First look at RF synchronisation for Gamma-Factory POP in SPS

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Introduction - Reminder

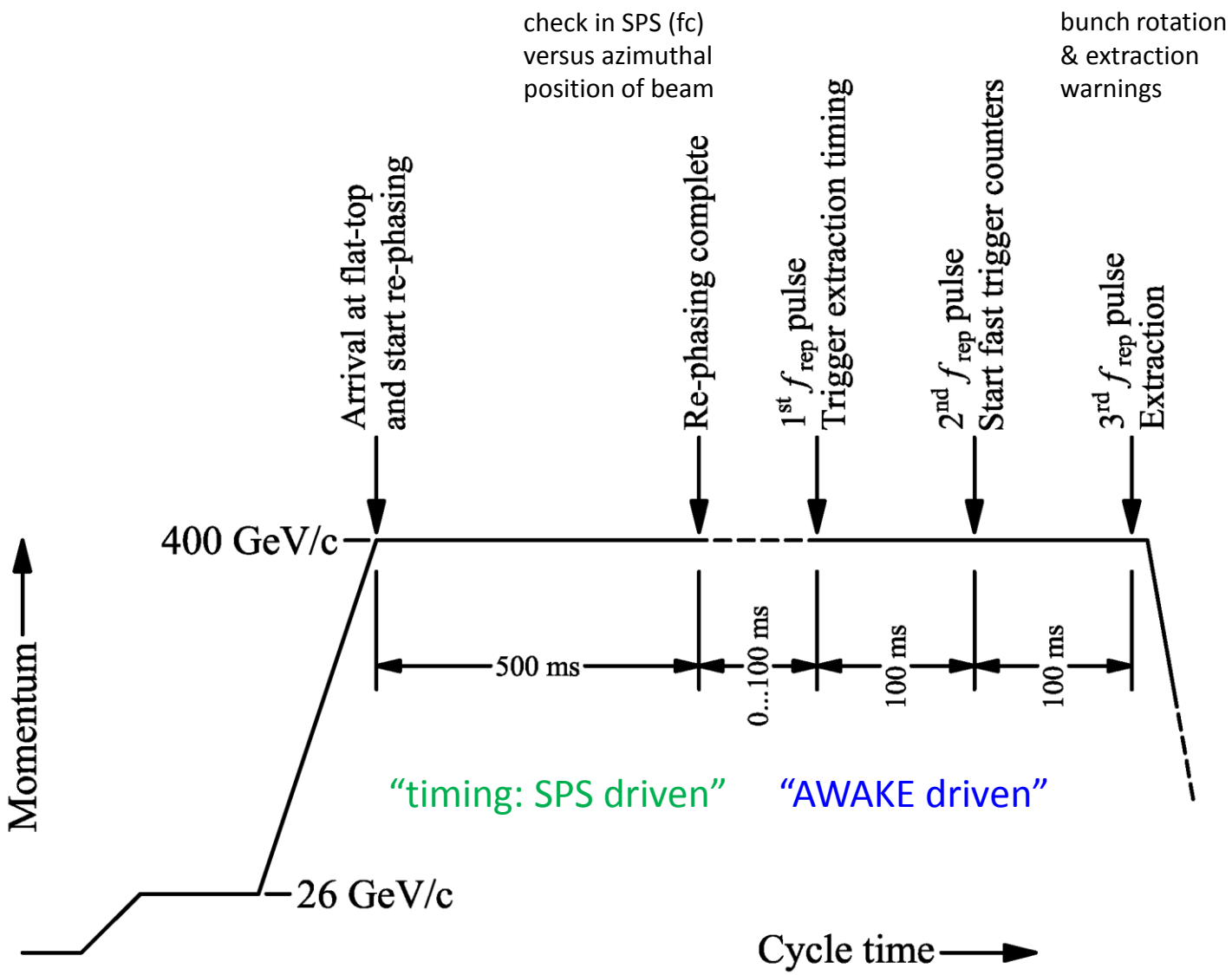
- SPS main RF system frequency is 200 MHz.
- SPS RF systems are located in point 3 of the SPS (cavities, power, LLRF).
- RF synchronization regularly done in the SPS for
  - extraction of beam to LHC (point 4 of LHC)
  - extraction of beam to AWAKE (point 4 of SPS)
  - during crab cavity MDs (prototype system in point 6 of SPS).
- Common to all schemes is that the beam is re-synchronized in the SPS to external reference signals from the receiving machine or experiment.
- During the process the beam can be shifted in time to the right position with respect to a fixed revolution frequency pulse of the SPS.
- A high precision of the synchronization requires distribution of RF signals with low drift and jitter.
- AWAKE synchronization has been the most precise implemented in the SPS
  - based on scheme developed for the beam transfer to LHC

Design choices for AWAKE synchronization at 400 GeV/c

- Choice of frequencies given by existing parameters and constraints
  - klystron frequency for electron beam (3 GHz) , *existing hardware*
  - SPS RF (200 MHz)
  - range of frequencies for laser mode locker
  - ratios as far as possible integers
  - If fractional ratios, small integer ratios preferred (choice 25/11) between SPS RF (200 MHz given) and Laser mode locker (→ 88 MHz)

Signal	Frequency	Ratio	"h"
Laser phase locked loop, f_{LPLL}	5.9958 GHz	1	870 x 691152
Electron acceleration, $f_{RF,e}$	2.9979 GHz	$f_{LPLL}/2$	870 x 345576
2×Laser mode-locker, $2f_{ML}$	176.347 MHz	$f_{RF,e}/17$	870 x 20328
Laser mode-locker, f_{ML}	88.1735 MHz	$f_{RF,e}/34$	870 x 10164
2×SPS RF system freq., $2f_{RF,SPS}$	400.8 MHz	$2f_{ML}\times25/11$	870 x 23100
SPS revolution frequency $f_{rev,SPS}$	43.3 kHz	$f_{ML}\times5/10164$	870 x 5
Common frequency, f_c	8.67 kHz	$f_{ML}/10164$	870
Laser Pulse repetition rate, f_{rep}	9.97 Hz	$f_c/870$	1

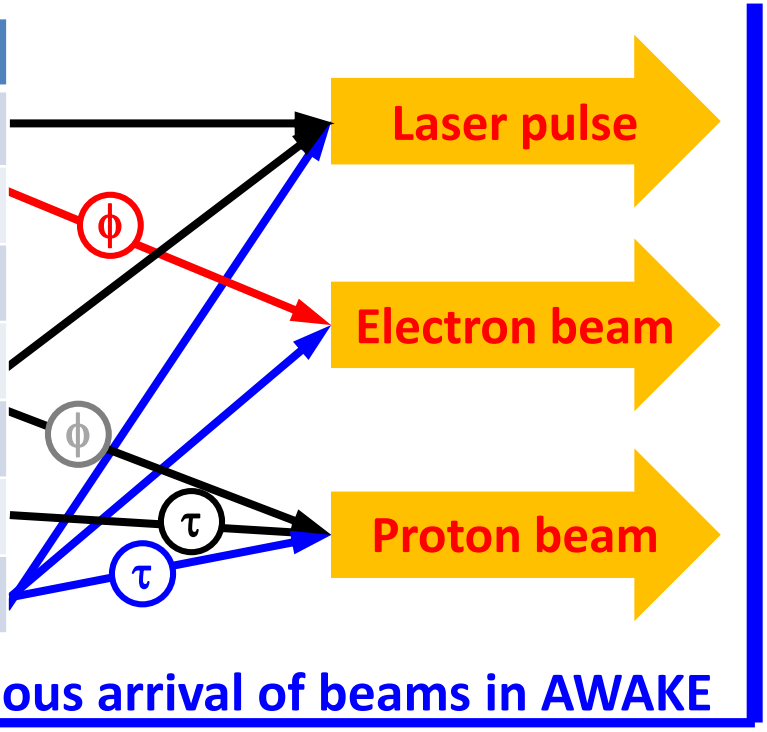
SPS AWAKE Cycle



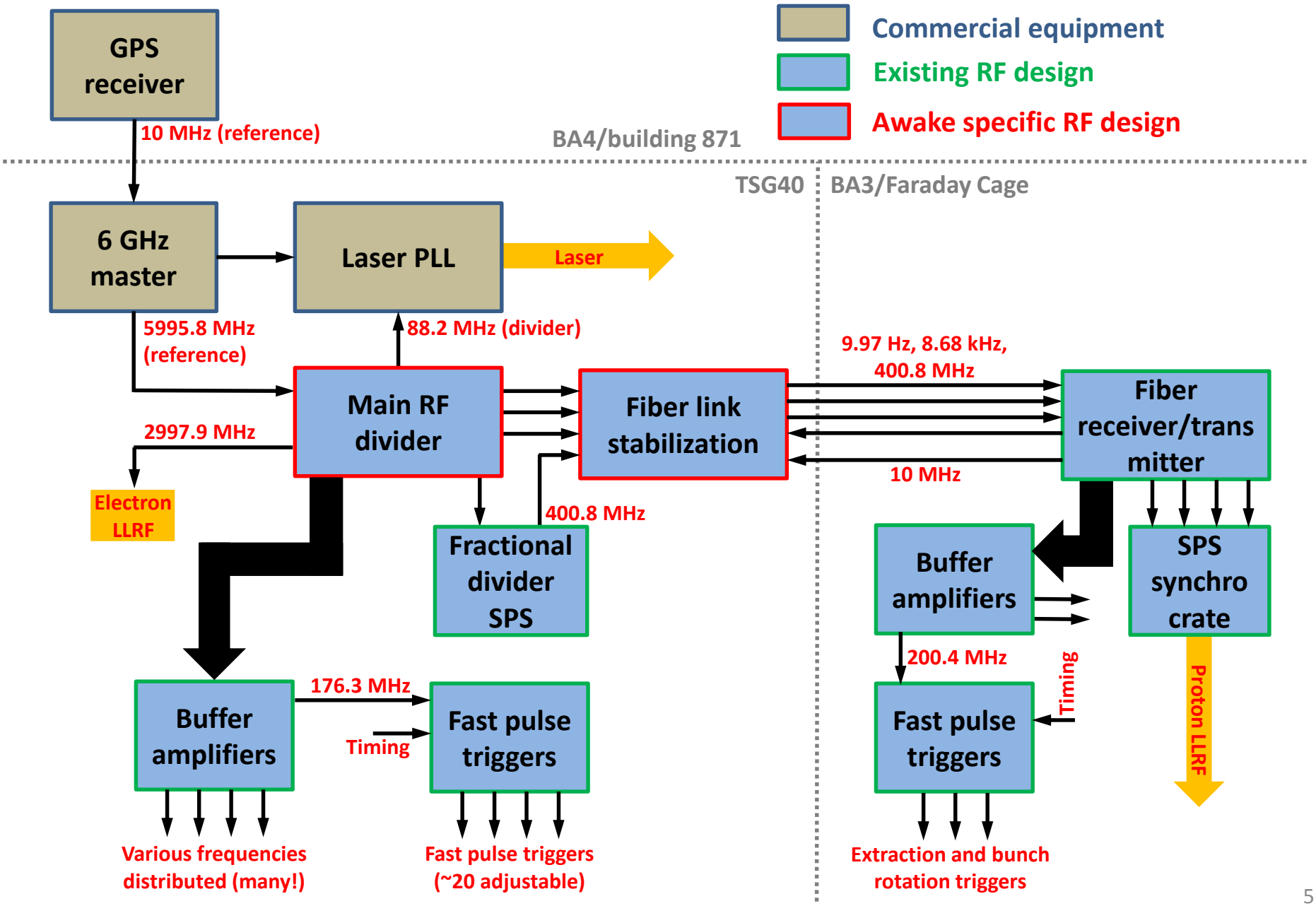
AWAKE: Synchronizing 3 Beams

- AWAKE Synchronization and RF distribution must deliver a **wide range of RF signals** for laser, electron and proton beams
- **Precision trigger pulses** for beam instrumentation
- **Reference: signals (f_{ML}, f_{rep}) for laser**
- Signals for proton/electron beams and fast triggers **shifted**

Signal	Frequency	Ratio
Laser phase locked loop, f_{LPLL}	5.9958 GHz	1
Electron acceleration, $f_{RF,e}$	2.9979 GHz	$f_{LPLL}/2$
2×Laser mode-locker, $2f_{ML}$	176.347 MHz	$f_{RF,e}/17$
Laser mode-locker, f_{ML}	88.1735 MHz	$f_{RF,e}/34$
2×SPS RF system freq., $2f_{RF,SPS}$	400.8 MHz	$2f_{ML}\times25/11$
Common frequency, f_c	8.68 kHz	$f_{ML}/10164$
Pulse repetition rate, f_{rep}	9.97 Hz	$f_c/870$



Simplified overview synchronization and RF distribution

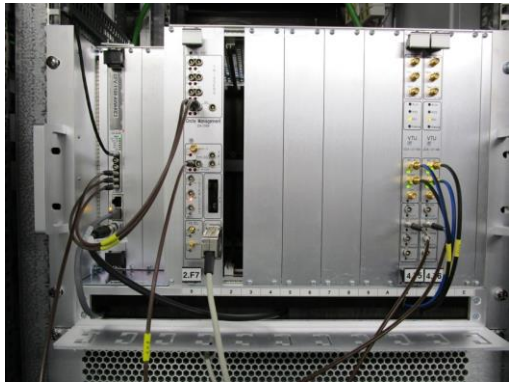


Hardware installation

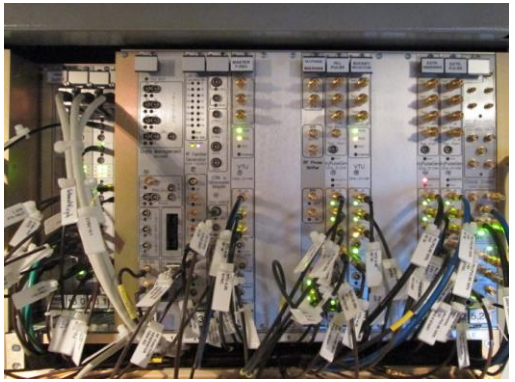
TSG40 | BA3/Faraday Cage

Link compensation

Fast triggers



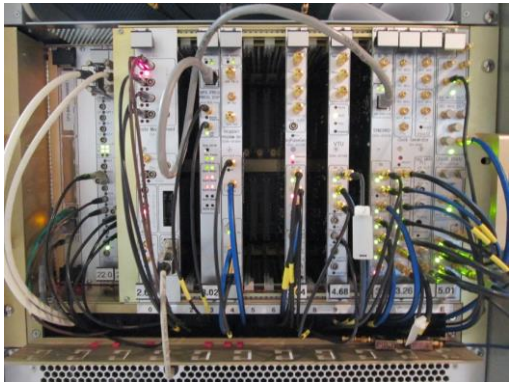
Synchro crate



Main divider, RF trains

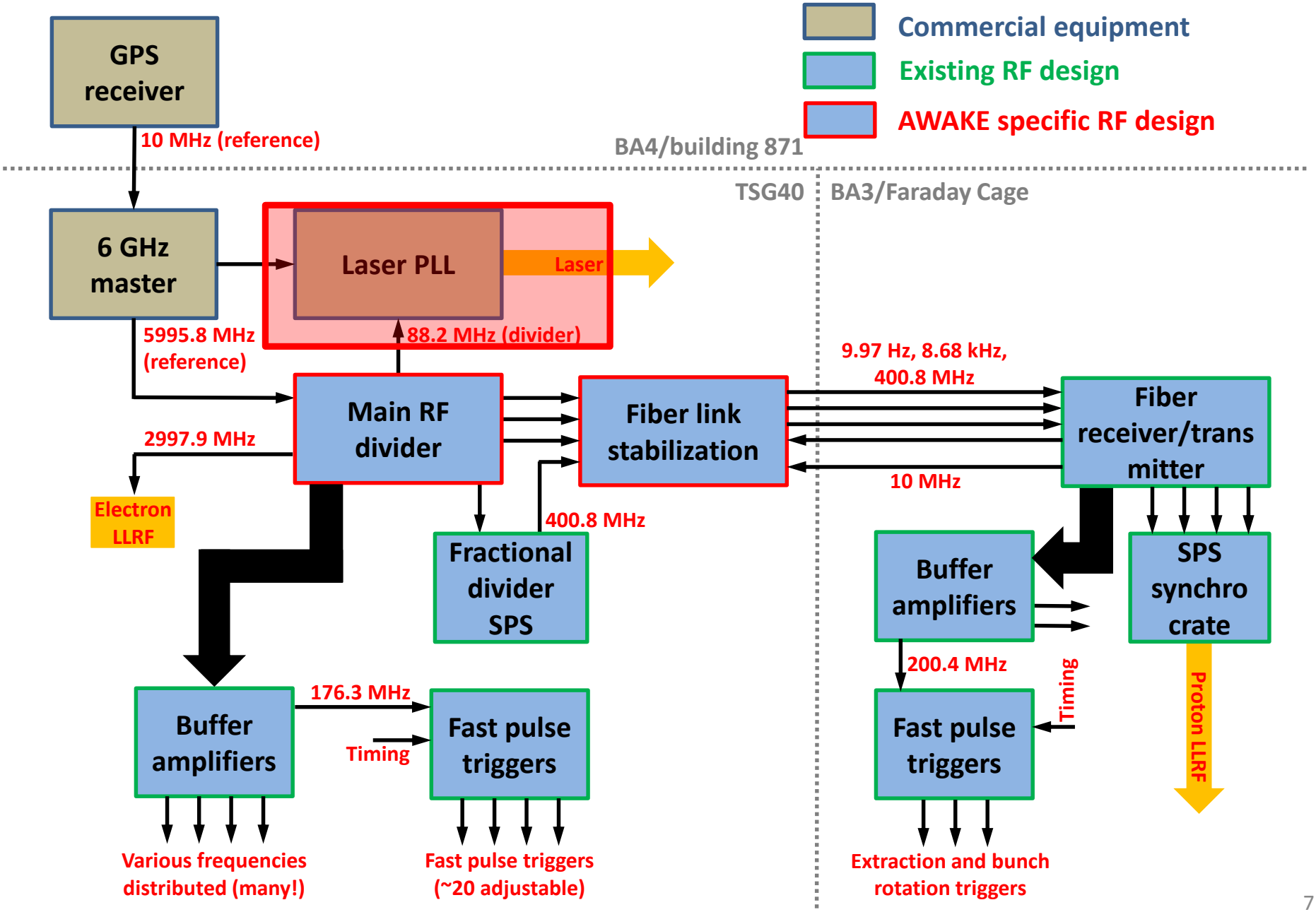
Distribution, frac. divider

AWAKE crate



\+ RF master oscillator, distribution EUROPA crate, optical distributions

Simplified overview synchronization and RF distribution



Laser synchronization

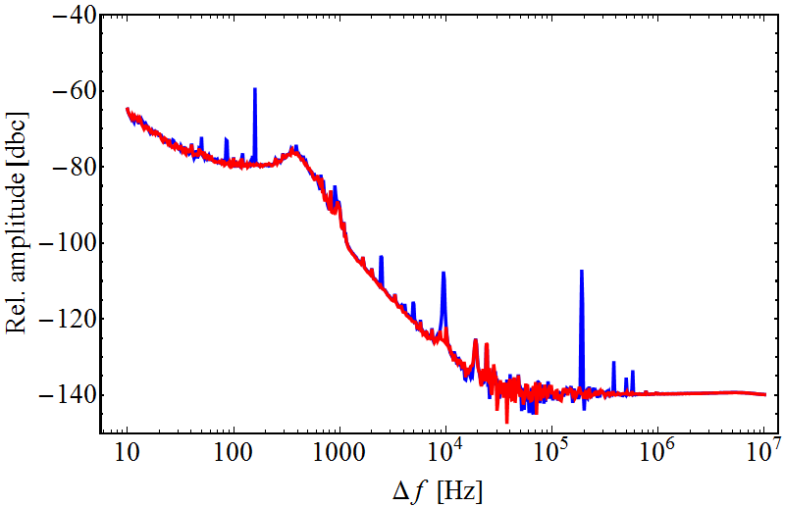
- Two stage synchronization process
  1. **Fundamental lock at f_{ML} = 88.2 MHz, commissioned**

  → **Unambiguously define phase of laser and f_{ML} from RF distribution**

  2. **Harmonic lock at 5.995 GHz (68 × f_{ML}), under test**

  → **Low jitter phase-lock of laser**

Jitter with 88 MHz fundamental lock



- Measured jitter 10 Hz – 10 MHz

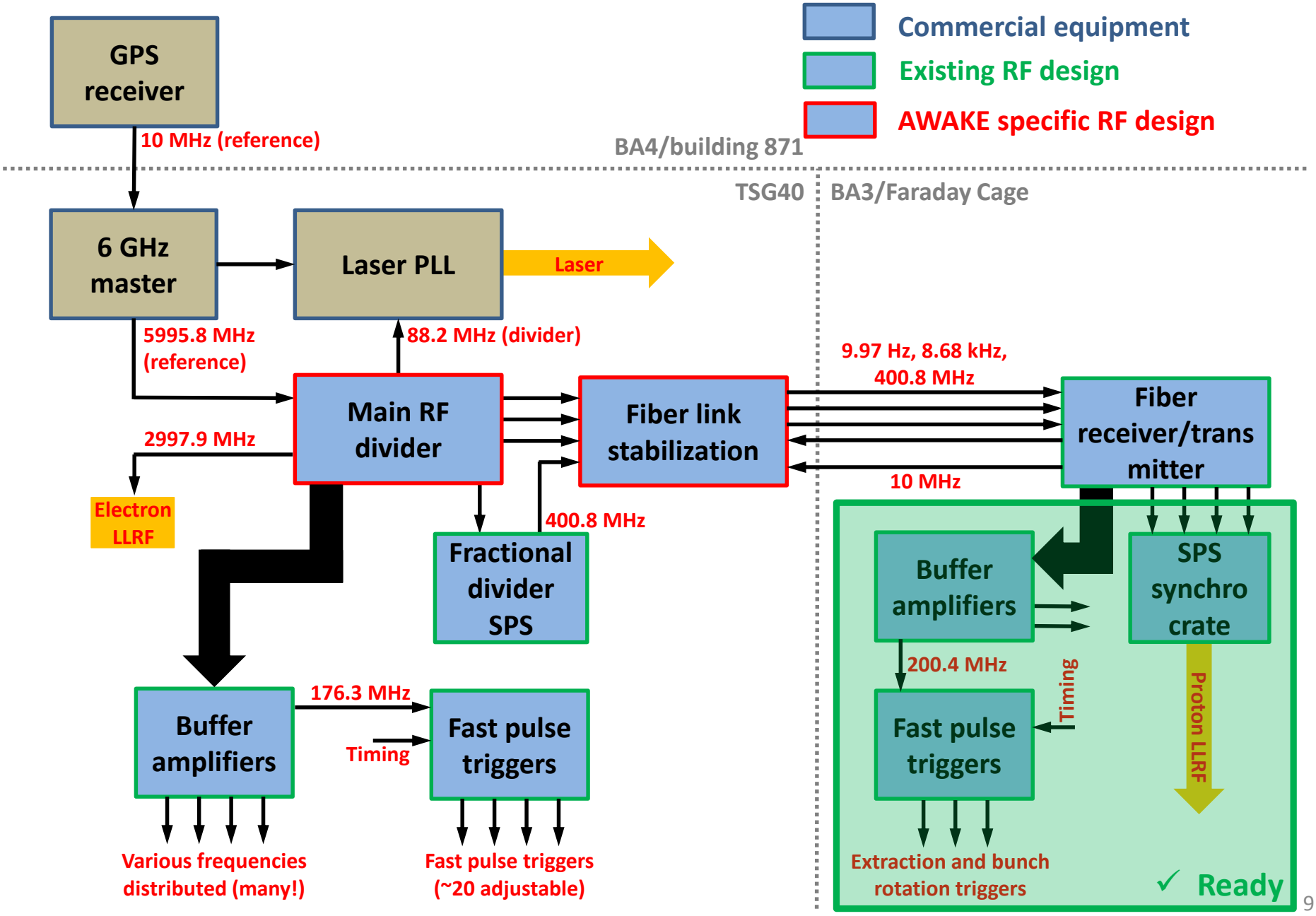
→ **~130 fs (without spurs)**

→ **~150 fs (with spurs)**

→ Decrease possible with harmonic lock (~ 30 fs)

Independent measurement with separate PD from Laser against external reference

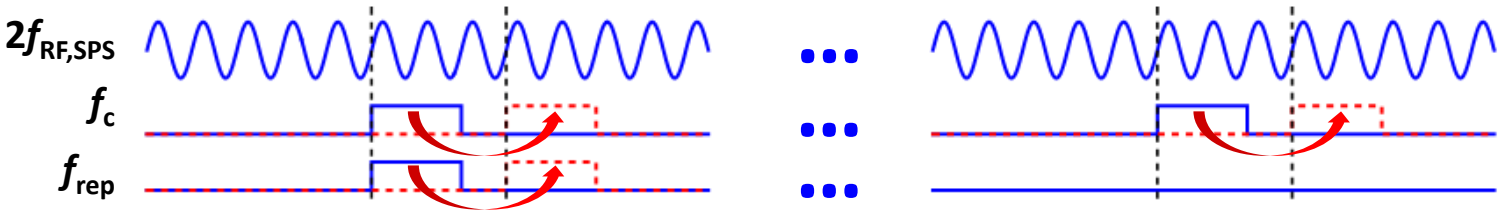
Simplified overview synchronization and RF distribution



Control of synchronous proton transfer to AWAKE

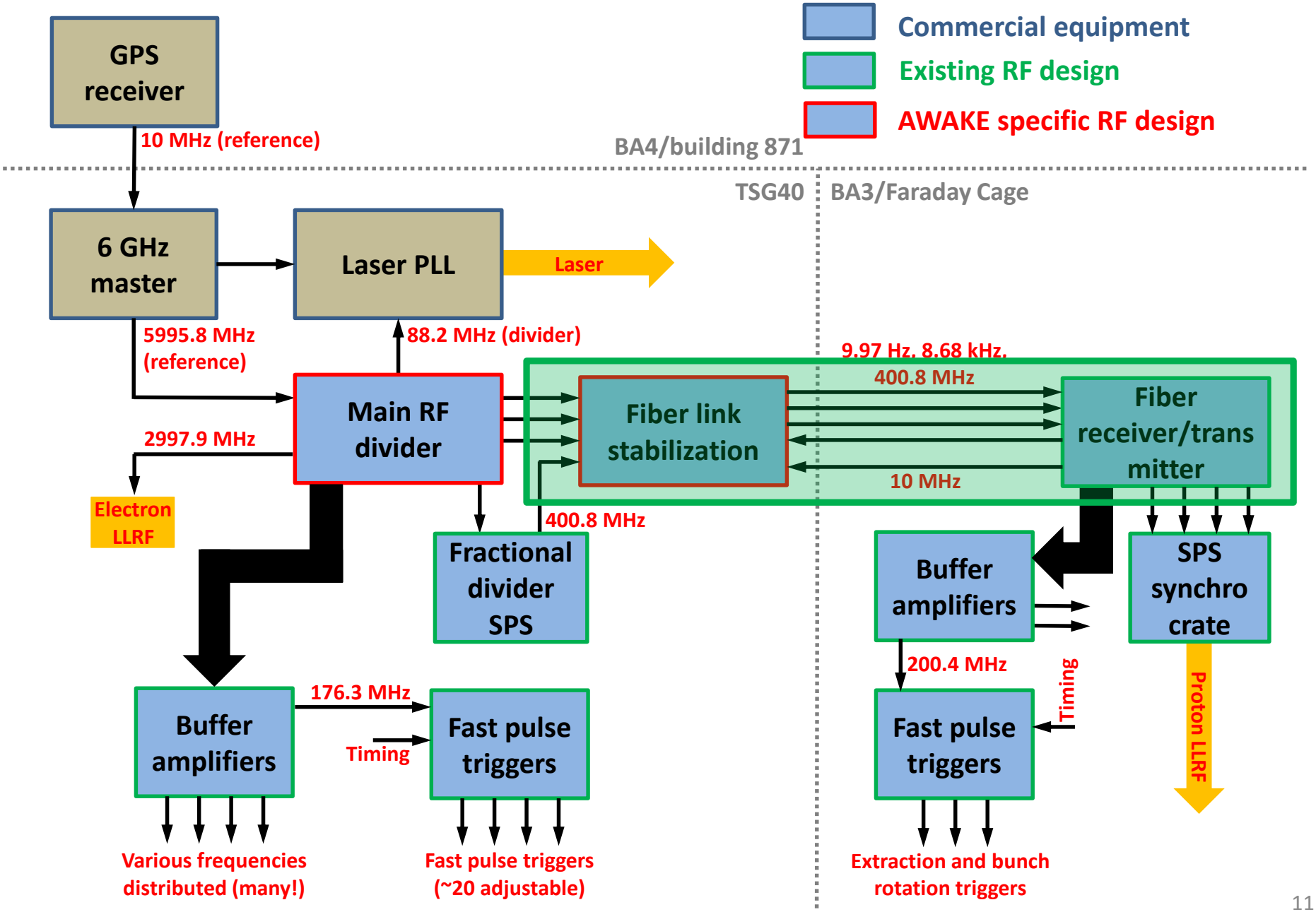
→ **Shift f_c, f_{rep} and $2f_{RF,\,SPS}$ sent to SPS with respect to internal signals** used in AWAKE (laser, precision triggers)

- 2-step shift process to move proton delay with respect to AWAKE:
  1. **Pre-settable number of $2f_{RF,\,SPS}$ clock periods (bucket number)**
  2. **Fine time/phase within a single period of $2f_{RF,\,SPS}$**



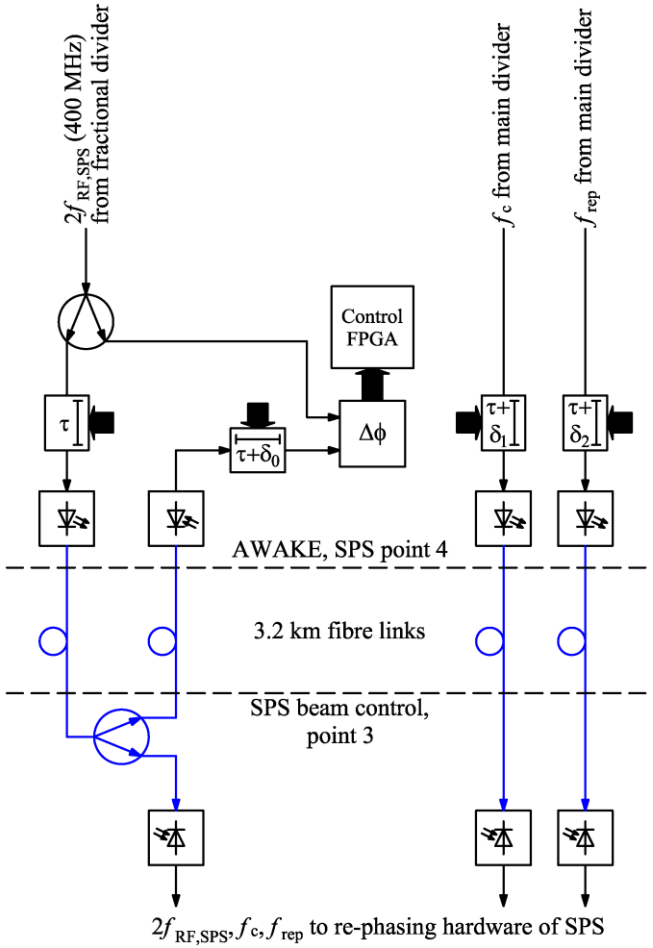
→ **Implemented programmable phase shift in new fractional divider**

Simplified overview synchronization and RF distribution

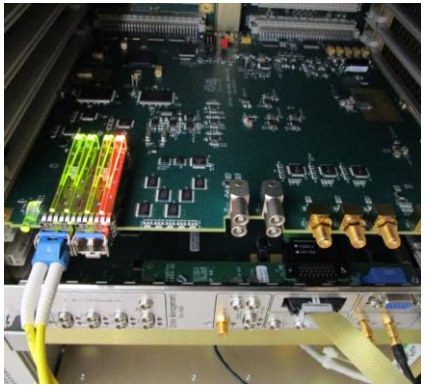


Fiber link stabilization

Simplified diagram



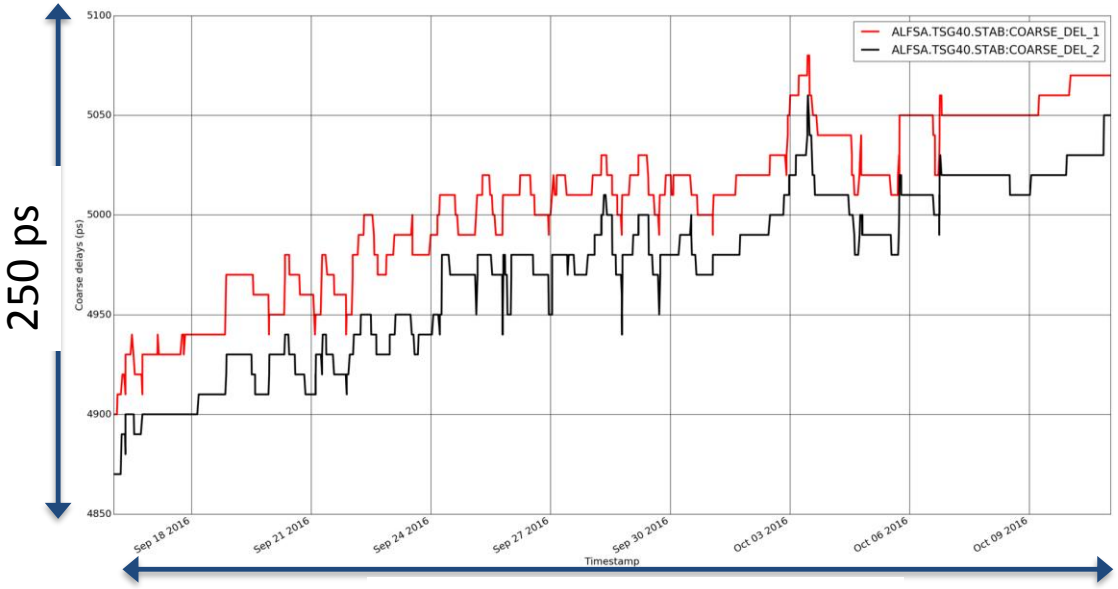
- **Installed and commissioned**
- **Also used for crab cavity tests**



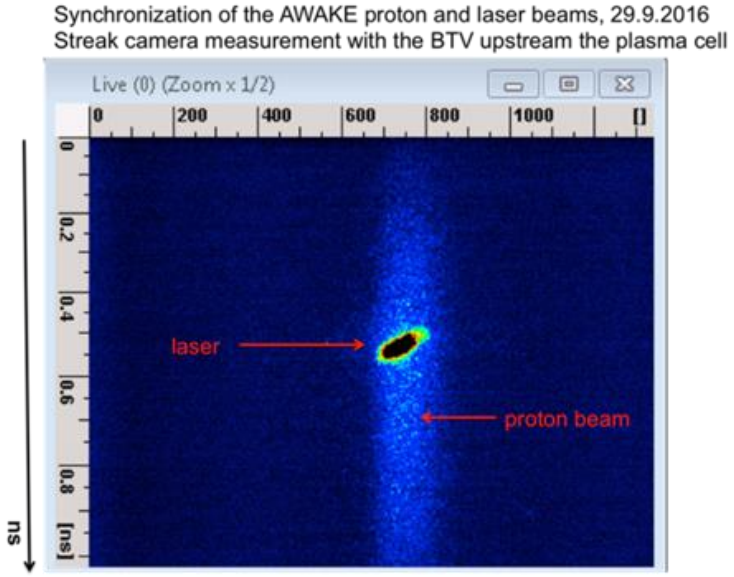
- **Logging of temperature and compensation delay for correlation**

D. Barrientos, J. Molendijk, *Phase stabilization over a 3 km optical link with sub-picosecond precision for the AWAKE experiment*, IEEE Real Time Conf., 2016

Fiber Link Stabilization - Results

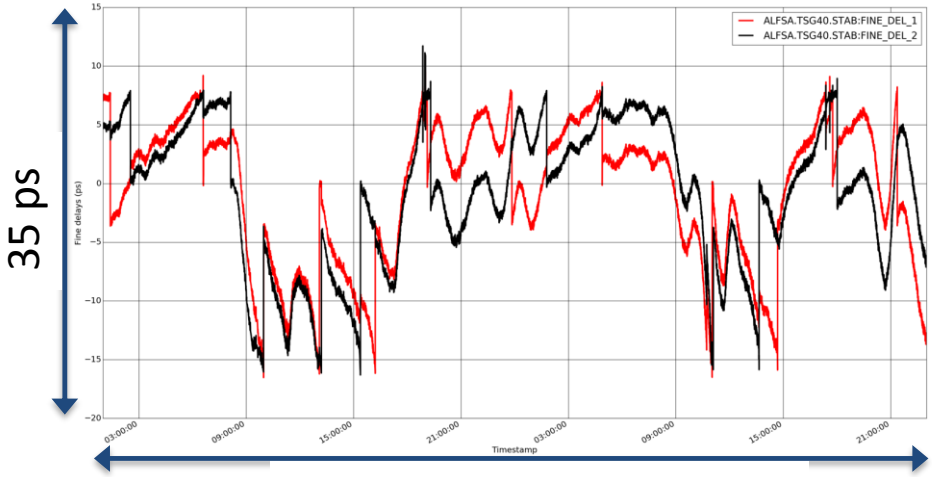


25 days - Coarse delay



- RF reference fiber link stabilization from AWAKE laser room to SPS BA3 FC (400 MHz signal)
- System operational since September 2016

→ It means without this stabilization we would have the above variations !



2 days - Fine delay

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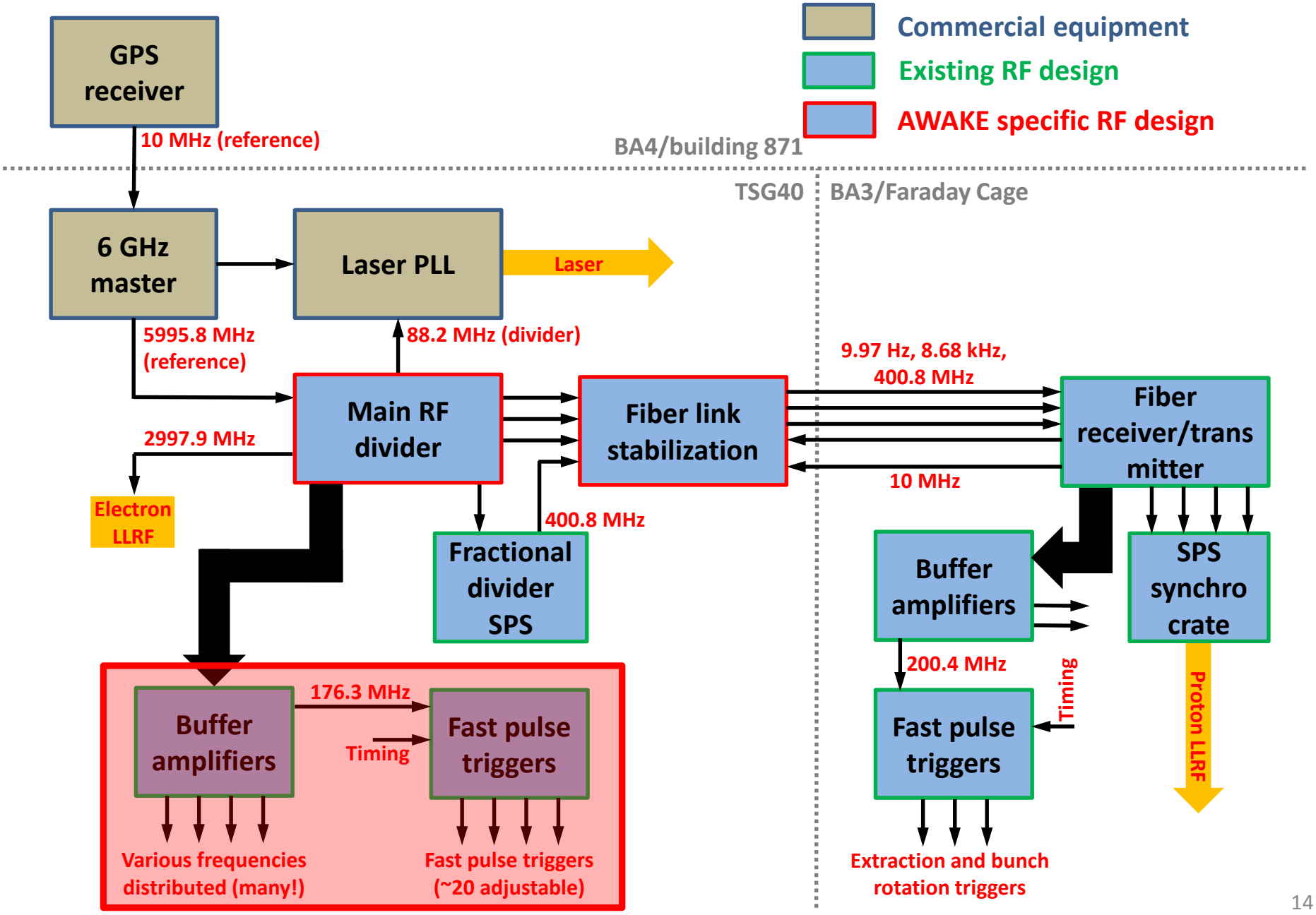


Precision triggers – in house developed RF VME board

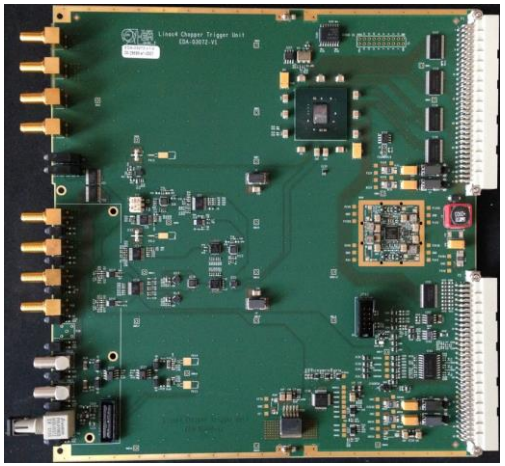
Synchronous trigger units (CTU)

- Generation of triggers from 400 MHz RF for beam observation
- Step size: 2.5 ns plus fine delay (ps resolution)
- Long delays possible (ms range)

→ dedicated firmware and software for AWAKE

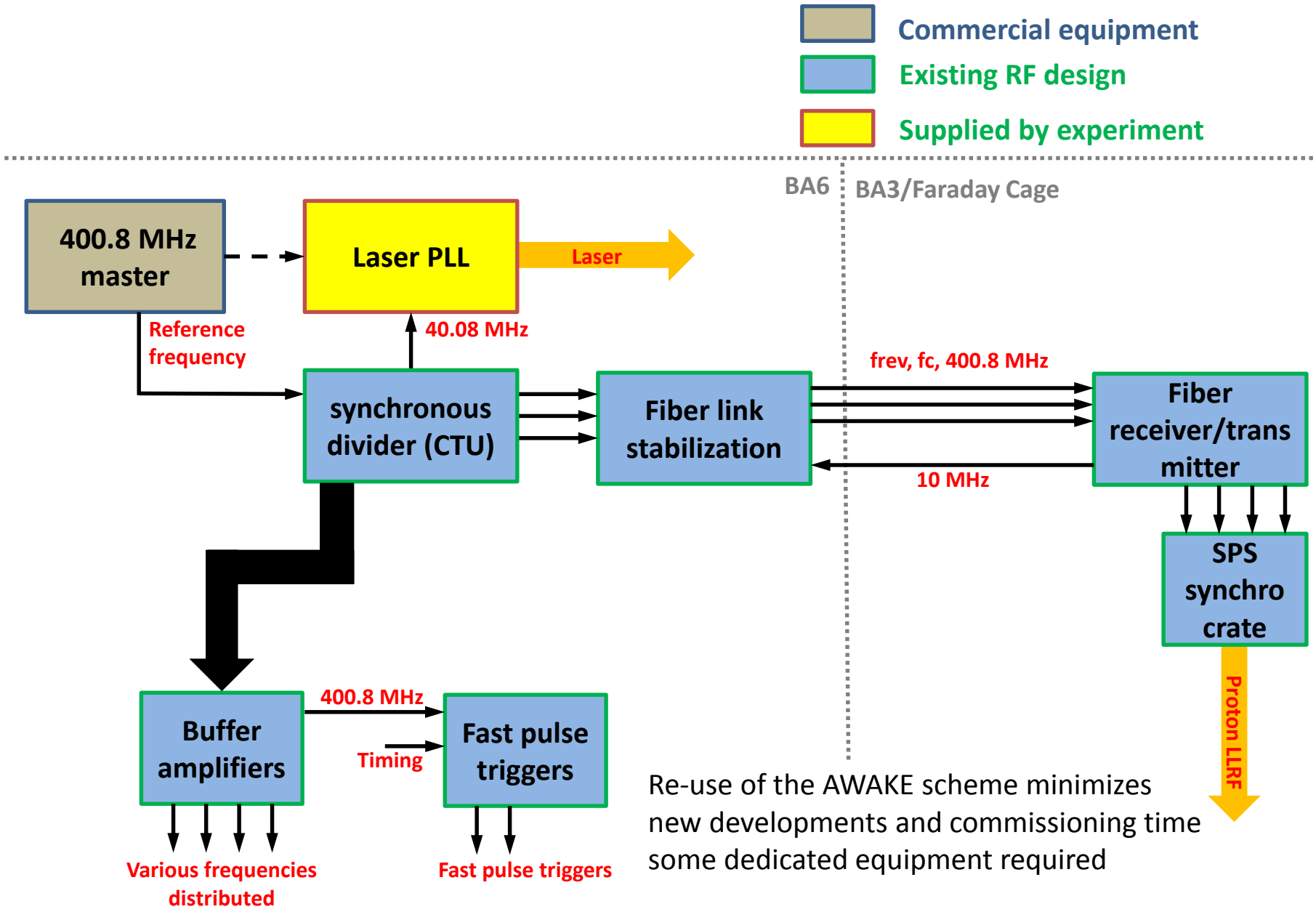
→ Triggers delivered to streak cameras

→ Switchable between single pulse and 10 Hz operation for AWAKE



G. Hagmann

A possible scheme for the γγ factory POP



Re-use of the AWAKE scheme minimizes new developments and commissioning time some dedicated equipment required

Next Steps

- SPS LLRF undergoes a complete upgrade of its electronics during LS2
- Interface to AWAKE synchronisation maintained operational
- Check functional specifications of SPS for any issues
  - special modes (storage “coast”)
  - modifying and scanning energy needs scrutiny
- Estimate cycle time required for synchronisation / re-phasing (will be longer for Pb^{79+} than for p to AWAKE), similar to Pb for LHC
- Agree within department to allocate resources to make a detailed plan
- Estimate resources for implementation
- Commit to a schedule only once a plan and resources are agreed upon in the department and with the project