Physics
OSAKA UNIVERSITY

対超放射のダイナミクス

田中 実（阪大）

共同研究者

吉村太彦、笹尾 登（岡山大）

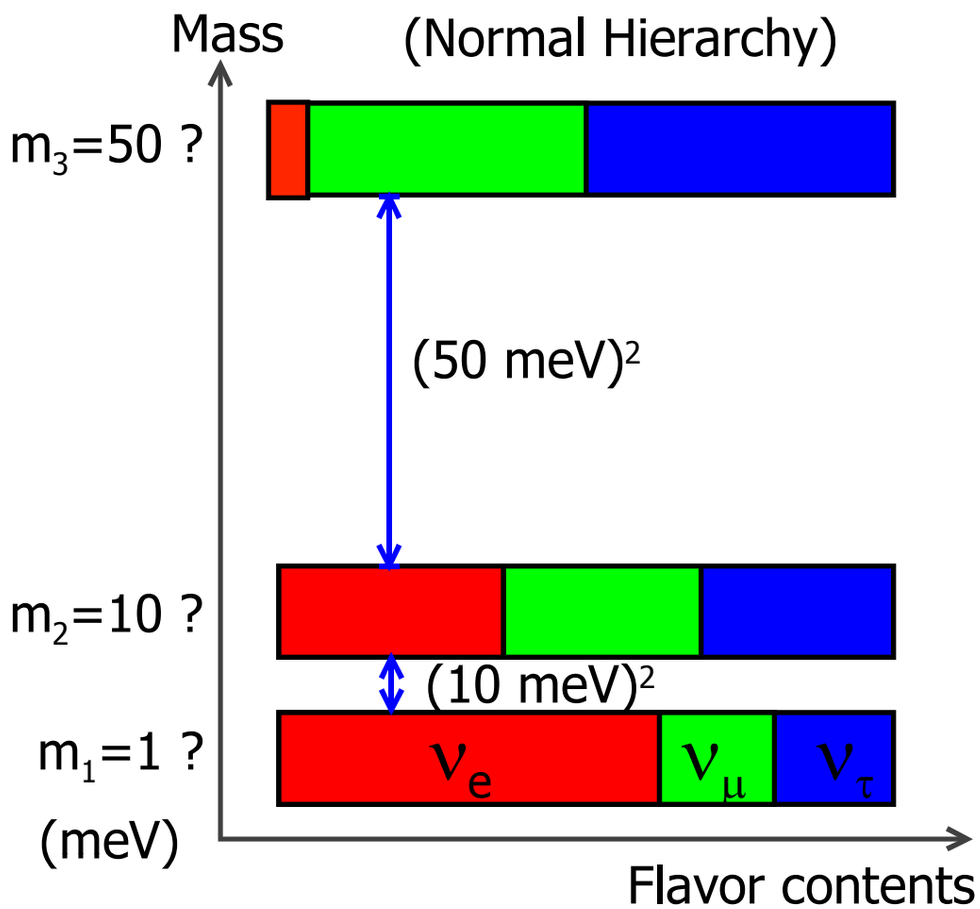
日本物理学会第67回年次大会

関西学院大学西宮上ヶ原キャンパス、2012/03/27

Introduction

Ultimate goal of the project:

Neutrino spectroscopy



Absolute mass?

Dirac or Majorana?

CP ?

Normal or Inverted?

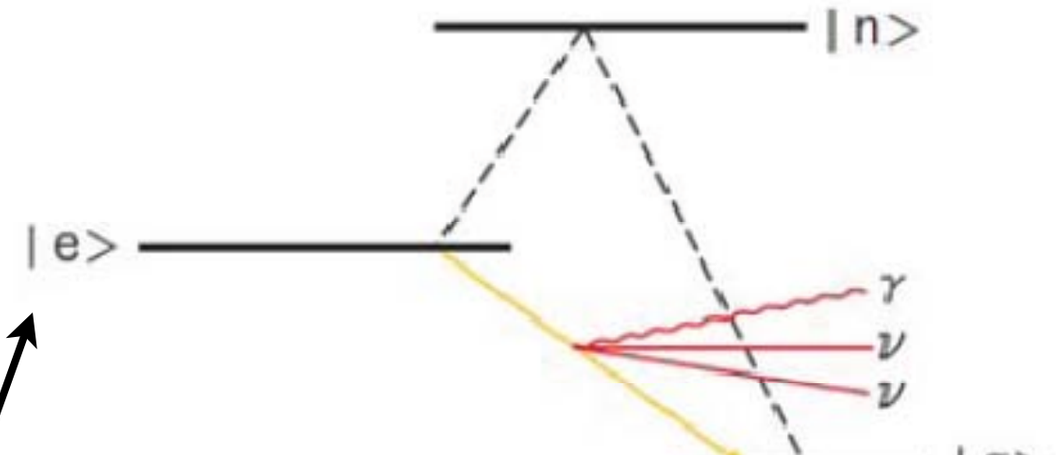
Radiative Neutrino Pair Emission (RNPE) from atoms/molecules

atomic/molecular energy scale ~ eV or less

Λ-type level structure

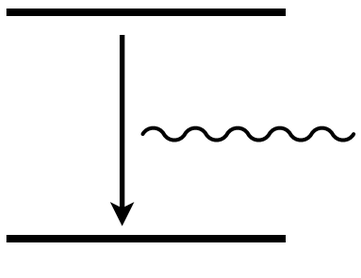
Ba, Xe, Ca+, ...

H_2, O_2,...

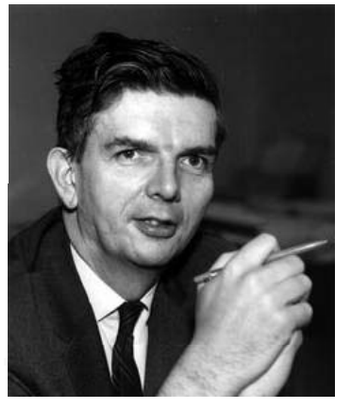


metastable

Rate enhancement by coherence



super-radiance $\Gamma \sim (n\lambda^3)^2$ R.H. Dicke, 1954



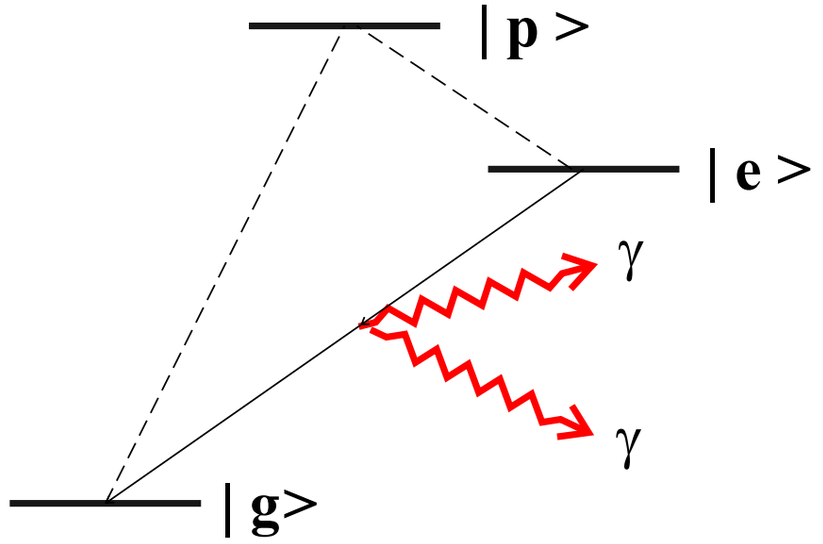
Single photon SR is well-established.

対超放射 Paired Super-Radiance (PSR)

$$|e\rangle \rightarrow |g\rangle + \gamma + \gamma$$

$$E_e - E_g = 2\omega$$

Not seen yet.



Should be established before RNPE.

Targets

para-H2 $X^1\Sigma_g^+\, v = 1 \rightarrow v = 0$

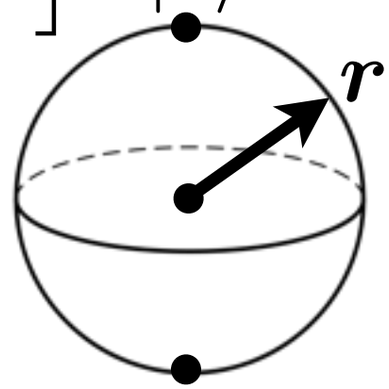
Ba vapor $^1D_2 \rightarrow {}^1S_0$ ← 大饗氏の講演

PSR Equations

Counter-propagating field/trigger (1+1 dim.)

$$e = \frac{1}{2}\left[e_R\, e^{-i(\omega t - kx)} + e_L\, e^{-i(\omega t + kx)} + \text{c.c.}\right]$$

Bloch vector: $r_i = \mathrm{tr}(\rho\sigma_i)/\mathrm{tr}\rho$



Wikimedia Commons

$$\partial_\tau r_1 = 4\gamma_-(|e_R|^2 + |e_L|^2)r_2 + 8\Im(e_R e_L)r_3 - \frac{r_1}{\tau_2},$$

$$\partial_\tau r_2 = -4\gamma_-(|e_R|^2 + |e_L|^2)r_1 + 8\Re(e_R e_L)r_3 - \frac{r_2}{\tau_2},$$

$$\partial_\tau r_3 = -8\left(\Re(e_R e_L)r_2 + \Im(e_R e_L)r_1\right) - \frac{r_3 + 1}{\tau_1},$$

τ_i: relaxation

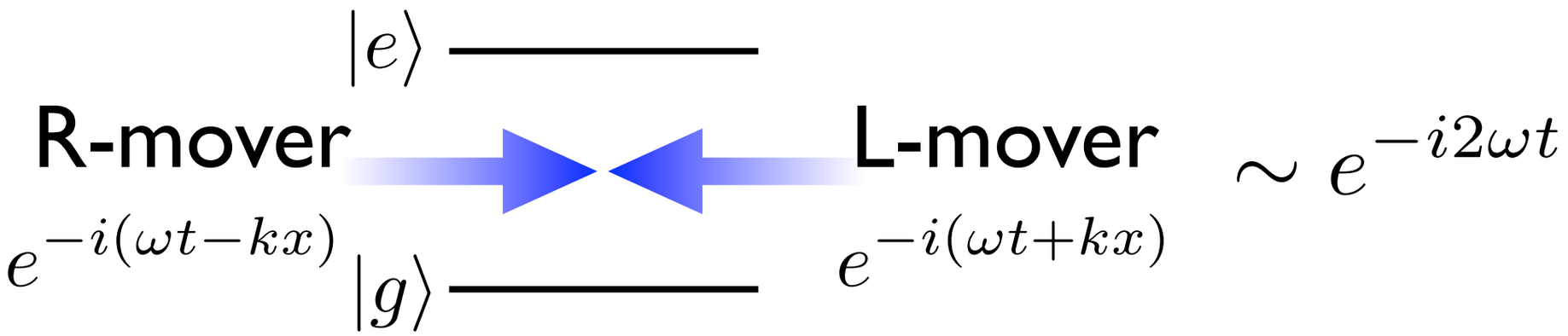
$$(\partial_\tau + \partial_\xi)e_R = \frac{i}{2}(\gamma_+ + \gamma_- r_3)e_R + \frac{i}{2}(r_1 - ir_2)e_L^*,$$

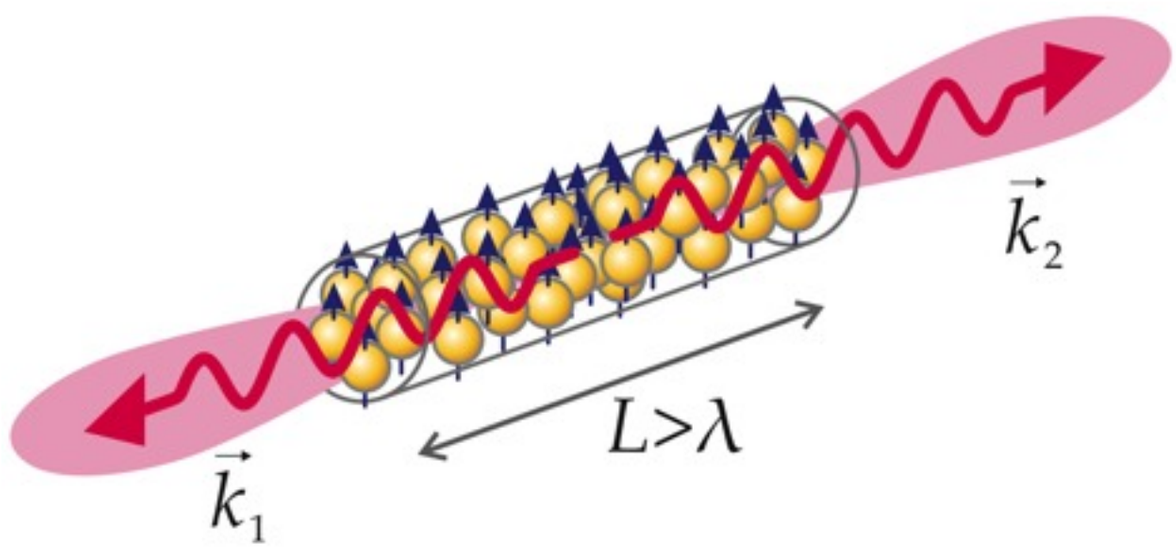
$$(\partial_\tau - \partial_\xi)e_L = \frac{i}{2}(\gamma_+ + \gamma_- r_3)e_L + \frac{i}{2}(r_1 - ir_2)e_R^*,$$

R-L couplings

Macro-coherence

Yoshimura et al. (2008)





$$\Gamma \propto (nV)^2$$

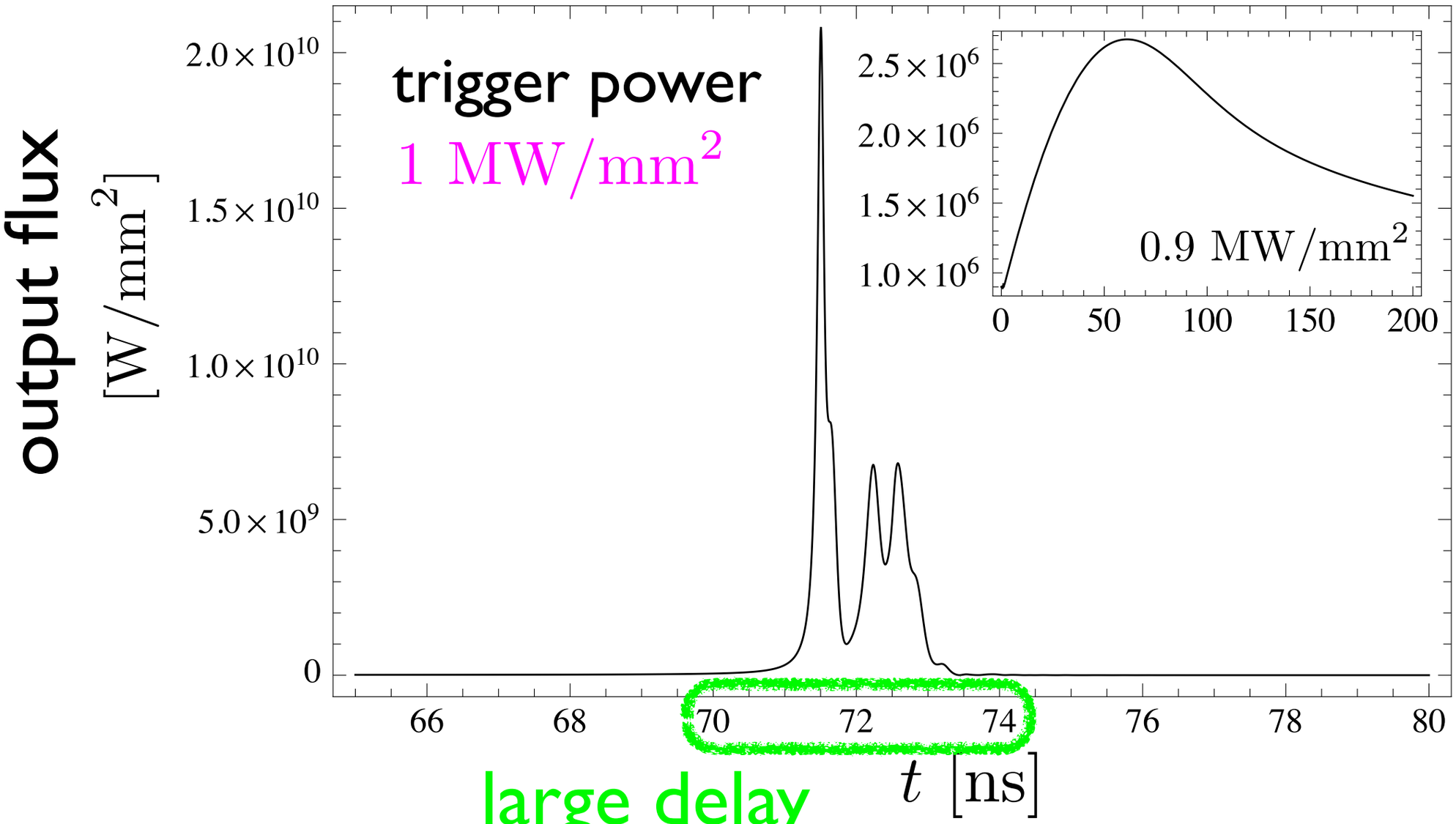
$$\Gamma(\mathrm{RNPE}) \sim \alpha G_F^2 E_\nu^5 N^2 \sim 1.5\,\mathrm{MHz}$$

Explosive PSR without initial coherence

para-H2 $n = 1 \times 10^{21}\,\mathrm{cm}^{-3}$, $L = 30\,\mathrm{cm}$, $T_1 = 1\,\mu\mathrm{s}$, $T_2 = 10\,\mathrm{ns}$

No initial coherence case: $r_1 = r_2 = 0,\ r_3 = 1$

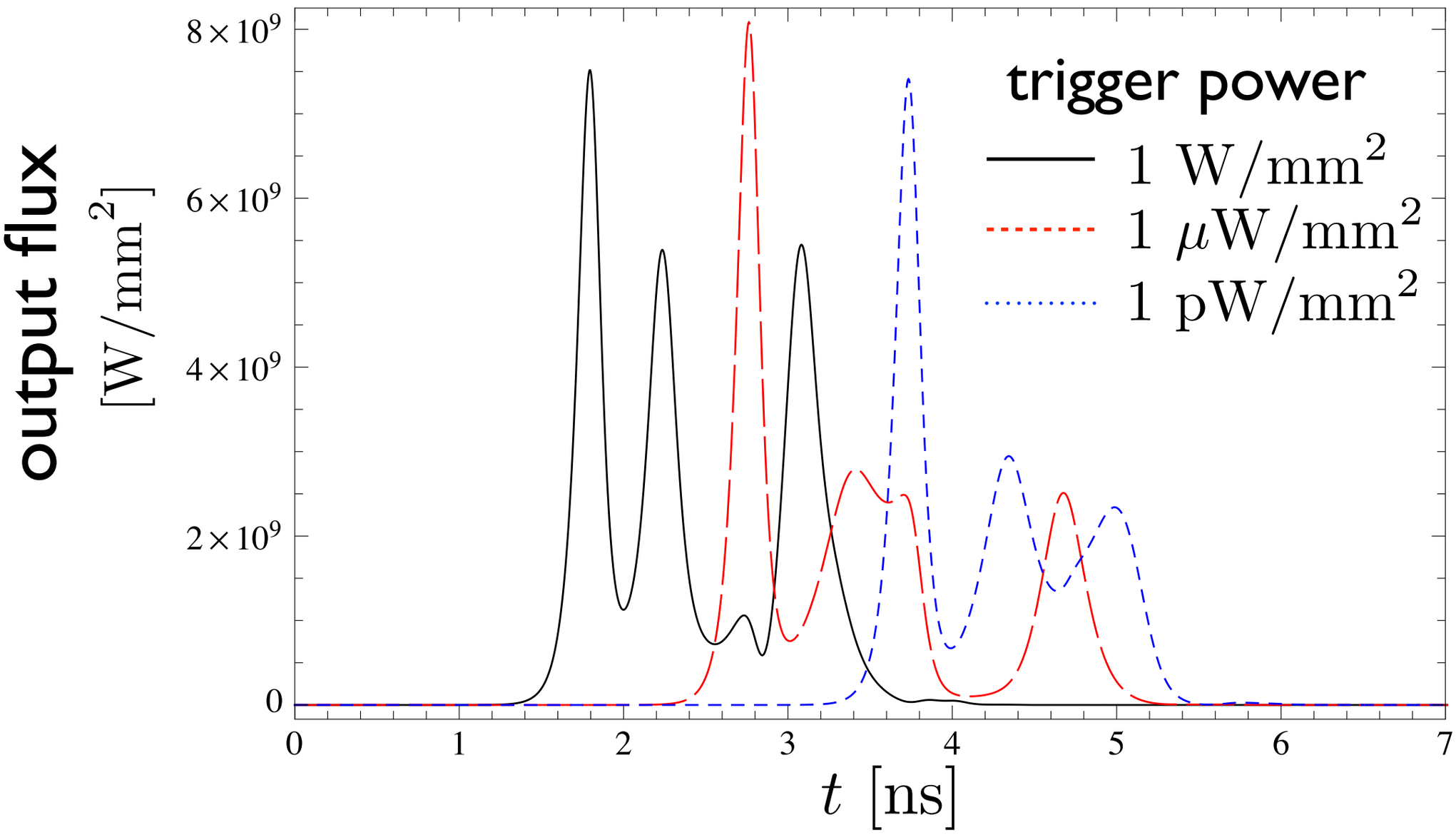
strong trigger required.



Explosive PSR with initial coherence

para-H2 $n = 1 \times 10^{21}\,\mathrm{cm}^{-3}\,,\ L = 30\,\mathrm{cm}\,,\ T_1 = 1\,\mu\mathrm{s}\,,\ T_2 = 10\,\mathrm{ns}$

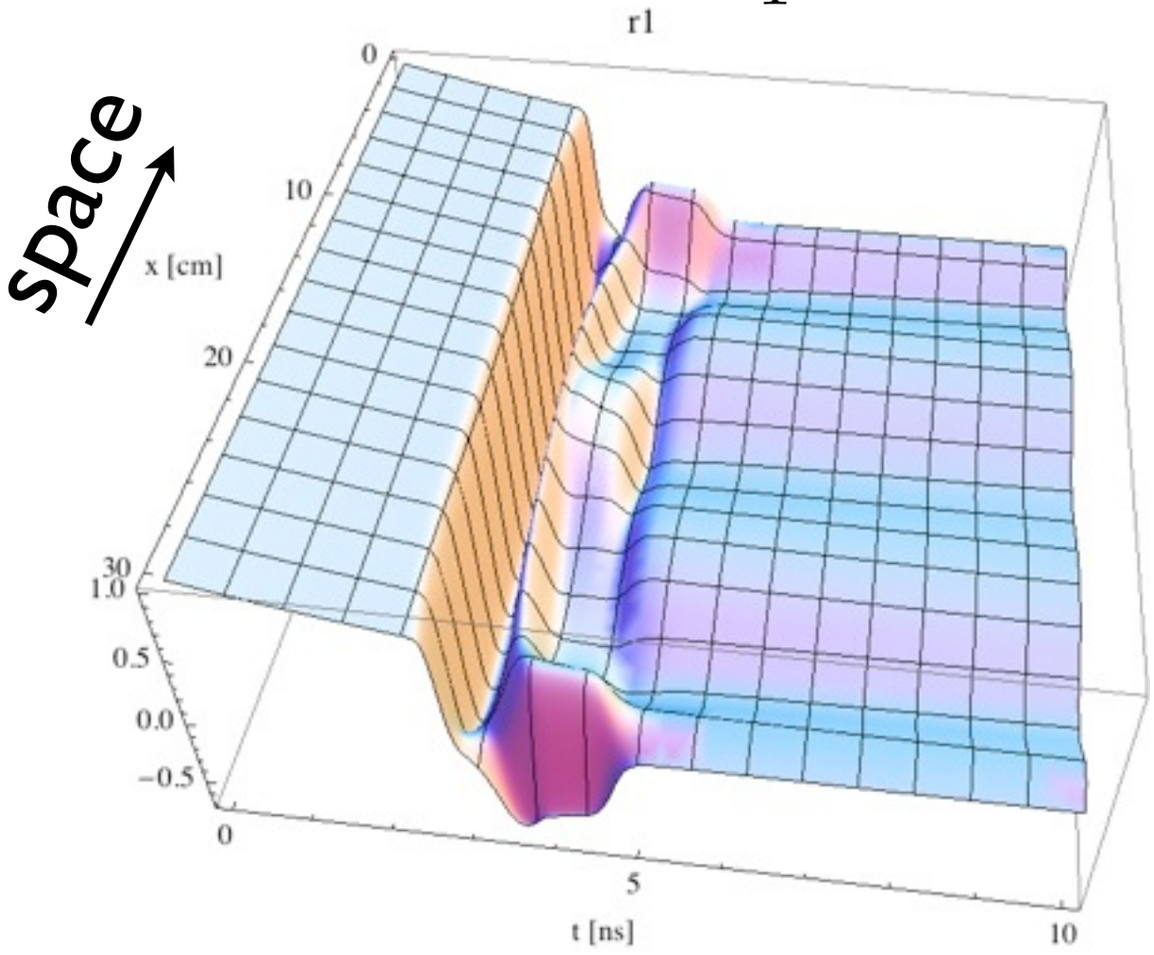
Coherent initial state: $r_1 = 1,\ r_2 = r_3 = 0$



Coherent initial state: $r_1 = 1,\ r_2 = r_3 = 0$

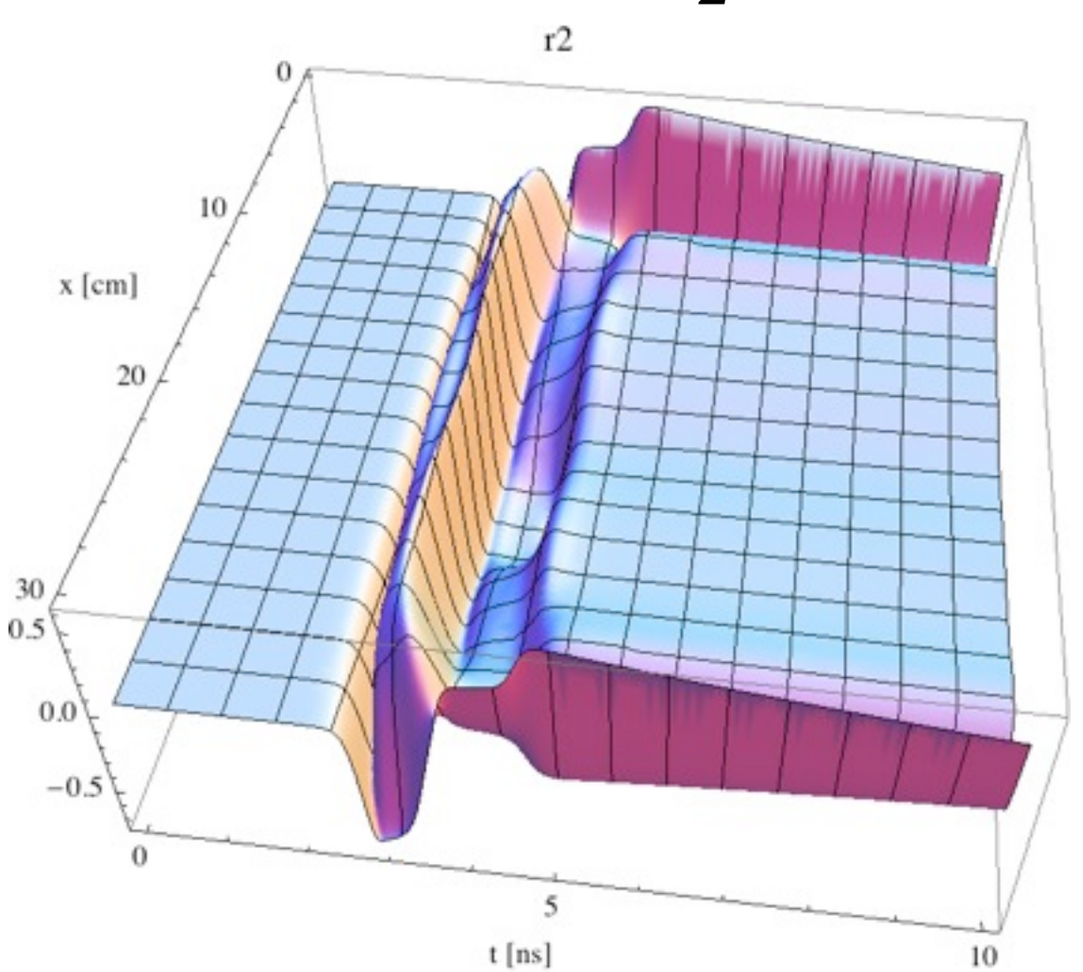
weak trigger $1\ \mu\mathrm{W/mm^2}$

r_1



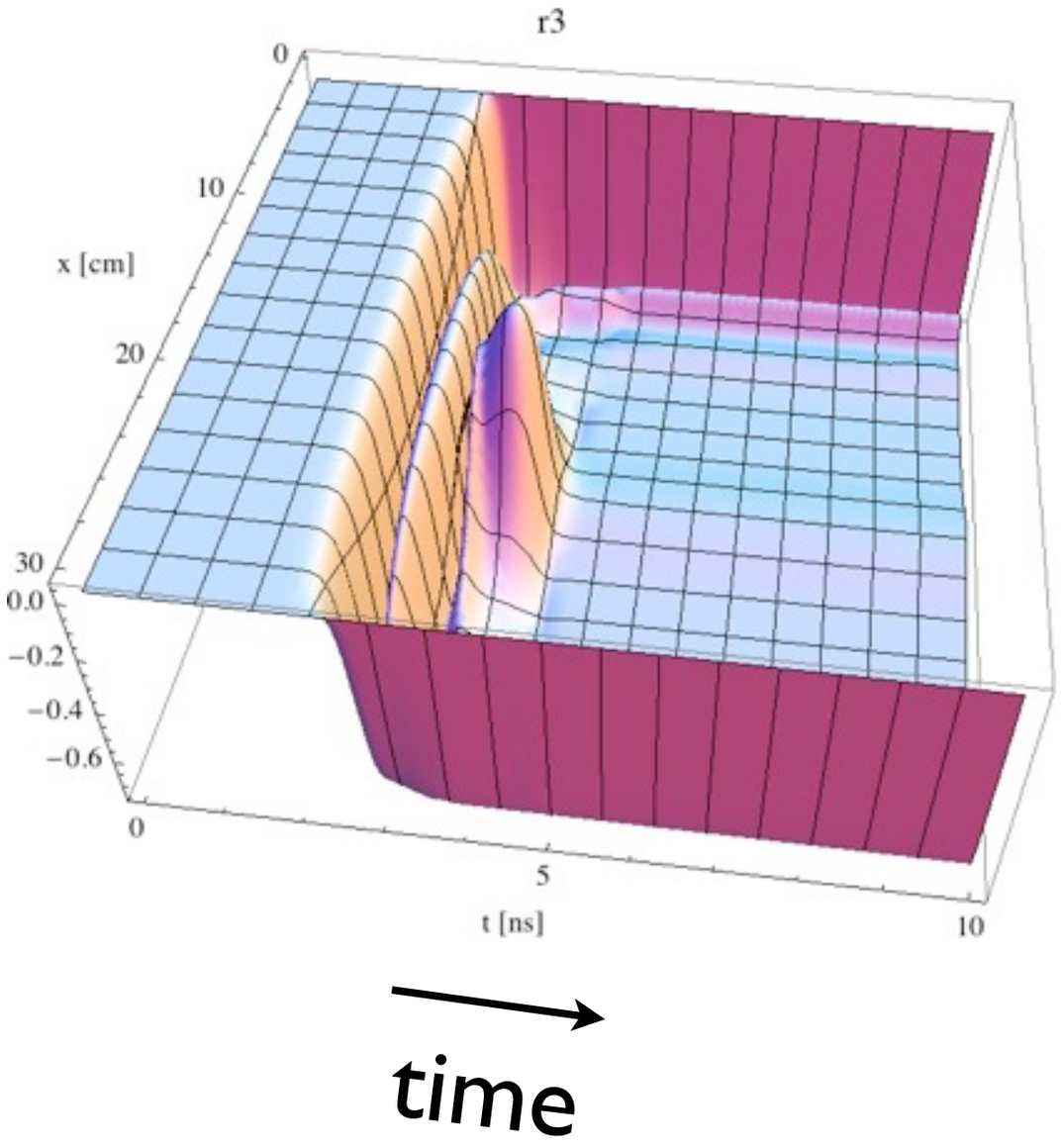
time

r_2



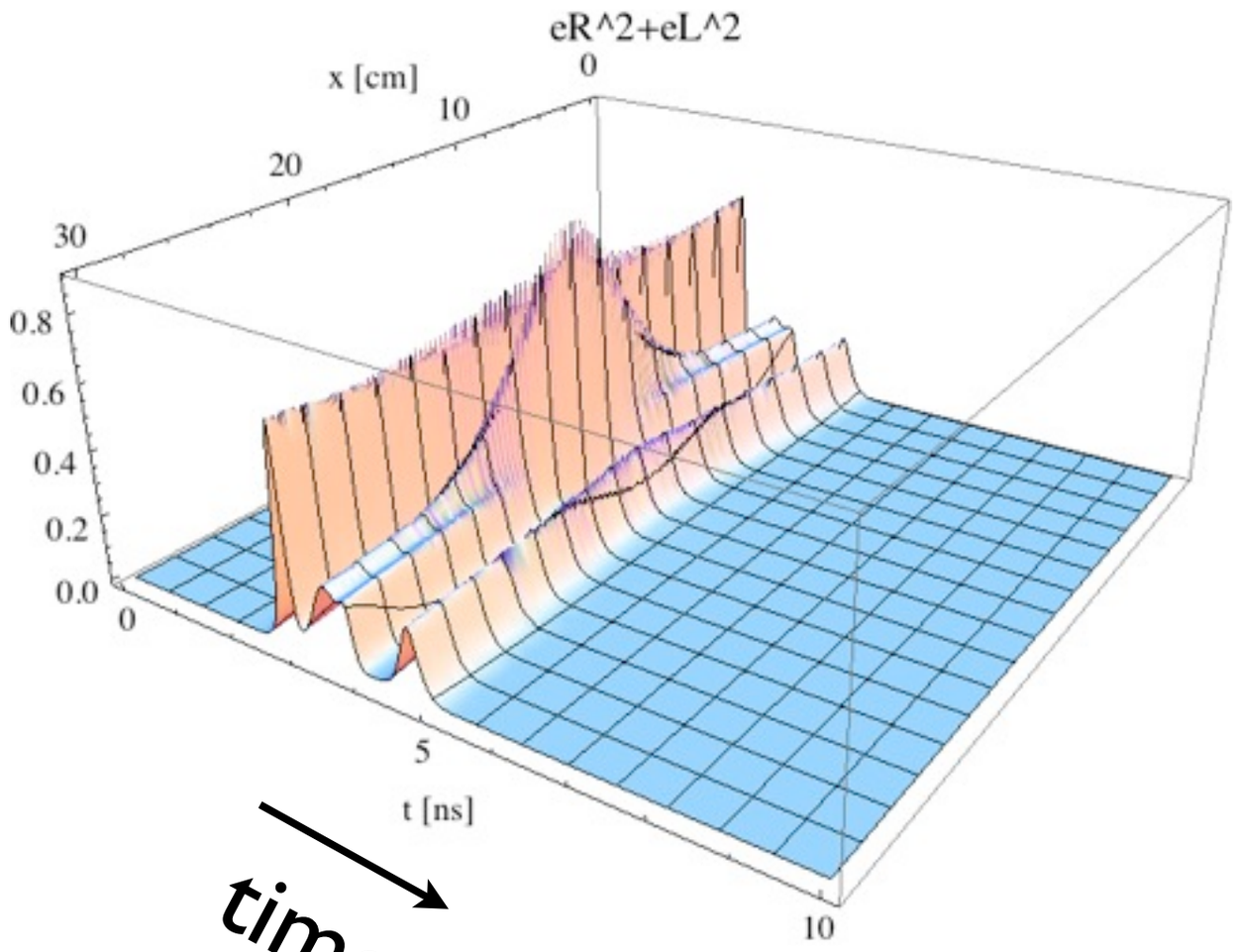
time

r_3



time

$|e_R|^2 + |e_L|^2$



time

Summary and Future Prospect

- Fundamental PSR equations are derived.
- Some numerical solutions are obtained.

  Initial coherence or strong trigger

  → explosive PSR
- To do
  - Quantitative condition for explosive PSR
    target preparation, trigger scheme
  - Dynamical formation of solitons
  - .....

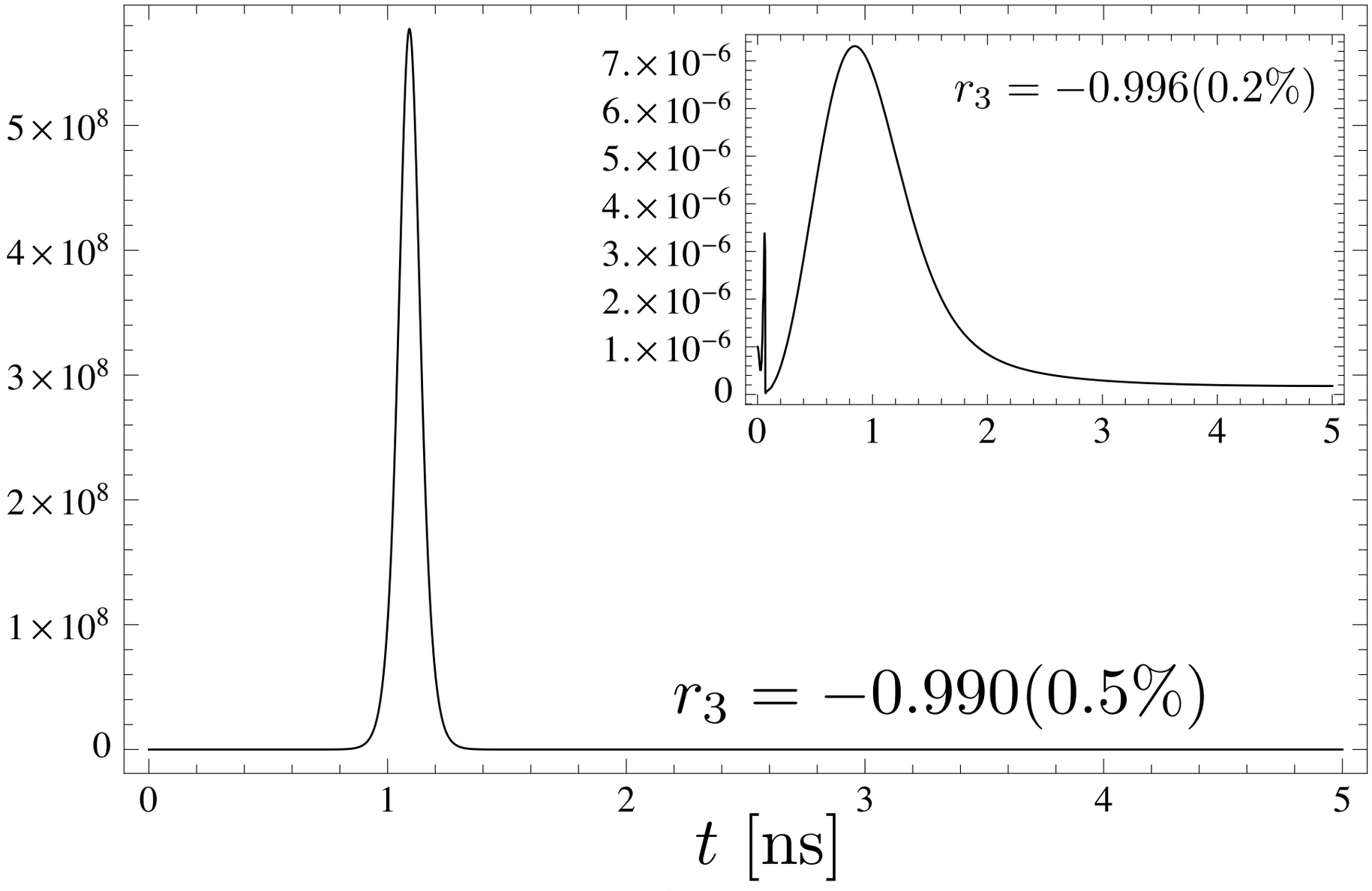
Backup Slides

Explosive PSR with high density target

solid para-H2:

$$n = 2.6 \times 10^{22}\,\mathrm{cm}^{-3}\,,\ L = 2\,\mathrm{cm}\,,\ T_1 = 1\,\mu\mathrm{s}\,,\ T_2 = 10\,\mathrm{ns}$$

trigger power $1\ \mu\mathrm{W/mm}^2$

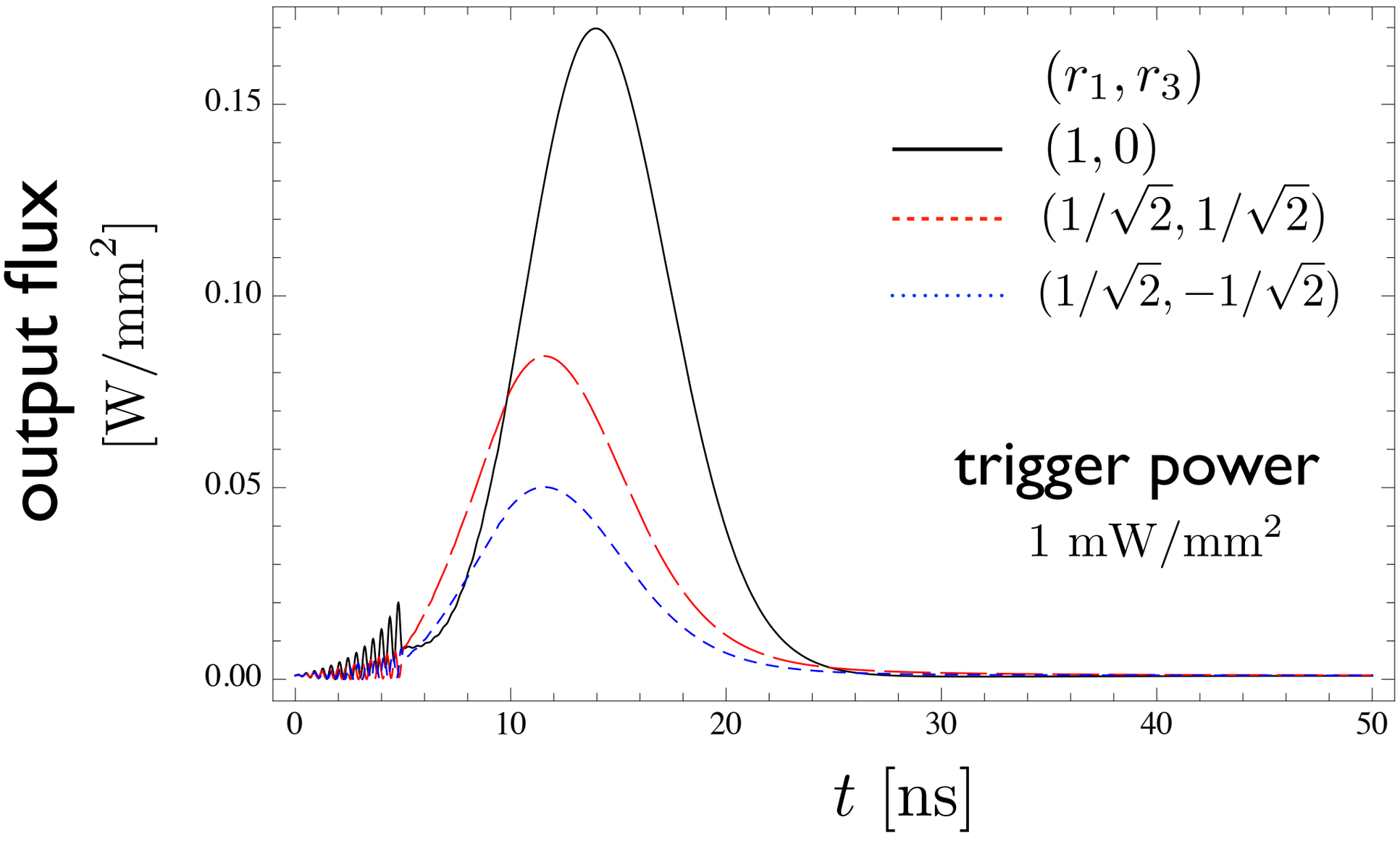


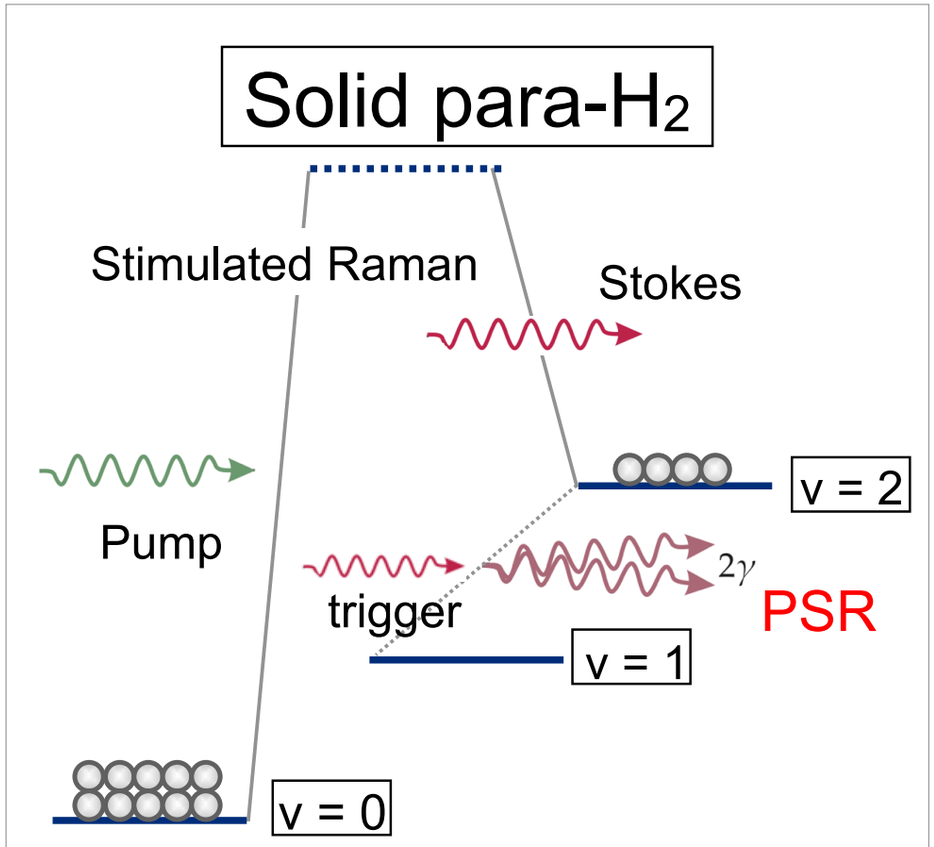
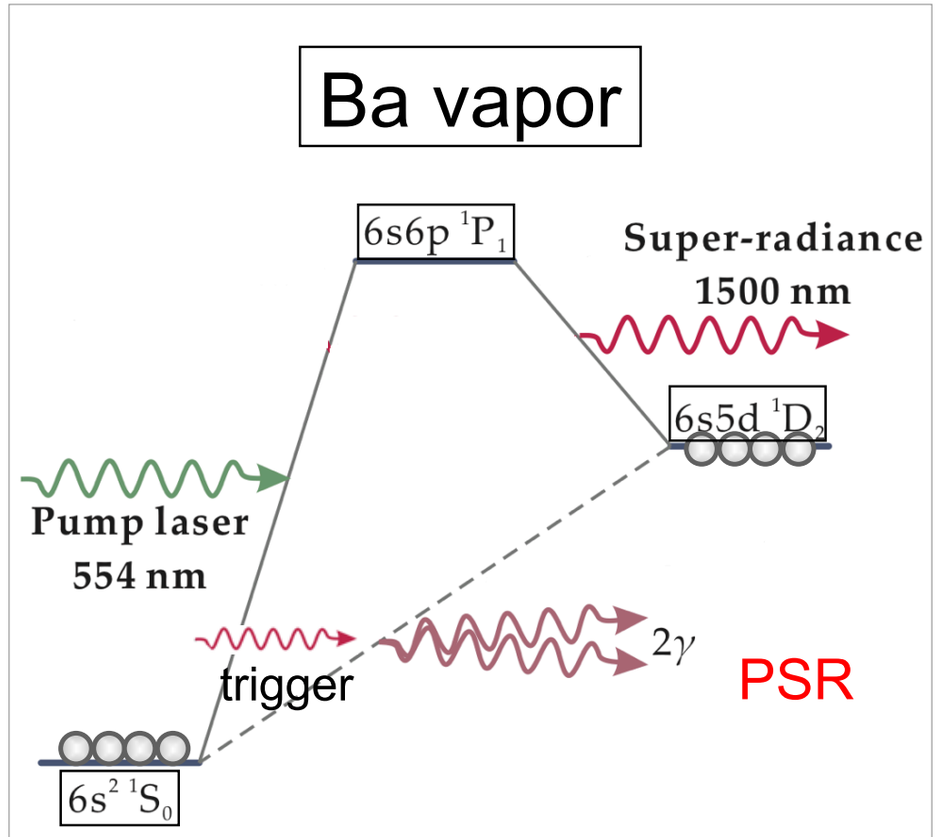
Modest PSR in the linear regime

para-H2:

$$n = 1 \times 10^{20}\,\mathrm{cm}^{-3}\,,\ L = 1.5,\mathrm{m}\,,\ T_1 = 1\,\mu\mathrm{s}\,,\ T_2 = 10\,\mathrm{ns}$$

output flux $\propto$ trigger power



			
PSR transition	Molecular vibrational transition $v = 2 \rightarrow v = 1$ in $X^1\Sigma_g$ (ground state†)		Atomic electronic transition $6s6p\ ^1P_1 \rightarrow 6s5d\ ^1D_2$
Excitation	Stimulated Raman in $v = 0 \rightarrow 2$		Pumping in $^1S_0 \rightarrow ^1P_1$ One-photon SR in $^1P_1 \rightarrow ^1D_2$