



U.S. DEPARTMENT OF  
**ENERGY**

Office of  
Science



# Snowflake Control Development

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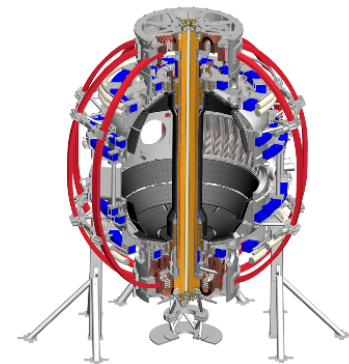
Princeton University

*With support from the ASC TSG and Plasma Control Group*

**NSTX-U Results Review 2016**

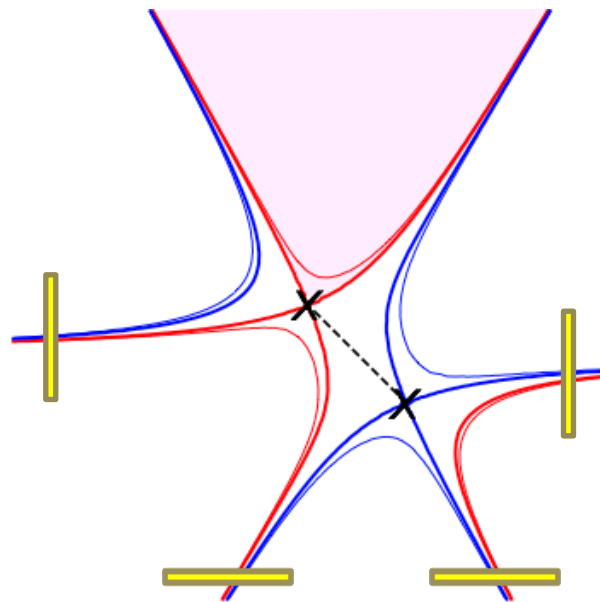
**PPPL B318**

**September 21, 2016**



# Snowflake Divertor Configurations

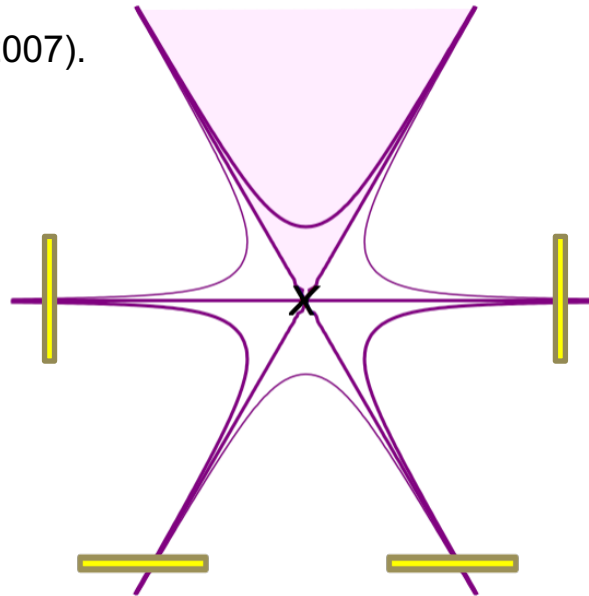
D.D. Ryutov. *Phys. Plasmas*. 14 (2007).



**Snowflake Minus**

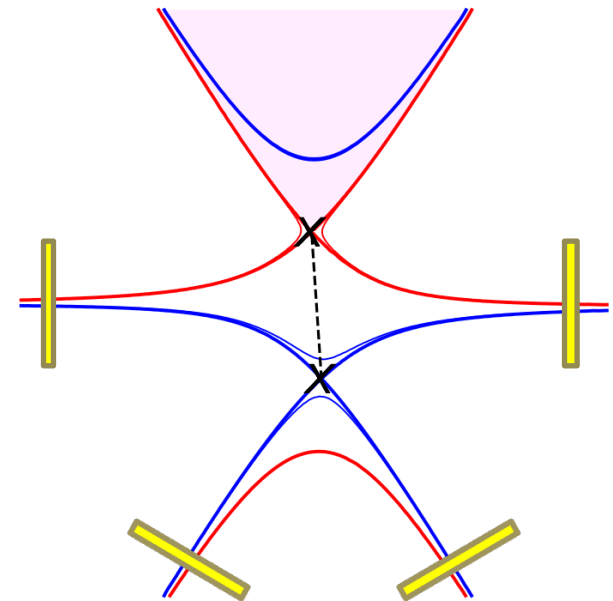
First-Order Primary Null on Separatrix

Secondary Null in Scrape-off Layer



**Perfect Snowflake**

Second-Order Null on Separatrix

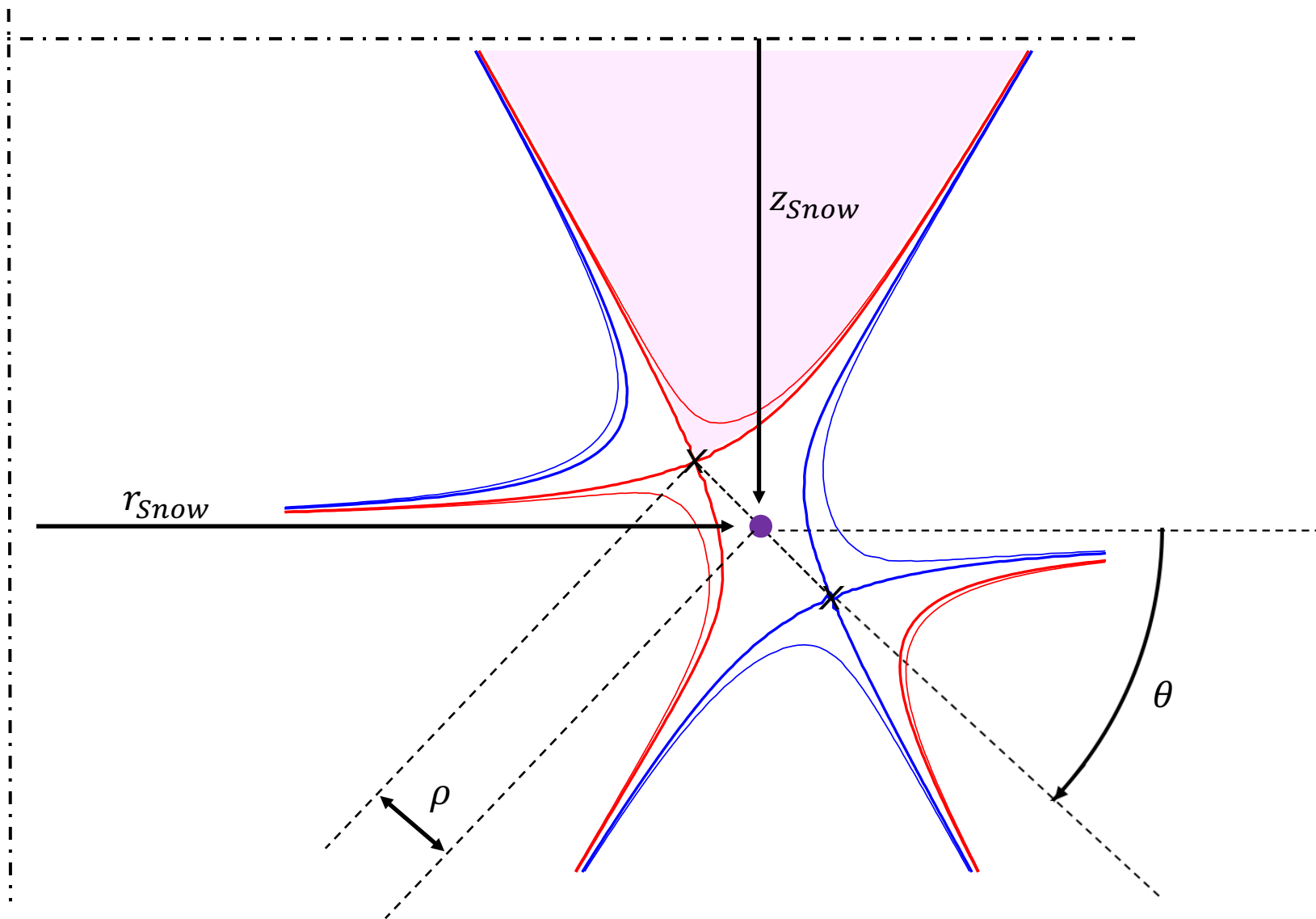


**Snowflake Plus**

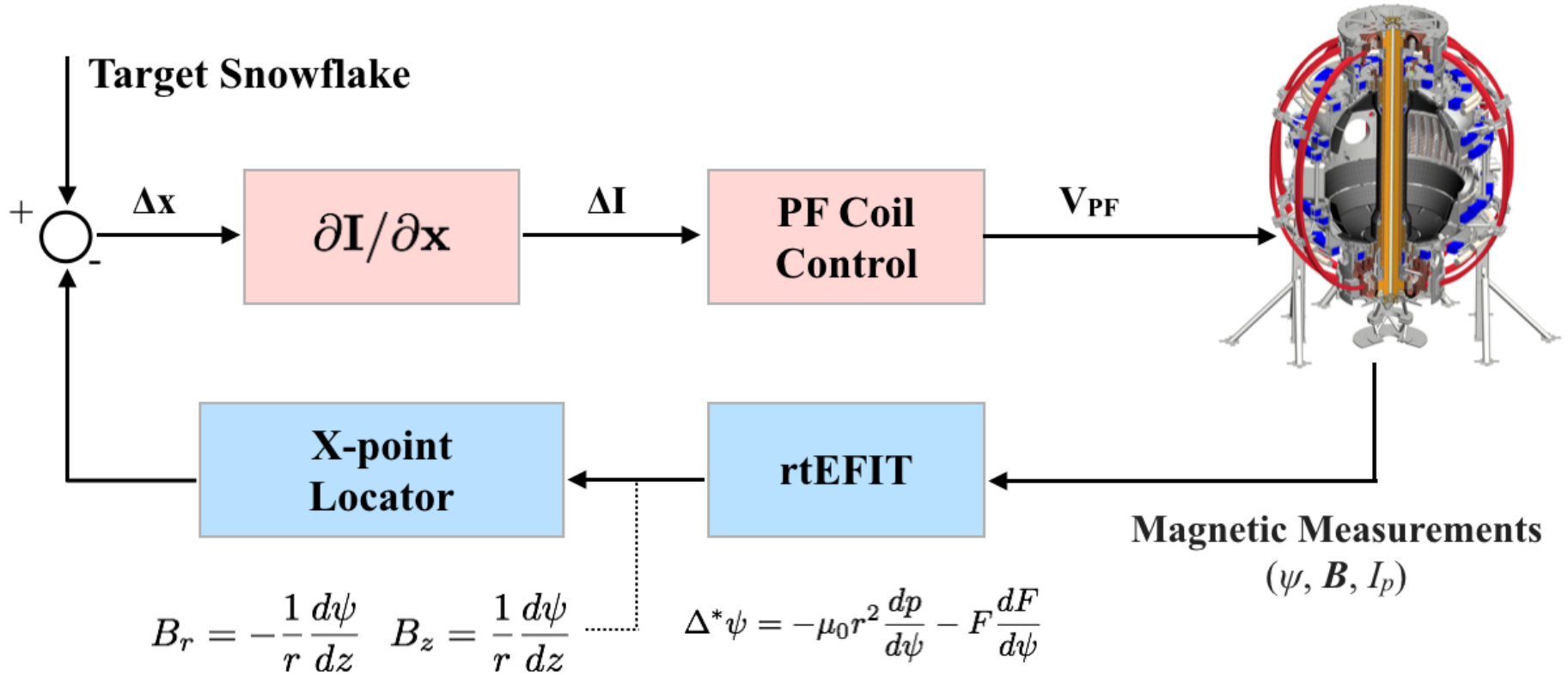
First-Order Primary Null on Separatrix

Secondary Null in Private Flux

# Snowflake Shape Descriptors



# Snowflake Control System



# Control Algorithm

## X-point Locator

Compute series solution  $\psi_{exp}(r, z)$  to the homogenous Grad-Shafranov equation,

$$r\partial_r (r^{-1}\partial_r\psi) + \partial_{zz}\psi = 0.$$


Coefficients of series are found using magnetic field values ( $B_r, B_z$ ) at 3 points. We then find the x-point locations by solving,


$$-r^{-1}\partial_z\psi_{exp} = 0, r^{-1}\partial_r\psi_{exp} = 0.$$

## $\partial\mathbf{I}/\partial\mathbf{x}$

Compute matrix  $\partial\mathbf{x}/\partial\mathbf{I}$  and its pseudoinverse. We then compute the required coil currents,

$$\Delta I = (\partial\mathbf{x}/\partial\mathbf{I})^\dagger \Delta x.$$

Coil current requests 

 Snowflake position errors

## PF Coil Control

PID controller computes voltage requests for the PF coils.

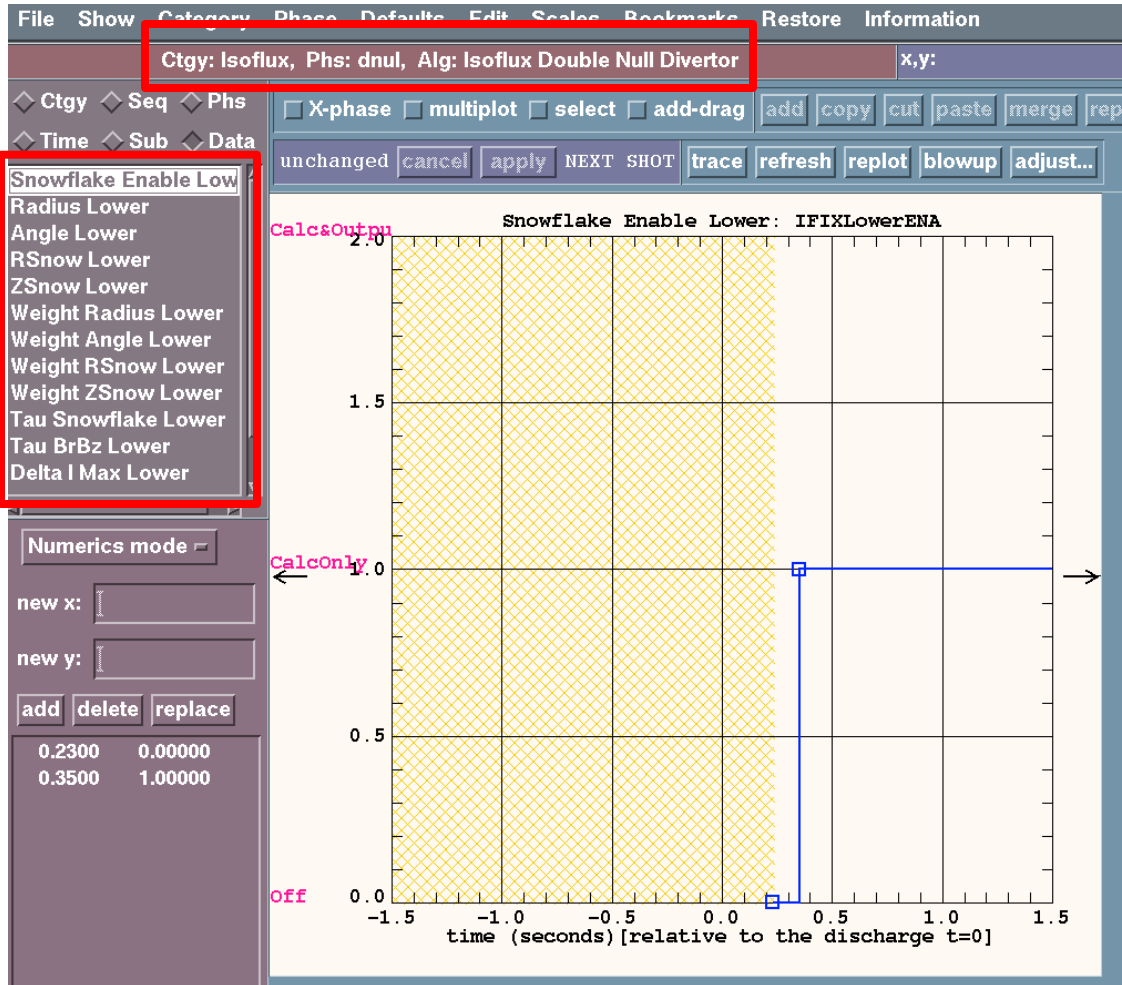
$$V(t) = V(t - 1) + R \cdot \text{PID}(\Delta I)$$

# PCS Development Status

- Snowflake algorithm has been implemented in the PCS.  
*(K. Erickson)*
- Code extensively tested offline using the data simserver.
- Code also tested in hardware simulation mode (on rt4).
- Testing “in-the-background” during a real shot.
- Snowflake control tests (PF control with snowflake algorithm).

# PCS Interface

Snowflake is really a “sub-algorithm” within Isoflux/ISODNULL. Separate subset for upper and lower divertor.



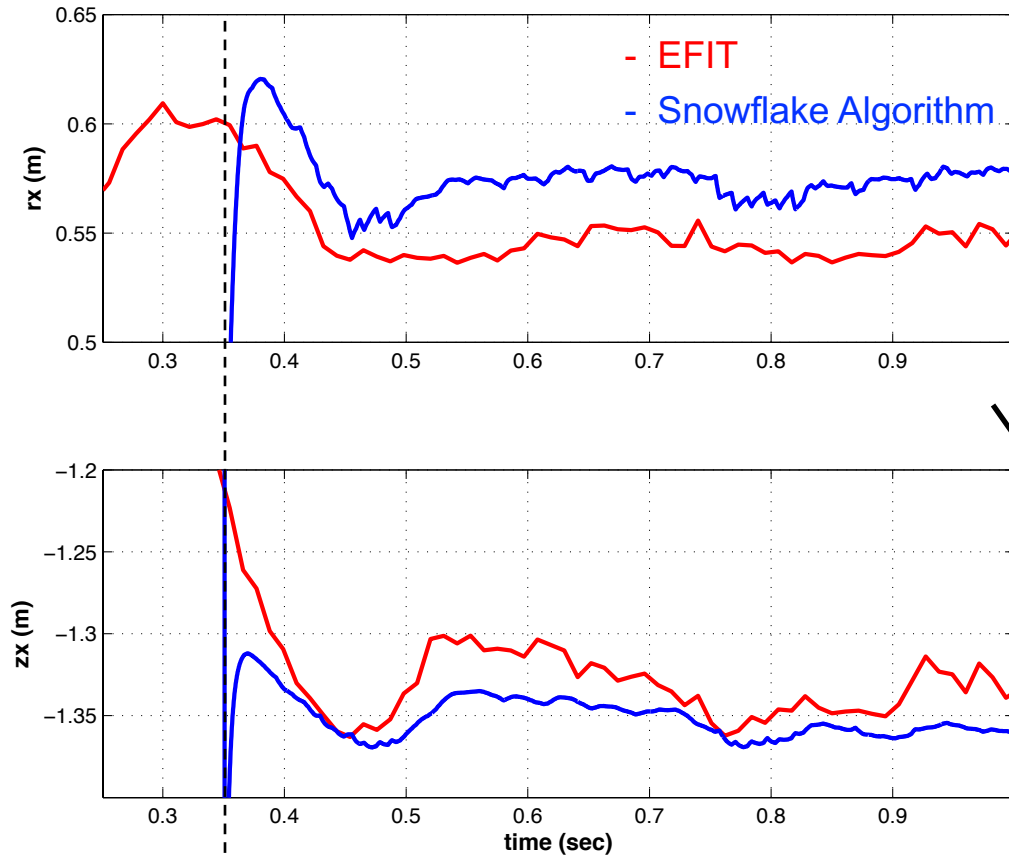
Four parameters define the desired snowflake configuration

- Radius
- Angle
- rSnow (centroid)
- zSnow (centroid)

Three modes of operation

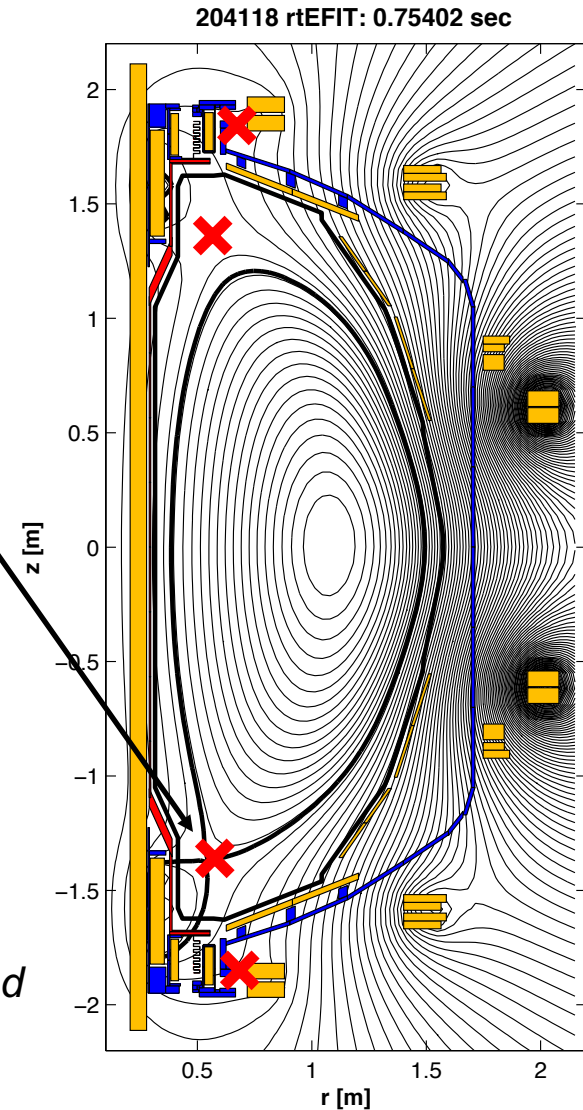
1. **Calc&Output**
  - Compute x-point locations.
  - Compute coil current requests.
  - Output requests to coils.
2. **CalcOnly**
  - Compute x-point locations.
  - Compute coil current requests.
  - No output. The “run-in-the-background” option.
3. **Off**

# Simsolver Results



Snowflake ON at 0.35 sec

Comparing the location of the primary x-point as computed by **EFIT01** and the **snowflake algorithm**.





# Summary

## ***Year 2015-2016***

- Unfortunately, no XMP or XPs were run during 2016.
- However, lots of code development, testing, and control simulation.
- PCS is ready for snowflake scenario development.

## ***Ongoing Work***

- Developing time-dependent, closed-loop simulations of the control using TokSys.
  - Currently working on model validation. Should be useful for general shape control, vertical control simulation.
- Further capabilities to be added to PCS (snowflake + strike point control for X-divertor).