POSIPOL 2012 WORKSHOP
FLASH

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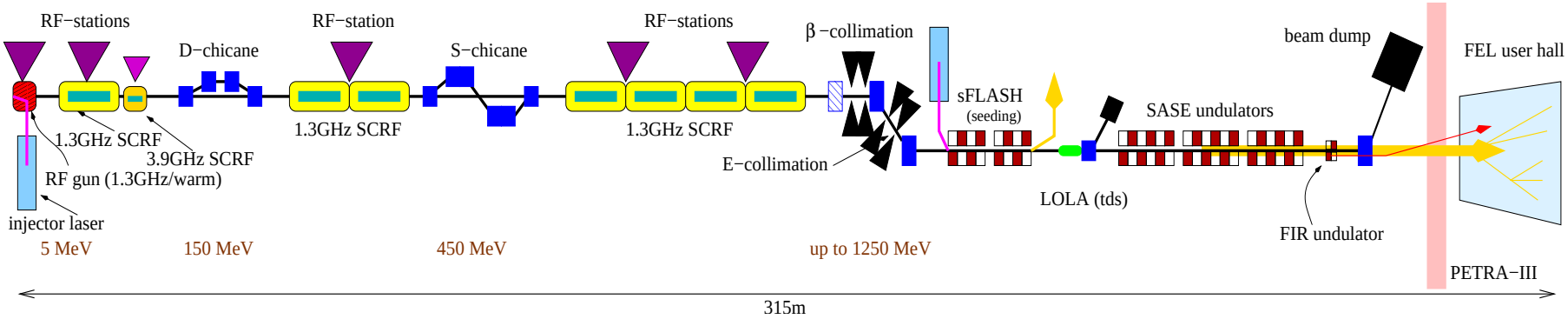
- **What is FLASH ?**
- **What can/can't FLASH offer ?**
- **Outlook : FLASH–2 (3?)**

DESY

FLASH
Free–Electron Laser
in Hamburg

FLASH Overview



- **FLASH** :=
  Free electr. LASer in Hamburg
- Normalconducting photo cathode RF–gun
- Superconducting (SC) LinAc (TESLA type cavities)
- Fixed gap planar undulator
  6× 4.5 m

⇒ **High brilliance, short pulse soft X–ray photon source**

- "Normal year",
  time (w/o maintenance):
  → 50% photon users
  → 35% FEL studies
  (perf. impr. , beamline service)
  → 15% General machine studies

FLASH Parameters 2011/2012

$\mathbf{e}^-$:		
emittance $\beta\gamma\varepsilon_{x,y}$		
(1 nC, on–crest, 90% rms)	1.4	mm mrad
charge	0.08 - 1.5	nC
beam energy	375 - 1250	MeV
bunches / train	1 - 500	
bunch spacing	1 - 25	μs
train repetition frequency	10	Hz
γ :		
wavelength (fundamental)	4.1 - 45	nm
average single pulse energy	10 - 400	μJ
pulse duration (fwhm)	50 - 200	fs
spectral width (fwhm)	0.7 - 2.0	%
peak power	1 - 3	GW
peak brilliance	10^{29} - 10^{31}	$(+)$
average brilliance	10^{17} - 10^{21}	$(+)$

$(+)$: photons/(s mm^2 mrad^2 0.1%bw)

A One–Page Intro to SASE FELs (xtremely rough!)

- particle/bunch trajectory in planar undulator ($\vec{B}_u \| \hat{y}$) is $\approx$ sinusoidal in (x, s)–plane
- superimpose lin.pol. plane e/m–wave $\vec{E} \perp \vec{B} \| \vec{B}_u \perp \vec{k}$

$\rightarrow$ at **resonance** $2\pi/k \approx \lambda_u/(2\gamma^2)(1 + K^2/2)$ particles can interchange energy w/ the plane wave coherently over the undulator length.
$\rightarrow \Delta E$ depends on "ponderomotive phase"

- Undulator: dispersion $\Rightarrow$ different $\eta := \delta E/E_0 \rightarrow$ different path length
$\rightarrow E$ modulation $\Rightarrow$ "micro–bunching" charact. size $2\pi/k$ (lab frame)

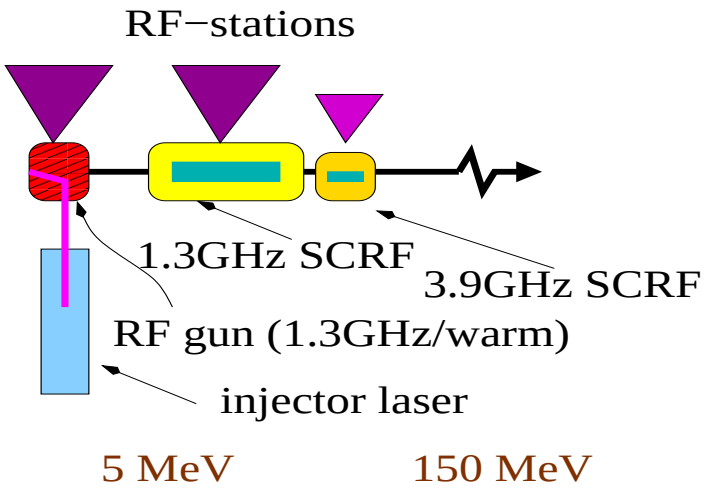
$\rightarrow$ coherent radiation from micro–bunches $P \propto \|E\|^2 \propto n^2$
(n particles in micro bunch)

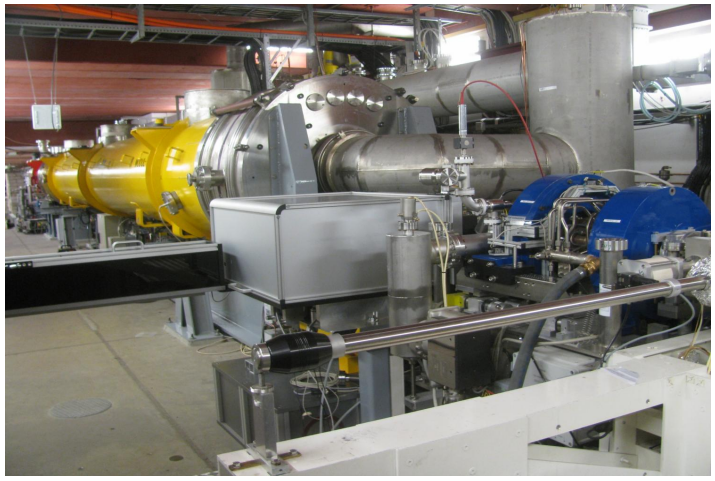
$\rightarrow$ this is an **instability** started from shot noise !

$\leftarrow$ . . . if everything is set up right $\Rightarrow$

- Needs high peak current, good overlap between γ & e^- in undulator,
small beam-size/emittance, low energy spread

Injector Laser / Photo Cathode RF Gun



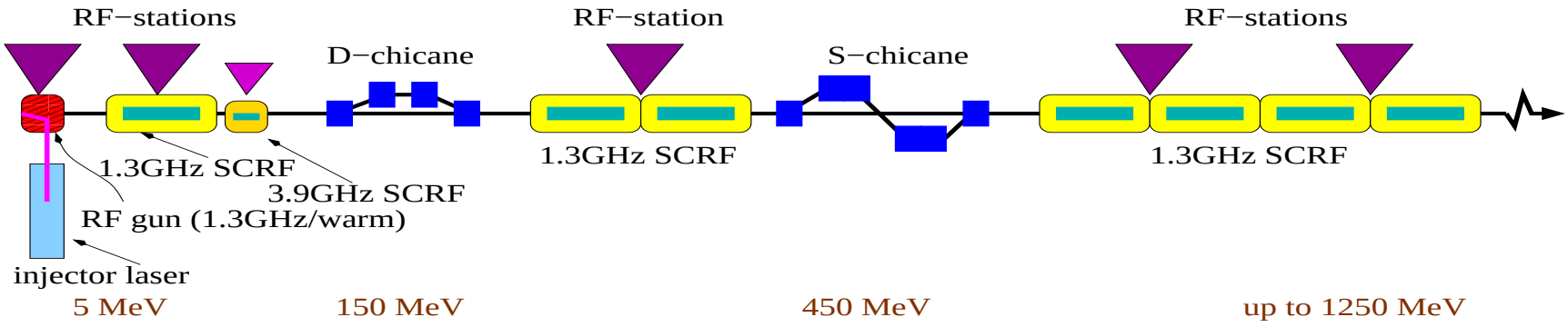


- Injector–laser: Mode–locked PTO $\oplus$ diode–pumped Nd:YLF amps $\oplus$ 2-stage freq. doubling to 262nm

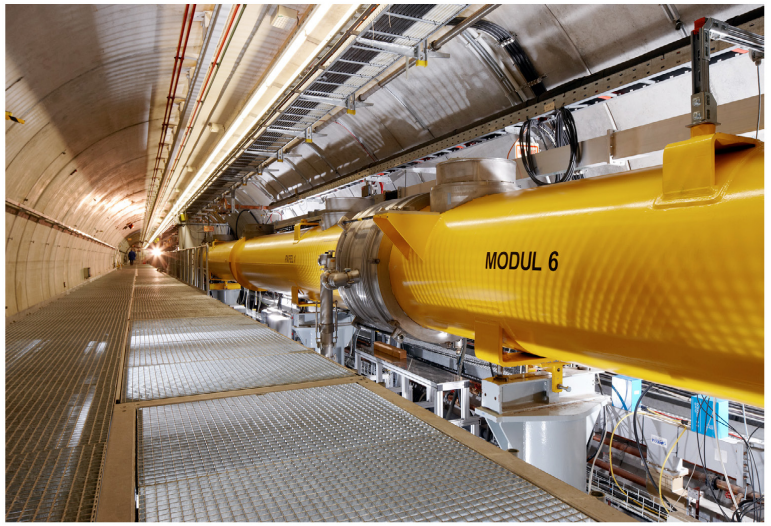
$\rightarrow$ Max 800 pulses at 1 MHz $\otimes$ 10 Hz or 2400 pulses at 3 MHz $\otimes$ 5 Hz $\Leftarrow$ heat load on Pockels cells!

- Photo–cathode: thin film of Cs_2Te on Mo plug
- Gun cavity: 1.5–cell 1.3 GHz (warm) copper cavity
- Solenoid for emittance preservation
- Operational: 80 pC to $\approx$ 2 nC /bunch

RF / LinAc



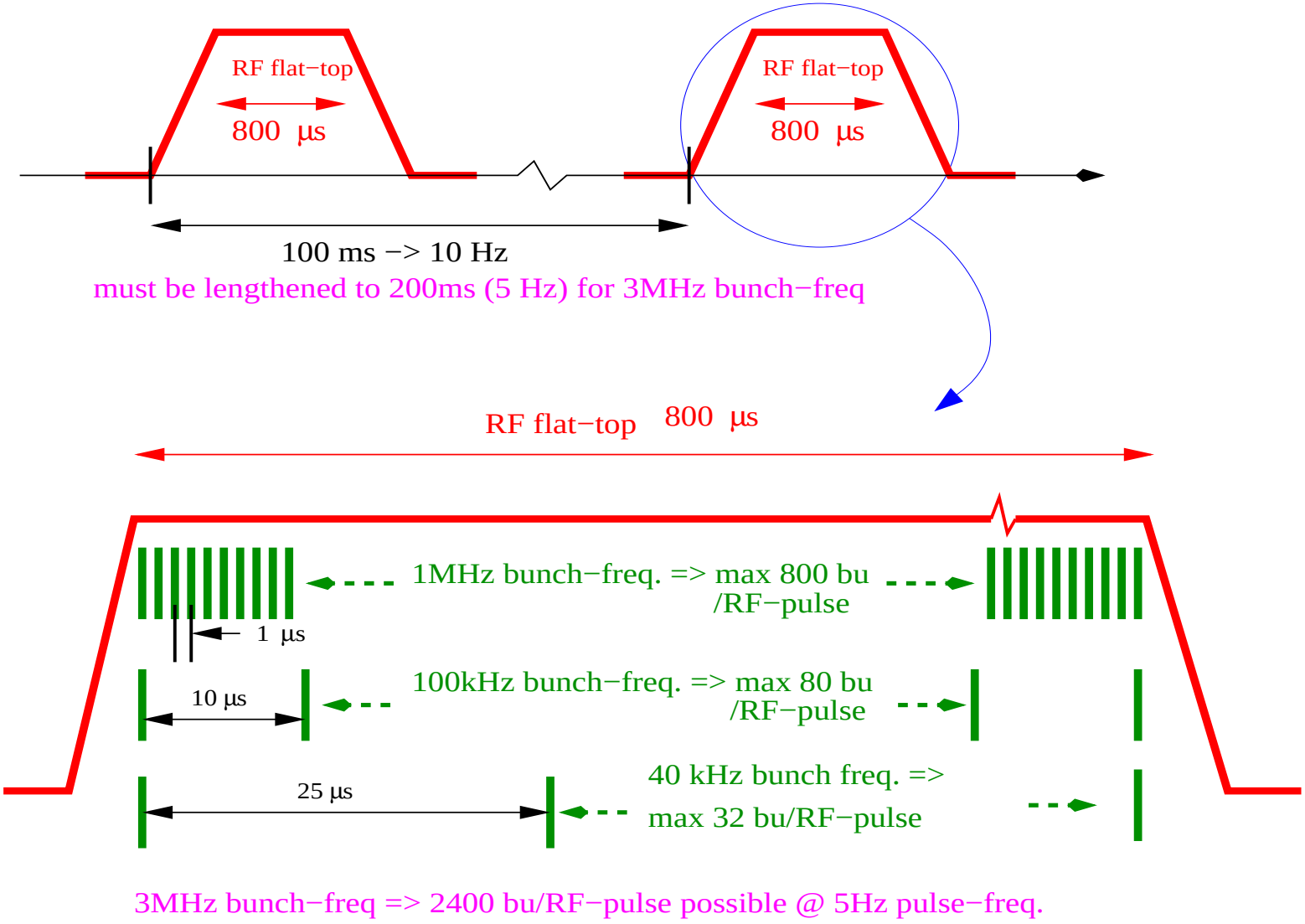
- 7× 1.3GHz modules w/ 8 nine–cell Nb–cavities each.
- E–gain/module:
  180 MeV (older modules) $\rightarrow$
  240 MeV (latest XFEL prototype).
- Bunch compr.:
  2 chicanes @ 150 MeV & 450 MeV
  $\oplus$ **3-rd harmonic** module (linearization).



Fotoshooting bei DESY, FLASH-Tunnel, Februar 2012
Fotos: Heiner Müller-Elsner

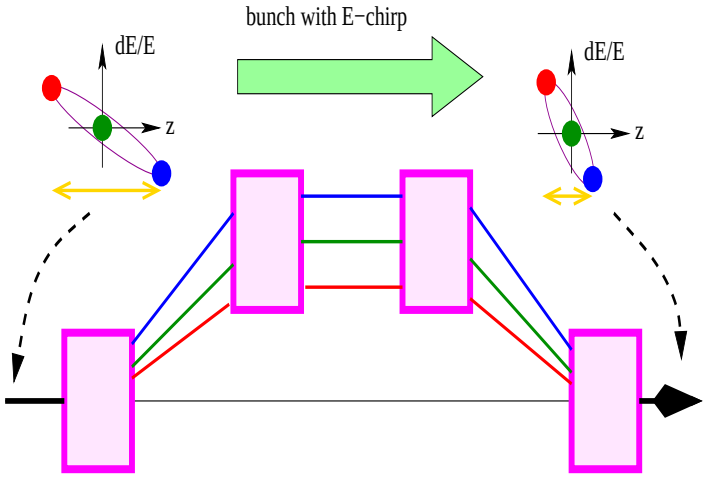
- E after LinAc: 375 MeV (deceleration!)
  to 1250 MeV "full steam ahead".

Interlude: The Time Structure of the FLASH Beam



3MHz bunch−freq => 2400 bu/RF−pulse possible @ 5Hz pulse−freq.

Inerlude: Linear Bunch Compression



- Ultrarelativistic e^-

→ **particles cannot overtake in straight beam line!**

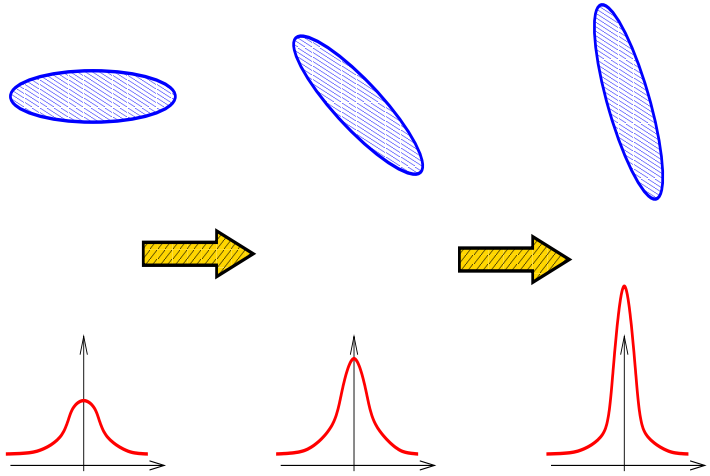
→ Magnetic chicane : path length depends on E

⇒ E–chirp $\oplus$ chicane ⇒BC!

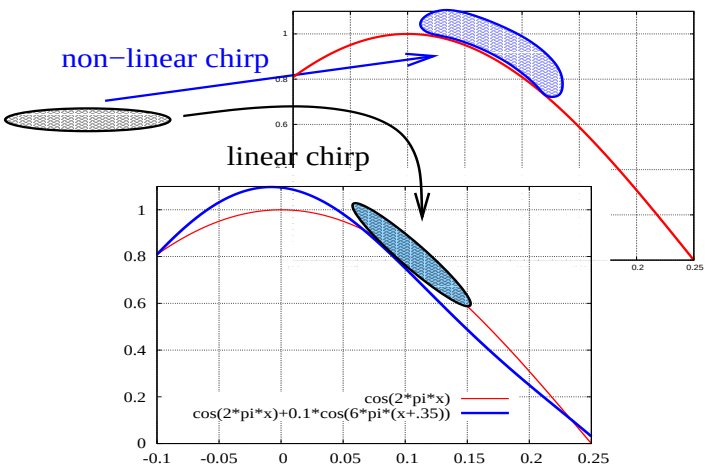
- Bunch compression is rather a rotation in phase space

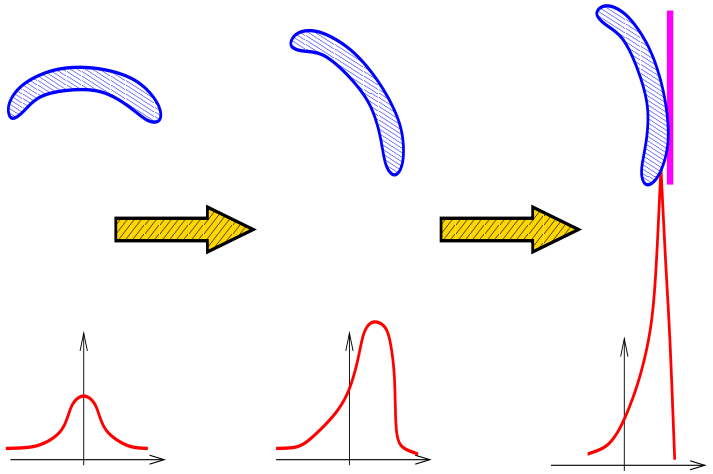
→ BC–map = Kick ∘ Drift

- **linear** BC gives nice Gaussian bunches of high I_{peak}



Interlude: Avoid Nonlinear Bunch Compression!





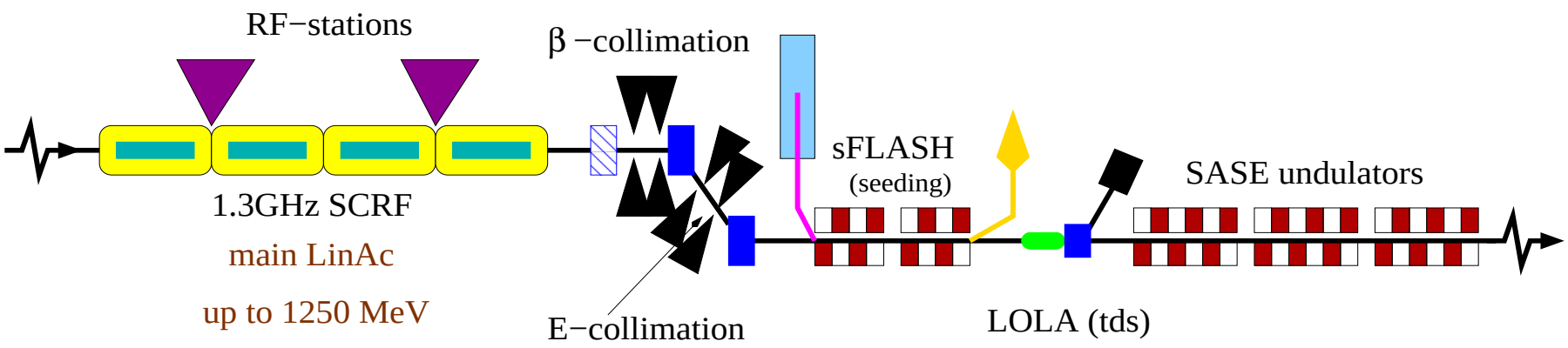
- Create E–chirp over bunch w/ RF operated at off–crest phases
- Cavity fields are sinusoidal $\Rightarrow$ "banana–shape" impregnated on bunch

$\Rightarrow$ nonlinear BC $\Rightarrow$ spiked densities — yuck !!!

$\rightarrow$ use **3-rd harmonic RF** to linearize $\sum$–voltage around bunch phase

$\rightarrow$ "done" :-)

Transport to Undulator / Collimation / Long. Diagnostics



- Protect undulators (permanent magnets!) :

1: β–tron collimation

2: off–E collimation (dispersive **"Dogleg"**)

- HHG seeding : sFLASH (see below)

- Long. phase space diagnostics → **LOLA**

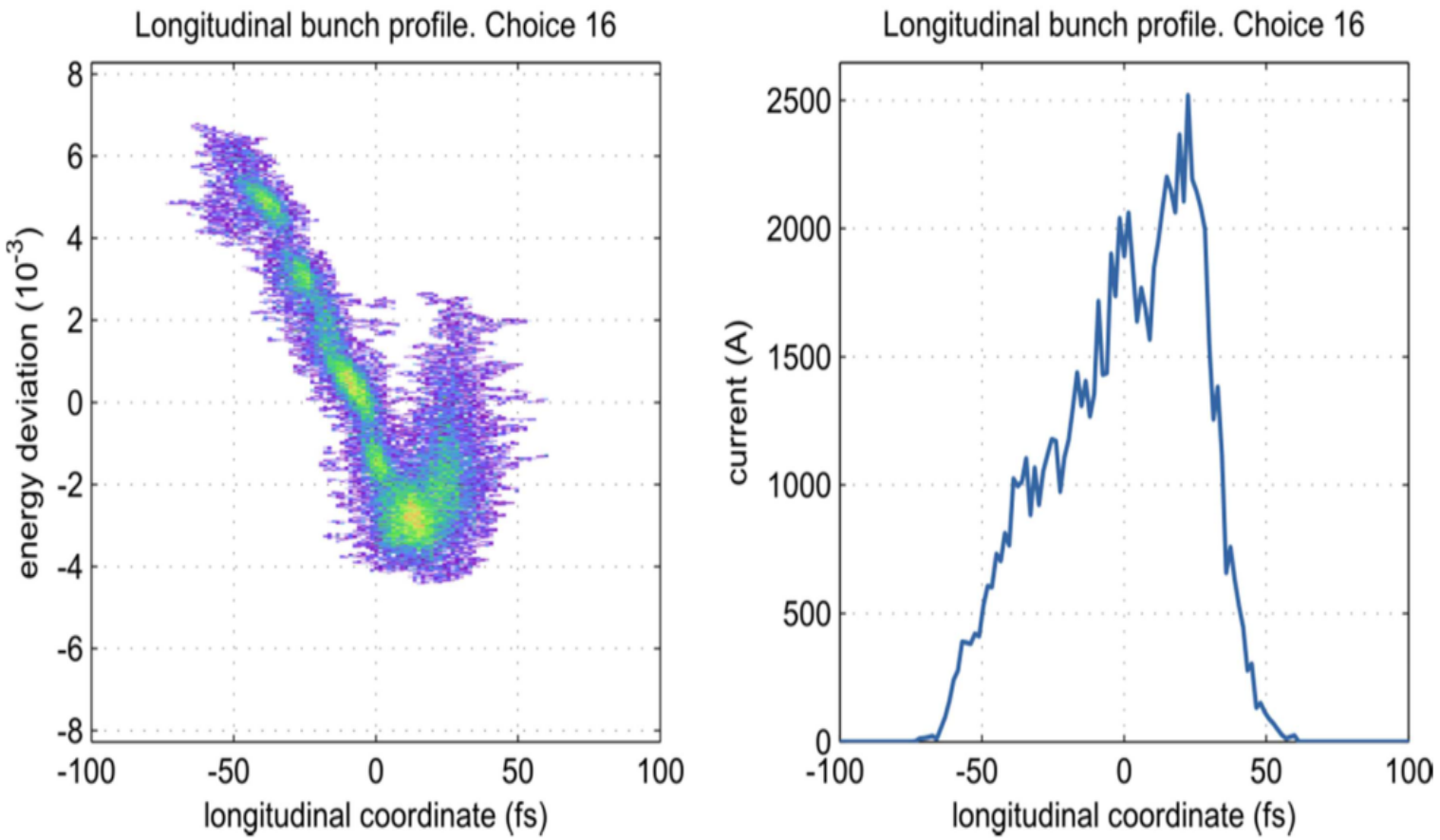
→ **T**ransverse **D**eflecting **S**tructure : $\tau \mapsto y$

→ Dispersive arm (dipole) : $\eta \mapsto x$

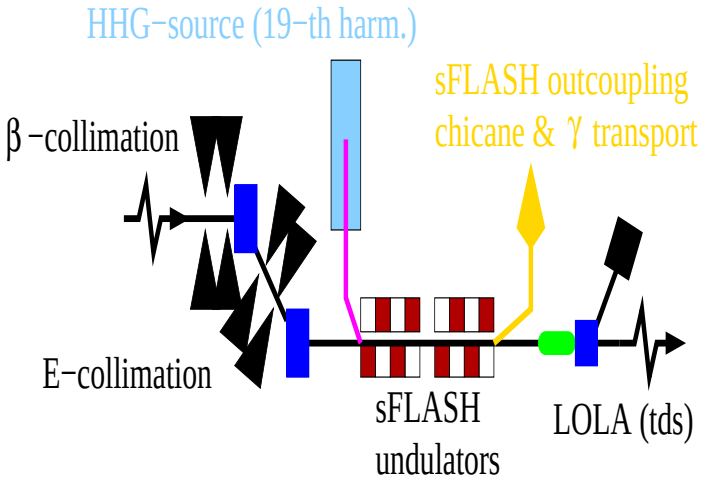
⇒ $\boxed{(\tau, \eta) \mapsto (x, y)}$

→ OTR–screen → CCD-camera

Longitudinal Phase Space (LOLA Image)



Seeding : sFLASH



- SASE $\leftrightarrow$ FEL starting from shot noise
- Seeding : start FEL process with external (laser) field

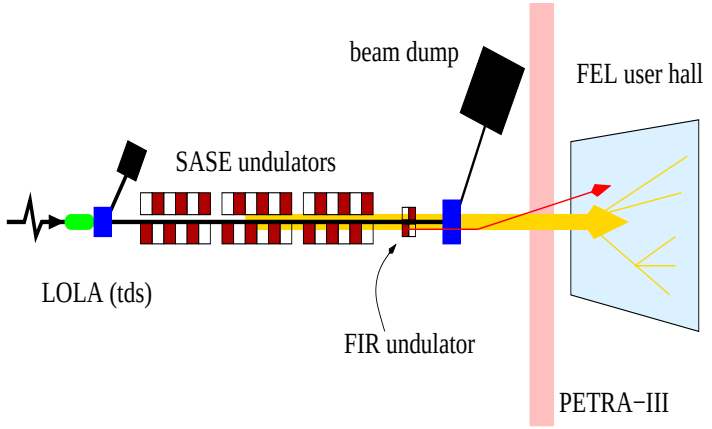
$+$ Better stability & coherence

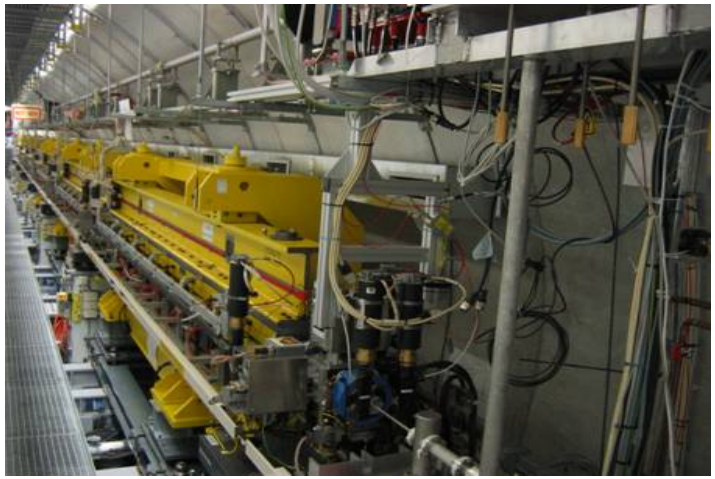
$-$ Needs transverse (x, x', y, y'), temporal (τ) and spectral $(\nu_{\mathrm{laser}} \leftrightarrow E_{\mathrm{beam}})$ matching

$\rightarrow$ much more complicated !

- **sFLASH : first seeding at 38 nm in April 2012 !!**

Main (SASE) Undulators / FIR Undulator / Photon Transport





- SASE undu.: 6× 4.5m, $\lambda_u = 27.3$ mm, $K = 1.23$ fixed gap undulators

→ vertical aperture 10/2 mm

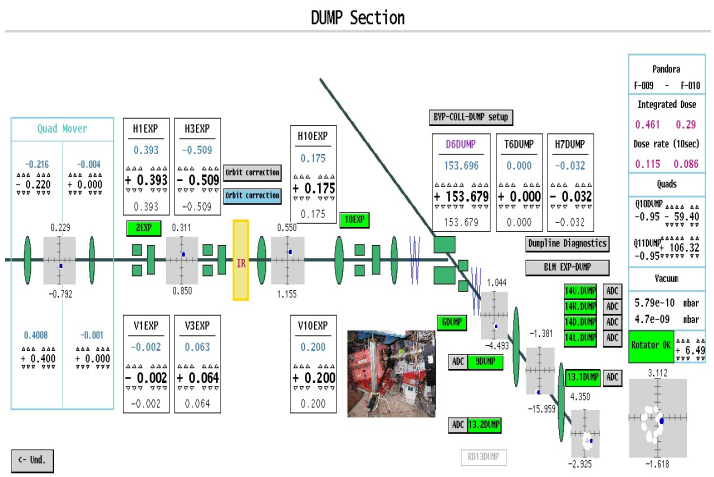
→ **BLMs for protecting the permanent magnets !!**

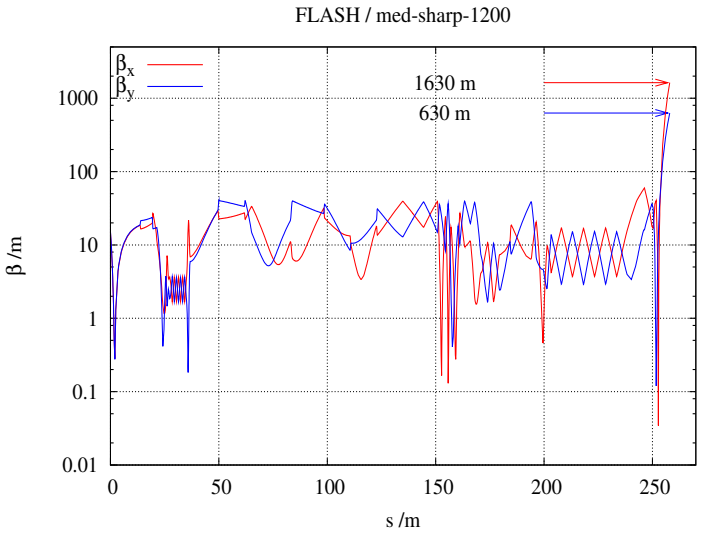
- Downstream: (electromagnetic) far-IR undulator for THz radiation

→ pump–probe
(& bunch diagnostics)

- γ–diag.: Ce:YAG, MCP, 2×GMD$\oplus\gamma$–BPM, spectrometer(s) in γ beam line **after** e^- beam separation (dipole).

The e^-–Beam Dump





- Dump beam line **widens** & rotates beam
  $\rightarrow$large β
  $\rightarrow$ex–HERA-e sextupole powered w/ 3-phase current $\rightarrow$ rotating dipole

$\Rightarrow$ protect dump window

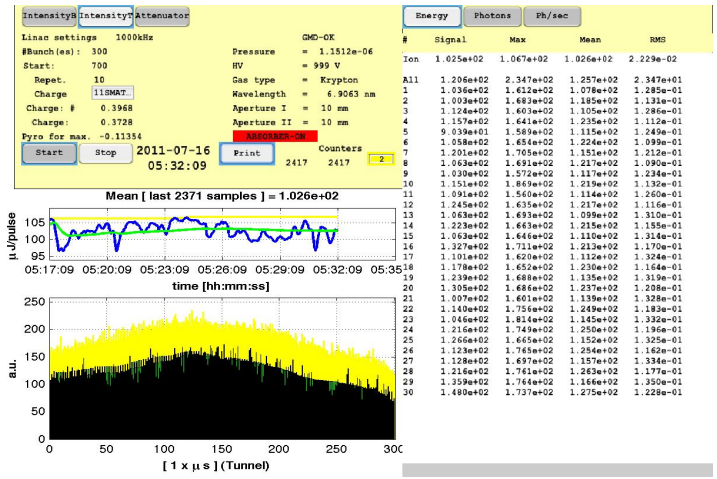
$\leftarrow$ $2400 \times 5 \times 3$nC @ 1200 MeV
$>$20 kW !!

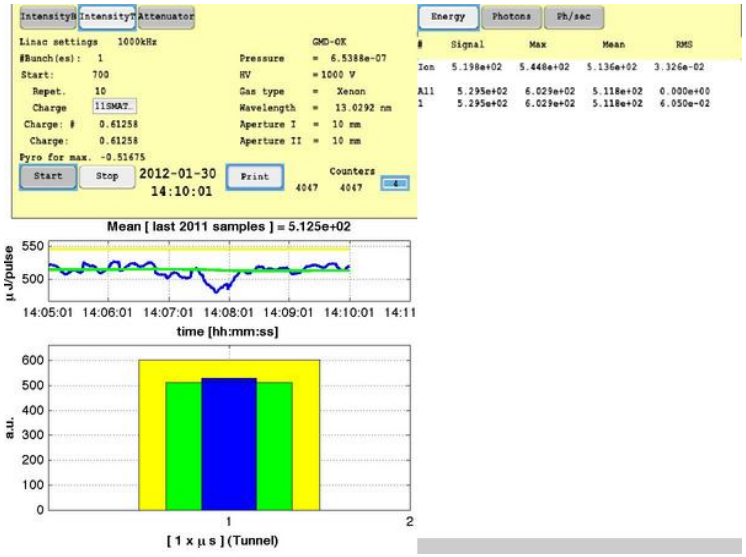
– Densely packed / partly inaccessible beam line

– Close to barely shielded "hockey bat" exit

$\Rightarrow$ No good place for conversion target tests !!

Some FLASH Statistics





(w/o maintenance & shutdown : γ-user:FEL-study:Acc-study $\approx 50 : 35 : 15\%$)

- **Users:** about 50/50 for single–bunch/multi–bunch

$\rightarrow$ γ pulse length: 25% : < 50 fs, $> 50\%$: 50-100 fs

$\rightarrow$ variable λ, bunch pattern,...

$\rightarrow$ critical pointing, bandwidth, pulse length,...

- **FEL studies:** test new hardw./softw. tools (γ & e^-), γ beam line set up
- **Acc studies:** sFLASH, ILC 9mA, LLRF–μTCA, OpticalDiffractionRadiation,...

Experience with "Fixed Target" Experiments

. . . like those potentially useful for **positron source development**. . .

- OpticalDiffractionRadiation (ODRI) : OTR-screen & **narrow** diffraction slit in former by–pass line above the undulators :

→ experiment suffered from loss of beam–permit ($\Rightarrow$ Kly→OFF for hours!)

- "Material Test Bench" in former by–pass line : ab–initio restricted to smth. like 100 shots in a life time by Radiation Safety Group (D3)
- Accidental mis–steering in EXP/DUMP region (after main undulator)

→ loss of beam–permit potentially for $\propto$ 4h

Shielding Issues & General Radiation Safety Constraints

- "Hockey bat" aisle to side entrance (truck accessible)

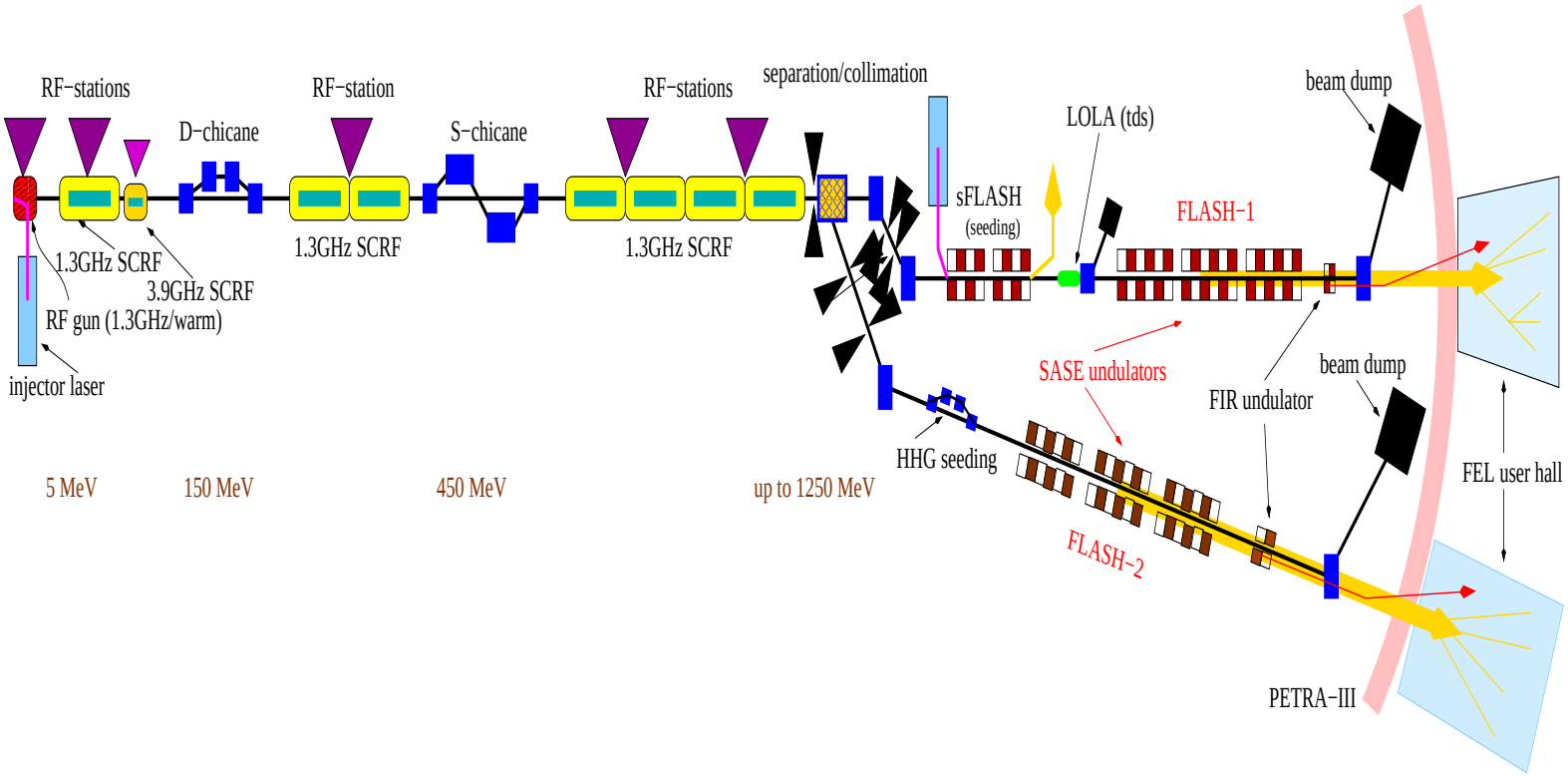
$\rightarrow$ "garage door" is insufficiently shielded

$\Rightarrow$ add. labyrinth of shielding stones necessary

$\leftarrow$ must be crane accessible though $\rightarrow$ "hole" close to ceiling :-(

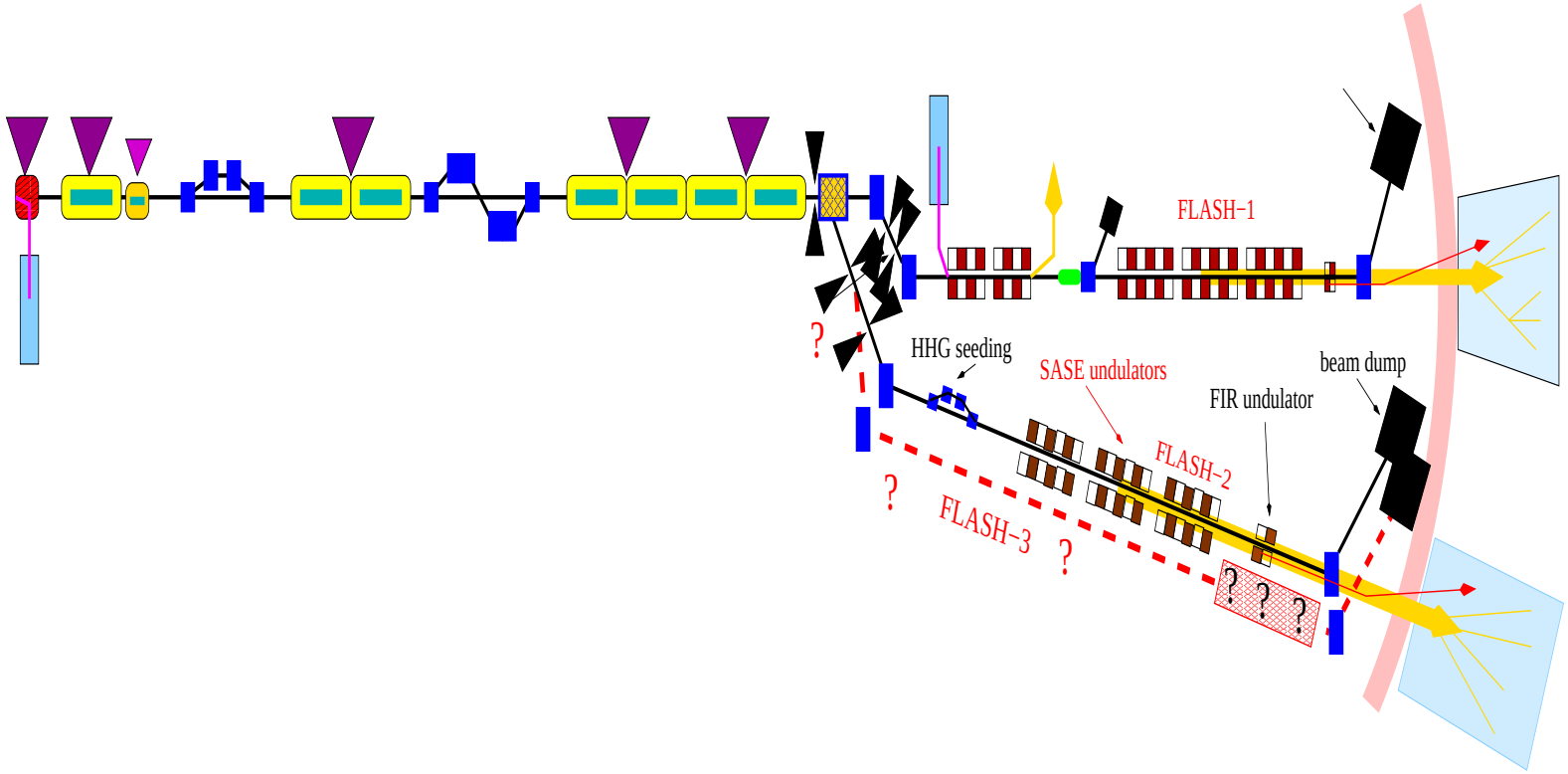
- RadiationWatchdog (Pandora) $\leftrightarrow$ beam–permit !!
- Max dump power is restricted
- Machine protection (mainly but not only: undulators !!) forbids "nasty' stuff in most areas
- "mini–dump" solutions only where MPS permits and only for 2-bunch mode at most !

Extension : FLASH–2



- FLASH–2 beam line is being built
  - \+ no "hockey bat" entrance exit
  - – dump line as densely packed as in FLASH–1
  - – need to widen beam on dump window → no focus close to dump
- **IF AT ALL,** a proposal has to be made asap !

X–Xtension : FLASH–3 ?



– not yet funded . . . however, dump pit already exists.

- Plan: build FLASH–2→3 extraction soon.
- no beam line designed so far. . . — Unclear if γ or "experimental" !
- LAOLA (LaserPlasmaWakefieldAcceleration) and others ?

Summary & Conclusion (w.r.t. potential e^+–source development)

- FLASH is mostly an FEL user facility with only roughly 15% dedicated beam time for accelerator experiments
- FLASH can deliver up to 800×10 bu/sec or 2400×5 bu/sec with charges from 80pC to ≈ 2nC at energies up to 1250 MeV
- The machine is NOT made for "fixed target operation" ! Neither personal–safety–wise nor machine–protection–wise !
- The current (FLASH–1) dump region is overcrowded and its closeness to the "hockey bat" is prohibitive for testing of production targets.
- **IF** such an experiment is possible at all at the FLASH–2 dump line it needs to be proposed/planned/designed/coordinated **asap**.
- Focusing a high power beam to small cross sections close to the dump window is extremely challenging if not impossible.
- **IF** FLASH–3 is going to be build, it might offer a chance for target tests.