Future Accelerator Challenges

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White Paper of CSN1


ISTITUTO NAZIONALE DI FISICA NUCLEARE
Laboratori Nazionali di Frascati
FRASCATI PHYSICS SERIES

INFN Commissione Scientifica Nazionale 1 (CSN1)

What Next: White Paper of CSN1

Proposal for a long term strategy for accelerator based experiments

Editors
F. Bedeschi, R. Tenchini, J. Walsh

- **Executive Summary**
  of the Executive Summary:
  - There is a self-consistent Standard Model…
  - …and evidence of new physics at cosmological scale.
  - Little clues on which is the fundamental interaction behind:
  - **Rich set of ideas to probe:**
    - Need to set ***priorities***
    - Make the transition from ***ideas*** to ***proposals***.

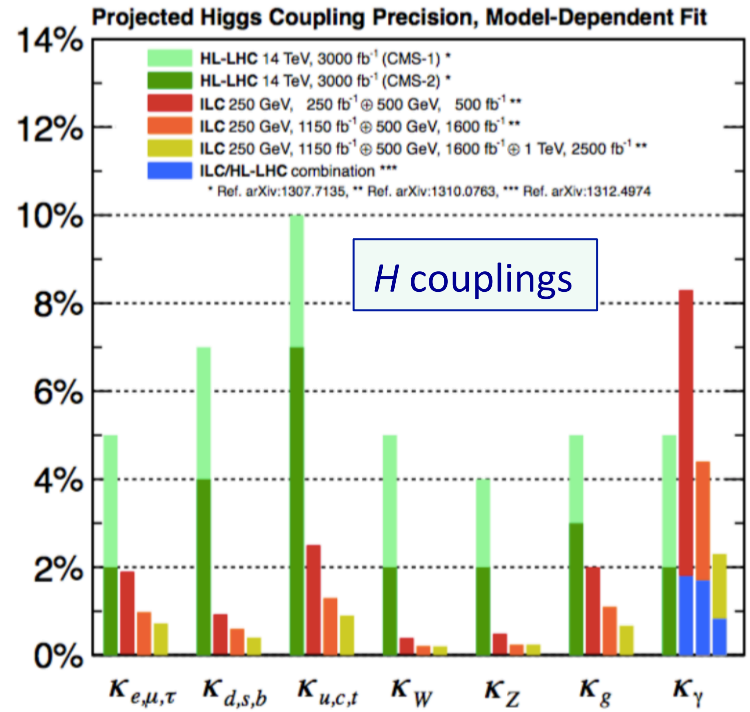
Next few slides are my personal poor attempt to summarize the document outcome

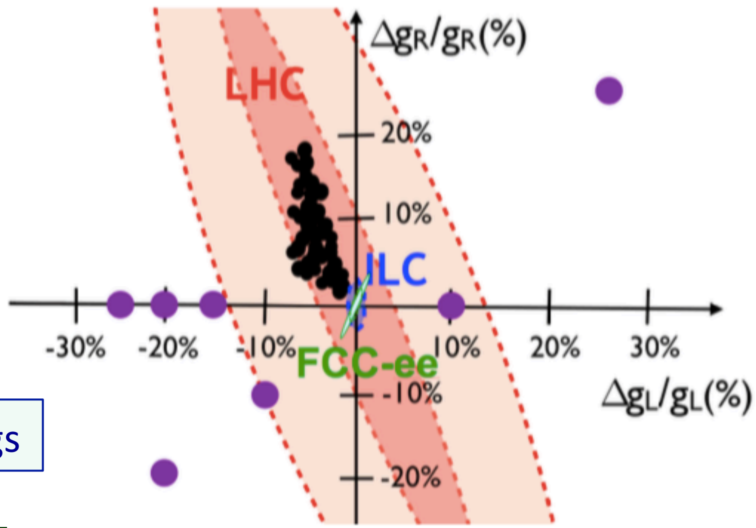
Standard Model

- Higgs boson properties
- Top properties
- Vector boson scattering

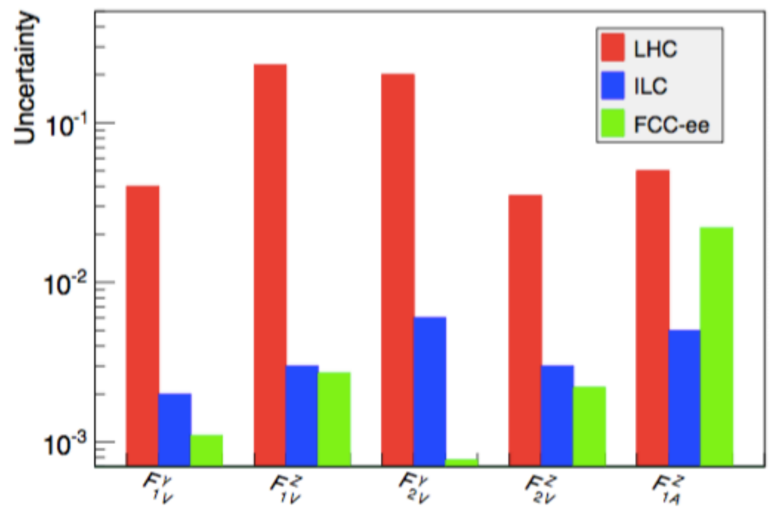
Measurement of SM processes IS search for NP

- HL-LHC is the first step in this program
- Further improvements require an electron-positron collider



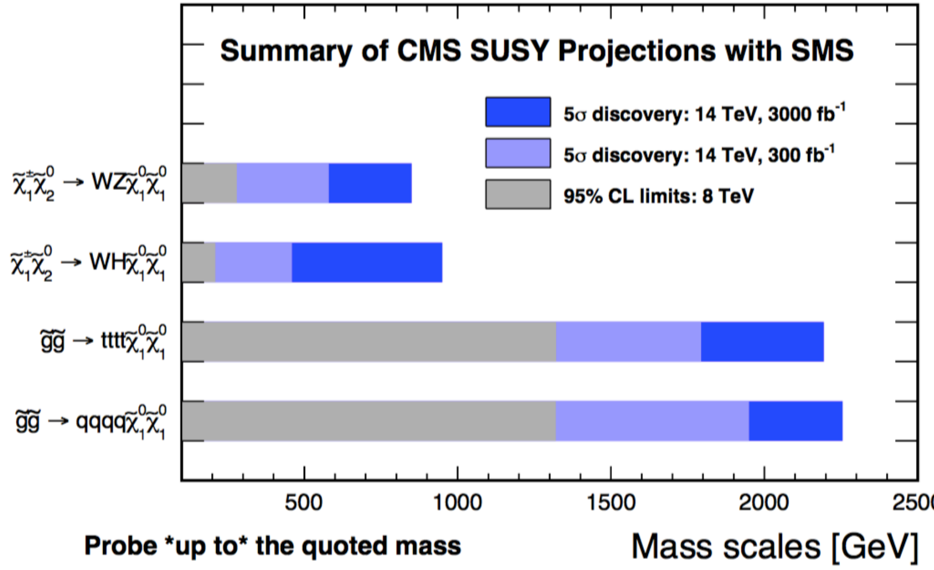


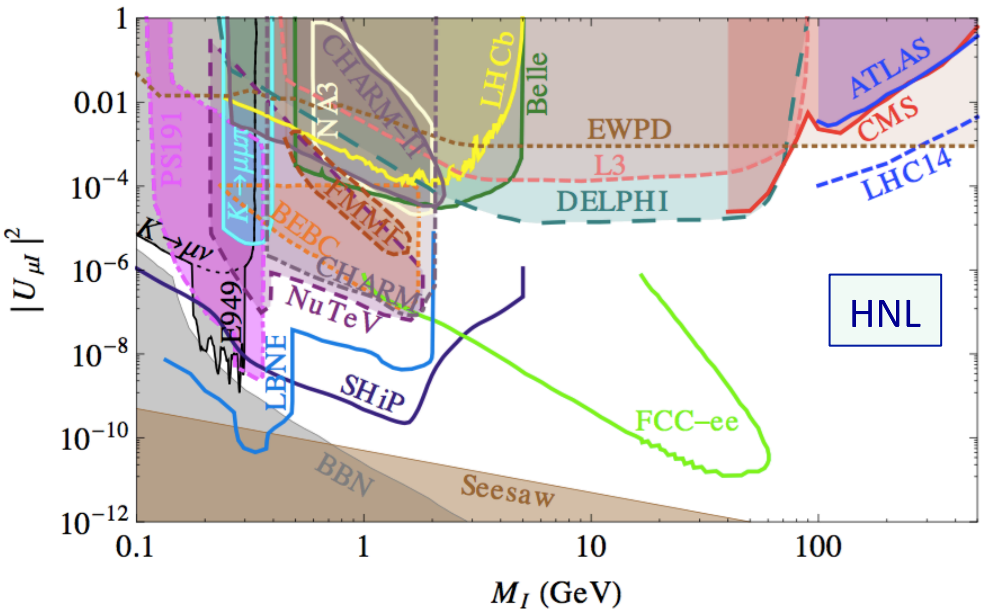
Ztt couplings

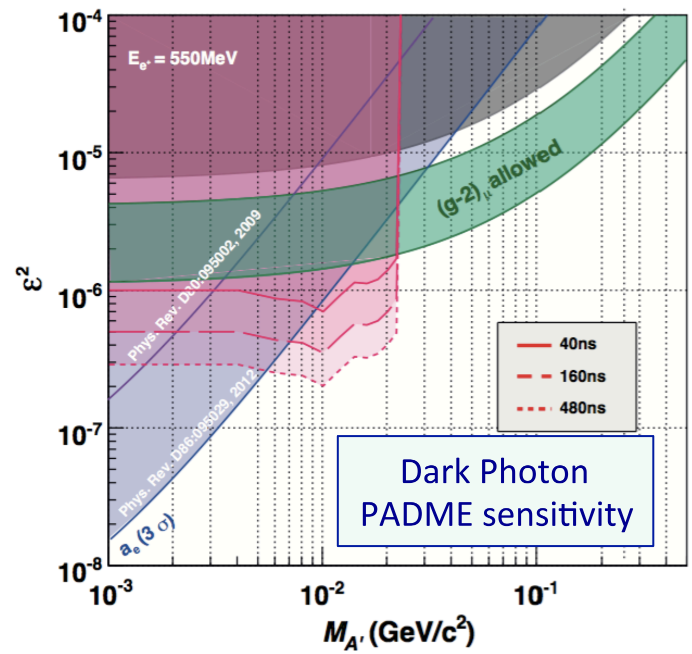


Direct search for new particles

- High-mass, EW / Strong couplings
  - SUSY, Technicolor, Dark Matter
  - HL-LHC + ILC@1 TeV / hh@100 TeV
- Low-mass, low coupling
  - Dark sectors @ fixed target experiment
  - Challenges are **beam intensities** and **background suppression**.

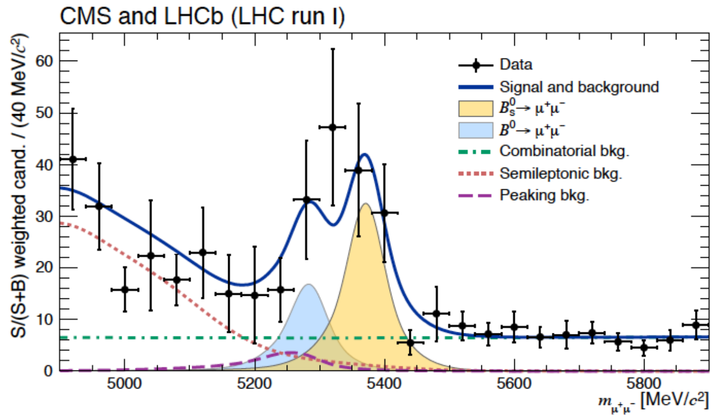


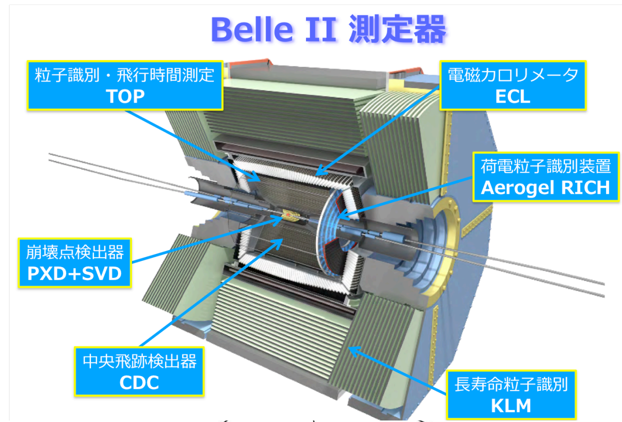


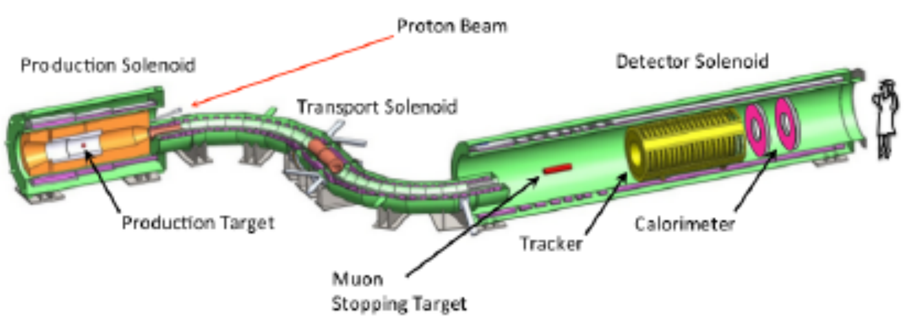


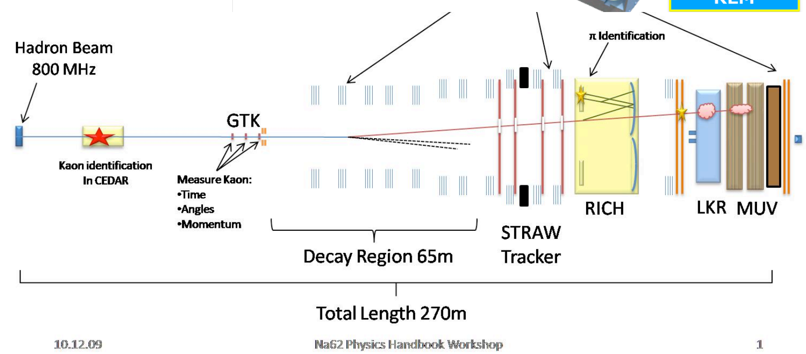
Flavour physics

- Probing new physics through
  - rare or forbidden decays, $K^+ \to \pi^+ \nu\nu$, $K^0_L \to \pi^0 \nu\nu$, Lepton Flavour Violation
  - and precision measurement of CKM matrix.
- Vast landscape of opportunities in the **next decade** from experiments **already running** or in **construction phase**.
- Further steps require to be able to manage
  - large statistical samples from high-luminosity colliders(10^{14} *b*-decays, 10^{15} *c*-decays)
  - high-intensity beams (10^{19} pot/year)









White Paper of CSN1

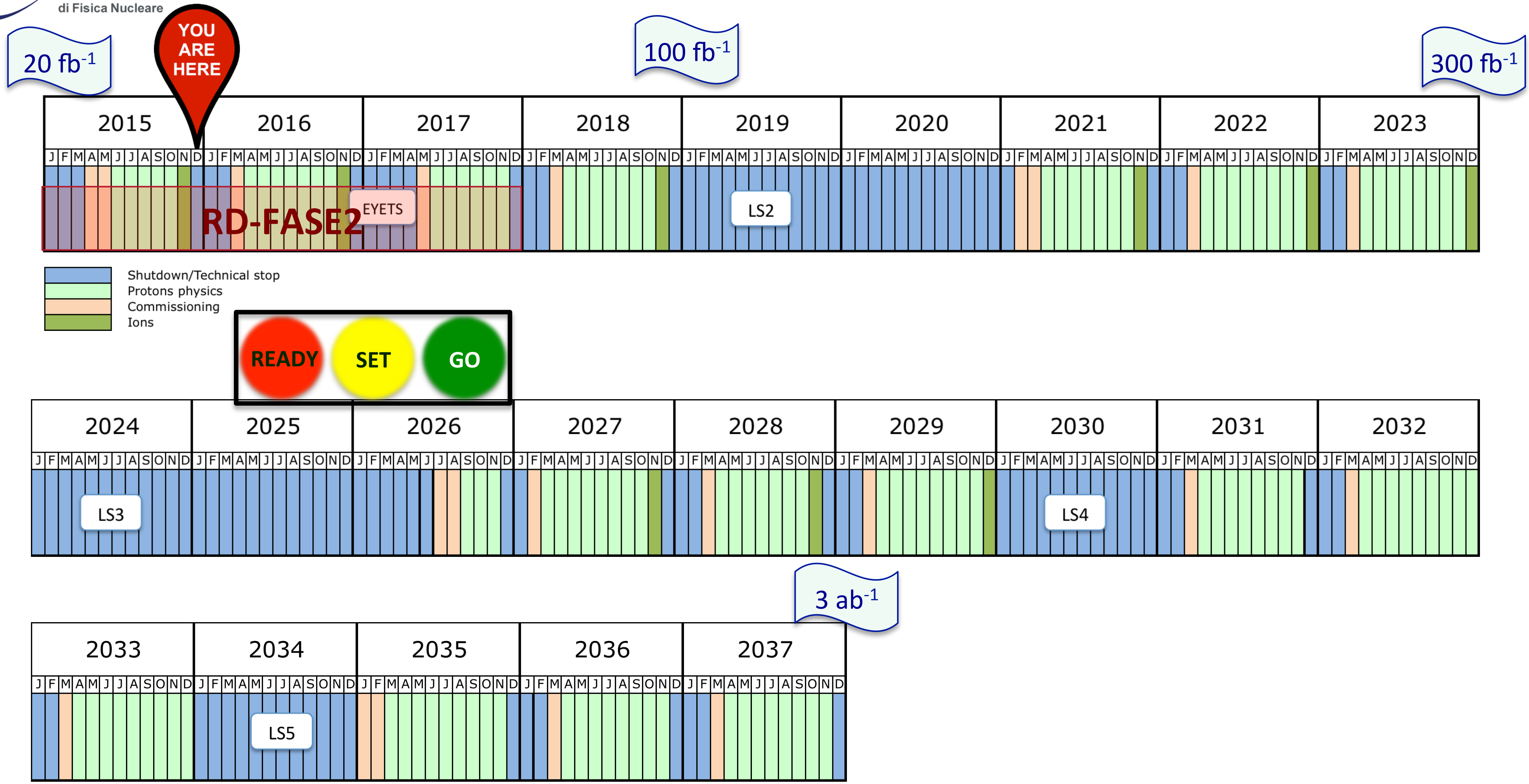
- Recommendation #6
  The ATLAS and CMS detector upgrades for HL-LHC are the highest priority of CSN1.
  - A lot of R&D plans presented at this workshop
  - Recommendation #3:
    We urge the experiments planned for HL-LHC to develop plans to deal with the computing issue. In particular efficient ways to reduce the data flow to storage should be studied by means of appropriate enhancements of their trigger and DAQ systems.

- Recommendation #5
  It is of great importance that well defined proposals be ready by mid-2017 to allow a realistic plan of how experiments at HL-LHC and other new CSN1 activities can coexist.
  - Physics: choices depending on the direction (or lack of directions) coming from the Run-2 of the LHC
  - Technology: development of new magnets, conventional and un-conventional accelerating techniques, **new detectors**, **DAQ**
  - Resources: host countries for future accelerators, INFN and extra-INFN funding, human resources

The first challenge

HL-LHC

HL-LHC Schedule

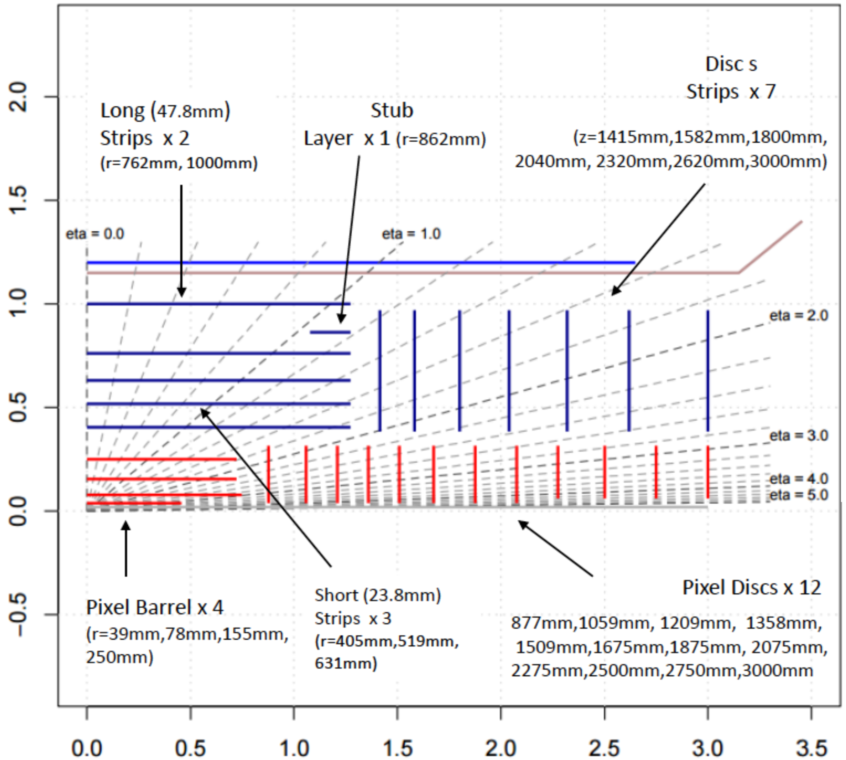


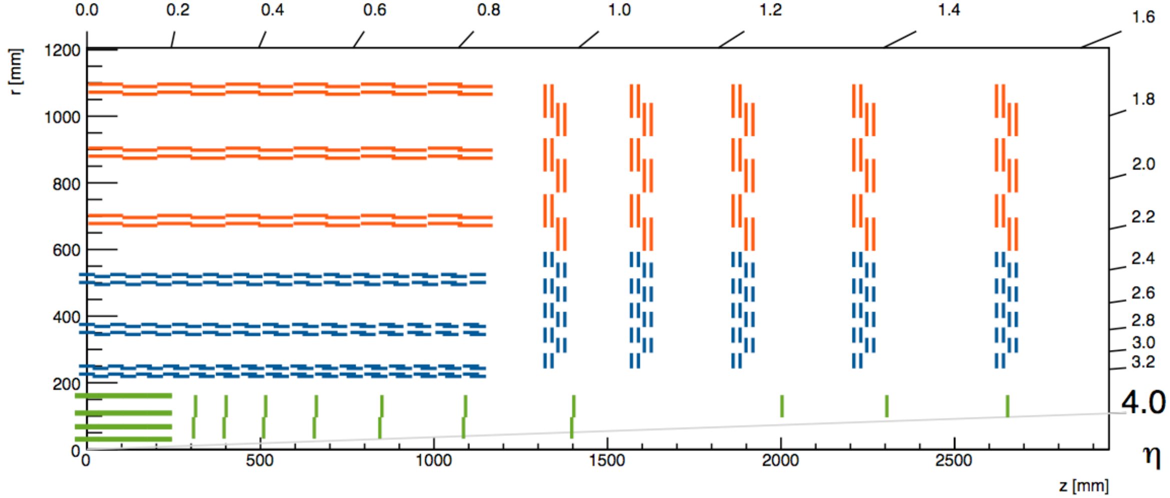
HL-LHC Performance Estimates

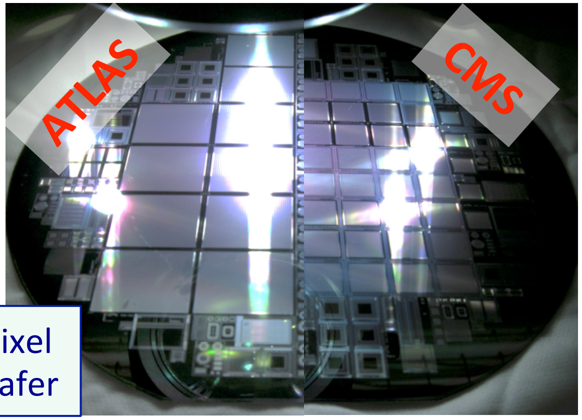
Parameter	Nominal	25ns – HL-LHC
Bunch population N_b [10^{11}]	1.15	2.2
Number of bunches	2808	2748
Beam current [A]	0.58	1.12
Crossing angle [μrad]	300	590
Beam separation [σ]	9.9	12.5
β^* [m]	0.55	0.15
Normalized emittance ε_n [μm]	3.75	2.5
ε_L [eVs]	2.51	2.51
Relative energy spread [10^{-4}]	1.20	1.20
r.m.s. bunch length [m]	0.075	0.075
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

G. Arduini, CSN1 30/09/2015

HL-LHC Trackers







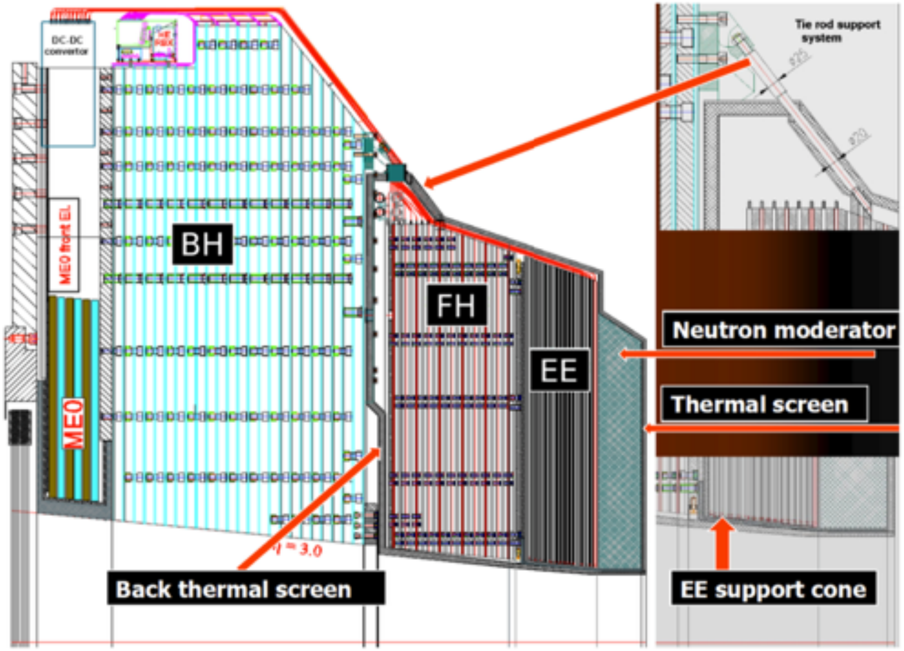
FBK planar pixel prototype wafer

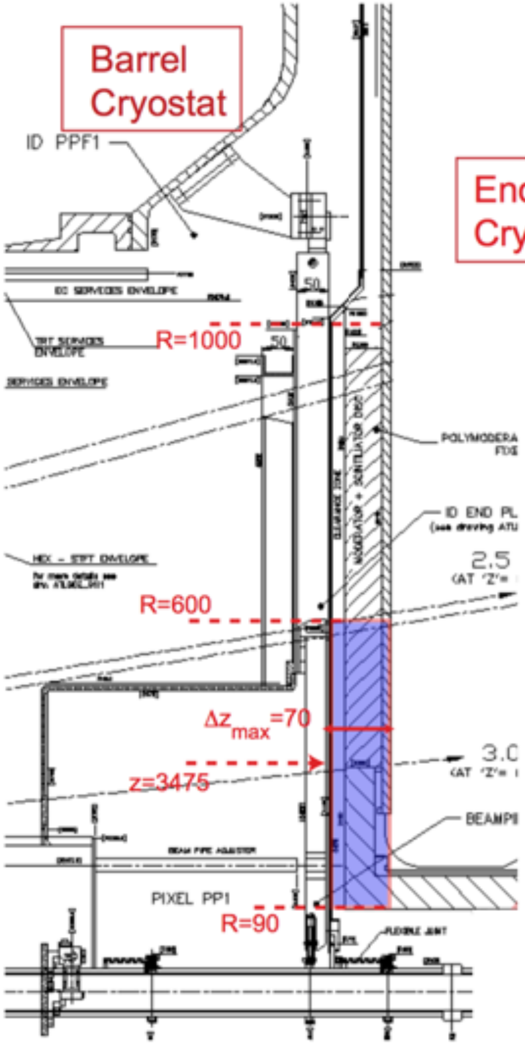
- Trackers completely redesigned
  - fluence 2×10^{16} cm^{-2}
  - extending coverage up to $|\eta|\sim4$
- INFN R&D concentrated in pixel detectors
  - 65 nm readout electronics
  - 25×100 or 50×50 μm^2
  - different technologies: planar, 3D, active edge, *HV-CMOS*

Talks by G. Della Betta, P. Giubilato, N. Cartiglia, M. Manghisoni

Calorimetry at HL-LHC

Talk by G. Gaudio & P. Meridiani, G. Collazuol



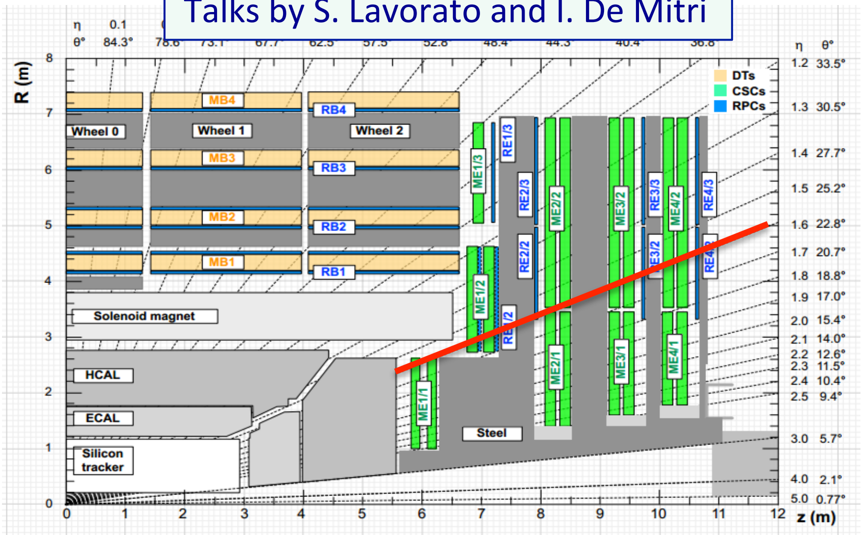


- High-granularity calorimeters foreseen in the forward region.
- Cope to 140 interaction pile-up (and match tracker extension)
- Most ambitious proposals aims to 10 × 10 mm^2 cell size or to **10 ps** time resolution

R&D for Forward Muon Systems

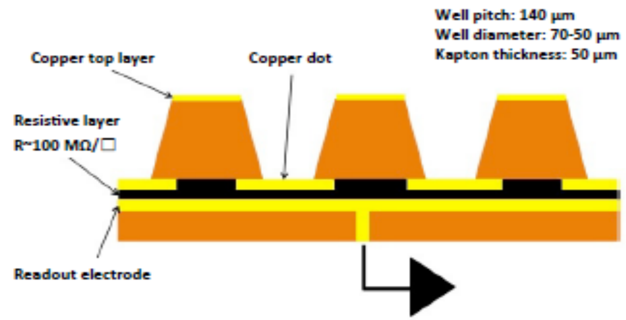
Talks by S. Lavorato and I. De Mitri

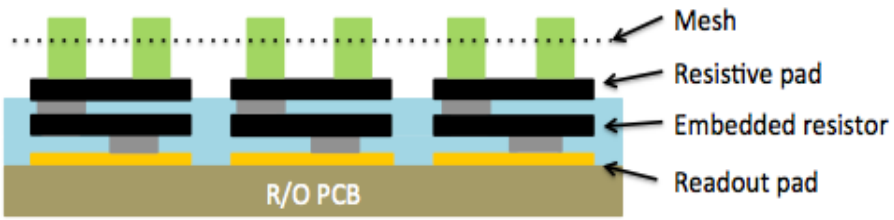
Forward region is most critical:
- **Highest rate** (also affecting trigger)
- **Detector Longevity**: large accumulated charge after years of LHC operation
- **Electronics Longevity**: electronics designed for phase-I occupancy and rates



New Resistive Plate Chambers (ATLAS/CMS)
- Electrode with lower resistivity (bakelite or glass)
- Reduced electrode thickness and multi-gap for **high time resolution**

Novel MPGD
- combining solutions and improvements proposed in the last years in the MPGD field (RD51): high spatial, time resolution and rate capability for large area detectors
- μ-Resistive Well (CMS): compact spark-protected single amplification stage MPGD
- Fast Timing MPGD (CMS): adding up the fast signals of the multi μgap preserving high rate capability and improve time resolution
- Small Pads Resistive Micromegas (ATLAS): 1 cm^2 – 2 mm^2 pad pattern with embedded resistors

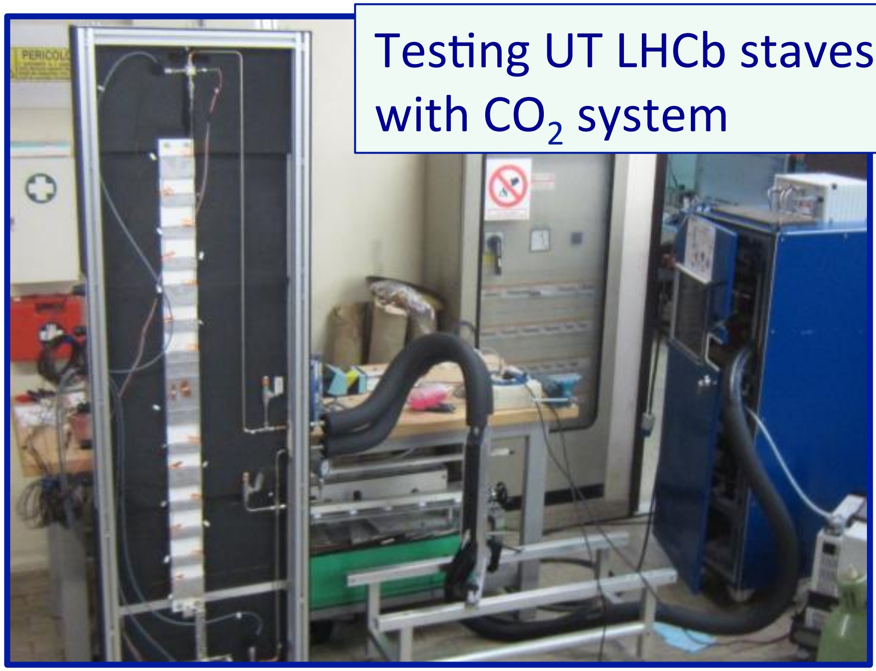


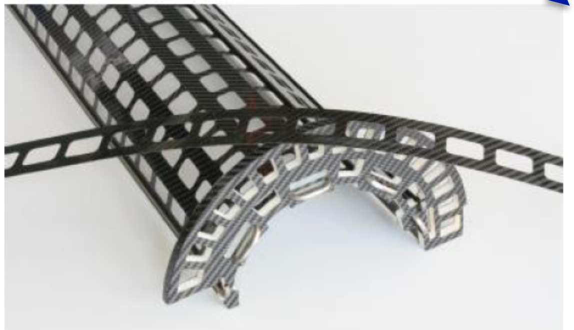


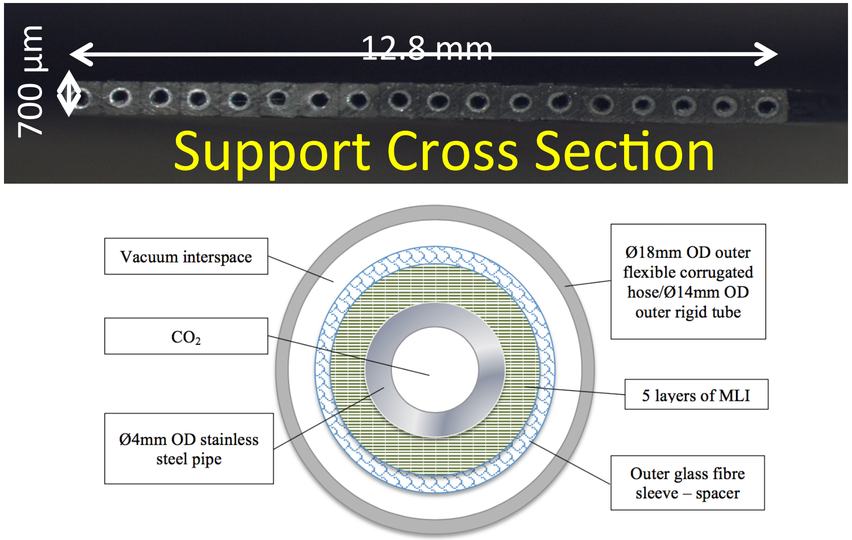
Services

- More radiation, more channels, more rate: **more stress on services**
- Serial powering to reduce number of cables
- Point-of-Load approach to power distributions
- CO_2 evaporative cooling to keep Si at ~-30 °C when quiescent
  - µchannel cooling, light pipes
- R&D for low mass mechanics

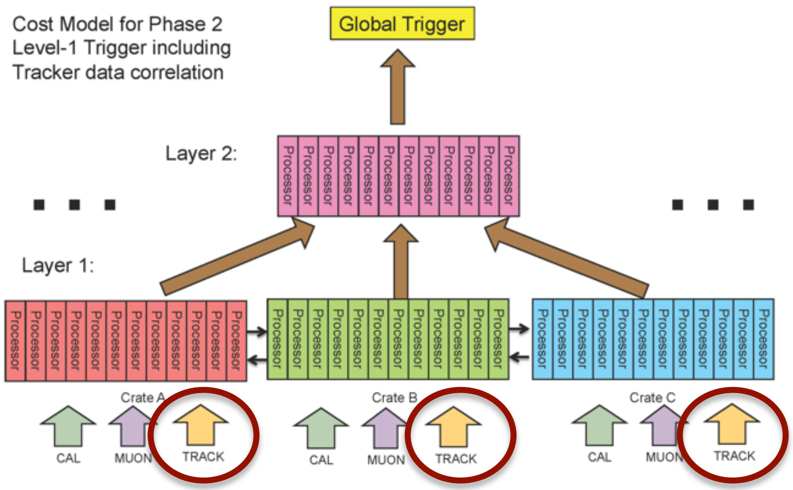
Testing UT LHCb staves with CO_2 system

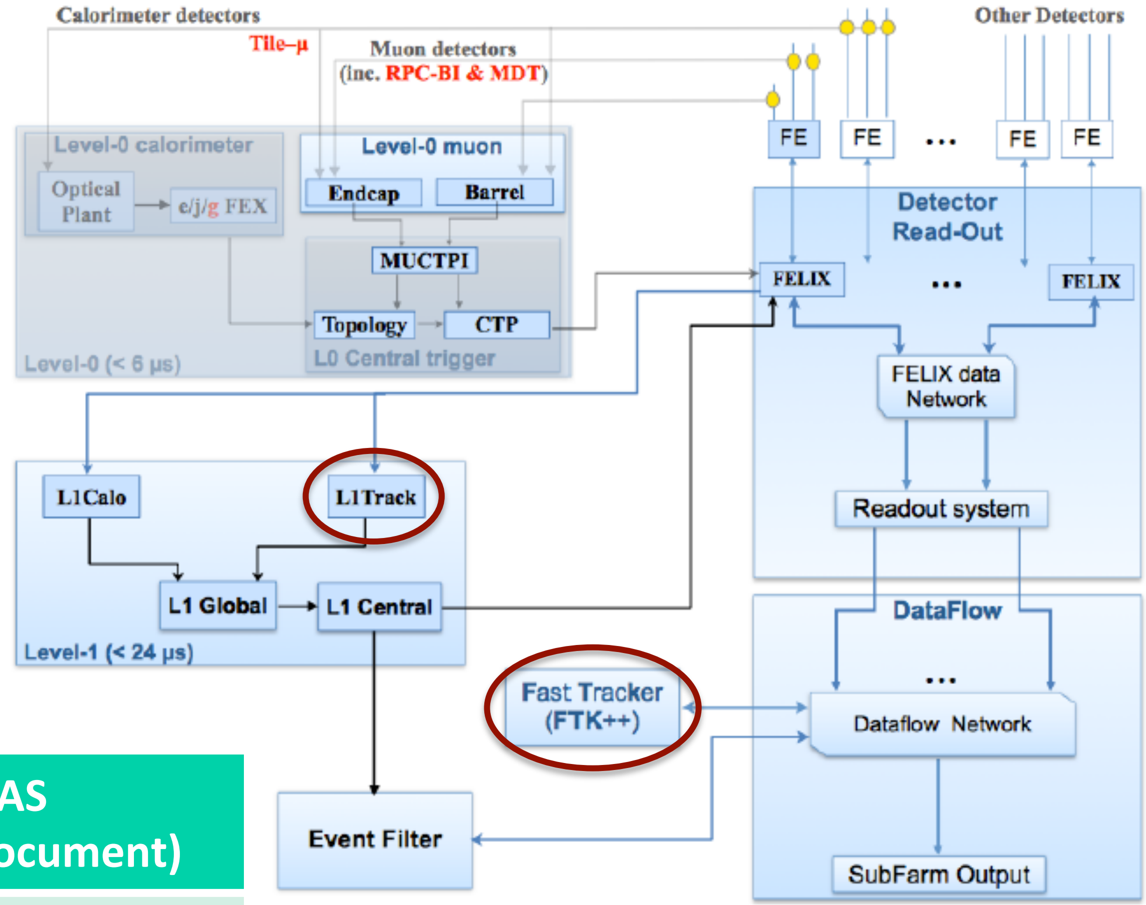






Trigger requirements





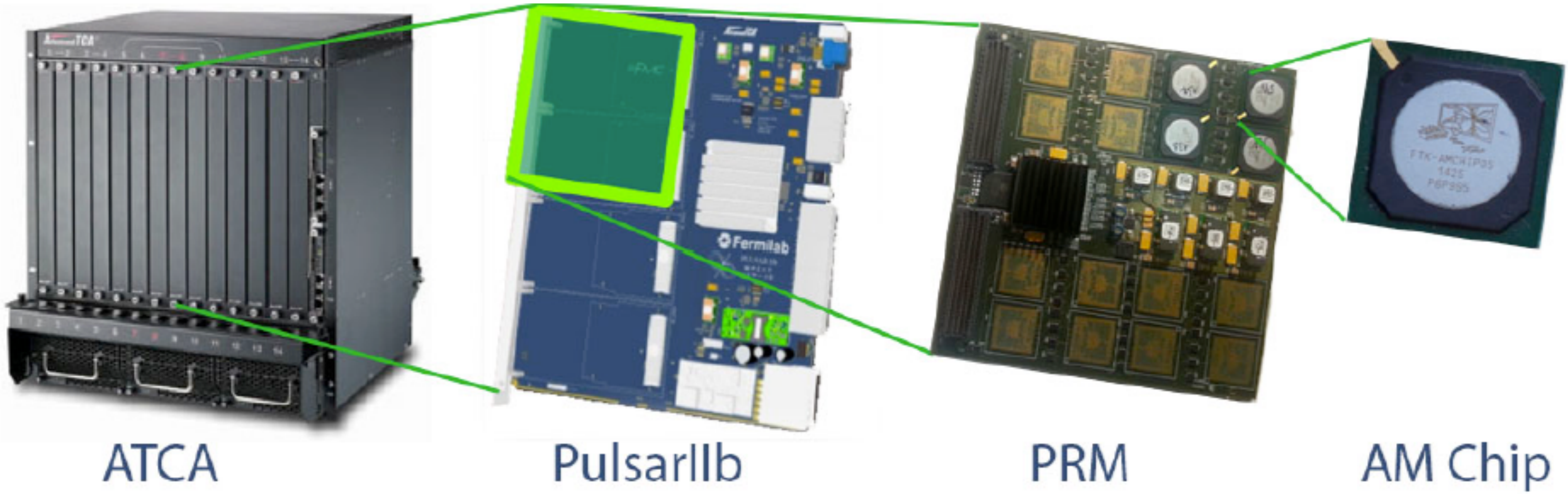
- Triggers are major upgrades for HL-LHC
  - Aim to keep same physics output
  - **L1 Track trigger** (pioneered by ATLAS FTK)

CMS (TP)	ATLAS (scoping document)
L1: 12.5 μs, 260 kHz (using track trigger)	L0: 6 μs, 1 MHz
	L1: 30 μs, 400 kHz
Event Storage: 7.5 kHz	Event Filter: 10 kHz

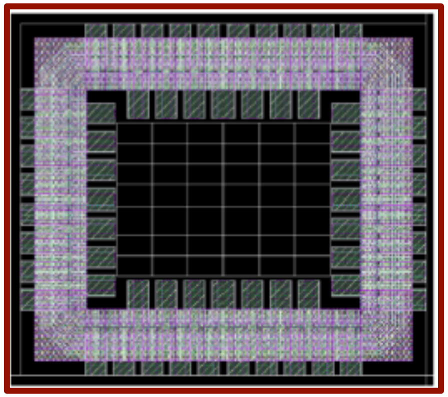
10× increase in saved events
3-4× increase in even size

Track trigger

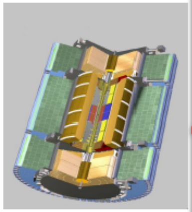
Talk by G. Punzi

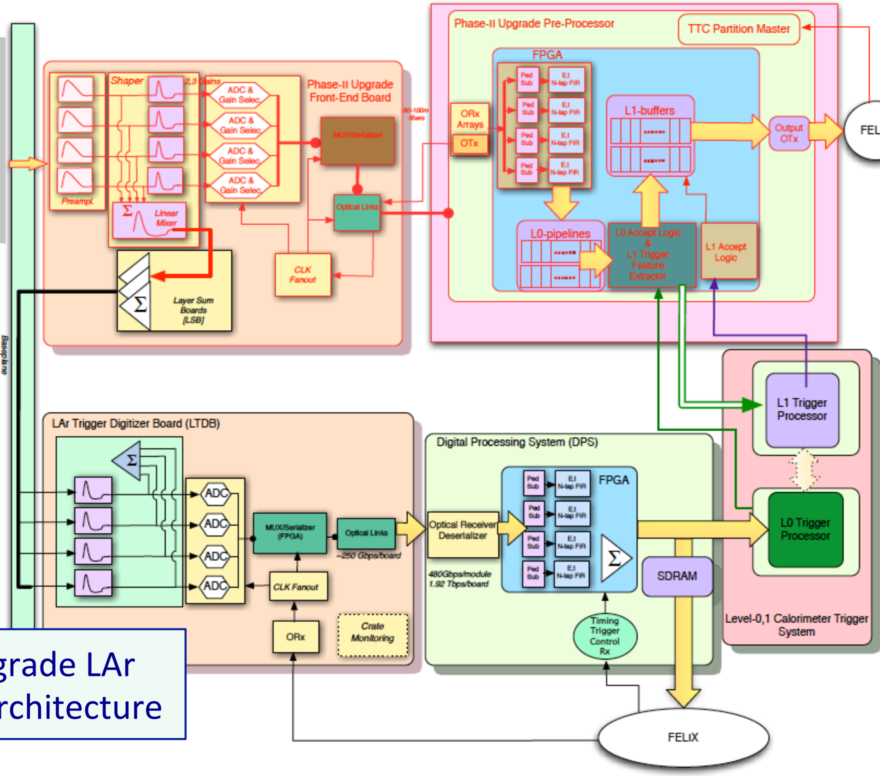


- Similar hardware model developed for both experiments
  - Pattern recognition in custom Associative Memory chips
  - Precision track fitting in FPGA
- First use case for HEP application of 28 nm electronic processes
  - 35% less **power** for same performance (W $MHz^{-1}bit^{-1}$)
  - 4× increase of pattern density

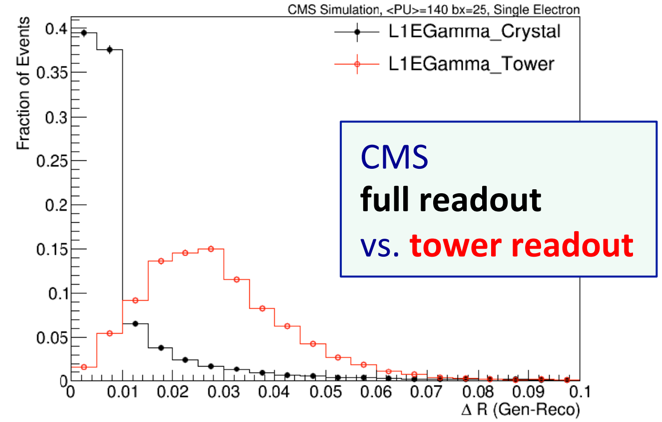


Readout electronics

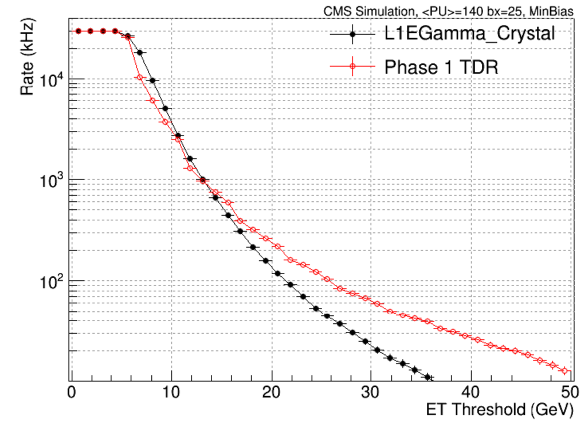




ATLAS upgrade LAr readout architecture



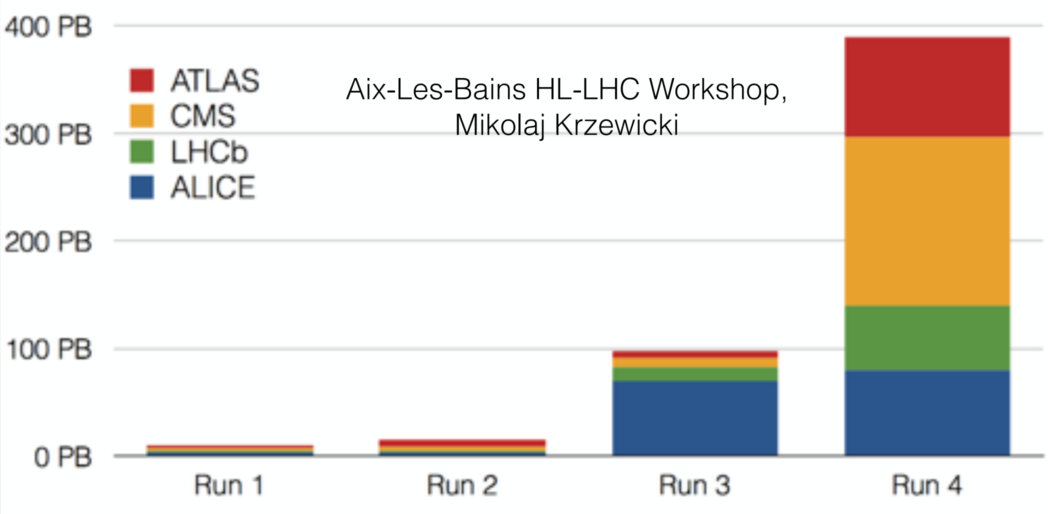
CMS **full readout** vs. **tower readout**



- Maintaining high performance at 10× the rate requires a generalized improvement of trigger electronics.
- Goal is to provide **thresholds and object quality** as **similar to offline reconstruction** as possible.
- Common issue for both calorimetric and muon systems
- **Example:** *electromagnetic calorimeters moving to maximum granularity readout*

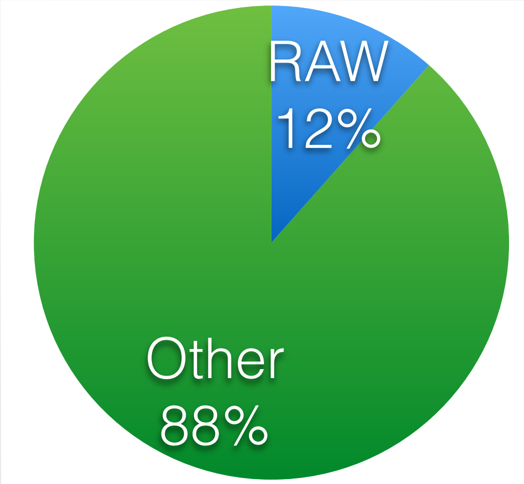
How to analyse HL-LHC data?

Istituto Nazionale di Fisica Nucleare



RAW data to offline for LHC experiments

Frazione di RAW data ATLAS includendo copie



Bisogno di CPU:
Run4/Run 1 > 100

- Evoluzione della tecnologia che permetteva di comprare ogni anno il doppio delle risorse allo stesso prezzo e' arrivata al limite e non aiuta. Da' una mano se si passa a sistemi paralleli.
- Non esiste una soluzione. Dobbiamo agire su vari fronti

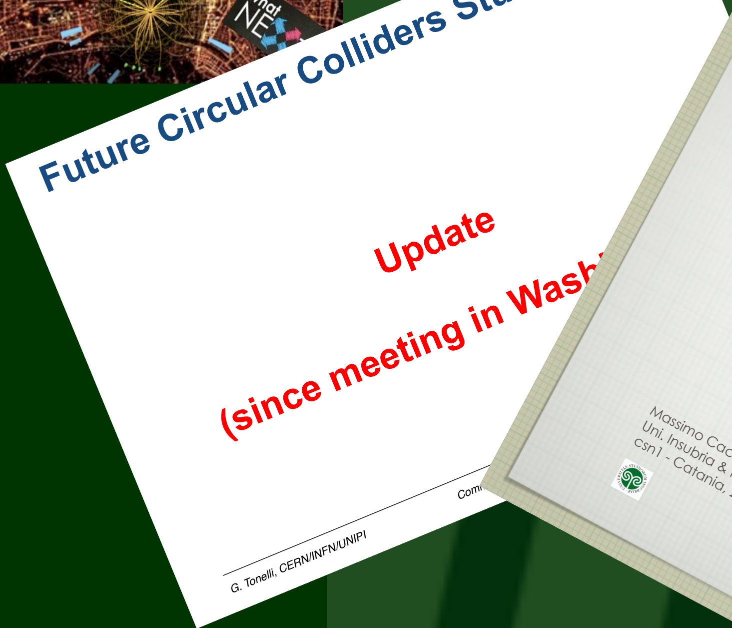
D. Lucchesi – Piano Triennale 2015

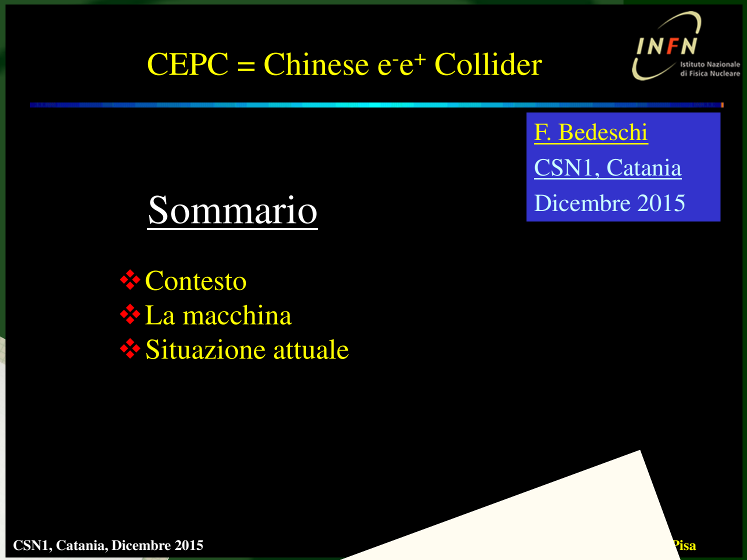
A new approach?

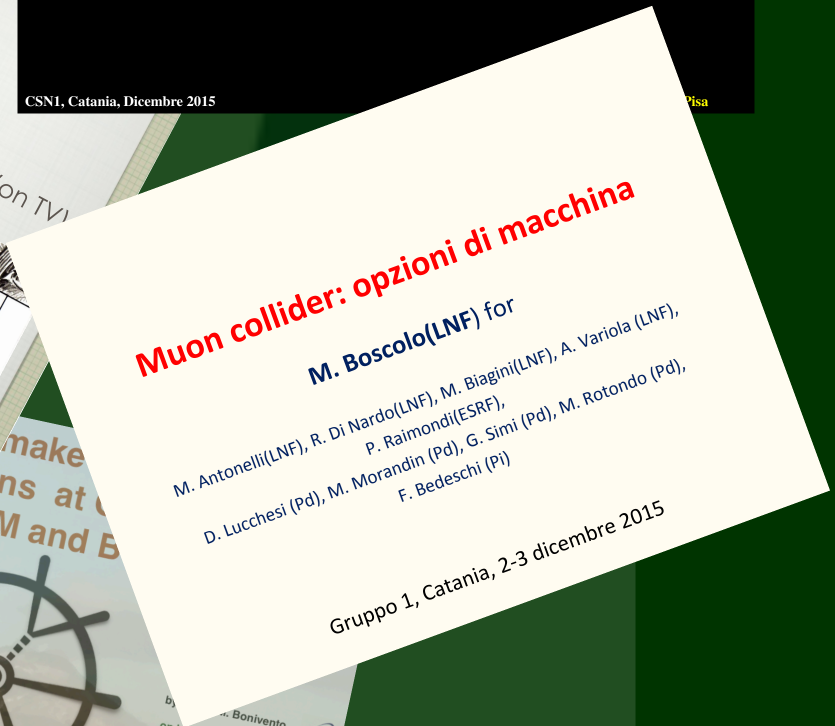
Cambiare la logica della raccolta dati

- Mole di dati raccolti troppo elevata per pensare di riprocessarli gia dopo il Run3. Serve scrivere RAW data?
- ALICE ha una farm di GPGPU per l'ultimo livello di trigger per ricostruzione veloce delle tracce. Parte degli eventi non interessanti non e' salvata
- LHCb studia una raccolta dati *trigger-less*, ricostruzione fatta in tempo reale su una farm di CPU (o mista con sistemi paralleli) permette una selezione degli eventi piu' raffinata e quindi efficiente

D. Lucchesi – Piano Triennale 2015







Just a couple of example

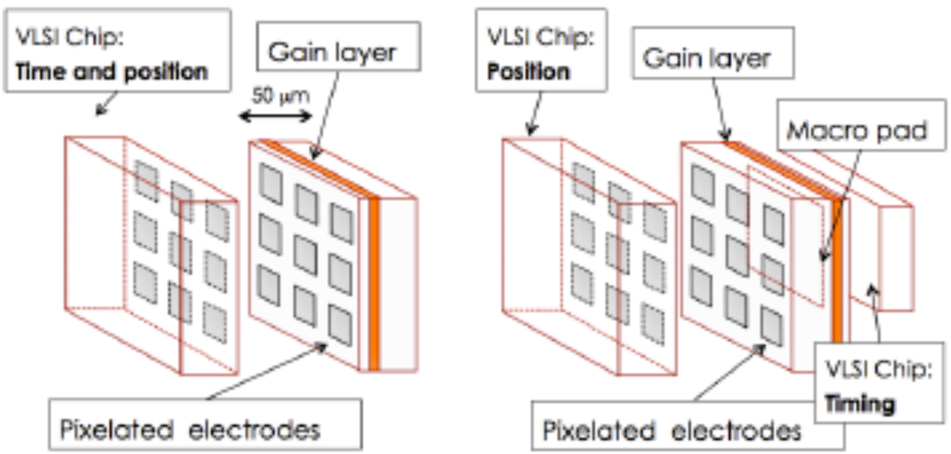
BEYOND HL-LHC

Extreme flavour experiment

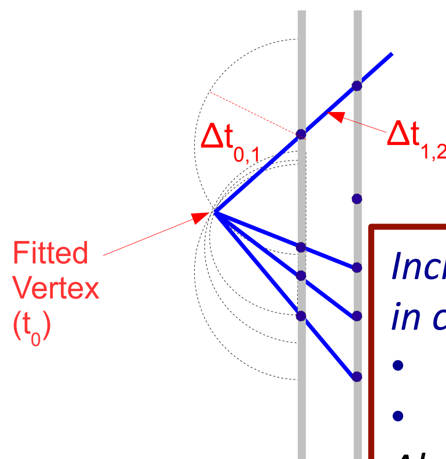
INFN Istituto Nazionale di Fisica Nucleare

- A way to push the intensity frontier, exploiting the full luminosity of hadron colliders:
  - A detector with strong online tracking capability
  - Readout at 40 MHz
  - Real time event reconstruction with offline-grade quality
  - On-line data analysis

Will this change of paradigm work?
- online detector calibrations
- systematic uncertainties
- ...but a way to address the computing limitations



Ultra Fast Silicon Detectors



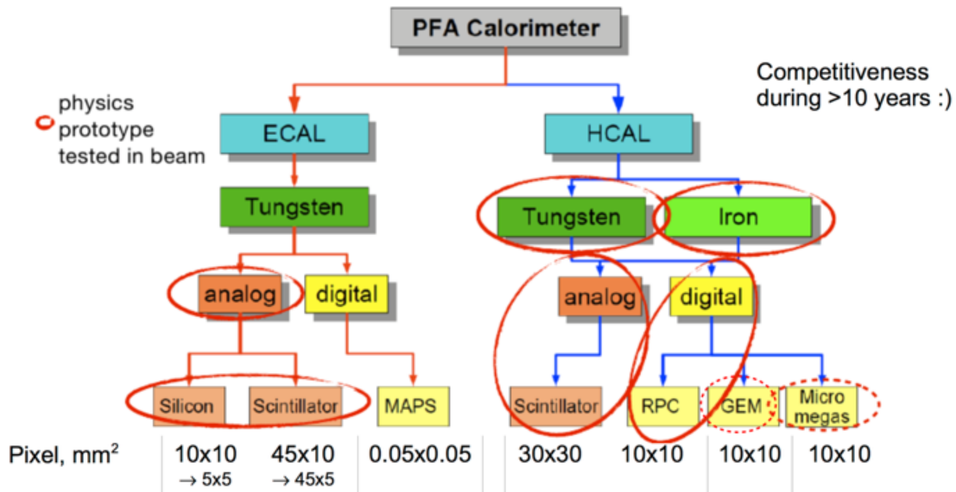
Real time tracking may exploit high time resolution tracking detectors

*Incidentally, **timing** is a big keyword in current R&D:*
- *mentioned on at least 3 slides*
- *and in many more talks*

Almost all the once cited + P. Lenzi

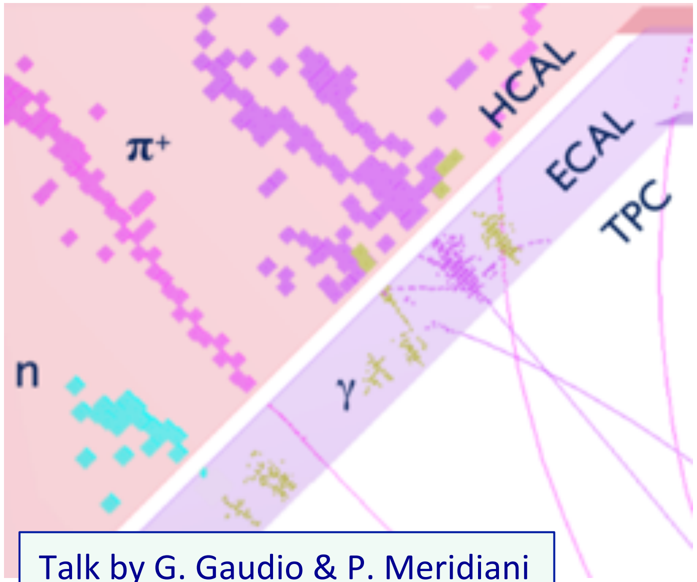
Lepton colliders

- e^+e^- colliders are the next feasible machines
- Targeting Higgs and Top physics
  - ILC or the FCC-ee CEPC incarnations
- Here challenge is to reach the best resolution:
  - Particle flow calorimeters
  - very low mass pixelated vertex detectors



Technology	Examples	Small pixels	Low mass	Low power	Fast timing
Monolithic CMOS MAPS	Mimosa CPS	++	++	++	-
Integrated sensor/amplif. + separate r/o	DEPFET, FPCCD	+/++	o	+	-
Monolithic CMOS with depletion	HV-CMOS, HR-CMOS	+	++	o	+
3D integrated	Tezzaron, SOI	++	+	o	++
Hybrid	CLICpix+planar sensor, HV-CMOS hybrid	+	o	+	++

D. Dannheim, LCWS 2015



Talk by G. Gaudio & P. Meridiani

Summary and conclusions

- The run of the High-Luminosity LHC is a clear priority for HEP
  - It is a real challenge and will keep community focus for the next 10 years
- But many other opportunities are under study
  - This workshop is the place to discuss the technological solutions
  - that will allow to move from ideas...

    ...to experiments

Thanks to the organizers for giving me the opportunity to present this overview.
...and to everybody who helpd me in preparing it
(especially A. Colaleo, G. Gaudio and N. Pastrone,)


IFD2015
INFN Workshop on Future Detectors
16-18 December 2015 - Torino - Italy
what
NEXT?

BACKUP