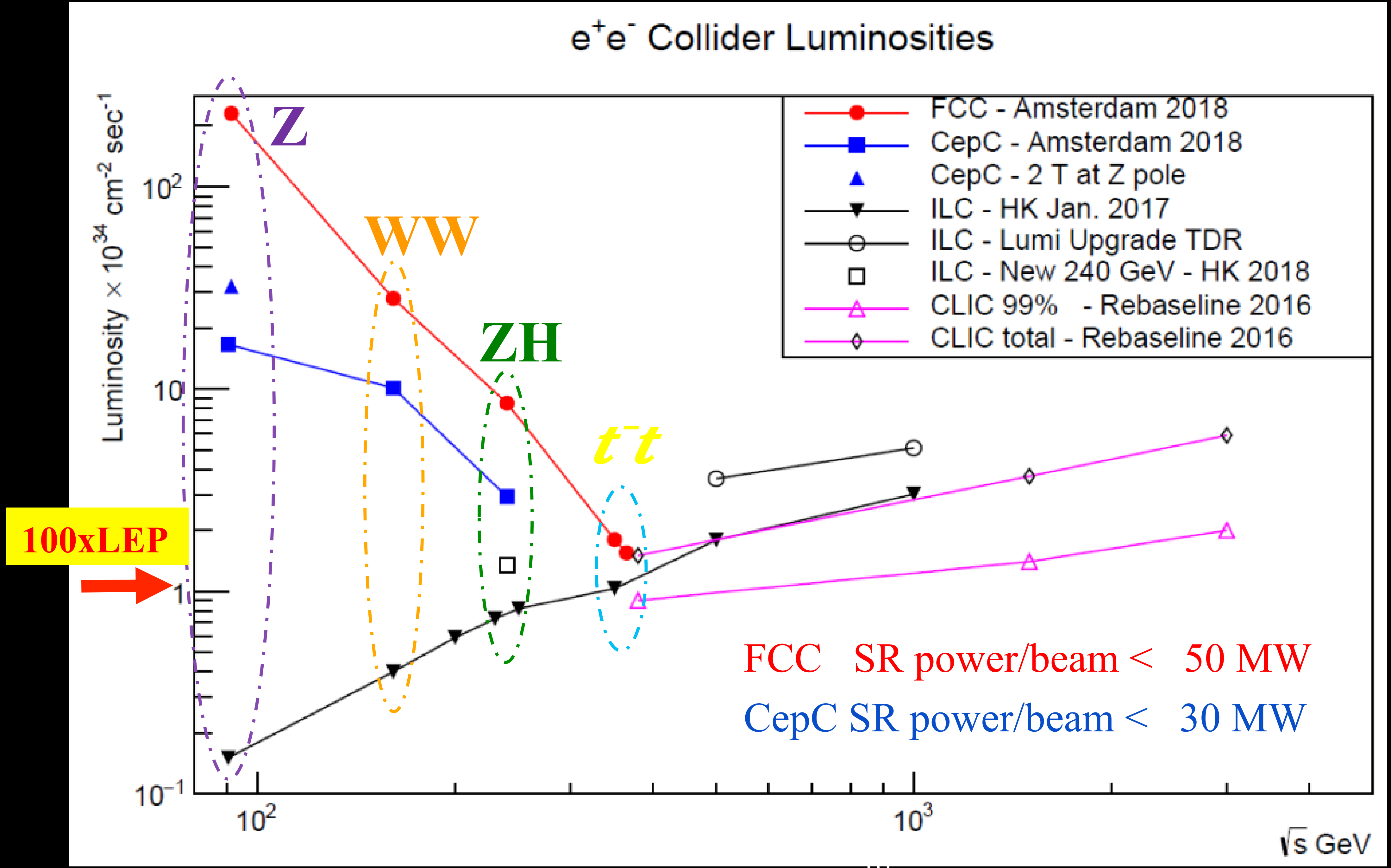
FUTURE ACCELERATORS: INPUTS FROM INFN

(Rome, 6-7 Sept 2018: "town meeting"
to prepare for EU strategy update)
(by kind invitation of Nando Ferroni, INFN president)

WHICH IS THE WAY TO NEW PHYSICS?

- "No experimental facility imaginable today can **guarantee** discovery of new physics" Here, will explore the **high-energy acceleration frontier**. If history is any guide, hopefully it will provide **direct** evidence of new physics.
- **e+e-**: the briefest mention
- HL-LHC and beyond: focus on **pp machines**
- **Muon** Colliders
- Plasma WakeField Acceleration **(PWFA)**
- Will make **no comparison of achievable precisions** in expected measurements - like H self-coupling, H decays, etc.

CepC, FCC, ILC, CLIC luminosity comparison



HL-LHC, HE-LHC, FCC

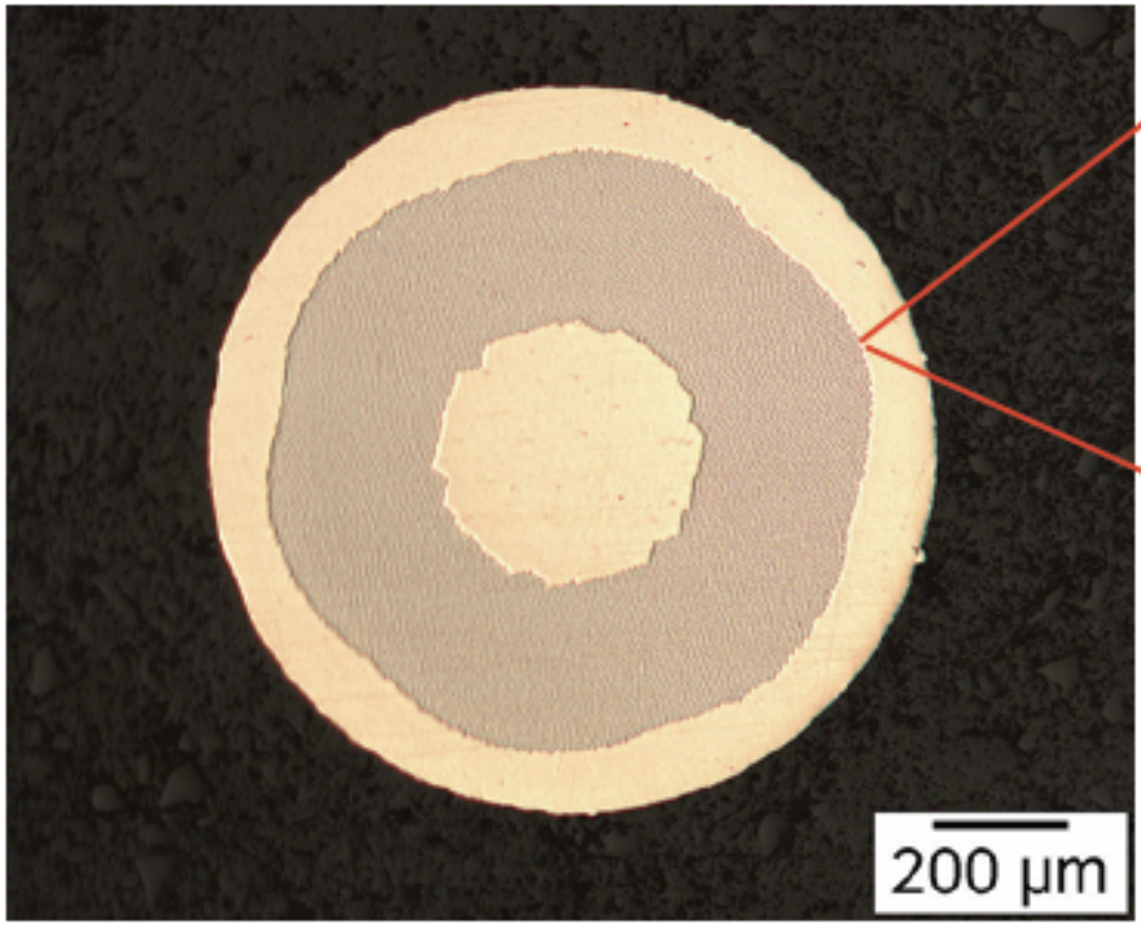
- **HL-LHC** will increase mass reach for SUSY by about x1.5 (good enough for 2026 + 10 years?)
- LHC Magnets: NbTi, 8.33T @ Ecm= 14TeV. It took **25 yrs** to progress from 1m, 9T, single-bore mags to full LHC magnet installation
- **HE-LHC**:16T Nb_3Sn magnets, 27 TeV
- **FCC**: same magnets, 100 km circle, 100 TeV

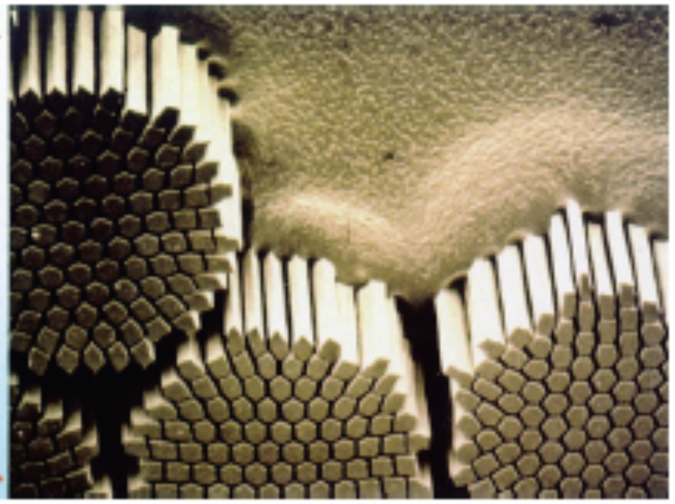
THE MAGNETS -1

(from the talk of Lucio Rossi,
HL-LHC Project Leader)

- Superconductor (SC) technology is first key to success
- Then, design of dipole/quadrupole field and mechanical constraint method is crucial
- LHC mags use NbTi SC. 14 TeV is near max B field
- 11T Nb_3Sn magnets developed. A few long dipoles and quads needed for HL-LHC. Production “in full swing”.

The key factor: superconductor (but not the only factor!)





Developing SC is the key in SC accelerators.
The perfection of LHC superconductor is such that we basically «forget» the SC effects and is the base of the repeatibility and optimal performance of the collider

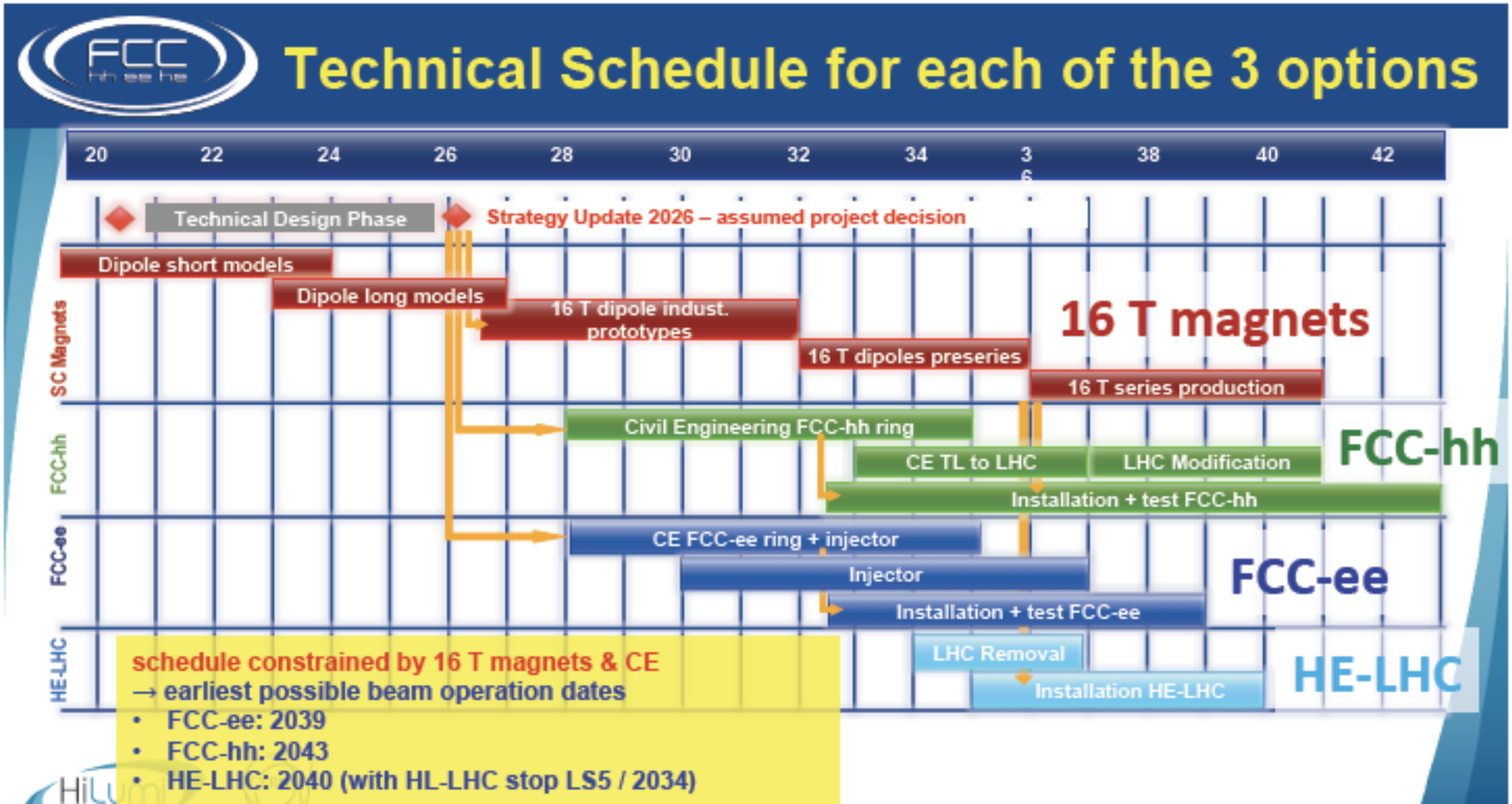
THE MAGNETS - 2

(again from L.Rossi's talk)

- 16 T Nb_3Sn magnets necessary for HE-LHC and FCC
- Nb_3Sn SC is more challenging than NbTi: brittle, needs rather different Rutherford cable.
- Mixed experience with pre-prototypes. Several independent international efforts ongoing. Different magnet designs. (Rossi: is this the best way to go?)
- Assumption is that long 16T mags will be mass-produced in time for either HE-LHC or FCC-hh. See schedule exercise shown at Amsterdam con earlier in 2018.
- (Rossi's minority opinion: If HE-LHC is approved, go for slightly lower B field and energy. 14 T mags could be built NOW.)

… AS SHOWN AT FCC WEEK, APR. 2018

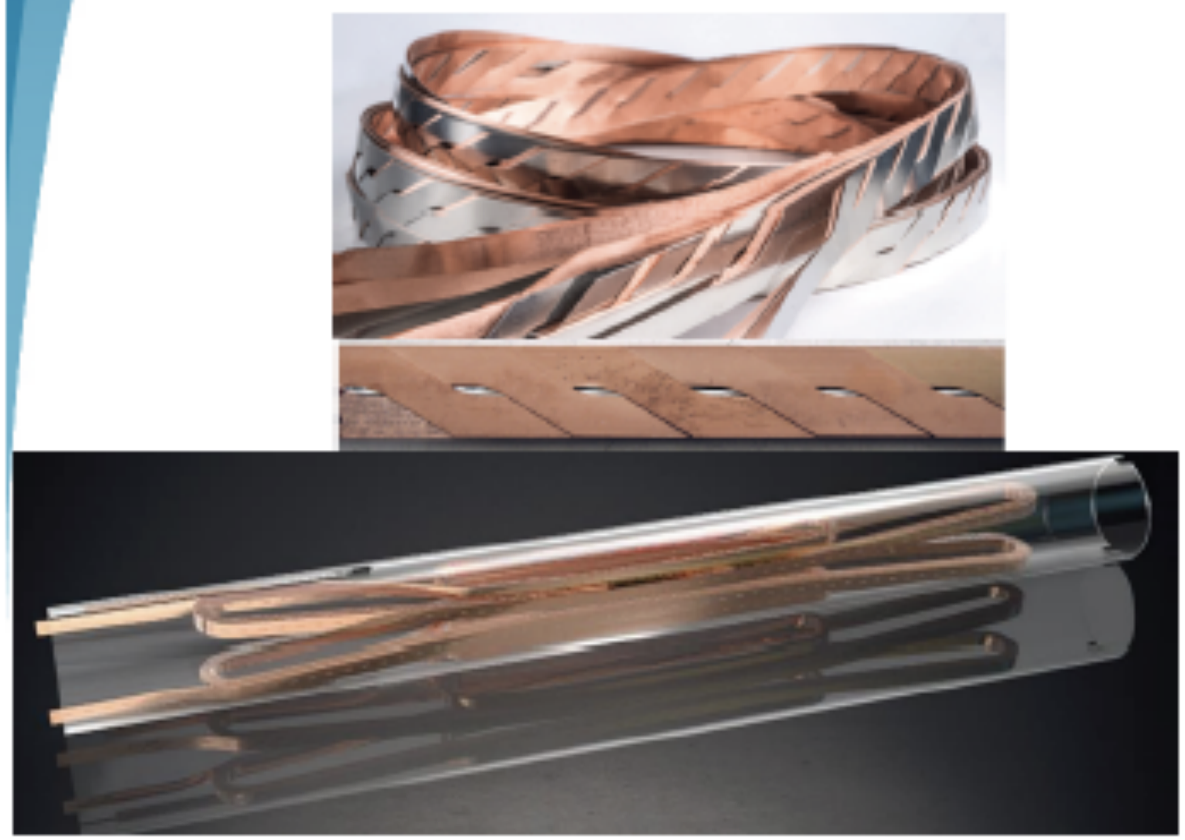
- Drawback of HE-LHC: FCC-hh **later by 30 yrs**
- Unless go for HE-LHC with 14T magnets, AND SHORTEN HL-LHC operations
- Compatibel with FCC-ee? (what if the Chinese go for CepC?



HIGH TEMP. SUPERCONDUCTORS (HTS):

only way to go beyond 16 T , perhaps up to 30 T

Working on new type of cables and magnets: reached 3.5 T, expected 7 T in January 2019



HTS situation and perspective

- Very expensive (5 times than Nb3Sn)
- Magnets are easier: great stability, no training!
- May work in He gas at 20 K: big advantage for power consumption and easier system…
- Basic R&D for 5-10 years to reach maturity is needed. Last 3 y has doubled performance! A solenoid of 32 T has been tested successfully.
- **We would not be alone… plenty of Institute (and companies) work on HTS**
- **This is the ground for basic focus R&D.**

MUON COLLIDERS?

(all info from M. Biagini's talk

WHY A MUON COLLIDER?

- All energy in CMS available for new particle production, as in electron-positron machines, and unlike in proton colliders
- Unlike electron-positron colliders, SR per turn is negligible
- Beamstrahlung too is negligible. Hence, cms energy spectrum is as tight as the collider's energy acceptance.
- Muon lifetime at rest is 2.2 microsec. If accelerated fast enough, it is not a show-stopper.
- A muon collider with cms energy = Higgs mass is interesting, because of m^2 dependence of muon-Higgs coupling (Rubbia)

THE EARLY APPROACH TO THE MUON COLLIDER

• Idea first introduced in 1979

•Most μ facility designs are based on μ production **as tertiary particles** by decay of π created with an intense, typically **several MW**, proton beam hitting a heavy material target

• To achieve high luminosity in the collider, the resulting μ beam, produced with low energy and hence a limited lifetime, with very broad transverse and longitudinal phase space, **has to be cooled by approximately five orders of magnitude in the 6D phase space.**

• Then it has to be accelerated rapidly to mitigate μ decays

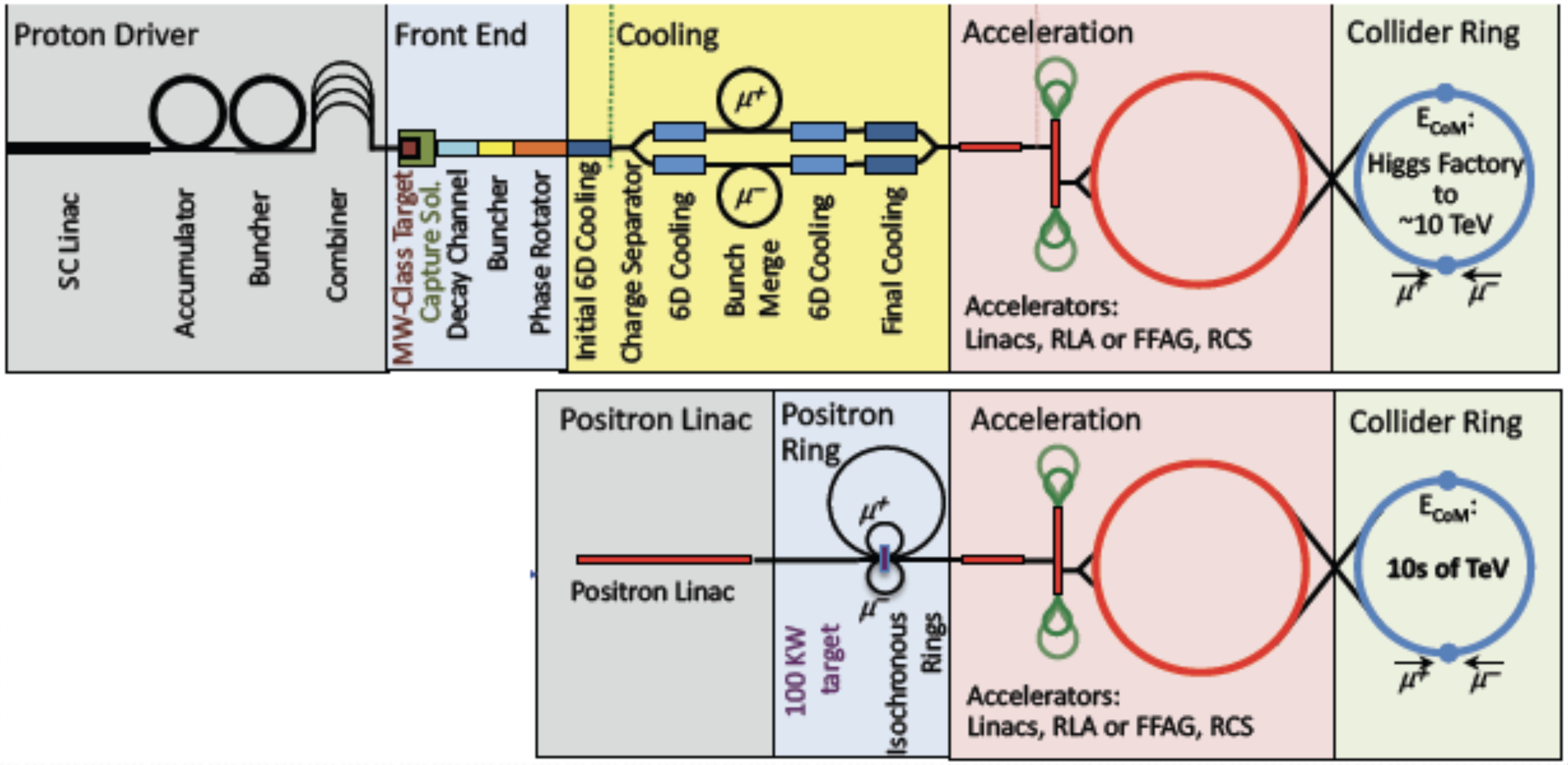
• US-based work on this approach **terminated by cut in funding in 2014**

NEW APPROACH RAPIDLY GREW INTO LARGE COLLABORATION: LEMMA

LEMMA studies

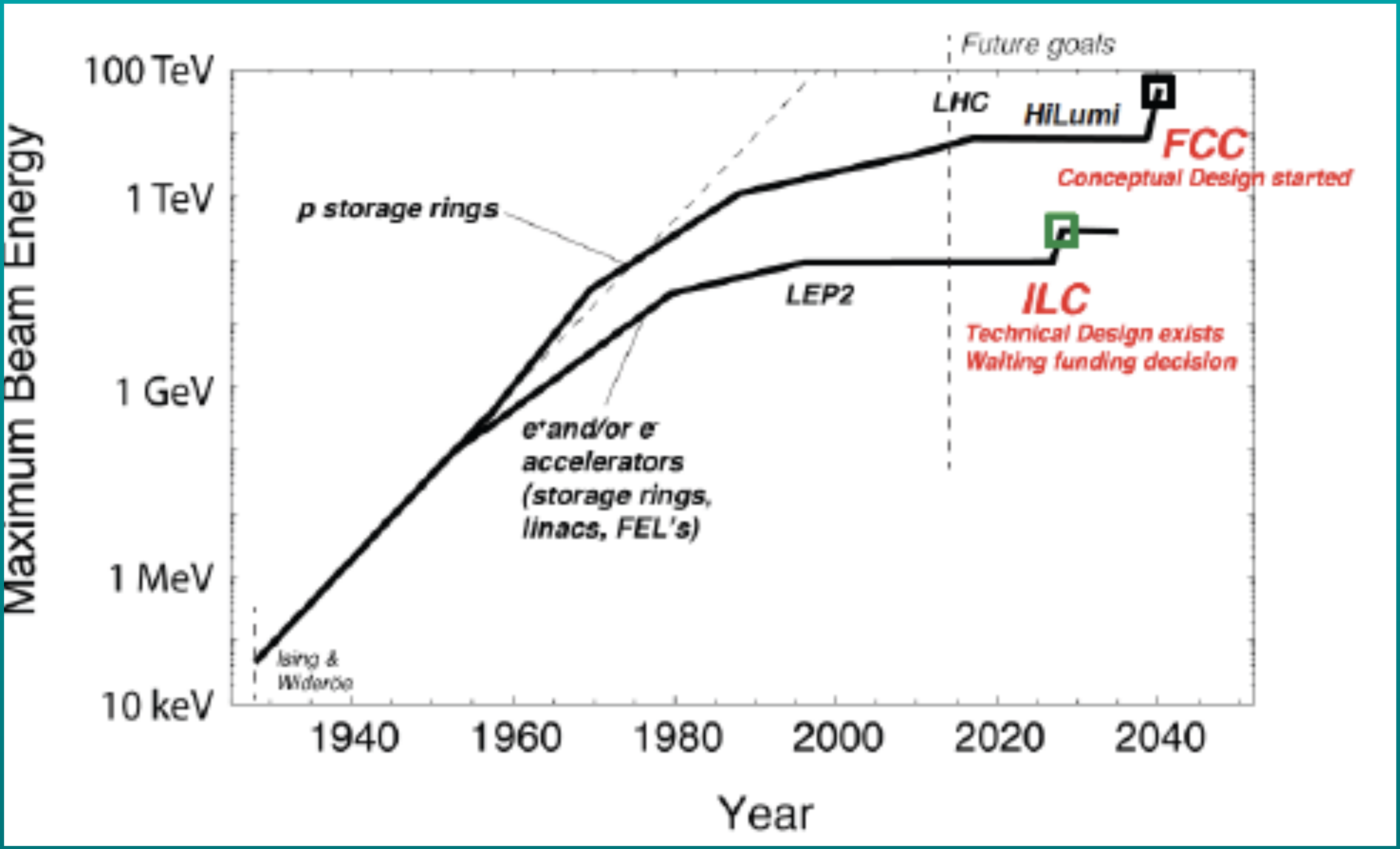
- Alternative concept (*idea from P. Raimondi & M. Antonelli first presented at Snowmass 2013*) developed at LNF in the past 2-3 years by a very small group
- At present collaboration includes LNF, Roma1, TO, PoliTO, PD, TS, FE, LAL/Orsay, ESRF → expanding!
- $\mu^{\pm}$ produced by e^+ beam interacting with e^- in a target → μ beam has small emittance and long laboratory lifetime due to the boost of the μ in the laboratory frame
- Most important properties of μ produced by e^+ on target:
  - low and tunable μ momentum in the center of mass frame
  - large boost of γ~200
- Advantages: final state μ highly collimated and with small emittance → cooling not required

LEMMA vs Proton Driver



OBVIOUSLY, THE LEMMA APPROACH IS MUCH SIMPLER BUT IT HAS ITS OWN CHALLENGES

NOVEL ACCELERATION METHODS: ACCELERATION IN RAREFIED PLASMAS

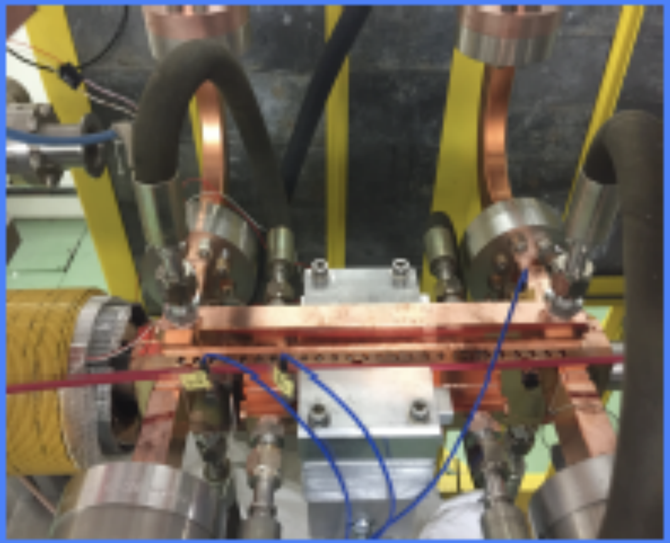


Livingston plot is obsolete. Extrapolating the original exponential, today we would have a 10 PeV machine!

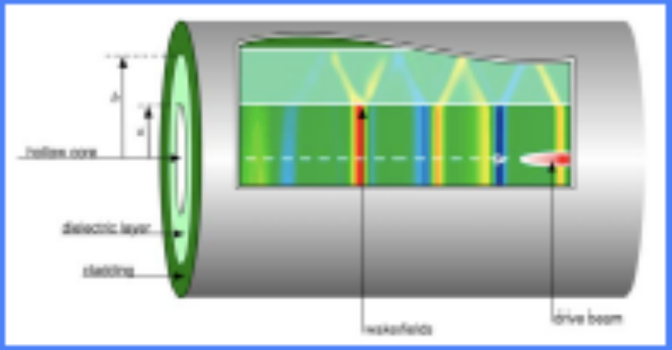
Time to aggressively explore higher gradient techniques!

High Gradient Options

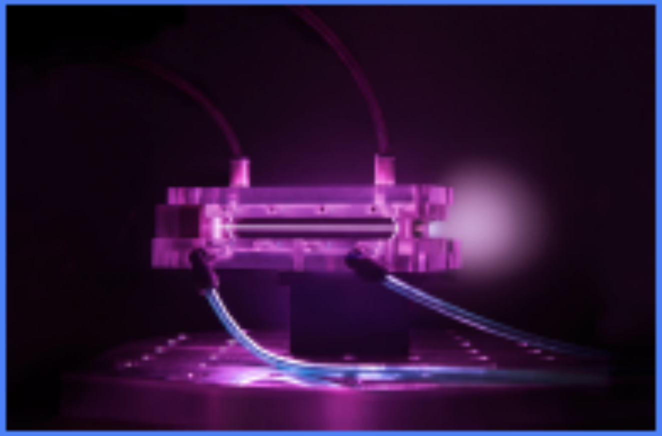
- RF accelerating structures, from X-band to K-band => 100 MV/m < E_{acc} < 1 GV/m



- Dielectrict structures, laser or particle driven => 1 GV/m < E_{acc} < 5 GV/m

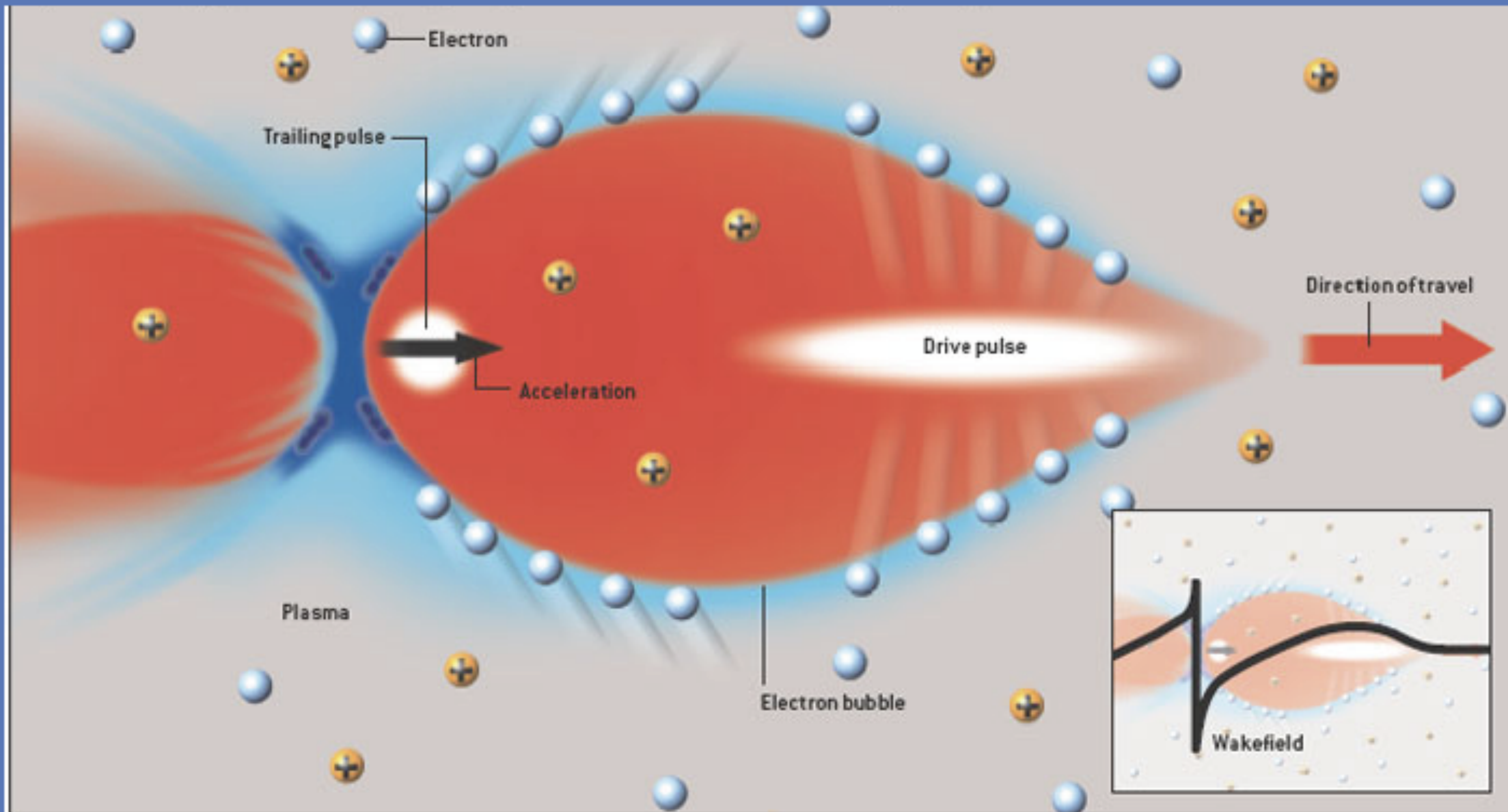


- Plasma accelerator, laser or particle driven => 1 GV/m < E_{acc} < 100 GV/m



(This section from Massimo Ferrario's talk)

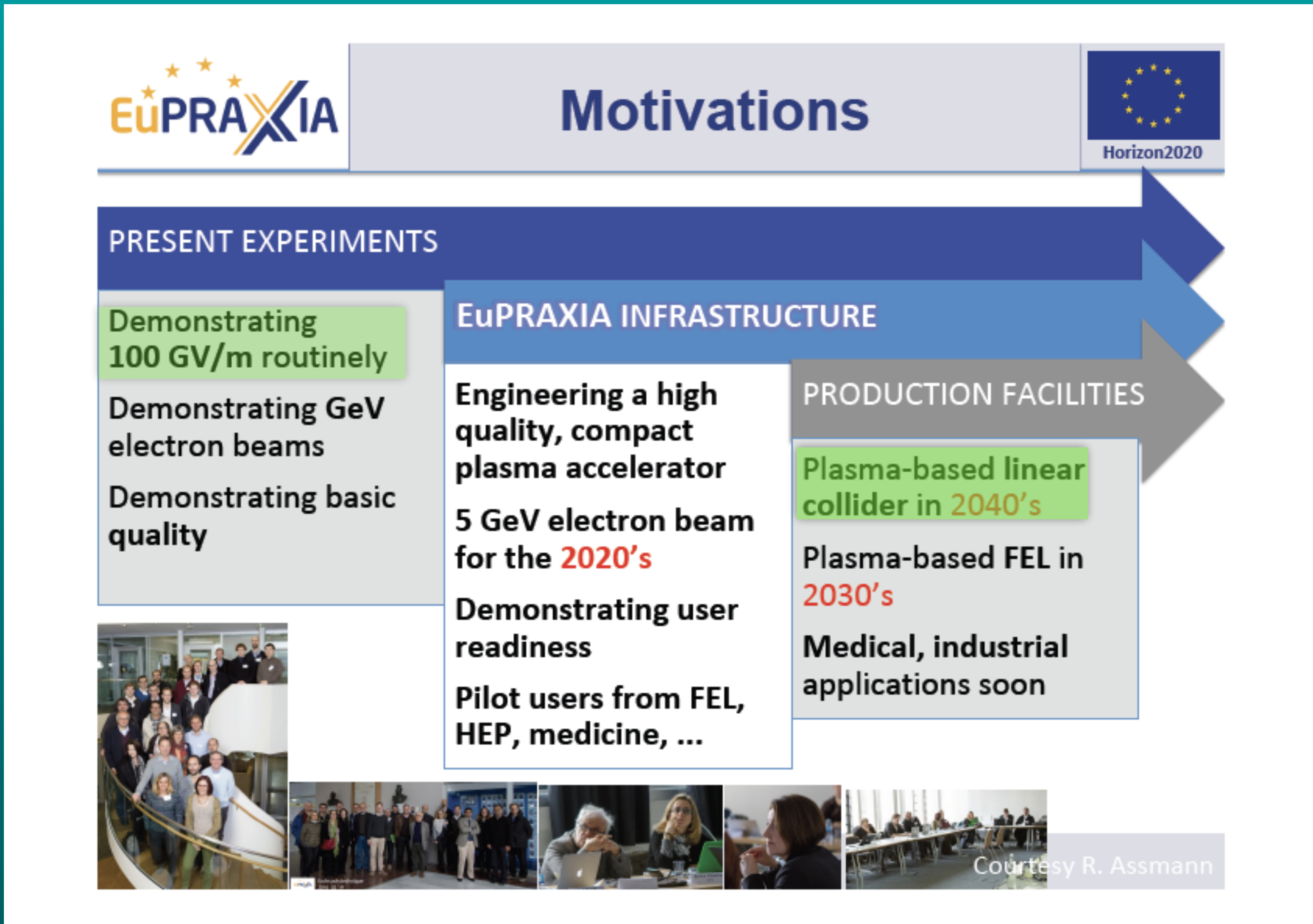
Plasma WakeField Acceleration: the concept



Breakdown limit?

$$E_0 = \frac{m_e c \omega_p}{e} \approx 100[\frac{GeV}{m}] \cdot \sqrt{n_0[10^{18} cm^{-3}]}$$

PWA work ongoing in about 20 labs, worldwide
Coalitions of labs formed, to produce accelerator prototypes



SUMMARIZING

- HE-LHC at about 25 TeV in cms: **feasible now,** both technically (and financially?).
- The 100 TeV FCC-hh needs more R&D. Financially possible in Europe? **“Needs full EU backing. CERN not enough” (**G. Tonelli, at INFN town meeting).
- Muon collider: “**Only feasible <u>multi-TeV</u> lepton collider**”. Practical? Time will tell.
- PWFA: promise of 100 GeV/m gradient linear accelerator! Many applications outside particle physics. **20-30 yrs away? (not more than FCC?)**. Stay tuned.

All these materials available at https://agenda.infn.it/conferenceOtherViews.py?view=standard&confId=15968.

Now, video of all talks athttps://agenda.infn.it/conferenceOtherViews.py?view=standard&confId=15968

- General talk: Bedeschi, day 1
- CERN FCC: Lucio Rossi, day 1
- Muon colliders: Biagini, day 1
- PWFA: Ferrario, day 1

Thank you

”Physics is like sex: sure, it may give some practical results, but that’s not why we do it”

R. P. Feynman

(quotation stolen from Marica Biagini)