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# Status of Beam Physics studies (WP2 et al.)

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"**Intense**" and "**exciting**" period:

**Connecting plasma acceleration stages to conventional transfer lines**

Because very... "**stressful**":

1. Can different people from different WPs and different institutes work closely together with necessary iterations?

**YES … but with some delay**

2. Will beam qualities, only just well for the moment, be strongly degraded when passing from a section to another?

**YES … but not every scheme has find out the solution**

# Restricted acceleration schemes

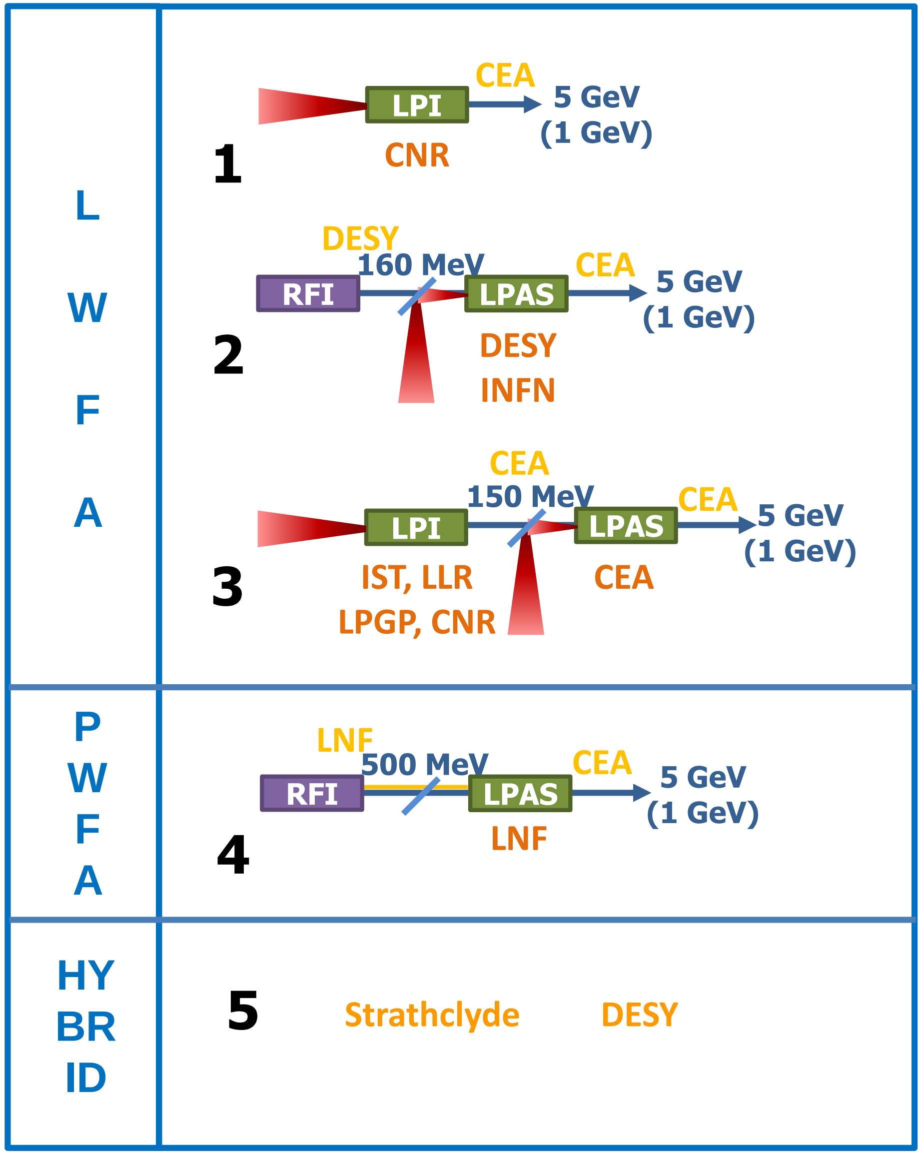


**Recall of Strategic Objective:**
(Lisbon yearly meeting, nov 2017)

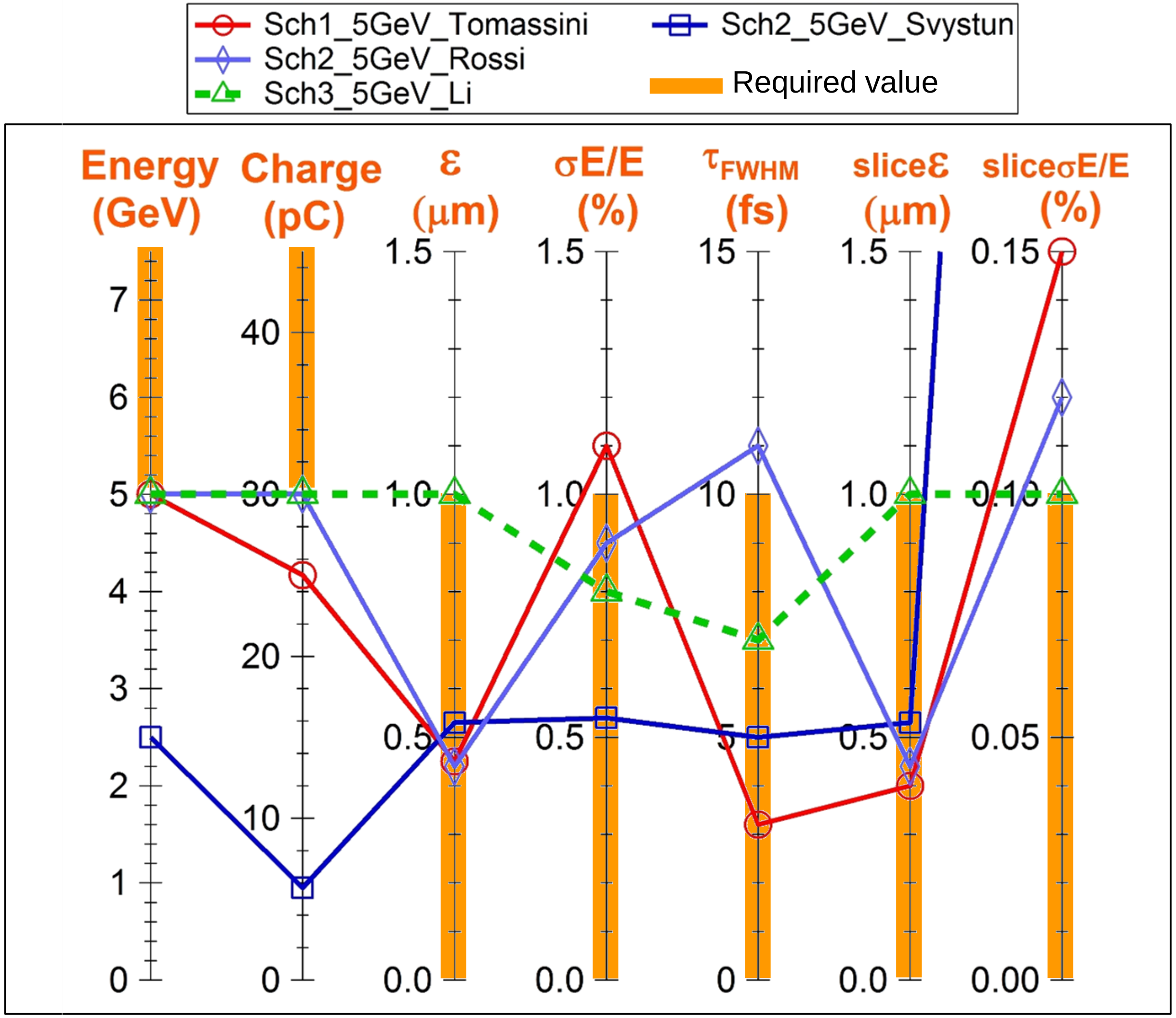
- Providing beam at **5 GeV** meeting 'perfectly' FEL and HEPA requirements

- Providing as well beam at **1 GeV** 'usable' for FEL and HEPA, as a 'commissioning' step

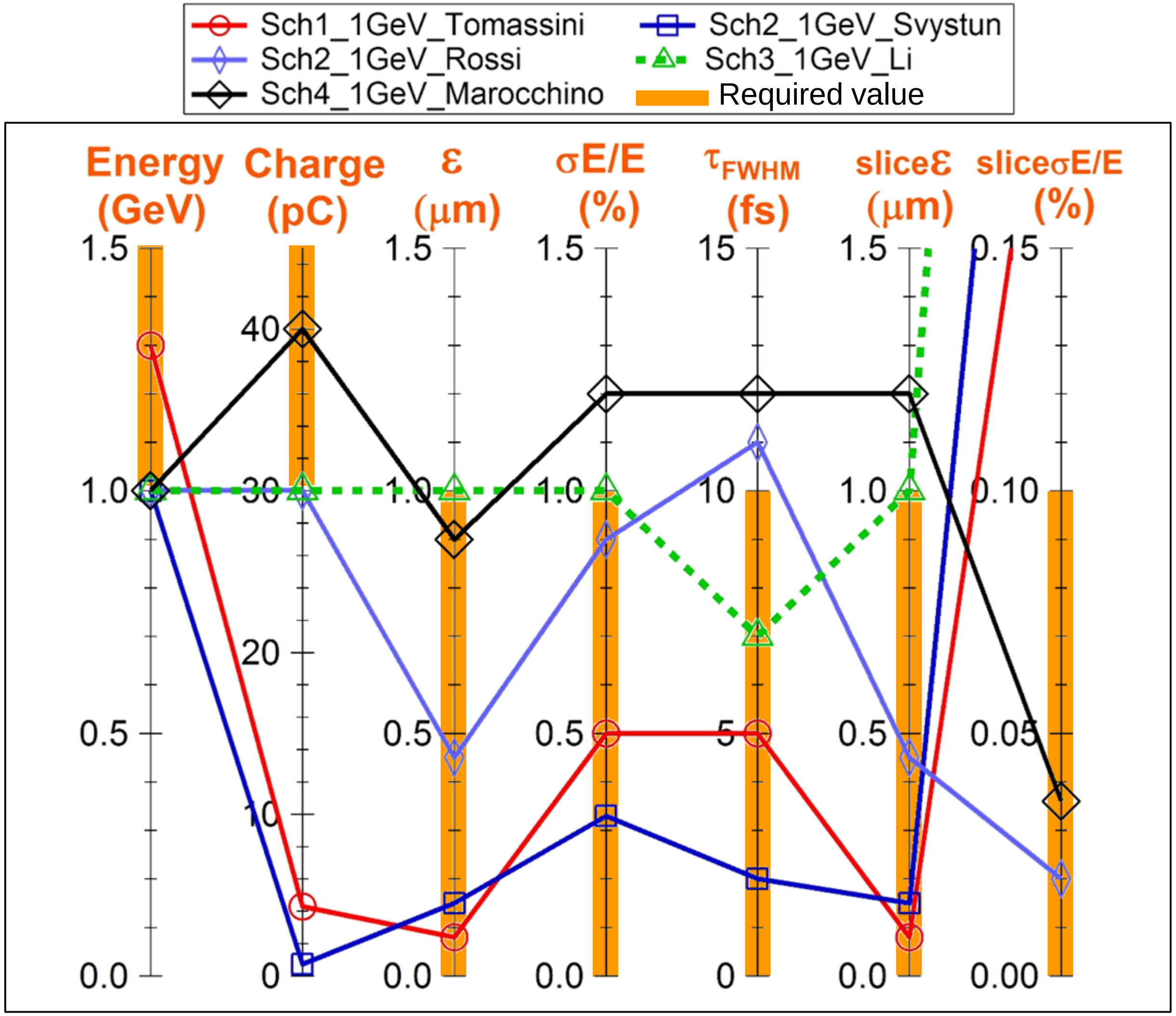
Newly added from WP14 →



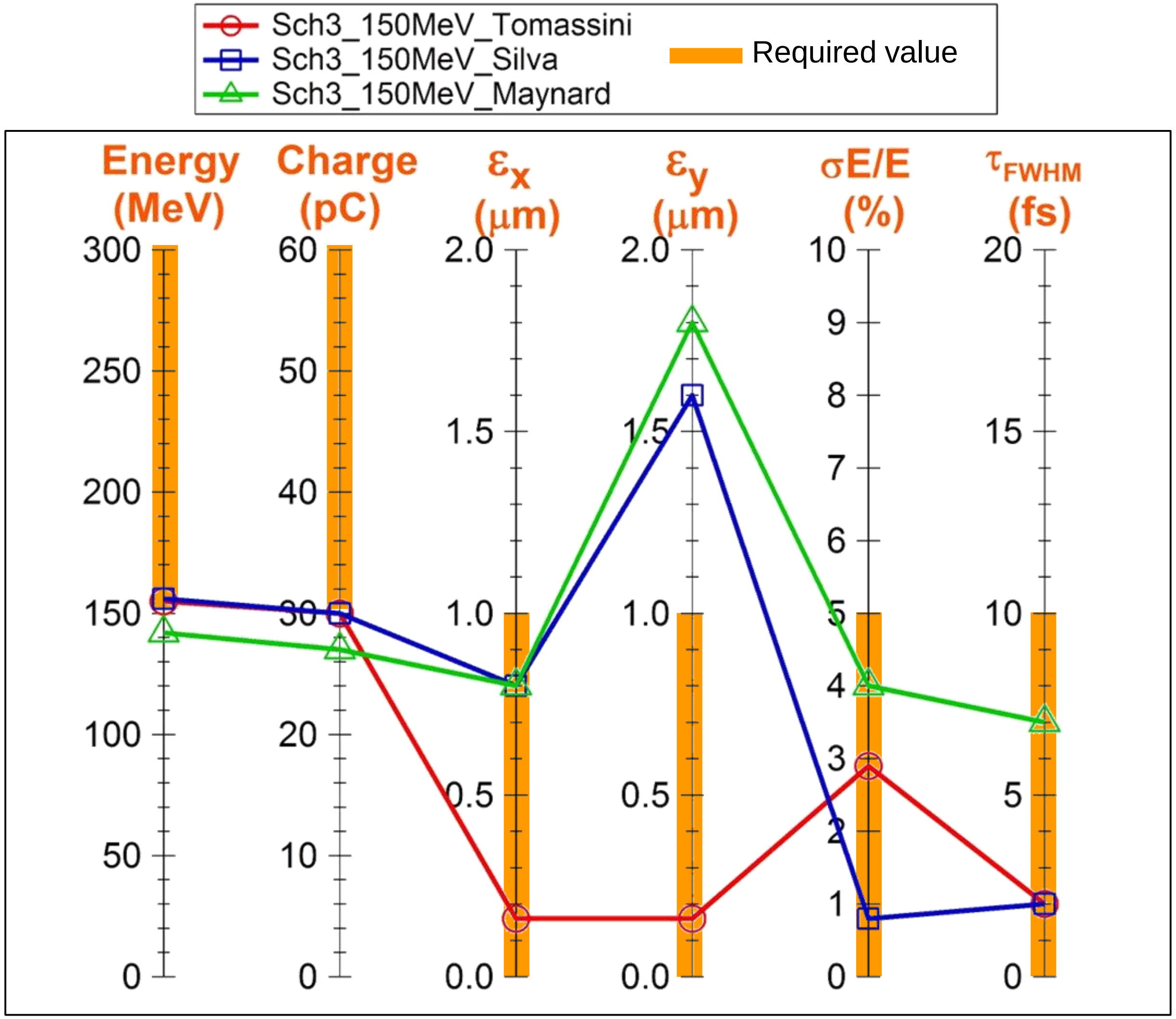
# Beam parameters obtained at 5 GeV



# Beam parameters obtained at 1 GeV



# Beam parameters obtained at 150 MeV



# Hybrid Scheme 5

| LASER/plasma parameters | | | 3D simulation (after 2 mm) | Extrapolation (after 7 mm) |
|---|---|---|---|---|
| $P_0$ | 98 TW | Average energy | 370 MeV | ~800 MeV |
| $\tau$ | 27 fs | Energy spread | 2.5% | ~2% |
| $w_0$ | 17 µm | Energy spread (sliced) | 1-2 % | ~1% |
| $a_0$ | 3.18 | Norm. emittance | ~5 µm | ~5 µm |
| Energy | 2.8 J | Charge | 190 pC | 190 pC |
| Plasma density | 2 x $10^{18}$ $cm^{-3}$ | Duration (fwhm) | 6 fs | 6 fs |
| Acc. distance | 2 - 7 mm | Peak current | 30 kA | 30 kA |
| Injection length | 0.2 mm | Brightness | 1.2 kA/µm$^2$ | 1.2 kA/µm$^2$ |

Table 1. Parameters for the drive-laser and the witness beam, from a 3D LWFA simulation with ionization injection.

| LASER/plasma parameters | | Witness beam (via ionization injection) | |
|---|---|---|---|
| $P_0$ | 980 TW | Average energy | 1 - 5 GeV |
| $\tau$ | 85 fs | Energy spread | ~2 % |
| $w_0$ | 54 µm | Energy spread (sliced) | 0.5 - 0.1 % |
| $a_0$ | 3.18 | Norm. emittance | ~15 µm |
| Energy | 88 J | Charge | 600 pC |
| Plasma density | 2 x $10^{17}$ $cm^{-3}$ | Duration (fwhm) | 19 fs |
| Acc. distance | 4 - 20 cm | Peak current | 30 kA |
| Injection length | 0.6 mm | Brightness | 0.12 kA/µm$^2$ |

Table 2. Parameters for the drive-laser and the witness beam, from a re-scaled 3D LWFA simulation with ionization injection.

Alberto de la Ossa
Bernhard Hidding

| | Driver beam parameters (assumption) | Witness beam parameters (simulation) |
|---|---|---|
| Average energy | 2 GeV | 5 GeV |
| Energy spread | 3 % | 1 % |
| Energy spread (sliced) | 3 % | 0.1 % |
| Norm. emittance | 10 µm | 0.1 µm |
| Charge | 190 pC | 11 pC |
| Duration (fwhm) | 19 fs | 1 fs |
| Peak current | 10 kA | 15 kA |
| Brightness | 0.1 kA/µm$^2$ | 1500 kA/µm$^2$ |

Table 3. Drive beam and witness beam parameters from a 3D PWFA simulation with wakefield-induced ionization injection.

# Plasma configurations used in simulations

- Plasma H, Ar, $N^{5+}$, N2 impurity, …
- Longitudinal: uniform plateau
  with ramps at entrance and exit
  Radial: parabolic
- Longitudinal: downramp for auto injection
- Gas jet, or capillary, or cell
- Length and density:
  LPAS 5 GeV: 17-28 cm, 0.1-2.5 $10^{17}$ $cm^{-3}$
  LPAS 1 GeV: 3-7 cm, 1-5 $cm^{-3}$
  LPI 150 MeV: 0.6-4 mm, 7-80 $10^{17}$ $cm^{-3}$

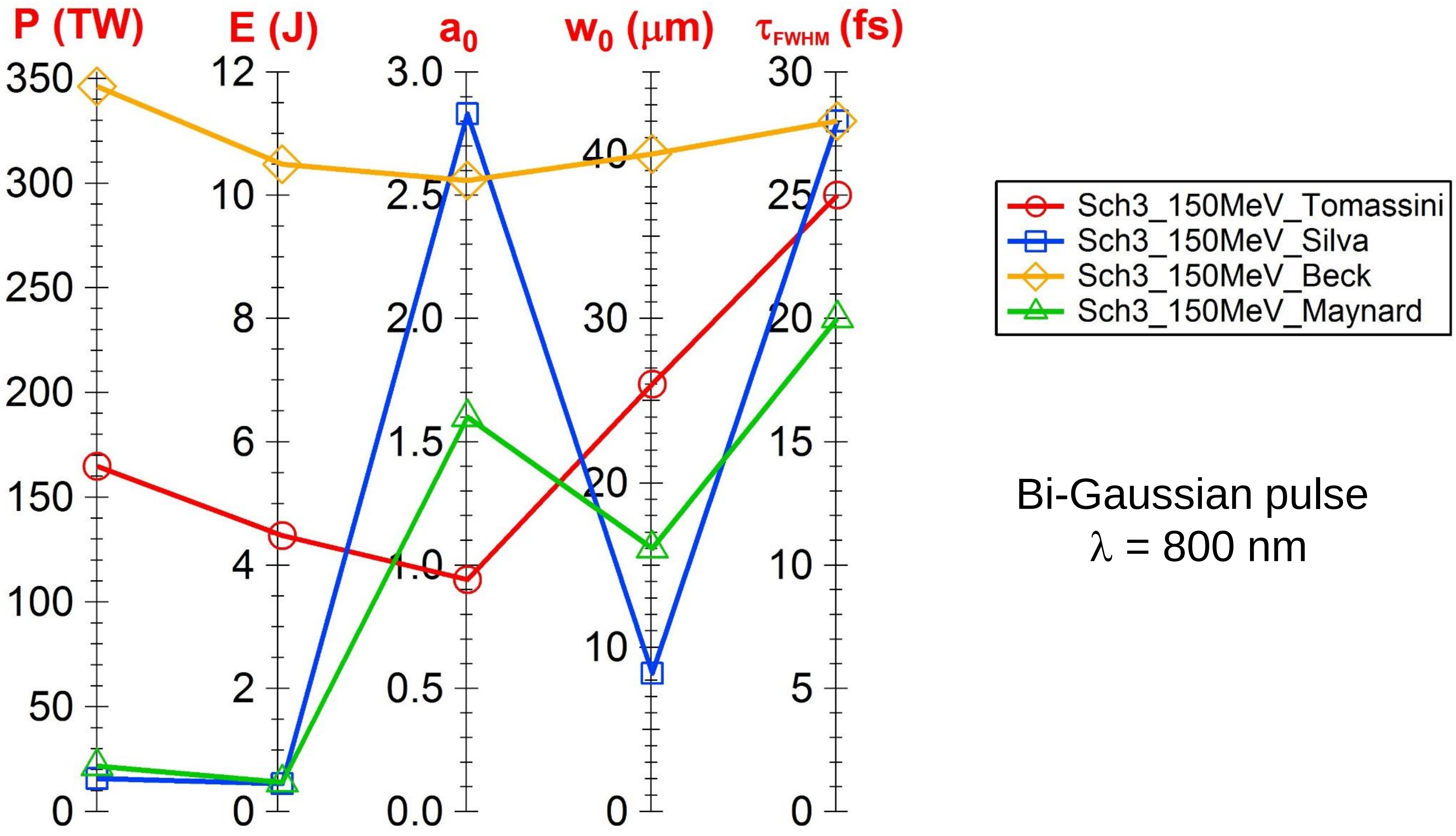
**A first estimate is given**:
- Realism level
- How to achieve
- Potential imperfections
- Suggestion of alternative

Brigitte Cros, T. Audet

| Scheme ID | Realistic? | How to achieve | Imperfections | Alternative |
|---|---|---|---|---|
| Scheme1B P. Tomassini | No (revised) | ? more details on requirements are necessary | Described gradient at entrance too sharp | are smoother gradient and transitions acceptable for the scheme? |
| Scheme 2B E Svystun et al | Yes | Capillary, ramps given by fluid simuls | Low density challenging for parabolic profile, reproducibility to be tested | Gas cell also an option for parabolic profile (OFI plasma) and length smaller than 20 cm |
| Scheme 2B A Rossi | No | ? details on requirements are necessary | Uniformity over 50cm to be determined for a discharge | Promising option: laser created plasma |
| Scheme 3B T Silva et al | No | Upramp gradient too sharp; Shock for downramp gradient | Gradient fluctuations | Shock injection with a smooth gradient at entrance |
| Scheme 3B A Beck | No | ? beyond state-of-the-art gas jet | Gradients are linear and too sharp | Gas jets with longer, exponential ramps |
| Scheme 3B G Maynard | yes | Gas cell | Density controlled better than 10% | Double gas jet |
| Scheme 3B P Tomassini A | Yes | Gas jet far from the nozzle, smooth gradients | Pure nitrogen may induce non uniform distribution: ionization level? | Gas cell, required profile needs to be specified |
| Scheme 3B P Tomassini B | No (revised) | Separation of areas with "pure" gas difficult inside gas jets | Ramps need to be determined | Two-stage gas cell |
| Scheme 3B X Li | Yes | Low density channel may be achieved with OFI in gas capillary | Plasma uniformity needs to be specified Delta n is of the order of fluctuations, 10% | Promising option: laser created plasma |
| Scheme 4B A Marocchino | ? yes if uniform plasma | Depends on transverse profile, uniform ok in capillary tube with OFI | Plasma uniformity needs to be specified | - |

# Laser parameters used in beam simulations

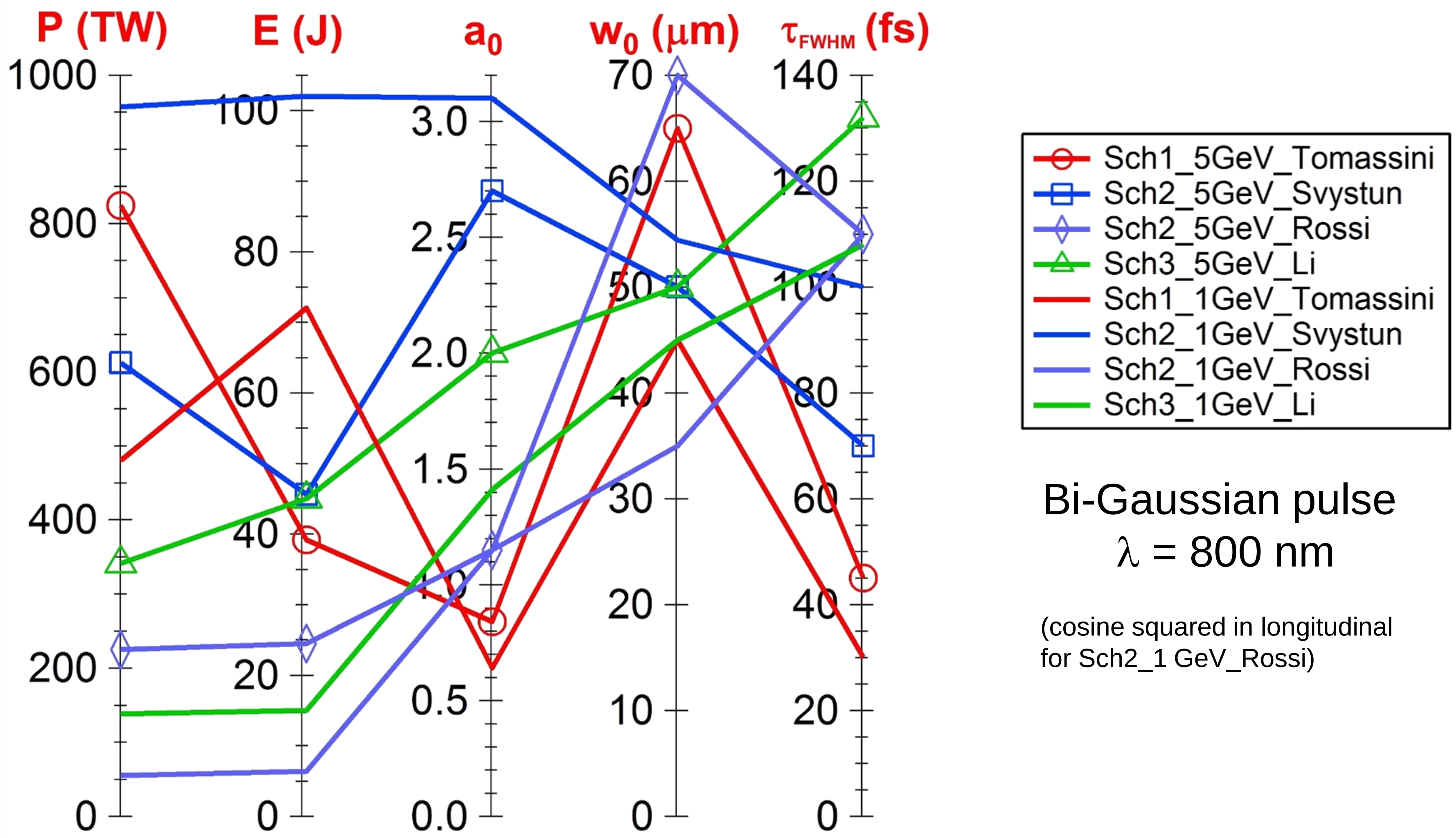
## for 150 MeV (LPI)




Bi-Gaussian pulse
$\lambda$ = 800 nm

# Laser parameters used in beam simulations

## for 5 GeV and 1 GeV (LPAS)




Bi-Gaussian pulse
$\lambda$ = 800 nm

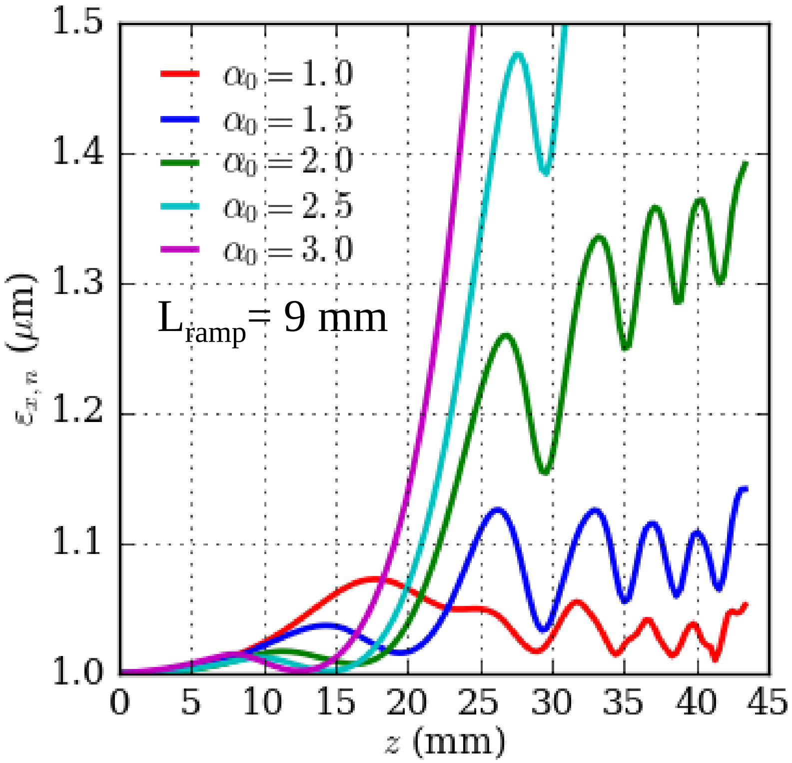
(cosine squared in longitudinal for Sch2_1 GeV_Rossi)

# Matching in and out a plasma stage

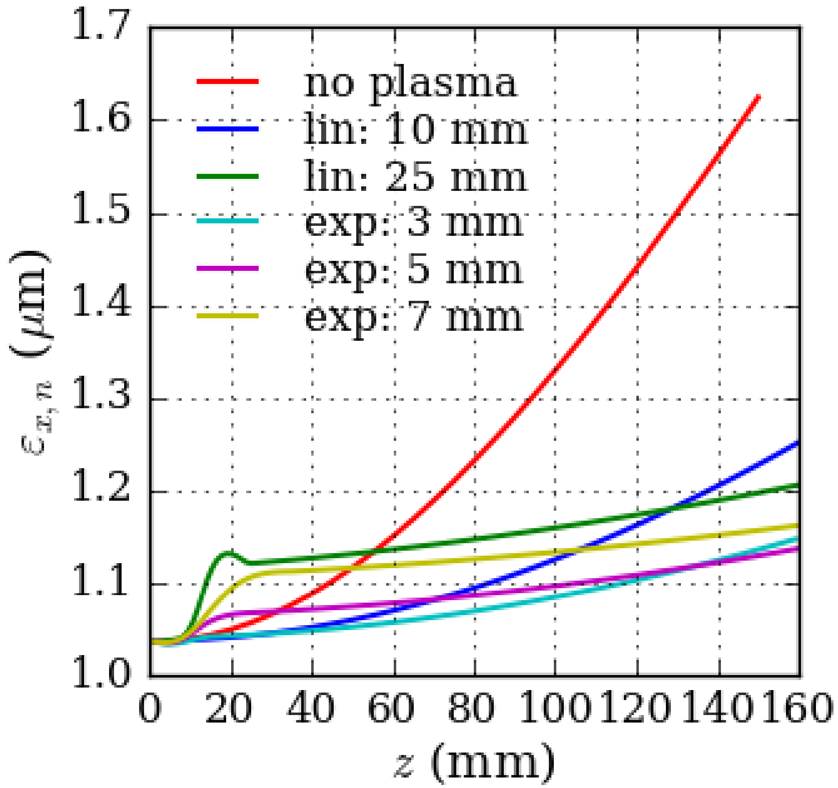
X. Li, A. Chancé & P.A.P. Nghiem

**1** **Up- and Downramp** with Linear or Exponential density profiles have been checked
Optimized length → Minimum emittance growth

## In (150 MeV)




## Out (5 GeV)




**2** **Transfer line**: number of quadrupoles = number of constraints
6 quadrupoles → emittance growth of only 10% at FEL entrance

**Encouraging** results **but** all need to be confirmed and consolidated:

For 5 GeV

Sch 1 with REMPI technique is not very far from requirements

Sch 2 with photoinjector 537 MeV, all the reqirements are met

BUT no margin and still waiting for lower injection energy

Sch 3, LPA with weakly nonlinear acc.regime, all the reqirements are met

BUT no margin and still waiting for LPI injection

For 1 GeV

Sch 2, all the requirements are met, BUT with photoinjector at 500 MeV

Sch 3, after only 1 trying, all requirements are met except for slice nrj spread

BUT still waiting for LPI injection

Sch 4, all the requirements are met, BUT with photoinjector at 500 MeV

For LPI 150 MeV (Sch 3)

REMPI: all requirements are met, BUT transfer to next satge remains to be studied

Hybrid is potentially promising, BUT remains to be simulated from start-to-end