Brahms Centrality Detector

Development Options

(Revised December 16, 1997)

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  - Electronics
  - ^Performance (also includes tpc1 rates for all options)
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Summary of changes since Collaboration Meeting of Aug. 25, 1997

- Includes results obtain by UA2 collaboration at CERN on Micron Semiconductor 7-strip detector (same as proposed for Brahms)
- Includes noise characterization of HQV810 preamp.
- Includes proposed mounting scheme for hybrid detector array.
- Includes new GEANT simulation for hybrid array in “realistic” mounting scheme.
- Expanded options for strip detector electronics development.

Summary of changes since Centrality Detector Meeting of June 27, 1997

- Strip-detector array geometry changed to use seven-strip, 6cm x 4 cm detectors available from Micron Semiconductor.
- Scintillator tile geometry changed to use closely spaced 12 cm x 12 cm tiles.
- Strip detector energy resolution taken as the greater of 100 keV or 2% of total energy.
- Scintillator tile energy resolution taken to be the greater of the photoelectron counting statistics, assuming 8 PE/MIP, or 3% of the total energy.
- New GEANT calculations performed for the revised geometries showing the potential accuracy of the multiplicity determination using the ϕ segmentation. This allows correction for particles leaving excessive energy in a given segment.
- Additional study of the possibility of vertex localization using the centrality array.
- Characterization of the centrality array response for $^{28}Si+^{28}Si$ events.
- Further study of using the Si strip detector array to downscale non-central events.
- Revised electronics scheme for Si strip detector array.
- Develop concept of hybrid strip detector/scintillator tile detector

Introduction.

- The primary purpose of the Brahms Centrality Detector is to obtain a measure of centrality on an event by event basis.
- A secondary role is to help develop the event trigger to allow prescaling of non-central events.
- Decisions need to be made concerning:
  - Final geometry of array, including mix of detectors.
  - Mounting of detectors.

Basic Premise

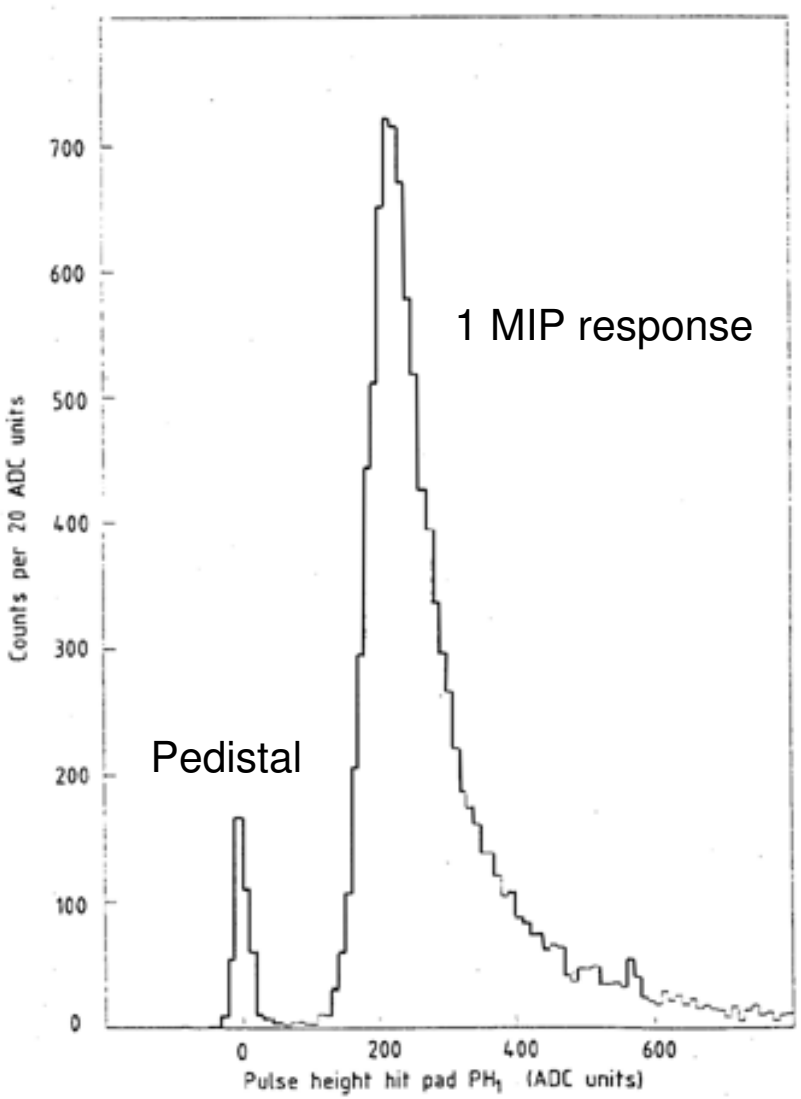
- A modestly segmented array can be used with the multiplicity determined by energy measurement. Either Si strip detectors or plastic scintillator tiles can be used for the energy measurement. This should allow use of “conventional” electronics.

$$\#\,particles = \left(\text{detected } E\right) \Big/ \left\langle \mathrm{E}_{\text{Charged Particle}} \right\rangle$$

Caveats

- The procedure for multiplicity determination works best if all of the detected particles originate from the reaction vertex and correspond to minimum ionizing particles (MIPs). This is not true.
- Monte-Carlo simulations of RHIC events with subsequent tracking of secondary interactions can be used to deduce an “effective” energy deposition per particle, but this will introduce a model dependency for any quoted multiplicity.
- Athough the absolute multiplicity will not be determined, the measurement should still allow for good determination of the relative particle multiplicity for events corresponding to different impact parameters.
- It is assumed that all particles striking a given array segment arrive within a period that is short compared to the rise time of the associated electronics. This condition should be satisfied for the geometries shown: the spread in arrival times for primary particles over the entire strip detector array is < 1 ns, and for the tile/fiber array is < 2ns. A scattered particle that arrives late and subsequently leaves a large amount of energy in a given array element could result in an anomalous energy determination. This is a rare occurrence, however.

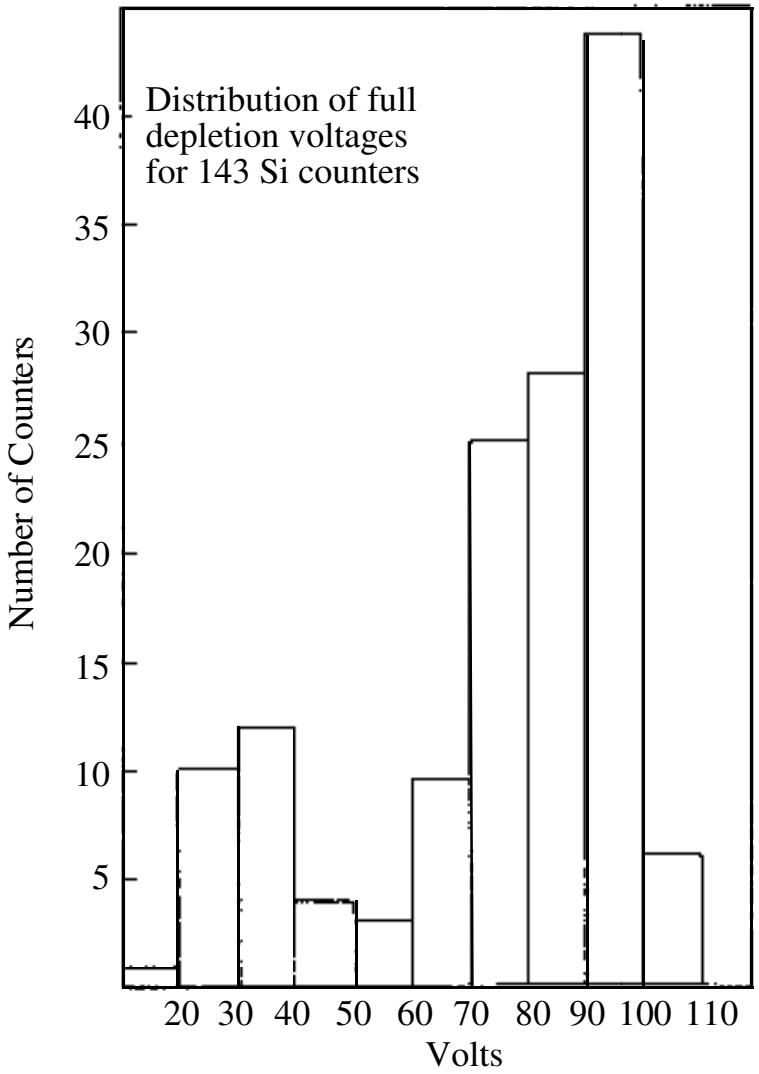
Si strip detector - Energy resolution & threshold

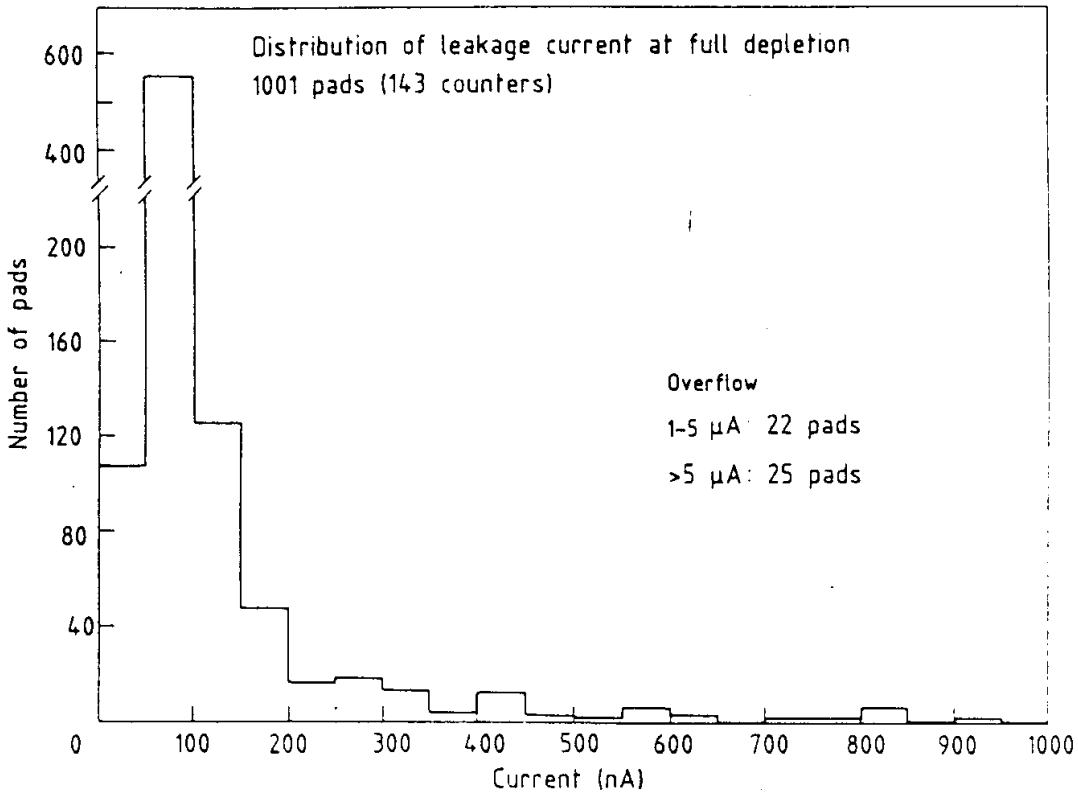


Borer et al., NIM A253, 548(1987)

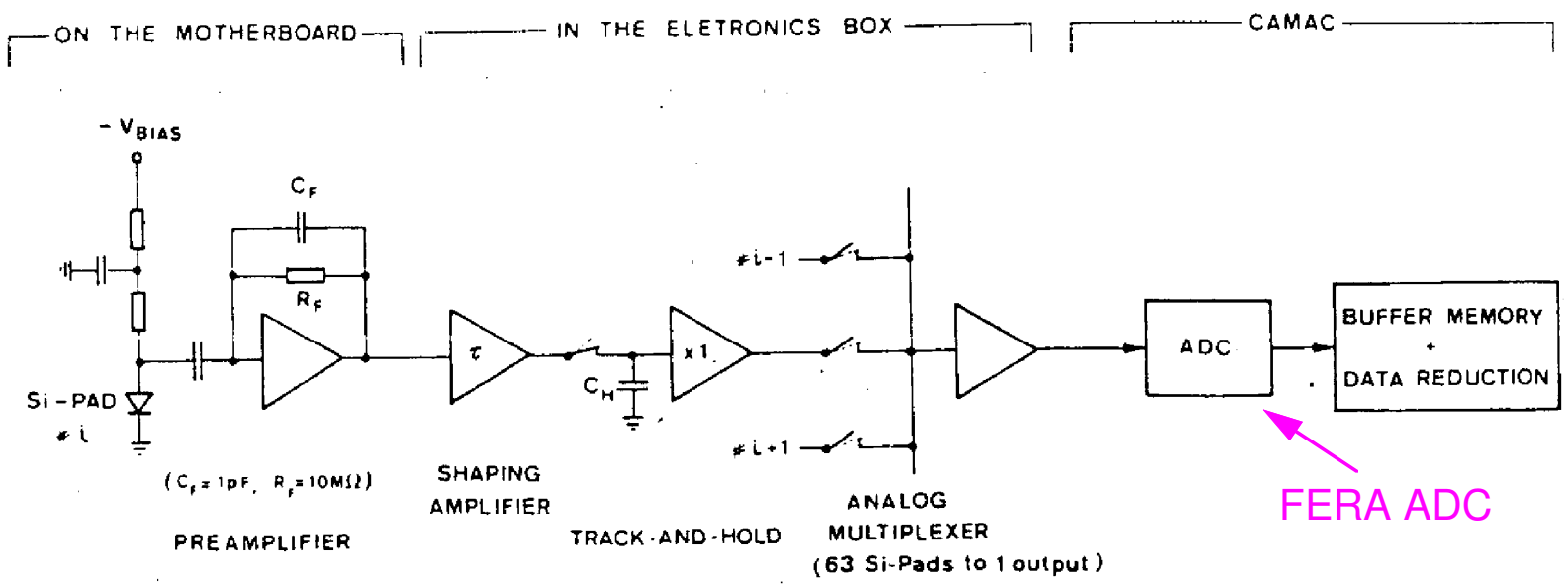
Note: This is the identical, 300 μm, seven strip detector from Micron Semiconductor that we are considering using.

Si strip detector - Distribution of full depletion voltage and leakage currents

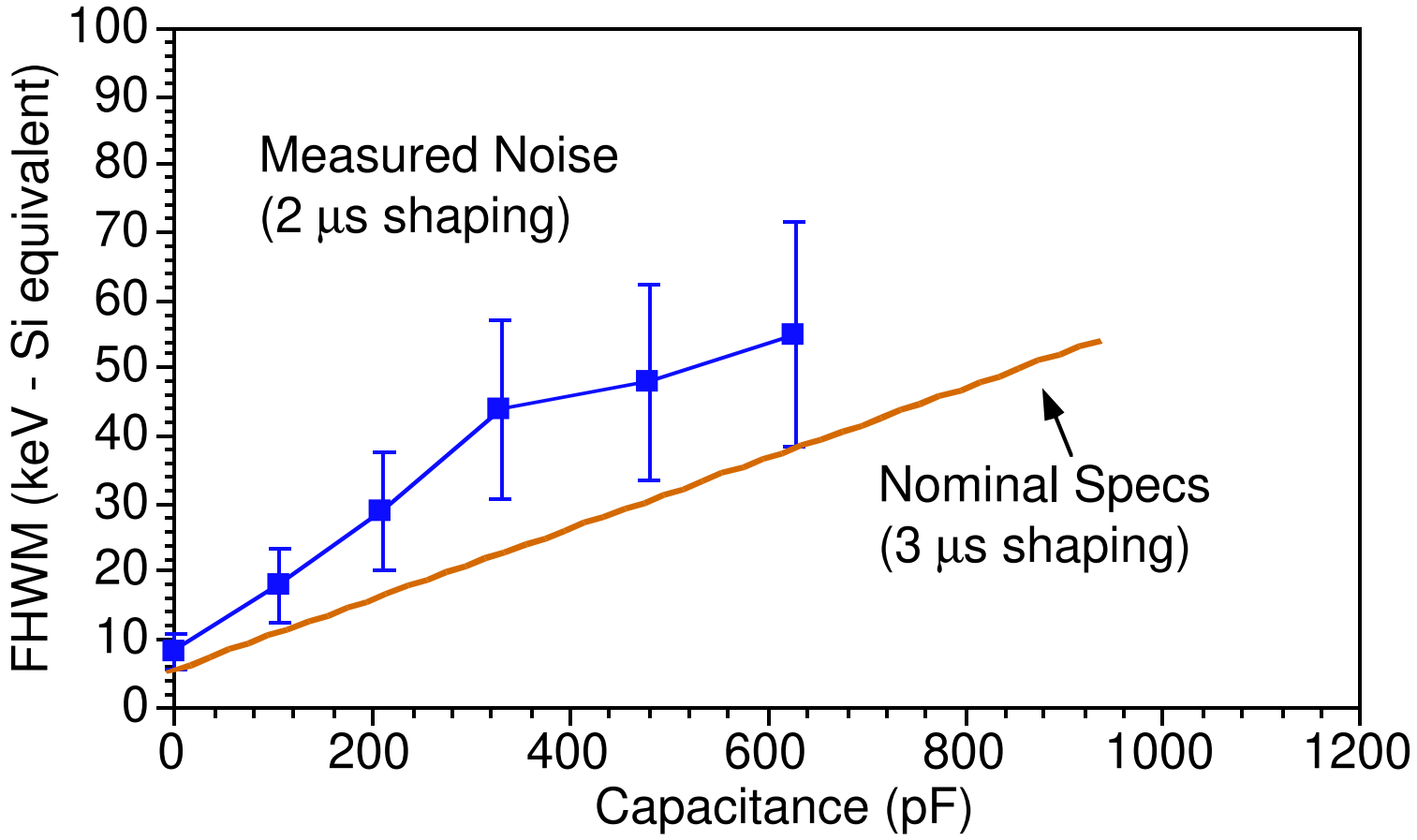




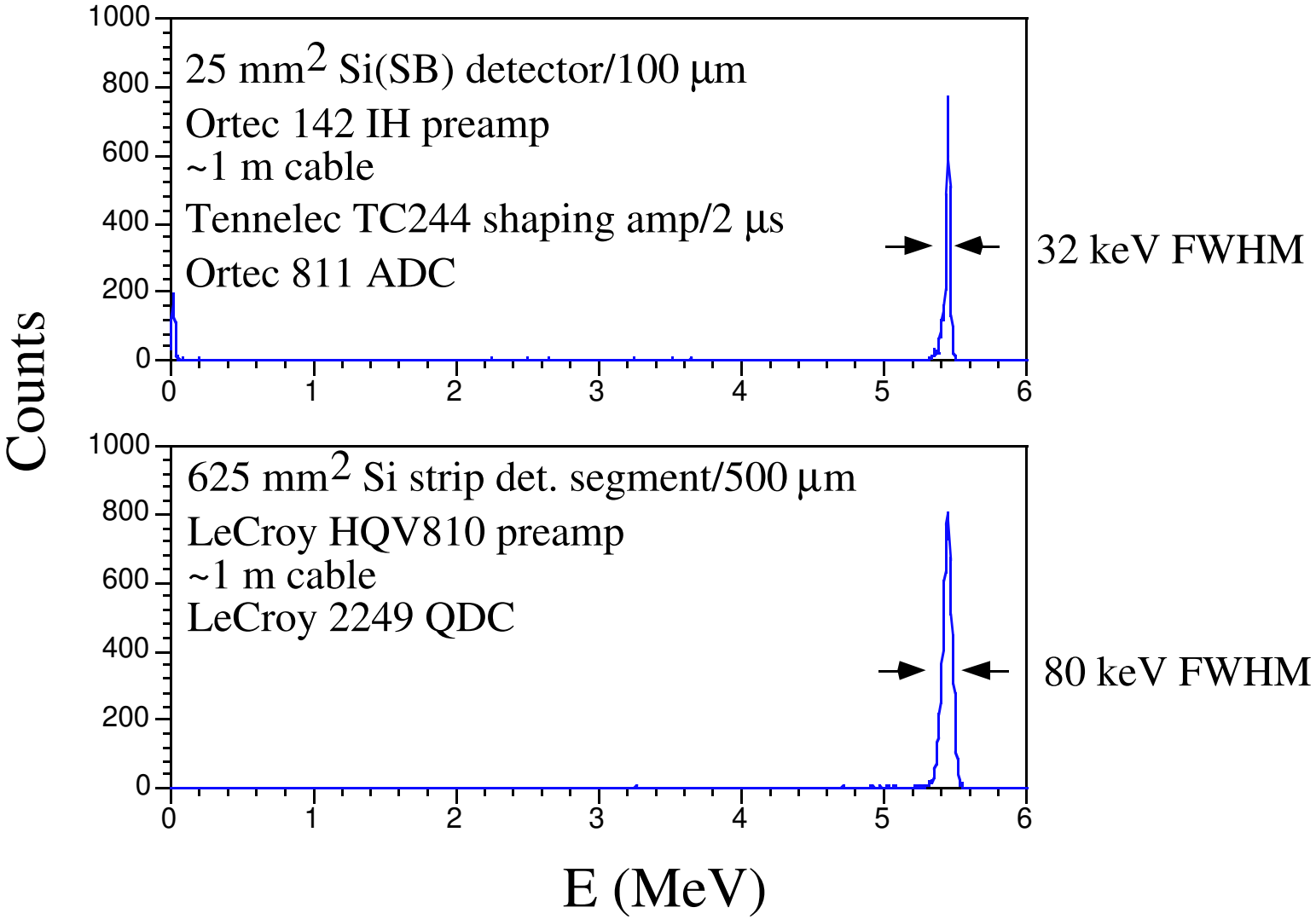
Block diagram of UA2 strip-detector electronics



Measured noise for LeCroy HQV 810 preamp



Test of HQV810 going directly into QDC



Strip detector electronic issues

- UA2 scheme
  - Good resolution
  - Flexible
  - Multiplexing can reduce costs
  - Requires development of shaping amplifier and multiplexer. (Both developments look reasonable straigtforward.)
- Direct to QCD
  - Modest resolution (may not work for single MIP detection)
  - Minimal development
  - Can use FASTBUS QDC for lower overall cost
- UA2 scheme without multiplexer
  - Good resolution and high rates
  - Requires development of shaping amplifier
  - Higher cost

Geometry of Centrality Array

- For either the strip-detector or plastic scintillator options, it is expected that the the centrality array will correspond to a barrel arrangement of many detector elements around the beam tube.
- The array should have as complete coverage in η and ϕ as possible to avoid introducing kinematic biases in the coincidence results with the primary Brahms' spectrometers.
- Extended coverage in η is also necessary to account for a potential offset of the interaction vertex along the beam axis.
- The primary constraint on the size of a scintillator tile array is interference with the mid-rapidity spectrometer in its forward-angle position.
- The primary constraint on the size of a strip detector array is the cost of the detectors and associated electronics.

Discussion with Micron Semiconductor

- "Standard" geometries include 6cm x 4cm (7 strips) and 4.8 cm x 3.8 cm (4 strips)
- For 6cm x 4 cm detector: $1750/300 μm, $2250/500 μm
- Custom masks: ≈$12,000 (only needed if "new" design required)
- 300 μm > 40 pf/cm^2 > 30 V bias > 55 keV α resolution
- 500 μm > 25 pf/cm^2 > 70 V bias > 55 keV α resolution
- Depletion depth uniformity: ±5μm/wafer; ±15μm across wafers
- Order lead time for 30-40 detectors: 8-12 weeks

MICRON SEMICONDUCTOR INC.
252 East Semoran Blvd., Suite 907, Casselberry, Florida 32707. USA
OFFICE Tel: 407-421-5977 Fax: 407-260-1732 E.Mail micron@magicnet.net
WORKS Tel: 1-212-603-6007 Fax: 1-212-603-6017 E.Mail micron@pavilion.co.uk

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June 24th, 1997

QUOTATION NO. 3363

FAX NO. 913-864-5262
Attention: Dr. Stephen Sanders (913-864-4933)
Ref: Telephone Discussion June 23rd, 1997
EXPERIMENT: RHIC BRAHMS
Subject: Silicon Detector Candidates

TECHNICAL

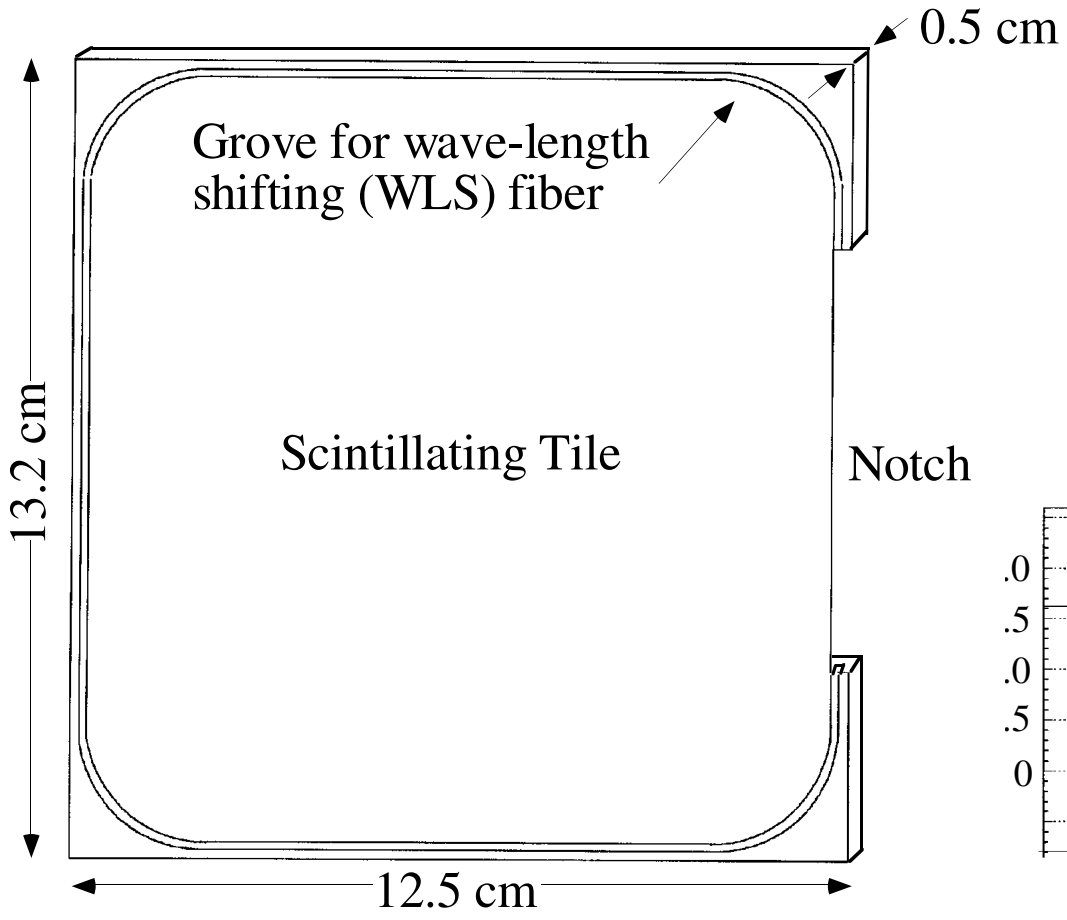
Micron Semiconductor DESIGN I-300 or DESIGN I-500
Design: Single Sided Totally Depleted DC Microstrip
Active Area 6cm x 4cm
No. of Channels 7
Strip Length 4cm
Strip Pitch 8.5mm
Element Separation 100um
Thickness (a) 300um (b) 500um
Ful Depletion(FD) (a) 50V maximum (b) 90V maximum
Total Leakage(FD) (a) 500nA (b) 1000nA
Operating Voltage FD to FD + 30V
Alpha Resolution (Junction)(1uS) 100KeV maximum
Metallising: Aluminium 2000A +- 1000A
Package: PCB Edge Support (3 sides no support)
Contacts: Vertical Pins
Biasing: Substrate (Cathode)+ve Strips (Anode) Negative or Substrate Ground
Elements: Negative, Guard Ring, Floated

FINANCIAL

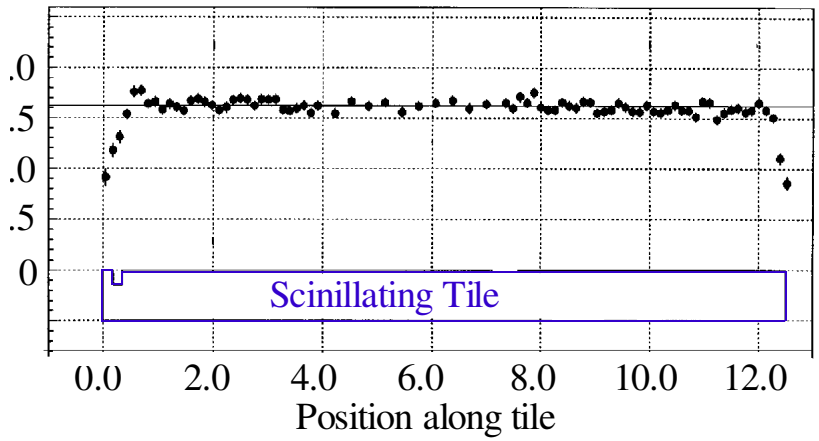
Supply Silicon Detector	DESIGN I-300		DESIGN I-500
Quantity 1 ONLY	UNIT PRICE $2,250	UNIT PRICE	$2,750
Quantity 2 - 9	UNIT PRICE $2,000	UNIT PRICE	$2,500
Quantity 10-49	UNIT PRICE $1,750	UNIT PRICE	$2,250

Prices: US Dolars, Ex. Works

Plastic Scintillator Tile/Fiber System



Based on
Star Note 274
O. Grachov



Fiber readout patterns.

Suggested pattern for Brahms

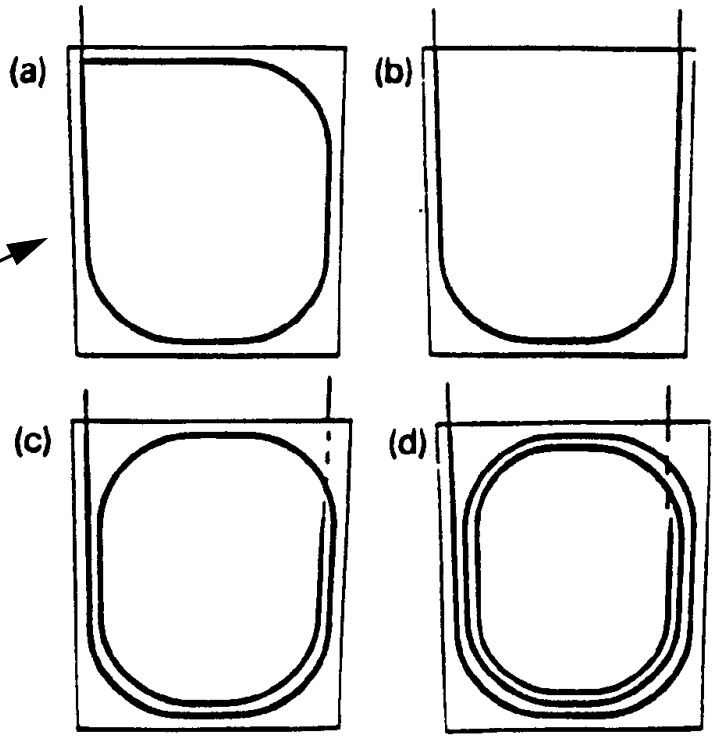


Fig. 7. Different layout patterns of fibers in the tile that were examined: (a) σ pattern with single fiber connected to photomultiplier. The end of the fiber remaining in the tile has been aluminized; (b) U-shaped pattern, with 2 readout fibers; (c) 2-spiral pattern with 2 readout fibers; (d) 3-spiral pattern with 2 readout fibers.

Photoelectron statistics

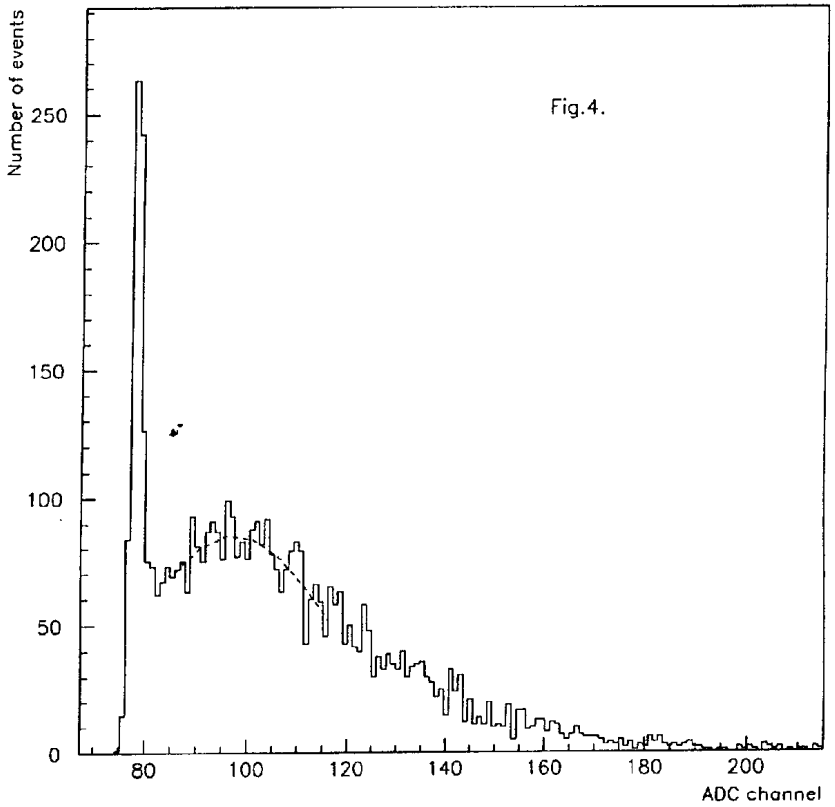


Fig.4. ADC pulse height spectrum for tile/fiber read-out system using 6.5 m green Bicron BCF91A WLS fiber.(The light yield is 1.6 p.e.)

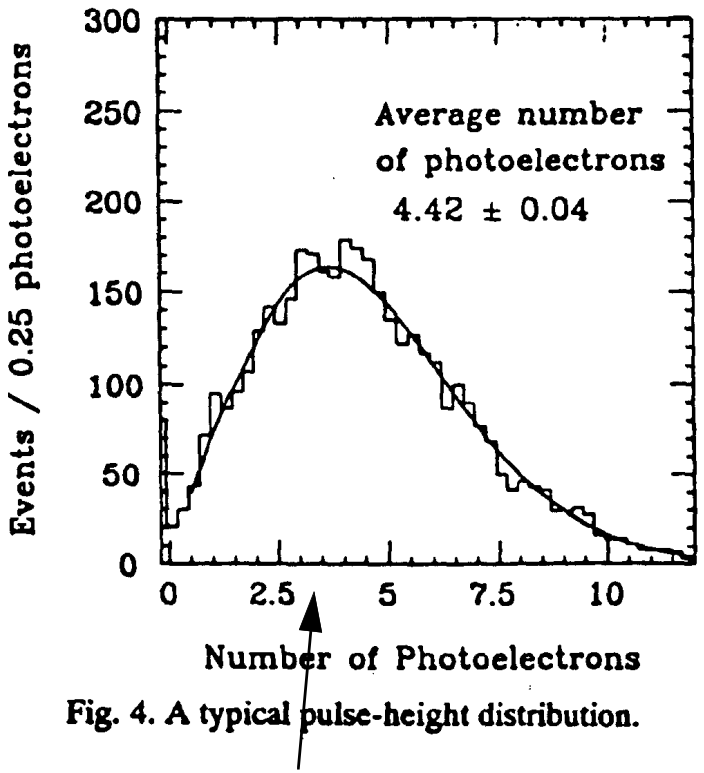


Fig. 4. A typical pulse-height distribution.

Single MIP Response

Dynamic Range for Tile/Fiber Elements

- Defined as the range between the minimum and maximum numbers of MIPs that maintain linearity at the output of the phototube.
- Upper limit based on the tube spec for the Hamamatsu R580-17 (green-extended, 10-stage): Linear to 2% with 150 mA anode current, sustainable anode current: 1 mA. With 400 photoelectrons in 2ns at cathode, have 3 pA. After amplication of 2×10^6, this results in a current of 6 μA.
- Lower limit: detection of a single MIP (≈3 photoelectrons, pessimistic value) is chancy.

Sample Megatile (provided by Bennett of Wayne State)

- Scintillator: BICRON BC 408, 5mm thick (15 cm x 15 cm)
- Optical separation of tiles: Titanium-dioxide impregnated epoxy resin, 3% cross talk
- Wavelength shifter: BICRON BCF91A, emission peak at 494 nm, multi-clad, 1mm diameter, attenuation length ≈1.5 m. (This is NOT the best material currently available.)
- Grove: Rectangular σ pattern, single fiber, two turns, no splicing to transparent fiber.

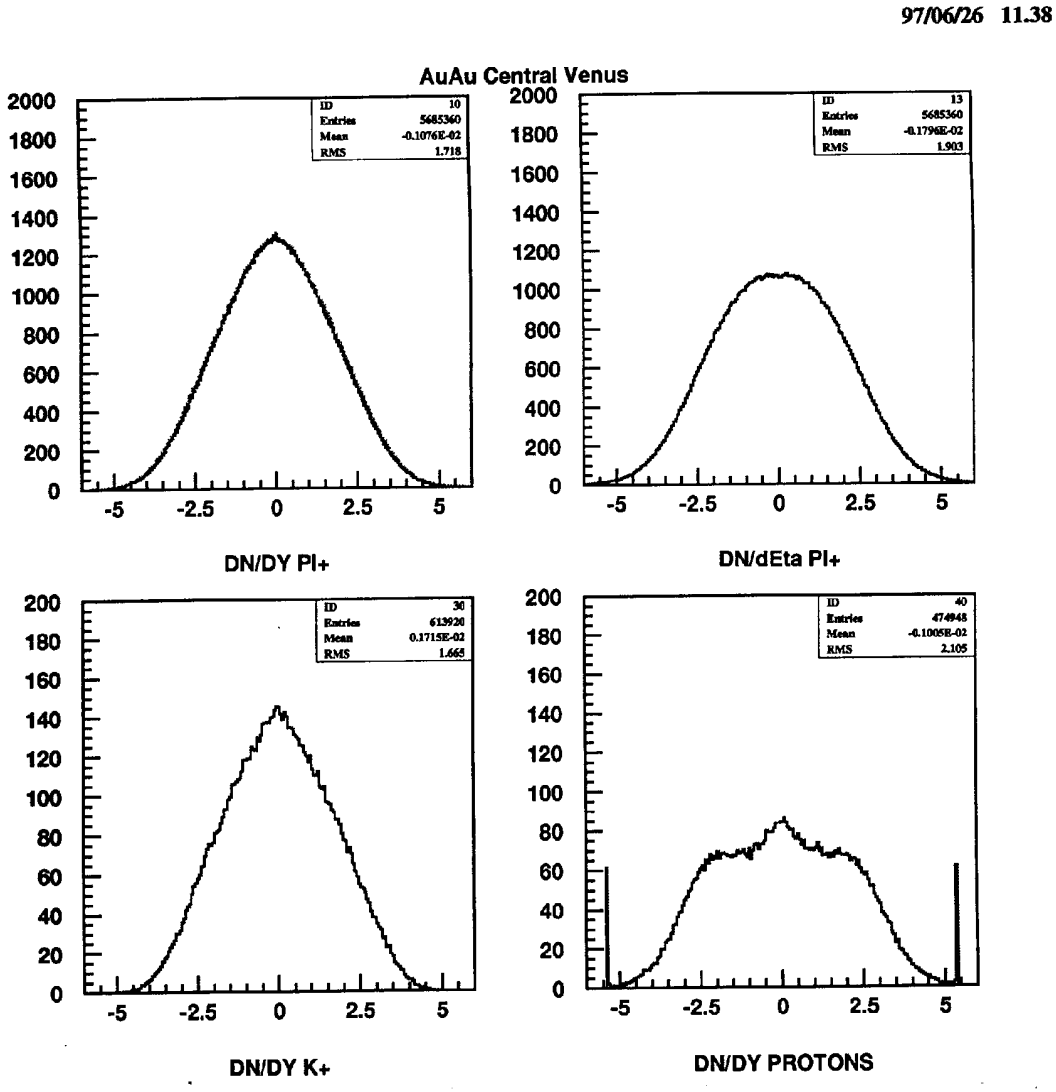
Fabrication of Scintillator Tile/Fiber

- Tile: Mill out rectangular grooves for one or two turns of WLS fibers. (Requires digitized milling machine, vacuum chuck, and cooling.)
- Megatile: Glue individual tiles together using TiO_2 impregnated epoxy for optical isolation and strength.
- If necessary, splice WLS fibers to transparent fibers. (Requires special instrumentation.)

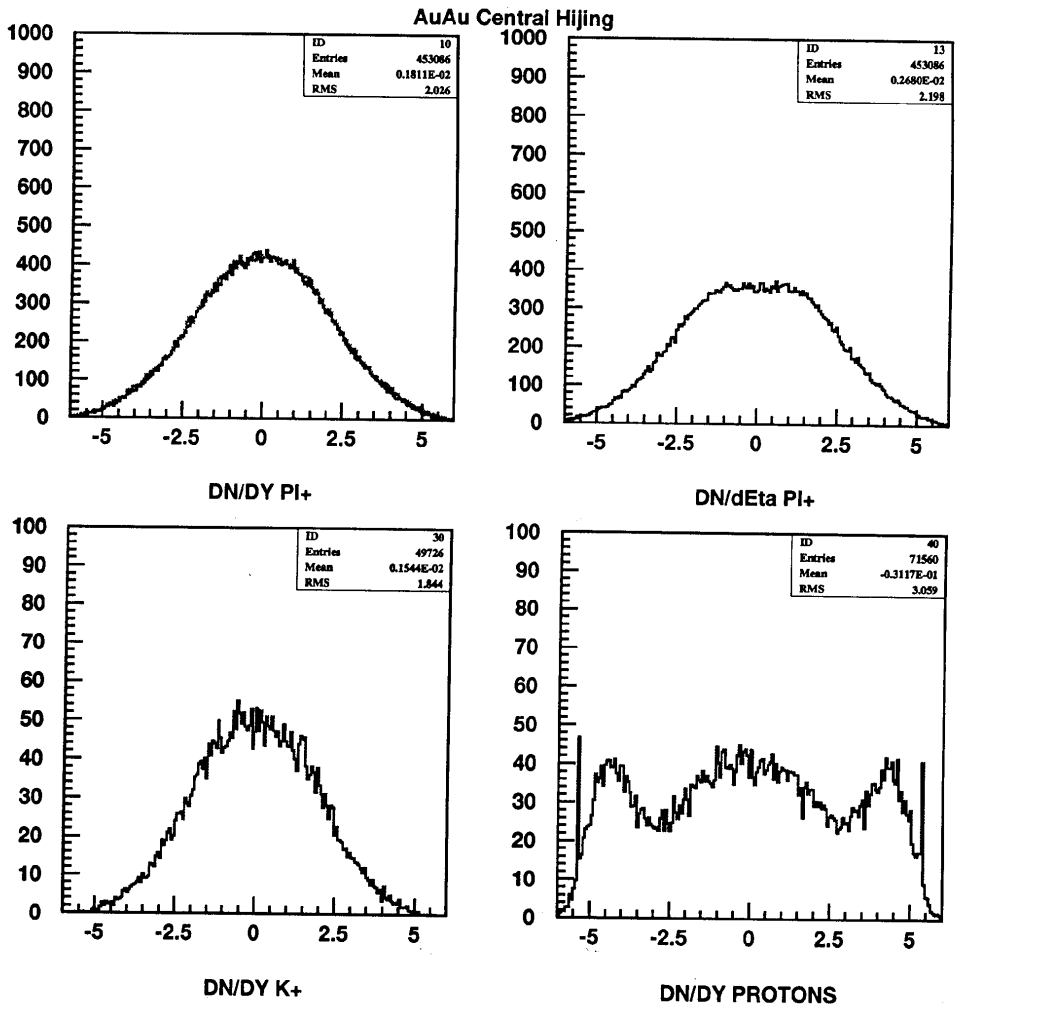
GEANT Simulations.

- Fritiof 7.02 event generator.
- Au+Au and Si+Si @ 200GeV/u
- $<E_{\text{Charged Particle}}>$ based on GEANT simulation.
- Assume $\Delta E/E$ (FWHM; Strip detectors)= Max{2%, 100 keV }
- Assume $\Delta E/E$ (FWHM; Scintillator detectors)= Max{3%, photoelectron PE counting statistics: 8 PE/MIP)}.
- Assume $E_{max}=200xE_{MIP}$(strip), set by dynamic range of preamp.
- Assume $E_{max}= 400xE_{MIP}$(scintillator), set by dynamic range of amplifier .
- Assume E_{min}=100 keV(strip), set by electronic noise level.
- Assume E_{min}=2000 keV(scintillator), set by dynamic range of amplifier.

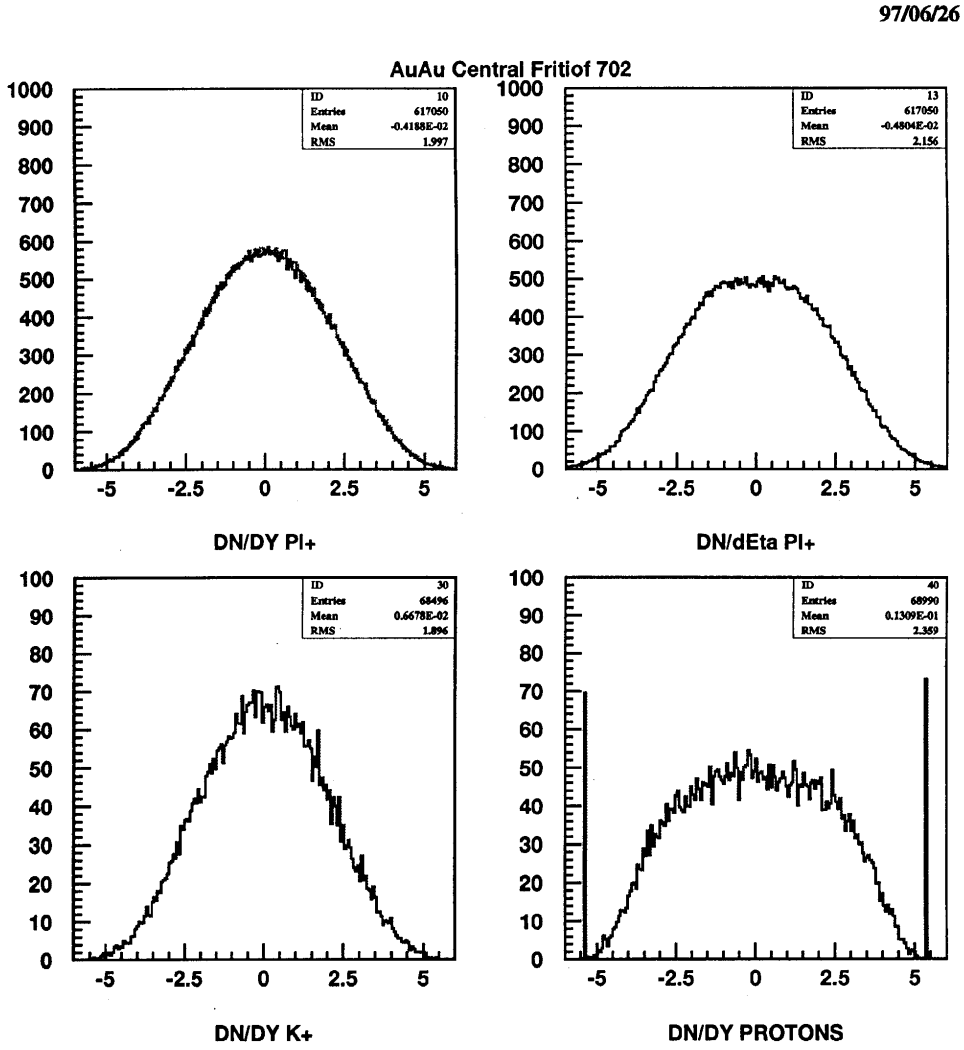
Pseudorapidity Distributions - Comparison of Different Models Venus Au+Au Central



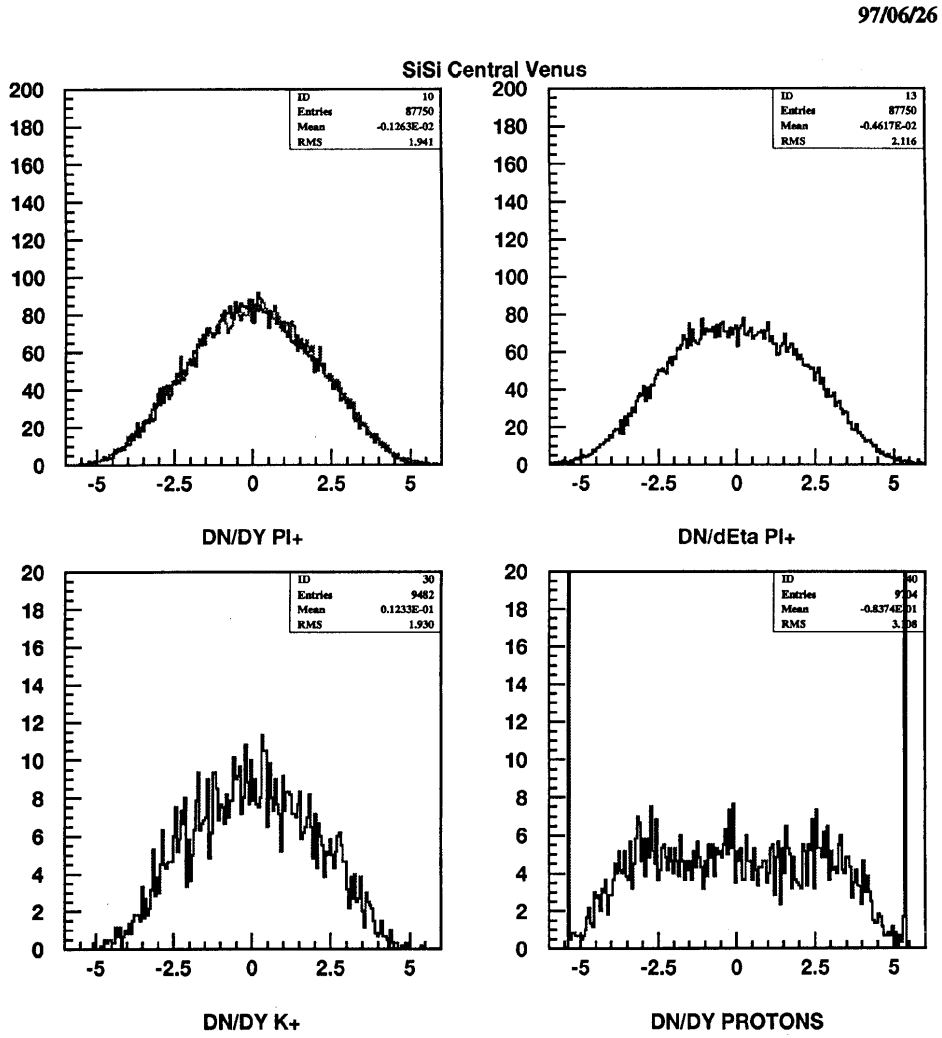
Pseudorapidity Distribuions
Hijing Au+Au Central



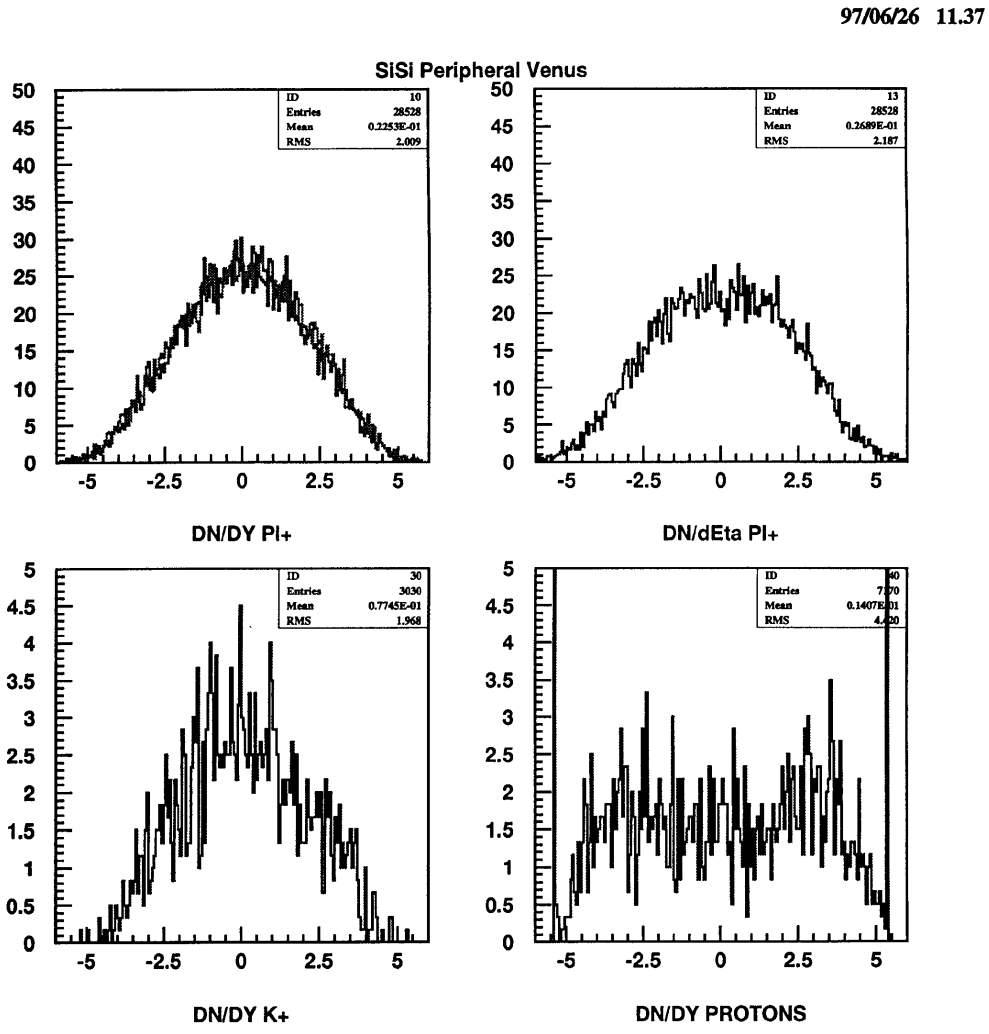
Pseudorapidity Distributions Fritiof 702 Au+Au Central



Pseudorapidity Distributions
Venus Si+Si Central



Pseudorapidity Distributions
Venus Si+Si Peripheral



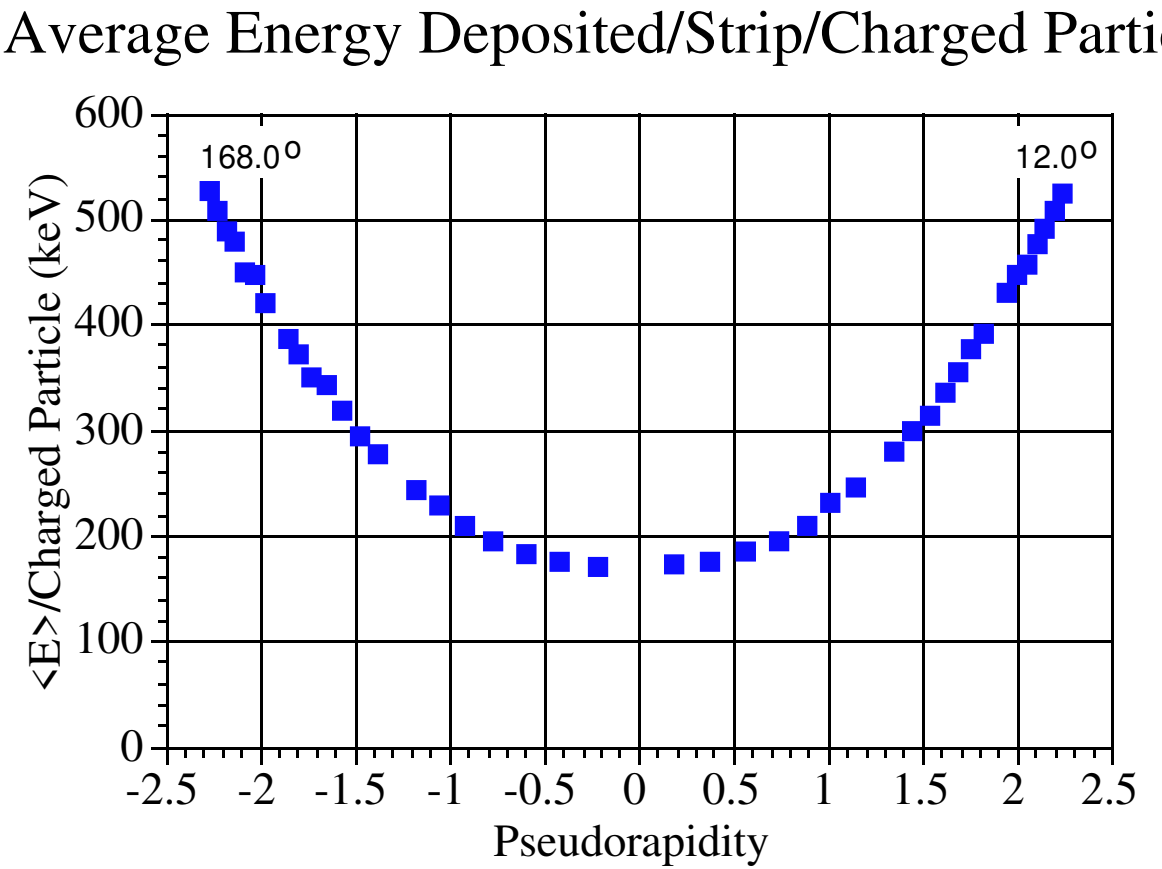
Reaction Rates

Simple estimates of Rates etc.

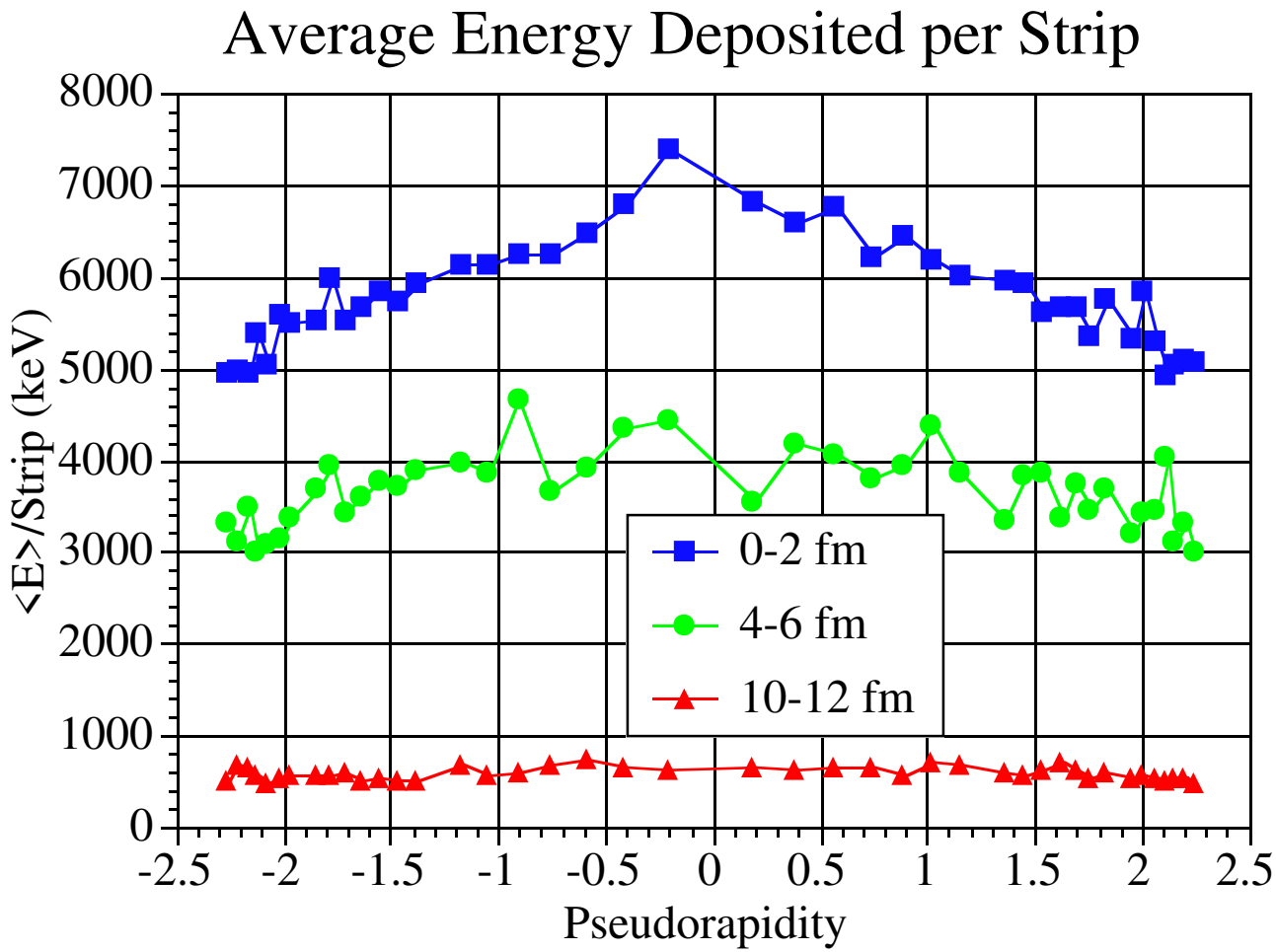
Beam	Luminosity	Collision type	sigma Barn	Rate c/sec	<t>/Int usec
pp	1.00E+31	Min Bias	0.04	400,000	3
OO	1.00E+29	Min Bias	1.1	110,000	9
	1.00E+29	Central	0.1	10,000	100
SiSi	1.00E+28	Min Bias	1.7	17,000	59
	1.00E+28	Central	0.2	2,000	500
I-I	3.00E+27	Min Bias	4.5	13,500	74
	3.00E+27	Central	0.5	1,500	667
Au-Au	2.00E+26	Min Bias	6.1	1,220	820
	2.00E+26	Central	0.6	120	8,333

Bunch Crossing is approx 108 nsec
57 bunches per beam

Strip Detector Energy Deposition

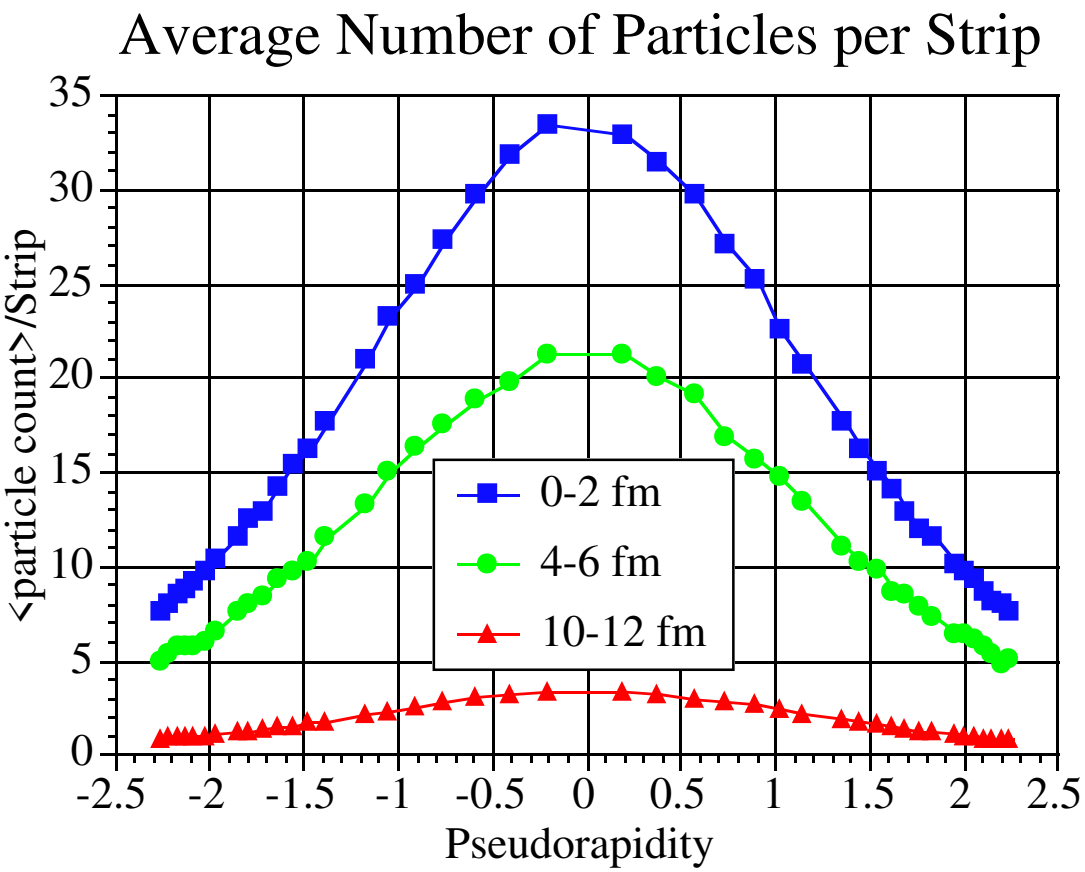


Strip Detector Energy Deposition- Au+Au

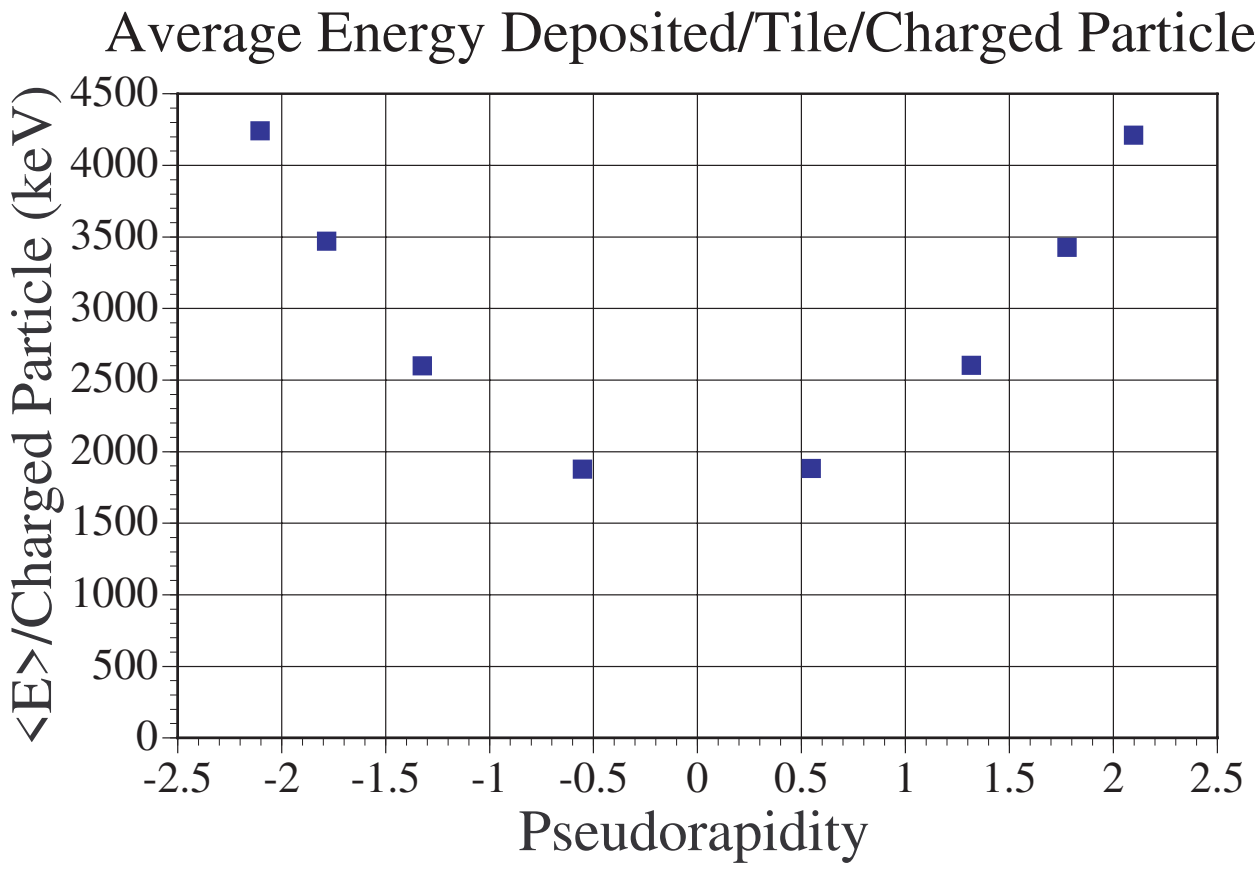


Strip Detector Array

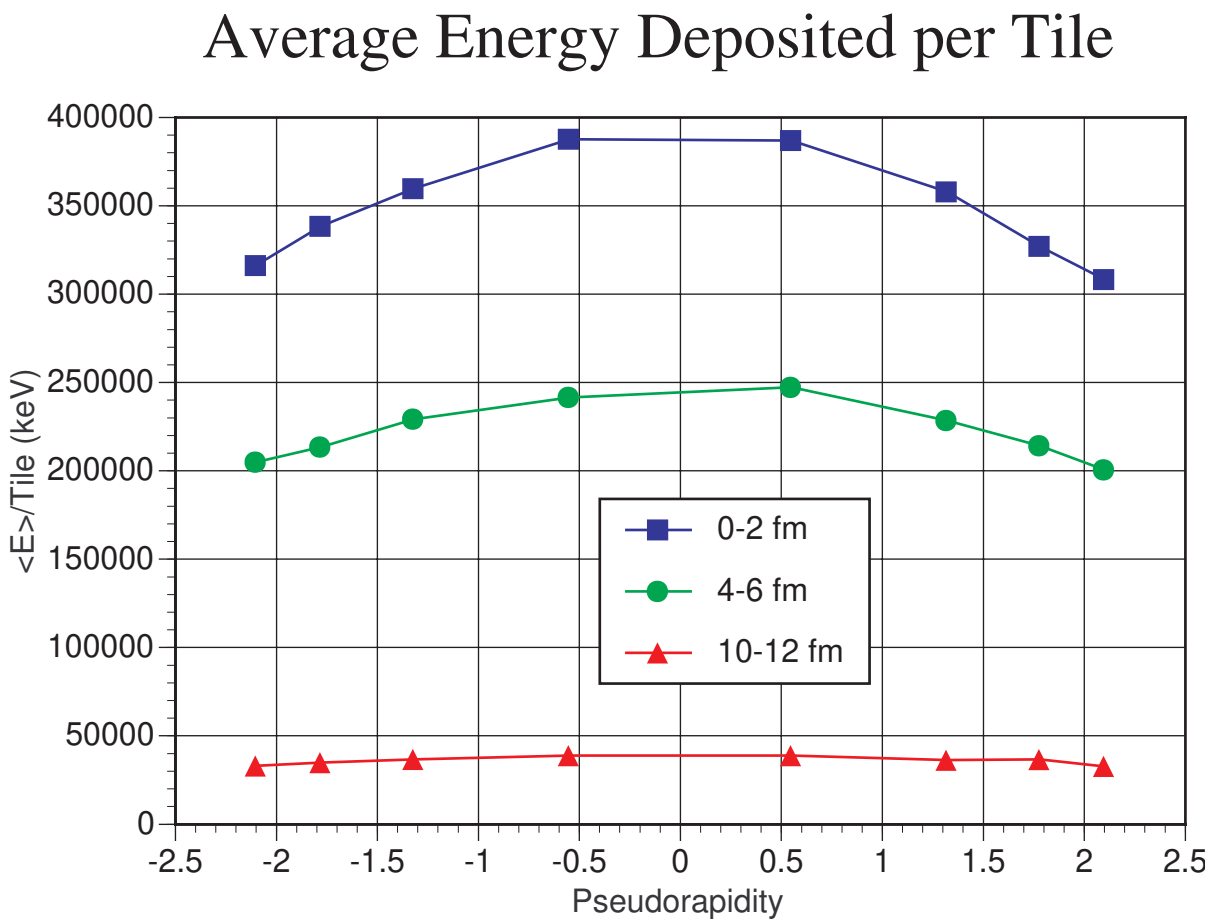
Number of particles hitting each strip



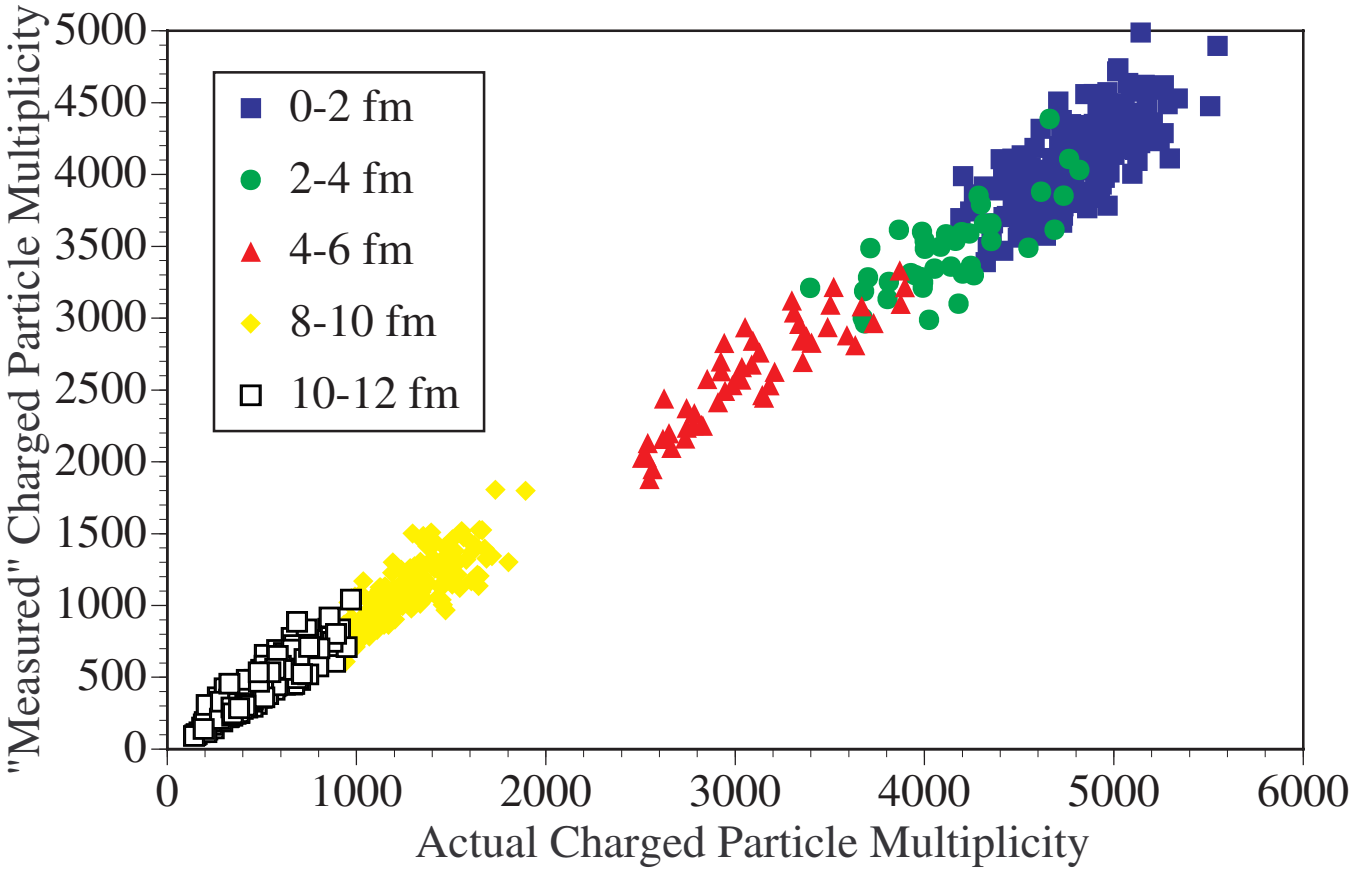
Tile / Fiber Energy Deposition



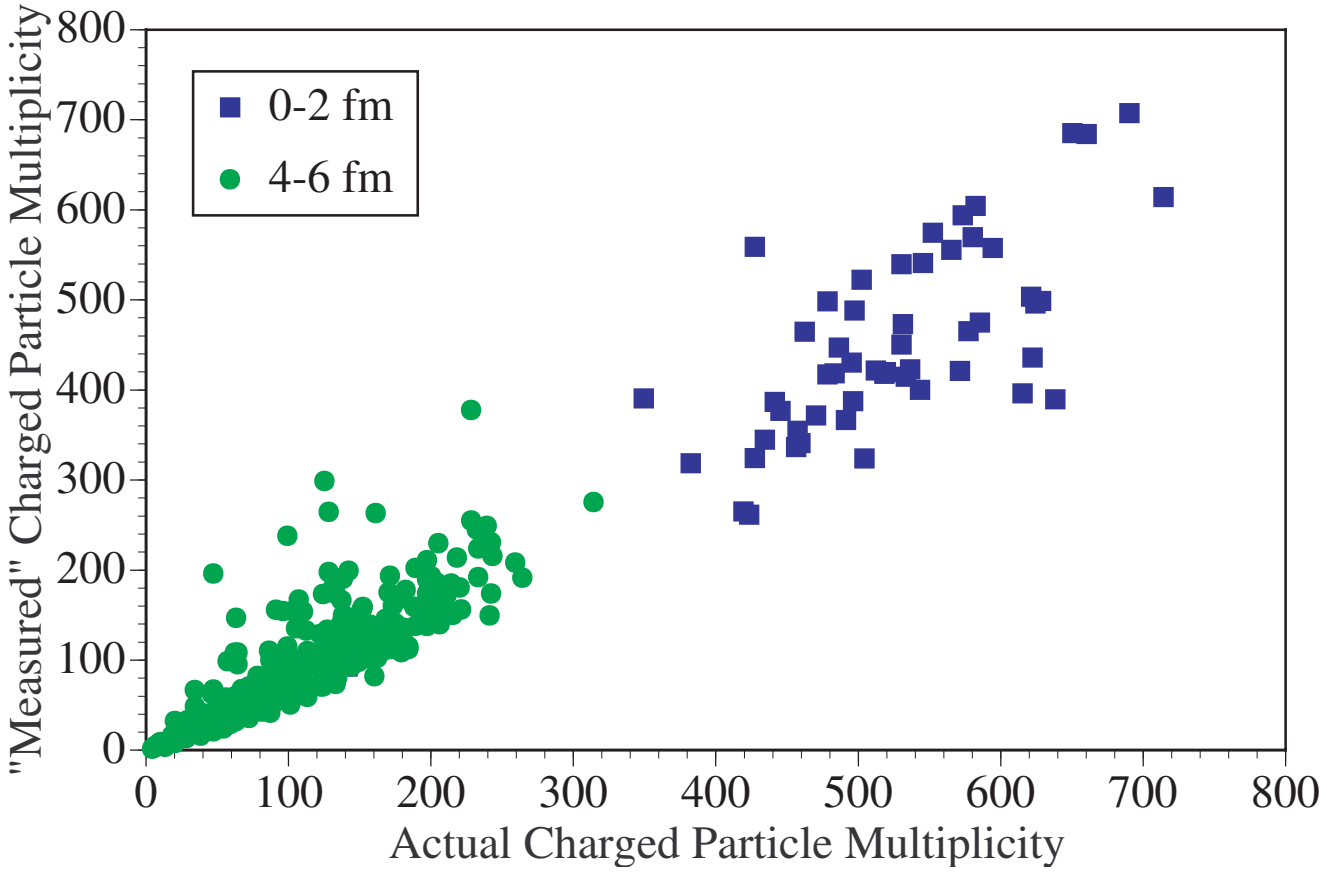
Tile/Fiber Energy Deposition Au+Au



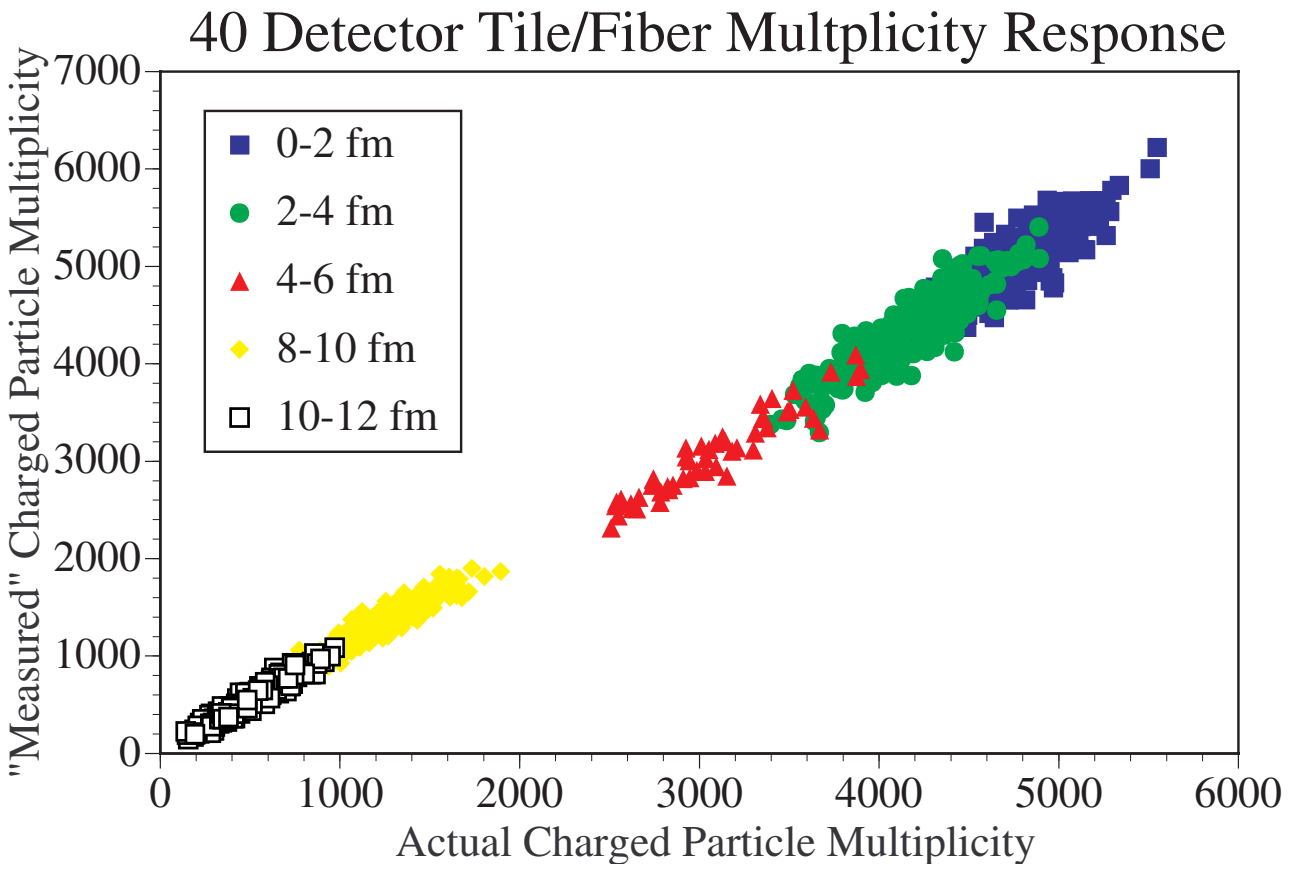
Multiplicity Response
Strip Detector Array - Au+Au



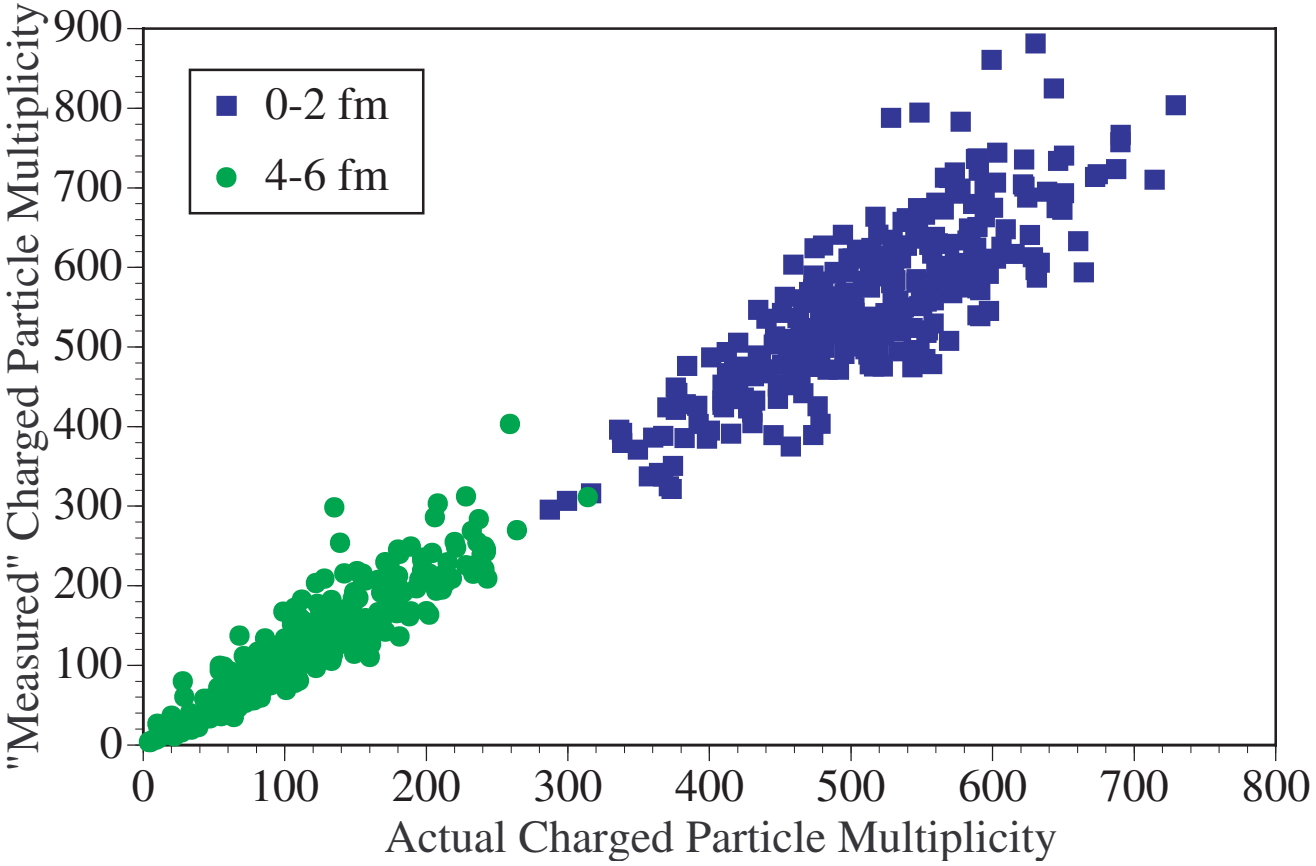
Multiplicity Response
Strip Detector Array - Si+Si



Multiplicity Response: Au+Au Tile/Fiber Geometry



Multiplicity Response: Si+Si Tile/Fiber Geometry



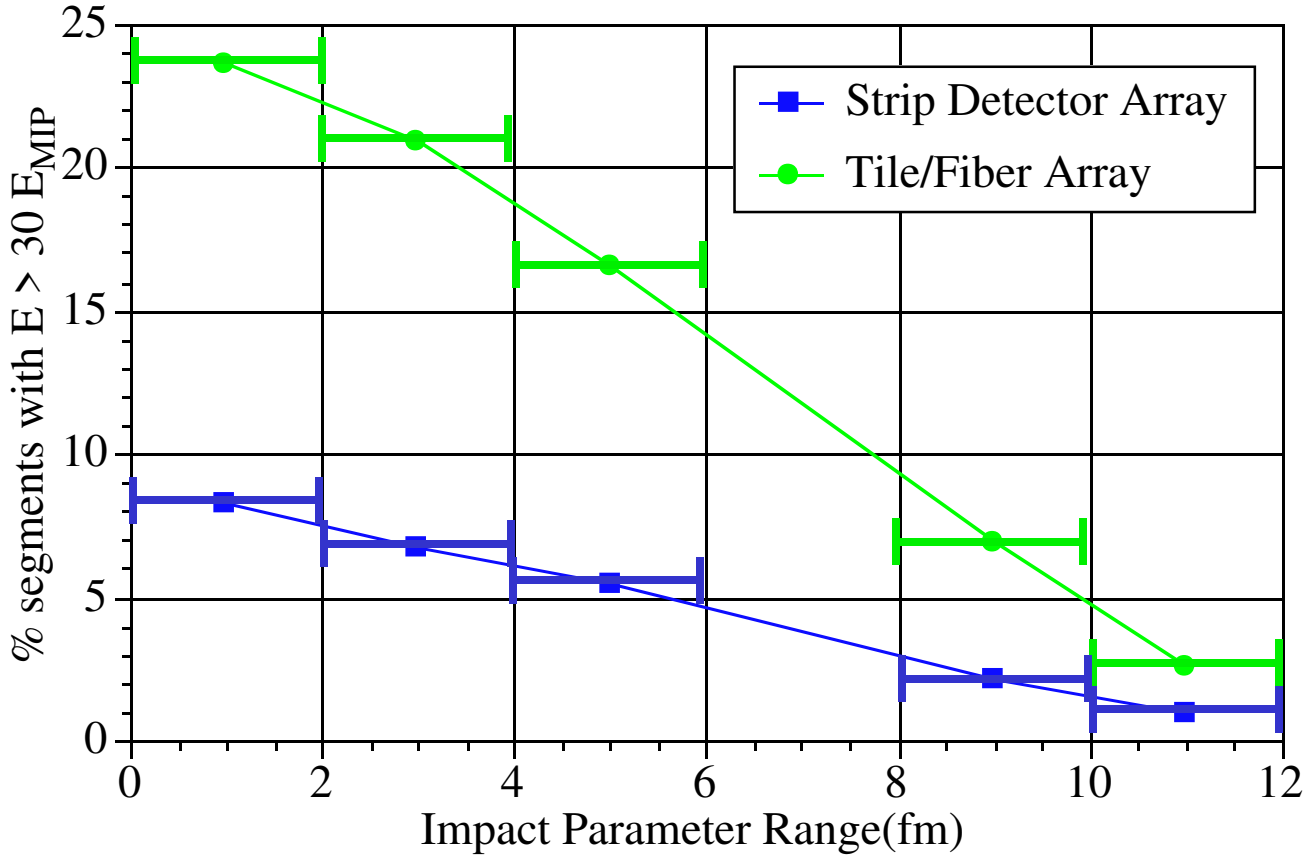
Accuracy of Multiplicity Determination

- Accuracy is defined with respect to the Fritiauf/GEANT model space.
- A significant influence on the array response is the presence of non-MIP interactions within the array elements. This can lead to a given element receiving a large amount of energy (>30 E_{MIP}).
- The multiple elements of the array can be used to adjust the deduced multiplicity value for excessive energy depositions.
- A simple procedure was devised for this "adjustment":
  - Find the average μ and standard deviation σ of the energy for detectors of a given η. (This corresponds to using 5 descrete "segments" for the considered detector arrangments.)
  - For elements with "excessive" energy, defined as $E > \mu + f\sigma$, with f chosen to give the best multiplicity reponse, replace the measured energy with the average energy of elements of the same and adjacent η that do not have excessive energy. (For example, if only one element of the array were found to have an excessive energy, the average of 14 adjacent elements would be used to estimate the energy of that element.)

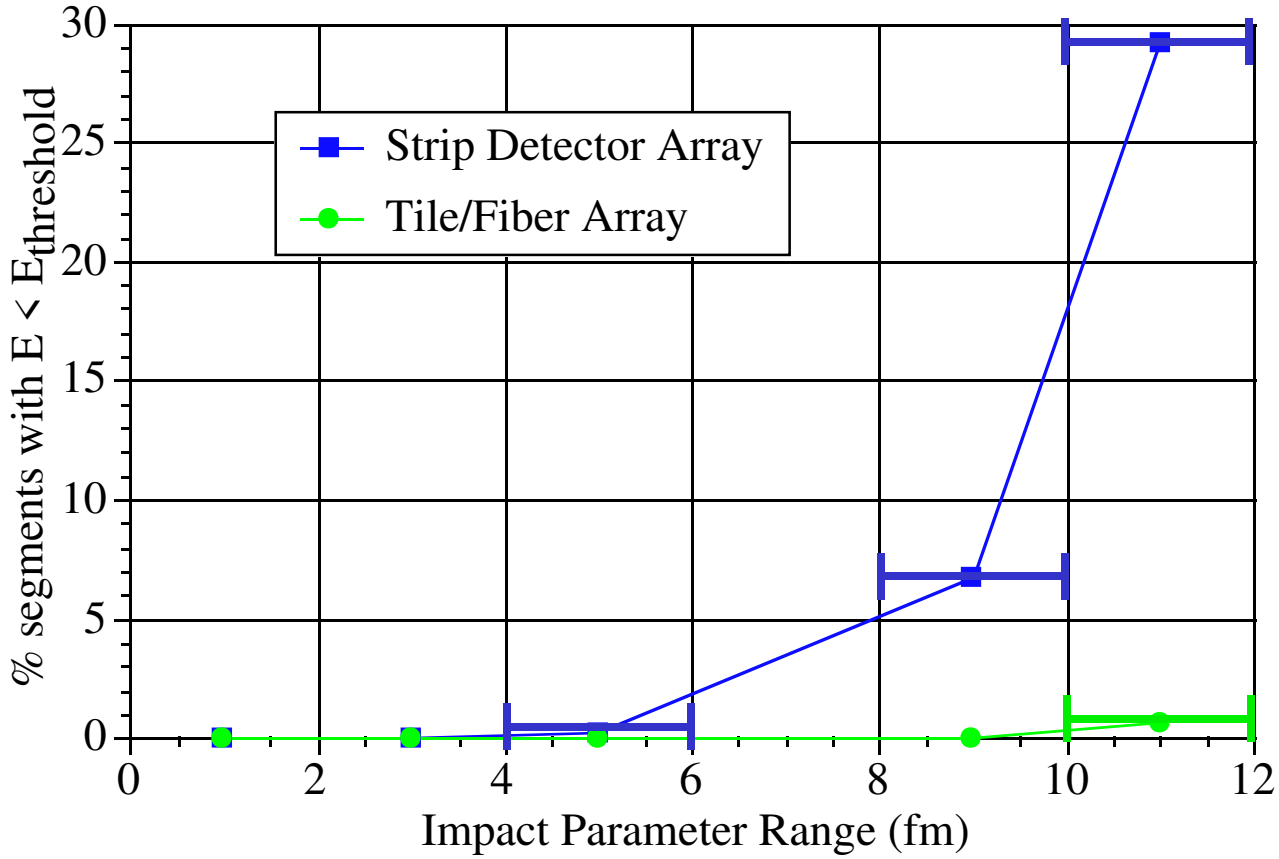
Accuracy of Multiplicity Determination, cont.

- The energy threshold and saturation values enter into the multiplicity determination. Energy saturation (as defined earlier) is treated the same as excessive energy deposition. For both detector arrangements the energy thresholds are expected to be set below that of a single MIP, although the assumed energy resolution and threshold value for the Si strip detector arrangement can lead to a single MIP in an element resulting in a sub-threshold energy.

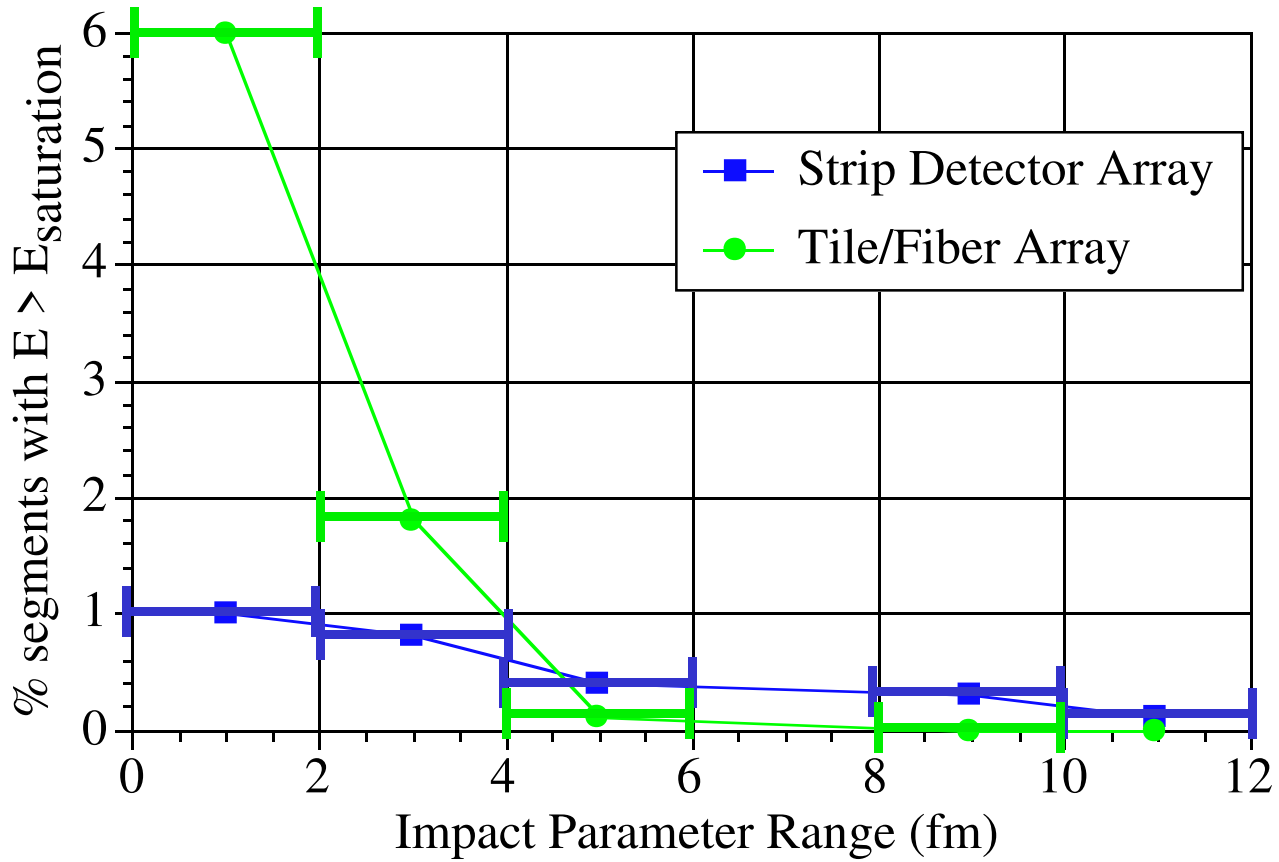
% of segments hit by particle with E>30 E_{MIP}



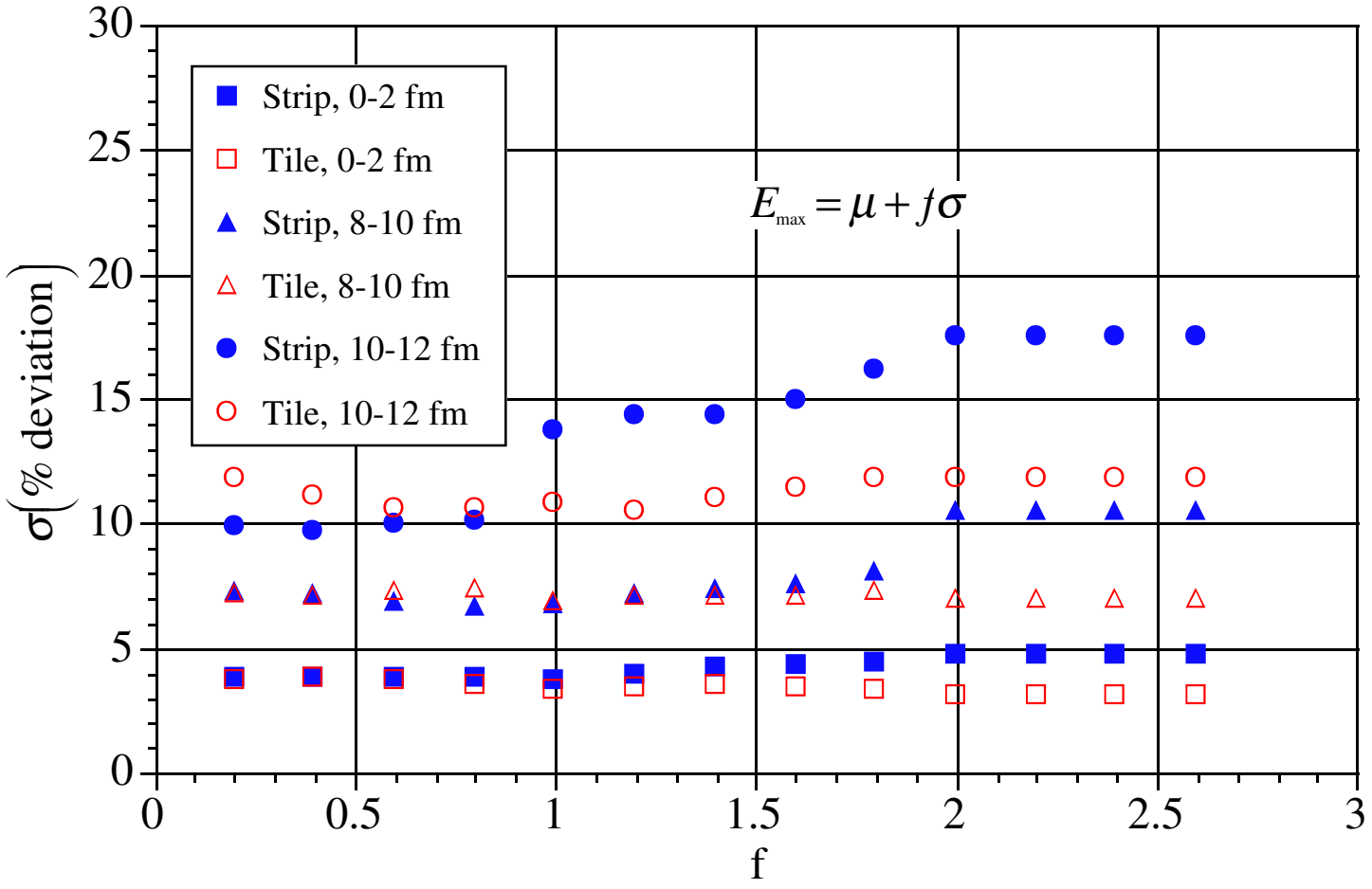
% of segments with $E < E_{threshold}$ (Includes segments that are not struck.)



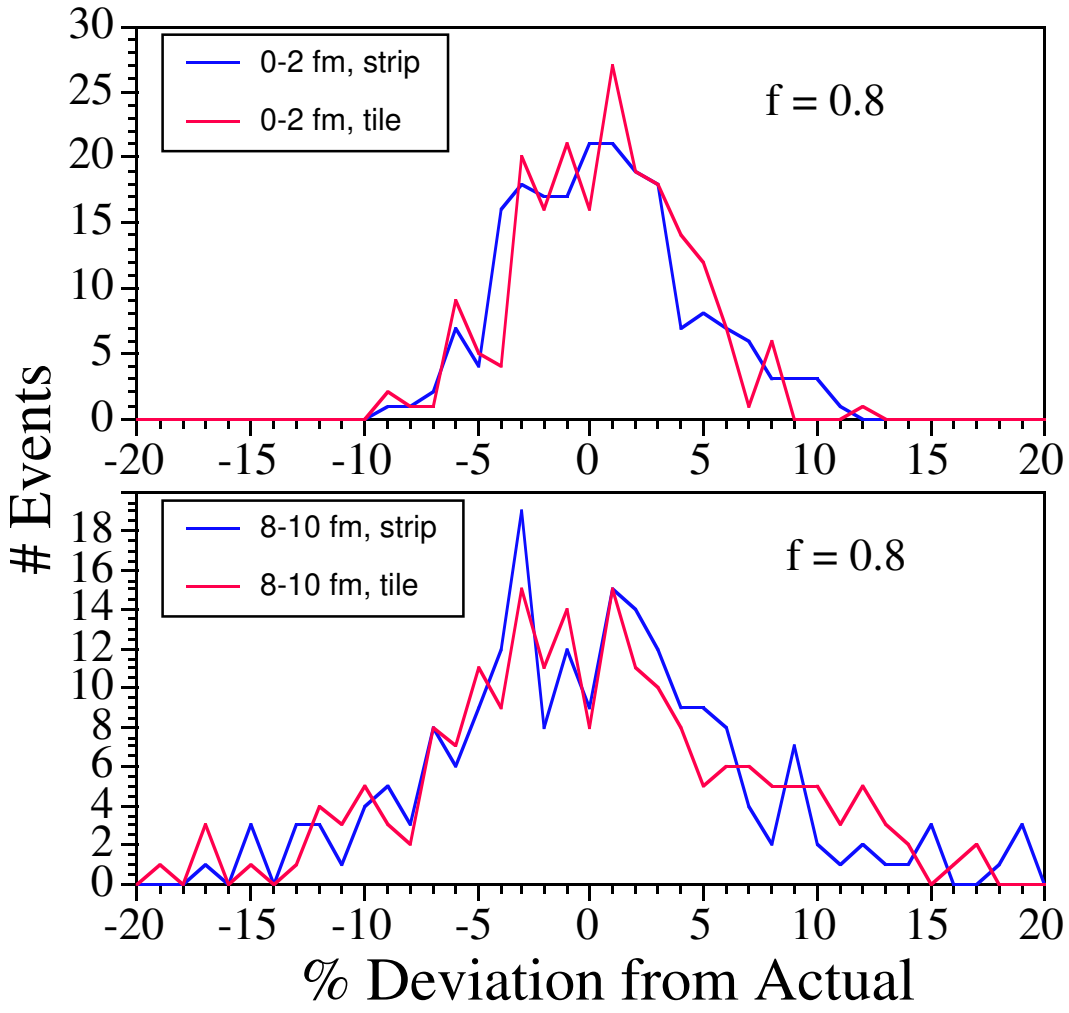
% of segments with $E > E_{saturation}$



Correction of Anomalous Energy Segments



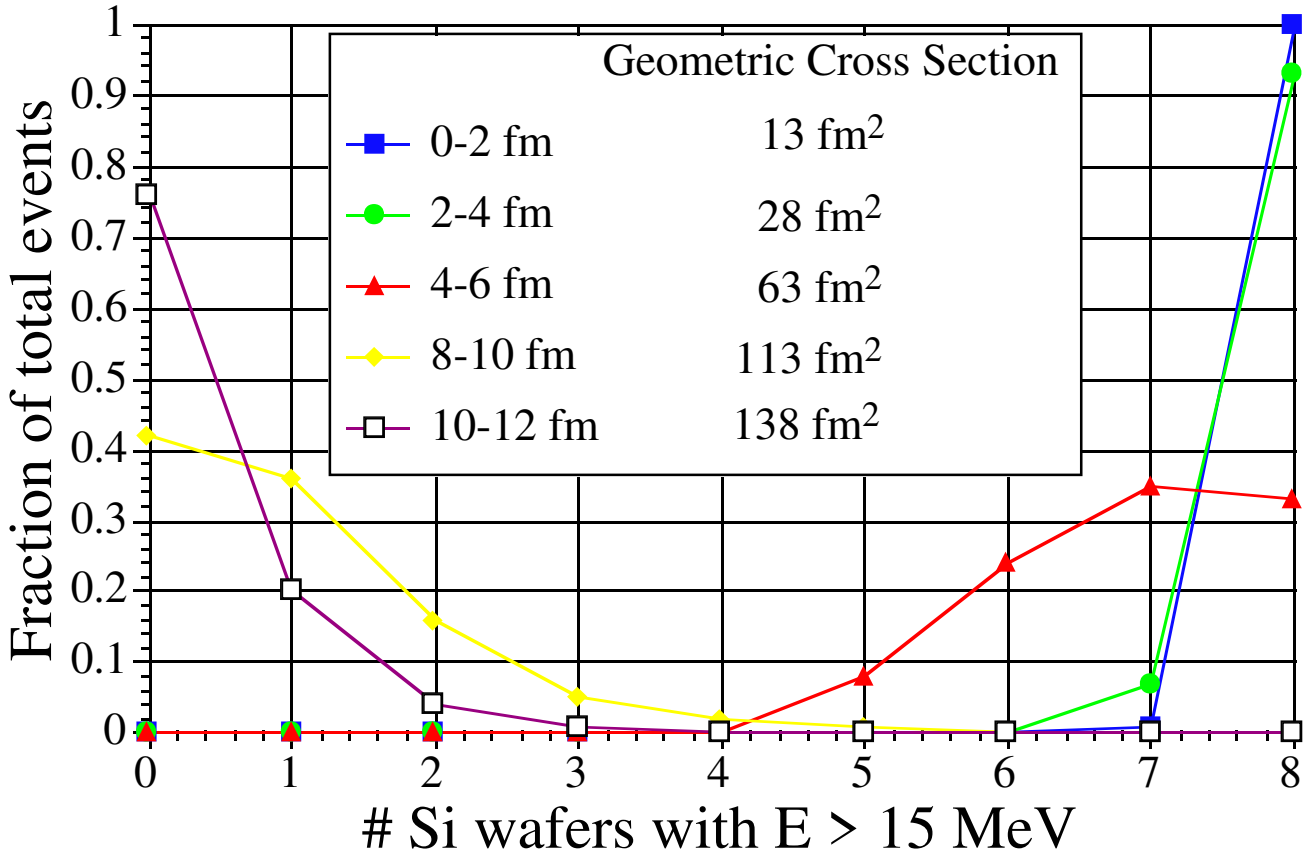
Accuracy of Multiplicity Distribution
Strip/Tile Comparison with f = 0.8



Prescaling of Non-Central Events

- One possibility is to make a cut based on the number of centrality array segments with energies exceeding a certain threshold.
- For the strip detector array, this information can be obtained reasonably promptly by taking the sum energy signal off of the anode of the detectors and using CFD thresholds.
- To reduce total costs, it is assumed that only eight of the strip detector wafers are sampled (six along one side, and two additional end wafers). This allows using a single CFD.
- A similar arrangment is possible using scintillator tiles. In a possible hybrid arrangement, the tiles would be used exclusively for this trigger information and the strip detectors would be used for better characterization of the multiplicity with η.

Prescaling with 8 Si wafers

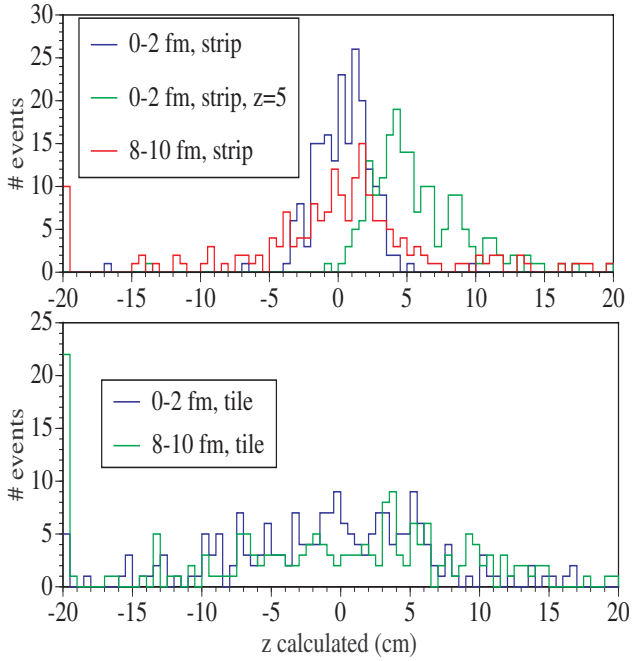


By requiring all eight wafers to have E>15 MeV, >95% of central events with impact parameters b < 4 fm are selected, with a factor of 9 reduction in the total number of events with b<12 fm, assuming geometric cross sections.

Vertex Localization

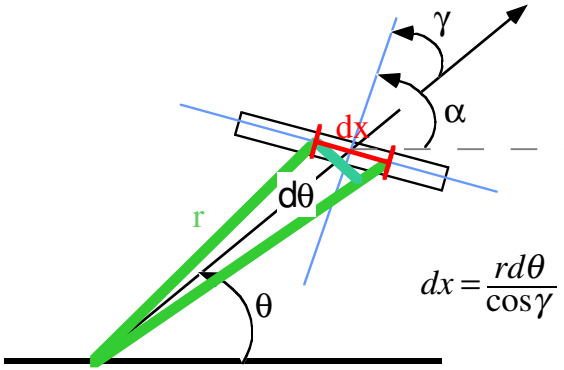
- The expected charged-particle pseudorapidity distribution varies sufficiently over the angular coverage of the centrality array that it may be possible to obtain some information concerning the vertex location from this distribution. In the following figure, the vertex location was found by fitting the observed distribution of $dE/d\eta$ with a parabola and then finding the abscissa of the vertex of the parabola .
- Calculations were done with the real vertex at the center of the array ($z = 0$) for central (0-2 fm) and peripheral (8-10 fm) events for both the strip detector and scintillator tile arrays. A calculation was also done with the vertex displaced to $z = 5$ cm for central events and using the strip detector array.
- The results are MUCH better using the more highly segmented strip detector array. It is not clear, however, that this information will be useful. The calculation probably can not be done in time to help develop the event trigger and even in the best case of central events using the strip detector array the reaction vertex is only located with an uncertainty of 6 cm FWHM.
- A better procedure for extracting the vertex location may be possible.

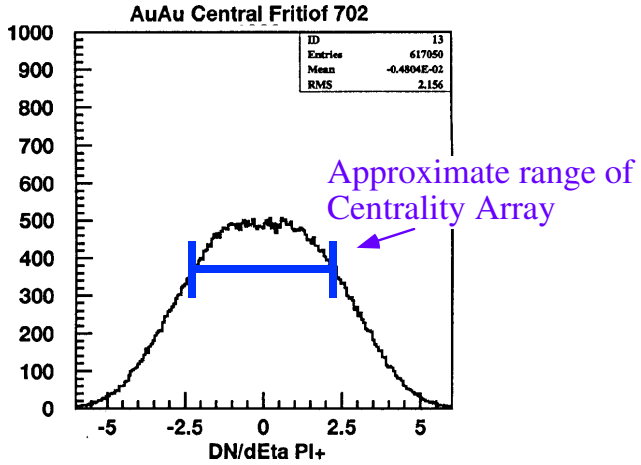
Calculation of Vertex Location using Multiplicity Array



Vertex Location Determination by measuring total energies in two detectors located at ±η.

Thanks to Chellis for showing why its (almost) hopeless...





Take a detector element of surface area dA = dx dy that is rotated at an angle α with respect to the horizontal and positioned at an angle θ with respect to the interaction vertex and the beam direction. Particles passing through this element see an effective detector thickness of

$$t_{eff} = \frac{t}{\cos\gamma}$$

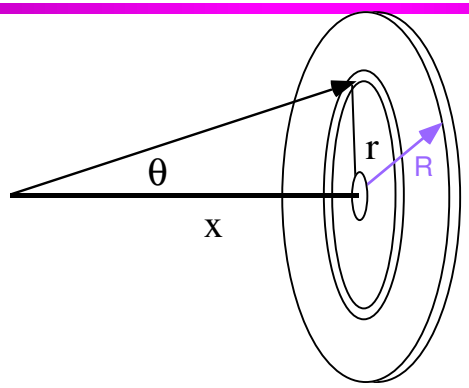
where t is the thickness of the detector. The total energy deposited in this segment is then

$$\Delta E = \left(\frac{dN}{d\Omega}d\Omega\right)\left(-\frac{dE}{dt}\right)t_{eff} = \left(\frac{1}{2\pi\sin\theta}\frac{dN}{d\theta}2\pi\sin\theta d\phi d\theta\right)\left(-\frac{dE}{dt}\right)t_{eff} = \left(\frac{dN}{d\theta}d\phi d\theta\right)\left(-\frac{dE}{dt}\right)t_{eff} = \left(\frac{dN}{d\eta}\frac{d\eta}{d\theta}\frac{dy}{r\sin\theta}\frac{\cos\gamma dx}{r}\right)\left(-\frac{dE}{dt}\right)\frac{t}{\cos\gamma}$$

where -dE/dt is the average differential energy loss for a particle passing through the detector and dN/dΩ is the differential particle multiplicity. Using the definition of pseudorapidity $\eta = \log\left(\tan\frac{\theta}{2}\right)$ it follows that $\frac{d\eta}{d\theta} = \frac{1}{\sin\theta}$ and then $\Delta E = \left(\frac{dN}{d\eta}\frac{dydx}{(r\sin\theta)^2}\right)\left(-\frac{dE}{dt}\right)t = \left(\frac{dN}{d\eta}\frac{dA}{r_\perp^2}\right)\left(-\frac{dE}{dt}\right)t$

When dN/dη ≈ constant, ΔE is independent of both the scattering angle θ AND the detector rotation angle α!

What about an End Cap?



Consider a disk of inner radius R_1 and outer radius R_2 whose axis is colinear with the beam axis. The disk is located a distance x away from the interaction vertex. Take a detector element of surface area $dA = 2\pi r dr$ positioned at an angle θ with respect to the interaction vertex and the beam direction. Particles passing through this element see an effective detector thickness of

$$t_{eff} = \frac{t}{\cos\theta}$$

where t is the thickness of the detector. The total energy deposited in this segment is then

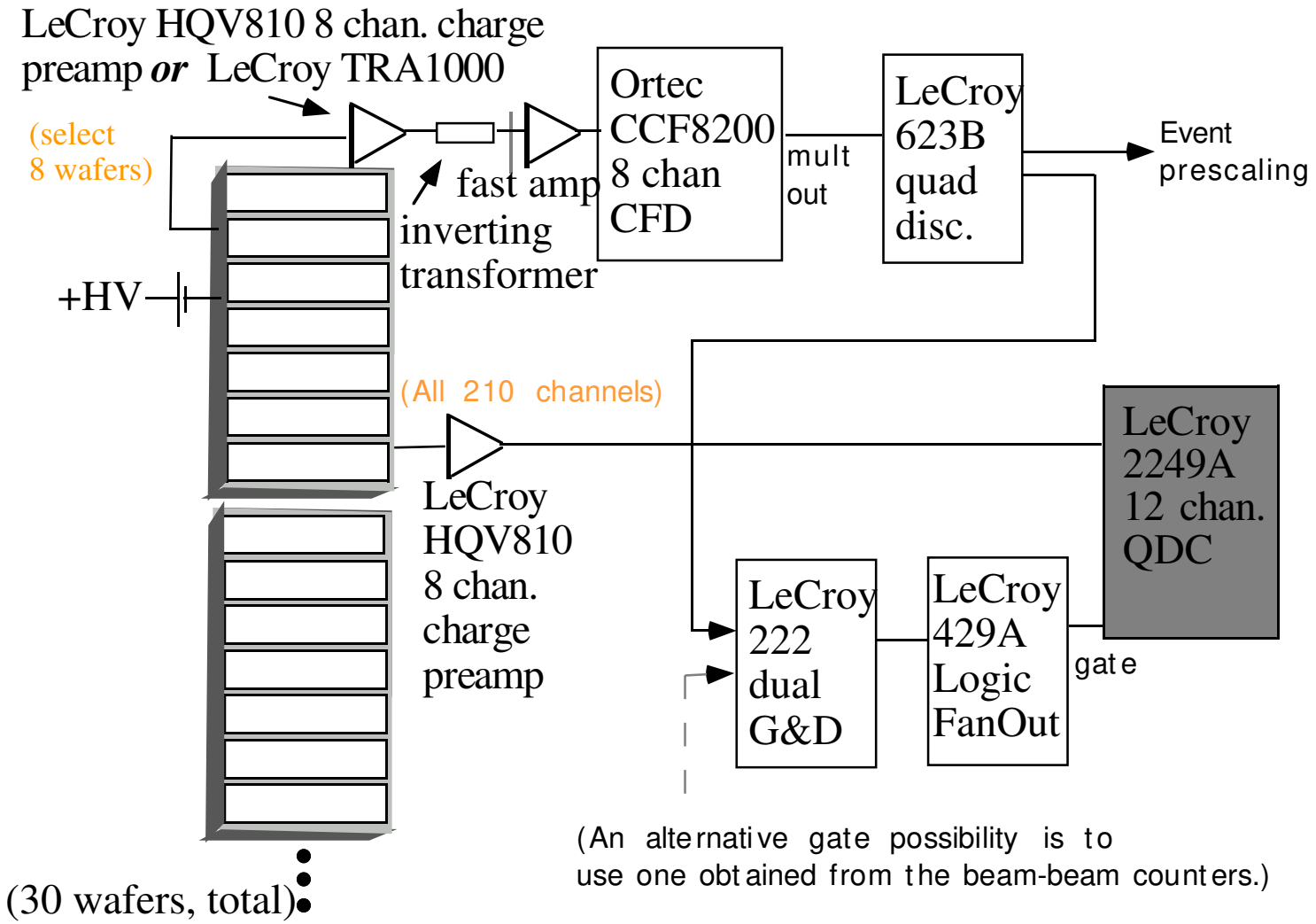
$$\Delta E = \left(\frac{dN}{d\Omega}d\Omega\right)\left(-\frac{dE}{dt}\right)t_{eff} = \left(\frac{1}{2\pi\sin\theta}\frac{dN}{d\theta}2\pi\sin\theta d\phi d\theta\right)\left(-\frac{dE}{dt}\right)t_{eff} = \left(\frac{dN}{d\theta}d\phi d\theta\right)\left(-\frac{dE}{dt}\right)t_{eff} = \left(\frac{dN}{d\eta}\frac{1}{\sin\theta}2\pi d\theta\right)\left(-\frac{dE}{dt}\right)\frac{t}{\cos\theta}$$

where -dE/dt is the average differential energy loss for a particle passing through the detector and dN/dΩ is the differential particle multiplicity. Then

$$\Delta E = 2\pi t\frac{dN}{d\eta}\left(-\frac{dE}{dt}\right)\int_{\tan^{-1}R_1/x}^{\tan^{-1}R_2/x}\left(\frac{1}{\sin\theta\cos\theta}\right)d\theta = 2\pi t\frac{dN}{d\eta}\left(-\frac{dE}{dt}\right)Log\left(\frac{R_2}{R_1}\right)$$

Again, there is no dependence on the distance from the vertex if dN/dη is constant!

Strip Detector Array Electronics.



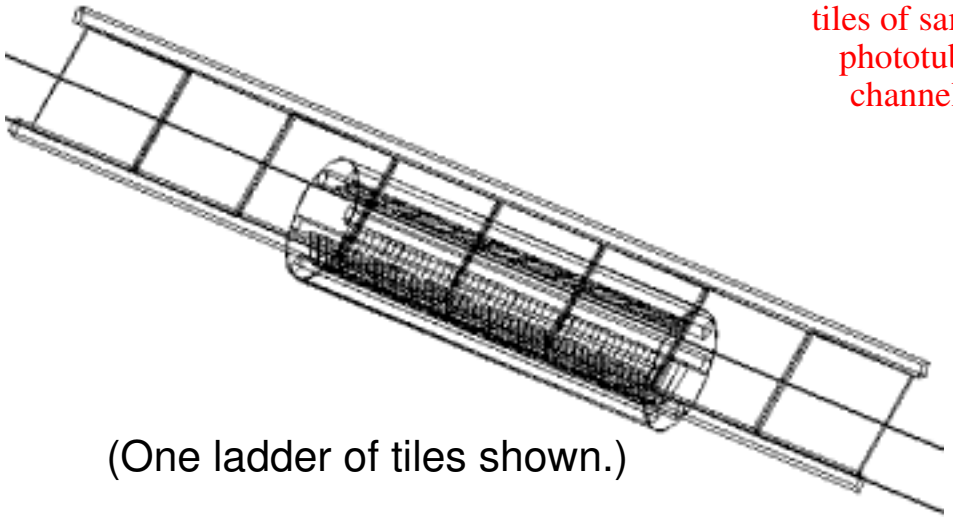
Strip Detector Electronics

- A normal incidence MIP leaves ≈150 keV in a 300 mm Si strip detector. This results in an ionization path with (150000 ev)/(3.6 eV/ e^-)=41,700 e^-= 6.67E^{-15} C.
- The capacitance of the seven-segment, 300 mm strip detector is 960 pf (full wafer) or 137 pf (strip). Additional cable capacitance can be figured at 29.5 pF/Foot (RG-58C/U).
- We need to opperate the HQV810 preamp in a positive input mode--it is specified for negative input. Argonne is using the preamp with +input and finds the only problem is a saturation level corresponding to about 25-30 MeV. This needs to be checked.
- The conversion gain of the HQV810 preamp is -0.5V/pC. A normal incidence MIP results in an output signal of -3.34 mV.
- The HQV810 preamp is specified with a maximum allowed input shunt capacitance of 300 pF. Assuming 200 pf input capacitance, its noise level is 1750 e^-. (Equivalent input noise (r.m.s.) = 550 e^- + 6 e^- /pF.)
- The rise time of the HQV810 preamp = 10ns+ 0.4ns/pF input capacitance = 90 ns for 200 pf input, or 410 ns for full wafer (1000 pf). For the full wafer measurements, it may be better to develop a circuit optimized for higher imput capacitance using the LeCroy TRA1000 preamplifier (a $20 op-amp chip).
- The fall time of the HQV810 preamp = 4 μs.
- The 2249A QCD has 10 bit resolution with a linear input range of -2mV to -1V. The full scale range is 256 pC. It accepts a gate input from 10 ns to 200 ns.
- Assuming 30 MeV saturation of the preamp, q= (30x10^6/(3.6 eV/ e^-))=1.33pC. V_{preamp}=-0.67V.The QCD has a 50 Ω imput impedance. To place a 30 MeV signal at full scale in the QCD then requires a gate width t_{gate}, with 256pC=(0.67V/50Ω)t_{gate}, or t_{gate} = 19.1 ns. A normal incidence MIP would fall in channel 5.

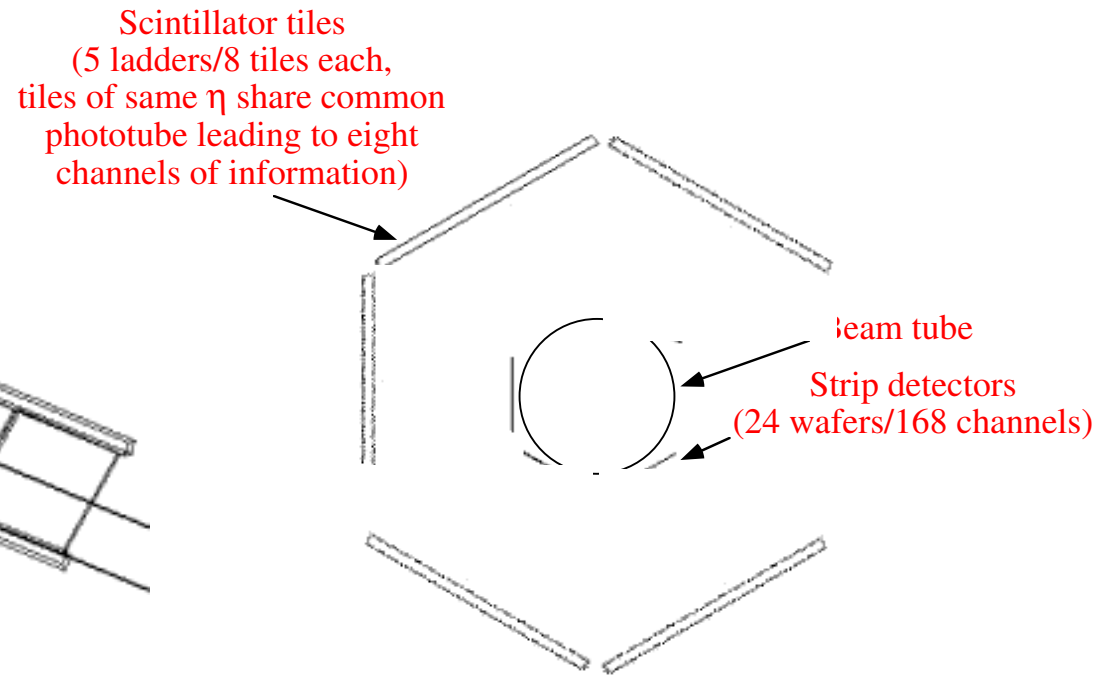
Motivation for Hybrid Array

- Strip detectors offer better segmentation and a very compact geometry. They result in a better determination of $dN/d\eta$. By having greater redundancy, they are less susceptible to analysis ambiguities resulting from particles leaving excessive energy in a given element. They are, however, expensive. To obtain fast information from the array for use in a triggering role requires separate electronics.
- The scintillator tiles are fast, easy, and cheap. In terms of triggering information they do as well as the Si strip detectors.
- The cost savings of removing one side of the Si strip detector array is sufficient to implement a relatively complete barrel of scintillator tiles, which can be used for triggering and redundancy in the multiplicity determination. The overall centrality detector response can be improved with very little, if any, loss of information.

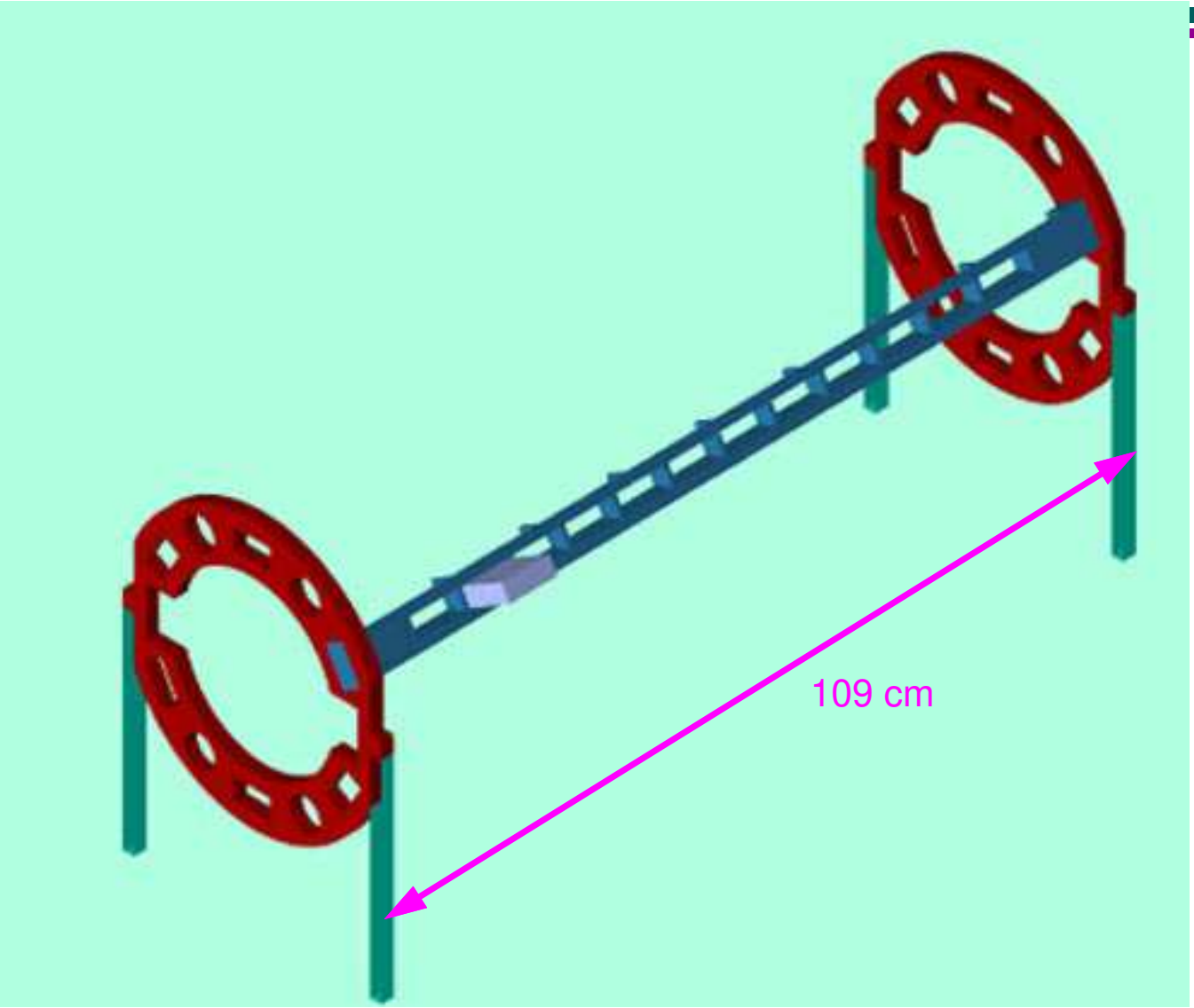
Schematic of Hybrid Array



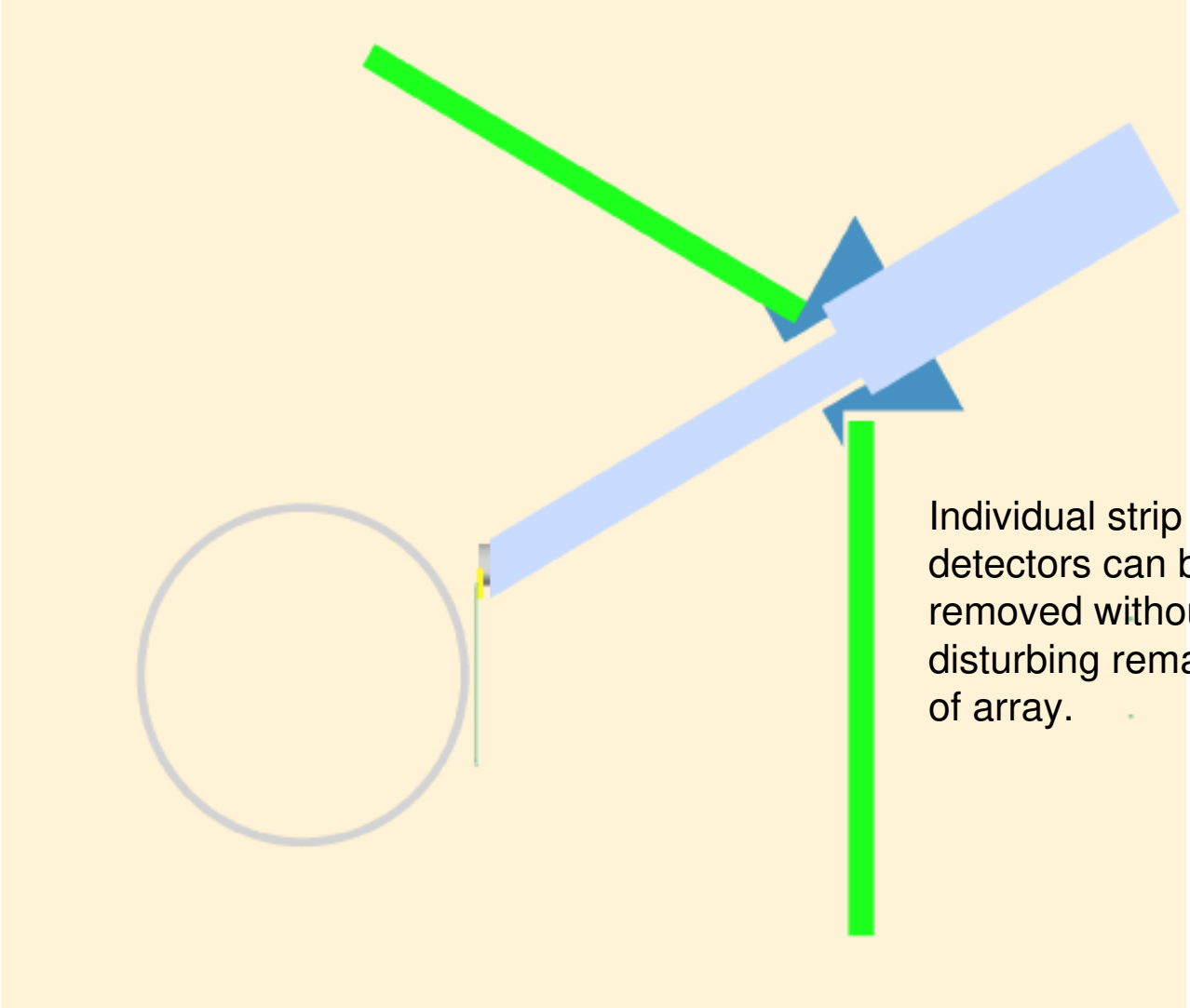
(One ladder of tiles shown.)



Hybrid Mount

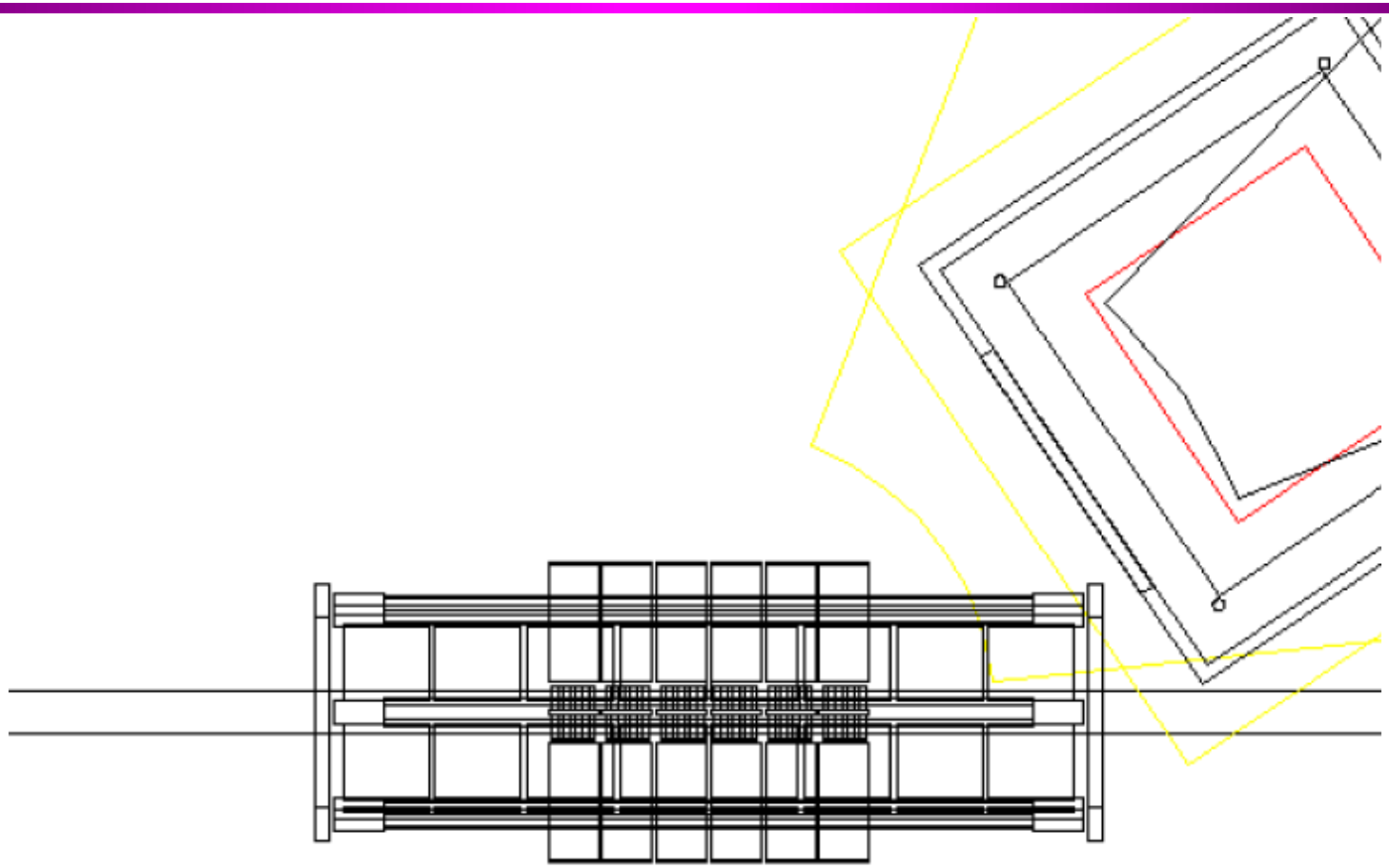


Hybrid Mount Section



Individual strip detectors can be removed without disturbing remainder of array.

Hybrid Mount- GEANT Model

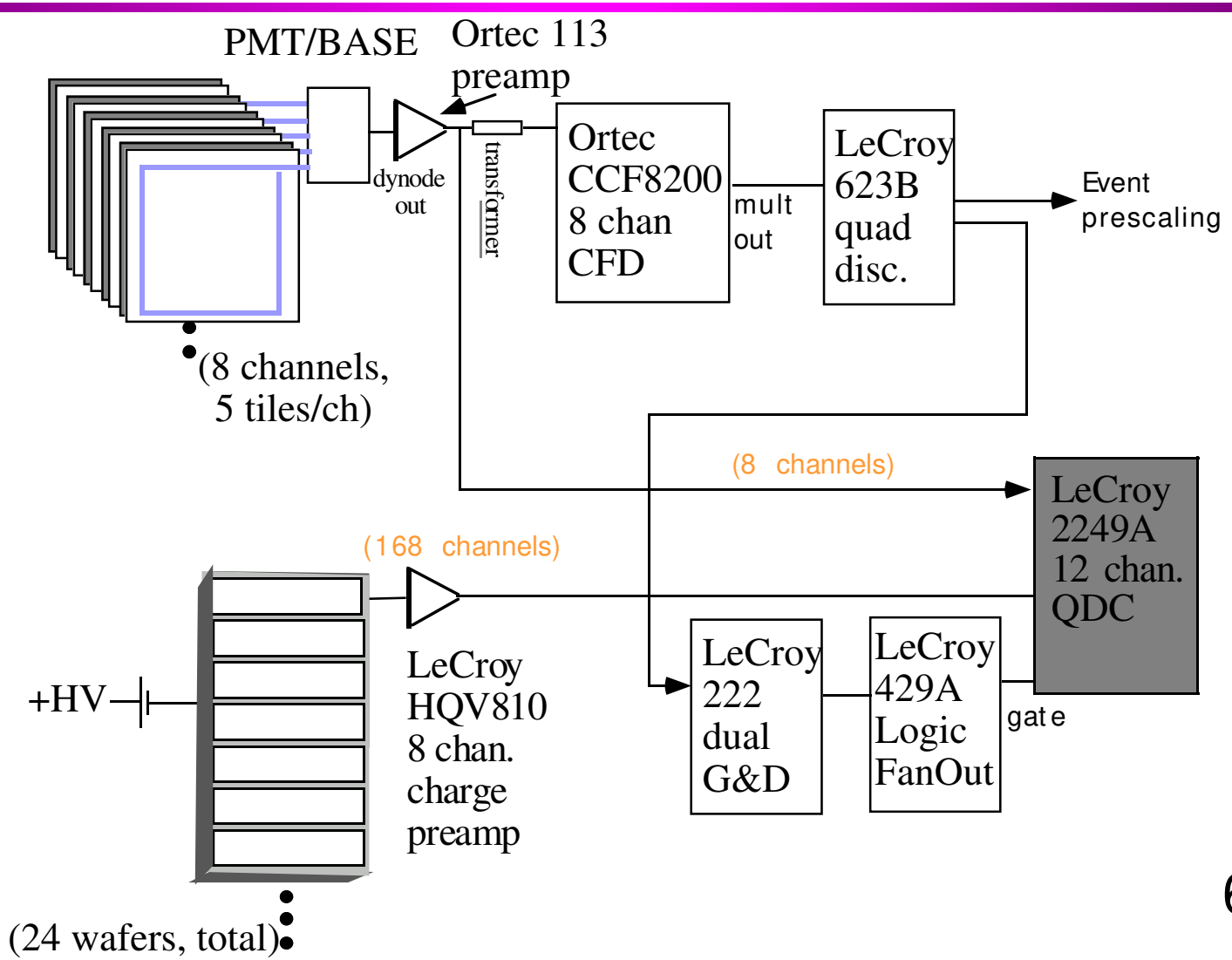


Mass Budget

- Strip detetector mounts: 24 @ 200 g ea. = 4,800 g
- Support bars: 6 @ 1800 g, ea. = 10,800 g
- End supports: 2 @ 2430 g, ea. = 4,860 g

Total without tiles: 20,460 g

Hybrid Electronics



Secondary Rates in TPC1 and Hybrid Performance

(Numbers in parentheses for "realistic" mounting scheme.)

Detector	TPC1 Primary Counts (per central event)	TPC1 Secondary Counts (per central event)	Accuracy (Au+Au) - σ(% deviation) 0-2 fm; f = 0.8	Accuracy (Au+Au) - σ(% deviation) 8-10 fm; f=0.8	Accuracy (Si+Si) - σ(% deviation) 0-2 fm; f = 0.8	Accuracy (Si+Si) - σ(% deviation) 4-6 fm; f=0.8
Strip alone	76	57	3.9	6.7		
Tile alone	77	52	3.6	7.4		
Hybrid	76(78)	55(54)				
strips			4.1(4.2)	7.2(8.2)	8.9	40.0
tiles			3.3(4.2)	6.9(8.0)	10.2	51.0
(strips+tiles)			3.0(3.4)	5.8(6.4)	7.5	33.0
no centrality	76	42				

(No E_{max} value applied for hybrid tiles.)

(3 out of 300 events removed for calculation, otherwise strip+tile=45%)

Electronics Costs.

Item	Unit Cost	Strip Detetector Array	Tile/Fiber Array	Hybrid Array
Strip Detectors	$1,750	32		26
LeCroy 1458 HV Mainframe (Low Power)	$6,490	1		1
LeCroy 1461 12-Ch HV card (modified)	$1,550	3		3
Ortec FTA820C (Octal x20 fast amp)	$850	1		
Ortec IT100 Inverting transformer	$55	8	8	8
PreAmp (LeCroy HQV 810)	$560	32		26
Ortec CCF8200 Quad CFD	$2,700	1		
LeCroy 623B Quad discriminator	$1,220	1		
Gate and Delay Generator (LeCroy 222)	$1,370	1		1
LeCroy 2249A 12 chan. QDC	$2,650	18		15
LeCroy 429A Logic Fan In/Fan out	$920	2		2
NIM Bins	$3,400	1	1	1
Cables	$70	220	12	200
Bicron BC-404 (30.5 cm x 30.5 cm x 0.5 cm)	$226		12	12
Bicron BC91A fiber/ 10, 1.5 m	$35		5	5
Hamamatsu R580-17, 1.5", 12 stage tubes	$350		40	8
High voltage supplies	$0		40	8
Ortec 113 preamp	$350		40	8
ADC	$0		5	0
Total Cost:		$159,980	$35,567	$140,487