# Time-resolved scattering of a single photon by a single atom

2016 2nd semester Journal club

Dec 6

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# Introduction

nature COMMUNICATIONS

ARTICLE

Received 7 Jun 2016 | Accepted 25 Oct 2016 | Published 29 Nov 2016

DOI: 10.1038/ncomms13716

OPEN

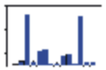
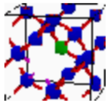
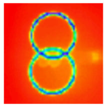
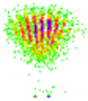
## Time-resolved scattering of a single photon by a single atom

Victor Leong[1,2,†], Mathias Alexander Seidler[1], Matthias Steiner[1,2], Alessandro Cerè[1] & Christian Kurtsiefer[1,2]

**Research interest**

- Experimental Quantum Information and Communication
- Single Photon Technologies
- Atom-Light Interaction

# Introduction

| | | |
|---|---|---|
|  | Atom-Photon interface | M.K. Tey, Z. Chen, S.A. Aljunid, B. Chng, F. Huber, G. Maslennikov and Ch. Kurtsiefer: *Strong interaction between light and a single trapped atom without the need for a cavity*<br>Nature Physics **4**, 924 (2008) |
|  | Four Photon States | M. Eibl, S. Gaertner, M. Mourennane, Ch. Kurtsiefer, M. Zukowski, H. Weinfurter: *Four photon entanglement from down-conversion*<br>Phys. Rev. Lett. **90**, 200403 (2003) |
|  | Quantum Cryptography | Ch. Kurtsiefer, P. Zarda, Matthäus Halder; H. Weinfurter, P.M. Gorman, P.R. Tapster, and J.G. Rarity: *A steptowards global key distribution*<br>Nature **419**, 450 (2002) |
|  | Single Photon Source | Ch. Kurtsiefer, P. Zarda, S. Mayer, and H. Weinfurter: *A stable solid-state source of single photons*<br>Phys. Rev. Lett. **85,** 290 (2000) |
|  | Entangled Photon Pairs | Ch. Kurtsiefer, M. Oberparleiter, and H. Weinfurter: *High efficiency entangled photon pair collection in type II parametric fluorescence*<br>Phys. Rev. A **64**, 010102(R) (2001) |
|  | Atomic Matter waves | Ch. Kurtsiefer, T. Pfau, and J.Mlynek: *Experimental determination of the motional Wigner function of a Helium atom*<br>Nature **386**, 150 (1997) |

## Research interest

- Experimental Quantum Information and Communication
- Single Photon Technologies
- Atom-Light Interaction

# Strong interaction between light and a

REVIEW OF SCIENTIFIC INSTRUMENTS **83**, 083104 (2012)

## Preparation of an exponentially rising optical pulse for efficient excitation of single atoms in free space

Hoang Lan Dao,[1,2] Syed Abdullah Aljunid,[1] Gleb Maslennikov,[1]
and Christian Kurtsiefer[1,3,a)]

PRL **111**, 103001 (2013) PHYSICAL REVIEW LETTERS week ending 6 SEPTEMBER 2013

## Excitation of a Single Atom with Exponentially Rising Light Pulses

Syed Abdullah Aljunid,[1] Gleb Maslennikov,[1] Yimin Wang,[1] Hoang Lan Dao,[2]
Valerio Scarani,[3] and Christian Kurtsiefer[3,*]

PRL **113**, 163601 (2014) PHYSICAL REVIEW LETTERS week ending 17 OCTOBER 2014

## Reversing the Temporal Envelope of a Heralded Single Photon using a Cavity

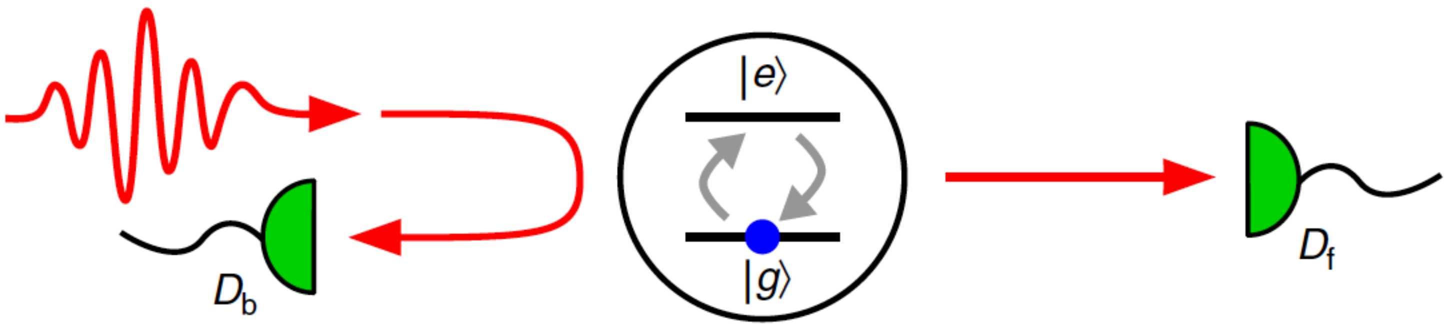
Bharath Srivathsan,[1] Gurpreet Kaur Gulati,[1] Alessandro Cerè,[1] Brenda Chng,[1] and Christian Kurtsiefer[2,*]

PHYSICAL REVIEW A **91**, 063829 (2015)

## Hong-Ou-Mandel interference between triggered and heralded single photons from separate atomic systems

Victor Leong,[1,2] Sandoko Kosen,[1,2] Bharath Srivathsan,[1] Gurpreet Kaur Gulati,[1] Alessandro Cerè,[1] and Christian Kurtsiefer[1,2,*]

**Simple.. Basic scheme..**



# Background research

The probability amp. of exponentially decaying and rising photons

$$\xi_{\downarrow}(t) = \frac{1}{\sqrt{\tau_p}}\Theta(t)e^{-\frac{1}{2\tau_p}} \quad \xi_{\uparrow}(t) = \frac{1}{\sqrt{\tau_p}}\Theta(-t)e^{\frac{1}{2\tau_p}}$$

$\tau_p$ : coherence time of photon

Analytic expression for the time-dependent population, $P_e(t)$

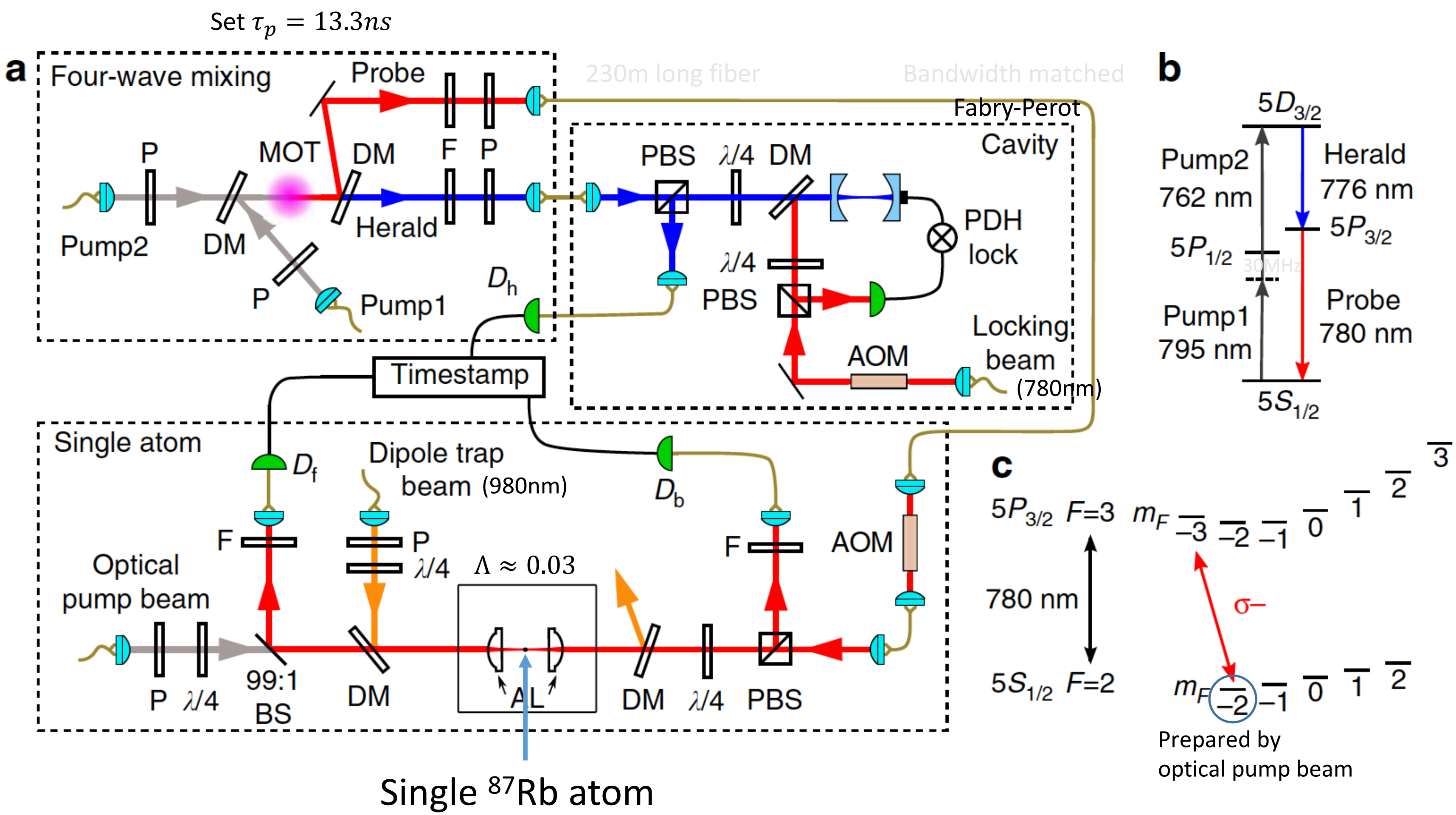
$$P_{e,\downarrow}(t) = \begin{cases} \frac{4\Lambda\tau_0\tau_p}{(\tau_0-\tau_p)^2}\Theta(t)\left(e^{-\frac{t}{2\tau_0}} - e^{-\frac{t}{2\tau_p}}\right)^2 & \text{for } \tau_p \neq \tau_0 \\ \frac{\Lambda t^2}{\tau_0^2}\Theta(t)e^{-\frac{t}{\tau_0}} & \text{for } \tau_p = \tau_0 \end{cases}$$

$$P_{e,\uparrow}(t) = \frac{4\Lambda\tau_0\tau_p}{(\tau_0+\tau_p)^2}\left[e^{\frac{t}{\tau_p}}\Theta(-t) + e^{-\frac{t}{\tau_0}}\Theta(t)\right]$$

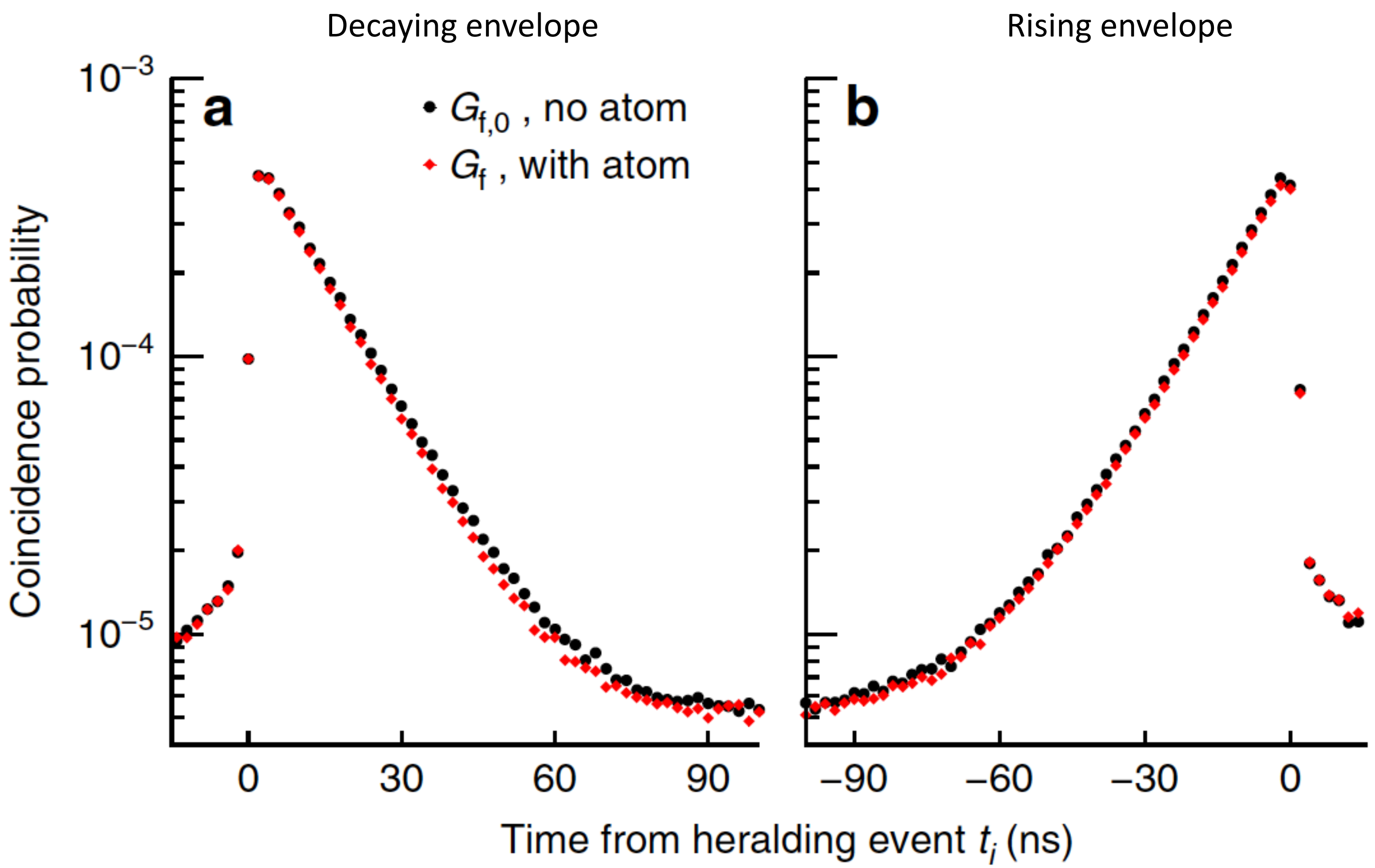
Where $\Lambda$ is spatial overlap of the atomic dipole mode with the propagating mode of the photon

Wang Y., Phys. Rev. A **83**, 063842 (2011)

# Set-up


Set $\tau_p = 13.3ns$
a
Four-wave mixing
Probe
P
MOT
DM
F
P
Pump2
DM
Herald
P
Pump1
$D_h$
230m long fiber
Bandwidth matched
Fabry-Perot
Cavity
PBS
$\lambda/4$
DM
PDH
lock
$\lambda/4$
PBS
Locking
beam
(780nm)
AOM
Timestamp
Single atom
$D_f$
Dipole trap
beam (980nm)
$D_b$
F
P
$\lambda/4$
$\Lambda \approx 0.03$
F
AOM
Optical
pump beam
P
$\lambda/4$
99:1
BS
DM
AL
DM
$\lambda/4$
PBS
Single $^{87}$Rb atom
b
$5D_{3/2}$
Pump2
762 nm
Herald
776 nm
$5P_{3/2}$
$5P_{1/2}$
30MHz
Pump1
795 nm
Probe
780 nm
$5S_{1/2}$
c
$5P_{3/2}$ $F$=3 $m_F$ −3 −2 −1 0 1 2 3
780 nm
σ−
$5S_{1/2}$ $F$=2 $m_F$ −2 −1 0 1 2
Prepared by
optical pump beam

# Time-resolved transmission of single photon

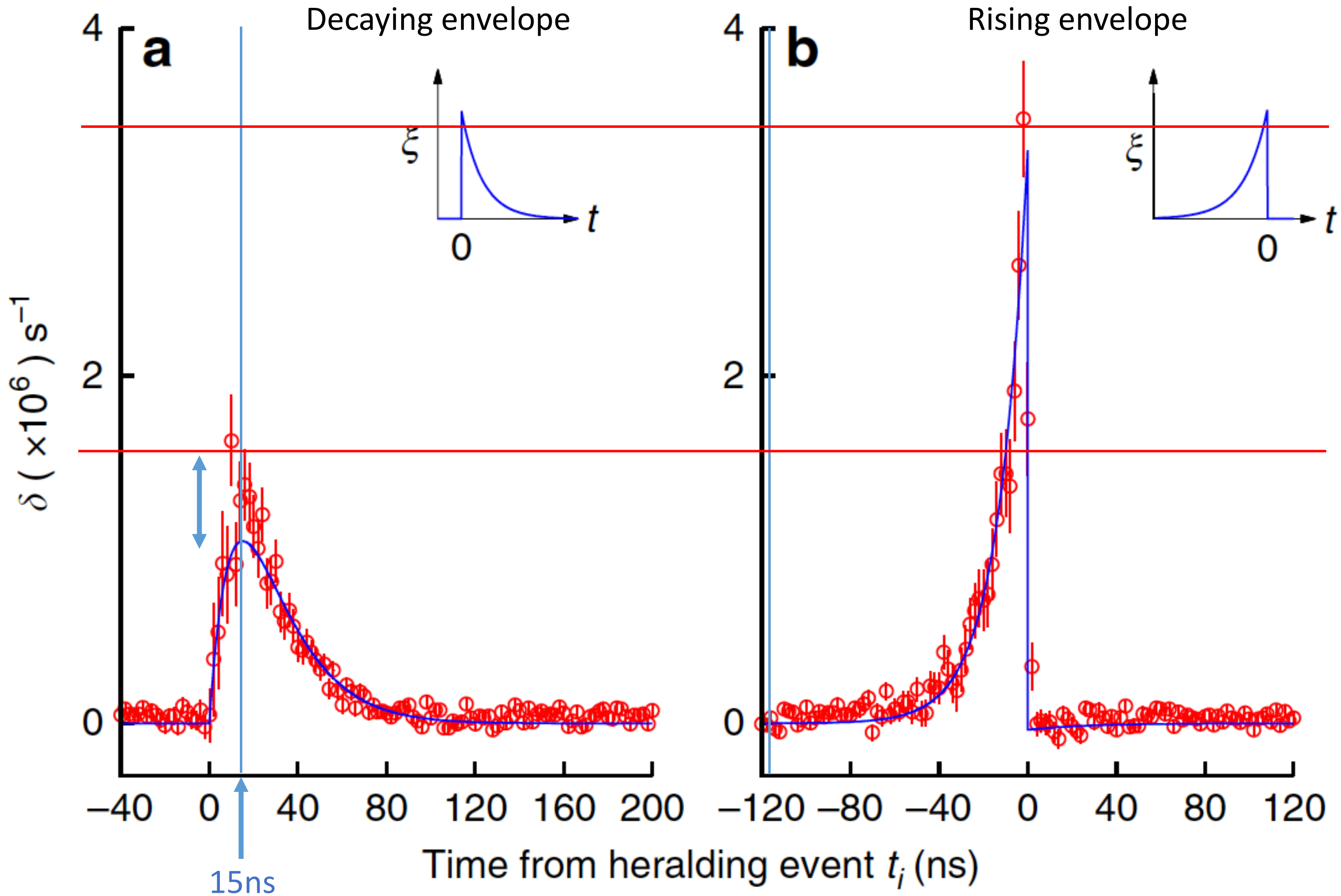



$$\xi_{\downarrow}(t) = \frac{1}{\sqrt{\tau_p}}\Theta(t)e^{-\frac{1}{2\tau_p}} \qquad \xi_{\uparrow}(t) = \frac{1}{\sqrt{\tau_p}}\Theta(-t)e^{\frac{1}{2\tau_p}}$$

$$\tau_p = 13.3ns$$

# Result ($\delta(t)$)

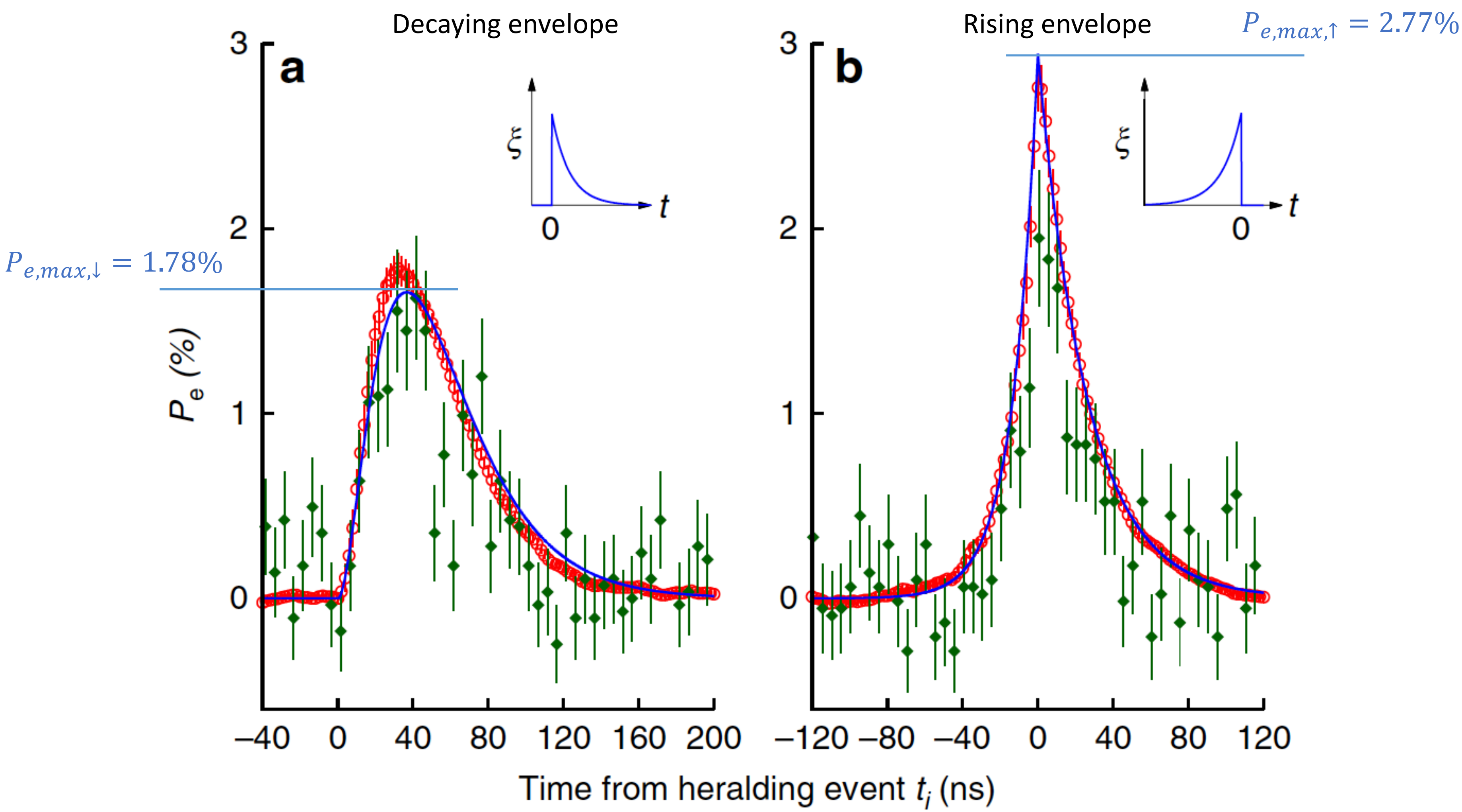
$$\delta(t) = R_{f,0}(t) - R_f(t)$$




$\tau_p = 13.3ns \quad \Lambda = 0.033$

# Result ($P_e$)

$\tau_p = 13.3ns \quad \Lambda = 0.033$




$$\dot{P}_e(t) = \delta(t) - \frac{(1-\Lambda)}{\tau_0} P_e(t)$$

$$P_e(t_i) = \frac{R_b(t_i)}{\eta_b \Gamma_0} = \frac{G_b(t_i)}{\tilde{\eta}_f \eta_q \eta_b \Gamma_0 \Delta t}$$

**Summary**

- Using FWM, they generated probe photon and herald photon
- Using asymmetric cavity to change the temporal profile of herald photon
- With the probe photon they scattered atom
- Exponentially rising temporal photon profile gives more excitation probability of an atom than exponentially decay temporal photon profile as they expected

*Thank you*