# The current status of the Lithium beam diagnostic at ASDEX Upgrade

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# Outline

Experimental setup

Edge ion temperatures

CX with $He^{2+}$

CX with $D^+$

Edge ion densities

Edge electron densities

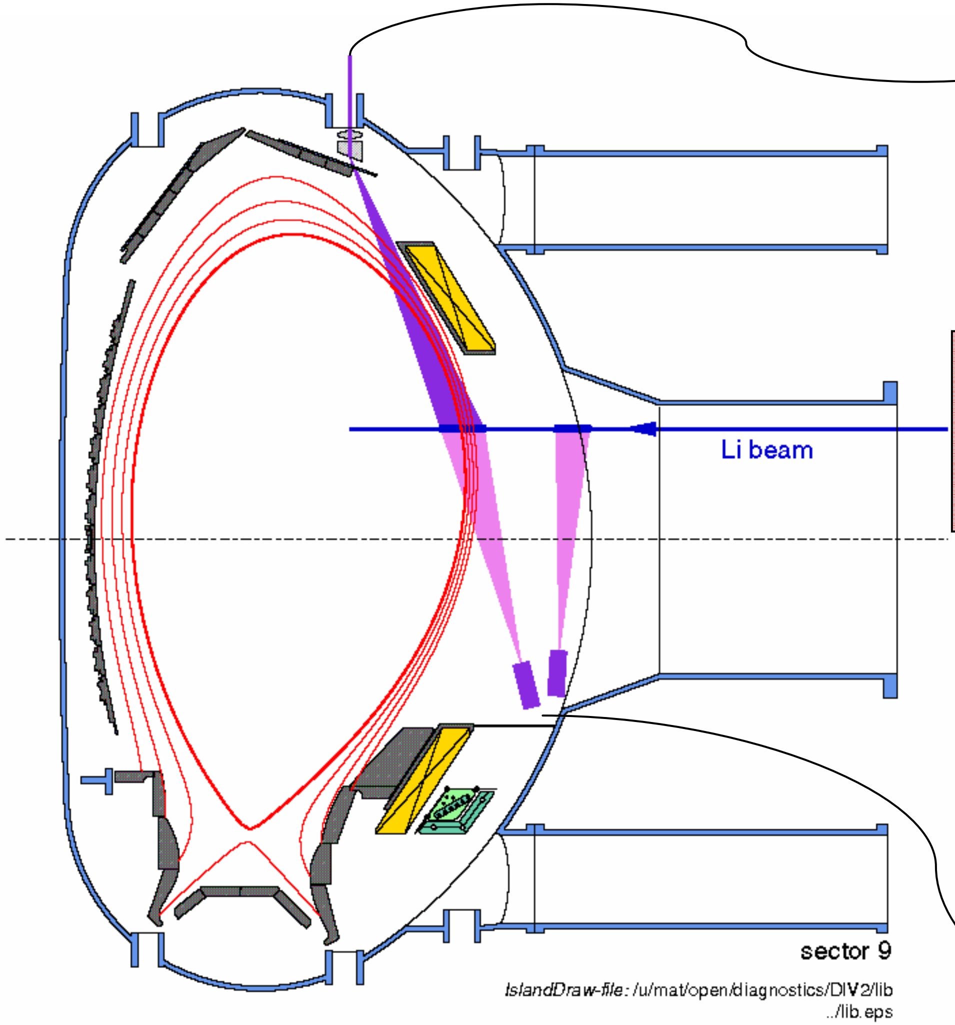
ELM resolved profiles

LID evaluation with Bayes integrated concept

Wide Filters: high temporal resolution

# Experimental setup






## Beam emission spectroscopy

Electron density measurement LID

Li$^0$ (2p-2s) @ 670.8 nm

Li-beam: 30 – 80 keV, 2-4 mA
∅12 mm

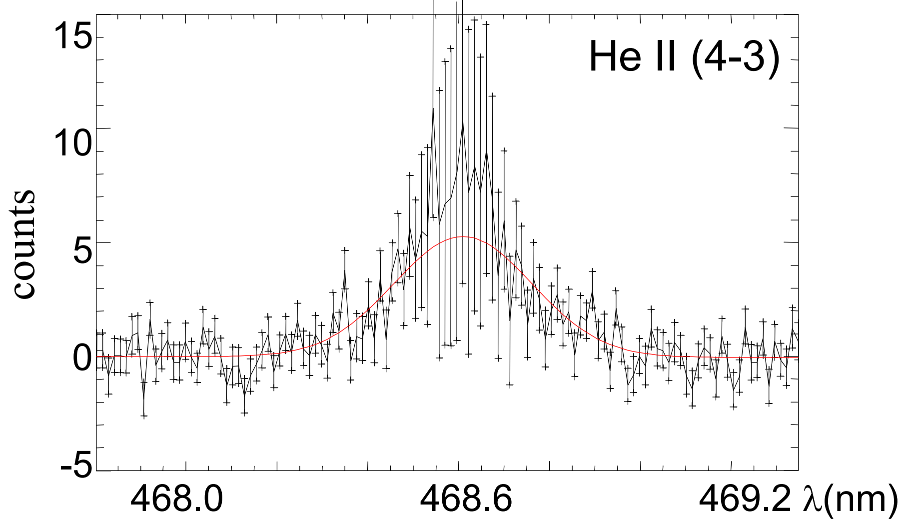
## Charge exchange spectroscopy

Ion temperature measurement LIT
M.Reich - Thesis

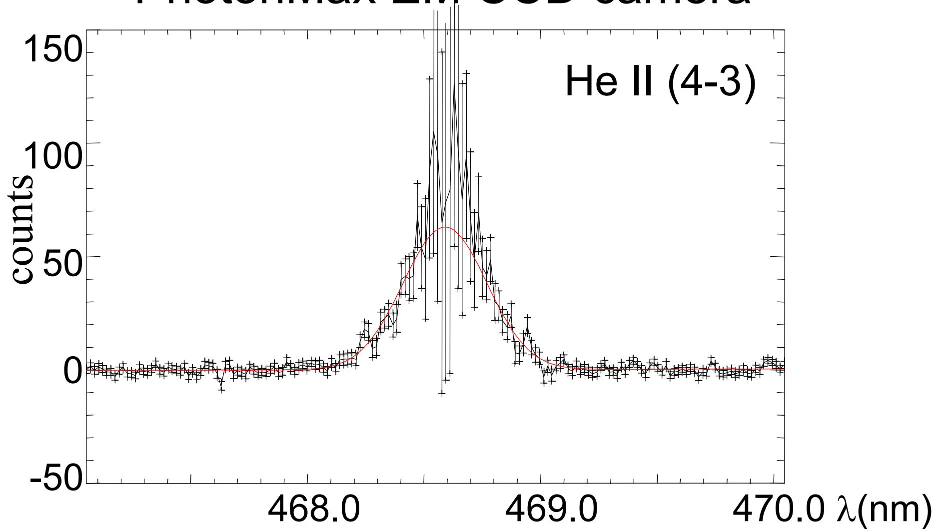
Ion density measurement LIS

# EM CCD improves availability of $T_i$ measurements.

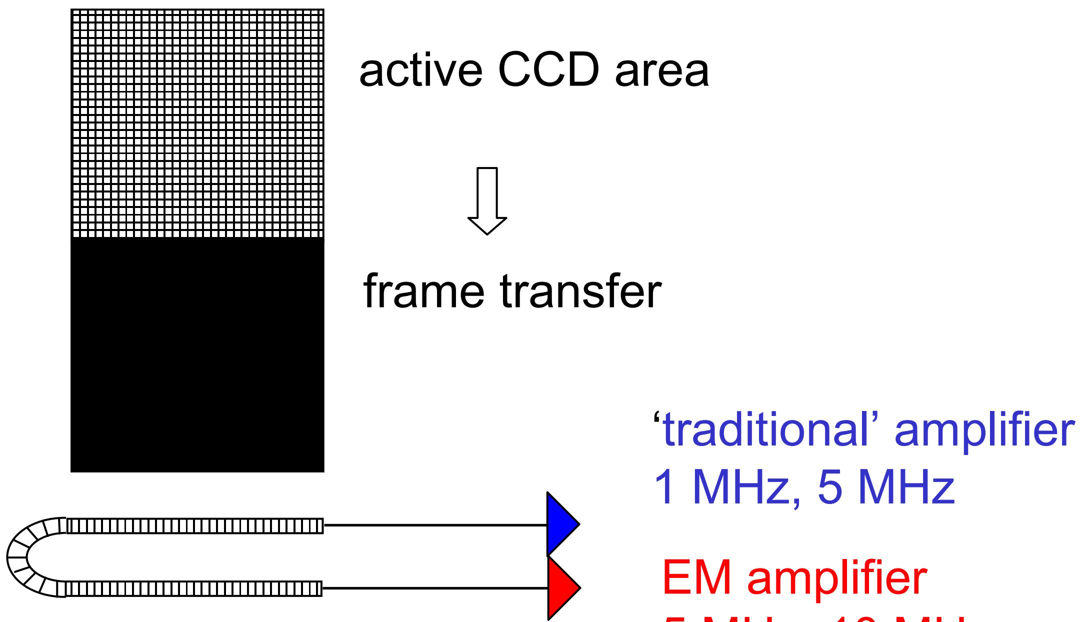
PI Micromax CCD camera




PhotonMax EM CCD camera

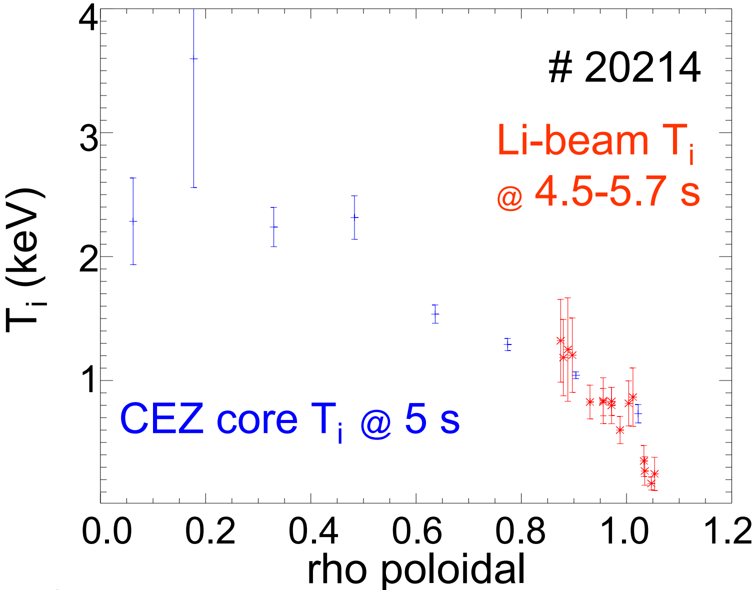


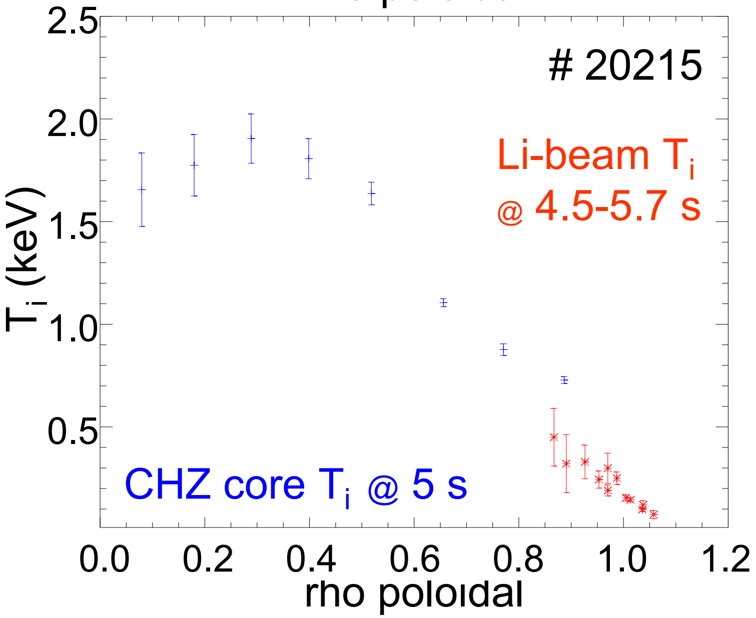

- Signal/noise ratio much improved due to EM technology
- Same radial position
- Measured temperatures agree, Ti = 370 eV
- Temporal resolution: 10 channels (LOS) on one CCD with 4 ms continuously




Extended serial register:
Electron multiplication via impact ionisation

# Edge ion temperature profiles



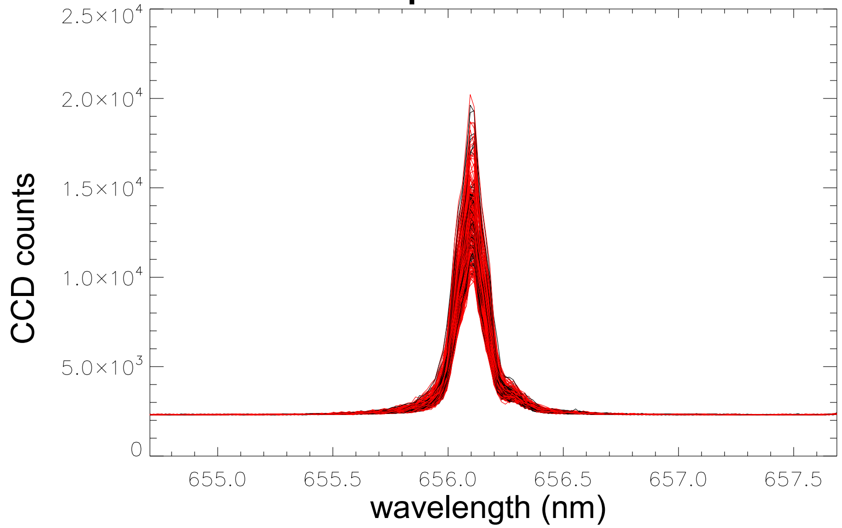




- Spatial resolution ~ 5 mm
- Temporal resolution not available:

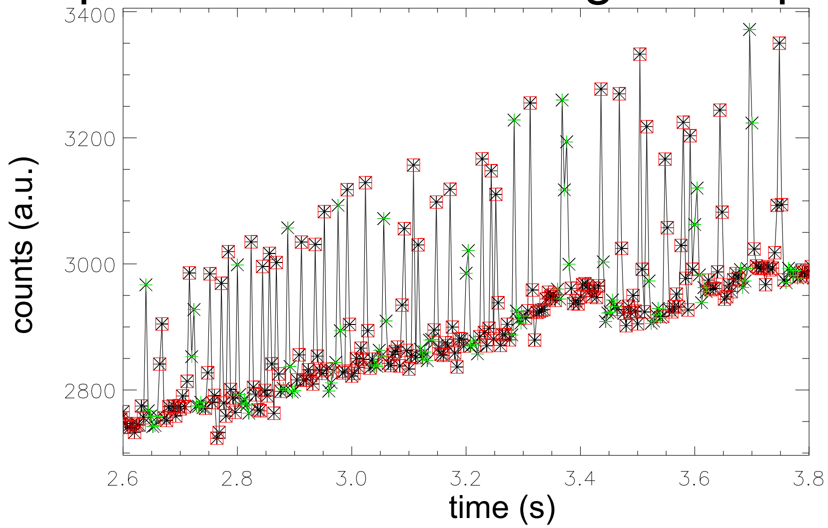
  Signal must be integrated over 1-2 s.
- He concentration > 10%.
- L-mode o.k.
- H-mode: only for $f_{ELM}$ < 100 Hz.

# New: CX measurements also possible with $D^+$ ions.

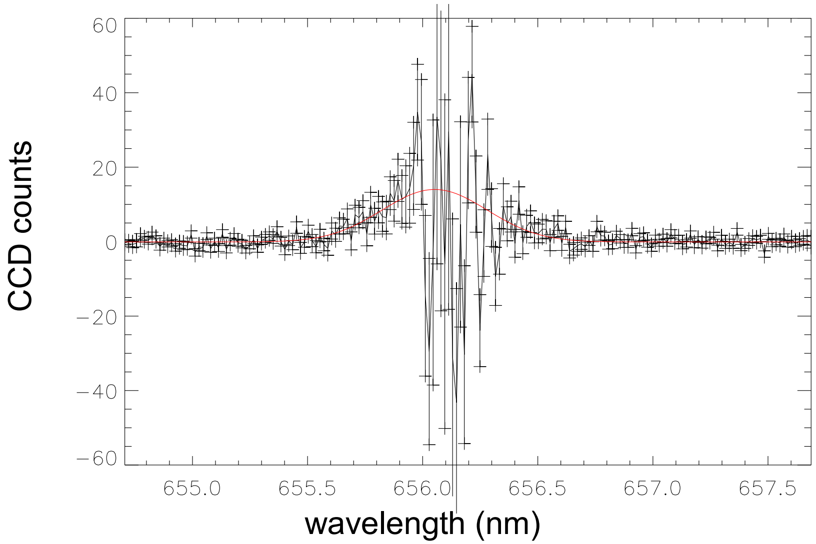
Raw data: spectrum




temporal evolution of integrated spectrum



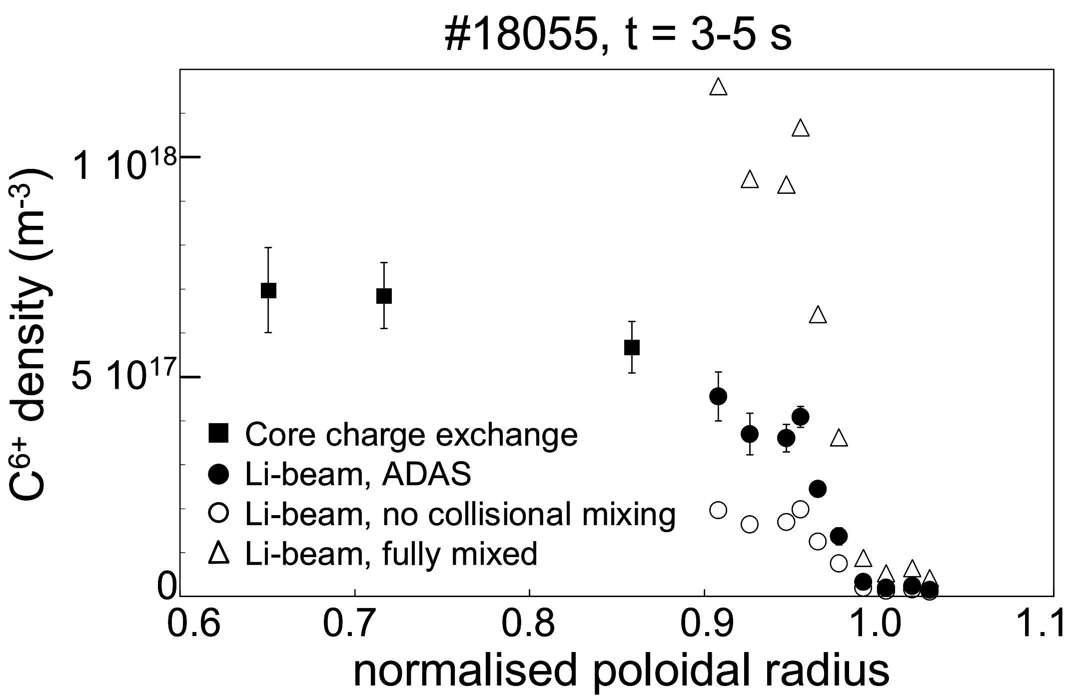

net spectrum

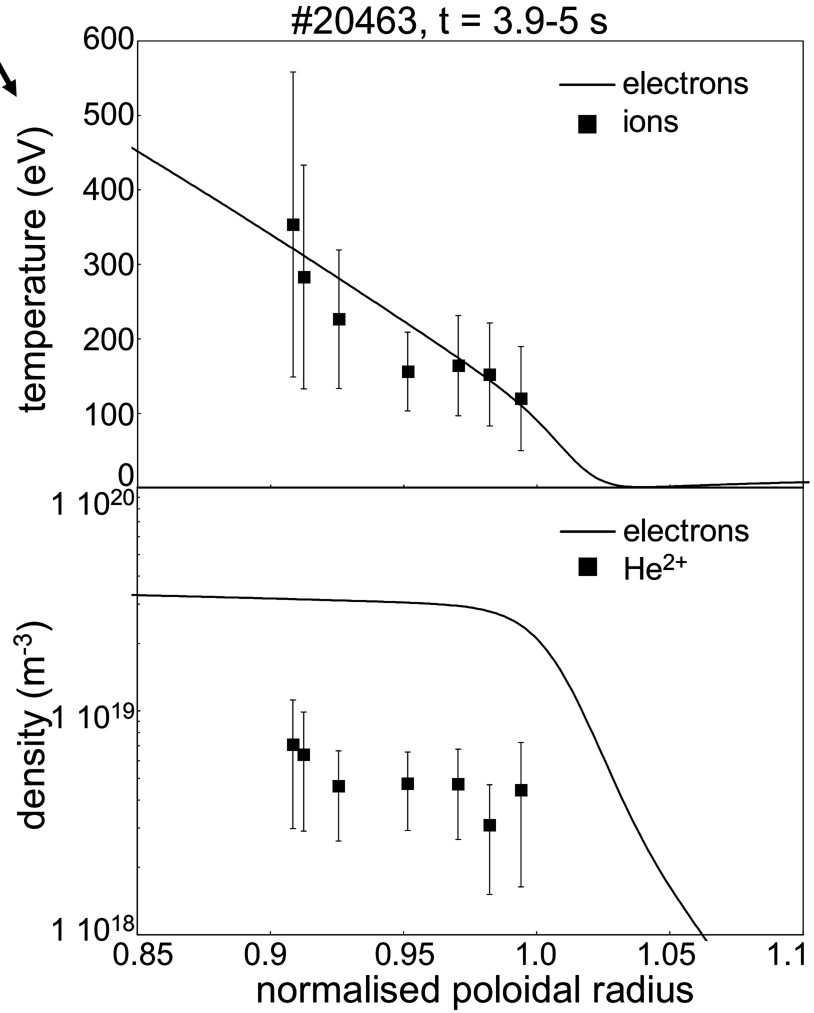



- No ELMs or regular ELMs
- ELMs have to be cut out
- $\Delta t > 500$ ms integration time
- Fit difficult because centre is always dominated by photon statistics of passive line emission
- Inclusion of CXS_fit in progress

# Edge ion densities, examples

$C^{6+}$ $He^{2+}$



# Beam emission spectroscopy BES

$$Li^0 + plasma \rightarrow Li(2p-2s)@670.8nm$$

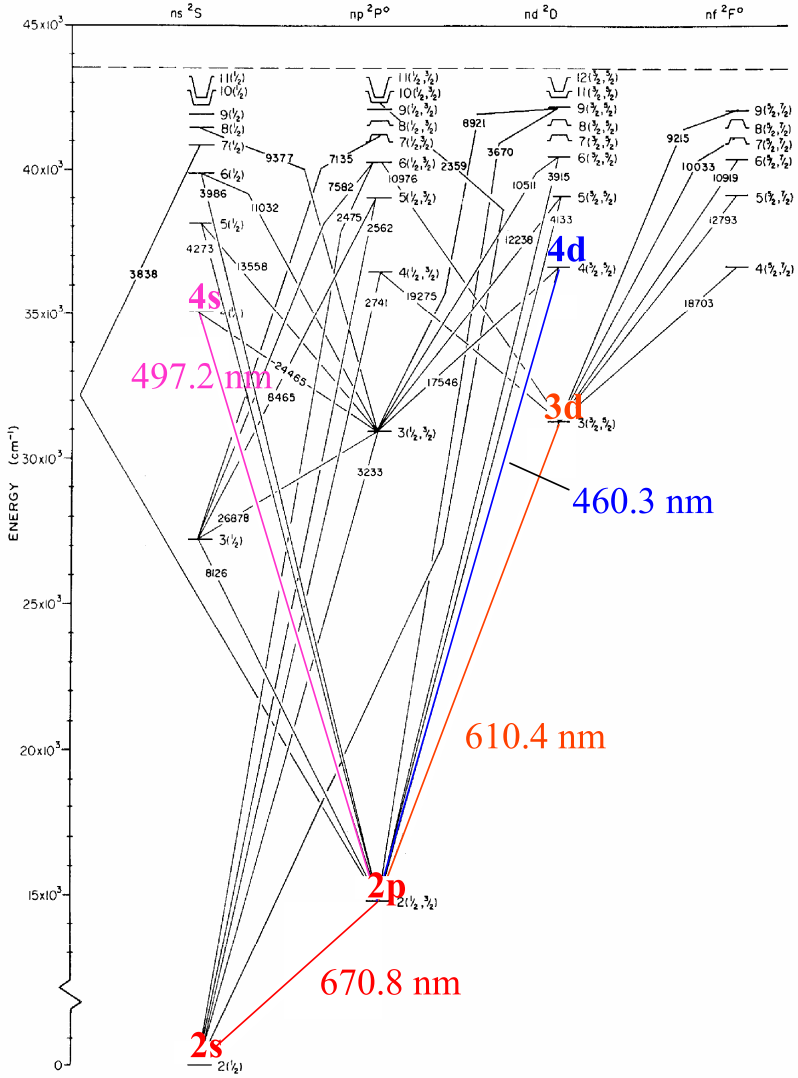
## Lithium beam attenuation code:

$$\frac{dN_i(z)}{dz} = \left[n_e(z)\cdot a_{ij}(T(z)) + b_{ij}\right]\cdot N_j(z)$$

$N_i$ relative occupation of state i (i=2s, 2p, …4f, $Li^+$)
$a_{ij}$ rate coefficients
$b_{ij}$ Einstein coefficients

$a_{ij}$:
Inelastic collisions with
protons, electrons and impurities

$b_{ij}$:
radiative transitions




Li I Grotrian diagram

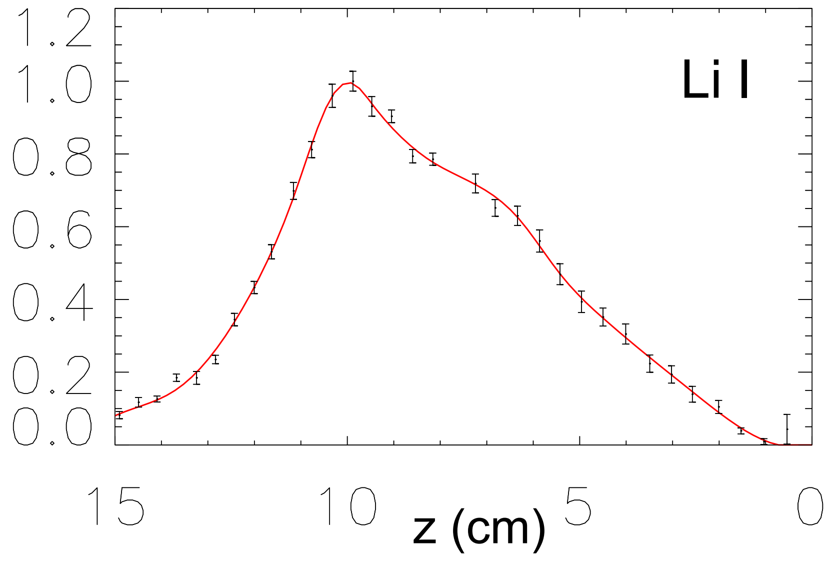
References:
Schweinzer et al: At.Data Nucl Data Tables 72 (1999) 239-273
Brandenburg et al: PPCF 31 (1999) 471-484

# Electron density measurements



Measured profile + errors

Produce fit to data




This relative profile $Li_{2p}(z)$ is directly related to occupation number of Li(2p). $\alpha Li_{2p}(z) = N_{2p}(z)$, $\alpha$ = const.

$\alpha$ is determined via 2 boundary conditions: $N_i(z=0) = \delta_{1i}$
$N_1(z_{end}) = 0$

Use second equation of

$$\frac{dN_i(z)}{dz} = \left[n_e(z) \cdot a_{ij}(T(z)) + b_{ij}\right] \cdot N_j(z)$$

to get $n_e$.

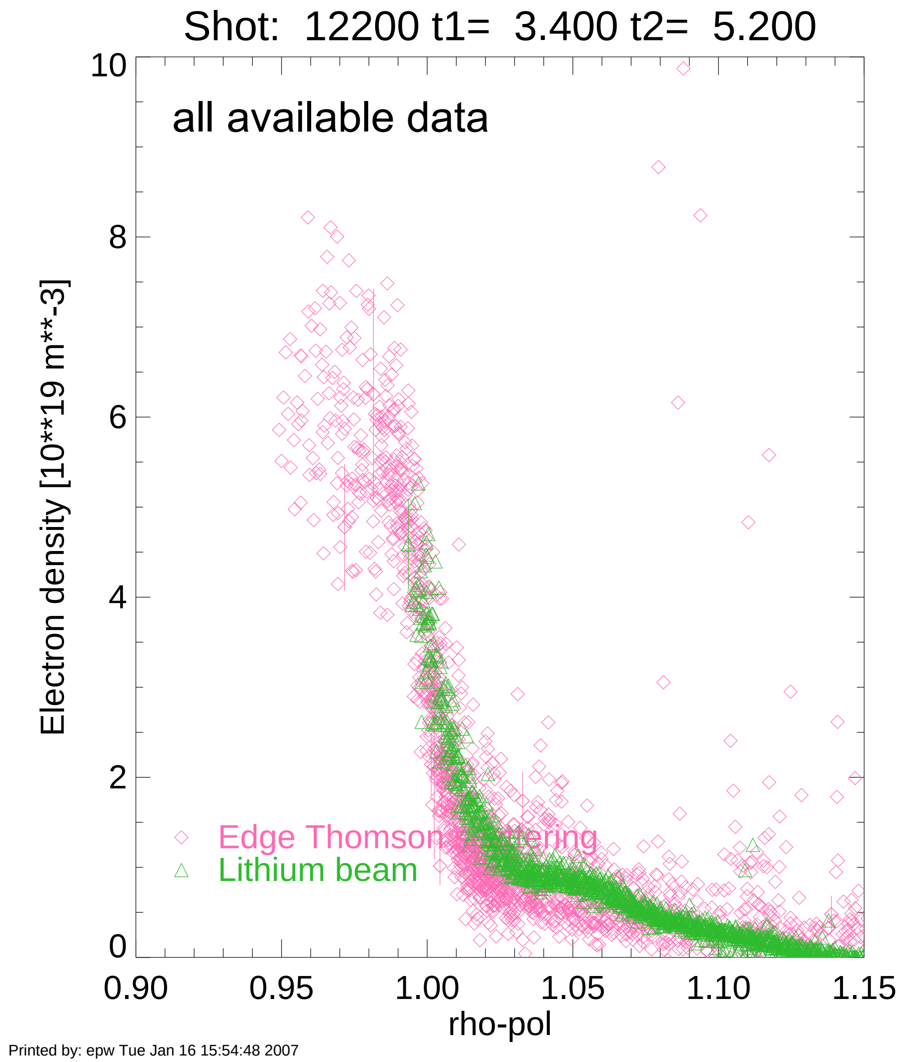
Lithium beam attenuation code

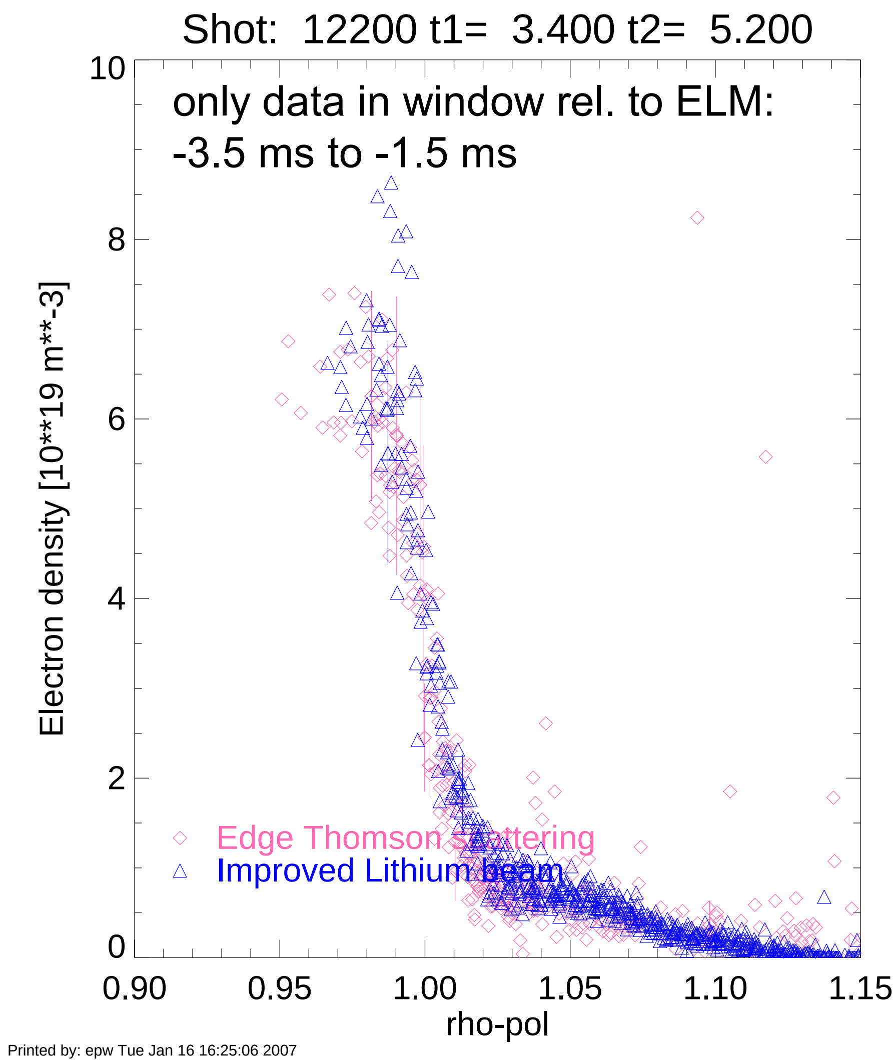
Singularity near maximum of Li(2p) profile.

# ELM resolved with int times ~ 1ms

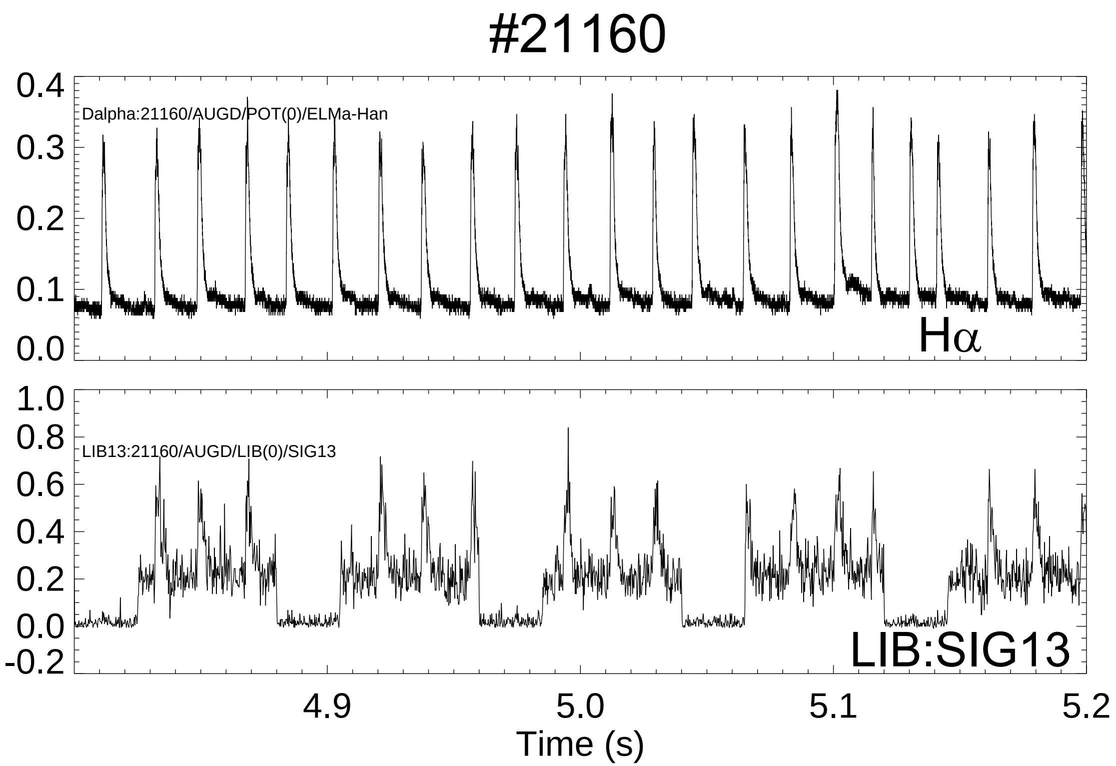
## Time interval extended to include Raus – scan:

LID with 1 ms temp. resolution



# Binning of raw signal relative to ELM yields density profiles across ELM.



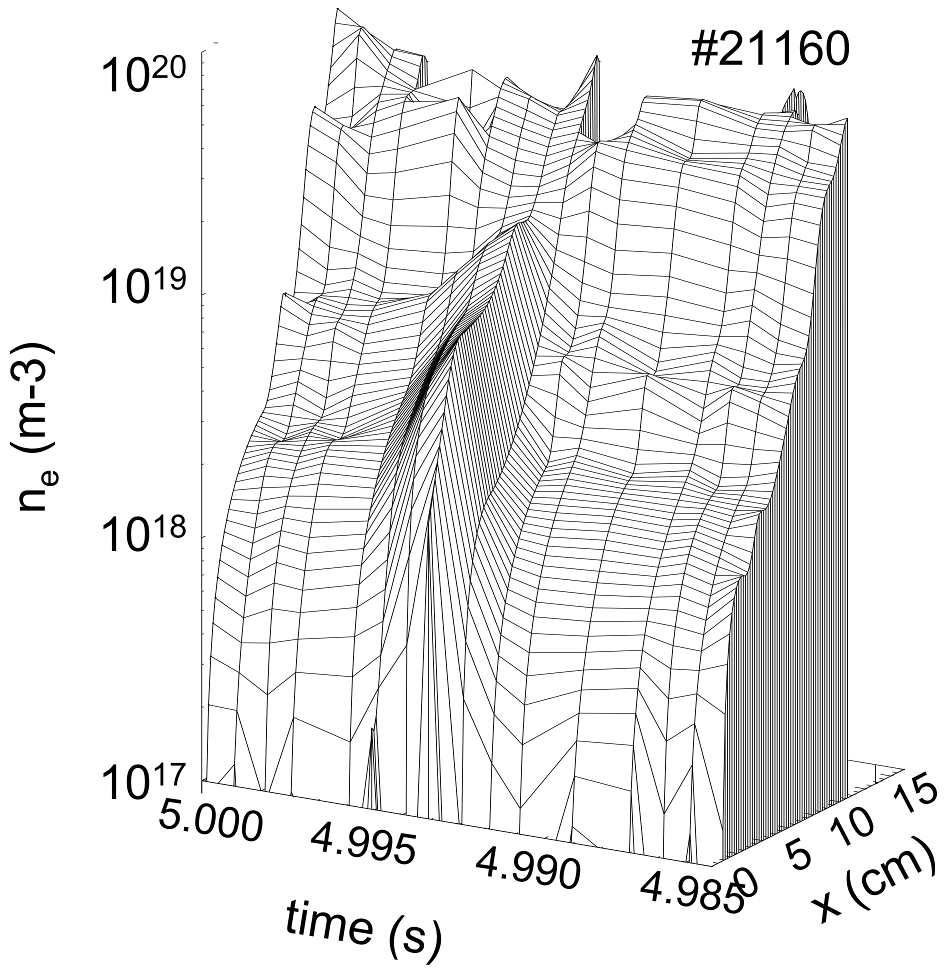

- Choose time interval with regular ELMs
- Determine for every t in LIB signal:

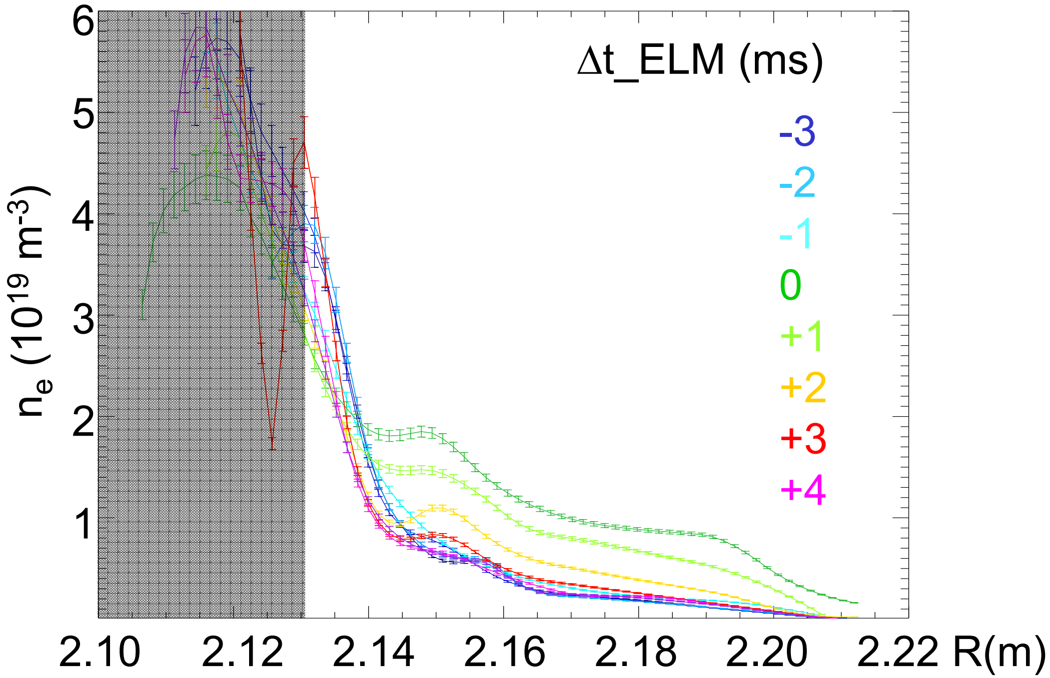
  Δt to previous ELM

  Δt to next ELM
- Add all signals with same temporal distance to ELM
- Calculate density profile

Attention:
ELMs should have about same size.
ELM shotfile must be checked carefully: no missed or additional ELMs.
Lithium beam must be very stable: no sparks.

# $n_e$ gradient in ETB region is recovered after 3 ms.



Determine electron density profile

given

Additional information: $n_e$ profile monotonic

Measured data of Li I (2p-2s) profile and their likelihoods

! accurate error determination !

Measurements of other diagnostics

Description of profile: 13 knots using Hermite polynomials

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Lithium beam attenuation code

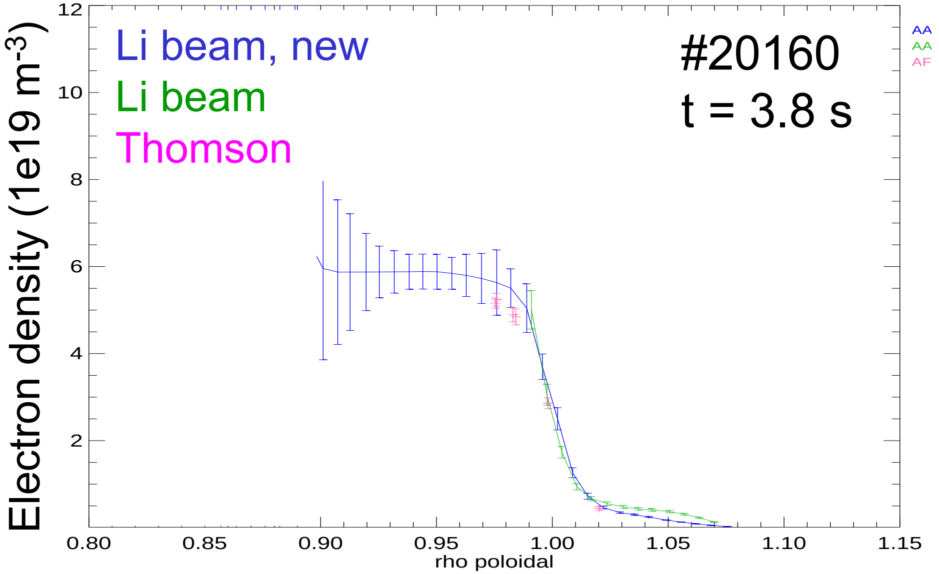
⇩

Li I (2p-2s) profile

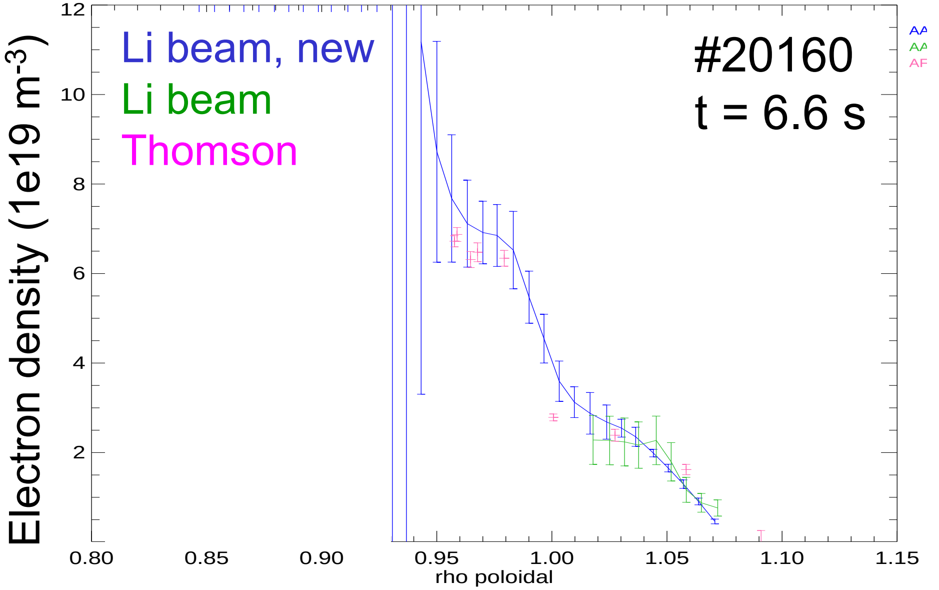
⇩

Chi² fit to the data * factor $\alpha$ to determine 13 knots and $\alpha$.

# Electron density profile evaluation now beyond point of singularity.




cview-prof (gdc) v2.49 - User: epw - Fri Jan 19 11:21:35 2007 /afs/ipp/home/e/epw/cview/StdSet/compRRF.cvp : 20160



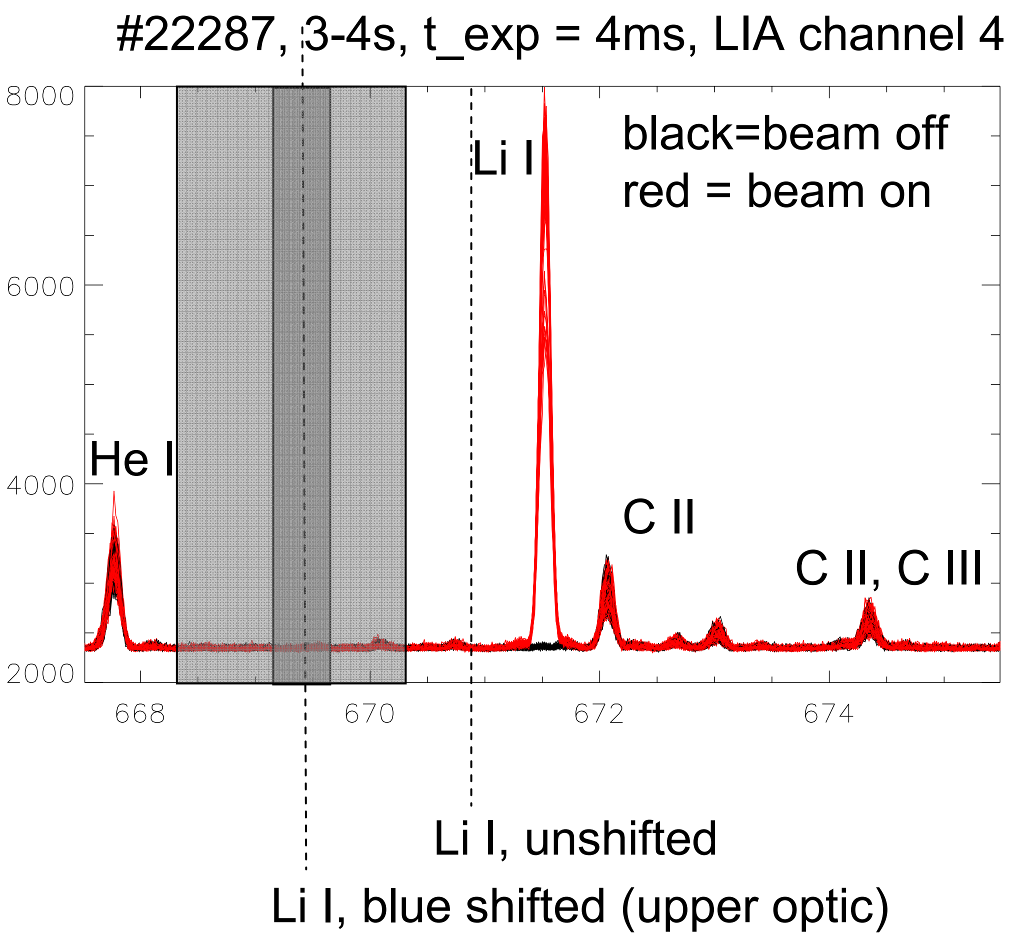

Medium core density:

- Pedestal well determined.
- Temporal resolution: 1 ms
- So far LID density evaluation stops just before turn.
- New: high certainty of profile up to $\rho_{pol} = 0.93$

High core density:

- So far LID density evaluation stops in SOL.
- New: reliable profile up to $\rho_{pol} = 0.96$

# Latest improvement: broader filters




- New filters: 2 nm FWHM, before 0.5 nm
- Easier to change to different beam velocity (no tilt adjustment necessary)
- Higher transmission (85%, before 50%)
- Signal ~ factor 10 larger
- Now 1.5 – 4 sec with 20 kHz (before 5 kHz)

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Allows faster data acquisition:

1.5 – 4 sec with 20 kHz (before 5 kHz)

## Summary

### Ion temperature profiles

- No temporal resolution ($\Delta t > 500$ ms)
- Good spatial resolution (5 mm)
- C: concentration now too low (< 0.4 %)
- He: good data if concentration > 10%
- D: good data if plasma quiet, e.g. ohmic or L-mode

### Ion density profiles

- Collisional mixing is important at the edge.

### Electron density profiles (main business!)

- Excellent temporal resolution (~ 1 ms).
- Li-beam electron densities can resolve ELM, if several light profiles are binned relative to ELM.
- Integrated concept: edge pedestal densities can be determined up to $n_e^{PED} \sim 7\ 10^{19}\ m^{-3}$.
- New filters give more photons, more flexibility and allow faster data acquisition (20 kHz).