HHG on Thin Target with Smilei & Happi Capabilities

Harmonics generation on thin plasma target with the UHI 100 laser. Front and rear side generation of the target. Experiment by Ludovic Chopineau and Adrien Denoeud.

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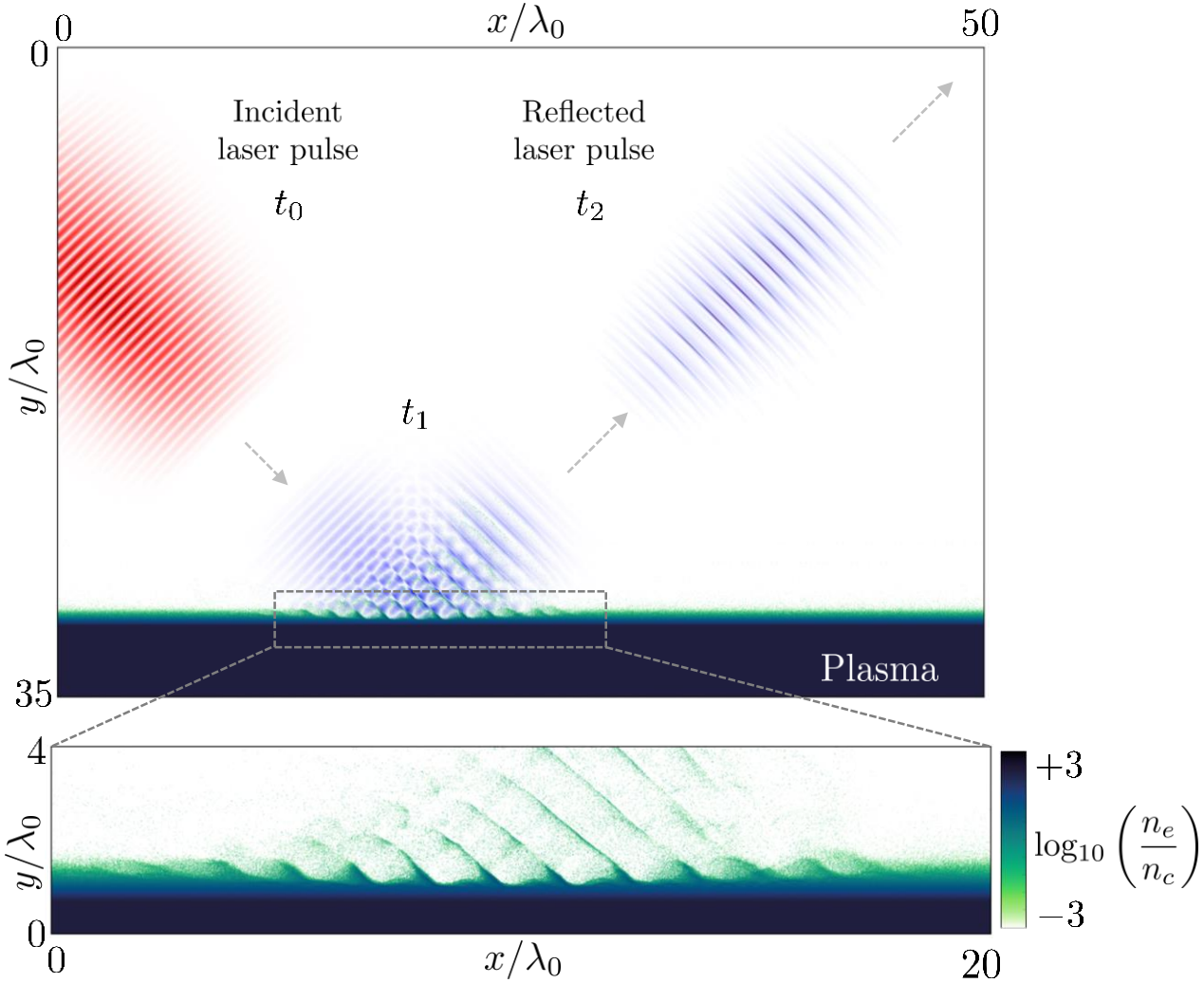
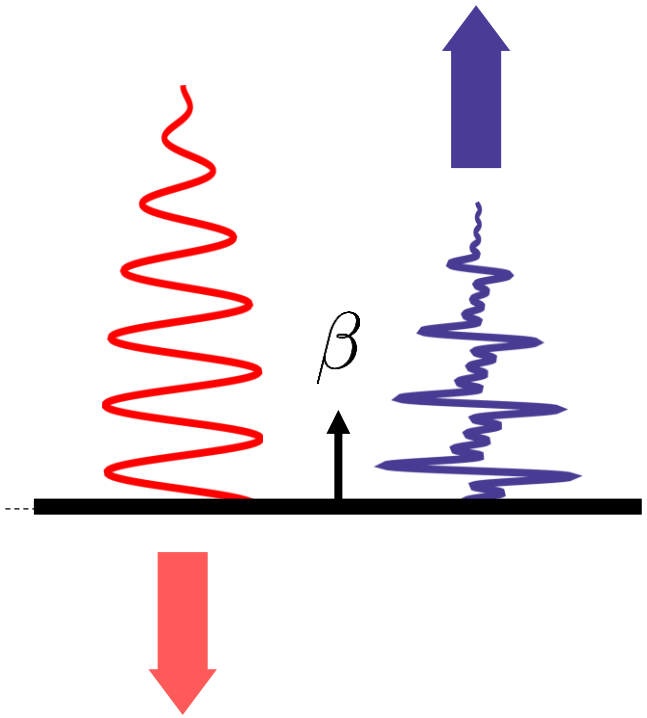
COMMISSARIAT À L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

Harmonics Generation on Thin Target

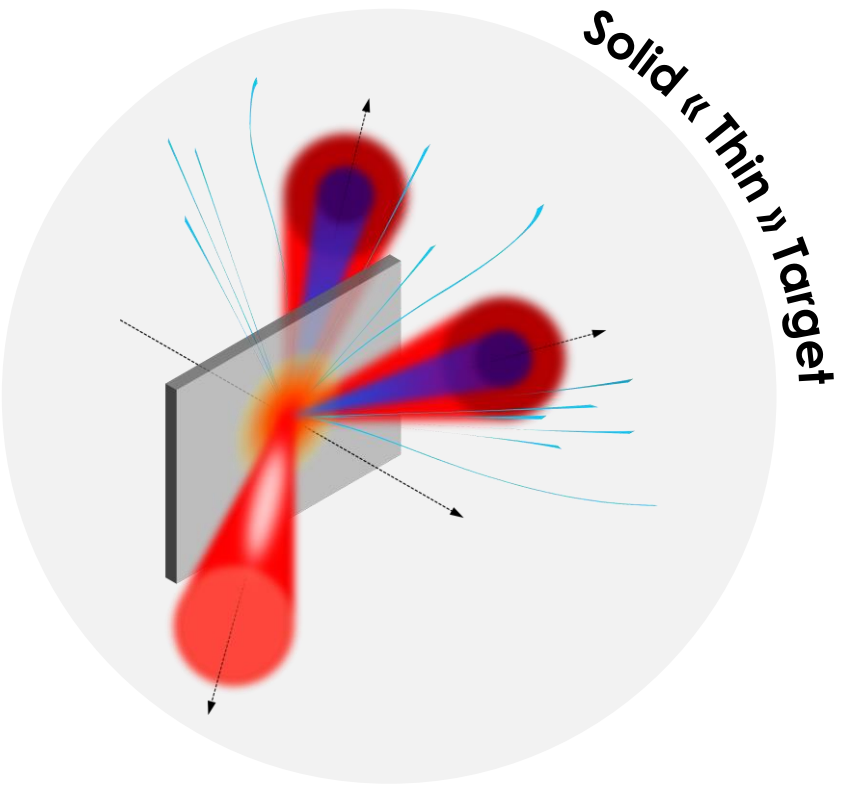
Plasma Mirror



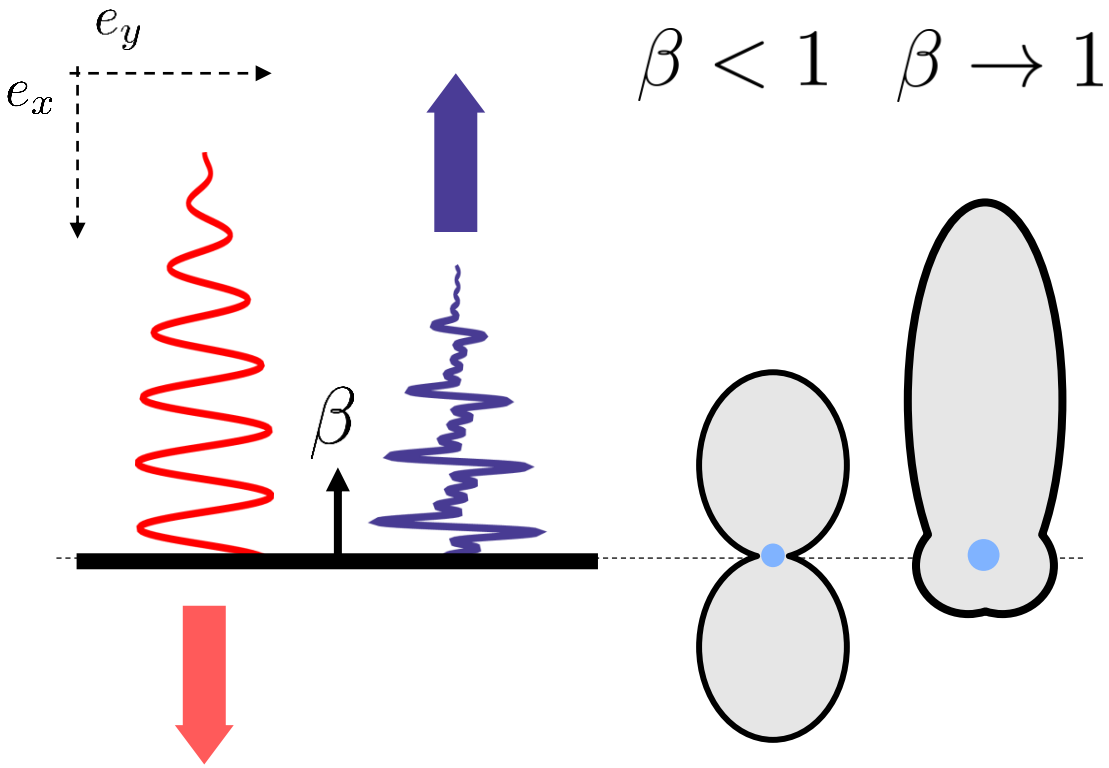


If $\beta > 0.4$ then the harmonic @ $2\omega_0$ is created

Harmonics Generation on Thin Target



Plasma Mirror



Lienard-Wichert radiated field

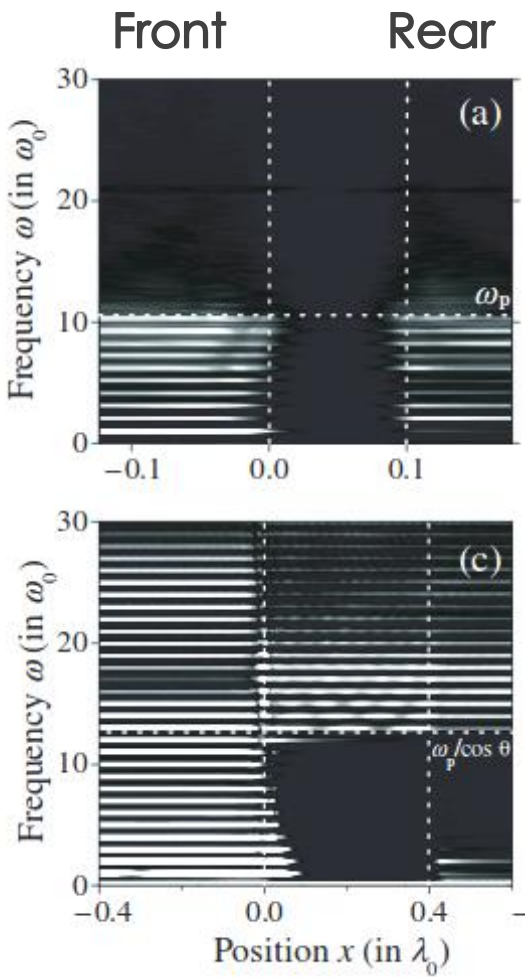
$$\mathbf{E} = \left\{ \frac{e}{4\pi\epsilon_0 c r} \left[\frac{\dot{\beta}_y}{(1+\beta_x)^2} - \frac{\beta_y \dot{\beta}_x}{(1+\beta_x)^3} \right] \right\}_{t_{ret}} \mathbf{e_y}$$

Harmonics Generation on Thin Target

THIN TARGET : « HISTORY »

Density gradient at front face

Relativistic Oscillating Mirror Efficiency $\eta(a_0, L_{grad})$



Target with density gradient at front and rear face :

- Coherent Wake Emission
- Resonant Absorption

Need : Density gradient, « low intensity »
Characteristic quantity : ω_{pe}

Target with no density gradient at front and rear face :

- Coherent Transition Radiation
- Coherent Synchrotron Emission

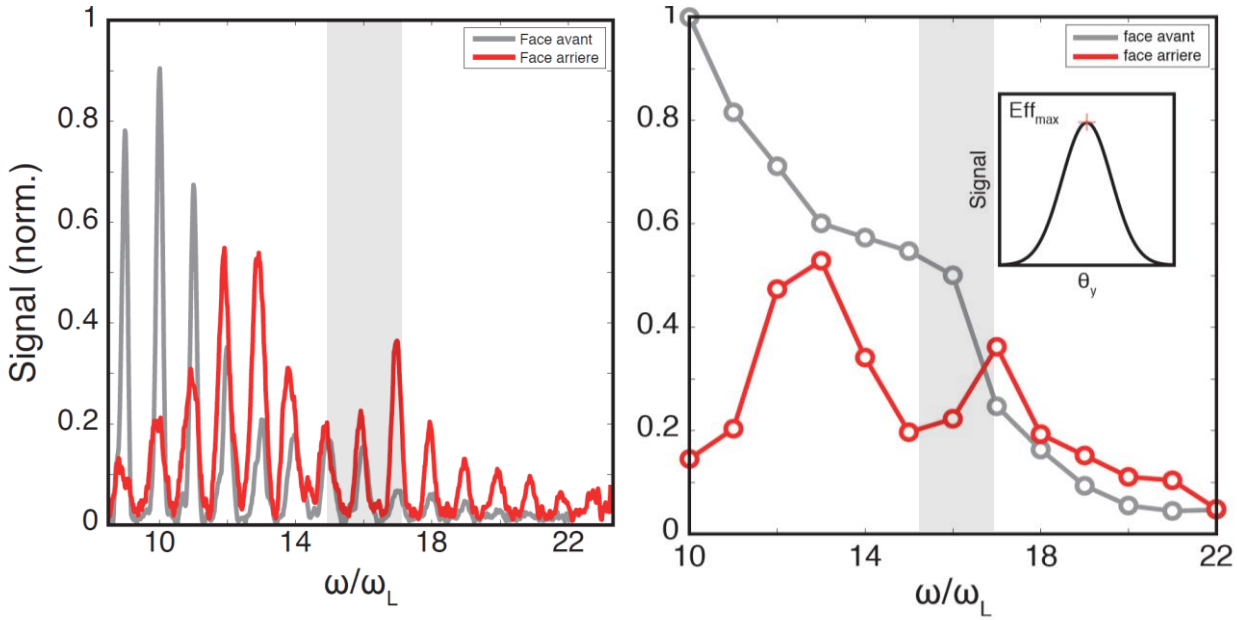
Need : Sharp density surface, « very high intensity »
Characteristic quantity : $\omega_{pe}/\cos(\theta)$

Harmonics Generation on Thin Target

EXPERIMENT @ UHI100

Harmonics efficiencies at the rear side on thin target

Ludovic Chopineau and Adrien Denoeud



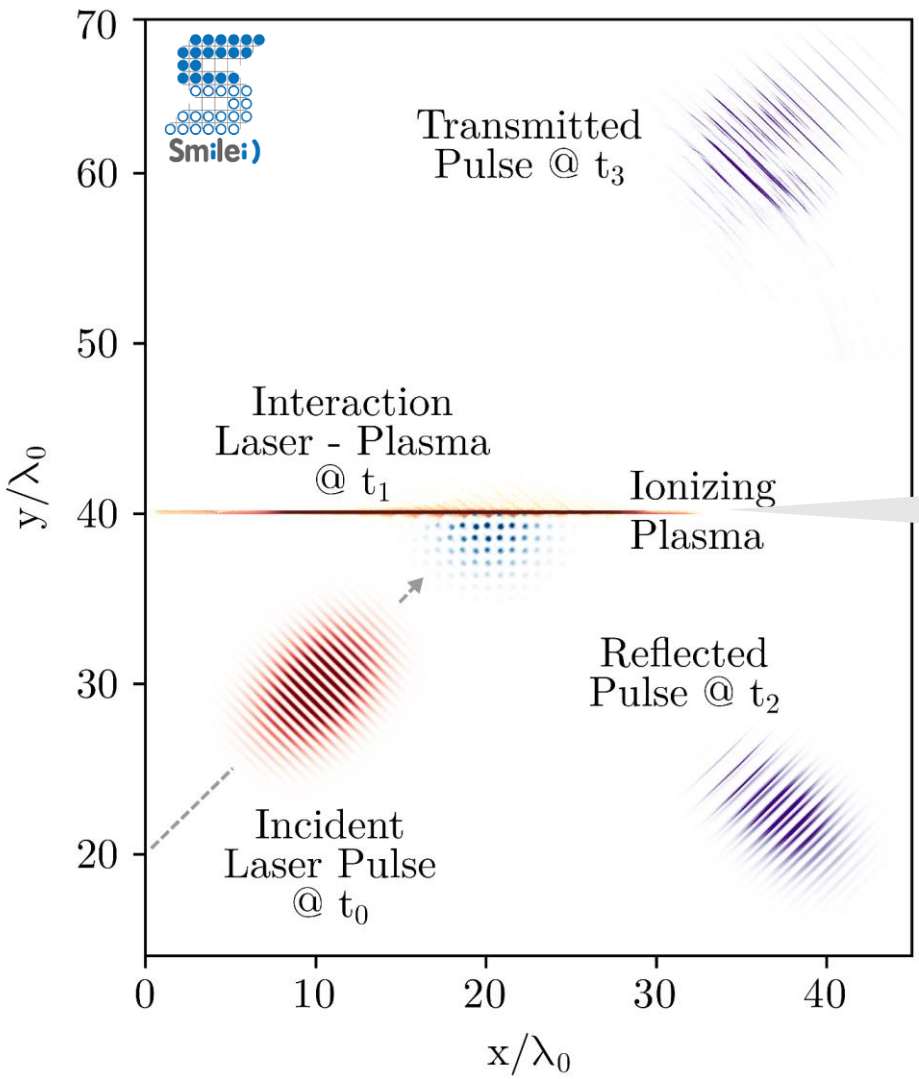
$I = 10^{19}$ W·cm^{-2} $n_e = 300\ n_c$ $\theta_{inc} = 60°$

« Transmit » harmonics *between* ω_{pe} *and* $\omega_{pe}/cos(\theta)$ not observed in experiments until now and 1D PIC(*) simulations.

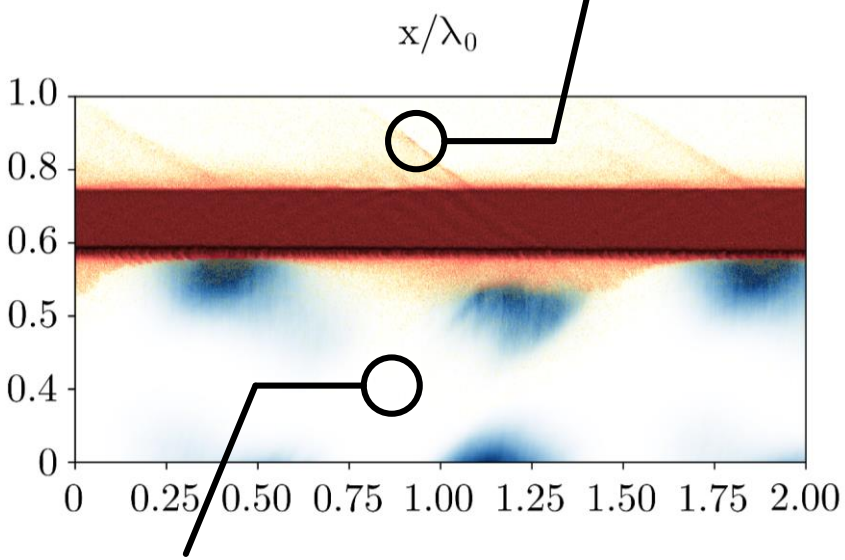
- Density variation (dynamics) ?
- Specifics conditions and parameters which allow rear side electron to radiate : *New process to understand ?*

Harmonics Generation on Thin Target

Box Presentation : The foundation



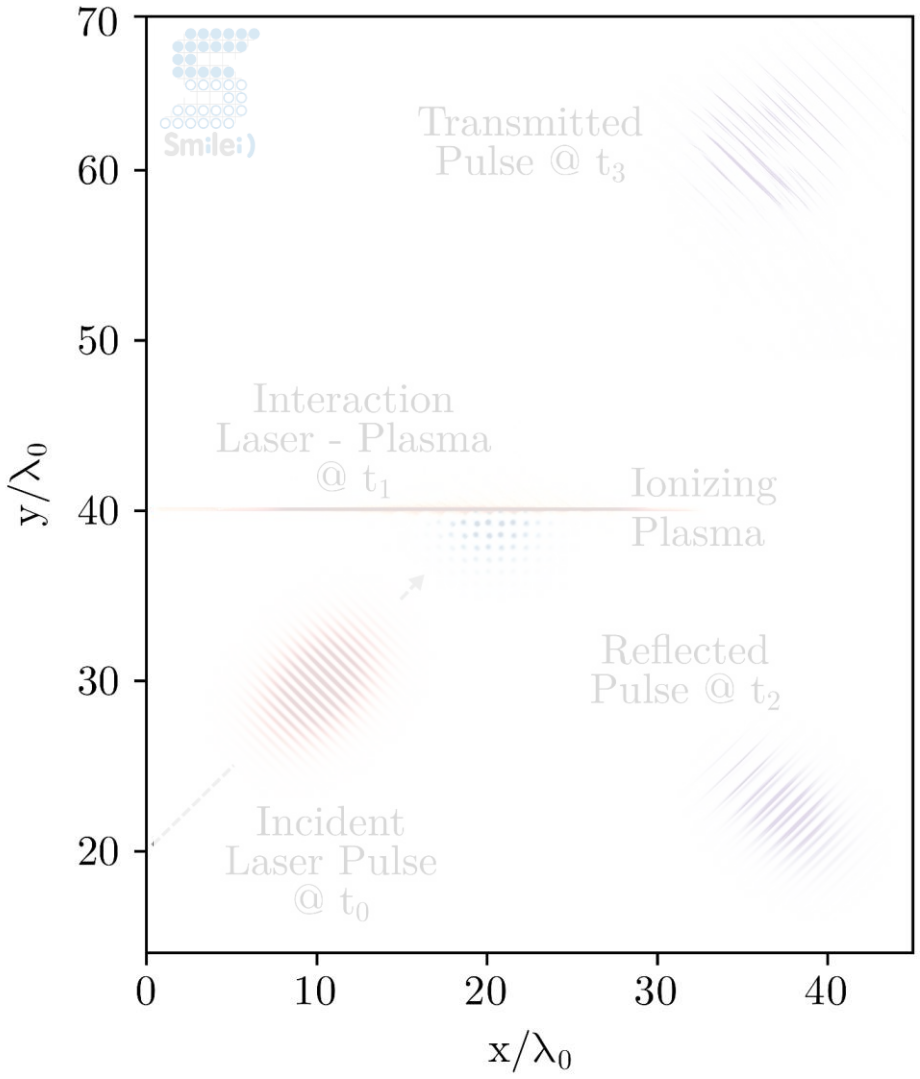
Bunches of electrons with high kinetic energy (~ 5-10 MeV typically)



Interference Patern where electrons mooves and radiates

Harmonics Generation on Thin Target

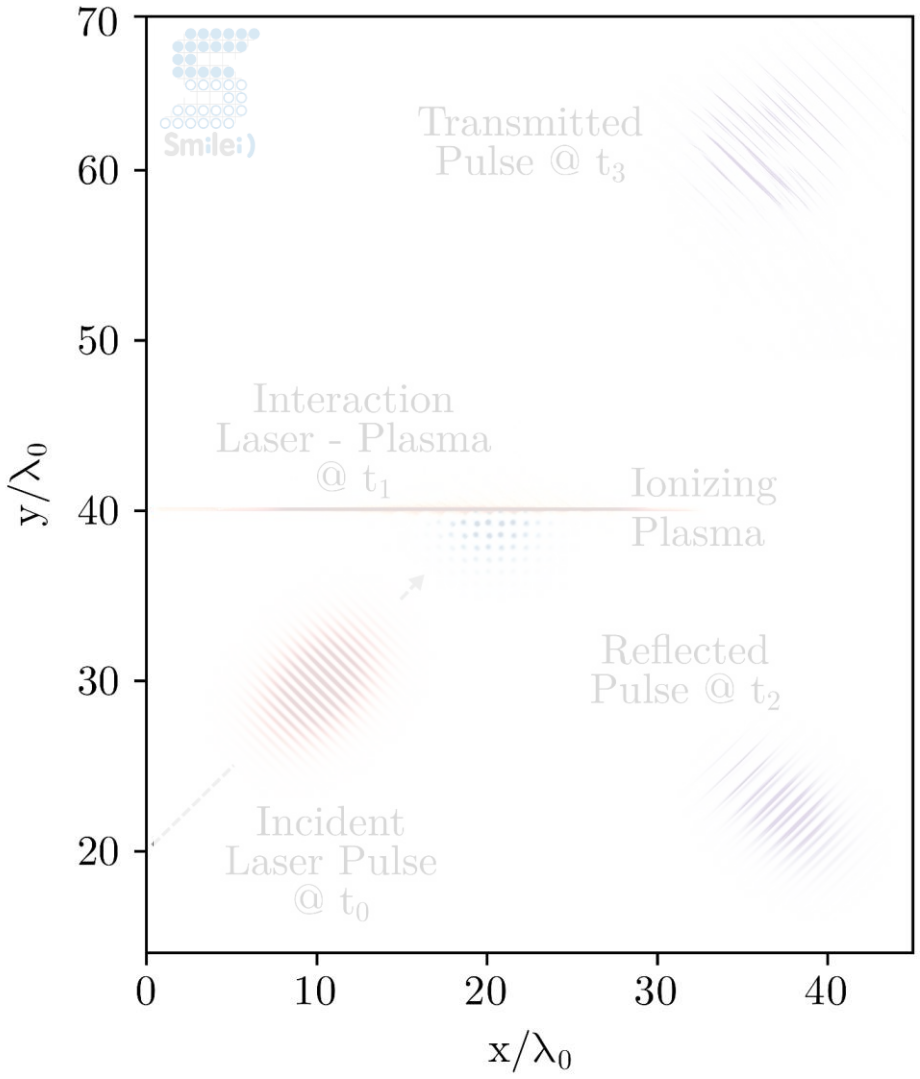
Box Presentation : Before all they was…




```
#!/usr/bin/python
import math as m
import numpy as np

l0 = 2.*m.pi                # laser wavelength
t0 = l0                     # optical cycle

resx  = 512.                # nb of cells in one laser wavelength x
resy  = 512.                # nb of cells in one laser wavelength y
rest  = 768.                # nb of cells/c in one laser wavelength
...
T_keV   = 1./511.           # Convert Temperature in KeV
aL = 5.
...
def density_carbon(x,y) :
        if (ymin < y < y0) :
                return 17.*m.exp( (y-y0)/L1 )
        if (y0 < y < y0+T) :
                return 17.
        if (y0+T < y < ymax) :
                return 17.*m.exp( -(y-(y0+T))/L2 )
        else :
                return 0.0
```

Harmonics Generation on Thin Target

Box Presentation : Main()




```
Main(
        geometry                        = "2Dcartesian",
        interpolation_order             = 2,
        timestep                        = t0/rest,
        simulation_time                 = Tsim,
        cell_length                     = [l0/resx,l0/resx],
        grid_length                     = Lsim,
        number_of_patches               = [2048,1],
        clrw                            = 1,
        EM_boundary_conditions          = [
                                          ["silver-muller","silver-muller"],
                                          ["silver-muller","silver-muller"]
                                        ],
        random_seed                     = smilei_mpi_rank,
        solve_poisson                   = True,
        reference_angular_frequency_SI  = 2.*m.pi*3e14/0.8,
        print_every                     = 1000
)
```

Spatiale resolution	λ_0 / 512
Time resolution (CFL)	T_0 / 768

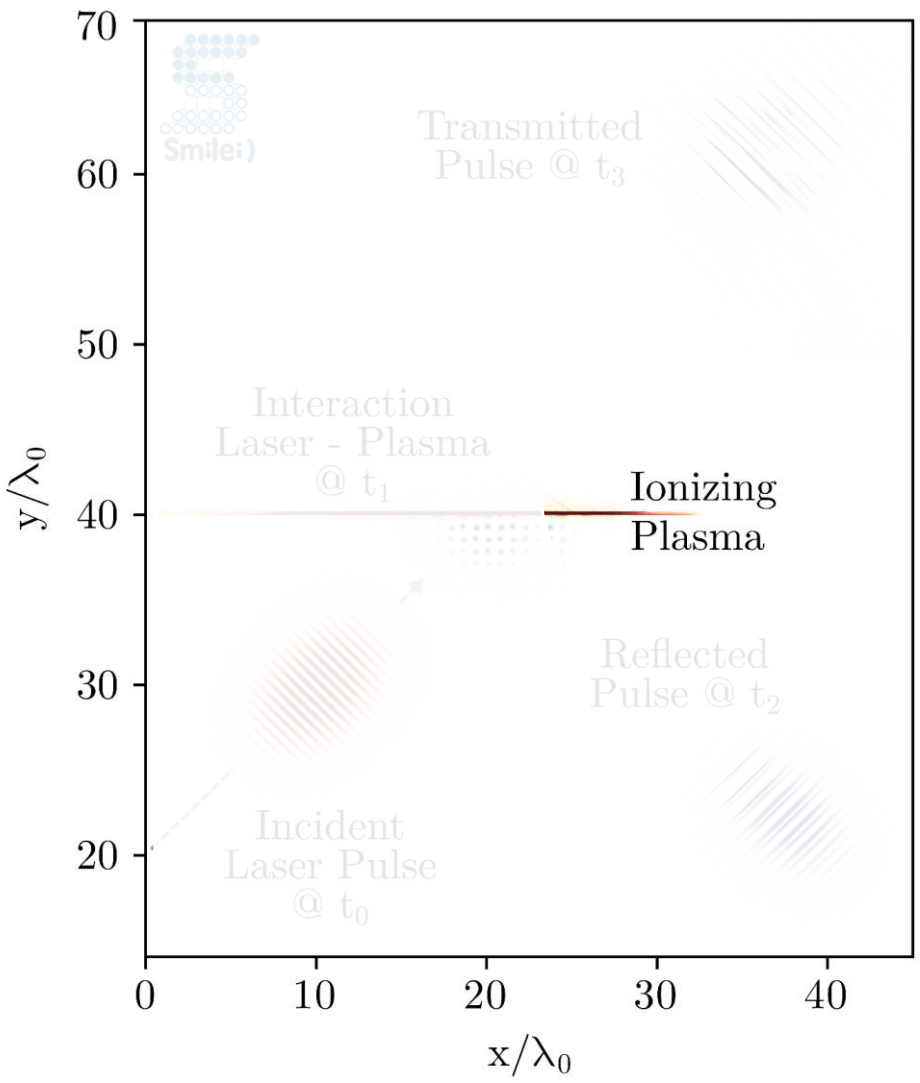
Box Presentation : LoadBalancing()

```
LoadBalancing(
        initial_balance     = False,
        every               = 1000000
)
```

No « load balancing »
2048 patches along x-direction only

Harmonics Generation on Thin Target

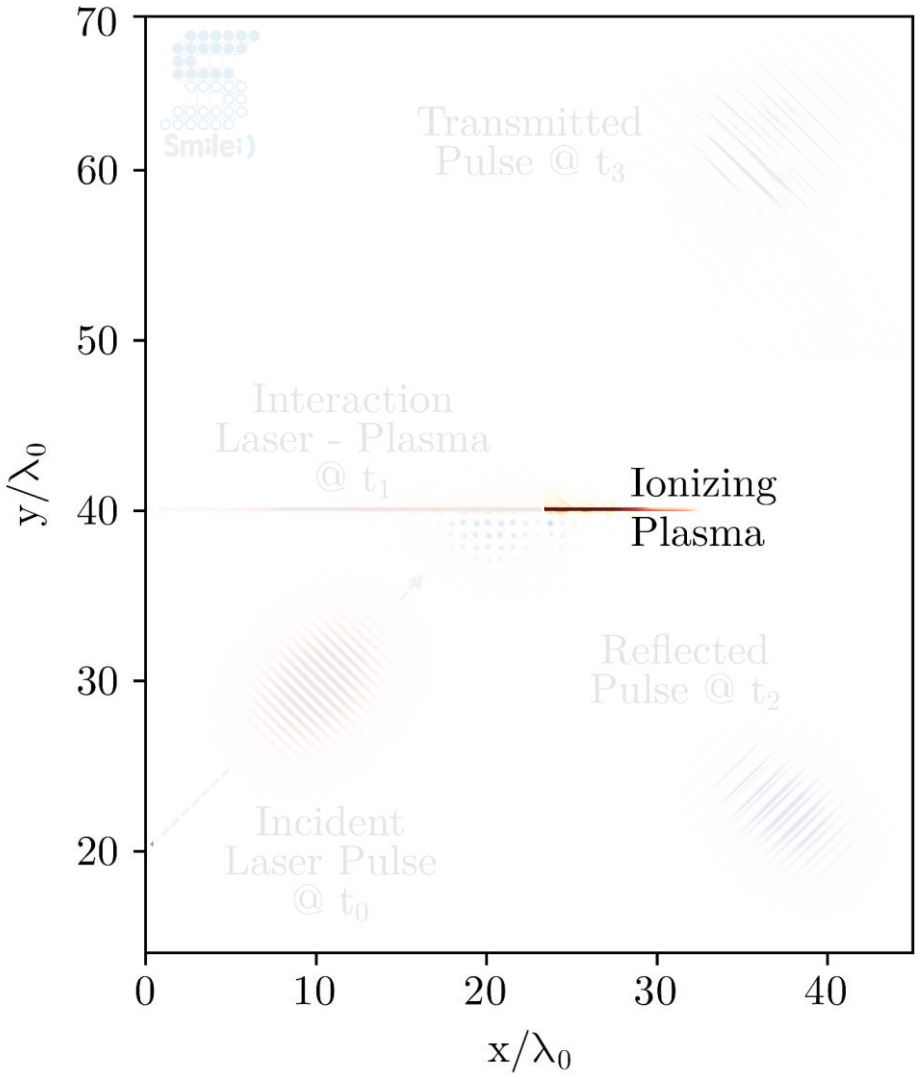
Box Presentation : Species()




```
Species(
        name                                    = "carbon",
        particles_per_cell                      = 25,
        atomic_number                           = 6,
        mass                                    = 12.*1836.0,
        charge                                  = 0.0,
        number_density                          = density_carbon,
        position_initialization                 = "random",
        momentum_initialization                 = "cold",
        time_frozen                             = 0.*t0,
        # temperature                           = [1e-12*T_keV],
        # thermal_boundary_temperature          = [1e-12*T_keV],
        # mean_velocity                         = [0., 0., 0.],
        # thermal_boundary_velocity             = [0., 0., 0.],
        ionization_model                        = "tunnel",
        ionization_electrons                    = "eon",
        boundary_conditions                     = [
                                                    ['remove','remove'],
                                                    ['remove','remove']
                                                  ]
)
```

Harmonics Generation on Thin Target

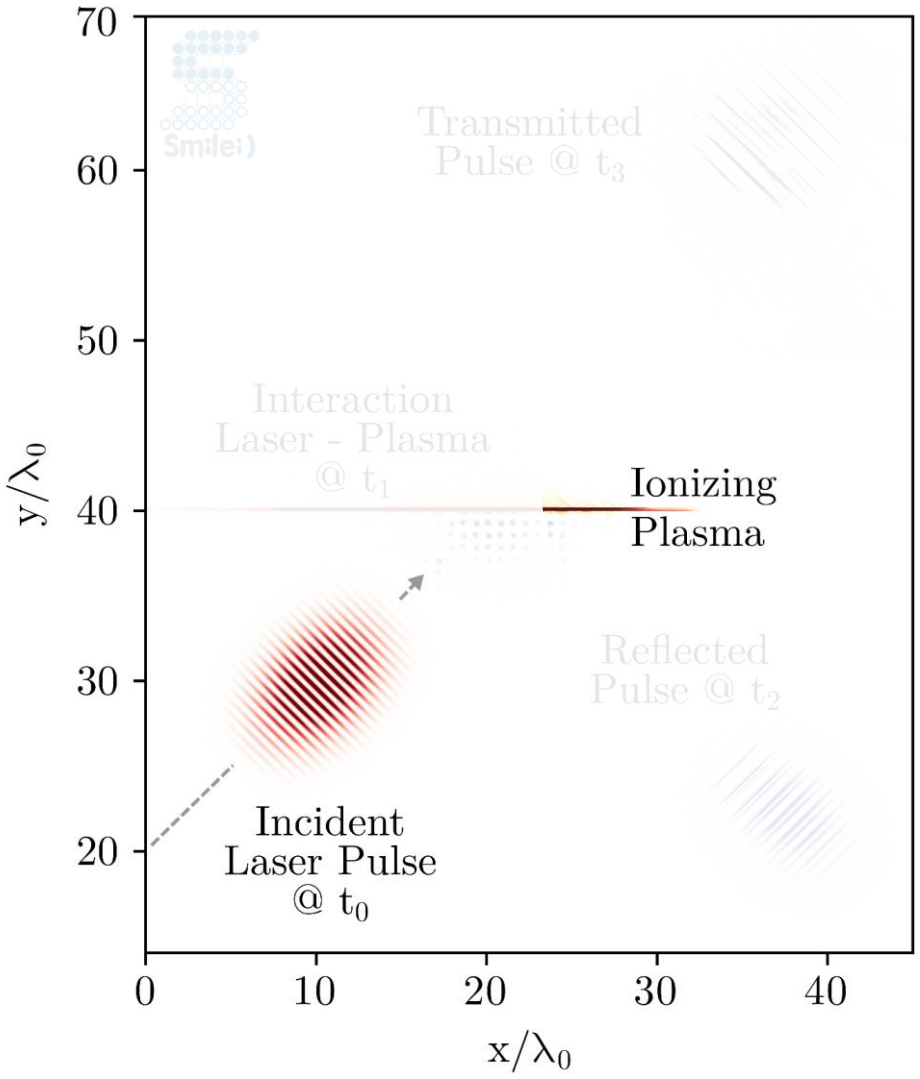
Box Presentation : Species()




```
Species(
        name                                = "eon",
        particles_per_cell                  = 0,
        mass                                = +1,
        charge                              = -1,
        number_density                      = 0,
        position_initialization             = "random",
        momentum_initialization             = "cold",
        time_frozen                         = 0.*t0,
        # temperature                       = [1e-12*T_keV],
        # thermal_boundary_temperature      = [1e-12*T_keV],
        # mean_velocity                     = [0., 0., 0.],
        # thermal_boundary_velocity         = [0., 0., 0.],
        boundary_conditions                 = [
                                              ['remove','remove'],
                                              ['remove','remove']
                                            ]
)
```

Harmonics Generation on Thin Target

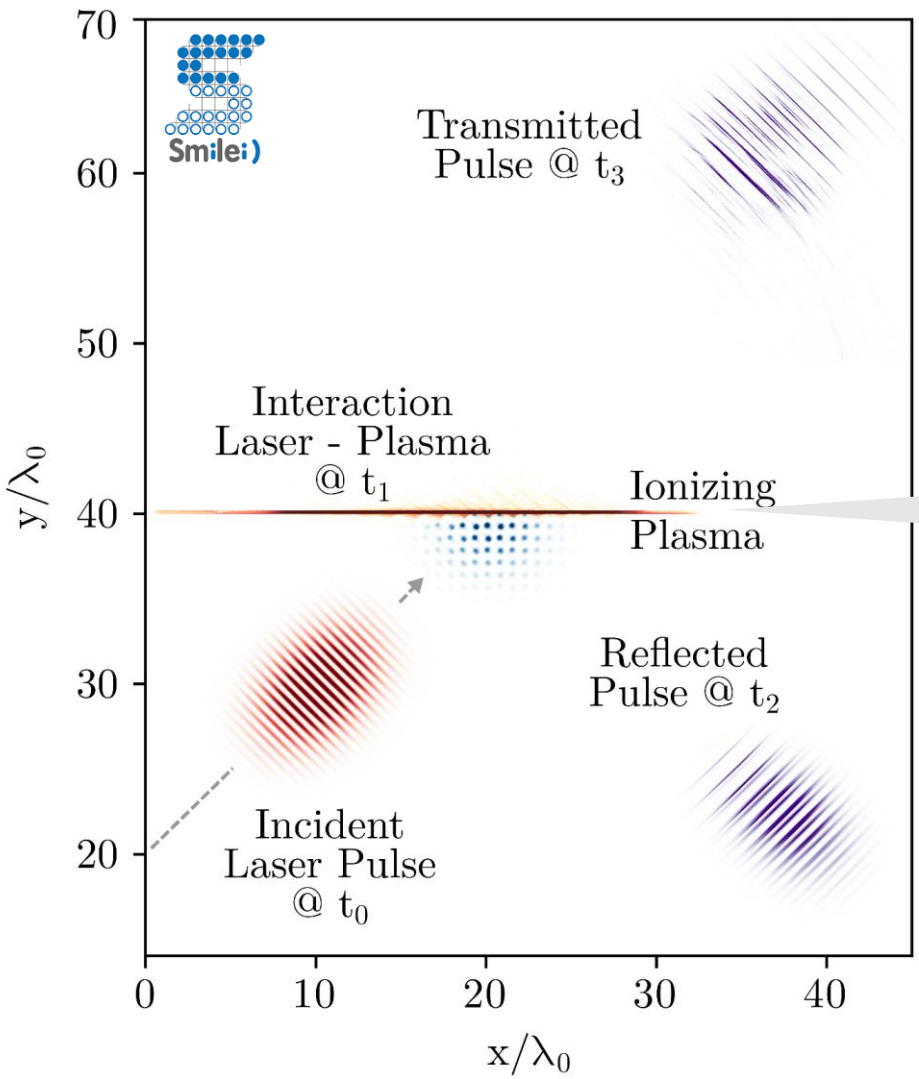
Box Presentation : Lasers()

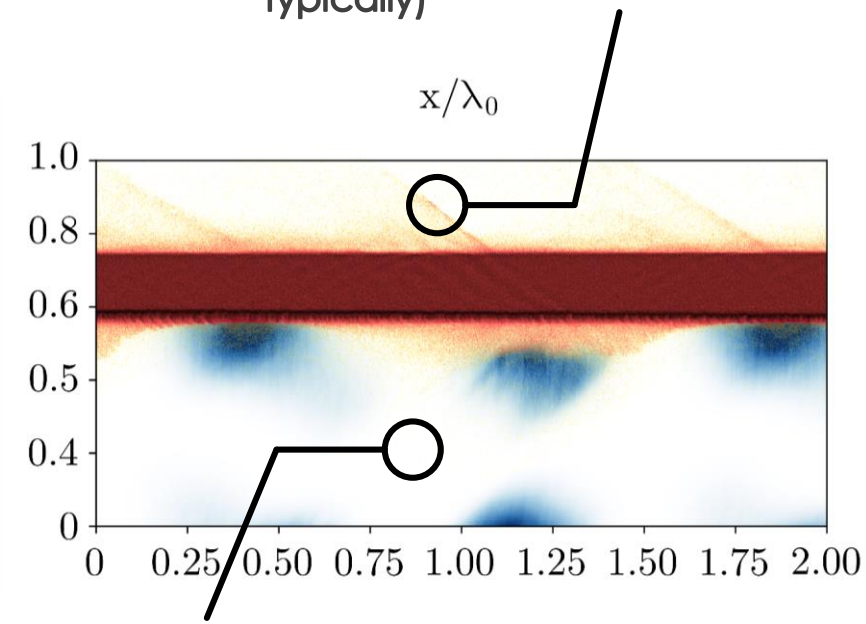



```
tcos1 = tcosine(
        base        = 0.,
        amplitude   = 1.,
        start       = 20.*t0,
        phi         = 2*m.pi/4.,
        duration    = 20*t0,
        freq        = 2*m.pi/(40.*t0)
)

tcos2 = lambda x : tcos1(x)**2

Lasers(
        box_side            = "xmin",
        a0                  = aL,
        omega               = 2*m.pi/l0,
        focus               = [20.*l0, 40.*l0],
        waist               = 4.*l0,
        incidence_angle     = 45.*m.pi/180.,
        time_envelope       = tcos2
)
```

Harmonics Generation on Thin Target

Diagnostics





Bunches of electrons with high kinetic energy (~ 5-10 MeV typically)

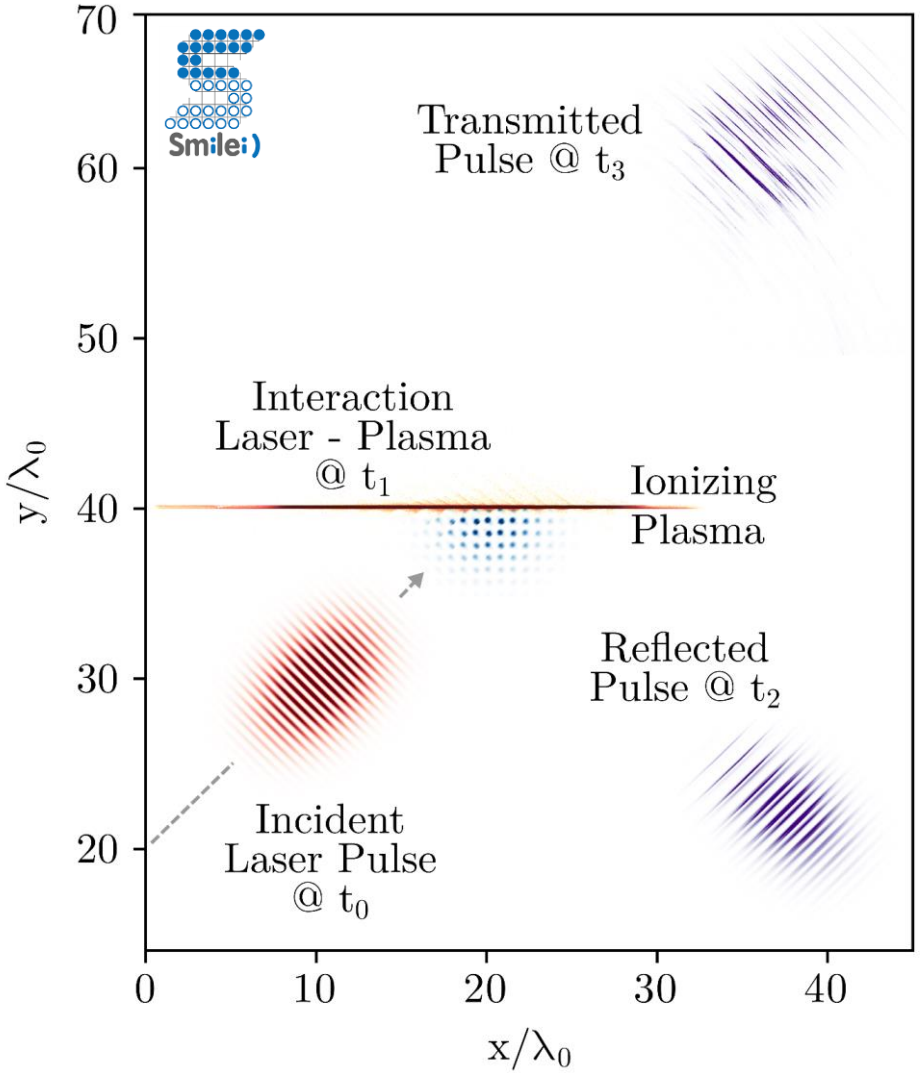
Interference Patern where electrons mooves and radiates

Diagnostics
"Because I'm happi..." [Pharell Williams]

```
# Don’t worry be happi
import happi

s = happi.Open(‘/my_path/smilei/simulation/’)

# List of diagnostics "Particles Binning"
s.ParticleBinning()

# Times extraction
times = s.ParticleBinning(3).times

xpy = s.ParticleBinning(1,data_log=True,timesteps=44000)
ypy = s.ParticleBinning(3,data_log=True,timesteps=44000)

xpy.plot(figure='xpy_phaseSpace')
ypy.plot(figure='ypy_phaseSpace’)

tpy = s.Particle(1,data_log=True,subset={'x’:[122.,136.,1]})

...
```

Harmonics Generation on Thin Target

Diagnostics Scalars & Fields
« Is my simulation ok ? »



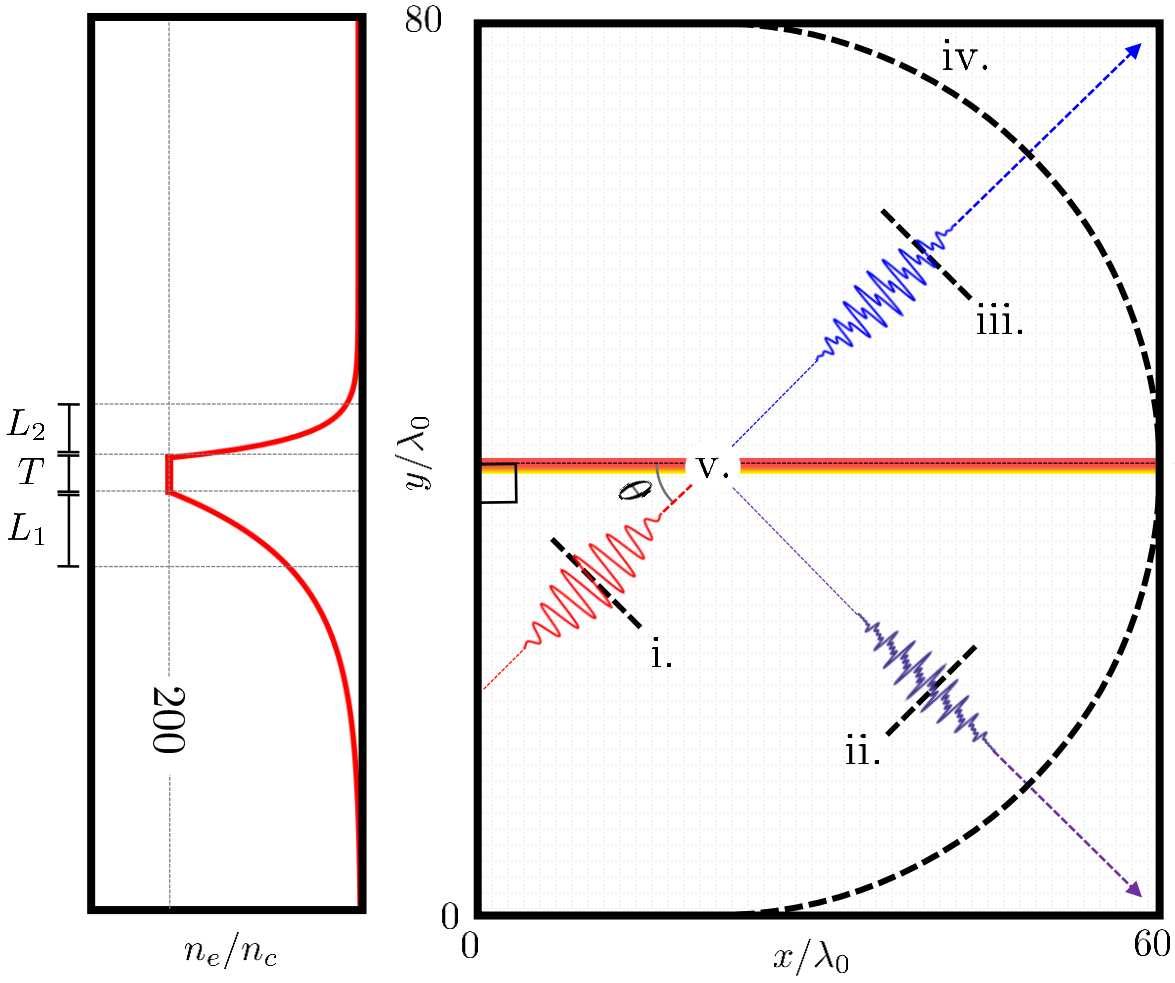

```
DiagScalar(
        every     = int(2*rest),
        vars      = ["Utot", "Ukin", "Uelm", "Ubal", "Ukin_bnd"]
)
```

```
DiagFields(
        every     = [T1,int(150.*rest)],
        fields    = ['Rho_eon','Bz','Ex','Ey']
)
```

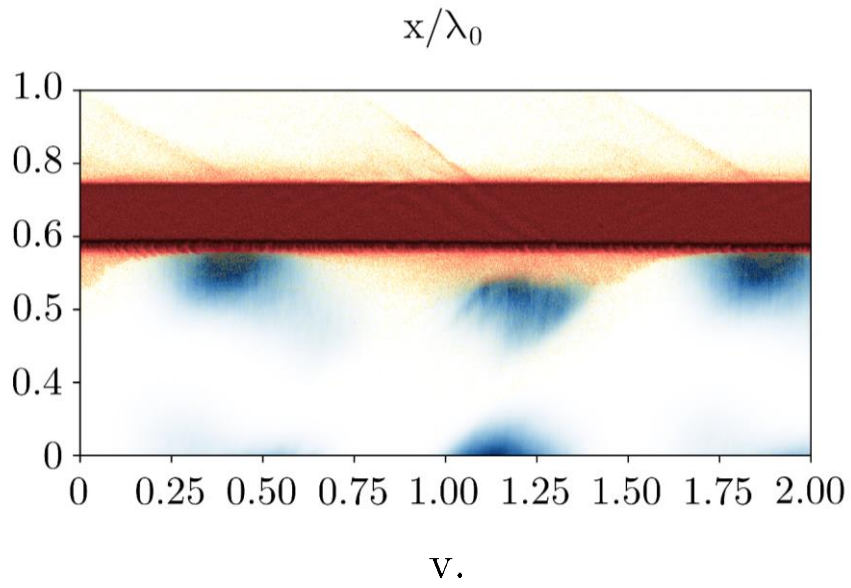
Harmonics Generation on Thin Target

Box Presentation : More Diagnostics…

« Experiments Like » Diagnostics

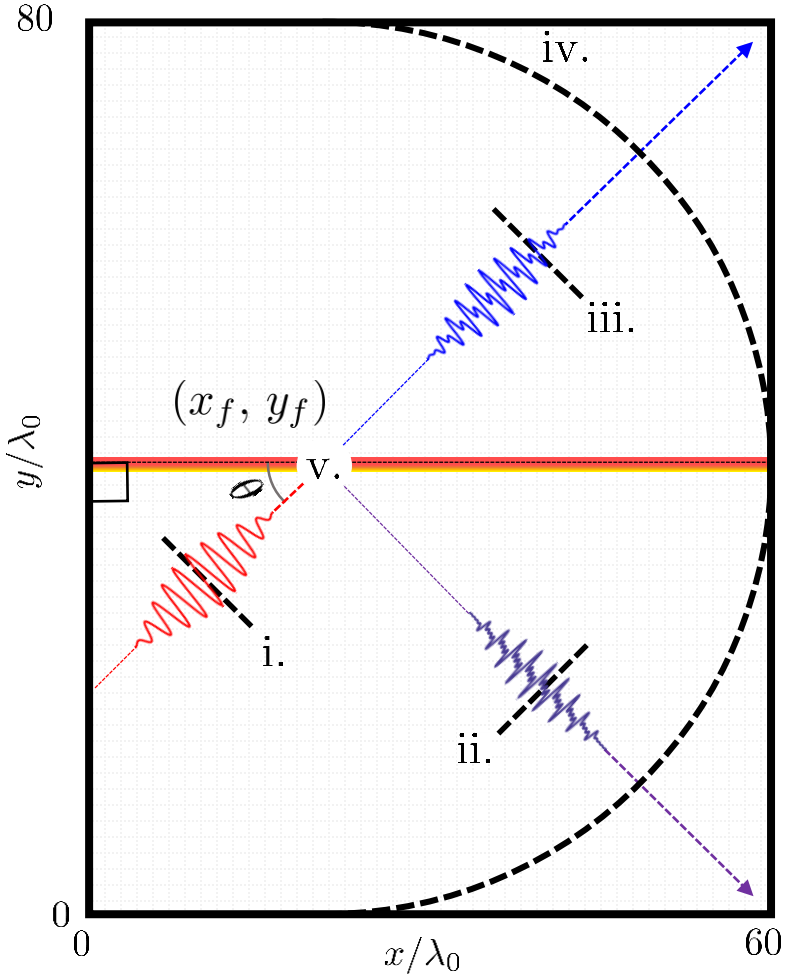


NOT « Experiments Like » Diagnostics Or « God View »



Harmonics Generation on Thin Target

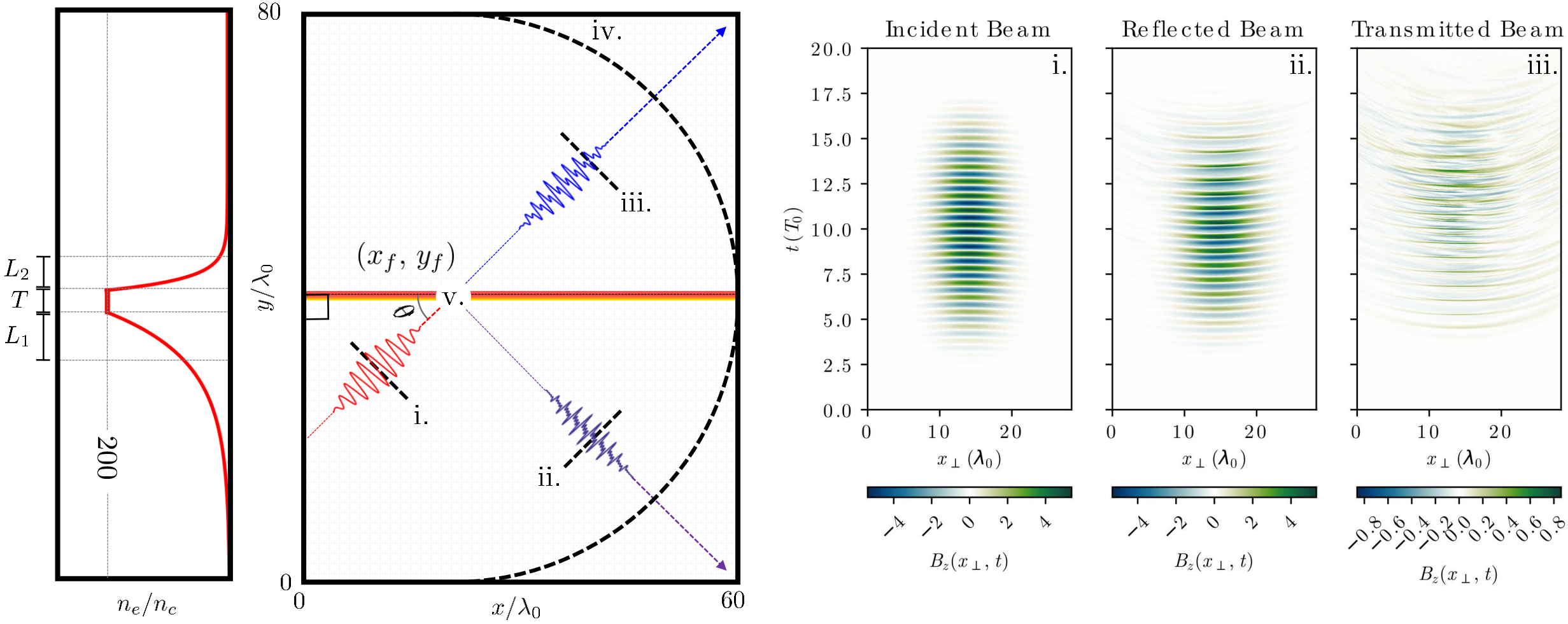
« Experiment Like » Diags : Probe 1D




```
DiagProbe(
        every           = [T1-int(12.5*rest),T1+int(12.5*rest),1],
        flush_every     = [T1-int(12.5*rest),T1+int(12.5*rest),1000],
        origin          = [00.0*l0,40.0*l0],
        vectors         = [
                            [+20.0*l0,-20.0*l0]
                          ],
        number          = [int(m.sqrt(2)*20.0*resx)],
        fields          = ["Bz"]
)
```

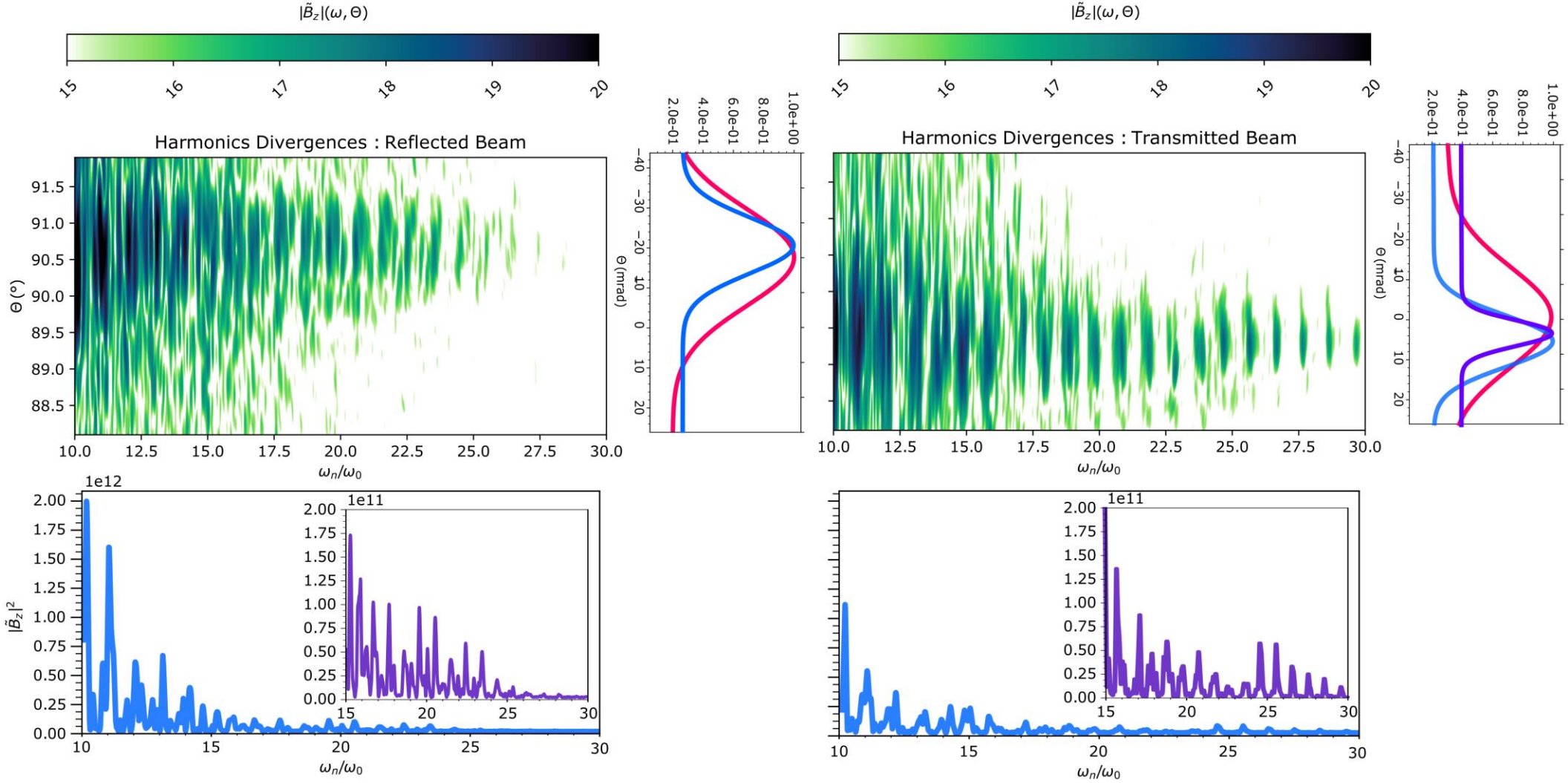
Harmonics Generation on Thin Target

« Experiment Like » Diags : Probe 1D



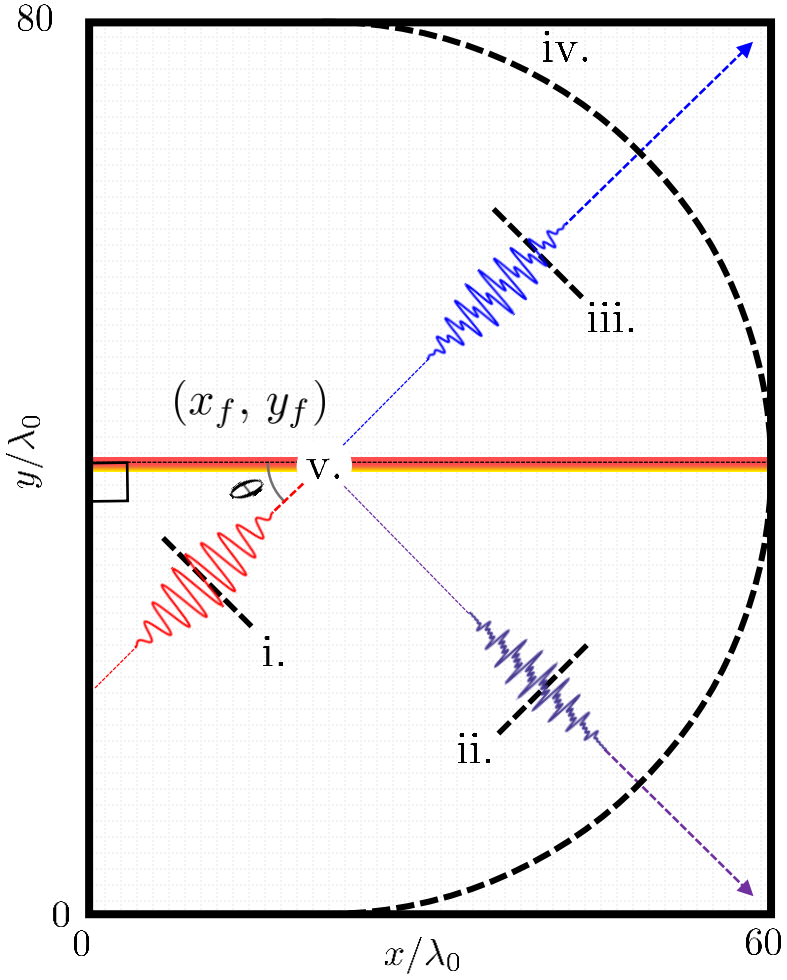
Harmonics Generation on Thin Target

« Experiment Like » Diags : Probe 1D



Harmonics Generation on Thin Target

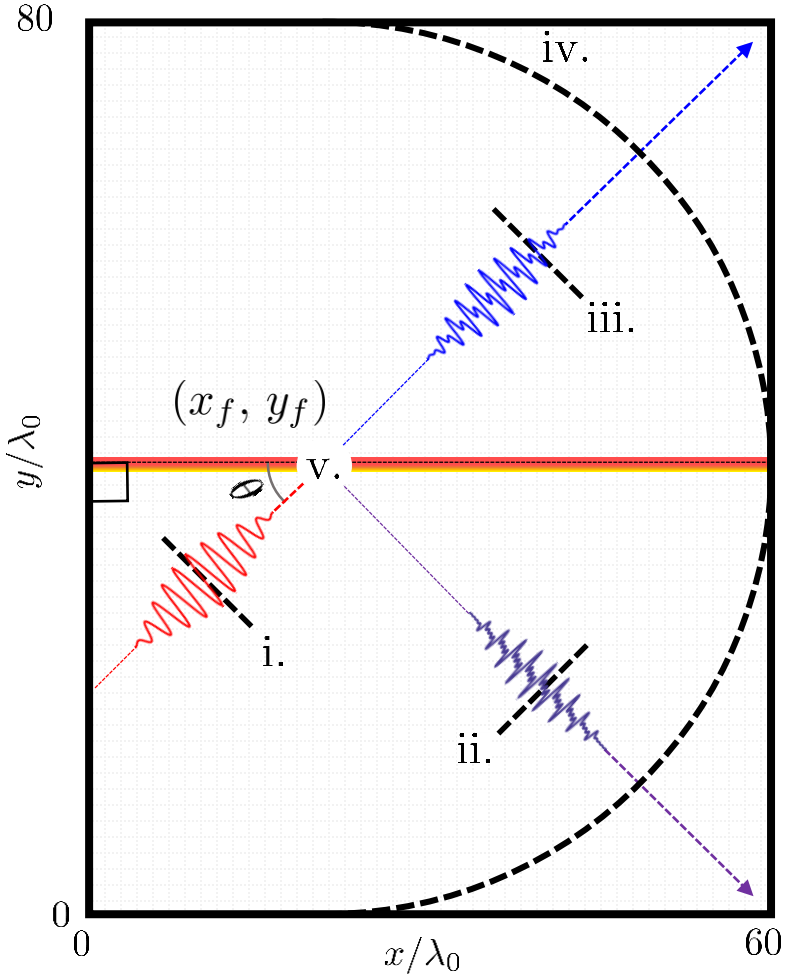
« Experiment Like » Diags : Screen

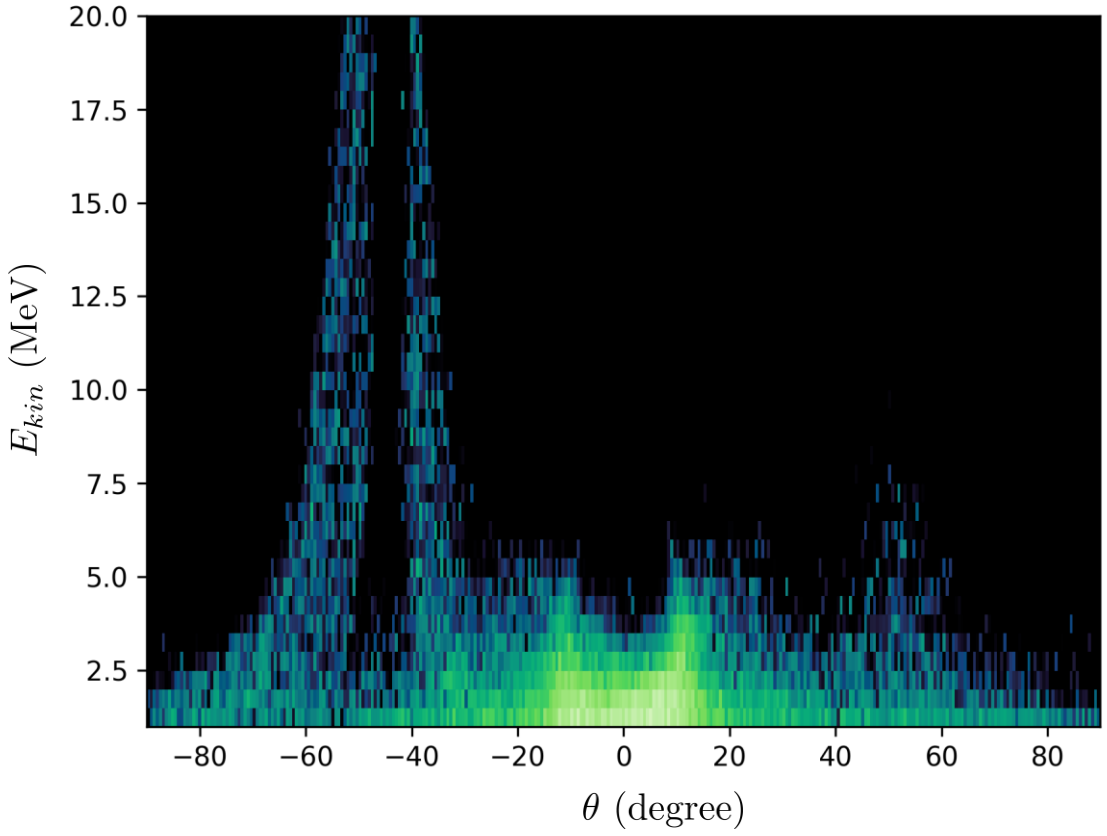



```
DiagScreen(
        every     = [int(118.*rest),int(150.*rest)],
        shape     = "sphere",
        point     = [20.*l0, 40.*l0],
        vector    = [40.*l0, 0.*l0],
        direction = "forward",
        output    = "weight",
        species   = ["eon"],
        axes      = [
                     ["ekin" , 2.,  40.,    38],
                     ["vx"   , -1,  +1,  2000],
                     ["vy"   , -1,  +1,  2000]
                    ]
)
```

Harmonics Generation on Thin Target

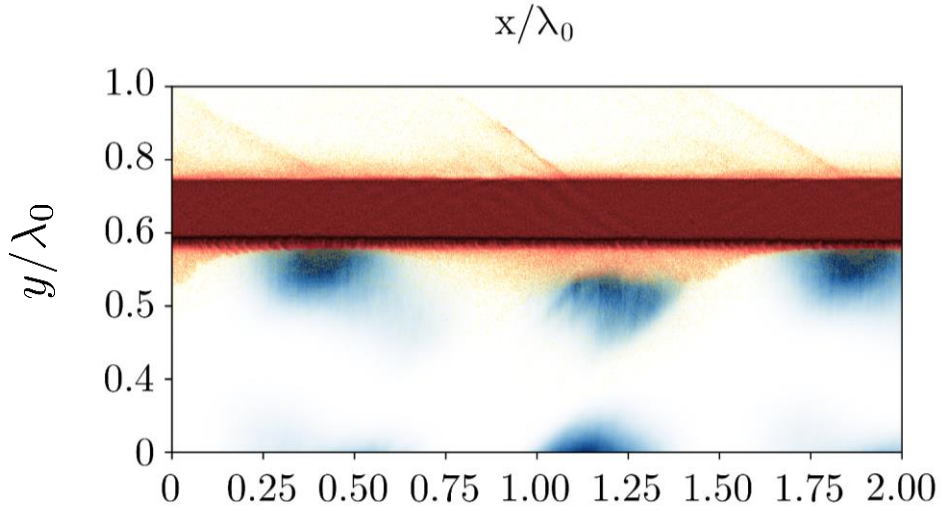
« Experiment Like » Diags : Screen





Harmonics Generation on Thin Target

NOT « Experiment Like » Diags : Probe 2D & Particle Binning

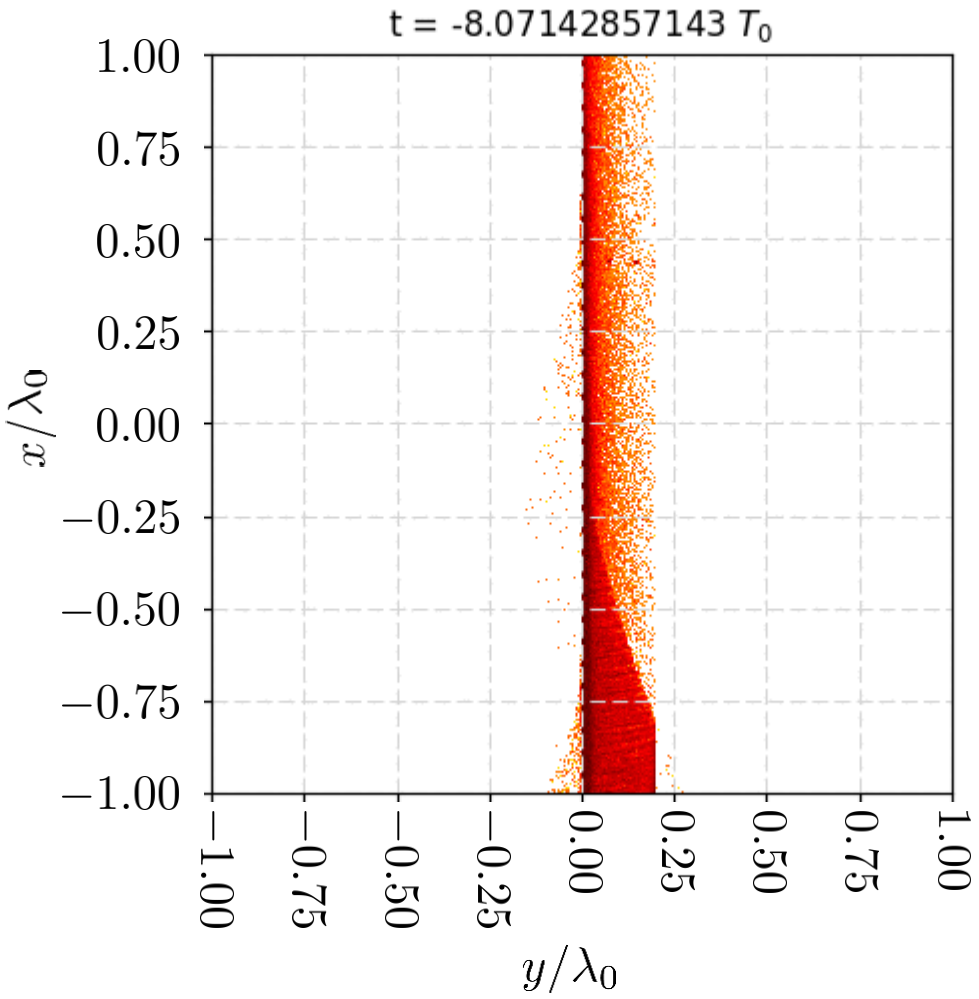


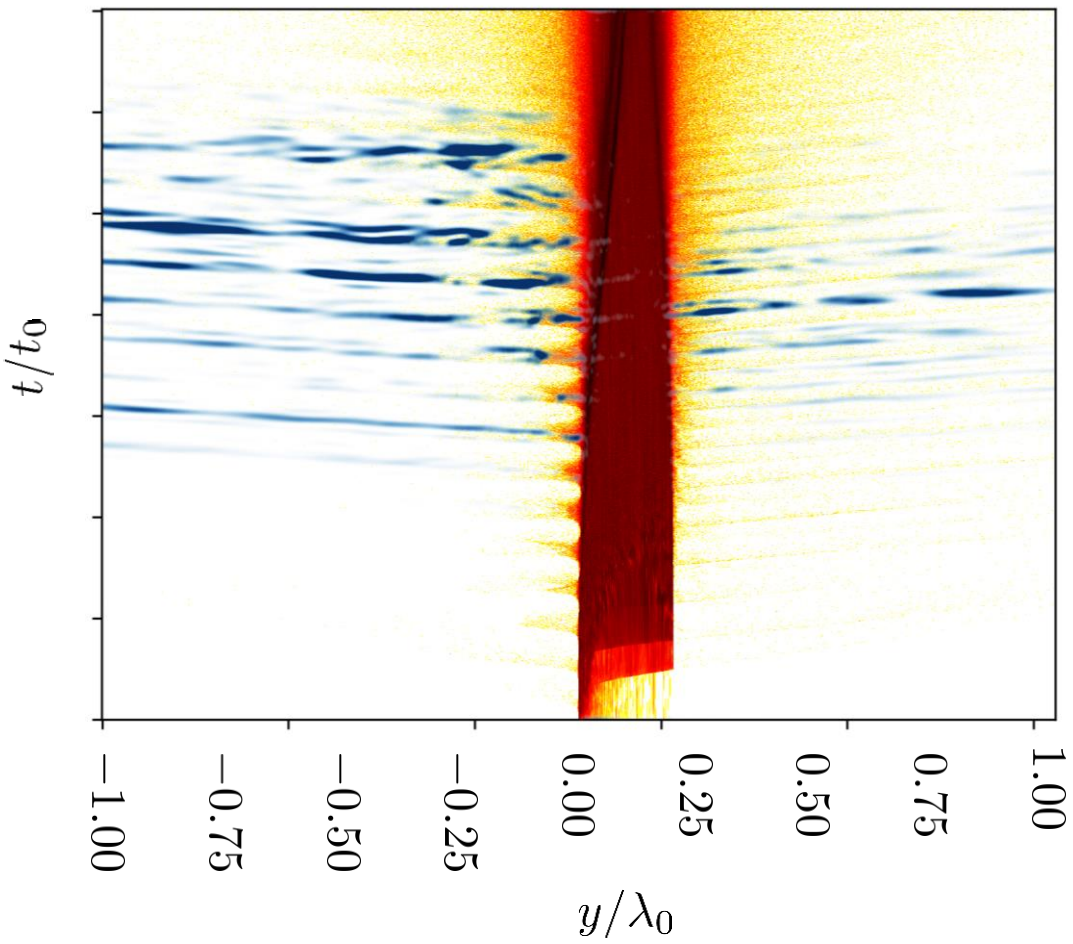

```
DiagParticleBinning(
        deposited_quantity      = "weight",
        every                   = [T1+int(5.*rest),T3-int(5.*rest),2],
        flush_every             = [T1+int(5.*rest),T3-int(5.*rest),1500],
        time_average            = 1,
        species                 = ["eon"],
        axes                    = [
                                    ["x",  018.0*l0,  022.0*l0, int(4.*resx/1.)],
                                    ["y",  038.0*l0,  042.0*l0, int(4.*resy/1.)]
                                  ]
)
```

```
DiagProbe(
        every                   = [T1+int(5.*rest),T3-int(5.*rest),2],
        flush_every             = [T1+int(5.*rest),T3-int(5.*rest),1500],
        origin                  = [18.0*l0,38.0*l0],
        vectors                 = [
                                    [04.0*l0,0.],
                                    [0.,04.0*l0]
                                  ],
        number                  = [int(4.*resx/1.),int(4.*resy/1.)],
        fields                  = ["Bz","Ex","Ey"]
)
```

Harmonics Generation on Thin Target

NOT « Experiment Like » Diags : Probe 2D & Particle Binning





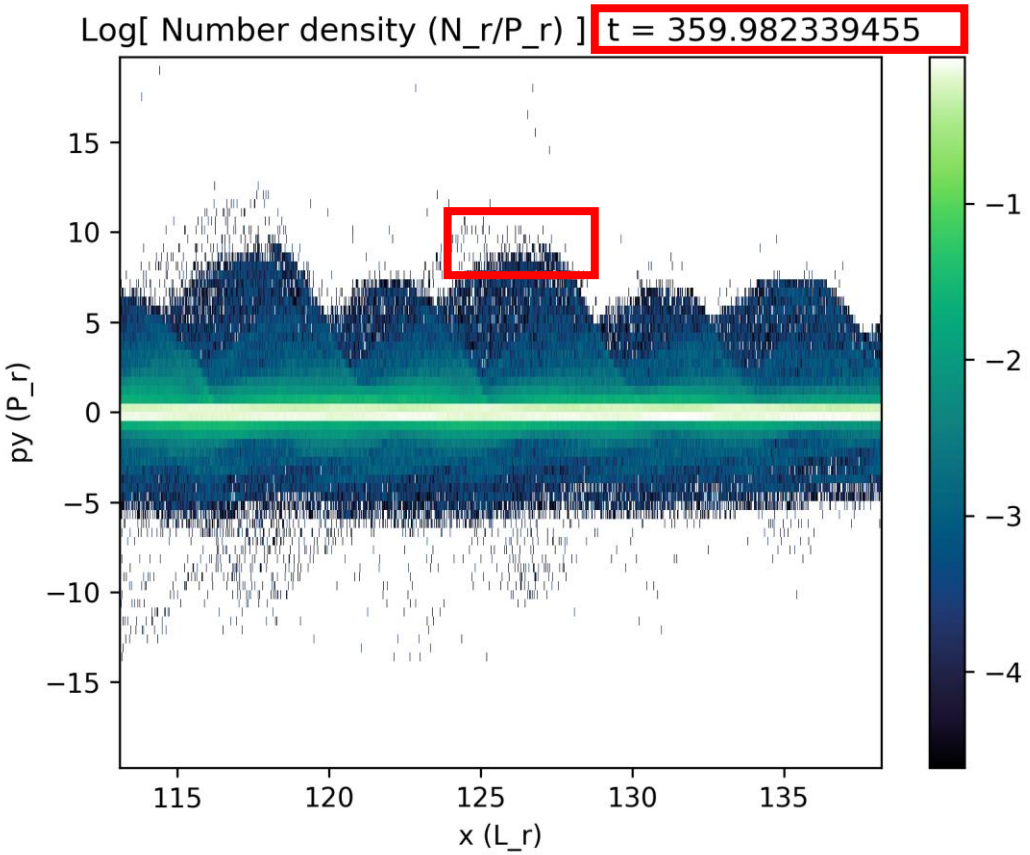
Harmonics Generation on Thin Target

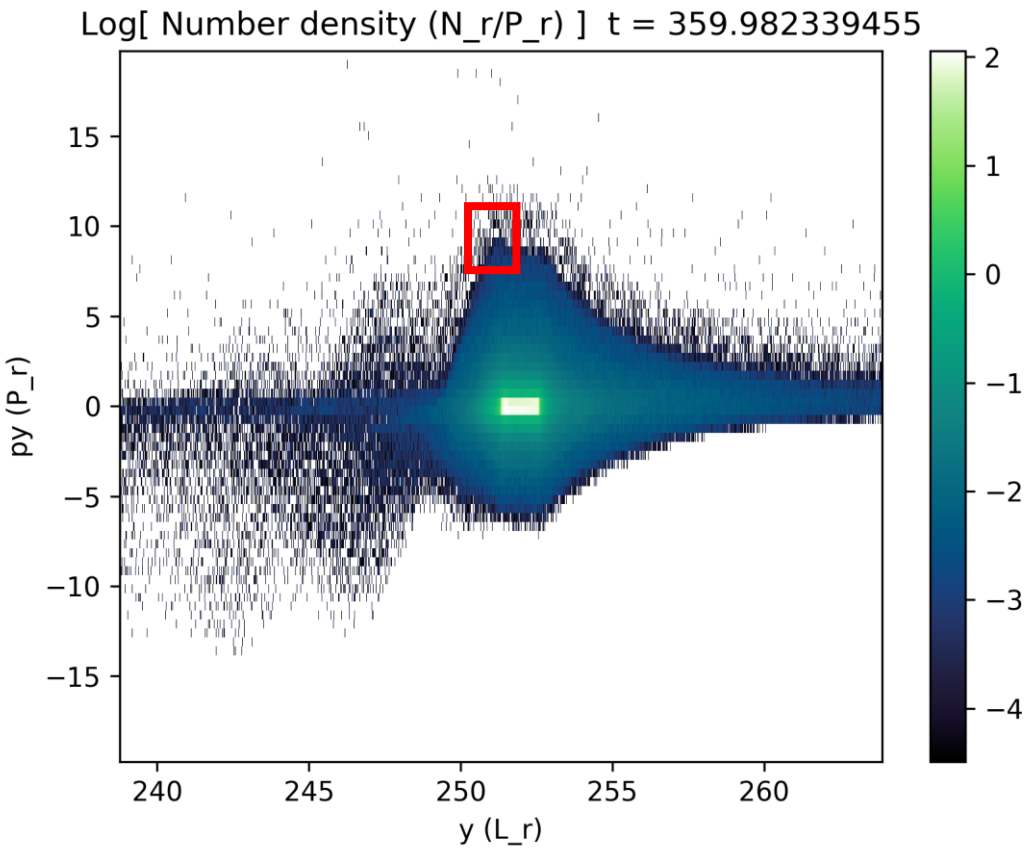
NOT « EXPERIMENT LIKE » DIAGS : TRACKS

```
def my_position_filter(particles) :

        ntot        = particles.id.size                     #  total number of particles
        n           = np.count_nonzero(particles.id)        # number of already filtered particles
        prob        = 0.1 - float(n)/ntot                   # 50% probability for chosen particles

        # Return True if Id>0 OR the particle is randomly chosen

        return (18.*l0<particles.x)*(particles.x<22.*l0)*((particles.id>0) + (np.random.rand(ntot)<prob))

DiagTrackParticles(
        species         = "eon",
        every           = [T1+int(5.*rest),T3-int(5.*rest),2],
        flush_every     = [T1+int(5.*rest),T3-int(5.*rest),1300],
        filter          = my_position_filter
)
```

Harmonics Generation on Thin Target

NOT « Experiment Like » Diags : Tracks





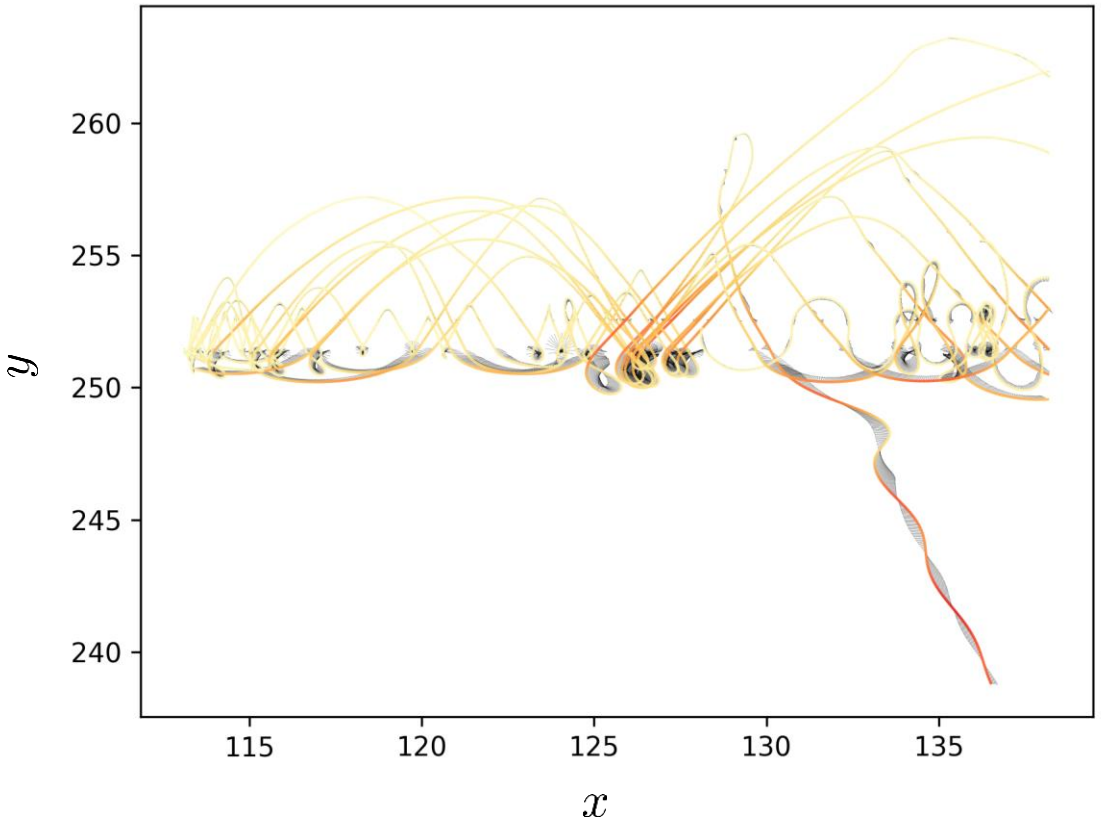
Harmonics Generation on Thin Target

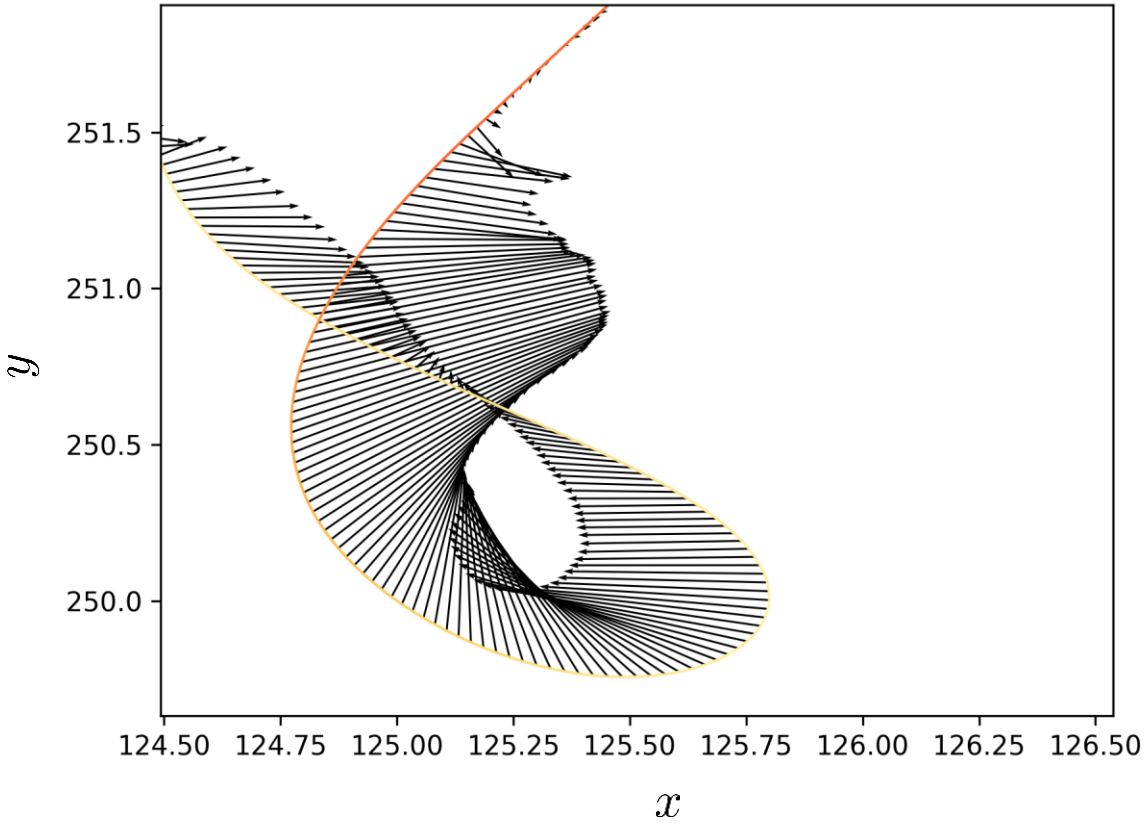
NOT « EXPERIMENT LIKE » DIAGS : TRACKS

```
# Particles Ordering & Filtering
# -----------------------------

# Time to take a coffee
s.TrackParticles(species='eon')

# With the help of Phase Spaces
my_selection ='any(t==44001,(124.5<x)*(x<128.5)*(250<y)*(y<252)*(5.<py)*(py<20.))'
Track = s.TrackParticles(species='eon',sort=True,axes=['x','y','px','py','pz','q','w'],select=my_selection)

# Time to take another coffee
Parts = Track.getData()
```

Harmonics Generation on Thin Target

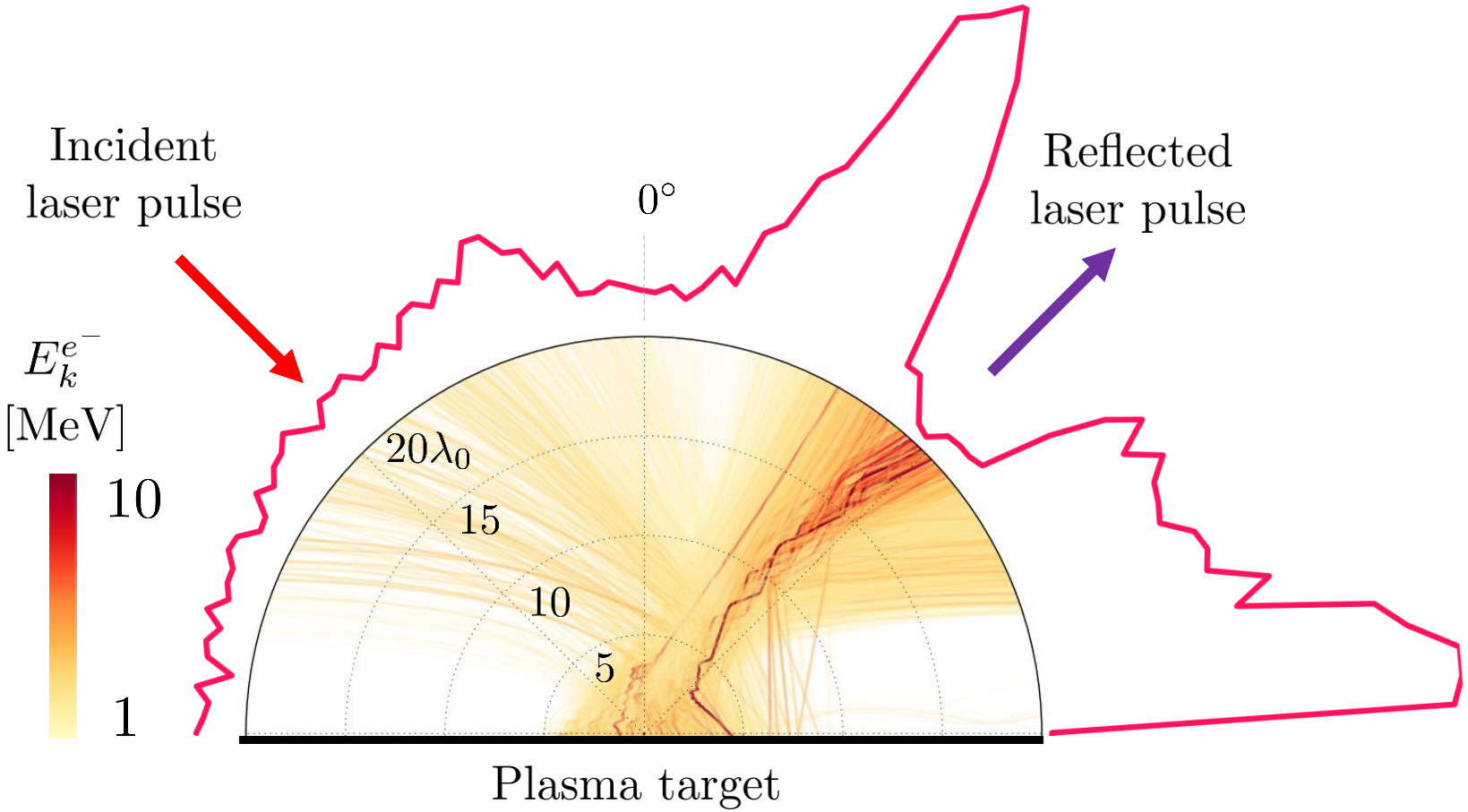
NOT « Experiment Like » Diags : Tracks





Harmonics Generation on Thin Target

An example of combination of Diags
Tracks + Screen



HHG on Thin Target with Smilei & Happi Capabilities

Harmonics generation on thin plasma target with the UHI 100 laser. Front and rear side generation of the target. Experiment by Ludovic Chopineau and Adrien Denoeud.

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CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE