

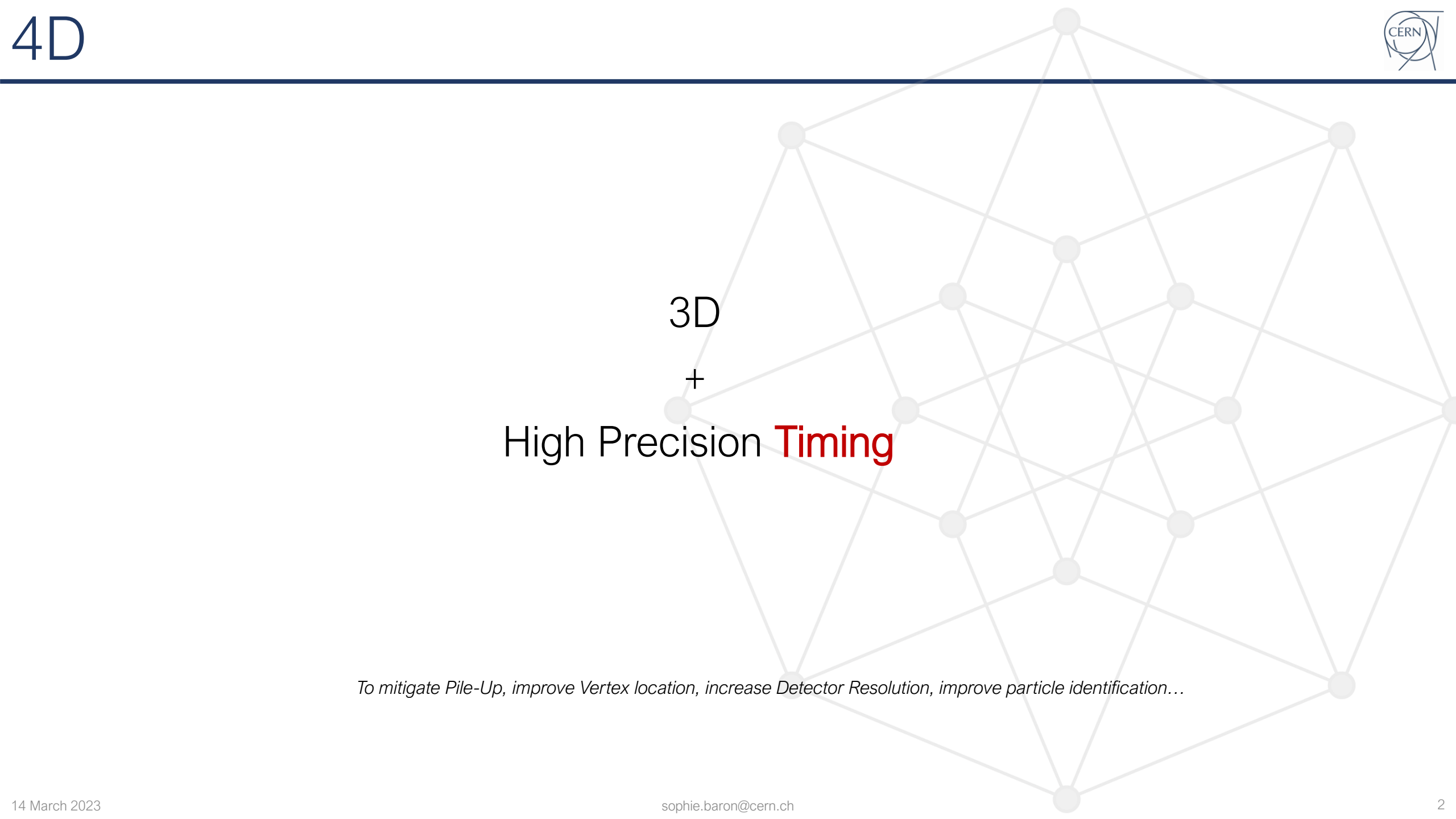
4D Techniques

DRDT7.3

Adriano Lai adriano.lai@ca.infn.it, Patrick Robbe patrick.robbe@ijclab.in2p3.fr,

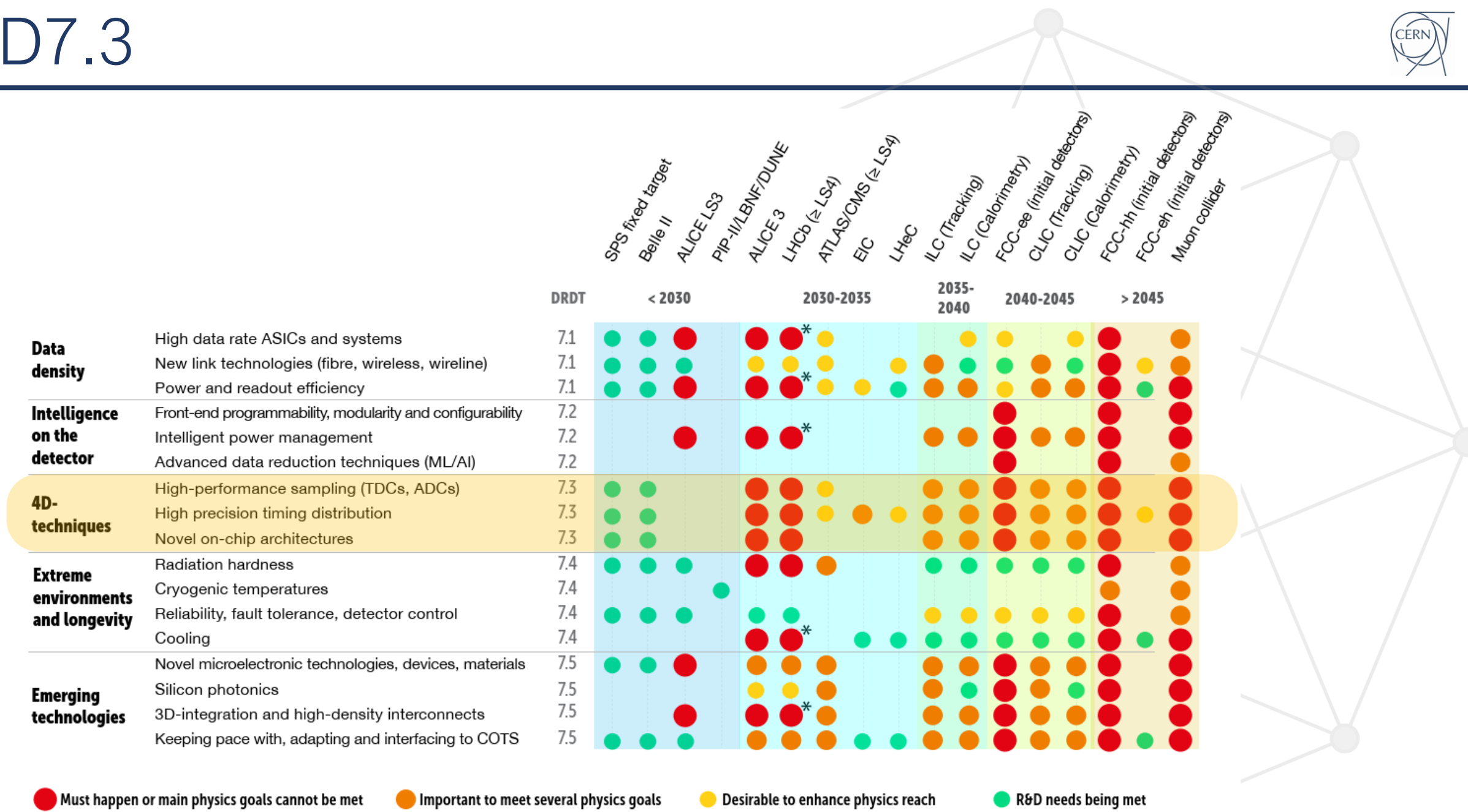
Marek Idzik idzik@ftj.agh.edu.pl, Sophie Baron sophie.baron@cern.ch

Introduction & Metrics



3D
+
High Precision **Timing**

To mitigate Pile-Up, improve Vertex location, increase Detector Resolution, improve particle identification...



SPS fixed target
 Belle II
 ALICE LS3
 PIP-II/LBNF/DUNE
 ALICE 3
 LHCb (\geq LS4)
 ATLAS/CMS (\geq LS4)
 EIC
 LHeC
 ILC (Tracking)
 ILC (Calorimetry)
 FCC-ee (initial detectors)
 CLIC (Tracking)
 CLIC (Calorimetry)
 FCC-hh (initial detectors)
 FCC-eh (initial detectors)
 Muon collider

DRDT < 2030 2030-2035 2035-2040 2040-2045 > 2045

Category	Requirement	DRDT	< 2030	2030-2035	2035-2040	2040-2045	> 2045
Data density	High data rate ASICs and systems	7.1	● ● ●	● ●* ●	● ● ●	● ● ●	● ● ●
	New link technologies (fibre, wireless, wireline)	7.1	● ● ●	● ● ●	● ● ●	● ● ●	● ● ●
	Power and readout efficiency	7.1	● ● ●	● ●* ●	● ● ●	● ● ●	● ● ●
Intelligence on the detector	Front-end programmability, modularity and configurability	7.2		● ●*	● ● ●	● ● ●	● ● ●
	Intelligent power management	7.2	●	● ●*	● ● ●	● ● ●	● ● ●
	Advanced data reduction techniques (ML/AI)	7.2		● ●*	● ● ●	● ● ●	● ● ●
4D-techniques	High-performance sampling (TDCs, ADCs)	7.3	● ●	● ● ●	● ● ●	● ● ●	● ● ●
	High precision timing distribution	7.3	● ●	● ● ●	● ● ●	● ● ●	● ● ●
	Novel on-chip architectures	7.3	● ●	● ● ●	● ● ●	● ● ●	● ● ●
Extreme environments and longevity	Radiation hardness	7.4	● ● ●	● ● ●	● ● ●	● ● ●	● ● ●
	Cryogenic temperatures	7.4		●			
	Reliability, fault tolerance, detector control	7.4	● ● ●	● ● ●	● ● ●	● ● ●	● ● ●
	Cooling	7.4		● ●*	● ● ●	● ● ●	● ● ●
Emerging technologies	Novel microelectronic technologies, devices, materials	7.5	● ● ●	● ● ●	● ● ●	● ● ●	● ● ●
	Silicon photonics	7.5		● ● ●	● ● ●	● ● ●	● ● ●
	3D-integration and high-density interconnects	7.5		● ●*	● ● ●	● ● ●	● ● ●
	Keeping pace with, adapting and interfacing to COTS	7.5	● ● ●	● ● ●	● ● ●	● ● ●	● ● ●

● Must happen or main physics goals cannot be met ● Important to meet several physics goals ● Desirable to enhance physics reach ● R&D needs being met

* LHCb Velo

4D-Techniques - Session Structure



- Timing Distribution & Simulation
 - Timing Metrics (*Sophie Baron, CERN*)
 - Highlight on Detector timing simulation (*Louis d'Eramo, CNRS*)
- 4D in trackers / Novel on-chip architectures
 - Main challenges overview (*Adriano Lai, INFN*)
 - The case of the LHCb Velo Upgrade (*Martin Van Beuzekom, Nikhef*)
- 4D in calorimeters & PID / High-performance sampling
 - Main challenges overview (*Marek Idzik, AGH & Patrick Robbe, IN2P3*)
 - The case of ECAL Upgrade II of LHCb (*Dominique Breton, IN2P3*)
- Discussion
 - identify key challenges and topics to be investigated in the future and potential space for collaborations
 - Your inputs will be key!

Our [biased] view of the challenges ahead, and a selection of examples

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Detector Performance

“**Precision** nanosecond-level **timing** also helps to mitigate pile-up effects”

“achieve a **timing performance** below the 10 ps level”

“**timing precision** down ~ 10 ps by 2030”

“**Timing resolution per track**”

“**Timing precision per hit**”

“**Timing resolution**”

“**Cluster timing**”

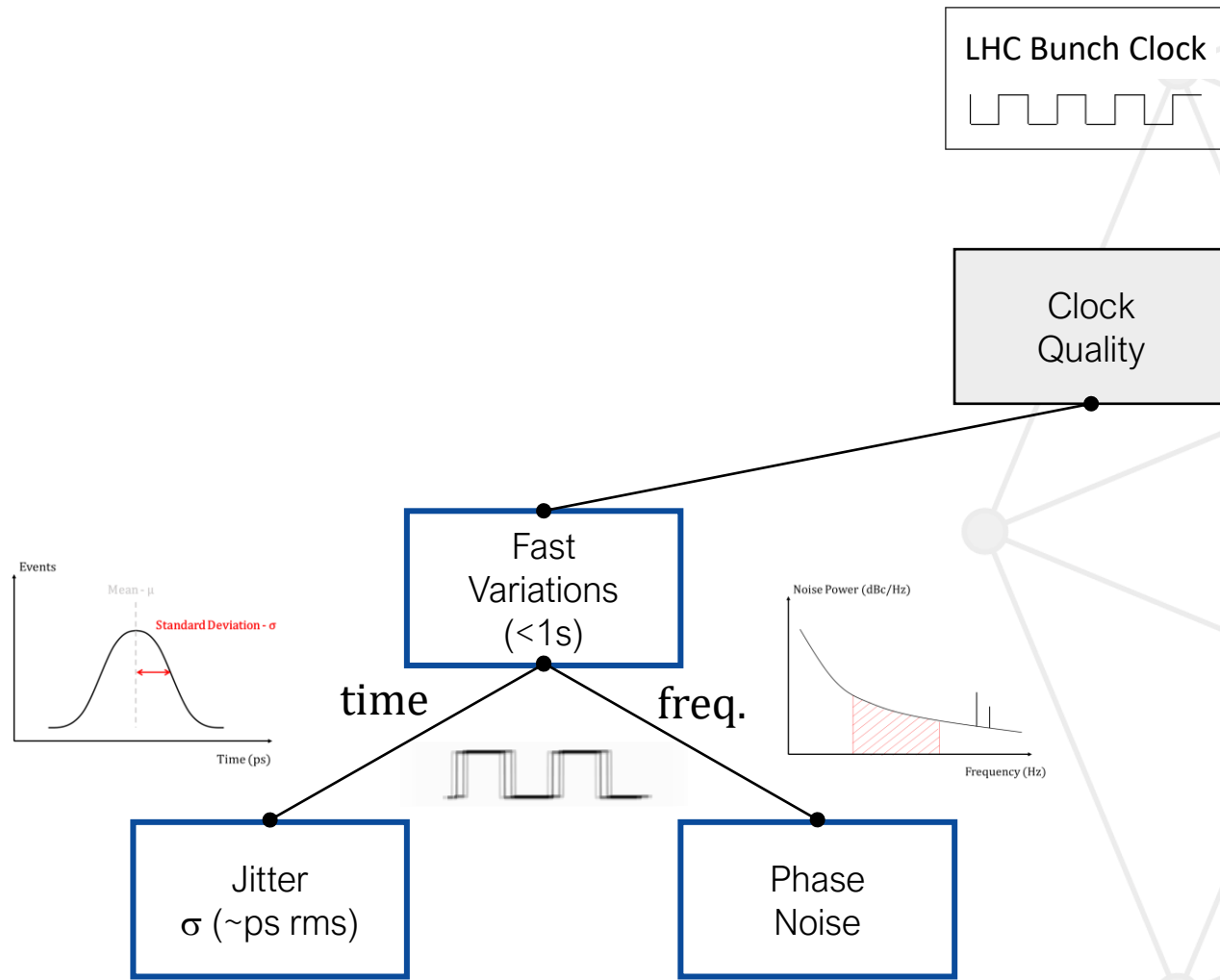
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“detection with **fast** (few tens of ps) **timing performance**”

“State of the art **timing** will also be important (O(10 ps) **binning**)”

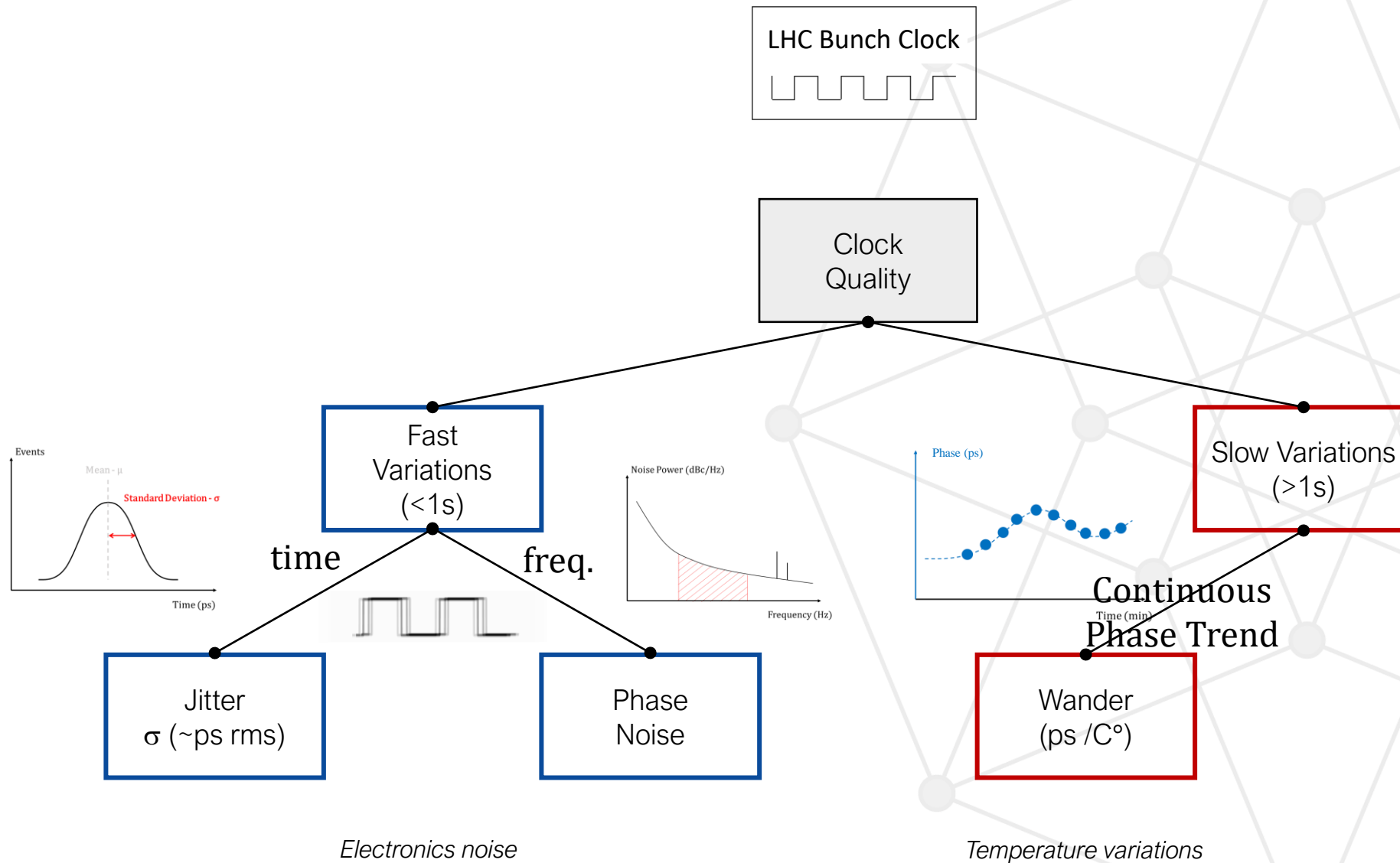


Timing Metrics

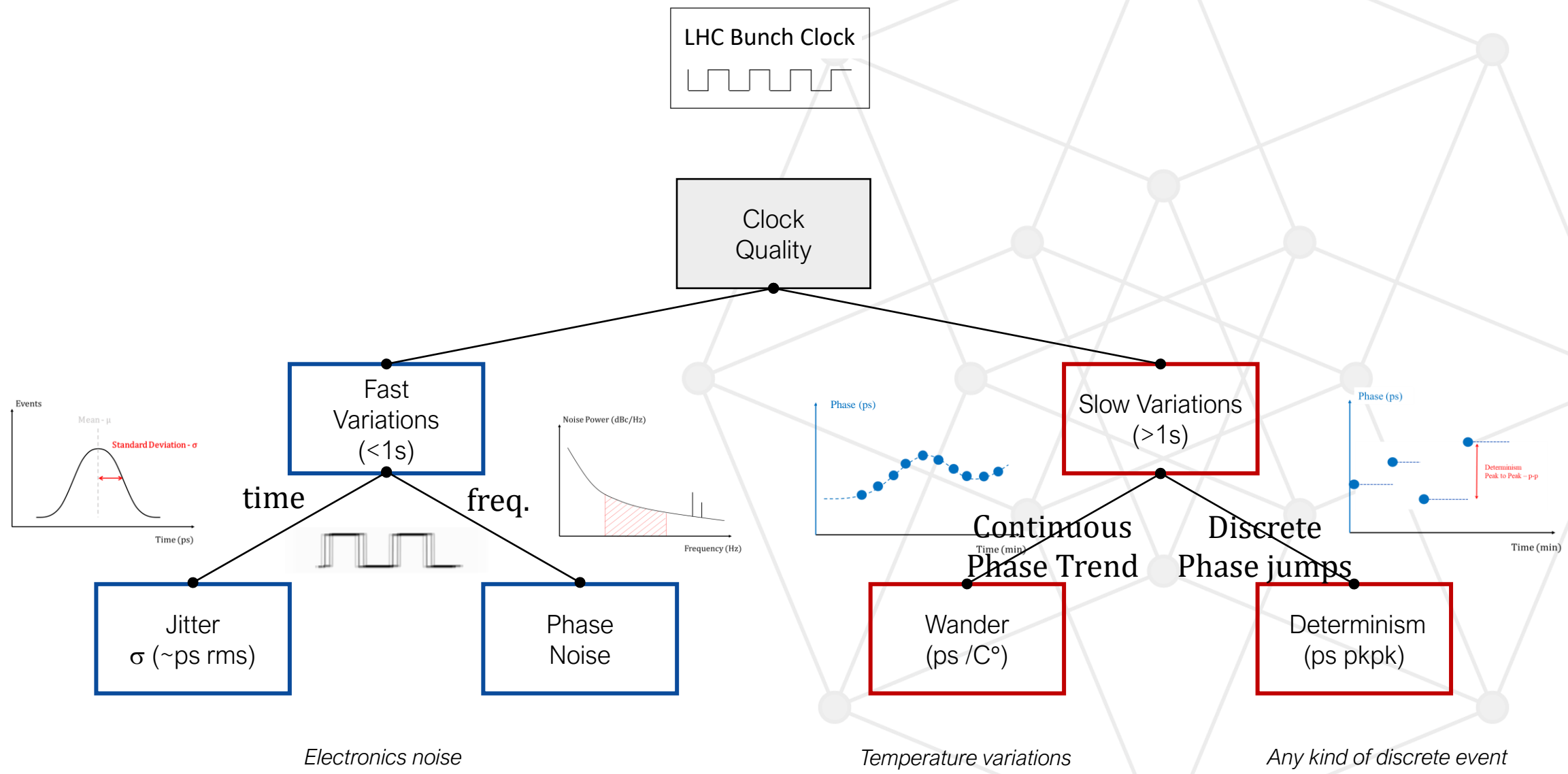


Electronics noise

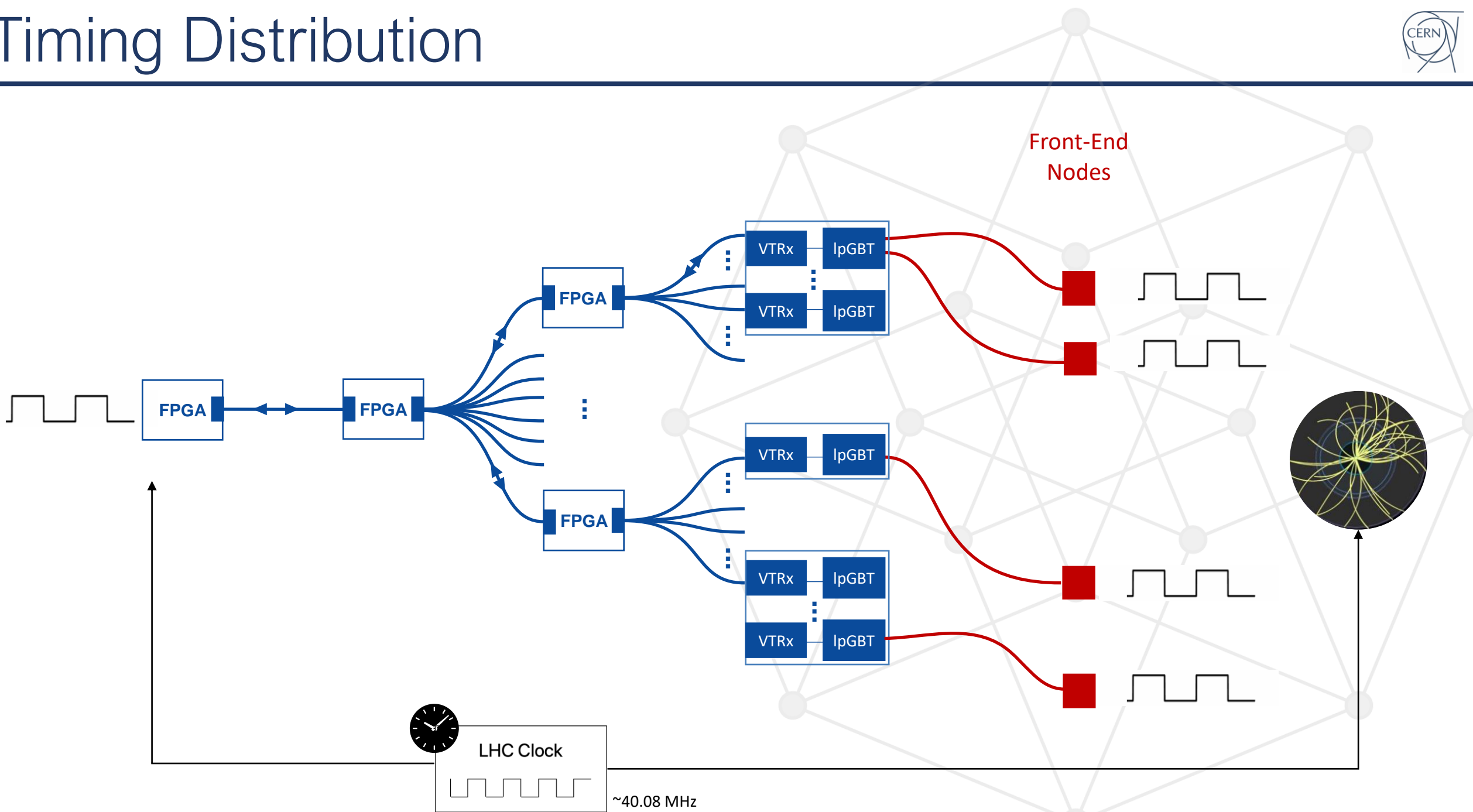
Timing Metrics



Timing Metrics

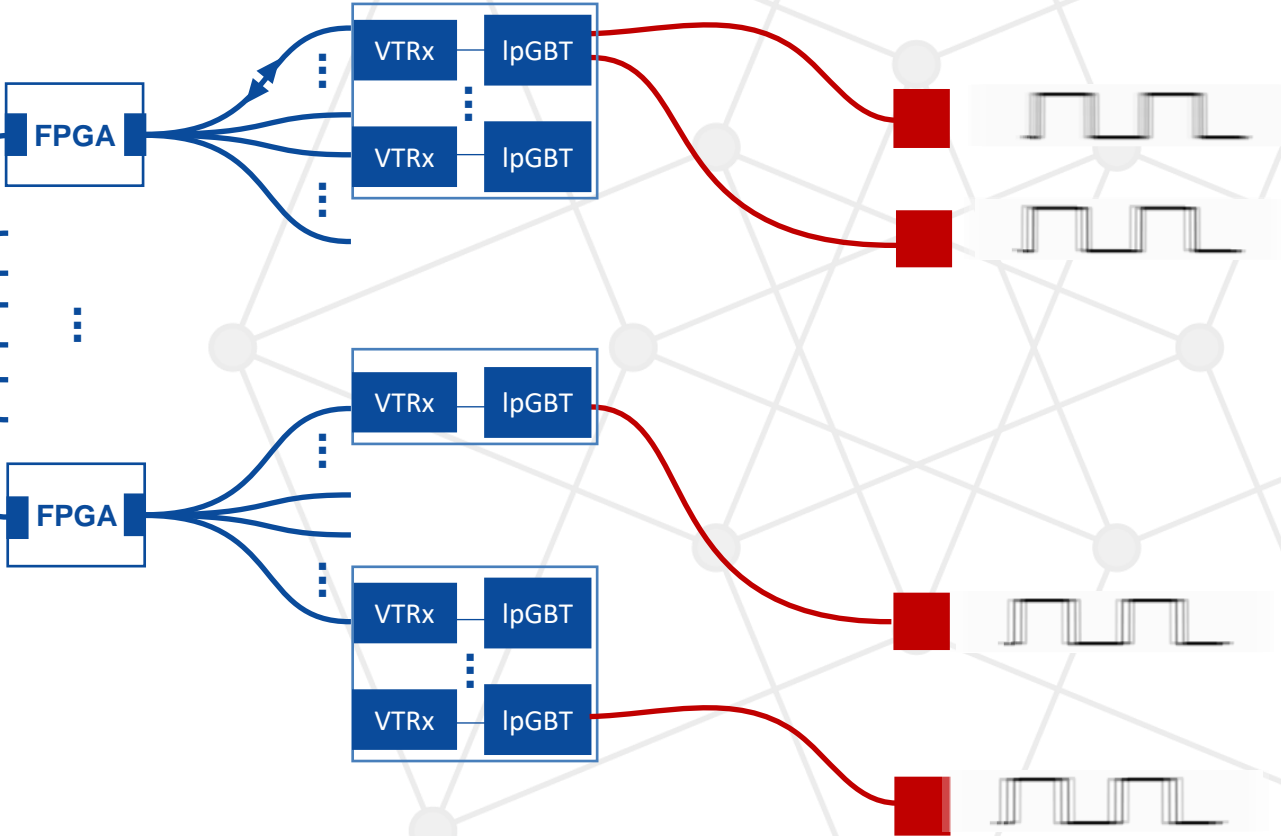
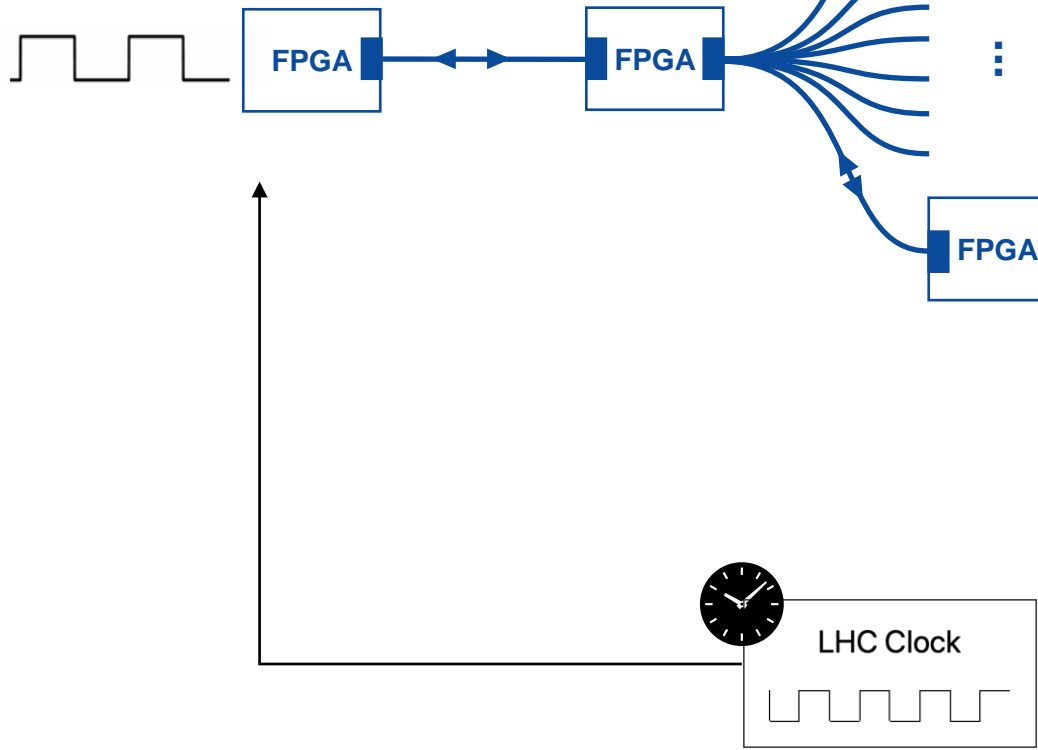
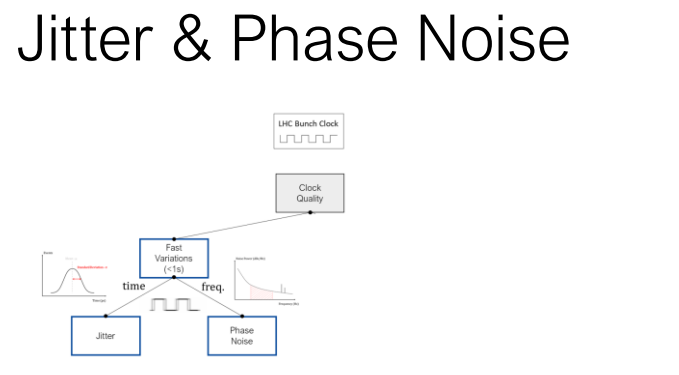


Timing Distribution



Timing Distribution & Metrics

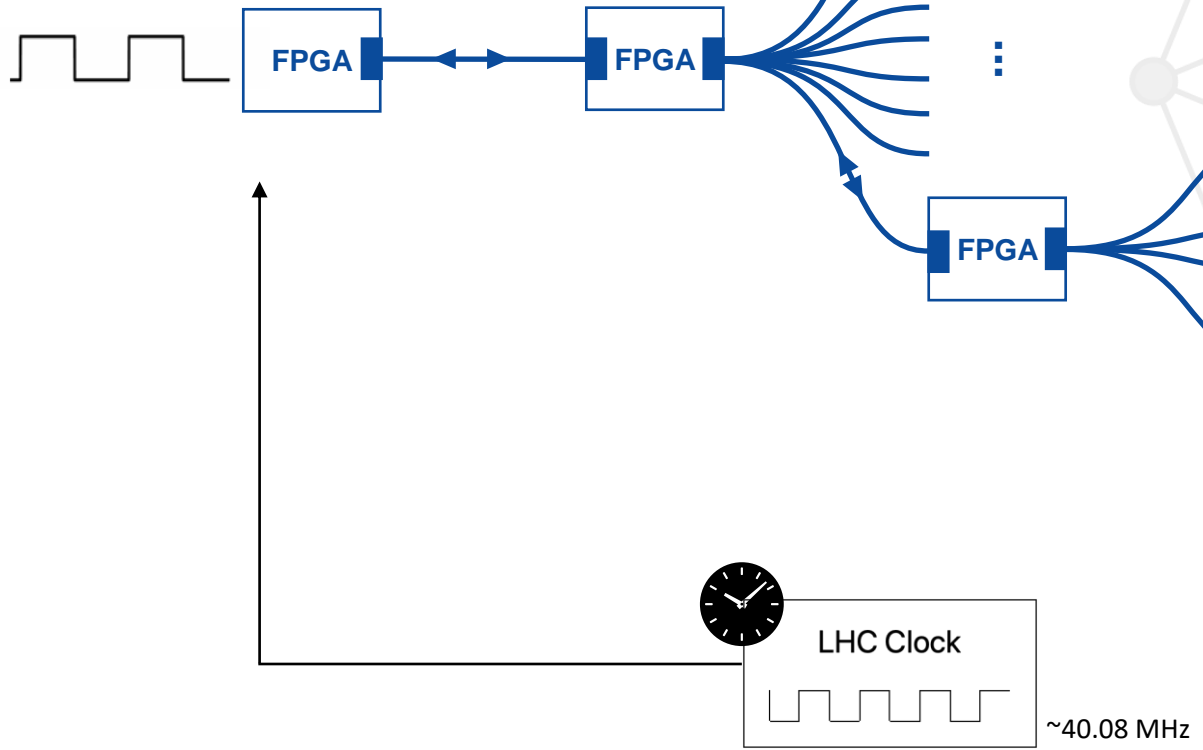
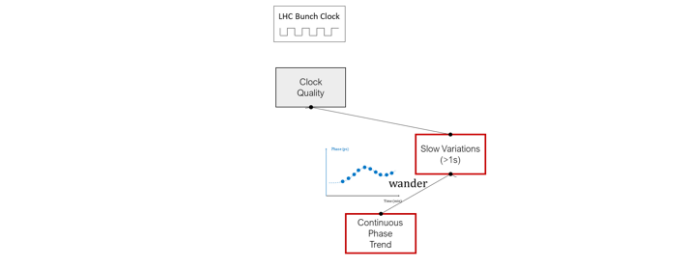
Fast & random effect



Currently: σ can be maintained below 5ps rms

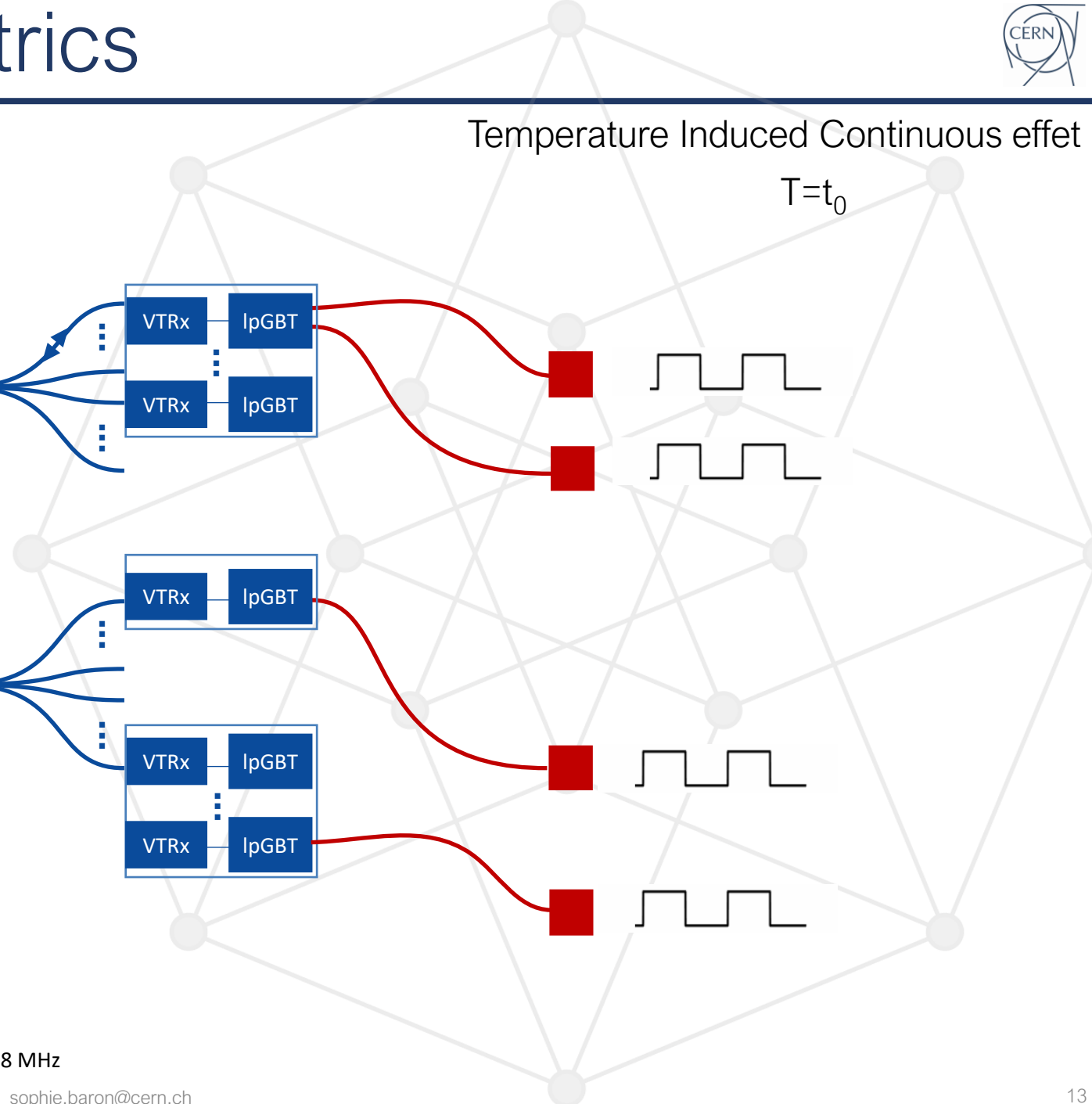
Timing Distribution & Metrics

Wander



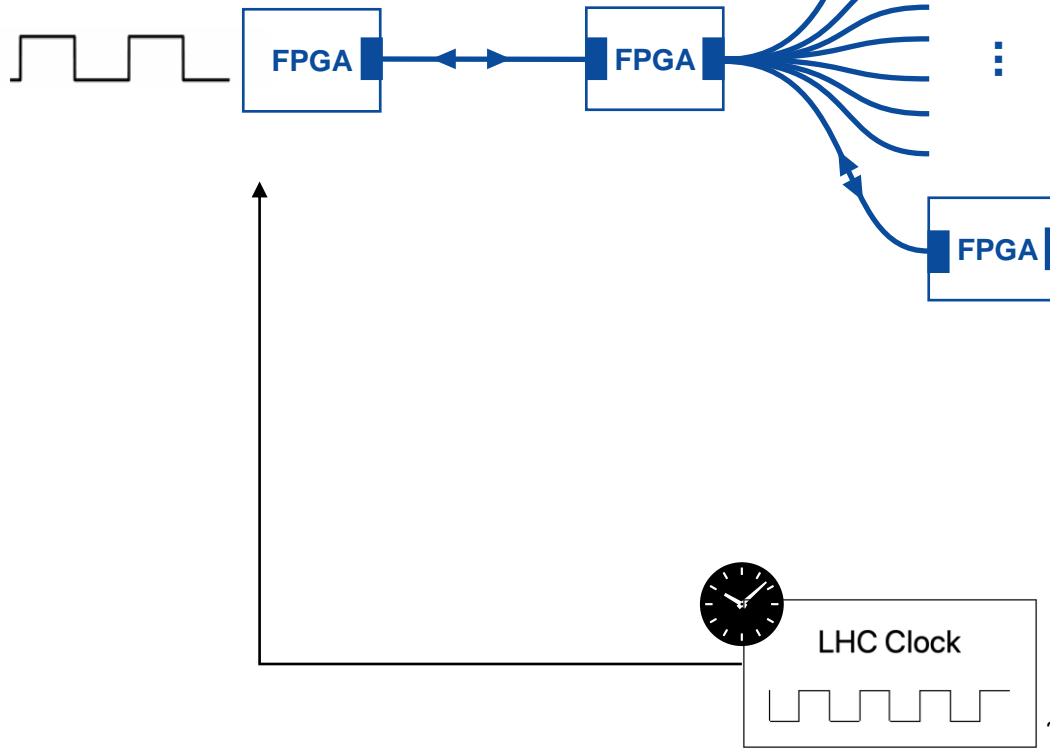
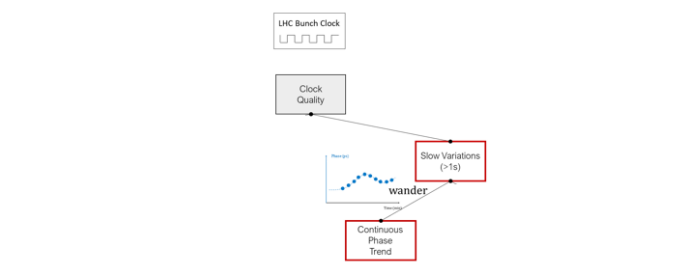
Temperature Induced Continuous effect

$$T=t_0$$



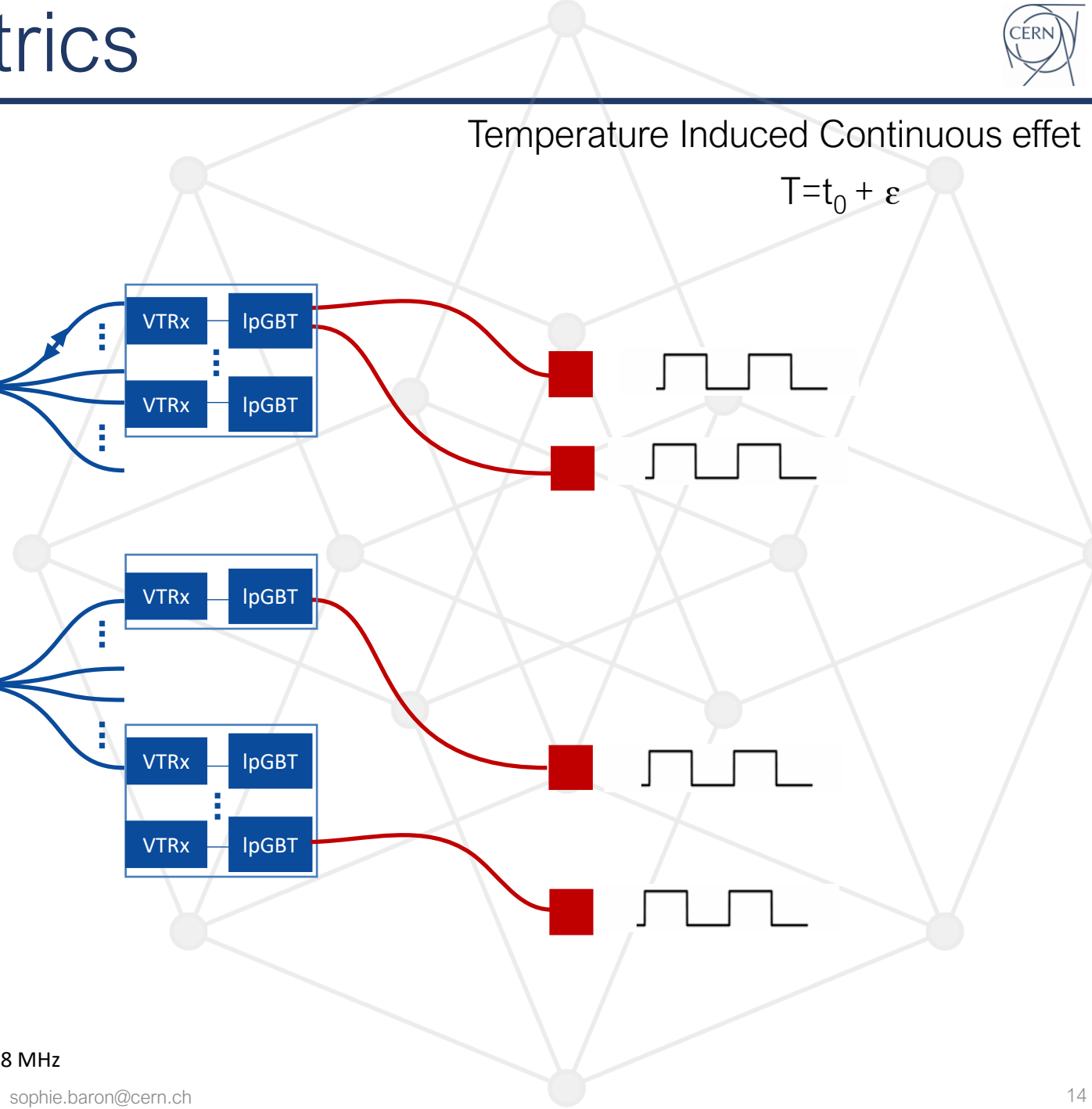
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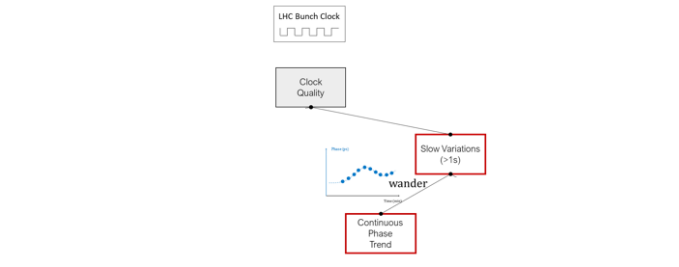
Temperature Induced Continuous effect

$$T = t_0 + \epsilon$$



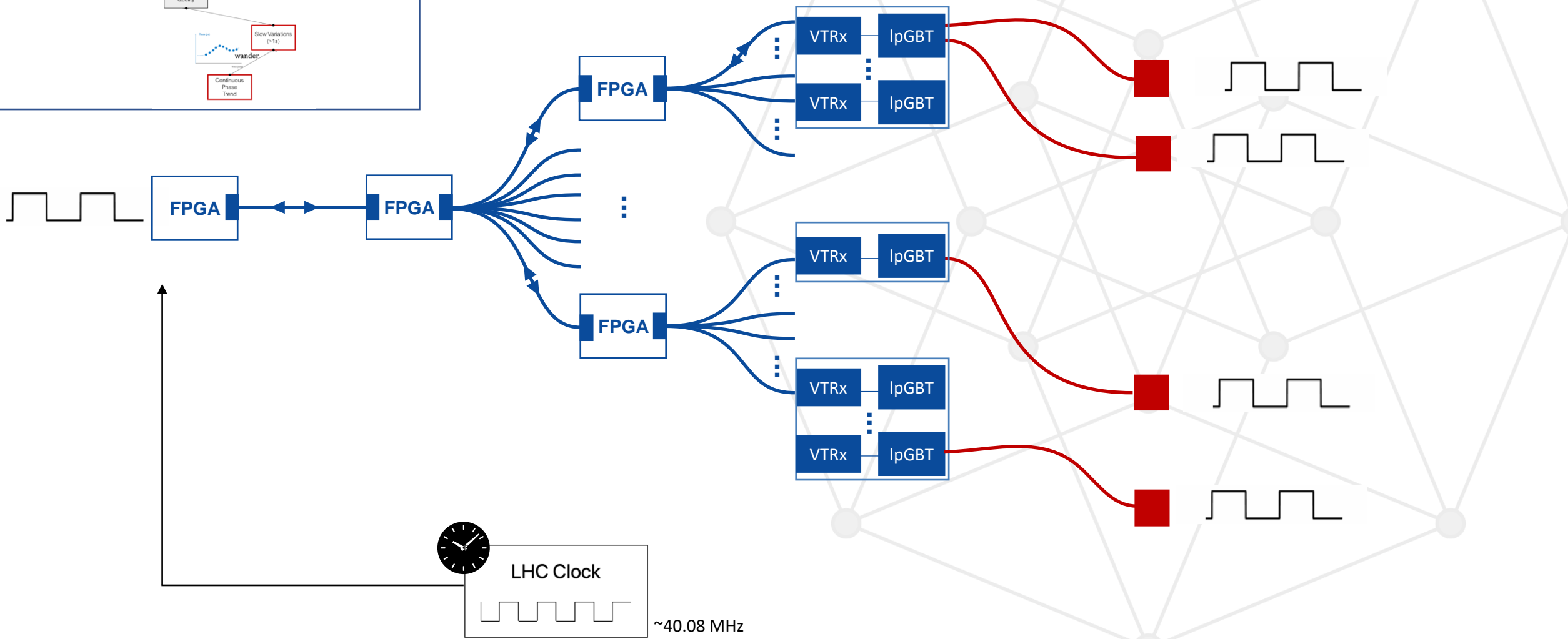
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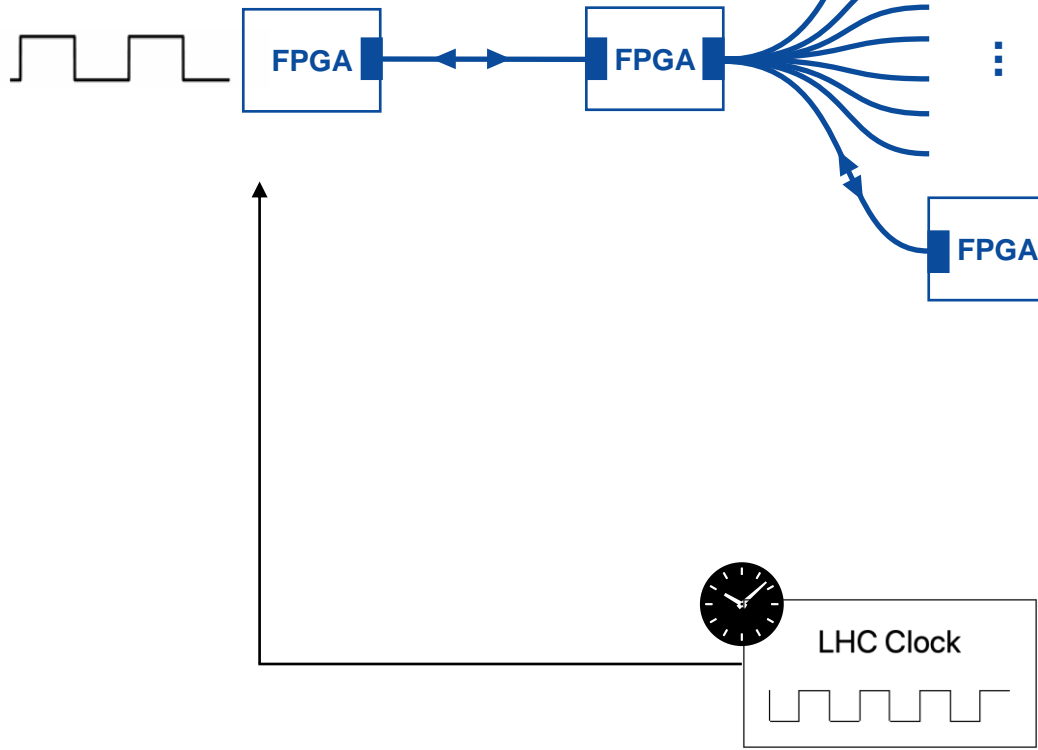
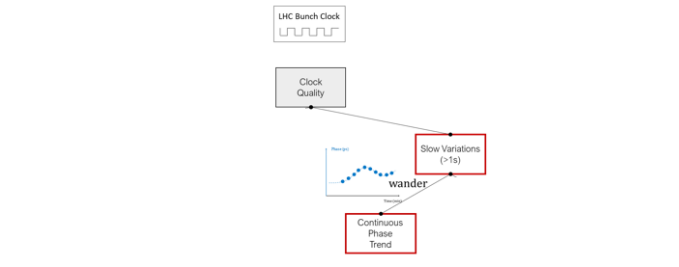
Temperature Induced Continuous effect

$$T = t_0 + 2\varepsilon$$



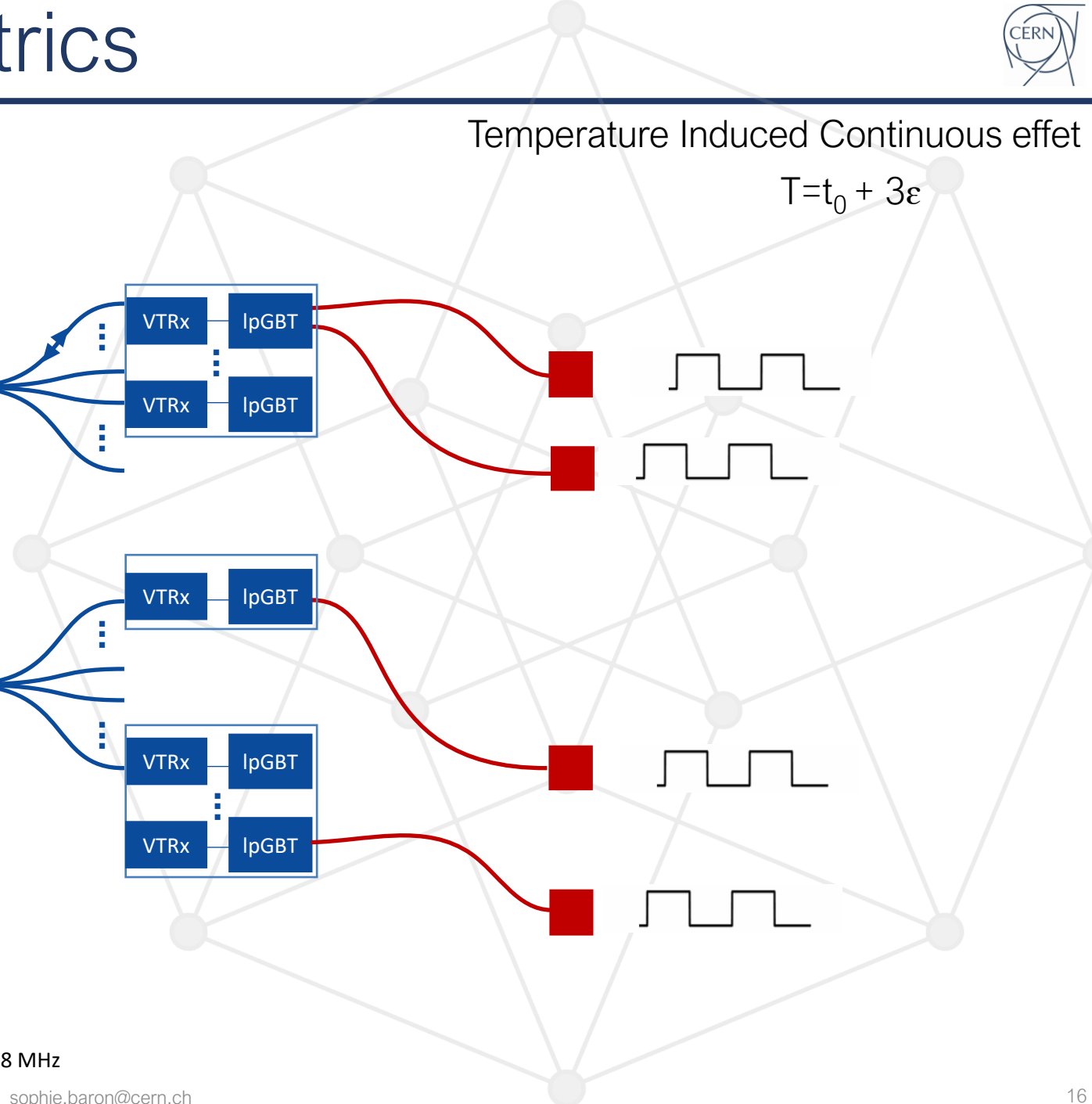
Timing Distribution & Metrics

Wander



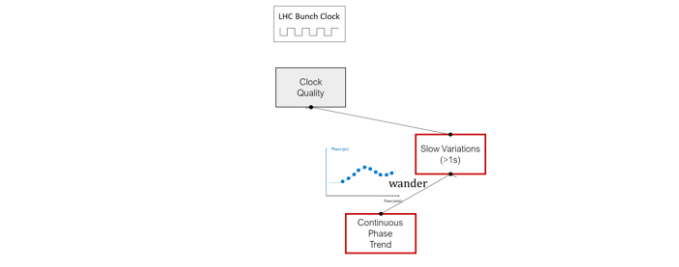
Temperature Induced Continuous effect

$$T = t_0 + 3\epsilon$$



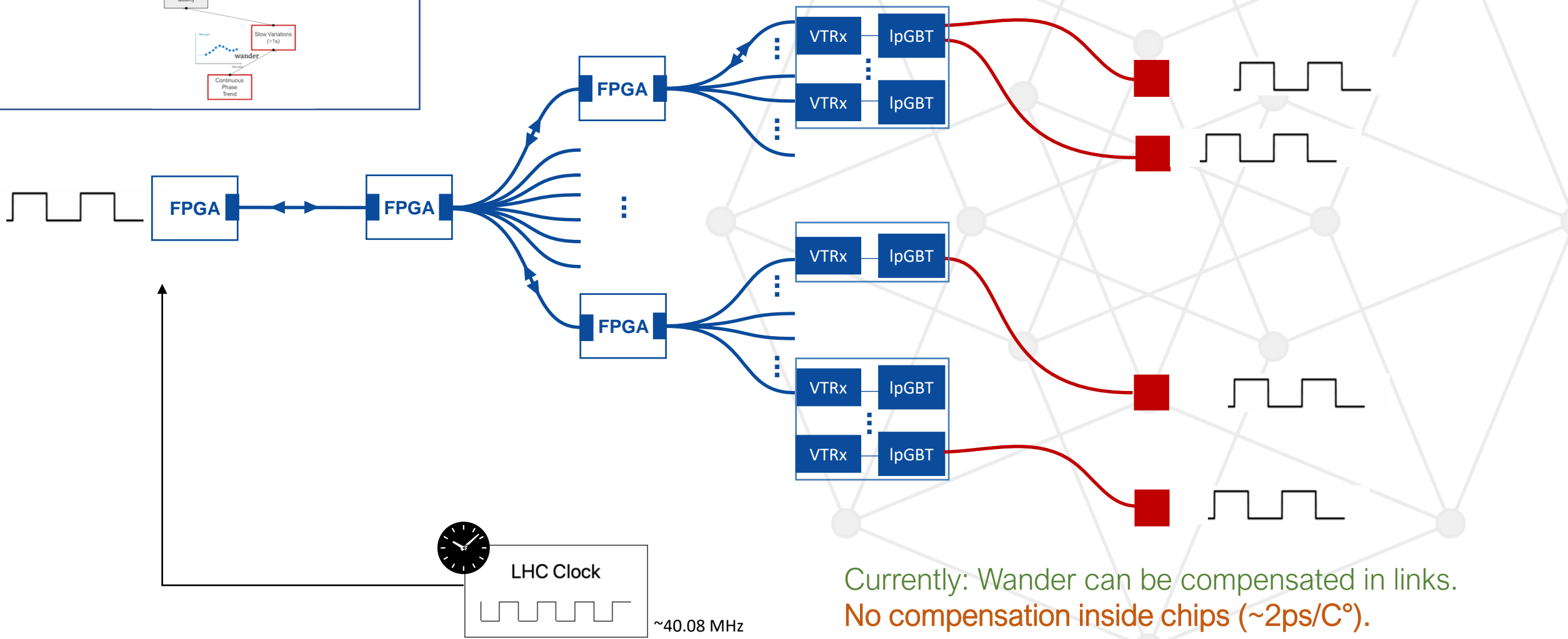
Timing Distribution & Metrics

Wander



Temperature Induced Continuous effect

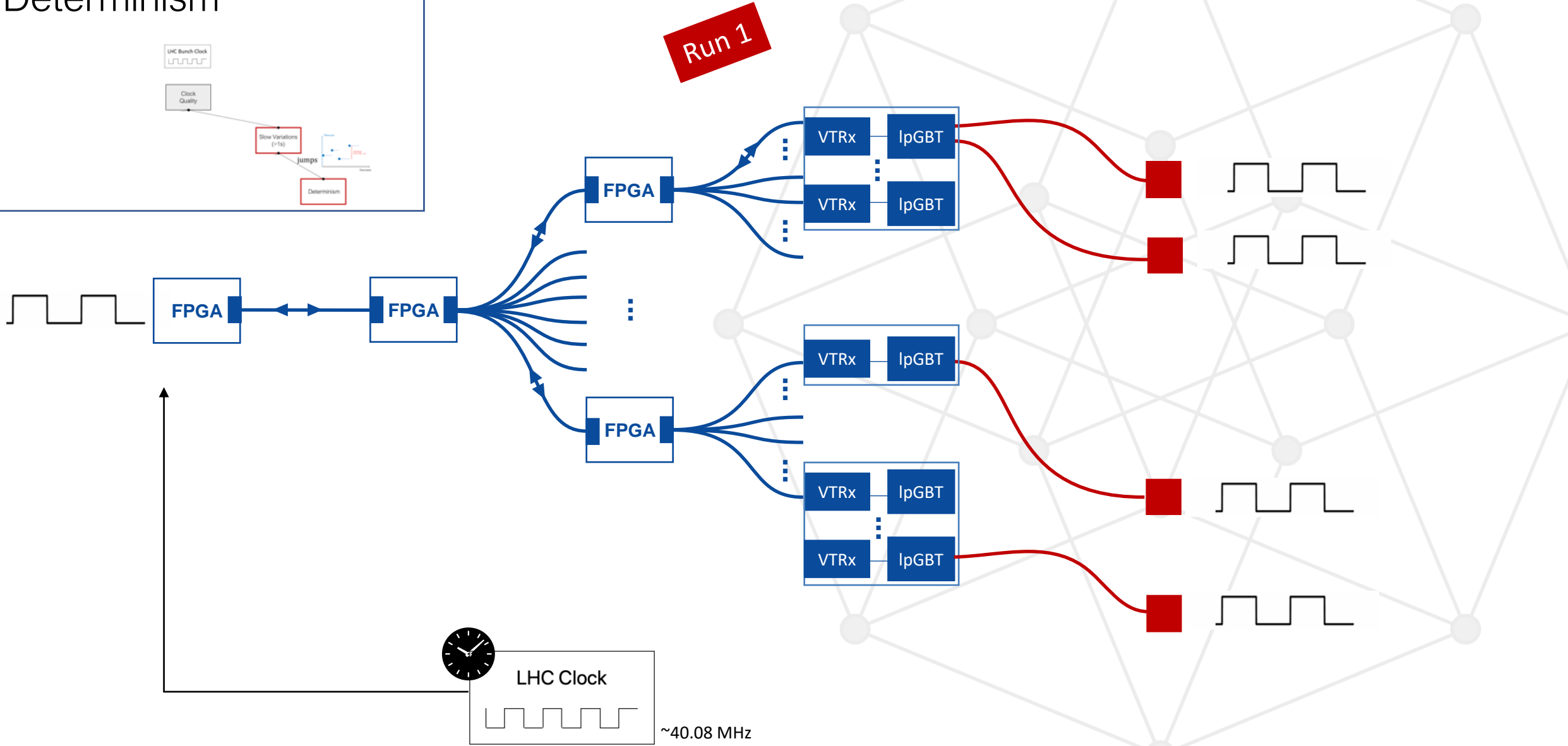
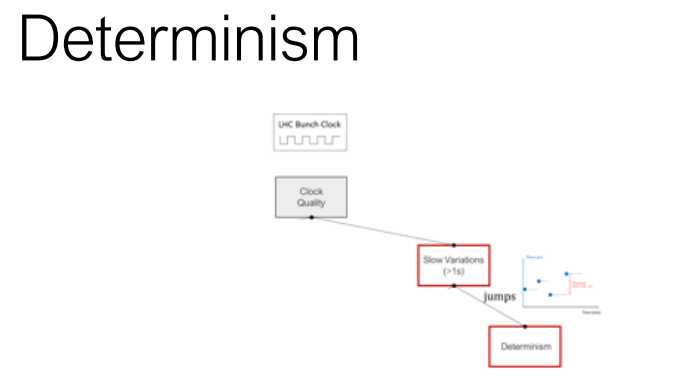
$$T = t_0 + 4\epsilon$$



Currently: Wander can be compensated in links.
 No compensation inside chips (~2ps/C°).

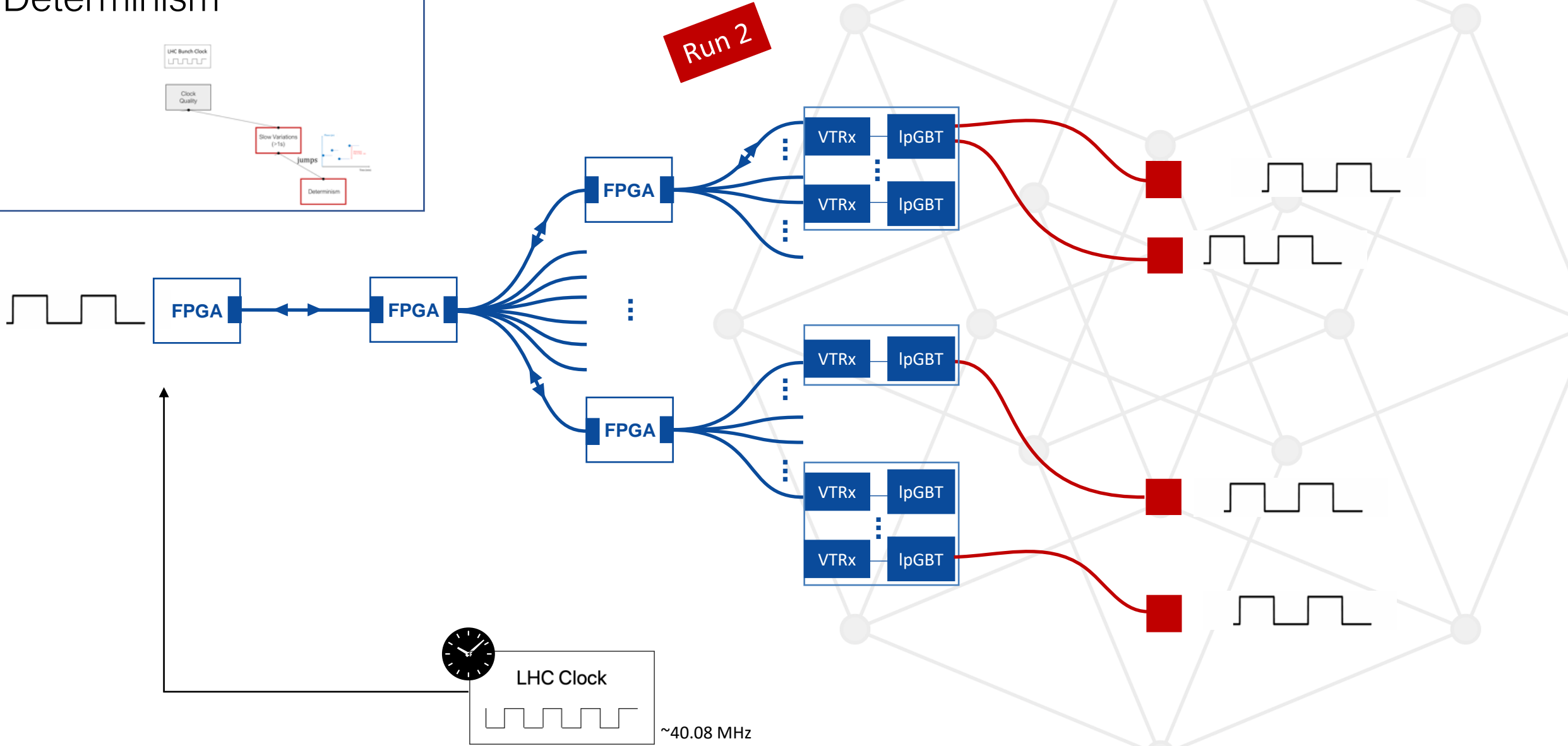
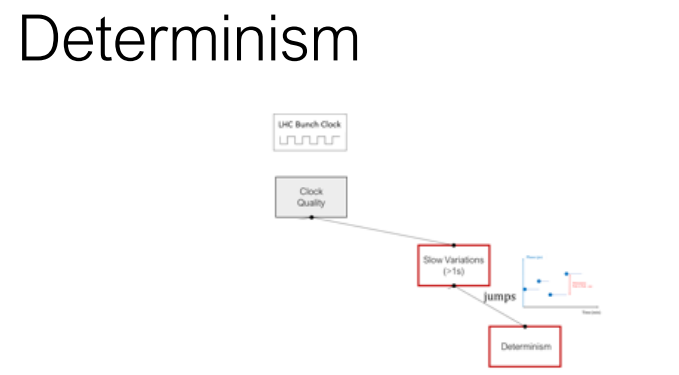
Timing Distribution & Metrics

DISCRETE effet



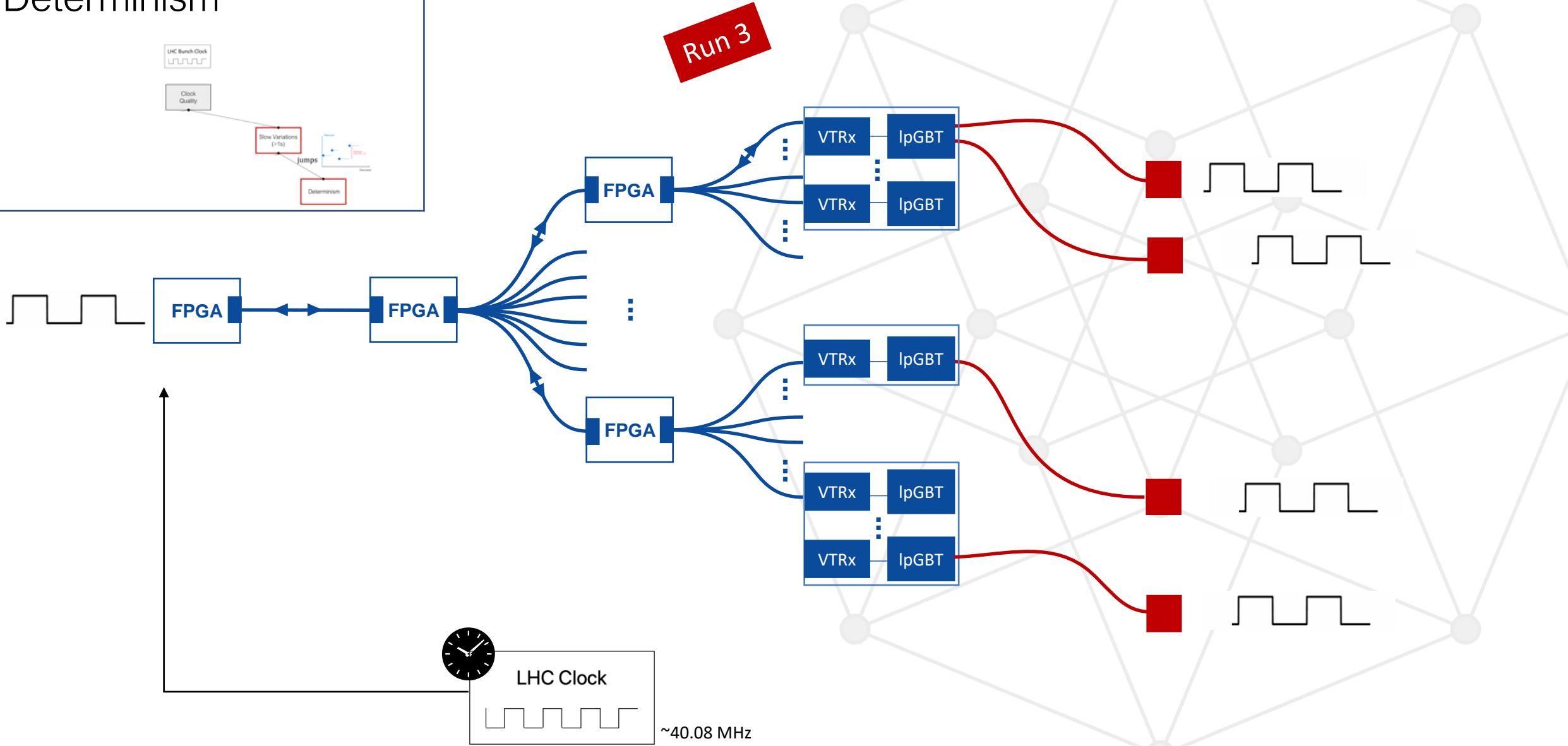
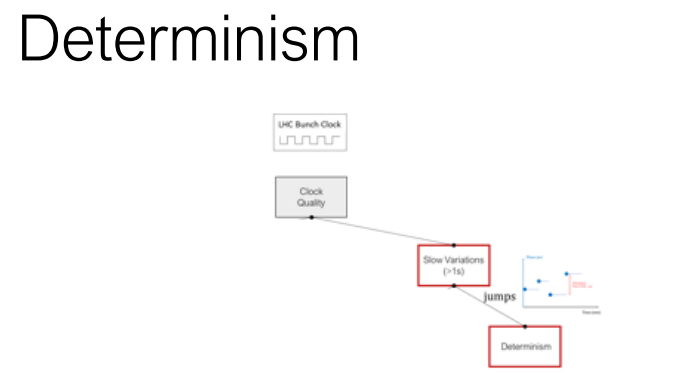
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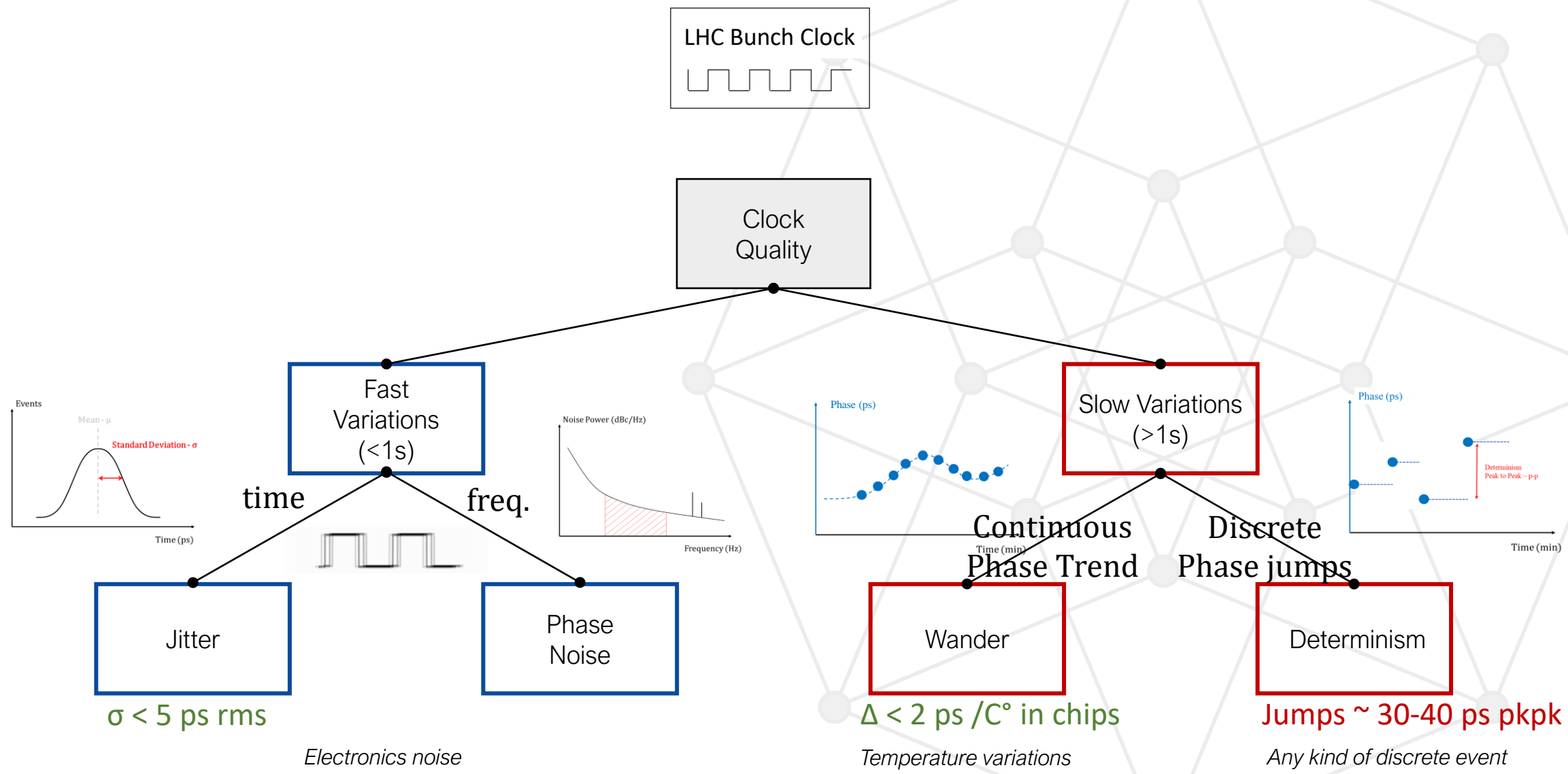


Timing Distribution & Metrics

DISCRETE effet



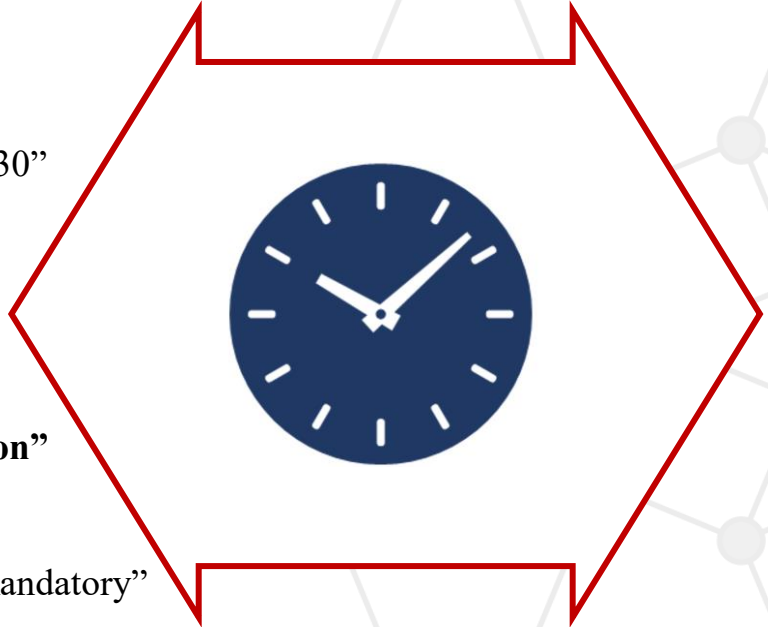
Timing Metrics (as of today)



Timing Distribution Challenges

Detector Performance

Timing Requirements



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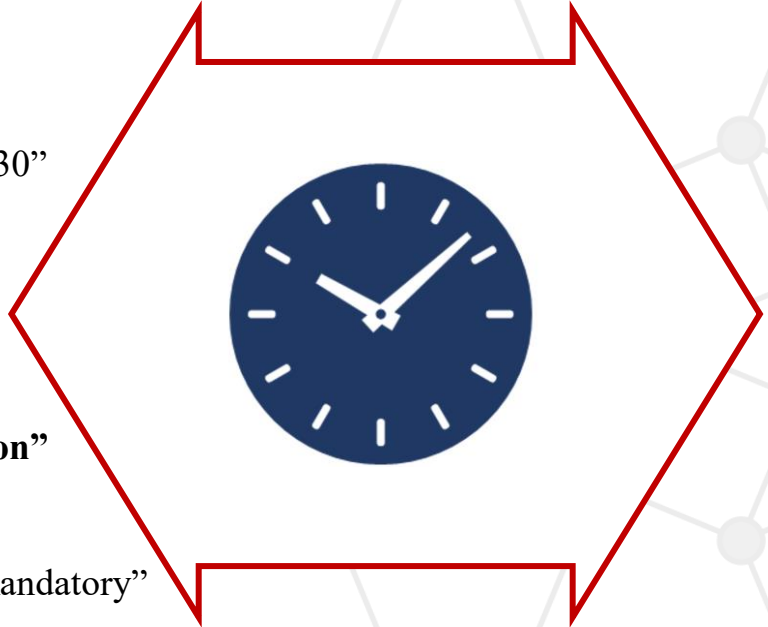
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Jitter
Phase Noise
Wander
Determinism

Timing Distribution Challenges

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Timing Requirements

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The answer comes in next talk:
Louis d’Eramo (CNRS-IN2P3) on
Simulation Challenges