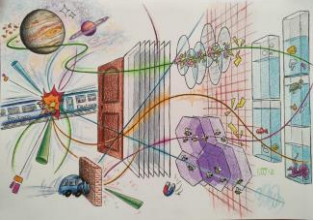


# DRD3 WG1 Monolithic CMOS

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**DRD3**

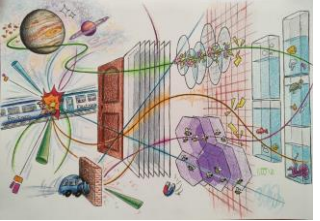
Toward a DRD3 WG1 deliverables/milestones implementation proposal  
mapping the strategic DRDTs of the ECFA roadmap and the community interests  
D. Bortoletto, D.Contardo, H. Pernegger, E. Vilella



# Broad brush matrix starting point

Different environmental constraints	Different detector requirements		
	Strategic Projects	Tracking Vertex Detector (VD) Central Tracker (CT)	Timing Layer (TL) + Calorimeter
	Heavy Ion	ALICE-3, EIC	ALICE-3 (LS4+), EIC
	Flavour collider	BELLE-3	BELLE-3
	Lepton collider	ILC, CLIC FCCee, Muon Collider	ILC, CLIC FCCee, Muon Collider
	pp collider	LHCb-2, ATLAS, CMS FCC-hh	LHCb-2, ATLAS, CMS FCC-hh

Note: fixed target experiments in the shadow of colliders, to be consolidated (some high precision timing targets in NA62/Klever by 2025)



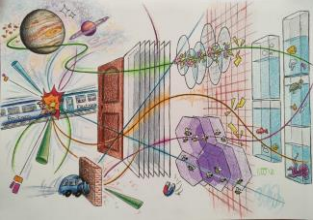
# 1<sup>st</sup> R&D phase, up to 2028-2029

Handle mandatory (independant) performance for strategic projects of 1<sup>st</sup> half of 2030's

Ball park generic performance targets\*  
mandatory/desireable

Milestones	Tracking VD/CT	Timing Layer + Calorimeter
Heavy Ion	<b>M1</b> ultralight low power tracker pitch 10 - 30 $\mu\text{m}$ @ O(100) MHz/cm <sup>2</sup> , O(1) $\mu\text{s}$	<b>M2</b> O(20) ps (TL)
Flavour collider	ultralight low power tracker pitch 10 - 30 $\mu\text{m}$ @ O(100) MHz/cm <sup>2</sup> , O(1) ns	O(20) ps in (TL)
Lepton collider	e-e : ultralight low power tracker pitch down to <10 $\mu\text{m}$ , @ O(100) MHz/cm <sup>2</sup> timing driven by power dissipation $\mu\text{-}\mu$ : O(20) ps rates and irradiation tbc	O(10) ps in TL O(< 50) ps in calorimeter driven by power dissipation
pp collider	<b>M3</b> HL-LHC: 25-50 $\mu\text{m}$ @ O(5) GHz/cm <sup>2</sup> 5x10 <sup>15</sup> to 5x10 <sup>16</sup> neq/cm <sup>2</sup> , 250 - 500 MRad timing O(<50) ps FCC-hh: < 10 - 20 $\mu\text{m}$ @ 30 GHz/cm <sup>2</sup> 4D tracking O(<10) ps up to O(10 <sup>18</sup> ) neq/cm <sup>2</sup> , up to O(50) GRad	<b>M4</b> HL-LHC: pitch O(<1) mm O(20) ps in TL, NIEL 5x10 <sup>15</sup> FCC-hh: 5D calorimeter O(<10) ps up to O(10 <sup>18</sup> ) neq/cm <sup>2</sup> , up to O(50) GRad

\* ranges representative, ex. for VD and CT with more stringent constraints to be achieved in VD



# 1<sup>st</sup> R&D phase, up to 2028-2029

DRD3

## Milestone 1, 2028-2029

strategic programs ALICE-3, LHCb-2, Belle-3, EIC: VD/CT

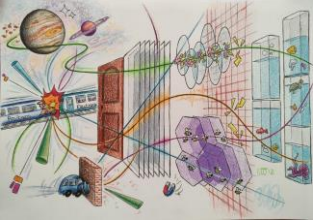
highest position precision at lowest power dissipation up to large wafer size

- Map of technologies performance versus pitch and thickness in range 10 - 30  $\mu\text{m}$
- Readout architecture options for particle rate up to  $O(100)$  MHz/cm<sup>2</sup> and timing down to  $O(1)$  ns
  - Deliverables :
    - MPWs\* in  $\neq$  nodes/foundries: small/large electrodes,  $\neq$  substrate nature & active thickness
      - with configuration variants in pitch, VD/CT configurations...
      - with readout architecture variants for power consumption
    - 2-3 iterations\*\* with channel matrix scaling up to wafer size\*\*\*
- Narrow down technology options for further R&D steps

\*\*\* in relation with DRD7

\* MPWs could be ER, depending on technology/goals, and cover more than 1 milestone

\*\* number of iterations can depend on technology prospect



# 1<sup>st</sup> R&D phase, up to 2028-2029

DRD3

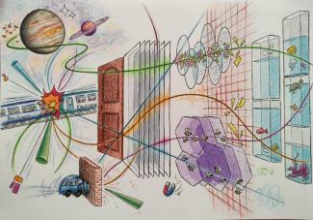
## Milestone 2, 2028-2029

strategic programs ALICE-3, LHCb-2, Belle-3, EIC, ATLAS/CMS Timing Layers, Calorimeters\*  
implementation of precision timing

- Map of technologies performance in the range 20 – 50 ps
- Readout architecture options for tolerable power dissipation versus granularity and rates
  - Deliverables :
    - MPWs in  $\neq$  nodes/foundries: same as M1 plus w/ amplification doping layer
      - with configuration variants pitch up to  $O(1-10)$  mm<sup>2</sup> pads\*
      - with readout architecture variants for power consumption\*\*
    - 2-3 iterations
- Narrow down technology options for further R&D steps

\* in relation with DRD6

\*\* in relation with DRD7



# 1<sup>st</sup> R&D phase, up to 2028-2029

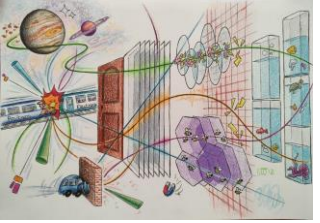
DRD3

## Milestone 3, 2028-2029

strategic programs LHCb-2 CT, [ATLAS/CMS TL](#)  
high density and rate readout architecture

- Readout architecture options @  $O(5)$  GHz/cm<sup>2</sup> and  $O(1)$  ns
  - Deliverables :
    - Variants in MPWs\* of previous milestones
    - Investigate/prepare 3D integration\*
    - 2-3 iterations
  - Narrow down technology options for further R&D steps

\* in relation with DRD7



# 1<sup>st</sup> R&D phase, up to 2028-2029

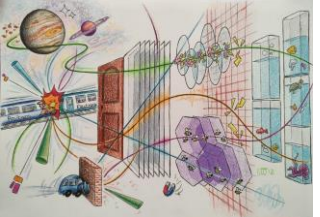
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DRD3

## Milestone 4, 2028-2029

strategic programs LHCb-2 CT, ATLAS/CMS TL  
high radiation tolerance

- Assess technologies performance beyond  $10^{15}$  neq/cm<sup>2</sup> and 300 MRad
  - Deliverables :
    - MPWs of previous milestones
    - 2-3 iterations
  - Narrow down technology options for further R&D steps



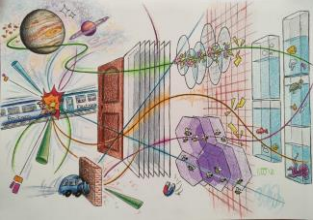
# 2<sup>nd</sup> R&D phase, up to 2034-2035

Integration of 1<sup>st</sup> R&D phase performance in full 4D devices for strategic programs of the 2040 decade

Ball park generic performance targets\*  
mandatory/desireable

Milestones	Tracking VD/CT	Timing Layer + Calorimeter
Heavy Ion	<b>M1</b> ultralight low power tracker pitch 10 - 30 $\mu\text{m}$ @ O(100) MHz/cm <sup>2</sup> , O(1) $\mu\text{s}$	<b>M2</b> O(20) ps (TL)
Flavour collider	ultralight low power tracker pitch 10 - 30 $\mu\text{m}$ @ O(100) MHz/cm <sup>2</sup> , O(1) ns	O(20) ps in (TL)
Lepton collider	<b>M5</b> e-e : ultralight low power tracker pitch down to <10 $\mu\text{m}$ , @ O(100) MHz/cm <sup>2</sup> timing driven by power dissipation $\mu\text{-}\mu$ : O(20) ps rates and irradiation tbc	<b>M6</b> O(10) ps in TL O(< 50) ps in calorimeter driven by power dissipation
pp collider	<b>M3</b> HL-LHC: 25-50 $\mu\text{m}$ @ O(5) GHz/cm <sup>2</sup> 5x10 <sup>15</sup> to 5x10 <sup>16</sup> neq/cm <sup>2</sup> , 250 - 500 MRad timing O(<50) ps	<b>M4</b> HL-LHC: pitch O(<1) mm O(20) ps in TL, NIEL 5x10 <sup>15</sup>
	<b>M7</b> FCC-hh: < 10 - 20 $\mu\text{m}$ @ 30 GHz/cm <sup>2</sup> 4D tracking O(<10)ps up to O(10 <sup>18</sup> ) neq/cm <sup>2</sup> , up to O(50) GRad	<b>M8</b> FCC-hh: 5D calorimeter O(<10)ps up to O(10 <sup>18</sup> ) neq/cm <sup>2</sup> , up to O(50) GRad

\* ranges representative, ex. for VD and CT with more stringent constraints to be achieved in VD



# 2<sup>nd</sup> R&D phase, up to 2034-2035

## Milestone 5, 2034-2035

strategic programs ILC, CLIC, FCCee, MC: VD/CT

further improvement of position precision

- Extend M1 to pitch  $< 10 \mu\text{m}$  in large wafer size
- Deliverables :
  - MPWs with M1-4 selected technologies
  - MPWs in new technology node

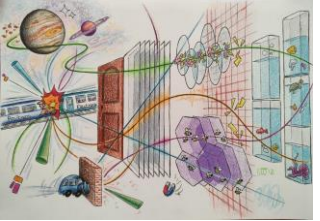
## Milestone 6, 2034-2035

strategic programs ILC, CLIC, FCCee, MC, FCC-hh

further improvement of timing resolution and steps toward 4D-tracking

- Extend M2 to time precision  $< 20 \text{ ps}$  @ low power dissipation
- Deliverables :
  - MPWs with M1-4 selected technologies
  - MPWs in new technology node
  - 3D wafer size integration

\* transitioning time of deliverables for 1<sup>st</sup> to 2<sup>nd</sup>  
R&D phase could be defined has milestones



# 2<sup>nd</sup> R&D phase, up to 2034-2035

## Milestone 7, 2034-2035

strategic programs CLIC, MC, FCC-hh

extend performance capabilities at very high rates

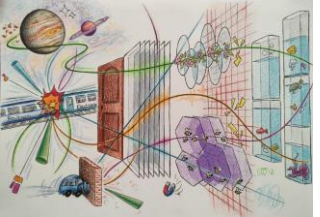
- Extend M3 to higher channel density and improved timing precision
- Deliverables :
  - MPWs with M1-4 selected technologies
  - MPWs in new technology node
  - 3D wafer size integration

## Milestone 8, 2034-2035

strategic programs MC, FCC-hh

extreme radiation tolerance

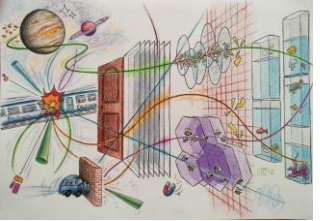
- Extend M4 toward  $O(10^{18})$  neq/cm<sup>2</sup> TID  $O(>30)$  GRad
- Deliverables :
  - MPWs with M1-4 selected technologies
  - MPWs in new technology node
  - MPWs in new materials



# Toward a technical deliverable planning for DRD3 WG1 proposal

What it could look like - **to be developed with the community inputs**  
(according to the ECFA roadmap implementation panel guidance)

Strategic Project	Requirements	Technology	Institutes interests	2024	2025	2026	2027	2028	2029	>2035
				Deliverables				Milestones		Milestones
ALICE ITS3 2027	12" stitched sensors, 10 - 20 $\mu\text{m}$ pitch, 10 MHz/cm <sup>2</sup> , 1 $\mu\text{s}$ ALPIDE-like architecture EM calorimeter FOCAL	TJ 65 nm (thin) 12"								
BELLE-2 2027	4", 10-20, 10-20 $\mu\text{m}$ pitch, 100 MHz, 0.1 $\mu\text{s}$ Monopix-like architecture	TJ 180 nm (thick) 4"								
ALICE-3 ITS4 EIC VD - CT	12" stitched sensors, 10 - 20 $\mu\text{m}$ pitch, 100 MHz/cm <sup>2</sup> <b>low power architecture, 25 ns</b>	technologies 1,2...		MPWi2, prepare /submit	MPI1 test MPI2 prepare/submit	MPI2 evaluation prepare wafer-size MPI3	MPI3 evaluation	<b>Milestone 1 - 4</b>		
BELLE-3 VD/CT	12", 10-20 $\mu\text{m}$ pitch, 100 MHz/cm <sup>2</sup> , <b>O(ns)</b>	technologies 1,2...		MPWj2, prepare /submit	MPj1 test MPj2	MPj2 evaluation prepare wafer-size MPj3	MPj3 evaluation			
LHCb-2 CT	12", 10-20 $\mu\text{m}$ pitch, <b>2 GHz, 25ns, strips, 5x10**15 neq/cm<sup>2</sup>, 250 MRad</b>	technologies 1,2...		MPWk2, prepare /submit	MPk1 test MPk2 prepare/submit	MPk2 evaluation prepare wafer-size MPk3	MPk3 evaluation	<b>Milestone 1 - 4</b>		
ALICE/EIC/ATLAS/CMS TL	12", pads mm pitch, 20 ps, 100 MHz 2x10**15 neq/cm <sup>2</sup> , 100 Mrad	technologies 1,2... small-large electrodes w/-w/o amplification		MPWI2, prepare /submit	MPWI1 test MPI2 prepare/submit	MPI2 evaluation prepare wafer-size MPI3	MPI3 evaluation	<b>Milestone 3 - 4</b>		
e-e Collider VD/CT	ILC, FCC-ee	selected from M1-M4	first step of common generic requirements of ALICE-3, EIC VD/CT					one step further in node, 3D, wafer size		<b>Milestone 5</b>
e-e Collider VD/CT	CLIC <b>5 GHz/cm<sup>2</sup>, 5 ns CLIC</b>	selected from M1-M4	first step of common generic requirements of Belle-3 + LHCb-2 VD/CT					one step further in node, 3D, wafer size		<b>Milestone 5 - 7</b>
Lepton Collider TL 4D VD/CT/Calorimeter	<b>&lt; 20 ps</b>	selected from M1-M4	first step of common generic requirements ALICE-3, EIC TL					one step further in node, 3D, wafer size		<b>Milestone 5 - 6</b>
Lepton Collider HGCAL/LumiCal	pads/analog - pixels/digital	selected from M1-M4	first step of common generic requirements (w/o thickness constraint)					one step further in node, 3D, wafer size		<b>Milestones 5 - 6</b>
Muon Collider	<b>4D &lt;20 ps</b>	selected from M1-M4	first step of common generic requirements ALICE-3, EIC, LHCb, ATLAS/CMS					one step further in node, 3D, wafer size		<b>Milestones 5 - 6</b>
FCC-hh VD/CT/HGCAL	<b>pitch &lt; 10 <math>\mu\text{m}</math>, 4D &lt;10 ps, 30 GHz/cm<sup>2</sup>, 10**18 neq/cm<sup>2</sup>, 30 Grad</b>	new materials?	Investigate new materials, 1st set of submissions					Investigate new materials, 2nd set of submissions		<b>Milestone 5 -6 - 7 - 8</b>

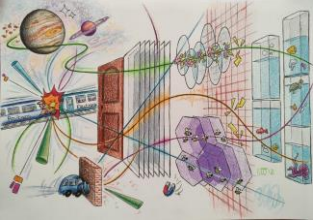


# Toward a cost scale exercise

- Foundry costs are relatively confidential and subject to negotiation with some level of volatility observed in recent orders
- Some foundries offer what we usually call MPW
  - eg. minimal area requested with /mm<sup>2</sup> cost, allowing relatively cheap solution for small scale studies with reasonable number of samples
- Engineering Runs are more expensive
  - but can be organised as MPWs with several design variants, this is typically already a practice for TJ 180 nm and TJ TPsco 65 nm, (they are needed for large size with stitching)
  - 12 wafers appears to be a reasonable scale for an ER with cost substantially depending on foundries, nodes...
  - There are also costs associated to back-end processing to consider

Assuming (an oversimplified) scheme of 3 ERs x 4 foundry costs of today (about 1.5 year cycle)  
a ballpark cost\* could be O(4-5) Mk (\$/€) over 4-5 years up to 2028  
Beyond submission costs environment costs need also to be evaluated

Note: R&D costs could reach production costs for small detector areas, generic R&D can therefore reduce overall experiment-specific costs



# Path toward DRD3 WG1 proposal (1<sup>st</sup> discussions today/tomorrow )

# DRD3

- Completing deliverable technical plan based on current technology developments  
TSI 180 nm, LFoundry 110/150 nm, TJ 180 nm, TJ TPSCO 65 nm, SiGe BiCMOS
  - map technologies to M1 - M4 goals (performance, detector type)
  - establish number of MPW\* types required to fulfil M1 to M4 (adjusted to goals and each technology)
  - establish an initial number of iterations for different MPW types
  - check generic requirement needs for strategic projects (beyond minimal specifications)
- Consolidate technical plan schedule against Strategic Programs plans
  - considering timeline for experiment-specific engineering and then production
- Establish mapping of technical plan with collaboration interests (see presentation of E. Vilella)
  - 1-2 iterations by DRD3 proposal submission
- Establish cost scale of the technical deliverable plan and assess strategic planning resource needs
  - As defined in the ECFA roadmap panel / DRDC guidance

\* MPWs could be ER, depending on technology/goals, and cover more than 1 milestone