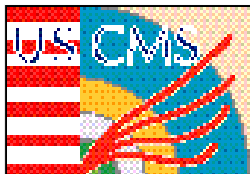


SiPM Signal Shaping

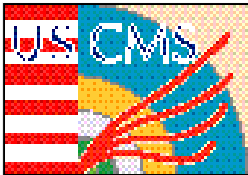
Sergey Los
FNAL/CMS/HCAL



SiPMs for HO

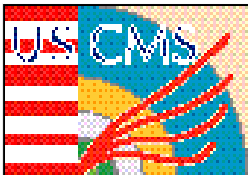
- There are still two candidates for the next HO photo sensor:
 - Hamamatsu MPPC
 - Zecotec MAPD
- Their parameters are very different, so blending them into existing QIE system requires specific approaches

Parameter of the Control Board	Hamamatsu 3x3	Zecotek 3x3
Operating voltage	72 V	91 V
Gain	750,000 (1V ov, 100ns gate)	35,000 (2V ov, 100ns gate)
Terminal capacitance	320 pf	150 pf
Number of microcells	3600	135,000
Quenching resistance	124k /cell	830k/cell + diode (see report by Yuri Musienko)
Leakage current after irradiation	150 uA (1E12 p/cm ²)	10uA (3E12 p/cm ²)
Cser/Rdrain used on prototypes	33 pf / 1K	150 pf / 10K
Effective gain after attenuation	6.3E4 (10fC/pe)	1.8E4 (2.9fC/pe)
These cells are intentionally left blank		



Hamamatsu and Zecotec for HO, Control Board Details

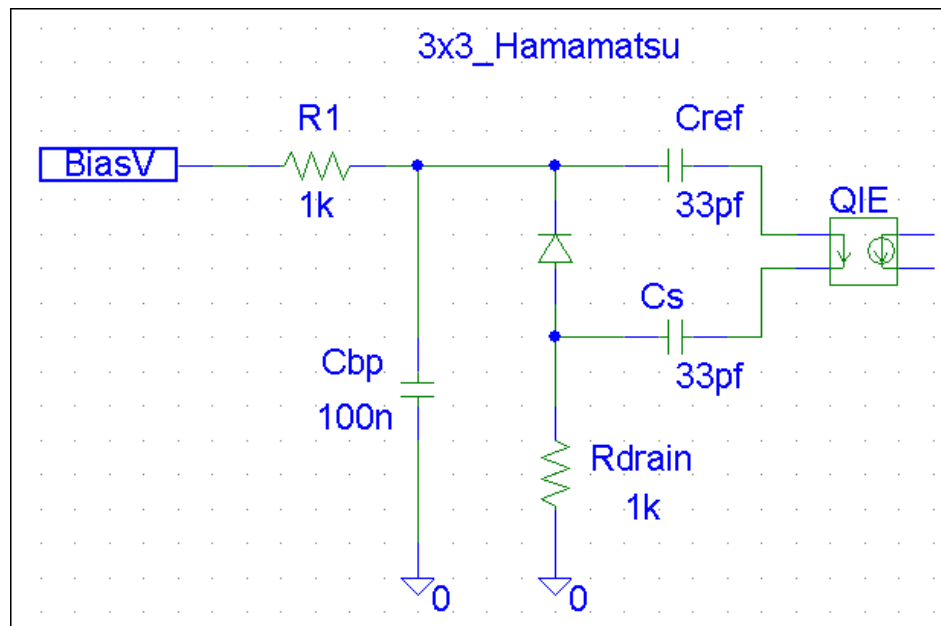
Parameter of the Control Board	Hamamatsu 3x3	Zecotek 3x3
Maximum DAC set BV	77 V	100 V
BV resolution	19 mV	24 mV
BV current limit (per diode)	200 μ A	100 μ A
Maximum measurable leakage current	40 μ A	4 μ A
Leakage current resolution	10 nA	1 nA
Diode grounding resistor	1 kOhm	10 kOhm
Attenuation capacitor	33 pf	150 pf

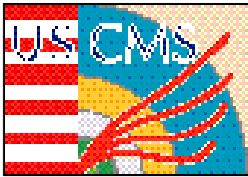


Hamamatsu MPPC Connection for HO

- This electric diagram shows how Hamamatsu MPPC was connected to the QIE for HO readout
- This “capacitive attenuation” scheme was in development since 2006
 - SiPM charge attenuation is determined by the ratio $Att = (C_{det} + C_s)/C_s$, where C_s – attenuation capacitor
 - SiPM recovery time constant is $T = C_{det} \times (R_{ser} + R_{drain})$, where R_{ser} is the effective series resistance of the diode
 - Recovery time constant determines duration of the signal undershoot
 - After an individual cell discharge effective voltage across other cells drops for the duration of the recovery time, the value of the drop depends on the number of the cells fired

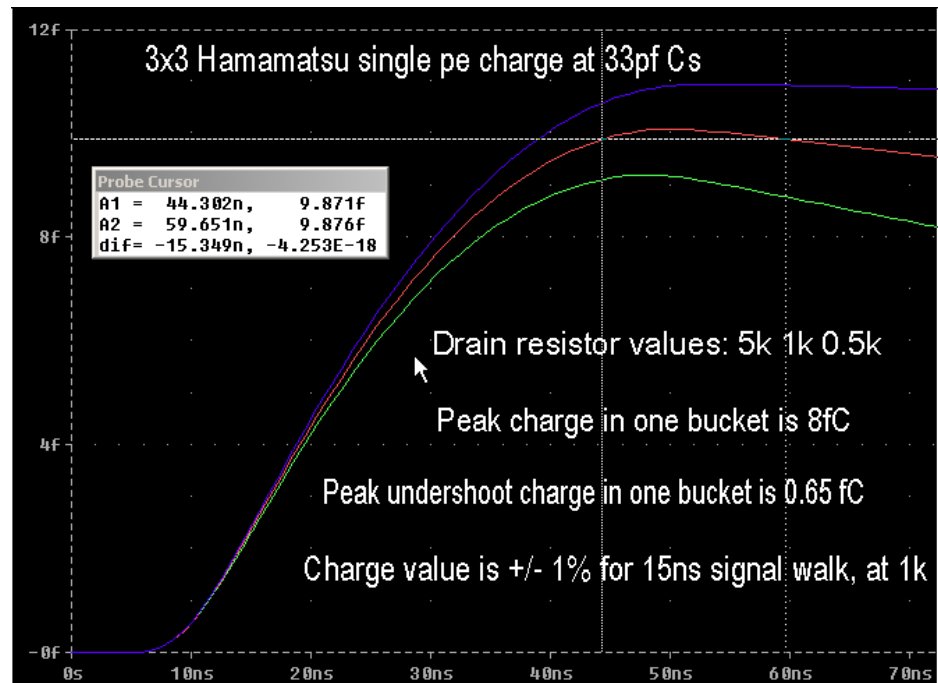
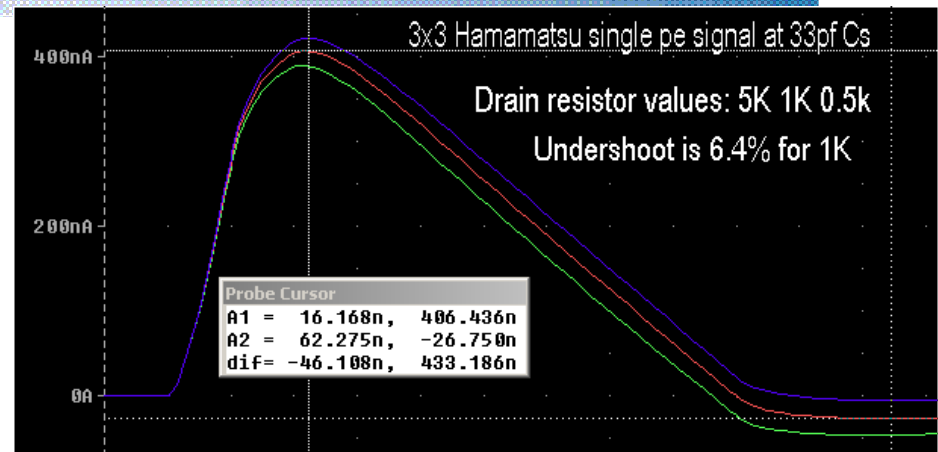
- The following input light pulse shape was used in the simulations
 - 5 ns rise time
 - 5 ns flat top
 - 35 ns fall time
- Most of the results shown are for a single pe signal

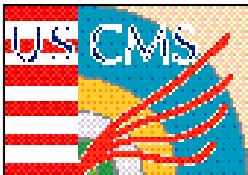




Hamamatsu Pulse Shape in HO

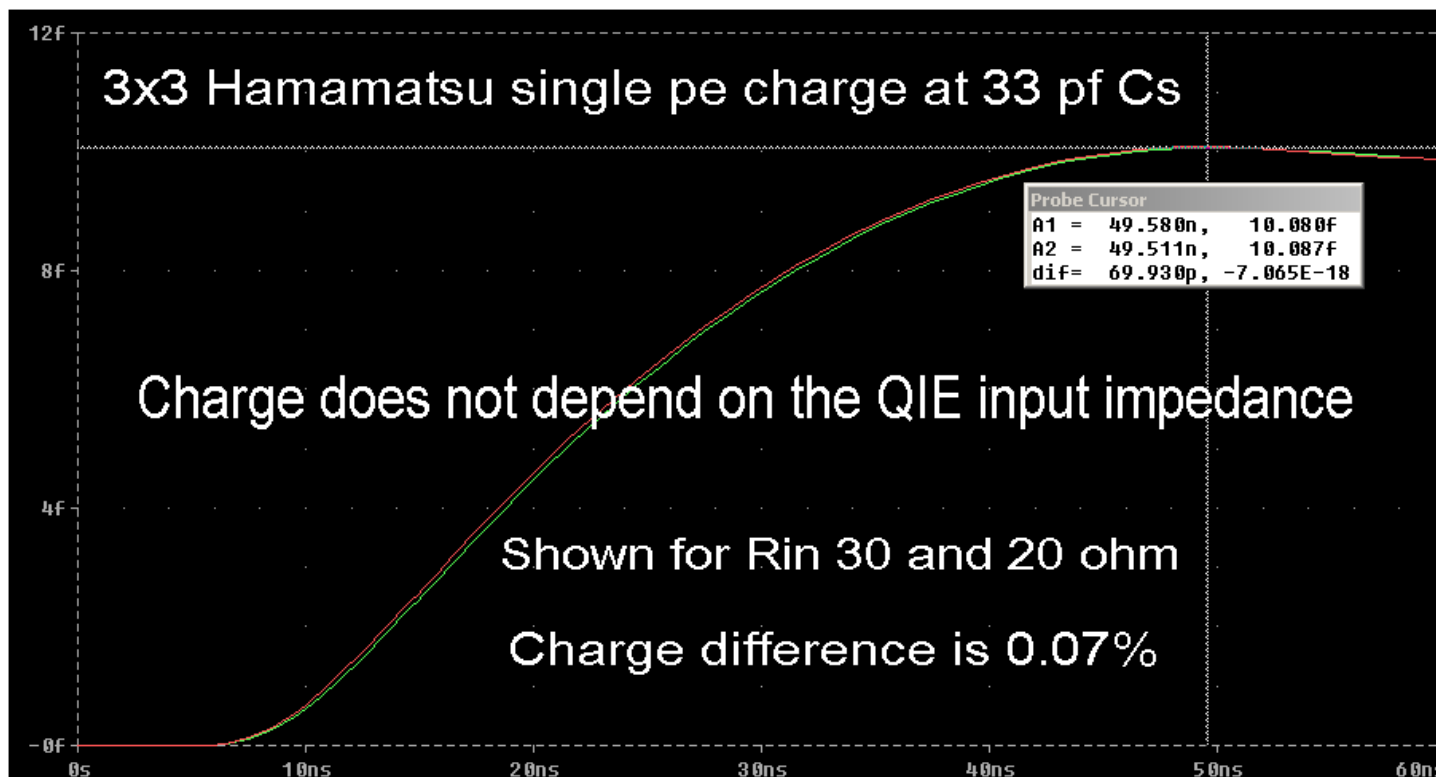
- There are several important issues related to the proposed AC coupling/attenuation scheme
 - Full charge integration time (40ns) (determined mostly by the light pulse duration)
 - Charge dependence on the signal timing (<1% for 15ns)
 - Charge linearity with signal amplitude (QIE input impedance changes with the input current), 0.07% for $R_{in} = 30$ and 20 ohm
 - After pulse undershoot value (8%)
 - Recovery time ($R_{dr} \times C_{det}$)=350ns
- Undershoot value can be controlled by the SiPM drain resistor (R_d) value (the one, that connects SiPM to the ground)
- Slope of the discharge is inversely proportional to the drain resistor value
- The main drawback of increasing the R_d is the voltage build-up due to the leakage current, and decrease of the voltage across the Diode
 - Can be mitigated by the BV adjustment
 - Can even be adjusted in hardware

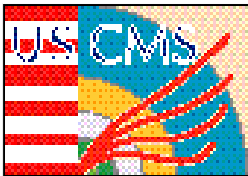




Hamamatsu Pulse Shape Stability

- In the proposed scheme of capacitive charge attenuation collected charge does not depend on the input impedance of the QIE
 - QIE input impedance changes from 30 to 20 ohm as input current increases from 0 to 0.5 mA
- This property guaranties linear charge registration from the photo detector



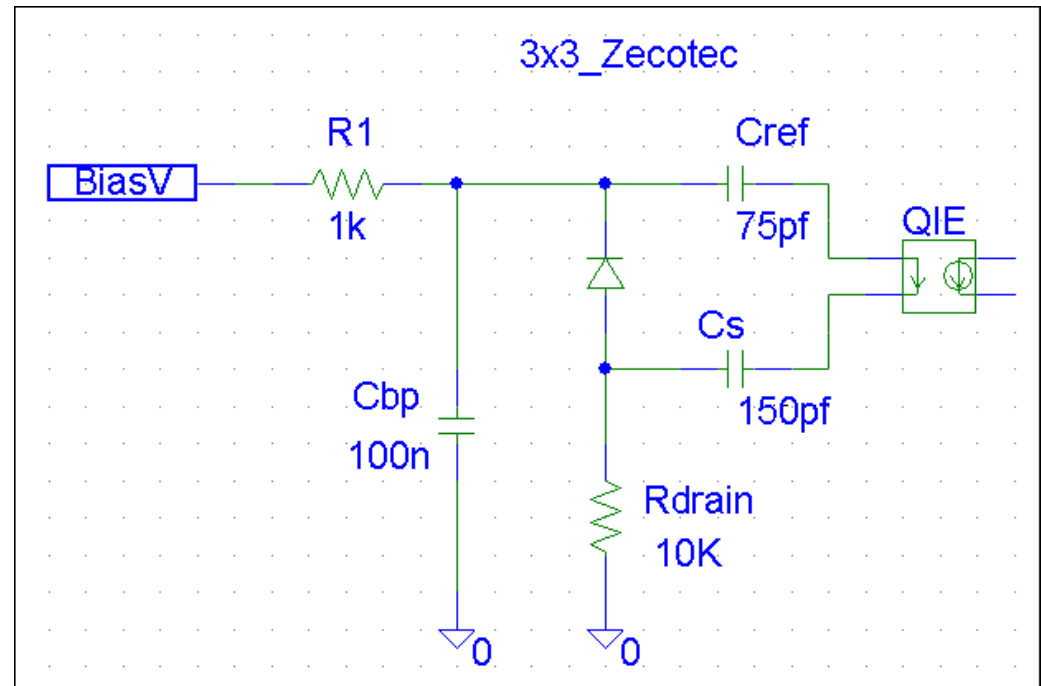


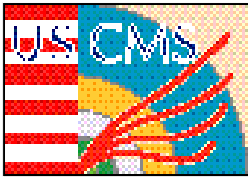
Zecotec MAPD Connection for HO

- This electric diagram shows how Zecotec MAPD was connected to the QIE for HO readout
 - Higher value of Cs (compared to the Hamamatsu diode) was used to compensate for lower device gain
 - Undershoot is a lesser problem for Zecotec MAPD, because we can use a higher value for the Rdrain, as the diode has much smaller leakage current

- Effects of the individual cell discharge through a diode structure (reported recently by Yuri Musienko) still have to be understood

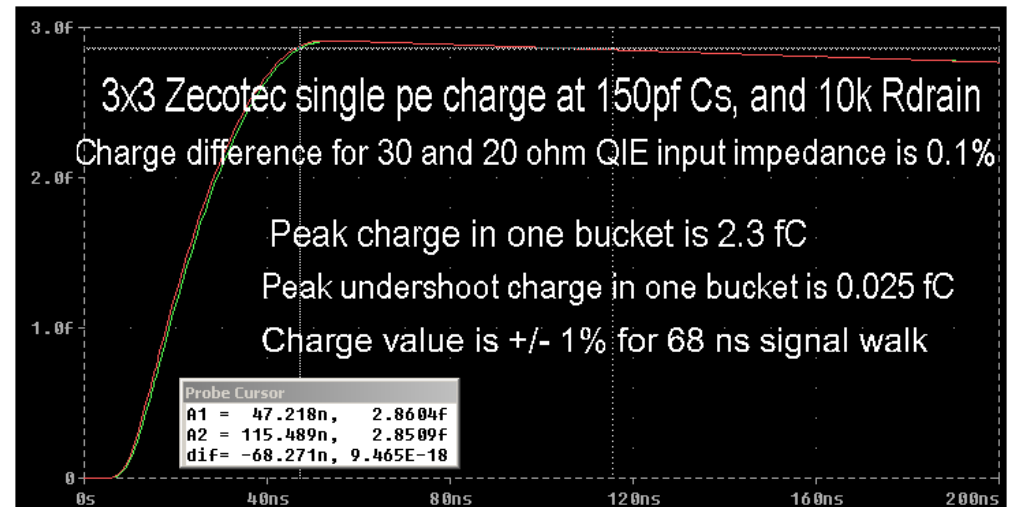
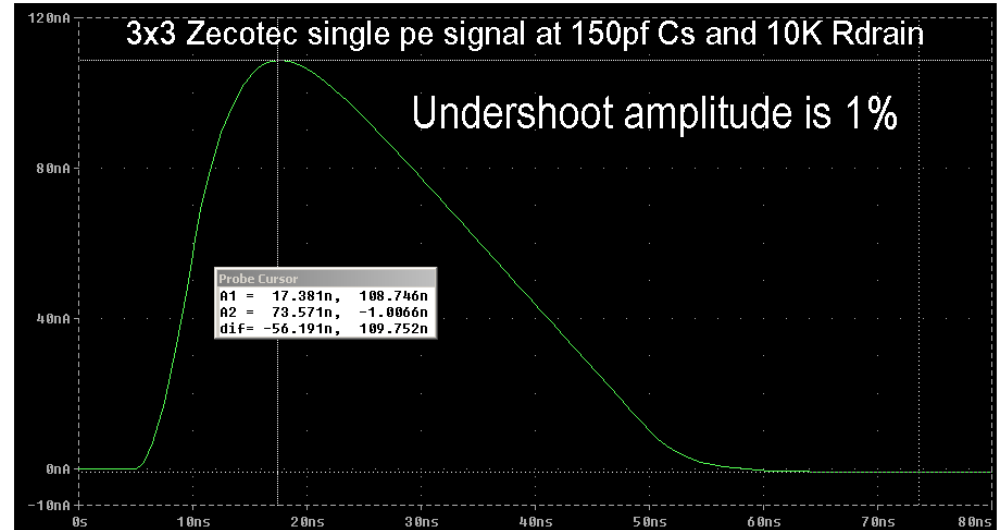
- It looks like they should be of a little effect for the pulse shape during charge integration time, and undershoot parameters
- **Definitely makes the last 20% of the cell recovery unbearable!**
- Increasing the overvoltage should increase the fast fraction of the pulse and speed-up recovery to the $(V_{ov}-0.7)/V_{ov}$ level

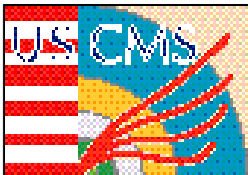




Zecotec Pulse Shape for HO

- Most of the parameters, when applying a linearized model, are better for the Zecotec diodes, compared to Hamamatsu
 - Full charge integration time (40ns) (determined mostly by the light pulse duration)
 - Smaller amplitude of the undershoot (1% of the peak signal value from QIE)
 - Better stability of the measured charge with respect to the signal walk (68 ns)
 - Effect of the varying QIE input impedance is still negligible (0.1%)
 - After pulse undershoot value (1.1%)
 - Recovery time is 3us is 10 times worse than for the Hamamatsu, but it also has x37.5 times more pixels **Here linearized model significantly deviates from Yuri's measurements (80%@60us, 90%@200us)**



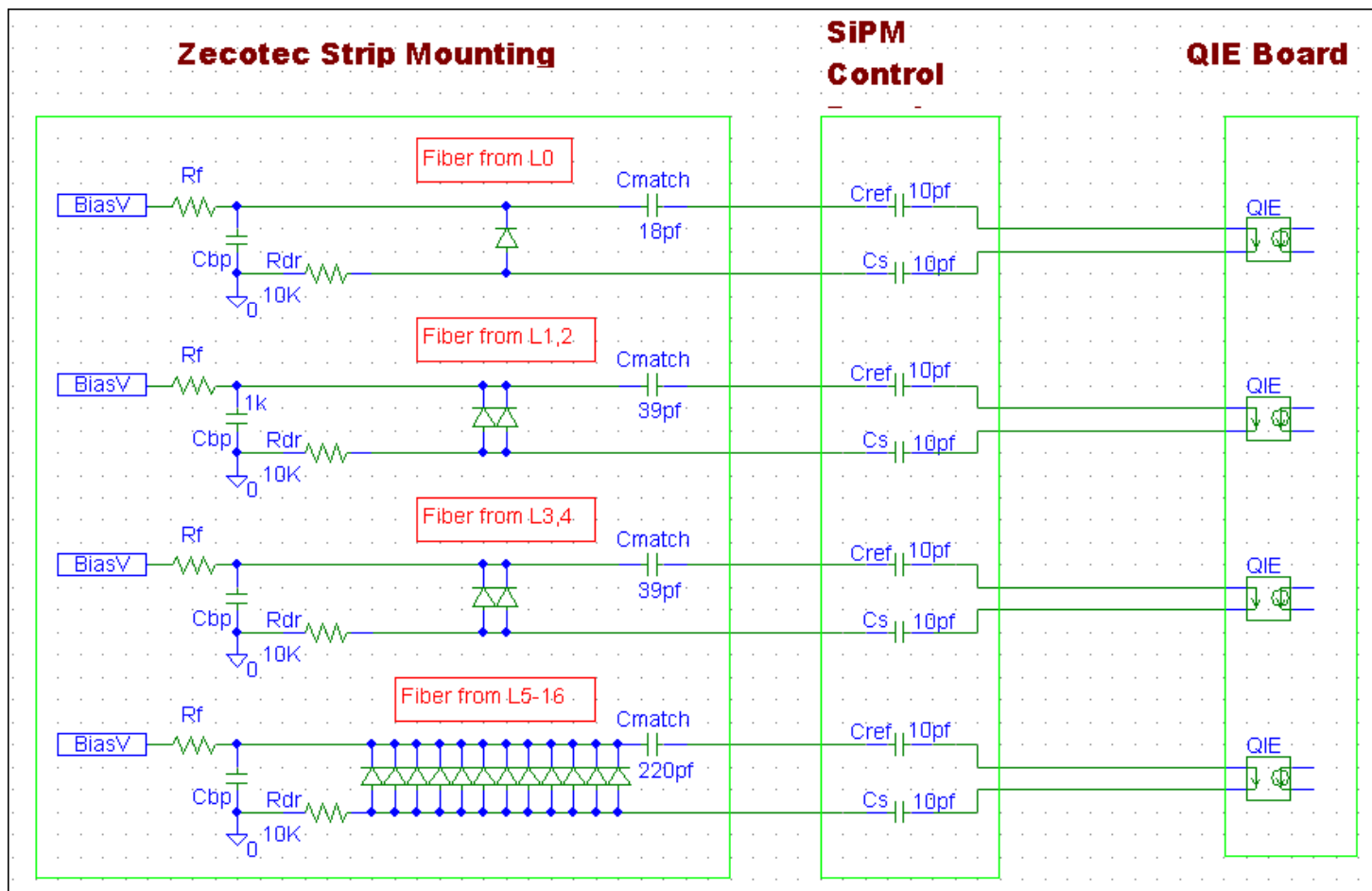


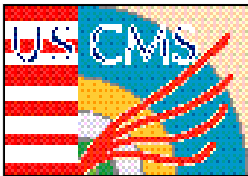
Zecotec MAPDs for HB/HE

- First prototype for HE/HB readout in 4 depth compartments was tested during the Summer 2009 Test Beam
 - Sensitivity was adjusted to have similar signals for a muon in all depth compartments

- Four depth compartments:

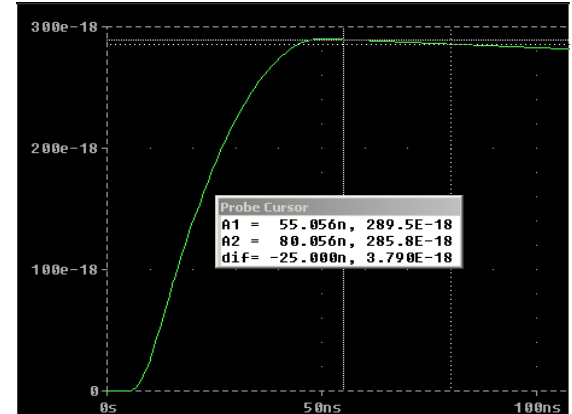
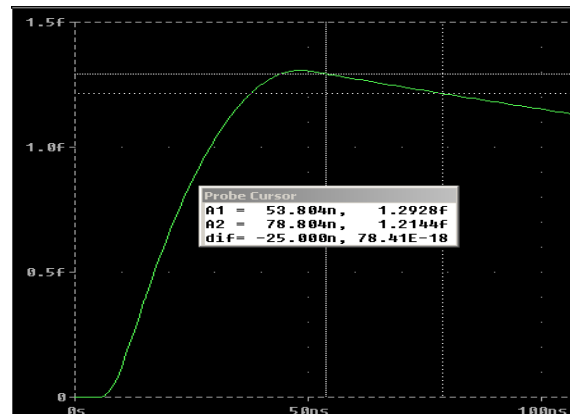
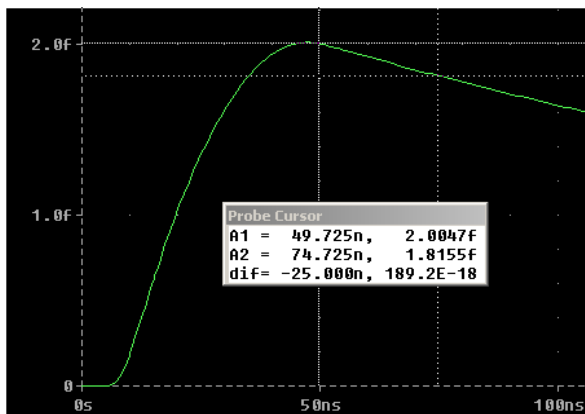
- Layer 0
- Layers 1,2
- Layers 3,4
- Layers 5-16

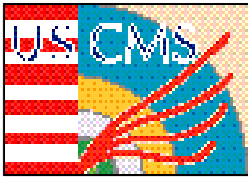




Zecotec HB RM Pulse Shapes

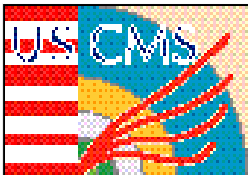
- Single pe pulse shapes for different depth compartments
 - Layer 0 - undershoot 11%
 - Layers 1,2 and 3,4 - undershoot 7.5%
 - Layers 5-16 - undershoot 1.6%
- Undershoots can be adjusted by proper selection of Rdrain, or adding compensation capacitance (this also allows to linearize energy, rather than muon response)





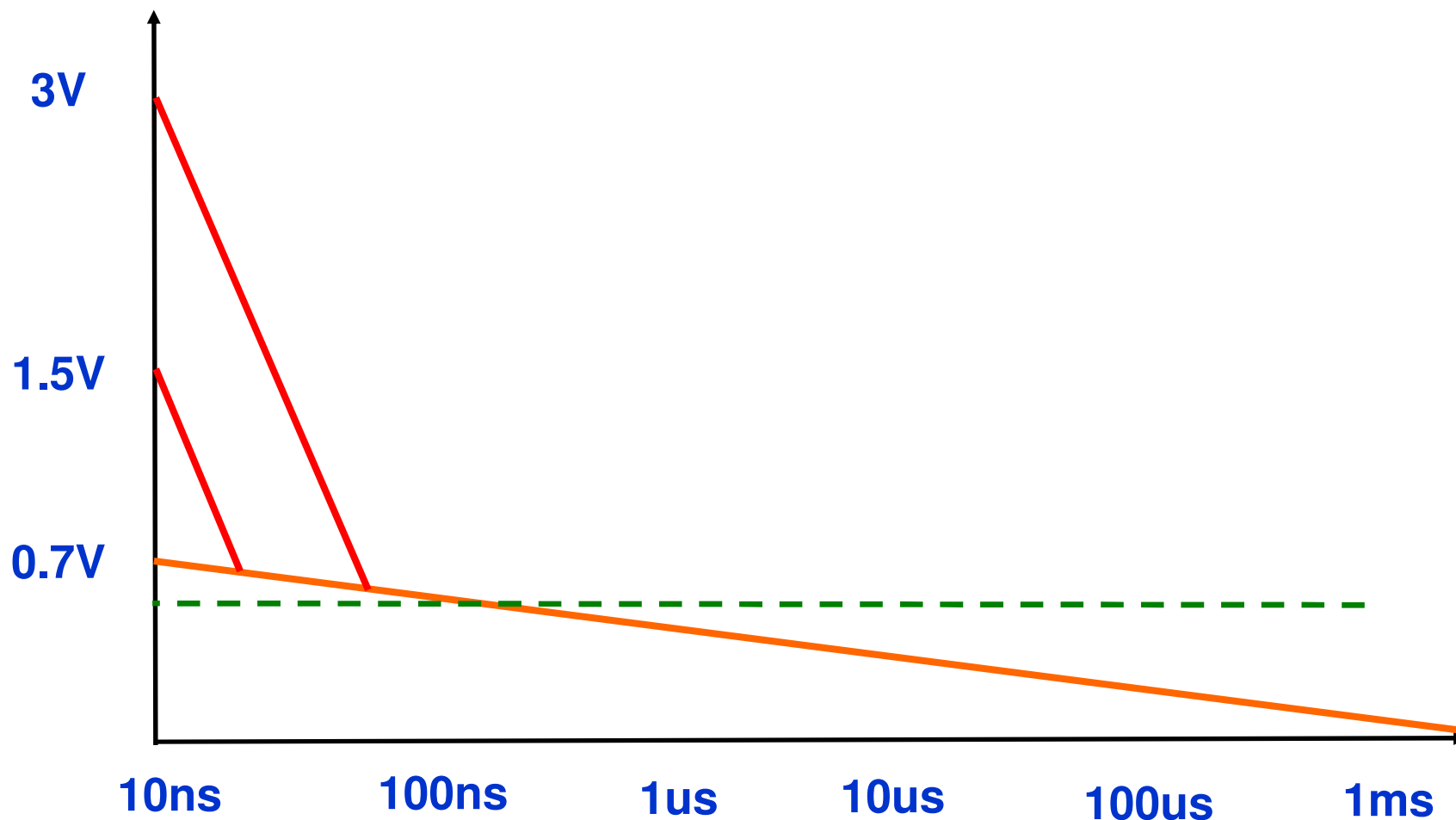
Slow Recovery of the Zecotec Diodes

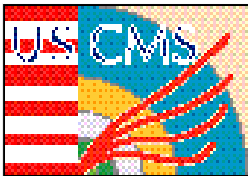
- **Logarithmic recovery of the Zecotec diodes, measured by Y. Musienko makes a lot of change in our understanding of their behavior, the main drawback being partially recovered cells in a situation with high occupancy**
- **Presented data showed about 40% recovery in the first 100ns, after which a recovery rate was about 13% / decade**
 - I'm not sure what overvoltage was used (my speculation is about 1-1.5V)
 - The point is that with increased overvoltage the fraction of the charge, available in the first 10-100ns should increase dramatically (the intrinsic time constant of a Zecotec MAPD is around 1ns for large signals)
 - The ohmic series resistance of MAPD is about 6 ohm
 - As soon as dynamic resistance of the diode sections increases above that value the discharge is being dominated by the logarithmic behavior
 - It should be relatively safe to speculate that that logarithmic discharge takes off at around 0.7V left on the cell to recover, whatever overvoltage was above 0.7V should be available at the $R \times C$ time scale
 - I'll start working on a non-linear simulation for Zecotec
 - It could be interesting (and may be even helpful) to see whether the recovery becomes faster if not the whole diode is illuminated to saturation, but a small section of it, say <10% of the area



Slow Recovery of the Zecotec Diodes

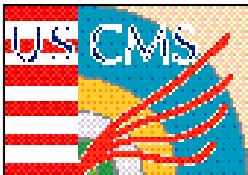
$$Q=CxV$$





TB2009 Afterthoughts

- **Zcotec Strips for TB2009 were made out of individual 1 mm diodes. If that is not financially prohibitive for the production run a number of opportunities presents:**
 - **DC coupled negative signal readout with negative biasing**
 - Pulse shape depends on the number of diodes attached, $\tau = 1-10$ ns
 - Leakage current measurement should be performed in the QIE, or a “high end current readout” implemented, which is not trivial, especially that it should be performed at the negative “high end”
 - No undershoot after a signal, but pedestal value increases with luminosity
 - Linear response to energy deposition
 - **AC coupled negative signal with positive biasing**
 - Pulse shape does not depend on the number of diodes attached
 - Leakage current measurement can be performed using already well honed technique
 - Small undershoot after the signal, and pedestal value decrease with luminosity
 - Arbitrary adjustable amplitude response to the energy in different depth compartments
 - Unavoidable attenuation of the signal, but smaller capacitance at the QIE input
 - **High capacitance AC coupled negative signal with positive biasing**
 - Has all benefits of DC coupling plus convenient positive “low end” leakage current readout
 - Pulse shape somewhat depends on the number of diodes attached
 - No undershoot after a signal, but pedestal value decreases with luminosity



Future Plans

- **Study the results of the October Control Board and parts irradiation at the MGH cyclotron**
 - Control board worked o.k. till $2.5E11$ p/cm²
 - No single event burnouts were observed for the BV transistors
 - No preliminary data for Peltier coolers
- **New layout for the HO Control and SiPM Mounting boards**
 - Take care of the I2C crosstalk to the signal lines
 - Implement hardware protection from cooling below a fixed temperature
 - Use old Peltier driving scheme to lower maximum power and prevent oscillations
 - Implement input BV measurement (BV mezzanine board output)
 - Investigate BV regulation on the mezzanine board
 - Investigate possibility of Peltier attachment without soldering to the board
- **Study different aspects of interfacing Zecotec strips to the QIE10 ASIC in HB/HE RBXes, and required adjustments to the QIE10 specs**