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Nonlinear injection kicker prototype for installation at the Australian Synchrotron

Beam Dynamics, Injection and Impedance Studies

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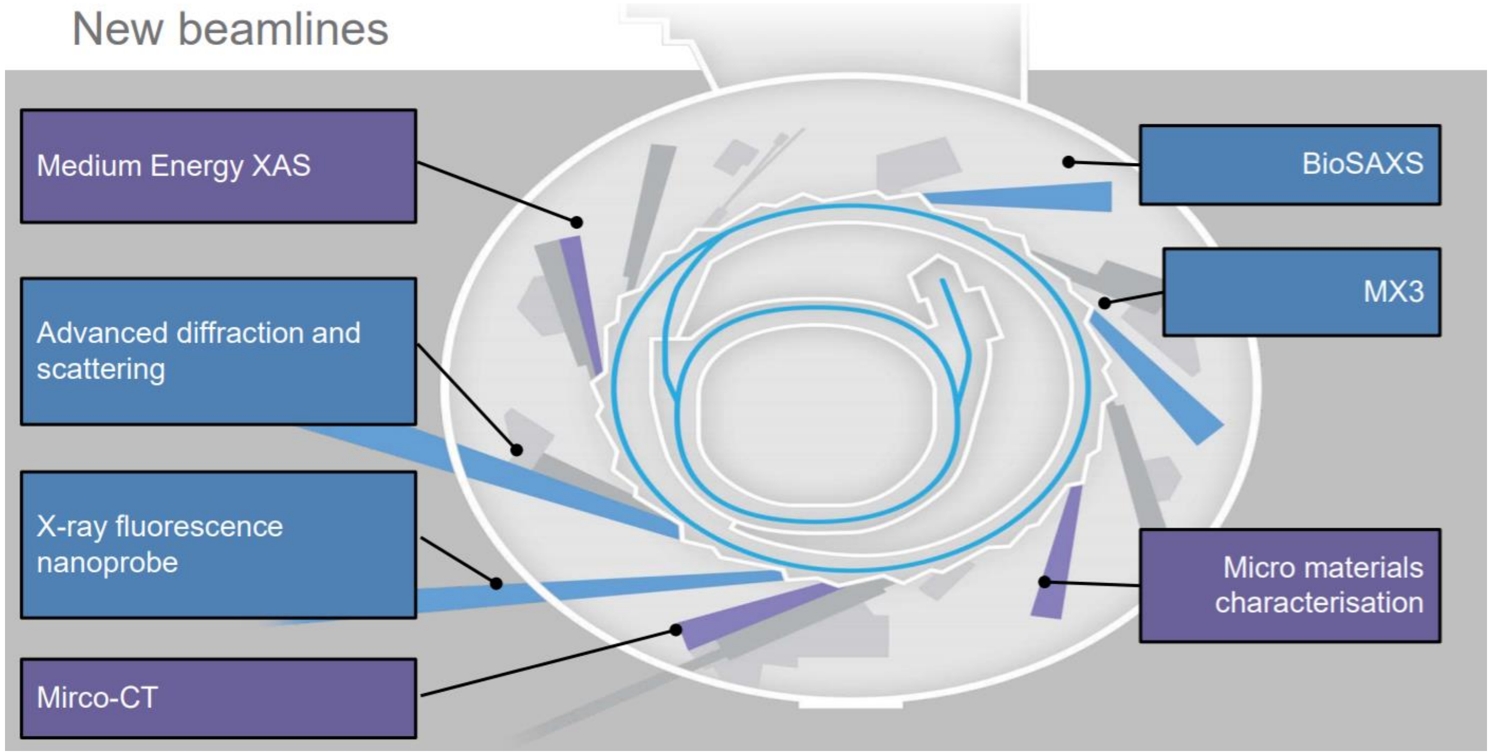
Science. Ingenuity. Sustainability.

The Australian Synchrotron Facility

BRIGHT program/Phase 2 development

- Bright beamlines
  - 7 new beamlines over the next 3-5 years



Ref Peele 2017 – Big Data at the Australian Synchrotron

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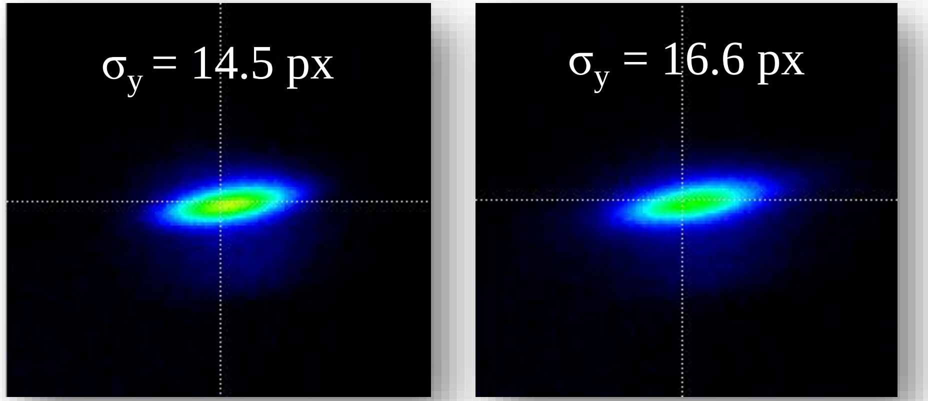
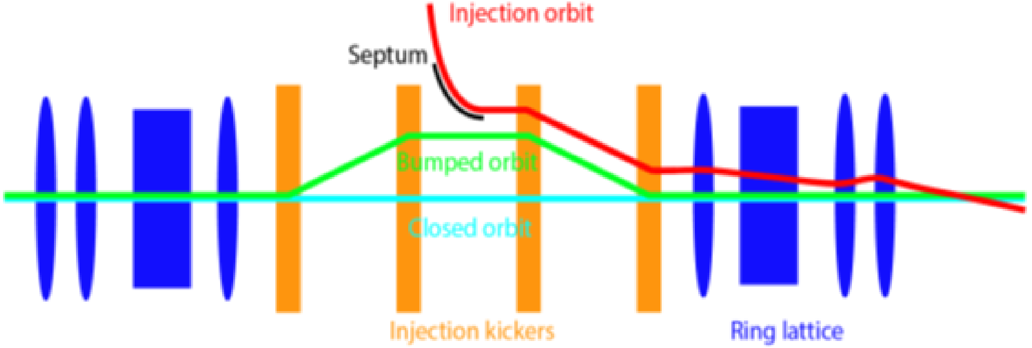
Future proofing

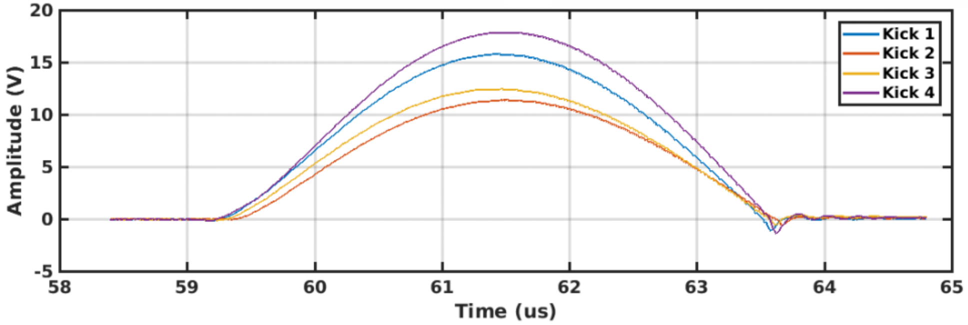
- Requirements for BRIGHT and next gen facility
  - Meet demands in medical and material
  - New beamlines to be installed
- The current configuration is insufficient for the future requirements/development

Insufficiencies in the current kicker configuration

- Not compact
  - Takes up 4 meters of space where a IVU will be installed
- Not transparent during top up
  - Impact on Far-IR beamline
- Jitter



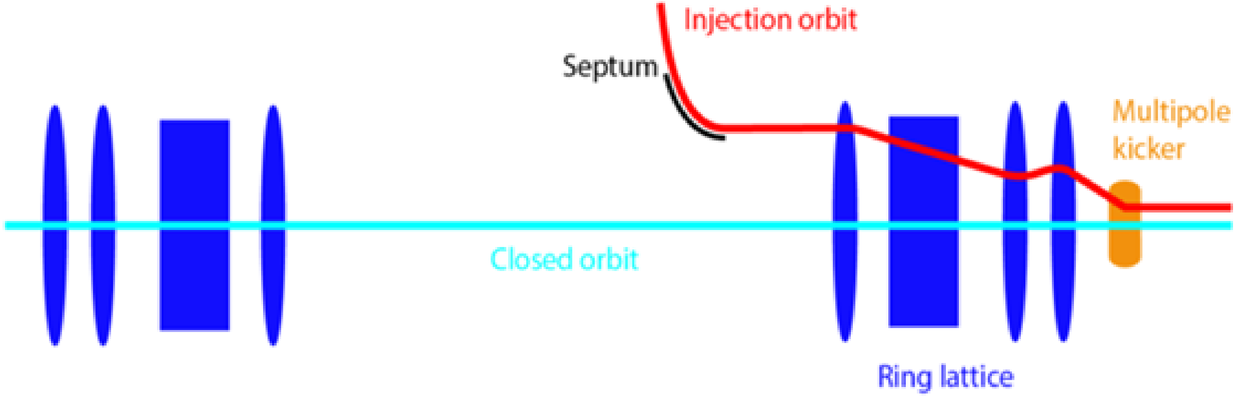




Ref Aiba 2015

The solution: a nonlinear kicker (NLK)

- What is an NLK?
  - A single kicker that produces a nonlinear field to kick the injected beam while leaving the stored beam untouched



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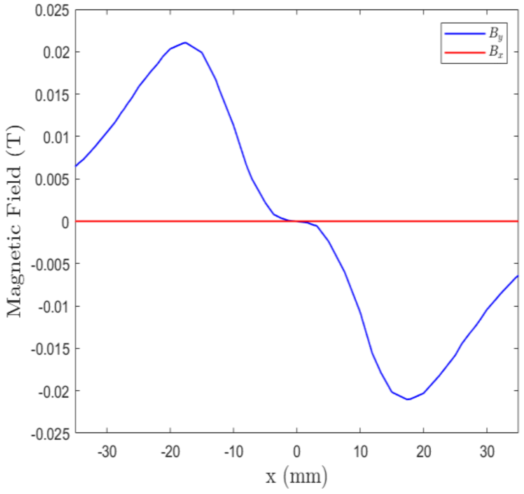
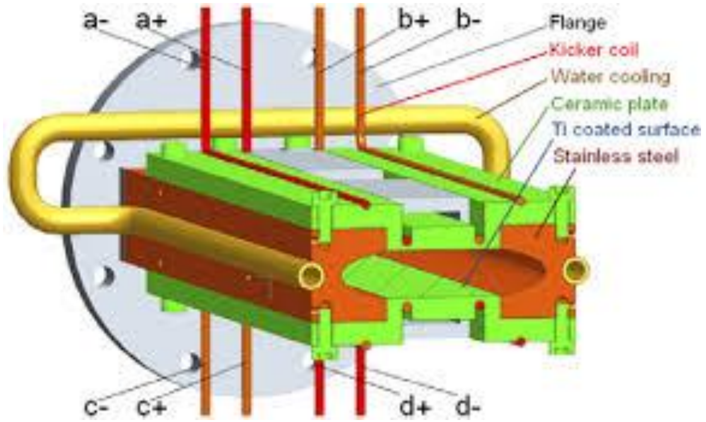
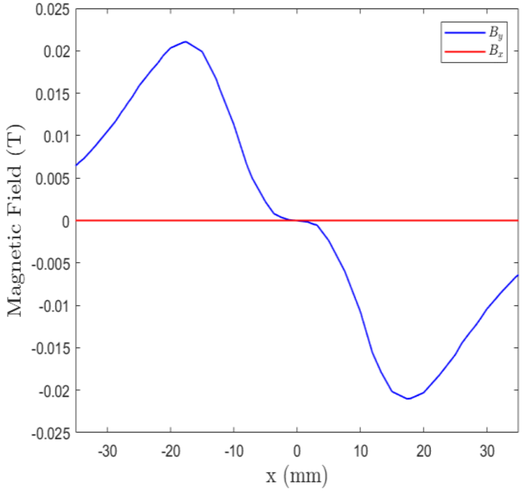


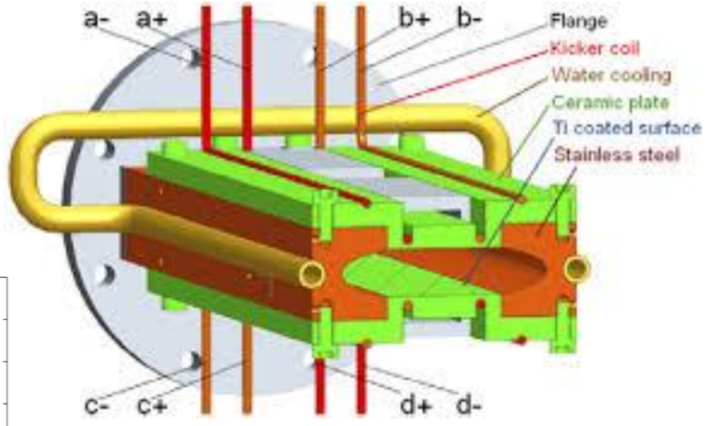


Ref Dressler 2011

The solution: a nonlinear kicker (NLK)

- Solves our BRIGHT problems
  - Stored beam is untouched
    - Stable jitter-free beam that is transparent in top-up
  - Compact and frees up precious real estate:
    - NLK = <u>**0.330 m**</u> of space
    - Current 4 kicker configuration: <u>**4 m**</u>
  - Transparent to beamlines
    - More frequent injections
    - Improve photon intensity stability





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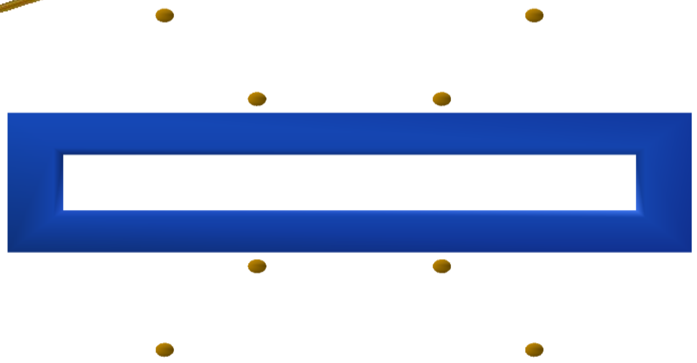
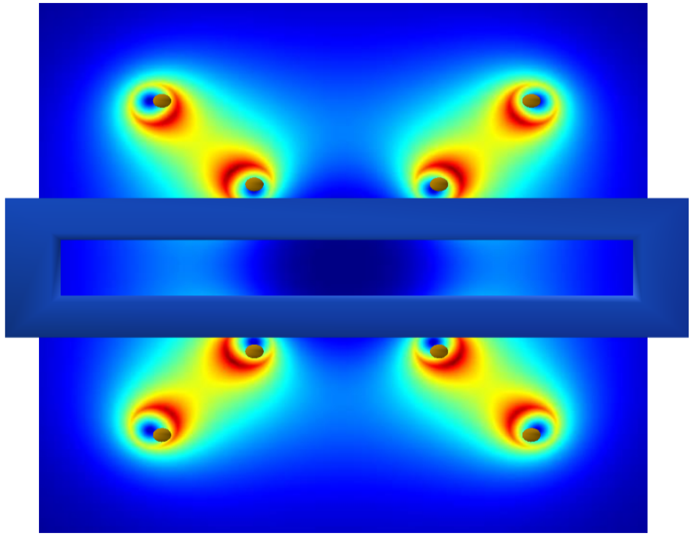
Preliminary NLK design

- Conductor layout and magnetic field profile without any conductive coating





Challenges other facilities have encountered

- Injection efficiency
  - ~99% theoretically but ~80%-90% when installed
- Ceramic chamber design:
  - Image currents induced on ceramic chamber
  - Stored beam passing through ceramic chamber induces impedance and heat load
  - Charge accumulation across ceramic
  - Needs a sufficient conductive coating to avoid

The complex trade-off in design variables

- Interplay of factors will impact the design and performance
- Need to characterize and optimize many features (both physically and logistically)
  - Conductive coating conductivity (Titanium or Titanium Nitride)
  - Conductive coating thickness (1 μm to 10 μm)
  - Aperture of ceramic chamber
  - Ceramic chamber thickness
  - Magnetic field response (sufficient kick of beam without gradation)
  - Copper conductor positions
  - Length of NLK
- Essentially a multi-objective optimization problem

The impact of conductive coatings

- Conductive coating inside chamber needs to:
  - Decrease beam impedance
  - Decrease charge accumulation across ceramic
  - Guide the image currents
- Coating impacts power deposition, heating, injection efficiency etc.
- Interplay of factors will determine optimal coating. For example a thin film coating provides:
  - Small field distortion ☑
  - Larger power deposition ☒
  - Larger thermal load ☒

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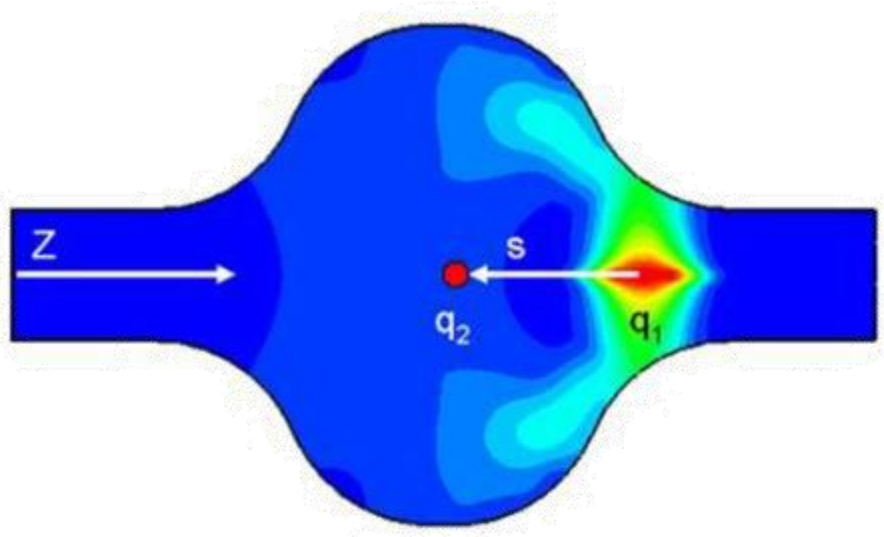
Design variables

- Wake impedance relationship with:
  - Stored beam (bunch length, current)
  - Conductive coating
    - Titanium or Titanium Nitride?
    - Coating thickness: 1 µm to 10 µm?
- Magnetic field response
  - Optimal Copper conductor positions to produce sufficient kick of beam without gradation across injected beam or perturbation of stored beam
  - Field Distortion from conductive coating
- Heat load from stored beam image currents
  - Aperture and length of ceramic chamber
  - Power deposition from stored beam



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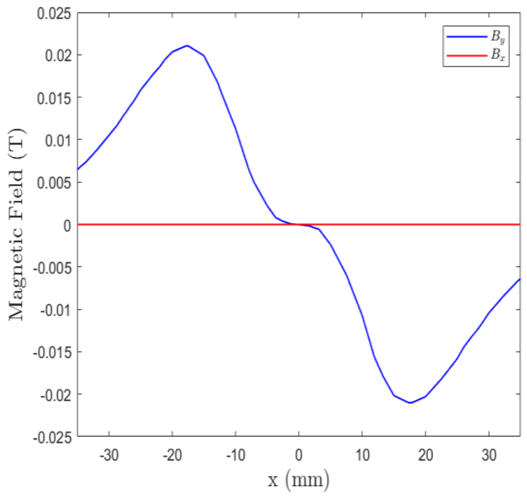

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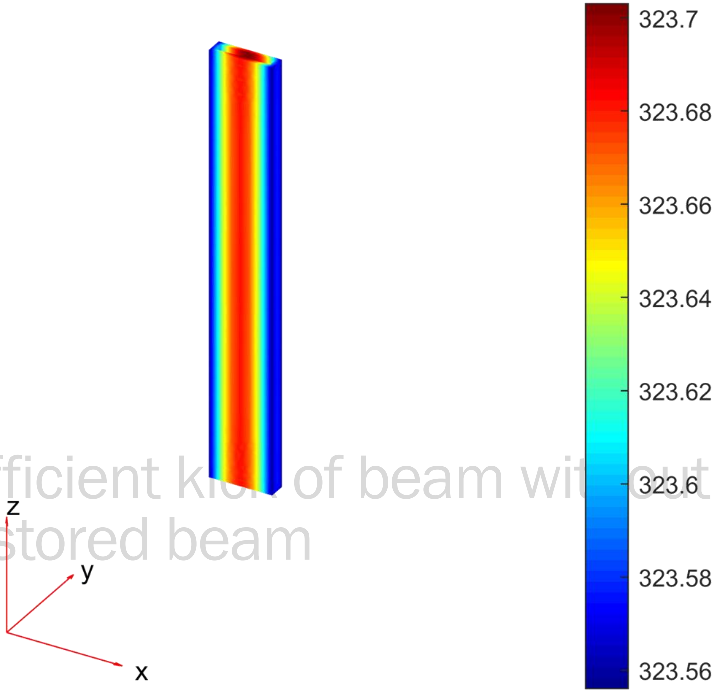
  - Optimal Copper conductor positions to produce sufficient kick of beam without gradation across injected beam or perturbation of stored beam
  - Field Distortion from conductive coating
- Heat load from stored beam image currents
  - Changes with aperture and length of ceramic chamber
  - Power deposition from stored beam



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Results

1. Conductive coating and impedance
2. Field Distortion
3. Power deposition and heat load
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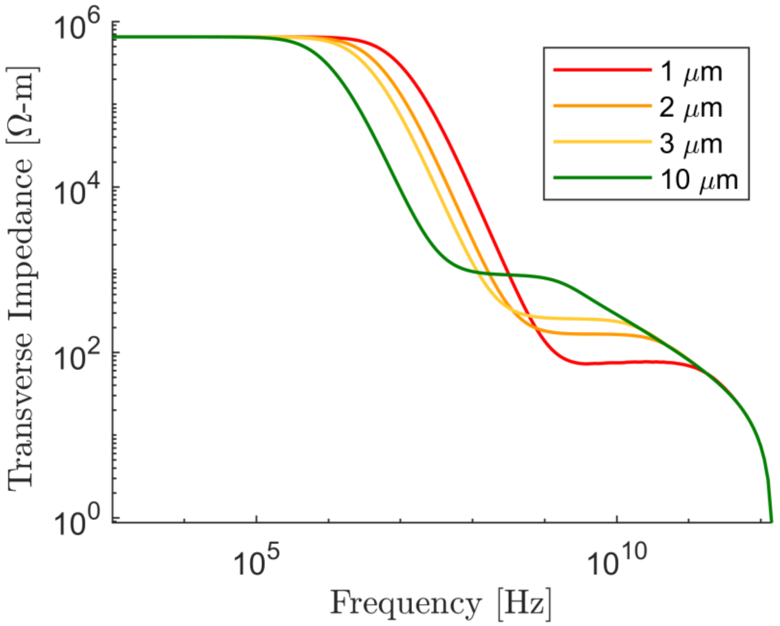
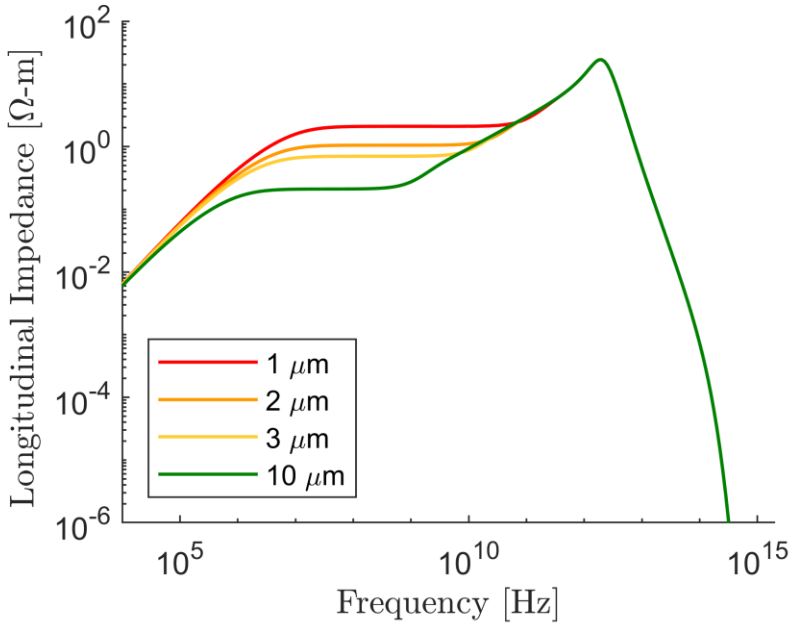
Wake potential and loss for the NLK chamber

- Longitudinal loss factor calculated using CST
- Note, some CST meshing issues
  - Thin film of very small magnitude → millions of cells in CST
- $k_{\parallel}$ = 0.1 V/pC for the NLK design with 2 μm Ti coating
  - Reasonable value

Impedance

- ImpedanceWake2D calculations to determine longitudinal and transverse impedances for various Ti and TiN thicknesses.





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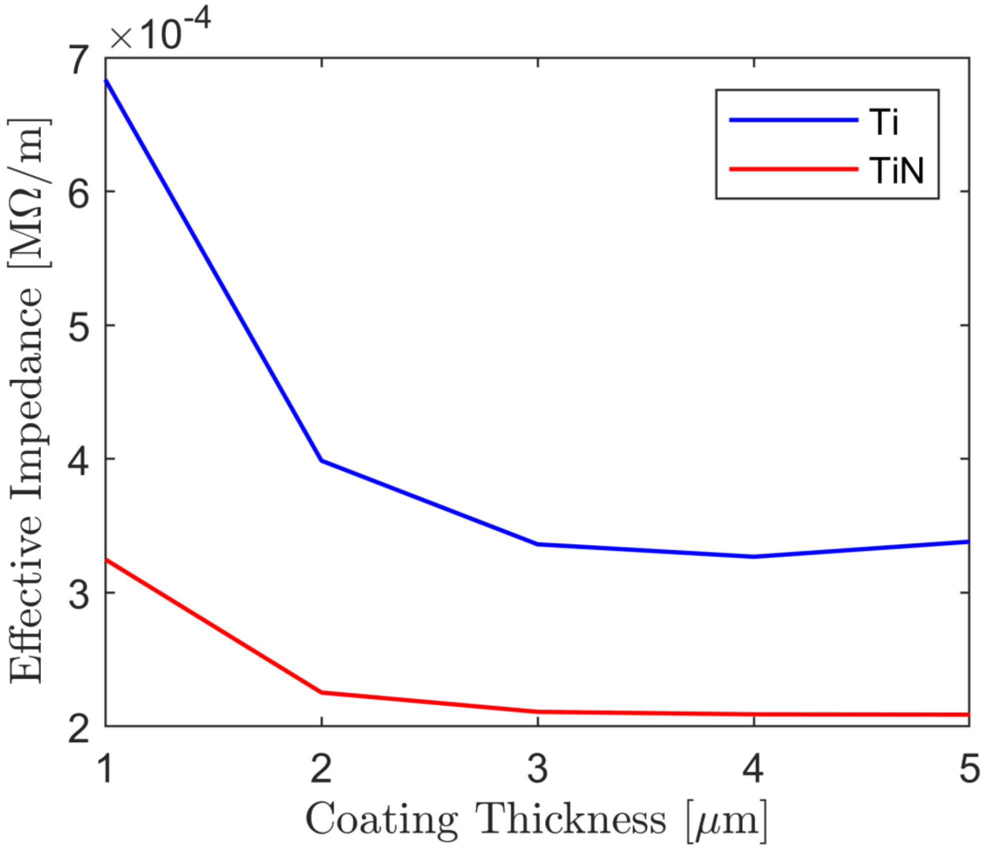
Effective Impedance

- For our beam parameters:
  - 3 μm coating will act like bulk Ti due to skin depth.
  - Rules out 4-10 μm Ti or TiN coating as candidates
- Turn to field, power and heat considerations to decide between 1-3 μm Ti/TiN



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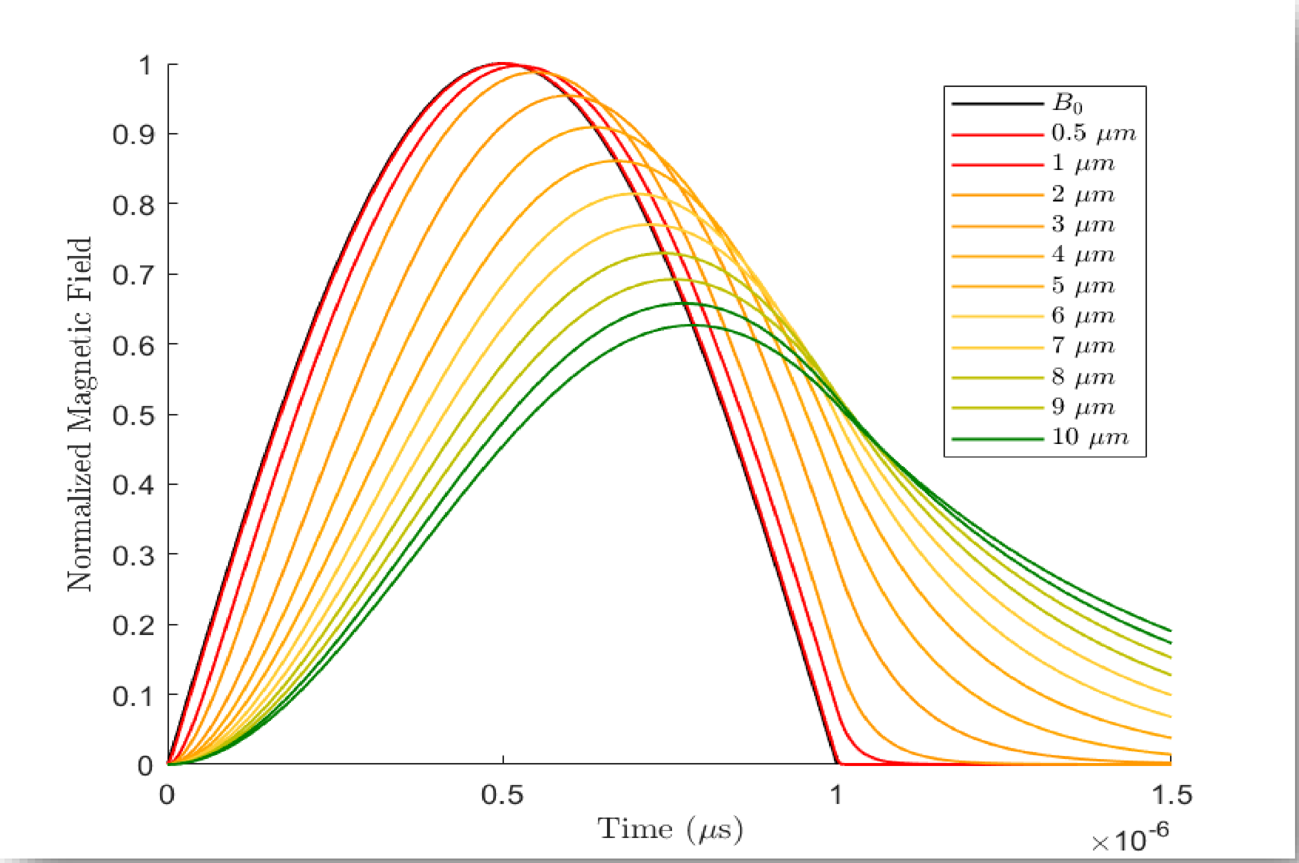
Field Distortion

- Assuming:
  - 100 ns bunch train
  - Storage ring (SR) revolution = 720.47 ns
  - Kicker maximum rise time = 620.47 ns
  - Flat top of 100 ns
  - Maximum fall time of 620 ns
- Delay:
  - 1 μm Ti: 45 ns
  - 2 μm Ti: 95 ns
  - 3 μm Ti: 135 ns
- Attenuation:
  - 1 μm Ti: 1.2 %
  - 2 μm Ti: 4.6 %
  - 3 μm Ti: 9.1 %



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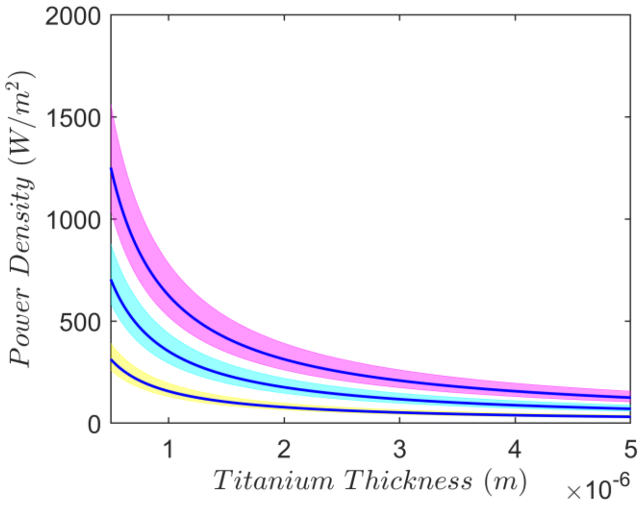
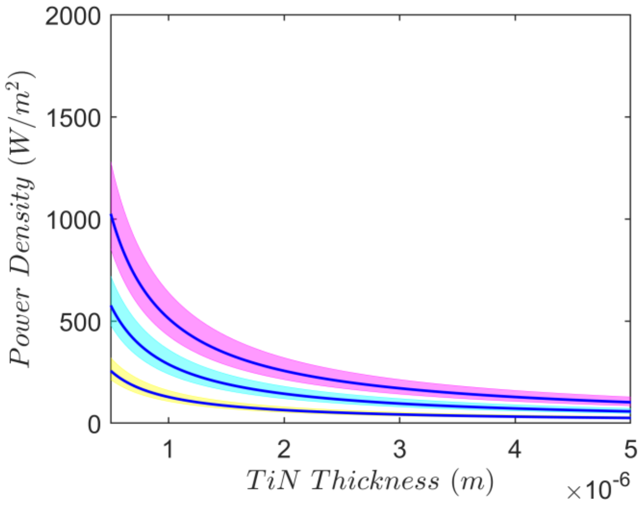
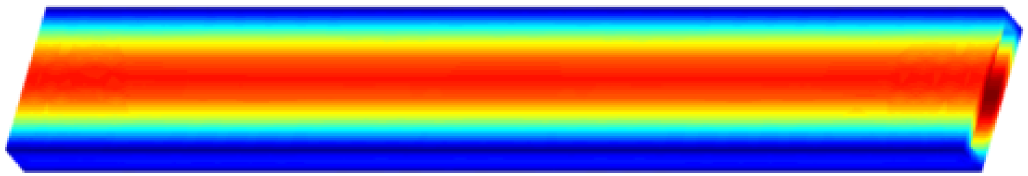
Power Deposition





Thickness (μm)	P_{Ti} (**W**/m^2)	P_{TiN} (**W**/m^2)	T_{Ti} ($^\circ C$)	T_{TiN} ($^\circ C$)
1	625.8	512.6	150.3	127.7
2	312.9	256.3	87.7	76.4
3	208.6	170.9	66.9	59.33
4	156.5	128.1	56.5	50.8
5	124.9	102.3	50.1	45.6
10	62.58	51.26	37.7	35.4



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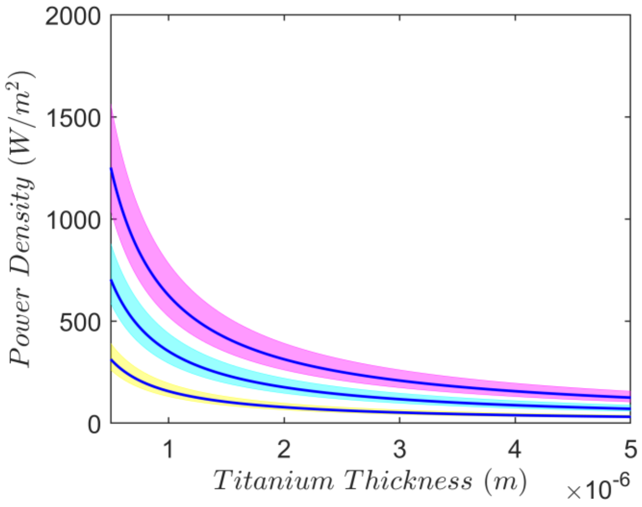

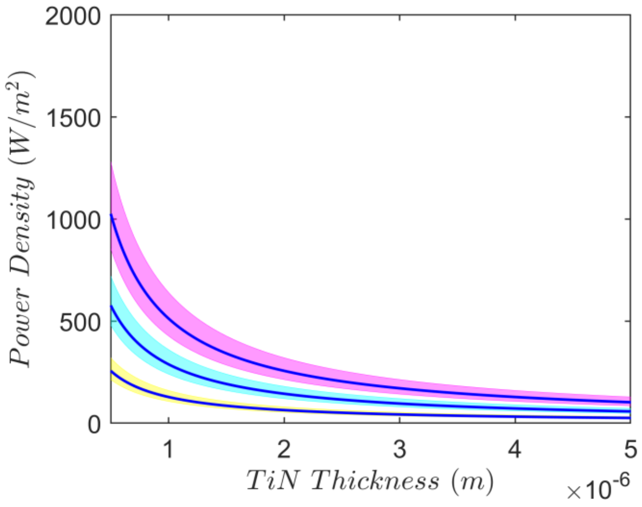

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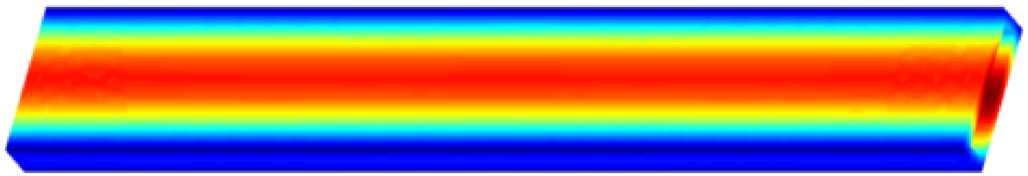

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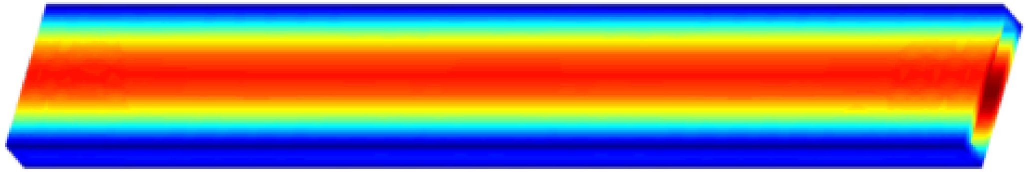
Thermal Analysis

- For extreme operating conditions: 400 mA, 260 bunches:
  - 2 µm:
    - Power: Ti = 312.9 W/m^2; TiN = 256.3 W/m^2
    - Max Temp: Ti = 87.7 °C; TiN = 76.4 °C
  - 3 µm:
    - Power: Ti = 208.6 W/m^2; TiN = 170.9 W/m^2
    - Max Temp: Ti = 66.9 °C; TiN = 59.3 °C



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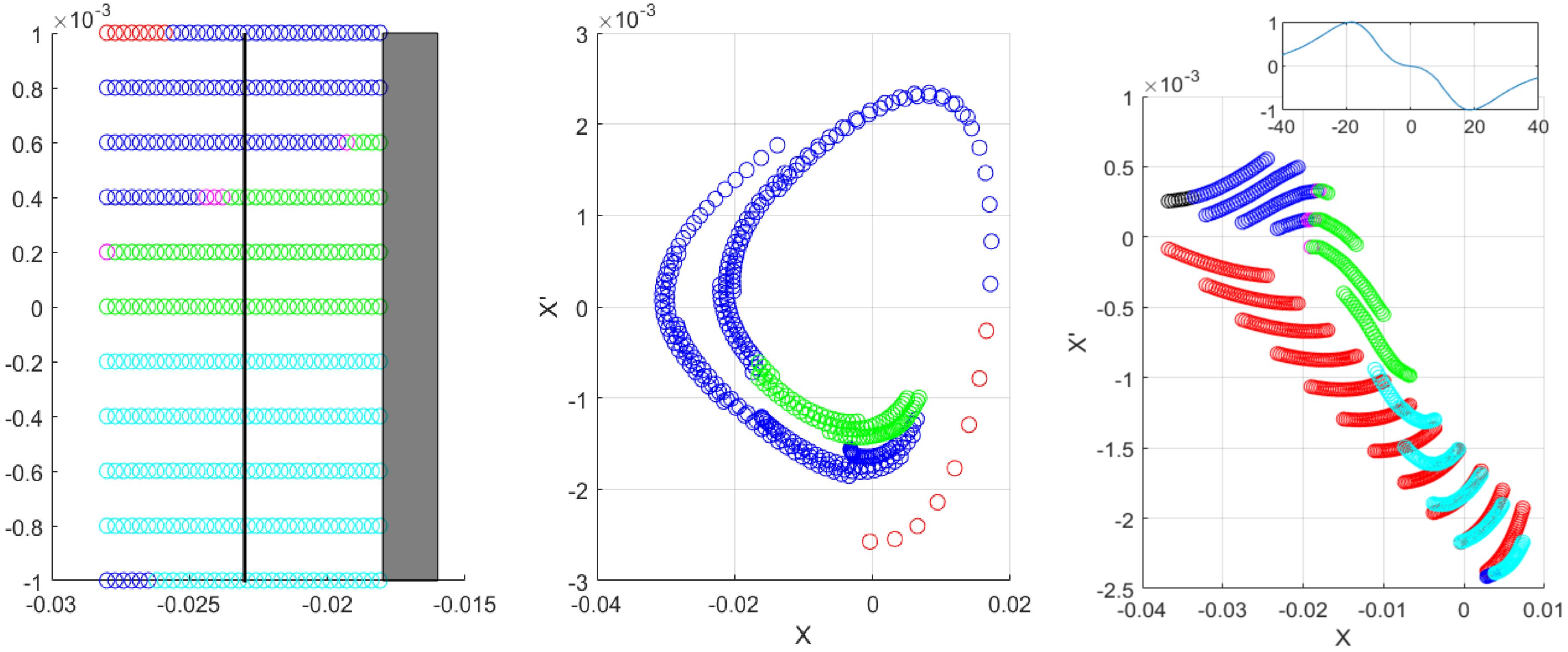
Injection efficiencies and simulations

- Tracking in Sector 5 for 1 mrad kick



Conclusion

- The Australian Synchrotron is looking toward our new BRIGHT beamline requirements (next 5 years) and next gen facility requirements (next 10-15 years)
- A nonlinear injection kicker is optimally positioned to provide the required space, transparency and functionality in our mission to provide cutting edge facilities to our user base
- We have highlighted the multiple (sometimes oppositional) design considerations for the NLK design for the A.S.

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Future work

- Refine the CST model
- Check if we have formed any cavities/resonant modes with our design with a IVU installed in same sector downstream
- Next steps: prototype development and commissioning
- Prototype construction late 2019

Acknowledgments

- AS Physics team and operators
- Mr. Olaf Dressler (Helmholtz Berlin)
- Dr. Theo Sinkovis (SAES, Italy)

Questions

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