Pair Monitor

- for beam profile measurement -

Hawaii – KEK - Tohoku

Hitoshi Yamamoto

Tohoku University/University of Valencia

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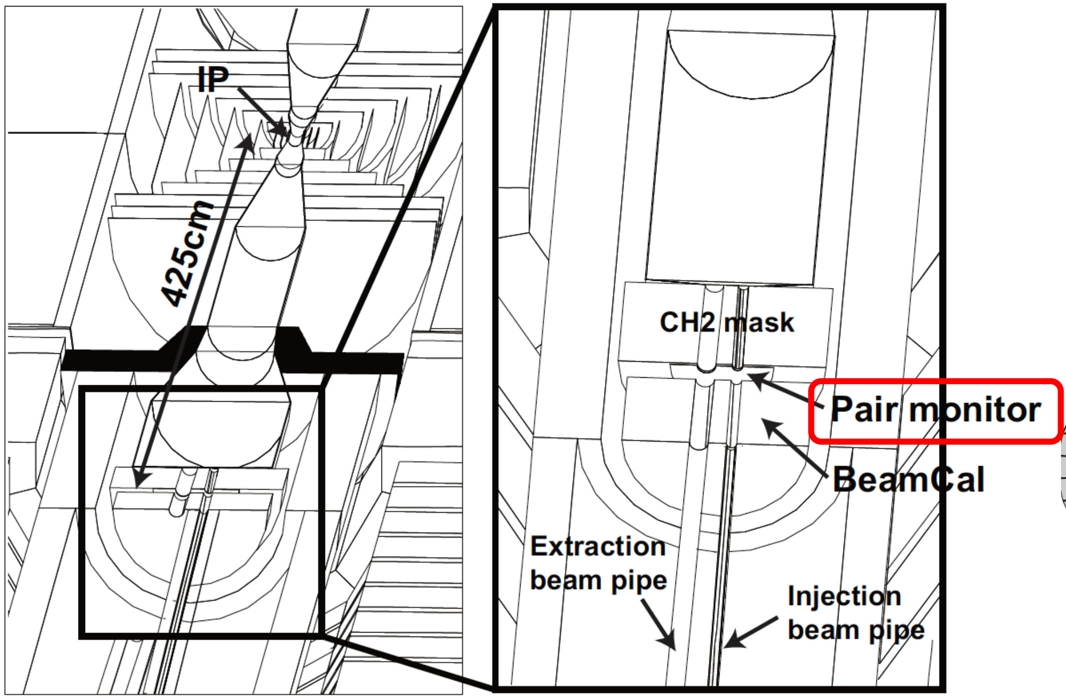
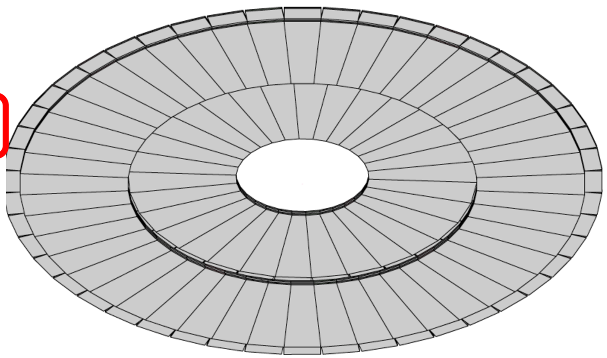
Location and Configuration



OD = ~8.5 cm

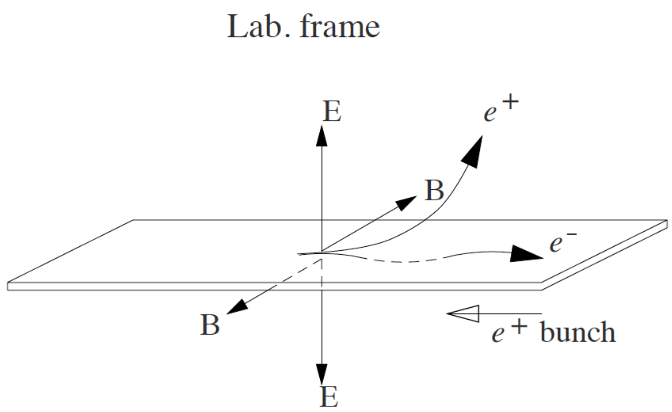


+ hole for incoming beam

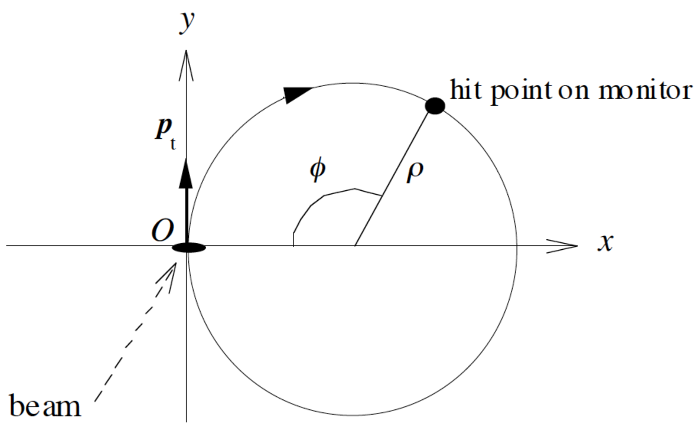
- One disk on each side of IP (in front of BEAMCAL)
- Single-layer silicon pixel detectors (a tracker, not a calorimeter)

Electron-Positron Pairs at IP

Simplified picture



Pairs are generalted in forward direction.
If the opposite bunch is e+,
e+ is deflected while e- is focused.



Helical motion of a deflected particle

ρ (cm) = pt(MeV)/3B(Tesla)

φ (rad) = 3B(Tesla)L(cm)/pz(MeV)

(L: distance from IP, B: solenoid field)

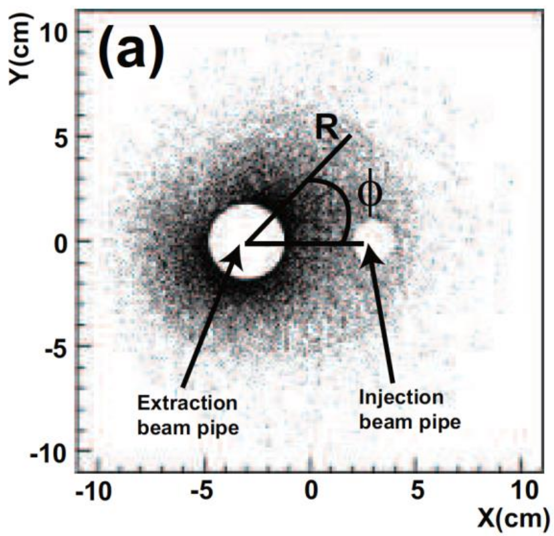
Reality:

- Beams are ~gaussian with tail
- Crossing angle + anti-DID
- Beam-beam effect

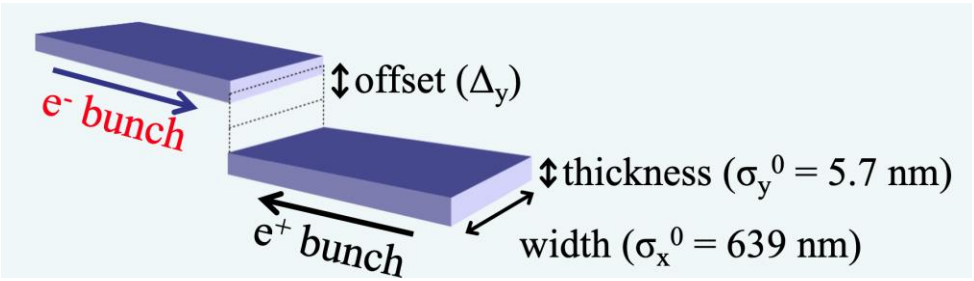
→ detailed simulations were performed (w/ CAIN)

Hit Distribution on Pair Monitor

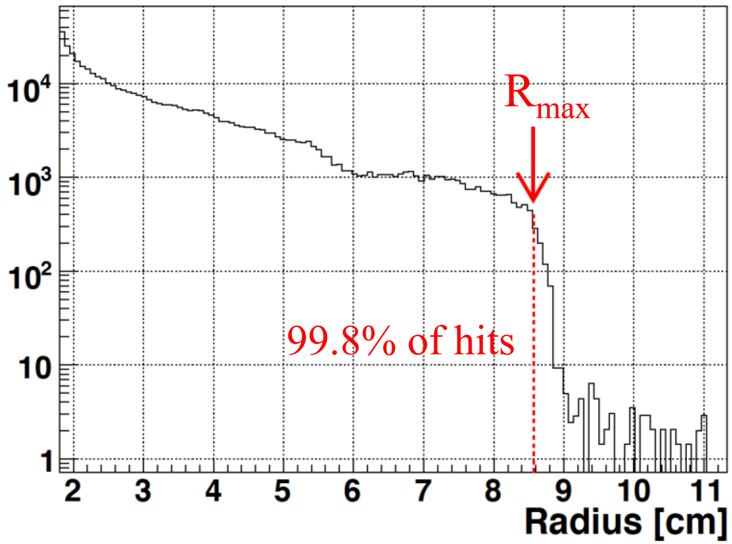
Parameter	Unit	
Center of mass energy	GeV	500
Number of particles per bunch	$\times 10^{10}$	2.05
Number of bunches per train		2625
Train repetition	Hz	5
Normalized horizontal emittance at IP	mm-mrad	10
Normalized vertical emittance at IP	mm-mrad	0.04
Horizontal beta function at IP	mm	20
Vertical beta function at IP	mm	0.4
Horizontal beam size at IP	nm	639
Vertical beam size at IP	nm	5.7
Longitudinal beam size at IP	μm	300
Crossing angle	mrad	14

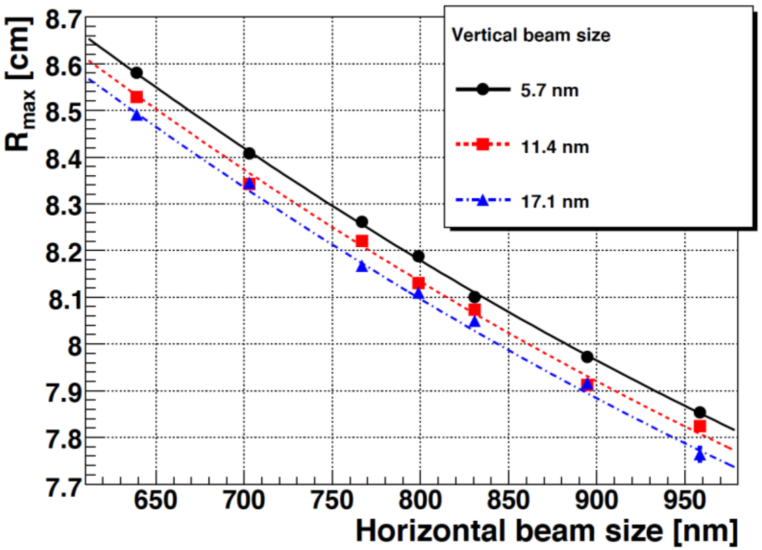


Beam parameters to be extracted



Dependence on σ_x (horizontal size)





$R_{max} \Leftrightarrow$ maximum p_t kick ~ E field of the opposite bunch

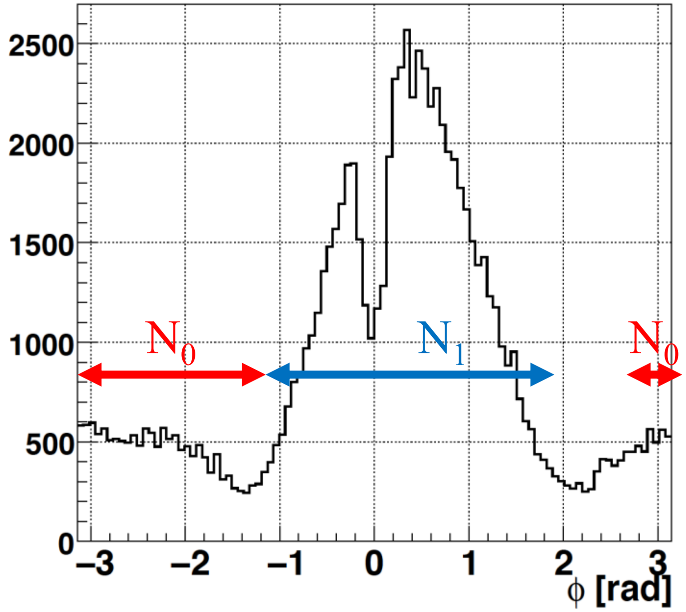
$\sim 1/\sigma_x$

For fixed number of particles per bunch,

Smaller $\sigma_x \rightarrow$ larger E field $\rightarrow$ larger R_{max}

Dependence on σ_y (vertical size) is weak

Dependence on σ_y (vertical size)



For $R > 0.5\ R_{max}$

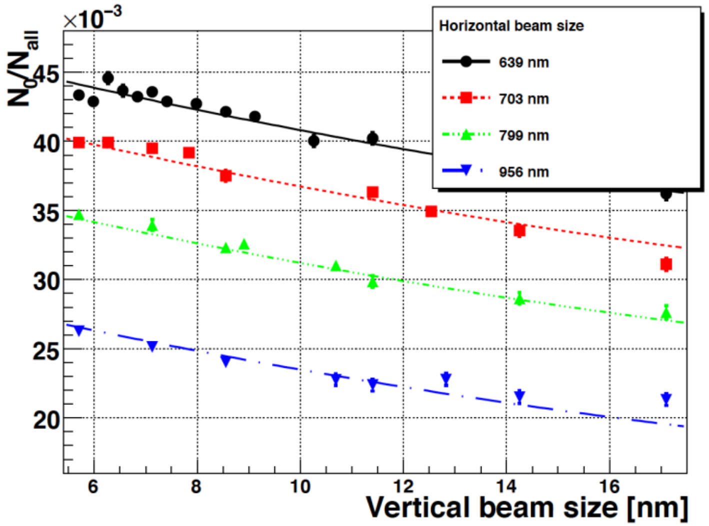
N_0 : number of hits in $-\pi<\phi<-1.2$, + $-1.2<\phi<2.7$

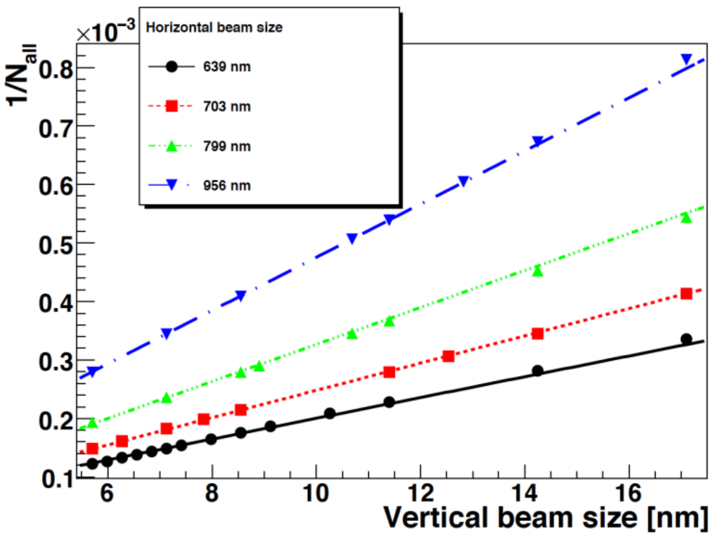
N_1 : number of hits in $-1.2<\phi<1.8$

Azimuthal hit distribution for $R > 0.5\ R_{max}$

The dip for f ~ 0 is due to the hole for the incoming beam

Dependence on σ_y (vertical size)





N_0/N_{all} has some sensitivity on σ_y.

It also depends on σ_x, but it is well constrained by R_{max}.

N_{all} is sensitive to σ_y

~ inversely correlated

Matrix Method

Taylor expansion of measurement variables around nominal beamsizes

measurement variables (M)

Beam parameter (X)

1st order

2nd order tensor

$$\begin{pmatrix} m_1 \\ \vdots \\ m_n \end{pmatrix} = \boxed{\mathbf{A}} \begin{pmatrix} \sigma_x \\ \sigma_y \\ \Delta_y \end{pmatrix} + \begin{pmatrix} \sigma_x & \sigma_y & \Delta_y \end{pmatrix} \boxed{\mathbf{B}} \begin{pmatrix} \sigma_x \\ \sigma_y \\ \Delta_y \end{pmatrix} + \cdots$$

$$= \mathbf{AX} + \mathbf{X}^{\mathrm{T}}\mathbf{BX} + \cdots$$

$$\mathbf{A} = \begin{pmatrix} \frac{\partial m_1}{\partial \sigma_x} & \frac{\partial m_1}{\partial \sigma_y} & \frac{\partial m_1}{\partial \Delta_y} \\ \frac{\partial m_2}{\partial \sigma_x} & \frac{\partial m_2}{\partial \sigma_y} & \frac{\partial m_2}{\partial \Delta_y} \\ \vdots & \vdots & \vdots \end{pmatrix}$$

Reconstruct beam size by multiplying the inverted matrix of coefficient

$$\mathbf{X} \equiv \begin{pmatrix} \sigma_x \\ \sigma_y \\ \Delta_y \end{pmatrix} = [\mathbf{A} + \mathbf{X}^{\mathrm{T}}\mathbf{B} + \cdots]^{-1}\mathbf{M}$$

Solve numerically and iteratively

J. Yan

Matrix Method

With improved measurement variables:

$$X = (\sigma_x, \sigma_y, \Delta_y) \qquad \Delta_y\text{: unit is } \sigma_y$$

$$M = (R_{shl}, \frac{N_{D1}}{N_{all}}, \frac{N_U}{N_{D2}}, \frac{1}{N_{all}})$$

R_{shl} : radius containing 97.5% of all hits

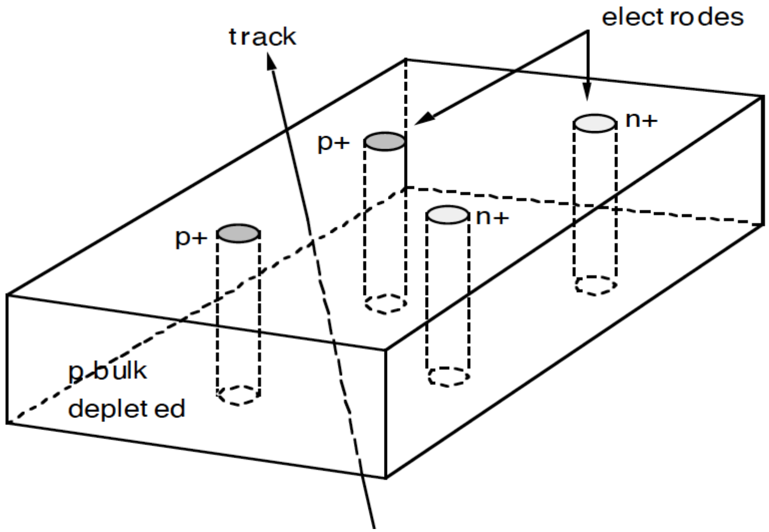
N_U : $0.3\ R_{shl} < R < 0.8\ R_{shl}$ & $0.8 < \phi < 1.6$

N_{D1} : $0.6\ R_{shl} < R < 0.8\ R_{shl}$ & $(-\pi < \phi < -2.0,\ 2.8 < \phi < \pi)$

N_{D2} : $0.3\ R_{shl} < R < 0.6\ R_{shl}$ & $(-\pi < \phi < -2.0,\ 2.8 < \phi < \pi)$

	Pair-monitor	BeamCal	Pair-monitor + BeamCal
σ_x	3.2 %	4.1 %	2.8 %
σ_y	10.1%	15.6 %	8.6 %
Δ_y	8.0 %	9.4 %	7.4 %

3D Pixel Sensor



• Pole electrodes transverse to the sensor plane.
• Drift field parallel to the sensor plane.

Merits:

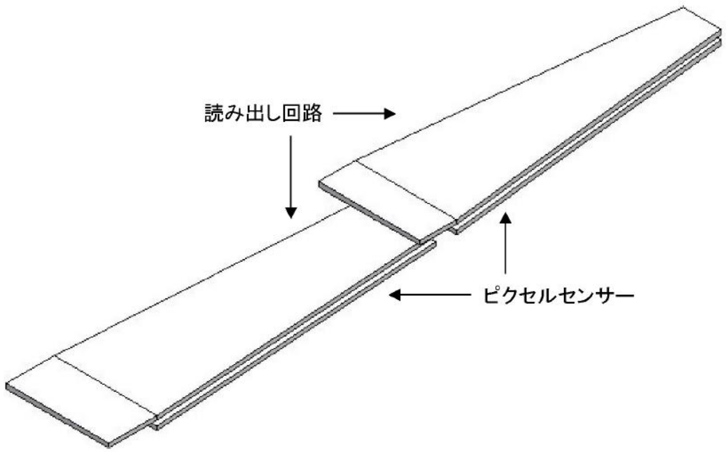
Fast: signal pulse 1/10 of typical pixel sensor.
$V_{depletion}$~ 5V (low!). Radhard.
Flexible geometry (e.g. trapisoid).
Active all the way to the edge (no guard rings).

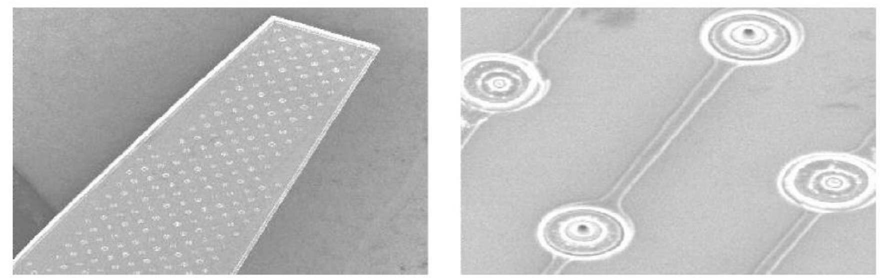
Drawbacks:

Requires a special etcher. (STF)
Technology not fully established.

→ Monolithic SOI for future

3D Pixel Sensor for Pair Monitor





Actual Prototype

Fabricated by U. Hawaii

Need RO chip (next) for testing

R_{max} ~ beam current

→ Inner radius should be as small as possible

For Pair Monitor Sensor

Pitch 100 ~ 400 μm

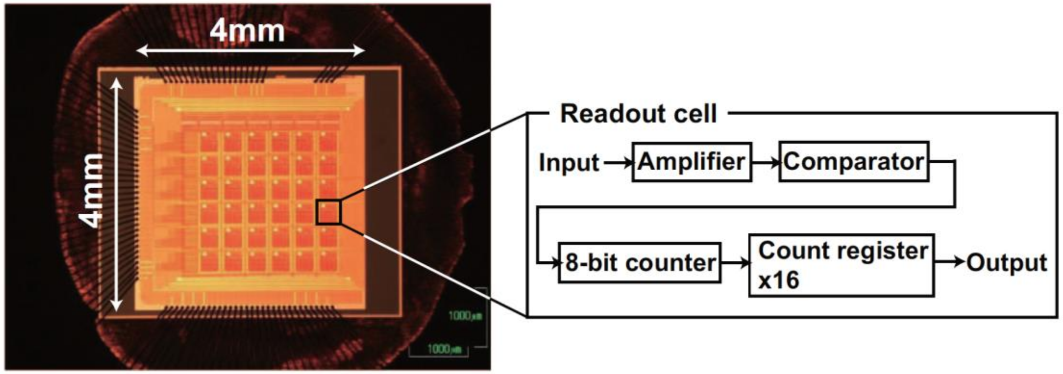
Thickness ~ 200 μm

$D_{electrode}$ ~ 25 μm

Readout

Spec:

- Number of cells ~ 200,000
- Count hits for 16 time slices in one train by 8-bit counter
  (2600 bunches / train) /16 = ~160 bunches integrated for each time slice
- Transmit data during inter-train gap (200 ms)

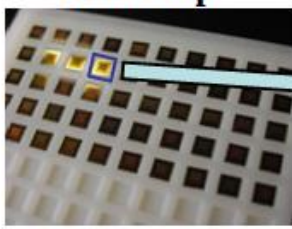


CMOS test chip

SOI Test Chip

OKI 0.2μm FD-SOI CMOS process

Bare chip



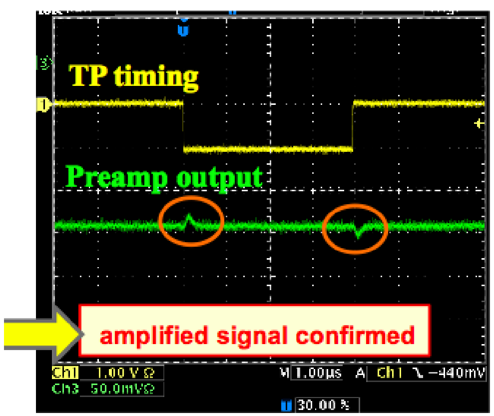
(2.5mm×2.5mm)

Package (QFP80)

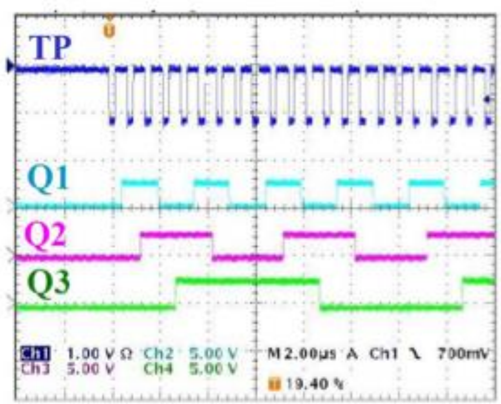
(14mm×14mm)

Test board

(10cm×10cm)



Amplifier



8-bit counter

Selected signal rise at 3rd pulse of clock

Cell selection

Current Status

- Hardware R&Ds are not progressing well. (funding!)
- Machine learning for extraction of beam parameters is being studied.