Pulse Dilation Photo Multiplier Tube

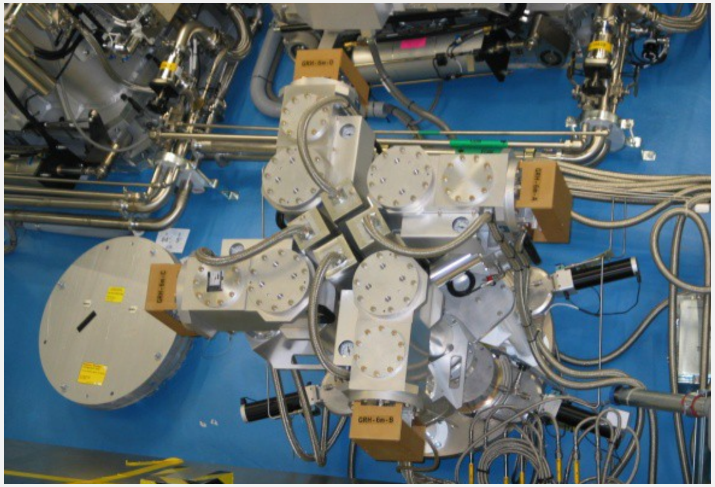
Aim to build a PMT with 10ps time resolution.
Achievable by making use of the drift time dilation technique which is already proven in the DIXI X-ray camera.

Kentech Instruments, UK
General Atomics, USA
Photek, UK
LANL, USA
AWE, UK
Sydor, USA

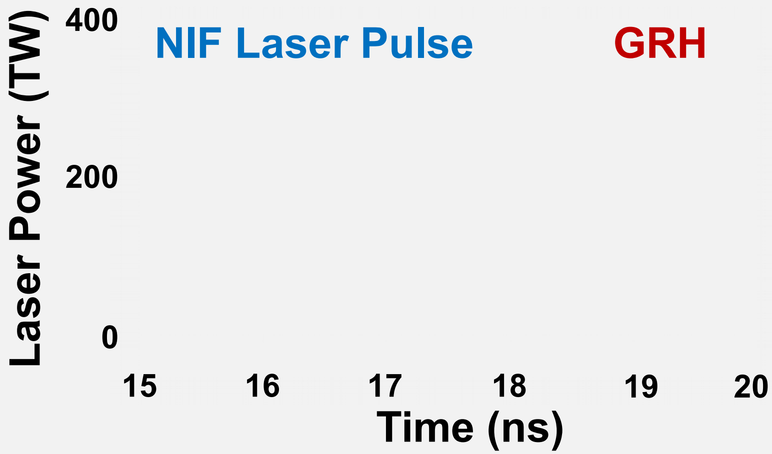
Motivation

- Fusion **Gamma Reaction History (GRH)** measures implosion bang time & burn width
- Burn width currently ~125 ps and expected to drop as performance improves
- **GRH's** Gas Cherenkov Detector inherently fast (10-40 ps), but limited by existing PMT technology to ~100 ps
- Faster detection will illuminate reaction history features not currently observable (e.g., shock inflections, skewness,…)
- Streak cameras have been considered, but suffer from poor SNR in this application/environment

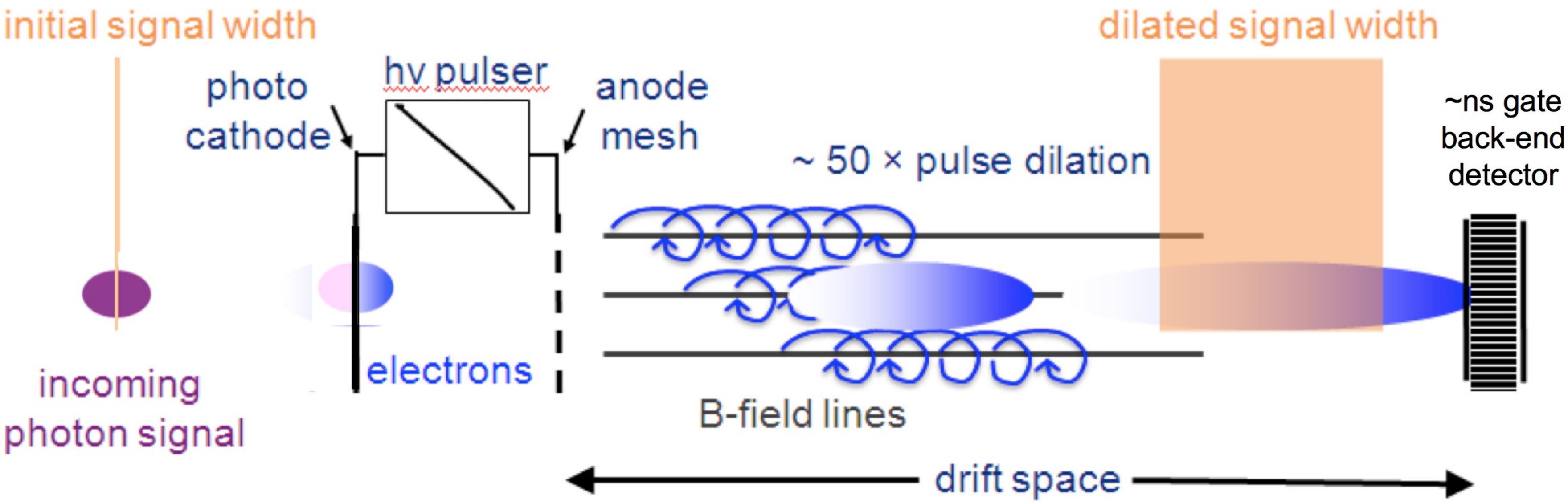
Gamma Reaction History



Gamma Reaction History data



Electron pulse-dilation expands incoming signal in time

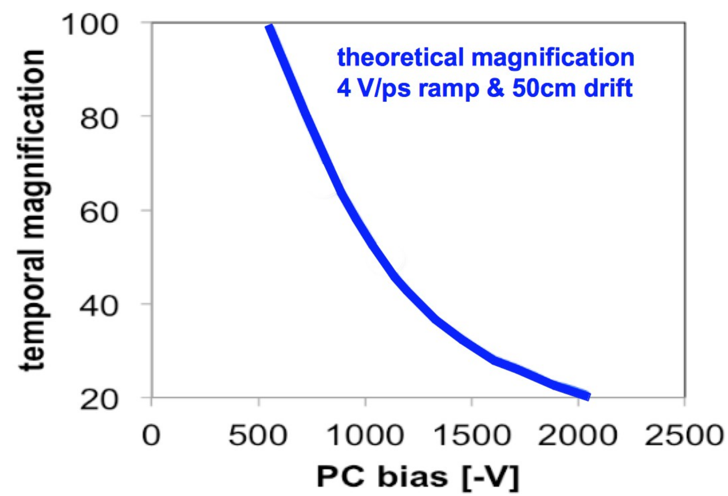


temporal magnification

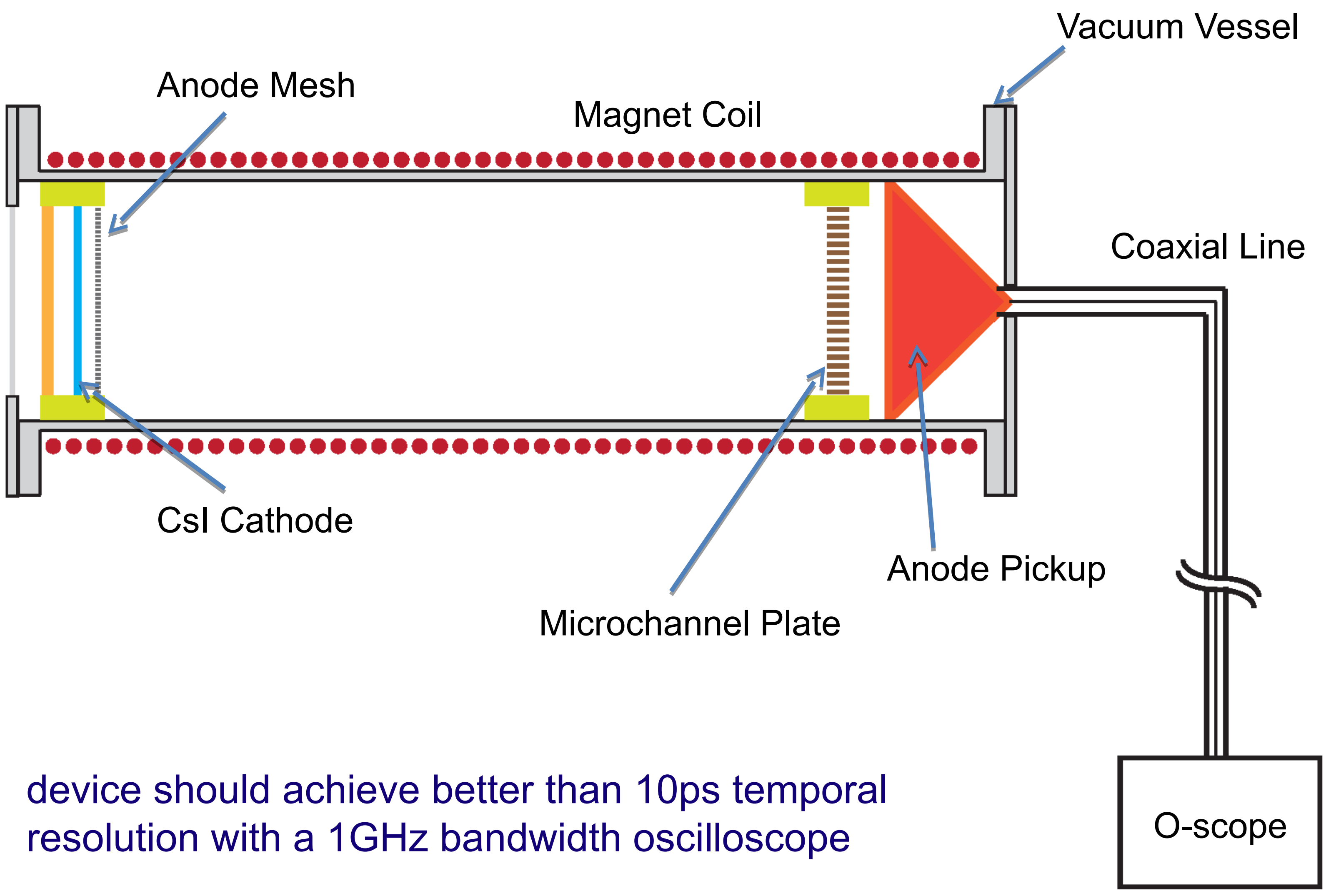
$$M \approx 1 + \frac{L}{2v_d(\varphi)} \frac{|\dot{\varphi}|}{\varphi} = 50$$

$L = 35\ \mathrm{cm}$	drift length
$\varphi = 1000\ \mathrm{V}$	drift potential
$v_d = 19\ \frac{\mathrm{mm}}{\mathrm{ns}}$	drift velocity
$\lvert\dot{\varphi}\rvert = 5\ \frac{\mathrm{kV}}{\mathrm{ns}}$	PC ramp

technique used in a 10 ps gated x-ray imager installed at the NIF (DIXI)

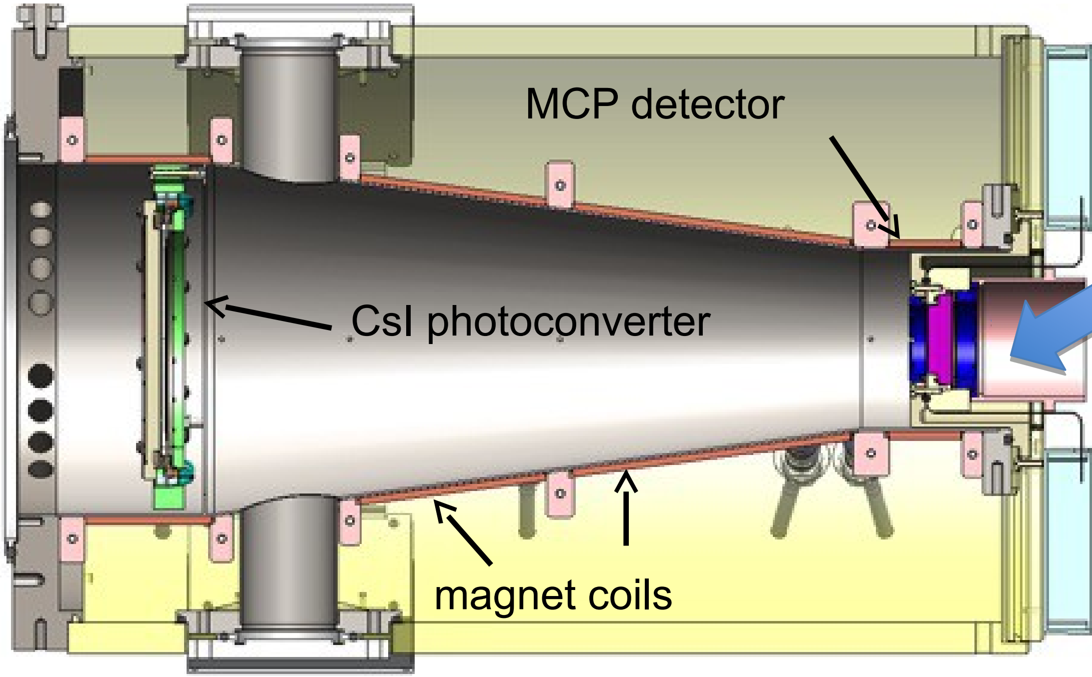


Schematic arrangement for pulse-dilation phototube

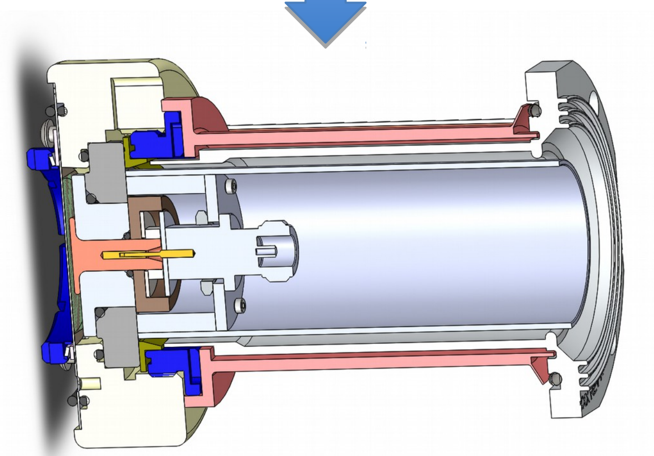


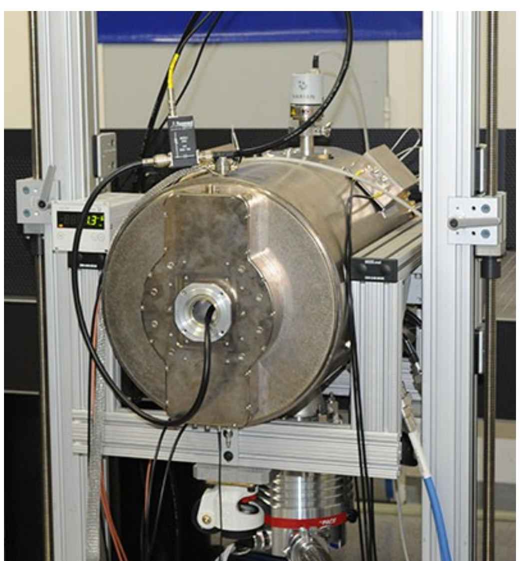
device should achieve better than 10ps temporal resolution with a 1GHz bandwidth oscilloscope

Dilation X-ray Imager (DIXI) modified into phototube



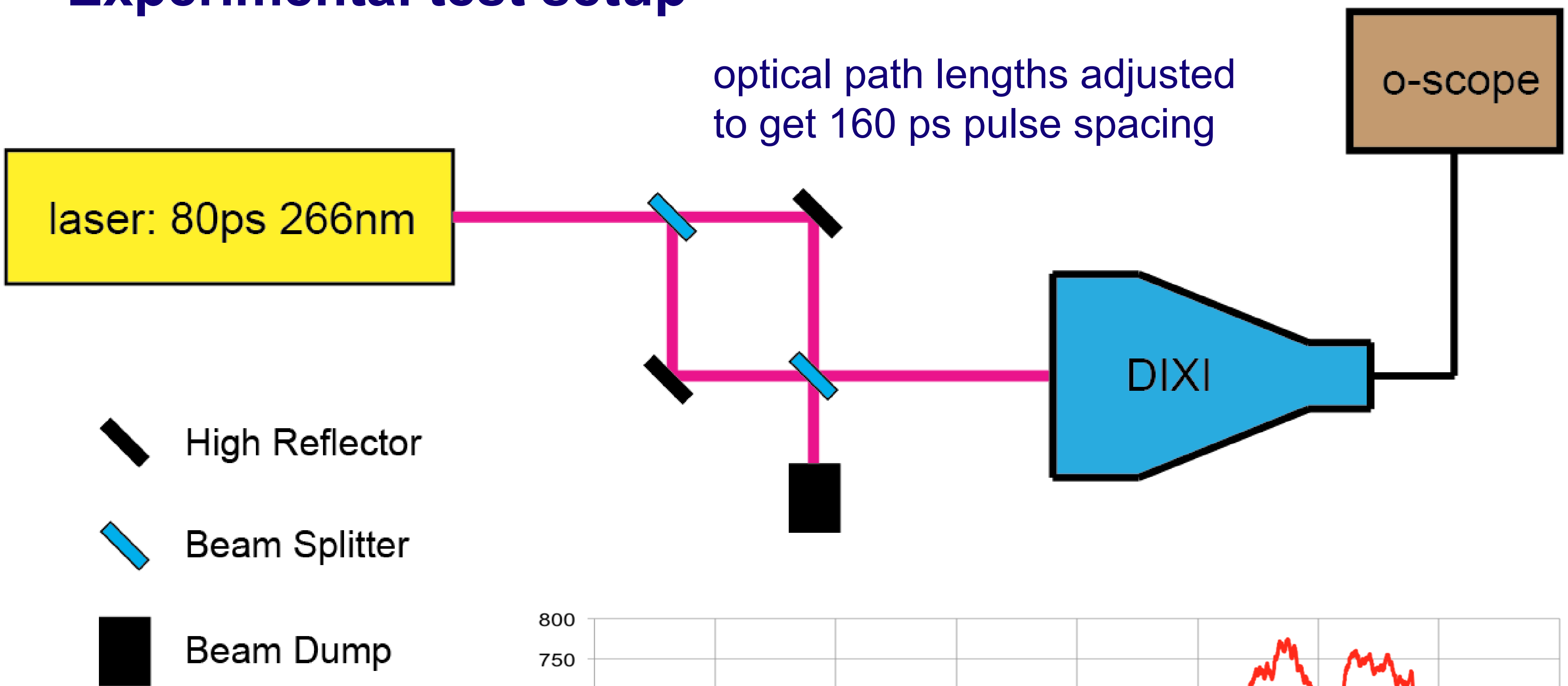
phosphor window replaced with collection anode with N-type coaxial connector

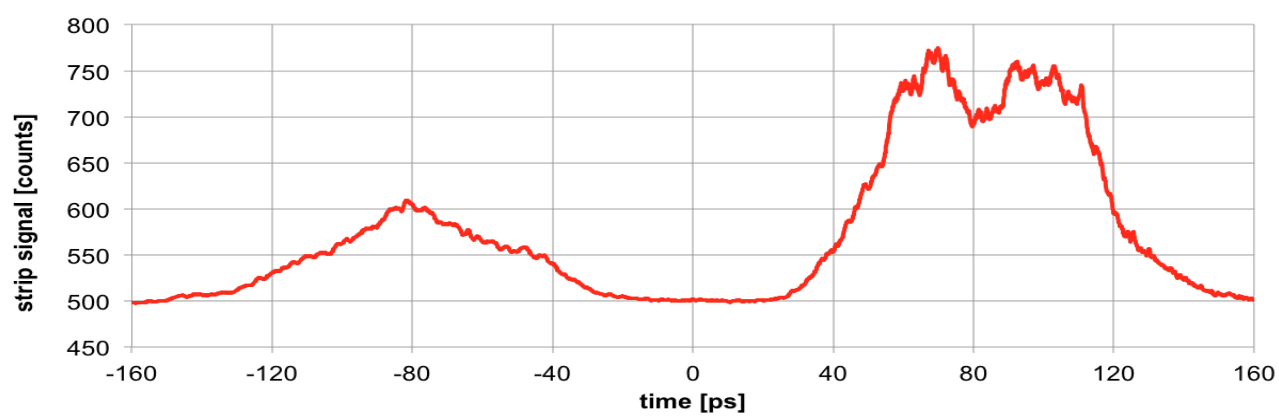




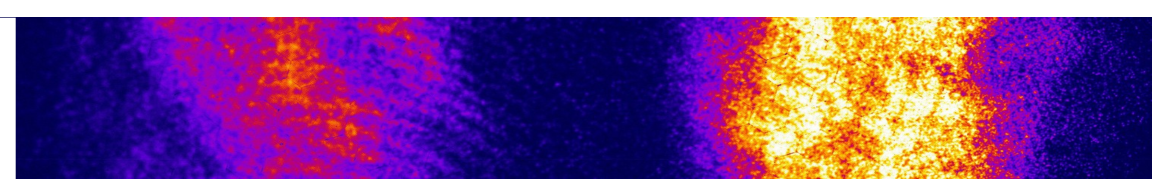
ground arrangement not ideal and resulted a in 0.5 GHz oscillation

Experimental test setup





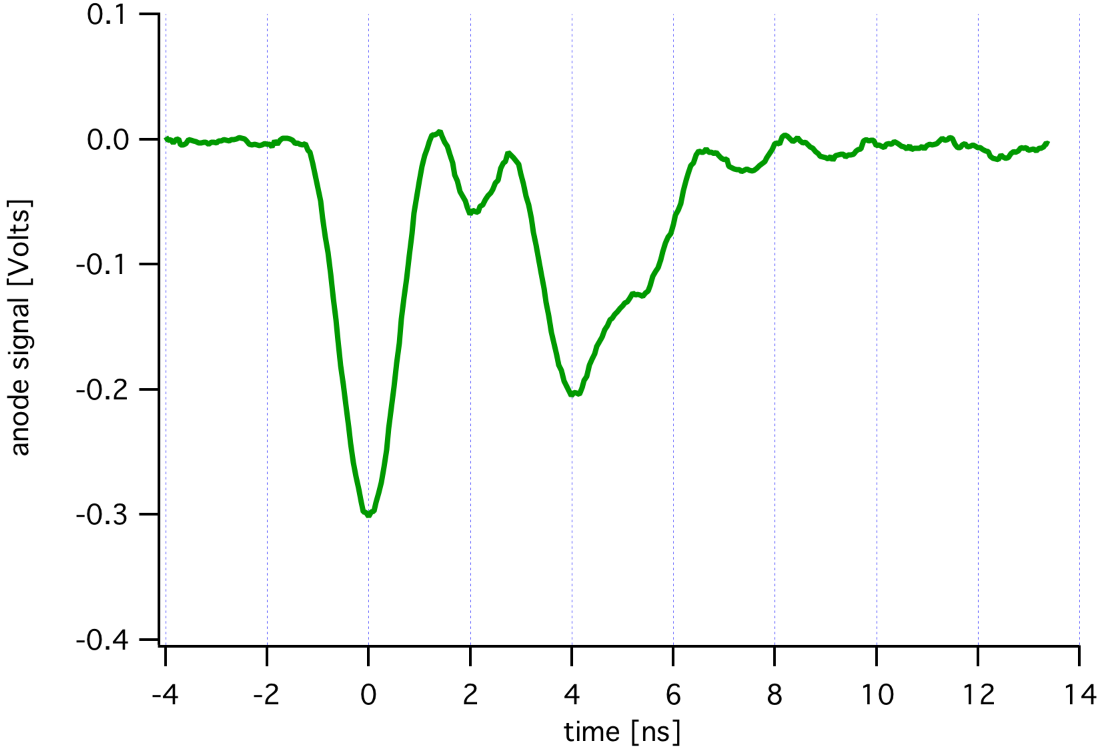
DIXI streak image to obtain pulse width and spacing



Experimental demonstration of pulse-dilated detection

output signals with pulse-dilation enabled and both pulses incident

2 pulses separated by 4 ns demonstrating a 25X signal stretch



A device capable of 10 ps temporal resolution

Our goal is to build a tube with a 10 mm active area which is capable of resolving 10 ps light pulse separation using a 250 ps rise time oscilloscope.

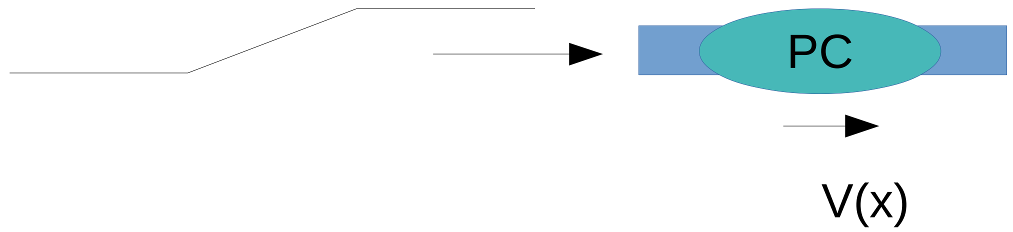
This requires a temporal magnification of ~50X

Pulse-dilation parameters:

L_{drift} = 35 cm V_{drift} = 1 kV dV/dt = 5 kV/ns

In order to preserve temporal information, voltage across the photocathode must be uniform to about 2%.

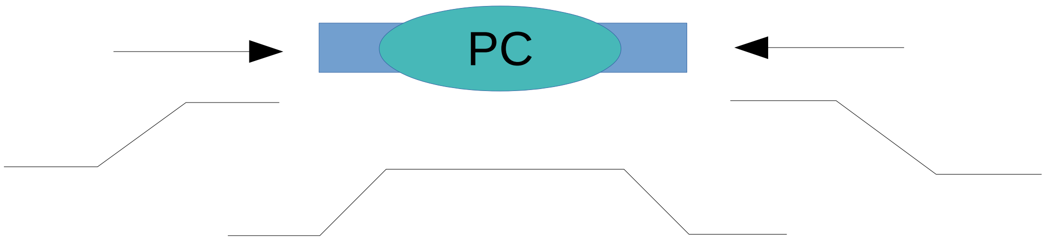
Traveling wave with 5kV/ns has 17 V/mm spatial voltage gradient which produces too much dispersion along the direction of propagation



at a given instant there is a voltage gradient along the cathode

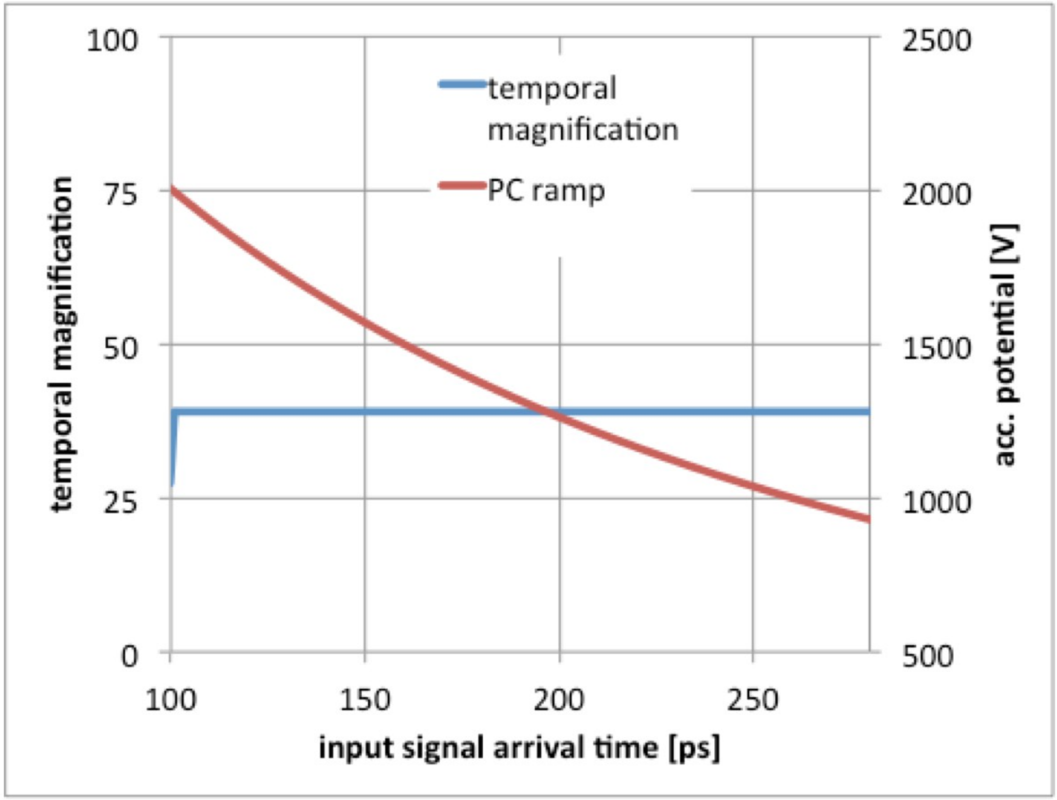
Collide pulses to reduce the voltage gradient

Spatial voltage gradient is cancelled completely for colliding linear pulses.



but the instantaneous temporal magnification is a function of voltage so a linear ramp results in a time dependent magnification.

Shape the cathode voltage for constant temporal magnification



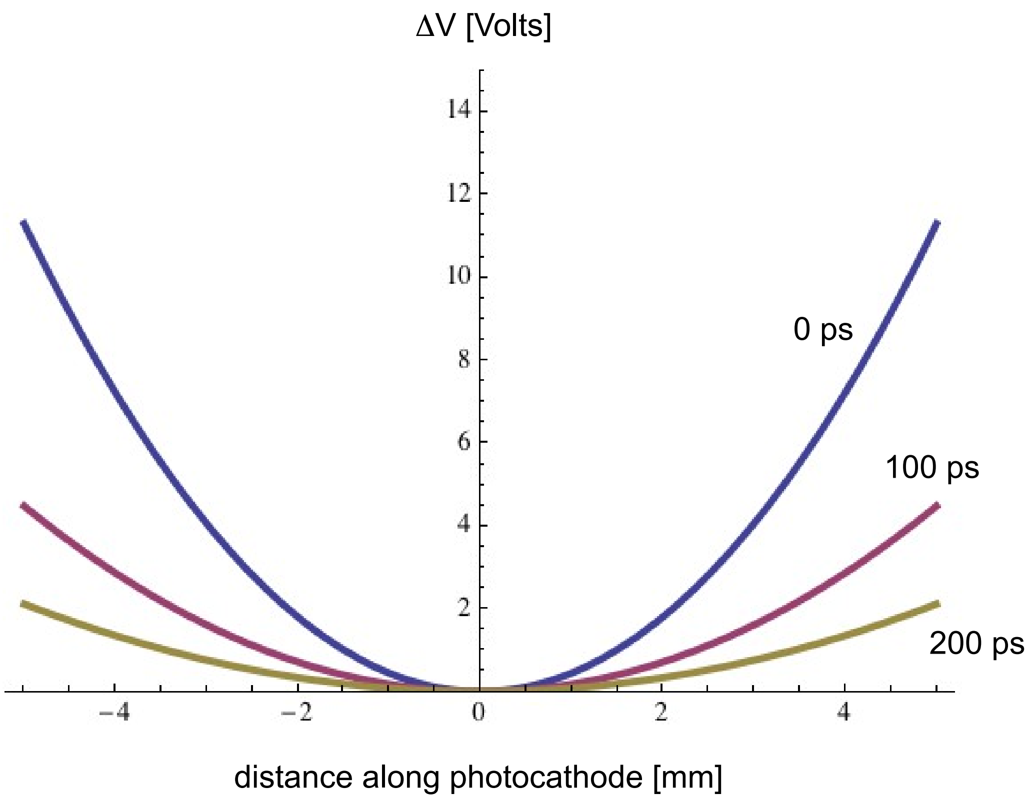
but then the cancellation of the voltage gradient by colliding pulses is not perfect.

Over what area of cathode can we maintain the timing to 10ps...

A colliding pulse ramp which gives uniform temporal magnification has a nonzero spatial gradient

10 mm wide photocathode has up to 10V change in potential during ramp between photocathode center and edges

Causes a variation in drift voltage across aperture which results in temporal dispersion at the output.



PC width [mm]	time spread [ps]
10	1
20	4
30	9

these results for 40X mag
effect increases with higher mag.

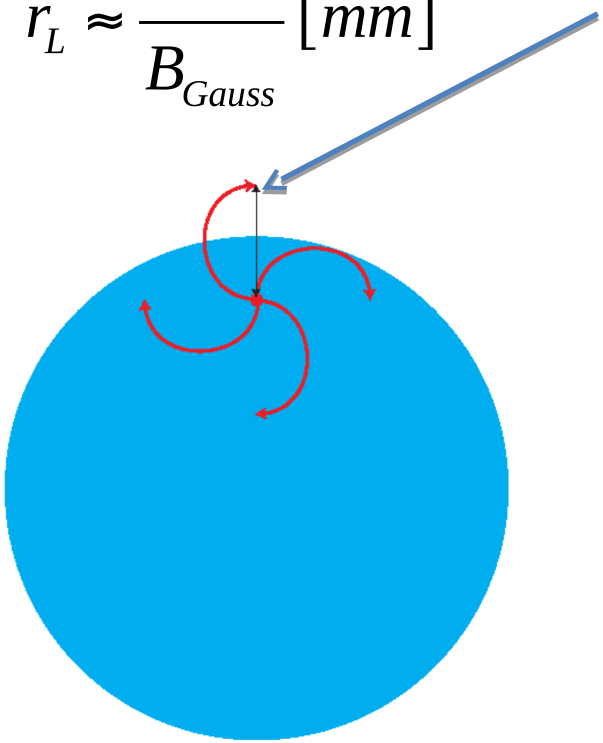
Magnetic field required to transport electrons from photocathode to collection anode

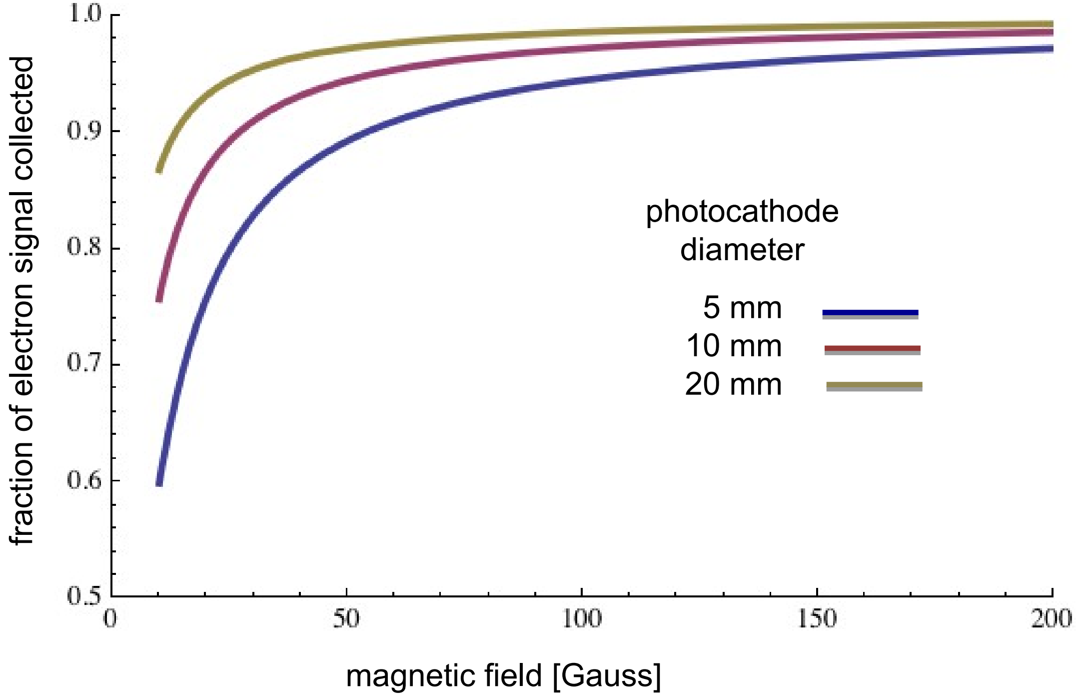
Electrons will follow magnetic field lines while executing Larmor orbits

Some electrons born near to the edge of the photocathode will land outside the collecting anode

$$r_L \approx \frac{17}{B_{Gauss}}\,[mm]$$

lost photoelectron





A sealed-off visible light PD-PMT

Sensitivity in the visible requires a sealed-off tube with a processed cathode.

Need to get fast signals into and out of the vacuum envelope.

Glass/metal seals use magnetic material (KOVAR). The guiding magnetic field must not be distorted by discontinuities in the envelope.

In order to maintain high time resolution the potential across the cathode must be uniform during the ramp.

Protection against excessive illumination - especially DC stray light. Blanking is highly desireable.

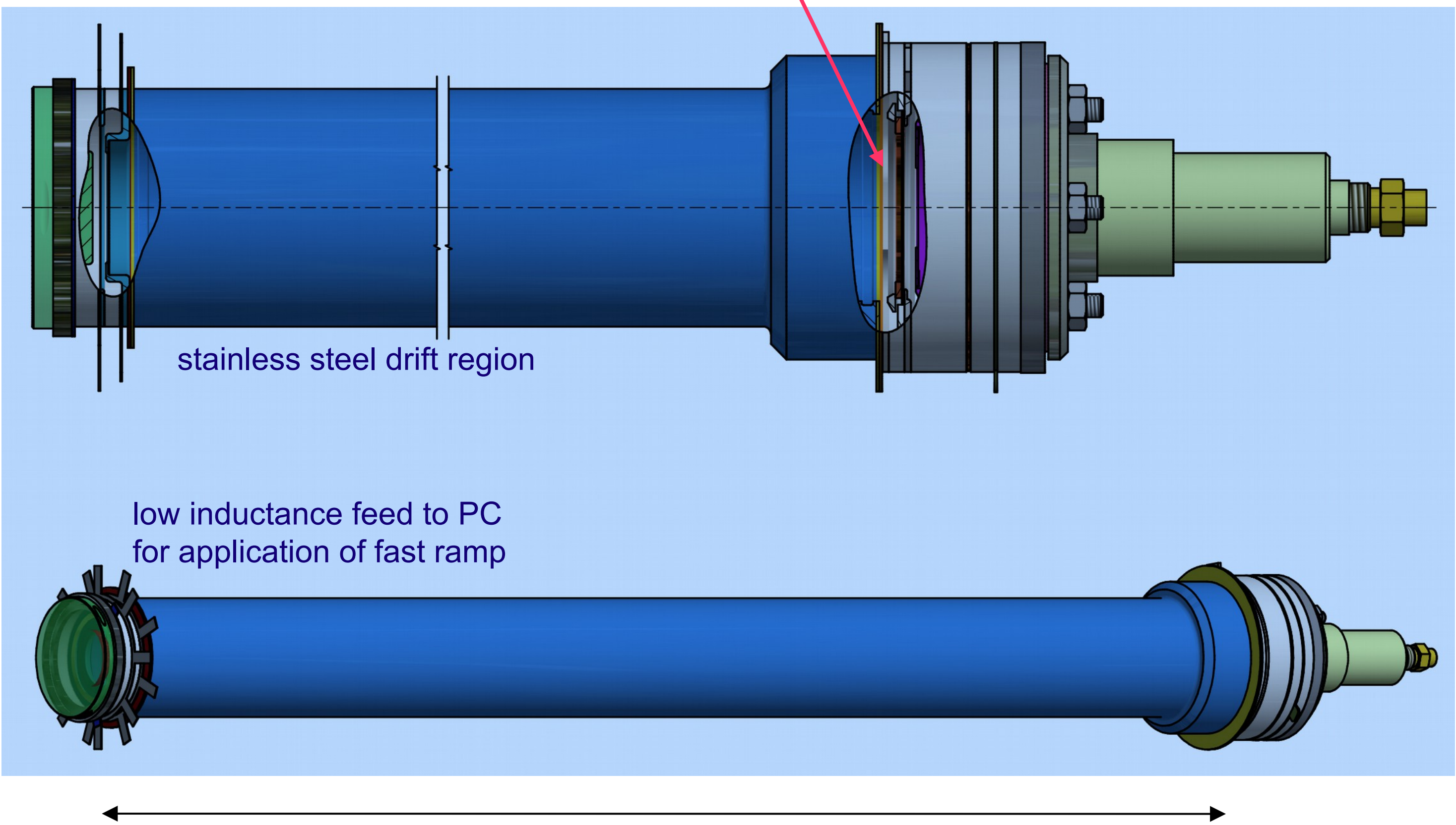
Screening of back end output from noise induced by the HV ramp on the front end.

First sealed off tube being built by Photek, based on an existing fast PMT

Photo-cathode and
mesh entry to drift region

MCP

High speed anode
output feed

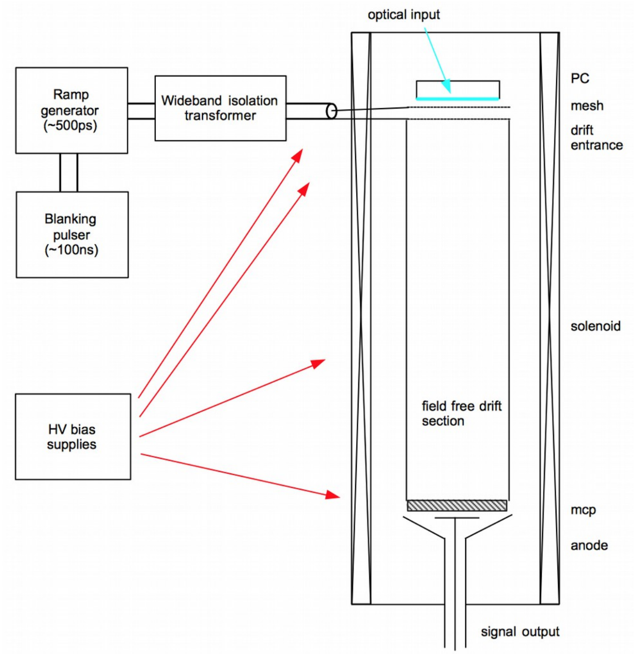


Drift length is 35cm

System parameters

First tube with S25 photocathode and an active diameter of 10mm.

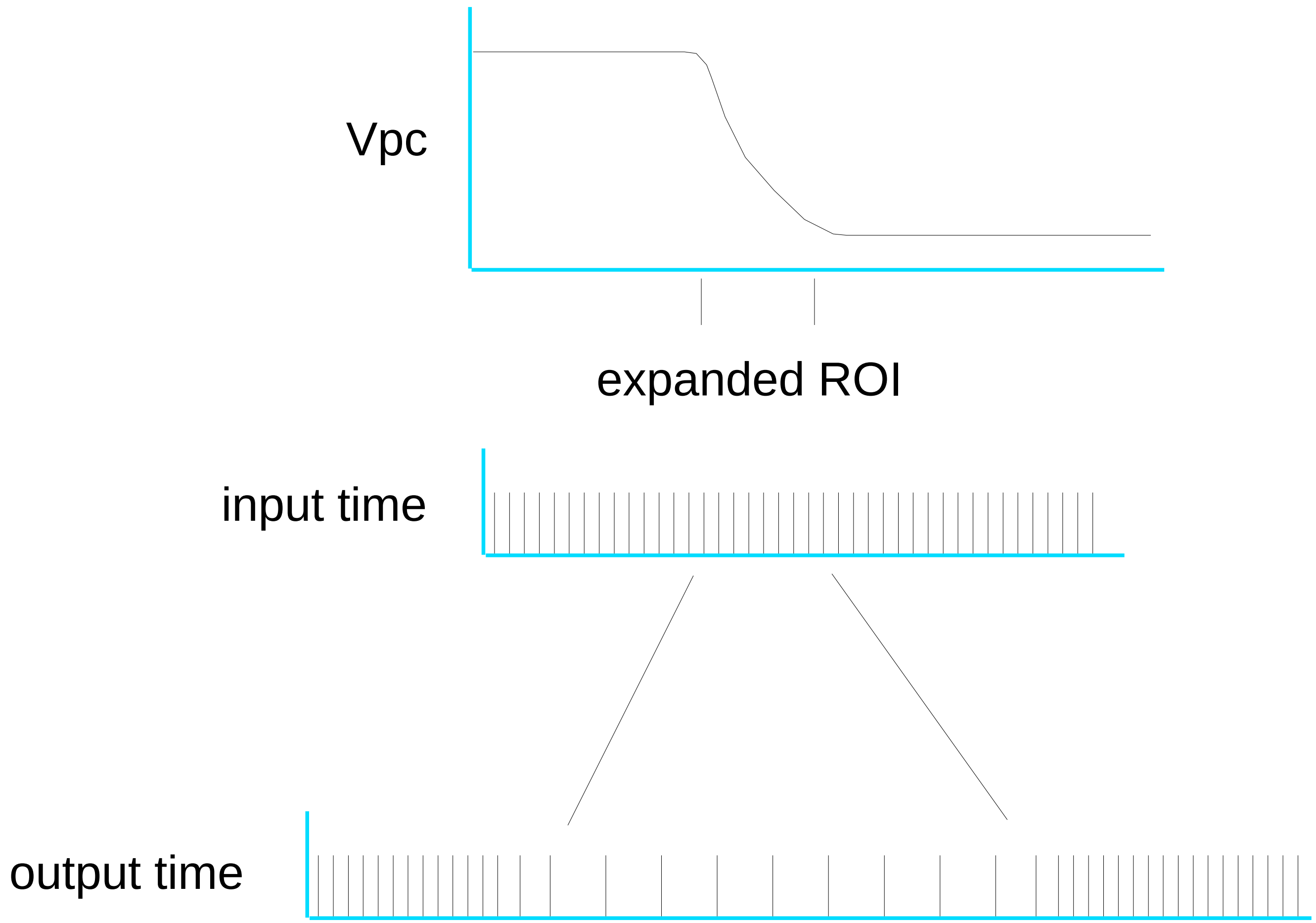
The drift length will be 35cm leading to a typical output record length of 12nsecs. With a 250ps back end time resolution this will give 50 samples of high speed recording.



The ramp generator will have a jitter of ~3ps rms and will allow the capture of an input record of duration of a few x 100ps with a temporal resolution of 5-10ps.

Unlike an imaging system only a modest magnetic field is required so a DC solenoid will allow repetitive operation.

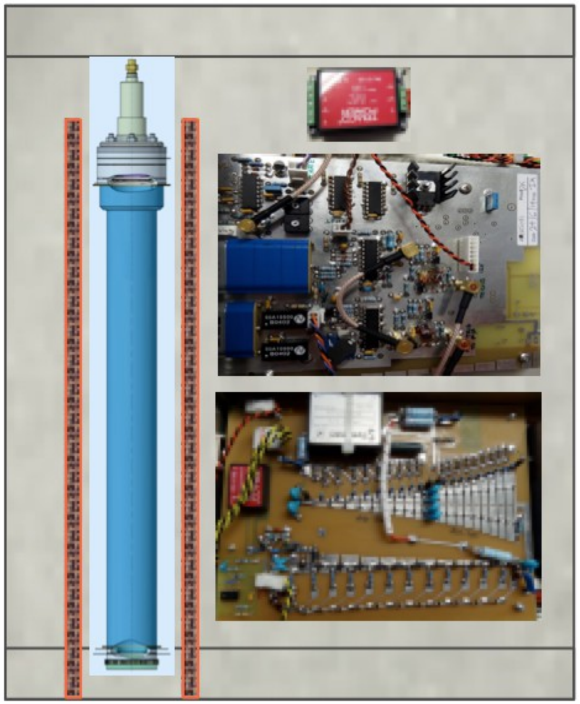
Continuous capture

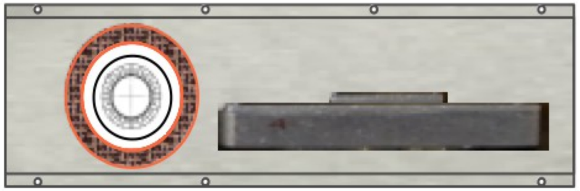


Photocathode pulser

POC system

Passive pulse forming for the ramp pulse shaping

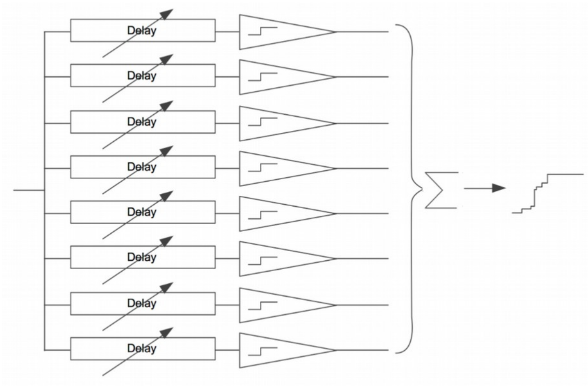




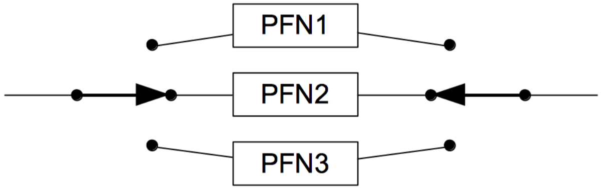
Electronics, tube and B field solenoid will be integrated.

Ultimately the PC pulse shape will be programmable to provide control over the record length

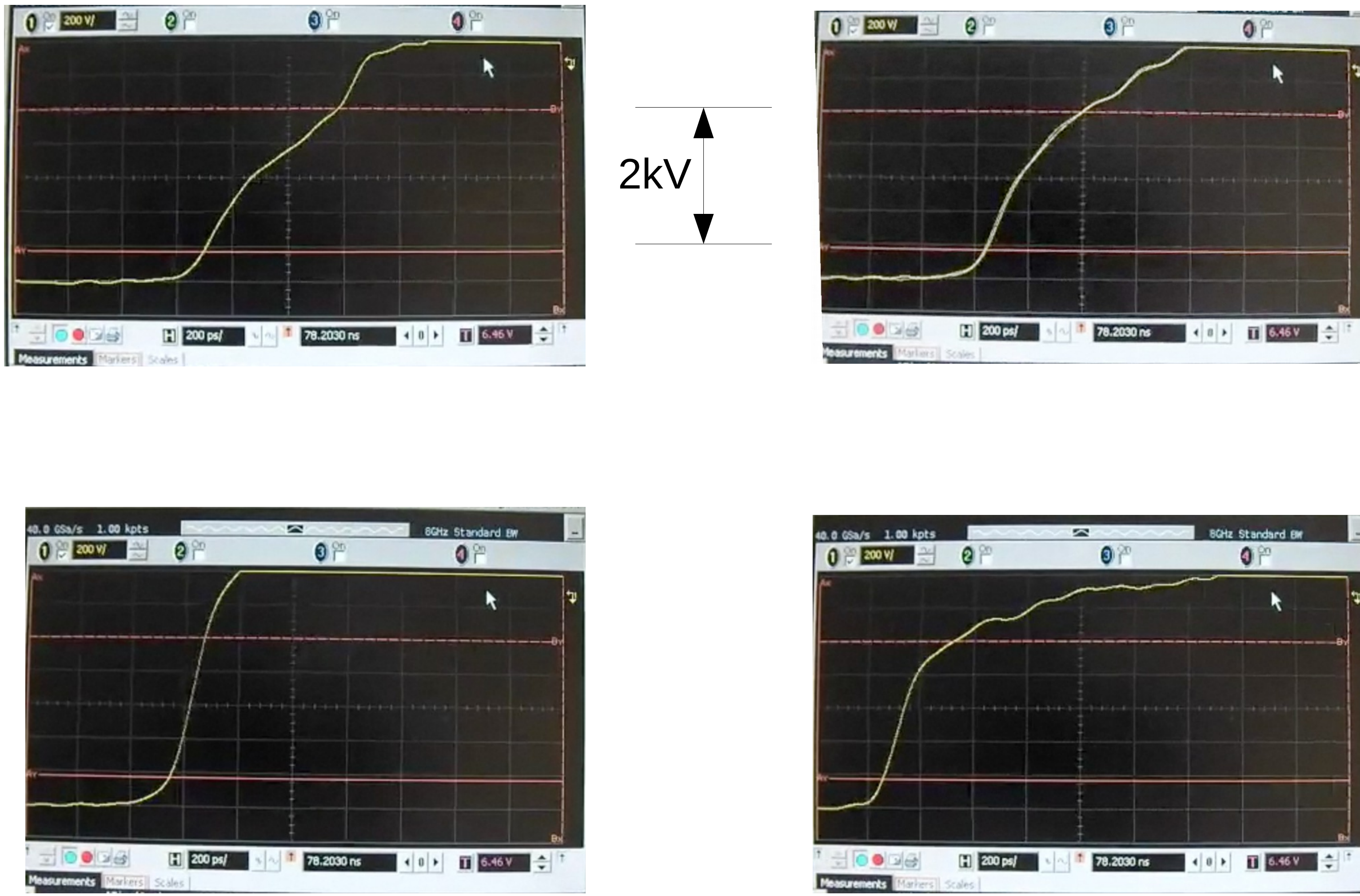
Multiple HV pulsers with relative delay control. Summed to give a programmable rise



May require the greater stability of a switched pulse forming system to give precise deconvolution. A similar system has already been incorporated into a GXD package for the CEA gated X-ray detectors.



Ramp shaping with 8 pulser channels plus delay as built for SLOS



Prospects for devices

•Input record length ~1ns with better than 5ps time resolution
Limited by physical drift length and minimum drift energy

•Careful pulse shaping at the PC allows a long record to be captured at 1:1 with a zoomed section
Eases timing setup and extends the time window

•Multiple discrete input channels
Segmented anode would yield multiple input channels

•Possibility of very high time resolution by making use of the pulsed nature of the fields
The PC ramp signal could be as short as a few nanoseconds which will allow very high fields to be applied

•Potential for sensitivity from IR to UV with suitable photo-cathodes