PAC-27 Questions to NSTX

1. PAC remains concerned about ability to fully exploit NSTX-U without more complete understanding of what heat-flux handling and pumping requirements, and capabilities are needed.

   Example - What divertor temperature rise do you expect for the various operational scenarios, and what are your mitigation strategies?

   Please provide more detail on NSTX near-term research plan (2010-12)

   – Answered by Maingi, Menard

2. What diagnostics are impacted by NSTX-U, and how does this impact the NSTX-U research program, and what are your plans to cope with the impact?

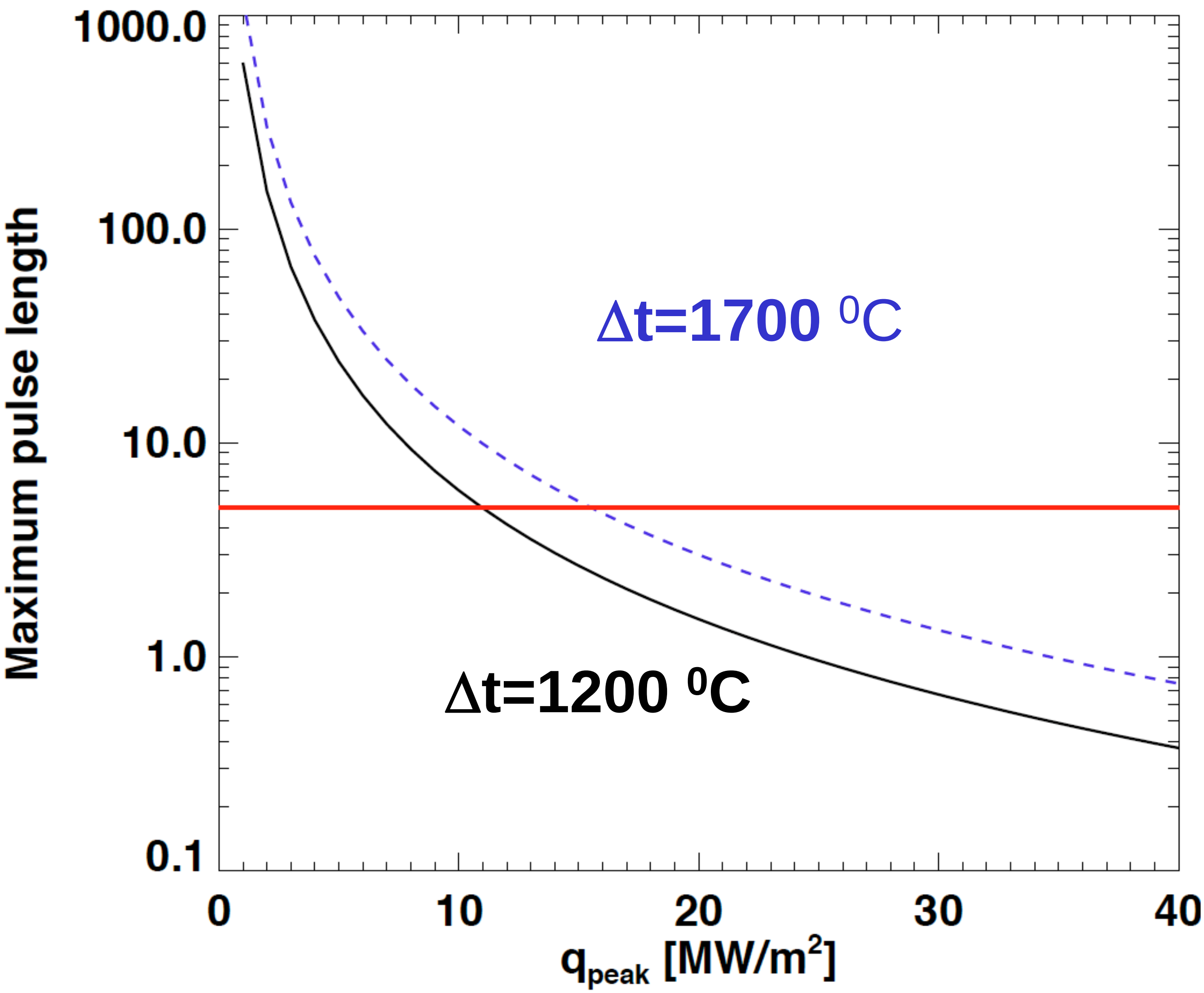
   – Answered by Menard

3. There is no discussion of v_θ measurements or implications, please provide a viewgraph or 2 on results and implications.

   – Answered by Kaye

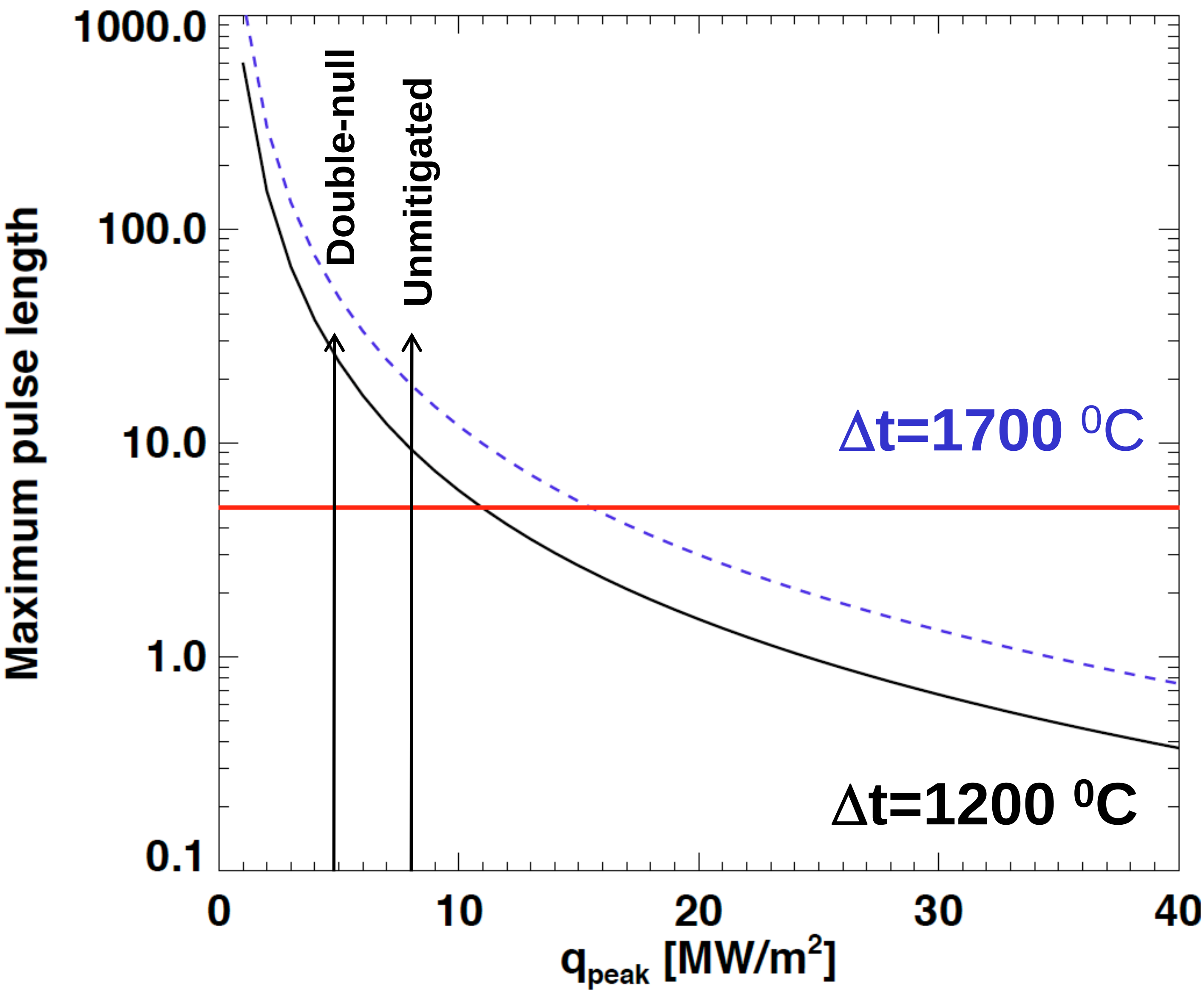
Question 1
Thermal calculations and FY10-12 plans to prep for NSTX-U divertor

Heat flux and pulse length limits of the ATJ graphite tiles



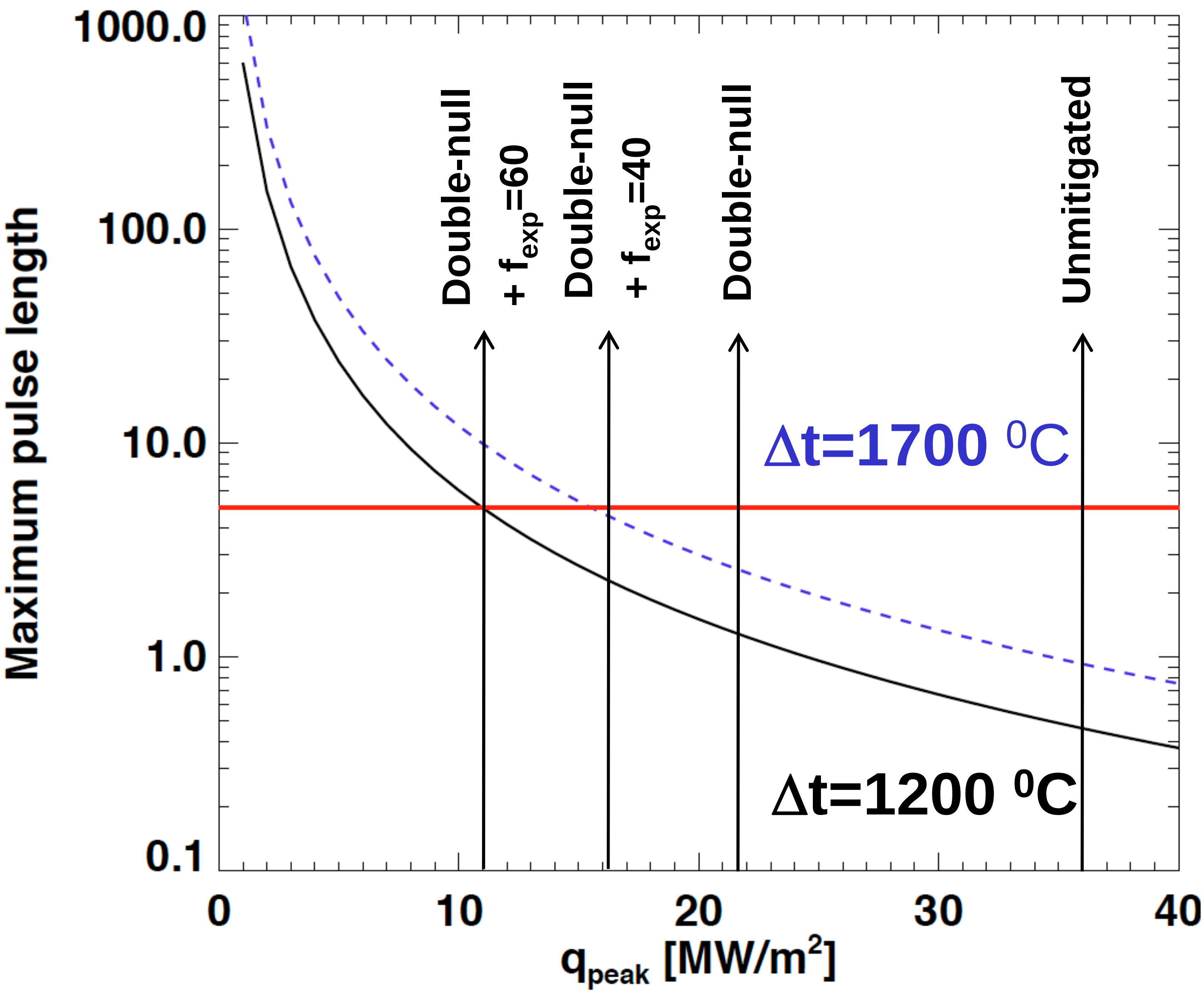
- ATJ tiles can withstand 11 MW/m² for 5 sec before Δt=1200⁰C
  - Administrative limit on tiles at 1200 ⁰C, based on Radiation Enhanced Sublimation concern predicted at t=1400 ⁰C
- Allowing Δt=1700⁰C increases q_{max} to 15 MW/m² for 5 sec pulse

1 MA, fully non-inductive scenario should not restrict pulse length for existing tiles



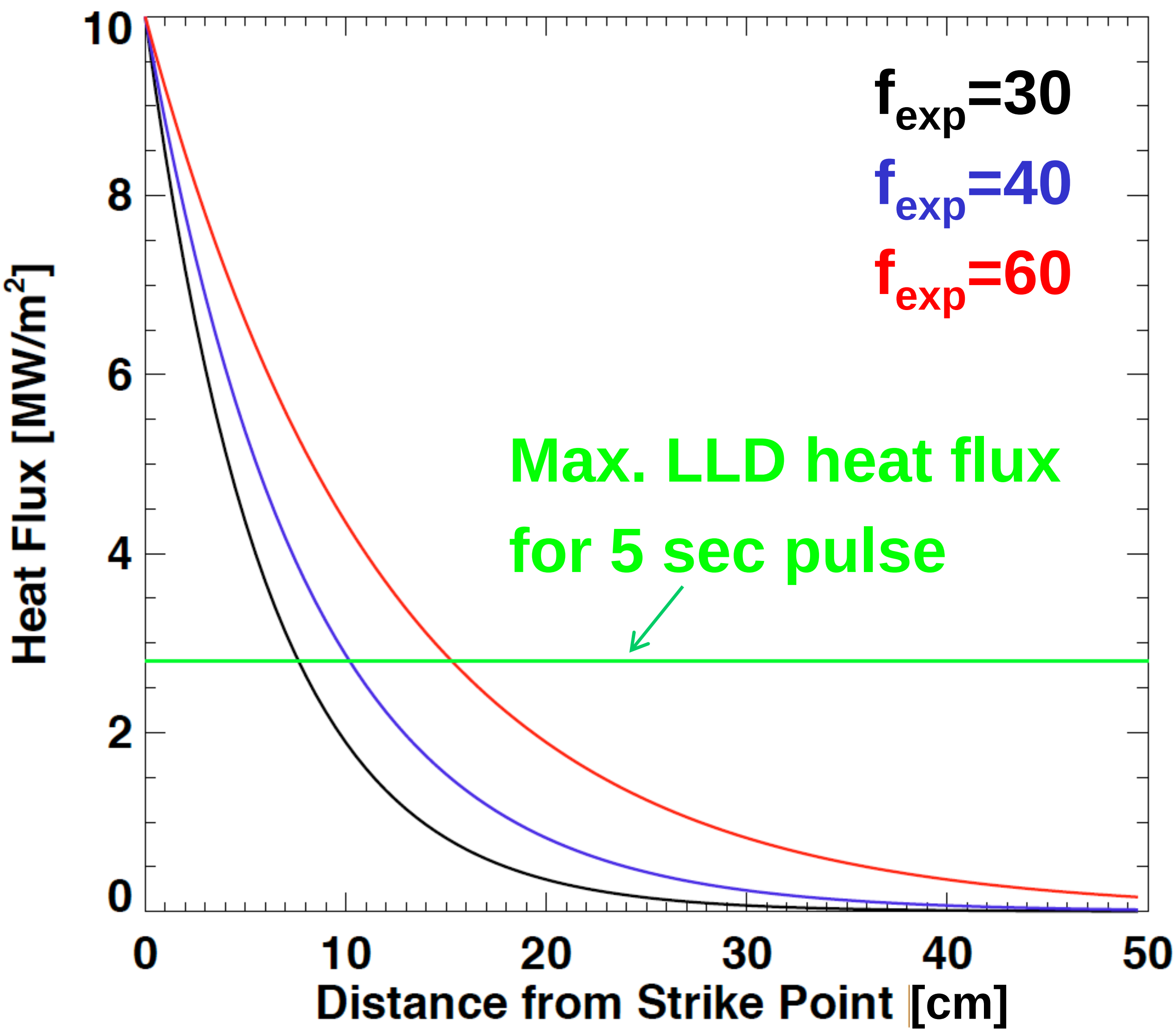
- 100% non-inductive scenario with 1 MA, n/n_{GW}=0.5, P=10 MW
  - f_{exp}=30
  - f_{div}=0.5
  - λ_q^{mid}=9 mm
- Going to double-null (60/40 down/up split) provides extra safety margin

2 MA, high PNBI scenario requires extra flux expansion for full pulse length for existing tiles



- High current scenario 2 MA, n/n_{GW}=0.5, P=15 MW would restrict pulse length
  - f_{exp}=30
  - f_{div}=0.5
  - λ_q^{mid}=3 mm
- Actual scenarios can use n/n_{GW}=0.7-1, which will widen the SOL width by an amount TBD
- Using DN and increased flux expansion would just manage for 5 sec

Heat flux profiles in divertor



- Max. LLD heat flux for 5 sec. pulse is 2.8 MW/m^2 (Nygren, SNLA)
- Graphite tiles will restrict qmax to ~ 10 MW/m^2 for a 5 sec. pulse
- Intersection between green line and heat flux profiles shows how close LLD could be placed to intended strike point location

FY10-12 NSTX research plans for LLD + high flux expansion for NSTX-U (1)

- Present plan: assess high flux expansion + LLD as baseline
  - **FY10-12 results will provide data on viability for NSTX, Upgrade**
  - Also refer to FY10 divertor upgrade analysis plan from Maingi talk
- FY10 – Assess LLD pumping, initial impact on pedestal, core
  - Pre-wet LLD before plasma ops
  - Develop plasma fiducials w/ and w/o LLD warm, w/ and w/o LITER
  - Characterize pumping of LLD vs LLD temperature, strike-pt location, etc.
  - Perform 2+ day MHD/confinement survey XP to assess impact of LLD
  - Milestone: Assess H-mode characteristics vs. collisionality and Li conditioning – important for NSTX Li program, and FY11 joint milestone
  - Further develop strike and x-point control for sustained snowflake
  - Assess C/Li impurity sources/transport (PhD thesis starting in 2010)
  - Assess radiative divertor with impurity seeding
  - Measure thermal response of LLD and bare Mo LLD to high heat flux

FY10-12 NSTX research plans for LLD + high flux expansion for NSTX-U (2)

- Based on LLD pumping data, and end-of-run results of FY2010 (LLD+high heat flux), decide on installation of inboard Mo tiles
  - Assuming tiles are ready for installation

- FY11-12: If decision to install Mo tiles is “yes”, then assess:
  - If outboard LLD successful, could enable test of inboard (high-δ) LLD
  - Reduce C impurity influx from divertor
    - Begins to informs choice of C or metallic divertor for NSTX Upgrade
  - Expected to improve CHI via reduction in C, O impurity content
  - Most probable implementation is via replacement of C tiles with Mo tiles
    - Replace lower horizontal + part of lower vertical (high-δ shapes) + bull-nose
    - May be possible to heat to ~250-300°C using existing bake-out capability

FY10-12 NSTX research plans for LLD + high flux expansion for NSTX-U (3)

- FY11 – Milestones: Relate LLD pumping to surface conditions, assess integrated plasma response to LLD/pumping
  - Use PMI probe for in-situ analysis of surface conditions
    - Cold/warm C/Mo samples near LLD, relation to pumping, plasma response
  - Utilize LLD (and HHFW) for density/collisionality modification
    - Assess impact on NBI and BS current drive, confinement, ELMs, impurities
  - Utilize high flux expansion routinely in advanced scenarios as available
- FY12 Milestone: Assess very high flux expansion divertor
  - If outboard/inboard LLD still in machine, assess interaction of snowflake with LLD as possible integrated heat/particle control solution for Upgrade
    - Assess divertor power handling, LLD pumping, impurity production, SOL turbulence, pedestal stability
  - If inboard metallic divertor installed, can also operate w/o Li, and could assess snowflake interaction with high-Z metallic divertor
  - If LLD/Mo not present, characterize snowflake with C divertor tiles

Question 2 – Diagnostics and NSTX-U

2^{nd} NBI will displace (eliminate) several presently utilized diagnostics
FY2010-12 goal is to fully exploit these diagnostics

- Tangential high-k microwave scattering
  - High-k fluctuation data very important for post-Upgrade transport research
  - Will initiate design of new high-k_θ system to replace high-k_r system
- 2D scanning Neutral Particle Analyzer (NPA)
  - Fast ion f(**v,t**) needed for fast-ion transport predictive capability
    - But have perpendicular FIDA, implementing tangential FIDA for FY11
  - Array of much smaller solid-state NPAs (SSNPA) under consideration
    - With sufficient channel count, provides spatial + energy + pitch-angle resolution
- Far IR Tangential Interferometer/Polarimeter (FIReTIP) (119μm, 6ch)
  - Would lose density normalization for Thomson scattering system, also lose real-time density measurement for n_e feedback control (in prep for FY2010)
  - Diagnostic bandwidth recently upgraded to measure TAE $\delta n/n$
    - But BES and upgraded reflectometer can measure TAE displacement profile
  - Plan to implement dedicated interferometer(s) for density measurement

Additional diagnostics impacted/eliminated by 2nd NBI

- CHERS: $T_i(r)$ and $V_\phi(r)$ (51 ch)
  - 2nd NBI eliminates existing background view
  - Will likely require NBI notches for accurate profiles measurements
    - Requires all 3 2nd NBI sources to be off – this should be acceptable if only 1 or maybe 2 2nd NBI sources are being used – need to analyze this further
    - Alternative solutions being sought (challenging so far)

- Other diagnostics that will be eliminated:
  - X-ray crystal spectrometer: $T_i(0)$, $T_e(0)$
    - Already/will rely on NBI/CHERS/MPTS for these measurements
  - Fast X-ray tangential camera
    - Previously used for imaging core MHD, but is presently not routinely utilized

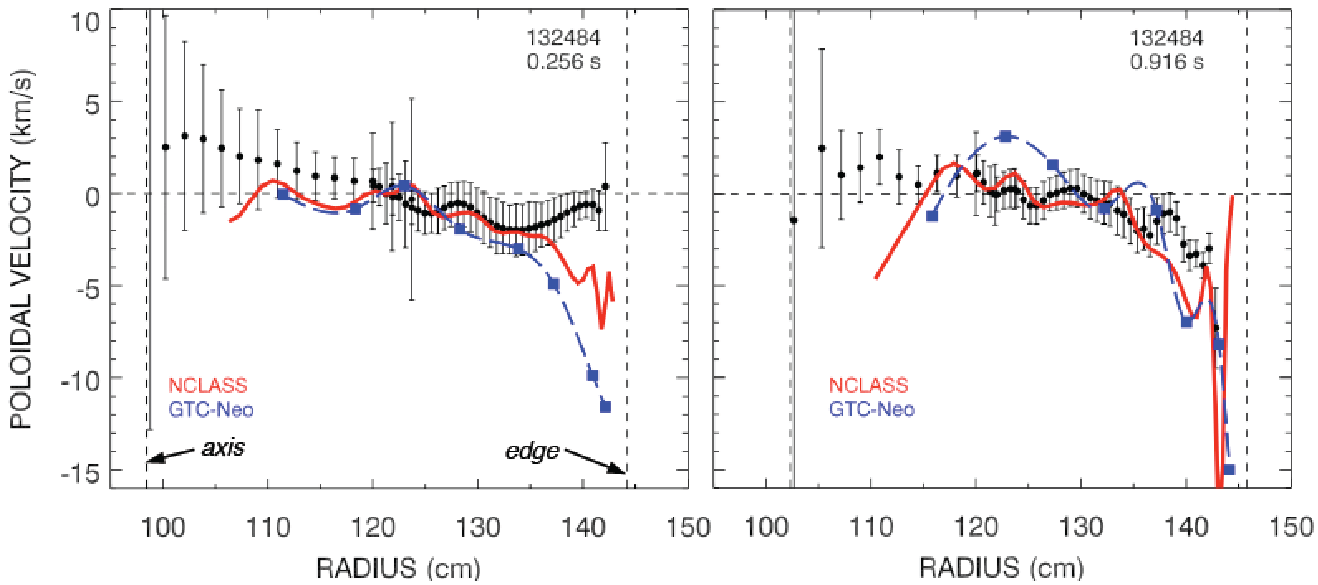
Question 3 – Poloidal Rotation Measurements

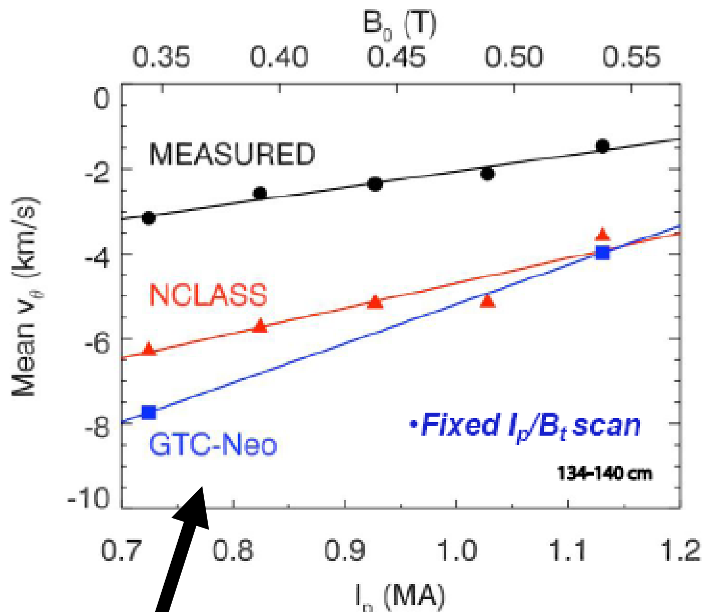
Knowledge of the poloidal velocity is required for determining E_r

- E_r and ∇E_r linked to turbulence suppression
  - Potentially important for edge stability, L-H transition physics, residual stress (rotation source)
- E_r needed for MSE measurements to obtain accurate field pitch measurements for j(r)
- V_θ measurements on conventional aspect ratio devices differ from neoclassical estimates by an order of magnitude
- Vertical CHERS for v_θ measurement implemented on NSTX in 2009
  - Low B_T minimizes dominant atomic physics effect (velocity component associated with gyro-orbit)
  - Up/down symmetric viewing geometry minimizes reliance on atomic physics (obtain differential velocity)

V_θ close to neoclassical in NSTX

- Measured v_θ consistent with neoclassical v_θ for inner core
- Large neoclassical v_θ at edge not seen at earlier times
- Better agreement with theory at later times

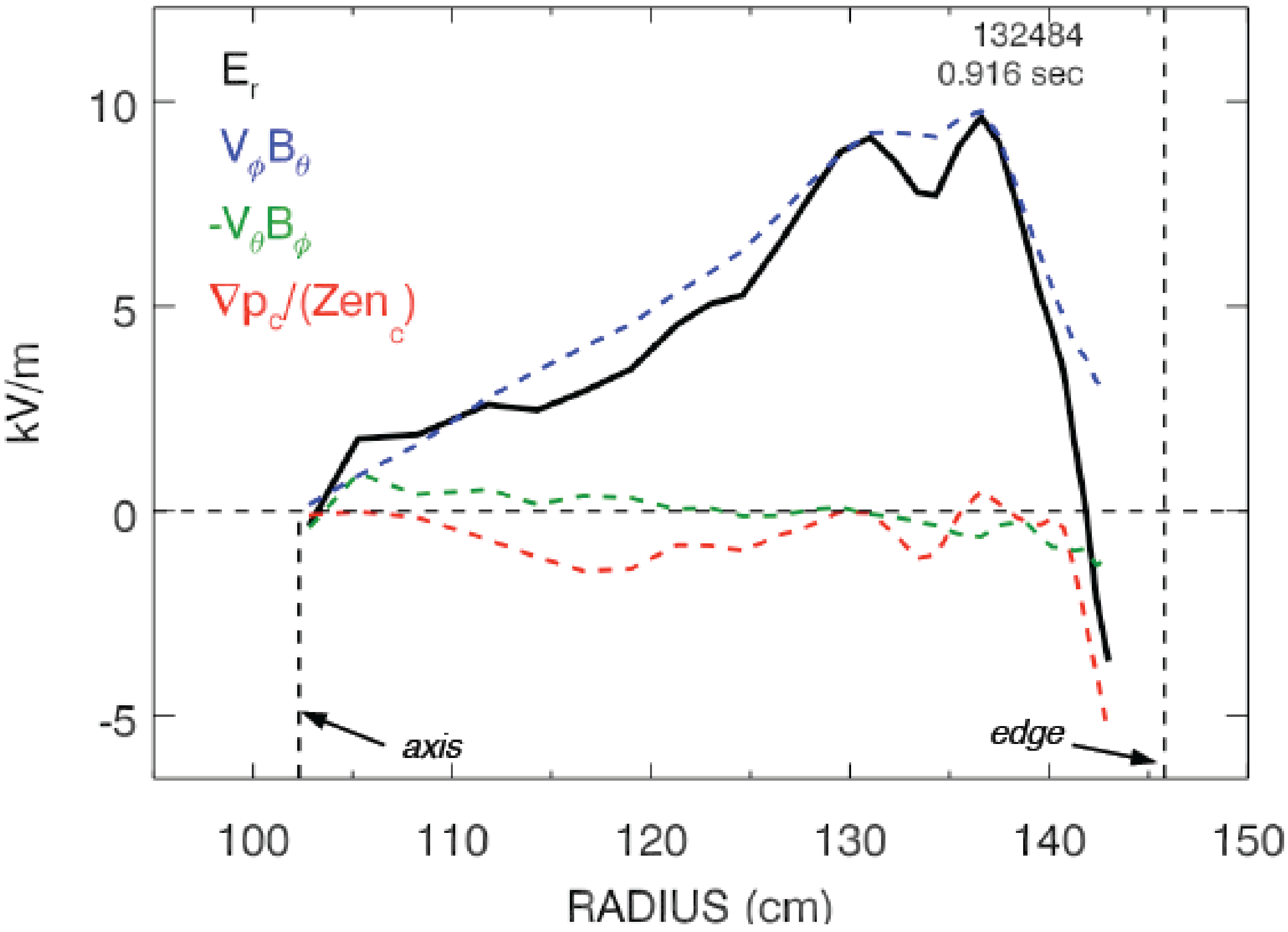




NCLASS: multi-species
GTC-Neo: finite banana orbit effects, impurity species

- I_p, B_T trends (including reversed TF, not shown) in measured v_θ consistent with neoclassical

v_θ makes only small contribution to E_r except possibly very close to plasma edge



Force Balance Equation:

$$E_r = v_{\phi i} B_\theta - v_{\theta i} B_\phi + \frac{\nabla p_i}{eZ_i n_i}$$

- Joint experiment with DIII-D (K. Burrell) being developed to understand differences between low and high aspect ratio for v_θ vs $v_{\theta,neo}$