

HIGH VOLTAGE UPGRADE OF THE 14UD TANDEM ACCELERATOR

A study of electron suppression
techniques in NEC acceleration
tubes for large accelerators



Australian
National
University



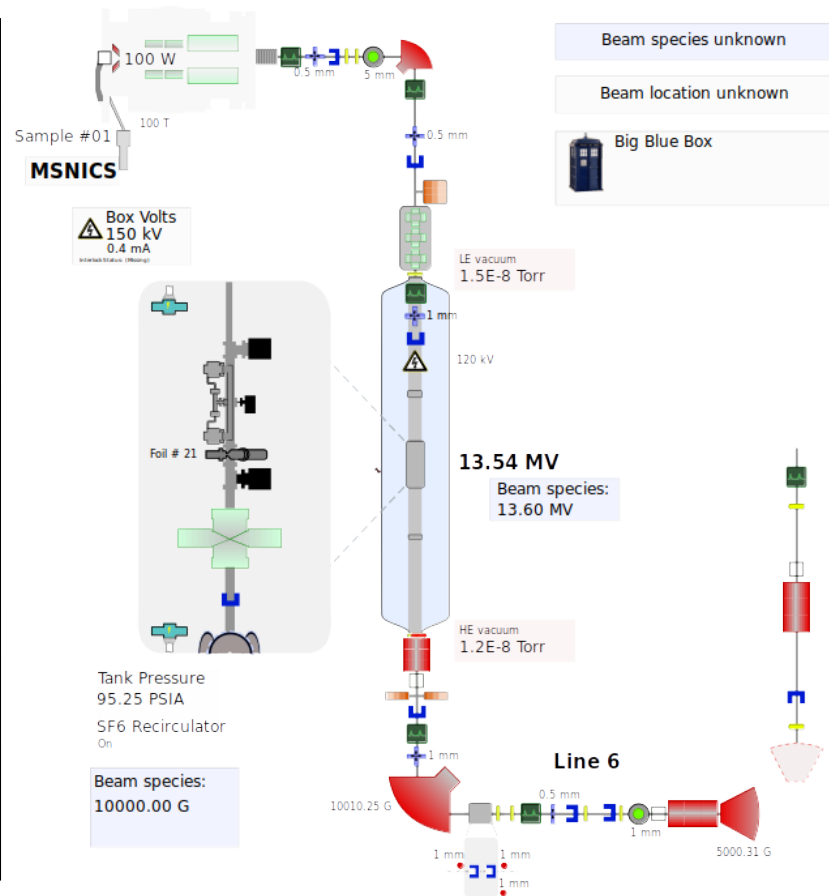
Introduction

- The ANU operates an NEC 14UD accelerator.
- The accelerator was built starting in mid 1971, and had first volts applied in February of 1973.
- The 14UD was the first of its kind.
- Build in an analog age, mostly digital today
- Very flexible
 - Accelerates everything which can be ionised in our SNICS, usable energy limited by 90 deg analysing magnet.
 - Source change on the fly.
 - Full configuration change << 1 day.



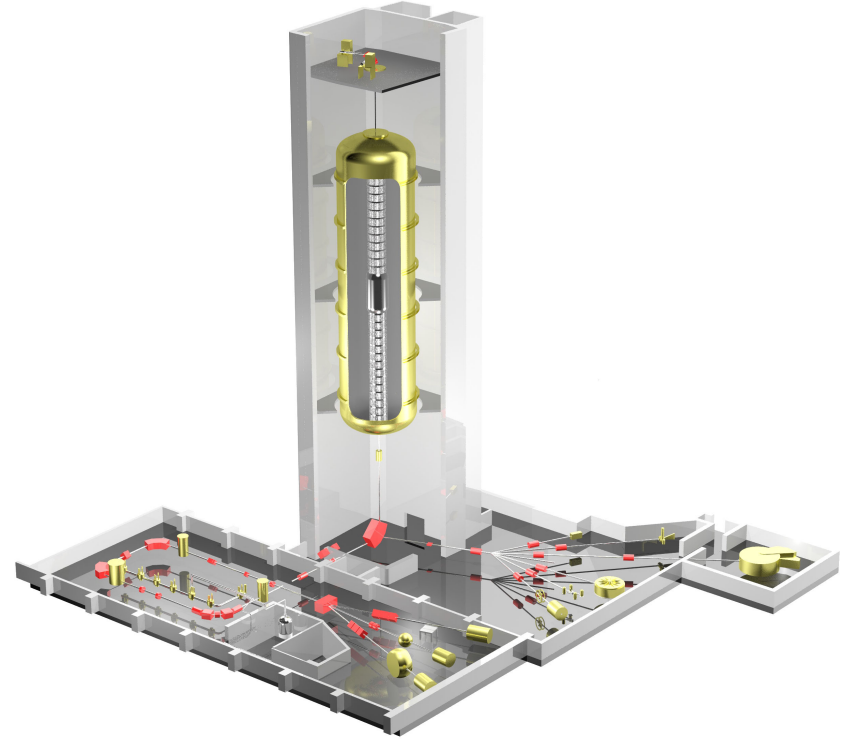
Introduction

- The ANU operates an NEC 14UD accelerator.
- The accelerator was built starting in mid 1971, and had first volts applied in February of 1973.
- The 14UD was the first of its kind.
- Build in an analog age, mostly digital today
- Very flexible
 - Accelerates everything which can be ionised in our SNICS, usable energy limited by 90 deg analysing magnet.
 - Source change on the fly.
 - Full configuration change << 1 day.



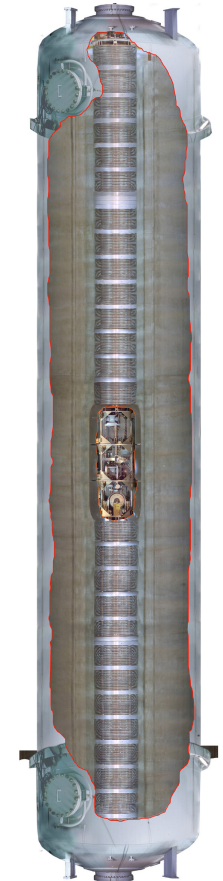
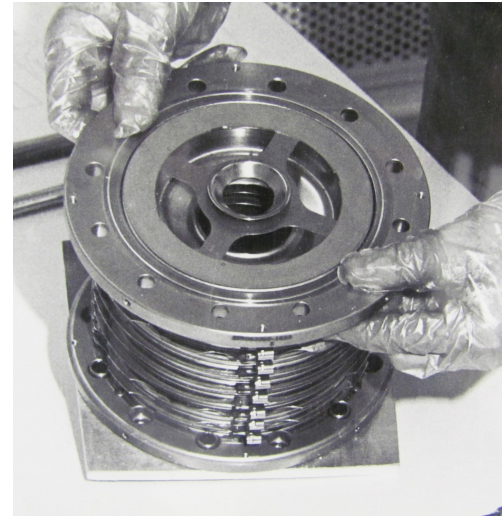
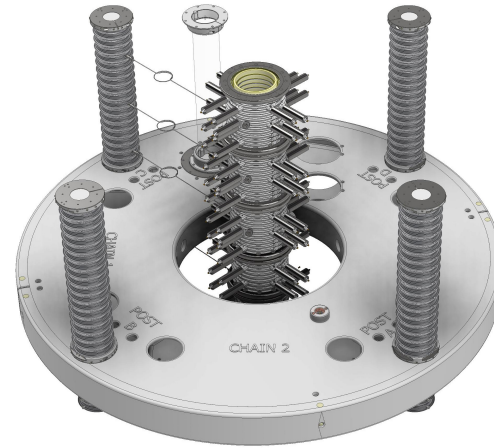
Introduction

- The ANU operates an NEC 14UD accelerator.
- The accelerator was built starting in mid 1971, and had first volts applied in February of 1973.
- The 14UD was the first of its kind.
- Build in an analog age, mostly digital today
- Very flexible
 - Accelerates everything which can be ionised in our SNICS, usable energy limited by 90 deg analysing magnet.
 - Source change on the fly.
 - Full configuration change << 1 day.



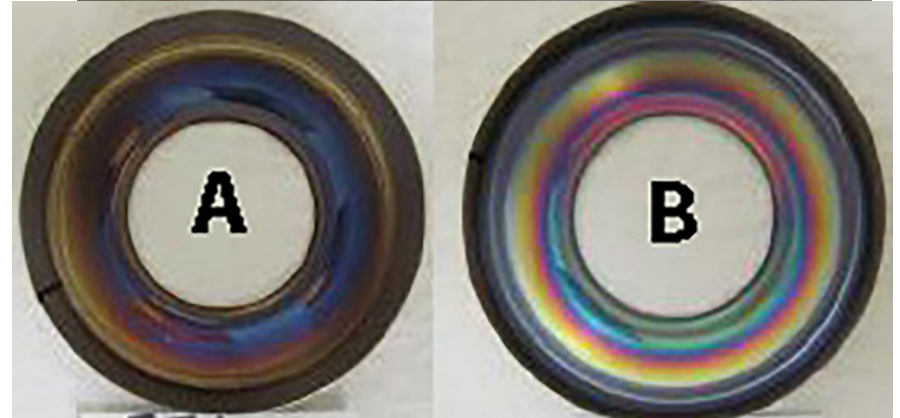
Introduction

- The accelerator utilises stacked titanium electrodes and ceramic insulators to build a gradient in two structures:
 - The tubes, under vacuum, through which the beam travels
 - The posts, which create the mechanical structure of the accelerator
- Consisting of 28 units (14 above the terminal and 14 below), it was originally installed with 3x11 ceramic gap tubes per unit.
- Each unit contains 3x11 ceramic gap tubes. In 1988 additional 8 gap tube have been installed between every second unit. The program was known as the 'Compressed Geometry Tube Upgrade'.
- Electron suppression is achieved through 'V' electrodes.



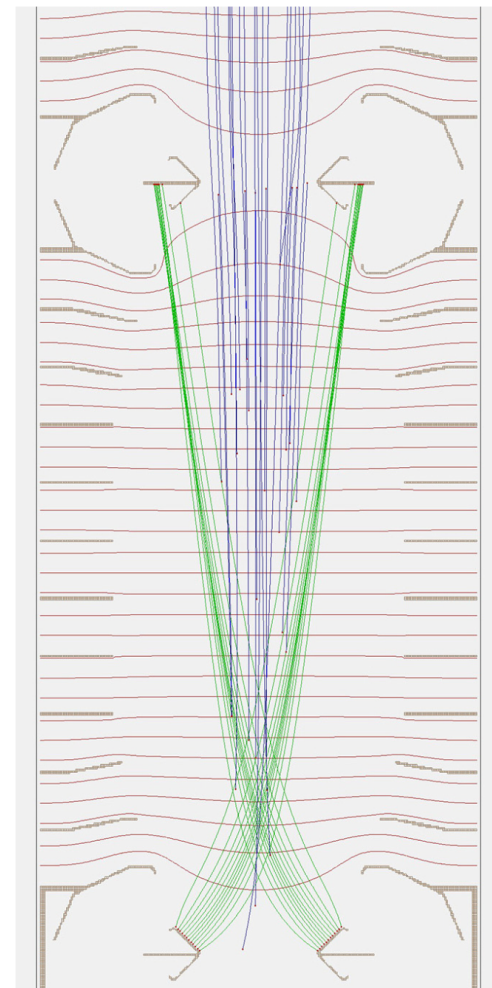
Introduction

- The accelerator utilises stacked titanium electrodes and ceramic insulators to build a gradient in two structures:
 - The tubes, under vacuum, through which the beam travels
 - The posts, which create the mechanical structure of the accelerator
- Consisting of 28 units (14 above the terminal and 14 below), it was originally installed with 3x11 ceramic gap tubes per unit.
- Each unit contains 3x11 ceramic gap tubes. In 1988 additional 8 gap tube have been installed between every second unit. The program was known as the 'Compressed Geometry Tube Upgrade'.
- Electron suppression is achieved through 'V' electrodes.



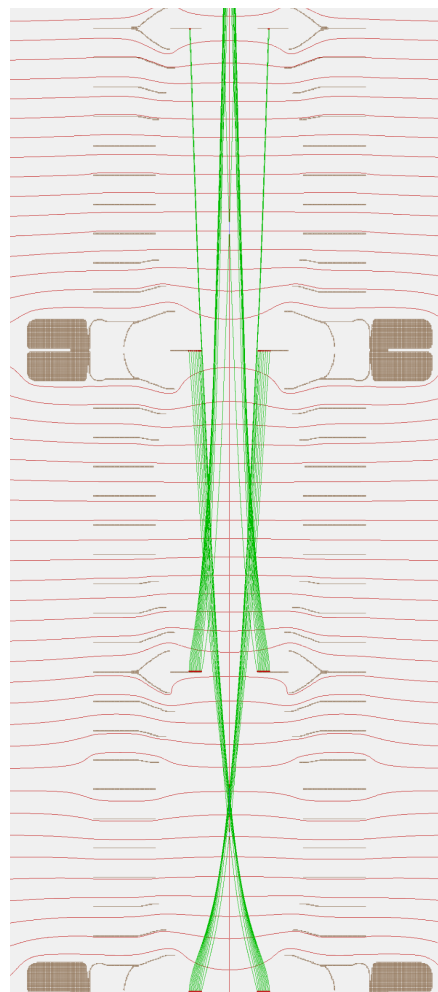
Electrostatic suppression

- 11 gap tubes with 'V' electrodes worked well for electrons generated at surfaces, but fail to suppress on axis generated electrons.
- 11 gap tube no longer available.
- NEC standard 20 gap tubes have insufficient electron suppression.
- Adding 'V' electrodes helps, but still no suppression for axial electrons.



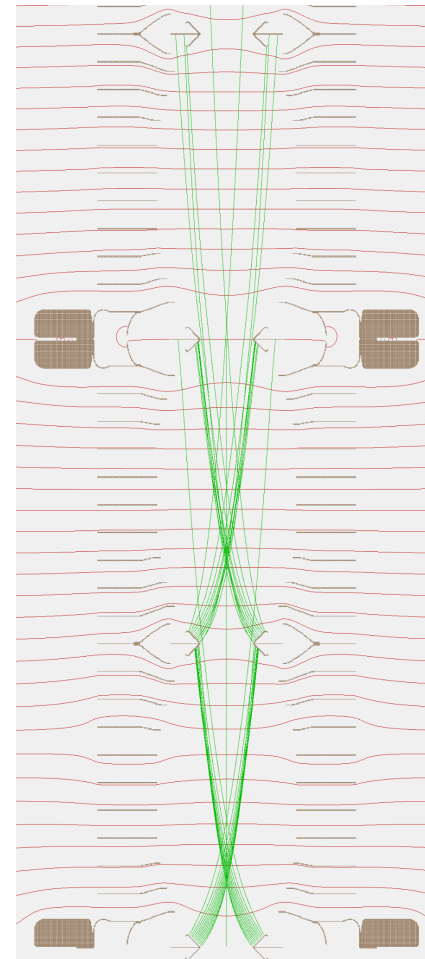
Electrostatic suppression

- 11 gap tubes with 'V' electrodes worked well for electrons generated at surfaces, but fail to suppress on axis generated electrons.
- 11 gap tube no longer available.
- NEC standard 20 gap tubes have insufficient electron suppression.
- Adding 'V' electrodes helps, but still no suppression for axial electrons.



Electrostatic suppression

- 11 gap tubes with 'V' electrodes worked well for electrons generated at surfaces, but fail to suppress on axis generated electrons.
- 11 gap tube no longer available.
- NEC standard 20 gap tubes have insufficient electron suppression.
- Adding 'V' electrodes helps, but still no suppression for axial electrons.



Electrostatic suppression

- 11 gap tubes with 'V' electrodes worked well for electrons generated at surfaces, but fail to suppress on axis generated electrons.
- 11 gap tube no longer available.
- NEC standard 20 gap tubes have insufficient electron suppression.
- Adding 'V' electrodes helps, but still no suppression for axial electrons.

	Section 1	Section 2	Section 3
Std. NEC 20 gap, electrons generated at flange	100	30	0
Std. NEC 20 gap, electrons generated at middle	100	100	100
V electrode at tube flange, and electrons generated at flange	8	0	0
V electrode at tube flange, and electrons generated at tube middle	100	100	100
All electrodes V, electrons generated at tube flange	8	0	0
All electrodes V, electrons generated at tube middle	36	9	0



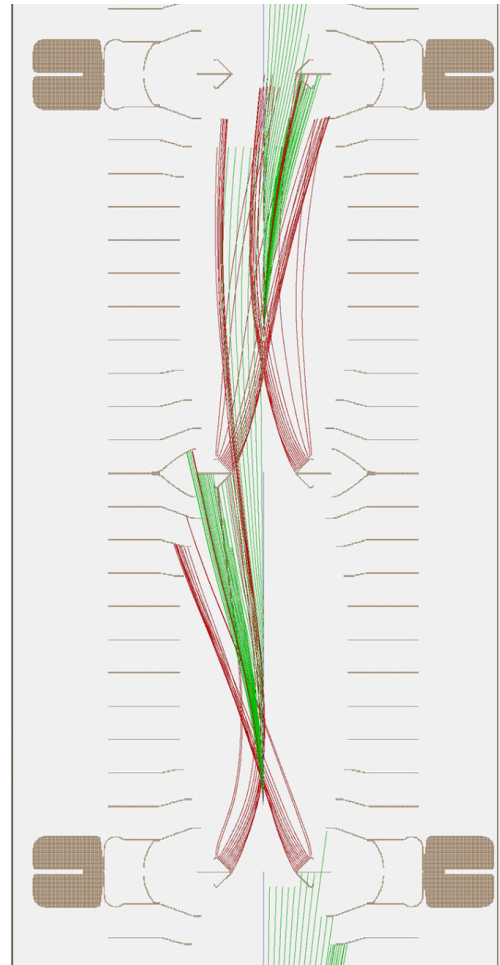
Magnetic suppression

- Today' s standard in < 6 MV NEC accelerators is magnetic suppression, which has been used for many decades now.
- Magnets are placed in the outer spark gaps, creating a magnetic field of $\sim 47\text{G}$ on axis.
- The magnets are oriented in a spiral fashion, so that every 7 or so gaps, the magnets are turned 90° so the field is perpendicular to the previous section. This is designed to reduce the net steering effect on the beam.



Magnetic suppression

- Today' s standard in < 6 MV NEC accelerators is magnetic suppression, which has been used for many decades now.
- Magnets are placed in the outer spark gaps, creating a magnetic field of ~47G on axis.
- The magnets are oriented in a spiral fashion, so that every 7 or so gaps, the magnets are turned 90° so the field is perpendicular to the previous section. This is designed to reduce the net steering effect on the beam.



Beam steering

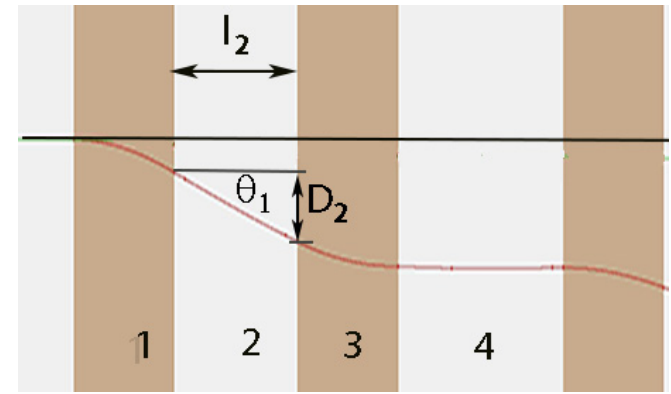
- Magnetic suppression comes with a price:
 - The beam path is modified.
- Estimating beam steering with a simplified analytical formula:

$$D_1 \approx 0.16 \times Q l_1^2 B / M \beta_1$$

$$D_2 \approx l_2 \times \theta = 0.32 \times Q l_1 l_2 B / M \beta_2$$

$$D_3 \approx 0.16 \times Q l_3^2 B / M \beta_3$$

- Standard NEC spiral B-field unacceptable.
- Alternatives: Snake, field varies only in one plane.



		LE section				HE section	
H ⁻¹	Displacement	Ni ⁻¹ Displacement		Ni ⁺¹² displacement			
	SIMION	Analytical	SIMION	Analytical	SIMION	Analytical	
T1 ENTRY	0	0.00	0	0.00	0	0.00	
T2 ENTRY	0.87	0.97	0.11	0.12	0.28	0.25	
T3 ENTRY	1.39	1.44	0.18	0.19	0.56	0.40	
T3 EXIT	1.78	1.82	0.23	0.23	0.89	0.53	



Beam steering

- Magnetic suppression comes with a price:
 - The beam path is modified.
- Estimating beam steering with a simplified analytical formula:

$$D_1 \approx 0.16 \times Q l_1^2 B / M \beta_1$$

$$D_2 \approx l_2 \times \theta = 0.32 \times Q l_1 l_2 B / M \beta_2$$

$$D_3 \approx 0.16 \times Q l_3^2 B / M \beta_3$$
- Standard NEC spiral B-field unacceptable.
- Alternatives: Snake, field varies only in one plane.

ION	$E_{inj},$ MV	$U_T,$ MV	LE section			HE section		
			M	Q	Displ, mm	M	Q	Displ, mm
Proton	0.1	14.5	1	1	6.02	1	1	3.20
Proton	0.1	3	1	1	14.03	1	1	7.03
C	0.15	14.5	12	1	1.97	12	5	3.23
C	0.15	6	12	1	2.93	12	5	5.02
Cl	0.15	14	37	1	1.14	37	7	2.36
Cl	0.15	10	37	1	1.33	37	7	2.79
Ni	0.15	14.5	60	1	0.88	60	12	2.59
Au	0.15	14	19 7	1	0.49	197	13	1.53



Beam steering

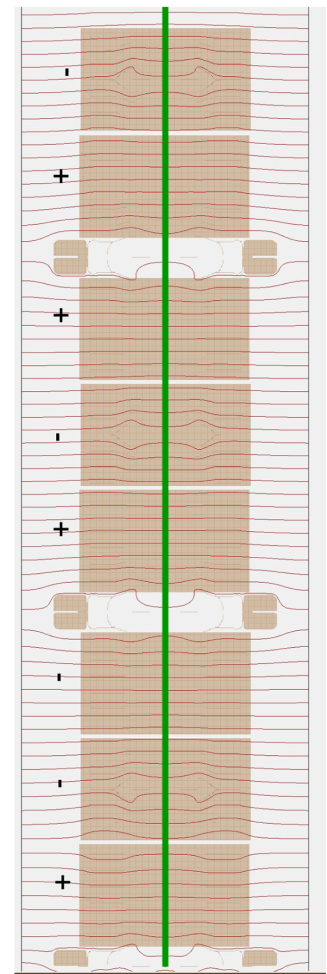
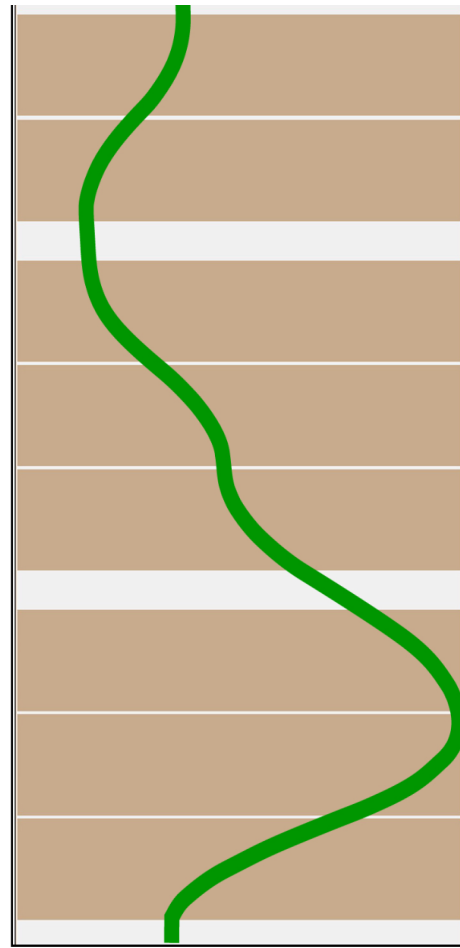
- Magnetic suppression comes with a price:
 - The beam path is modified.
- Estimating beam steering with a simplified analytical formula:

$$D_1 \approx 0.16 \times Q l_1^2 B / M \beta_1$$

$$D_2 \approx l_2 \times \theta = 0.32 \times Q l_1 l_2 B / M \beta_2$$

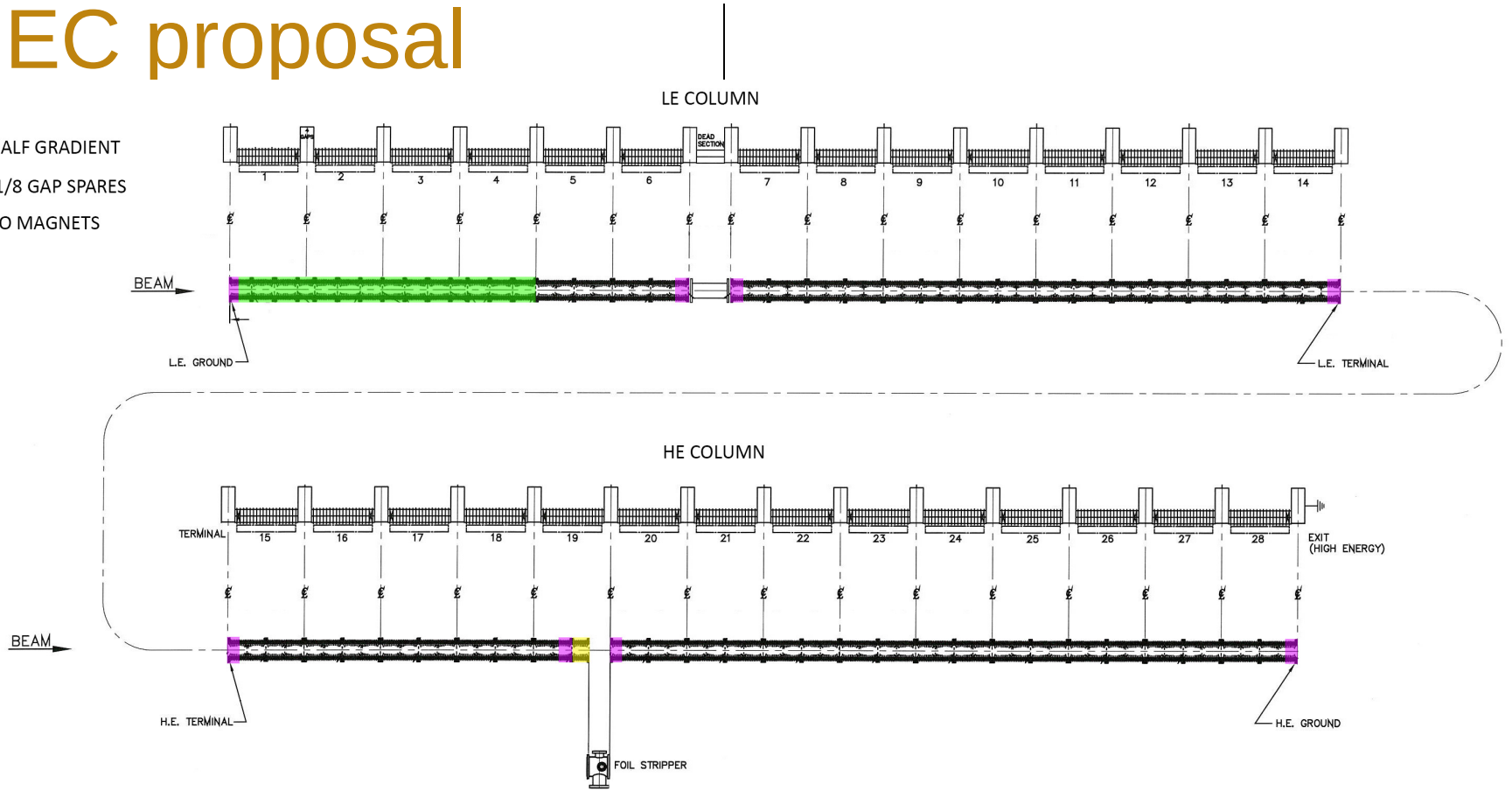
$$D_3 \approx 0.16 \times Q l_3^2 B / M \beta_3$$

- Standard NEC spiral B-field unacceptable.
- Alternatives: Snake, field varies only in one plane.



NEC proposal

- HALF GRADIENT
- 11/8 GAP SPARES
- NO MAGNETS



How to quantify?

- Maximum Terminal Voltage hasn't changed much in ~ 50 years.
- Production of X-ray's without beam and with different beams / beam intensities.
- Maximum stable beam current with different species.
- Transmission through the accelerator.
- Charging current/lost charge as a function of beam current for different species.
- Any other ideas?



Acknowledgements

Thank you to the team at NEC for their willingness to work with us to refine their suppression scheme to make it suitable for use in the 14UD.

Mark Sundquist

Mike Mores

Stephanie Stodola



Acknowledgements

Battisson, Stephen
Cooper, Alan
Heighway, Justin
Kafer, Chris
Kitchen, Tom
Linardakis, Peter
Lobanov, Nikolai
Tempra, Daniel
Tranter, Ben
Tranter, Ross
Tunningley, Thomas



THANK YOU

