Measurement of the heavy-ion collision event characteristics with the ATLAS experiment at the LHC using computing resources of ACK Cyfronet

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LHC accelerator - CERN

The Large Hadron Collider (LHC) is the world's largest and most powerful particle accelerator.

Some facts:

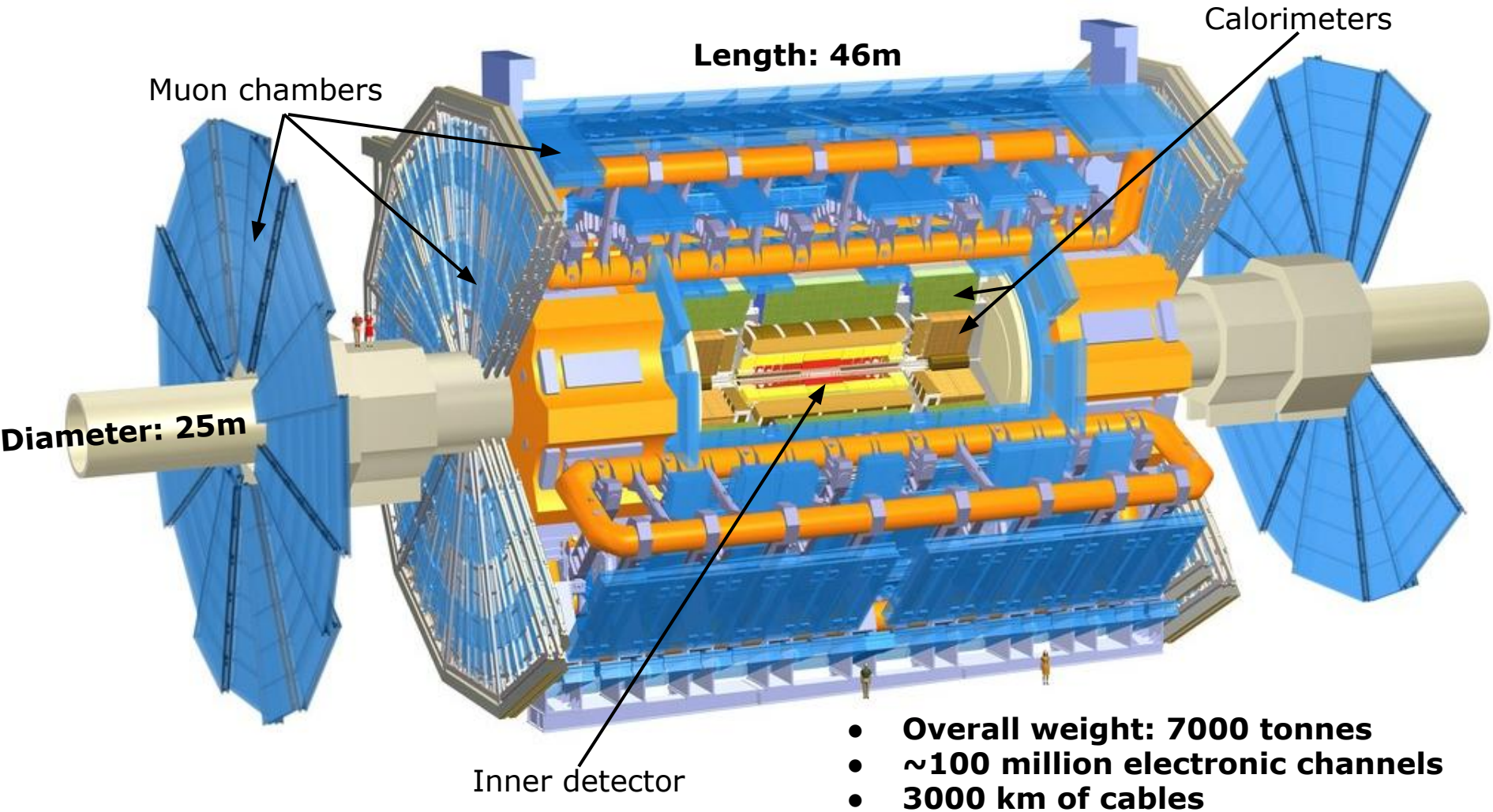
- 27km length, ~100 m underground near Geneva
- 40M collisions per second
- each proton travels 11,245 times the ring in one sec.
- v=0.99999c
- 11,850 amperes
- 8.4 tesla magnetic field (>100k times more powerful than the Earth's magnetic field)
- 1,232 dipole magnets (15m) and 392 quadrupole magnets (5-7m)
- Superconductivity: main magnets operate at a temperature of 1.9 K (outer space; 2.7 K)
- Four particle detectors – **ATLAS**, CMS, ALICE and LHCb.

ATLAS collaboration

3,000 physicists from over 175 institutions in 38 countries

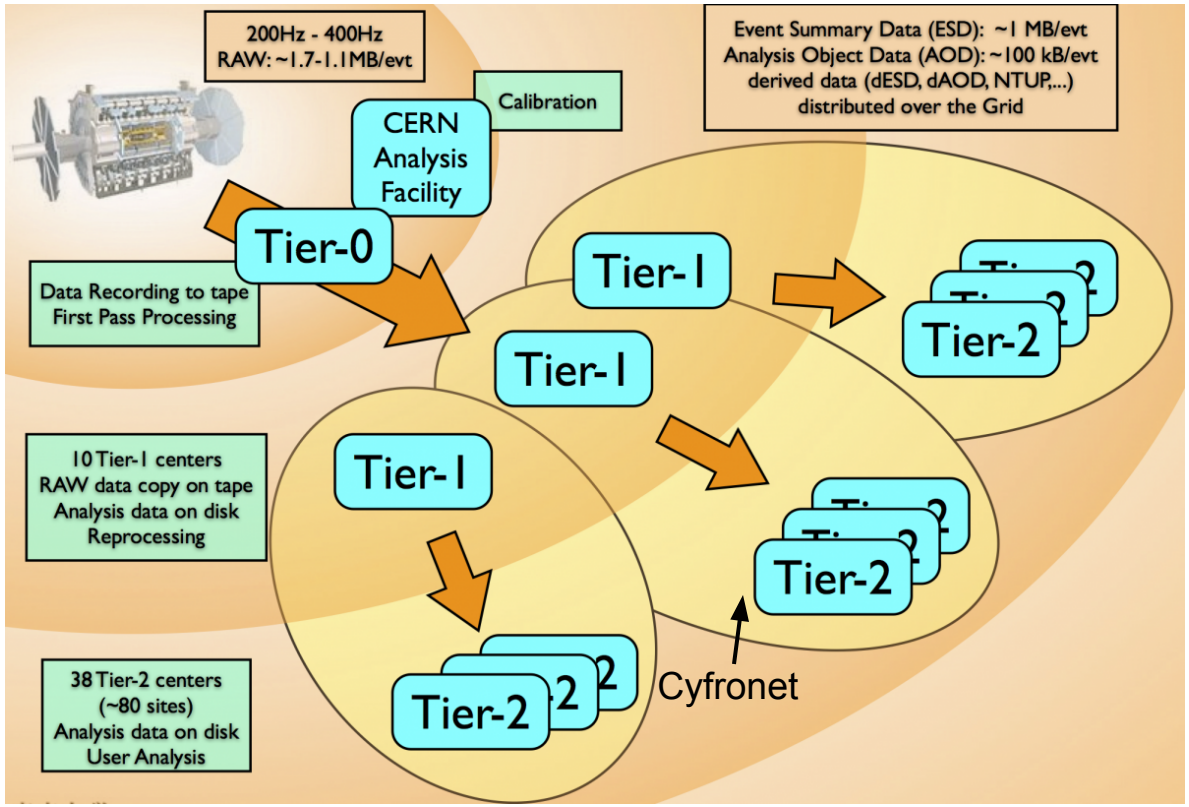
Distributed data analysis (democratic access to the data)

ATLAS detector



- **Overall weight: 7000 tonnes**
- **~100 million electronic channels**
- **3000 km of cables**

The Worldwide LHC Computing Grid (WLCG)



- **reconstruction of the raw data from the detectors**
- **producing MC simulations of what the theory predicts should be seen in the detector**
- **physics analysis**

“ATLAS at work”

Bunches of ~10^{11} protons cross with frequency 40MHz → 1 billion events per second

Trigger and Data Acquisition (TDAQ):

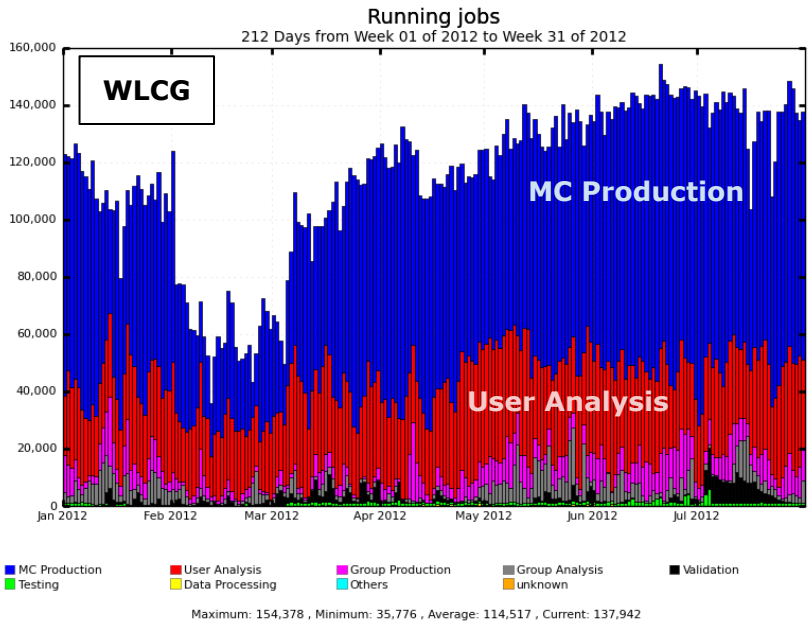
PB/s → ~500MB/s using 3 steps reduction

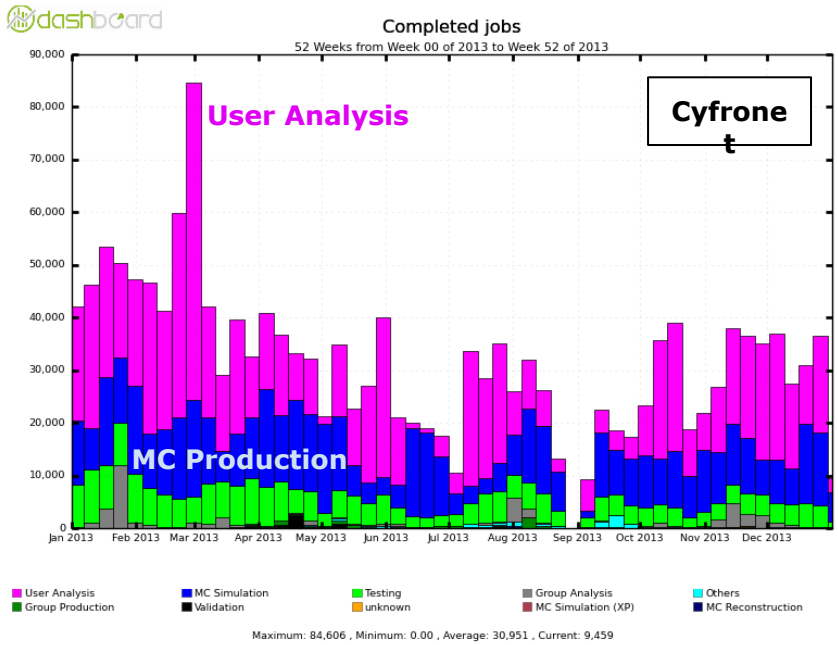
	Incoming event rate per second	Outgoing event rate per second	Reduction factor
Level 1	40 000 000	100 000	400
Level 2	100 000	3 000	30
Level 3	3 000	200	15

WLCG (2012): Average running jobs >100,000 / day

Cyfronet (2013): Average completed jobs >30,000 / week

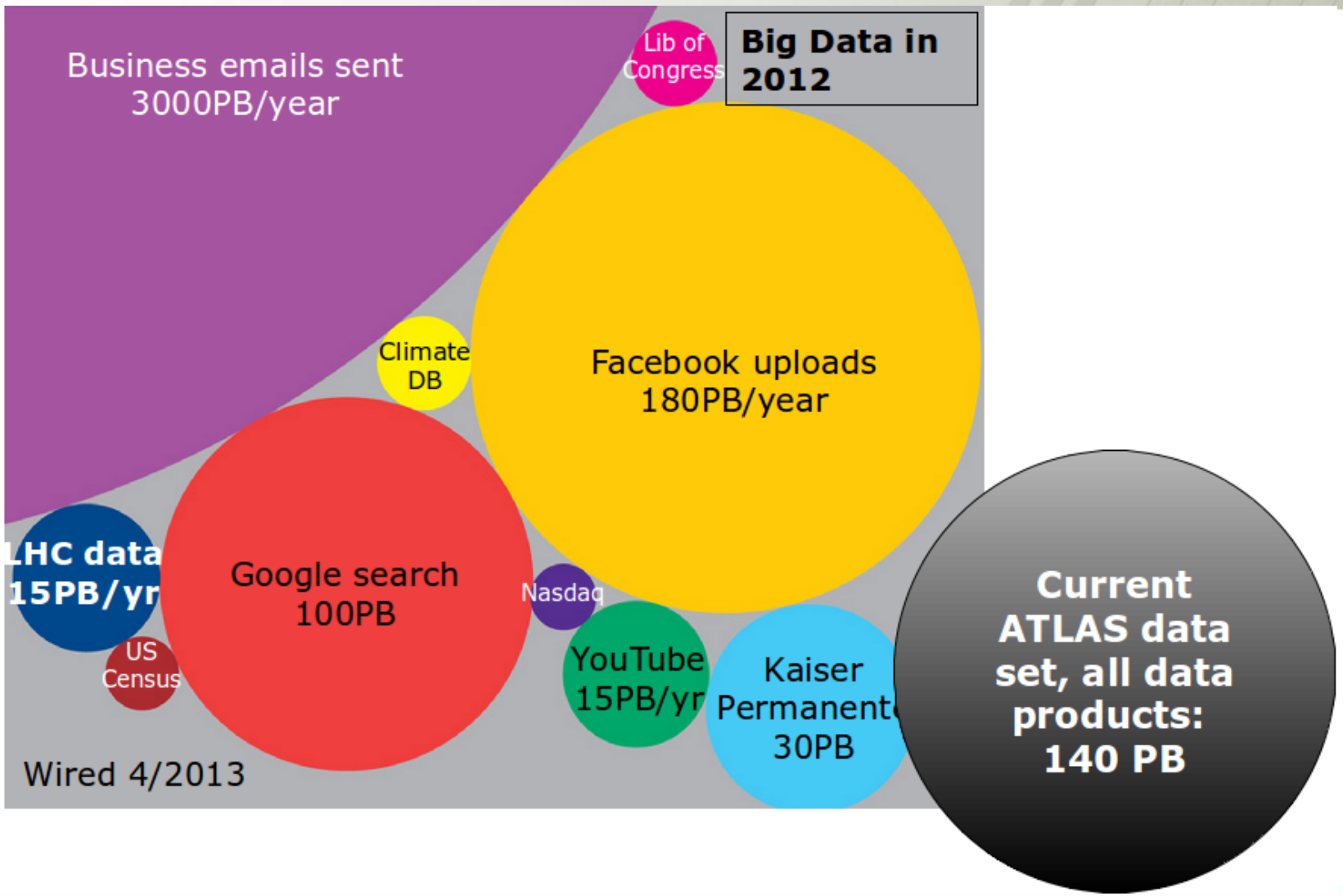
Recorded	per event	per year
raw data	1.6 Mbytes	3 200 Tbytes
reconstructed data	1 Mbytes	2 000 Tbytes
physics data	0.1 Mbytes	200 Tbytes





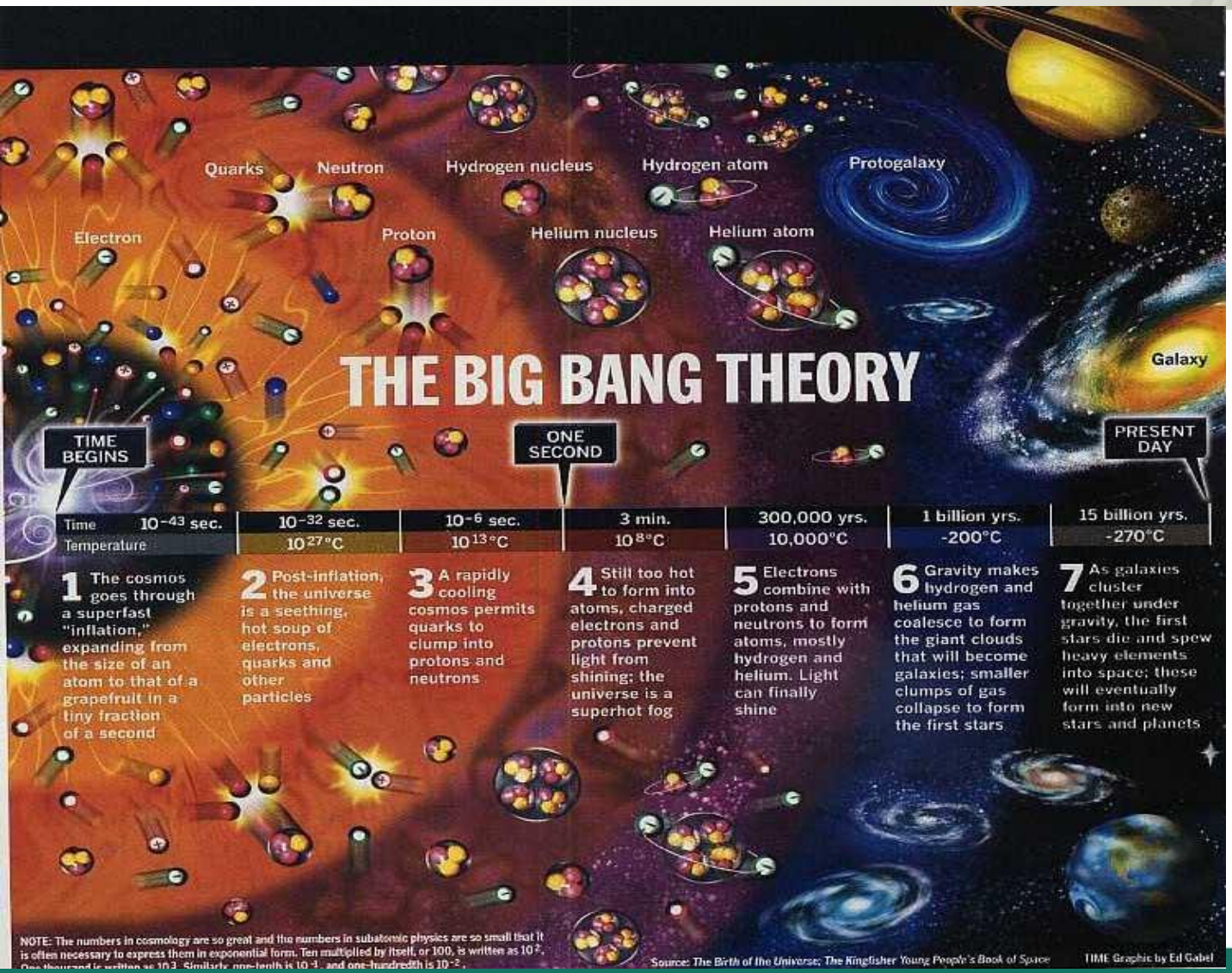
http://www.isgtw.org/feature/how-grid-computing-helped-cern-hunt-higgs

Amount of data produced by ATLAS



http://www.wired.com/magazine/2013/04/bigdata/

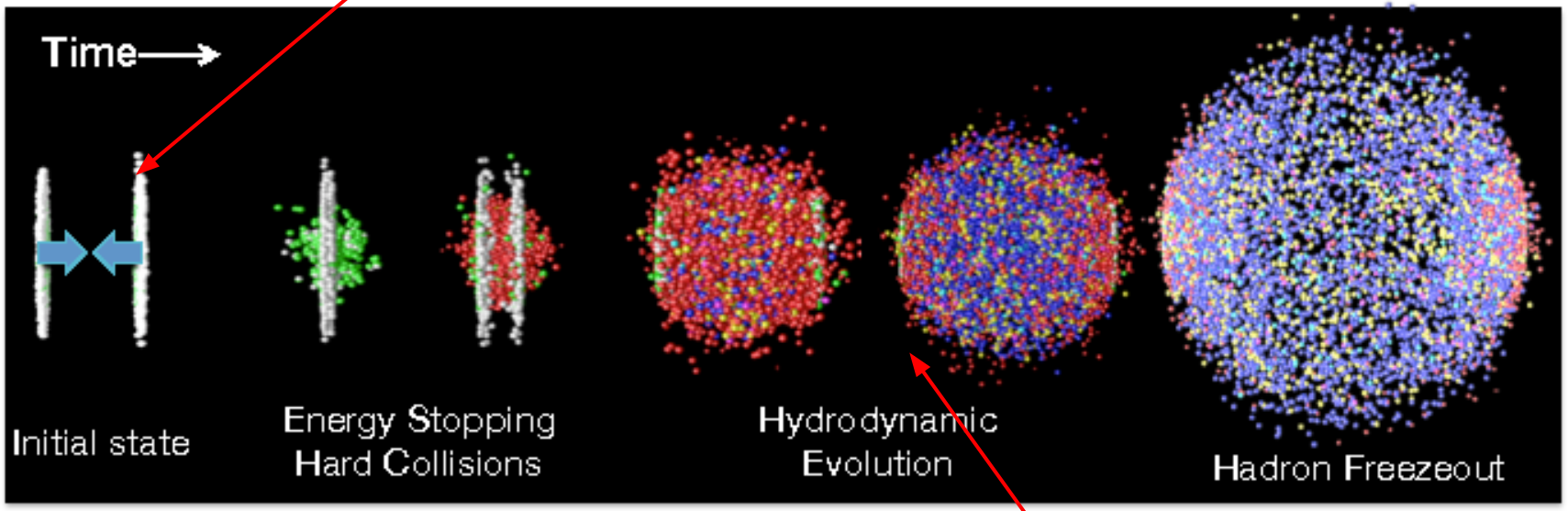
The Big Bang



- **The state of early Universe can be predicted by heavy ion collisions (eg. Pb-Pb)**
- **At very high energies and temperatures a new state of matter can be observed - Quark Gluon Plasma (QGP)**

Time evolution of HI collision

Lorentz contraction



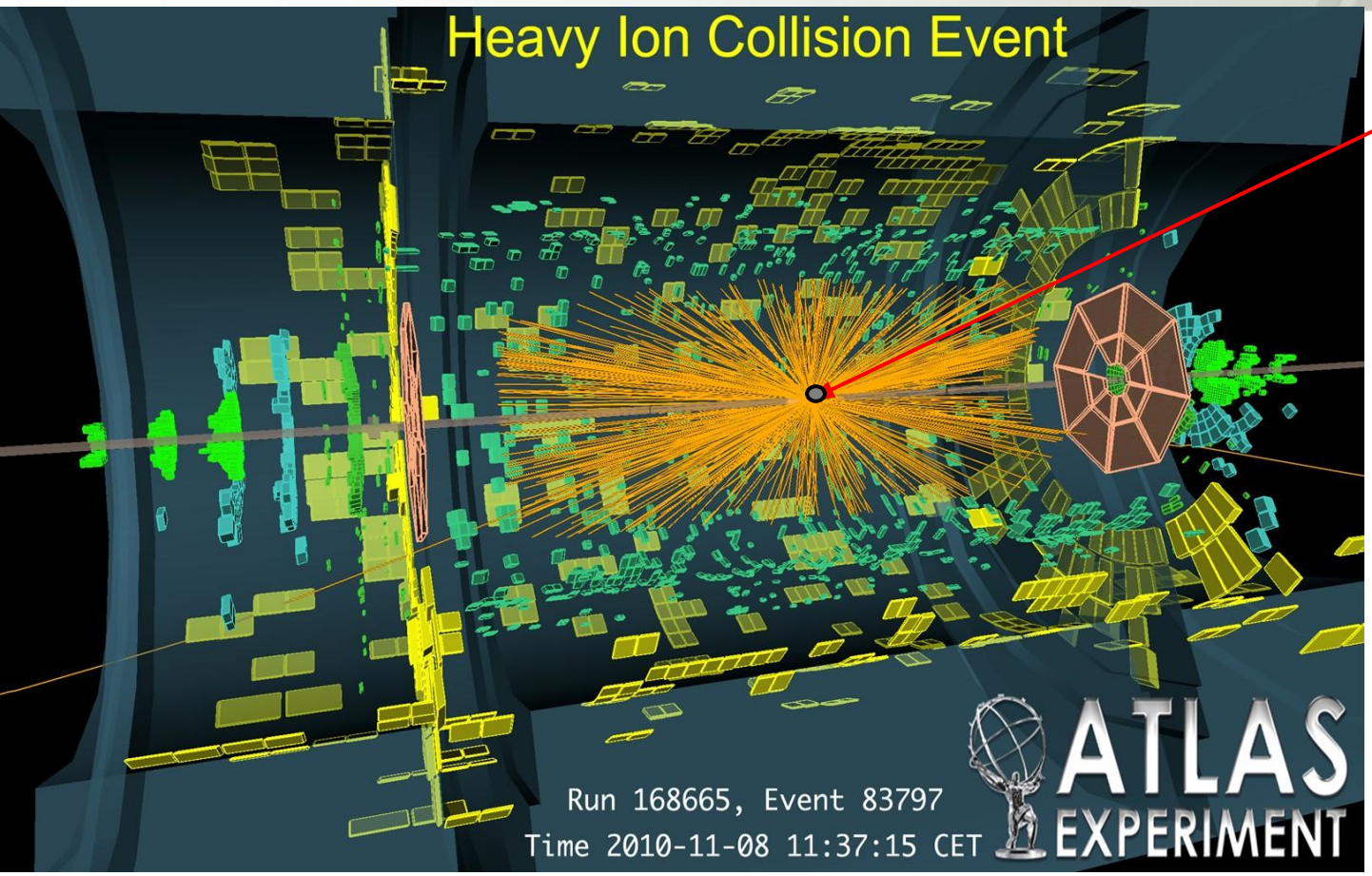
Ultra central collision

Effects of the hydrodynamical evolution observed experimentally!

- Temperature : ~10^{12}K
- Volume: ~3000 fm^3
- Lifetime: 5-10 fm/c (~10^{-25}s)

- Deconfinement of QGP → quarks and gluons observed as free particles!

Sample lead - lead collision



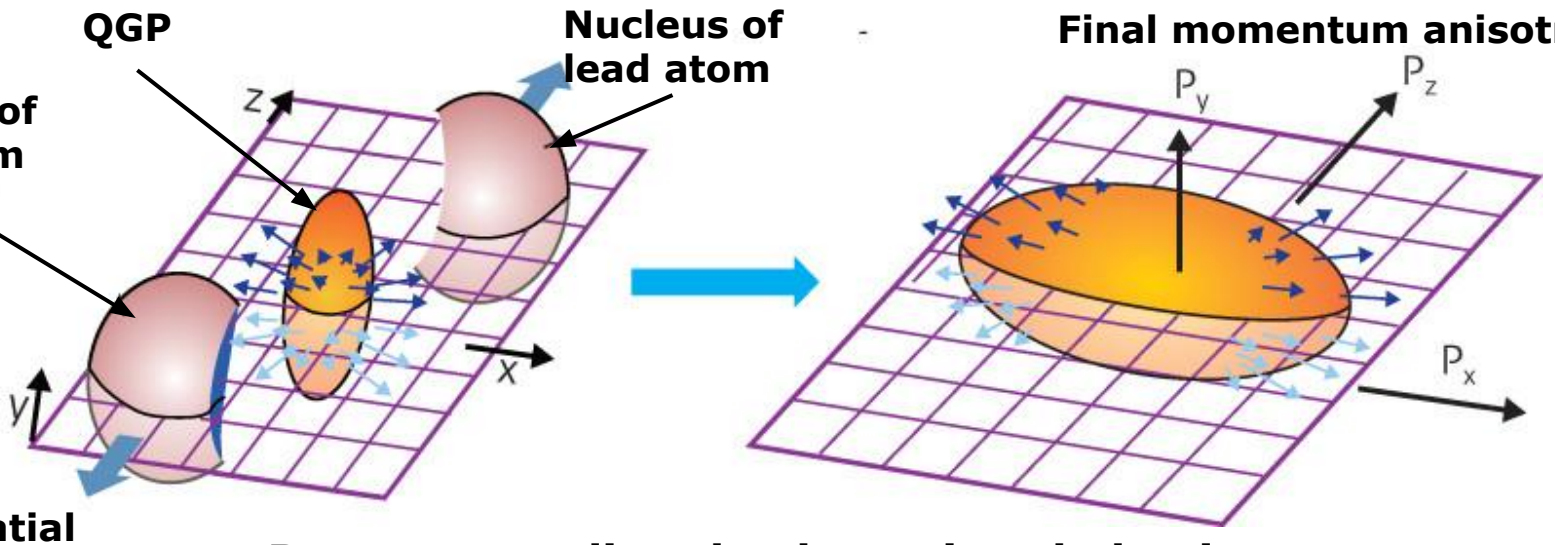
Interaction point

Tracks of produced particles

Energy deposited in calorimeters

- **Each analysis requires writing complicated code (generally in C++ and using ROOT to make plots)**
- **Presented analysis requires processing ~ TB of data! → millions of collisions**

Azimuthal anisotropies



Pressure gradient lead to azimuthal anisotropy

$$\frac{dN}{d\phi} = N_0\left(1 + 2v_1\cos\left(\phi - \Psi_1\right) + 2v_2\cos\left(2\left(\phi - \Psi_2\right)\right) + 2v_3\cos\left(3\left(\phi - \Psi_3\right)\right) + \ldots\right)$$

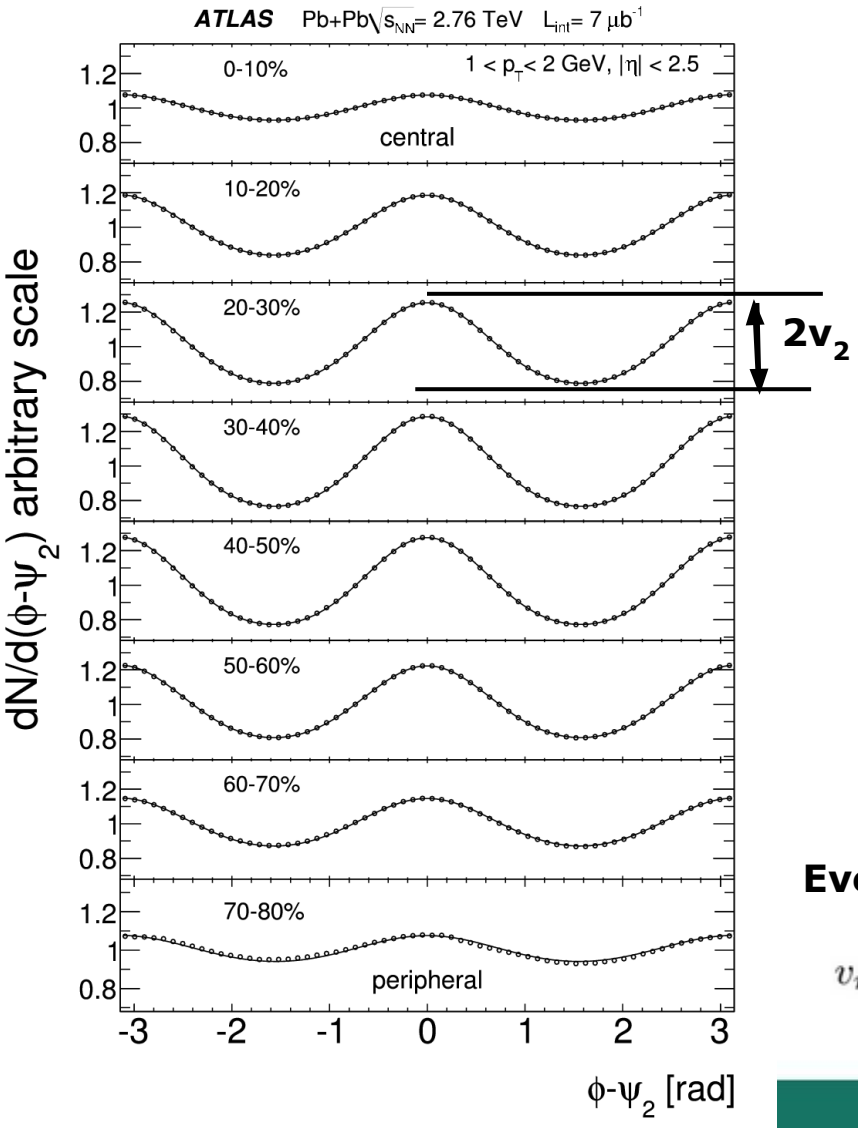
directed flow — elliptic flow — triangular flow

$$v_n = \langle\cos\left(n\left(\Phi - \Psi_n\right)\right)\rangle$$ - **Fourier harmonic**

v_2 - initial shape of the interaction region

v_n - initial spatial fluctuations of interacting nucleus observed non-zero up to v_6 → very low viscosity of QGP (honey - water)

Measurement techniques



Flow vector (average angle):

$$Q_n = |Q_n| e^{in\Psi_{RP}} = \frac{1}{N} \sum_j e^{in\phi_j}$$

- **Anisotropies are global → average event angle can be measured in all detector.**
- **Reconstructed charged particles correlated with the average angle.**
- **The v_2 studied as a function of many variables: centrality, charged particle momenta etc.**
- **Many methods developed for this type of measurements.**

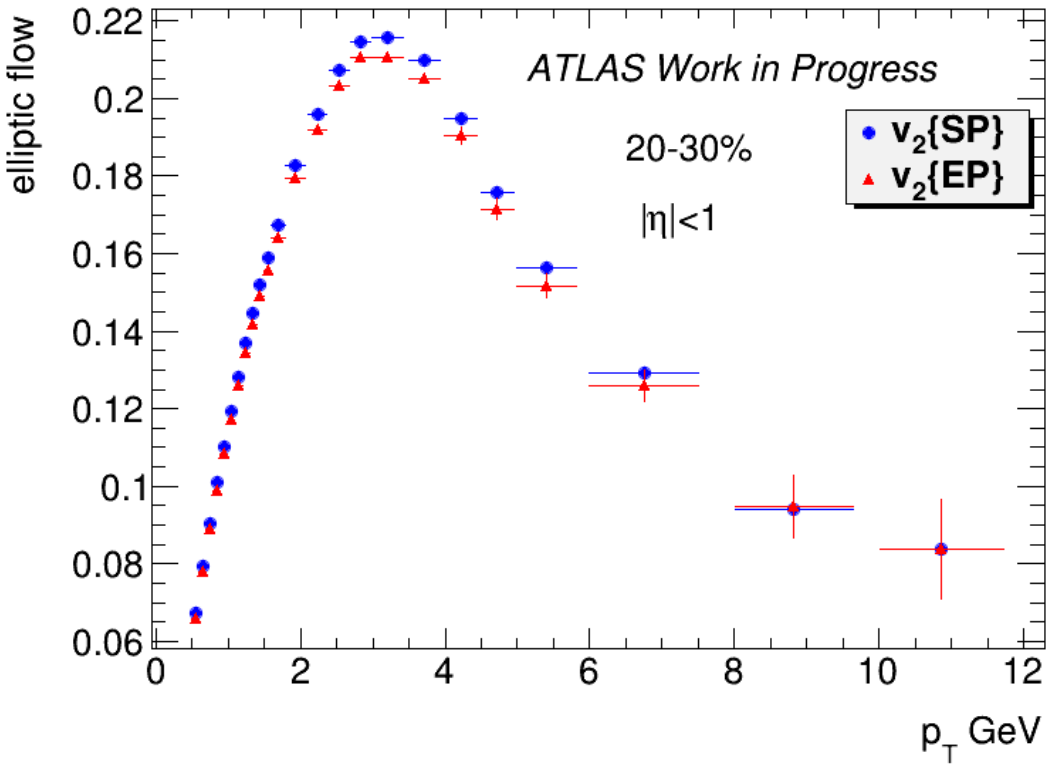
Event Plane:

$$v_n\{EP\} \sim \left\langle Q_n \frac{Q^*_{nA}}{|Q_{nA}|} \right\rangle$$

Scalar Product:

$$v_n\{SP\} \sim \left\langle Q_n Q^*_{nA} \right\rangle$$

Work in progress



All centrality intervals show:

- **Rapid rise in $v_2(p_T)$ up to p_T ~ 3 GeV**
  - **hydrodynamics**
- **Decrease out to 7-8 GeV**
- **Weak p_T- dependence above 9-10 GeV**
  - **other phenomena - QGP opacity**

The strongest elliptic flow is observed in centralities 30-50 % → biggest asymmetry of the collision shape

Summary

- LHC is a unique research device
- Allows for big discoveries (like the Higgs boson)
- ATLAS experiment at LHC allows for various studies from the elementary particle properties to the nuclear research
- Big data volumes produced and managed using data grids
- In Heavy Ion collisions ATLAS reproduce conditions present in fractions of a second after Big Bang
- Surprising properties of the very hot and dense matter (QGP) are observed
- That matter behaves like nearly perfect fluid

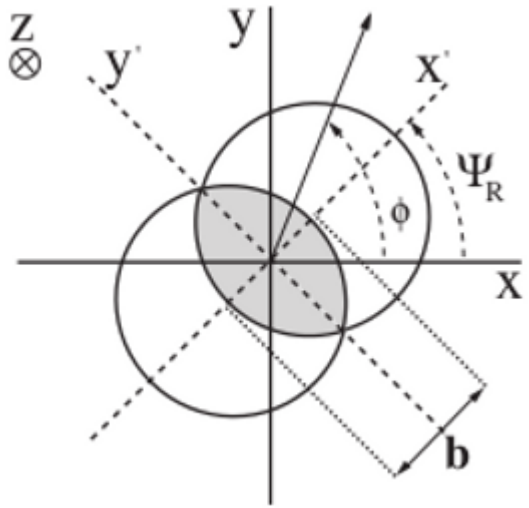
AGH

Thank you for your attention

Backup slides

Average angle

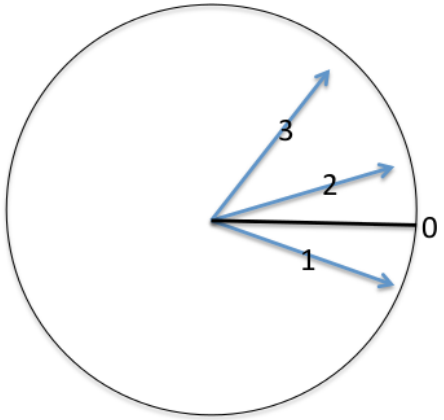
Reaction plane:



$$Q_x = |Q_n| cos(n\Psi_n) = \frac{1}{N}\sum_j cos(n\phi_j)$$

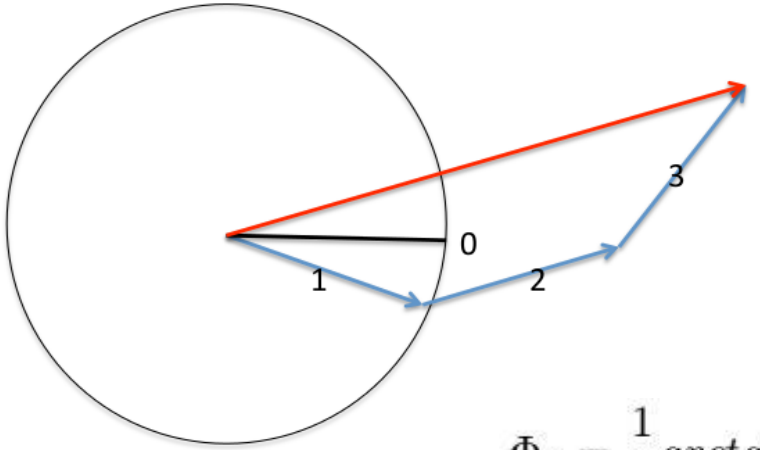
$$Q_y = |Q_n| sin(n\Psi_n) = \frac{1}{N}\sum_j sin(n\phi_j)$$

$$Q_n = |Q_n| e^{in\Psi_{RP}} = \frac{1}{N}\sum_j e^{in\phi_j}$$



Arithmetic mean of the angles is not a good estimator → eg. 2 measurements: 1^0 i 359^0 → 180^0

Solution → vector addition



$$\Phi_n = \frac{1}{n} arctg(\frac{Q_y}{Q_x})$$