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Single shot burst imaging of electric fields measured by split excitation electric field induced second harmonic generation (SEE-FISH)

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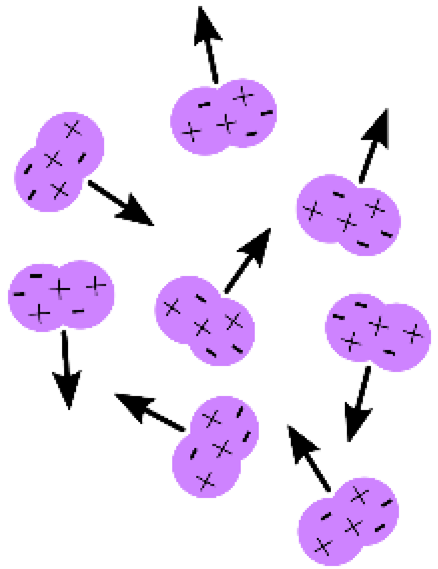
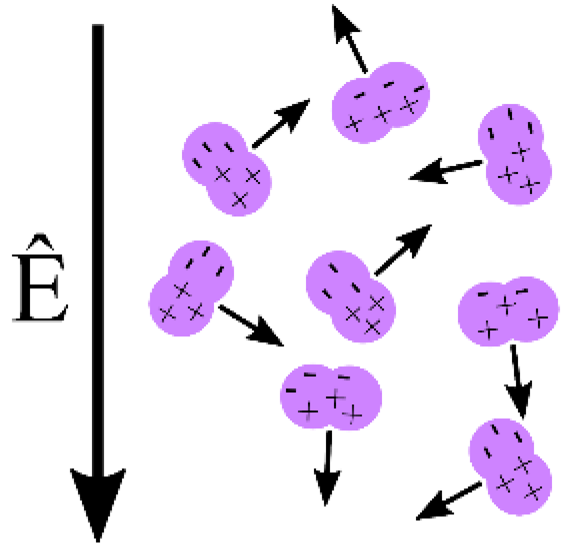
Basics of the E-FISH Method

Centrosymmetric System



- In centrosymmetric media, second harmonic generation is impossible
    - There can be no coherent buildup of radiation due to random molecular distribution

With Electric Field Present



- A net dipole is generated when an external electric field is present
    - Allows for coherent build up of radiation when acted upon by an intense laser light source

Basics of the E-FISH Method

Basic governing relationship:

- $I^{(2\omega)} = A \cdot N^2 (E_{Ext})^2 \left(I_{Pump}\right)^2$
  - $I^{(2\omega)}$ is SHG intensity
  - A is an experimentally determined calibration constant
  - N is the number density
  - I_{Pump} is the pump beam intensity

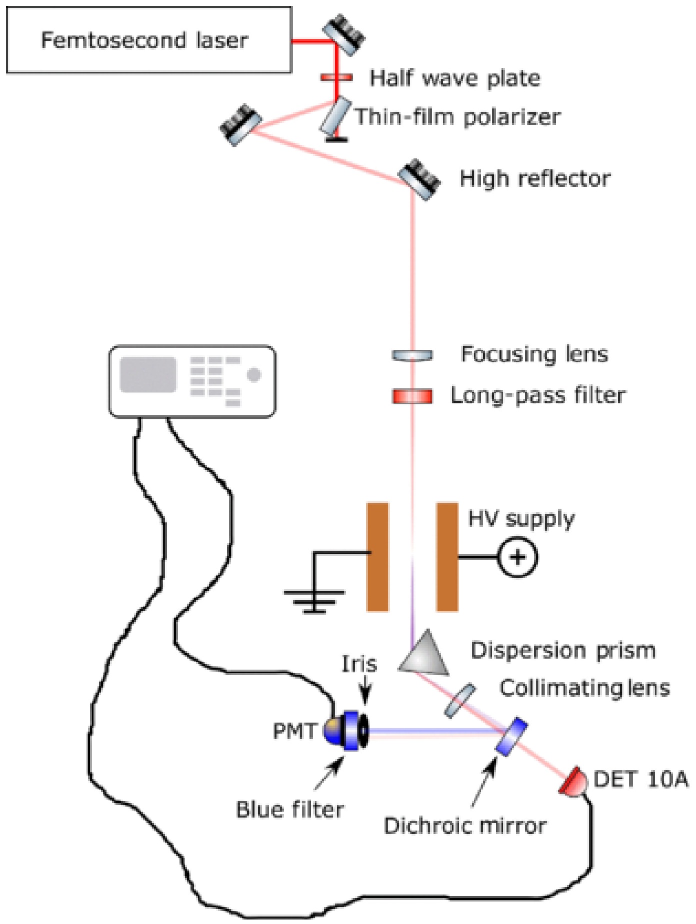
Benefits of the method

- Field vector sensitive
- Works in most gasses
- Time response (typically) determined by laser properties

Overview of recent results

- First proposed (A. Dogariu et al., PRA **7**(2), 2017) and used for plasma measurements at Princeton University (B. Goldberg et al., APL **112** (6), 2018)
- Quickly adopted for use at Ohio State University (M. Simeni-Simeni et al., PSST **27** (10), 2018 amongst others)
- Most recent results from Ecole Polytechnique (TL Chng et al., PSST 2020)
  - See presentation by TL Chng (PDL-02/AMT-28)

General E-FISH Experiment Setup



High intensity laser light source focused into field region

- Spherical or cylindrical focusing can be used

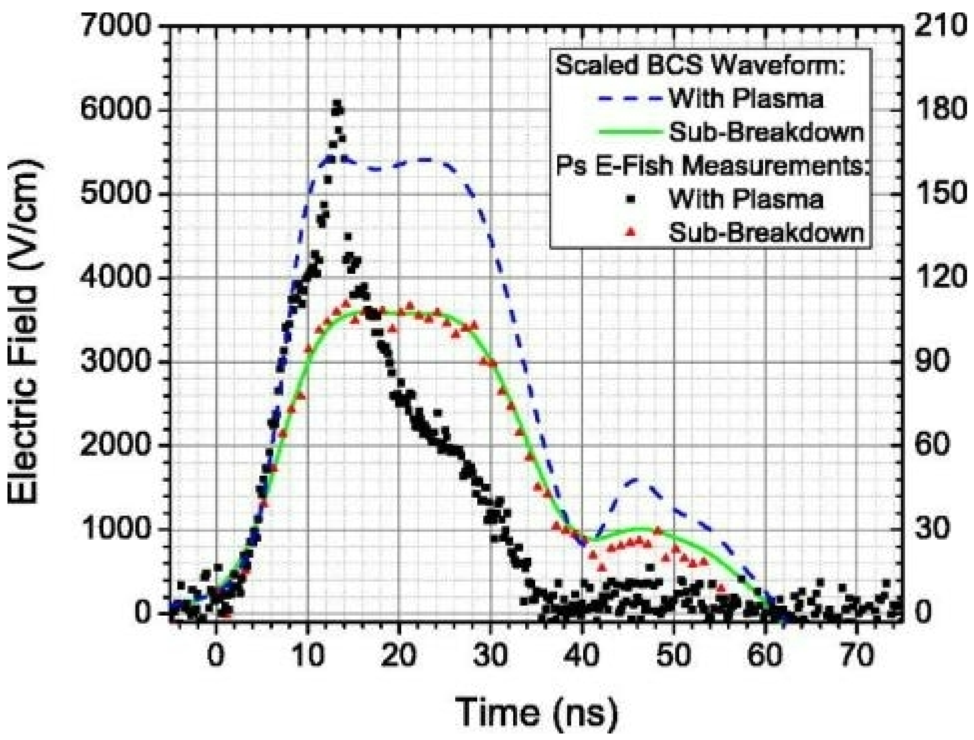
Signal spectrally separated from pump using prisms and filters

Detection done using some intensified device

- PMT for point and ICCD for camera

A. Dogariu et al., PRA 7 (2), 2017

General E-FISH Experiment Analysis



External calibration done in sub-breakdown applied electric field

- Ideal to use same gas and electrodes (attempt to match extent of the field with a plasma as much as possible)

Time response determined by averaging and binning into discrete time bins

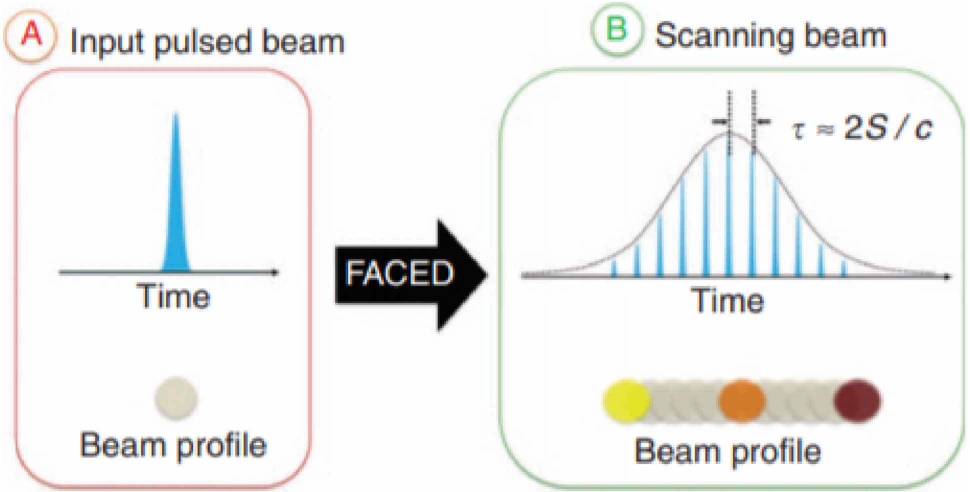
- Possible errors include: Sampling frequency, detector responses, pulse to pulse jitter

Is there a way to make a single shot "video" of a dynamic electric field?

B. M. Goldberg et al., APL 112 (6), 2018

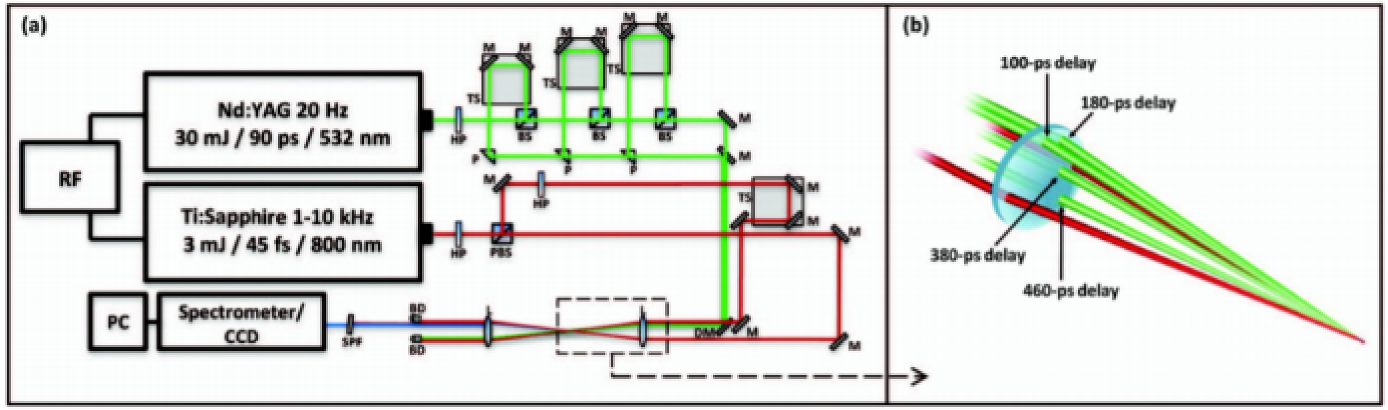
Can look to field of active ultrafast imaging for inspiration

FACED, Wu et al. Light Sci. Appl. 2017



Imaging laser ablation using STAMP

K. Nakagawa et al. Nat. Photonics 2014



Single shot fs/ps CARS time-domain linewidth measurements
B.D. Patterson et al., Opt. Lett. 2013

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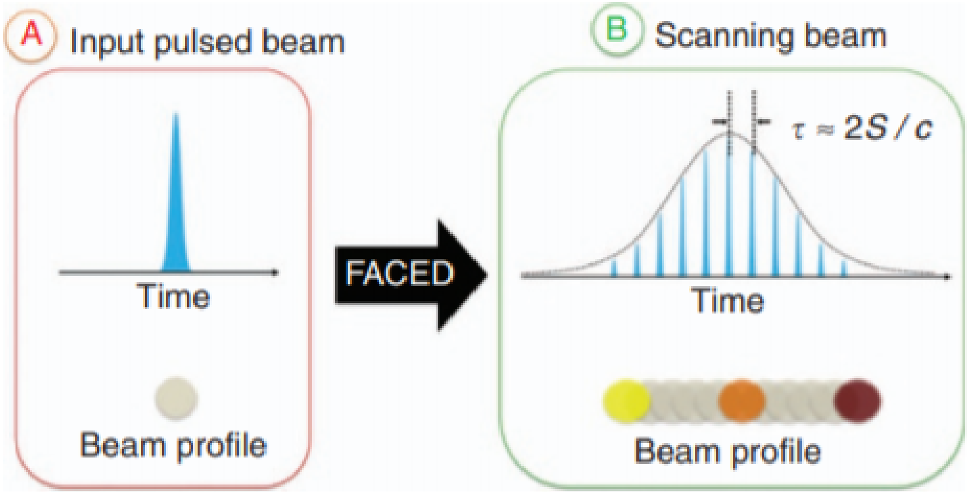

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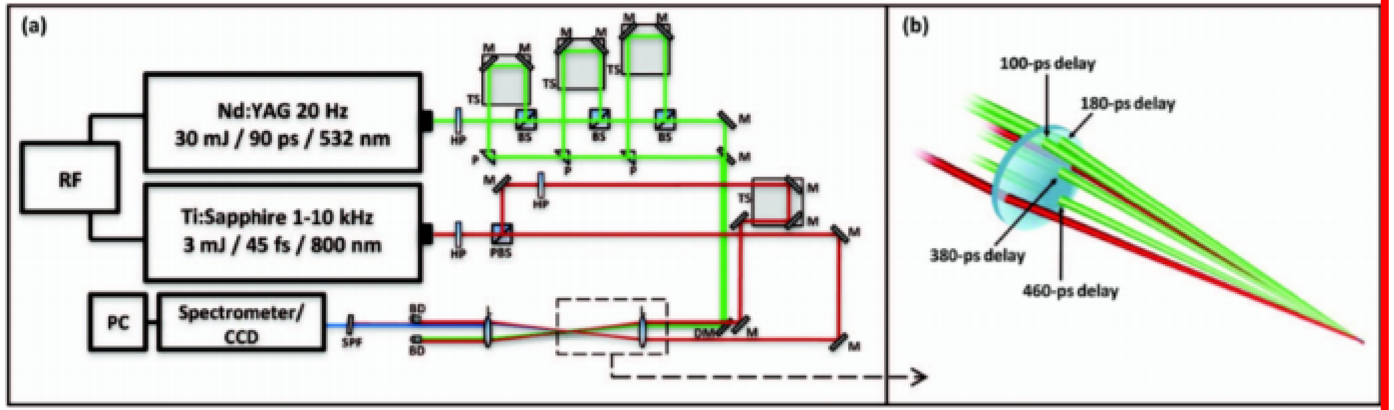
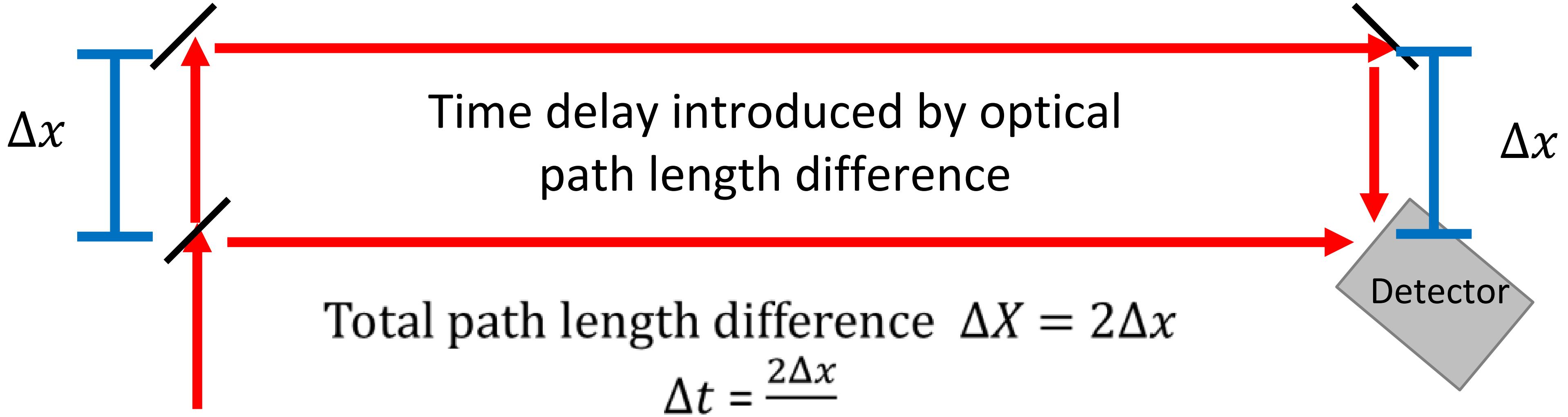


Single shot fs/ps CARS time-domain linewidth measurements

B.D. Patterson et al., Opt. Lett. 2013

We propose a split excitation E-FISH (SEE-FISH) method for single shot burst imaging of dynamic electric fields



Total path length difference $\Delta X = 2\Delta x$

$$\Delta t = \frac{2\Delta x}{c}$$

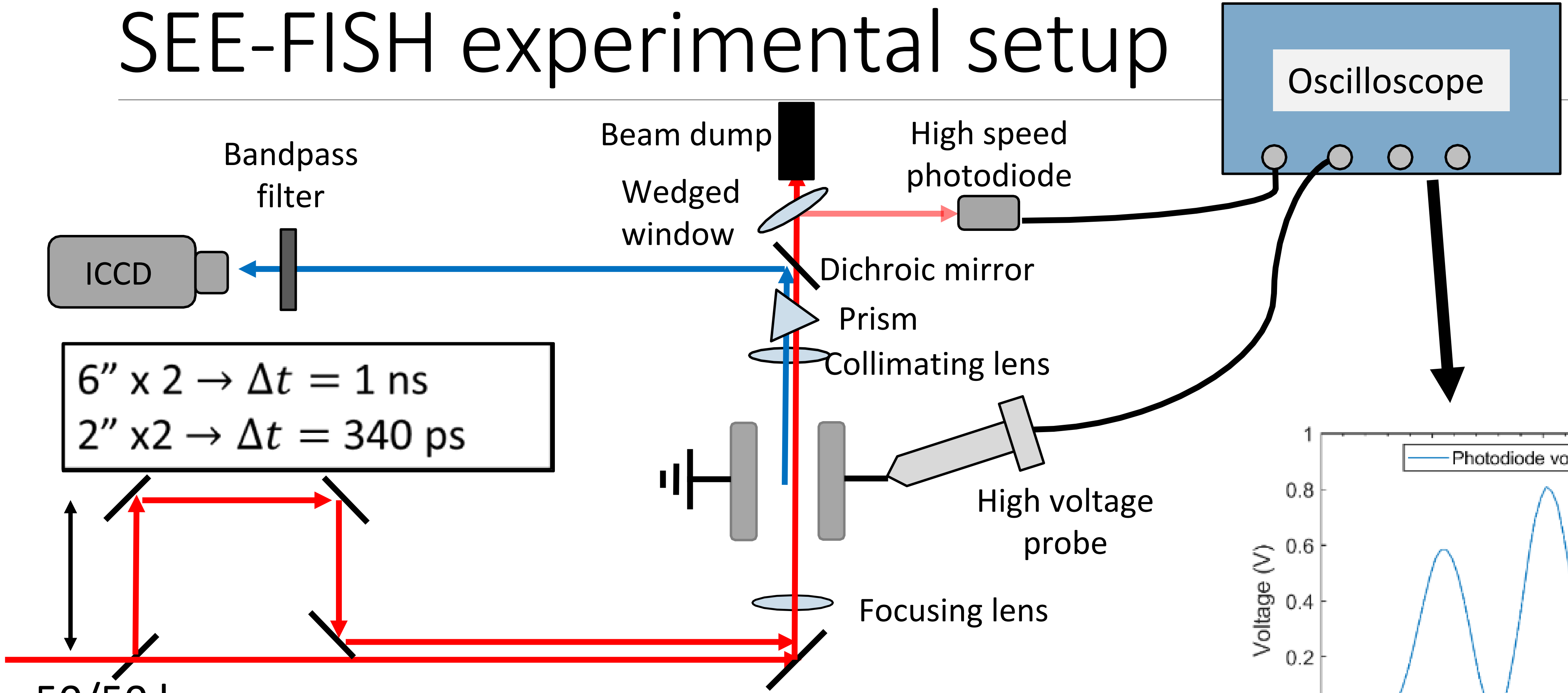
Advantages:

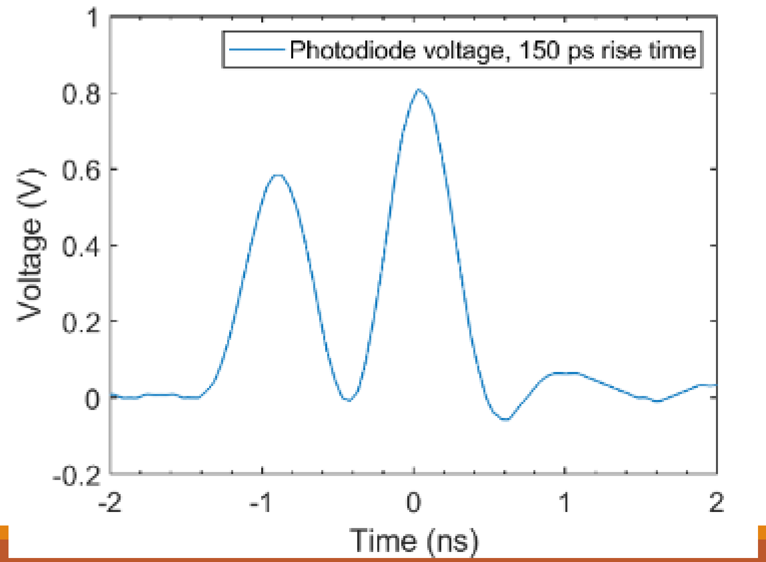
Pulse to pulse timings are fixed i.e. no **relative** timing jitter

Can capture time evolution of non-repetitive transient events in a single laser shot

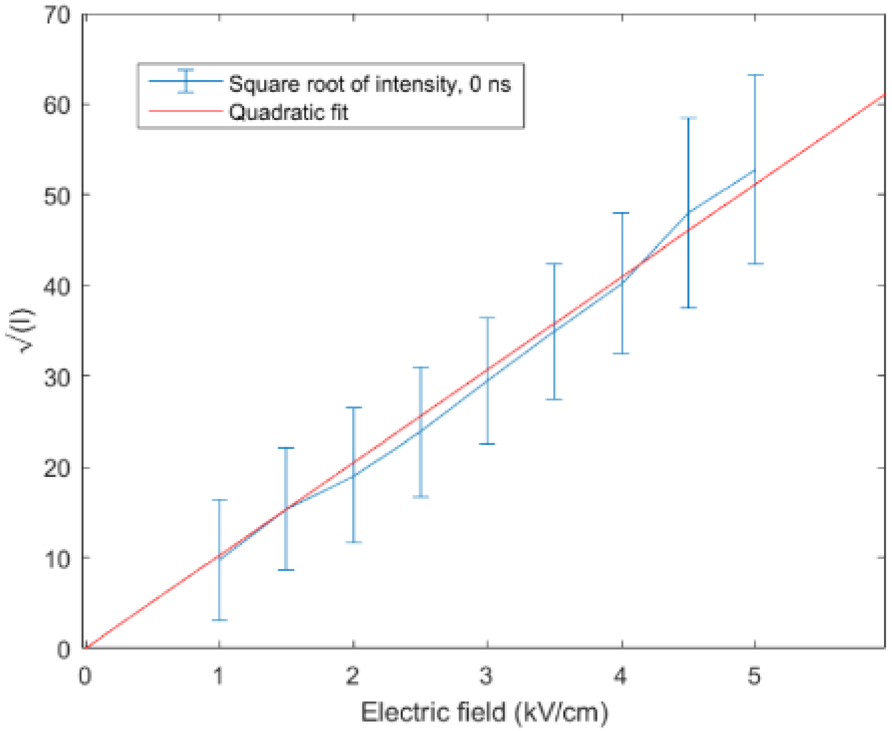
- E.g. Plasma-assisted ignition, discharges in high speed flow facilities, atmospheric pressure plasma jets

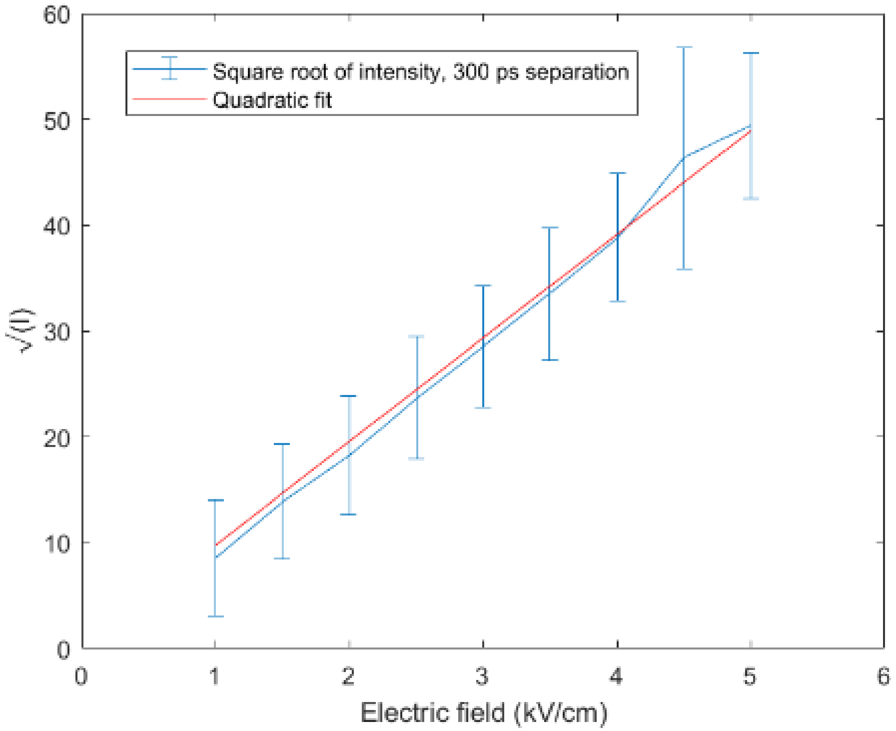
SEE-FISH experimental setup





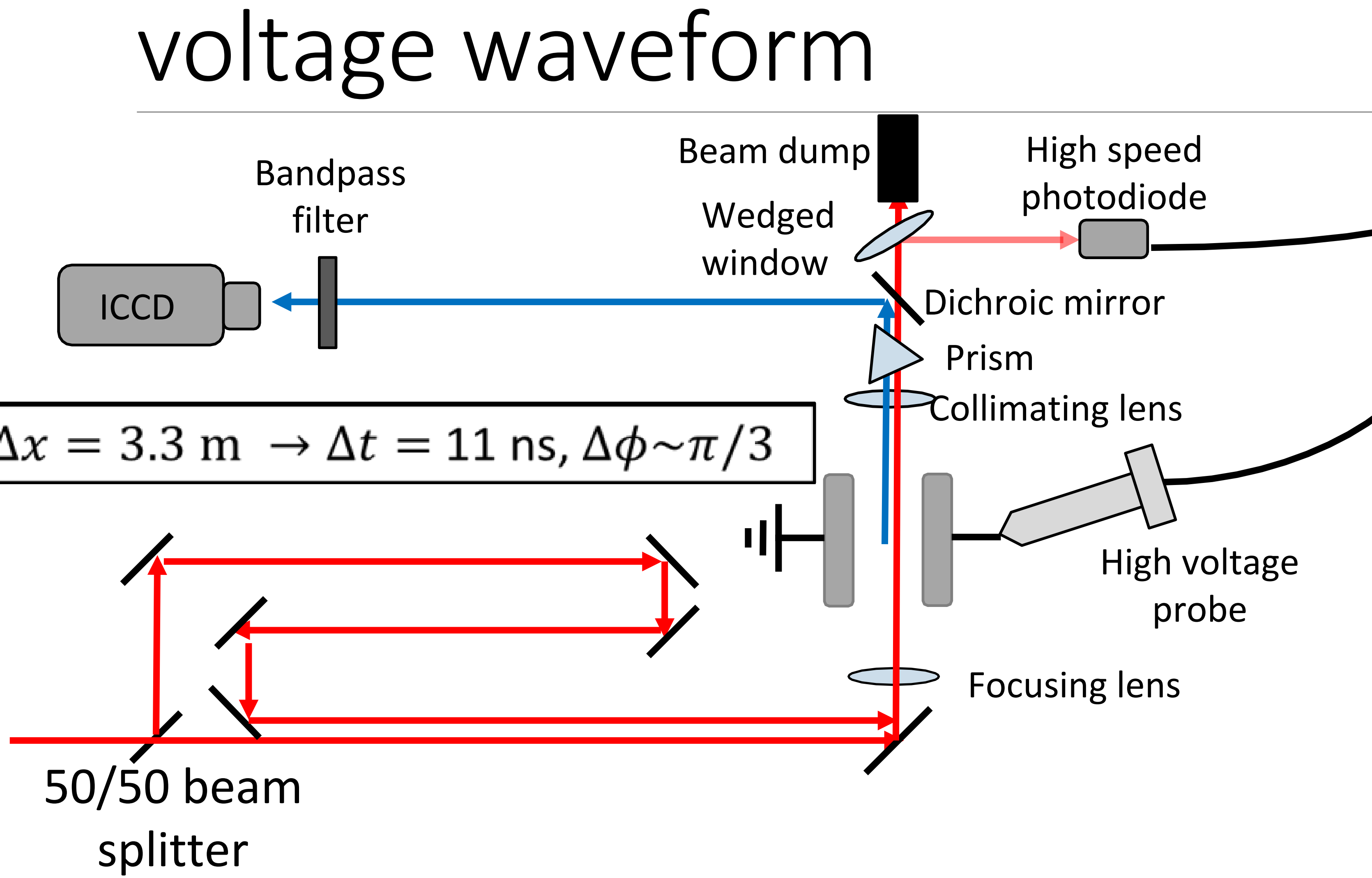
DC calibration is quadratic even for 340 ps pulse spacing



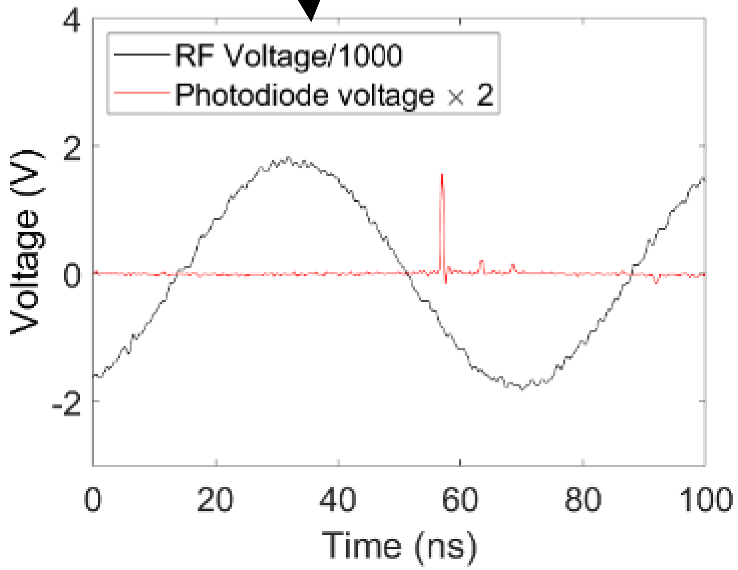


SEE-FISH time resolution can be below 0.5 ns!

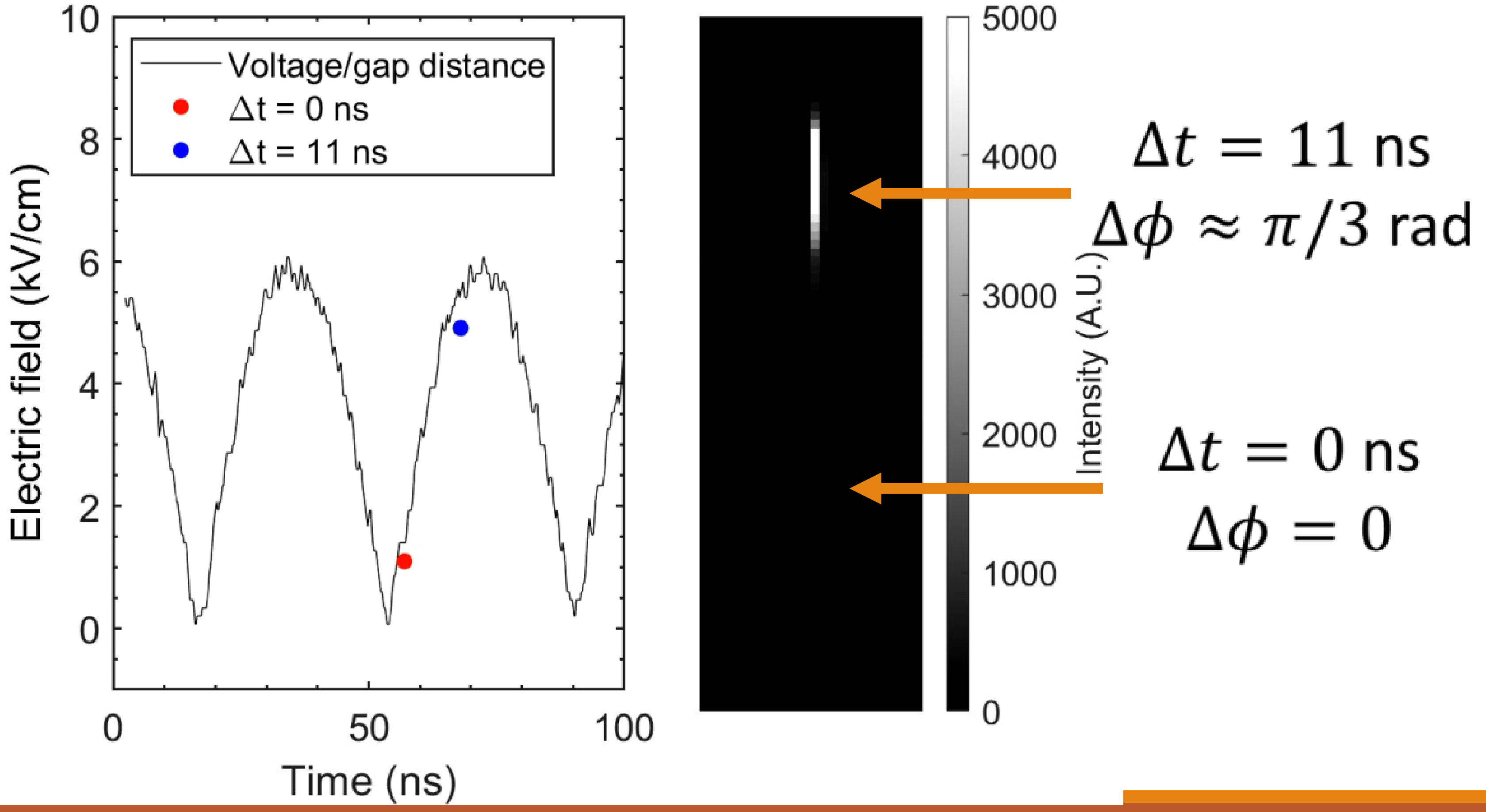
SEE-FISH for 13.56 MHz RF voltage waveform



$\Delta x = 3.3\text{ m} \rightarrow \Delta t = 11\text{ ns}, \Delta\phi \sim \pi/3$



Single shot 2-frame SEE-FISH of a radio frequency (RF) voltage



Conclusion and future work

- Developed a new method, SEE-FISH, for single shot burst imaging of dynamic electric fields
- Demonstrated temporal resolution down to 340 ps (>2 GHz) in DC field
- Measured a time-varying electric field generated by 13.56 MHz RF voltage at 100 MHz
- Additional beams will be added to increase number of frames

Acknowledgments

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Questions?