Definition of parameters for e+e-, including exploratory sets of parameters taking advantage of the ANA specific properties (WG2 CMD)

D. Schulte for WG 2 conveners

D. Schulte, A. Seryi, H. Yamamoto

Goals

- We want to help making novel acceleration technologies useful for colliders

- Short-term: Prepare some input for the European Strategy Process
  - Could range from putting forward a project proposal to providing input for an R&D plan
  - Obviously, we need to come to some consensus

- Expectation management is key
  - Generating too high expectations in funding agencies will backfire later
  - Not identifying the potential would be missing an opportunity

Considered High Energy Frontier Collider

Circular colliders:

- FCC (Future Circular Collider)
  - FCC-hh: 100 TeV proton-proton cms energy, ion operation possible
  - FCC-ee: Potential intermediate step 90-350 GeV lepton collider
  - FCC-he: Lepton-hadron option
  - HE-LHC: Stronger magnets in LHC tunnel
- CEPC / SppC (Circular Electron-positron Collider/Super Proton-proton Collider)
  - CepC : e^+e^- 90 - 240 GeV cms
  - SppC : pp 70 TeV cms

Linear colliders

- ILC (International Linear Collider): e^+e^- 250 GeV cms energy, Japan considers hosting project
- CLIC (Compact Linear Collider): e^+e^- 380 GeV - 3 TeV cms energy, CERN hosts collaboration

Need to find a good reason for novel acceleration technologies

- Potentially lower cost to reach high energies (3 TeV and well above, e.g. 14 TeV)
- Power efficiency for luminosity production? I am sceptical
- Improved luminosity production? Difficult but essential, I think

Example: Laser-driven Plasma Accelerator (LPA)

Parameters from

Beamstrahlung considerations in laser-plasma-accelerator-based linear colliders
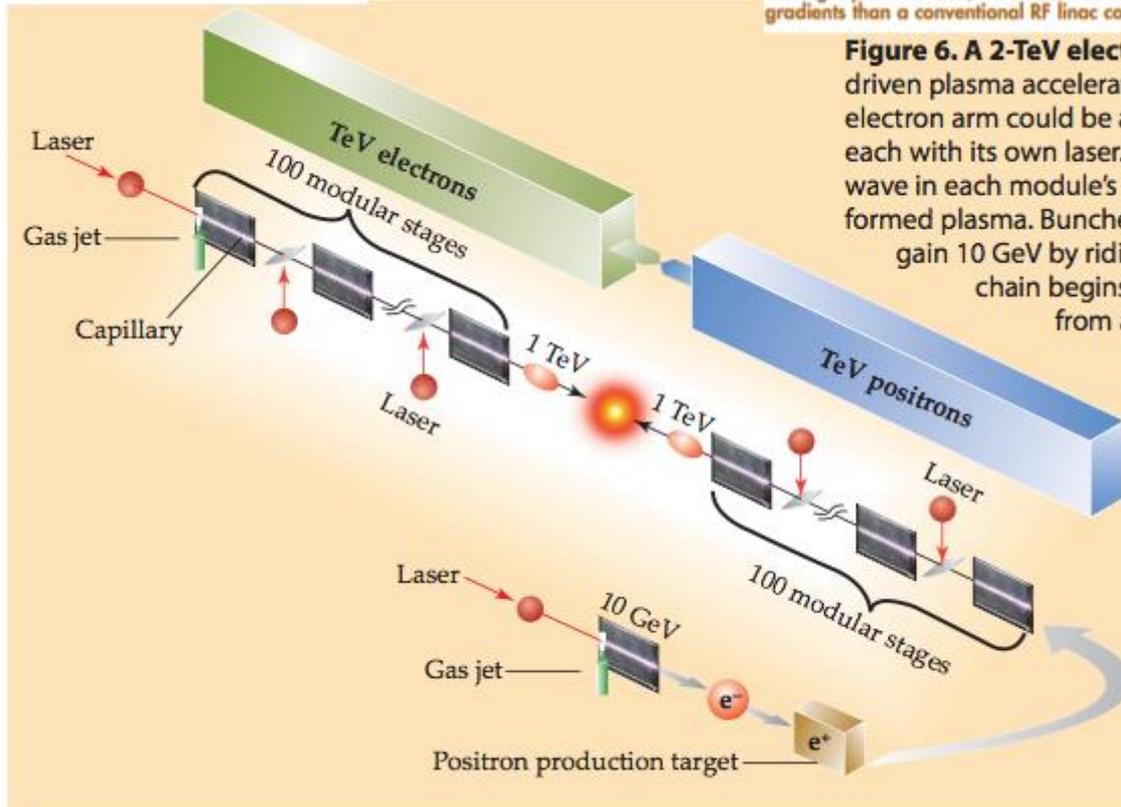
C. B. Schroeder, E. Esarey, and W. P. Leemans

Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA
(Received 23 November 2011; published 4 May 2012)

44   March 2009   Physics Today

Laser-driven plasma-wave electron accelerators
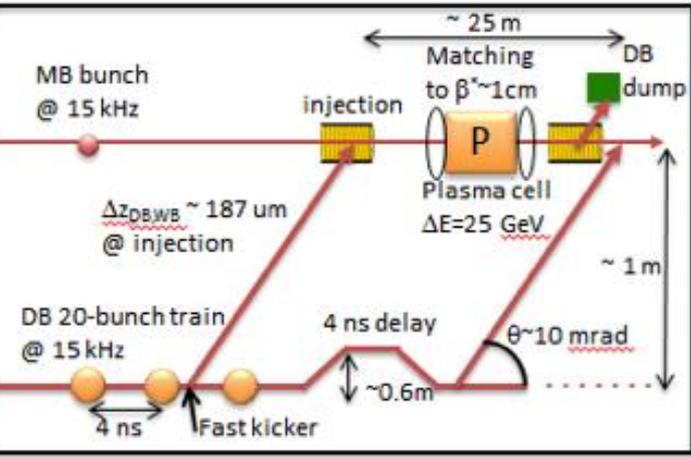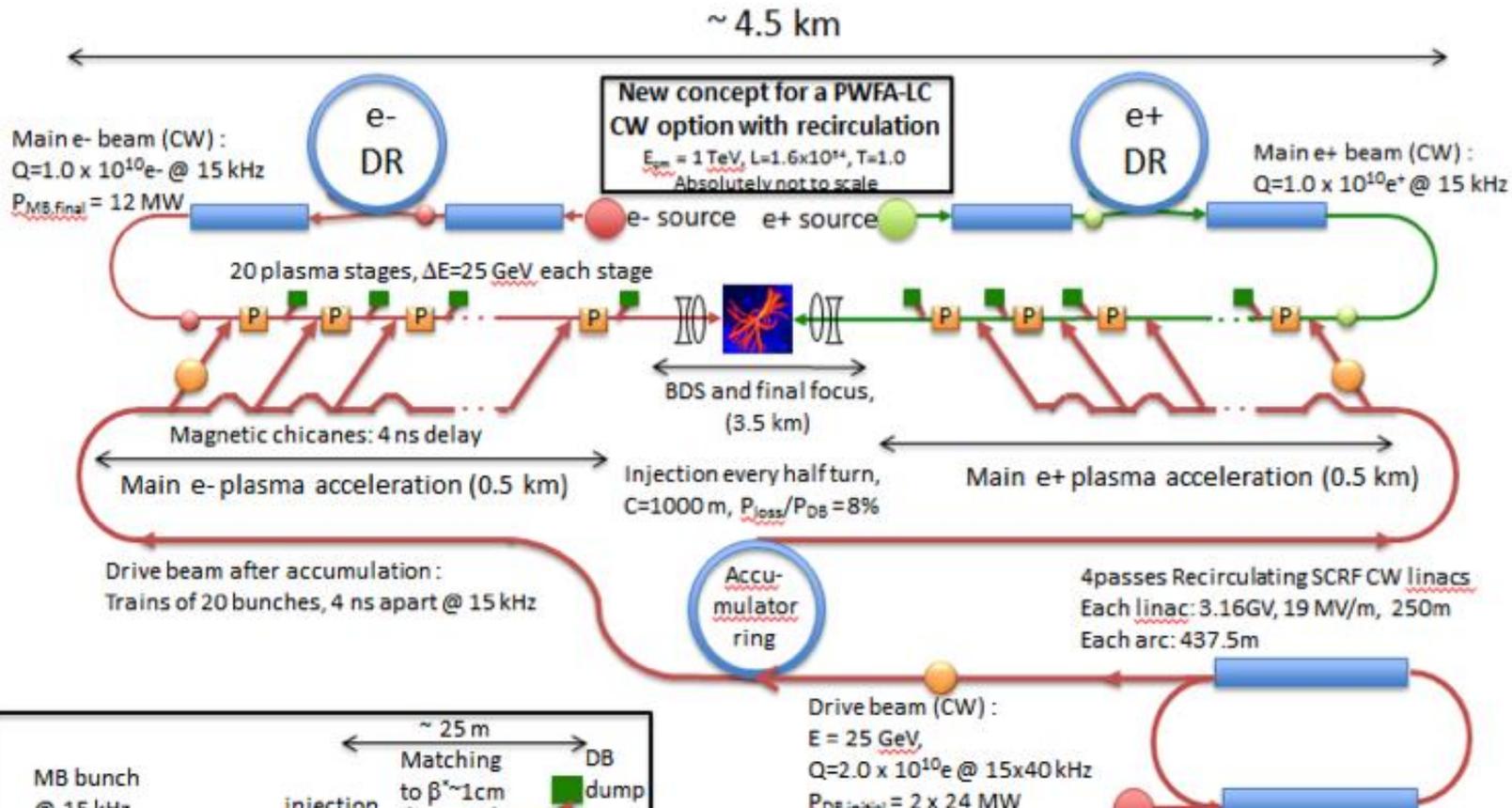
Wim Leemans and Eric Esarey

Surfing a plasma wave, a bunch of electrons or positrons can experience much higher accelerating gradients than a conventional RF linac could provide.

Figure 6. A 2-TeV electron–positron collider based on laser-driven plasma acceleration might be less than 1 km long. Its electron arm could be a string of 100 acceleration modules, each with its own laser. A 30-J laser pulse drives a plasma wave in each module's 1-m-long capillary channel of pre-formed plasma. Bunched electrons from the previous module gain 10 GeV by riding the wave through the channel. The chain begins with a bunch of electrons trapped from a gas jet just inside the first modul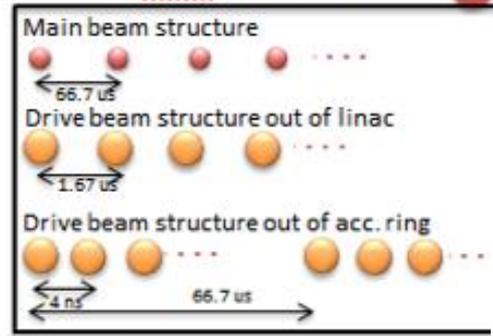e's plasma channel. The collider's positron arm begins the same way, but the 10-GeV electrons emerging from its first module bombard a metal target to create positrons, which are then focused and injected into the arm's string of modules and accelerated just like the electrons.
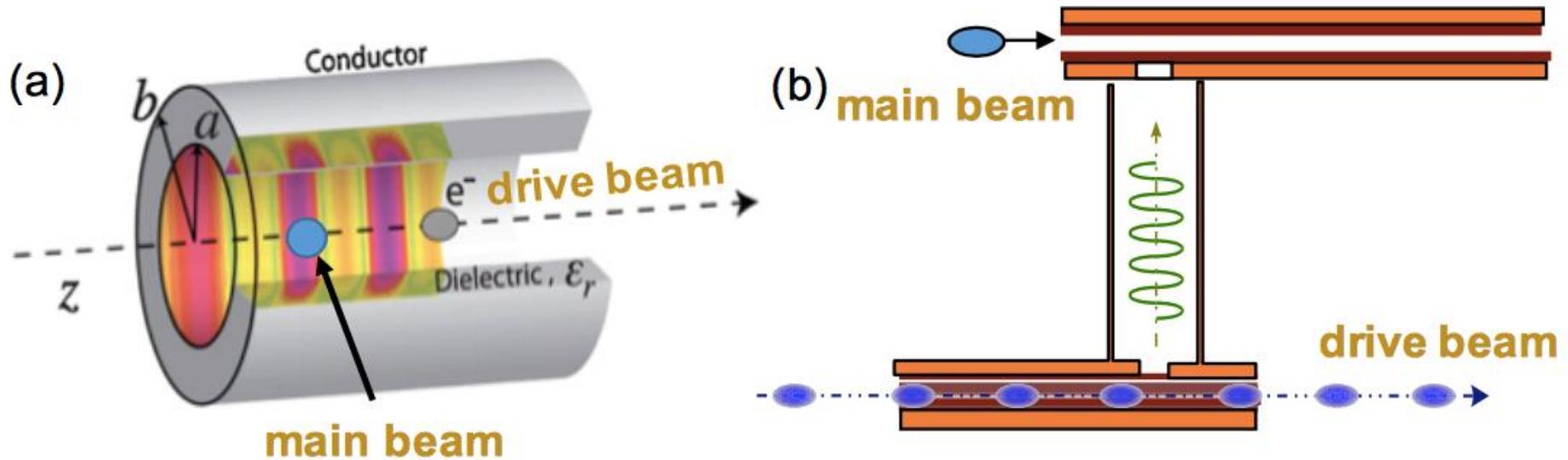
Example: Beam-driven Plasma Accelerator (PWFA)

~ 4.5 km

New concept for a PWFA-LC CW option with recirculation
$E_{cm} = 1$ TeV, $L=1.6\times10^{14}$, $T=1.0$
Absolutely not to scale

Main e- beam (CW): $Q=1.0 \times 10^{10}$e- @ 15 kHz
$P_{MB,final} = 12$ MW

Main e+ beam (CW): $Q=1.0 \times 10^{10}$e+ @ 15 kHz

e- DR   e+ DR

e- source   e+ source

20 plasma stages, $\Delta E=25$ GeV each stage

BDS and final focus, (3.5 km)

Magnetic chicanes: 4 ns delay

Main e- plasma acceleration (0.5 km)

Injection every half turn, C=1000 m, $P_{loss}/P_{DB} = 8\%$

Main e+ plasma acceleration (0.5 km)

Drive beam after accumulation: Trains of 20 bunches, 4 ns apart @ 15 kHz

Accu-mulator ring

4 passes Recirculating SCRF CW linacs
Each linac: 3.16GV, 19 MV/m, 250m
Each arc: 437.5m

Drive beam (CW): E = 25 GeV, $Q=2.0 \times 10^{10}$e @ 15x40 kHz
$P_{DB,initial} = 2 \times 24$ MW

~ 25 m

MB bunch @ 15 kHz

injection

Matching to $\beta^* \sim 1$cm

DB dump

P Plasma cell $\Delta E=25$ GeV

$\Delta z_{DB,WB} \sim 187$ um @ injection

~ 1 m

DB 20-bunch train @ 15 kHz

4 ns delay

$\theta \sim 10$ mrad

~0.6m

4 ns   Fast kicker

Main beam structure
66.7 us
Drive beam structure out of linac
1.67 us
Drive beam structure out of acc. ring
4 ns   66.7 us

e- source

D. Schulte   Oxford, March 2018   5

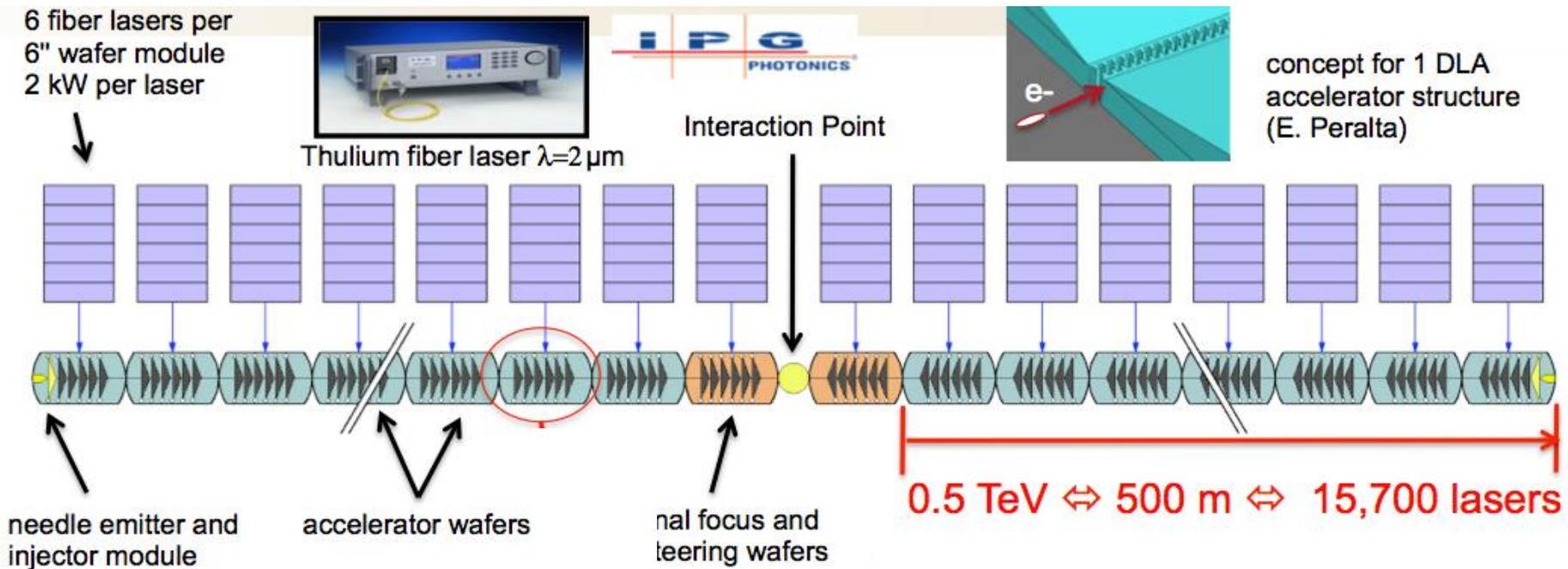# Example: Beam-driven Dielectric Acceleration (SWFA)

Basically a technology improvement for linear colliders
- Maybe higher gradients
- Maybe better transverse to longitudinal impedance
- Maybe cheaper fabrication

My naïve view:
- This is fully justified work on better technology, similar to better magnets for circular colliders
- Collaboration with CLIC RF team exists
- Could be also a **technology upgrade**

Example: Dielectric Laser Collider (DLA)

6 fiber lasers per 6" wafer module 2 kW per laser

Thulium fiber laser λ=2 μm

iPG PHOTONICS

Interaction Point

concept for 1 DLA accelerator structure (E. Peralta)

e-

needle emitter and injector module

accelerator wafers

nal focus and teering wafers

0.5 TeV ⇔ 500 m ⇔ 15,700 lasers

R. J. England et al.

Core Linear Collider Challenges

damping
ring

e- source

RTML

damping
ring

e+ source

Plasma acceleration has plenty of gradient
- Main issue is having stages
- Potentially cheap
- Optimistically: cost is driven mainly by power systems
  => need to limit power consumption

Easiest is to simply replace main linac
- Do not change anything else if not necessary
- Much effort has been required to design all subsystems
  for linear colliders
- But I feel that this strategy might not work too well
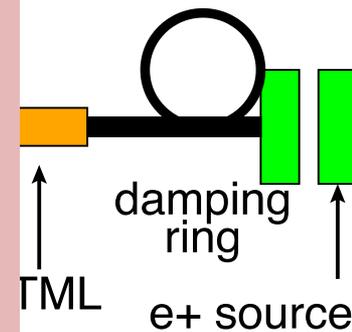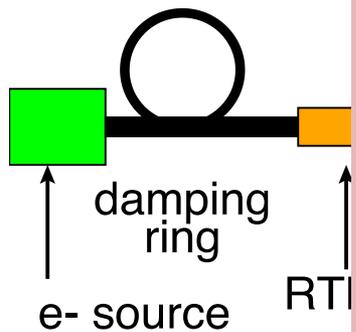
Achieve the c

- Main cost

Achieve high luminosity (good beam quality and high efficiency)

- Damping ring, RTML, ML, BDS and collision point contribute
- Lots of work has gone into the design/optimisation of these systems

Example Linear Collider Parameters

Parameter	Symbol [unit]	ILC	CLIC	LPA	PWFA	DLA
CMS energy	E_{cm} [GeV]	500	3000	3000	3000	3000
Luminosity	$L [10^{34} \, \text{cm}^{-2}\text{s}^{-1}]$	1.8	6	10	6.3	10.7 (4.4)
Luminosity in peak	$L_{0.01} [10^{34} \, \text{cm}^{-2}\text{s}^{-1}]$	1	2	7	2.3	5.2
Total beam power	[MW]	10.5	28	48	48	68.8
Loaded gradient	G [MV/m]	31.5	100	3000	7600	1000
Particles per bunch	$N [10^9]$	20	3.72	1.19	10	$3 \cdot 10^{-5}$
Bunch length	σ_z [μm]	300	44	8	20	0.0028
Interaction point beam size	σ_x/σ_y [nm/nm]	474/6	40/1	18/0.5	194/1.1	0.75/0.75
Normalized emittances	ϵ_x/ϵ_y [nm]	$10^4/35$	660/20	50/5	$10^4/35$	0.1/0.1
Beta functions	β_x/β_y [mm]	10/0.4	7/0.07	-/-	11/0.1	16.5/16.5
Initial beam energy spread	σ_E [%]	O(0.1)	0.35	—	—	—
Bunches per train	n_b	1312	312	1	1	159
Bunch distance	Δz [ns]	554	0.5	$11.9 \cdot 10^3$	10^5	$6.7 \cdot 10^{-6}$
Repetition rate	f_r [Hz]	5	50	$84 \cdot 10^3$	10^4	$3 \cdot 10^7$

I would think that consolidation of novel technology parameters is required
- e.g. consider limitation of efficiency due to transverse effects

Luminosities are comparable at 3TeV

Already at 3TeV large beam power is used to produce luminosity

PDFA: E. Adli et al.
LPA: D.B. Schroeder et al.
DLA: J. England

Luminosity in Linear Colliders

Usual luminosity formula

$$\mathcal{L} = H_D \frac{N^2}{4\pi \sigma_x \sigma_y} n_b f_r$$

Number of photons from beamstrahlung

$$n_\gamma \propto \left(\frac{\sigma_z}{\gamma}\right)^{\frac{1}{3}} \left(\frac{N}{\sigma_x + \sigma_y}\right)^{\frac{2}{3}}$$

Leads to

$$\mathcal{L} \propto H_D \frac{n_\gamma^{\frac{3}{2}}}{\sqrt{\sigma_z}} \frac{1}{\sigma_y} \frac{R+1}{R} \frac{\eta P_{wall}}{\sqrt{\gamma} m c^2}$$

$R = \sigma_x / \sigma_y$

Beam-beam Effect

Intense beams for luminosity
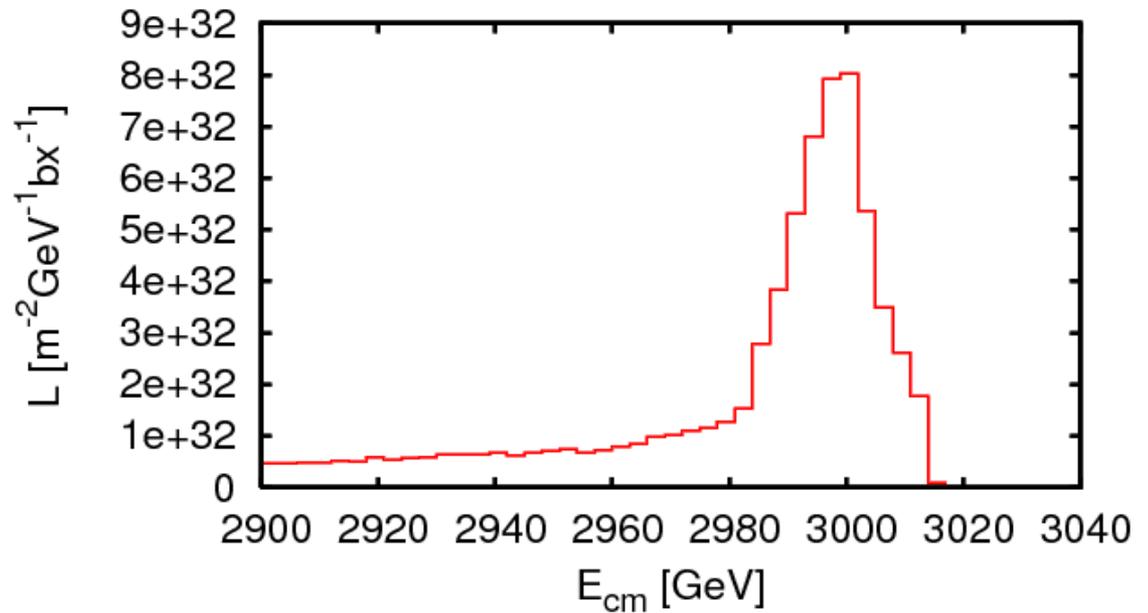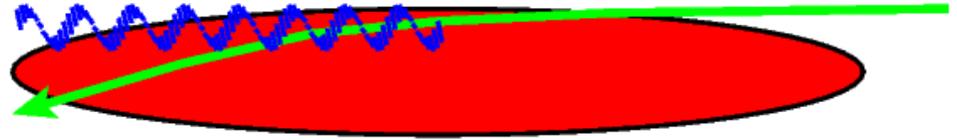
⬇

Strong electromagnetic fields

⬇

Particles travel on curved
trajectories

⬇

They emit O(1) photons
(beamstrahlung)

⬇

They can collide with less
than nominal energy

Beamstrahlung Optimisation

$$n_\gamma \propto \left(\frac{\sigma_z}{\gamma}\right)^{\frac{1}{3}} \left(\frac{N}{\sigma_x + \sigma_y}\right)^{\frac{2}{3}}$$

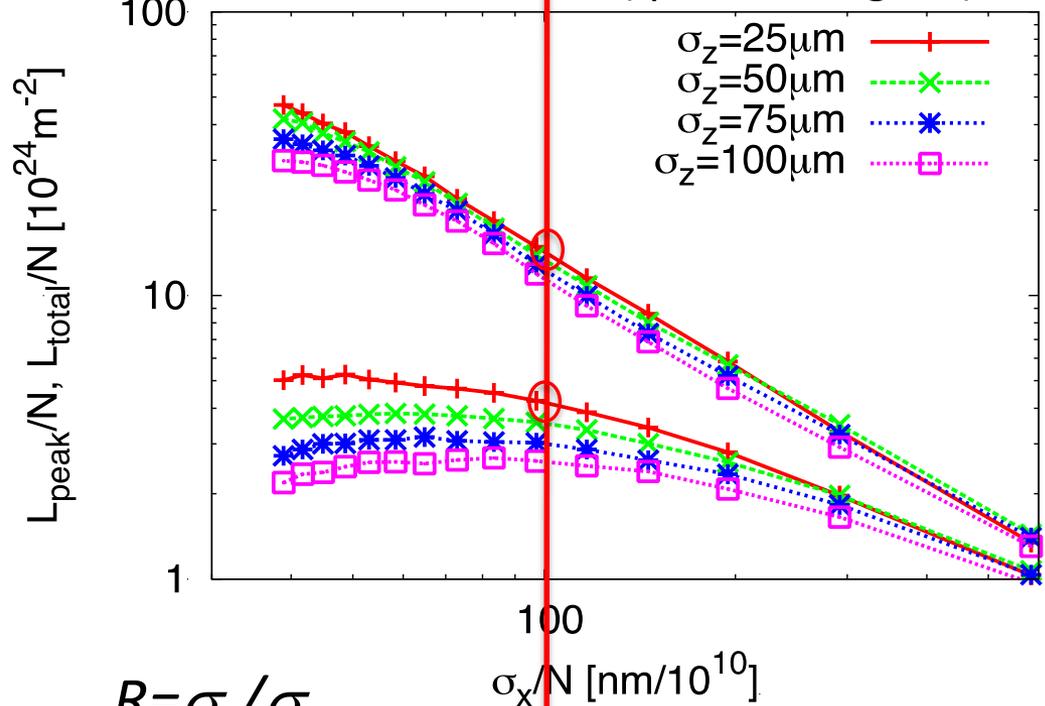$$\mathcal{L} \propto \frac{N}{\sigma_x \sigma_y} \, I_{beam}$$

$$\sigma_x \gg \sigma_y \qquad \sigma_x + \sigma_y \approx \sigma_x \qquad R = \sigma_x/\sigma_y$$

$$\mathcal{L} \propto H_D \frac{n_\gamma^{\frac{3}{2}}}{\sqrt{\sigma_z}} \frac{1}{\sigma_y} \frac{R+1}{R} \frac{\eta P_{wall}}{\sqrt{\gamma} mc^2}$$

For CLIC at 3TeV (quantum regime)

L_{peak}/N, L_{total}/N [10^{24}m^{-2}]

σ_x/N [nm/10^{10}]

- σ_z=25µm
- σ_z=50µm
- σ_z=75µm
- σ_z=100µm

CLIC parameter choice $n_\gamma \approx 2$

Or use very short bunches?

Luminosity Challenge for Linear Colliders

$$\mathcal{L} \propto H_D \frac{n_\gamma^{\frac{3}{2}}}{\sqrt{\sigma_z}} \frac{1}{\sqrt{\epsilon_y \beta_y}} \frac{R+1}{R} \frac{\eta P_{wall}}{mc^2}$$

Efficiency will limit beam power in plasma-based colliders
- Likely find practical efficiency to be smaller in plasma-based colliders than assumed now
- Also efficiency of positron acceleration has to be considered

$\Rightarrow$ Have to improve luminosity per beam current
  $\Rightarrow$ Could be useful for linear colliders in general, but also means no low-hanging fruit known

$\Rightarrow$ Still have to push efficiency as much as possible

Efficiencies

CLIC at 3TeV:
Mains to drive beam: 58%
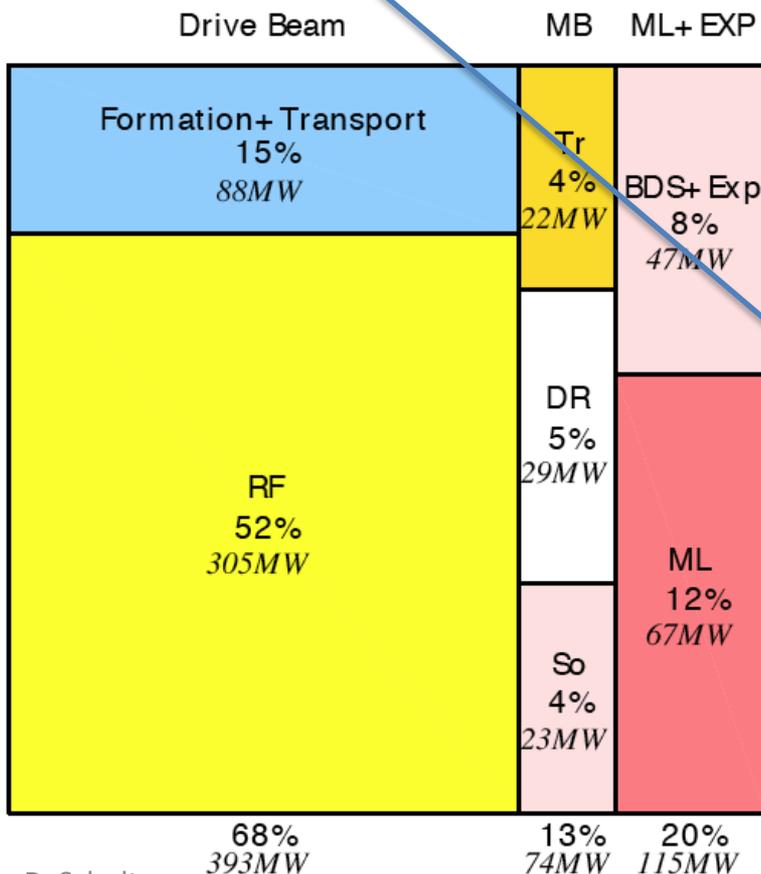Drive beam to main beam: 22%
Total 12.7%
(With overheads 11% and other systems 5%)

Plasma colliders:
60% is ambitious goal for a laser
60% is OK for CW superconducting linac

Adli et al. (PWFA):
50% appears possible for unshaped bunches (77% driver to plasma and 65% plasma to beam) in bubble regime

Schroeder et al. (LPA):
20% laser to beam in quasi-linear regime
More in hollow plasma
Could be similar or better for plasma accelerator

Careful review required
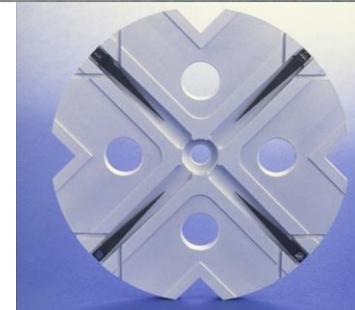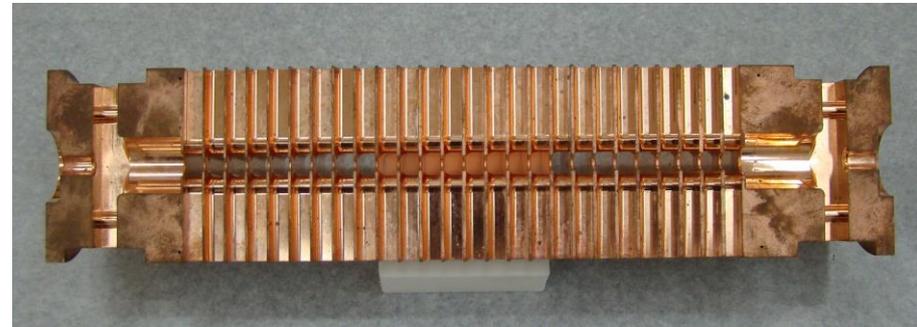In particular bunch charges

Efficiencies similar to CLIC

Drive Beam | MB | ML+ EXP

Formation+Transport
15%
88MW

Tr
4%
22MW

BDS+ Exp
8%
47MW

RF
52%
305MW

DR
5%
29MW

ML
12%
67MW

So
4%
23MW

68%
393MW

13%
74MW

20%
115MW

Note: Main Linac Parameter Choice for CLIC

Highest beam current leads to highest RF to beam efficiency
$\Rightarrow$ Maximise bunch charge
$\Rightarrow$ Minimise bunch distance

Short-range longitudinal wakefields induce energy spread, compensated with RF
$\Rightarrow$ bunch charge defines bunch length $\sigma_z(N, W_L)$

Short-range transverse wakefields can make beam instable
$\Rightarrow$ limits the bunch charge N $(W_T \sigma_z(N))$

Transverse long-range wakefield can make the beam instable
$\Rightarrow$ limits the distance between bunches

Beam stability for strongest practical lattice defines beam parameters

$$\mathcal{L} \propto H_D \frac{n_\gamma^{\frac{3}{2}}}{\sqrt{\sigma_z}} \frac{1}{\sqrt{\epsilon_y \beta_y}} \frac{R+1}{R} \frac{\eta P_{wall}}{mc^2}$$

CLIC single bunch extracts 0.3% of stored energy in accelerating structure (ignoring losses in copper)
• multi-bunch is key

Note: Beam Stability in Plasma Linac

Highest beam current leads to highest RF to beam efficiency
$\Rightarrow$ Maximise bunch charge
$\Rightarrow$ Minimise bunch distance

Short-range longitudinal wakefields induce energy spread, compensated with RF
$\Rightarrow$ bunch charge defines bunch length $\sigma_z(N,W_L)$

Short-range transverse wakefields can make beam instable
$\Rightarrow$ limits the bunch charge ($W_T \sigma_z(N) N$)

Transverse long-range wakefield can make the beam instable
$\Rightarrow$ limits the distance between bunches

Beam stability for strongest practical lattice defines beam parameters

Wakefield in LPA is $O(10^7)$ larger than CLIC
• Strong focusing
    • hollow channel does not provide this
• Energy spread helps

$$\delta \approx -\frac{\beta^2}{E} N e^2 W_\perp (\Delta z)$$

In plasma $\mu \dfrac{1}{n}$

Realistic studies of beam stabilities are key
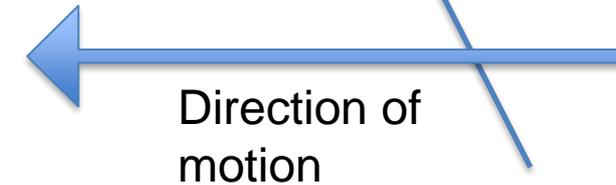• Wakefield model (actually two-stream model)
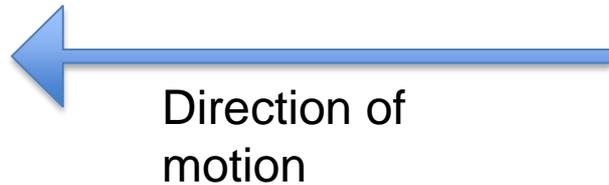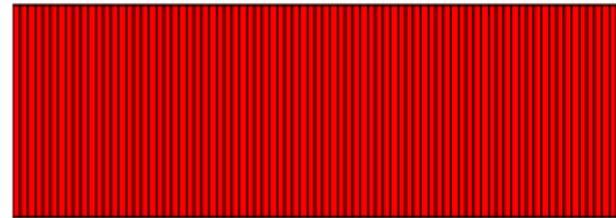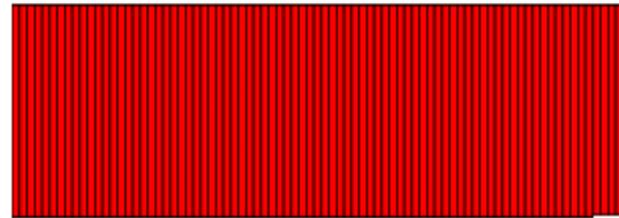• Mitigation techniques
    • allowed energy spread

Beam Stability

No BNS damping (energy spread)

Tail and centre flap quite a lot

With BNS damping (energy spread)

Tail still flaps a little bit

Direction of motion

Direction of motion

Simple betatron oscillation

Simple betatron oscillation

Centre of bunch is much more stable

Luminosity Challenge for Linear Colliders

$$\mathcal{L} \propto H_D \frac{n_\gamma^{\frac{3}{2}}}{\sqrt{\sigma_z}} \frac{1}{\sqrt{\epsilon_y \beta_y}} \frac{R+1}{R} \frac{\eta P_{wall}}{mc^2}$$

Reduce the vertical beamsize (betafunction and emittance) as much as possible

Plasma-based linacs might lead to larger energy spreads
$\Rightarrow$ R&D required to get to same beamsizes as with conventional technology
$\Rightarrow$ Or reduce energy spread, if possible

- Smaller emittances needs
    - better emittance preservation in main linac (but more difficult than in LC)
    - better sources
        - e.g. undulator-based damping?

- Smaller betafunction could be achieved using novel beam delivery system design
    - Plasma lenses?
    - Crystals?
    - Electron/proton lenses?
    - RF quadrupoles to correct correlated energy spread?

- Have to keep the tiny beams in collision
    - but high repetition rate would help

Damping Ring and Transverse Emittances

Can deliver $O(10^4)$ bunches/s
E.g. CLIC with 5ns kickers could cool 200 bunches at any time
Some beam dynamics issues but probably manageable

Other solutions for electrons could be possible
But for positrons that are created in collisions?

LPA could be here
Depends on DR energy

DLA is down here

CLIC

ILC

PWFA somewhere between CLIC and ILC

Vetrical emittance [pm]

Horizontal emittance [nm]

MAXIII, PEPII, ANKA, APS, LEP, ASTRID, ELETTRA, ALBA, CESRTA, BESSYII, PETRAIII (3GeV), ALS-U, BAPS-U, PEPX, SLSII, NSLSII, PETRAIII, SPRING8, SPEARIII, SPring-8 II, NLC, SOLEIL II, SOLEIL, τUSR, ESRF II, ATF, ESRF, ALS, DIAMOND II, MAXIV, DIAMOND, SLS, APS II, FCC-ee (Z), ILC, FCC-ee (H), CLIC DR, SIRIUS, Australian LS

Example: Energy Spread and Bunch Length

Final focus system has limited energy bandwidth

⇒ Need to limit beam energy spread

⇒ In CLIC 0.35% RMS spread

⇒ This is an important limitation for CLIC

Lattice design is very challenging

International collaboration worked on a demonstration for years
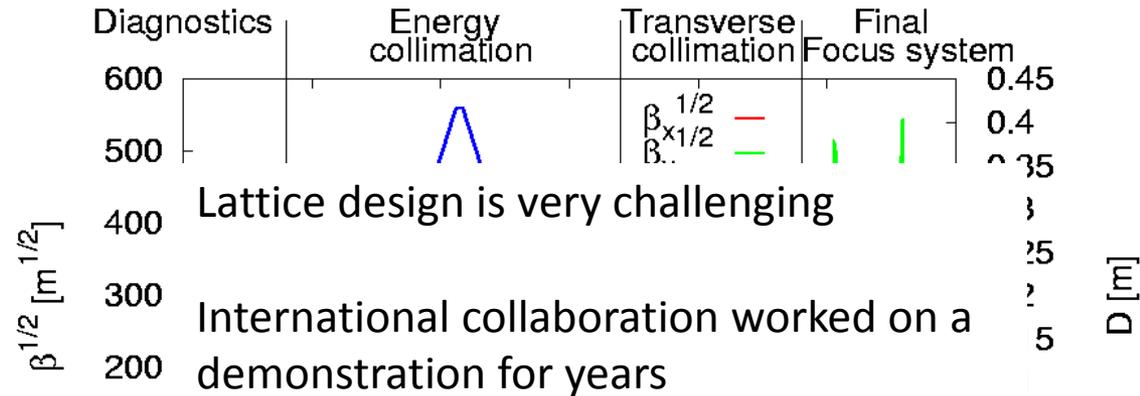
Energy stability required for CLIC is O(0.1%)

- Due to limited final focus system acceptance
- Corresponds to 0.2°(=15μm) coherent phase tolerance drive-beam to main-beam
- Challenging task, similar to XFEL

ATF-2 beam size development

June: reaching 44 nm, very close to ILC goal
(37 nm corr. to 6nm at ILC)

Field quality improvements, orbit stabilisation through feedback, shorted turn in 6-pole magnet, beam size monitor improvements
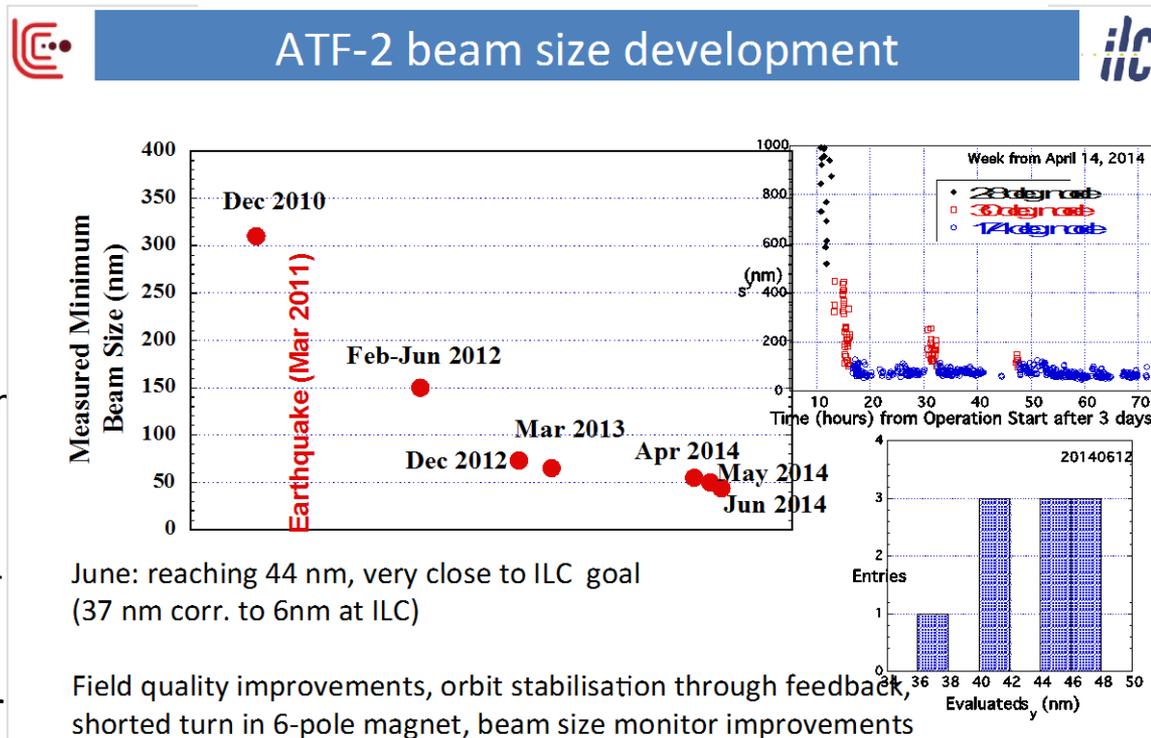
Example: Beamloading and Tolerance

Plasma acceleration tends to give larger energy spreads for high beamloading
- E.g. O(3%) in PWFA with unshaped bunches and 50% efficiency (E. Adli)

Need to
- Reduce energy spread (by bunch shaping?)
- Find better focus system (tough…)

Longitudinal bunch profile critical
$\Rightarrow$ Explicit design important to identify issues
$\Rightarrow$ In particular for shaped bunches

Plasma field varies along the bunch
For large beamloading this has to be O(G)

Use PWFA and simple harmonic field as example
$\Rightarrow 10^{-3}$ gradient jitter equals $0.09°=O(0.025\sigma_z)$
$\Rightarrow$ Very tight jitter tolerances for plasma accelerators O(50nm)
$\Rightarrow$ Detailed analysis seems important
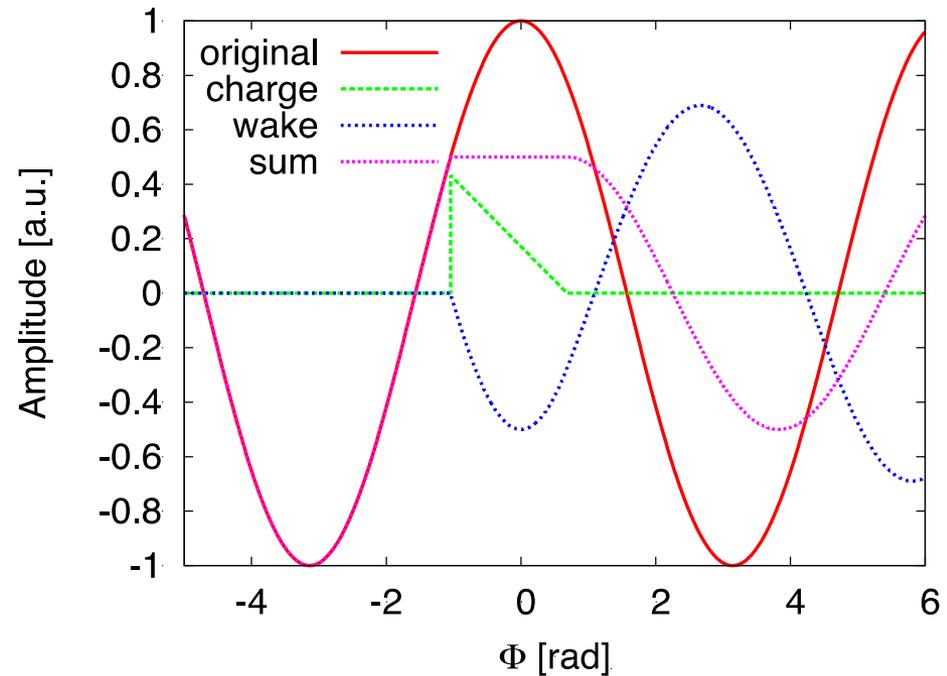
Energy spread is critical limitation

Important to understand tolerances correctly

R&D programme essential on timing systems
Current state of the art O(3000nm)

Example: Transverse Tolerance

First order estimate for middle part of cell

Laser or drive beam centre defines centre of the focusing

$$\sigma_{x,y} \approx 41\,\text{nm} \left(\frac{10^{16}\,\text{cm}^{-3}}{n_0} \frac{\text{GeV}}{E} \right)^{\frac{1}{4}} \sqrt{\frac{\epsilon_{x,y}}{\text{nm}}}$$

Centre of cell

Centre of drive beam

Main beam trajectory
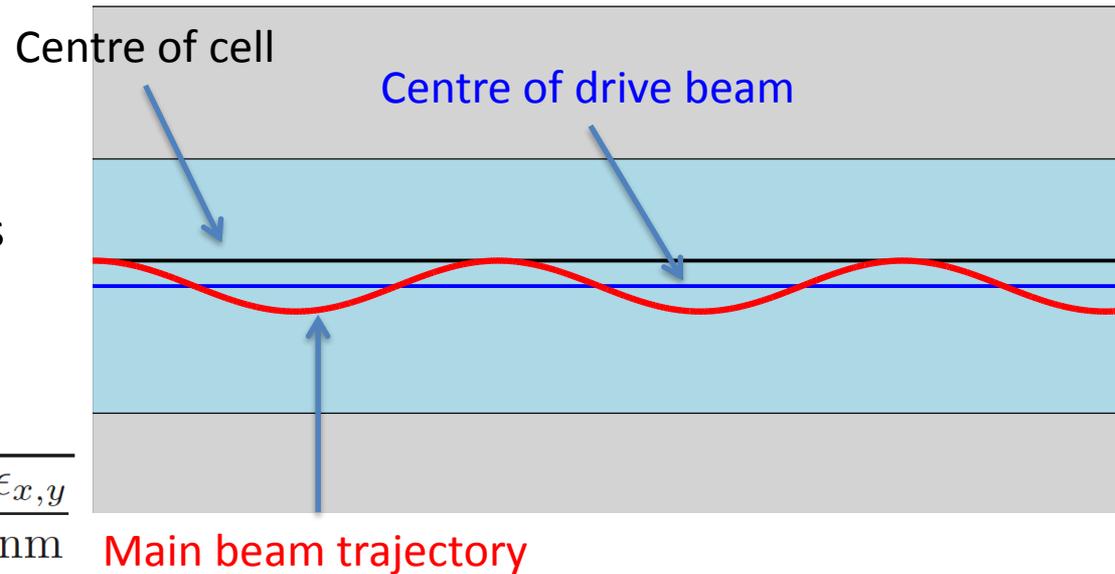
Example PWFA:

⇒ 2% luminosity loss budget leads to required jitter stability of 1.4 nm

⇒ Could use phase advance of 2nπ

⇒ Or much larger beta-function (lower plasma density) at ends of cells

Important to understand tolerances correctly

R&D programme essential on transverse alignment and stabilisation

Example: Angular Tolerance

Again a first order estimate for middle part of cell

• no effect from the ends of the plasma is included

Assume drive beam/laser moves on straight trajectory with waist at entrance of plasma cell

Exit of drive beam

Laser or drive beam centre defines centre of the focusing

Using PWFA numbers:
Need an angular jitter below 0.5nradian

Example ε_{drive}=1µm
• drive beam size is 490nm
  – 0.3% stability required
• divergence is 42µrad
  – 1.2×10^{-5} angular stability required

Larger betafunctions at entrance might help
Shorter cells help
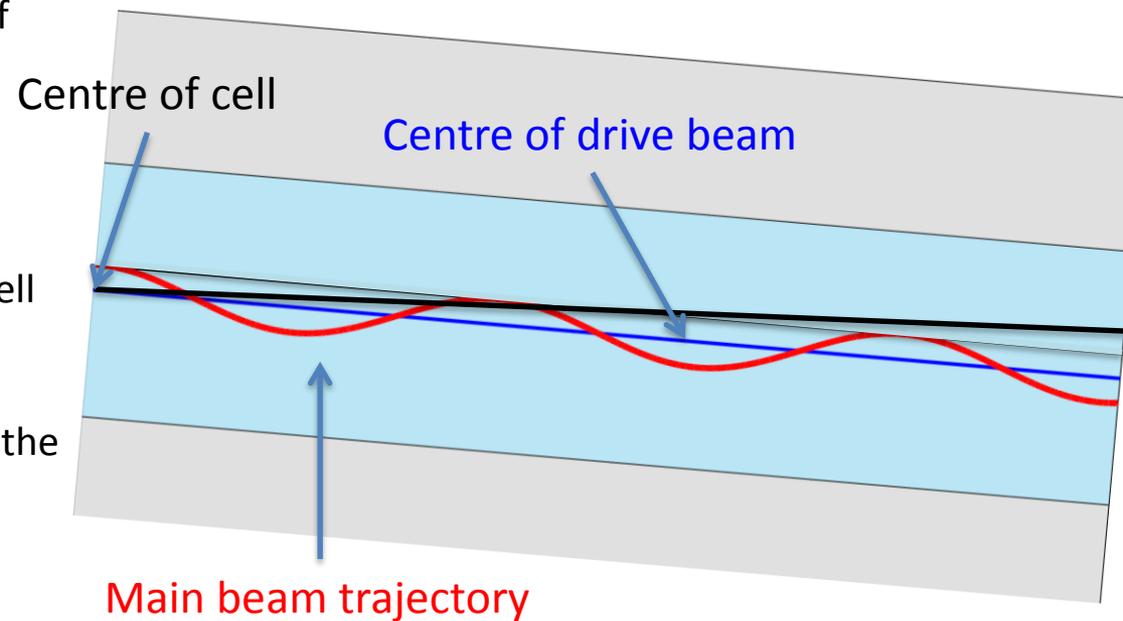
Centre of cell

Centre of drive beam

Main beam trajectory

Important to understand tolerances correctly

R&D programme essential on transverse alignment and stabilisation

Luminosity Challenge for Linear Colliders

$$\mathcal{L} \propto H_D \frac{n_\gamma^{\frac{3}{2}}}{\sqrt{\sigma_z}} \frac{1}{\sqrt{\epsilon_y \beta_y}} \frac{R+1}{R} \frac{\eta P_{wall}}{mc^2}$$

Suppress beamstrahlung?
- e.g. let four bunches collide to cancel fields
    - but find tight tolerances
- Use muons?
    - but difficult to get emittances, circular collider might be better
- Collide photons?
- Shorter bunches
    - But not a free parameter
    - limits from trident cascade at some point

No/reduced beamstrahlung allows to increase luminosity by increasing N/σ_x
- Smaller beams require smaller horizontal betafunctions or emittances
    - $\Rightarrow$ Better sources (round beams?), e.g. undulator-based source
    - $\Rightarrow$ Better focusing (note: currently small β_x makes small β_y more difficult)

- Increases N/σ_z increases deflection of background
    - $\Rightarrow$ Should decrease N
    - $\Rightarrow$ Need to produce even smaller σ_x

$$\epsilon_x \propto \frac{N^2 \sigma_z}{n_\gamma^3} \frac{1}{\beta_x}$$

Note: Gamma-gamma Collider Concept

Based on e⁻e⁻ collider

Collide electron beam with laser beam before the IP

$$x = \frac{4E_0\hbar\omega_0}{m^2c^4}$$

$$\hbar\omega_m = \frac{x}{x+1}E_0$$

α

ϑ
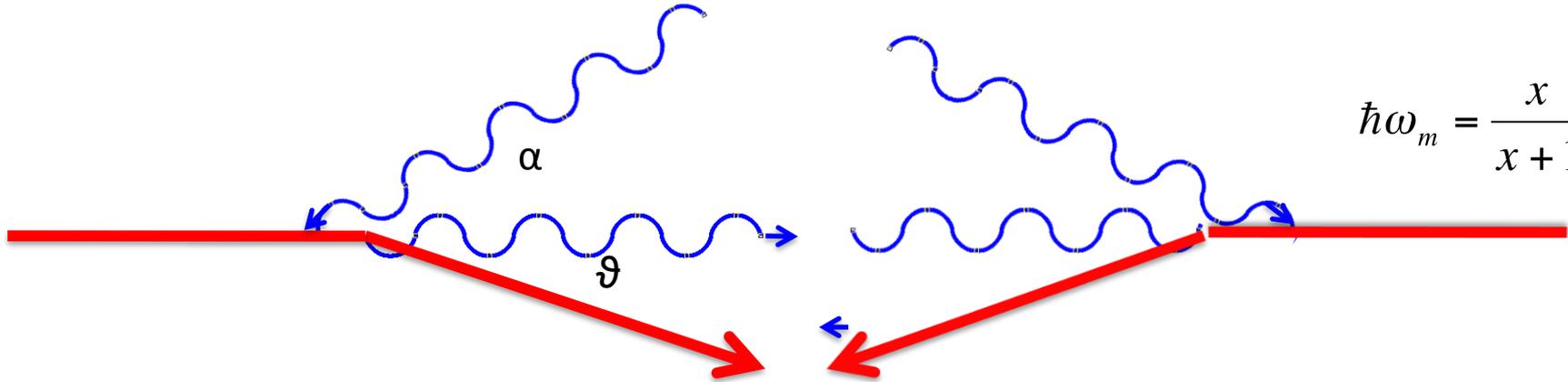
Backscattered photons form a spectrum

Practical maximum energy is 83% of electron energy

Luminosity
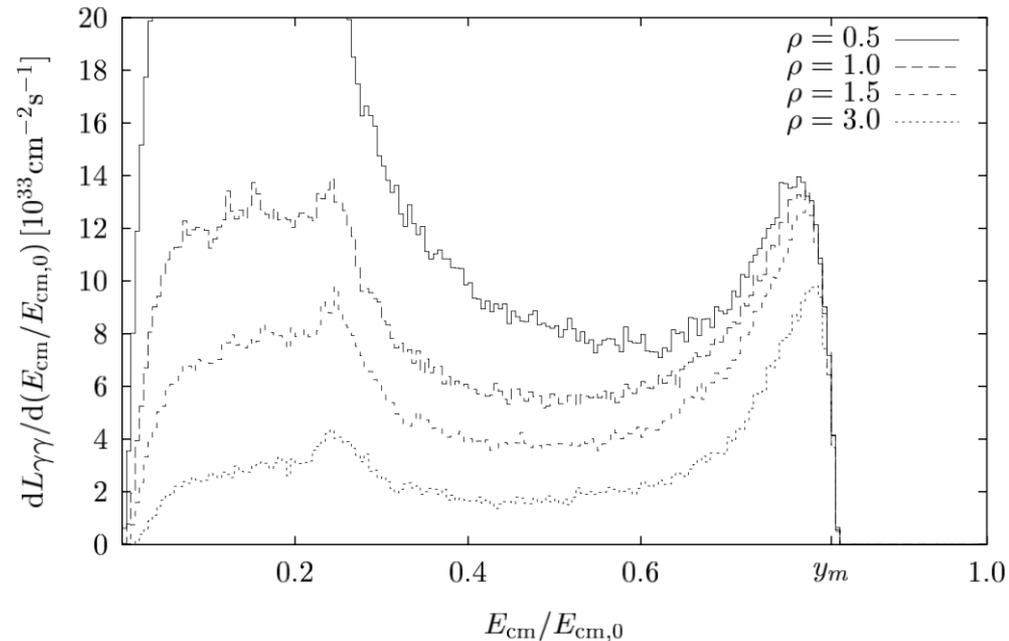
How to proceed? A short View into the Past

Linear colliders faced similar challenges in the past
- A number of competing approaches existed

The R&D work has been guided by defining goals and critical issues

Two comparative studies were carried out in the past to access the maturity of the designs and help to define the R&D goals
- So-called "Technical Review Committees"
- Experts from all projects reviewed the proposals and developed R&D lists with priorities
- That has been a very healthy process

We think that a similar process is required for novel acceleration technologies
- It has to be adapted to the maturity of the proposals

Rankings

- R1: R&D needed for feasibility demonstration of the machine
  - The objective of these R&D items is to show that the key machine parameters are not unrealistic. In particular, proof of existence of the basic critical constituents of the machine should be available upon completion of rank 1 R&D items.

- R2: R&D needed to finalize design choices and ensure reliability of the machine
  - These R&D items should validate the design of the machine, in a broad sense. They address the anticipated difficulties in areas such as the architecture of the subsystems, beam physics and instabilities, and tolerances. A very important topic is also to examine the reliability and operability of the machine, given the very large number of components and their complexity.

Rankings

- R3: R&D needed before starting production of systems and subcomponents
  - These R&D items describe detailed studies needed to specify machine components before construction and to verify their adequacy with respect to beam parameters and operating procedures.

- R4: R&D desirable for technical or cost optimization

And Novel Acceleration Technologies?

- Should define a similar list of R&D issues
  - Can serve to justify use of resources now and in the future

- For the TRC II (end 2003) the technical maturity of the projects was much more advanced than for NAT now
  - Concrete design of the machine (lattice decks existed)
  - Many tolerances were known

- However also important technical R&D remained
  - Accelerating gradient in some cases
  - Emittance preservation

- We sent out a request to help with this process
  - The experts know best what is missing

Mega-tables

Table 1: ALEGRO megatable – overall parameters of advanced acceleration collider concepts

Parameter	Concept 1	Concept 2	...	Concept N
Colliding species	e^+e^-	...	...	...
Upgrade or stand-alone	...	...	...	...
Final E CM, TeV	1.0	...	...	...
Luminosity, $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	...	...	...	...
Effective L*, m	...	...	...	...
Detector forward exclusion angle, mrad	...	...	...	...
Total length, km	...	...	...	...
Length of beam delivery, km	...	...	...	...
Repetition rate, Hz	...	...	...	...
Total wall plug power, MW	...	...	...	...
Colliding beam power, MW	...	...	...	...
IP beam sizes, X/Y, nm	...	...	...	...
IP beam length, Z, mm	...	...	...	...
IP beam n-emittance, X/Y, nm	...	...	...	...
IP beam E-spread, %	...	...	...	...
Colliding bunch population, 10^{10}	...	...	...	...
Initial E of colliding bunches, GeV	...	...	...	...
Driver type	laser	e-bunch	p-bunch	...
Adv.acc. media	plasma	diel	...	...
Driver E/bunch, J	...	...	...	...
Adv.acc. transformer ratio	...	...	...	...
Length of single adv.acc stage, m	...	...	...	...
Number of adv.acc stages	...	...	...	...
Effective gradient of adv.acc media	...	...	...	...

General

All collider projects have a large number of important issues that have to be addressed before their realization. It is important to identify the key issues that have to be addressed early in order to establish the feasibility of the project. For linear colliders such a prioritization of issues has been performed repeatedly, both in a collaboration between different proposals and within individual projects. These processes have been very beneficial for defining the R&D goals and in focusing the work programs on these goals. The lists of critical issues also have been instrumental in establishing the feasibility. The R&D results could be easily benchmarked against the set goals.

In a similar fashion, we therefore aim to identify the R&D items that are key in establishing the use of novel technologies in future colliders. **The goal is to support the importance of ongoing R&D** that is needed for colliders and **to identify R&D that has to be launched**. In order to help this process, please help to identify the relevant R&D issues for your proposal.

Some of the issues might be very fundamental, such as the potential to accelerate positrons. Other items might be linked to the final performance that can be achieved. Currently it appears that the main challenges would be expected in the realization of the high luminosity that is required for physics. In order to help the discussion, questions based on the linear collider experience are given below.

Systems

Beam Parameter Evolution

In case that you have a concrete proposal please highlight the beam parameter evolution along the collider. In particular, the bunch charge, length, energy spread and transverse emittances.

Beam Production

The production of brilliant beams is a key challenge in linear colliders. Please detail the concept to obtain the beam parameters at the beginning of the main accelerator and identify the key R&D required to achieve this.

Beam Acceleration

Beam break-up is a key limitation of the beam parameters in linear colliders. Please indicate the theoretical and experimental studies that support that your choice of beam parameters is consistent with stable beam acceleration.

In linear colliders the transverse beam emittance degrade during acceleration. Please detail the expected beam quality degradation during acceleration and the associated specifications for maximum imperfections.

Systems, cont.

Beam Focusing

The focusing of the full energy beam to the small beam size at the collision point is a key challenge in linear colliders. Please detail the beam parameters before this beam delivery system and at the collision point. Describe the focusing system concept and highlight the studies that will be needed to demonstrate its feasibility. Please also give the tolerances that need to be met to achieve the target performance.

Positron production and acceleration

Depending on the technology the production and acceleration of positrons will pose additional challenges.

Power

Please detail the target wall plug to beam power efficiency, compare to the state-of-the-art and indicate the R&D required to meet the target.

Examples for Plasma-based Acceleration

Just some examples:

- allowed plasma density fluctuations
- allowed fluctuations of the drive beam or laser pulse intensity and length
- allowed phase jitter of drive beam or laser pulse and the main beam
- allowed transverse jitter (angle and offset) of the drive beam or laser beam
- allowed misalignment between the drive beam or laser and the main beam
- allowed misalignment of components
- required stability of components
- …

Selected Example Main Linac Issues

- Positron acceleration in bubble regime
- Lattice design
  - Main beam focusing has huge impact on beam stability
  - Drive beam/laser in and out
  - For PWFA, clearly lower drive beam energy would be beneficial
- Two stream instability main beam in plasma (similar to wakefields in CLIC)
- Making a hollow channel for positrons (beam stability with no focusing)
- Channel alignment for hollow channel
  - Similar to structure alignment in CLIC, but likely tolerance very tight
- Drive beam/laser to main beam alignment/jitter stability
- Plasma density stability, in particular with longitudinal profiles
- Heating of the plasma (O(100 kW/m))
  - 75% of drive beam power to plasma, 65% from plasma to main beam
- Many more imperfections
  - This has been critical for conventional linear colliders
- ...

Key Questions to Physics

- What are important energy and luminosity goals for electron-positron collisions?
  - Obviously more is better, but what is important enough to justify a project

- Is gamma-gamma valid as a stand-alone project?
  - Might solve several issues for the positrons and avoids the beamstrahlung limit

Conclusion

- Important to identify R&D required to make NAT technologies credible options for future colliders
  - Support foreseen R&D
  - Help to launch new R&D

- Concrete proposals with parameters are required for judgment
  - Not every thing will be demonstrated nor even studied
  - But it defines goals

- Even with no concrete parameter list R&D can be defined
  - But obviously this might be for a longer timescale

- My tentative conclusion: try to use NAT to make high energies cheap and find novel ways to make luminosity production more efficient
  - But the latter is hard

Reserve

Note: CLIC Efficiency

Mains	
	0.89
Modulators	
Klystrons	
	0.7
Waveguide	
	0.985
RF structures	
	0.95
Drive beam	

Drive beam	
	0.97x0.9
PETS	
	0.98
Waveguides	
	0.92
RF structures	
	0.44x0.64
Main beam	

Total wall plug to drive beam efficiency   0.58

Total drive beam to main beam efficiency   0.22

Total 12.7%

Adding overheads etc: 11%