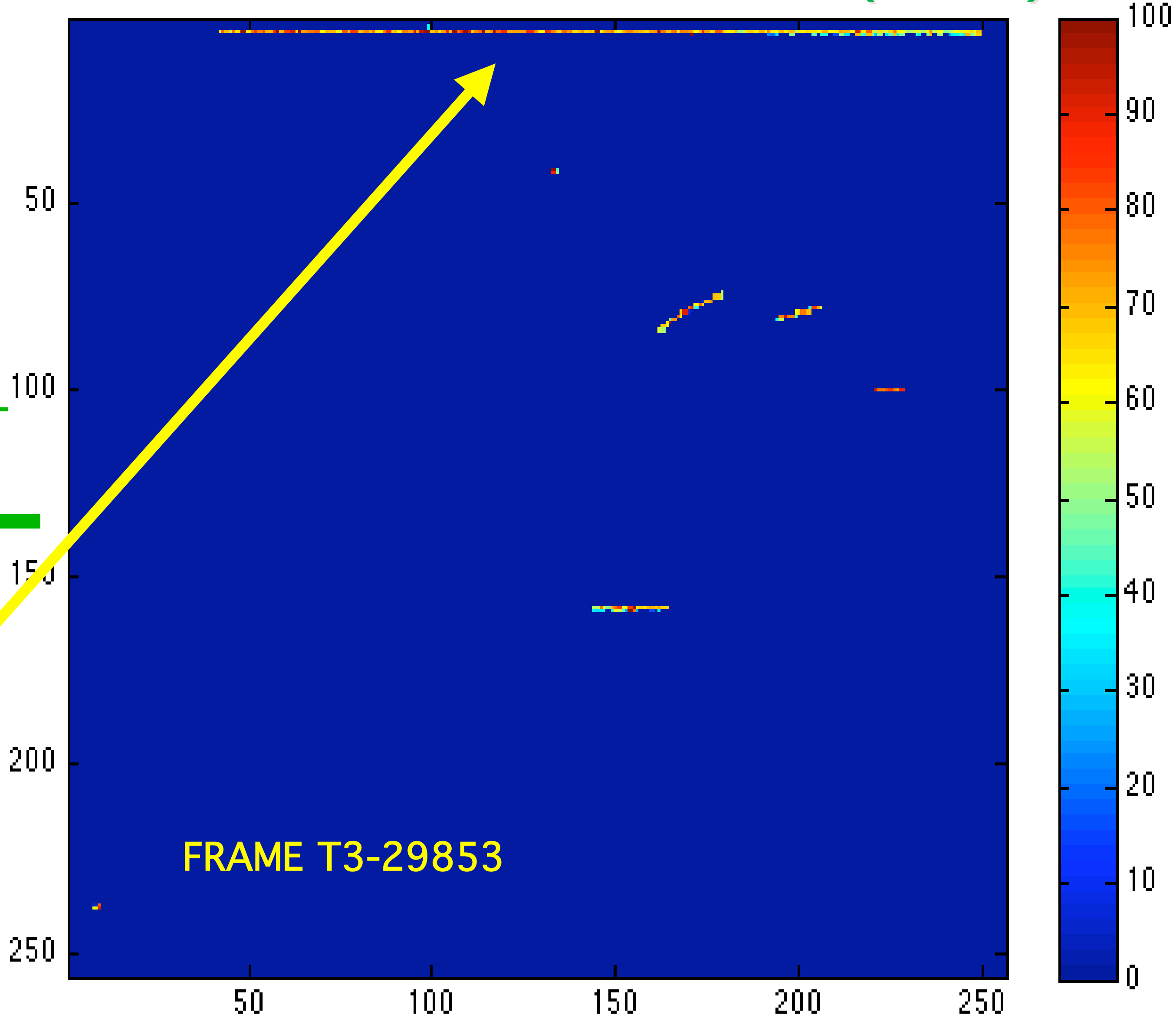
MUONS
H6 in EHN1

June 2007

INCIDENT from RIGHT

BEAM

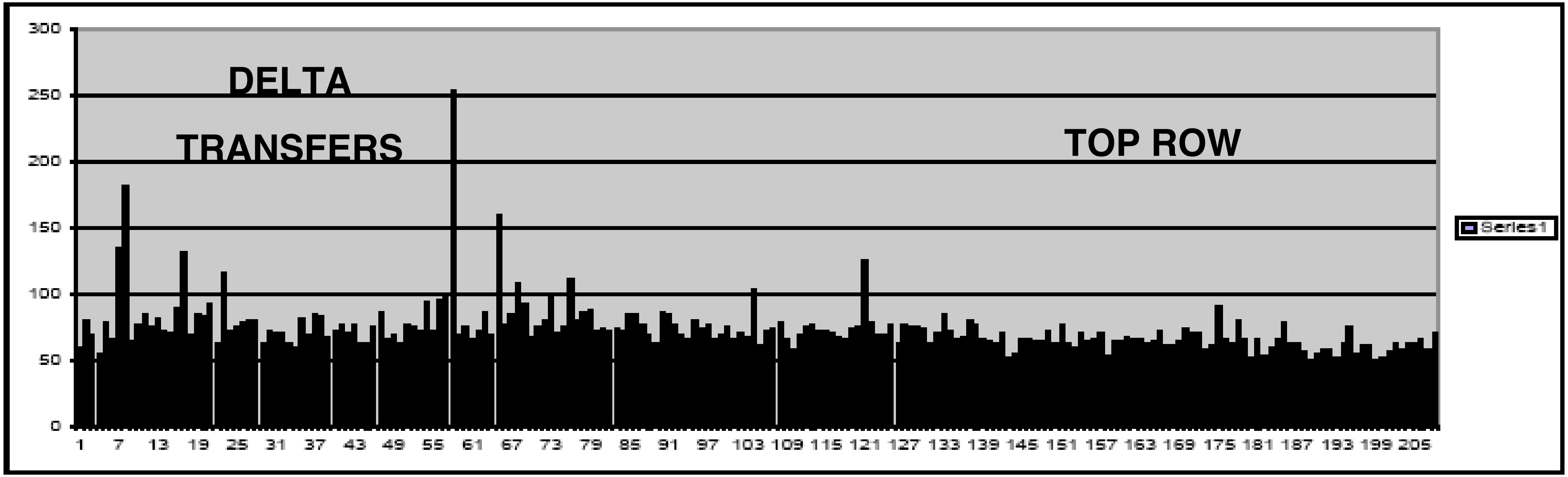
ANALYZED TRAIL



JOHN IDARRAGA
DOMINIC GREIFFENBERG
ERIK HEIJNE

M.I.P. TYPICALLY DEPOSITS 200 - 300 eV per um
11- 16.5 keV in PIXEL TOT RANGE 70-95 (1 keV~6 COUNTS)

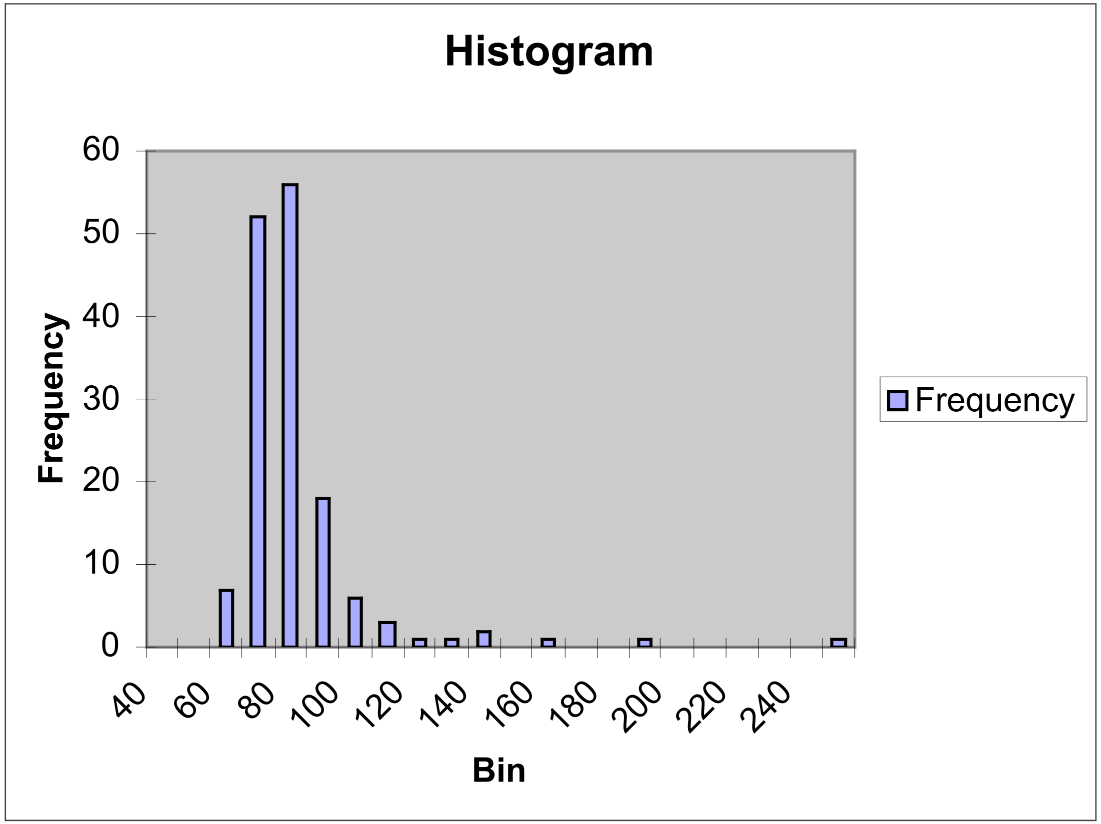
TRAIL ANALYSIS FRAME 29853



SHOWS 4 ENERGETIC DELTA δ e- TRANSFERS EVEN IF THESE REMAIN WITHIN THE PIXEL

SOMETIMES SUCH ENERGETIC ELECTRONS TRAVEL THROUGH SEVERAL PIXELS

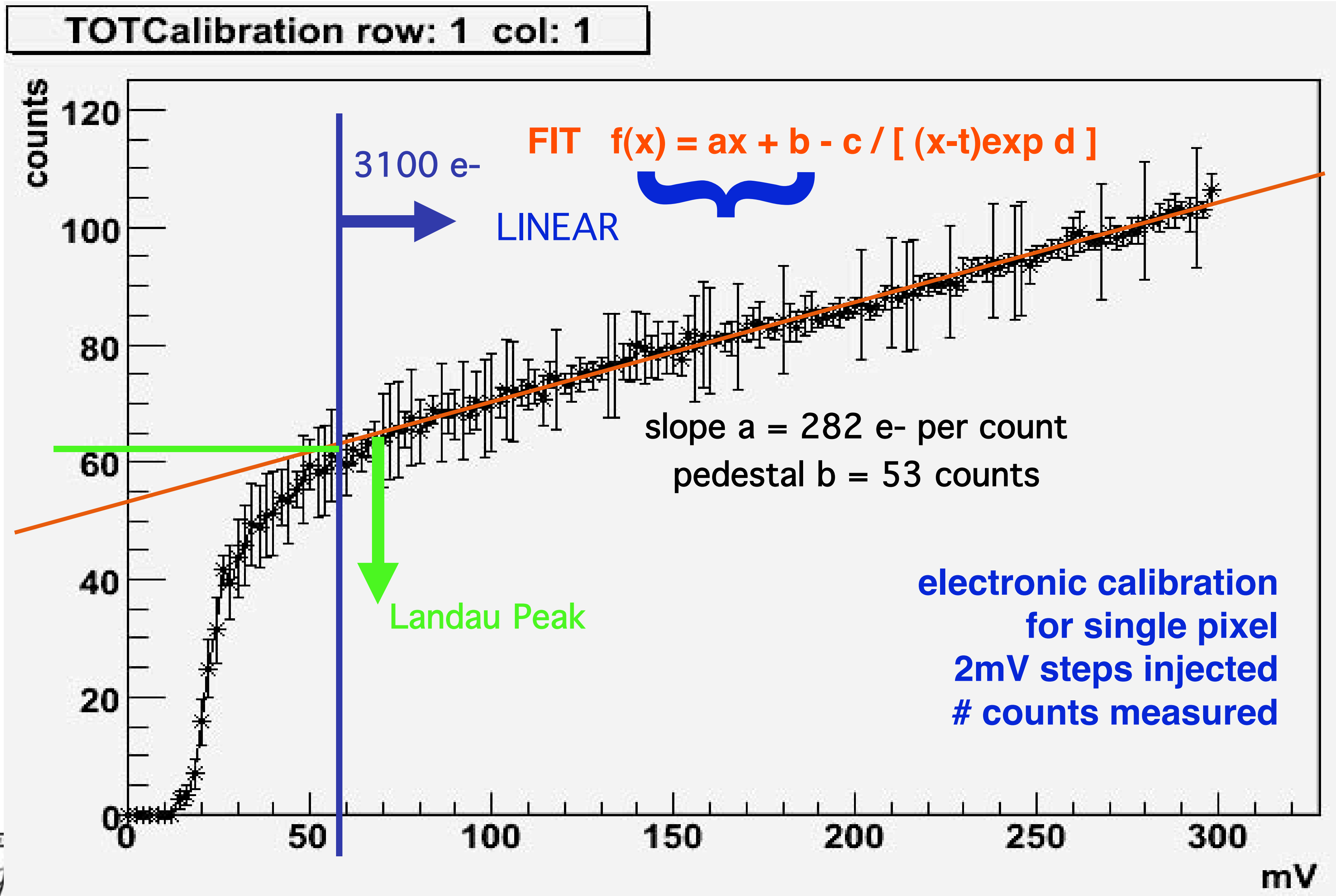
TRAIL ANALYSIS FRAME 29853

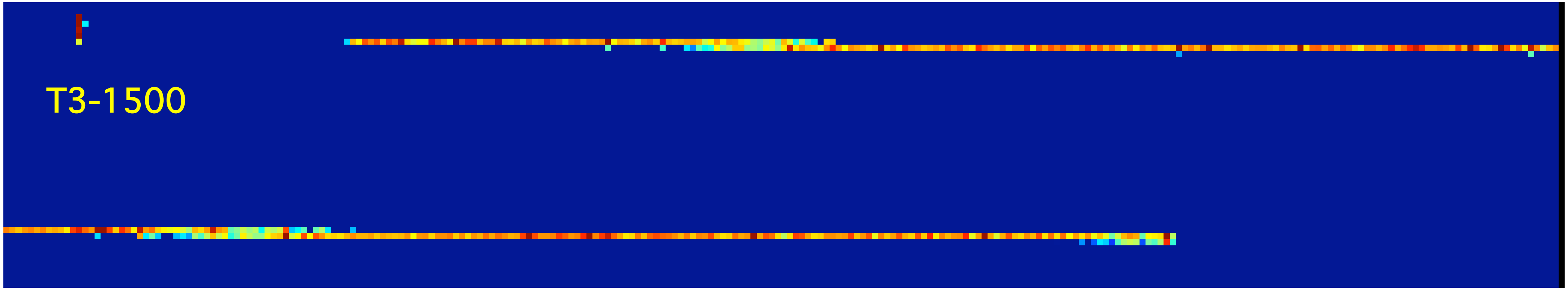


50	0
60	7
70	52
80	56
90	18
100	6
110	3
120	1
130	1
140	2
150	0
160	1
170	0
180	0
190	1
200	0
More	1

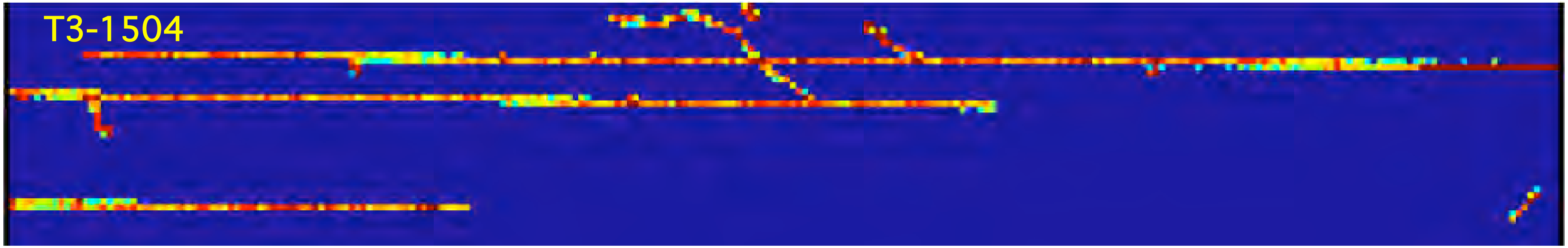
TYPICAL "LANDAU" DISTRIBUTION

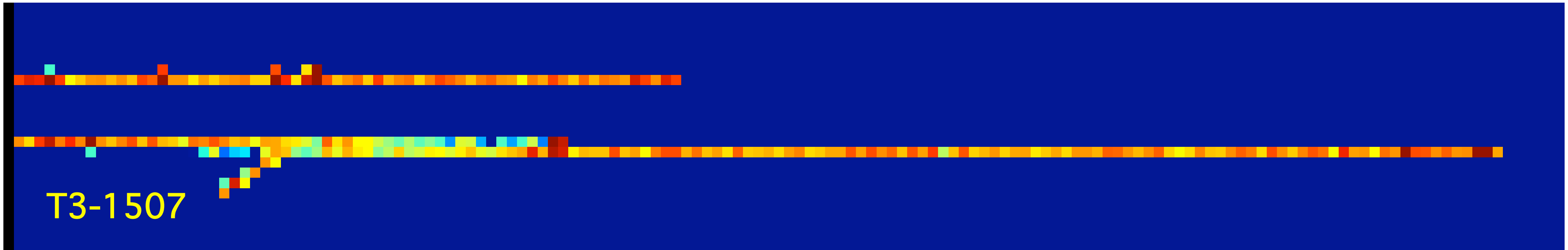
PIXEL CALIBRATION TOT (1,1)

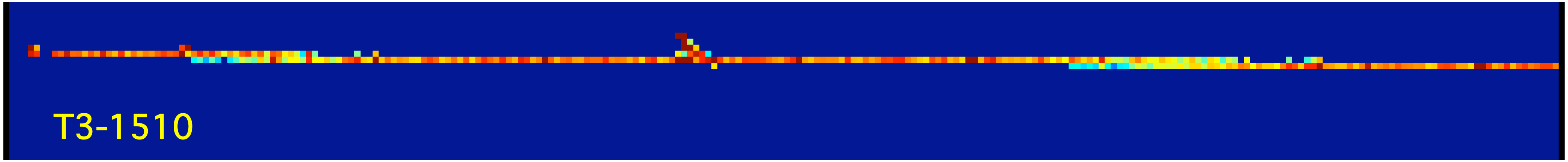


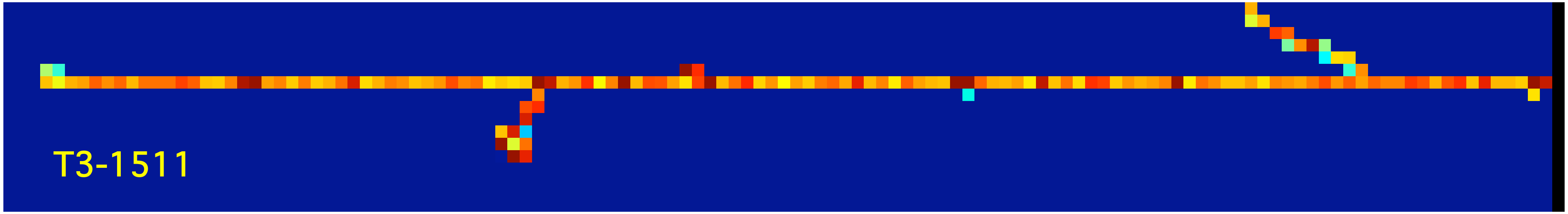


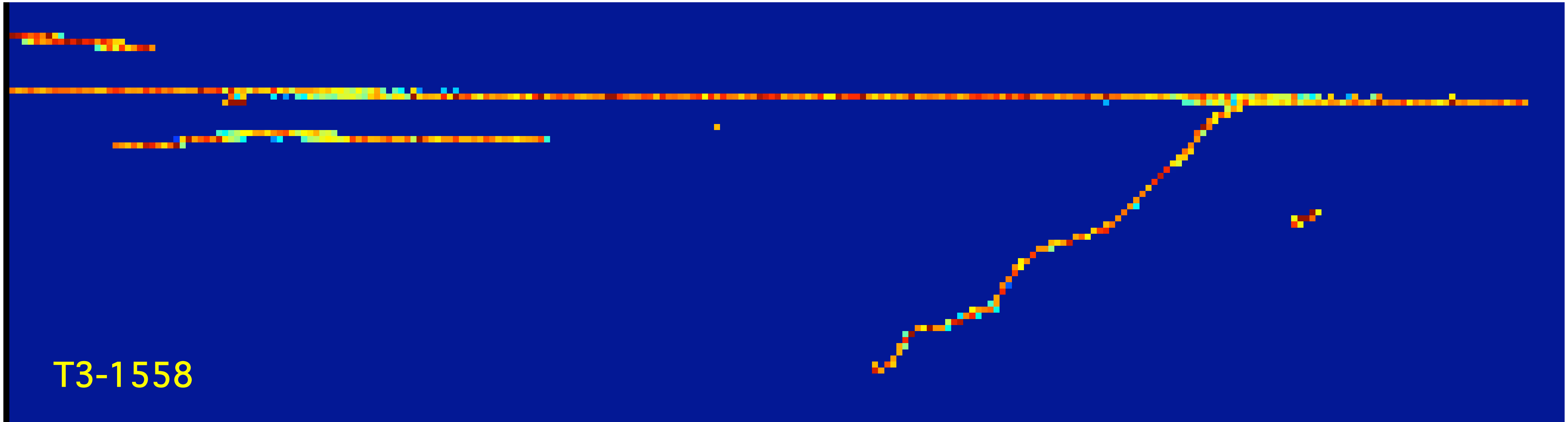
TYPICAL TRAILS ...

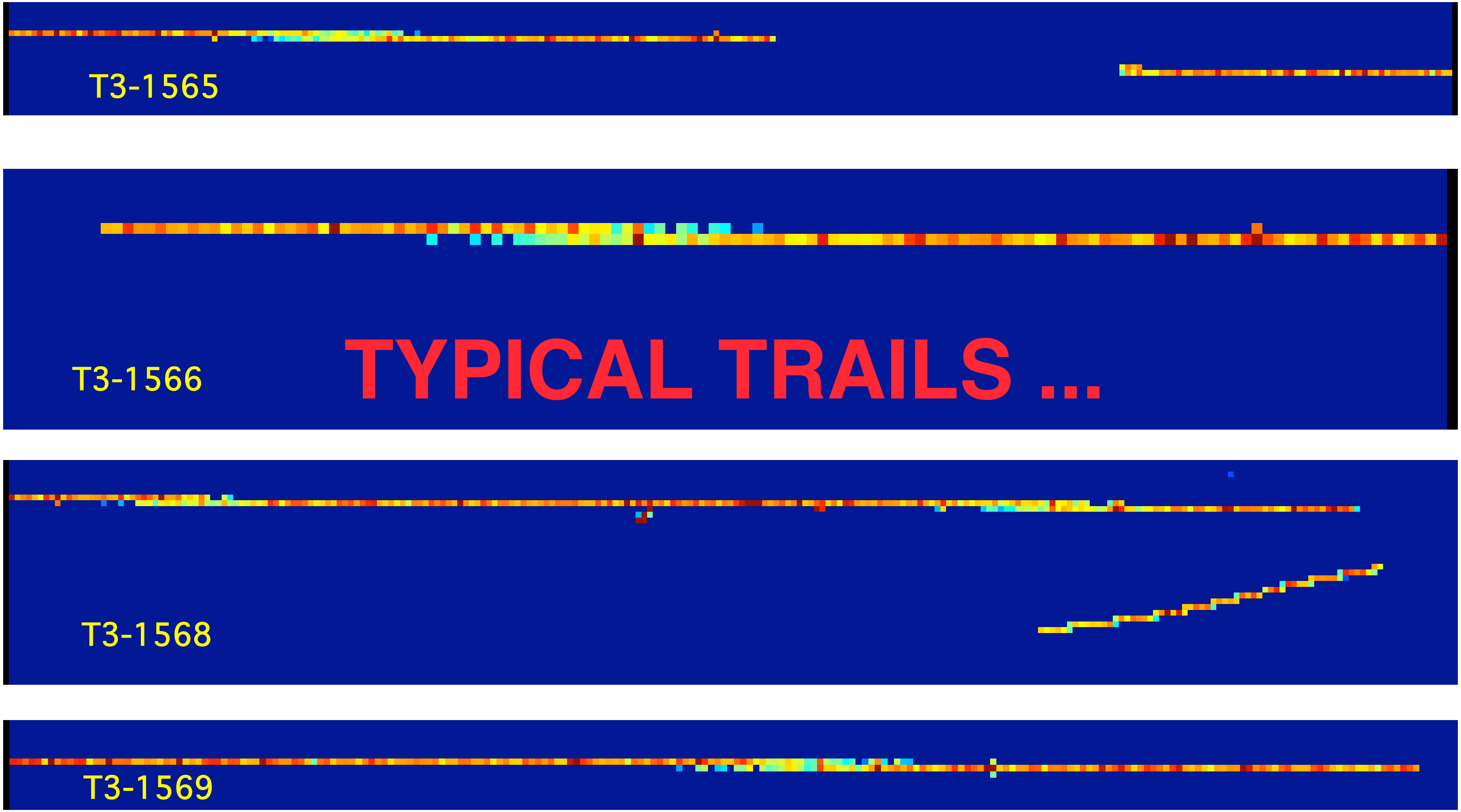





T3-1510


T3-1511


T3-1558


T3-1565
T3-1566
TYPICAL TRAILS ...
T3-1568
T3-1569

DELTA ELECTRON OCCURRENCE

CORRUPTED PIXEL >55μm OFF-TRAJECTORY

FRAMES #	TRAILS #	LENGTH mm Si	PIXEL EXTENSION 1	2-5	≥6	mm / EVENT	PROBABLY CORRUPT 300μm Si
15	54	315	98	11	7	2.7 mm	1 on 9
16	49	334	119	24	18	2.1 mm	1 on 7
17	52	326	120	21	7	2.2 mm	1 on 7

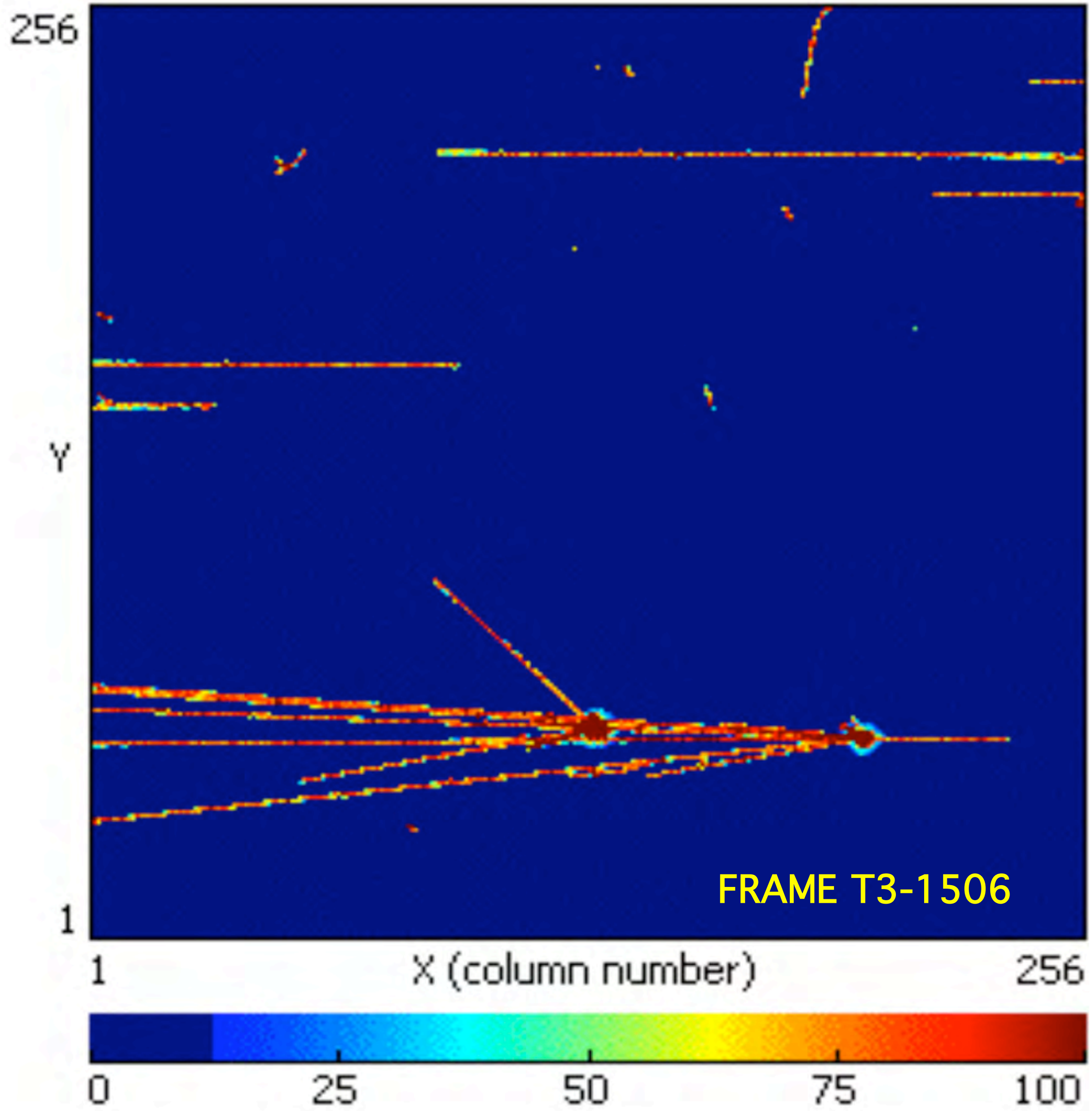
3 SIMILAR DATASETS, SAME PIXEL THRESHOLD

TIMEPIX as SILICON 'EMULSION' or 'BUBBLE CHAMBER'

H6 PION BEAM 2007

INCIDENT from RIGHT

BEAM



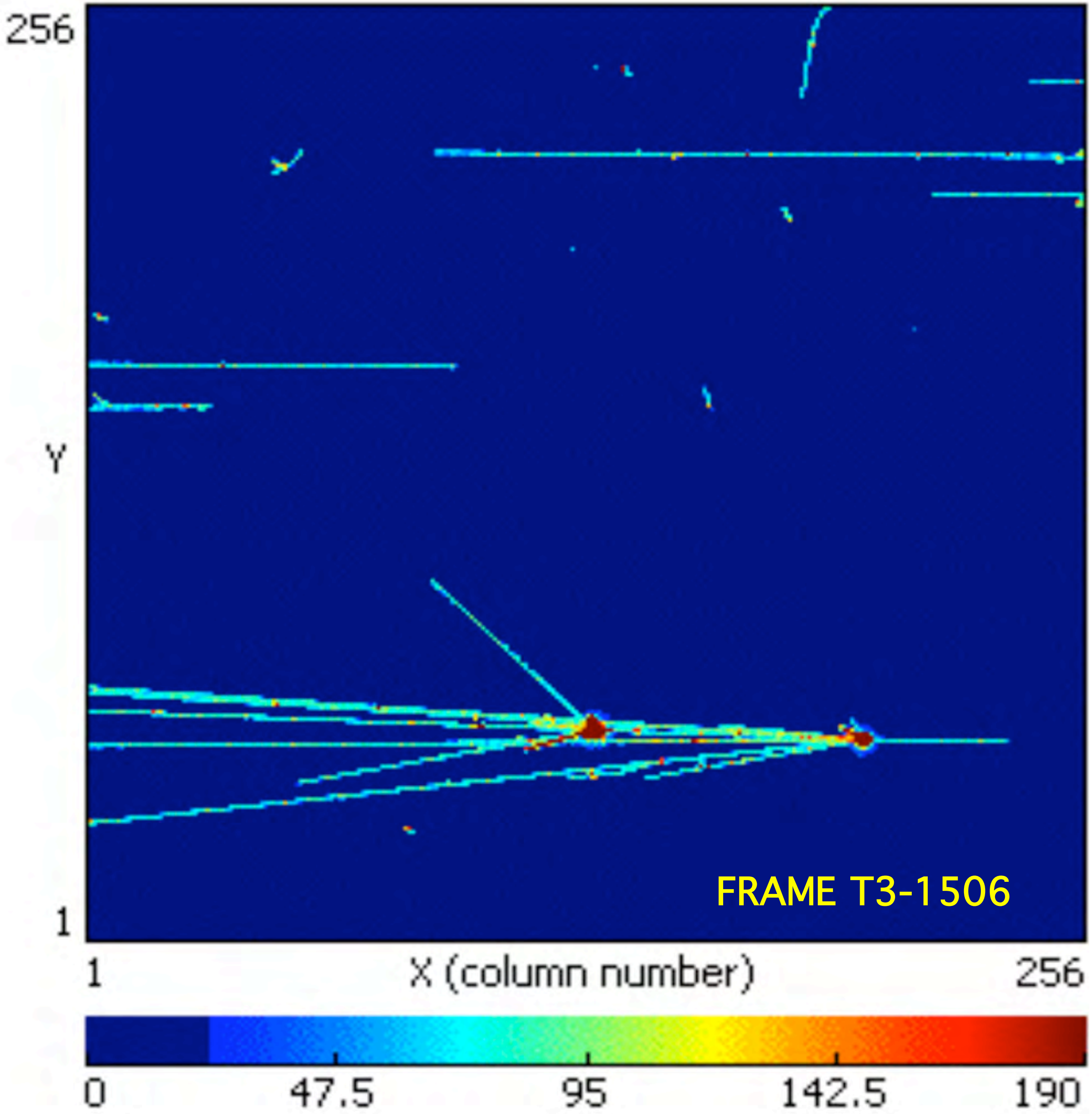
with John Idarraga / Montréal

TIMEPIX as SILICON 'EMULSION' or 'BUBBLE CHAMBER'

H6 PION BEAM 2007

INCIDENT from RIGHT

BEAM



with John Idarraga / Montréal

TIMEPIX as SILICON 'EMULSION' or 'BUBBLE CHAMBER'

H6 PION BEAM 2007

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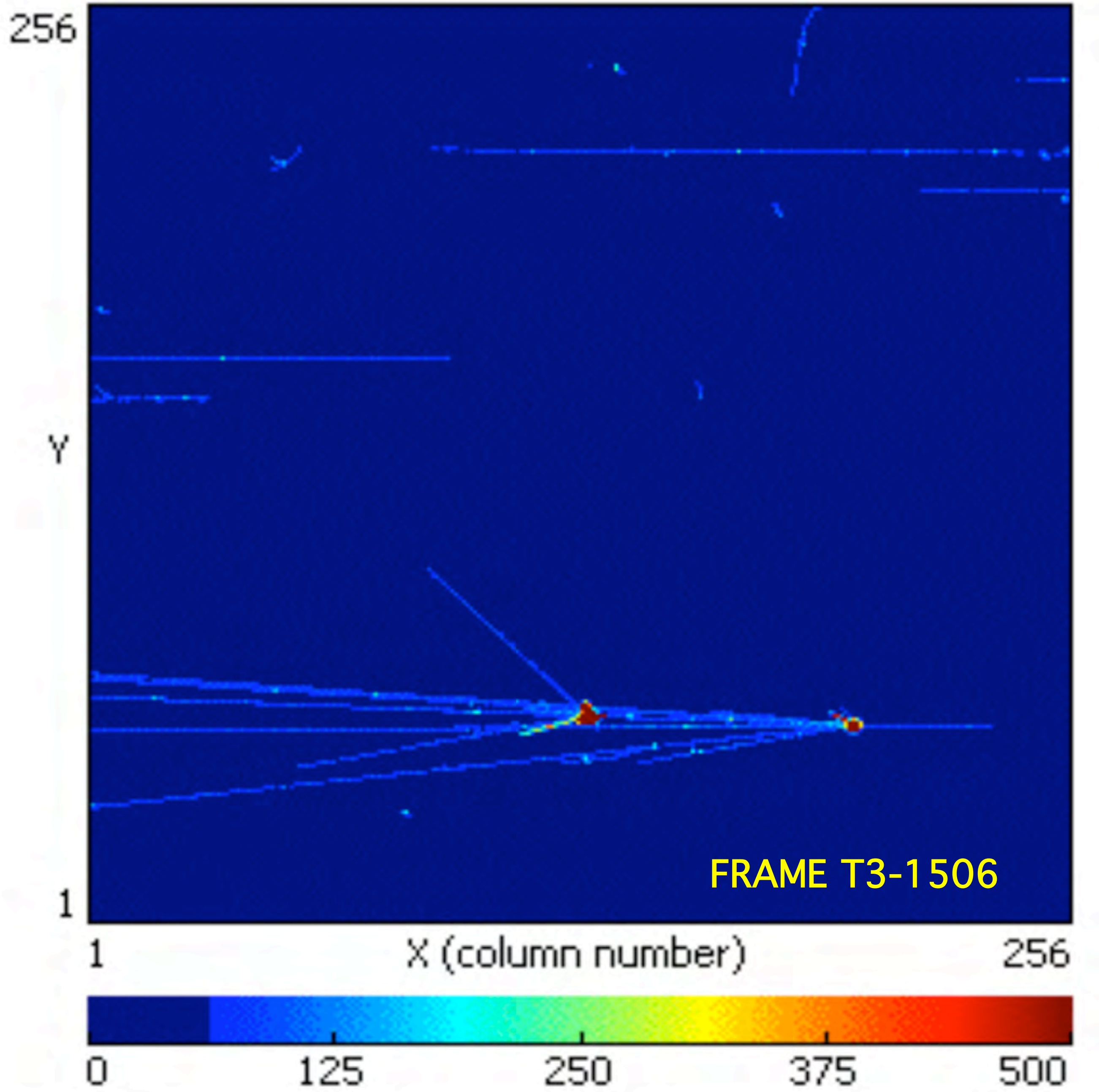
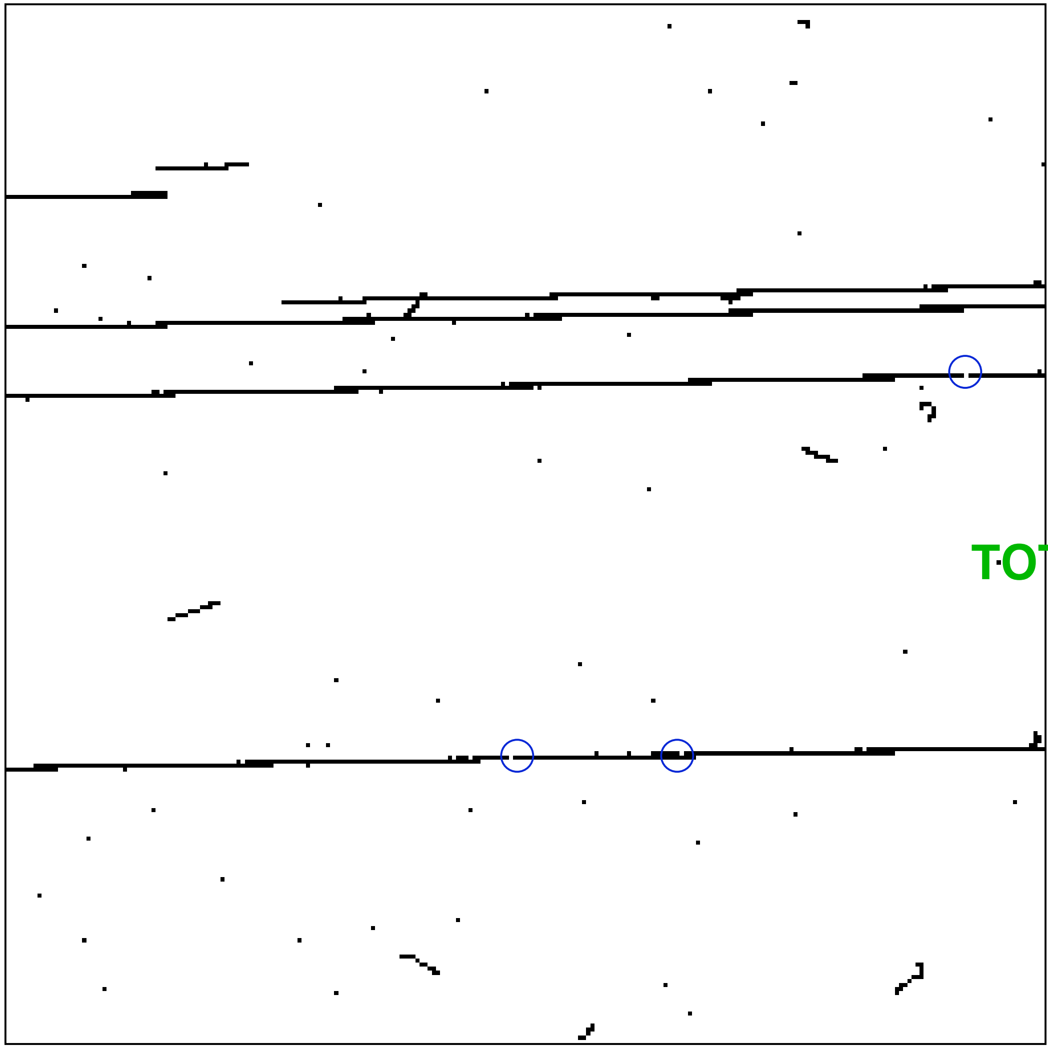


with John Idarraga / Montréal

MUONS from π, K DECAY

ANALYSIS with MEDIPIX only
already SHOW SUBMICRON PRECISION

H6 120 GeV MUONS : REDUNDANCY -> PRECISION



ROW_OVERLAPS are ESSENTIAL

4 "CLOSED SEGMENTS"

TOTAL ENERGY/CHARGE in a TRAIL

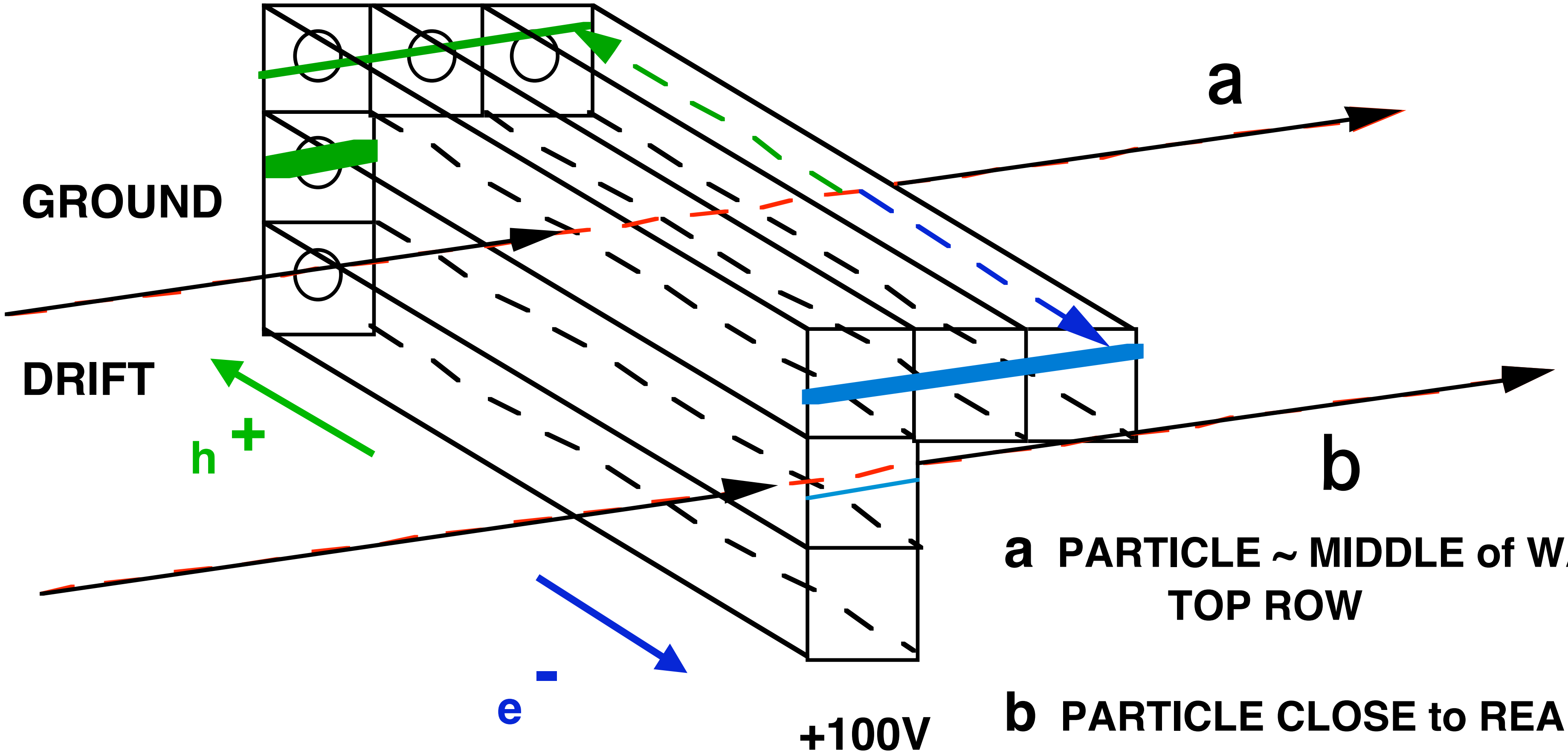
3.4 MeV or ~1M e^-

FEW DEAD PIXELS

NO EFFECT on EFFICIENCY

Parallel Medipix M-01-0013

CHARGE COLLECTION & LATERAL DIFFUSION

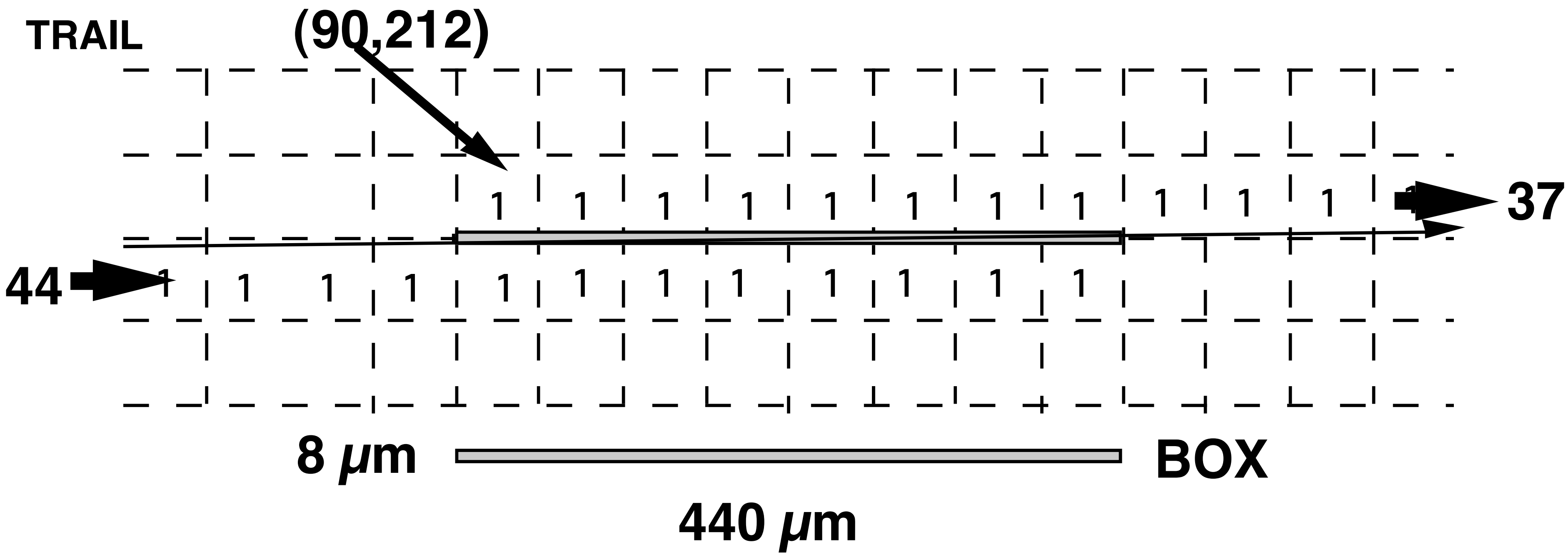


a PARTICLE ~ MIDDLE of WAFER
TOP ROW

b PARTICLE CLOSE to REAR
MIDDLE ROW

DIFFUSION width of CARRIERS
is shown EXAGGERATED

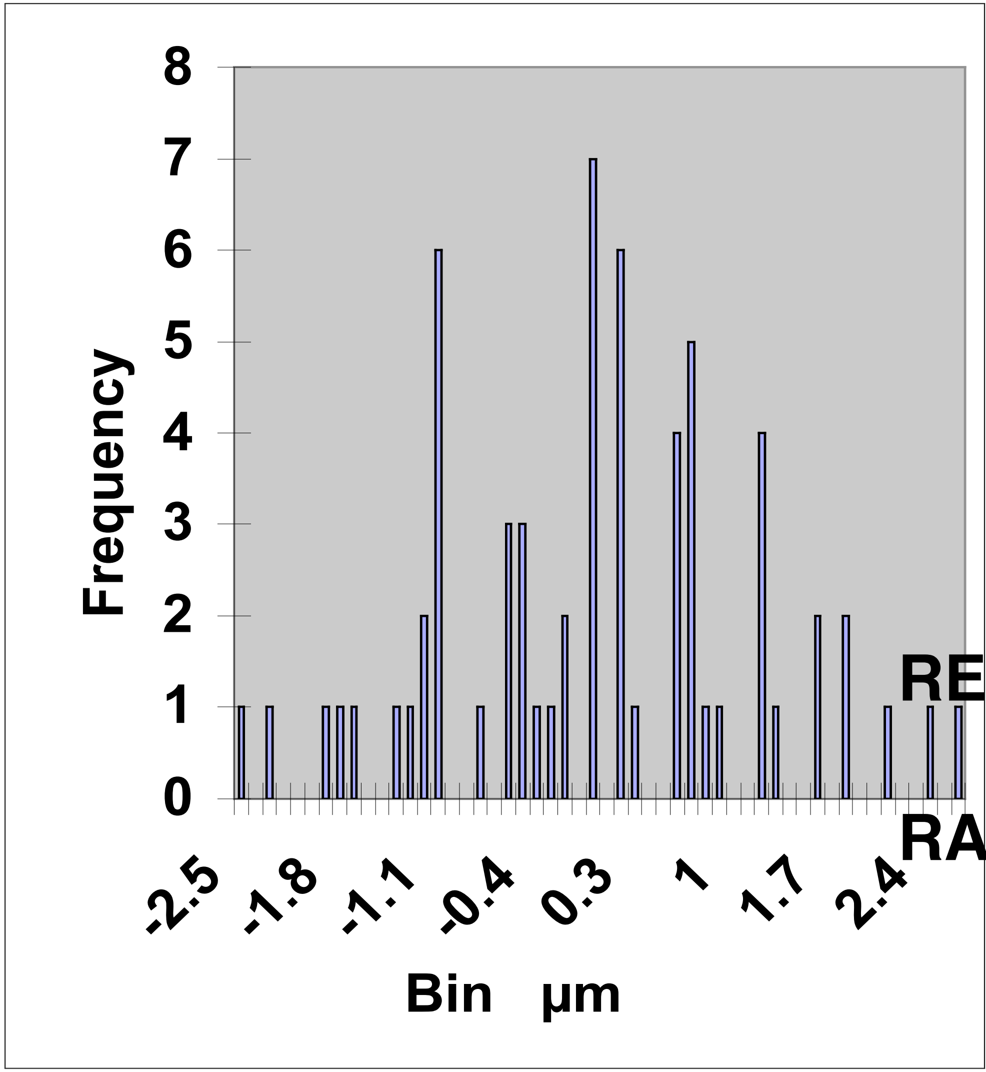
EXCELLENT RECONSTRUCTION PRECISION



SEQUENCE of DOUBLE HITS ---> PRECISE ROW TRANSITION POINTS CONSTRAIN TRAJECTORY in the MIDDLE to ~ 0.05 μm on VERTICAL

Parallel Medipix M-01-0013

PRECISION : AUTO - RESIDUALS



USE MUON TRAIL SEGMENTS TO PREDICT POSITIONS in ROW OVERLAP POINTS

(TAKE ALWAYS MIDDLE OF SEQUENCE)

RESIDUAL DISTRIBUTION

RANGE ± 2.5 μm → σ = 0.8 μm

IMPROVING VERTEX TRACKING DETECTORS

COPING with SLHC DENSITY & EVENT RATE

INVESTIGATE DIFFERENT APPROACHES

DETERMINE QUICKLY THE RELEVANT PRIMARY VERTEX
REDUCE AMBIGUITIES
IMPROVE PATTERN RECOGNITION

VECTOR COORDINATES for TRAILS

USE MANY MORE POINTS ON TRAIL

RESPECT LIMITATIONS on POWER & COST

MICRO → NANO ELECTRONICS

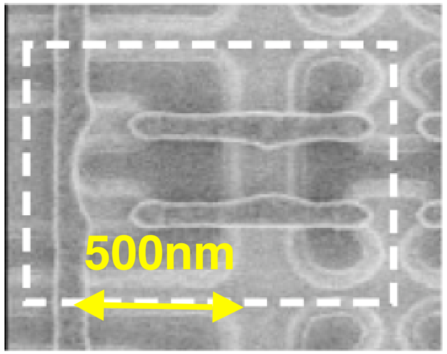
NEW APPLICATIONS NEED MORE ADVANCED nm CMOS

INTEL : IMPROVED LITHOGRAPHY in 45 nm

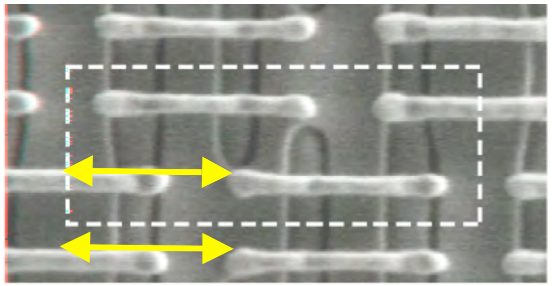
MINIMAL SRAM CELL

ALSO, SEVERAL CHARACTERISTICS IMPROVED BEYOND EXPECTATIONS

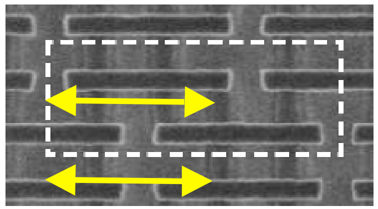
90 nm



65 nm



45 nm



~ TO SCALE

Mrs Kelin KUHN, IEEE IEDM 2007

45 nm INTEL : LESS VARIABILITY

Mrs Kelin KUHN, INTEL 18.2

SRAM CELL

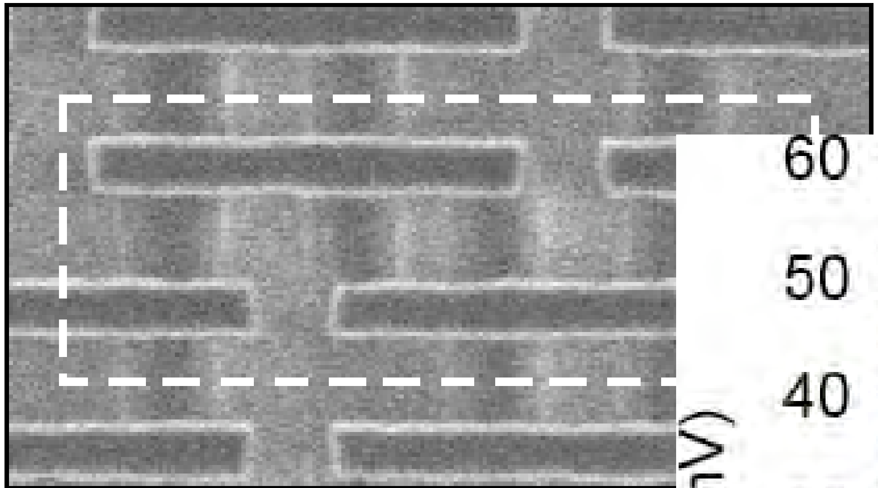


Fig. 4 Diffusion and poly layers of 0.346 μm²

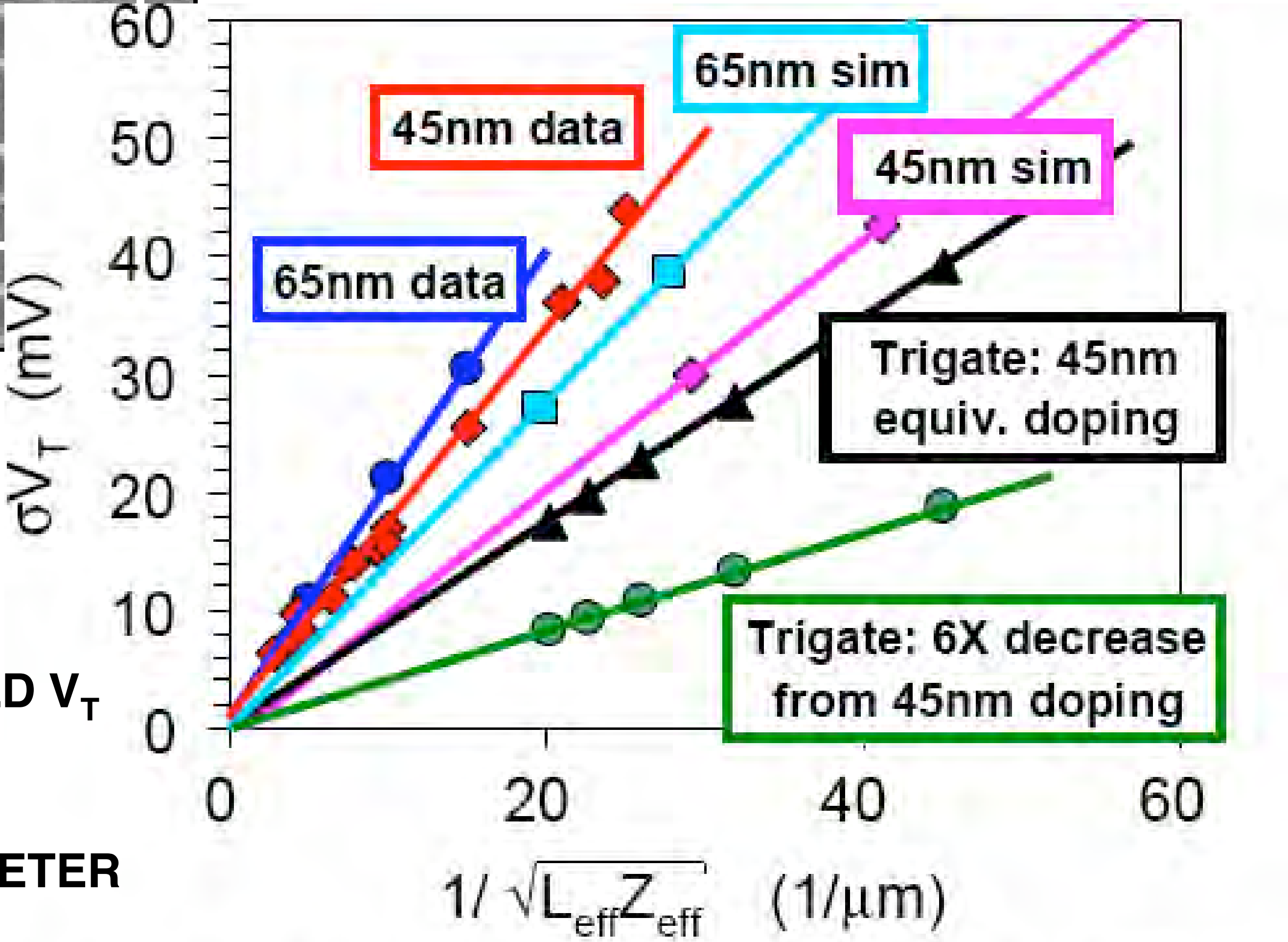


Fig.5. 65nm and 45nm transistor variation, additional benefit of a fully-depleted geometry such as Trigate

DISPERSION σ on THRESHOLD V_T
vs 1/DIMENSION

A BASIC 'MATCHING' PARAMETER

PROGRESS in Si SENSORS

HAND-in-HAND with AVAILABLE INDUSTRIAL TECHNOLOGY

0-D	SINGLE DIODE	1955
1-D	SEGMENTED DIODE mm	1960
QUASI 2-D	DOUBLE-SIDED STRIPS	1965
TRUE 2-D	CCD/MOS MATRIX	1971
	PIXELS MONOLITHIC or HYBRID	1989
	PILLARS '3D'	1998
TRUE 3-D	VOXELS next step	?

DEMONSTRATION of Si VECTOR DETECTOR

HIGHLY REDUNDANT TRAILS with SMALL VOXELS

PRECISE SPACE VECTOR instead of FEW SPACE POINTS

RESOLVE DIRECTIONAL AMBIGUITIES in PROJECTIONS

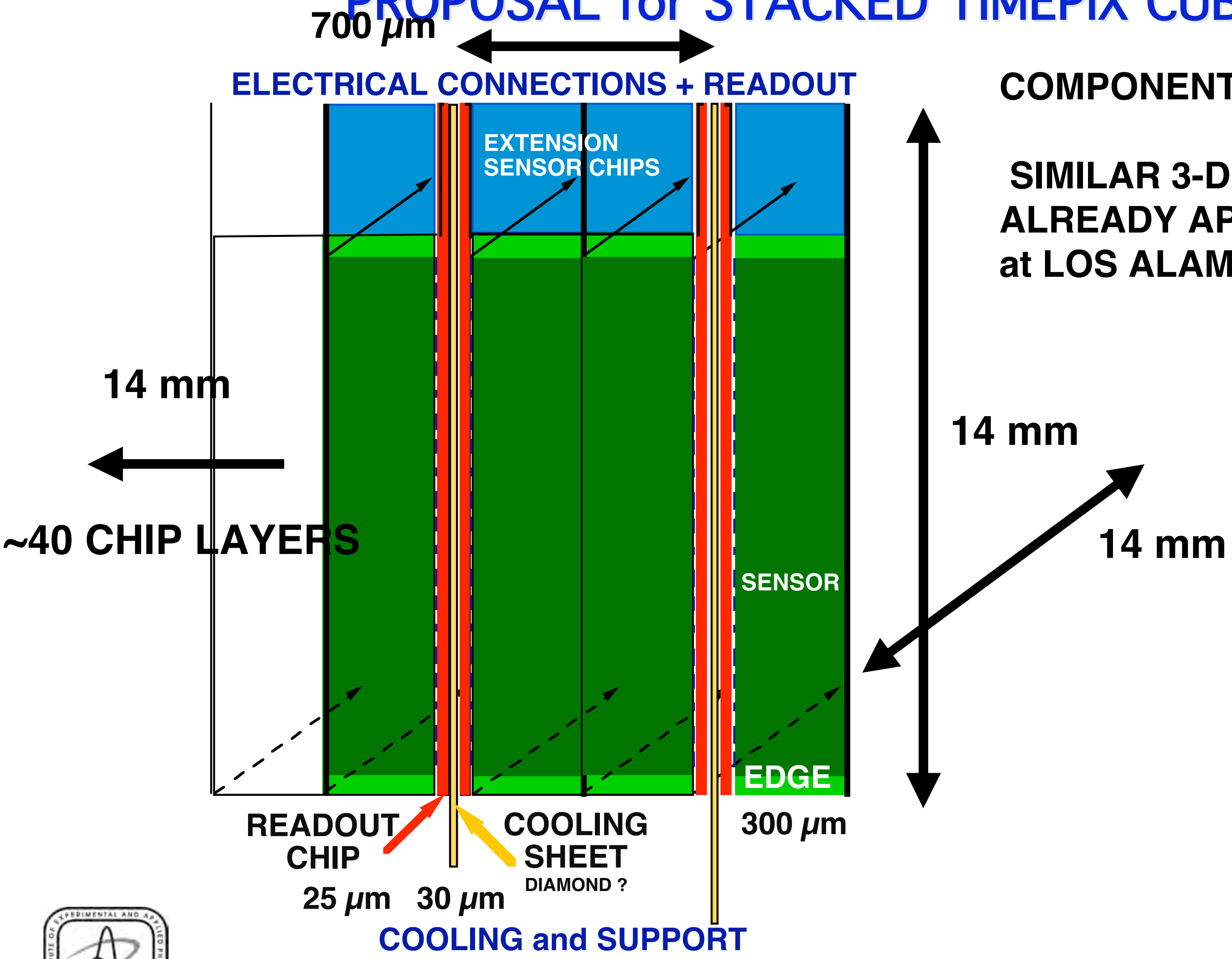
EXCLUDE CORRUPT MEASUREMENT POINTS (DELTA e-)

TRACKING PRECISION < 1 um USING ~20-40 pixels

...

END

PROPOSAL for STACKED TIMEPIX CUBE



COMPONENTS 'EXIST'

SIMILAR 3-D TECHNOLOGY
ALREADY APPLIED
at LOS ALAMOS

OPERATION in H6 BEAM CERN CAN BE REAL EASY

SOME POTENTIAL APPLICATIONS

ACTIVE Si TARGETS

INTEREST 1985-1995 BUT:
EXPLOIT FIXED TARGET BEAMS in FUTURE
'CENTRAL' DETECTOR at NEUTRINO FACTORY

CALORIMETER PRE-SHOWER

HIGH PRECISION ENTRY SHELL
PARTICLE RECOGNITION by PATTERN

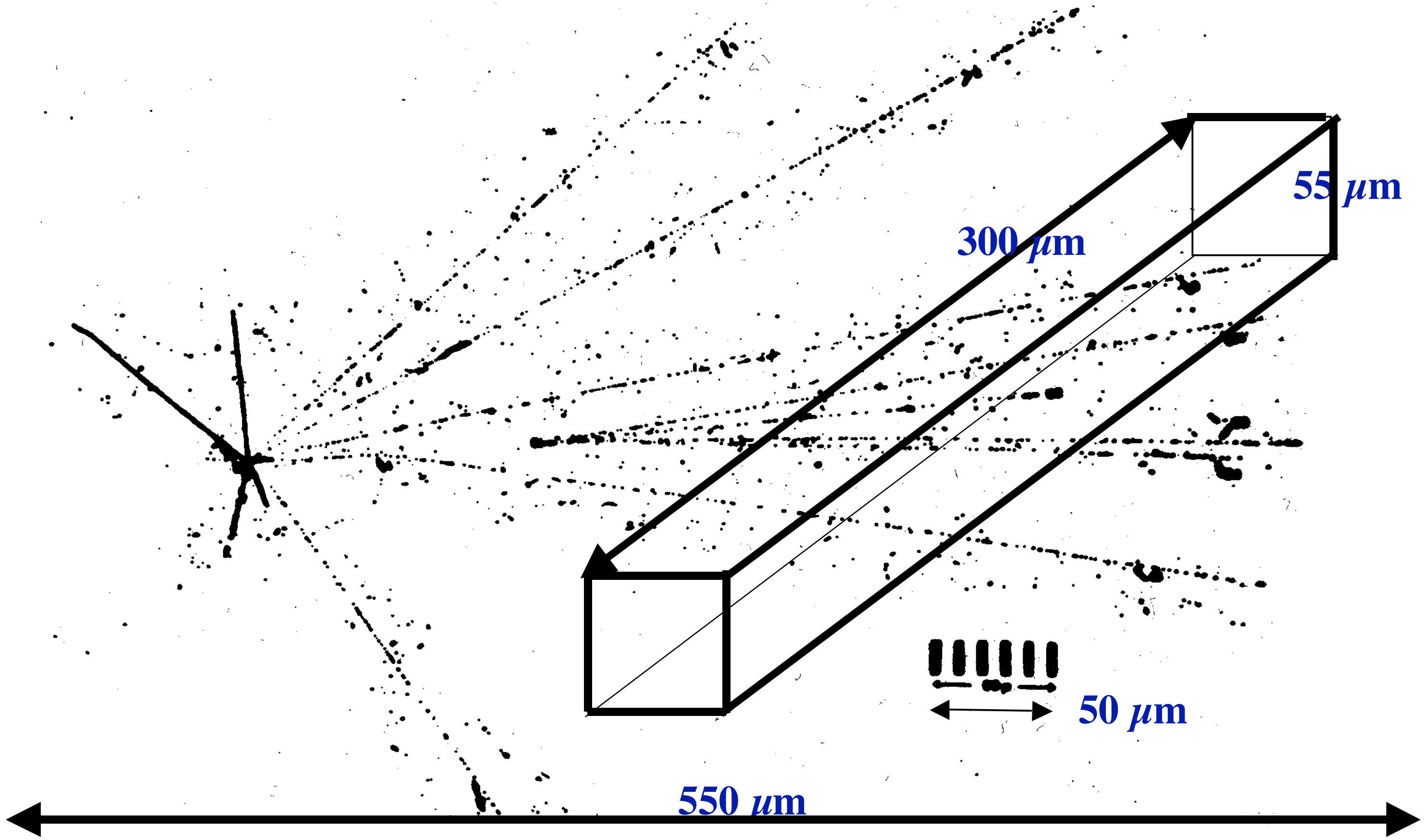
PARTICLE IDENTIFICATION p,π,K,e^-,μ

NEEDS ANALOG SIGNAL --> TIMEPIX CHIP

MANY SAMPLES ARE POSSIBLE

COMPARE EMULSION with MEDIPIX

55um x 55um x 300um PIXELS



FAIRLY LARGE BACKGROUND NOISE in EMULSION