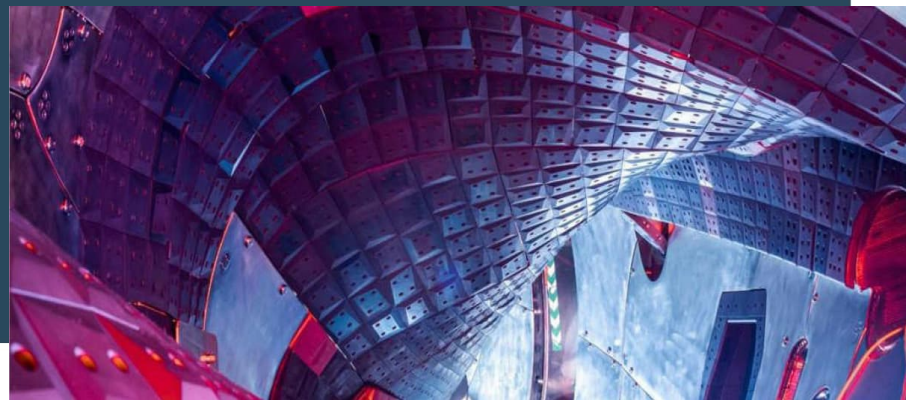
MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

Status of the profile analysis

Marc Beurskens for E3-Dia1 and E3-Dia2 and heating

Max-Planck-Institut für Plasmaphysik (IPP), Greifswald, Germany



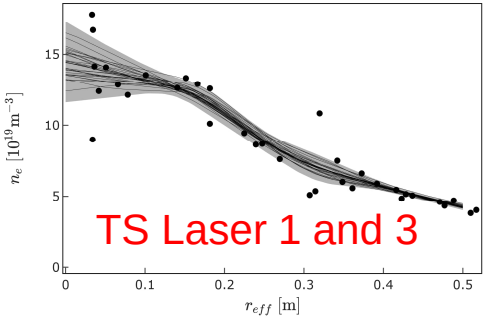
EUROfusion

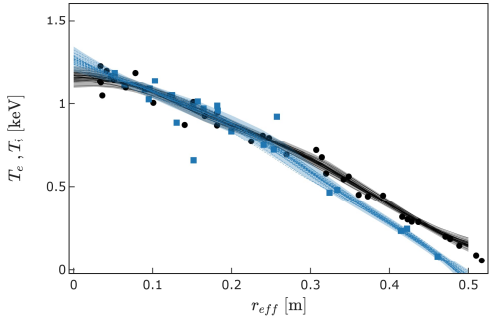
This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Profiles of most diagnostics are available: recommended tool is W7xdia or ProfileCooker for easy access to profiles:

TS (BOZ, or fast analysis), ECE (cold resesonance Minerva), CXRS (JAVA), XICS (Python IDL code)

W7X20230323.032, 5.0000-5.3000





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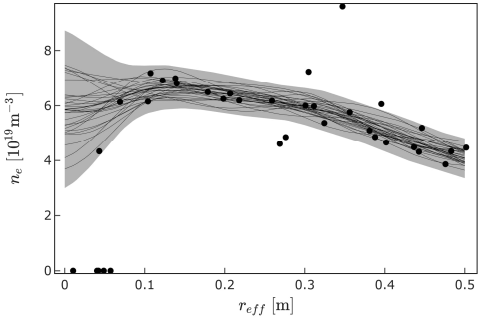

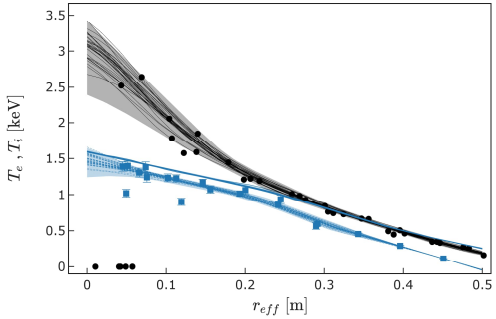

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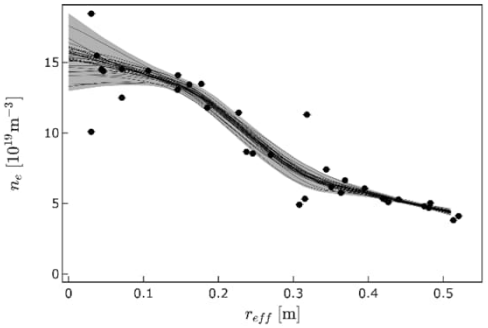

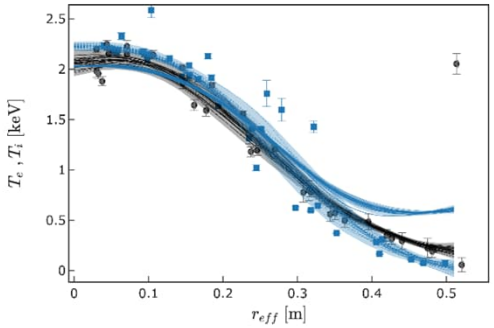

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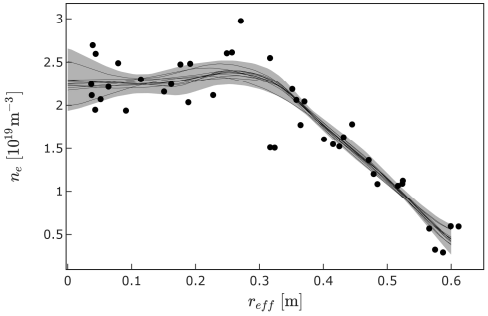
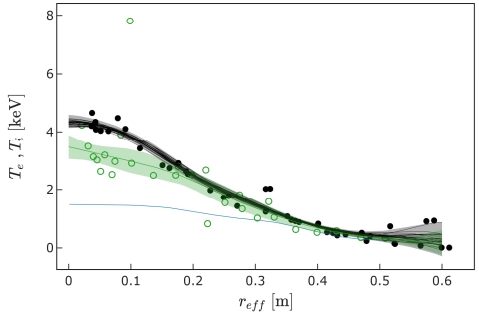




use w7xdia library or profile-cooker (https://w7x-profiles.ipp-hgw.mpg.de/) to access this data – ref: Sergey Bozhenkov

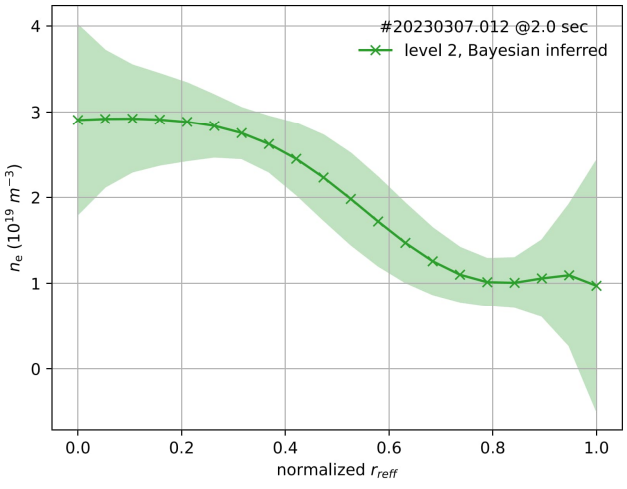
ECE diagnostic data of OP2.1 using Minerva analysis

Level 0 - Cold resonance mapped profile

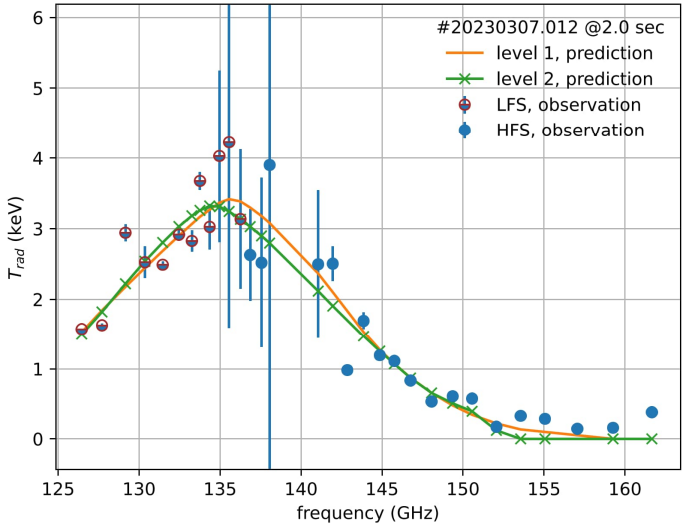
Level 1- Bayesian inferred profile from integrated forward model with parametric prior

Level 2 - Bayesian inferred profile from integrated forward model with non-parametric prior

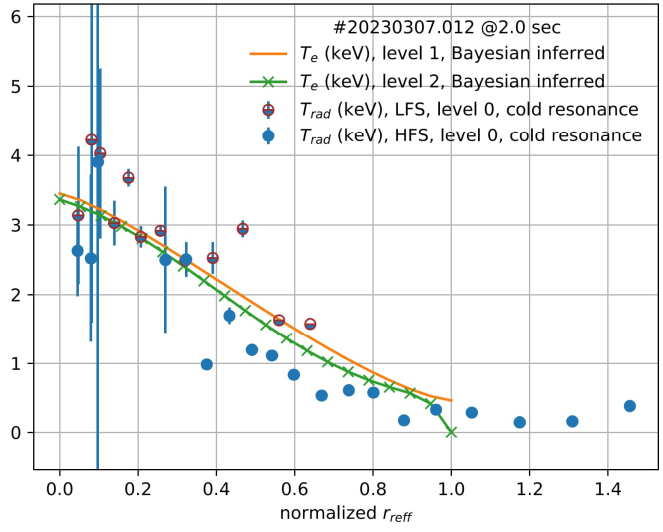
n_e profile



T_{rad} profiles



T_e profiles



- Level 0: data available in archiveDB for all valid OP2.1 shots
- Level 1: in progress, takes 2-6 hrs for 10s shot
- Level 2 Single profile computational time 2-3 days

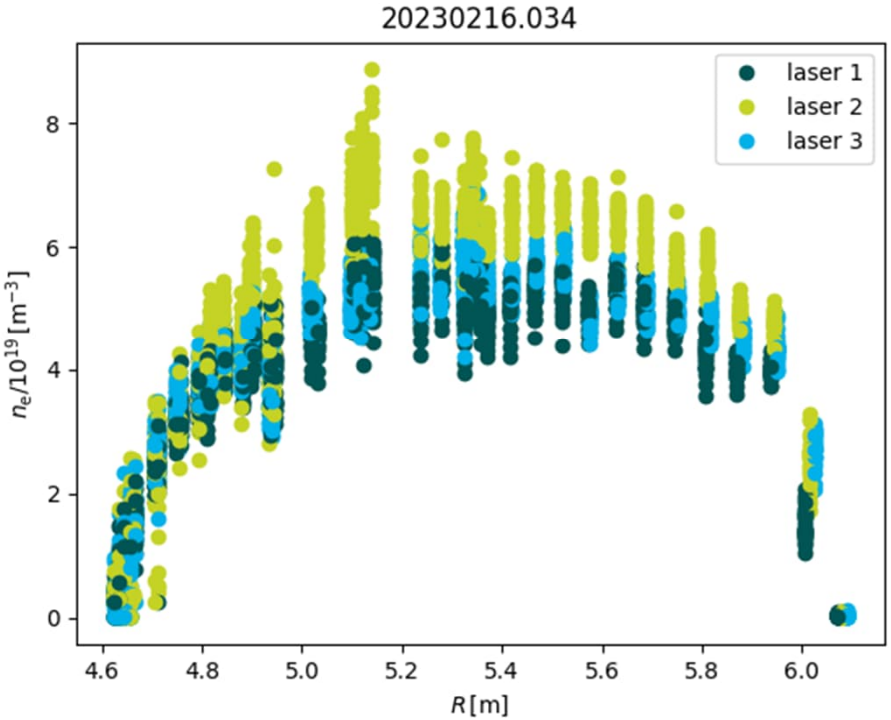
N. Chaudhary, M. Hirsch et al

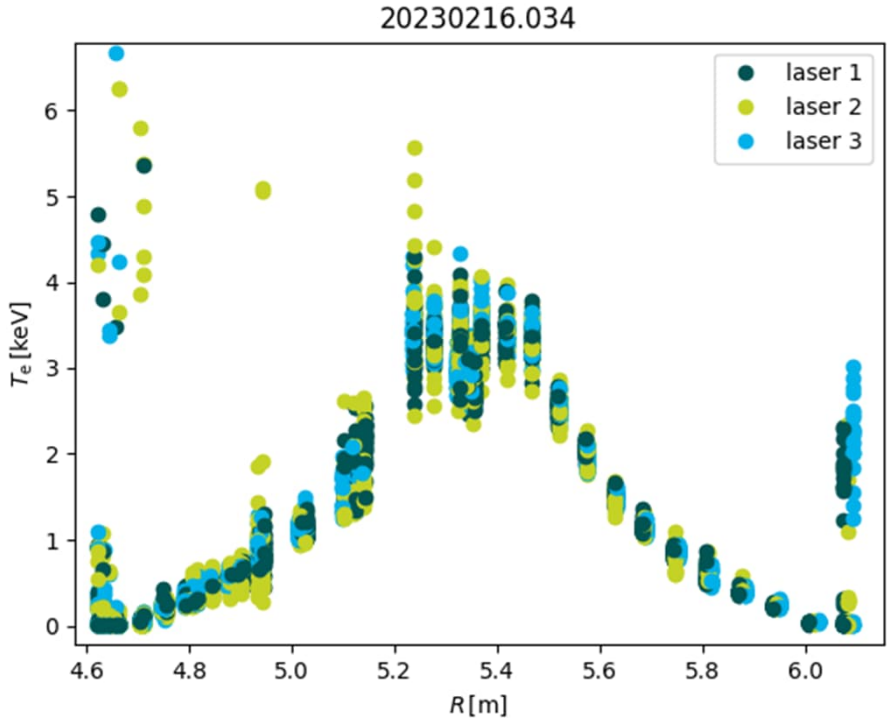
Thomson scattering example with Minerva code

- **Ne analysis sensitive to alignment/vibrations**

  → Laser 1 and 3 are probably of good quality, laser 2 probably of lower quality.

- **T_e is robust against alignment changes.**
  - Profiles are reliable even if the laser position has changed.





G. Fuchert, J Brunner, S Bozhenkov

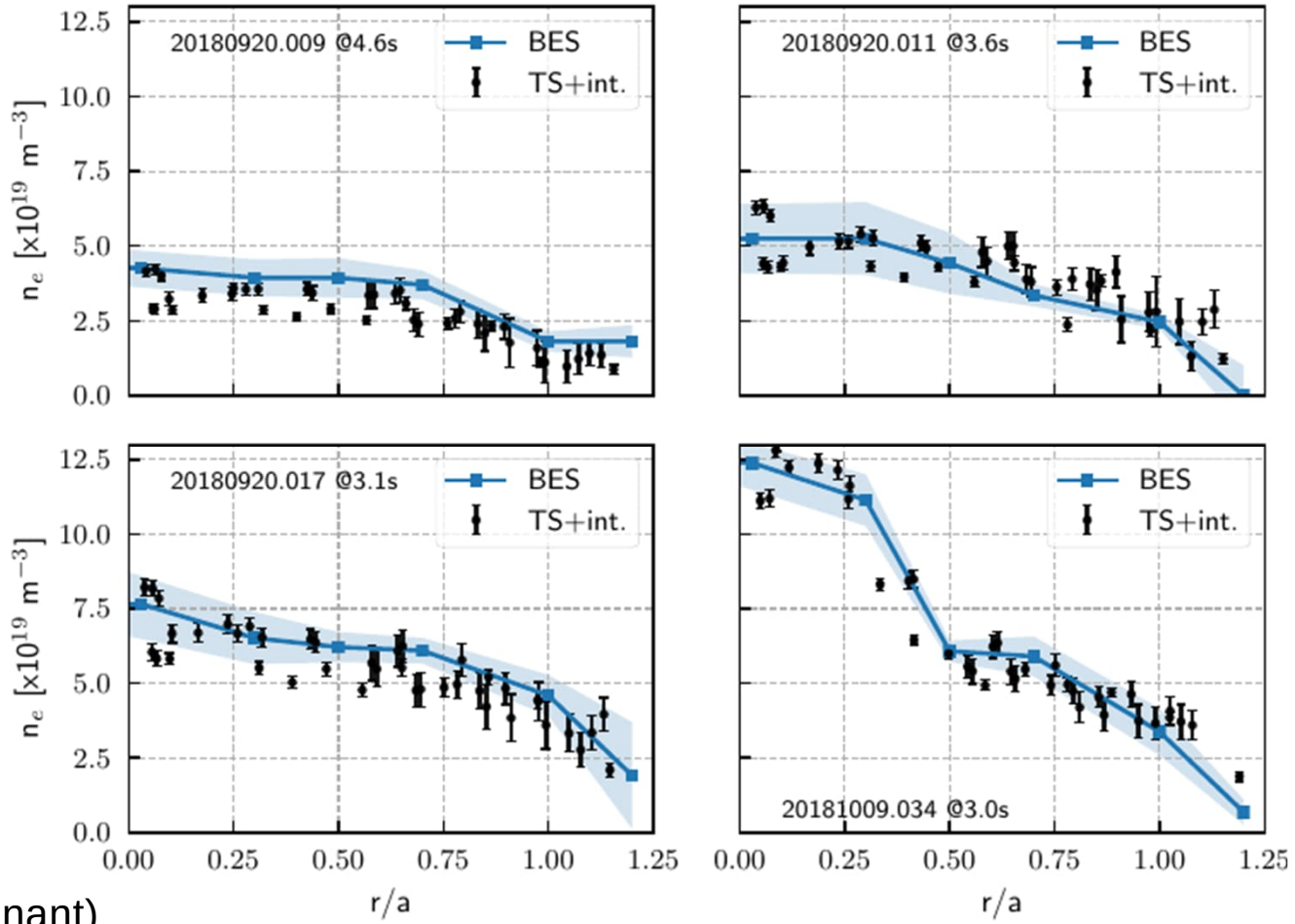
Thomson scattering Minerva analysis is available

- **TG profiles priority list has been analysed**
- **Overall analysis is at November 2022 an running**
- **The new data are not yet in the profile cooker – data format has changed**
  - **Preliminary profiles from Sergey Bozhenkov already available**
  - **Preliminary profiles from Jakob Brunner already available**

Electron density profile inference from BES/HES

Test set:

- 3 ECRH heated discharges at different density levels in standard magnetic configuration with NBI blips (20180920.009 / .011 / .017)
- 1 NBI heated discharge in high mirror configuration exhibiting a peaked density profile (20181009.034)
- Data for comparison: Thomson scattering data renormalized using the interferometer data



Results:

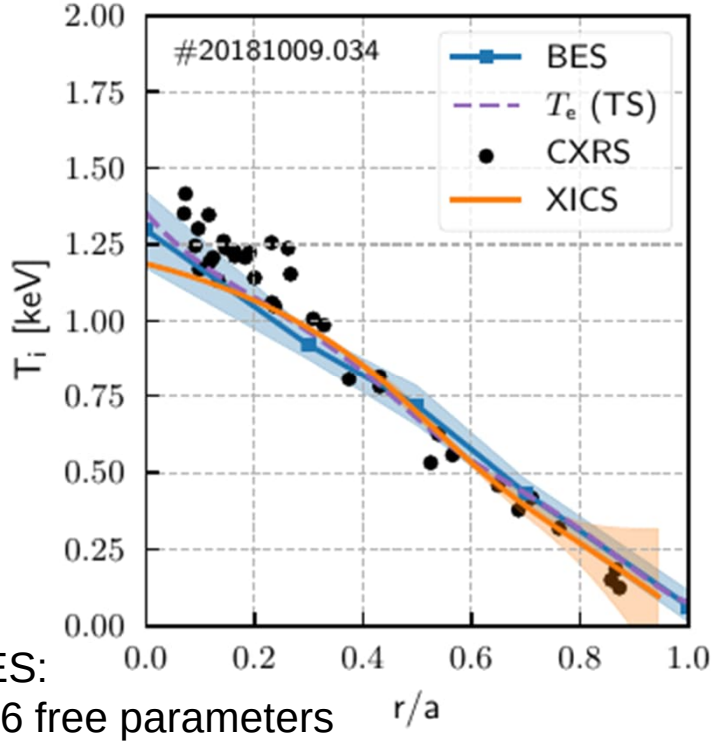
- Profiles well reconstructed
- Model not able to infer physical profiles (gradients) on finer grid
- error bars: statistical error + estimated systematic uncertainties (which are dominant)

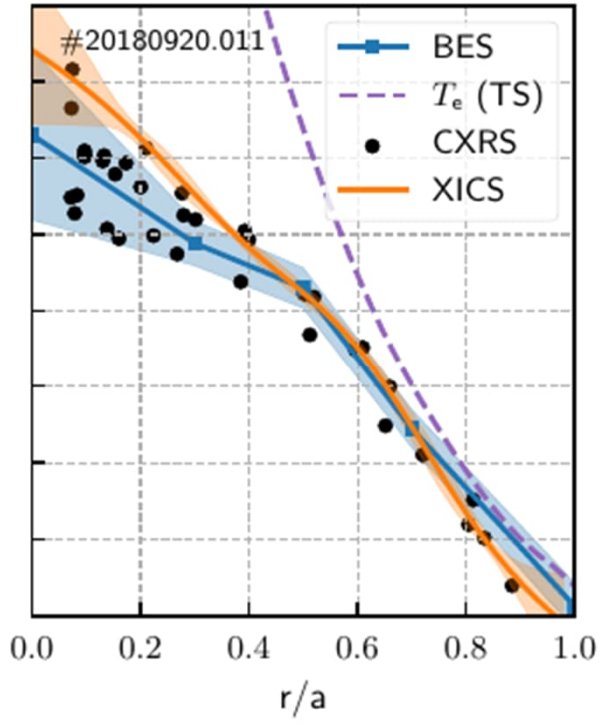
S. Bannmann, O Ford

Ion temperature profile inference from BES/HES

Information about ion temperature contained in halo emission → Doppler broadening + CX diffusion coeff.

- Ion temperature profile can be inferred simultaneously with density profile
- Inferred profile agrees very well with XICS (corrected by -200eV) and CXRS data from r/a=0.2 to 0.8

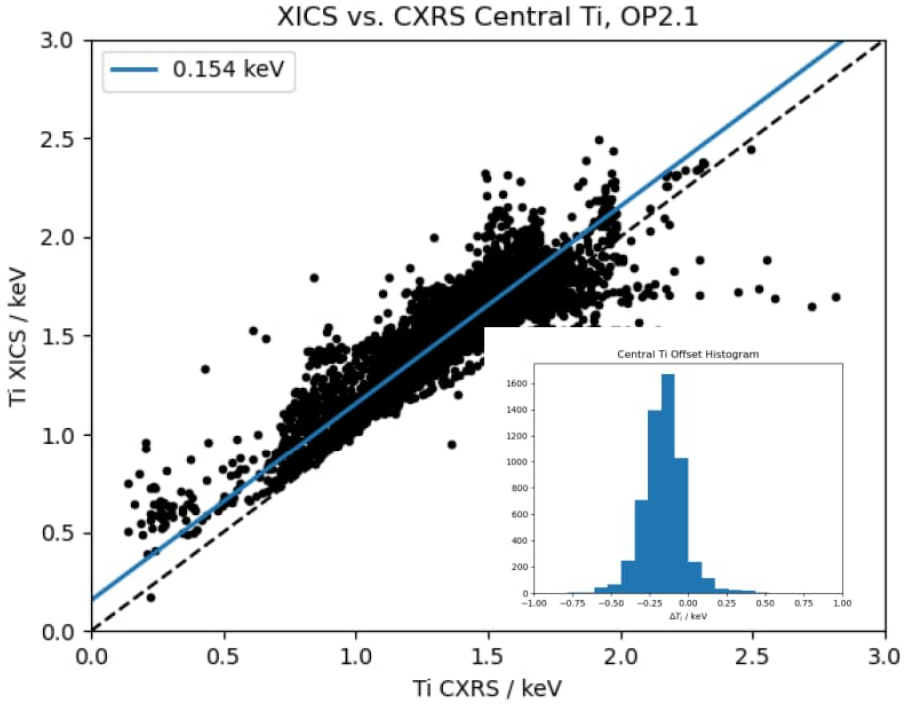


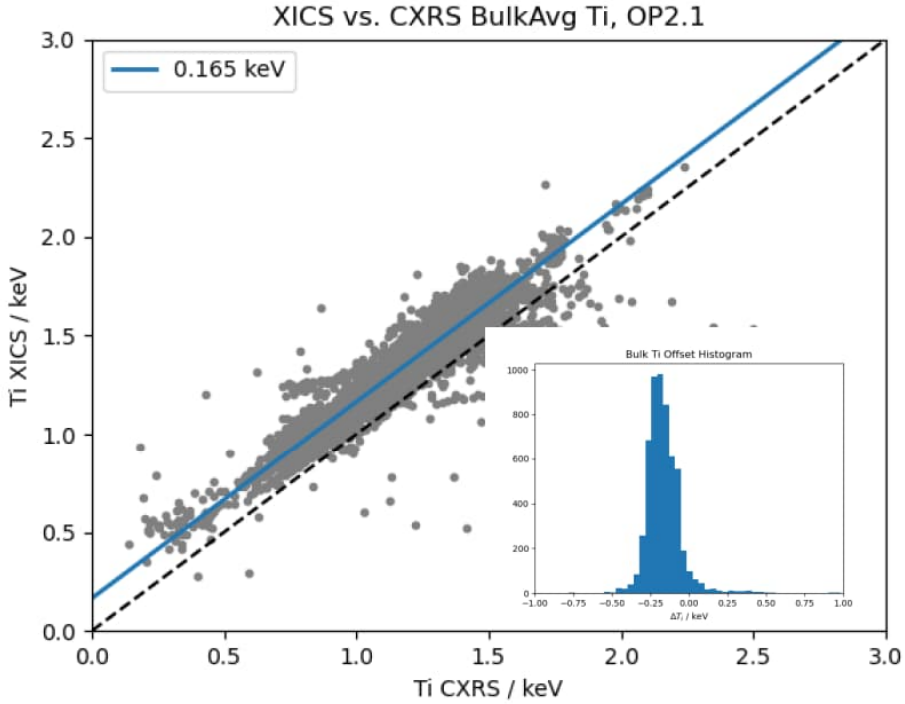


- No bulk profile analysis with BES/HES: on 6 cores and profiles represented by 6 free parameters a single time point takes around 15 minutes. A fast, less accurate evaluation ignoring the halo emission and modeling takes around 5 minutes.

S. Bannmann, O Ford

Ti from XICS and CXRS: 160 eV offset to be subtracted from T_{XICS}





- Averaged (5620 data points) 160 eV T_i offset between XICS and CXRS to be considered
- Most probably an additional XICS instrument function (T_i XICS – 0.16 keV) use w7xdia or profile-cooker for data

- - - ▸ E_r can also be provided by both diagnostics on request (requires Thomson scattering profiles)

A Langenberg, N Pablant, Oliver Ford

Mitigation strategy to guarantee OP2.2 reliable profile availability

Standard/interpulse analysis: **move away from MINERVA** to assure that:

1) all R.O.‘s know and can maintain their sofware
2) Provide fast(er) interpulse Analysis

Move away from SCHEDULER and (initially) return to <u>decentral analysis triggering</u>

1) SCHEDULER had reliability issues: access rights, bugs, personell availability…
2) Many days where the SCHEDULER was not available… end hence delay in slow data processing

OP2.1 standard analysis codes – Launched by the Scheduler

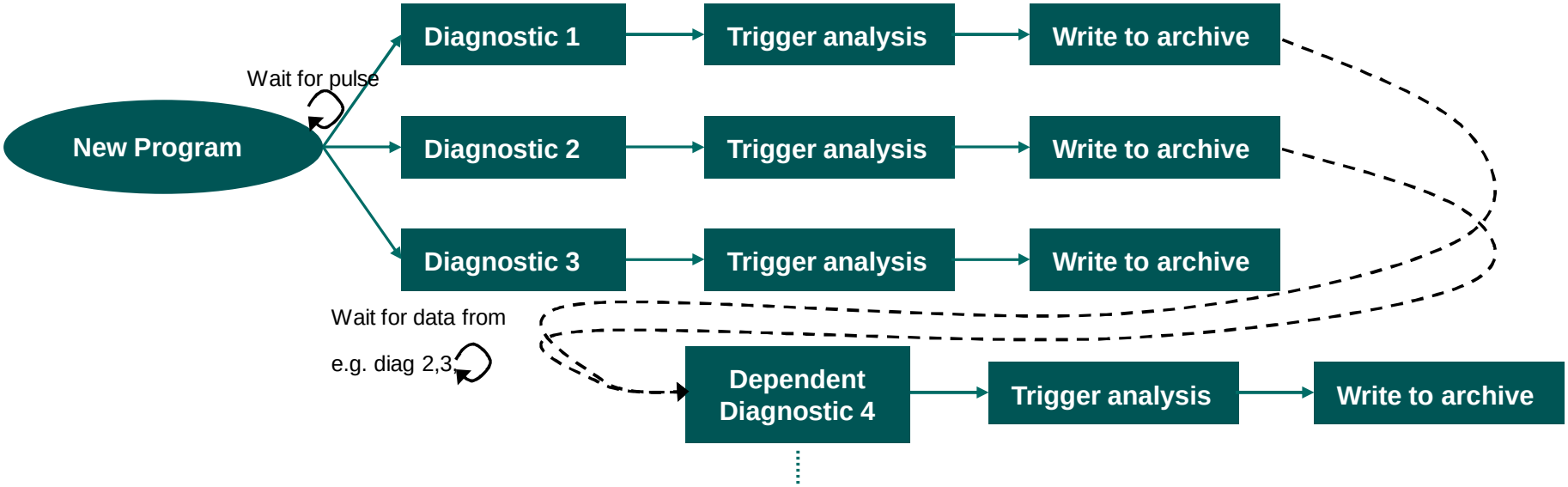
Diagnostic	Standard analysis	Advanced analysis:
Thomson scattering	Minerva code (now ready)	idem
ECE	Minerva code	idem
XICS	Python/IDL script (now ready)	Minerva
CXRS-T_i	JAVA code	Ask R.O. expertise
CXRS-n_{imp}	Python/Minerva	Ask R.O. expertise
Zeff line	Minerva (TS dependency not available during campaign)	Ask R.O. expertise
Wdia	Minerva	
ECRH-depo profile	No code available (not ready during campaign)	
NBI-depo profile	Look-up table for P_{NBI} WEB service for S_{NBI}	

Heavy MINERVA dependency in Standard Analysis

Planned for OP2.1 standard analysis codes

Diagnostic	Standard analysis	Advanced analysis:
Thomson scattering	Minerva code → Python (not ready)	Minerva
ECE	Minerva code → Python	Minerva
XICS	Python/IDL script (not ready)	Minerva
CXRS-T_i	JAVA code	Ask R.O. expertise
CXRS-n_{imp}	Python/Minerva – not critical	Ask R.O. expertise
Zeff line	Minerva – not critical	Ask R.O. expertise
Wdia	Minerva → matlab (ready)	Minerva
ECRH-depo profile	Still no code available	
NBI-depo profile	Look-up table for P_{NBI} WEB service for S_{NBI}	Ask R.O. expertise

Profile analysis in OP1.2: decentralised on Diagnostic PCs

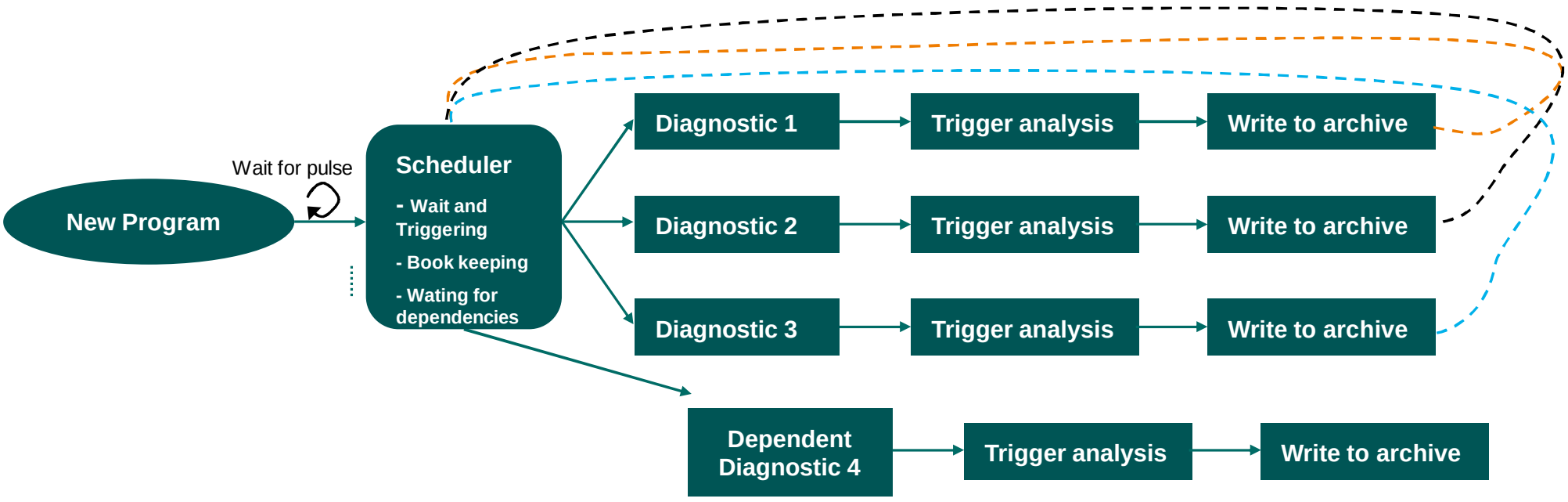


Each diagnostic had a code snippet on the diagnostic PC:

- that waited for a new pulse to occur
- OR for data of another diagnostic to be available,

Completely decentral analysis without book keeping, worked reliably → reprocessing was a nightmare

Analysis Chain of OP2.1: quasi-centralised analysis



Scheduler was a hybrid solution:

- Central book keeping
- launching analysis on decentral diagnostic PCs
- Simplified reprocessing

During operation the scheduler:

- Had issues with diagnostic PC access rights
- Written in Minerva, with limited support/staff during campaign – situation is worse for OP2.2
- Had various reliability issues

For OP2.2 and beyond we follow a two fold strategy

Track 1: Return to decentral analyis chain as in OP1.2: ready for commissioning phase,

- blunt but proven to be reliable
- Code snippets on diagnostic PC waiting for pulse and/or dependencies
- Difficult reprocessing of the chain, as no book keeping

Track 2: parallel development of a central CHAIN analysis (similar to JET-CHAIN1):

- Choice of professional data analysis management tool
- Central handling of „standard analyis“ code on analysis cluster (not on diagnostic PC)
- Central book keeping of analysis status.
- Easy reprocessing
- Re-employing advantages of the SCHEDULER, but getting rid of the inherent issues

Employment of a CHAIN1 R.O. and deputy R.O. is desired

VMEC issue going forward

- Current VMEC service ("version 8"), has some small dependency on a few frozen Minerva libraries. I think this can continue running for some years, until the OS/Java versions force an upgrade.

- A new VMEC service ("version 9") has been developed by Jonathan which heavily integrates with Minerva and will be deployed in the coming weeks/months by Michael and Jonathan.

Since V9 would make our entire chain dependent on Minerva (aside from breaking the cardinal rule of "don't fix what ain't broke"), we have asked Michael to deploy the new version at a new address, not replacing the existing V8.

New contract with SEED (Minerva) to assure continued support

Given the importance of Minerva for the IPP program and the number of IPP projects relying on it, IPP strives to maintain Minerva access in the future

Minerva community projects are hosted centrally

long term support (LTS) versions of Minerva

No major changes to the LTS versions supplied to IPP that are not approved by IPP

help desk service, with sufficiently short response to allow an uninterrupted development (1day?)

END

Reference slides

TS analysis status: more info https://indico.euro-fusion.org/event/2770/

Thomson scattering issues OP2.1

- **The analysis software was not ready**
  - Existing code worked well, but needed a lot of attention.
  - Full integration into Minerva attempted for OP2.1, but not completed before the campaign.
- **The measured data in the archive is inconsistent**
  - The time stamps when “a laser” fired are known precisely.
  - Without “expert knowledge” you cannot recover which laser fired, with which energy, and which raw data is associated with that.
- **The laser control was not reliable**
  - Possibly corrupt data and dangerous situations (for the diagnostic, not people)
  - This was binding a lot of our attention in the control room.
- **The lasers were not running reliably**
  - Issues with modified laser setup and hardware components that typically do not require service.
  - Laser service was required during the campaign (not ideal…).
  - One laser actually broke during the final calibration (but enough data was taken).

Thomson scattering Minerva analysis is available

- **TG profiles priority list has been analysed**
- **Overall analysis is at November 2022 an running**
- **The new data are not yet in the profile cooker – data format has changed**
  - **Preliminary profiles from Sergey Bozhenkov already available**
  - **Preliminary profiles from Jakob Brunner already available**

Thomson scattering Minerva analysis is available

- **ArchiveDB/raw/Minerva/Minerva.ThomsonScattering.Profiles/Standard_DATASTREAM/**
  - ne, te
  - ne_std, te_std
  - rho (only for plotting), R, Phi, Z
  - Volume Number
  - (laser ID – not yet implemented)

- **ArchiveDB/raw/Minerva/Minerva.Thomson.Lasers/laser_DATASTREAM/**
  - Has more time slices than the profiles. Need to be matched by time stamp.

- **The profiles are versionized with the latest version being the latest evaluation.**
  - Use the last version unless you have a good reason not to.

Reference slides

ECE analysis status: see also as part of https://indico.euro-fusion.org/event/2672/

Level 0 - Cold resonance mapped profile

ECE Logbook-https://w7x-logbook.ipp-hgw.mpg.de/components?id=QME#dataaccess

Data-streams-

- High resolution 1MHz T_{rad}

http://archive-webapi.ipp-hgw.mpg.de/ArchiveDB/raw/Minerva/Minerva.ECE.RadiationTemperatureTimetraces/relative_calibrated_signal_DATASTREAM/

- 1 kHz T_{rad}

http://archive-webapi.ipp-hgw.mpg.de/ArchiveDB/raw/Minerva/Minerva.ECE.DownsampledRadiationTemperatureTimetraces/

- Cold resonance mapping to plasma radius

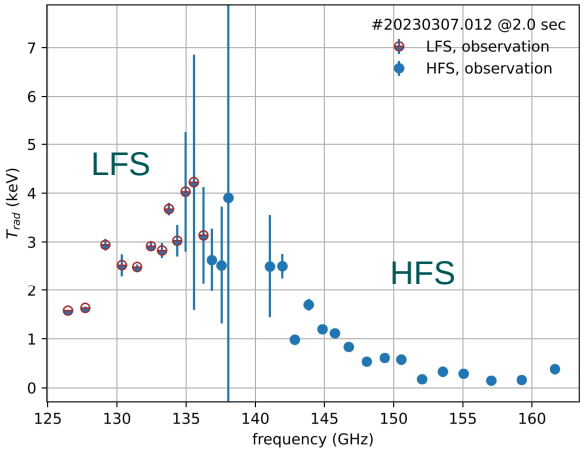
http://archive-webapi.ipp-hgw.mpg.de/ArchiveDB/raw/Minerva/Minerva.ECE.ColdResonance/cold_resonance_DATASTREAM/

Equilibrium calculated using a single W_{dia} value from entire shot.

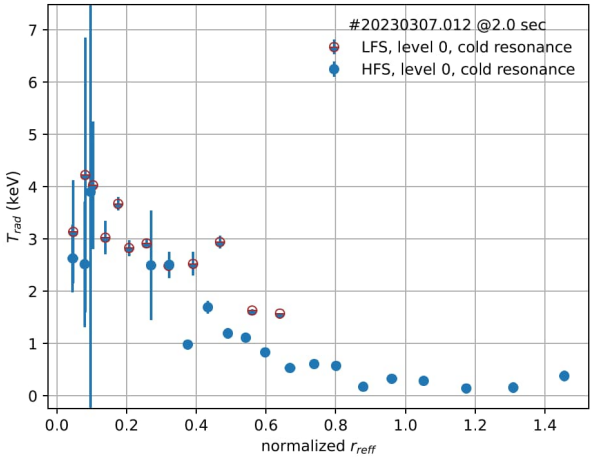
ECE radiation temperature T_{rad}

- only optically thick core channels can be taken as T_e
- cautious while interpreting optically thin edge channels (contains info of both T_e and n_e)
- data available in archiveDB for all valid OP2.1 shots

ECE spectra

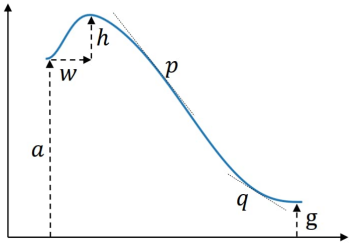


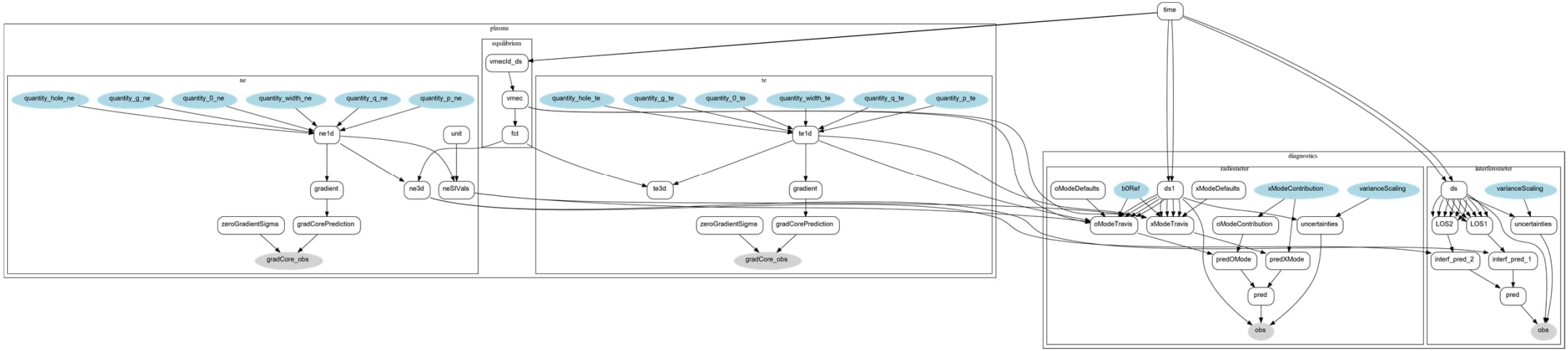
T_e profile



Level 1- Bayesian inferred profile from integrated forward model with parametric prior

- Free parameter-
  - T_e profile (parametric prior) ---------→ $T_e(\rho) = a(g - h + (1 + h - g))(1 - \rho^p)^q + h(1 - e^{-\rho^2/w^2}))$
  - n_e profile (parametric prior)
  - Central B scaling
- Observation-
  - ECE T_{rad}
  - Line integrated density, $\int n_e dl$





Level 1- Bayesian inferred profile from integrated forward model with parametric prior

- Data-stream-

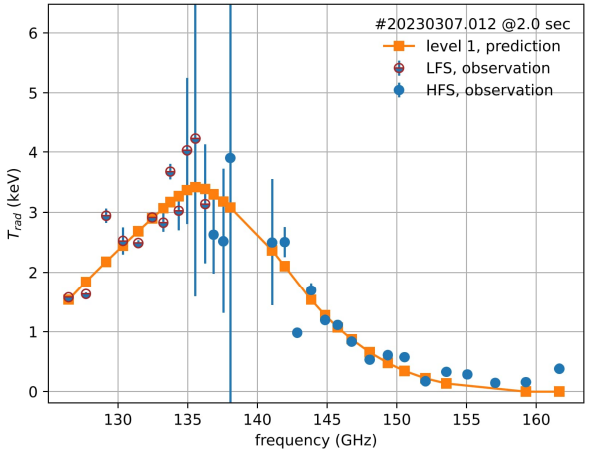
http://archive-webapi.ipp-hgw.mpg.de/ArchiveDB/raw/Minerva/Minerva.ECE.ElectronTemperature/profiles_DATASTREAM

- Map convergence condition is set for minimizing inference time on the expense of quality of profiles,
  - inferred profile could be better with more MAP iterations
  - however, **goal for level 1 analysis is overnight/weekend profiles during a running campaign**

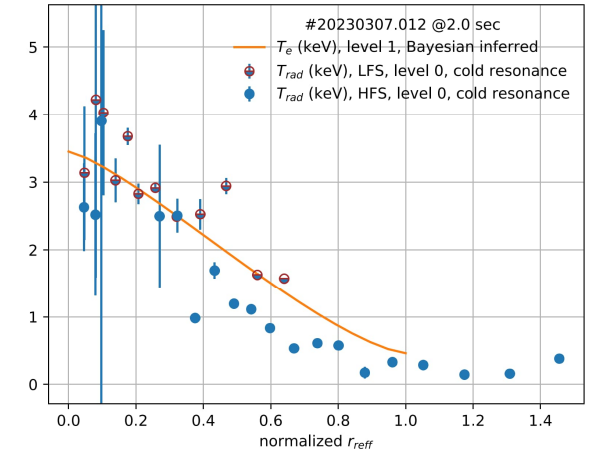
- Sampling frequency
  - 10 Hz, currently not possible to upload at a higher sampling rate in a reasonable time as it's computationally expensive

- Upload status
  - in progress, takes 2-6 hrs for 10s shot
  - will take months to upload entire OP2.1 data
  - upload will be prioritized (under tg profiles) for certain shots

ECE spectra

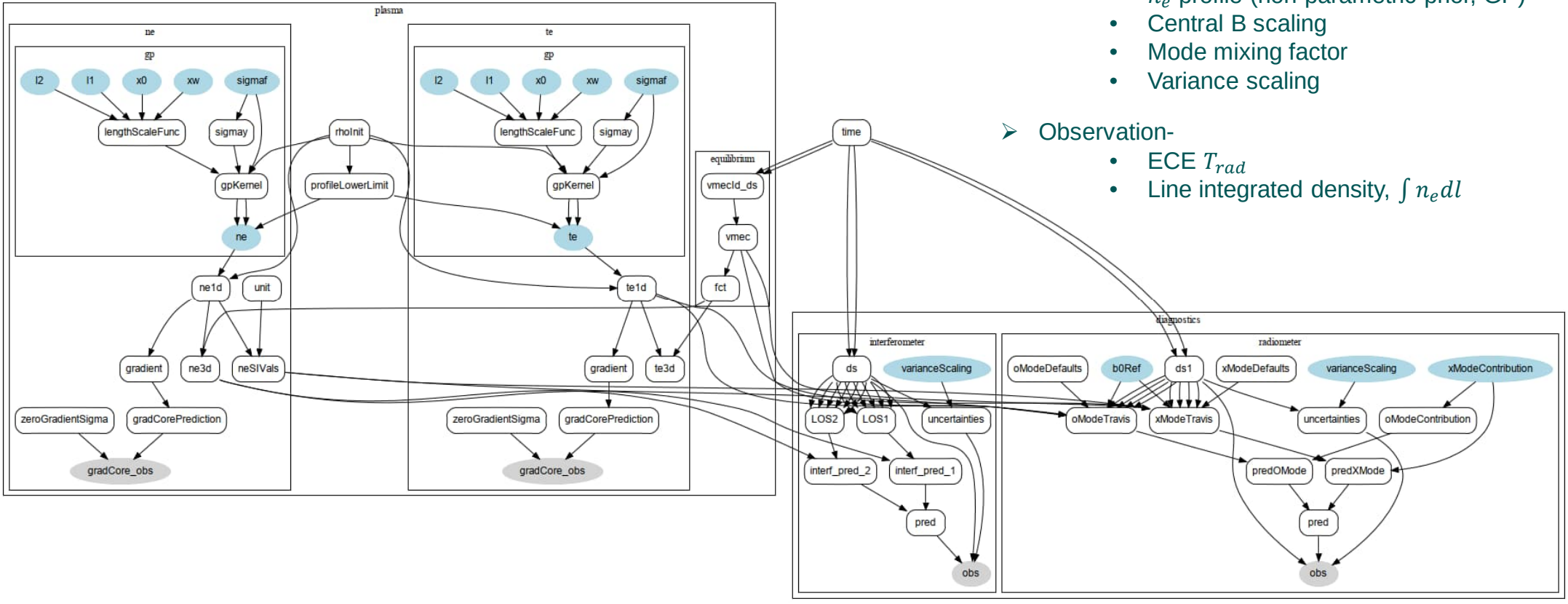


T_e profile



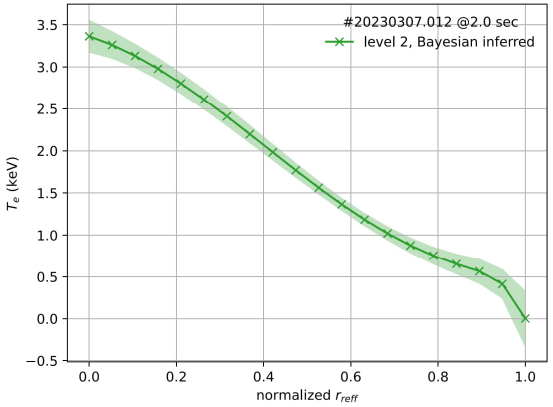
Level 2 - Bayesian inferred profile from integrated forward model with non-parametric prior

- Free parameter-
  - T_e profile (non-parametric prior, GP)
  - n_e profile (non-parametric prior, GP)
  - Central B scaling
  - Mode mixing factor
  - Variance scaling
- Observation-
  - ECE T_{rad}
  - Line integrated density, $\int n_e dl$

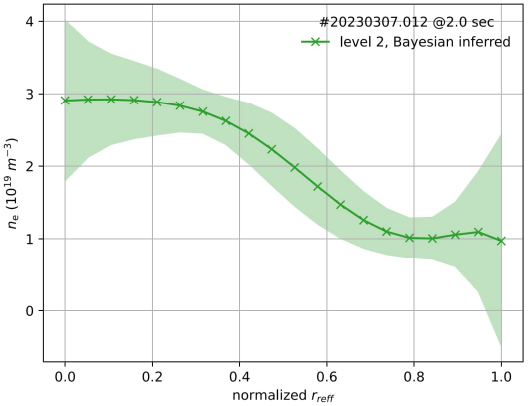


Level 2 - Bayesian inferred profile from integrated forward model with non-parametric prior

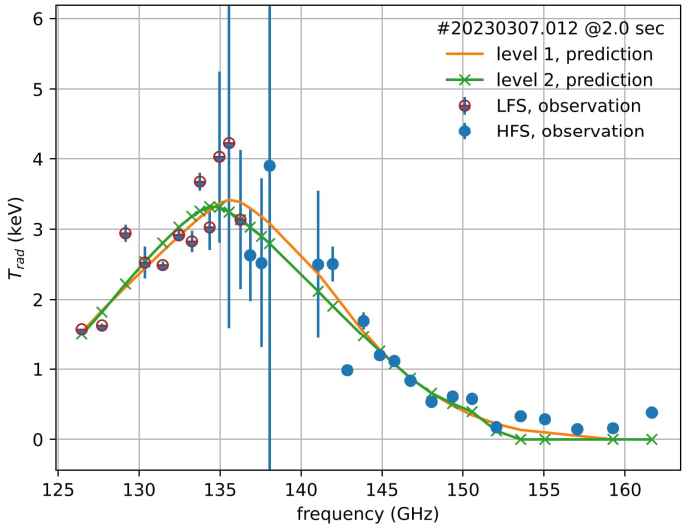
T_e profile

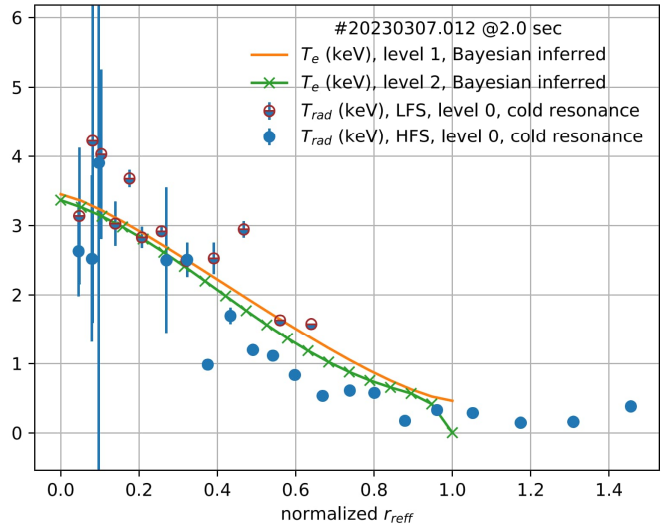


n_e profile



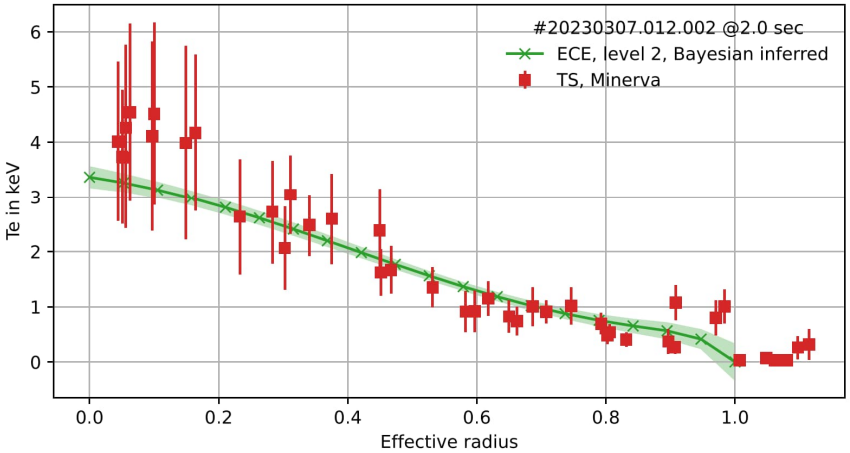
Profile comparison

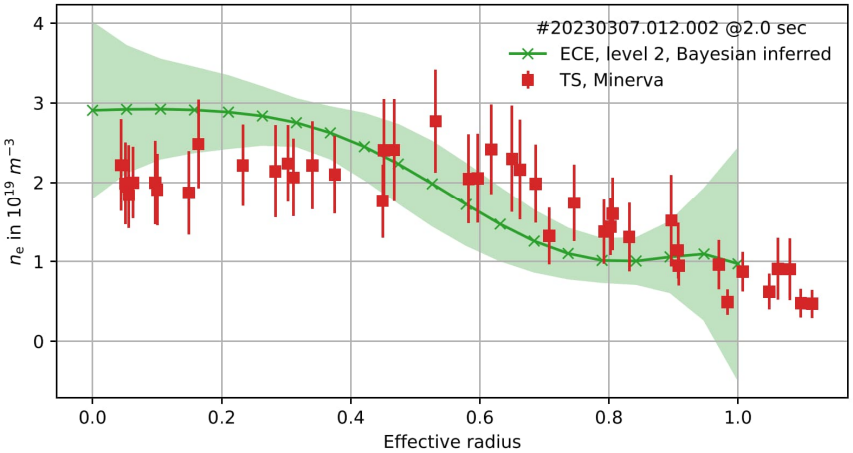




- Availability status - only available on request
- Single profile computational time
  - 2-3 days

ECE vs TS profiles





Reference slides

CXRS analysis status: BES analysis https://indico.euro-fusion.org/event/2834/

CXRS analysis status

CXRS – Status of OP2.1 Data Analysis, November 2023

***T_i**: (O. Ford)*

Processed T_i stored in archive for each and available via w7xdia (example on wiki) and Profile Cooker. Some users also read data directly (e.g. Lazerson).

For NI21 blips <= 100ms:

Automatically processed data written after shot OK. Reprocessed all in May 2023 with some improvement and to fill in remaining gaps. A few shots where primary spectrometer is missing ('ILS_Green'). Most shots have additional points from secondary ('NIFS_C').

Quality of carbon T_i is adversely affected by significant neon seeding. In these cases contact T. Romba for T_i analysis from neon.

More Ti data is technically available from other species Ar, He, H… etc but this is a lot of work and we don't have the manpower to process it for other people yet.

For NI21 continuous (>100ms):

Most shots automatically processed during operation.

Background subtraction is difficult – often needs reprocessing with modified settings.

~Half already reprocessed since with improved settings. Will re-process the rest by end of next week.

Pure NBI: With strong impurity accumulation, whole profile is biased by strong core passive emission. This requires detailed modelling (probably in Minerva) that is not started yet.

CXRS analysis status - continued

Data will not be systematically investigated by diagnostic team. Users should contact them if they need careful consideration **of specific time slices**, or if the data ‘looks funny’.

n_Z (*T. Romba) :*

Processing impurity densities requires a beam model and electro density → waiting for Thomson.

Prospective:

Carbon: Carbon density will be available for almost all shots.

Helium: Also in principle for all shots, but requires more detailed processing.

Argon: Depends on settings, but ionisation states of argon are available for much of OP2.1.

E_r $V_{//}$ (J. De la Riva Villen, A. Alonso) :

On-going PhD project and not available as standard yet.

FIDA *(P. Pölöskei) :*

On-going Post-Doc project and not available as standard yet. Data is only easily usable in specific experiments with modulated NI21 vs NI20.

Basic time-trace changes can be examined more quickly.

CXRS analysis status

n_{beam}, n_e (S. Bannmann, Minerva) :

App now available as JAR to calculate beam density and fuelling. Will be made available as a web service hopefully soon.

Electron density profiles from beam (BES) and halo (HES) emission soon possible on special request. Paper and presentation in preparation. Sneak peak: Next pages

n_0: (P. Poloskei, T. Romba, O. Ford, F. Reimold, ...) :

Development project for recycling source profile inside plasma from warm Hα spectroscopy. Time traces of changes in fuelling are easy to see. Data available for all shots without NBI.

Some data of shots with NBI available for 2023 part of OP2.1.

Electron density profile inference

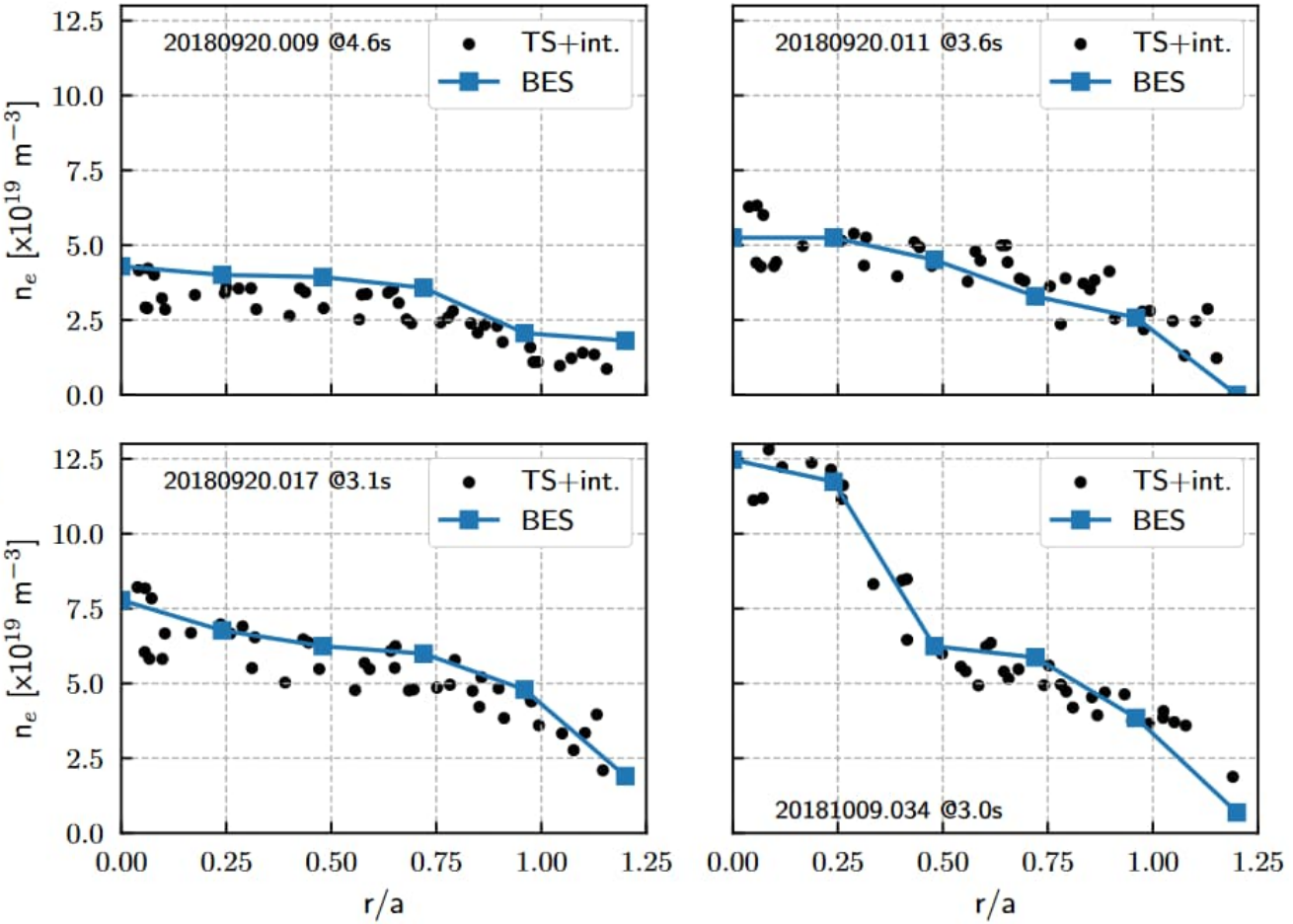
From BES and HES

Test set:

- 3 ECRH heated discharges at different density levels in standard magnetic configuration with NBI blips (20180920.009 / .011 / .017)
- 1 NBI heated discharge in high mirror configuration exhibiting a peaked density profile (20181009.034)
- Data for comparison: Thomson scattering data renormalized using the interferometer data

Results:

- Profiles well reconstructed
- Model not able to infer physical profiles (gradients) on finer grid



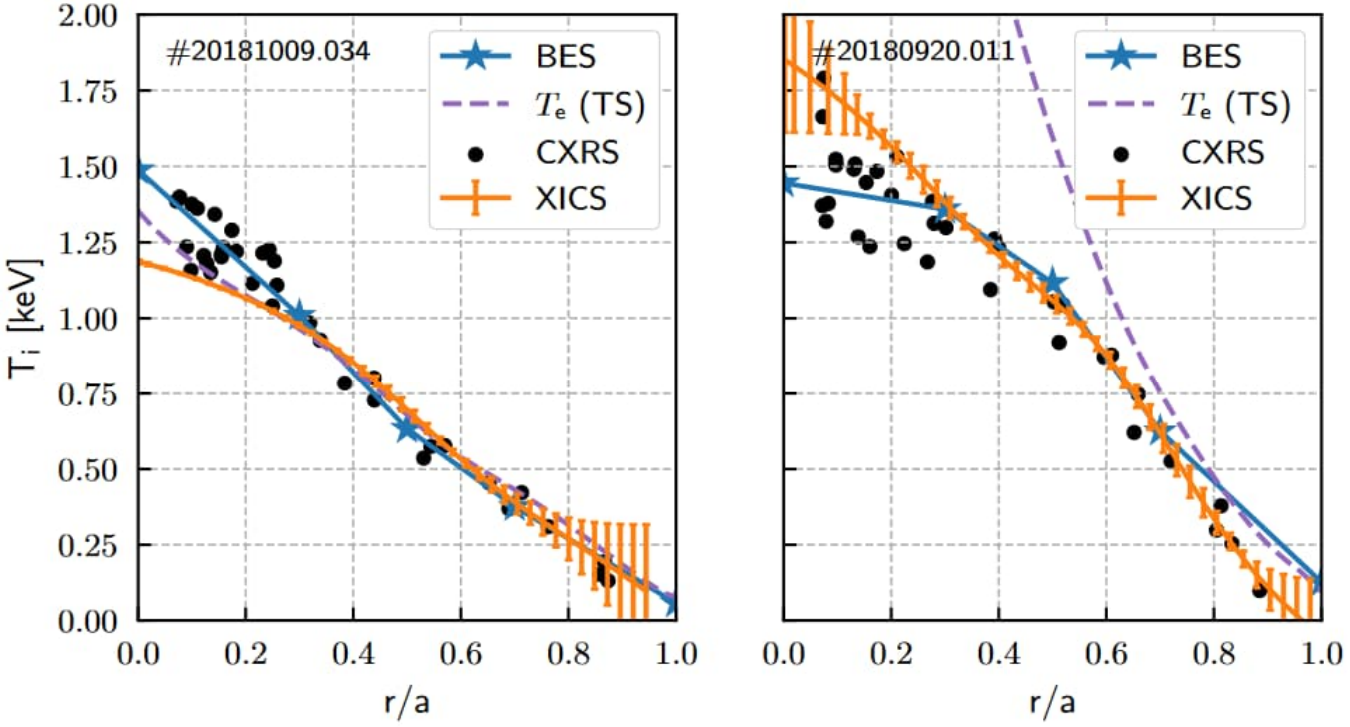
S. Bannmann, O Ford

Ion temperature profile inference

From BES and HES

Information about ion temperature contained in halo emission → Doppler broadening + CX diffusion coeff.

- Ion temperature profile can be inferred simultaneously with density profile
- Inferred profile agrees very well with XICS (corrected by -200eV) and CXRS data from r/a=0.2 to 0.8



S. Bannmann, O Ford

Reference slides

XICS analysis status: https://event.ipp-hgw.mpg.de/event/956/

Reference slides

Decentralised Chain analysis