Head-Tail DAQ Upgrade Meeting

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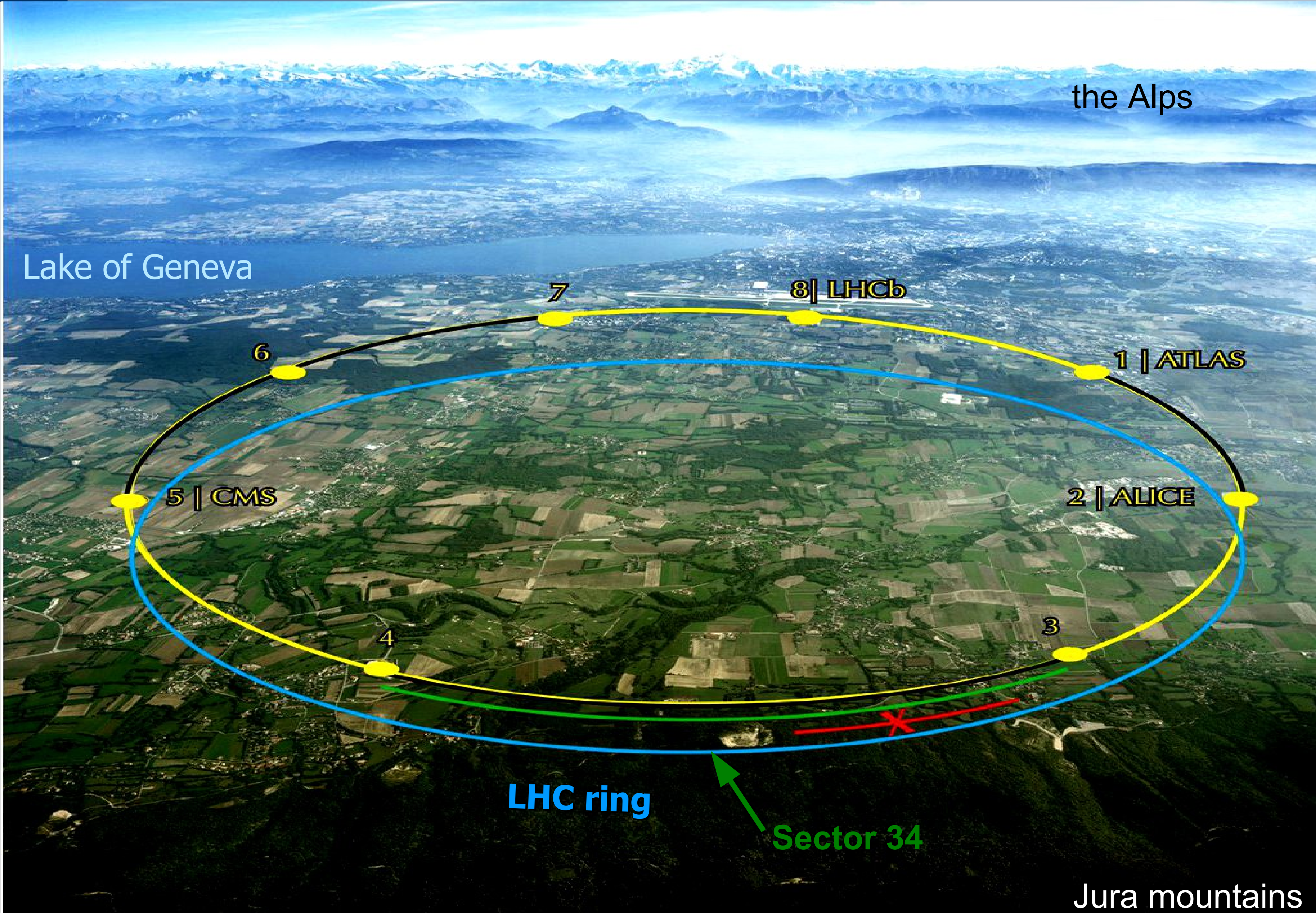
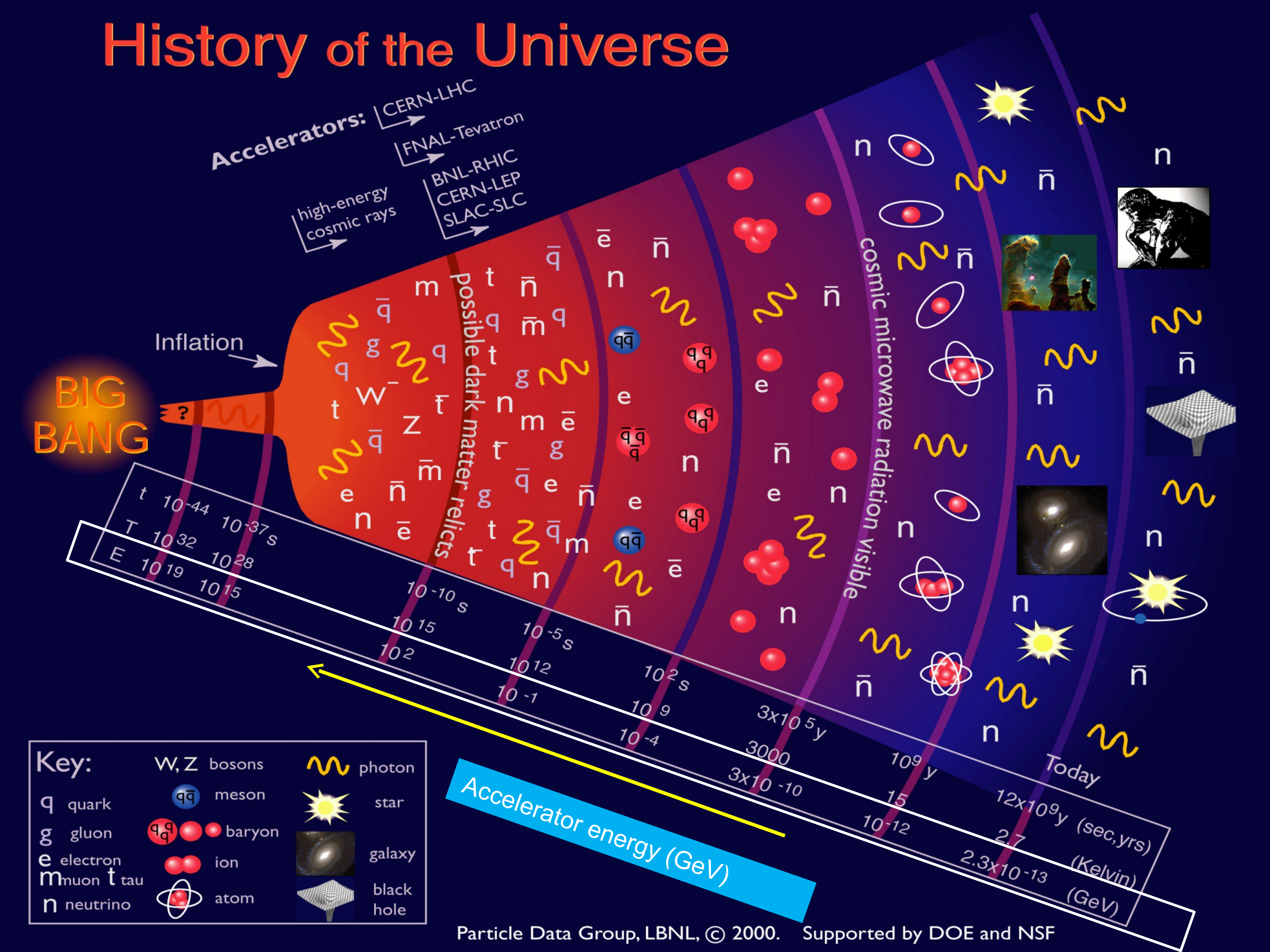
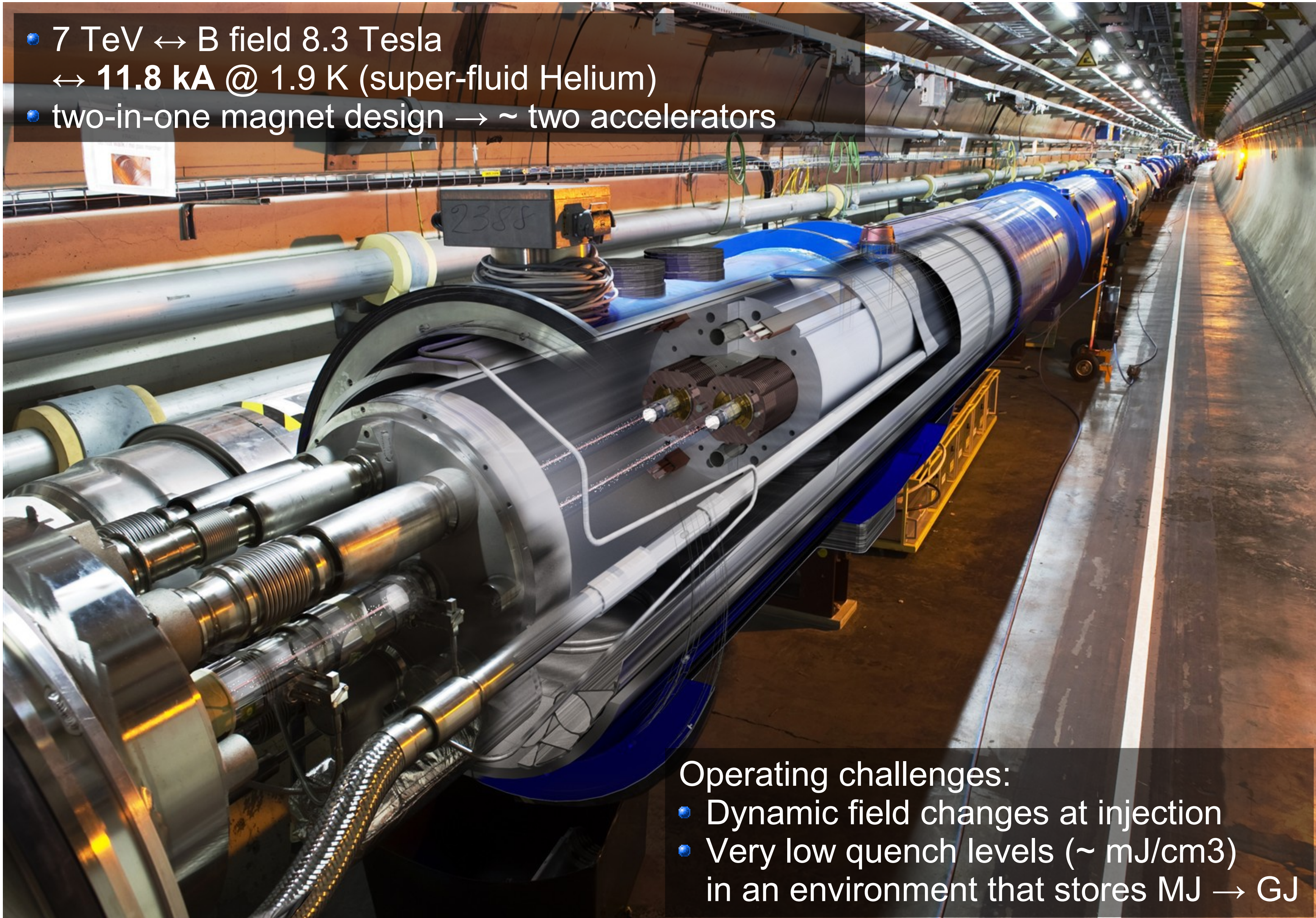
The Large Hadron Collider LHC
Installed in the LEP tunnel, 27 km, Depth of 70-140 m




History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Inflation
BIG BANG
?
possible dark matter relicts
cosmic microwave radiation visible
t 10-44 10-37 s 10-10 s 10-5 s 102 s 3x105 y 109 y Today 12x109y (sec,yrs)
T 1032 1028 1015 1012 109 3000 15 2.7 (Kelvin)
E 1019 1015 102 10-1 10-4 3x10-10 10-12 2.3x10-13 (GeV)
Accelerator energy (GeV)
Key:
q quark
g gluon
e electron
m muon t tau
n neutrino
W, Z bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

27 km Circumference – 1232 LHC dipole magnets

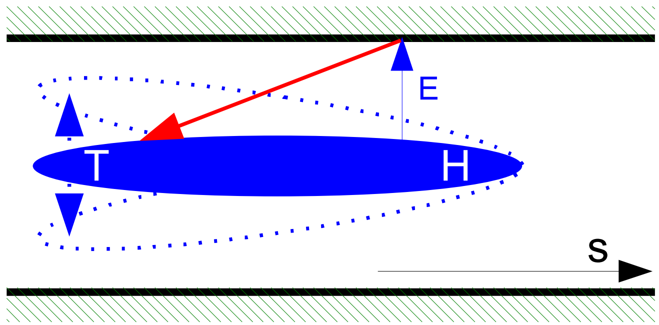
- 7 TeV ↔ B field 8.3 Tesla
  ↔ **11.8 kA** @ 1.9 K (super-fluid Helium)
- two-in-one magnet design → ~ two accelerators



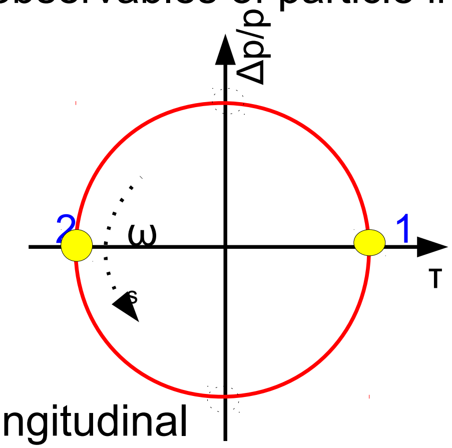
Operating challenges:
- Dynamic field changes at injection
- Very low quench levels (~ mJ/cm3)
  in an environment that stores MJ → GJ

Motivation – HeadTail Oscillations
What we love to see also in the SPS/LHC

- Intra- and inter-bunch beam motion is one of the observables of particle instabilities

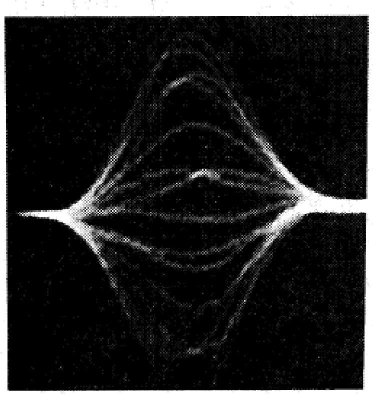


transverse

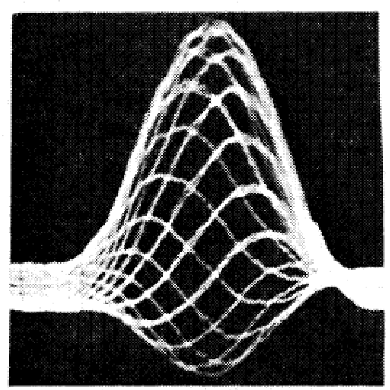


longitudinal

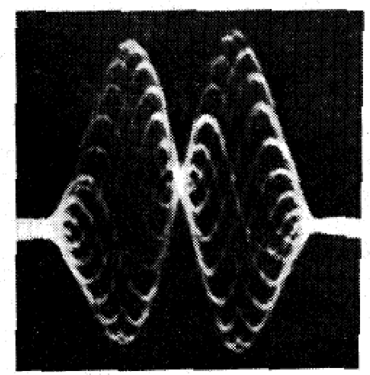
- e.g. J. Gareyte, "Head-Tail Type Instabilities in the PS and Booster", CERN, 1974



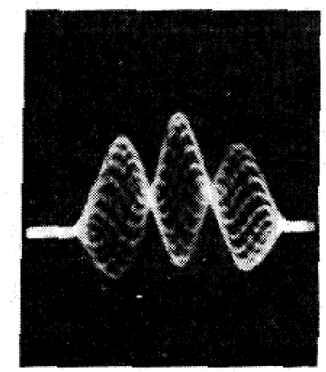
a) mode m = 0, χ = 0



b) m = 0, χ = 2.3 radians



b) m = 1, χ = 6.9 radians

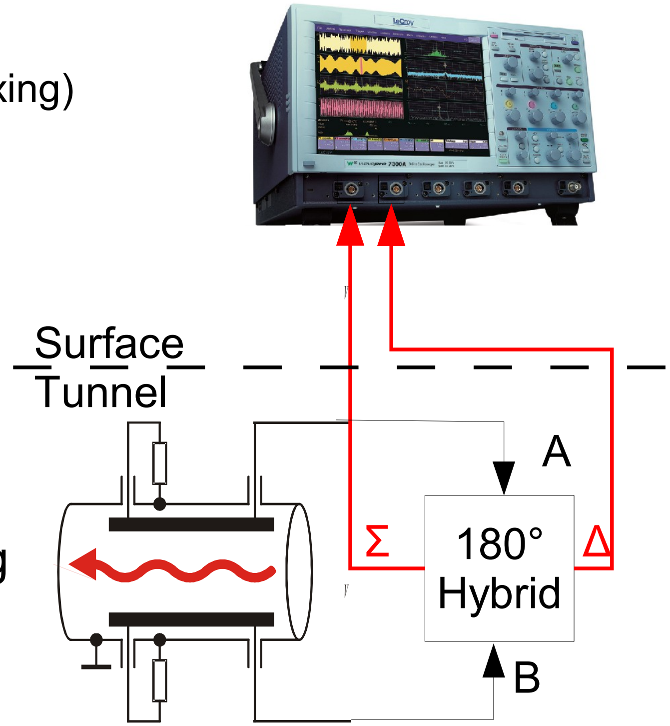


d) m = 2, χ = 6.9 radians

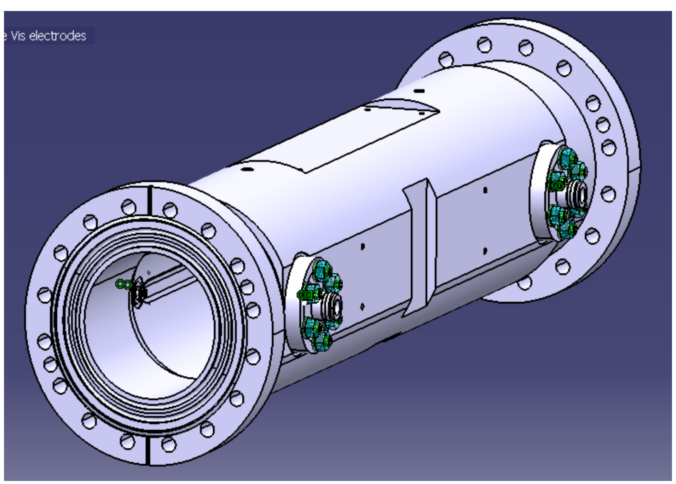
- PS: 120 ns bunch length ↔ less demanding in terms of bandwidth
- SPS/LHC: bunch length down to 1 ns → requires GHz analog bandwidth

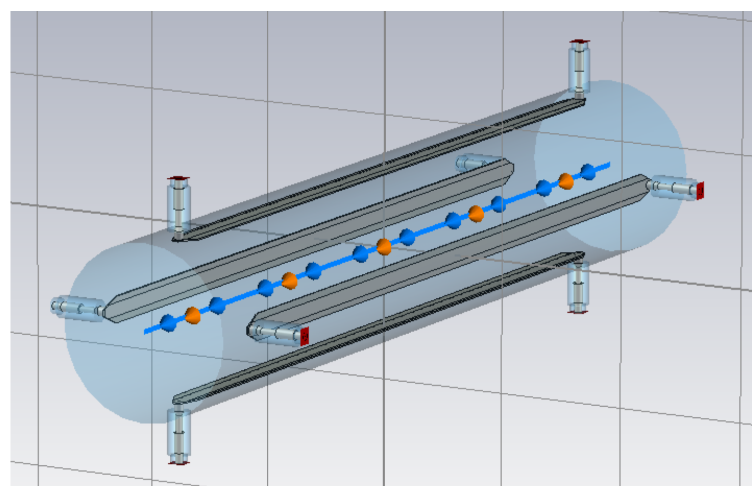
Implemented/tested at CERN-SPS, Tevatron, LHC:

- Long strip-line BPM (60 cm, to avoid signal-reflection mixing)
- Σ-Δ hybrid (removes common mode signal)
- Fast-sampling to resolve internal bunch structure
  - ~ ns bunch length → GHz scope bandwidth



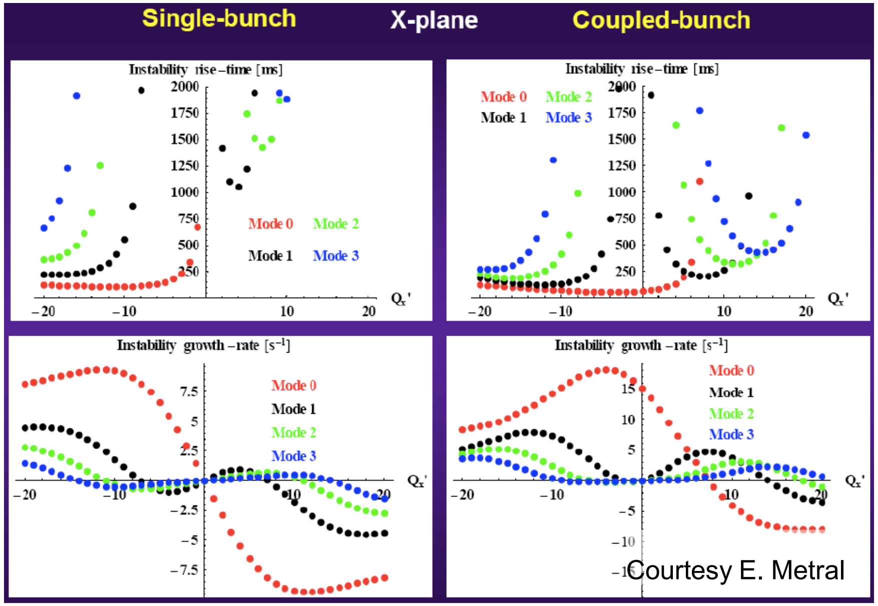
- Need to compensates for non-beam effects:
  - pickup- & hybrid response,
  - cable dispersion, …
  - cable reflection, imperfect impedance matching
  - electrical offsets

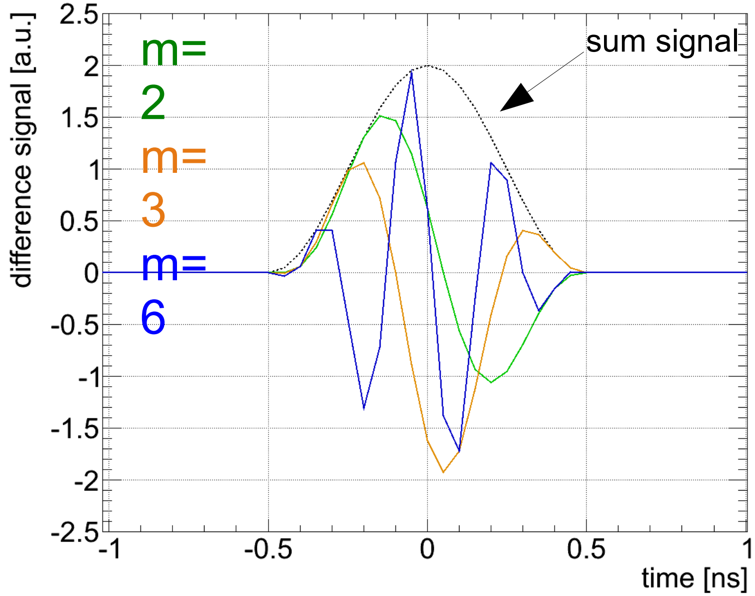


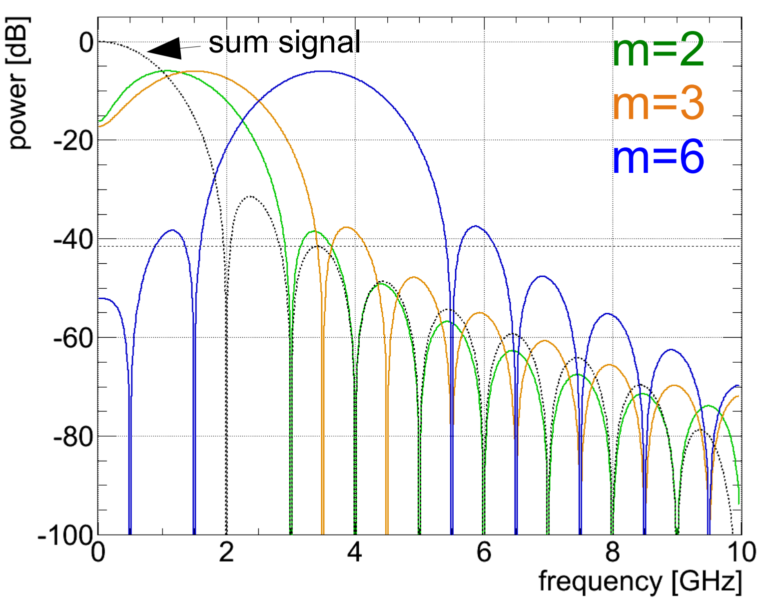


Head-Tail Motion Signal-Spectra Simulation

- Higher-order HT instabilities
- Can be detected e.g. via:
  - time-domain: counting number of zero-crossing, rising/falling-edges
  - freq.-domain: standard peak search, provides also indication for
    - mixed modes
    - HT mode strengths

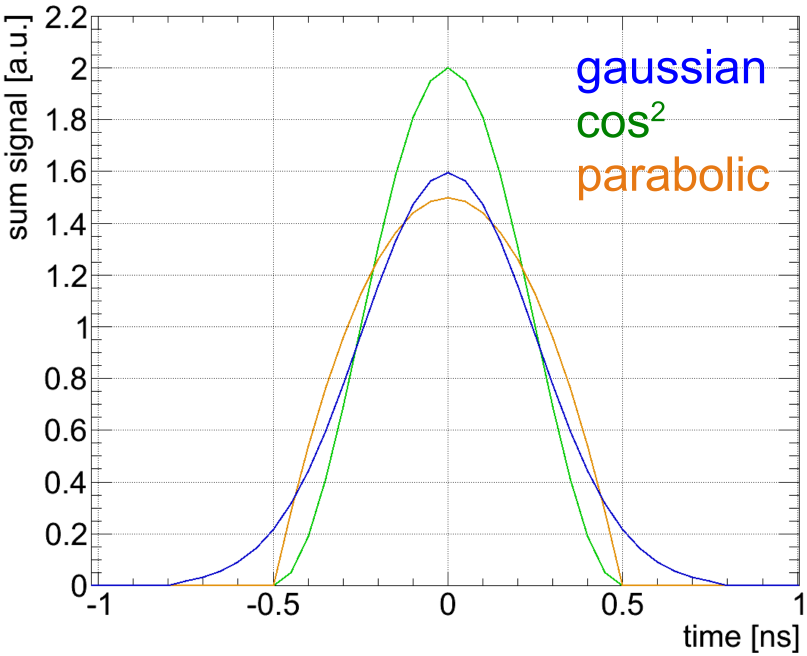


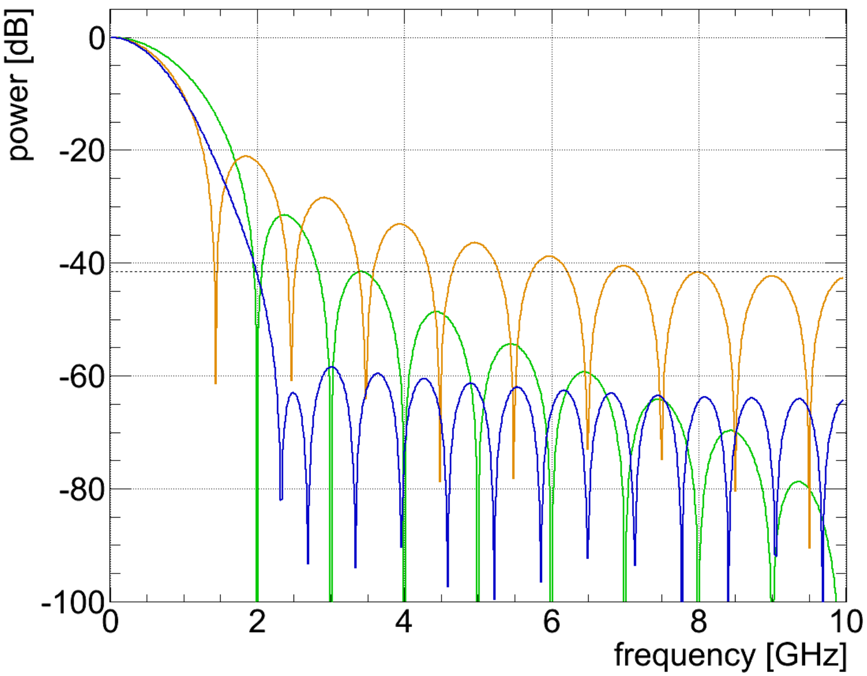




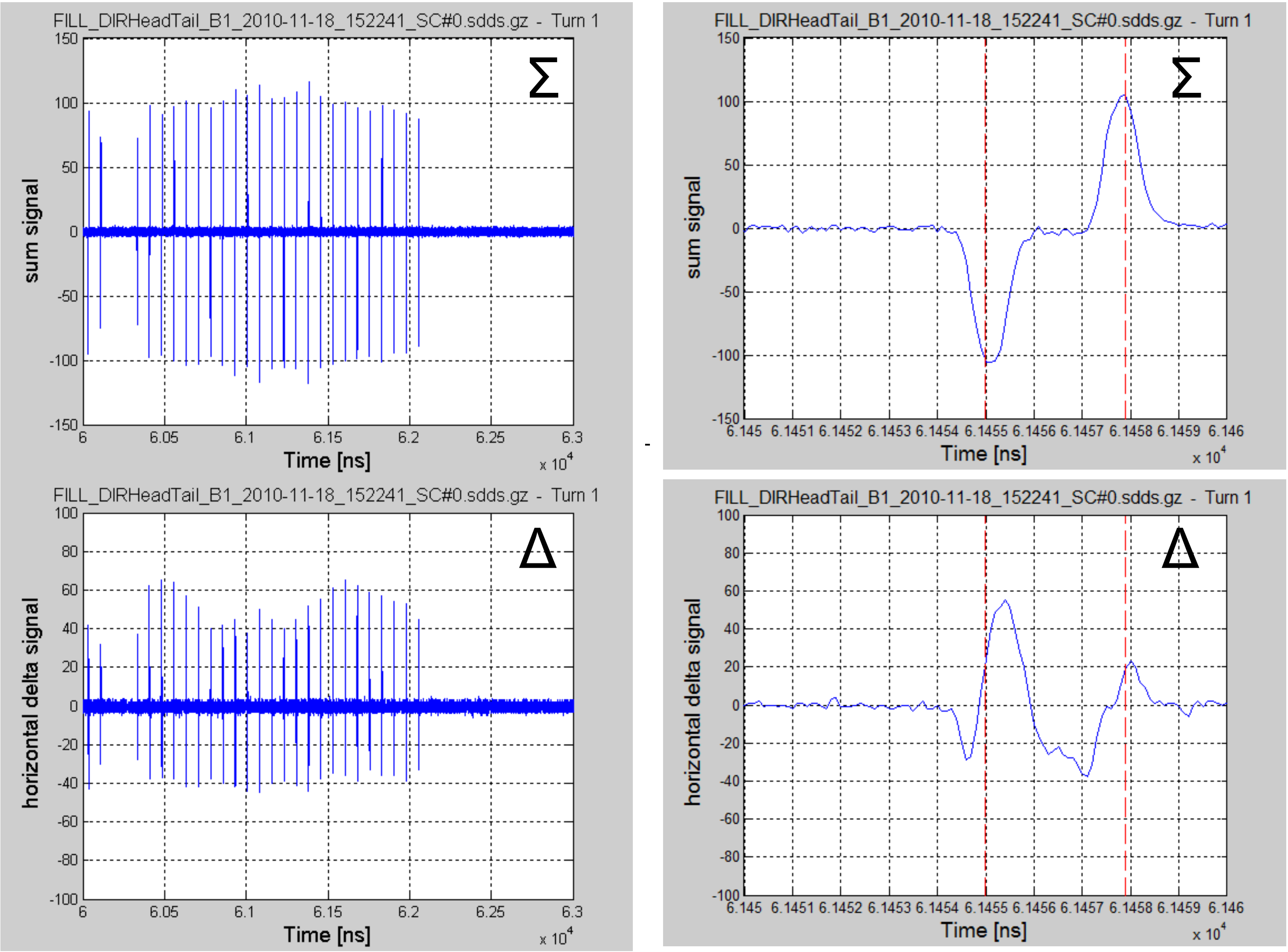
Head-Tail Motion Signal-Spectra Simulation

- Additional diagnostics: power spectrum is sensitive to bunch shape, bunch length, bunch intensity, longitudinal phases, …
  - But signal decreases significantly
    → amplification by 40 dB above 1-2 GHz





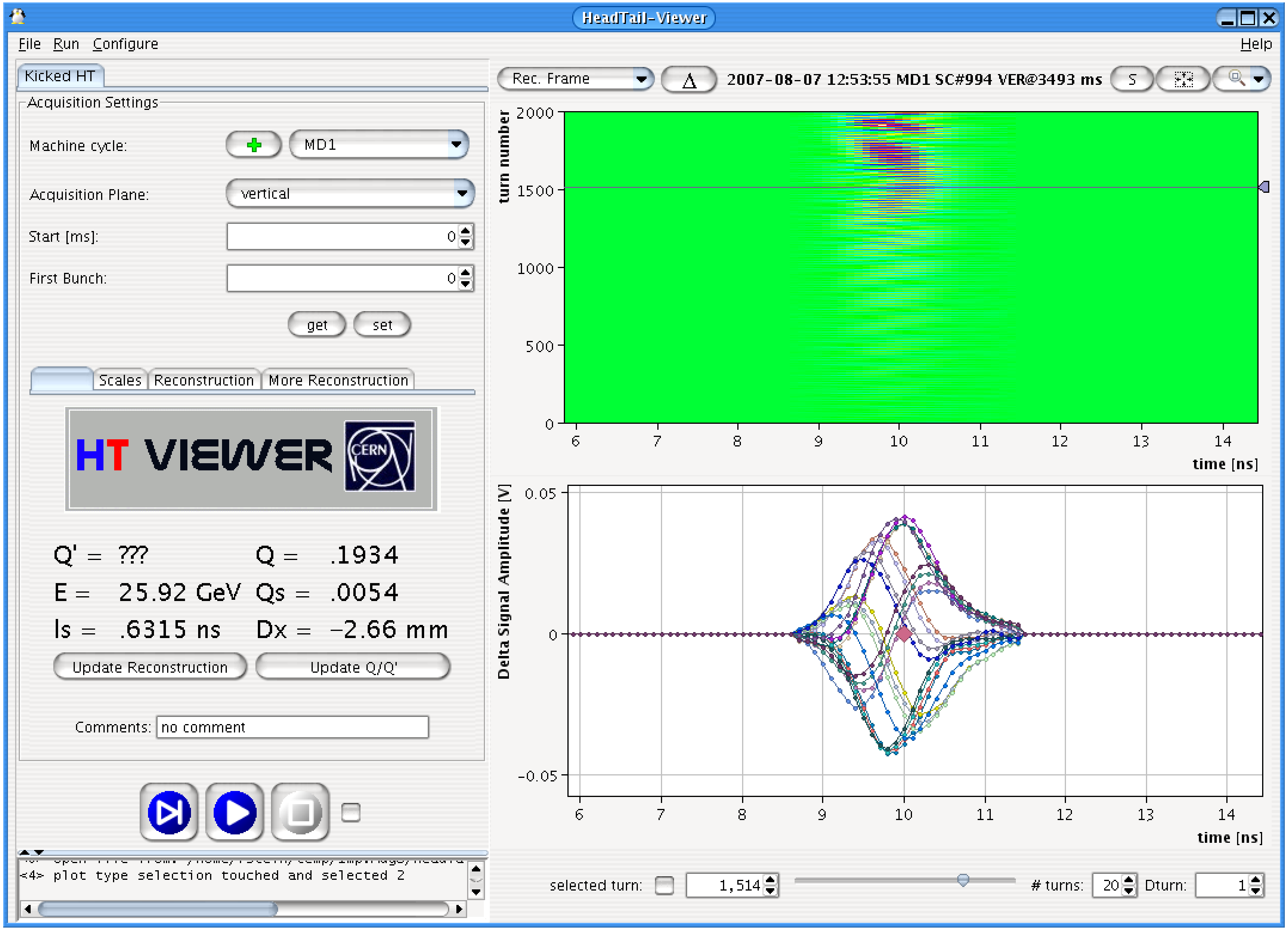
Head-Tail Signal Example SPS



animation courtesy B Salvant (2010)

Limits of Classical Head-Tail Monitoring Approach

- What our ABP colleagues like to see (here: HT mode 'm=1'):



Digital Acquisition System Upgrade I/II

- First steps, tackle existing DAQ limitations, initial system was designed to:
  - track 1 bunch over 1000 turns
    → now need to track batches of bunches over 1000 turns
    - Requires more memory → more post-processing to reduce data rates
  - measure 'm=1' HT modes (~1 GHz) → need to go higher for 'm>1' modes

- Limited number of suppliers for systems with f_{bw}>2 GHz bandwidth, all providing systems with >6 GHz bandwidth but with difference w.r.t. RAM:
    - Agilent (DAQs and Scopes): up to 1 GB/channel
    - LeCroy (Scopes only): up to 256 MB/channel
    - Tektronix (Scopes only): up to 128 MB/channel
    - Guzik (DAQ): up to 32 GB/channel

- Huge buffers simplify triggering and data selection but also make smart memory management, online and automatic post-processing mandatory, i.e. *"1 GB of data requires >10 seconds for read-out with standard Gigabit Ethernet link – no post processing yet" we ideally desire an answer/pre-analysis every ~30 seconds"*
  - technically feasible but should be kept in mind during design stage

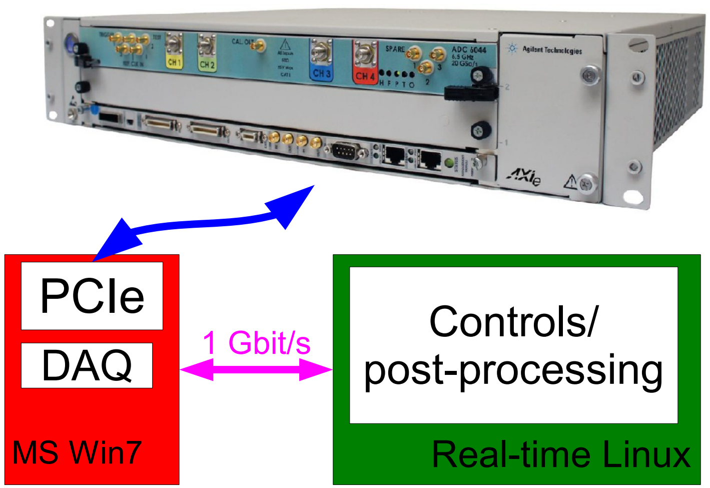
Digital Acquisition System II/II

- Gigabyte Sampling Buffers: The aim is not to systematically process, analyse and store the whole buffer but to allow data-mining in case of instabilities:
  - Use-case example 1: Unstable bunches or batches are not known in advance. However, the unstable ones and timing can be identified with e.g. FastBCT and other instruments after the instability occurred → can be used to narrow the range of the data to be retrieved
  - Use-case example 2: instrument could be used by several users with different diagnostics indicators at the same, e.g. 'user 1' monitors few bunches over maximum number of turns while 'user 2' acquires the first 500 full turns looking for bunch-by-bunch oscillations but at a reduced sampling frequency.
  - Use-case example 3: do not just fulfil the minimum required but keep specification open to allow future upgrades and R&D, i.e. present HT monitor was designed to measure Q' but not as instability monitor, larger buffer and bandwidth allowed the exploitation for other beam studies outside the scope during the design.

    (N.B. small difference in price for going from 2.5 → 6 GHz, ~ 25% of total costs)

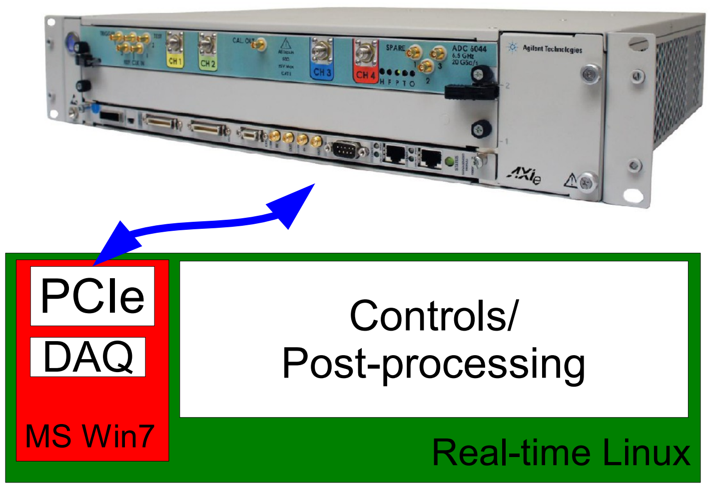
Integration options

- Option A – using dedicated machine



- bottleneck: Ethernet or increased costs/integration of 40 Gbit/s link

- Option B – using VMware



- Much faster data transfer
  → limited only by PCIe x4 (x8)
- However: VMware PCI-Express bridge needs to be demonstrated

Reserve slides

Head-Tail based Q' Diagnostic I/II

- Instability can be exploited to give in estimate on Q' in the first place:
  - track two slices, 'head' and 'tail' in the bunch distribution: $\Delta z_{HT}(n) \propto \sin(\psi_{HT}(n))$

    (tune: Q, long slice position: τ, synchrotron frequency: ω_s, turn: n)

    - Phase difference of betatron oscillations:

$$\psi_{HT}(n) = 2\pi Q \cdot n + \Delta\phi_\beta \quad \textit{with} \quad \Delta\phi_\beta \approx Q' \cdot \underbrace{\frac{\omega_0 \hat{\tau}}{\eta} \cdot \sin(\omega_s \cdot n)}_{\Delta p/p \, modulation}$$