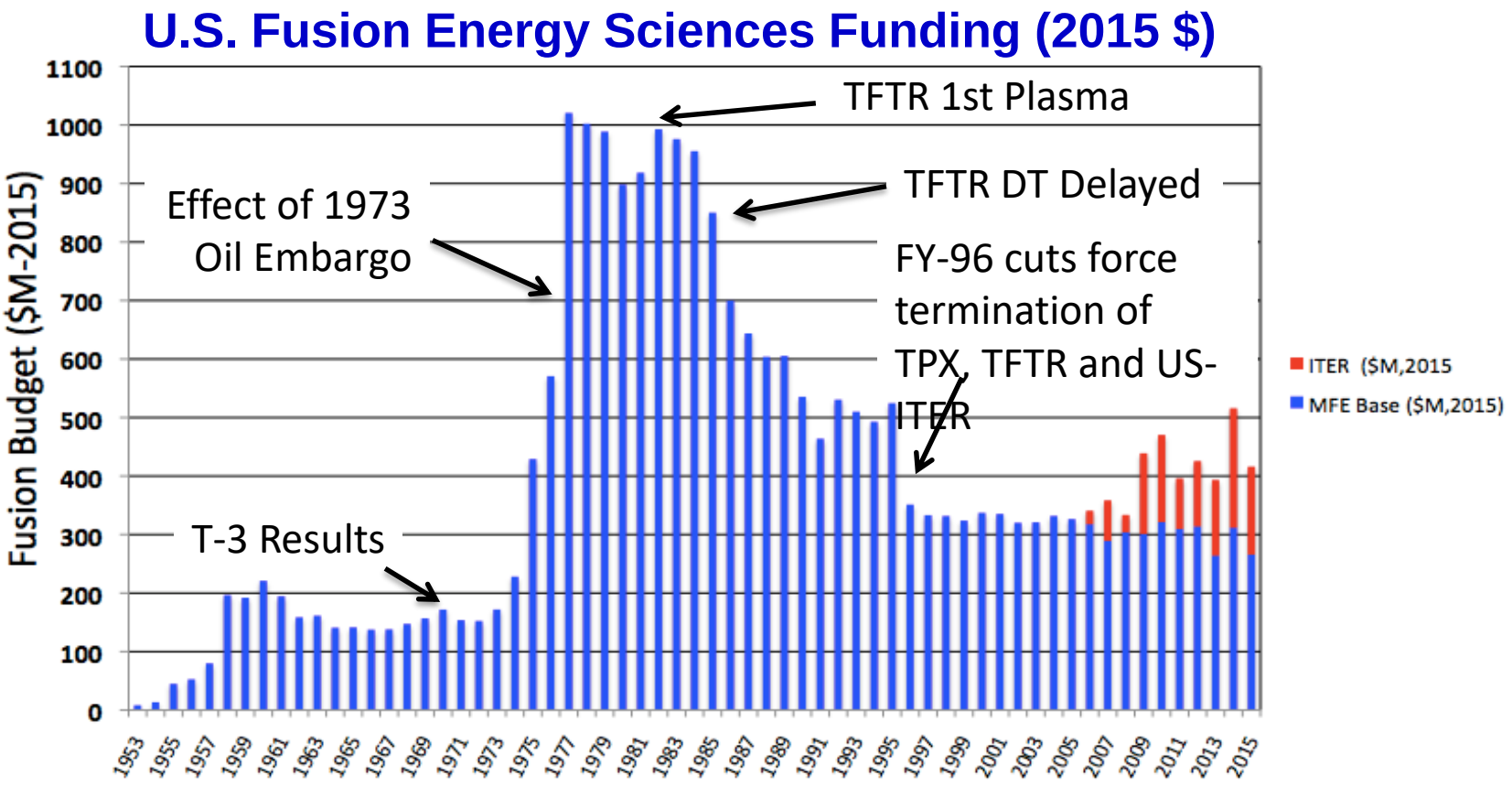
Комментарий к FEC-2023
(последний тритиевый эксперимент)

С.Мирнов

АО «ГНЦ РФ ТРИНИТИ»

2023г.

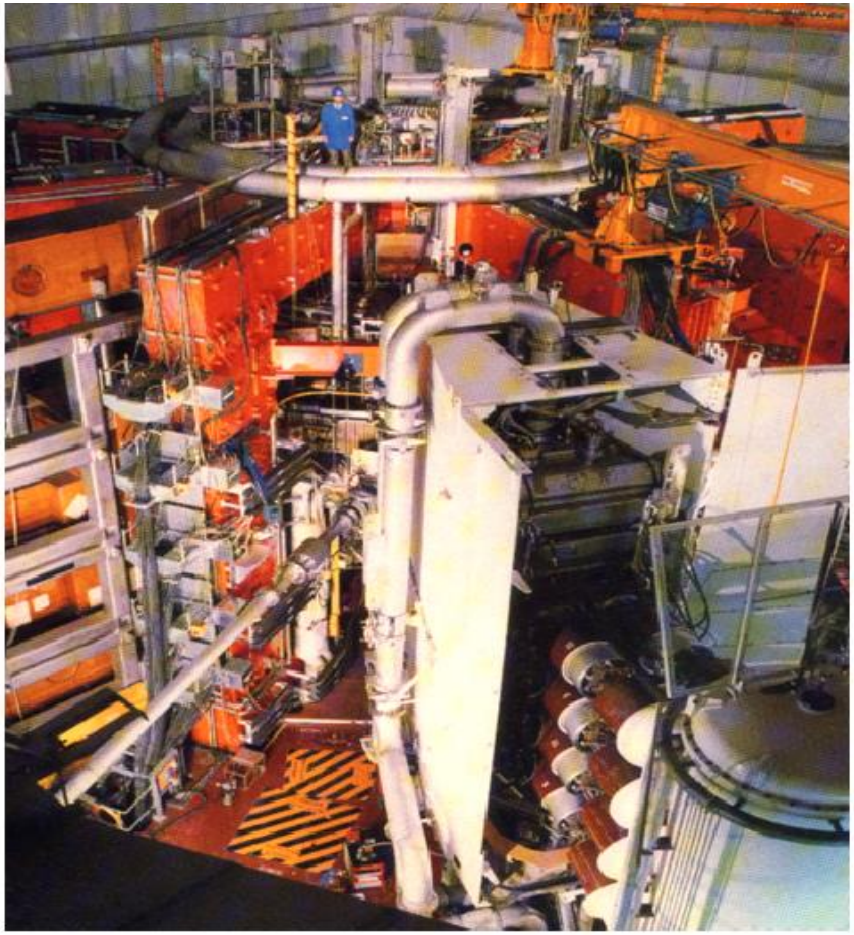
Начало (1979) и конец - 2023 тритиевого эксперимента



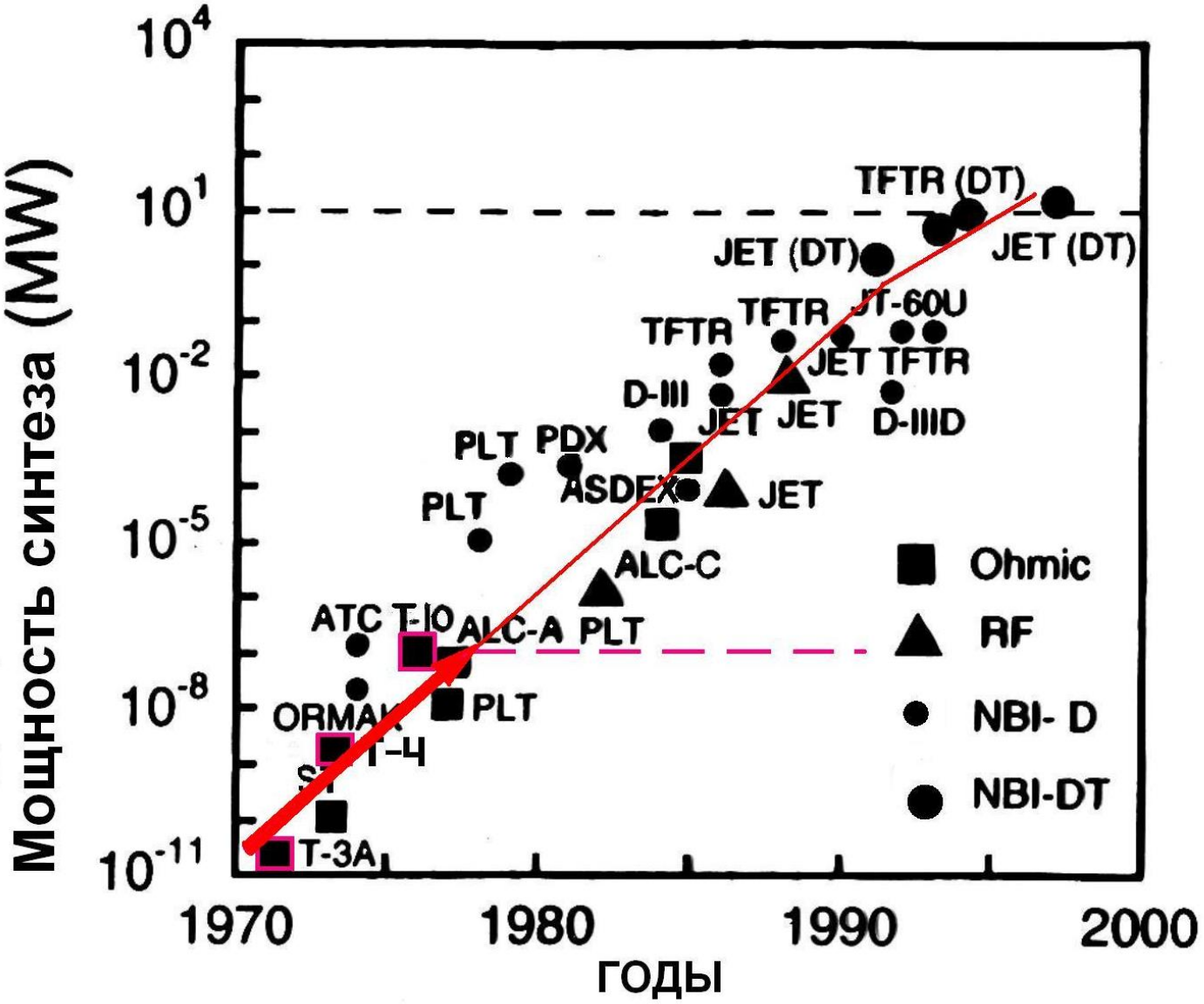
Временной график финансированиея УТС –программы США 1953-2015гг

TFTR

JET

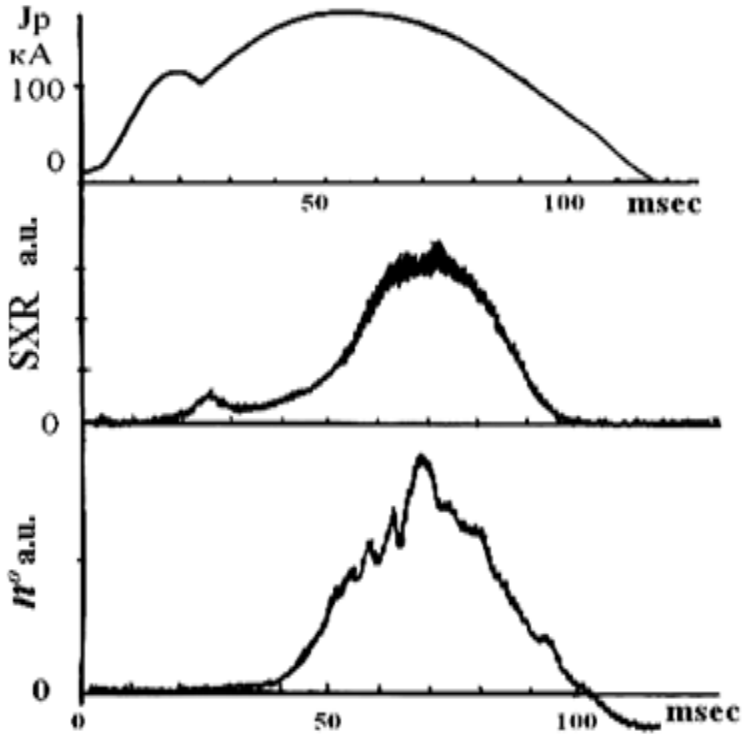


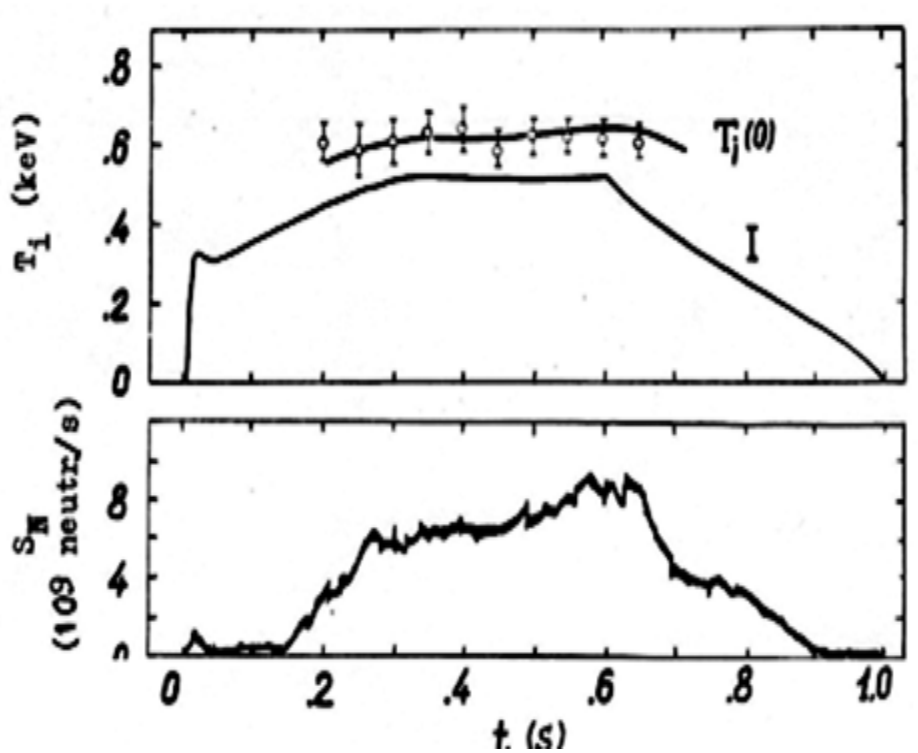
Мировая динамика развития управляемого синтеза в токамаках (high performance shots)



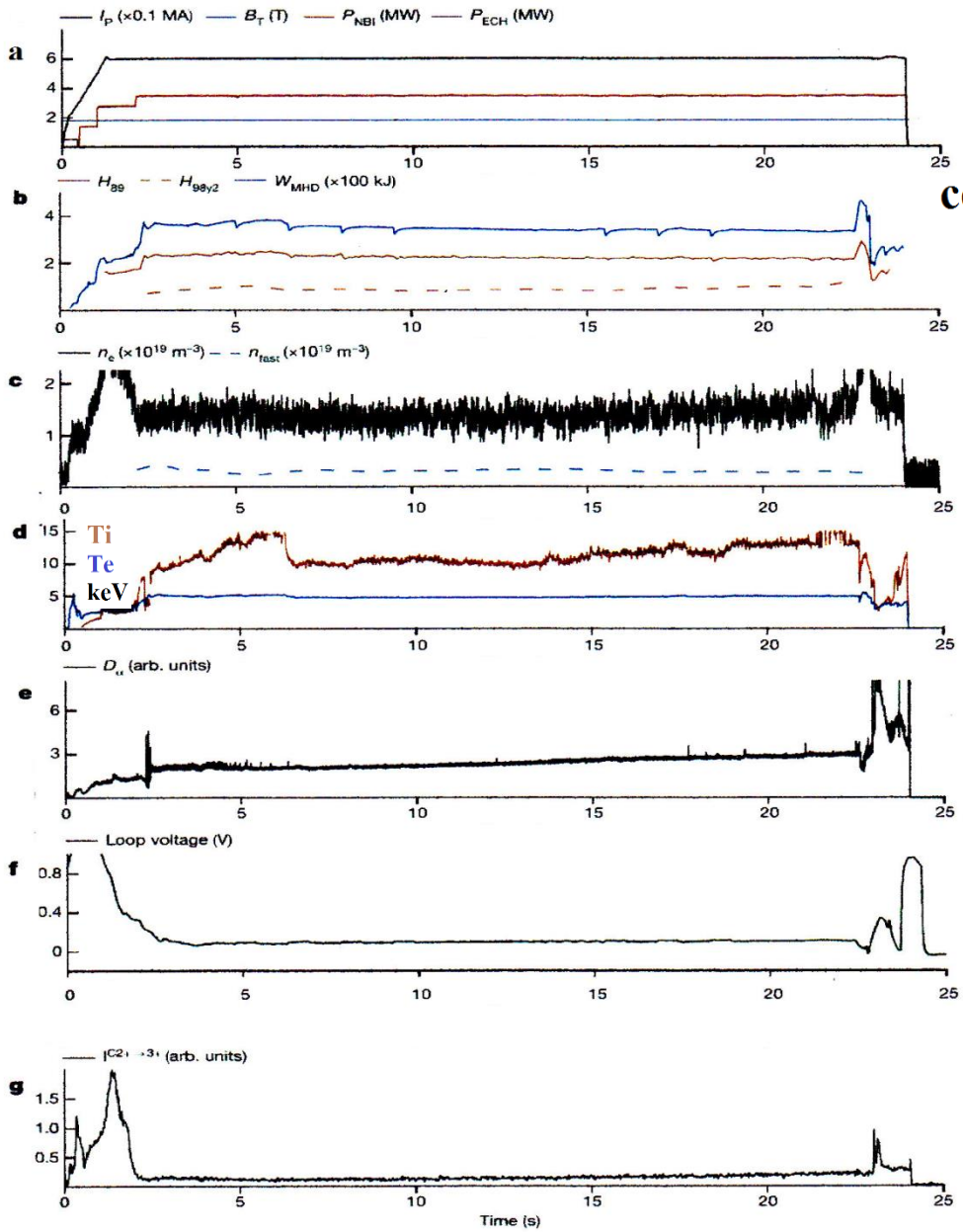
Отечественные DD-рекорды

Т-4 («Т-3») 1972г. Т-10 1976г.





KSTAR (Jap.) FEC-2023 г.

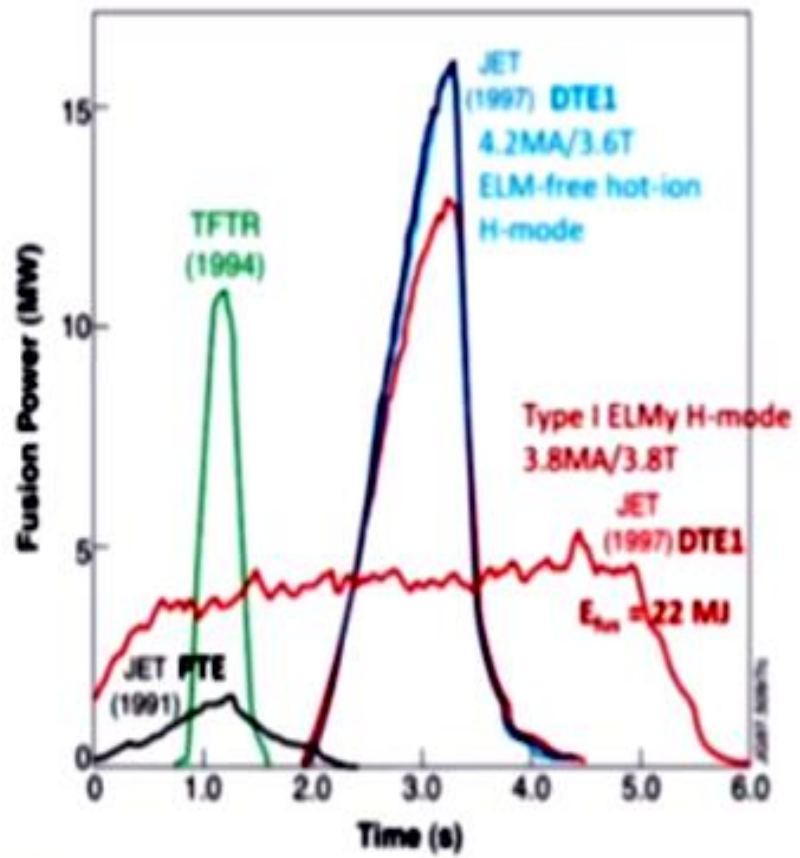


сек

сек

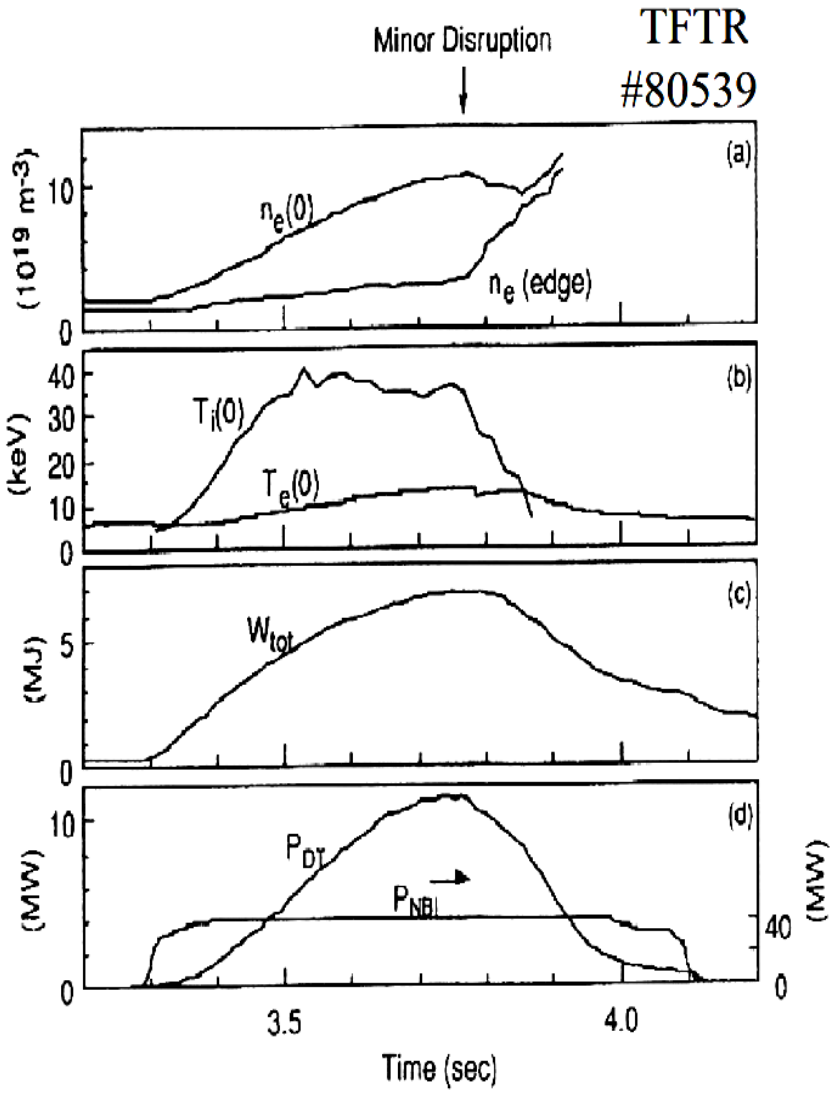
Прогресс в DT экспериментах

D-T experiments in magnetic confinement fusion before 2021

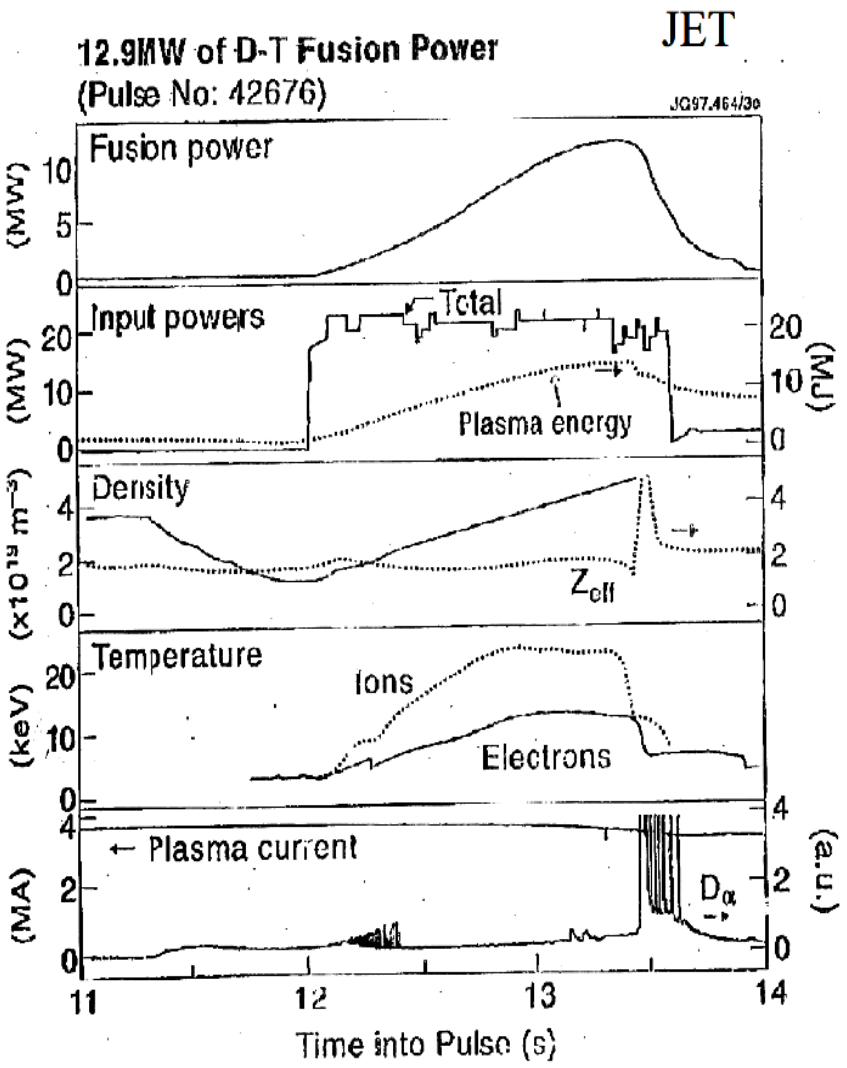


- Previous D-T experiments:
  - 1991: PTE - JET
  - **1994-96: TFTR – Princeton USA**
  - **1997: DTE1 – JET**
  - (2003 trace T exp. - JET)
- Carried out in tokamaks with carbon wall

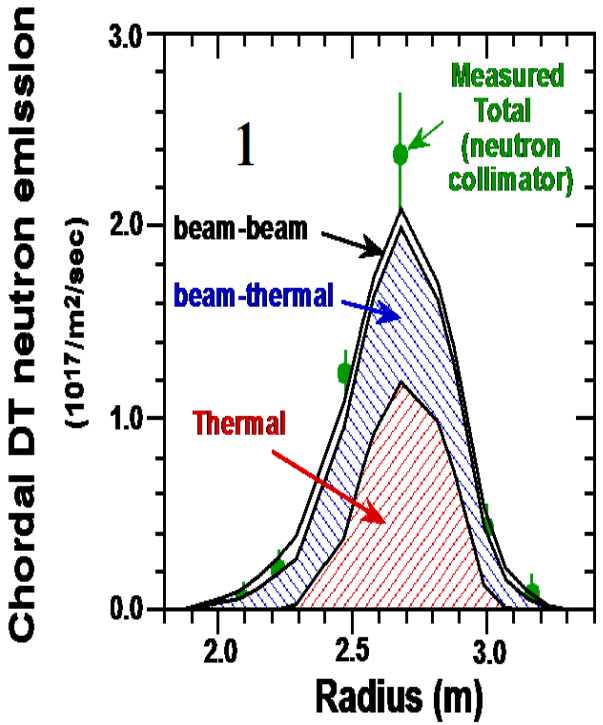
1994г Q≈0.3

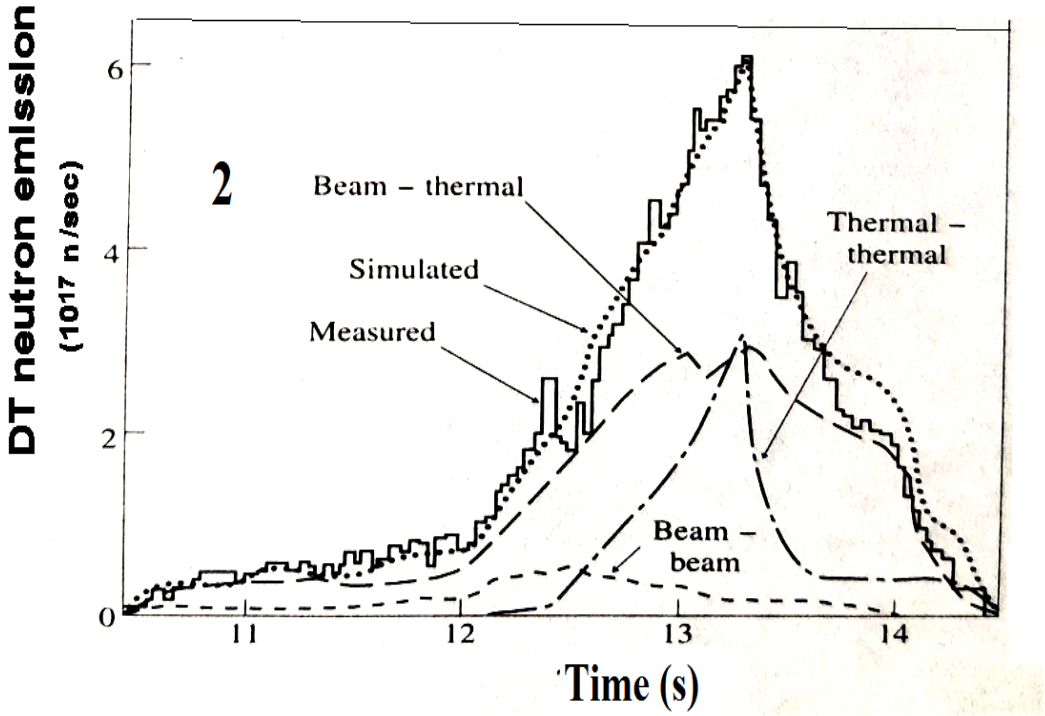


1997г Q=0.65



Измеренное (точки) и расчетное хордовое распределение нейтронных источников разной физической природы по сечению плазменного шнура TFTR: “thermal”, “beam-thermal ” и “beam-beam” – столкновения противоположно направленных пучков. 2 – временной ход интегрального нейтронного излучения для JET с расчетным разделением на отдельные фракции (пунктир)





2022г

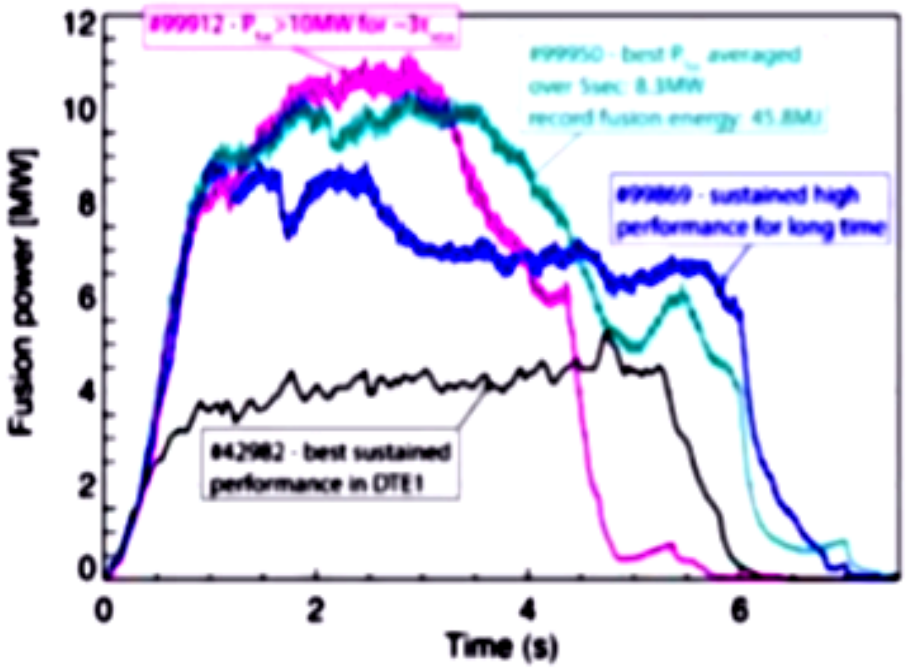
JET 50-50 D-T hybrid scenario achieved record, sustained P_{fus}

Hybrid scenario run for the first time in 50-50 D-T and Be/W wall

- 2.3MA/3.45T, q_{95} ~ 4.8, β_N ~2.5, β_{pol} ~ 1.4
- Gas injection only (type I ELMy pedestal)
- Lower density, $T_i > T_e$

[Hobirk et al, NF SI on JET T & D-T 2023]

Hobirk, EX-C #1880 (Friday)

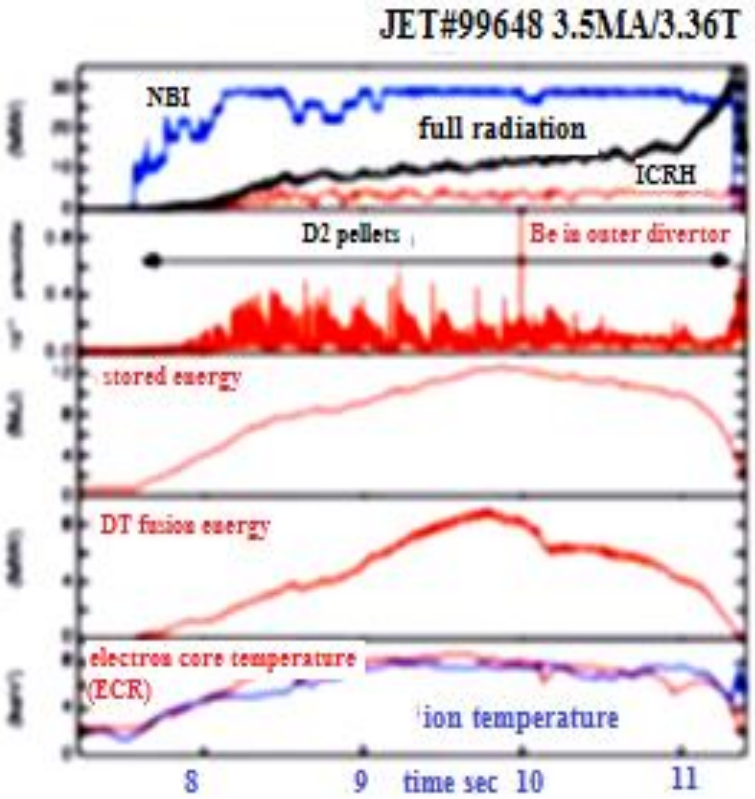


- **Sustained high fusion power for long time**
- Record 50-50 D-T fusion power averaged over 5s ~ 8.3 MW and record D-T fusion energy ~45.8MJ
- D-T fusion power >10MW for > 3 α-particle slowing down times

H-T Kim Stancar Ivanova Stanik Alessi

Рост излучения в ходе нагрева! Снижение мощности синтеза! Поведение плотности ??? Разбавление?

JET Baseline scenario: reduced operational space in 50-50 D-T



Garzotti, EX/C #1943 (Friday)

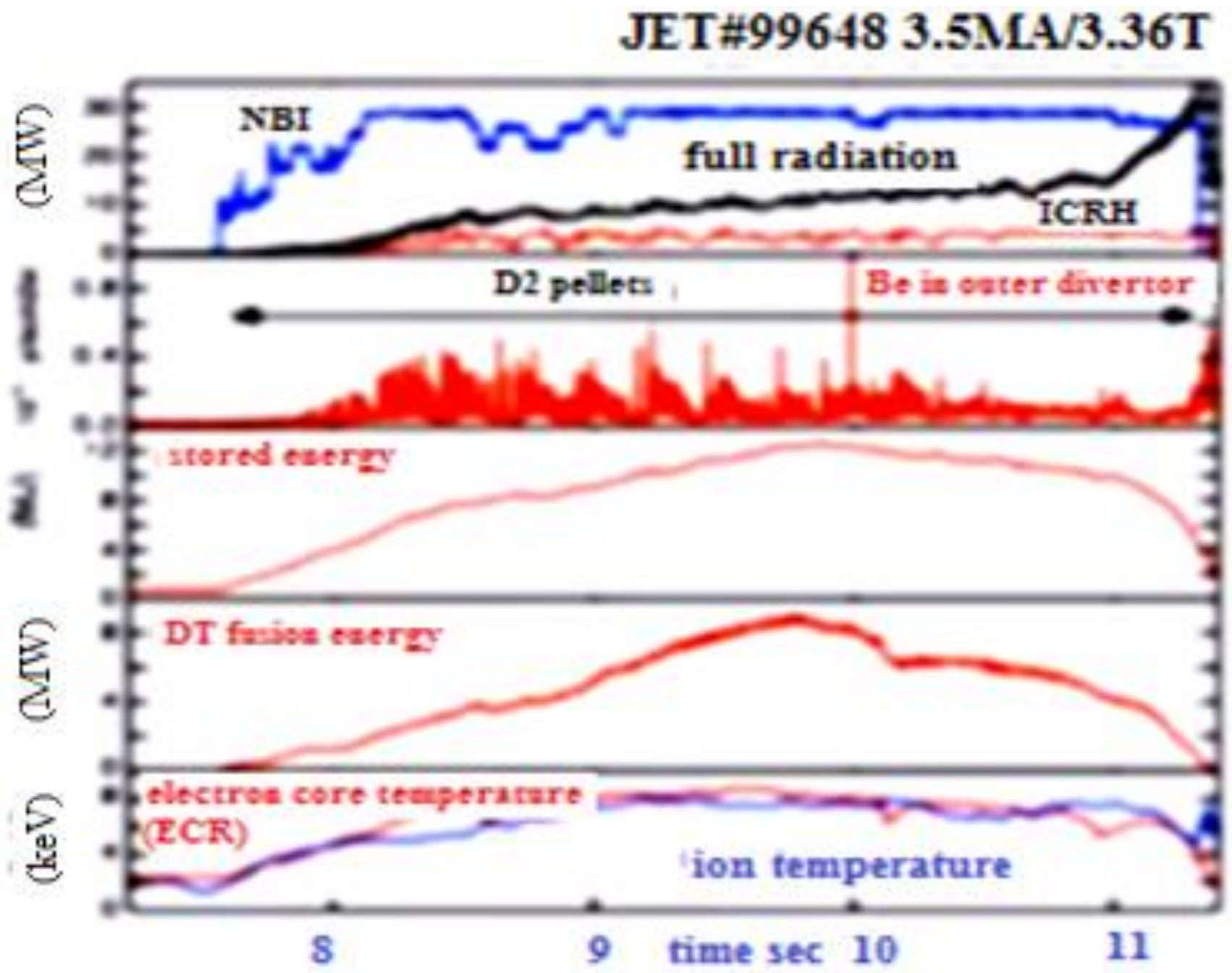
3.5 MA/3.35T, $q_{95} \sim 3$, $\beta_N < 2$

- Optimised fuelling (gas + D-pellets) for
  - ELM control (W flushing) – W radiation at LFS
  - improved pedestal pressure
- Mixed compound / type I ELMs
- High density, $T_i \sim T_e$, $H_{98} \sim 0.9$

- Steady for 5s in D
- Not sustained for 5s in D-T (and in T) due to uncontrolled increase in density and radiation

Stancar H T Kim Valovic

Nowak Alessi


JET#99648 3.5MA/3.36T
(MW)
NBI
full radiation
ICRH
D2 pellets
Be in outer divertor
stored energy
DT fusion energy
(MW)
(keV)
electron core temperature
(ECR)
ion temperature
8
9
time sec
10
11

3.5 MA/3.35T, $q_{95} \sim 3$, $l_i < 2$

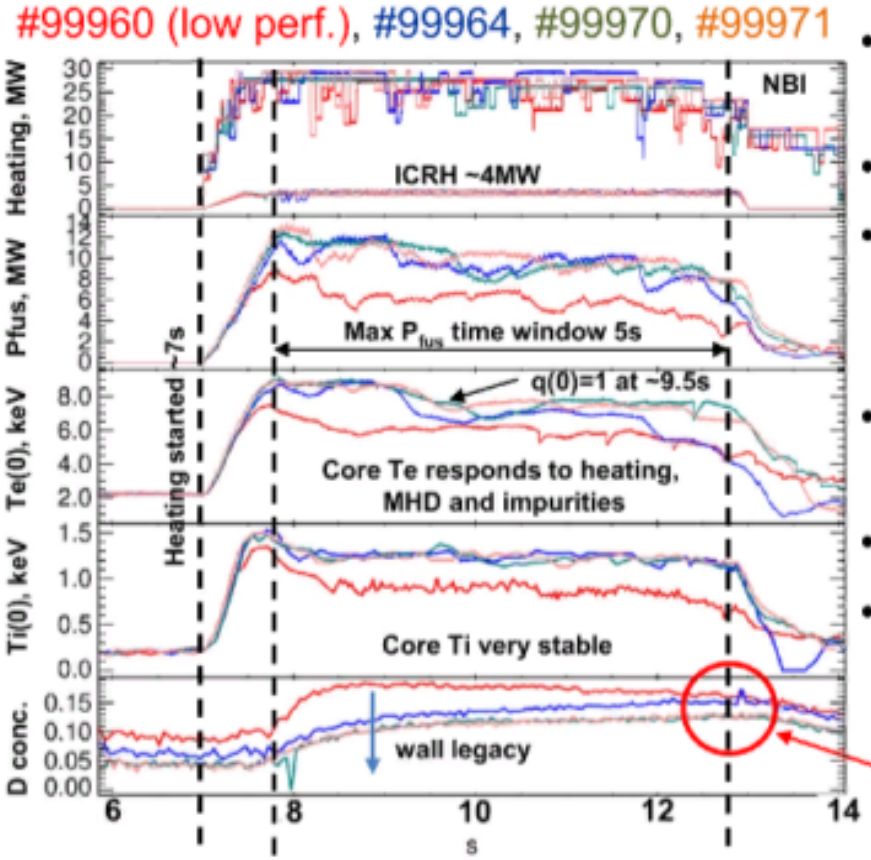
- Optimised fuelling (gas • D-pellets) for
  - ELM control (W flushing) – W radiation at LFS
  - improved pedestal pressure
- Mixed compound / type I ELMs
- High density, $T_i \sim T_e$, $H_{98} \sim 0.9$

- Steady for 5s in D

- Not sustained for 5s in D-T (and in T) due to uncontrolled increase in density and radiation

«Слайд Маслова»

High fusion power pulses



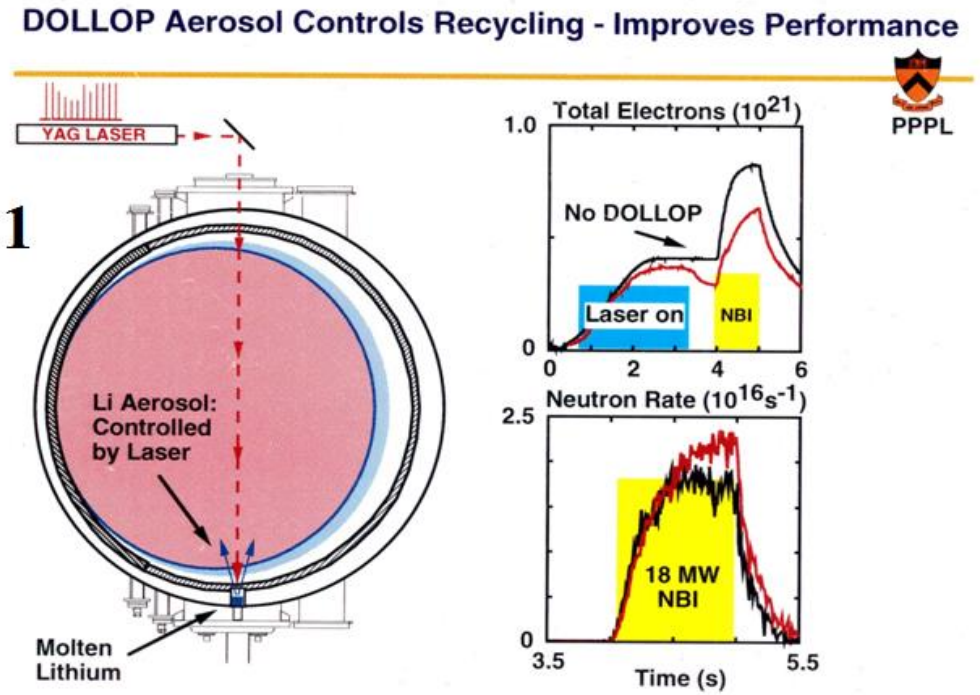
- NBI system converted to full D-NBI for the last 2 days of DTE2
- **9** technically successful pulses performed
- **4** pulses were stable during 5s high power phase, others experienced high-Z impurity accumulation.
- **~450MJ** of fusion energy produced in the series, **59MJ** in the best single pulse
- Best 5s #99971: $<P_{fus}>$=10.1MW Q=0.33
- Best 2s #99972: $<P_{fus}>$=12.5MW Q=0.38

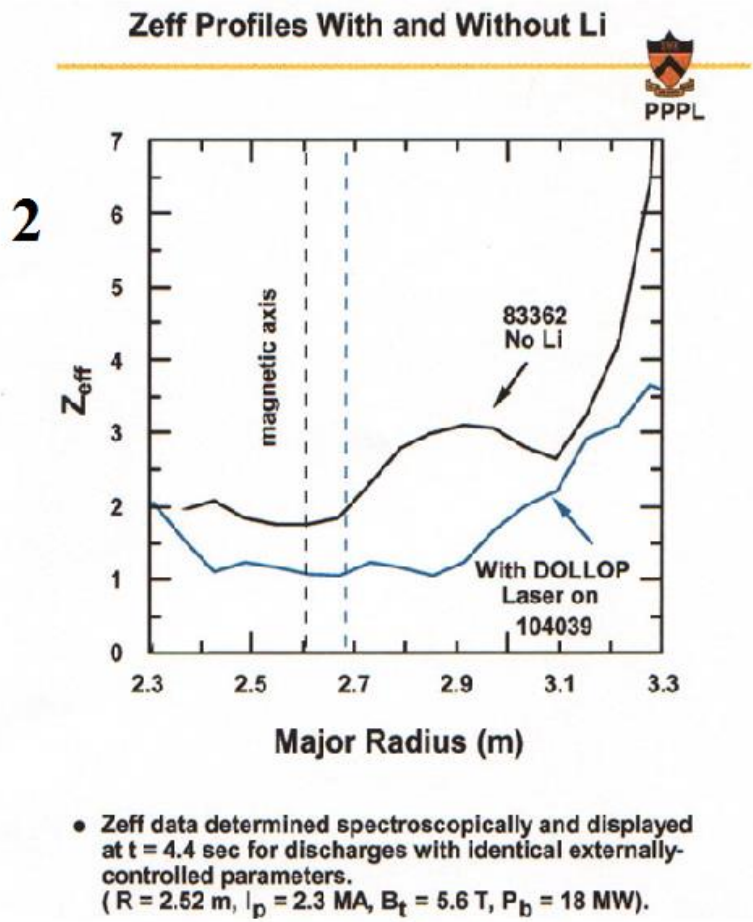
D/T ratio around ~15/85

Литиизация (TFTR) , как способ решения проблемы

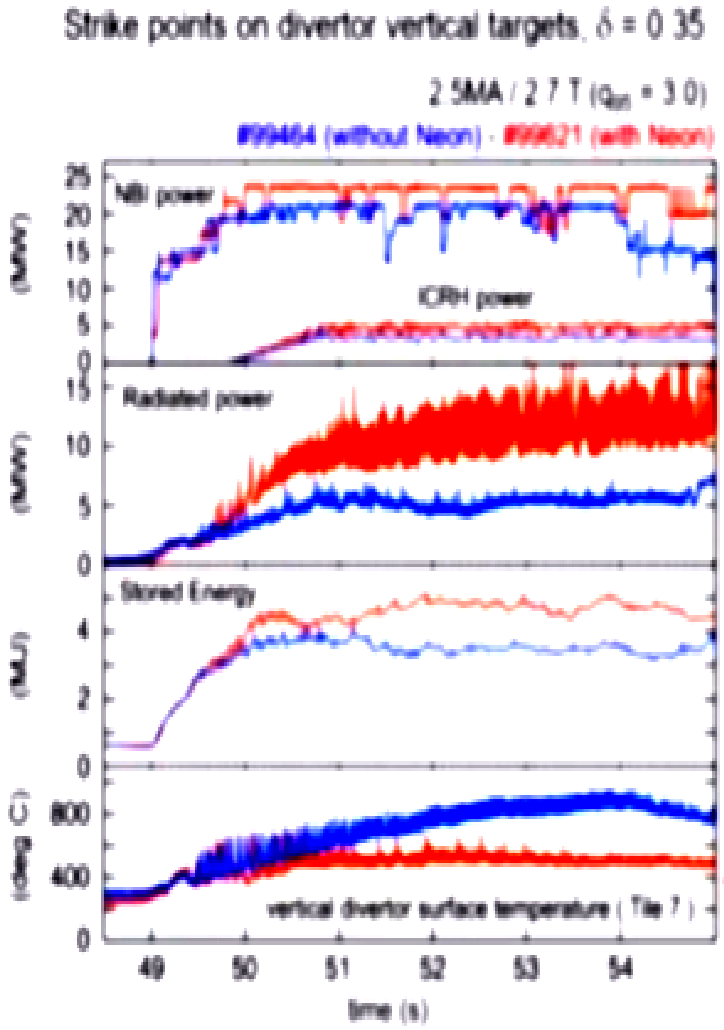
1 – Лазерная инжекция литиевого аэрозоля (метод DOLLOP) в ходе DD разряда TFTR, снижение плотности и рост нейтронного выхода.

2- Снижение Z_{eff} в центре (R=2.5 -2.9м) с 2-3 до 1. Падение эмиссии CII в ходе DOLLOP – эксперимента





Integrated Ne seeded radiative H-mode demonstrated in D-T



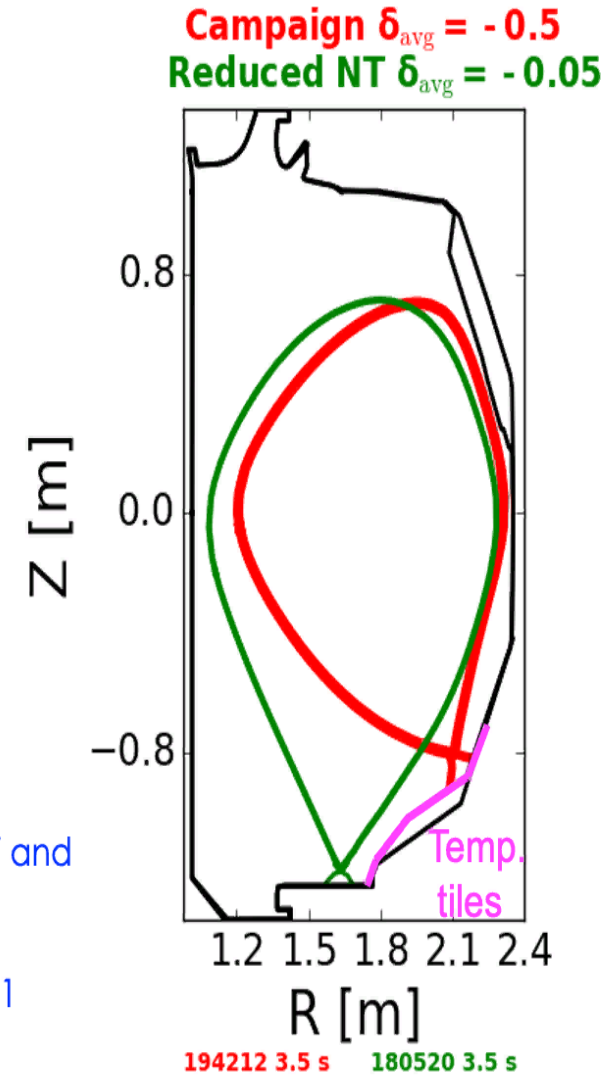
- **Integrated scenario with Ne seeding demonstrated for the first time in 50-50 D-T with Be/W wall**
- Well-controlled long pulse
- Partially-detached divertor plasma
- High radiated power fraction
- Good plasma energy confinement
- Small, high frequency ELMs
- **Confirms Ne as promising extrinsic radiator for ITER**

Giroud

Strongly reduced divertor temperature with Ne seeding

Negative Triangularity (NT) Potentially Transformative Scenario for Fusion Energy

- **Promise of NT first demonstrated on TCV[1] with doubling of confinement compared to positive triangularity (PT)**
  - Inspired NT experiments on AUG[2] and DIII-D[3]
- **Month-long DIII-D NT campaign performed in 2023[4]**
- **DIII-D NT plasmas achieved high performance ($\beta_N > 2.5$ and $H_{98y2} \gtrsim 1$) in an ELM-free regime at high power**
  - Talk will focus on **campaign** and **reduced NT** shapes



[1]Pochelon et al., Europhysics 1998, Camenen et al., NF 2007 and Coda et al., NF 2021
[2]Happel et al., NF 2022
[3]Austin et al., PRL 2019, Marinoni *et. al.*, PoP 2019 and NF 2021
[4]Paz-Soldan et al., ArXiv 2023

DIII-D NATIONAL FUSION FACILITY

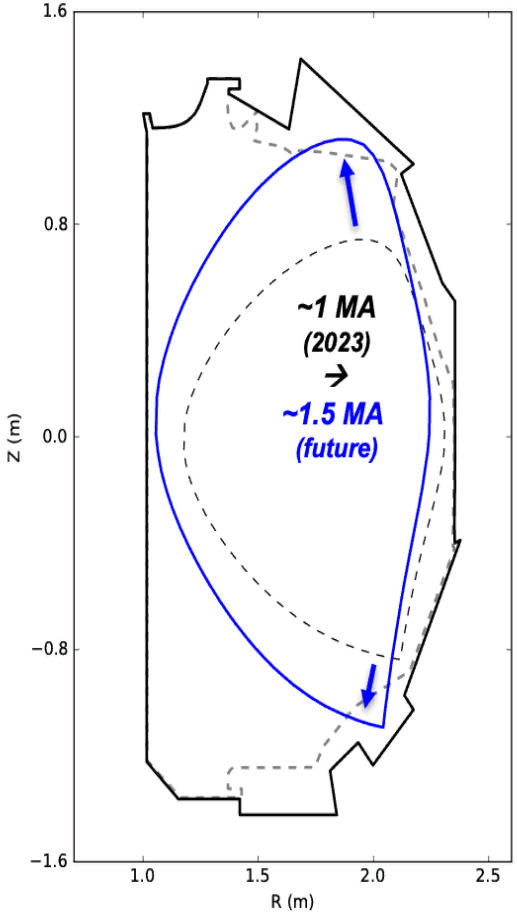
Future Work: Outstanding Questions from DIII-D NT Campaign Motivate Further Exploration of NT World Wide as a Solution to Core-Edge Challenge

- **Questions about scaling confinement to reactors remain**
  - DIII-D confinement results potentially show "strong" power degradation and slight dependence on rotation
  - **Multi-machine studies required**
  - More RF dominant cases needed

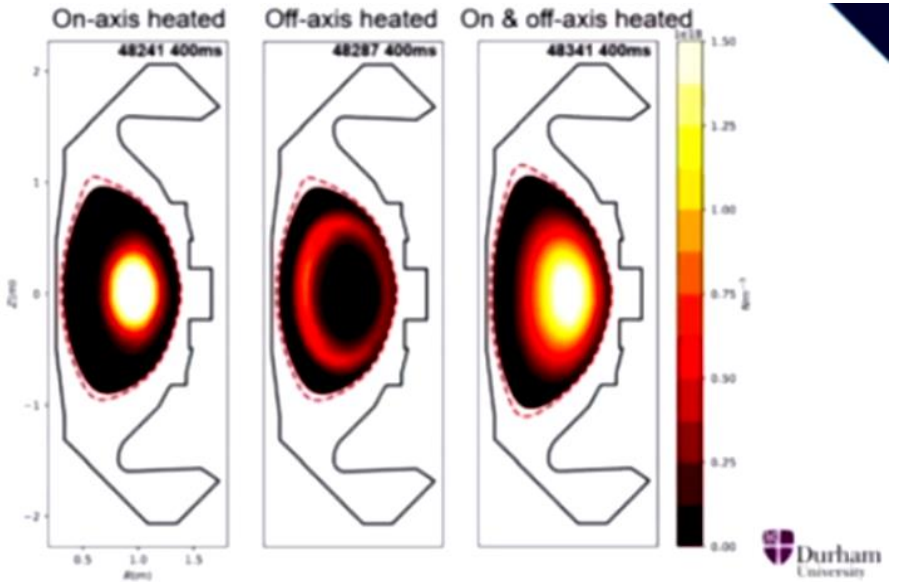
- **Campaign challenged by open divertor with short parallel connection length**
  - Improved core-edge integration should be possible with baffled and possibly pumped divertor

Other DIII-D NT Contributions:
A. Marinoni: CGYRO Simulations Poster: Now
L. Casali: Core Radiation Poster: Saturday AM
A. O. Nelson: L-H Physics: Poster: Friday AM
A.O. Nelson: MANTA NT Reactor Design Poster: Sat AM

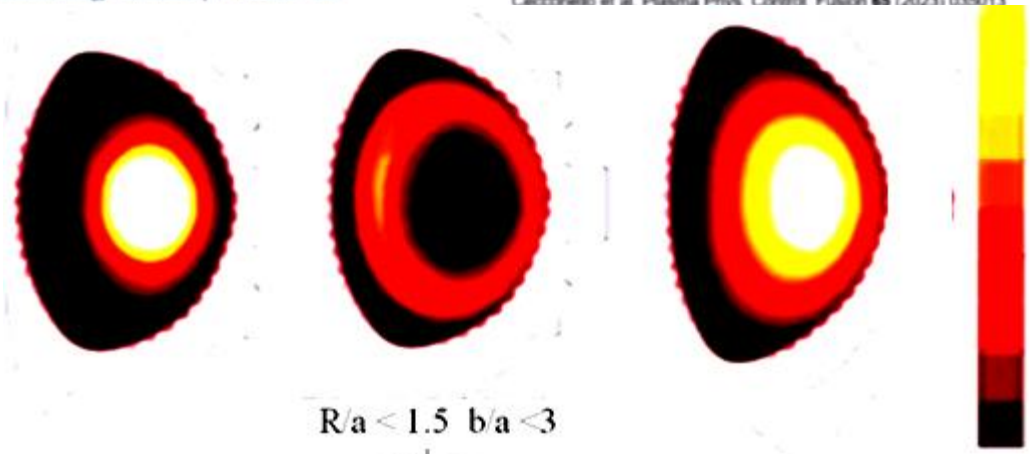
Cartoon of Possible Future DIII-D NT Work

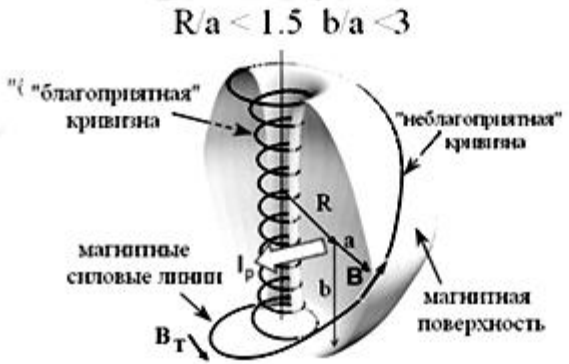


Impact of on and off-axis NBI on neutron emissivity profile in good agreement with neutron camera



Cecconello et al. Plasma Phys. Control. Fusion 65 (2023) 035013





MAST

OV/3-3

J.Harrison

Ovtuviev of physics results from MAST Upgrade towards core-pedestal-exhaust integration UK

Спасибо за внимание!