Indirect measurement of the Seeded Self-Modulation in the AWAKE experiment at CERN

M. Turner and the AWAKE collaboration

Outline

- ❏ Introduction to the idea and physics behind AWAKE

- ❏ The seeded self-modulation

- ❏ The measurement setup

- ❏ Results of the measurements

- ❏ Summary

What is AWAKE?

- AWAKE stands for: **A**dvanced Proton Driven Plasma **Wak**efield **E**xperiment.

- AWAKE is a R&D project to study proton driven plasma wakefields at CERN.

- **Final Goal:** Design high quality & high energy electron accelerator based on acquired knowledge.

Plasma wakefield

Laser

400 GeV/c protons

A.Petrenko (CERN)
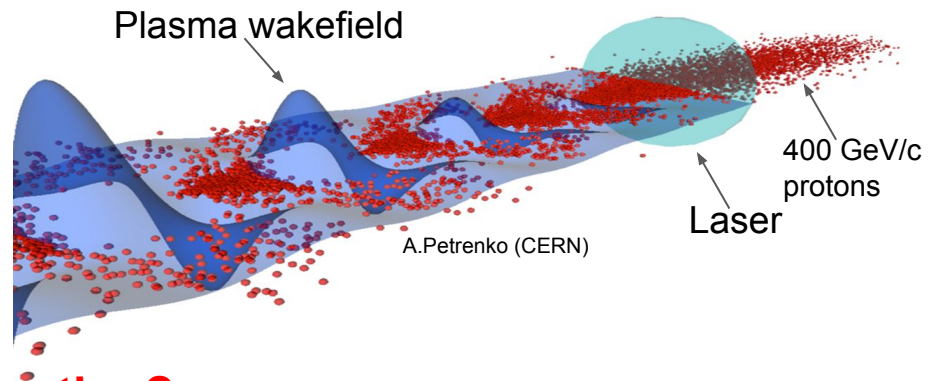
Why is plasma wakefield acceleration interesting?

$$eE_{max} \approx 1\,[\text{eV/cm}] \cdot n^{1/2}\,[\text{cm}^{-3}]$$

$$\lambda_{pe} \approx 1\,\text{mm} \sqrt{\frac{10^{15}\,\text{cm}^{-3}}{n_{pe}}}$$

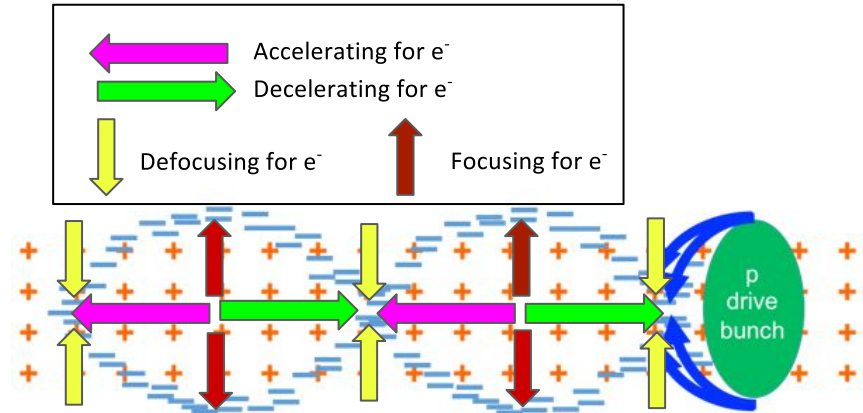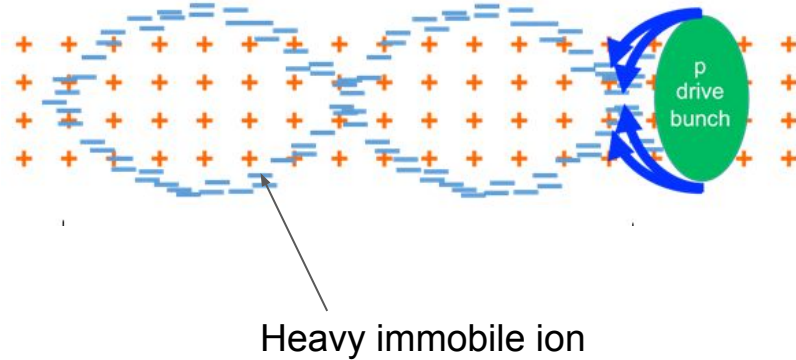i.e. 1 GeV/m for a plasma density (n) of 10^{14} electrons/cm^3.

For LWFA: n~10^{18} electrons/cm^3
$\Rightarrow$ 100 GeV/m

Larger plasma e⁻ density implies smaller plasma e⁻ wavelength
$\Rightarrow$ smaller structures

Physics Behind AWAKE

What are plasma wakefields?

Fields sustained by a plasma wave.

Heavy immobile ion

$$\lambda_{pe} \approx 1 \text{ mm} \sqrt{\frac{10^{15} \text{ cm}^{-3}}{n_{pe}}}$$

⇒ defines the optimal drive bunch length

How do we create the AWAKE plasma?

Rubidium vapour density: 7×10^{14} /cm^3
Ionizing laser pulse: 100 fs, 400 mJ

$\Longrightarrow$ 10 m long plasma with a radius of ~ 1 mm

The Seeded Self-Modulation

Why protons?:

Lasers: ~40 J/pulse, electron drive beam: 30 J/bunch, proton drive beams: SPS 19 kJ/pulse, LHC 300 kJ/bunch.

⇒ In order to create plasma wakefields effectively, the **drive bunch length** has to be in the order of the **plasma wavelength**. --> mm scale proton bunches do not exist.

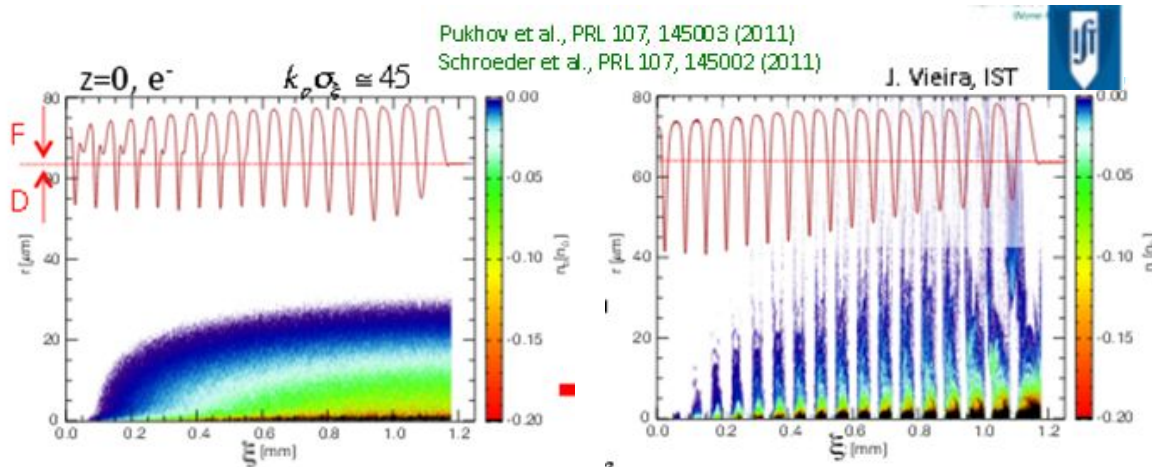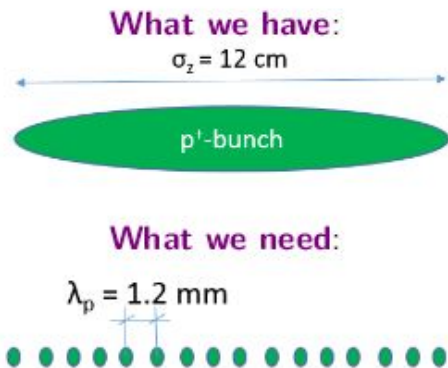**CERN SPS proton bunch: very long!**

Longitudinal beam size (σ_z = **12 cm**) much longer than plasma wavelength **(λ_{pe} ~ 1mm, n_{pe} = 7 x 10^{14} e^-/cm^3)**, eE_{max} = 2.5GV/m
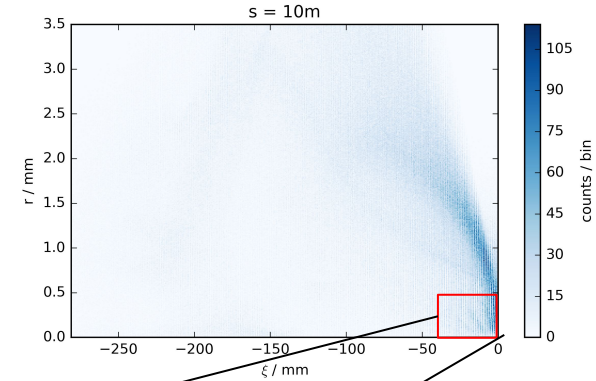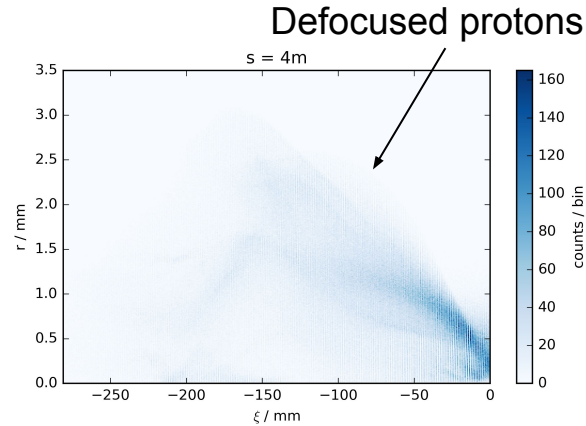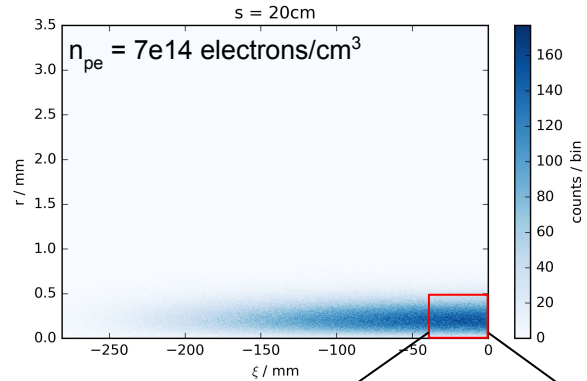
⇒ **Seeded Self Modulation (SSM)**

The measurement of the SSM is the main topic of this talk!

Micro-bunches can then resonantly drive the plasma wave.

Pukhov et al., PRL 107, 145003 (2011)
Schroeder et al., PRL 107, 145002 (2011)

J. Vieira, IST

5

SSM Simulation Results
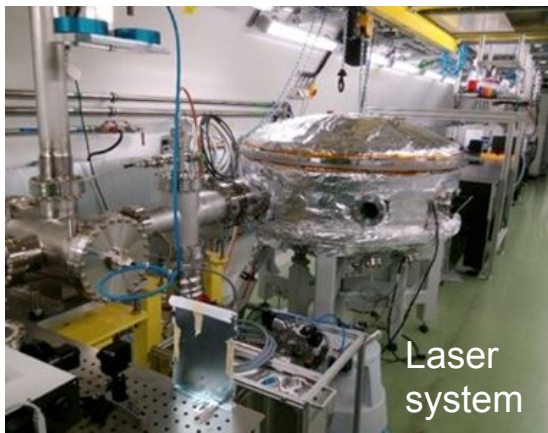

Defocused protons

$n_{pe} = 7e14$ electrons/cm^3

Zoom into the front:
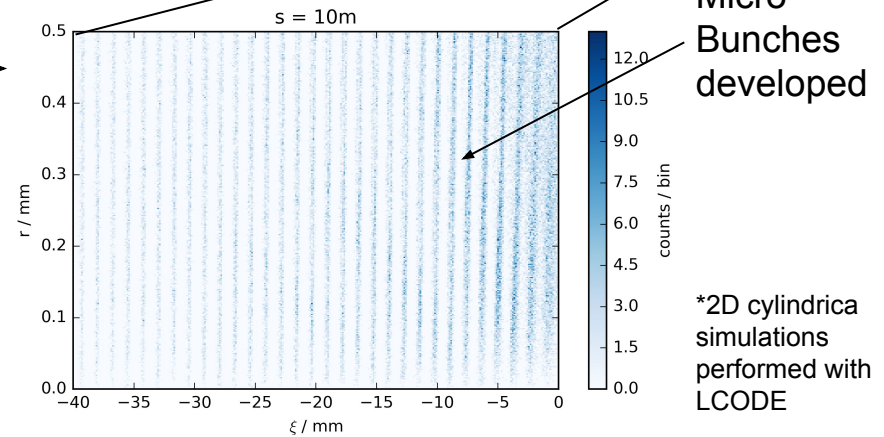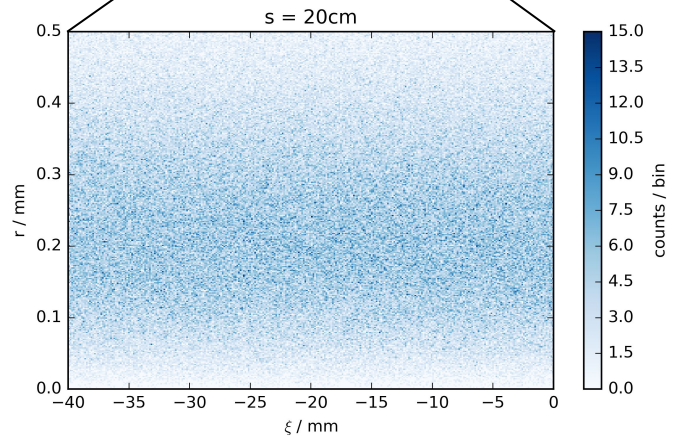
Micro-Bunches developed
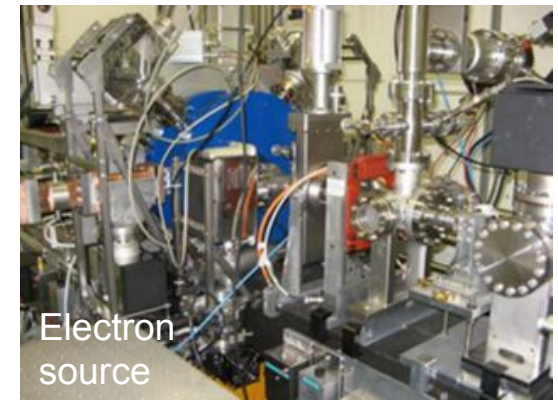
*2D cylindrica simulations performed with LCODE

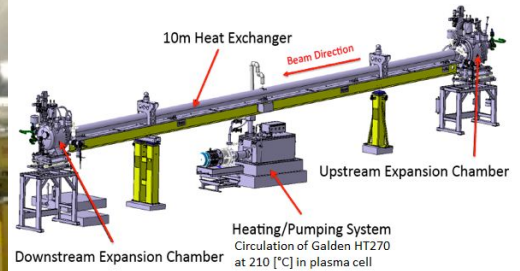# Components of the R&D Proton Driven Plasma Wakefield Accelerator

❏ Rubidium vapor
❏ Laser

10 m of plasma

❏ Proton beam (400 GeV/c)

⇒ **Driver**

❏ Electron beam (10-20 MeV)

⇒ **Witness**

❏ **Diagnostics!**
   ❏ Proton
   ❏ Laser
   ❏ Electron

Laser system

Plasma source

Electron source

10m Heat Exchanger

Beam Direction

Upstream Expansion Chamber

Heating/Pumping System
Circulation of Galden HT270
at 210 [°C] in plasma cell

Downstream Expansion Chamber
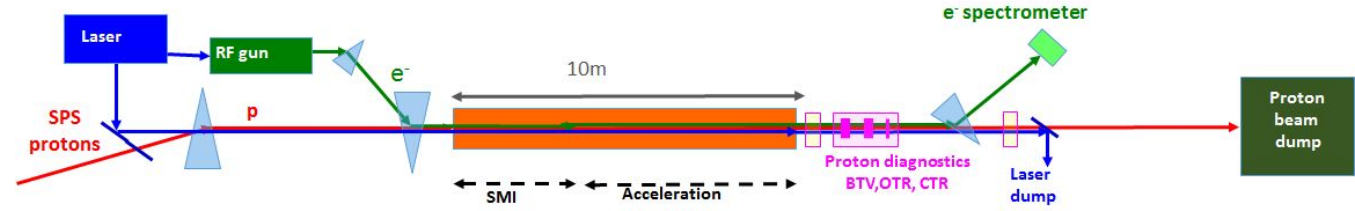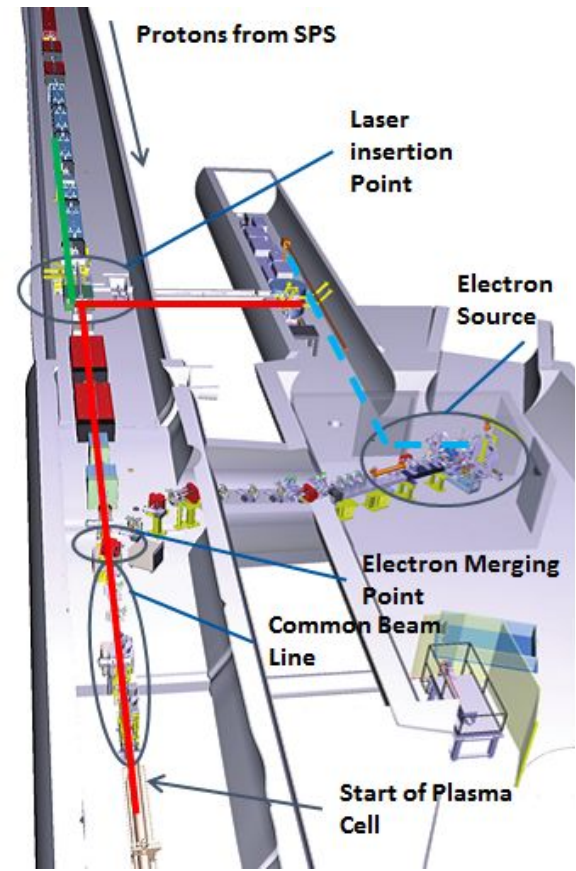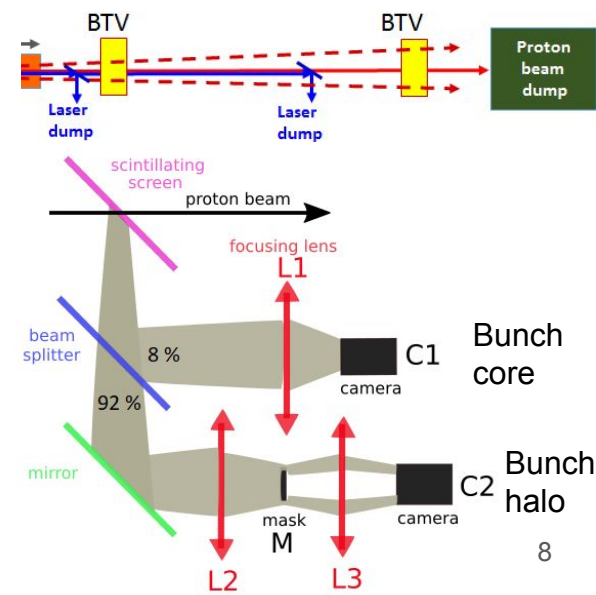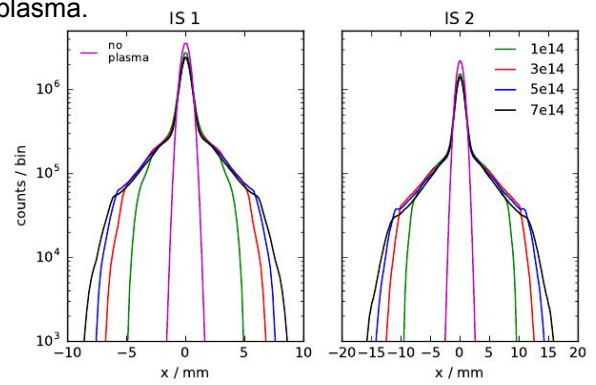
750m proton beam line

The Measurement Setup

SSM two-screen measurement:

Two imaging stations to measure the radial proton beam distribution 2 and 10 m downstream the end of the plasma.

Goal: Image protons that got defocused by the strong plasma wakefields
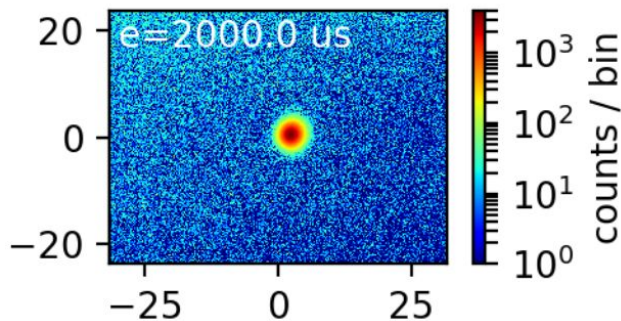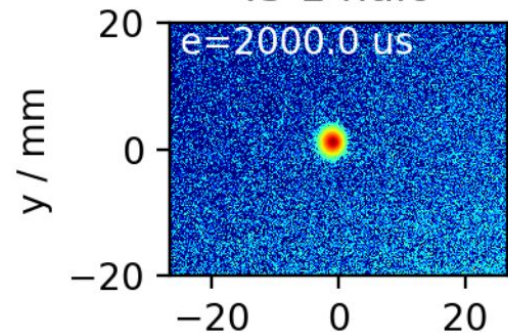To prove that plasma wakefields were present in plasma.

Two-Screen Measurement Results
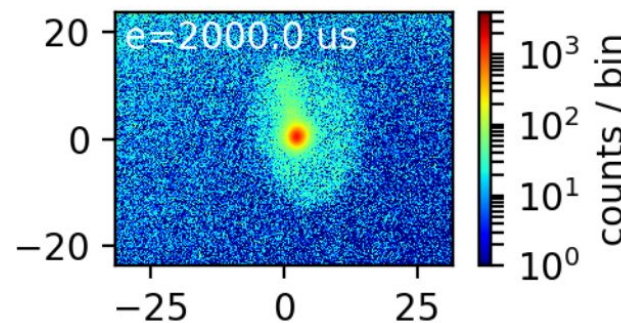
Laser off:

Laser on:

Preliminary!

Plasma density:

- ❏ **2.1e14/cm³**
- ❏ **Same filter**
- ❏ **Same camera exposure time**
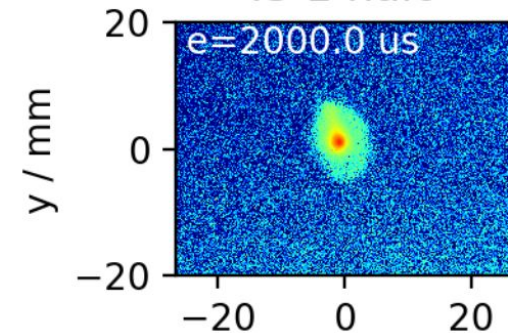
We observe:

- ❏ Defocused protons

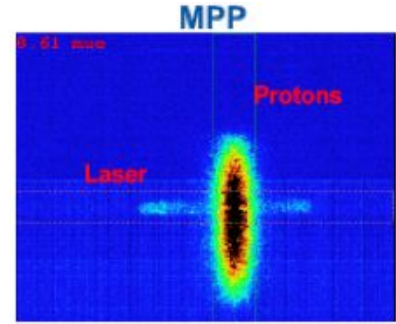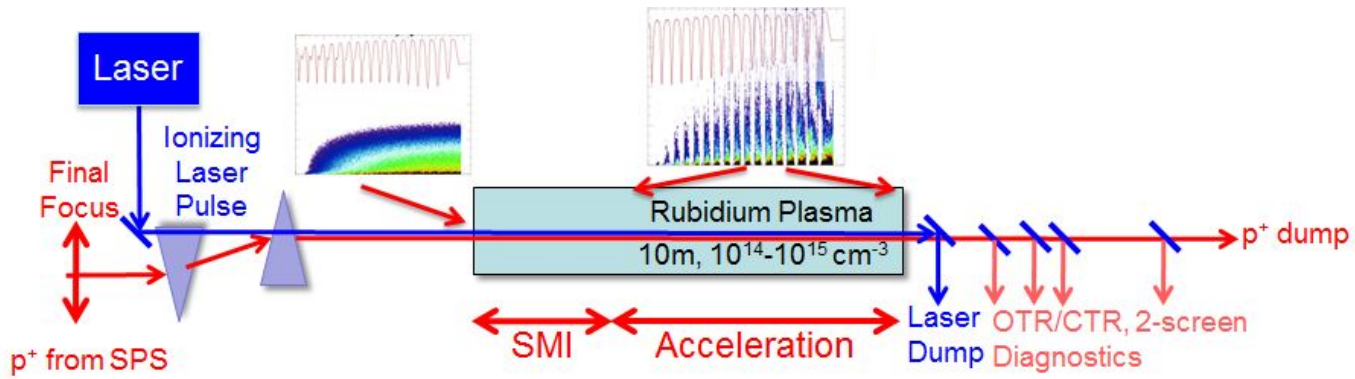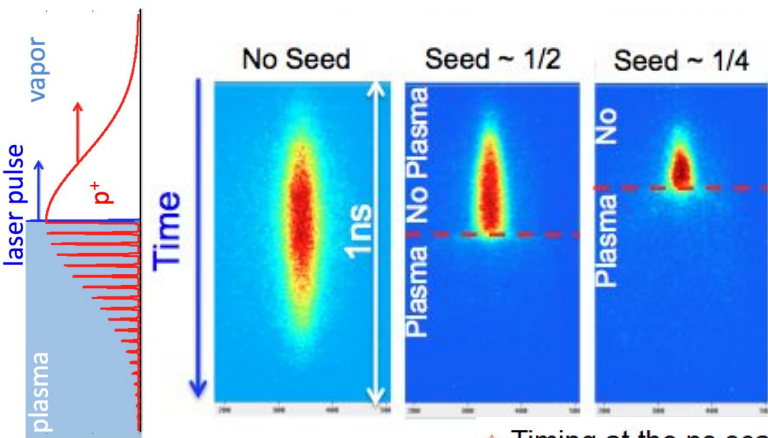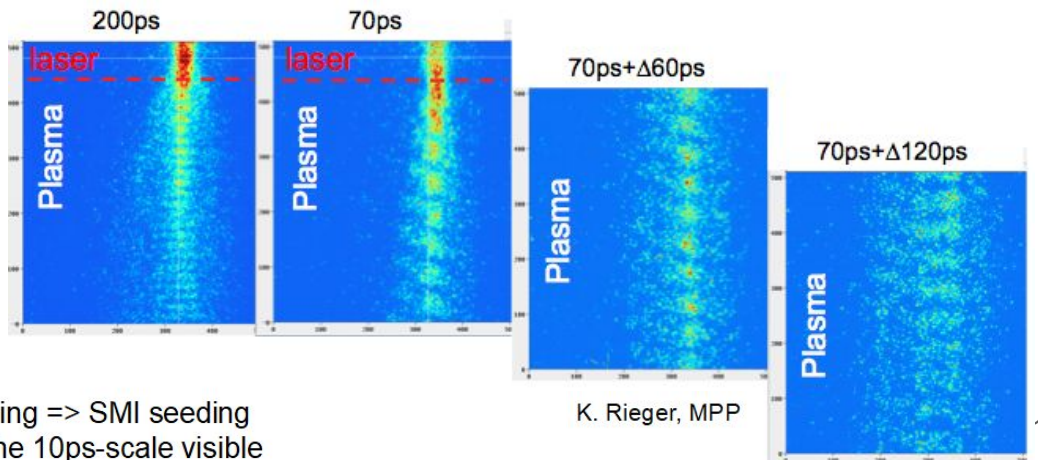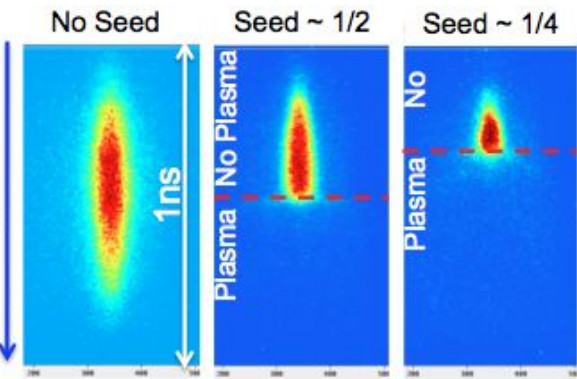- ❏ Intensity drop of the beam core

Other Diagnostics Results

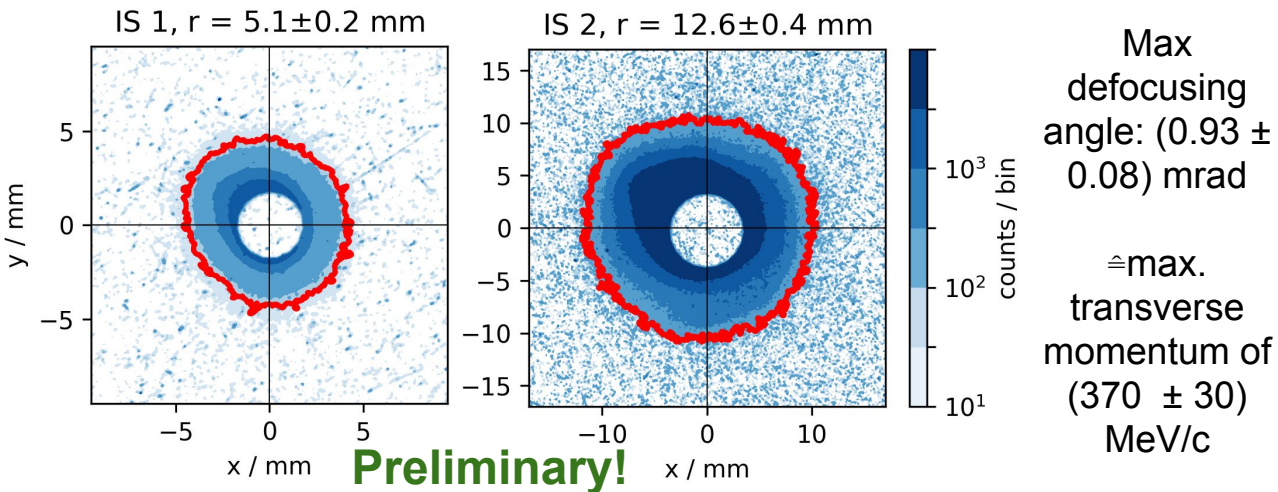Streak camera measurement of the timing between the proton and laser pulse.

Preliminary!

K. Rieger, MPP
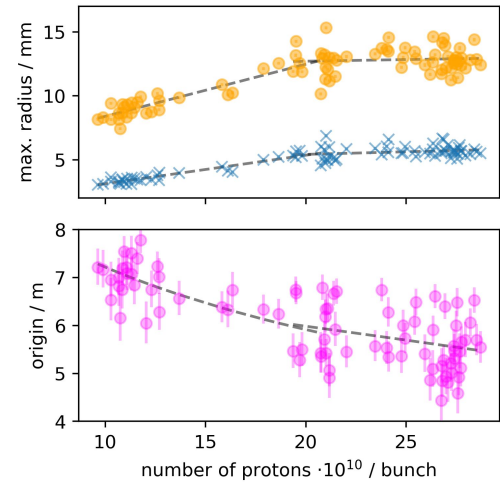
- ✧ Timing at the ps scale
- ✧ Effect starts at laser timing => SMI seeding
- ✧ Density modulation at the 10ps-scale visible

Growth of the Seeded Self-Modulation

IS 1, r = 5.1±0.2 mm   IS 2, r = 12.6±0.4 mm

Preliminary!

Max defocusing angle: (0.93 ± 0.08) mrad

≙max. transverse momentum of (370 ± 30) MeV/c

Further analysis to learn about SSM physics

The total transverse momentum is a sum of the:
- Initial transverse momentum: ~20 MeV/c (known from emittance and beam size at the waist).
- Average wakefield strength times the interaction distance of the proton with the wakefield.

The transverse seed wakefield amplitude is ~10 MV/m over 10 m plasma ⇒ 100 MeV/c.

Since 370 MeV/c is larger than 120 MeV/c, **the wakefield strength grew and the SSM developed**.

Summary

- ❏ AWAKE is a **R&D project** to study proton-driven plasma wakefields at CERN. AWAKE uses for the first time ever protons to drive plasma wakefields.

- ❏ The **plasma** is created by ionizing 10 m of rubidium vapour with a laser pulse and wakefields are driven by the self-modulated, 400 GeV/c proton bunch.

- ❏ AWAKE results show that the proton bunch **self-modulates** within less than the 10 m of plasma and that the wakefields are larger than the initial seed wakefields.

- ❏ Two-screen diagnostics gives access to SSM physics

- ❏ Electron **acceleration** planned for 2018.