Padova – July 3, 2018

Muon Collider Workshop

ARIES

Muon Collider

Input ideas and proposals for the European Strategy Update

Nadia Pastrone

INFN TORINO

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

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

ARIES workshop organized with perfect timing to review status of the art studies, available technologies, new ideas and dreams

What can we reasonably submit as input to the EU Strategy update?

Why Muons?

Physics Frontiers

- **Intense and cold muon beams ⇨ unique physics reach**
  - Tests of Lepton Flavor Violation
  - Anomalous Magnetic Moment (g-2)
  - Precision sources of neutrinos
  - Next generation lepton collider

$$m_\mu = 105.7\,MeV/c^2$$
$$\tau_\mu = 2.2\,\mu s$$

Colliders

- **Opportunities**
  - s-channel production of scalar objects
  - Strong coupling to particles like the Higgs → $\sim \left(\frac{m_\mu^2}{m_e^2}\right) \cong 4 \times 10^4$
  - Reduced synchrotron radiation ⇨ multi-pass acceleration feasible
  - Beams can be produced with small energy spread
  - Beamstrahlung effects suppressed at IP
- ***BUT* accelerator complex/detector must be able to handle the impacts of μ decay**

Collider Synergies

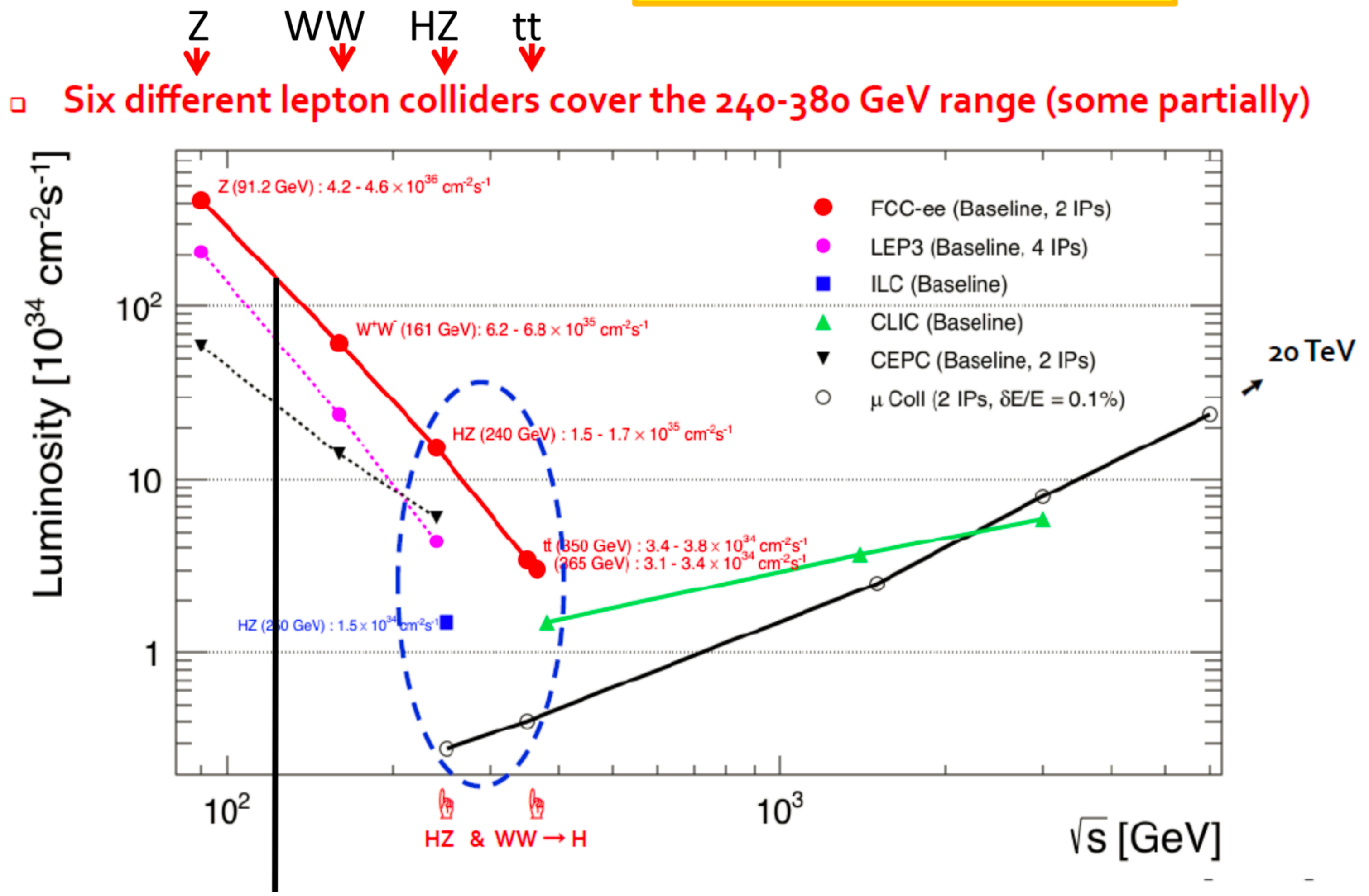
- High intensity beams required for a long-baseline Neutrino Factory are readily provided in conjunction with a Muon Collider Front End
- Such overlaps offer unique staging strategies to guarantee physics output while developing a muon accelerator complex capable of supporting collider operations

$$\mu^+ \to e^+ \nu_e \bar{\nu}_\mu$$
$$\mu^- \to e^- \bar{\nu}_e \nu_\mu$$

Higgs needs precise studies

Alain Blondel Future Colliders

Higgs factories



Lepton Colliders @ m_H

Back on the envelope calculation:

$$\sigma(\mu^+\mu^- \to H) = \left(\frac{m_\mu}{m_e}\right)^2 \times\sigma(e^+e^- \to H) = \left(\frac{105.7 MeV}{0.511\ MeV}\right)^2 \times\sigma(e^+e^- \to H)$$

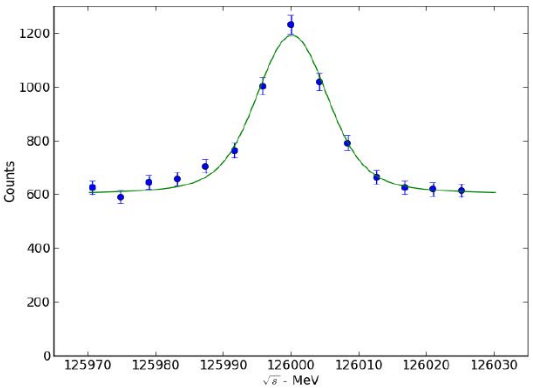
$$\sigma(\mu^+\mu^- \to H) = 4.3\times10^4\times\sigma(e^+e^- \to H)$$

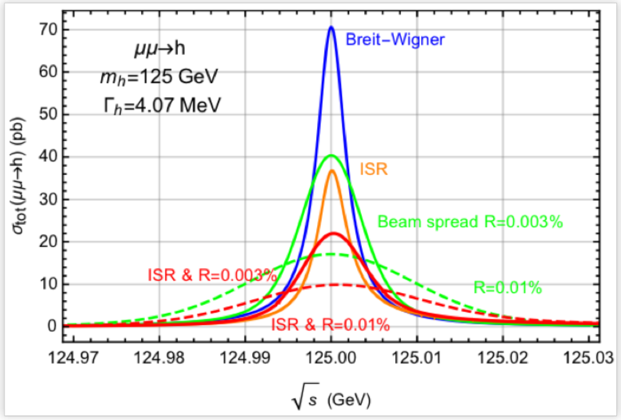
More precise determination done by M. Greco et al. (arXiv:1607.03210v2)

- Assumed Higgs width 4.2 MeV
- Energy Scan:
  $H \to b\bar{b}$ event count as function of √s
- Critical parameter : Beam Energy Spread ~10^{-5}

σ(BW)	ISR alone	R (%)	BES alone	BES+ISR
$\mu^+\mu^-$: 71 **pb**	37	0.01	17	10
		0.003	41	22
e^+e^-: 1.7 **fb**	0.50	0.04	0.12	0.048
		0.01	0.41	0.15

R: percentage beam energy resolution, key parameter





Muon colliders

- **Advantages**
  - Large cross sections $\sigma\,(\mu^+\mu^- \rightarrow h) = 35$ pb in s-channel resonance and 0.2 pb for $\mu^+\mu^- \rightarrow ZH$ of at $\approx \frac{1}{2}$ TeV.
  - Small size footprint: they may fit within the ESS site
  - No synchrotron radiation and beamstrahlung problems
  - Precise measurements of line shape and total decay width Γ
  - Exquisite measurements of all channels and tests of SM.
  - The cost of the facility, provided cooling will be successful, is of the order of a fraction of one of the LHC.
- **Challenges.**
  - A low cost demonstration of muon cooling must be done first.
  - Muon 2D and 3D cooling needs to be demonstrated
  - Need ultimately very small c.o.m energy spread (0.003%)
  - Backgrounds from constant muon decay
  - Significant R&D required towards end-to-end design

Muon vs Hadron Collider

Hadron Coll.
operating energy $\sqrt{s_H}$
to give same
BSM cross section
at E= $\sqrt{s_L}$
as Muon collider

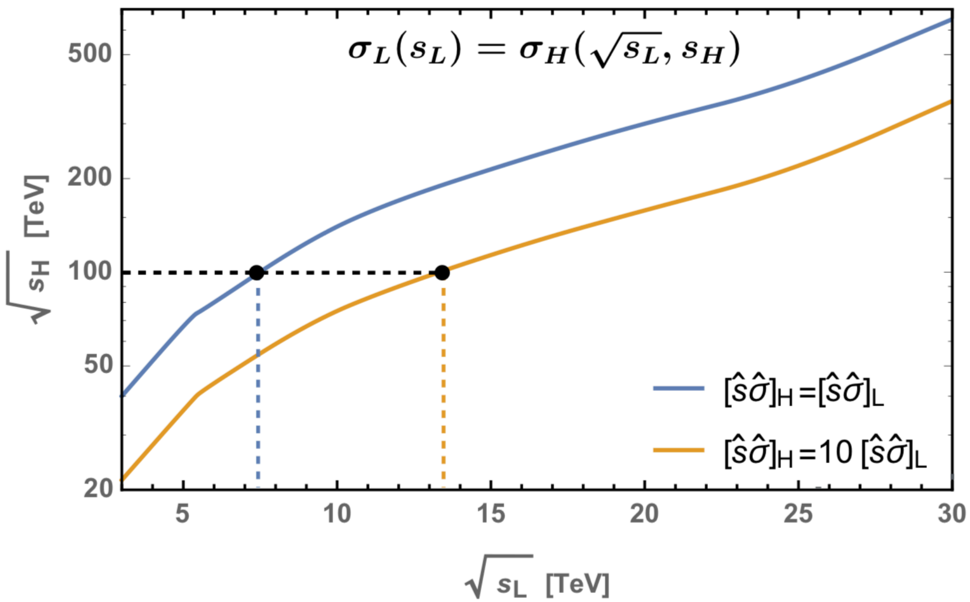


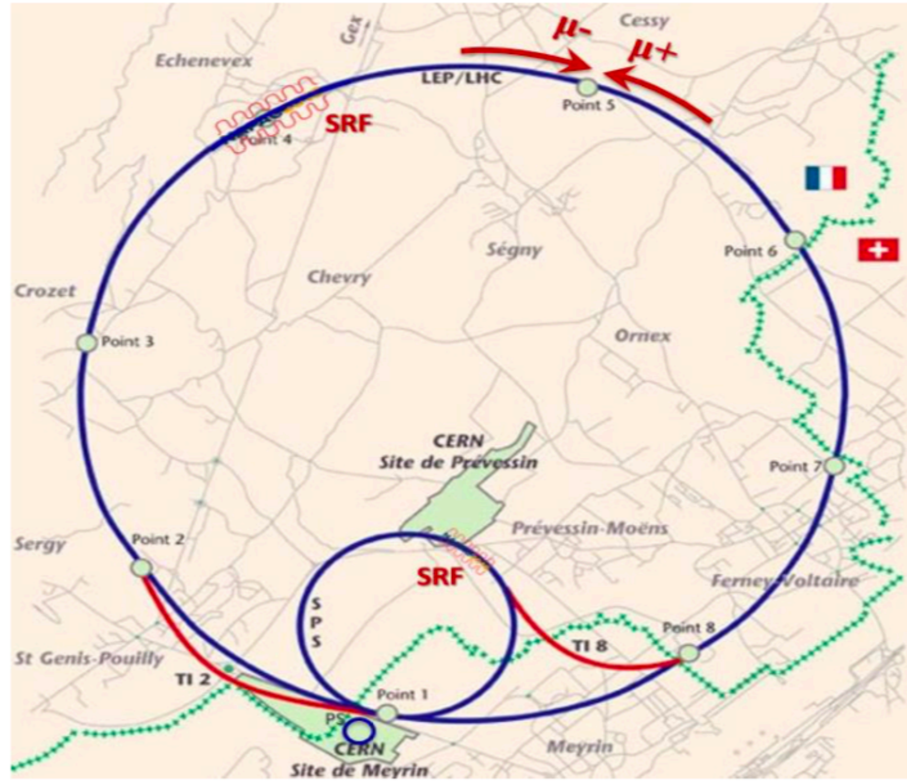
Fig. by A. Wulzer

~10 TeV Muon colliders
comparable to
~100 TeV Hadron colliders

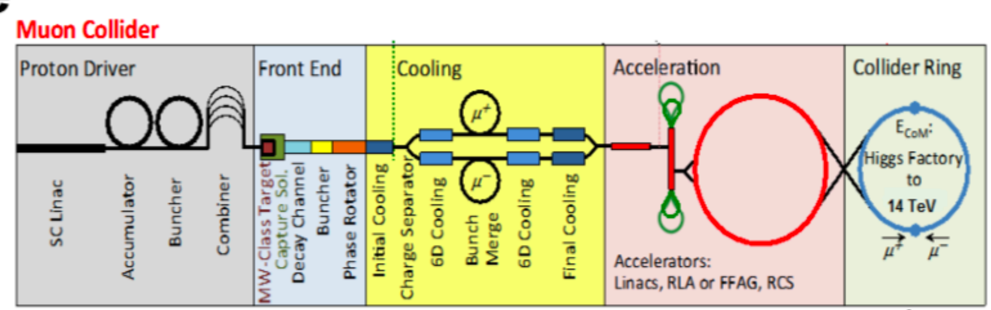
Illustrative for	$\sqrt{s_L}$ equiv. to $\sqrt{s_H}$ =100 TeV
QCD-Neutral BSM	~7-8 TeV
QCD-Colored BSM	~13-14 TeV

14 TeV "Next Muon Collider" 7×7 TeV

- **CERN needs world-class collider**
- **Use LHC tunnel**
  - Fill with accelerator and collider ring(s)
- **Result:**
  - 7 x 7 TeV collider
- **Reuses existing infrastructure**
  - ~100 m deep tunnel
  - cost possible ?
- **Must add a muon source**
  - high intensity



Shiltsev & Neuffer, IPAC 18



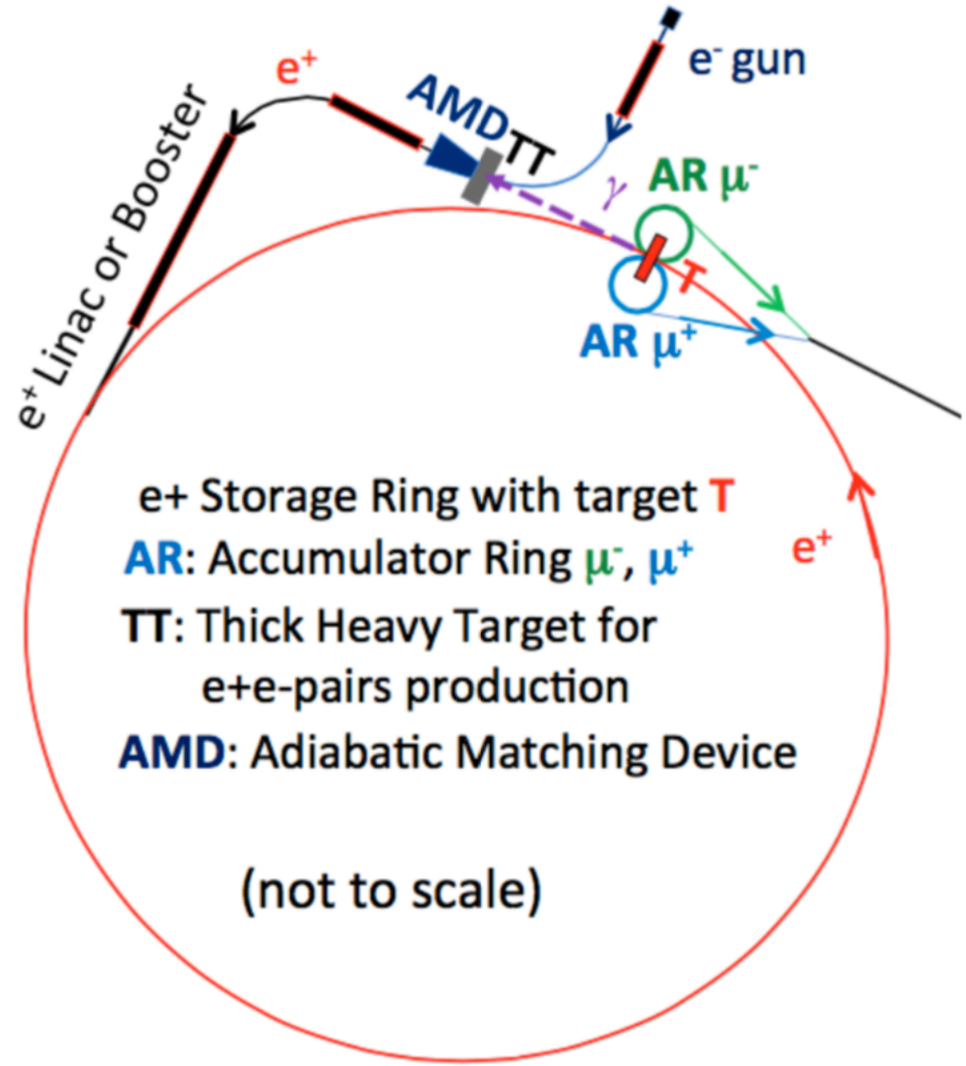
The LEMMA in a Nutshell

Developed by M. Boscolo et al.

Use positron storage ring at 45 GeV to produce low-emittance muon beam in a thin target

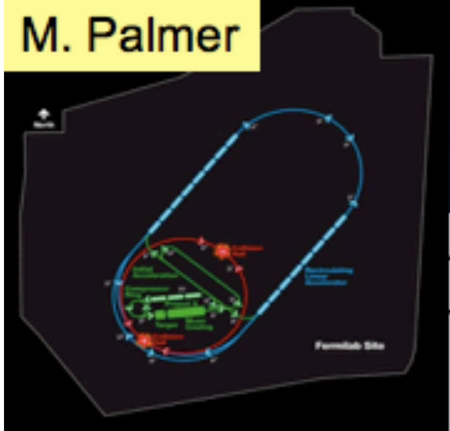
Muon beams make 2500 turns in rings then are accelerated

=> 2000 bunches per second



M. Palmer

Muon Collider Parameters



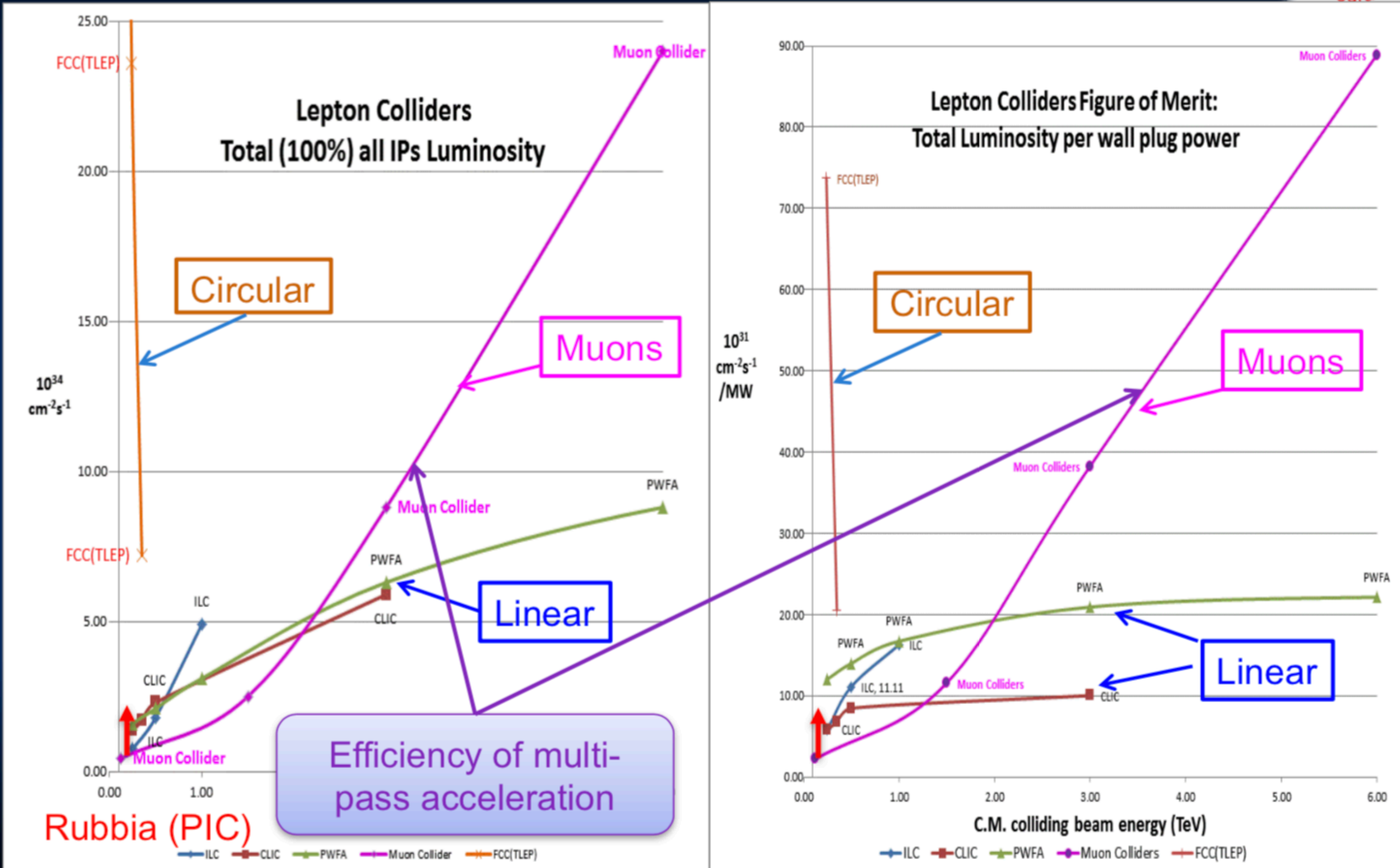
Muon Collider Parameters					
		Higgs	**Multi-TeV**		
Parameter	***Units***	*Production Operation*			*Accounts for Site Radiation Mitigation*
CoM Energy	TeV	**0.126**	**1.5**	**3.0**	**6.0**
Avg. Luminosity	$10^{34}cm^{-2}s^{-1}$	0.008	1.25	4.4	12
Beam Energy Spread	%	0.004	0.1	0.1	0.1
Higgs Production/10^7sec		13,500	37,500	200,000	820,000
Circumference	km	0.3	2.5	4.5	6
No. of IPs		1	2	2	2
Repetition Rate	Hz	15	15	12	6
β^*	cm	1.7	1 (0.5-2)	0.5 (0.3-3)	0.25
No. muons/bunch	10^{12}	4	2	2	2
Norm. Trans. Emittance, ε_{TN}	π mm-rad	0.2	0.025	0.025	0.025
Norm. Long. Emittance, ε_{LN}	π mm-rad	1.5	70	70	70
Bunch Length, σ_s	cm	6.3	1	0.5	0.2
Proton Driver Power	MW	4	4	4	1.6
Wall Plug Power	MW	200	216	230	270

Exquisite Energy Resolution Allows Direct Measurement of Higgs Width

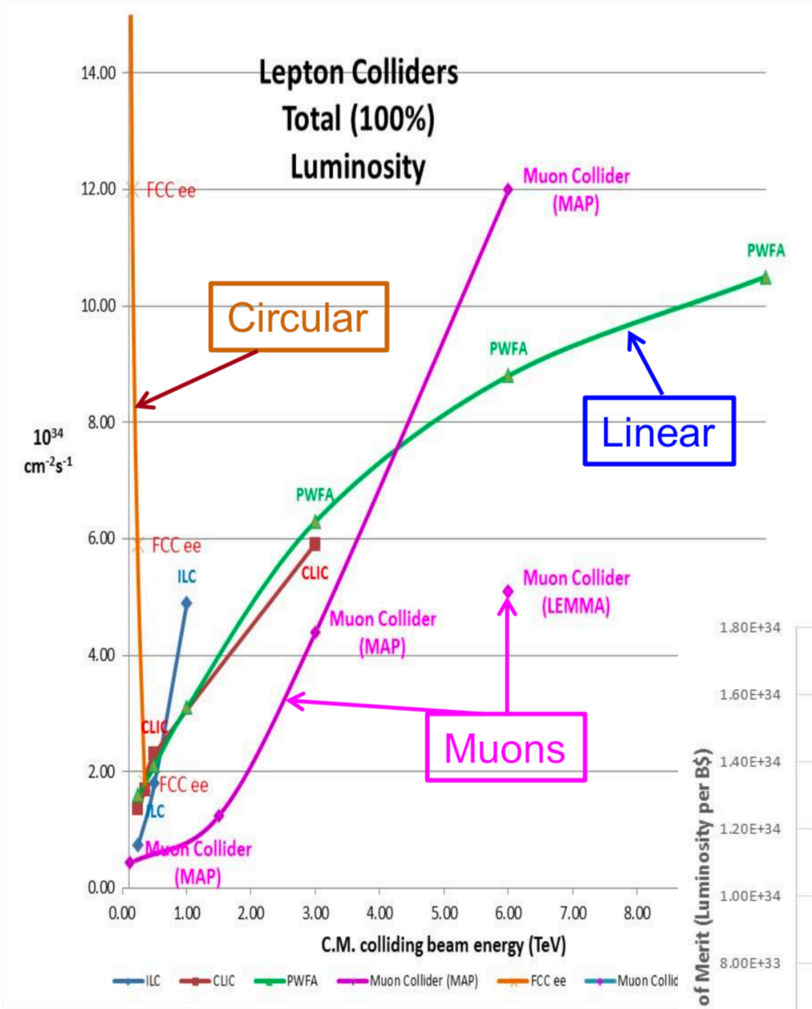
Success of advanced cooling concepts
⇨ several ✕ 10^{32} [Rubbia proposal: 5✕10^{32}]

Fermilab

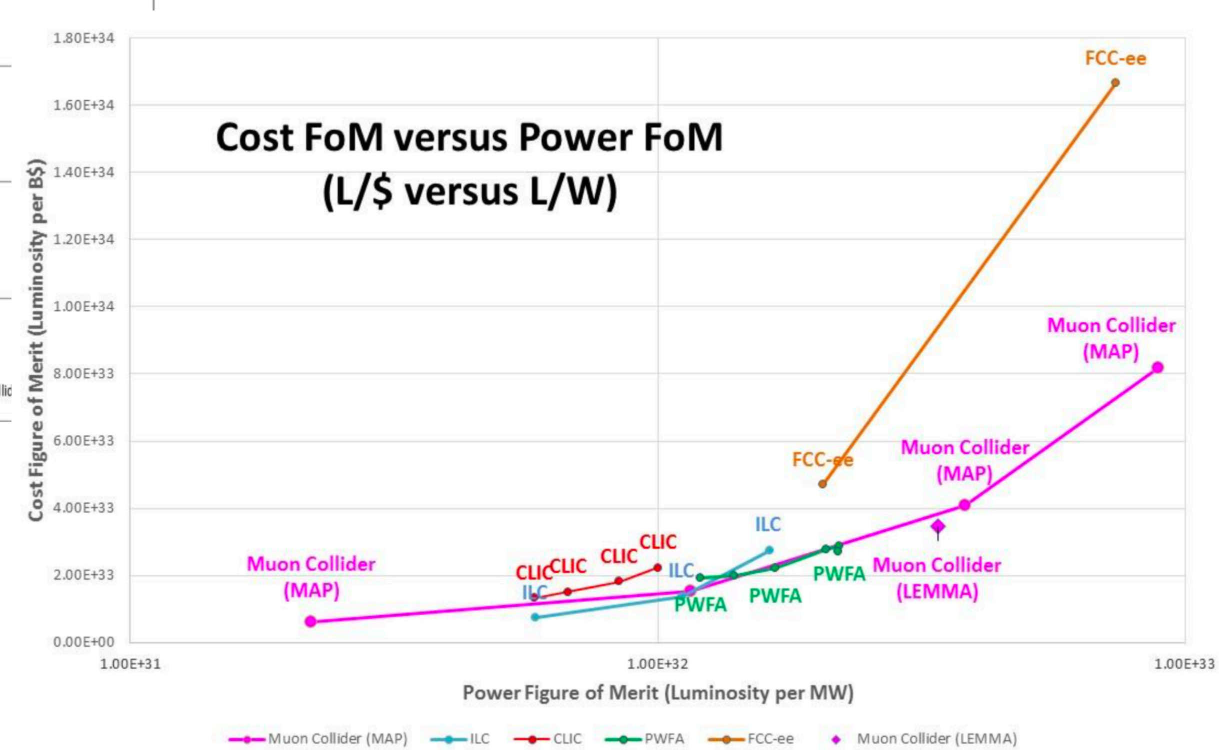
Muon Colliders –
Efficiency at the multi-TeV scale



New comparison



J.P.Delahaye



Neutrinos hazard and background studies

One concept

Table 4. Constraints on lattice designs to limit neutrino radiation.

E	B(min)	L(max)	$\mathscr{L}$
TeV	T	m	10^{34} cm^{-2} s^{-1}
1.5	0.25	2.4	0.008
3.0	1.5	0.28	0.6
6.0	1.5	0.28	12*

* constrained by ν radiation

- Solution beyond 10 TeV unclear at present†

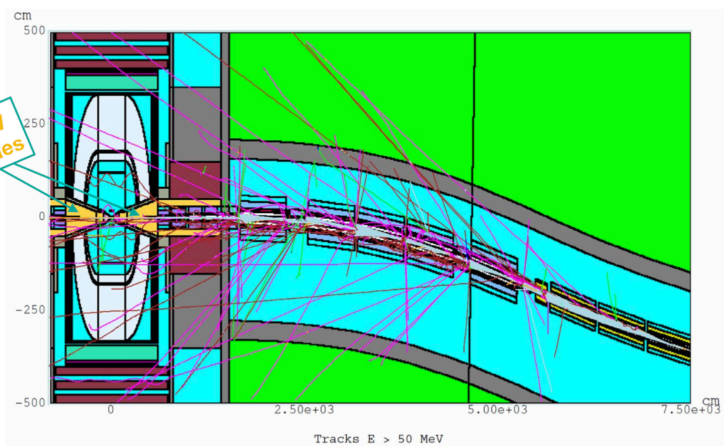
† although cf. AIP Conf. Proc. 1507 (2012) 860

D. M. Kaplan Muon Collider '18, U Padova 7/1–3, 2018 12/17

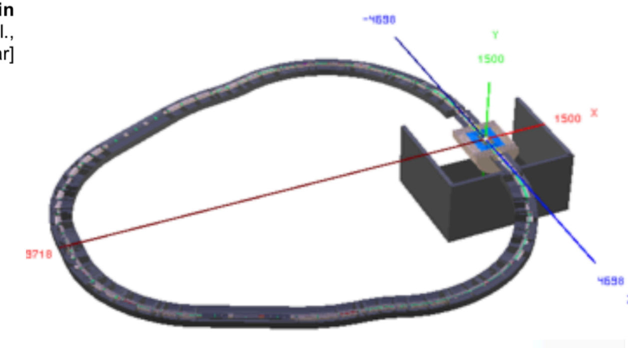
[**The Higgs Factory Muon Collider Superconducting Magnets and Their Protection Against Beam Decay Radiation**, N.V. Mokhov, et al., arXiv:1806.08883; JINST, to appear]

[**A Study of Muon Collider Background Rejection Criteria in Silicon Vertex and Tracker Detectors,** V. Di Benedetto, et al., arXiv:1806.08883; JINST, to appear]

- Machine–Detector Interface:

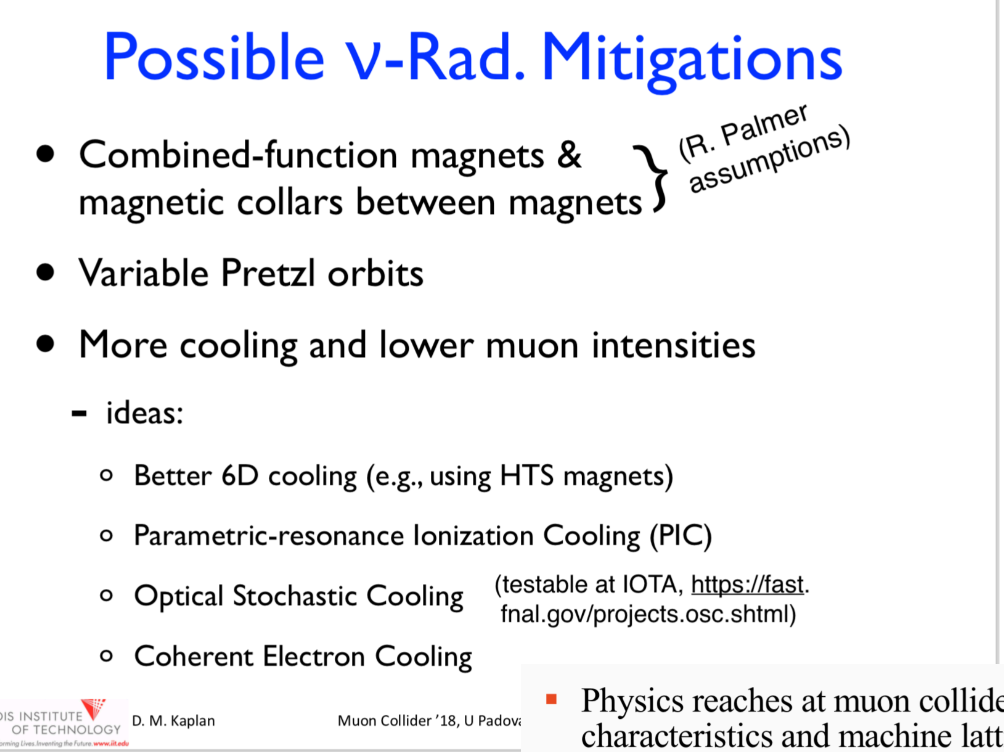


- Obtain $>10^3$ rejection of detector hits



D. M. Kaplan Muon Collider '18, U Padova 7/1–3, 2018 10/17

Neutrinos hazard and background studies



- Physics reaches at muon collider strongly depend on machine background which depends on beam characteristics and machine lattice in particular on the IR design
- MAP collaboration has studied in details cases for 1.5 TeV center of mass energy and did start the Higgs factory simulation
- We resumed the MAP simulation package with goals
  - Study the Higgs line-shape, this is the most difficult case due to the overwhelming background
  - Evaluate performances for physics benchmarks in the high energy case to be compared with other colliders
  - Compare the muon decay background obtained with MARS with the one simulated with FLUKA
  - Study physics benchmarks for other sources of muons, this can be done only in strong collaboration with accelerator experts to define IR and MDI

We are starting a working group that meets every two weeks to perform physics case studies

Quest for the Muon Collider

- Physiscs motivations
- Machine studies:
  - results
  - needed simulations and R&Ds
- Backgrounds and radiation hazards on:
  - machine
  - detector
- International community

WG mandate to submit a document

The Laboratory Directors Group @ CERN formed a Muon Colliders Working Group in charge to prepare the input for discussion towards the 2020 European Particle Physics Strategy Update (EPPSU)

- The goal of the WG is to assess the present status of past studies in the field and to identify, review and recommend further R&D to be compared to the other future accelerator projects for HEP (lepton and hadron colliders):
  - common physics benchmarks as well as a set of machine parameters must be agreed and defined
  - different options must be evaluated to highlight potential and issues.
  - feasibility studies could be proposed to complete the study after 2018 on novel ideas, while issues and resources need to be estimated

Jean Pierre Delahaye, CERN
Marcella Diemoz, INFN. Italy
Ken Long, Imperial College, UK
Bruno Mansoulie, IRFU, France
Nadia Pastrone, INFN, Italy, chair
Daniel Schulte, CERN
Andrea Wulzer, EPFL and CERN
Lenny Rivkin, EPFL and PSI, Switzerland (ex officio)
+++ MAP, LEMMA et al. support/discussions

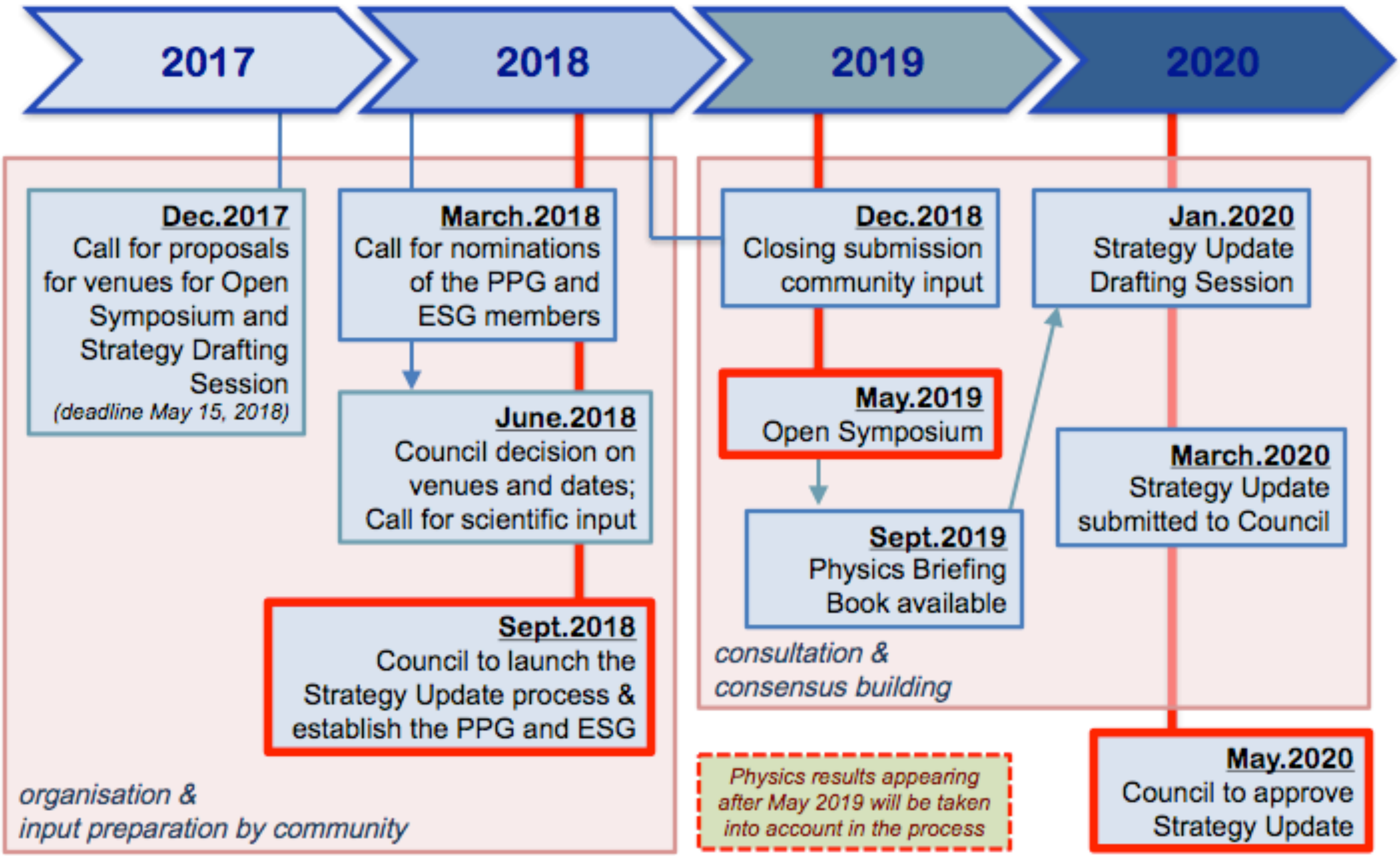
Personal view

- Not a comprehensive review
- Many discussions and new ideas
- Such a new challenging machine and detector to train a new generation of experimental physicists (accelerator and detector experts)

Many thanks to ARIES
and Padova group
for the organization

extra

European Particle Physics Strategy *Update*



Call for INPUT

Open call to all members of the particle physics community

The CERN Council has set itself the objective of updating the European Strategy for Particle Physics by May 2020. To achieve this, it has established a Strategy Secretariat to which it has assigned the task of organising the update process.

The Strategy update process will include two major events: an “Open Symposium” and a “Strategy Drafting Session”.

At the Open Symposium, to be held in the second half of May 2019, the community will be invited to debate the scientific input into the Strategy update, which will take the form of a “Briefing Book”. This will be prepared over the summer of 2019 by a Physics Preparatory Group (PPG) and submitted to the European Strategy Group (ESG) for consideration before and during its Strategy Drafting Session to be held in the second half of January 2020.

To prepare the Open Symposium, the Strategy Secretariat hereby calls upon the particle physics community in universities, laboratories, national institutes and institutions to submit written input following the enclosed guidelines.

The deadline for input is **18 December 2018**.

Input should be submitted via a portal that will be created on the Strategy update website, which will be available from the beginning of October 2018, once the Strategy update has been formally launched by the CERN Council. The link to this website will appear on the CERN Council’s web pages - https://council.web.cern.ch/en - and be widely communicated through the appropriate channels.

The Strategy Secretariat
Update of the European Strategy for Particle Physics
EPPSU-Strategy-Secretariat@cern.ch

February 2018

INPUT Guidelines

European Strategy Update

Contact:
EPPSU-Strategy-Secretariat@cern.ch

Guidelines for submitting input for the 2020 update of the European Strategy for Particle Physics

Cover page (1 page)
Each document submitted should carry a single cover page containing no more than the title, the contact person(s) and an abstract.

Comprehensive overview (maximum 10 pages)
This core part of the document must be no more than 10 pages long (excluding the cover page) and must provide a comprehensive and self-contained overview of the proposed input. It should address:

- scientific context,
- objectives,
- methodology,
- readiness and expected challenges.

Addendum
A separate addendum is to be provided addressing the following topics (where relevant):

- interested community,
- timeline,
- construction and operational costs (if applicable),
- computing requirements.

Format and deadline for submission
The cover page and the comprehensive overview are to be submitted as a single file, the "main document", in portable document format (pdf) by 18 December 2018. The addendum is to be submitted as a separate file by the same deadline. A dedicated submission portal will be available on the EPPSU website as of October 2018, once the Strategy update has been formally launched by the Council at its September 2018 Session. The link to the EPPSU website will appear on the CERN Council's web pages - https://council.web.cern.ch/en - and be widely communicated through the appropriate channels.

Distribution
Both documents submitted (main and addendum) will be passed on to the Physics Preparatory Group (PPG) and the European Strategy Group (ESG). Unless explicitly requested otherwise, they will also be made public. The option not to make either document public will be available upon submission via the dedicated portal