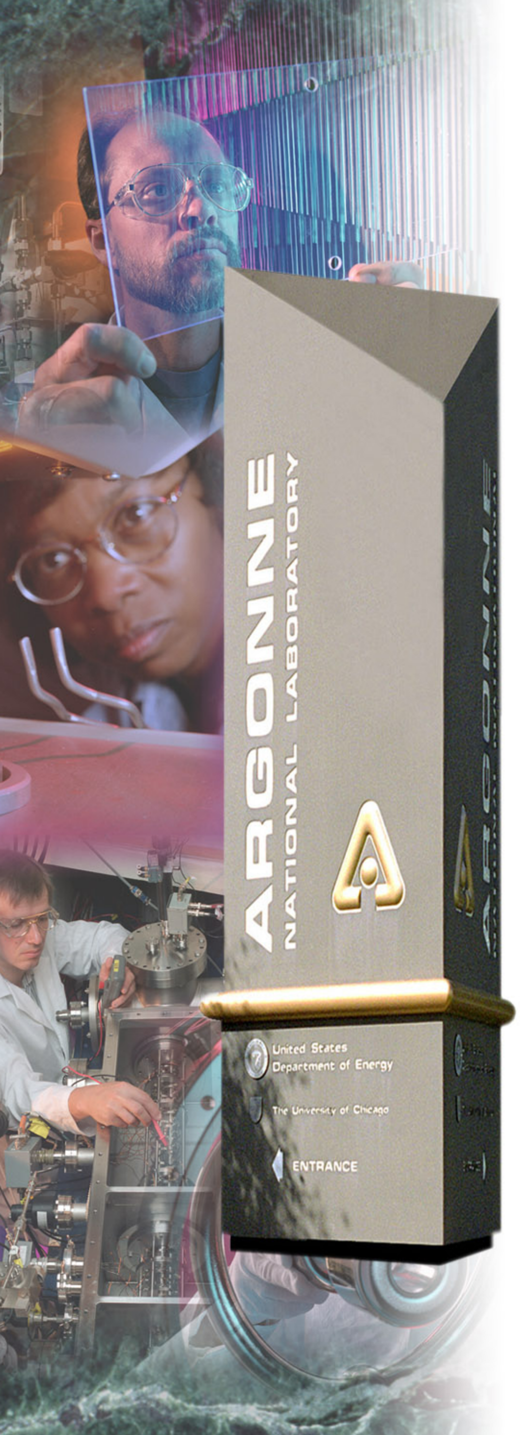

Interesting Problems that we Can't Do Yet…

Presented at the 2004 Advanced Accelerator Concepts workshop

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Murphy's Law in Context:

- **Any really new idea is bound to break at least one simulation code. Why? Because it'd be a feature of some code, somewhere, if someone thought of it already.**

- **Lewellen's Corollary: You will probably break at least one simulation anyway, just trying to do something old, only better.**

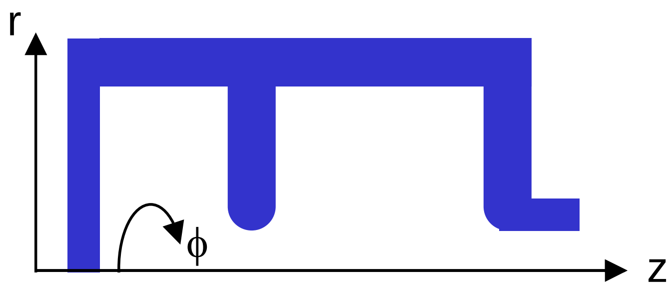
Outline

- Structure Scales and What Matters
- High-power design needs
- Ultra-low emittance design needs
- Next-generation cathode simulation needs
- Wrap-up

Structure Scales

Consider a canonical S-band 1.6-cell photoinjector (λ=10.25 cm)

- **one cathode cell, length 0.6 * ½ λ ≅ 3 cm**
- **one full cell, length ½ λ ≅ 5 cm**
- **radius ~ 4 cm**



“Area” in z-r space ~ 33 cm^2

“Volume” in z-r-ϕ space ~ 400 cm^3

Two Beam Scales of Interest

“Canonical” S-band Gun Beam

- ε_n: 1 μm
- σ_r' ~ 1 mrad
- σ_r ~ 1 mm
- σ_z ~ 3 mm (10 ps)

Aspect ratio ~ 1:1

“Area” in z-r space: 0.03 cm^2

“Volume” in z-r-ϕ space: 0.01 cm^3

$$\frac{A_{gun}}{A_{beam}} = 1100$$

$$\frac{V_{gun}}{V_{beam}} = 40{,}000$$

“RF Microscope” Gun Beam

- ε_n: 1 nm
- σ_r' ~ 1 mrad
- σ_r ~ 1 μm
- σ_z ~ 3 mm (10 ps)

Aspect ratio: ~ 1000:1

“Area” in z-r space: $3 \cdot 10^{-4}$ cm^2

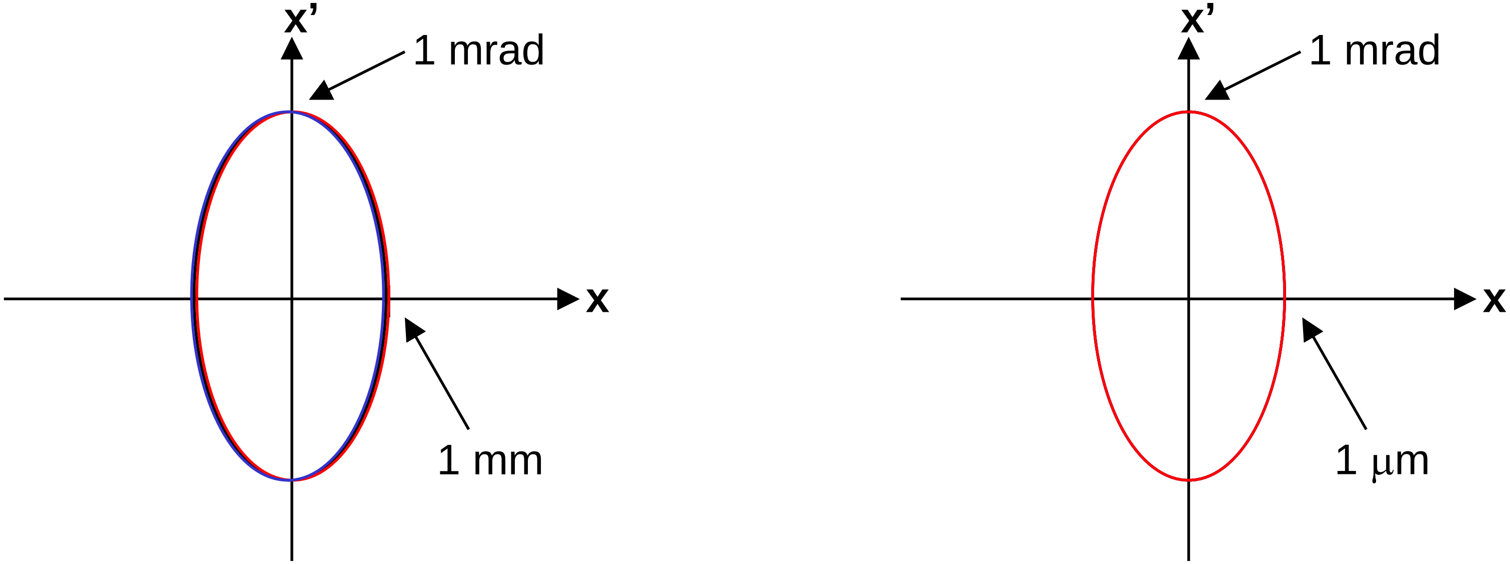
“Volume” in z-r-ϕ space: $9 \cdot 10^{-7}$ cm^3

$$\frac{A_{gun}}{A_{beam}} = 110{,}000$$

$$\frac{V_{gun}}{V_{beam}} = 4.4 \cdot 10^8$$

So what…?

- **A uniform-grid PIC code is not a good idea, especially for the microscope beam**
- **The “microscope” beam will also be more susceptible to field-related problems, e.g. head-tail kicks:**



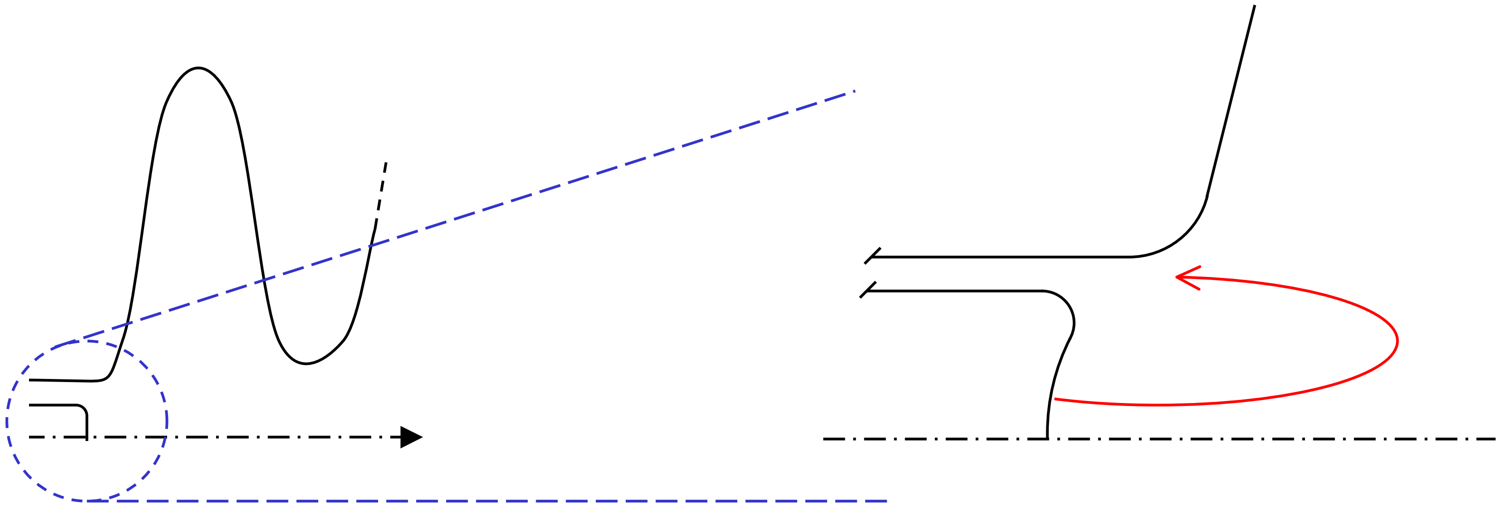
$\Delta\varepsilon/\varepsilon \sim 10^{-3}$ $\qquad$ $\Delta\varepsilon/\varepsilon \sim 2$

New Structures Pose New Problems

SRF Photoinjector with Cathode-Region Focusing

- Development at Rossendorf ("Drossel Collaboration")
- Further studies & design done at AES

Multipactoring is an immediate concern with a cathode-stalk design



What matters for all designs?

- Everything matters more as beams become more extreme
- Multi-length scale, multi-time scale codes are already necessary
- Some codes already support multi-frequency, multi-field overlays
- Methods for better handling wakefields, surface effects, etc., are required
- Photoemission process modeling will require true multiphysics approach, as well as raw data for the models
- “Integrated” codes that can also do, e.g. mutlipactoring, field emission, etc., are also needed.

High-Power Design Needs

- **Cavity-beam power exchange**
  - transient build-up
  - wakefields & beam break-up
- **Cathode-region charge flow (for surface heating modeling)**
- **Multipactoring / Arc Modeling / Field Emission**
- **Halo Formation & Tracking**

"Nano-Beam" Design Needs

- **Large-aspect-ratio beam space-charge models**
- **Very precise knowledge of cavity fields**
- **Detailed halo formation**
- **Field emission / arcing / multipactoring**
- **Detailed cathode emission model**

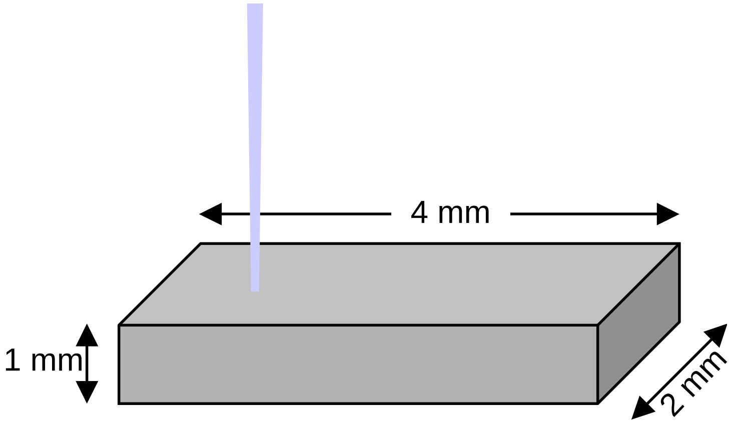
Cathode Emission Models Needed For…

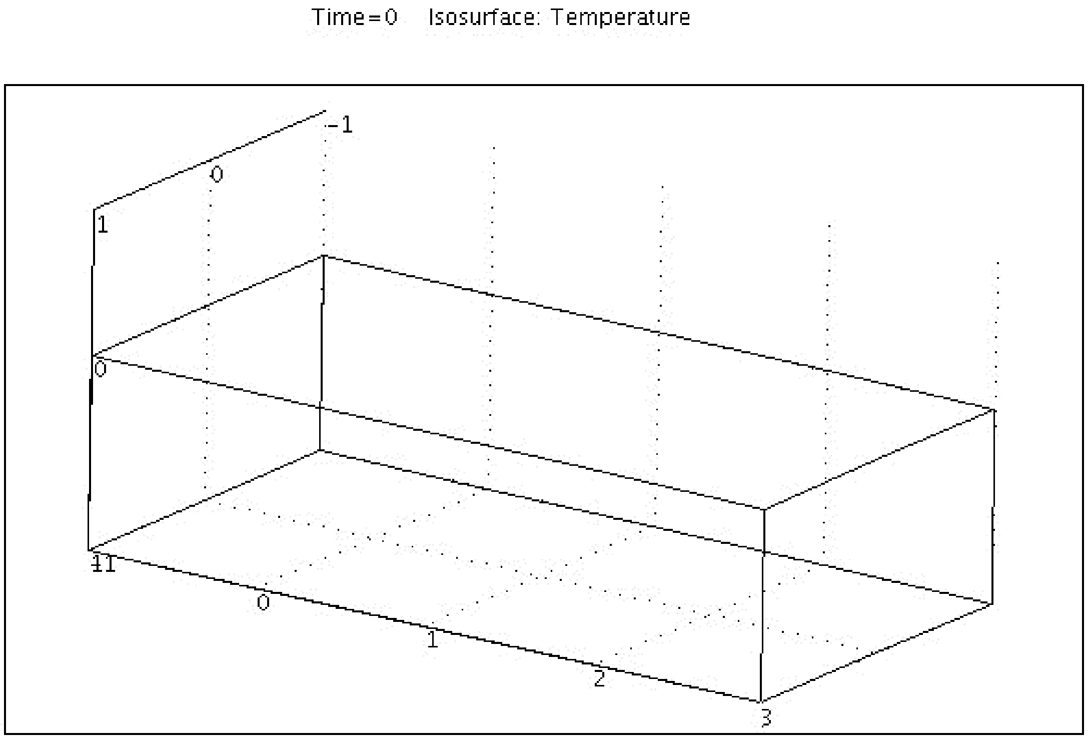
- **Ultra-Low Emittance Beam**
  - Needle tip emission modeling, field effect modeling, etc.
  - Very fine-scale surface roughness modeling
- **ANL Cathode-Region Focusing**
  - requires modifications to image-charge handling
- **BNL Super-QE Cathode Design**
  - needs to be a materials science code as well as an injector code
  - multiple stages of electron emission, beam strike, secondary emission, etc.
- **Thermal emittance prediction and inclusion, especially!**

Beam-Strike Effects

- **Inputs:**
  - Beam power: 9 kW
  - Spot size: 100 μm
  - Translation rate: 2 m/sec
  - Penetration depth: 0.15 mm
  - Material: 6063 Aluminum

$\Rightarrow$ 286 GW / m^2





Wrap-Up

- **Simple scaling suggests modeling injectors is hard**
- **Existing injector codes work with today's beams, but…**
  - "microscope" beams are very different in a number of ways
  - high-power beams require integrated multipactoring, wake analysis, etc.
  - all need better emission modeling
- **More data / experiments are needed for cathode model data**
- **Some of the implications are very interesting!**