Forward photon measurement and generic detector R&D

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Contents

- CGC-related γ-physics at forward
  - Related to RHIC & LHC
  - Calculable from the 1^{st} principle.
  - To be addressed 5-10 years down the road.

- Relevant generic detector R&D
  - Si/W sandwich calorimeter
  - SiPM (Silicon photomultiplier)
  - 무엇보다 한국이 우수한 잠재력을 갖춘 영역에서

CGC-related γ-physics at forward

- Application domain
  - Perturbative QCD : $\Lambda_{QCD} << p_T$, $p_T \sim Q_s$
  - High parton density at small x : bigger effect at forward/backward
- Parton kinematics
  - Projectile : large x (~valence quarks)
  - Target : Small x (~gluons → CGC)
- Study based on Jamal Jalilian-Marian's work (PRD66(2002)014021, PRD66(2002)094014, PRD67(2003)074019, NPA753(2005)307)

Baseline prediction

- Forward hadron suppression
  - Jet quenching?
  - Parton coalescence model?

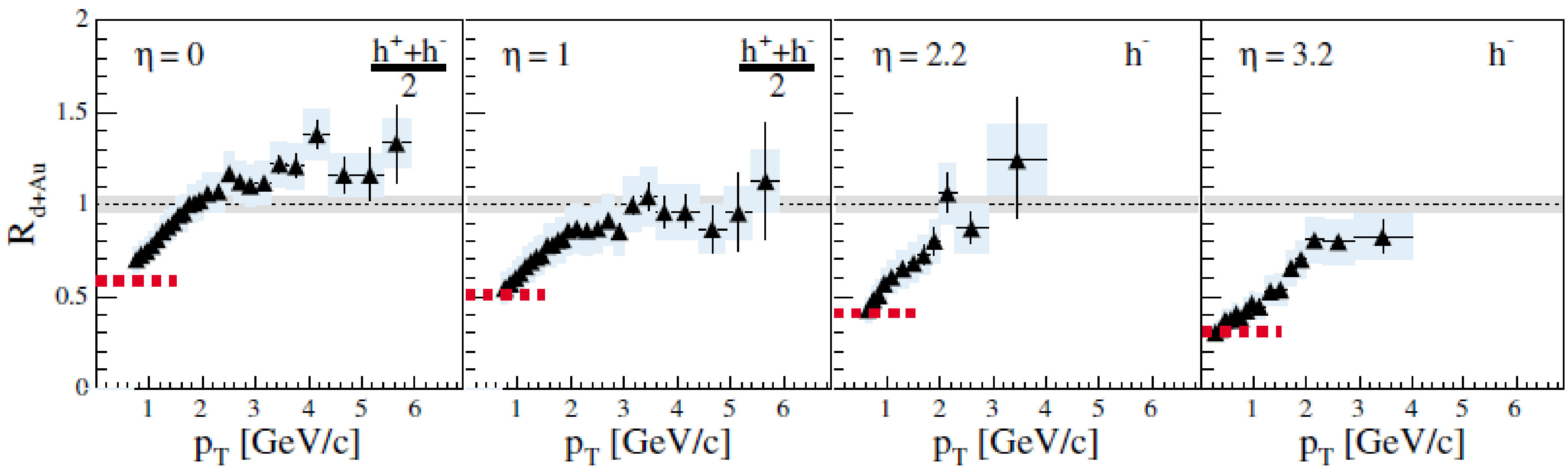


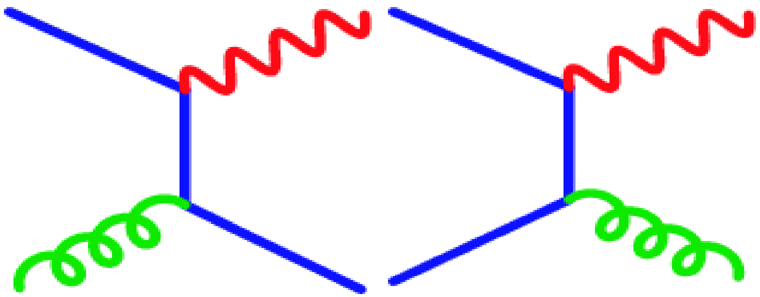
FIG. 2 (color online). Nuclear modification factor for charged hadrons at pseudorapidities $\eta = 0$, 1.0, 2.2, 3.2. One standard deviation statistical errors are shown with error bars. Systematic errors are shown with shaded boxes with widths set by the bin sizes. The shaded band around unity indicates the estimated error on the normalization to $\langle N_{coll} \rangle$. Dashed lines at $p_T < 1.5$ GeV/c show the normalized charged-particle density ratio $\frac{1}{\langle N_{coll} \rangle} \frac{dN/d\eta(\mathrm{Au})}{dN/d\eta(pp)}$.

Motivation : Direct γ production

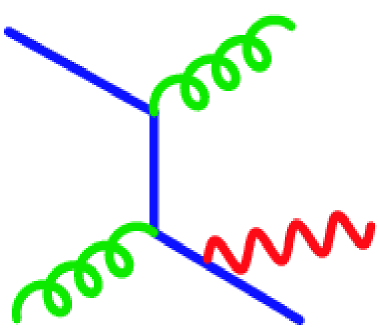
- Direct γ production in p+p

  → <u>One of the best known QCD process…</u>

Really?



→ Leading order diagram
in perturbation theory



Hard photon : Higher order pQCD
Soft photon : Initial/final radiation,
Fragmentation function

Baseline approach

$$q(p)+A\to q(q)+\gamma(k)+X\,,A$$

A : Background field, Color Glass Condensate at small x

$$\left\langle \left\{ q(\vec{q})\gamma(\vec{k}) \right\}_{out} \middle| q(\vec{p})_{in} \right\rangle = \left\langle 0_{out} \middle| a_{out}(\vec{k}) b_{out}(\vec{q}) b_{in}^{+}(\vec{p}) \middle| 0_{in} \right\rangle$$

Using reduction formalism,

$$\left\langle 0_{out} \middle| a_{out}(\vec{k}) b_{out}(\vec{q}) b_{in}^{+}(\vec{p}) \middle| 0_{in} \right\rangle$$

$$= \frac{e}{Z_2\sqrt{Z_3}} \int d^4x d^4y d^4z \cdot e^{i(k\cdot x+q\cdot z-p\cdot y)} \times \overline{u}(\vec{q})\left(i\vec{\not{\partial}}_z - m\right)$$

$$\times \left\langle 0_{out} \middle| T\psi(z)\varepsilon\cdot J(x)\overline{\psi}(y) \middle| 0_{in} \right\rangle \times \left(i\overleftarrow{\not{\partial}}_y + m\right) u(p)\,,\; J_\mu(x)\equiv \overline{\psi}(x)\gamma_\mu\psi(x)$$

$$\left\langle 0_{out} \middle| T\psi(z)\overline{\psi}(x)\not{\varepsilon}\psi(x)\overline{\psi}(y) \middle| 0_{in} \right\rangle = -G_F(z,x)\not{\varepsilon}G_F(x,y)$$

$$G_F(x,y) \equiv \langle 0_{out} | T\overline{\psi}(y)\psi(x) | 0_{in} \rangle$$

$$= \quad G_F^0(x-y) + \int d^4z\,\delta(z^-)[\theta(x^-)\theta(-y^-)(U^+(z_T)-1)$$

$$-\theta(-x^-)\theta(y^-)(U(z_T)-1)]G_F^0(x-z)\gamma^- G_F^0(z-y)$$

$$U(x_T) \equiv Te^{-ig^2\int_{-\infty}^{\infty} dz^- \frac{1}{\nabla_T^2}\rho_a(z^-,z_T)t^a}$$

$U(z_T)$: a unitary matrix containing the interactions between the quark and CGC.

in coordinate space and in the “singular” gauge.
L. McLerran and R. Venugopalan, Phys. Rev. D59, 094002(1999)

$$\left\langle \left\{ q(\vec{q})\gamma(\vec{k}) \right\}_{out} \middle| q(\vec{p})_{in} \right\rangle = -ie\bar{u}(q)\left[\frac{\gamma^-(\not{p}-\not{k}+m)\not{\epsilon}}{(p-k)^2-m^2} + \frac{\not{\epsilon}(\not{q}+\not{k}+m)\gamma^-}{(q+k)^2-m^2} \right] u(p)$$

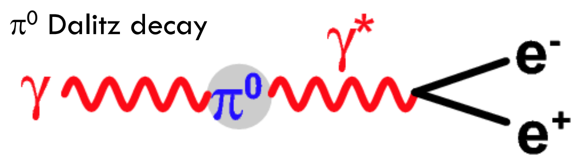
$$\times 2\pi\delta\left(q^- + k^- - p^-\right)\int d^2x_T e^{i\left(\vec{q}_T+\vec{k}_T-\vec{p}_T\right)\cdot\vec{x}_T}\left(U\left(\vec{x}_T\right)-1\right)$$

$$= 2\pi\delta\left(q^- + k^- - p^-\right) M\left(\vec{p} \mid \vec{q}\vec{k}\right)$$

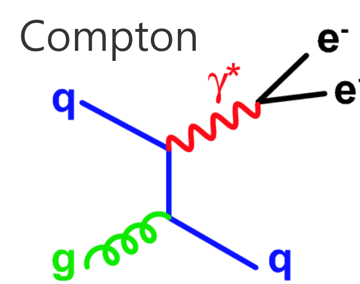
$$d\sigma = \frac{d^3\vec{k}}{(2\pi)^3 2k_0}\frac{d^3\vec{q}}{(2\pi)^3 2q_0}\frac{1}{2p^-} \times M\left(\vec{p} \mid \vec{q}\vec{k}\right) M^*\left(\vec{p} \mid \vec{q}\vec{k}\right) \cdot 2\pi\delta\left(p^- - q^- - k^-\right)$$

$\gamma^*(e^+e^-$ pair) measurement

- Motivation:
  Low p_T : large π^0, η background
- Internal conversion
  - Any source of real photons also emits virtual photons
  - Well known example:



  - ◆ Rate and m_{ee} distribution calculable in QED (Kroll-Wada formula)



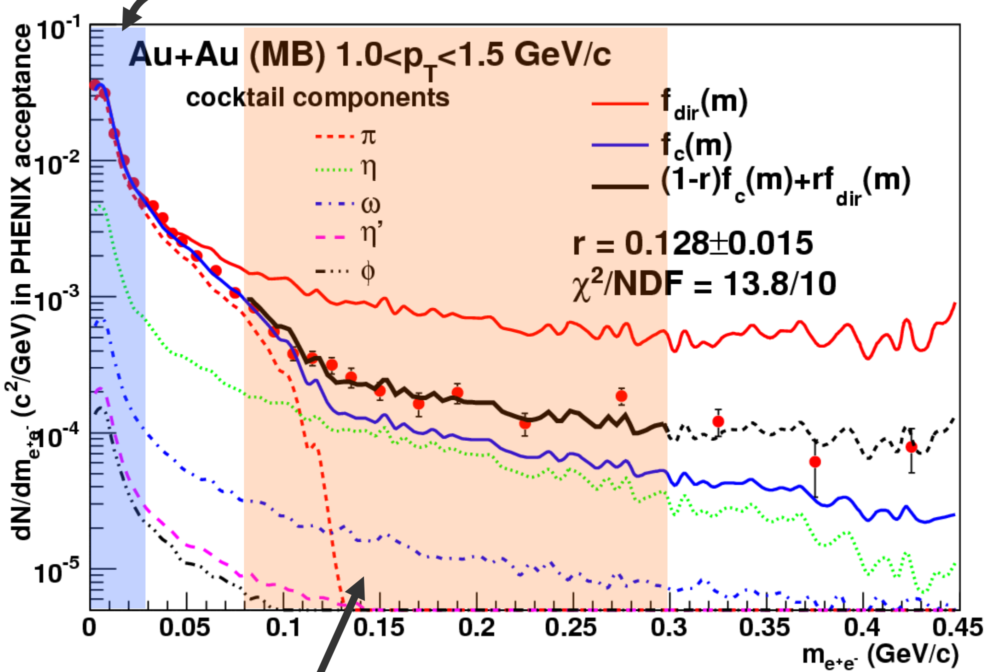
- ■ Hadron decays: $m_{ee} < M_{hadron}$
- ■ Essentially not such limit for point-like source.

Improve signal-to-background ratio by measuring e^+e^- pairs with $m_{ee} > \sim M_{pion}$

Extraction of γ signal

$$f(m_{ee}) = (1-r)\cdot f_{\text{cocktail}}(m_{ee}) + r\cdot f_{\text{direct}}(m_{ee})$$

Separately normalized to data at m_{ee} < 30 MeV



Fit range: 80 < m_{ee} < 300 MeV

- Interpret deviation from hadronic cocktail (π, η, ω, η', φ) as signal from virtual direct photons
- Extract fraction r with two-component fit

$$r = \left.\frac{\gamma^*_{\text{direct}}}{\gamma^*_{\text{inclusive}}}\right|_{m_{ee}<30\text{ MeV}}$$

- Fit yields good χ^2/NDF (13.8 / 10)

γ Production vs γ* production

$$d\sigma = \frac{d^3\vec{k}}{(2\pi)^3 2k_0}\frac{d^3\vec{q}}{(2\pi)^3 2q_0}\frac{1}{2p^-}\times M\left(\vec{p}\,|\,\vec{q}\vec{k}\right)M^*\left(\vec{p}\,|\,\vec{q}\vec{k}\right)\cdot 2\pi\delta\left(p^- - q^- - k^-\right)$$

$$M\left(\vec{p}\,|\,\vec{q}\vec{k}\right) = -ie\bar{u}(q)\left[\frac{\gamma^-\left(\not{p}-\not{k}+m\right)\not{\epsilon}}{(p-k)^2-m^2}+\frac{\not{\epsilon}\left(\not{q}+\not{k}+m\right)\gamma^-}{(q+k)^2-m^2}\right]u(p)$$

$$\times\int d^2x_T e^{i\left(\vec{q}_T+\vec{k}_T-\vec{p}_T\right)\cdot\vec{x}_T}\left(U\left(\vec{x}_T\right)-1\right)$$

$$d\sigma = \frac{d^4\vec{k}}{(2\pi)^4}\frac{d^3\vec{q}}{(2\pi)^3 2q_0}\frac{1}{2p^-}\frac{2\alpha_{em}}{3k^2}\times M^\mu\left(\vec{p}\,|\,\vec{q}\vec{k}\right)M^*_\mu\left(\vec{p}\,|\,\vec{q}\vec{k}\right)\cdot 2\pi\delta\left(p^- - q^- - k^-\right)$$

$$M^\mu\left(\vec{p}\,|\,\vec{q}\vec{k}\right) = -ie\bar{u}(q)\left[\frac{\gamma^-\left(\not{p}-\not{k}+m\right)\gamma^\mu}{(p-k)^2-m^2}+\frac{\gamma^\mu\left(\not{q}+\not{k}+m\right)\gamma^-}{(q+k)^2-m^2}\right]u(p)$$

$$\times\int d^2x_T e^{i\left(\vec{q}_T+\vec{k}_T-\vec{p}_T\right)\cdot\vec{x}_T}\left(U\left(\vec{x}_T\right)-1\right)$$

Universality (DIS)

$$\sigma_{DIS} = \int_0^1 dz \int d^2 r_T \left|\Psi\left(k^{\pm}, k_T \mid z, r_T\right)\right|^2 \sigma_{dipole}(r_T)$$

$$= \int_0^1 dz \int d^2 r_T F_{known} \cdot \sigma_{dipole}(r_T)$$

$$\sigma_{dipole}(r_T) \equiv \frac{2}{N_c} \int d^2 X_T Tr \left\langle 1 - U\left(X_T + \frac{r_T}{2}\right) U^{+}\left(X_T - \frac{r_T}{2}\right)\right\rangle_{\rho}$$

$$d\sigma_{\gamma^*} = \frac{d^4\vec{k}}{(2\pi)^4} \frac{d^3\vec{q}}{(2\pi)^3 2q_0} \frac{1}{2p^-} \frac{2\alpha_{em}}{3k^2} \times M^{\mu}\left(\vec{p} \mid \vec{q}\vec{k}\right) M^*_{\mu}\left(\vec{p} \mid \vec{q}\vec{k}\right) \cdot 2\pi\delta\left(p^- - q^- - k^-\right)$$

$$= \frac{2}{N_c} \int d^2 X_T Tr \left\langle 1 - U\left(X_T + \frac{r_T}{2}\right) U^{+}\left(X_T - \frac{r_T}{2}\right)\right\rangle_{\rho} \cdot G_{known}$$

Issues…

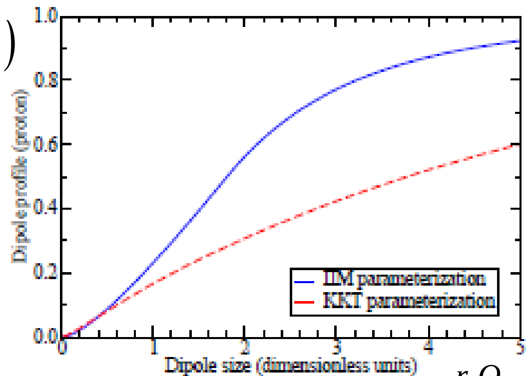
Phenomenological models for the dipole cross sections…
(baseline JIMWLK equations)

Dipole cross section

$$N\left(x, r_T, b_T\right) = \frac{1}{N_c} Tr\left\langle 1 - V^{+}\left(x_T\right) V\left(y_T\right)\right\rangle$$

$$x_g = 1.6 \times 10^{-4}$$

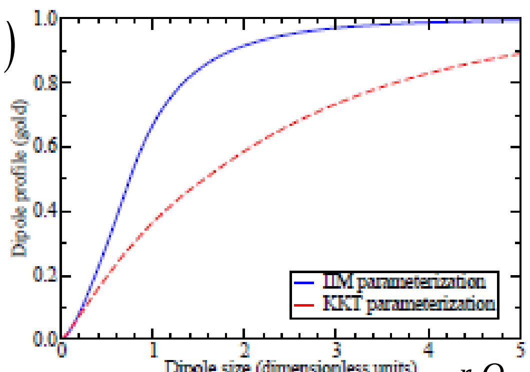
$N(x_g, r_T, b_T)$



$r_T Q_s$

Figure 1: Quark anti-quark dipole profile for a proton target.

$N(x_g, r_T, b_T)$



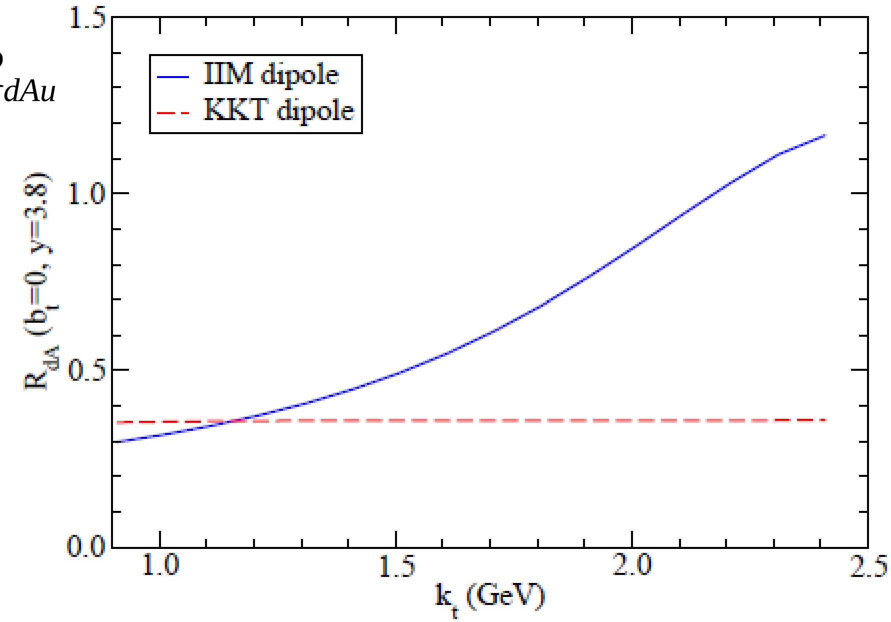
$r_T Q_s$

Figure 2: Quark anti-quark dipole profile for a nuclear target.

$$R_{dAu} \equiv \frac{\dfrac{d\sigma^{dA\to\gamma X}}{dy\, d^2k_T\, d^2b_T}}{2A\dfrac{d\sigma^{pp\to\gamma X}}{dy\, d^2k_T\, d^2b_T}}$$

RHIC

R_{dAu}



J. Jalilian-Marian, NPA753 (2005) p307-315

Summary

- Forward γ production at RHIC/LHC
  - Extension of pQCD possible
  - Extreme higher twist(large Q_s) and CGC.
  - Universality in dipole cross section (DIS & Forward γ production)
  - Dipole cross section is not yet calculated from baseline JIMWLK equation, but models for it exist.

Generic detector R&D

한국의 잠재역량

R&D environment

6 inch fabrication line

8 inch fabrication line

MEMORAND

(1) Youngil Kwon, Mann-Ho C
(2) Edward Kistenev, Andrey S
(3) John Lajoie, Physics and As
(4) Yongsun Yoon, BT division,
(5) Kwun-bum Chung, Elecropl
(6) Zheng Li, SDDPL, Instrum

(7) Jinsoo Kim, National Nano

I. Purpose & Scope

The purpose of this MOU is to
the '**Radiation damage and**
planning to contribute their ov
studies. This MOU clarifies the areas of pa … rties will
collaborate by sharing their expertise and se … ticipating
parties for the stated academic goal.

II. Responsibilities Under this MOU

A. Dr. E. Kistenev, and Prof. J. Lajoie, and Prof. Y. Kwon will propose silicon semiconductor detectors/devices to achieve academic goals in their field of interest in the experimental nuclear and high energy physics.

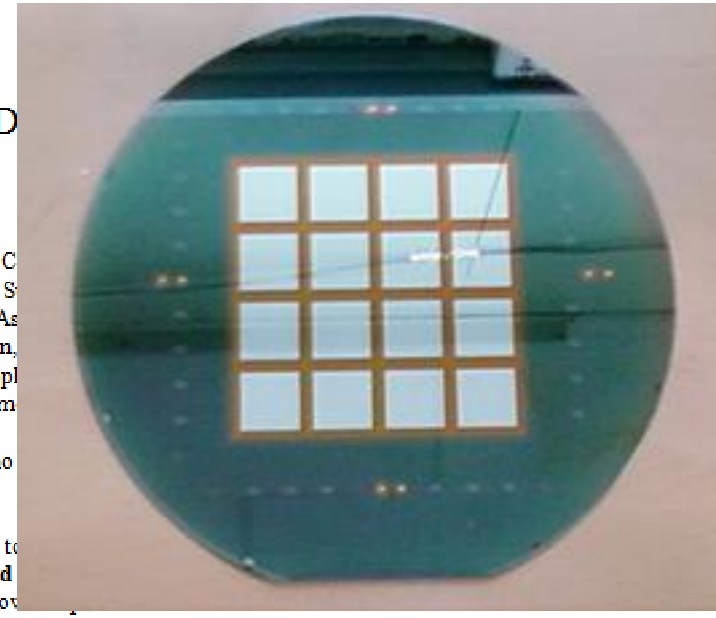
B. Dr. Z. Li will design the proposed silicon semiconductor detectors/devices using standards approved by industry for large area radiation hard Si devices and will advice on the radiation induced defects in Si devices.

C. Dr. A. Sukhanov will advice on the electronic design and implementation of the readout electronics for silicon semiconductor device testing.

D. Dr. Yoon will inspect designs of the proposed detectors/devices and advise on matching design ideas to fabrication technologies. He will also perform his own radiation hardness testing of the devices he develops.

E. Prof. M.-H. Cho, Prof. G. T. Park, and Prof. K. B. Chung will advise on possible defects in silicon sensors/devices and will study radiation defects in the produced sensors/devices exposed to different kinds of radiation.

F. Mr. Kim, leader of nano patterning process team in National Nanofab Center, will assist in fabrication of the silicon sensors/devices with university discount program and consult on details of silicon detector/device fabrication process.

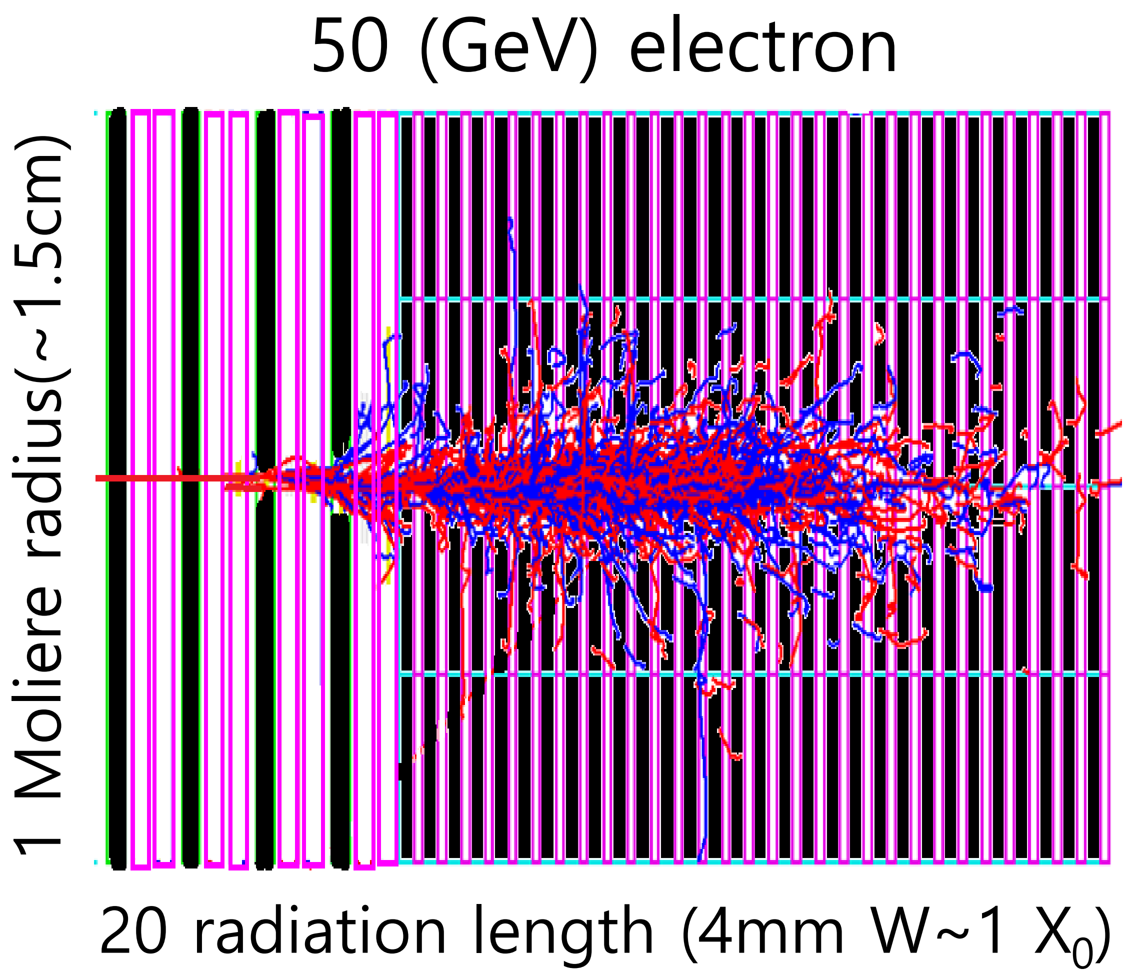


300 cm^2 ~ \$ 500

FOCAL

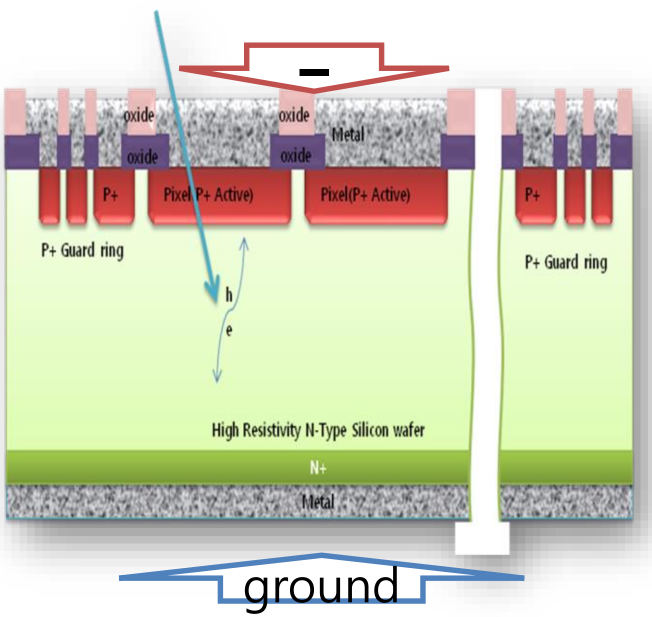
- A compact sampling electromagnetic calorimeter
  - deals with large particle flux at forward
  - observes part of the energy deposited by particle for the optimized shower
  - measures key particles, e, γ and π^o, within small space
  - measures energy.

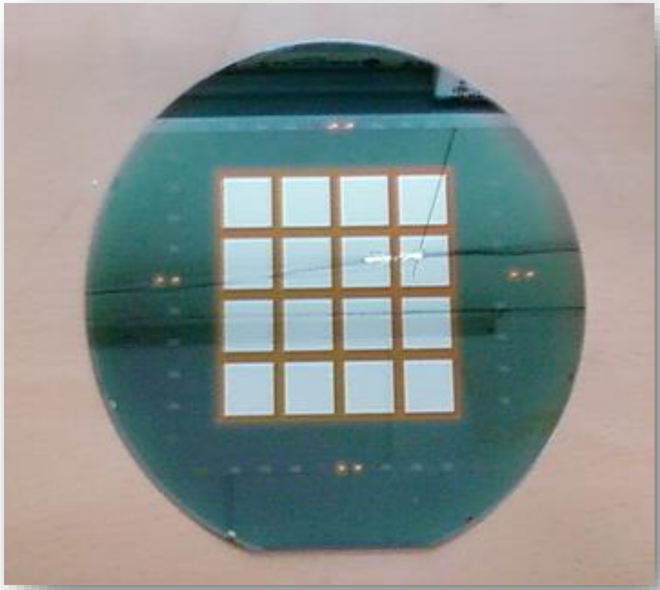
A compact EMCal, Si/W sandwich calorimeter

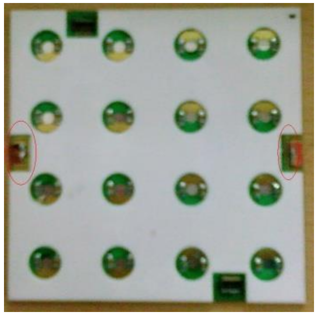


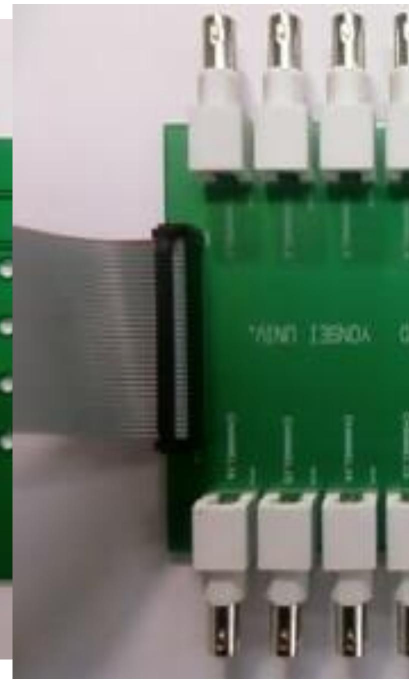
Silicon pad sensor

- **Basically** PN junction diode in reverse bias mode.
  - N-type substrate and p-type pattern for high energy application => electrons are carriers
- **16 square(1.5cm×1.5cm) pads in one micro-module**

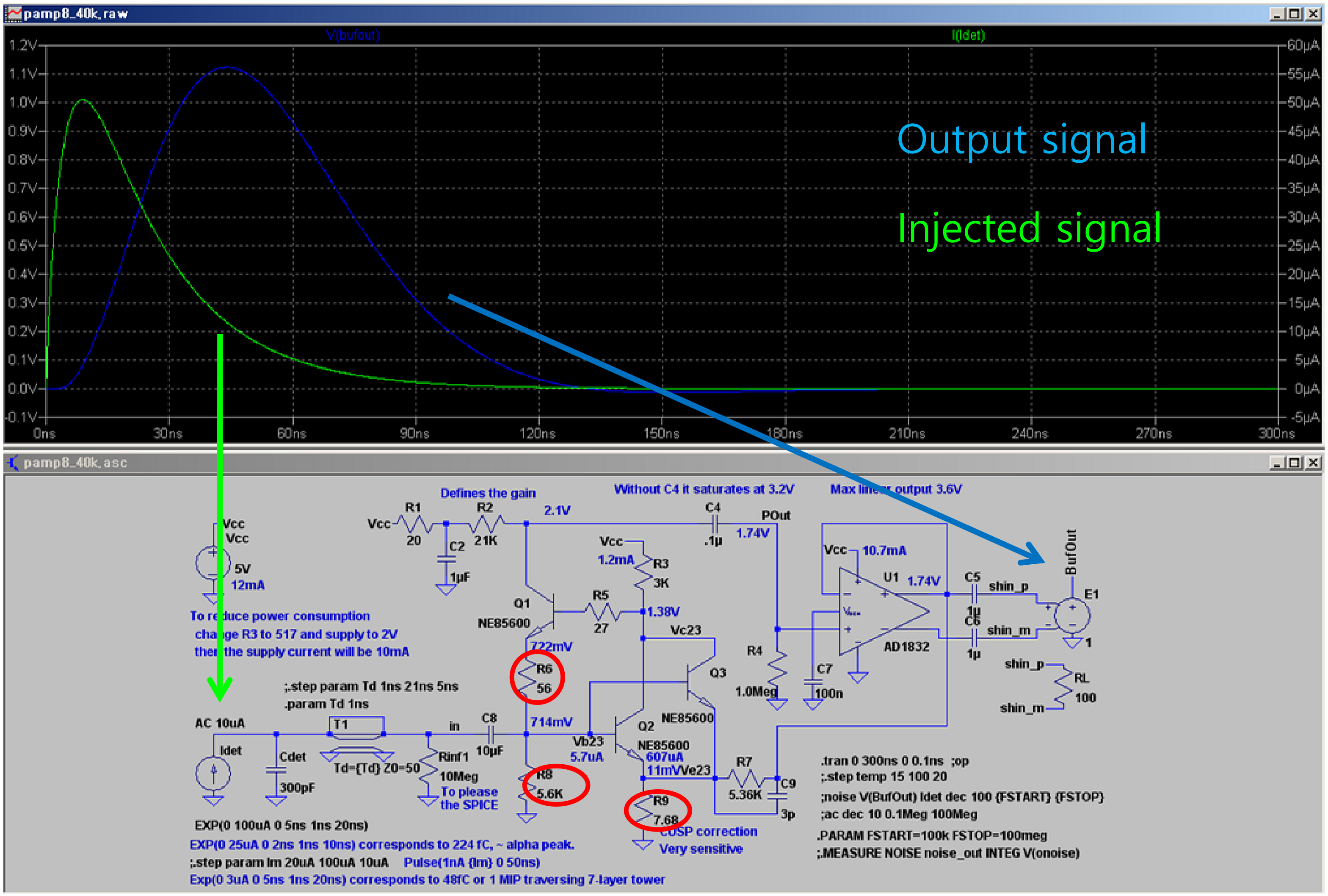






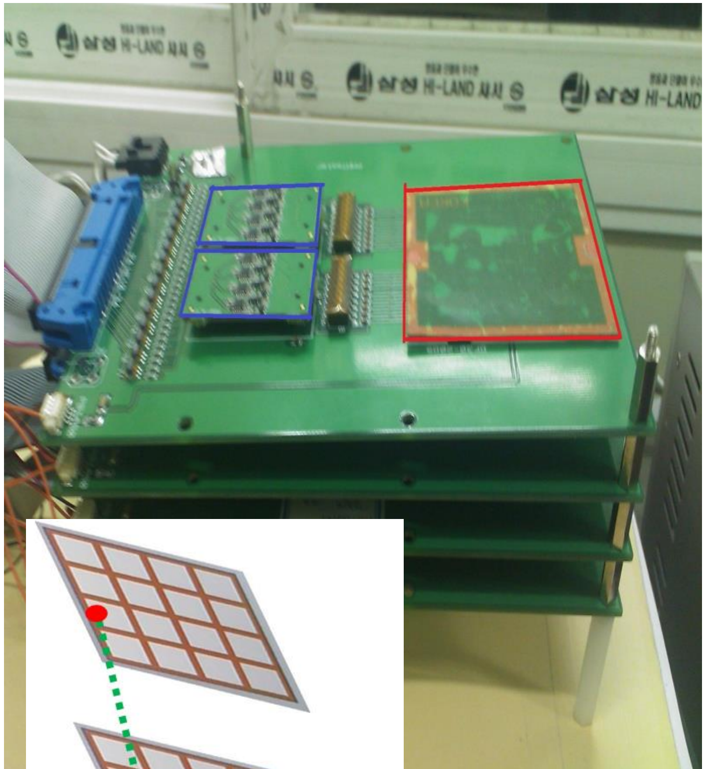



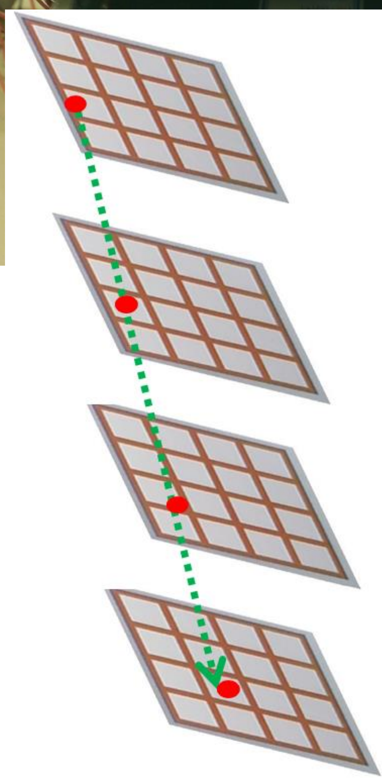

Preamp

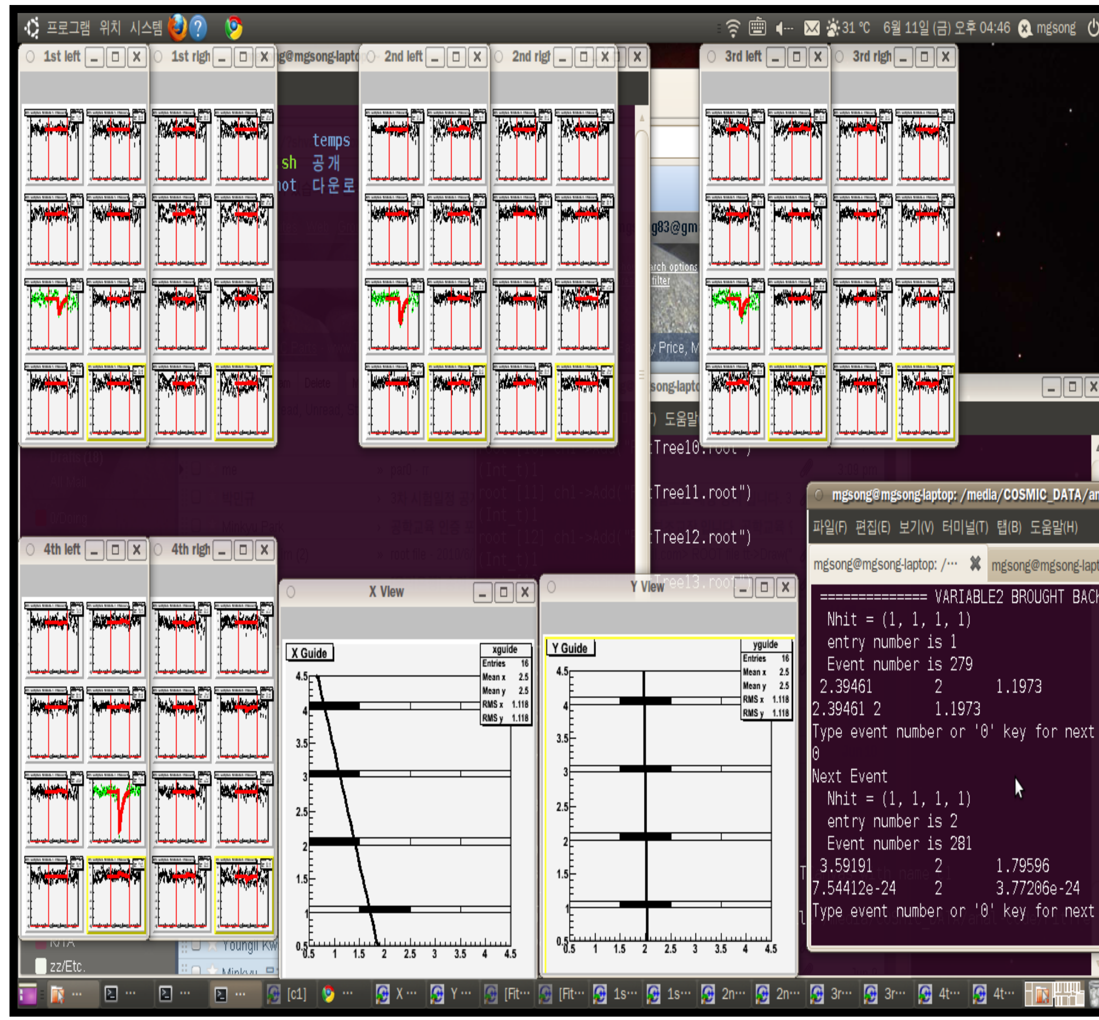


pamp8_40k.raw
V(bufout)
I(Idet)
Output signal
Injected signal
pamp8_40k.asc
Defines the gain
Without C4 it saturates at 3.2V
Max linear output 3.6V
To reduce power consumption
change R3 to 517 and supply to 2V
then the supply current will be 10mA
;.step param Td 1ns 21ns 5ns
.param Td 1ns
AC 10uA
Td={Td} Z0=50
To please the SPICE
COSP correction
Very sensitive
EXP(0 100uA 0 5ns 1ns 20ns)
EXP(0 25uA 0 2ns 1ns 10ns) corresponds to 224 fC, ~ alpha peak.
;.step param Im 20uA 100uA 10uA Pulse(1nA {Im} 0 50ns)
Exp(0 3uA 0 5ns 1ns 20ns) corresponds to 48fC or 1 MIP traversing 7-layer tower
.tran 0 300ns 0 0.1ns ;op
;.step temp 15 100 20
;noise V(BufOut) Idet dec 100 {FSTART} {FSTOP}
;ac dec 10 0.1Meg 100Meg
.PARAM FSTART=100k FSTOP=100meg
;.MEASURE NOISE noise_out INTEG V(onoise)

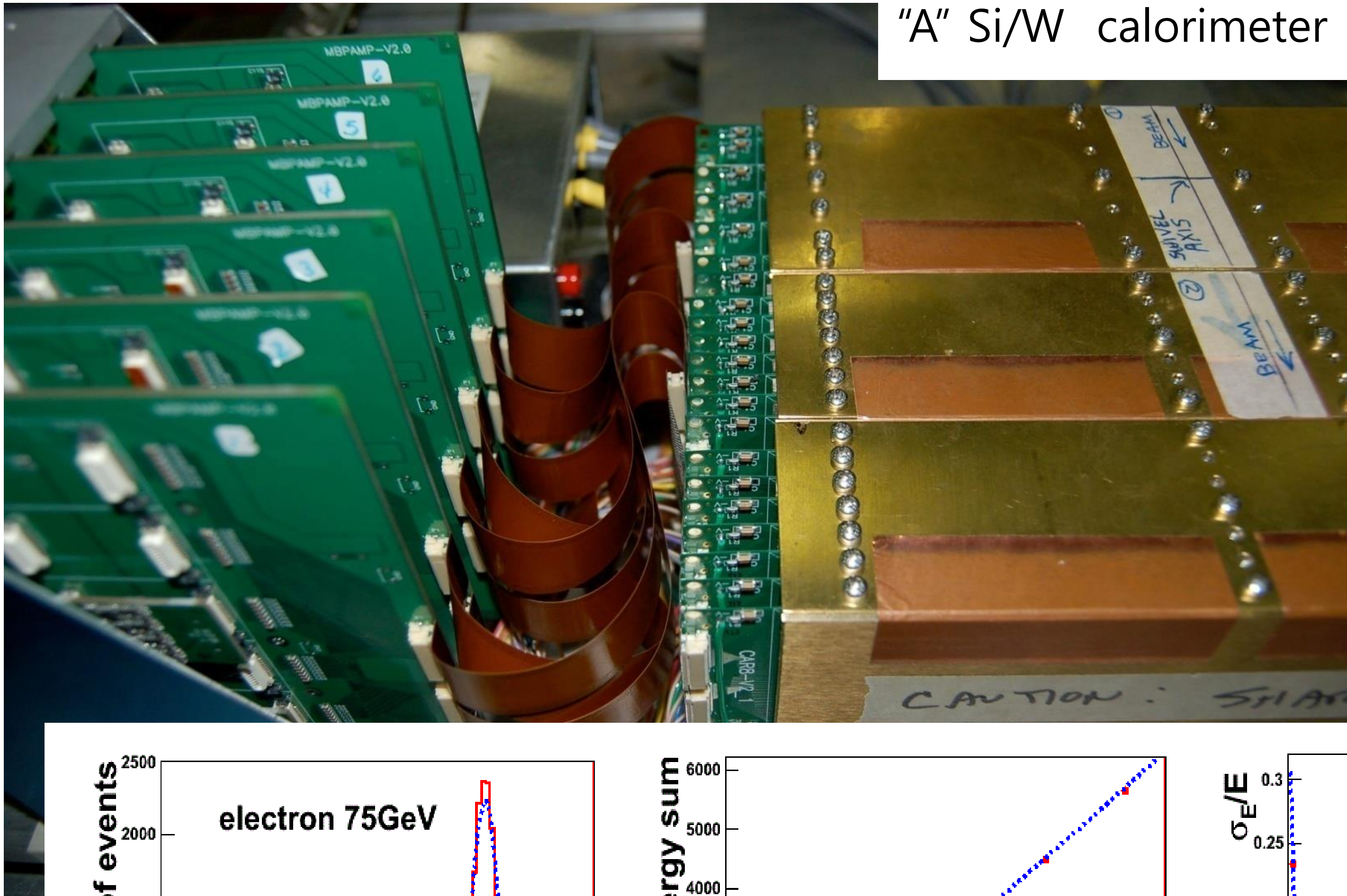
Cosmic muon test

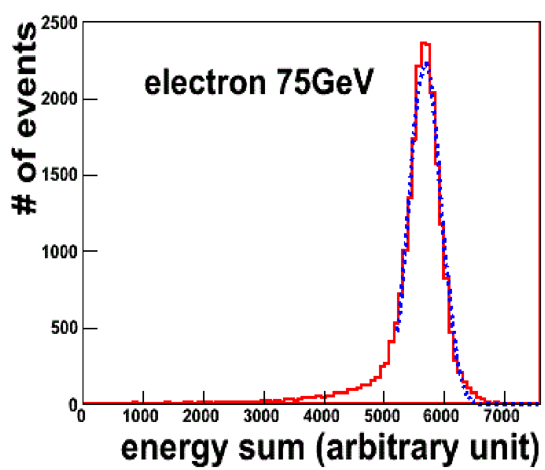




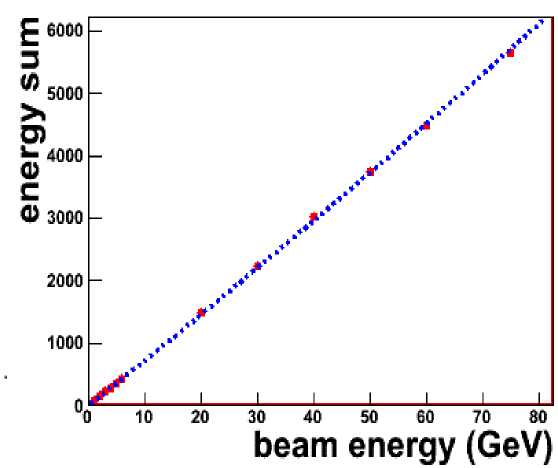


"A" Si/W calorimeter prototype

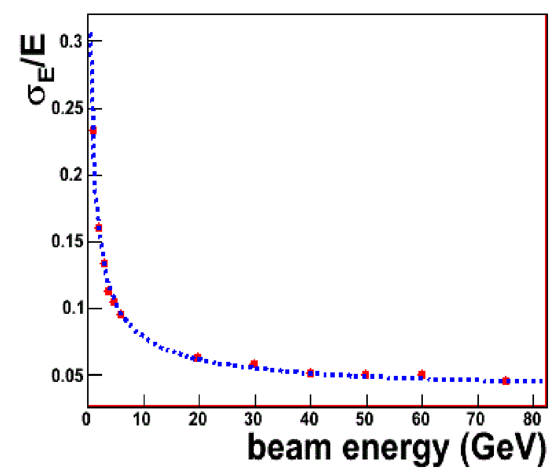




(a)



(b)



(c)

KPS, Fall 2010

High sensitivity photon sensor (SiPM)

~ 10^5-10^6 electrons for a photon in visible range

구조와 동작

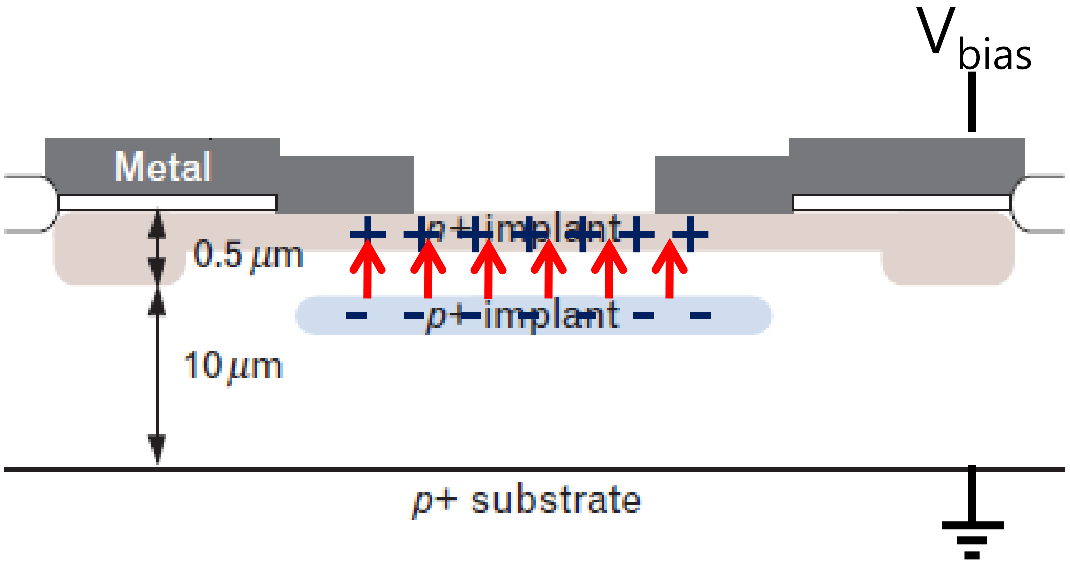
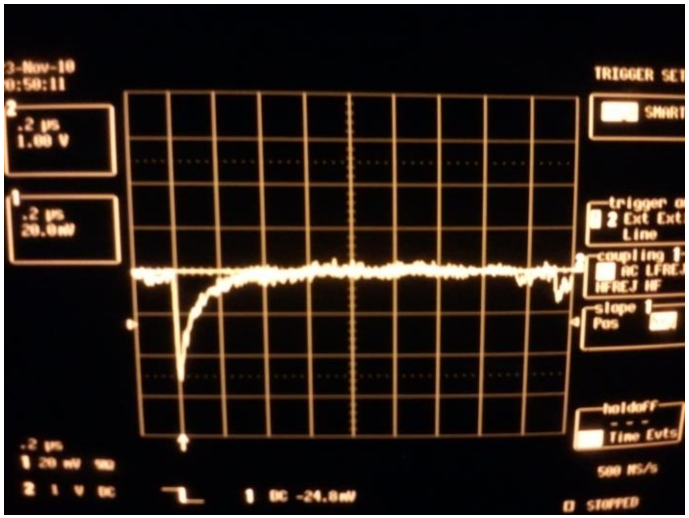
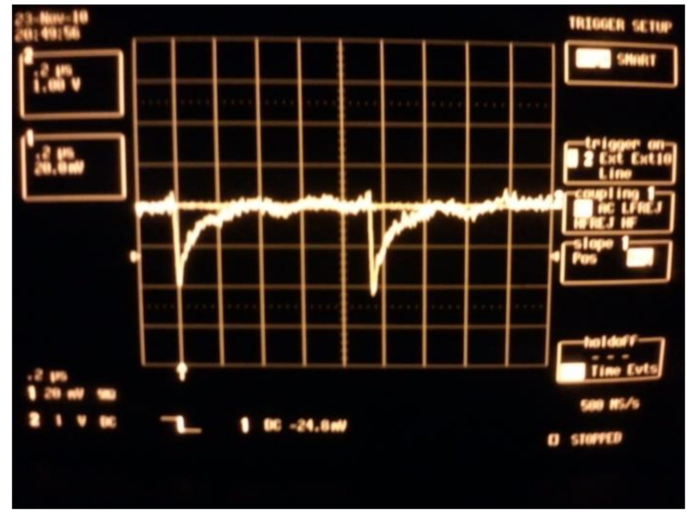


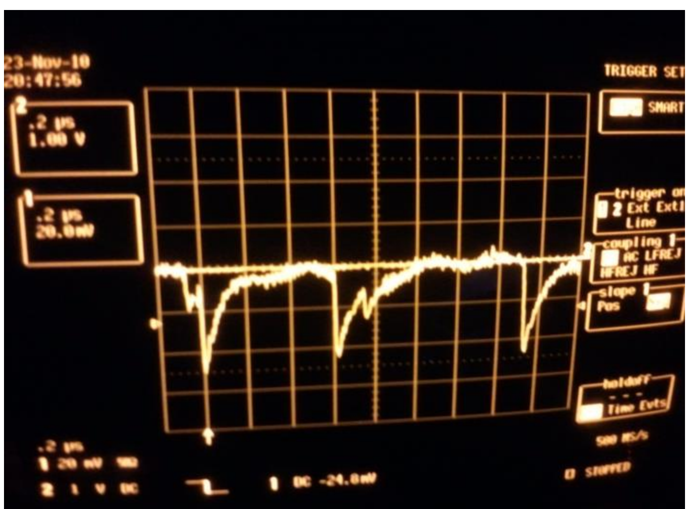
FIGURE 7. Cross-section of the basic APD device structure. The APD is fabricated in a lightly *p*-doped epitaxial layer grown o… e heavily *n*-doped (*n*+) … he diode and the subs… implant creates a she… ure into regions of low electric field (below the implant), where photon absorption takes place, and high electric field (above the implant), where impact ionization occurs.

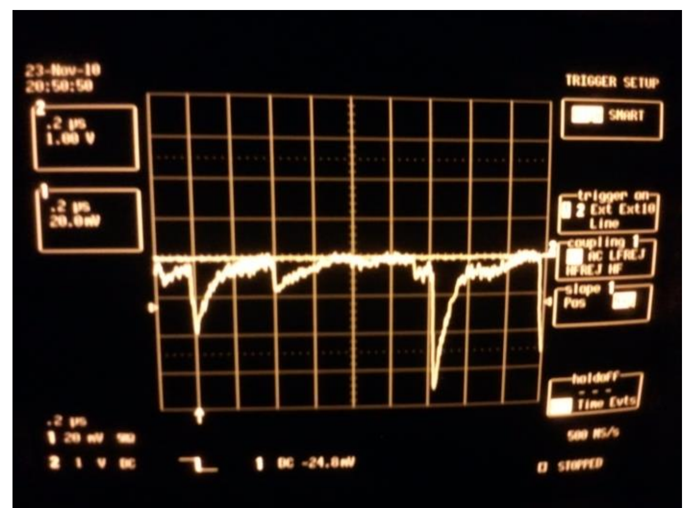
$$\Delta E = \frac{1}{2} C V_{bias}^{2} - \frac{1}{2} C V_{B.D.}^{2}$$

Noise signal

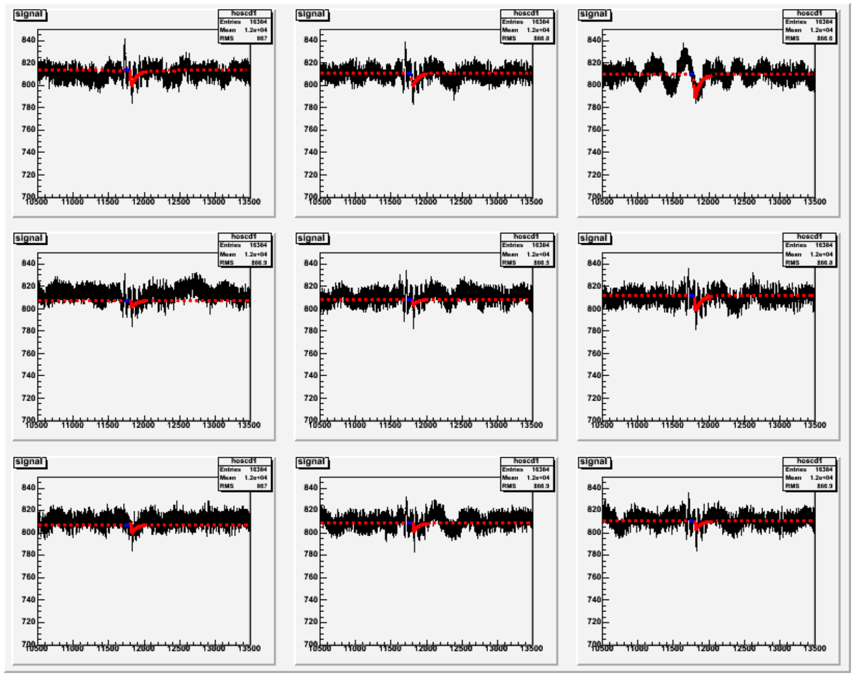


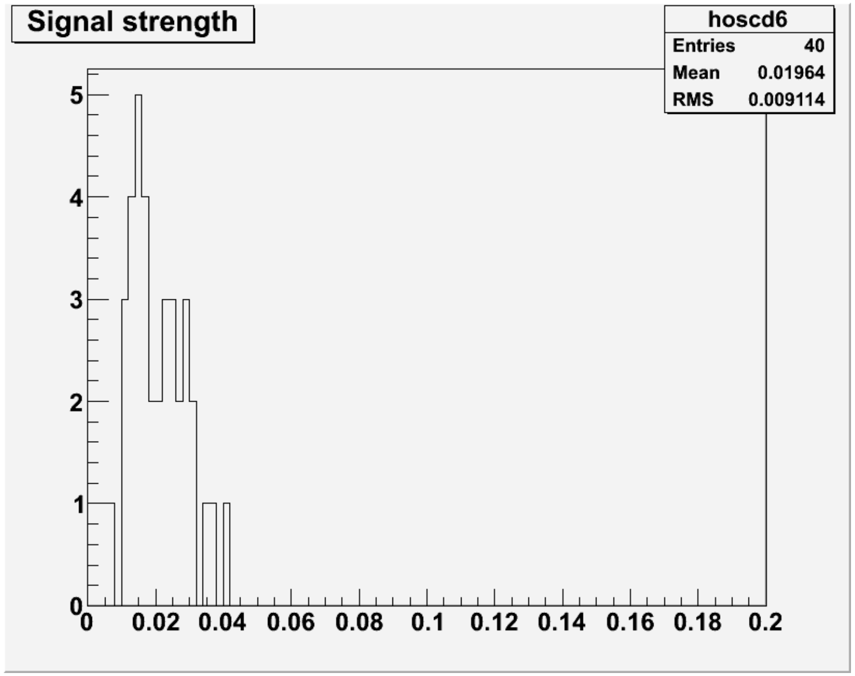




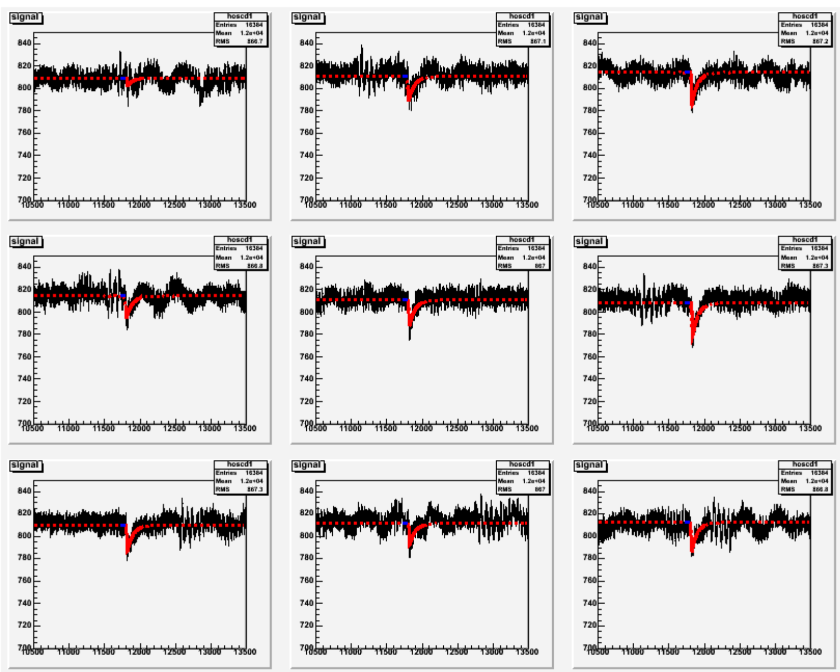


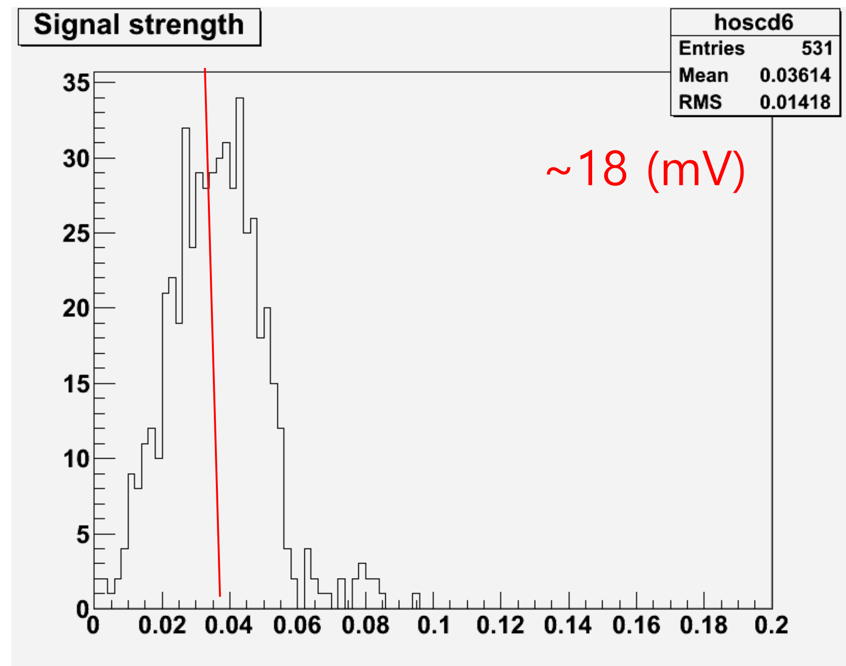
24.5 (V) : Under breakdown





25.5 (V) : Breakdown





27.0 (V) : Over breakdown