1. Introduction – why do we need new technologies?

2. Plasma Wakefield Acceleration
   a) In general
   b) Beam driven
   c) CERN demonstration experiment for proton-driven PWA

Allen Caldwell
Max-Planck-Institut für Physik
The nuclear structure story ...

Rutherford

Few MeV alpha particles

SLAC-MIT, ...

7-18 GeV electrons

HERA:

high resolution proton structure measurements

27.5 GeV electrons

920 GeV protons

The nuclear structure story ...
The most important tool in this story was the particle accelerator.
Particle physicists are convinced there are more discoveries to come:

Standard Model not consistent without the Higgs particle – expect to discover at LHC

Many things not explained in the standard model:

- why three families
- matter/antimatter imbalance
- neutrinos and neutrino mass
- hierarchy problem/unification
- dark matter
- dark energy
- ...
Beyond the Standard Model...

Supersymmetry

Extends symmetries (fermion-boson symmetry)
→ possible candidate for dark matter
→ unification of forces at extremely high energies
→ >1/2 the particles have not been seen [and still no sign at LHC]
Superstrings? Smallest objects are not point-like but finite-dimensional. 10 space dimensions, 3 are discovered. Most of the others small, invisible. Some large extra dimensions?
Practical limit for accelerators at the energy frontier: Project cost increases as the energy must increase! New technology needed...

The Livingston plot shows a saturation ...
Why a Linear Electron Collider or Muon Collider?

But, charged particles radiate energy when accelerated.

**Power α (E/m)^4**

Need linear electron accelerator or m large (muon 200 heavier than electron)
Linear Colliders are expensive with today’s gradients

$e^+e^- \text{ collisions at } 500-1000 \text{ GeV}$

$>30 \text{ km, } > 10G\$$
Acceleration of Electrons in a Plasma Wave


Original proposal – use a laser

\[ eE_{\parallel} \approx mc\omega_p \cdot \frac{\delta n}{n} \sim 1 \text{ TeV/m} \]

\[ \omega_p^2 = \frac{4\pi n_pe^2}{m} \quad k_p = \frac{\omega_p}{c} \]

\[ \lambda_p = \frac{2\pi}{k_p} = 1mm \sqrt{\frac{1 \cdot 10^{15} \text{ cm}^{-3}}{n_p}} \]
GeV Beam Generation

312 μm diameter and 33 mm length capillary

1 GeV beam: $a_0 \sim 1.46$ (40 TW, 37 fs)

Laser Wakefield Acceleration

Divergence

Energy spectrum

Divergence (rms): 2.0 mrad
Energy spread (rms): 2.5%
Resolution: 2.4%
Charge: $>30.0$ pC
But – Acceleration is **DEPLETION-LIMITED**
i.e., the lasers today do not have enough energy to accelerate a
bunch of particles to very high energies

e.g.,

\[ 10^{10} \text{ electrons} \cdot 10^{12} \text{ eV} \cdot 1.6 \cdot 10^{-19} \text{ J/eV} = kJ \]

This is orders of magnitude larger than what can be done today.

If use several lasers – need to have relative timing in the 10’s of fs range
Many stages, effective gradient reduced because of long sections
between accelerating elements ...
Strawman design of a TeV LPA Collider

Leemans & Esarey, Physics Today, March 2009
I) Generate homogeneous plasma channel:

Ionization of gas via:
- Laser
- Beam
- RF

II) Send dense relativistic electron beam towards plasma (E field radial in rest frame of plasma):

Beam density $n_b$
Gas density $n_0$
III) Excite plasma wakefields:

Electrons are expelled

Space charge force of beam ejects plasma electrons promptly along radial trajectories
Positively charged channel is left
Electron motion solved with ...

**driving force:** Space charge of drive beam displaces plasma electrons.

**restoring force:** Plasma ions exert restoring force

Longitudinal fields can **accelerate** and **decelerate**!

**Plasma also provides super-strong focusing force!**
*(many thousand T/m in frame of accelerated particles)*
Located in the FFTB

- Ionizing Laser Pulse (193 nm)
- Li Plasma $n_e \approx 2 \cdot 10^{14} \text{ cm}^{-3}$
- Optical Transition Radiators
- Bending Magnet
- Cerenkov Radiator
- Dump
- Streak Camera (1 ps resolution)

- $N = 2 \cdot 10^{10}$
- $\sigma_z = 0.6 \text{ mm}$
- $E = 30 \text{ GeV}$
- $L \approx 1.4 \text{ m}$
- $12 \text{ m}$
- X-Ray Diagnostic

- Experimental Layout (E-157)
SLAC beam
- 42 GeV
- 3 nC @ 10 Hz
- focused to 10 µm spot size
- compressed to 50 fs

- Some electrons double their energy: from 42 to > 80 GeV
- E=50 GV/m over 0.8 meters

Why not continue with electrons ???

There is a limit to the energy gain of a trailing bunch in the plasma:

\[ R = \frac{\Delta T^{\text{witness}}}{\Delta T^{\text{drive}}} \leq 2 \quad T \text{ is the kinetic energy} \]

(for longitudinally symmetric bunches). See e.g. SLAC-PUB-3374, R.D. Ruth et al.

This means many stages required to produce a 1TeV electron beam from known electron beams (SLAC has 45 GeV)

Proton beams of 1TeV exist today - so, why not drive plasma with a proton beam ?
Why Proton-Driven Wakefield Acceleration

Both laser-driven and electron-bunch driven acceleration will require many stages to reach the TeV scale.

We know how to produce high energy protons (many TeV) in bunches with population $> 10^{11}$/bunch today, so if we can use protons to drive an electron bunch we could potentially have a simpler arrangement - single stage acceleration.

Linear regime ($n_b<n_0$):

$$E_{z,\text{max}} \approx 2 \text{ GeV/m} \cdot \left( \frac{N_b}{10^{10}} \right) \cdot \left( \frac{100 \text{ \mu m}}{\sigma_z} \right)^2$$

Need very short proton bunches for strong gradients. Today’s proton beams have

$$\sigma_z \approx 10 - 30 \text{ cm}$$
Issues with a Proton Driven PWA:

- Small beam dimensions required

\[ eE_{\text{linear}} = 240(\text{MeV/m}) \left( \frac{N}{4 \cdot 10^{10}} \right) \left( \frac{0.6}{\sigma_z(\text{mm})} \right)^2 \]

\[ \sigma_z = 100\mu m, N = 1 \times 10^{11} \] yields 21 GeV/m

Can such small beams be achieved with protons? Typical proton bunches in high energy accelerators have rms length >20 cm
Issues with a Proton Driven PWA:

- Phase slippage because protons heavy (move more slowly than electrons)

\[
\delta = \frac{\pi L}{\lambda_p} \left[ \frac{1}{\gamma_{1i}\gamma_{1f}} - \frac{1}{\gamma_{2i}\gamma_{2f}} \right] \approx \frac{\pi L}{\lambda_p} \left[ \frac{M_p^2 c^4}{E_{\text{driver},i}E_{\text{driver},f}} \right]
\]

\[
L \leq \frac{1}{2} \left[ \frac{E_{\text{driver},i}E_{\text{driver},f}}{M_p^2 c^4} \right] \lambda_p \approx 300 \text{ m for } E_{\text{driver},i} = 1\text{TeV}, E_{\text{driver},f} = 0.5\text{TeV}, \lambda = 1\text{mm}
\]

Few hundred meters possible but depends on plasma wavelength
Issues with a Proton Driven PWA continued:

• Longitudinal growth of driving bunch due to energy spread

\[ d = \Delta v \cdot t \approx \Delta \beta \cdot L = (\gamma_1^{-2} - \gamma_2^{-2})L \approx 2\left(\frac{\Delta E}{E}\right) \frac{M_p^2 c^4}{E^2} L \]

For \( d = 100 \mu m, \quad L = 100 m, \quad E = 1 TeV, \quad \frac{\Delta E}{E} = 0.5 \)

Large momentum spread is allowed!
Issues - continued

• Proton interactions

\[ \lambda = \frac{1}{n\sigma} < \frac{1}{n(10^{-23} \text{ cm}^2)} \quad n = 1 \cdot 10^{15} \text{ cm}^{-3} \quad \Rightarrow \quad \lambda = 1000 \text{ km} \]

Only small fraction of protons will interact in plasma cell

Biggest issue identified so far is proton bunch length.

Need large energies to avoid phase slippage because protons are heavy.

Large momentum spread is allowed.
Simulation study

Assume proton bunch compression solved!

Quadrupoles used to guide head of driving bunch

## Simulation

Table 1: Table of parameters for the simulation.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protons in Drive Bunch</td>
<td>$N_P$</td>
<td>$10^{11}$</td>
<td></td>
</tr>
<tr>
<td>Proton energy</td>
<td>$E_P$</td>
<td>1</td>
<td>TeV</td>
</tr>
<tr>
<td>Initial Proton momentum spread</td>
<td>$\sigma_p/p$</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Initial Proton longitudinal spread</td>
<td>$\sigma_Z$</td>
<td>100</td>
<td>$\mu$m</td>
</tr>
<tr>
<td>Initial Proton bunch angular spread</td>
<td>$\sigma_\theta$</td>
<td>0.03</td>
<td>mrad</td>
</tr>
<tr>
<td>Initial Proton bunch transverse size</td>
<td>$\sigma_{X,Y}$</td>
<td>0.4</td>
<td>mm</td>
</tr>
<tr>
<td>Electrons injected in witness bunch</td>
<td>$N_e$</td>
<td>$1.5 \times 10^{10}$</td>
<td></td>
</tr>
<tr>
<td>Energy of electrons in witness bunch</td>
<td>$E_e$</td>
<td>10</td>
<td>GeV</td>
</tr>
<tr>
<td>free electron density</td>
<td>$n_p$</td>
<td>$6 \times 10^{14}$</td>
<td>cm$^{-3}$</td>
</tr>
<tr>
<td>Plasma wavelength</td>
<td>$\lambda_p$</td>
<td>1.35</td>
<td>mm</td>
</tr>
<tr>
<td>Magnetic field gradient</td>
<td></td>
<td>1000</td>
<td>T/m</td>
</tr>
<tr>
<td>Magnet length</td>
<td></td>
<td>0.7</td>
<td>m</td>
</tr>
</tbody>
</table>
Densities & Fields

$E_Z, \text{GeV/m}$

$X, \text{mm}$

$Z, \text{mm}$

$n_e, 10^{15} \text{ cm}^{-3}$

$Z, \text{mm}$

$E_Z, \text{GeV/m}$, loaded vs unloaded
Magnetic bunch compression (BC)

- Beam compression can be achieved:
  1. by introducing an energy-position correlation along the bunch with an RF section at zero-crossing of voltage
  2. and passing beam through a region where path length is energy dependent: this is generated by bending magnets to create dispersive regions.

- To compress a bunch longitudinally, trajectory in dispersive region must be shorter for tail of the bunch than it is for the head.
Phase space of beam

See A. Caldwell, G. Xia et al., Preliminary study of proton driven plasma wakefield acceleration, Proceedings of PAC09, May 3-8, 2009, Vancouver, Canada

RF phase: -102 degree
2600 cavities
final energy is 986.487 GeV
total length of BC 4131 m

Too long – use in combination with other compression schemes
PDPWA-based LC

V. Yakimenko, BNL, T. Katsouleas, Duke

Concept for high repetition rate of proton driven plasma wakefield acceleration

3 ring + injectors + recovery
Luminosity

\[ L = f \frac{N_1 N_2}{4 \pi \sigma_x \sigma_y} \quad \text{Gaussian shaped beams} \]

suppose \( N_1 = N_2 = 10^{11} \)

SPS cycle time 22s 288 bunches so assume \( f = 15 \text{ Hz} \)

\[ L \approx \left( \frac{1 \, \mu \text{m}^2}{\sigma_x \sigma_y} \right) 10^{30} \, \text{cm}^{-2} \, \text{s}^{-1} \]

Will need very small cross section beams for significant luminosity
PWA via Modulated Proton Beam

Producing short proton bunches not possible today w/o major investment. Not an option for the short term ...

Instead, we investigated modulating a long bunch to produce a series of ‘micro’-bunches in a plasma.

The microbunches are generated by a transverse modulation of the bunch density (transverse two-stream instability). The microbunches are naturally spaced at the plasma wavelength, and act constructively to generate a strong plasma wake. Investigated both numerically and theoretically \( \text{(N. Kumar, A. Pukhov, and K. V. Lotov, Phys. Rev. Lett. 104, 255003 (2010))} \).
Alternative to short bunch – modulation of long bunch

1 cm length, $5.5 \times 10^{10}$ particles, in $4 \times 10^{15}$ 1/cc plasma

Few hundred MeV/m expected. Under study.

SPS beam simulation, A. Pukhov
• Kick-off meeting-PPA09 held at CERN December 2009. Several workshops/meetings since (Munich, London, CERN)

• PS and SPS options considered. From simulation studies, concluded SPS is much better. An unused SPS tunnel for demonstration experiment located.

• Experimental plan has crystallized: demonstrate 1 GeV acceleration of injected electrons within 10 m of plasma.

PPA09 workshop photo

Longer term – design/proposal 100 GeV acceleration in 100m.
electric field from one microbunch:

\[ E_{\mu,z,\text{max}} = e N_{\mu} Z(k_p, \sigma_z) R(k_p \sigma_r) \]

where \( N_{\mu} \) is the number of protons in the microbunch and \( \sigma_z \approx \sqrt{2} k_p^{-1} \) is the rms length of the protons in the microbunch. If we assume for hard edged beams that all microbunches within \( \pm \sigma_z,0 / 2 \) of the center of the proton bunch add coherently to the produced electric field, then we have

\[ E_{z,\text{max}} = e \frac{0.38 \cdot N}{2} Z(k_p, \sigma_z) R(k_p \sigma_r). \]

We now calculate the maximum electric field by taking \( k_p \sigma_r = 1 \), substituting \( \sigma_z \approx \sqrt{2} k_p^{-1} = \sqrt{2} \sigma_r \), and using (3), (4). This yields

\[ E_{z,\text{max}} \approx 0.07 \frac{N e}{\sigma_r^2} \approx 0.1 \text{(GV/m)} \cdot \left( \frac{N}{10^{10}} \right) \left( \frac{100 \text{ \mu m}}{\sigma_r} \right)^2. \]

The maximum field from this expression is given in Table 2. The fields can be compared to the wave-breaking field

\[ e E_0 = mc^2 \frac{\omega_p}{e} \]

to determine the dimensionless field amplitude

\[ \alpha = \frac{E_{z,\text{max}}}{E_0} \approx 0.018 \left( \frac{N}{10^{10}} \right) \left( \frac{100 \text{ \mu m}}{\sigma_r} \right). \]

Table 1. PS, SPS and LHC parameter sets. The different symbols are defined in the text. SPS-LHC means the standard parameters of bunches in the SPS for injection into the LHC. SPS-Totem means the special parameters for bunches for use by the Totem experiment.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PS</th>
<th>SPS-LHC</th>
<th>SPS-Totem</th>
<th>LHC</th>
</tr>
</thead>
<tbody>
<tr>
<td>( W_P ) (GeV)</td>
<td>24</td>
<td>450</td>
<td>450</td>
<td>7000</td>
</tr>
<tr>
<td>( N_P ) ( \times 10^{10} )</td>
<td>13</td>
<td>11.5</td>
<td>3.0</td>
<td>11.5</td>
</tr>
<tr>
<td>( \sigma_p ) (MeV)</td>
<td>12</td>
<td>135</td>
<td>80</td>
<td>700</td>
</tr>
<tr>
<td>( \sigma_z,0 ) (cm)</td>
<td>20</td>
<td>12</td>
<td>8</td>
<td>7.6</td>
</tr>
<tr>
<td>( \sigma_r ) (\mu m)</td>
<td>400</td>
<td>200</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>( c/\omega_b ) (m)</td>
<td>2.3</td>
<td>4.0</td>
<td>3.2</td>
<td>6.3</td>
</tr>
<tr>
<td>( \sigma_\theta ) (mrad)</td>
<td>0.25</td>
<td>0.04</td>
<td>0.02</td>
<td>0.005</td>
</tr>
<tr>
<td>( L_\theta ) (m)</td>
<td>1.6</td>
<td>5</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>( \epsilon ) (mm-mrad)</td>
<td>0.1</td>
<td>0.008</td>
<td>0.002</td>
<td>5 \times 10^{-4}</td>
</tr>
</tbody>
</table>

Table 2. Characteristics of beam interaction with the uniform density plasma.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PS</th>
<th>SPS-LHC</th>
<th>SPS-Totem</th>
<th>LHC</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n_p ) ( \times 10^{15} \text{ cm}^{-3} )</td>
<td>0.18</td>
<td>0.7</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>( \lambda_p ) (mm)</td>
<td>2.5</td>
<td>1.3</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>( W_f ) (eV)</td>
<td>180</td>
<td>280</td>
<td>100</td>
<td>410</td>
</tr>
<tr>
<td>( W_{tr} ) (eV)</td>
<td>750</td>
<td>360</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>( e E_{z,\text{max}} ) (GeV/m)</td>
<td>0.08</td>
<td>0.3</td>
<td>0.3</td>
<td>1.1</td>
</tr>
<tr>
<td>( e E_0 ) (GeV/m)</td>
<td>1.3</td>
<td>2.5</td>
<td>5.3</td>
<td>5.3</td>
</tr>
<tr>
<td>( \alpha )</td>
<td>0.06</td>
<td>0.1</td>
<td>0.05</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Modulations will eventually destroy the beam. Density step freezes modulations.
Accelerator chain of CERN (operating or approved projects)

LEP/LHC

SPS

CNGS

Vers Grand Sasso

North Area

West Area

AD

TT61

n-ToF

neutrons

p (proton)

ion

neutrons

(p (proton))

(proton/antiproton conversion)

neutrinos

AD Antiproton Decelerator

PS Proton Synchrotron

SPS Super Proton Synchrotron

LHC Large Hadron Collider

n-ToF Neutrons Time of Flight

CNGS Cern Neutrinos Grand Sasso
TT61 tunnel today

“Up” bends (bring beam horizontal to the old exp. area) - can be used as the spectrometer

End tunnel to be converted to beam dump
Schematic layout

PDPWA experiment

(not to scale)

Underground installations

Switch... (50m)

p beam
(LHC injection type, 400 - 450 GeV)

TT61 tunnel
6-7 % slope

TT4 (70 m)

TT5 (50 m)

Plasma cell (5 - 20 m)

~ 600 m total footprint

PDPWA

Other tests
{compact electron test beam, ...}

TW laser lab

Laser Plasma Injector (1 GeV, fs)

e beam inj. (10-20 MeV)

Beam dump

Surface installations

Example: Proton driven plasma structure

HiRadMat (Completion Sep 2011)
A long SPS drive beam will be sent into a 5-10m long plasma cell. A self-modulation of the beam due to the transverse wakefield occurs which produces many ultrashort beam slices. 

The modulation resonantly drives wakefields in the 100-1000 MV/m regime.

Particle-in-cell simulations predict acceleration of injected electrons to beyond 1 GeV.

Expected Results
Plasma Cell ideas:

Metal vapor, a la SLAC experiment:
UCLA, Max Planck Institute for Physics

Discharge: IST, Imperial College

Helicon – Max Planck Institute for Plasma Physics
Diagnostics

Electro-optical sampling for modulations, field strength:
University College, RAL, DESY, Imperial College, Cockroft Institute, Strathclyde, MPP

Coherent transition radiation

Electron spectrometer:
CERN, Imperial College, Cockroft Institute, Strathclyde, KIT, UCL, D

Injector/spectrometer for electron bunch
Proto-collaboration with 25 institutes, including world-experts in all needed categories

Date: May 31, 2011

Letter of Intent for a Demonstration Experiment in Proton-Driven Plasma Wakefield Acceleration


1 Brookhaven National Laboratory, Brookhaven, USA
2 Budker Institute of Nuclear Physics, Novosibirsk, Russia
3 CERN, Geneva, Switzerland
4 Cockroft Institute, Daresbury, UK
5 DESY, Hamburg, Germany
6 Universität Heidelberg, Heidelberg, Germany
7 Heinrich Heine University, Düsseldorf, Germany
8 Instituto de Plasmas e Fusao Nuclear, IST, Lisboa, Portugal
9 Imperial College, London, UK
10 John Adams Institute for Accelerator Science, Oxford, UK
11 Karlsruher Institute of Technology KIT, Karlsruhe, Germany
12 LAL, Univ Paris-Sud, CNRS/IN2P3, Orsay, France
13 LOA, Laboratoire dOptique Applique, CNRS/ENSSTA/X, France
14 Los Alamos National Laboratory, NM, USA
15 Ludwig Maximilian University, Munich, Germany
16 Max Planck Institute for Physics, Munich, Germany
17 Max Planck Institute for Plasma Physics, Greifswald, Germany
18 Panjab University, Chandigarh, India
19 Rutherford Appleton Laboratory, Chilton, UK
20 State Key Laboratory of Nuclear Physics and Technology, Peking University, China
21 Tsinghua University, Beijing, China
22 University of California, Los Angeles, CA, USA
23 University College London, London, UK
24 University of Oslo, Oslo, Norway
25 University of Strathclyde, Glasgow, Scotland, UK
Outlook

Long term prospects for modulated proton bunch intriguing:

simulation of existing LHC bunch in plasma with trailing electron bunch ...  

Miracle: no guiding magnetic fields necessary!
Conclusions

Accelerator based particle physics has had a tremendous impact on our knowledge and has been the key to the development of the Standard Model of particle physics.

But, we are in need of novel ideas ...

Plasma Wakefield Acceleration has been proposed many years ago – steady progress in developing the technology, but there is still a long way to go.

Look for interesting developments in the next 5 years
Work Packages CERN
(under discussion)

- WP C1: CERN project management.
- WP C3: Beam/plasma simulations to observation points.
- WP C4: Proton beam switch, transfer line, beam delivery, collimation and beam dump.
- WP C5: Electron beam RF acceleration, beam transport, beam delivery, collimation, beam separation and dump.
- WP C6: Experimental area.
- WP C7: Radiation protection and safety.
- WP C8: Future uses of CERN advanced test facility.
Work Package C2

• WP C2: Interaction region design p-beam, e-beam and laser light.
  – Theoretical study and simulations of interaction region.
  – Specification for proton delivery system (magnets, collimation, dump)
  – Specification for e-beam delivery system (magnets, collimation, dump)
  – Specification for laser light path (optics)
  – Specification for incoming beams and laser (emittance, stability, momentum, energy spread, ...)
  – Specification for timing system
  – Specification for diagnostics (p-beam, e-beam, laser, plasma, position, intensity, losses, transverse size, energy spread, momentum, ...)
  – Specification of correction system (dipoles, matching sections, ...).
  – Specification for vacuum system (apertures, windows, pumping, ...)
  – Specification for spectrometer(s)
  – Definition of all interfaces
  – Integration, design and drawings.
Note

• This is THE difficult area for this experiment.
  – Bring together electron beam, proton beam, laser light beam and long plasma cell within tolerances.
  – Beam position/angle in 6D is characterized by \( x, x', y, y', t, p \)
  – Beam size/divergence in 6D is characterized by \( \sigma_x, \sigma_x', \sigma_y, \sigma_y', \sigma_z, \sigma_p \)
  – Similar for laser light and plasma column...

• In total: \( \sim 48 \) parameters for our CERN experiment!
  – These parameters must first be measured
  – Then they must be matched to each other in the plasma cell
  – Side injection does not make things easier!
  – Then we must separate beams and diagnose plasma effect

• Was much easier for the SLAC experiment:
  – Best results by just sending the electron beam into the gas, creating the plasma column itself (no laser light beam and no proton beam)
Some examples...

• Radiation constraints will define transverse distances to respect, e.g. proton beam delivery to electron source to laser ...
• This defines length of guiding, transport and delivery → overall longitudinal footprint.
• We must try to use standard components as much as possible → fixes apertures that are realistic.
• This will impose constraints on proton/electron beam energies, emittances, stability/reproducibility, ...
• Number of required windows (e.g. Beryllium) will impose additional constraints. Safety might impose some windows!
• Shows that we need approved conceptual layout before we can start to agree on components. A good solution here will make us successful...
Collaborative Help Needed

• This is a very complicated experiment (2 beams, 1 laser and 1 plasma cell): **this is what makes it so interesting!**
• We cannot prepare the facility with a decoupled CERN team:
  – Need to learn about lasers and plasmas.
  – Need rapid turn-around in simulations: input from plasma specialists outside CERN.
  – Outside teams need to understand CERN boundary conditions.
• The 1 year goal for a technical design report is short!!!
• Hope for a team of ~20 persons regularly present and working at CERN (~12 from CERN – not full time).
  – Can easily accommodate 3 good PhD students plus 5 visitors from outside institutes.
  – Now we need people who invest time at CERN.