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Low Emittance Muon Accelerator: proposte di tesi

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3 steps to lower the cost of future highest-energy circular colliders

- reduce SC/magnet cost
- build on a site with existing injector complex
- consider staging

(e$^+$e$^-$ 1st, *pp* 2nd, and $\mu^+\mu^-$ 3rd?)

FCC-ee FCC-hh "FCC-μμ"?
CEPC SPPC

[F. Zimmermann]

The strength of a μ−beam facility lies in its richness:

- Muon rare processes
- Neutrino physics
- Higgs factory
- Multi-TeV frontier

Take 1

Get 4 !

μ−colliders can essentially do the HE program of e^+e^- colliders with added bonus (and some limitations)

Giudice

Muon based colliders great potential

As with an e^+e^- collider, a $\mu^+\mu^-$ collider offers a precision probe of fundamental interactions without energy limitations

- **By synchrotron radiation (limit of e^+e^- circular colliders)**
- **By beam-strahlung (limit of e^+e^- linear colliders)**

Muon Collider is the ideal technology to extend lepton high energy frontier in the multi-TeV range with reasonable dimension, cost and power consumption

Muon based Higgs factory takes advantage of a strong coupling to Higgs mechanism by s resonance

IF THE MUON BEAM NOVEL TECHNOLOGY CAN BE DEMONSTRATED TO BE FEASIBLE

Muons: Issues & Challenges

- **Limited lifetime: 2.2 μs (at rest)**
  - Race against death: generation, acceleration & collision before decay
  - Muons decay in accelerator and detector ☹
    - Shielding of detector and facility irradiation
    - Collider and Physics feasibility with large background environment?

      Not by beamshtrahlung as with e+/e- but by muon decay (e, ν)

      Reduced background at high energy due to increased muon lifetime
  - Decays in neutrinos: ☺
    - Ideal source of well defined electron & muon neutrinos in equal quantities whereas Superbeams by pion decay only provide muon ν:

$$\mu^+ \rightarrow e^+ \nu_e \overline{\nu}_\mu$$
$$\mu^- \rightarrow e^- \overline{\nu}_e \nu_\mu$$

The neutrino factory concept

- **Generated as tertiary particles in large emittances** ☹
  - powerful MW(s) proton driver and pion decay
  - novel (fast) cooling and acceleration methods

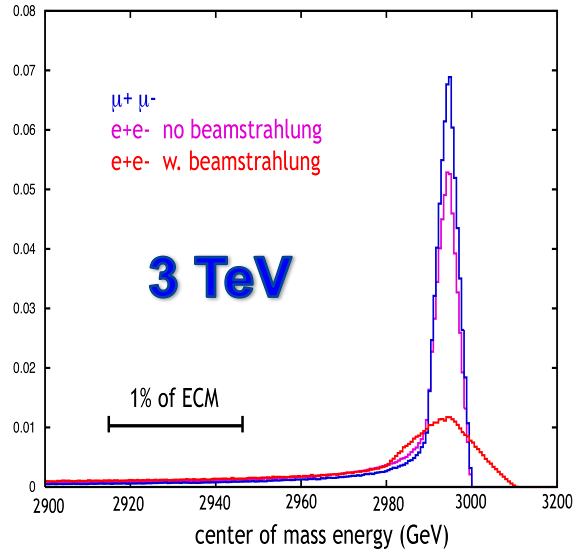
$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$
$$\pi^- \rightarrow \mu^- + \nu_\mu$$

Development of novel technologies with key accelerator and detector challenges

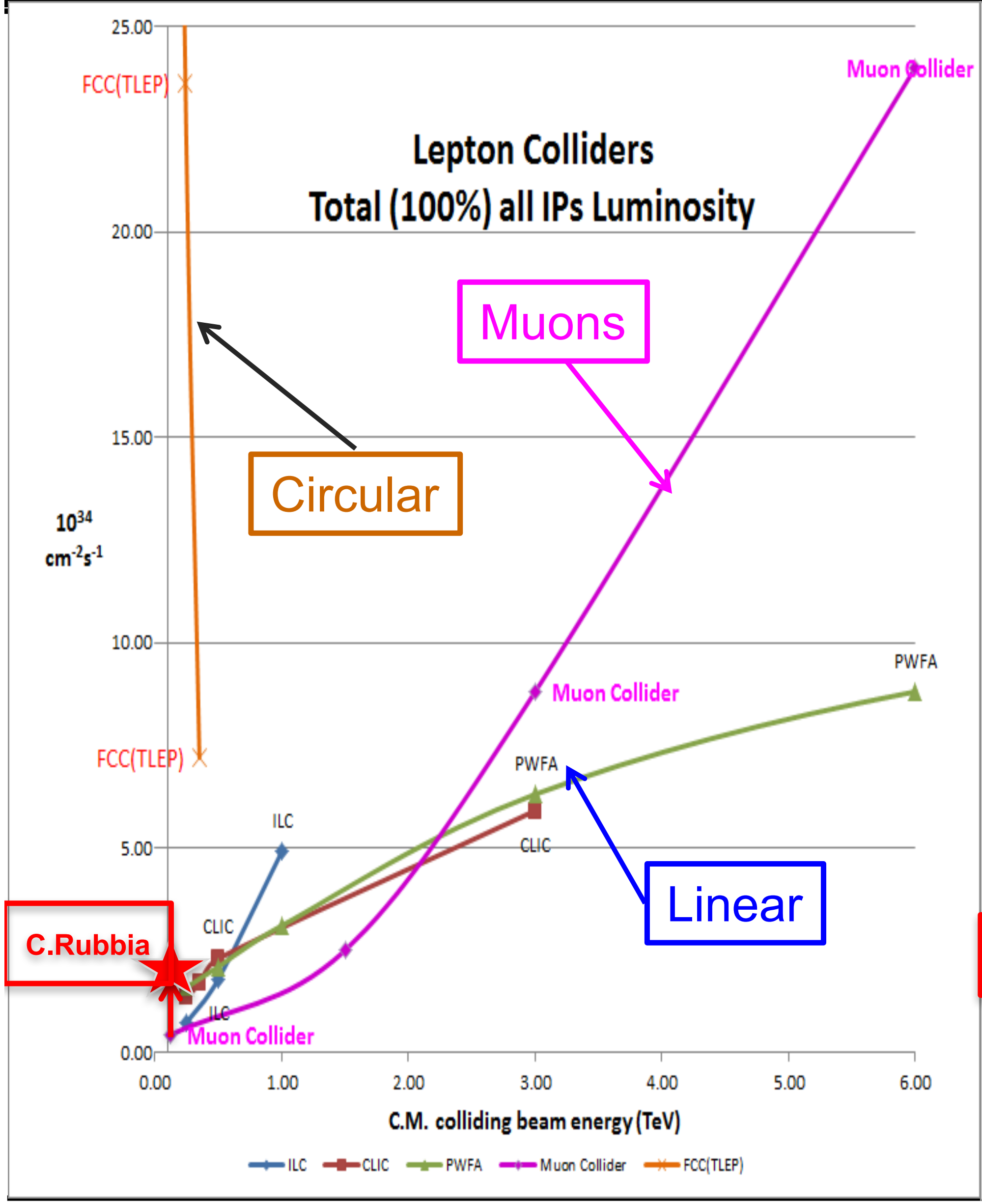
Muon beams specific properties

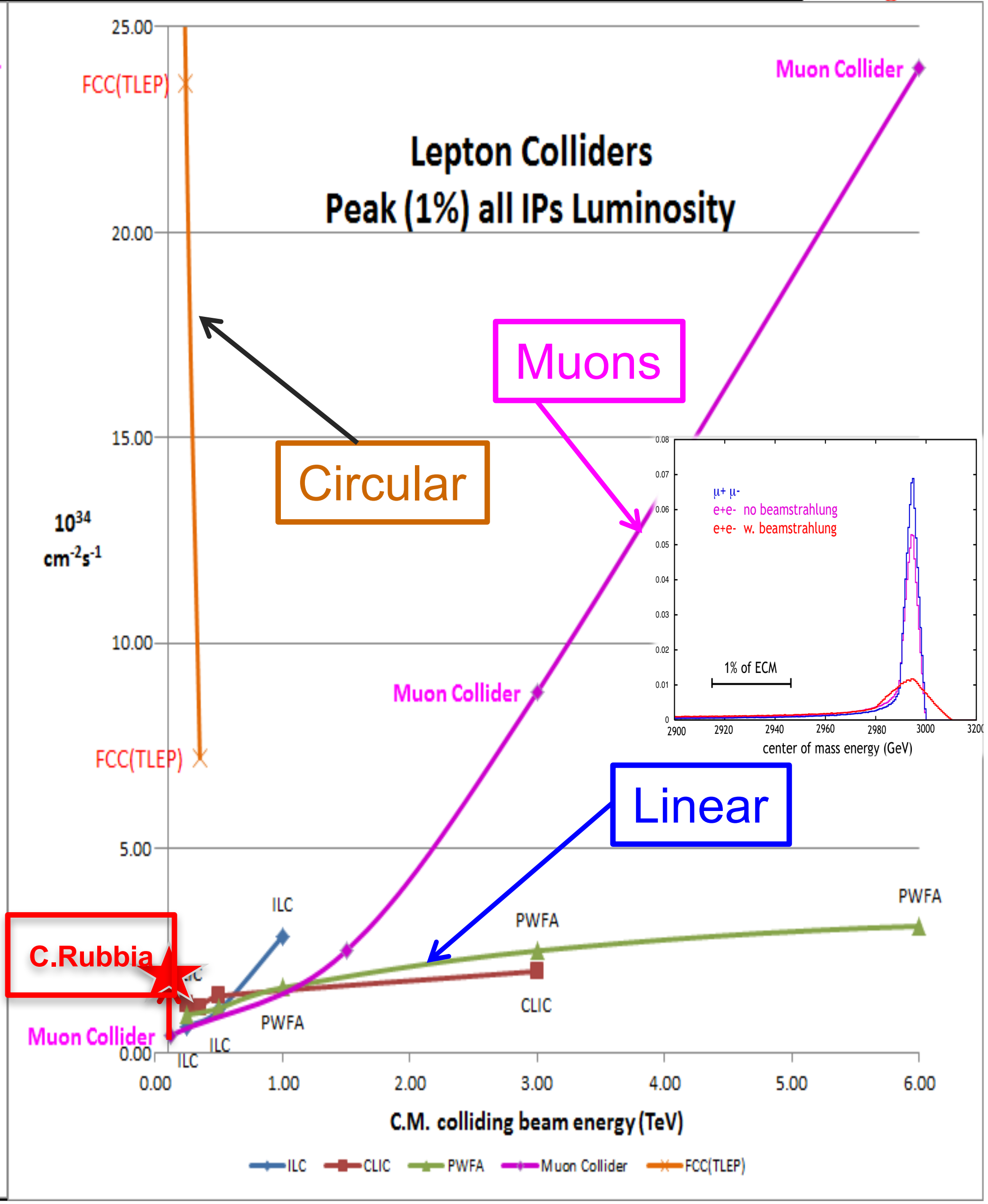
Muons are leptons like electrons & positrons
but with a mass (105.7 MeV/c^2) 207 times larger

- **Negligible synchrotron radiation emission (α m^{-2})**
  - **Multi-pass collisions (1000 turns) in collider ring**
    - **High luminosity with reasonable beam power and wall plug power consumption**
      - **relaxed beam emittances & sizes, alignment & stability**
    - **Multi-detectors supporting broad physics communities**
    - **Large time (15 μs) between bunch crossings**
  - **No beam-strahlung at collision:**
    - **narrow luminosity spectrum**
  - **Multi-pass acceleration in rings or RLA:**
    - **Compact acceleration system and collider**
    - **Cost effective construction & operation**
  - **No cooling by synchrotron radiation in standard damping rings**
    - **Requires development of novel cooling method**

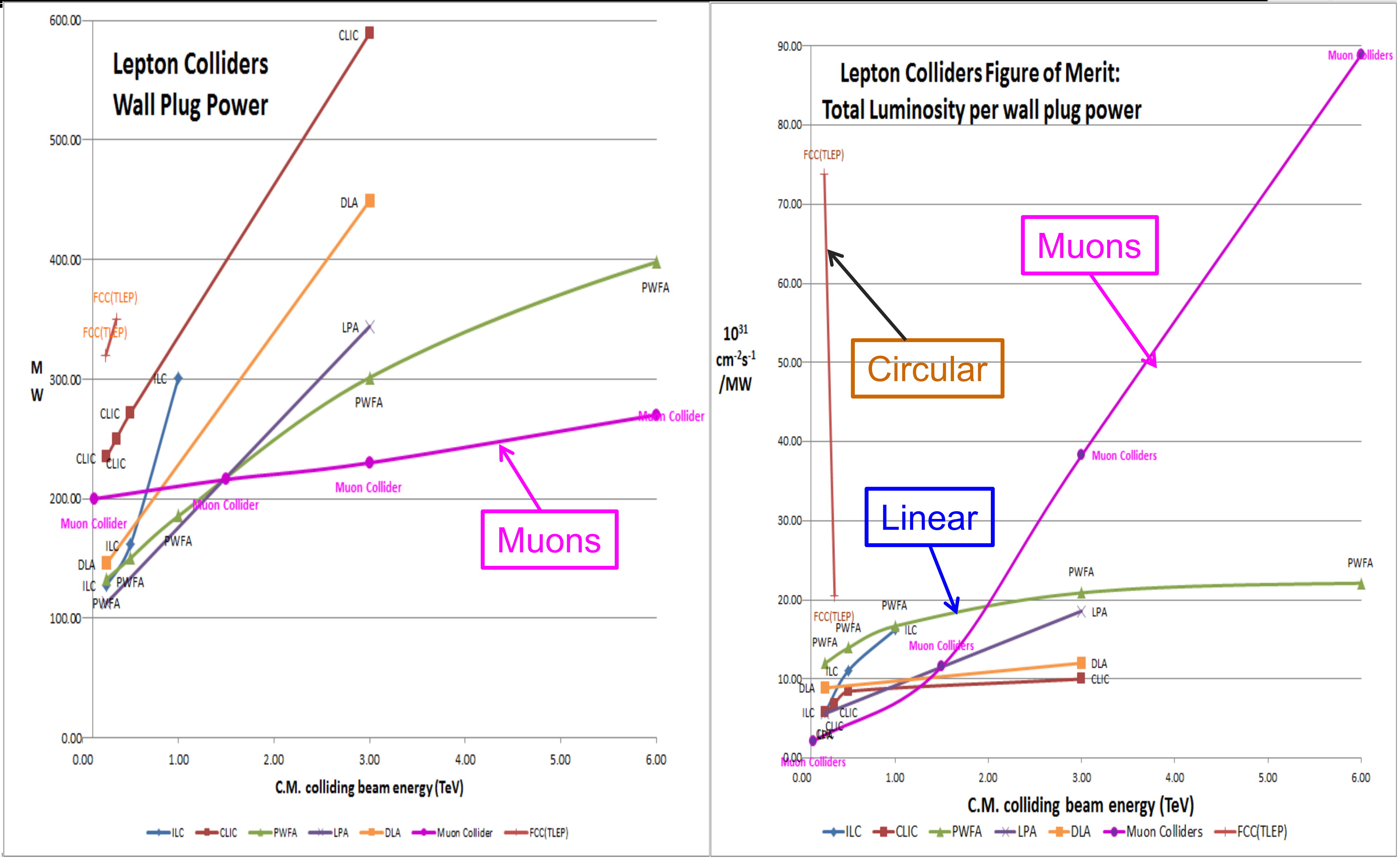


Muon Colliders potential of extending leptons high energy frontier with high performance





Muon Colliders extending leptons high energy frontier with potential of considerable power savings



Idea for low emittance μ beam

Conventional production: from **proton on target**

π, K decays from proton on target have 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 μ production point → **cooling** needed!

Novel proposal: **direct μ pair production: $e^+e^- \rightarrow \mu^+\mu^-$**

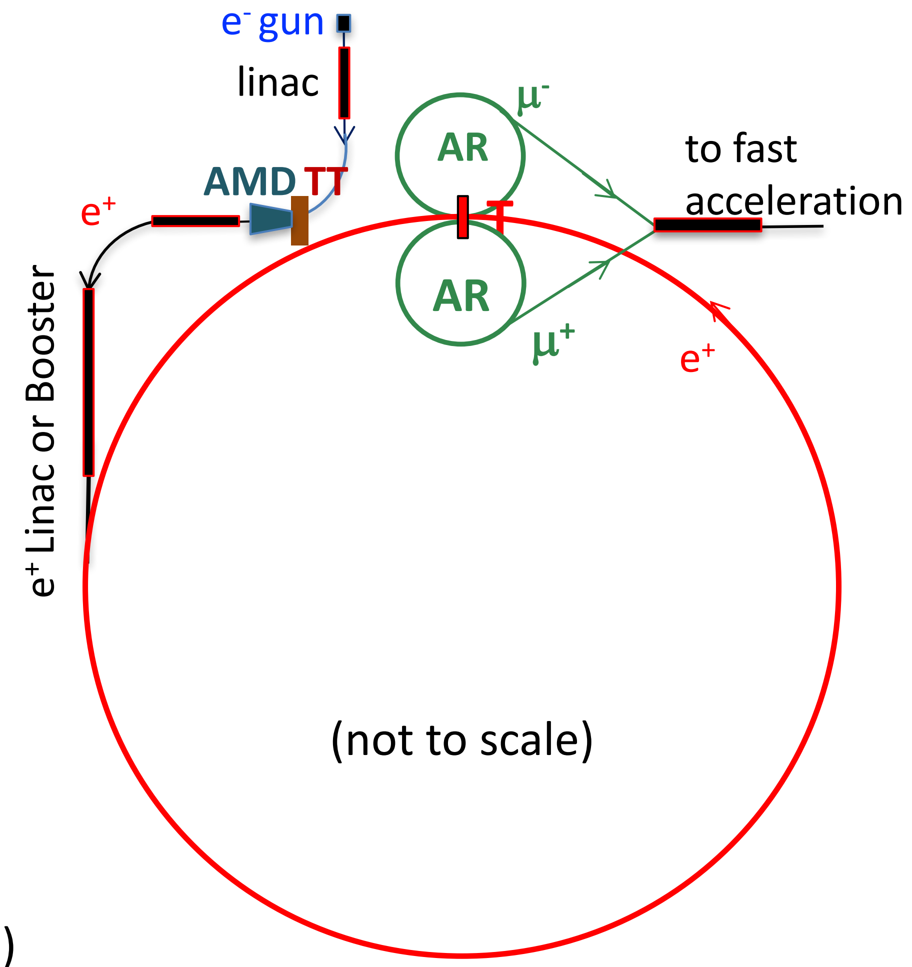
just above the $\mu^+\mu^-$ production threshold ($\sqrt{s} \approx 0.212$ GeV) with minimal muon energy spread, with direct annihilation of ≈ 45GeV e^+ with atomic e^- in a thin target O(0.01 radiation length)

very small emittance at μ production point→ **no cooling** needed!

Preliminary scheme for low emittance μ beam production

e+ ring parameter	unit	
Circumference	km	6.3
Energy	GeV	45
bunches	#	100
e^+ bunch spacing = T_{rev} (AR)	ns	200
Beam current	mA	240
N(e^+)/bunch	#	$3 \cdot 10^{11}$
U_0	GeV	0.51
SR power	MW	120

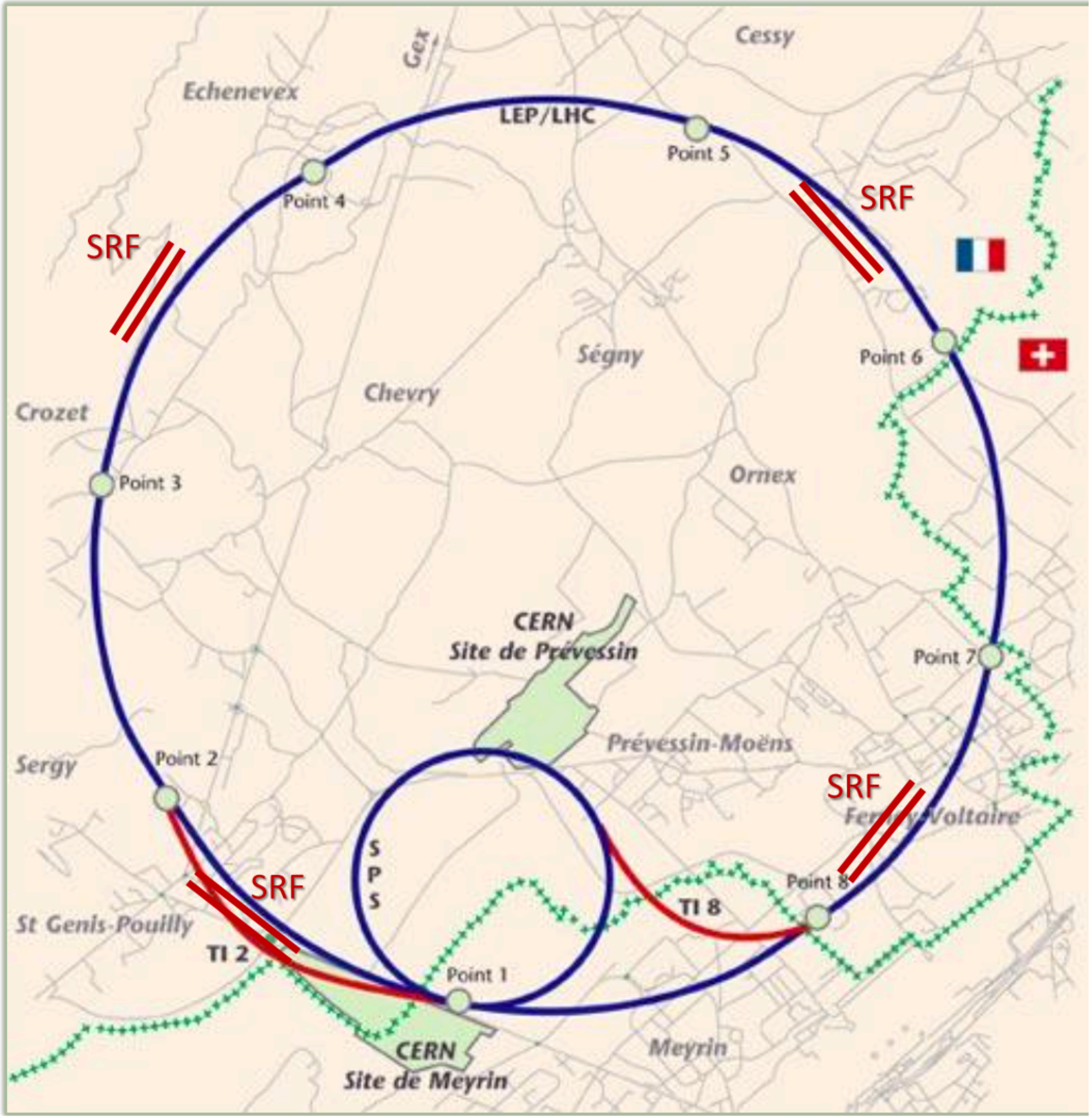
(also 28 km foreseen to be studied as an option)



CMC

CERN Muon Collider

- *14 TeV cm*
- *LHC tunnel*
- *SPS tunnel and mb PS*
- *~7GeV SRF*
- *pulsed magnets*
- ***cost ~LHC***



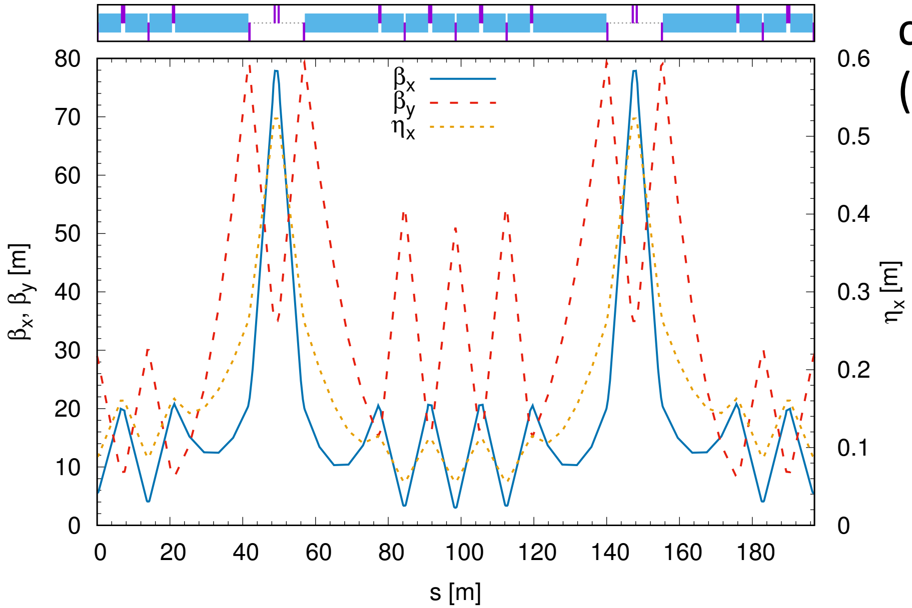
V. Shiltsev

Argomenti di tesi:

- **Beam dynamics (LNF, ESRF, Roma1)**
  - **Low emittance and high momentum acceptance 45 GeV e^+ ring**
  - **High momentum acceptance muon accumulator rings**
  - **Muon collider parameters**
  - **Beam recirculation test at DAFNE**
- **Target study (LNF, CERN, Roma1)**
  - **O(100 kW) class target in the e^+ ring for $\mu^+ \mu^-$ production**
  - **Target thermo-mechanical stresses tests**
- **Positron source (LNF, Mi, LAL, Roma1)**
  - **Positron production scheme**
  - **Collection, acceleration and injection system**
- **HEP Experiment(LNF, Roma1, Pd, Ts, Co, Pi):**
  - **Muon production: experiment @ H4 (July/August 2017), continue next year**

Low emittance 45 GeV positron ring

cell

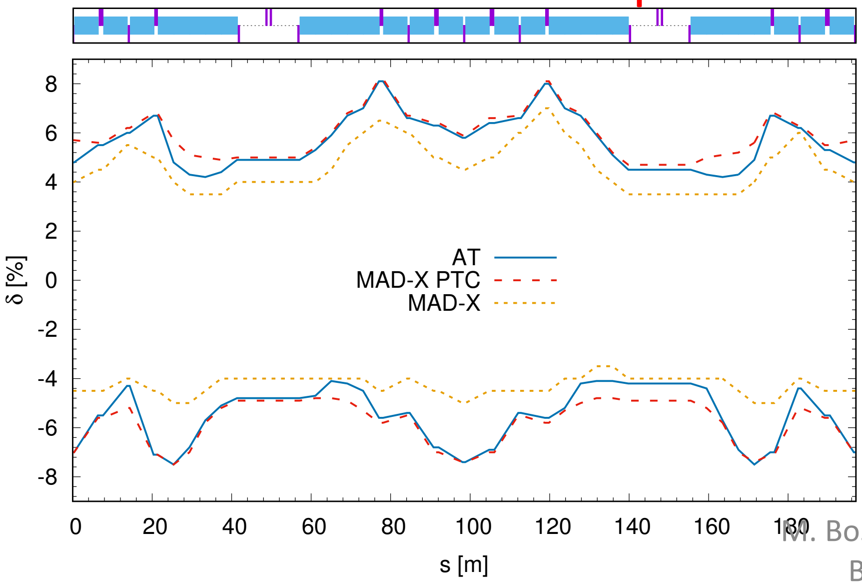


circumference 6.3 km: 197 m x 32 cells
(no injection section yet)

Table e+ ring parameters

Parameter	Units	
Energy	GeV	45
Circumference	m	6300
Coupling(full current)	%	1
Emittance x	m	5.73×10^{-9}
Emittance y	m	5.73×10^{-11}
Bunch length	mm	3
Beam current	mA	240
RF frequency	MHz	500
RF voltage	GV	1.15
Harmonic number	#	10508
Number of bunches	#	100
N. particles/bunch	#	3.15×10^{11}
Synchrotron tune		0.068
Transverse damping time	turns	175
Longitudinal damping time	turns	87.5
Energy loss/turn	GeV	0.511
Momentum compaction		1.1×10^{-4}
RF acceptance	%	± 7.2
Energy spread	dE/E	1×10^{-3}
SR power	MW	120

momentum acceptance

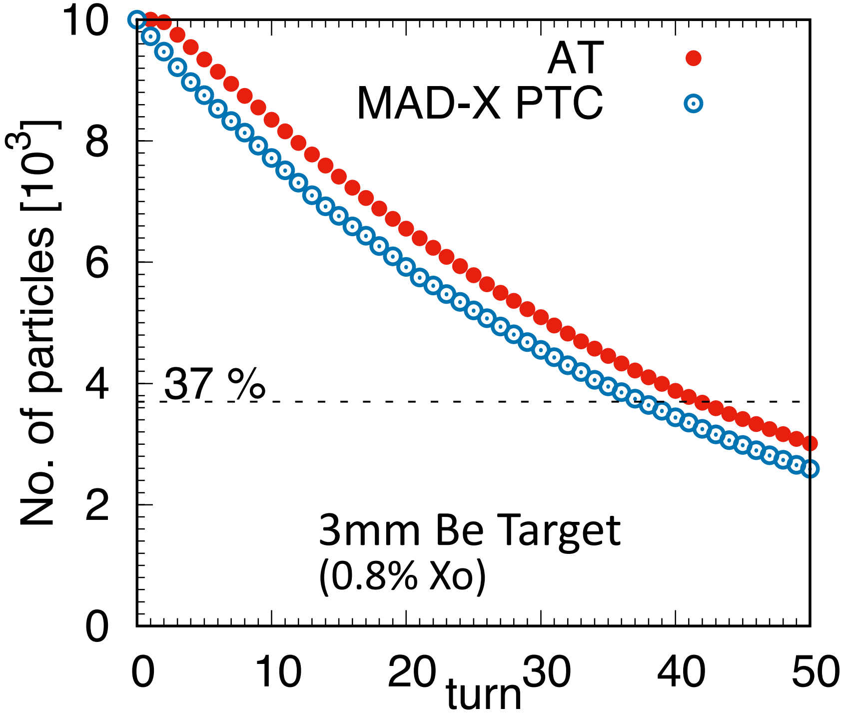


Physical aperture=5 cm constant

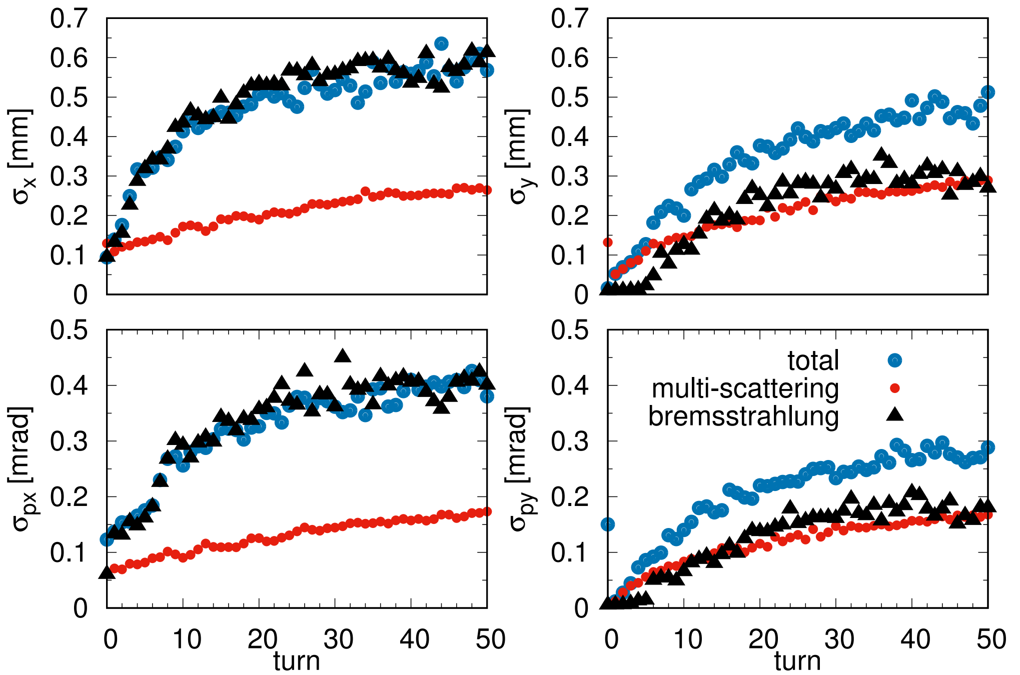
no errors

Good agreement between MADX PTC / Accelerator Toolbox, both used for particle tracking in our studies

e+ lifetime



3mm Be Target (0.8% Xo) at center of IR



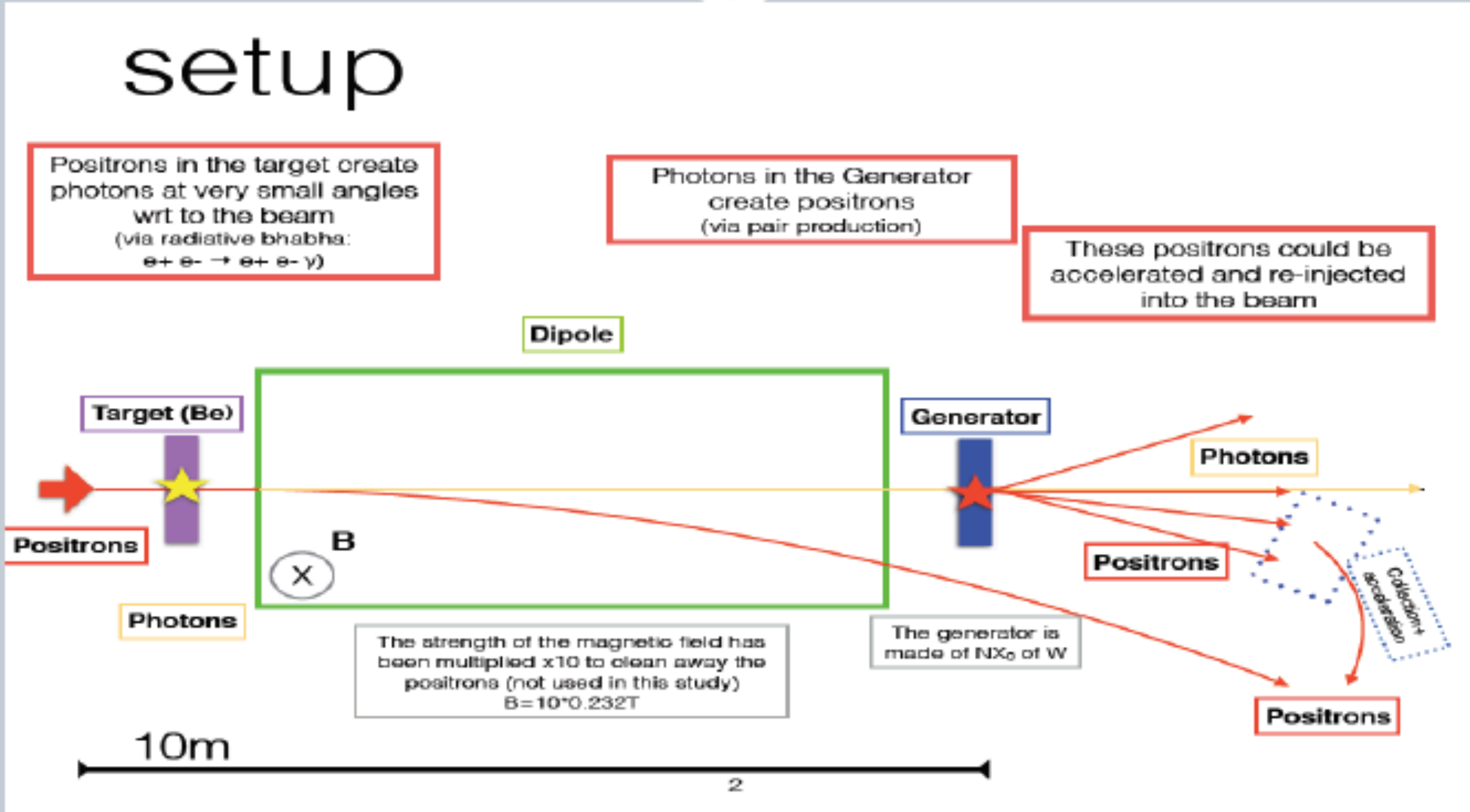
determined by **bremsstrahlung and momentum acceptance**

Lifetime with ~ 40 turns

agreement within 10%

2-3% e+ losses happen in the first turn

FOCUSING SYSTEMS FOR POSITRON SOURCES



Target considerations

Beam size as small as possible (matching various emittance contribution), but

- constraints for power removal (200 kW) and temperature rise
- to contrast the temperature rise

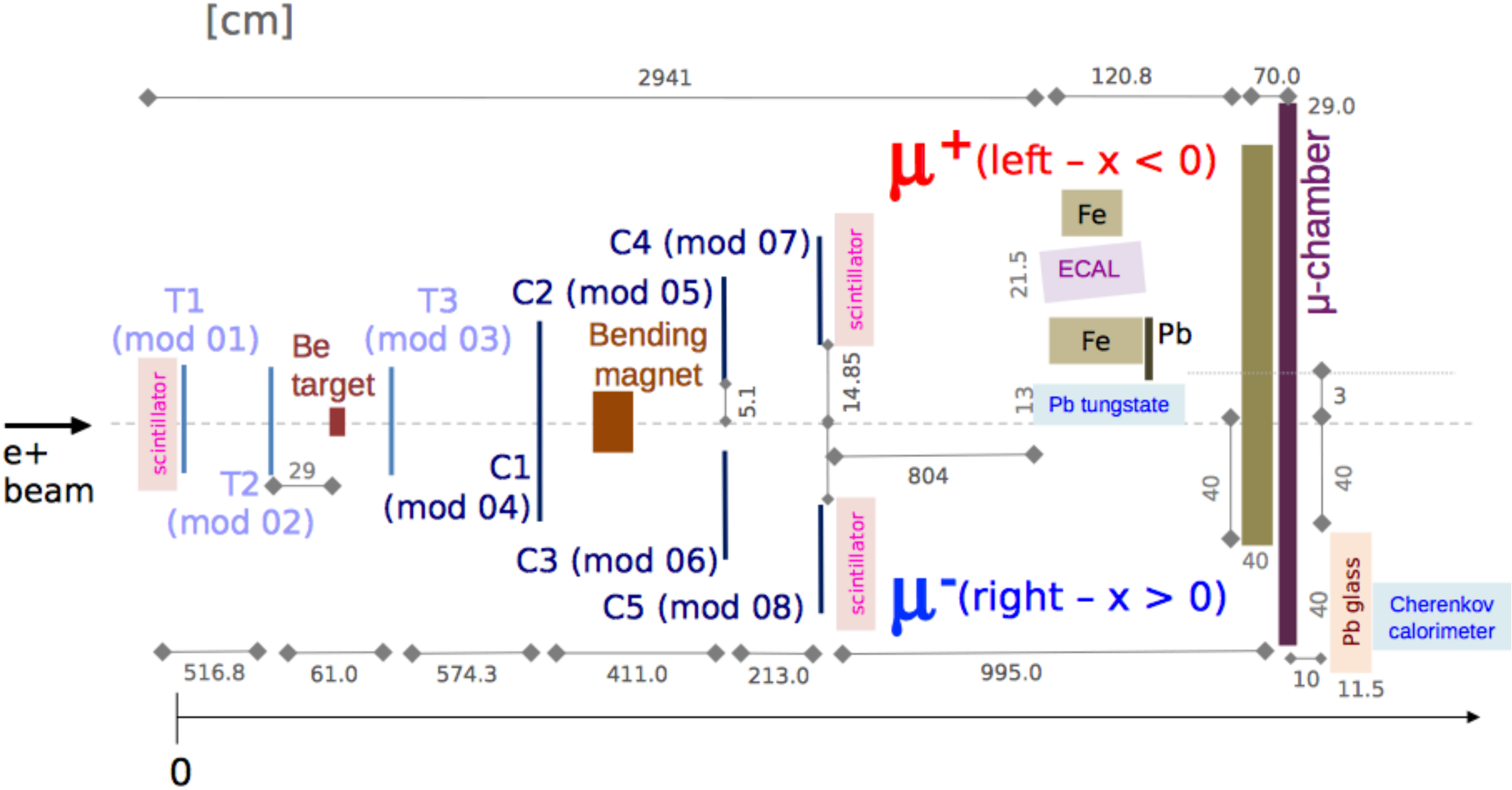
  move target (for free with liquid jet) and

  e^+ beam bump every 1 bunch muon accumulation

- **Solid target**: simpler and better wrt temperature rise
  - Be, C [Kavin Ammigan 6th High Power Targetry Workshop]
    - Be target: @HIRadMat safe operation with extracted beam from SPS, beam size 300 μm, N=1.7x10^{11} p/bunch, up to 288 bunches in one shot
- **Liquid** target: better wrt power removal (200kW)
  - Li, difficult to handle lighter materials (H, He)
    - LLi jets examples from neutron production, Tokamak divertor

(200 kW beam power removal seems feasible) , minimum beam size to be understood

EXPERIMENTAL SETUP



EXPERIMENTAL SETUP

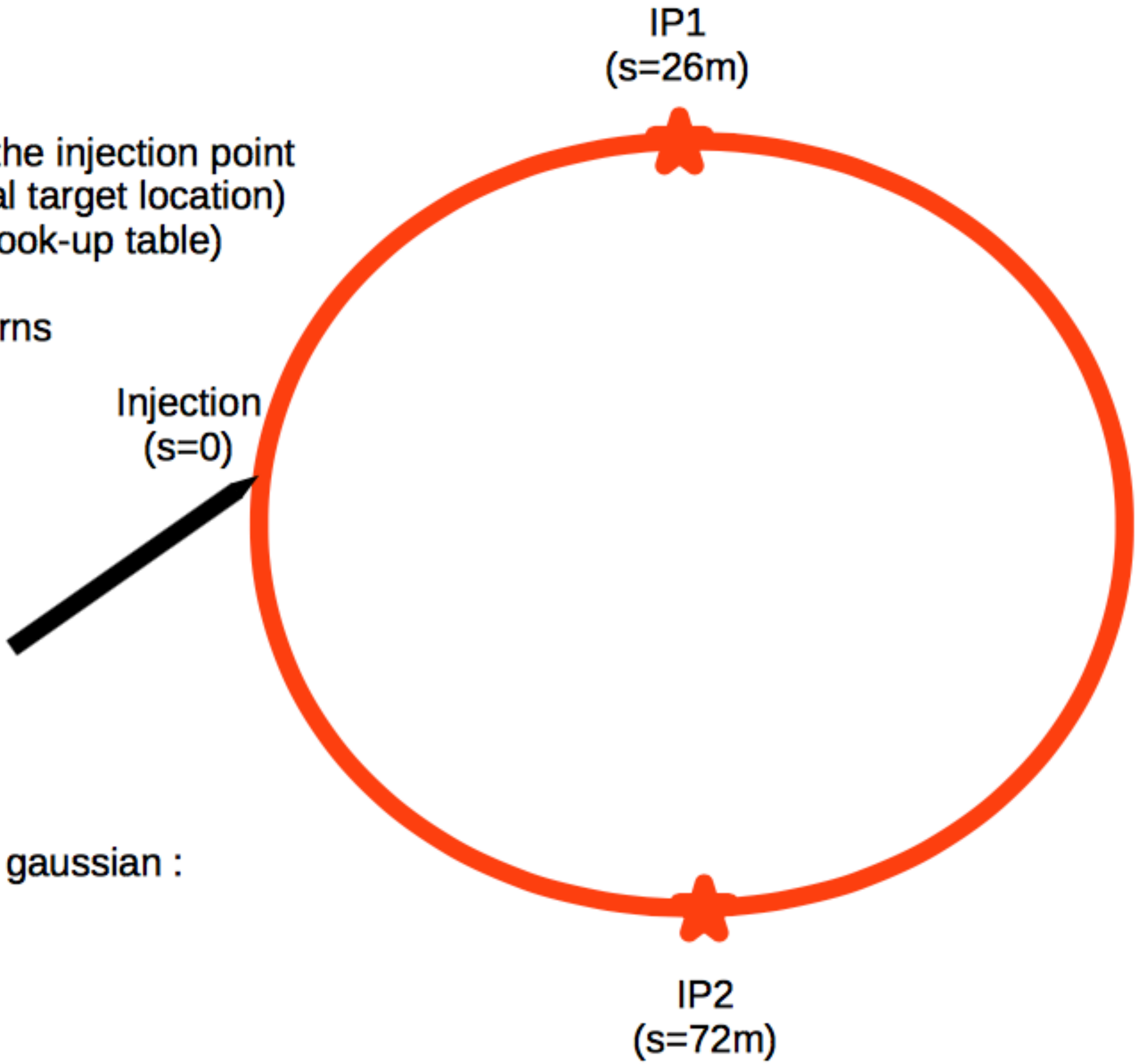
Test at storage ring: DAFNE

Tracking

1) We generate a beam at the injection point
2) We track to the IP1 (initial target location)
3) We simulate the target (look-up table)
4) We track back to the IP1
5) Repeat 3) and 4) for n turns

AT INJECTION :
betx 9.66173518
bety 1.159677223
dx -1.572838958

energy 0.51
ex 2.8e-07
ey 2.1e-09
et 1.6e-05
sigt 0.016
sige 0.001



At injection the beam is a gaussian :
$\sigma x = 1.6mm$
$\sigma y = 49um$
$\sigma s = 16mm$

Referenze e contatti

References:

- M. Boscolo et al, *"STUDIES OF A SCHEME FOR LOW EMITTANCE MUON BEAM PRODUCTION FROM POSITRONS ON TARGET "* **IPAC 2017**
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- M. Antonelli, *"Performance estimate of a FCC-ee-based muon collider"*, **FCC-WEEK 2016**
- M. Antonelli, M. Boscolo, R. Di Nardo, P. Raimondi, *"Novel proposal for a low emittance muon beam using positron beam on target"*, **NIM A 807 101-107 (2016)**
- P. Raimondi, *"Exploring the potential for a Low Emittance Muon Collider"*, in **Discussion of the scientific potential of muon beams workshop**, CERN, Nov. 18th 2015
- M. Antonelli, **Presentation Snowmass 2013**, Minneapolis (USA) July 2013, M. Antonelli and P. Raimondi, Snowmass Report (2013) also INFN-13-22/LNF Note

SLAC team:

L. Keller, J. P. Delahaye, T. Markiewicz, U. Wienands:

- *"Luminosity Estimate in a Multi-TeV Muon Collider using $e^+e^- \rightarrow \mu^+\mu^-$ as the Muon Source"*, MAP 2014 Spring workshop, Fermilab (USA) May '14
- Advanced Accelerator Concepts Workshop, San Jose (USA), July '14

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