Bursts in TCABR Tokamak and Texas Helimak

Zwinglio Guimarães Filho

F. Pereira[1], D. Toufen[2], W. Baquero[1], C. Crepaldi[1], T. Dias[1],G. Grenfell[1], M. Zurita[1], I. Caldas[1], I.C. Nascimento[1], K. Gentle[3]

[1] *Institute of Physics, University of São Paulo, São Paulo, Brazil*

[2] *Federal Institute of Education, Science and Technology of São Paulo, Guarulhos, Brazil*

[3] *Federal Institute of Education, Science and Technology of São Paulo, Guarulhos, Brazil*

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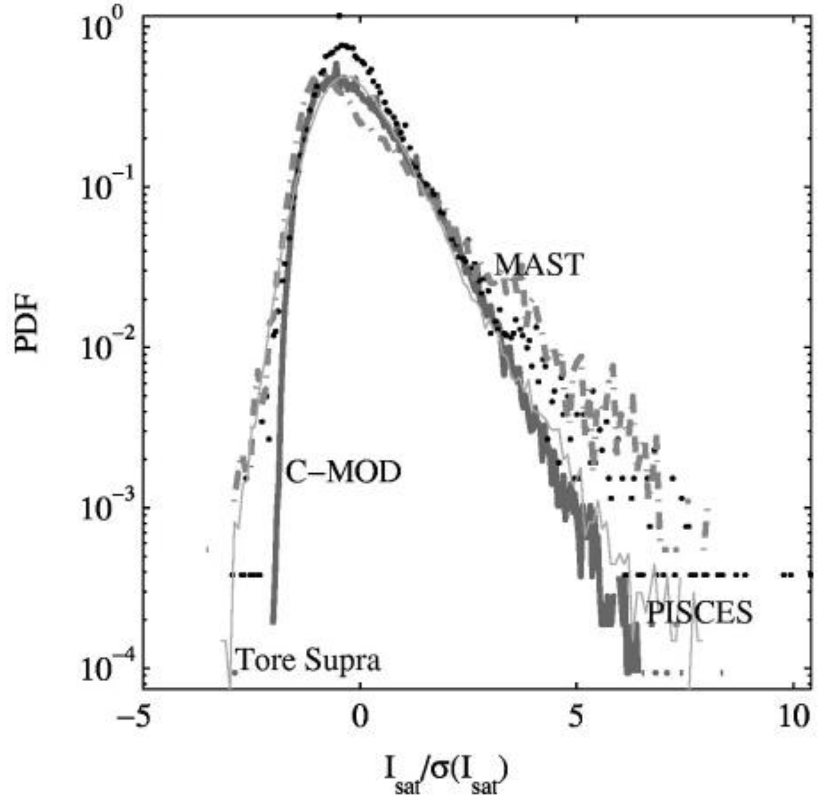
Motivation

- Turbulence at the edge region of magnetically confined plasmas defines the confinement quality
- Local density in this region presents large variations (standard deviation comparable with the main value)
- Density peaks several standard deviations above the mean value are often observed (bursts)
    - **Turbulent properties has similar behavior in different devices (universality)**
- These extreme events are related to coherent structures propagating in the plasma edge



PDF of normalized Ion Saturation Current in several devices
[G. Antar, Phys. of Plasmas (2003) 419]

Comparative study of Bursts spatial and propagation properties

TCABR Tokamak

- Small size tokamak at the IF-USP, Brazil
  - $R = 60\ cm$
  - $a = 18\ cm$
  - $B_T \cong 1.1\ T$
  - $I_P \cong 100\ kA$
  - Hydrogen plasmas
  - Ohmic heating
  - Plasma duration 120 ms
- Suitable to use Langmuir probes

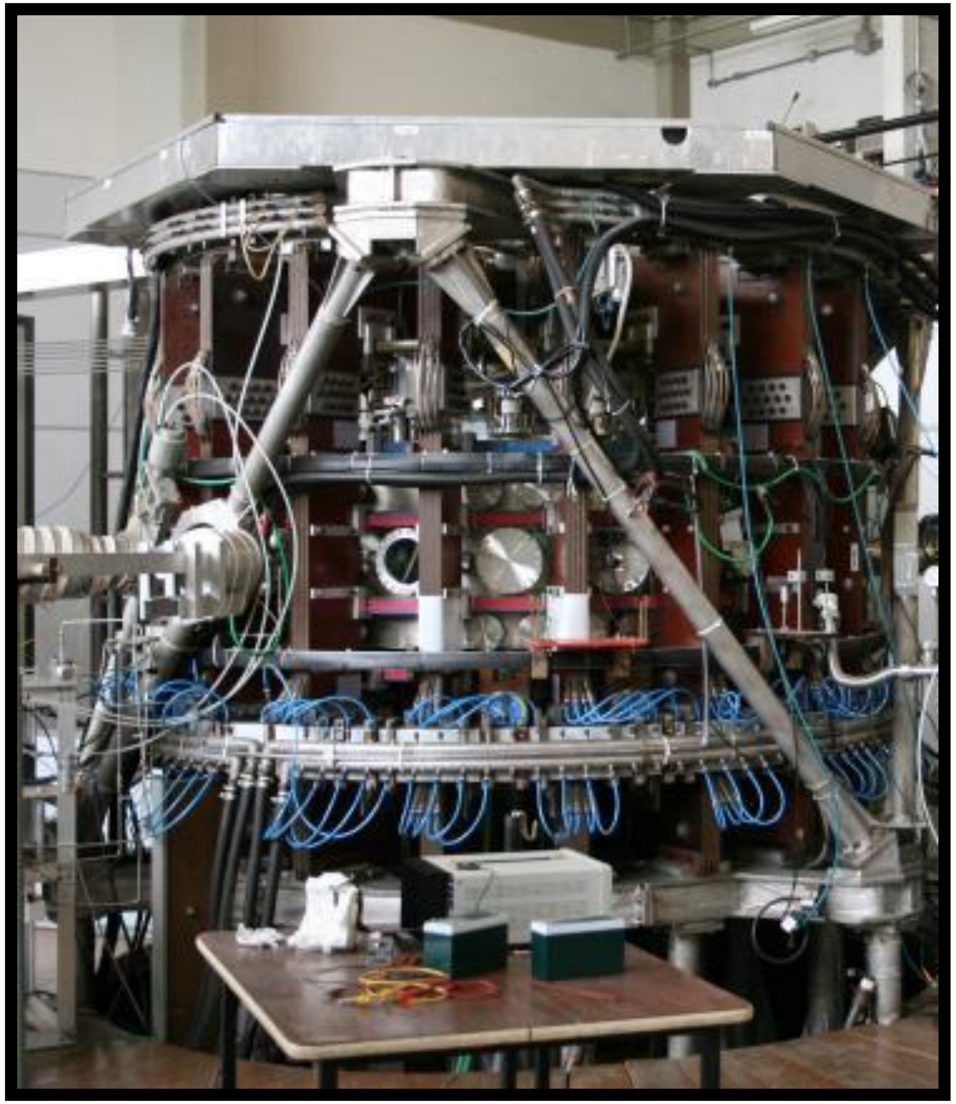
R. M. O. Galvão, Plasma Phys. Control. Fusion **43**, 1181 (2001)

Texas Helimak

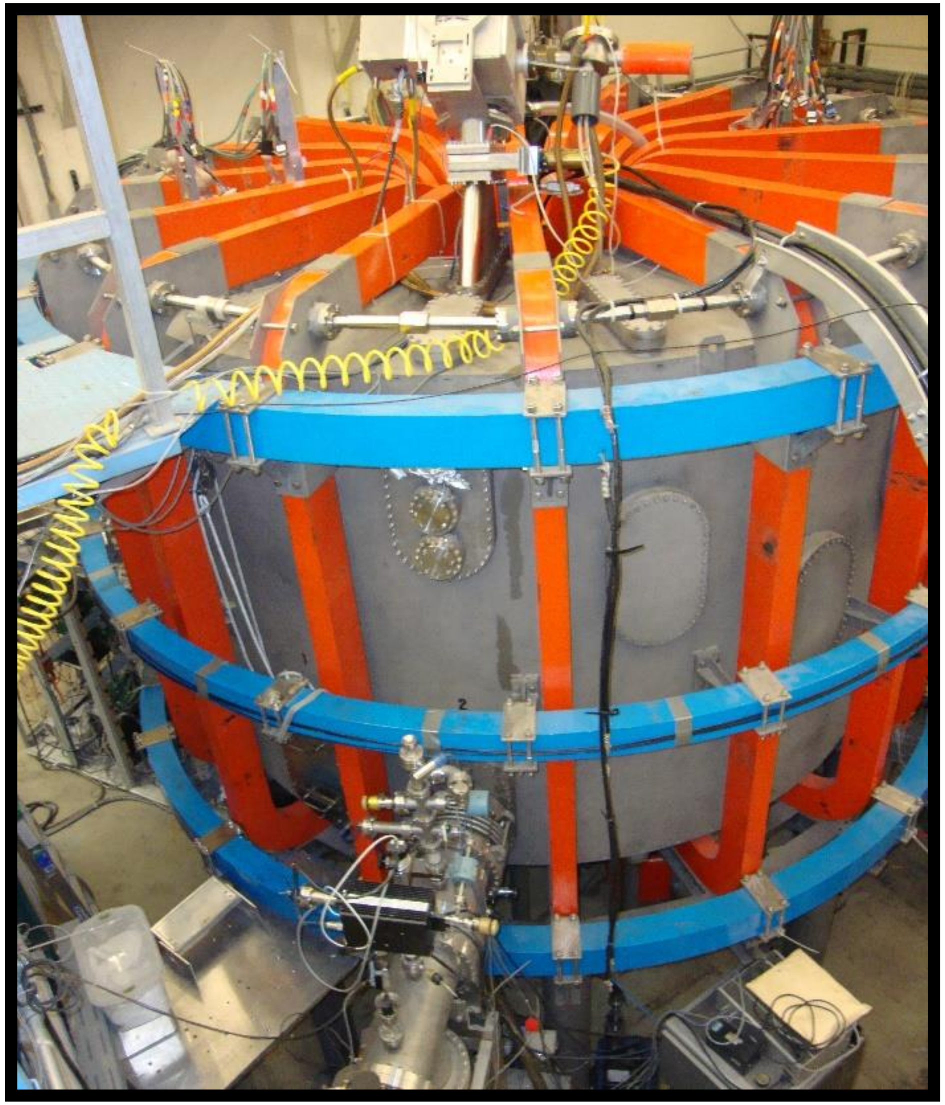
- Toroidal plasma device at the IFS-UT at Austin, USA
  - $R = 1.1\ m$
  - $H = 2.0\ m$
  - $B_T \cong 0.05 \sim 0.13\ T$
  - ECRH heating, Argon plasmas
  - Plasma duration 30 s
- Very suitable to use Langmuir probes
  - 700 probes available

K. W. Gentle, Plasma Sci. Technol. **10**, 284 (2008)

TCABR Tokamak



Texas Helimak

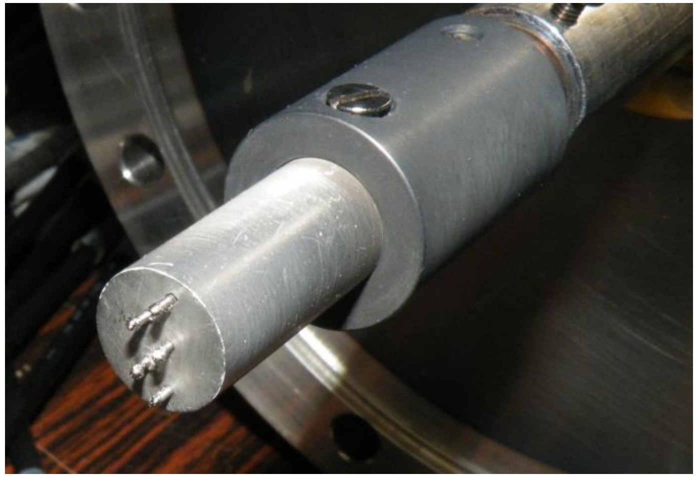


Langmuir probes at TCABR and Helimak

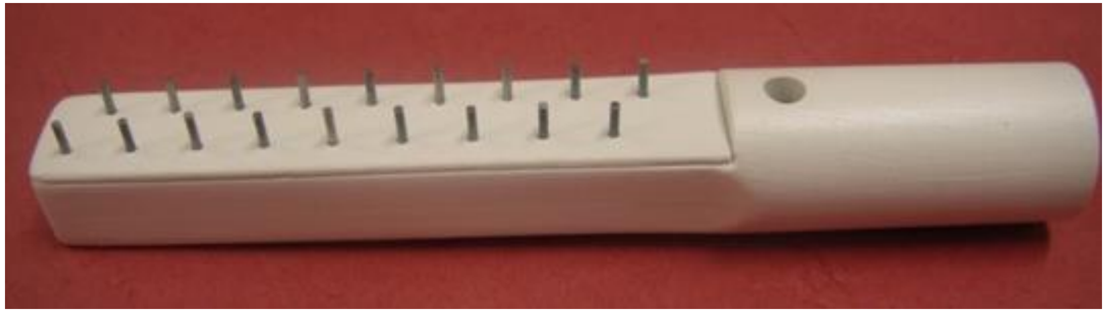
TCABR

5-Pin probe →

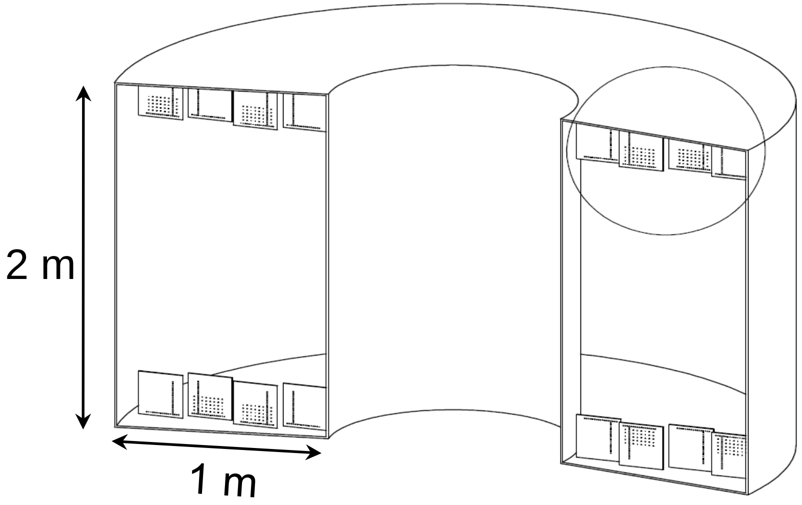
3+2 poloidal array

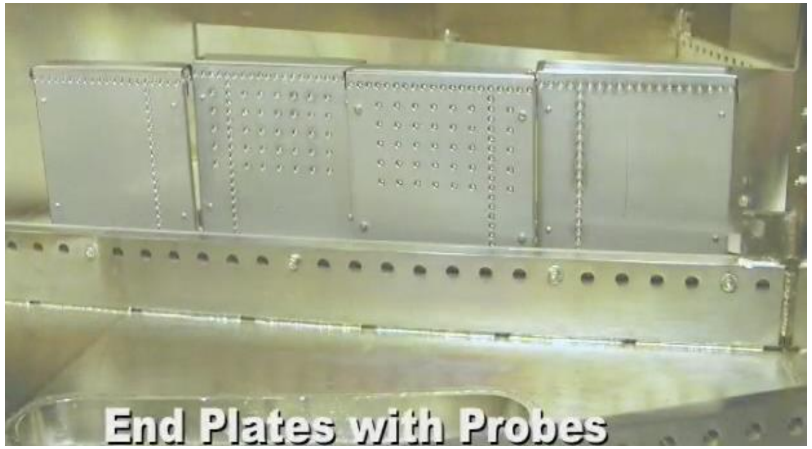


18-Pin rake probe ↓ 9 + 9 radial array



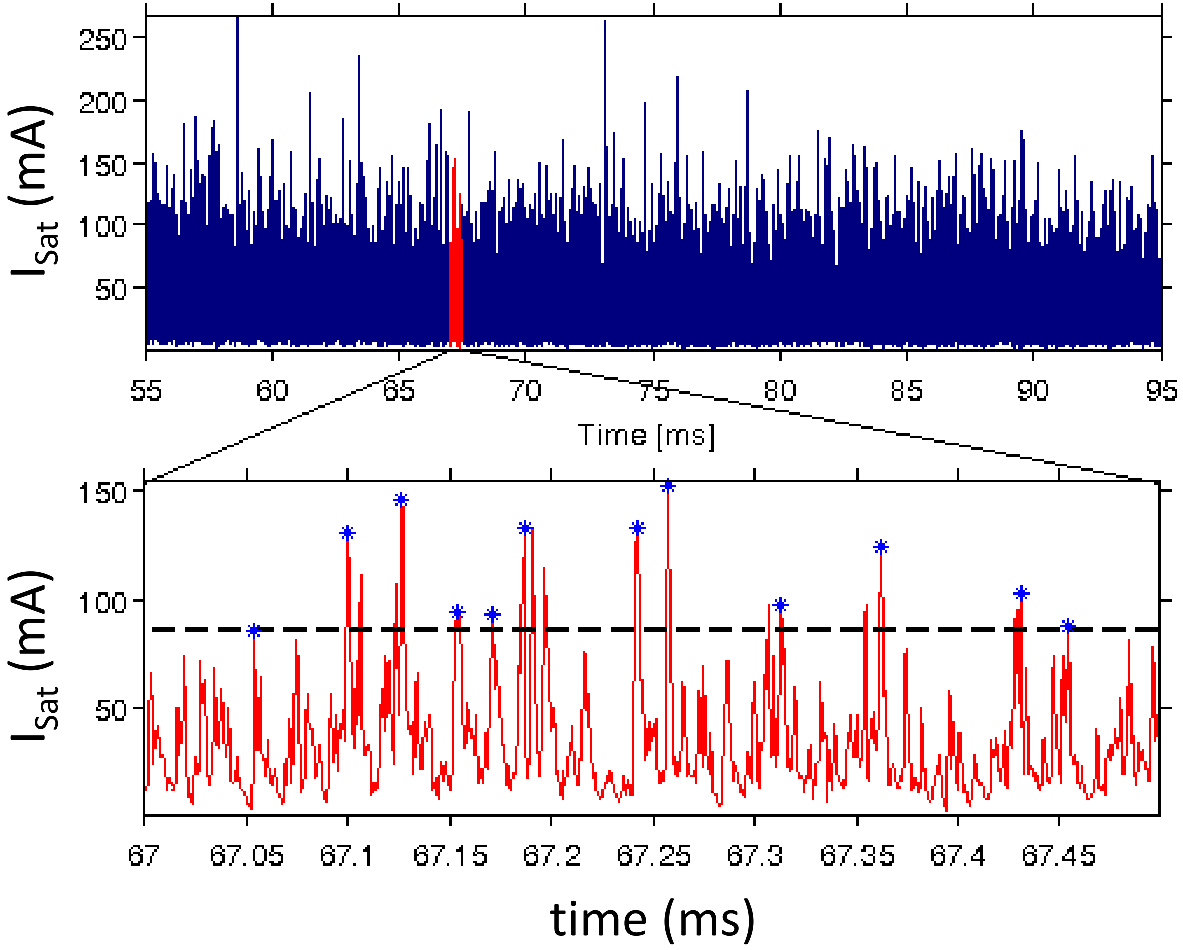
Helimak



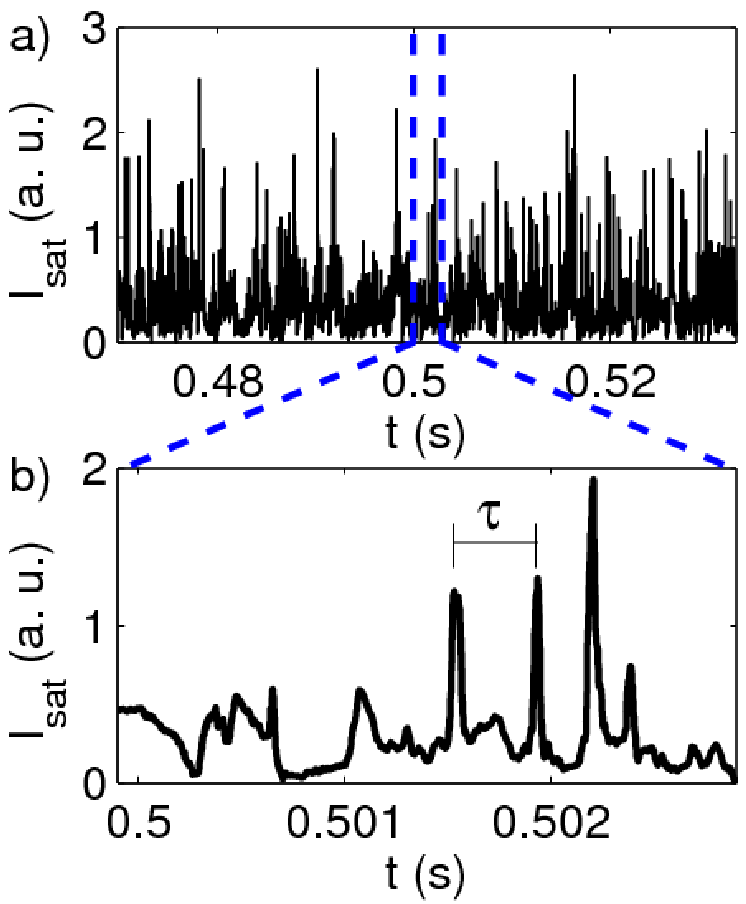


Turbulence and Bursts in TCABR and Helimak

TCABR

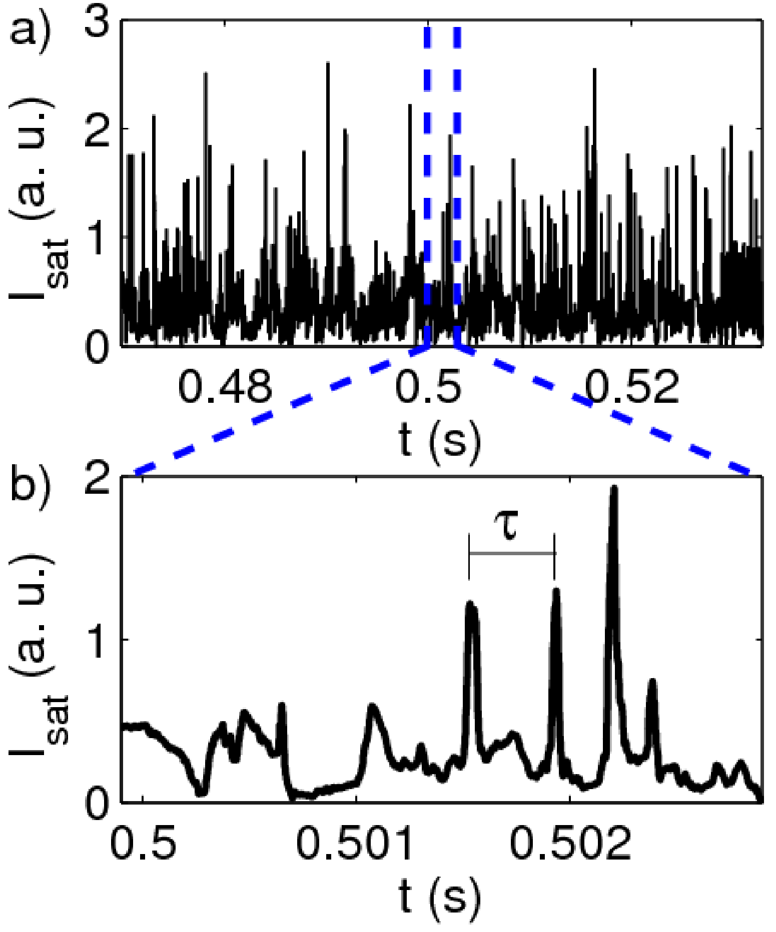


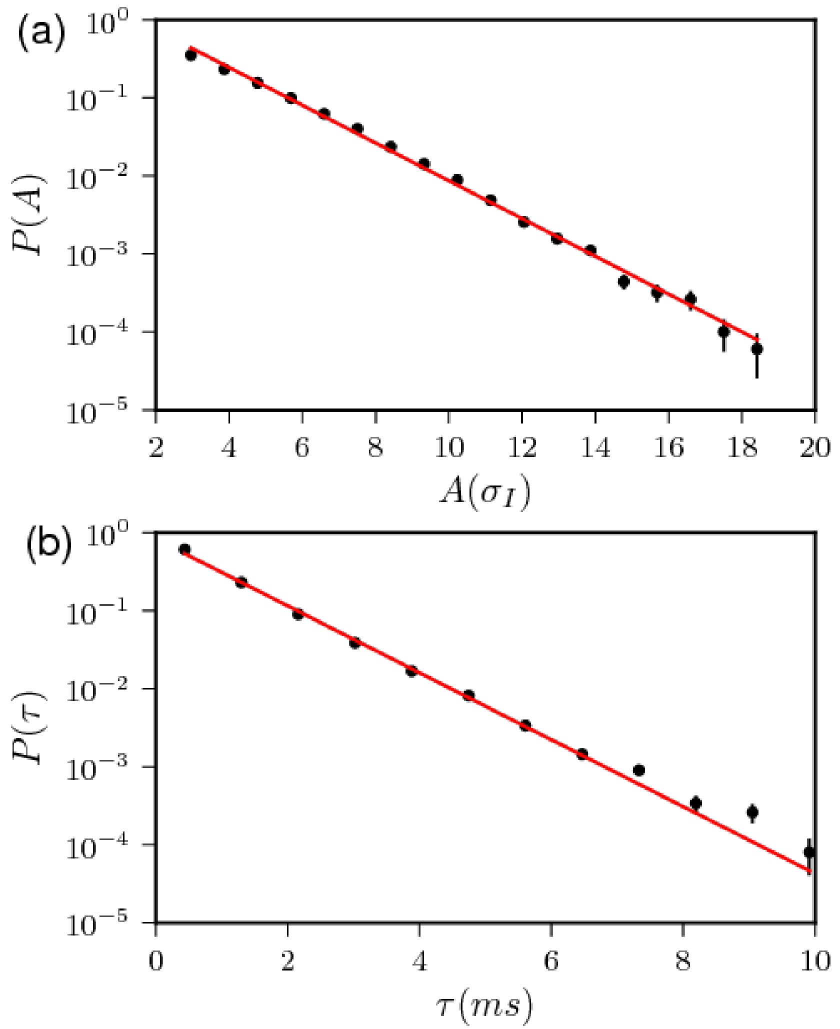
Texas Helimak



General description of Bursts

The PDFs of burst amplitudes and time between bursts are exponential



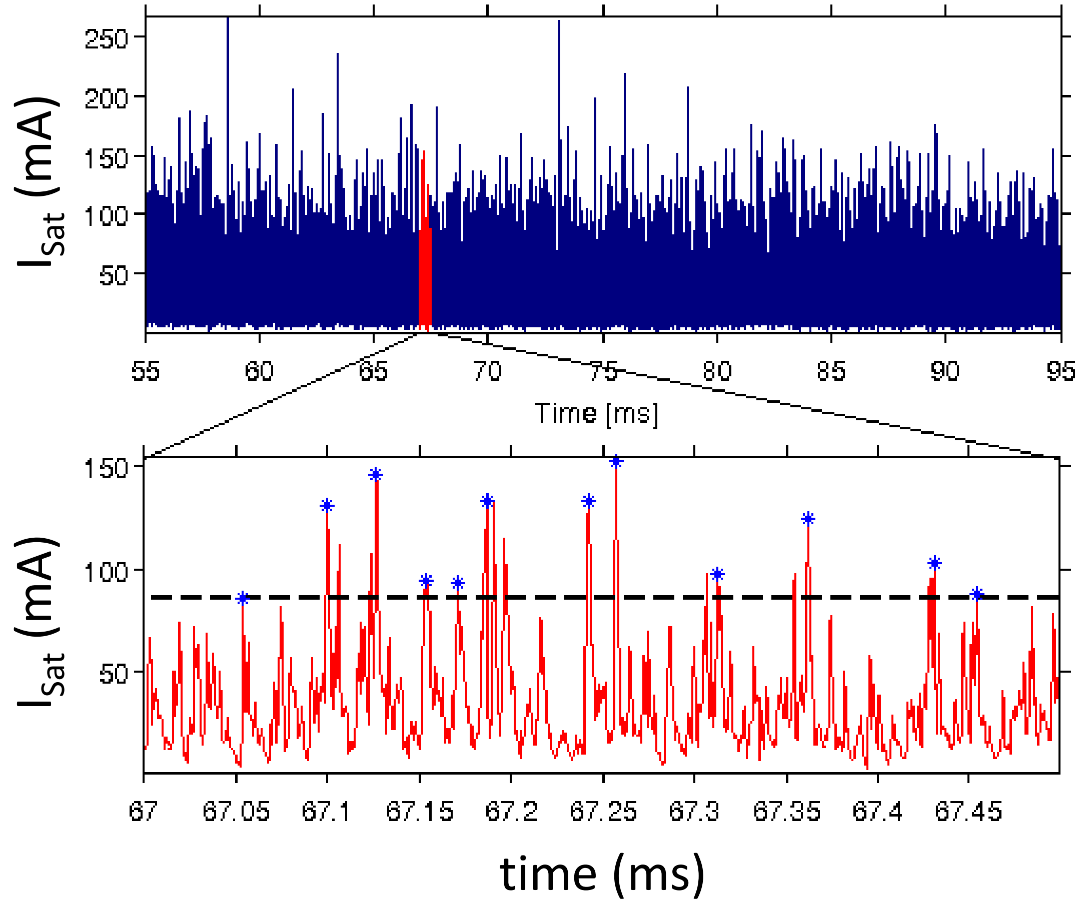


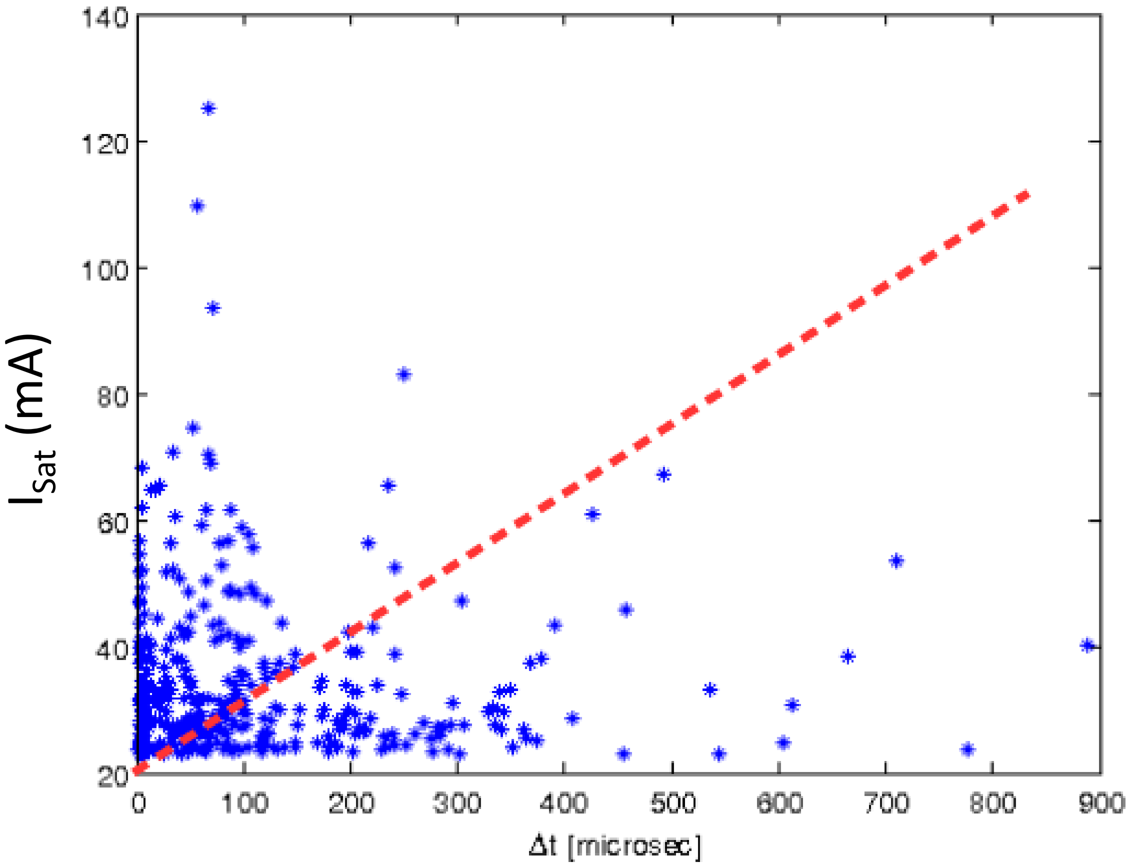
$$P(A) \sim \exp\left(\frac{-A}{\lambda_A}\right)$$

$$P(\tau) \sim \exp\left(\frac{-\tau}{\lambda_\tau}\right)$$

General description of Bursts

The burst amplitude does not depend on the time between bursts (it is not a charge-discharge phenomena)

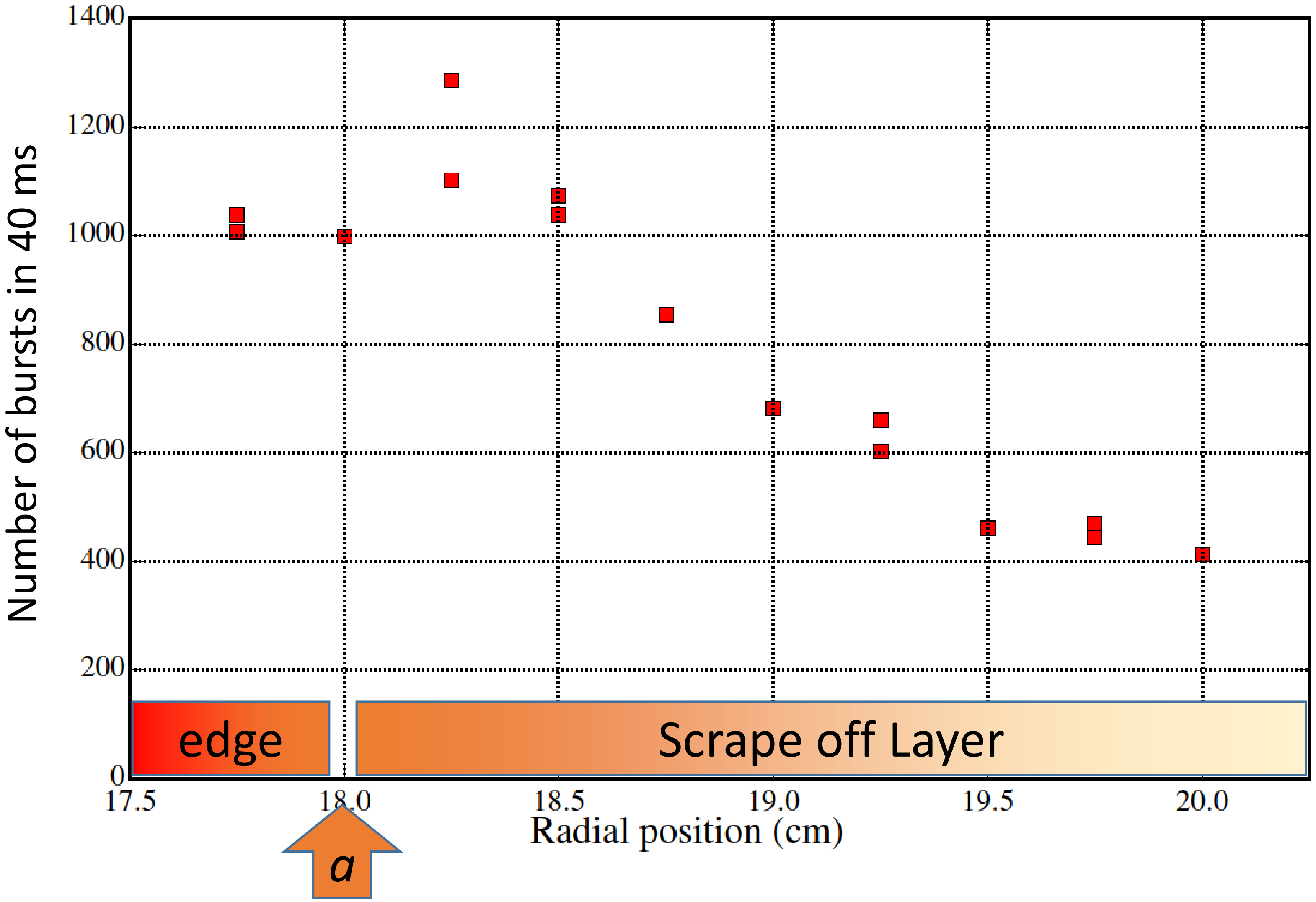




Bursts in TCABR tokamak

Bursts rate in TCABR

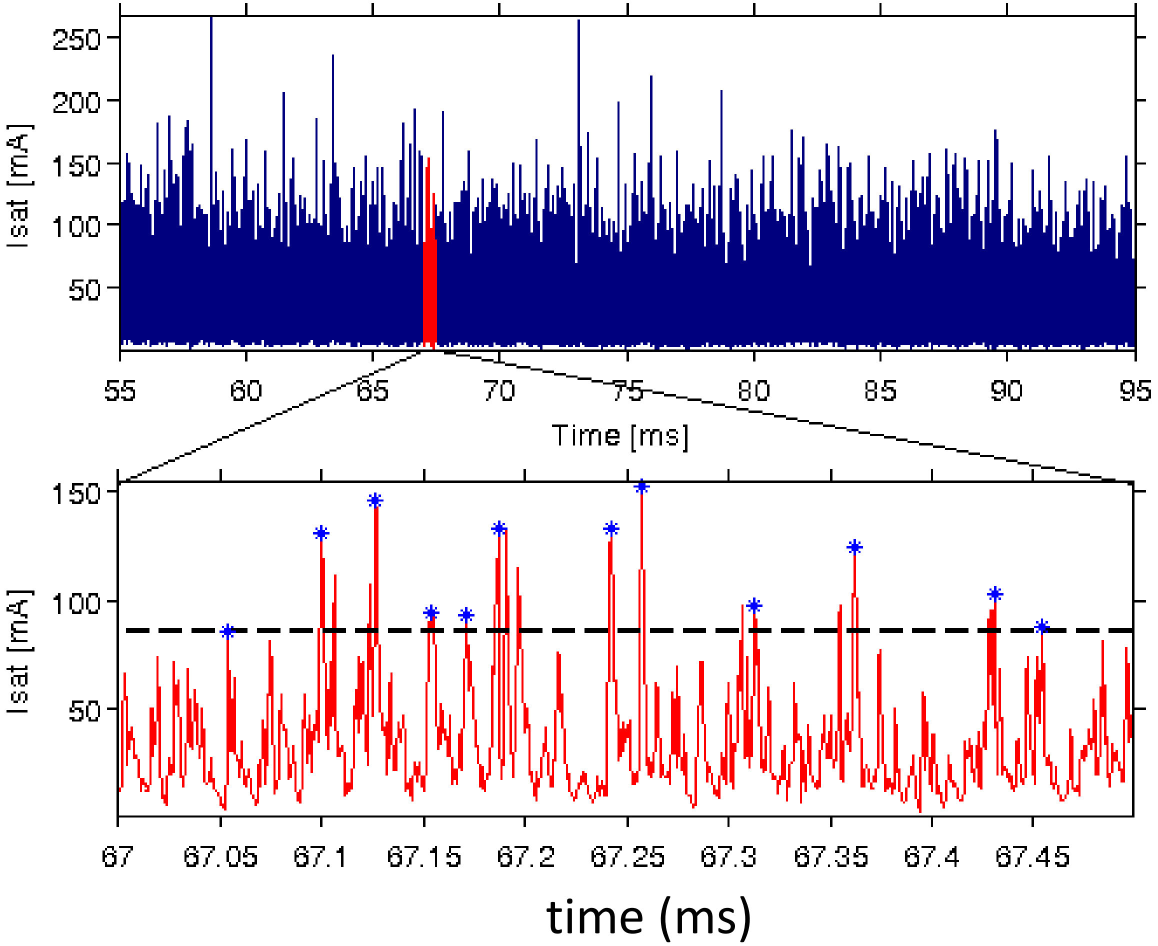
The burst rate depends on the probe radial position



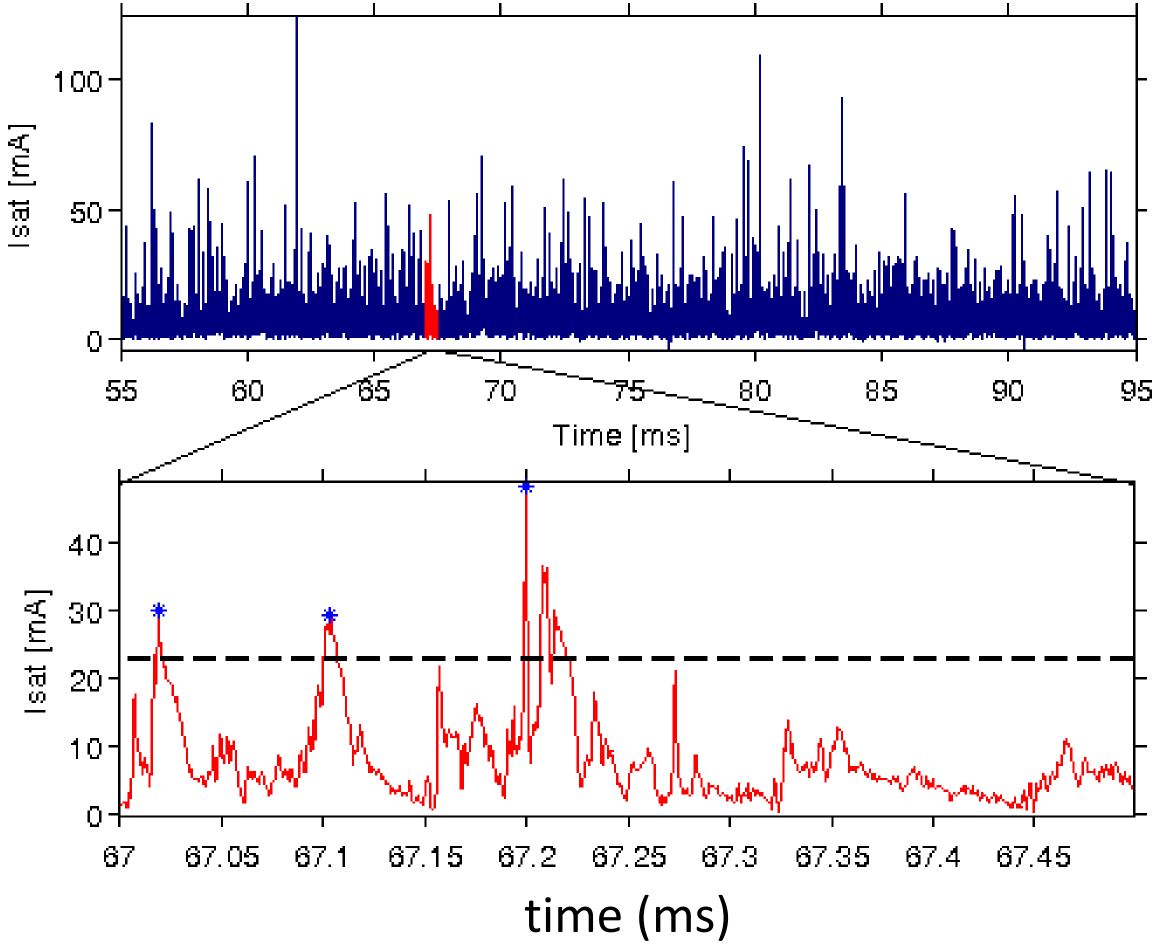
Bursts shape in TCABR

The burst shape depends on the radial position

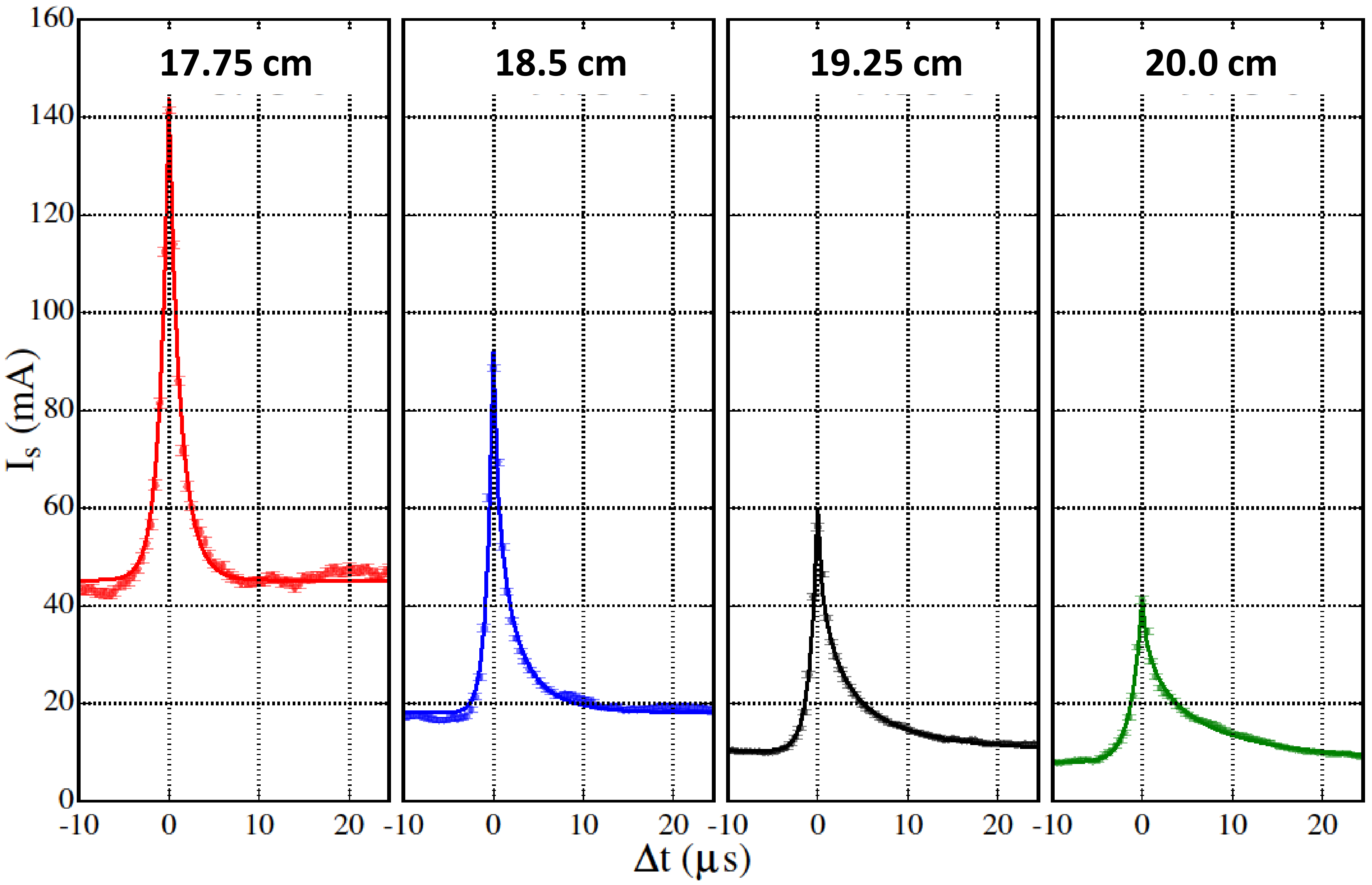
r = 18,0 cm (plasma border)



r = 20,0 cm (scrape-off-layer)



Burst shape dependence with radial position



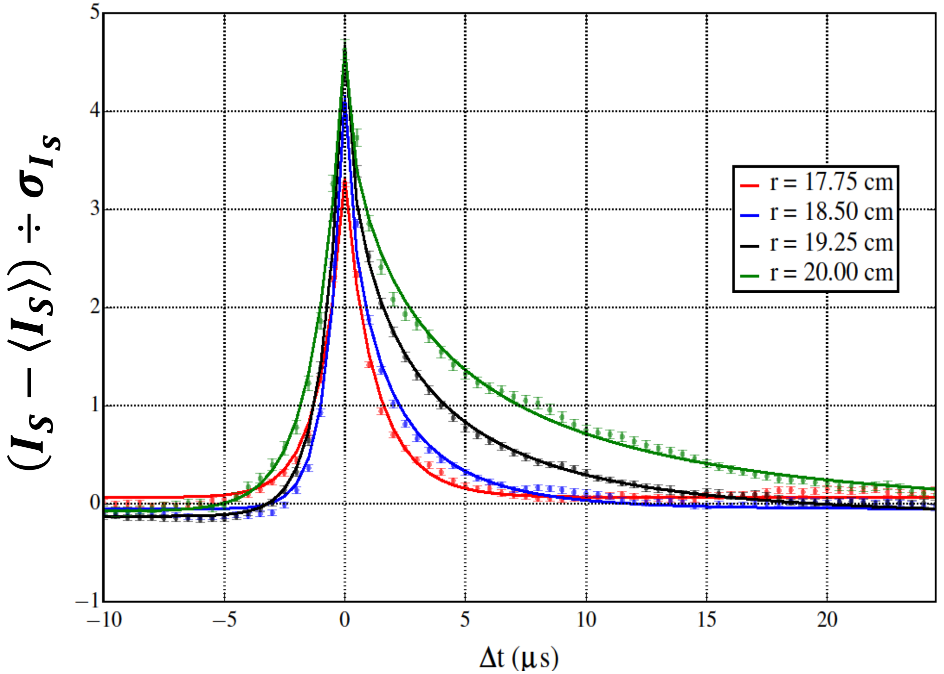
The average burst shape depends on the radial position

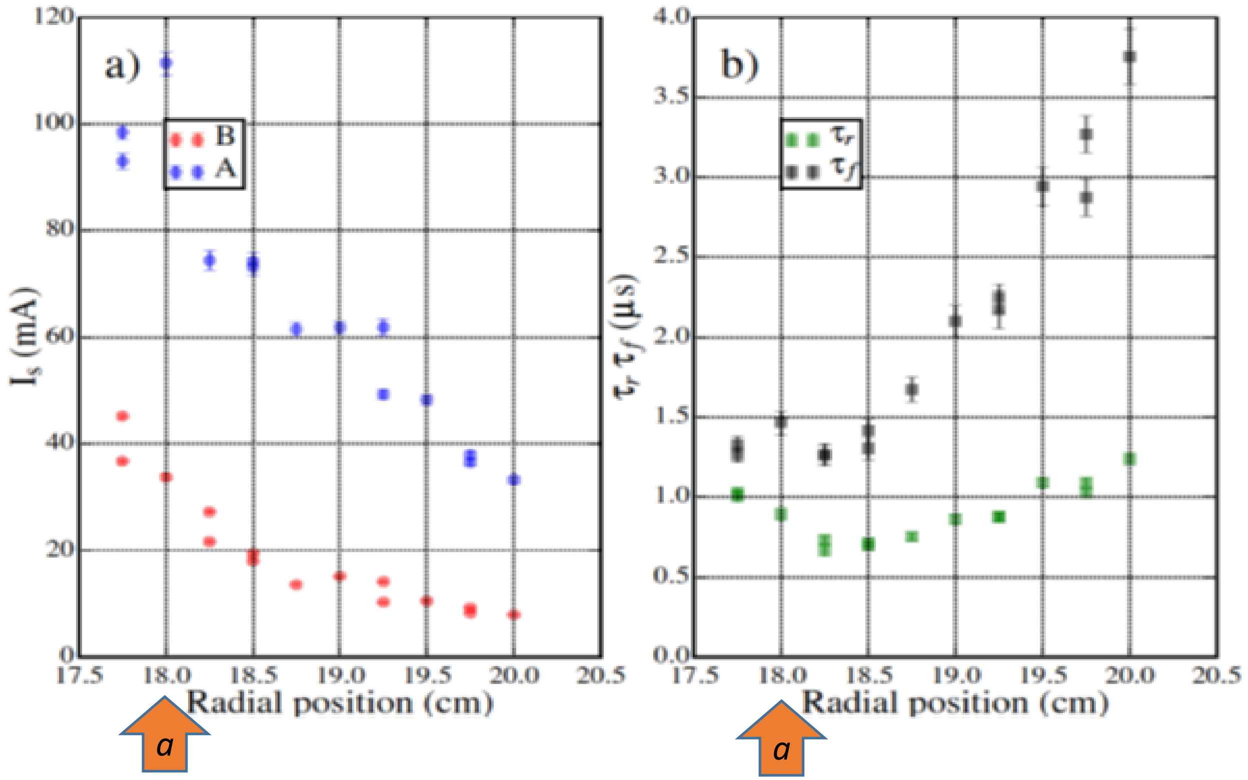
Burst are shorter and almost symmetric at the plasma edge

Both the asymmetry and duration increase with the radial position

Radial position dependence of Burst shape in TCABR

$$I_S = \boldsymbol{B} + \begin{cases} \boldsymbol{A}.\exp\left(\dfrac{t}{\boldsymbol{\tau_r}}\right) & t \leq 0 \\ \boldsymbol{A}.\exp\left[-\left(\dfrac{t}{\boldsymbol{\tau_f}}\right)^{\boldsymbol{\gamma}}\right] & t \geq 0 \end{cases}$$



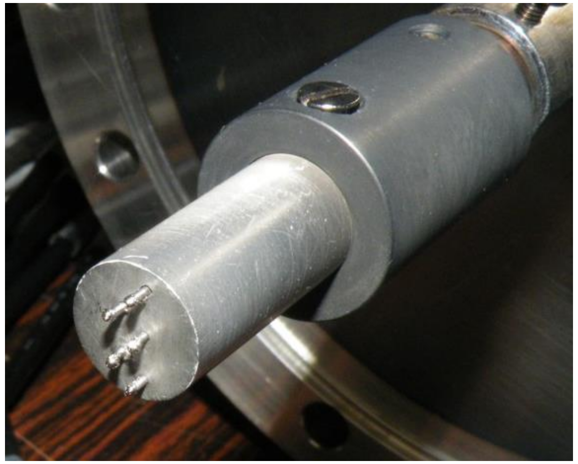


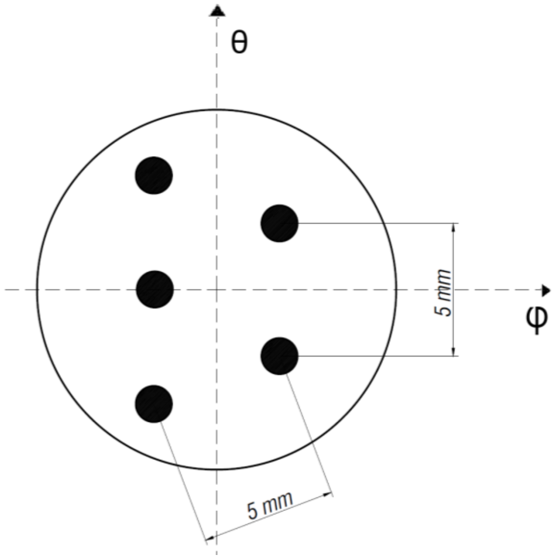
a) Burst amplitude is several times the background

b) Falling times are bigger than the rise ones

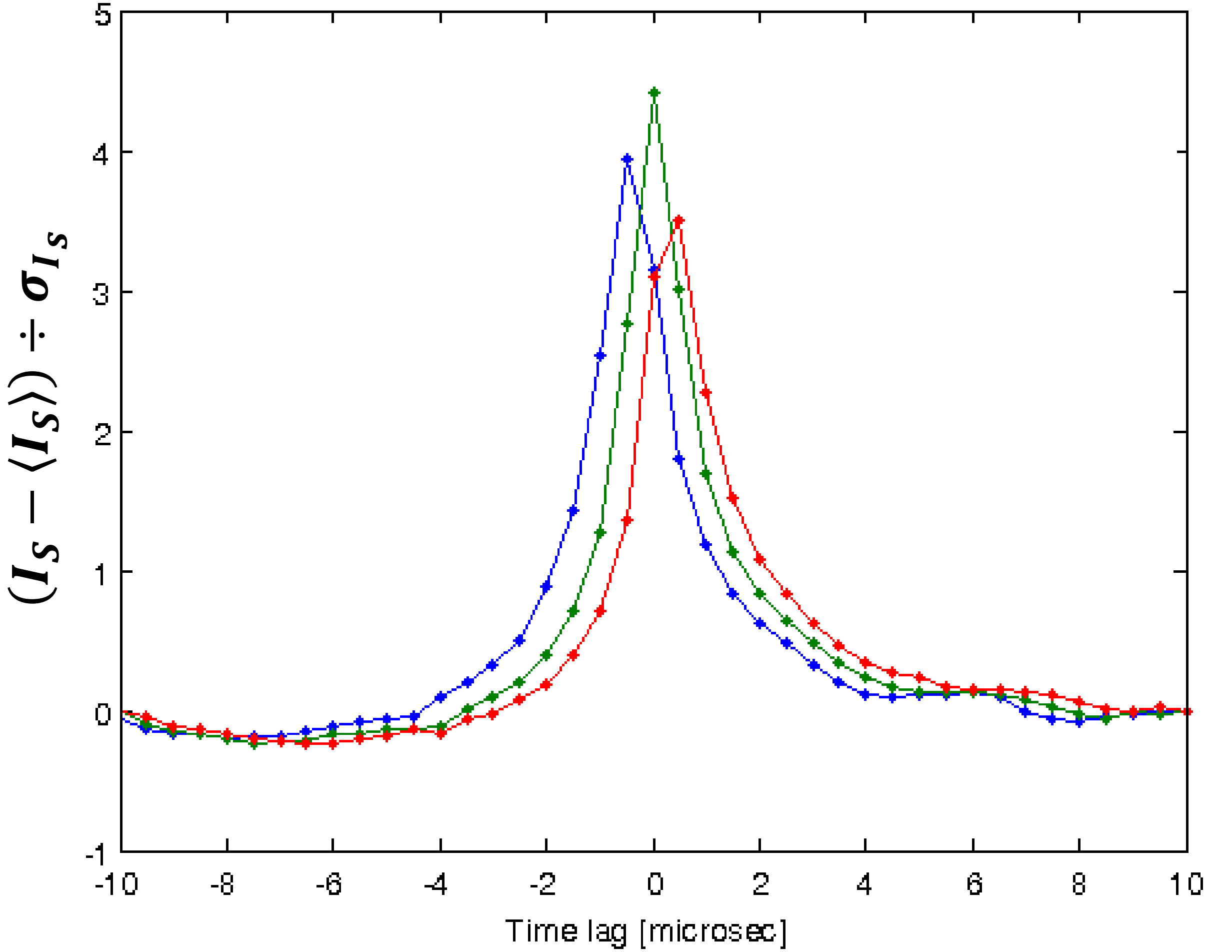
c) The burst duration increases at larger radius

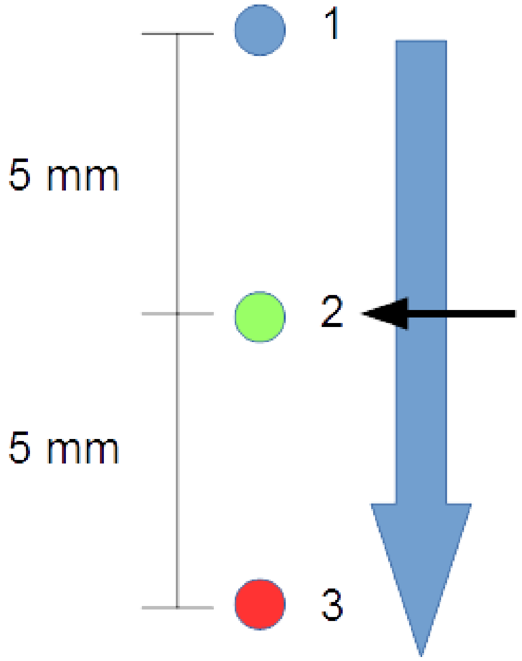
Delay between burst detection in nearby probes of TCABR poloidal array





r = 18,0 cm (plasma border)

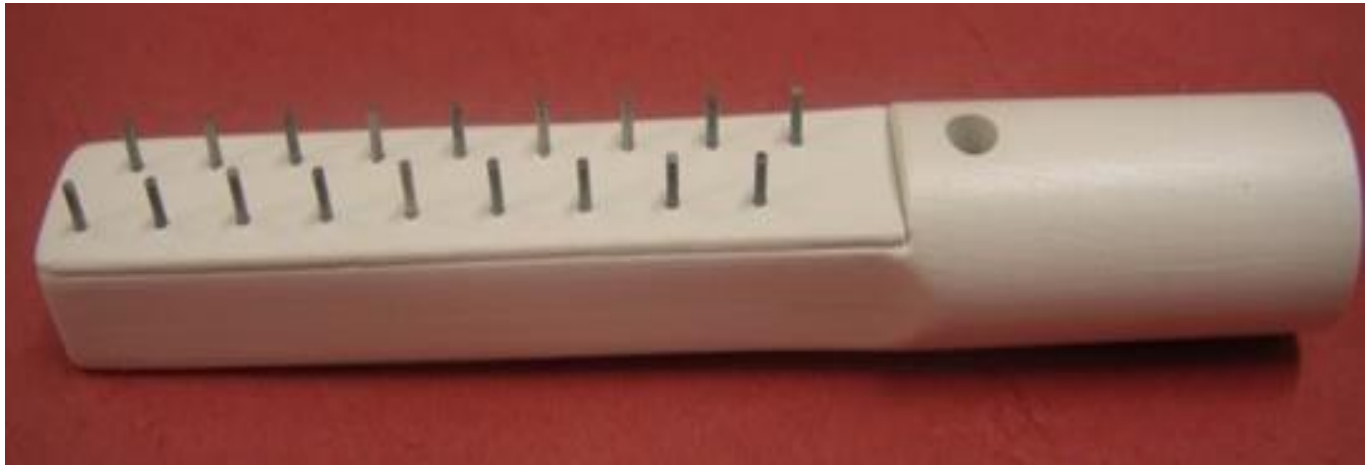


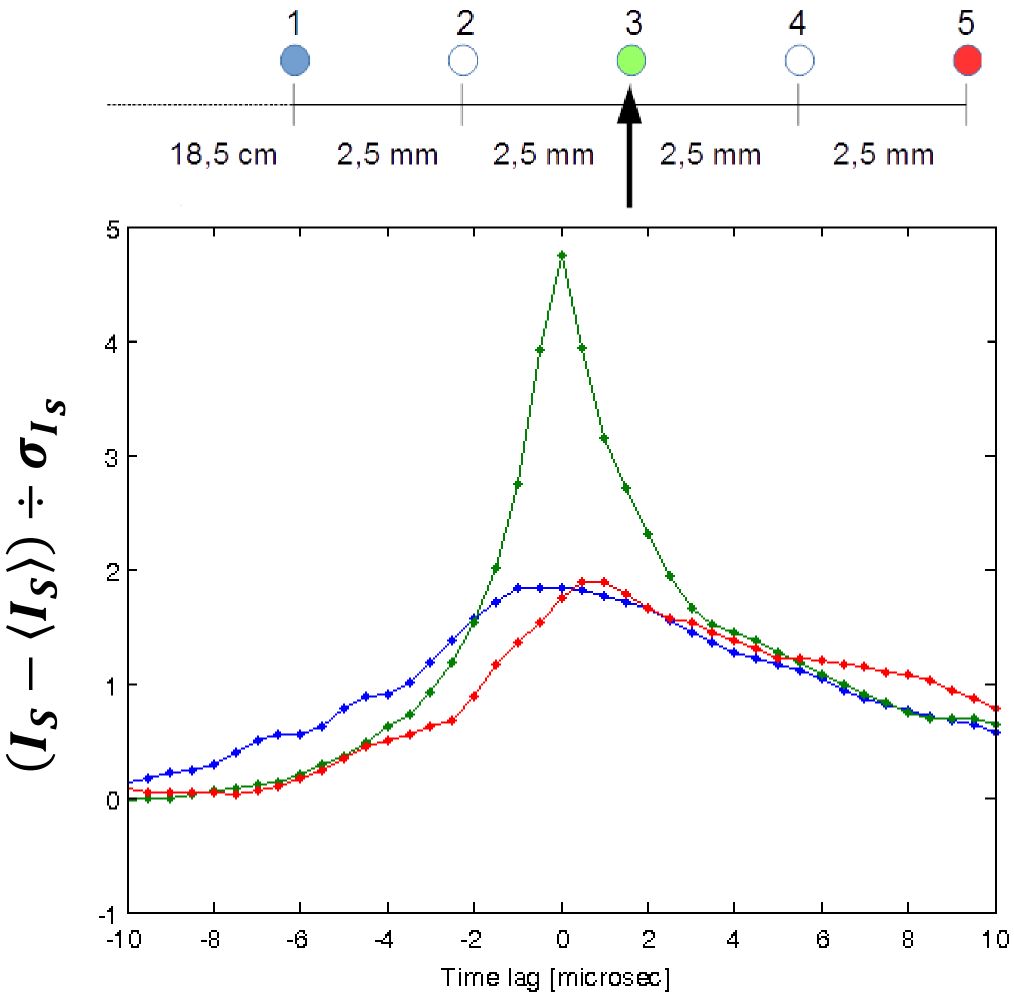


Bursts are detected from top to bottom

Delay between burst detection in the radial array

18-Pin rake probe ↓ **9 + 9 radial array**

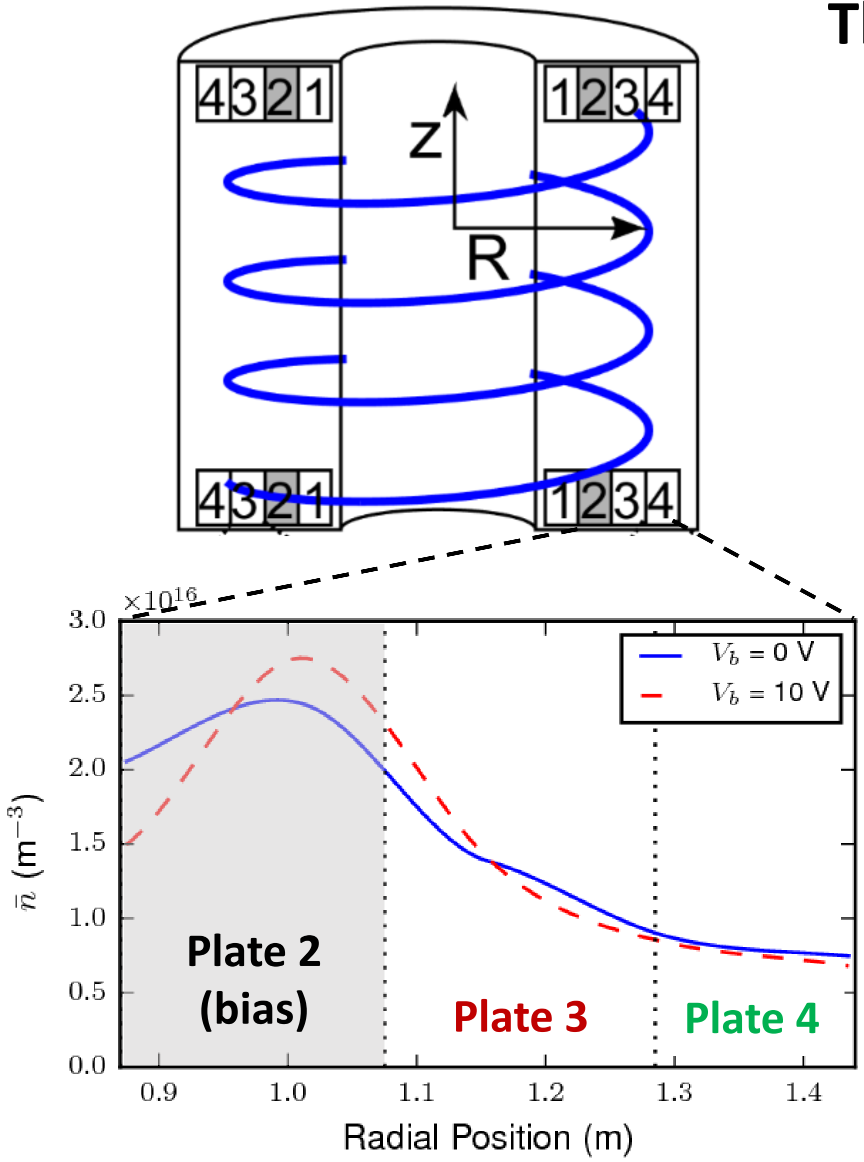




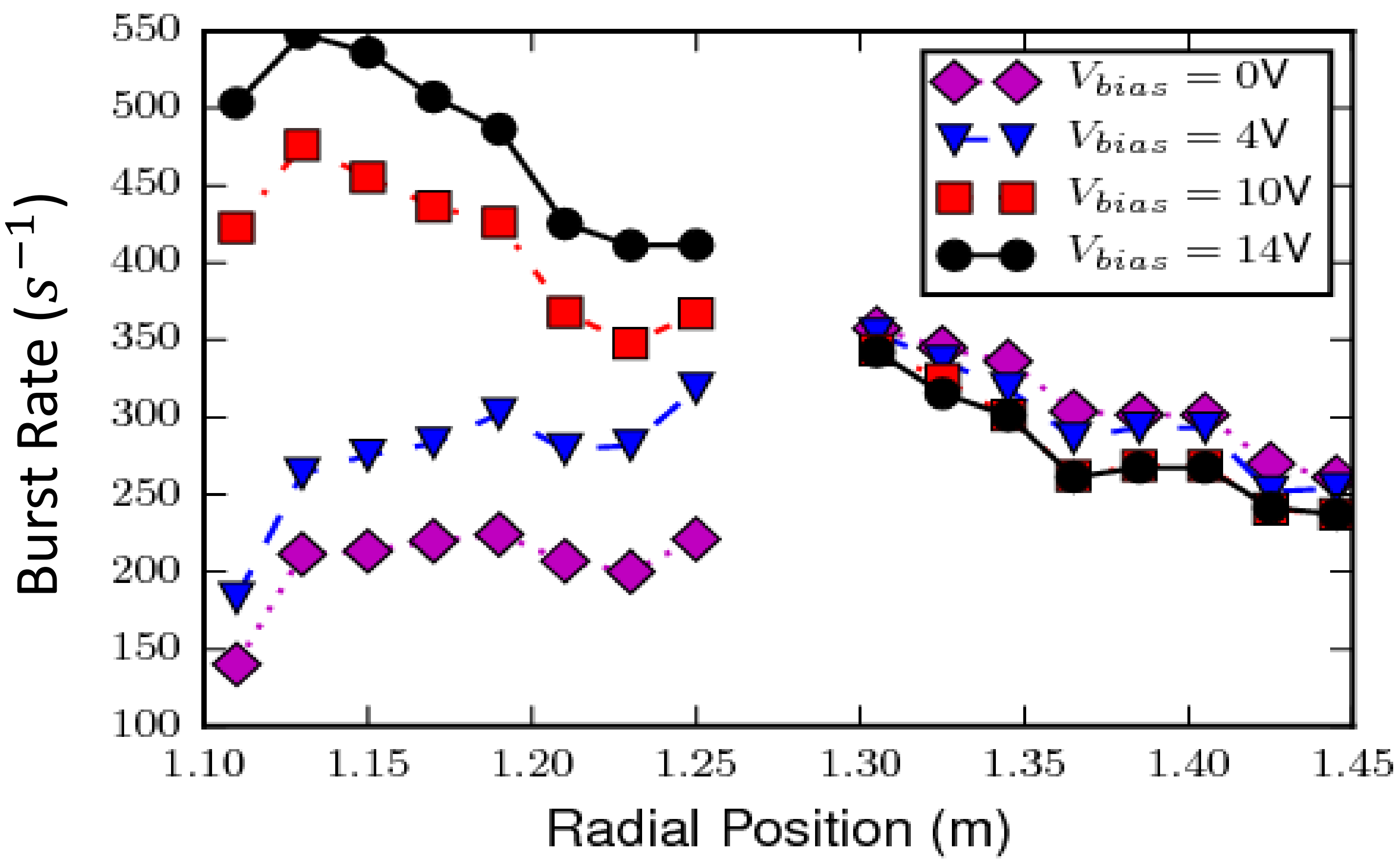
Bursts are detected from more internal pins to more external ones.

Bursts in Texas Helimak

Bursts rate in Texas Helimak



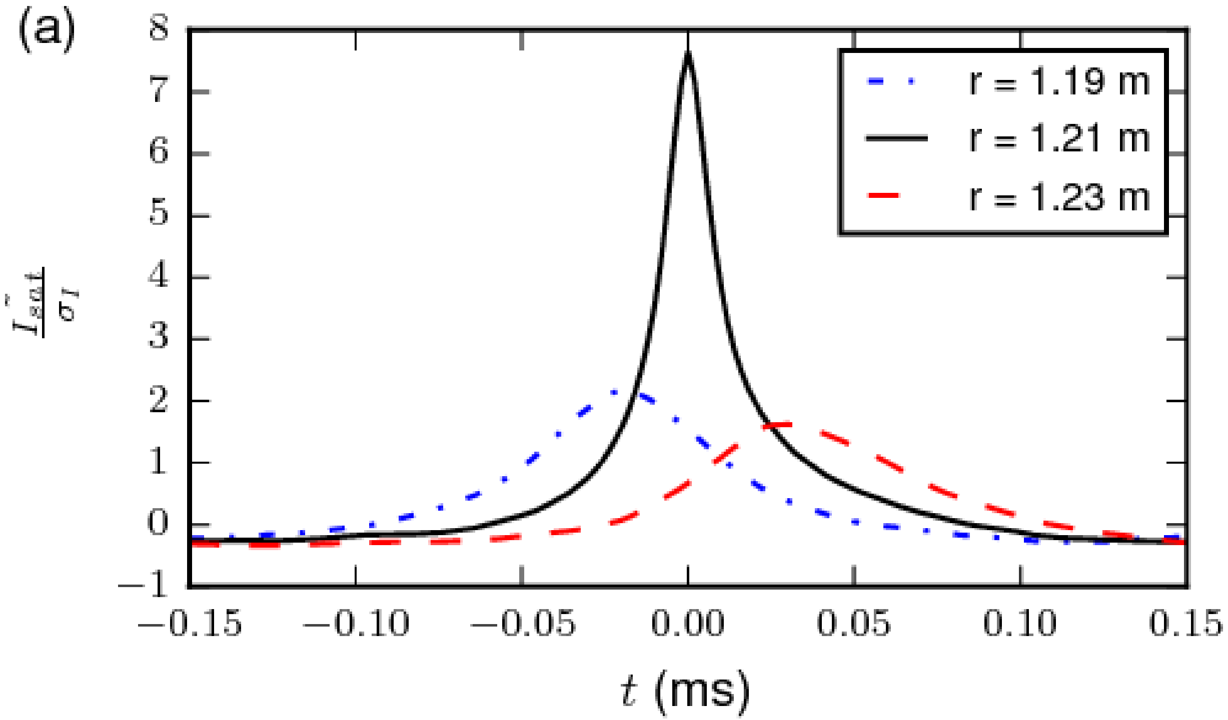
The burst rate depends on the applied bias and radial position



Burst rate changes with bias in the density gradient region (plate 3) and with the radial position in the almost uniform density region (plate 4).

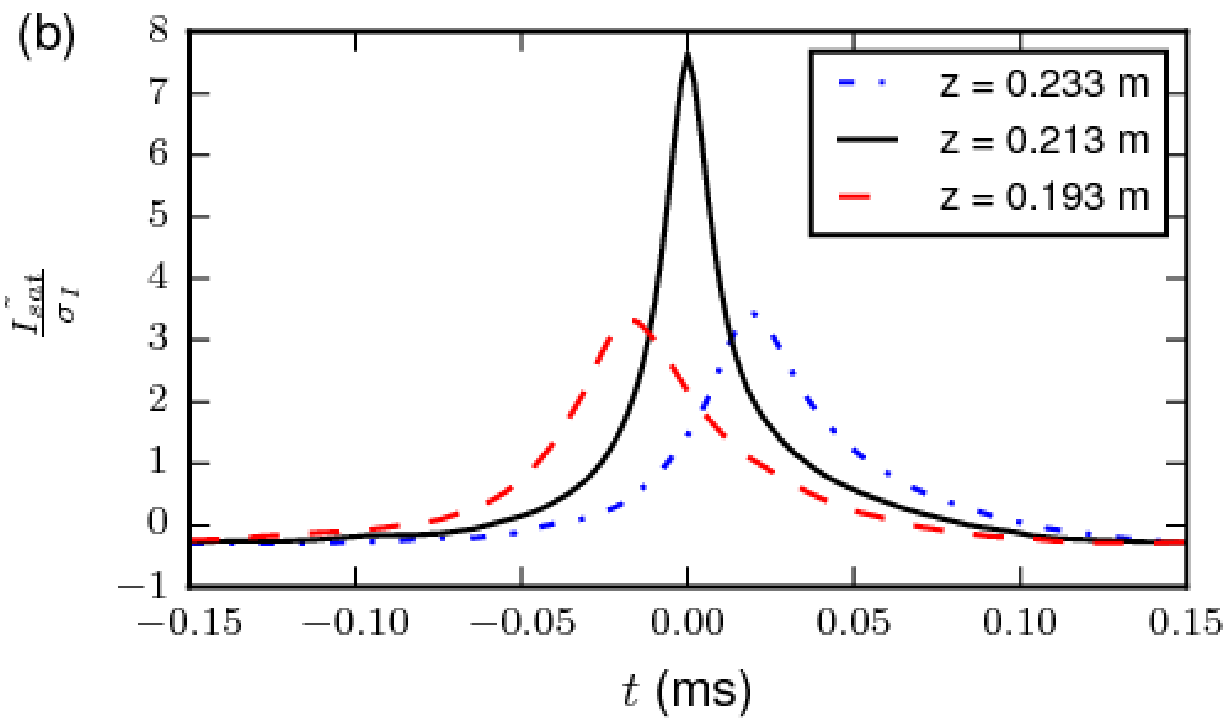
Time delay between Bursts in nearby probes

(a) Radial propagation



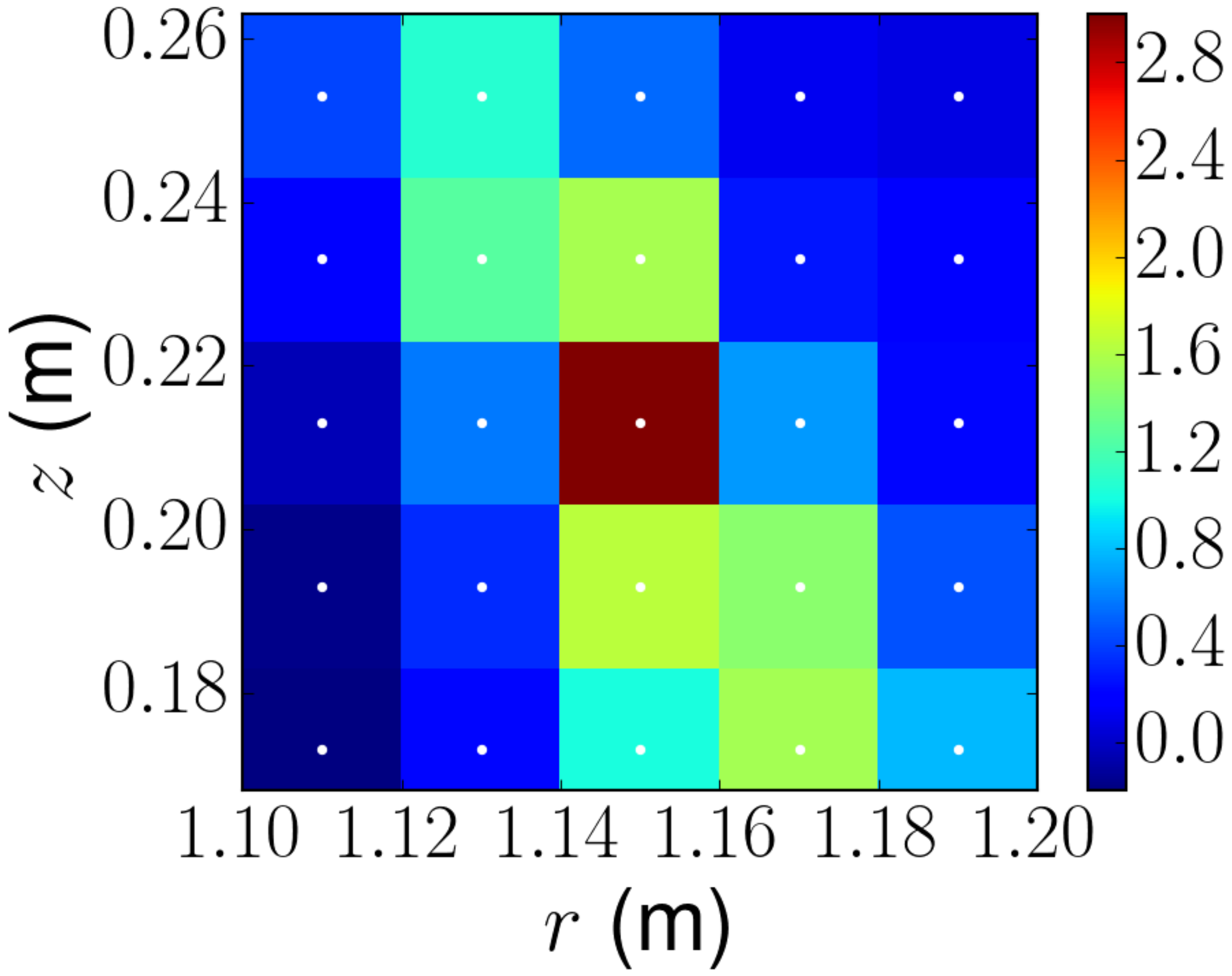
Bursts are detected from more internal pins to more external ones.

(b) Vertical propagation



Bursts are detected from bottom pins to top ones.

Burst shape from 2D array of probes

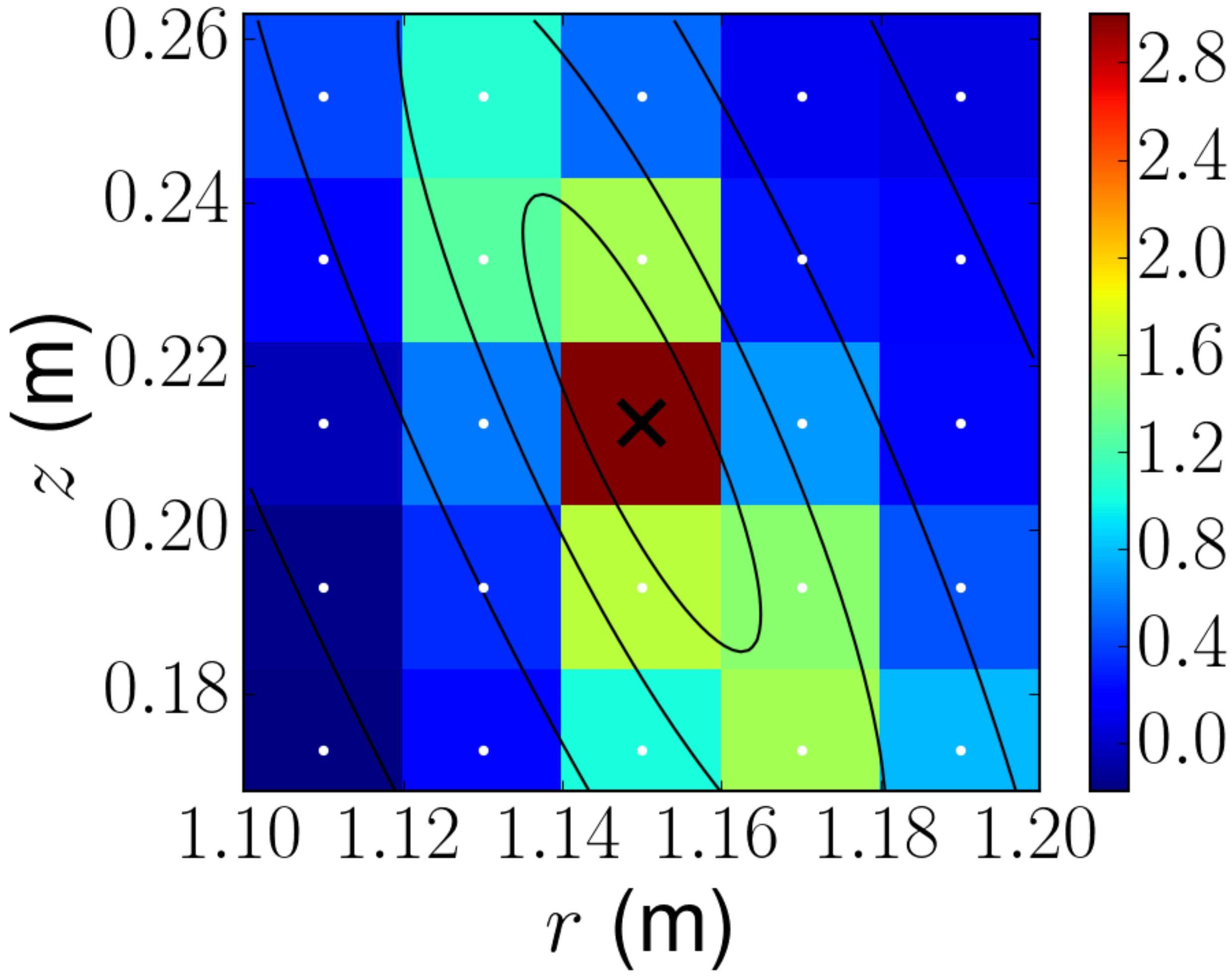


- Burst size is much bigger than the space between the probes

- The average 2D burst shape is ellipsoidal

➢ The major and minor radius are tilted with respect to the radial and vertical directions

A model to fit the 2D burst shape



Phenomenological model to fit the 2D burst shape:

$$I(r,z) = \boldsymbol{B} + \frac{\boldsymbol{A}}{1 + \left(\frac{\delta_1}{\boldsymbol{\sigma_1}}\right)^2 + \left(\frac{\delta_2}{\sigma_2}\right)^2}$$

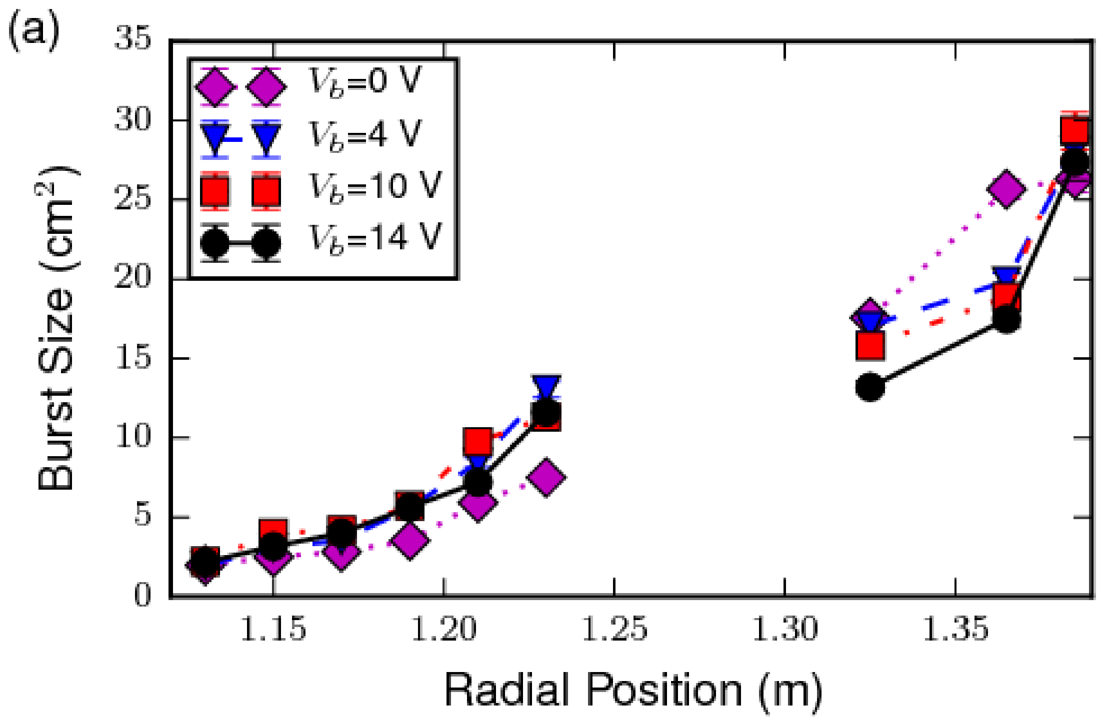
where: $\sigma_2 = \boldsymbol{\lambda}\sigma_1$

$$\delta_1 = (r - r_*)cos\boldsymbol{\theta} + (z - z_*)sin\boldsymbol{\theta}$$

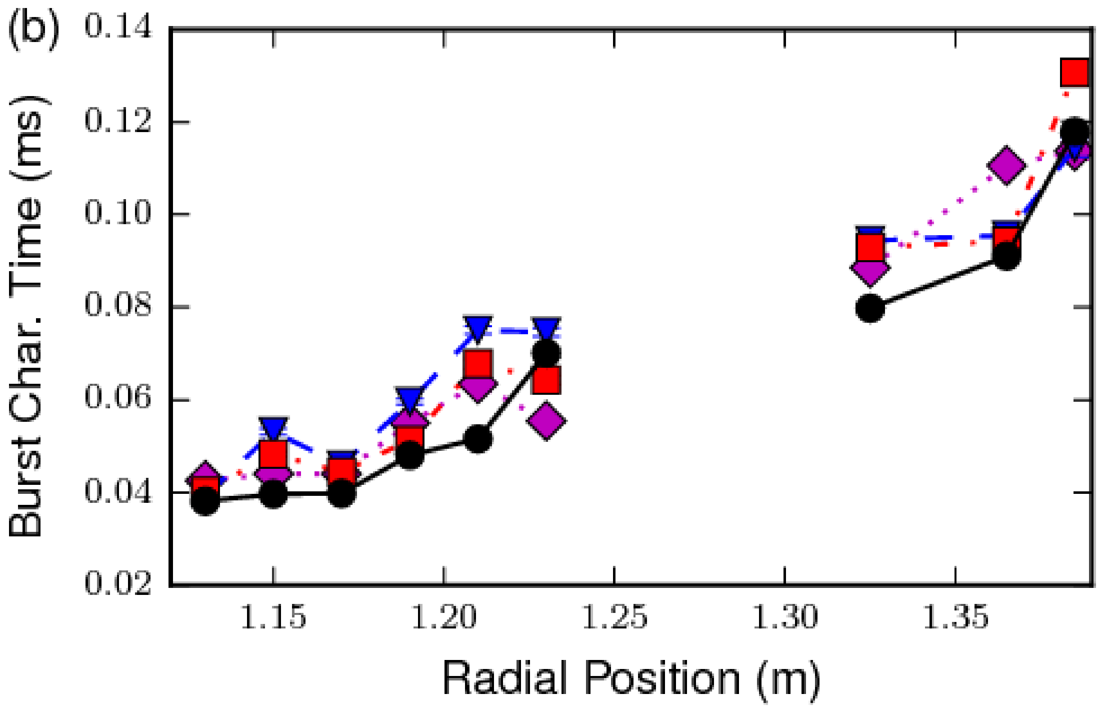
$$\delta_2 = (r - r_*)sin\boldsymbol{\theta} + (z - z_*)cos\boldsymbol{\theta}$$

Burst size and characteristic time in Texas Helimak

(a) Burst size $(\pi\sigma_1\sigma_2)$



(b) Burst characteristic time

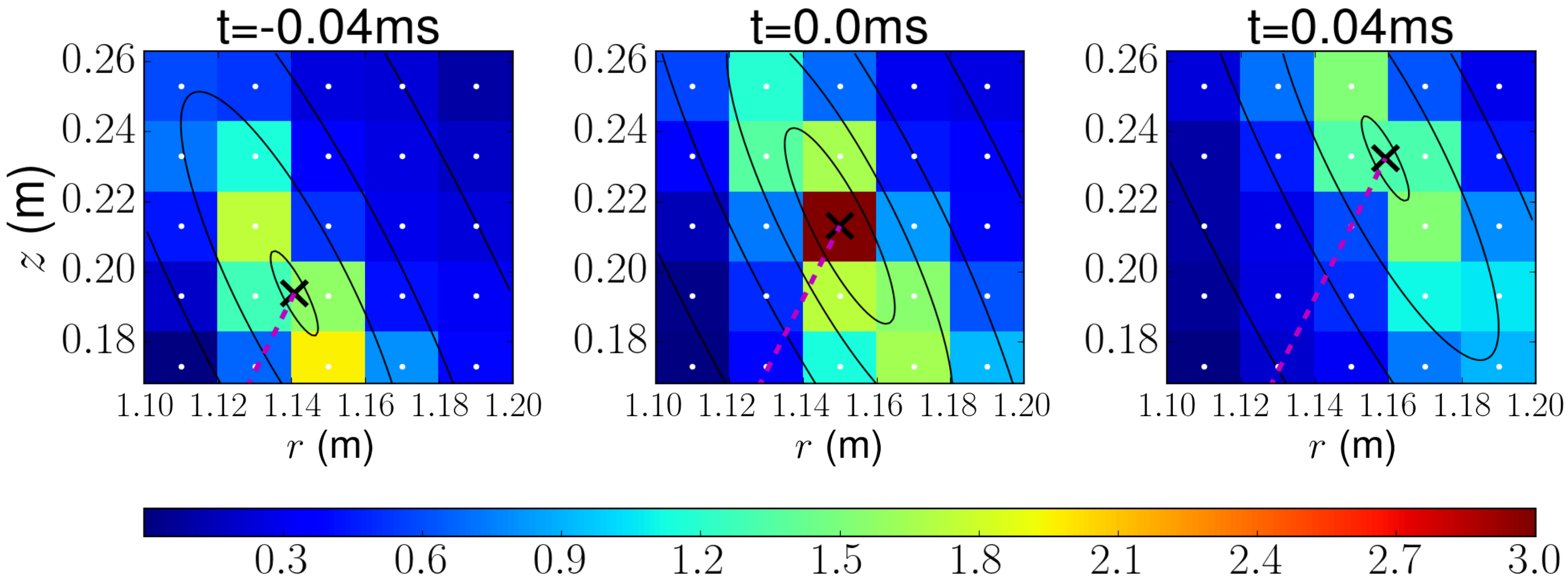


Both burst size and burst characteristic time mainly depend on the radial position.

As in TCABR, the burst duration increases with the radial position.

Burst propagation from 2D array of probes

The burst propagation can be determined by fitting the 2D burst shape in time frames before and after the peak of the burst in the reference probe:



To much free parameters: there are 7 parameters to be fitted in each time frame.

The fit is not good for time frames where the burst is near the edge of the probe region.

Burst propagation from 2D array of probes

Phenomenological model to fit the full 2D burst propagation:

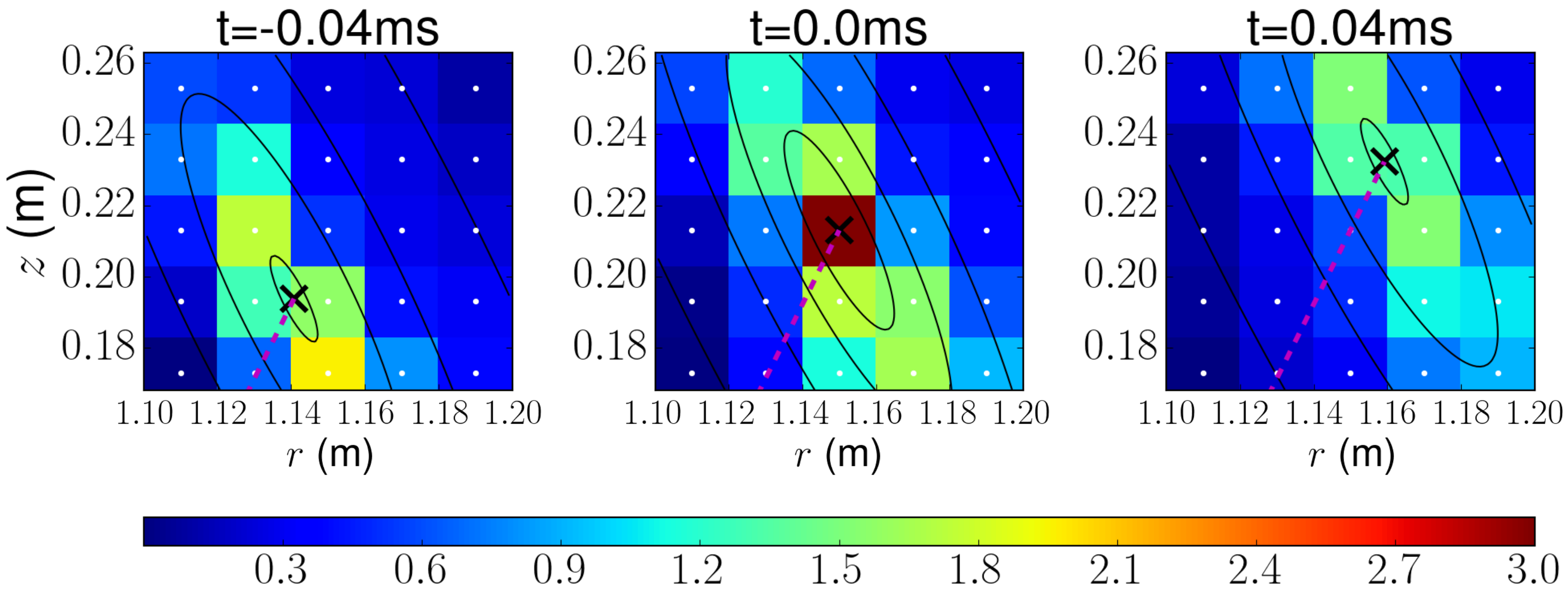
$$I(r,z,t) = B + \frac{A}{1 + \left(\frac{\delta_1}{\sigma_1}\right)^2 + \left(\frac{\delta_2}{\lambda\sigma_1}\right)^2}$$

$$\delta_1 = (r - r_0)cos\theta + (z - z_0)sin\theta$$

$$\delta_2 = (r - r_0)sin\theta + (z - z_0)cos\theta$$

By modeling the burst position, amplitude and size evolutions

the full movie can be fitted with only 9 parameters



$$A = A_0 e^{-\mu|t|}$$

$$\sigma_1 = \sqrt{(\sigma_0)^2 + \alpha|t|}$$

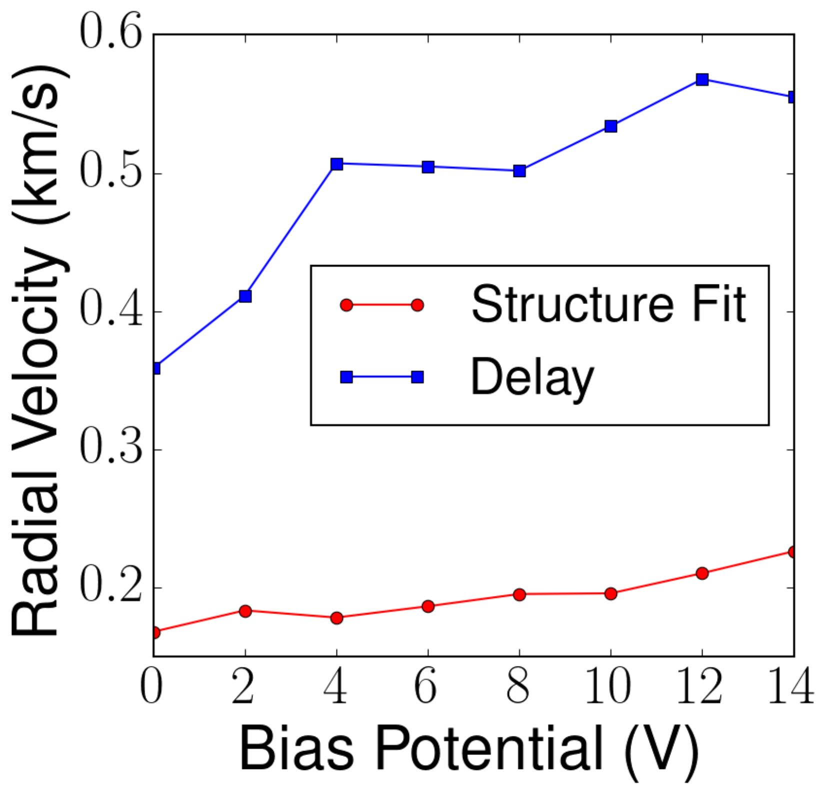
$$r_0 = r_* + v_r t$$

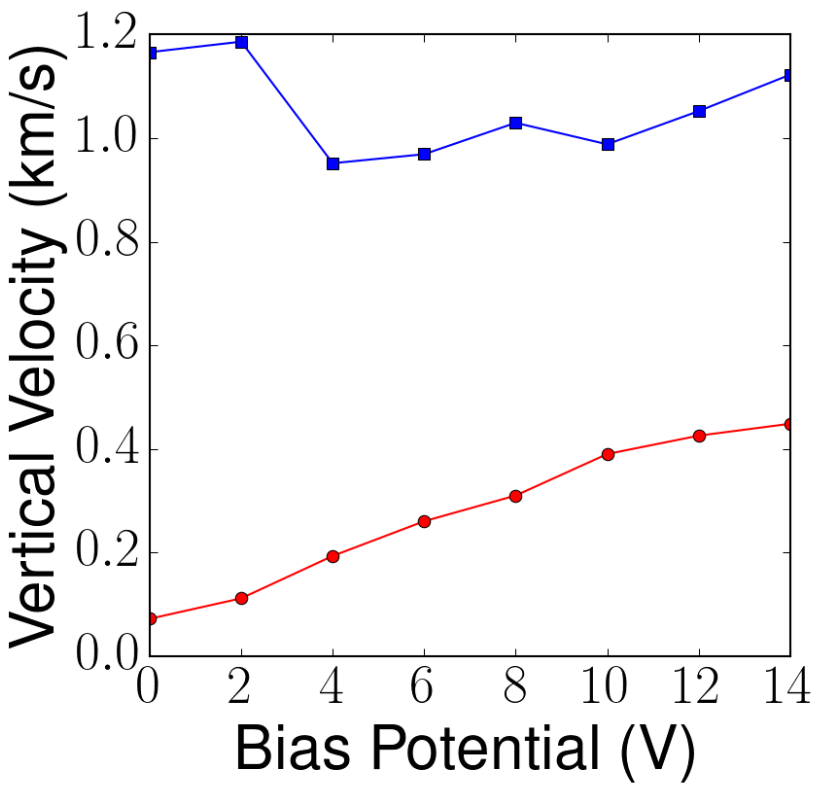
$$z_0 = z_* + v_z t$$

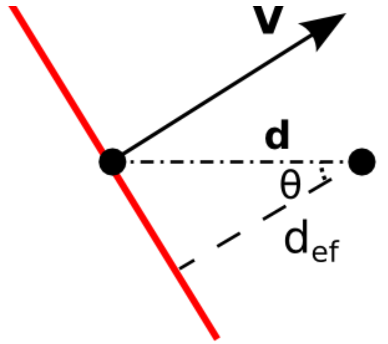
[D.L. Toufen, Phys. of Plasmas (2014) 122302]

Comparison of burst velocities estimated from time delay and from the 2D fits

Due to the elongation shape of the bursts, the time delay method cannot be used to determine the radial and vertical velocities:





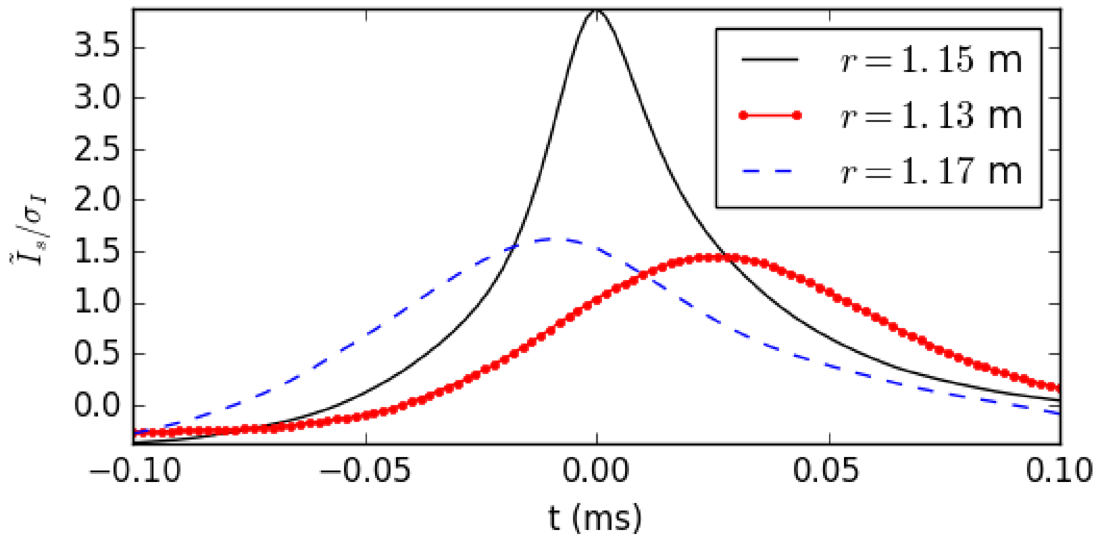


$$\Delta t = \frac{d_{ef}}{V}$$

$$V_{ap} = \frac{d}{\Delta t} = V\frac{d}{d_{ef}} = \frac{V}{\cos\theta}$$

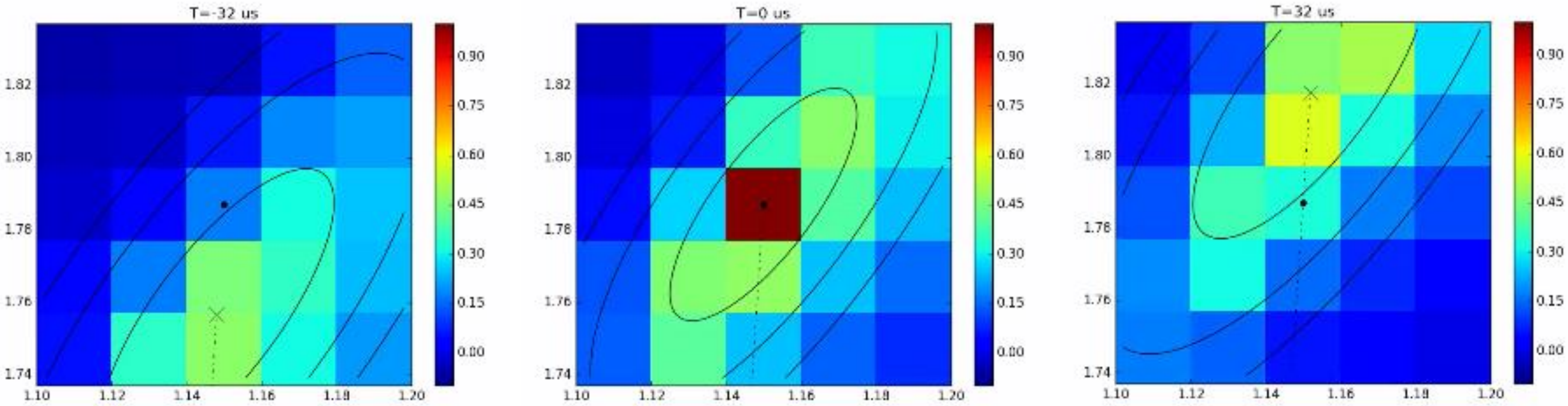
- **The time delay method always overestimate the burst velocity**

The time delay method may even indicates a wrong direction



The time delay method suggests inward propagation

The full 2D movie shows an outward propagation



Conclusion

- Comparison study of the coherent density peaks in TCABR Tokamak and Texas Helimak reveals several some similarities:
  - The burst rate decreases for larger radial position
  - The burst shape depends on the radial position, with the burst duration and size increasing outward
- However, the rising and falling time asymmetry observed for larger radius in TCABR does not occurs in Texas Helimak
- The full 2D array of probes in Texas Helimak allows to see that the burst shape is elongated with tilted axis
- The 2D burst structure propagation in Texas Helimak shows that the time delay method gives wrong velocity estimations