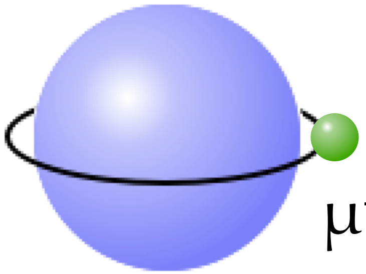
Development of wire chamber with tolerance for high rate burst pulse for DeeMe experiment.

Hiroaki Natori
on behalf of DeeMe Collaboration

IBS CAPP

Mu-e conversion

Nucleus



Muonic atom

92%(C), 33%(Si)

8%(C), 66%(Si)

Not discovered yet

$e^- \nu_\mu \bar{\nu}_e$

- Muon Decay in Orbit (DIO)

$\mu^- \rightarrow e^- \nu_\mu \bar{\nu}_e$

ν_μ

- Muon Capture (MC)

$\mu^- + (A, Z) \rightarrow \nu_\mu + (A, Z - 1)$

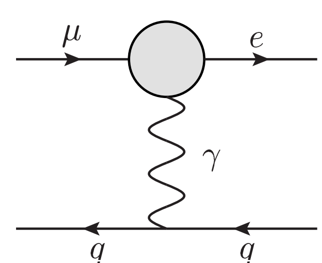
Lifetime (depends on nucleus)

- τ = 2.0 μs (C) 0.76 μs (Si)

e^-

- μ-e conversion

$\mu^- + (A, Z) \rightarrow e^- + (A, Z)$



etc.

Forbidden in the Standard Model

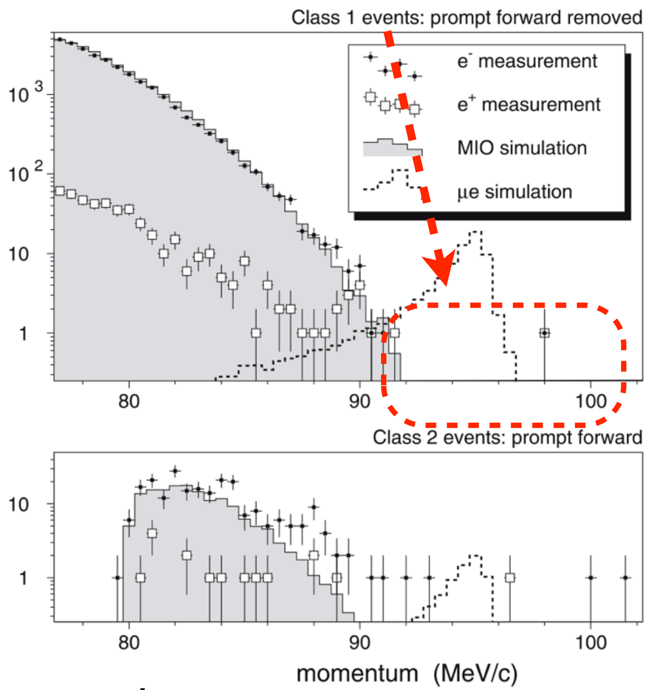
Clear evidence of the new physics

Key feature of signal

- ~105MeV/c > DIO
- Delay time from primary

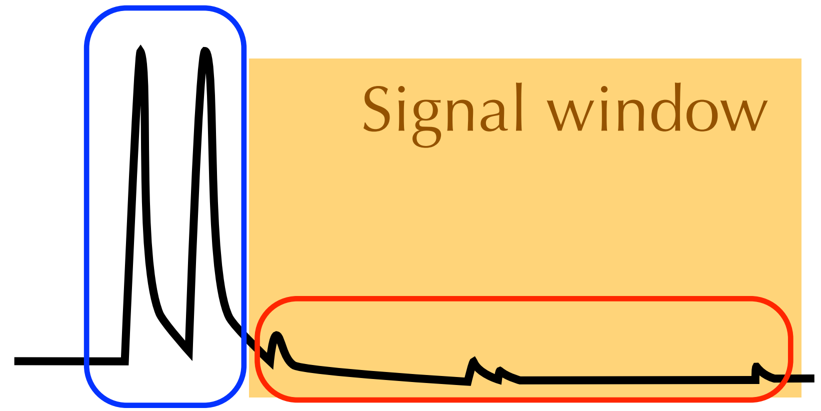
Experimental strategy

- SINDRUM II
  - DC beam, heavy nuclei
  - O(1) beam or cosmic B.G.



Eur. Phys. J. C 47, 337–346 (2006)

Br(μ-e conv. w/ Au) < 7 × 10^{-13}



Prompt B.G.

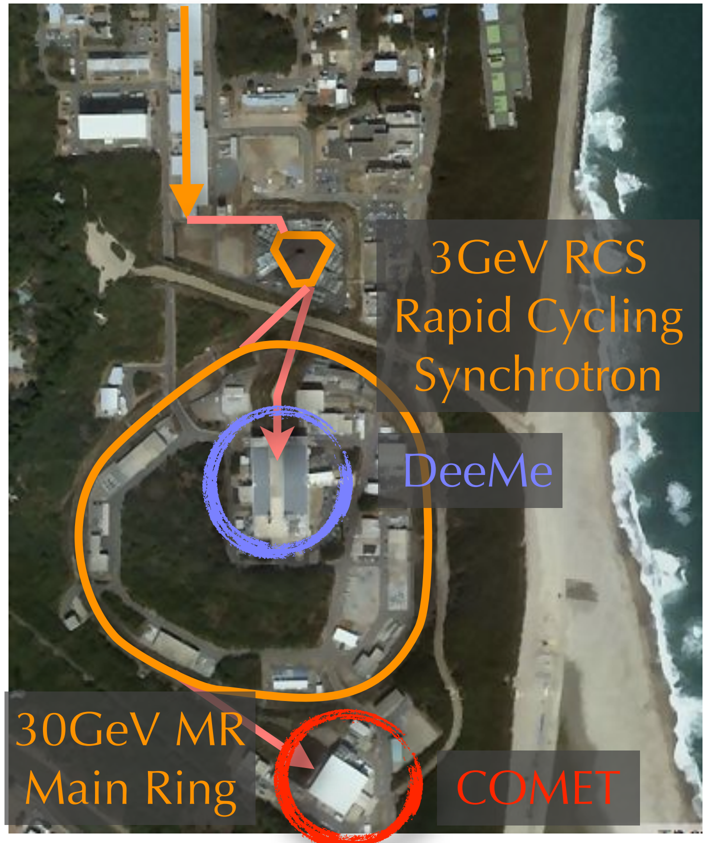
$\pi^- + (A, Z) \rightarrow (A, Z-1)^*$,

$\gamma \rightarrow e^+e^-$ etc.

DIO (<105MeV/c) or signal (=105MeV/c) e^-

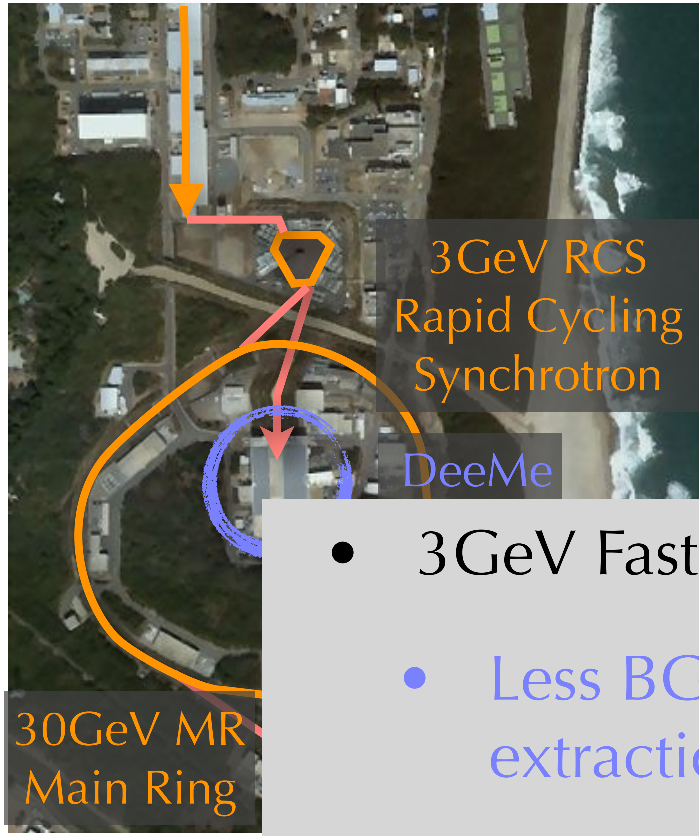
- Our approach
  - Pulsed beam, delayed signal window, light but not too light nucleus
    - Heavier nucleus, larger overlap with muon wave function, but shorter lifetime
- Need more intense beam

DeeMe vs Mu2e or COMET



	COMET, Mu2e	DeeMe
Primary Beam	8GeV, ~1us between bunches	3GeV, ~40ms between bunches
Anti-proton background	Possible (8GeV initial proton)	No (3GeV initial proton)
B.G. by off-timing proton	Possible (Slow extraction)	No in principle (Fast extraction)
Cosmic-ray B.G.	Needs cosmic ray veto counter	Negligible (Small duty factor, horizontal track)
Run start	2018~(COMET Phase-I) 2020~(COMET Phase-II, Mu2e)	Soon after H-line construction in 2016
S.E.S.	$O(10^{-15})$(COMET Phase-I), $O(10^{-17})$(COMET Phase-II, Mu2e)	1×10^{-13}(Carbon) 2×10^{-14}(SiC)

DeeMe vs Mu2e or COMET



	COMET, Mu2e	DeeMe
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S.E.S.	$O(10^{-15})$(COMET Phase-I), $O(10^{-17})$(COMET Phase-II, Mu2e)	1×10^{-13}(Carbon) 2×10^{-14}(SiC)

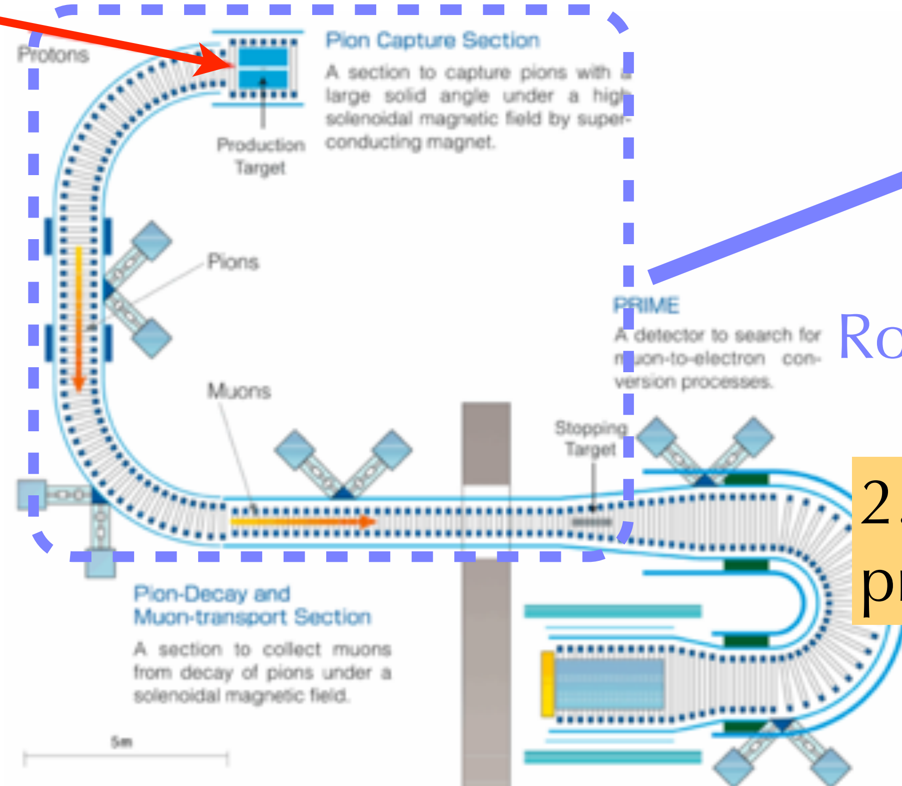
- 3GeV Fast extraction vs 8 GeV Slow extraction
  - Less BG in delayed signal window with Fast extraction
  - More protons hits the production target → More prompt charged particles

DeeMe vs Mu2e or COMET

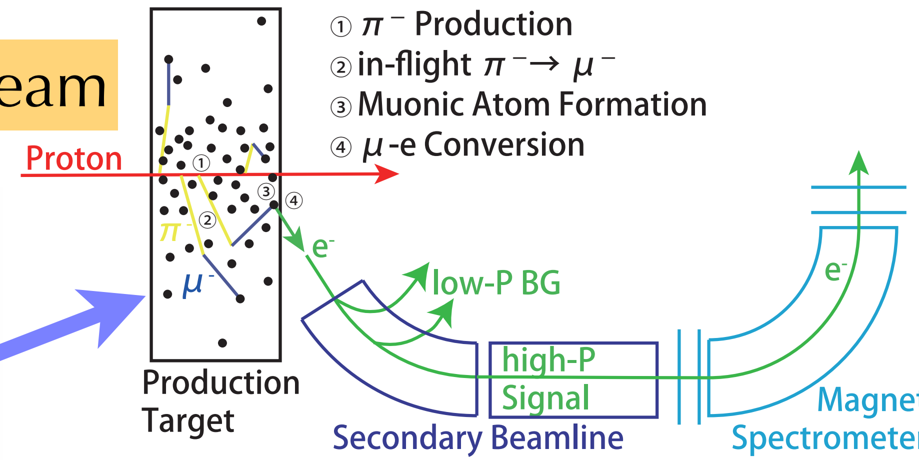
RCS 3GeV/c, 1MW
Fast extraction 40ms cycle

MR 8GeV/c, 56kW
Slow extraction 1μs cycle

1. Prompt beam



COMET



DeeMe

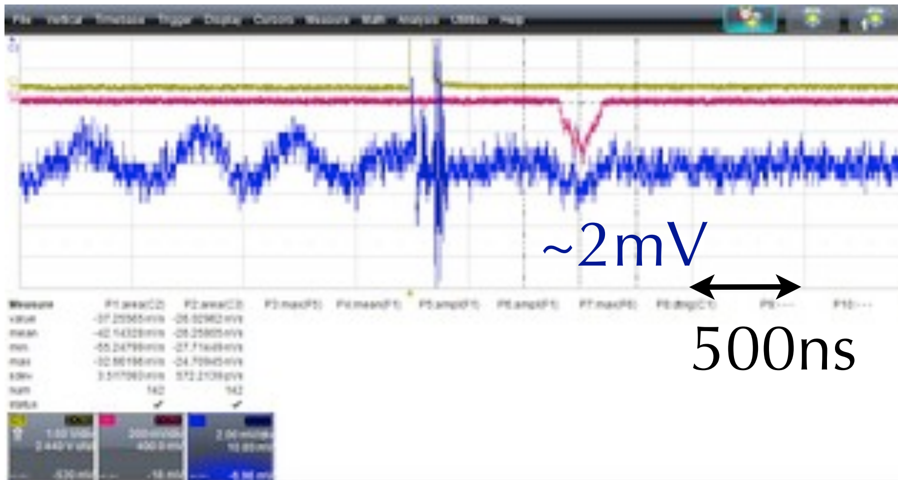
Roll of all these parts in a production target

2. Beamline between production-stopping target

- Simple, early realization
- Less sensitivity
- Huge prompt burst

What happens on MWPC with prompt burst?

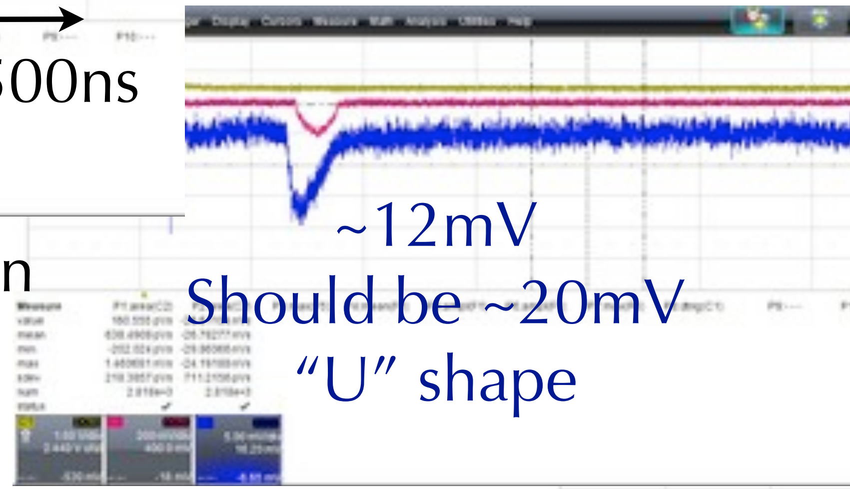
Beam counter
(Acrylic plate + PMT)
Prototype MWPC
raw waveform (i.e. w/o amplifiers)



~2mV

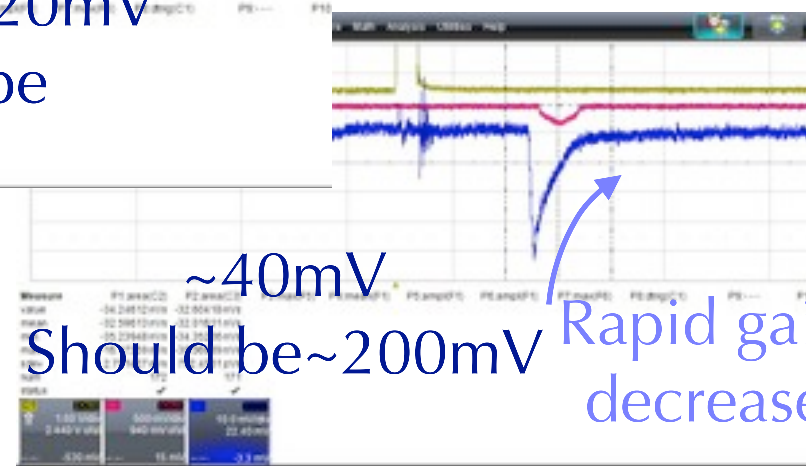
500ns

~1/1000 of final condition



~12mV
Should be ~20mV
“U” shape

~1/100 of final condition

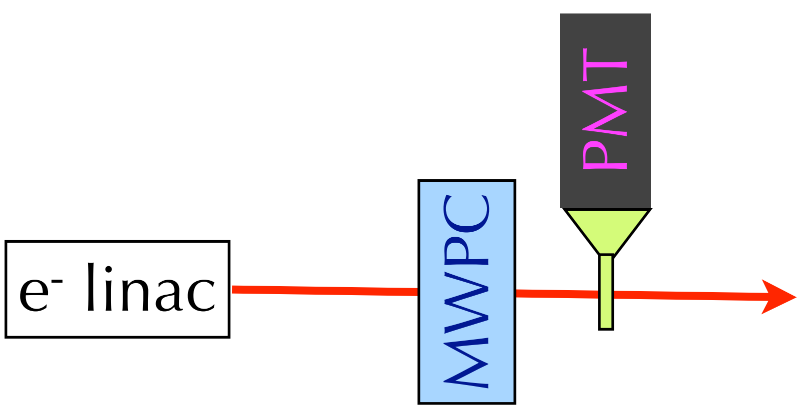


~40mV
Should be~200mV

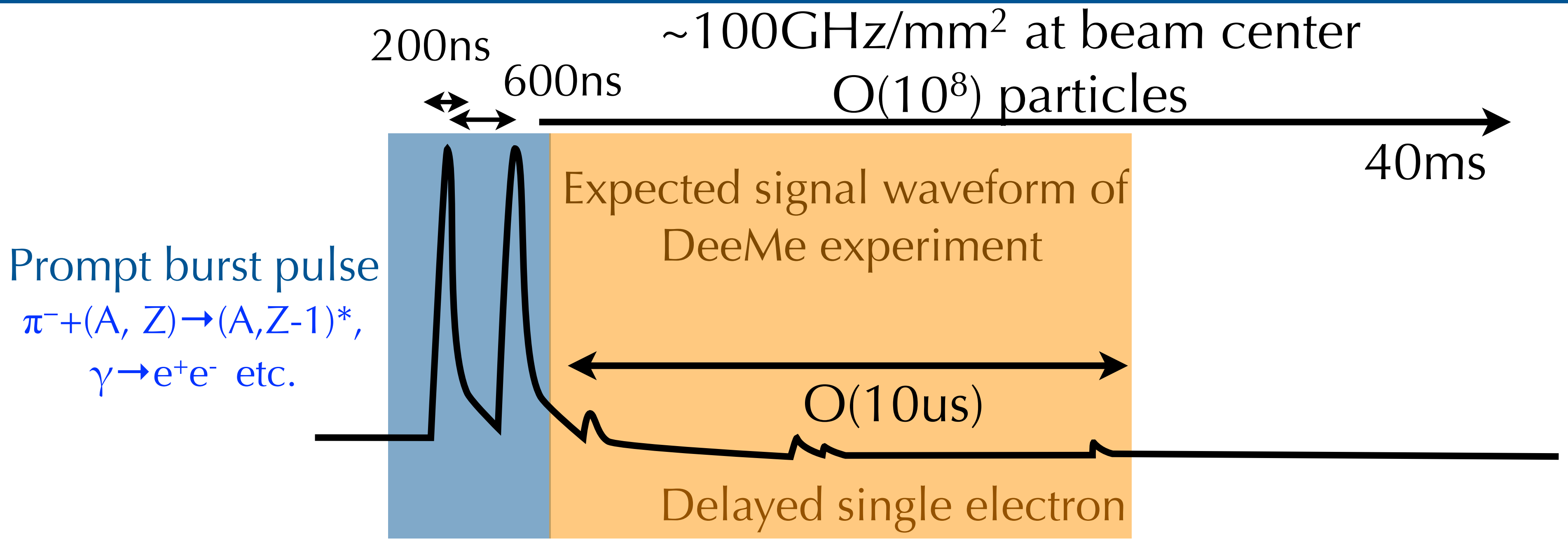
Rapid gain decrease

~ 1/10 of final condition
(10GHz/mm^2)

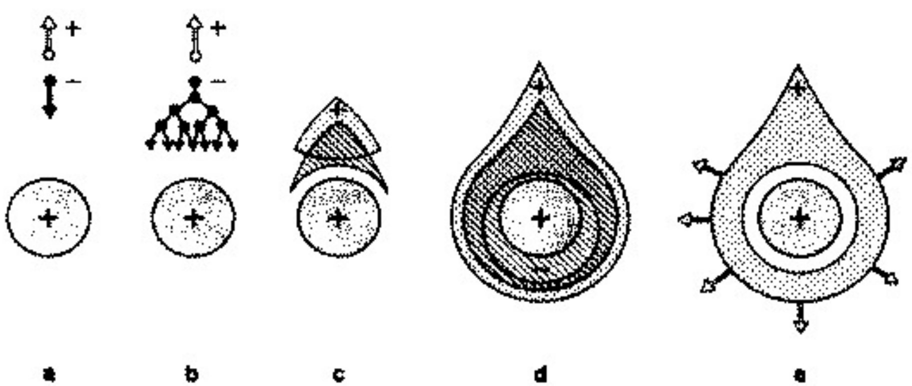
Question: Why?



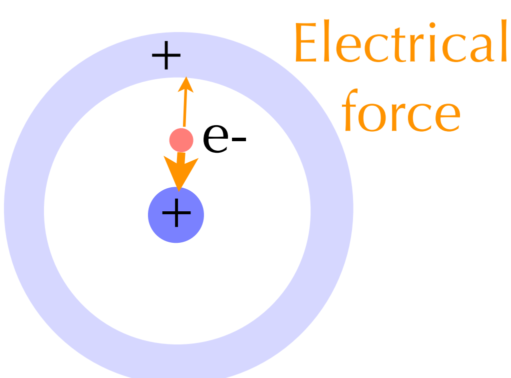
Space charge effect



Unwanted burst pulses comes before the signal

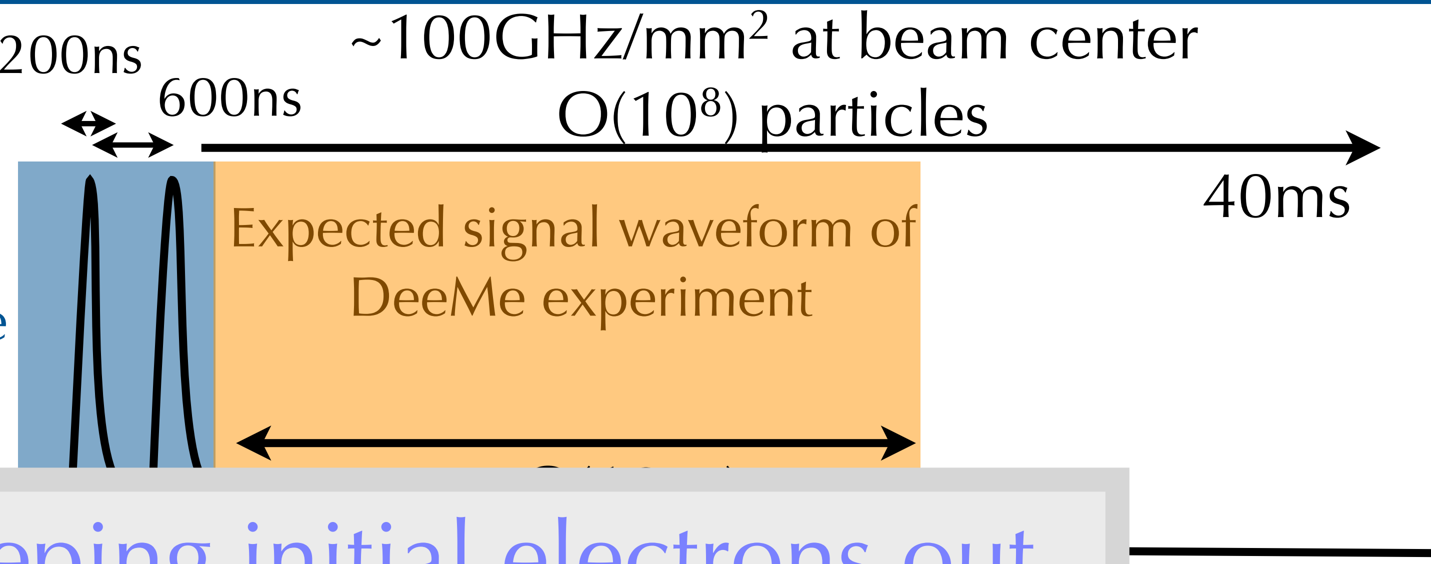


Avalanche multiplication makes a sheath of ions along wire



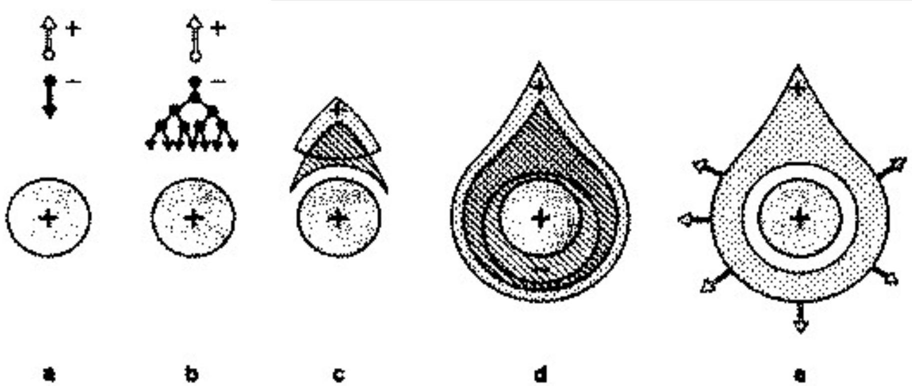
Too many prompt burst × avalanche multiplication = dense sheath of ions

Space charge effect

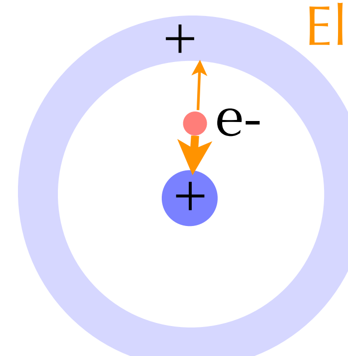


Prompt burst pulse
$\pi^- + (A, Z) \rightarrow (A, Z-1)^*$,
$\gamma \rightarrow e^+e^-$ etc.

Sweeping initial electrons out
w/o generating ions will solve it!

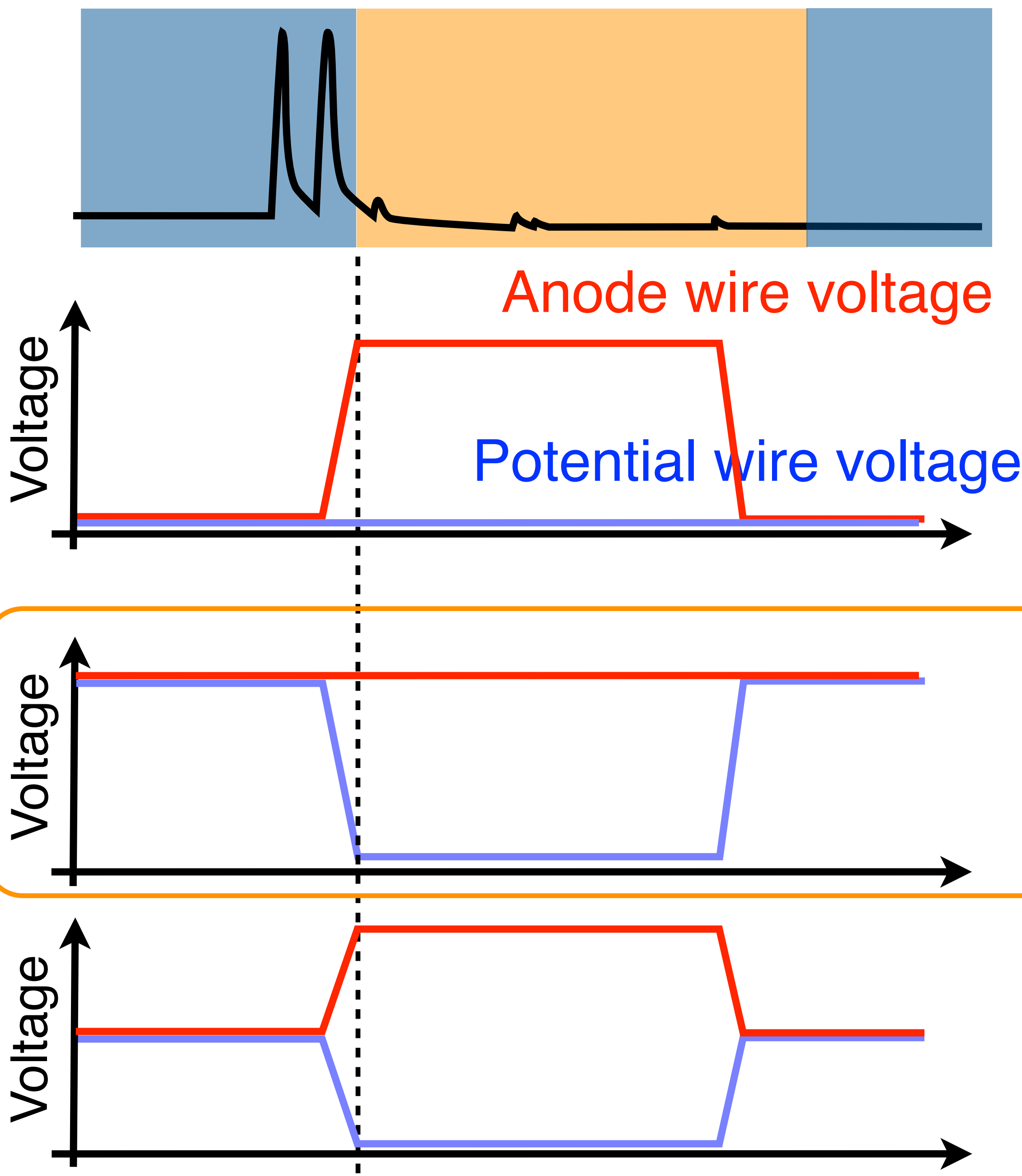


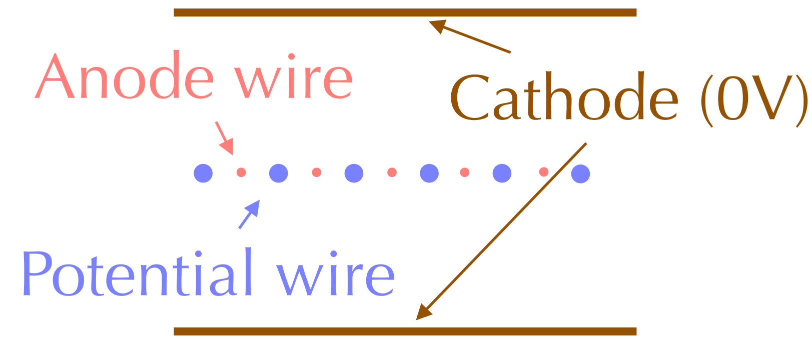
Avalanche multiplication makes
a sheath of ions along wire



Too many prompt burst × avalanche
multiplication = dense sheath of ions

HV switching



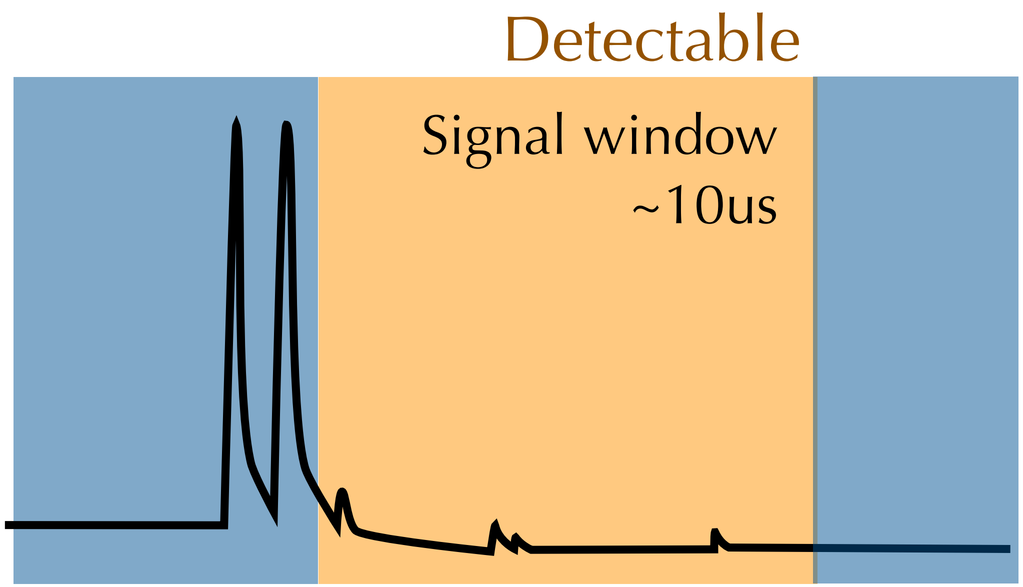


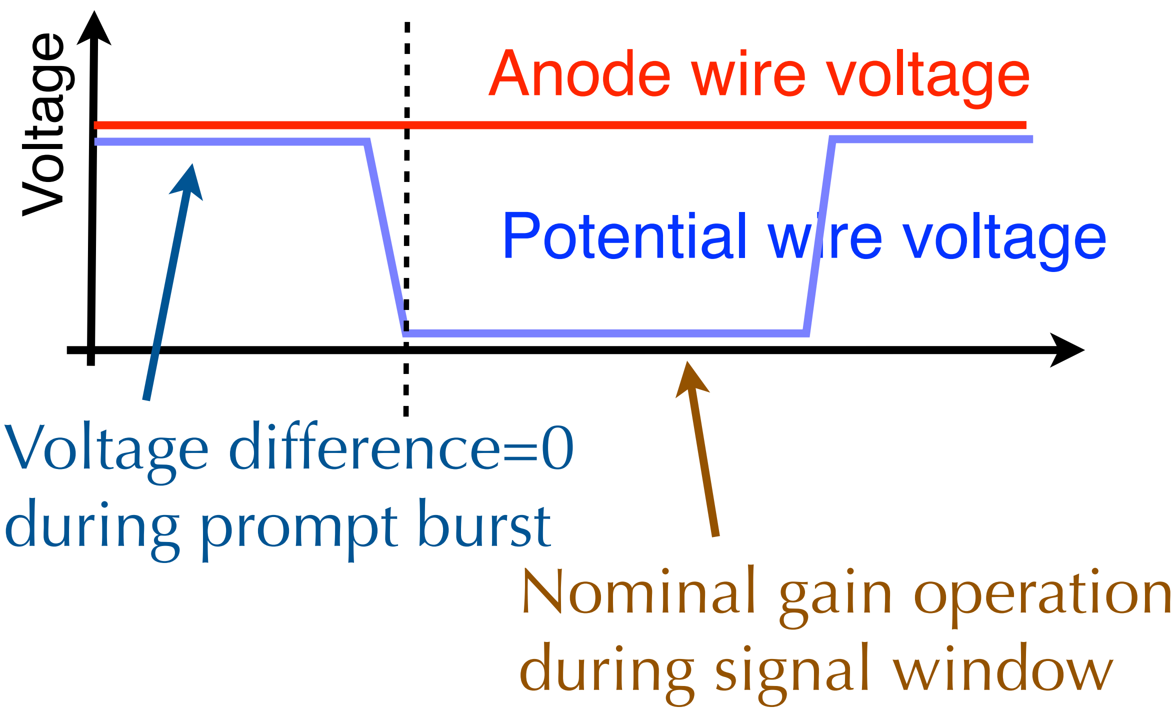
Scheme 1.
Initial electrons are multiplied when switching on.
-> Meaningless

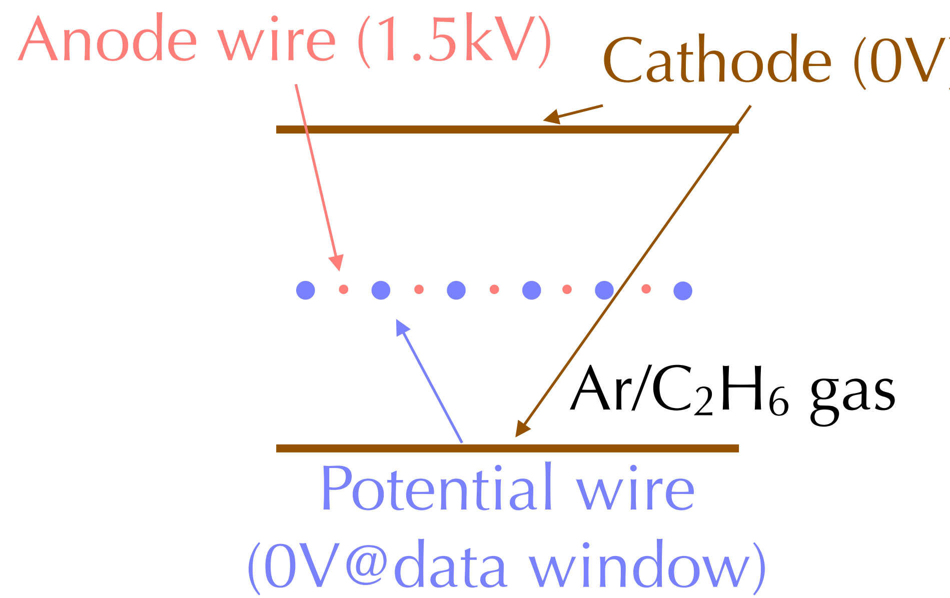
Scheme 2.
We took this

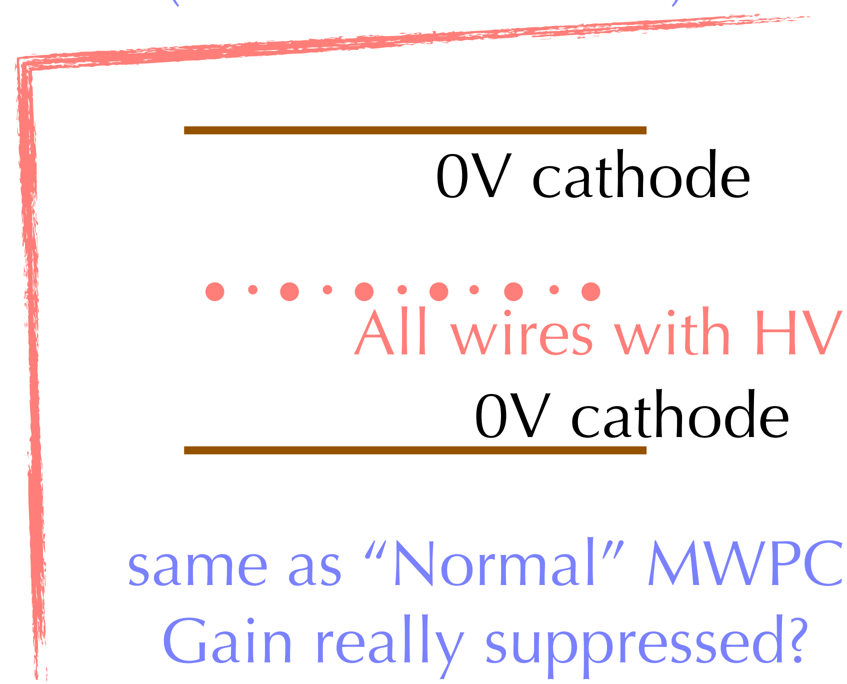
Scheme 3.
Could be better, but more difficult. Not tested yet.

HV switching



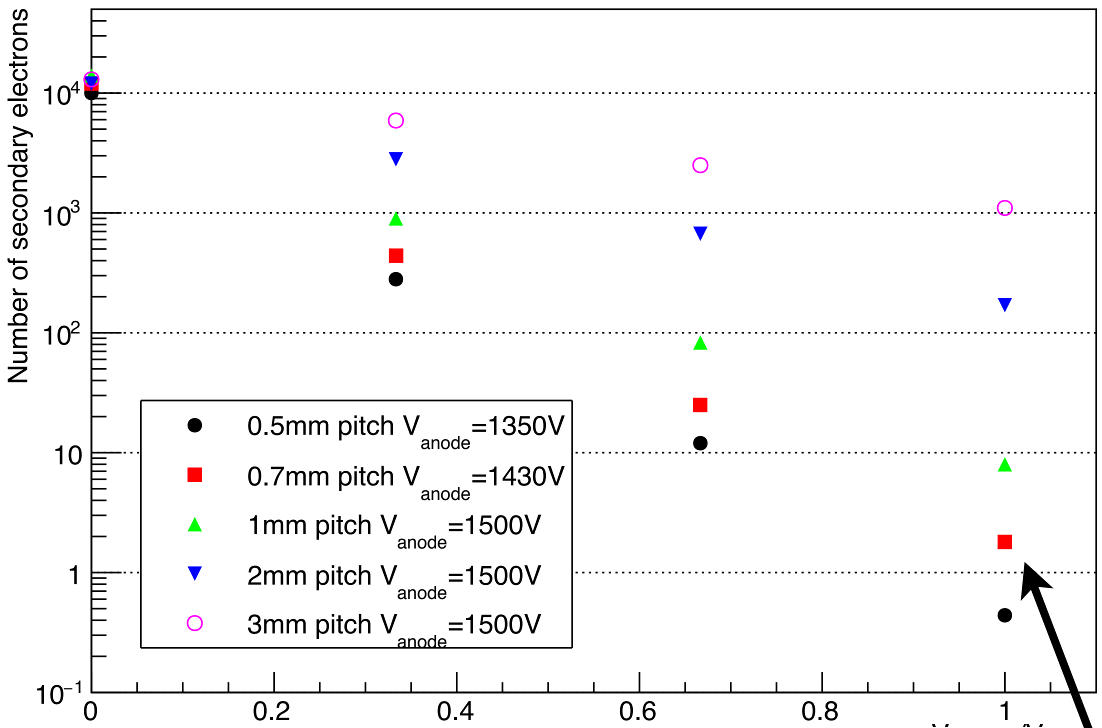




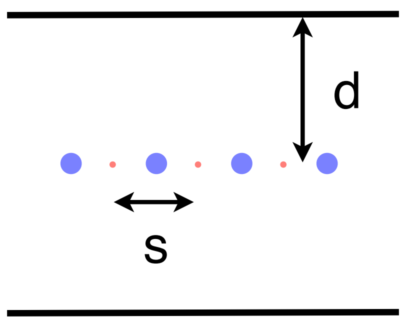


Geometry of chamber for switching

Special geometry is needed for dynamic gas gain control with potential wire HV switching



# of secondary electrons by MIP when d = 3mm, GAFIELD++



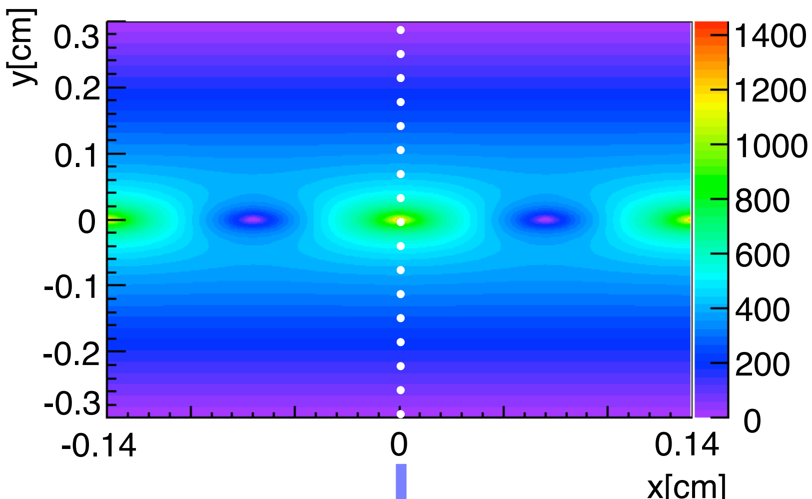
s << d,
ΔV(anode-pot.) dominantly determine gas gain

1/2 s = 0.7mm, d=3mm seems fine

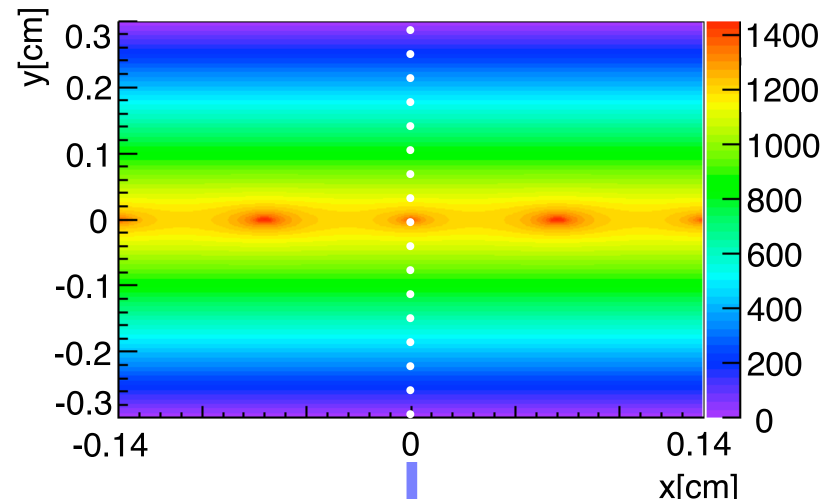
Gas gain and voltage on potential wire (by GARFIELD++)

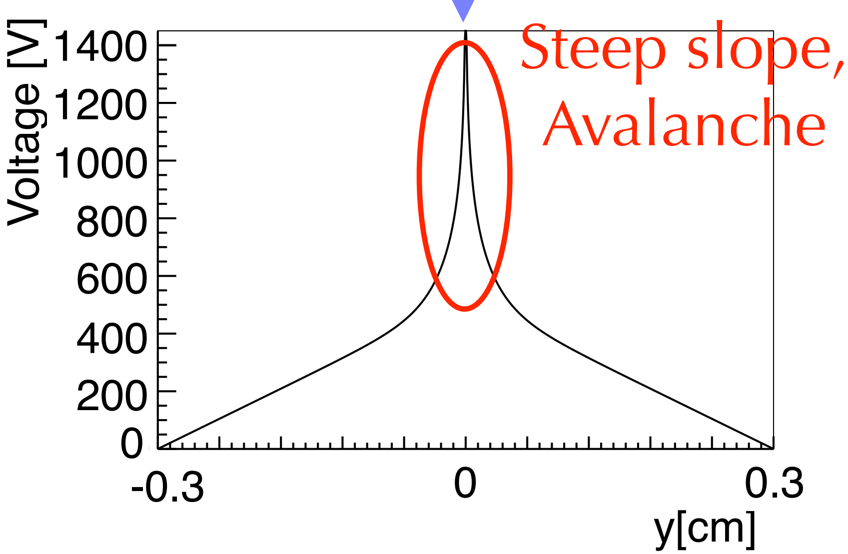
Anode wire: 1450V
Potential wire: 0V
Expected gas gain: 10^4

Anode wire: 1450V
Potential wire: 1450V
Expected gas gain: 3

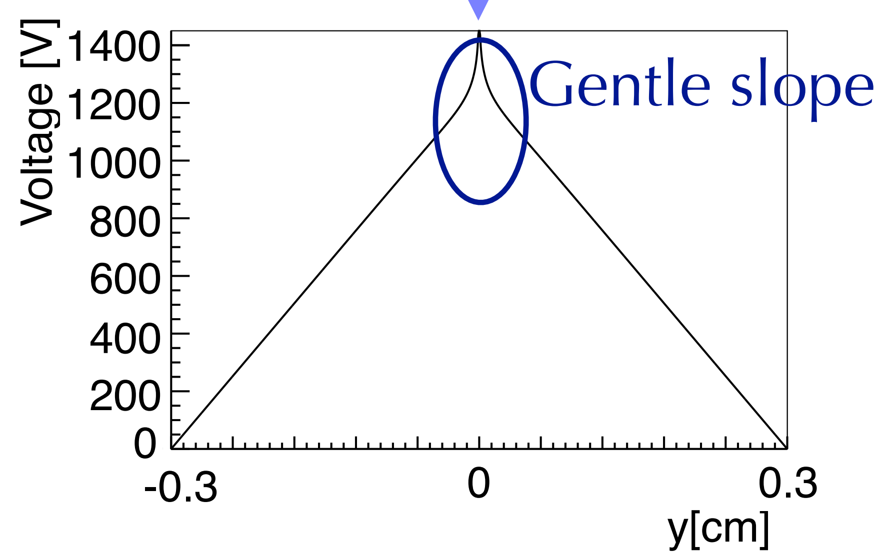


Electric filed contour

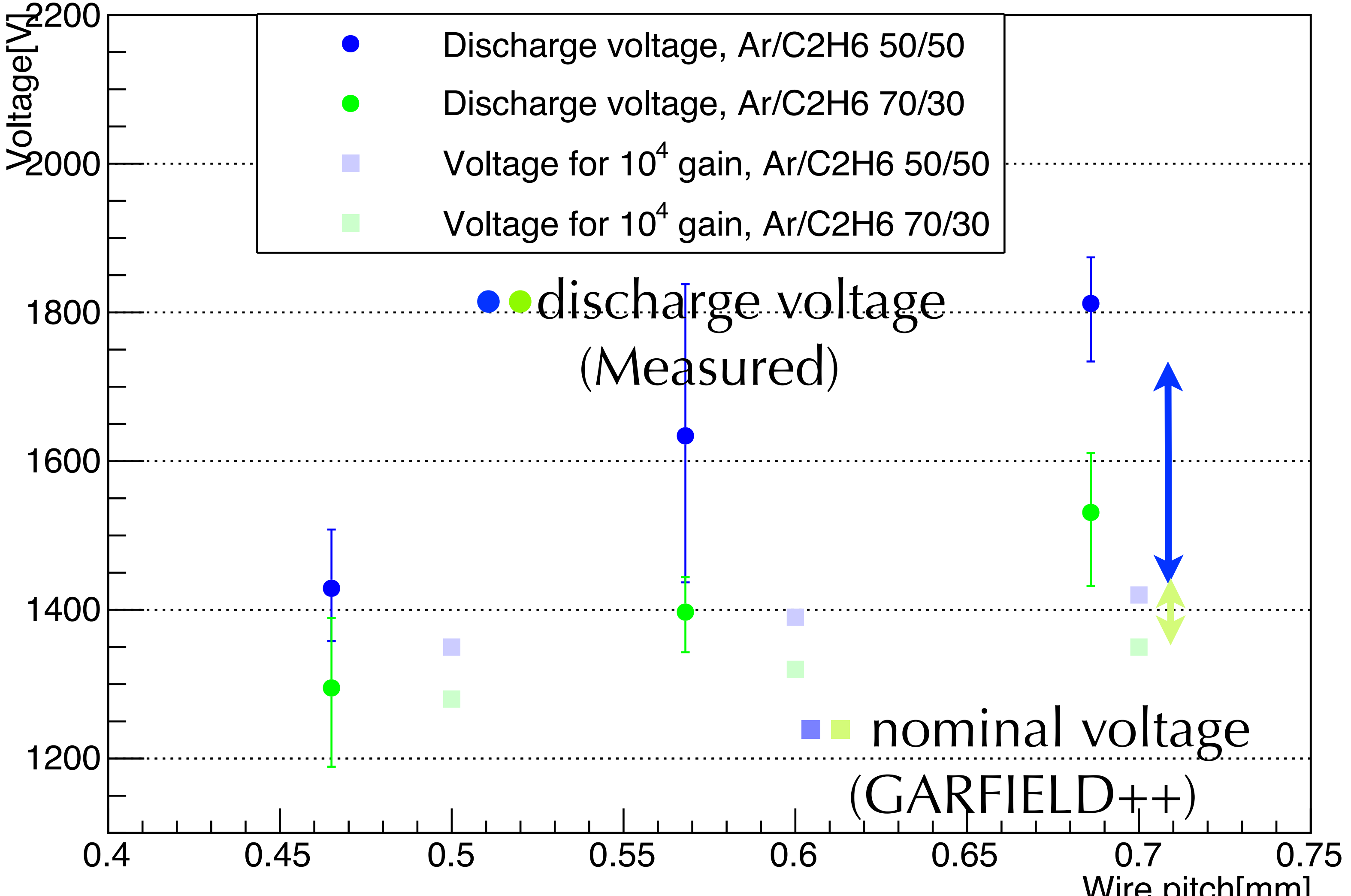




Electric field profile



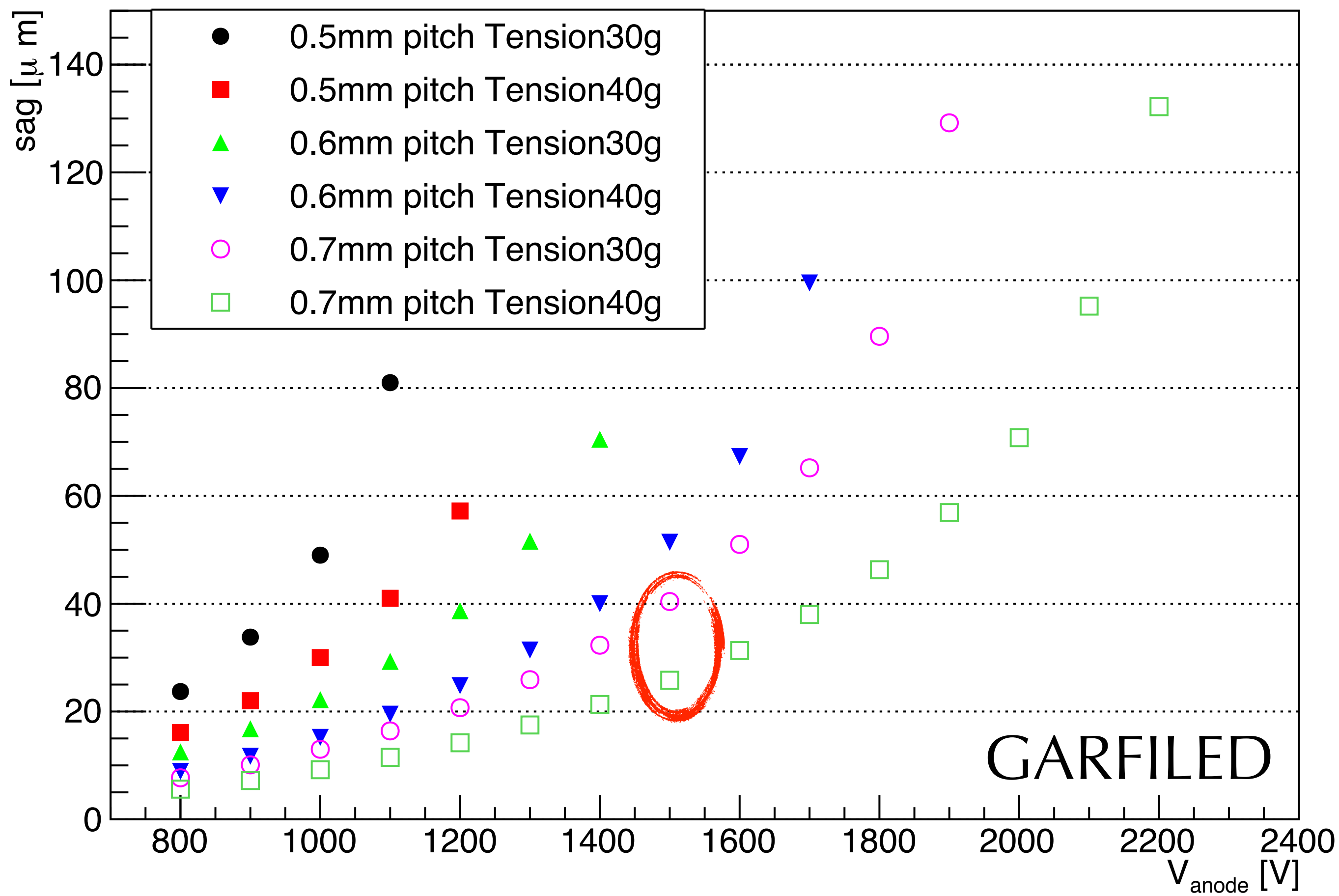
Discharge voltage vs wire pitch



by Y. Takezaki Osaka City Univ.

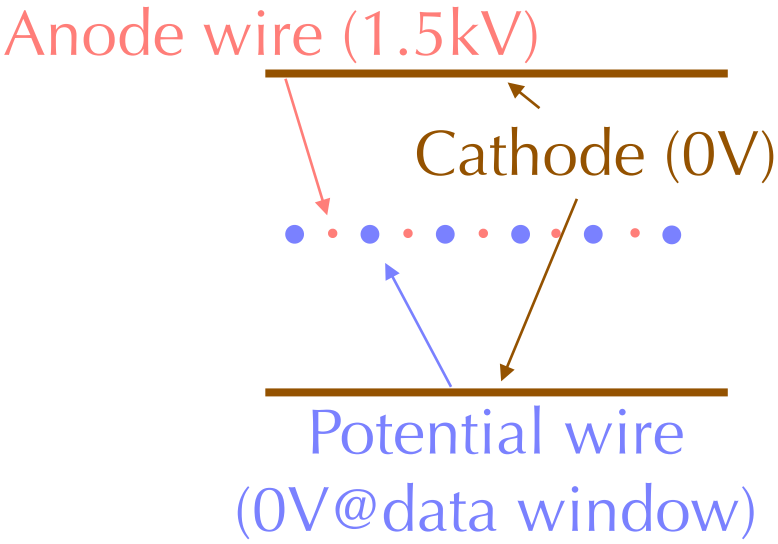
- pitch 0.7mm, Ar/C2H6=50/50 enough separation between discharge-nominal voltage

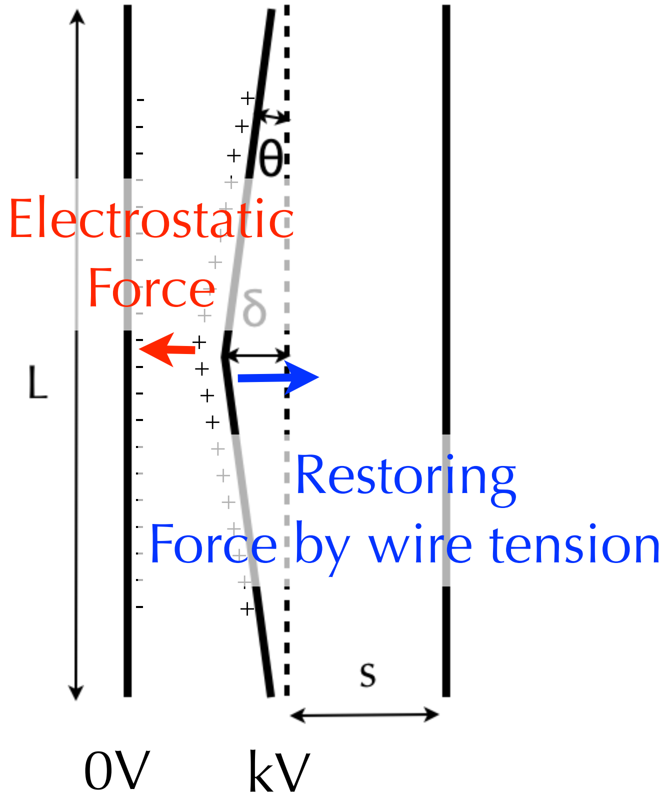
Wire sag due to electrostatic force

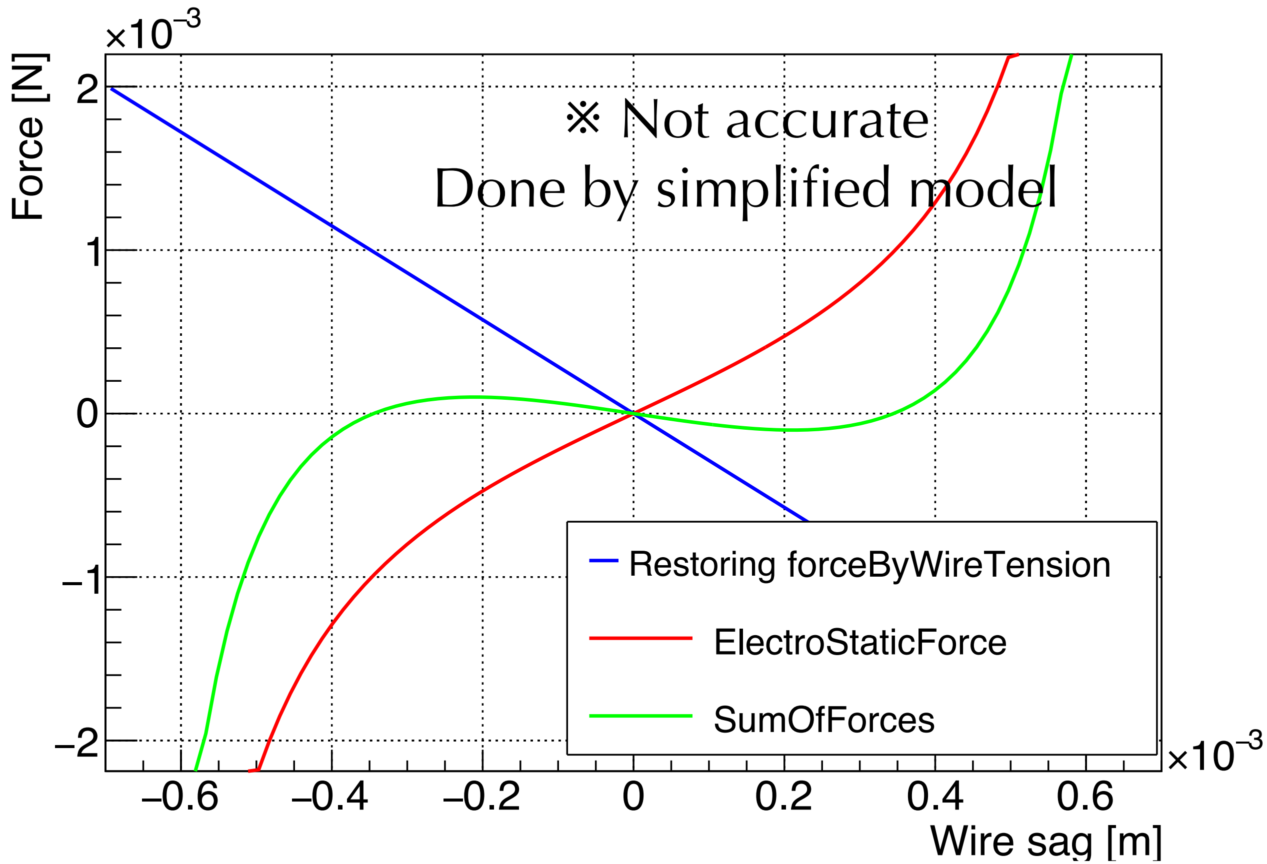


Wire sag < 50um for 0.7mm pitch at nominal voltage, but …

Force on wire





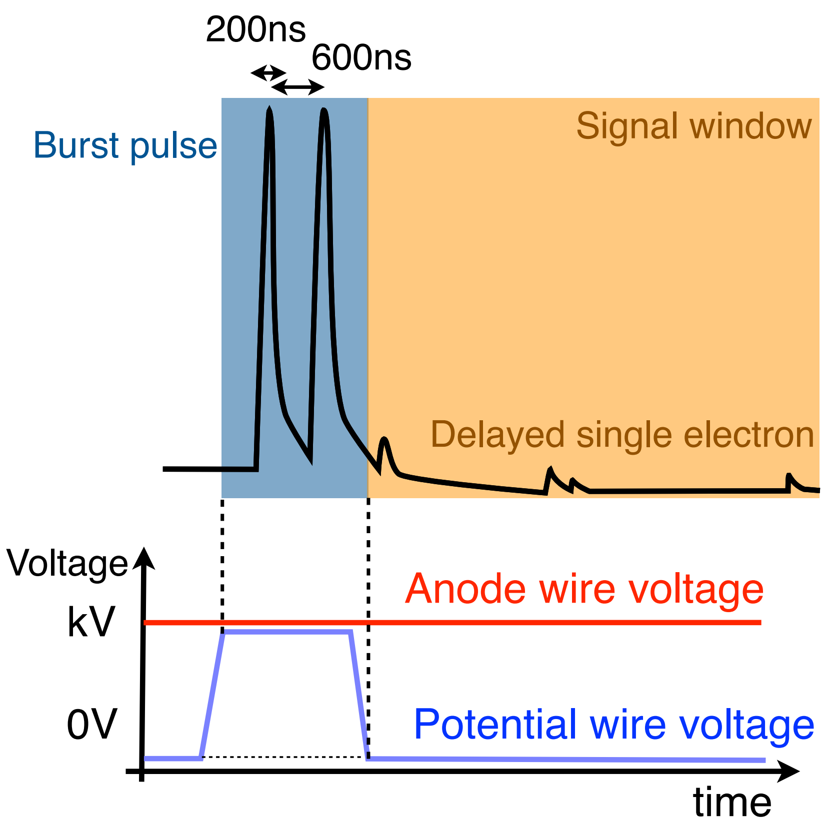


Strong electrostatic force due to short wire distance

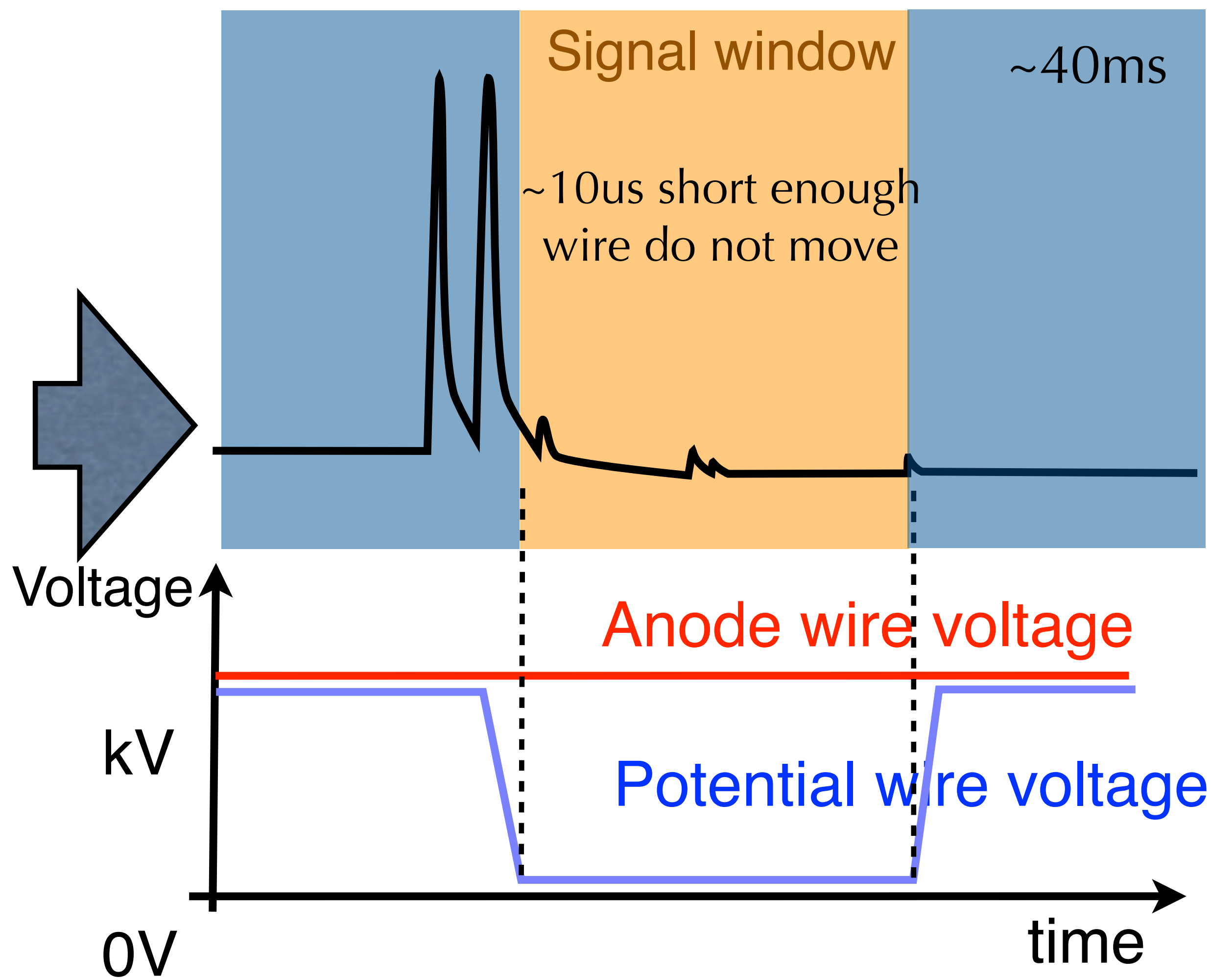
Effectively, small restoring force.
Small shock may move wire large

A few 100um wire movement -> Electrical short

Switching operation scheme



Attractive force between wires
Risk of short by small shock



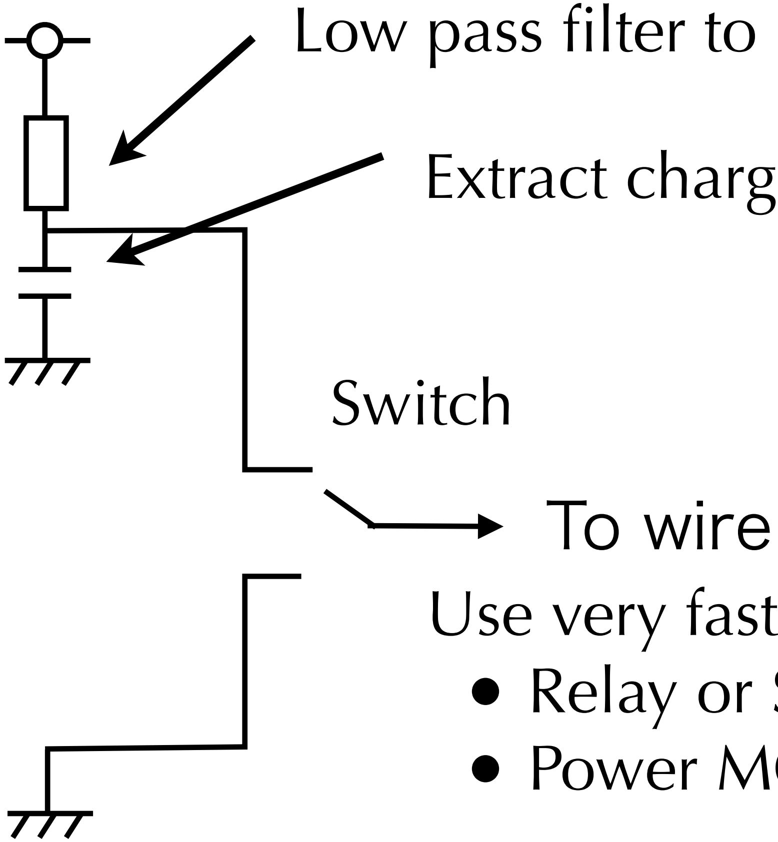
Repulsive force keeps wire distance
Discharge ends within ~10us

10us << natural frequency, small impact

How to achieve fast ramping (O(100ns))?

Low pass filter to remove noise of HV

Extract charge from large C >> (sum of wire capacitance)



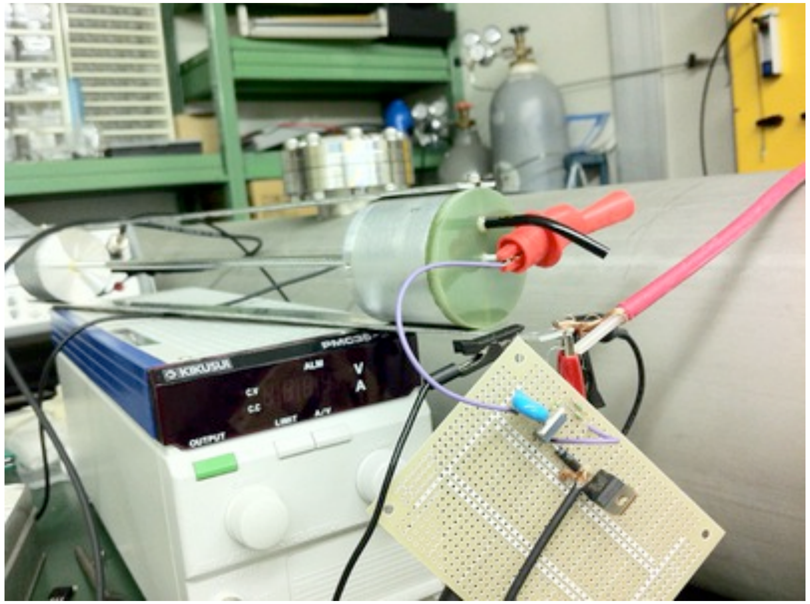
Use very fast relay

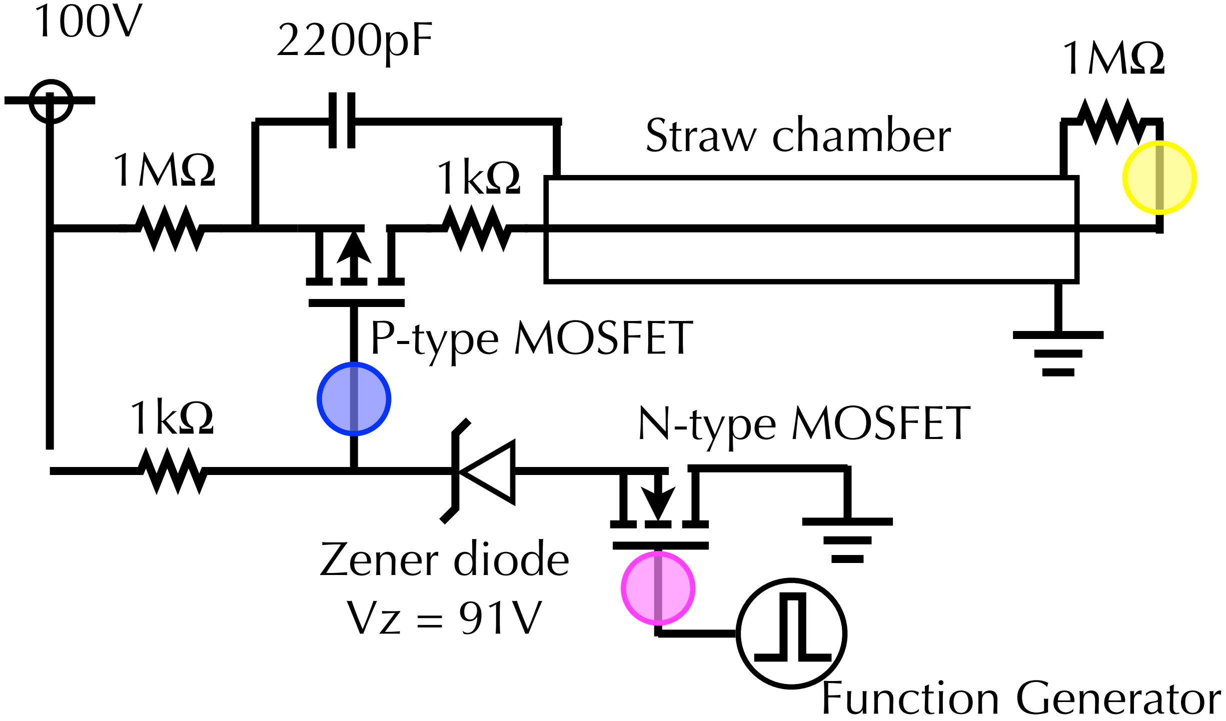
- Relay or Solid state relay(SSR): O(ms)
- Power MOSFET ~2kV switch with <100ns

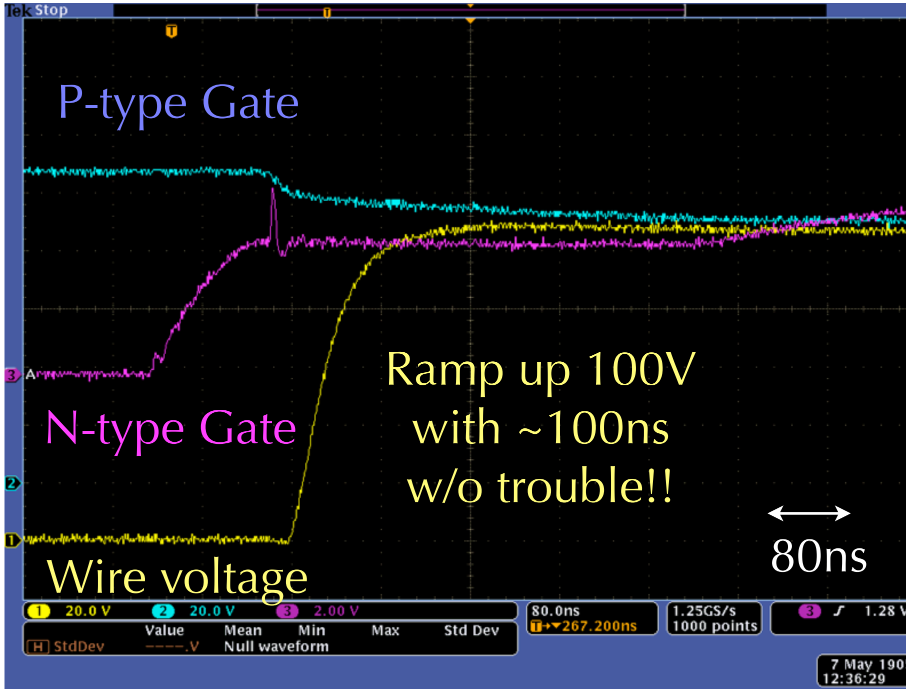
Example: WPH4003-1E
Drain-Source voltage=1700V, Drain current=3A
Turn on/off delay time= 19/200ns, Rise/Fall time=21/55ns

Question: Anode wire have R, L, C
Driving it ~100ns is trivial?

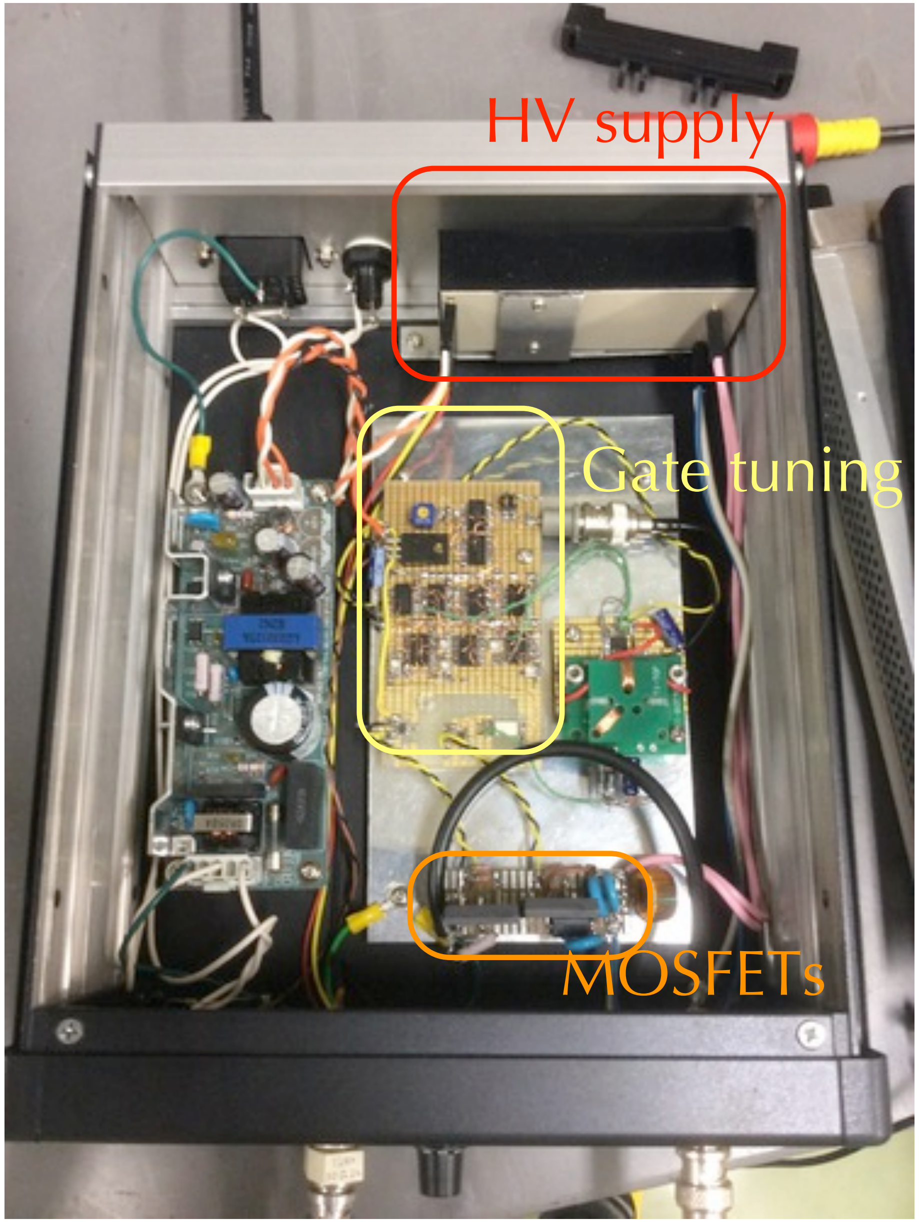
Wire ramping test with handmade circuit

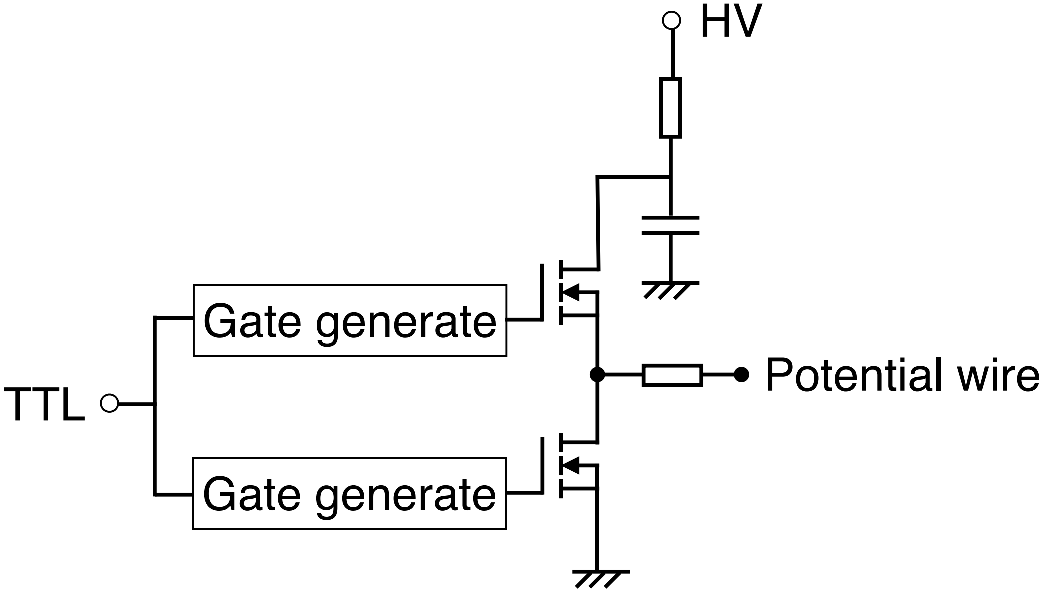






Prototype HV switching module





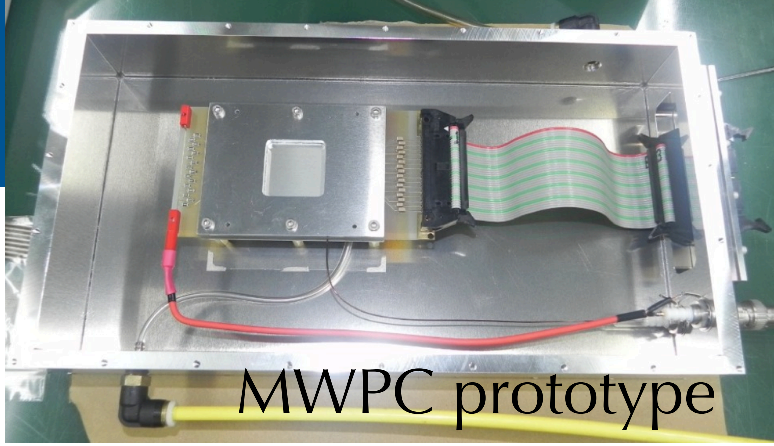
Ordered a company for design and construction. Prototype HV switching module.

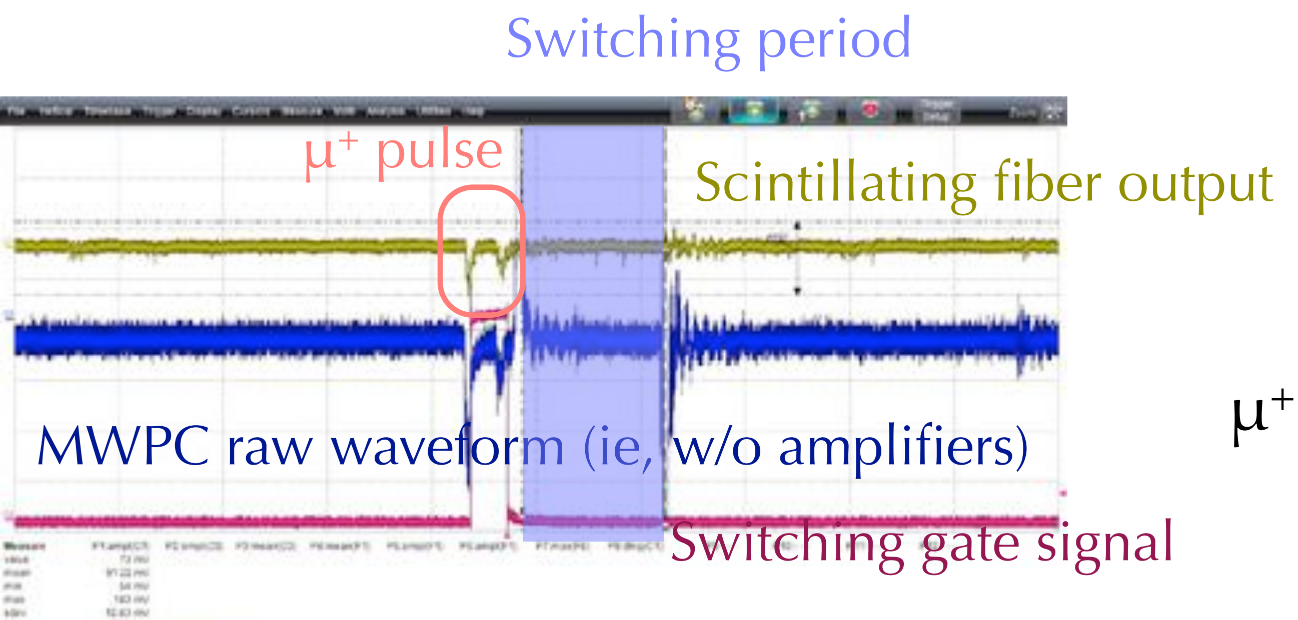
(FYI, recent MOSFET made of SiC gives better performance)

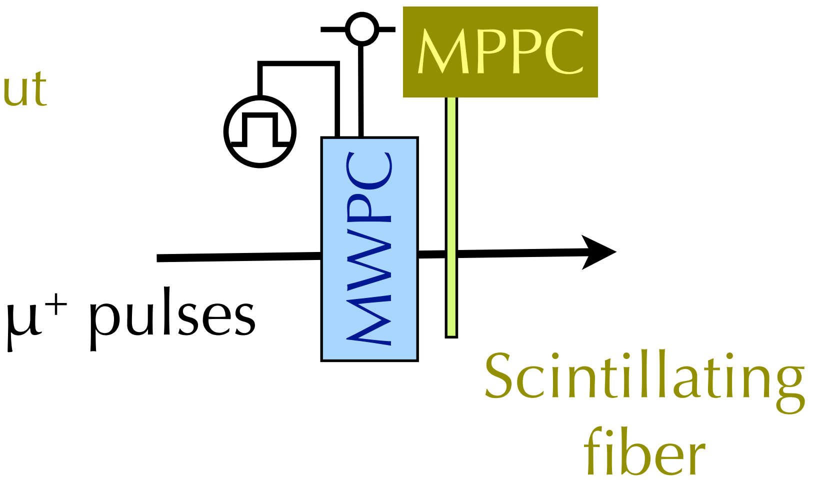
TTL timing input

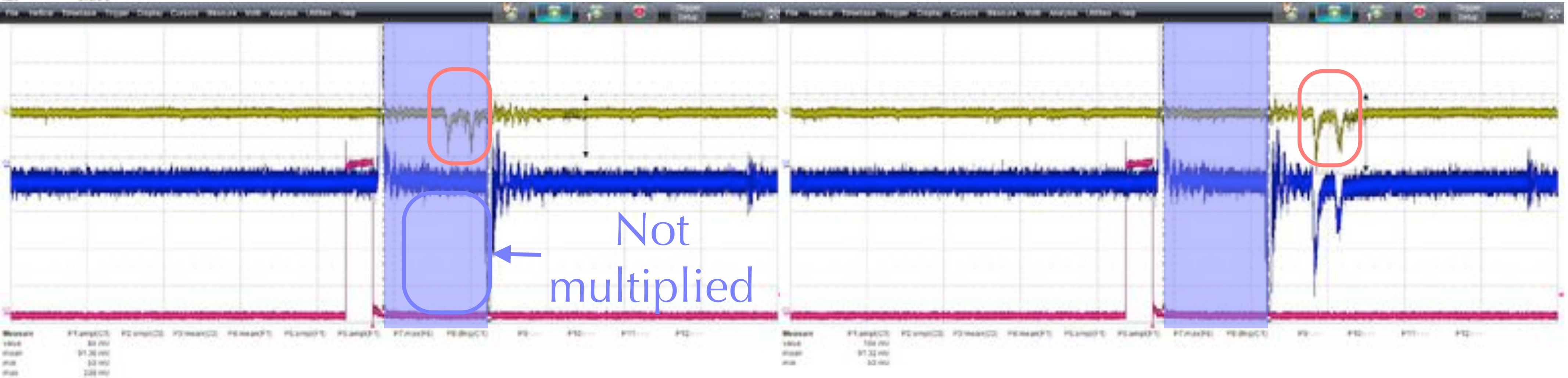
Pulsed HV output

Operation verification







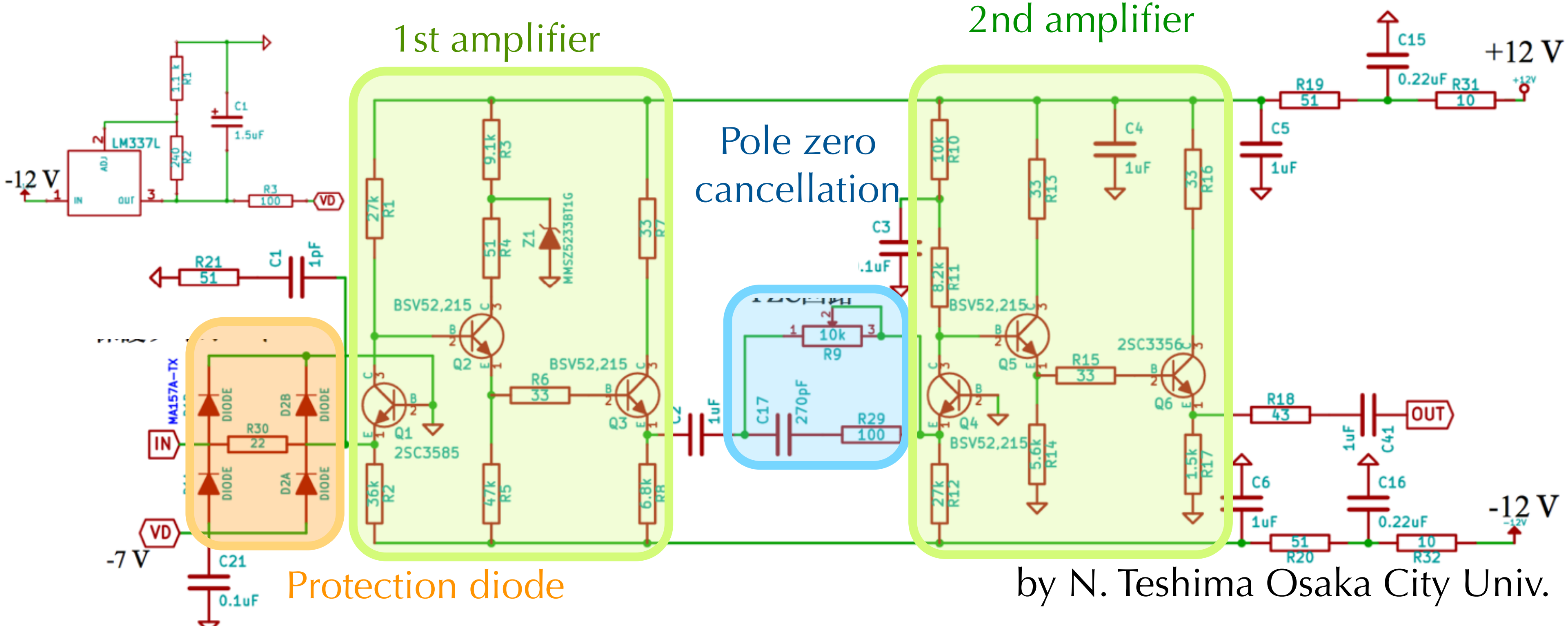


Succeeded dynamic gas gain control

Construction of final chamber

- One of the final chamber
  - 250mm x 200mm active region
  - 0.7mm wire pitch
  - 3mm between cathode-wires
  - 3mm strips for X readout, 15mm strips for Y
  - Quit wire readouts. Only cathode strip readouts (To minimize channel)

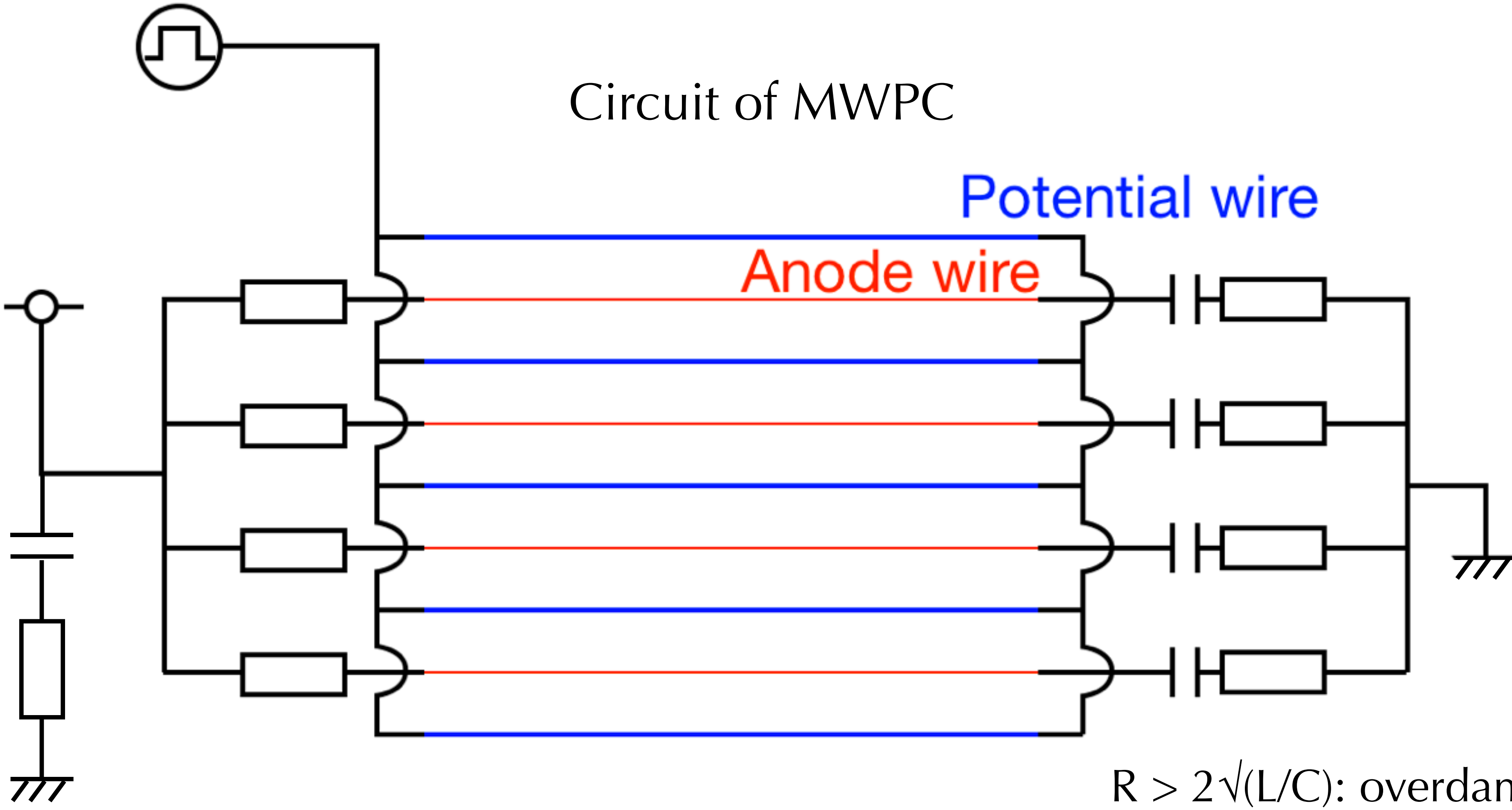
Readout amplifier w/ high current tolerance



by N. Teshima Osaka City Univ.

- Developed from 2-stage “RADEKA” amplifier
- PZC for canceling long tail by slow ion movement
- Large current tolerance by tuning capacitance, resistance etc.

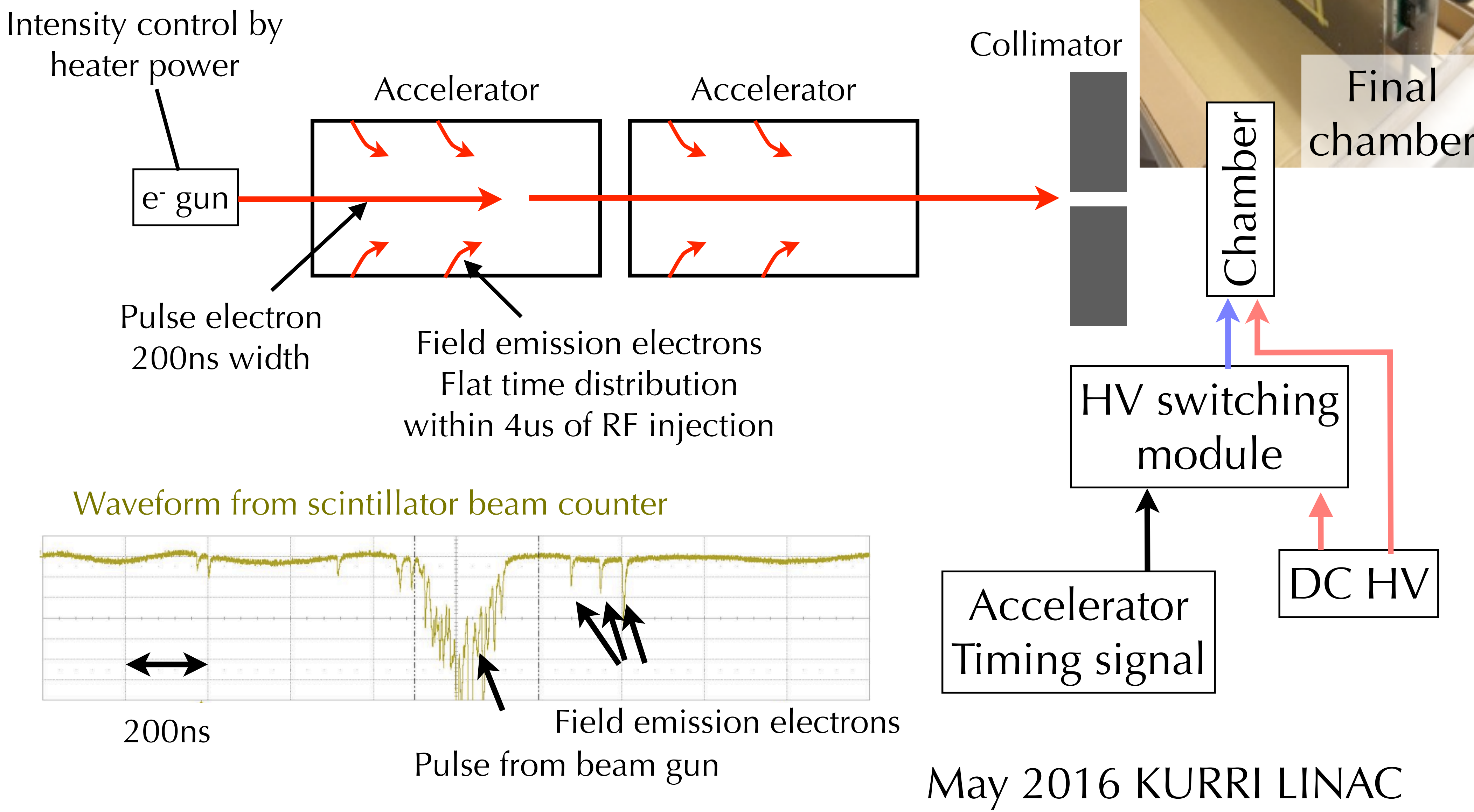
Damping resonance



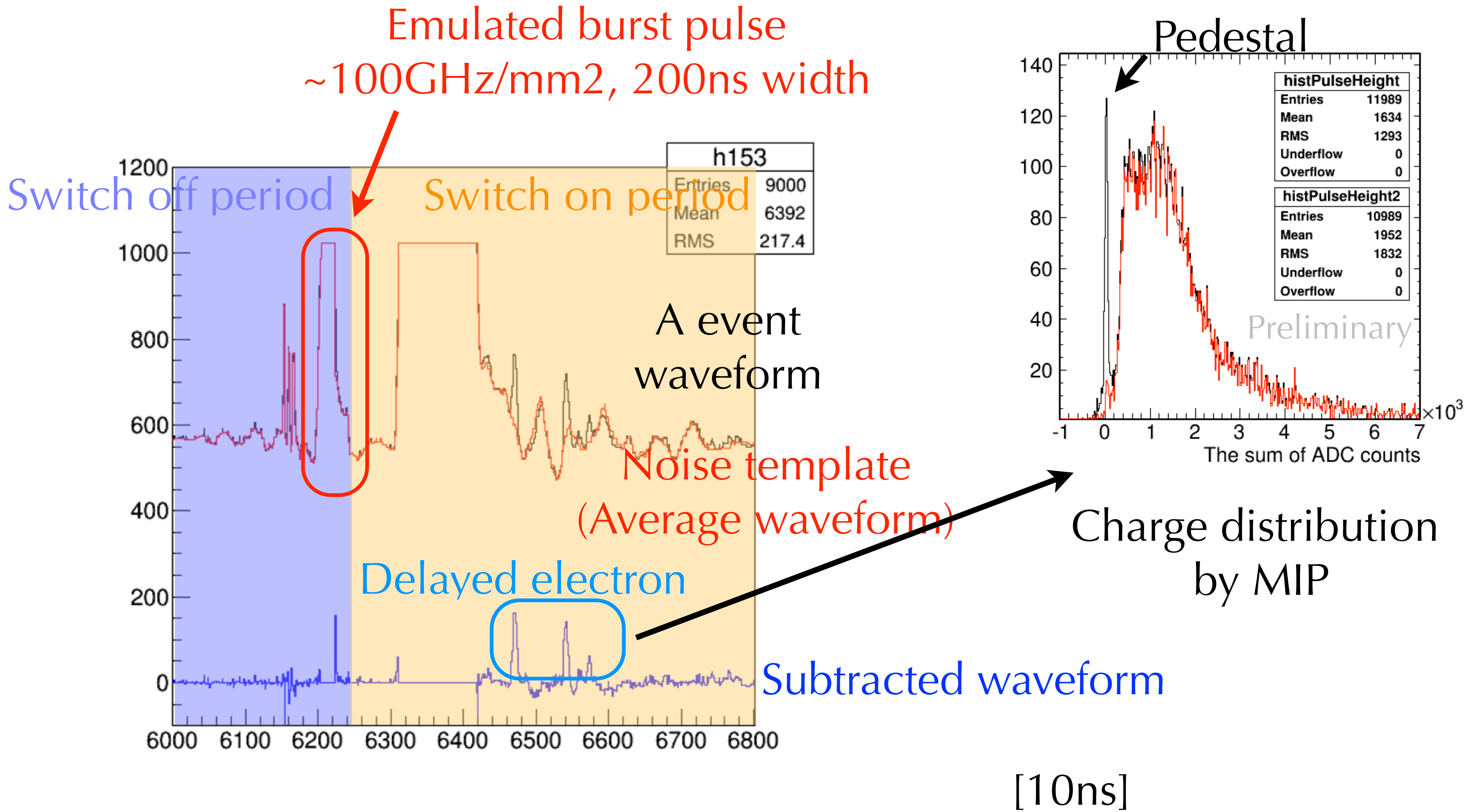
RC snubber for damping resonance in SHV cable

R > 2√(L/C): overdamping
Prevent LCR resonance

Test experiment setup



Delayed signal observation



Successfully observed delayed electron after a prompt burst equivalent pulse
2days operation w/o trouble.

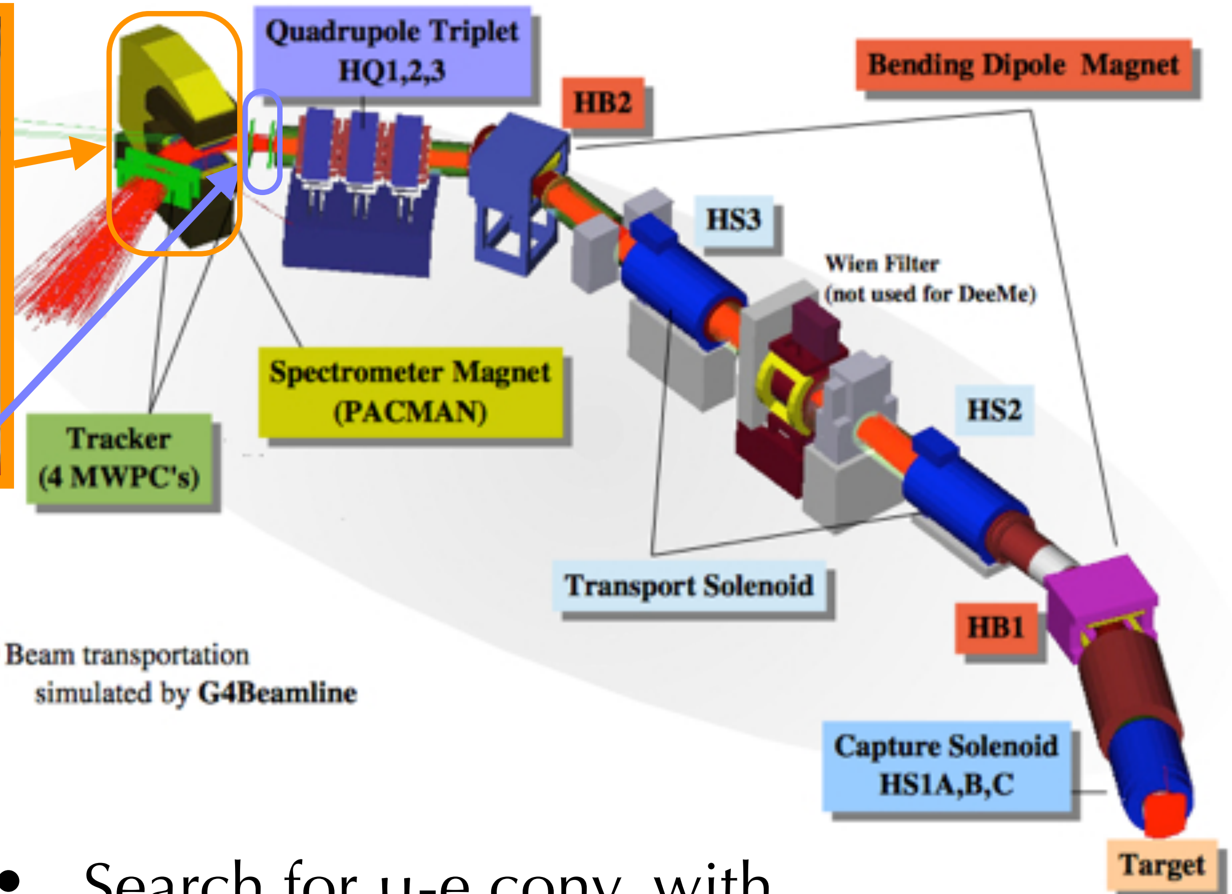
- Developed a wire chamber which tolerate to huge prompt burst and detect electron w/o effect of space charge effect by dynamic gain control with HV switching.

- I'm happy if this work stimulate your interest. Idea of application to the other experiments are welcome.

- Thanks for your attention.

End of slide

DeeMe



- Search for μ-e conv. with
  - S.E.S.=1×10^{-13} (Graphite)
  - S.E.S.=2×10^{-14}(SiC)

Keys of DeeMe

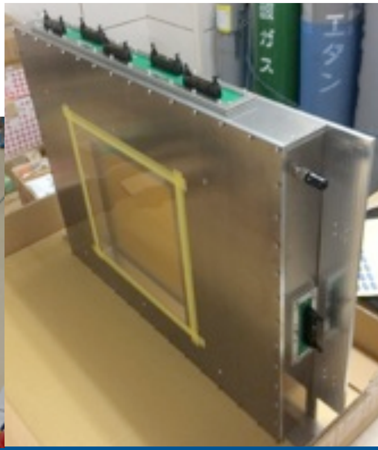
- Unique scheme of using production target also as muon stopping target
  - Simpler, then earlier realization : OK
- Fast extraction of primary 3GeV proton
  - Less backgrounds (Beam related, Cosmic) : Good
- Novel detector, not normal one: why?
  - Too much prompt burst particles!!

Detector requirement

- Low mass for less multiple scattering for better tracking
  - Gas chamber suits. Thin (<300um XY reading) Si detector can be another candidate, but too expensive.
- $O(10^8)$ prompt particles / pulse
  Instantaneous hit rate ~100GHz/mm^2
  - Normal gas chamber become blind for delayed signal
- Invented HV switching technique, which enables dynamic gas multiplication gain control

Preparation status

- Facility
  - RCS 3GeV, 500kW currently, will be upgraded to 1MW
  - H-line construction in 2016
  - At first starts with current graphite target. SiC under development
- DeeMe
  - Detector operation verification done
  - 1st,2nd chamber constructed, small modification will be done
  - 3rd,4th chamber parts constructed. Assemble soon.
  - Spectrometer magnet ready
  - Readout electronics ready



- **Single Event Sensitivity (S.E.S)**

$$S = \frac{1}{R_{\pi^-} \times f_{\pi^- \to \mu^- \text{stop}} \times f_C \times f_{MC} \times A_{\mu-e} \times T}$$

$R_{\pi^-} \times f_{\pi^- \to \mu^- \text{stop}} = \mu^-$ stopping rate per second

$f_C =$ atomic captur rate

$f_{MC} =$ muon nuclear capturefraction

$A_{\mu-e} =$ total acceptance for μ-e electrons

$T =$ time length of the measurement

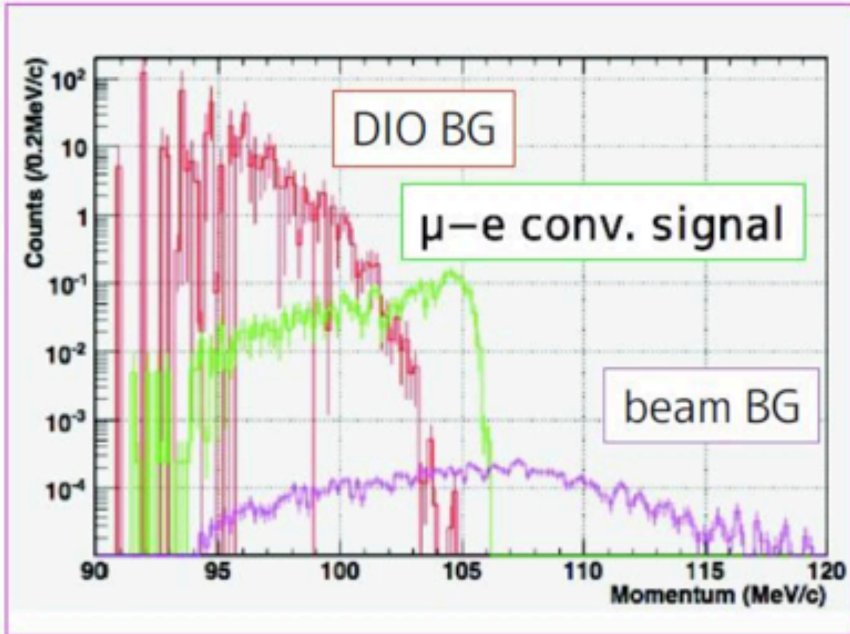
- Running time = **2 × 10⁷ sec** (1 year run)
- Background (MC estimated)
  - Decay in Oribit **0.09**
  - After proton rate (R_{AP}) < 10^{-18}

    → After proton < **0.027** (0.05 90% C.L.)
  - Cosmic induced

    e < **0.018**, μ < **0.001**

    → Detector live-time duty = **1/20000**

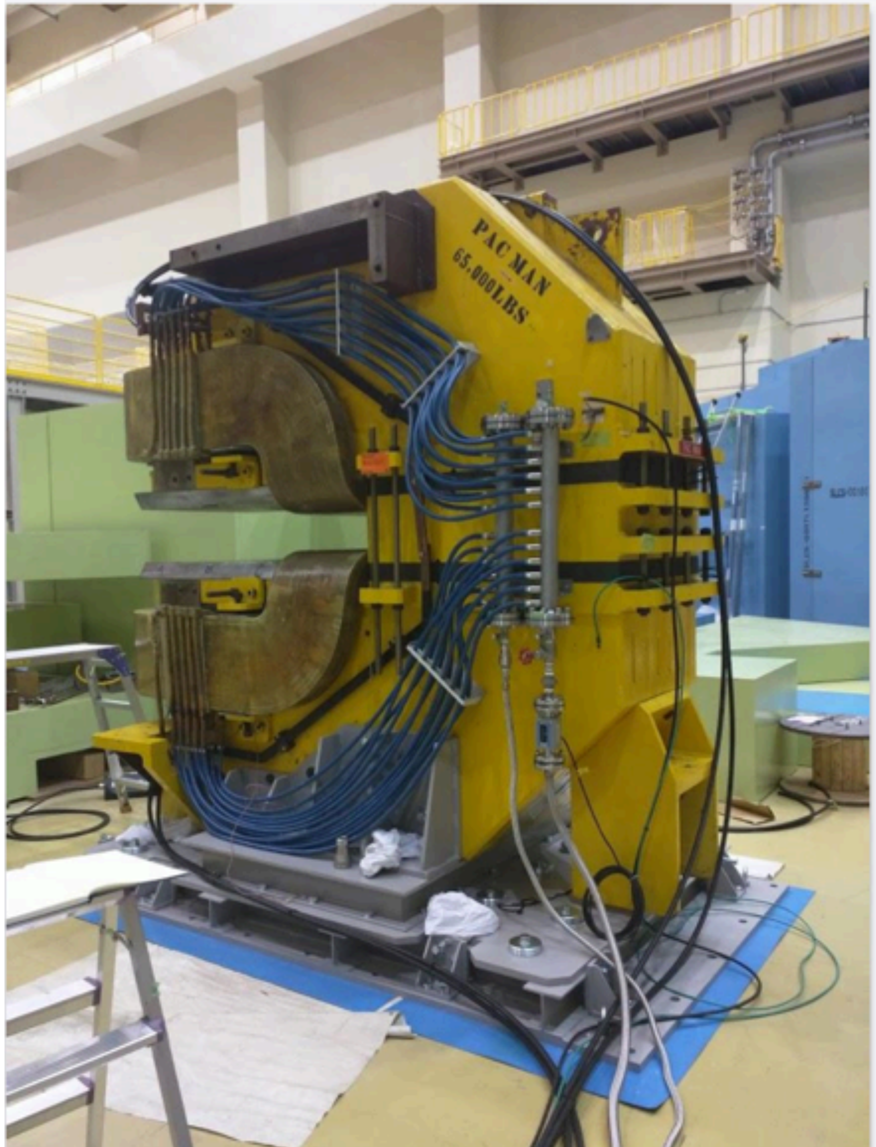
    ⇒ Cosmic ray backgrounds are well suppressed.



- **S.E.S estimated by Monte Carlo study**
- **2.1 × 10⁻¹⁴** for <u>SiC</u> target
- **1.2 × 10⁻¹³** for <u>C</u> target

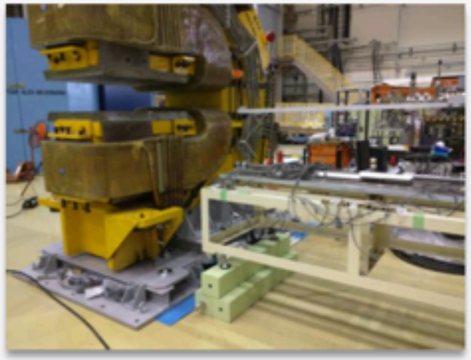
current upper limit

BR(μ⁻ Au → e⁻ Au) < **7 × 10⁻¹³** (SINDRUM-II)



PACMAN Magnet

- used for PIENU exp. @ TRIUMF, Canada
- transported from TRIUMF to J-PARC
- central field = **0.4 T** (300A)
  for **105 MeV/c** , **70 degree** bending
- Test operation was successfully done in J-PARC MLF.
- Field measurement was performed.



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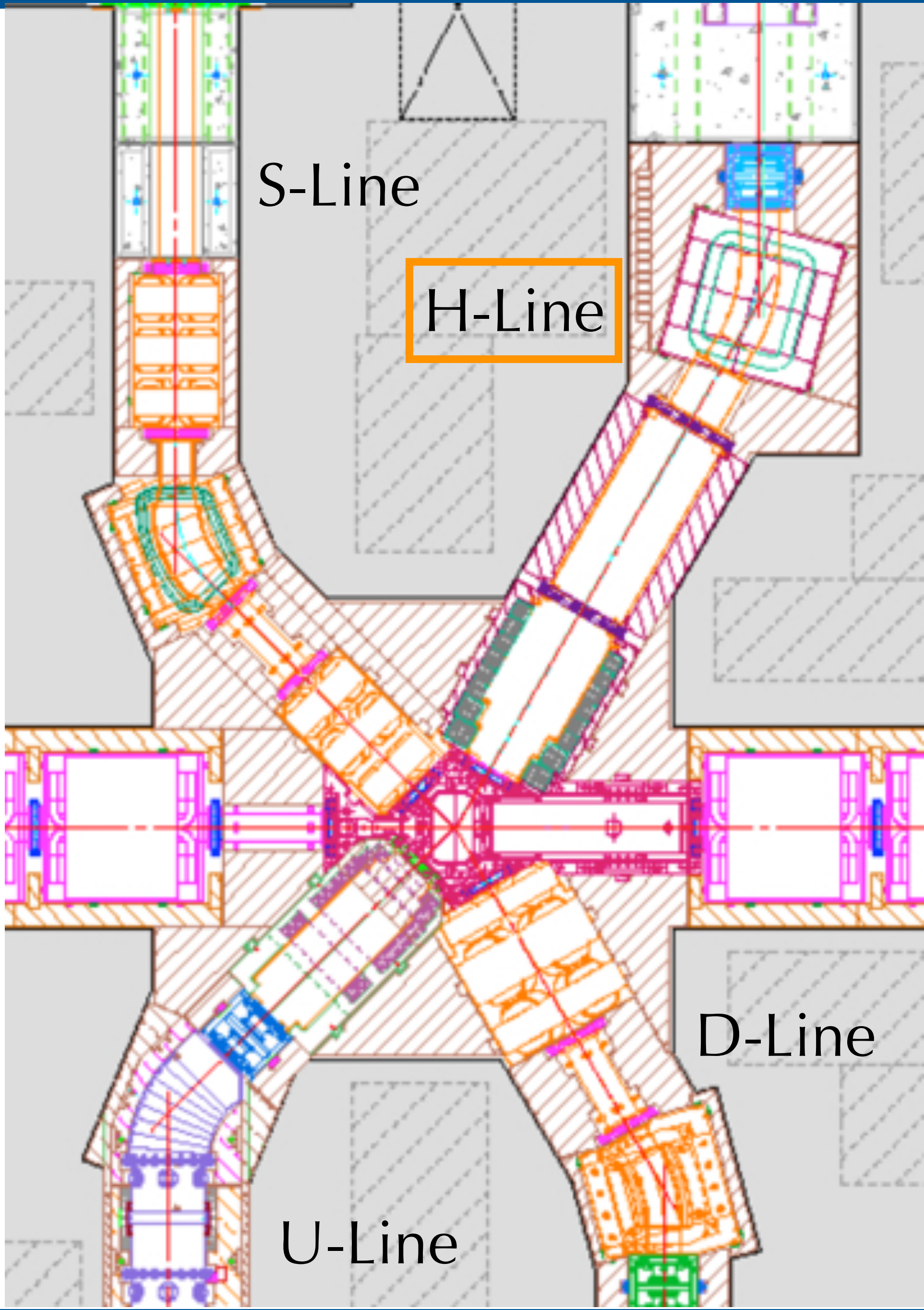
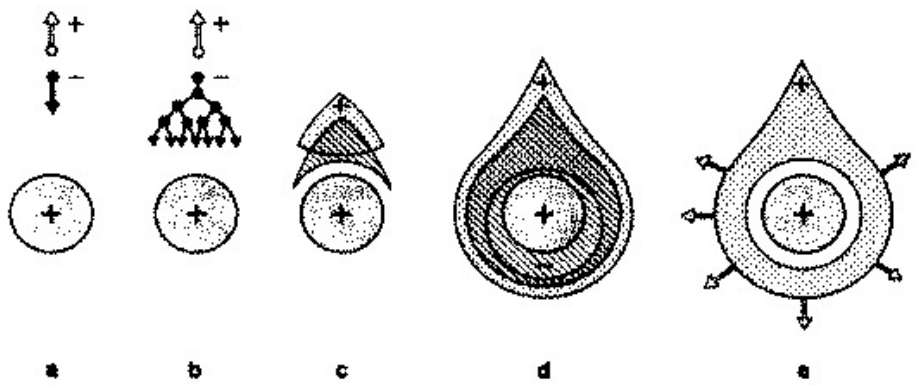
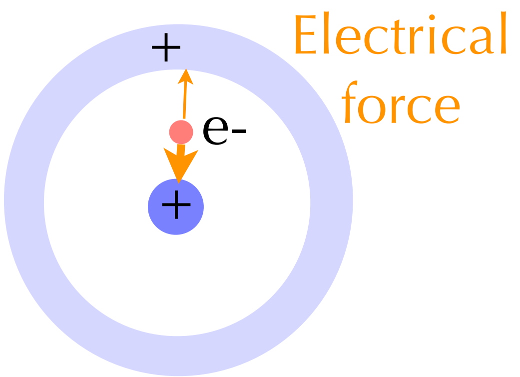
J-PARC MUSE beamlines

- D-Line (Decay Muon Line)
  - Operating
- U-Line (Ultra Slow Muon Line)
  - Under commissioning
- S-Line (Surface Muon Line)
  - Under construction
- H-Line (High Momentum Line)
  - Large acceptance (130msr)
  - Momentum tunable
  - Mu HFS, g-2, DeeMe mu-e conversion experiments are proposed



Space charge effect





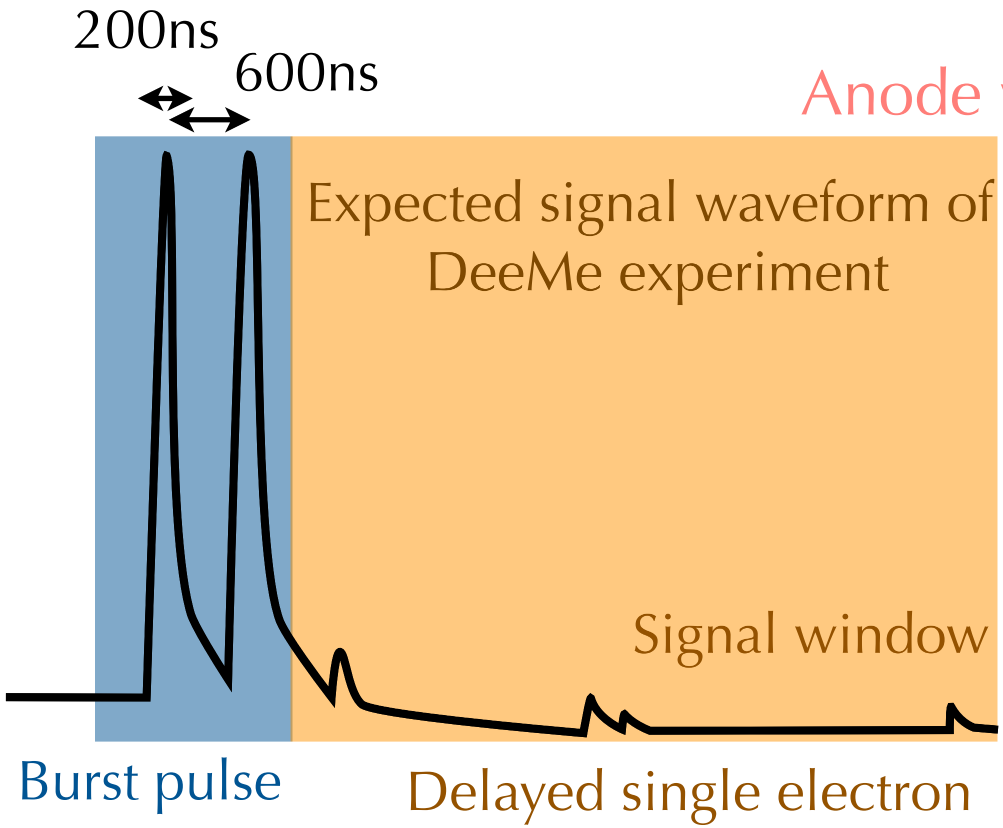
Steep slope of electrical field near wire accelerate electron
Energy in mean free path > ionization, then avalanche occur

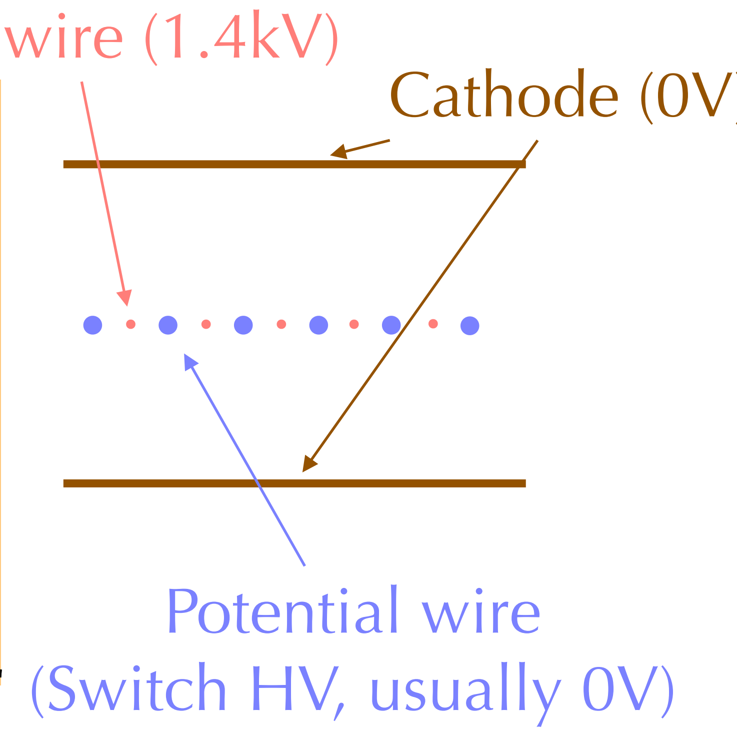
Too many ions near wire suppress acceleration of electron.
Resulting in gain reduction

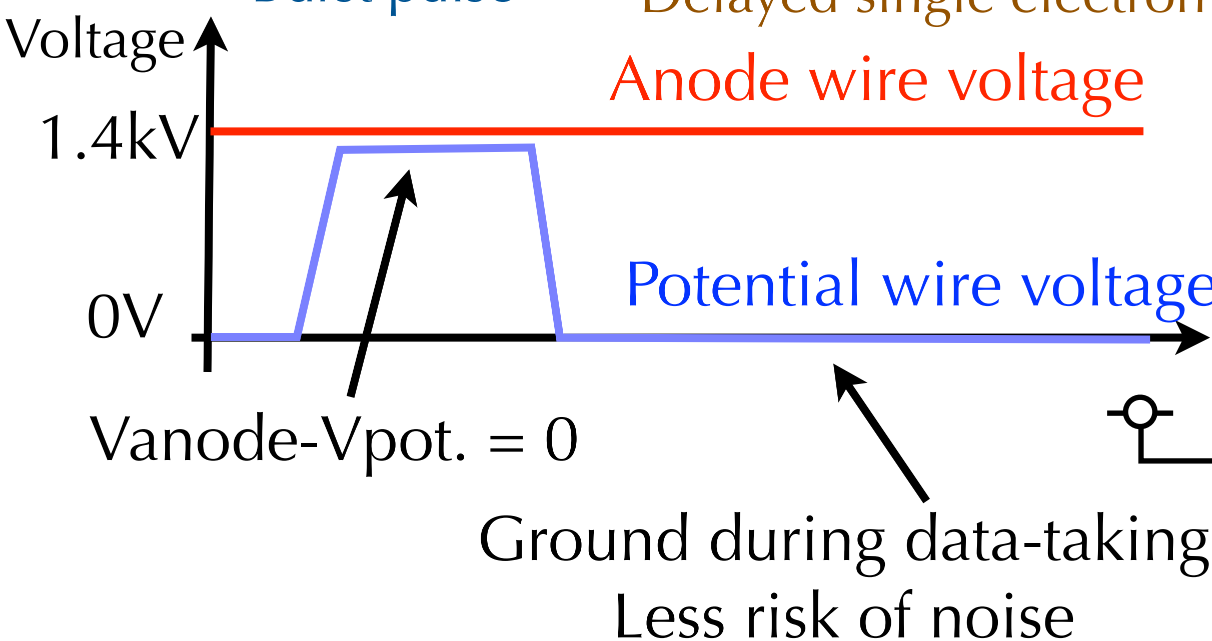
Cause: too lot ions

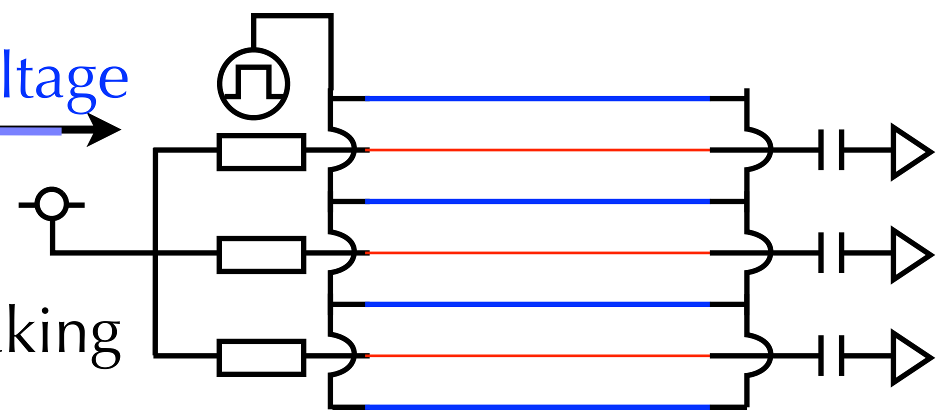
Solution: Sweeping out initial electrons by prompt burst w/o avalanche

How to operate chamber w/o kicker magnet







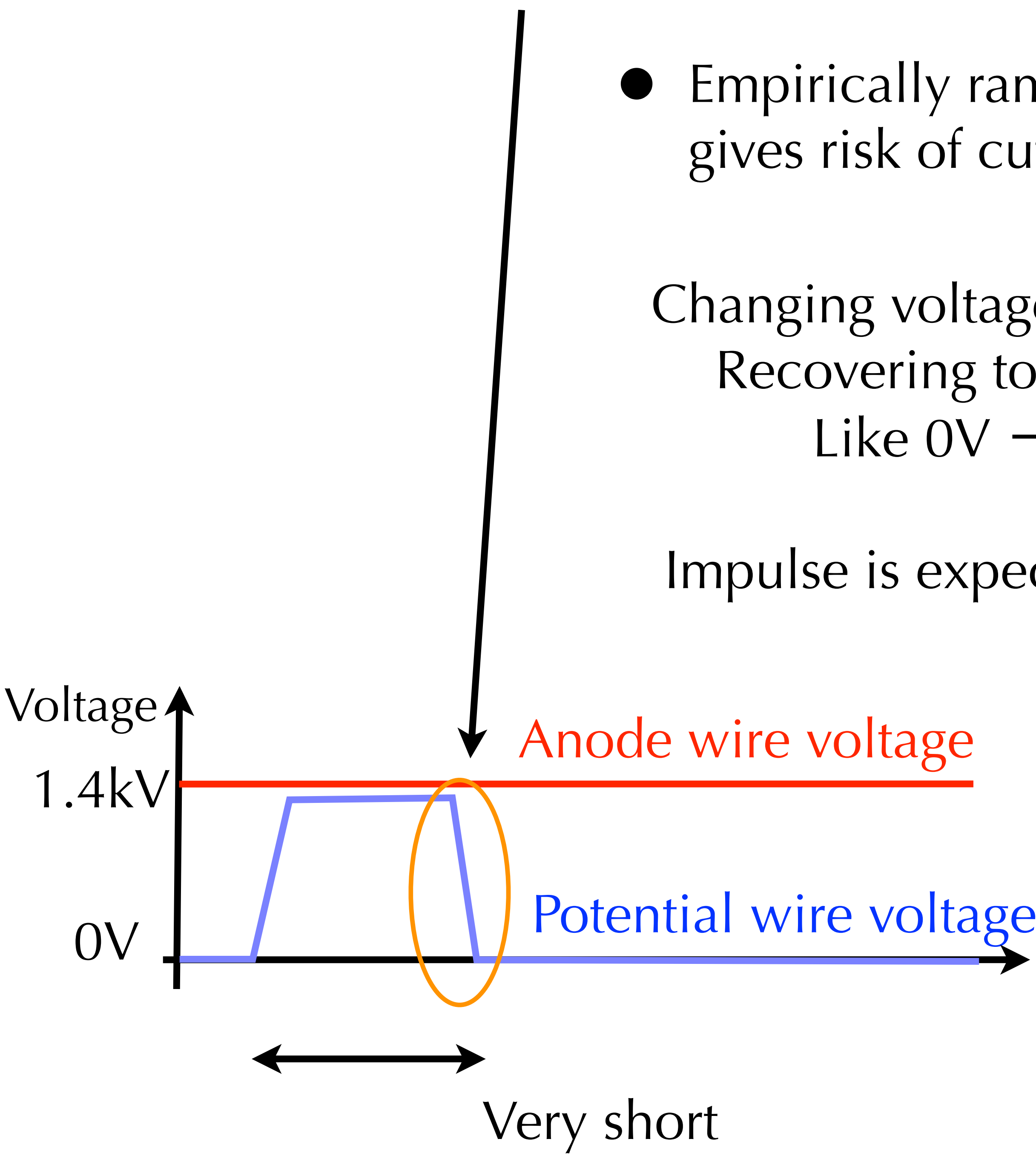


Ramping down ~1.5kV within a few 100ns

- Empirically ramping up >100V within <1s gives risk of cutting wires

But,
Changing voltage very short term and
Recovering to the former voltage
Like 0V → 1.4kV → 0V

Impulse is expected to be very small

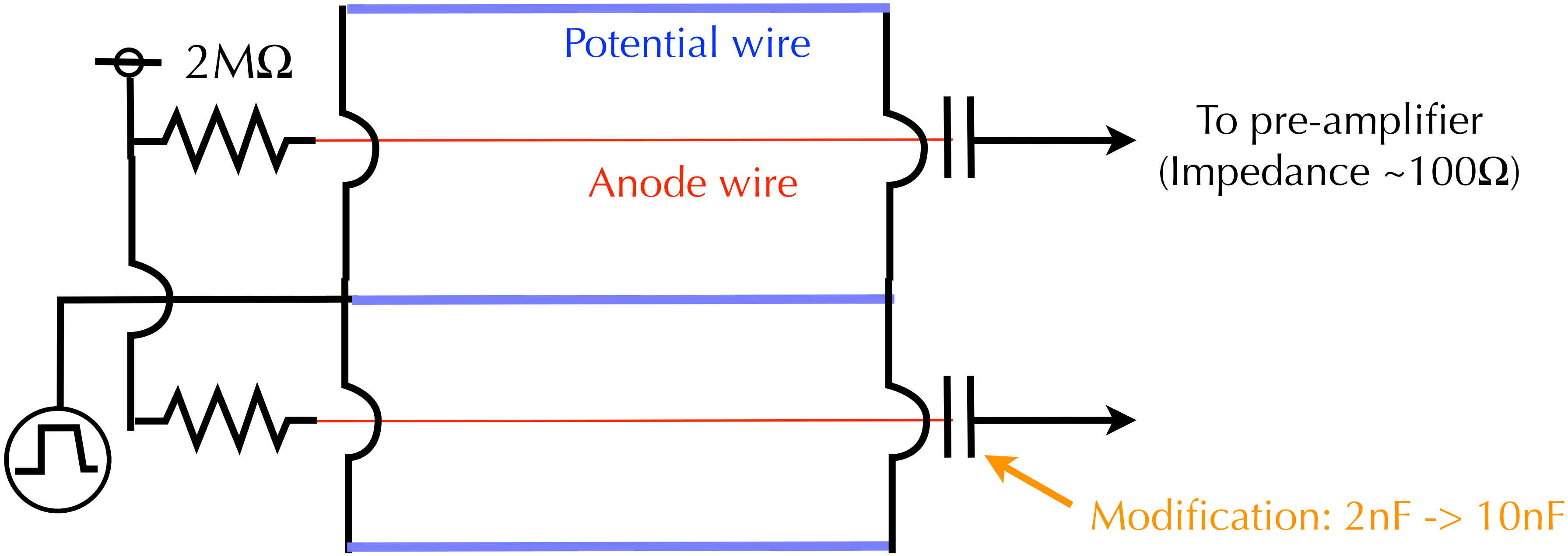


Amplifier output

Two issues

- Chamber: LC resonance
- Amplifier: Saturation

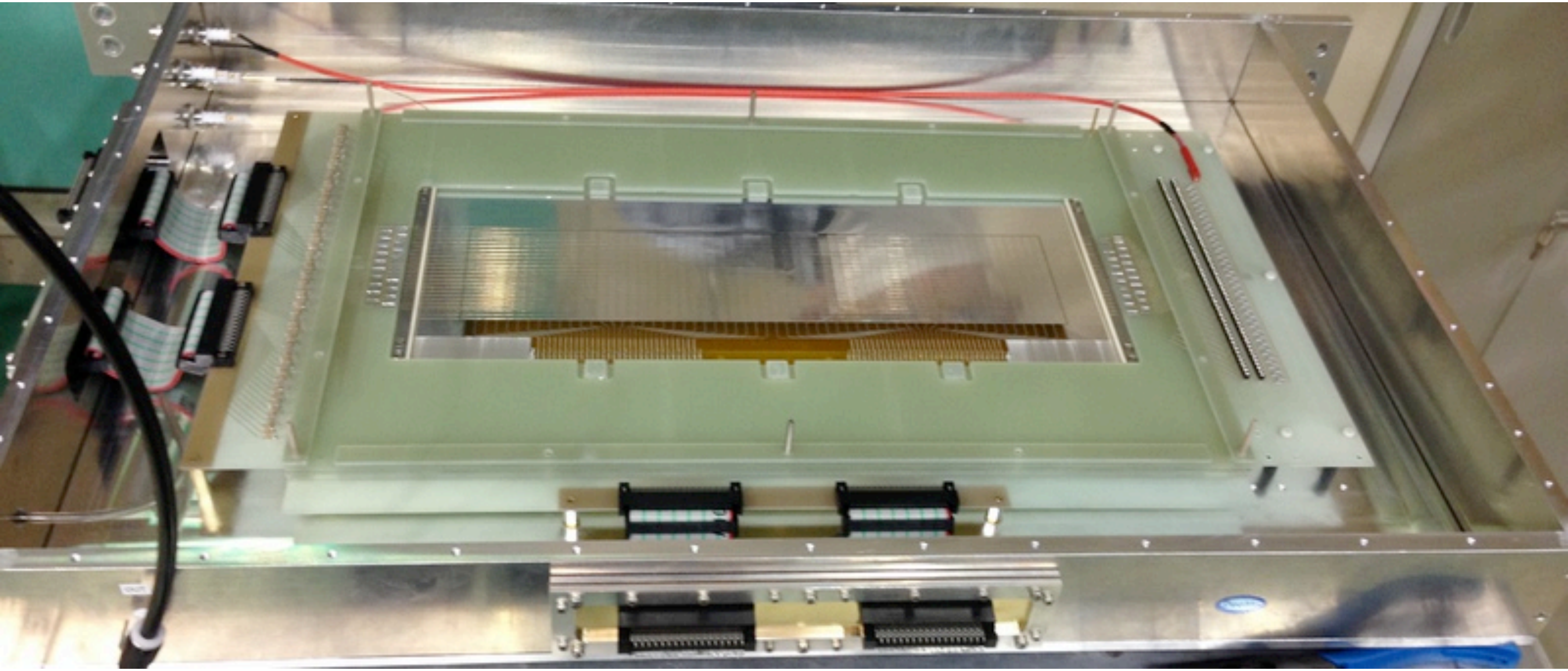
LC resonance



Probably LC resonance circuit exists somewhere
Increased readout capacitance 2nF -> 10nF

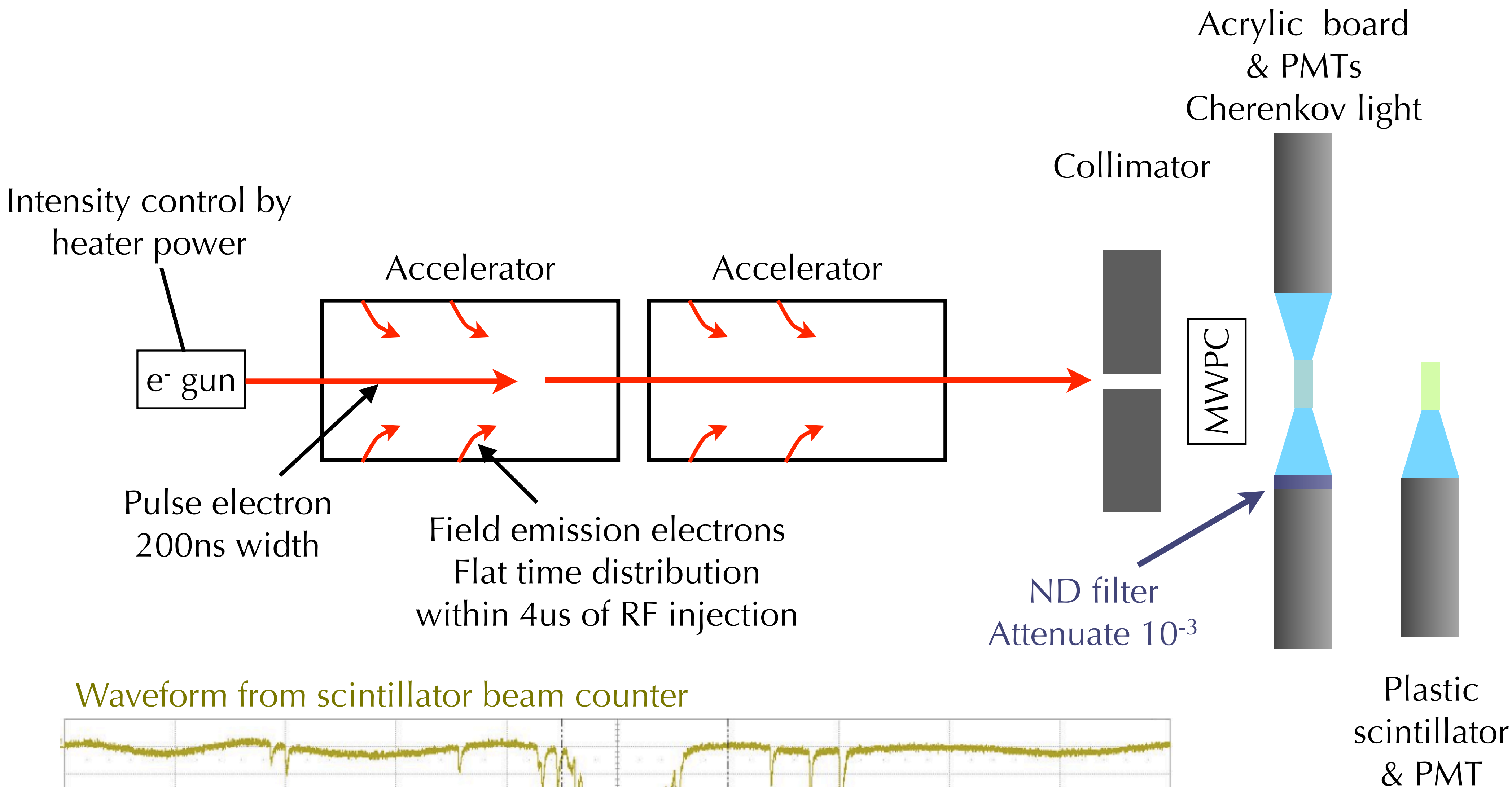
Overdamping when
$R^2 > 4L/C$

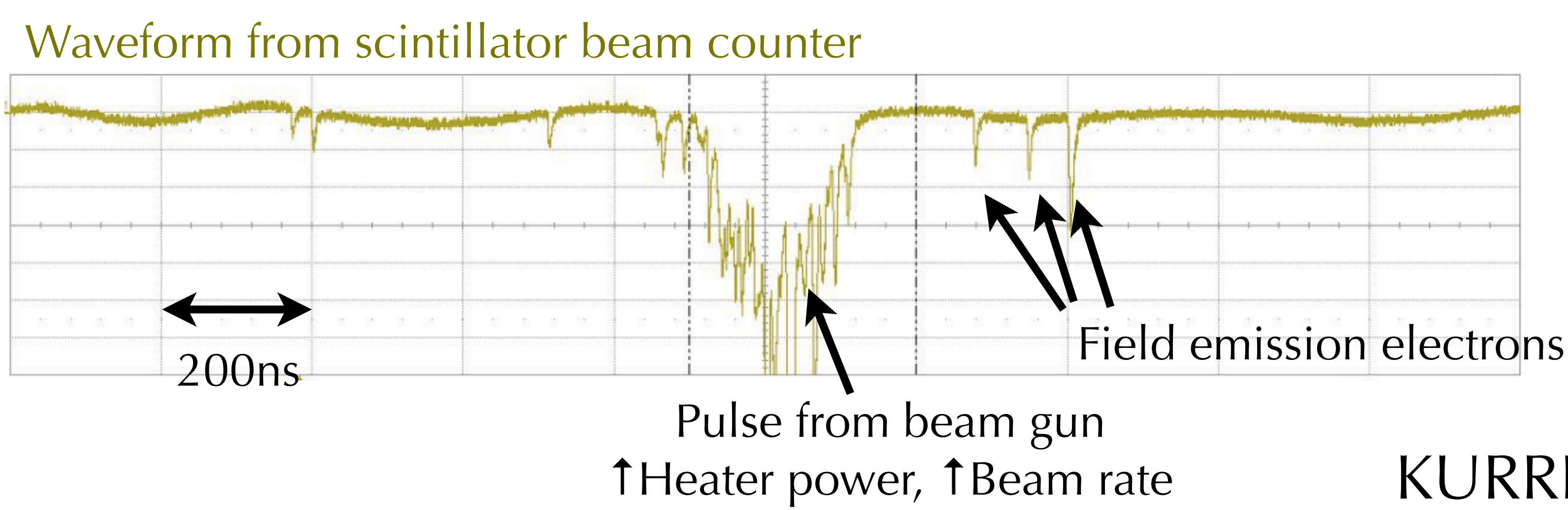
Large prototype chamber

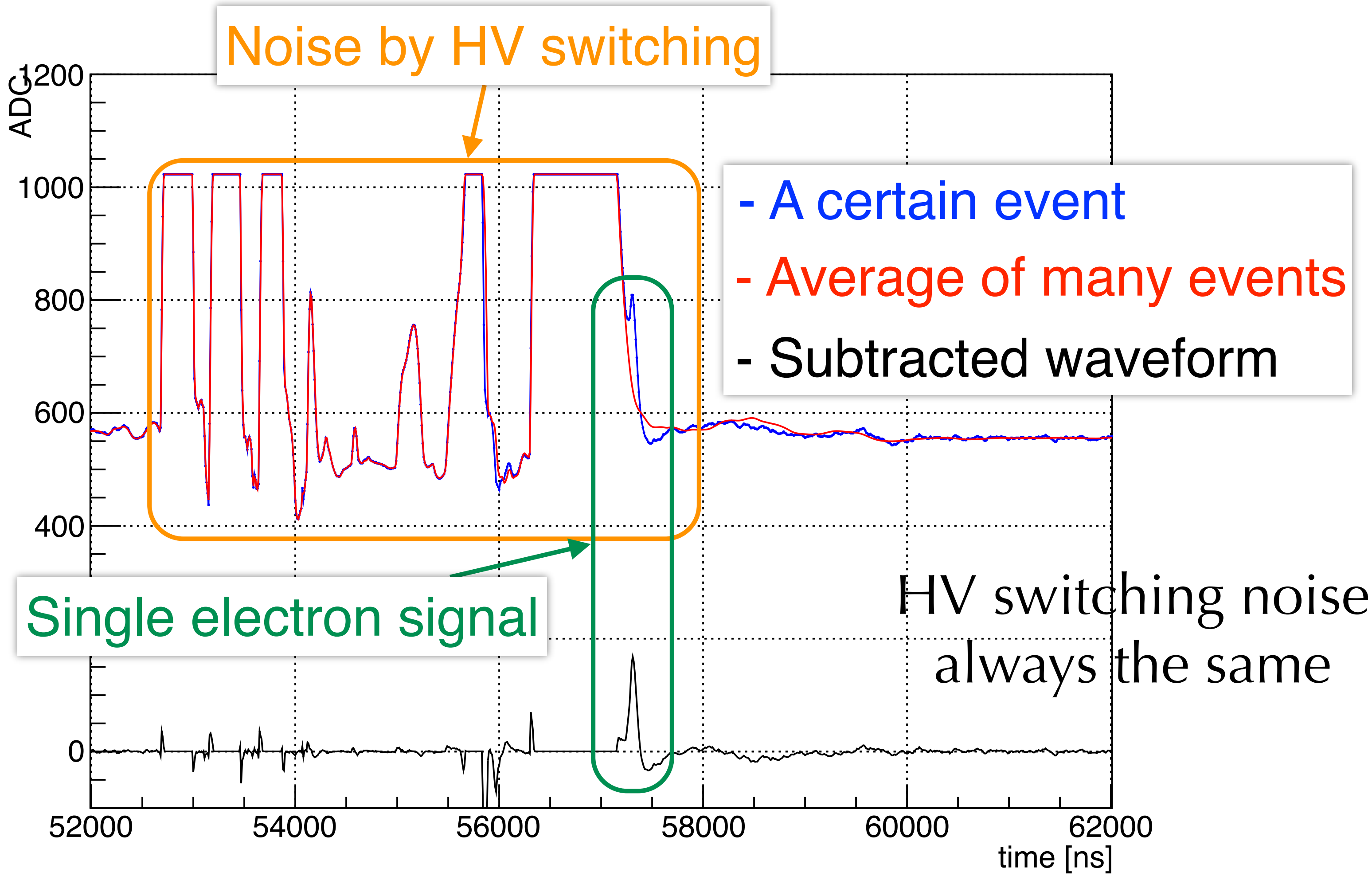


- 0.7mm pitch 300mm length
- Wire + cathode readout

Setup of test beam experiment





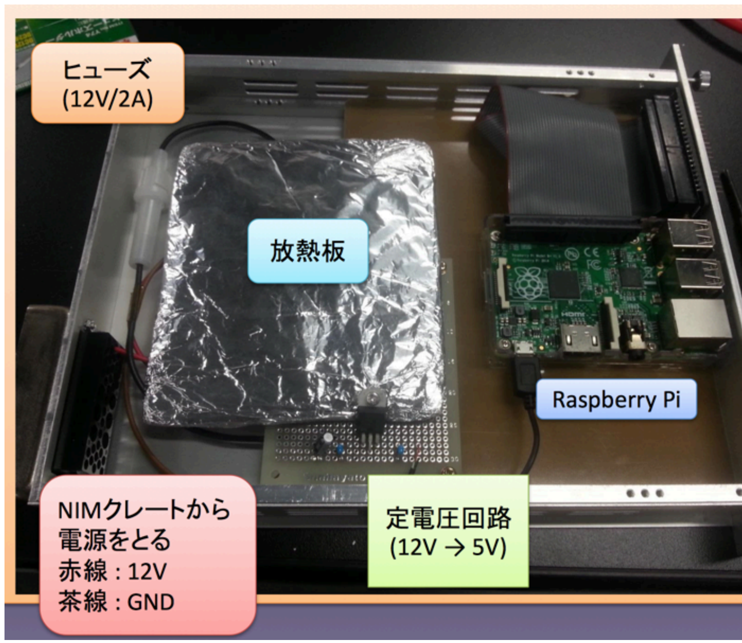


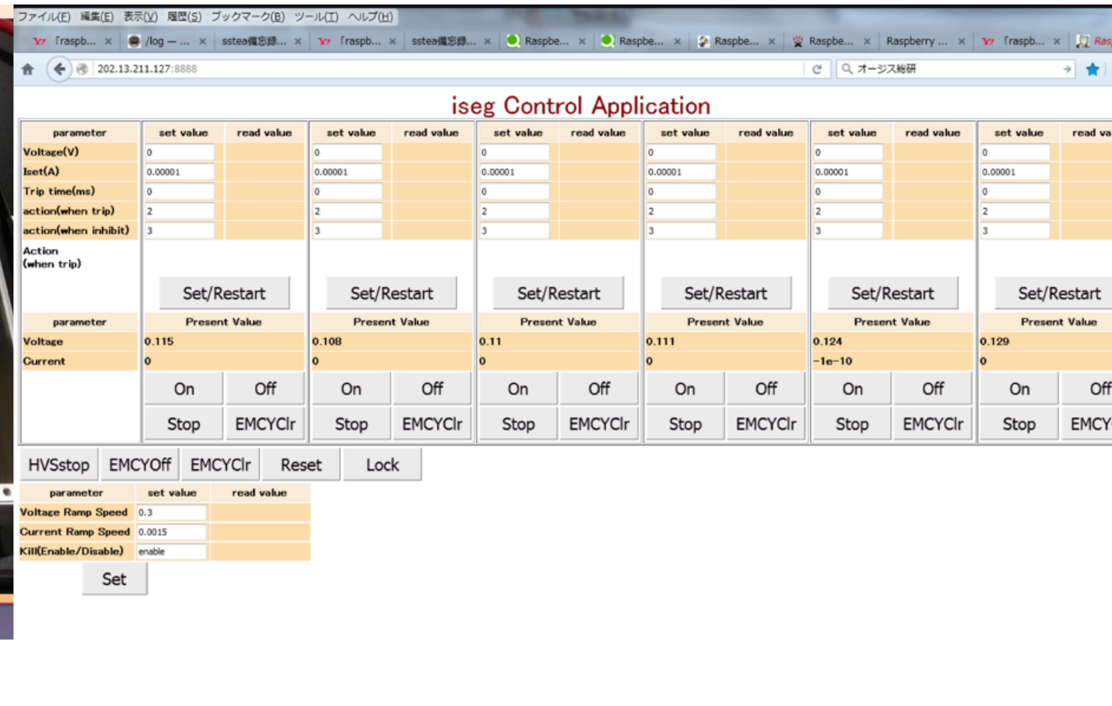
- Succeed to observe delayed electron after a burst pulse (instantaneous rate ~70GHz/mm^2, pulse width200ns) Approximately full condition with large prototype chamber

But discharge occur after several hours of operation

HV control with Raspberry-pi

(By Y. Takezaki Osaka City Univ.)

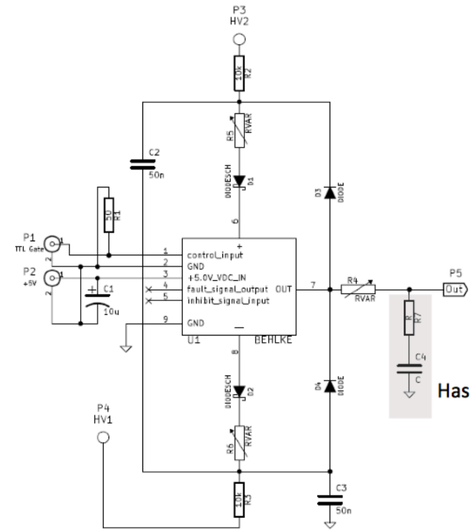


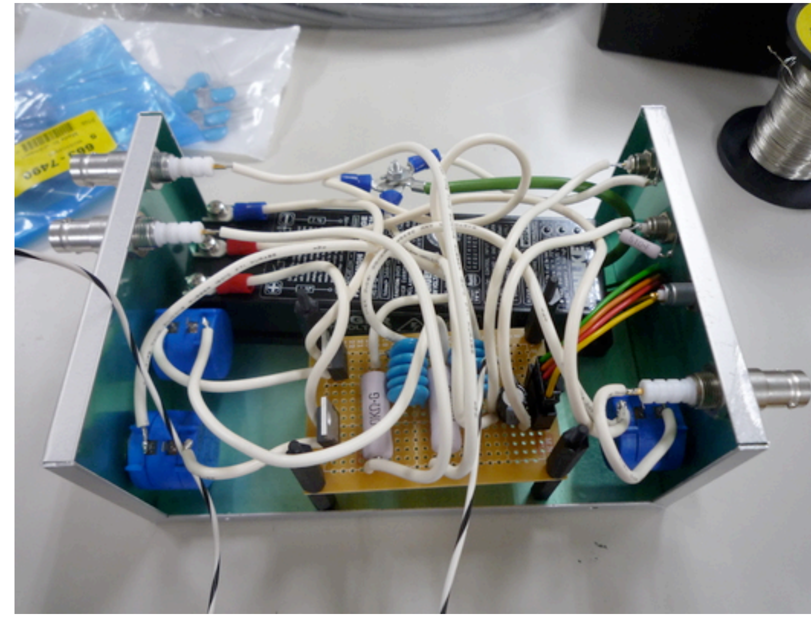


- Connect iseg HV module with Raspberry-pi
- Python program gives web GUI interface and controls the module
- Trip of either anode or potential wire voltage trigger fast shut down of both the wires

Handmade HV switching module

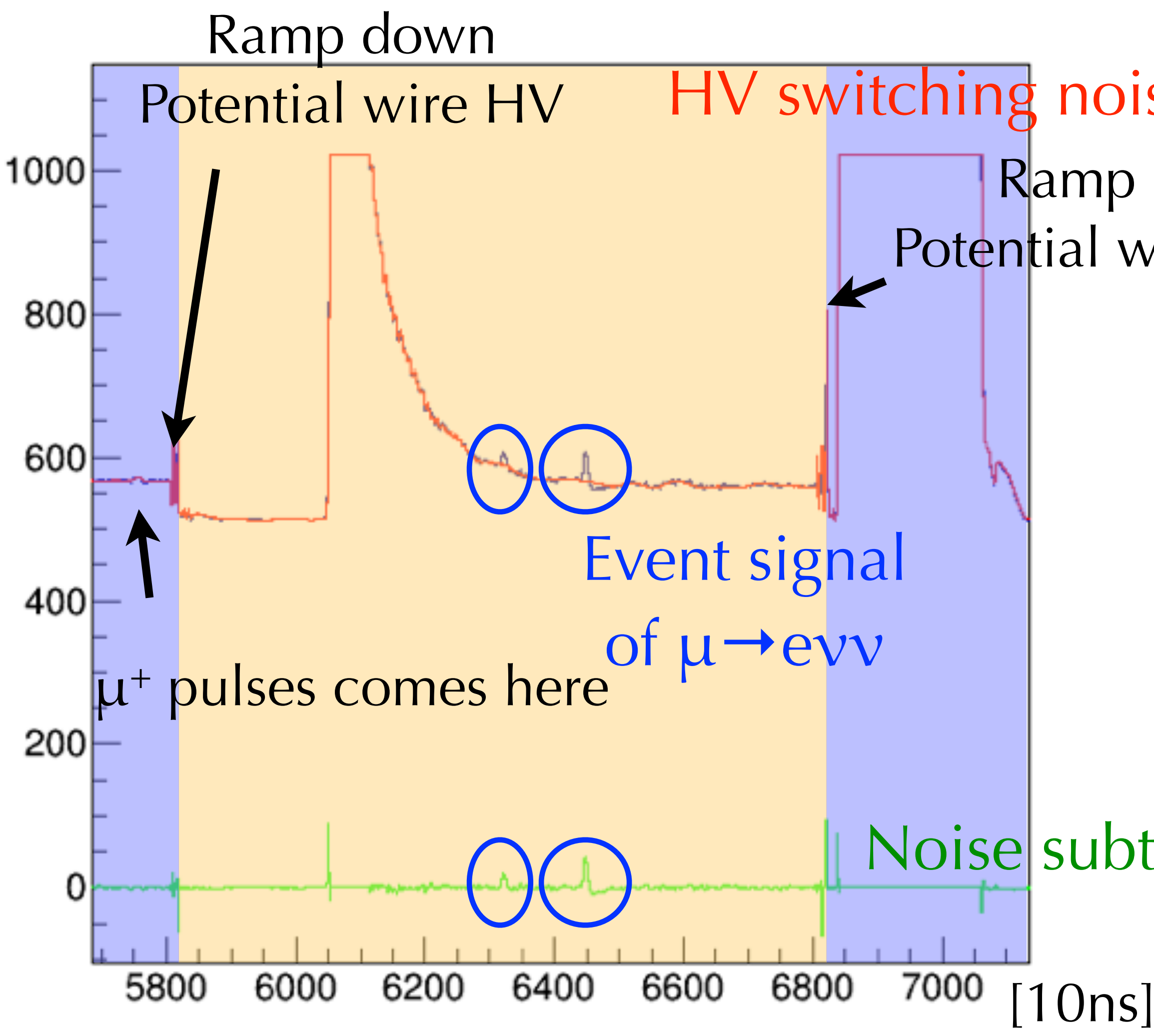
- Former HV module was not suite for new scheme

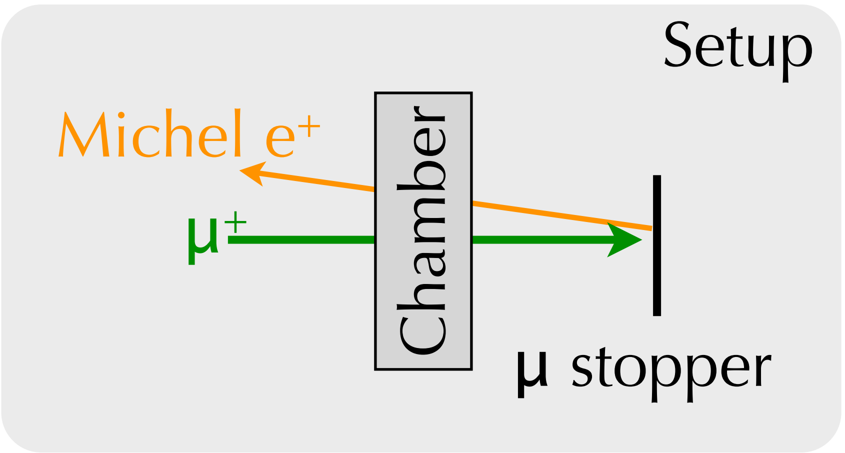




- Utilized MOS-FET based Behlke switching module
  - Partially because having not enough time to be ready for beam experiment

- Behlke module have protection for the module, stopping when detecting something
  - Due to this protection, we should have make the switching ramping up speed very slow (a few μs)

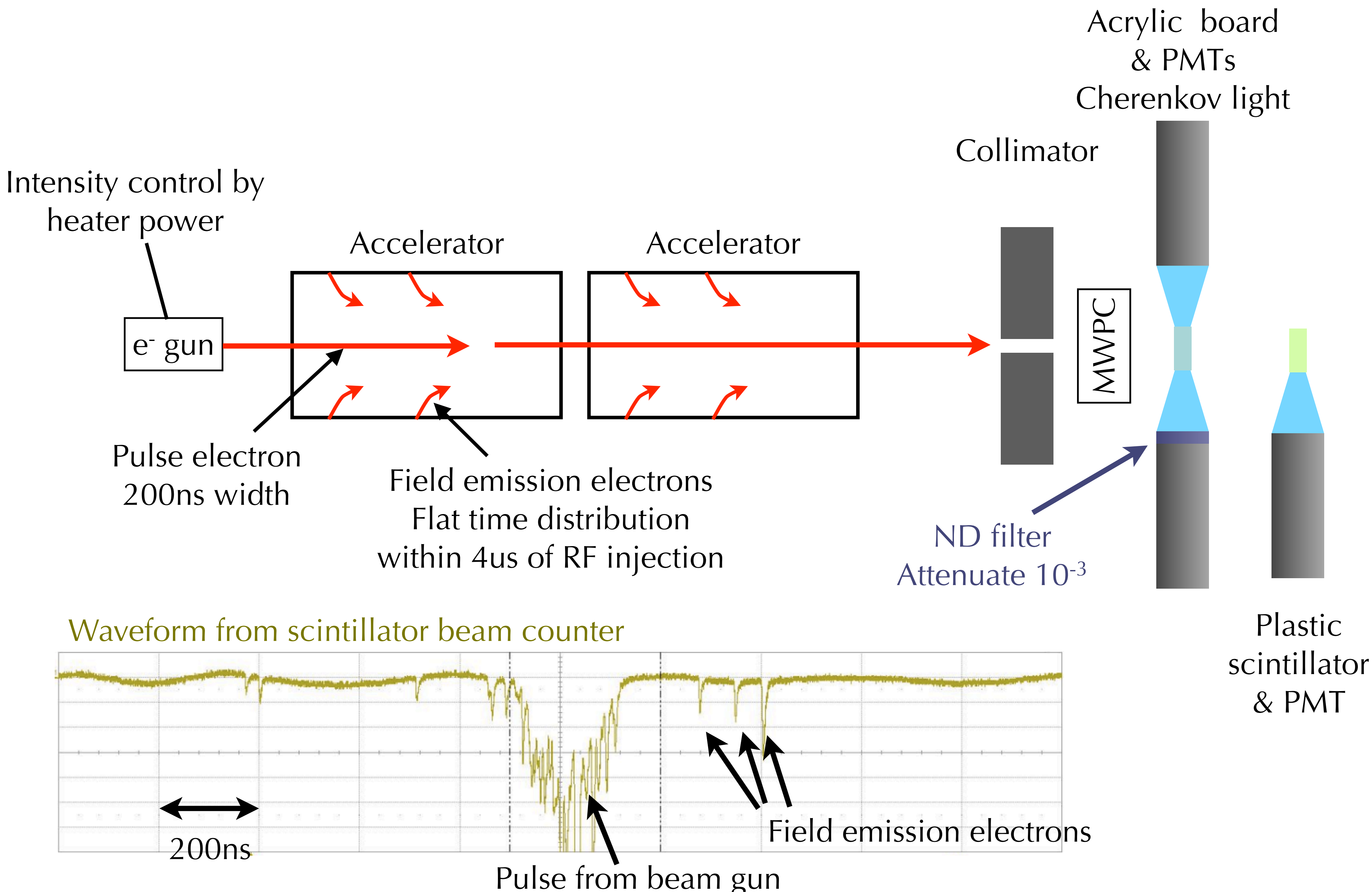


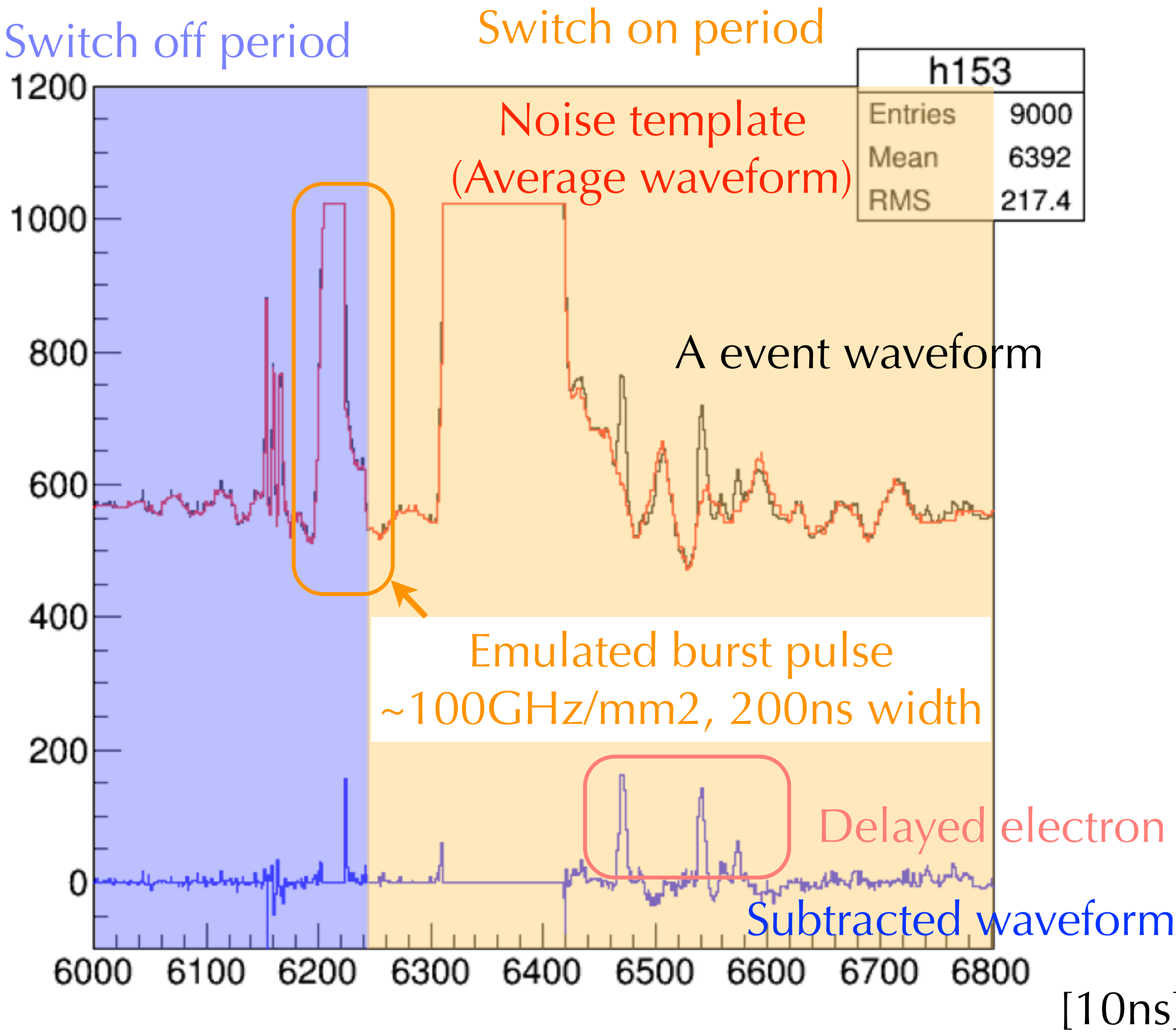


Chamber worked during 2 days of data taking time,
giving delayed signal of $\mu \to e\nu\nu$ after μ^+ pulses with 10^4 gain operation

Voltage application for 3×10^4 gain was ok, waited for beam, but beam didn't come

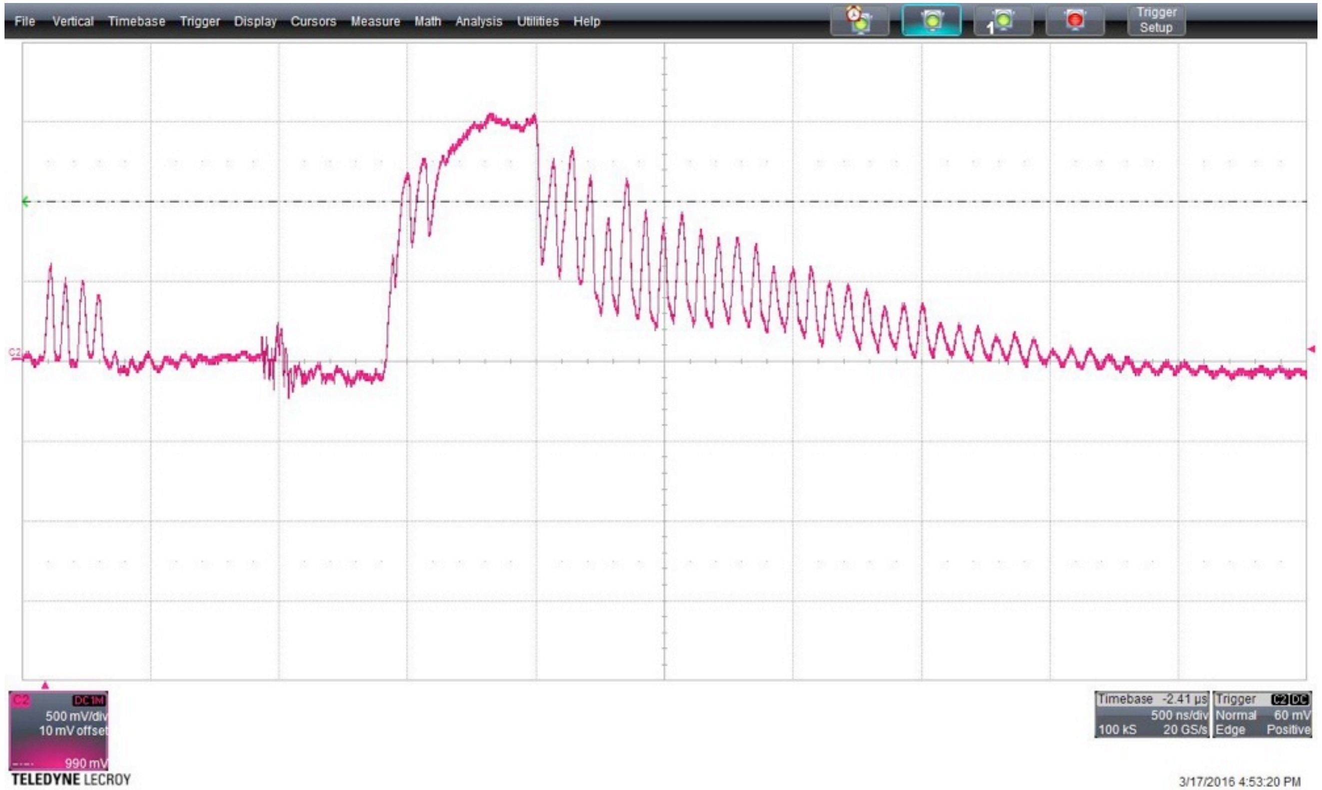
Again, This setup



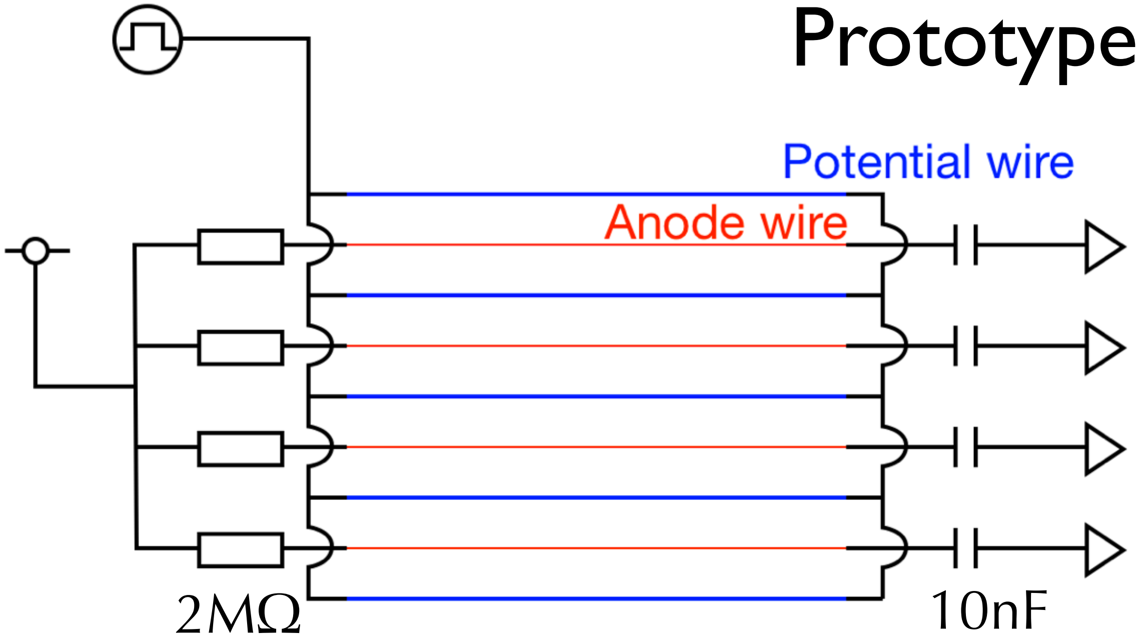


Successfully observed delayed electron after a prompt burst equivalent pulse
2days operation w/o trouble.

LC resonance with Final chamber



Prototype

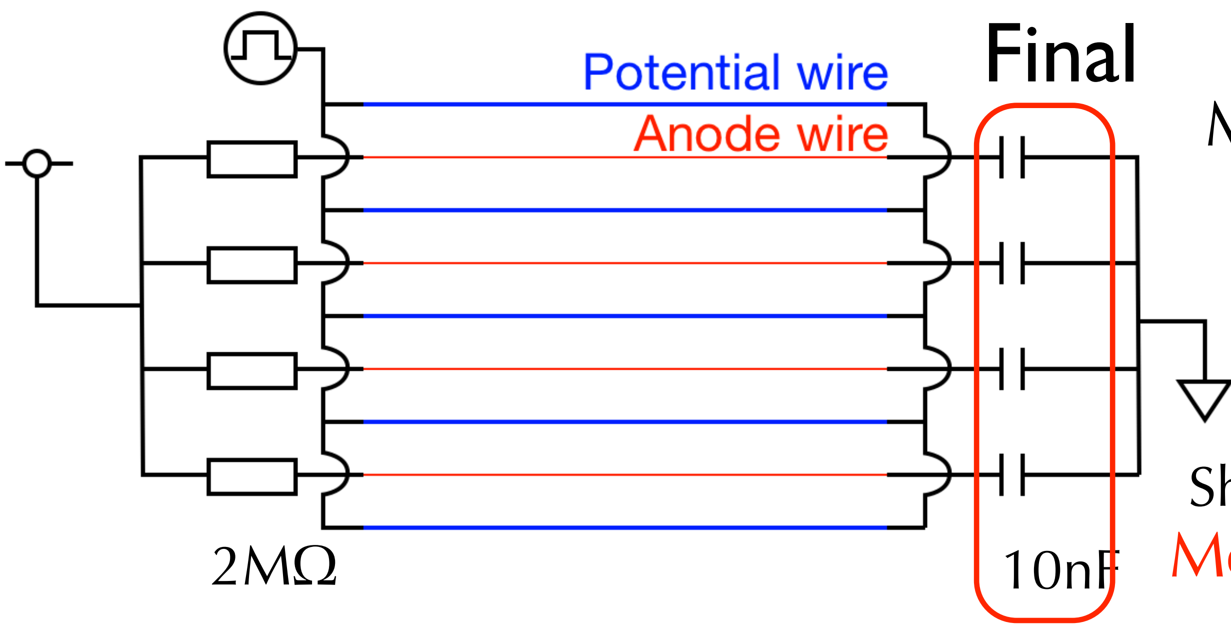


To amplifier (~100Ω impedance)

Resonance disappeared after changing C 2nF→10nF

(R > 2√(L/C): overdamping)

Final



My fault

R = 0 < 2√(L/C): LC oscillation

Shunt to ground

Modified → R=1kΩ, C=2nF
And solved!!