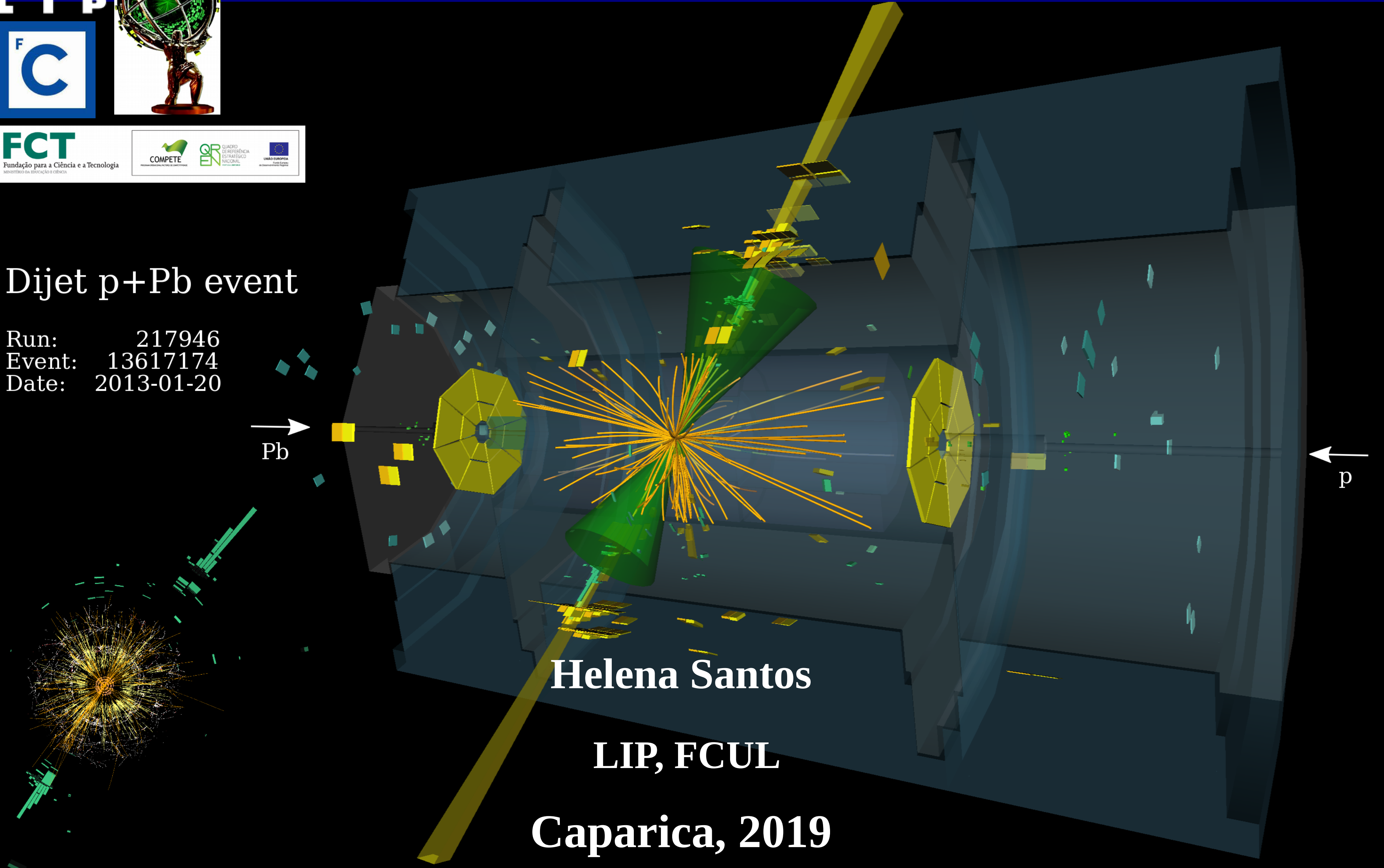
Heavy Ions at the ATLAS-LHC



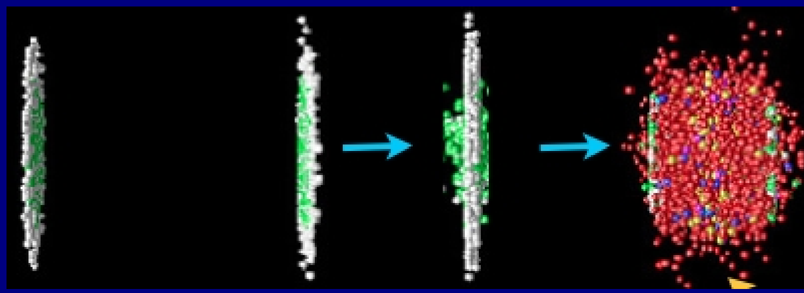
Helena Santos

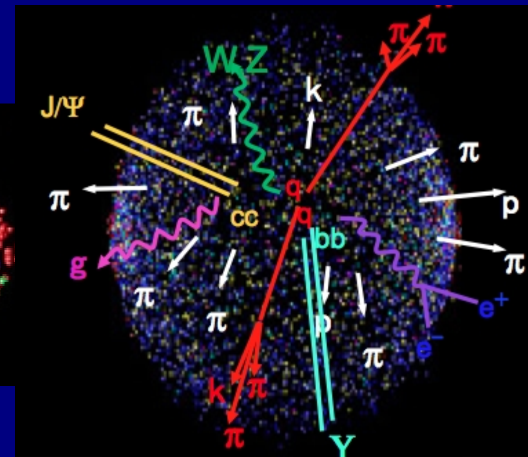
LIP, FCUL

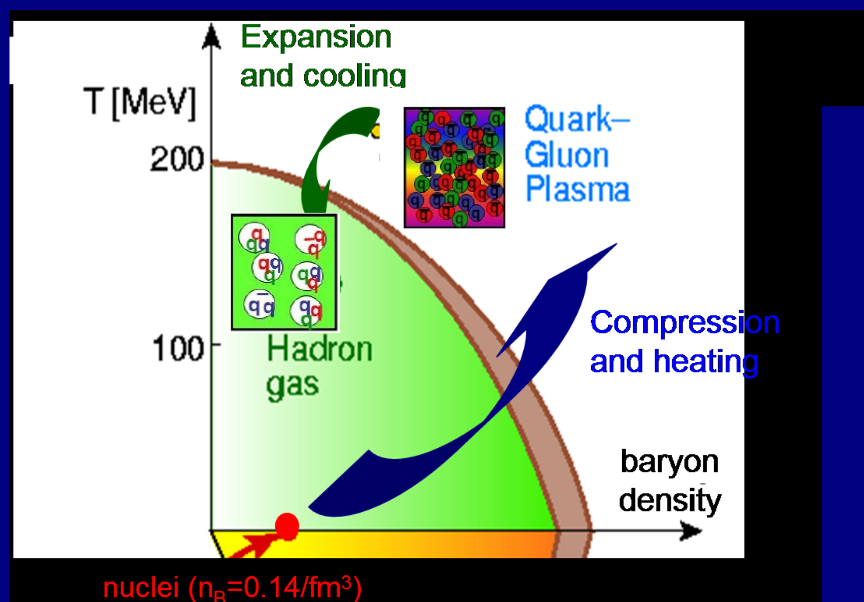
Caparica, 2019

Quark Gluon Plasma created at the LHC

Heavy Ion (Pb+Pb) collisions

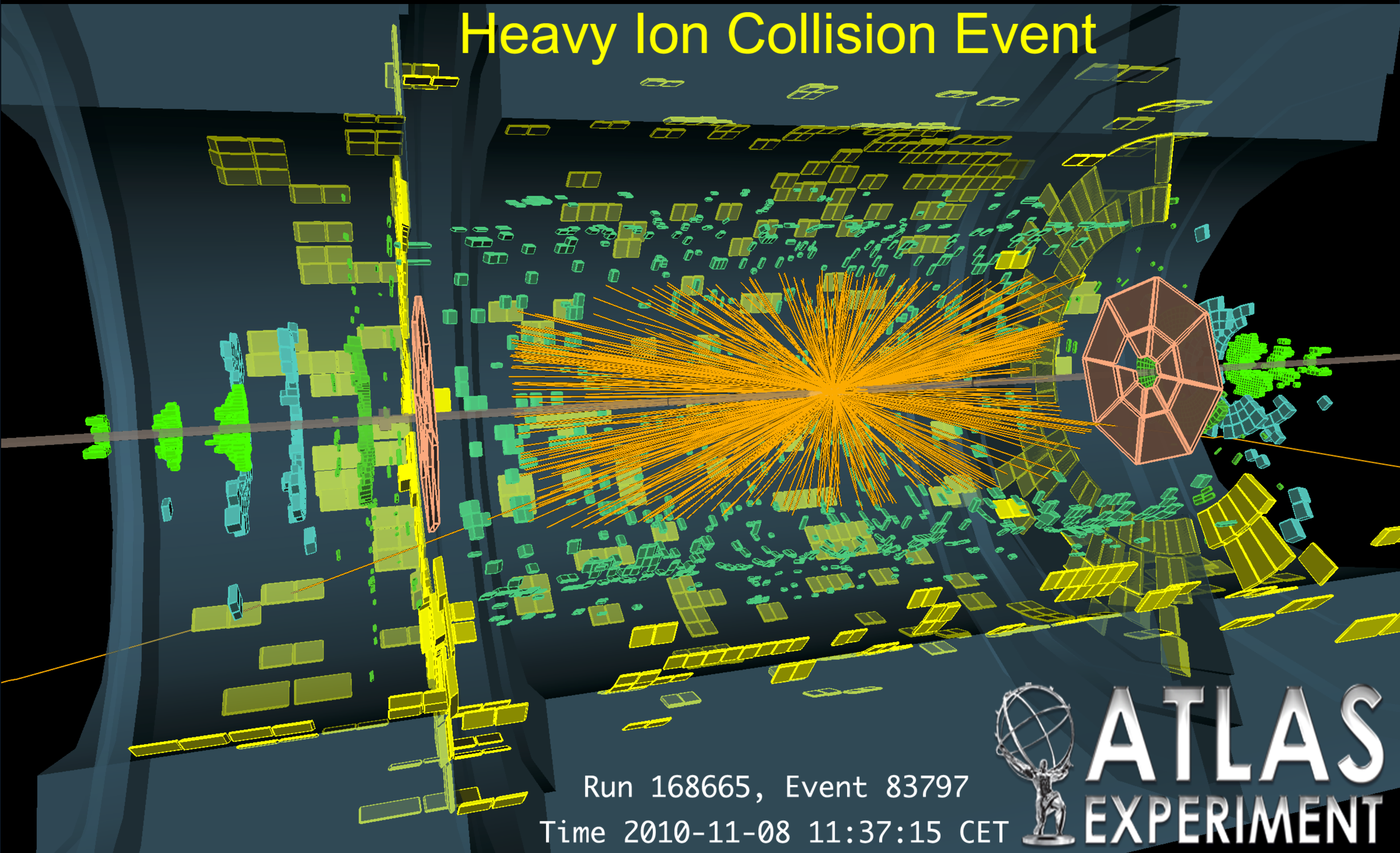




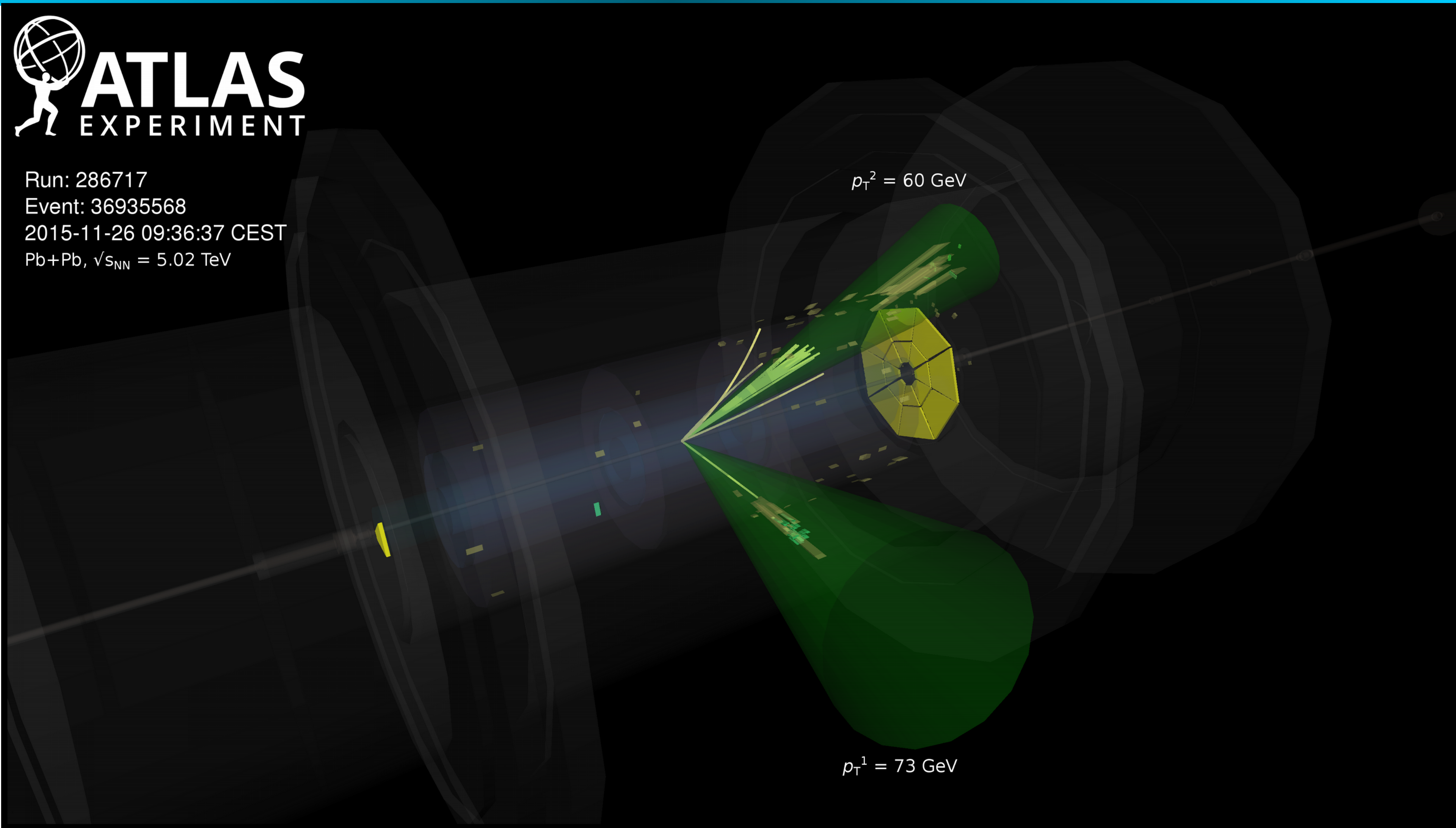


The conjecture is that the QGP has ocurred soon after the Big Bang (up 10^{-10} s) and should constitute the core of the neutron stars.

Heavy Ion Collision Event

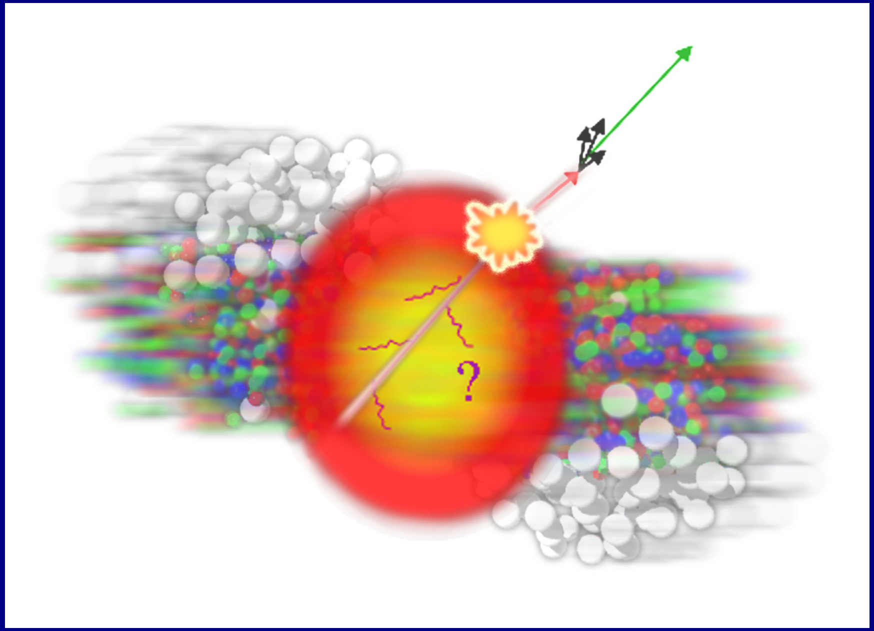


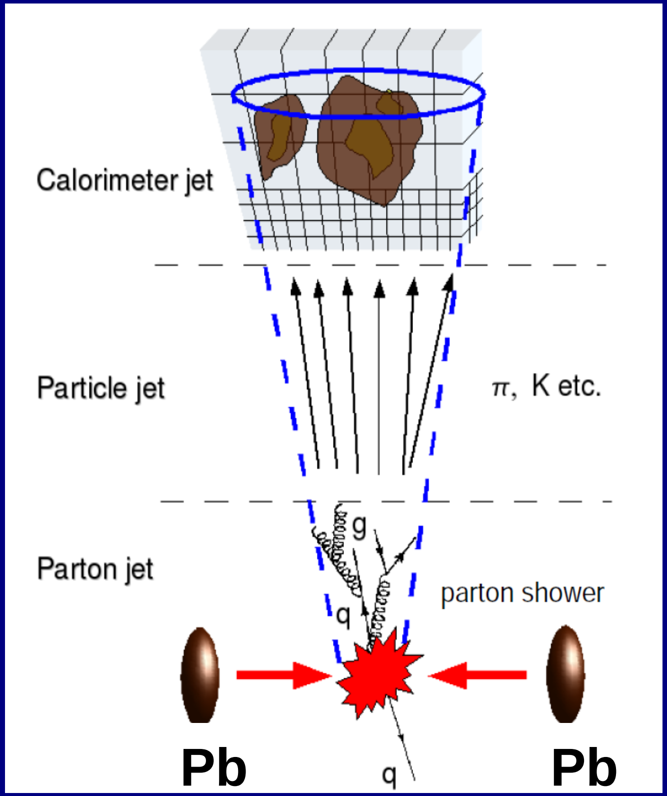
Jets


ATLAS EXPERIMENT
Run: 286717
Event: 36935568
2015-11-26 09:36:37 CEST
Pb+Pb, $\sqrt{s_{NN}}$ = 5.02 TeV
p_T^2 = 60 GeV
p_T^1 = 73 GeV

Jets as probes of the QGP

Quark Gluon Plasma is opaque to coloured partons.
How do parton showers in the hot and dense medium differ from those in vacuum?





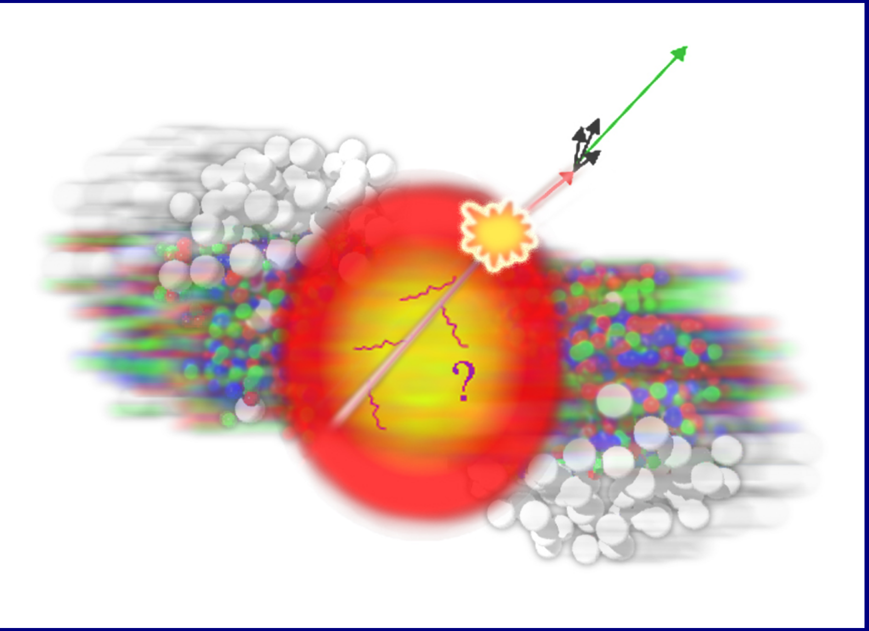
What is expected:

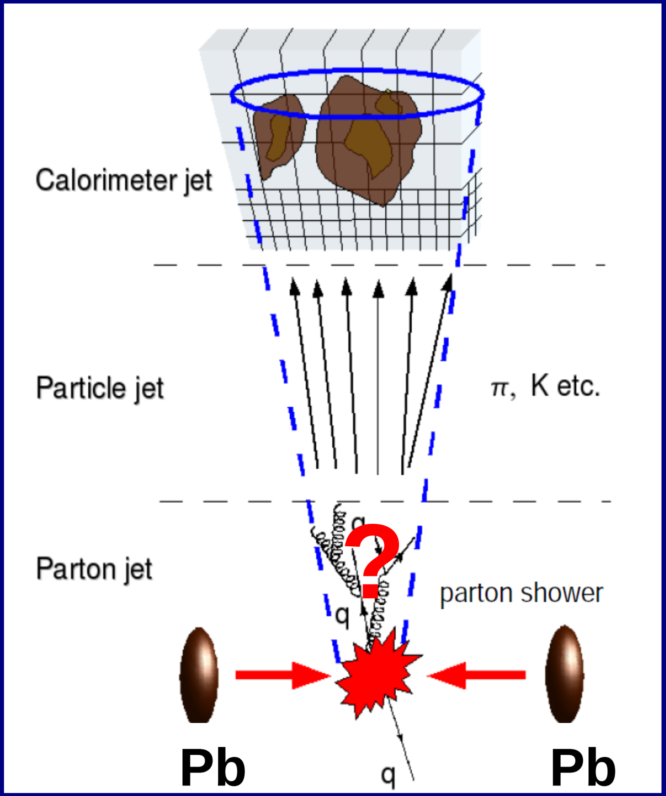
Partons lose energy, resulting in jet “quenching”.

Jets probe the very first phase of the collision → they carry relevant information about the QGP .

Jets as probes of the QGP

Quark Gluon Plasma is opaque to coloured partons.
How do parton showers in the hot and dense medium differ from those in vacuum?





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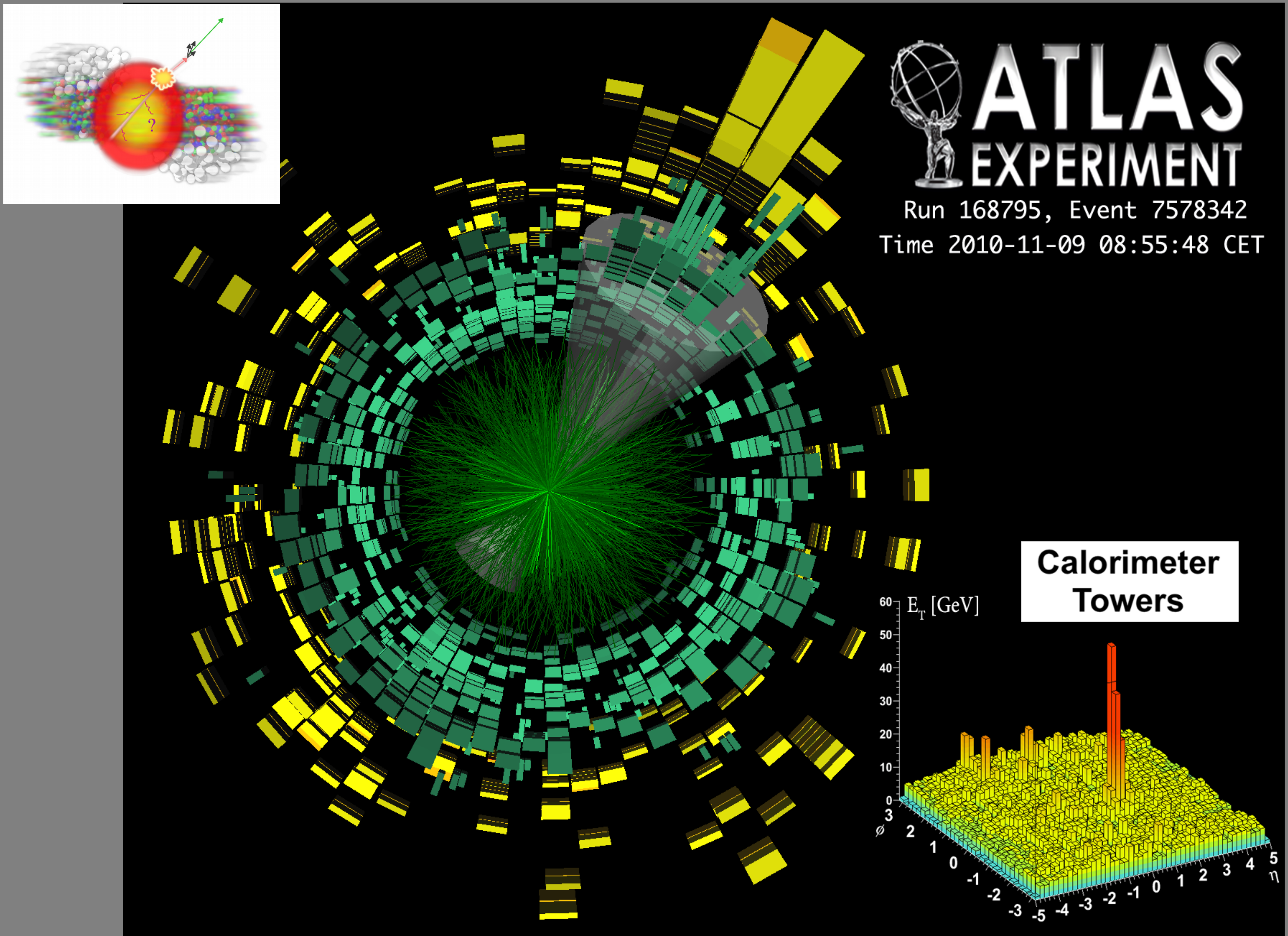
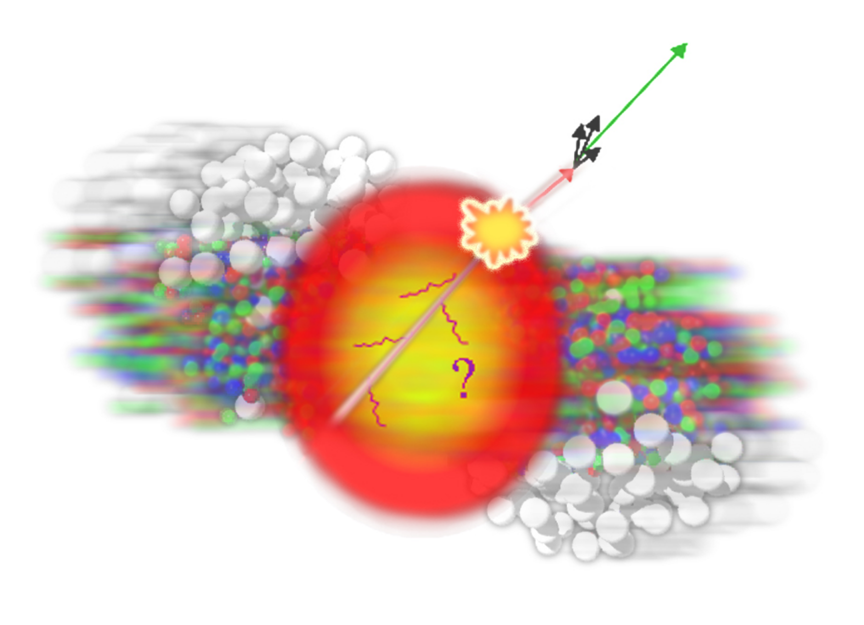
Monojet!


ATLAS
EXPERIMENT
Run 168795, Event 7578342
Time 2010-11-09 08:55:48 CET
Calorimeter
Towers
E_T [GeV]
60
50
40
30
20
10
0
3
2
1
0
-1
-2
-3
ø
-5
-4
-3
-2
-1
0
1
2
3
4
5
η

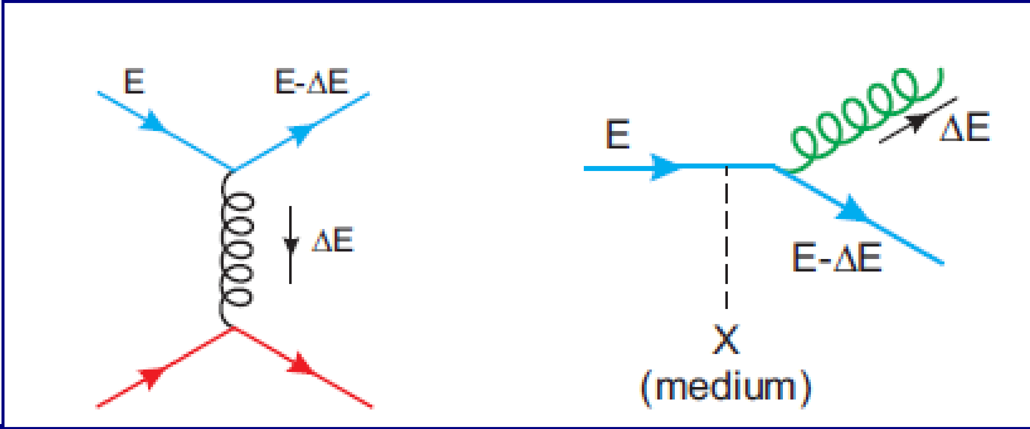
Flavour tagging in heavy-ion events

Heavy-Flavour jets (we are particularly interested in *b*-jets) are important in the QGP research → nature of energy loss in the hot and dense medium, top quark searches...



Collisional energy loss

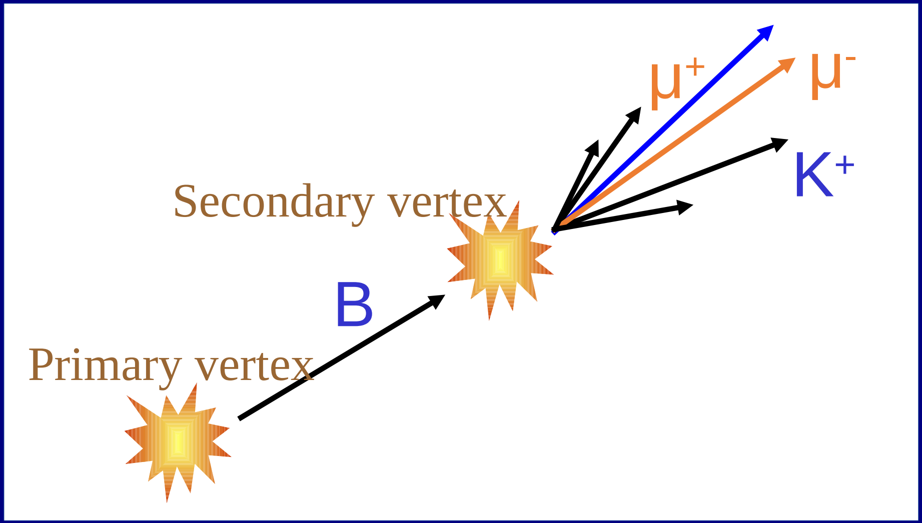
Radiative energy loss



Flavour tagging in heavy-ion events

Experimental signature: how Heavy-Flavour jets look in the ATLAS detector?

Algorithms: tagging of Heavy Flavour jets (so called ***b*-tagging**) use the properties of the B mesons: large mass, long $c\tau$, and harder fragmentation.



Calibration: how do we understand the performance of a ***b*-tagging** algorithm in the data.

Trigger: how to search in real time for valuable events containing *b*-jets?

Flavour tagging in heavy-ion events

No sophisticated b-tagging was available for ATLAS heavy-ion events

- Characteristics of HI collisions (e.g. huge underlying event) mean that pp algorithms would not work properly

***b*-tagging algorithms in HI are now incorporated in ATLAS software chain – LIP group achievement.**

- Essential step to start heavy flavour jet analysis in HI collisions
- Tests on real ATLAS HI data are ongoing

Trigger was very successful in the Pb+Pb HI in the Fall of 2018 – Strong contribution from LIP group.

Room for algorithm improvement (machine learning) and data analysis → Master and PhD Theses at ATLAS-LIP

The ATLAS-LIP Dream Team

~30 members from Lisboa, Coimbra and Minho LIP poles and from several portuguese and spanish universities.

The ATLAS-HI Group

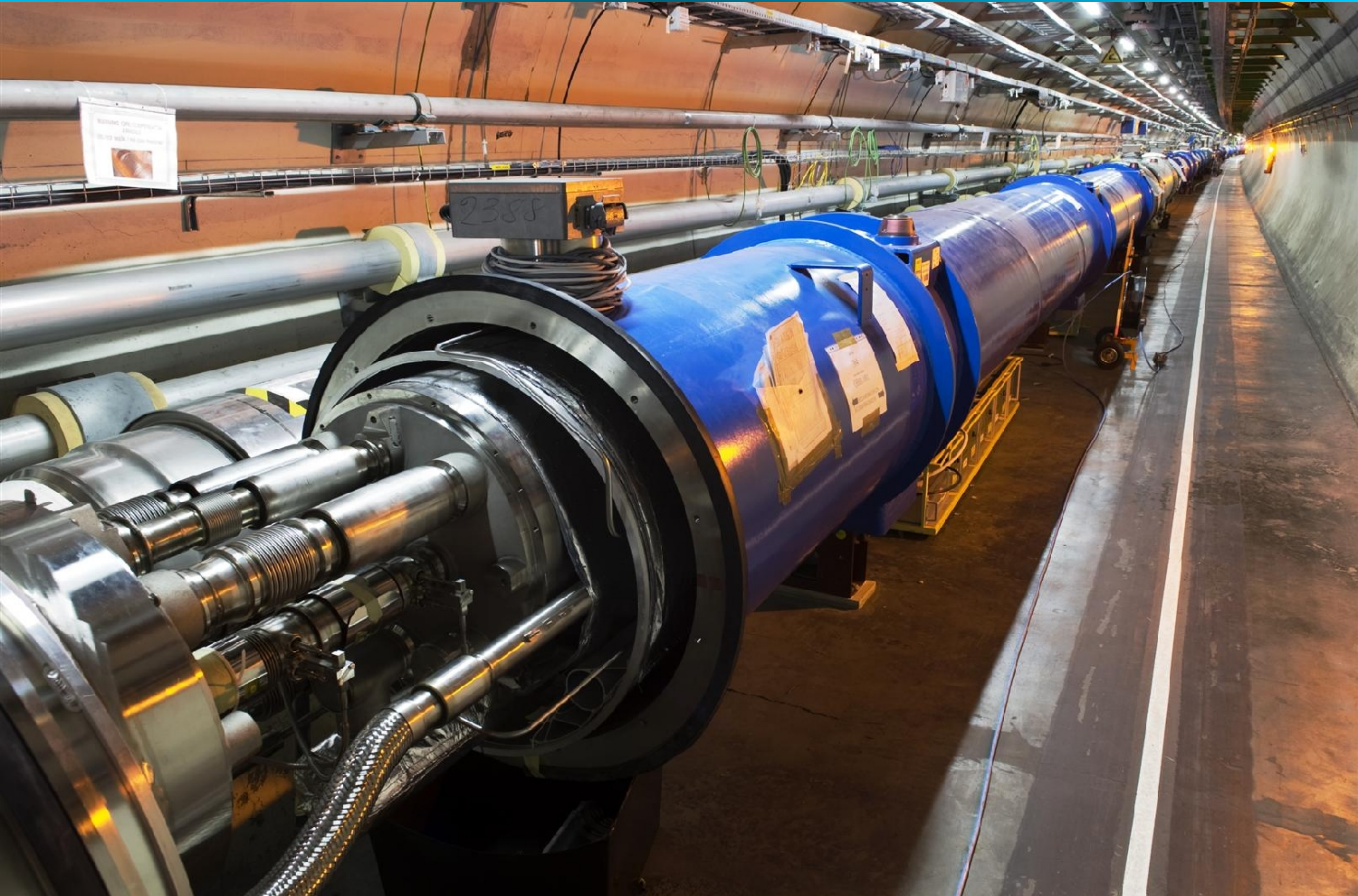
~50 members from around the world

The ATLAS Collaboration

~3000 members from 38 countries, 177 universities, ~1000 studants. Our (CERN) model of cooperation brings the world together.

Backup

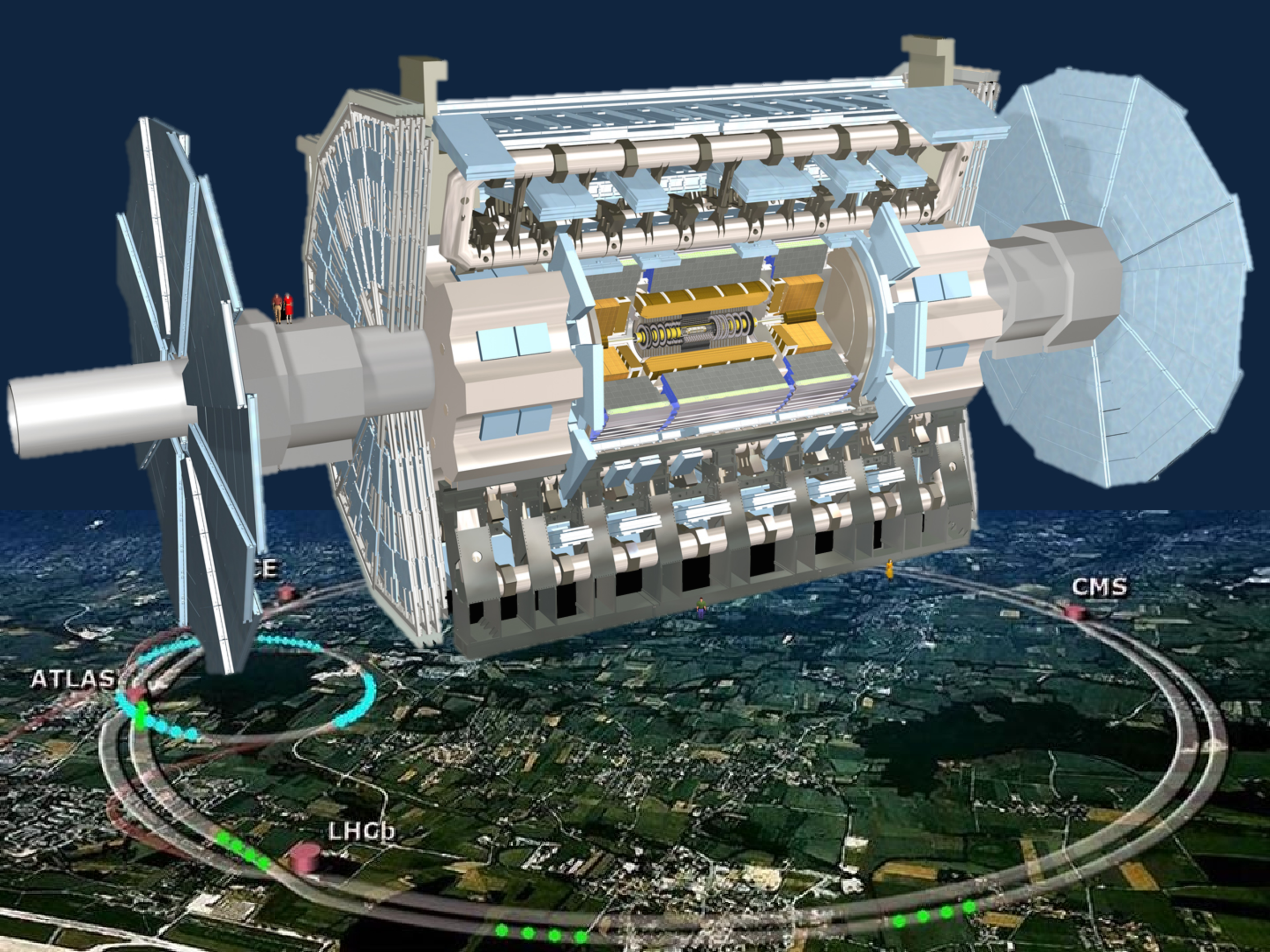
Large Hadron Collider



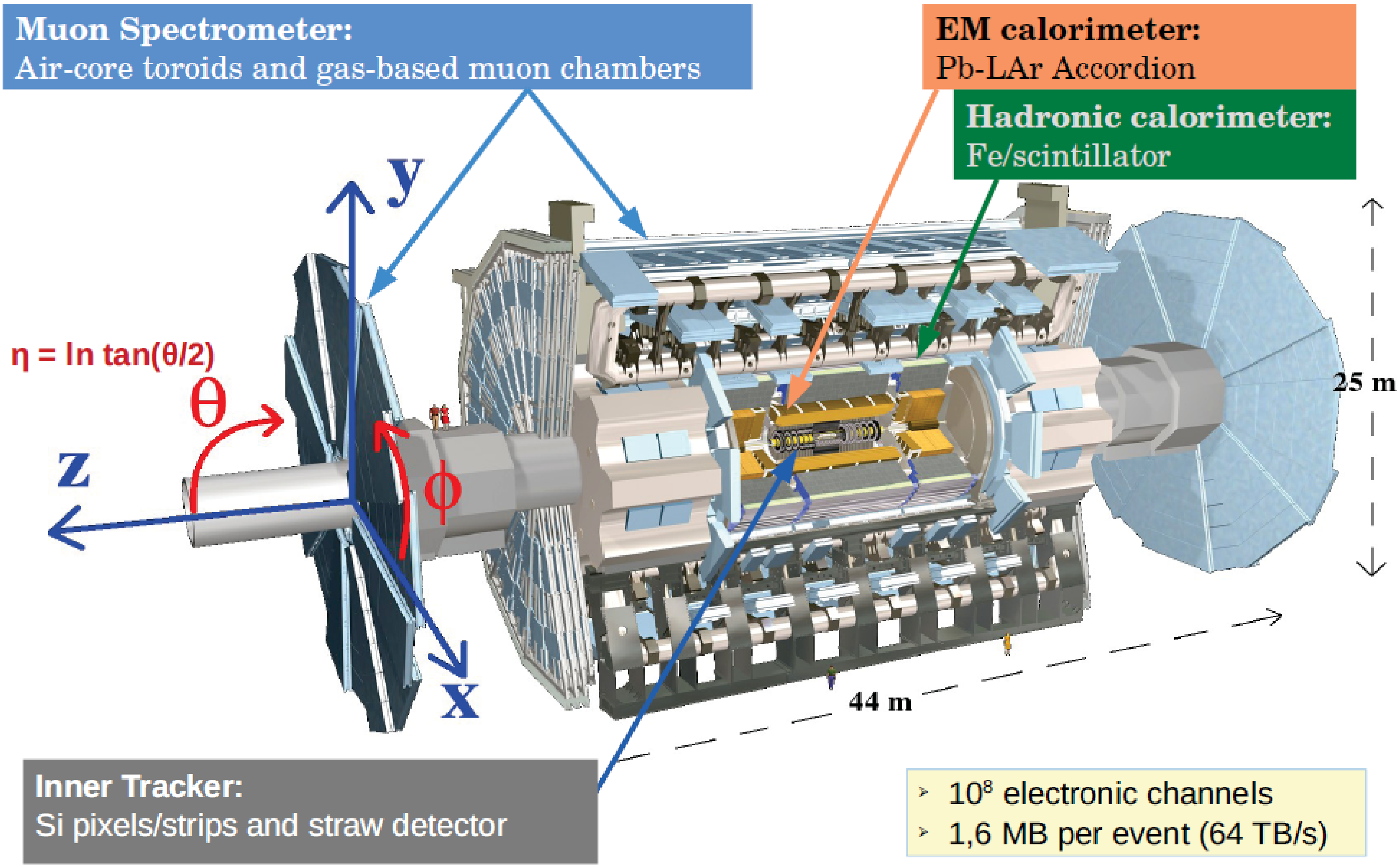
Large Hadron Collider

O Grande Colisionador de Hadrões

- túnel de 27 km a 100m de profundidade
- 9,300 magnetos (para curvar e focar)
- 7,600 km de cabos supercondutores
- Temperatura -271 C, mais frio do que o espaço
- Vácuo quase perfeito (10^{-13} atm, Lua...)
- Potência 120 MW (consumo de Coimbra)
- Armazena 300 milhões de Joules
- Pacotes de 100 mil milhões de protões
- Dão 11,000 voltas/segundo
- 99.9999991 % da velocidade da luz
- Densidade de energia como a de
  1/1,000,000,000,000 s depois do Big Bang
- Custo 3.1 mil milhões euros (menos que um porta-aviões) + os detectores


ATLAS
LHCb
CMS

ATLAS



Muon Spectrometer:
Air-core toroids and gas-based muon chambers
EM calorimeter:
Pb-LAr Accordion
Hadronic calorimeter:
Fe/scintillator
y
z
x
η = ln tan(θ/2)
θ
ϕ
25 m
44 m
Inner Tracker:
Si pixels/strips and straw detector
10⁸ electronic channels
1,6 MB per event (64 TB/s)

The predictions of Jet Quenching

Energy Loss of Energetic Partons in Quark-Gluon Plasma:
Possible Extinction of High p_T Jets in Hadron-Hadron Collisions.

Publicado em 1982!

FERMILAB-PUB-82-059-T

J. D. BJORKEN
Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

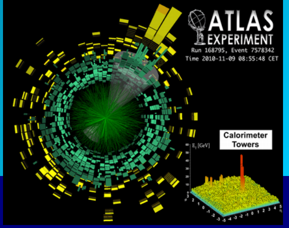
Abstract

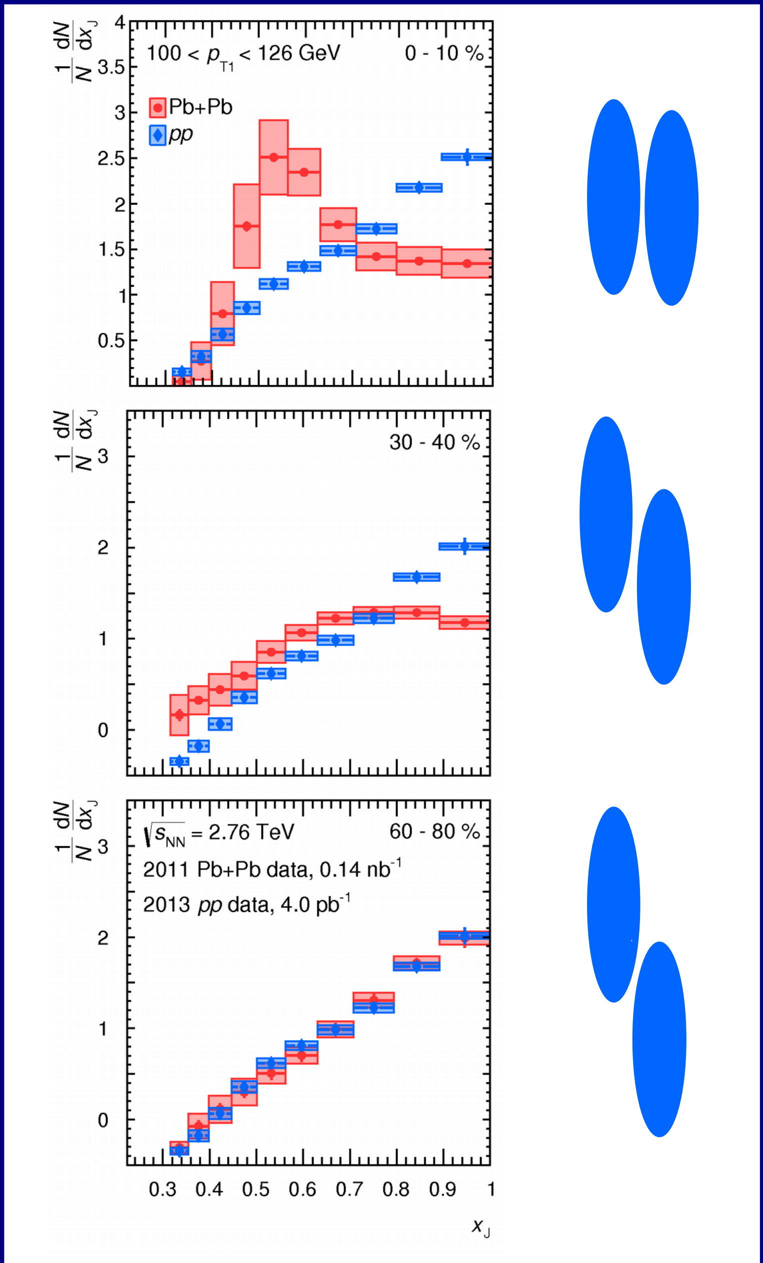
High energy quarks and gluons propagating through quark-gluon plasma suffer differential energy loss via elastic scattering from quanta in the plasma. This mechanism is very similar in structure to ionization loss of charged particles in ordinary matter. The dE/dx is roughly proportional to the square of the plasma temperature. For hadron-hadron collisions with high associated multiplicity and with

The predictions of Jet Quenching

transverse energy dE_T/dy in excess of 10 GeV per unit rapidity, it is possible that quark-gluon plasma is produced in the collision. If so, a produced secondary high-p_T quark or gluon might lose tens of GeV of its initial transverse momentum while plowing through quark-gluon plasma produced in its local environment. High energy hadron jet experiments should be analysed as function of associated multiplicity to search for this effect. An interesting signature may be events in which the hard collision occurs near the edge of the overlap region, with one jet escaping without absorption and the other fully absorbed.

$x_J = p_{T2} / p_{T1}$





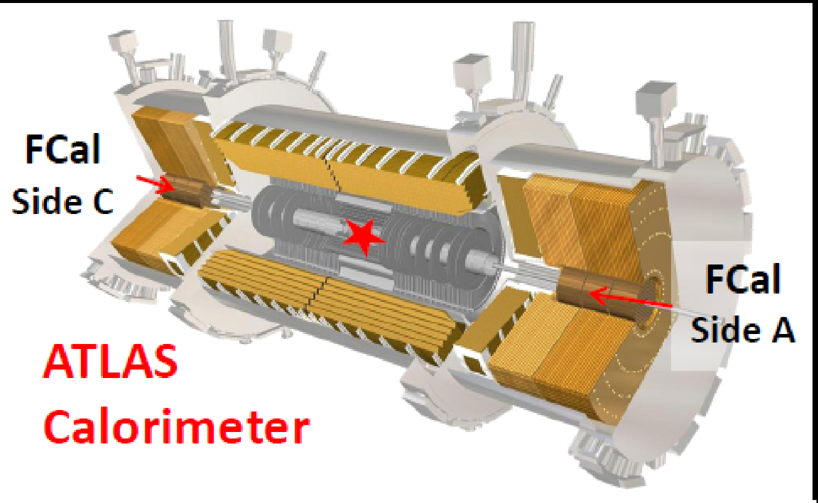
Dijet asymmetry probes differences in quenching between the two parton showers.

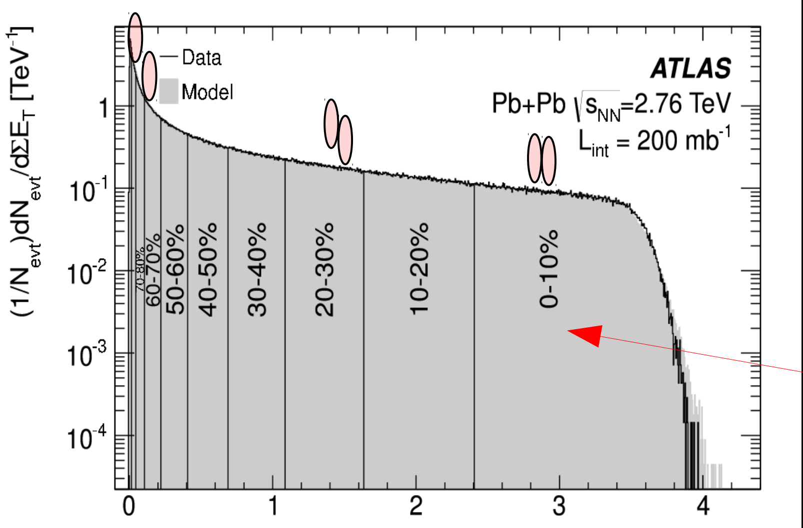
- ★ The asymmetry in peripheral collisions is well compatible with pp collisions (no QGP formation)
- ★ The asymmetry increases with nuclear overlap

Leading contribution from LIP ATLAS group

Physics Letters B 774 (2017) 379

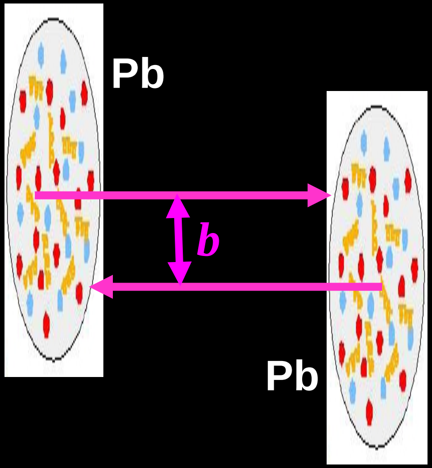
Collisions' "Centrality"





PLB 707 (2012) 330

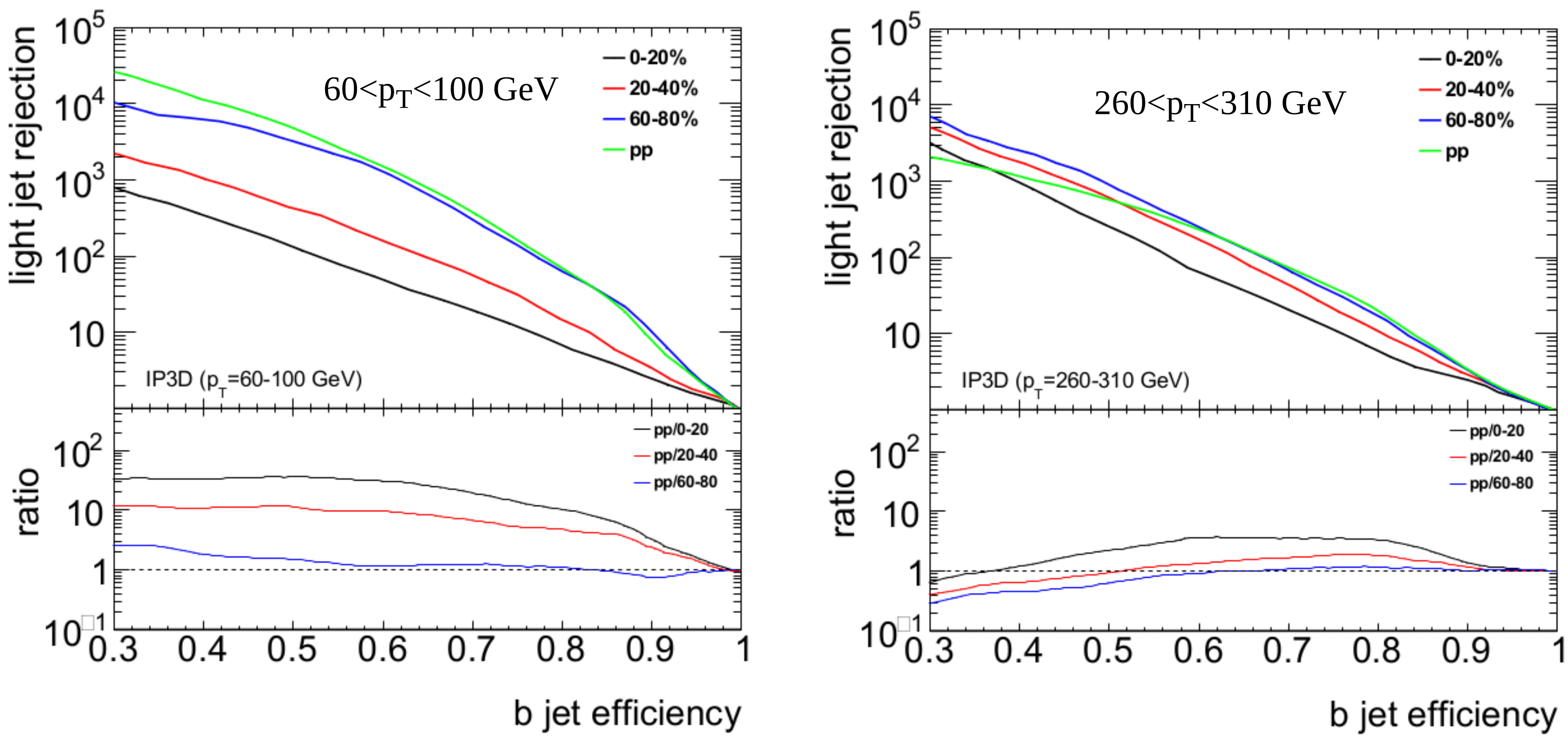
HI collision's dynamics controlled by impact parameter "*b*"



Transverse energy, E_T, deposited in Forward Calorimeter compared to Glauber model of nucleon-nucleon collisions.

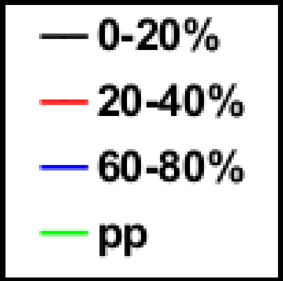
N_{coll} and N_{part} for each centrality interval estimated with the same Glauber model.

HI flavour tagging: centrality effect



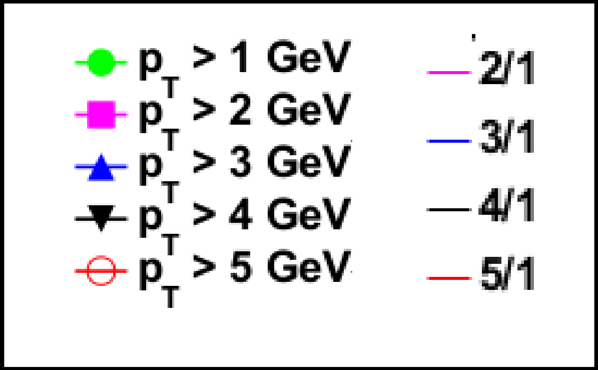
Example shown: IP3D

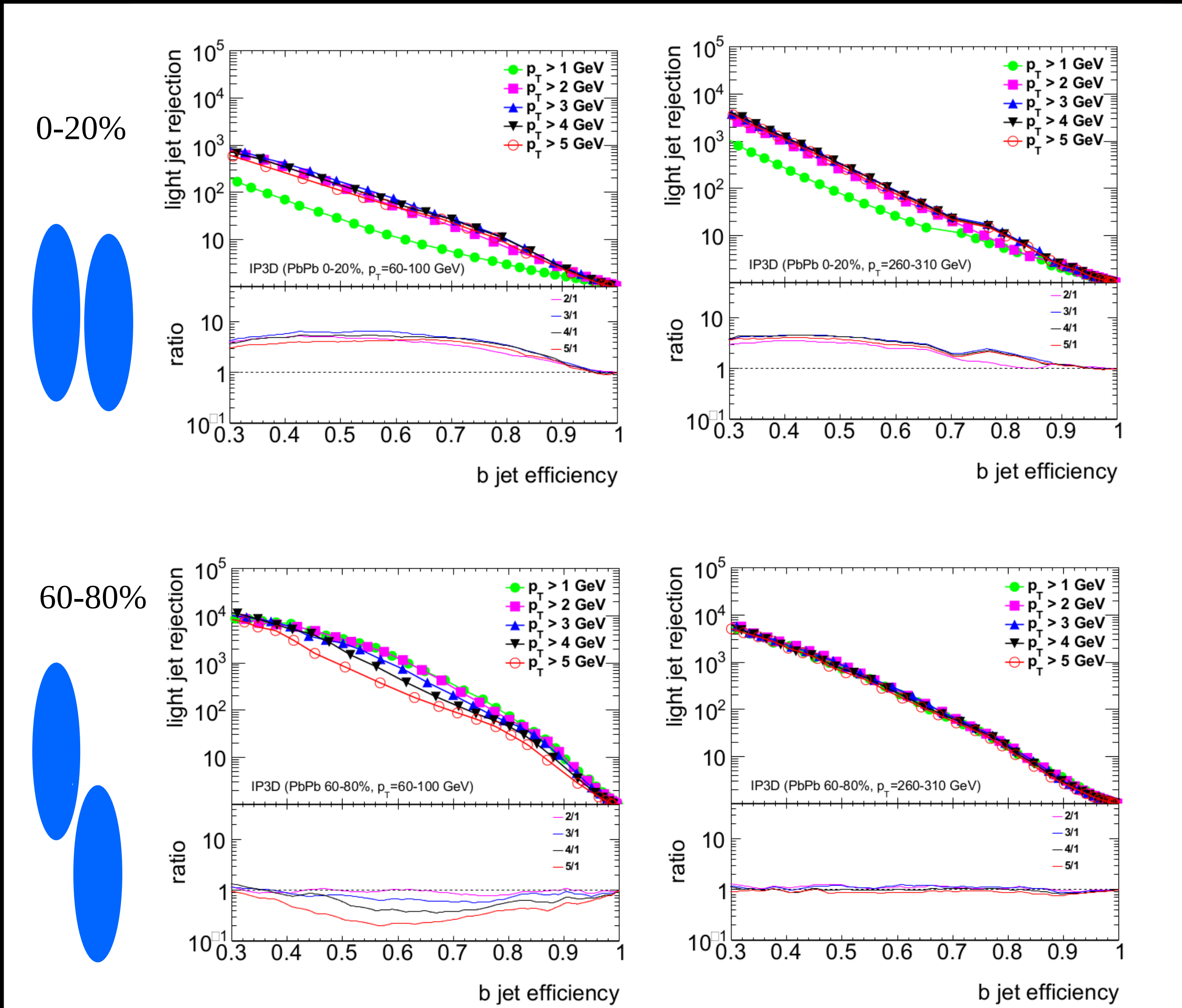
- Better result for peripheral collisions (similar to pp) than for central collisions - working to improve result for central
- Effect of centrality is stronger for jets with lower p_T



IP3D track p_T cut optimization

- **Track p_T cut has effect on flavour tagging quality**
- Major difference in effect between central and peripheral events, and between low and high jet p_T
- **Best compromise is cut at 2 GeV**

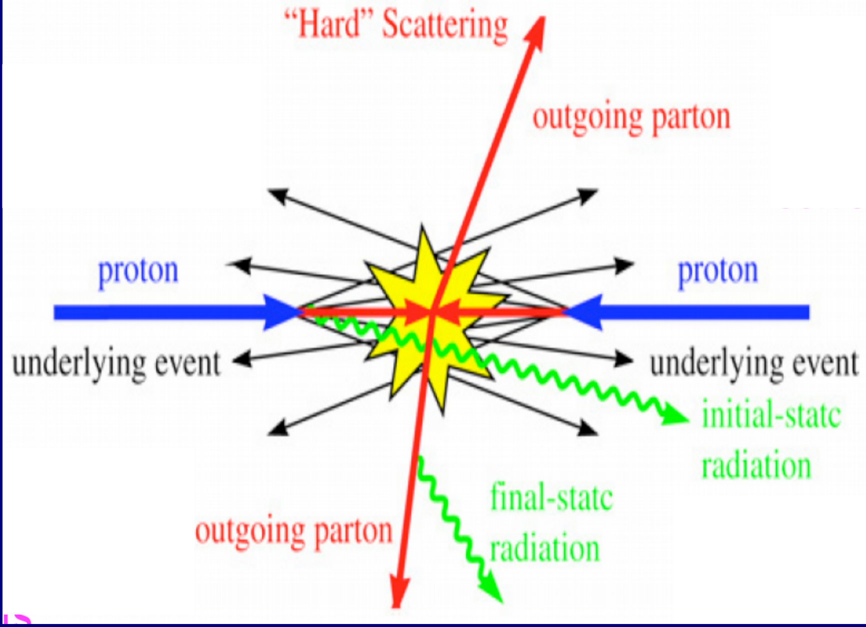


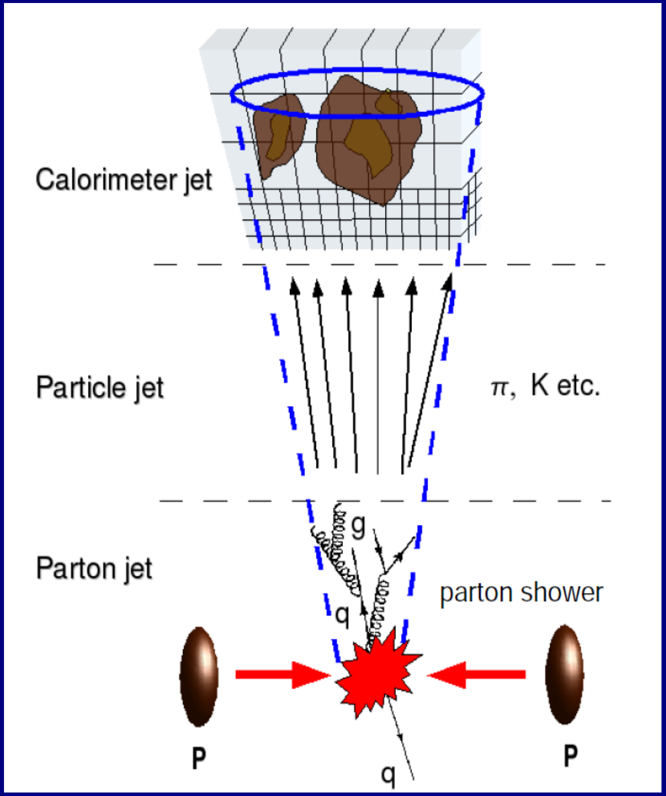


$60<p_T<100$ GeV $260<p_T<310$ GeV

Jets in p+p – a baseline for Pb+Pb

The common picture (p+p):



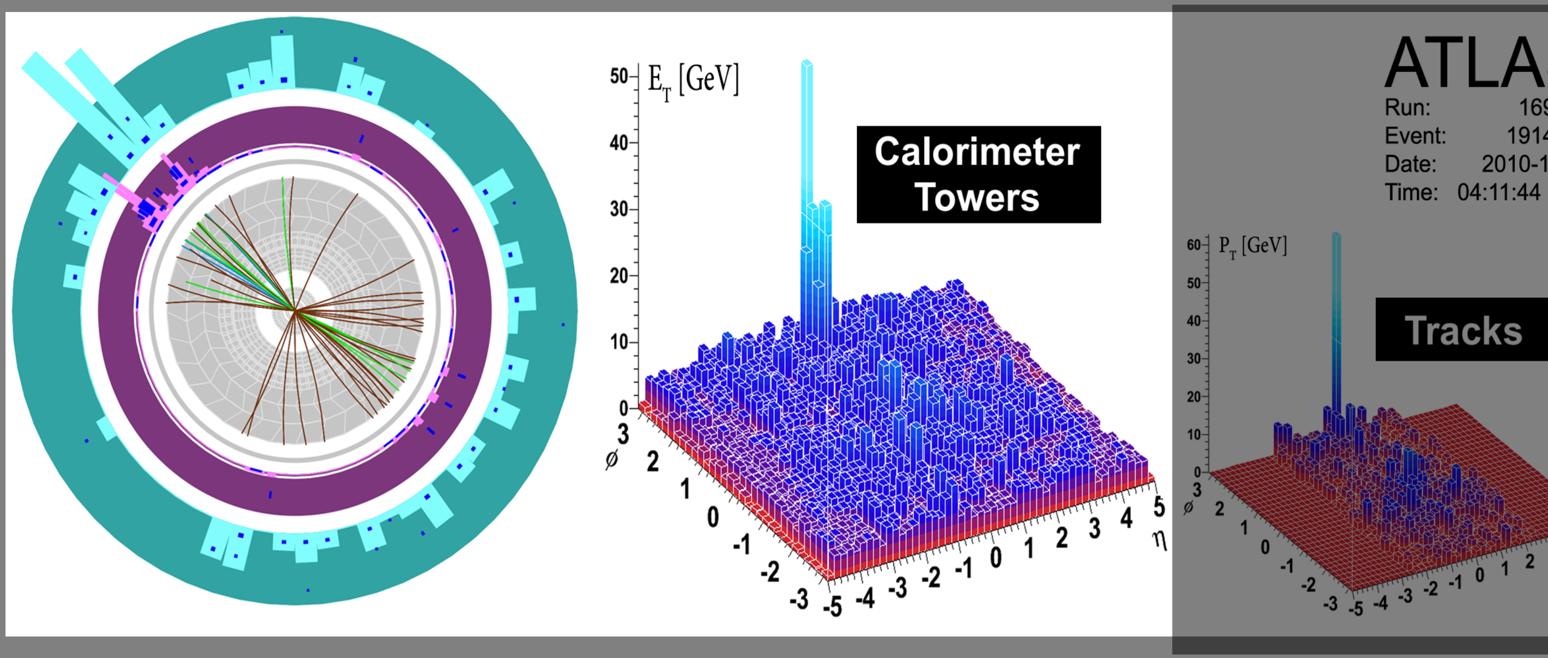


Jets produced in p+p collisions are well understood and constitute a reliable baseline to study medium-dependence effects.

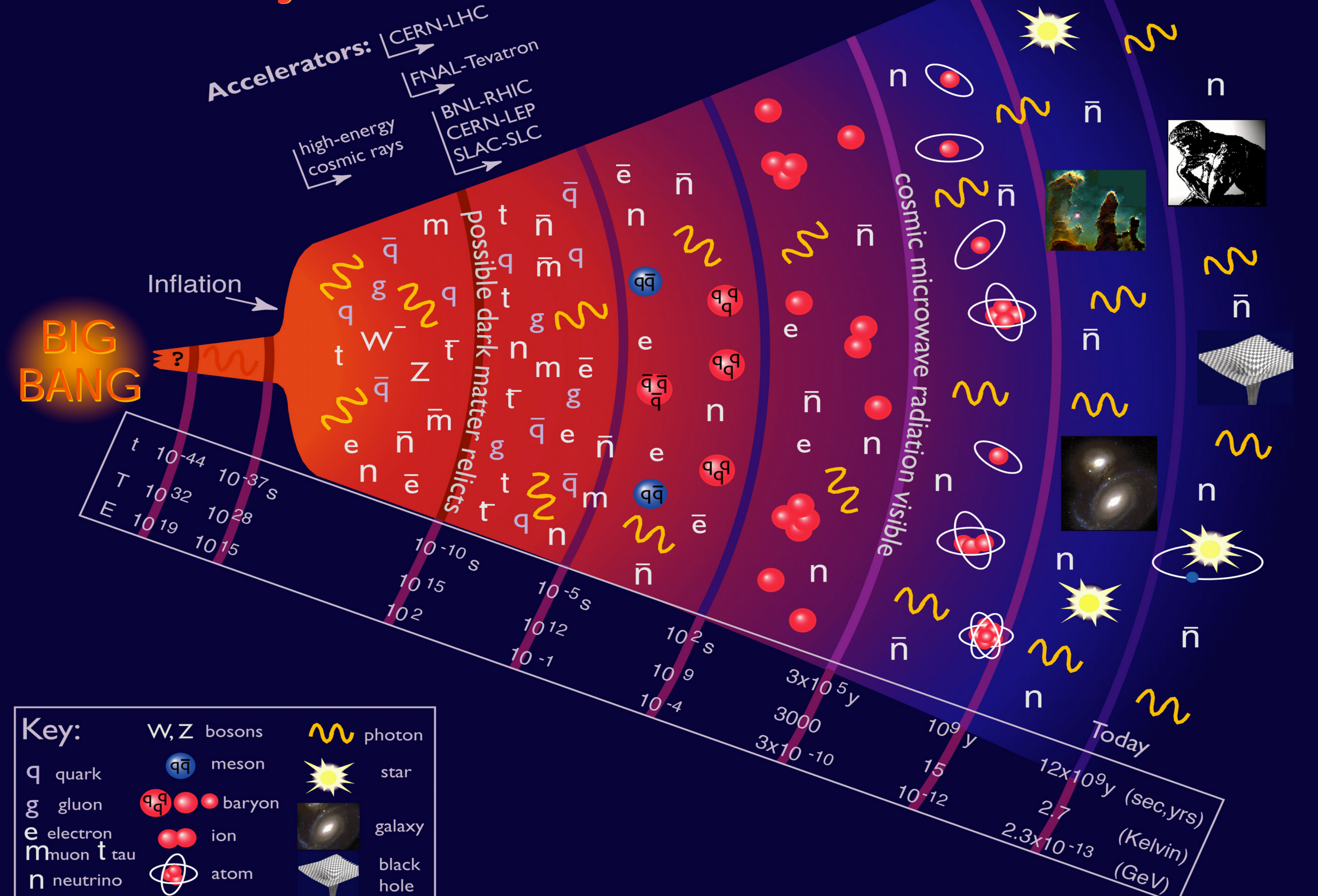
Jet Reconstruction in the Detector

- Jets are reconstructed by computational algorithms that group "towers" of energy deposited in the calorimeters.

- The Underlying Event ("background") is estimated event-by-event, excluding the jet candidate.



History of the Universe



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