INSTITUTE OF PLASMA PHYSICS OF THE CZECH ACADEMY OF SCIENCES

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RUNAWAY ELECTRON STUDIES VIA HXR SPECTROSCOPY AT GOLEM, COMPASS AND TCV

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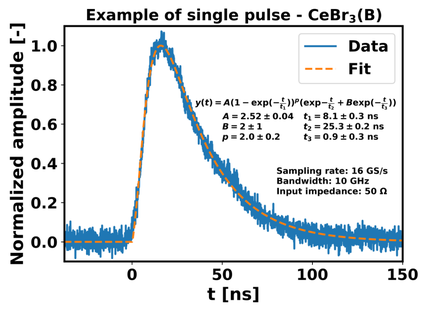
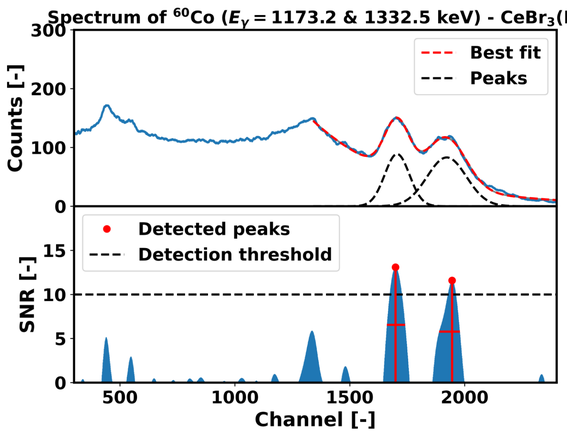
MOTIVATION

Runaway electrons (RE) = high energy particles generated under some experimental conditions in tokamaks – high toroidal electric field and low plasma density
→ impact of RE can cause a serious damage to plasma facing components
→ generation of RE needs to be avoided or mitigation strategies needs to be developed
Electron bremsstrahlung radiation - generated during collisions between electrons and plasma particles or solid state materials → could be used for RE characterization e.g. estimation of RE population, estimation of RE energy
→ same set of $CeBr_3$ installed at three tokamaks to characterized RE and viability of a such system

SCINTILLATION DETECTORS USED

- generated bremsstrahlung radiation caused by runaway electrons measured by set of detectors
- two scintillation detectors equipped by $CeBr_3$ scintillation crystals → fast decay time (18-25 ns) and superior energy resolution (4% FWHM at 662 keV) to NaI(Tl) – standard in gamma spectroscopy





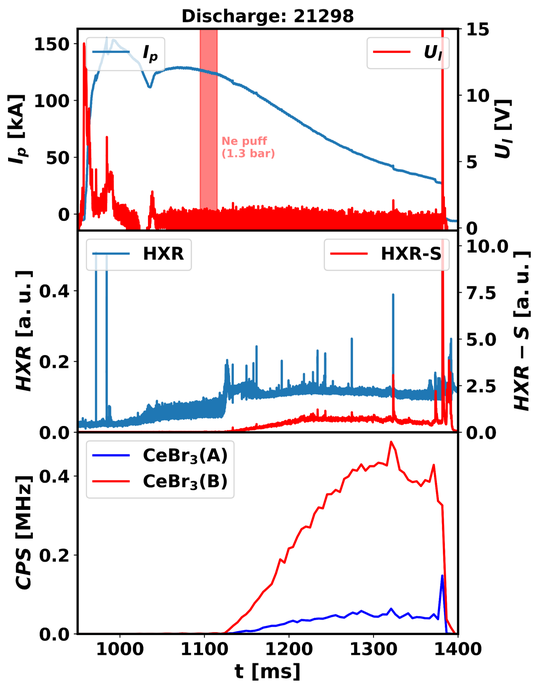
- $CeBr_3$ spectrometers applied at three different tokamaks – GOLEM, COMPASS, TCV
→ Routinely operated at GOLEM tokamak
- Demountable scintillation crystals manufactured by Scinonix

Detector	Photomultiplier tube	Crystal size
$CeBr_3$ (A)	Hamamatsu R3998-02	1"x1"
$CeBr_3$ (B)	Hamamatsu R1234A	1"x1"

- Semi-automatized peak detection algorithm and fitting procedure

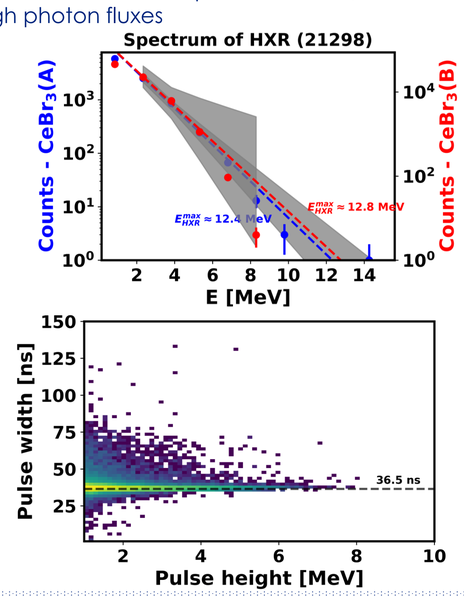
COMPASS

R [m]	a [m]	I_p [kA]	B_T [T]
0.56	0.23	< 400	1.15 - 2.1
t_{plasma} [s]	I_{RE} [kA]	N_{RE} [-]	E_{RE}^{Max}[MeV]
< 1	<130	$<10^{15}$	< 20



- Operated till 8/21 at IPP in Prague, suitable testbed for RE physics ← high flexibility and rich set of RE oriented diagnostics
- **Standard available HXR diagnostics:**

HXR - NaI(Tl) crystal coupled to PMT connected to high impedance and slow DAS – signal proportional to photon flux, weak energy dependence, located in exp. hall
HXR-S – EJ410 scintillator coupled to PMT, primarily neutron detector, but sensitive to high photon flux, located in experimental hall
blind PMT – disconnected photomultiplier tube located outside of experimental hall, sensitive to high photon fluxes

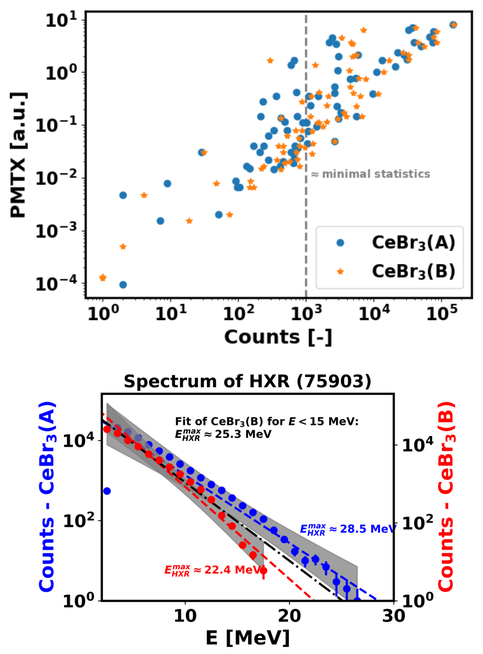


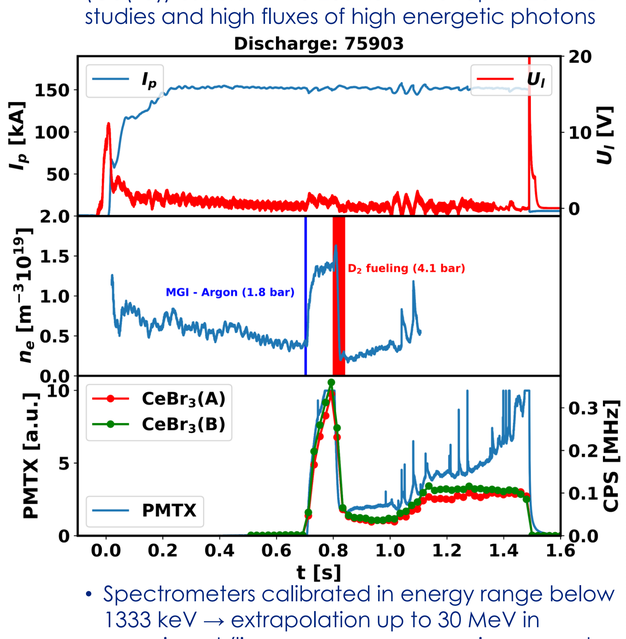
TCV

R [m]	a [m]	I_p [kA]	B_T [T]
0.88	0.25	< 1000	< 1.43
t_{plasma} [s]	I_{RE} [kA]	N_{RE} [-]	E_{RE}^{Max}[MeV]
< 2	< 150	$< 10^{16}$	< 25

- **Standard available HXR diagnostics:**

PMTX - blind photomultiplier located in experimental hall – measurement of flux of photons, weak dependence on photon energy
HXRS – tomographic hard x-ray camera system (Cd(Te)) usable for 10-250 keV – not optimized RE studies and high fluxes of high energetic photons



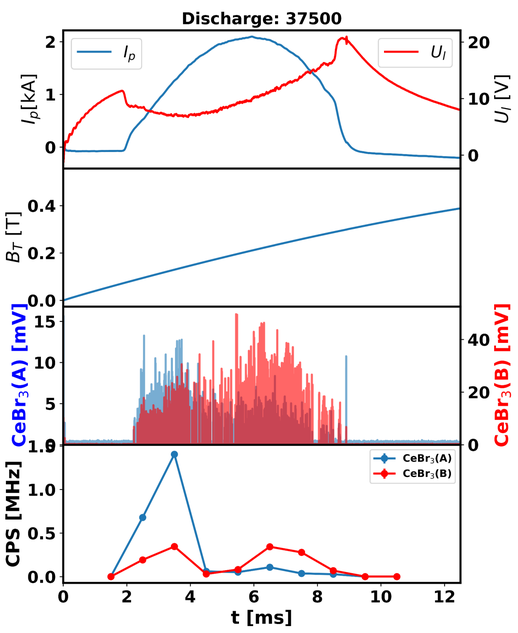


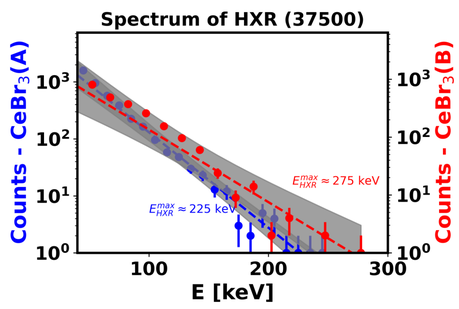
- Spectrometers calibrated in energy range below 1333 keV → extrapolation up to 30 MeV in experiment (linear energy response is assumed

GOLEM

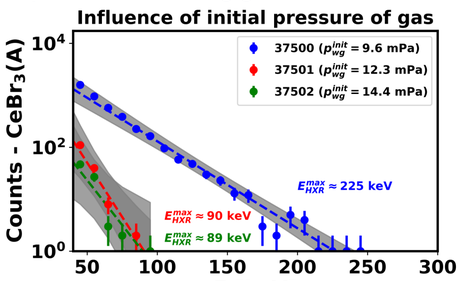
R [m]	a [m]	I_p [kA]	B_T [T]
0.4	0.085	< 8	< 0.8
t_{plasma} [s]	I_{RE} [kA]	N_{RE} [-]	E_{RE}^{Max}[MeV]
< 0.02	< 2	$< 10^{14}$	< 0.5

- Small size tokamak operated at FNSPE CTU in Prague (former tokamak CASTOR operated at IPP Prague – plasma wave interaction, edge plasma)
- Dedicated to educational purposes and diagnostic testing or RE oriented research
- Various scintillation detectors operated in pulse mode with dedicated fast data acquisition system
→ 2x $CeBr_3$, YAP(Ce), 2x NaI(Tl) coupled to PMTs





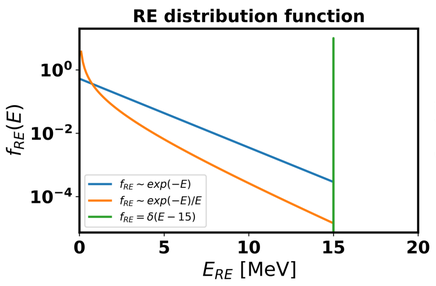
- Favorable conditions for runaway electron generation
→ high loop voltage (E ≈ 2-5 V/m)
→ low density ($n_e \approx 10^{18}$ m^{-3})
- Density of plasma could be partially controlled by initial pressure of working gas



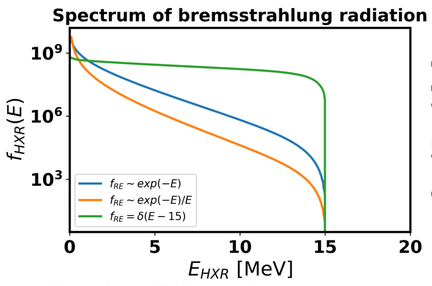
CONCLUSION

- Experiments successfully conducted at the three different devices – GOLEM, COMPASS, TCV
→ viability of a diagnostic concept was shown and diagnostic was tested under different experimental conditions (pioneering tests for further diagnostic development at all devices)
- Acquired spectra needs to be further verified and calibration needs to be revisited → modelling of radiation transport with MC code is essential (e.g. FLUKA, GEANT4)
- Simplified forward modelling of expected pulse height spectra using FLUKA → exponential-like shape of pulse height spectra could be obtain for exponential-like energy distribution of RE

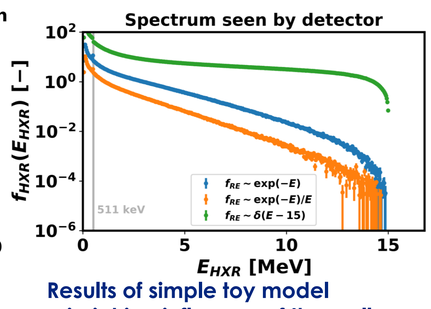
MODELING OF HXR RADIATION USING FLUKA



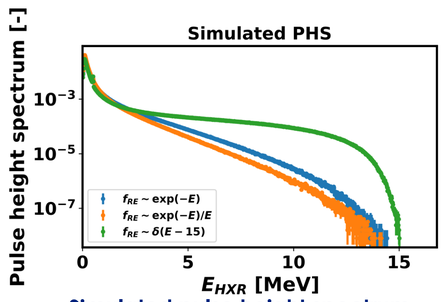
Example of RE distribution



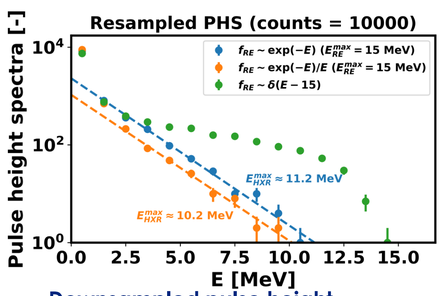
Resulting HXR spectrum based on Selzer & Berger bremsstrahlung cross section



Results of simple toy model mimicking influence of the wall (effect of shielding)



Simulated pulse height spectrum recorded by $CeBr_3$ detector



Downsampled pulse height spectrum recorded by $CeBr_3$ detector

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