



# First Beam Extraction Experiments at BATMAN Upgrade

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## BATMAN



On "Bavarian Test Machine for Negative Ions" negative ion RF source development since 1996:

- RF source of 1/8 of the ITER source size,
- extraction system of 63 cm<sup>2</sup> with 8 mm apertures,
- Cs evaporation,
- various diagnostics like OES, TDLAS, CRDS, LP, diodes. ITER requirements for the ion currents achieved in pulsed

operation (5 s).

=> RF source was chosen as the ITER reference source.

#### Drawbacks of the Testbed:

- Extraction system based on a positive ion system:
  - o Geometry not optimized for negative ions,
  - o maximum beam energy of only 23 kV,
    - => high beam divergence
- Filter field produced by permanent magnets.



# From BATMAN to BATMAN Upgrade (BUG)

PP

#### BATMAN operation parallel to ELISE

- more flexible,
- better access for diagnostics,
- Allows testing new source concepts.

**Upgrade** from 2016 to 2018 to overcome the drawbacks by

- ITER Like Grid System (ILG) similar to one beamlet group of the ITER source,
- filter field generated by permanent magnets or by the PG current up to 3 kA,
- self-excited RF generator replaced by solid-state generators,
- higher reliability by renewing all electrical circuits and the cooling system.





# Extraction system: ITER Like Grid system (ILG)



- 5 x 14 apertures of  $\phi$  14 mm, extraction area 108 cm<sup>2</sup>
- Higher voltage holding capability: from 23 kV to 45 kV,
- At high extraction voltage higher acceleration voltage possible
  => low beam divergence at high extracted ion currents
- Additional "repeller electrode (RE) on 2 kV positive potential
  - $\Rightarrow$  No back-acceleration of H<sup>+</sup>/D<sup>+</sup> ("back streaming ions")
  - $\Rightarrow\,$  Better space charge compensation of the beam





## Magnetic field topology with permanent magnets and PG current







 $U_{ex}$  = 4 kV,  $U_{acc}$  = 27 kV



Visualisation of

- single beamlet divergence,
- beam homogeneity
- deflection of the beamlets by the magnets in the extraction grid,
- Calculation of the **power density**

### Source performance with PG filter





By evaporation of caesium and after some days of plasma operation

#### 25 mA/cm<sup>2</sup> with 65 kW

have been achieved.



#### First results

- About 20 % lower extracted ion currents with permanent magnet filter
- With PG filter lower electron currents possible by raising the PG current

# $U_{acc}$ scan of the ion currents with repeller grid on ground potential



- Lower fraction on the calorimeter j<sub>wc</sub>/j<sub>ex</sub> < 0.75 than in 3 grid extraction system (ELISE) Reason: Additional current on the repeller grid measured by water flow calorimetry about the same as on the grounded grid j<sub>gg</sub>
- Lower j<sub>gg</sub> with PG filter
- Minimum of j<sub>gg</sub> reached at mimimum beam divergence



#### Beam divergence measured by BES 129 cm from the GG:

- At U<sub>ex</sub> = 6kV minimum at U<sub>acc</sub> = 28kV about 1.3°,
- With PM field divergence inhomogenous,
- Much more homogenous beam with PG current

## Beam profiles on the calorimeter





#### Main changes for BATMAN Upgrade:

- ITER like extraction system (ILG),
- magnetic filter generated by a PG current ,
- improved beam diagnostics

#### **Results of first beam extraction:**

- Higher source performance and lower electron currents with a field generated by a PG current
- Much lower beam divergence with the new ILG
- Beam drift only with field generated by permanent magnets
- More homogenous beam field generated by a PG current



- Focus of future experiments on **beam optics**
- Comparison with/wo repeller grid and with different potentials,
- **CW operation of the source** by replacing the Ti evaporation pumps by cryo pumps,
- **CW beam extraction** by replacing the short pulse calorimeter
- Test of more efficient driver concepts:

Race-track shaped driver,

Helicon source



width x height x length =  $32 \times 19 \times 58 \text{ cm}^3$ 

# Thank you for your attention