Introduzione:
l’upgrade di CMS per HL-LHC

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Presentazione alla Sezione delle attività di Upgrade di CMS per HL-LHC
18 ottobre 2017

LHC / HL-LHC Plan

SPLICES

INIETTORI

low-β triplets

LHC

HL-LHC

Run 1 | Run 2 | Run 3 | Run 4 - 5...

7 TeV | 8 TeV | 13 TeV | 13.5-14 TeV | 14 TeV | 14 TeV | energy

LS1: splice consolidation, button collimators, R2E project; experiment beam pipes

EYETS

LS2: injector upgrade, cryo Point 4, DS collimation, P2–P7(11 T dip.), Civil Eng. P1-P5; experiment upgrade phase 1

cryolimit interaction regions

radiation damage

LS3: HL-LHC installation; experiment upgrade phase 2

2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2037

75% nominal luminosity

nominal luminosity

2 x nominal luminosity

$30\ fb^{-1}$ | $150\ fb^{-1}$ | $300\ fb^{-1}$ | $3000\ fb^{-1}$ | integrated luminosity

$30\ fb^{-1}$

$O(150) fb^{-1}$

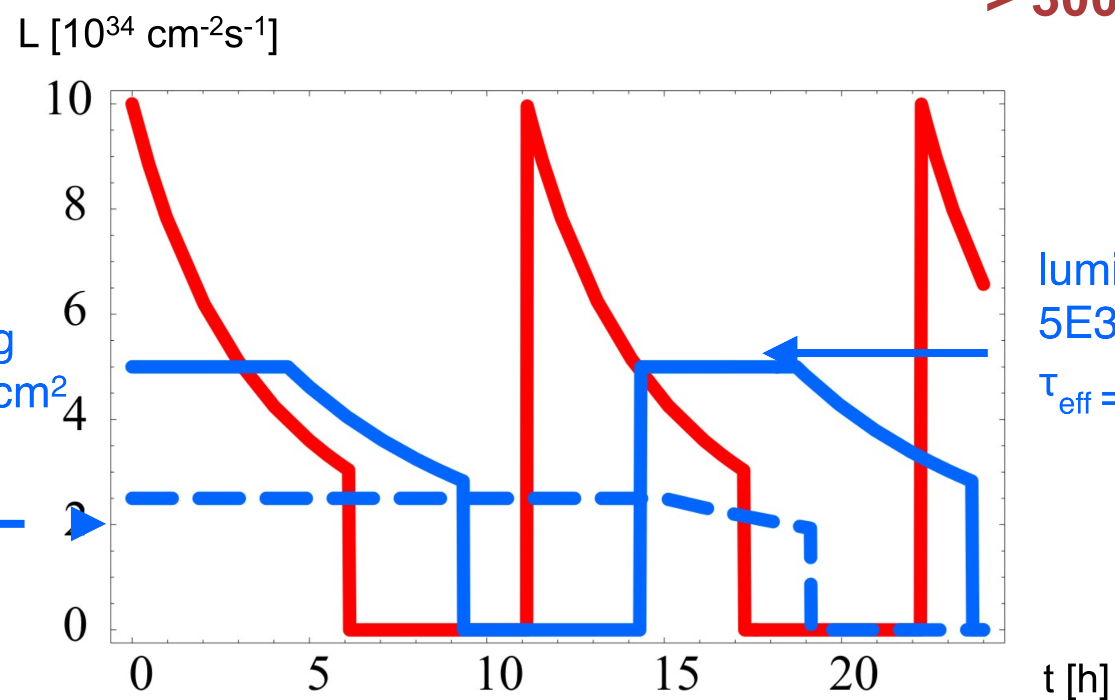
$O(300) fb^{-1}$

$O(3000-4000)\ fb^{-1}$
$> 300\ fb^{-1}/yr$

Rates di riferimento (ATLAS/CMS) per HL-LHC:

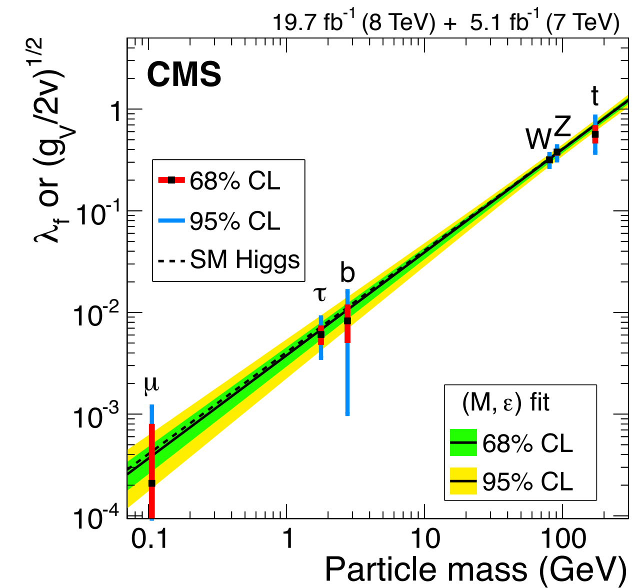
- **L~ 5-7.5 E34 Hz/cm²**
- **<PU> ~ 140-200 int / bx**

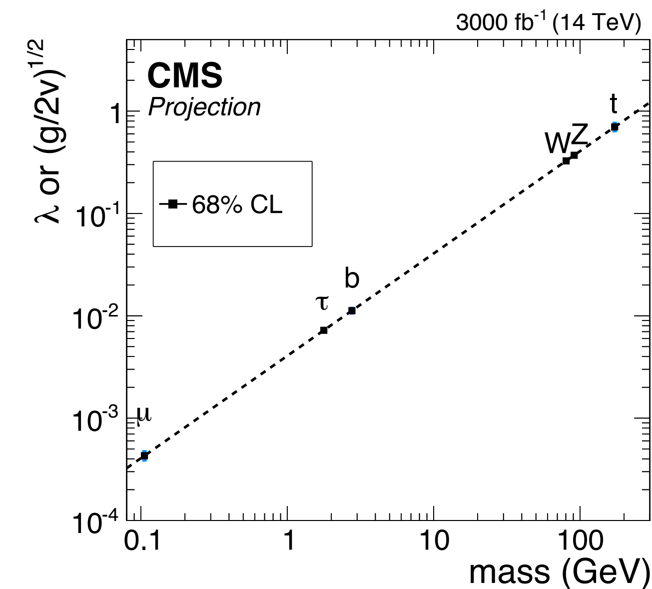
lumi leveling
2.5E34 Hz/cm²
τ_{eff} = 30 h

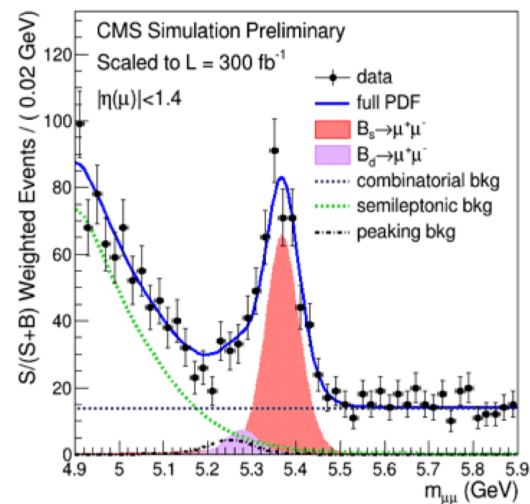


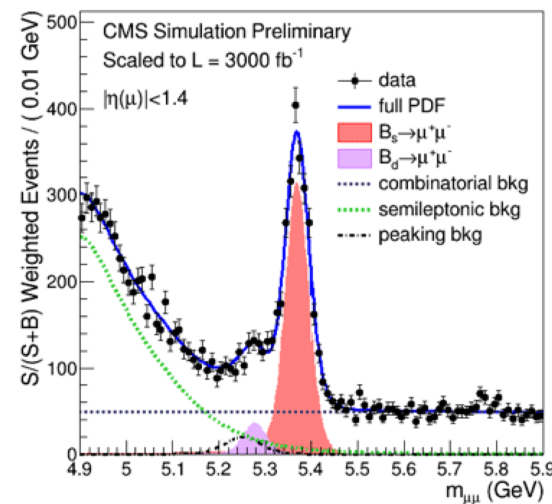
Fisica di precisione → oltre il MS

- Prospettive nel settore dell'Higgs
  - Accoppiamenti a qualche %
  - processi rari H→ $\mu\mu$, H → Z γ
  - self-coupling: σ(HH) ~ 1/1000 σ(H)
- Vector Boson Scattering
- Decadimenti rari del B
  - (es.) FCNC in $B_{d,s}$ → $\mu\mu$





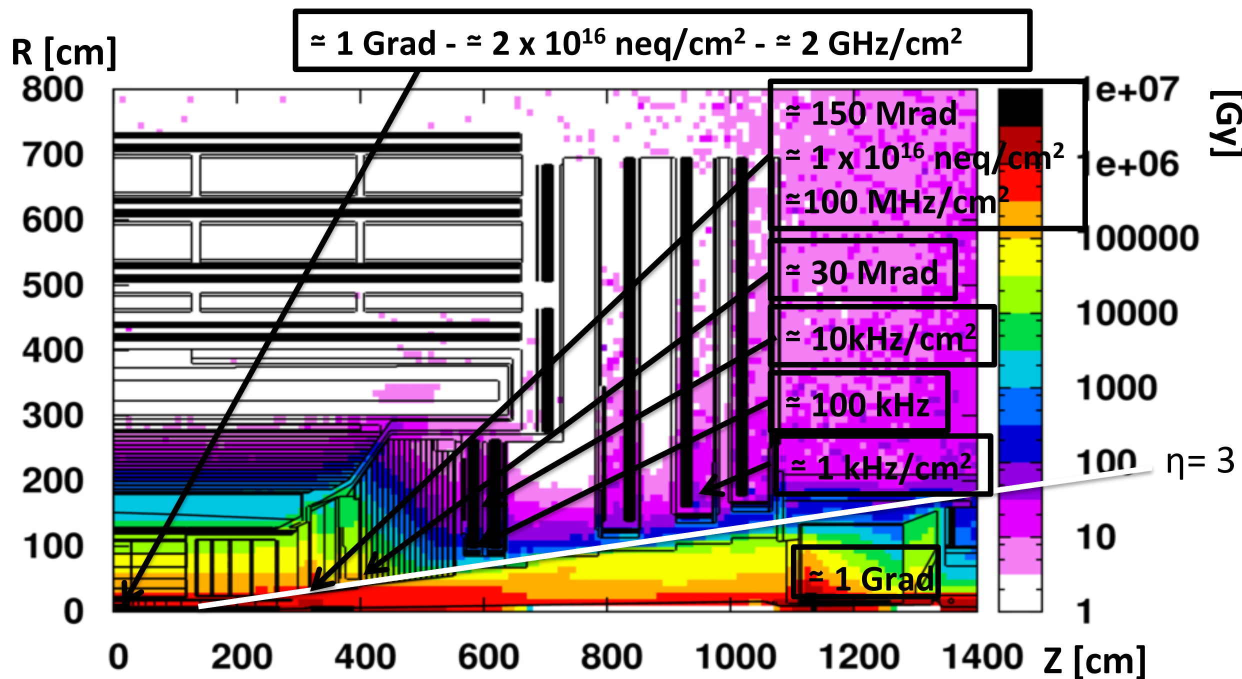




https://agenda.infn.it/conferenceDisplay.py?confId=13658

Alcune considerazioni generali

Alti livelli di radiazione   alto data rate



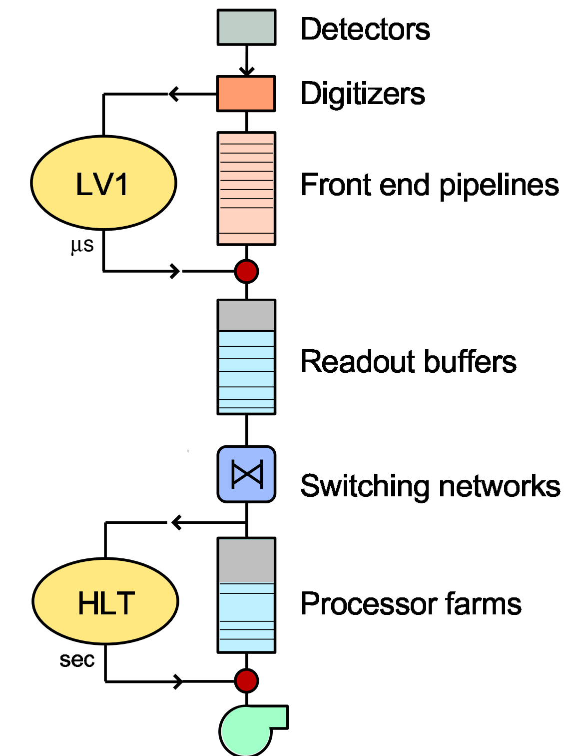
CMS radiation dose map, neutron equivalent fluence and particle rates for luminosities of 3000 fb^{-1} (integrated) and 5 x 10^{34} Hz/cm^2 (instantaneous)

L1 trigger (hw)

- rate 100KHz → 750 kHz
- latency ~ 3 μs → 12.5 μs

HLT (sw)

- 2-300 Hz → 7.5 kHz



uso TRK @ Lv1 (Track Trigger)

CMS, phase 2 upgrades

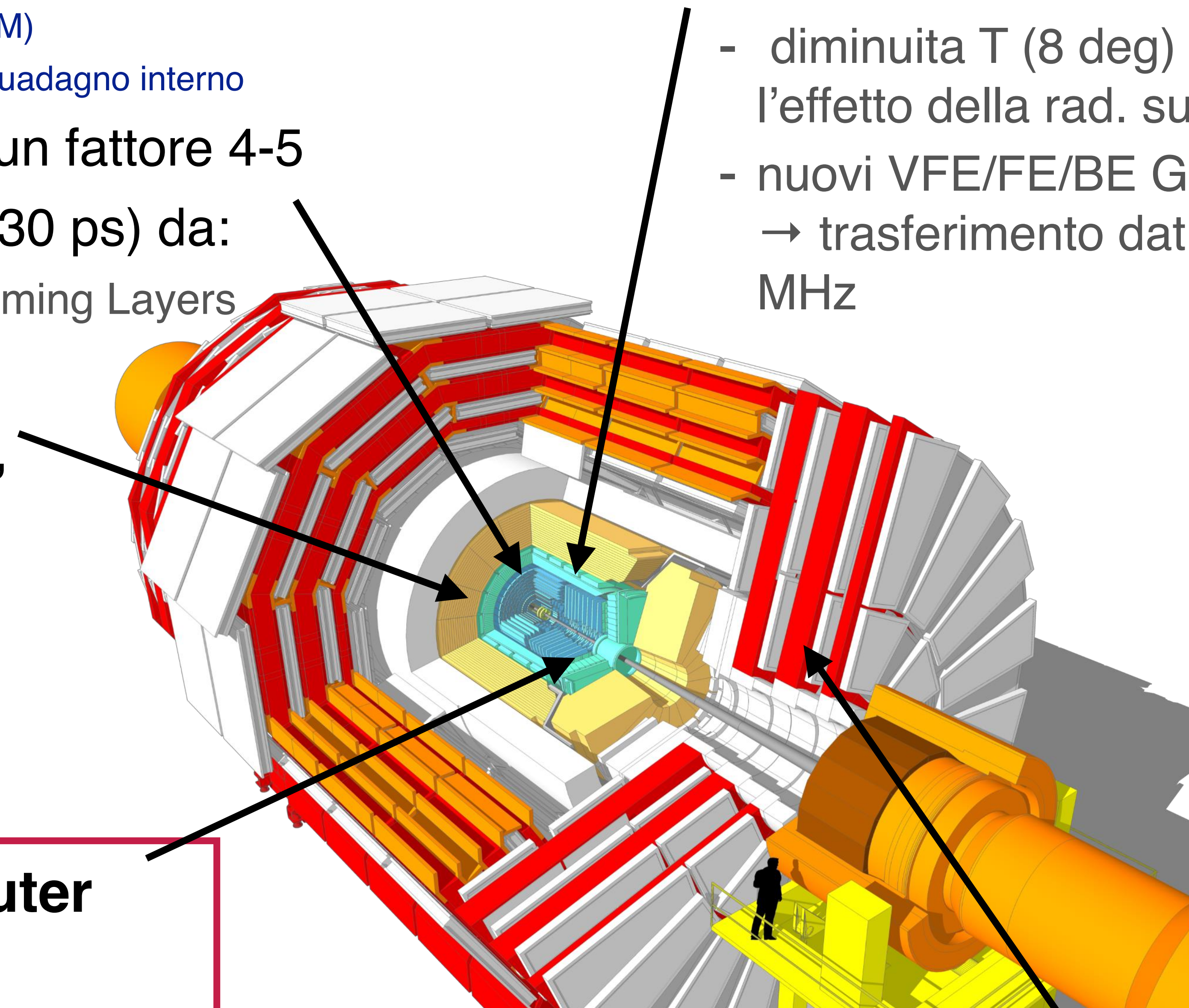
- **timing detectors (MTD)**
  - ✓ barrel: LYSO con lettura veloce (SiPM)
  - ✓ endcap: LGADs rivelatori al Si con guadagno interno
  - riduzione effetti del PU di un fattore 4-5
  - uso dell'info temporale (~ 30 ps) da:
  - ECAL (γ), HGCAL (HEH + γ), Timing Layers

Nuovo endcap "High Granularity Calorimeter"

- Rad. tolerant
- segmentazione trasversale e longitudinale
- capacità di timing

- **Nuovo tracciatore: px+outer tracker**
  - Rad. tolerant - più leggero - maggiore granularità
  - r/o selettivo a 40 MHz per L1 trigger
  - Accettanza estesa fino a $\eta \simeq 3.8$

+ NEW **TRIGGER**



ECAL B:

- diminuita T (8 deg) → mitigato l'effetto della rad. sulla risoluzione
- nuovi VFE/FE/BE GBT @ 10Gbps → trasferimento dati dai cx a 40 MHz

Potenziamento rivelazione *μ*

- nuova elettronica FE/BE per (DT+CSC)
- complete RPC coverage $1.6 < \eta < 2.4$
- *μ*-tagging ad alto η: GEM/iRPC per $2.4 < \eta < 3$

Tracker Upgrade

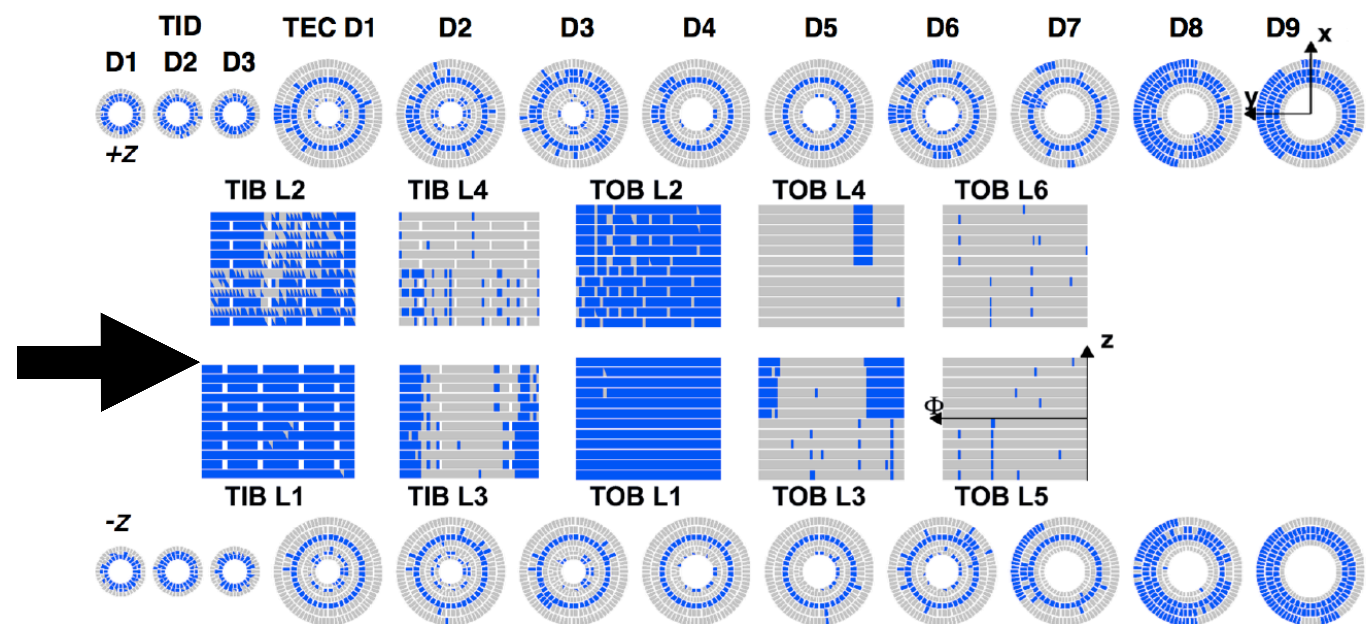
Tracker phase1: the end

	Design limitations of current Tracker	HL-LHC conditions
Pileup	20-30	140-200
int. lumi.	< 1000 fb^{-1}	3000-4000 fb^{-1}

Radiation damage will lead to many non-functional modules

- Increased leakage current cannot be compensated by cooling anymore

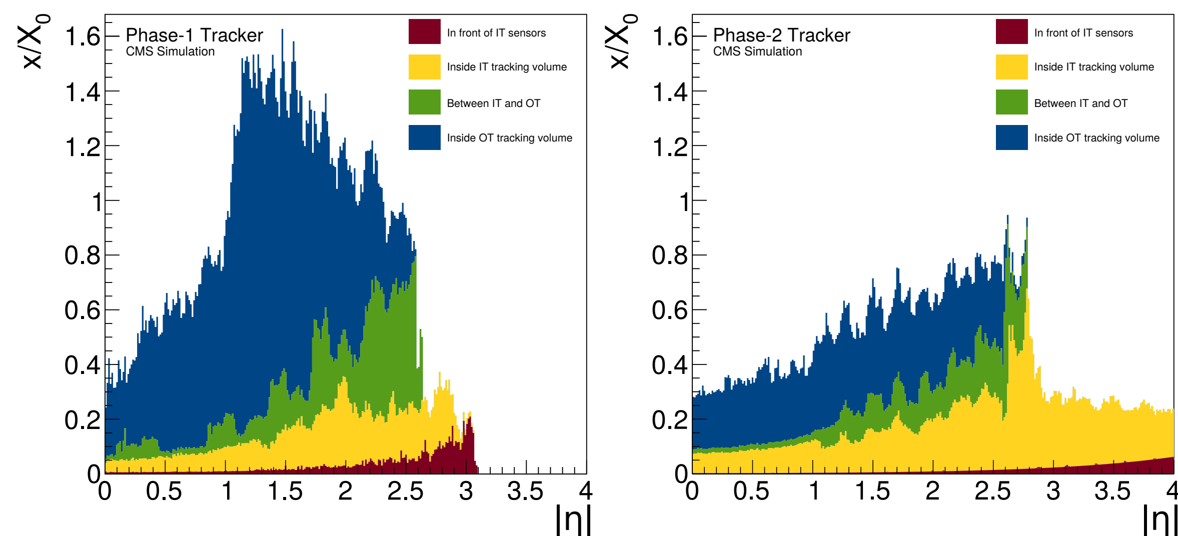
Simulation of non-functional modules of the current tracker (in blue) after 1000 fb^{-1} int. luminosity.



New Phase2 Tracker

sensori n-in-p

- tracciatura fino a $\eta=4$
- L1 track trigger fino a $\eta = 2.4$
- alta granularità
- material budget ridotto



OT

IT

TB2S

TBPS

TEDD

TBPX

TFPX

TEPX

r [mm]

z [mm]

η

TB2S = Tracker Barrel Strip Strip
TBPS = Tracker Barrel Pixel Strip
TEDD = Tracker Endcap Disks

TBPX = Tracker Barrel Pi...

TF...

TE...

CMS Phase-2 Simulation 14 TeV

Tracking efficiency

CMS Phase-2 Simulation 14 TeV

Tracking fake rate

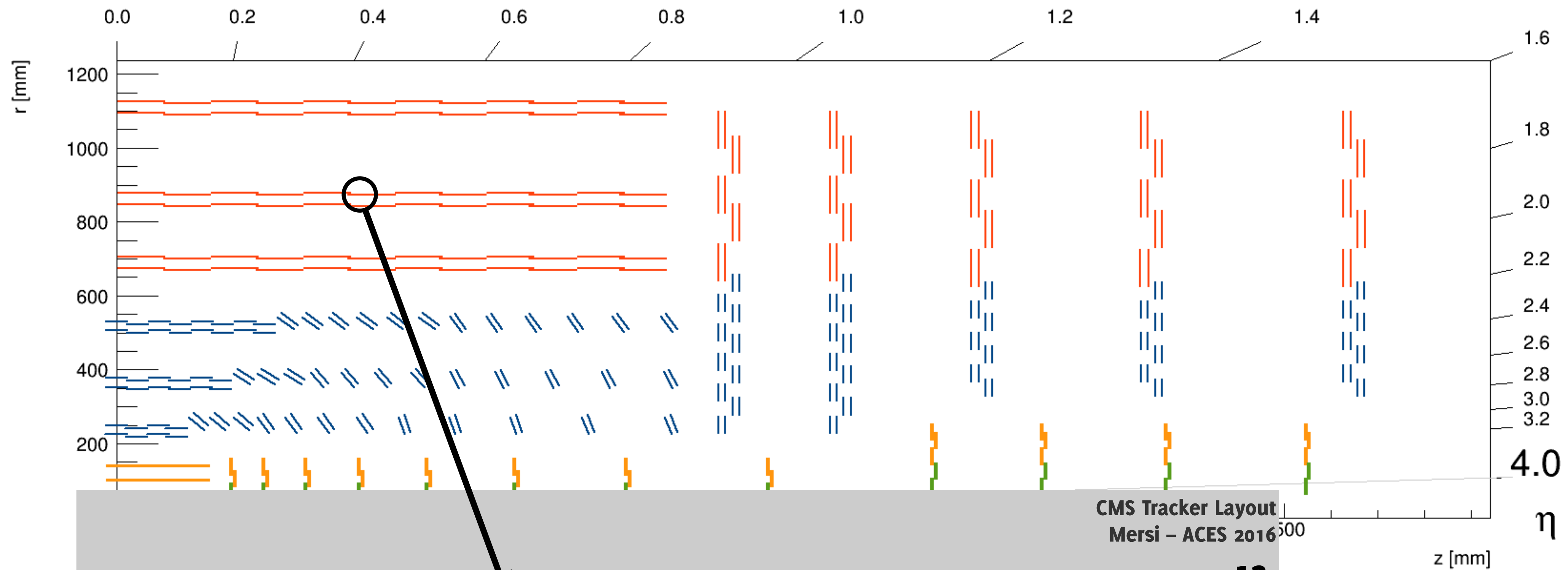
<PU> = 140

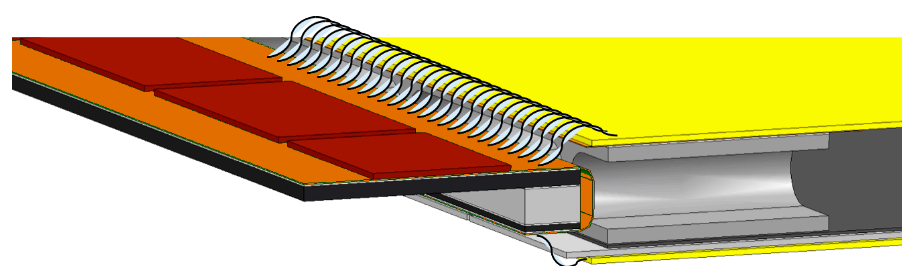
<PU> = 200

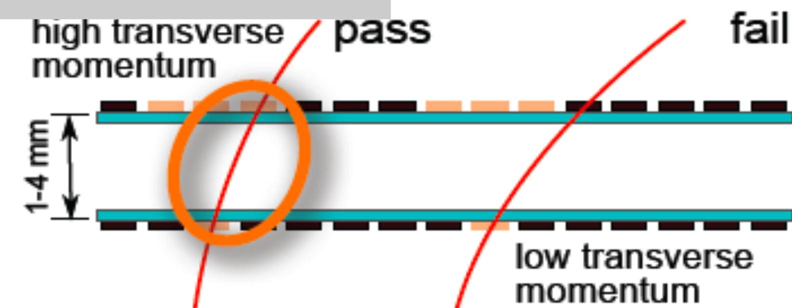
Tracks from tt̄ events

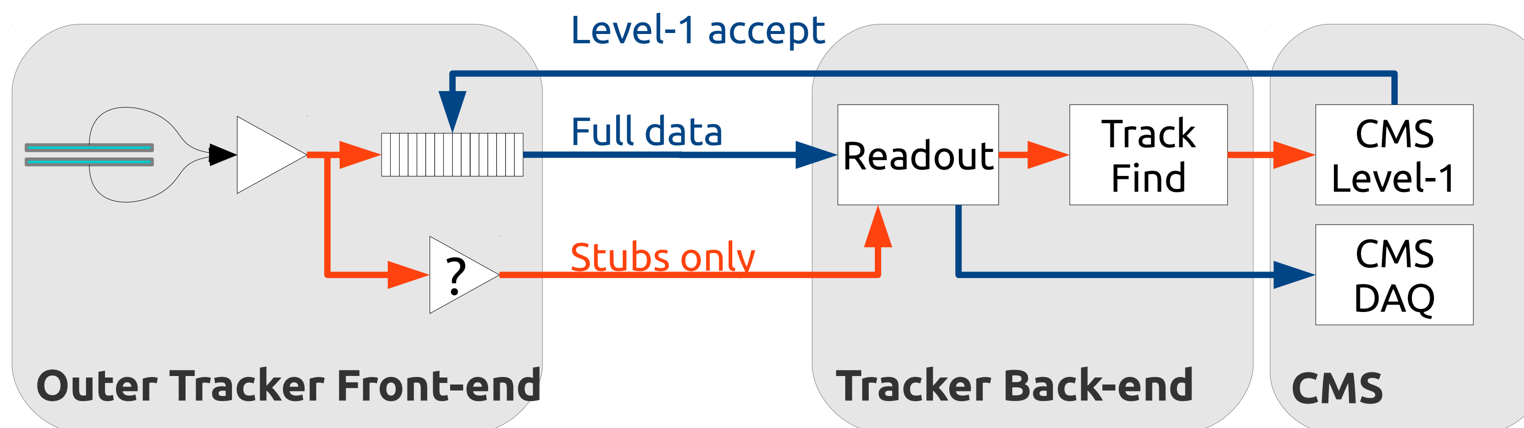
$p_T > 0.9$ GeV

Pt discriminating modules









Gli "stub" vengono inviati al BE ed utilizzati per creare tracce a L1 con pt > 2 GeV @ 40MHz

@ 40 MHz – Bunch crossing
@ 750 kHz – CMS Level-1 trigger

OT Modules

2S module	PS Module	total
7680	5616	**13296**

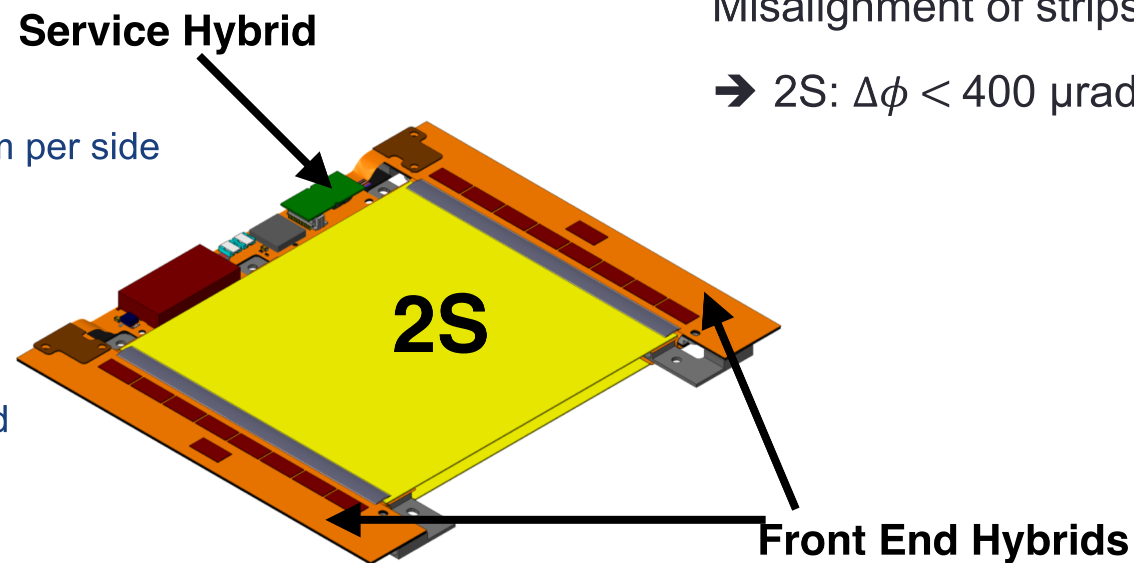
Critical assembly requirements:

Misalignment of strips on both sensors < 40 µm

➔ 2S: $\Delta\phi < 400$ µrad; PS: : $\Delta\phi < 800$ µrad

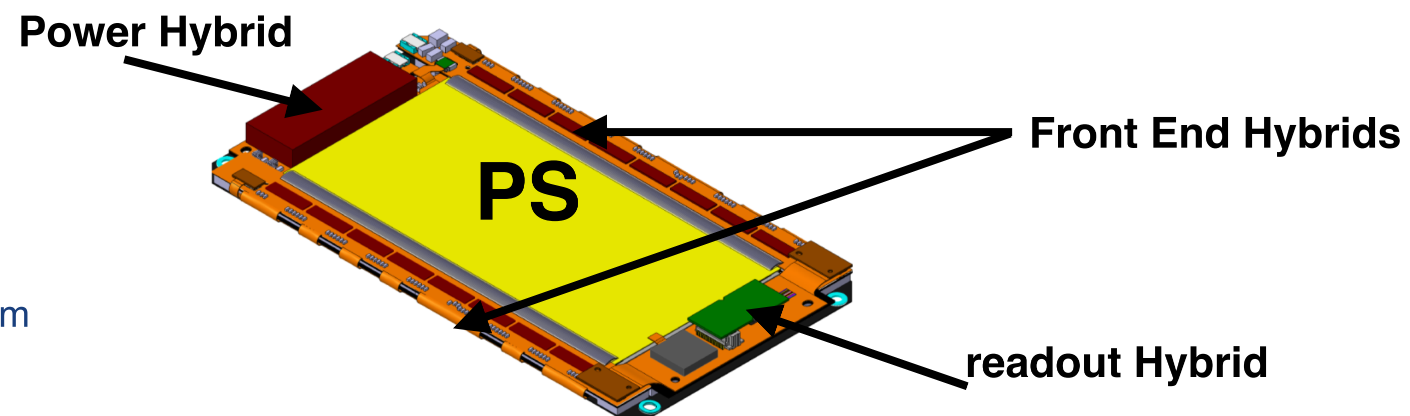
2S Modules

- 2 Strip Sensors: 2 × 1016 strips 5cm × 90 µm per side
- 90 cm^2 active area
- For R > 60 cm
- Spacing 1.8 mm and 4.0 mm
- Two front-end hybrids and one service hybrid (opto + power).



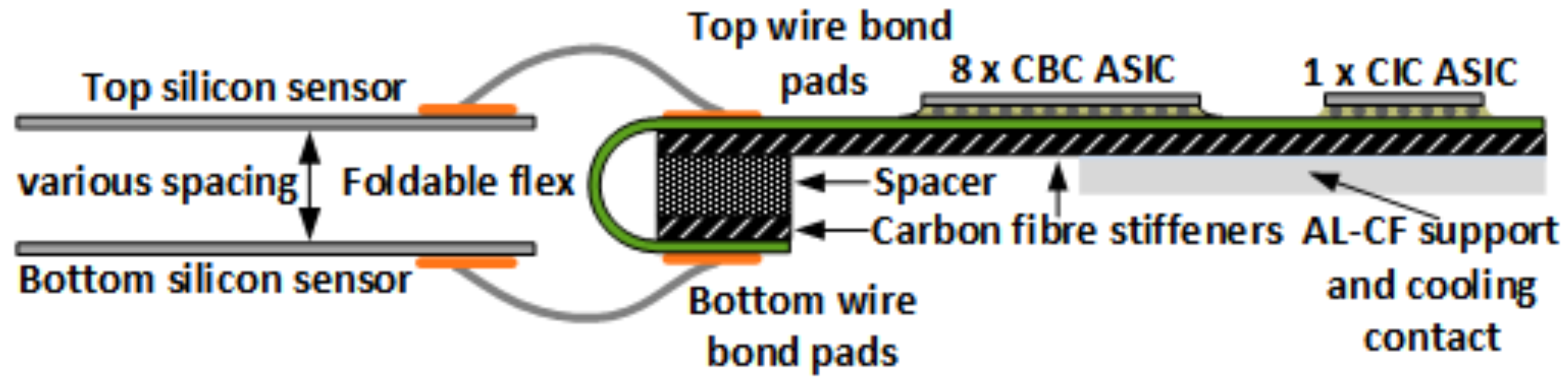
PS Modules

- Pixel + Strip Sensors
- 2 × 960 Strips 2.5 cm × 100 µm
- 32 ×960 macro-pixels 1.5 mm × 100 µm
- 45 cm^2 active area
- For R > 20 cm
- Spacing 1.6 mm, 2.6 mm and 4.0 mm

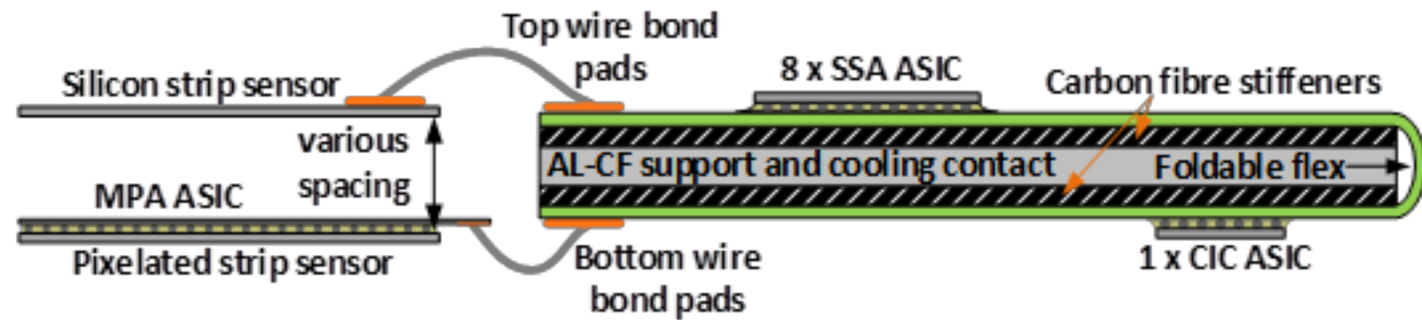


Cooling Set Point: -30 ºC

2S Hybrid



PS Hybrid



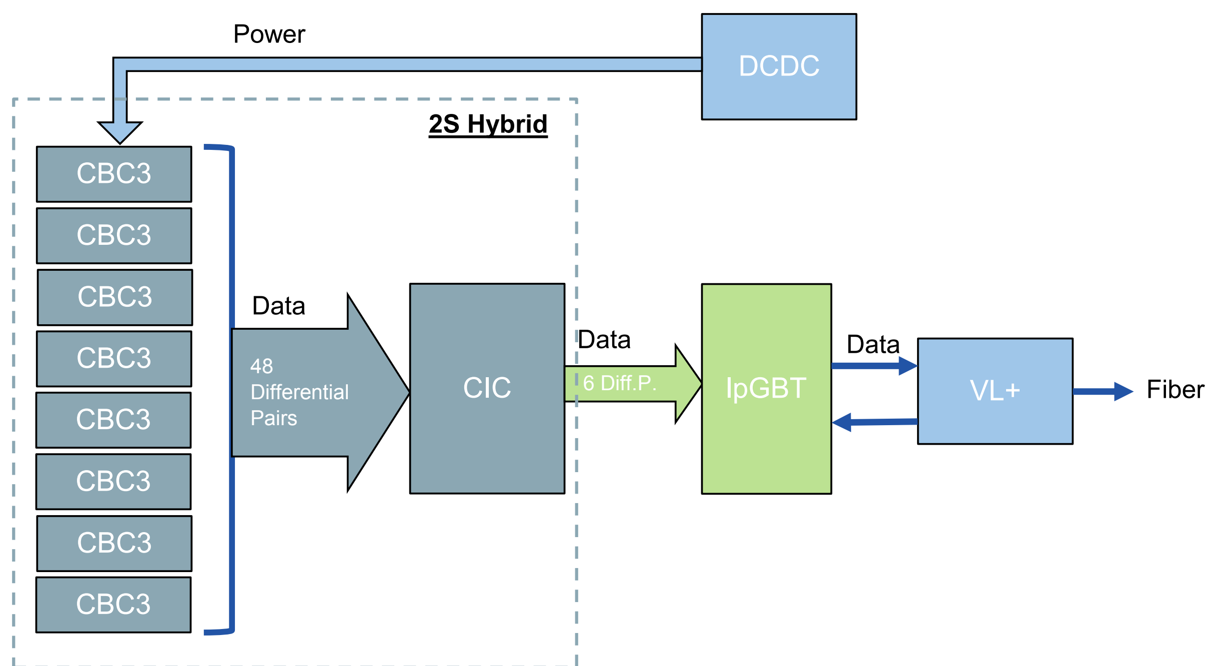
CBC = CMS Binary Chip
CIC = Concentrator Integrated Circuit

SSA = Short Strip ASIC
MPA =Macro Pixel ASIC

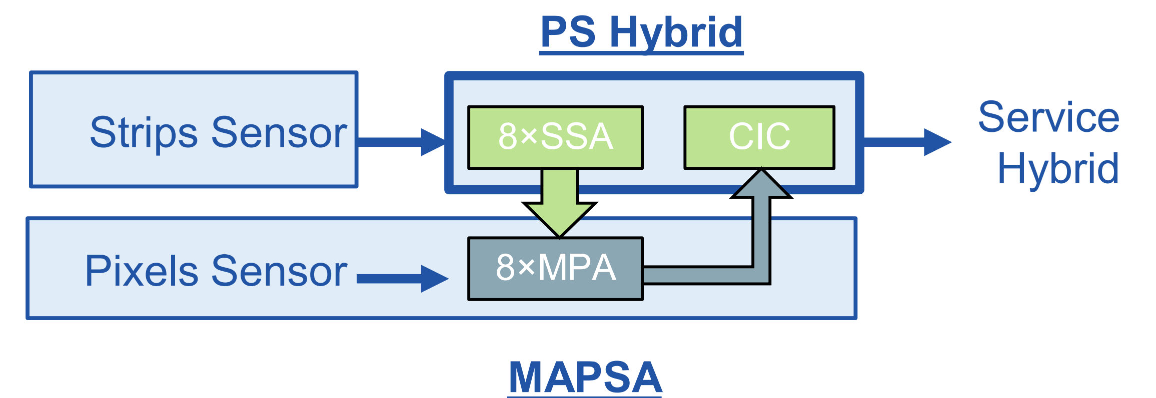
LpGBT = Low Power Gigabit Transceiver
VL+ = Versatile Link Plus
VTRx+ = Versatile TRansceiver Plus

DTC = Data, Trigger and Control Board
3 data streams: Data,TRIG, Timing and Control

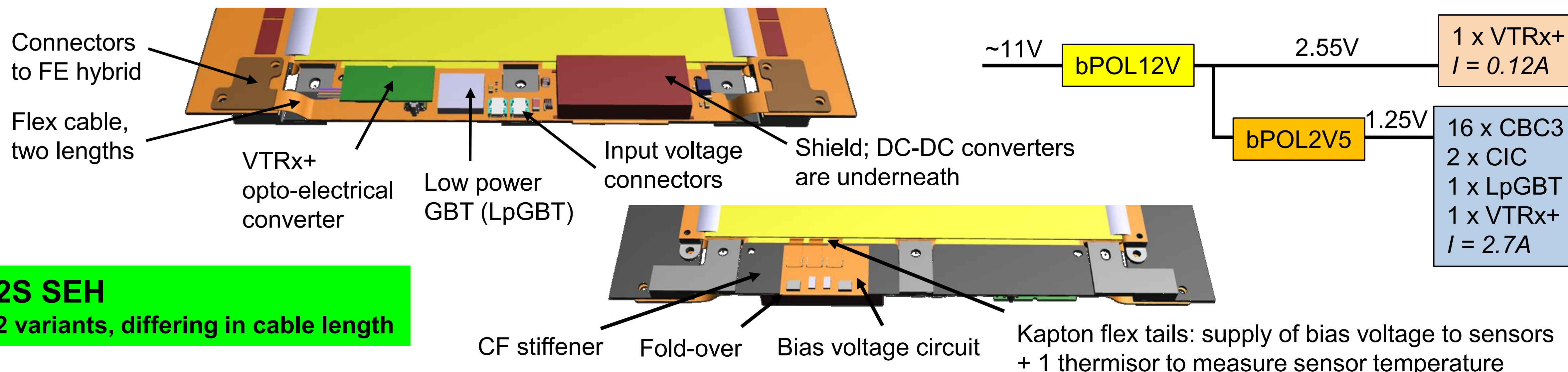
data path: moduli 2S



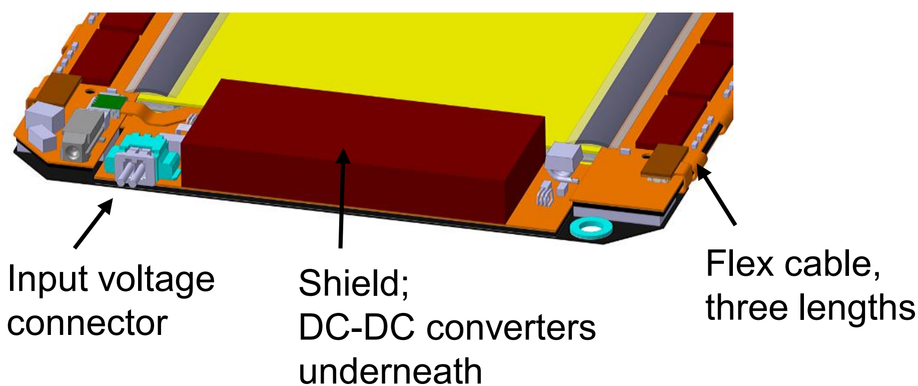
data path: moduli PS



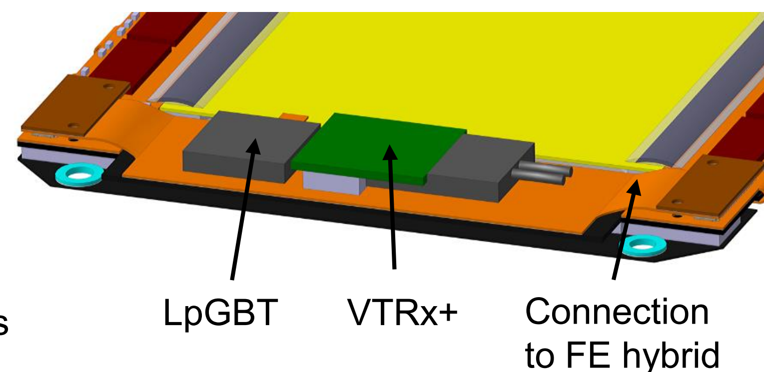
Service Hybrids in 2S and PS Modules

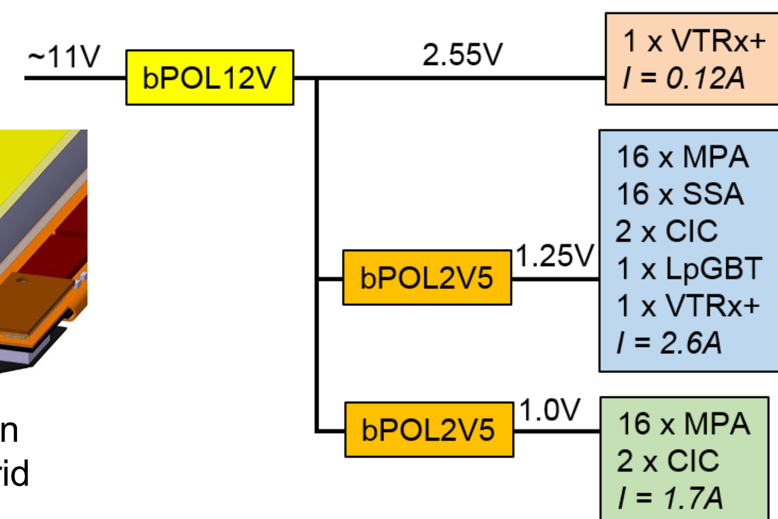


PS Power Hybrid (POH)
3 variants, differing in cable length



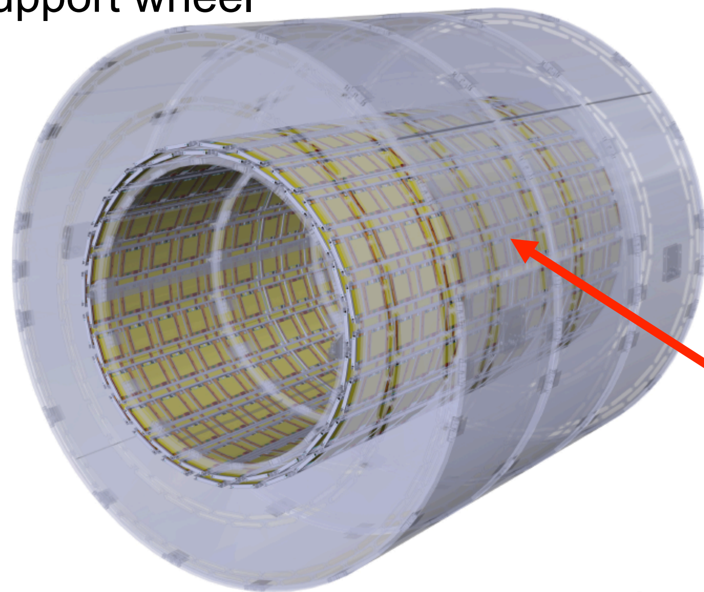
PS Readout Hybrid (ROH)



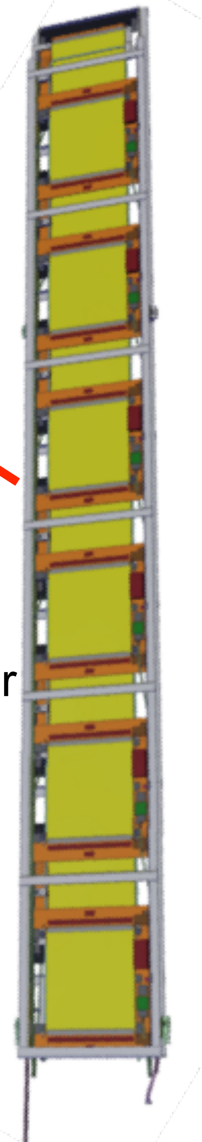


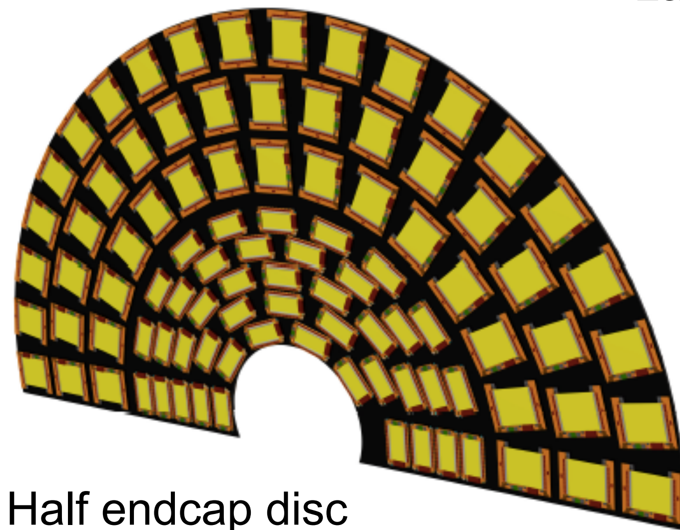
Moduli 2S

Support wheel



Ladder

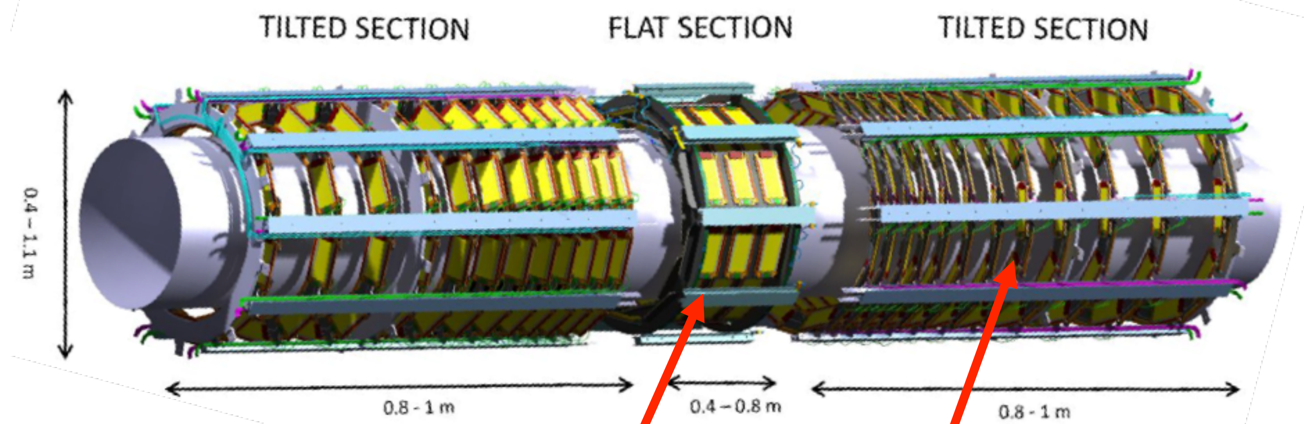


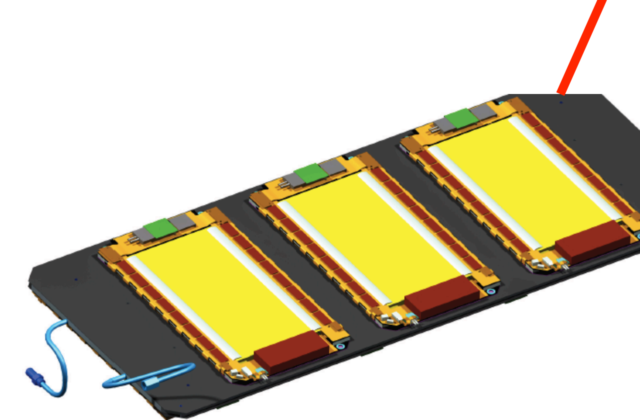


Half endcap disc

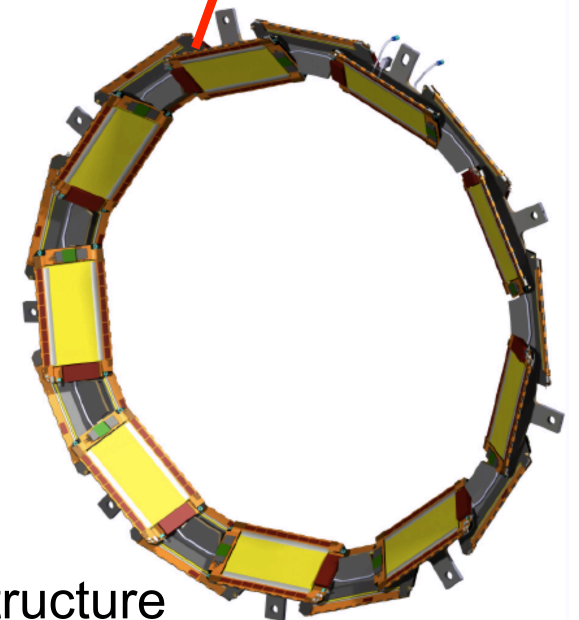
Moduli PS

Innermost layer of outer tracker





Plank structure



Ring structure

Ruolo italiano in OT

Produzione e montaggio di 72 rings del Tilted Barrel (TBPS)
1920 PS modules → (≈ 40 m^2 superficie)

- **Centri produzioni moduli (Ba, Pg)**
- **Test sensori**: (**Pg**)
- **Elettronica :** test ibridi (**Ct,Ge**)
- **Sistema Alimentazione:** Disegno dello schema di alimentazione, specifiche, procurement per i power supplies (**Fi**) e cavi (**Pg**)
- **Tracking Trigger:** contributo allo sviluppo e test di DTC e Track Finder. **(Pi)**
- **DAQ: (Ct), control e Safety System: (Pl)**
- **Integrazione OT: (Pi) camere pulite**

Produzione moduli OT

Center	Institutions	2S modules	PS modules
Aachen	RWTH Aachen	1000	-
Karlsruhe	KIT	2000	-
Belgium	ULB, VUB, Antwerpen	2000	-
India	NISER, IIT-BBS, IOP Bhubaneswar, SINP Kolkatta, IITM	2000	-
Pakistan	NCP Islamabad	2000	-
US Midwest	Bethel, Fermilab, Iowa, Purdue, UC Davis, Wayne State	1000	1250
US Northeast	Brown, Princeton, Rutgers	1000	1250
DESY	DESY	-	1000
Bari	Bari	-	1000
Perugia	Perugia	-	1000
Total pledged		11000	5500
Total needed		7680	5616

Inner Tracker

In 3000 fb 1:

- Dose up to **1.2 Grad**
- hadron fluence up to **2.3 E16** n_{eq}/cm^2

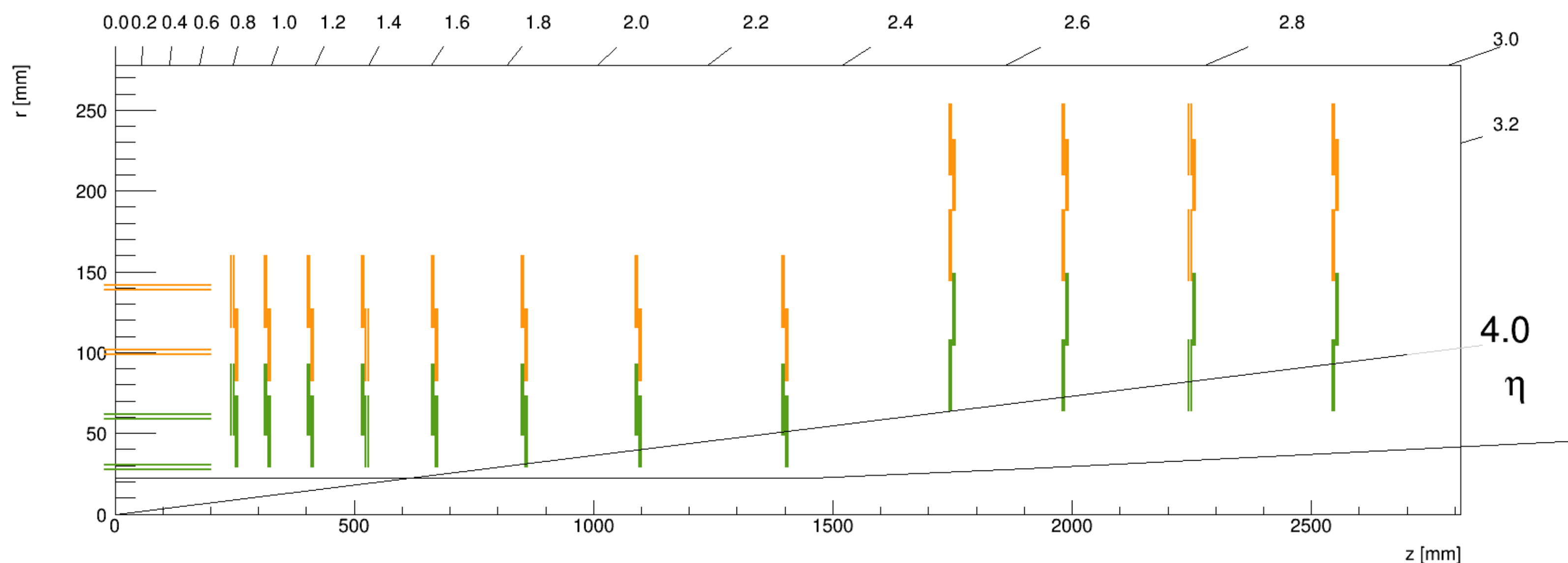
~ **3 GHz/cm2** hit rate

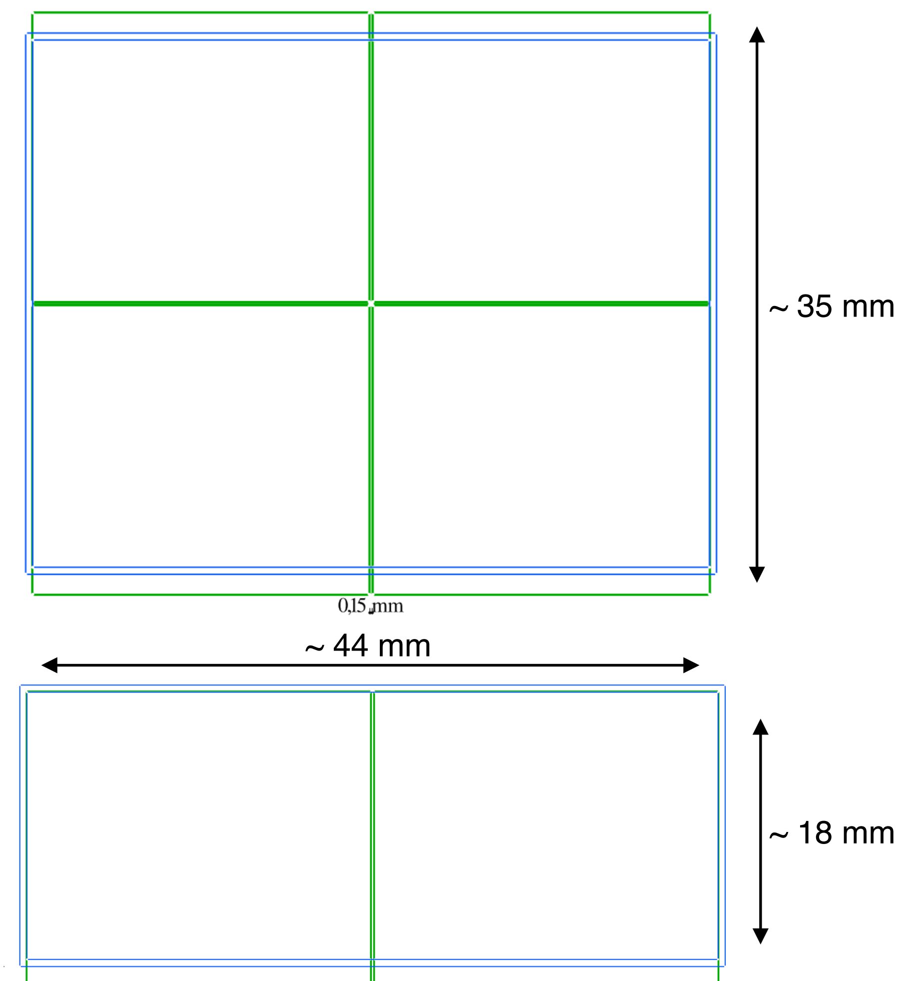
50x50 or. 150x25 μm^2 pixel cells

	moduli
2-chip	1892
4-chip	2352
	4244

~ 13.2 k r/o chips

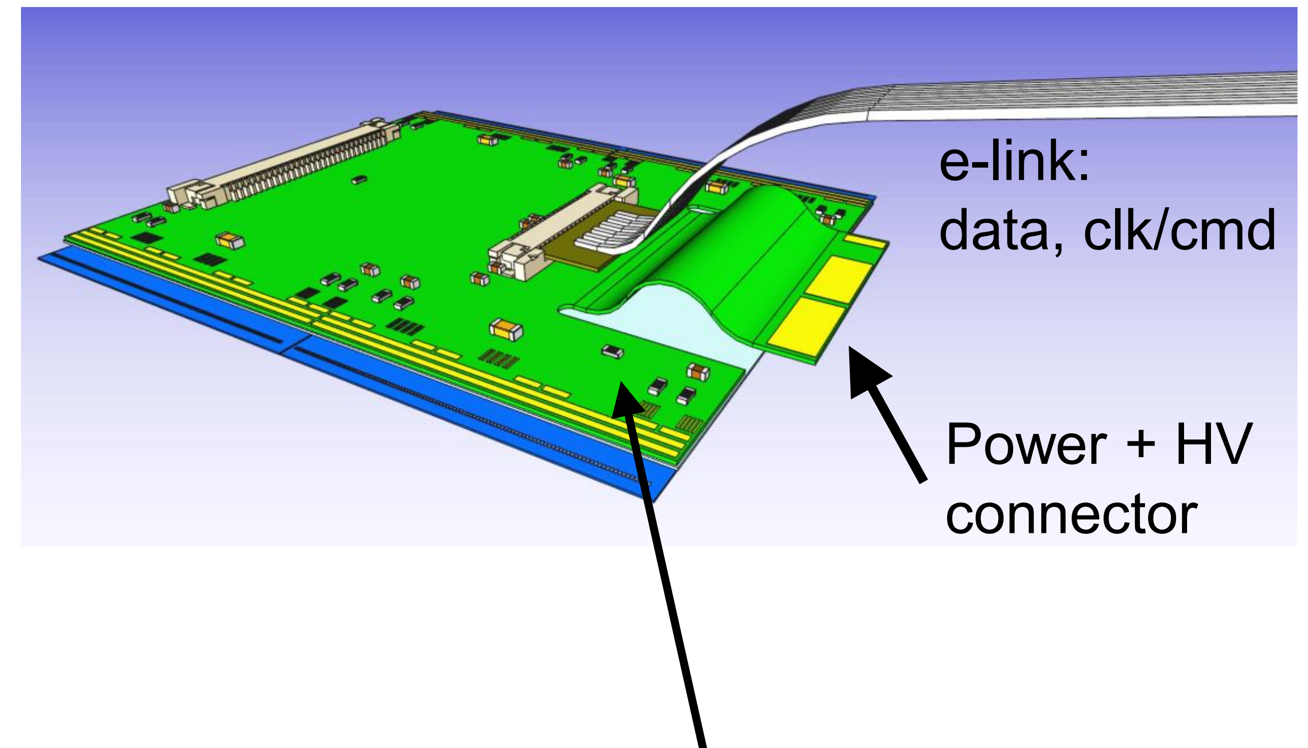
2-chip modules: TBPX L1, L2 & R1, R2 (“4A” chains)
4-chip modules: TBPX L3, L4 & R3, R4, R5 (“8A” chains)

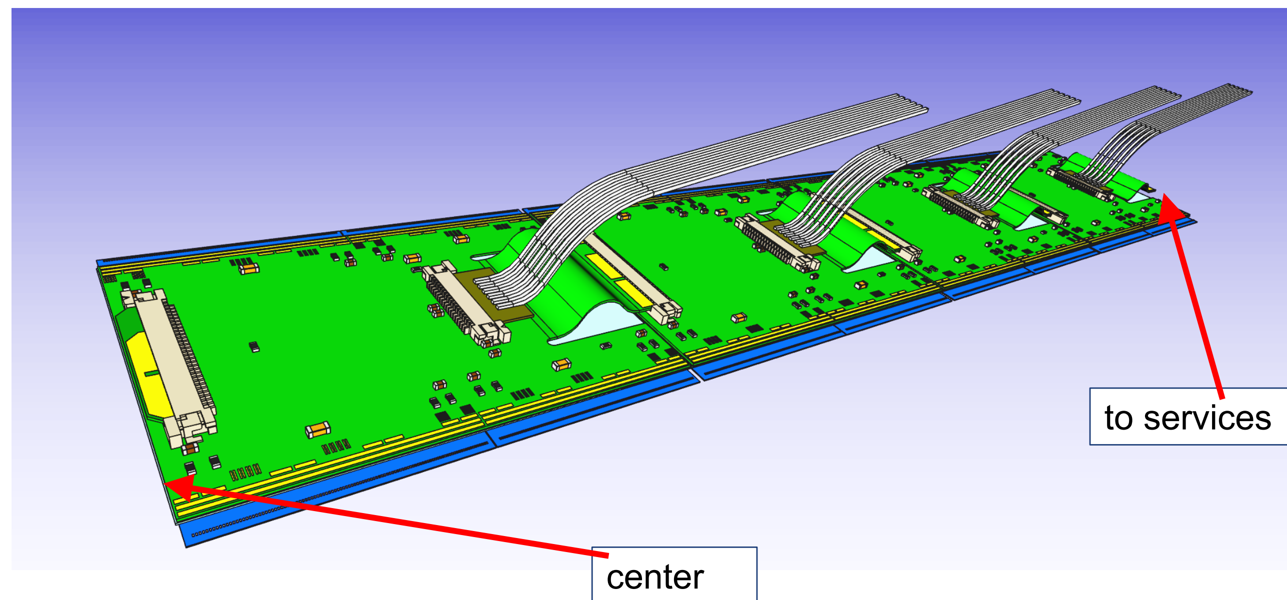




IT Modules Design

- alimentazione serial powering
- ROC è il solo componente attivo sul modulo
  - il sistema di trasmissione ottica col backend (DAQ e controllo) è staccato dal modulo e localizzato su apposite “port cards” alla periferia del detector
  - e-link tra ROC e “port cards”



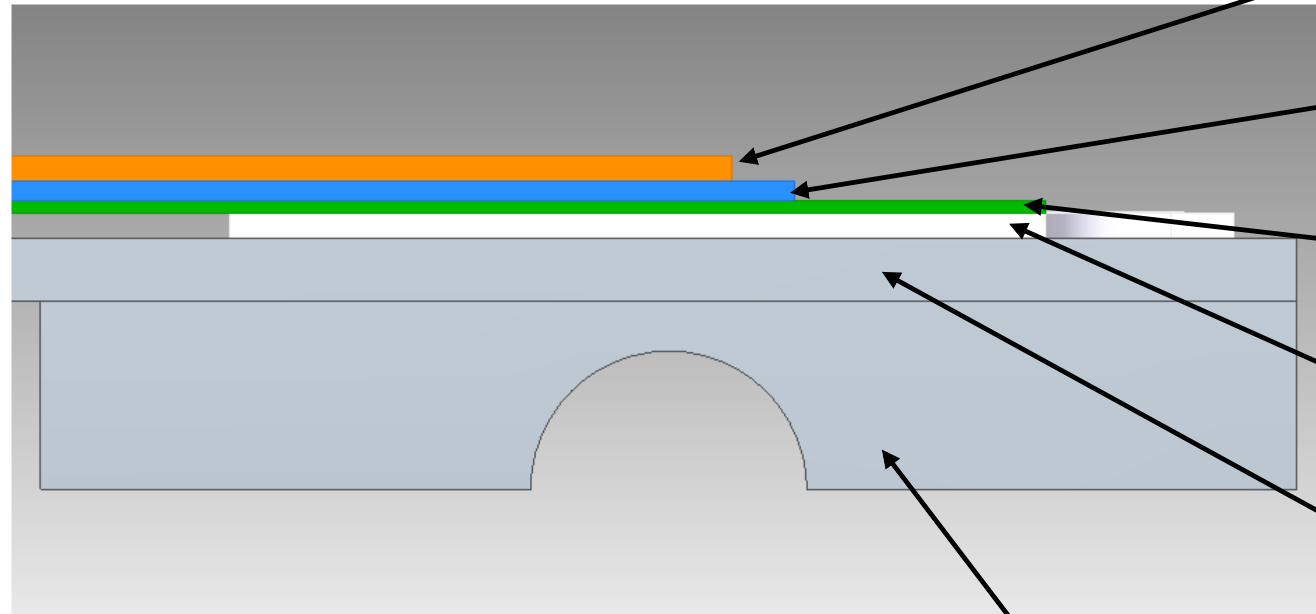


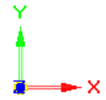
High **D**ensity **I**nterconnect
flex circuit (kapton):

- data out
- clock, trigger and control
- power distribution

→ collegato ai ROC tramite μwire bonding

Thermal conductivities





HDI – 200 µm - Kapton
λ = 0.3 W/mK

Pixel Sensor – 150 µm – Silicon
λ = 148 W/mK

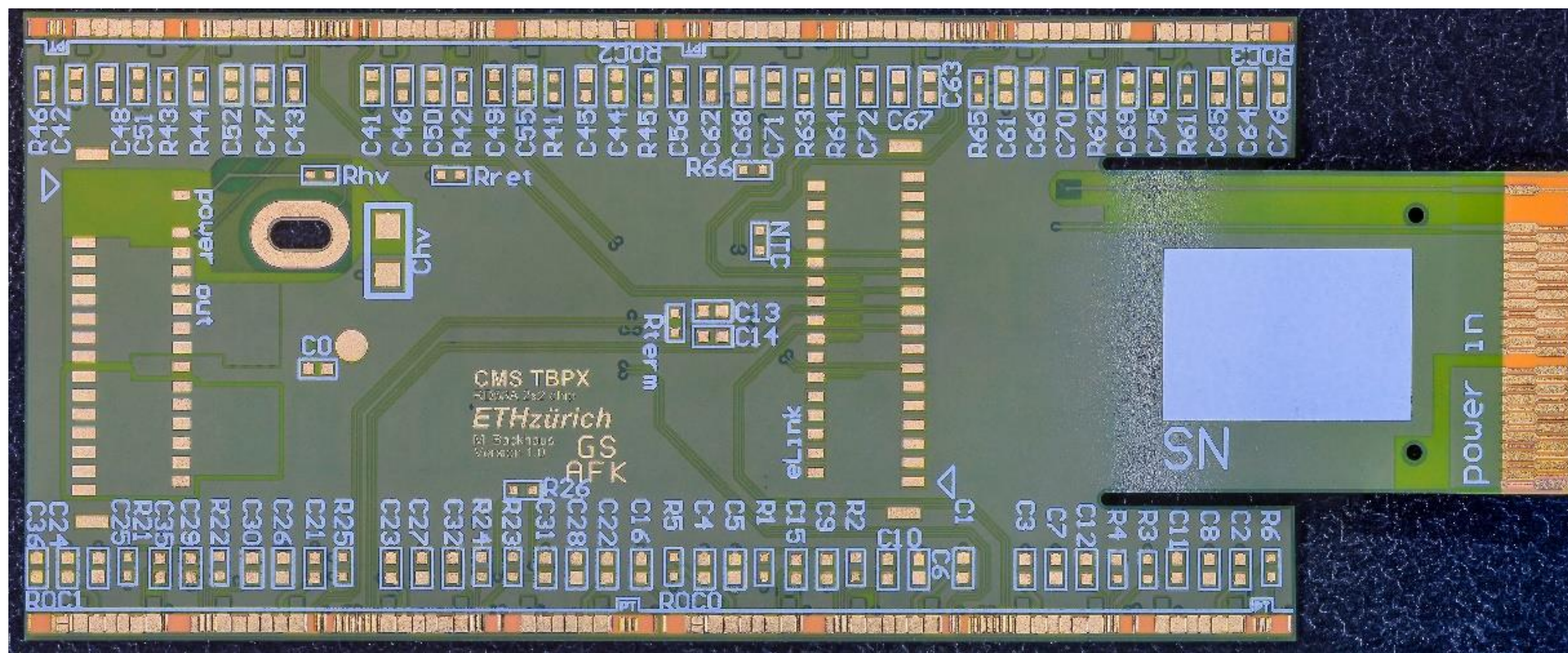
PROC – 100 µm - Silicon
λ = 148 W/mK

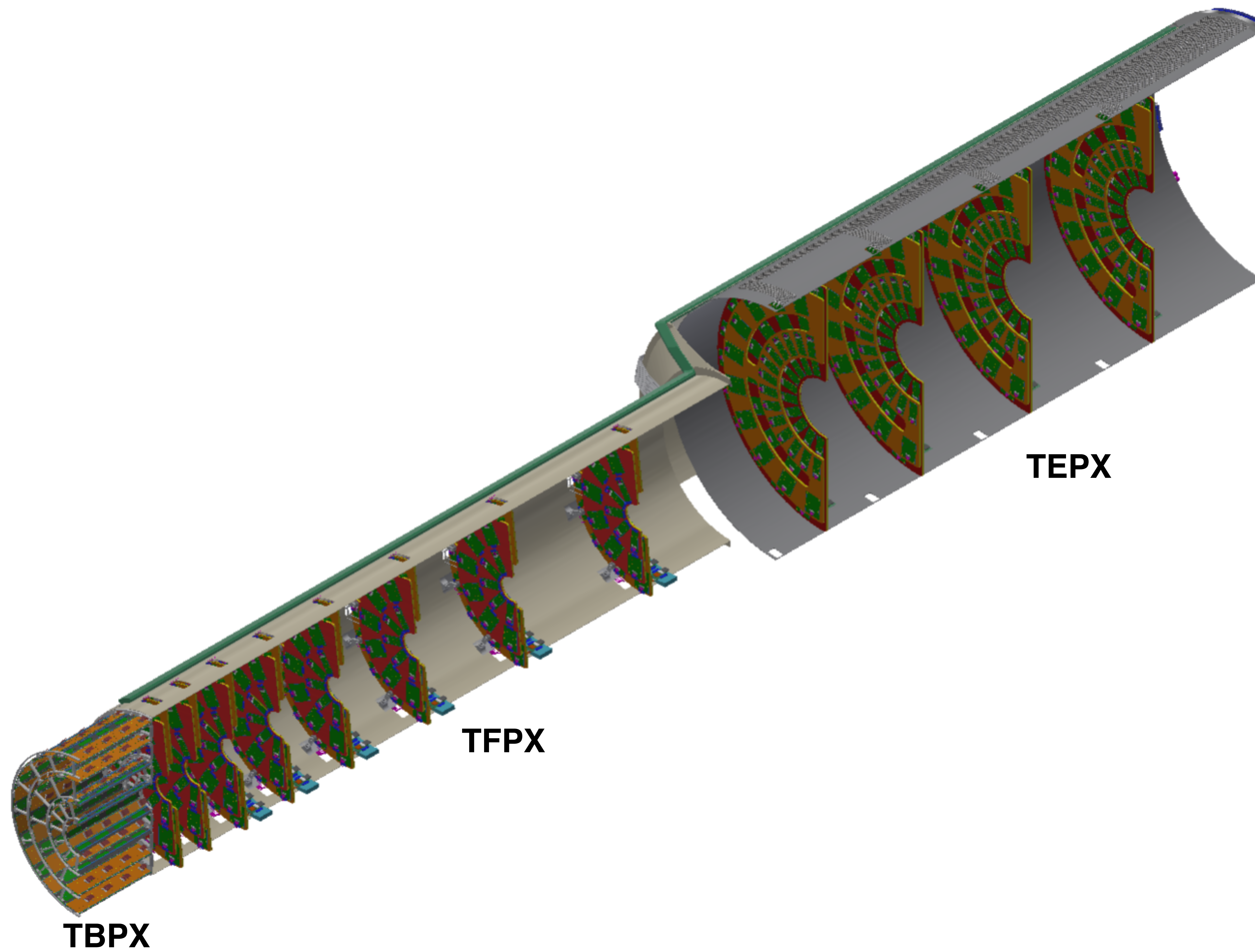
Module rails – 200 µm - Alumina nitride
λ = 200 W/mK

High conductivity carbon fiber – 0.5 mm λ_{xz} = 250 W/mK - λ_y = 1.5 W/mK

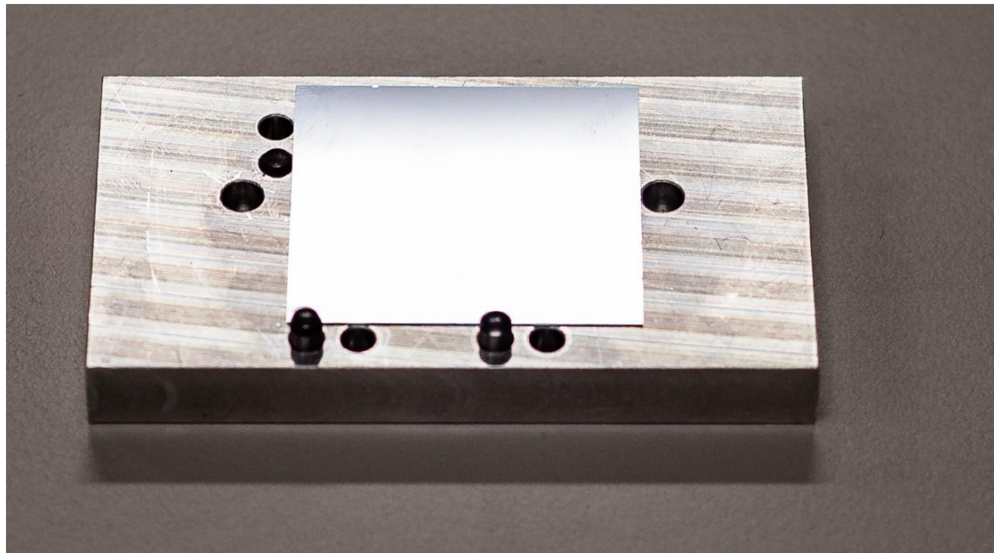
Housing pipe

- TPG – λ_{xz} = 1000 W/mK - λ_y = 6 W/mK
- Aluminum carbon fiber - λ_{xz} = 230 W/mK - λ_y = 120 W/mK



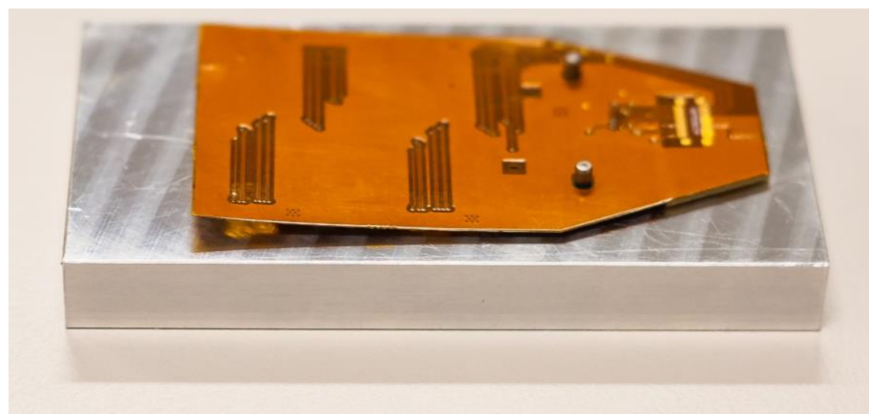

TEPX
TFPX
TBPX

possibile sequenza di assemblaggio dei moduli pixel

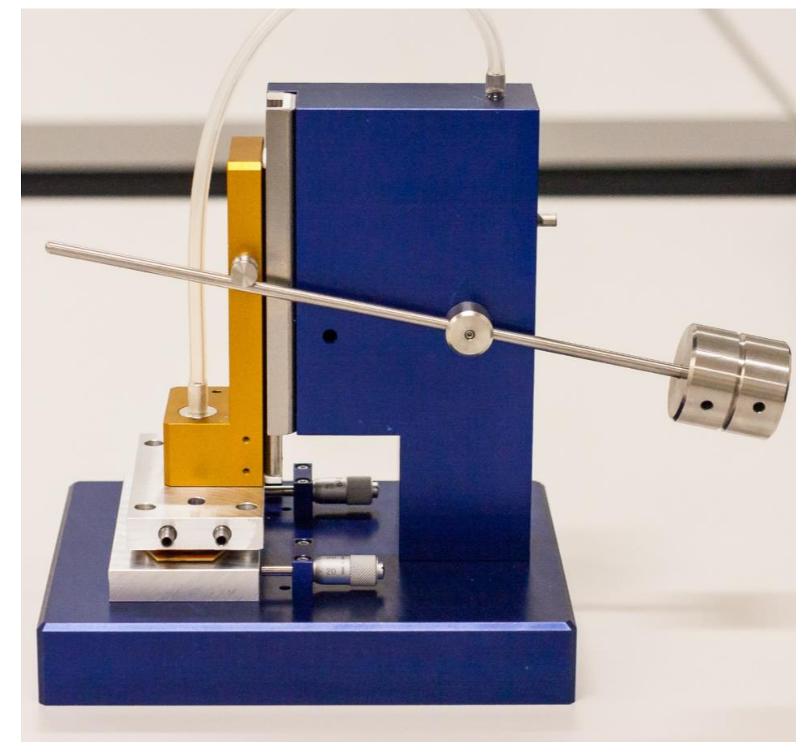


module (sensor + chip bump-bonded) positioning tool with alignment pins

module pick-up jig (vacuum)



HDI positioning + glue application



Module lowering + glue curing

Coinvolgimento italiano in IT

- Produzione di 1128 moduli Pixel integrati nei layer interni (L1, L2) TBPX e negli anelli interni (R1, R2) dei dischi 1-4 di TEPX
- Integrazione e test dell'intero TBPX

- **Produzioni dei moduli**
- **Sviluppo meccanica (PI, Pg, TO)**
- **Sviluppo schema serial power (FI)**
- **Disegno, sviluppo e procurement del backend di alimentazione (FI)**
- **Sviluppo del software per DAQ (MI)**
- **Sviluppo del chip di lettura RD53 (TO, BA, PV, BG, PI)**

Rilevante il contributo italiano su RD53

Chip di readout in comune con i pixel di ATLAS

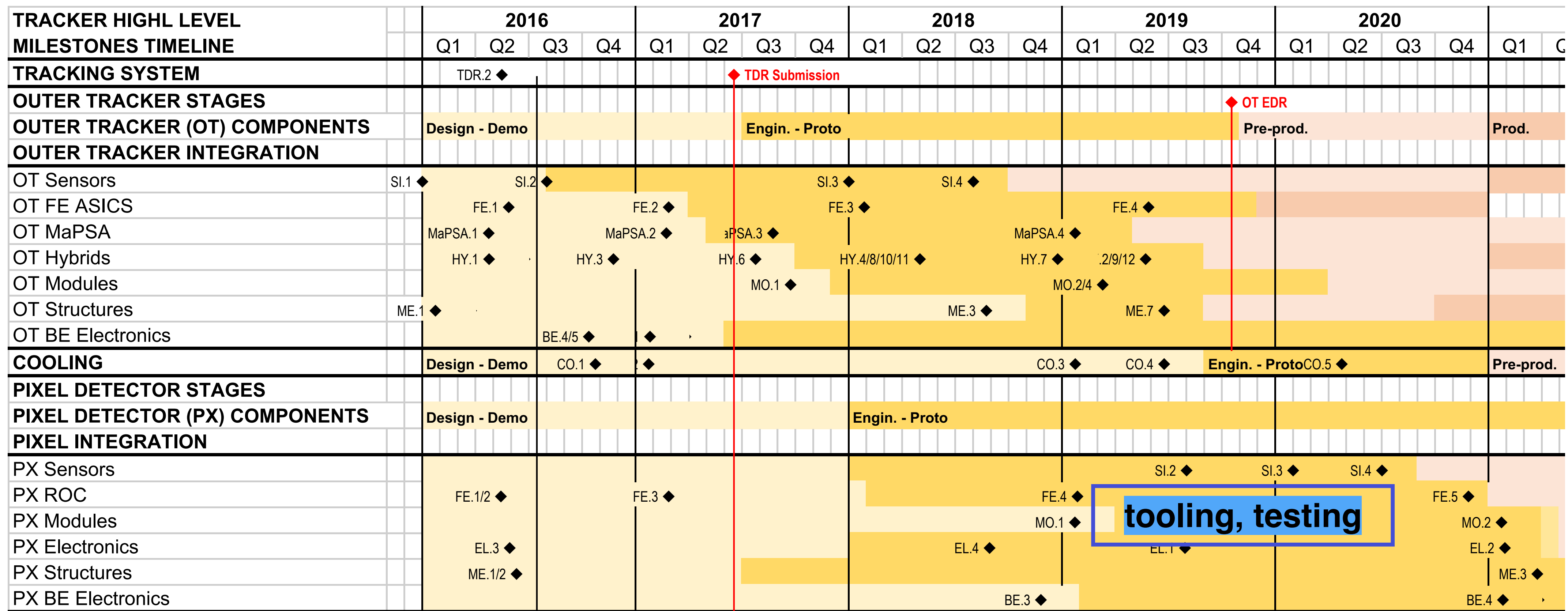
Sviluppo del serial powering in parallelo ai colleghi di ATLAS

Tracker Fase-2
Sommario attività INFN 2018

Sede	Attivita' 2018
BARI	Assemblaggio Moduli TBPS
	Pixel Chip
CATANIA	Test-beam
	Test FE-Hybrid OT
FIRENZE	R&D sui sensori px fase2
	Serial powering per l'IT
	Produzione di moduli IT
	Sistema alimentazione (IT e OT)
GENOVA	Service Hybrid di OT
MILANO	RD sensori Pixel
	DAQ per IT / RD53A
PADOVA	Setup Irraggiamento RD53A
PAVIA	Attività Pixel Chip
PERUGIA	PQC – OT Sensors
	Assemblaggio Moduli TBPS
	Alimentatori e cavi (OT)
	Meccanica IT
PISA	Meccanica IT Barrel
	Tracking Trigger
	Pixel Sensor test
	Module testing TBPS
	Attività Pixel Chip
TORINO	Attività Pixel Chip
	Simulazione Pixel Phase-2
	Test moduli
	RD Sensori IT
	Meccanica Pixel

RESPONSABILITA':

- G.Sguazzoni, tracker upgrade deputy project manager
- S. Paoletti : work-group convener sistemi alimentazione
- E. Migliore: work-group convener simulazioni ph-2
- F.Loddo : work-group conver ASIC IT
- L.Demaria: RD53 CB chair, membro TUSG
- F.Palla : membro TUSG
- M.Meschini, coord. INFN R&D sui sensori pixel



TRACKER HIGHL LEVEL MILESTONES TIMELINE
2021 2022 2023 2024 2025 2026
Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4
TRACKING SYSTEM
OUTER TRACKER STAGES
OT Installation
OUTER TRACKER (OT) COMPONENTS
Prod.
OUTER TRACKER INTEGRATION
Integ.
Float
Comm.
OT Sensors
OT FE ASICS
OT MaPSA
OT Hybrids
OT Modules
OT Structures
OT BE Electronics
COOLING
Pre-prod.
Prod.
Float
PIXEL DETECTOR STAGES
PX EDR
PX Installation
PIXEL DETECTOR (PX) COMPONENTS
Pre-prod.
Prod.
PIXEL INTEGRATION
Integ.
Float
Comm.
PX Sensors
PX ROC
PX Modules
PX Electronics
PX Structures
PX BE Electronics
E.5
MO.2
EL.2
ME.3
BE.4
preprod.
Production.
RUN 3
LS3

Gli impegni di costruzione a Firenze

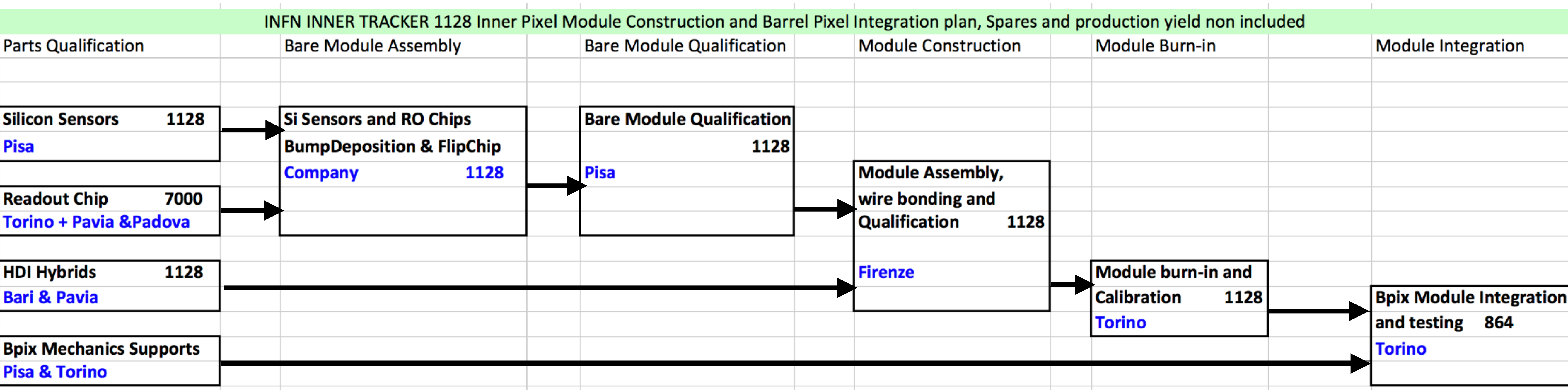
Simone Paoletti - INFN sez. Firenze

Presentazione alla Sezione delle attività di Upgrade di CMS per HL-LHC
18 ottobre 2017

costruzione moduli IT: impegno INFN

1128 moduli Pixel (2 chip) integrati in:

- TBPX L1, L2
- R1, R2 Disks 1-4 di TEPX



2019-21	2021-22	2022-24
tests/prototipi	preprod.	produzione

Impegni a Firenze

- Produzione moduli IT:
  - Assemblaggio meccanico di 1128 “bare modules” all’HDI.
  - Wire bonding (~ 400 saldature per modulo) tra bare-module e HDI
  - Test completo di qualifica

- Sviluppo del serial powering system (IT)
- Sviluppo dei sensori (IT)
- Contributo al system test (IT)
- Sviluppo, procurement e commissioning del sistema di backend power supplies (IT + OT)

—> present. dedicate

Risorse necessarie:

- Uso intensivo della camera pulita:
  - Stand di incollaggio
  - Microsaldatura
  - Area per tests post produzione
  - R&D sui sensori e serial powering

- Personale tecnico per attività di costruzione e di R&D in camera pulita:
  - ✓ 1 FTE (Mirko Brianzi) 2019-2024
- Supporto del servizio di elettronica

Necessità di personale

Documento sugli impegni di fase2:

- sottoposto a referaggio in CSN1
- sottomesso al CTS dell'INFN (~agosto 2018)
- si aspetta approvazione del direttivo

Nel documento vengono esplicitate le richieste di manpower addizionale per fare fronte alla costruzione

Institute	2018 FTE	TASK	Average Man Power (FTE) 2018-2025			REQUEST of MANPOWER [FTE]							
			Physicists & Engineers	Technicians	PhD /Temporary	2018	2019	2020	2021	2022	2023	2024	2025
Firenze	7,4	IT Module construction	5,1	1	1,5				1	1	1		
		IT system test											
		IT Serial Power electronics						1	1	1	1		
		TK Power System						1	1	1	1	1	1

Costruzione dei moduli. Manut. Camera pulita.

Test di sistema, attività serial powering

Sviluppo del sistema di alimentazione

Test e commissioning del sistema di alimentazione al CERN

Infrastrutture

- Cofinanziamento a Firenze concesso dalla GE per infrastrutture legate all'upgrade:
  - bonding machine: contributo 112 k€
  - probe station: contributo di 150 k€ (?)

Backup

attività di Firenze

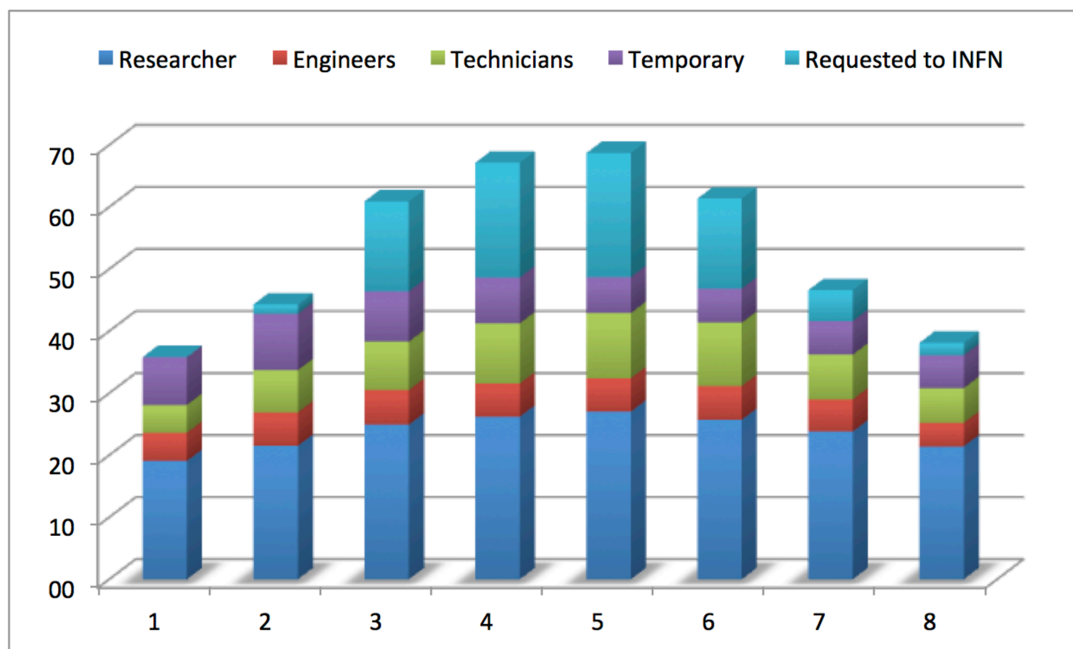
Tasks IT:

- **module production**
- **on detector service electronics Power**

Tasks OT:

- **Power**

	Profile	2018	2019	2020	2021	2022	2023	2024	2025	ToT	Task
FIRENZE										**73.6**	
Barbagli Giuseppe	RI	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.3	2.4	IT 5,12; OT 5
Ciulli Vitaliano	PA	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	1.7	IT 5
Civinini Carlo	PR	0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.5	3.3	IT 4,5
D'Alessandro Raffaello	PA	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	3.1	IT 4,12; OT 12
Focardi Ettore	PA	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4	2.4	IT 5,12; OT 12
Latino Giuseppe	PA	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.3	1.4	IT 5
Lenzi Piergiulio	RU	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.4	2.3	IT 5
Meschini Marco	DR	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	8.0	IT 4,5
Paoletti Simone	RI	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	8.0	IT 4,5,12; OT 12
Sguazzoni Giacomo	PR	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	8.0	IT 4,5,12; OT 12
Tecnico INFN	Tec	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	6.4	IT 4,5,12; OT 12
Tecnico UNIV	Tec	0.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0	1.6	IT 4,12; OT 12
Dottorando Firenze	PhD	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	4.0	IT 4,5
Assegnista Firenze 1	Adr	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	4.0	IT 4,12; OT 12
Assegnista Firenze 2	Adr	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	4.0	IT 4,12; OT 12
request to INFN	Tec	0.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	6.0	IT 12; OT 12
request to INFN	AdR	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	4.0	IT 4
request to INFN	AdR	0.0	0.0	0.0	1.0	1.0	1.0	0.0	0.0	3.0	IT 5
TOTAL	**FTE/year**	**7.4**	**7.7**	**9.1**	**10.2**	**10.4**	**10.9**	**9.0**	**8.9**		



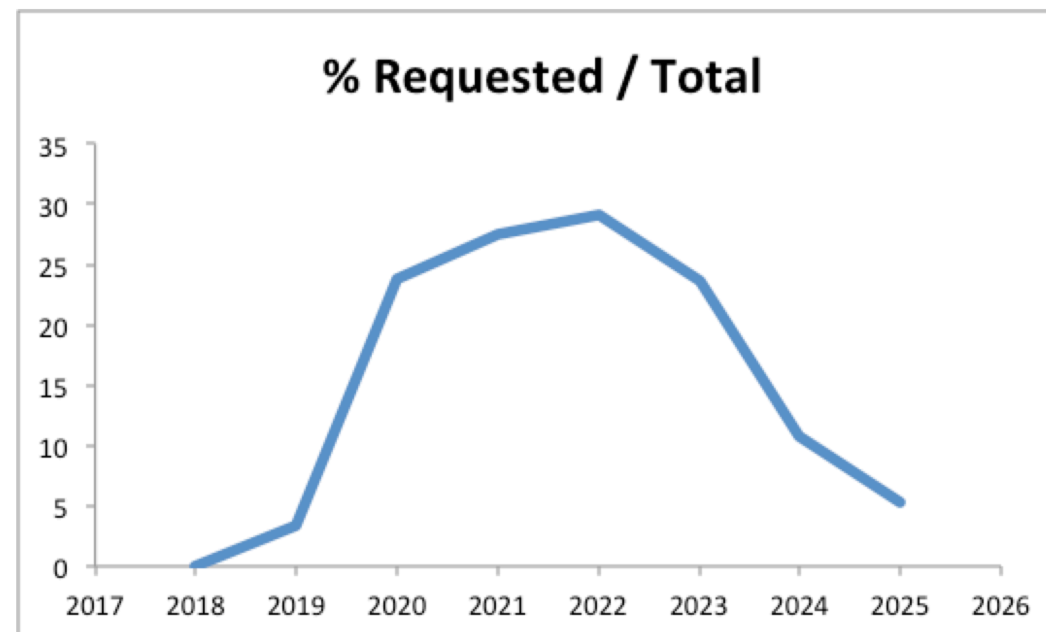


Figure 28: Manpower for the CMS Tracker upgrade across the year: breakdown of men-years across the years (left); percentage of requested manpower over the total manpower versus relative year.

Legend:
X = interest in this item
OT = interest in this item for the entire OT
TBPS = interest in this item for the TBPS
TB2S = interest in this item for the TB2S
TEDD = interest in this item for the TEDD
IT = interest in this item for the entire IT
TBPX = interest in this item for the TBPX
TFPX = interest in this item for the TFPX
TEPX = interest in this item for the TEPX

Institute	Sensor Quality Control	ASICs Quality Control	FE Hybrid Quality Control	Bump bonding Quality Control	On-detector Service Electronics	Module production	Module burn-in	Integration of sub-assemblies	Mechanics	Beam pipe	Optical Data links	DAQ hardware	DAQ software	L1 track finder	Dry gas system	Safety system	Cooling system	Power system	Power cables	Commissioning	Installation	Construction database
INFN Sezione di Bari and Università di Bari, Bari, ITALY			TBPX TEPX			TBPS														OT		
INFN Sezione di Catania and Università di Catania, Catania, ITALY			TBPS										OT	X						OT		
INFN Sezione di Firenze and Università di Firenze, Firenze, ITALY					TBPX TEPX	TBPX TEPX							IT					X		IT		
INFN Sezione di Genova and Università di Genova, Genova, ITALY					TBPS															OT		
INFN Sezione di Milano-Bicocca and Università di Milano-Bicocca, Milano, ITALY													IT							IT		
INFN Sezione di Padova and Università di Padova, Padova, ITALY		IT								X										IT		
INFN Sezione di Pavia, Università di Pavia and Università di Bergamo, Pavia, ITALY		X	TBPX TEPX																	IT		
INFN Sezione di Perugia and Università di Perugia, Perugia, ITALY	OT					TBPS								X				OT		OT		
INFN Sezione di Pisa, Università di Pisa and Scuola Normale Superiore di Pisa, Pisa, ITALY	IT			TBPX TEPX			TBPS	TBPS	TBPX				OT	X		X				OT	IT	
INFN Sezione di Torino, Università di Torino and Politecnico di Torino, Torino, ITALY		IT					TBPX TEPX	TBPX TEPX	TBPX				IT							IT	IT	

TRACKING SYSTEM TIMELINE
2017 2018 2019 2020 2021 2022 2023 2024 2025 2026
Q1 Q2 Q3 Q4 (each year)
TDR Submission
OUTER TRACKER
OT EDR
OT Installation
Construction: Design, Prototyping, Pre-production, Production

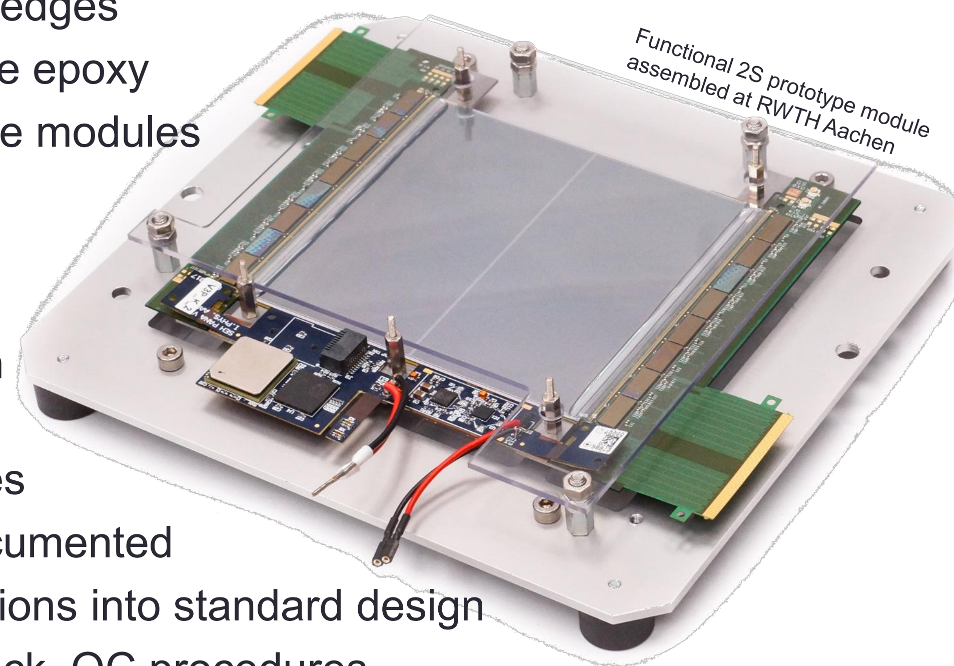
Assembly procedures for 2S modules

- Dedicated fixture for each assembly step designed at CERN
- Sensors are aligned using physical edges
- Parts stay in fixture overnight to cure epoxy
- CERN built 5 functional 2S prototype modules
- Other centers are implementing the same procedure
- KIT, RWTH Aachen, Fermilab have built one functional 2S module each
- Precision and HV specifications were met for all functional prototypes

➔ Assembly well established and documented

➔ Need to feed back fixture modifications into standard design

➔ Define metrology for alignment check, QC procedures



Functional 2S prototype module assembled at RWTH Aachen

Fixture based PS assembly

- Dedicated fixture for each assembly step
  - Design based on 2S fixtures designed at CERN and adapted for PS modules
- Sensors are aligned using physical edges
- Parts stay in fixture overnight to cure epoxy
- Brown University has assembled several dummy PS modules and Princeton has wirebonded them
- Bari and Perugia are also implementing a fixture based assembly
- Precision specifications have been met for all dummy modules; HV cannot be tested

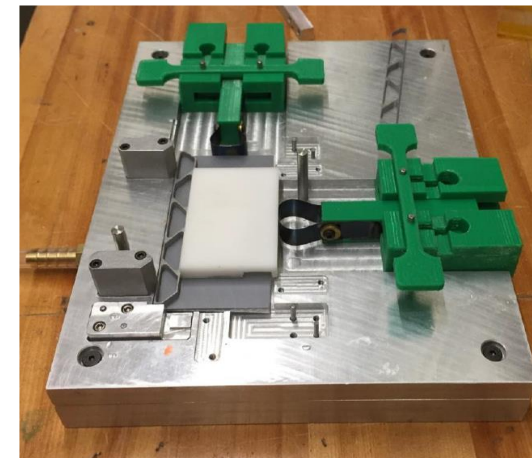
➔ Basic procedures exist

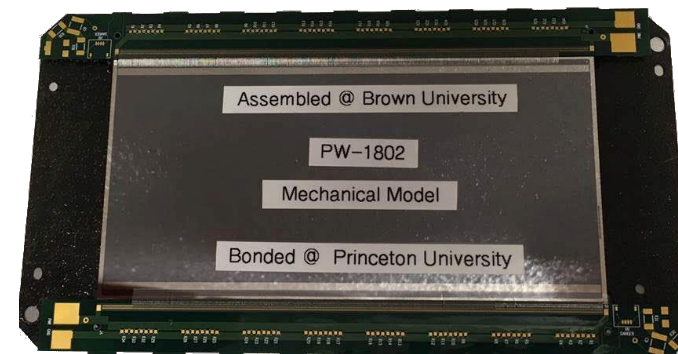
➔ Kapton glueing needs to be tested

➔ Need to document, standardize fixture design

➔ Define QC procedure

Assembly fixture at Brown University

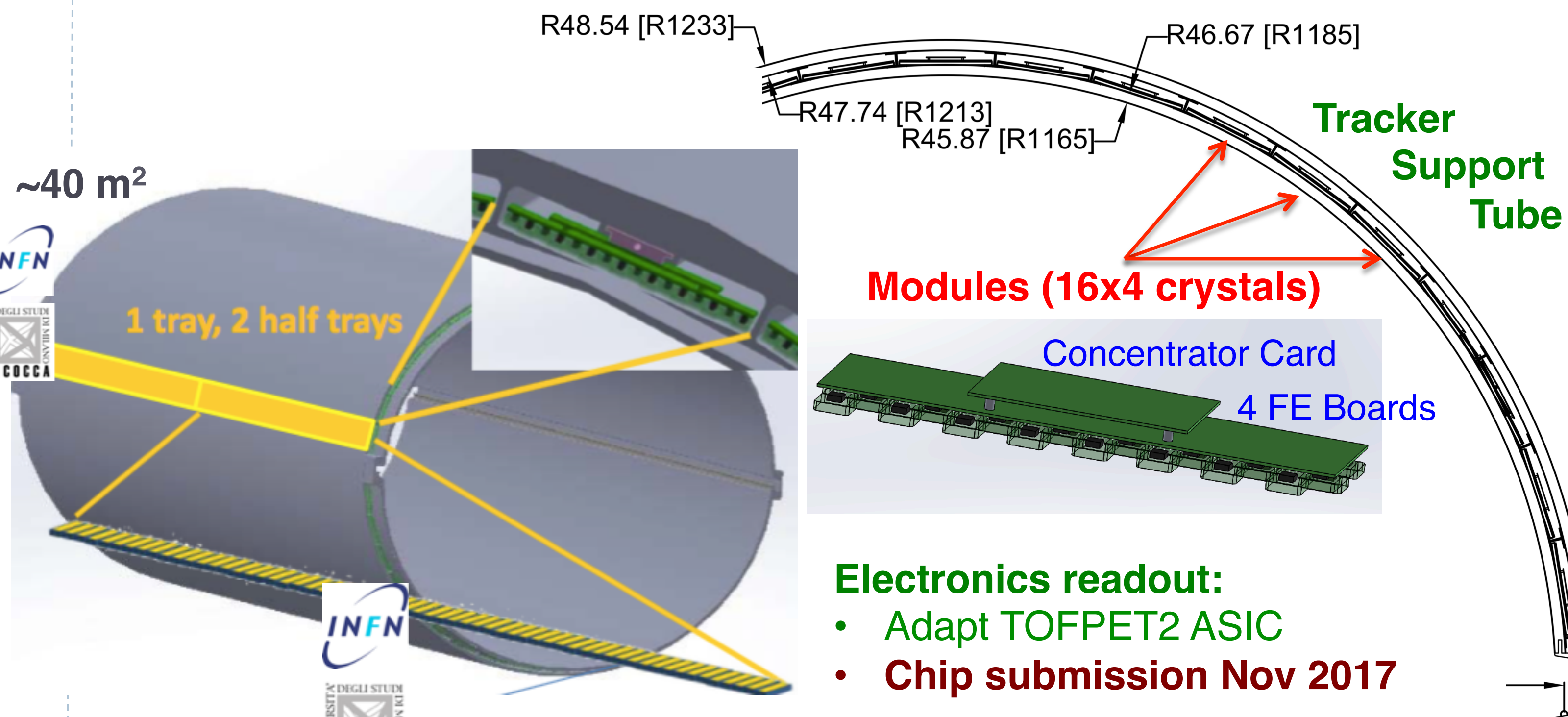




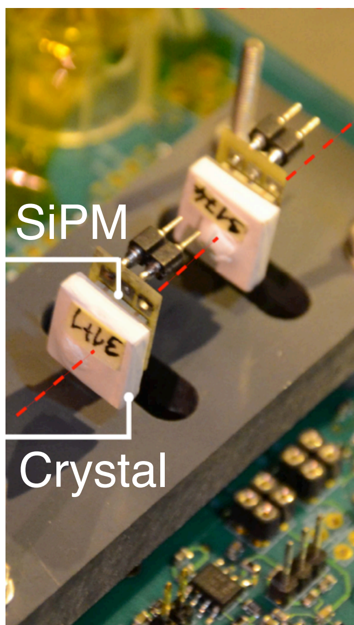
Dummy PS module assembled at Brown University and wirebonded at Princeton University

Barrel MIP Timing Detector

- **LYSO crystals + SiPM embedded in the Tracker tube**
  - Ready before TK integration (mid 2022)
  - Maintain performance at radiation level **2×10^{14} n_{eq}/cm^2**



Electronics readout:
- Adapt TOFPET2 ASIC
- **Chip submission Nov 2017**



Test Beam LYSO:Ce (CPI) 10x10x3 mm - HPK 6x6 mm

uncorrected

amp. walk correction

R_{BS} < 2.0 mm

σ_{CT}^{gaus} = (47.9 ± 1.0) ps

σ_{CT}^{gaus} = (30.6 ± 0.6) ps

σ_T^{single} ~21 ps

Counts

PRELIMINARY Simulation: Crystal 12x12 + SiPM 4x4 + glue - thick4

σ_t [ps]

PDE = 10 %
PDE = 15 %
PDE = 20 %
PDE = 25 %
PDE = 30 %

FBK4x4 +1.5V
*FBK3x3 +1.5V
HPK4x4 +1.5V
HPK4x4 +2V
*HPK3x3 +1.5V
*HPK3x3 +2V

DCR [counts per second] $\times10^9$

) + 4x4 mm² SiPMs
ms
SiPMs
k rate)

.IMINARY Simulation: Crystal 12x12 + SiPM 4x4 + glue - th

PDE = 10 %
PDE = 15 %

Endcap MIP Timing Detector

Endcap sensors (ultra-fast Si detectors)

Nominal geometry: 4.8 x 9.6 cm² modules with 1x3 mm² sensors

16 ASICs bump-bonded to sensors

3:1 ganging in the TDC at small η (3x3 mm² granularity)

Single sensors shown to have $\sigma_t \leq 50$ ps up to 10^{15} n_{eq}/cm²

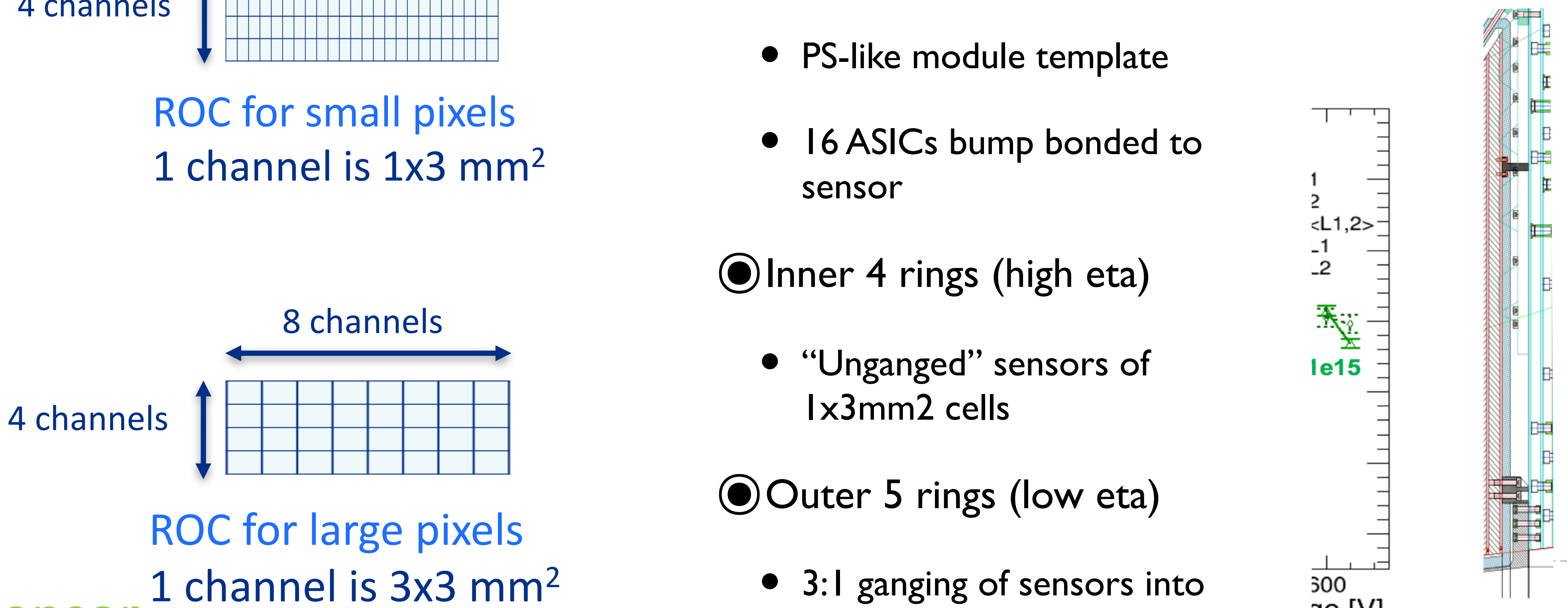
Readout ASIC in development

Choice of an ETL Reference Design

Fermilab

Fermilab

- Readout parameters constrained



sensor

Fermilab

Lindsey Gray, FNAL

1 channel is 3x3 mm²

- 3:1 ganging of sensors into 3x3 sensors

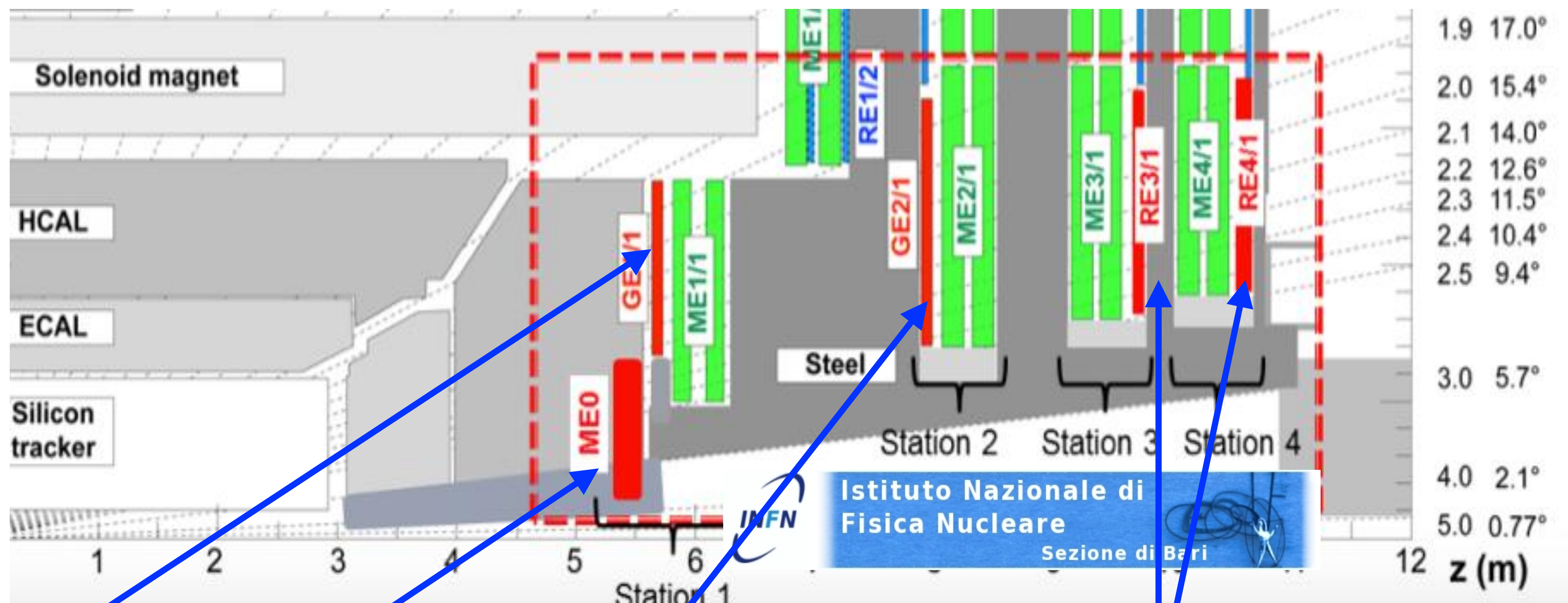
sensor

Fermilab

Lindsey Gray, FNAL

Parameter	**Nominal**	**HL-LHC**
Bunch population N_b [10^{11}]	1.15	2.2
Number of bunches	2808	2748
Beam current [A]	0.58	1.12
Stored Beam Energy [MJ]	362	677
Full crossing angle [μrad]	285	590
Beam separation [σ]	9.9	12.5
Min β^* [m]	0.55	0.15
Normalized emittance ε_n [μm]	3.75	2.5
r.m.s. bunch length [m]	0.075	0.081
Virtual Luminosity (w/o CC) [10^{34} cm^{-2}s^{-1}]	1.2 (1.2)	21.3 (7.2)
Max. Luminosity [10^{34} cm^{-2}s^{-1}]	1	5.1
Levelled Pile-up/Pile-up density [evt. / evt./mm]	26/0.2	140/1.25

μ system upgrade

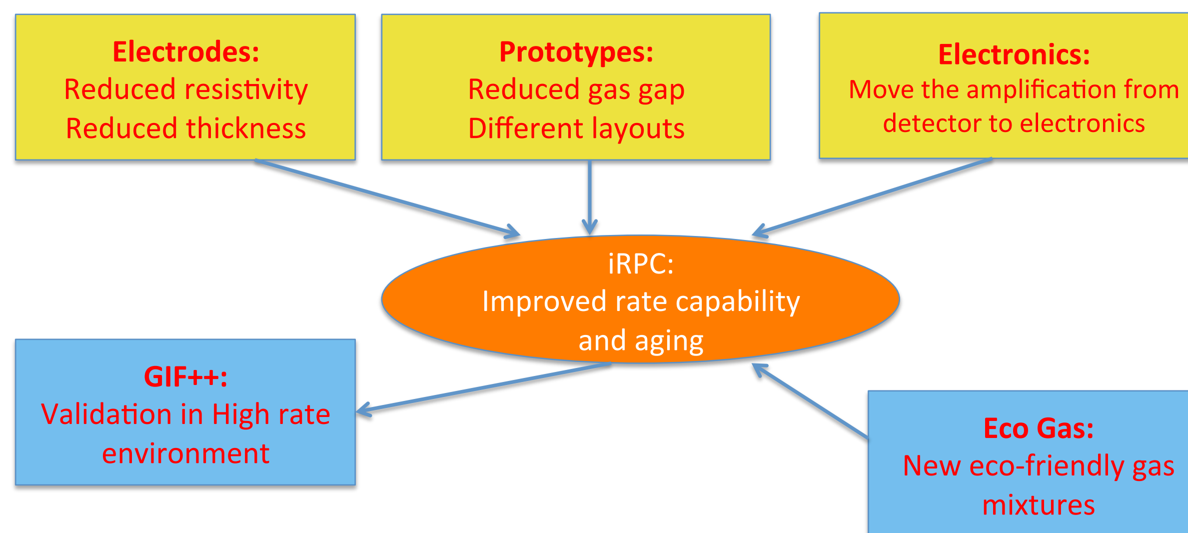


GE 1/1 : “triple GEM” (Gas Electron Multiplier) chambers
inst. LS2

MEO: MUON tagger high η (η < 2.8)
GEM chambers
inst. July 2024

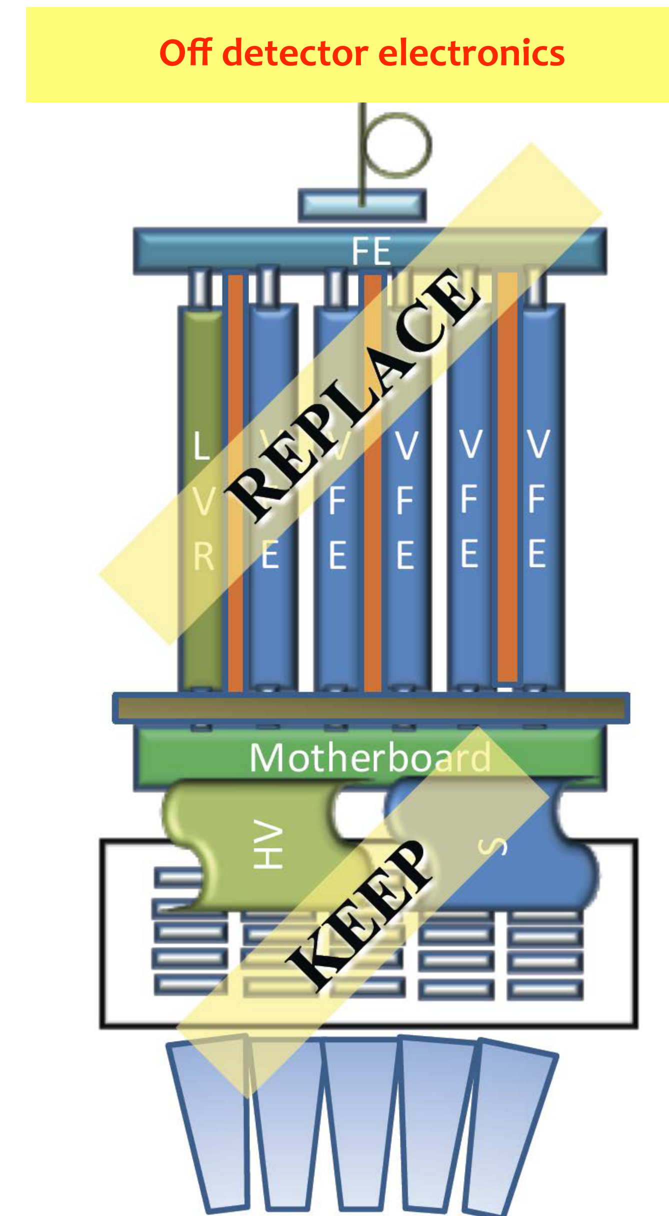
GE2/1: 1.6 < η < 2.4
installation: YETS 2022
“triple GEM” . Alternatia: *μ*-RWELL

RE3/1, RE4/1 “improved RPC”



ECAL barrel upgrade

- Sostituzione completa del VFE
  - per soddisfare le nuove L1 trig latency e L1 accept rate
  - uso di Versatile link con GigaBit Transceiver (GBT) per mandare informazione dai singoli cristalli al Trig L1 (trigger primitive off-detector)
  - mitigazione dell'effetto degli spikes
  - nuovo amplificatore ottimizzato per timing di precisione
    - ✓ possibili ~30ps su γ da 25GeV
- raffreddamento a 8 C
  - mitigazione dark-current negli APD

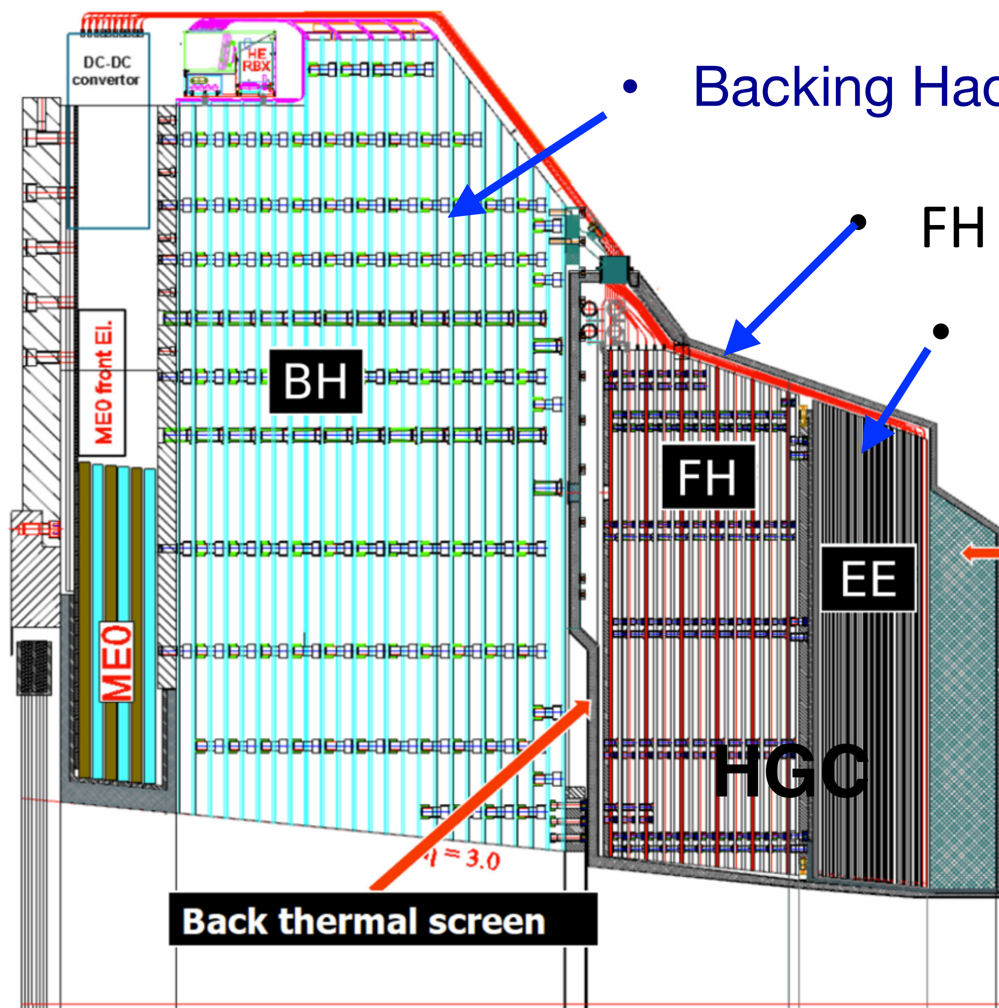


PATRIZIA BARRIA UNIVERSITY of VIRGINIA

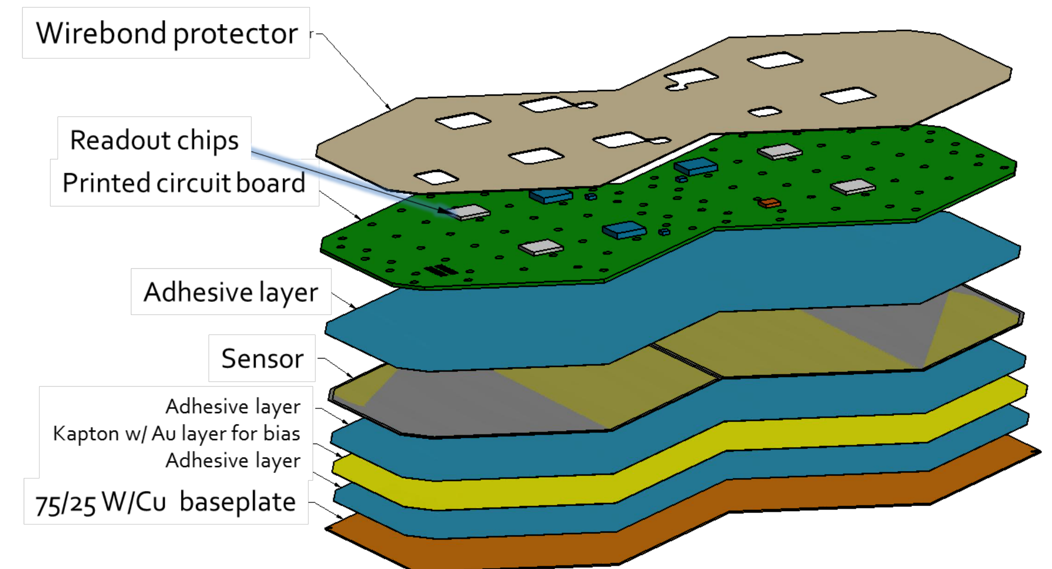
Endcap Calorimeter

- Dose e fluenza → danno troppo elevato a e cristalli → Sostituzione completa di Endcap Calorimeter
- ~50 ps timing (cell level) for pile-up rejection
- specializzato nella misura di jets, τ-jets, boosted jets, VBF jets

- *593 m^2 di silicon*
- *6M canali, celle di 0.5-1 cm^2*
- *52 layers*
- *21,660 moduli (sensori 8” o 2x6”)*



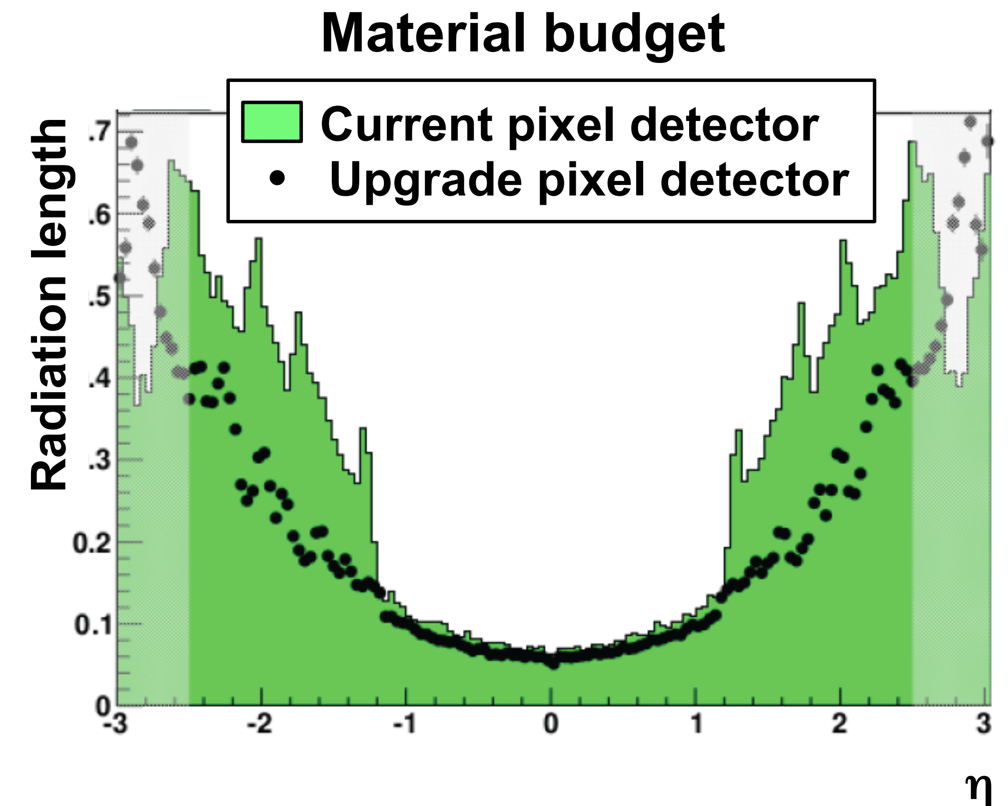
- Backing Hadronic: (5.5 λ) → 12 layers di Scintillatore/ottone
- FH :parte adronica: (3.5 λ): 12 layers di Silicio/ottone
- parte e.m. (25 X_0, 1.5λ): 28 layers di Silicio con assorbitore W/Cu

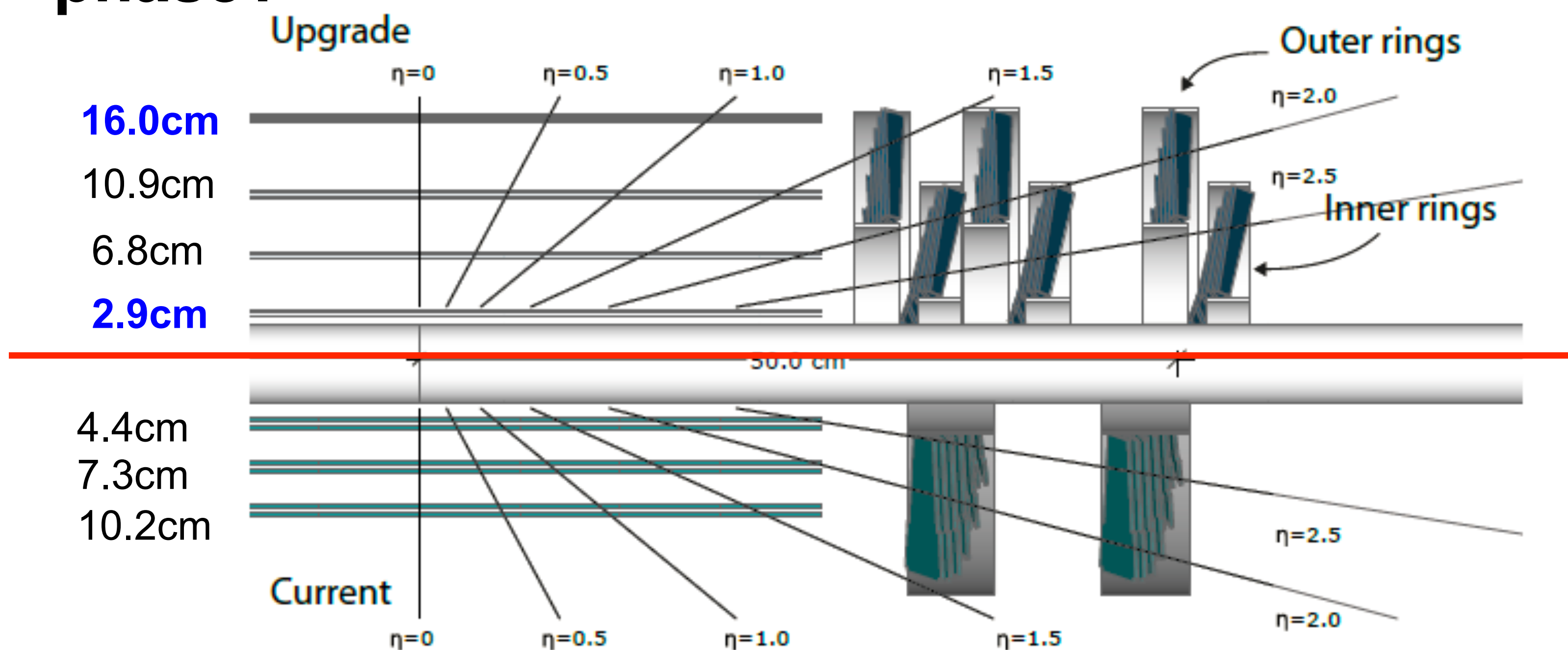


-30 °C

Il rivelatore pixel di fase1 di CMS

- necessario per operare efficientemente alle luminosità previste per il RUN3 (~ 2.0 E34 Hz/cm2), fino a L_int~500 fb^{-1}
- accettanza estesa:
  - 4 layer barrel, 3 dischi → migliorata risoluzione in IP e efficienza HLT
- riduzione material budget → nuova meccanica di supporto e nuovi servizi:
  - DC-DC power, μ-channel cooling bifase a CO2





- sensori n^{+}-in-n 100x150 μm2
- r/o chip con tecnologia a 0.25μm:
  - FPIX e layers 2,3,4 di BPIX: PSI46dig (fino a 120 MHz/cm2)
  - BPIX layer 1: PROC600 (fino a 600 MHz/cm2)