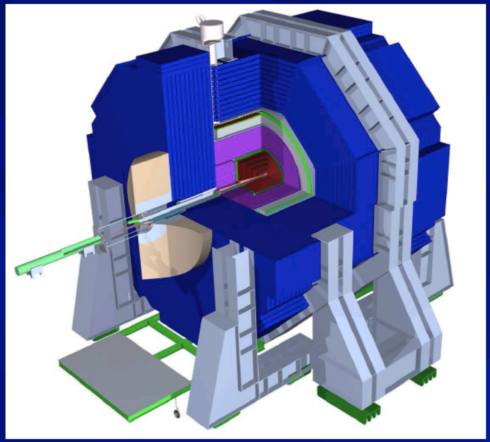
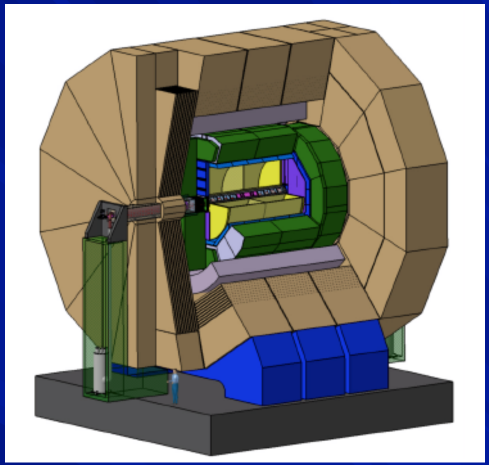
Introduction to TDAQ





Z.A.LIU, TriggerLab, IHEP

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Fast Electronics and Detector Summer School,
SDU/Weihai, China, Aug. 2018

Outlook of this talk:
T/DAQ: Evolution of architectures, tools and techniques

- Basic about Trigger and DAQ
  - Common terms, T/DAQ in physics
  - Example with BESIII/BEPC
- Technologie for future experiments
  - LHC upgrade
  - FAIR-PANDA
  - ILC/FCC/CEPC
  - CEPC/SppC
  - What next in TDAQ
    - the 'Ultimate' Trigger concept -→ The Software trigger
- Summary

Technologie for future experiments

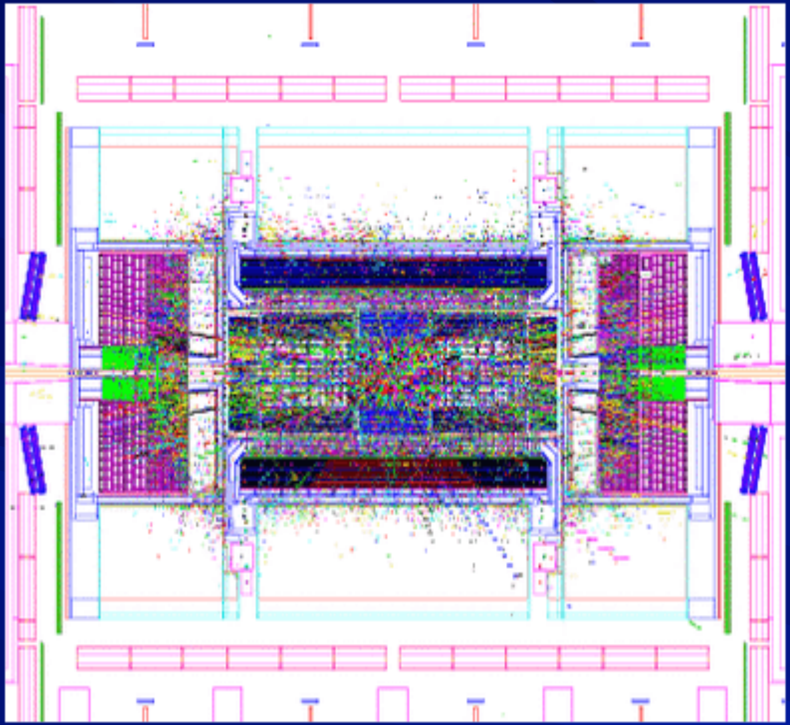
LHC upgrades

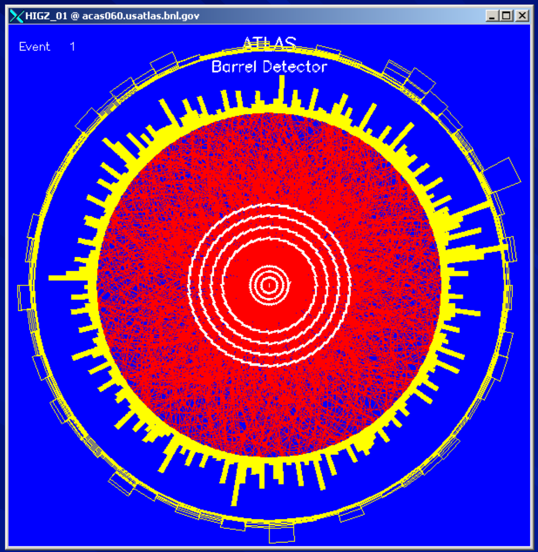
Few words …

Requirements for LHC phases of the upgrades: ~2010-2020

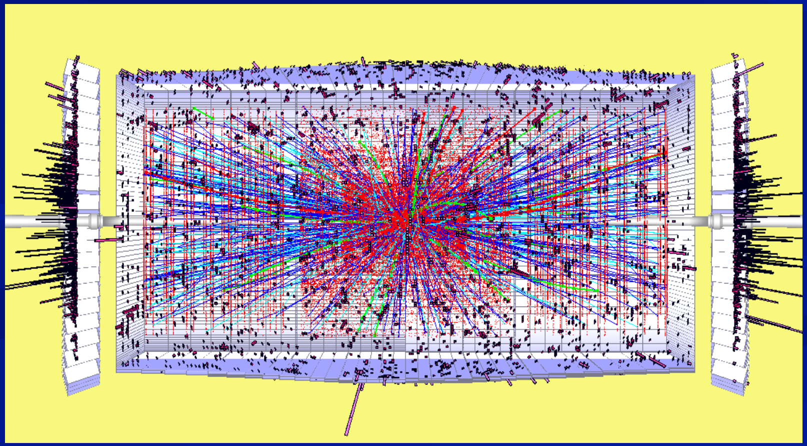
- Phase 1: (2016)
  - Goal of extended running in second half of the decade to collect ~100s/fb
  - 80% of this luminosity in the last three years of this decade
  - About half the luminosity would be delivered at luminosities above the original LHC design luminosity
  - Trigger & DAQ systems should be able to operate with a peak luminosity of up to 2×10^{34}
- Phase 2: High Lumi LHC (2022?)
  - Continued operation of the LHC beyond a few 100/fb will require substantial modification of detector elements
  - The goal is to achieve 3000/fb in phase 2
  - Need to be able to integrate ~300/fb-yr
  - Will require new tracking detectors for ATLAS & CMS
  - Trigger & DAQ systems should be able to operate with a peak luminosity of up to $5\text{~}8 \times 10^{34}$

Expected Pile-up at High Lumi LHC at 10^{35}





$N_{ch}(|y| \leq 0.5)$



- 230 min.bias collisions per 25 ns. crossing
- ~ 10000 particles in |h| £ 3.2
- mostly low pT tracks
- requires upgrades to detectors
- AND TRIGGERS

Trigger/DAQ upgrades

- Need more data to measure Higgs properties and make further discoveries, the LHC will deliver this
- Constrained with the same trigger rates in the near future
- Simply raising thresholds is a bad strategy, cut into phase space for the studies and negates effect of extra luminosity
- Need to have better algorithms and more flexibility in combining requirements, possibly add tracker to LVL1 trigger
- Maintenance and obsolescence, electronics have advanced since the original trigger system was designed and built
- can build something simpler and easier to maintain now

Lessons :Simplify,simplify,simplify .....

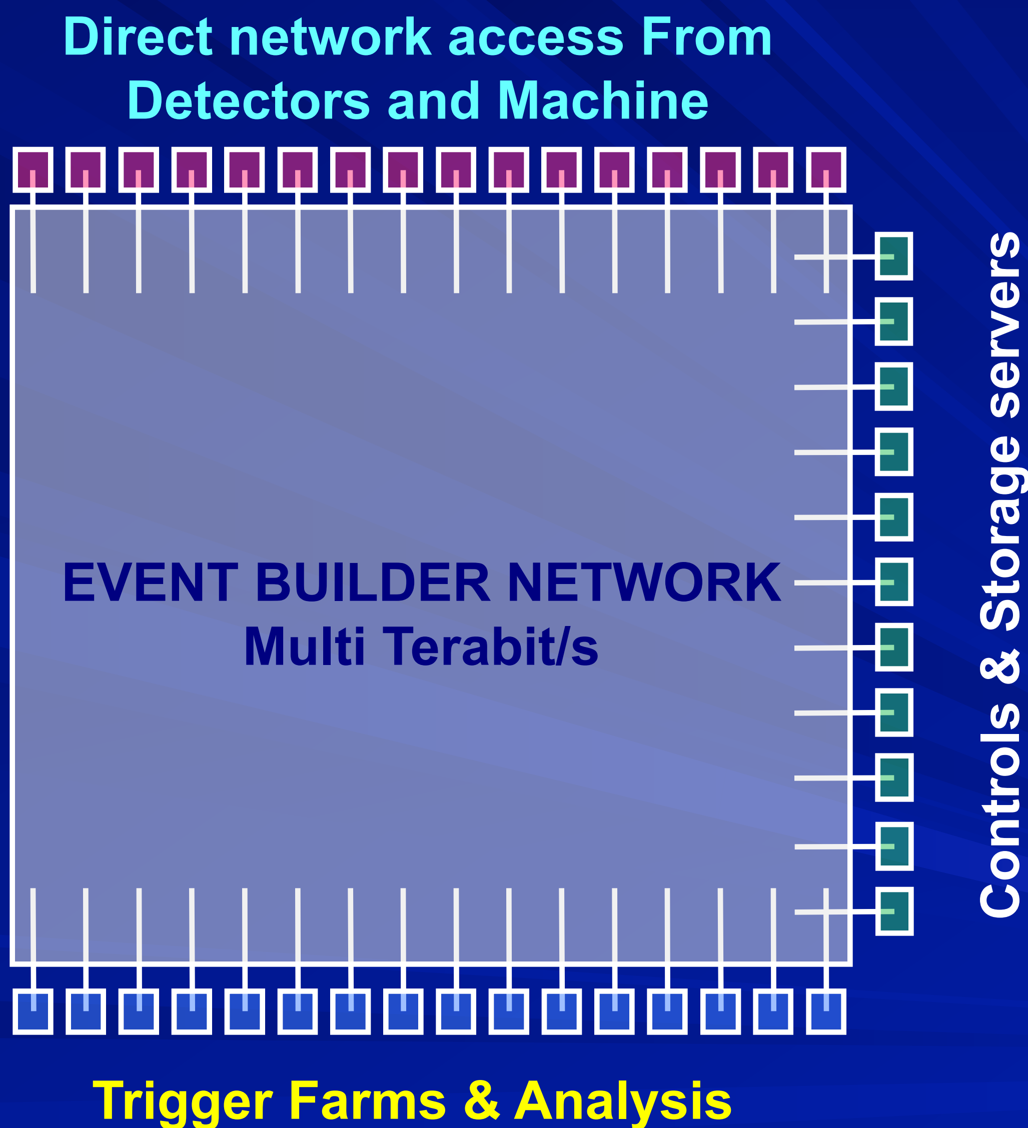
- Aim for higher integration
  - use larger FPGAs, build system in more compact way
  - fewer, more generic / interchangeable boards
- Use standardized electronics where possible
  - COTS (Commercial off-the-shelf) component like µTCA
- Use optical links
  - higher data rates (higher precision, more trigger objects)
  - less space for connectors (µTCA instead of 9U-VME)
- HLT
  - New network/swithes
  - New powerfull processors (GPU's..)

Modern DAQ architectures

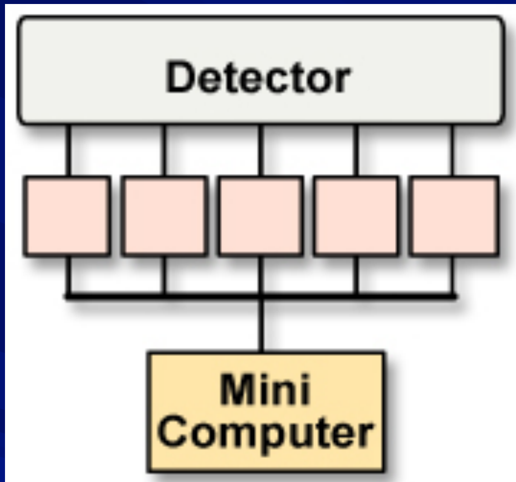
PANDA @ GSI-FAIR
LHCb @ CERN

There are many others but I am a bit bias!

DAQ = Global Experiment Network



Evolution of DAQ technologies and architectures

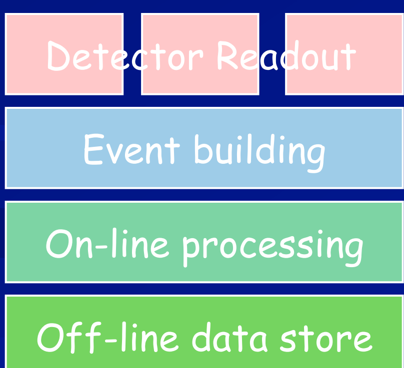


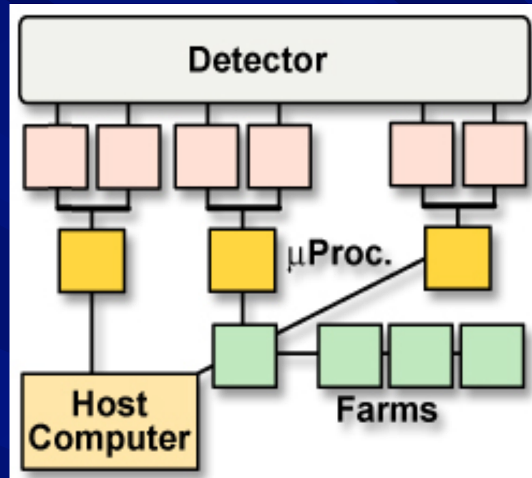
1970-80

CERN PS/SPS

Minicomputers

Readout custom design
First standard: CAMAC
kByte/s



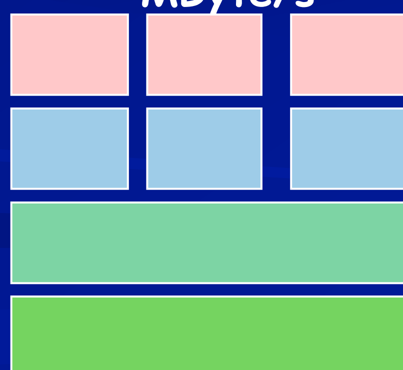


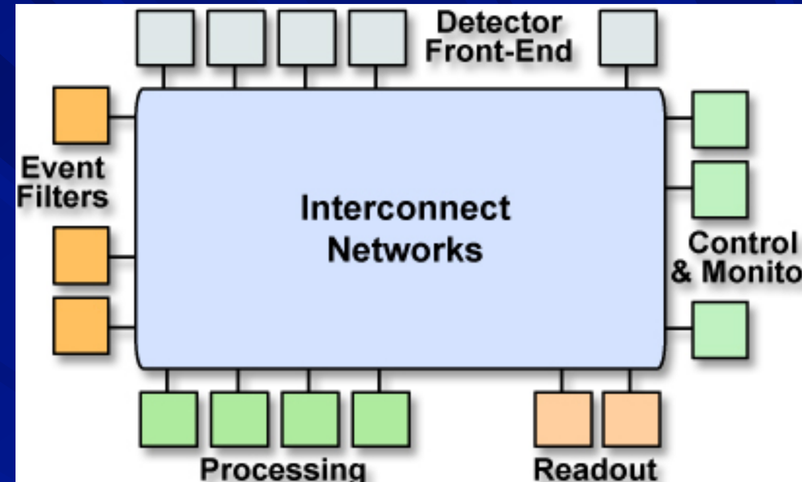
1980-90

LEP

Microprocessors

HEP standards (Fastbus)
Embedded CPU,
Industry standards (VME)
MByte/s



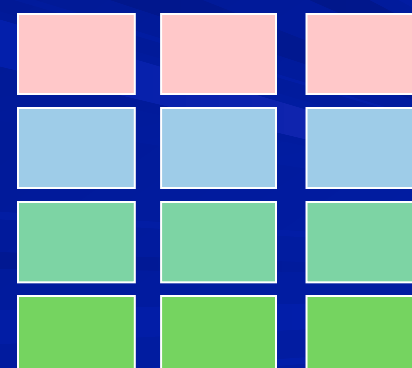


2007 …

LHC (CMS)

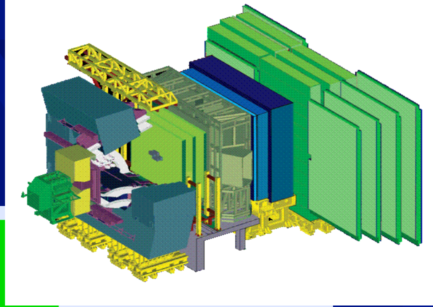
Networks/Grids

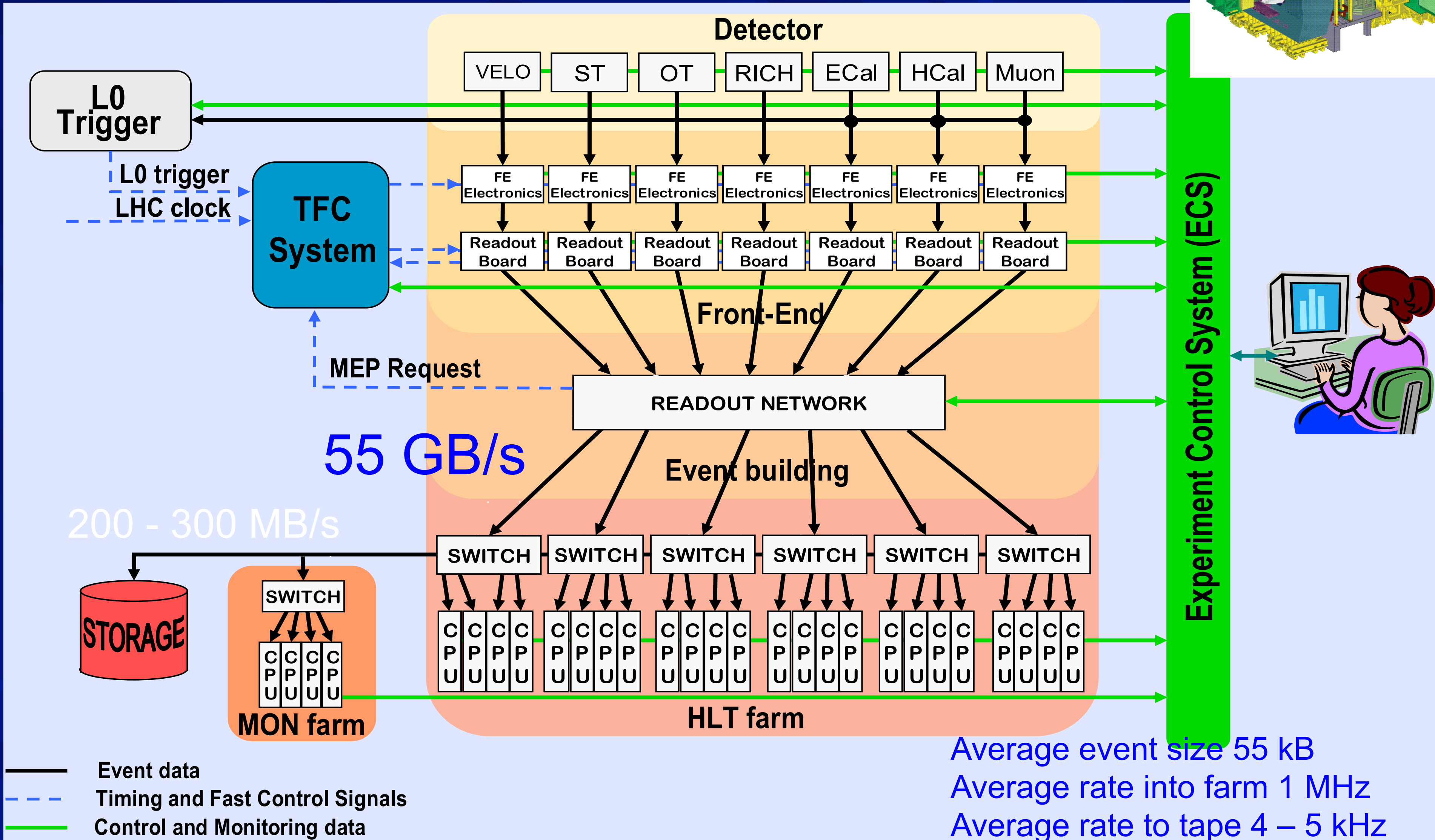
IT commodities, PC, Clusters
Internet, Web, etc.
GByte/s



From S. Cittolin

LHCb DAQ





Average event size 55 kB
Average rate into farm 1 MHz
Average rate to tape 4 – 5 kHz

LHCb DAQ as of 2018

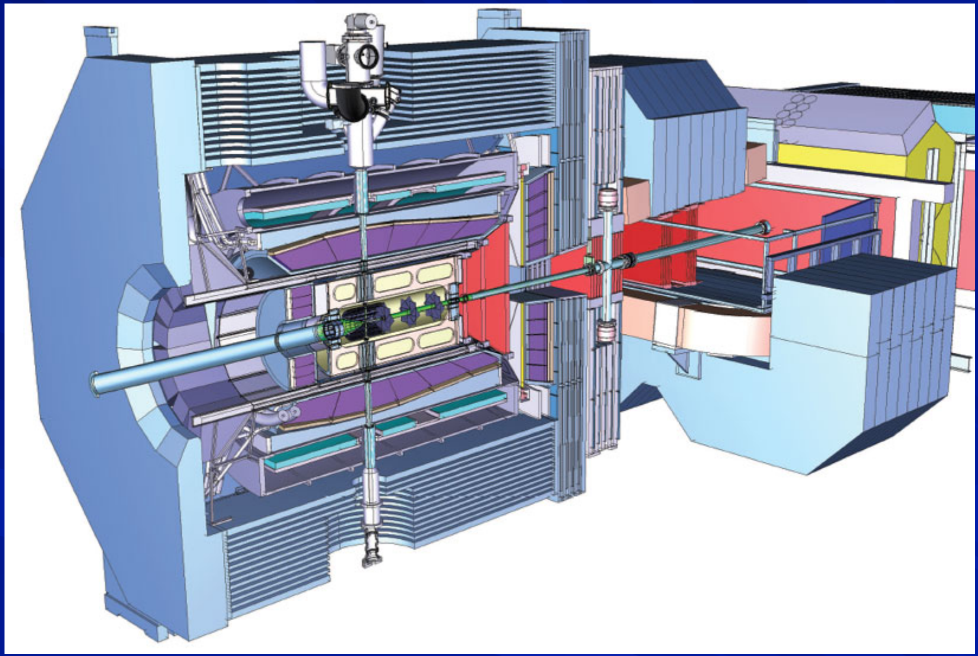
- GBT: custom radiation- hard link, 3.2 Gbit/s (about 10000)
- Input into DAQ network (10/40 Gigabit Ethernet (1000 to 4000)
- Output from DAQ network into compute unit clusters (100 Gbit Ethernet (200 to 400 links)
- Compute units could be servers with GPUs or other coprocessors

PANDA exp @ FAIR (GSI) → 2016

JLU Giessen, GSI Darmstadt,

IHEP Beijing, UNIV. Krakow, TU Muchen,……

$\bar{p}+p,\ \bar{p}+A < 15\ GeV/c$



High Rates
Total σ~ 55 mb
10^7interactions/s
Micro Vertexing
Charged particle ID(e,μ,π,p,...)
Tracking /TPC
Elm. Calorimetry (γ,π^0,η)
Forward capabilities (leading particles)
Sophisticated event selection max

Requirements for PANDA DAQ

- Interaction rates up to 30MHz
- typical event sizes 4 -8 kB.
- data rates after front end pre processing 40GB/s -200 GB/s
- High flexibility and selectivity at very high data rates

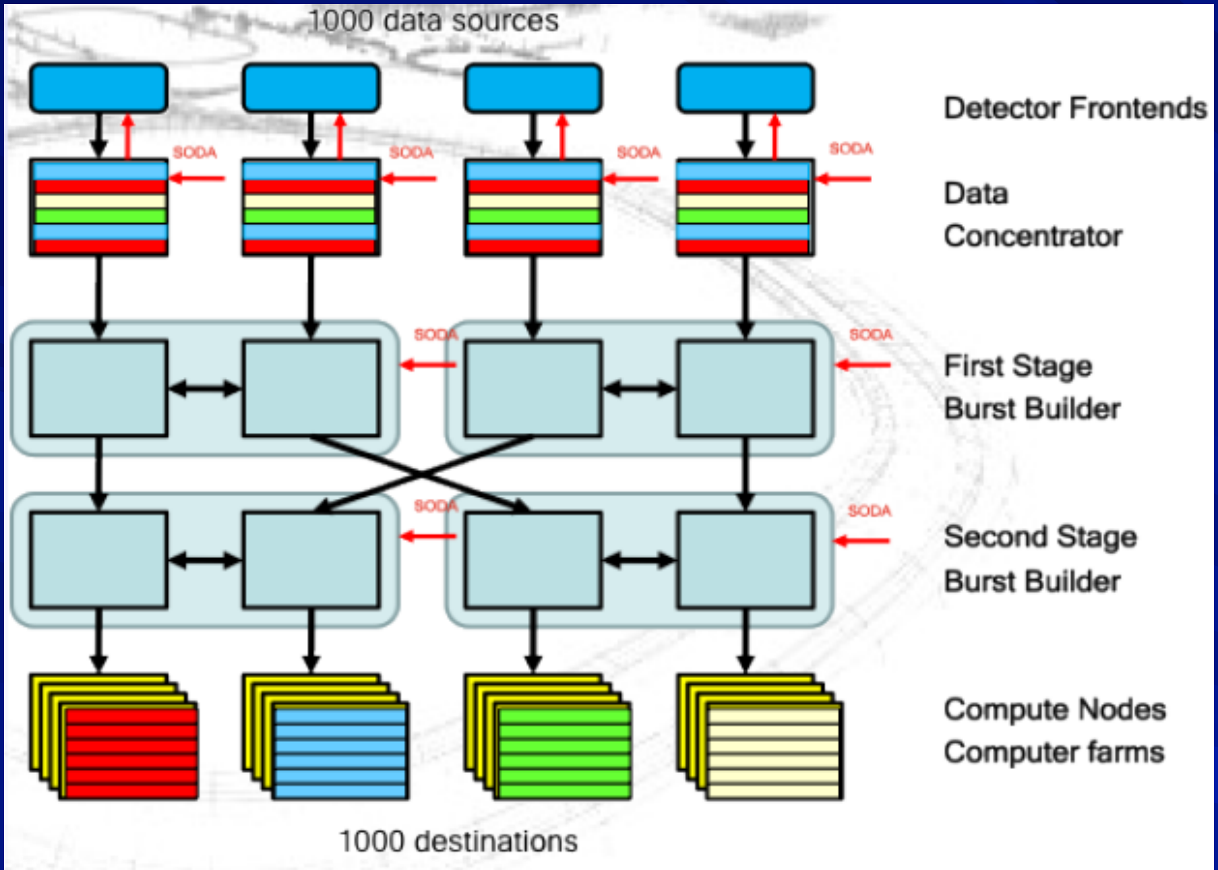
and with different processes measured in parallel

- Solution: ---> self triggered read out
  - continuously sampling data acquisition (No synchro)
  - No hardware triggers（？）
- Event selection in programmable processing units
- Connection via high speed networks

Concept of PANDA DAQ

- Interaction rates up to 30MHz
  - typical event sizes 4 -8 kB.
  - data rates after front end pre processing 40GB/s -200 GB/s
- Main Features
  - No hardware trigger（Tanditional)
  - Self triggered → Continuous sampling (No synchro) , data reduction and feature extraction in FEE
  - Time distribution system tags data
  - Data burst building in high speed network
  - Event building in compute nodes
  - Software trigger
  - On line Event reconstruction and data logging

PANDA T/DAQ Conceptual Architecture



- Data Concentrator
  - Feature extraction
    - Time & Amplitude
    - Clusterization
    - Zero Suppression
- Burst builder
  - Combine data:
    - One burst = one data block
- Compute Node & Computer farm
  - On line data peocessing
  - Accept/reject decision

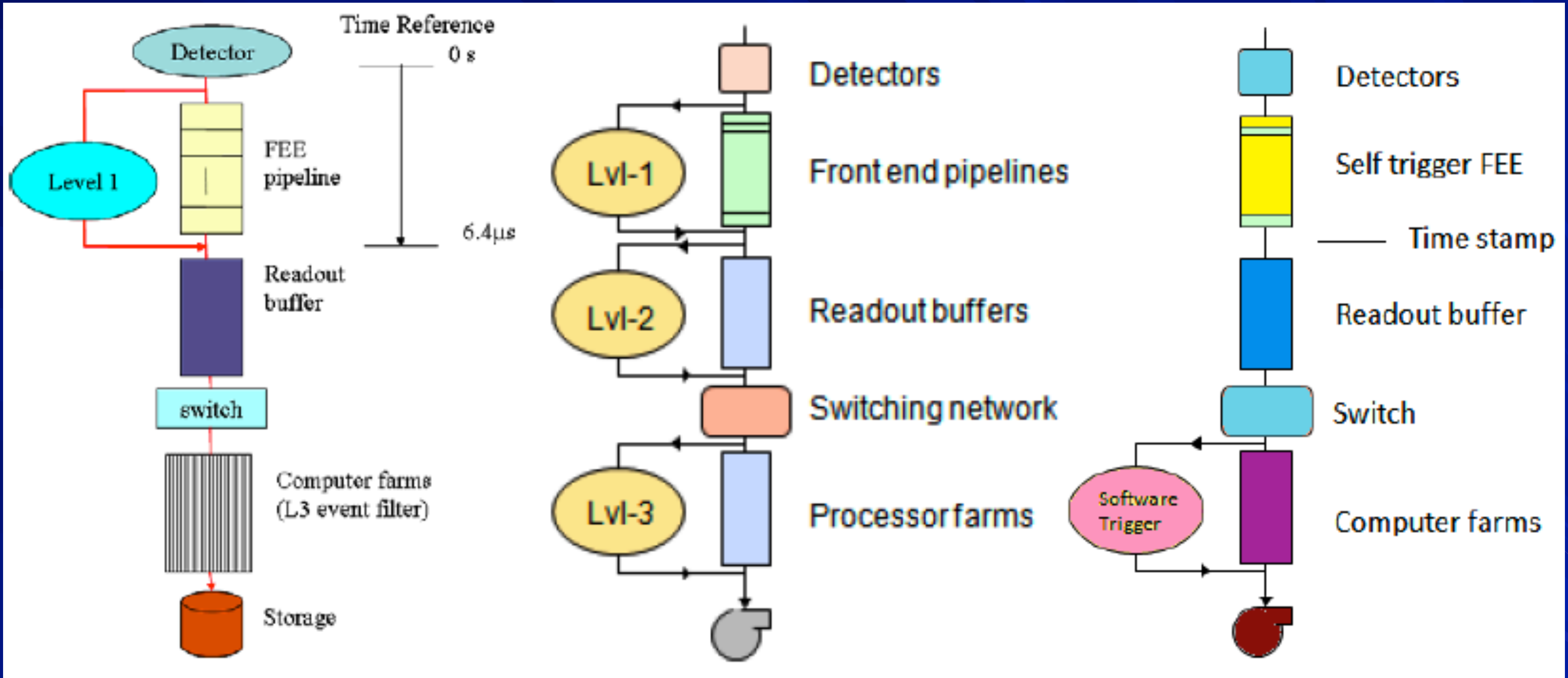
XU, Hao

"Introduction of PANDA Data Acquisition System"

Trigger and Data Acquisition Systems

TIPP 2011 -Chicago

Example of 'Trigger less DAQ'

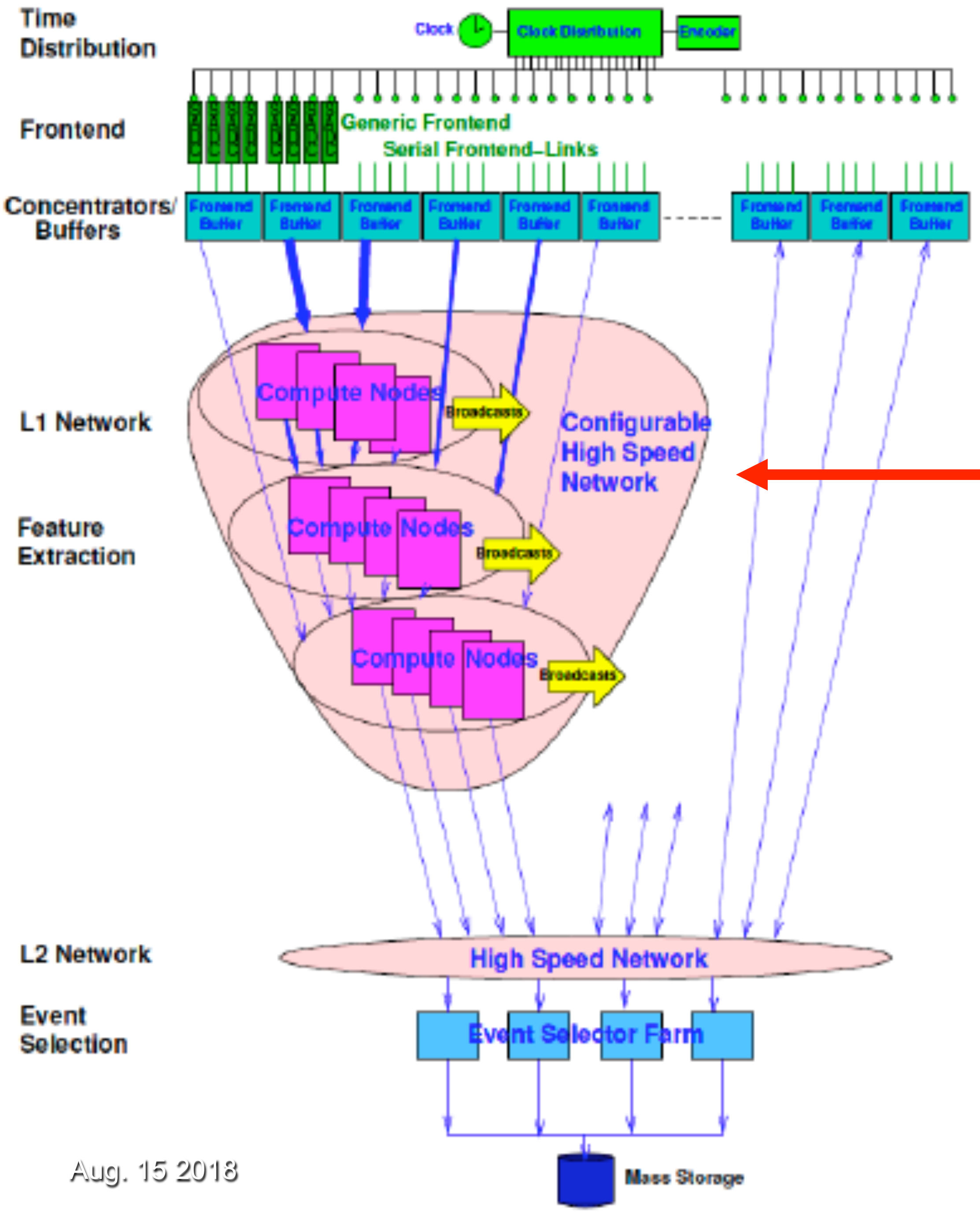


CDF/D0-BES3

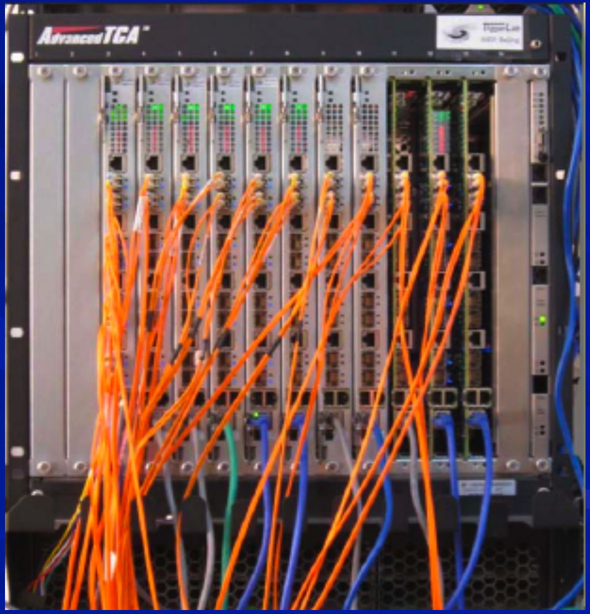
LHC-Atlas/

PANDA

PANDA Architecture



- Compute Node by IHEP Beijing/JLU Giessen



What next ?

- CEPC/Sppc
- International Linear Collider
- Software trigger concept
- Evolution of technologies

A Chinese Dream

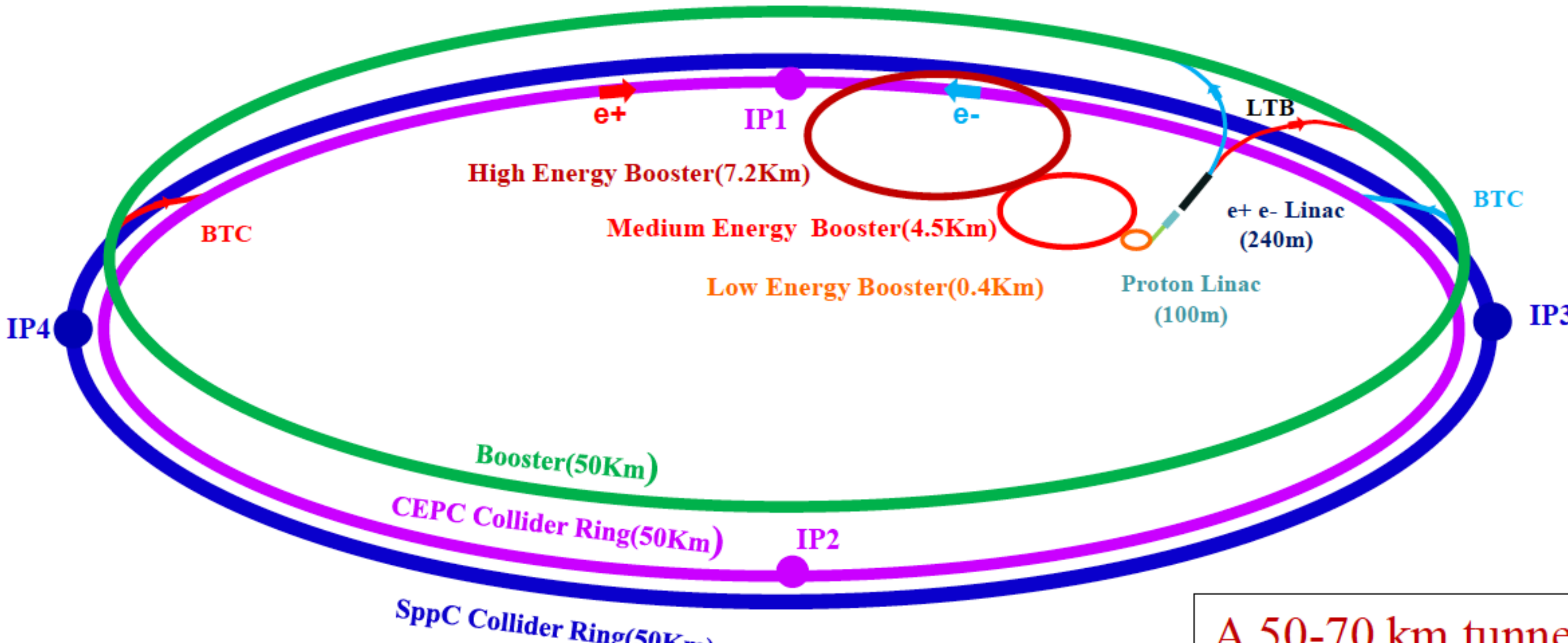
CEPC-SppC: an initiative from China for the future of HEP

Yifang Wang

Institute of High Energy Physics, Beijing

UChicago, Jan. 22, 2016

- Thanks to the low mass Higgs, we can build a Circular Higgs Factory(CEPC), followed by a proton collider(SppC) in the same tunnel
- A natural continuation of BEPC→BEPCII→CEPC→SppC



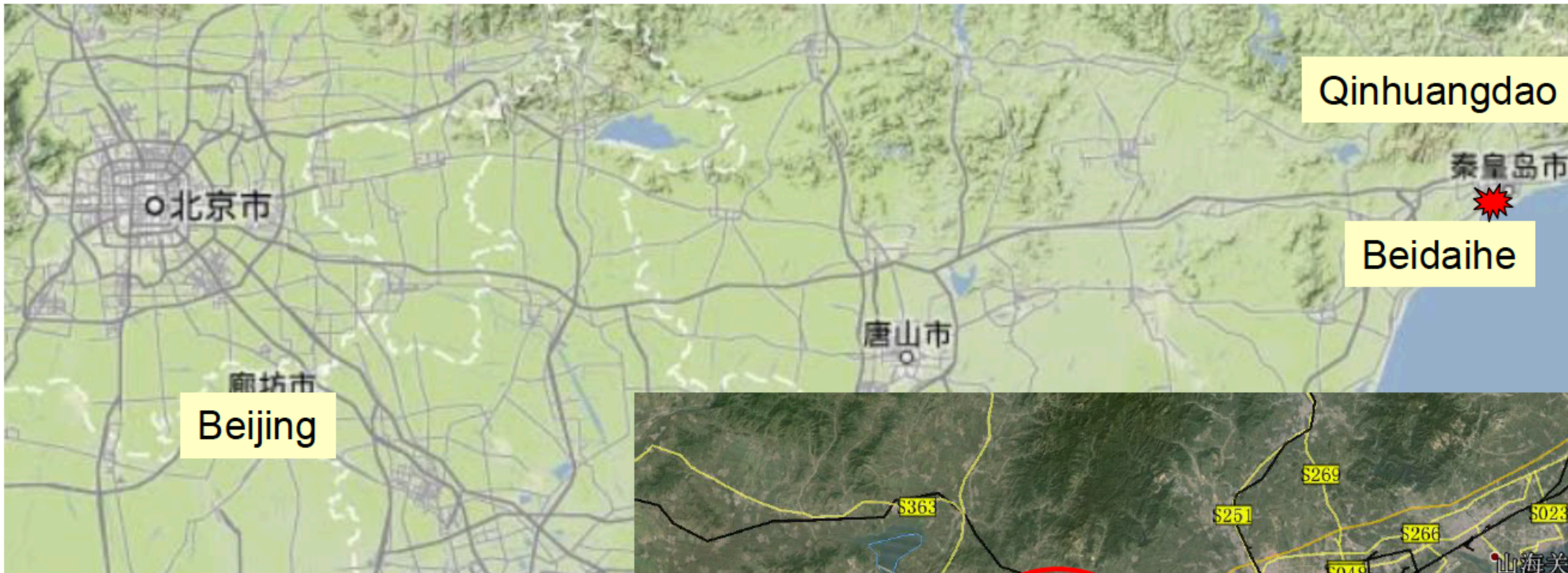
A 50-70 km tunnel is

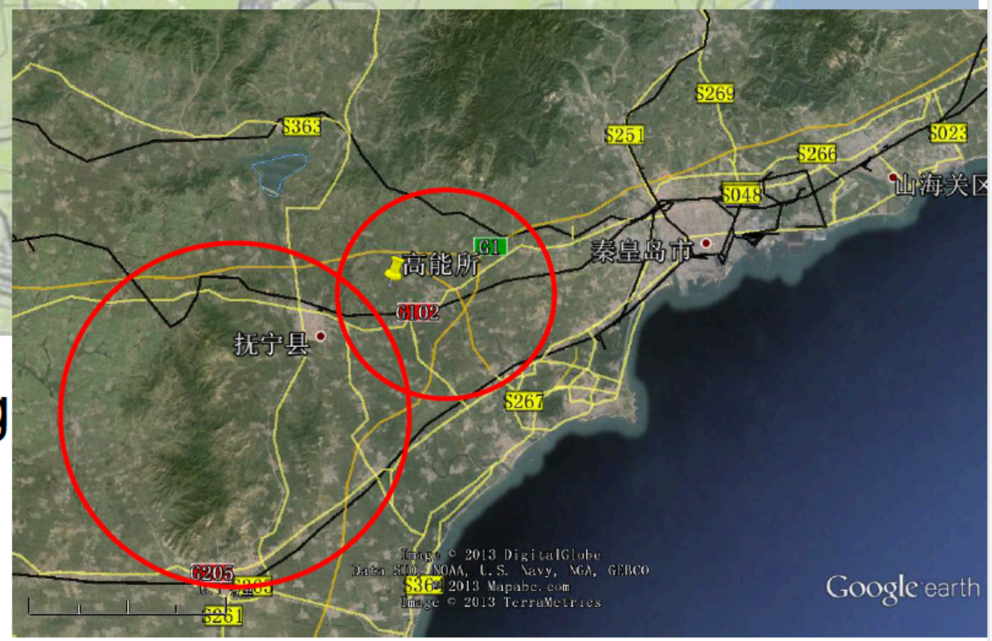
Science

- **Electron-positron collider(90, 250, 350 GeV)**
  - Higgs Factory: Precision study of Higgs(m_H, J^{PC}, couplings)
    - Similar & complementary to ILC
    - Looking for hints of new physics
  - Z & W factory: precision test of SM
    - Deviation from SM ? Rare decays ?
  - Flavor factory: b, c, τ and QCD studies
- **Proton-proton collider(~100 TeV)**
  - Directly search for new physics beyond SM
  - Precision test of SM
    - e.g., h^3 & h^4 couplings

Precision measurement + searches:
Complementary with each other !

A Candidate Site





- 300 km from Beijing
- 3 h by car
- 1 h by train

ILC machime conditions

2004 International decision: « cold » machine ‘ à la Tesla’

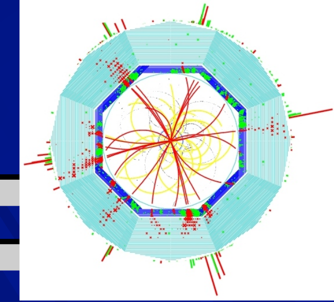
Machine parameters close to

- 2 x 16 km superconducting
Linear **independant** accelerators
- Max 2 interaction points
→ **2 detectors ???**
- Energy
  - nominale : 500 Gev
  - maximum : 1 Tev
- IP beam size ~ few µm
- L= 2. 10 ^{34} cm^{-1}s^{-1}

The LC is a pulsed machine

- repetitian rate 5
- bunches per train 2820 → **x 2 ?**
- bunch separation 337 ns →150ns
- train length 950 ns
- train separation 199 ms

-> *long time between trains*
(short between pulses)

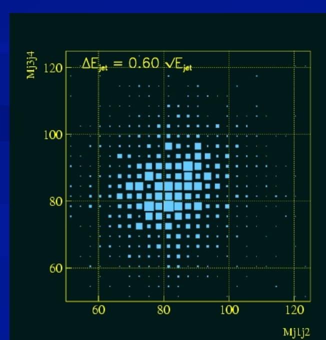


ILC vs LEP/SLD

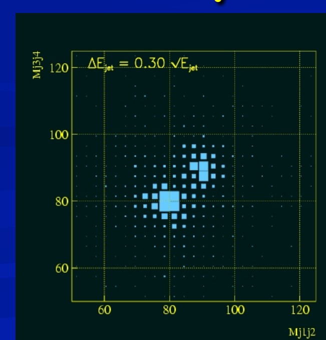
- Jets & leptons are the fundamental quanta at the ILC. They must be identified & measured well enough to discriminate between Z's, W's, H's, Top, and new states. **This requires improving jet resolution by a factor of two. Not trivial!**
- Charged Particle tracking must precisely measure 500 GeV/c (5 x LEP!) leptons for Higgs recoil studies. …. **This requires 10 x better momentum resolution than LEP/SLC detectors and 1/3 better on the Impact Paramater of SLD!**
- To catch multi-jet final states (e.g. t tbar H has 8 jets), need real 4π solid angle coverage with full detector capability. **Never been done such hermiticity & granularity!**

LEP-like resolution

$60\%\sqrt{E}$



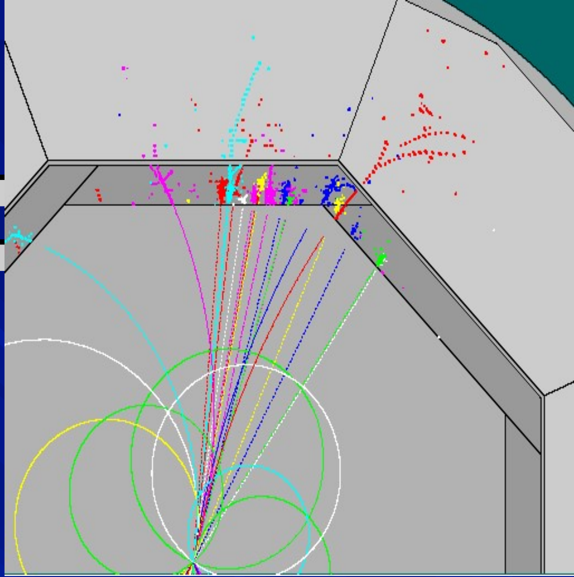
2 Jets separation



ILC goal

$30\%\sqrt{E}$

ILC vs LHC

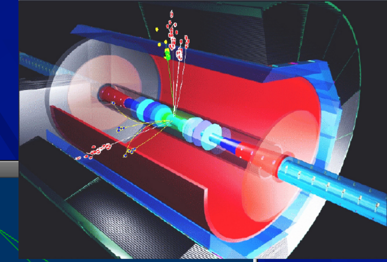


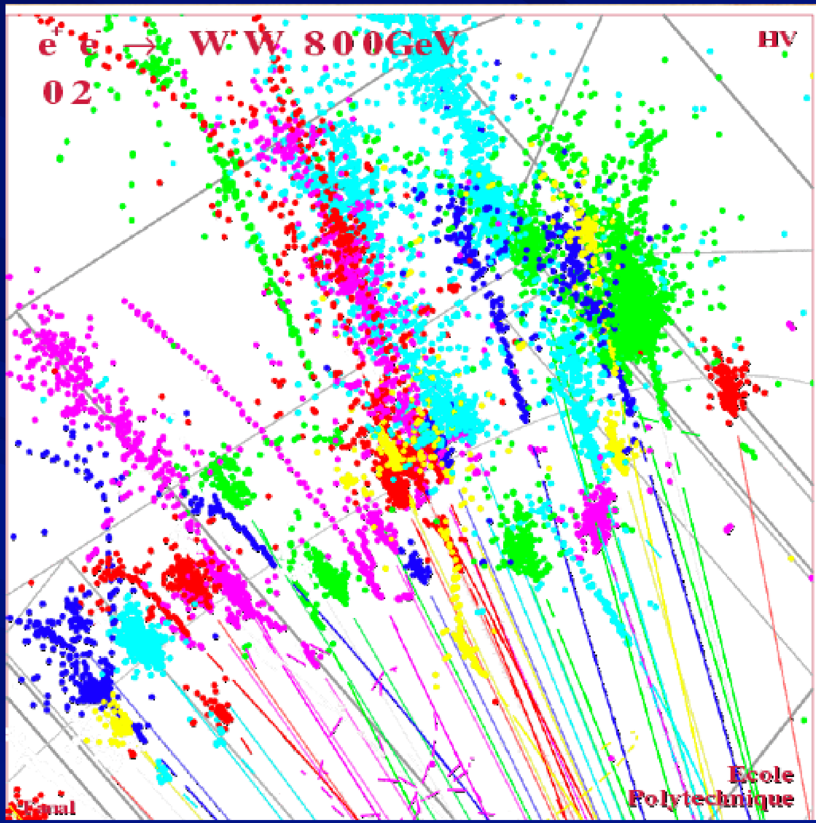
- **Less demanding …..**
  LC Detector doesn't have to cope with multiple minimum bias events per crossing, high rate triggering for needles in haystacks, radiation hardness…
  → hence many more technologies available, better performance is possible.

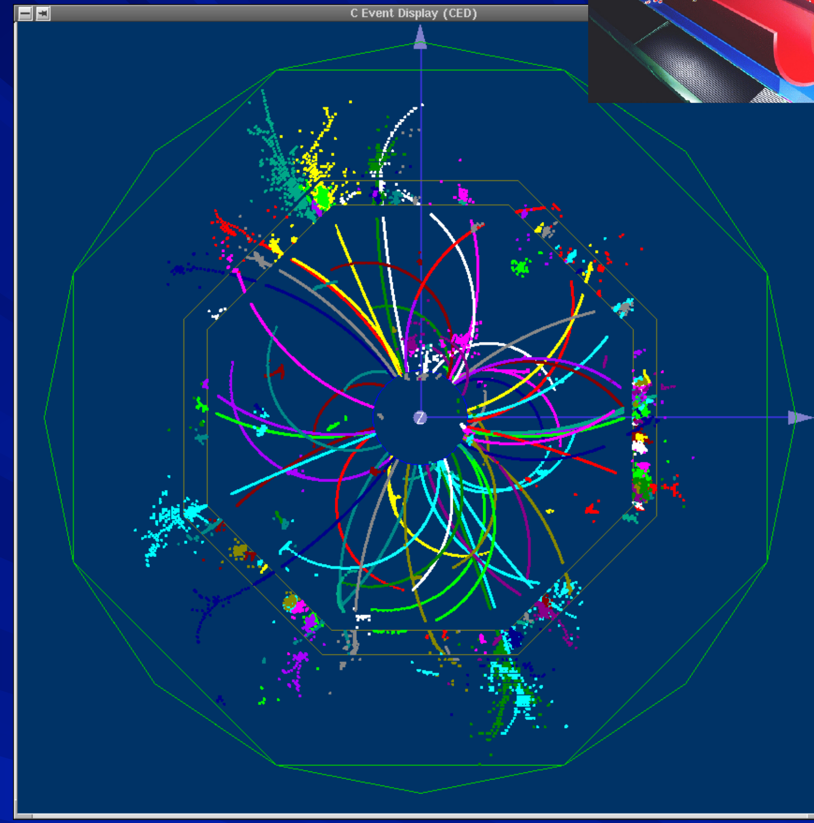
- **BUT** → LC Detector does have to cover full solid angle, record all the available CM energy, measure jets and charged tracks with unparalleled precision, measure beam energy and energy spread, differential luminosity, and polarization, and tag all vertices,…
  → hence better performance needed, more technology development needed.

- **Complementarity with LHC → discovery vs precision**
  The 'Particle flow' paradigm in calorimeters !
  → LC should strive to do physics with ***all*** final states.
  Charged particles in jets more precisely measured in tracker
  Good separation of charged and neutrals

ILC Particle Flow Algorithm (PFA)





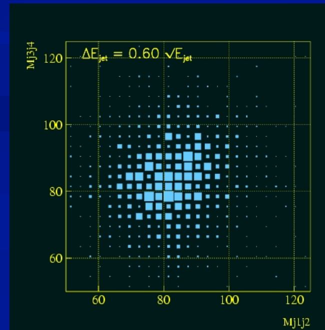


PFA simulation

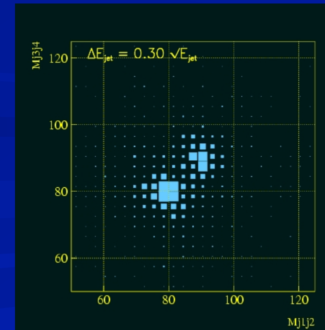
e.g. tt event in LDC

LEP-like resolution

$60\%\sqrt{E}$



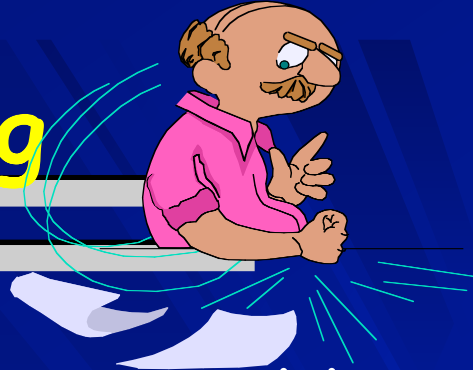
2 Jets separation



ILC goal

$30\%\sqrt{E}$

Summary of present thinking



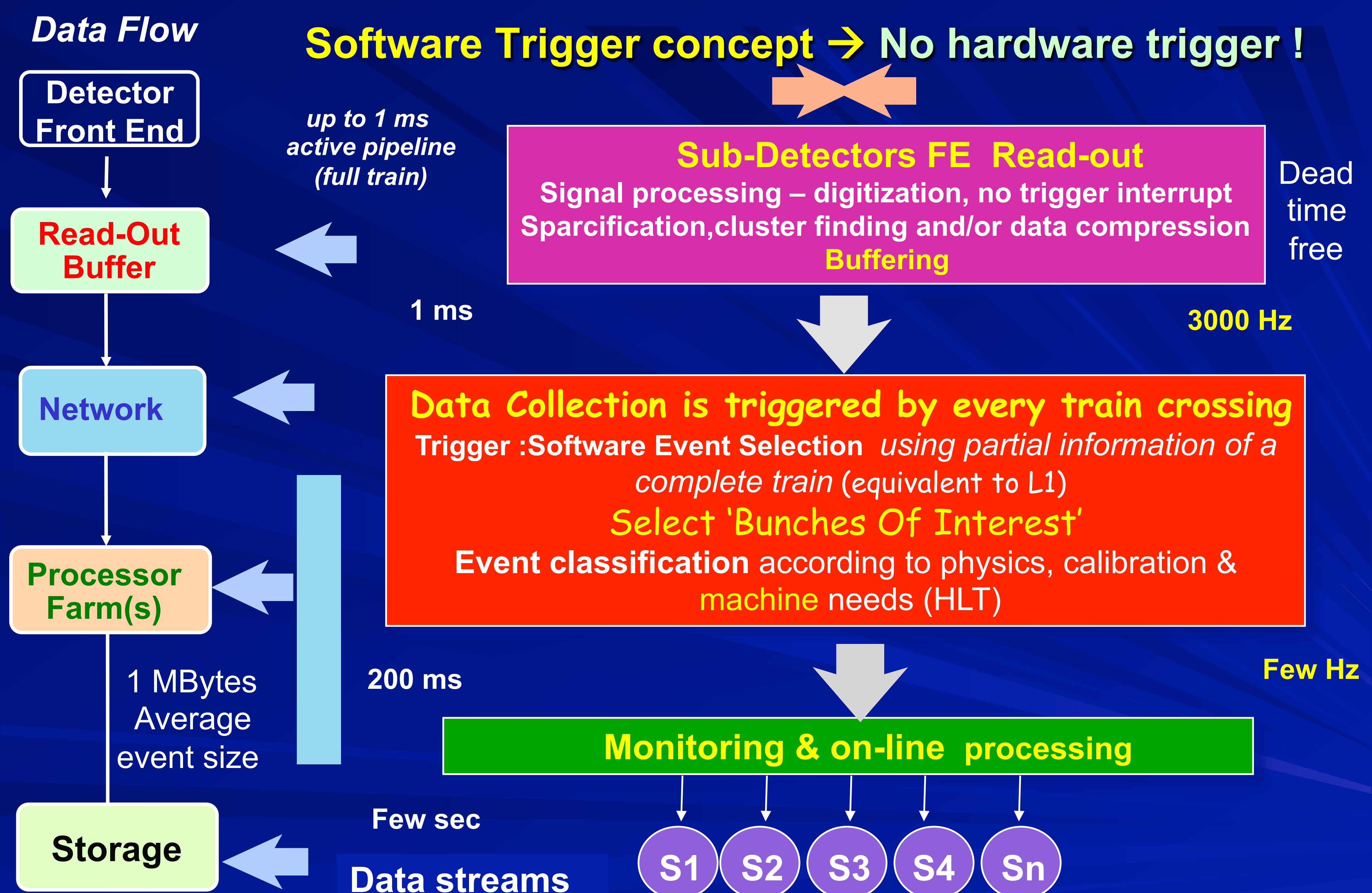
The ILC environment poses new challenges & opportunities which will need new technical advances in Data Collection

→ NOT LEP/SLD, NOT LHC !

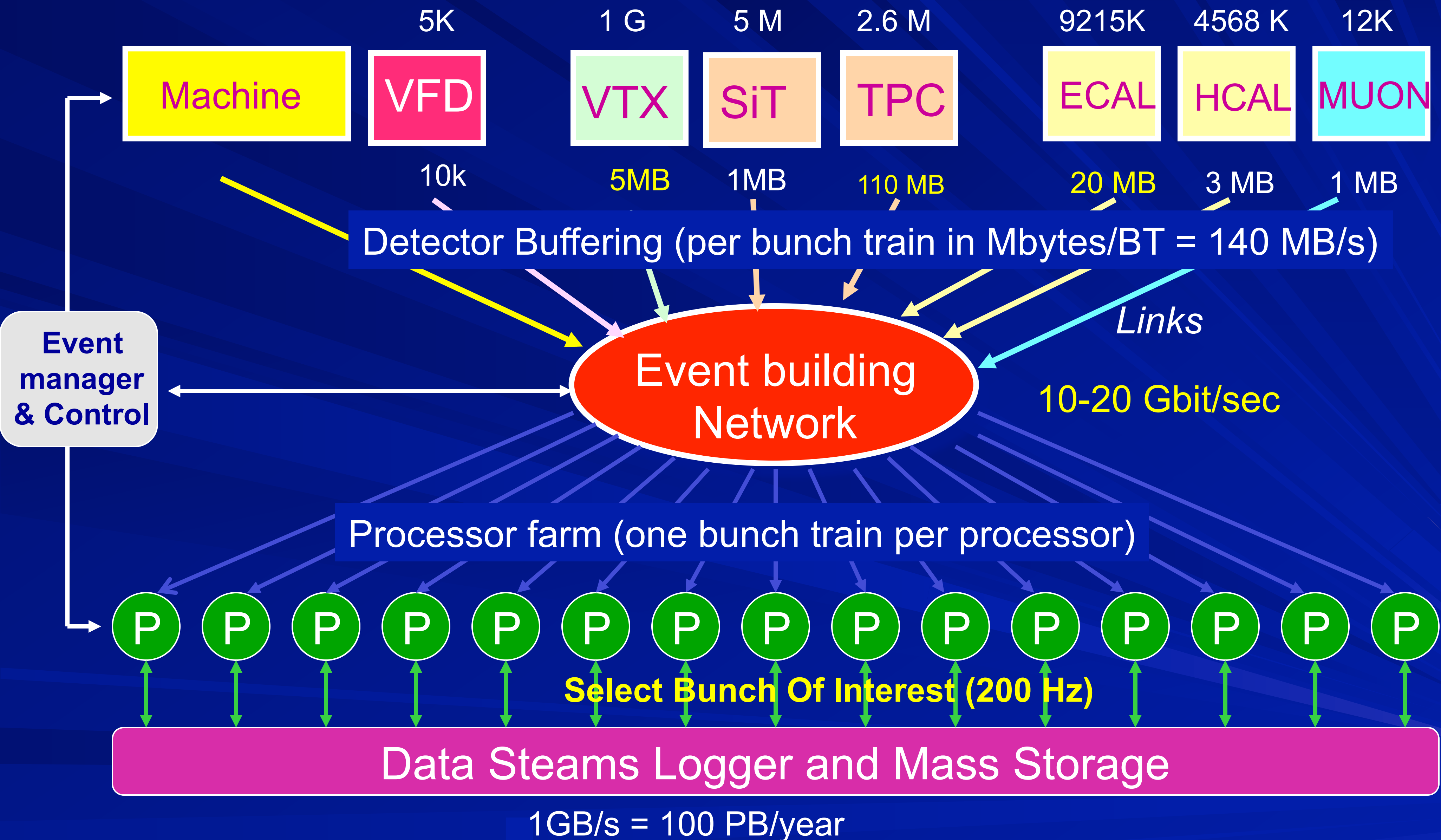
- The FEE integrates everything
  - →From signal processing & digitizer to the RO BUFFER …
- Very large number of channels to manage (Trakers & ECal)
- Interface and feedback between detector & machine is fundamental
  - →optimize the luminosity → consequence on the DAQ architecture
- Classical boundaries are moving : Slow control, On/Off line ….
- Burst mode allows a fully software trigger !
  - → Flexible, scalable and cost effective…

→Looks like the Ultimate Trigger: Take EVERYTHING & sort later !

→ **GREAT! A sociological simplification!**


Data Flow
Software Trigger concept → No hardware trigger !
Detector Front End
up to 1 ms active pipeline (full train)
Sub-Detectors FE Read-out
Signal processing – digitization, no trigger interrupt
Sparcification,cluster finding and/or data compression
Buffering
Dead time free
Read-Out Buffer
1 ms
3000 Hz
Network
Data Collection is triggered by every train crossing
Trigger :Software Event Selection using partial information of a complete train (equivalent to L1)
Select 'Bunches Of Interest'
Event classification according to physics, calibration & machine needs (HLT)
Processor Farm(s)
1 MBytes Average event size
200 ms
Few Hz
Monitoring & on-line processing
Few sec
Storage
Data streams
S1
S2
S3
S4
Sn

ILC DAQ conceptual (ILD) Architecture



About systems boundaries …..moving due to !
→ evolution of technologies,sociology …..

NEW !

Machine
Synchronization
Detector feedback
Beam BT adjustment

Subdetectors
FE Read Out
Signal processing
Local FE Buffer

Uniform interface

Read out Node
Partitionning
(physical and logical)

Full Integration
of Machine DAQ
In the data
collection system

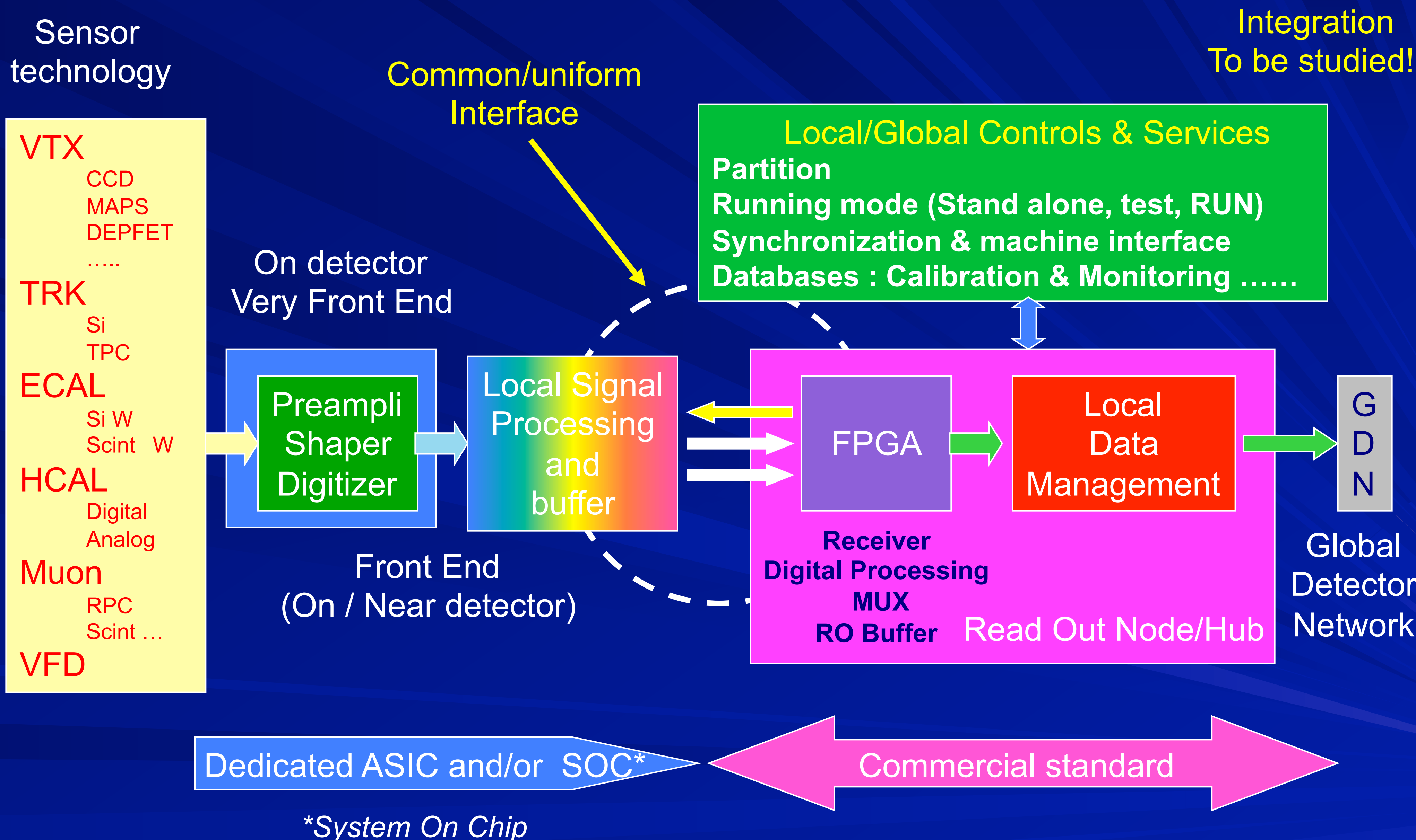
Data Collection (ex on-line)

Bunch Train data collection from Buffer RO
Bunch Of Interest selection
SW trigger & algorithms
Event Building
Control - supervisor
On line Processing
Global calibration ,monitoring and physics
Local (temporary) Data logging (Disks)

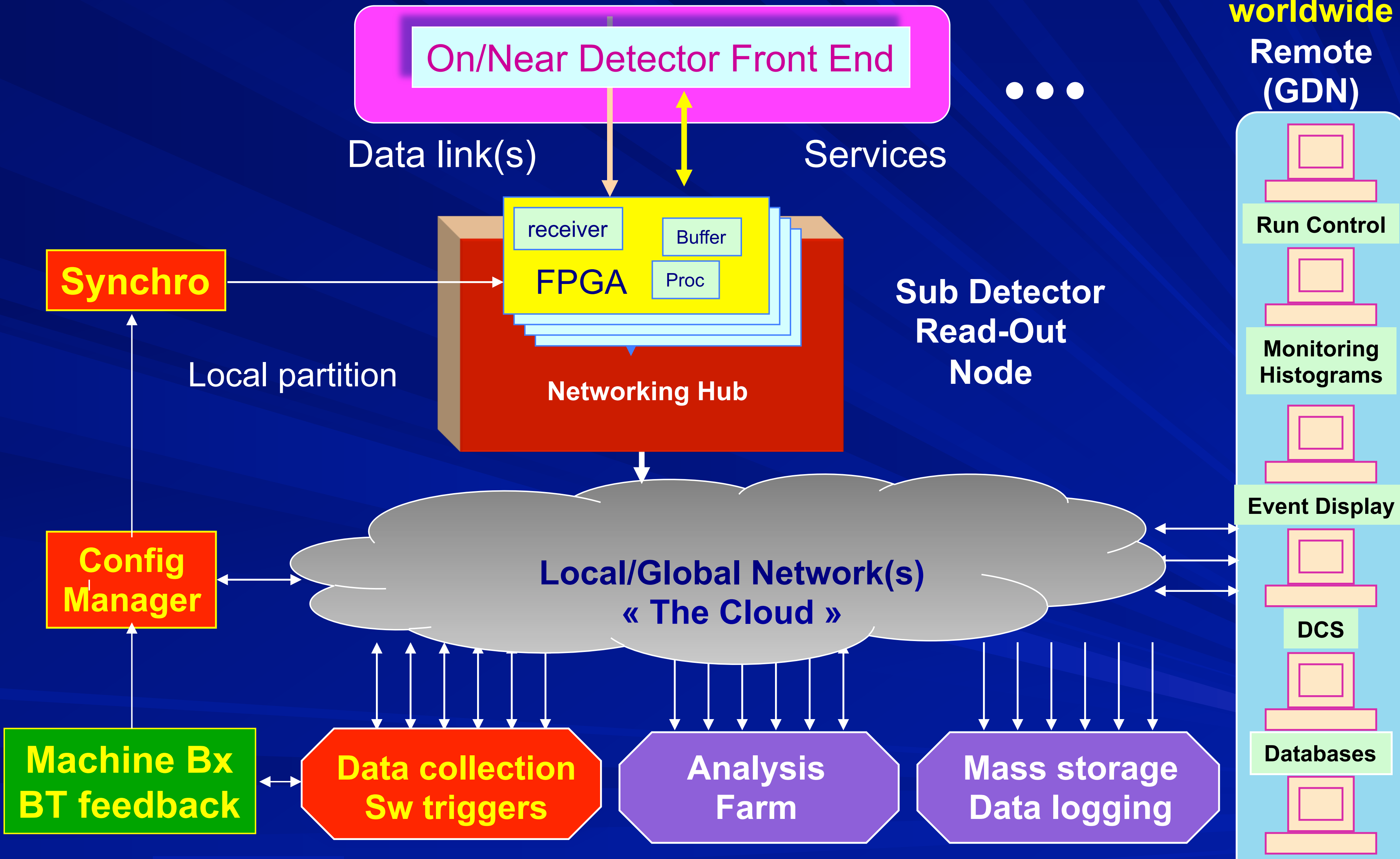
Global Detector Network (worlwide)

- Detector Integration
- Remote Control Rooms (3?)
  - Running modes
    - Local stand alone
    - Test
    - Global RUN
  - Remote shifts
    - Slow control
    - Detector Monitoring
- Physics & data analysis (ex On- Off line)
  - Farms
  - GRID …
- Final Data storage

Current view of a uniform RO architecture



ILC 'today' Data Collection Network model



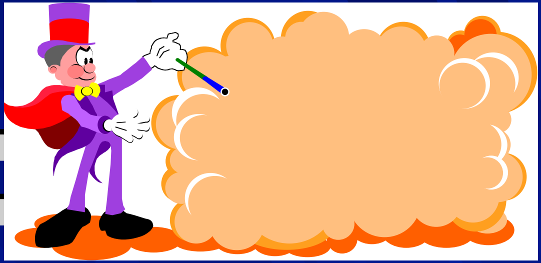
NO On line – Off line boundary

Some examples

Technology forecast summary

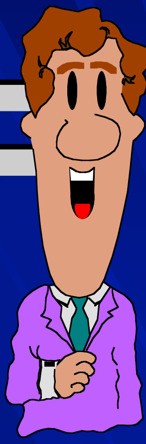
- End of traditional parallel backplane bus paradigm
  - Announced every year since ~1989
  - VME-PCI still there
    - watch PCI Express, RapidIO, xTCA
- Commercial networking products for T/DAQ
  - Conferences:
    - ATM, DS-Link, Fibre Channel, SCI
  - Today: Gigabit Ethernet (1 → 10 → 30 GB/s(40GbE))
- The ideal processing / memory / IO BW device
  - The past:
    - Emulators (370E),Transputers, DSP's, RISC processors
  - Today: FPGA's →
    - Integrates receiver links, PPC, DSP's and memory

Technology forecast (Con't)



- **Point-to-point link technology**
  - The old style: Parallel Copper – Serial Optical
  - The modern style: Serial Copper – Parallel Optics(12/24)
    - Today 10Gb/s → 30Gb/s
- **Processors** → Moore's law still true until 2015 ..at least!
  - Continuous increasing of the computing power
  - Today :10 to 15 GHz --> tomorrow ??? !
- **Memory size → quasi illimited !**
    - Today : few GBytes
    - 2015: > T GB …
- **Modern wisdom (about technology)**
  - *"People tend to overestimate what can be done in one year, and underestimate what can be done in 10 years."*

Final conclusions



- A lot of exciting things to investigate and do
  - From physics
    - Algorithms and selection strategy
  - To state of the art NEW technologies
  - Toward a 'Software trigger' that solve many problems for the next generation of experiments (SLHC, ILC/ CLIC …)
  - Plus an interesting sociological environment
  - COULD BE APPLY TO OTHER FIELDS
- xTCA is the Next Trigger /DAQ standard

Thanks a lot for your attention !

References

Proceedings of NSS-MIC conferences

Transaction on Nuclear Sciences (TNS)

http://www.nss-mic.org/2013/NSSMain.asp

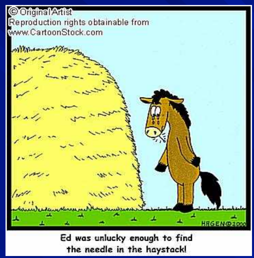
Further Reading

- Buses
  - VME: http://www.vita.com/
  - PCI http://www.pcisig.com/
- Network and Protocols
  - Ethernet "Ethernet: The Definitive Guide", O'Reilly, C. Spurgeon
  - TCP/IP "TCP/IP Illustrated", W. R. Stevens
  - Protocols: RFCs www.ietf.org in particular RFC1925 http://www.ietf.org/rfc/rfc1925.txt "The 12 networking truths" is required reading
- Conferences
  - IEEE Realtime
  - ICALEPCS
  - CHEP
  - IEEE NSS-MIC
- Journals
  - IEEE Transactions on Nuclear Science, in particular the proceedings of the IEEE Realtime conferences
  - IEEE Transactions on Communications

Wikipedia (!!!) and references therein – for all computing related stuff this is usually excellent

实验物理中Trigger/触发的困难

大海捞针：find a needle in a Haystack



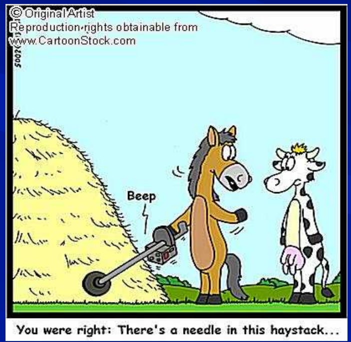
1.怎么办哪？？
无从下手！！

5.愁死
啦！！！

2.苦干加
实干不
信找不
到！！

4.有没有
可能？？？

3.不行啊，
哪天能
找到
啊！！



6.别愁啦，快找
触发组啊！！

实验物理中的Trigger/触发
加速器物理实验中的触发判选

本底事例

好事例

- 设计高效的触发判选
  - 定义好事例(缝衣针)和本底(麦秸)的特征
  - 找出不同(界限)
  - 节省资源
  - 高效
  - 实时

本底事例

找到的好事例