Towards a Staged ILC – Options and Questions

Some thoughts triggered by Omori-San's Questionnaire

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Benno List
DESY –IPP–

ILC@DESY Project Meeting
24.1.2014

HELMHOLTZ GEMEINSCHAFT

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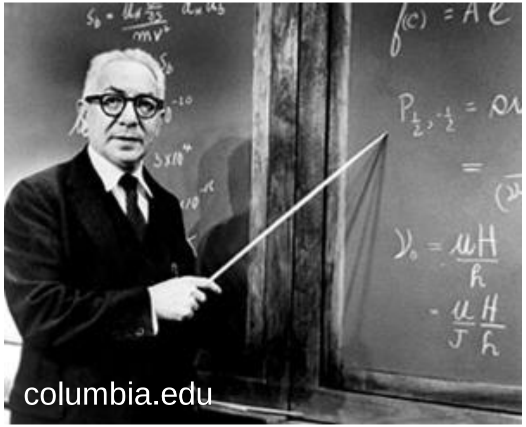
Introduction

- Common wisdom: Start ILC at 250GeV, build tunnel for 500, plan for 1TeV
- Based on proposal by JAHEP in Oct. 2012
  http://www.jahep.org/office/doc/201202_hecsubc_report.pdf
  http://www.jahep.org/office/ doc/201210_ILC_staging_e.pdf
- Motivation: Start with the minimal configuration useful for Higgs physics
- Don't look a gift horse into the mouth, but…
- … can / should one tweak the 250 or 500 a bit?
- Which configuration matches the physics goals of the ILC best?



"Who ordered that?"
I. Rabi, 1937

Proposal for Phased Execution of the ILC Project

The Japan Association of High Energy Physicists (JAHEP) accepted the recommendations of the Subcommittee on Future Projects of High Energy Physics[1] and adopted them as JAHEP's basic strategy for future projects, in March 2012. Later in July 2012 a new particle consistent with a Higgs Boson was discovered at LHC, while in December 2012 the Technical Design Report of the International Linear Collider (ILC) will be completed by the worldwide collaboration.

On the basis of these developments and following the subcommittee's recommendation on ILC, JAHEP proposes that ILC shall be constructed in Japan as a global project based on agreement and participation by the international community in the following scenario:

(1) Physics studies shall start with precision study of "Higgs Boson" and will evolve into studies on top quark, "dark matter" particles, and Higgs self-couplings, by upgrading the accelerator. A more specific scenario is as follows:

(A) A Higgs factory with a center-of-mass energy of approximately 250 GeV shall be constructed as a first phase.

(B) The machine shall be upgraded in stages up to a center-of-mass energy of ~500 GeV, which is the baseline energy of the overall project.

(C) Technical extendability to a 1 TeV region shall be secured.

ILC = Global Project

(2) A guideline for shares of the construction costs is that Japan covers 50% of the expenses (construction) of the overall project of a 500 GeV machine. The actual shares, however, should be left to negotiations among the governments.

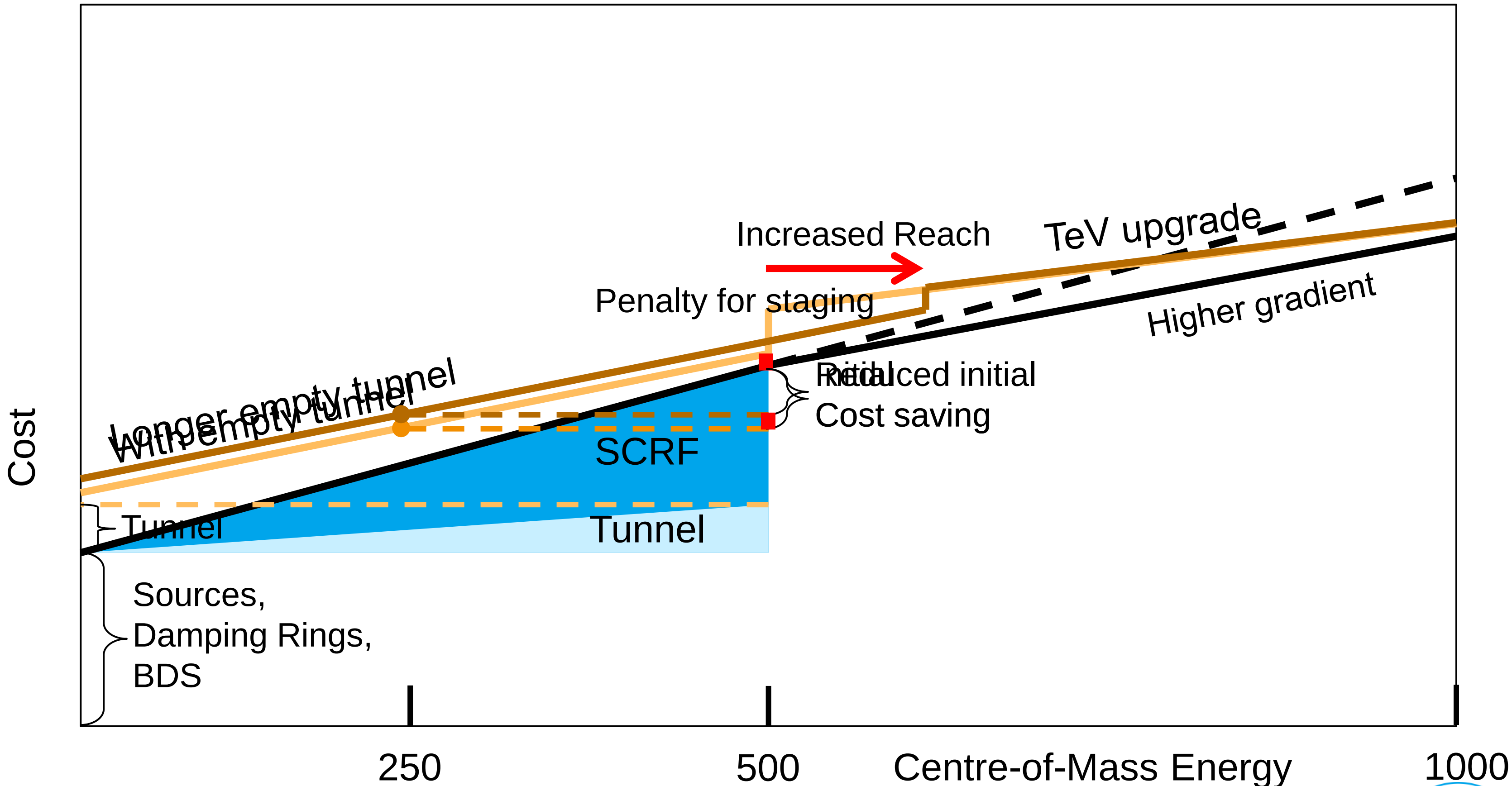
(a translation of the official JAHEP statement, Oct 2012)

lide: Toshi Mori, at LCWS 12, Arlington, TX
AHEP statements: http://www.jahep.org/office/doc/201202_hecsubc_report.pdf
pdate: http://www.jahep.org/office/ doc/201210_ILC_staging_e.pdf

A Misconception

- A common misconception from the circular collider days:
  Even a little more energy costs a lot of money and watts,
  and reduces performance (lumi, beam lifetime, availability)
- This is not true for a linear collider!
- At a linear collider:
  a little more energy costs a little more money and a little more watts,
  at equal or improved performance (lumi goes up with E_beam)
- For a helical undulator source:
  Around its design threshold energy, higher (“drive” beam) energy drastically improves performance (more production margin)
- This means: The best operating energy for a Linear Higgs Factory is **not necessarily** “as close to threshold as possible”, in contrast to a circular machine!
  -> 270GeV may be easier than 235GeV

The motivation for staging



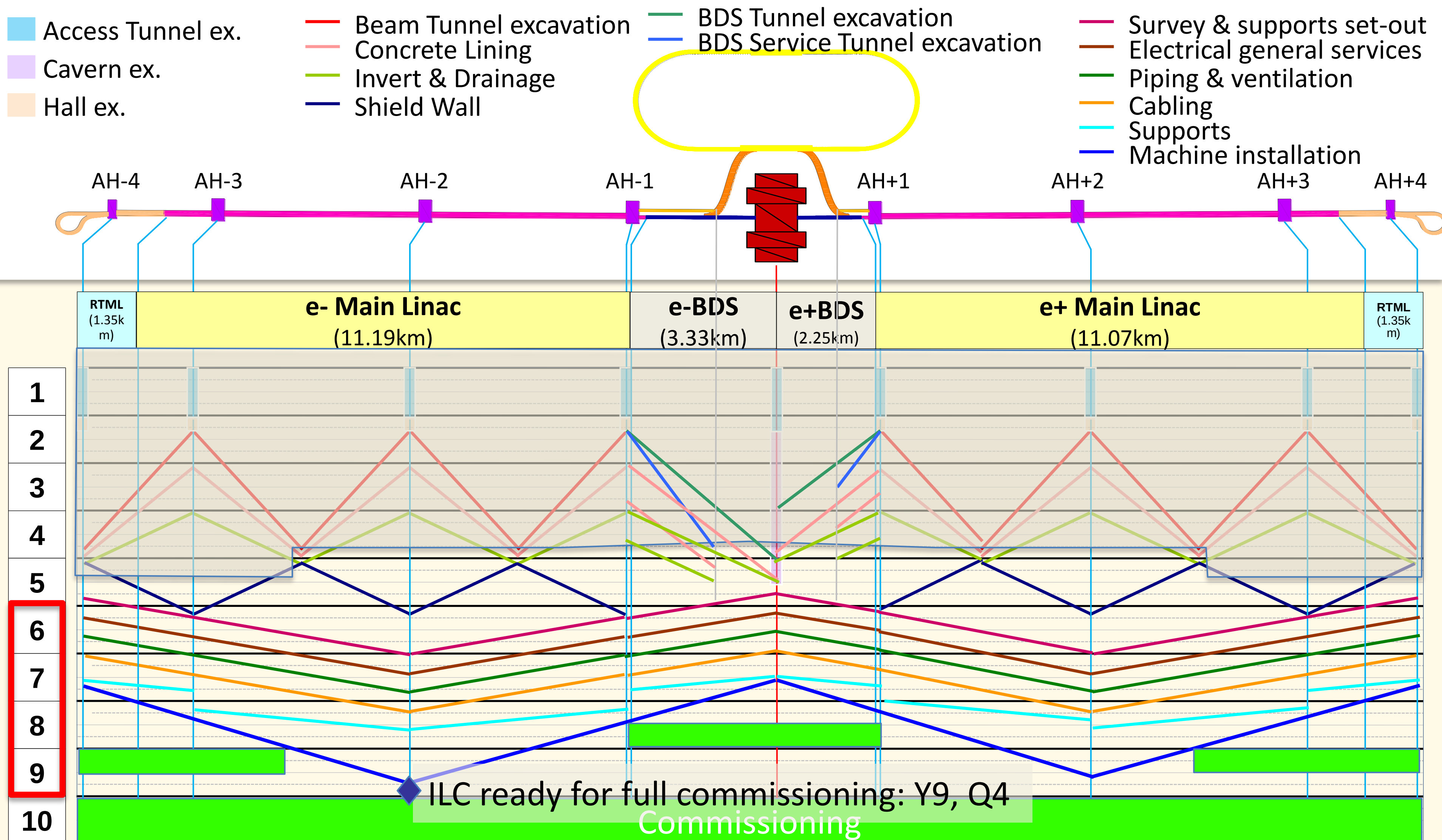
How much empty tunnel? For 500 GeV?

- Common wisdom: We start at 250GeV and build enough tunnel for 500.
- “Excuse me, I am not convinced.” (Joschka Fischer, Munich, 8.2.2003)
- In 2006, 500 was as good as any number between 200 (LEP2) and 1000 (too expensive)
- Today, 500GeV is just a bit to small to do good tth physics

- The good news: Empty tunnel is relatively cheap! In a staged scenario, it would be much easier to plan for more, e.g. 550 or 600 GeV, compared to a plan to build the full machine at once

Additional Motivation for Staging: Cryomodule Production / Schedule

- Construction time is unlikely to change much (<12months), because experimental hall and experiments require time
- But CM installation work is reduced -> reduces risk
- And CM production rate can be reduced
  -> reduces risk, and may save some money: need less cavity and CM production infrastructure, can amortize infrastructure over longer time / more parts
  -> unit cost might go down in real terms: real savings in total cost!
  - but mind inflation
- But this benefit may needs continued cavity/CM production after first stage, otherwise prizes will not go down, may even go up



Access Tunnel ex.
Cavern ex.
Hall ex.
Beam Tunnel excavation
Concrete Lining
Invert & Drainage
Shield Wall
BDS Tunnel excavation
BDS Service Tunnel excavation
Survey & supports set-out
Electrical general services
Piping & ventilation
Cabling
Supports
Machine installation
AH-4
AH-3
AH-2
AH-1
AH+1
AH+2
AH+3
AH+4
RTML (1.35km)
e- Main Linac (11.19km)
e-BDS (3.33km)
e+BDS (2.25km)
e+ Main Linac (11.07km)
RTML (1.35km)
1
2
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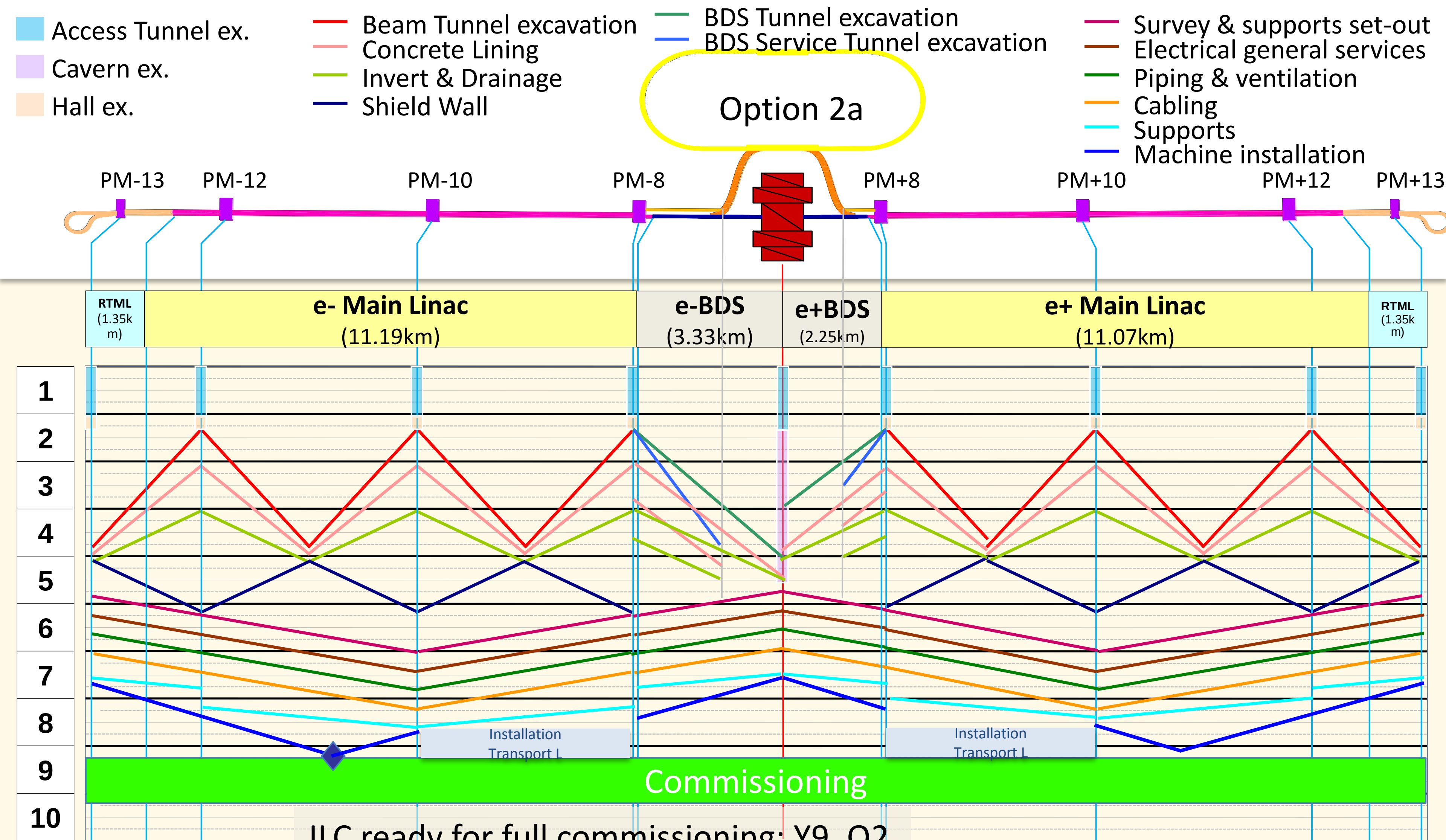
ILC ready for full commissioning: Y9, Q4
Commissioning


Access Tunnel ex.
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Option 2a
Survey & supports set-out
Electrical general services
Piping & ventilation
Cabling
Supports
Machine installation
PM-13
PM-12
PM-10
PM-8
PM+8
PM+10
PM+12
PM+13
RTML (1.35km)
e- Main Linac (11.19km)
e-BDS (3.33km)
e+BDS (2.25km)
e+ Main Linac (11.07km)
RTML (1.35km)
1
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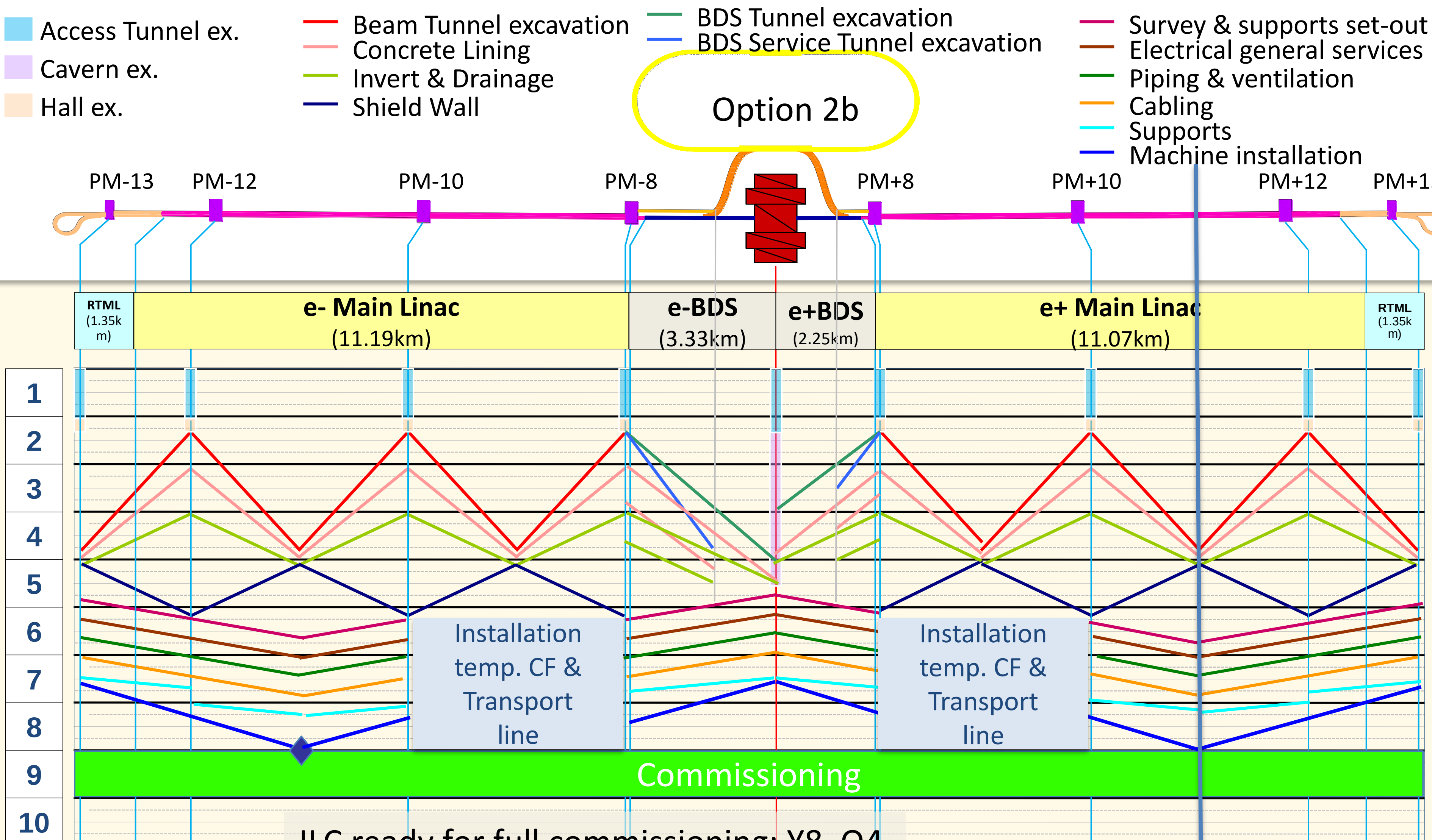
Installation Transport L
Installation Transport L
Commissioning
ILC ready for full commissioning: Y9, Q2

Option 2b



ILC ready for full commissioning: Y8, Q4

Plan for a first stage only, or the complete machine?

- Do we order all cryomodules at once (makes them cheaper)?
- Do we continue CM production at approximately constant rate after first stage?
- Or does one stop component production after the first stage,
  - At the risk of never starting it again…
  - With an increased cost per unit (vendors have to write off their equipment earlier)
  - But: at a reduced cost that needs to be pledged by funding agencies initially

A plan is needed. Soon.

- Definition of stages needs to be worked out by experimentalists together with accelerator people
- Experimentalists say what they need (and what not!)
- Accelerator people say what can be built, in which time and at which cost
- Needs also input from funding agencies a.k.a. politics: What is conceivable

How was the scope for the baseline defined?

- The Heuer panel defined the scope of the ILC project in 2003, with an update in 2006
- These parameters were never revisited to account for
  - The Higgs discovery
  - The LHC results in general (no SUSY yet)
  - The anticipated cost and performance of the machine, as found in the TDR
  - The timeline of a (now) conceivable ILC project in Japan in parallel to LHC at CERN
  - The Japanese political/financial situation
  - A staged approach

A new Parameters Panel?

- A new Parameters Panel would
  - Have a common charge from LCC and Japan if possible
  - Be endorsed by the physics community to represent the experimentalists
  - Include accelerator experts to explain the pros and cons
  - Seek/heed advice what is politically feasible
- We need a parameter set for the accelerator that matches the physics case. Any external review (JSC!) will look at this first!
- Time is running: Anything that “looks” like a consensus can hardly be revised later. The 250GeV first stage is an example.
- The international community (LCC) needs to form its opinion now, instead of waiting for Japan to ask (does not happen), or criticize them later (must not happen)

One Approach: Omori-San's Questionnaire
(as presented by Sabine Riemann on Jan 10)

Low energy operation of undulator based e+ source

Issues: Physics

(1) Do we need scan at Ecm = 208 – 240 GeV?
(2) Do we need Z-pole (Ecm = 91 GeV) running (Giga-Z)?
(3) Do we need running at W-pair production (Ecm = 161 GeV)?

Options: Accelerator

(1) Do not employ 10Hz operation. Employ 230m undulator. (Andriy)
We can make initial and operation cost reduction.
Do we give up Giza-Z, W-pair, and 208 – 240 GeV? -> If No ->

(a) Add 10Hz later.
-> Change all refrigerators and modulators (Klystron PSs).
Very expensive additional investment, not realistic.

(b) Apply 2.5+2.5 Hz operation.
-> We can go to any low energy with 1/2 luminosity.

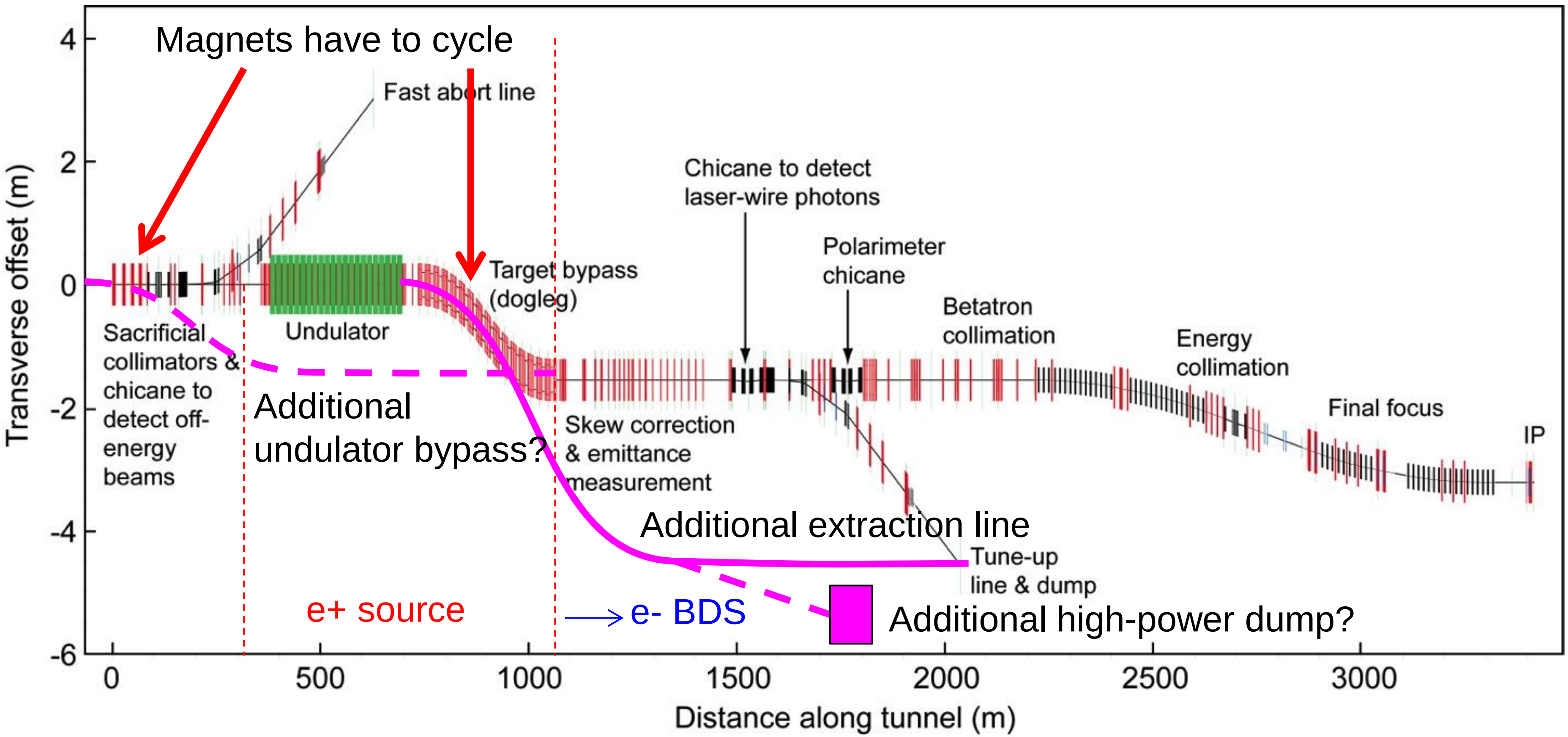
(2) Employ 10Hz operation. Employ 147m undulator. (RDR solution)
We can make low energy running at Ecm = 91, 161, 208-240 GeV.

(3) Employ 10Hz operation. Employ 230m undulator.
We can make operation cost reduction, but slightly higher initial cost.
We can make low energy running at Ecm = 91, 161, 208-240 GeV.

What is "10Hz" Operation?

- Run alternating e- beams at 150GeV (for e+ production) and lower energy (for physics): 5Hz + 5Hz = 10Hz
- At a 2x250GeV machine, there is enough cryo power to allow doubling the ML rate when running at reduced gradient (beam energy)
- 10Hz scheme requires additional modifications:
  - More RF power and wigglers in the damping rings, for shorter damping time (included in baseline)
  - More complicated target bypass dogleg design, with variable field dipoles, an extra extraction line, possibly an extra dump (foreseen, but no design available, not costed)
  - More than 1/3 of the beam power are used only for e+ production!
- For a <u>staged machine</u> operating at full gradient at 125GeV beam energy, the 10Hz-scheme **doubles the necessary cryogenic power** in the e- ML -> either provide more cooling power per cavity than for full machine, or reduce the rate

Modifications for 10 Hz at Positron Source



Operation at low CM energy: below 2x undulator threshold

- Assume we build an undulator long enough so that we can run at 125GeV e- beam energy (at IP) -> gives 250GeV CM
- 3 ways to go below 250GeV:
  - Run undulator at low energy: loses e+ intensity, but may work to E_{beam}=110GeV or so
  - Run with alternating e- beams for physics and e+ production ("10Hz scheme"): works to any energy, wastes a lot of electricity
    - caveat: for a staged machine, running at full gradient at 125GeV, 10Hz may be too much, maybe only 5-6 Hz are possible
  - Running with asymmetric beam energies, reduce only e+ beam energy to get lower Ecm = sqrt (2*E(e-)*E(e+)): may work, lumi performance needs some studies
    - caveat: CM system is boosted, may not be nice for asymmetry measurements (Z0!) or calibration purposes
    - but might work well for WW and Zh thresholds (small boost, no interest in asymmetries)

Remarks on Omori-Sans Transparencies

(as presented by Sabine Riemann on Jan 10)

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We can make low energy running at Ecm = 91, 161, 208-240 GeV.

Two distinct issues:
Giga-Z and Z^0 runs for calibration!

Seems to mean that 10Hz would not be possible initially

- Modulators and klystrons are no problem
- Couplers need to be modified for 10Hz
- Cryo plants needed for 500GeV operation would be enough -> doable
- Needs more RF and wigglers in DR -> doable
- Needs space for addt'l extraction lines / dumps!

Only if extraction lines / dumps exist!

Issue is not so much 5+5 vs 2.5+2.5, but:
Can one do alternating e+ production and physics beams at all?

Option (c): Reduce only e+ beam energy.
Does that work for Z^0 calibration?

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Questions to the Physics Community

- No need to wait for committees, panels, etc; just work out your favourite physics scenario
- For each potential energy step (250, 350, 400, …) define
  - The physics goal(s)
  - The luminosity required to reach that goal
  - How that lumi changes with Ecm and δE – define a "quality factor" for lumi
  - At which point does "saturation" set in
- Give priorities, distinguish textbook measurements (spin?) from measurements that advance science (CP-odd admixture? Branching ratios/couplings?)

Minimum and Maximum useful integrated Luminosity

- At any given energy step, there may be
  - a minimal amount of integrated luminosity necessary to fulfill a physics goal,
  - and a maximal amount, after which results do not improve significantly anymore
- Only specific physics cases require staying at an energy:
  -> but for how long???
  - Higgs recoil mass measurement – are 250fb^{-1} really needed?
  - Top threshold scan – 10 x 10fb^{-1}?
  - W threshold scan - Very little???
- Others profit from energy increase:
  - Higgs branching ratios

Luminosity Quality Metric

- To develop a sensible running scenario, one needs a **metric** that says how much is a fb^{-1} worth to you at a given energy (and beam parameters such as energy spread, disruption parameter)
- Define your metric as a quality factor q for the luminosity, such that for a given observable O the error is
  $\delta O = \delta O_0 / \sqrt{(q\ L/L_0)}$,
  where δO_0, L_0 are the error and luminosity at a standard set of conditions
- The machine people can contribute the cost ($) and time (T) to reach an integrated luminosity L at a given running scenario
- With this experimental input, the machine can be laid out such that a given physics result δO can be reached in minimal time / at minimal cost -> this is also a political issue (trade running and investment costs)

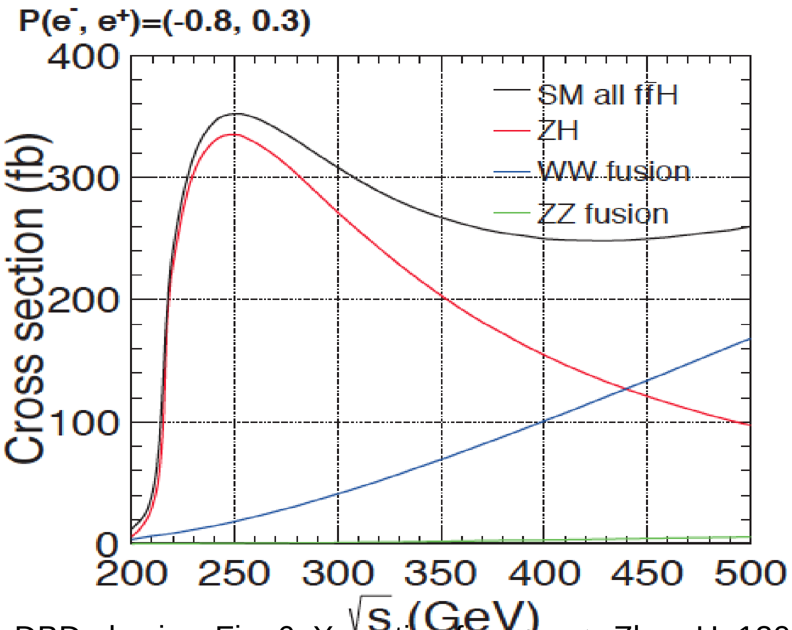
More precisely: 250 GeV stage

- What are the physics goals at 250GeV?
  - Higgs recoil mass measurement
  - Absolute ZH coupling, absolute Higgs width
  - Higgs branching ratios (but: can be done better at higher energy)
- How much integrated lumi is needed at 250 GeV?
  - Determined by ZH coupling and Higgs width measurement
- How does that depend on Ecm and δE?
  - Recoil measurement resolution deteriorates above 240GeV, cross section is maximal at ~260 GeV -> need to multiply benefit-per-lumi times lumi-per-$ to find optimum
  - Investigate how benefit-per-lumi changes with energy spread
  - Optimal parameters need to be balanced between recoil measurement and other topics (branching ratios) where more lumi and energy is always better

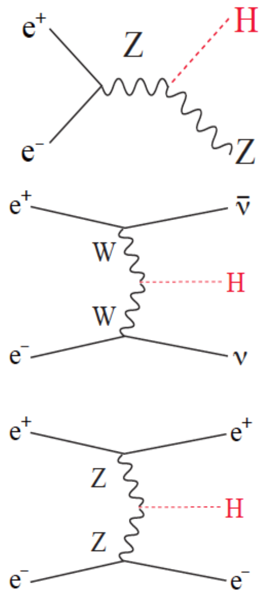
The hZ Peak Region

Difficult interplay between

- **Machine performance (may degrade below 250 GeV)**
- **Cross section**
- **Kinematics:**
  Higgs recoil mass best determined if Higgs is almost at rest



DBD physics, Fig. 6, X-section for e+e- -> Zh, mH=120GeV

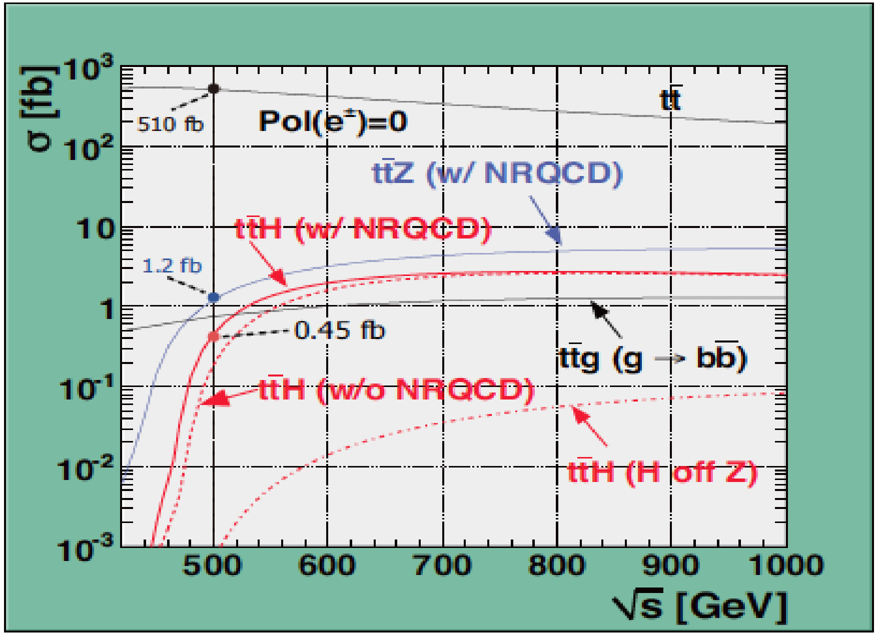


350 GeV – 400GeV stage

- What are the physics goals?
  - Top mass from threshold scan
  - Top properties – which ones?
  - Continued Higgs physics
- How much lumi is needed?
  - 10 points with $10fb^{-1}$ each for top threshold scan around 350GeV
  - The move to ~400 GeV for top + Higgs physics
- How does top and Higgs physics depend on Ecm?
  - Higher Ecm gives boost – better jet pairing etc
  - Cross sections rise
  - Again: need quantitative input to find best machine operating point

"500GeV" Stage

- What is the next reasonable energy to run?
- Top-Higgs-Coupling: threshold at 475GeV, maximum around 800GeV
- 550 or 600 looks **much** better than 500GeV



DBD physics, Fig. 13, X-section for e+e- ->tth mH=120GeV

CME	sigma	% of max
500	0.36fb	15%
550	1.34fb	55%
600	2.01fb	82%
800	2.44fb	100%

X 3.7!!

Farrell & Hoang, PR D72 (2005) 014007:
(mh=120, mt=180)

Giga-Z

- Remember: Giga-Z is not part of the baseline, i.e. it was deliberately taken out by the Heuer panel in 2006
- New undulator position and 10Hz scheme allow operation at Z0, but this is not very efficient. Lumi is unclear
- To bring back "Giga-Z" requires a physics case that convinces a new panel, and needs study of a technical solution
- Z0 physics has not changed since 2006
- But importance of indirect precision measurements may have changed in the absence of BSM particle signals at LHC
- Giga-Z is very difficult for undulator source; 10Hz scheme would mean that about 60% of beam power are used only for e+ production ☹
- Giga-Z probably needs a dedicated machine upgrade (new source)

Running at 160GeV

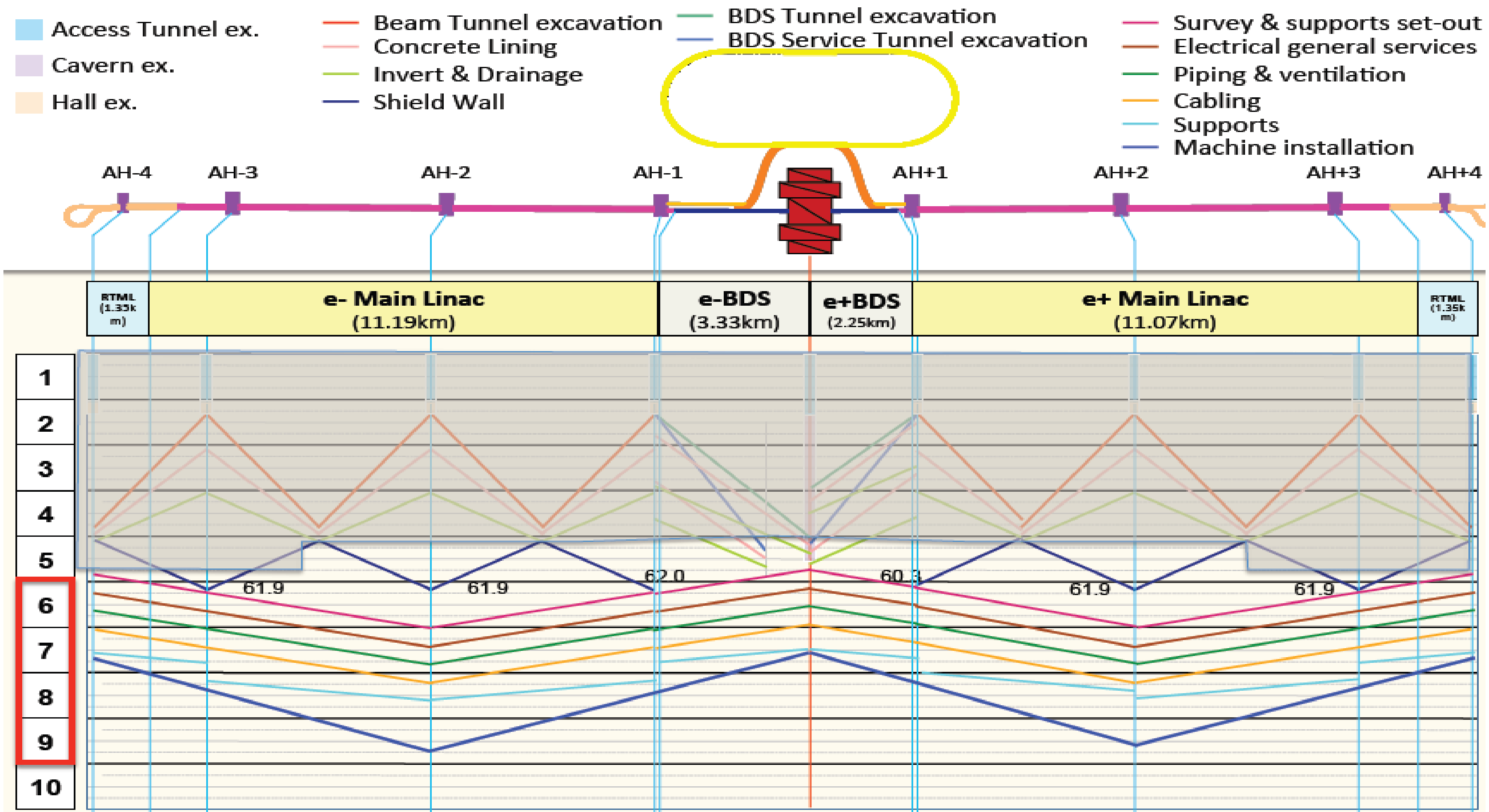
- Measurement of W mass by threshold scan at 160 GeV
- Why didn't we do that better at LEP1.5???
- Can it be done better? (Energy calibration?)
- How much lumi would be needed? (At LEP1.5, it was a few pb^{-1})
- Although 160GeV is officially below the baseline energy range of 200-500GeV, running for short time at 160GeV is certainly possible if lumi requirements are low
- -> 160GeV is probably a non-issue

Conclusions

- The relationship between the physics goals of the ILC and the proposed accelerator needs to be (re)defined in view of Higgs, LHC, Japan
- Everybody can contribute by making studies that quantify how much physics one gets per fb^{-1} at a given CM energy, energy spread, polarization
- Lets stay realistic, don’t hope for a 800GeV tunnel as first stage

Backup

Schedule for 500 GeV Machine



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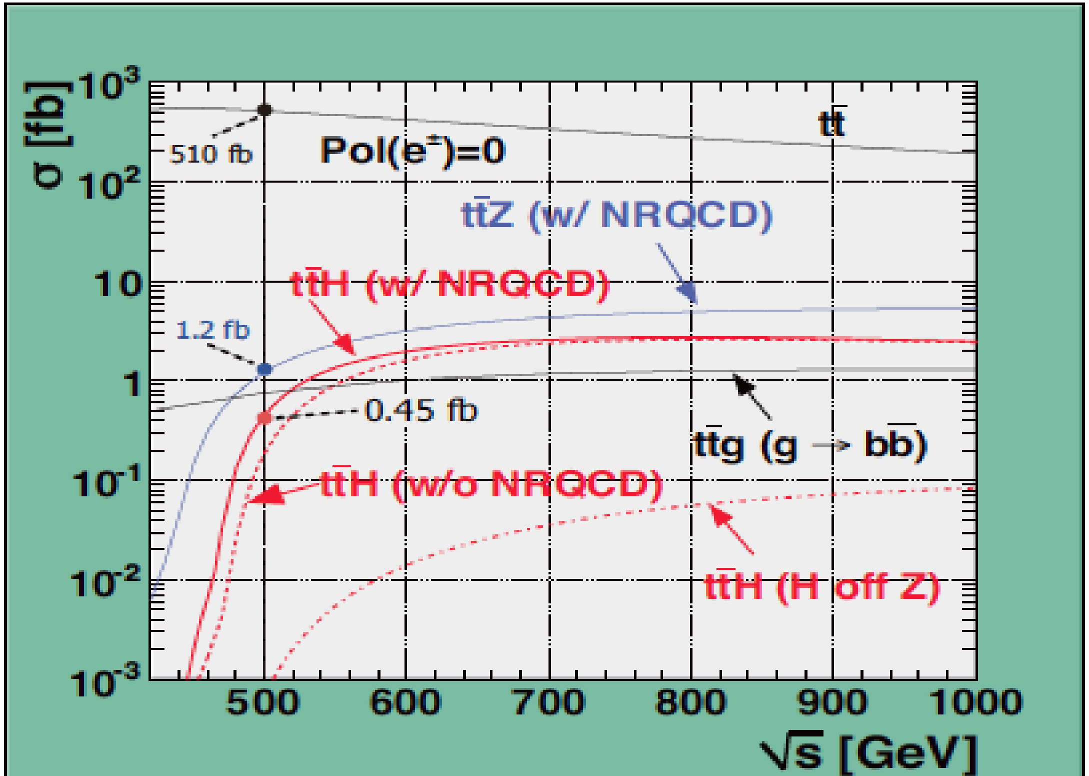
Running at low (<= 300GeV) energy

- What is the minimum electron energy needed?
  Defines initial electron linac length, operation scheme (5 or 10Hz), undulator length (is a special undulator needed for low energy running?)
  - Does one ever want to run at 100 x 100 GeV for 200GeV CME? NO!
  - Does one want to run at 117.5 x 117.5 GeV for 235GeV?
    Or is an asymmetric configuration as good?
    Or should one run at 250GeV???
  - Where is the best CME for the Higgs recoil mass measurement? (needs metric)!
  - Does one need a Higgs threshold scan at 215GeV???
- How long does one really want to spend on ~235 GeV?
  It makes a big difference whether it is 2 years, or 4-5.
- What about a W mass threshold scan? Is this a high-priority item, or can it be done towards the end of the physics program?

tth cross section



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X 3.7!!

ILC Published Parameters

Centre-of-mass independent:

Luminosity Upgrade

Collision rate	Hz	5	
Number of bunches		1312	2625
Bunch population	$\times 10^{10}$	2	
Bunch separation	ns	554	366
Pulse current	mA	5.8	8.8
Beam pulse length	ms	730	960
RMS bunch length	mm	0.3	
Horizontal emittance	µm	10	
Vertical emittance	nm	35	
Electron polarisation	%	80	
Positron polarisation	%	30	

http://ilc-edmsdirect.desy.de/ilc-edmsdirect/item.jsp?edmsid=D00000000925325

ILC Published Parameters

Centre-of-mass dependent:

Centre-of-mass energy	GeV	200	230	250	350	500
Electron RMS energy spread	%	0.21	0.19	0.19	0.16	0.12
Positron RMS energy spread	%	0.19	0.16	0.15	0.10	0.07
IP horizontal beta function	mm	16	16	12	15	11
IP vertical beta function	mm	0.48	0.48	0.48	0.48	0.48
IP RMS horizontal beam size	nm	904	843	700	662	474
IP RMS veritcal beam size	nm	9.3	8.6	8.3	7.0	5.9
Vertical disruption parameter		20.4	20.4	23.5	21.1	24.6
Enhancement factor		1.83	1.83	1.91	1.84	1.95
Geometric luminosity	$\times 10^{34}$ $cm^{-2}s^{-1}$	0.25	0.29	0.36	0.45	0.75
Luminosity	$\times 10^{34}$ $cm^{-2}s^{-1}$	0.50	0.59	0.75	0.93	1.8
% luminosity in top 1% DE/E		92%	90%	84%	79%	63%
Average energy loss		1%	1%	1%	2%	4%
Pairs / BX	$\times 10^{3}$	41	50	70	89	139
Total pair energy / BX	TeV	24	34	51	108	344

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Higgs Factory

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Centre-of-mass energy	GeV	200	230	250	350	500
Electron RMS energy spread	%	0.21	0.19	0.19	0.16	0.12
Positron RMS energy spread	%	0.19	0.16	0.15	0.10	0.07
IP horizontal beta function	mm	16	16	12	15	11
IP vertical beta function	mm	0.48	0.48	0.48	0.48	0.48
IP RMS horizontal beam size	nm	904	843	700	662	474
IP RMS veritcal beam size	nm	9.3	8.6	8.3	7.0	5.9
Vertical disruption parameter		20.4	20.4	23.5	21.1	24.6
Enhancement factor		1.83	1.83	1.91	1.84	1.95
Geometric luminosity	$\times 10^{34}$ $cm^{-2}s^{-1}$	0.25	0.29	0.36	0.45	0.75
Luminosity	**$\times 10^{34}$ $cm^{-2}s^{-1}$**	**0.50**	**0.59**	**0.75**	**0.93**	**1.8**
% luminosity in top 1% DE/E		92%	90%	84%	79%	63%
Average energy loss		1%	1%	1%	2%	4%
Pairs / BX	$\times 10^3$	41	50	70	89	139
Total pair energy / BX	TeV	24	34	51	108	344

http://ilc-edmsdirect.desy.de/ilc-edmsdirect/item.jsp?edmsid=D00000000925325