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Design of High Gradient Laser Plasma Accelerating Structure (WP3) Update

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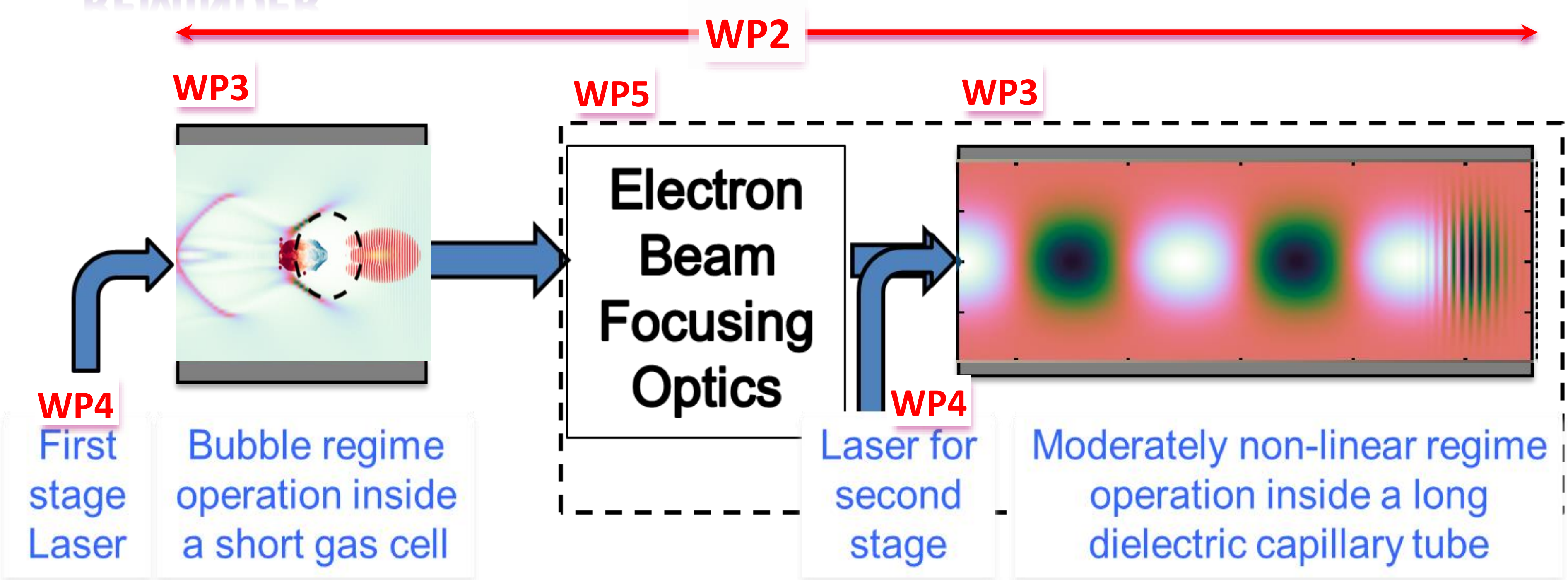
Overview and work repartition

Horizon 2020

REMINDER



- 1st stage: strong gain, 2nd stage: control, filtering and stability during acceleration
- Scientific and technical challenges related to stability and synchronisation

WP3 : all tasks completed

Task	Description	Milestone	Due Date	Status
3.2	**Design plasma structures** (injector & accelerator)	MS14	April 2017	**Completed**
3.3	**Design plasma chamber & environment** (beam coupling…)	MS20	october 2017	**Completed**
3.4	**Diagnostics** for plasma, wakefield and electron parameters	MS21	July 2018	**Completed**
3.5	**Staging plasma structures**	MS26	July 2018	**Completed**
All	**Final Delivery Report**	**D3.1**	October 2018	**Completed**

Task 3.2. Design plasma structures (injector & accelerator)
3.2.1: Define the regime of operation: Identify laser intensity, plasma density range and volume (effective acceleration length and transverse structure), repetition rate, …
3.2.2 : Plasma creation
3.2.3: Laser confinement
MS14: M3.1 REPORT Design for an electron injector and a laser plasma stage proposed,
Task 3.3: Design plasma structure
3.3.1 : Determine requirements for plasma structure along with beam combining
3.3.2 : Study specific tasks
3.3.2a : Laser focussing
3.3.2b: Laser plasma alignment and control
3.3.2c: Vacuum system (gas load, sputtering)
3.3.2d: Activation (chamber, local shielding)
3.3.2e: Laser beam removal from electron axis
MS20: M3.2 REPORT Design for interaction chambers proposed
Task 3.4: Diagnostics
3.4.1: plasma diagnostics
3.4.2: plasma wave diagnostics
3.4.3: diagnostics of electrons in the plasma
3.4.4: laser diagnostics around focus, in/out plasma
MS21: M3.3 REPORT Design for implementation of proposed diagnostics
Task 3.5: design multistage LPA
3.5.1: Designing succesive plasma structures, identifying scalability parameters
3.5.2: Laser plasma coupling
3.5.2a: Plasma mirrors
3.5.2b: other options
3.5.3: Engineering issues for stability, timing and overlap
MS26: M3.2 REPORT Design for multi-stage coupling proposed

Plasma target characteristics have been compared

Target type	Length mm	n_e value cm^{-3}	n_e tailoring	n_e stability	rep rate	life time
Gas jet	< 20 self-foc.	10^{18}	multiple jets	turbulent flow	10 Hz	> 24 h
Gas cell	> 1 self-foc.	10^{17} - 10^{19}	machining	gas feed dependent	10 Hz	laser quality dependent
Plasma channel HE	< 30 guiding	$(1-5) \times 10^{18}$ parabolic	similar to gas jet	laser quality dependent	10 Hz	>24h
Plasma channel discharge	$10-90$ guiding	5×10^{17} - 10^{19} parabolic	multiple gas feed	discharge dependent	10 Hz	laser quality dependent
Cap tube	10-1000 guiding	$(0-5) \times 10^{17}$ homogeneous	multiple gas feed	gas feed static	10 Hz	laser quality dependent

Main conclusions on plasma target determination

- Plasma stability and laser quality will determine the stability of the electron beam from LPI and LPA

- Gas cell most stable and suitable for density tailoring of short plasma (injector)
- Plasma channels more suitable for guiding in the QL regime (accelerator)

Targeted parameters for electron beam generated by LPI

- Energy 150 to 400 MeV, 1 GeV

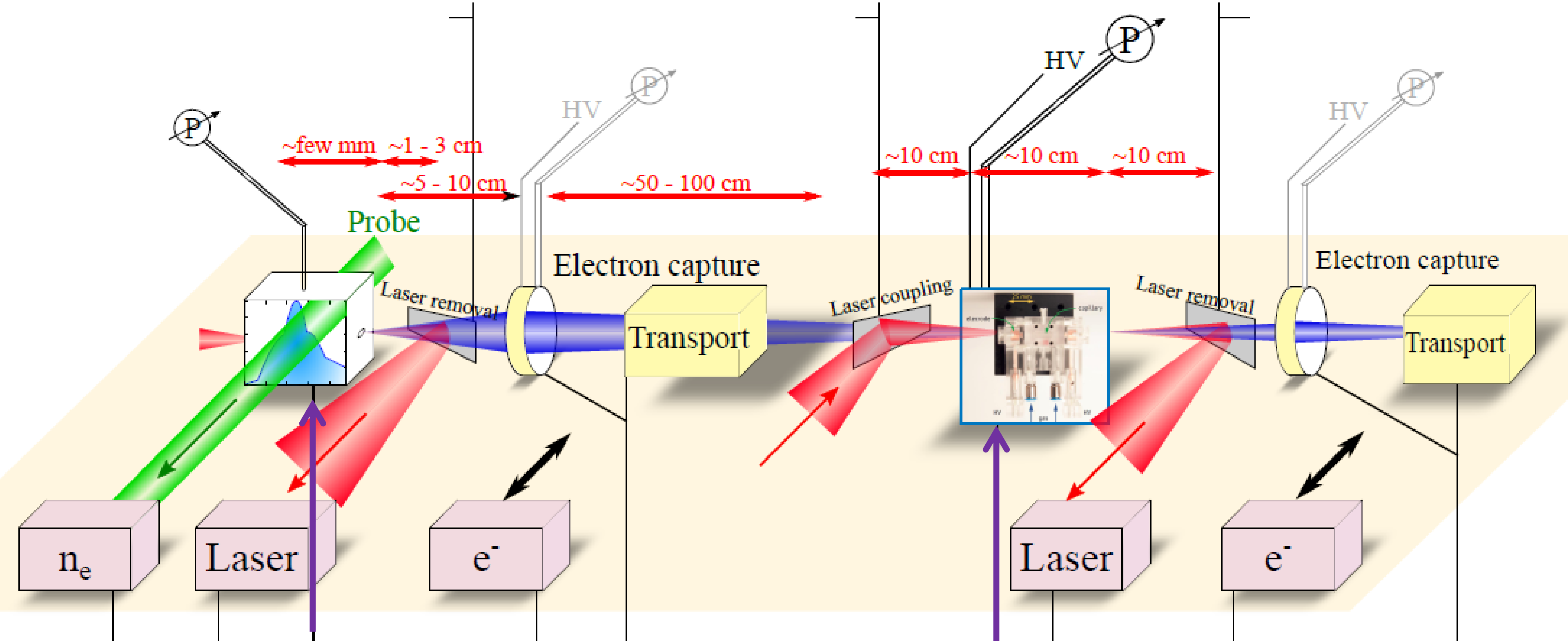
Symbol	Baseline	Range (Best $\rightarrow$ Acceptable)	
Q	100	$100 \rightarrow \geq 30$	[pC]
$\Delta E/E$	5%	$\leq 1\% \rightarrow 10\%$	
$\varepsilon_{\perp}$	1	$\leq 1 \rightarrow 10$	[mm.mrad]
τ	5	$3 \rightarrow 10$	[fs]
f	10	$100 \rightarrow 1$	[Hz]

LPI and LPA parameter range

- LPI similar for 150MeV to 400MeV, Gas cell
- LPI at 1GeV, guiding needed →channel
- LPA in QL regime, guiding needed
- Use of 2 stages allows for electron selection with transport system and beam shaping

Parameter	LPI 150MeV	LPI 400MeV	LPI 1GeV	LPA 5GeV
n_e [10^{18}cm^{-3}]	3 - 8	3 - 5	1 - 6	1 - 3
L_{plasma} [mm]	0.6 - 1.5	0.8 - 1.6	9 - 30	250 - 1000
L_{grad} [mm]	0.3 - 0.5	0.6 - 0.8	0.9 – 2.1	8.5 – 14.8
I_{max}[10^{18}cm^{-3}]	4 - 17	15 - 43	3.1 - 32	2 - 9
a_0	1.4 - 2.8	2.6 – 4.5	1.2 – 3.9	1 - 2

LPI + LPA conceptual design



LPI

1. **Gas cell**
2. Cap discharge
3. Gaz jet

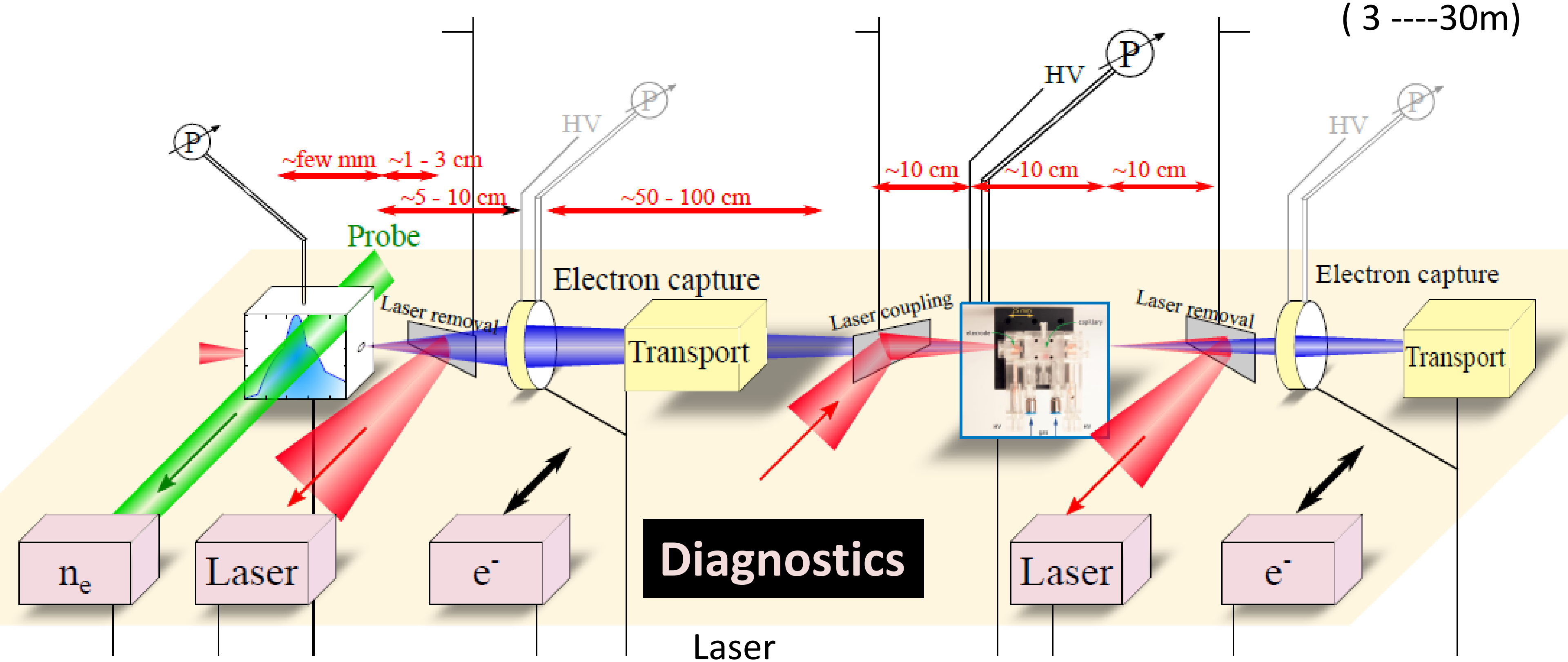
LPA

Plasma channel

Cap discharge / Laser generated

LPI + LPA conceptual design

Most compact option with plasma mirrors and lenses



Plasma Density Cavity (Ep)

Laser Energy Spectrum pointing

Electron parameters

Laser Energy Spectrum pointing

Plasma Density Cavity (Ep)

Laser Energy Spectrum pointing

Electron parameters

SAC recommendations for WP3

Horizon 2020

Rec9. *SAC recommends* ***decreasing this number [of configurations under investigation]*** *in the short term with appropriate metric and thereafter to perform tolerance studies for the main parameters.*

Rec 10*. SAC recommends detailed evaluation of* ***plasma & laser diagnostics****, laser beam/electron beam alignment and synchronization for the CDR.*

Rec11*. SAC recommends performing a* ***thermal study of the plasma cell*** *considering the significant increase of laser average power and to prototype the plasma cell according to final design for any activity following the design study.*

Rec 9:

LPI & LPA selected

Joint Exp in preparation for stability study of LPI

Rec 10: plasma diagnostics described MS Rep 3.4

Laser/e- alignt and synch : to do, interaction WP4 & 5 this week

Rec 11: to do

Need 10Hz facility for testing prototypes (current operation at 0.03 Hz)

Contributions to WP3

- **CNRS** : **B. Cros**, T Audet, G. Maynard P. Lee, F. Matthieu
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