MAX-PLANCK-GESELLSCHAFT

AWAKE

Future Accelerators Group 2012 Project Review

Presented by:
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FUTURE ACCELERATORS SCIENTISTS

Diploma Student

Tobias Rusnak (TUM)

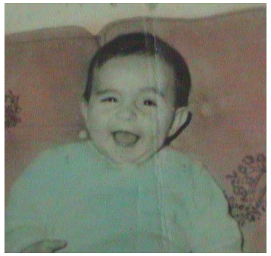
Master Student (prospective)

Jan Machasek (TUM)

Graduate Student

Scott Mandry (UCL)

Postdocs



Erdem Oz

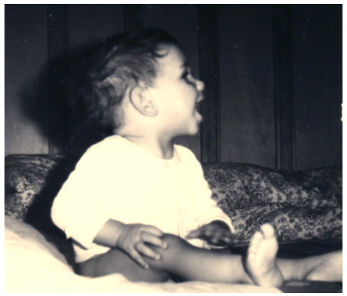
Roxana Tarkeshian

Jorge Vieira (IST, Humboldt Fellow)

Staff

Allen Caldwell

Olaf Reimann



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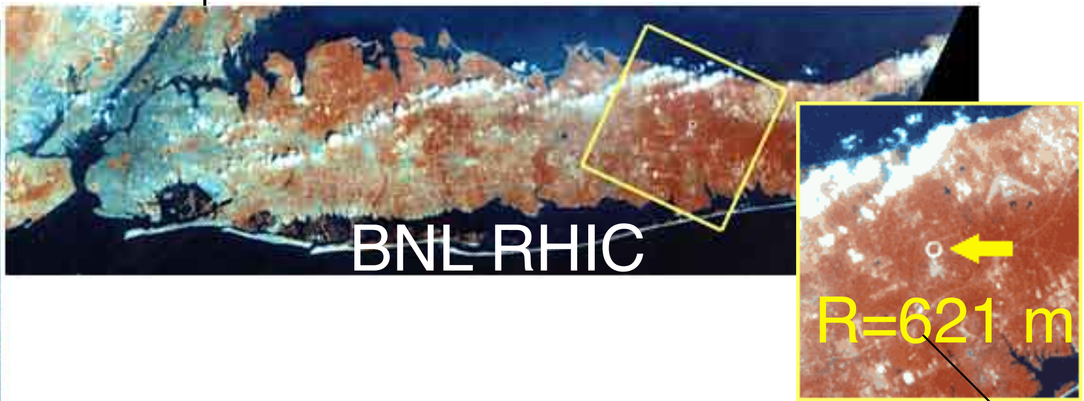
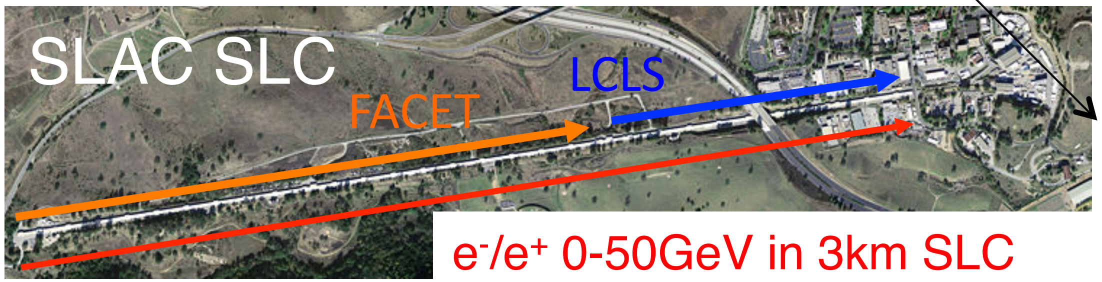
PARTICLE ACCELERATORS

"The 2.4-mile circumference RHIC ring is large enough to be seen from space"





e^-/e^+ 0-50GeV in 3km SLC
e^-/e^+ 0-23GeV in 2km FACET
e^- 0-14GeV in 1km LCLS

- Some of the largest and most complex (and most expensive) scientific instruments ever built!
- All use rf technology to accelerate particles
- Can we make them smaller (and cheaper) and with a higher energy?

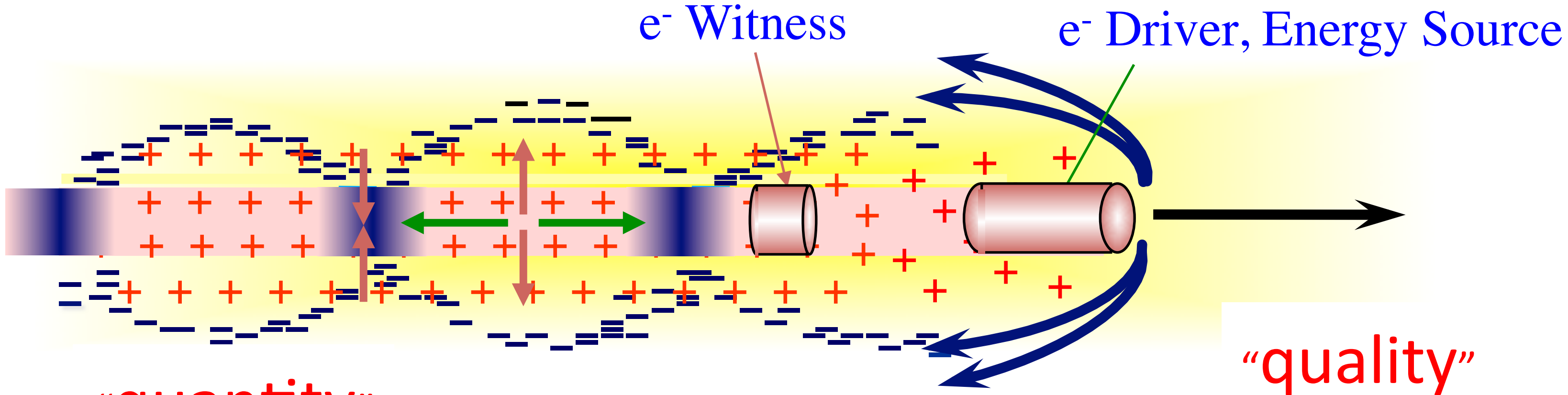
PARTICLE ACCELERATORS

Could plasmas be used to accelerate particles at high-gradient (>>100MeV/m) and reduce the size and cost of a future linear e^-/e^+ collider or of an x-ray FEL?

e^-/e^+ 0-50GeV in 3km SLC
e^-/e^+ 0-23GeV in 2km FACET
e^- 0-14GeV in 1km LCLS

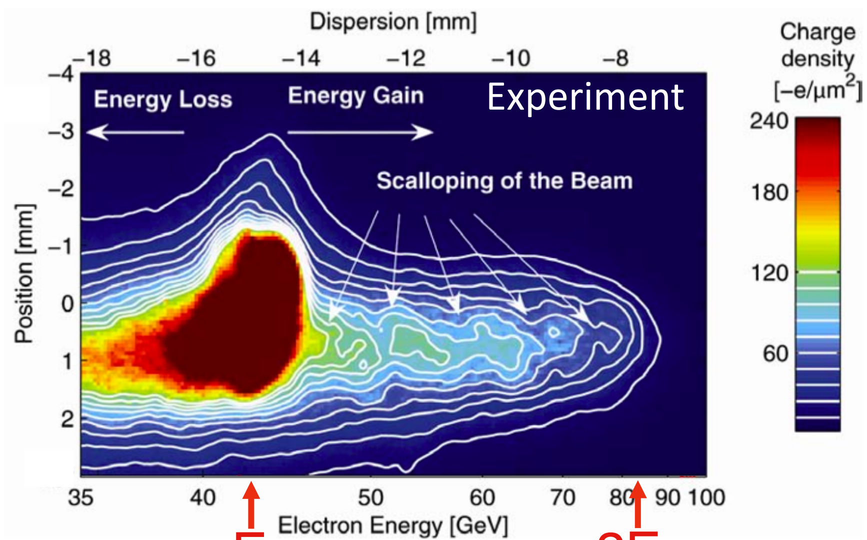
- Some of the largest and most complex (and most expensive) scientific instruments ever built!
- All use rf technology to accelerate particles
- Can we make them smaller (and cheaper) and with a higher energy?

PLASMA WAKEFIELDS (e^-)



"quantity"

Blumenfeld, Nature 445, 2007



E_0 $2E_0$

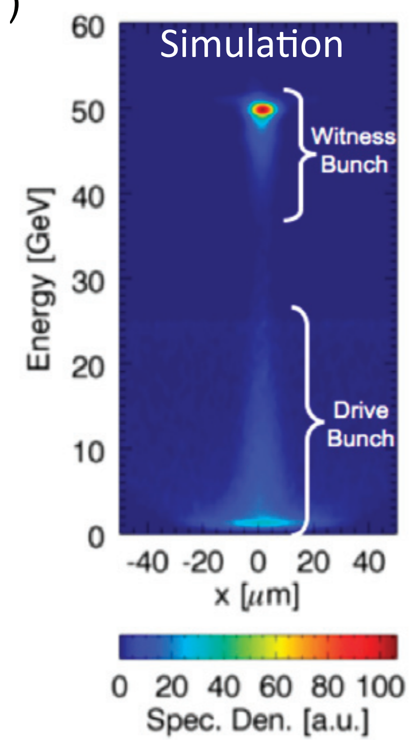
42 => 84GeV in 85cm! 52GeV/m

ivisti… bunc… force… celera… > acceleration … ivistic wake … le… LWFA

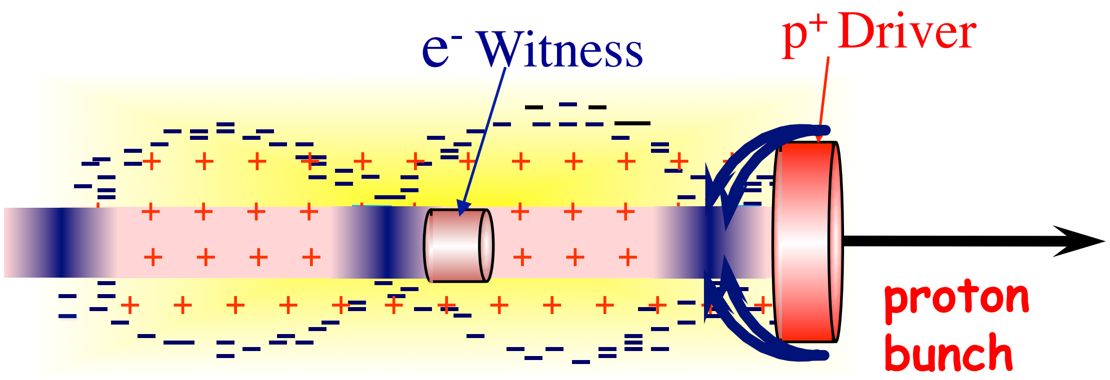
SLAC FACET

Hogan, NJP 12, 2010

"quality"



P^{+}-DRIVEN PLASMA WAKEFIELDS (p^{+}+e^{-})

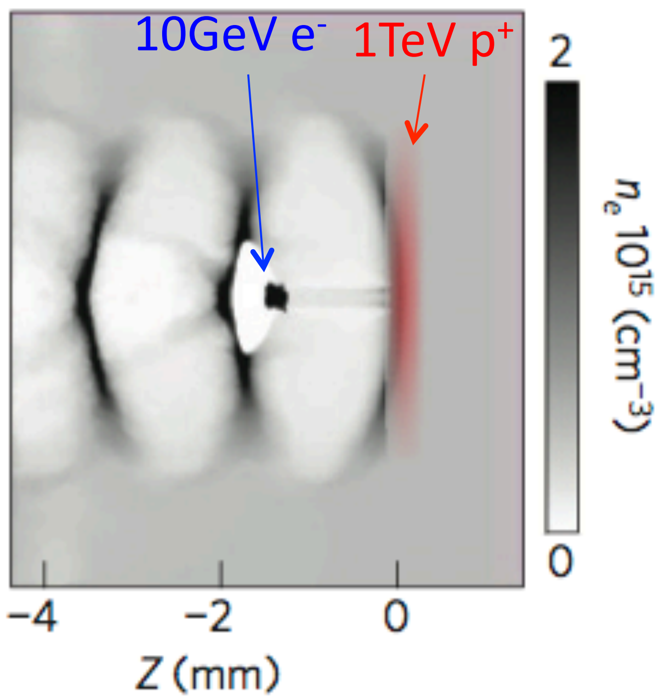


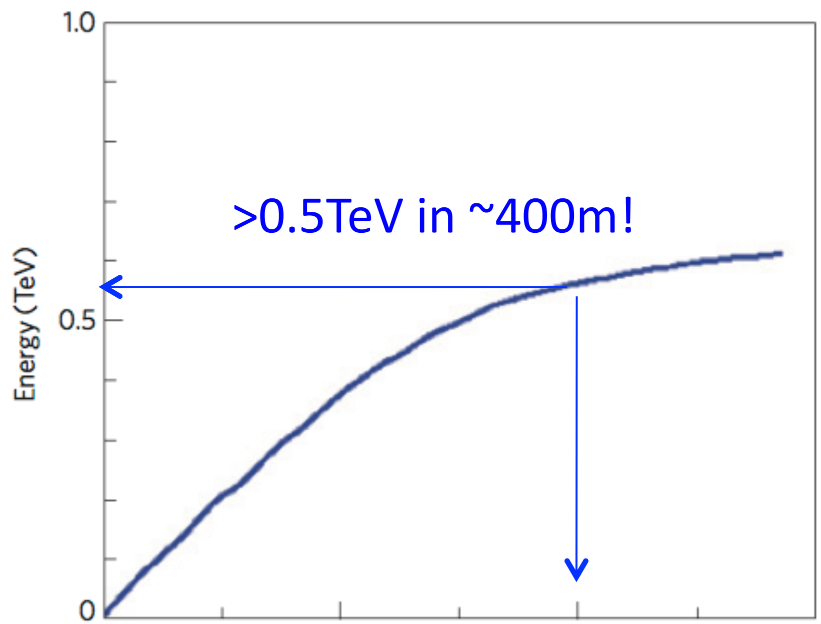
- SLAC, 20GeV bunch with $2x10^{10}e^{-}$ ~60J
  ILC, 0.5TeV bunch with $2x10^{10}e^{-}$ ~1.6kJ
- SLAC-like driver for staging (FACET= 1 stage, collider 50^{+} stages)
- SPS, 450GeV bunch with $10^{11}p^{+}$ ~7.2kJ
  LHC, 7TeV bunch with $10^{11}p^{+}$ ~112kJ
- A single SPS or LHC bunch could produce an ILC bunch in a single PWFA stage!
- Large <u>average</u> gradient! (≥1GeV/m, 100's m)

PROTON-DRIVEN PWFA

Caldwell, Nat. Phys. 5, 363, (2009)

2D Simulations

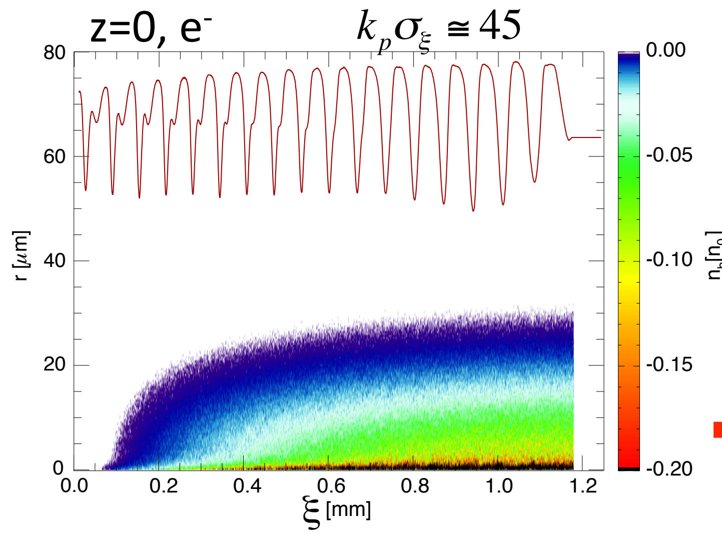


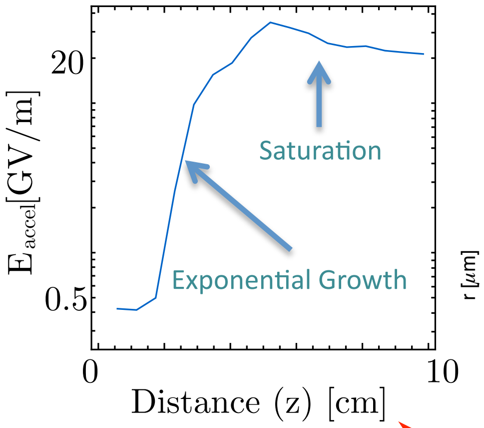


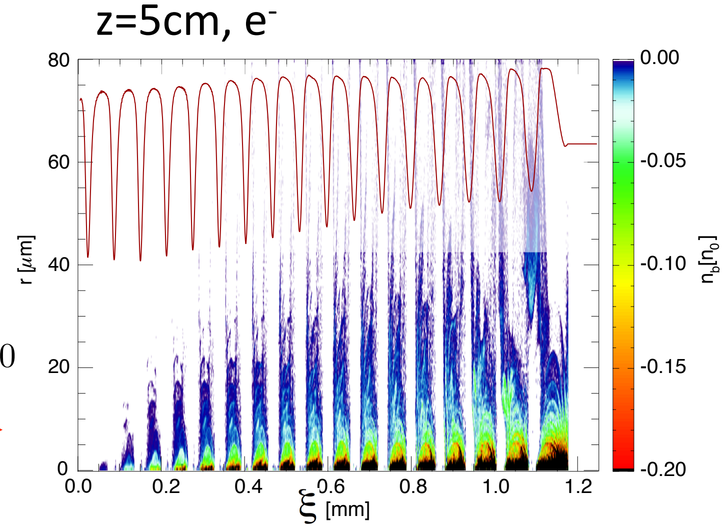
- Use "pancake" p^+ bunch to drive wakefields (cylinder for e^- driver)
- Loaded gradient ~1.5GV/m, efficiency ~ 10% (recycling?)
- ILC-like e^- bunch from a single p^+-driven PWFA
- $\sigma_z \approx 100\mu m$ do not exist!

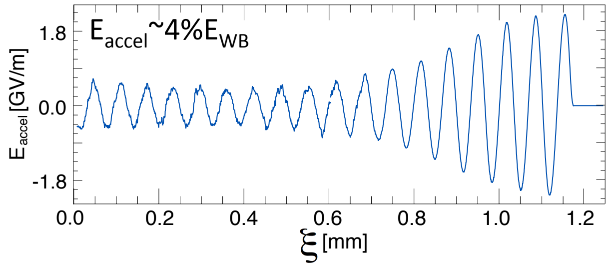
SELF-MODULATION INSTABILITY (SMI)

Propagation of a long bunch in a dense plasma: $\sigma_z > \lambda_{pe}$







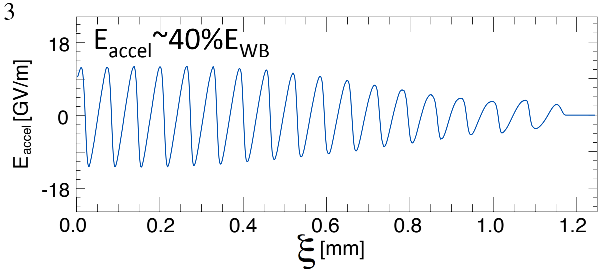


J. Vieira, P. Muggli et al., Phys. Plasmas 19, 063105 (2012).

$$N_{exp} \cong \frac{3\sqrt{3}}{4}\left(\frac{n_b}{n_e}\frac{m_e}{M_b}\left(k_p|\xi|\right)\left(k_p z\right)^2\right)^{1/3}$$

Grows along the bunch & along the plasma

Convective instability

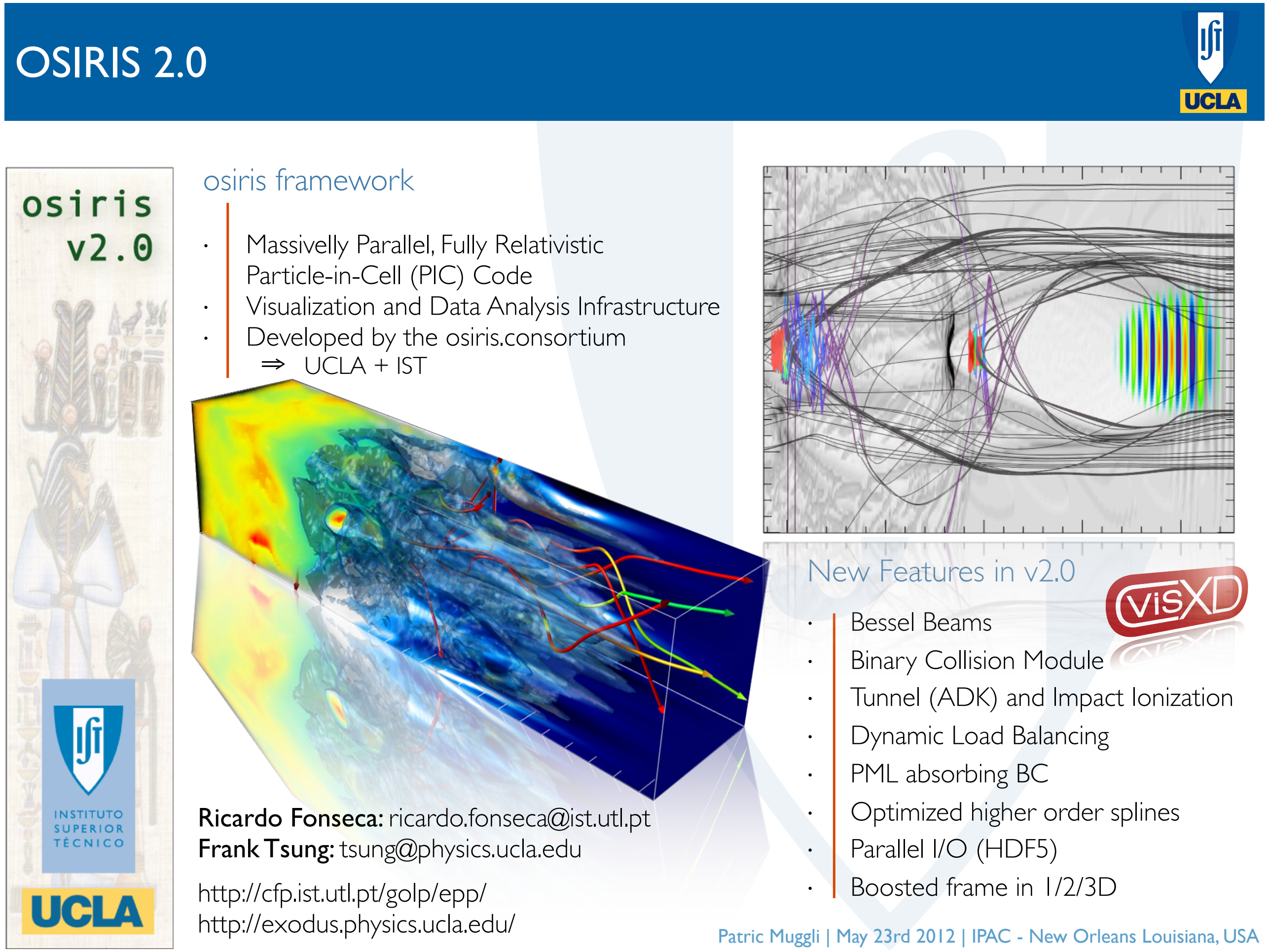


Pukov et al., PRL 107, 145003 (2011)

Schroeder et al., PRL 107, 145002 (2011)

- Initial small transverse wakefields modulate the bunch density
- Longitudinal wakefields reach large amplitude through resonant excitation
- Acceleration of an injected witness bunch

PROTON-DRIVEN PWFA SIMULATIONS



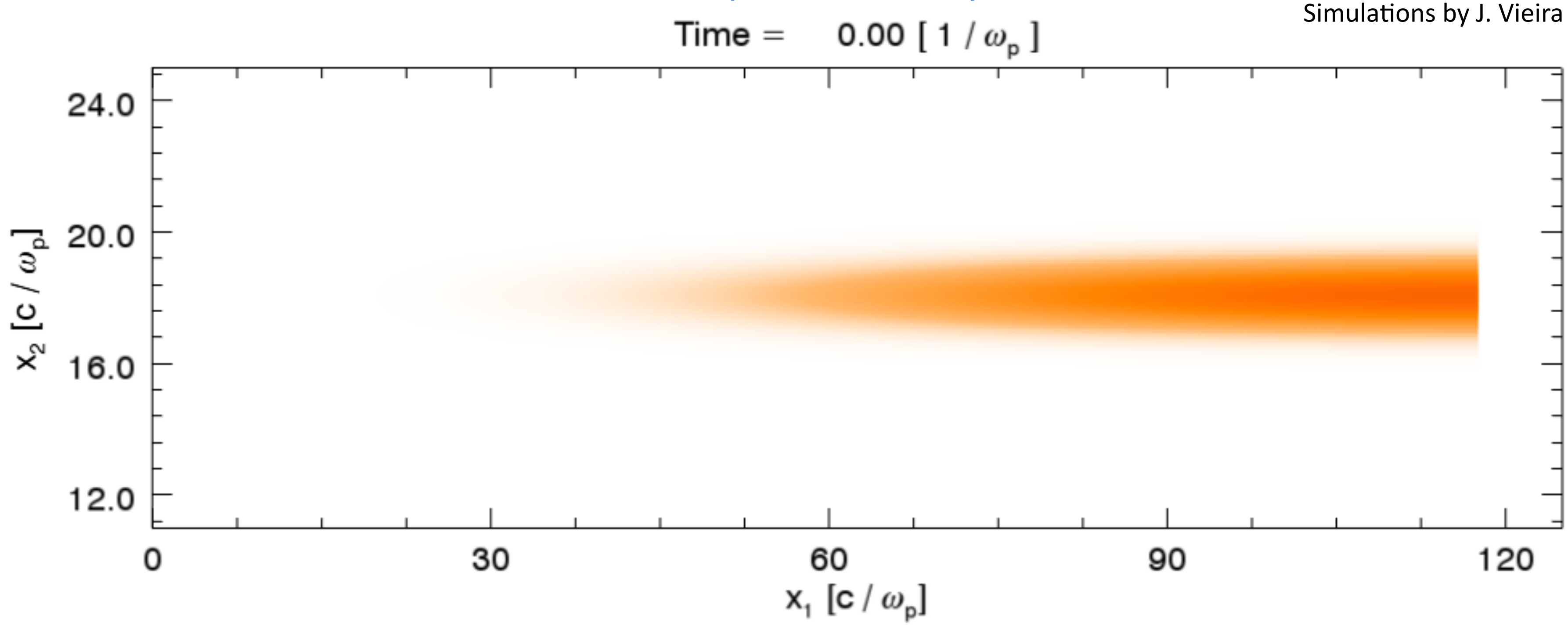
- VLPL A. Pukhov, J. Plasma Phys. 61, 425 (1999)
- LCODE, K. V. Lotov, Phys. Rev. ST Accel. Beams 6, 061301 (2003)

SELF-MODULATION INSTABILITY (SMI)

SLAC-like electron bunch, 2D-slab geometry, “cut bunch”

Caption: Red-yellow colors: electron bunch density
Blue: electron plasma density

Simulations by J. Vieira

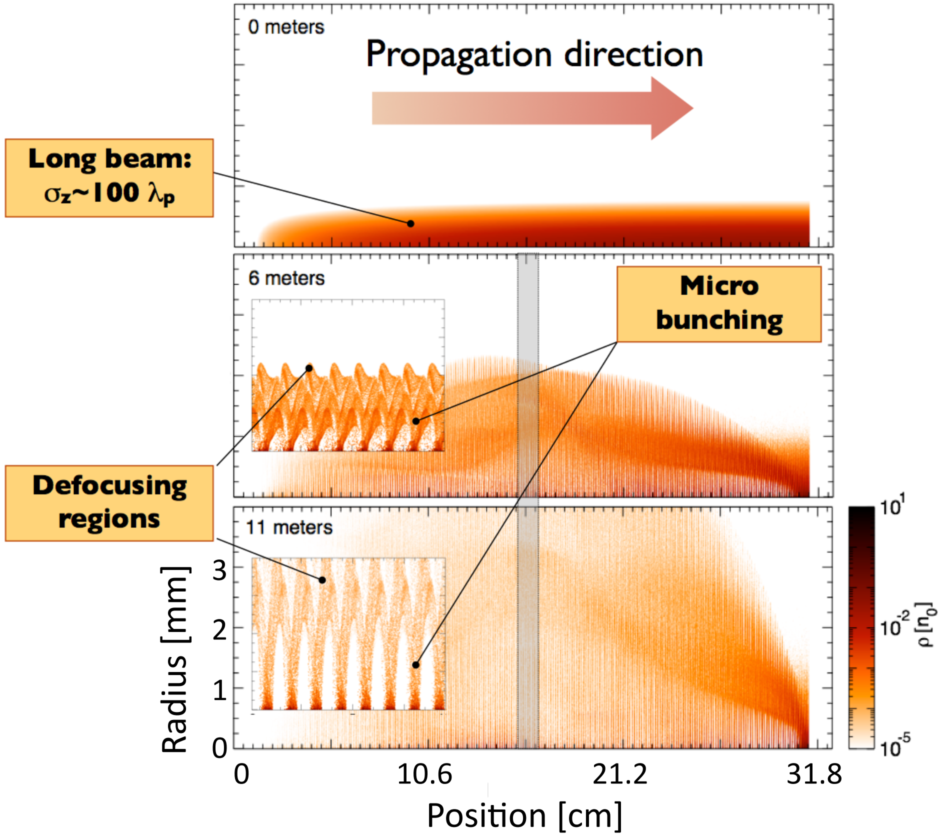


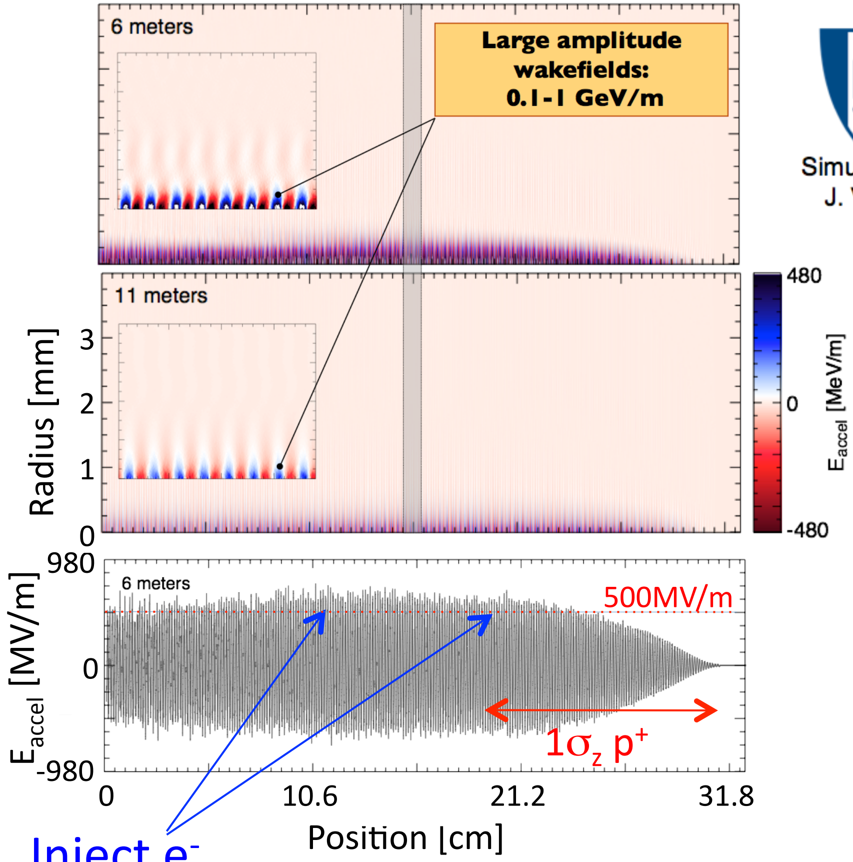
J. Vieira, P. Muggli et al., Phys. Plasmas 19, 063105 (2012).

- “cut bunch” for seeding of the instability
- Particles in the defocusing field regions are defocused and leave the simulation
- Acceleration of an injected witness bunch

PROTON-DRIVEN PWFA @ CERN

- SMI of long (~12cm), 450GeV SPS bunch @ $\lambda_{pe}\approx1.2mm$





Simulations: J. Vieira

Inject e$^-$
Gain e few GeVs in a few meters!!!!!

- Drives large amplitude (0.1-1GV/m) accelerating fields
- E_z (acceleration) sampled by injecting (~20MeV) e$^-$ bunch

MAX-PLANCK-GESELLSCHAFT

AWAKE

Proton-driven Plasma Wakefield Acceleration Collaboration

WHAT WE (MPP) DO IN AWAKE

Project Structure

AWAKE Collaboration
Spokesperson: Allen Caldwell
Deputy: Matthew Wing

Experiment Coordinator
Patric Muggli

- **Metal Vapor Plasma Cell WP** – Erdem Öz
- **Helicon Plasma Cell WP** – Olaf Grülke
- **Pulsed Discharge Plasma Cell WP** – Nelson Lopes (R. Tarkeshian, O. Reimann)
- **Electron Spectrometer WP** – Simon Jolly
- **Optical Diagnostics WP** – TBD (R. Tarkeshian, O. Reimann)
- **Electron Source WP** – Tim Noakes

Simulation/Theory Coordinator
Konstantin Lotov

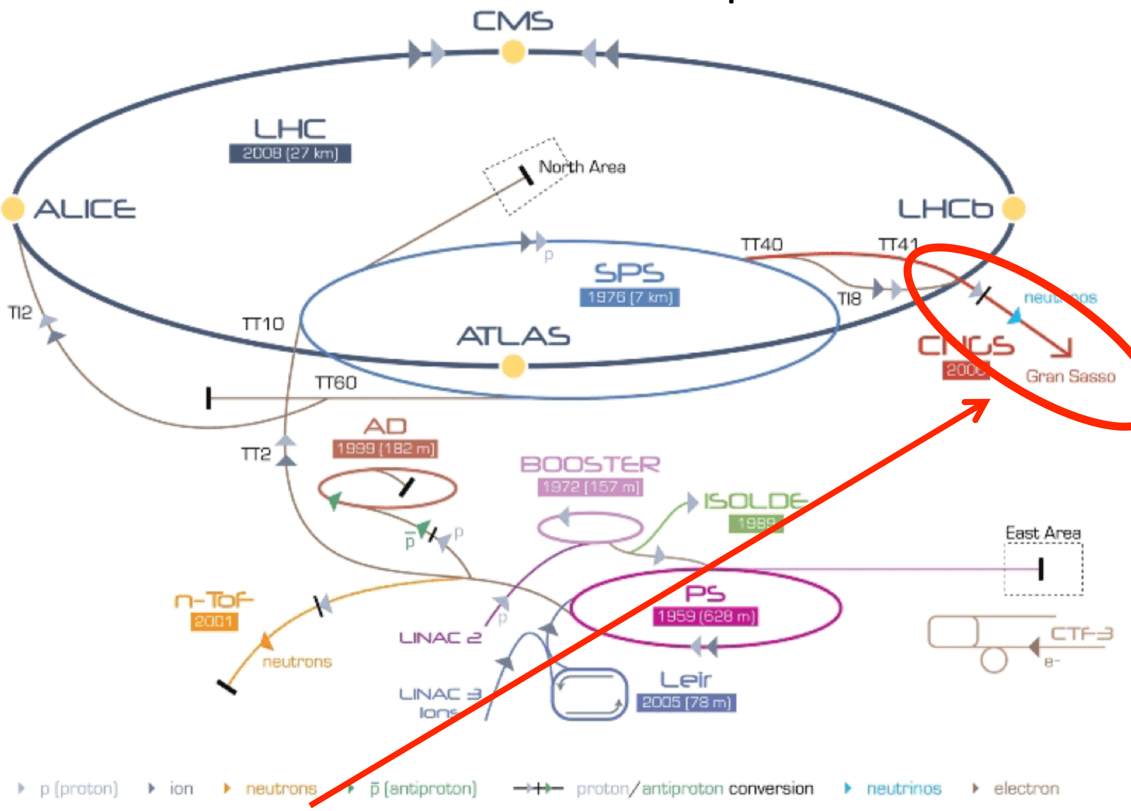
- **Simulations WP** – Konstantin Lotov

Accelerator & Infrastructure Coordinator
Edda Gschwendtner (CERN Project leader)

- **Project Management WP** – Edda Gschwendtner
- **RP and Safety WP** – Helmut Vincke
- **Experimental Area WP** – Edda Gschwendtner
  - **Interface p/e/laser/plasma WP** – Edda Gschwendtner
  - **Layout, Integration Coordination WP** – Ans Pardons
  - **Secondary Beam Diagnostics WP** – TBD
  - **General Services WP** – TBD
- **SPS Beam WP** – TBD
- **Beam-Line WP** – Chiara Bracco
  - **Proton Beam-Line WP** – Chiara Bracco
  - **Electron Beam-Line WP** – Chiara Bracco

AWAKE: Proton Beams @ CERN

CERN Industrial Beam Complex



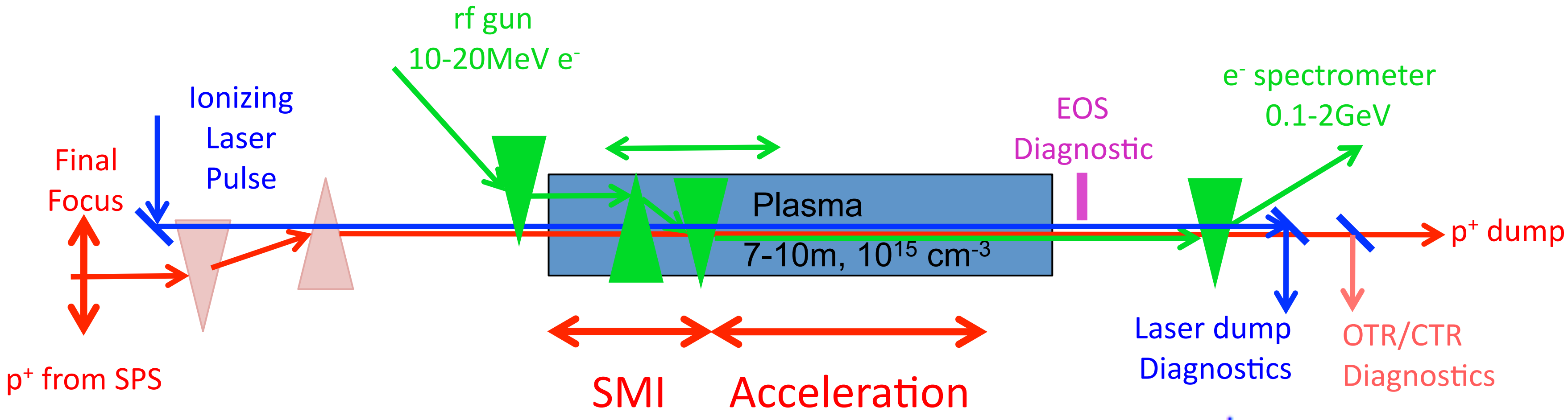
Parameter	PS	SPS	SPS Opt
E_0 (GeV)	24	450	450
N_p (10^{10})	13	10.5	30
$\Delta E/E_0$ (%)	0.05	0.03	0.03
σ_z (cm)	20	12	12
ε_N (mm-mrad)	2.4	3.6	3.6
σ_r^* (μm)	400	200	200
β^* (m)	1.6	5	5

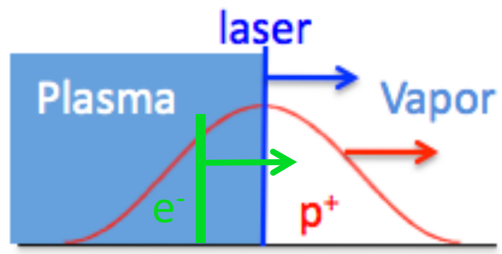
L_p~5-10m
n_e~7×10^{14}cm^{-3} ($k_p\sigma_r\approx1$)
λ_{pe}~1.3mm<<σ_z
f_{pe}~240GHz

CNGS experimental area

- Choose SPS beam
- Higher energy, lower σ_r^*, longer β^*
- Initial goal: ~GeV gain by externally injected e^-, in 5-10m of plasma in self-modulated p^+ driven PWFA

BASE-LINE EXPERIMENTAL SETUP

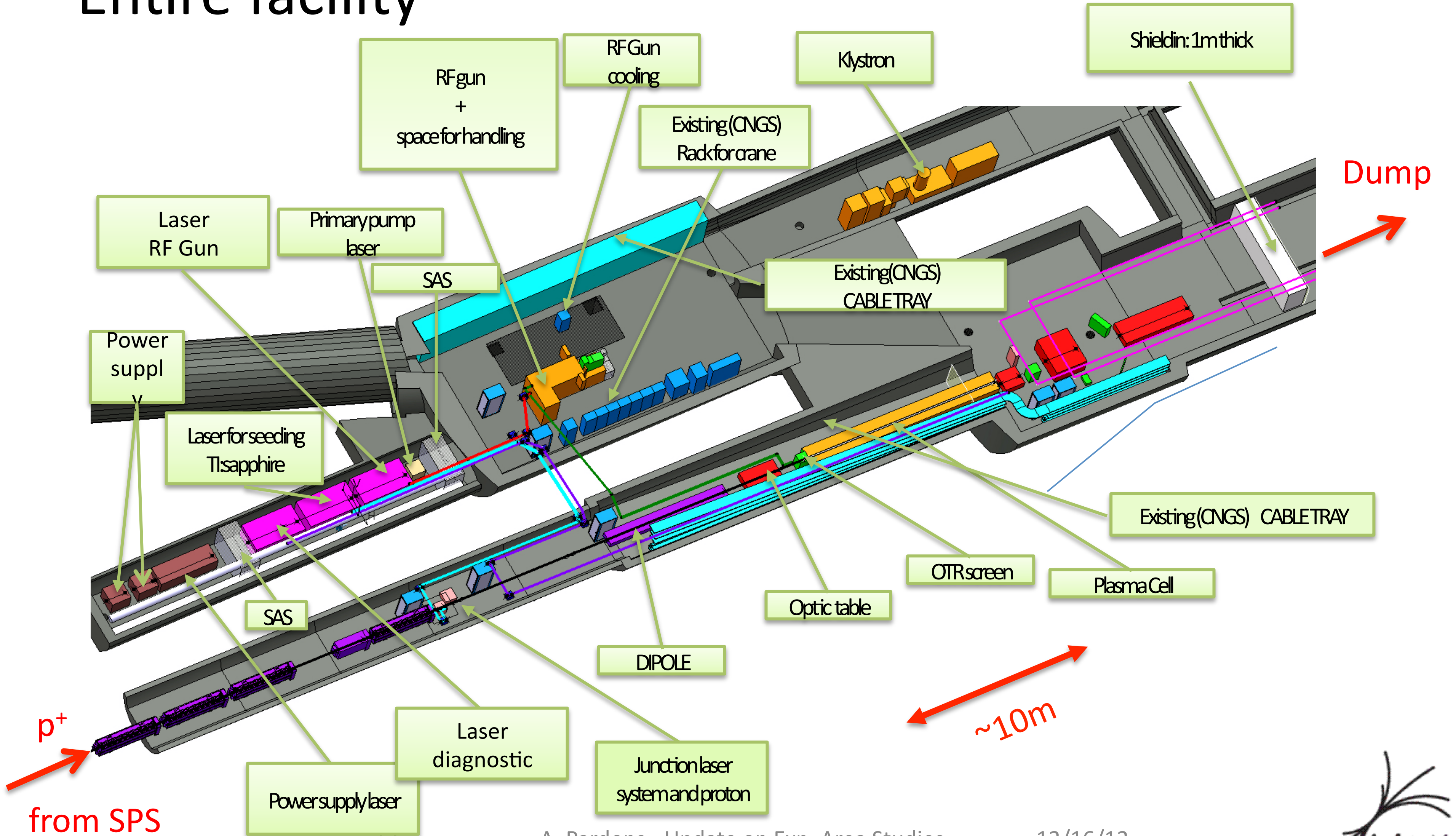




- Laser ionization of a metal vapor (Li, Rb, etc.), 7-10m plasma, $n_e=10^{14}$-$10^{15}cm^{-3}$
- Injection of 10-20MeV test e- at the 3m point (SMI saturated, $v_{\phi}=v_{p+}$)
- SMI-acceleration separated
- 0.1-2GeV electron spectrometer
- OTR + streak camera, electro-optic sampling for p^+-bunch modulation diag.
- Goal: study SMI physics and accelerate a witness e^--bunch to multi-GeVs in a self-modulated p^+-driven PWFA

Awake in CNGS

- Entire facility



What Do We Do?

- Lead the experimental program
- Coordinate the experiment
- Develop the laser-ionized, metal vapor (Rb) plasma source (E. Oz, P. Muggli)
- Develop beam and plasma diagnostics (R. Tarkeshian, S. Mandry, O. Reimann)
- Strongly interact with the “simulationists” (J. Vieira, K. Lotov, A. Pukhov)

Broad Timeline

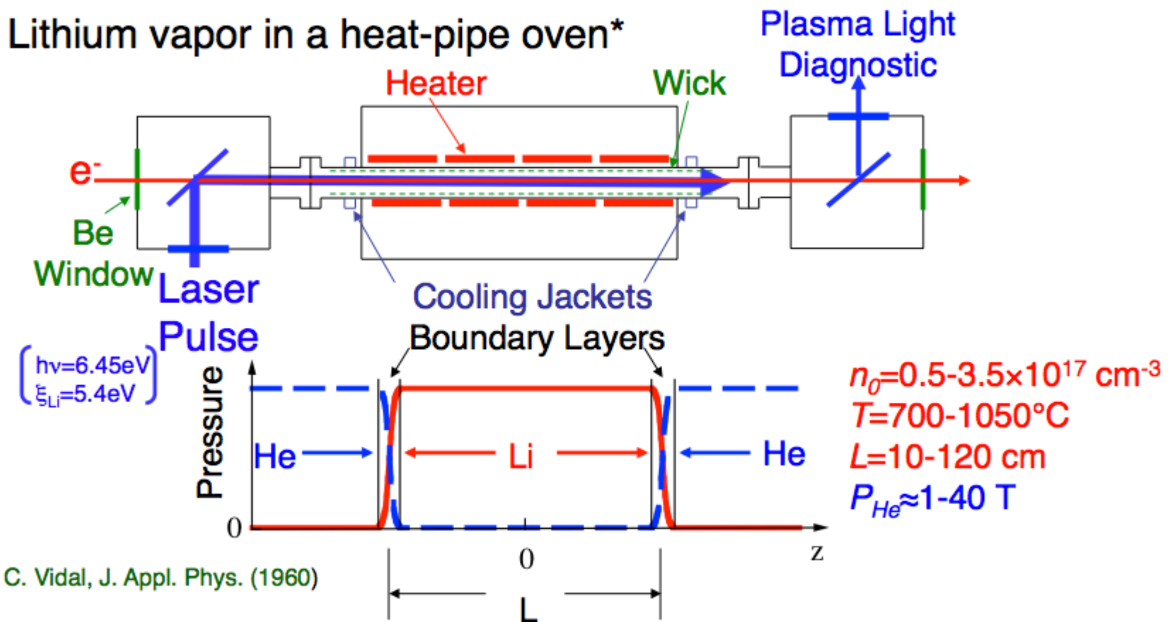
- Early 2012, letter of intent was favorably review by CERN SPSC and resources committee, CERN project leader was chosen: Edda Gschwendtner
- Conceptual design report due in March 2013
- Experiments start in 2015 in CNGS area

METAL VAPOR PLASMA SOURCE DEVELOPMENT

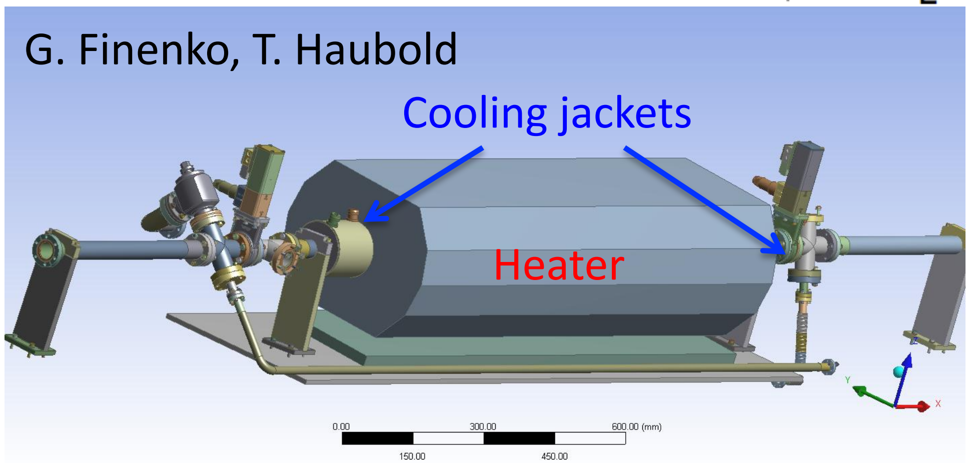
E.Oz, P. Muggli

P. Muggli *et al.*, IEEE Trans. on Plasma Sci. 27, 791 (1999).

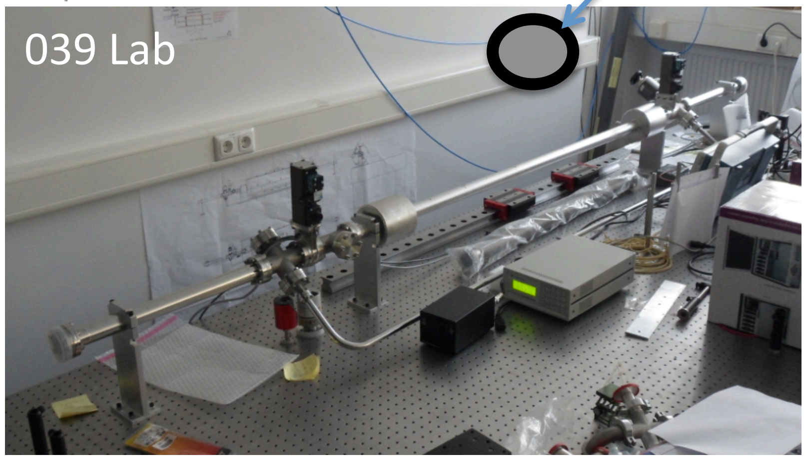
- Lithium vapor in a heat-pipe oven*



* C. Vidal, J. Appl. Phys. (1960)



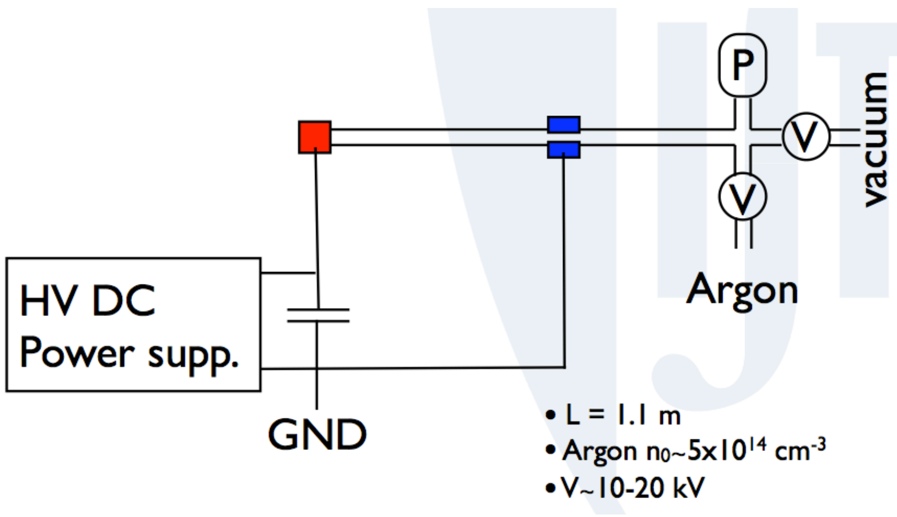
Hole in the wall for laser beam from 038

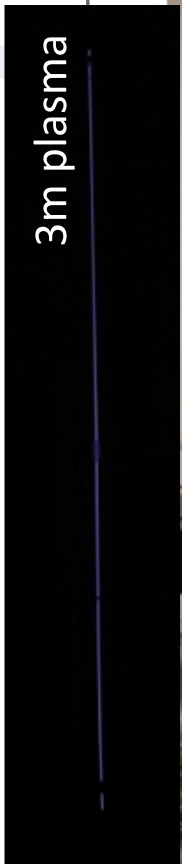


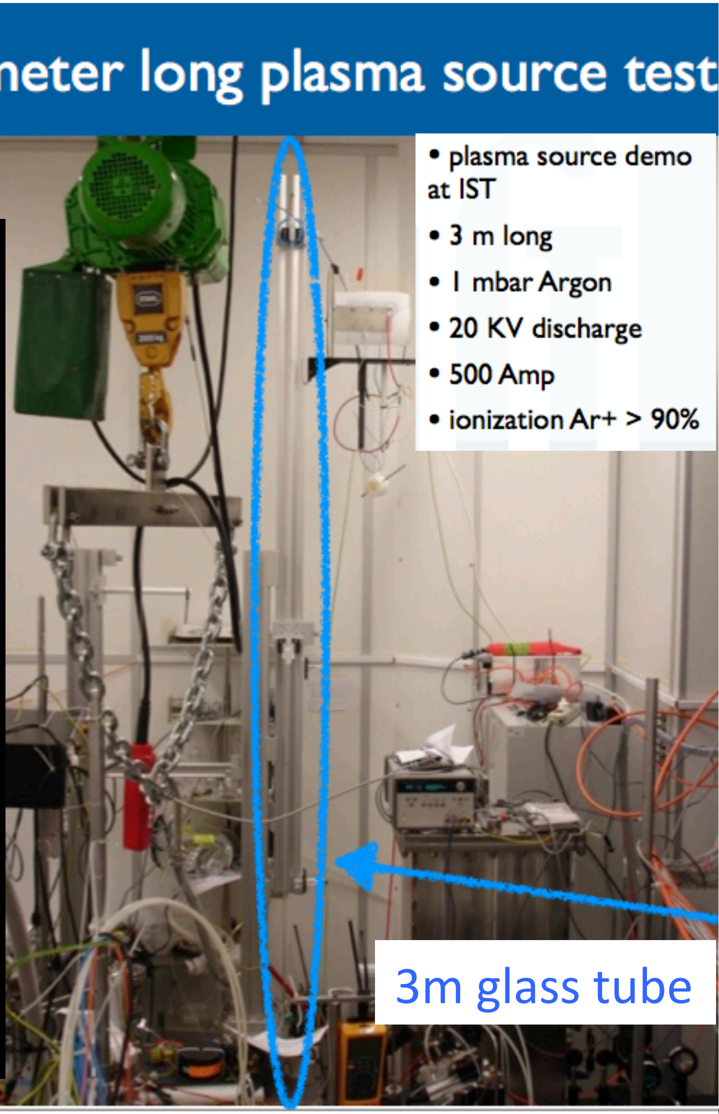
- Plasma produced by laser ionization of the rubidium vapor

DISCHARGE PLASMA SOURCE DEVELOPMENT

N. Lopes IST Portugal, O. Reimann, R. Tarkeshian

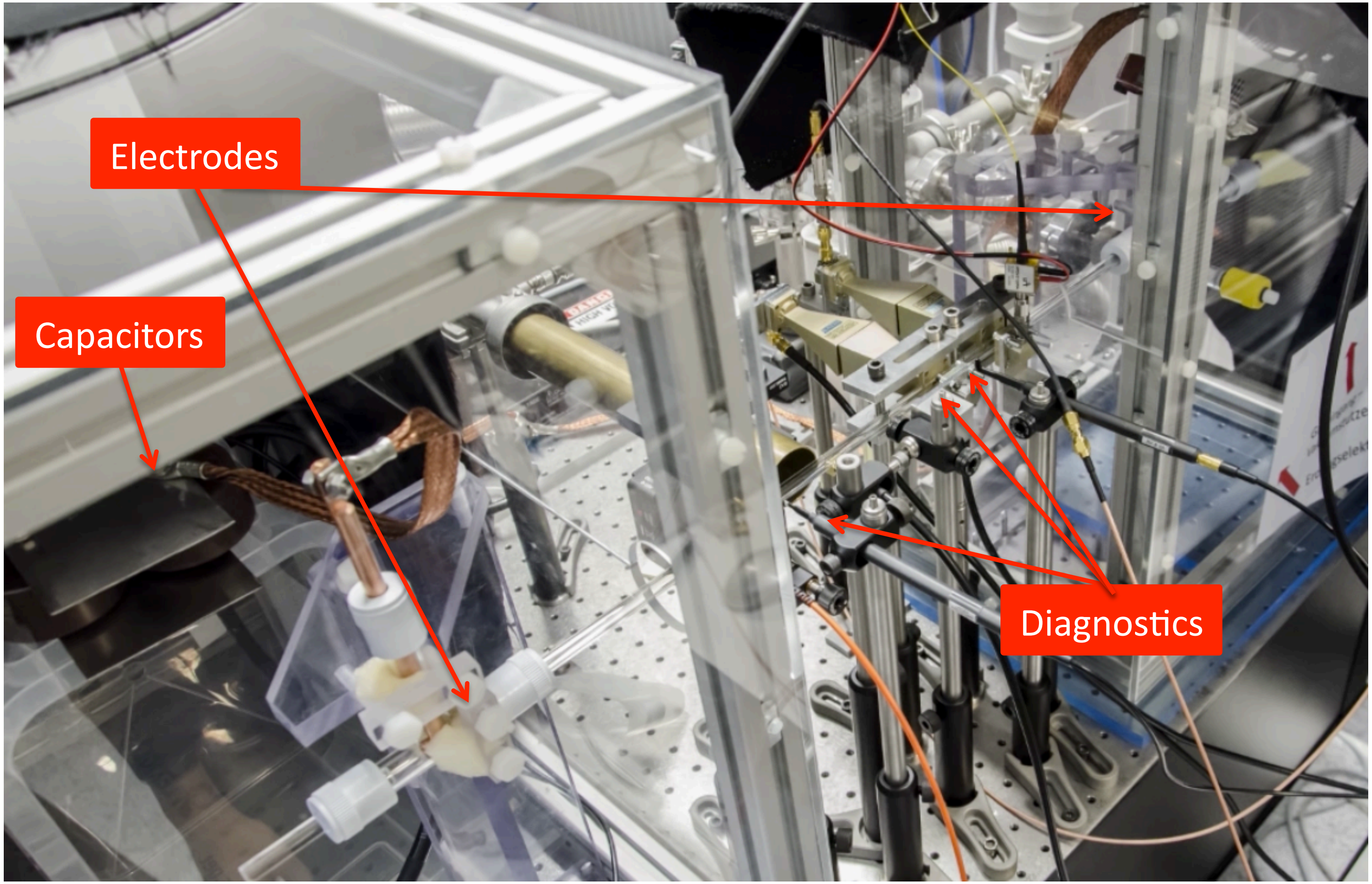




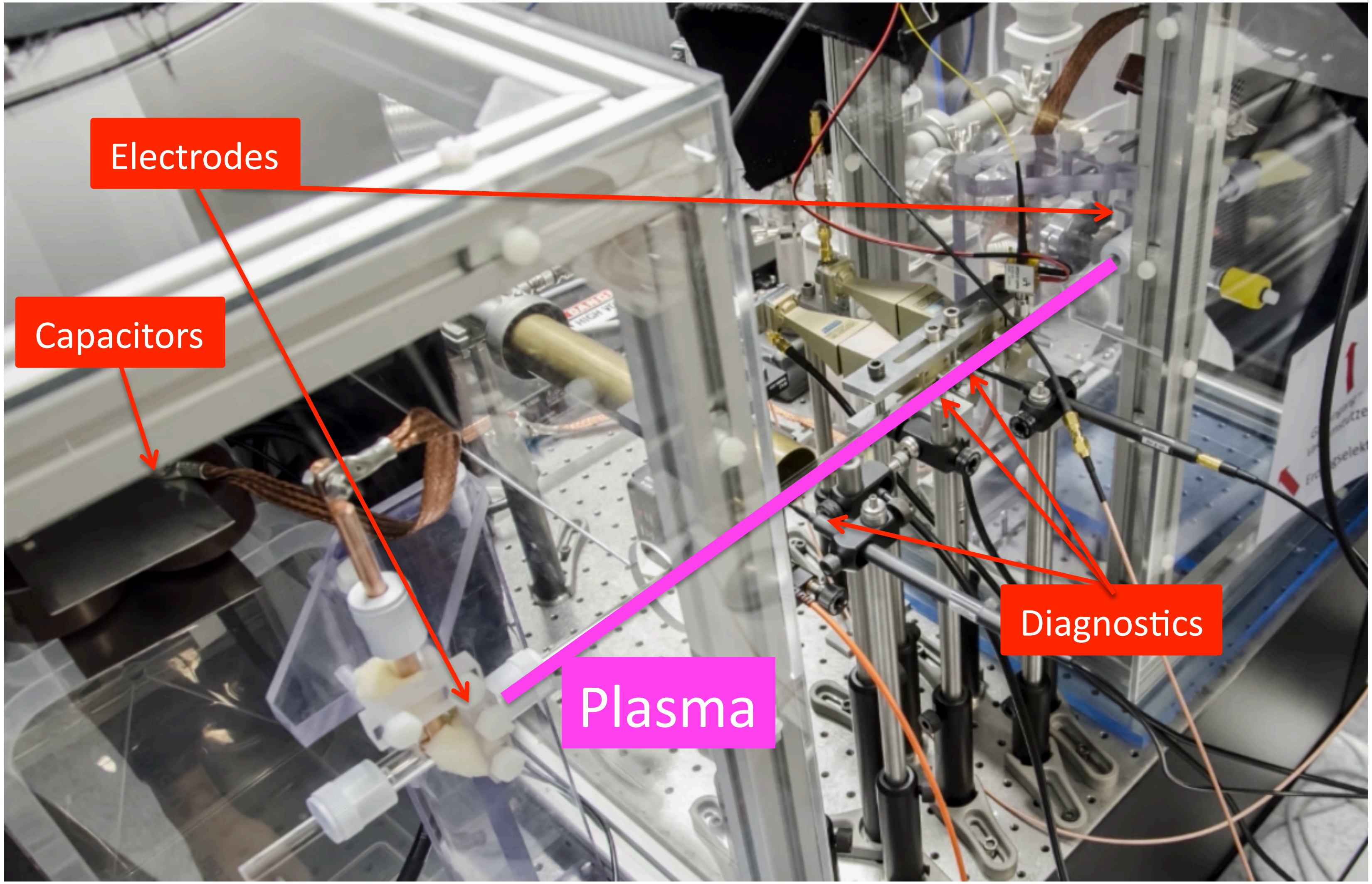


- "Low tech" source
- "Can be meters-long
- Challenges: reproducibility, plasma density uniformity

DISCHARGE PLASMA SOURCE DEVELOPMENT

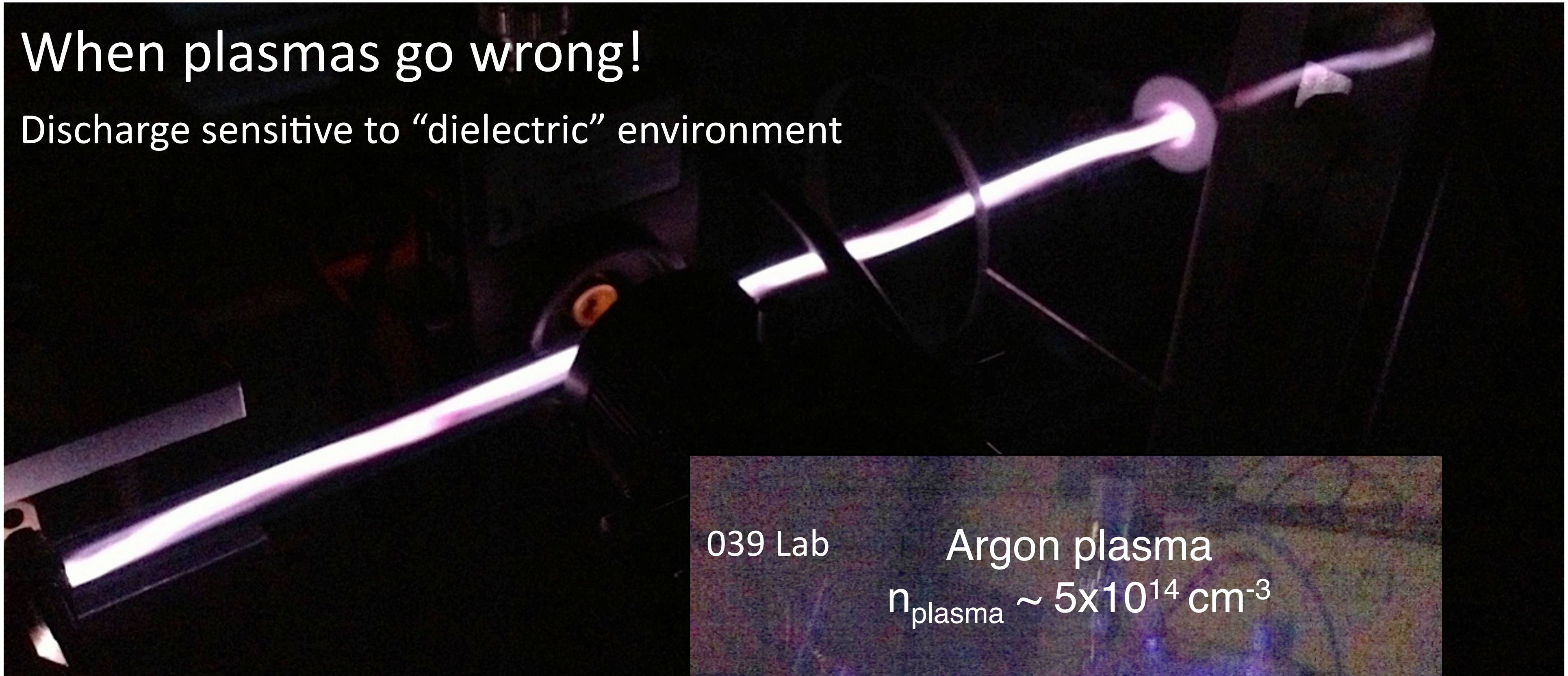


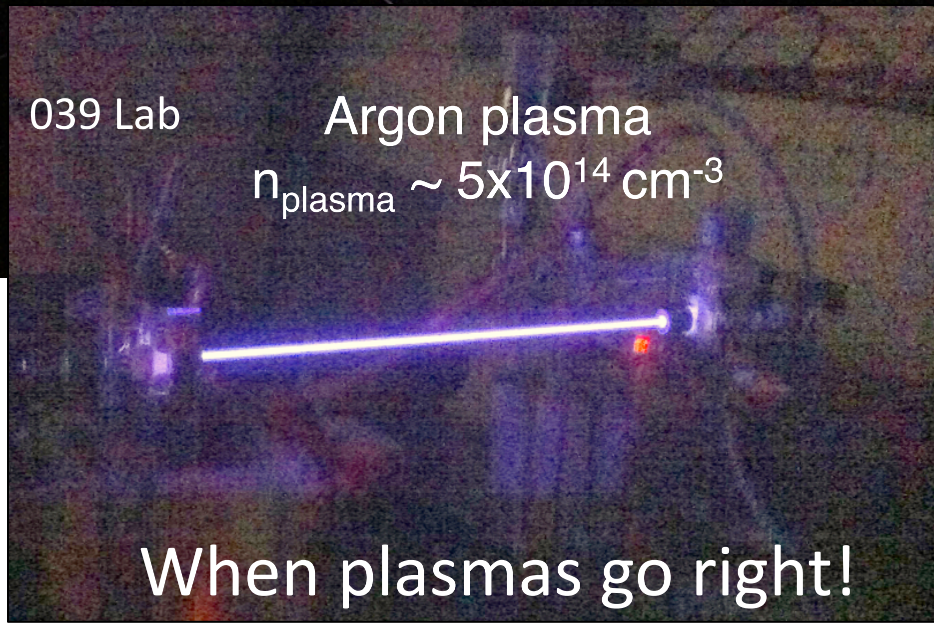
DISCHARGE PLASMA SOURCE DEVELOPMENT



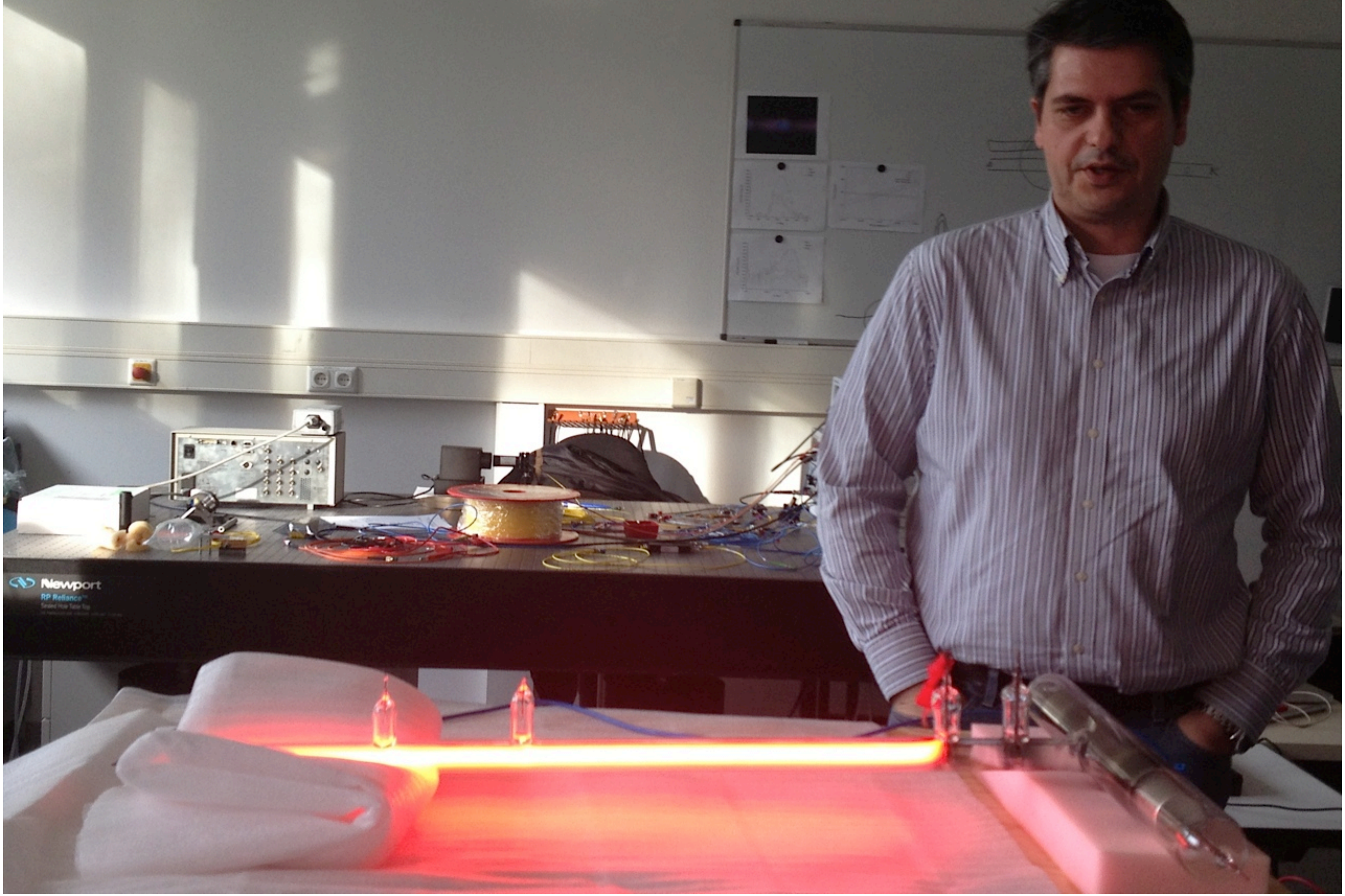
When plasmas go wrong!

Discharge sensitive to “dielectric” environment



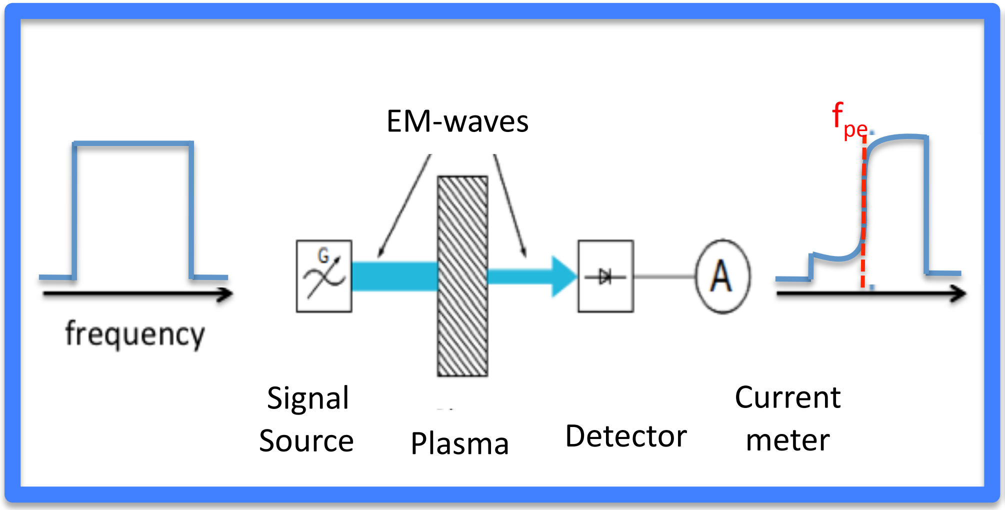


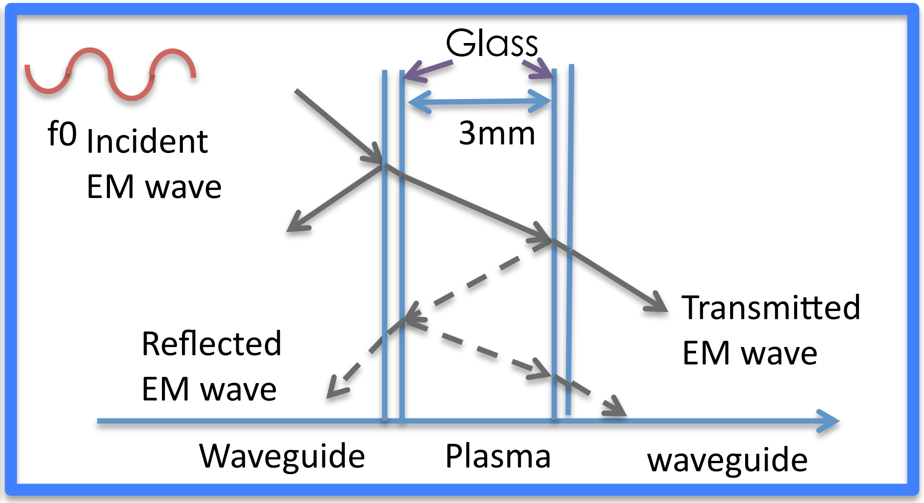
Low DC plasma discharge (n_e~10^{11}-10^{12}cm^{-3}) for diagnostic development
(O. Grulke, MPI Greifswald)



BEAM &-PLASME DIAGNOTICS

O. Reimann, R. Tarkeshian, S. Mandry



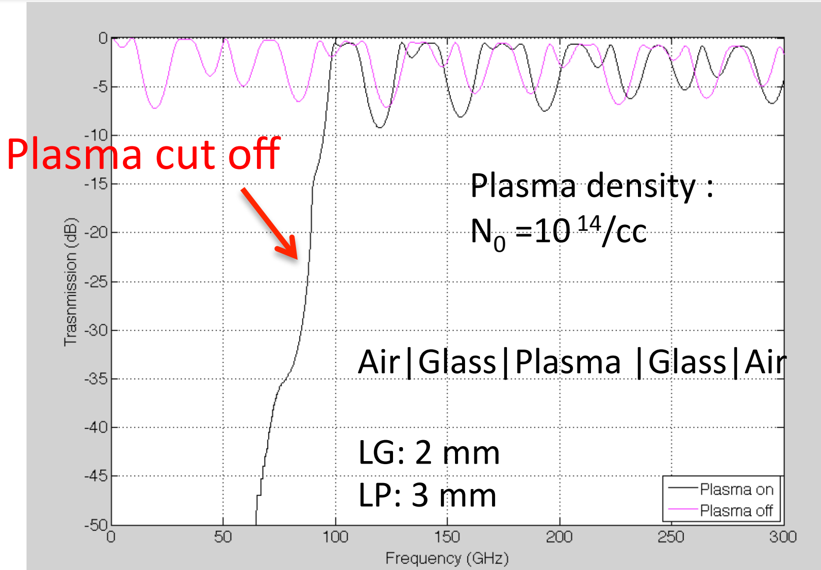


$\omega_{pe}=(n_e e^2/\varepsilon_0 m_e)^{1/2}$

$$\varepsilon = 1 - \frac{\omega_P^2}{\omega^2+\nu^2} + i\frac{\nu}{\omega}\frac{\omega_P^2}{\omega^2+\nu^2}$$

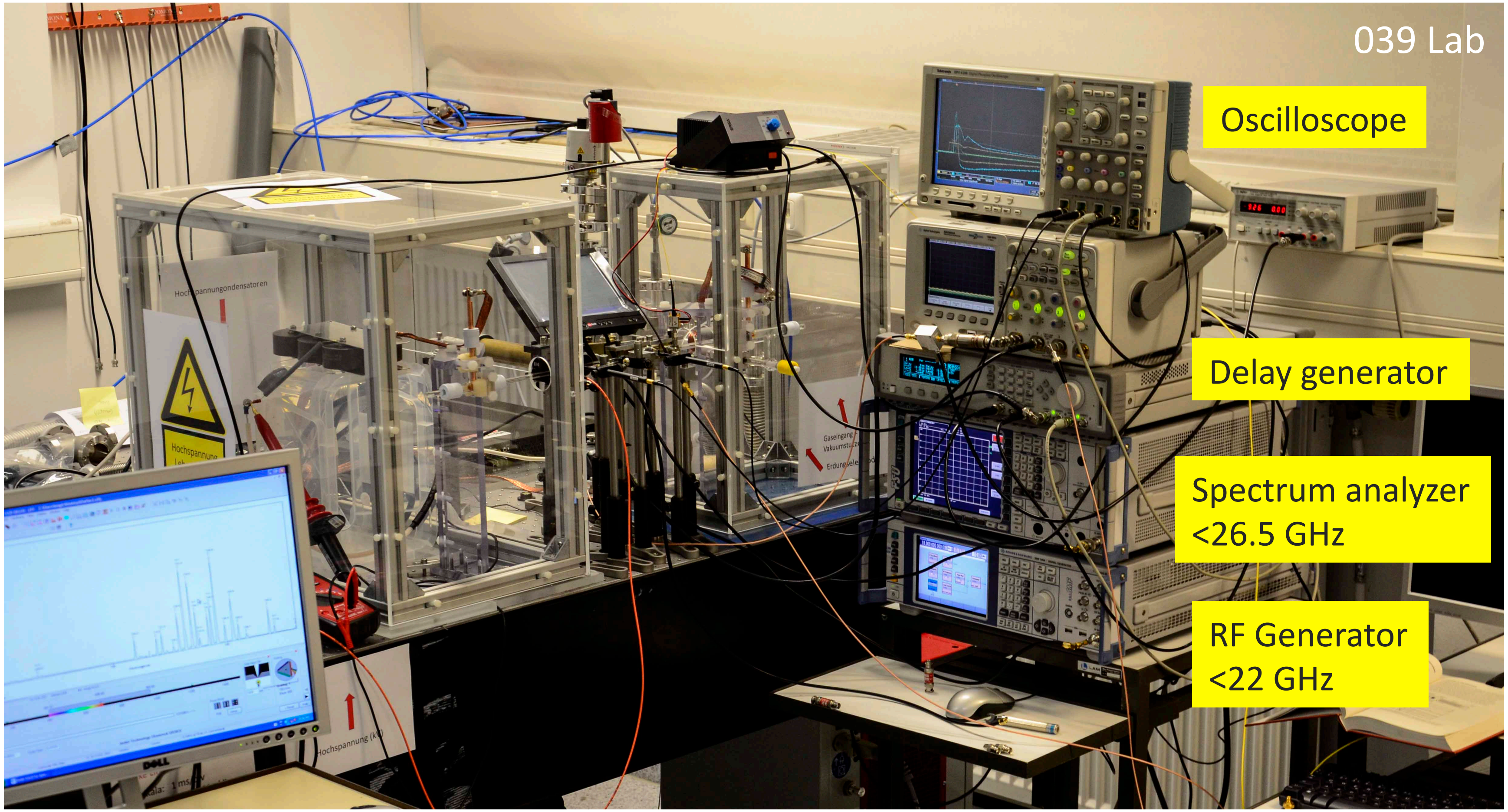
$T(\omega)$:
- 0 if $\omega \ll \omega_{pe}(n_e)$
- Cut off $\omega=\omega_{pe}$
- 1 if $\omega \gg \omega_{pe}(n_e)$

n_e (1/cm³)	f_{pe} (GHz)
7e14	237.5
3e13	50
9e12	26
1e11	2.8



- Develop THz radiation diagnostics for plasma density and p^+ bunch modulation

Experimental setup



- Frequency Difference generation with two laser pulses to generate f_0:
  FDG(193THz+f_0;193THz) -> 5GHz$<f_0<$1THz
- Plasma optical diagnostics, time and frequency resolved

SUMMARY

- We have an exciting experimental program
- We have a well qualified and fun team
- We are pushing to get AWAKE approved at CERN
- CDR due in March 2013
- Hope for experiments in 2015 at the CNGS experimental area
- Goal of these experiments: - Study the SMI of long p^+ bunches in dense plasmas
  - Accelerate a witness e^--bunch to GeVs in a plasma
- Goal of the program: build a complete research program in high-gradient, plasma-based accelerators as well as in beam-plasma interaction at CERN
- Approved experiment to study the SMI of e^- and e^+ bunches at SLAC FACET, 2013
- New ideas? New people? Call us: 0800-be-AWAKE


Is a new accelerator born?
Thank you to everyone at MPP!
Merry Christmas and Happy New Year
from the Future Accelerators Group!