Session on PWFA at CALIFES

CALIFES workshop 2016

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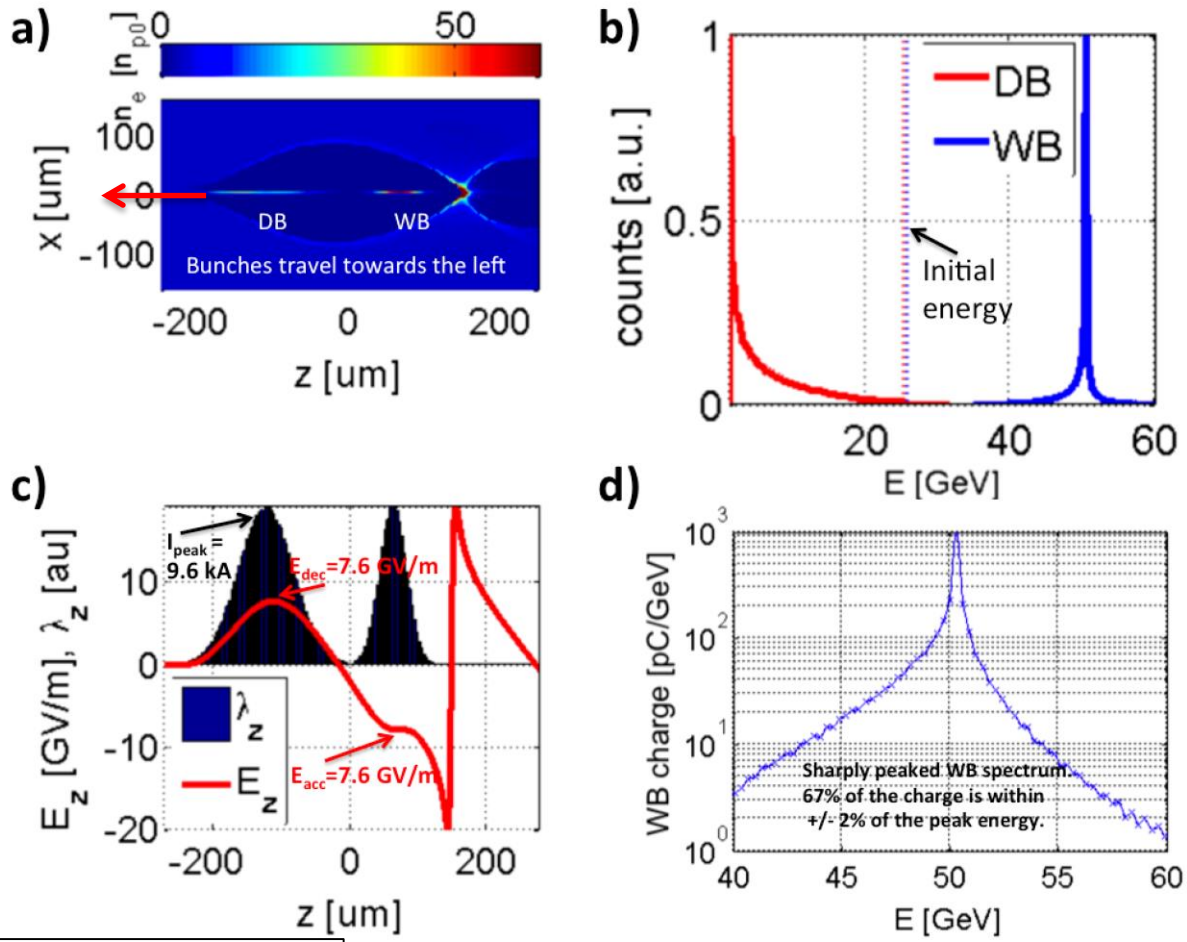
Beam driven PWFA

PWFA:
Two-beam acceleration. A **D**rive **B**eam drives a plasma wake, a **W**itness **B**eam extracts the wake energy (energy transformer a la CLIC).

PWFA has potential for:
- High gradient (>10 GV/m)
- High efficiency (>50%)
- Low energy spread (<1%)
- High charge (~nC)
- Linear focusing

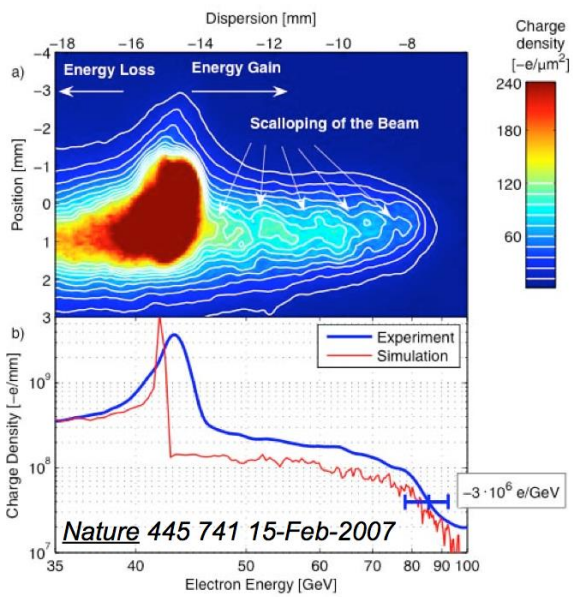


Above: PIC simulation based on example parameters from PWFA-LC study

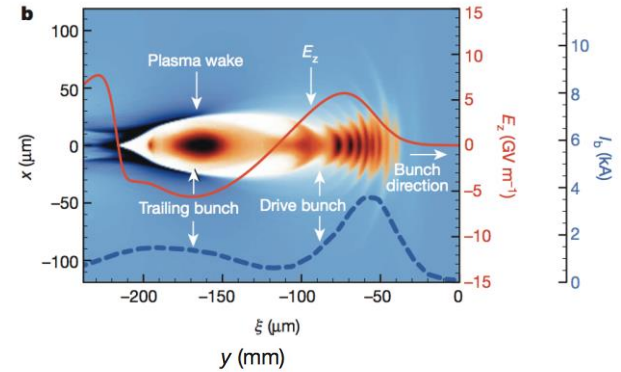
Not discussed here: laser wakefield acceleration, LWFA.
- more accessible for smaller national labs
- PWFA has some advantages with respect to LWFA for HEP application

Experimental progress in PWFA

High gradient (~50 GV/m) demonstrated several years ago; SLAC linac energy doubling of beam tail.



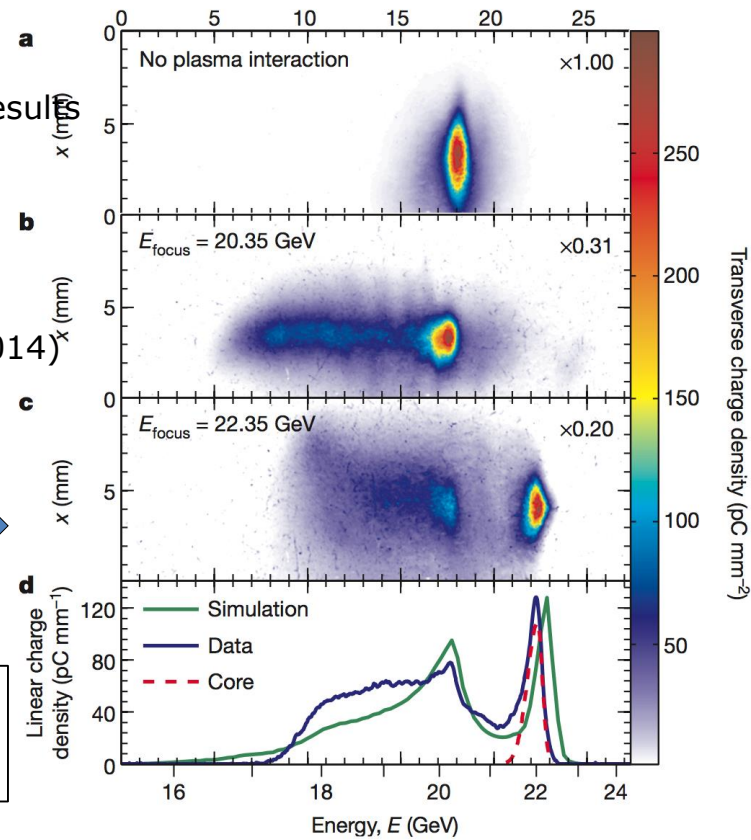
Blumenfeld, I. et al.
Nature **445**, 741 (2007)



(A large number of other recent results are not discussed here).

M. Litos et al.,
Nature **515**, 92 (2014)

Acceleration of a witness beam, with high efficiency (>30% wake to beam), high gradient (5 GV/m) and low energy spread (~1%) recently demonstrated at SLAC/FACET.



PWFA gradient well proven. An equally important next steps : demonstrate PWFA beam quality and stability.

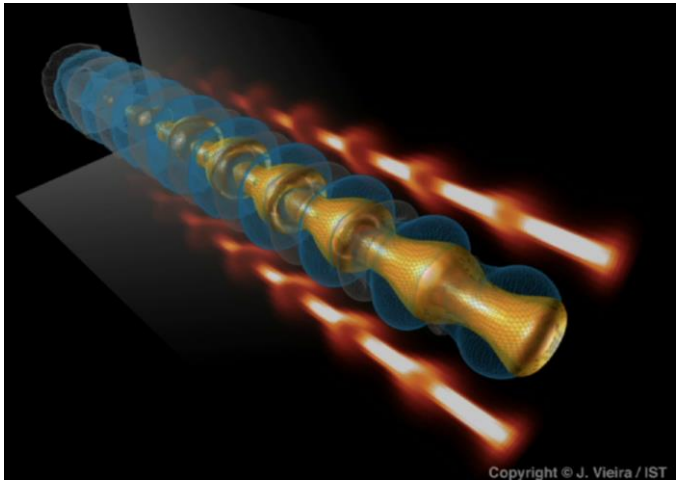
Possible paths toward TeV-scale energies

Proton Driven PWFA

- TeV-scale in single stage?

A. Caldwell et al. Nat. Phys. **5**, 363 (2009)
A. Caldwell and K. Lotov, Phys. Plas. **5**, 103101 (2011)
E. Gschwendtner et al., Nucl. Instrum. Methods in Phys. Res. A **829,** 76 (2016)

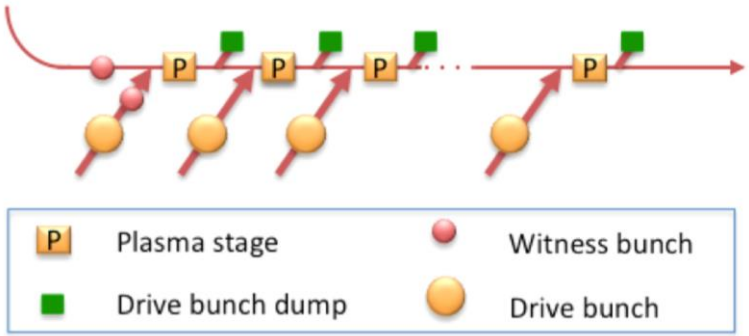
(See Edda's talk)



Relies on **self-modulation** of a long proton beam; main topic of the Run 1 of AWAKE (2016-2018).

Staged e- driven PWFA

- use many (low energy) drive bunches to power each main bunch



PWFA linear collider concepts outlined in *A. Seryi et al (PAC'09), E. Adli et al. (***arXiv**:1308.1145) with aim of identifying challenges and guide work towards HEP applications. Challenges include :

- emittance preservation (ion motion, scattering, field non-linarites)
- plasma matching and inter-staging
- plasma source development
- efficient drive beam schemes
- better understanding of tolerances
- positron acceleration

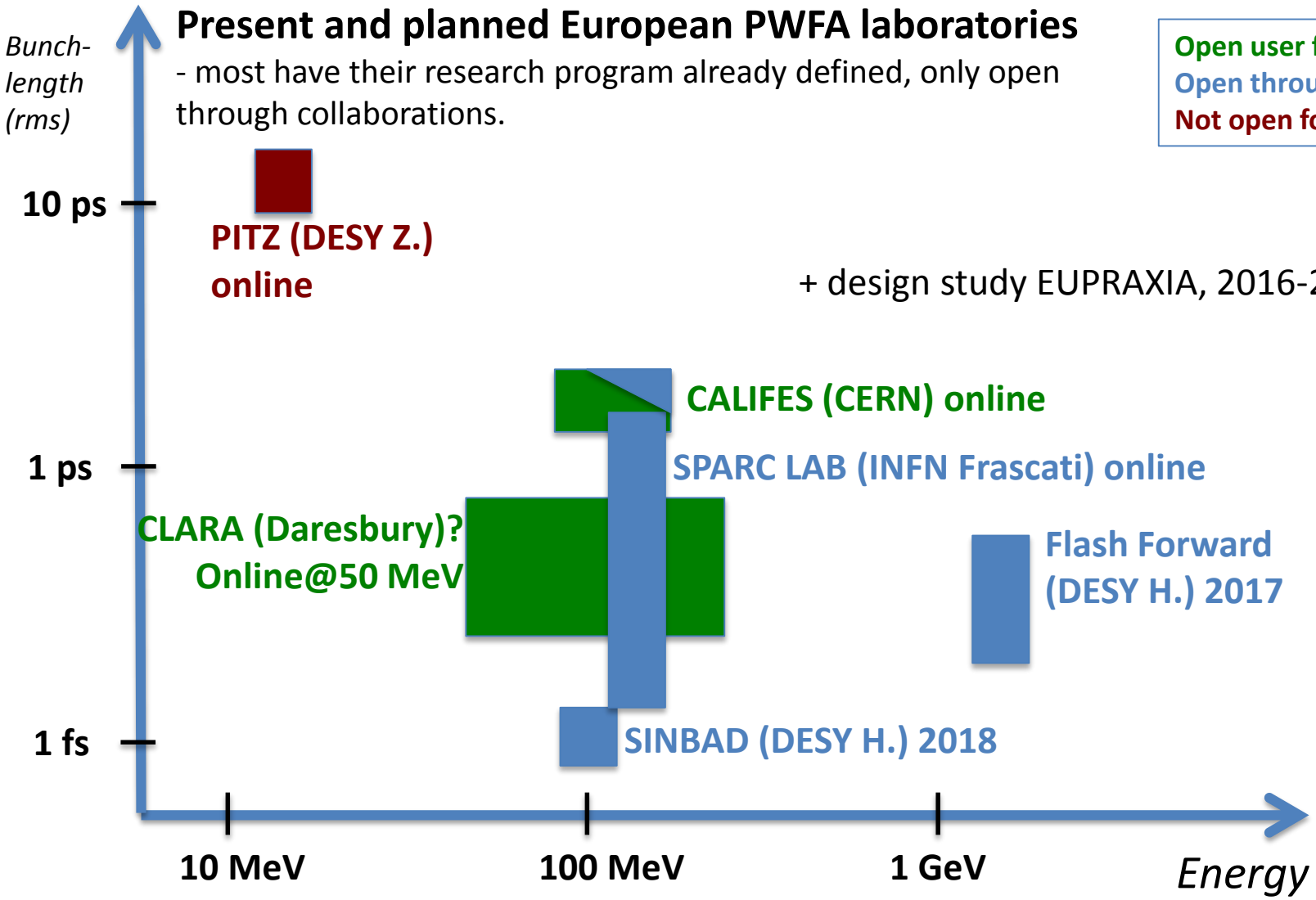
PWFA test-facilities

USA: SLAC **FFTB** and **FACET** (2012-2016). FACET-II planned to come online ~2019.
- a **gap of 3-4 years** for PWFA research at SLAC (the main PWFA research lab. in the USA)

In addition ATF/ATF2 at BNL, and AWA at Argonne.

Present and planned European PWFA laboratories

- most have their research program already defined, only open through collaborations.



Rationale for a PWFA program in CALIFES

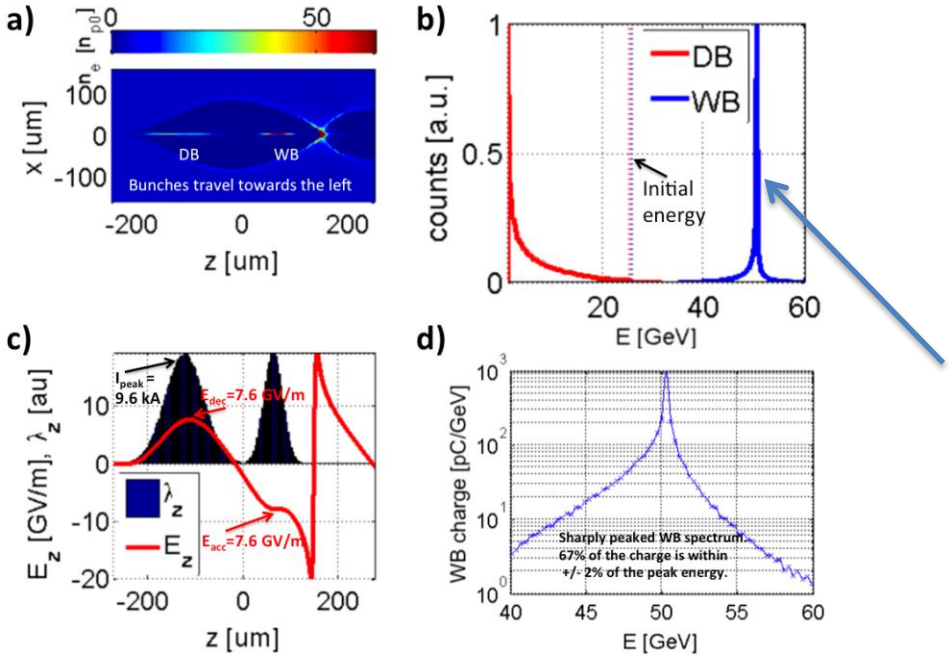
- With the recent advances in PWFA and the subsequent suggestions of PWFA for HEP applications, the conventional accelerator community **demands answers to questions of beam quality and stability**; can only be addressed by experiments.
- A large number studies needs to be performed to address this topic, **too few facilities** to accommodate them.
- To properly assess PWFA as a long-term option for high-energy physic especially colliders, it would **be fruitful to have CERN linear collider expertise** in closer contact with experimental activities
  - the LC community knows the requirements
  - still a culture gap in how you work with and describe beams (trivial example: how to define energy spread)
- **AWAKE long term plans** may profit from CALIFES as well (see next talk)

Program

Ingredients for a PWFA activity in CALIFES: must have **plasma sources**; an important technical development in itself. With sources in place, additional experiments can be defined using the sources. The selected program focused on key R&D challenges (sources, interstages, emittance preservation ...). Much of the program is interesting on **a short time scale** (2017 and 2018).

Introduction	*Erik Adli*	
503-1-001 - Council Chamber, CERN	16:10 - 16:20	
AWAKE plans and possible use of CALIFES	*Edda Gschwendtner*	
503-1-001 - Council Chamber, CERN	16:25 - 16:35	
Discharge source	*Nelson Lopes*	
503-1-001 - Council Chamber, CERN	16:40 - 16:55	
Apochromatic plasma lens lattices	*Mr. Carl Lindstrøm*	
503-1-001 - Council Chamber, CERN	17:00 - 17:15	
Emittance preservation studies	*Sebastien Corde*	
503-1-001 - Council Chamber, CERN	17:20 - 17:30	
Plasma-based bunch compression techniques	*Spencer Gessner*	
503-1-001 - Council Chamber, CERN	17:35 - 17:45	
Compact plasma based beam dump	*guoxing xia*	
503-1-001 - Council Chamber, CERN	17:50 - 18:00	
Existing equipment at Cockcroft Institute; emittance growth due to scattering in plasma.	*Oznur Mete*	
503-1-001 - Council Chamber, CERN	18:05 - 18:15	

Longer term PWFA : two-bunch experiments in CALIFES ?



Demonstration of a PWFA-LC stage :
Double the energy of a ~25 GeV main bunch in ~1 meter

Can a 200 MeV CALIFES beam do anything relevant?

The CTF3 parameters are far from SLAC parameters (20 GeV beams, short bunches), however, the basic physics scales with the plasma density, n_0.

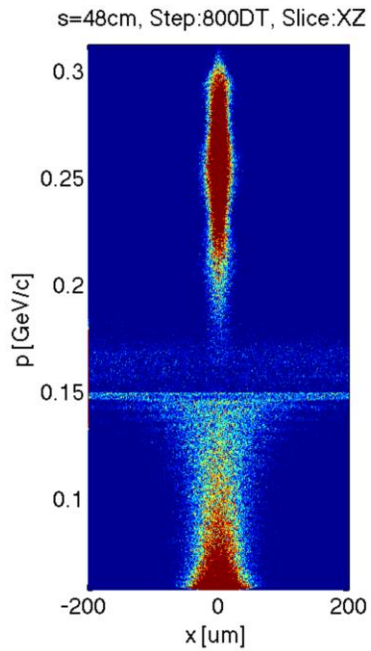
Reduced plasma density leads to
-> reduced gradient : $E_0 \sim \sqrt{n_0}$
-> increased length scales : $\lambda_p \sim \sqrt{1/n_0}$
PWFA-LC: $n_0 \sim 1e16cm^3 - 1e17/cm^3$, gradient$\sim 10GV/m$, **plasma cell length:** $\sim$1 **m**, $\lambda_p \sim 100\mu m$
CTF3: $n_0 \sim 1e14cm^3$, gradient, few $\sim$100 MV/m, **plasma cell length:** $\sim$**1m**, $\lambda_p \sim$ mm

CALIFES has potential for demonstrating two-bunch PWFA energy doubling.

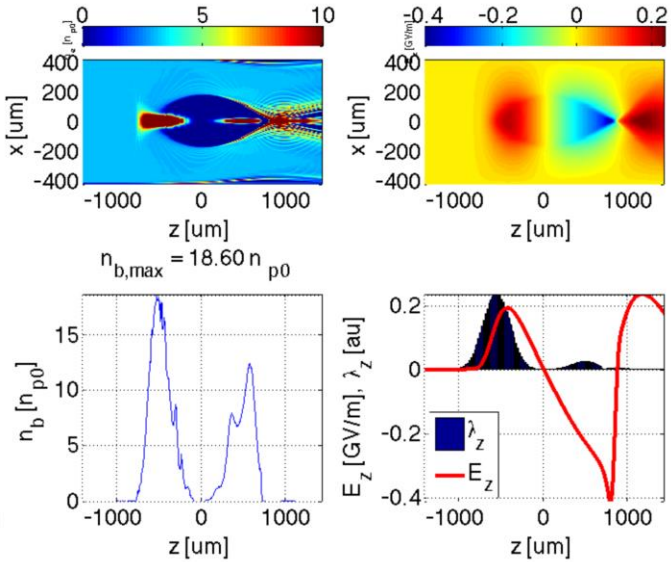
Longer term PWFA : upgrades needed

Parameters required :

	Ideal for test facility
E	~> 150 MeV (DB and WB)
ε_N	few 10 μm (DB)
σ_z	**~150 μm (DB and WB)**
σ_E/E	1%
f	$\geq$ 1 Hz
f_{micro}	**single bunch**
N_{micro}	**single bunch**
Q_{micro}	$\geq$ 1.5 nC
$\hat{I}$	**$\geq$ 1kA (for DB)**
n_b	$\geq$1e15/cm3 (for DB)
$\phi_{stability}$	~few 10 fs



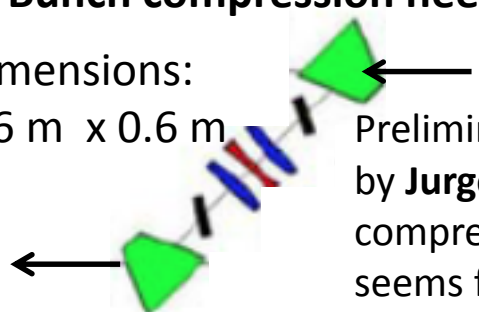
CALIFES: energy doubling of a 150 MeV electron beam (DB 150 MeV)



PIC simulations, see [E. Adli, CLIC PM Dec 2014: https://indico.cern.ch/event/356495/](https://indico.cern.ch/event/356495/)

1) Bunch compression needed :

Dimensions:
2.6 m x 0.6 m



Preliminary dogleg-study by **Jurgen Pfingstner**: compression to 60 um seems feasible.

ϕ_{RF}	E_{DL}	R_{56}	C_z	$\sigma_{z,c}$	$\sigma_{\delta,c}$	θ_{DP}	B_{DP}
30°	181 MeV	4.2 cm	6.76	62.42 μm	1.04 %	9.5°	1.00 T
35°	174 MeV	3.5 cm	7.75	56 μm	1.2 %	8.9°	0.89 T
45°	159 MeV	2.6 cm	9.66	43.68 μm	1.68 %	7.5°	0.69 T

2) Second bunch, independently timed, needed : A independent second injector would be ideal, in order to individually tune the two bunches. Can be low energy: few 10 MeV probably enough.

3) Stronger focusing optics may be needed.

See Sebastien's talk for more details.