LHC e oltre

Giornate di studio sul Piano Triennale

LNL – 2 Dicembre 2016

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

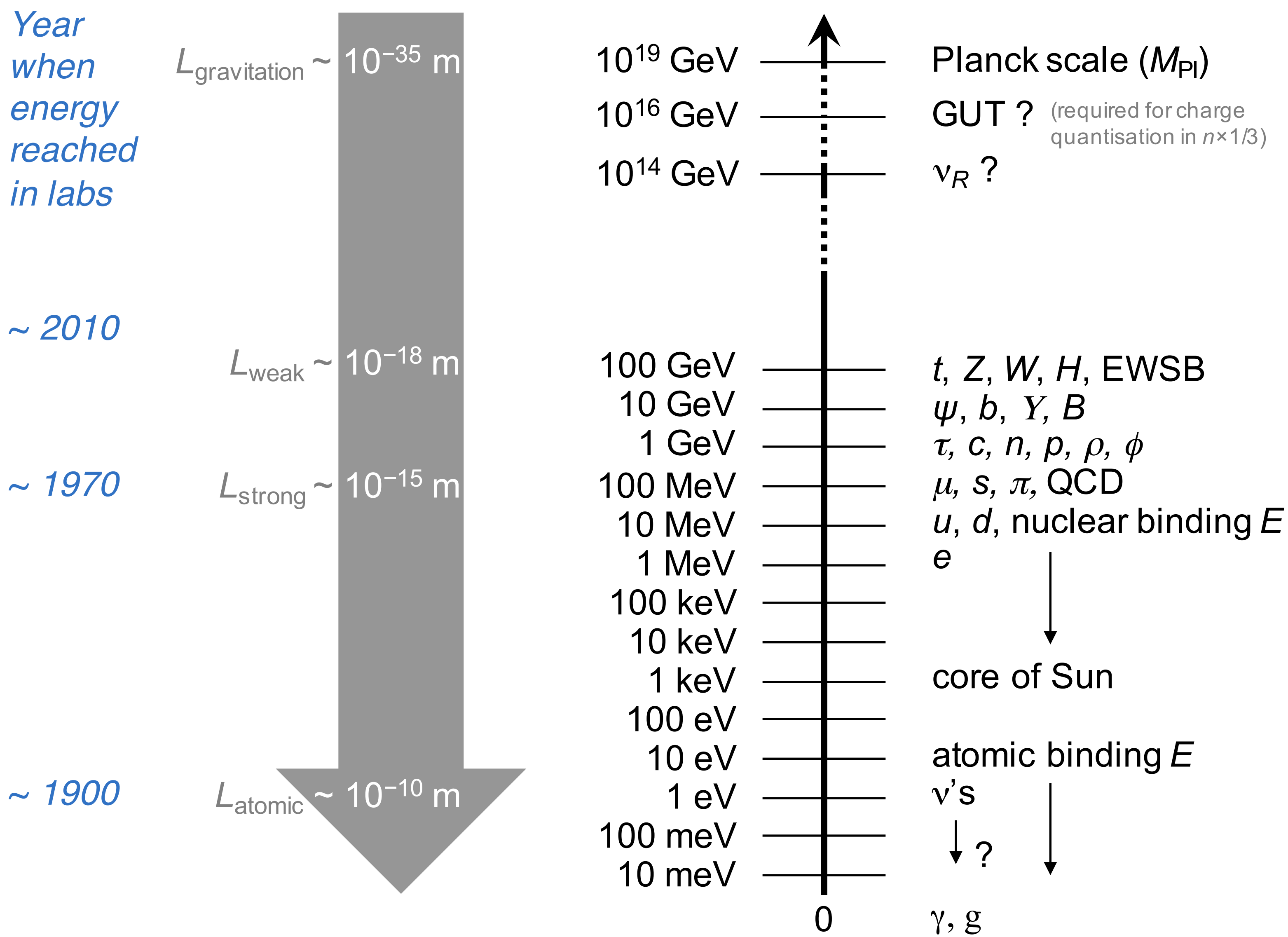
Enrico Fermi Presentazione all'American Physical Society, NY, **Jan. 29th 1954**
"What can we learn with High Energy Accelerators?"

Nadia Pastrone
INFN TORINO

Direct Exploration of the Energy Frontier

Andrea Wulzer

Scales in particle physics



INFN nasce insieme al boom della fisica agli acceleratori negli anni ’50

Acceleratori: strumento **indispensabile** e/o **complementare** di **scoperta, indagine** e **misura** in **fisica delle particelle**

Gran parte delle **tecnologie** sviluppate per gli esperimenti agli acceleratori vengono poi riutilizzate con successo in altri campi

LHC rappresenta una sfida epocale per impegno, dimensioni e durata

Il progetto **HL-LHC** è stato definitivamente approvato nel 2016

perchè andare oltre? come? quando?

misure più precise, nuova frontiera d'energia/intensità in laboratorio

tipologia di fascio, dimensioni/costi da ridurre

→ **sviluppi tecnologici cruciali**

→ **ruolo INFN**

CERN: 11% laboratorio italiano

Impegni condivisi oltre LHC e per il futuro:

- magneti superconduttori ad alto campo
- studi per futuri acceleratori: CLIC, FCC (include HE-LHC)
- aperta discussione su opportunità sperimentali differenti

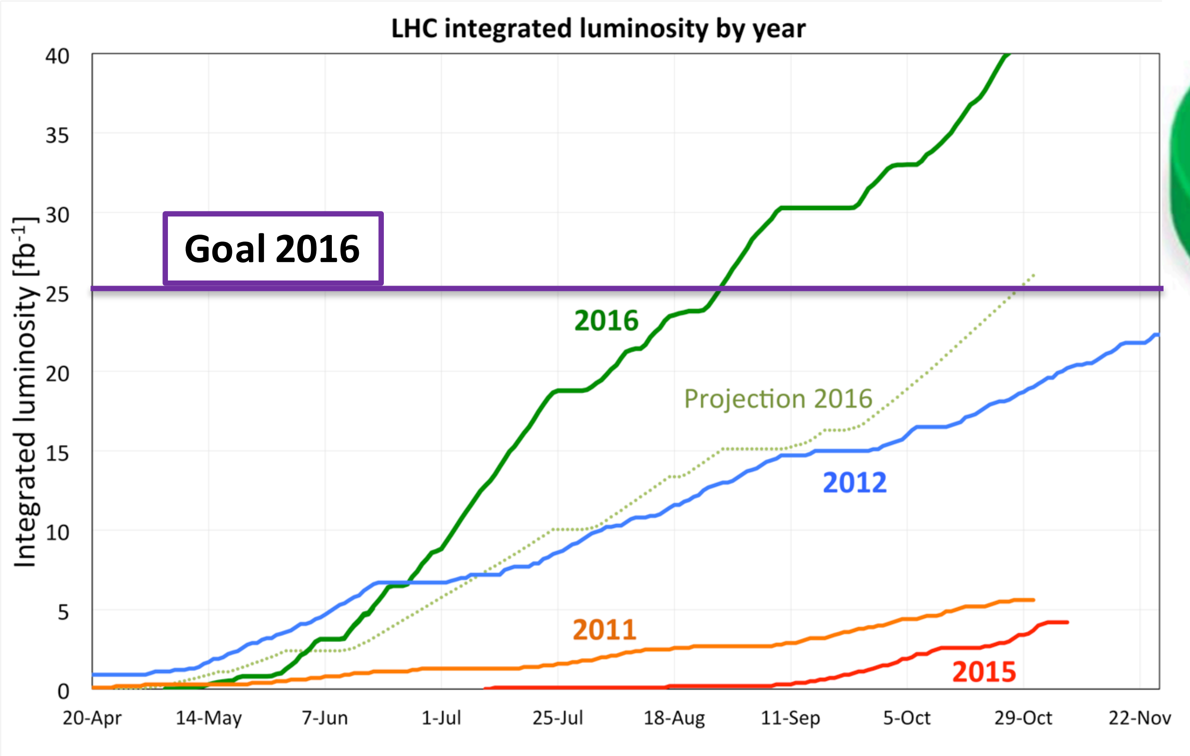
SCADENZA IMPORTANTE: aggiornare entro ~ 2019-2020
i piani della European Strategy for Particle Physics (ESPP)

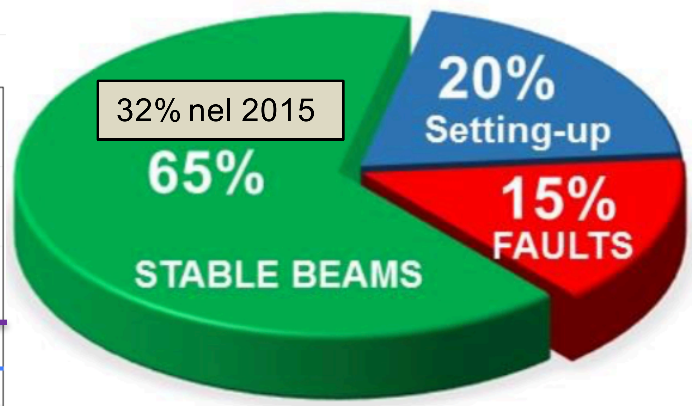
LHC: collisioni pp

Raggiunta luminosità istantanea di picco superiore al disegno: 1.5 10^{-34} $cm^{-2}s^{-1}$

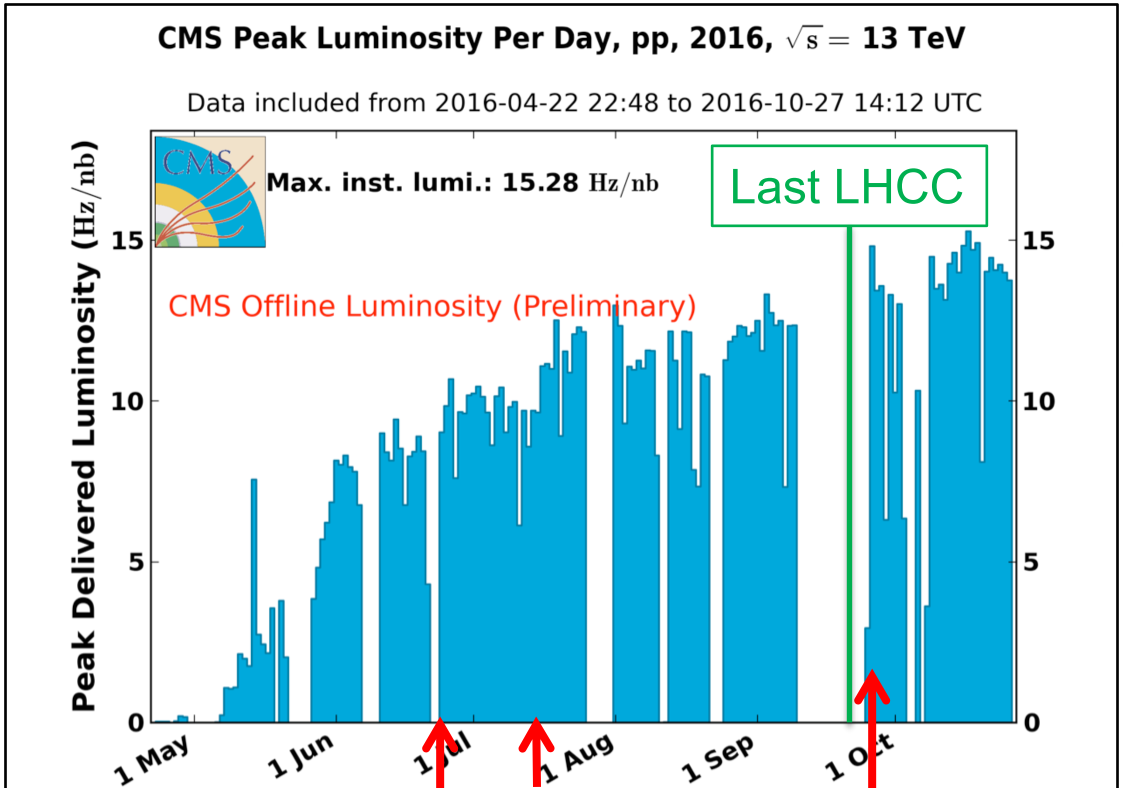
Altissima efficienza di produzione dati e ottima qualità

Raccolti @ 2016 ~ 40 fb^{-1} da ATLAS e CMS, 1.9 fb^{-1} in LHCb





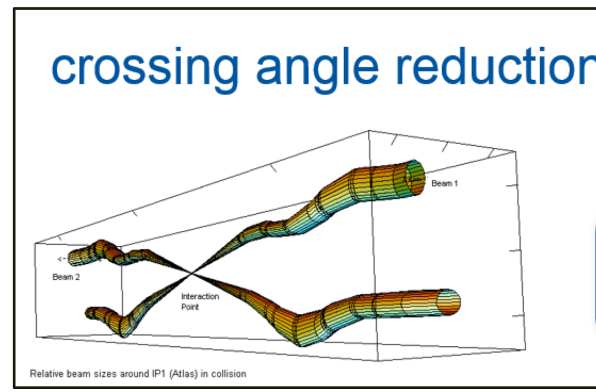
LHC: record luminosità



1.5×10^{34} cm^{-2}s^{-1}

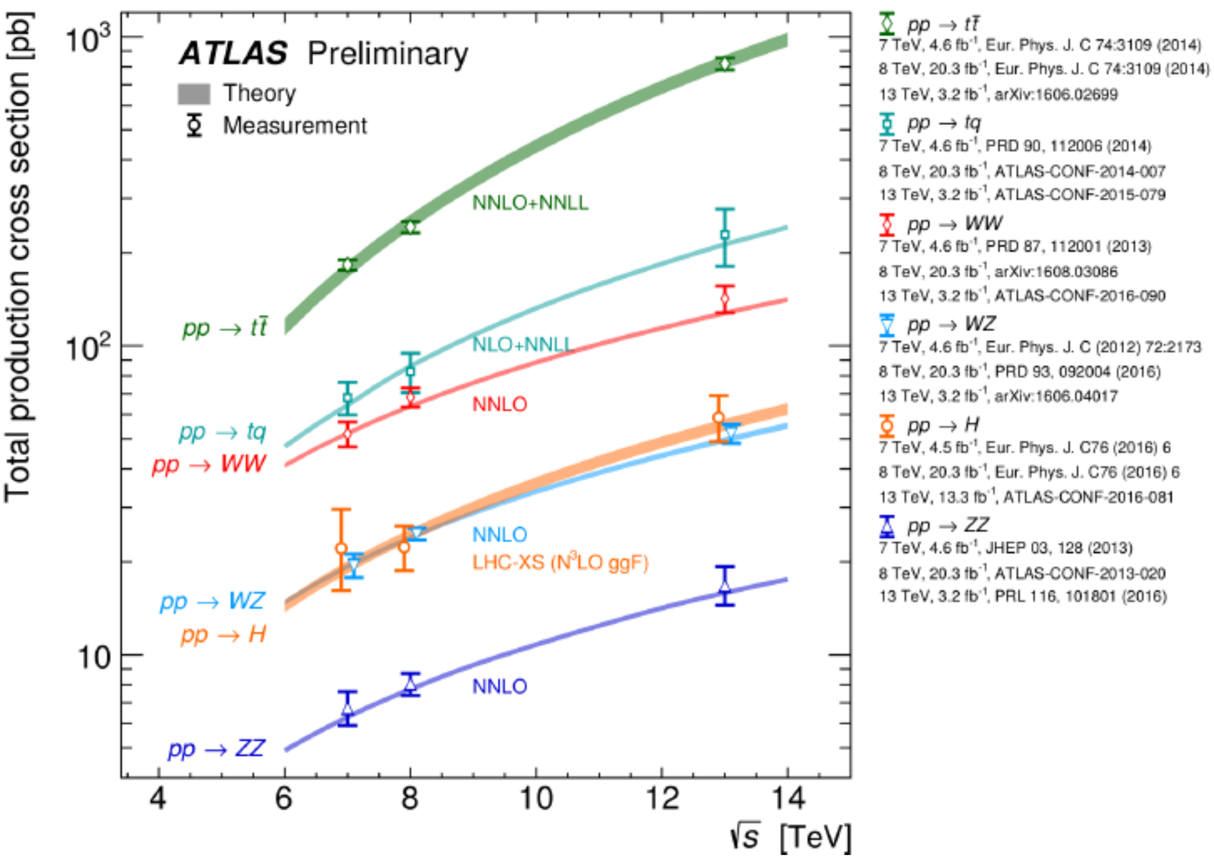
10^{34} BCMS

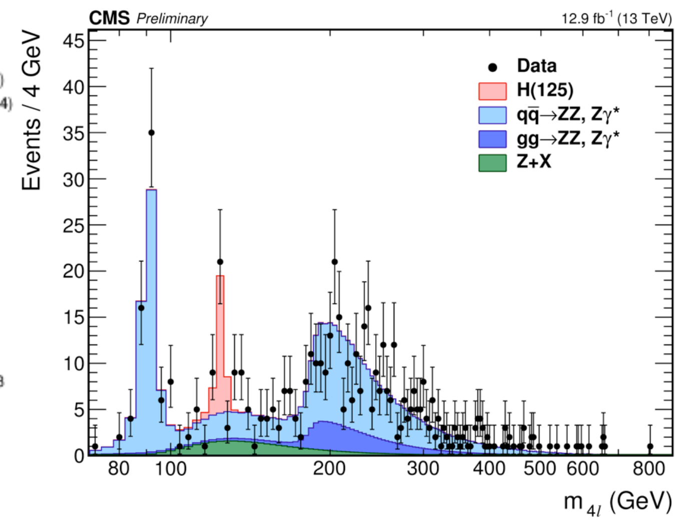
Reduced crossing angle

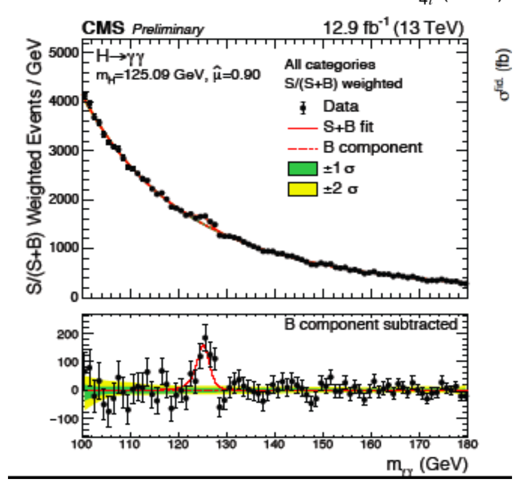


INFN @ LHC

- Risultati eccellenti: scoperta del bosone di Higgs, misure di precisione e ricerca di evidenza di segnali oltre il Modello Standard

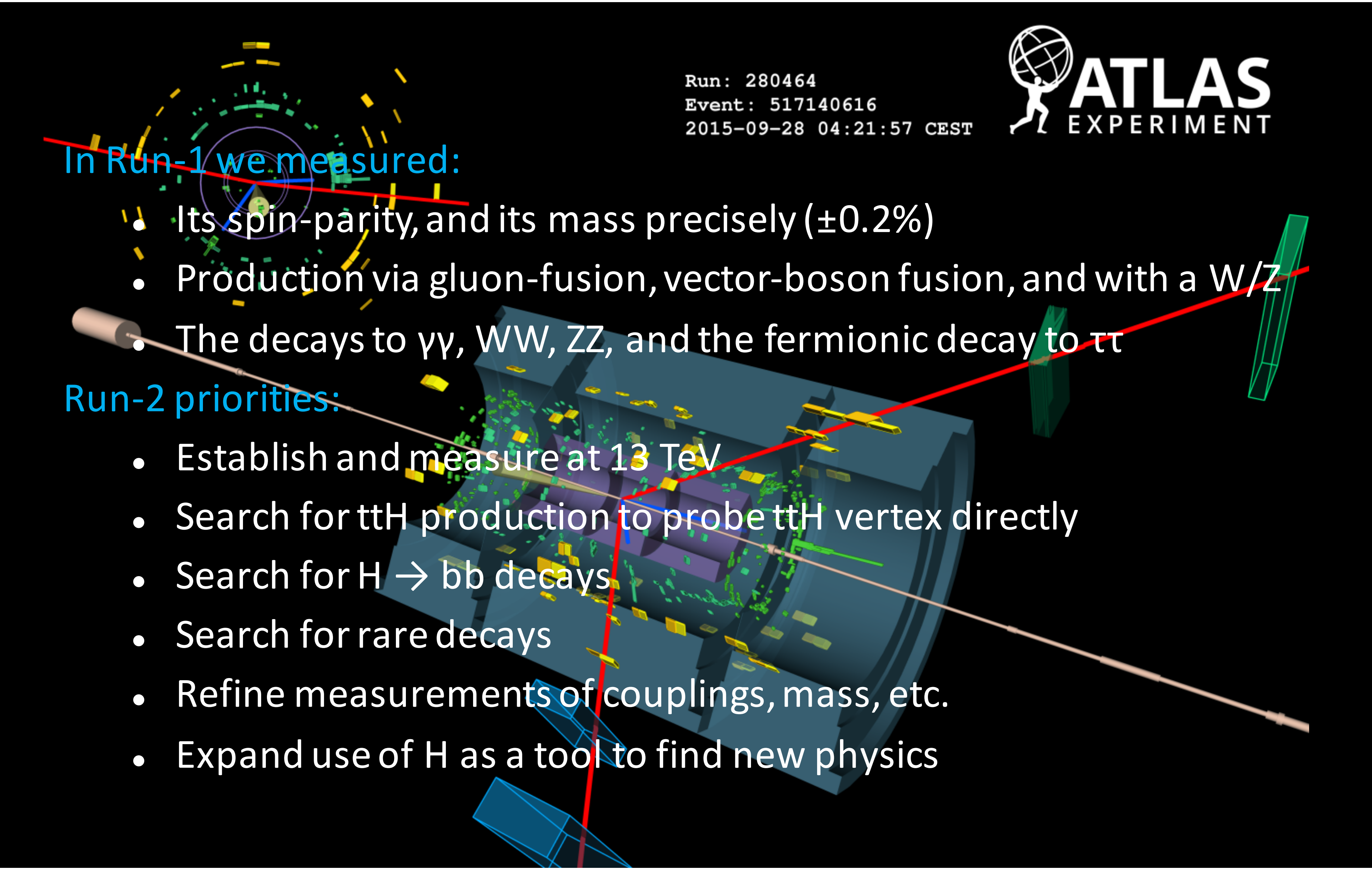







dal dicembre 2011
una pista difficile ma tracciata
per studiare il bosone di Higgs

Refining the Higgs Investigation



In Run-1 we measured:

- Its spin-parity, and its mass precisely (±0.2%)
- Production via gluon-fusion, vector-boson fusion, and with a W/Z
- The decays to γγ, WW, ZZ, and the fermionic decay to ττ

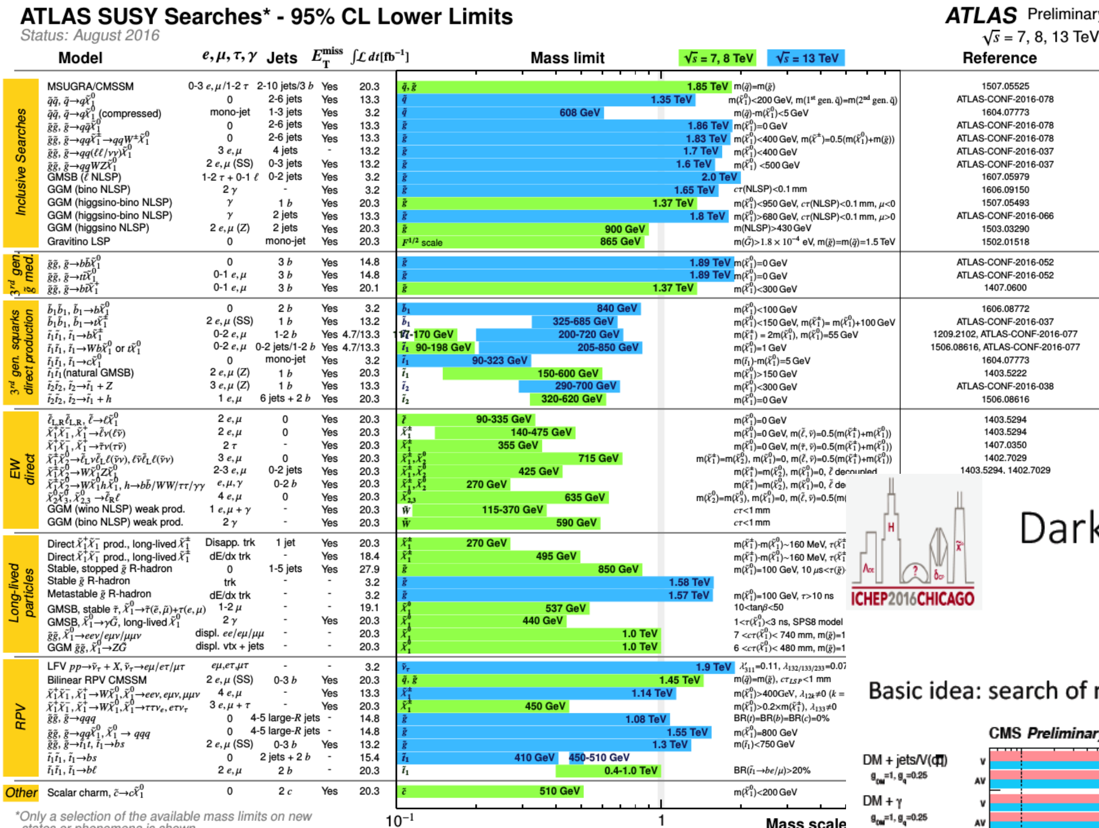
Run-2 priorities:

- Establish and measure at 13 TeV
- Search for ttH production to probe ttH vertex directly
- Search for H → bb decays
- Search for rare decays
- Refine measurements of couplings, mass, etc.
- Expand use of H as a tool to find new physics

INFN @ LHC

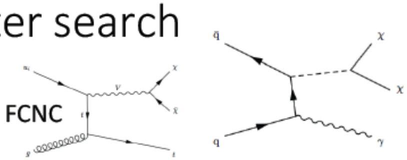
- Fortissimo contributo tecnologico su acceleratori, rivelatori, trigger e calcolo → continui sviluppi
- Essenziale il coinvolgimento di tutte le competenze dell'Ente
- Grande impegno a livello internazionale → responsabilità
- Moltissimi giovani in Italia e all'estero con incarichi rilevanti
- Notevoli competenze acquisite, distribuite e da trasmettere

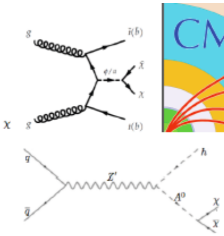
RICERCA DI SUSY e Dark Matter



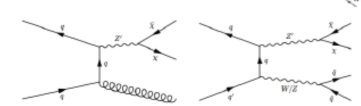
Dark Matter search

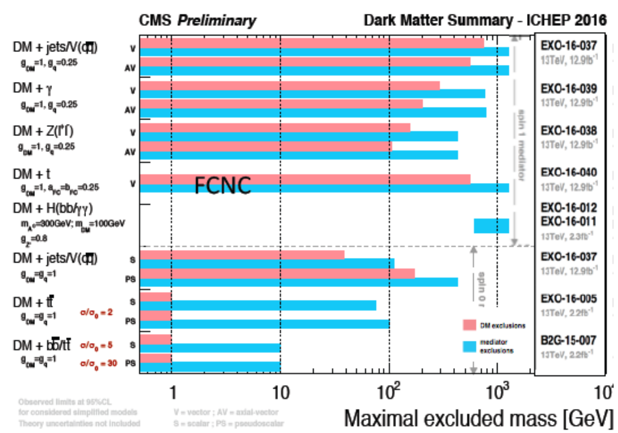
FCNC

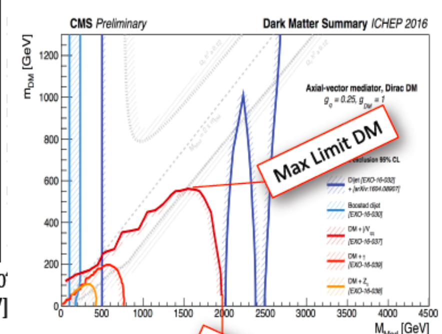




Basic idea: search of mono-object recoiling against MET

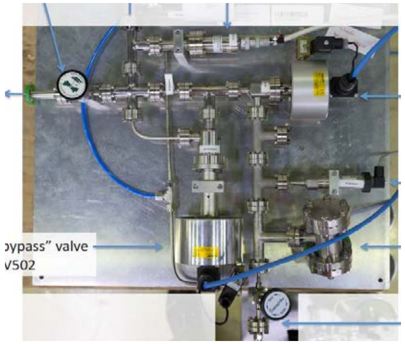






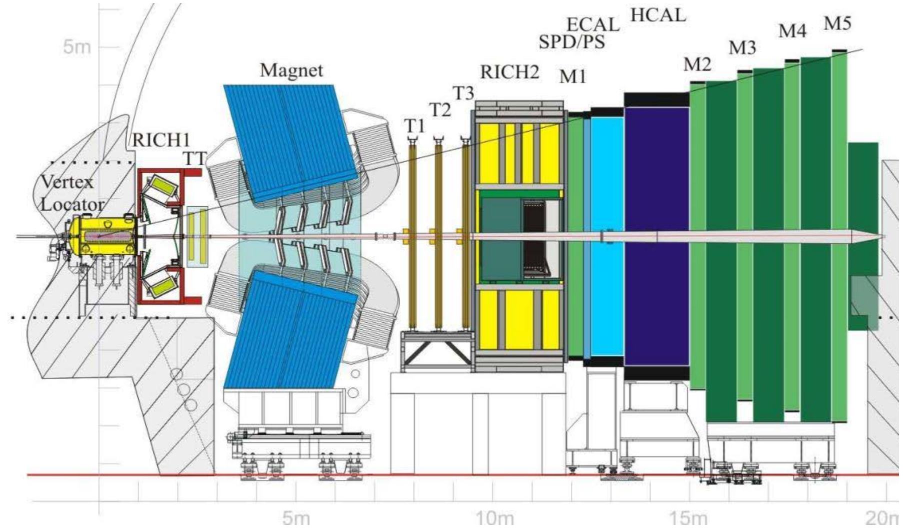
Summary of all Dark Matter Searches in Run II
Max and Min Limits on mediator search (blue) decaying to dark matter (red)

Internal gas target (AFTER)

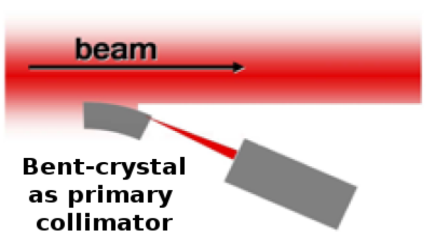


e.g. SMOG

Upstream of LHCb and/or ALICE

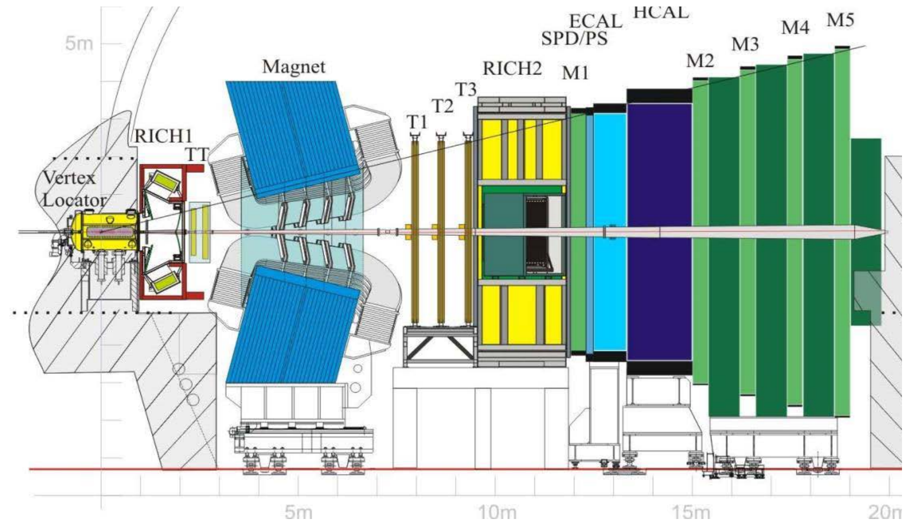


Crystal extraction

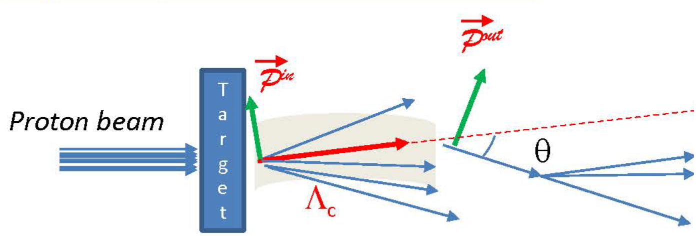


UA9

Upstream of LHCb and/or ALICE



$$\frac{dN_i}{N_{0i}\, d\cos\theta_i} = \frac{1}{2}(1 + \alpha P_i \cos_i \theta_i)$$



Proposed for measurement of magnetic moments of short lived baryons

Could test anomalous magnetic moments of heavy quarks

Crystal collimation: a TT opportunity

time line for LHC crystal collimation

S. Redaelli

- 2015-2016 (start of Run II): crystal test stand on beam 1

  two crystals, one per plane. Different technologies (quasi-mosaic / strip)

- 2017-2018 (last 2 years of Run II): New crystal test stand also on beam 2

  plan an installation during this end-of-year technical stop (EYETS2016): 2 crystals
  aim at testing new technology for goniometer; need better control of bending angles
  want 50.0 ± 2.5 μrad, for first installation got ~40μrad (quasi-mosaic) and ~65μrad (strip)

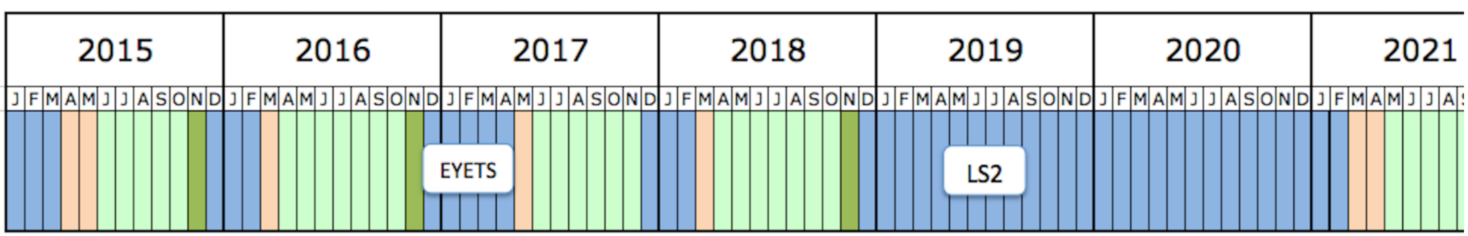
- EYETS2017: possible upgrade of "old" beam 1 goniometers.

  if beam experience indicates need for testing the new goniometers on both beams

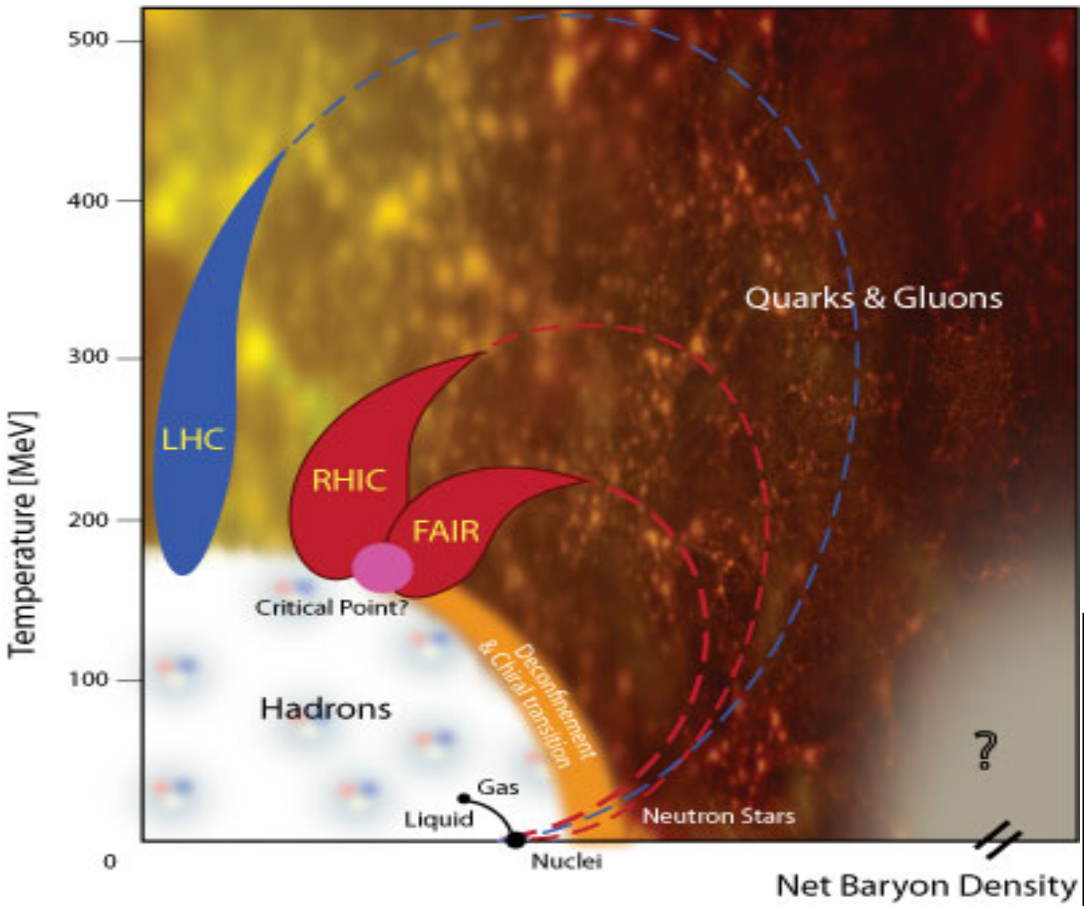
- LHC second long shutdown (LS2): 4 new crystals for ion collimation

  NOT a baseline within the HL-LHC project, but R&D funding available to prepare for this; use of 4 crystals requires production of ~10 units (including spares)

- crystals for LHC fixed target experiment – larger angles above 200 μrad – waiting for feedback from recent "Physics Beyond Colliders" workshop



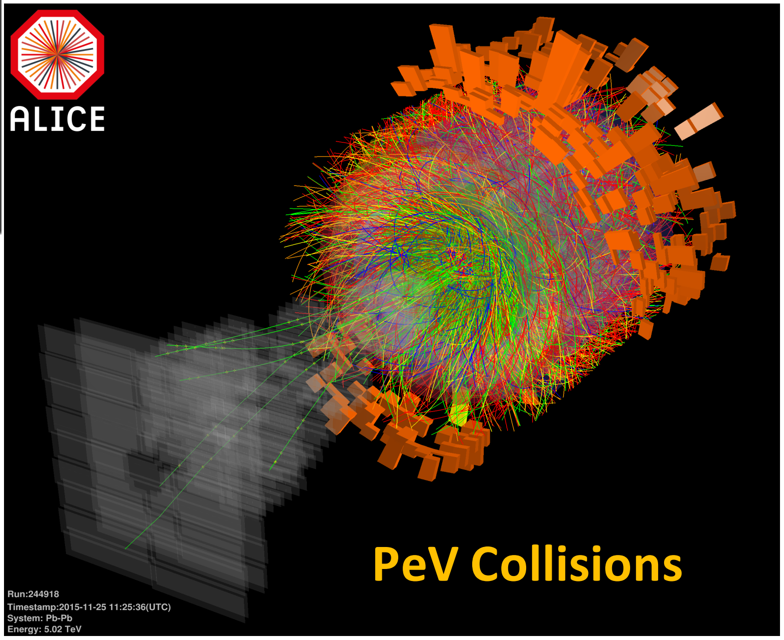
LHC e la Materia Nucleare



- Caratterizzazione del sistema complesso del Quark Gluon Plasma alla temperatura più elevata raggiunta in laboratorio e confronto con RHIC e FAIR
- ALICE, ATLAS, CMS e LHCb – apparati di grande accettanza per studiare collisioni Pb-Pb, p-Pb, Pb-p e per confronto pp

Studio delle proprietà della materia che interagisce forte con condizioni di alta temperatura e densità:

plasma deconfinato di quark e gluoni (QGP)

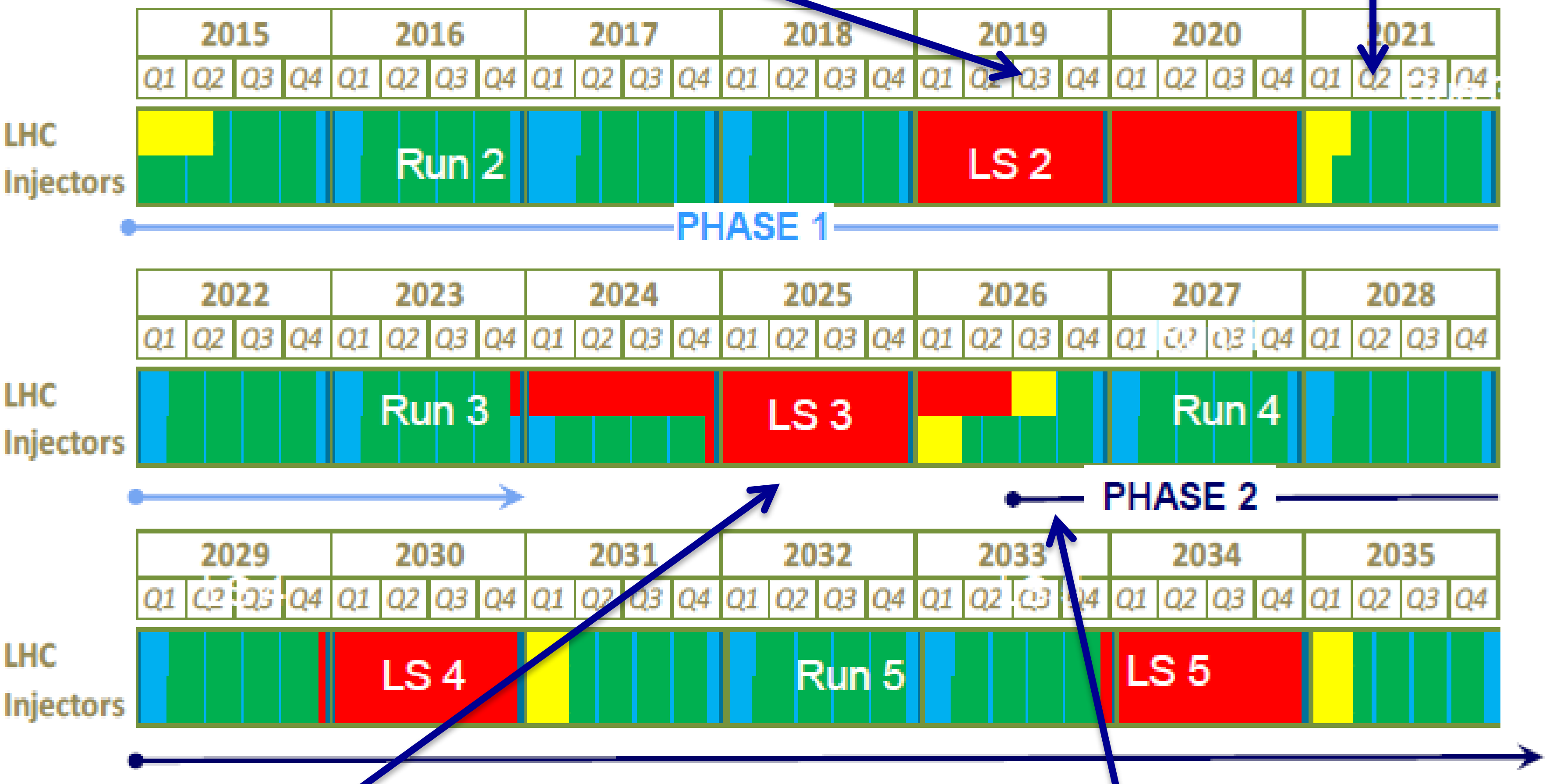


non abbiamo finito ……
siamo preparati ad esplorare tutto il Modello Standard e a cercare oltre sempre meglio?

Piano temporale LHC

Upgrade FASE1
ALICE, LHCb major upgrade
ATLAS, CMS minor upgrade

Heavy Ion Luminosity from 10^{27} to 7 $x10^{27}$



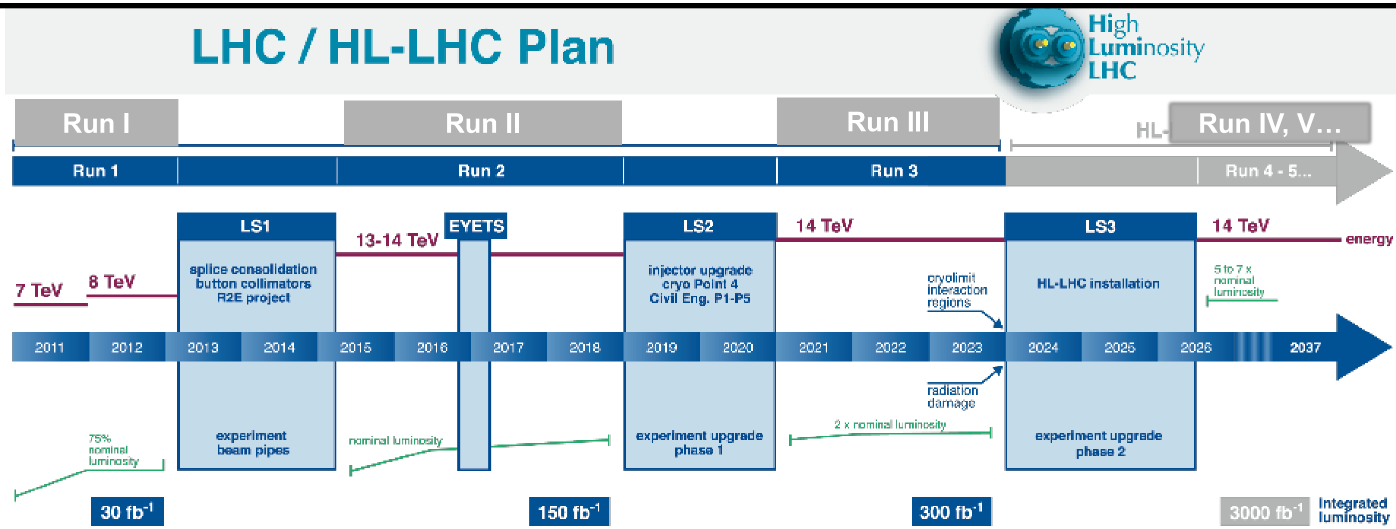
PHASE II Upgrade
ATLAS, CMS major upgrade

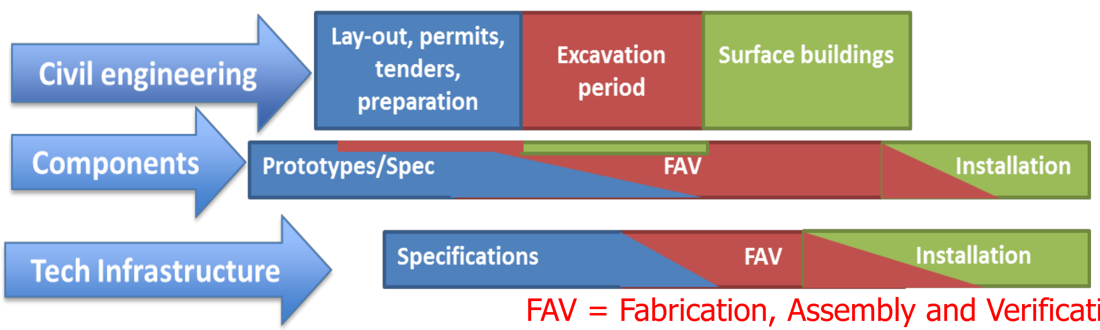
HL-LHC, pp luminosity from 10^{34} (peak) to 5 $x10^{34}$ (levelled)

HL-LHC

- a "landmark project" in the ESFRI roadmap
- formally approved by the CERN Council

Nominal LHC: $\sqrt{s}$ = 14 TeV, L= 1×10^{34} cm^{-2} s^{-1}
Integrated luminosity to ATLAS and CMS: 300 fb^{-1} by 2023 (end Run3)





FAV = Fabrication, Assembly and Verification

HL-LHC: $\sqrt{s}$ = 14 TeV, L= 5×10^{34} cm^{-2} s^{-1} (levelled)
Integrated luminosity to ATLAS and CMS: 3000 fb^{-1} by ~ 2035

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 $|\eta|\sim4$) **
- 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

10 × rate eventi "registrati" / 3-4 × event size

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

HL-LHC scheduled start in 2026

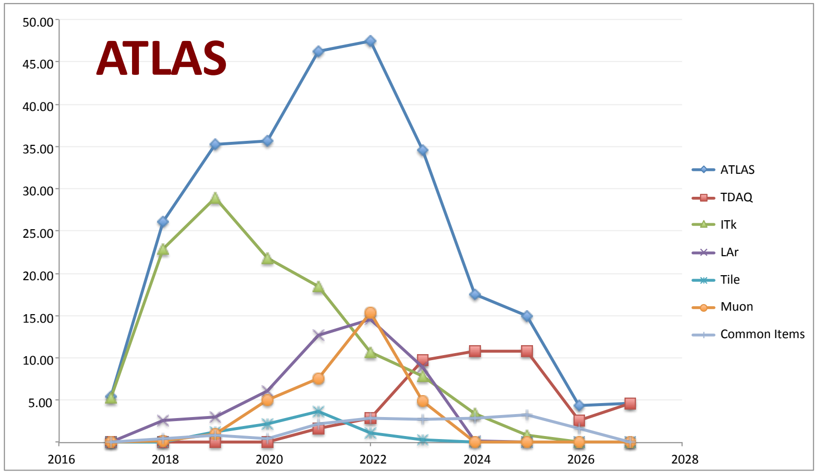
- ✓ **"baseline" peak luminosity 5 x 10^{34} $cm^{-2} s^{-1}$** (pileup PU) 140
- ✓ **"Ultimate" peak luminosity 7.5 x 10^{34} $cm^{-2} s^{-1}$** ➔ 200 PU
- ✓ Radiation tolerance - full performance at 3000 fb^{-1} - margin up to 4000 fb^{-1}

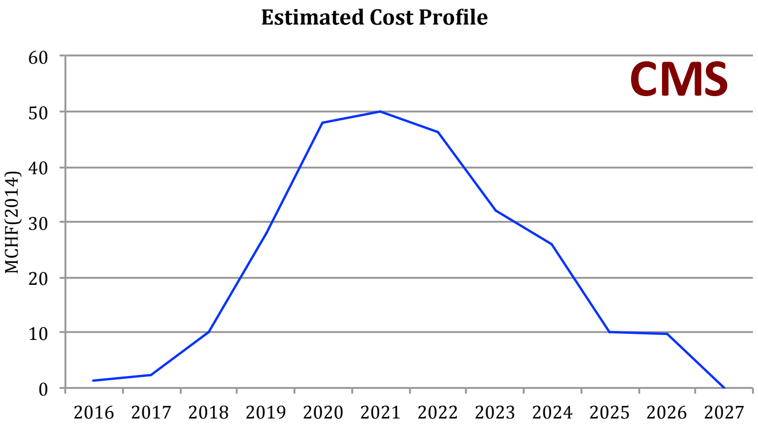
New projects requirements:
Physics motivations
Lab/infrustructures/industry in Italy
Manpower committed

Manpower

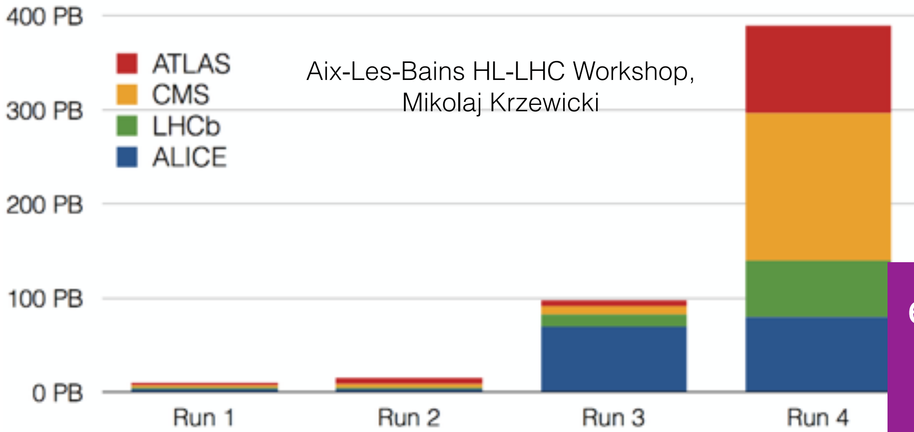
➔ skilled and younger physicists/engineers need a future in INFN!

- ✓ **R&D ongoing towards TDR in 2017-2018**
- ✓ **ATLAS/CMS full upgrade cost ~ 270 MCHF**

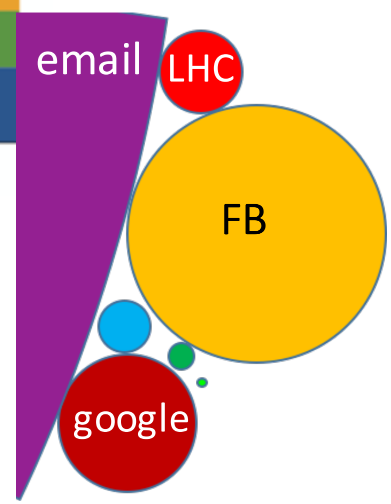




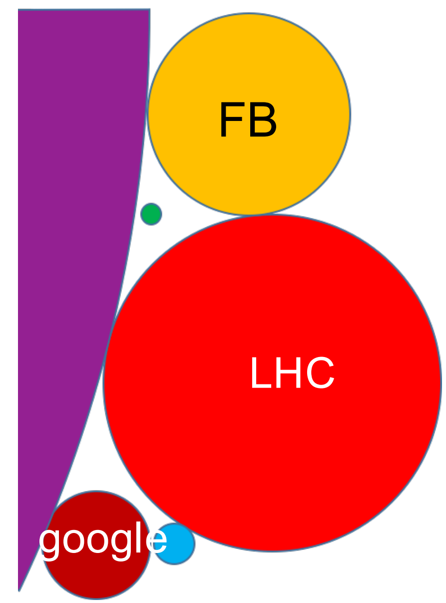
LHC: era di BIG DATA!



RAW data to offline for LHC experiments



2016 big data



2027 big data

Storage
Raw 2016: 50PB -> 2027: 600PB
Derived 2016: 80PB -> 2027: 900PB

CPU
x60 2016

CPU requirements can be mitigated by use of the technology advancement: use of heterogeneous computing facilities HPC/GRID/CLOUD

↓

need to introduce parallelism into applications to exploit the computing gains

↓

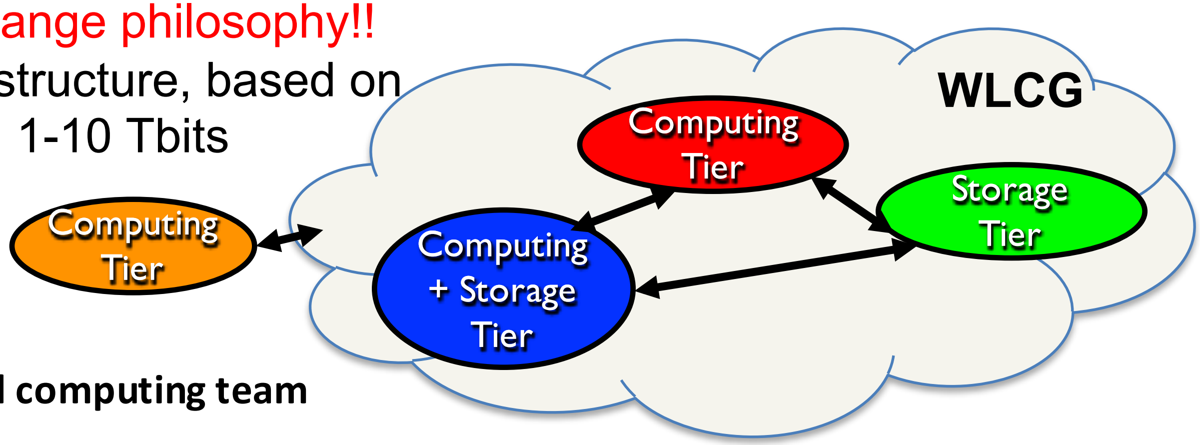
need to develop expertise in concurrent programming

Need of a new profile the “data physics scientist” -> new 15 post-doc positions on *Research and development of innovative solutions for the computing of LHC experiments*

Storage needs not possible to mitigate with technology advancements

Building up a strategy:

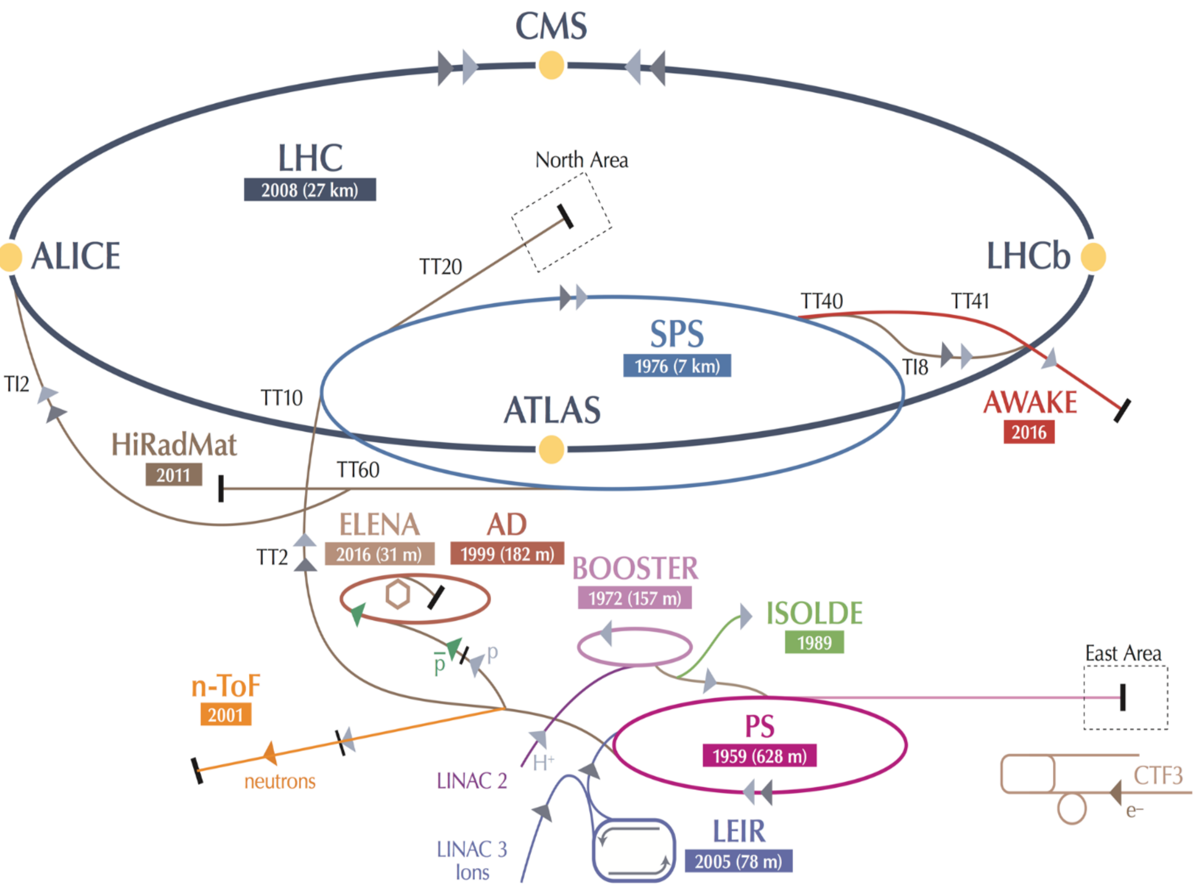
- Computing, namely data processing (= data reconstructions and analysis), must be and it is taken into account when design detectors and triggers methods! Change philosophy!!
- New computing infrastructure, based on high speed network: 1-10 Tbits



Thanks to Donatella Lucchesi and computing team


Futuro
non sappiamo cosa ci aspetta…
siamo pronti a tutto???

CERN's scientific diversity programme



Exploits unique capabilities of CERN's accelerator complex; complementary to other efforts in the world.

~20 experiments, > 1200 physicists

AD: Antiproton Decelerator for antimatter studies

AWAKE: proton-induced plasma wakefield acceleration

CAST, OSQAR: axions

CLOUD: impact of cosmic rays on aeorosols and clouds → implications on climate

COMPASS: hadron structure and spectroscopy

ISOLDE: radioactive nuclei facility

NA61/Shine: heavy ions and neutrino targets

NA62: rare kaon decays

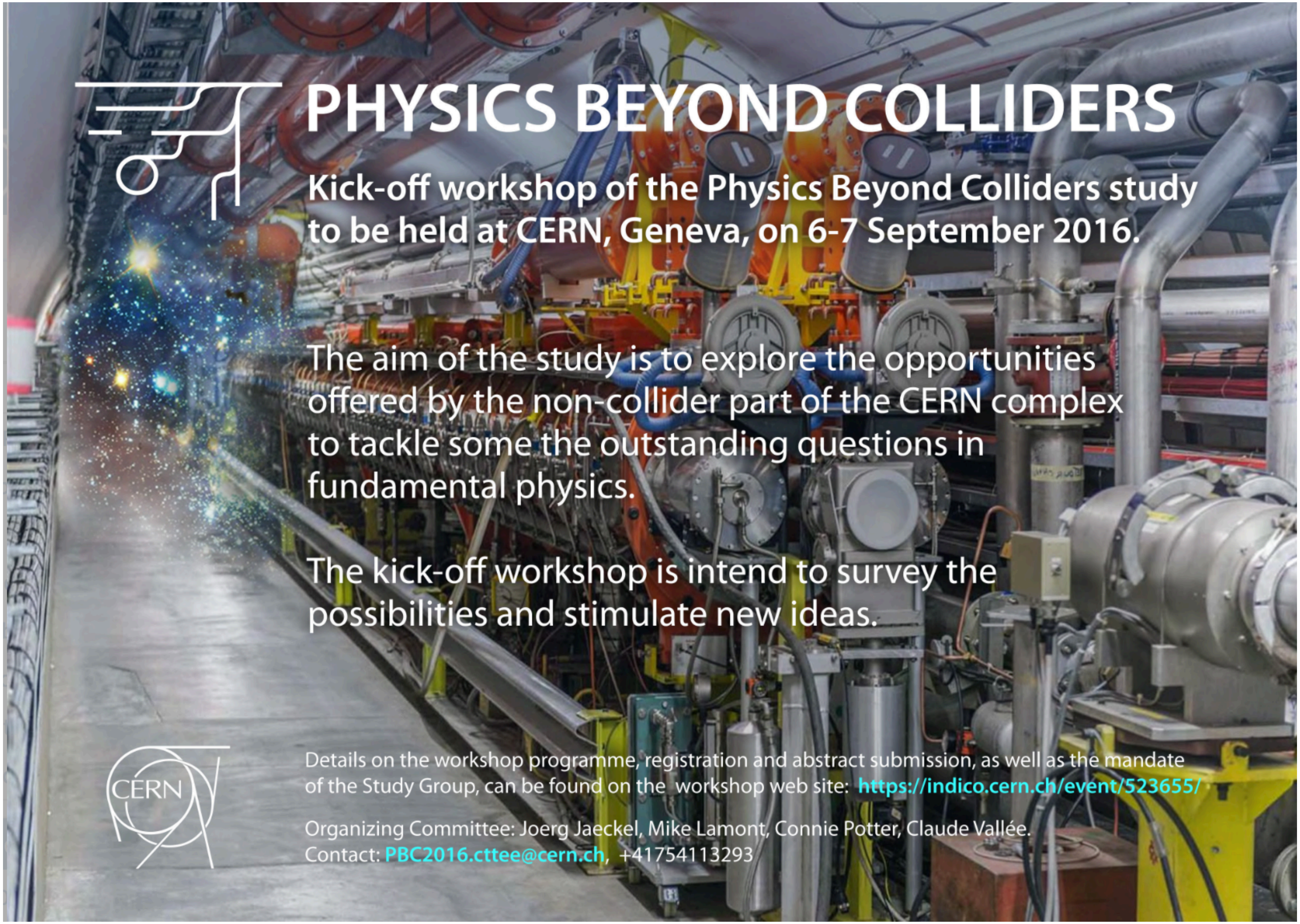
NA63: radiation processes in strong EM fields

NA64: search for dark photons

Neutrino Platform: ν detectors R&D for experiments in US, Japan

n-TOF: n-induced cross-sections

UA9: crystal collimation

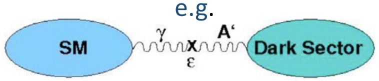

PHYSICS BEYOND COLLIDERS
Kick-off workshop of the Physics Beyond Colliders study to be held at CERN, Geneva, on 6-7 September 2016.
The aim of the study is to explore the opportunities offered by the non-collider part of the CERN complex to tackle some the outstanding questions in fundamental physics.
The kick-off workshop is intend to survey the possibilities and stimulate new ideas.
Details on the workshop programme, registration and abstract submission, as well as the mandate of the Study Group, can be found on the workshop web site: https://indico.cern.ch/event/523655/
Organizing Committee: Joerg Jaeckel, Mike Lamont, Connie Potter, Claude Vallée.
Contact: PBC2016.cttee@cern.ch, +41754113293
CERN

Dark sector come esempio

$L = L_{SM} + L_{mediator} + L_{HS}$

Visible Sector

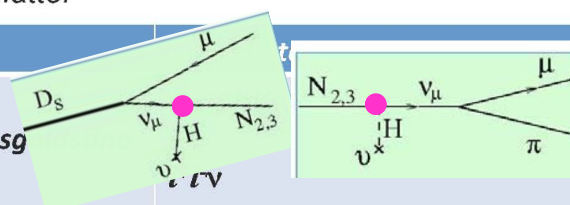
Mediators or portals to the HS:
vector, scalar, axial, neutrino
e.g.



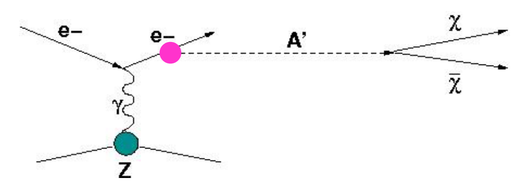
Hidden Sector
Naturally accommodates Dark Matter (may have rich structure)

- *Long-lived objects*
- *Interact very weakly with matter*

Models
HNL, SUSY neutralino
Vector, scalar, axion portals, SUSY sg
HNL, SUSY neutralino, axino
Axion portal, SUSY sgoldstino
SUSY sgoldstino



2 methods



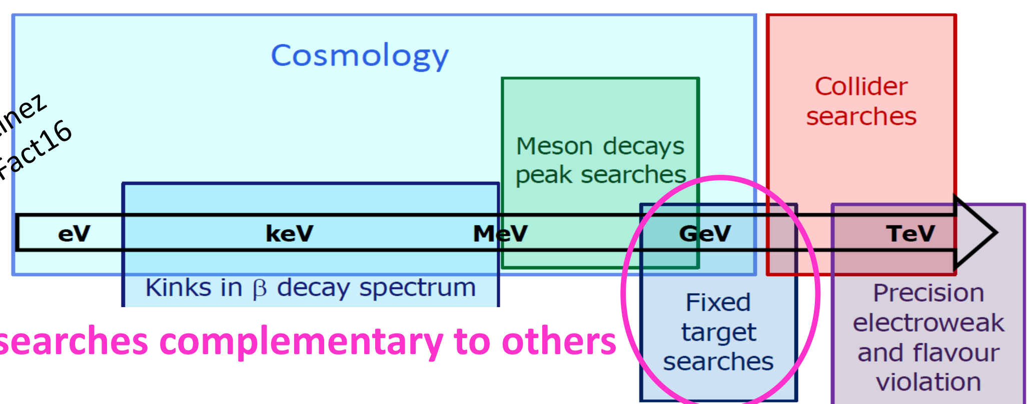
Production + decay of new particle:
2 couplings → needs high intensity

Invisible decay of new particle:
accommodates lower intensity

C. Vallée, ECFA, 25.11.2016 Physics Beyond Colliders at CERN 19

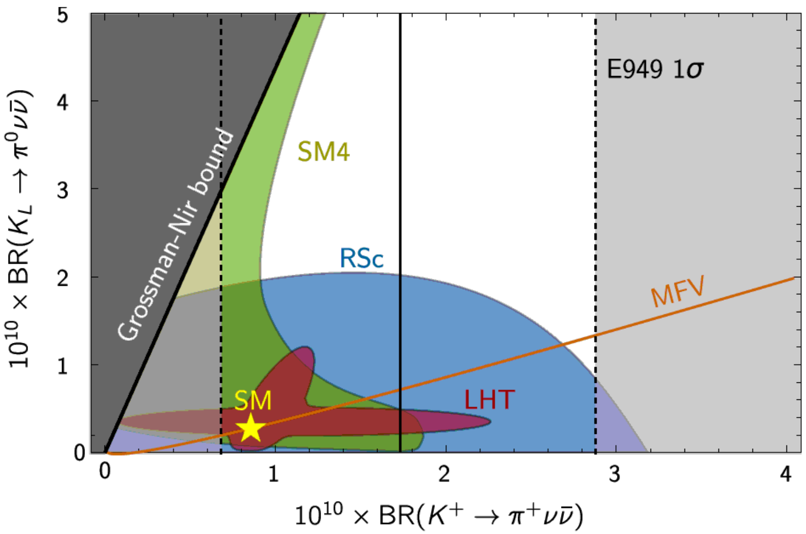
A similar situation as the search for neutrino oscillations in the 70 – 80's:
do not know if they exist and where they stand !

Martinez NuFact16

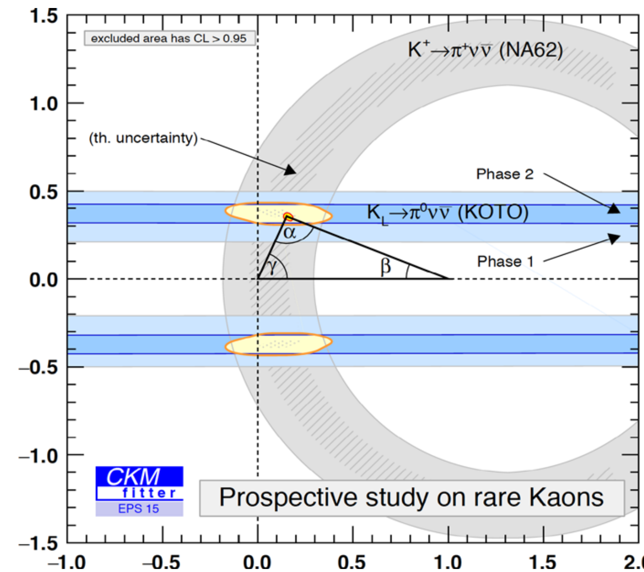


Fixed Target searches complementary to others

NA62 @ SPS: futuro

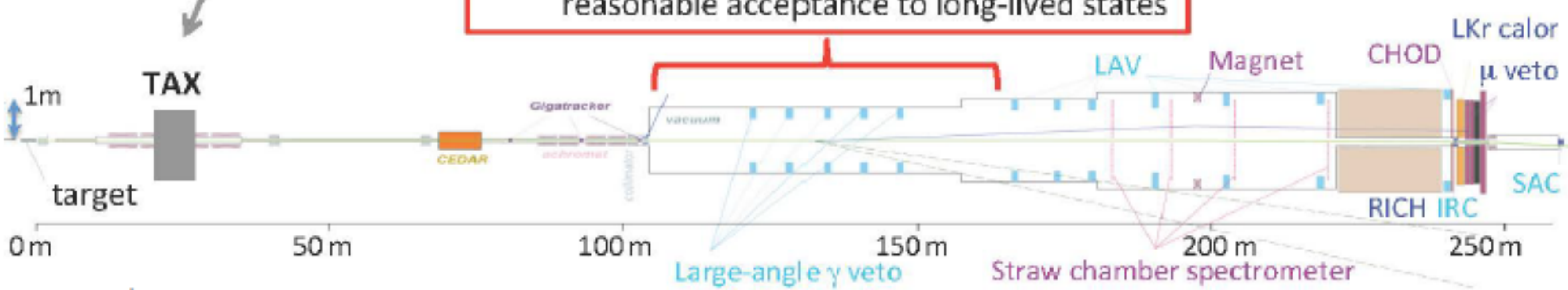


Expected ~ 100 events/ 3 years full intensity



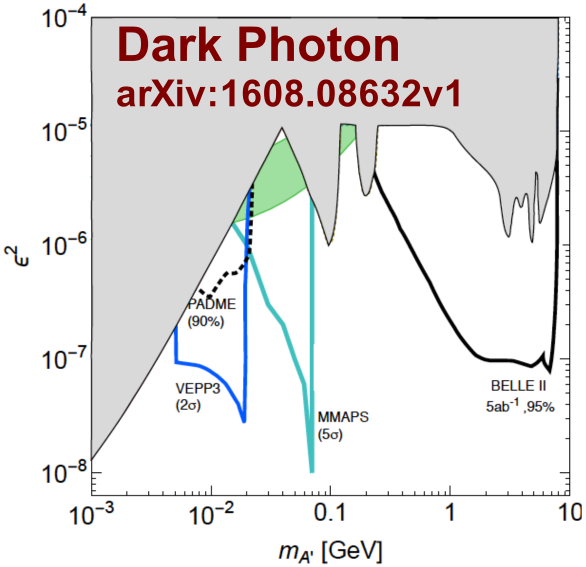
Compact beam dump: ~11 λ_I Cu-based beam-defining collimator (TAX)
radioprotection-compliant even if target removed

Decay volume ~ 60 m long (in vacuum):
reasonable acceptance to long-lived states



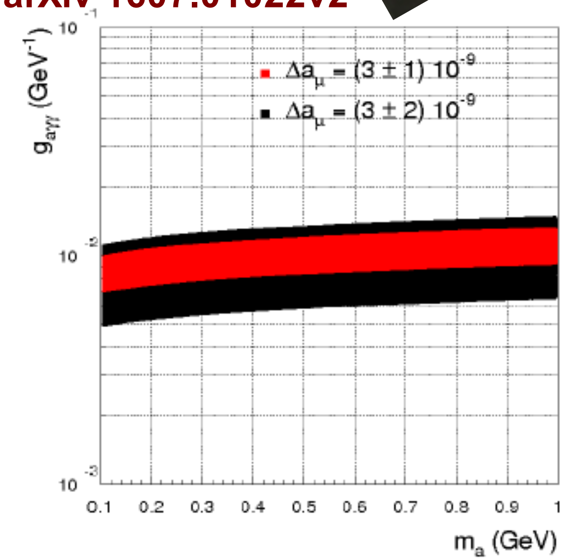
PADME @ BTF-LNF

~ 10 FTE



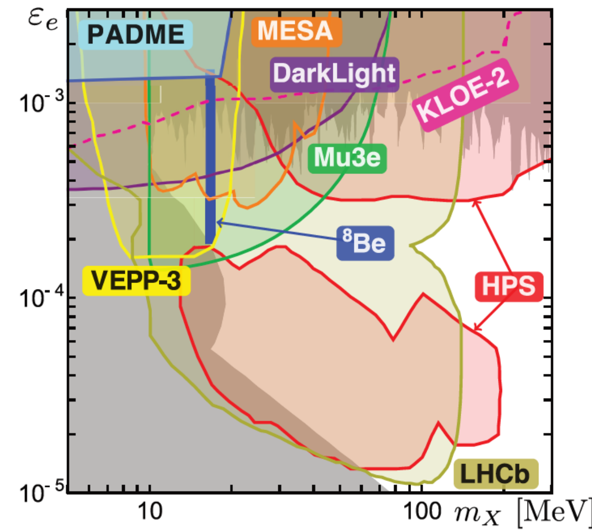
Invisible final state $e^+e^- \rightarrow \chi\chi$

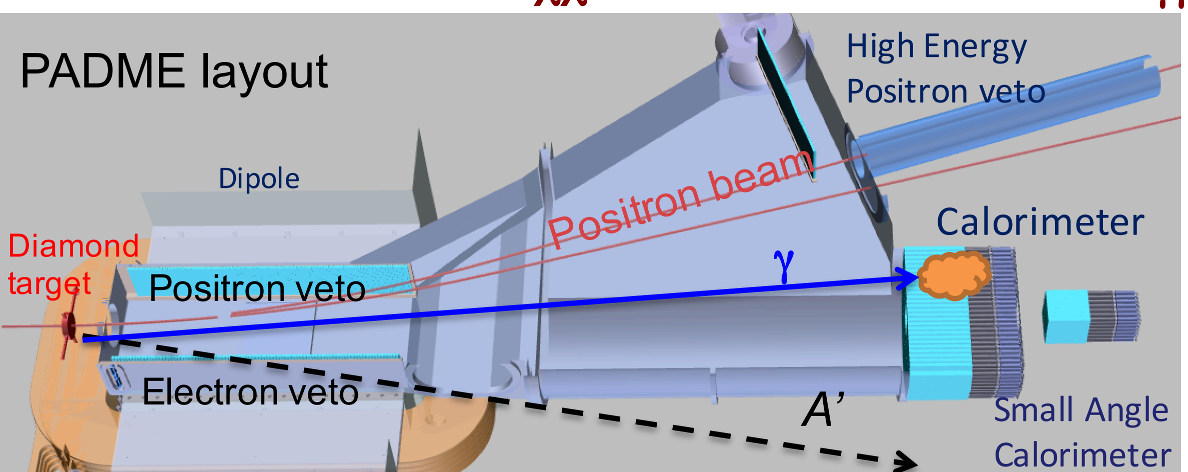
ALPs and g-2
arXiv 1607.01022v2



ALPs final state $a \rightarrow \gamma\gamma$

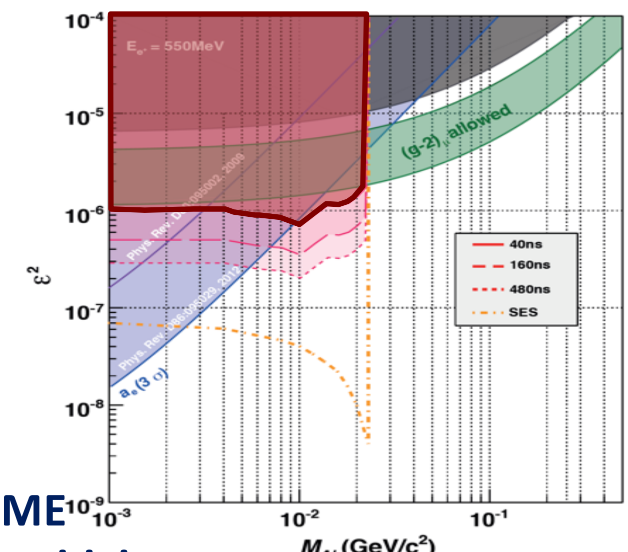
Fifth force
arXiv:1608.03591v1





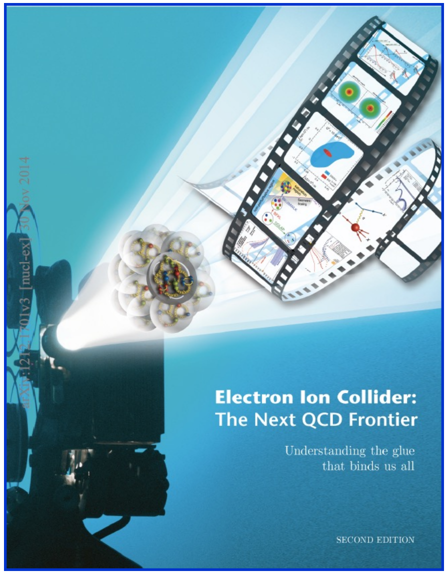
$$\frac{\Gamma(e^+e^- \rightarrow U\gamma)}{\Gamma(e^+e^- \rightarrow \gamma\gamma)} = \frac{N(U\gamma)}{N(\gamma\gamma)} * \frac{Acc(\gamma\gamma)}{Acc(U\gamma)} = \epsilon^2 * \delta$$

Final state X→ee



PADME A' sensitivity

Electron Ion collider @ USA



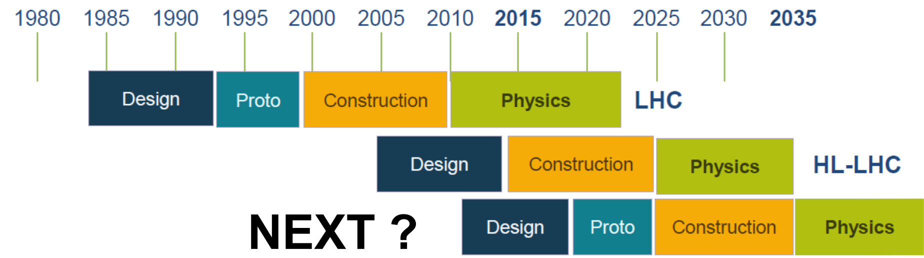
EIC – Electron-Ion Collider – POLARIZED !!!

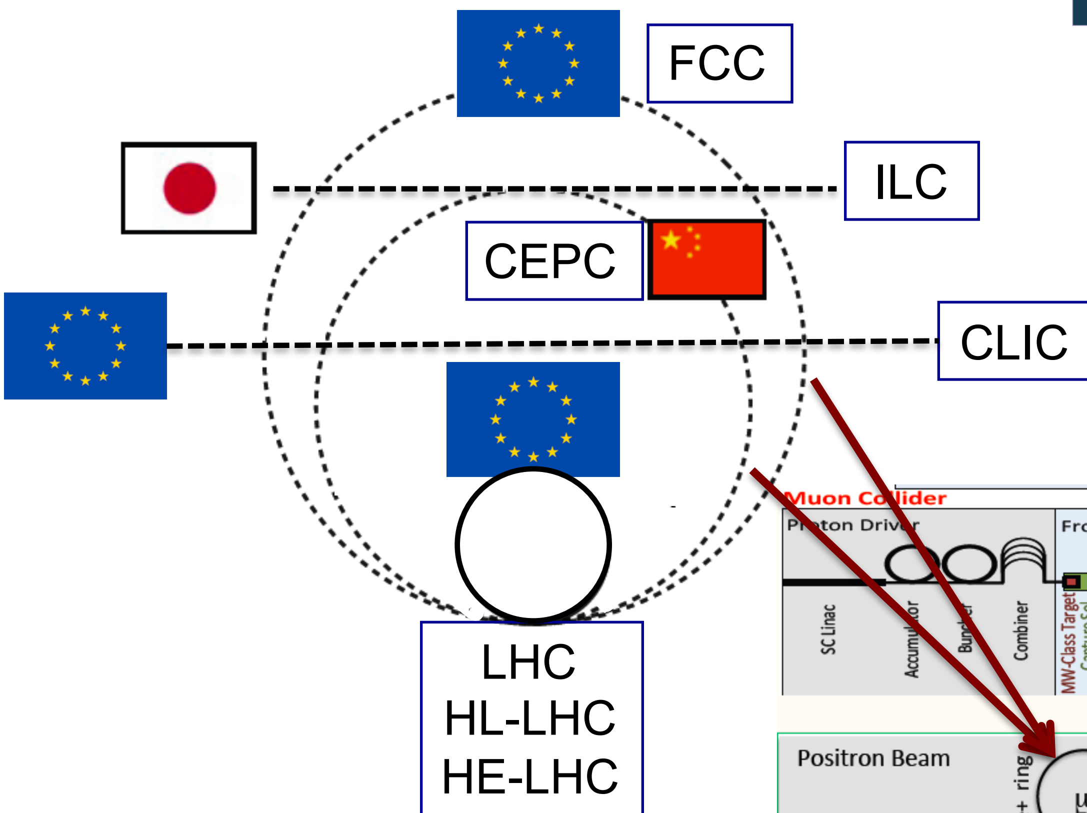
- recommendation by the U.S. nuclear physics community in the 2015 Long Range Plan:
  EIC is the highest priority for new facility construction
  - Starting physics in 2025 (optimistic), 2027 (realistic)
  - **Nucleon Spin and its 3D Structure and Tomography**
  - **g saturation in nuclei, q and g in nuclei**
  - **Beyond SM with electroweak physics**
- **2 options for the collider:**
  - eRHIC @ BNL
    - 1.3-21 Gev (e), 25-250 GeV (p)
    - L : $10^{33} – 10^{34}$ /cm^2/s
  - MEIC @ Jlab
    - 3-12 Gev (e), 25-100 GeV (p)
    - L : 10^{34} /cm^2/s (later, if upgraded, 10^{35})

Certamente per prepararsi ad andare oltre HL-LHC
sarà bene guardare anche da un'altra prospettiva……

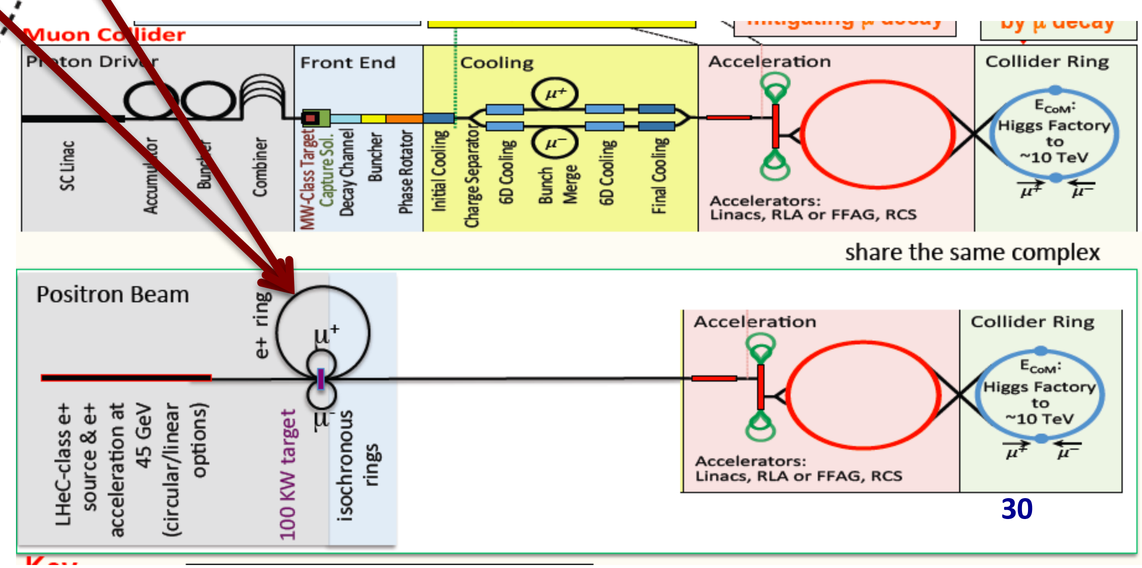
abbiamo pensato di creare un luogo comune di studio e R&D
dove si possano sviluppare e completare le idee per il futuro

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



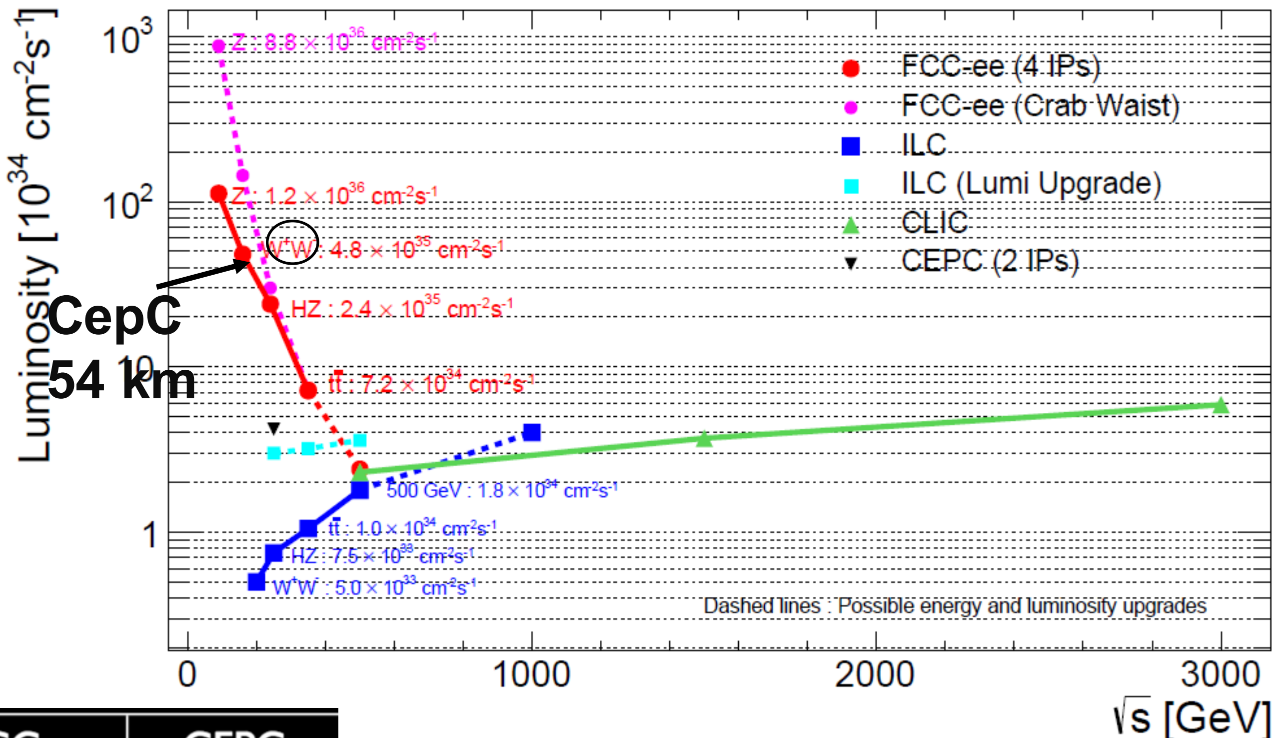


MUON COLLIDER

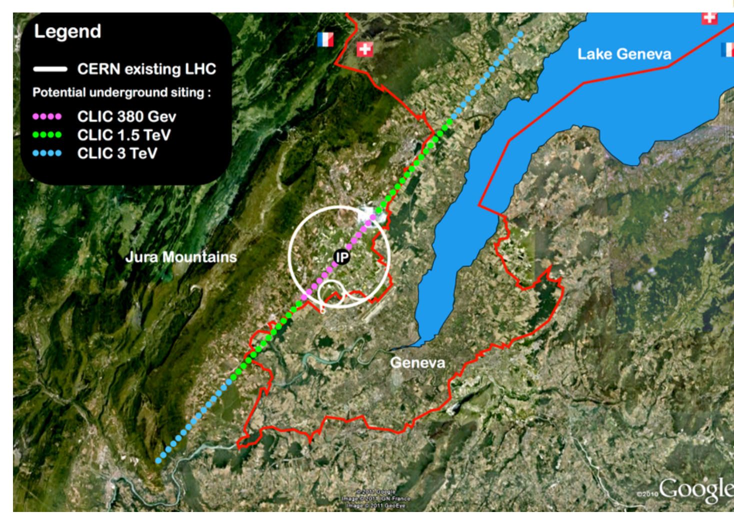


Fasci estratti intensi/beam dump: μ, K, p,....

Collider e^+e^-



	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?	



Collider circolari e^+e^-

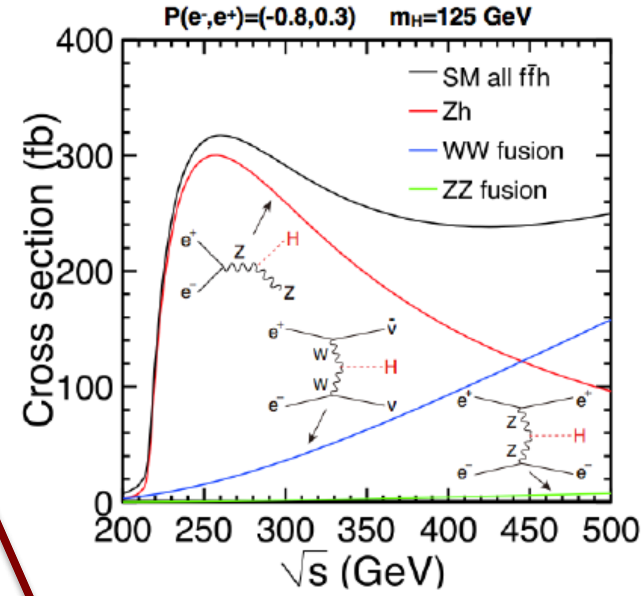
Dopo la scoperta dell'Higgs ➔ proposta TLEP

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

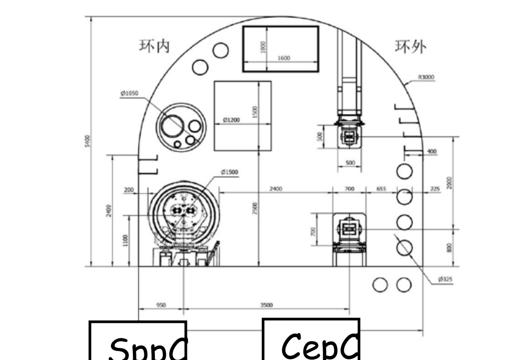
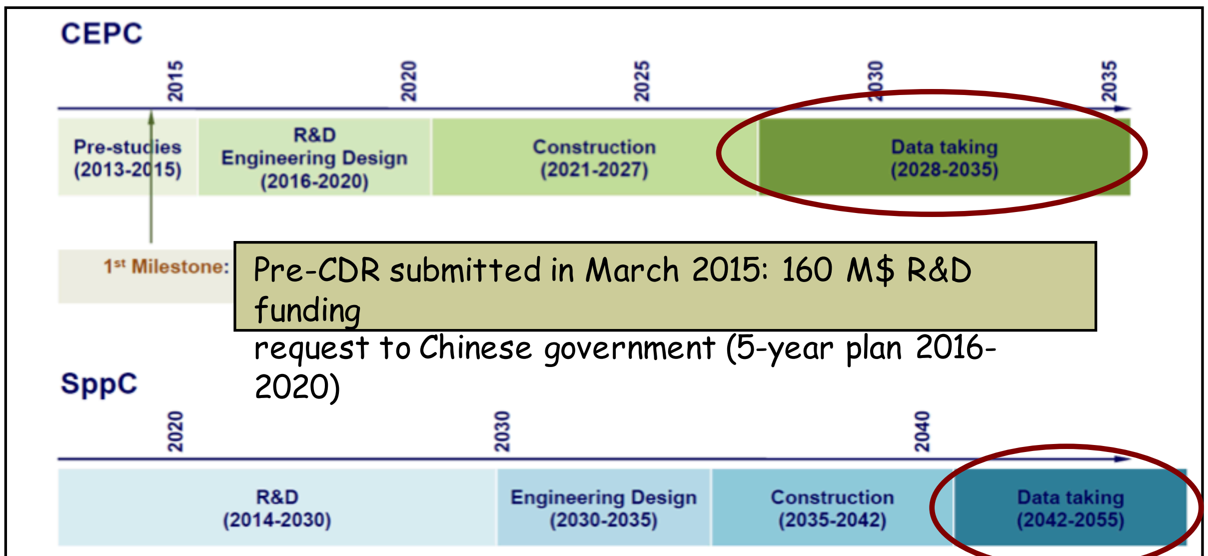


Figure 3.2: Tu... The magnet ... superconducting magnet of the SPPC, the magnets on the right are for the CEPC collider (bottom) and the Booster (top), respectively. The tunnel width is 6 m.



Future Circular Collider (FCC)

Conceptual design study of a ~100 km ring:

- pp collider (FCC-hh): ultimate goal → defines infrastructure requirements

  $\sqrt{s}$ ~ 100 TeV, L~2x10^{35}; 4 IP, ~20 ab^{-1}/expt

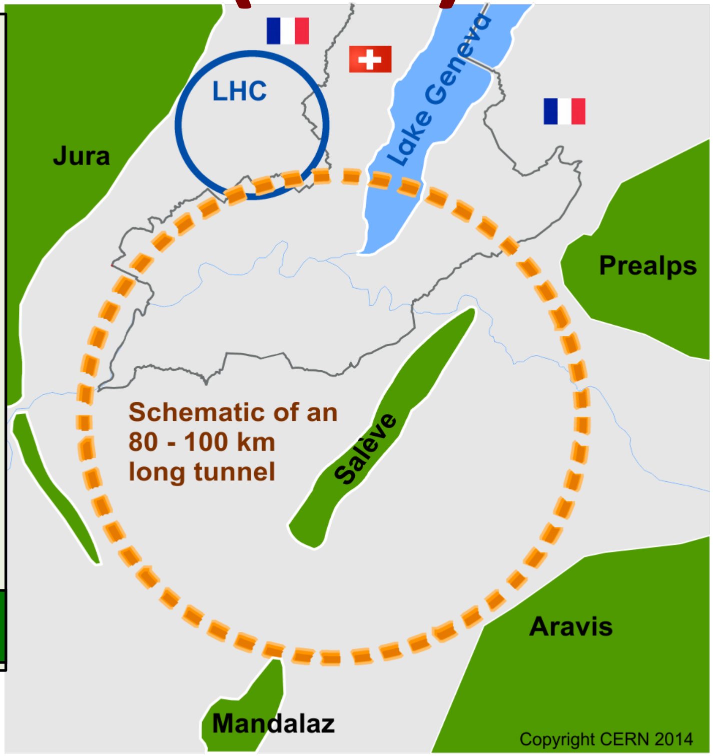
- e^+e^- collider (FCC-ee): possible first step

  $\sqrt{s}$ = 90-350 GeV, L~200-2 x 10^{34}; 2 IP

- pe collider (FCC-he): option

  $\sqrt{s}$ ~ 3.5 TeV, L~10^{34}

Goal: CDR in time for next ES



FCC-hh: ~100 TeV pp collider is expected to:

- explore directly the 10-50 TeV E-scale
- conclusive exploration of EWSB dynamics
- say the final word about heavy WIMP dark matter

Also part of the study: HE-LHC: FCC-hh dipole technology (~16 T) in LHC tunnel → $\sqrt{s}$ ~ 30 TeV

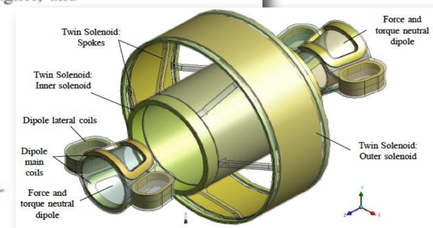
FCC-ee: 90-350 GeV

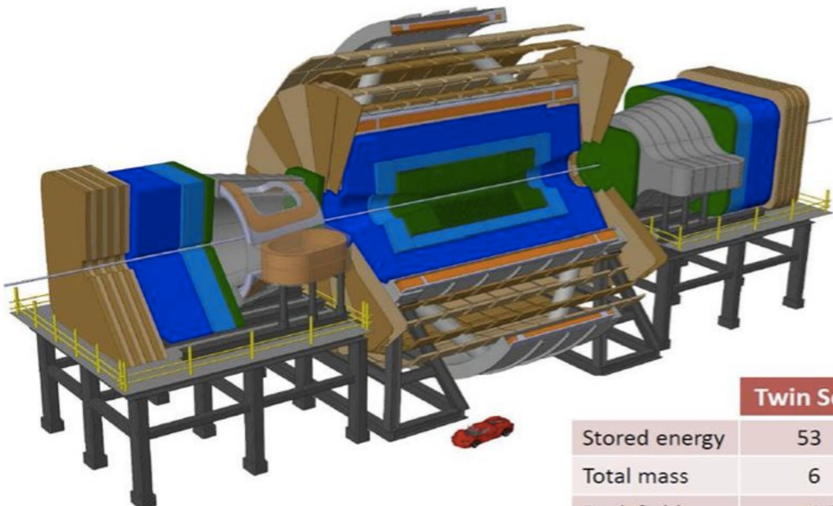
- measure many Higgs couplings to few permill
- indirect sensitivity to E-scale up to O(100 TeV) by improving by ~20-200 times the precision of EW parameters measurements, ΔM_W < 1 MeV, Δm_{top} ~ 10 MeV

“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}

Future collider dipole field requirements: FCC-hh

FCC-hh

A. E_{cm}=100 TeV , 100 km ring: B = 16 T Project Baseline

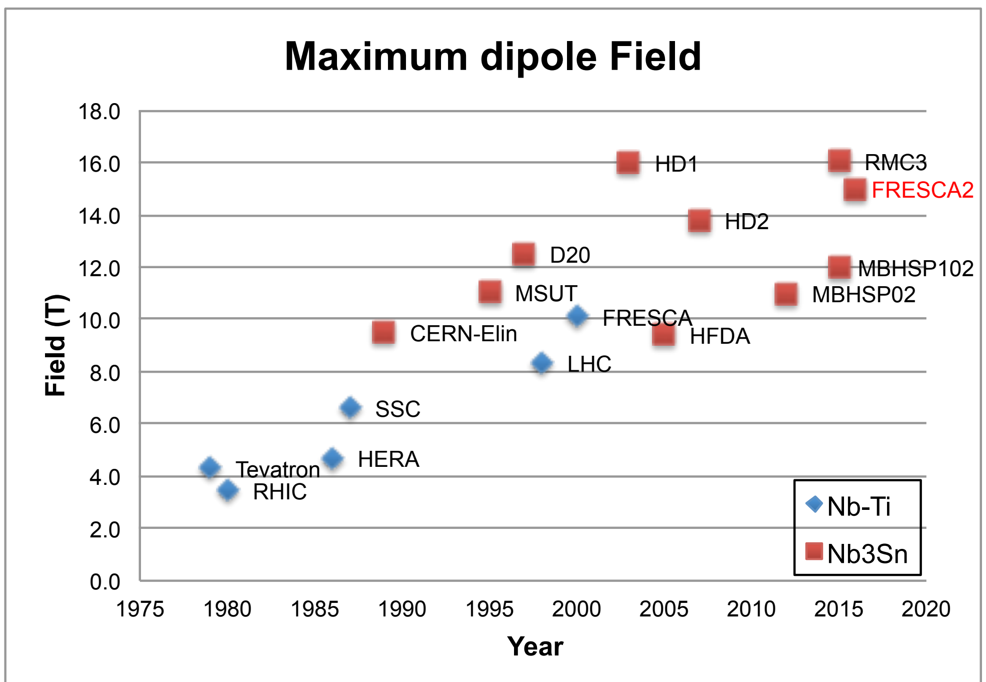
B. E_{cm}=100 TeV , 80 km ring: B = 20 T

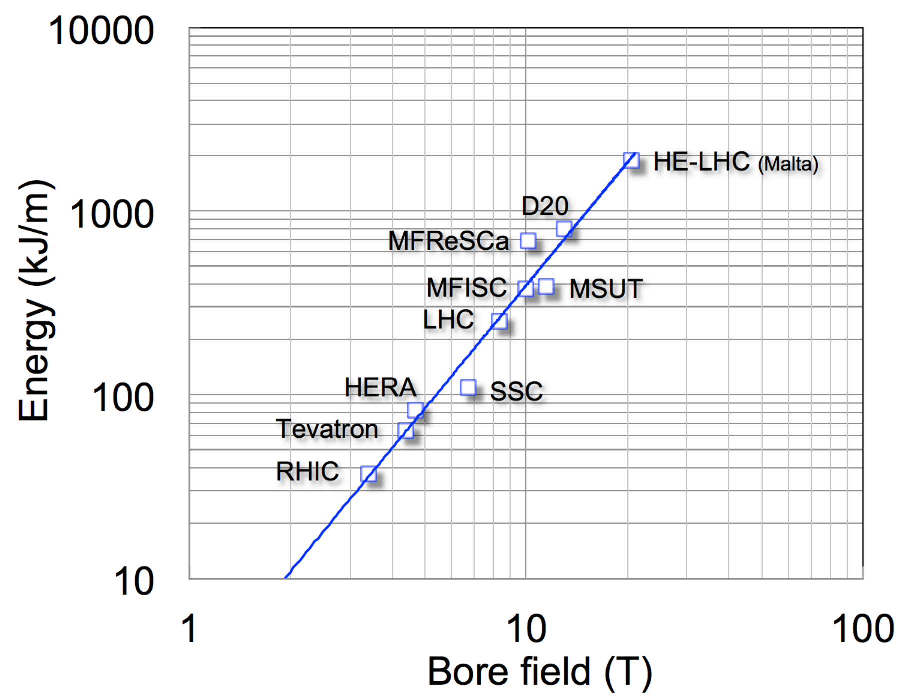
What would this mean in the LHC ring for a potential HE-LHC ?

A. E_{cm}=25 TeV , 27 km ring: B = 16 T

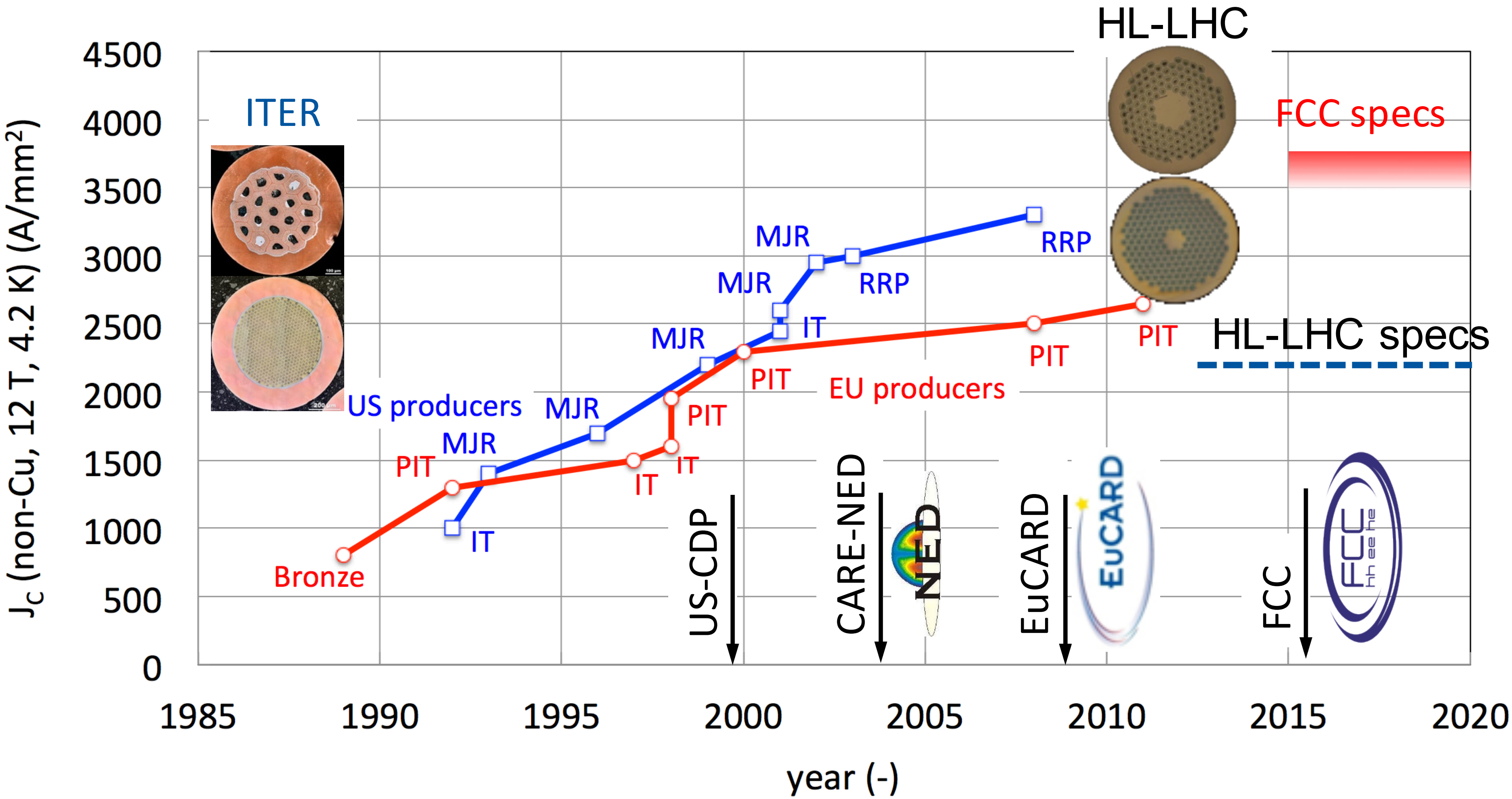
B. E_{cm}=33 TeV , 27 km ring: B = 20 T

➔ Work towards 16 T in a first step and 20 T in a second step





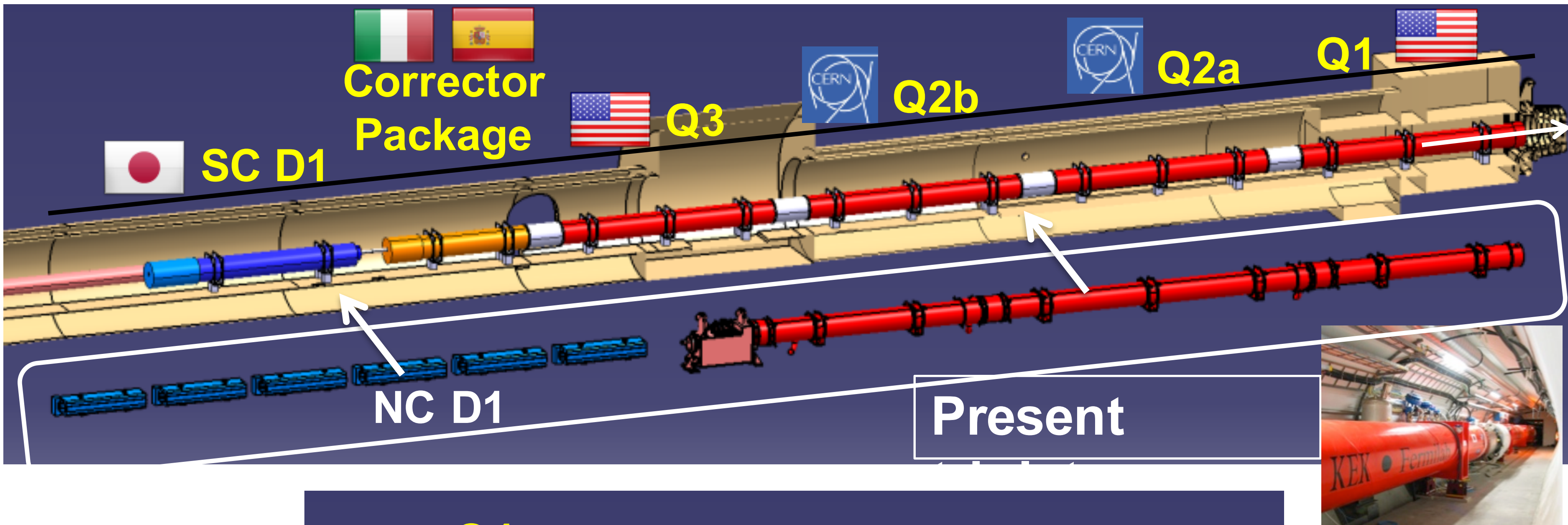
Conductor development (1998-2008)

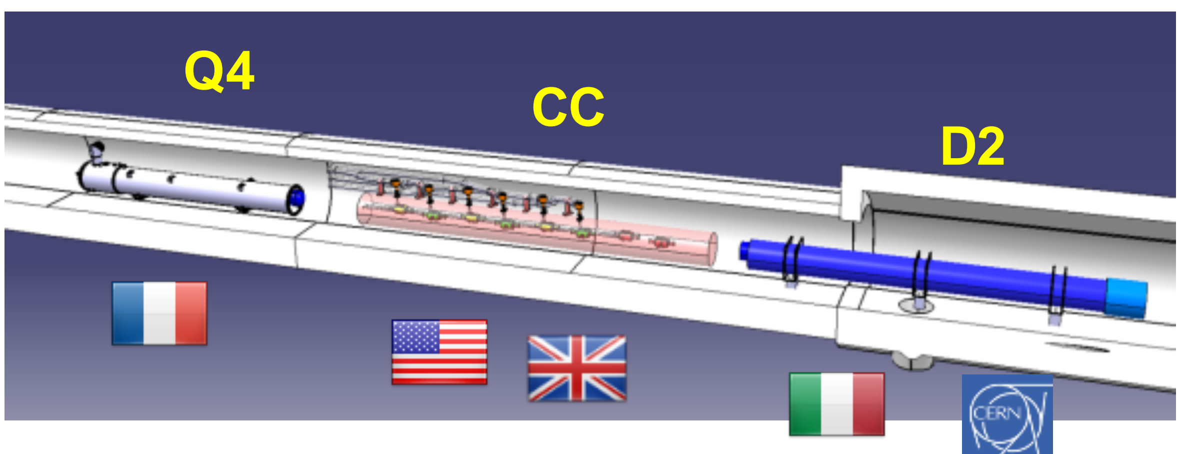


after 10 years of development the US and EU development gave us the Nb_3Sn conductor for HILUMI.

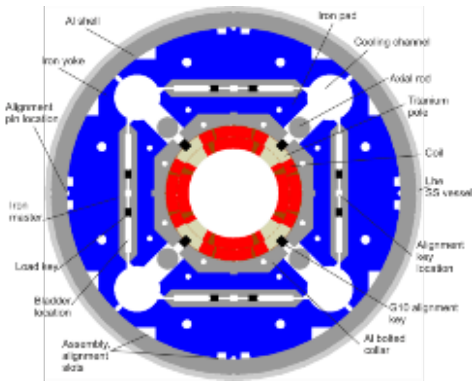
New triplet for HHILUMI

Lower b value in the interaction points : larger apertures needed in the triplet of the machine (from 70 mm to 150 mm)

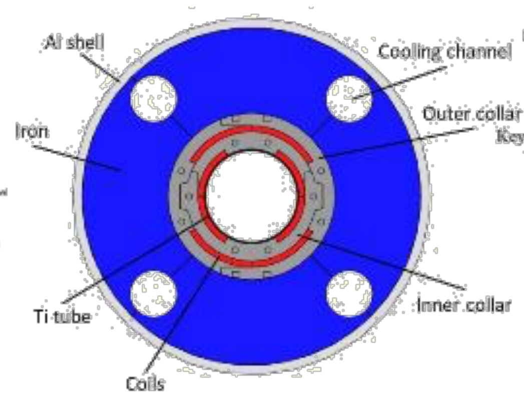




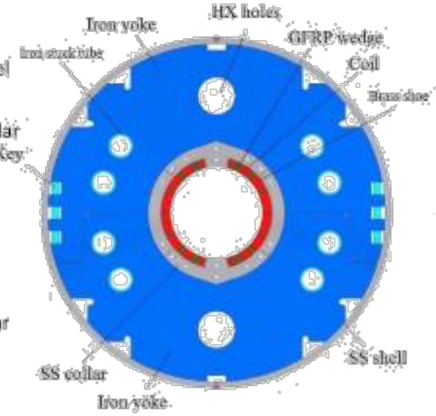
HILUMI IT magnet zoo



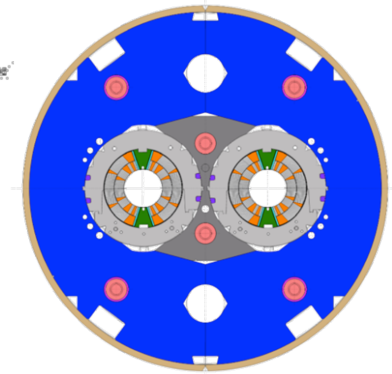
Triplet QXF (LARP and CERN)



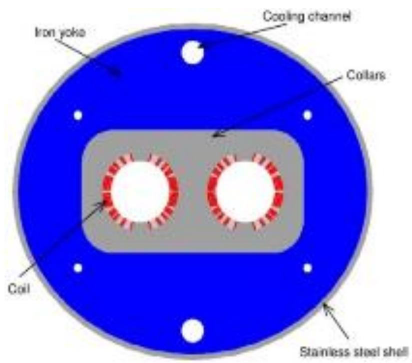
Orbit corrector (CIEMAT)



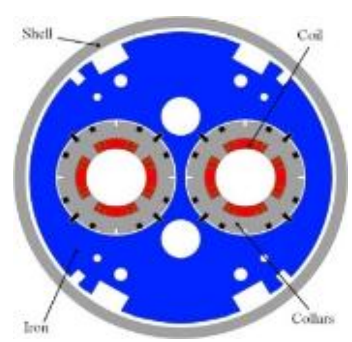
Separation dipole D1 (KEK)



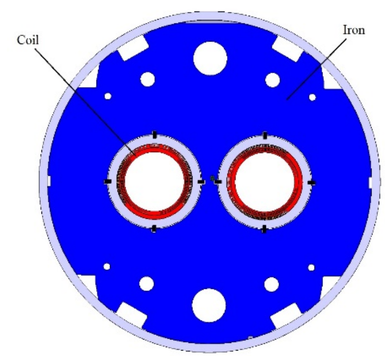
11 T dipole (CERN)



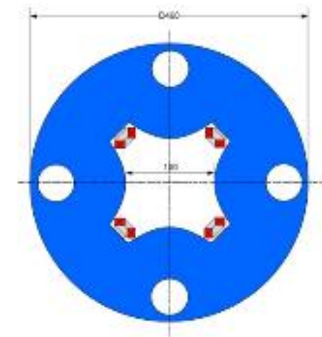
Recombination dipole D2 (INFN)



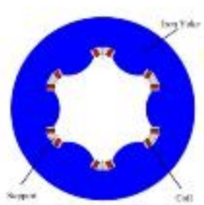
Q4 (CEA)



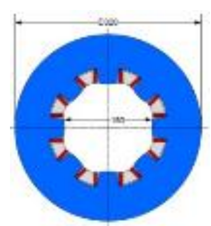
D2/Q4 orbit corrector (CERN)



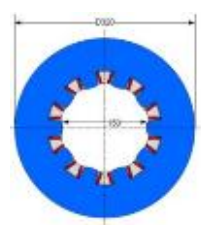
Skew quadrupole (INFN)



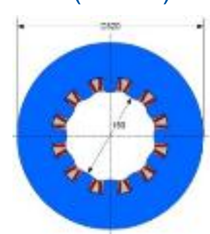
Sextupole (INFN)



Octupole (INFN)



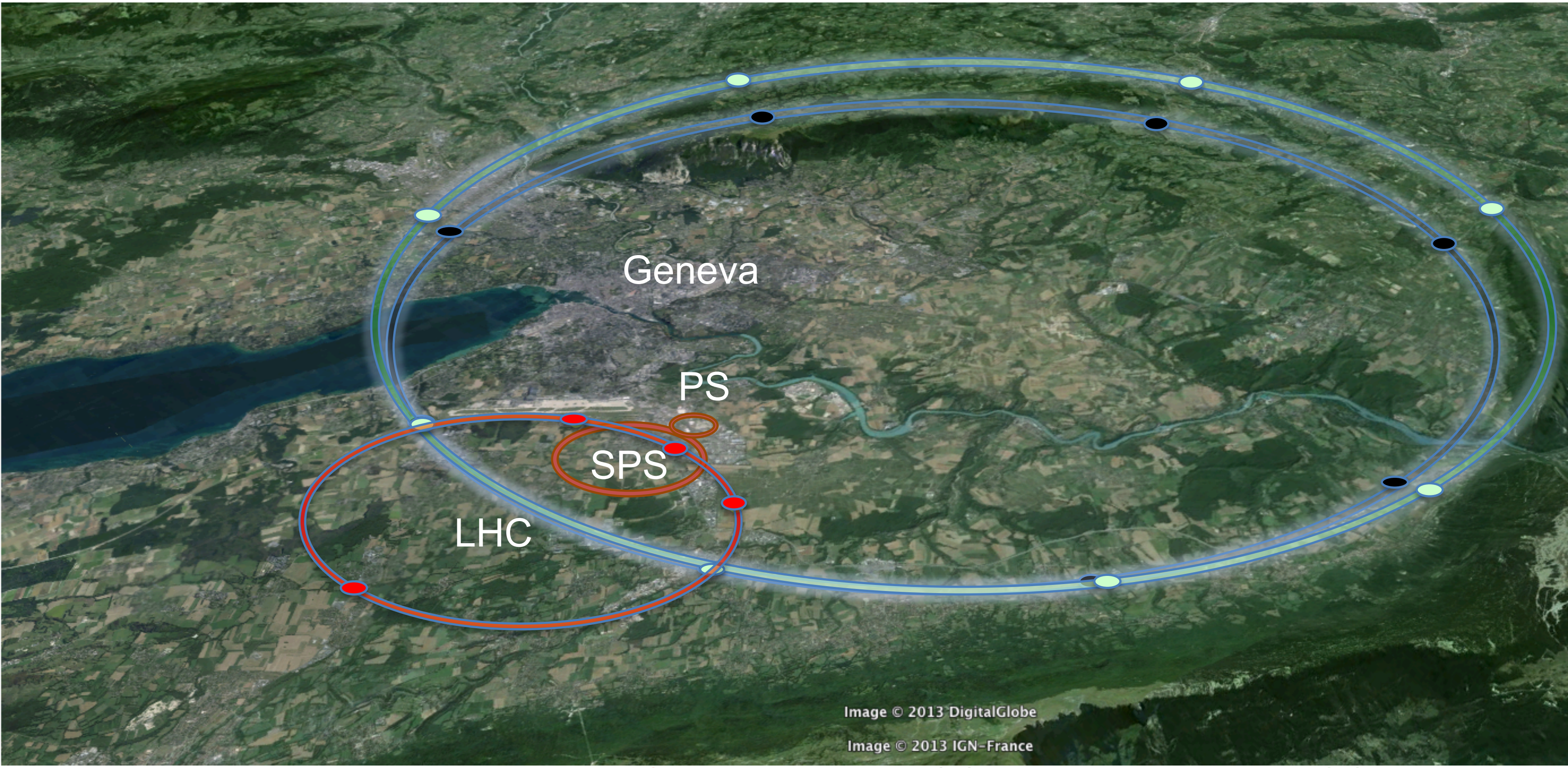
Decapole (INFN)



Dodecapole (INFN)

Courtesy E. Todesco

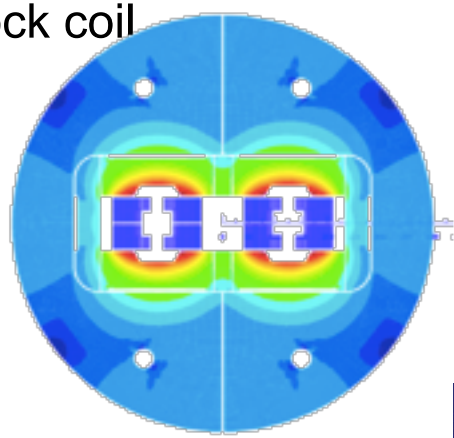
FCC development (2014 - ...)



LHC	HE-LHC	FCC-hh	FCC-hh
27 km, 8.33 T	27 km, **20 T**	80 km, **20 T**	100 km, **16 T**
14 TeV (c.o.m.)	33 TeV (c.o.m.)	100 TeV (c.o.m.)	100 TeV (c.o.m.)

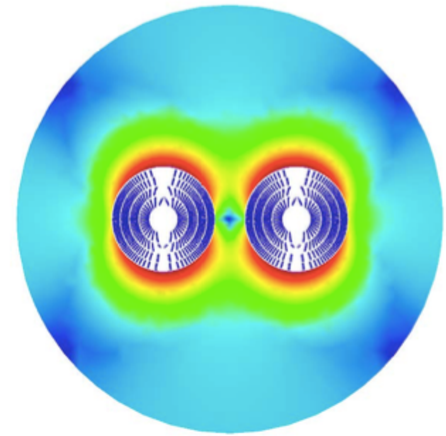
FCC: 16T dipole options

Block coil



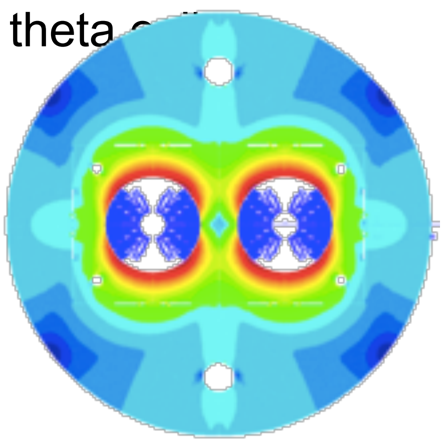
C. Lorin, M. Durante (CEA)

Canted Cos-theta



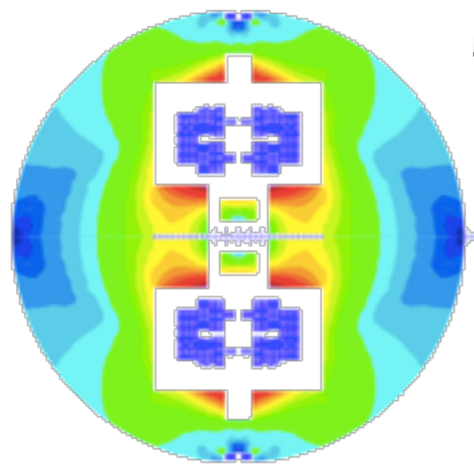
B. Auchmann (CERN/PSI)

Cos-theta

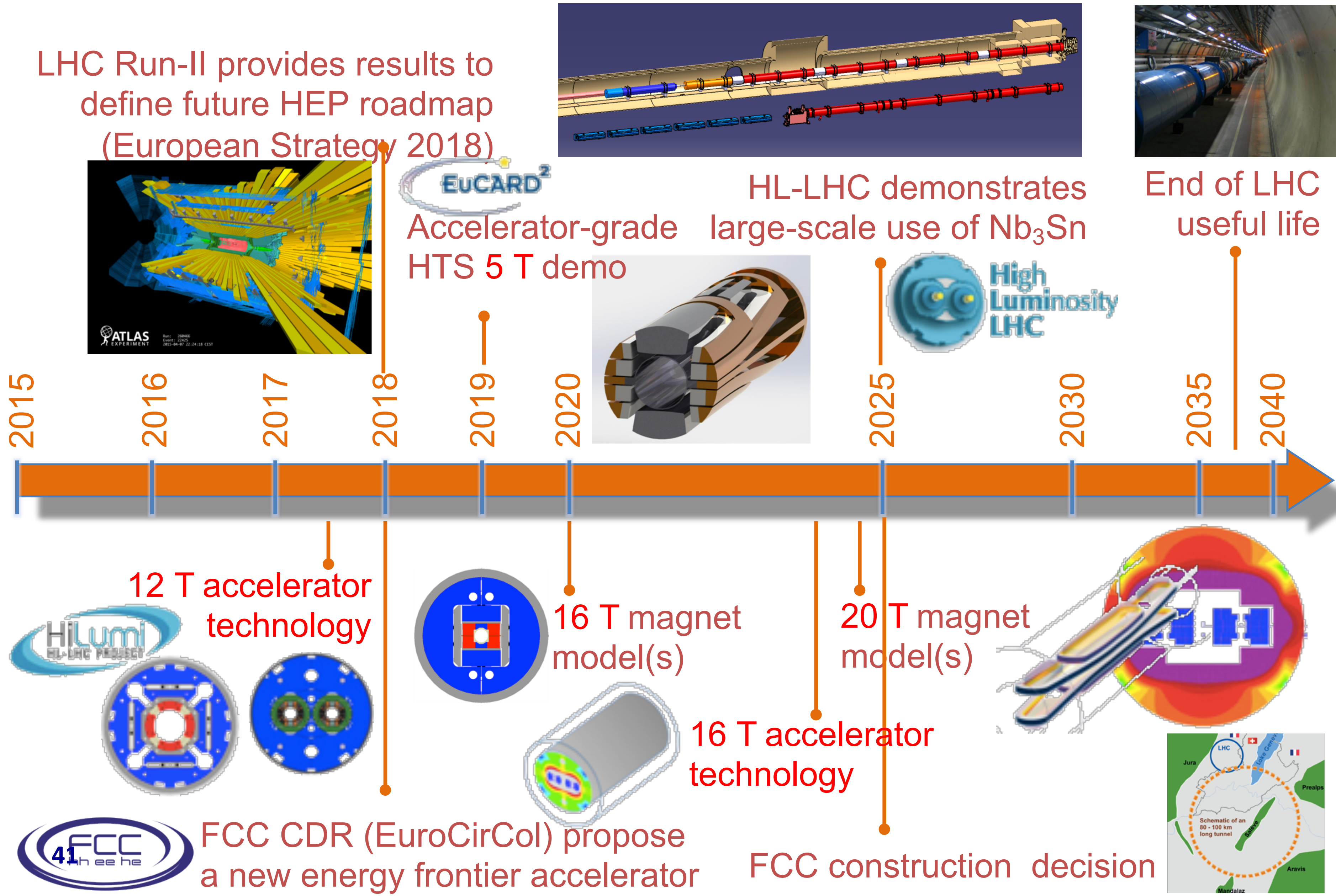


S. Farinon, P. Fabbricatore (INFN)

Common coils



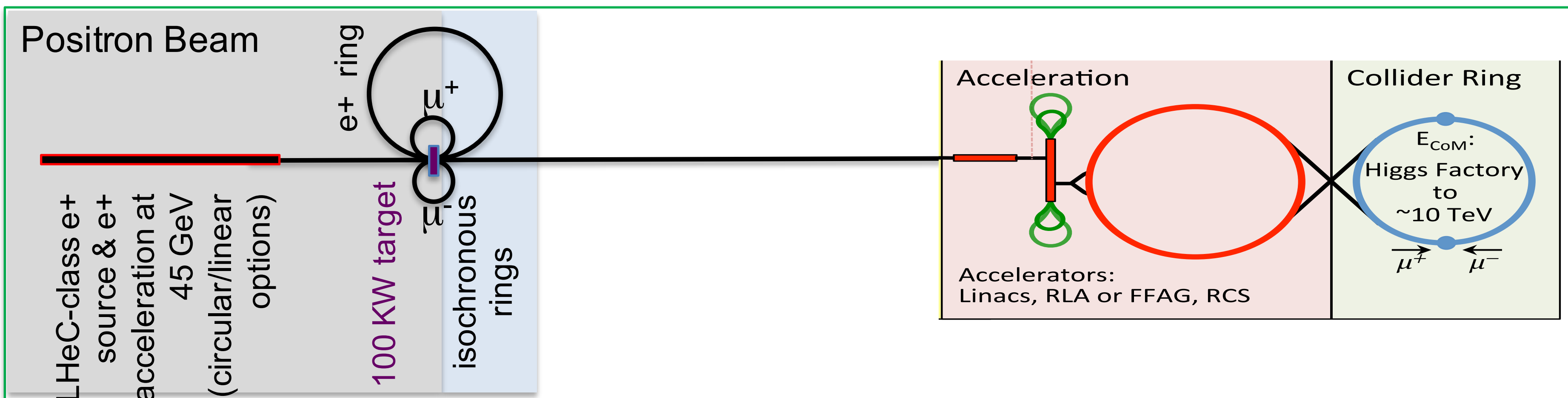
F. Toral (CIEMAT)


LHC Run-II provides results to define future HEP roadmap (European Strategy 2018)
ATLAS EXPERIMENT
EuCARD²
Accelerator-grade HTS 5 T demo
HL-LHC demonstrates large-scale use of Nb_3Sn
End of LHC useful life
High Luminosity LHC
2015
2016
2017
2018
2019
2020
2025
2030
2035
2040
12 T accelerator technology
HiLumi HL-LHC PROJECT
16 T magnet model(s)
20 T magnet model(s)
16 T accelerator technology
FCC hh ee he
FCC CDR (EuroCirCol) propose a new energy frontier accelerator
FCC construction decision
LHC
Jura
Prealps
Schematic of an 80 - 100 km long tunnel
Aravis
Mandalaz

Very low emittance Muon Beam using positron beam on target

Da Snowmass 2013 M.Antonelli, P.Raimondie molti altri….

Muon Collider:
Schematic Layout for positron based muon source

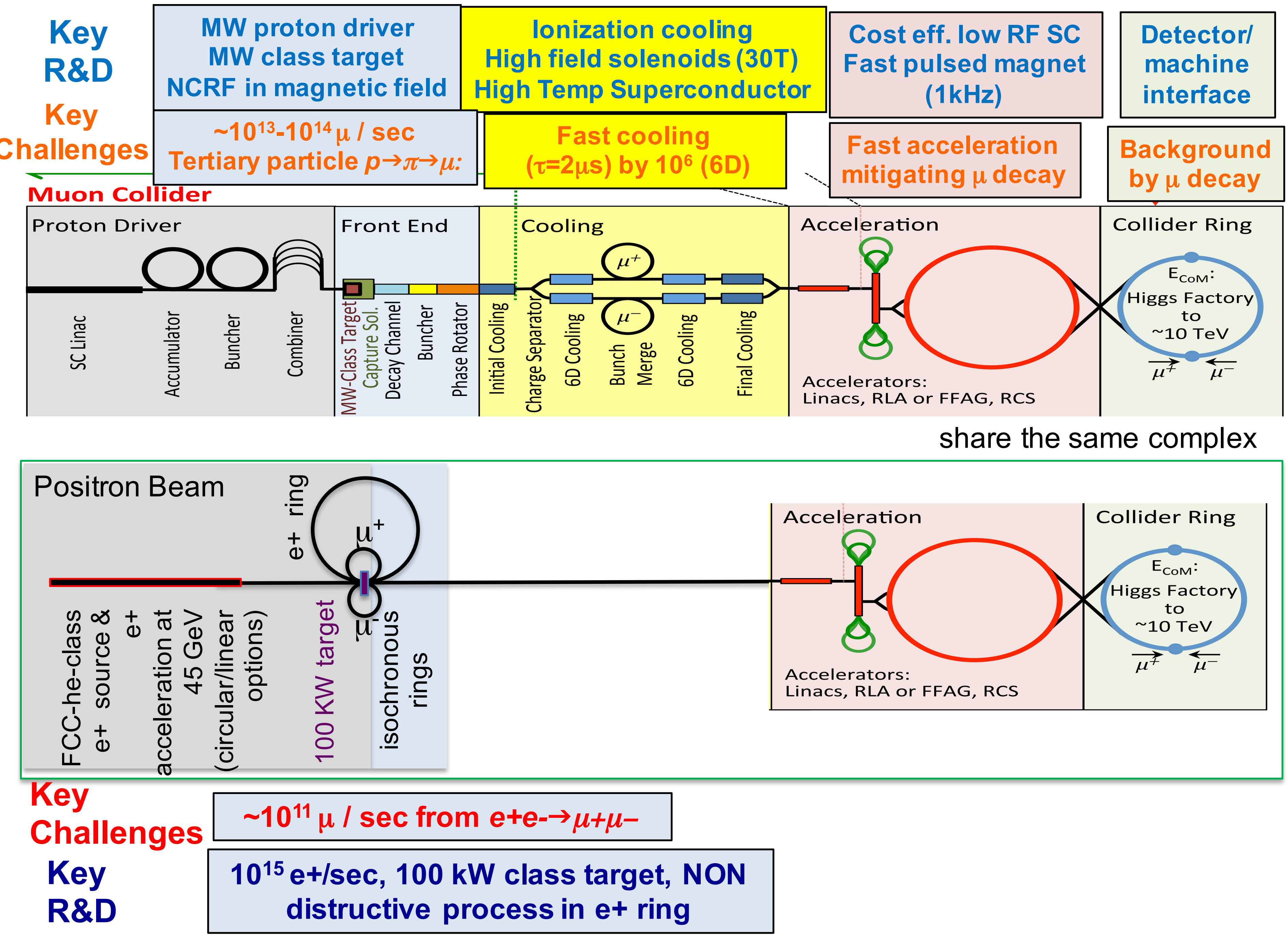


Key Challenges

~10^{11} μ / sec from e+e-→μ+μ−

Key R&D

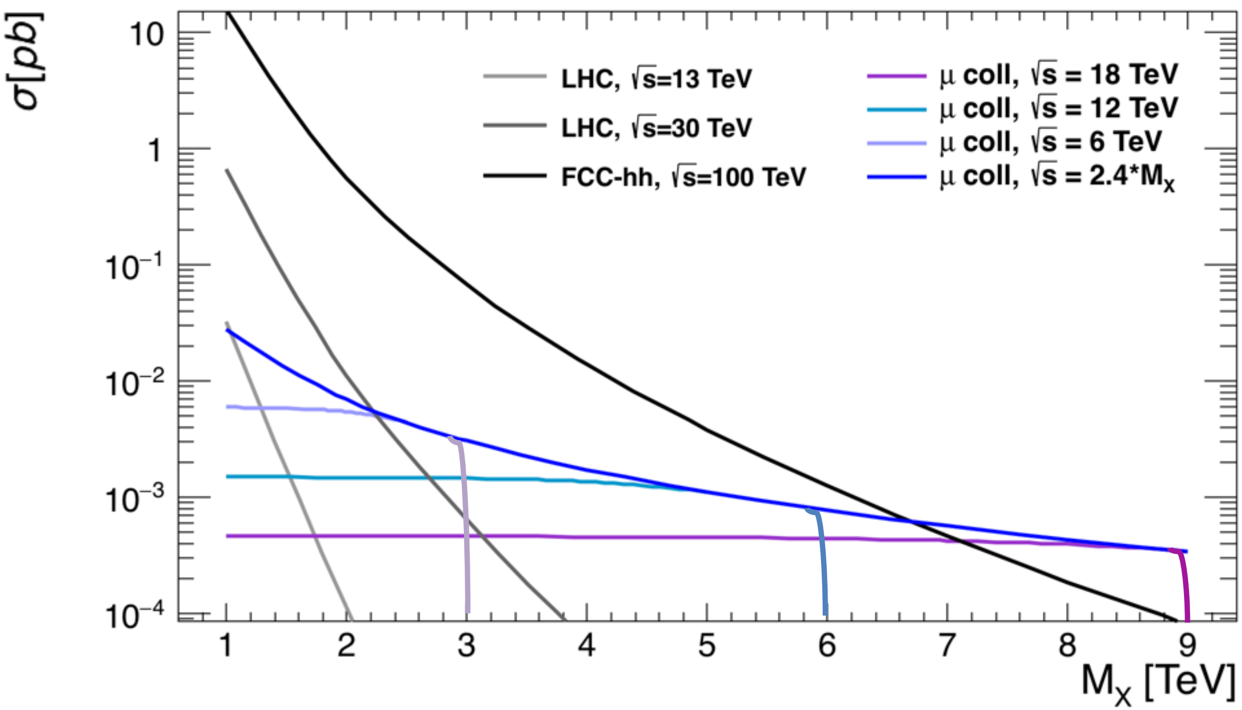
10^{15} e+/sec, 100 kW class target, NON distructive process in e+ ring



Key R&D
MW proton driver
MW class target
NCRF in magnetic field
Ionization cooling
High field solenoids (30T)
High Temp Superconductor
Cost eff. low RF SC
Fast pulsed magnet (1kHz)
Detector/ machine interface
Key Challenges
~10^{13}-10^{14} μ / sec
Tertiary particle p→π→μ:
Fast cooling (τ=2μs) by 10^6 (6D)
Fast acceleration mitigating μ decay
Background by μ decay
Muon Collider
Proton Driver
SC Linac
Accumulator
Buncher
Combiner
Front End
MW-Class Target
Capture Sol.
Decay Channel
Buncher
Phase Rotator
Cooling
Initial Cooling
Charge Separator
6D Cooling
μ^+
μ^-
Bunch Merge
6D Cooling
Final Cooling
Acceleration
Accelerators: Linacs, RLA or FFAG, RCS
Collider Ring
E_{CoM}: Higgs Factory to ~10 TeV
μ^+
μ^-
share the same complex
Positron Beam
FCC-he-class e+ source & e+ acceleration at 45 GeV (circular/linear options)
e+ ring
μ+
μ-
100 KW target
isochronous rings
Acceleration
Accelerators: Linacs, RLA or FFAG, RCS
Collider Ring
E_{CoM}: Higgs Factory to ~10 TeV
μ^+
μ^-
Key Challenges
~10^{11} μ / sec from e+e-→μ+μ–
Key R&D
10^{15} e+/sec, 100 kW class target, NON distructive process in e+ ring

Muon collider reach: an example

- Study the same benchmark used for White Paper:
  - New heavy particles, both colored and EW charged (~vector like quarks)➔ xsec can be predicted
  - FCC reach stops at M_X = 7 TeV
- Hadron machine pays the price of the exponentially falling PDF ➔ multi-TeV muon machine can be competitive!



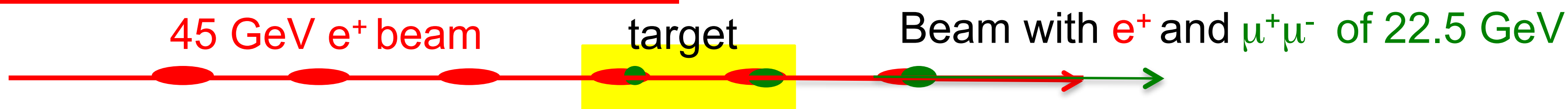
Idea for low emittance μ beam

Conventional production:

μ from **proton on target** (K,π decays)
typical **P_μ~ 100 MeV/c** (π, K rest frame)
whatever is the boost P_T will stay in Lab frame → **very high emittance** at production point → **cooling needed**!

Direct μ pair production:

Muons produced from $e^+e^- \rightarrow \mu^+\mu^-$ at $\sqrt{s}$ around the $\mu^+\mu^-$ threshold **($\sqrt{s}$~0.212 GeV)** in asymmetric collisions to collect μ^+ and μ^- (e^+ on target)



Ideally muons will *copy* the positron beam

Advantages:

1. **Very Low emittance possible** in $e^+e^- \rightarrow \mu^+\mu^-$
2. **Lower background:**
3. **Reduced losses from decay:** muons produced with a relatively high boost (γ~200)
4. **Energy spread:** Muon Energy spread **also small very close to threshold**,
5. **Disadvantages:**

Rate: much smaller cross section wrt protons $\sigma(e^+e^- \rightarrow \mu^+\mu^-)$ ~ 1 μb at most

i.e. Luminosity(e+e-)= 10^{40} cm^{-2} s^{-1} → gives μ rates 10^{10} Hz

parameter	FCC-ee	LEMC
energy/beam [GeV]	**45**	**45**
bunches/beam	90000	**1700**
beam current [mA]	1450	**240**
luminosity/IP x 10^{34} $cm^{-2}s^{-1}$	**70**	
energy loss/turn [GeV]	0.03	**~0.4**
synchrotron power [MW]	100	
RF voltage [GV]	0.08	
rms bunch length (SR,+BS) [mm]	1.6, 3.8	
rms emittance $\varepsilon_{x,y}$ [nm, pm]	0.09, 1	**>0.1,>100**
longit. damping time [turns]	1320	
crossing angle [mrad]	30	
beam lifetime [min]	251	**>>1s**

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"?

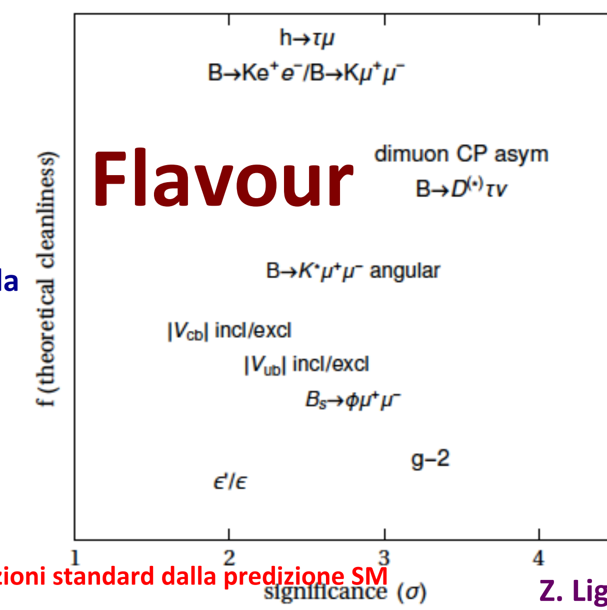
Beyond SM

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

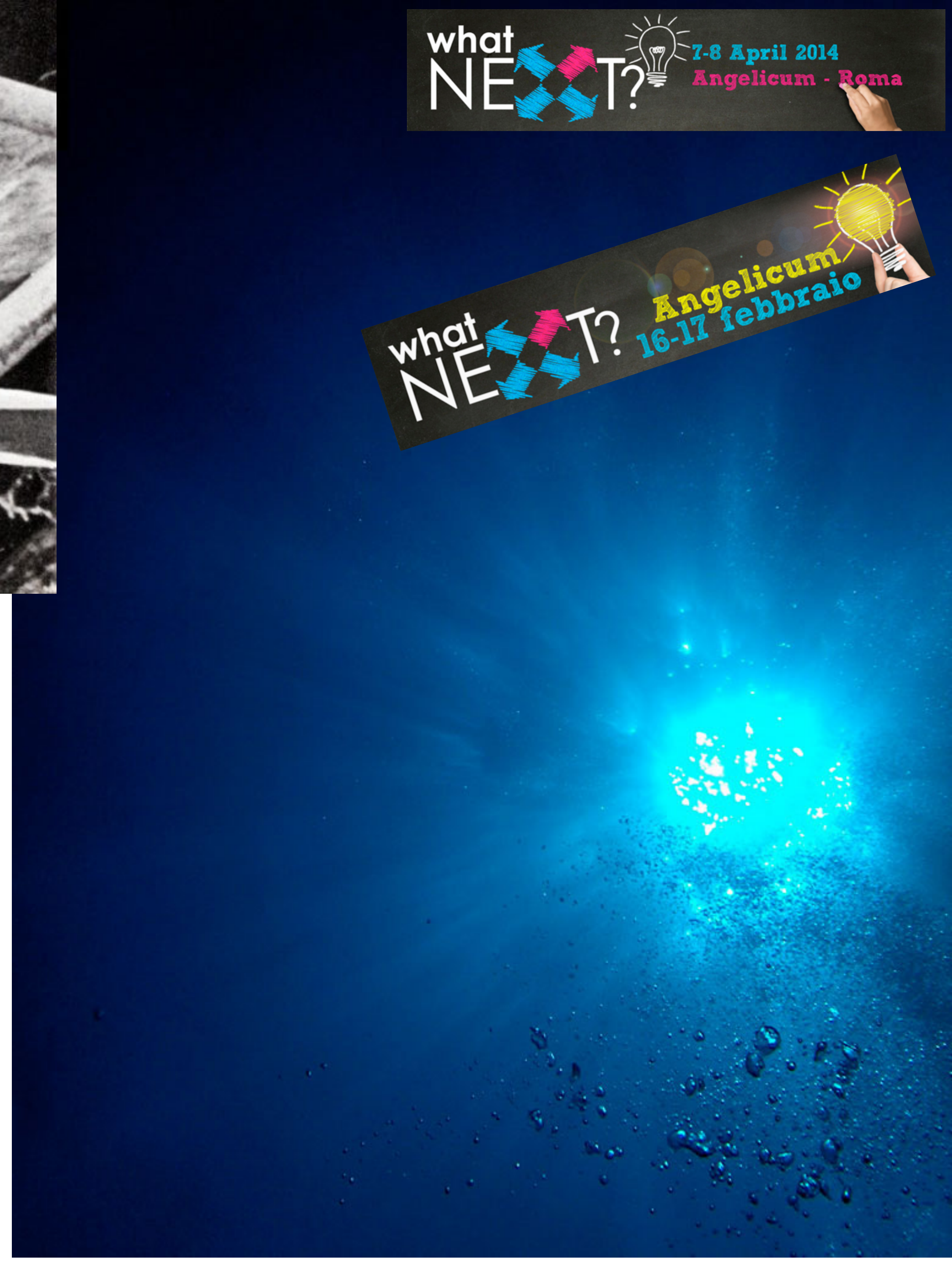


Quante deviazioni standard dalla predizione SM

Z. Ligeti, LP 2015

I miei pensieri

- Necessaria discussione ampia, aperta e senza pregiudizi per fare anche alcune scelte, ma soprattutto cogliere indizi di fisica
- Competenze differenziate devono essere coltivate e messe a disposizione con lungimiranza: personale e infrastrutture
- Storicamente fortissimo contributo tecnologico su acceleratori, rivelatori, trigger e calcolo
- Indispensabile individuare nuove metodologie di calcolo
- Indispensabile lo sviluppo di nuovi magneti
- Sicuramente importante perseguire tecniche acceleratrici “non convenzionali” per il futuro
- Partecipare agli studi di fisica e agli R&D a livello internazionale è cruciale per mantenere il ruolo INFN nelle decisioni future



l'impossibile è un'opinione

Enzo Maiorca