Determining the Optimum Hardware for Generation of 260 nm Light

Physics 582

Bryce Gadway

Prof. Tom Weinacht

The general path to UV

Second-Harmonic Generation (SHG)

With a single input field at λ_1 = 780 nm, convert pairs of photons into higher energy λ_2 = 390 nm in a $\chi^{(2)}$ material

Delay Compensation

Account for mismatched Group Velocities in SHG

Sum-Frequency Generation (SFG)

Convert two fields entering a $\chi^{(2)}$ material into a field at frequency $\omega_3 = \omega_1 + \omega_2$

Goal: **To find the nonlinear crystals which produce the most 260 nm light given reasonable constraints**

SNLO

Free program from Sandia National Laboratories

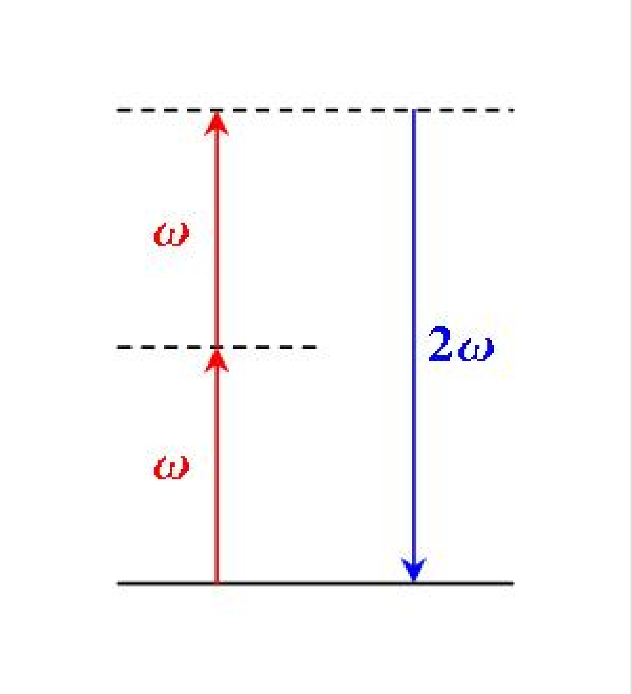
Database for properties of many nonlinear crystals

Provides numerical simulations of crystal performance in difference tasks such as Wave-Mixing and OPO.

Second-Harmonic Generation

First: Look for general trends in energy output and narrow down crystal choice

Second: Use SNLO to do a more complete modeling



Second-Harmonic Generation

General Solution yields coupled differential equations for the two field Intensities

Simplifies for null Second-Harmonic input field, Perfect Phase-Matching, Lossless Media

$$\Delta k = 2k_1 - k_2 = 0$$

Intensity of Second-Harmonic Scales as

$$I_2 \propto \tanh^2\left(\frac{8\pi\omega_1 d_{eff} L\sqrt{2\pi I_0}}{\sqrt{n_2 n_1^2 c^3}}\right) \underset{\propto}{\approx} \frac{d_{eff}^2 L^2}{n_2 n_1^2}$$

For low values

The possible crystals

Need to transmit over the range 390-780 nm

Look for high d_{eff} values, lower n values
High Damage Thresholds

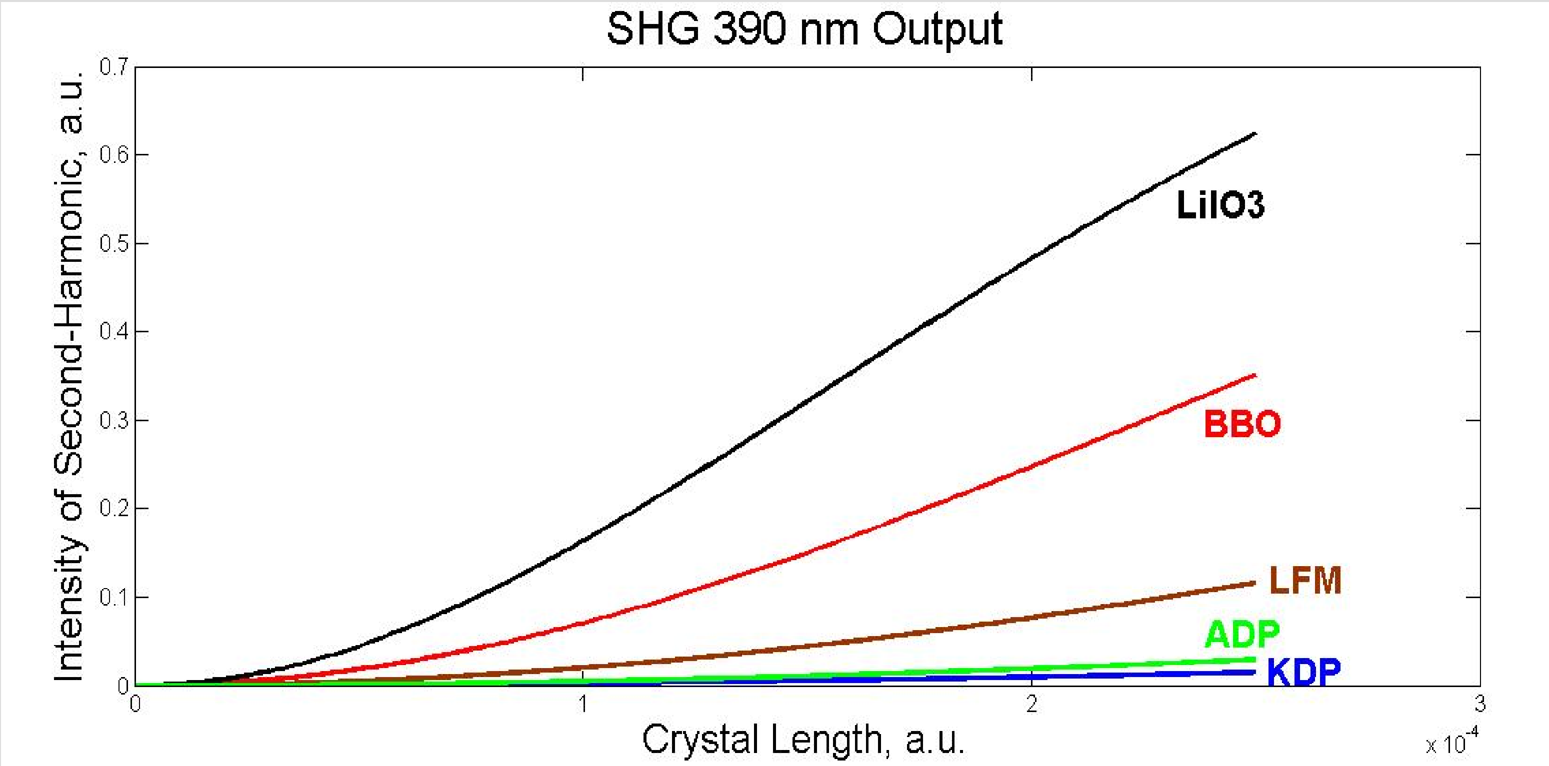
<u>Some good candidates</u>

BBO - Beta-Barium Borate (d_{eff} = 1.99)
$LiIO_3$ - Lithium Iodate (d_{eff} = 3.73, higher n's, low DT)
KDP - Potassium dihydrogen Phosphate (d_{eff} = 0.308)
LFM - Lithium Formate (d_{eff} = 0.867)

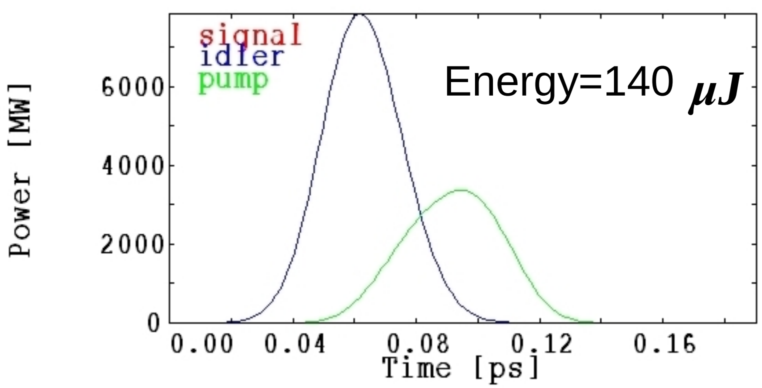
General Trend in Total Output

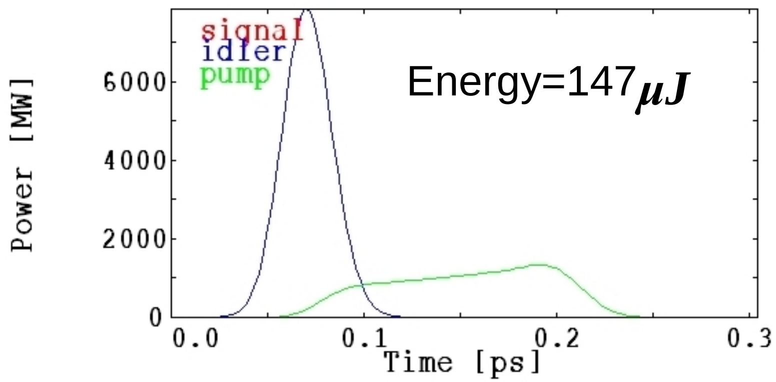
If we look just at the total Output

$LiIO_3$ and BBO look to be the best, then LFM

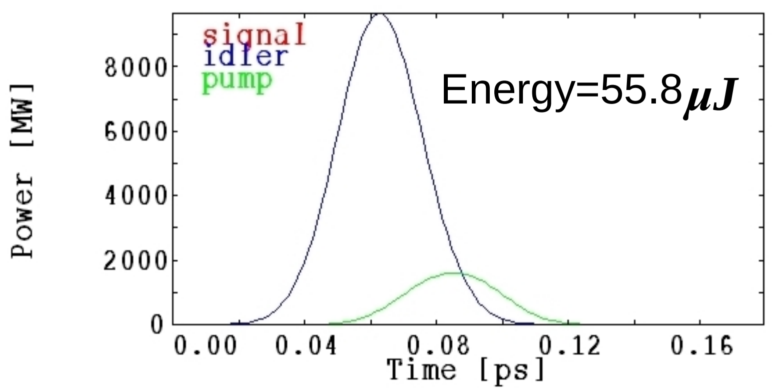


Modeling with SNLO



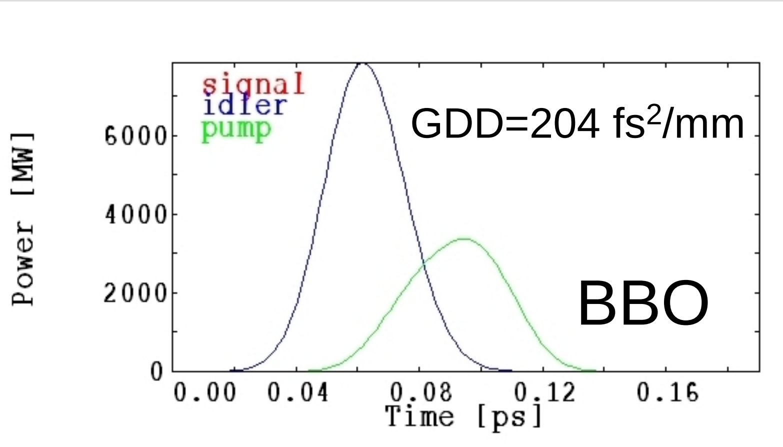


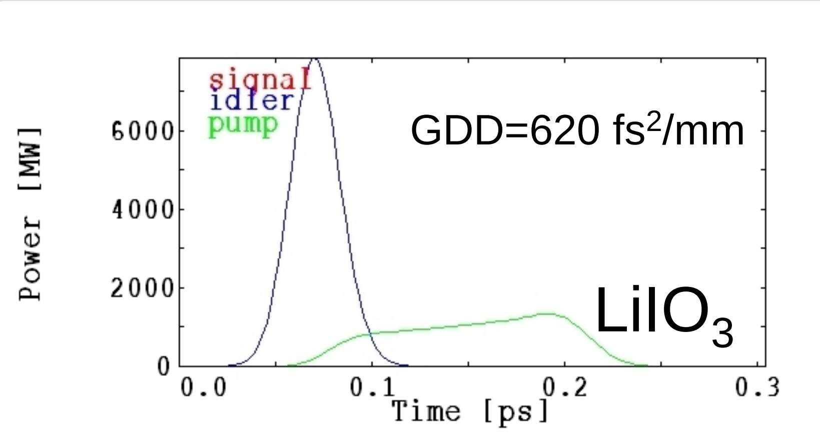
The total energy output in the Second-Harmonic matches somewhat with the naïve predictions



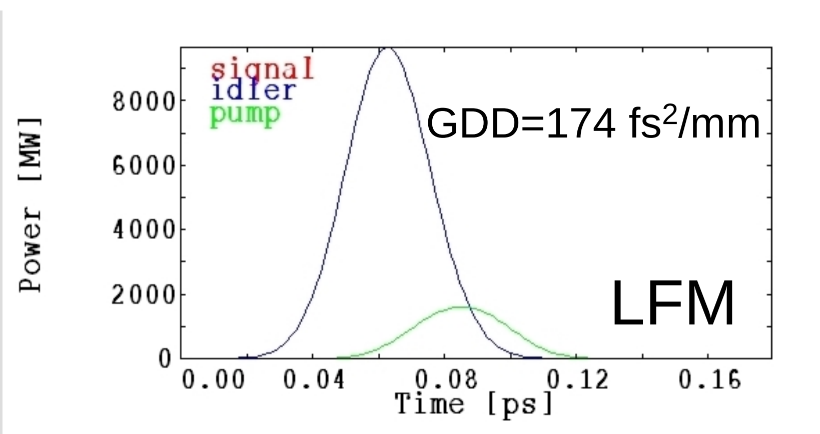
All Crystal Lengths = 250 μm

Modeling with SNLO





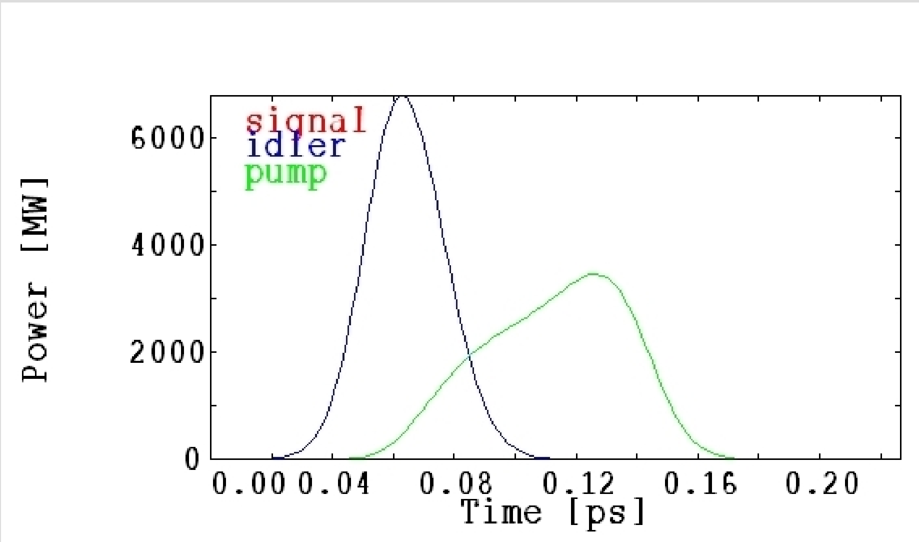
Poor Matching of Group Velocities causes the Second-Harmonic to lag behind, temporally spread (Group-Delay Dispersion)



All Crystal Lengths = 250 μm

What about a longer crystal

More pulse energy at Second-Harmonic.
But larger temporal spread due to group velocity mismatch. Will look later to see how this affects Sum-Frequency Generation.



Crystal Length = 400 μm

Energy=211 μJ

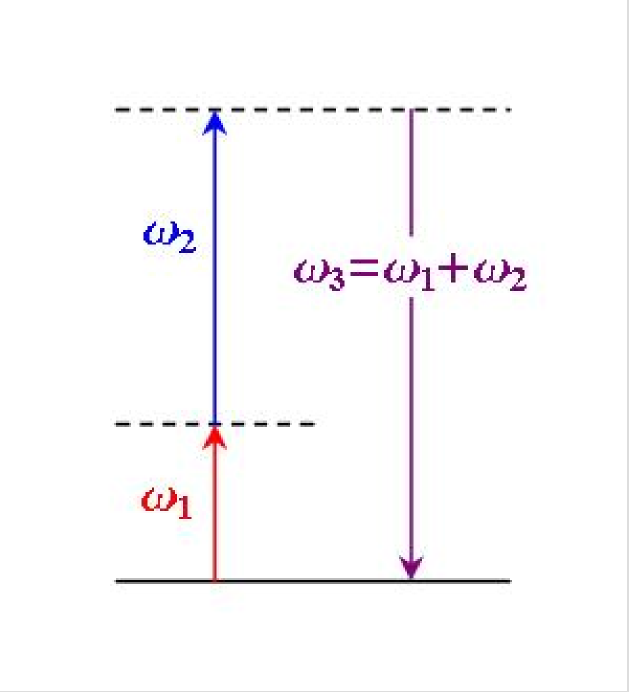
Sum-Frequency Generation

Similar phase-matching Condition

$$\Delta k = k_1 + k_2 - k_3 = 0$$

+ Other assumptions yield

$$I_3 \propto \frac{d_{eff}^2 L^2}{n_1 n_2 n_3} \operatorname{sinc}^2(\Delta k L/2)$$

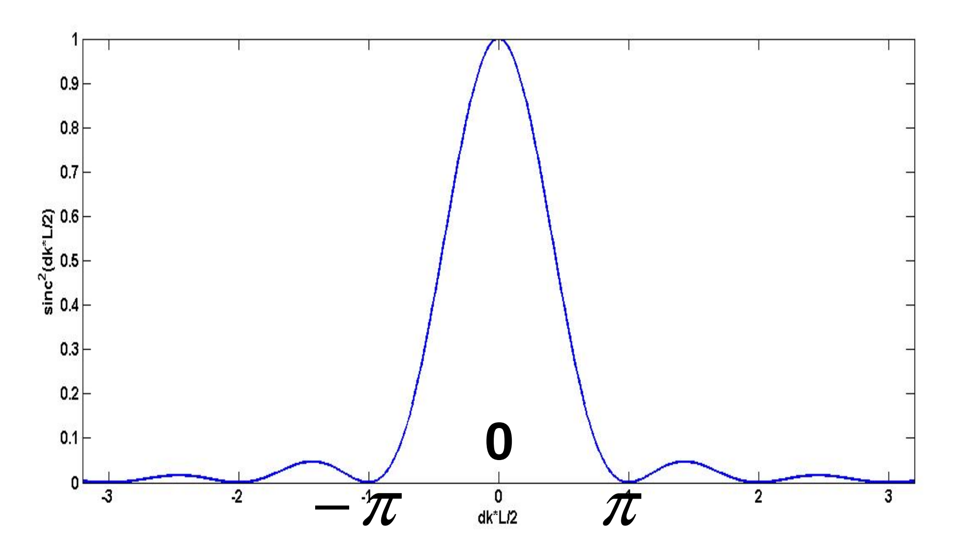


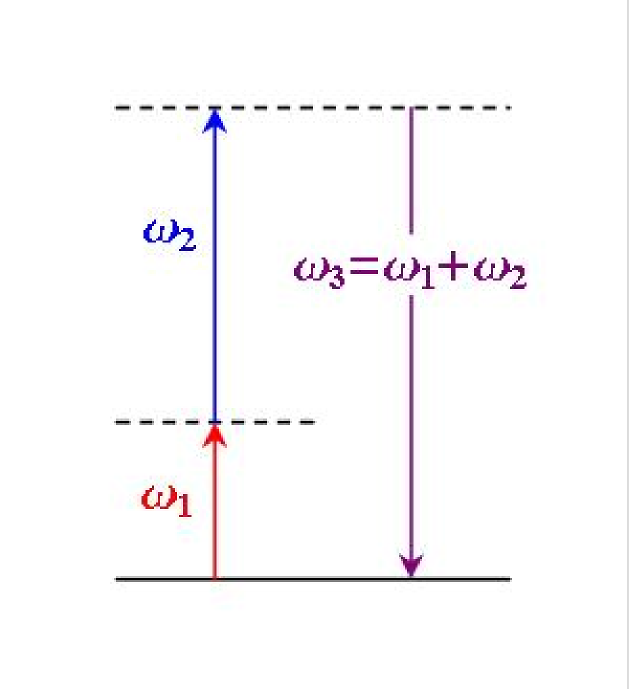
Sum-Frequency Generation

Similar phase-matching Condition

$$\Delta k = k_1 + k_2 - k_3 = 0$$

+ Other assumptions yield





The Crystals

Larger Wavelength range of 260-780 nm

<u>Few good candidates</u>

BBO - (d_{eff} = 1.84)

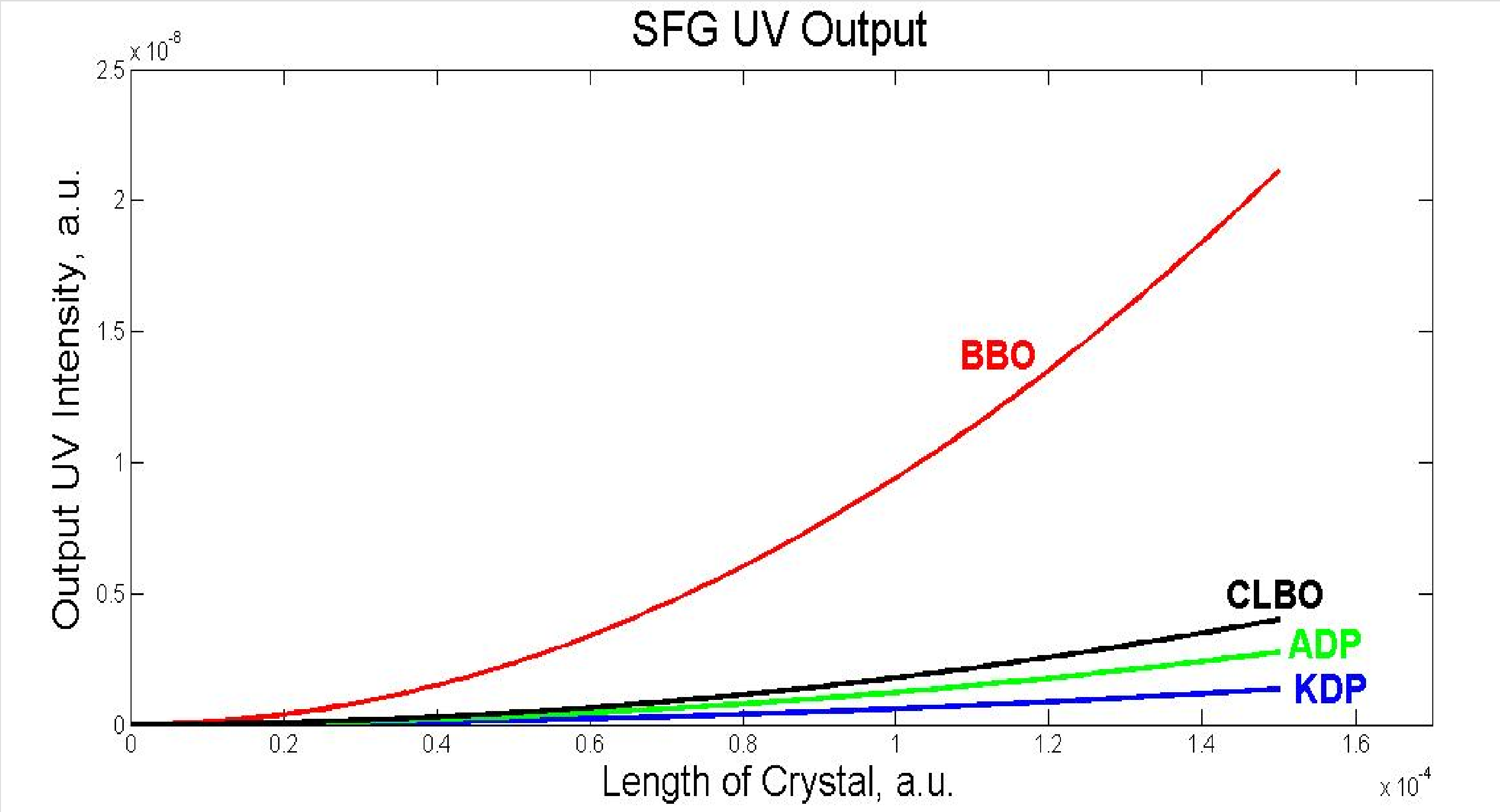
CLBO – Cesium Lithium Borate (d_{eff} = 0.776)

KDP - (d_{eff} = 0.457)

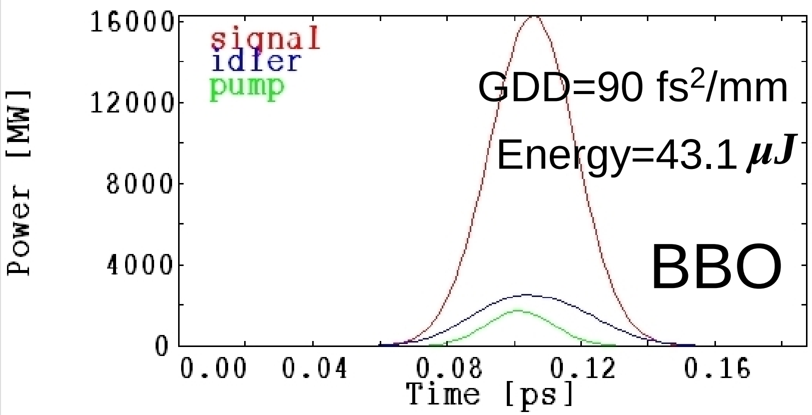
ADP – Ammonium dihydrogen Phosphate (d_{eff} = 0.663)

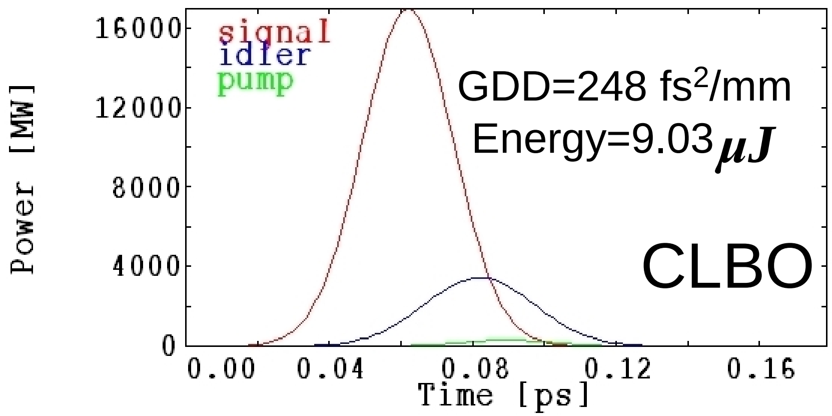
General Trend in Total Output

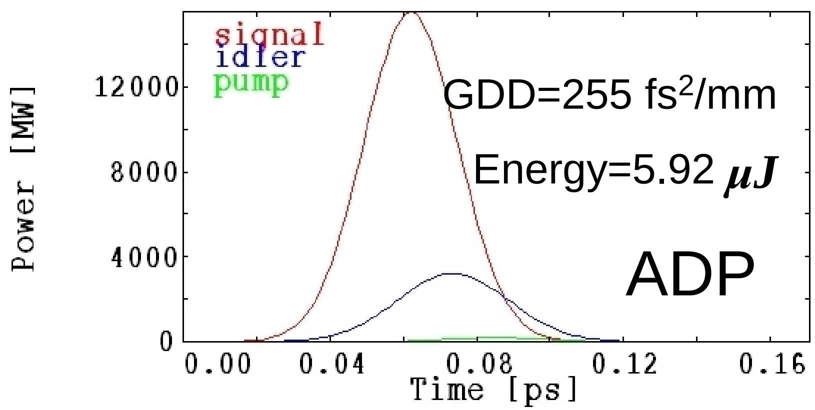
BBO is strongly favored, due to large d_{eff} value



Comparison to SNLO



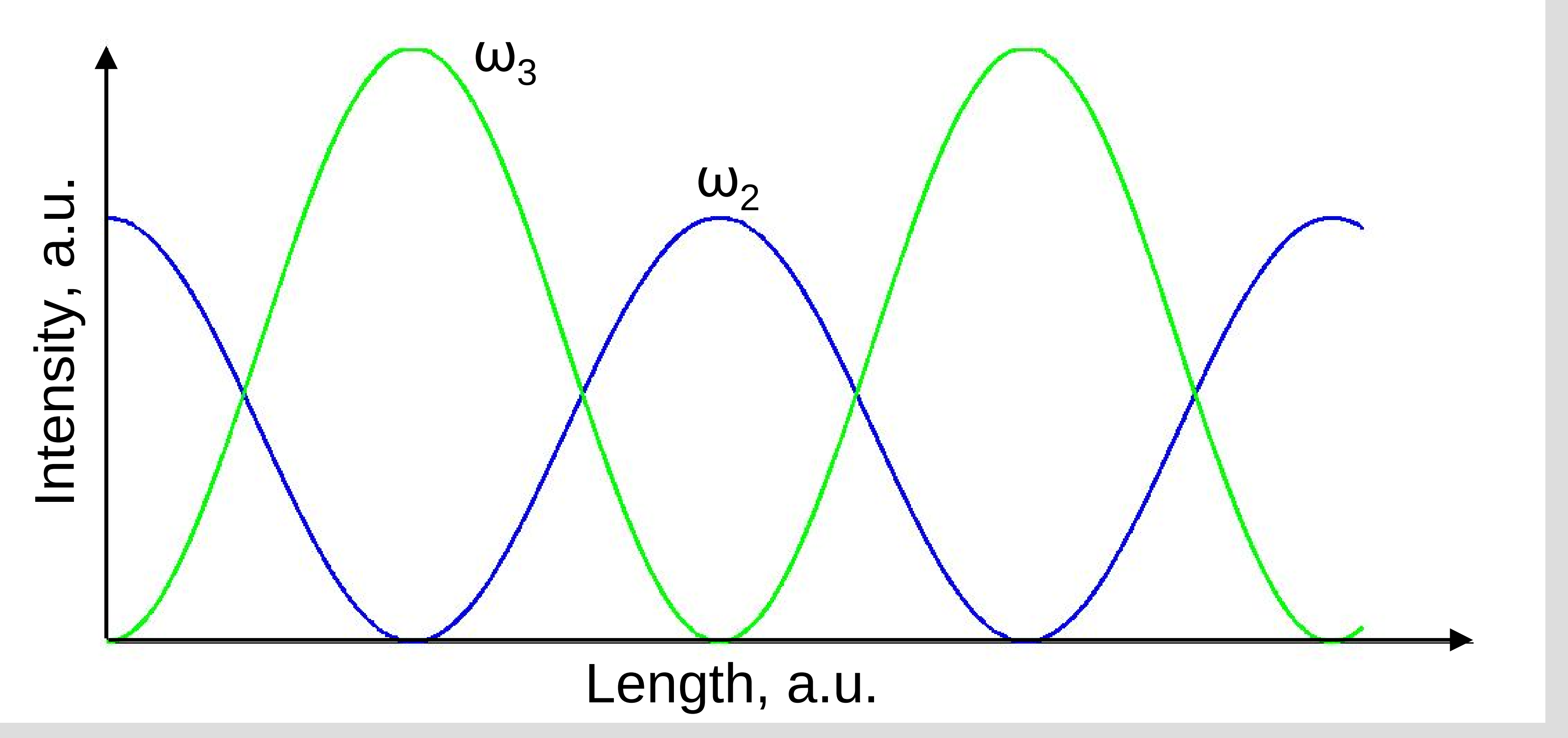




All Crystal Lengths = 100 μm

What about a longer crystal?

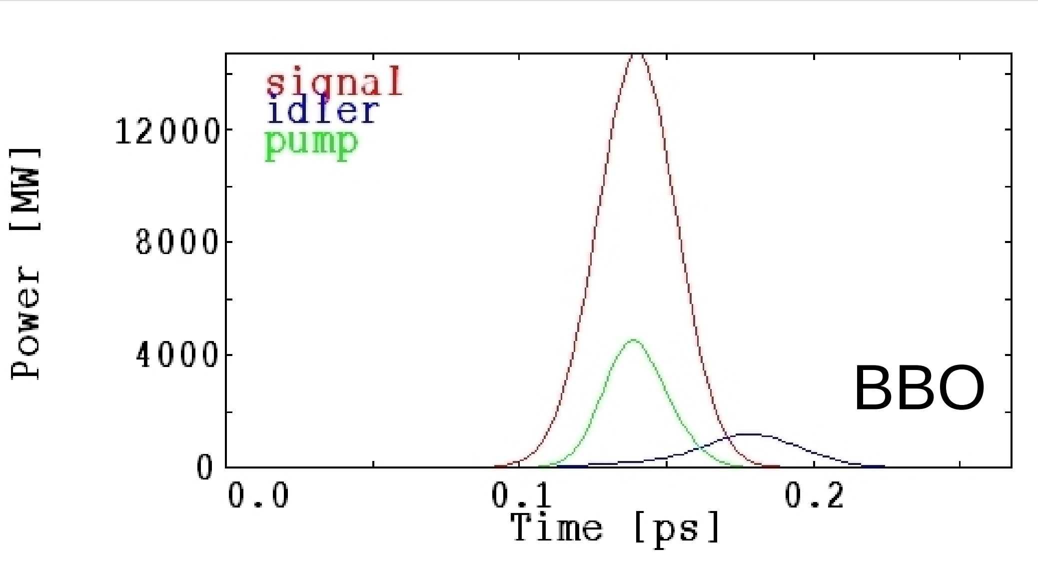
Ideally, with no input ω_3 field, after some length ω_2 should be depleted and ω_3 should be at a max



What about a longer crystal?

Ideally, with no input ω_3 field, after some length ω_2 should be depleted and ω_3 should be at a max

So if Δk is low enough, it may be ideal to explore longer crystals (would be cheaper as well)



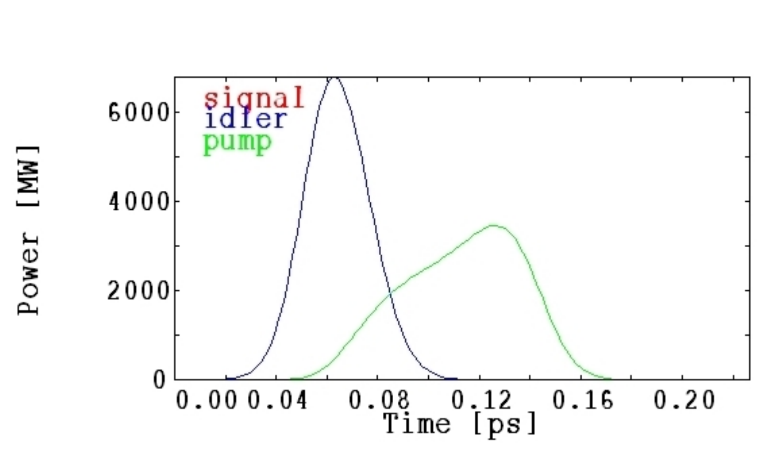
Crystal Length = 270 μm

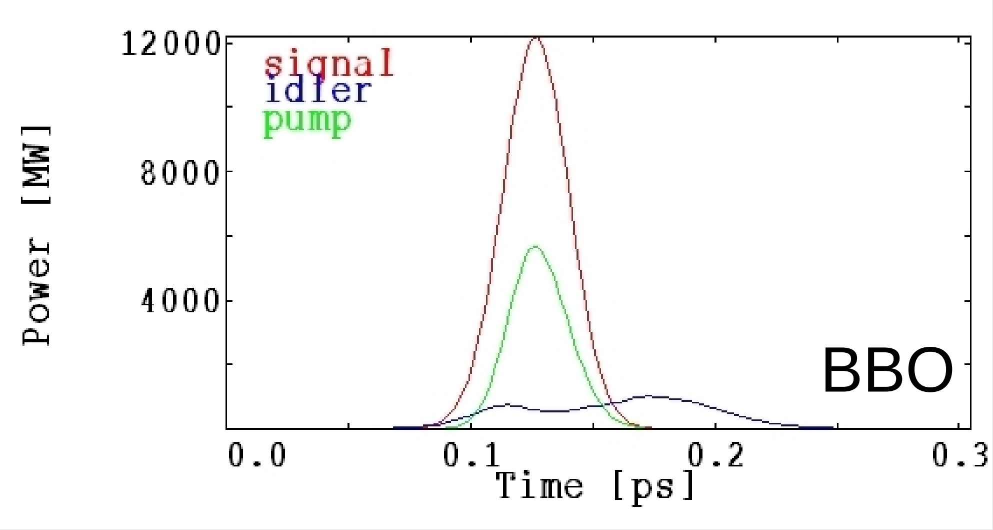
UV Pulse Energy=123 μJ

Longer crystal for SHG and SFG

Use the earlier output (roughly) from a longer SHG crystal

(211 μJ over 67 fs)





Crystal Length = 270 μm

Input pulses are now from SHG with a 400 μm crystal

UV Pulse Energy=172 μJ

Final Determination

BBO is the crystal of choice for both upconversion processes.

High d_{eff}

Low Group Delay Dispersion

Comparable Damage Thresholds

<u>Recommendations</u>: Look more closely at the advantages gained from a longer crystal length in SFG (aside from cheaper cutting). Optimize pulse delay for maximum overlap of ω_1 and ω_2 in SFG.

Thanks

- Prof. Tom Weinacht
- Dr. Martin Cohen
- Dominik Geissler

References

- R. W. Boyd, *Nonlinear Optics*, Academic Press, San Diego, 2003.
- A. V. Smith, Proceedings of SPIE, **4972**, 50-57, 2003.