All-optical Laser Cooling and Beam Diagnostics for Relativistic C^{3+} Ion Beams at ESR.

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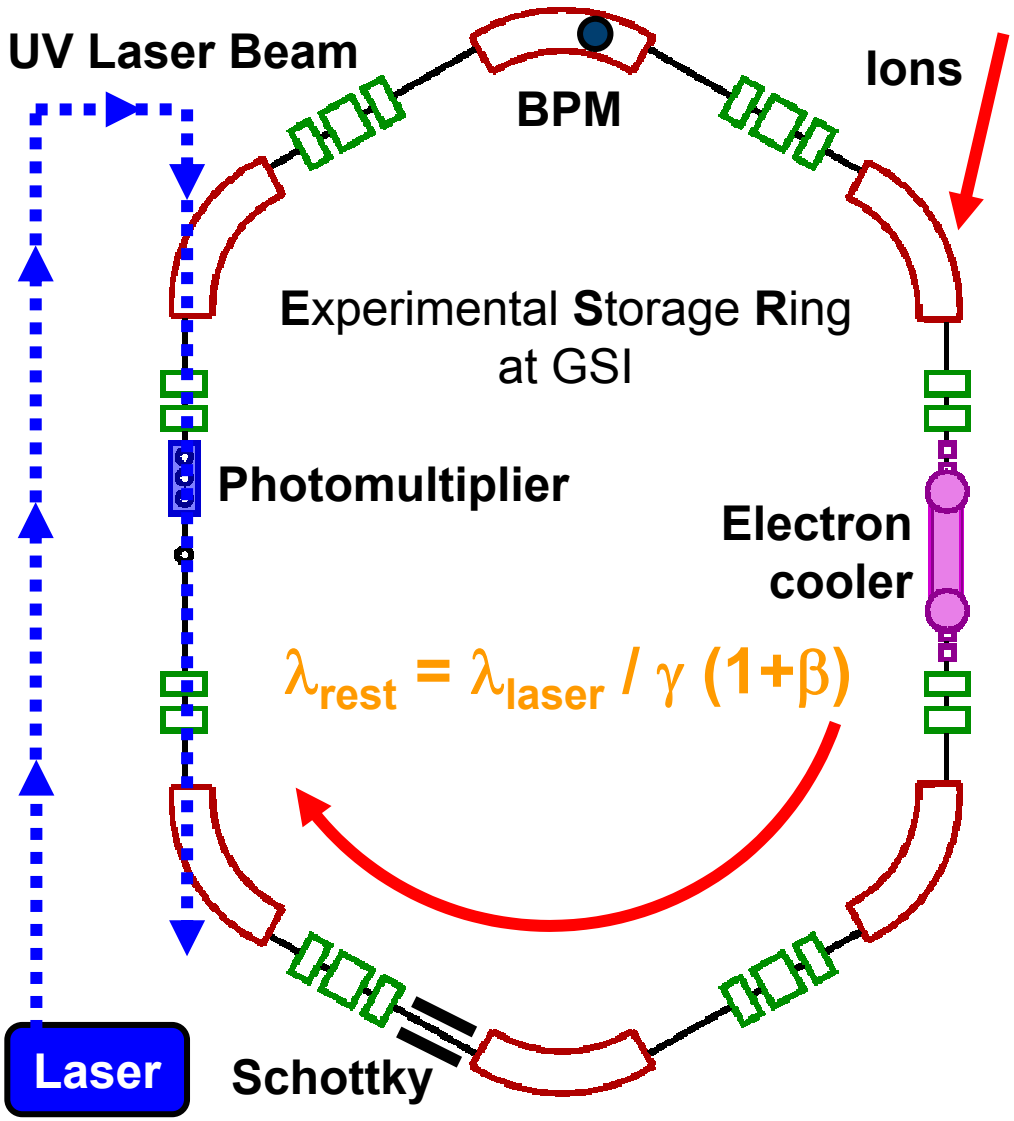
Experimental Setup (2004/2006)



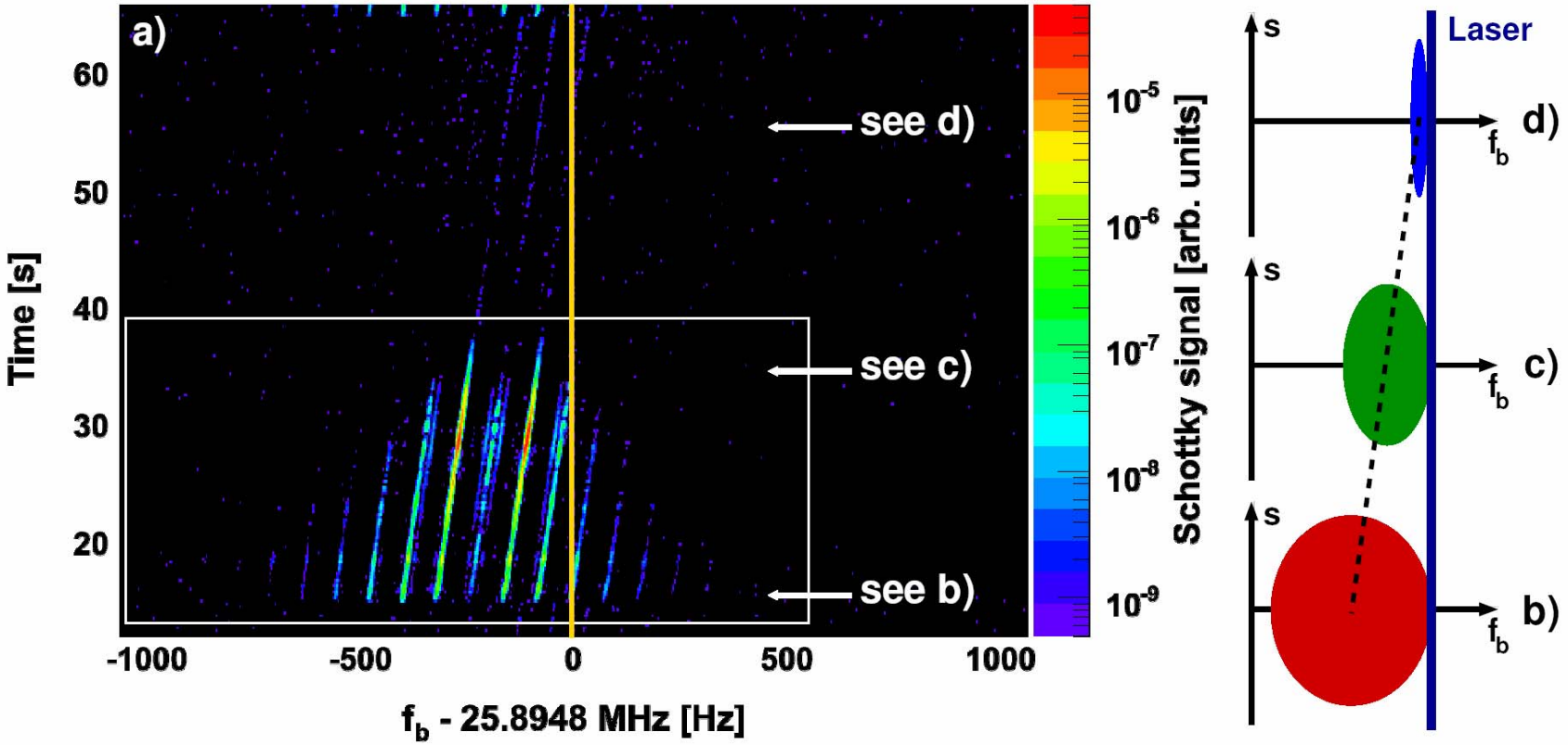
Ion Species: C^{3+}

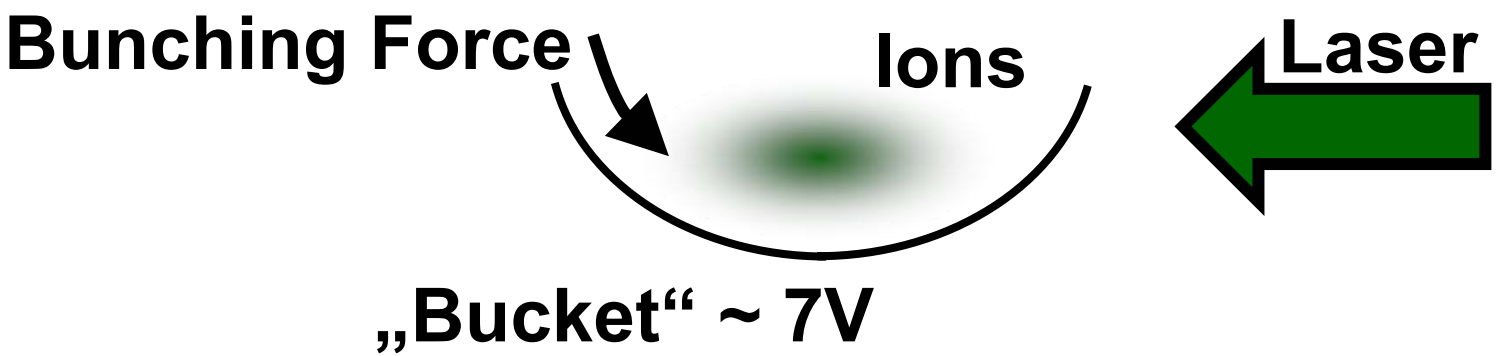
E_{beam} = 122 MeV/u
= 1.47 GeV
(β = 0.47, γ = 1.13)
f_{rev} = 1.295 MHz
τ_{beam} ~ 450 s, 270 s
(no cooling)

Ar^{+} ion laser (cw)
SHG
λ_{laser} = 257.34 nm

$2S_{1/2} \rightarrow 2P_{1/2}$
λ_{rest} = 155.07 nm
τ_{rest} = 3.8 ns

Bunching to counteract Laser Force





Motivation

What we know

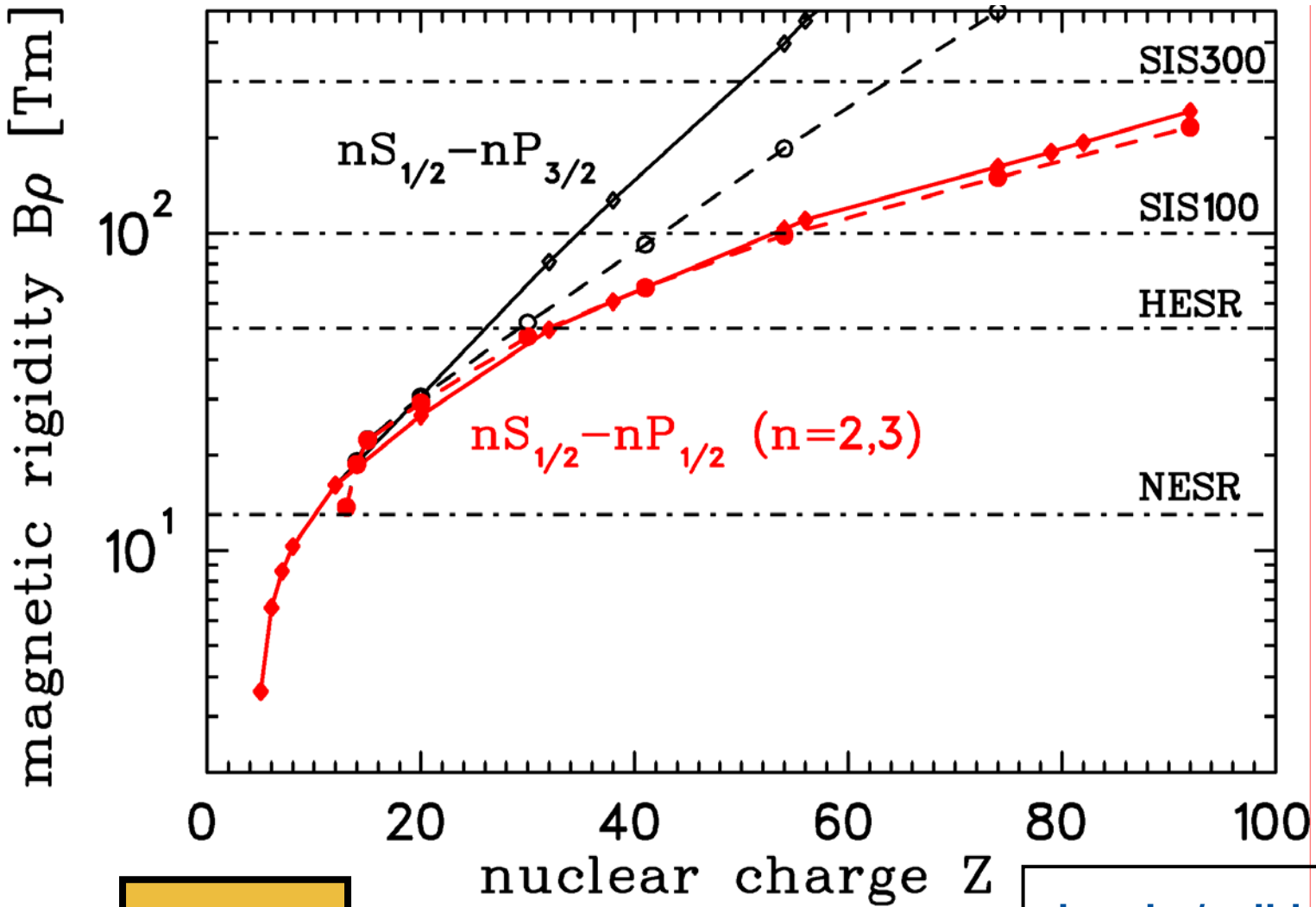
Most promising cooling method at high energies

Can reach strong coupling at ESR

Accelerator diagnostics limited in resolution

Fluorescence detection important but difficult

Many Ion Species can be Cooled @ FAIR



γ → Bρ

rhombs/solid: Li-like
circles/dashed: Na-like

Ultralow Momentum Spread & Strong Coupling

- ♦ pure electron cooling
- ◊ pure laser cooling
- ★ laser cooling + electron cooling (1 mA)

Dashed lines:

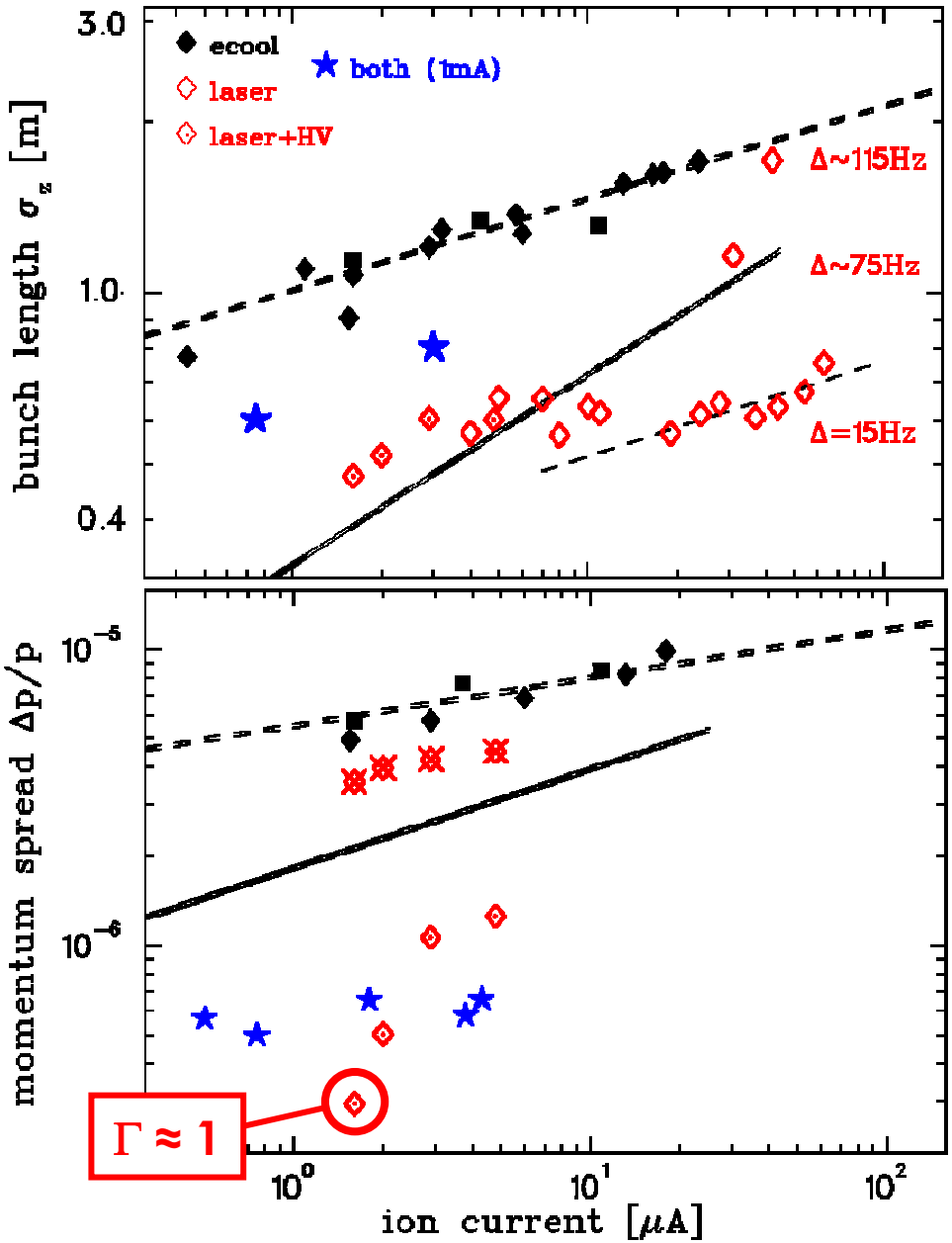
~ $N^{1/6}$ (IBS)

Solid lines:

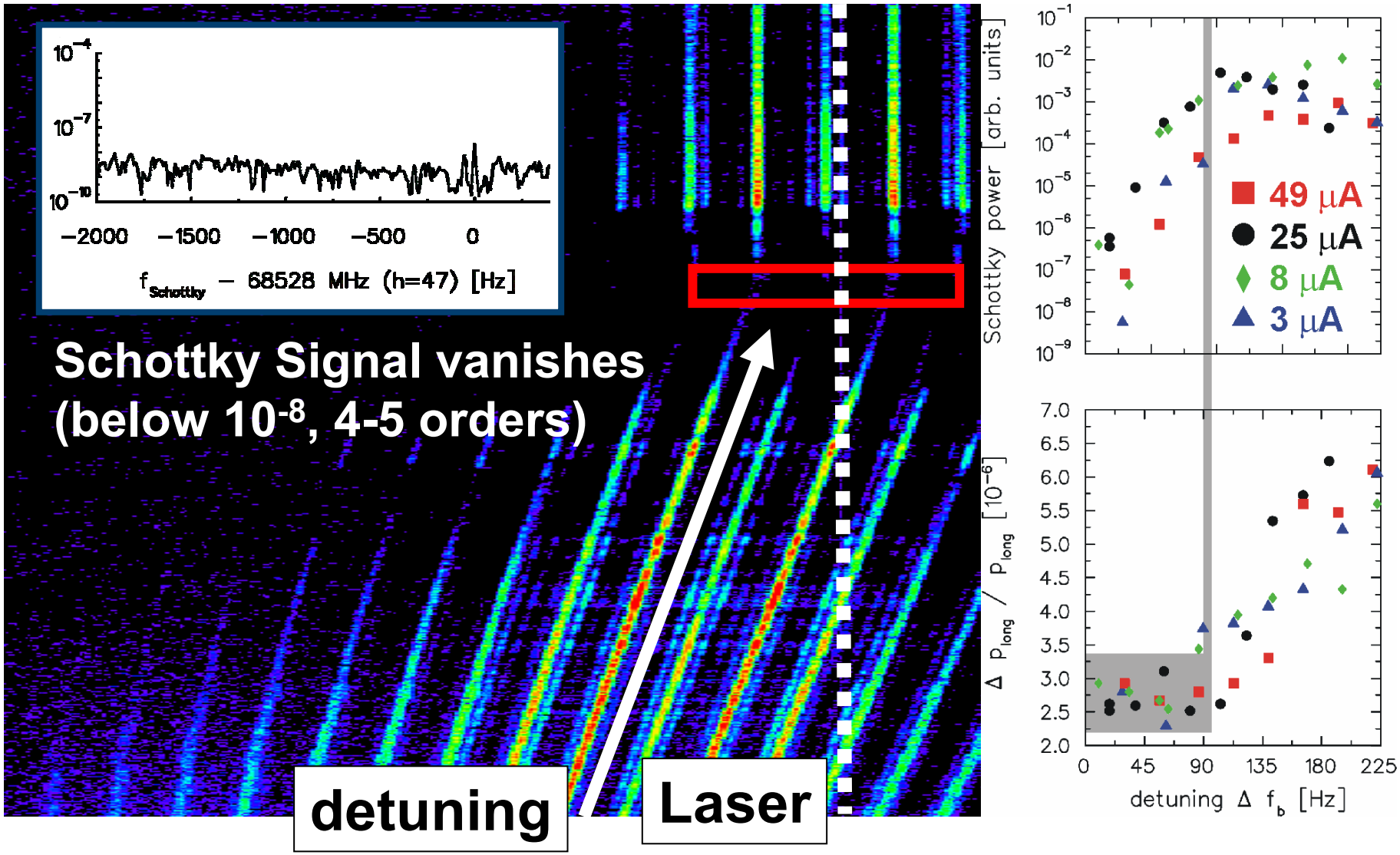
~ $N^{1/3}$ (space charge)

10 x smaller Momentum Spread

Strong Coupling observed (Needed for Crystallization)



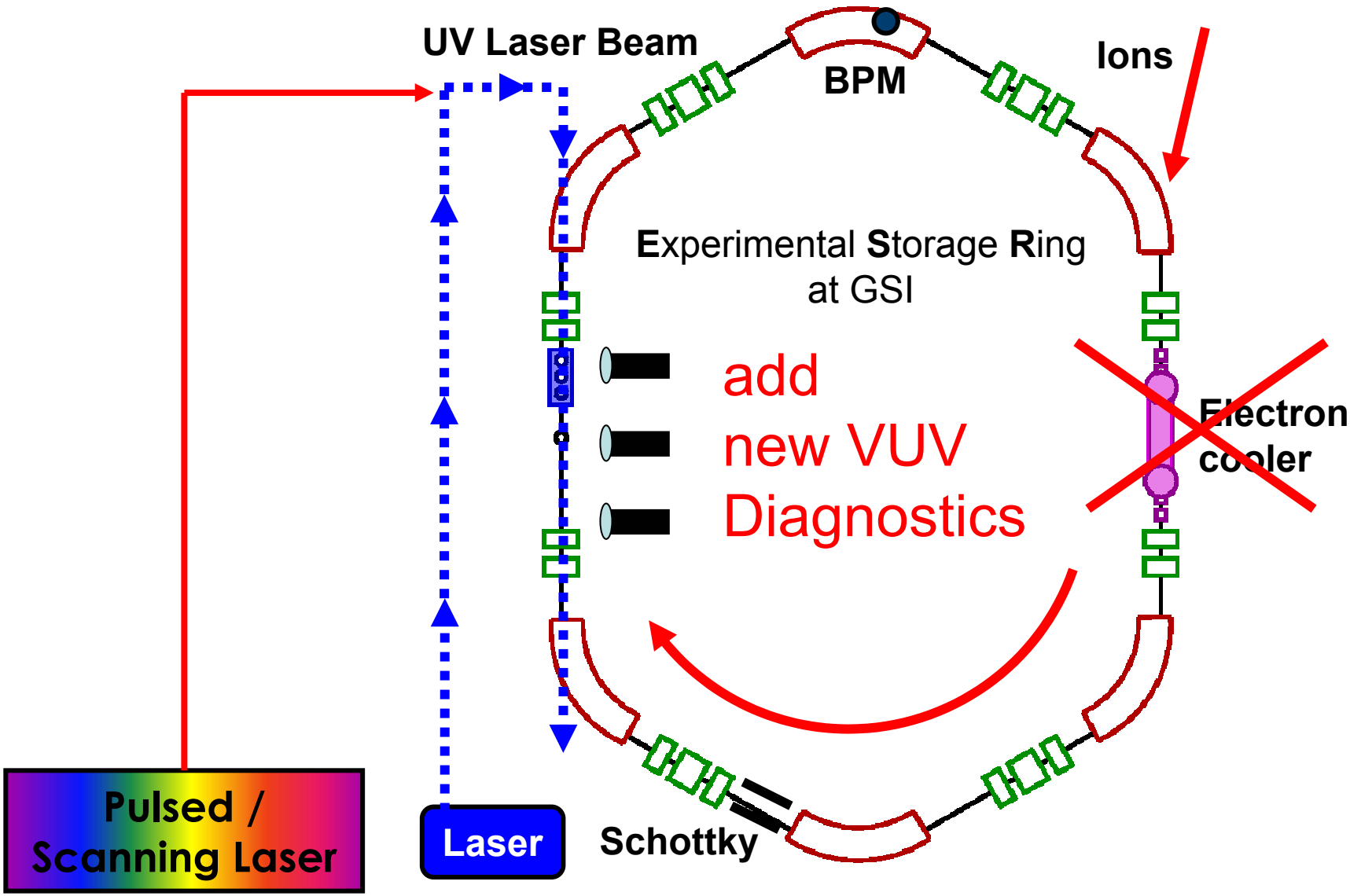
Axial Ion Dynamics – What happens at small Detuning?



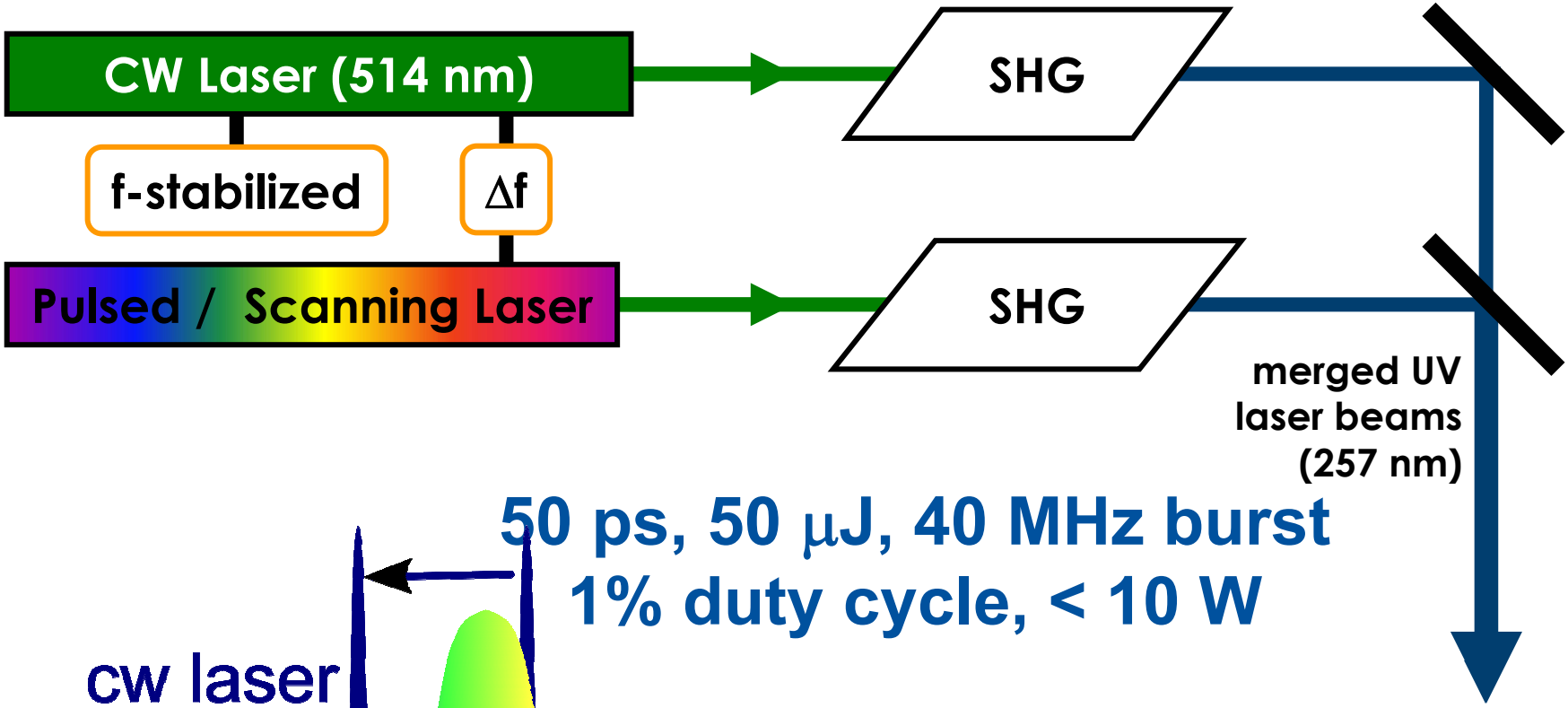
h = 20 I_{ion} = 16 ❍A bunch length 1.01…0.78 m bunch width = 5.26 mm I_{ecool} = 2 mA

New Experiment @ ESR

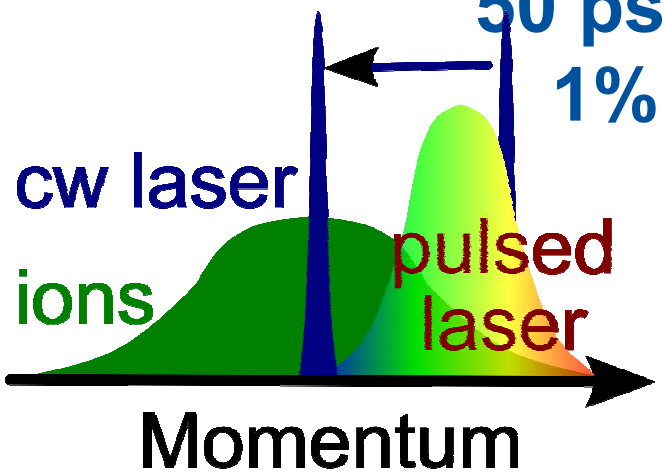
Experimental Improvements for Proposed Beamtime



New Laser Systems (Scanning + Pulsed)



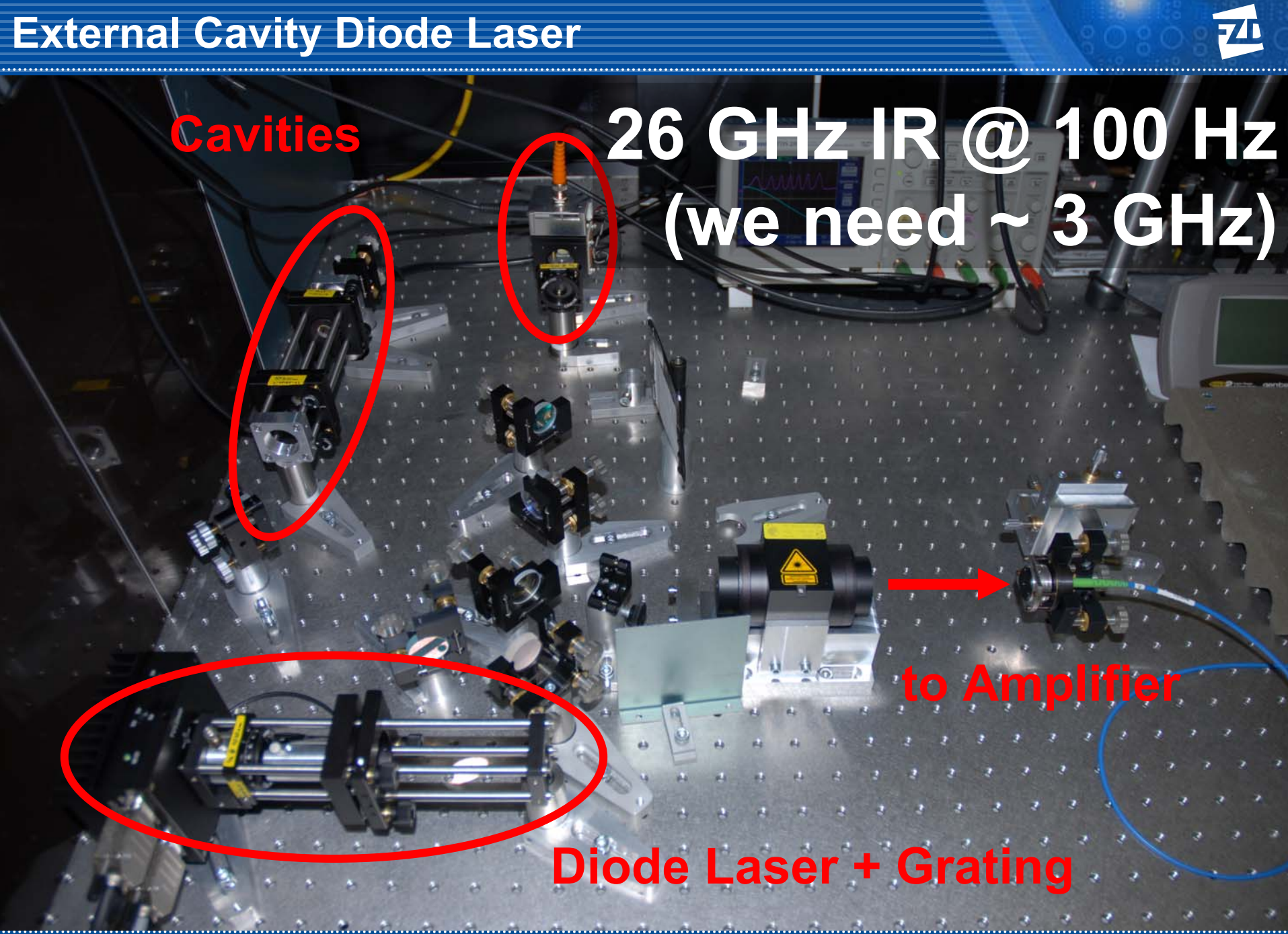
50 ps, 50 μJ, 40 MHz burst
1% duty cycle, < 10 W



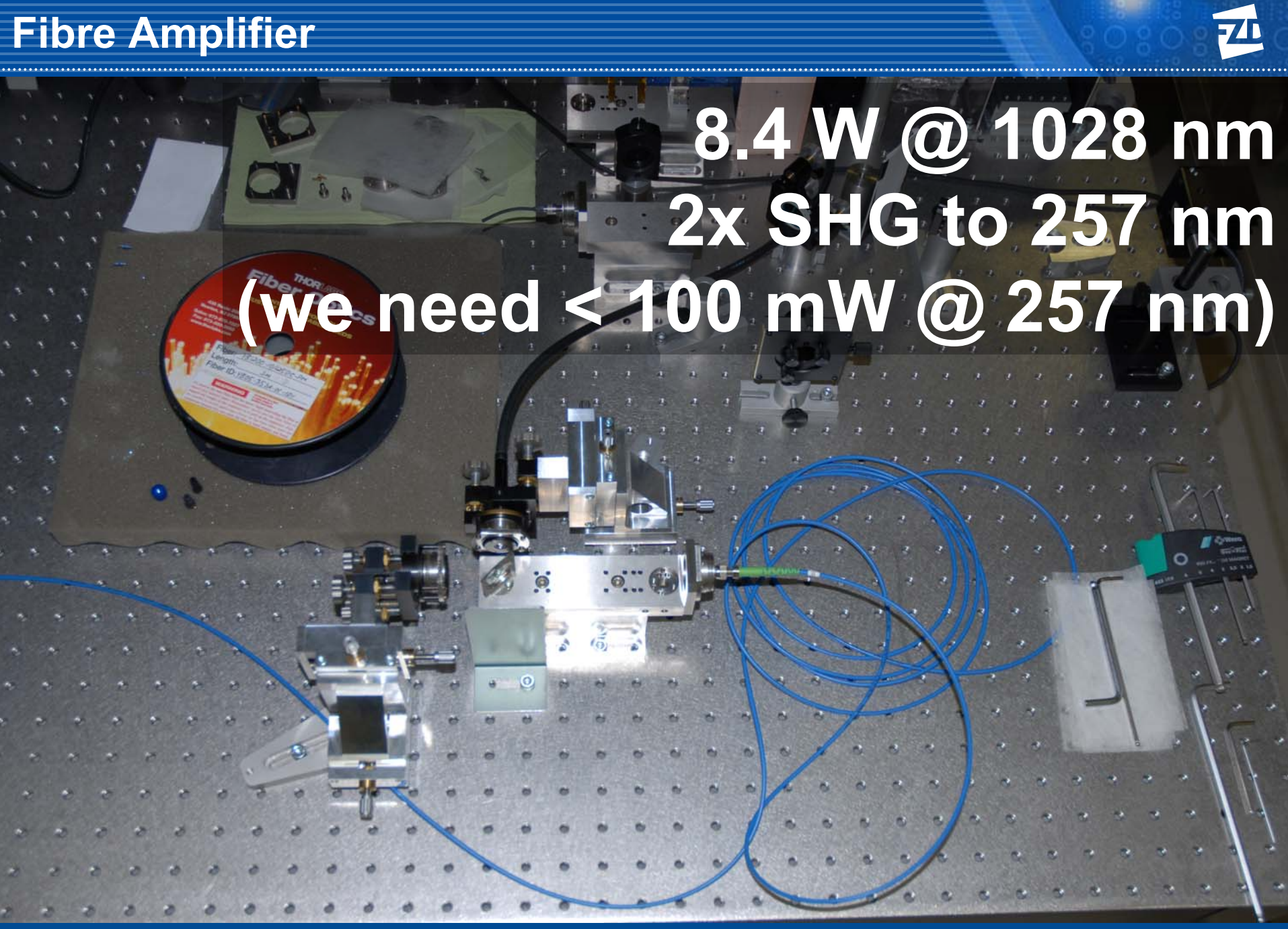
Match Laser Force to Initial Momentum Spread without Electron Cooling

CW Laser System

External Cavity Diode Laser



Fibre Amplifier



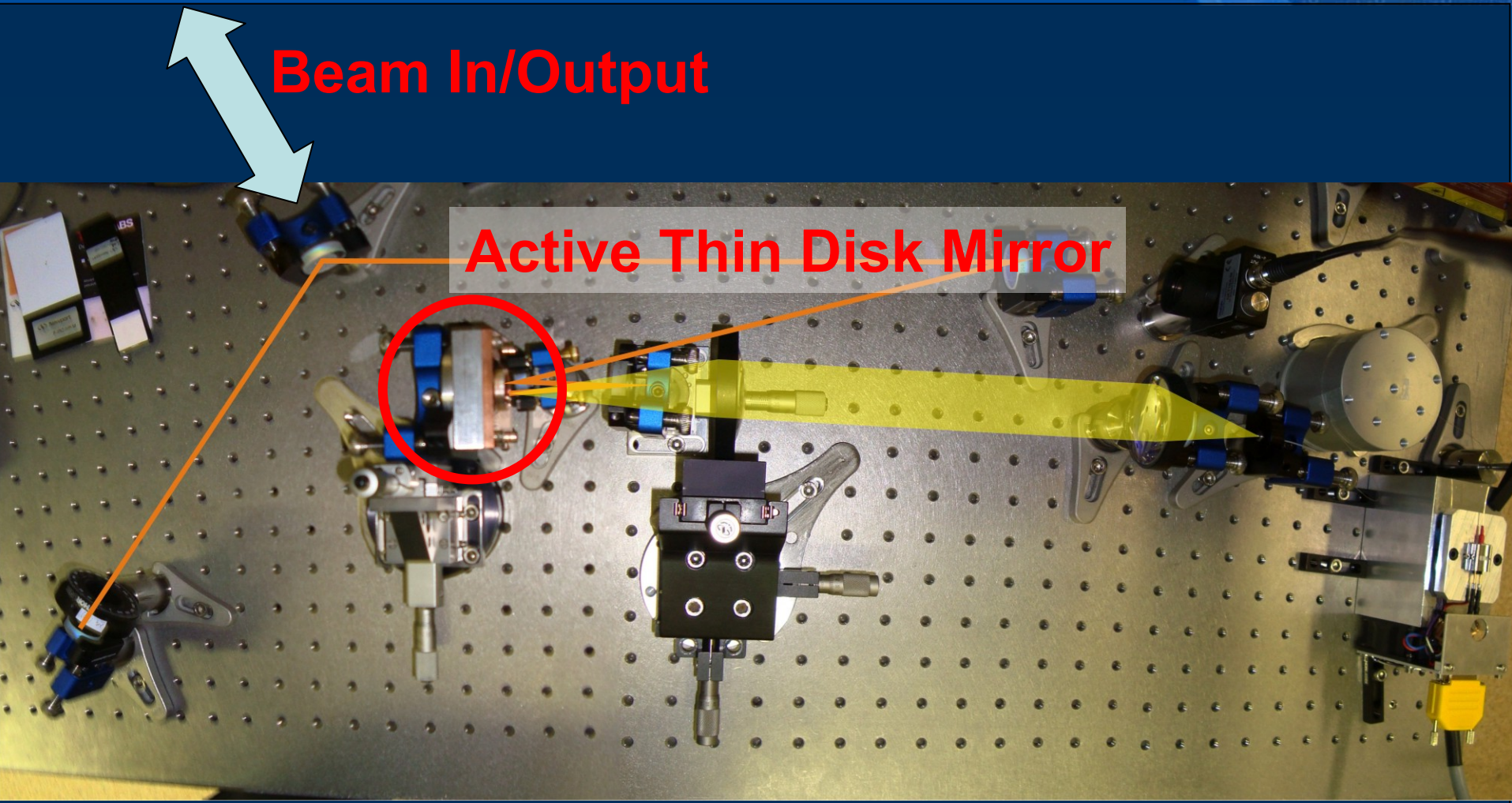
Tobias Beck et al.

A new laser system for ion beam cooling at the ESR

Poster Session!

Pulsed Laser System

Master Oscillator + Power Amplifier (MOPA)



50 ps, 50 μJ pulses in bursts (tunable, typical 40 MHz in 0.1 ms)
1 % duty cycle (rep rate 100 Hz), < 10 W output @ 1028 nm (Yb:YAG)
central frequency after quadrupling (2 x SHG): 256 – 259 nm

Mathias Siebold et al.

50ps-source for laser cooling

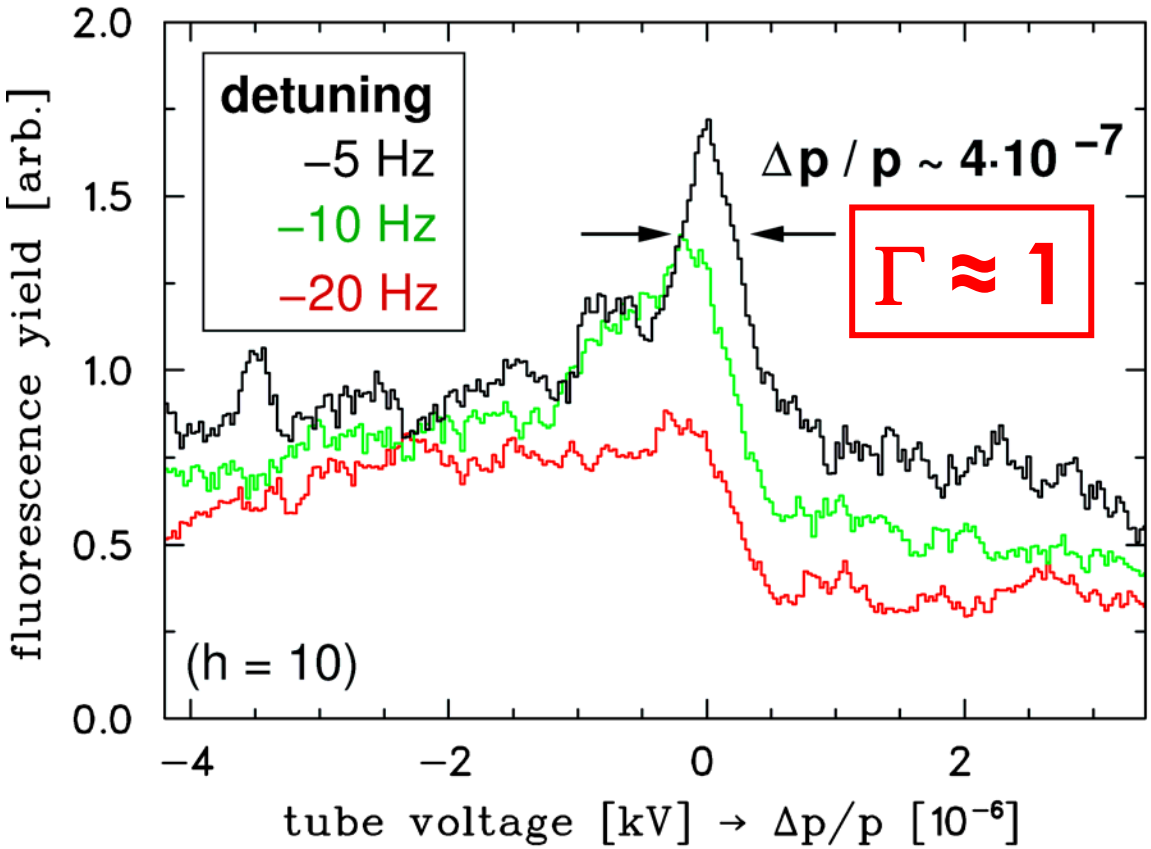
Poster Session!

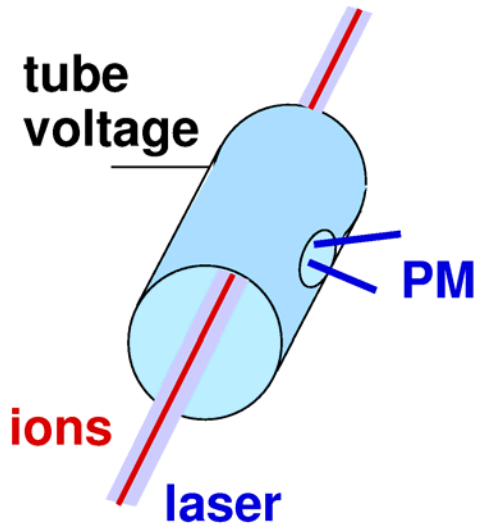
VUV Detection System

VUV Optical Detectors

Optical detection may give new results …

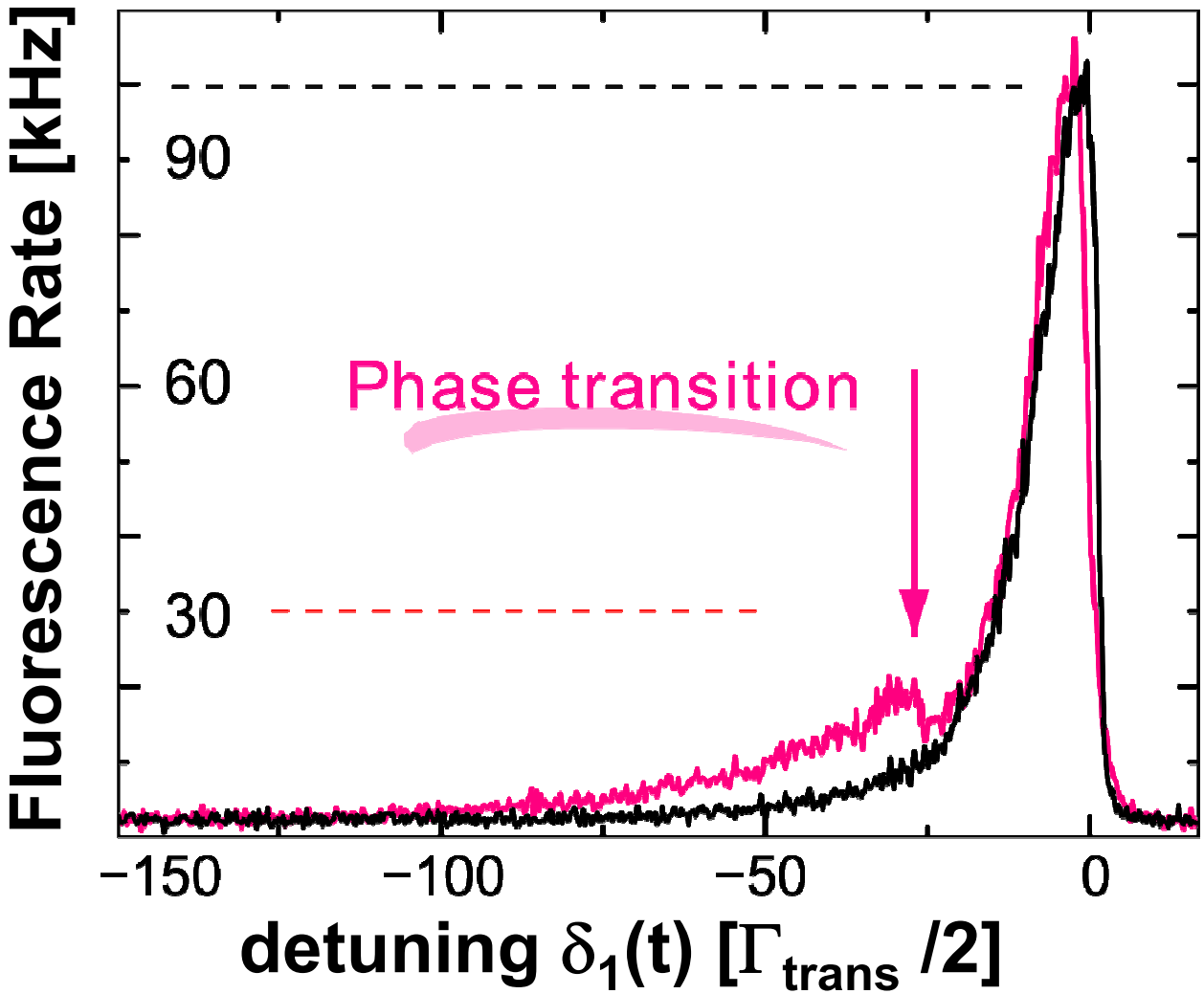
Local change in beam energy via a fast drift tube voltage scan



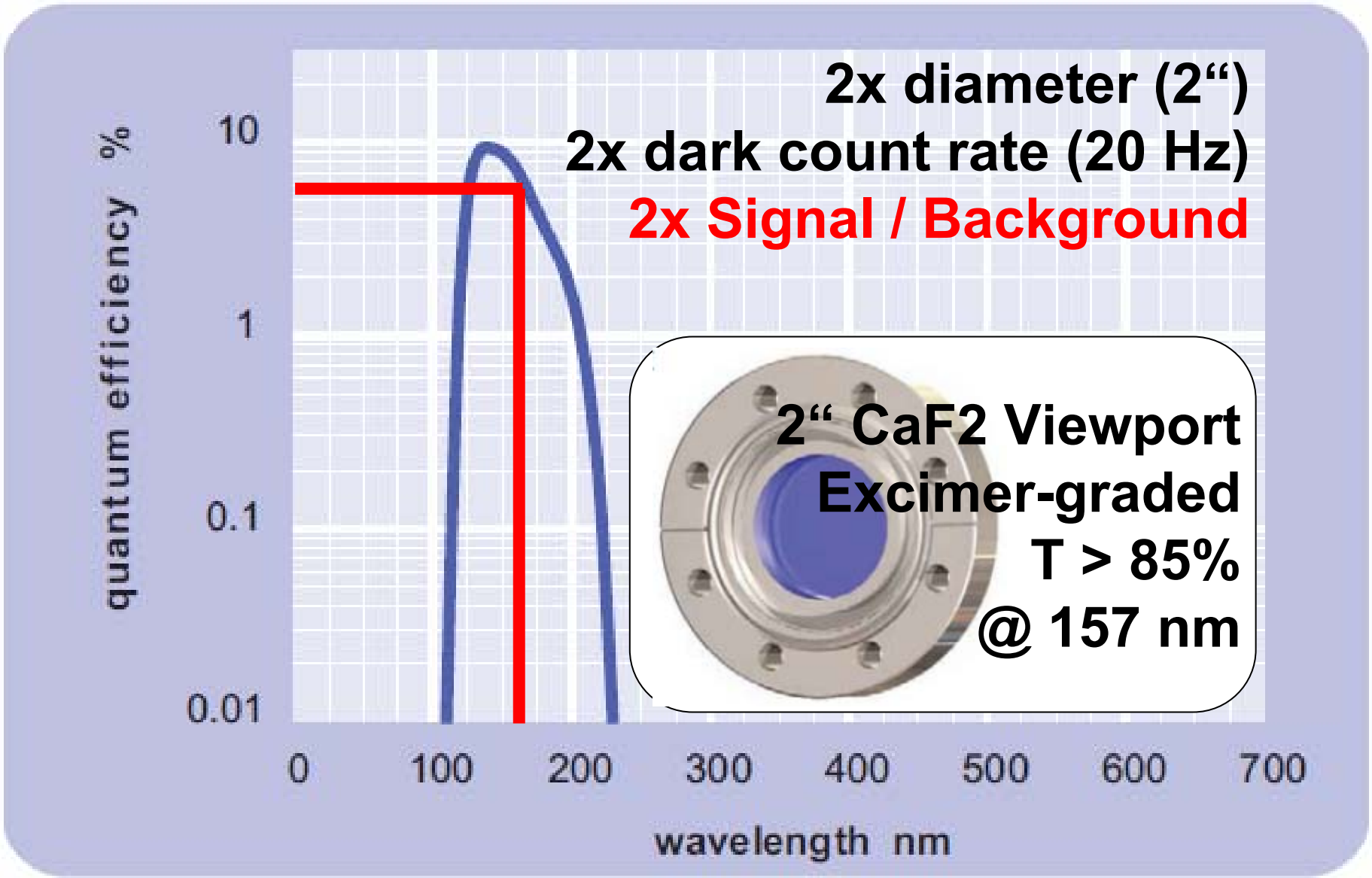


$N_i \approx 1.5 \times 10^6$ $I_i = 1\,\mu A$ $h = 10$ $\Rightarrow$ $\Gamma_P \leq 1$

Scanning the Laser Frequency - Crystalline Beam

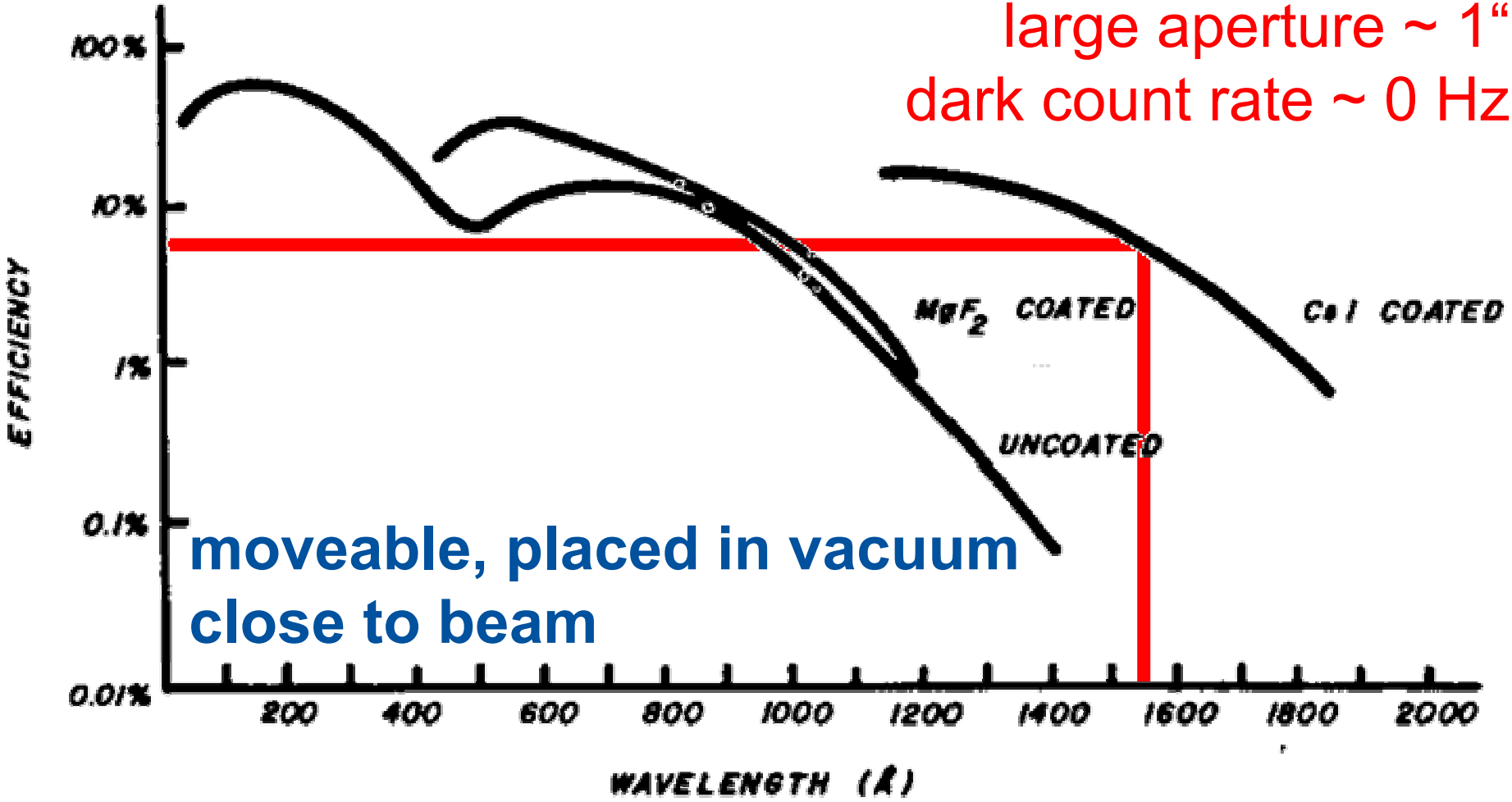


VUV Detectors – Photomultiplier Tube + CaF2 Viewports



VUV Detectors – CsI-coated Channeltrons

large aperture ~ 1“
dark count rate ~ 0 Hz

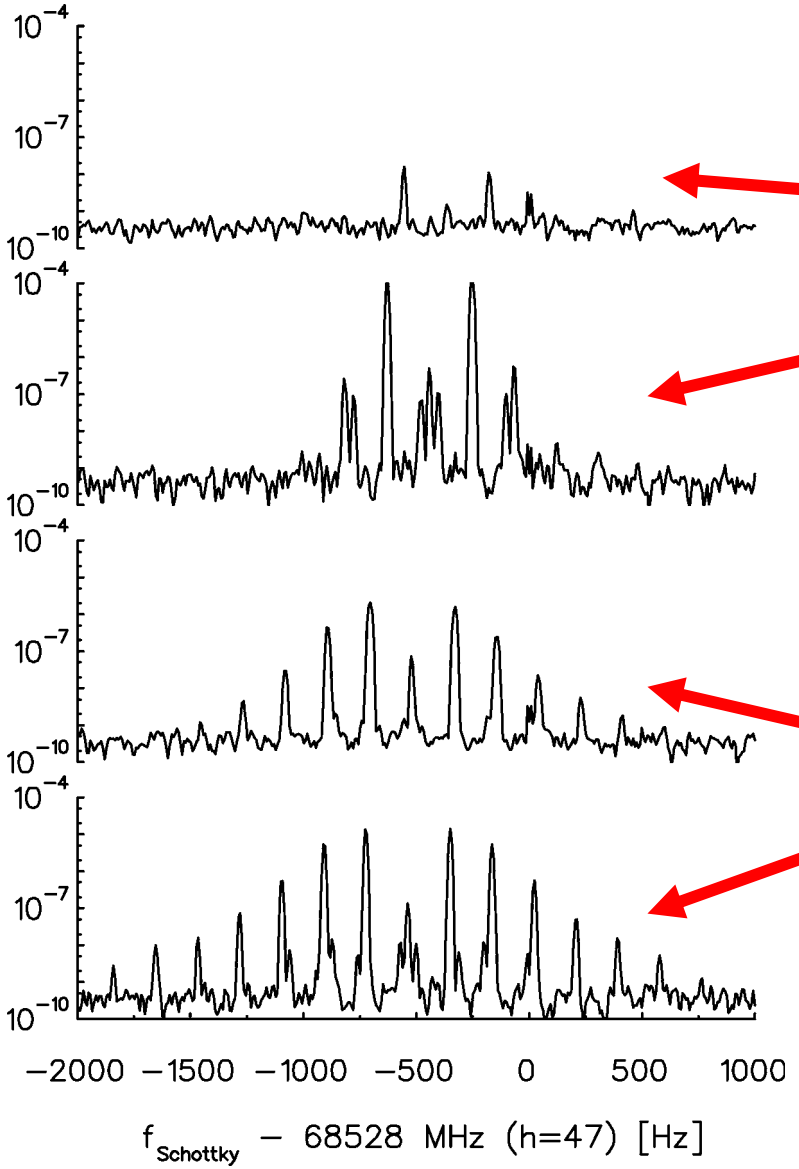


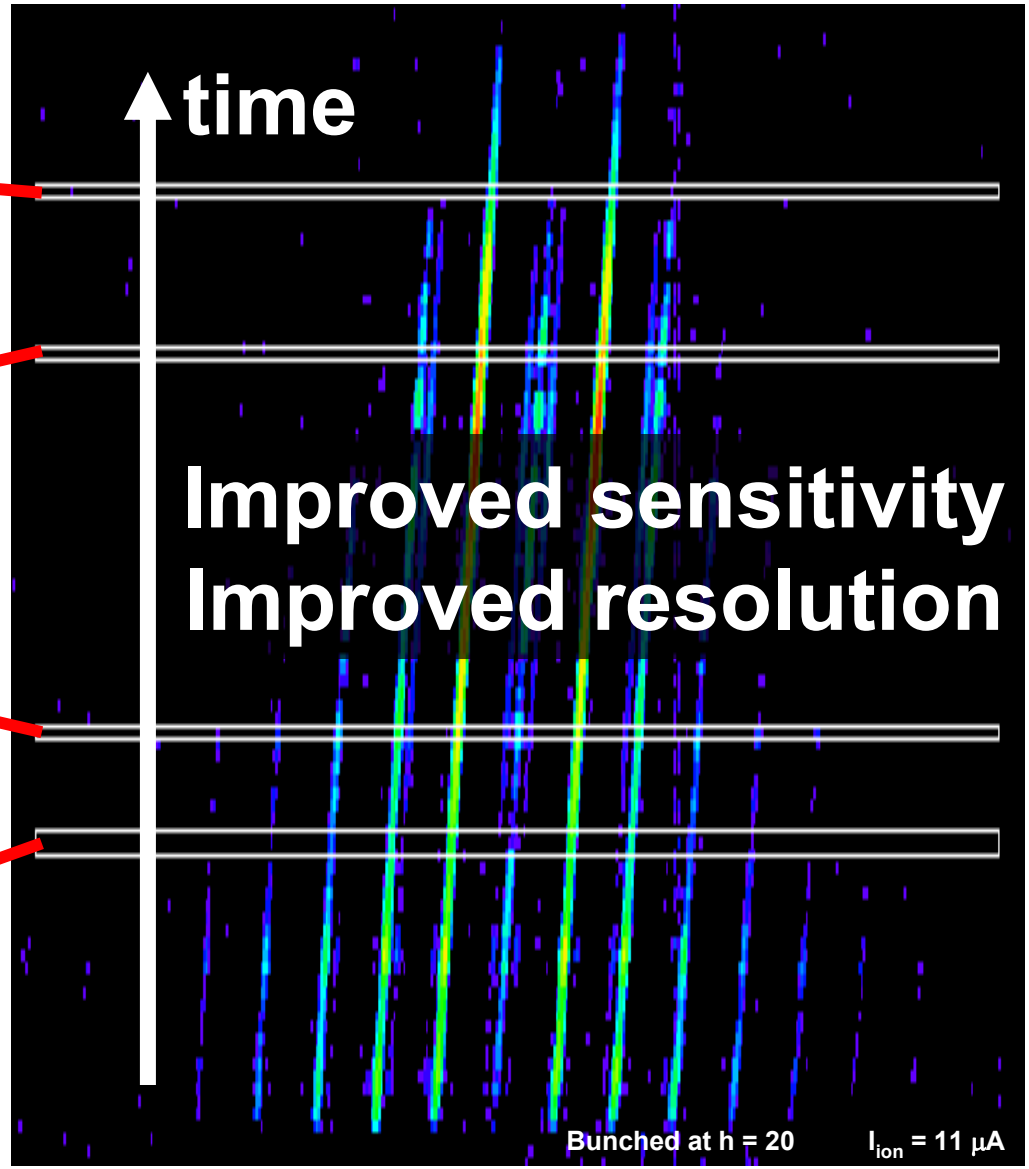
moveable, placed in vacuum
close to beam

Absolute detection efficiency vs wavelength.

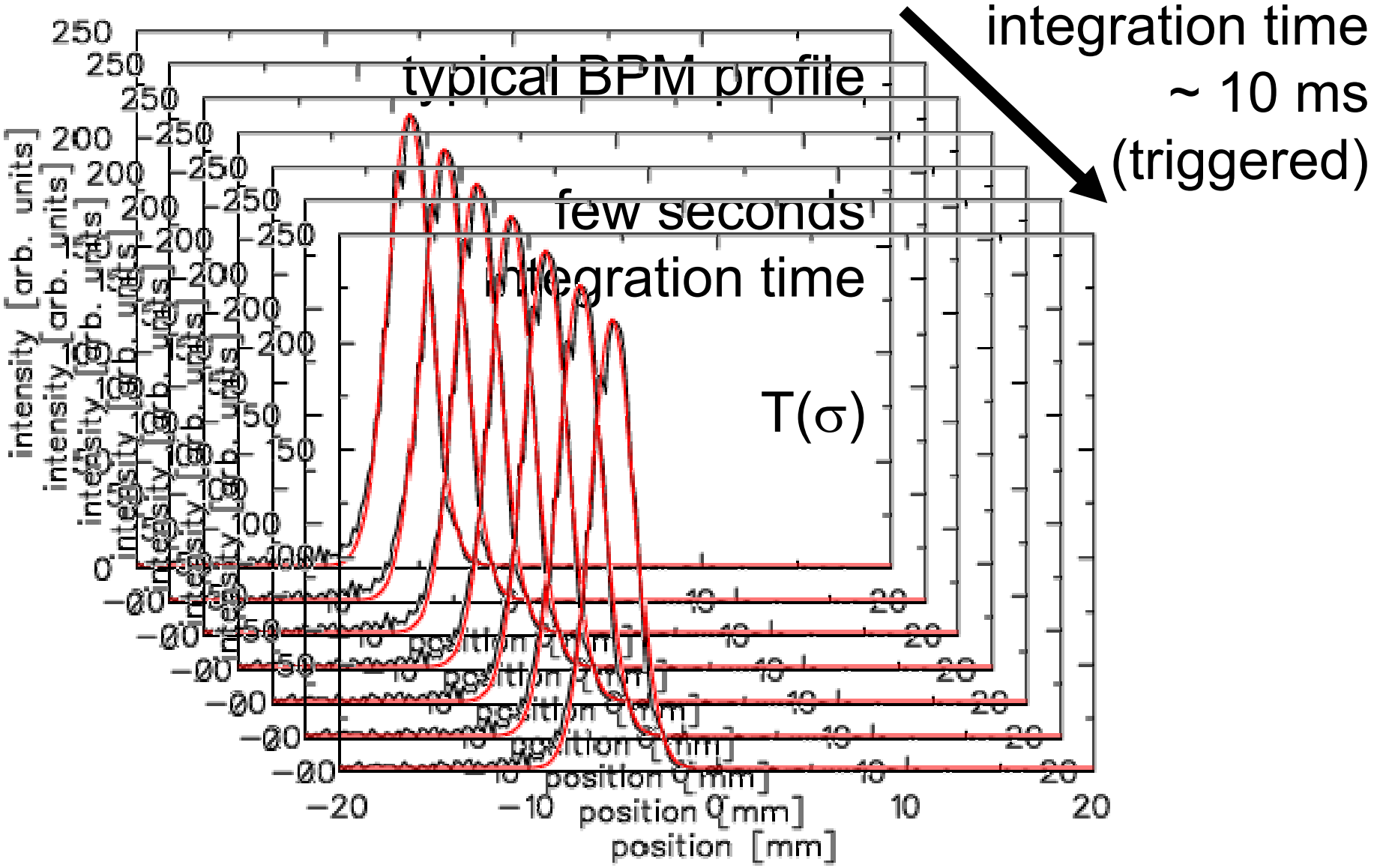
Improved ESR Diagnostics

Schottky: Continuous measurement of axial Ion Dynamics



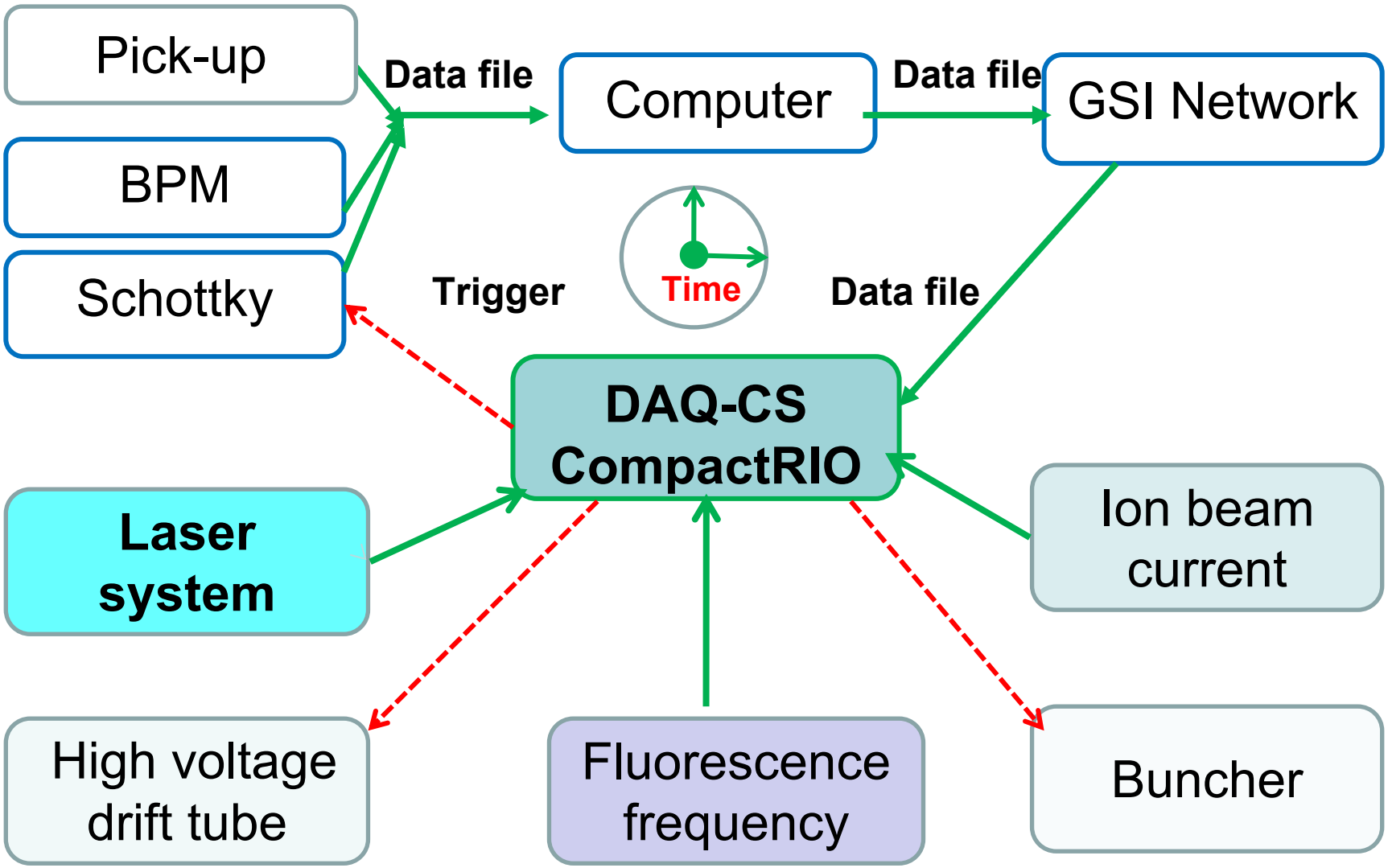


Beam Profile Monitor: Radial Temperature



Data Acquisition and Control System

Data Acquisition + Control System Layout



Wen Weiqiang et al.

Data-Acquisition and Control-System for Laser Cooling of Relativistic Ion Beams

Poster Session!

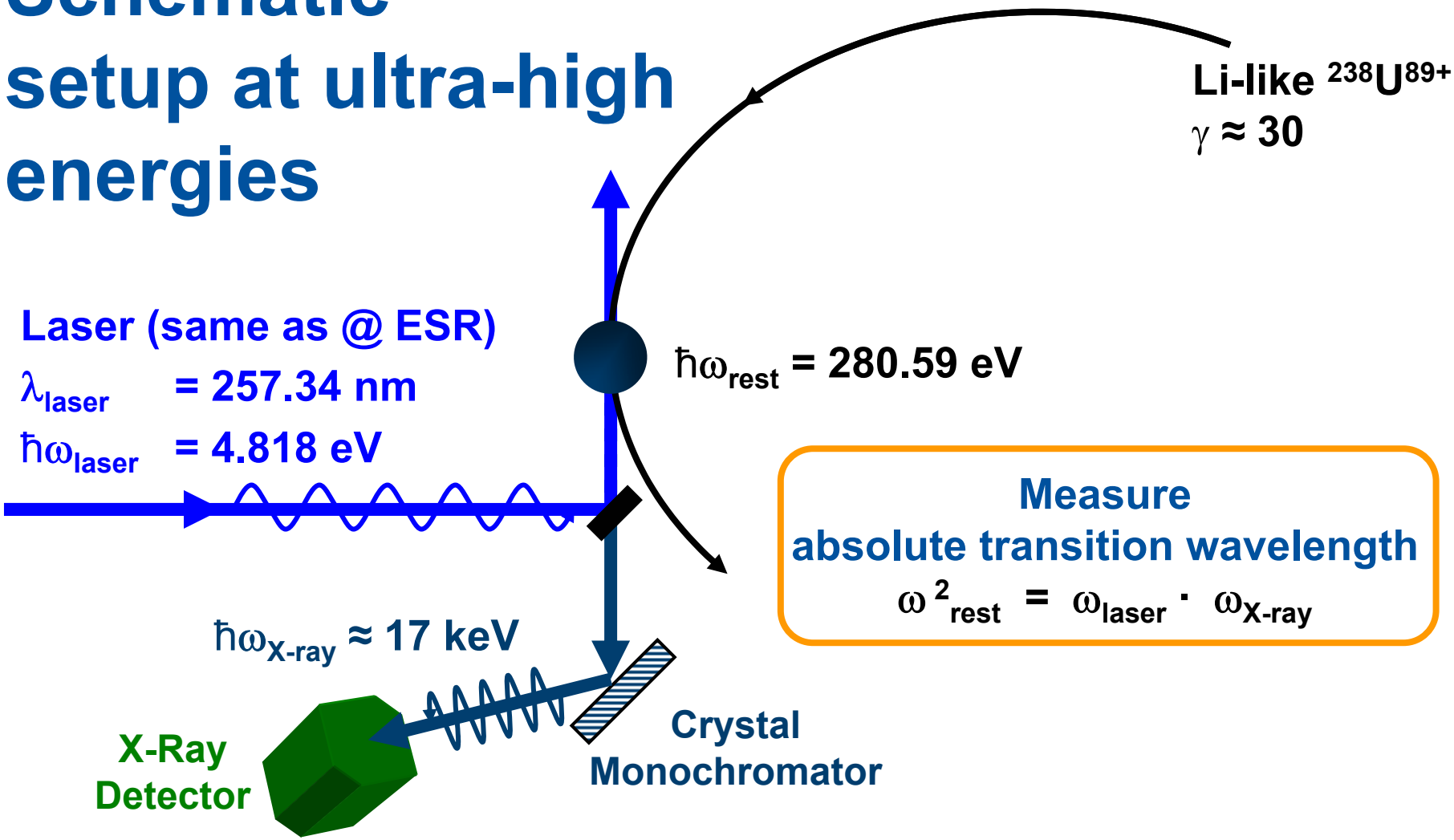
Applications

Precision VUV Laser Spectroscopy

Uncertainty in absolute ion energy

	● $(2S_{1/2} \rightarrow 2P_{1/2})$ [nm]	● $(2S_{1/2} \rightarrow 2P_{3/2})$ [nm]
ESR C3+ experiment	**155.0705 (39) (3)**	**154.8127 (39) (2)**
Theory (I. Tupitsyn, V. Shabaev)	**155.0739 (26)**	**154.8173 (53)**

Schematic setup at ultra-high energies



All-Optical Cooling @ ESR

Scanning cw Laser System (~ 100 GHz UV / 10 ms)

Pulsed Laser System (50 ps, 50 μJ, 40 MHz burst)

Dynamical Phase-Space Evolution @ 10 ms

New VUV Detection System (2 PMT + Channeltron)