Two-bunch operation for Compact Light: Sub-harmonic deflector design progress

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17.6.2020

Outline

1. Introduction to sub-harmonic deflector

2. Sub-harmonic transverse deflecting cavity design

3. Sub-harmonic transverse deflector system

4. Summary

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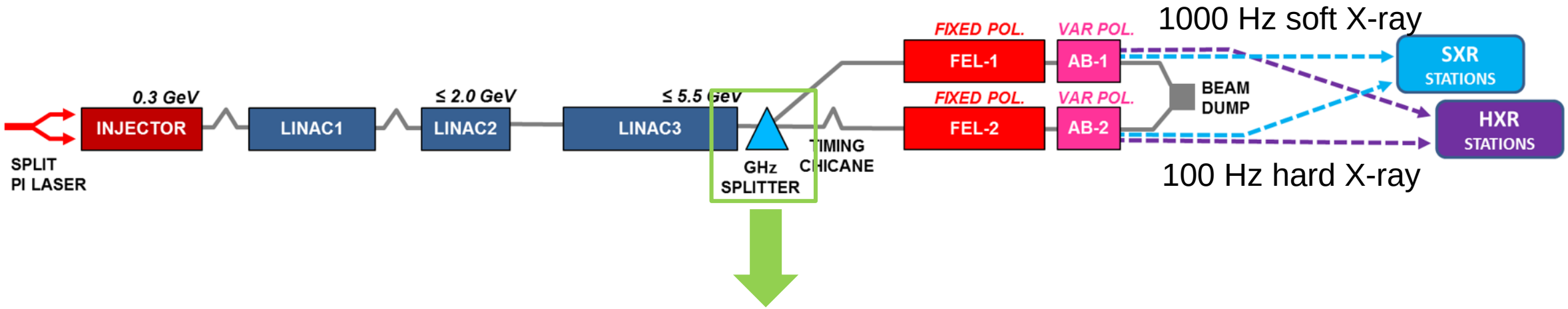
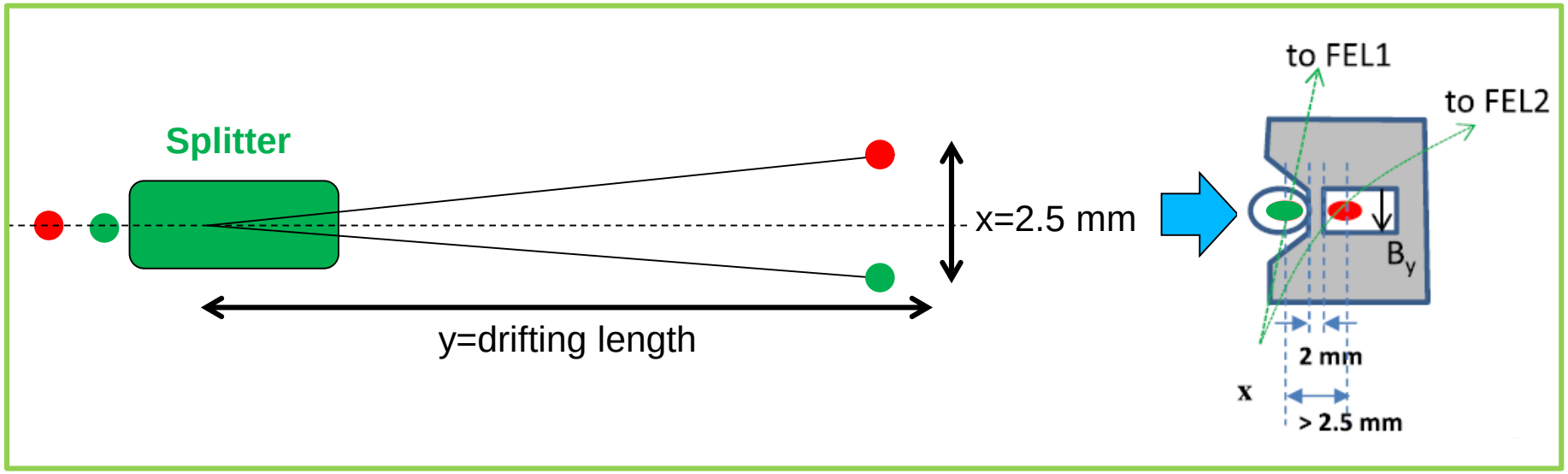
Bunch splitter before FEL structure



Need a splitter to separate the two bunches into two FEL lines

Distance between the two bunches should be over 2.5 mm at the entrance of septum

Use transverse deflecting cavity to spit the two bunches



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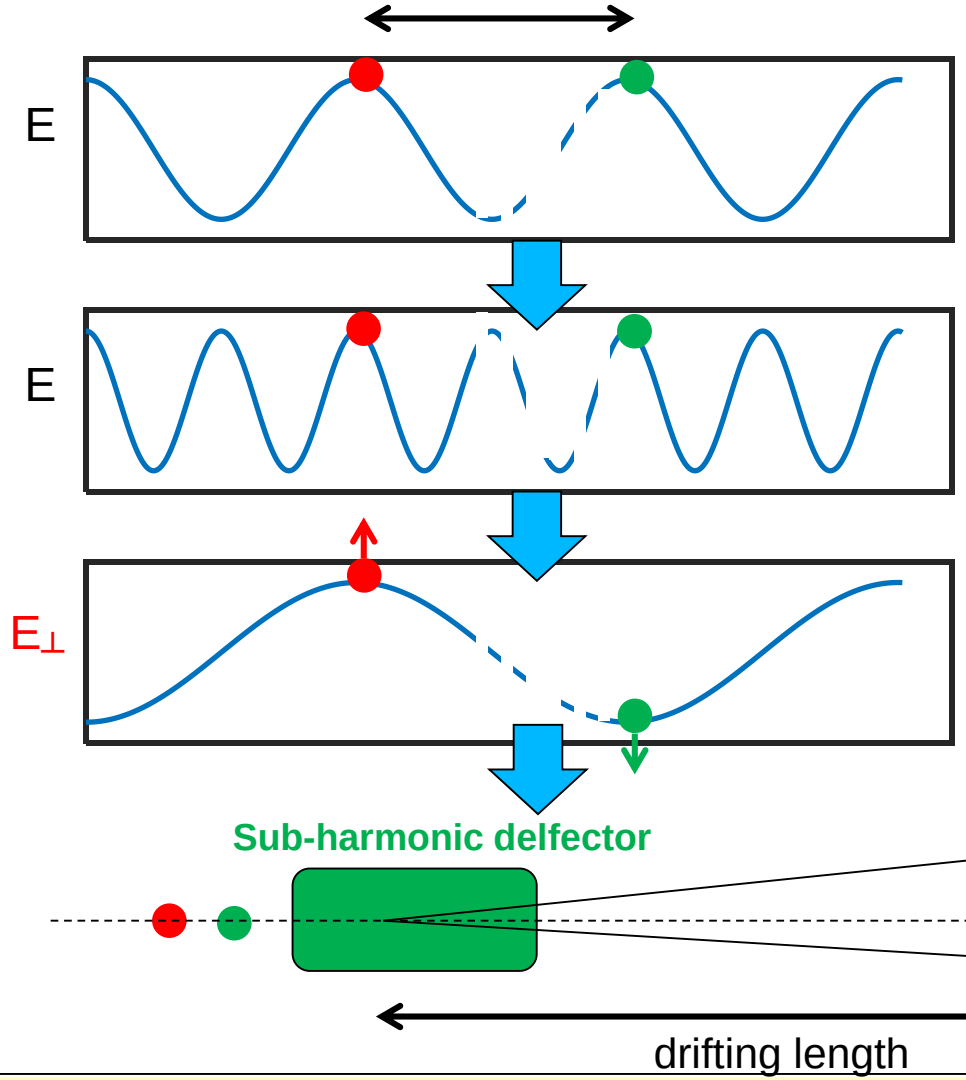
Sub-harmonic delfector and spacing between two bunches

Compact

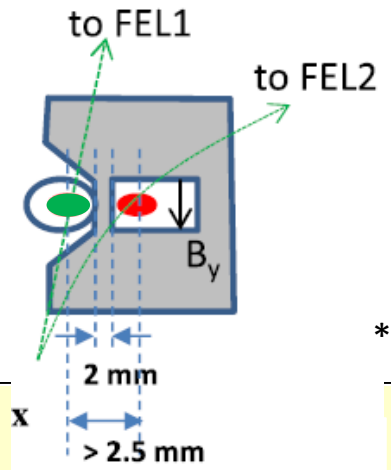
$\Delta t = n\,\tau_{gun}$, n = 1,3,5...

$\Delta s = n\,\lambda_{gun}$



n (C-band)	Δt	Δs	n (X-band)	n (S-band)
1	166 ps	50 mm	2	0.5
3	500 ps	150 mm	6	1.5
5	833 ps	250 mm	10	2.5
7	1.16 ns	350 mm	14	3.5
9	1.5 ns	450 mm	18	4.5

Spacing between the two bunches should be 2, 6, 10, 14… X-band rf cycles

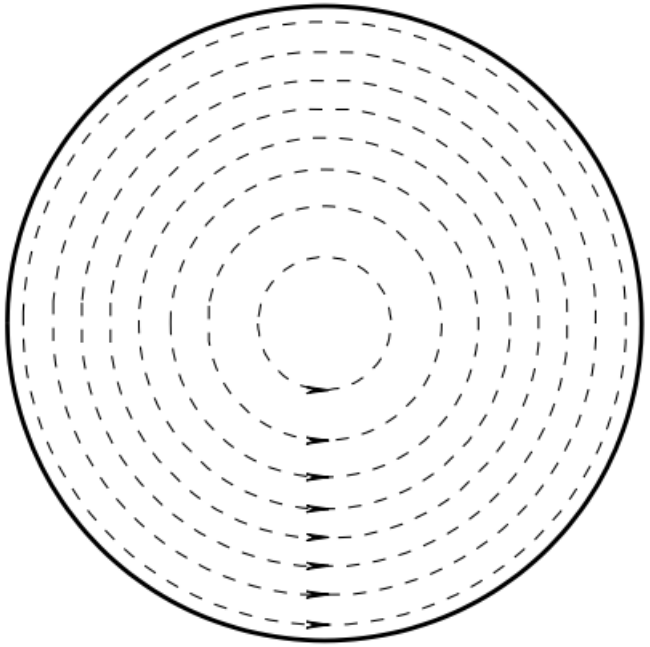


* Courtesy by N. Thompson

TM110 mode in transverse deflecting cavity

Transverse magnetic field of TM010 and TM110 in pillbox cavity

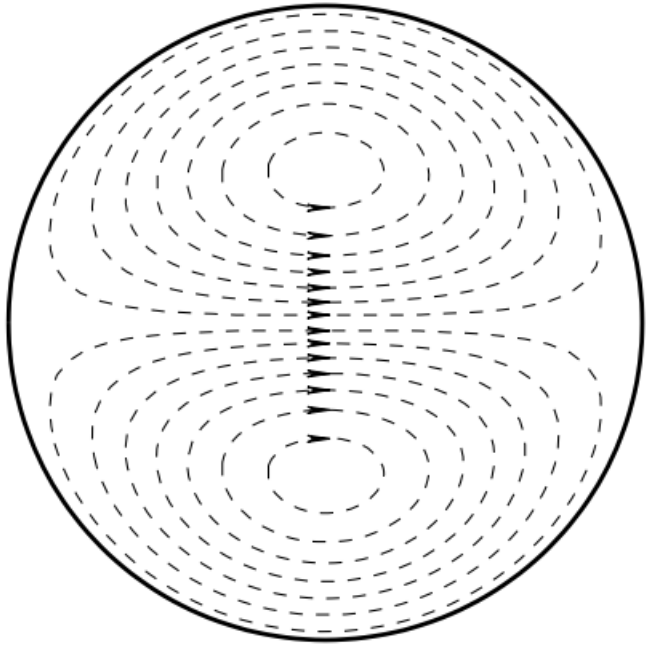
TM010 mode



Accelerating mode

$$\frac{f_{TM_{110}}}{f_{TM_{010}}} = 1.59$$

TM110 mode



Dipole mode
Transverse kick to beam

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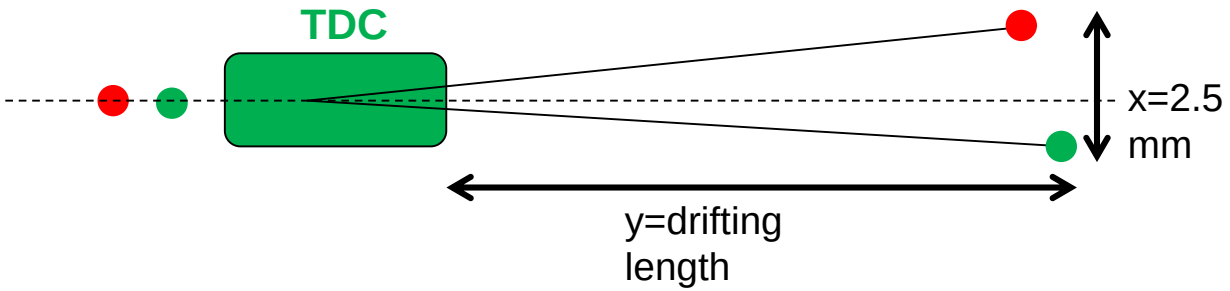
Transverse deflecting cavity (TDC) design

Hard X-ray mode: 5.5 GeV bunch
x=2.5 mm, y is drift length

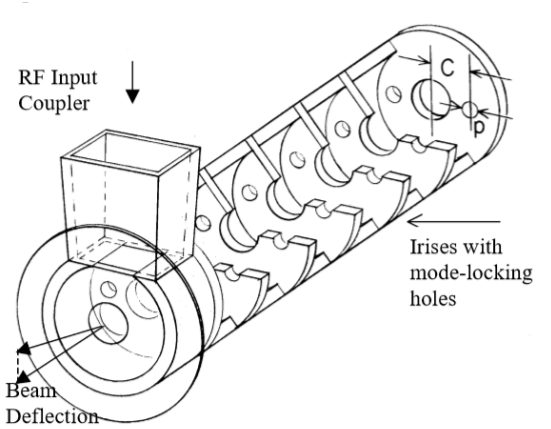
$$\frac{V_\perp e}{E} = \frac{x/2}{y}$$



Voltage of deflector could be reduced if we increase the drift length
Longer drift length makes standing-wave deflecting cavity possible

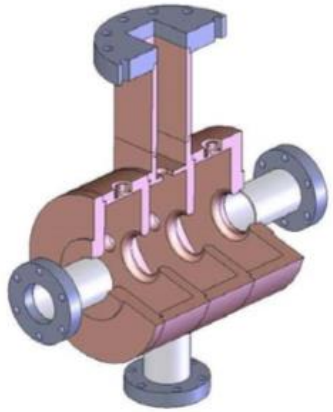
Three options for the transverse deflecting cavity
1. Traveling-wave structure
2. Standing-wave structure, 3-cell structures
3. Standing-wave structure, 5-cell structures

Traveling-wave structure



SLAC type LOLA TDC
TM110, 2π/3 mode
Length=2.4 m
Filling time~ 300 ns

Standing-wave structure



Tsinghua University type 3-cell structure

INFN type 5-cell structure

Loew, G. A., & Altenmueller, O. H. DESIGN AND APPLICATIONS OF RF DEFLECTING STRUCTURES AT SLAC. 1965
Shi, J. phD thesis. 2009
Alesini, D., et al. RF deflector design and measurements for the longitudinal and transverse phase space characterization at SPARC. Nucl. Instrum. Methods Phys. Res. A, 568(2), 488-502. 2006

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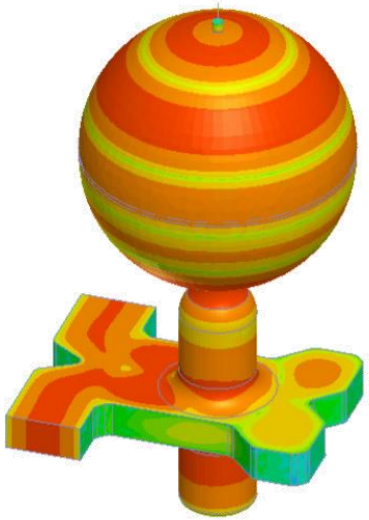
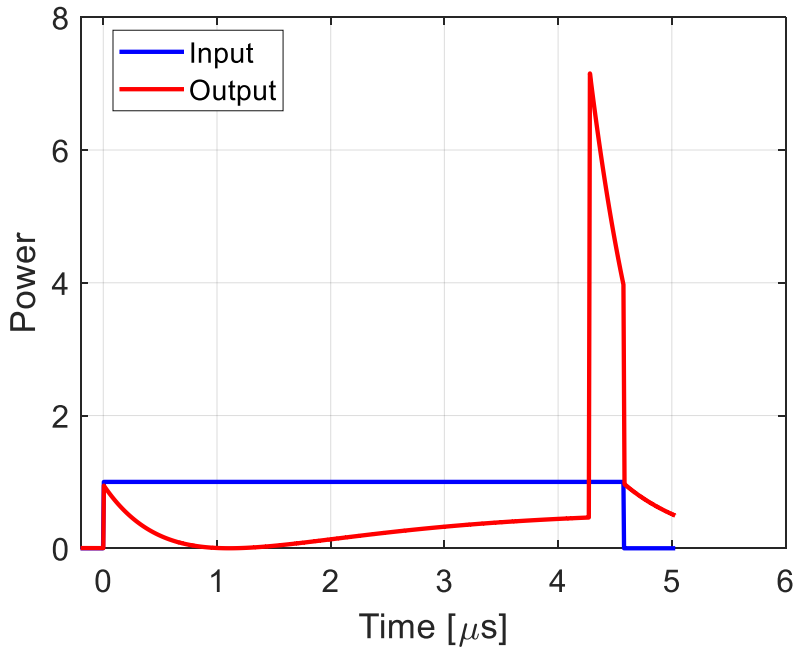
Power capability

CPI S-band Klystron (VKS8262G1):
7.5 MW, 5.0 μs, 400 Hz flat pulse
already applied in IFIC S-band test stand in Valencia

With spherical pulse compressor:
39.7 MW, 300 ns (Avg. without loss) compressed pulse





Spherical pulse compressor	
frequency	2.998 GHz
Q_0	100000
Coupling factor	7
Compression ratio	15
Peak power gain	7.15
Average power gain	5.29

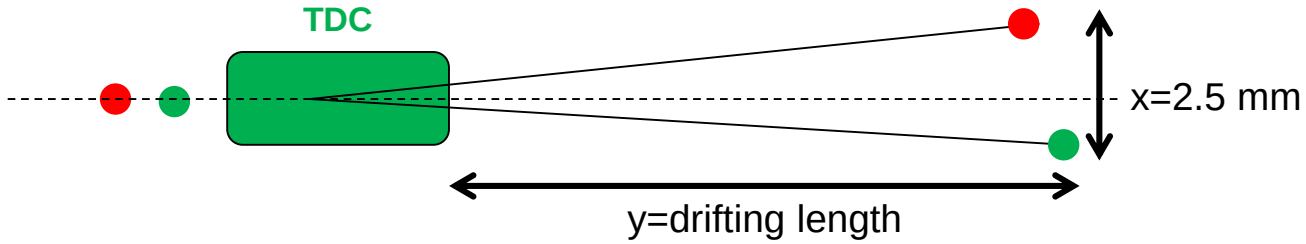
Esperante Pereira, Daniel, et al. "Construction and Commissioning of the S-Band High-Gradient RF Laboratory at IFIC." J. Phys. Conf. Ser.. Vol. 1067. 2018.

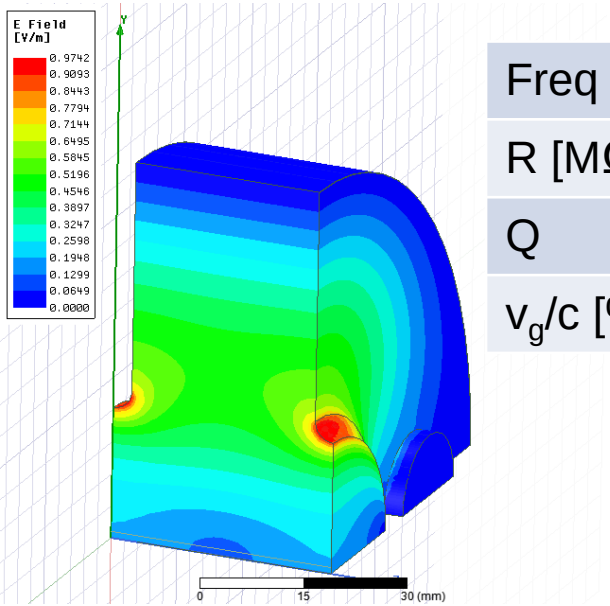
Traveling-wave transverse deflecting structure design

Increasing the drift length can reduce the length of traveling-wave structure

Work at 2π/3 mode

6 MW, 4.5 μs klystron pulse
30 MW, 300 ns compressed pulse





Freq [GHz]	2.998
R [MΩ/m]	20
Q	12000
v_g/c [%]	3

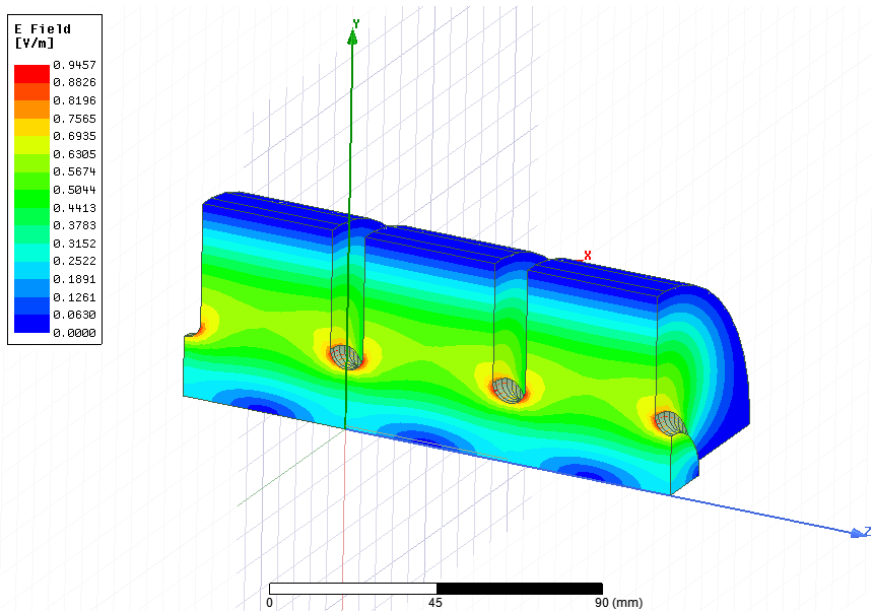
Drift length [m]	Deflecting voltage [MV]	Traveling wave (2π/3)		
		klystron power [MW]	Stru. Length w/ PC [m]	Stru. Length w/o PC [m]
0.5	13.75	6	1.45	3.65
1.0	6.875	6	0.70	1.64
1.5	4.583	6	0.46	1.06
2.0	3.438	6	0.35	0.79

Standing-wave transverse deflecting structure design

TM110 Eigen mode results

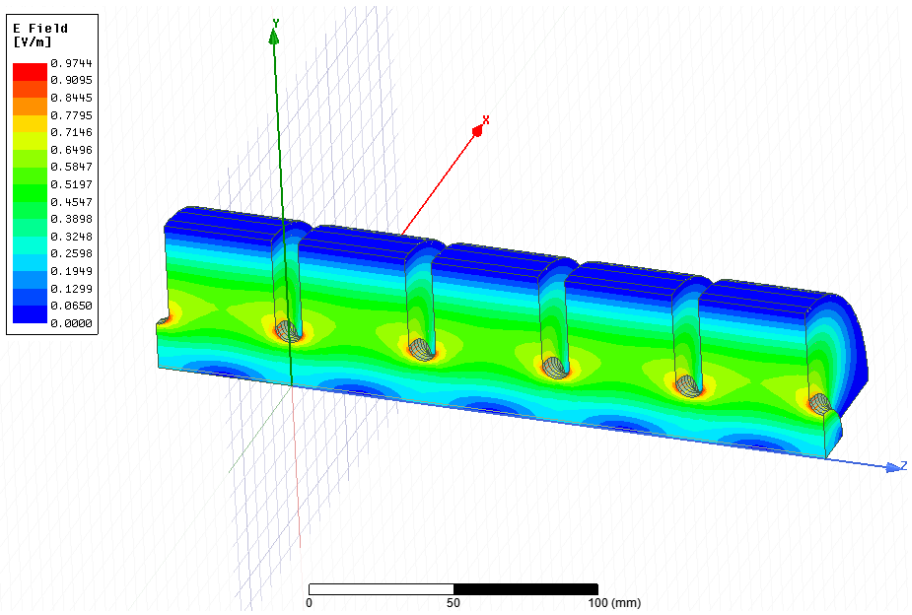
3-cell structure

R [MΩ]	Freq [MHz]	Q
3.03	2996	15337



5-cell structure

R [MΩ]	Freq [MHz]	Q
5.02	2996	15271



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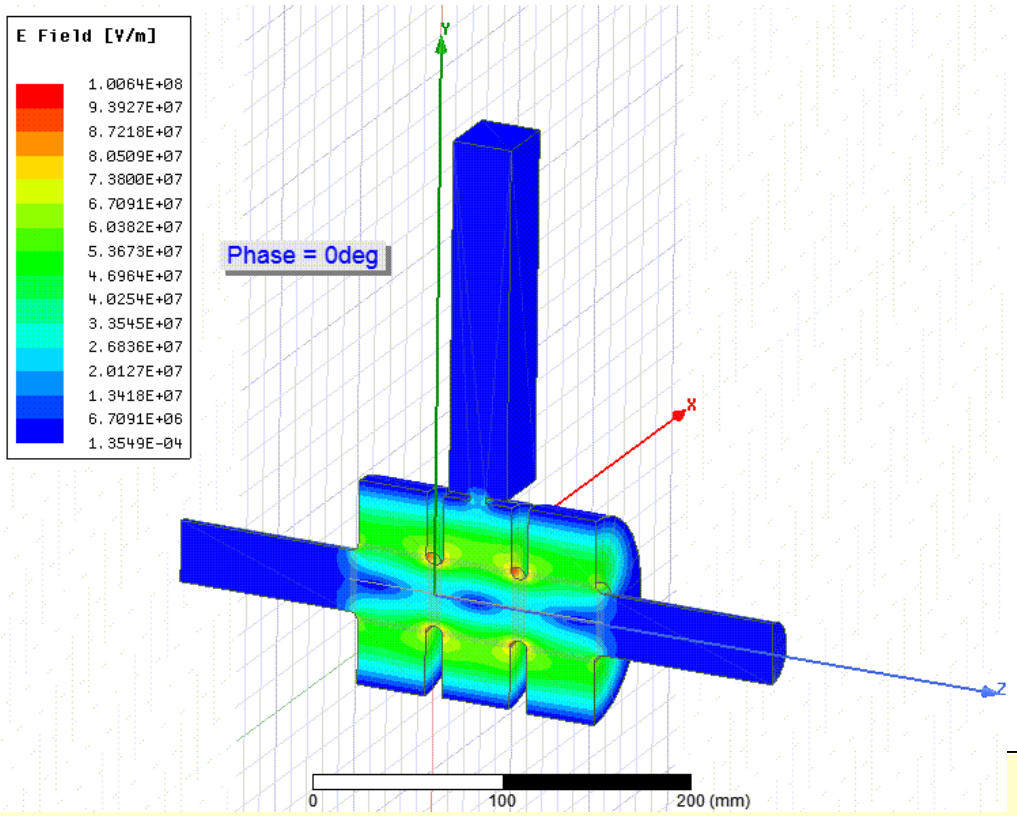
3-cell standing-wave TDC coupler design

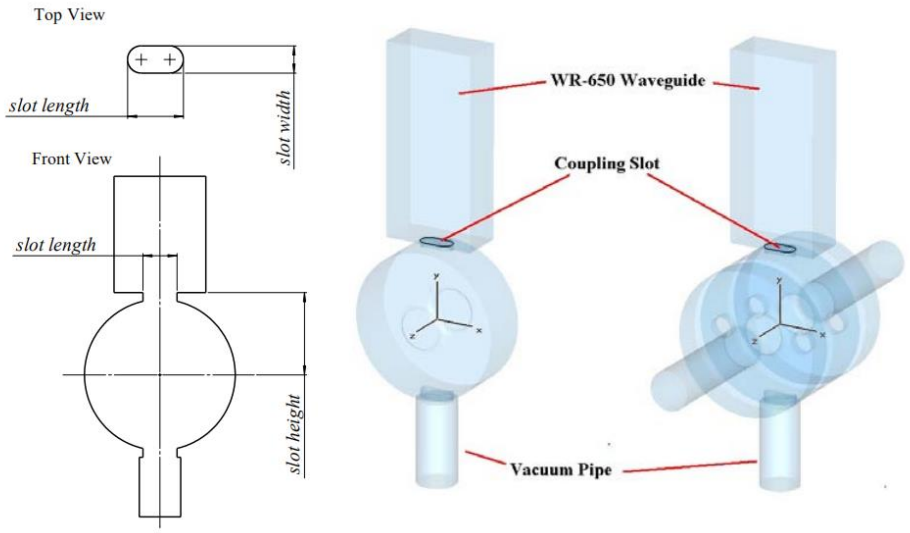
Use race track shape coupling hole

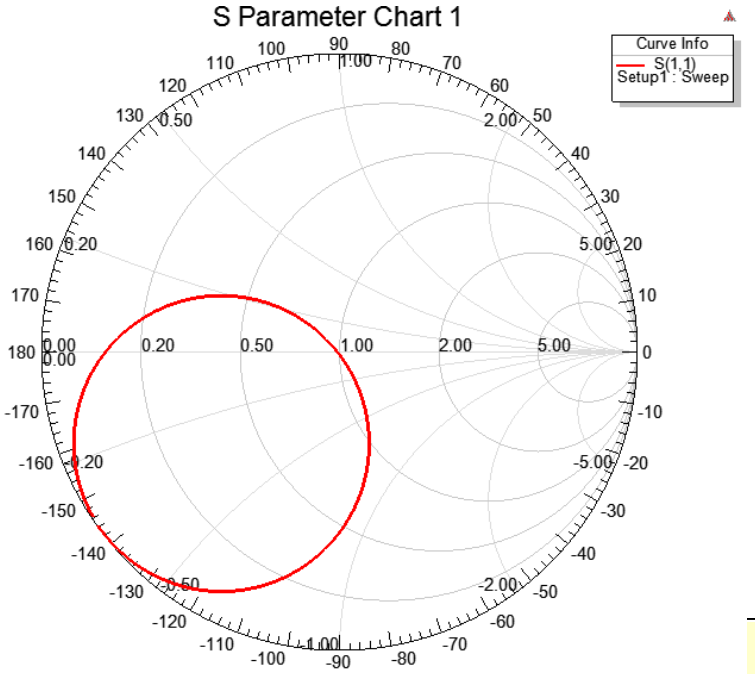
4.14 MV deflecting voltage @ 6 MW input power

Maximum surface field around 100 MV/m

Filling time~820 ns







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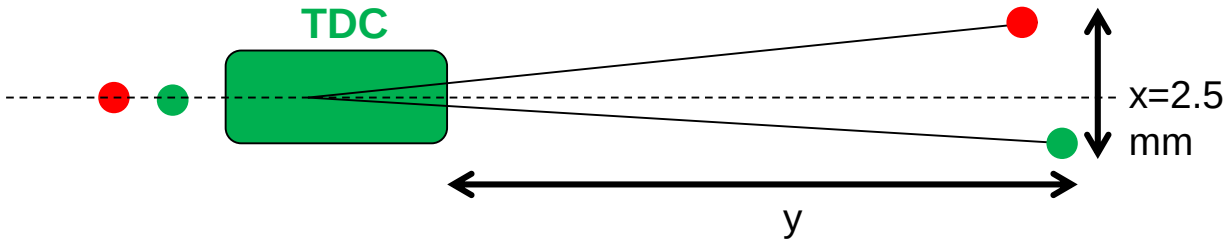
TDC System design

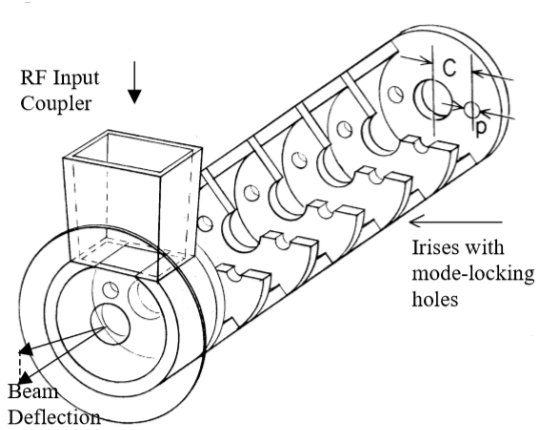
HXR mode: 5.5 GeV bunch
x=2.5 mm, y is drift length

$$\frac{V_\perp e}{E} = \frac{x/2}{y}$$

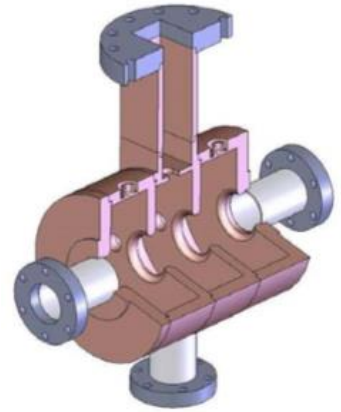


Two options for the transverse deflecting cavity
1. Traveling-wave structure
2. Standing-wave structure

Traveling-wave structure



Standing-wave structure



RF parameters

2998 MHz	Traveling-wave (2π/3)	Standing-wave
Cell number	N	3/5
Single cell length [m]	0.033	0.05
Structure length [m]	N*0.033	0.15/0.25
Shunt impedance [MΩ/m]	15.3	20
Filling time [ns]	111/meter	~820

Power capability

Klystron: VKS8262G1 model built by CPI
Maximum rf peak power of 7.5 MW→6 MW within loss
Pulse length of up to 5 μs
Repetition rate of 400 Hz

Pulse compressor: spherical pulse compressor
Increase the average power:
6 MW, 4.5 us →40 MW, 300 ns (Avg.)

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Traveling-wave vs Standing-wave deflecting system

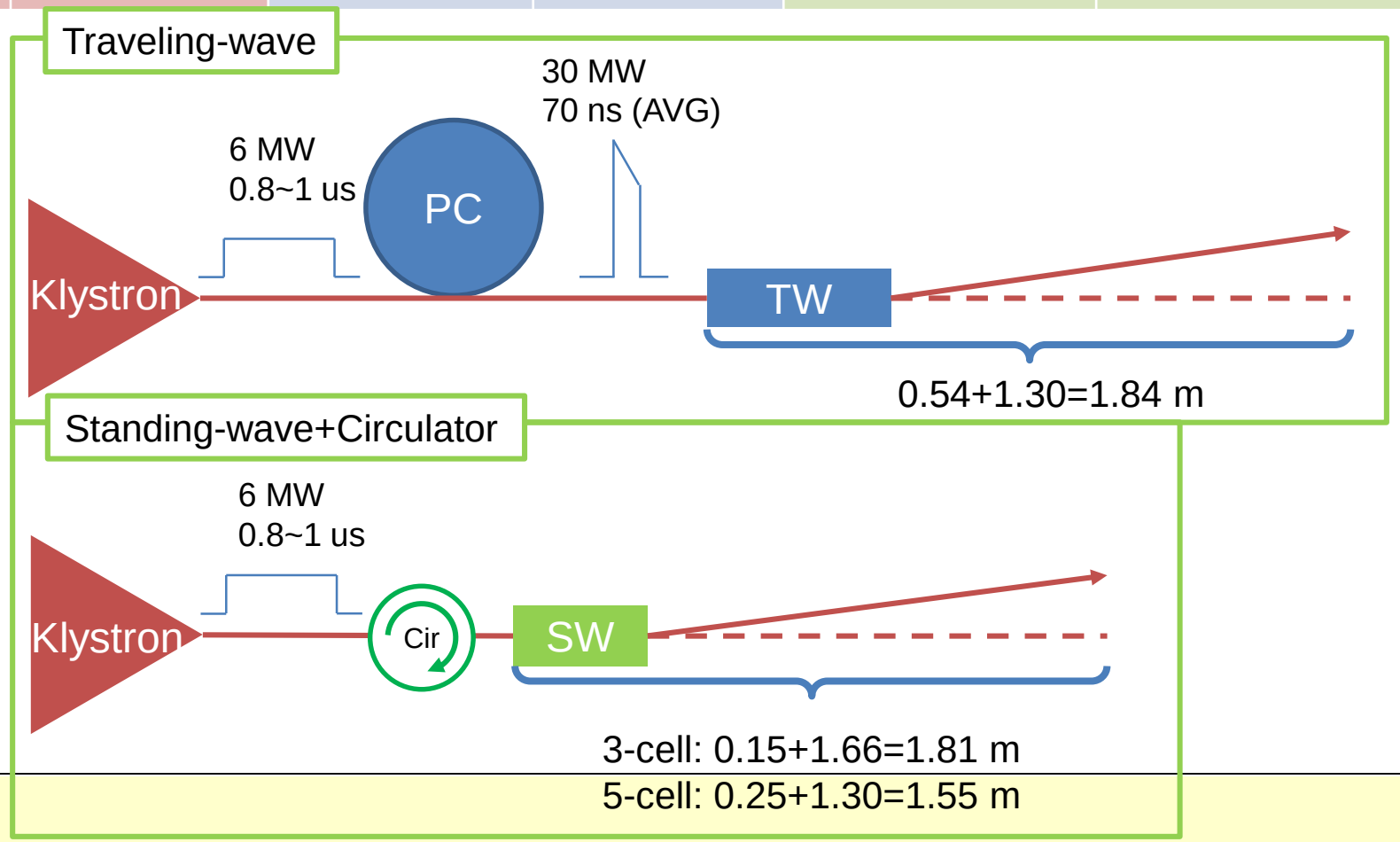
Drift length [m]	Deflecting voltage [MV]	Input power [MW]	Traveling-wave (2π/3)		Standing-wave	
			Stru. Length w/ PC [m]	Stru. Length w/o PC [m]	Stru. length 3-cell [m]	Stru. length 5-cell [m]
1.66	4.14	6	0.42	0.96	0.15	X
1.30	5.30	6	0.54	1.24	X	0.25

Use the maximum output power (6 MW with loss) from VKS8262G1

1. Klystron, pulse compressor, 0.54 m traveling-wave structure@1.30 m drifting length

2. Klystron, circulator, 0.15 m standing-wave structure (3-cell) @1.66 m drifting length

3. Klystron, circulator, 0.25 m standing-wave structure (5-cell) @1.30 m drifting length



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Double standing-wave structures deflecting system

Compact

Drift length [m]	Deflecting voltage [MV]	Input power [MW]	Traveling-wave (2π/3)		Standing-wave*2
			Stru. Length w/ PC [m]	Stru. Length w/o PC [m]	Stru. length [m]
1.17	5.85	6	0.59	1.38	0.15*2
0.83	8.27	6	0.85	2.02	0.25*2

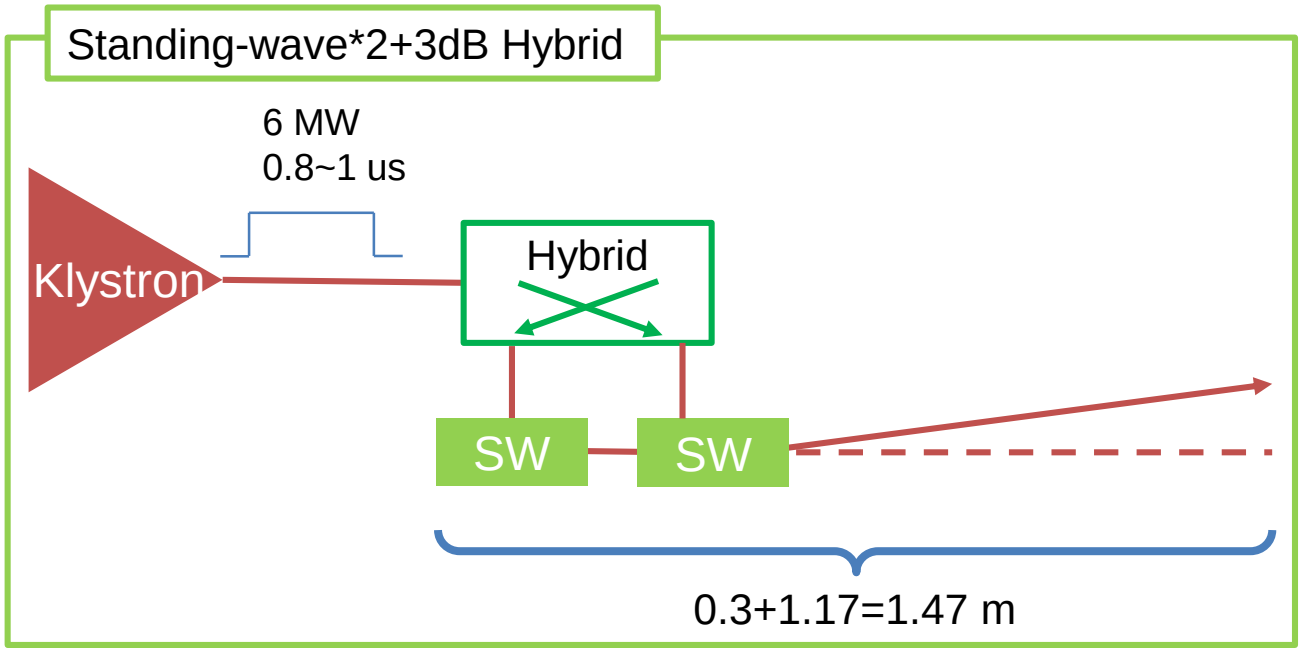
Use 3 dB hybrid and two standing-wave structures to avoid circulator

Use the maximum output power (6 MW with loss) from VKS8262G1

1. Klystron, pulse compressor, 0.59 m traveling-wave structure @1.17 m drifting length

2. Klystron, 3dB hybrid, 0.15 m standing-wave structure*2 @1.17 m drifting length

3. Klystron, 3dB hybrid, 0.25 m standing-wave structure*2 @0.83 m drifting length



Summary

Sub-harmonic deflecting system was proposed to separate the two bunches before the FELs

Three promising deflecting system options (within 2 meters)

1. Pulse compressor + traveling-wave structure
2. circulator + standing-wave structure
3. 3 dB hybrid+ standing-wave structure*2

Decision to be made by taking the followings in to account

1. cost calculation
2. beam dynamics verification
3. availability of the RF components

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Thank you!

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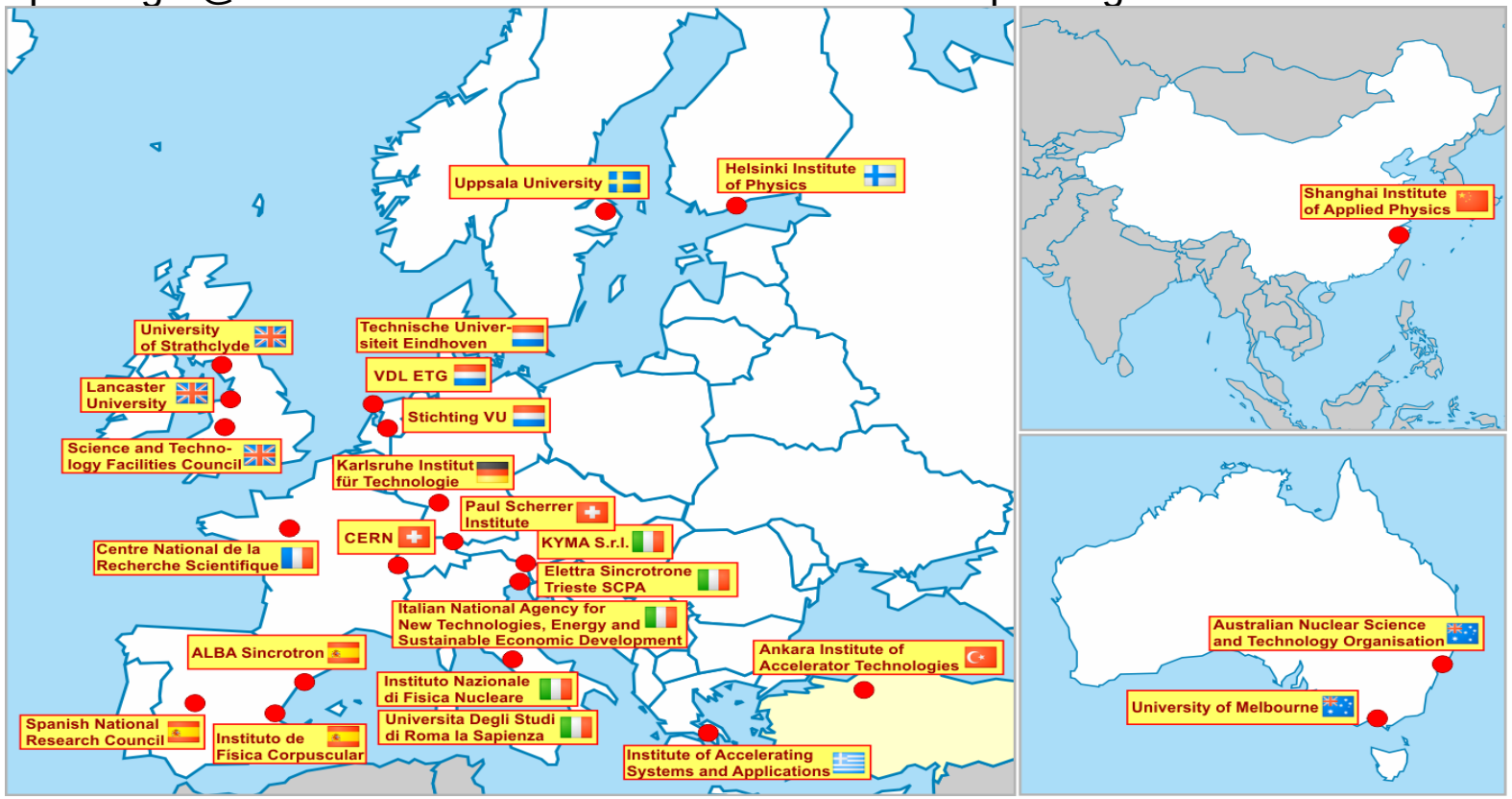

CompactLight is funded by the European Union's Horizon2020 research and innovation programme under Grant Agreement No. 777431.