# Coupling of NIMROD to MCCC* (Monte Carlo Coulomb Collision code) for improved runaway electron orbits

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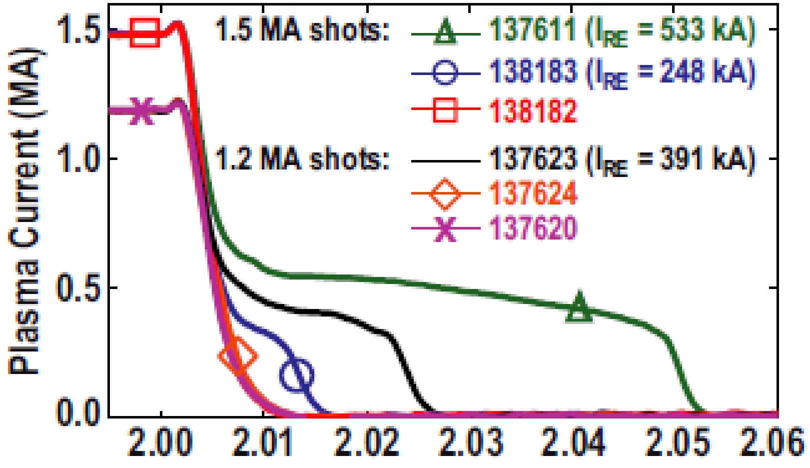
# Outline

- Motivation for RE orbits in NIMROD
- The existing NIMROD RE orbit model, what it's useful for and what it's limitations are
- The coupling to mccc and what advantages that offers
- Initial tests of the coupled model
- Summary

# Runaway Electrons are the most serious concern for ITER disruptions




Example DIII-D discharges with RE current plateaus

- Very high electric field during disruptions can produce large numbers of high energy (~10MeV) runaway electrons
- Once an electrons exceeds the runaway threshold it is accelerated continuously ("free-fall") as it orbits until radiation becomes important or the orbit is not confined (curvature drift)
- Secondary runaways through the knock-on avalanche effect, where a RE collides with a thermal electron and pushes it above the threshold.
- The secondary effect is an exponential process with the initial plasma current in the exponent → situation in ITER may be much more serious than any smaller tokamak
- Theory needed to fully understand sources and loss terms in physical and momentum space

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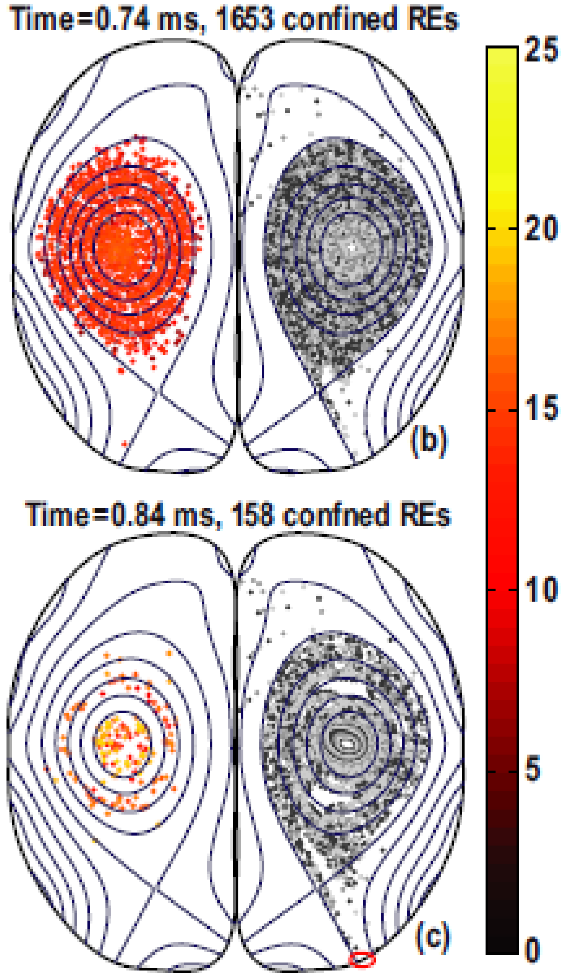
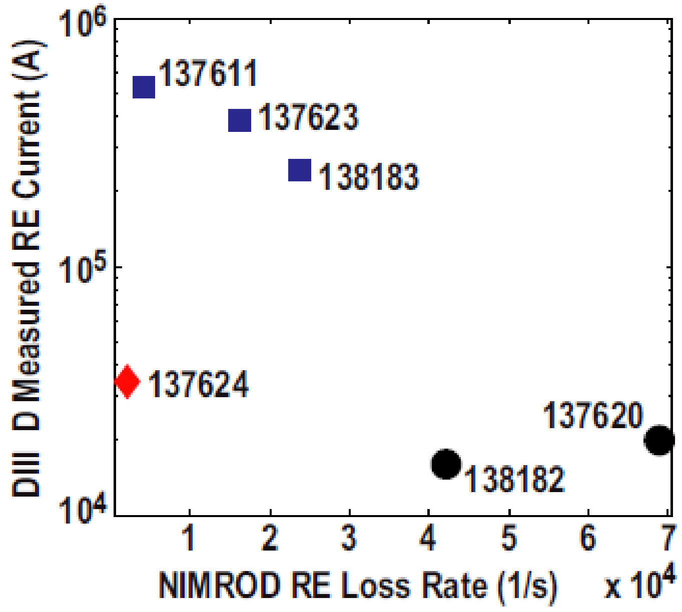
# NIMROD RE orbit model designed to follow drift orbits of RE test particles during disruption simulations




- Not the most complete RE orbit model, but the only one coupled to an MHD code to calculate orbits as the 3D fields evolve through a disruption

- Successfully correlated NIMROD predicted loss rates during the TQ with DIII-D measure RE currents for a variety of diverted equilibria

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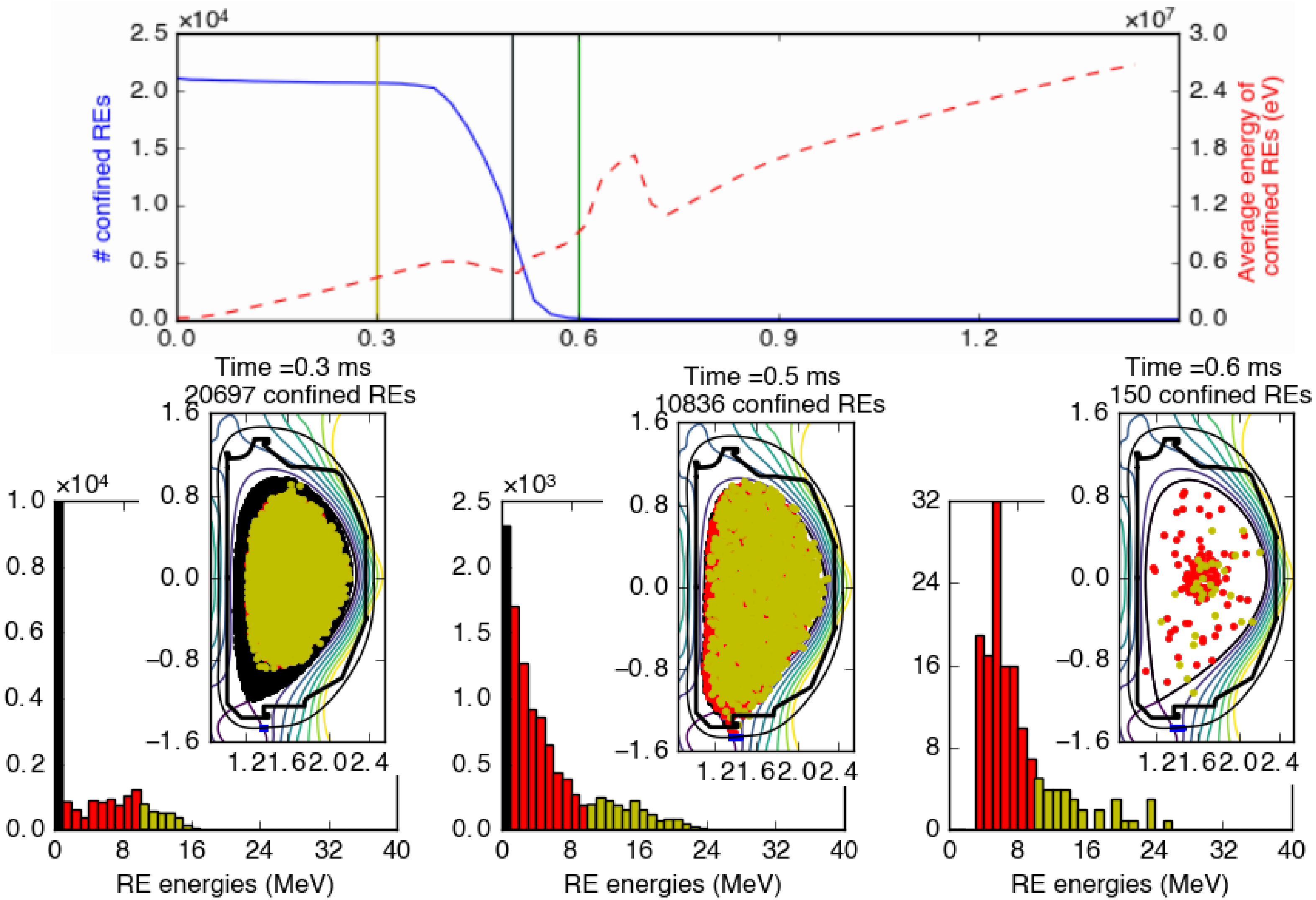
# Recently pushing to larger numbers of RE orbits for better statistics



# NIMROD orbit model assumes a small pitch angle and a supra-thermal parallel energy

Bakhtiari, Kramer, and Whyte Phys. Plasmas **12**, 102503 (2005)

$$\frac{dp_{\parallel}}{dt} = eE_{\parallel} - \frac{n_e e^4 \ln \Lambda m_e}{4\pi\epsilon_0^2}\gamma(Z_{\text{eff}} + 1 + \gamma)\frac{p_{\parallel}}{p^3} - (F_S + F_B)\frac{p_{\parallel}}{p}, \quad (1)$$

Collisional drag term that I have assumes $V_e \sim c >> V_{th}$

**Interactions of relativistic electron beams with high atomic-number plasmas**

David Mosher

*Naval Research Laboratory, Washington, D.C. 20375*

(Received 15 November 1974)

**II. THE RELATIVISTIC COLLISION TERM**

Here, the change in the relativistic-electron-beam distribution function due to small angle, Coulomb encounters with plasma ions and electrons is computed. The thermal velocities of plasma particles are treated as small compared with the velocity of beam electrons (comparable to the velocity of light). Therefore, the field (plasma) particles are assumed to be stationary before a collision so that plasma distribution-function effects can be ignored. Since the following calculation is, with the exception of relativistic effects, similar to that used to evaluate the Fokker–Planck collision term in the fast-electron distribution-function limit,[10] other sources can be used to fill in gaps between equations.

# Coupling to MCCC (AMCC) replaces small angle collisional drag term and adds large angle scattering term

AMCC documentation

February 23, 2017

This is the documentation for the Adaptive Monte Carlo Coulomb collisions (*AMCC*) code. *AMCC* solves test particle collisions with background obeying Maxwell-Jüttner statistics. The program is written in Fortran 95. *AMCC* is not intended for stand-alone use but to be used within Monte Carlo codes requiring efficient and robust collision operator. However, a test program is provided for verifying that the collision operators lead to known analytical results.

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## Features

*AMCC* features Monte Carlo collision operators that integrate the particle state when the particle interacts with the given plasma background for a given time. *AMCC* is a fully relativistic code meaning both test particle and plasma can be relativistic. The Monte Carlo method is implemented for both the three-dimensional particle momentum space, $(u_x, u_y, u_z)$, and the five-dimensional guiding center phase space , $(X_x, X_y, X_z, u, \xi)$. The integration method supports both fixed and adaptive time step schemes. In latter, the integrator chooses the time step so that user-set tolerances are obeyed. In addition to collision operators, a simple algorithm for solving particle trajectory due to the Lorentz force is included. The code is not parallelized.

Working with Eero Hirvijoki (PPPL) as part of SCREAM collaboration

Checked into nimdevel under trunk/extlibs/mccc

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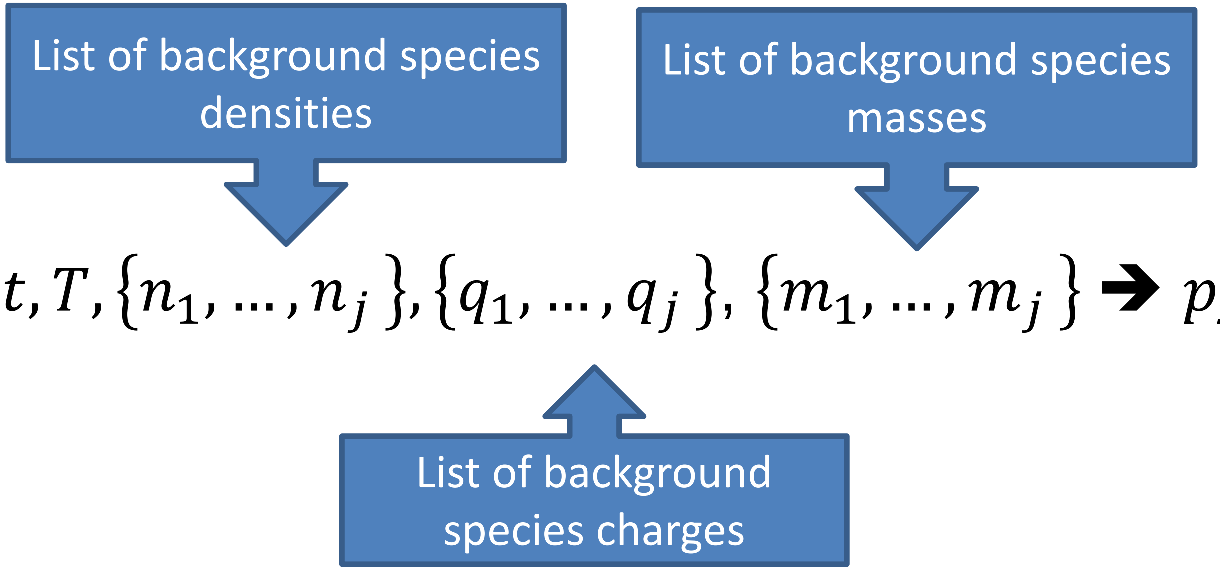
# MCCC is invoked once per nimrod time step to update the momentum vector




$$p_x, p_y, p_z, \Delta t, T, \{n_1, \ldots, n_j\}, \{q_1, \ldots, q_j\}, \{m_1, \ldots, m_j\} \rightarrow p_x', p_y', p_z'$$

# In NIMROD a random gyrophase is chosen each time MCCC is called

$$p_{||}, p_{\perp}, (random\ gyrophase), B_r, B_z, B_\phi \Rightarrow p_r, p_z, p_\phi$$

$$p_r, p_z, p_\phi \Rightarrow p_x, p_y, p_z$$

$$p_x, p_y, p_z, \Delta t, T, \{n_1, \dots, n_j\}, \{q_1, \dots, q_j\}, \{m_1, \dots, m_j\} \Rightarrow p_x', p_y', p_z'$$

$$p_x', p_y', p_z' \Rightarrow p_r', p_z', p_\phi'$$

$$p_r', p_z', p_\phi', B_r, B_z, B_\phi \Rightarrow p_{||}, p_{\perp}$$

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# Most of the new coding is in the coordinate transforms

get_runaways.F90 - /global/project/projectdirs/nimrod/izzo/nimroot/nimall2/nimdevel/closures/kprad/ (on edison06)

File Edit Search Preferences Shell Macro Windows

```
          CALL mccc_clog(ms(1),qs(1),mbs,qbs,nbs,                    &
     &                     kboltz*tbs/(mbs*clight**2.0_r8),             &
     &                     ppll,clogab)


          pr=ppll*b_xyz(1)/bmag + pprp*(b_xyz(2)*sin(thgyr)/bmag -      &
     &                             b_xyz(3)*cos(thgyr)/bmag)
          pz=ppll*b_xyz(2)/bmag + pprp*(b_xyz(1)*cos(thgyr)/bmag -      &
     &                             b_xyz(3)*sin(thgyr)/bmag)
          pph=ppll*b_xyz(3)/bmag + pprp*(b_xyz(1)*sin(thgyr)/bmag -     &
     &                             b_xyz(2)*cos(thgyr)/bmag)

          px=pr*cos(redata(ire)%var(3))-pph*sin(redata(ire)%var(3))
          py=pph*cos(redata(ire)%var(3))+pr*sin(redata(ire)%var(3))

          CALL mccc_push(mcccdat,ms(1),qs(1),clogab,mbs,qbs,nbs,        &
     &                    kboltz*tbs/(mbs*clight**2.0_r8),              &
     &                   dt,REAL((/rand(),rand(),rand()/),8),(/px,py,pz/),      &
     &                   pout,mcccerr)

          IF (abs(px+py+pz)>0.0 .AND. abs(SUM(pout))==0.0) THEN
          WRITE(*,*) ire, ppll, pprp, tbs, nbs, mcccerr
          ENDIF
          pr=pout(1)*cos(redata(ire)%var(3))+pout(2)*sin(redata(ire)%var(3))
          pz=pout(3)
          pph=pout(2)*cos(redata(ire)%var(3))-pout(1)*sin(redata(ire)%var(3))

          ppll=pr*b_xyz(1)/bmag+pz*b_xyz(2)/bmag+pph*b_xyz(3)/bmag
          pprp=sqrt(pr**2.0_r8+pz**2.0_r8+pph**2.0_r8-ppll**2.0_r8)

```

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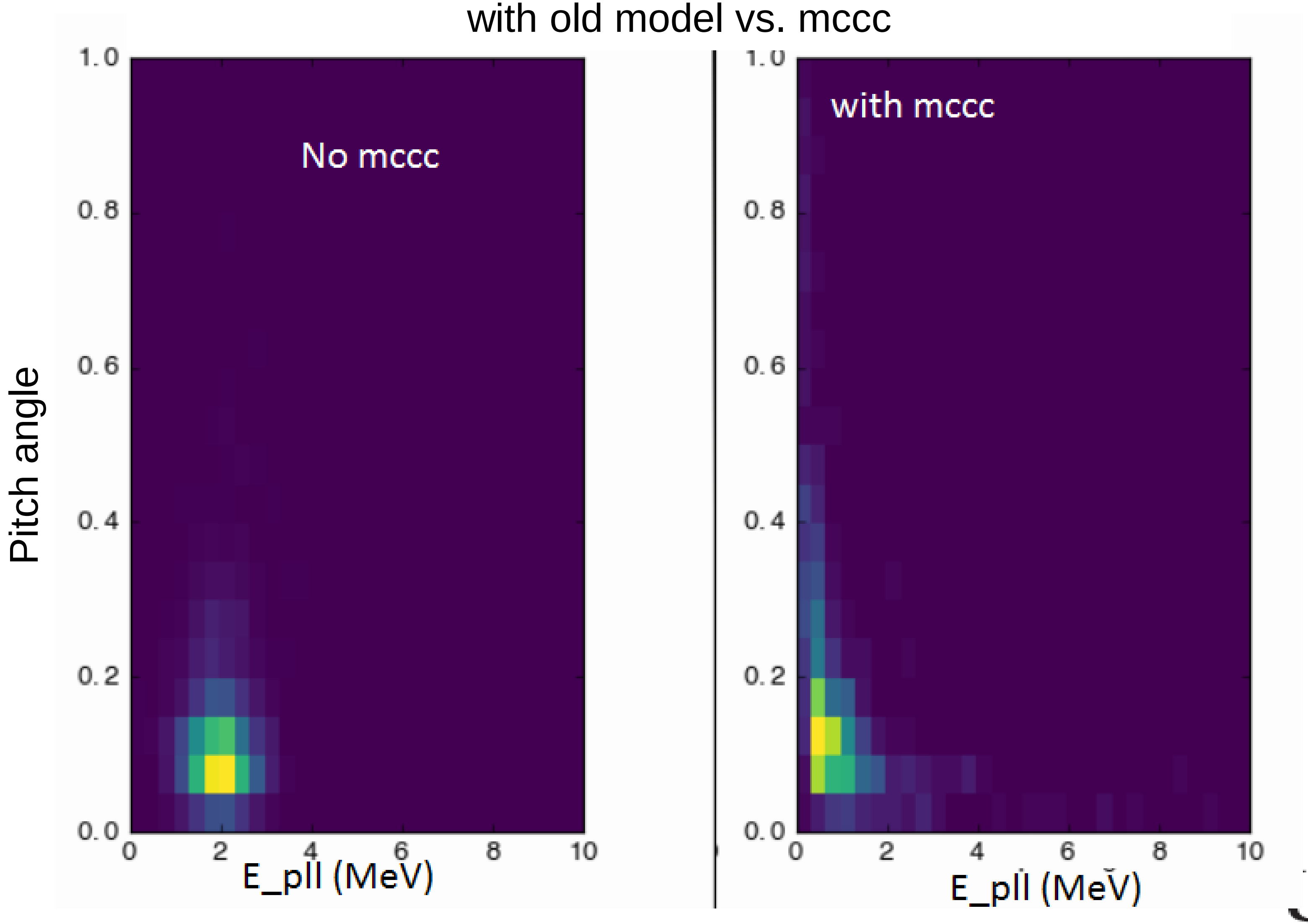
# Initial test show reasonable looking distribution functions

Comparison of pure deuterium case ~2000 test electrons,
with old model vs. mccc

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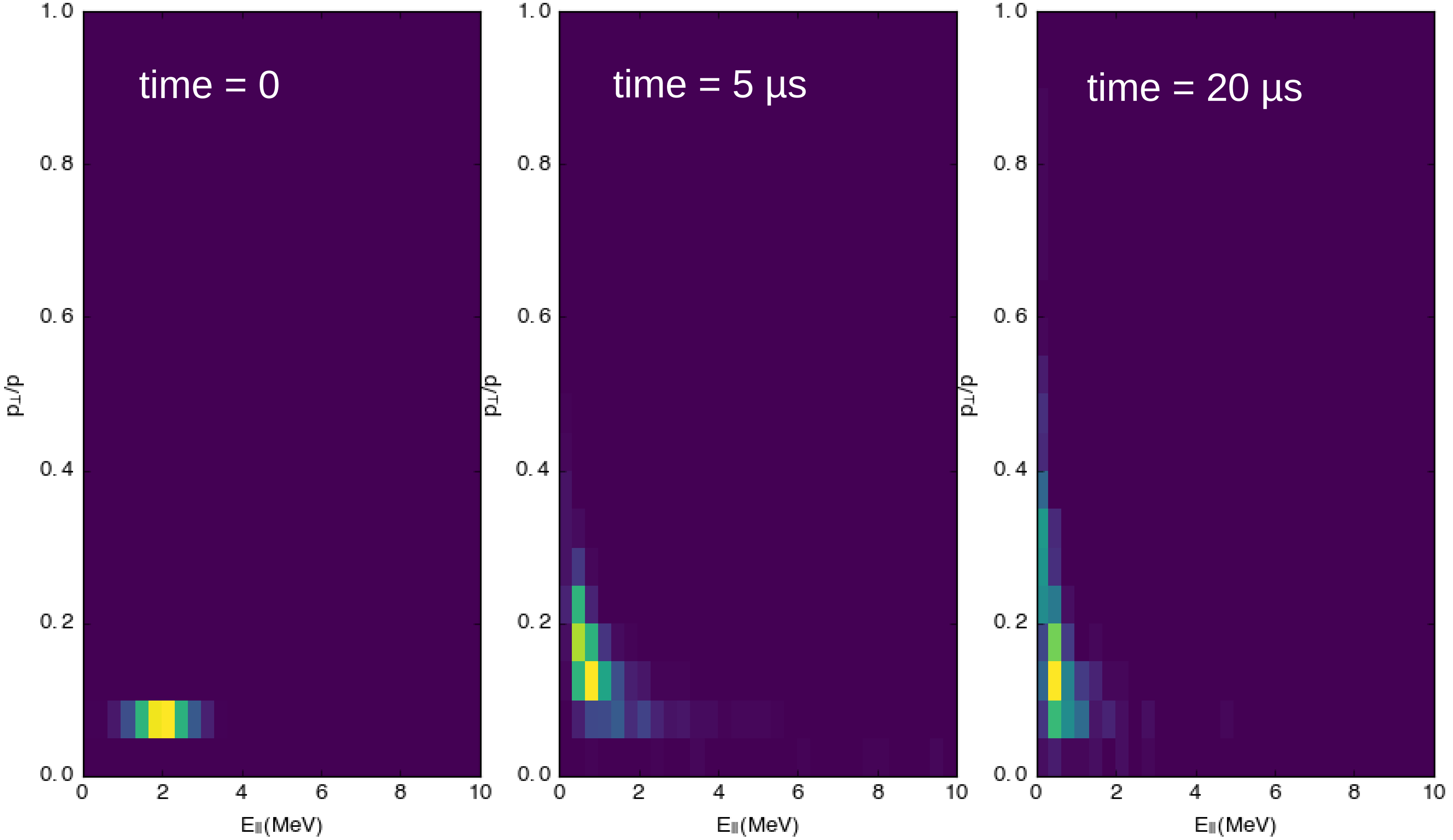
# Initial test show reasonable looking distribution functions

Short test case with Ar impurities



# What can we get out of NIMROD/MCCC

- Account for momentum space as well as orbit losses, particularly in disruption mitigation cases with high-Z impurity injection

- Runaway generation: beginning with thermal test particles, both Dreicer and hot-tail runaway generation should be built in the physics already (?). Could predict RE seed current
  - Secondary generation still requires additional physics

# Summary

- MCCC has been coupled to NIMROD and is running
- Short initial tests produce reasonable results
- Will first reproduce previous disruption mitigation run to compare with old model
- Explore possibilities for RE primary generation modeling