NSTX-U Disruption PAM Working Group Meeting

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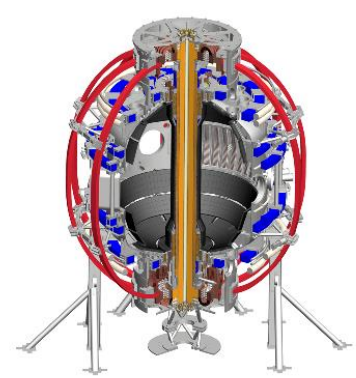
For the NSTX-U DPAM Working Group

NSTX-U DPAM Working Group Meeting
PPPL
10/29/15

Slides: http://nstx.pppl.gov/DragNDrop/Working_Groups/DPAM/2015/DPAM_mtg_10-29-15/

V1.3



Outline / Agenda

- Interface to the FES Workshop on Transient Events
- Connection to JRT-16 Joint Research Target Milestones
- Disruption characterization and forecasting approach and present analysis implementation
- Group discussion on disruption identification and "homework"

Significant progress since last meeting addressing charges to Working Group

- Strong interface to the FES Workshop on Transient Events
  - S.A. Sabbagh was leader of Disruption Prediction sub-panel
  - Disruption Prediction panel work completed in July, final report due Nov

- Significant DPAM milestones for JRT-16
  - For disruption prediction, avoidance, and mitigation

- Code written for automated analysis of Disruption Event Characterization And Forecasting (DECAF code)

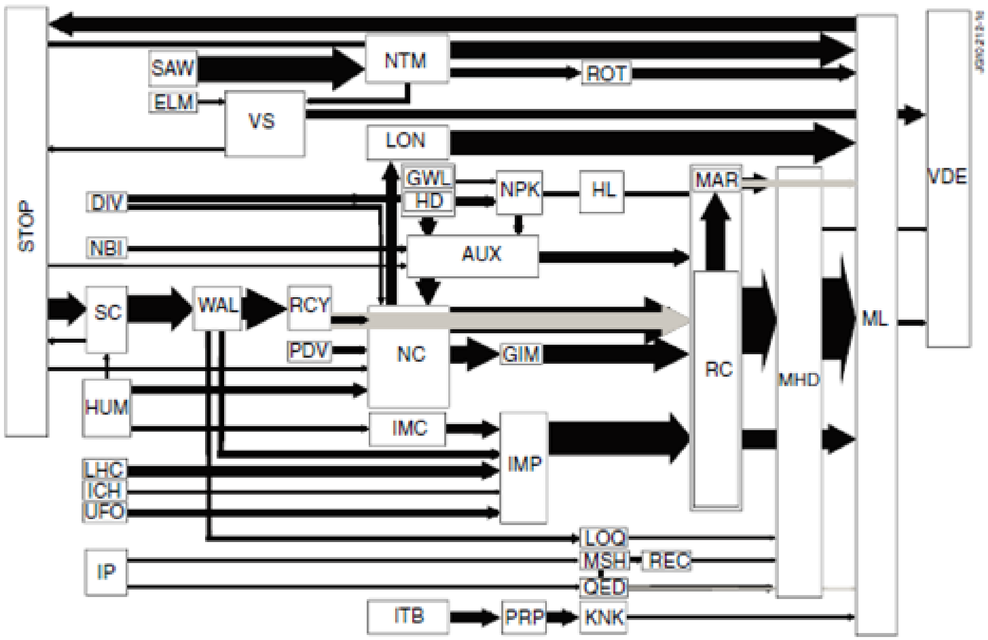
- Communication of initial DECAF results to organizations
  - To DOE, ITPA (MDC-21 (Global mode stabilization) and MDC-22 (Disruption Prediction), PPPL TSD (disruption) mtg, smaller meetings
  - Strong interest expressed to test DECAF on DIII-D when code is ready

1. Interface to the FES Workshop on Transients and Product of the Disruption Prediction sub-panel

- Web page
  - https://www.burningplasma.org/activities/?article=Transients
- Disruption Prediction panel report brief outline (59 pages)
  - Overview and summarized recommendations
  - Disruption detection: measured & modeled triggers (<u>how</u> to cue action)
    - Plasma response and instabilities
    - Confinement transitions
    - Power balance and plasma heating
    - Density limits
    - Tokamak dynamics
    - Technical problems and human error
  - Triggering thresholds (<u>when</u> to cue action)
  - Modeling and measurement – further considerations
  - Accomplishments since ReNeW 2009
  - Research evolution for future devices (ITER, FNSF, DEMO)
  - Ten-year research plan RECOMMENDATIONS (5 “Pursuits” defined)
  - Resources needed
  - Expected impact of research

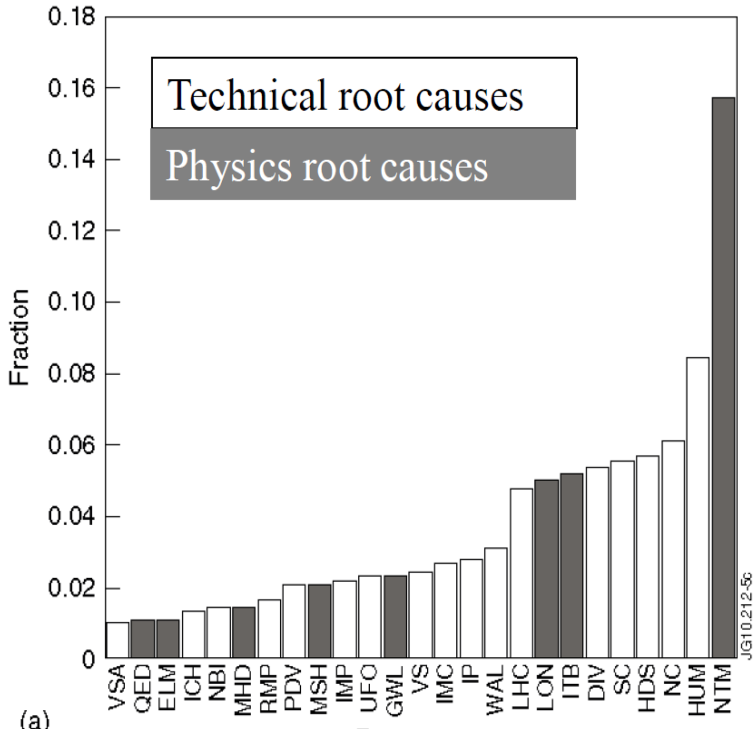
JET disruption event characterization provides framework to follow for understanding / quantifying DPAM progress

JET disruption event chains



P.C. de Vries *et al.*, Nucl. Fusion **51** (2011) 053018

Related disruption event statistics

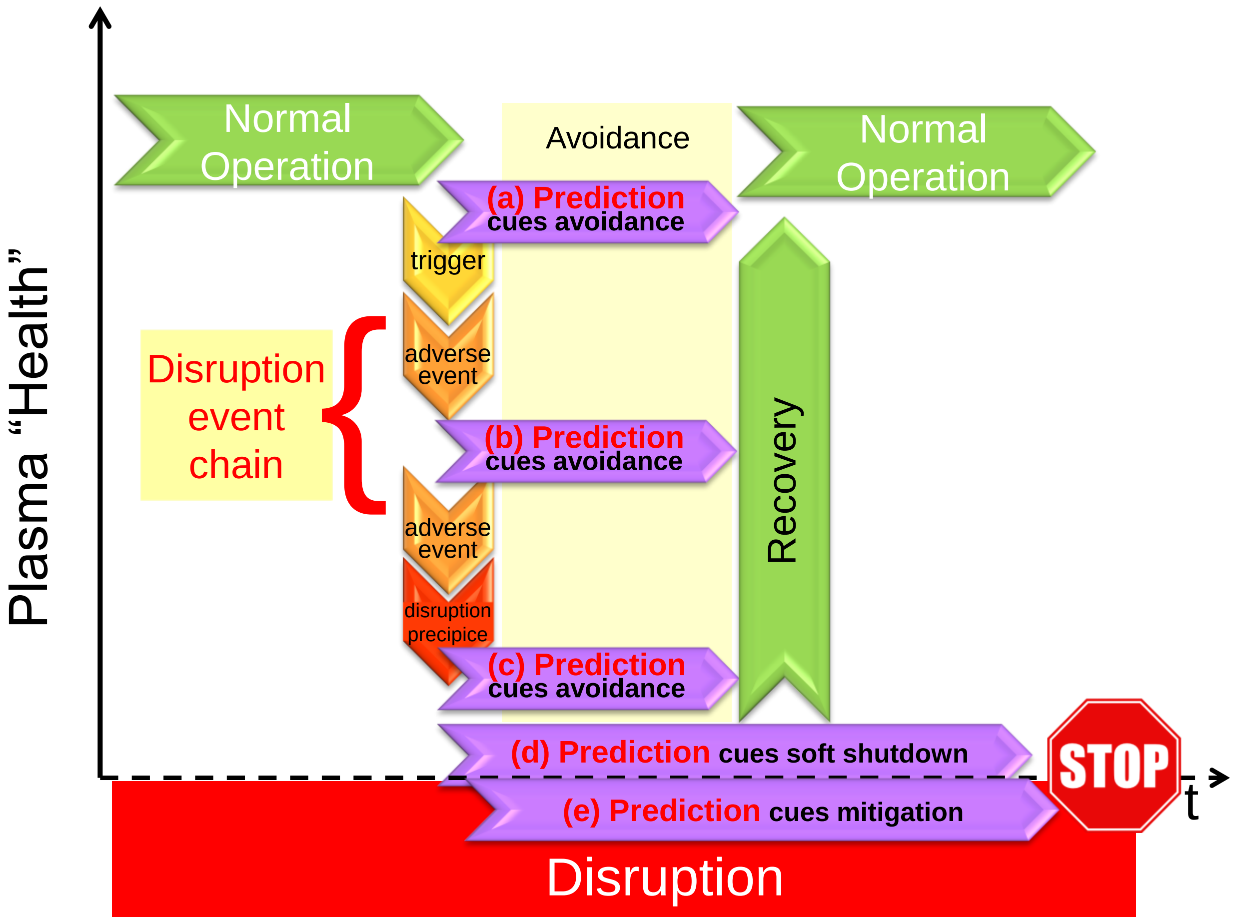


de Vries, NF (2011)

- JET disruption event chain analysis performed by hand, desire to automate
- NSTX-U DPAM Working Group formed
  - List of disruption chain events defined, interested individuals identified

Disruption event chain characterization capability started for NSTX-U as next step in disruption avoidance plan

Disruption prediction framework from upcoming DOE "Transient Events" report

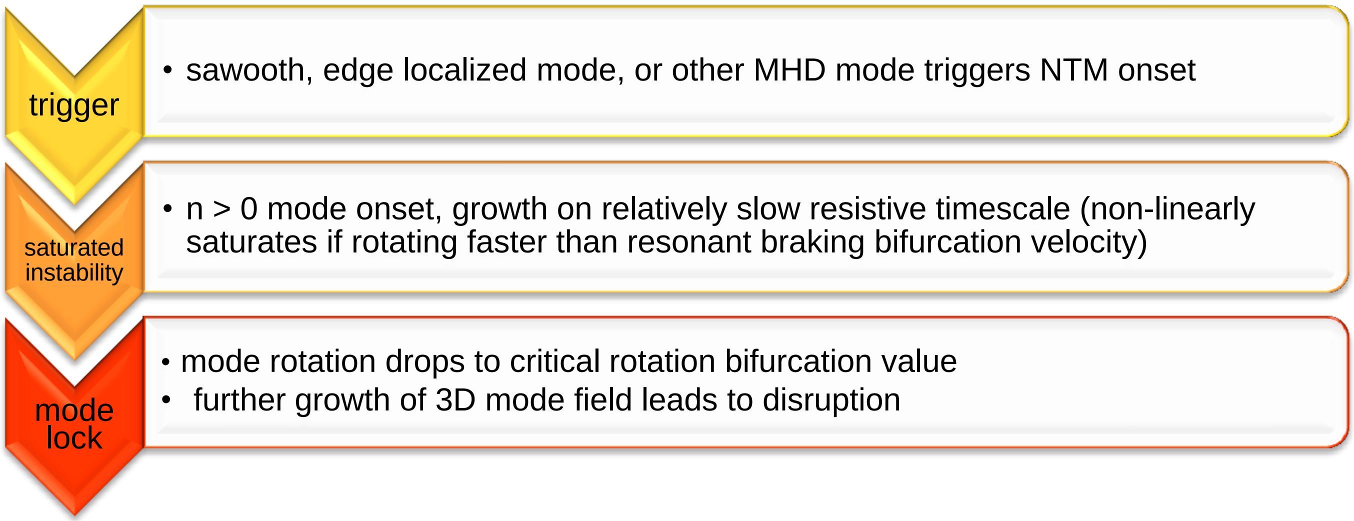


- Approach to disruption prevention
  - Identify disruption event chains and elements
  - Predict events in disruption chains
    - Attack events at several places
    - Give priority to early events
  - Provide cues to avoidance system to break the chain
  - Provide cue to mitigation system if avoidance deemed untenable

S.A. Sabbagh (for Disruption Prediction panel)

Significant physics research is needed to predict opportunities for avoidance in disruption event chain

Example: A typical NTM disruption event chain (see Prediction Section 3.1.1.1)



- Examples of gaps in physics understanding
  - Prediction of stability in low rotation plasmas
  - Accurate non-ideal MHD stability maps
  - Physical understanding of how mode locking produces disruption
  - More comprehensive, validated physical understanding of role of rotation and profile in MHD stability

Disruption Prediction is a Multi-disciplined Task

- Theoretical investigation
  - Understanding of underlying physics of triggers and events required to create and extrapolate prediction algorithms to unexplored frontiers of next-step tokamak operation
- Tokamak experiments
  - Validate theory and determine reproducibility of the events
- Modeling at several levels (e.g. quasi-empirical, linear, non-linear)
  - Connect theory and experiment – the basic component of creating prediction algorithms; from r/t modeling coupled to sensors, etc. - to full non-linear MHD
- Diagnostics
  - Develop sensors required for advanced prediction algorithms in present tokamaks; to survive harsher conditions in next-step, fusion-producing devices
- Control theory and application
  - Design/test the compatibility and success of the coupled prediction and avoidance elements in the real-time disruption avoidance systems
- Predictive analytics
  - Use data, statistical algorithms and machine-learning techniques to identify the likelihood of future outcomes based on historical trends (AND physical models)

2. Joint Research Target JRT-16 – focuses on elements of disruption mitigation, prediction, and avoidance

- FY16 DOE Joint Research Target summary (1 page)
  - File: http://nstx.pppl.gov/DragNDrop/Working_Groups/DPAM/Repository/JRT16QuarterlyMilestones-V9.pdf

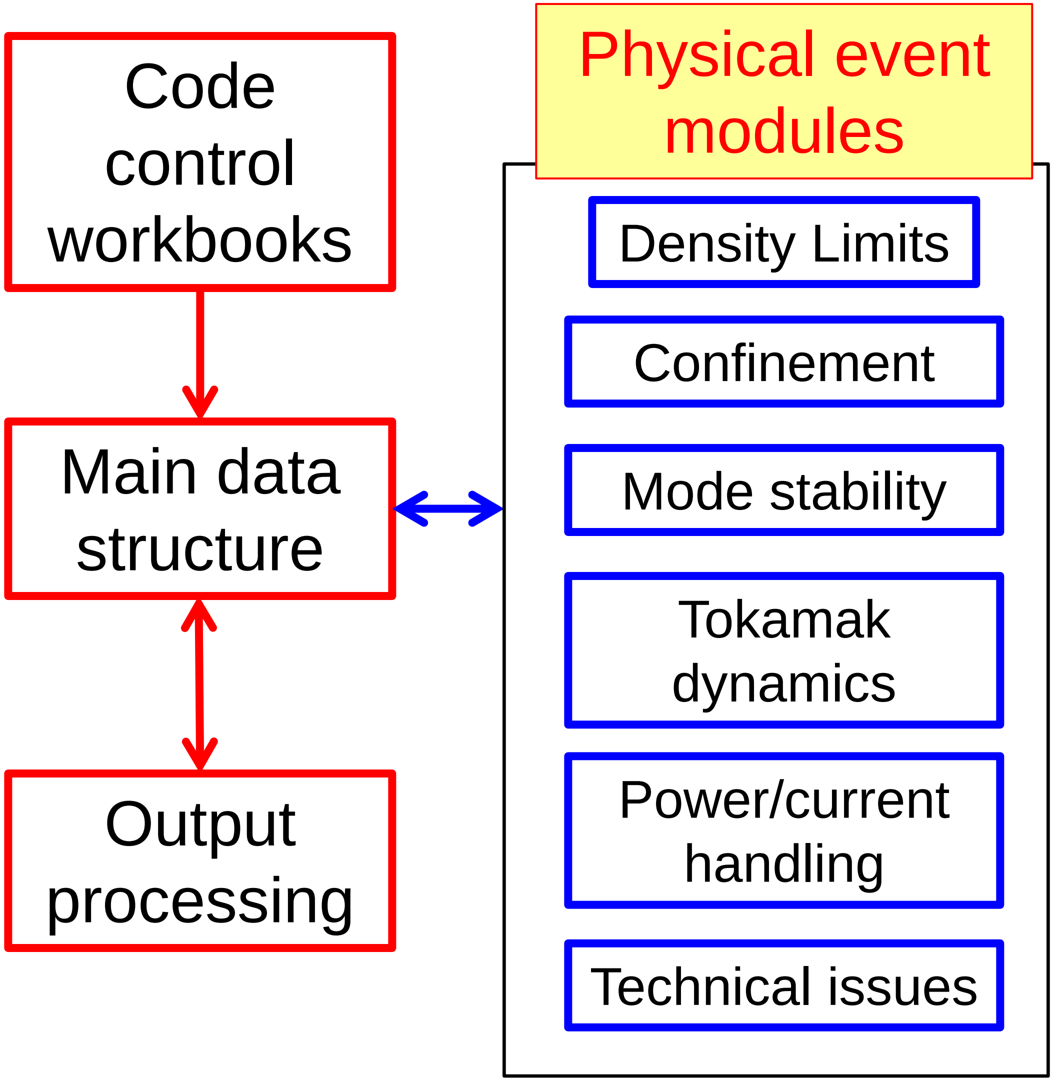
Culminating Milestones

- Mitigation
  - Test newly-designed ITER-type massive gas injection valve to study benefits of private flux region massive gas injection vs. mid-plane inj.
- Prediction / Avoidance
  - Use disruption prediction algorithm to characterize the reliability of predicting a few types of common disruptions from at least two devices
  - Report on capability to reduce disruption rate through active improvement of plasma stability
  - Test on at least one facility to detect in real time an impending disruption and take corrective measures to safely terminate the plasma discharge

3. Disruption Event Characterization And Forecasting (DECAF) code has been written – development continues…

- DECAF code development guidance
  - Code is portable (and needs to stay that way)
  - Code must be able to accept and process data from several tokamaks
- DECAF code characteristics – high-level overview
  - Written in Python for portability
    - Runs on Linux and Windows distributions of Anaconda (Python 2.7)
      - At the moment, the plan is to not use IDL or proprietary libraries
    - Code written to easily allow reading data from various machines without changes to source code
    - Code related to disruption events and physics models are separated into modules for ease of parallel development of code
  - Under Git version control
    - In a controlled repository on PPPL cluster – not GitHub
  - Analysis started / development continues
    - First using NSTX data; directly applicable to NSTX-U and other devices

DECAF is structured to ease parallel development of disruption characterization, physics criteria, and forecasting



- Physical event modules separated
  - Present grouping follows work of deVries – BUT, is easily appended or altered
- Warning algorithm
  - Present approach follows work of Gerhardt, et al. – BUT is easily appended or altered
- General idea:
  - Build from successful foundations – BUT keep approach flexible

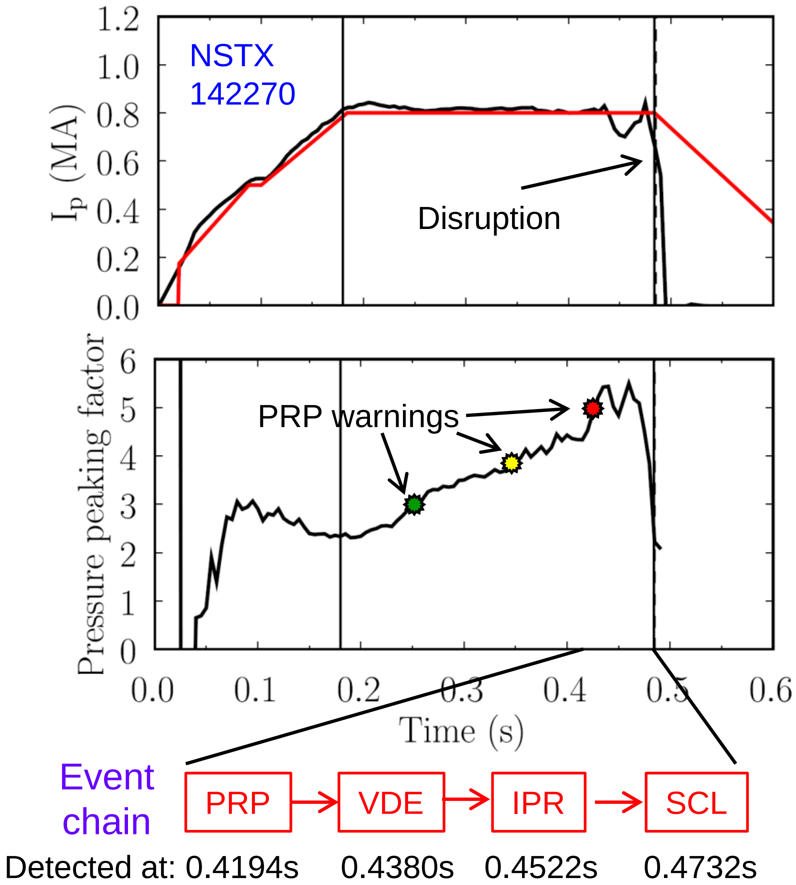
Control workbook concept eases use and development - and keeps source code from devolving into a hardwired mess!

	A	B	C	D	E	F	G	H	I
1	Disruption Event Characterization And Forecasting (DECAF) code - Disruption Chain Events and Tests								
2									
3									
4			Grayed area below is the named range: **dceevents**			Grayed area below is the named range: **dcetests**			
5			NOTE: Names in the grayed ranges below are arbitrary, but column order must be maintained						
6									
7									
8	Disruption Event Group	Group	Disruption chain event	DCE	DCE Point Threshold	Test ID	Test Criteria	Test Thresholds	Unit
9	**Density Limits**	NL	Impurity control	IMP					
10			Greenwald limit	GWL	3	GWL-01	Greenwald density limit	[0.7,0.8,0.9]	
11			Low density (Error field)	LON	3	LON-01	Decrease in line density too large	[-10.0,-20.0,-30.0]	10^14c
12						LON-02	Line density too low	[0.3,0.2,0.1]	10^14c
13			Wall conditions	WCS					
14			Off-normal material intrusion	OMI					
15	**Confinement Transition**	CT	Internal transport barrier formation	ITB					
16			H-L mode back-transition	HLB			Pressure peaking and dFp/dt increase		
17							Poor global confinement as disruption precursor		
18							Poor neutron production as disruption precursor		
19	**Mode Stability**	MS	Vertical stability	VDE	2	VDE-01	Vertical stability - axis position	[0.05,0.075]	m
20						VDE-02	Vertical stability - axis velocity	[5.0,10.0]	m/
21						VDE-03	Vertical stability - excessive ZdZdt	[0.1,0.2]	m^2
22							Vertical stability - operational space		
23			Locked tearing mode	LTM	3		Loop voltage too large		

Control | Shotlists | Measurements | **EventsAndTests** | Characterization | Notes

- Essential for portability
  - Future code development can't afford to "cut corners" by sacrificing code generality and flexibility

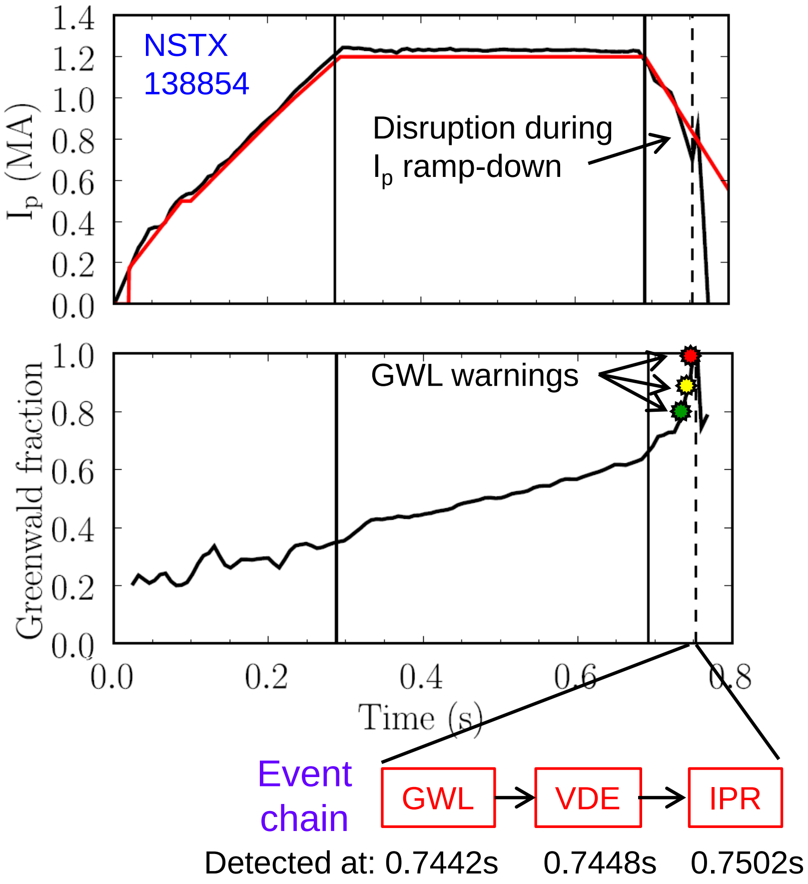
Disruption Event Characterization And Forecasting Code (DECAF) yielding initial results (pressure peaking example)



- 35 physical disruption chain events identified; 12 technical/human error events
- 10 physical events are presently defined in code with quantitative warning points
  - Code written to be easily expandable and portable to other tokamaks
- This example: Pressure peaking (PRP) disruption event chain identified by code before disruption
  1. (PRP) Pressure peaking warnings identified first
  2. (VDE) VDE condition subsequently found 19 ms after last PRP warning
  3. (IPR) Plasma current request not met
  4. (SCL) Shape control warning issued

J.W. Berkery, S.A. Sabbagh, Y.S. Park (Columbia U.)

Disruption Event Characterization And Forecasting Code (DECAF) yielding initial results (density limit example)



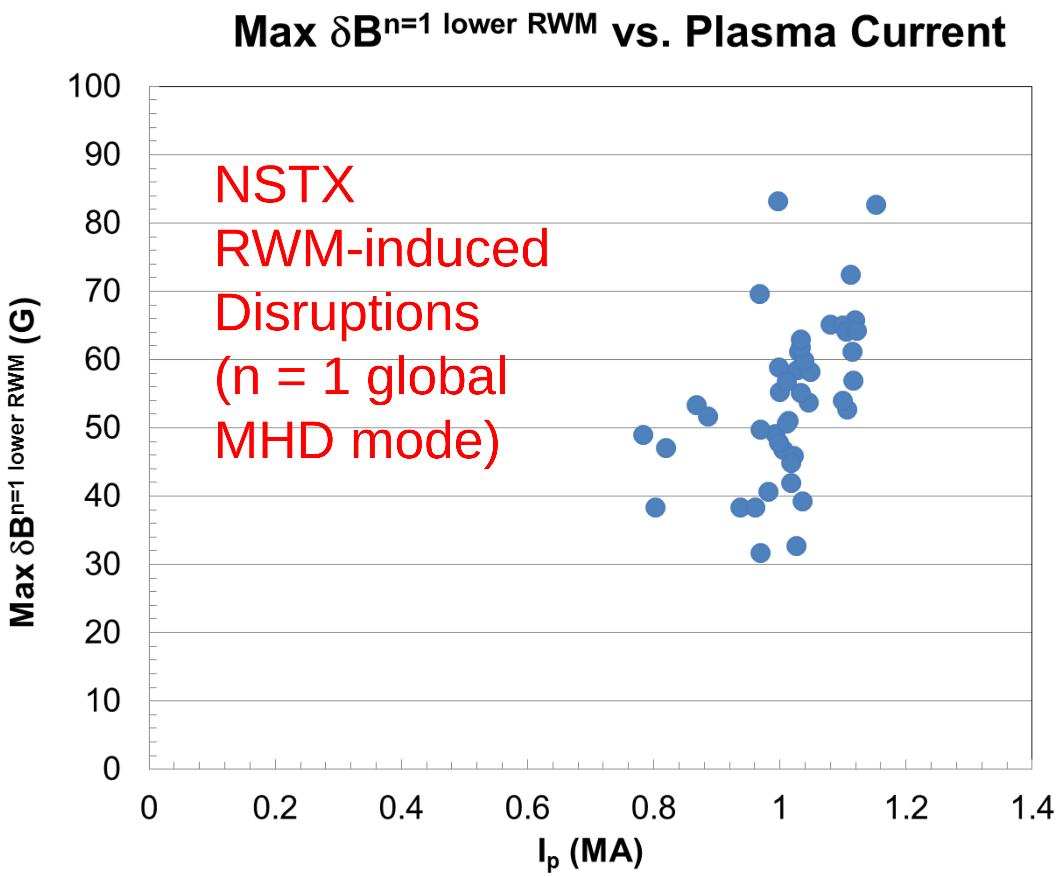
- This example: Greenwald limit disruption event chain identified by code during I_p rampdown before disruption

  1. (GWL) Greenwald limit warning issued
  2. (VDE) VDE condition then found 0.6 ms after GWL warning
  3. (IPR) Plasma current request not met

J.W. Berkery, S.A. Sabbagh, Y.S. Park (Columbia U.)

ITER High Priority need: What levels of plasma disturbances (δB_p; $\delta B_p/B_p(a)$) are permissible to avoid disruption?

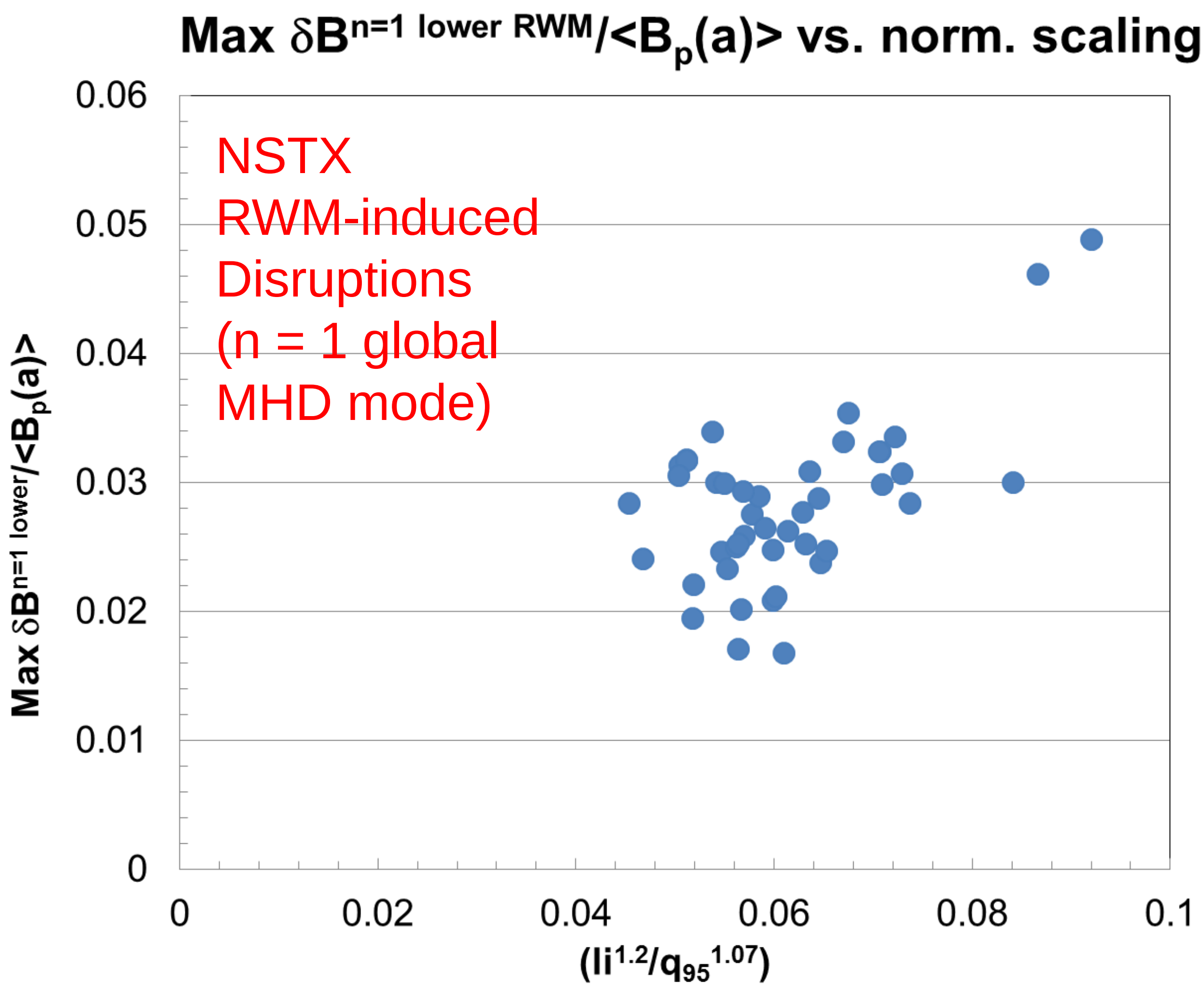
- NSTX RWM-induced disruptions analyzed
- Analyze events leading to disruption using new analysis code "DECAF" (Disruption Event Characterization And Forecasting)
  - See MDC-22 talk by G. Pautasso for more initial DECAF results
- Compare maximum δB_p (n = 1 amplitude) causing disruption vs I_p



- Maximum δB_p increases with I_p
- Next step: add results from other devices

Maximum $\delta B_p/\langle B_p(a)\rangle$ might follow a de Vries-style scaling l_i^{p1}/q_{95}^{p2}

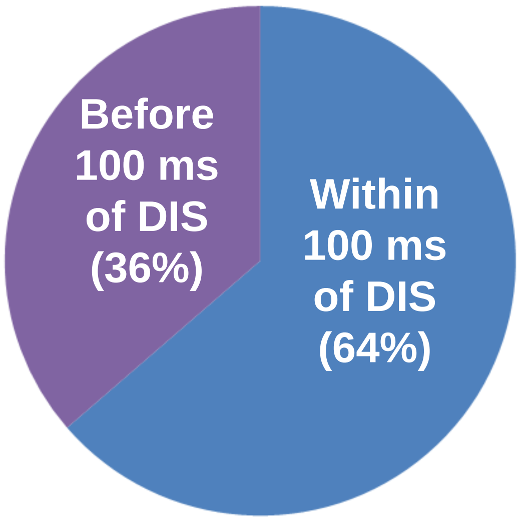
- NSTX RWM-induced disruptions analyzed
- Compare maximum δB_p causing disruption vs. de Vries locked NTM scaling
  - Normalized parameters
- NSTX analysis uses kinetic EFIT reconstructions
  - l_i instead of $l_i(3)$
  - $\langle B_p(a)\rangle_{fsa}$ used



(Although thresholds are not at all optimized yet) what did DECAF show when applied to this 44 shot NSTX database?

- These events found for all shots
  - DIS: Disruption occurred
  - RWM: RWM event warning
    - Note: this module is not smart enough yet to distinguish RWM from locked TM
  - VDE: VDE warning (42 shots)
  - IPR: Plasma current request not met
  - LOQ: Low edge q warning
- Very simple RWM event criteria
  - RWM $B_P^{n=1}$ lower sensor amplitude used
  - Simple criterion + no threshold optimization at all ➔ “false positive” rate is high; adjust criteria to reduce it
- Code already sees common disruption event chains
  - (event)➔VDE➔SCL➔IPR occurs in 52% of the shots
  - “false positives” on VDE affecting this %

“RWM event” warning timing (simple criterion, no optimization)



Common event chain

(event) → VDE → SCL → IPR

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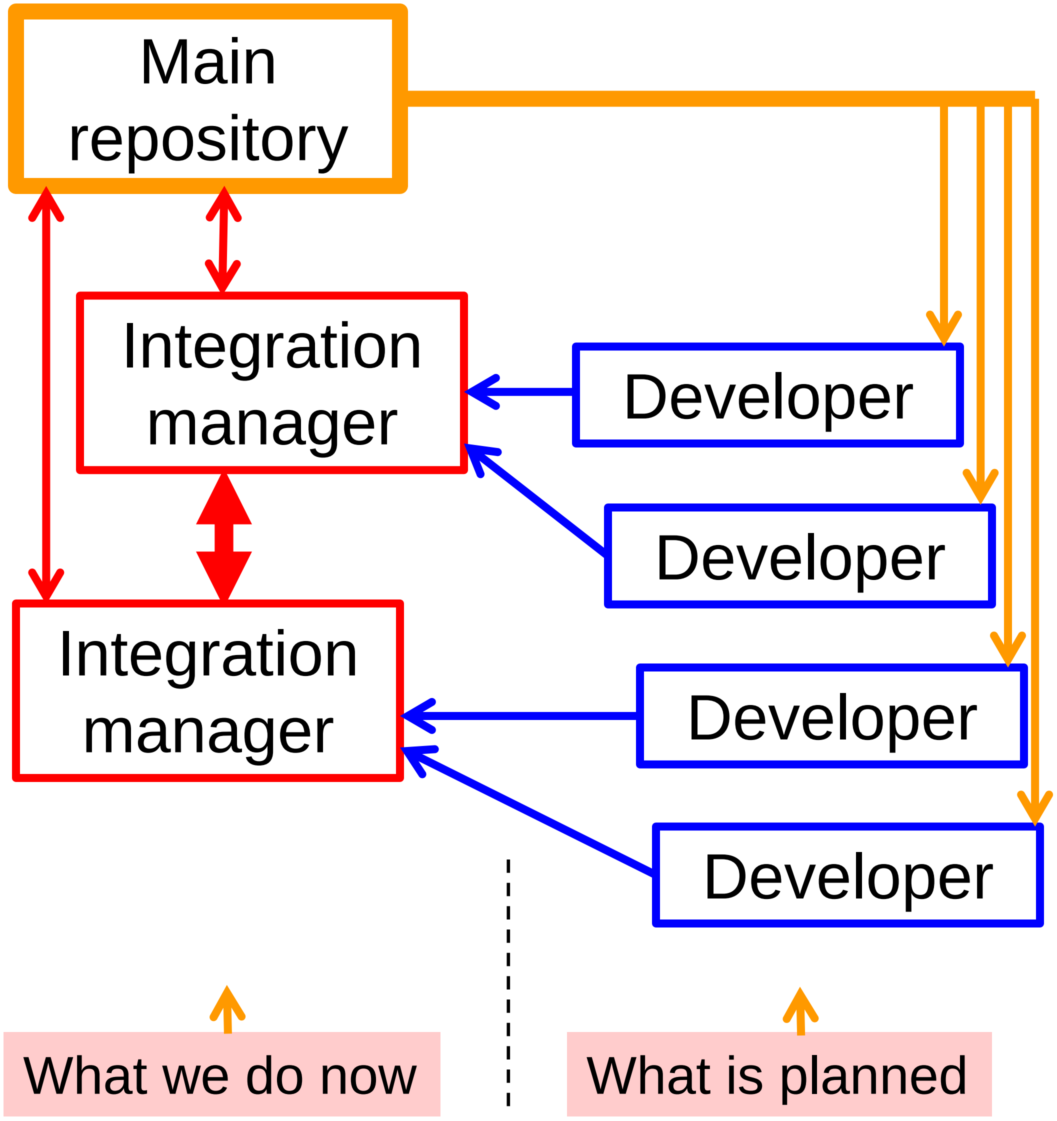
How to participate in the DECAF effort

- Contribute to defining criteria in physics modules
  - Specific discussions on defining measured & modeled triggers for disruption forecasting / detection will be a main focus of future NSTX-U DPAM Working Group meetings
    - Includes all “levels” of modeling and diagnostic input
    - Focused on producing quantitative formulations of disruption prediction
- (in the near future) Help develop code
  - Contributing to the physics modules
    - Main communication through NSTX-U DPAM WG
  - (If desired, contribute to code functionality as well)
    - Main communication through smaller “code” meetings

Future DECAF development aims to follow an Integration Manager Workflow using Git



- Integration managers organize tasks to minimize effort duplication and code conflicts
  - Communication to group via DPAM meetings, web site, etc.
- Developers can pull code from main repository
- Integration managers gather code to inspect that
  - Coding guidance is followed
  - Conflicts are avoided
- Integration managers push code to main repository
  - After cross-checks are made among integration managers

4. Next steps in DECAF code development – improve accuracy of physics-based event determination/forecasting

(Starting the process of DECAF improvement: For group discussion / participation)

- How should the time of disruption (thermal & current quench) be defined; what are the best measurements to define it?

- What do you see are the zeroth-order physics-based criteria that should be evaluated in the DECAF Python modules?

(Send email on these topics if you have more ideas after the meeting)

"Homework Assignment" for those willing to help the disruption prediction effort (and able to read NSTX data)

- In your opinion, what caused the disruptions that occurred in the following NSTX shots? (No cheating by checking the logbook!)
  - 133753
  - 133778
  - 137442
  - 138786
  - 138793
  - 138854 (note: comment on the minor disruption and full current quench)
  - 139341
  - 140580
  - 141202 (note: comment on the minor disruption and full current quench)
  - 142270
- Please send your conclusions (include as much detail as desired from your analysis!) by 11/11/15 to sabbagh@pppl.gov

Supporting Slides Follow

NSTX-U DPAM Working Group meeting: List of disruption chain events defined, interested individuals identified

- Impurity control (NC)
  - bolometry-triggered shutdown (SPG); "tailoring" radiation-induced TM onset (LD, DG)
  - change plasma operational state / excite ELMs, etc. (TBD – perhaps JC)
- Greenwald limit (GWL)
  - density/power feedback, etc. (DB)
- Locked TM (LTM)
  - TM onset and stabilization conditions, locking thresholds (JKP,RLH,ZW)
  - TM entrainment (YSP)
- Error Field Correction (EFC)
  - NSTX-U EF assessment and correction optimization (CM,SPG)
  - NSTX-U EF multi-mode correction (SAS, YSP, EK)
- Current ramp-up (IPR)
  - Active aux. power / CD alteration to change q (MDB, SPG)
- Shape control issues (SC)
  - Active alteration of squareness, triangularity, elongation – RFA sensor (SPG,MDB)
- Transport barrier formation (ITB)
  - Active global parameter, V_ϕ, etc. alteration techniques (SAS,JWB,EK)
- H-L mode back-transition (HLB)
  - Active global parameter, V_ϕ, etc. alteration techniques (SAS,JWB,EK)
- Approaching vertical instability (VSC)
  - Plasma shape change, etc. (SPG, MDB)
- Resistive wall mode (RWM)
  - Active global parameter, V_ϕ, etc. alteration techniques (SAS,JWB)
  - Active multi-mode control (SAS,YSP,KT)
- Ideal wall mode (IWM)
  - Active global parameter, V_ϕ, etc. alteration techniques (JEM)
- Internal kink/Ballooning mode (IKB)
  - Active global parameter, V_ϕ, etc. alteration techniques (SAS,JWB)
  - Active multi-mode control (SAS, YSP, KT)

Abbreviations:
JWB: Jack Berkery
AB: Amitava Bhattacharjee
DB: Devon Battaglia
MDB: Dan Boyer
JC: John Canik
LD: Luis Delgado-Aparicio
DG: Dave Gates
SPG: Stefan Gerhardt
MJ: Mike Jaworski
EK: Egemen Kolemen
RLH: Rob La Haye
JEM: Jon Menard
CM: Clayton Myers
JKP: Jong-Kyu Park
YSP: Young-Seok Park
RR: Roger Raman
SAS: Steve Sabbagh
KT: Kevin Tritz
ZW: Zhirui Wang
TBD: (To be decided)

- Interest from Theory
  - Amitava Bhattacharjee, Allen Boozer, Dylan Brennan, Bill Tang have requested involvement

Interested? contact:
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