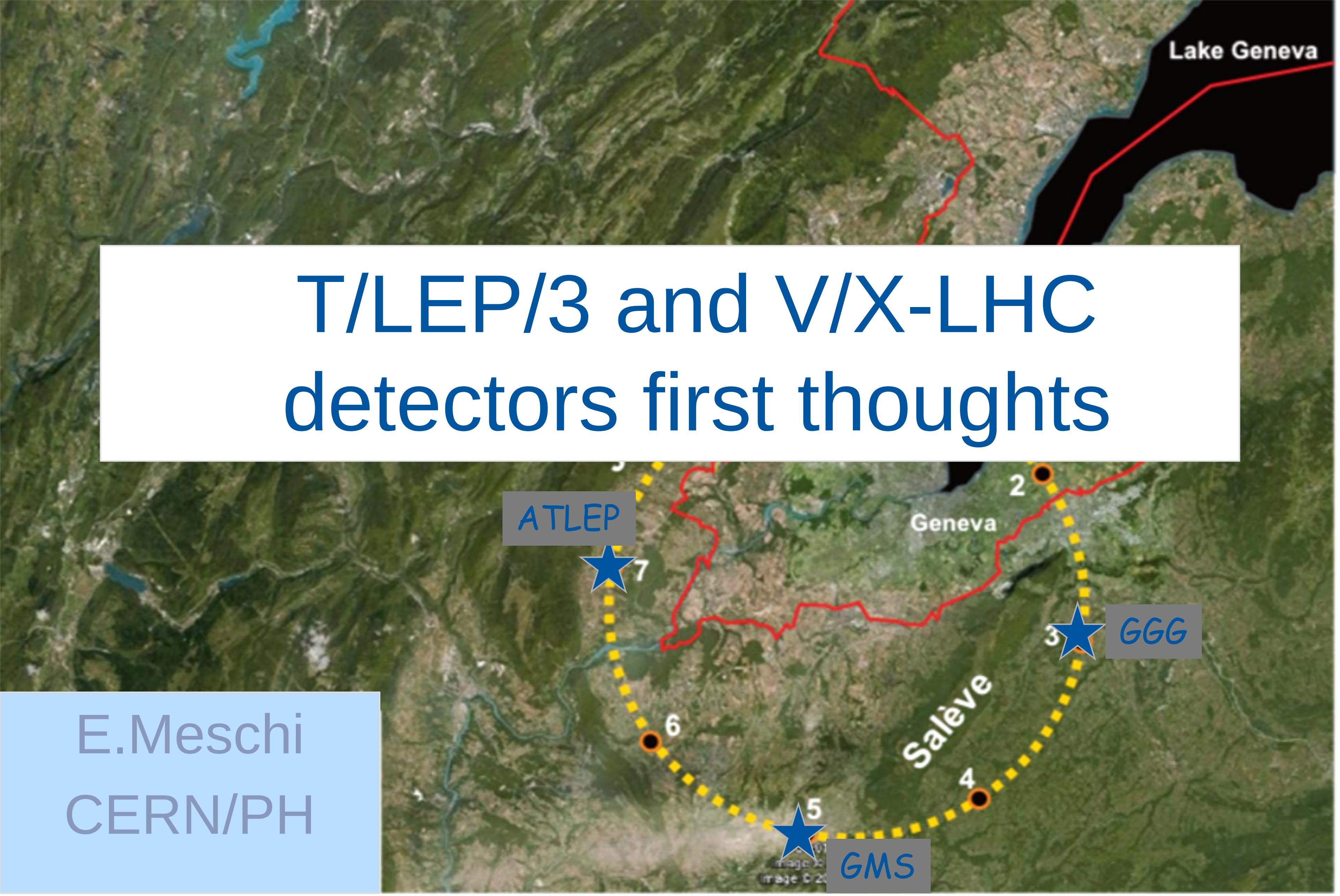
T/LEP/3 and V/X-LHC detectors first thoughts



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Disclaimer

- What follows is the result of few days of reading, “brainstorming” and (mainly) coffee conversations
- It is premature to talk about detector design
- It is however important to bootstrap the process, initiate the discussion
  - So that aspects of the machine design that may affect experiments are not overlooked
  - To identify possible showstoppers or critical aspects
- Could imagine establishing a “reflection group”
  - work in strict coordination with machine designers
  - Produce a convincing “**blueprint**” outlining the fundamental parameters and features of a T/LEP/3 detector – this is a fundamental step for a project to start
  - Keep an eye on “options” TeraZ, MegaWW
  - IMPORTANT: **Integrate the notion of a future 80TeV pp collider**
  - Feasibility to evolve into a “concept” detector at some later stage
    - Very much dependent of whether TLEP becomes a realistic possibility on the <2030 horizon

Thanks to P. Janot, M. Zanetti, F. Zimmermann for useful input

Errors and misconceptions are entirely my responsibility

Subjects touched

- Timeline and why it's important – approach – "definition" of the problem - pros and cons of a circular machine from the detector's standpoint
- Machine aspects that (may) affect detector design
- Beam parameters, the relevance of the "options"
- Basic requirements
- Modular approach, TeraZ and (VL)(X)LHC
- Some requirement and technology outlook (very first pass)

- Next steps?

Timeline and why it's important

2013 2023 2025 ILC? 2040???

CLIC???

LS1 LS2 HL-LHC

DETECTOR BUILDERS
WILL FREE UP FROM PHASE2
UPGRADES ~2022

LEP3-H
ATLAS
CMS

TLEP-H
GMS-2T
ATLEP
…

TeraZ/
GigaW
GMS-2T
GATLEP
...

XLHC
XLHeC
GMS-4T
ATTLAX
GGG
GIZMO

TLEP WILL BE
CLEARLY IN
ALTERNATIVE TO
SWITCHING
TO ILD/SiD OR
OTHER PROJECTS

TLEP-T
GMS
ATLEP
…

XLHC DETECTORS
CAN BE REGARDED
AS A "NATURAL"
EVOLUTION OF TeraZ

EXPERIMENT INFRASTRUCTURE (CAVERNS,
SERVICES, MAGNETS ETC.) STAY THE SAME

	LEP2	LHeC	LEP3	TLEP-Z	TLEP-H	TLEP-t
beam energy E_b [GeV]	104.5	60	120	45.5	120	175
circumference [km]	26.7	26.7	26.7	80	80	80
beam current [mA]	4	100	7.2	1180	24.3	5.4
#bunches/beam	4	2808	4	2625	80	12
#e-/beam [10^{12}]	2.3	56	4.0	2000	40.5	9.0
horizontal emittance [nm]	48	5	25	30.8	9.4	20
vertical emittance [nm]	0.25	2.5	0.10	0.15	0.05	0.1
bending radius [km]	3.1	2.6	2.6	9.0	9.0	9.0
partition number J_ε	1.1	1.5	1.5	1.0	1.0	1.0
momentum comp. α_c [10^{-5}]	18.5	8.1	8.1	9.0	1.0	1.0
SR power/beam [MW]	11	44	50	50	50	50
β^*_x [m]	1.5	0.18	0.2	0.2	0.2	0.2
β^*_y [cm]	5	10	0.1	0.1	0.1	0.1
σ^*_x [μm]	270	30	71	78	43	63
σ^*_y [μm]	3.5	16	0.32	0.39	0.22	0.32
hourglass F_{hg}	0.98	0.99	0.59	0.71	0.75	0.65
ΔE^{SR}_{loss}/turn [GeV]	3.41	0.44	6.99	0.04	2.1	9.3
L/IP[10^{32}cm^{-2}s^{-1}]				10335	490	65
number of IPs				2	2	2
Rad.Bhabha b.lifetime [min]				74	32	54

LEP3 (in the LHC tunnel)

- Markus gave a very exhaustive and interesting summary of the potential of an existing LHC detector (CMS) at LEP3
- The obvious choice for LEP3
- Almost the same physics potential fo[...]s of the Higgs sector
- From the detectors standpoint:
  - One might want to reconsider [...]ned phase2 detector upgrades IFF LEP3 is deem[...]*native* or addition to HL-LHC
  - Some limitations (e.g. c[...]arity) cannot be overcome without essentially rebuilding[...]
- Experiment-wise[...]g for the buck
- Seems the m[...]g for accelerator technology and engineering
- Almost impo[...] do away with long bypasses (i.e. many more km of tunnel a[...]ay…)
  - Synergy with LHeC

THIS IS MY ONLY SLIDE ON LEP3
IT IS CLEARLY A GREAT IDEA **IF IT CAN BE DONE**
A FAST PATH TO PRECISION HIGGS PHYSICS
AT A LIMITED COST

TLEP and beyond

Pros and (very few) cons

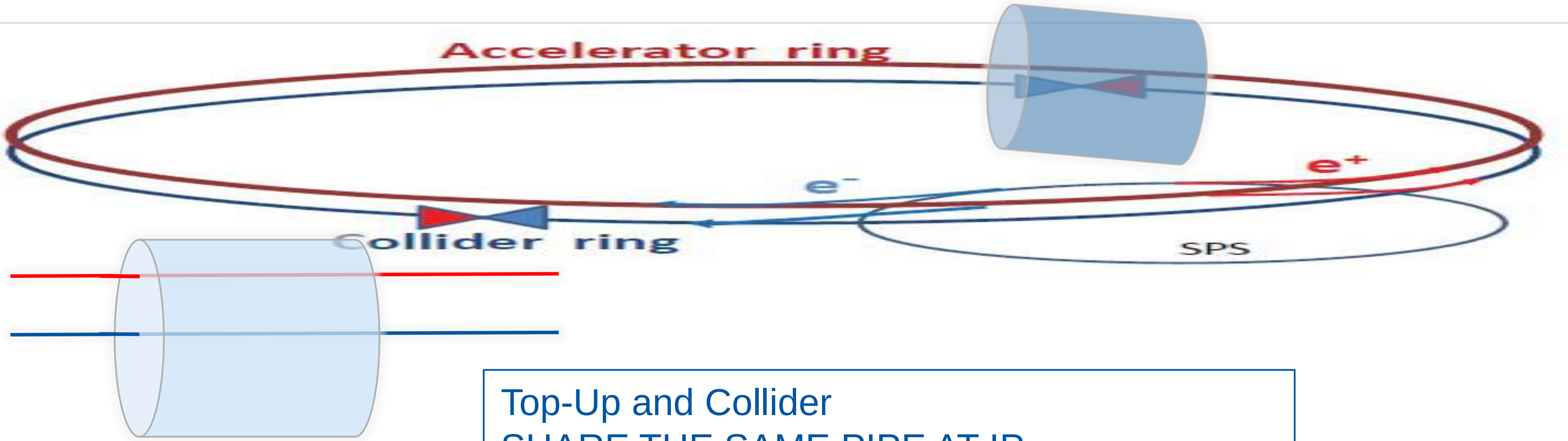
- Machine backgrounds
  - beamstrahlung photons
  - e+e−-pairs from beam-beam interactions
  - radiative Bhabha events
  - hadrons or muons from γγ interactions
- All of these are being estimated, but expected to be manageable, either because they are very forward (beamstrahlung/pairs) or because they can be clearly identified (rBhabha/γγ)
- **They represent much more serious challenges for the detectors at a LC**

- Beam structure: for TLEP-H **few 10s equally spaced bunches** can provide the target luminosity
  - The train burst structure represents a serious challenge for the detectors' readout at the LC
- Multiple interaction points
  - Up to 4 independent experiments can integrate luminosity and cross check results
- Top-up ring required
  - Avoiding expensive long bypasses requires some clever idea to pass TWO beams through the center of the detector
- Final focus very close to IP
  - **Same as for LC**

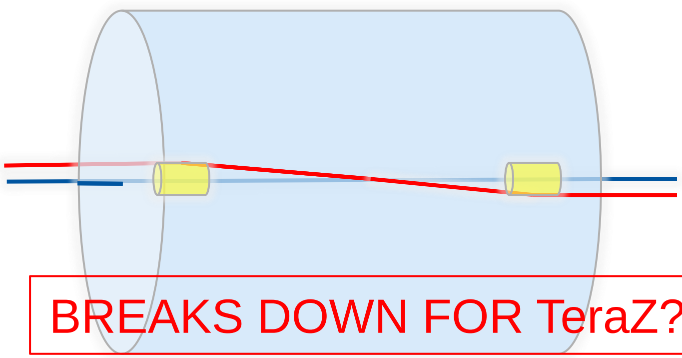
Interaction Points

- Top-up ring position with respect to detector
  - Relative position
  - Passthrough
    - Horror scenarios: all detectors have a circular 10cm(?) hole in the calorimeter
  - Bypass option and implications
  - Even more exotic possibilities ?
- Final focusing quads position and size
  - Impact on detector design
  - Options for the magnet

Passthrough



Top-Up and Collider
SHARE THE SAME PIPE AT IP
CLEVER ARRANGEMENT OF BEAM TIMING
REQUIRES DIPOLE AT FFQ

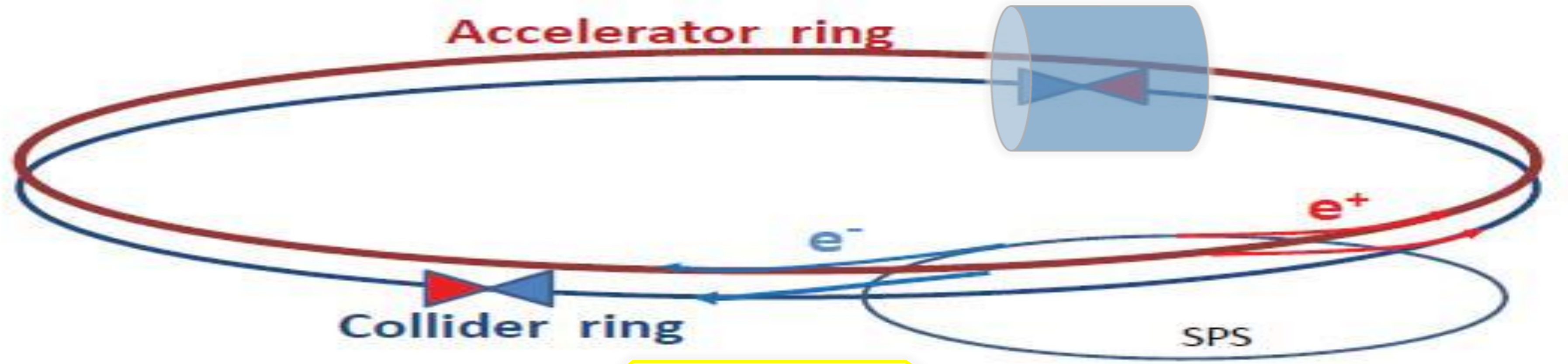


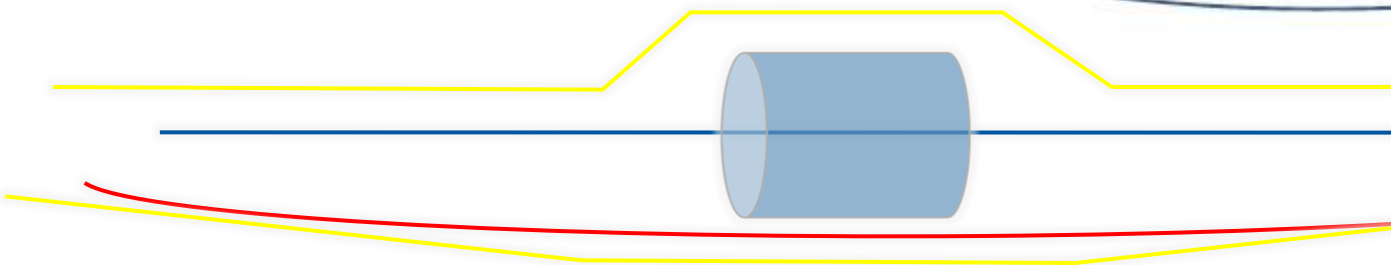
BREAKS DOWN FOR TeraZ?

M.Zanetti

accelerating beam outside FFQ, crossing the IP region with an angle w.r.t the colliding beam line, in this case at most atan(0.3/5).
At FFQ (say 4m) accelerating Beam at 24 cm (FFQ radius 10cm).
integration of a D1 magnet with the focusing quads?

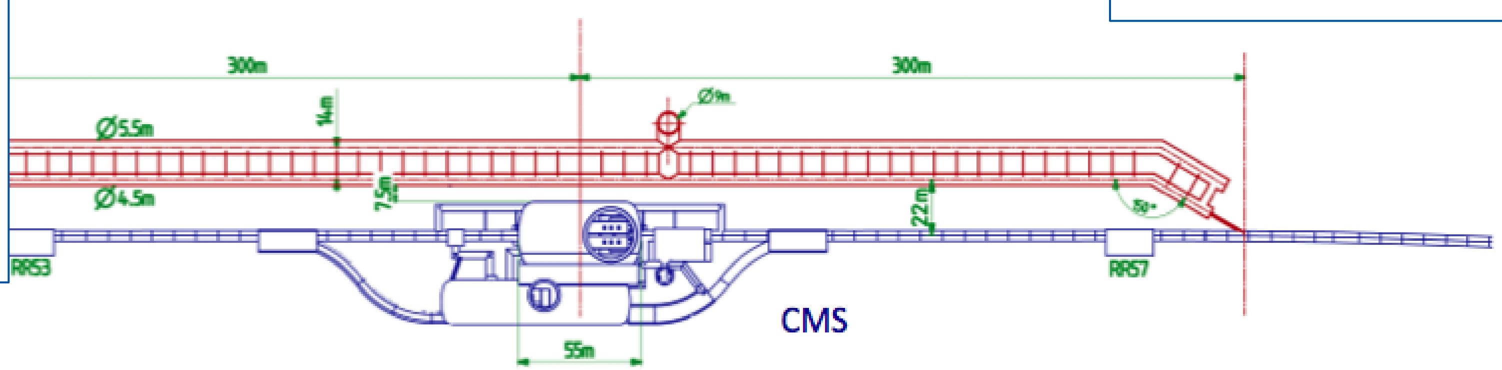
Bypass





CLEVER RELATIVE ARRANGEMENT OF ARCS AND SS POSSIBLE ? LENGTH OF NON-STANDARD TUNNEL SIZE ? COST ?

BYPASS SCHEME FOR LHeC… LENGTH NEEDED FOR TLEP ? COST ?



A Holistic Look (in an ideal world)

- Experimental Infrastructure (civil engineering, Interaction point design, size of the caverns) are tailored for the ultimate pp collider (100 TeV, 5E35)
- Modular detector design allows to evolve them from TLEP-H to XLHC
  - By adding or replacing, or simply turning on features
  - Pay attention to not introduce brick walls
- "Options" (TeraZ, GigaWW) are a clear way to foster the above (e.g. TeraZ 2600 bunches, lumi ~1E36!!!)
- Some design choices will lend themselves better than others to this modular, evolutionary scheme
  - Identify them and promote R&D in that direction

Some example

- Solenoid: at XLHC strong fields and large lever arm will be needed to preserve *some* momentum resolution for multi-TeV tracks
- Large bore diameter solenoids would allow bigger lever arm
  - Relatively compact silicon tracker (or TPC) sufficient for TLEP (and all its variations) – material budget fundamental
    - Cooling, infrastructure
    - Power distribution and readout -> low-power rad-hard VFE, on-chip photonics (lots of fun R&D)
    - Will pay off already at the TeraZ stage
  - Additional layers can be added (resolution ~ $1/L^2\sqrt{N}$) -> large silicon surfaces… R&D needed, cost, channel count ☹
  - Initial cost of calorimeters higher ☹ due to larger volume to cover
  - Can be partially compensated (in the active material) by reducing granularity as showers will be “opened up” further ☺
  - Absorber cost will definitely increase ☹

Some example

- LEP-H poses most stringent requirements on i.p. resolution (e.g. c-tagging)
- Unlike LC or LHC, beam structure makes readout relatively “easy”
  - Already no longer the case for TeraZ (2600 bunches, 100ns)
  - Always design for the most demanding option
    - keeping evolutionary/modular architecture open

- Calorimetry
  - ECAL: Moderate increase in transverse segmentation (wrt LHC detectors) sufficient to reach necessary resolutions for LEP-H
    - Can be profited of in pp
    - Longitudinal segmentation, what are the real needs ?
  - HCAL: Increasing the solenoid field and/or radius may help a bit the Particle Flow algorithms by separating the charged/neutral components further

Basic requirements

- Vertex detector capable of transverse i.p. resolution of order 5 μm in barrel (~10GeV)
  - For b and c tagging
  - Single point resolution of the same order and >4 layers required
  - For comparison, CMS ~20 μm
- ECAL intrinsic resolution better than 1% @60GeV
  - To reconstruct H->γγ
- Jet energy resolution
  - Integrate particle-flow techniques
  - Less stringent requirements on HCAL resolution
  - Good granularity required (ECAL)
  - Shower barycenter determination more important than standalone resolution (HCAL)
  - Goal of σ(E)/E better than 4% for PF jets
- Momentum resolution $\sigma(p_T)/p_T^2$ better than 10^{-4} for TLEP-H
  - Very different situation at TLEP and XLHC
  - TLEP: tradeoff between B strength and sufficient number of high resolution points
    - TPC an option… (breaks down at TeraZ)
  - XLHC: multi-TeV objects -> play with lever arm (N points) and B strength
- Muon Identification >95%
  - Envision modular extensions to cover XLHC (multi-TeV muons)

Magnet

- TLEP-H/W/Z require a modest magnetic field
  - No point in making a more compact tracker
    - Because of power distribution, cooling and readout issues
- However…
  - ECAL/HCAL MUST be inside the solenoid
    - Only way to have acceptable resolution for photons
    - Support PF jet algorithms
- Current experience: CMS (similar parameters as ILC detectors)
  - Larger bore diameters deemed to be challenging to engineer
  - Is this going to evolve in the future? (new SC materials, progress in cryogenics, experience with operating current SC magnets,…)

Vertex Detector

- Flavor tagging the real challenge: extreme demand in impact parameter resolution
  - Beam pipe material
  - Innermost layer radius
  - Lightweight construction to minimize multiple scattering

$$\sigma(d) = \sqrt{(a^2 + b^2/p^2\sin^3\theta)}$$

  - Good point resolution (a) useless if m.s. term (b) large
- ILC/CLIC R&D
  - Thin sensors
  - lightweight CF structures
  - Open structure with gas flow cooling
- Must look into: power distribution, low-power VFE, integrated on-chip cooling and photonics
- $\sim 10^9$ channels: readout a challenge

Tracking

- An all-silicon tracker seems clearly preferable
  - Moderate number of high-precision points (not different in scale from CMS)
    - Forward tracking more important than at LEP
  - Challenges again are lightweight support structure and services (power distribution, cooling)
  - R&D for LHC phase2 detectors certainly relevant
    - Optimized power distribution, use of store capacitors
      - Compact large capacitance dev for portables and other applications
    - Front-end electronics with longer pipelines, low-power optical systems
    - Cooling in relationship to all of the above
- TPC (with solid-state readout) is an option for TLEP-H
- Again many technological challenges and ultimately a large number of channels to readout and process

Calorimetry

- ILC/CLIC Tungsten/SiPad multilayer sampling ECAL with extreme segmentation (CALICE)
  - Probably insufficient resolution for H->γγ (S~15%, C~1%)
  - But attractive as an evolutionary solution for XLHC
  - Study tradeoff for segmentation/number of channels
- $PbWO_4$ crystals (CMS)
  - Cost, readout, transverse segmentation
  - Containment and transparency for XLHC
  - Longitudinal segmentation ☹
- HCAL challenge: reasonable resolution and granularity sufficient to support PF algorithms
  - Analog vs. digital HCAL
  - Absorber material, photodetectors
  - Combined analog and binary readout ? On-detector shower barycenter ?
- Clearly should explore other solutions as well

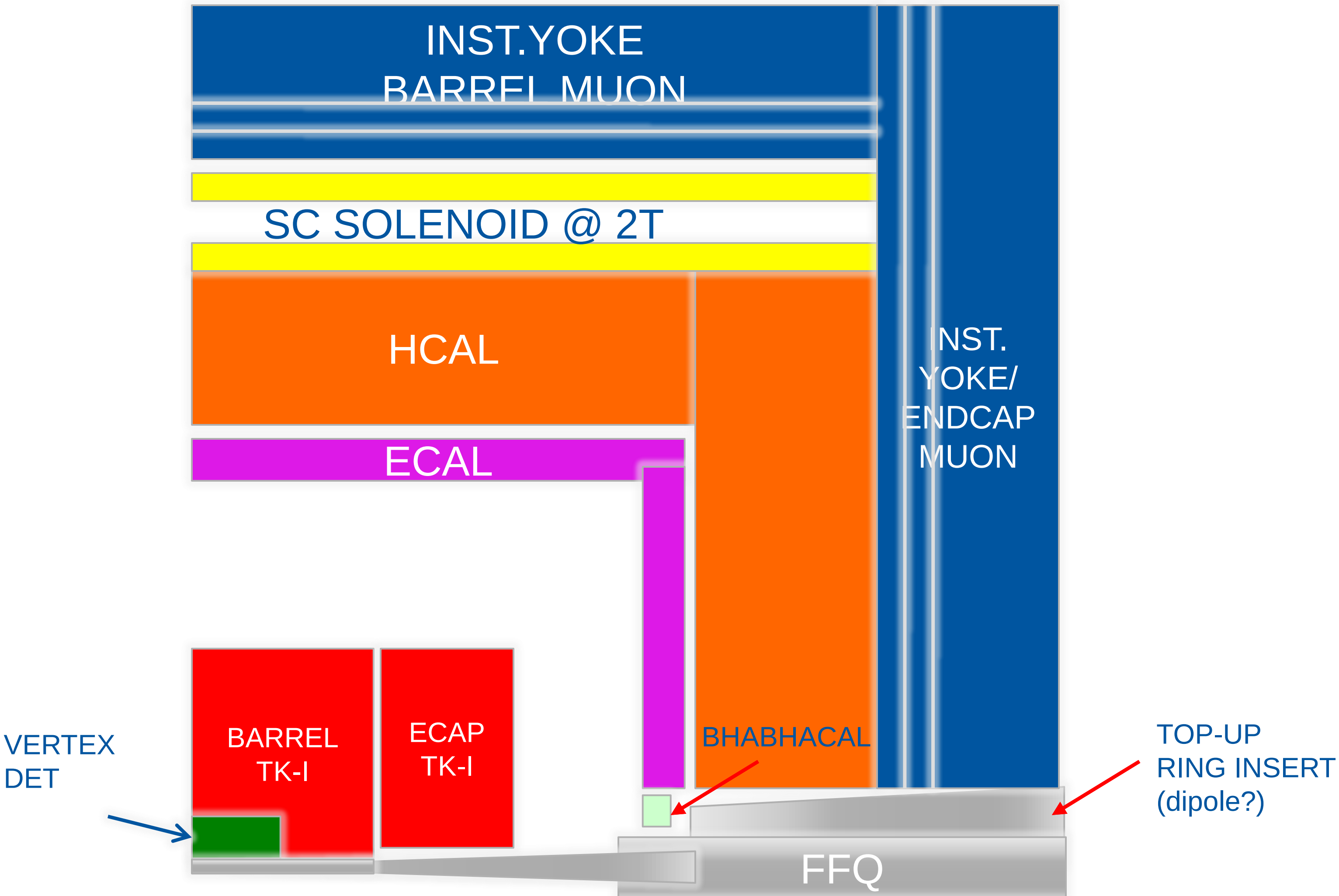
DAQ and (Trigger)

- Can we read out and record data from a detector with ~10^9-10^{10} channels ?
- Do we need a trigger ?
- TLEP-H/T
  - Low occupancy, sparse readout, zero suppression, Bx rate ~100 kHz -> can and should read out every bunch crossing !
  - Rate of interesting events (including background) <1 kHz
  - Event size ?: 1-10MB depending on quality of zero-suppression/compression algorithms affordable at front-end
    - -> switched networks with aggregated b/w up to 1TB/s (e.g. planned 1MHz readout for LHC phase 2 CMS)
    - Technology is in hand today (cost ☹)
  - Also explore other possibilities: e.g. integrate over (multiple) turn
- Trigger
  - Front-end electronics built to support it wherever possible
  - optical fast paths, configurable pipelines…
  - To be looked at for TeraZ and beyond
  - Privilege read out speed and software HLT wherever possible

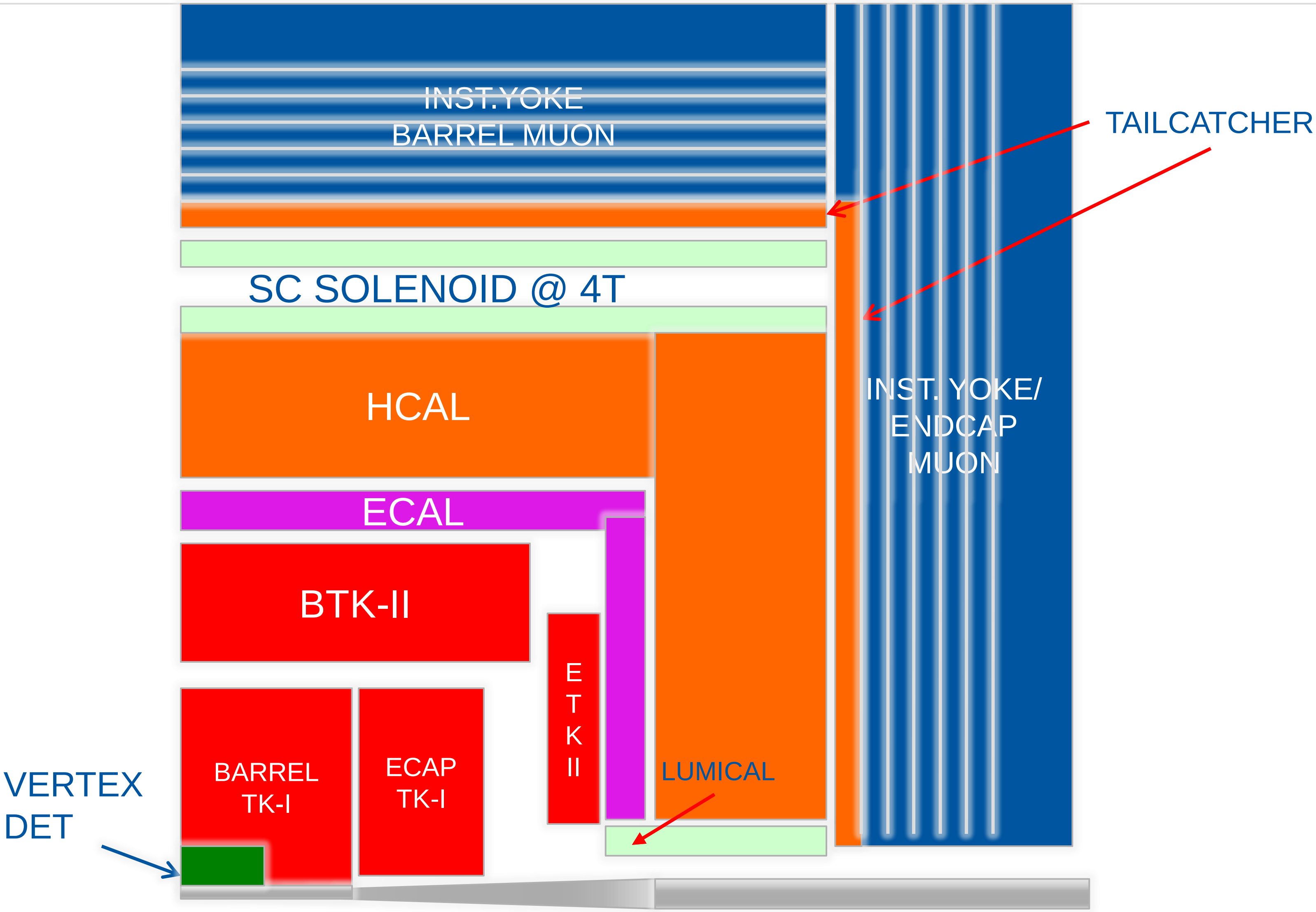
Summary

- Many many aspects not even touched, for example
  - Muon detectors
  - Small angle coverage
  - Luminosity detector(s)
  - Complexity, reconstruction, computing…
  - Just to name a few…
- Hard to decide where to start…if we start
  - Reflection group to address critical items… then…
  - Obvious option: use an LHC detector as a baseline and prepare a small number of variations, use simulation to evaluate physics performance on selected benchmark processes
    - Privilege areas not accessible to LHC
    - Choose specific benchmarks in a binary decision tree to rule out alternative options

GMS-2T


INST.YOKE
BARREL MUON
SC SOLENOID @ 2T
HCAL
ECAL
INST.
YOKE/
ENDCAP
MUON
BARREL
TK-I
ECAP
TK-I
VERTEX
DET
BHABHACAL
TOP-UP
RING INSERT
(dipole?)
FFQ

GMS-4T



INST.YOKE
BARREL MUON
TAILCATCHER
SC SOLENOID @ 4T
HCAL
INST. YOKE/
ENDCAP
MUON
ECAL
BTK-II
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T
K
II
BARREL
TK-I
ECAP
TK-I
LUMICAL
VERTEX
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