Nuove Tecnologie @ Acceleratori

> Whay we can learn impossible to guess....main element surprise....some things look for but see others.....Experiems on pions....sharpening

Enrico Fermi Presentazione all'American Physical Society, NY, **Jan. 29th 1954**

"What can we learn with High Energy Accelerators ? "

- ✓ INFN nasce con la fisica agli acceleratori anni ’50
- ✓ Acceleratori: strumento **indispensabile** e/o **complementare**
- ✓ Gran parte delle tecnologie sviluppate per esperimenti agli acceleratori vengono poi riutilizzate in altri campi
- ✓ Da decidere: quale futuro acceleratore/tempistica
- ✓ **Ideale:**
  - alta energia
  - alta intensità
  - dimensioni/costi ridotti
- ✓ **Tecnologia in fase di sviluppo**

  ➔ progetto/finanziamento internazionale causa alti costi

Tuesday, 16 February 2016

11:00 - 11:15	INTRODUZIONE
11:15 - 12:30	GdL ONDE GRAVITAZIONALI
12:30 - 13:30	GdL RADIAZIONE COSMICA
13:30 - 14:30	Pranzo
14:30 - 15:15	GdL MISURE DI PRECISIONE SM
15:15 - 16:00	GdL NEUTRINI (DBD, Oscillazioni)
16:00 - 16:45	GdL FLAVOUR
16:45 - 17:15	Pausa caffè
17:15 - 18:15	GdL MATERIA OSCURA
18:15 - 19:30	GdL BEYOND SM

Wednesday, 17 February 2016

09:00 - 10:00	GdL FISICA FONDAMENTALE
10:00 - 11:00	GdL NEW DIRECTIONS

Esplorazione e misure di precisione

- Ricerca sperimentale non sarà più **verifica**, ma **esplorazione**
- **Future Colliders**: esplorazione diretta e/o indiretta della nuova frontiera dell'energia
  1. **Garantiscono misure** in condizioni sperimentali nuove
  2. **Garantiscono ricerche** di nuova fisica su fondi noti
  3. **Non garantiscono** scoperte
  4. **Nessuna** ragione scientifica per **non** farli
  5. **Alternative?** Di uguale portata e costo comparabile?
  6. Sforzo **tecnologico** (ritorno short-term?) può renderli "economici"?

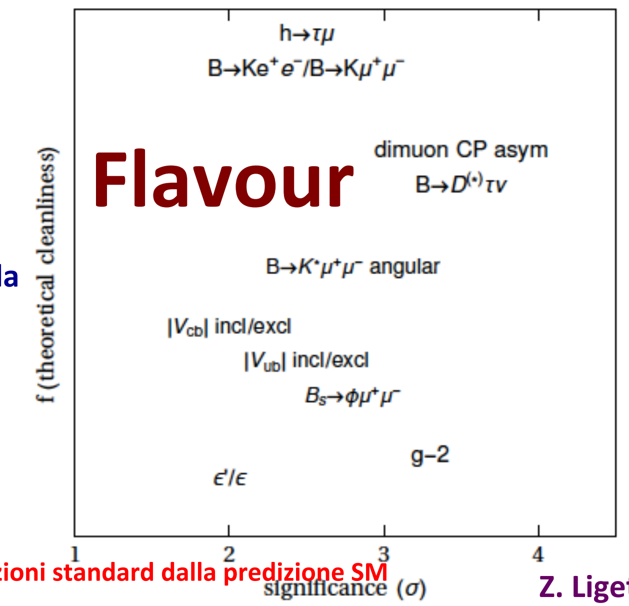
Beyond SM

Non manca qualche indicazione di deviazione dalle predizioni del SM (fisiologico?)

SM

- Il bosone scalare di massa 125 GeV scoperto nel Luglio 2012 sembra a tutti gli effetti il pezzo mancante
  - **sono necessarie misure di precisione delle sue proprietà per mettere in luce i legami tra il nuovo bosone scalare e fisica al di la dello SM**
  - Inoltre misure di precisione di processi standard **(e.g. top couplings, W mass)** sono promettenti per aprire l strada alla rivelazione di nuovi fenomeni

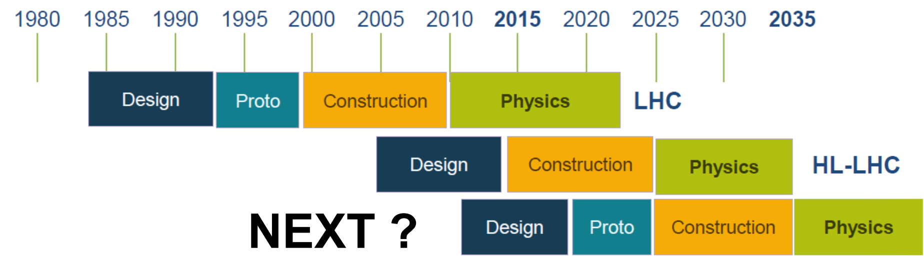
Quanto e' affidabile il conto teorico della predizione SM

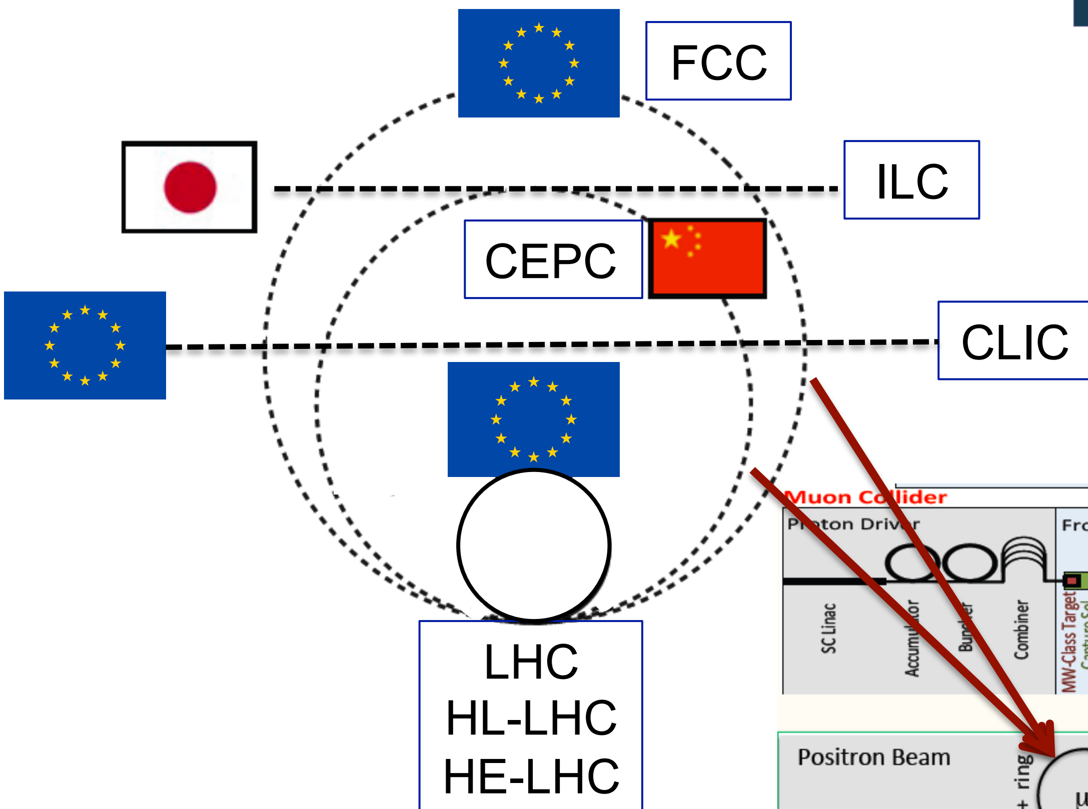


Quante deviazioni standard dalla predizione SM

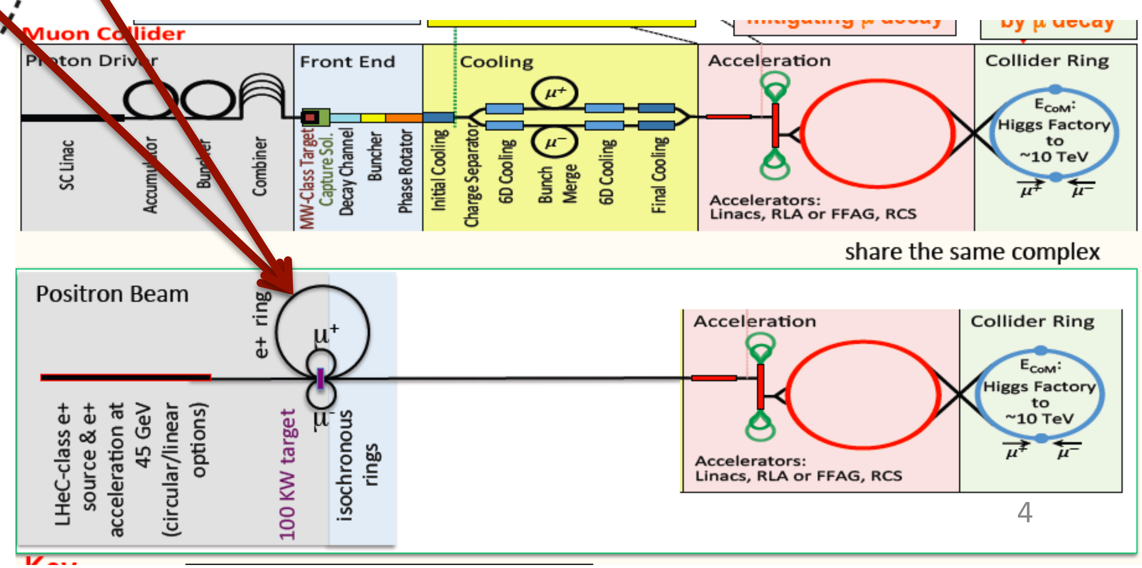
Z. Ligeti, LP 2015

Quali strumenti per le misure?
What's Next Accelerator? (After LHC)





MUON COLLIDER



Fasci estratti intensi/beam dump: μ, K, p,....

Electron-ion collider @ USA

For e-N collisions at the EIC:

- ✓ Polarized beams: e, p, d/^{3}He
- ✓ e beam 5-10(20) GeV
- ✓ Luminosity L_{ep} ~ 10^{33-34} $cm^{-2}sec^{-1}$
  100-1000 times HERA
- ✓ 20-100 (140) GeV Variable CoM

For e-A collisions at the EIC:

- ✓ **Wide range in nuclei**
- ✓ Luminosity per nucleon same as e-p
- ✓ Variable center of mass energy

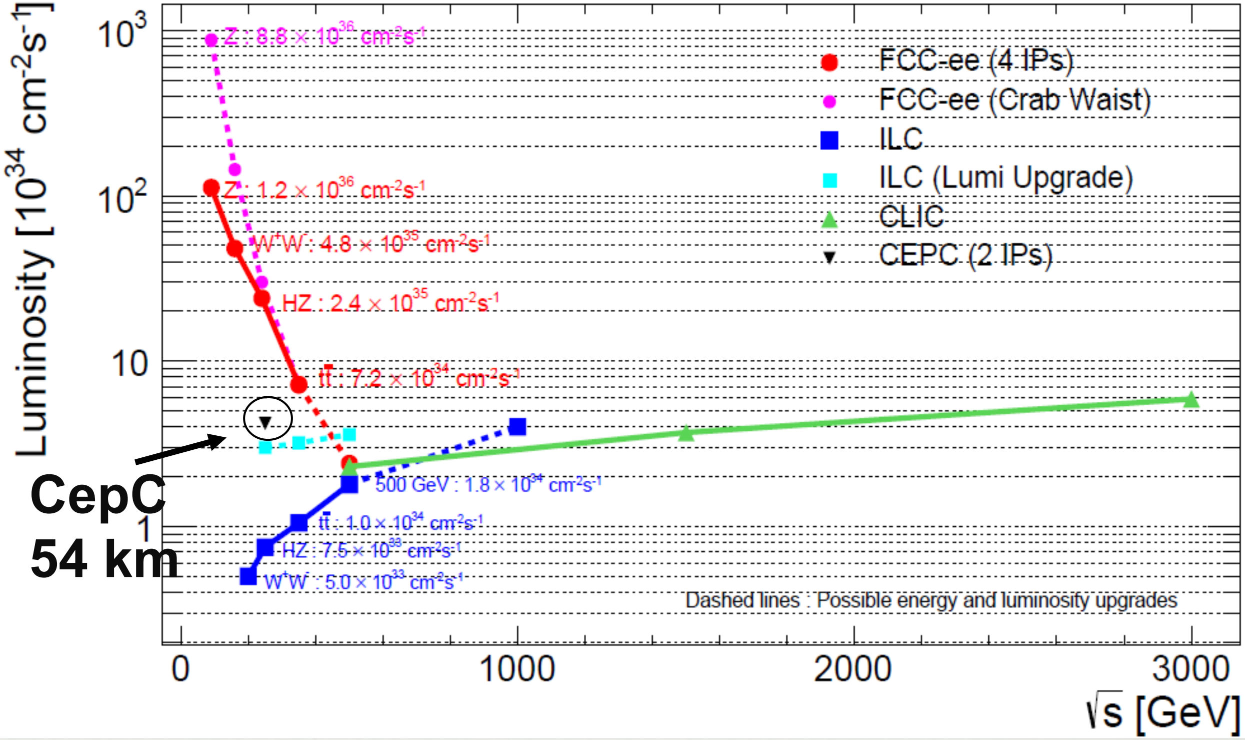
World's first
Polarized electron-proton/light ion
and electron-Nucleus collider

NICA @ JINR

NICA
Nuclotron-based
Ion Collider fAcility

new accelerator complex designed at Dubna, Russia to study properties of dense baryonic matter

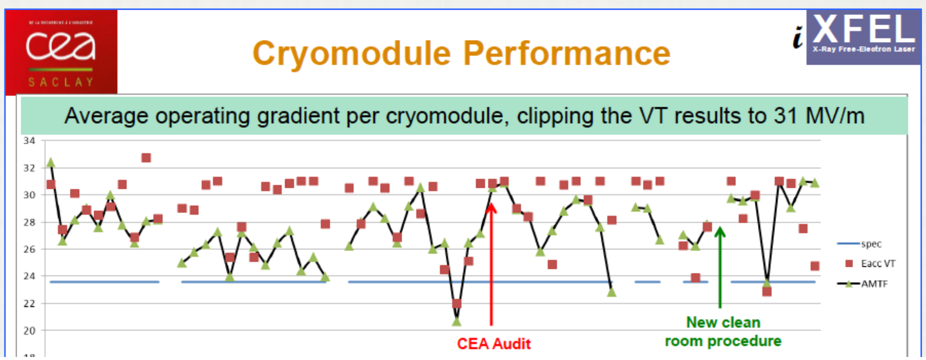
Collider e+e-



ILC

- sulla macchina, E-XFEL garantisce che l'engineering continuo e sia qualificato (oltre il 90 % delle 800 cavità sono state prodotte ed il 65 % dei 100 criomoduli sono stati assemblati e testati)

	ILC	FCCee	CEPC
lumi (250) 10^{34}	0.75 (x2)	6	2.0
lumi (350) 10^{34}	1.0 (x2)	1.6	0
lumi (500) 10^{34}	1.8 (x2)	0	0
polarization	80%/30%	0/0	0/0
max energy	1 TeV	350 GeV	240 GeV
power (MW)	128	280	
cost	$8B	€8B?	



Decisione ritardata di ulteriori 2-3 anni

Collider circolari e^+e^-

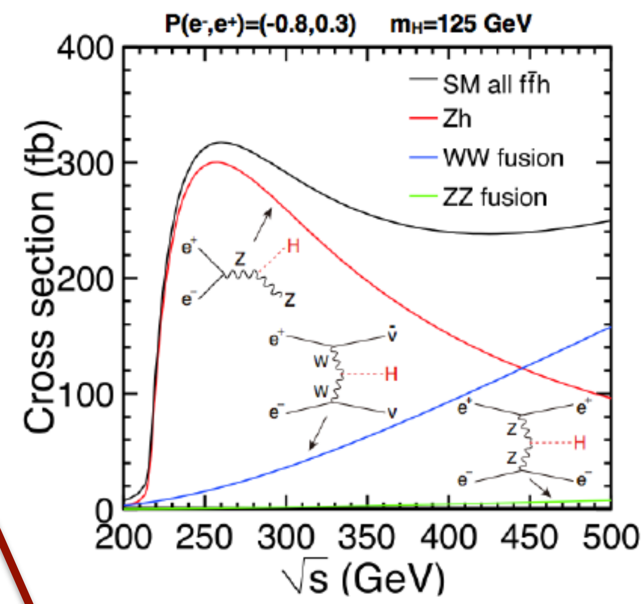
Dopo la scoperta dell'Higgs ➔ proposta TLEP

Energia ~ 240 GeV per produzione associata ZH

➔ fino a 350 GeV soglia di produzione t-tbar

Luminosita' > ~ 10^{34} (sensibilita' accoppiamenti Higgs)

- FCC-ee (100 km-Geneva)
- CepC (54-100 km-Qinghuangdao)
- Tunnel puo' contenere nuova macchina pp da 70-100 TeV (FCC-pp,SppC)



Iniettore di positroni per muon collider

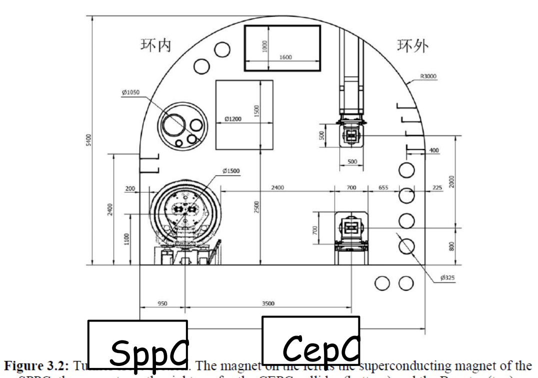
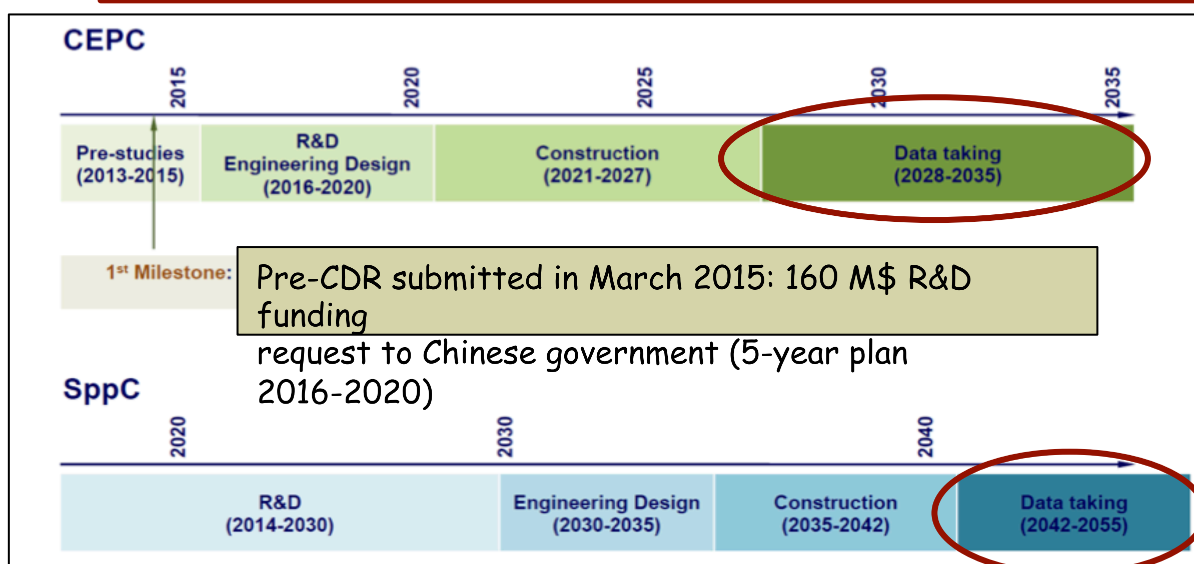
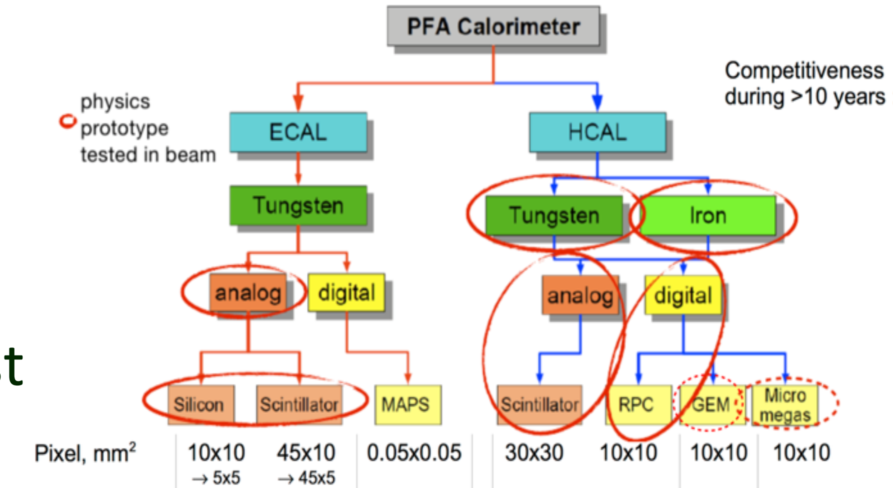


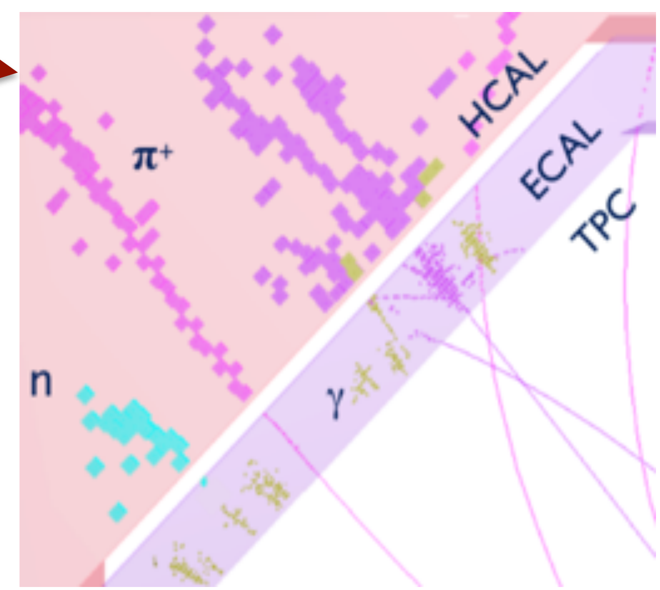
Figure 3.2: Tu[...]. The magnet on the left is the superconducting magnet of the SPPC, the magnets on the right are for the CEPC collider (bottom) and the Booster (top), respectively. The tunnel width is 6 m.



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:
  - New generation calorimeters
  - very low mass tracker 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

INFN contributions to FCC accelerator studies

FCC-hh Hadron Collider:

- Machine Detector Interface (LNF)
- Cryogenic beam vacuum system (LNF)
- High field (16 T) magnet R&D (Ge, Lasa)

in the framework of
EU H2020 Grant EuroCirCol:
started on June 1st 2015, for 4 years.
Core aspects of 100 TeV energy frontier hadron collider design
(422k€ INFN grant)

FCC-ee Lepton Collider

in the framework of **MoU** INFN-CERN

- Machine Detector Interface (LNF)-Convenership
- Impedance Evaluation (Sapienza, INFN-Roma1)
- Thin film technology for SRF cavities (Legnaro)

Parameter	FCC-hh	LHC
Energy [TeV]	100 c.m.	14 c.m.
Dipole field [T]	16	8.33
# IP	2 main, +2	4
Luminosity/IP_{main} [$cm^{-2}s^{-1}$]	5 - 25 x 10^{34}	1 x 10^{34}
Stored energy/beam [GJ]	8.4	0.39
Synchrotron rad. [W/m/aperture]	28.4	0.17
Bunch spacing [ns]	25 (5)	25

Phase 1 (baseline): 5 x 10^{34} $cm^{-2}s^{-1}$ (peak),
250 fb^{-1}/year (averaged)
2500 fb^{-1} within 10 years (~HL LHC total luminosity)

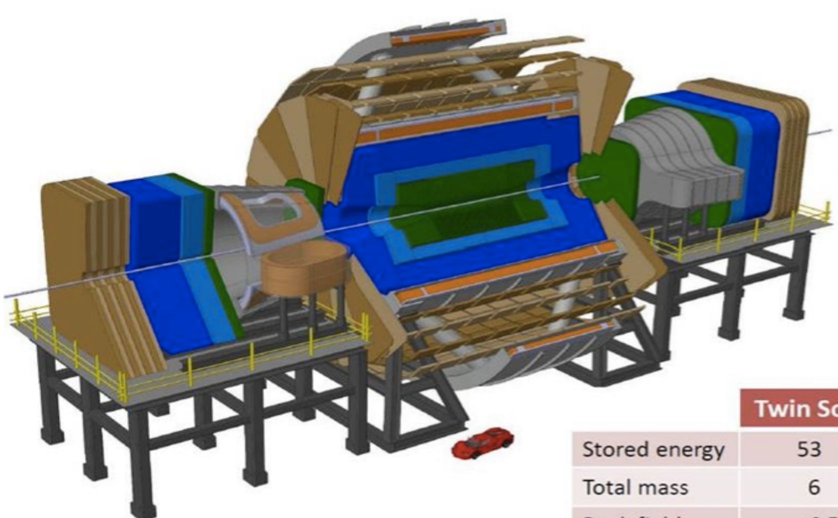
Phase 2 (ultimate): ~2.5 x 10^{35} $cm^{-2}s^{-1}$ (peak),
1000 fb^{-1}/year (averaged)
➔ 15,000 fb^{-1} within 15 years

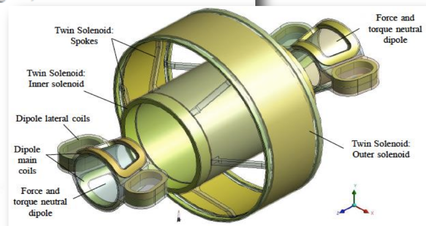
Yielding total luminosity O(20,000) fb^{-1} over ~25 years of operation

"baseline" esperimento @ FCC

Twin solenoid + Dipole

Matthias Mentink, Alexey Dudarev, Helder Filipe Pais Da Silva, Christophe Paul Berriaud, Gabriella Rolando, Rosalinde Pots, Benoit Cure, Andrea Gaddi, Vyacheslav Klyukhin, Hubert Gerwig, Udo Wagner, and Herman ten Kate





FCC Air core Twin solenoid and Dipoles

State of the art high stress / low mass design.

	Twin Solenoid	Dipole
Stored energy	53 GJ	2 x 1.5 GJ
Total mass	6 kt	0.5 kt
Peak field	6.5 T	6.0 T
Current	80 kA	20 kA
Conductor	102 km	2 x 37 km
Bore x Length	12 m x 20 m	6 m x 6 m

Abstract—An aggressive low mass and high stress design of a very large detector magnet assembly for the Future Circular Collider (FCC-hh), comprising a "Twin Solenoid" and two dipoles, is presented. The twin solenoid features two concentric solenoids. The inner solenoid provides 6 T over a free bore of 12 m and a length of 20 m, enclosing the inner particle trackers as well as electron and hadron calorimeters. The outer solenoid reduces the stray field of the inner solenoid and provides additional bending power for high-quality muon tracking. Dipoles are included providing 10 Tm of bending power in a 6 m mean free bore covering the forward directions for $\eta \geq 2.5$ particles. The overall length of this magnet assembly is 43 m.

The presence of several separate magnets in the system presents a challenge in terms of forces and torques acting between them. A rigid support structure, part of the cold mass, holds the

	Dose [MGy]
First layer of the IB (R =2.5 cm)	600
max in forward detector	10^4
max in barrel muon chambers	10^{-2}
max in end-cap muon chambers	10^{-1}

HL-LHC: 2025-2035

CRUCIALE R&D congiuto

- ✓ Luminosità istantanea 5x ➔ 5x pile-up
  ➔ aumento tempo CPU (non-lineare)
- ✓ Dose radiazione integrata 6x

Importanti richieste sugli apparati sperimentali ➔ in definizione

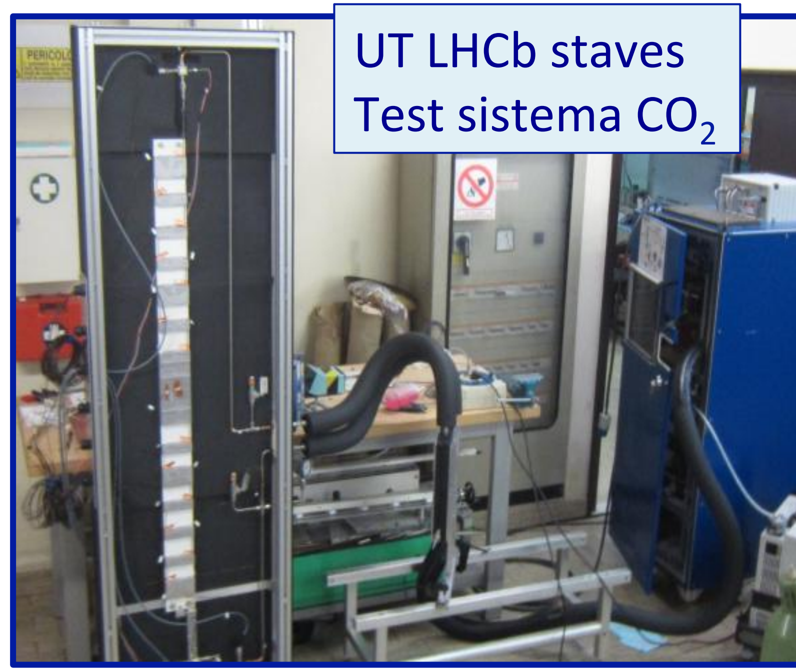
- Nuovi tracciatori al silicio rad-hard con trigger di traccia a L1 (1 MHz➔10 kHz) (fluenze 2×10^{16} cm^{-2} e copertura estesa a |η|~4) **

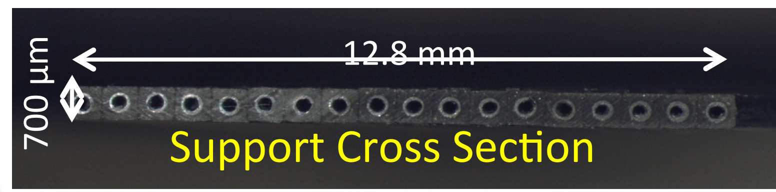
  10× rate eventi "registrati" / 3-4× event size
- Nuovi calorimetri in avanti rad-hard e ad alta granularità (particle flow vs dual read-out ➔ critici fotosensori)
- Timing in fase di studio sui tracciatori e i calorimetri
- Nuovi trigger, nuova elettronica, nuovi rivelatori a muoni (MPGD)
- Nuovo modello di calcolo

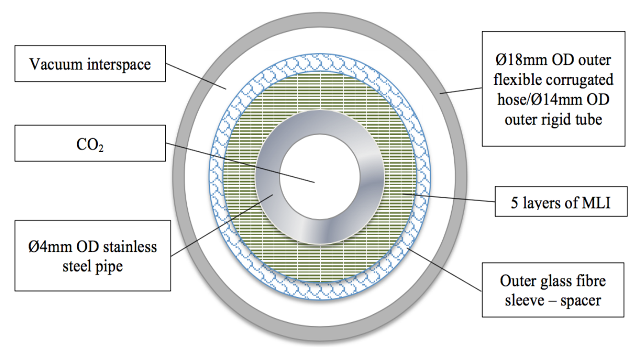
** @ Flavour: notevole incremento della statistica
colliders(10^{14} *b*-decays, 10^{15} *c*-decays)
high-intensity beams (10^{19} pot/year)

Servizi

- Incremento radiazione, numero canali, rate: **stress sui servizi**
- Riduzione numero cavi ➔ serial powering
- Distribuzione di potenza
- Raffreddamento con CO_2 evaporativo ➔ Si at ~-30 °C
- µchannel cooling ➔ strutture leggere
- R&D per meccanica leggera





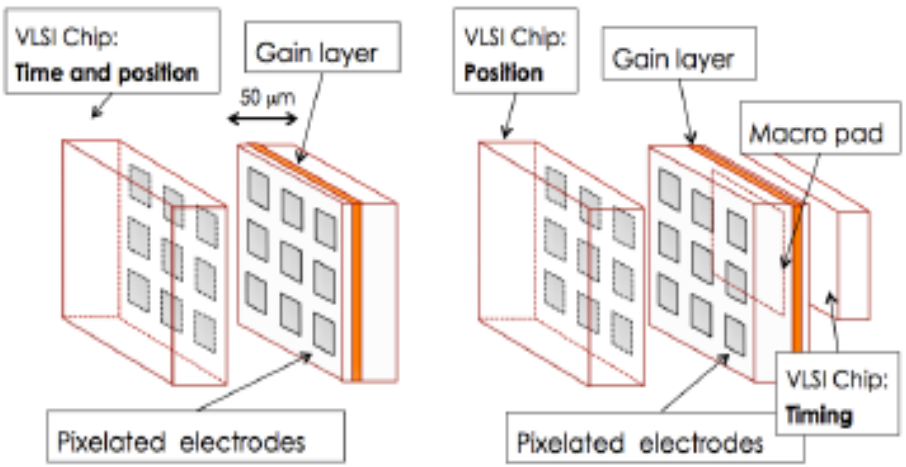


Extreme flavour experiment

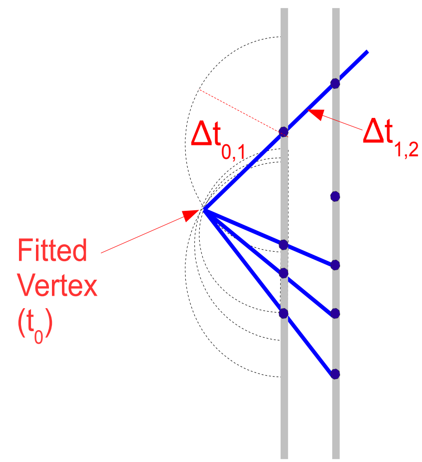
- A way to push the intensity frontier, exploiting the full luminosity of hadron colliders:
  - A detector with strong online tracking capability
  - Readout at 40 MHz
  - Real time event reconstruction with offline-grade quality
  - On-line data analysis

Will this change of paradigm work?

- online detector calibrations
- systematic uncertainties
- ...but a way to address the computing limitations



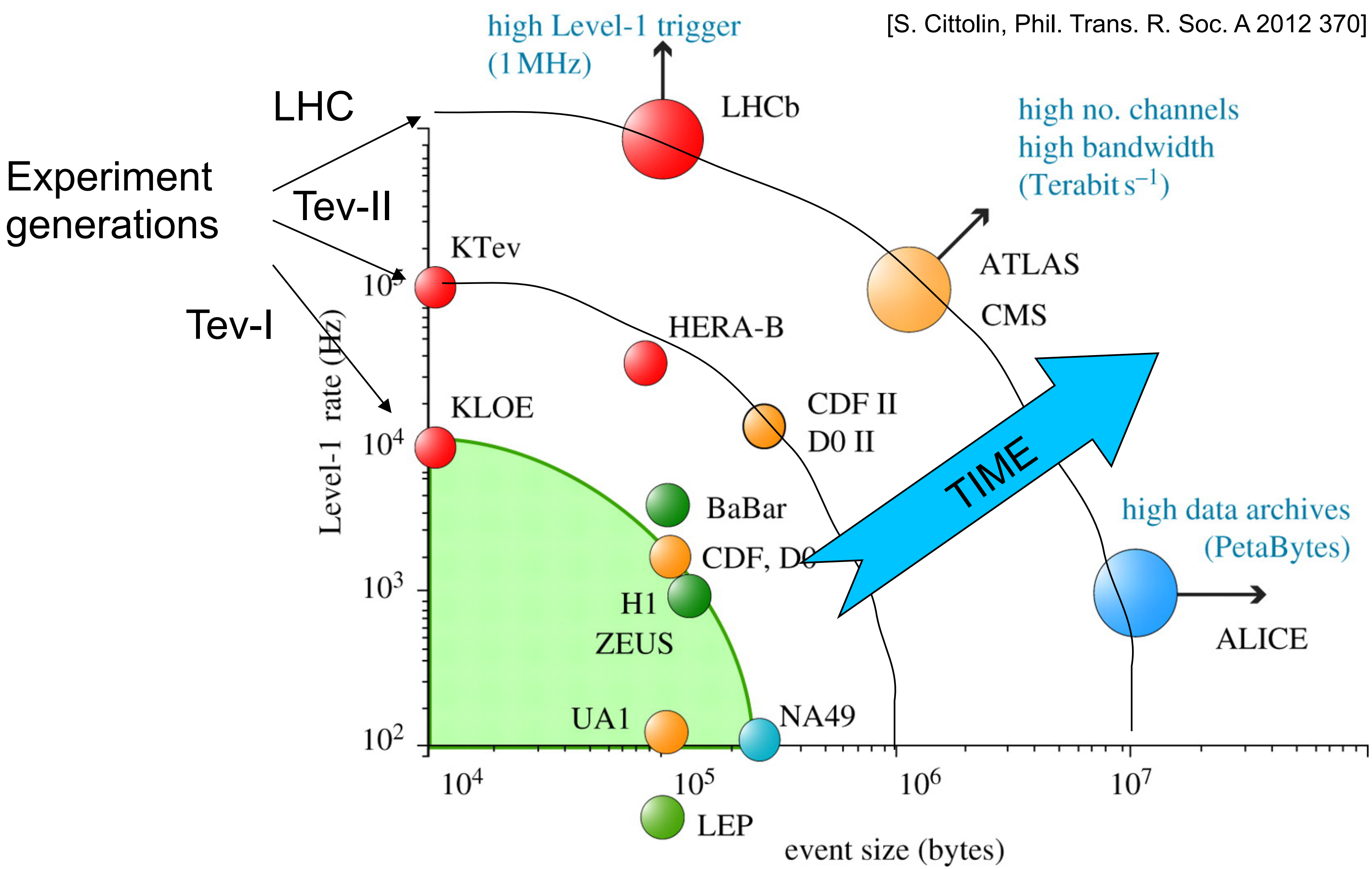
Ultra Fast Silicon Detectors



Real time tracking may exploit high time resolution tracking detectors

*Incidentally, **timing** is a big keyword in current R&D:*

Summary view of HEP Data Processing

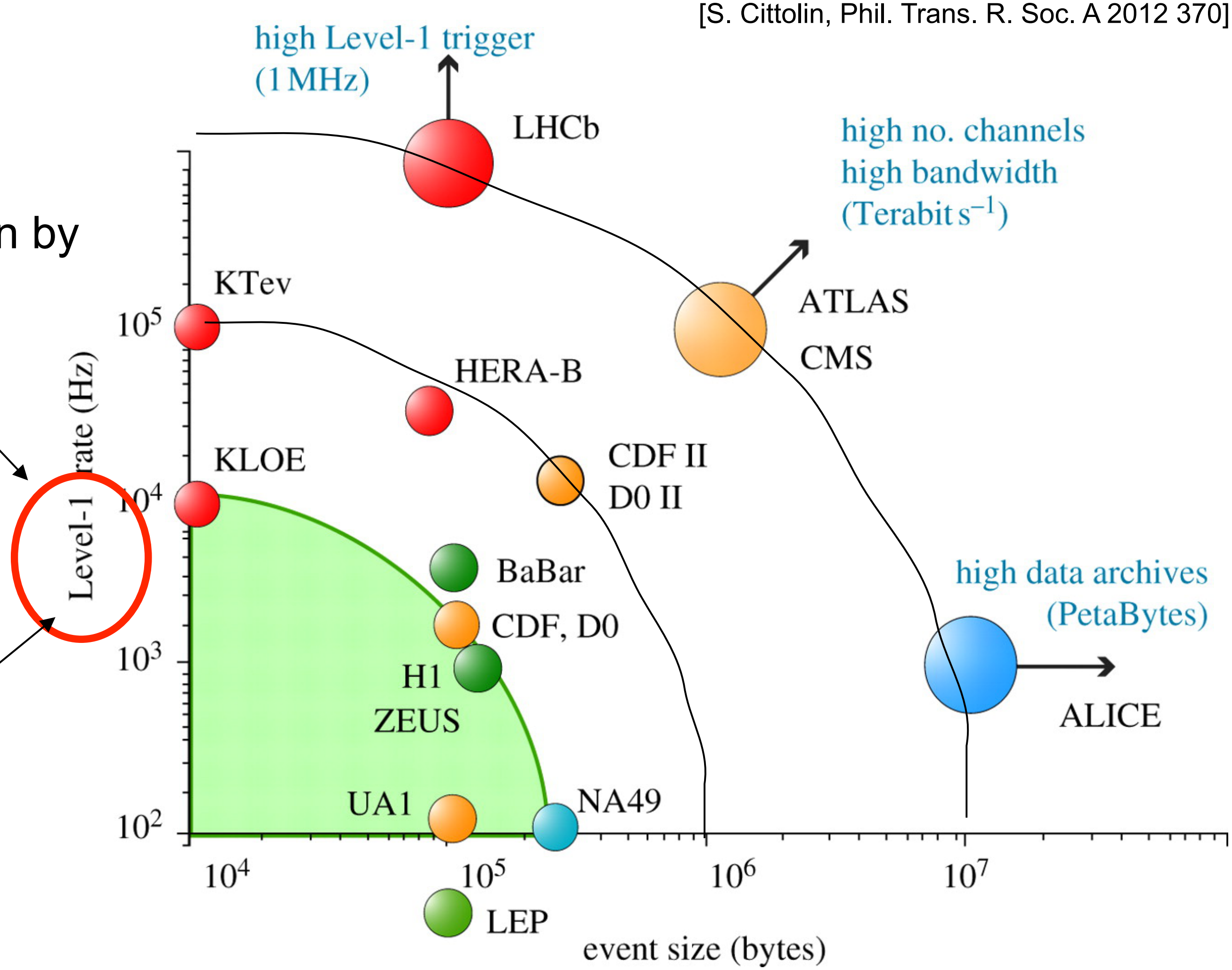


Future HEP experiments will increasingly depend on large processing power at the earliest possible stage

Summary view of HEP Data Processing

[S. Cittolin, Phil. Trans. R. Soc. A 2012 370]

This is NOT the full rate ! $>10^2$ reduction by Level-1 pre-selection



Going to be more of a challenge in future

A key enabler of progress will be the continuing development of technology of real-time reconstruction by special-purpose processors for Level-1 pattern recognition

Big Data Challenges include analysis, capture, data curation, search, sharing, storage, transfer, visualization, querying and information privacy. (wikepedia)

- The **LHC Big Data** fully stresses the «3Vs» Big Data key attributes

Volume: size of a data set

The «3Vs» problem for the Big Data

Variety: complexity and variety of the data set

Velocity: data creation speed (real time)

- The LHC data, as opposite of the major data providers like AMAZON, GOOGLE, etc., are spread across hundreds of sites around the world.

  Crucial is:
- Adequate computing power;
- Well optimized analysis code;
- Very fast network to allow data movement and remote access of the data across all the LHC sites;
- Fast and parallel storage systems

G. Maron

Come analizzare i dati HL-LHC?

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

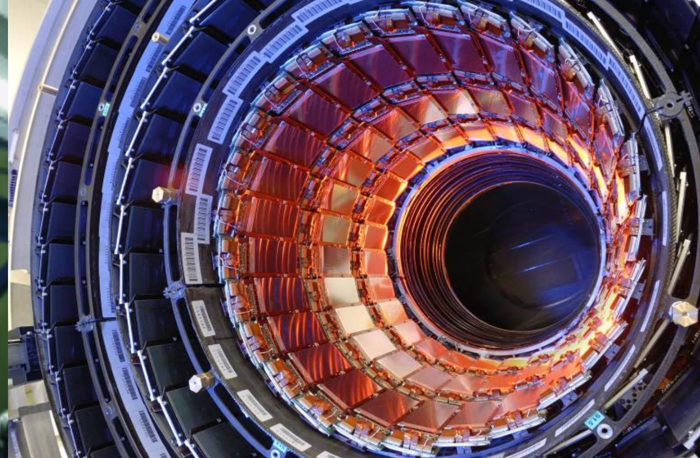
D. Lucchesi – Piano Triennale 2015

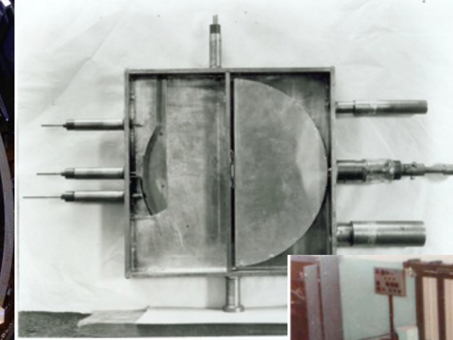
Conclusioni

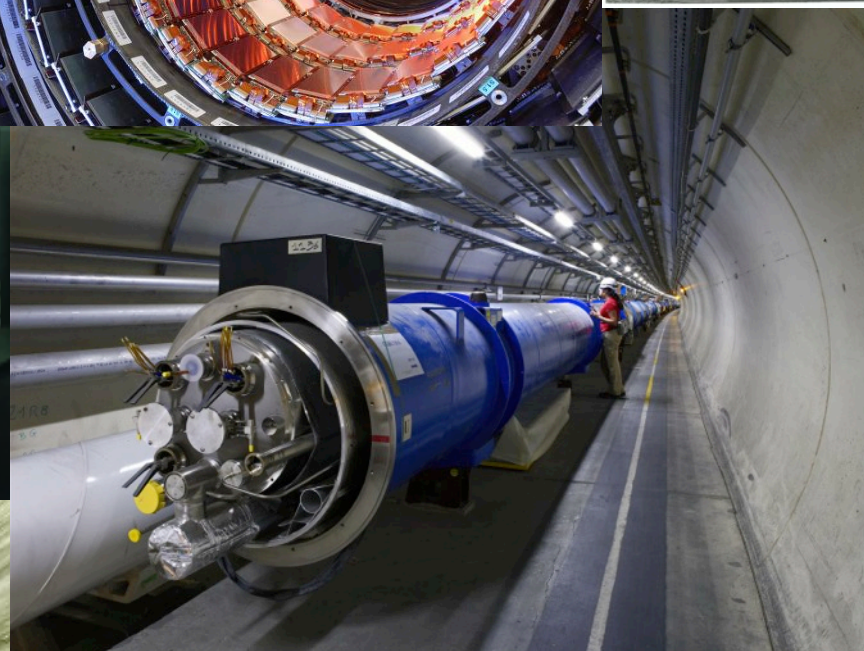
- ✓ Fortissimo contributo tecnologico su acceleratori, rivelatori, trigger e calcolo → continui sviluppi
- ✓ Indispensabile sviluppo di nuovi magneti
- ✓ Sicuramente auspicabile lo sviluppo di tecniche acceleratrici "non convenzionali"
- ✓ Grande ruolo INFN a livello internazionale
- ✓ Notevoli competenze acquisite, distribuite e da trasmettere
- ✓ Fondamentale la partecipazione agli R&D e alla decisione sui futuri acceleratori " motivate da goal di fisica"

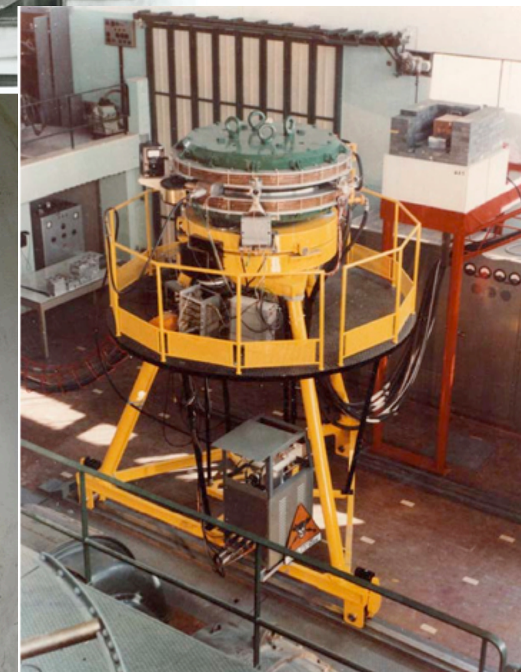
Grazie a quanti hanno contribuito

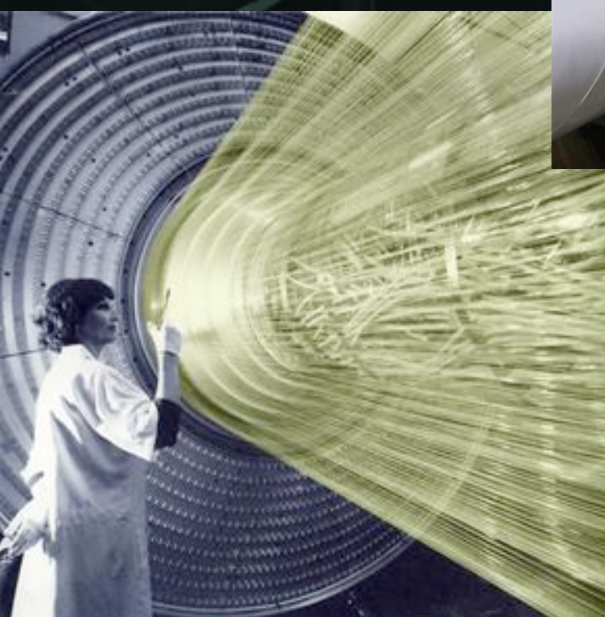
La storia insegna

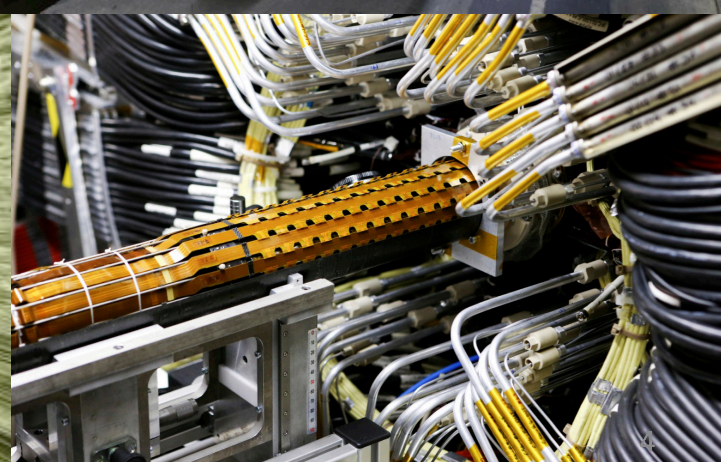


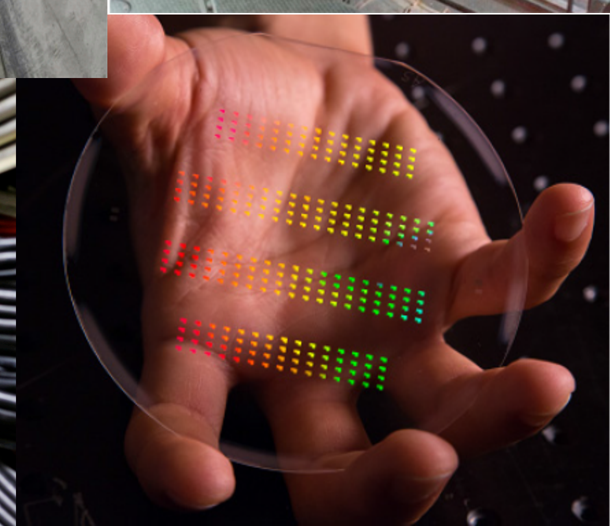










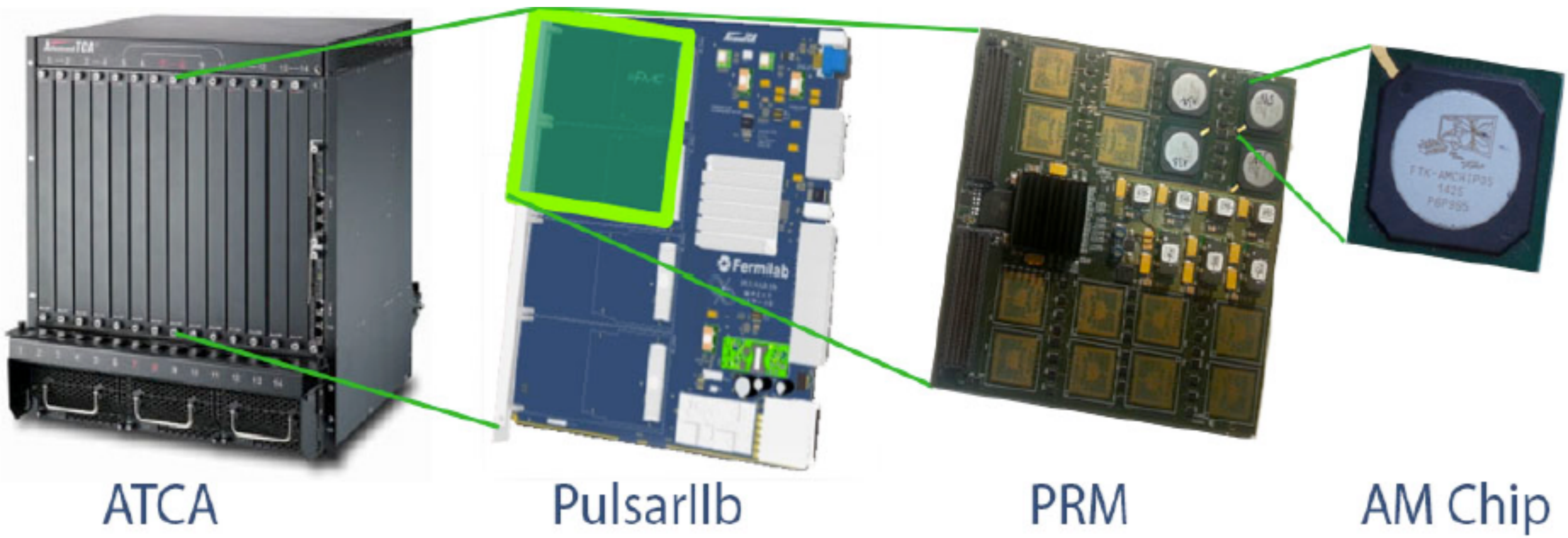


HL-LHC Performance Estimates

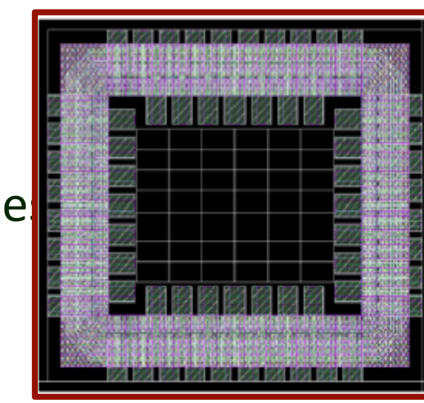
Parameter	Nominal	25ns – HL-LHC
Bunch population N_b [10^{11}]	1.15	2.2
Number of bunches	2808	2748
Beam current [A]	0.58	1.12
Crossing angle [μrad]	300	590
Beam separation [σ]	9.9	12.5
β^* [m]	0.55	0.15
Normalized emittance ε_n [μm]	3.75	2.5
ε_L [eVs]	2.51	2.51
Relative energy spread [10^{-4}]	1.20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

Track trigger



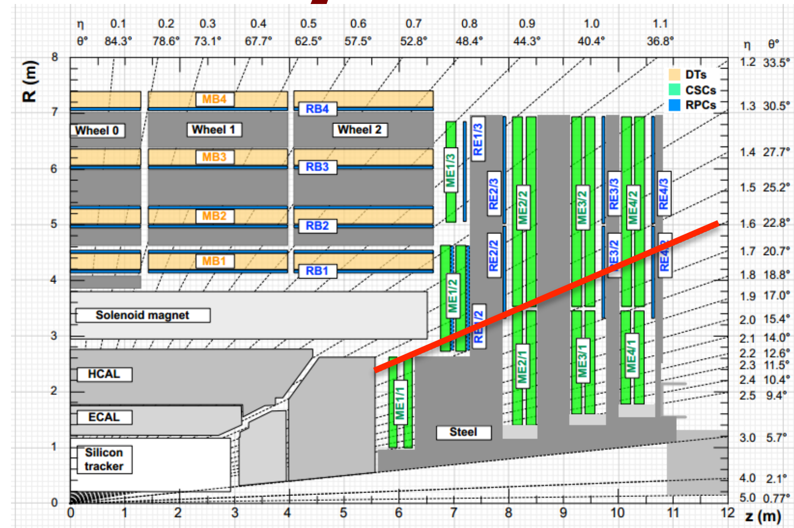
- Similar hardware model developed for both experiments
  - Pattern recognition in custom Associative Memory chips
  - Precision track fitting in FPGA
- First use case for HEP application of 28 nm electronic processes
  - 35% less **power** for same performance (W $MHz^{-1}bit^{-1}$)
  - 4× increase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



R&D for Forward Muon Systems

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

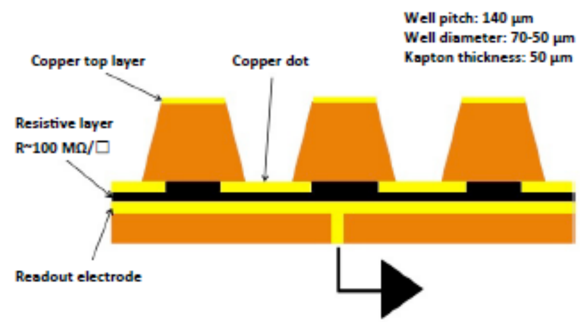


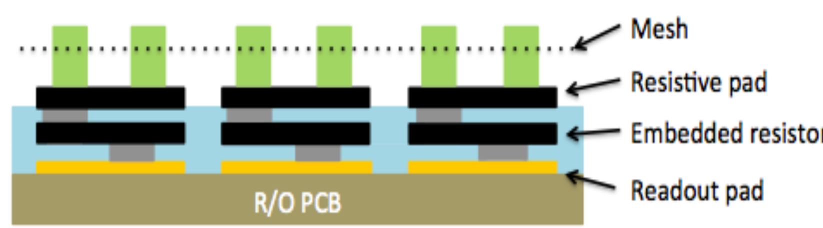
New Resistive Plate Chambers (ATLAS/CMS)

- 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 pad pattern with embedded resistors



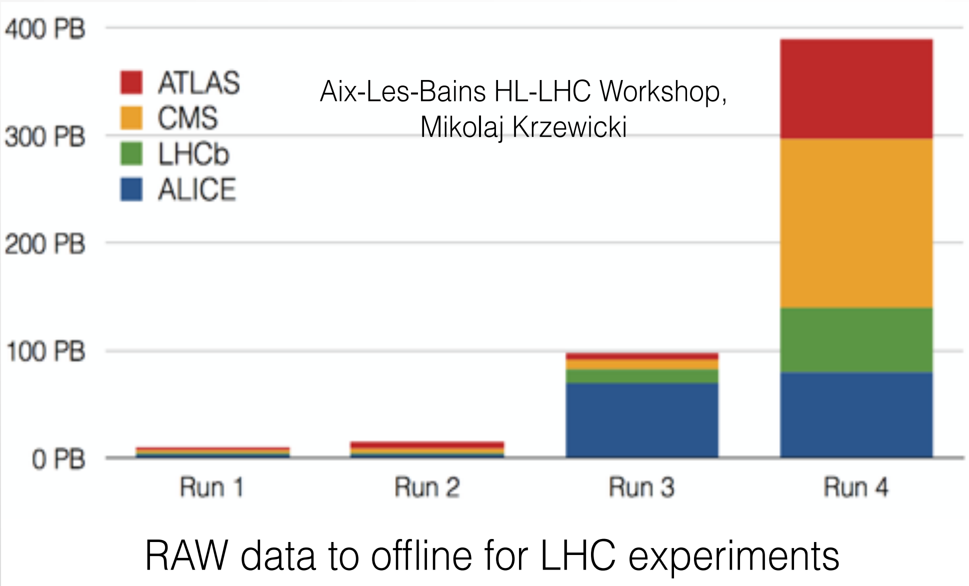


An "Extreme Flavour" (XFX) experiment?

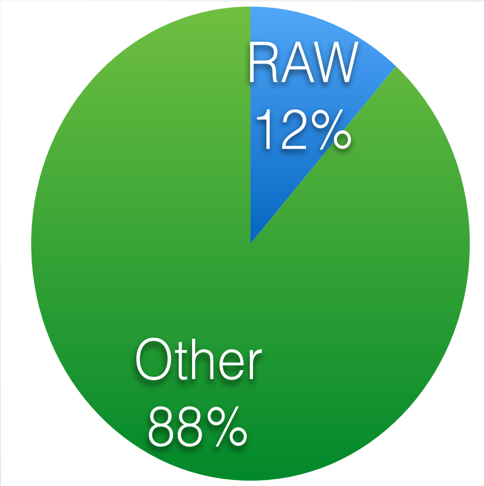
- Currently planned experiments at the HL-LHC will only exploit a small fraction of the huge rate of heavy-flavoured hadrons produced
  - ATLAS/CMS: full LHC integrated luminosity of 3000 fb^{-1}, but limited efficiency due to lepton high p_T requirements
  - LHCb: high efficiency, also on charm events and hadronic final states, but limited in luminosity, 50 fb^{-1} vs 3000 fb^{-1}
- Would an experiment capable of exploiting the full HL-LHC luminosity for flavour physics be conceivable?
  - Aiming at collecting O(100) times the LHCb upgrade luminosity → 10^{14} b and 10^{15} c hadrons in acceptance at $L=10^{35}$ $cm^{-2}s^{-1}$

Punzi

Come analizzare i dati HL-LHC?



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

LHC Big Data Challenge

EVOLUZIONE
MODELLO GRID

Nuove tecnologie:

Cloud/Virtualizzazione

Data Federation, intelligent data placement, caching

Federated Identities

FEDERATION of DATA

- Access any data from any site without the need to first copy it
- Network access to LHC Tier sites and data will be fast and cheap
- Moving data around reduced to minimum as required fast storage (disks)