Layout of the PSI 250MeV Injector Synchronization System and Latest Results

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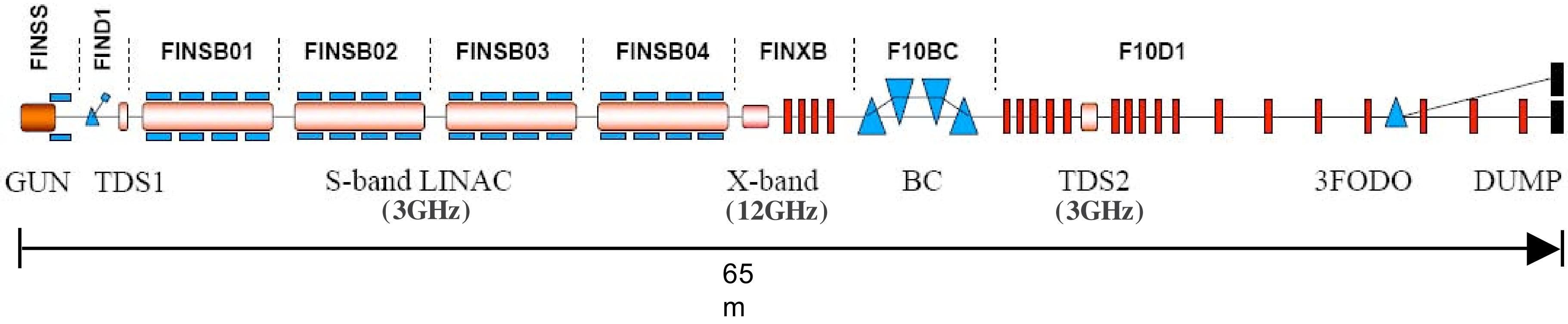
- **Overview**
- **Details on the electrical RF distribution system**
- **Time schedule**
- **Details on the optical distribution system**
- **Next steps**

Overview: PSI 250MeV Injector



Overview: PSI 250MeV Injector Building

Overview: Electrical and optical reference distributions

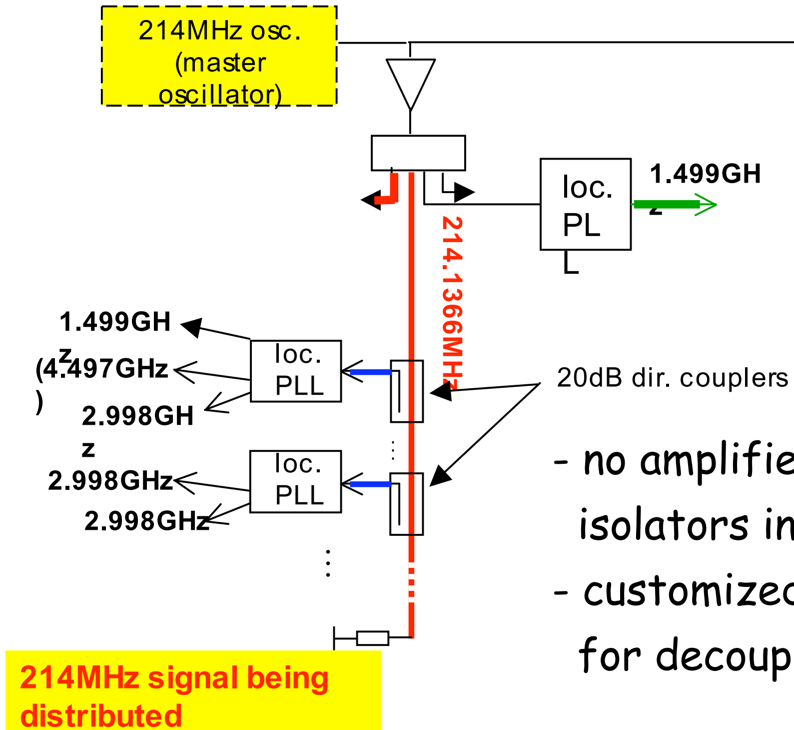
Required for RF, LLRF and diagnostics.
Optical distribution required for fs resolution measurements (BAM, EOS, link stab.).

1st step:
- **Electrical** MO and coax cable based ref. distribution (well known technology, fallback)
- Then: start with **optical** MO and optical reference distribution for bunch arrival time monitors (BAM)

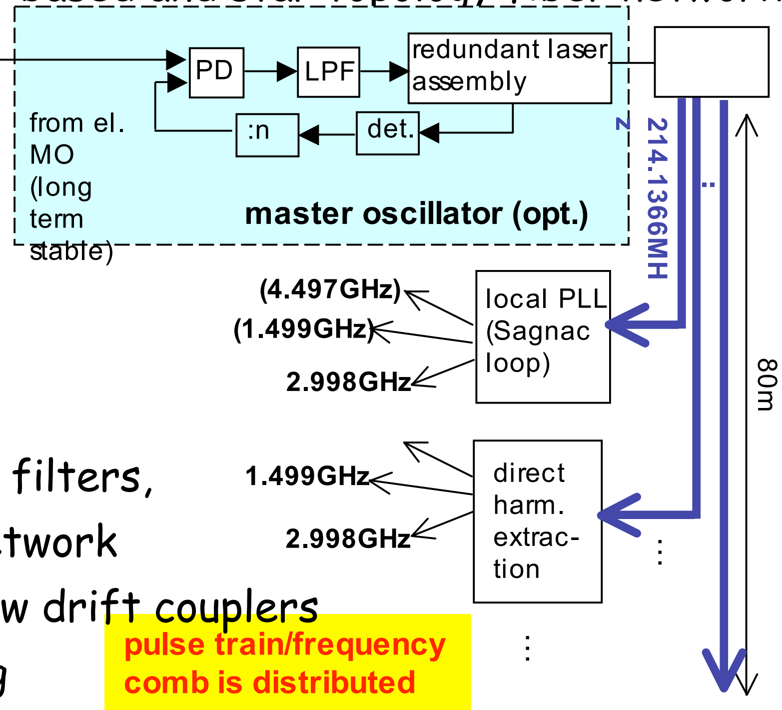
2nd step:
- Establish fiber-based **optical** distribution (better performance, extended functionality and flexibility)

Overview: Electrical and optical reference distributions

Electrical (coaxial cable based):



Optical (1550nm mode-locked laser based and star topology fiber network):



- no amplifiers, filters, isolators in network
- customized low drift couplers for decoupling

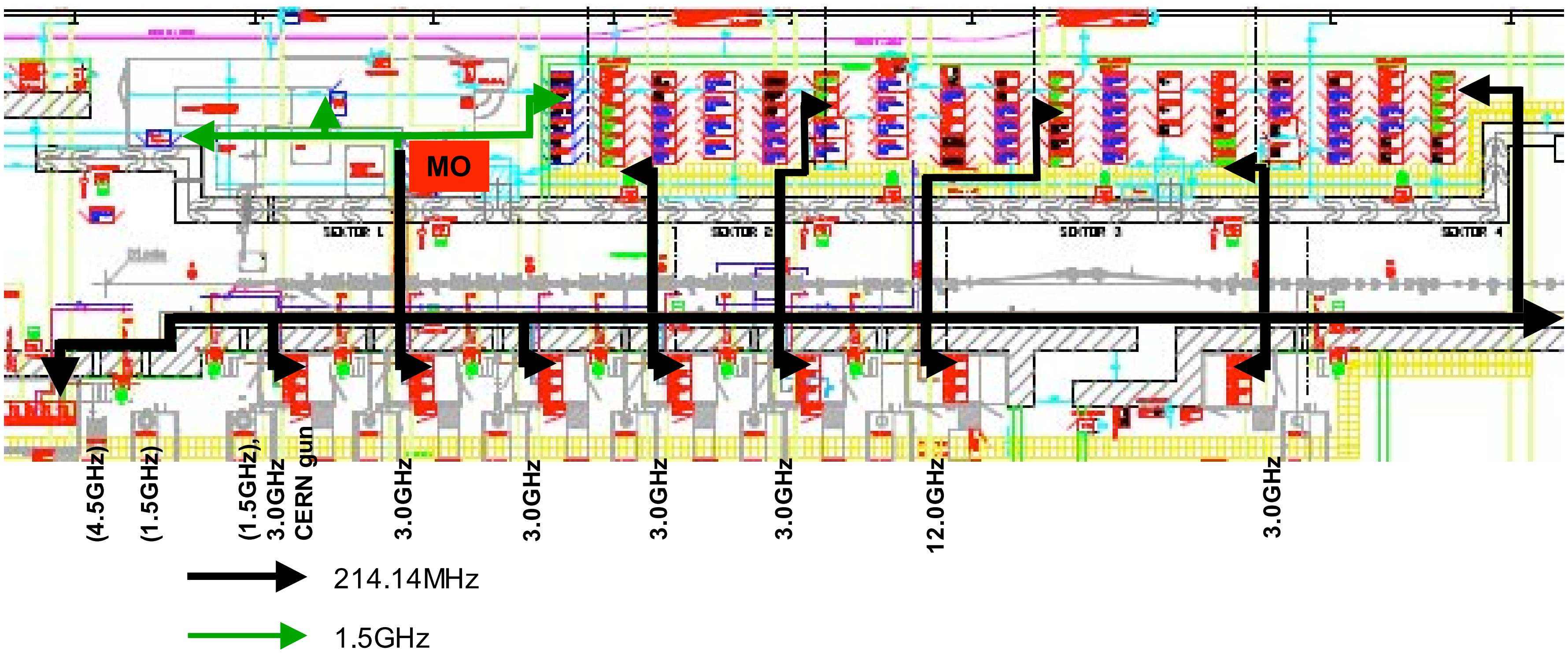
temperature stabilized coaxial cable trunk line

actively stabilized optical fiber links using optical cross-correlation based control loop

Overview: Master oscillator and reference distribution

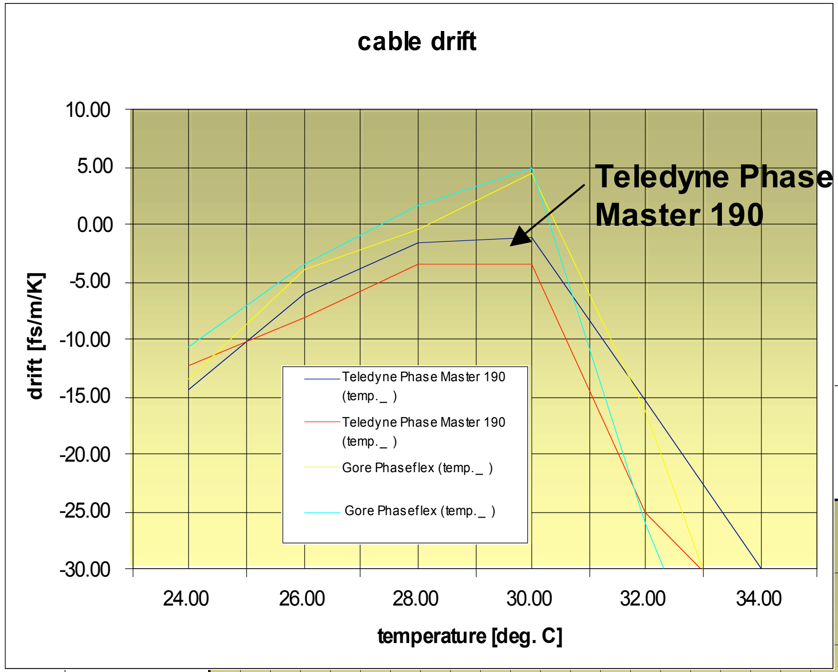
what	spec.	goal	initial	ultimate
el. sync. system rms jitter (some kHz..10MHz)	<100fs	10fs	10..20fs	some fs
el. distribution drift, gun (long term: hours)	40fs	≈40fs	100fs, lower?	≈10fs
opt. sync. system rms jitter (some kHz..10MHz)	8fs	some fs	10fs	sub fs
opt. distribution drift (long term: hours)	some 10fs	some fs	≈10..30fs	≈fs

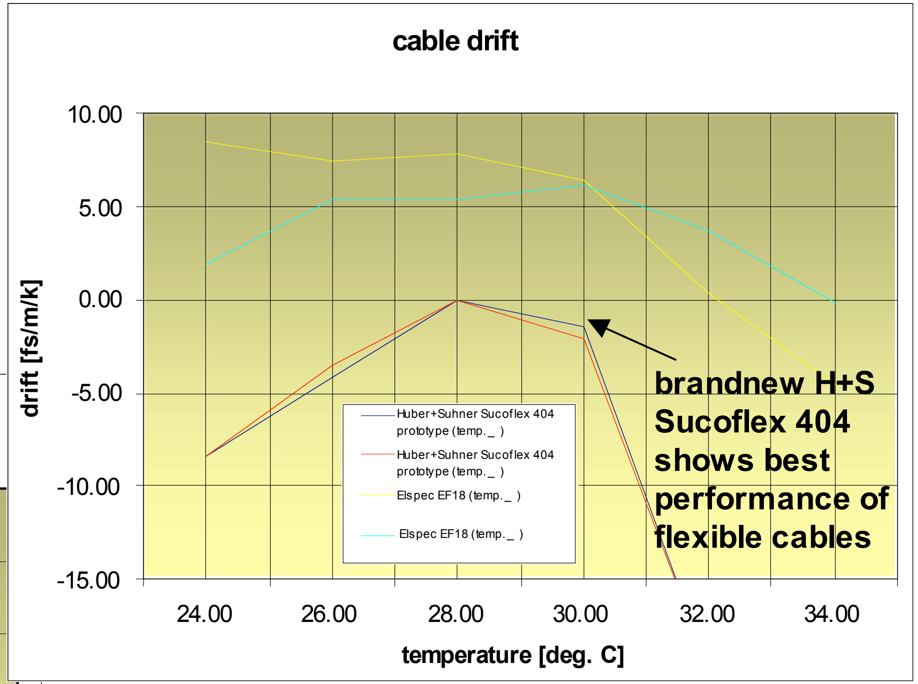
Electrical reference distribution: Layout

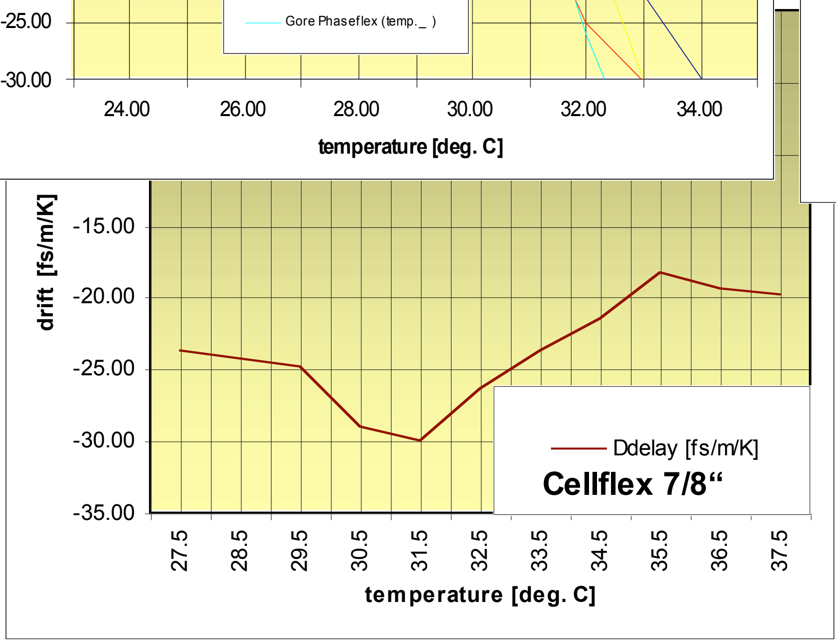


- thermally isol. tubes on polystyrene-like bars in cable ducts and pallets (thermal decoupling from foundation and walls)
- tunnel temperature: 27..28°C (±≤0.1°C), may slightly vary over the year
- temperature compensated couplers with ≈3fs/K drift (std. is ≈300fs/K)

Electrical reference distribution: Cable drifts



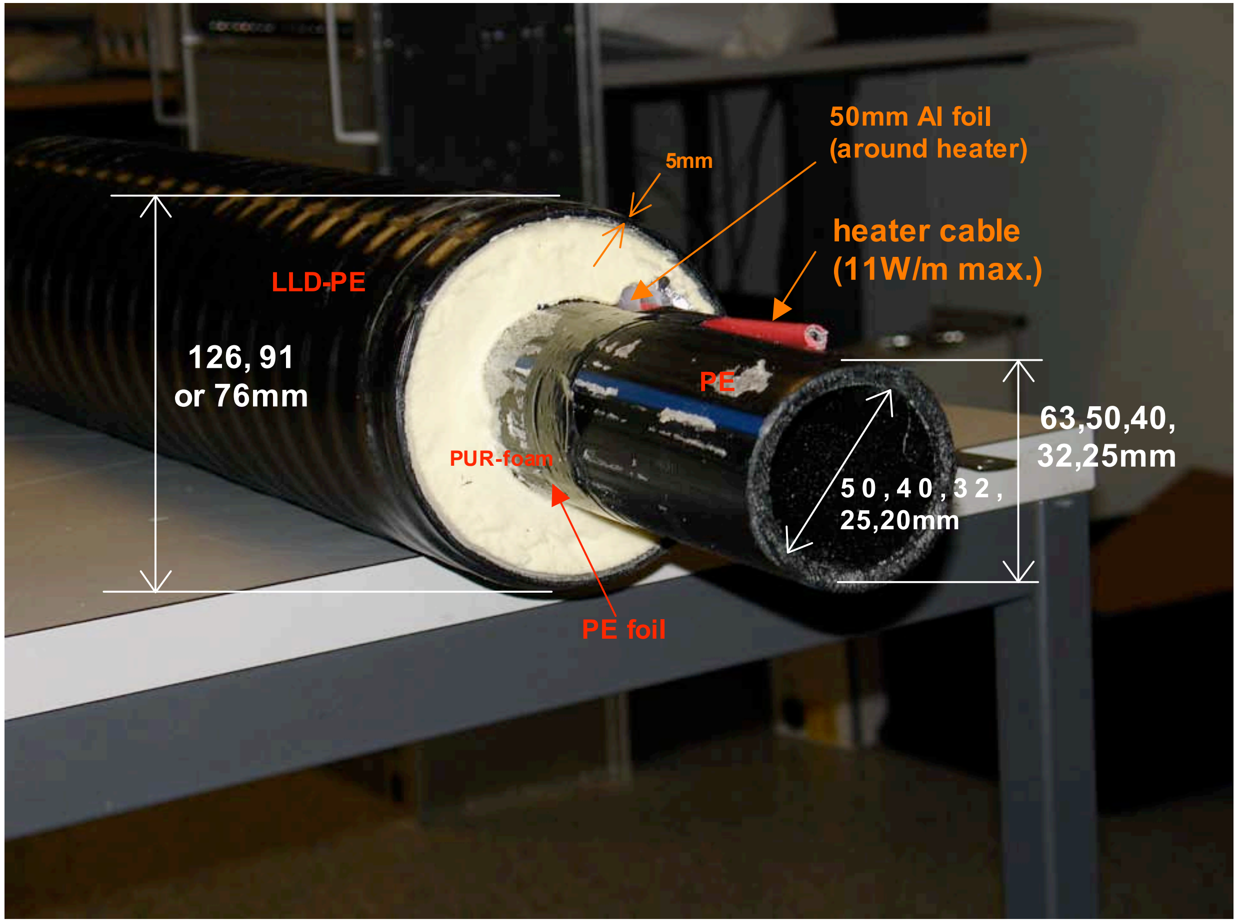




25m of <u>REAL</u> Cellflex 7/8“ in a stable thermal environment (0.1..0.2°C stability): 50..100fs drift (factor 10 higher than with datasheet values)!

3/8“ Heliax could be an alternative (tests in March 2009). 3dB higher loss over whole injector. All other low loss cables do not even have the potential for low drift.

Electrical reference distribution: cable temperature stabilization

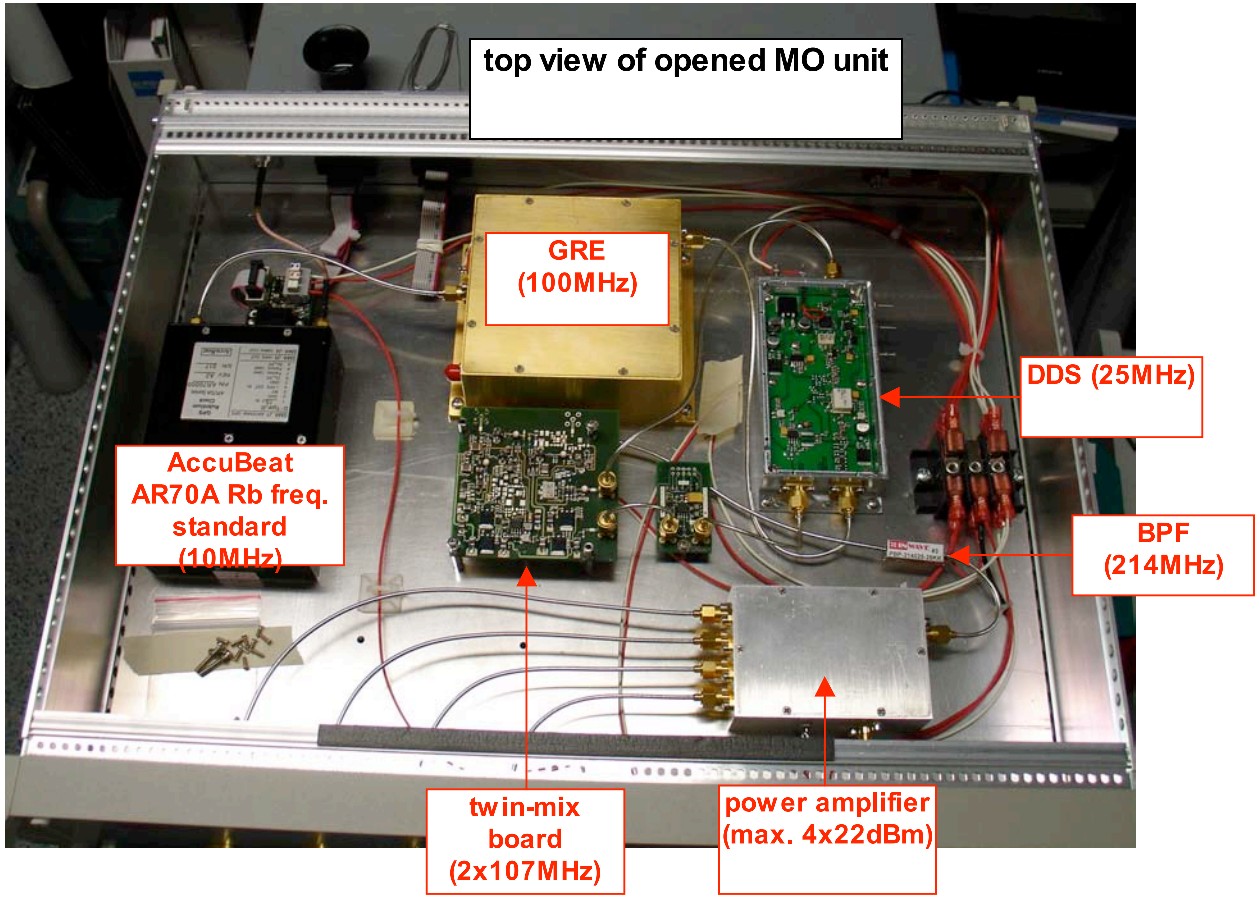


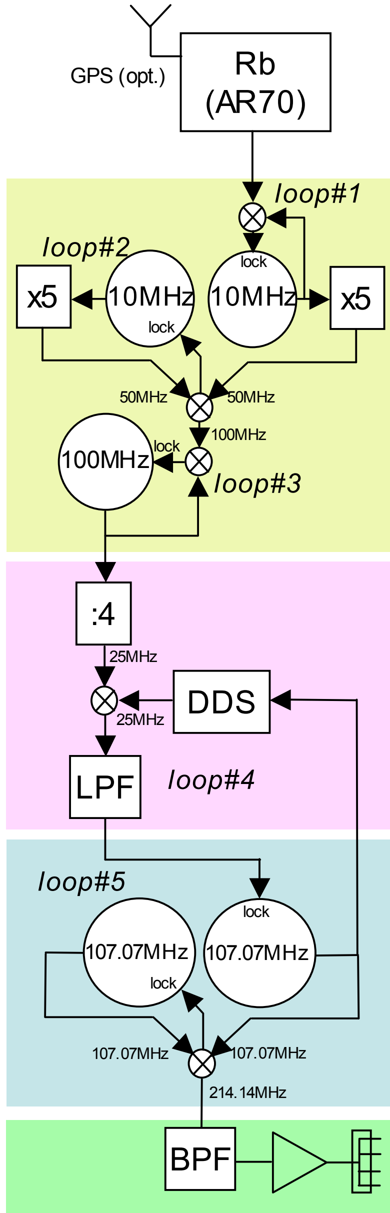
- provides stable thermal environment for cables (as long and medium term th. stability of tunnel is unknown, also during machine build-up)
- smearing out temp. inhomogeneities
- temperature sensors located on the inner tube
- heater control loop
- ≈45€/m

Electrical distribution: Inwave 214.14MHz MO

	jitter fc=214MHz Df=10Hz.. 10kHz	long term stability	comments
specification PSI	<15..20fs	<0.01ppm/yr	close-in jitter (<100Hz) uncritical
Inwave 214MHz master oscillator	13/9.5fs (guar./typ.)	<6e-4ppm/yr	5 loops, incl. Rb and GPS

Electrical MO (214.14MHz), Inwave GmbH

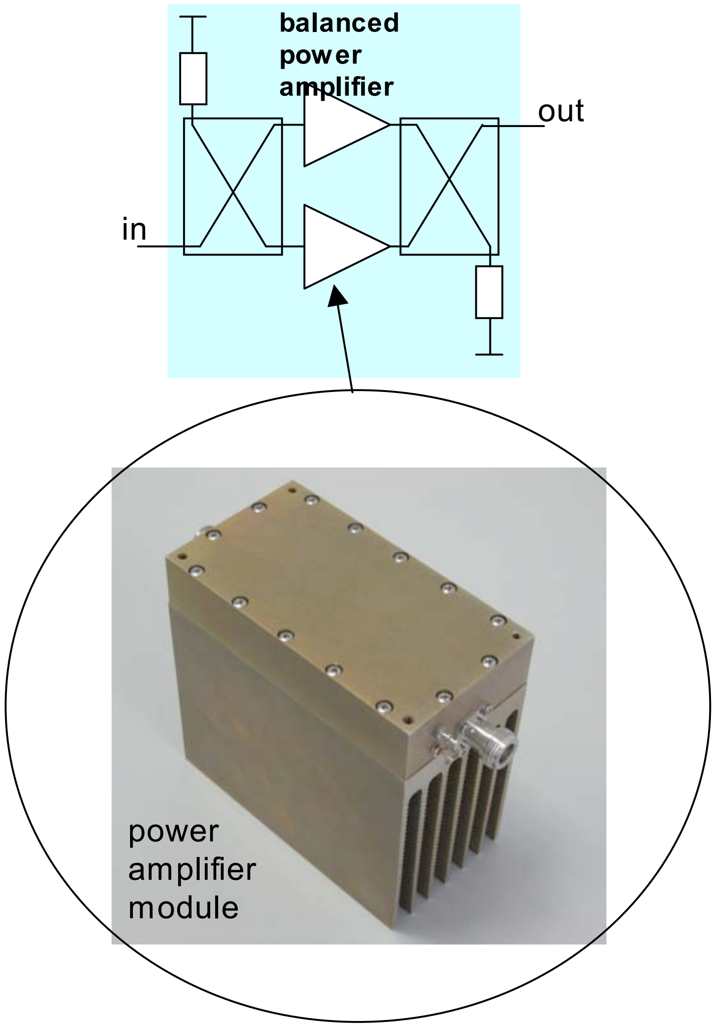




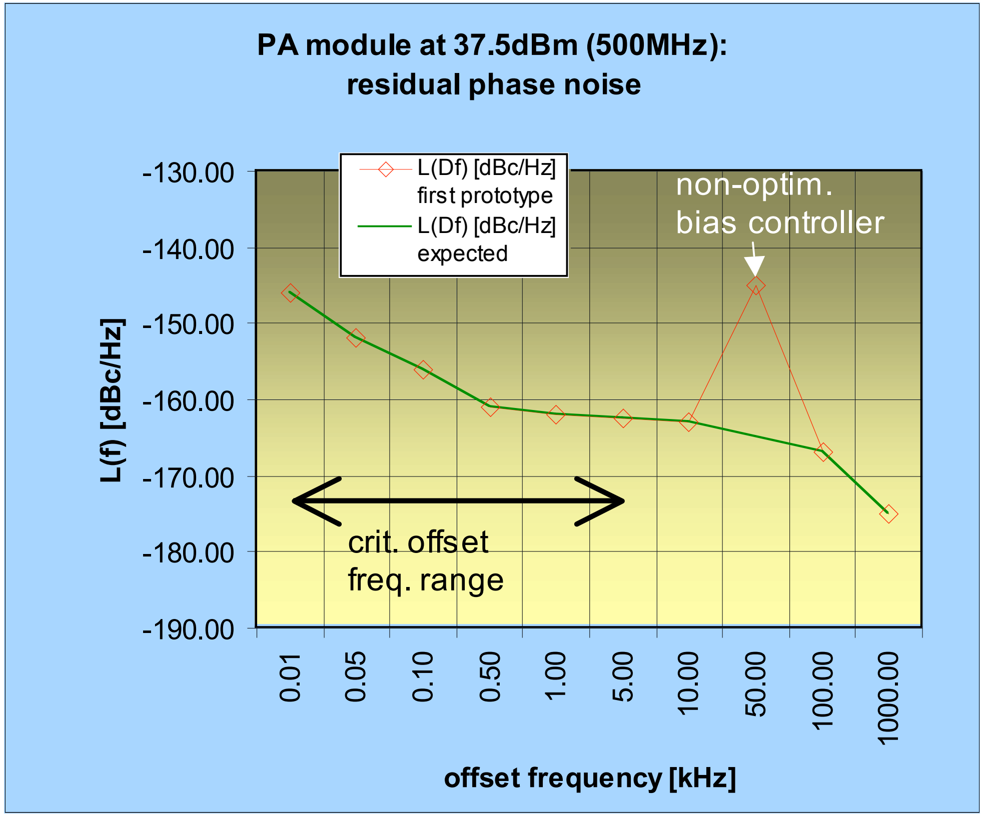
DC supply:

dedicated ultra-low noise linear power supply (ripple<0.5mV_{rms})

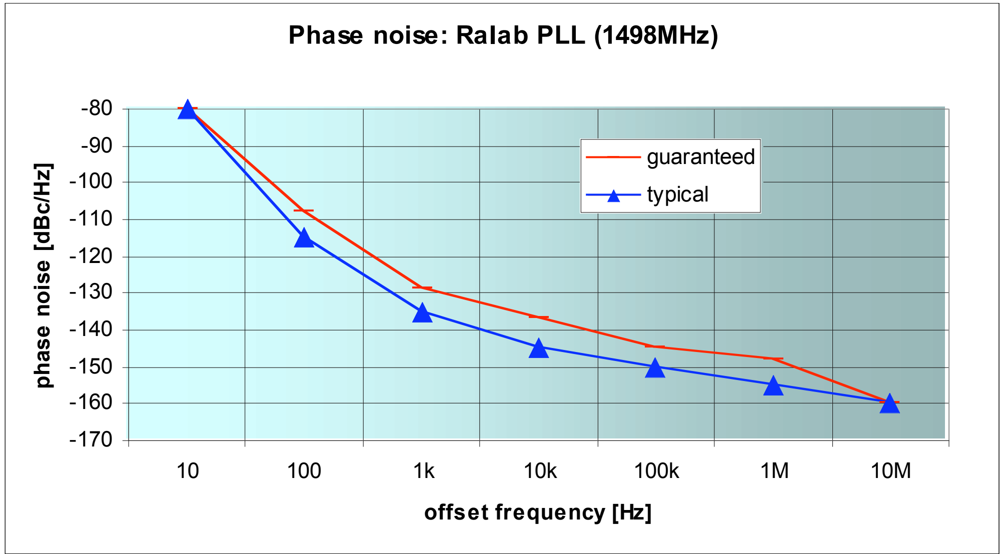
Electrical reference distribution: power amplifier (214.14MHz), Synergy Microwave/PSI



- linear LDMOS class A design
- dedicated low noise linear power supply
- 40dBm operating output power
- fan-less 19" unit



Electrical reference distribution:
Expected RF ref. signal jitter (Ralab PLO locked to Inwave MO)



jitter (guar., typ.):	1kHz..10MHz, f_0=3GHz	10Hz..10kHz, f_0=214.14MHz
MO		13/9.5fs
PLO (locked to MO)	11.3/6.7fs	

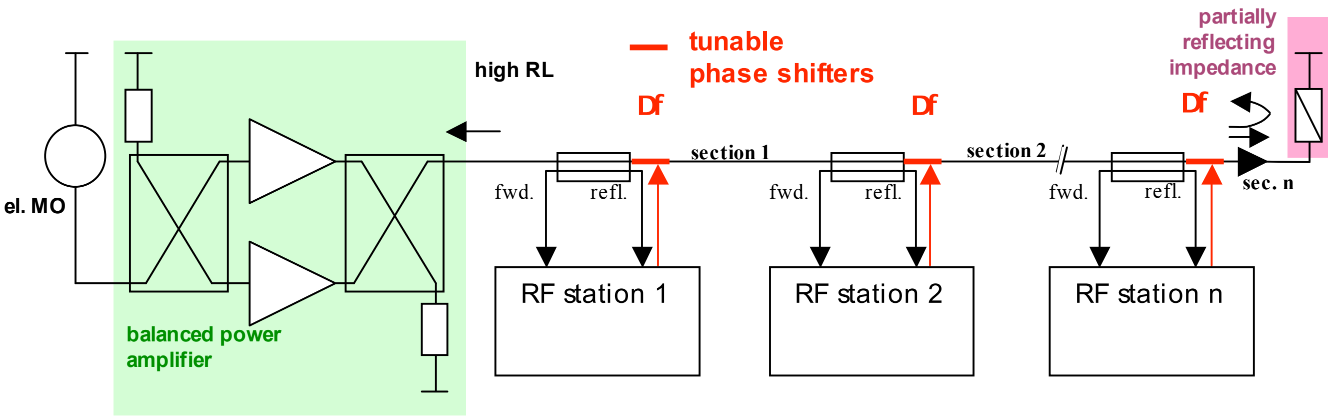
- electrical MO already shipped
  but loop bandwidths yet to be
  adjusted

- MO: 107MHz section
  currently being optimized
  (quartz)

Electrical RF distribution: Time schedule

item	delivery	commis-sioning	operational	require-ment	responsibility
electrical master oscillator (214MHz)	2nd half of March 2009	May 2009	June 2009	Aug. 2009	Inwave GmbH
phase locked oscillators (1x1.5 and 2x3.0GHz)	2nd half of March 2009	May 2009	June 2009	Nov. 2009	Ralab AG
phase locked oscillators (4x3.0GHz)	2nd half of April-May 2009	June 2009	June-July 2009	Nov. 2009	Ralab AG
RF distribution inside laser hutch	April-May 2009	May-June 2009	June-July 2009	Nov. 2009	PSI
ultra stable dir.couplers	May 2009	May-June 2009	June-July 2009	Nov. 2009	Synergy uW Research
phase locked oscillator (1x12.0GHz)				Nov. 2010	Ralab AG
phase locked oscillator (1x1.5 and 4.5GHz)	?	?	?	?	
installation outside laser hutch (RF)	April-July 2009	May-Aug. 2009	Oct. 2009		PSI, Brugg Pipe Sys.

Electrical distribution: Optimization and link stabilization (R+D)



- redundant distribution allows continuous optimization during operation

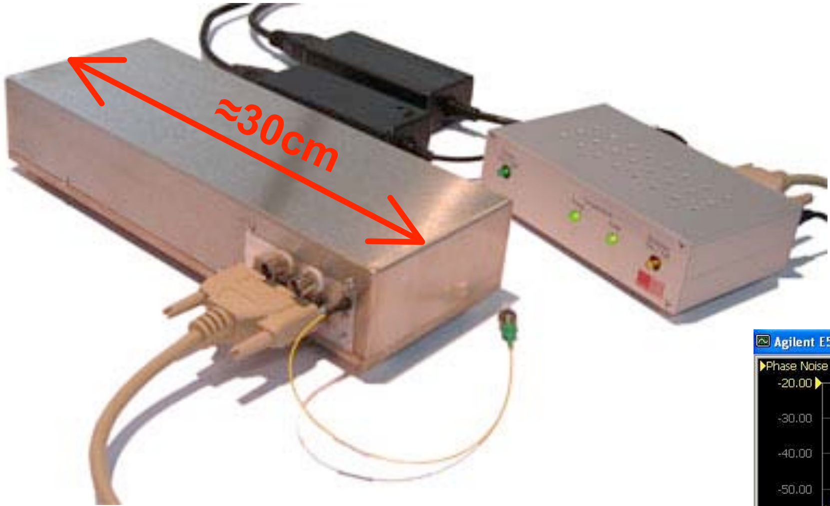
- eliminates temperature drift of passive structure

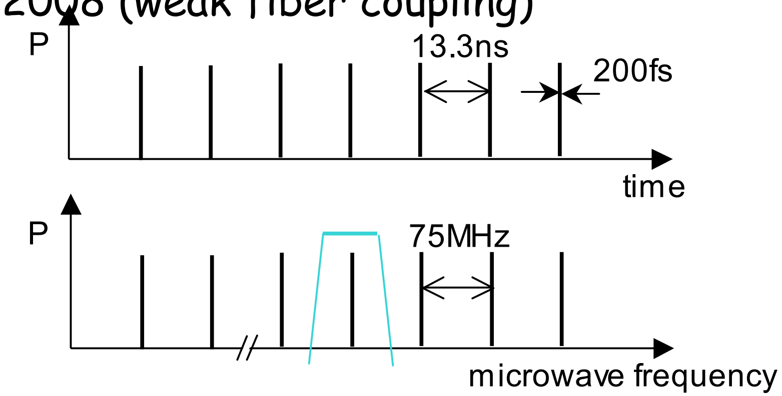
- requires self-calibrating phase detector (R+D project with DESY), ready in about 1yr from now

Optical distribution: Pulse generation with mode locked laser

First measurements with (damaged) demo laser in 2008 (weak fiber coupling)

Commercial product: Onefive "Origami"



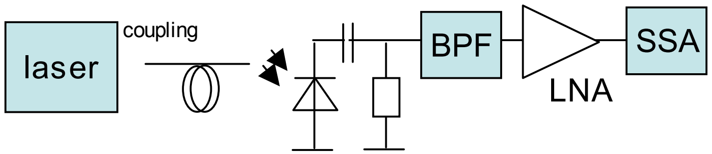


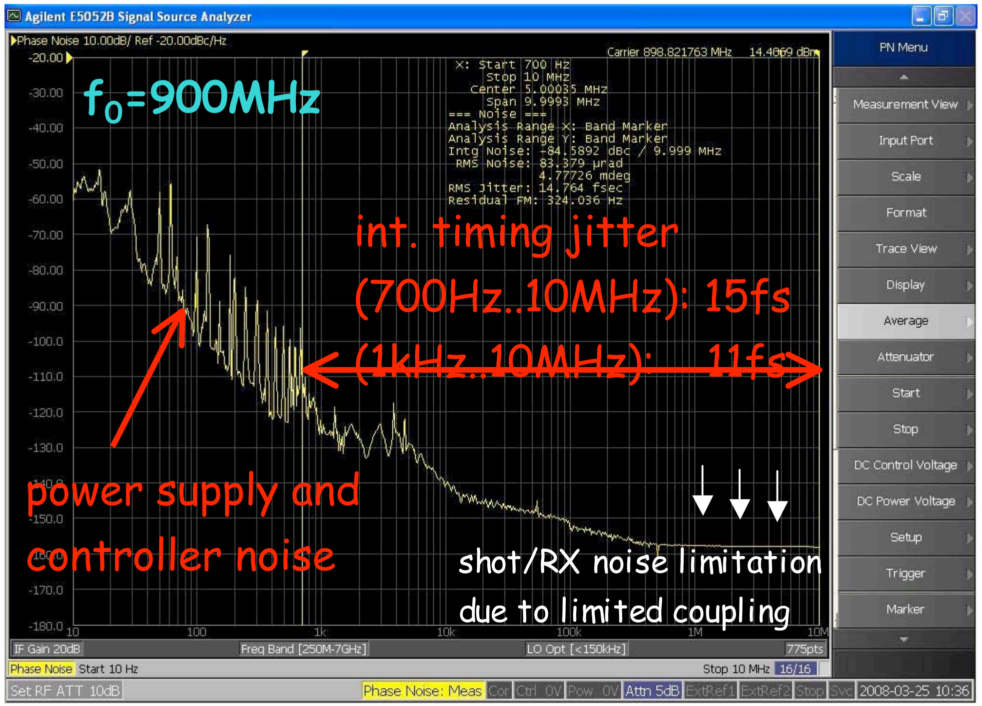
75MHz rep rate (up to 240MHz available)

≈60mW avg. optical power

fiber coupled, temp. controlled

Harmonic extraction setup for phase noise measurement:





Optical distribution:
link stabilization, harmonic extraction, Sagnac loop PLL

Essential functional blocks for optical distribution:

1) Fiber dispersion compensation is required for fs pulse transmission (link stab.).

2) Link stabilization is mandatory to achieve low close-in jitter/drift

3) Sagnac-loop PLL w. E/O phase detector (MIT, DESY) enables low drift and low phase noise floor performance of harmonic generation:
   - most stable, lowest jitter, mandatory for most jitter- and drift-critical signals
   - commercial development by Menlo Systems, based on MIT research

4) Direct harmonic extraction from detected optical pulse train:
   - simple, cheaper than 2), OK for less drift-critical signals
   - larger drift than 2) due to PD/filter/amplifier
     → optimum PD, packaging, circuit design and opt. pulsewidth at PD,
     as low opt. power as required only, low drift filter, low drift amplifier

5) Beam arrival time monitor. Based on DESY approach (F. Loehl):

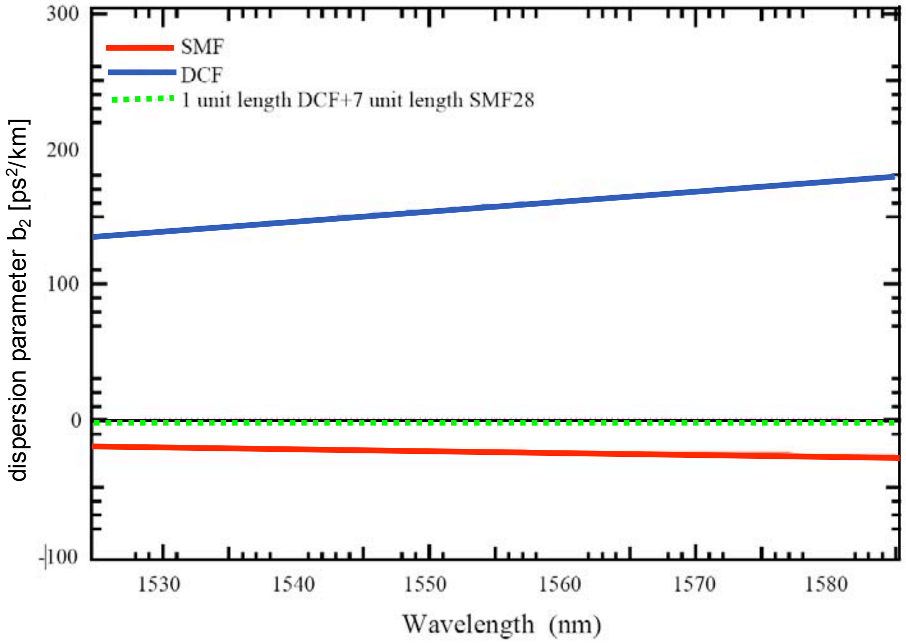
Optical distribution: Dispersion compensation

Fiber chromatic dispersion:

Pulse broadening ≈ 50..100ps/100m

LP mode prop. "constant"

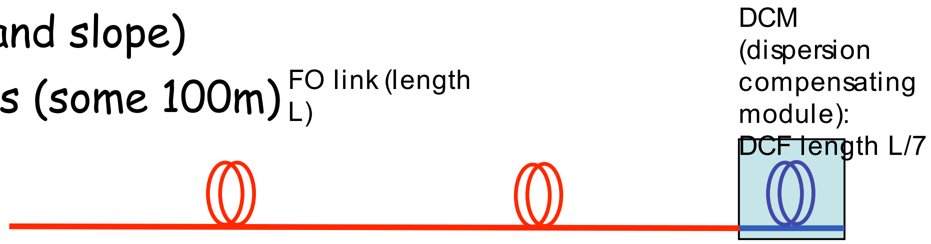
$$\beta(\omega) = \beta_0 + \tau_g(\omega-\omega_0) + \beta_2/2(\omega-\omega_0)^2 + \beta_3/6(\omega-\omega_0)^3 + \ldots$$



Dispersion compensating fiber

compensates for 2nd and 3rd order dispersion (abs. disp. and slope)

→ residual disp. <100fs (some 100m)



Next steps

1) Installation of cables, fibers, couplers, MO, power amplifier, PLOs in 250MeV Injector

2) Cable temperature stabilization: Initial investigations done. Being installed in Summer 2009.

3) DSP-based laser synchronization controller: Development starting now.

4) Optical-to-RF converter (harmonic extraction):
Systematic investigation and minimizatioon of drift effects (photodiodes, filters, amplifiers).
Optimum conditioning of optical signal incident on PD. Theory of operation.
Initial experiments started.

5) Fiber link stabilization and Sagnac loop based optical-to-RF converter: Prefer to implement existing/commercial solution.

6) BAM: Frontend design (EO modulator, fiber-optics) starting this year. Procurement started.

7) Investigating influence of mech. noise on ref. distribution.

8) Continuous optimization of electrical reference distribution after installation.

9) Low drift phase detector development (DESY/PSI).

10) Coaxial link stabilization may start (this or) next year.