2D SELF FOCUSING OF A LASER BEAM INTO A PLASMA: PCGO APPROACH

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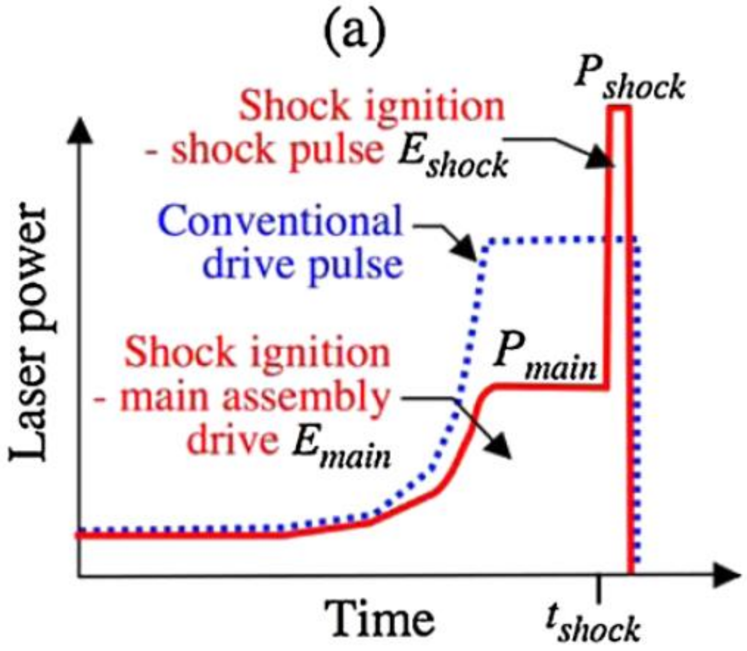
FRAMEWORK AND MOTIVATION: ICF-SI



- Shock ignition (SI): decoupling compression phase from the ignition phase[1]
- Spike-pulse: 10^{16} W/cm^2 ⟶ hot spot in ponderomotive self-focusing regime[2] + other LPIs
- Novel interest in self-focusing
- Need: theoretical study of nonlinear laser-plasma interactions -> fluid codes: CHIC
- In Chic, new module allowing to approximate laser intensity envelope 2D planar PCGO -> improvement of laser description
- Ponderomotive effects and self-focusing never properly investigated in the PCGO context

[1] R. Betti *et al*, Phys. Rev. Lett. 98, 155001 (2007), L. J. Perkins et alt Phys. Rev. Lett. **103**, 045004, 2009
[2] D. Batani et alt, Nucl. Fusion **54** (2014) 054009, 2014

AIM

- Novel interest in self-focusing

- Ponderomotive effects and self-focusing never properly investigated in the PCGO context

AIM

STUDY OF SELF-FOCUSING OF A GAUSSIAN BEAM INTO THE PLASMA IN THE PCGO APPROACH: BENCHMARK WITH HARMONY CODE

PONDEROMOTIVE SELF FOCUSING

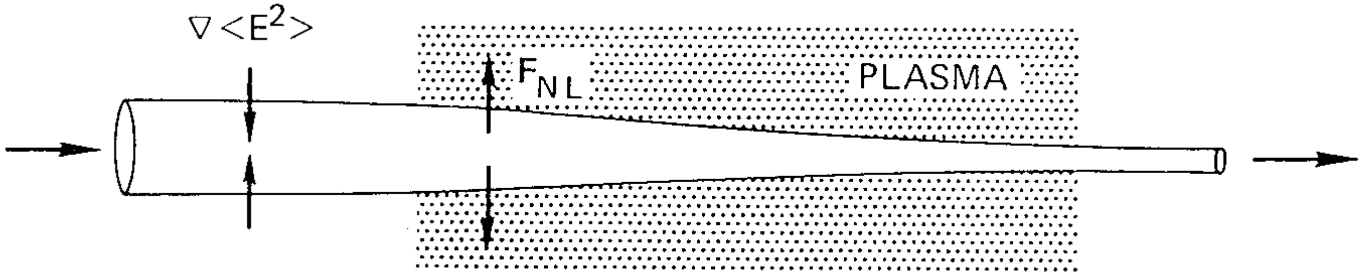
- Non linear laser-plasma interaction, long pulse (ps-ns)
- Transverse averaged force on electrons -> density changing -> Laser pinching -> Intensity increasing

$$f_p = -\frac{e^2}{4m_e\omega_{0p}^2}\nabla|E|^2$$

Ponderomotive force

$$n = n_0 e^{\frac{e^2|E|^2}{4\omega_0 m_e(T_e+T_i)}}$$

Plasma reponse



- Main physical parameters[1]:
  - Beam power normalized to the critical power

$$\frac{P}{P_c} \simeq 1.8\ \frac{I_i\lambda_0^2}{10^{15}W\,cm^{-2}\mu m^2}\ \frac{n_0}{n_c}\ \frac{1KeV}{T_e}\ \left(\frac{w_i}{\lambda_0}\right)^2$$

  - plasma density saturation

$$\alpha = \frac{w_i^2\omega_{0p}^2}{c^2}$$

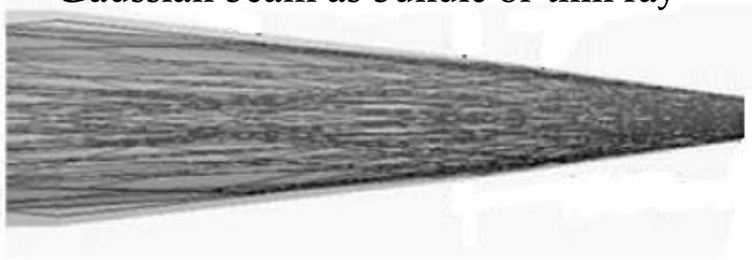
[1] V.T. Tikhonchuk et *al*, Physics of Plasmas **4**, 4369 (1997)

RAY-TRACING AND PCGO

- NOVELTY in CHIC: 2D extension of the ray tracing in **planar** geometry
  Thick Ray approach[1], based on the Paraxial Complex Geometrical Optics (PCGO)[2]

Standard Ray-Tracing

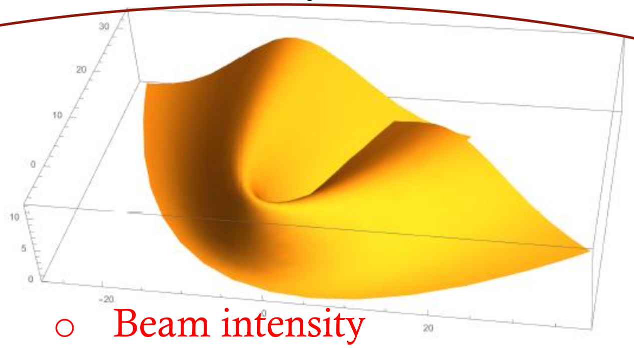
Gaussian beam as bundle of thin ray



$$\frac{d\boldsymbol{r}}{d\tau'} = \boldsymbol{p}$$

$$\frac{d\boldsymbol{p}}{d\tau'} = \frac{c^2}{2}\nabla\epsilon'(\boldsymbol{r})$$

Thick ray-PCGO



- Beam intensity

$$I_0(\tau') = \frac{c\sqrt{\epsilon_c'}\epsilon_0}{2}|u(0,\tau')|^2 = \frac{c\epsilon_0}{2}|\tilde{A}(0)|^2\left(\frac{w_0}{w}\right)\exp\left(-k_{\mathrm{FS}}\int_0^{\tau'} c\epsilon_c'' d\tilde{\tau}'\right)$$

✓ Ponderomotive force added as a pressure term in the HPE

$$\rho_m\left(\frac{\partial}{\partial t} + \mathbf{u}_m.\nabla\right)\mathbf{u}_m = -\nabla P_m + F_{\mathrm{ext}} \qquad F_{ext} = -\frac{n_e e^2}{4\omega_0}\nabla|E|^2$$

1] A Colaïtis, G Duchateau, P Nicolaï, V Tikhonchuk, Physical Review E 89 (3), 033101
2] Yu. A. Kravtsov, P. Berczynski, Gaussian beams in inhomogeneous media: A review, 2007, Volume 51, Issue 1, pp 1–36

COMPARISON HARMONY PCGO-CHIC: MODELS

2D Harmony[1]

- Paraxial wave-based solver

$$L_{par}(E) = -\frac{i\omega_0}{2n_c}(N_0 - N_{eq})E$$

$$L_{par} = \partial_t + v_g \frac{\partial}{\partial x} + \imath \frac{c}{2\omega_0^2} \frac{\partial^2}{\partial y^2}$$

2D CHIC-PGCO

- Ray-tracing+laser intensity

$$\partial_\tau^2 \mathbf{r} \propto \nabla^2 n$$

$$I_0(\tau') = \frac{c\sqrt{\epsilon_c'}\epsilon_0}{2}|u(0,\tau')|^2 = \frac{c\epsilon_0}{2}|\tilde{A}(0)|^2 \left(\frac{w_0}{w}\right) \exp\left(-k_{\mathrm{FS}} \int_0^{\tau'} c\epsilon_c'' d\tilde{\tau}'\right)$$

[1] Huller S. *et al, Physics of Plasmas* 2006; 13: 22703

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REFERENCE

2D CHIC-PGCO

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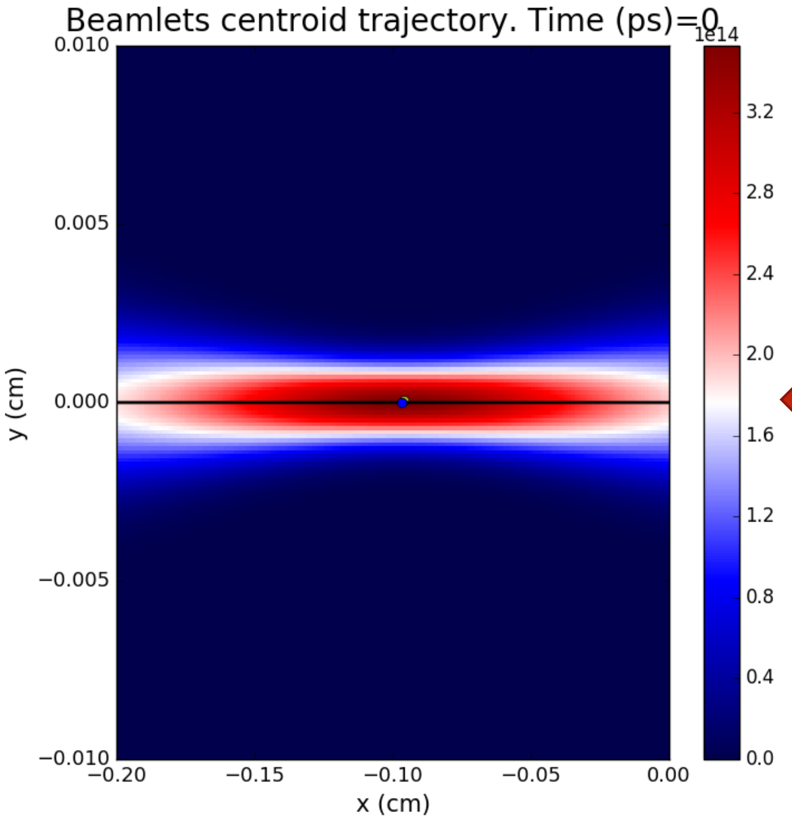
APPROXIMATION

[1] Huller S. *et al, Physics of Plasmas* 2006; 13: 22703

COMPARISON HARMONY PCGO-CHIC: SIMULATIONS PARAMETERS

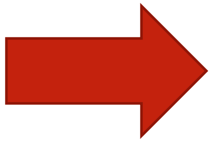
- Propagation of a Gaussian beam into an underdense, nonabsorbing plasma with constant density
- Parameters:
  - ✓ Power: P/Pc=1-2-4-6
  - ✓ Density: n/n_c=0,1-0,05
- Plasma temperature T_e=1 KeV
- Laser pulse duration= 250 ps
- Wavelength λ=1,05 μm
- Aperture f#=30

200 λ

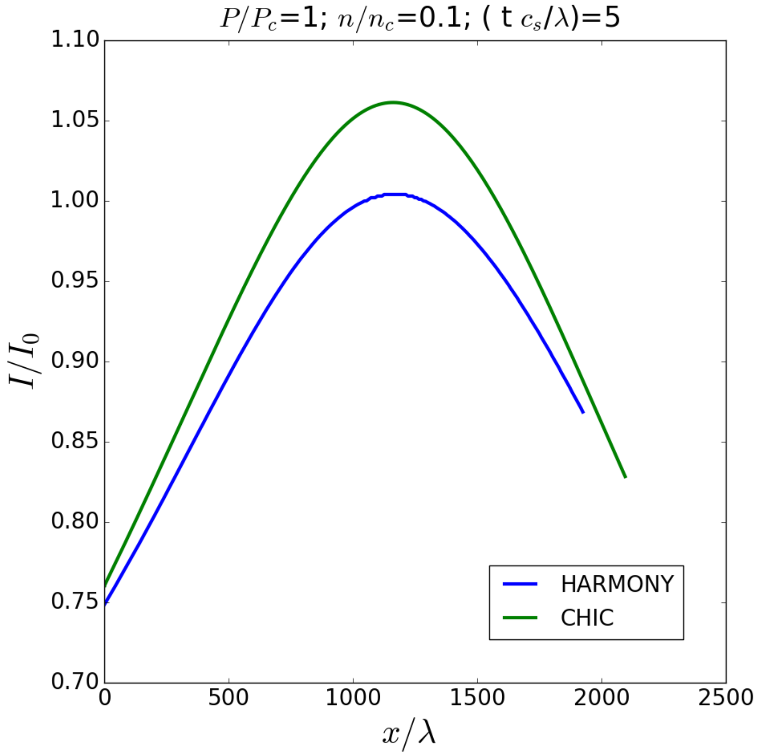


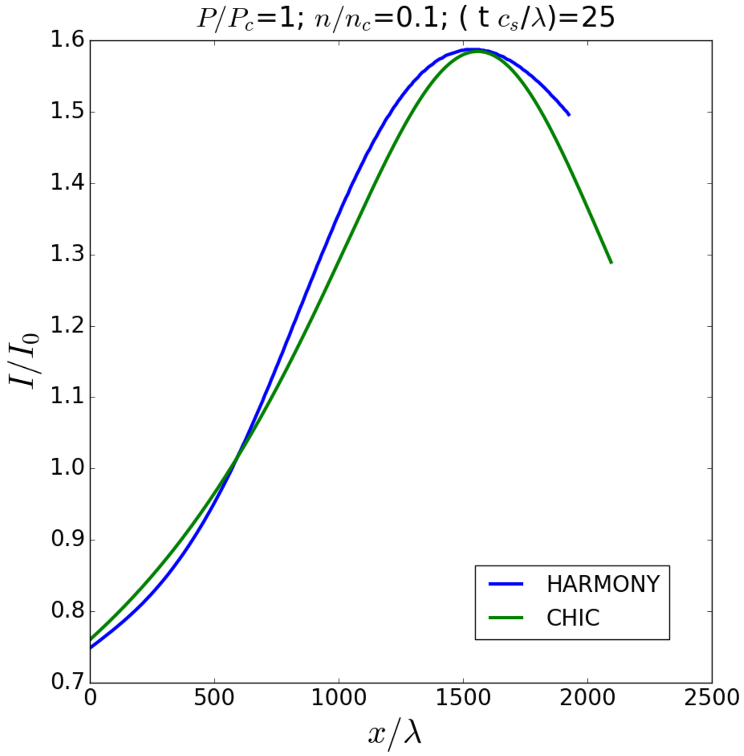
2000 λ

RESULTS COMPARISON PCGO HARMONY: ON-AXIS INTENSITY



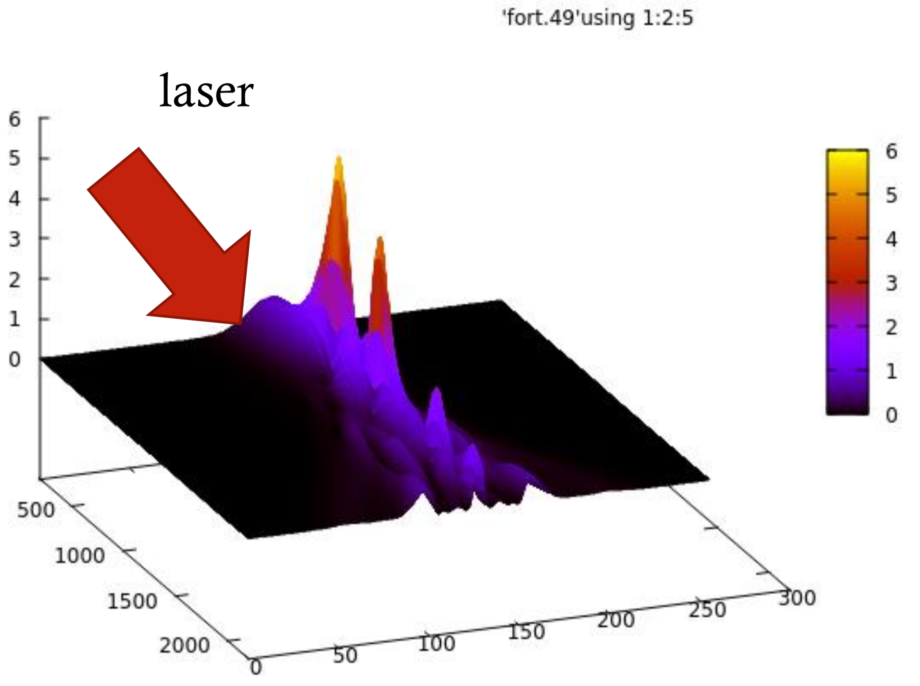
laser



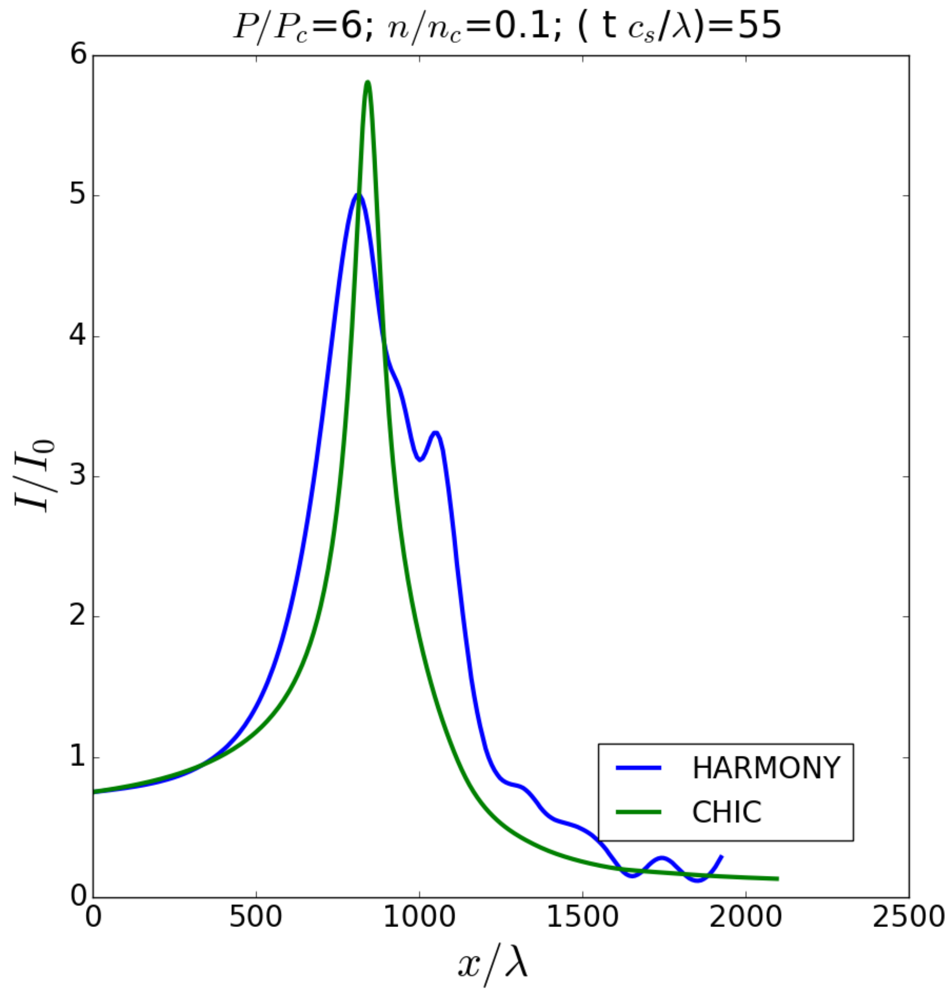


P/Pc=1
n/n_c=0,1

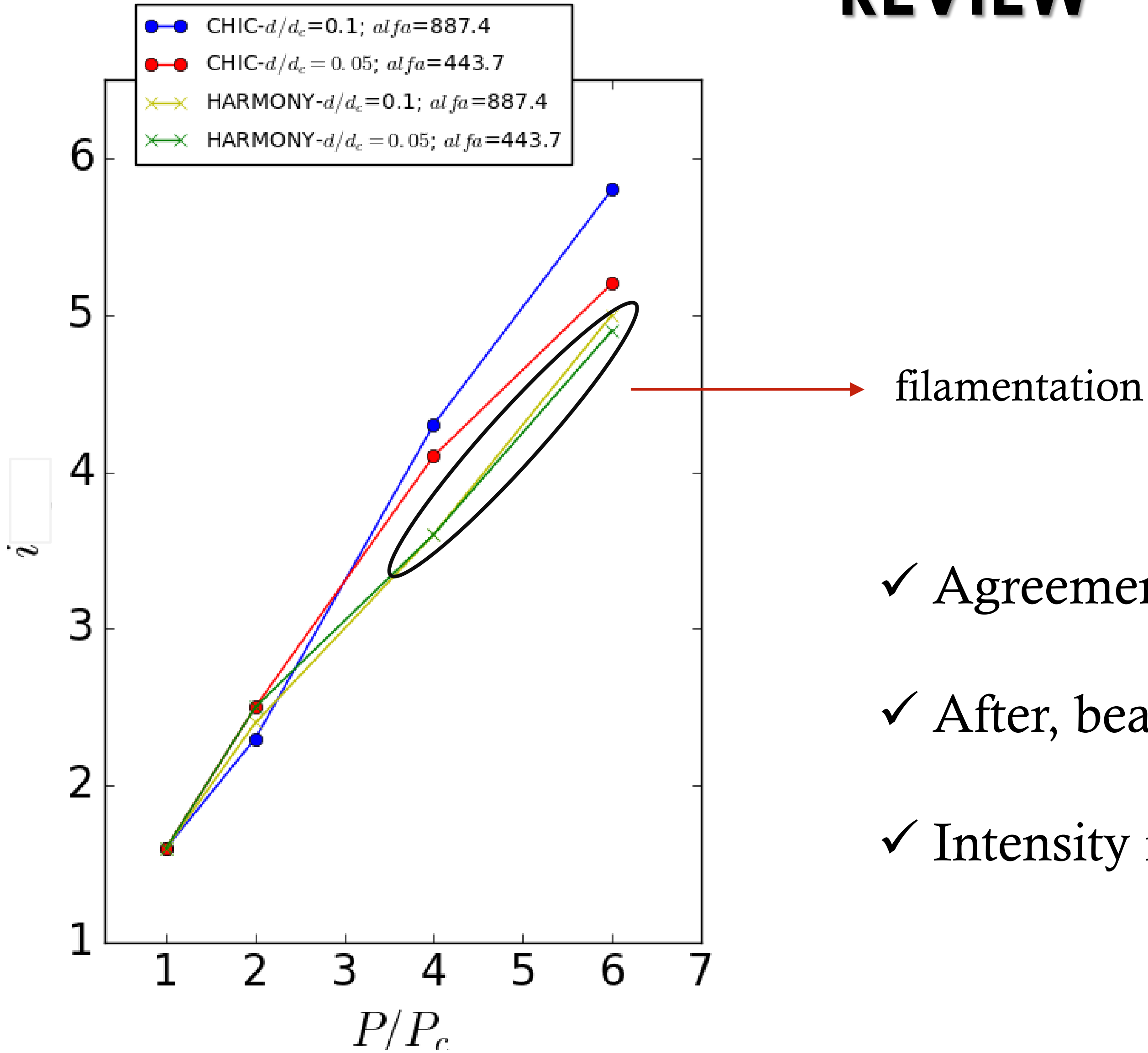
RESULTS COMPARISON PCGO HARMONY: FILAMENTATION



P/Pc=6
n/n_c=0,1

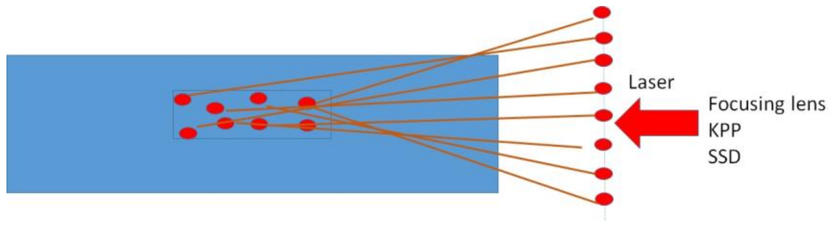


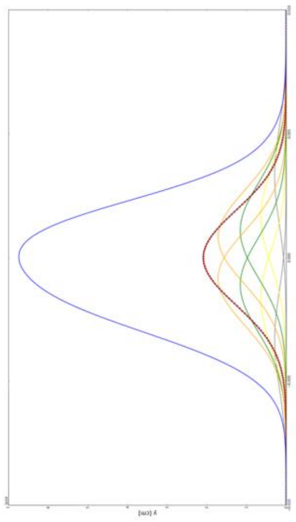
RESULTS COMPARISON PCGO HARMONY: REVIEW



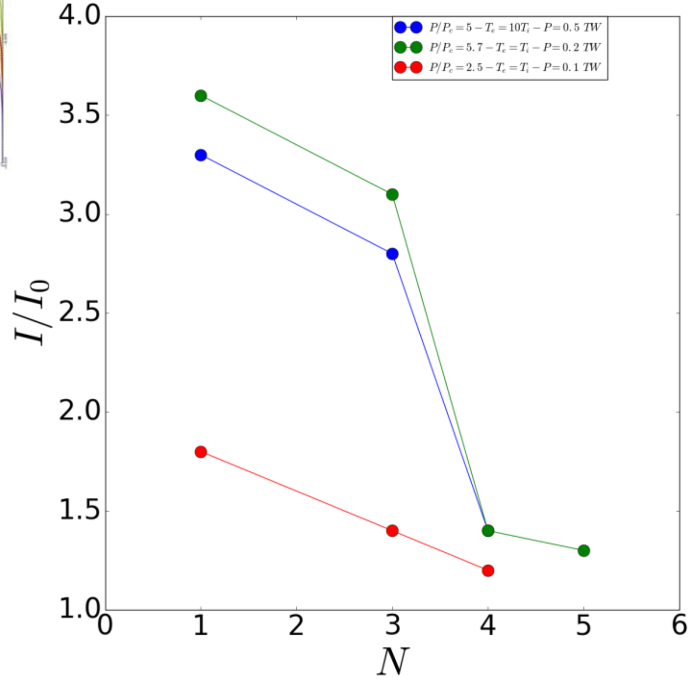
- ✓ Agreement as long as P/Pc<3-4
- ✓ After, beam filaments, so PCGO fails
- ✓ Intensity incresing diverging

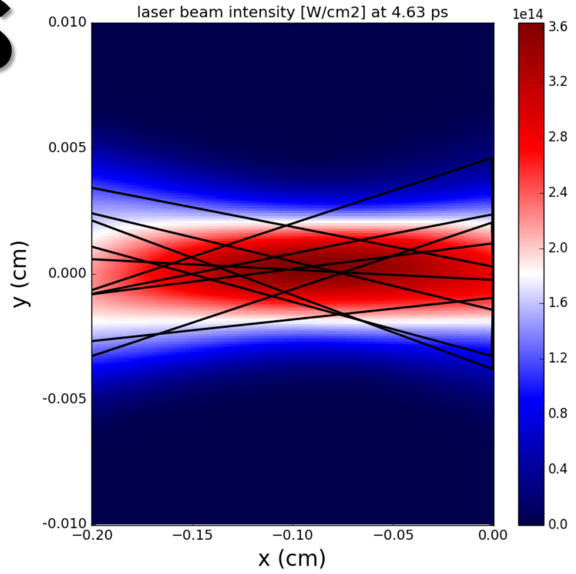
CONTROLLING SELF-FOCUSING BY SUPERPOSITION OF GAUSSIAN BEAMLETS





- Gaussain beam intensity split on several beamlets
- Beamlets focalized randomly in the plasma





Allowed to control total beam self-focusing

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CONCLUSIONS

- MOTIVATION:
  1. self-focusing concerning for SI approach;
  2. checking self-focusing with PCGO-CHIC

- Preliminary study of Self-focusing within CHIC-PCGO

- Elementary Gaussian beam self-focusing: strong dependency on critical power:
  - ✓ agreement with Harmony for P/Pc<2
  - ✓ Filamentation for P/Pc>2: no predictable with PCGO-> intensity increasing divergence

PERSPECTIVES

- Continue the study: different densities- higher power: dependency on n?

- Controlling self-focusing via superposition of Gaussian beamlets

- Modelling real ICF-SI laser beams: spatial temporal smoothed beams

- Coupling self-focusing with plasma flow/beam bending

- Cross-beam energy transfer in the ponderomotive regime

MERCI DE

VOTRE ATTENTION