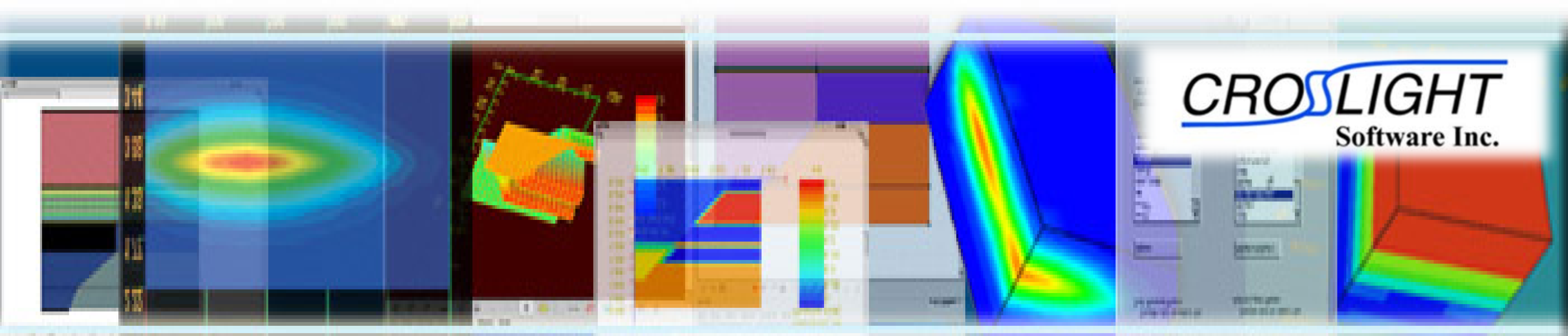
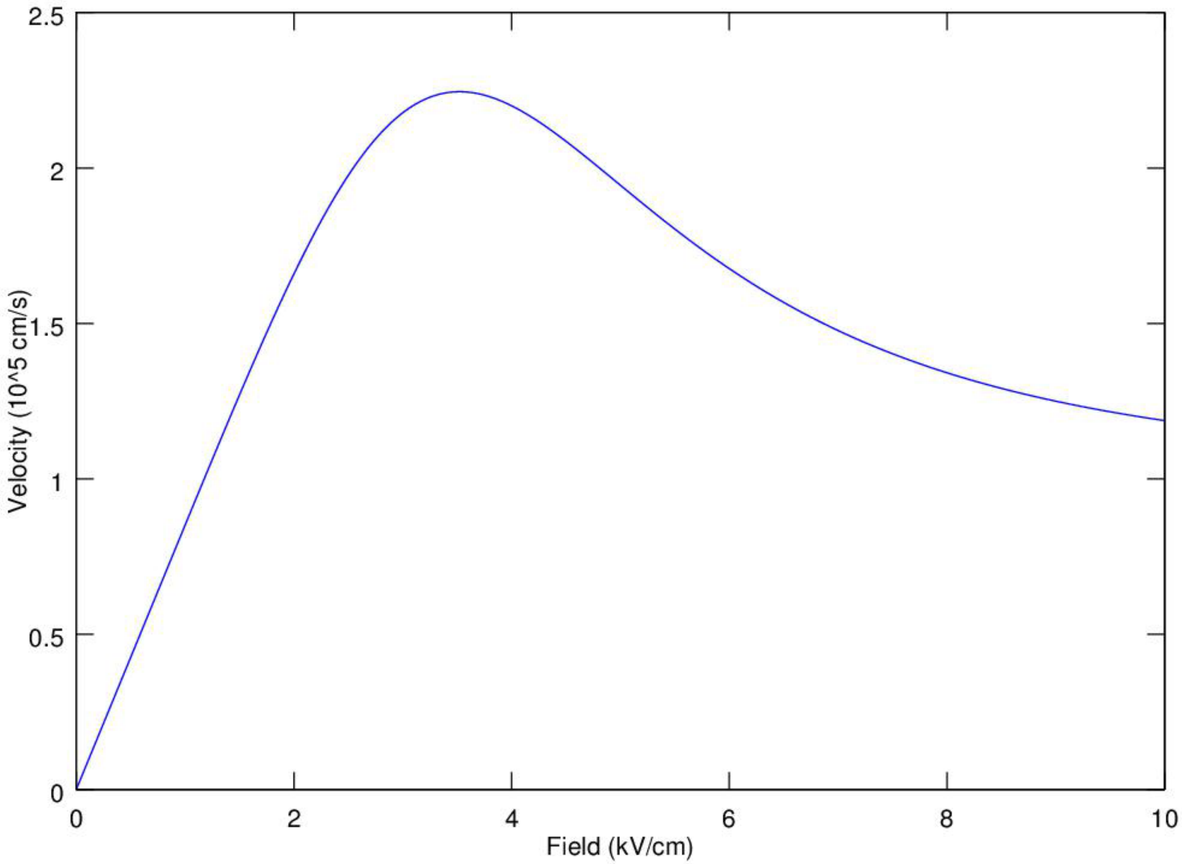


Lighting up the Semiconductor World…

Gunn Diode Modeling in APSYS

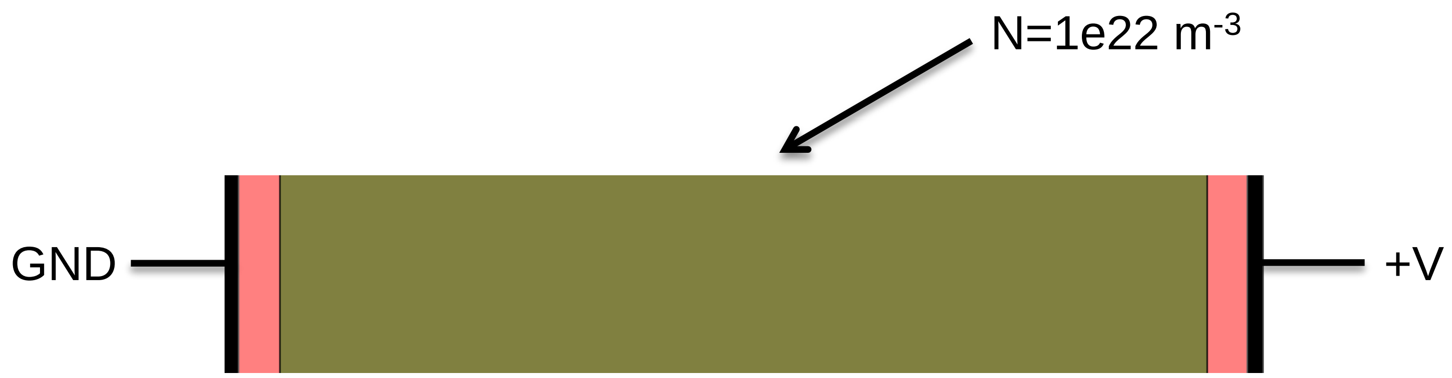
By: Michel Lestrade

Transferred Electron Effect



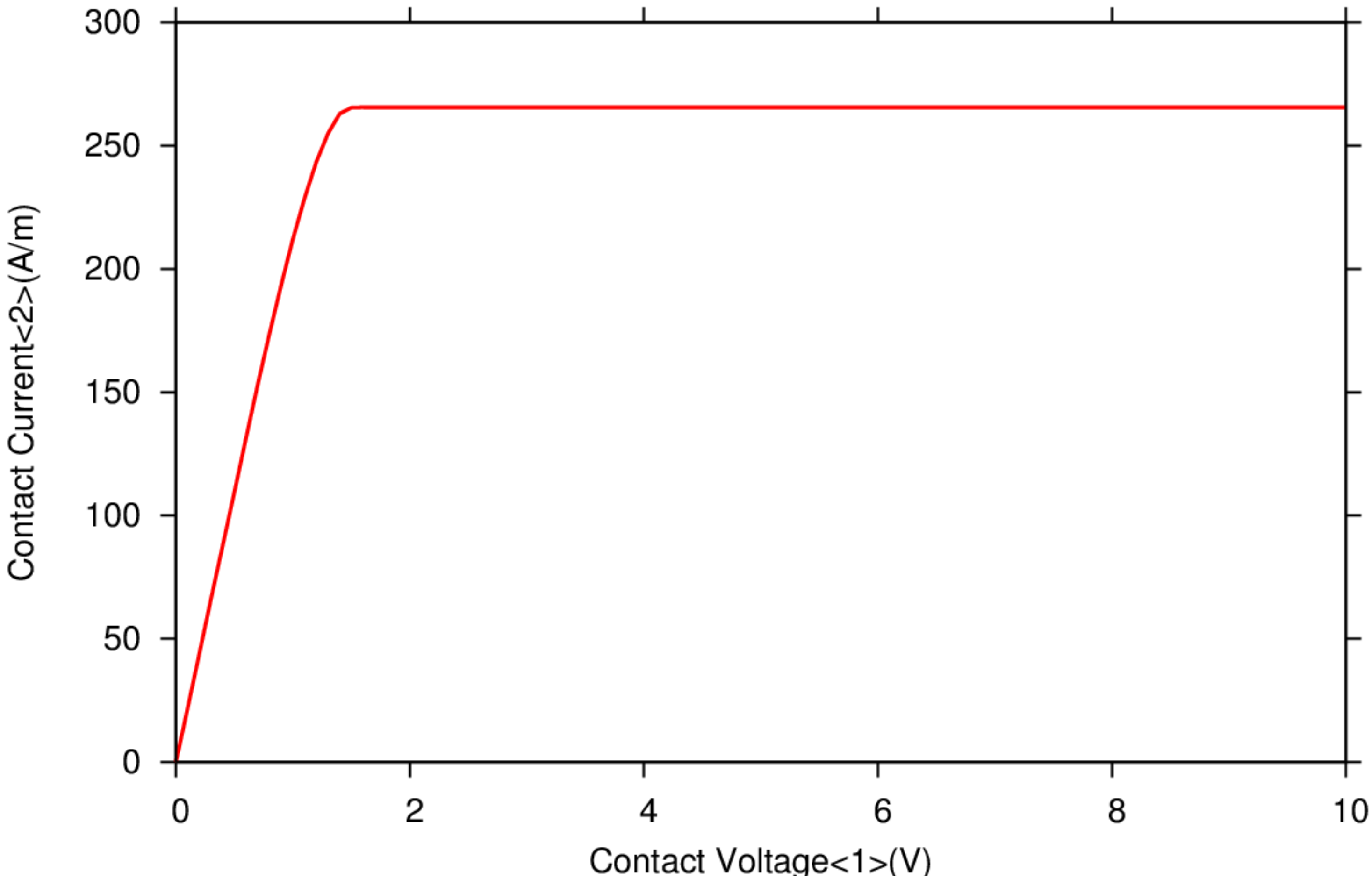
- Found in materials such as GaAs, negative differential resistance (NDR) as electrons get transferred from Gamma to L band valleys at high fields
- Implemented in Crosslight default macro through field-dependent mobility model n.gaas

Gunn Diode



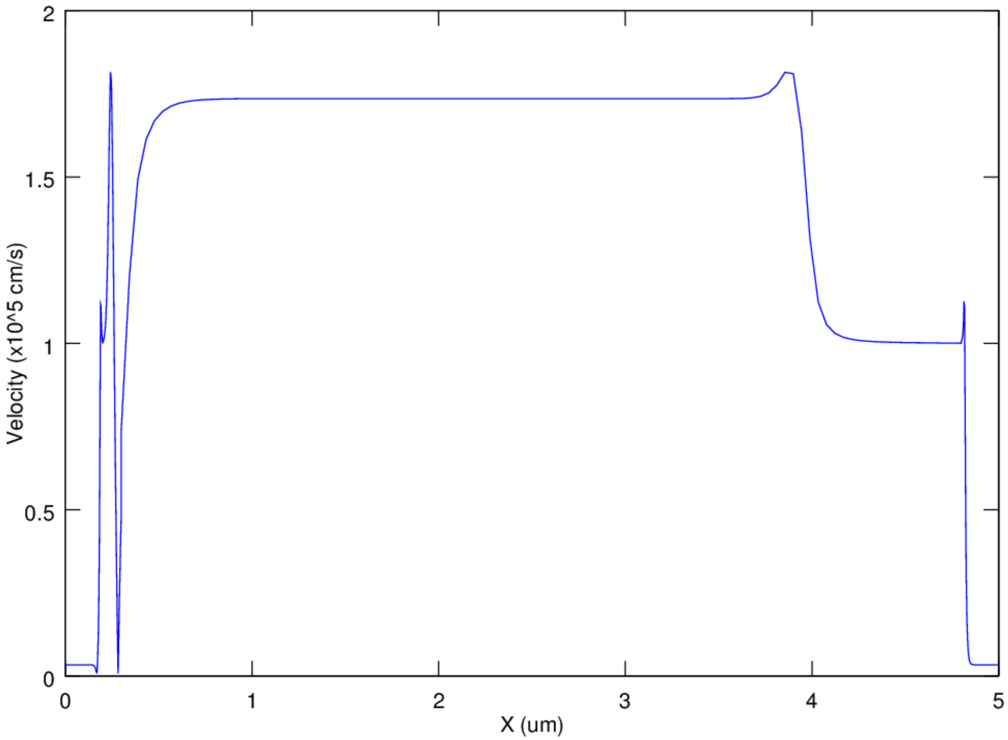
- Basic GaAs n-type unipolar device with ohmic contacts
- Generates microwave self-pulsations under experimental DC bias (Gunn, 1963)

Steady-State Simulation



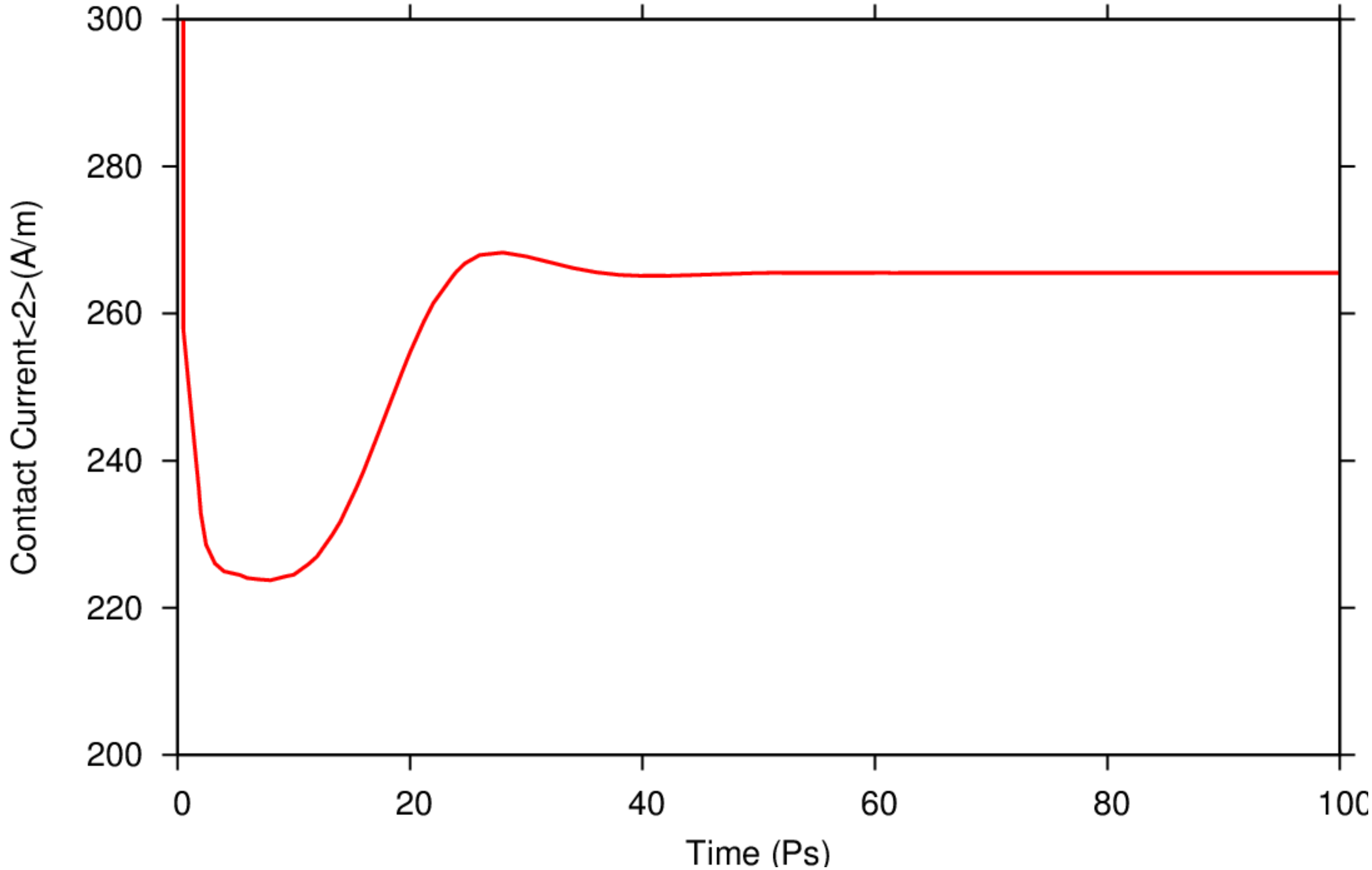
- From Drift-Diffusion model, no pulsations can be observed under steady-state conditions (all $\frac{d}{dt}$ terms are zero)

I-V Curve: Lack of NDR



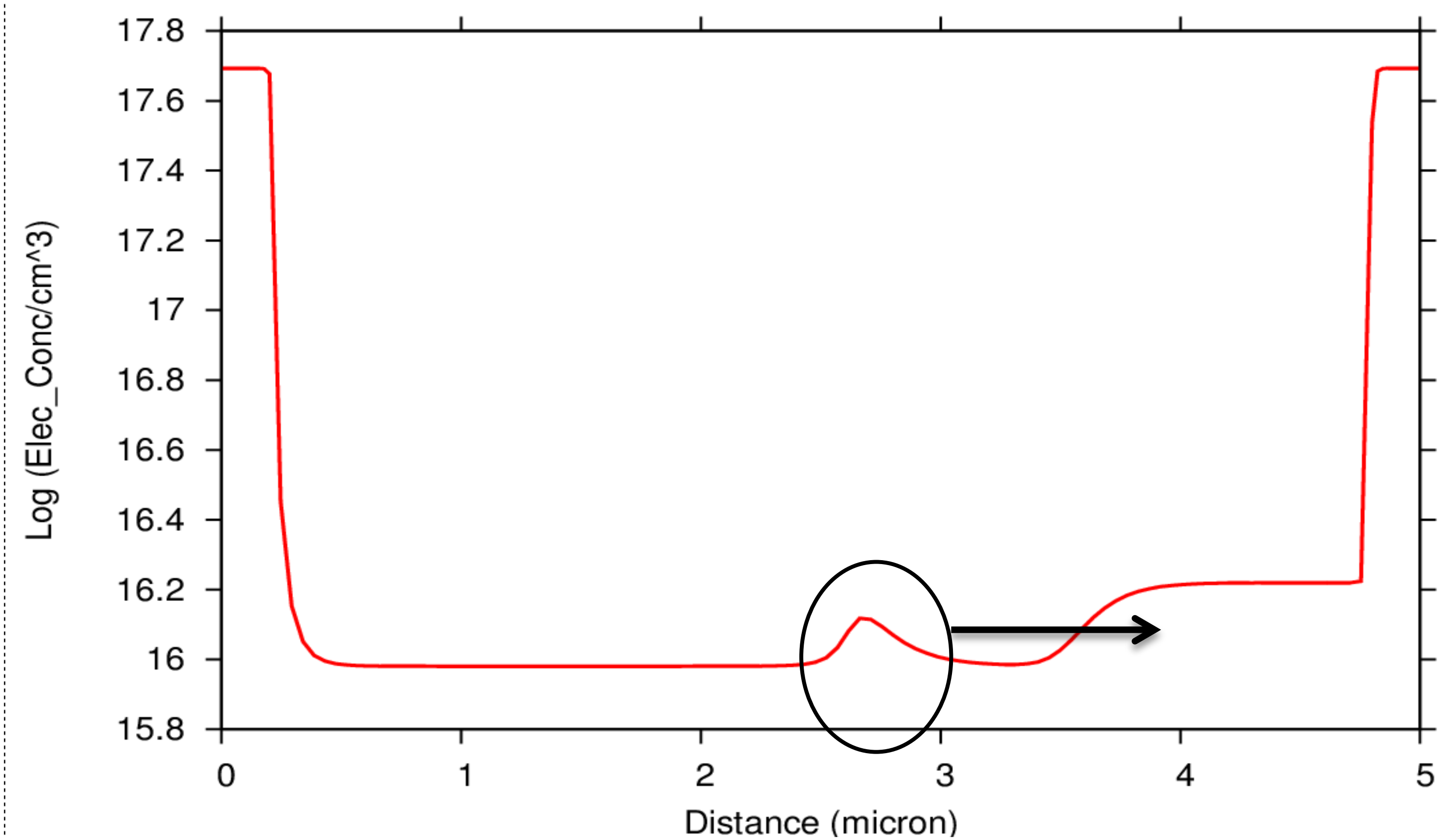
- No NDR observed: presence of field spikes at n/n+ interfaces and non-uniform field in n region. Situation more complex than many textbook models.
- Localized high-field regions means reduced velocity (NDR) also localized ($\vec{v} = \mu * \vec{F}$).
- To maintain net current continuity in steady-state, increased carrier density in those regions ($\overrightarrow{J_n} = n\mu\vec{\nabla}E_{fn} \approx n * \vec{v}$)

Transient Simulation



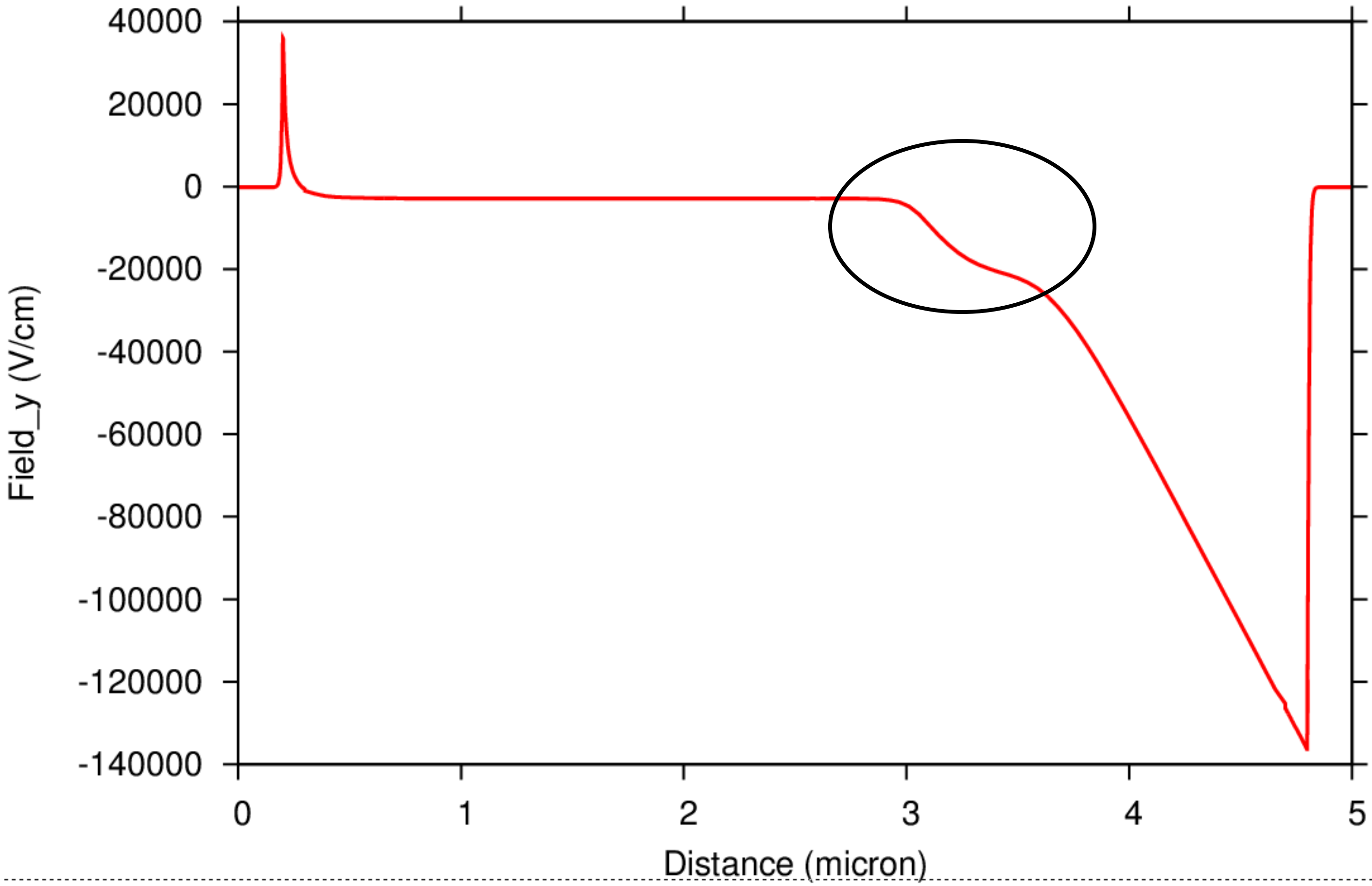
- Step response (10->11 V step applied over 1 fs)
- Perturbation rapidly decays to new steady-state
- No self-pulsation is observed: why ?

Anode-Trapped Domain



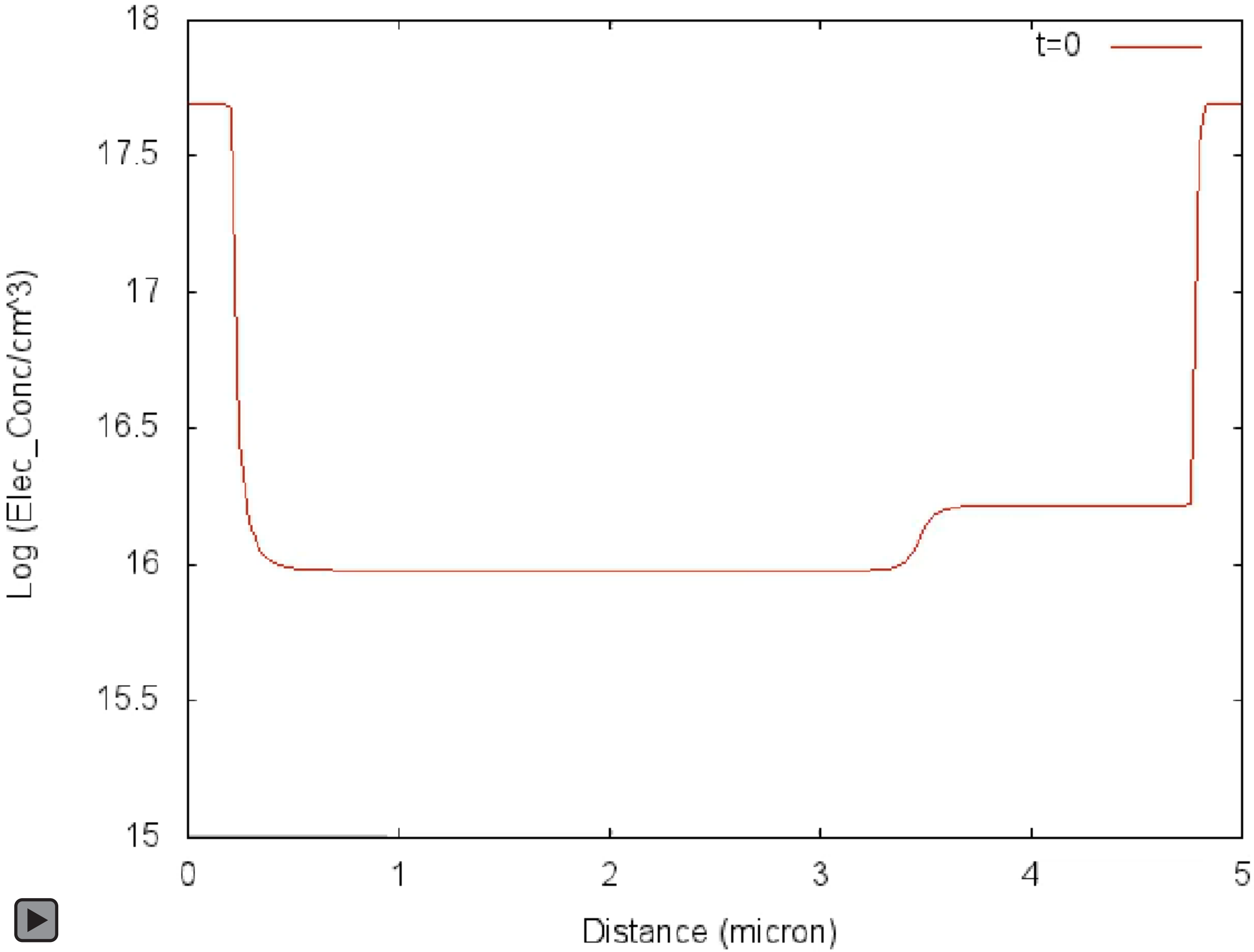
- Initial voltage pulse introduces an accumulation region ($n>n_0$) which propagates towards the anode in order to accommodate the new voltage bias.

Anode-Trapped Domain (2)

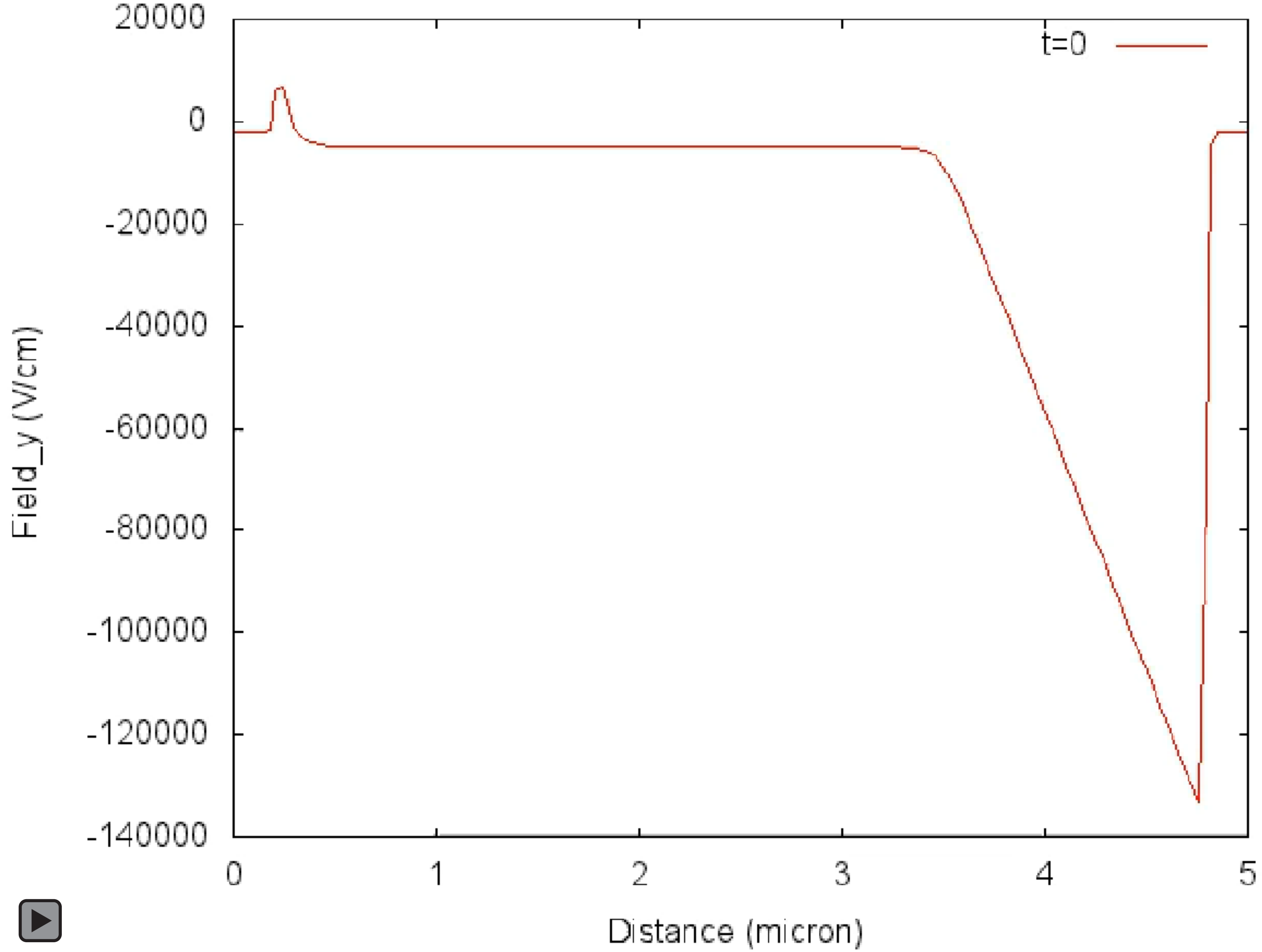


- Field perturbation from voltage pulsed “merged” into existing high-field region: no formation of separate field domains.

Temporal Evolution – Carrier Density



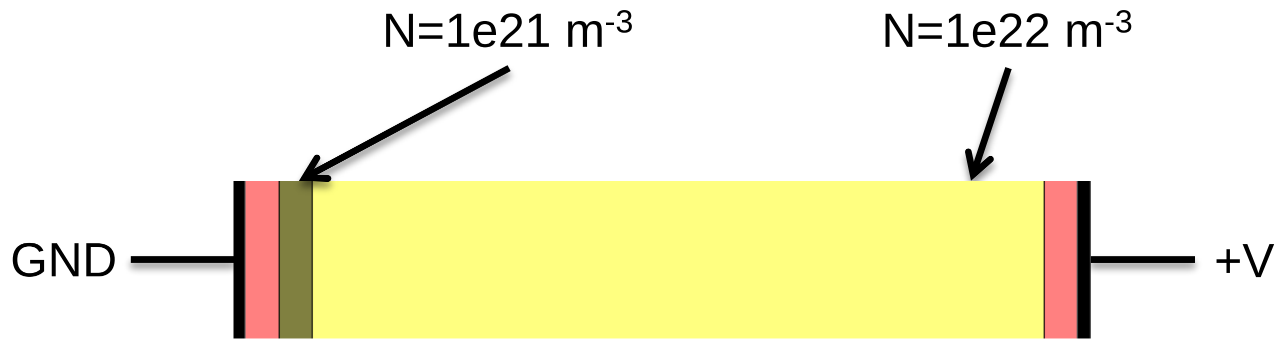
Temporal Evolution – Electric Field



Lack Of Self-Pulsation For Trapped Anode Domain

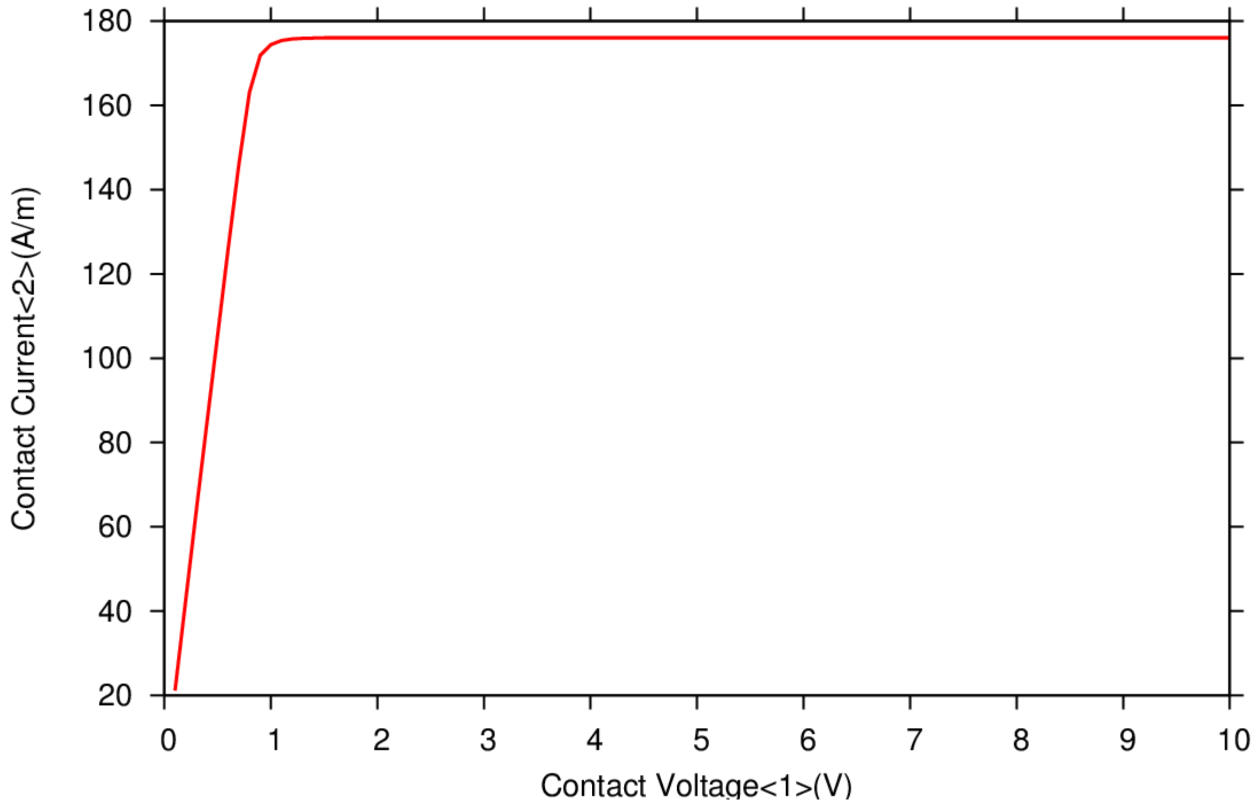
- Instability required for self-pulsation not present in this device
- Current oscillations => carrier density (electron) pulses traveling from cathode to anode
- In order to support this without external oscillating voltage, carrier pulse must regenerate after reaching anode
- Device must have distinct high/low field regions where carrier densities can build up before drifting across the device
- No “seed” for oscillation defined for this device: needs doping and/or trap inhomogeneity to create localized field build-up

Gunn Diode With Notch Doping



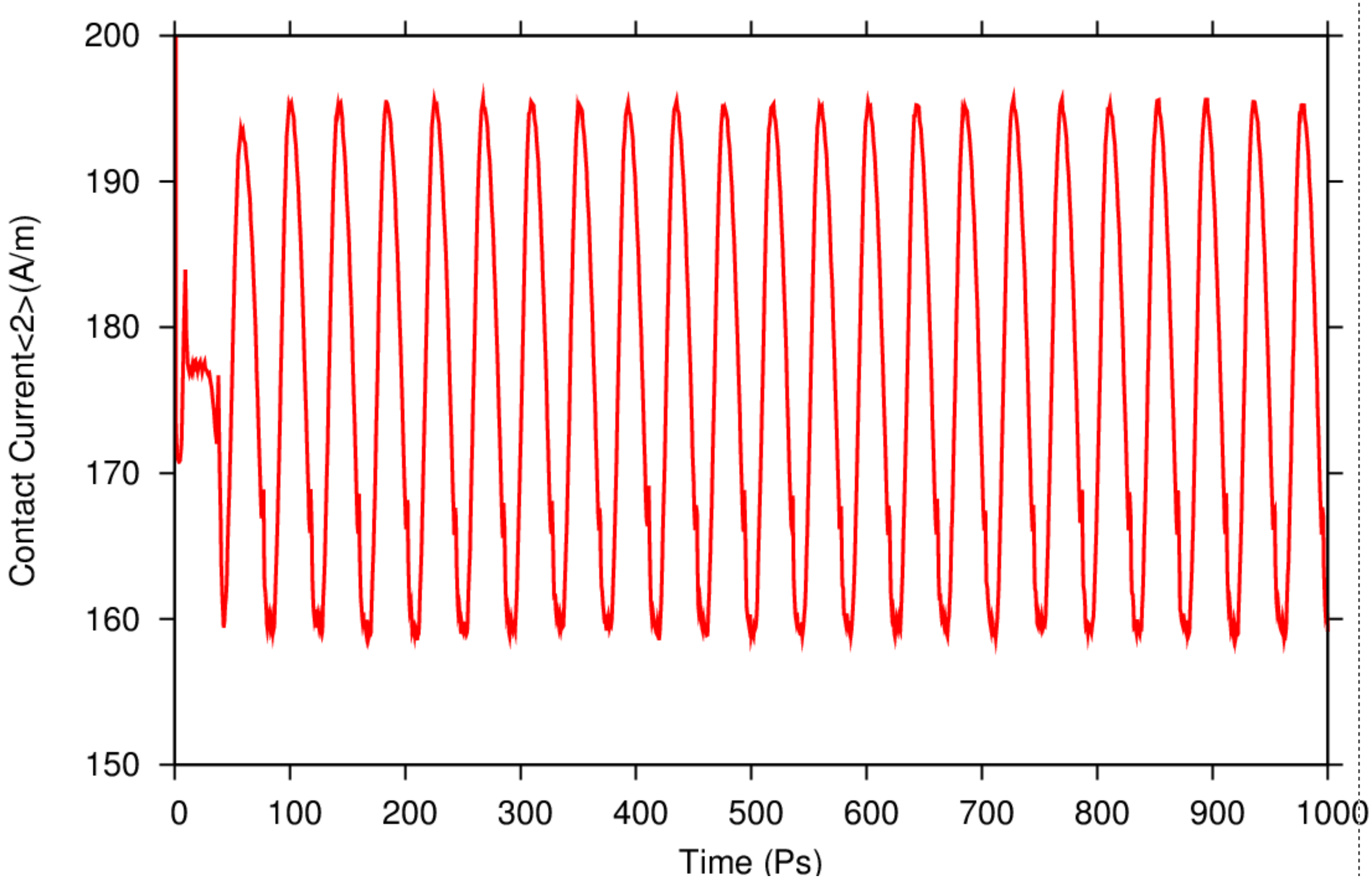
- Modified version of 1st design with a small region of low-doped GaAs near the cathode
- Doping notch provides "seed" of dipole for self-pulsation

Steady-State Simulation



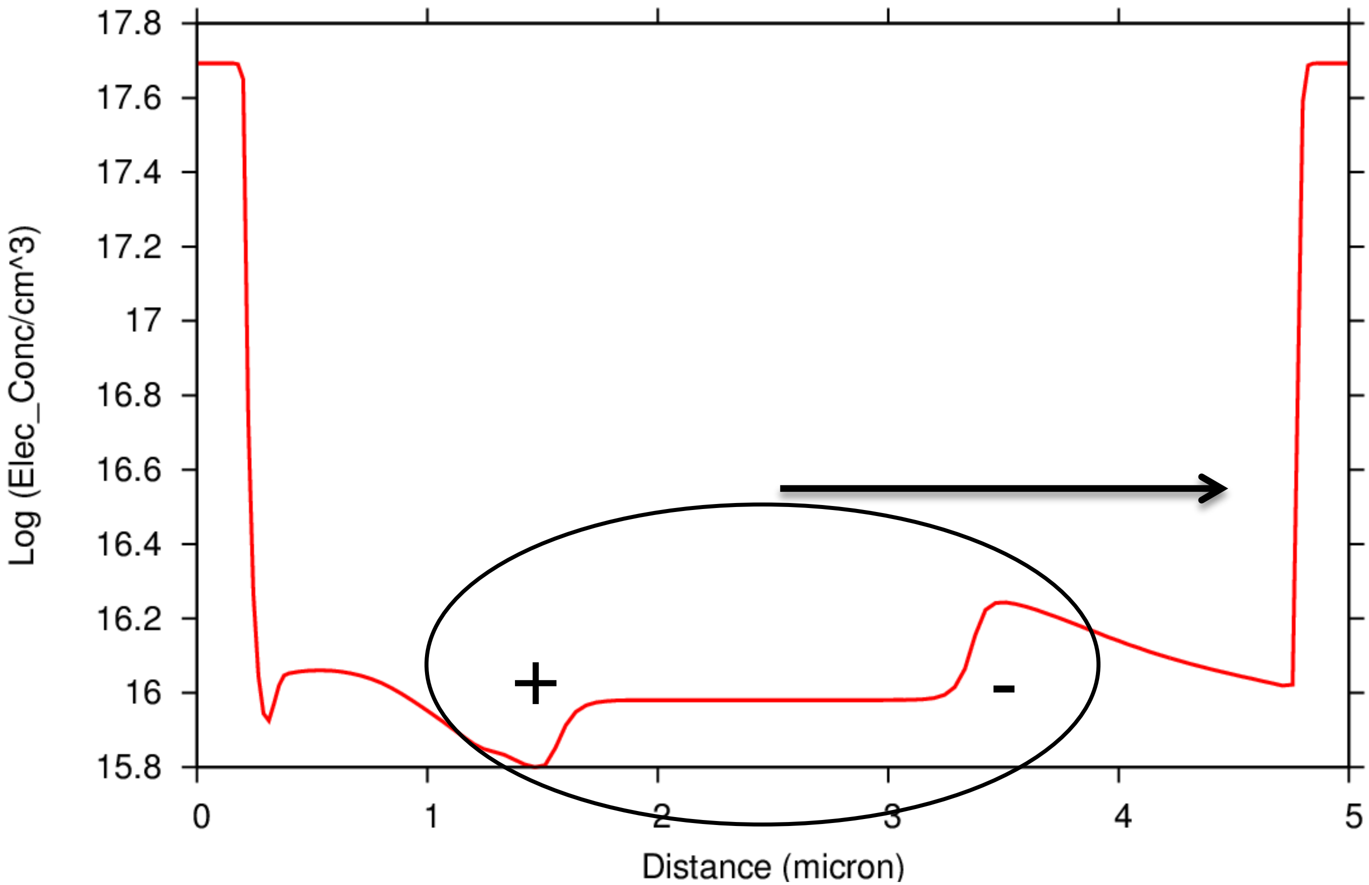
- Similar steady-state I-V without NDR

Transient Simulation



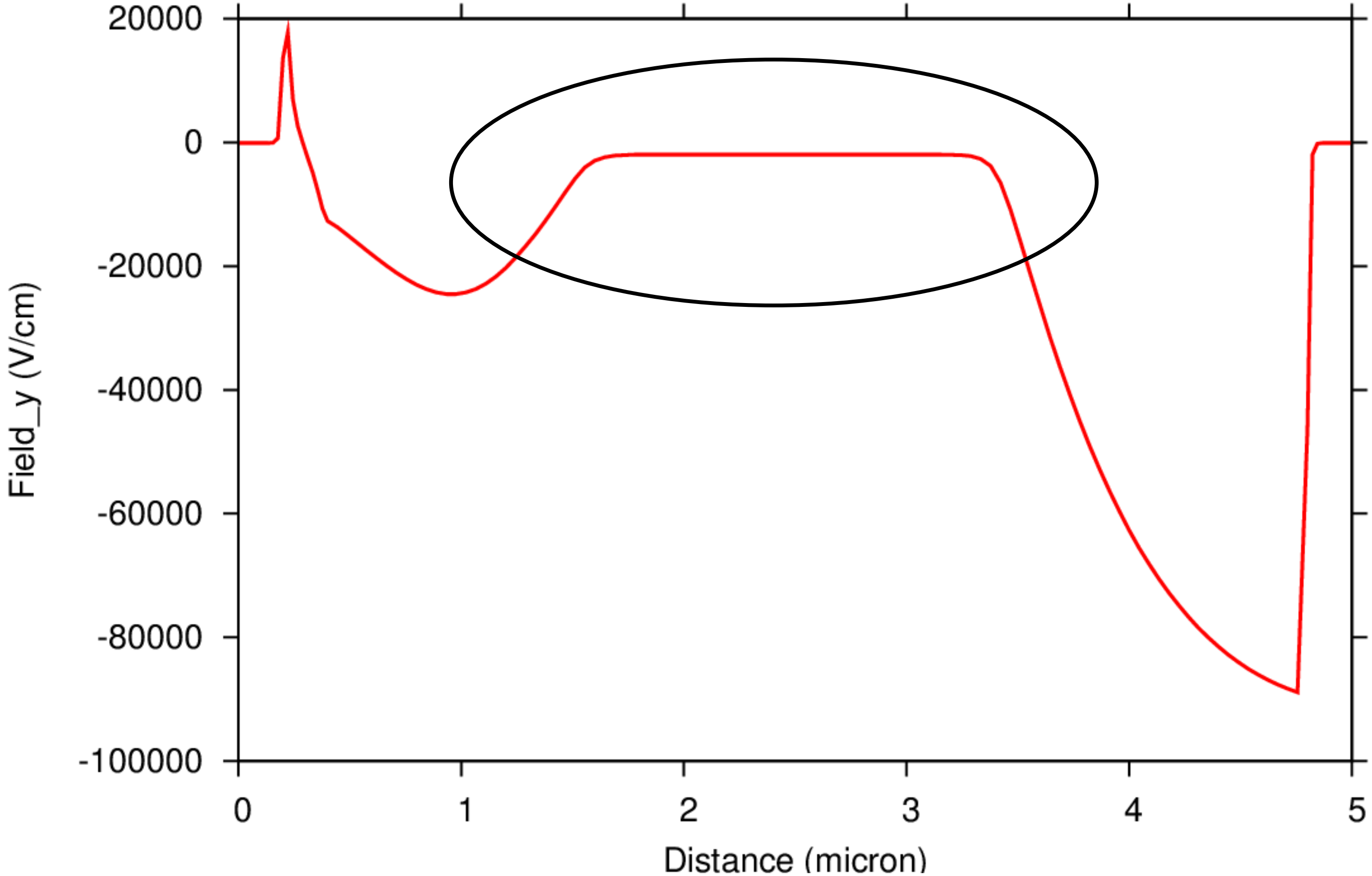
- Step response (10->11 V step applied over 1 fs). Max. step 1 ps.
- Perturbation rapidly builds up into steady self-pulsation
- T~40 ps => f ~25 GHz

Gunn Domains



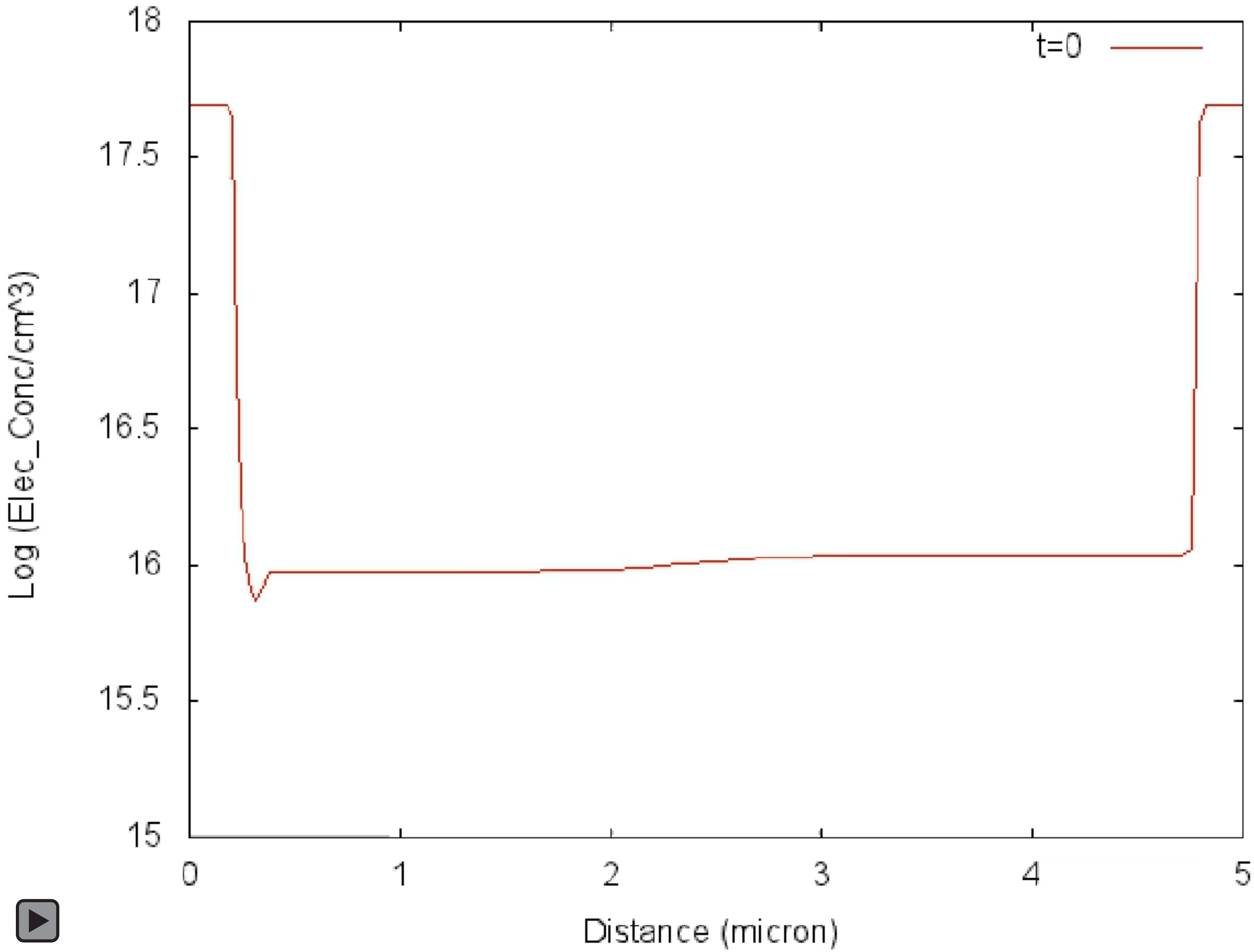
- Perturbation introduces a dipole which propagates in the device
- When part of the dipole gets absorbed at the anode, it gets regenerated near the cathode, leading to self-pulsation

Gunn Domains (2)

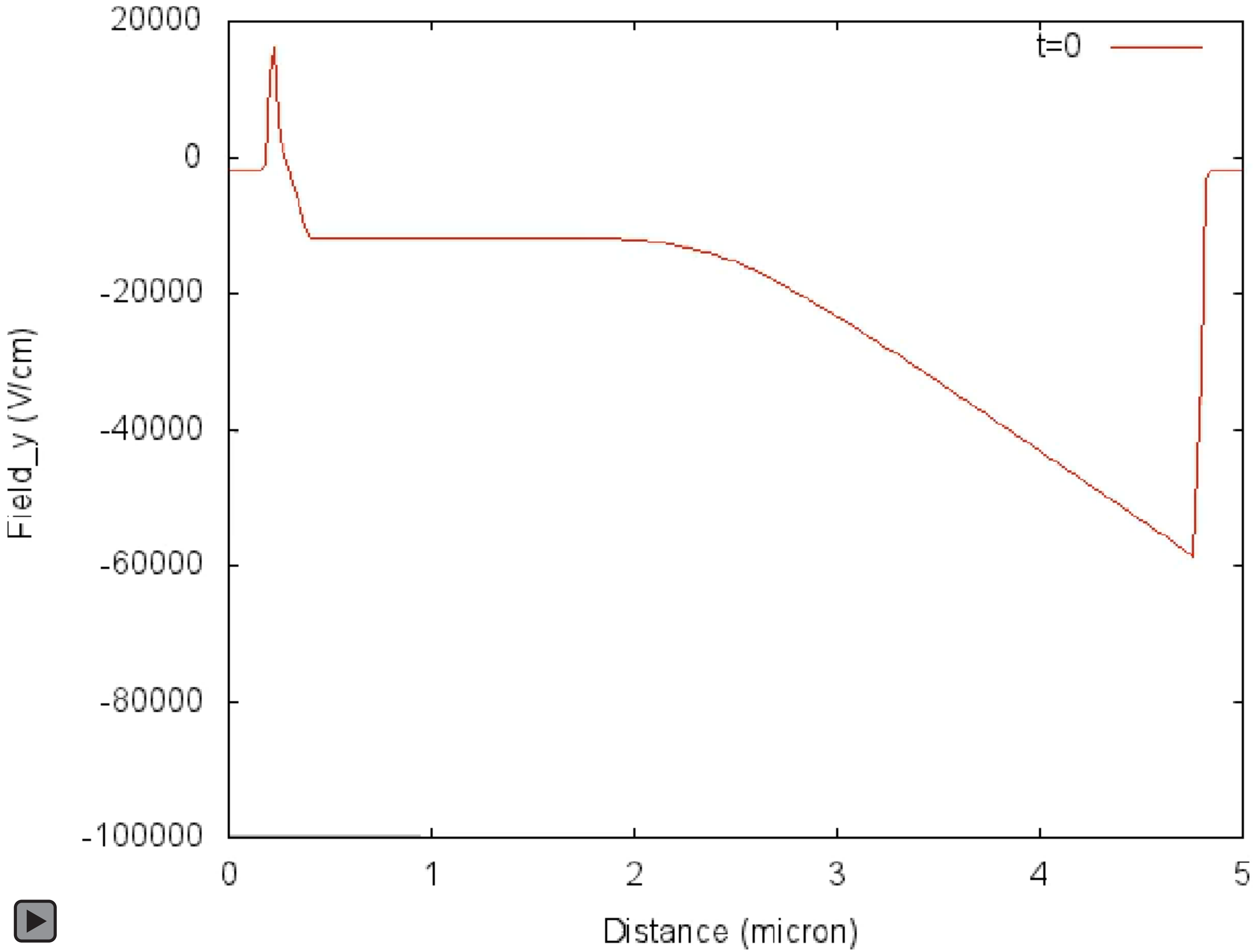


- Dipole induces local field separate from the one caused by the applied bias

Temporal Evolution – Carrier Density



Temporal Evolution – Electric Field



Self-Pulsation Mechanism

- After initial pulse, applied voltage is constant
- Voltage drop across drift region: $\Delta V = \int \vec{F} \cdot \overrightarrow{dl}$
- When part of the dipole is absorbed, new high-field region must be created to maintain ΔV (“equal-areas rule”)
- This allows the dipole to be recreated and propagate again. From Sze: “Transit-Time Dipole-Layer Mode”
- Period of self-pulsation linked to transit time of the domain across the drift region

Conclusion

- Demonstration of self-pulsating Gunn diode.
- Transient simulation with perturbation key to observing the effect
- Inhomogeneity in carrier/field profiles key to seeding the self-pulsation.
- Perturbations must be defined by user since transient Drift-Diffusion is not a stochastic noise-driven model.
- Early experimental observations likely due to unintentional fluctuations of doping profiles.

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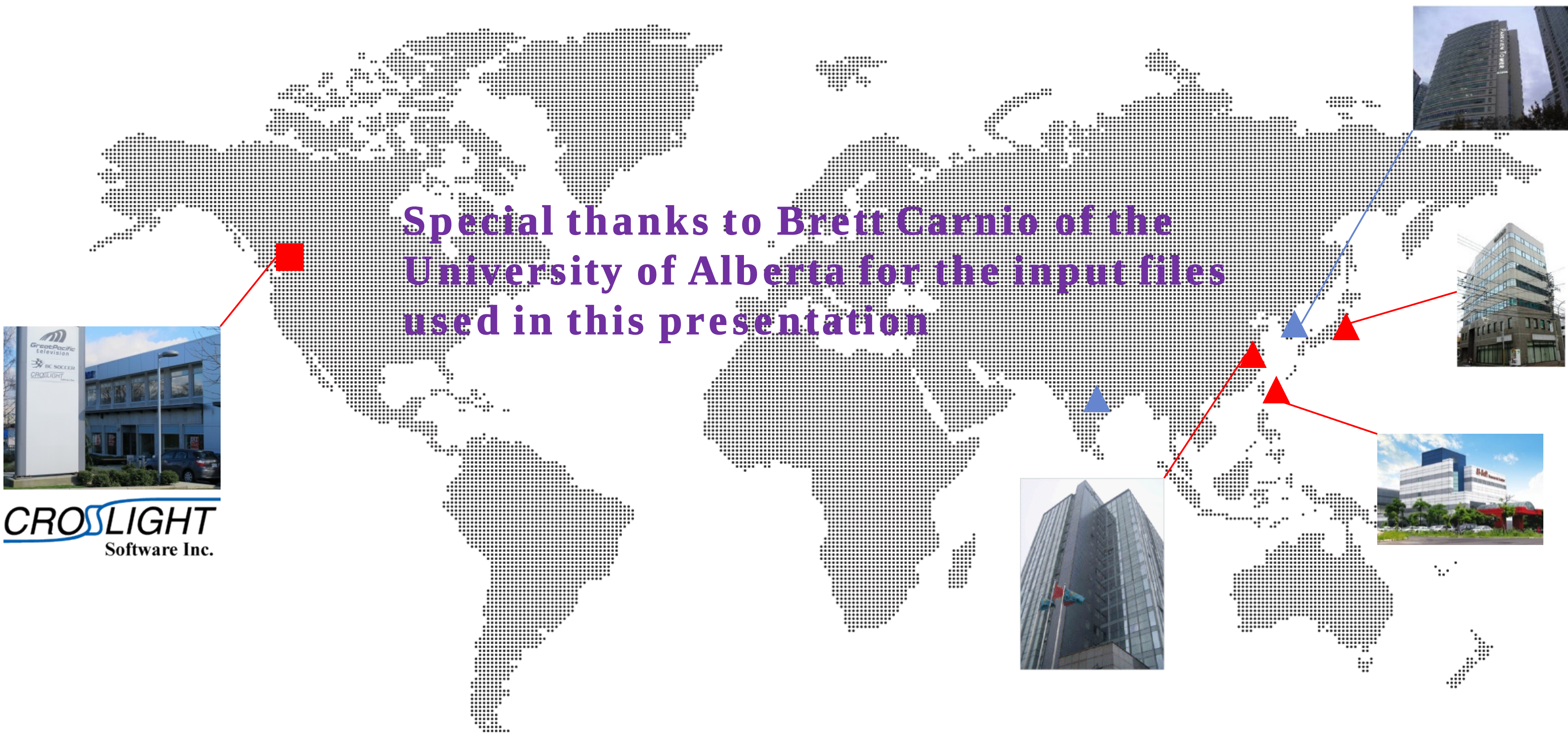

Special thanks to Brett Carnio of the University of Alberta for the input files used in this presentation

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