NIMROD simulations of flux injection in a coplanar gun

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Inductive Flux Injection Model

- NIMROD has two available flux injection models[a]
  - direct flux injection via Faraday's law (specifying tangential **E** field at the boundary)
  - inductive flux injection via Ampere's law (specifying a tangential **B** field at the boundary)
- inductive flux injection (i.e. specifying input current) is closer to (coaxial gun source) experiment
- exploit integral Ampere's law $\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 I$
- specify B_ϕ at the boundary corresponding to coaxial gap to induce poloidal current in simulation domain

[a] C. Sovinec, "Ohmic Current Drive in NIMROD Simulation", NIMROD internal note, 2005

Inductive Flux Injection Model cont.

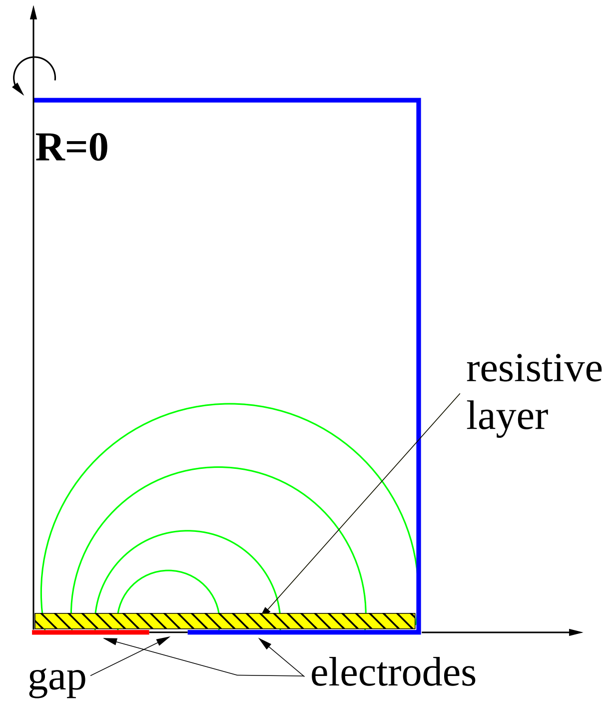
- along the boundary corresponding to flux gap specify $B_\phi R$
  - otherwise boundary condition is no-slip perfect conductor
- prescribed $B_\phi R$ induces a poloidal current in the simulation domain
- amplitude of $B_\phi R$ may vary with time (e.g. constant slope or programmed from experiment)

? thin highly resistive layer along bottom to rapidly diffuse flux across bottom

- the resulting $\mathbf{J} \times \mathbf{B}$ force pulls in the flux, drives columnation

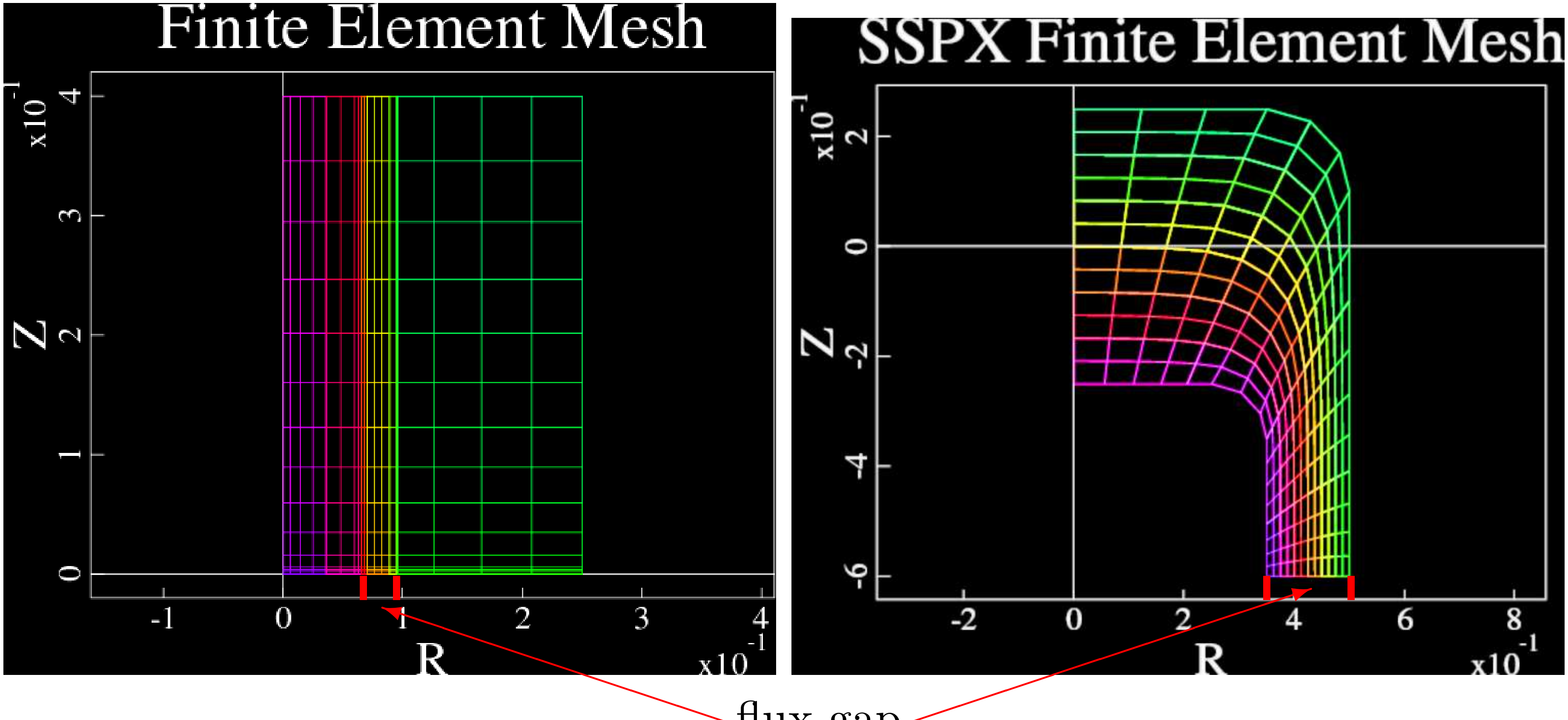
Coplanar Flux Injection Simulation

- cylindrical vessel with small flux gap of a few centimeters



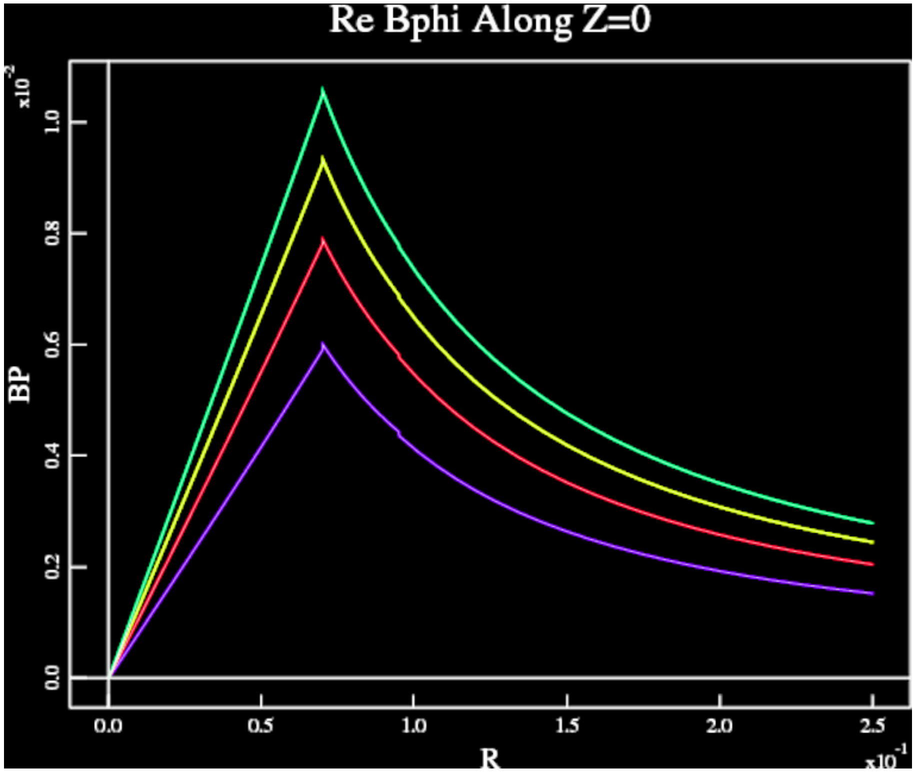
- vacuum field is dipole-like $\sim .1mWb$
  - flux gap located at top of the arc
- peak current is $40 - 100kA$ ramped over $4 - 15\mu s$
- thin highly resistive layer across bottom 10^5 larger than background resistivity

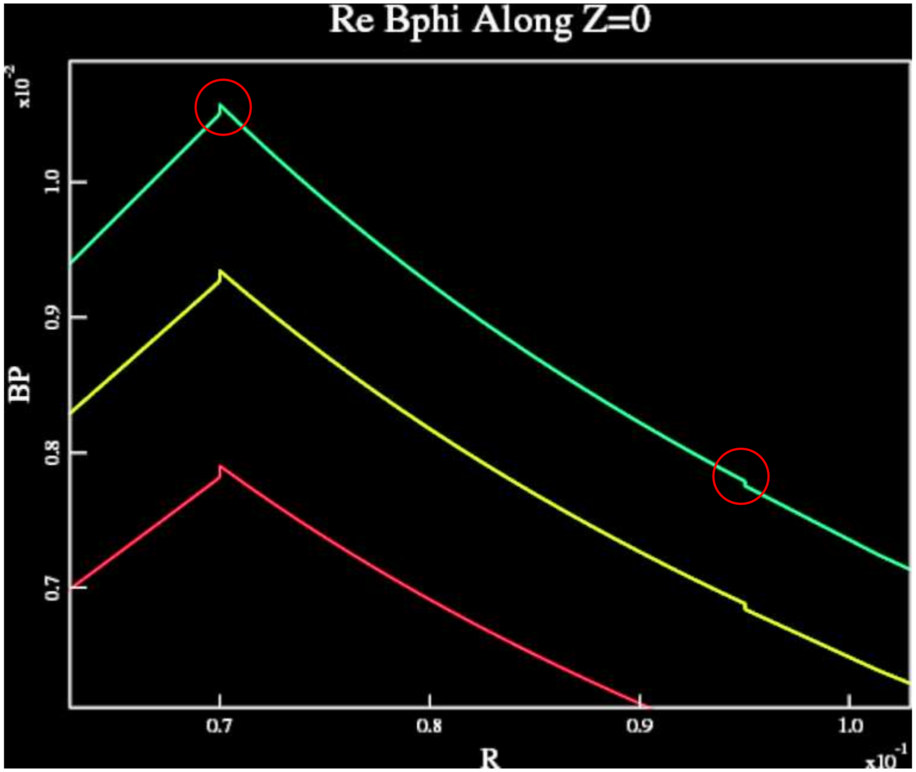
Coplanar Flux Injection is more challenging than coaxial injection



- larger inductive **E** field
- coaxial gun is well resolved
- discontinuous jump in $\frac{\partial B_\phi}{\partial R}$
- $\lambda_g^{SSPX} \sim 10 - 15 m^{-1}$ - we attempt $\lambda_g \sim 10 - 100 m^{-1}$

B_ϕ along Z=0 shows discontinuity

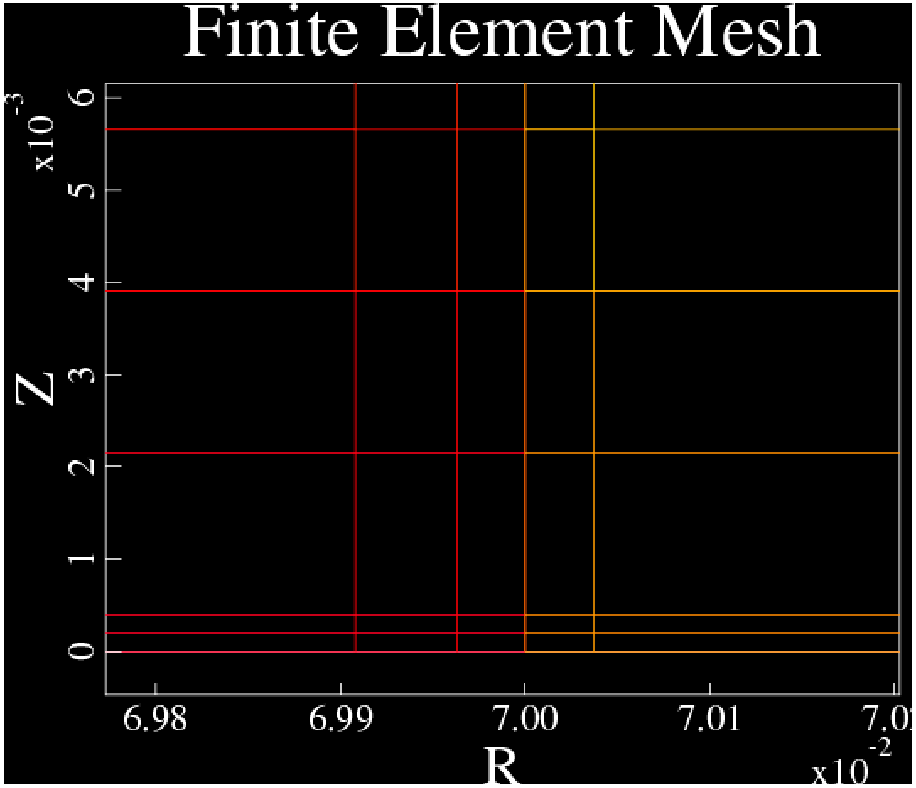


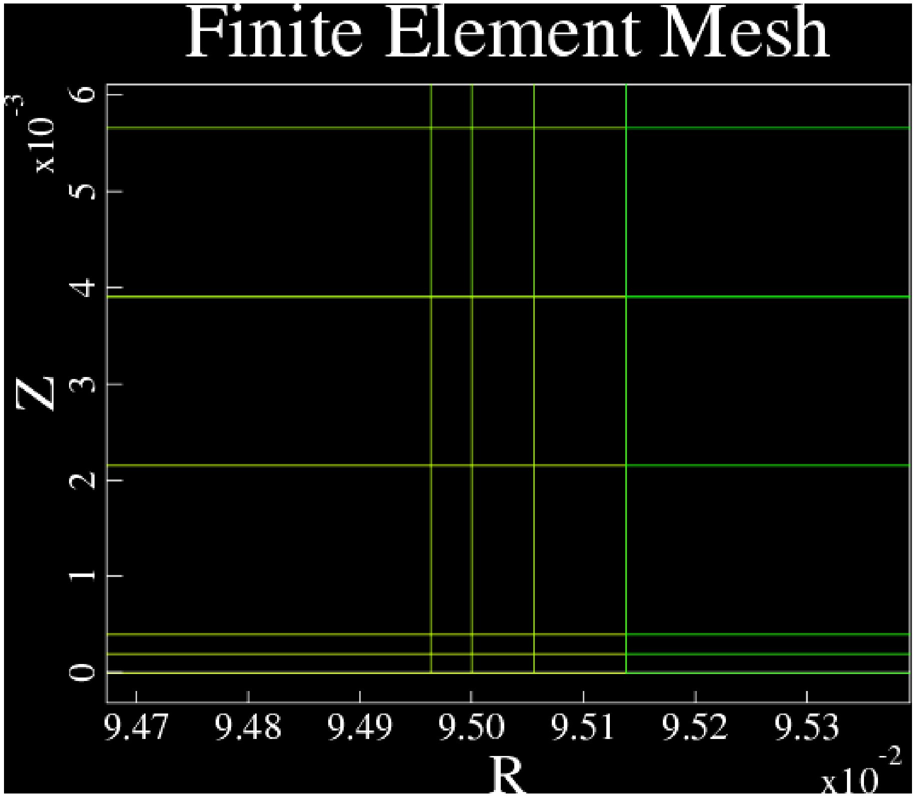


- 4 curves are at $t = [.53, .69, .82, .93]\mu s$
- note discontinuity at $R = .07$ and $.095$ where boundary condition is specified
- note strong effect of diffusive layer

Zoomed in view of Coplanar Injection grid

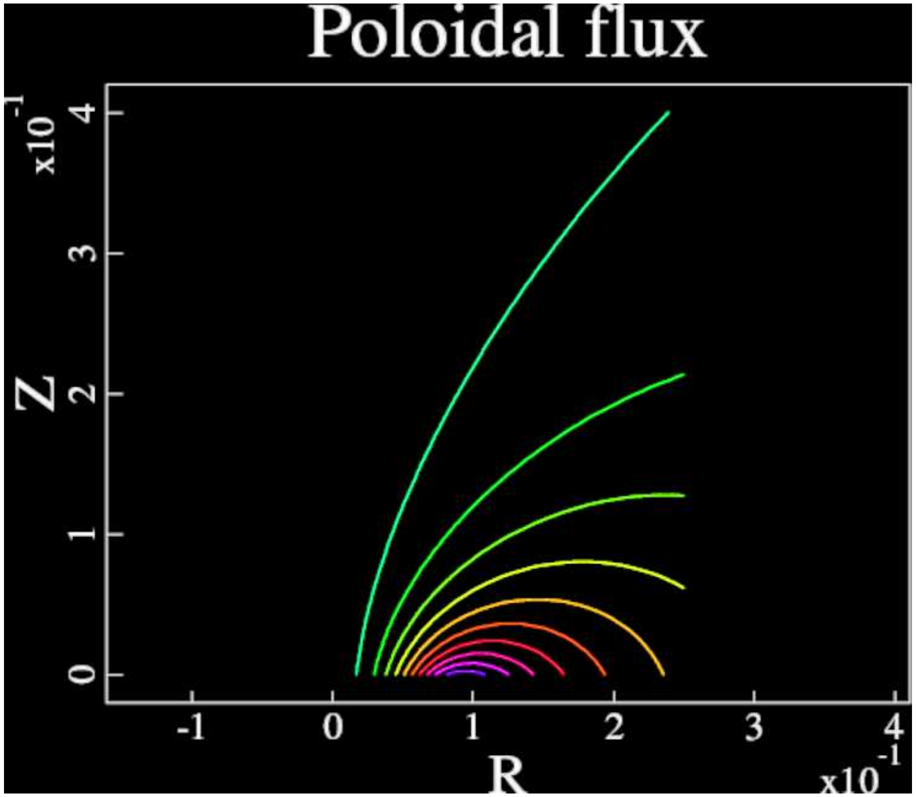
discontinuous jump in $\frac{\partial B_\phi}{\partial R}$ requires high resolution

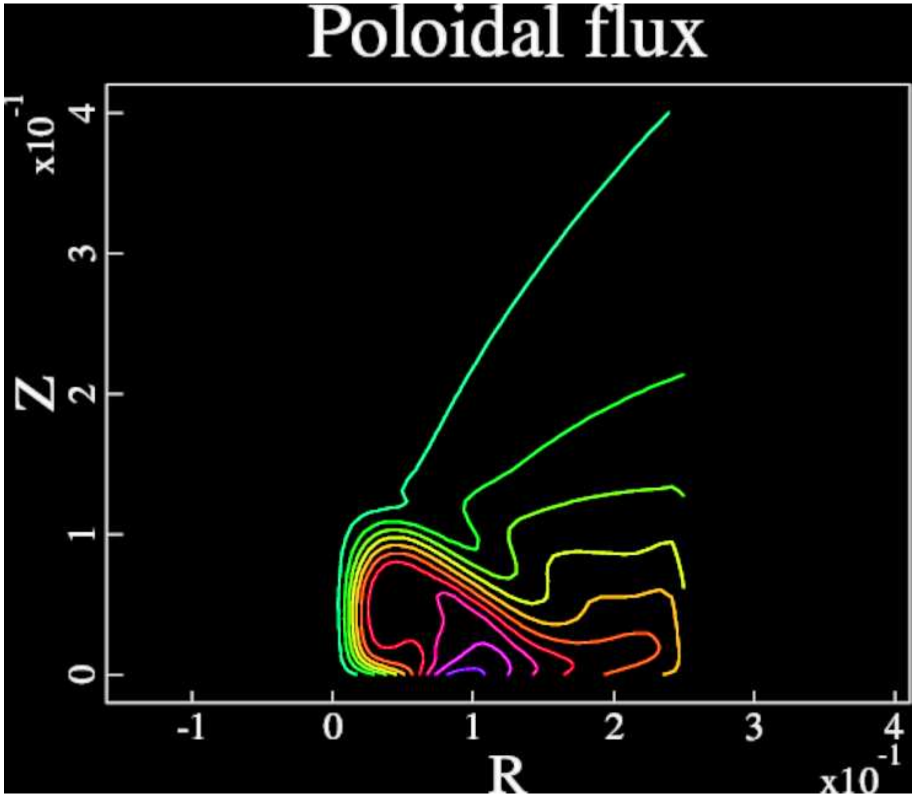




note the scale

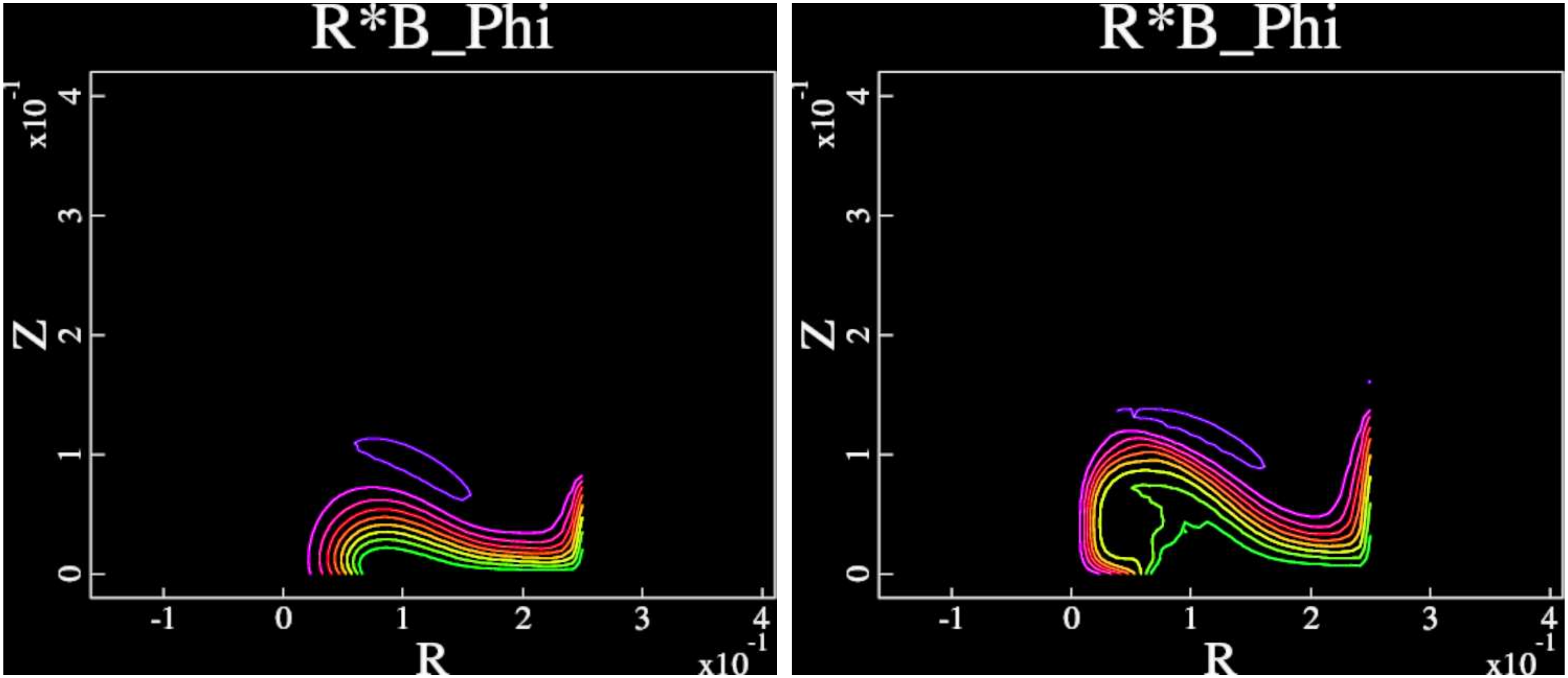
Poloidal Flux Compression after $\sim 4.5\mu s$



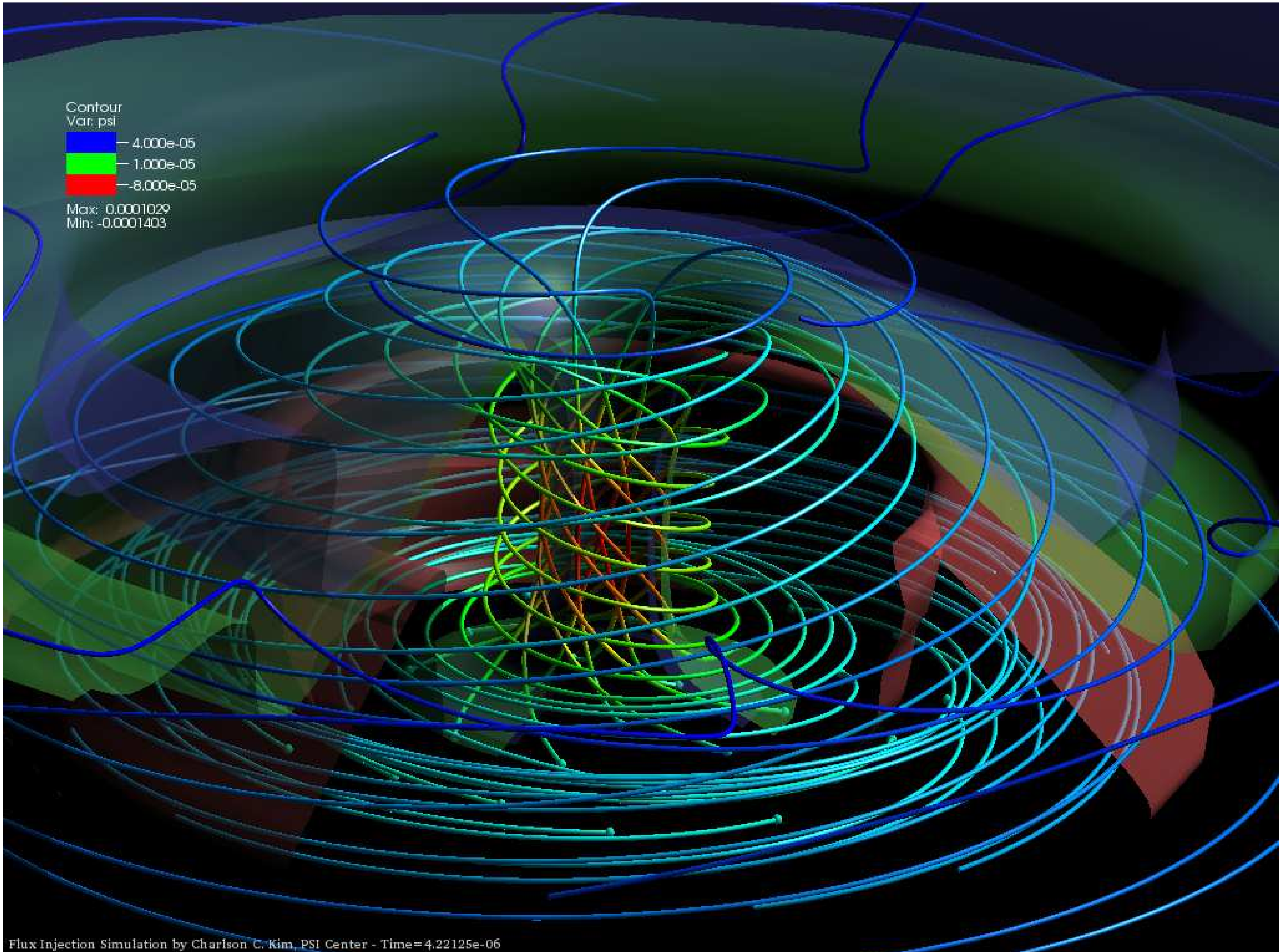


- 10 contour lines $[-.13, .9]mWb$
- contour lines same value in both plots

Evolution of Poloidal Current



- left plot at $2.9\mu s$, contour range $[1.2, 11.7]kA$
- right plot at $4.2\mu s$, contour range $[1.8, 16.9]kA$
- current ramp time $10\mu s$, peak current $40kA$


Contour
Var: psi
4.000e-05
1.000e-05
-8.000e-05
Max: 0.0001029
Min: -0.0001403
Flux Injection Simulation by Charlson C. Kim, PSI Center - Time=4.22125e-06

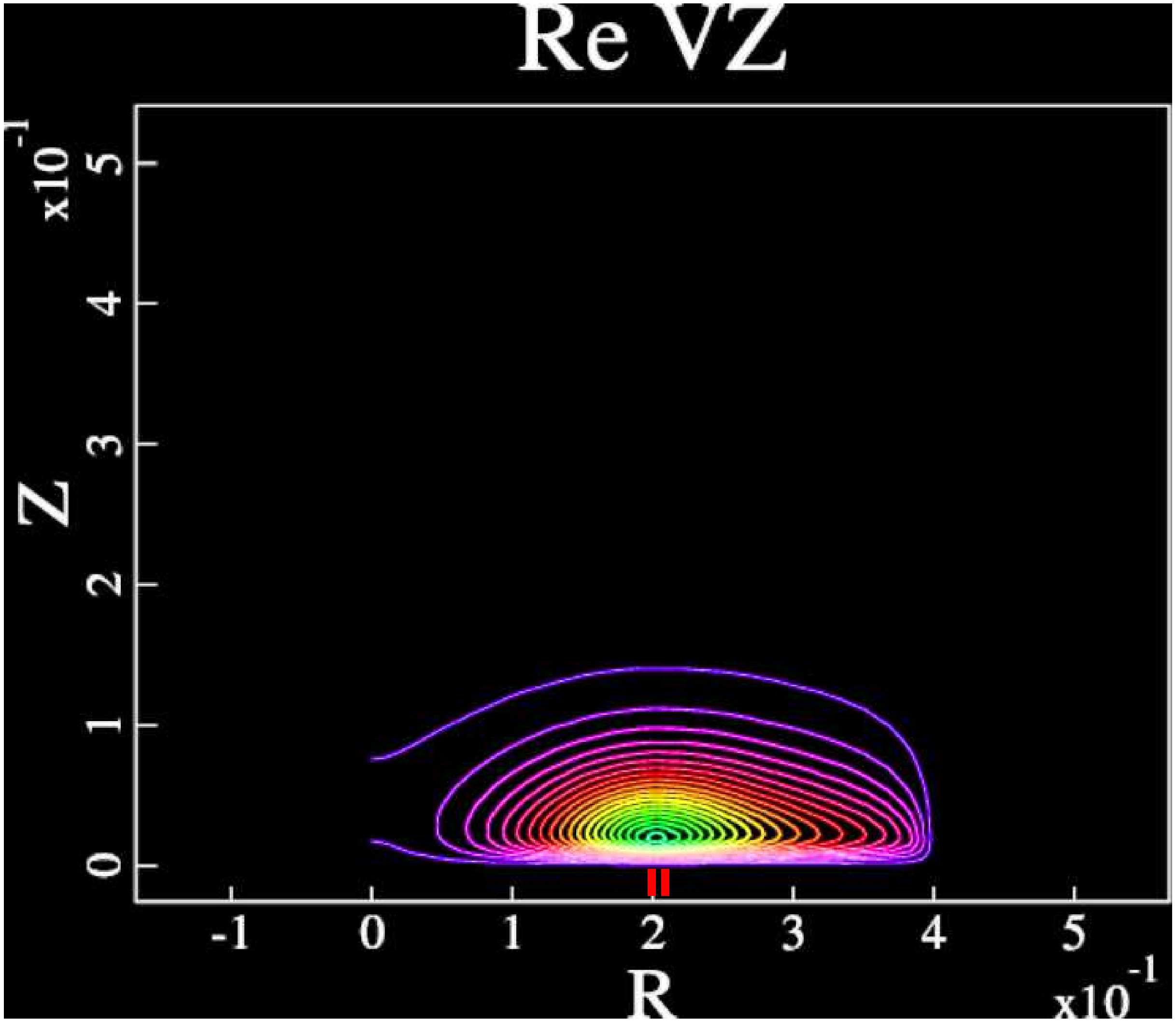
Some Heuristic Considerations

- specifying B_ϕ meant to induce I_{pol}
- but fast injection also results in $\dfrac{\partial B_\phi}{\partial t} = -\left(\nabla \times \mathbf{E}\right)_\phi$
- i.e. $\dfrac{\partial E_R}{\partial Z}$ and $\dfrac{\partial E_Z}{\partial R}$
- as B_ϕ increases $\mathbf{E}$ becomes more $E_\perp$
- requires strong perpendicular flow in resistive model
- Hall physics removes inertial from field line evolution

? what about $E_{||}$

- in resistive model requires $J_{||}$
- Hall provides additional $\nabla_{||} p_e$

Strong Alfvenic flows



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Summary, Ongoing Work, and Issues

- for resistive MHD fast injection results in strong Alfvenic flows
- Hall physics helps relieve strong flow issues
  - but could drive smaller scale fluctuations
  - still constrained by strong flows
  - are there parameters to fiddle
- flux gap model is incomplete
  - no-slip perfect conductor b.c. no longer applies
  - consistent b.c. remains to be resolved

Slides among friends

Initialize logical for setting boundary condition

```
      IF (gridshape=='bell') THEN
        xov0=xo
        IF (wpack(1).gt.0._r8)
     $      xov0=xo-wpack(1)*ATANH(1._r8-2._r8*amp(1))*wpack(3)
        yov0=yo
        IF (wpack(2).gt.0._r8)
     $      yov0=yo+wpack(2)*ATANH(1._r8-2._r8*amp(2))*wpack(3)
c-------------------------------------------------------------------------
c    use xo and yo to set the current injection region
c-------------------------------------------------------------------------
        DO ibl=1,nrbl
          nv=seam(ibl)%nvert
          DO iv=1,nv
            ivn=iv-1
            IF (ivn==0) ivn=nv
            IF ((seam(ibl)%vertex(iv)%zgeom.EQ.ymin)
     $          .AND.(seam(ibl)%vertex(iv)%rgeom.GE.xov0)
```

```
$             .AND.(seam(ibl)%vertex(iv)%rgeom.LE.yov0)) THEN
              seam(ibl)%applV0(1,iv)=.TRUE.
            IF (seam(ibl)%excorner(iv))
$             seam(ibl)%applV0(1,iv)=.FALSE.
            IF ((seam(ibl)%vertex(ivn)%zgeom.EQ.ymin)
$             .AND.(seam(ibl)%vertex(ivn)%rgeom.GE.xov0)
$             .AND.(seam(ibl)%vertex(ivn)%rgeom.LE.yov0))
$             seam(ibl)%applV0(2,iv)=.TRUE.
            write(*,*)'in bell',ibl,iv,'is true aplv0(2) is',
$                                    seam(ibl)%applV0(2,iv)
          ENDIF
        ENDDO
      ENDDO
    ENDIF
```

Use the logical for applying boundary condition

```
        DO ibl=1,SIZE(exblock_list)
          ibe=exblock_list(ibl)
          DO iv=1,seam(ibe)%nvert
            IF (seam(ibe)%applV0(1,iv)) THEN
              ix=seam(ibe)%vertex(iv)%intxy(1)
              iy=seam(ibe)%vertex(iv)%intxy(2)
              DO imode=1,nmodes
                IF (keff(imode)==0) be(ibe)%arr(3,ix,iy,imode)=
     $            gun_cur/rb(ibe)%rz%fs(1,ix,iy)
     $              *MAX(oneflg1,
     $       .5_r8*(TANH((rb(ibe)%rz%fs(1,ix,iy)-xov0)/wpack(1))+1))
     $              *MAX(oneflg2,
     $       .5_r8*(TANH((yov0-rb(ibe)%rz%fs(1,ix,iy))/wpack(2))+1))
              ENDDO
            ENDIF
          ENDDO
        ENDDO
```