PAC-29 Day 1 questions

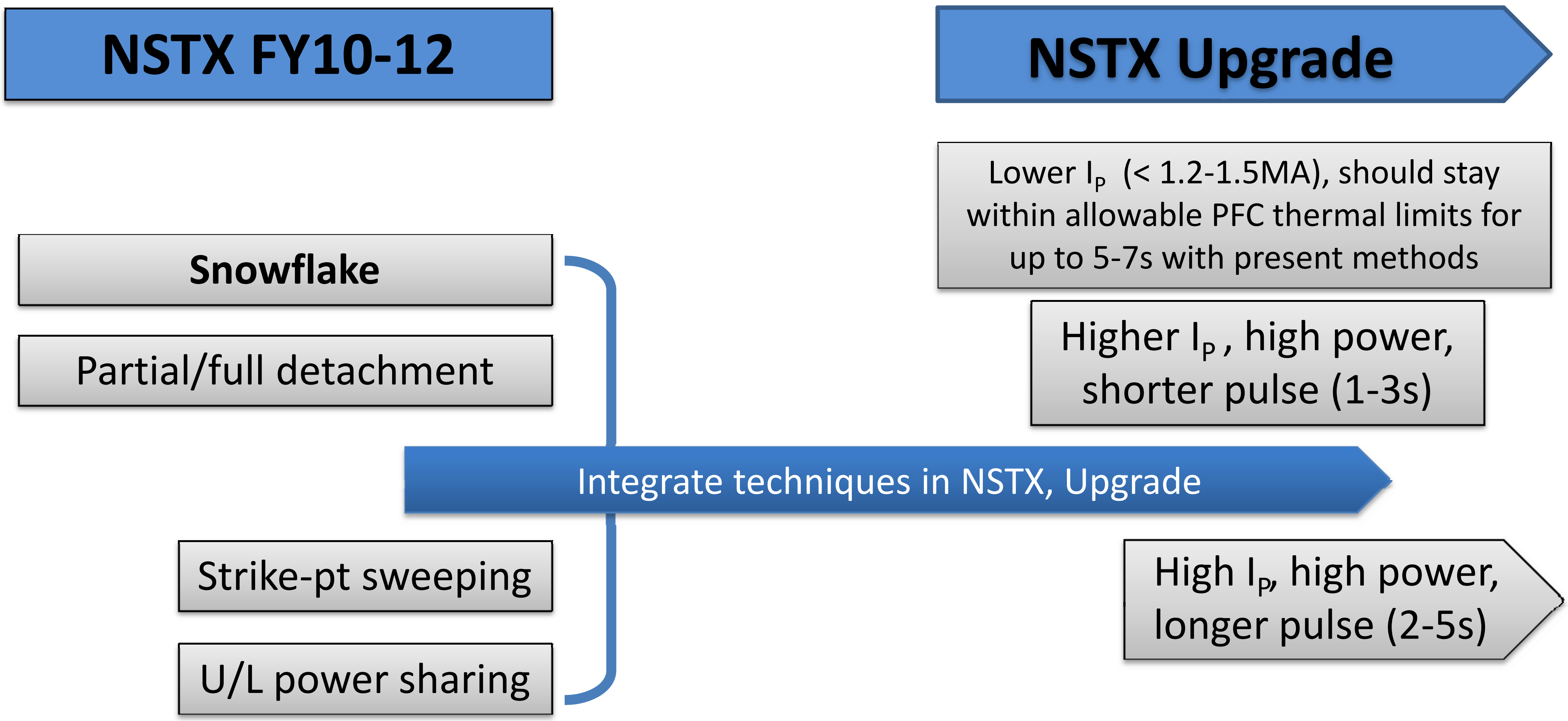
- Q1 - The PAC remains concerned about the readiness of integrated divertor solutions (high heat flux mitigation, main-ion density control, impurity control) in preparation for supporting NSTX Upgrade scenarios
  - What is your plan to address this for the near and longer-term post-Upgrade period - for example the beginning and end of your next 5 year plan period?

- Q2 - For the next run, what is the relative priority among the following 3 milestones/high priority research areas:
  - Li research
  - Particle and impurity control
  - Heat flux handling

Approach to addressing these questions:

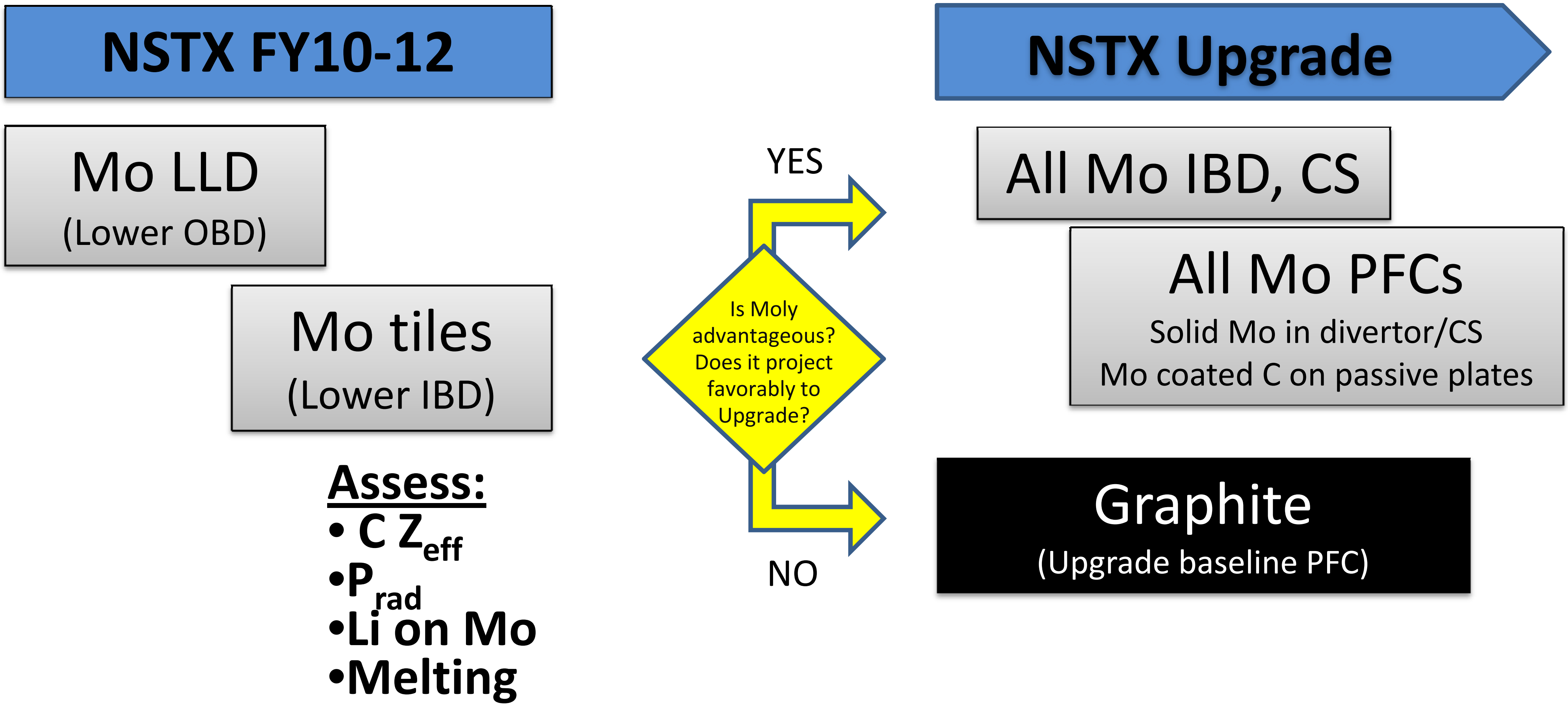
- Describe key decision points, questions for program
  - Budgets, schedules, plans, elements highly subject to change
- Show a few results that inform decisions
- Actual plan will be formulated based on:
  - PAC input
  - Research forum/near-term team discussion
  - FY11-12 results and analysis in FY12-13
  - 5 year plan proposal of NSTX team

Heat flux mitigation



- Major goal of high current, high-power scenarios is to access higher T to reduce ν^* to study transport, pedestal & global stability
  - These studies only require 1-3s pulse length to get good initial data
  - Longer pulses enable further profile equilibration, support advanced PMI R&D

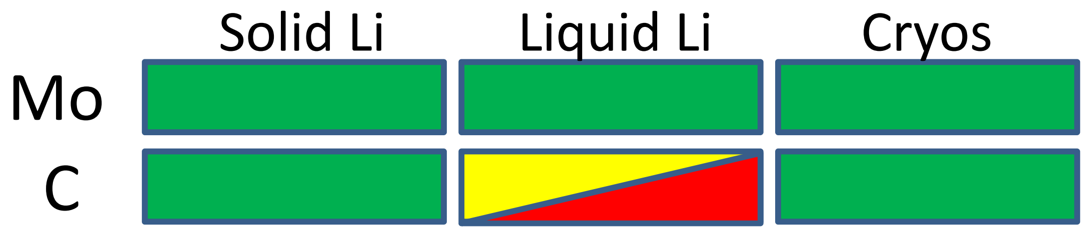
PFC decisions – Mo vs. C



- Carbon is lower Z, more forgiving (no melting), cheaper
- Lower sputtering yield of Mo could reduce core C Z_{eff}
- Mo is better substrate for liquid Li
- High-Z PFC (Mo) more relevant than C for FNSF/next-steps

Pumping decisions – cryo/Li staging

Choice of pumping scheme linked to choice of PFC:



- Carbon PFCs favor cryos (assuming cryos project to Upgrade scenarios)
- Already have solid Li delivery systems (evaporators, droppers)

NSTX FY10-12

Li evaporation onto C, LLD

Fueling: LFS, HFS, SGI, shoulder

Li onto Mo tiles
(Lower IBD)

NSTX Upgrade

Li evaporation, droppers

Pellets, CT injection, plasma jets?

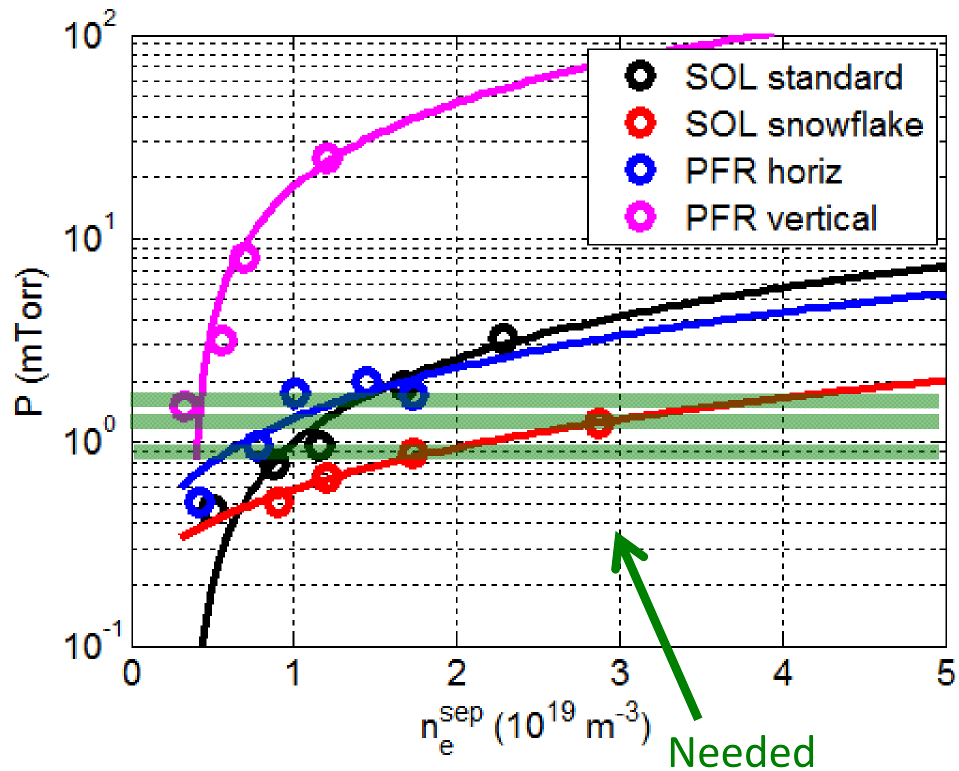
Cryos

Cryos and/or

Next-gen LLD

Preliminary cryo-calcs show promise for full range of operating scenarios in Upgrade

- *Pressures shown are with no pumping*
  - *With pumping, pressure will be reduced by C/(C+S) ~ 50%*
- <n_e> estimated as twice separatrix density



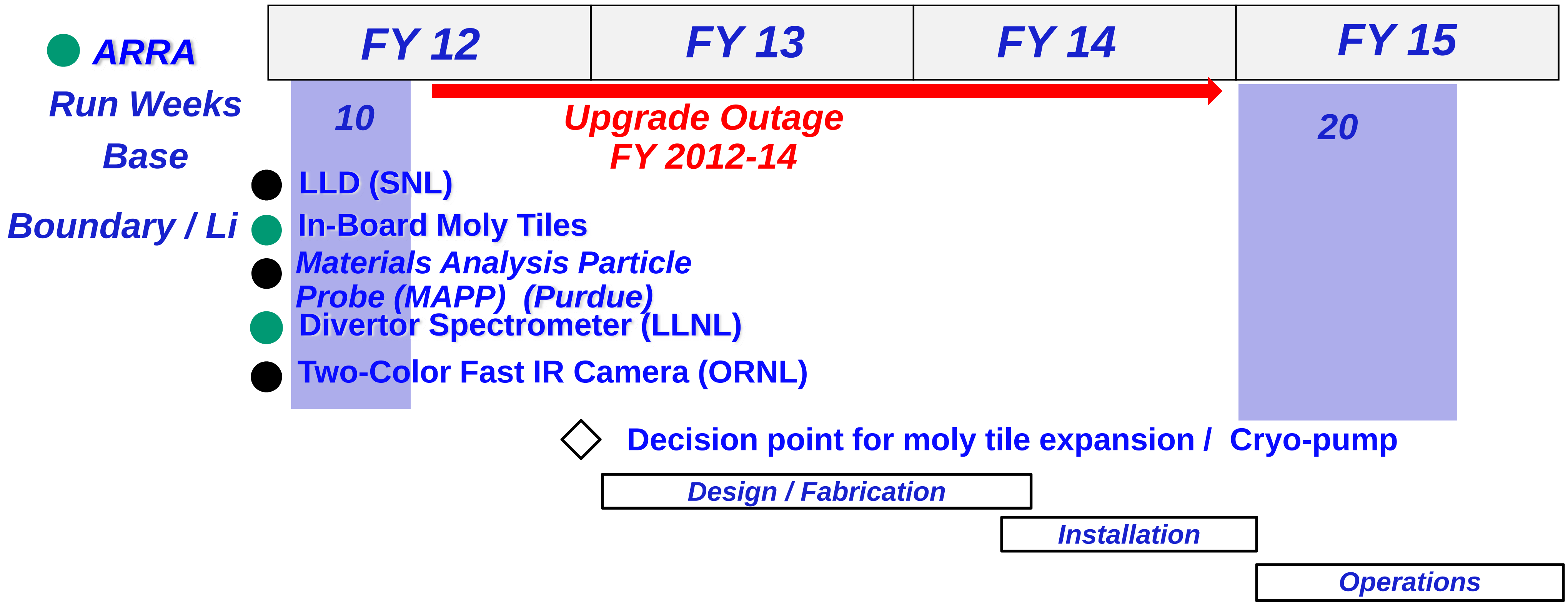
Minimum f_G for pumping (NBI fueling only)

	SOL std	SOL snow	PFR horiz	PFR vert
Long pulse	0.21	0.43	0.14	0.09
High NI	0.34	0.86	0.29	0.11
Max I_p	0.15	0.42	0.14	0.05

- Only snowflake at low I_P (800kA) is marginal
- But this scenario does not require snowflake
- And only single cryo was modeled, so could likely use top and bottom cryos to test snowflake in full NI scenario

Canik

Possible NSTX facility plan during Upgrade outage supporting long-pulse pumping/PMI



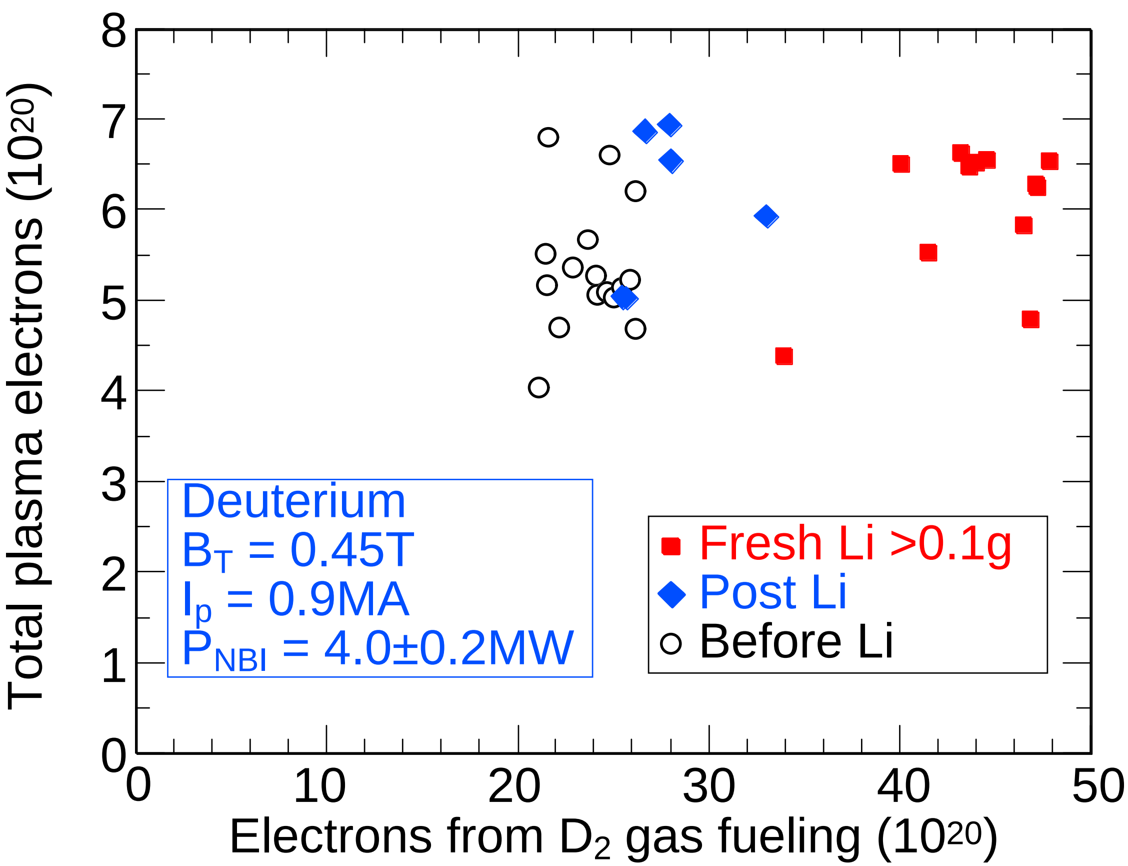
- **Significant time ~ 1 -2 years available for design, fabrication, installation of boundary physics facility upgrade:**
  - **Upgrade Project has the resource priority during the upgrade outage**
  - **Cost of design / installation ~ cost of fabrication of moly tile/ cryo-pump**
  - **However, researchers and some of the engineering technical staff will be available for facility enhancement / improvements for high priority tasks**
  - **Fabrication procurement possibly paid out of the facility enhancement fund**

NSTX Upgrade Outage Period Budget Summary ($M)

	FY2012		FY 2013		FY2014	
Budget cases	**Base**	**Incr.**	**Base**	**Incr.**	**Base**	**Incr.**
Run Weeks	**10**		**0**	**0**	**0**	**0**
Facility Operations	15.9		7.1		6.6	
Fac. Enhancements	1.1		1.8	0	1.5	0
CS & 2nd NBI	14.6	4.5	25.3	5.0	27.50	5.0
Facility Total	**31.6**	**4.5**	**34.2**	**5.0**	**35.6**	**5.0**
PPPL Research	11.7	0	12	0.0	12	0.0
Collab Diag Interf.	0.4	0	0.4	0.0	0.4	0.0
Collaborations	6.1	0.	6.3	0.0	6.3	0.0
Science Total	**18.2**	**0**	**18.7**	**0.0**	**18.7**	**0.0**
NSTX Total	**49.8**	**4.5**	**52.9**	**5.0**	**54.3**	**5.0**

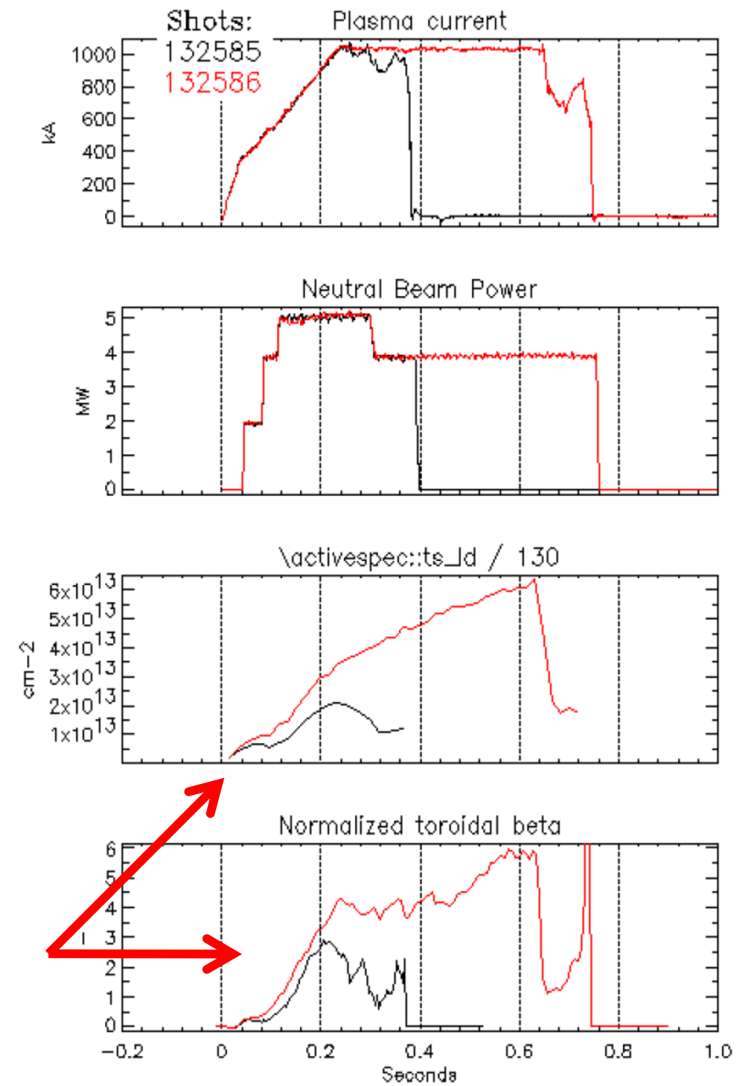
- **FY 2013 – FY 2014 Budget allows some high priority non - “NSTX Upgrade Project”**
- **If moly surface and cryo-pump are high priority tasks, we would try to fit them in since we have a long down time, a rear opportunity for in-vessel installation. Design and installation work maybe supported by the existing engineering and research staff.**
- **Highly preliminary estimates of fabrication ~ $ 1- 2M each for full Mo coverage and single cryo-pump connected to NBI cryo-plant assuming no passive plate reconfig.**

Lithium edge conditions require factor of 2-3x fueling increases to maintain density, avoid instability



High-field side fueling plenum pressure:

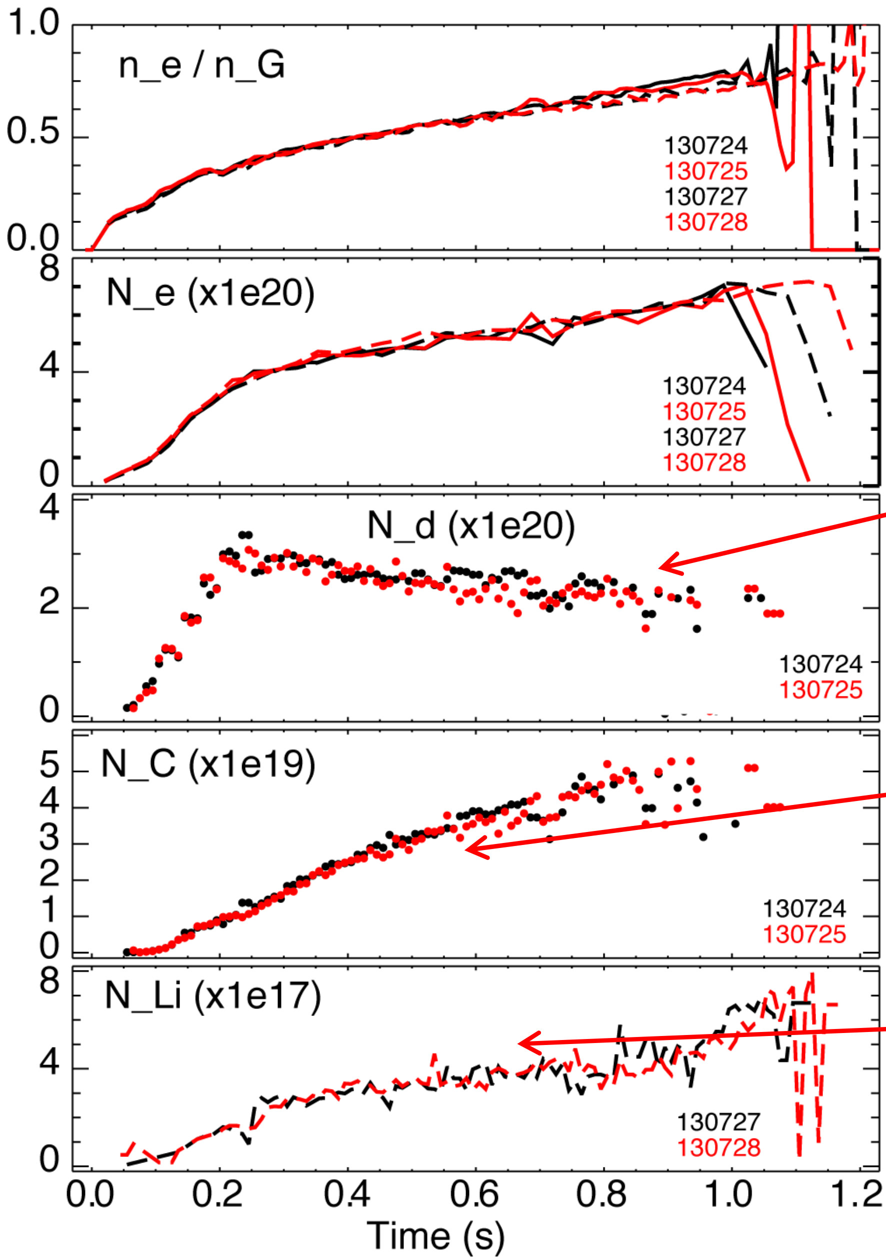
1350 Torr 1500 Torr



FY11-12 plans:

- Improve plasma stability at reduced fueling, density (R12-3)
- Quantify D pumping from Li to compare to cryo projections, assess extrapolation to Upgrade (LRTSG)

With lithium coating pumping, deuteron inventory is constant or even decreasing, C accumulates, Li saturates



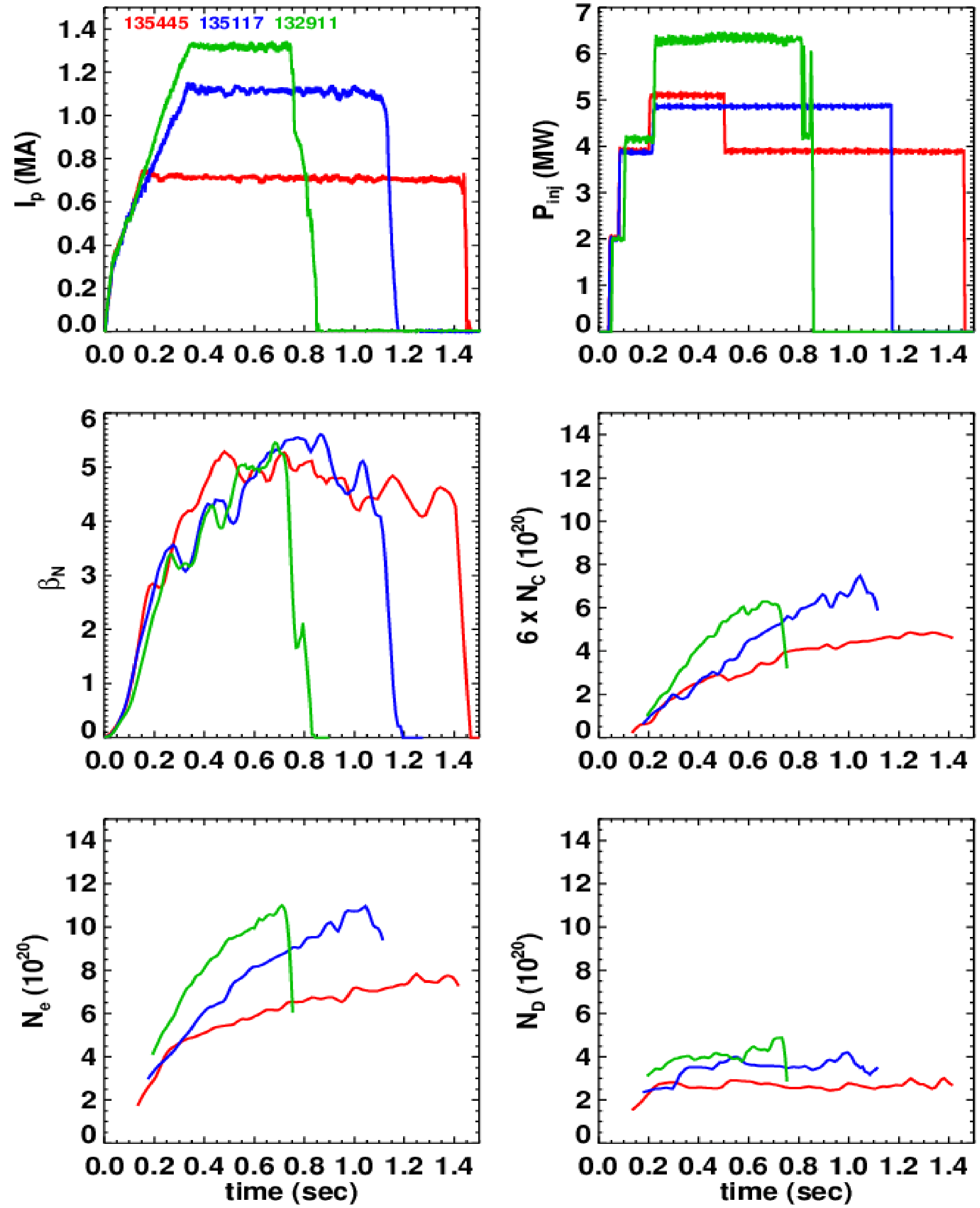
Some discharges exhibit D inventory pump-out

C inventory increases

Li inventory increases more slowly, saturates at low value

NSTX can maintain constant deuterium inventory with Li evaporation for range of operating scenarios

- Range of optimization targets:
  - Long Pulse
  - Sustained high-β_T
  - Maximized W_{MHD}
- Strong LITER evaporation and few or no ELMs.
- Carbon is accumulated, but Deuterium inventory is constant.



Greenwald fractions evolve similarly for range of I_P

- Definitions:
  - Electron Greenwald fraction.

$$f_{GW,e} \propto \frac{\overline{n}_e}{I_p} a^2$$

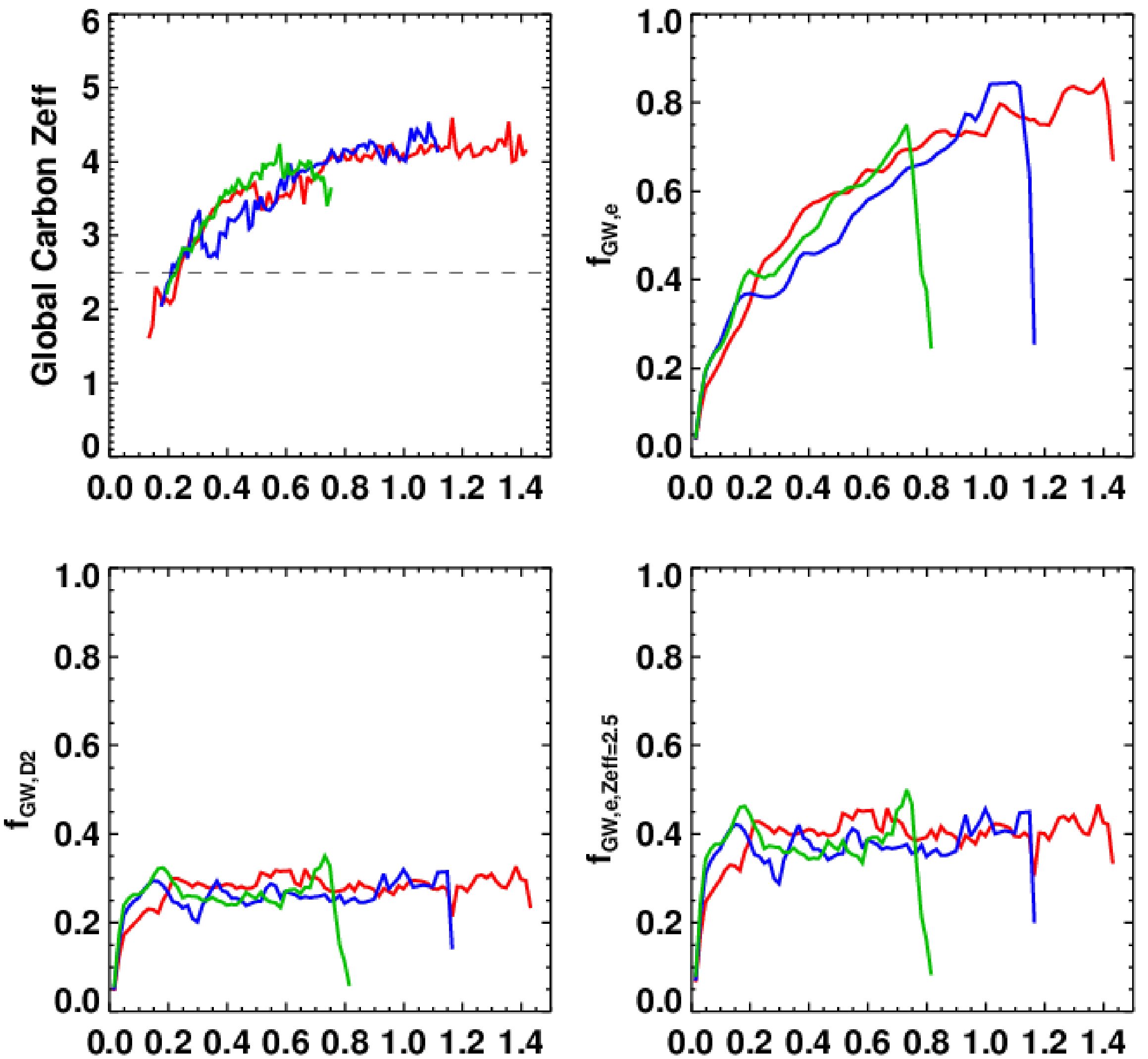
  - Inventories: N_C, N_D, N_E.
  - Deuterium Greenwald Fraction (i.e. Zeff=1)

$$f_{GW,D2} \propto f_{GW,e} \frac{N_D}{N_E}$$

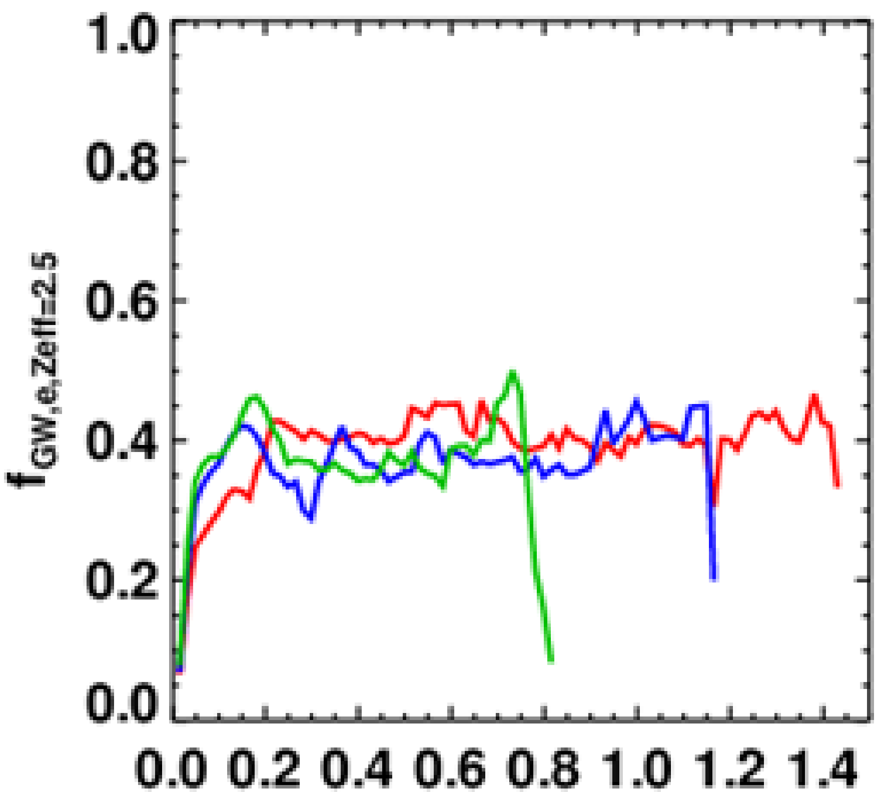
  - Equivalent Greenwald Fraction for a given requested Z_{eff}.

$$N_{E,Zeff} = \frac{5N_D}{6 - Z_{eff}}$$

$$f_{GW,Zeff} \propto f_{GW,e} \frac{N_{E,Zeff}}{N_E}$$



If C Z_{eff} could be controlled to 2.5, LiTER coatings are projected to provide pumping for Greenwald fraction = 0.4



- **This Greenwald fraction and C Z_{eff} would be sufficient for all proposed Upgrade operating scenarios**
- D pumping sustained for at least 1.4s at 4MW
  - Consider long-pulse scenario: **7s at 6MW could require up to 7x more Li**
- Can evaporate 7x more Li between shots w/ 20min shot cycle to test
  - Would likely require improved LiTER
  - Need to develop scenarios compatible with this level of Li/pumping – R12-3

- Strong motivation for improving C impurity control with Li

Impurity control

NSTX FY10-12

Increase Li coverage on PFCs

Heat flux mitigation methods could also reduce sputtering, erosion

ELM triggering with 3D fields, shaping, less Li, central RF heating…

NSTX Upgrade

Continue higher Li coverage

In-vessel RMP coils could provide faster 3D ELM pacing, and/or ELM suppression with increased impurity transport

Pellet pacing?

Integrate techniques in NSTX, Upgrade

- How does increased Li coverage impact C and higher-Z impurities?
- Does Li on Mo reduce core C Z_{eff}, protect Mo PFCs?

PAC-29 question 2

- First, all 3 research areas are high priority
  - Particle/impurity control is emphasis of new ITER/CC TSG
  - Li research, high flux expansion have dedicated milestones
- Prioritization:
  1. Particle and impurity control
     - Especially C impurity control with Li ELM free – provides foundation for using long-pulse D pumping with LiTER if new cryos/LLD unavailable
     - Goal: get D and C inventories to plateau at n/n_{gw} = 0.7-1, C $Z_{eff} \leq 2.5$
  2. Li research
     - Needed for assessing solid (and liquid) Li for Upgrade operations – in particular extrapolation of LiTER to longer pulse, higher power
  3. Heat flux handling – Snowflake
     - Very important, but initial lower I_P scenarios may not require this
     - Required for highest I_P /power/long-pulse = longer term research goal