Beam instrumentation based on Electro-Optical detection

T. Lefevre for BI group

Outline

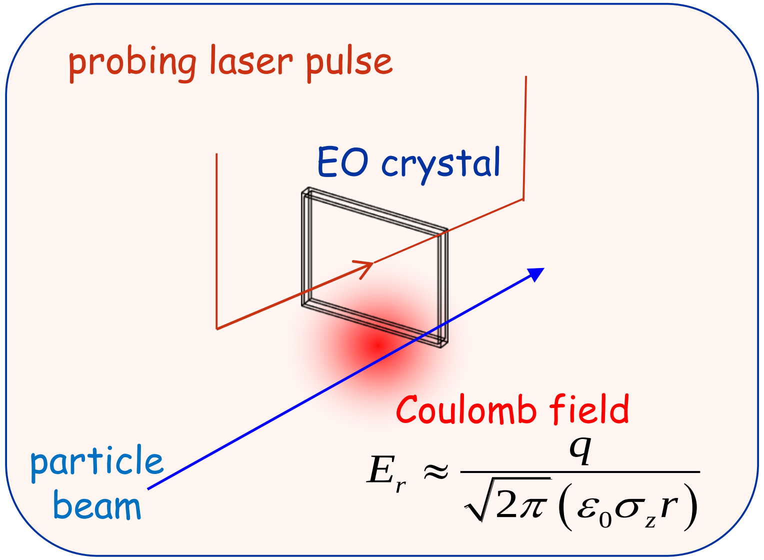
- Electro-optical detection
- Commercial products and R&D work
- On-going work in SY-BI
- Future needs and possible synergies with EP-ESE

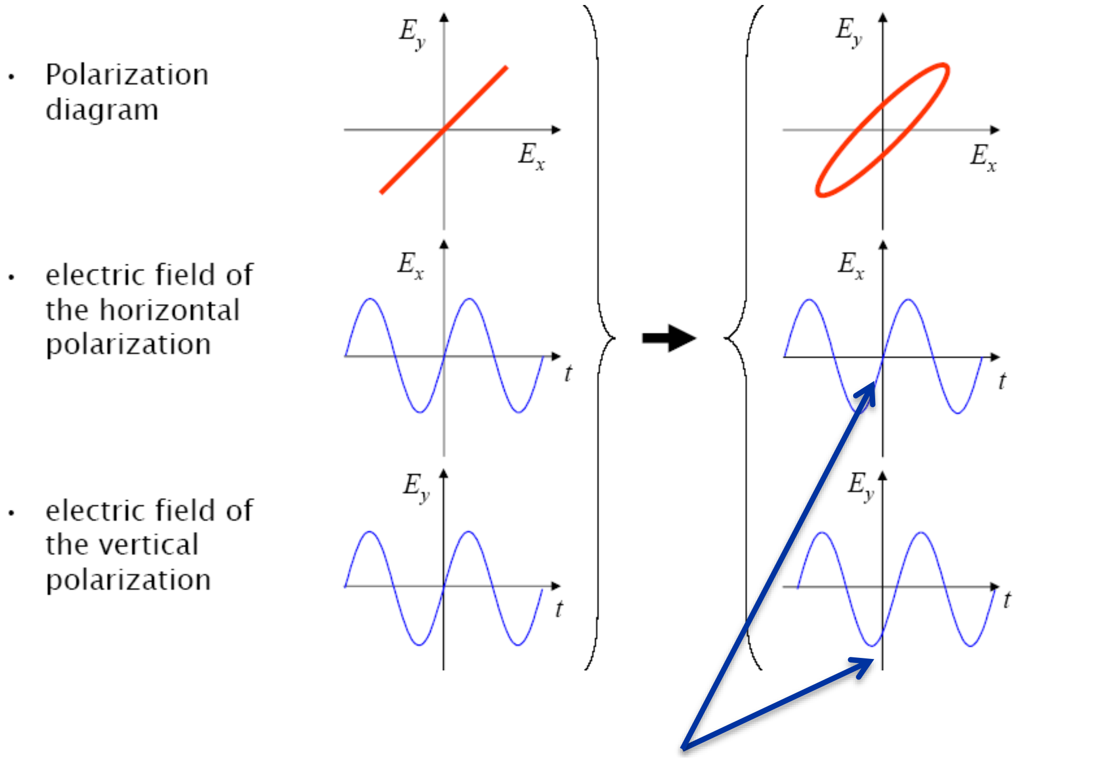
Electro-optical detection in Beam instrumentation

Aim : *Convert Coulomb field of e-bunch or beam induced voltage signals into an optical intensity variation*

How: *Use the polarization/phase change of a laser beam which passes through a birefringent crystal itself polarized by the electric field of charged particle beams*

Pockel/Kerr effect





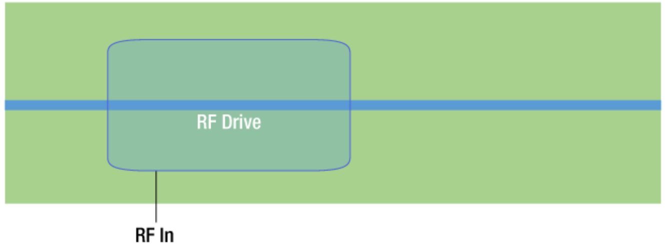
$$G=\frac{2pd}{l_0}\left(n_x - n_y\right)=\frac{2pd}{l_0}n_0^3 r_{41} E_r$$

Relative phase shift between polarizations increases with the beam electric field

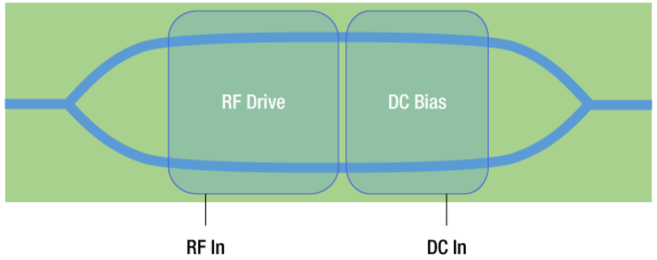
Electro-optical detection in Beam instrumentation

Commercial E-O modulators used in many applications in laser technology and telecommunications

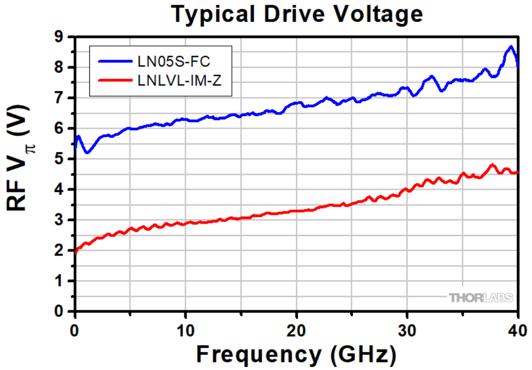
Phase/intensity modulator
without/with polariser

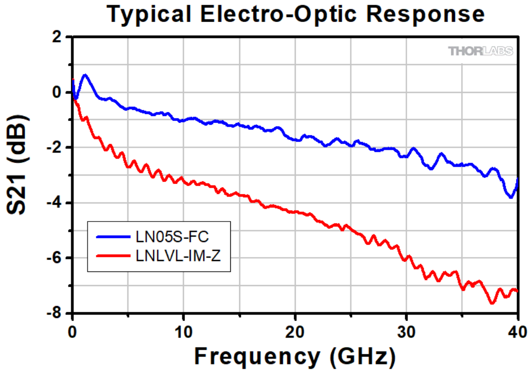


Intensity modulator
using Mach-Zehnder
interferometer



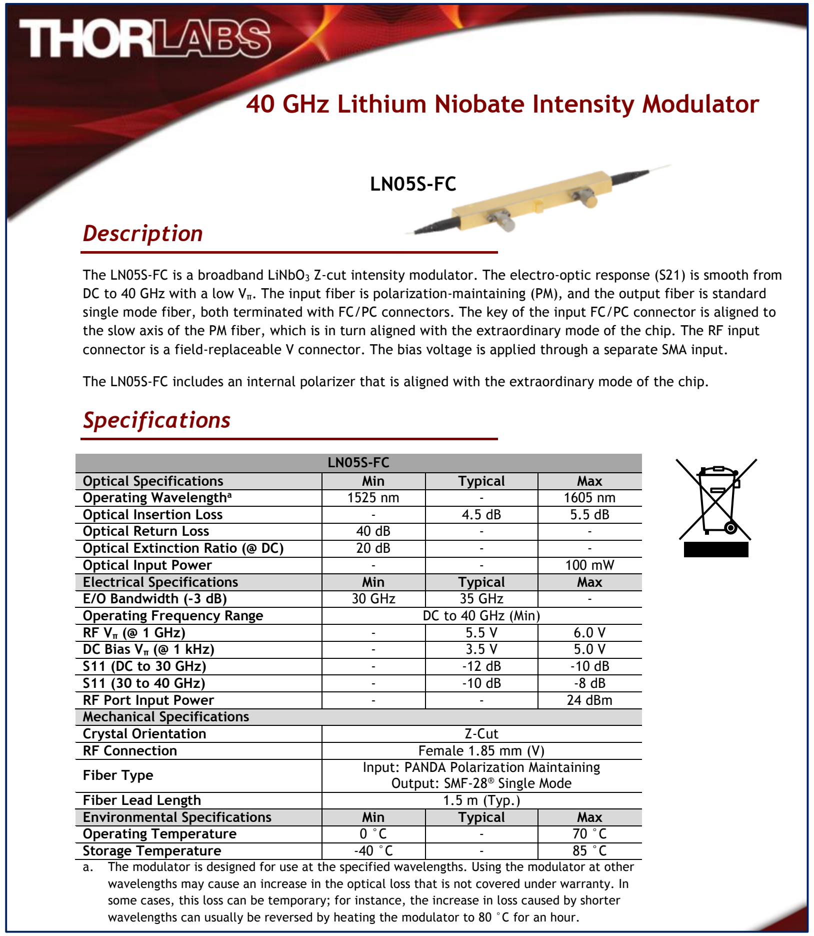
IQ Intensity modulator
using Mach-Zehnder
interferometers





Electro-optical detection in Beam instrumentation

Commercial E-O modulators used in many applications in laser technology and telecommunications



THORLABS

40 GHz Lithium Niobate Intensity Modulator

LN05S-FC

Description

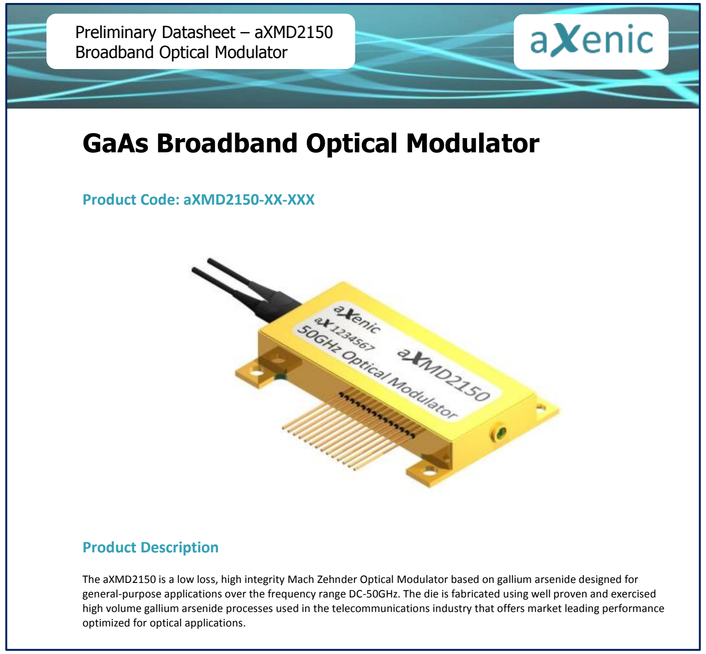
The LN05S-FC is a broadband $LiNbO_3$ Z-cut intensity modulator. The electro-optic response (S21) is smooth from DC to 40 GHz with a low V_π. The input fiber is polarization-maintaining (PM), and the output fiber is standard single mode fiber, both terminated with FC/PC connectors. The key of the input FC/PC connector is aligned to the slow axis of the PM fiber, which is in turn aligned with the extraordinary mode of the chip. The RF input connector is a field-replaceable V connector. The bias voltage is applied through a separate SMA input.

The LN05S-FC includes an internal polarizer that is aligned with the extraordinary mode of the chip.

Specifications

LN05S-FC			
Optical Specifications	**Min**	**Typical**	**Max**
Operating Wavelength[a]	1525 nm	-	1605 nm
Optical Insertion Loss	-	4.5 dB	5.5 dB
Optical Return Loss	40 dB	-	-
Optical Extinction Ratio (@ DC)	20 dB	-	-
Optical Input Power	-	-	100 mW
Electrical Specifications	**Min**	**Typical**	**Max**
E/O Bandwidth (-3 dB)	30 GHz	35 GHz	-
Operating Frequency Range	DC to 40 GHz (Min)		
RF V_π (@ 1 GHz)	-	5.5 V	6.0 V
DC Bias V_π (@ 1 kHz)	-	3.5 V	5.0 V
S11 (DC to 30 GHz)	-	-12 dB	-10 dB
S11 (30 to 40 GHz)	-	-10 dB	-8 dB
RF Port Input Power	-	-	24 dBm
Mechanical Specifications			
Crystal Orientation	Z-Cut		
RF Connection	Female 1.85 mm (V)		
Fiber Type	Input: PANDA Polarization Maintaining Output: SMF-28® Single Mode		
Fiber Lead Length	1.5 m (Typ.)		
Environmental Specifications	**Min**	**Typical**	**Max**
Operating Temperature	0 °C	-	70 °C
Storage Temperature	-40 °C	-	85 °C

a. The modulator is designed for use at the specified wavelengths. Using the modulator at other wavelengths may cause an increase in the optical loss that is not covered under warranty. In some cases, this loss can be temporary; for instance, the increase in loss caused by shorter wavelengths can usually be reversed by heating the modulator to 80 °C for an hour.



Preliminary Datasheet – aXMD2150
Broadband Optical Modulator

aXenic

GaAs Broadband Optical Modulator

Product Code: aXMD2150-XX-XXX

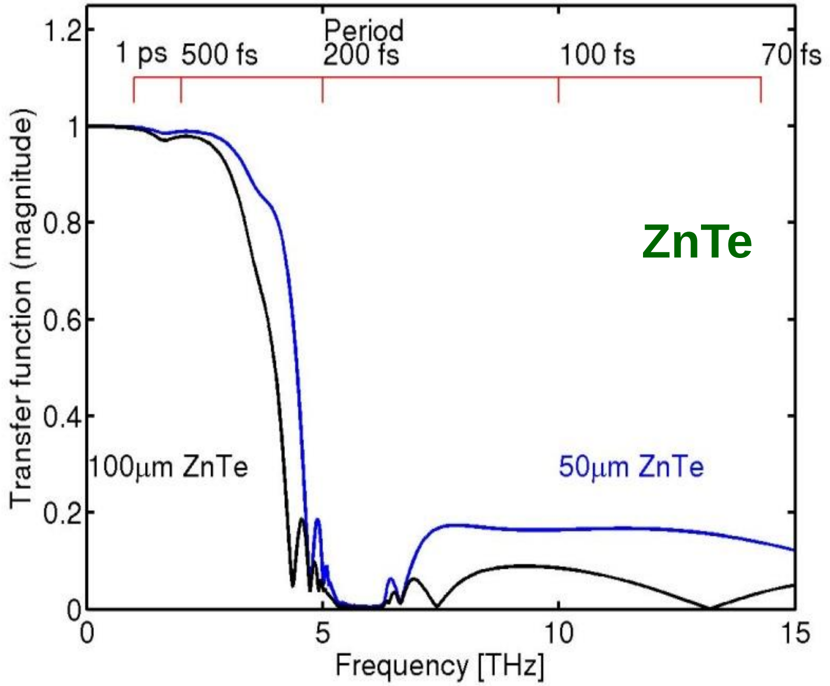
Product Description

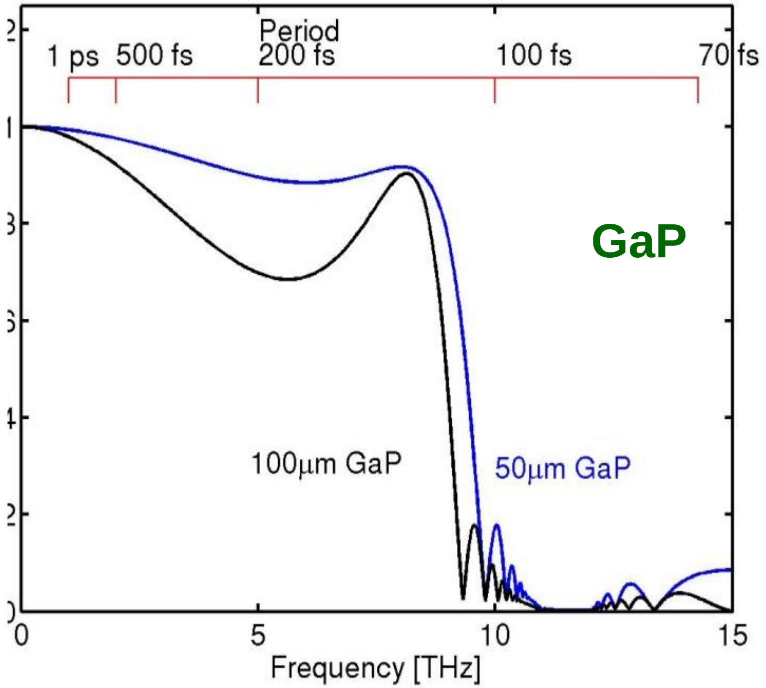
The aXMD2150 is a low loss, high integrity Mach Zehnder Optical Modulator based on gallium arsenide designed for general-purpose applications over the frequency range DC-50GHz. The die is fabricated using well proven and exercised high volume gallium arsenide processes used in the telecommunications industry that offers market leading performance optimized for optical applications.

- LiNbO3, LiTaO3, GaAs, BGO, ..
- Large bandwidth from DC to 50GHz

Electro-optical detection in Beam instrumentation

R&D on E-O techniques in accelerators for short bunch length monitoring (sub picosecond time response)



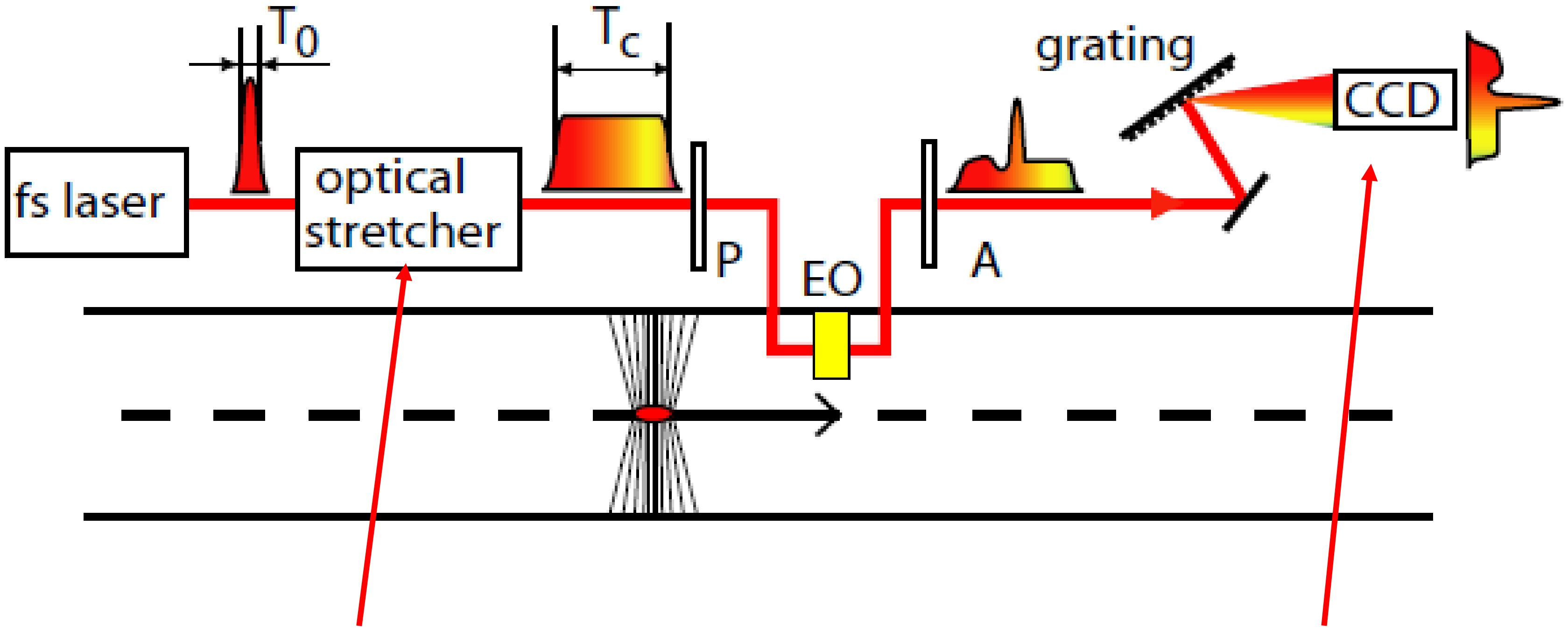


Thinner crystal - need higher power (short pulse) laser

Electro-optical detection in Beam instrumentation

R&D on E-O techniques in accelerators for short bunch length monitoring (sub picosecond time response)

Spectral Decoding



Encoding
Time to Frequency

➡

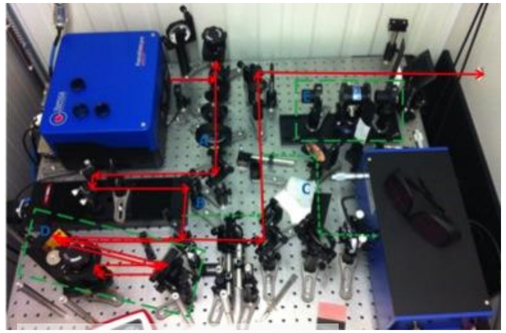
Decoding
Frequency from Position

Wilke et.al., PRL 88 (2002) 124801

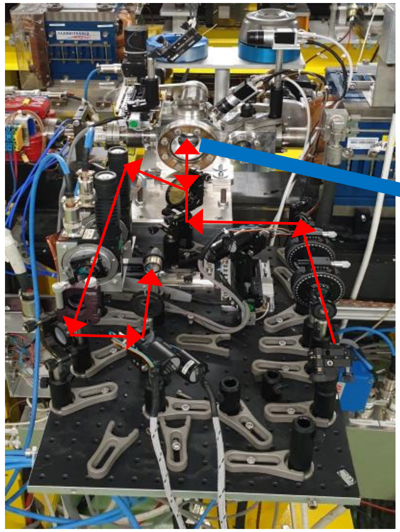
Time ➡ Position

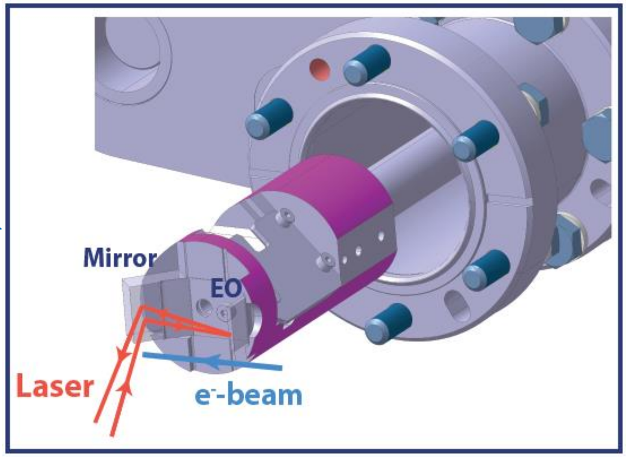
E-O systems in SY-BI

- Spectral decoding EO system at CLEAR for short bunch length measurement

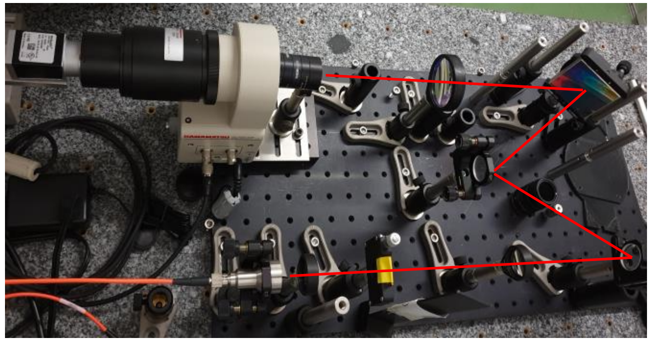


Er laser 780nm
150fs – 12ps

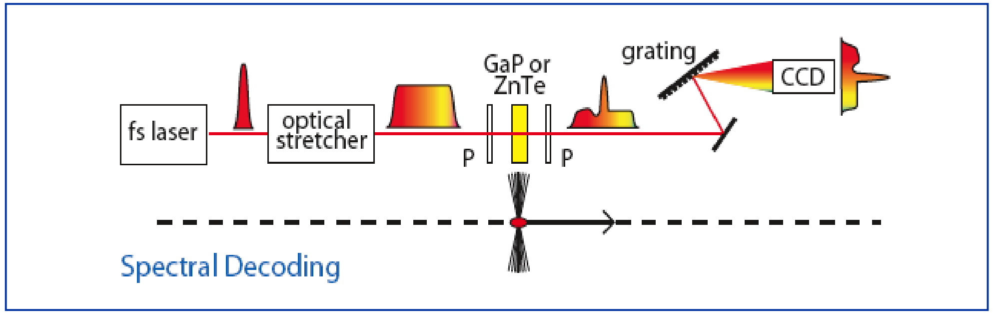


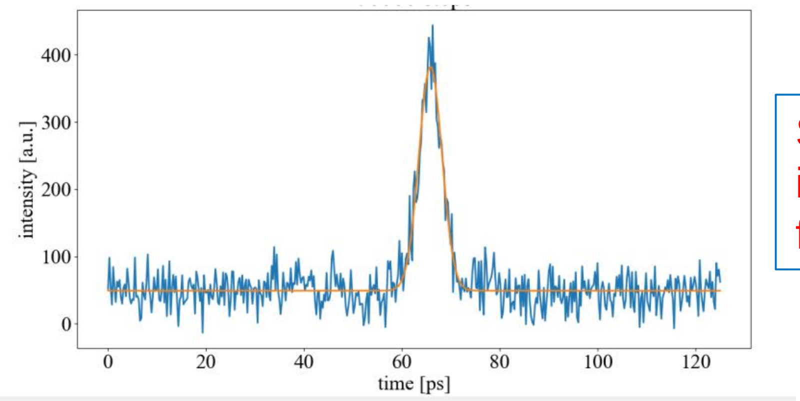


ZnTe Crystal in between crossed polarisers



Spectrometer with grating and intensified gated CCD camera





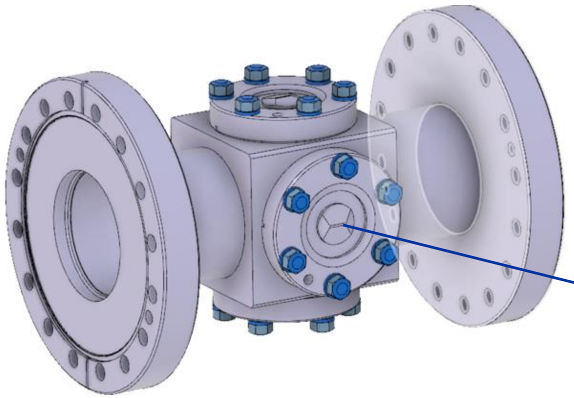
System being simplified for integration in AWAKE and upgraded for measuring 1ps long bunches

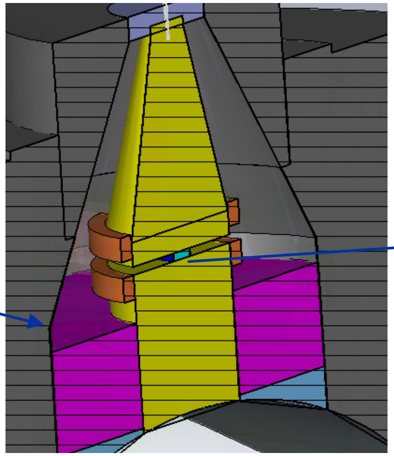
S. Mazzoni and E. Senes

E-O systems in SY-BI

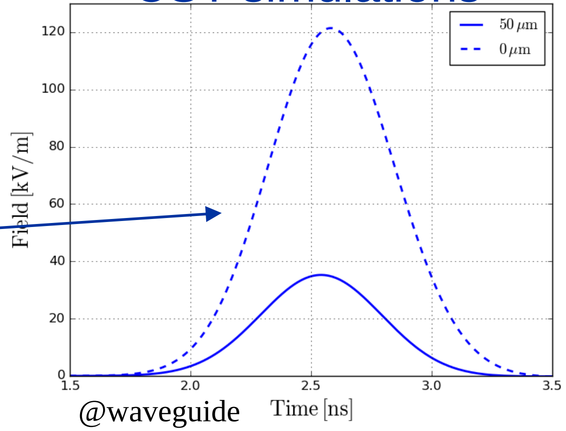
- EO development for high bandwidth (20ps resolution) intra-bunch beam position monitor at LHC

Button with custom brazed electrode

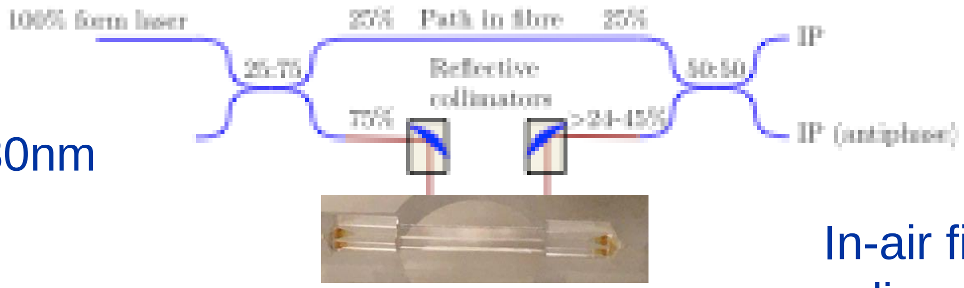




CST simulations



DC Laser at 780nm

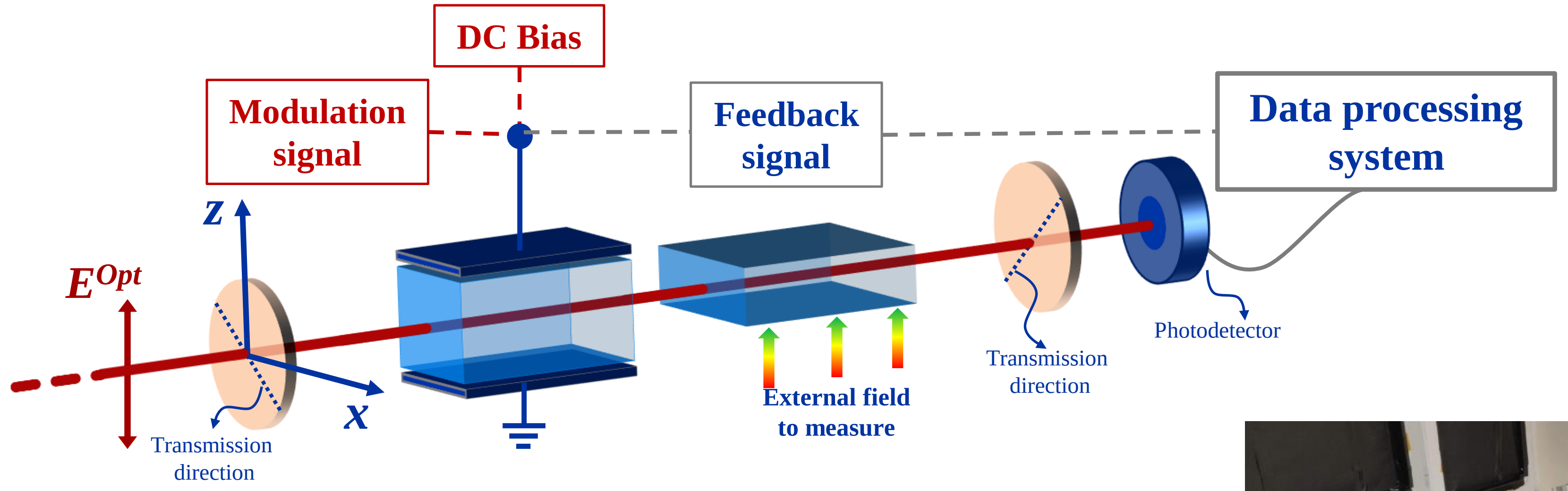


In-air fiber based EO waveguide encoding manufactured by UK industry

Collab. with RHUL

E-O systems in SY-BI

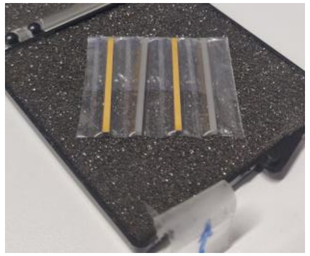
- EO BPM measurement for DC beams in SPS

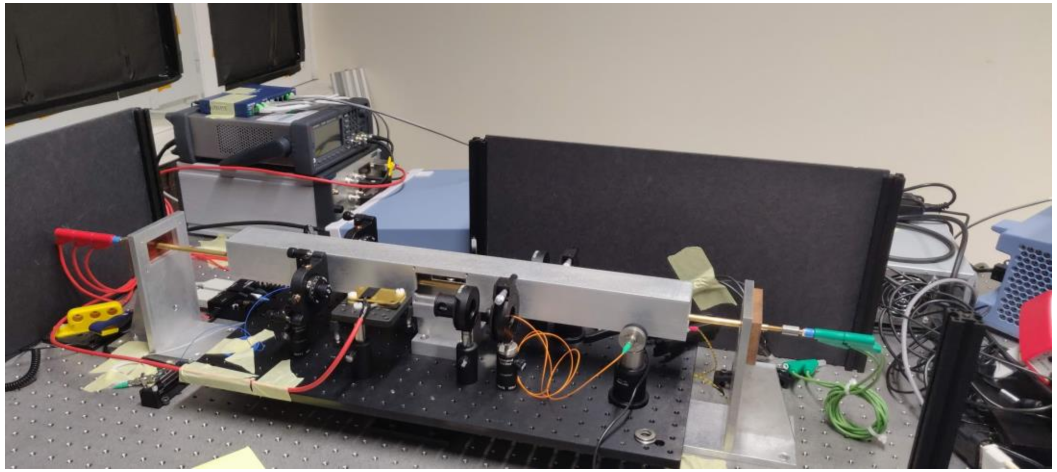


Laser at 1550nm

LiNbO3

LiTaO3



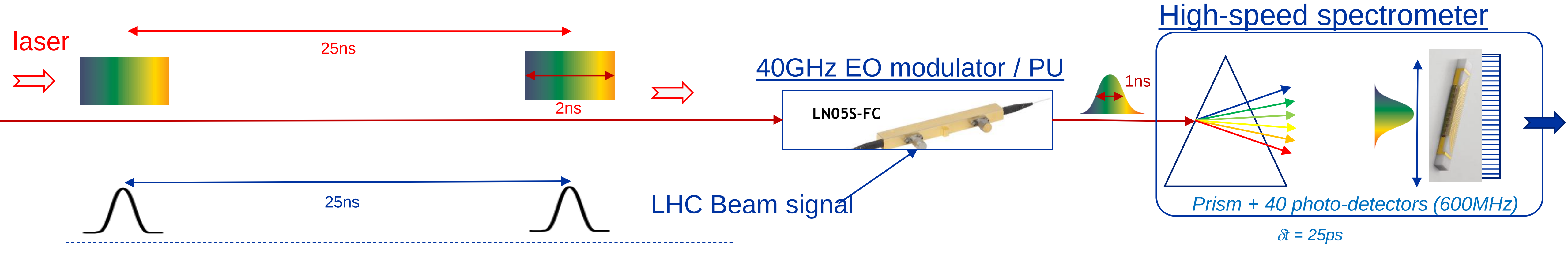


A. Cristiano and M. Krupa

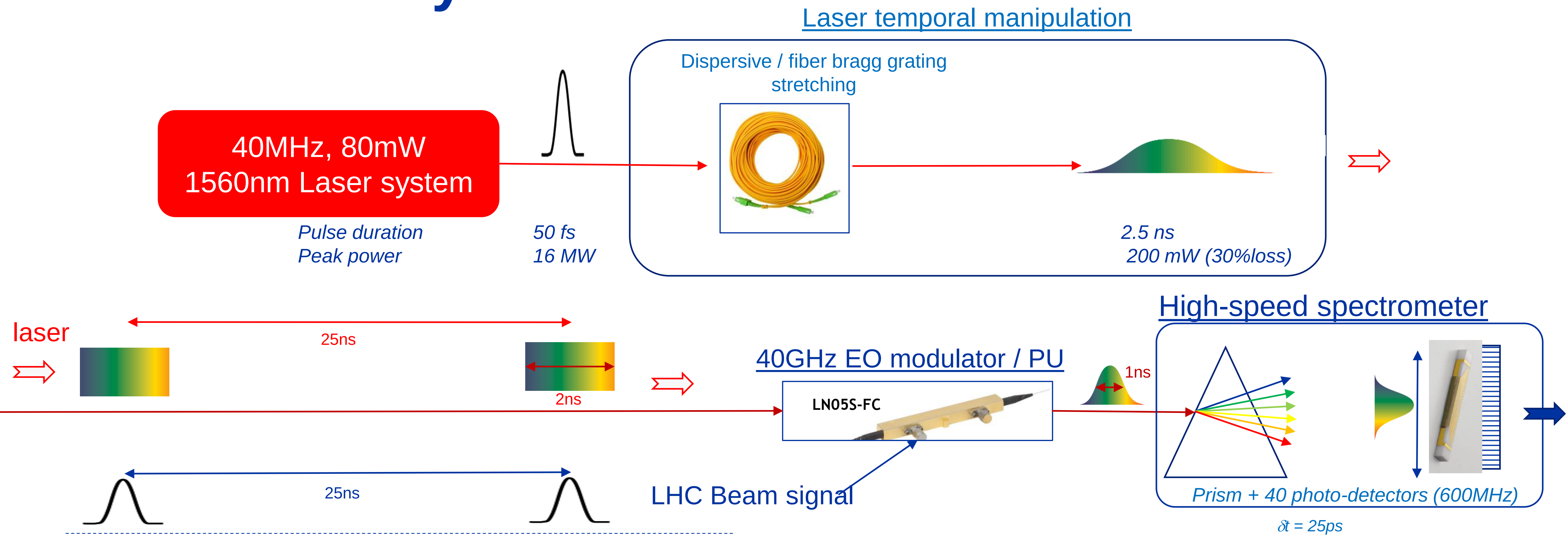
E-O systems in SY-BI

- All systems aim at fiber based solutions
- Possibly generalising time stretch techniques (spectral decoding) to improve the time resolution

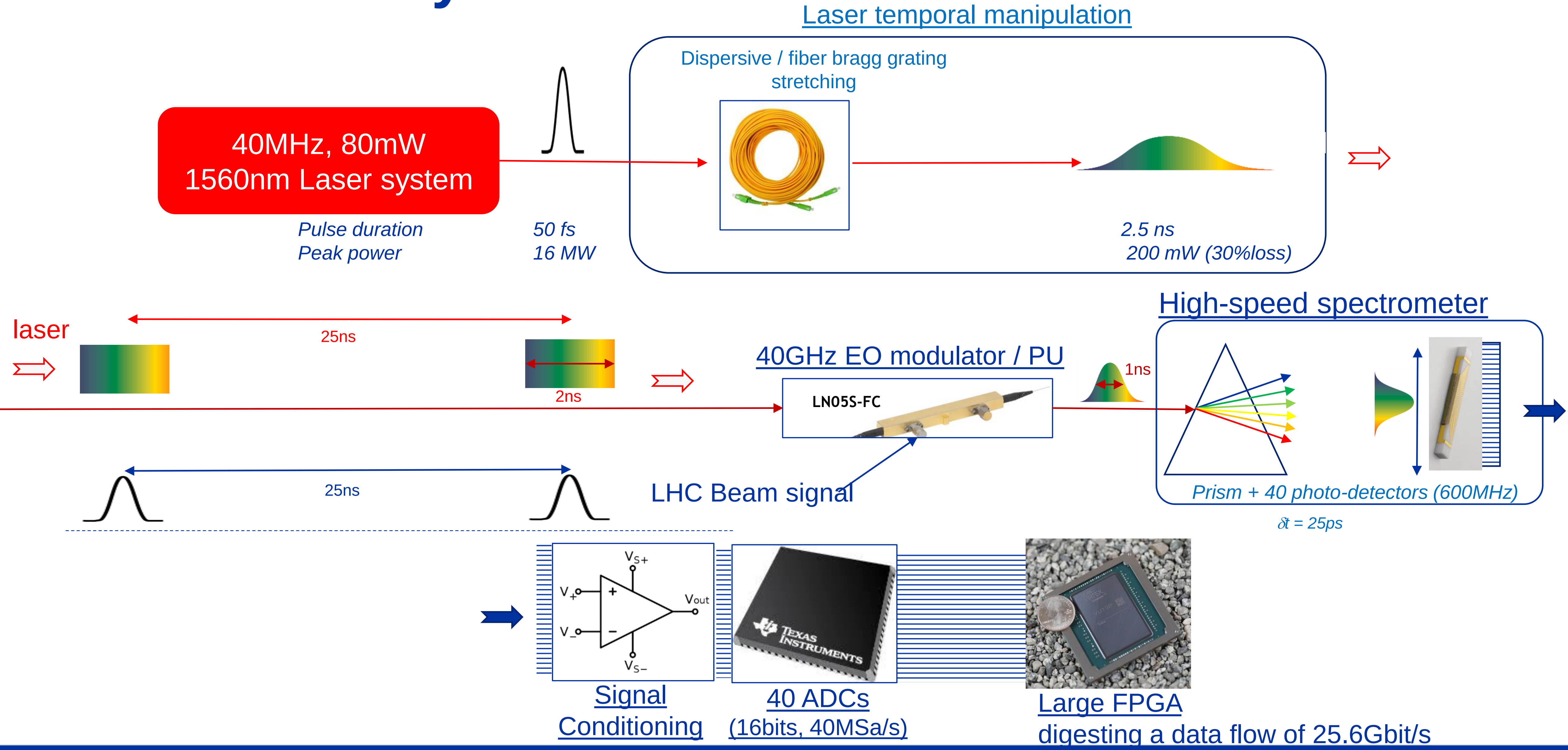
EO detection system for LHC



EO detection system for LHC



EO detection system for LHC



EO detection system for LHC

Laser temporal manipulation

Dispersive / fiber bragg grating stretching

40MHz, 80mW
1560nm Laser system

laser

- Equivalent Bandwidth of **40GHz**
- Time resolution of **25ps**
- **Sensitivity** would depend on **EO modulator/photo-detectors noise/DR**
- Measuring all bunches (40MHz) - **Ok**
- **Acquiring larger number of turns – depending on DAQ**

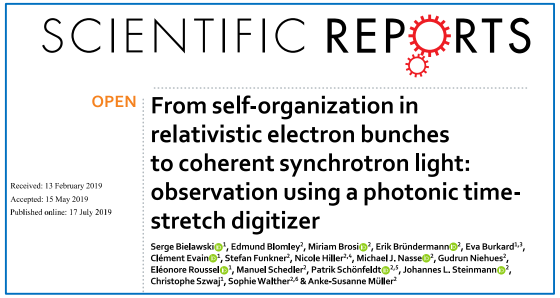
V_{S-}

Signal Conditioning

40 ADCs (16bits, 40MSa/s)

Large FPGA digesting a data flow of 25.6Gbit/s

EO detection system for short bunches



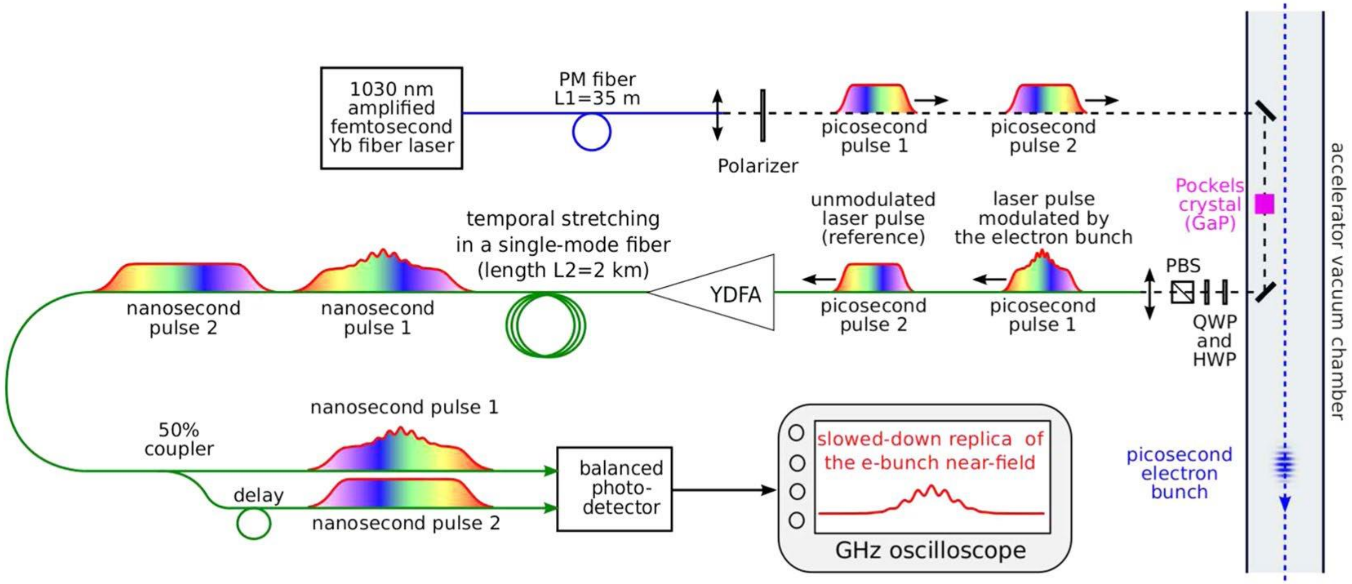
SCIENTIFIC REPORTS

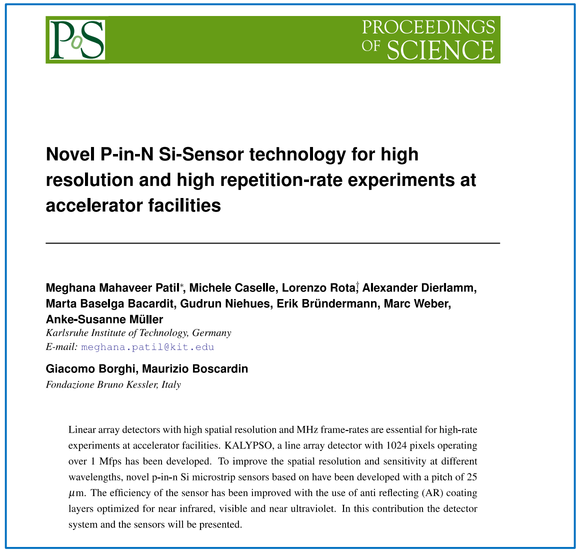
OPEN

Received: 13 February 2019
Accepted: 15 May 2019
Published online: 17 July 2019

From self-organization in relativistic electron bunches to coherent synchrotron light: observation using a photonic time-stretch digitizer

Serge Bielawski[1], Edmund Blomley[2], Miriam Brosi[2], Erik Bründermann[2], Eva Burkard[1,3], Clément Evain[1], Stefan Funkner[2], Nicole Hiller[2,4], Michael J. Nasse[2], Gudrun Niehues[2], Eléonore Roussel[1], Manuel Schedler[2], Patrik Schönfeldt[2,5], Johannes L. Steinmann[2], Christophe Szwaj[1], Sophie Walther[2,6] & Anke-Susanne Müller[2]





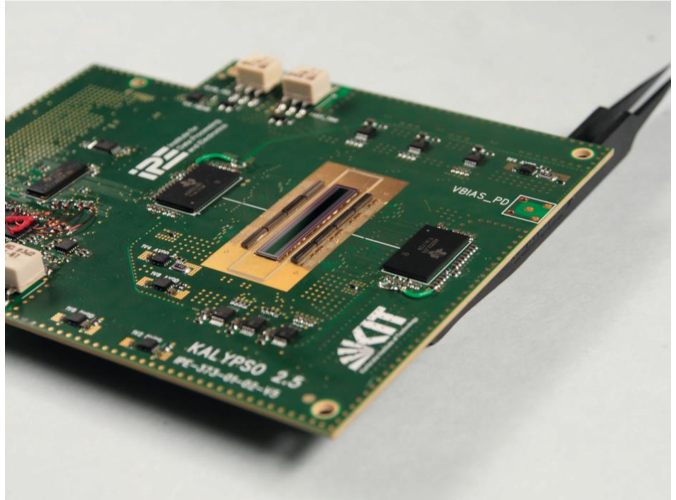
PROCEEDINGS OF SCIENCE

Novel P-in-N Si-Sensor technology for high resolution and high repetition-rate experiments at accelerator facilities

Meghana Mahaveer Patil*, Michele Caselle, Lorenzo Rota†, Alexander Dierlamm, Marta Baselga Bacardit, Gudrun Niehues, Erik Bründermann, Marc Weber, Anke-Susanne Müller
Karlsruhe Institute of Technology, Germany
E-mail: meghana.patil@kit.edu

Giacomo Borghi, Maurizio Boscardin
Fondazione Bruno Kessler, Italy

Linear array detectors with high spatial resolution and MHz frame-rates are essential for high-rate experiments at accelerator facilities. KALYPSO, a line array detector with 1024 pixels operating over 1 Mfps has been developed. To improve the spatial resolution and sensitivity at different wavelengths, novel p-in-n Si microstrip sensors based on have been developed with a pitch of 25 μm. The efficiency of the sensor has been improved with the use of anti reflecting (AR) coating layers optimized for near infrared, visible and near ultraviolet. In this contribution the detector system and the sensors will be presented.



Future…a fully integrated..

High rep rate chirped Fiber laser…. Stretching

…Custom fiber coupled EO modulator… Stretching

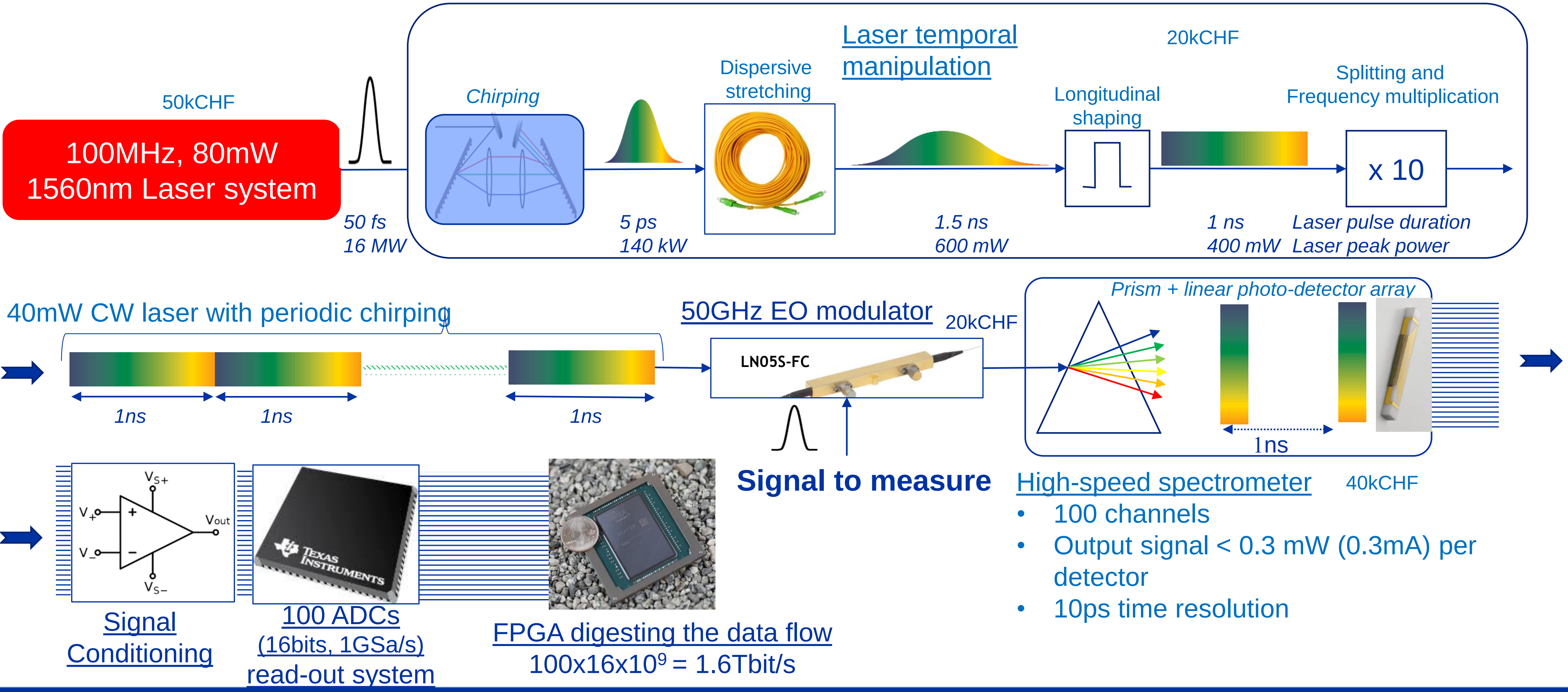
…Dispersive Grating…

… linear array of Si/InGaAs photosensor…

….ADC/FPGA

Thanks for your attention

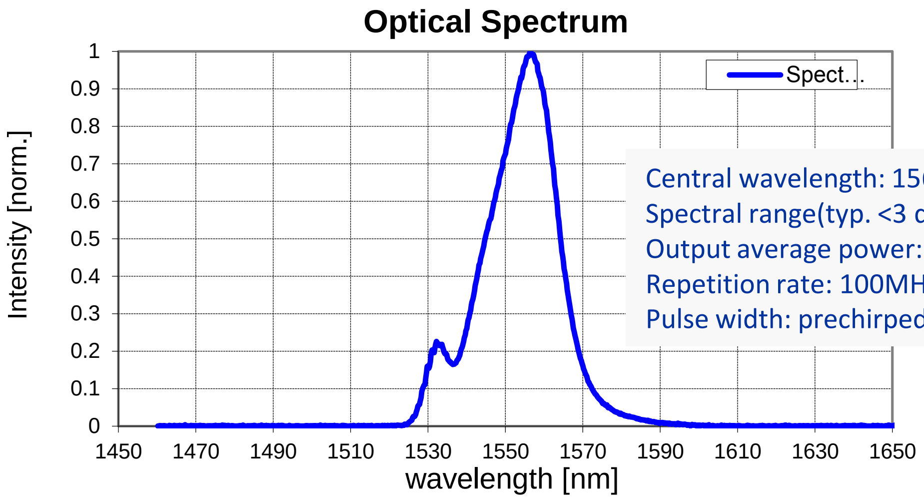
100GSa/s -16bits (E-O) Oscilloscope (250kCHF)



Laser for E-O detection at LHC

MenloSystems

50kCHF with synchronisation
ΔFrev of few kHz



Central wavelength: 1560nm +/- 20nm
Spectral range(typ. <3 dB): ~ 20nm;
Output average power: 130mW (linear amplifier)
Repetition rate: 100MHz +/- 1MHz
Pulse width: prechirped to 1ns using 2 fiber bragg gratings

C-Fiber 780

Femtosecond Fiber Laser 780 nm

SPECIFICATIONS	C-FIBER 780	C-FIBER 780 HIGH POWER
Center Wavelength	780 nm ± 10 nm	780 nm ± 10 nm
Average Power	>100 mW	>250 mW
Pulse Energy	>1.0 nJ	>2.5 nJ
Pulse Width	<100 fs (<70 fs with FEMTOSCALE)*	
Repetition Rate	100 MHz (50-250 MHz with VARIO)**	
Repetition Rate Instability	<1 ppm over 20 hours at constant temperature	
Timing Jitter	<2 fs [rms, 10 kHz.. 10 MHz]	
Output Port	free space	
Auxiliary Output Port***	free space, 1560 nm, >250 mW	free space, 1560 nm, >500 mW
Additional Fiber-Coupled Seed Port	1 (up to 4 with MULTIBRANCH)	
Polarization	linear, s-polarized	
Beam Height	75 mm	

*Compressor unit integrated in laser head module. **Please inquire for your specific combinations of average power, pulse duration and repetition rate. *** User can switch between 780 nm and 1560 nm port (arbitrary splitting ratios possible).

C-Fiber

Femtosecond Fiber Laser 1560 nm

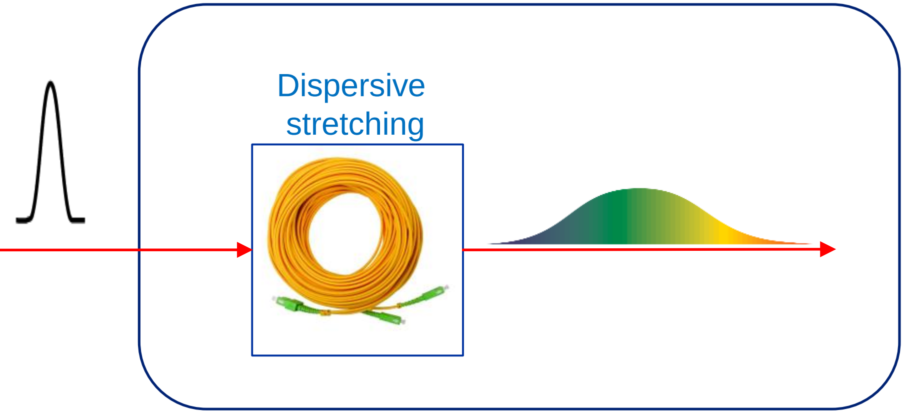
SPECIFICATIONS	C-FIBER	C-FIBER HIGH POWER
Center Wavelength	1560 nm ± 20 nm	1560 nm ± 20 nm
Average Power	>100 mW	>500 mW
Pulse Energy	>1 nJ	>5 nJ
Pulse Width	<90 fs	
Repetition Rate	100 MHz (50-250 MHz with VARIO)*	
Repetition Rate Instability	<1 ppm over 20 hours at constant temperature	
Timing Jitter	<2 fs [rms, 10 kHz.. 10 MHz]	
Output Port	fiber-coupled (FC/APC)	free space
Additional Fiber-Coupled Seed Port	1 (up to 4 with MULTIBRANCH)	
Polarization	linear, PM fiber	linear, s-polarized
Beam Height	n.a.	102 mm

*Please inquire for your specific combinations of average power, pulse duration and repetition rate.

Time stretching for E-O detection at. LHC

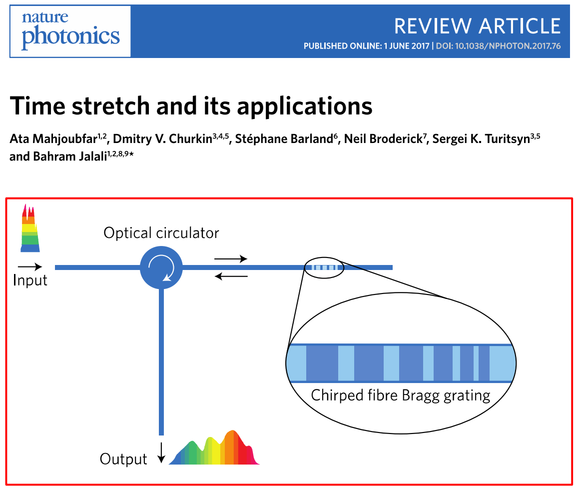
MenloSystems

Laser temporal manipulation



- **Study time streching methods**
  - Dispersion in long fibers
  - Fiber bragg grating
  - Combination of both

- **Characterise and optimise** : spectral flatness vs peak power
  - Work can start re-using the CLEAR EO laser system


nature photonics

REVIEW ARTICLE

PUBLISHED ONLINE: 1 JUNE 2017 | DOI: 10.1038/NPHOTON.2017.76

Time stretch and its applications

Ata Mahjoubfar[1,2], Dmitry V. Churkin[3,4,5], Stéphane Barland[6], Neil Broderick[7], Sergei K. Turitsyn[3,5] and Bahram Jalali[1,2,8,9]*

Linear photodetector atLHC

- *Would also need to launch price enquiry : Need to work on specifications first*

HAMAMATSU
PHOTON IS OUR BUSINESS

Selection guide - September 2017

InGaAs Photodiodes

Photodiode arrays

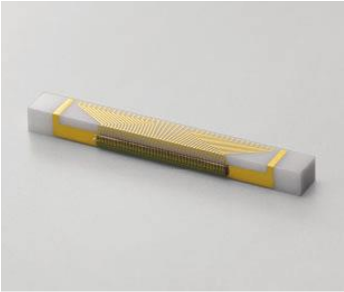
(Typ. Ta=25 °C)

Type no.	Photosensitive area (mm)	Spectral response range λ (µm)	Peak sensitivity wavelength λp (µm)	Photosensitivity S λ=1.55 µm (A/W)	Dark current I_D per element (nA)	Cutoff frequency fc V_R=1 V (MHz)	Package	Photo
G6849	ϕ2 (quadrant)	0.9 to 1.7	1.55	0.95	0.5 (V_R=1 V)	30	TO-5	
G6849-01	ϕ1 (quadrant)				0.15 (V_R=1 V)	120		
G7150-16	0.45 × 1.0 (× 16-element)				2.5 (V_R=1 V)	30	Ceramic	
G7151-16	0.08 × 0.2 (× 16-element)				0.1 (V_R=1 V)	300		
G8909-01	ϕ0.08 (× 40-element)				0.02 (V_R=5 V)	1000 (V_R=5 V)	Ceramic (unsealed)	
G12430-016D	0.45 × 1.0 (× 16-element)				0.5 (V_R=1 V)	30	Ceramic	
G12430-032D	0.2 × 1.0 (× 32-element)				0.25 (V_R=1 V)	60		
G12430-046D	0.2 × 1.0 (× 46-element)				0.25 (V_R=1 V)	60		

Linear photodetector for HT on LHC

- ***Would also need to launch price enquiry : Need to work on specifications first***

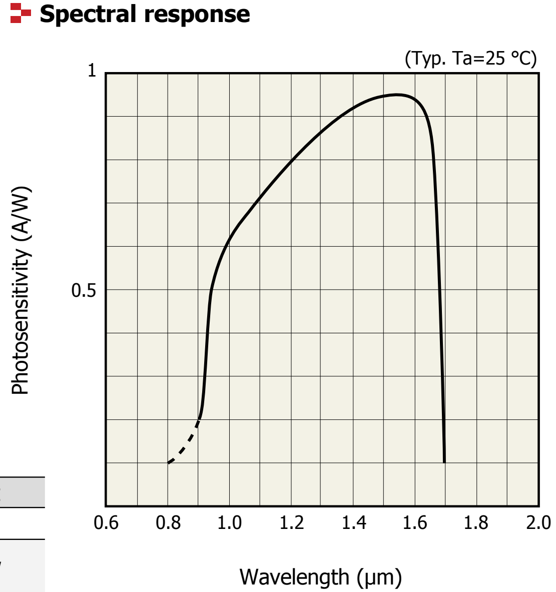
HAMAMATSU
PHOTON IS OUR BUSINESS

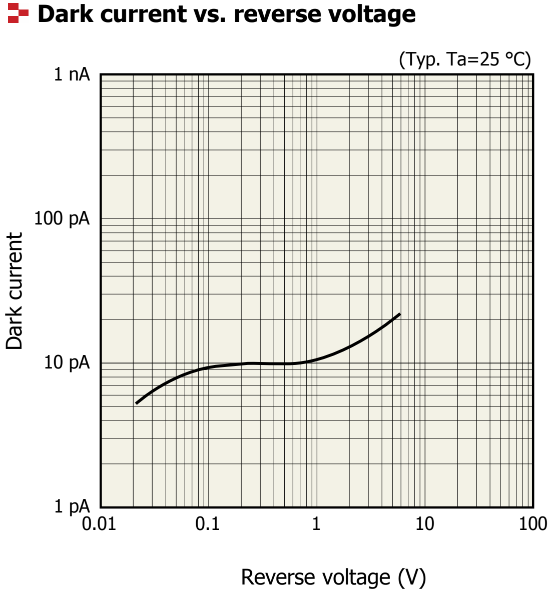


InGaAs PIN photodiode array

G8909-01

Photodiode array for DWDM monitor



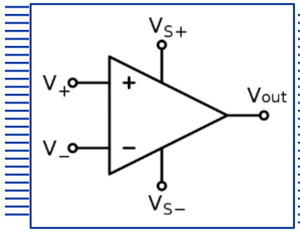


Electrical and optical characteristics (Ta=25 °C, per 1 element)

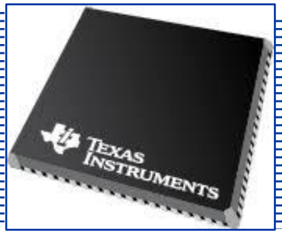
Parameter	Symbol	Condition	Min.	Typ.	Max.	Unit
Spectral response range	□		-	0.9 to 1.7	-	µm
Photosensitivity	S	□=1.31 µm	0.8	0.9	-	A/W
		□=1.55 µm	0.85	0.95	-	
Photoresponse nonuniformity	PRNU		-	-	±5	%
Dark current	I_D	V_R=5 V	-	0.02	0.2	nA
Shunt resistance	Rsh	V_R=10 mV	-	8	-	G□
Terminal capacitance	Ct	V_R=5 V, f=1 MHz	-	1.4	-	pF
Crosstalk	-	V_R=0.1 V	-	-33	-	dB

DAQ for HT at LHC

- *What exists on the Market ?*

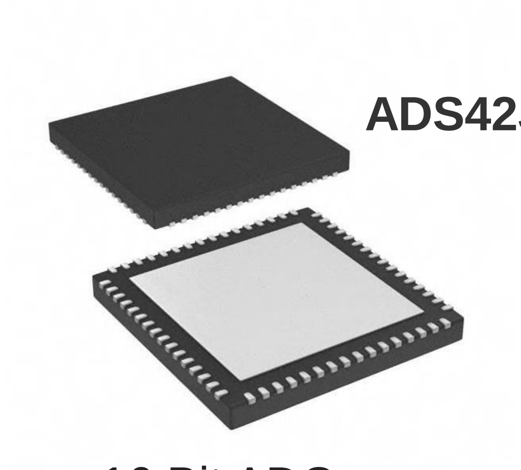


Signal Conditioning



40 ADCs
(16bits, 40MSa/s)

FPGA
digesting a data flow of
25.6Gbit/s



ADS42JB69IRGCT

- 16 Bit ADC
- 2 Inputs
- 220k/pieces

Arria 10 GX 660

- 48 transceivers
- memory bandwidth of up to 128 Gbps
- 4k

- 96 transceivers
- memory bandwidth of up to 512 GBps
- 12k