Stepping Up Theoretical Investigations of Ultrashort and Intense Laser Pulses Interaction with Overdense Plasmas.

Combining Particle-in-Cell Simulations with Machine Learning & Big Data

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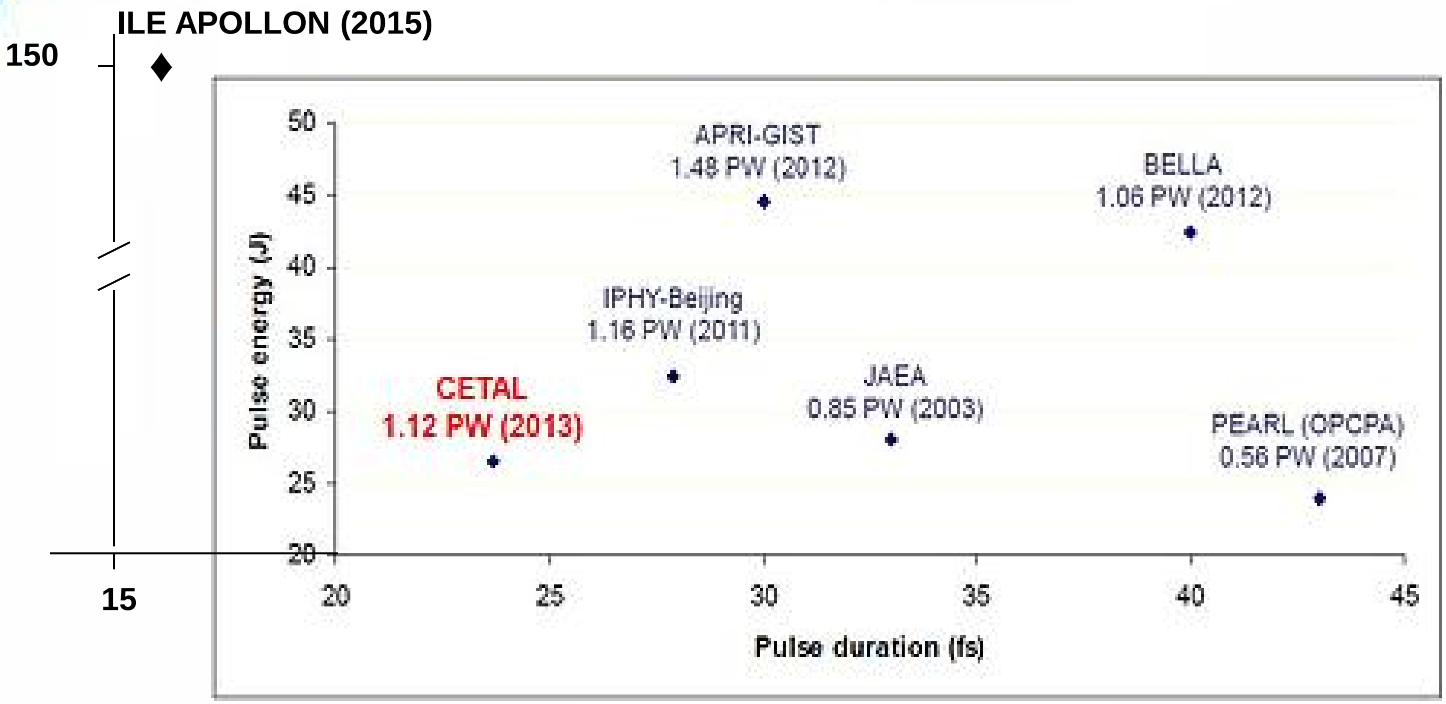
outline

- CONTEXT & MOTIVATION
- BIG DATA & ADVANCED ANALYTICS FOR LASER-PLASMA INTERACTION SCENARIOS.
- USING BIG DATA & MACHINE LEARNING FOR PREDICTIVE MODELLING OF HIGH HARMONICS GENERATION.
- CONCLUSIONS AND PERSPECTIVES

High Power Laser Projects- The Global Picture



• The availability of *fs* laser pulses opened opportunities for intense investigations of the rapidly heated matter in extreme conditions.

laser energy transfer to matter

• **Traditionally Modelled with:** Collisionless Vlasov, PIC, Hybrid Codes

• **PIC codes:**

- used in almost all areas of plasma physics, suitable for analyzing highly transient processes.
- they are the most intensive computational modelling tool employed in plasma physics
- have evolved towards improved performances, incorporating physics packages beyond the traditional method & taking advantage of the advent of HPC systems

• **PIC codes have evolved towards**

• Increased dimensionality
• Full-parallelization
• Fully-relativistic
• Incorporating new diagnostic capabilities
• Improved visualization packages
• Object Orientation
• Migration from Fortran to better performing languages

HOWEVER…

•Statistical noise
•Non-physical instabilities
•Non-conservation
•Numerical heating
•Require considerable computational resources

HOWEVER…

- There is experimental and simulation data already available in the literature

- The advent of cloud technology, Big Data & of platforms like Hadoop

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analyzing data is on the verge of becoming trivially inexpensive

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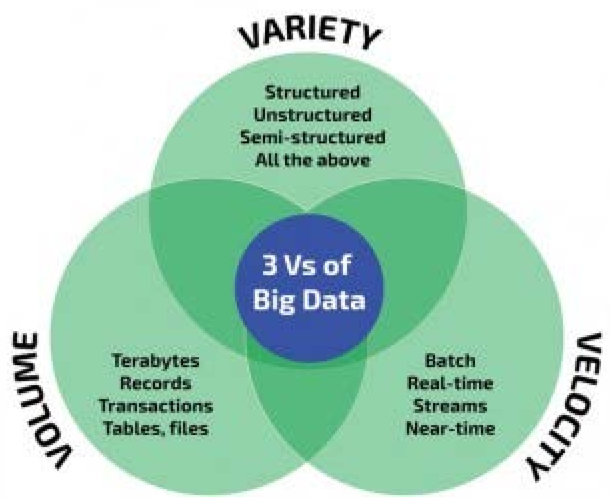
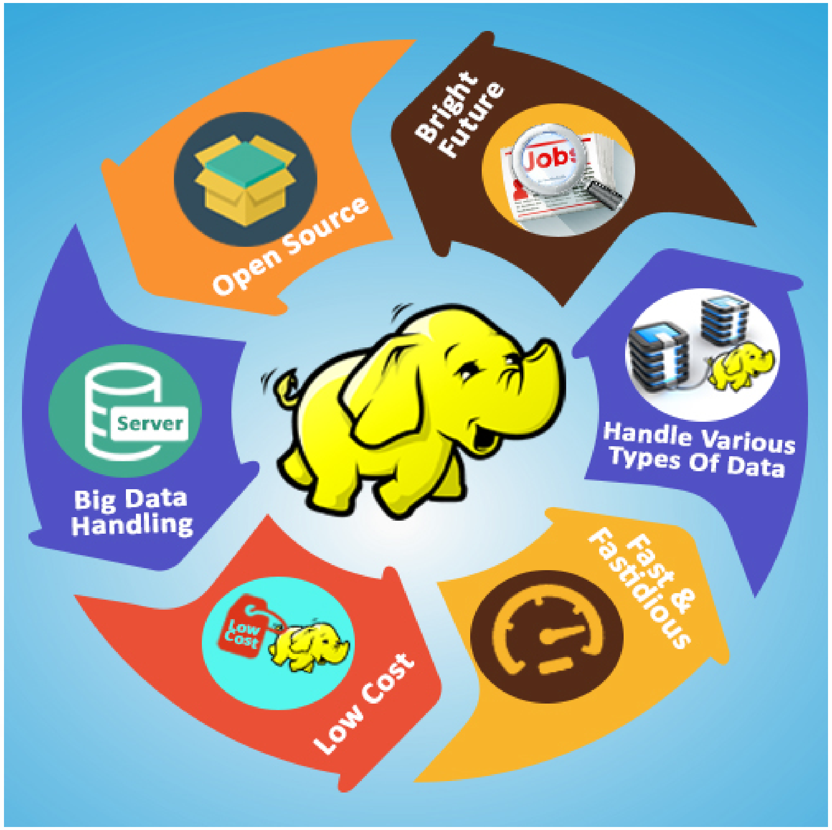
MACHINE LEARNING

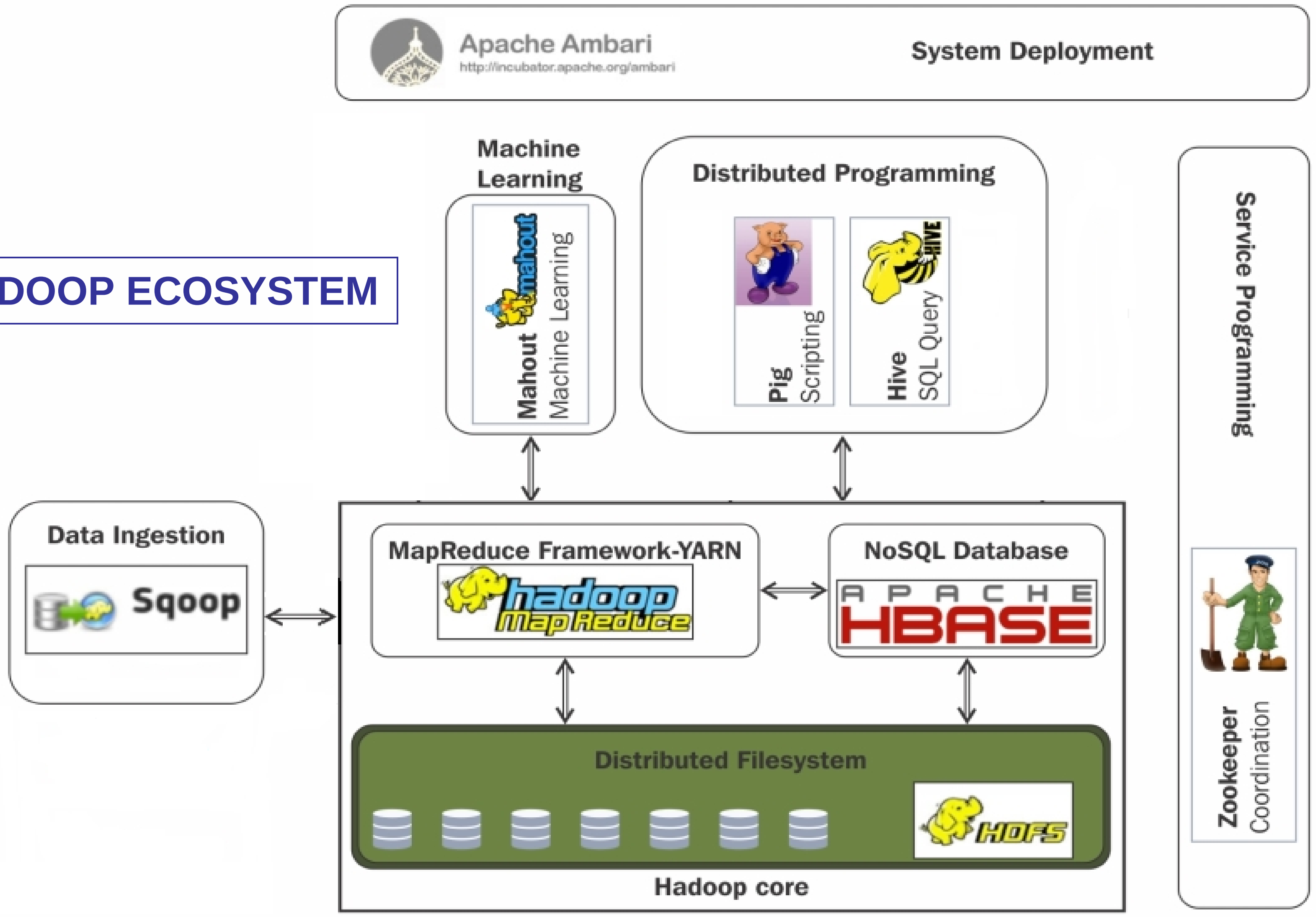
BIG DATA & ADVANCED ANALYTICS FOR LASER-PLASMA INTERACTION SCENARIOS.





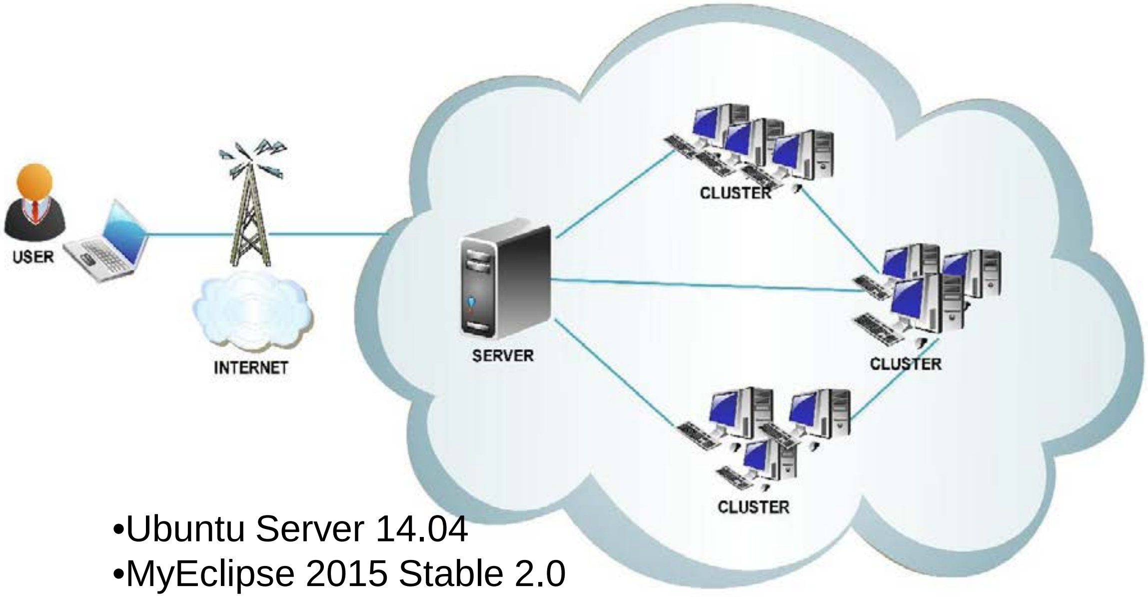
BIG DATA & ADVANCED ANALYTICS FOR LASER-PLASMA INTERACTION SCENARIOS.

HADOOP ECOSYSTEM



BIG DATA & ADVANCED ANALYTICS FOR LASER-PLASMA INTERACTION SCENARIOS.

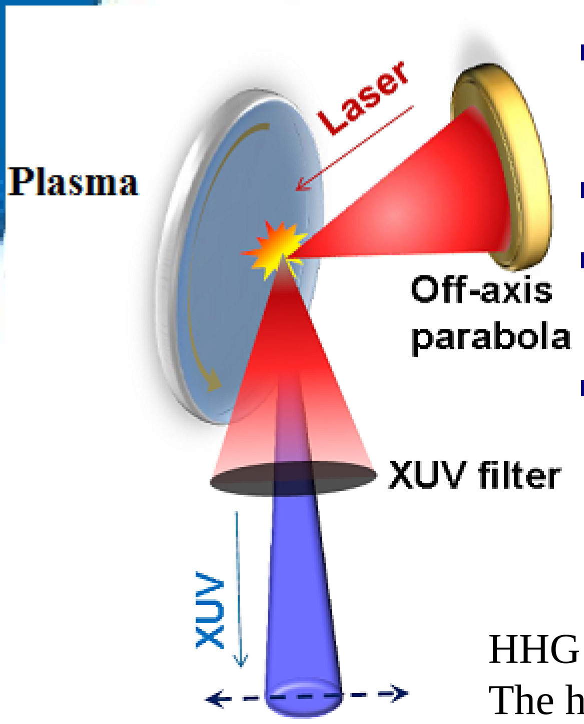
- Communication with users
- User requests
- Manipulation &Treatment of data
- Data Storage



- Ubuntu Server 14.04
- MyEclipse 2015 Stable 2.0
- Tomcat 8.0
- JDK 1.7.0_80
- Hadoop 2.6.0
- Hive 1.2.1

- 1QuadCore CPU
- HDD(500GB,6Gbps, 7200rpm,16MB cache)
- 1000Mbps connectivity card

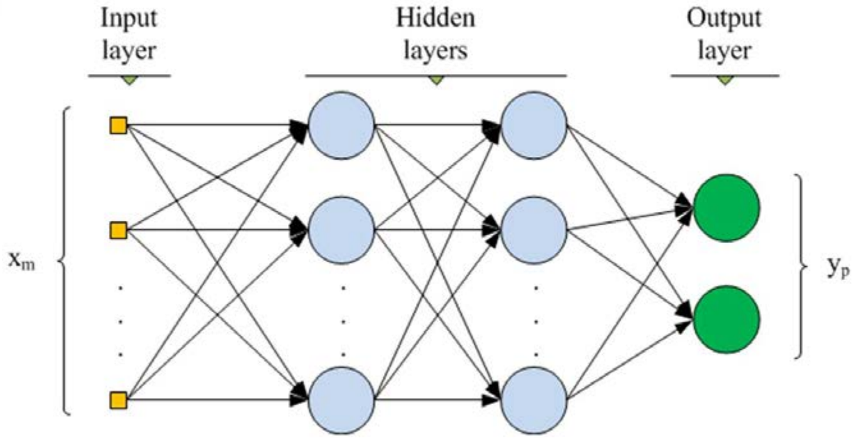
USING BIG DATA & MACHINE LEARNING FOR PREDICTIVE MODELLING OF HIGH HARMONICS GENERATION



- Higher conversion efficiency than HHG in gases
- Tunable source of XUV/Soft X rays, typically from 100 to 10 nm but even down to 3 nm
- No limitation on the intensity of the incident laser
- Better source from the coherence point of view
- HH exhibit a very tight angular confinement, sometimes with less divergence than that of the fundamental field and near Gaussian beam profiles

HHG is strongly influenced by the laser-plasma interaction itself.
The harmonics are a promising tool for obtaining info on plasma parameters such as the local electron density & on the presence of large electric and magnetic fields, plasma waves, and the electron transport inside the target.

I. Estimating the harmonics order for a particular laser-plasma interaction scenario



- **MLP**
- **Training set**

INPUT VECTOR: laser intensity, laser wavelength, pulse duration, polarization,incidence angle, type of plasma,initial plasma density

DESIRED OUTPUT: maximum observable harmonics order, intensity values for different harmonics, harmonic wavelength, harmonics duration, harmonic conversion efficiency

USING BIG DATA & MACHINE LEARNING FOR PREDICTIVE MODELLING OF HIGH HARMONICS GENERATION

- **MLP1 configuration:**

  INPUT LAYER: 8 Adaline neurons
  HIDDEN LAYERS: 2, all sigmoidal neurons,
  12 neurons in each layer.
  OUTPUT LAYER: 5 sigmoidal neurons

Batch training, Cost Function optimized with Steepest Descent

- **MLP2 configuration:**

  INPUT LAYER: 8 Adaline neurons
  HIDDEN LAYERS: 3, all sigmoidal neurons,
  10 neurons in each layer.
  OUTPUT LAYER: 5 sigmoidal neurons

Batch training, Cost Function optimized with Resilient BKP

USING BIG DATA & MACHINE LEARNING FOR PREDICTIVE MODELLING OF HIGH HARMONICS GENERATION

Laser: intensity $2 \cdot 10^{18} W/cm^2$

$\lambda = 800nm$

pulse duration $\tau = 150\ fs$

Incidence angle $\alpha = 45$

polarization p

Plasma

$n_e = 4n_c = 6.875 \cdot 10^{21} cm^{-3}$

	Highest Observable Harmonic				
	Max. Ord.	Intensity W/cm^2	Duration fs	Wavelength nm	Conv. Efficiency
Lit. Data [14]	50	$2 \cdot 10^{11}$	20	16	10^{-7}
PIC Data	58	$2.1 \cdot 10^{11}$	19	13.8	10^{-7}
MLP1	54	10^{11}	21	14.4	10^{-7}
MLP2	56	10^{11}	20	14.8	10^{-7}

II. Estimating electron temperatures within the plasma along with the corresponding fractions of electrons

- **MLP**
- **Training set**

INPUT VECTOR: laser intensity, laser wavelength, pulse duration, polarization,incidence angle, type of plasma, initial plasma density, initial electronic temperature

DESIRED OUTPUT: electron temperatures, corresponding fractions of electrons that have these temperatures, corresponding time moments

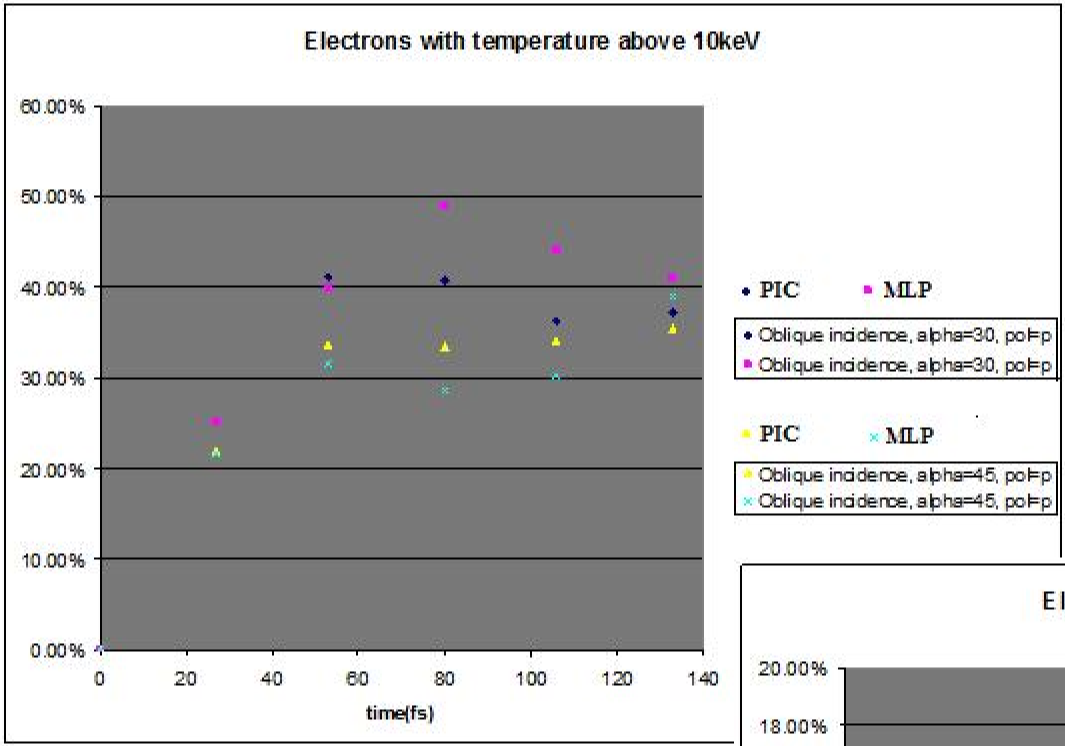
- **MLP1 configuration:**

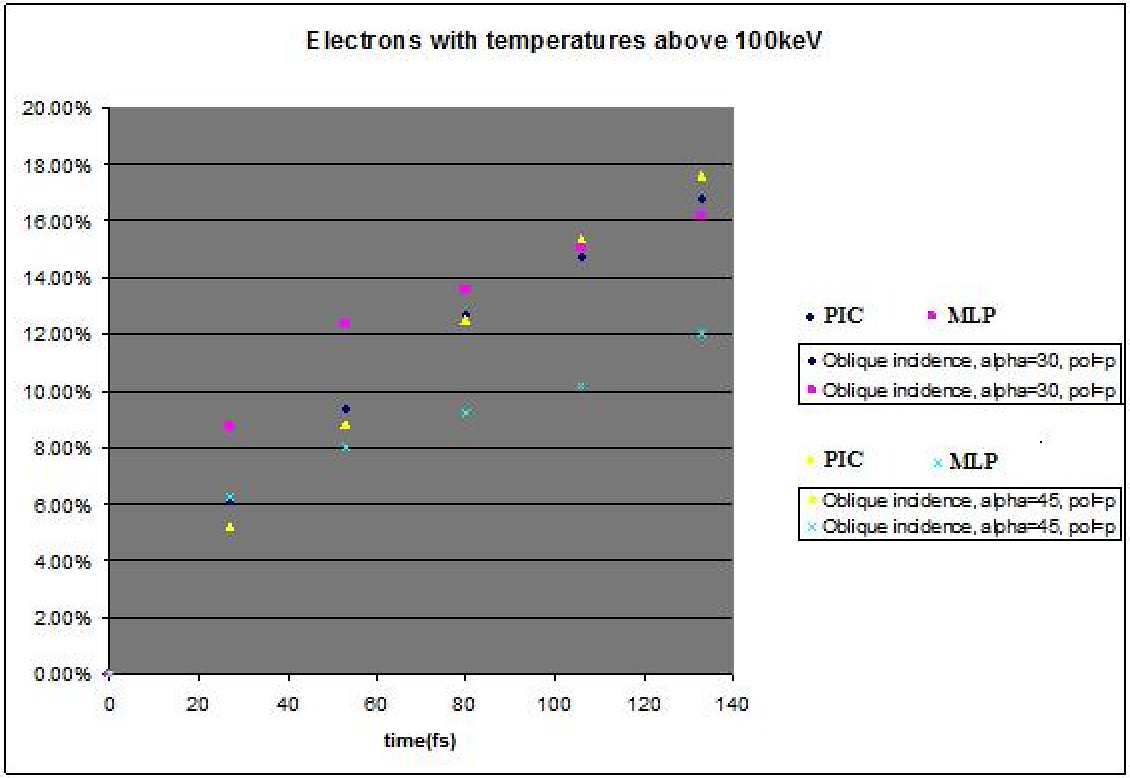
INPUT LAYER: 9 Adaline neurons

HIDDEN LAYERS: 2, all sigmoidal neurons, 11 neurons in each layer.

OUTPUT LAYER: 3 sigmoidal neurons

Incremental training, Cost Function optimized with Resilient BKP


Electrons with temperature above 10keV
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
0
20
40
60
80
100
120
140
time(fs)
PIC
MLP
Oblique incidence, alpha=30, pol=p
Oblique incidence, alpha=30, pol=p
PIC
MLP
Oblique incidence, alpha=45, pol=p
Oblique incidence, alpha=45, pol=p


Electrons with temperatures above 100keV
20.00%
18.00%
16.00%
14.00%
12.00%
10.00%
8.00%
6.00%
4.00%
2.00%
0.00%
0
20
40
60
80
100
120
140
time(fs)
PIC
MLP
Oblique incidence, alpha=30, pol=p
Oblique incidence, alpha=30, pol=p
PIC
MLP
Oblique incidence, alpha=45, pol=p
Oblique incidence, alpha=45, pol=p

CONCLUSIONS AND PERSPECTIVES

- An alternative to PIC and various plasma kinetics simulations

  - the goal is to have a predictor system

- Technologies like cloud, big data and machine learning have tremendous potential of shaping a new face to laser-plasma interaction simulations