Scalable interference from long ion strings

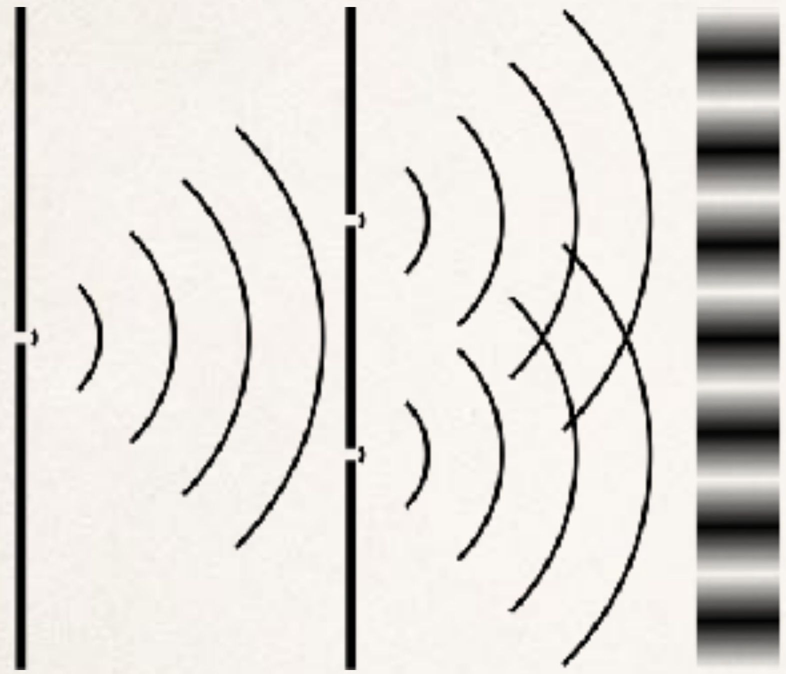
P. Obšil[1], A. Lešundák[2], T. Pham[2], G. Araneda[3], M. Čížek[2], O. Číp[2], R. Filip[1] and L. Slodička[1]

[1]Department of Optics, Palacký University in Olomouc, Czech Rep.
[2]Institute of Scientific Instruments of CAS, Brno, Czech Rep.
[3]Institut für Experimentalphysik, Innsbruck, Austria

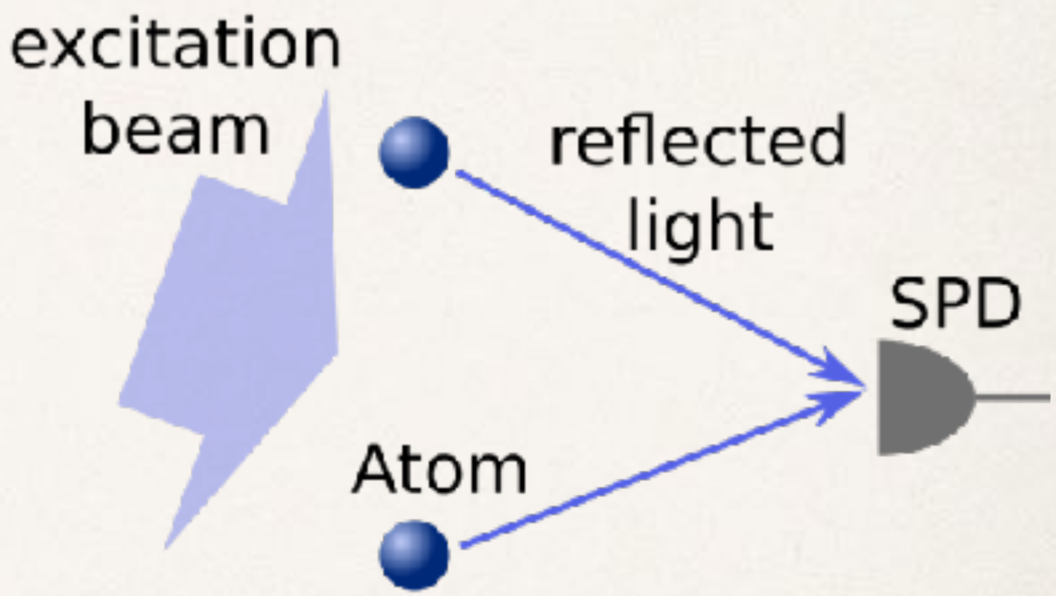
Rehovot, ECTI 2018, 22nd November 2018

Coherent scattering of light from atoms

Young's interference experiment



Phase interference with individual atoms



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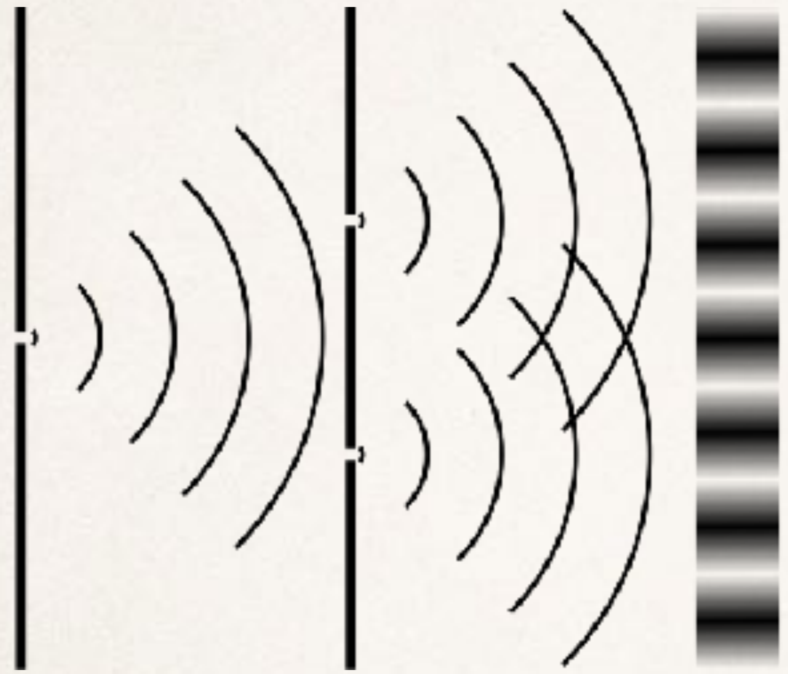
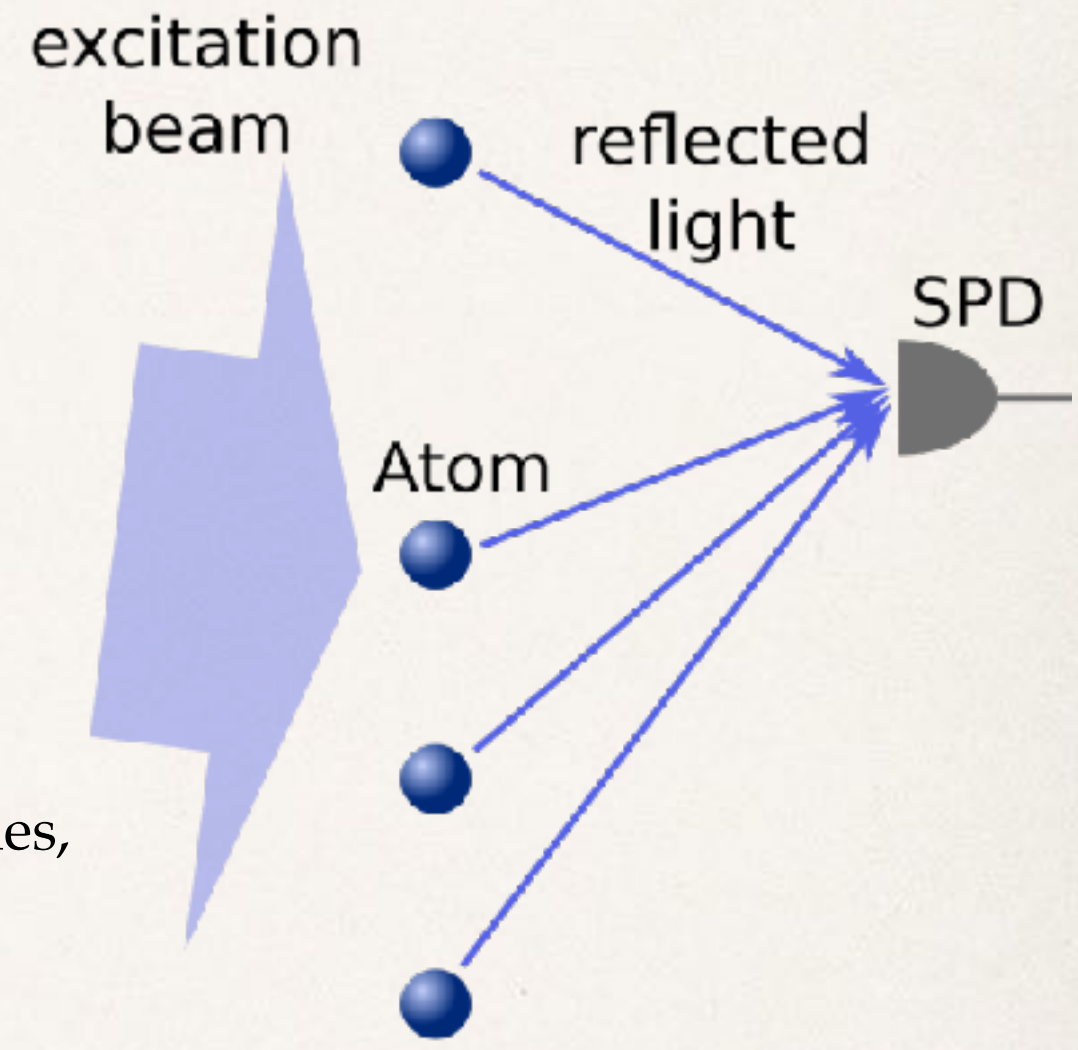


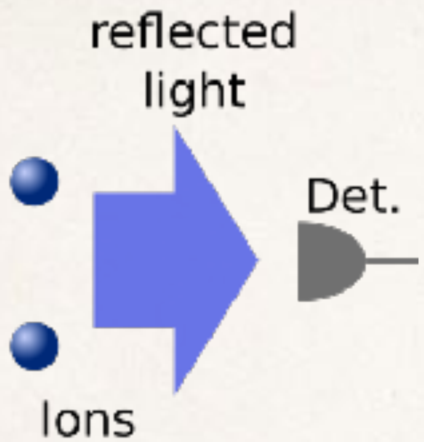
Phase interference with individual atoms

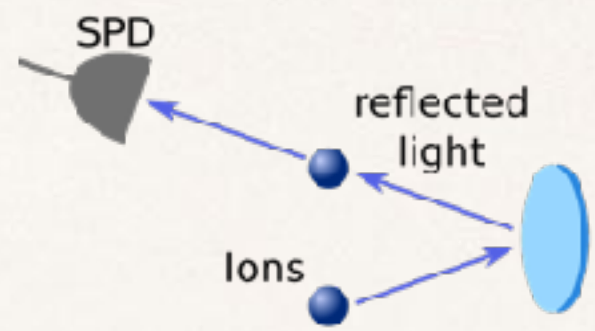


Entanglement generation using single-photon schemes,
C. Cabrillo et al., PRA 59, 1025 (1999)
Directional emission, extinction of laser beam,
D. Porras and J. I. Cirac, PRA 78, 053816 (2008)
M. K. Tey et al., New Journal of Physics 11, 043011 (2009)
Enhanced squeezing of resonance fluorescence
W. Vogel and D.-G. Welsch, PRL 54, 1802 (1985)

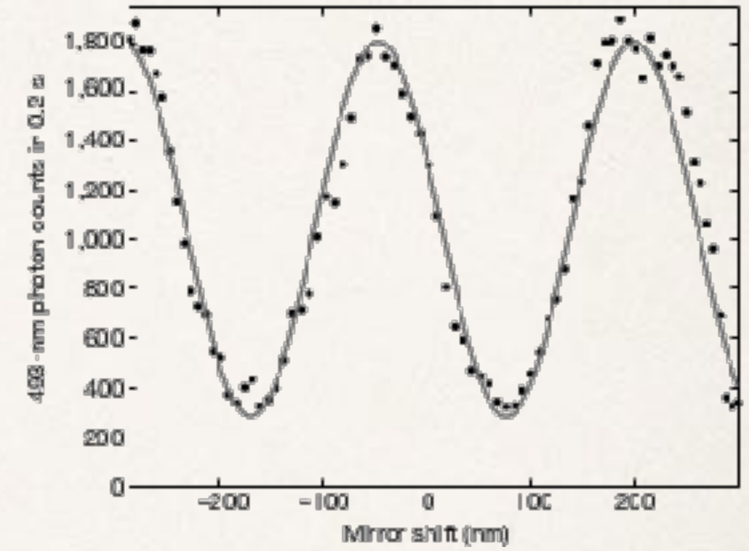
Gives very precise information about temperature, motion, laser excitation parameters
L. Slodička et al., PRA 85, 043401 (2012), S. Wolf et al., PRL 116, 183002 (2016)

Observations of coherent light scattering with trapped ions

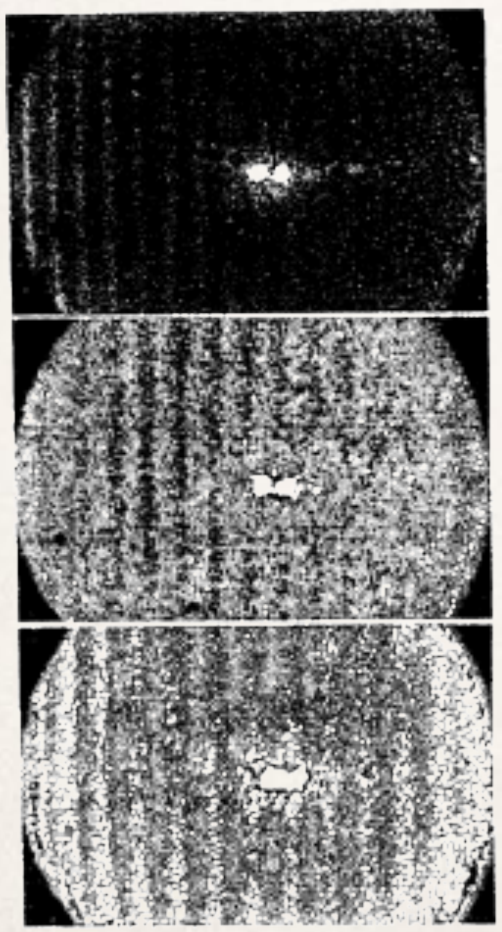


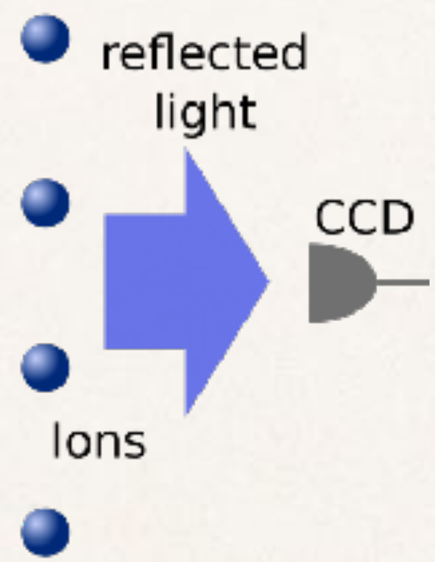


J. Eschner et al., Nature 413, 495 (2001)

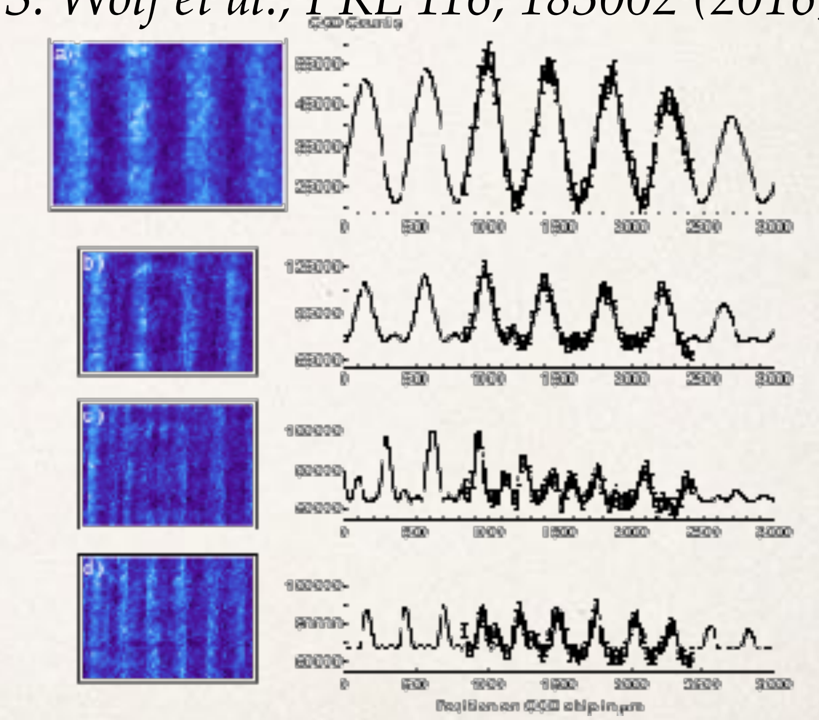


U. Eichmann et al., PRL 70, 2359 (1993)





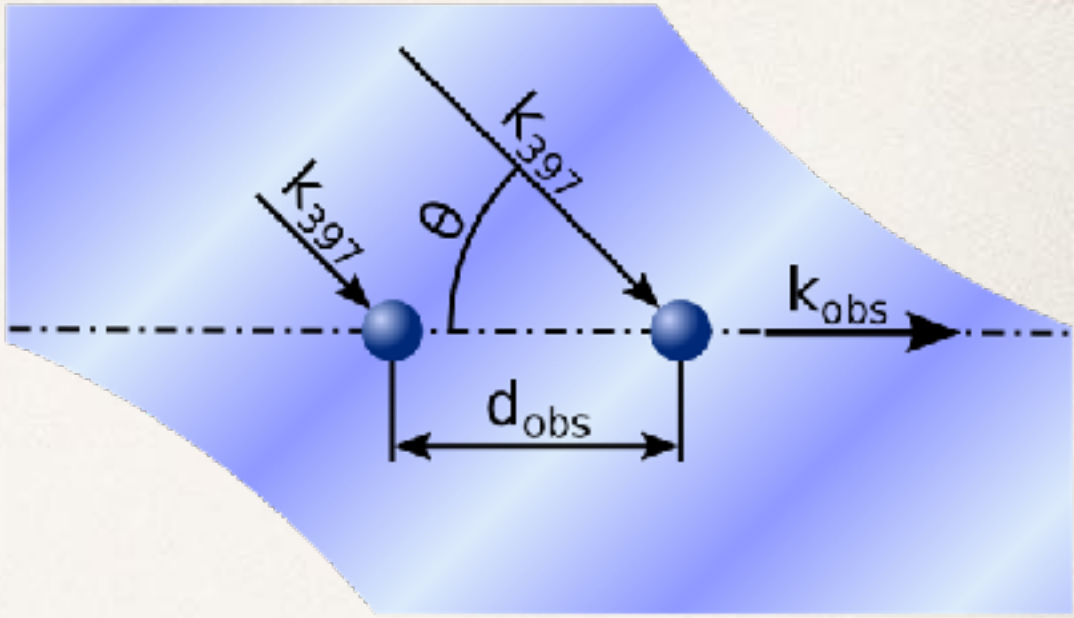
S. Wolf et al., PRL 116, 183002 (2016)



Possibility of scaling up to high ion numbers?

Scalable spatial indistinguishability

Solution - look along the ion string symmetry axis

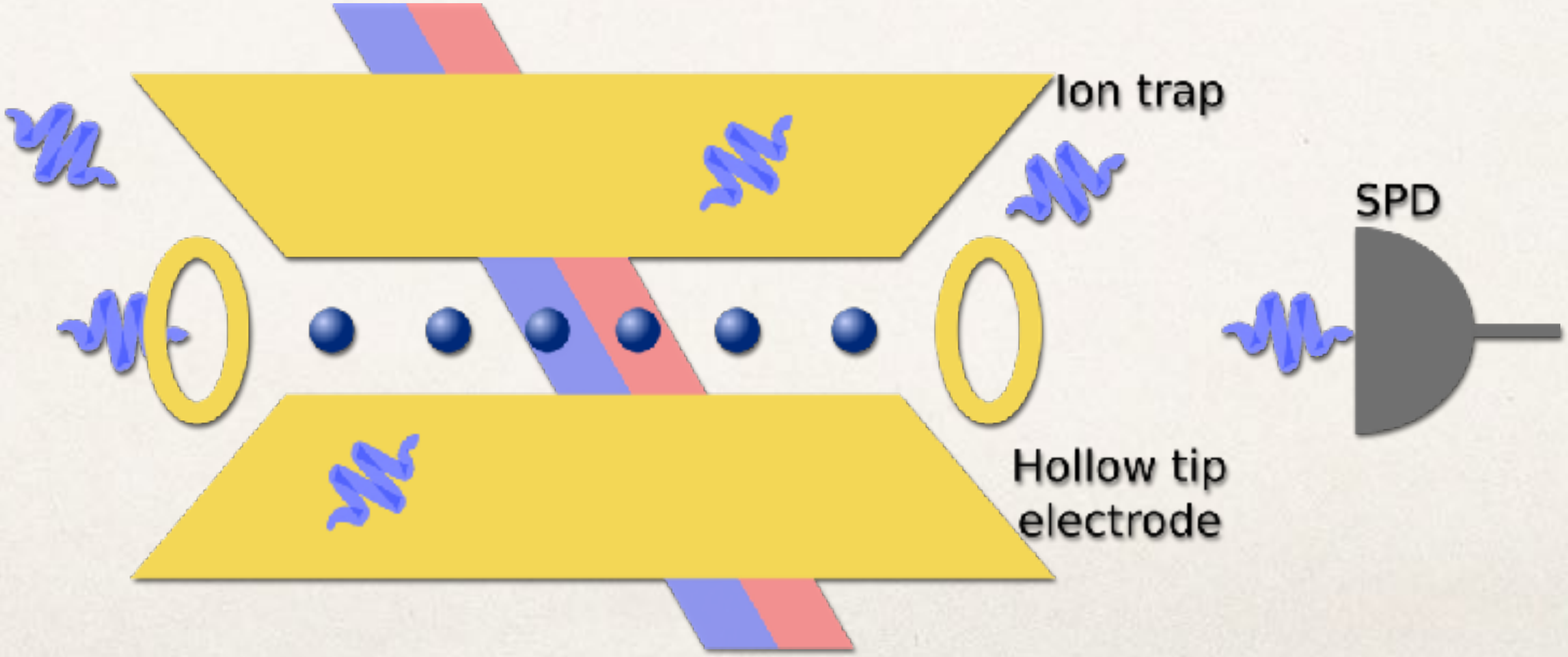


Guarantees spatial indistinguishability

Minimizes the gradient of interference pattern as function of observation angle

Preserves the fundamental addressability of individual ions

Convenient and repeatable interference pattern tuning by axial potential change



Scalable spatial indistinguishability

Axial observation direction - utilisation of tip apertures

Diameter 0.5 mm ~ solid angle fraction $1.3 * 10^{(-5)}$

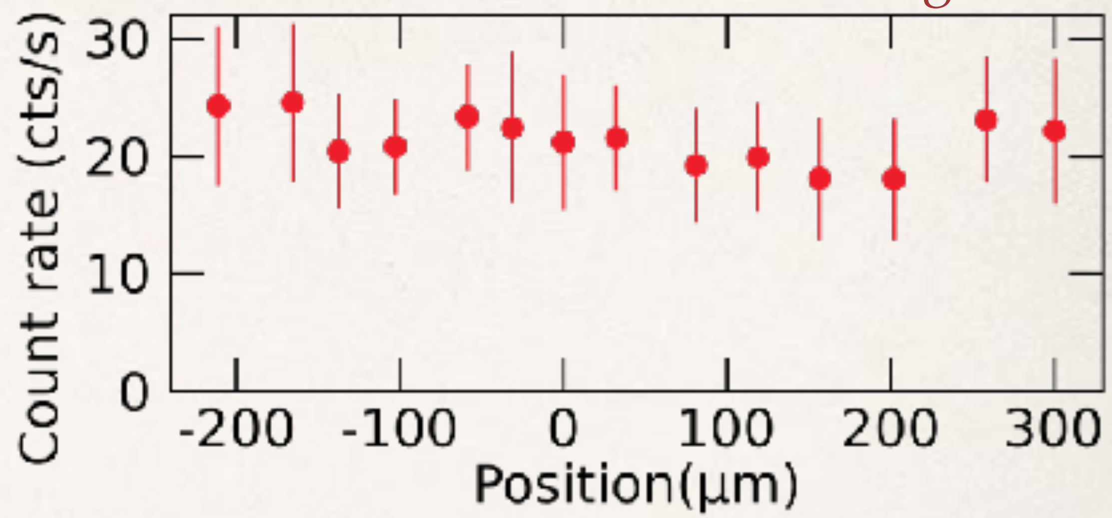
Overall calculated efficiency $3.7 * 10^{(-6)}$

Overall measured efficiency $(3.6+-0.4) * 10^{(-6)}$

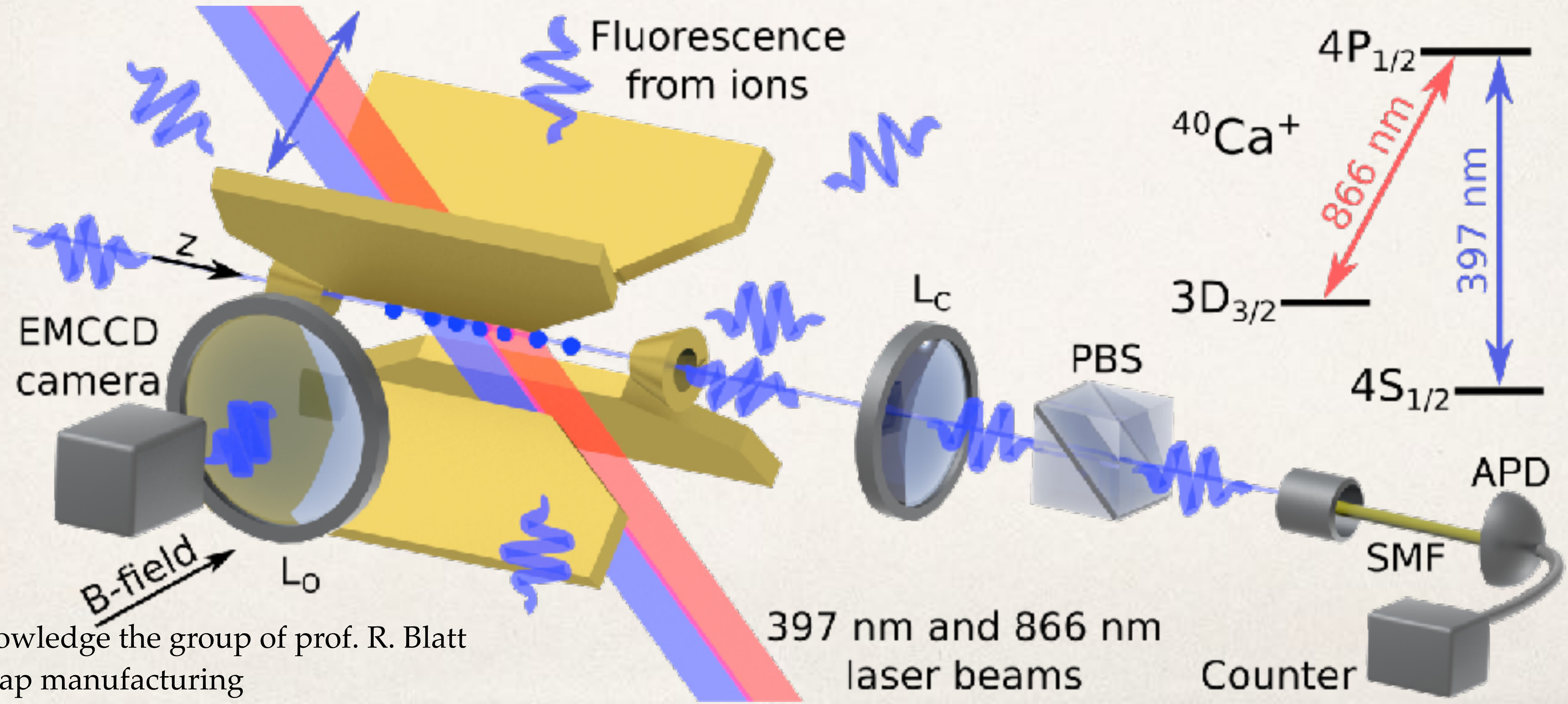
Signifies perfect overlap between emission radiation pattern and detection spatial mode within the given solid angle

Observation mode (gaussian) w_0=17.4um, z_R=2.4mm

Count rate measured with single ion



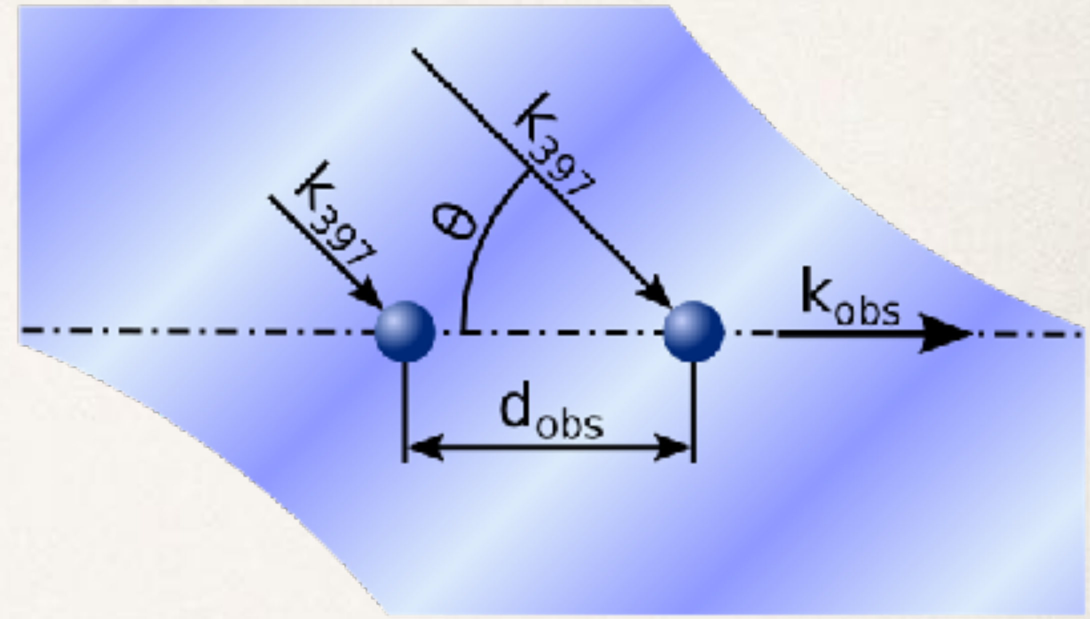
Constant count rate for single ion in unprecedented range of axial positions



We acknowledge the group of prof. R. Blatt for the trap manufacturing

Two-ion case

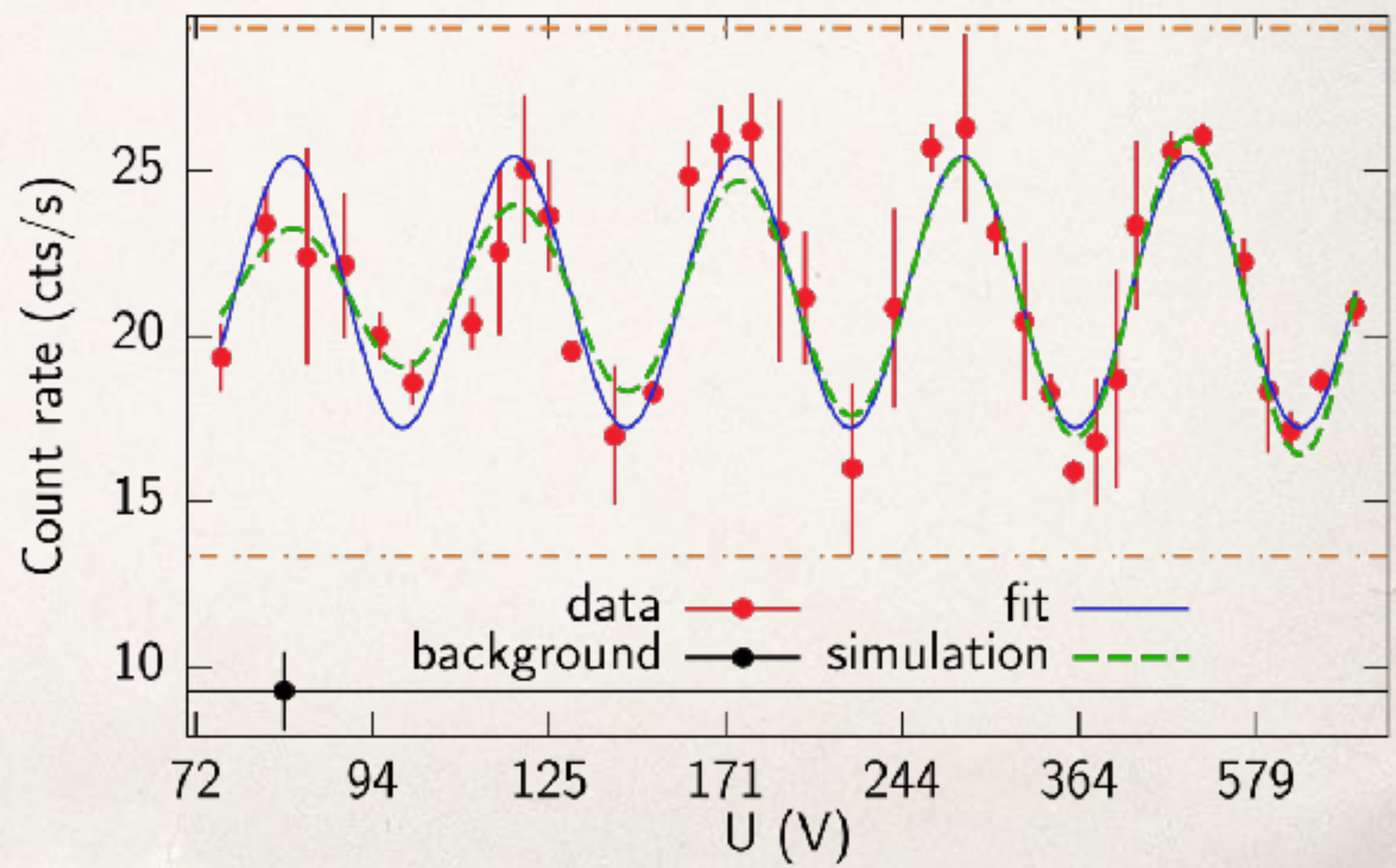
Benchmarking the main decoherence mechanisms



Light reflection vs. spontaneous emission
Relative phase jitter of individual reflectors - motion

- Inelastic scattering reduces interference by factor 0.66 (Estimated from dark resonance spectra)

- The residual coherence reduction by factor 0.5 corresponds well to independently evaluated motional jitter (estimated from spectroscopy on 729 nm $4S_{1/2}$ - $3D_{5/2}$ transition)



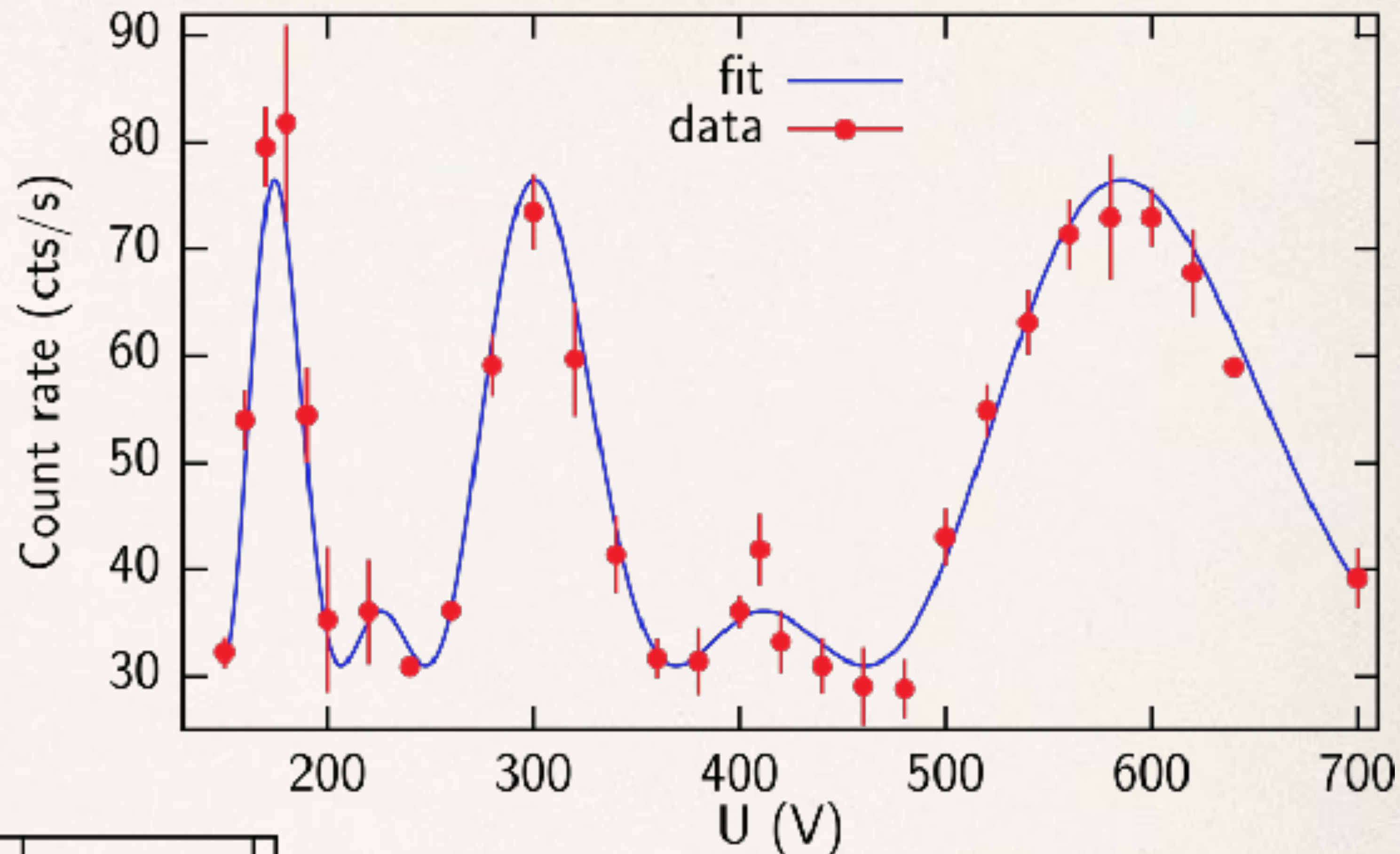
Simulation - no free parameters

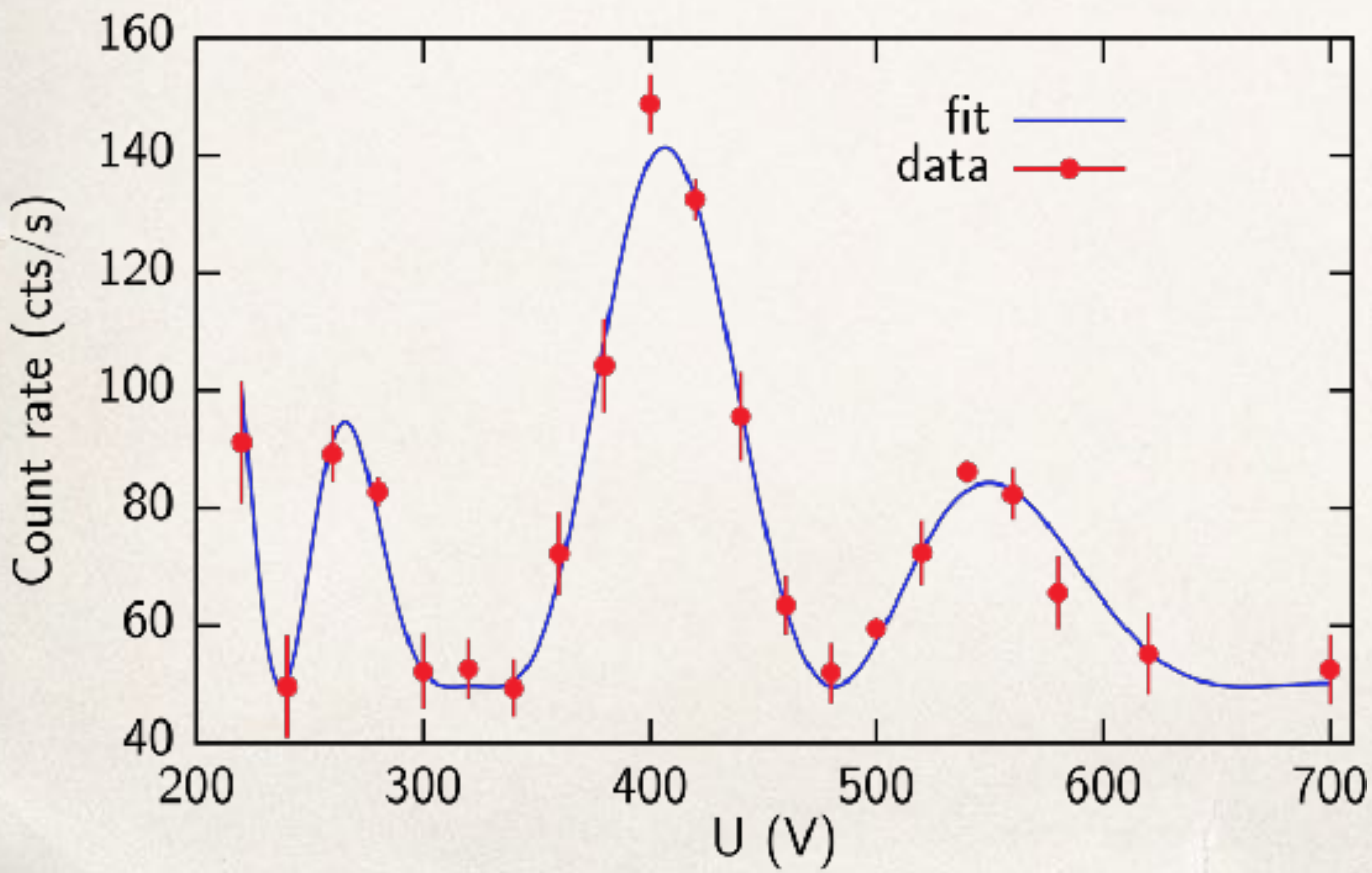
Scaling up the ion number

Blue curve - simulation of interference pattern from the calculated ion positions, only intensity is fitted

- 3 ions - Still equidistant spatial distribution

Positions with competing constructive and destructive interference appear



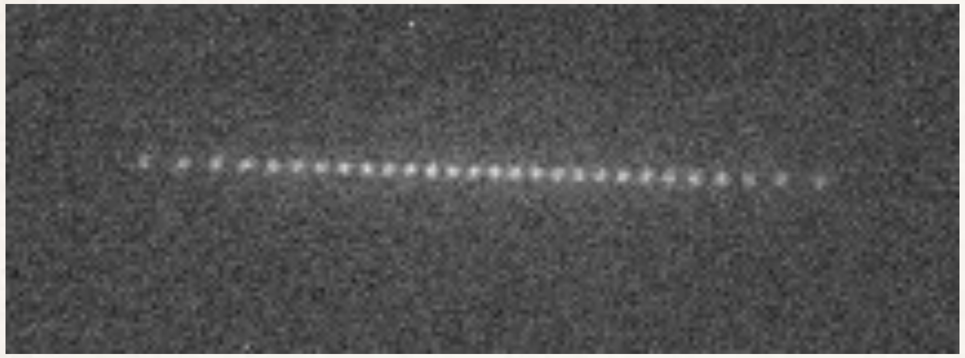


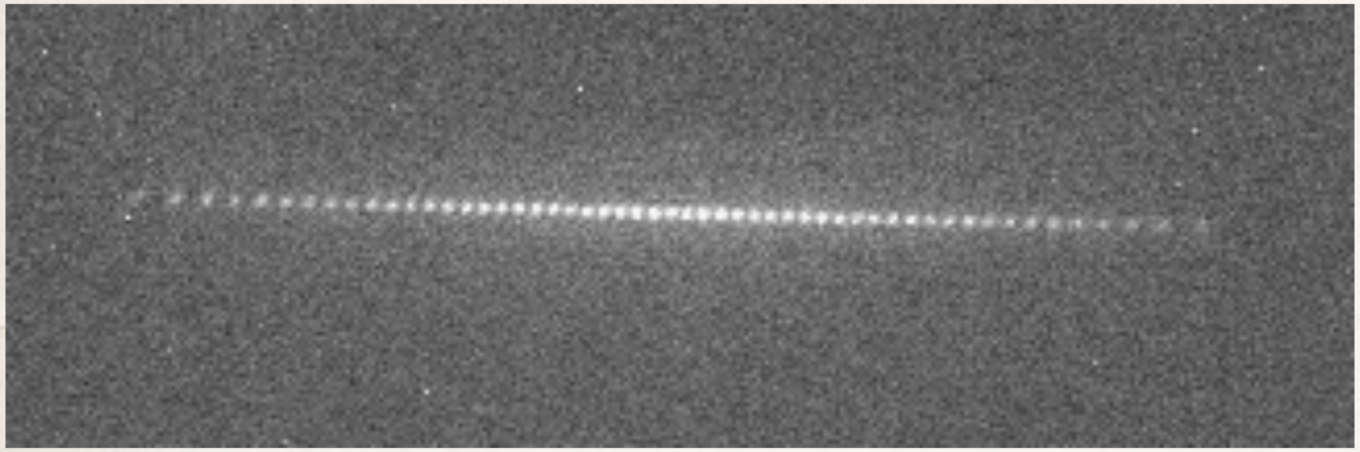
- 4 ions - Non-equidistant positions

Near perfectly constructive position still achievable

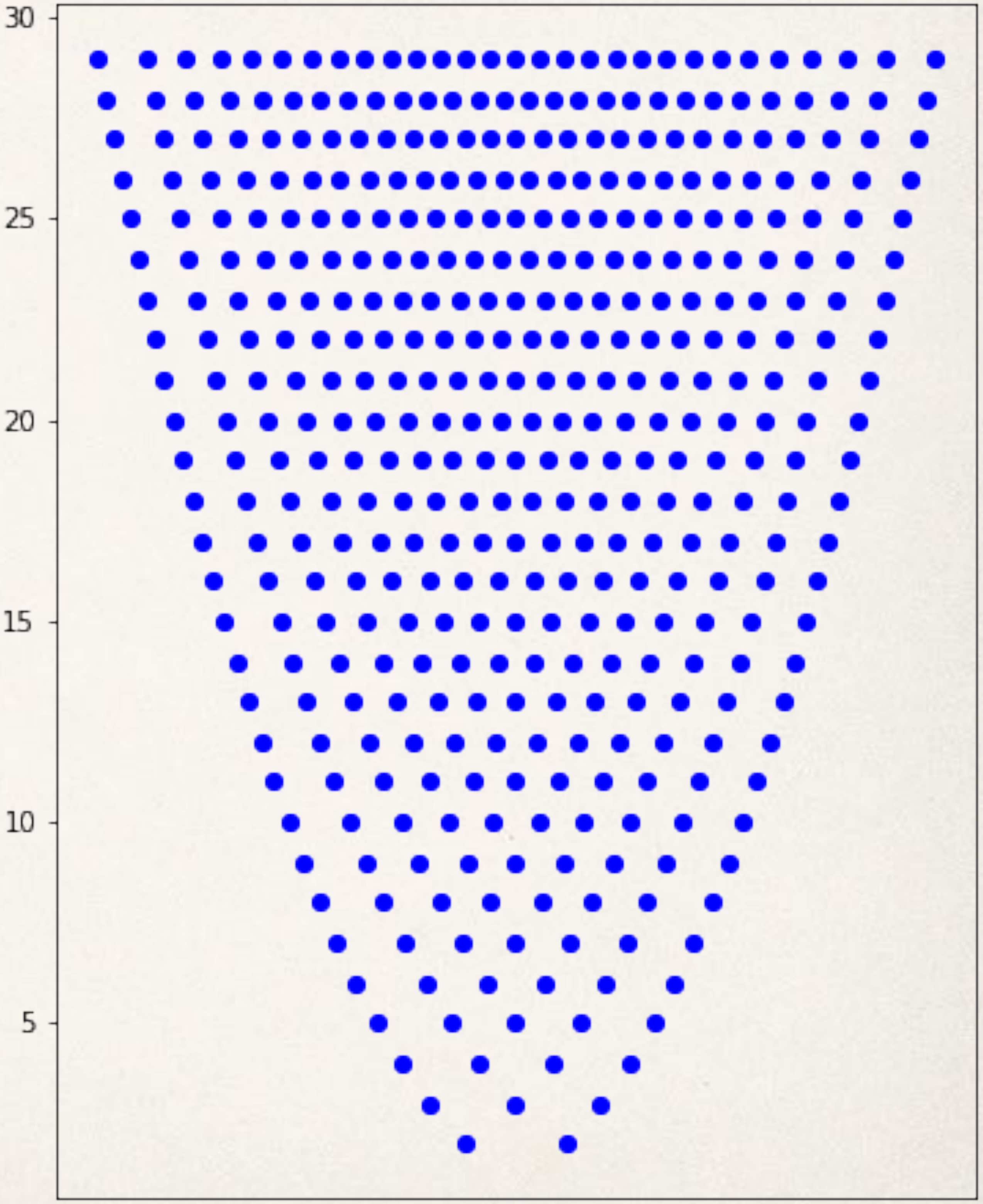
Ion-string spatial structure

Non-equidistant ion positions





We observe superb crystal stability and absence of chemistry on up to hundreds of ions for many hour time scales!

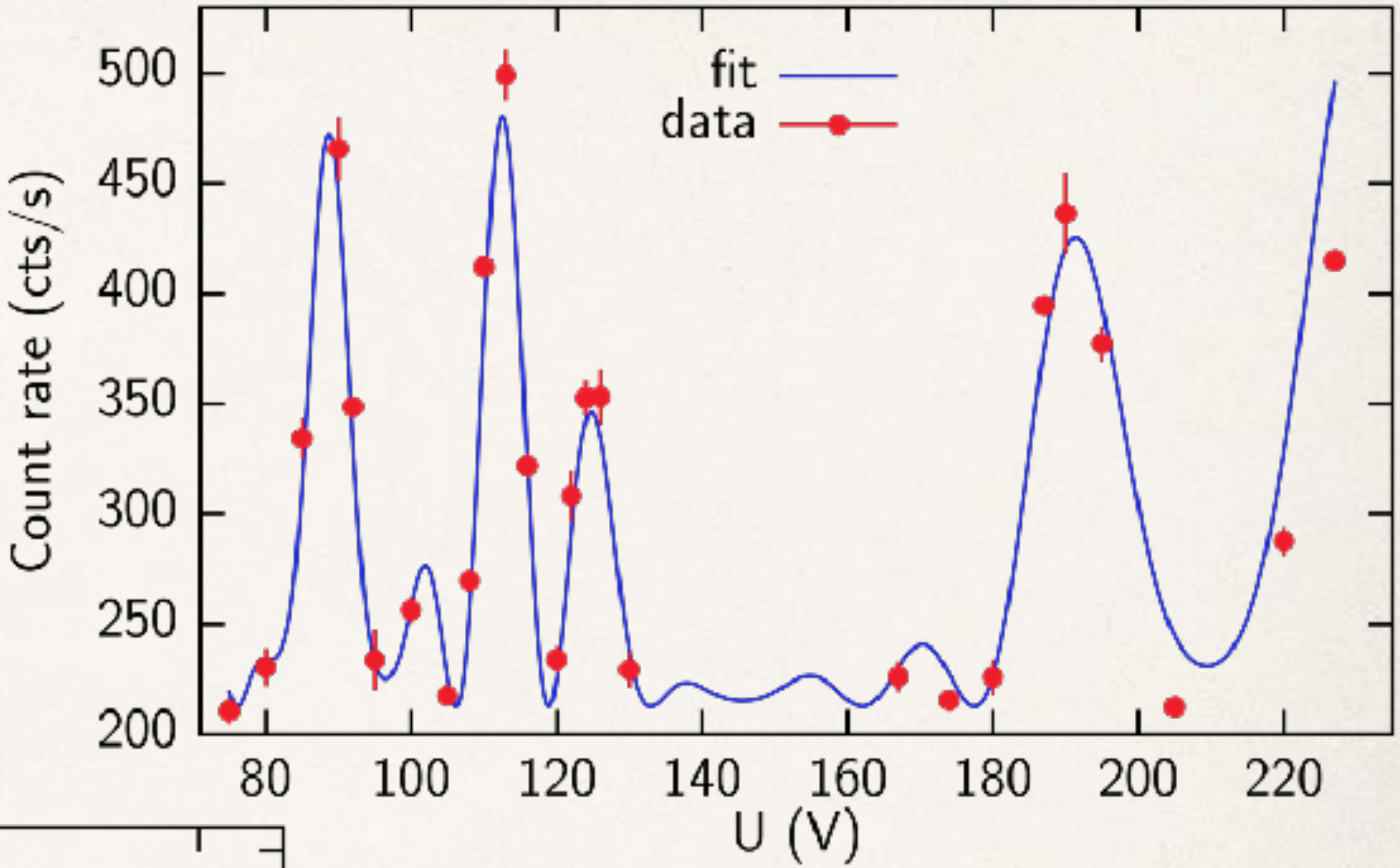


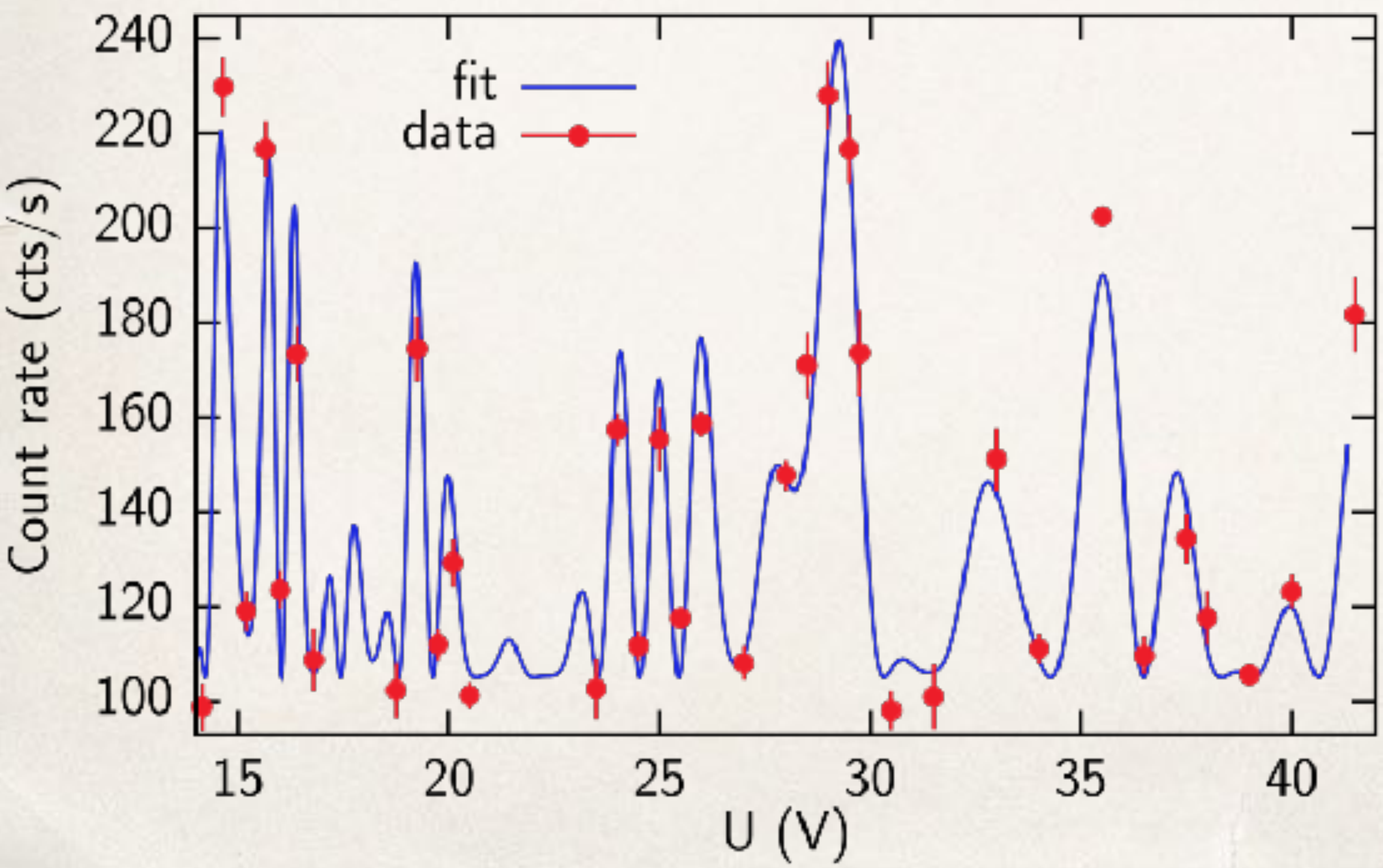
D.F.V. James, Appl. Phys. B 66, 181 (1998)

Interference from many ions

Blue curve - simulation of interference pattern from the calculated ion positions, only intensity is fitted

- 10 ions



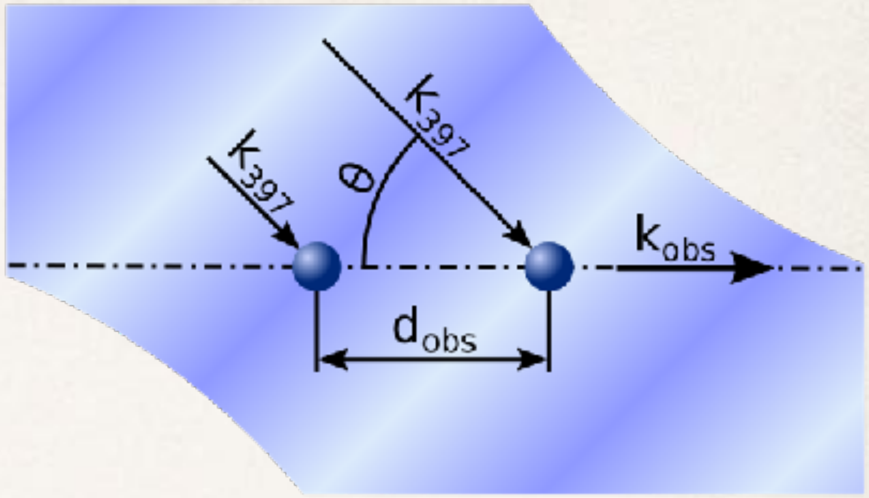


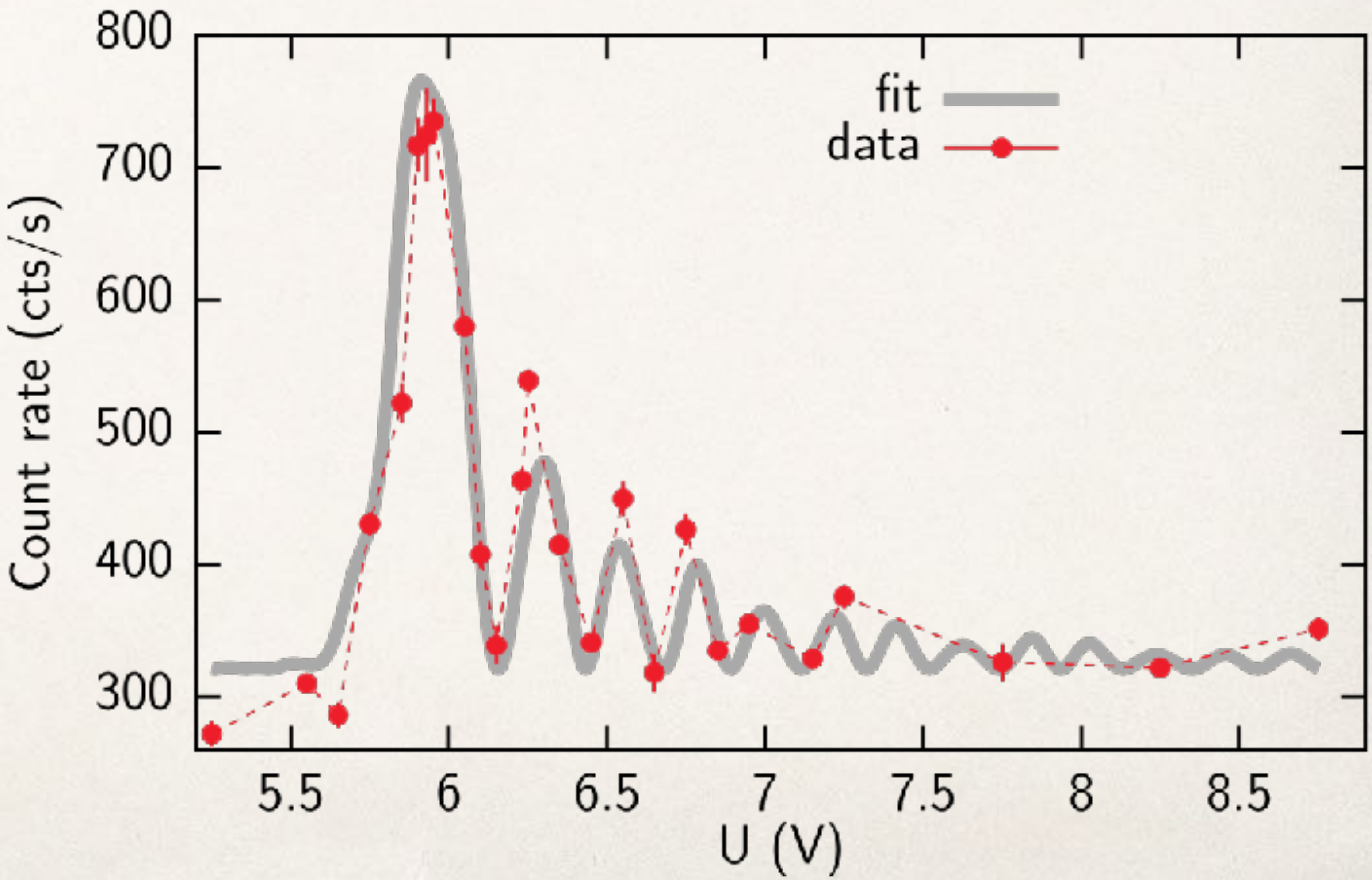
- 20 ions

53 ions

- **Still interferes**
  We need to include the beam intensity profile to fit the pattern plausibly!

- Excitation 493 nm beam waist estimated from the best fit w=115 um

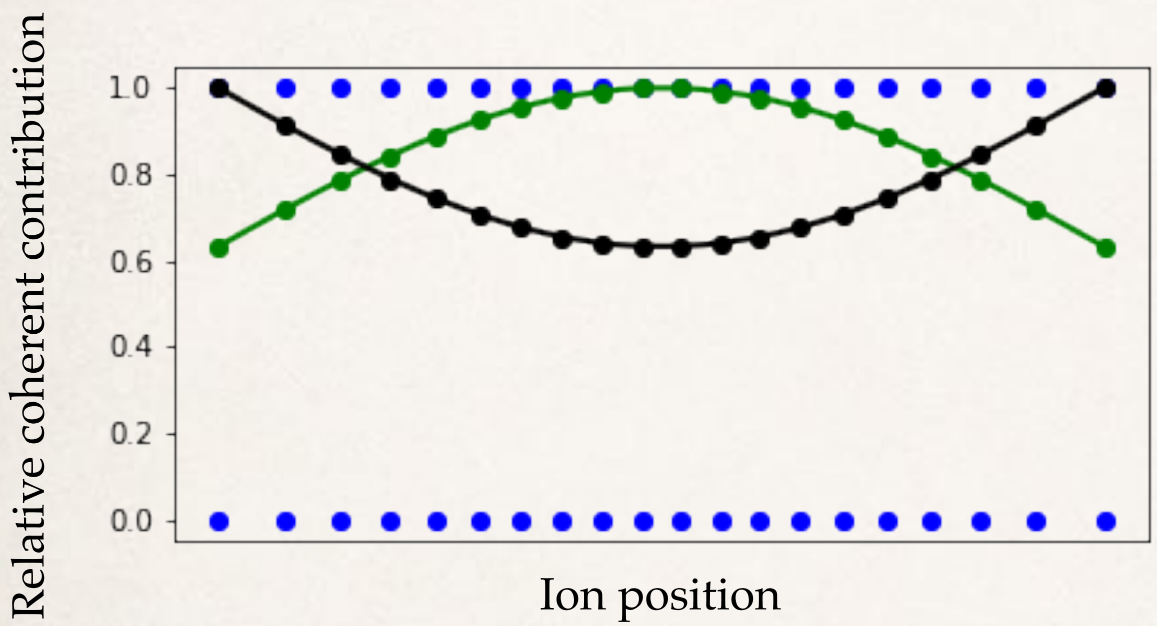




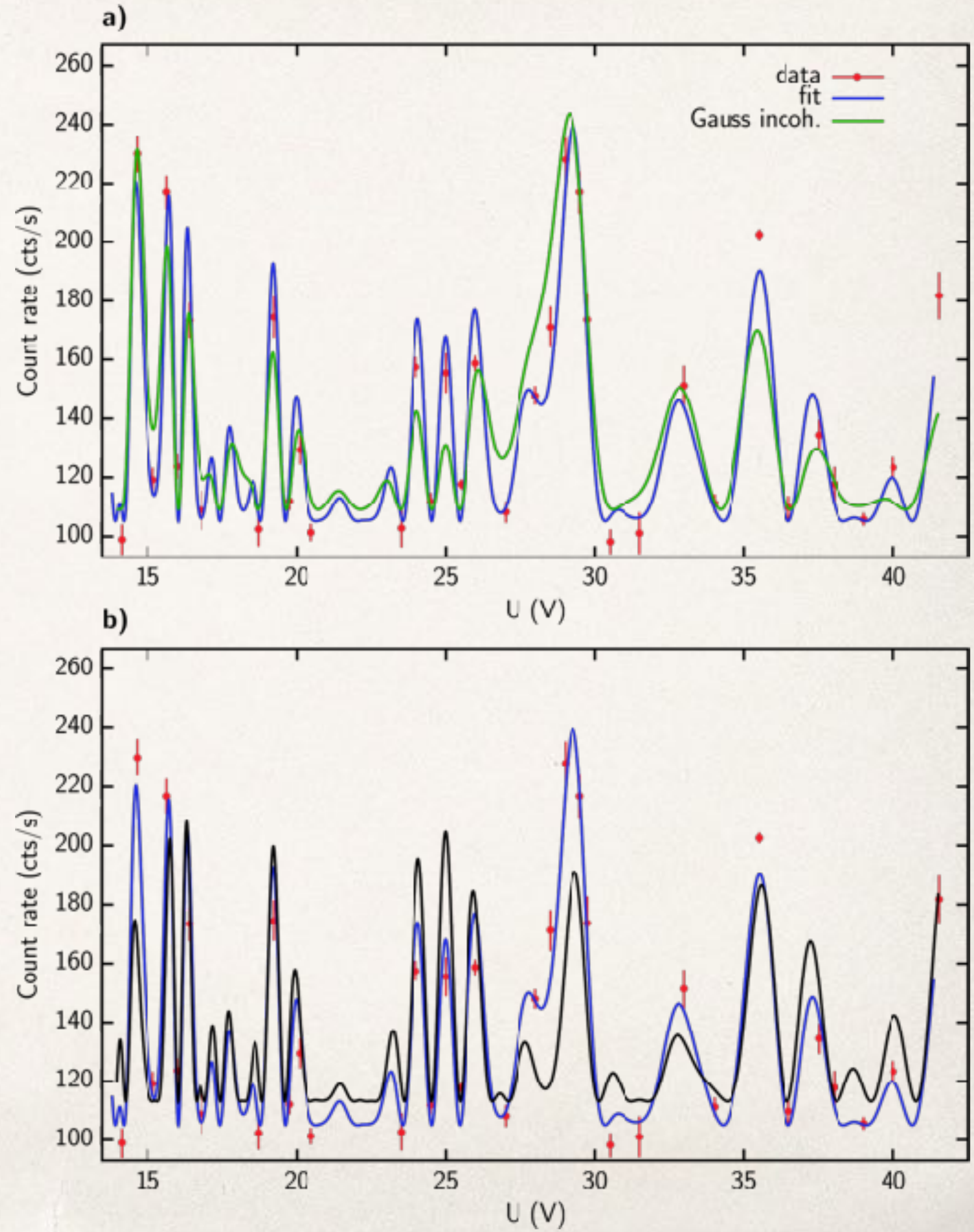
Quantitative similarity of coherent contributions

20 ion fringe,
do all ions contribute?

Most probable modulation of coh. contributions is Gaussian



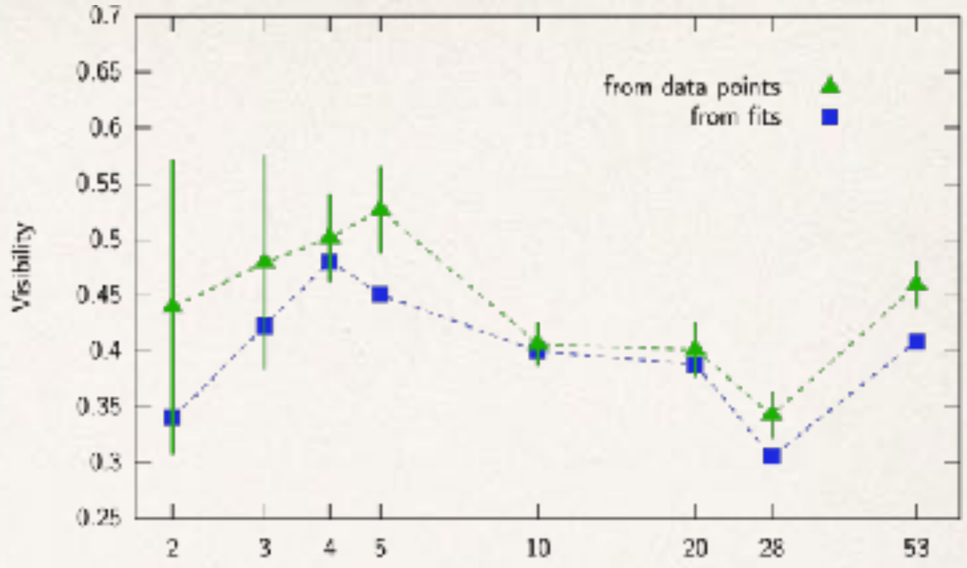
Qualitatively excludes any deeper Gaussian modulation of coherent contributions



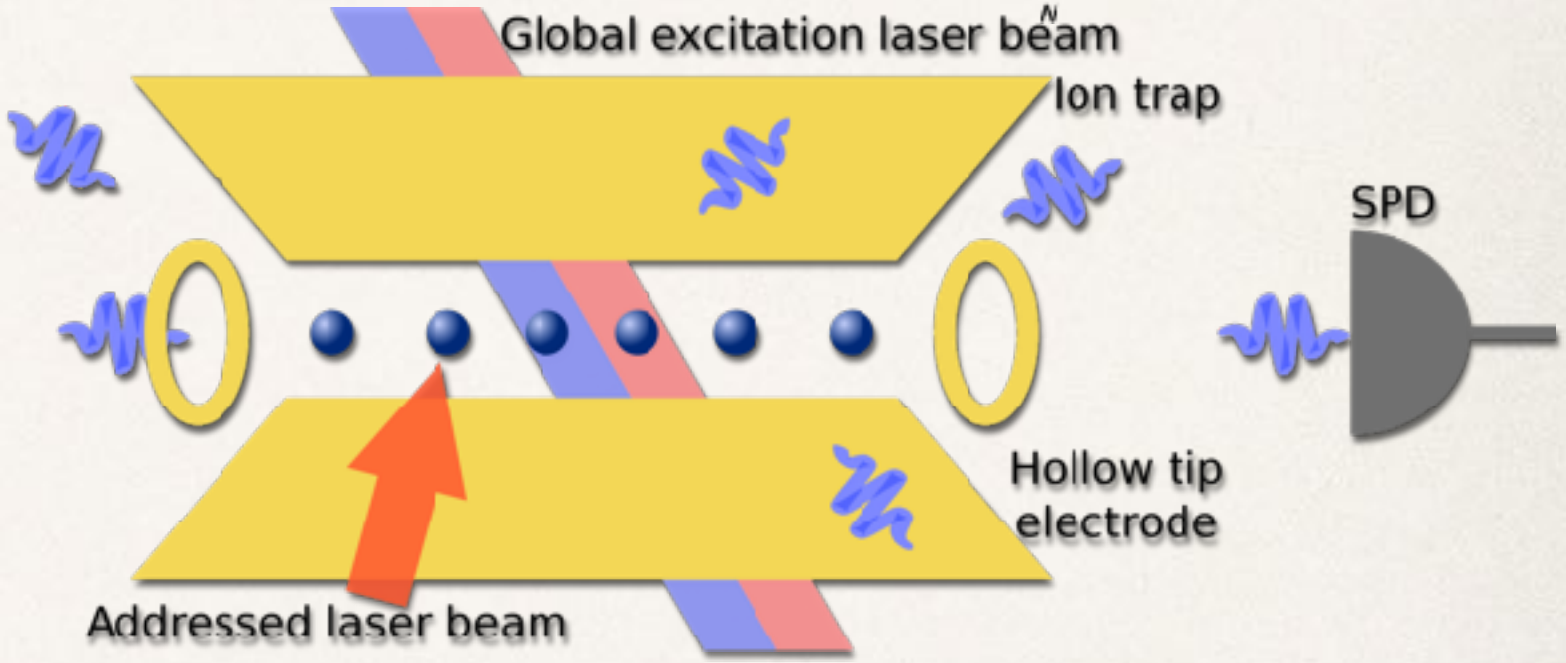
Summary and outlook

The optical coherence can be preserved for large strings of individual and addressable ions

Visibility doesn't decrease



Towards the realization of efficient and **programable nonclassical light source**



Generate and control the collective light emission

Generate W entangled states of long ion strings by coherent light scattering

Utilize addressing to modify interference pattern

Summary and outlook

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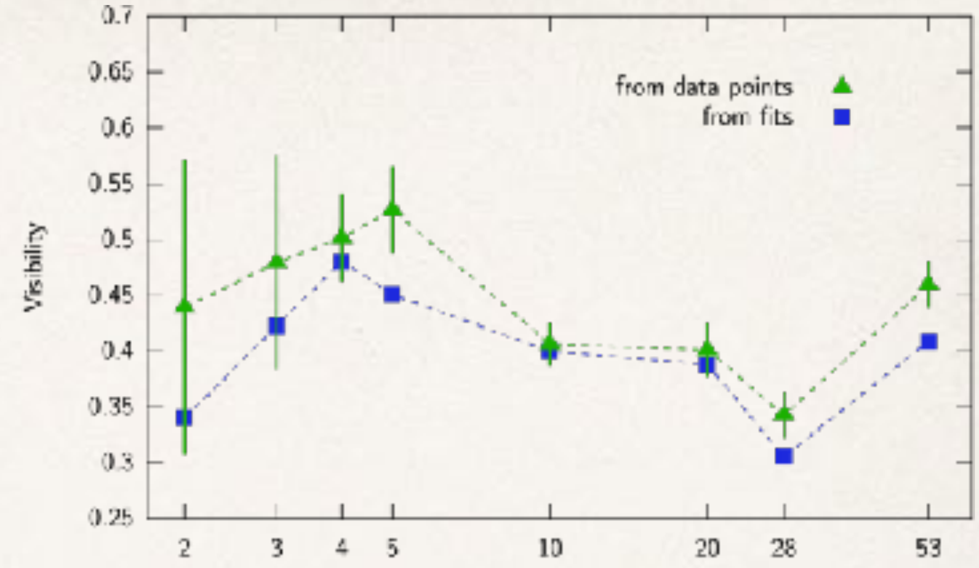

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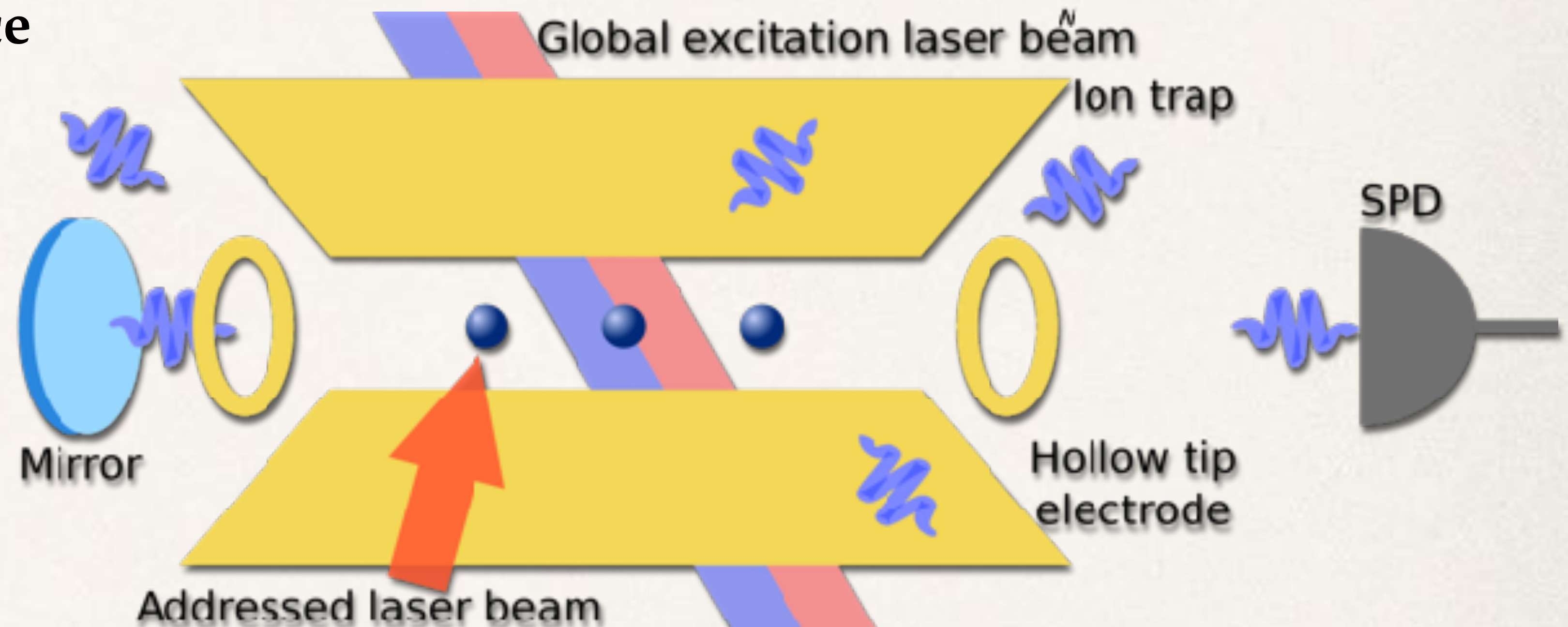

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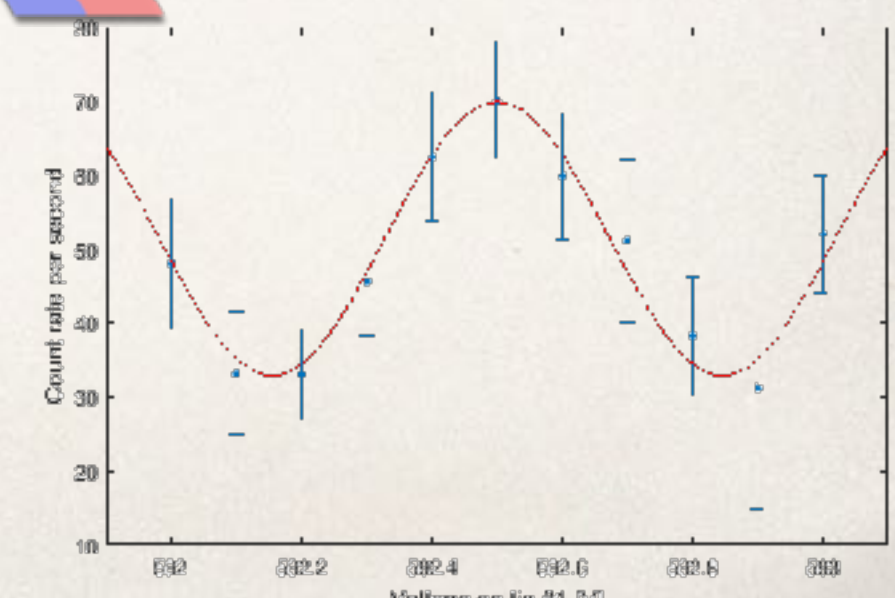

We succeeded in merging the collective directional scattering with half-cavity enhancement

Thank you for your attention