T2K Proton Beam Position Monitors

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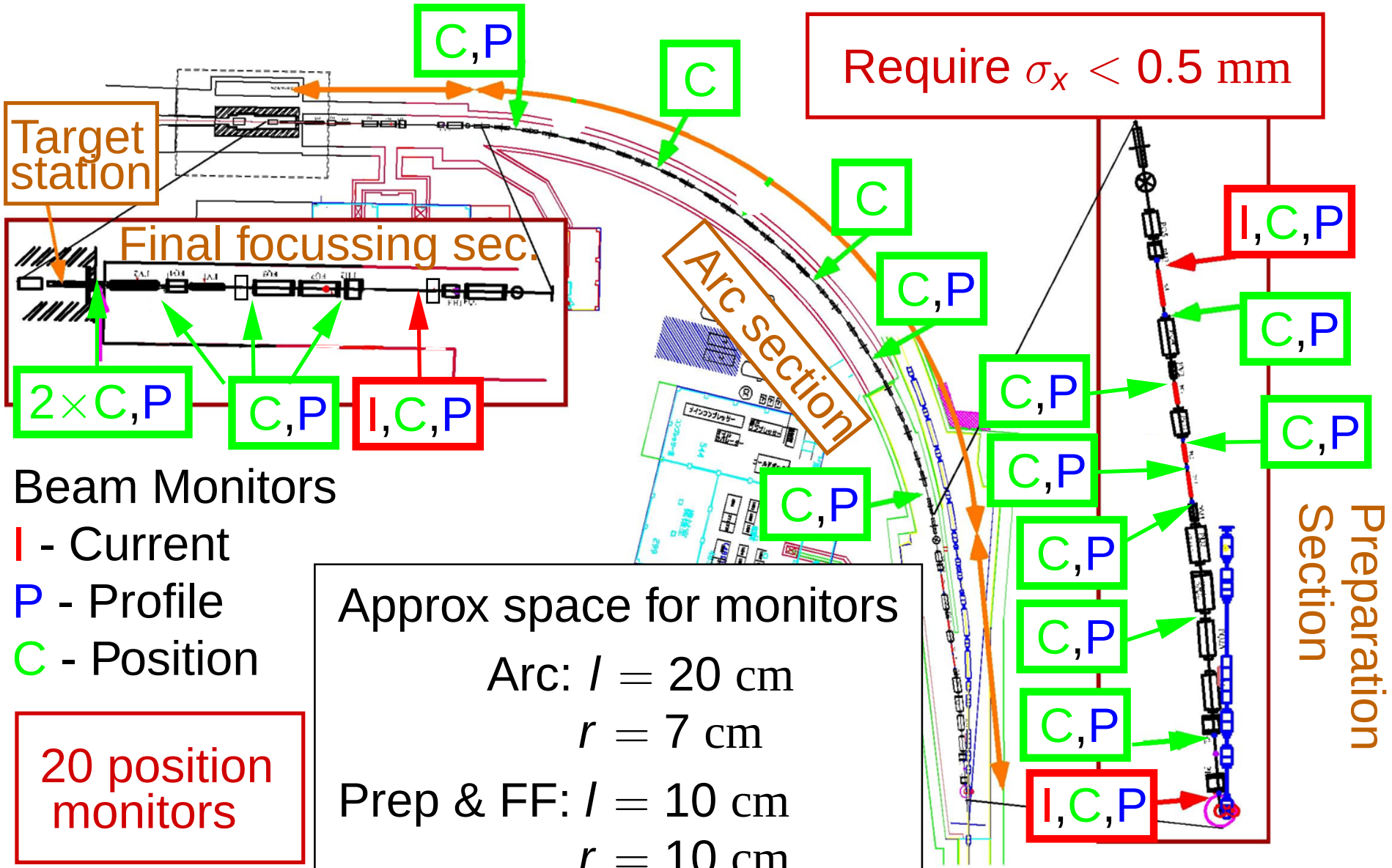
Neutrino Beams & Instrumentation 2006

Introduction



Beam Monitors

I - Current

P - Profile

C - Position

20 position monitors

Approx space for monitors

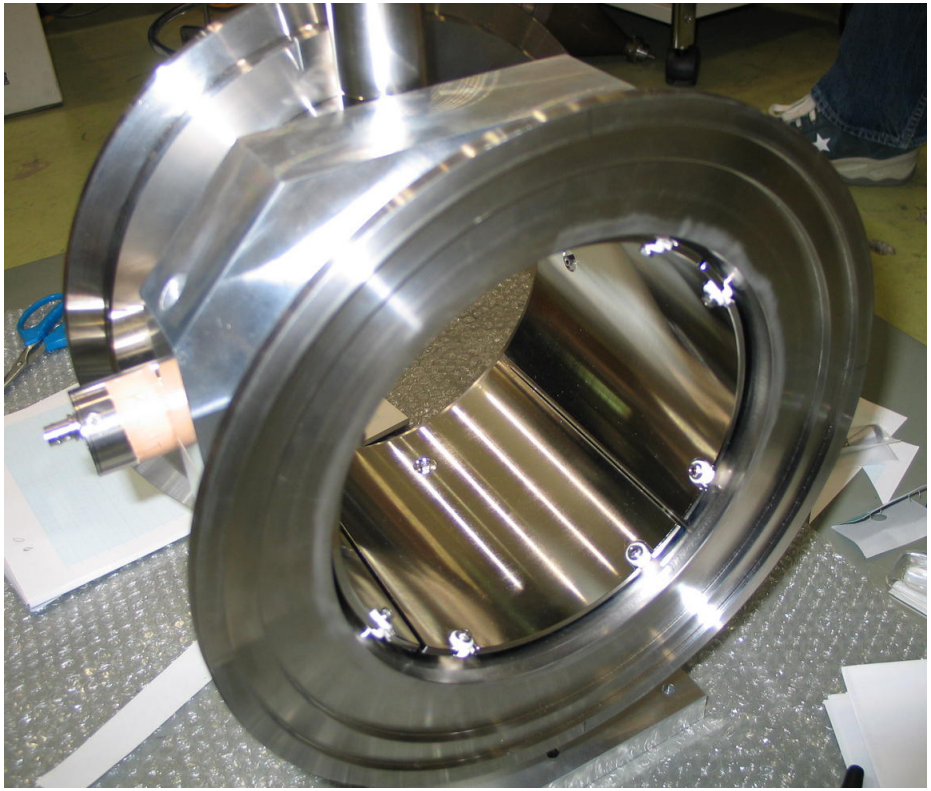
Arc: $l = 20$ cm

$r = 7$ cm

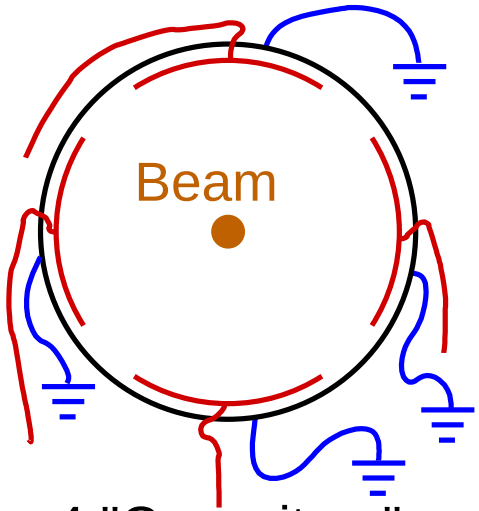
Prep & FF: $l = 10$ cm

$r = 10$ cm

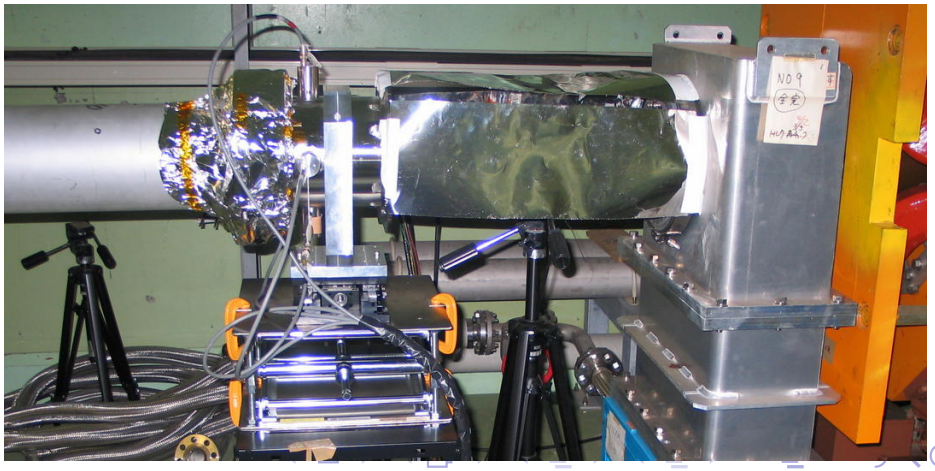
Beam Test in the K2K beamline



Electrostatic Monitor (ESM)

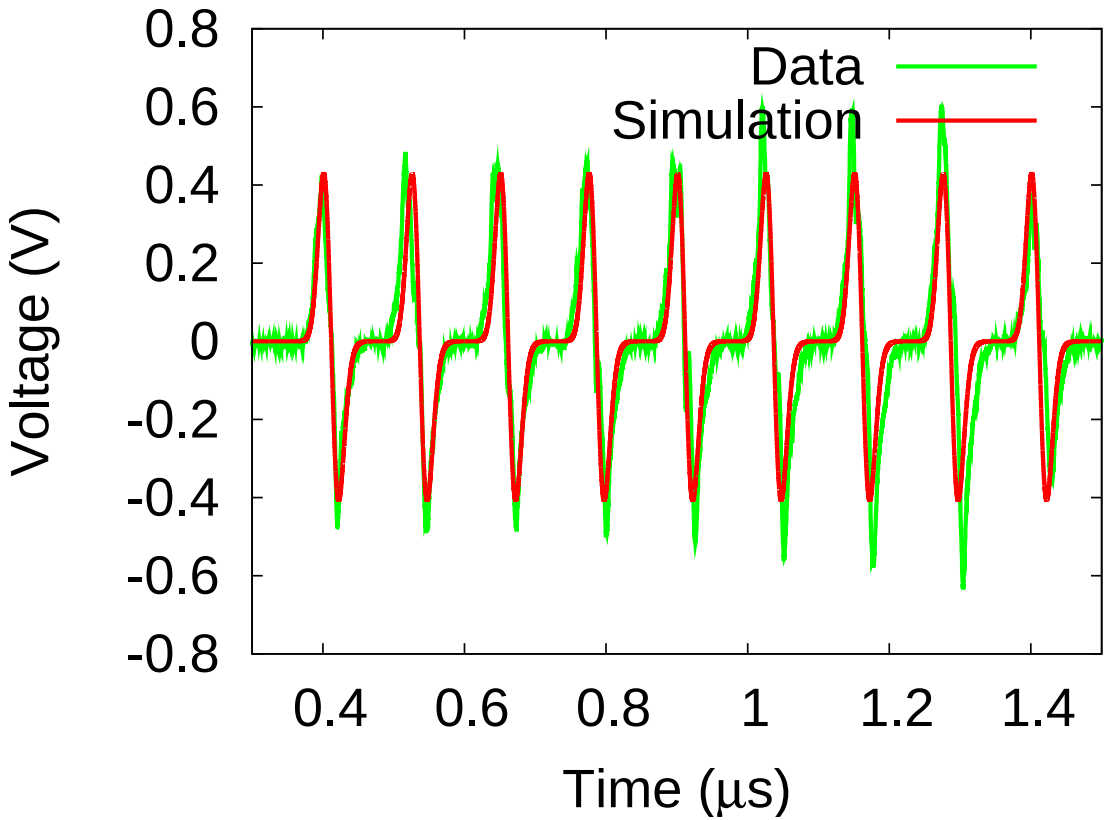


- Confirmed suitability of basic monitor design
- ESM (not LPM, strip etc.)
- Four $\pi/2$ electrodes
- No transformers on outputs



Simulation vs. Data (qualitative)

Macro structure

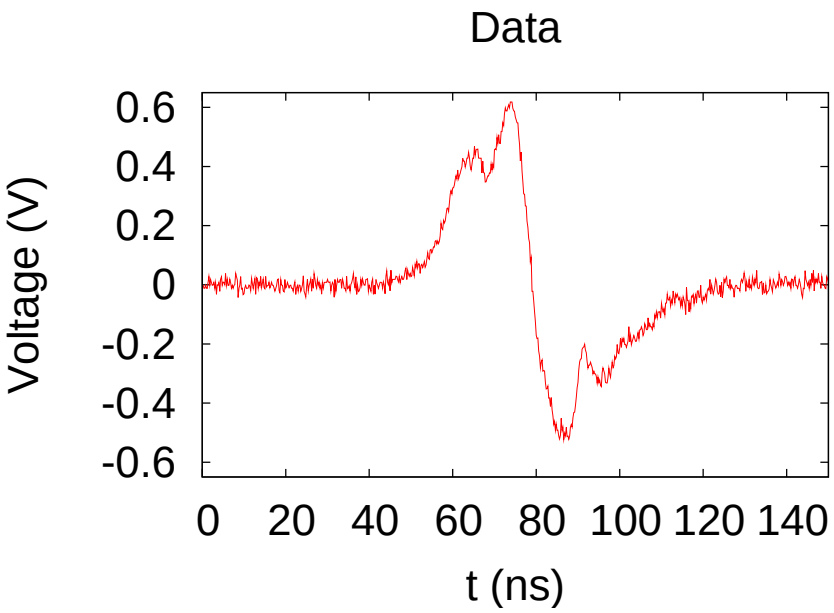


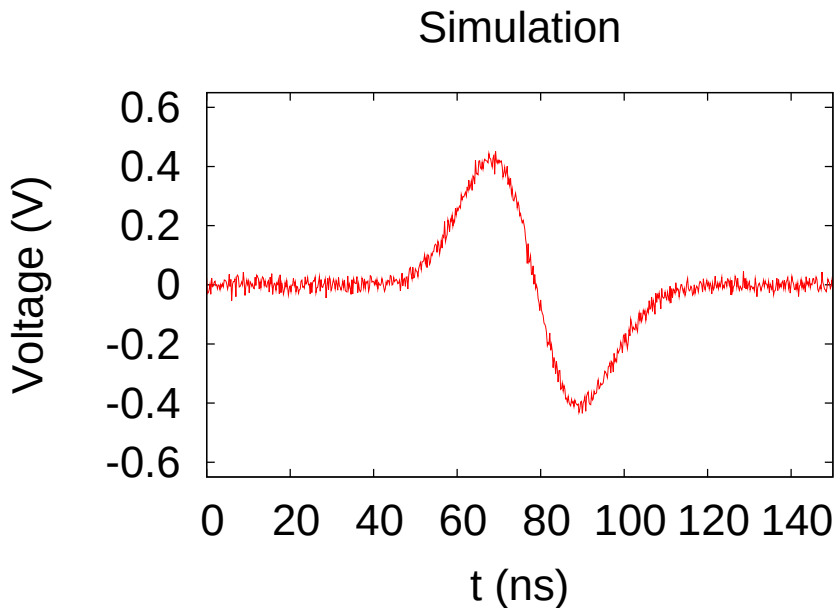
Gaussian bunches	
p/spill	2.8×10^{12}
N_{bunch}	9
σ_{bunch}	10 ns
T_{bunch}	125 ns

- Simulation scaled by 50% (5.9 dB for 100 m) ($F_{\text{signal}} < 100$ MHz) to account for cable attenuation

Simulation vs. Data (qualitative)

Micro structure





- 50% cable atten (in freq range of signal).
- Data taken with 5 $\mathrm{GS/s}$ oscilloscope
- White(ish) noise observed in data: from oscilloscope
  $\rightarrow$ Overlay 17 mV RMS noise to simulation (bin-by-bin)
- Strange signal shapes due to slightly non-Gaussian beam
- Reasonable agreement

Simulation vs. Data (quantitative)

Spill by spill fluctuation in measured beam pos. gives monitor resolution

$$A \equiv \frac{L-R}{L+R} = 2\frac{x}{r}\frac{\sin\phi/2}{\phi/2}\{1 - \frac{2}{r^2}\frac{\sin\phi}{\phi}(\sigma_x^2 - \sigma_y^2 + x^2 - y^2) + \ldots\}$$

$$\Rightarrow x \simeq \frac{r}{1.8}A, \quad \sigma_x \simeq \frac{r}{1.8}\sigma_A$$

Results

$$\sigma_x^{\text{data}} = (0.202 \pm 0.005)\ mm$$

$$\sigma_x^{\text{sim}} = (0.164 \pm 0.002)\ mm$$

- Reasonable agreement ($\simeq$ 20% deviation)
  - Non Gaussian beam
  - Fluctuations in actual beam position?
- Good enough for these purposes
- Can now simulate T2K configuration

Simulating for T2K beamline

The “known” factors

Study

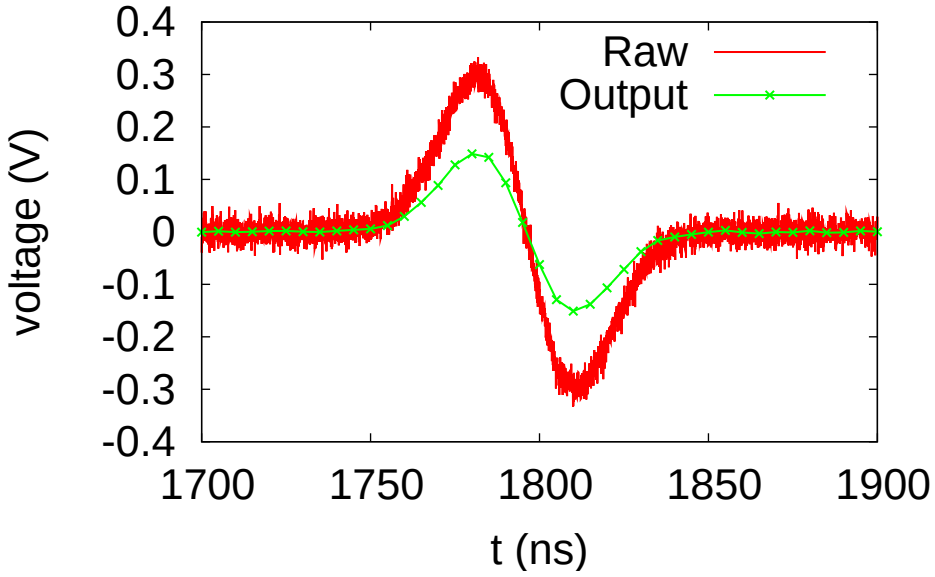
- Fixed parameters
  - Commissioning beampower
  - Least sensitive ESM (smallest electrode and larges radius)
  - Realistic cable attenuation
- Variables
  - Different sampling rates
  - Different precision (number of ADC bits)

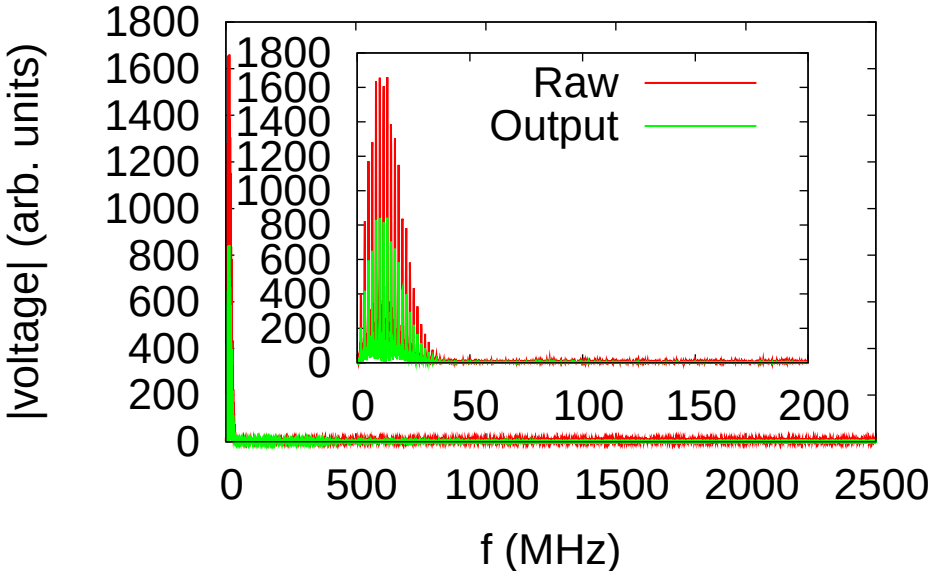
Simulating for T2K beamline

The “unknown” factors

- Beam test showed significant white noise
- Must be from oscilloscope since long cable acts as lowpass filter (no reduction of noise at high freq. observed)
- Will use VME sampling ADCs for T2K: expect little noise from electronics
- Achieved resolution critically dependant on noise
- Don’t know what noise to expect
- For now, introduce white noise before cable

Sample output





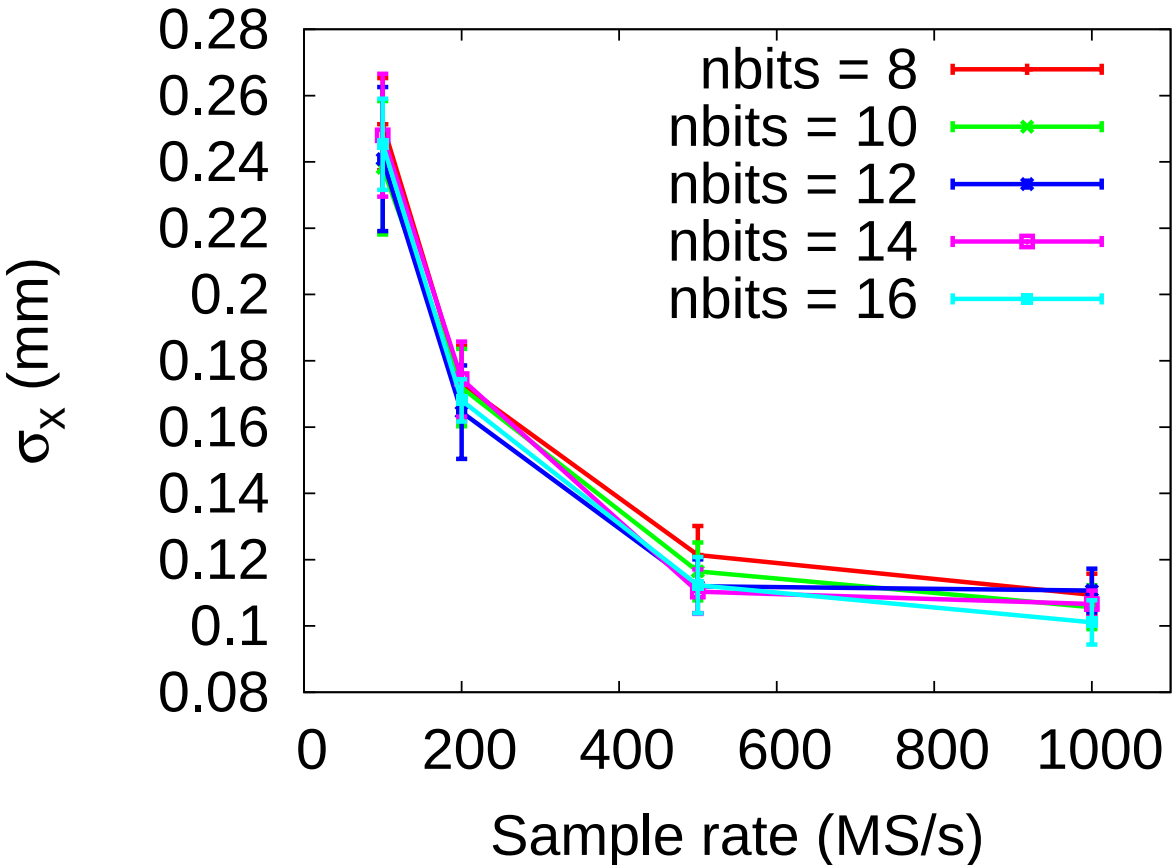
- Simulate T2K beam with 1% power
- Signal size of about 150 mV
- 15 V to 30 V at 100% beam power

$\rightarrow$ Attenuators required after commissioning phase

Attenuation of 100 m cable

$f_{\max}$ MHz	dB	V_1/V_2
100	5.9	2.0
200	8.4	2.6
400	12.1	4.0
900	18.8	8.7
1200	22.1	12.7
1500	25.0	17.8
>1500	28.6	26.9

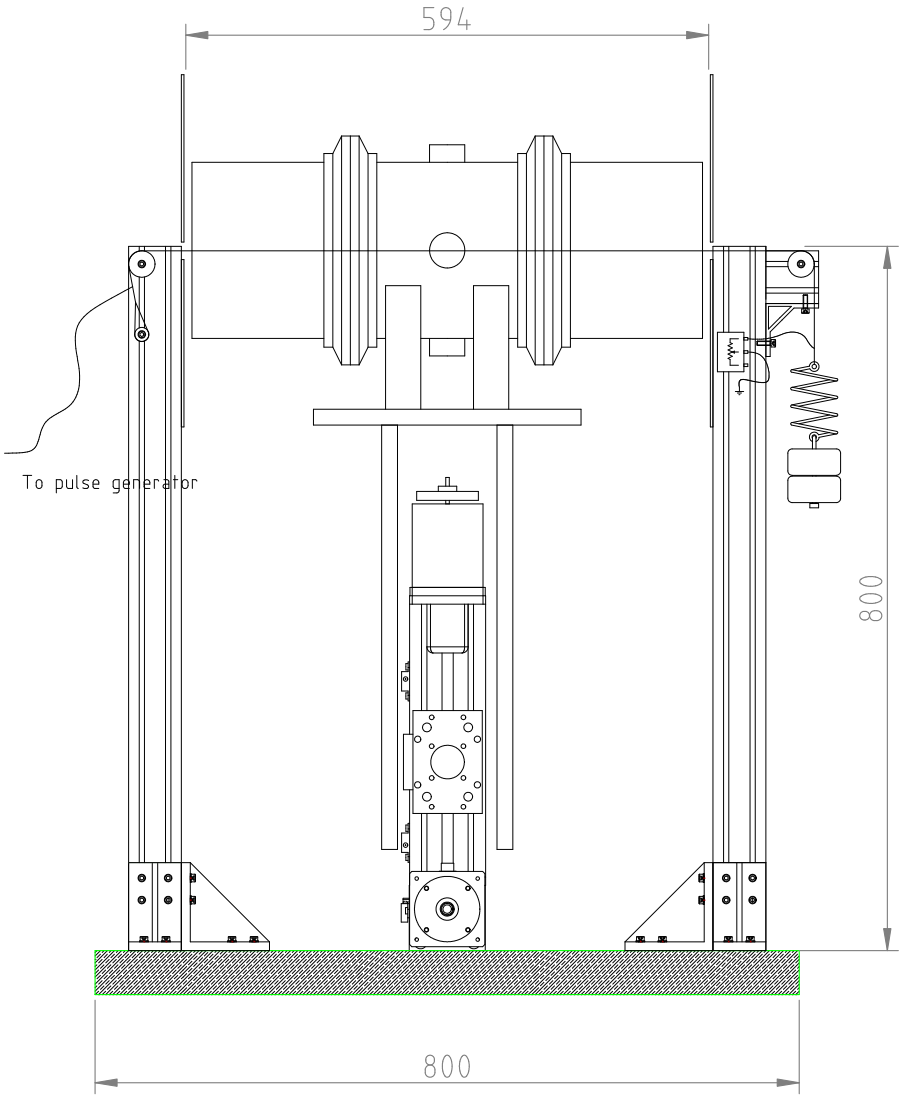
T2K ESM performance



- Design spec asks for $\sigma_x < 0.5$ mm
- Plan to use 100 MS/s 12 bit VME ADC from U. Washington

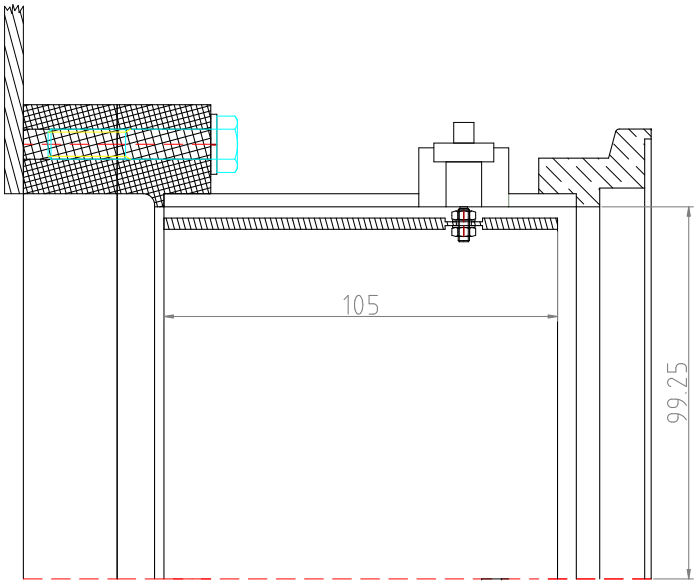
Calibration System

- Computer controlled 2D stage
- Map 100 mm $\times$ 100 mm grid

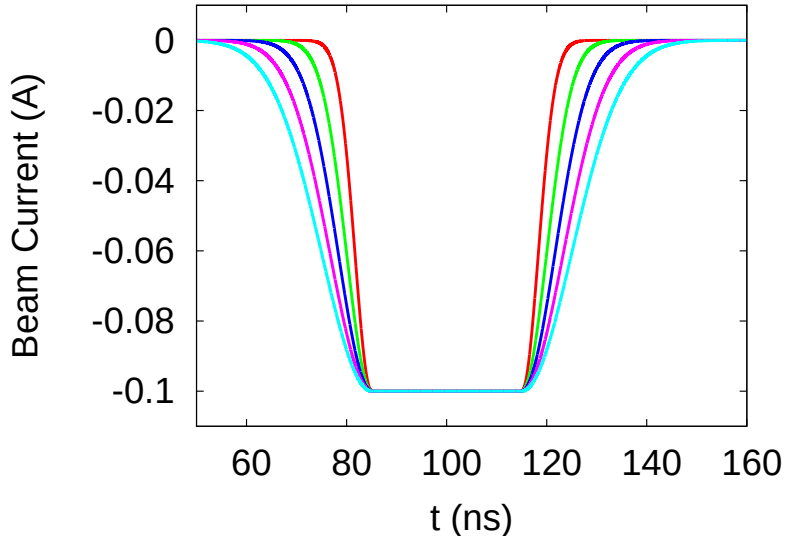


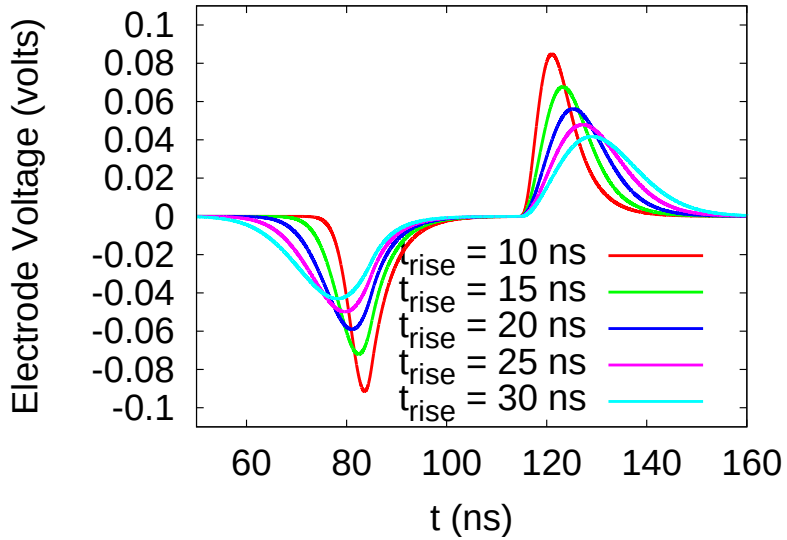
Production and Kyoto Beamtest

- Production drawings now being made (sketch below)
- Expect first ESM next month
- Beam test at Kyoto electron linac in December
- Test monitor and electronics

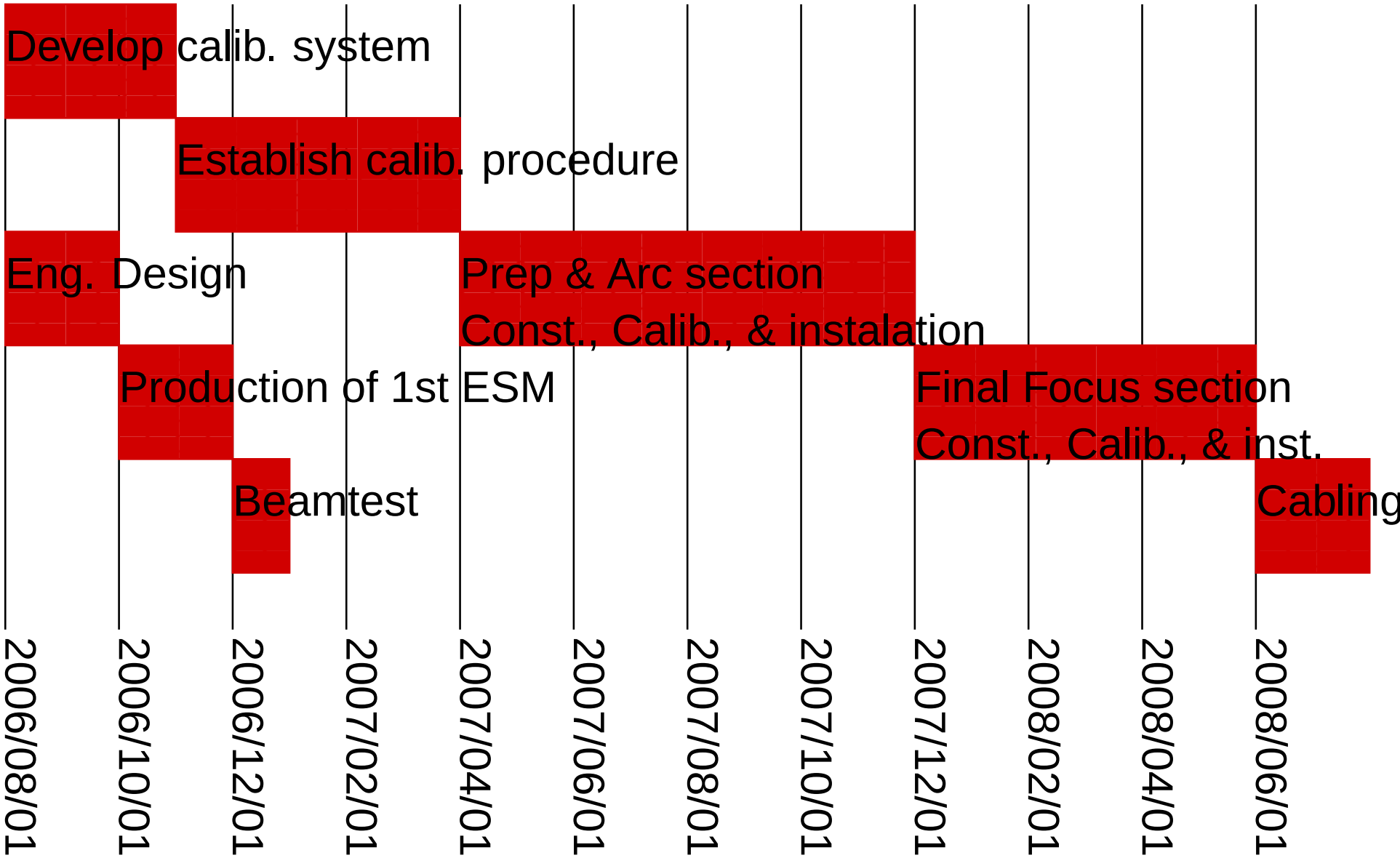


Expected test beam & signal





Schedule


Develop calib. system
Establish calib. procedure
Eng. Design
Prep & Arc section
Const., Calib., & instalation
Production of 1st ESM
Final Focus section
Const., Calib., & inst.
Beamtest
Cabling
2006/08/01
2006/10/01
2006/12/01
2007/02/01
2007/04/01
2007/06/01
2007/08/01
2007/10/01
2007/12/01
2008/02/01
2008/04/01
2008/06/01

Summary

- Using Electrostatic Monitors (ESM) with $\pi/2$ electrodes
- First real ESM expected in October
- Calibration system being developed
- Custom 12 bit, 100 MS/s
- Final performance heavily dependant on noise at JPARC
- Schedule tight... as usual

Supplementary Material

- Simulations
- Beam and ESM Parameters
- Calibration Stage

Simulations

Current density at point $\vec{a}(a,\theta)$ on beampipe wall ($\simeq$ electrode):

$$J_{\text{img}}(\vec{r},\vec{a}) = \frac{I_{\text{beam}}(r,\phi)}{2\pi a}\frac{a^2-r^2}{a^2-2ar\cos(\theta-\phi)+r^2}$$
$$= \frac{I_{\text{beam}}(r,\phi)}{2\pi a}\left[1+\sum_{k=1}^{\infty}\left(\frac{r}{a}\right)^k \cos k(\theta-\phi)\right]$$

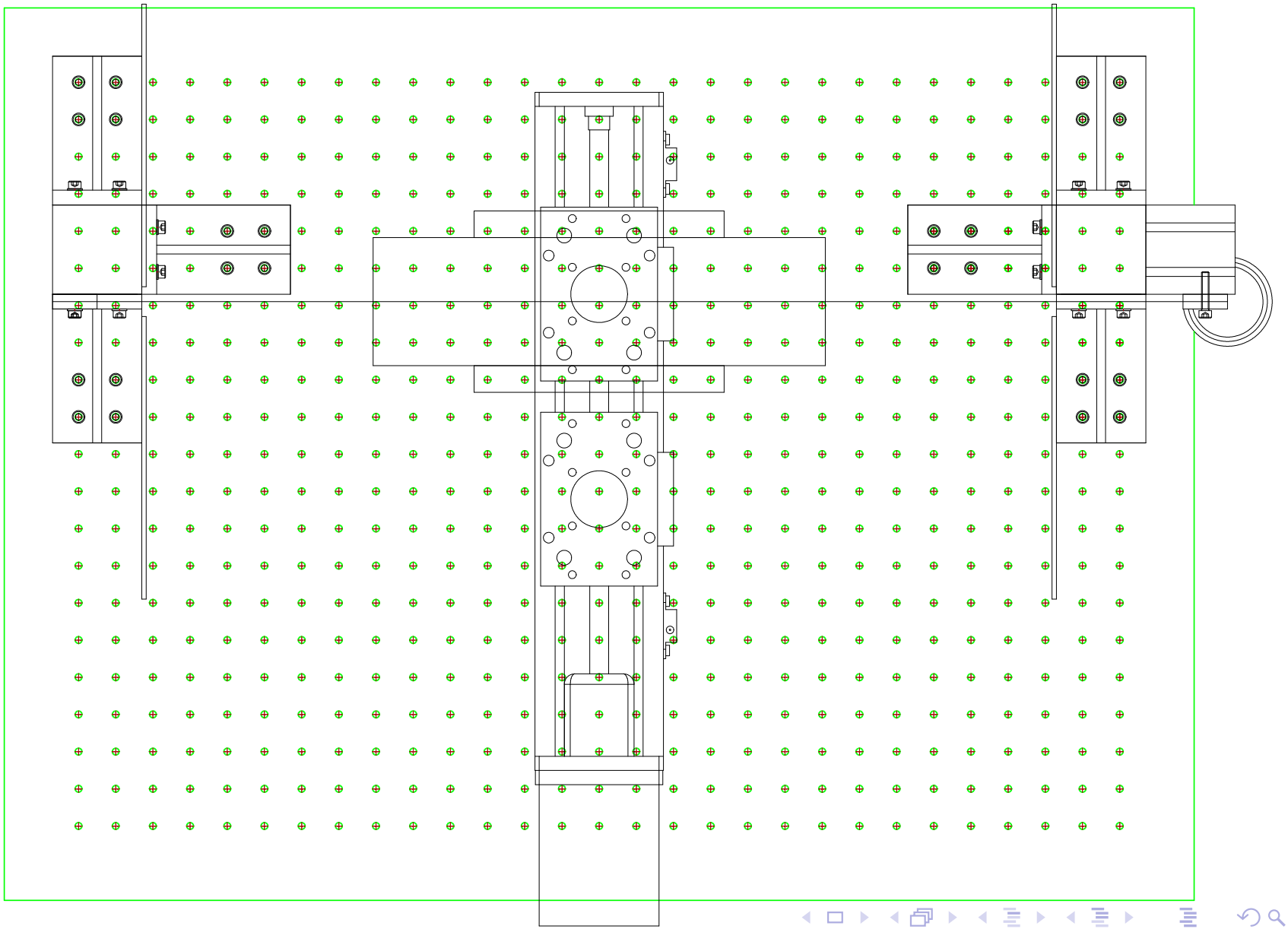
- Expand to 3rd order, integrate over θ for the electrode ($\pm\frac{\pi}{4}$) $\rightarrow$ line charge density (lcd)
- Convolve electrode (lcd) w/ beam profile $\rightarrow$ image charge
- Time derivative $\rightarrow$ current source
- Simulate electronics $\rightarrow$ voltage

Beam and ESM Parameters

Parameter	K2K	T2K
Protons/pulse	2.8×10^{12}	3.3×10^{12}
Bunches/pulse	9	8
Protons/bunch	0.31×10^{12}	0.41×10^{12}
Bunch width	10 ns(RMS)	58 ns(Full width)
Bunch spacing	125 ns	598 ns
Electrode length	20 cm	10 cm
Electrode coverage	$\pi/2$	$\pi/2$

- Using T2K 1% beam power
- ESM geometry in normal conducting section (least space)
- Assume T2K RMS=(Full width)/4

Calibration Stage



Calibration Stage