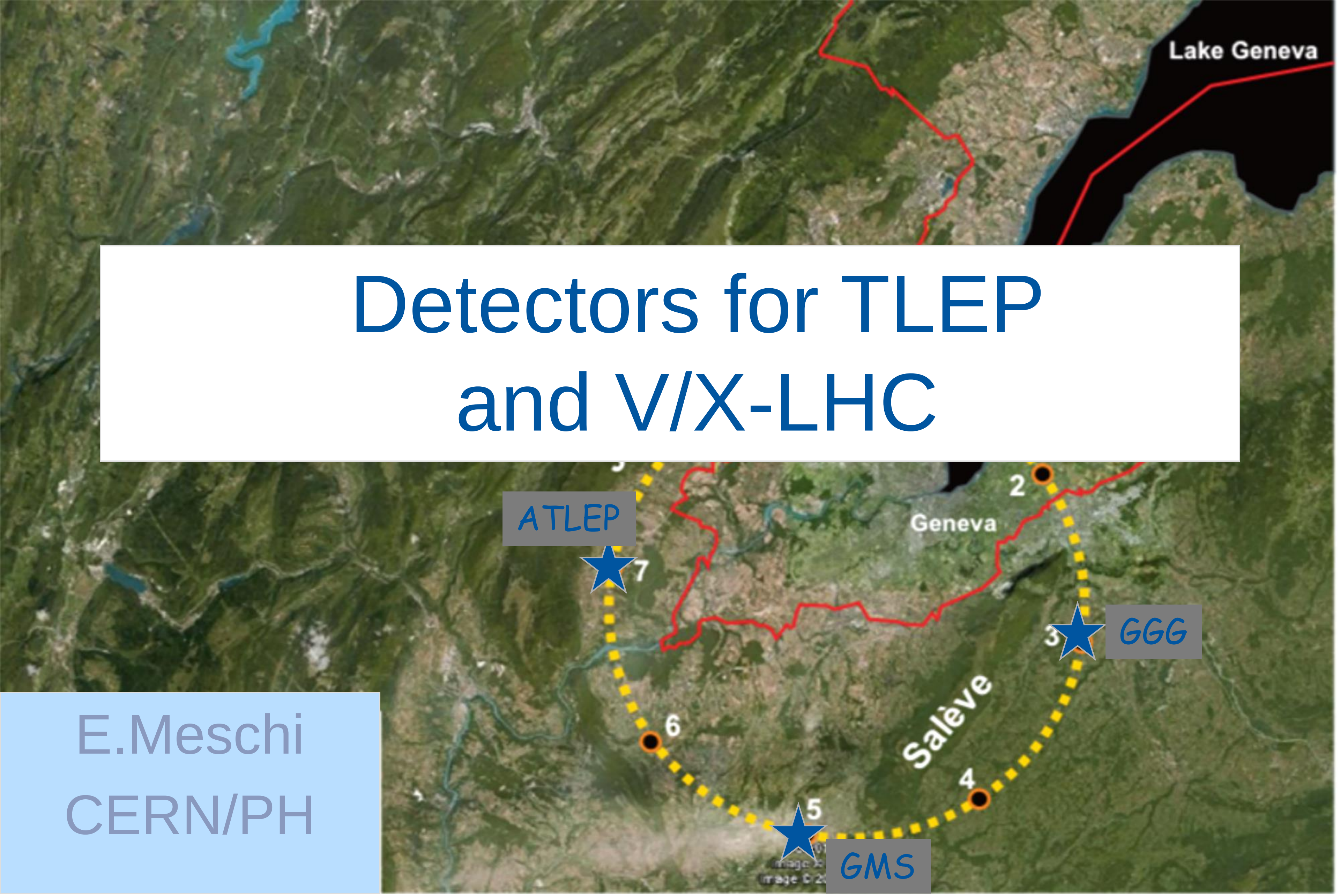
Detectors for TLEP and V/X-LHC



E.Meschi
CERN/PH

Reminder: Disclaimer (from last workshop, still holds)

- 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

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

Errors and misconceptions are entirely my responsibility

Guidelines

- Design caverns, services and detectors (at least the basic structure) to be re-used in pp collisions (as new)
- TeraZ sets the scale for DAQ (2600 bunches)
  - also forward EM calorimetry (lumi)
- TLEP(H) sets the scale for precision (tracker, ECAL, particle flow, b-tagging)
- X-LHC sets the scale for magnetic field, calorimeter depths, tracker pT reach
- A tenable cost sets the ultimate scale for what can be done
  - Given technology evolution to be expected, targeting detectors at same total final cost as ATLAS/CMS seems realistic

But first, a proposal

…remember the Tevatron punchline about the "Energy Saver" ….?

TLEP: the Money Saver

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

Not quite a detector issue but…

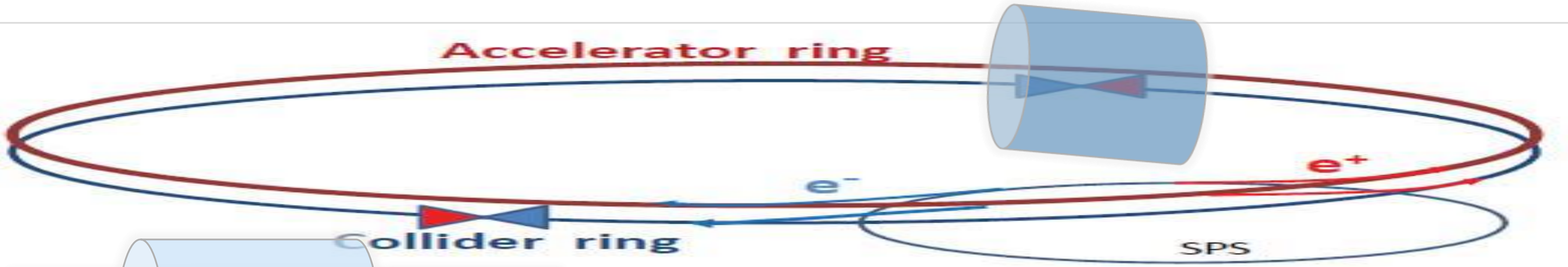
…a subject that I hold dear:

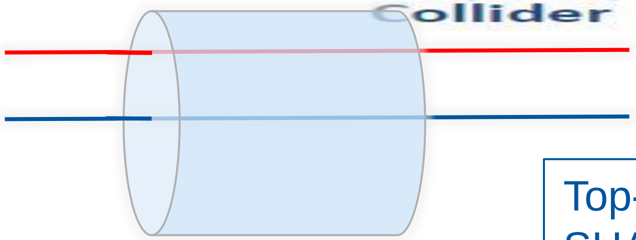
don’t drill a hole in our detectors !

Interaction Points

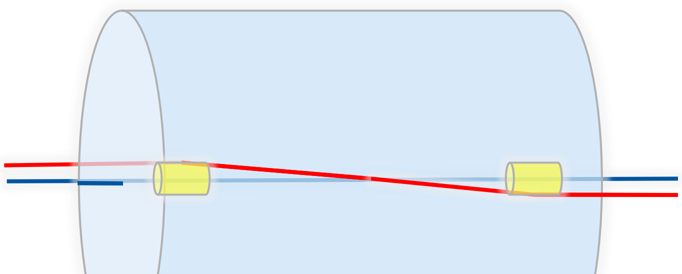
- Top-up ring position with respect to detector
  - Relative position
  - Passthrough
    - Horror scenarios: all detectors have a circular … cm(?) hole in the calorimeter
  - Bypass option and implications
  - Even more exotic possibilities ?
- Final focusing quads position and size
  - Impact on detector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

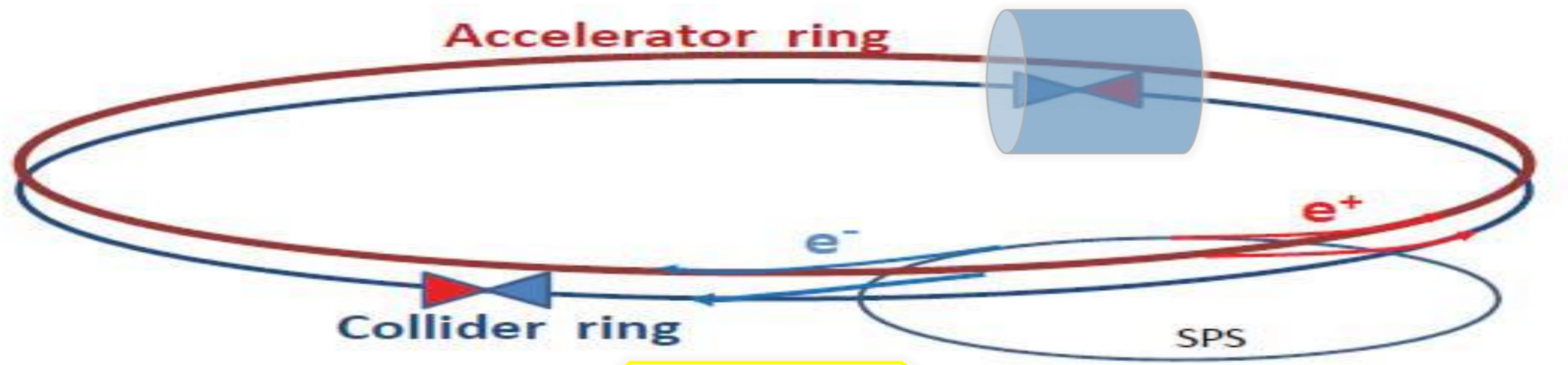


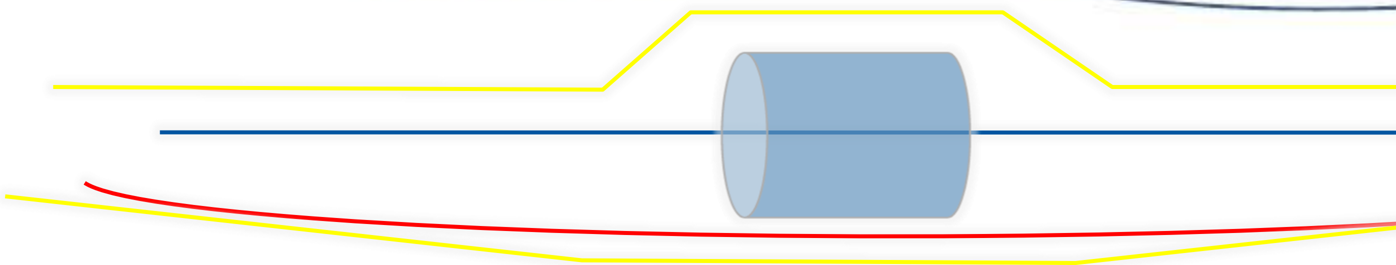
BREAKS DOWN FOR TeraZ?

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?

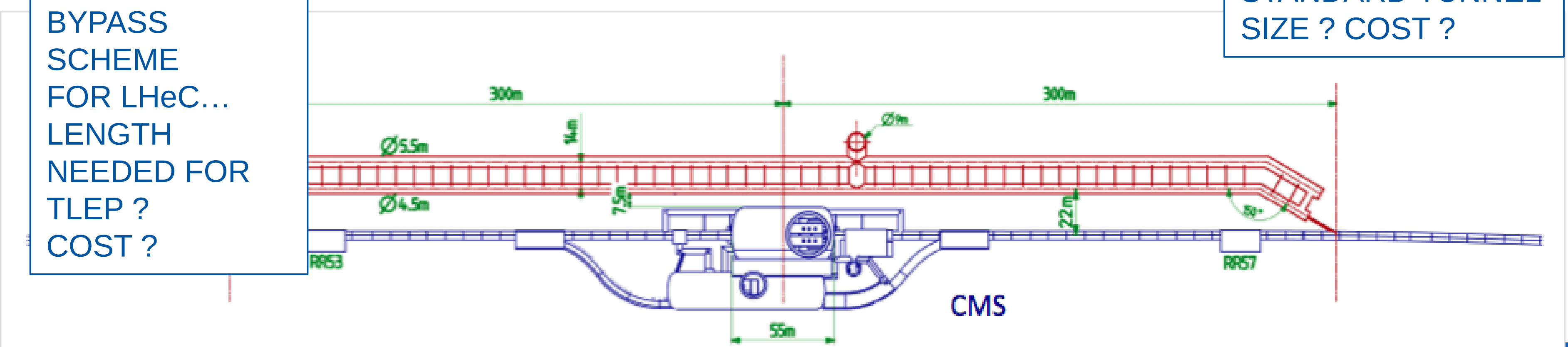
Bypass





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

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



TLEP and XLHC detectors

Magnetic Structure

- 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
  - large tracking detectors…
    - 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 ☹
- Alternative magnetic structures (a la ATLAS) would allow staging the toroids

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,…)

Tracking

- 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
- 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

Tracking

- 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 ☹

- 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

Vertex Detector

- 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
- So… flavor tagging is 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

Calorimetry

- 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
- 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

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 ☹
- Lar???
- 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

Muons

- The real challenge is for XLHC
- Muon Identification >95%
  - Envision modular extensions to cover XLHC (multi-TeV muons)

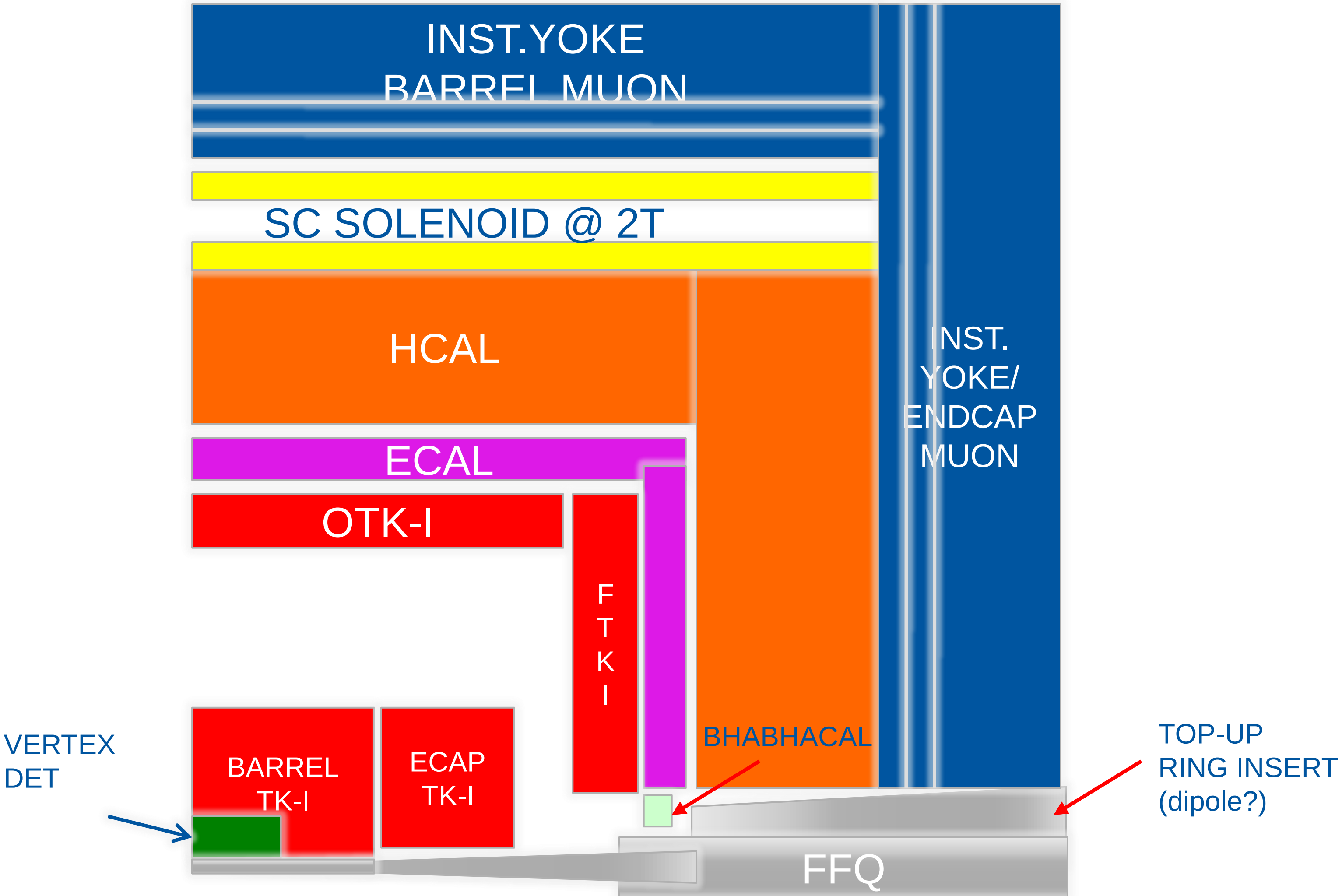
DAQ and (Trigger)

- 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

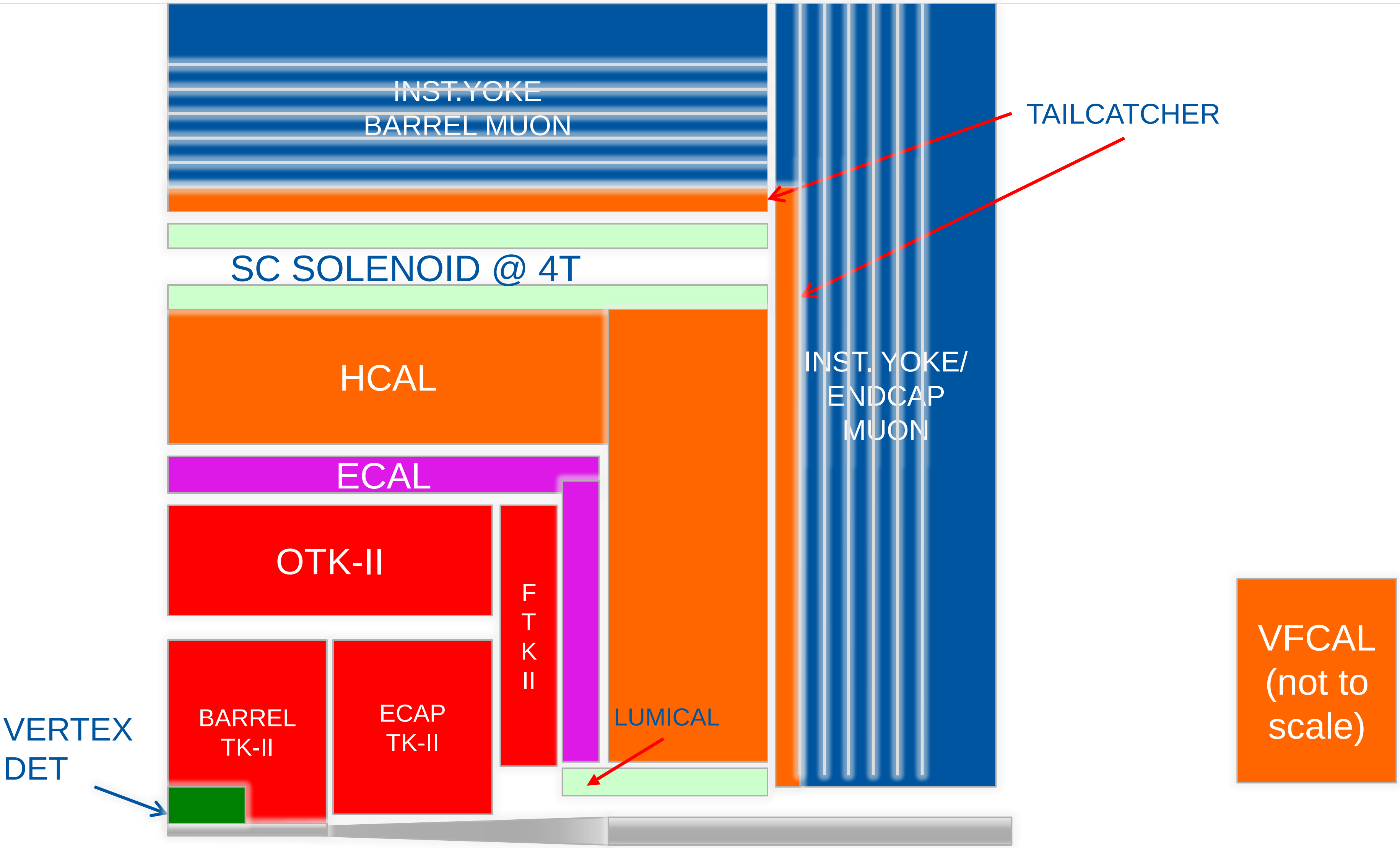
BLUEDEPTH

- a BLUEprint Detector Proposal for TLEP and the next Hadron collider
- Identify (one or two) common structure(s) for all potential design
- Identify two or three technologies to study in depth for each subdetector
- Parametric simulations of core parameters (coverage, resolution, efficiencies) (Delphes)
- Detailed simulation of one or two more promising alternatives (GEANT ?)
- Build on the experience and infrastructures of the current LHC detectors (simulation, sw infrastructure)
- Always include a modular evolution for the proton machine in the design

BLUEDEPTH@TLEP



BLUEDEPTH@XLHC



- Many many aspects not even touched, for example
  - Muon detectors
  - Small angle coverage
  - Luminosity detector(s)
  - Complexity, reconstruction, computing…
  - Just to name a few…

Summary

- Start the detector studies… how ?
  - Define a skeleton blueprint detector
  - 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
      - Use fast parametric simulation (Delphes ?)
  - Converge on one or two designs to simulate in detail
    - GEANT simulation and use existing reconstruction framework
  - Have a clear plan for the evolution of the detector towards the pp machine