Multi-Gigabit Wireless Data Transfer for High Energy Physics Applications

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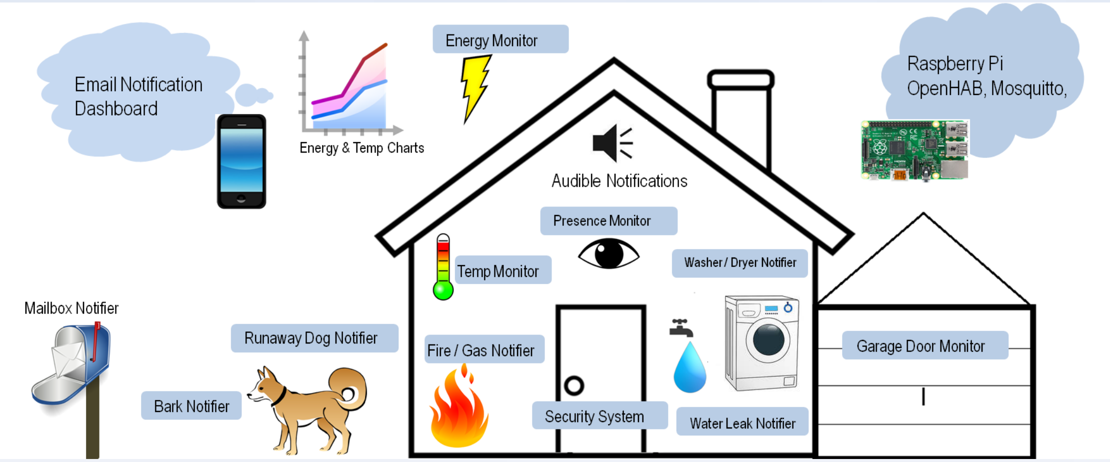
CEA-IRFU, Saclay

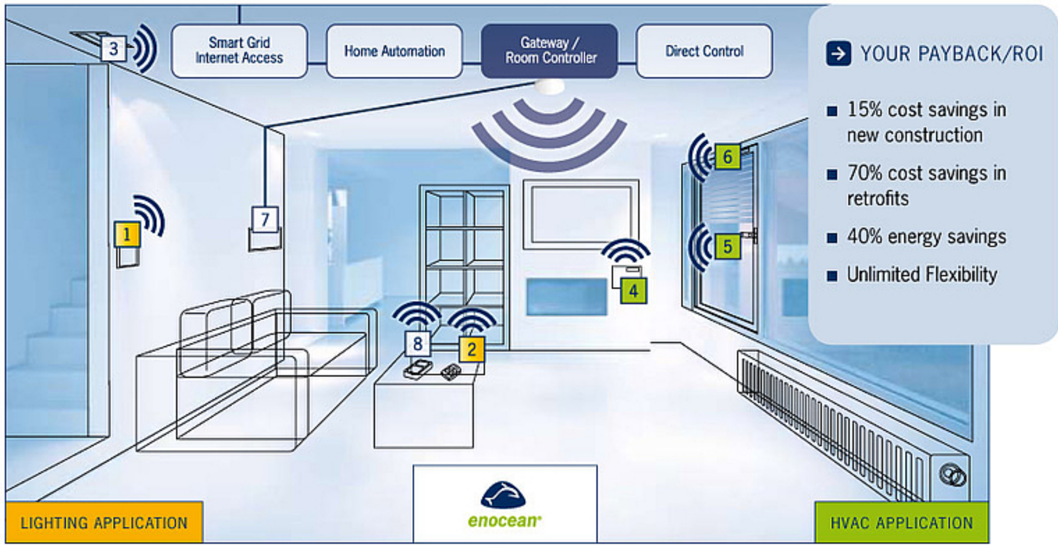
on behalf of the WADAPT working group

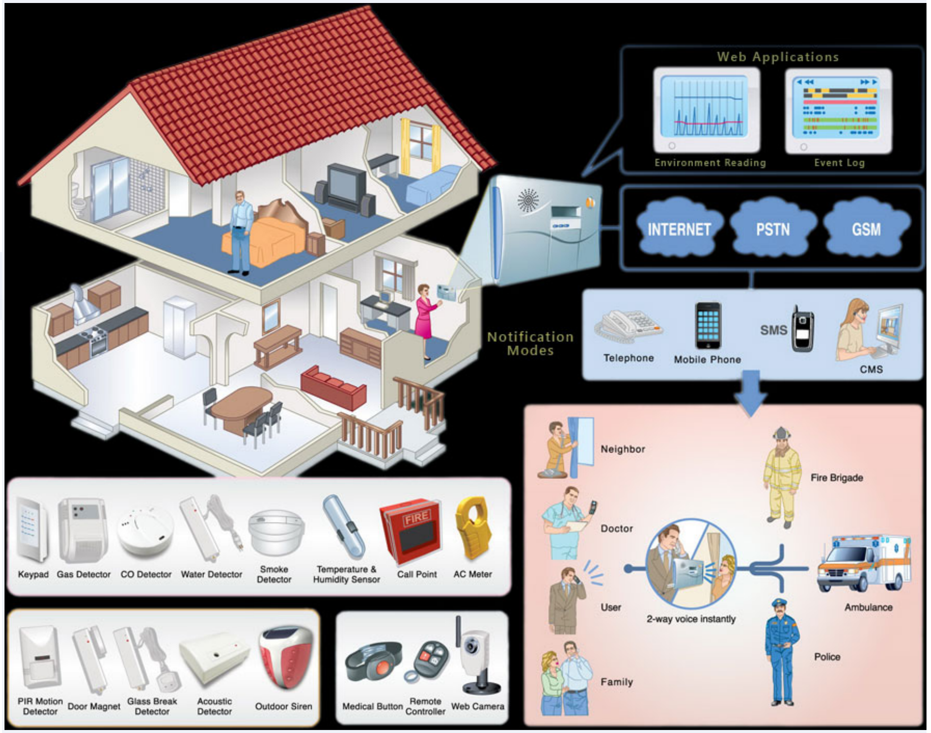
Saclay, 15.12.2017

"TELL ME AGAIN THE BENEFITS OF WIRELESS."

HOME AUTOMATION







INNOVATIVE HEALTH CARE

Ten Targets for Wireless Medicine

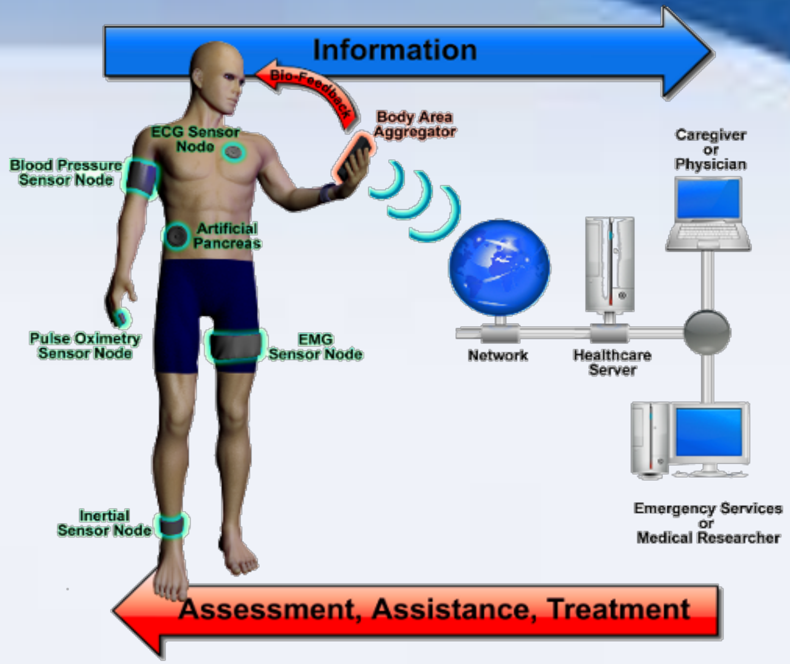
Disease	No. Affected	Wireless Solutions
Alzheimer's	5 M	Vital signs, location, activity, balance
Asthma	23 M	RR, FEV1, Air quality, oximetry, pollen count
Breast cancer	3 M	Ultrasound self-exam Web
COPD	10 M	RR, FEV1, Air quality, oximetry
Depression	21 M	Med Compliance, Activity, Communication
Diabetes	24 M	Glucose, Hemoglobin A1C
Heart Failure	5 M	Cardiac pressures, weight, BP, fluid status
Hypertension	74 M	Continuous BP, Med compliance
Obesity	80 M	Smart scales, Glucose, Caloric in/out, Activity
Sleep Disorders	40 M	Sleep phases, quality, apnea, vital signs

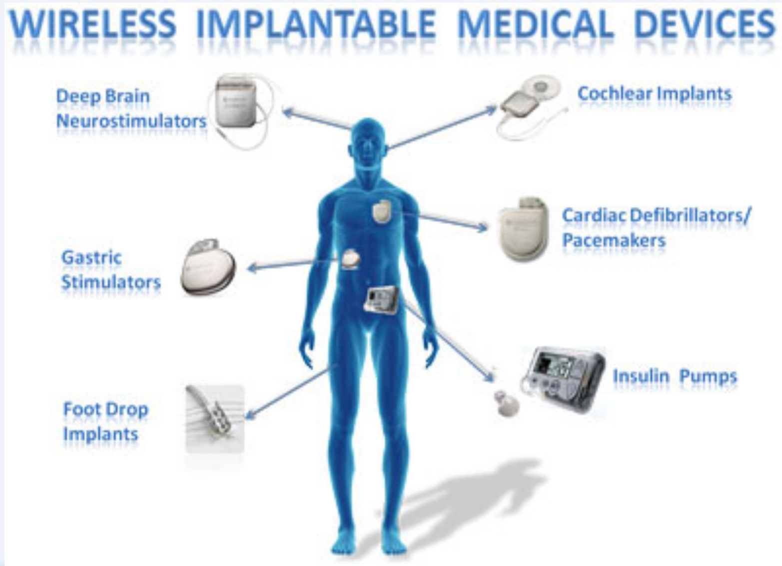
Savings With Remote Monitoring Per Year

Disease	Emergency Care	Hospitalization	Nursing Home	Total Savings
Congestive Heart Failure	$50 M	$7.4 B	$2.7 B	$10.1 Billion
Diabetes	$100 M	$3.5 B	$2.5 B	$6.1 Billion
Chronic Obstructive Pulmonary Disease	$200 M	$2.9 B	$1.8 B	$4.9 Billion

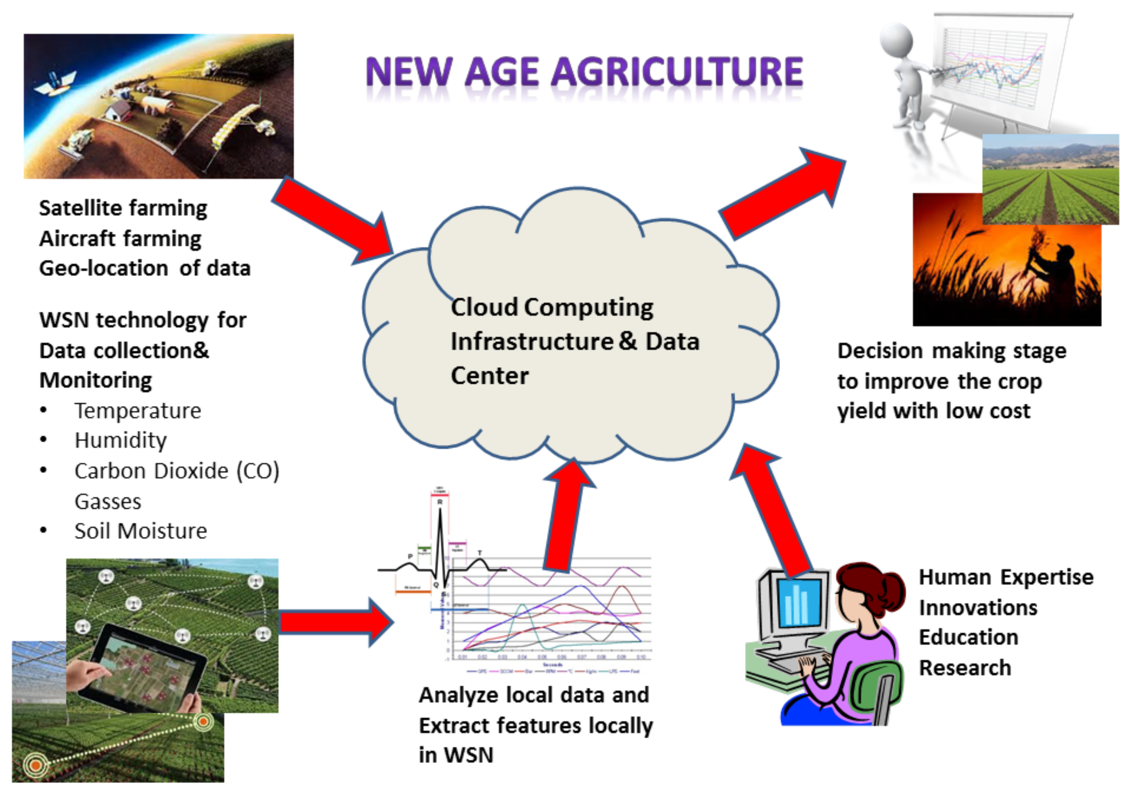
October 2008 Report, Vital Signs via Broadband; Windhover Information

Gary & Mary West Wireless Health Institute

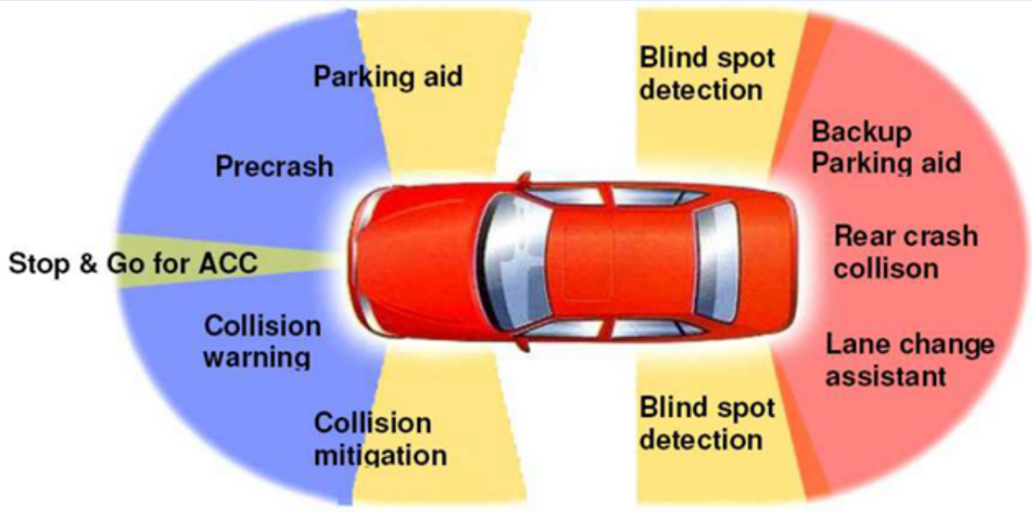


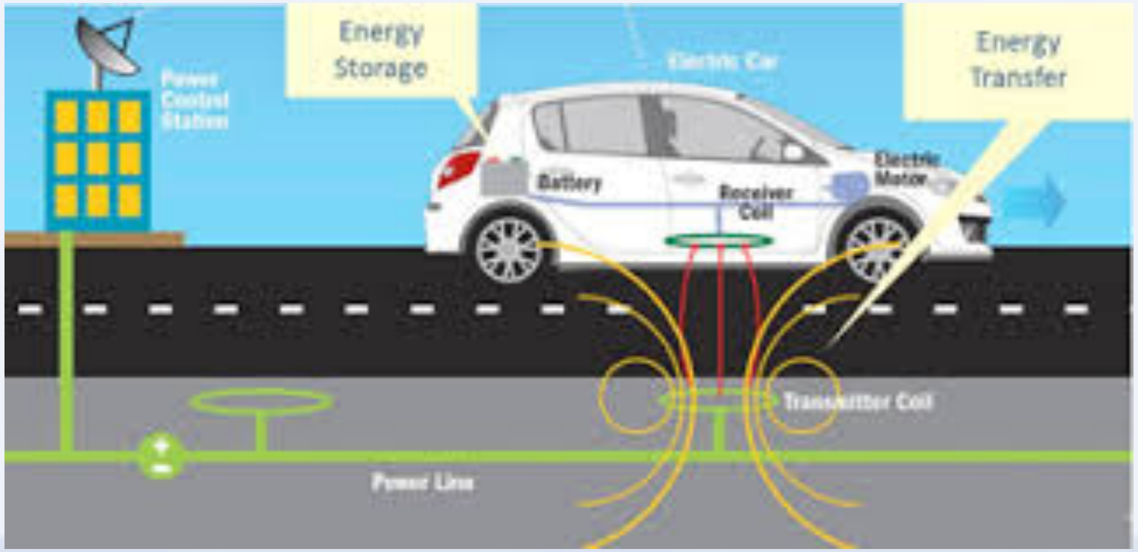


AGRICULTURE AUTOMATION



SMART TRANSPORTATION



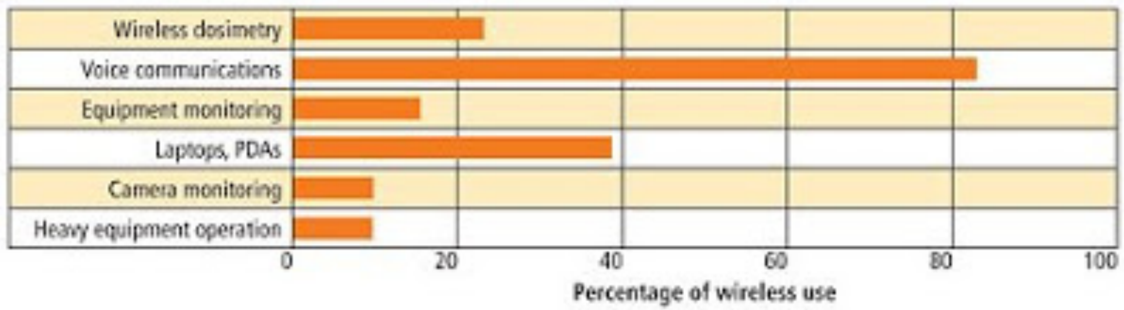


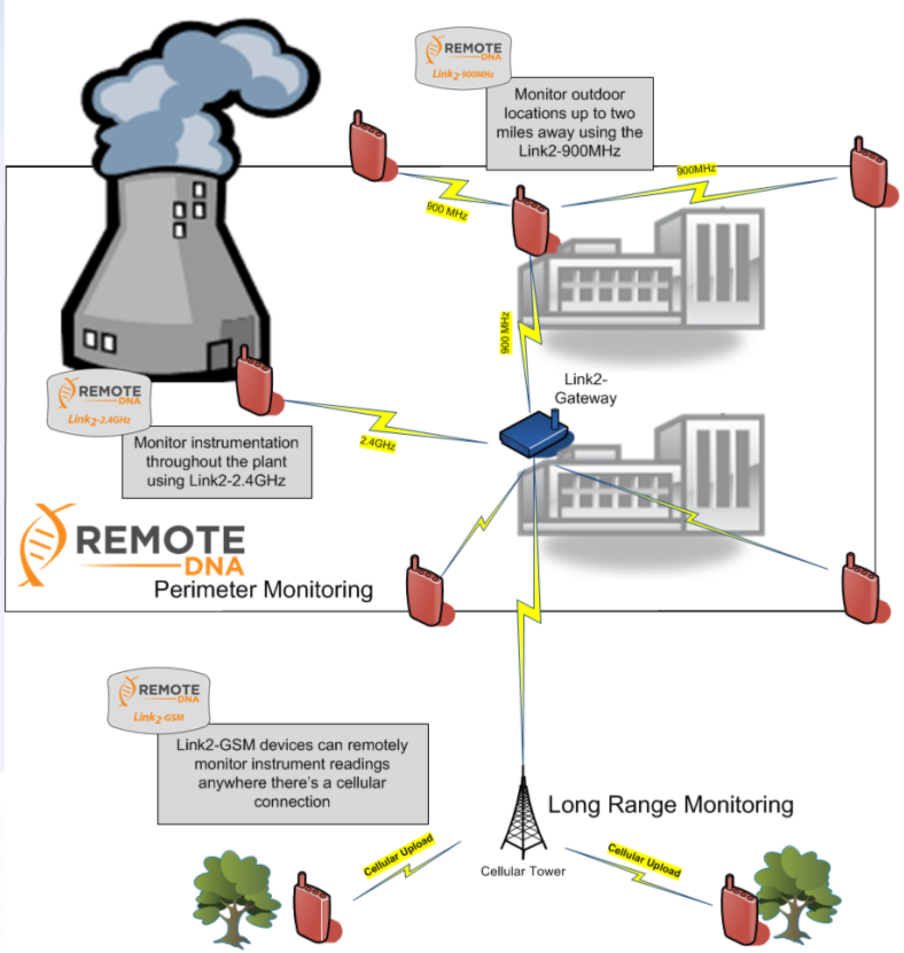
INDUSTRY AUTOMATION

Points at nuclear plants conducive to wireless technology use

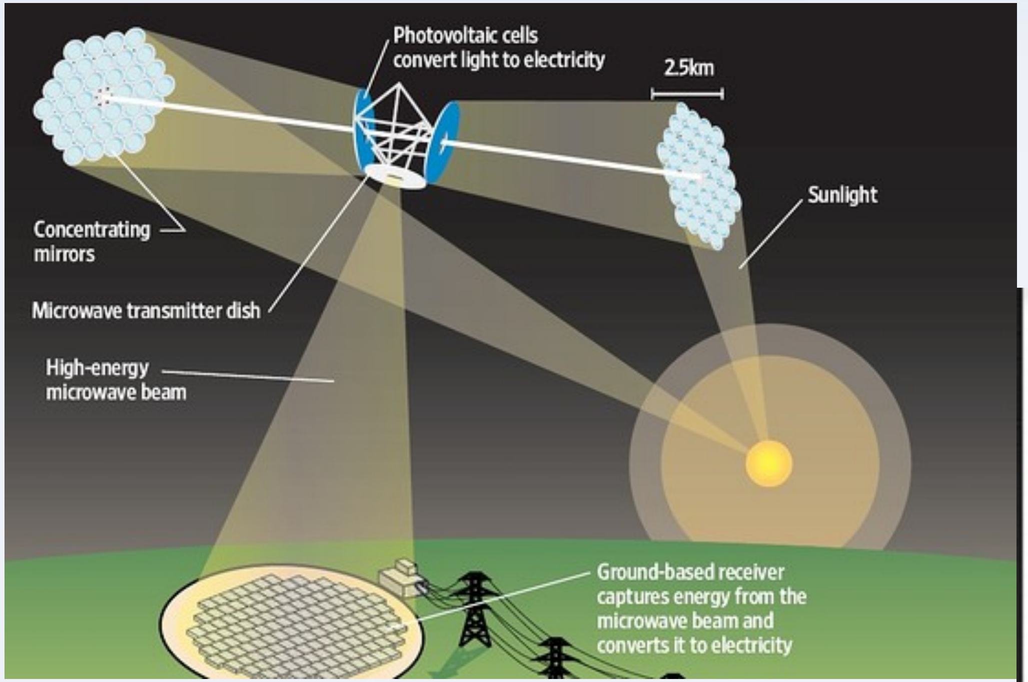
Nuclear plant system	Wireless measurement(s)	Application
Heat Exchangers	Temperature	Monitor ambient temperature to take into account the effects of such factors as seasonal changes in weather.
Secondary Side Valves	Position Indication	Replace periodic, labor-intensive valve indication readings with continuously monitored wireless measurements.
Inlet Water Intake	Level, Temperature, Flow	Monitor factors that affect performance such as changes in level, seasonal temperature variations, and intake flow.
Rotating Equipment (pumps, valves, motors, compressors, fans)	Temperature, Vibration, Motor Current	Monitor temperatures, vibration signatures, and load fluctuations to assess condition and improve performance.
Diesel Generators	Temperature, Level, Vibration, Motor Current	Augment existing sensor readings to provide redundancy and comprehensive performance assessment.
Spent Fuel Dry Cask Storage	Temperature, Radiation	Eliminate need for underground cabling and conduit by monitoring temperature and radiation with wireless sensors.
Weather Station	Temperature, Wind Velocity, Pressure, Humidity, etc.	Improve monitoring by replacing failure-prone equipment and cabling with wireless measurements.

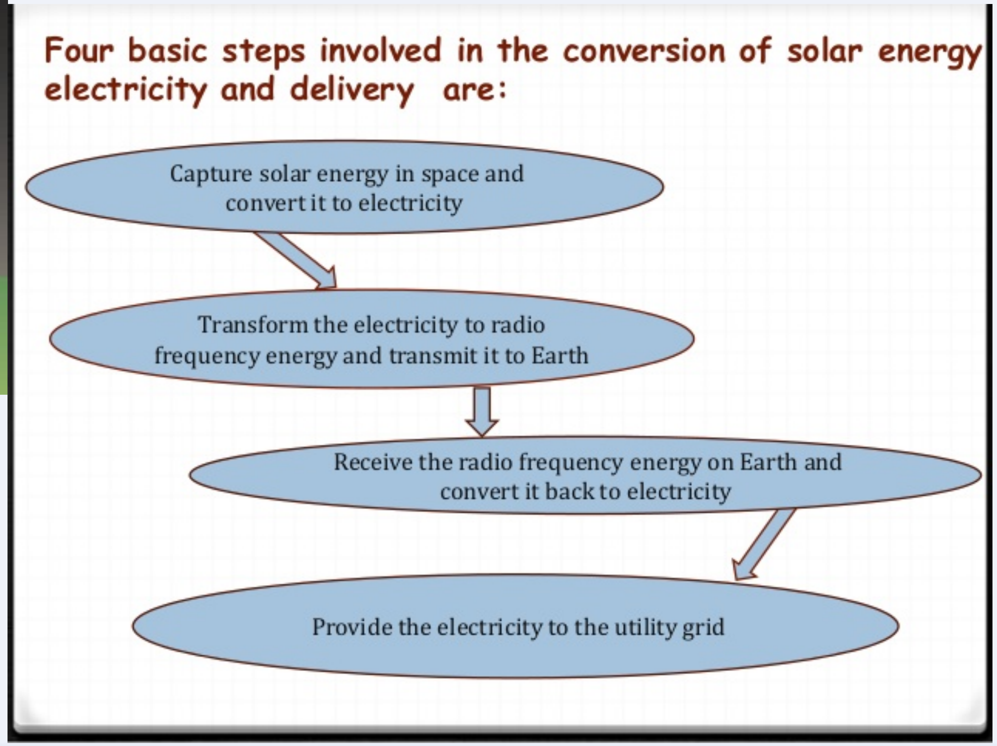
Current wireless use in nuclear power plants



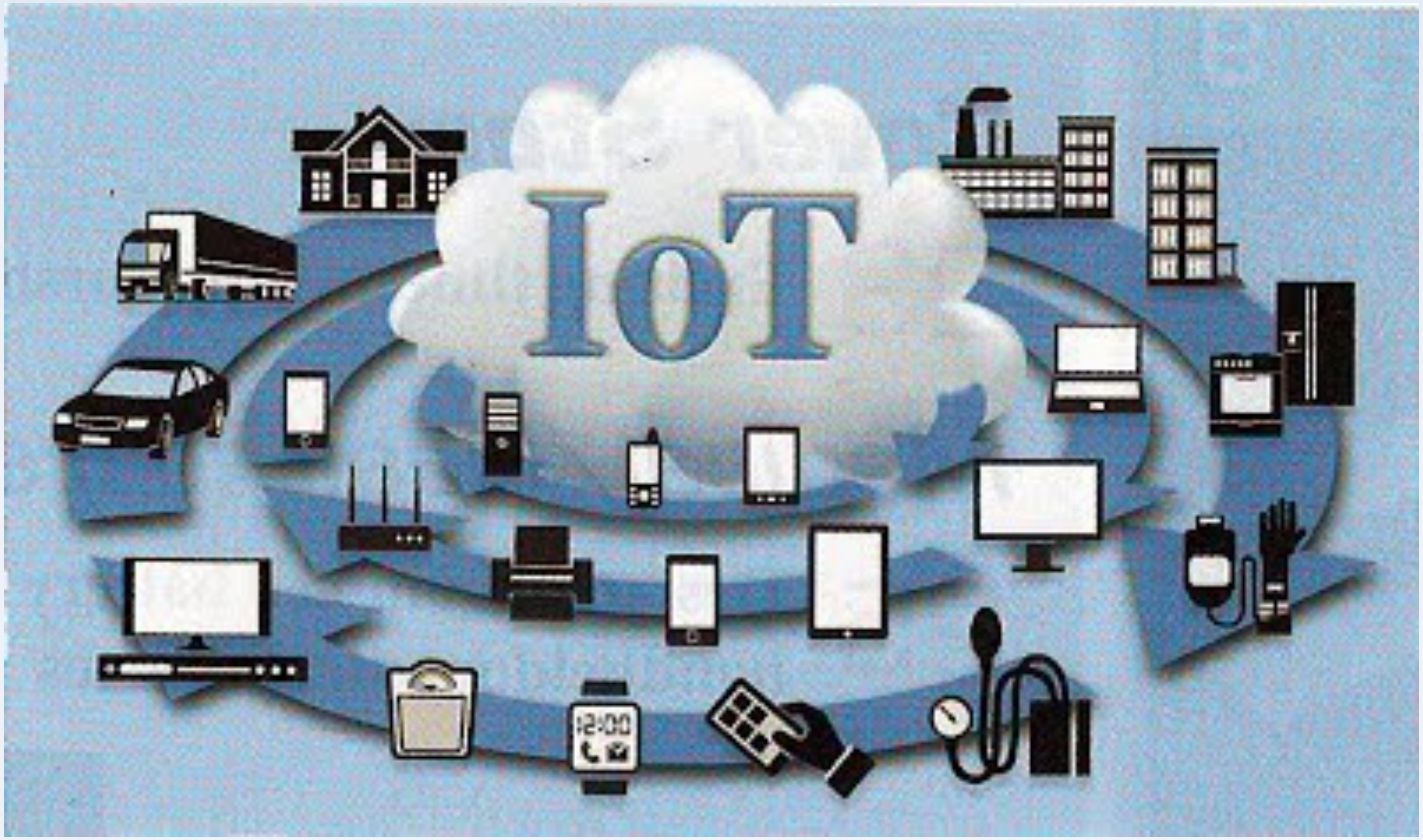


SMART ENERGY



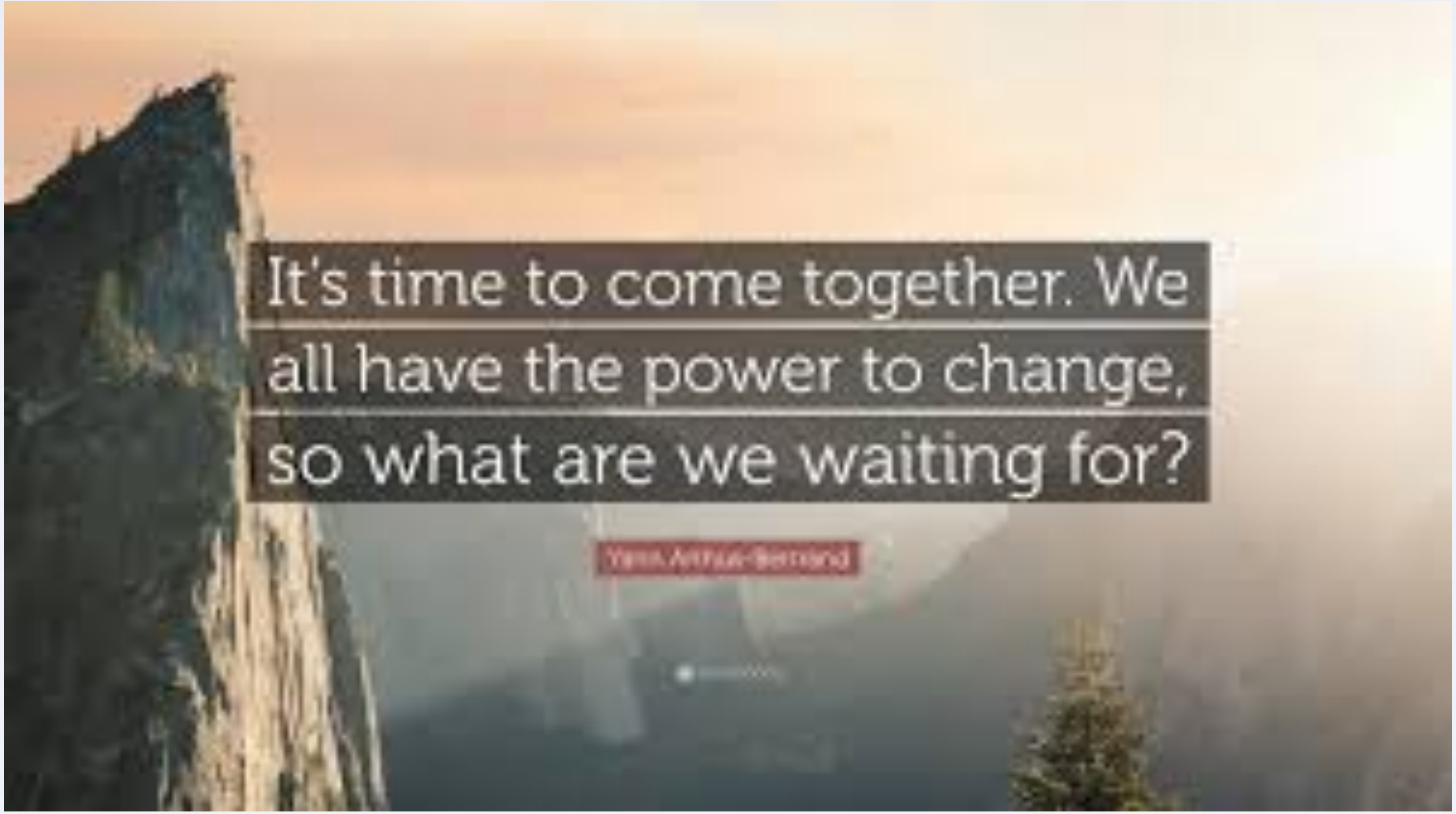


THIS IS WHAT IS CALLED THE INTERNET OF THINGS



ANYTIME, ANYWHERE, BY ANYONE AND ANYTHING

THE HEP COMMUNITY IS NOT AN EXCEPTION !



The WADAPT (Wireless for Data and Power Transmission) Project

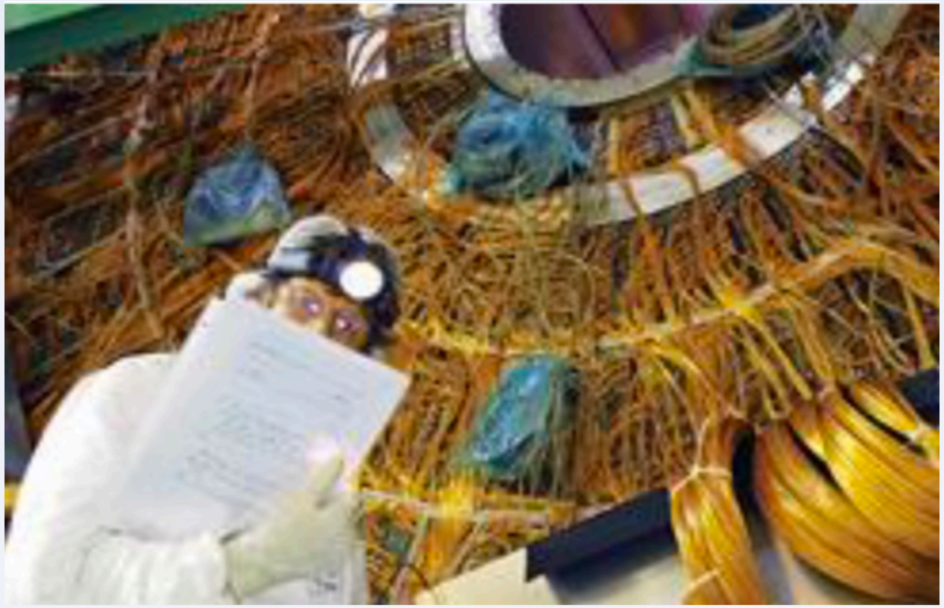
formed to identify specific needs of projects that might benefit from wireless technologies

arXiv:1511.05807 [physics.ins-det]   CERN-LHCC-2017-002 ; LHCC-I-028. - 2017.

- **HEP Context & Motivation for wireless**
- **Status of the Collaboration**
- **Introduction to millimeter Wave, focus on 60 GHz**
- **Features of the 60 GHz band**
- **RF integrated circuit architecture and design**
- **Antenna requirement, design and integration**
- **Feasibility tests for HEP**
- **Technology roadmap**
- **Demonstration**

- presented by C. DEHOS , CEA- Leti

➢ HEP Context & Motivation for wireless

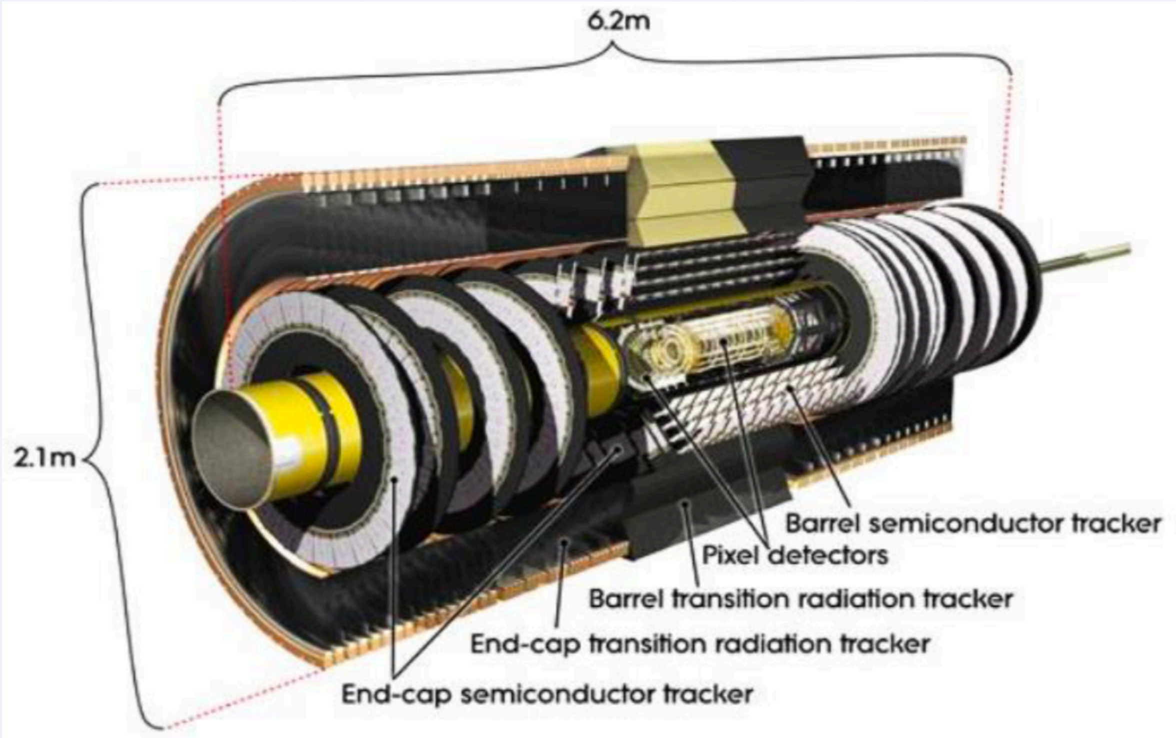


CMS alone contains 22,780 separate cables, many of them with multiple strands, that put end-to-end would stretch 725 kilometers, or 450 miles—roughly the distance from Brussels to Geneva or Chicago to Pittsburgh.
Laying and connecting all that CMS cable requires 38 people working full-time.
Archana Sharma, CERN

➢ HEP Context

Large data readout

Example: ATLAS inner detector



Pixel Detector	Semiconductor Tracker	Transition Radiation Tracker
80 M channels	6 M channels	350 000 channels

➢ HEP Context & Motivation for wireless

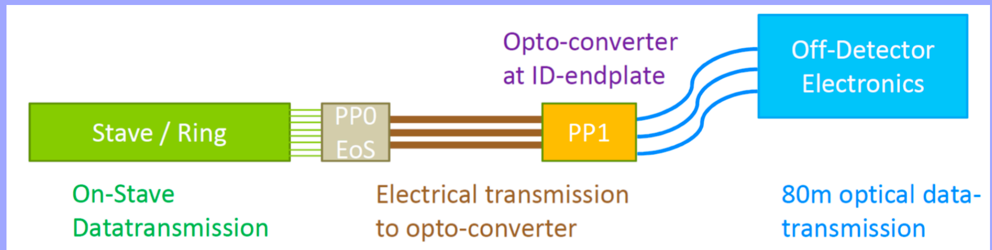
Bandwidth

- High demand on **bandwidth** in present & future experiments

- Especially true for **highly granular** tracking detectors operated at **high beam luminosities**

Example: ATLAS Phase II New Inner Tracker Pixel Detector

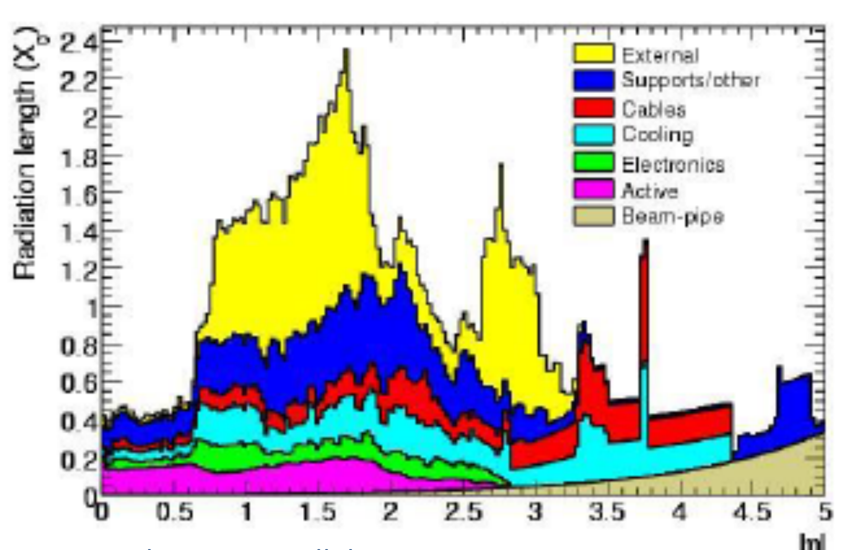
- 1m radius pixel detector with five barrel layers and four end-cap rings and a silicon strip detector with four layers and six end-cap disks
- Readout at up to 4MHz (25µs) L0 rate
- Downlink: Broadcast trigger and control signal at 160Mb/s
- Uplink: over 10000 links at 5 Gb/s
- Distance between stave and opto-electrical converters: 5 -7 m on copper cables (twisted pair, TwinAx or Flex cables)



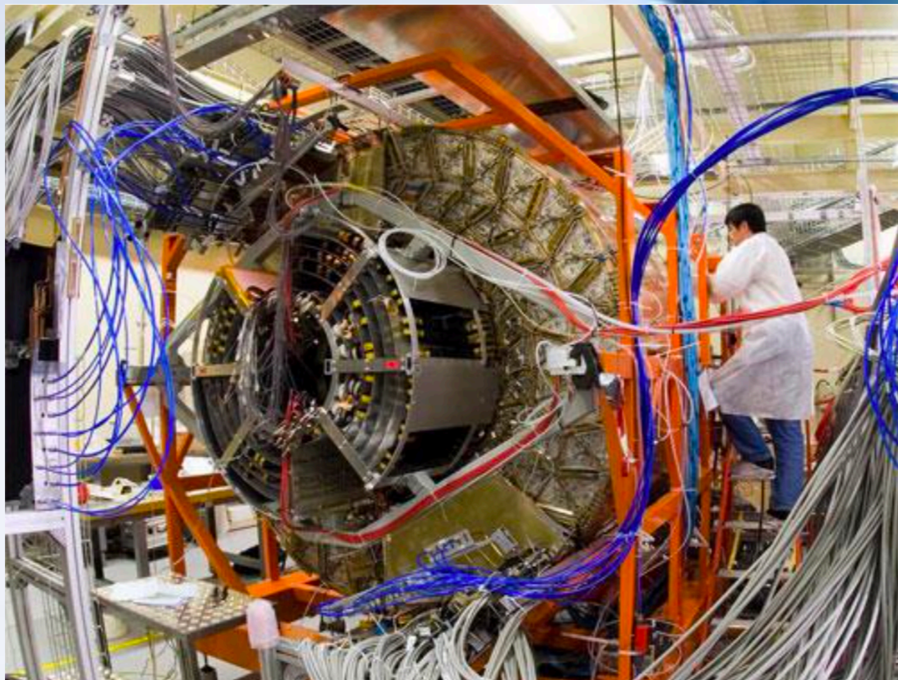
➢ HEP Context & Motivation for wireless

Massive cable plants

- **Impact on the installation and operation**
  - Cables and connectors are fragile
  - Cable path is not so flexible
  - Design constraints
  - Significant cost contribution



The ATLAS Collaboration 2008 JINST 3 S08003
doi:10.1088/1748-0221/3/08/S08003



assembly of ATLAS TRT with SCT © CERN

- **Impact on the measurements**
  - Multiple scattering and nuclear interactions
  - Energy resolution (calorimeters)
  - Dead-zone areas

Multiple scattering in ATLAS/CMS

multiple scattering is the main contribution to the momentum resolution for pt<50 GeV/c at η=0.

The uncertainty of the track parameters is affected by multiple scattering of the charged particle by the material of the spectrometer.
A particle of momentum p traversing a length x of material, with a radiation length X0, is deflected by multiple Coulomb scattering from nuclei.
The projection of this deflection angle on a plane containing the original direction is roughly Gaussian distributed around zero and

$$\theta_{\rm rms} = \frac{13.6\,{\rm MeV}}{\beta p}\sqrt{\frac{x}{X_0}}.$$

Assuming that the position accuracy is dominated by multiple scattering,

$$\frac{\delta p_{\rm t}}{p_{\rm t}} = \frac{1}{0.3B}\frac{0.0136}{\beta}\sqrt{\frac{C_N}{X_0 L}},$$

L = length of the spectrometer
C_N depends on the number of position measurements
(C_N = 1.3 in this example)

$$\frac{\delta p_t}{p_t} = (1.6 \oplus 0.034 \times p_t(\mathrm{GeV}))\%$$ ATLAS*

$$\frac{\delta p_t}{p_t} = (0.8 \oplus 0.015 \times p_t(\mathrm{GeV}))\%$$ CMS*

for a spatial resolution of 30 μm

⟹ In both detectors the multiple scattering is the main contribution to the momentum resolution for pt<50 GeV at η=0.

Multiple scattering
also **affects**
- **precision of the alignment**
- **track extrapolation to the vertex**
- **trigger efficiency**

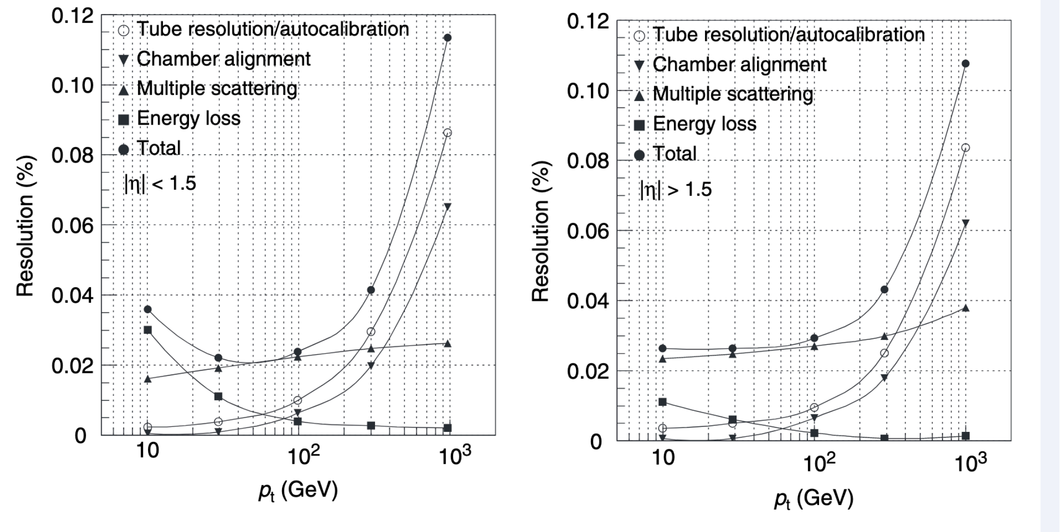
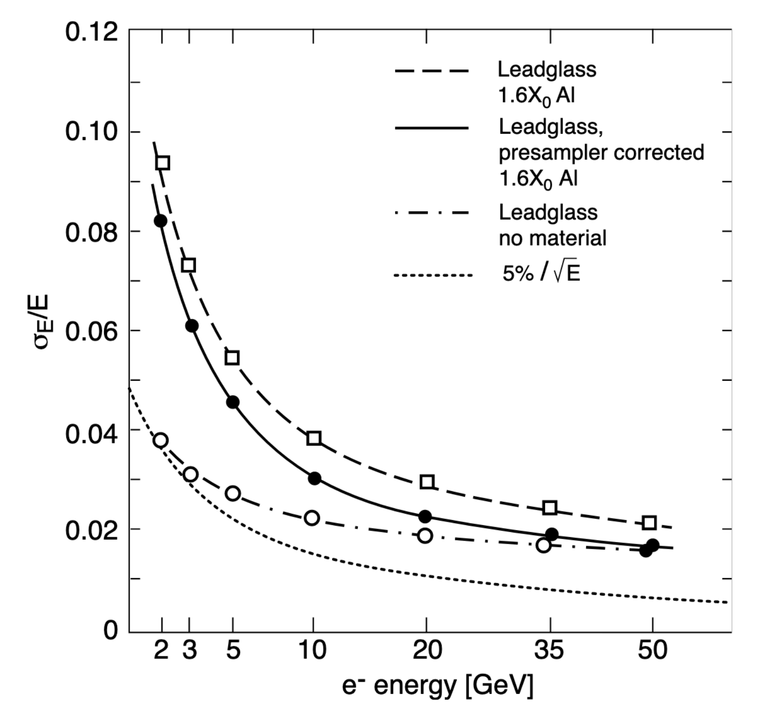


Figure 8. Breakdown of the contribution of the different effects to the momentum resolution as a function of the muon transverse momentum for the ATLAS muon spectrometer [12]; left: barrel ($|\eta| < 1.5$); right: end-caps ($|\eta| > 1.5$).

from https://iopscience.iop.org/article/10.1088/1367-2630/9/9/336/pdf

* *perhaps not the most up-to-date numbers*

❑ Calorimeter energy-resolution deterioration by material



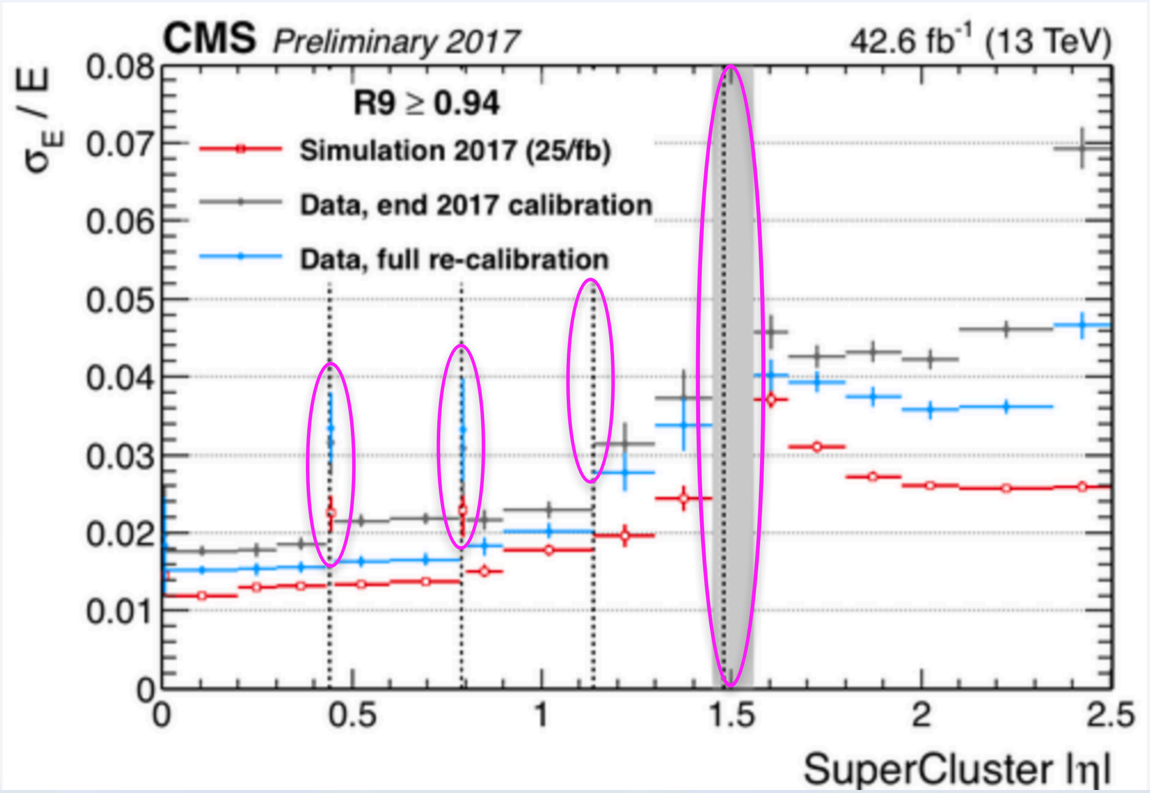
over the energy range 10 to 50 GeV,
the **calorimeter resolution is deteriorated** by a factor of 1.7 to 1.3 **by the presence of additional material**

(from http://lappweb.in2p3.fr/~chefdevi/Detector_reports/Calorimetry/Fabjan.pdf)

❑ Dead spaces

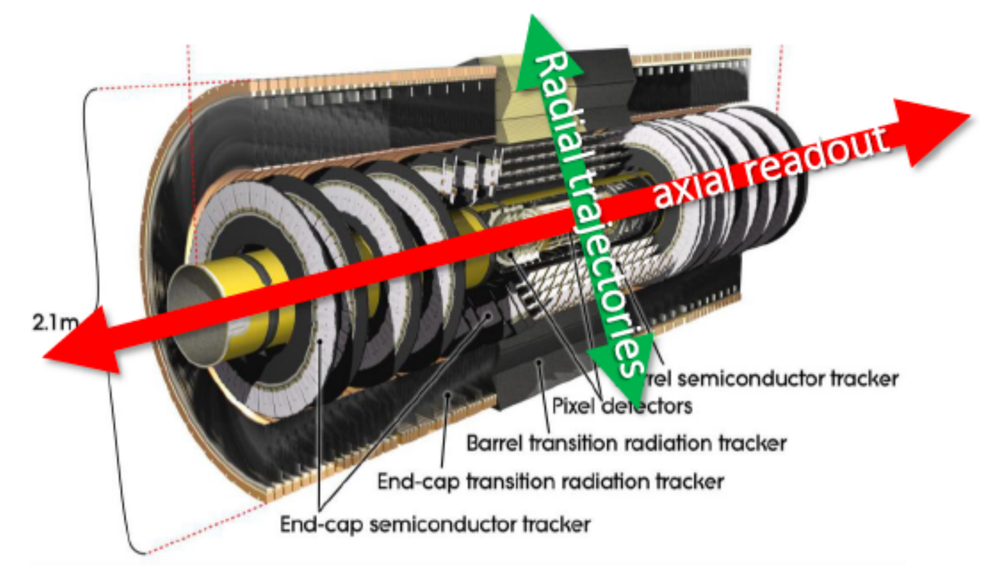
Cables cause additional dead layers

- ⟹ **signal degradation**,
- ⟹ **dead spaces** between the calorimeter towers
- ⟹ **reduced hermeticity**.



➢ HEP Context & Motivation for wireless

Readout topologies

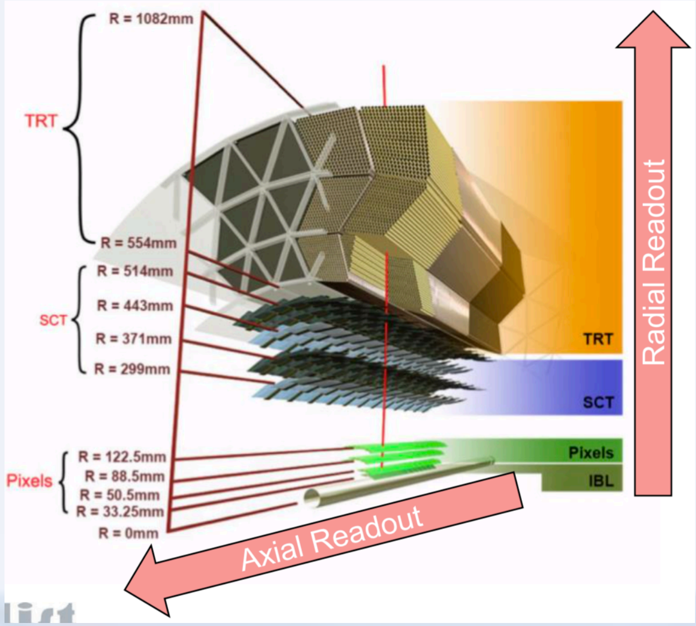


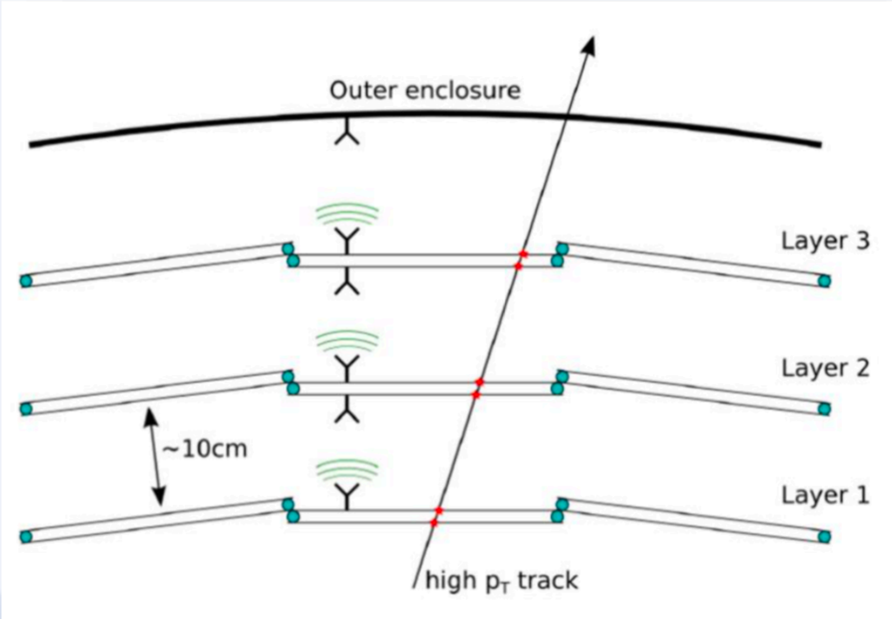
- **Fast signal transfer & efficient detector partition in topological regions of interest** facilitate **fast track trigger decisions**

- Application specific considerations :
  - link density
  - signal reflection & transmission
  - ...

➢ HEP Context & Motivation for wireless

- **Minimize material budget of cables/connector**
  Reduction of massive services between barrel and endcap disks ⟶ limited number of X_0
- **Direct communication between layers via radial readout**
  Axial readout induce important latencies
- **More flexible transceiver placement**
- **Point-to-Multipoint links, interlayer intelligence**
- **Data readout follows event topology enabling fast triggering**





➢ HEP Context & Motivation for wireless

An efficient track-trigger may offer groundbreaking opportunities for new physics searches (*https://arxiv.org/abs/1705.04321*) by increasing sensitivity to

- processes with small branching fractions
- long-lived particles

by extending the track trigger to off-pointing tracks

Examples:

- rare Higgs decays into new particles with lifetime ~ a few mm
- dark sector cascades
- low mass jetty final states

At future hadron colliders the high collision rates and demands for high granularity will significantly increase the data rate coming out of the detector.

Triggering of both low energy anomalous objects, such as disappearing tracks, and high pT objects demands more sophisticated high data volume readouts and high speed pattern recognition, especially under the onset of pileup.

➢ HEP Context & Motivation for wireless

The inclusion of the timing information in the event reconstruction can almost fully offset the increased particle density foreseen at future hadron colliders (HL-LHC, FC-hh)

Examples: at HL-LHC

- **ATLAS/CMS**

  10-15% of the vertices recognized as a single vertex are actually two vertices overlapping in space .

- **LHCb**

  Degradation of factor 10 in assigning the b and c hadrons to their primary vertex

With a timing capability, performance at low luminosity can be recovered

- **ATLAS/CMS**

  Timing associated to each track; 30-40 ps precision is needed.

- **LHCb**

  Timing associated to each point of the track; 100 ps precision may be enough.

Would the transceiver provide this capability?

➢ Status of the Collaboration

First draft in 2015: **arXiv:1511.05807 [physics.ins-det]**

Since then:

- Multiple talks:
    - seminars in Saclay, CERN
    - contributions to FCC weeks
    - contributions to conferences:
        - Vertex 2016
          PoS Vertex2016 (2017) 040 , Conference: C16-09-26 Proceedings
        - Connecting the dots / Intelligent Trackers 2017 Workshop
          EPJ Web Conf. 150 (2017) 00002 ,DOI: 10.1051/epjconf/201715000002
        - **EPS-HEP2017** proceedings

- Publications:
    - **Nucl.Instrum.Meth. A830 (2016) 417-426** ,DOI: 10.1016/j.nima.2016.06.016
    - **LoI**, CERN-LHCC-2017-002 ; LHCC-I-028. – 2017, accepted by LHCC
    - **TP**, first draft examined in closed session of LHCC, May 2017.

➢ Status of the Collaboration

LHCC comments :

- *Considered it **worth of further development**, encouraging the proponents to prepare a full technical proposal following some recommendations*
- *The committee believes there is **tremendous value in the research being proposed** and is eagerly looking forward to receiving an updated Technical Proposal taking into account the above recommendations and suggestion*
- *The LHCC would like to thank the proponents for the submission of a Technical Proposal concerning a **very timely development of a new technology** for particle physics experiments that has the **potential to realize a new paradigm for data and power transmission in particle physics detectors***

➢ Status of the Collaboration

LHCC recommendations :

- *A **research program** (for data and power wireless transmission), within a **3-yr timeframe**, with clearly spelled-out milestones and deliverables focused on a **demonstrator** based on specific technologies, the configuration of which would allow to set a **proof-of-principle** for a use in a future HEP experiment.* **Done** (see next slide)

- *A **detailed development plan** describing the organization and structure of the project, **sharing of responsibilities** and description of **resources** involved for each sub-project, a description of the organization and operation of the collaboration and its **governance**, and **who (nominally) is responsible for the different WPs**, and **who is contributing from which institute** at what number of **FTEs** to the different milestones and deliverables, should be provided.* **Pending**

- *A clear articulation of the **added value for this proposed R&D to become a CERN RD** Collaboration, in particular, a detailed list and timeframe of CERN resources and support, that the project would need or could benefit.* **Done**

➢ Status of the Collaboration

- Research program

WP0	**Project Management**
T0.1	Project coordination, risk management and financial management
T0.2	IPR Management
WP1	**Global requirement, architecture & system studies**
T1.1	Global system requirements
T1.2	Study of integration of mmw links in LHC
T1.3	Sub-THz architecture and system definition
WP2	**60GHz experiments and proof of concept**
T2.1	Prototypes and commercial products environmental tests
T2.2	Interfacing vertex detector ADC with wireless readout
T2.3	Test of wireless data transfer in HL-LHC environement
WP3	**Integrated transceiver design**
T3.1	Design of optimized transceiver at 60GHz
T3.2	
WP4	**Signal confinment & antennna design**
T4.1	Compact and directive 60GHz antenna design for point to point link
T4.2	Sub-THz integrated antenna design
T4.3	Intra layer confinement and crosstalk mitigations
WP5	**Wireless power transfer**
T5.1	Study of deca cm range Wireless Power Transmission
T5.2	Prototyping and experiments
WP6	**Dissemination and exploitation**
T6.1	Dissemination activities
T6.2	Exploitation

➢ Status of the Collaboration

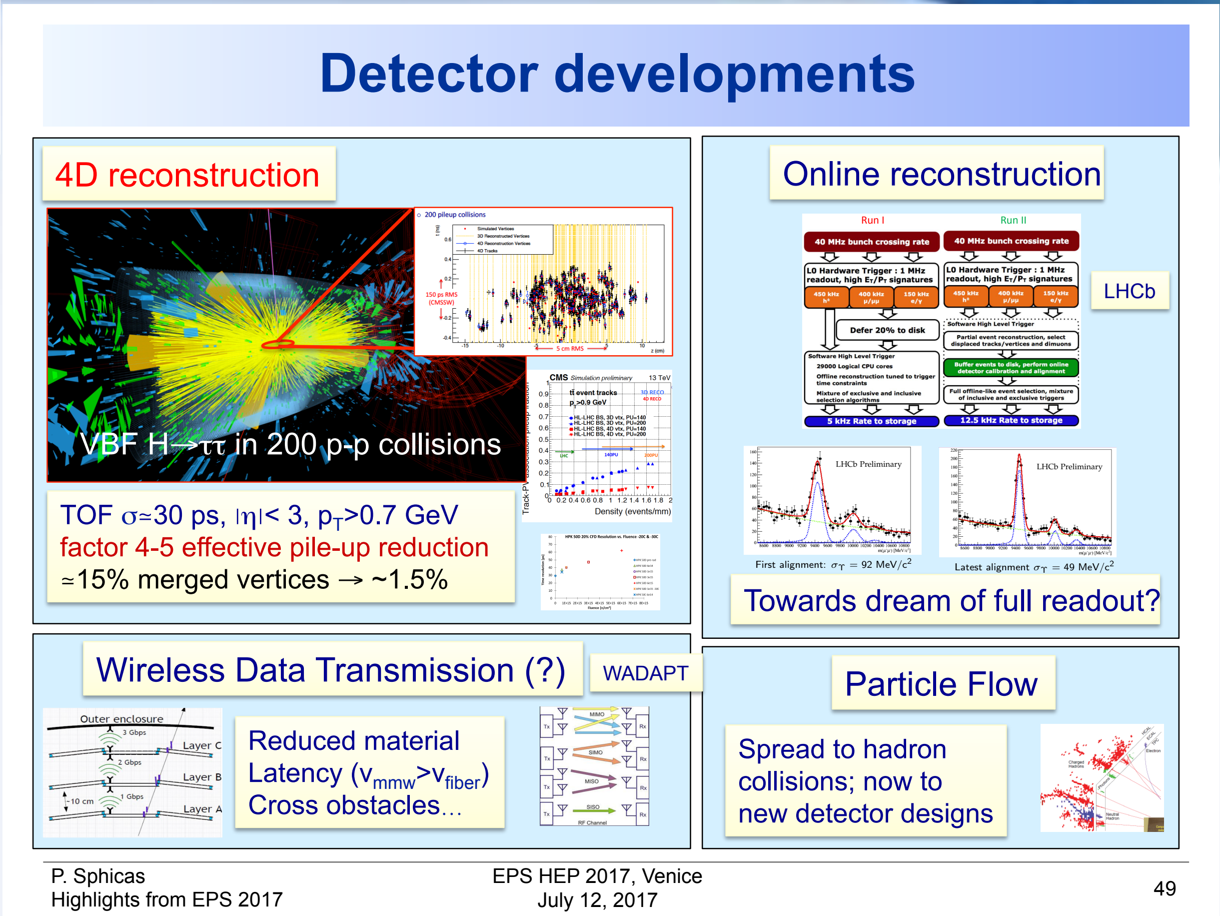
Development plan: sharing of responsibilities, resources:

For this we need:

- **more partners in France**, and from other institutes worldwide.
- **ressources:**

  will be considered in the “blue sky” line of AIDA++

  More is needed!



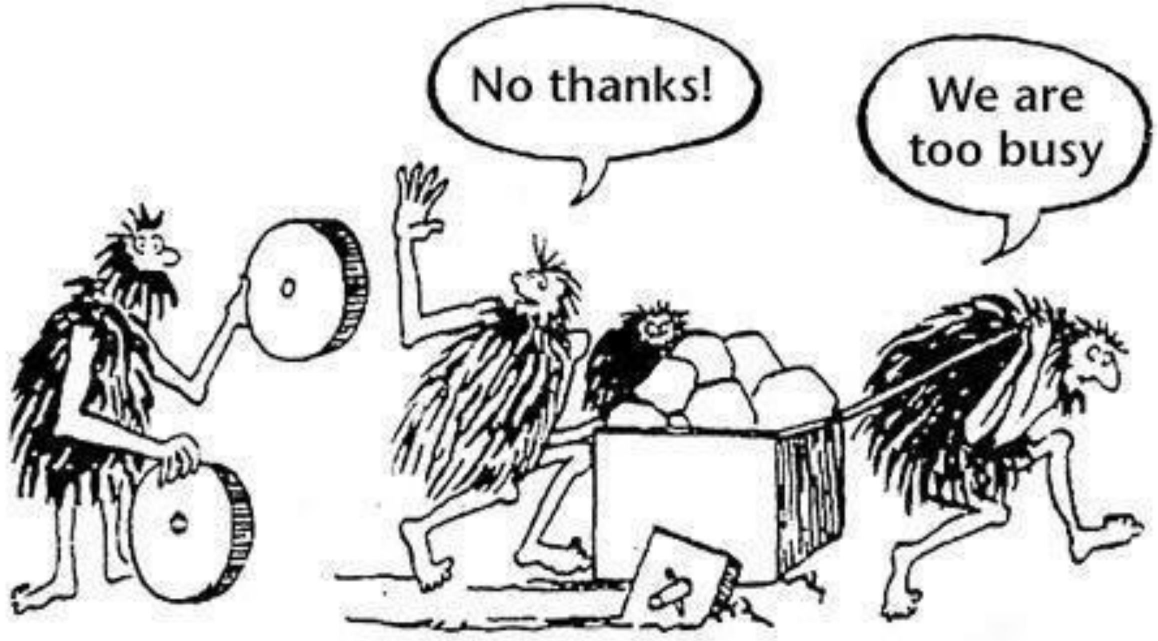
Mentionned as:

"THE FUTURE"

LET'S BE PART OF IT!

Yes, it has never been done before for our detectors:
Most of the things we are using today were never done before and have required R&D

"This really is an innovative approach, but I'm afraid we can't consider it. It's never been done before."



We are very busy with upgrades:
Quite true! We need extra resources!

Let's overcome this!

Let's prepare the future now!