Max-Planck-Institut für Plasmaphysik

Overview of recent and upcoming activities at the BATMAN Upgrade test facility

Christian Wimmer,
S. Briefi, M. Fröschle, B. Heinemann, N. den Harder, A. Hurlbatt, A. Mimo,
R. Nocentini, G. Orozco and U. Fantz

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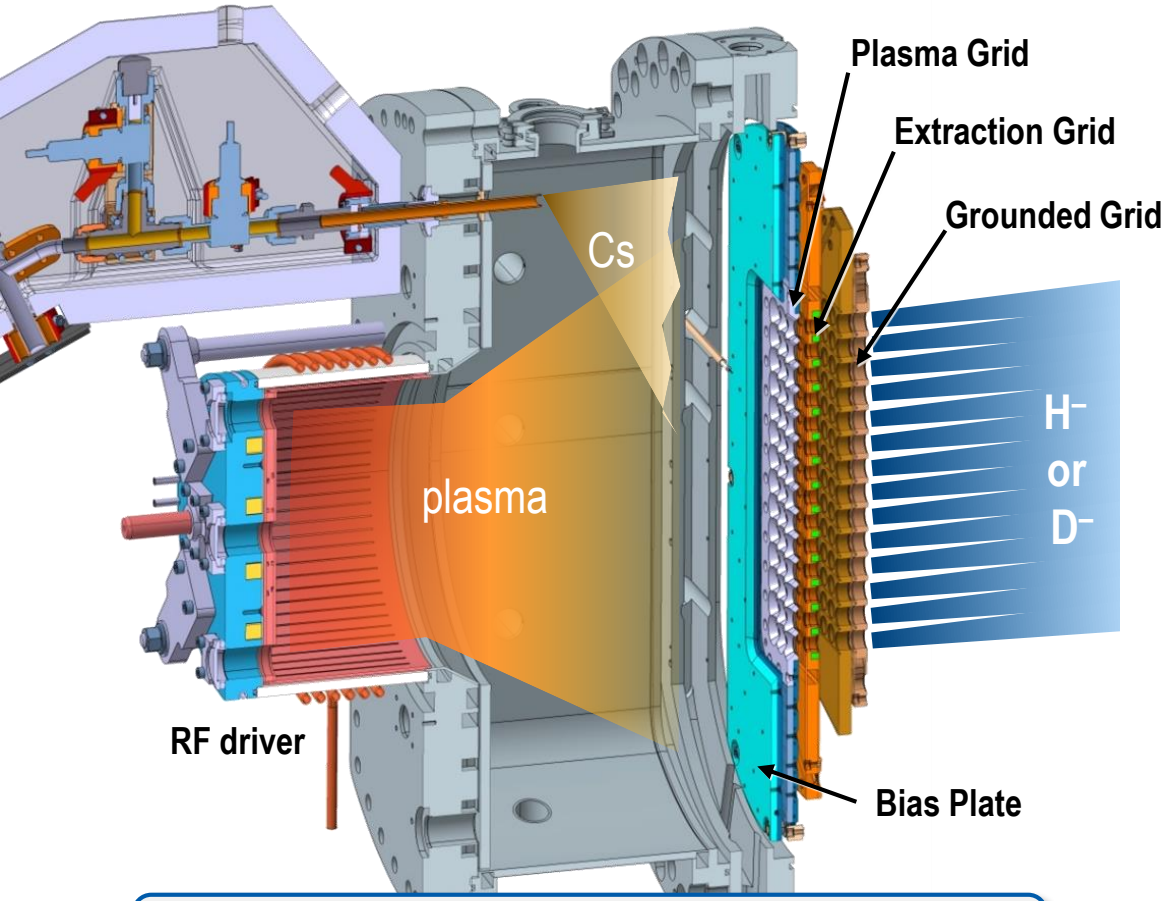
BATMAN Upgrade: role on the roadmap for future NBI



General overview of IPP NNBI research:
talk U. Fantz, today 07:30

- Neutral Beam Injection (NBI) for large fusion machines (e.g. ITER):
  Large sources for negative hydrogen ions required!
- **Plasma production in RF driver,**
  H^- production on caesiated (low work function) surfaces
- **Extraction & acceleration in multi-stage grid system**
  (up to 1 MeV for ITER NBI in 6 stages)
- **Magnetic removal of co-extr. electrons**
  (magnets in EG, i.e. 2nd grid)

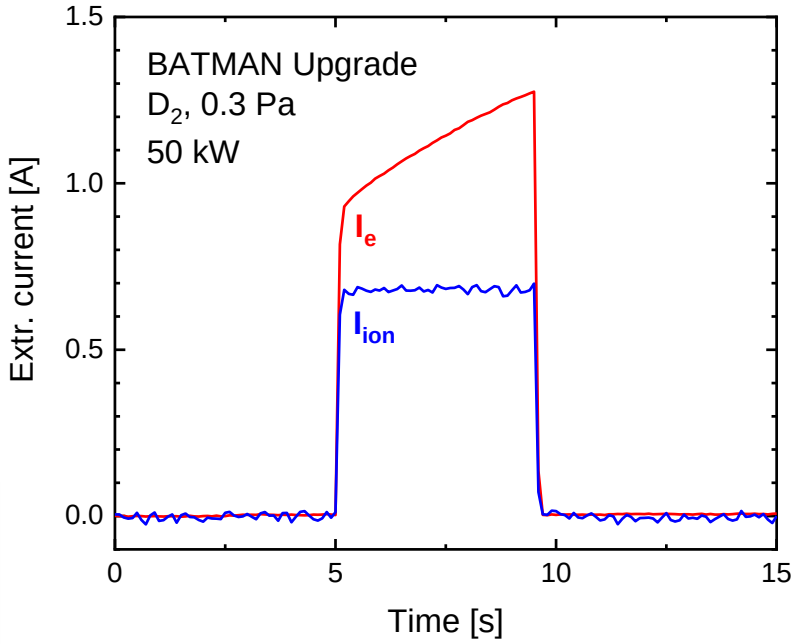
BATMAN Upgrade

- 1/8 ITER-source size
- flexible for diagnostic access / exchange of components
- contributes towards the ITER NBI development & beyond

BATMAN Upgrade: role on the roadmap for future NBI

ITER source requirements
deuterium (hydrogen)

- Extracted ion current density j_{ex}: 286 (329) A/m^2
- Co-extr. electrons: $j_e/j_{ex} \leq 1$
- Pulse duration: 1h (1000 s)
- $p_{fill} \leq 0.3$ Pa
- Beam homogeneity > 90 %
- Beam divergence (core) < 7 mrad



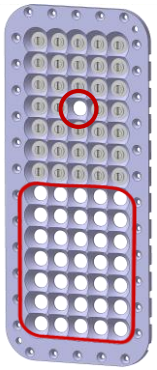
Challenges

Co-extracted electrons
- Deuterium
- Asymmetry
- **Long-pulse stability → Cs dynamics**

Beam optics
- Homogeneity
- **Divergence**

BATMAN Upgrade contributions

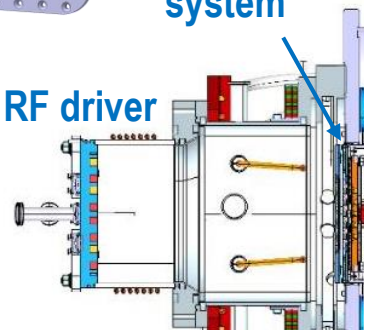
Beam diagnostic capabilities at BATMAN Upgrade

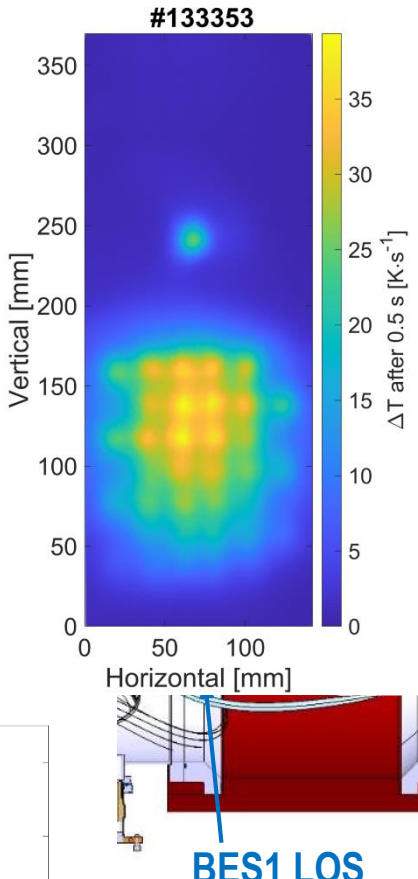


isolated & grouped apertures

Extraction system

RF driver

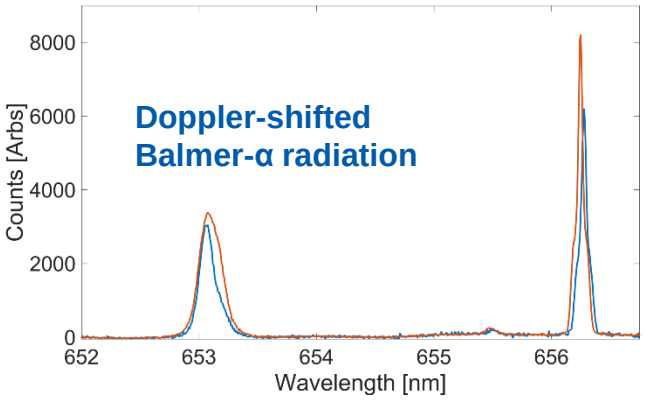




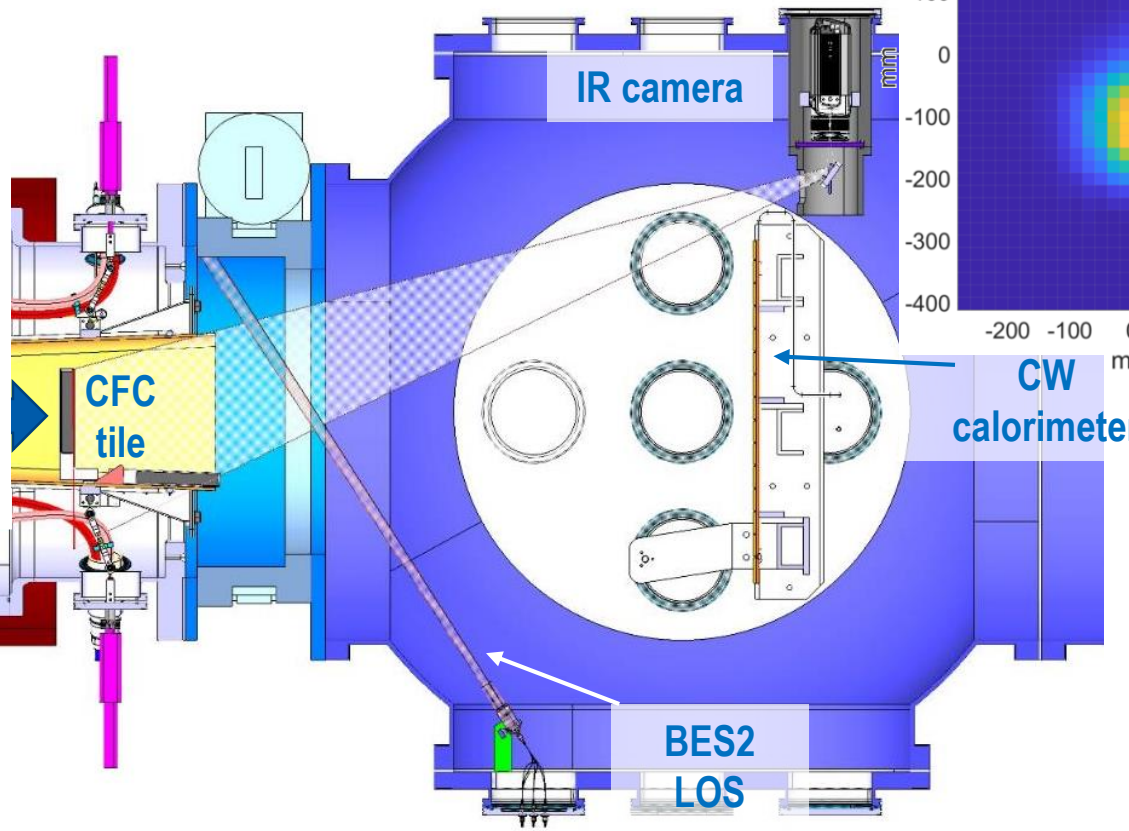
CFC footprint

CFC tile

BES1 LOS



Doppler-shifted Balmer-α radiation

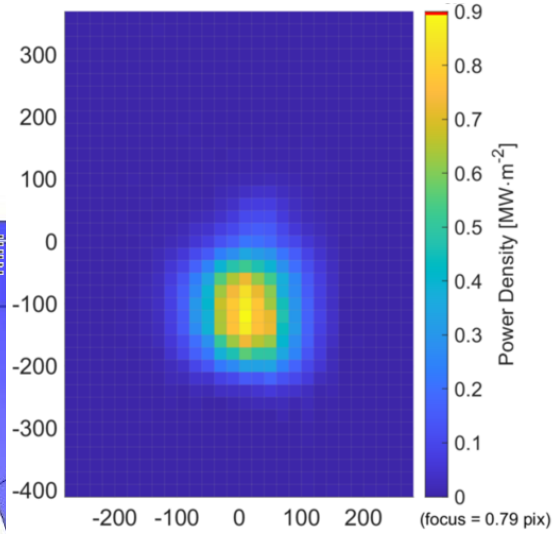


IR camera

CW calorimeter

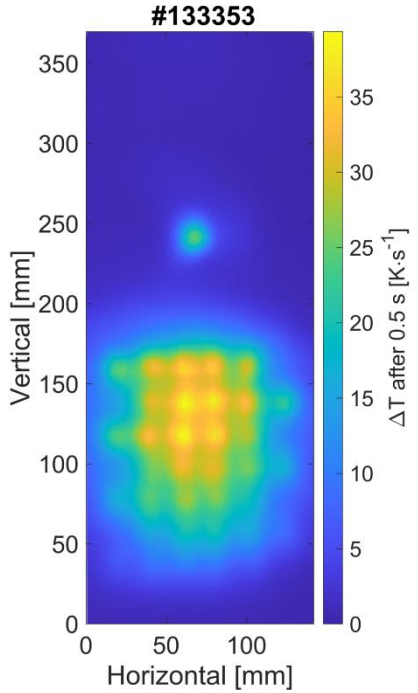
BES2 LOS

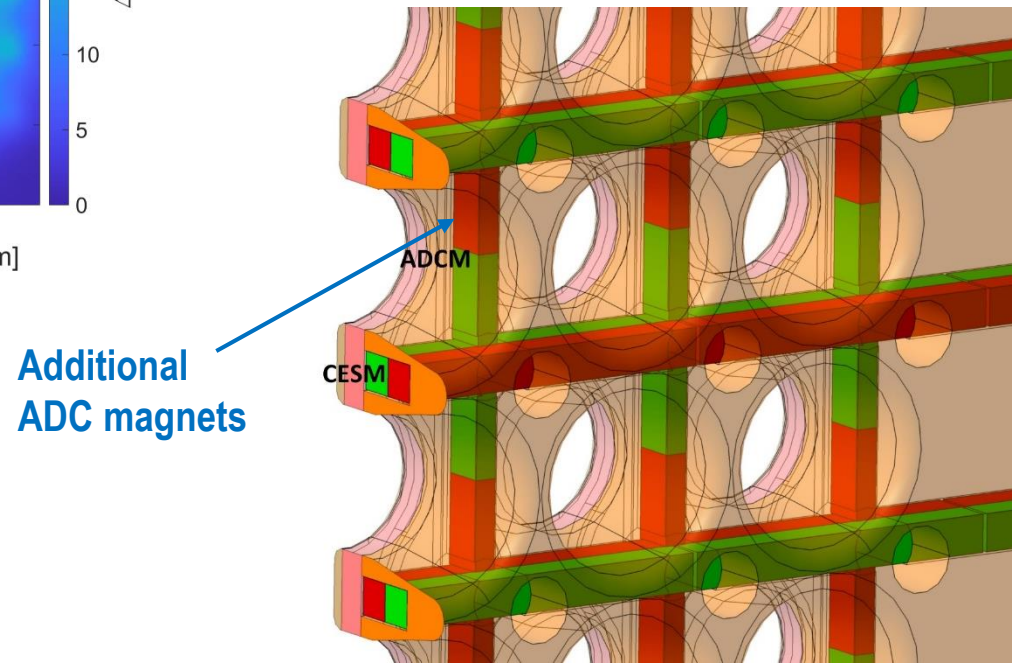
CW calorimeter footprint



Zig-zag compensation of beamlet rows

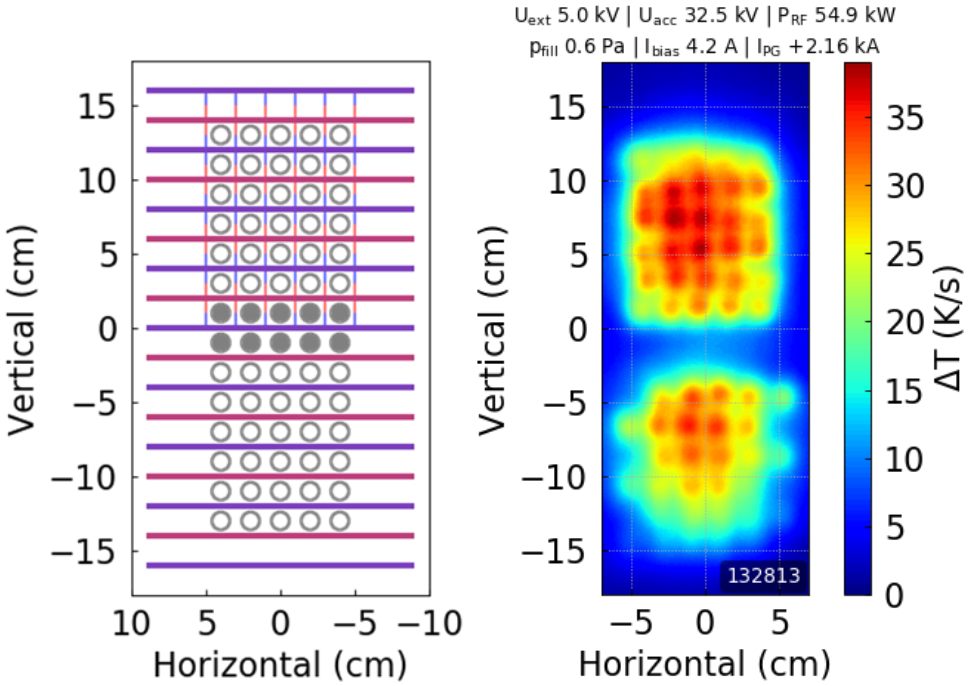
- **Row-wise zig-zag deflection** created by alternating polarity of Co-extracted Electron Supression Magnets (CESM) in EG
- **Additional asymmetric deflection compensation magnets** (ADCM):
  harmonize vertical B-field & cancel out row-wise zig-zag deflection
  (pioneered by Consorzio RFX)
- Joint project with ITER Organization:
  Test at BATMAN Upgrade
- Compensation designed with IBSimu simulations for BATMAN Upgrade,
  new EG (& PG) manufactured & installed

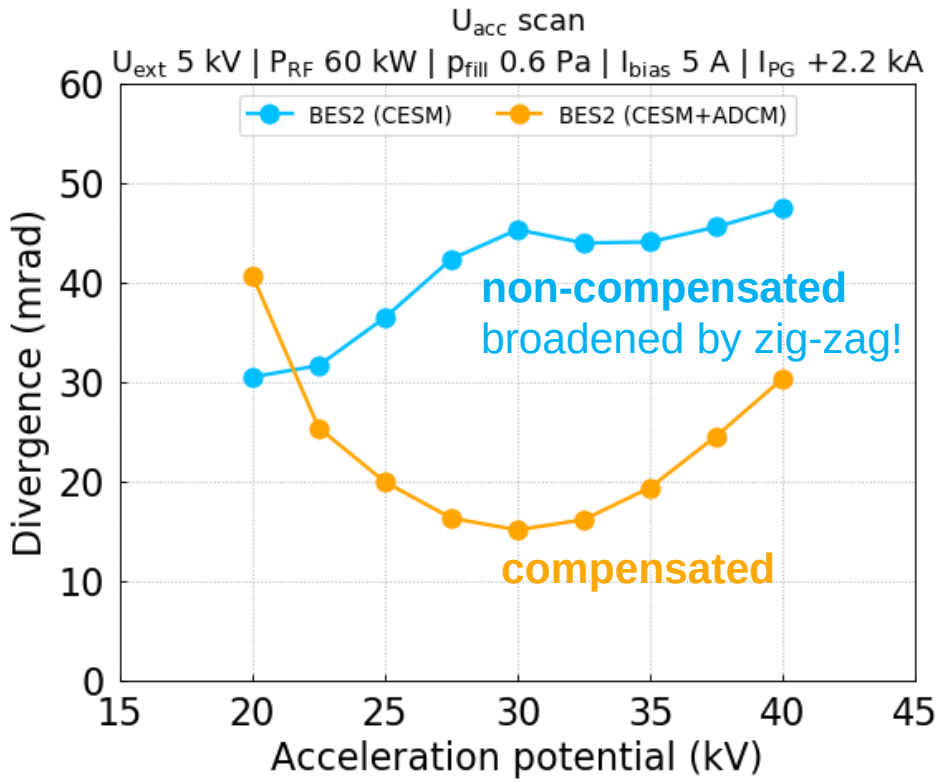




Zig-zag compensation of beamlet rows

- **ADCM mounted only in upper grid half**
- **CFC footprint:** good compensation to be seen visually
- **Lower BES2 divergence at compensated grid half**
  (BES collects signal created by a manifold of beamlets!)
- **Proof of IBSimu predictions**

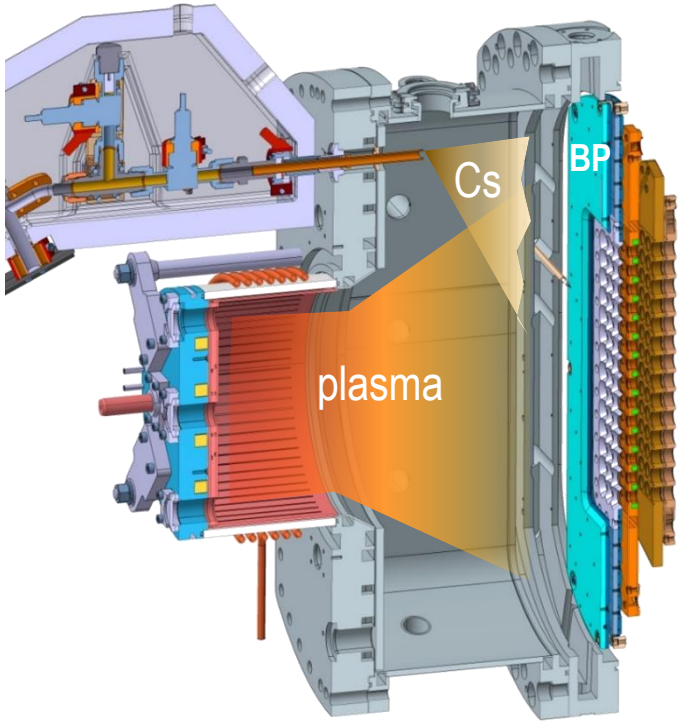




Further details:
poster N. den Harder
(poster session 1)

Upgrades towards long pulses

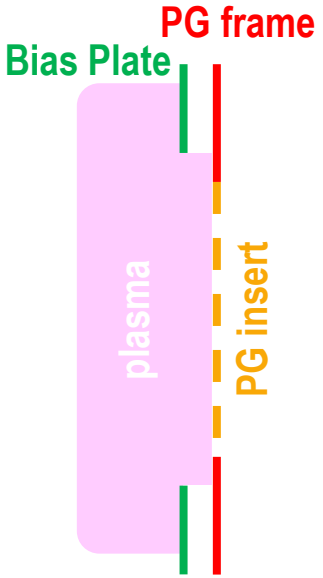
- **After upgrading BATMAN to BATMAN Upgrade in 2017:**
  Pulse length still limited to a few seconds (typical: 10 s plasma including 4.5 s beam)
- **Limiting components:**
  - High-speed vacuum pump (Ti getter pumps):
    replaced in 2019 by a cryopump (42 000 mbar l regeneration limit allows 2–3 h gas injection)
  - Beam dump calorimeter: replaced in 2020 by CW capable one
  - Heat-up of not-directly cooled PG & BP by plasma
    - Both components can withstand several 100 °C technically
    - Experience from former MANITU test facility:
      heat-up of source components significantly influence Cs dynamics
    - What is the tolerable temperature threshold?

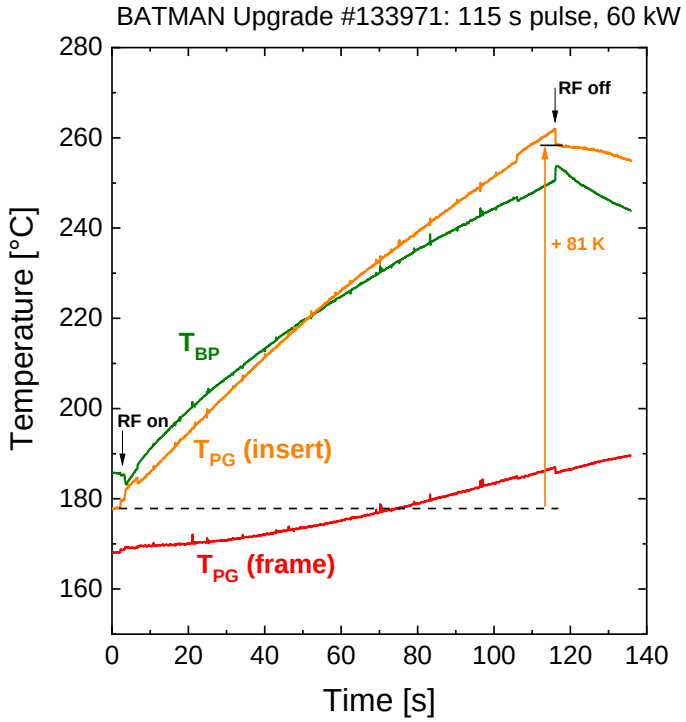


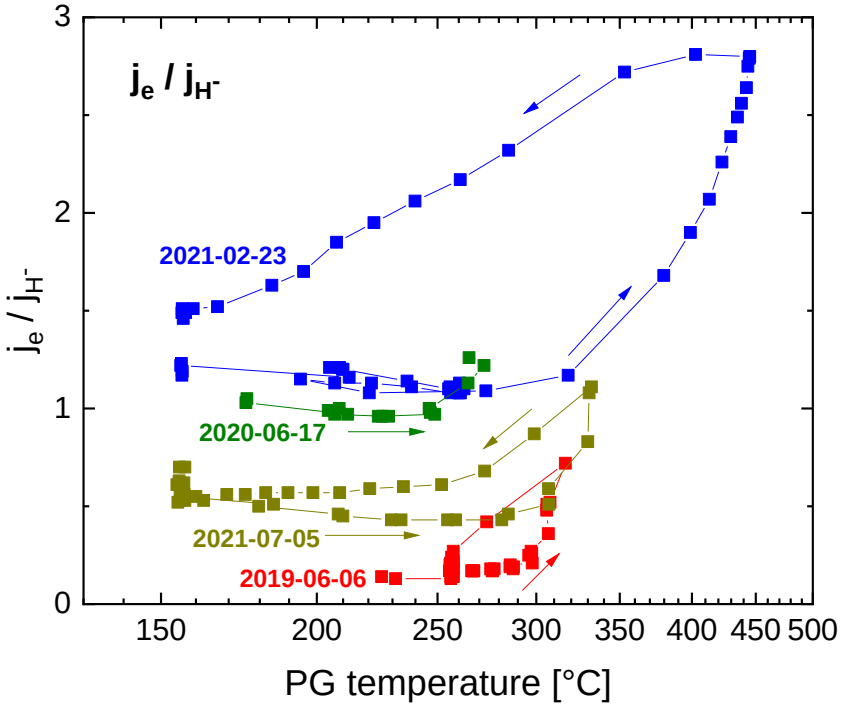
Need for PG/BP temperature control

- **Increase of PG temperature (& bias plate temperature) up to 81 K in 115 s pulse**
- **Check of influence of PG temperature on source performance (short pulses with active PG heating): PG temperature should not exceed 250 °C** (thermal Cs desorption becomes dominant)

→ **present limitation of pulse length to ≈ 100 s, cooling required for longer pulses** (design phase started)



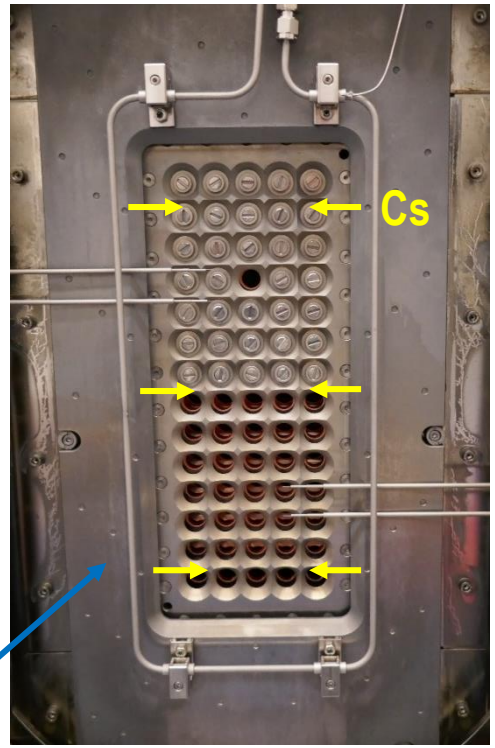




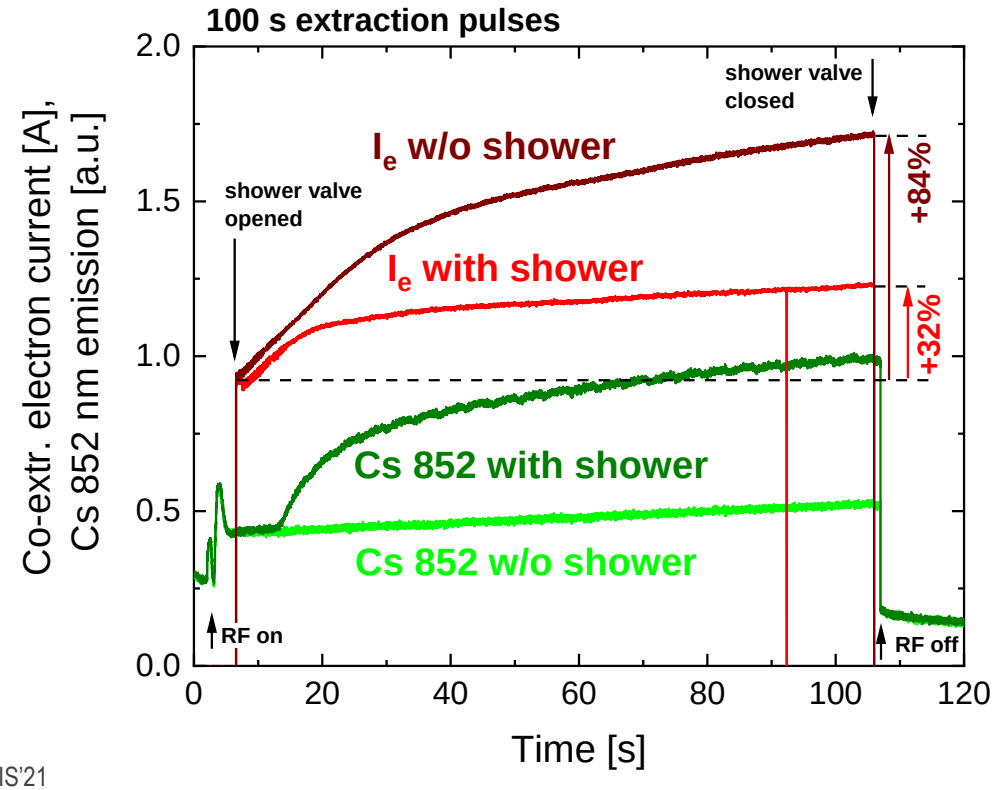
Alternative Cs evaporation concepts

- **Test of alternative Cs evaporation concepts** (aim: increase of neutral Cs flux onto PG in long pulses)
- **Promising first results** (additional Cs evaporation from shower reduces increase of co-extr. electron current)
- **Further tests required** (HV holding of grid system, deuterium)

Further details:
talk A. Mimo, Friday 09:40



Shower tube
(54 holes,
0.4 mm diam.)



Summary and Outlook

BATMAN Upgrade

ion source for Neutral Beam Injection research, flexible, 1/8 ITER ion source size

Beam optics investigations

- **Beam diagnostics enhanced:**
  BES, CFC tile calorimetry,
  CW beam dump calorimeter
- **Magnetic compensation system for zig-zag correction succesfully characterized**
  → IBSimu simulations confirmed

Long pulse stability

- **Upgrade towards long pulses:**
  present limitation is heat-up of PG & BP by plasma
  - Temperatures > 250 °C lead to a strong decrease of the source performance
  - Pulse length limited to ≈ 100 s
- **Test of alternative Cs evaporation concepts:**
  Cs shower shows promising first results