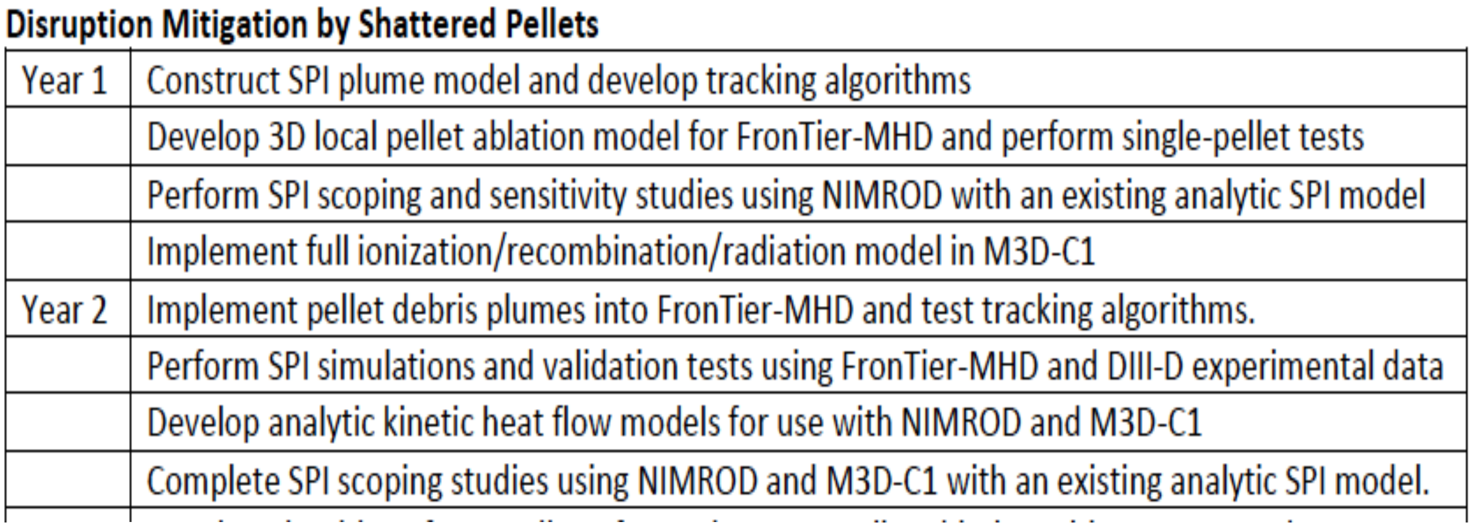
CTTS APS Physics Planning Meeting

Disruption Mitigation Modeling

2017/10/22

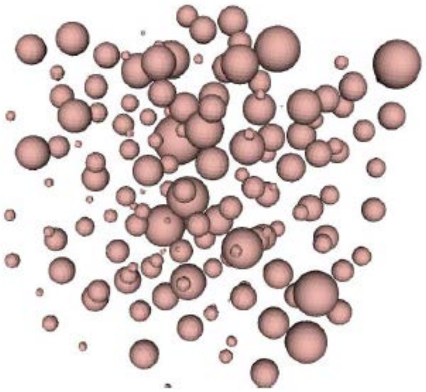
- **Project Objective: Develop, verify, and validate 3D models for disruption mitigation by SPI for future tokamak design and optimization**
- **Original proposed activities 2017/09/01 – 2022/08/31**
  - ***Lao, Izzo, Parks, Samulyk, Jardin, postdoc***

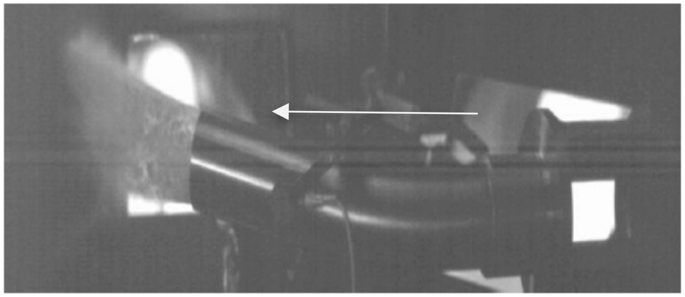
Frontier-MHD SPI Plum Initialization



Disruption Mitigation by Shattered Pellets

Year 1	Construct SPI plume model and develop tracking algorithms
	Develop 3D local pellet ablation model for FronTier-MHD and perform single-pellet tests
	Perform SPI scoping and sensitivity studies using NIMROD with an existing analytic SPI model
	Implement full ionization/recombination/radiation model in M3D-C1
Year 2	Implement pellet debris plumes into FronTier-MHD and test tracking algorithms.
	Perform SPI simulations and validation tests using FronTier-MHD and DIII-D experimental data
	Develop analytic kinetic heat flow models for use with NIMROD and M3D-C1
	Complete SPI scoping studies using NIMROD and M3D-C1 with an existing analytic SPI model.





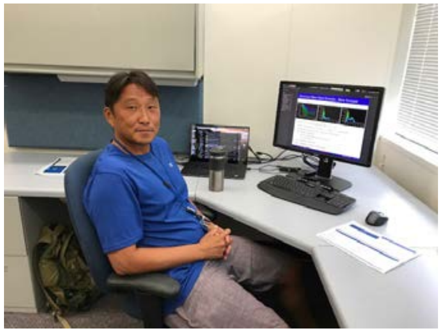
ORNL 16 mm NE SPI Pellet Experiment 400 m/s from Right
Baylor Fusion Sci. Technol. <u>68</u>, 211 (2015)

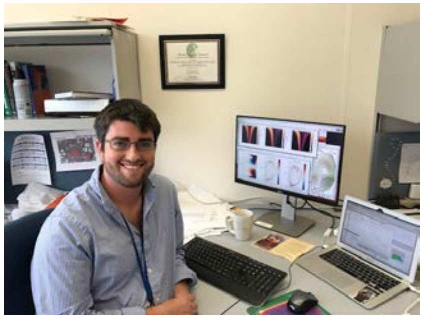
CTTS Disruption Mitigation Modeling

GA/UCSD Personnel Changes

2017/10/22

- **Val left GA/UCSD early August**
- **Charlson Kim: GA Consultant/Subcontractor**
  - **SLS2 Consulting**
  - ***NIMROD* simulations of ITER disruption mitigation scenario**
- **Brendan Lyons: GA Theory Staff**





To a Lady named Valerie
She traveled from MIT to San Diego
She engages with fusion and NIMROD
She likes tokamaks and computing
She challenges RE disruptions with MPI
From MHD to atomic physics, from C-Mod to DIII-D and ITER
After 10 years with GA-UCSD
She decides to return home

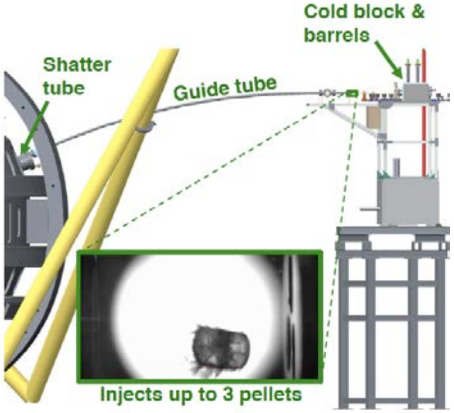
CTTS Disruption Mitigation Modeling

Updated Plan and Activities 2017/10/22

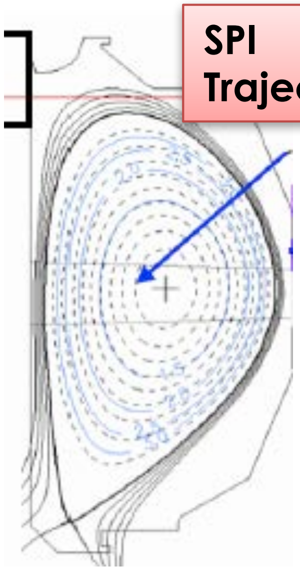
Year 1: ***Lao, Kim, Lyons, Parks, Samulyk, Jardin, postdoc***

- **Construct SPI plume model and develop tracking algorithms**
- **Develop 3D local pellet ablation models**
  - ***FronTier-MHD*** **and PiC based**
  - **single-pellet tests**
- **Review and improve NIMROD and KPRAD coupling algorithms**
- **Test new PiC based SPI model against DIII-D and improve model**
- **Perform SPI scoping and sensitivity studies using *NIMROD* with existing analytic and new PiC based SPI models**
  - **Fragment size, mixture ratio, injection speed and angle**
  - **Radiated energy fraction, thermal quench onset and duration, assimilation efficiency**
- **Implement full ionization, recombination, and radiation model in *M3D-C1***

DIII-D SPI



SPI Trajectory



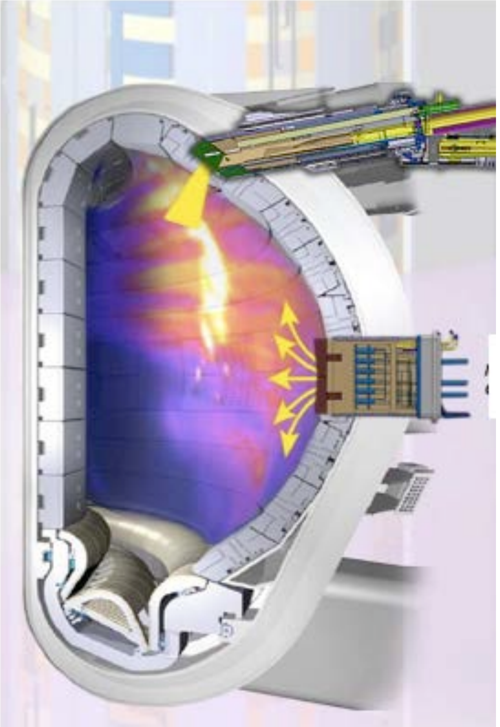
CTTS Disruption Mitigation Modeling

Agenda

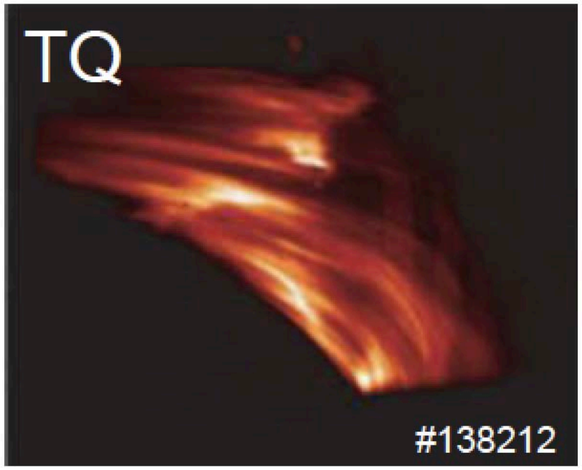
2017/10/22

- **Status and Plan** <u>**Lao**</u>
  - **Status of DIII-D SPI Experiments and Modeling Needs**
  - **SPI Models** *Parks*
- ***Frontier-MHD* SPI Calculations** <u>**Samulyk**</u>
- **PPPL SPI Experiments and Modeling Needs** <u>**Raman**</u>
- **DIII-D SPI Calculations with *NIMROD*** <u>**Kim**</u>
  - **ITER PiC Based SPI Simulations**

ITER SPI DMS



DIII-D SPI Disruption Mitigation Experiment
Commaux Nucl. Fusion <u>51</u>, 103001 (2011)

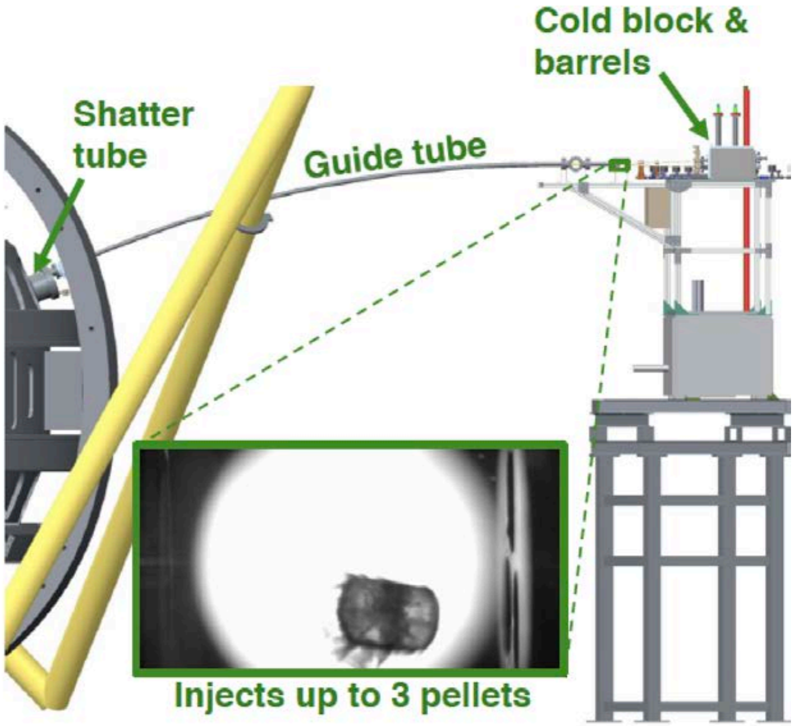


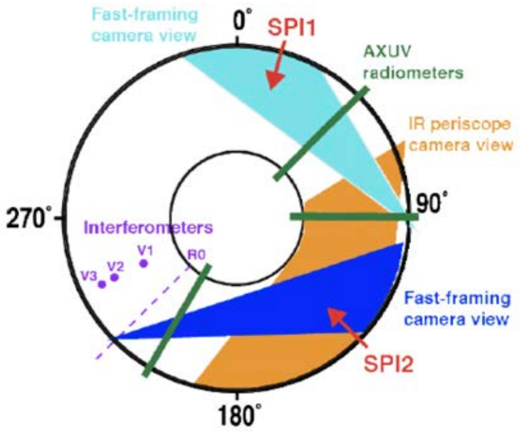
CTTS Disruption Mitigation Modeling

DIII-D SPI Experiments

2017/10/22

- **Second SPI system installed and experiments began**
  - **ITER prototype design**
- **Initial results**
  - **Observed slight difference SPI1 and SPI2 but overall good mitigation**
  - **No obvious evidence of large heat load near injection port**
  - **SPI mitigation more effective with deeper penetration angle**
  - **Unclear whether multiple pellets can reduce radiation asymmetries or superimpose to provide high densities**





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Wed PM PO4:1

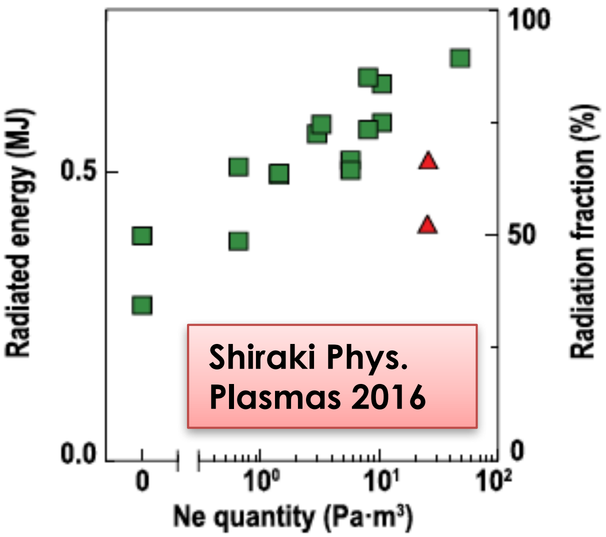
CTTS Disruption Mitigation Modeling

DIII-D SPI Experiments Modeling Needs

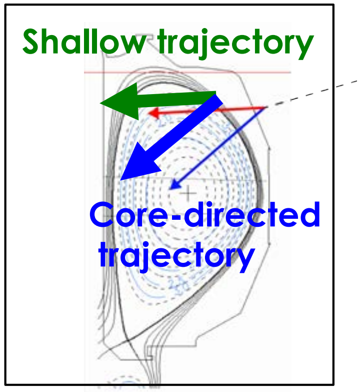
2017/10/22

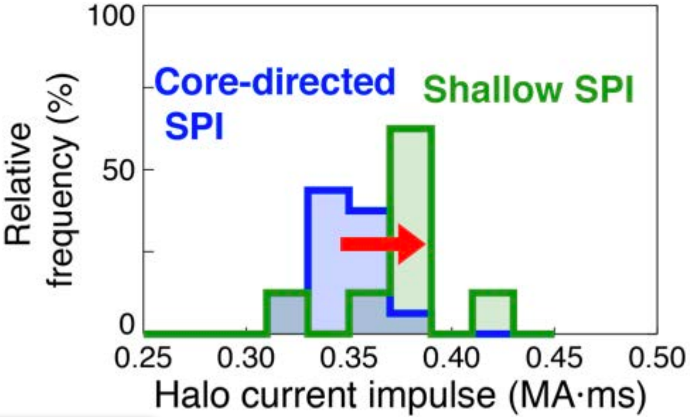
Eidietis

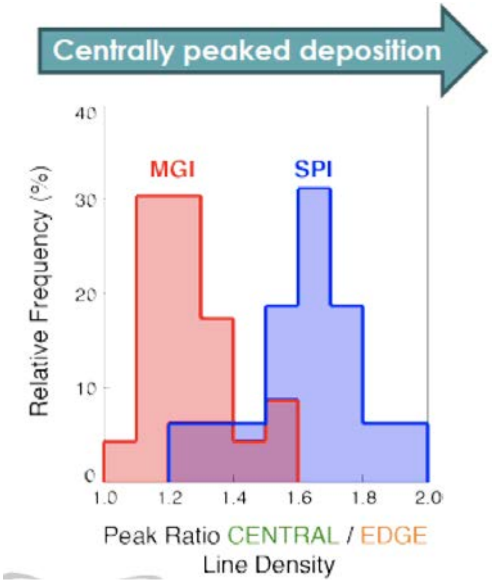
- **Variation in SPI radiated energy with Ne quantity**
  - **Ne/D_2 mixture, total pellet size constant**
- **Variation in SPI assimilation with injection angle**
  - **Relative strength of ballistic versus MHD mixing**
- **Interpretation of dual SPI experiments**
  - **Multiple pellets appear to not sum directly**



Shiraki Phys. Plasmas 2016







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Summary: Discussions with DIII-D Disruption Team

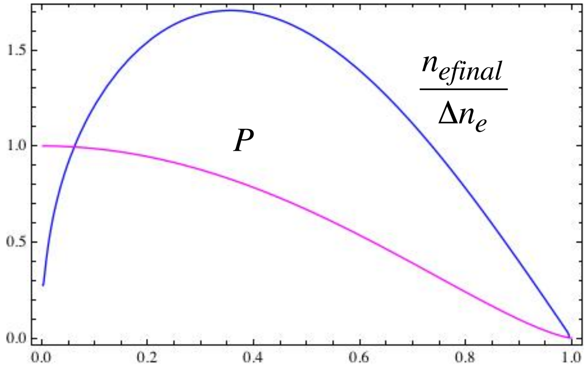
Input and Analysis *2017/09/26*

- Test *NIMROD* simulations against a discharge from DIII-D SPI experiments
  - DIII-D team will provide 1-2 well diagnosed discharge for testing
  - 2 injectors multi-pellets
- Perform SPI scoping and sensitivity studies to guide planning of DIII-D SPI experiments
  - Fragment size, mixture ratio, injection speed and angle
- Questions to address
  - DIII-D MGI discharges observe core *n* =1 MHD mode that enhances impurity mixing. Why did not observe such *n* =1 MHD mode in DIII-D SPI discharges ?
- DIII-D Disruption Team to provide inputs by emails
- Next meeting after APS
  - Discuss DIII-D SPI experiments
  - PiC SPI model

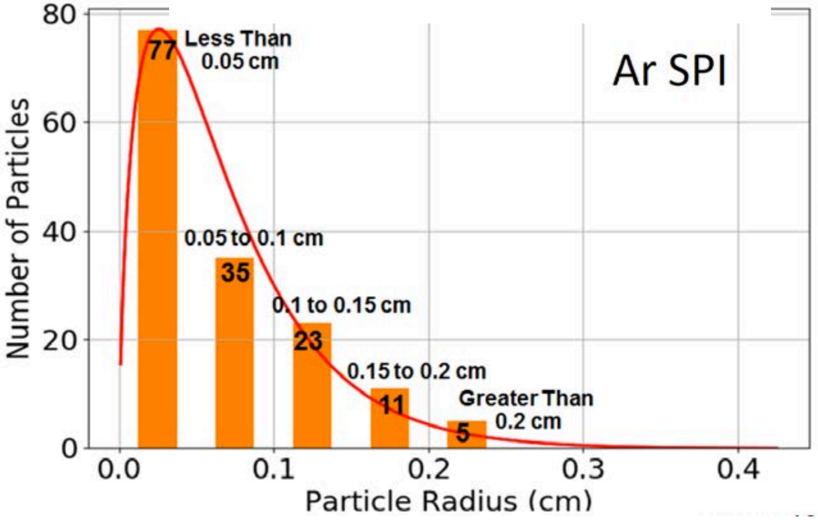
Shattered Pellet Injection Model

Parks TSDW 2017

- **For optimized injection, the added density profile is skewed towards the magnetic axis**

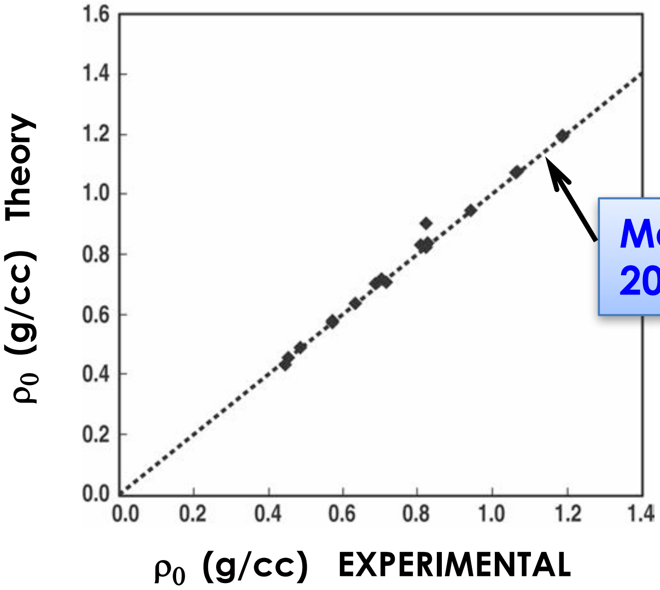


Pellet cluster size distribution data agrees with Parks fragmentation model (2016)



$f(r) = \alpha r K_0(\beta r)$

- α = 3800
- β = 23
- Fits data better than other two models based on Energy and Maximal Entropy



Mass density of hybrid neon-deuterium pellets (Parks model 2016) agrees with experimental data from ORNL

$$\rho_0(X) = \frac{(1-X)+XW_{D_2}/W_{Ne}}{(1-X)/\rho_{Ne}+(XW_{D_2}/W_{Ne})/\rho_{D_2}} \qquad (\mathrm{g-cm^{-3}})$$

$$\rho_{Ne} = 1.444 \qquad \rho_{D_2} = 0.20 \qquad W_{Ne} = 20.183\ \mathrm{g/mole} \quad W_{D_2} = 4.0282\ \mathrm{g/mole}$$

Penetration of a Hybrid (Ne-D$_2$) Shattered Pellet

Cluster Stream

Parks

- **Derived optimum velocity for central penetration and total assimilation**

$$V=\left(\frac{10\eta_0}{21}\right)^{4/3} F(0)^{7/3}\,\frac{a}{t_{abl}}\left(\frac{n_{e0}}{\Delta n_e}\right)^{4/3} \qquad t_{abl}=\frac{2.8\times10^5}{n_{e014}^{1/3}}\left(\frac{r_0}{T_0}\right)^{5/3}\frac{\rho_0(X)}{\lambda(X)}$$

solid density of hybrid pellet

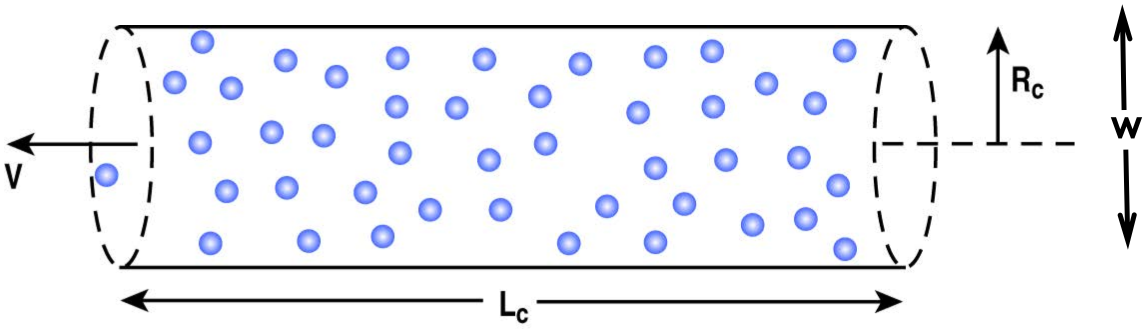
- **More added mass** $\Delta n_e / n_{e0}$ **more self-cooling** → **lower velocity**

- **In ITER with** $\Delta n_e / n_{e0} = 30$

$$V = 1037\ \text{m/s}\quad \text{for}\ X = 1\ \ (\text{pure}\ D_2)$$
$$V = 576\ \text{m/s}\quad \text{for}\ X = 0.9\ \ (\text{mostly}\ D_2)$$
$$V = 210\ \text{m/s}\quad \text{for}\ X = 0.5$$

$$X=\frac{N_{D_2}}{N_{Ne}+N_{D_2}}$$

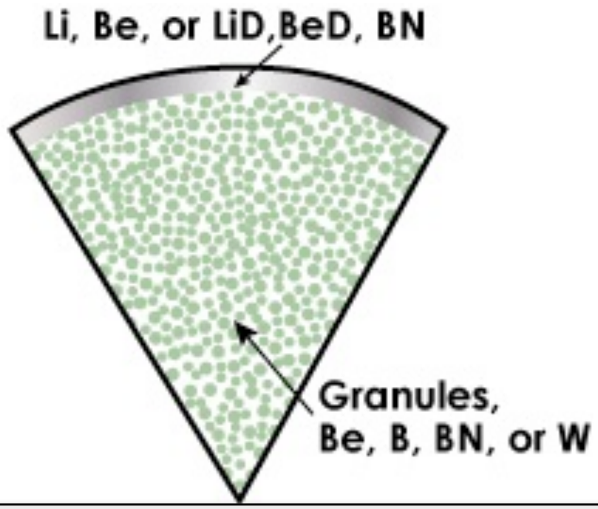
- **Extend 1-D analytic model for the penetration of pellet cluster stream in a plasma to 2-D (axial and radial structure) and improve kinetic cooling model for a the multiply-ionized gas deposited by the pellets.**



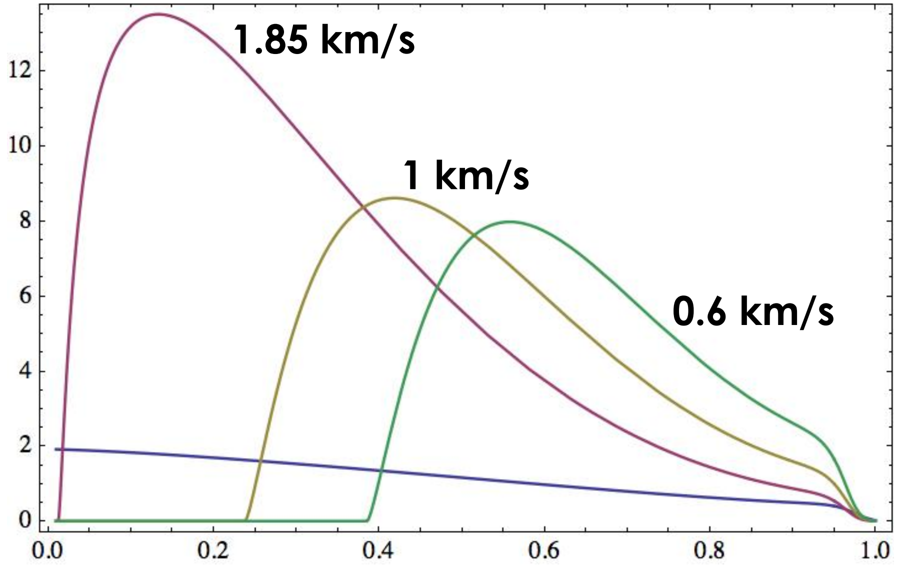
Two types of Low-Z Advanced Pellets May Promote a Thermal quench with Minimal MHD

Parks

Hybrid pellets



To be published: "The ablation rate of some low-Z pellets driven by plasma electrons in a fully kinetic transport model" P.B. Parks 2017



Deposition profiles for a solid 3.55 g Be pellet injected to ITER using 3 different velocities

Magnetically screened light metal pellets Be, or Li P.B. Parks US patent pending (2017)