Particle Colliders Under Active Development

- Energy frontier colliders under active design/development stage
  - Europe, Japan, China
- The goal of this talk is to briefly summarize status of these activities
- European high energy physics strategy planning process

Dmitri Denisov, Fermilab

Medium Term Colliders Projects Under Development

- **ILC - International Linear Collider**
  - 250 GeV linear e^+e^- collider (recent option has “staging” with second stage at 500 GeV)
  - Higgs factory (and top quark factory after upgrade)
  - Location – Japan. Start of construction ~2019? Estimated cost ~$6B.
- **CepC – Circular Electron Positron Collider**
  - ~380 GeV circular e^+e^- collider (the tunnel could be later used for pp collider)
  - Higgs factory and top factory
  - Location – China. Start of construction ~2021. Estimated cost ~$5B
- **FCC – Future Circular Colliders**
  - 350 GeV e^+e^- and/or ~100 TeV pp and HE-LHC
  - Higgs factory and/or next energy frontier
  - Location – CERN. Start of construction - ? Estimated cost - ?
- **CLIC – Compact LInear Collider**
  - 380 GeV linear e^+e^- collider (with potential upgrade up to 2 TeV)
  - Higgs factory and top factory
  - Location CERN. Start of construction - ? Estimated cost $6B.

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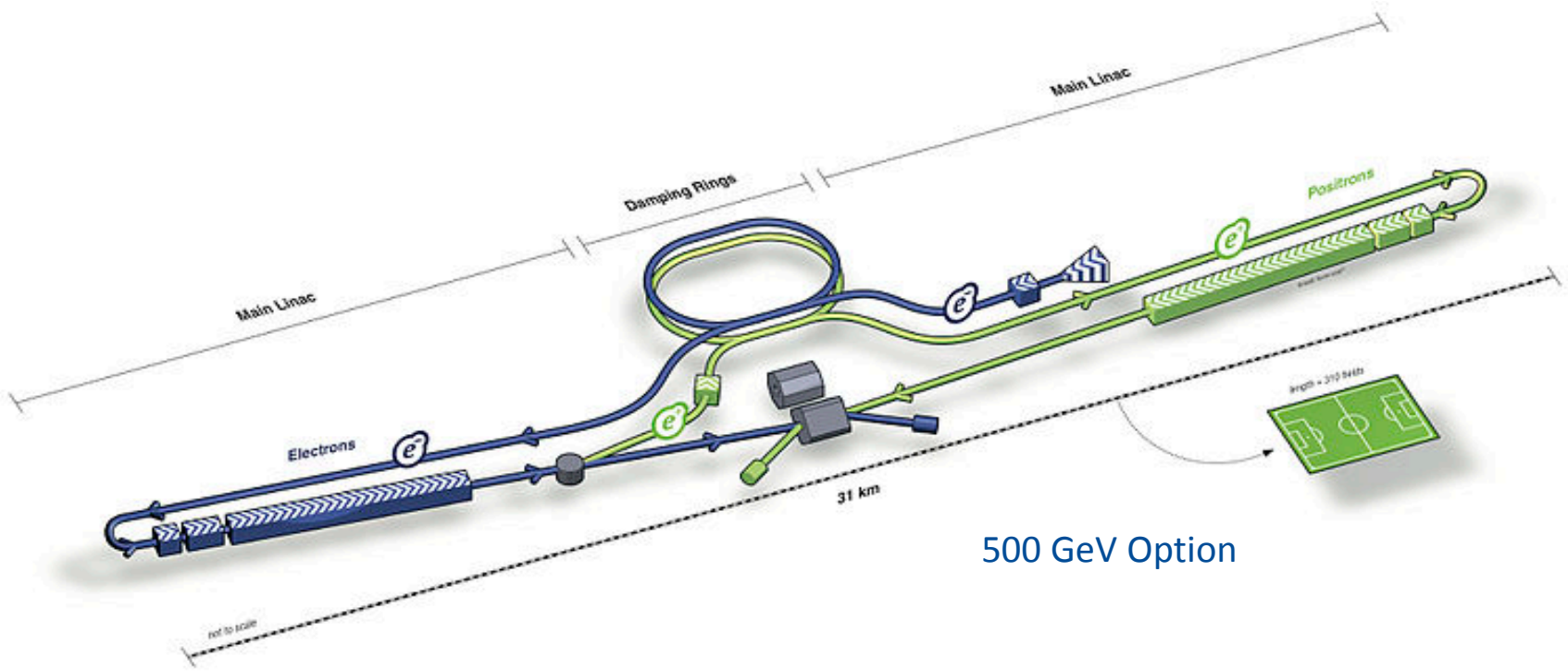
International Linear Collider



500 GeV Option

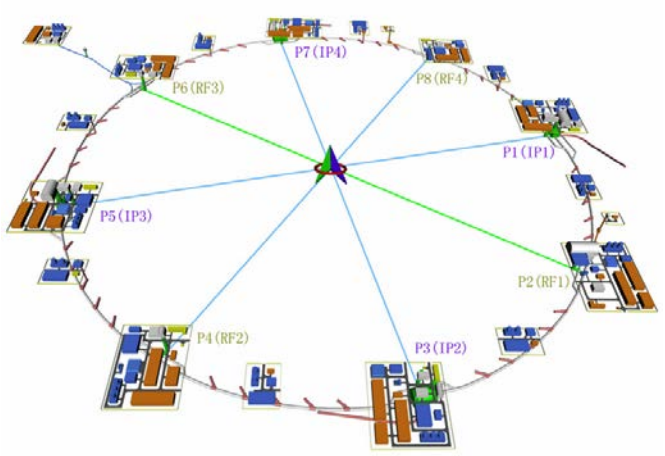
- ILC is e^+e^- linear collider based on superconducting RF technology
  - Center of mass energy 250 GeV (enough to produce Higgs in ZH final state)
  - Luminosity $>10^{34}\ cm^{-2}s^{-1}$
- Long tunnel to accelerate to ~125 GeV/beam with ~31 MV/m rate
  - Colliding point-like particles
  - Excellent Higgs factory with many Higgs production and decay channels accessible

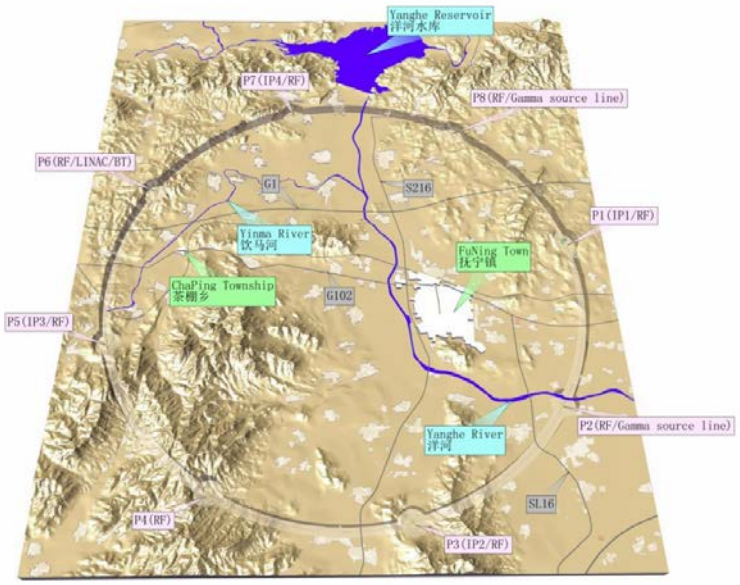
ILC Status and Plans

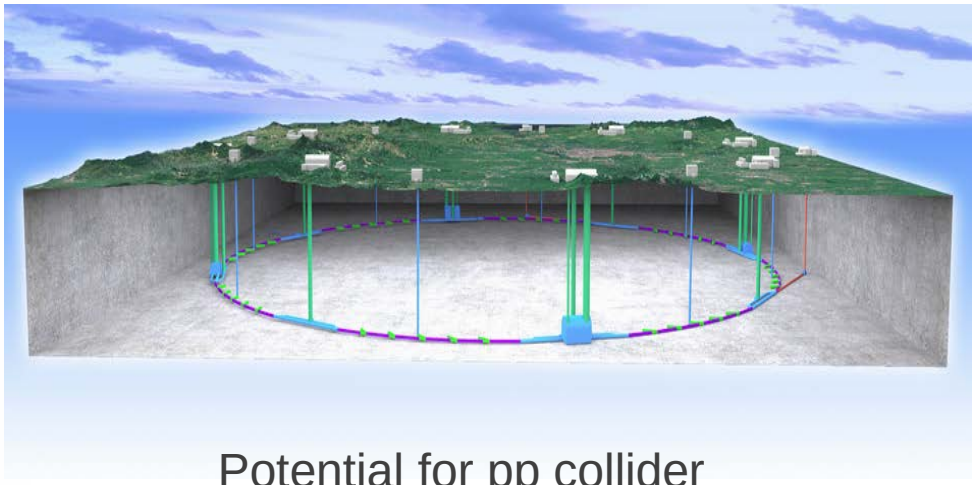
- Starting in 2008 Global Design Effort (GDE) progressed developing
  - Technical design of the ILC
  - Cost estimate and international cooperation plan
- GDE concluded in 2012
  - Including designs for the accelerator and detectors
  - Physics case strengthened with the Higgs discovery
- In 2012 Japan expressed strong interest to host the ILC
- Over last four years
  - Substantial progress in the accelerator developments
  - Development of cooperation between Governments
- All involved agree that ILC project should be international project with Japan as the host country
  - Over last ~4 months decided to stage the design
    - Start from ~250 GeV with initial cost of ~$6 billion
  - Decision by Japan expected before the end of 2018

Proposal for Collider in China: CepC

- CepC – Circular Electron Positron Collider
  - 100 km long ring
    - Increase in comparison with original proposal
  - 90-250-380 GeV in the center of mass
  - Z boson, Higgs and top factory
- Main technologies
  - Low field magnets, superconducting RF



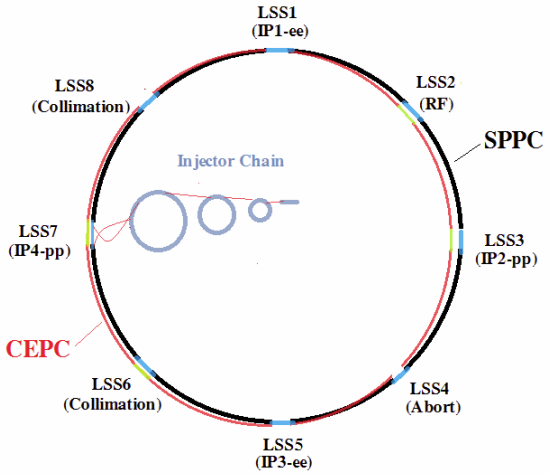




Potential for pp collider
in the same tunnel with 100 TeV

Future Collider in China

- Active progress with design over last two years
  - International reviews (positive) of the conceptual proposals in Spring of 2015
- Plan is to get funding for detailed technical design report
  - ~$50 million per year effort
  - Completed by ~2020
- Construction to start in 2021
  - Completed in ~2027
  - Data collection 2028-2035
- The proposal is based on
  - Experience with existing e^+e^- collider in China
  - Relatively inexpensive tunneling in China
  - Strong Chinese Government interest in scientific leadership
- Recent development
  - Increase ring length to ~100km and reach ~380 GeV



FCC – Future Circular Colliders at CERN

- FCC activity follows European particle physics strategy recommendation to develop future energy frontier colliders at CERN
  - "…to propose an ambitious post-LHC accelerator project….., CERN should undertake design studies for accelerator projects in a global context,…with emphasis on proton-proton and electron-positron high-energy frontier machines.…."

- There are three options in ~100 km long tunnel
  - pp collider with energy of ~100 TeV
  - e^+e^- collider with energy of ~350 GeV
  - ep collider

- Similar to "LEP then LHC" option of starting from 350 GeV e^+e^- collider and later going to 100 TeV pp collider is considered
  - But in no way decided
- There is also an option to double LHC energy (HE-LHC) with ~16 T magnets
  - Also part of FCC program

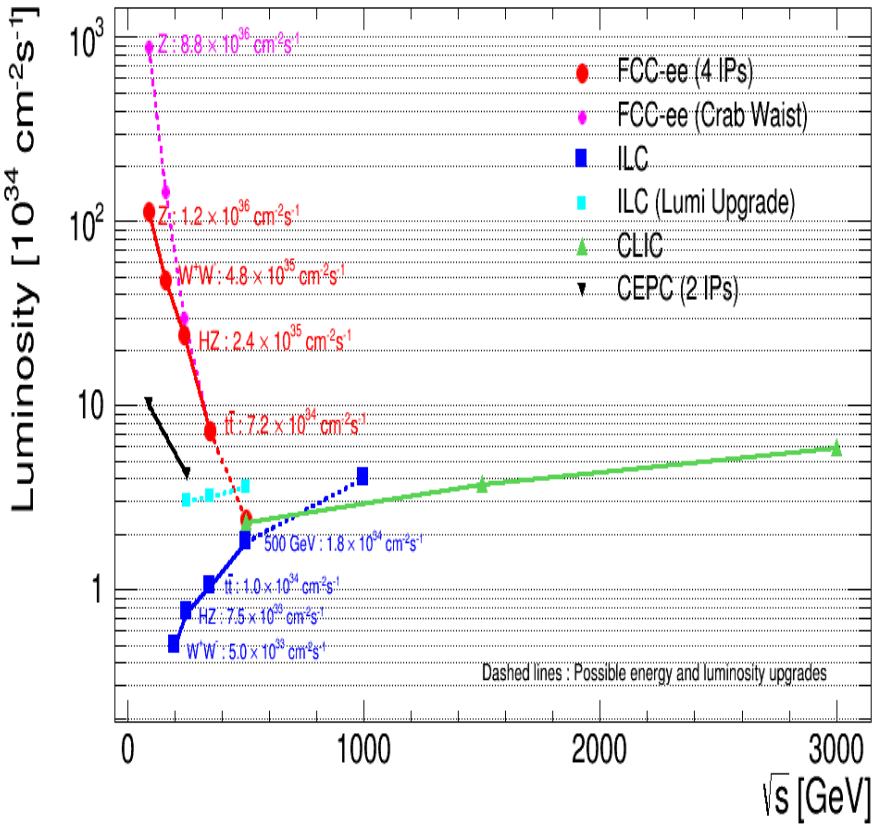
CERN's pp 100 TeV collider

Parameter	FCC-pp	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}	5 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

- Main challenges
  - Long tunnel, high field magnets, high synchrotron radiation load (yes for pp collider…)
- Tevatron and LHC experience demonstrate feasibility of such a collider

FCC study is expected to finish by the end of 2018 as an input to the next European Strategy discussion and to provide technical proposals and cost estimates for all three options: pp, ee and ep

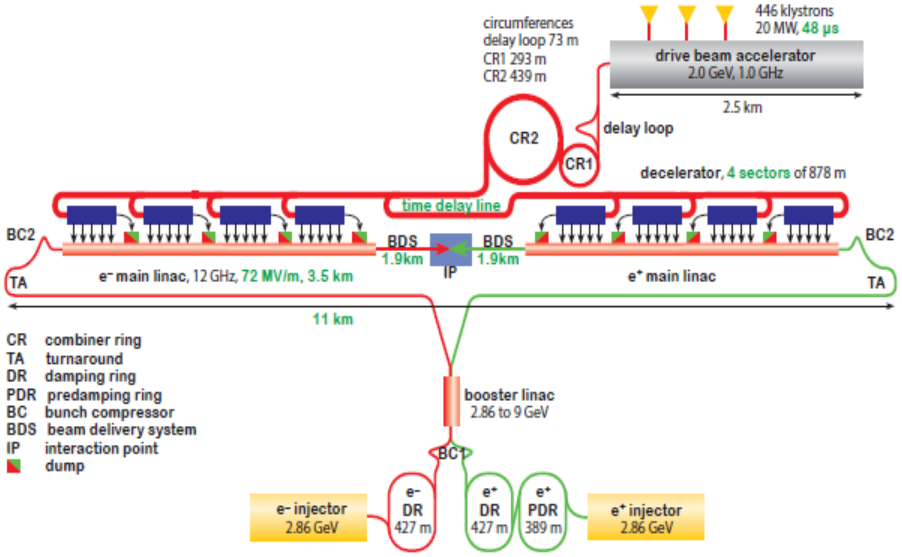
FCC e^+e^- Collider

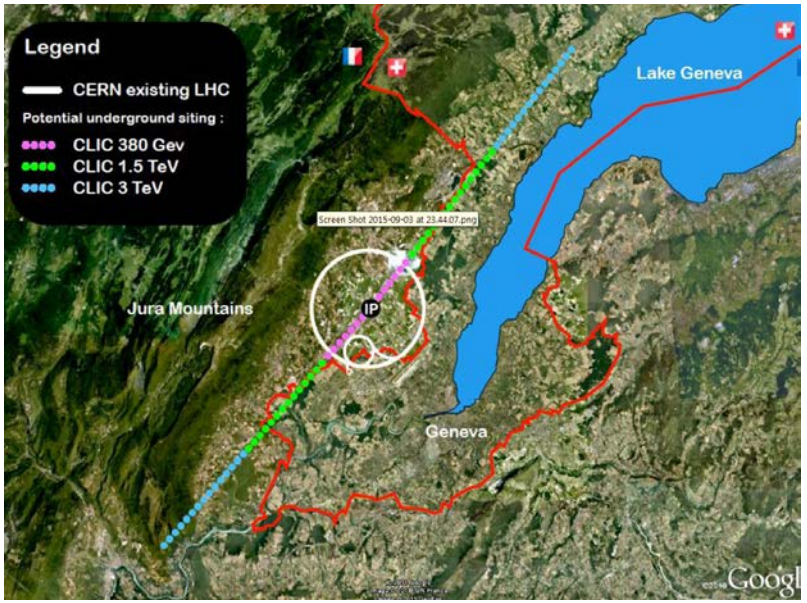


Parameter	FCC-ee			LEP2
Energy/beam [GeV]	45	120	175	105
Bunches/beam	13000-60000	500-1400	51- 98	4
Beam current [mA]	1450	30	6.6	3
Luminosity/IP x 10^{34} cm^{-2}s^{-1}	**21 - 280**	**5 - 11**	**1.5 - 2.6**	0.0012
Energy loss/turn [GeV]	0.03	1.67	7.55	3.34
Synchrotron Power [MW]	100			22
RF Voltage [GV]	0.3-2.5	3.6-5.5	11	3.5

- Circular e^+e^- collider designed on successful LEP experience
- With 350 GeV center of mass – Z, Higgs and top factory
- Main challenges: long tunnel and high synchrotron losses requiring demanding superconducting RF system and high power consumption

CLIC Collider at CERN





- CLIC is linear e^+e^- collider based on "warm" RF technology with 70+ MV/m acceleration
  - The only way to get to multi-TeV e^+e^-
- 11km long for 380 GeV in the center of mass
- Under active design development

Parameter	Unit	380 GeV	3 TeV
Centre-of-mass energy	TeV	0.38	3
Total luminosity	$10^{34}cm^{-2}s^{-1}$	1.5	5.9
Luminosity above 99% of √s	$10^{34}cm^{-2}s^{-1}$	0.9	2.0
Repetition frequency	Hz	50	50
Number of bunches per train		352	312
Bunch separation	ns	0.5	0.5
Acceleration gradient	MV/m	72	100
Site length	km	11	50

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Next European Strategy Timeline

- European particle physics community, lead by CERN, is poised to develop program beyond current HL-LHC
- Currently expected timeline
  - By end of 2018 proponents of various projects should finish their preliminary developments, including technical feasibility and estimated cost
  - During 2019 community wide discussions about option(s) to select
  - Spring of 2020 CERN council will provide recommendations for the next European strategy
- We expect that Japan and China will make the decisions about hosting ILC and CepC before European strategy concludes
- At this moment the expectation is that in 2020 the number of future options for CERN will be reduced, while it might be that the choice of the project(s) will be done a few years later
  - After more detailed technical and cost estimates are finalized
- Next US Snowmass/P5 process will probably start after European strategy is announced
  - Preparations for the process are the main reason for our discussions