Preparation for heavy ions at LHC in ALICE and the other experiments

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thanks to:

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Outline

- Why Heavy Ions at the Large Hadron Collider?
  - strongly-interacting matter in extreme conditions
  - expectations for the LHC and first measurements
- LHC as a heavy-ion collider
  - experimental conditions for upcoming Pb run
- ALICE: an experiment designed for heavy ions
- ATLAS and CMS: the heavy ion challenge
- Trigger and DAQ for heavy ions
- First measurement: particle multiplicity
  - tracks and tracklets reconstruction
- Summary

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Why Heavy Ions at the LHC?

Fundamental Questions:

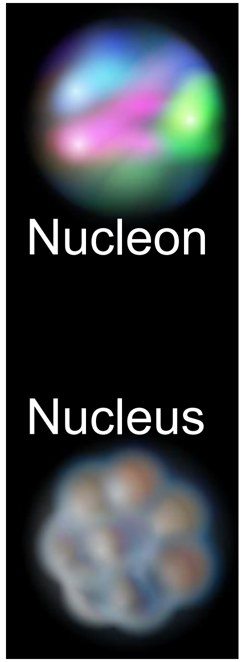
- *Can the quarks inside the protons and neutrons be freed?*
- *Why do protons and neutrons weigh 100 times more than the quarks they are made of?*
- *What happens to matter when it is heated to 100,000 times the temperature at the centre of the Sun?*

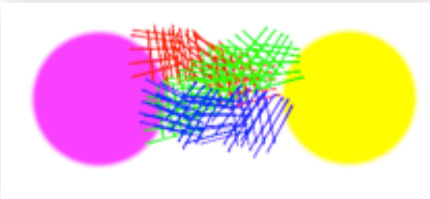
Strongly-interacting matter, QCD, and confinement

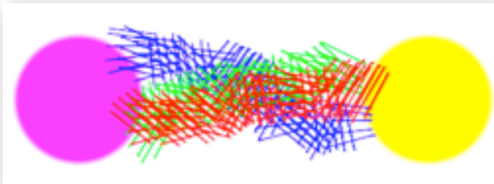
- Strong interaction: keeps together
  - quarks inside protons and neutrons
  - protons and neutrons inside atomic nuclei

  and is carried by the colour charge (quarks, gluons)
- Quantun ChromoDynamics (QCD) is the theory that describes the strong interaction
- Main feature of QCD: *confinement*

  → no free quarks

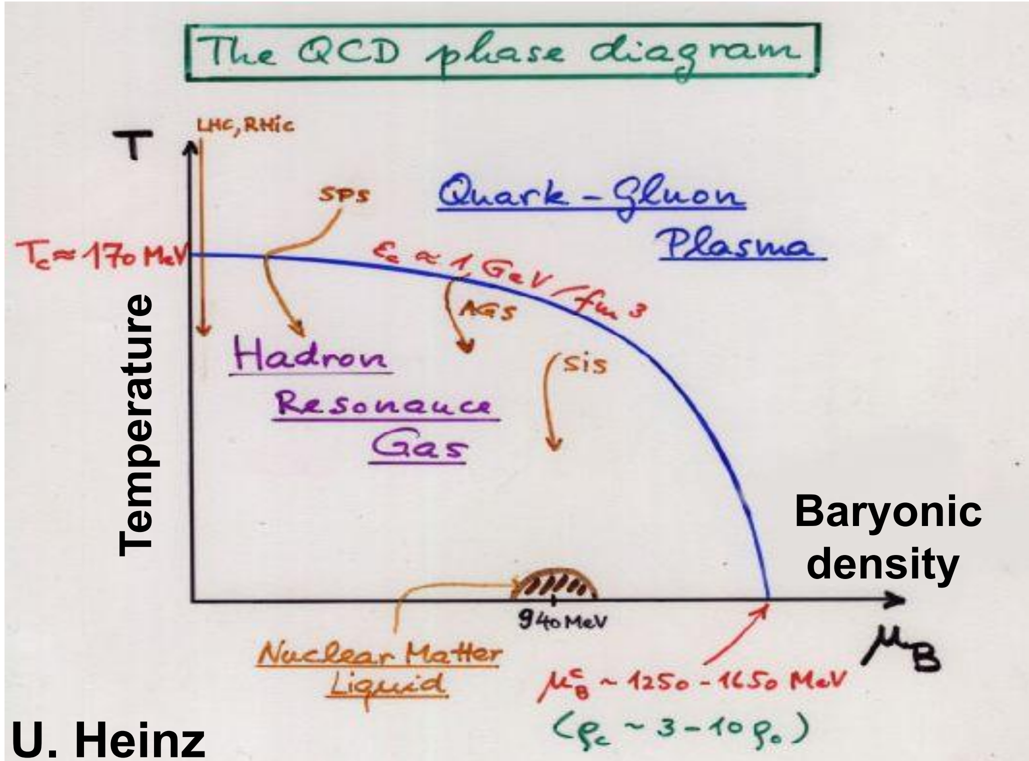






cartoon of a quark and anti-quarkbeing "pulled apart" and their colour connection

Phase diagram of strongly-interacting (QCD) matter



At high energy density (high temperature and/or high density) hadronic matter undergoes a phase transition to the *Quark-Gluon Plasma (QGP)*

- *a state in which colour confinement is removed*
- *and chiral symmetry is restored*
- *a high-density QCD medium of "free" quarks and gluons*

critical energy density ε_c ~ 1 GeV/fm^3 ~ 10 $\varepsilon_{nucleus}$

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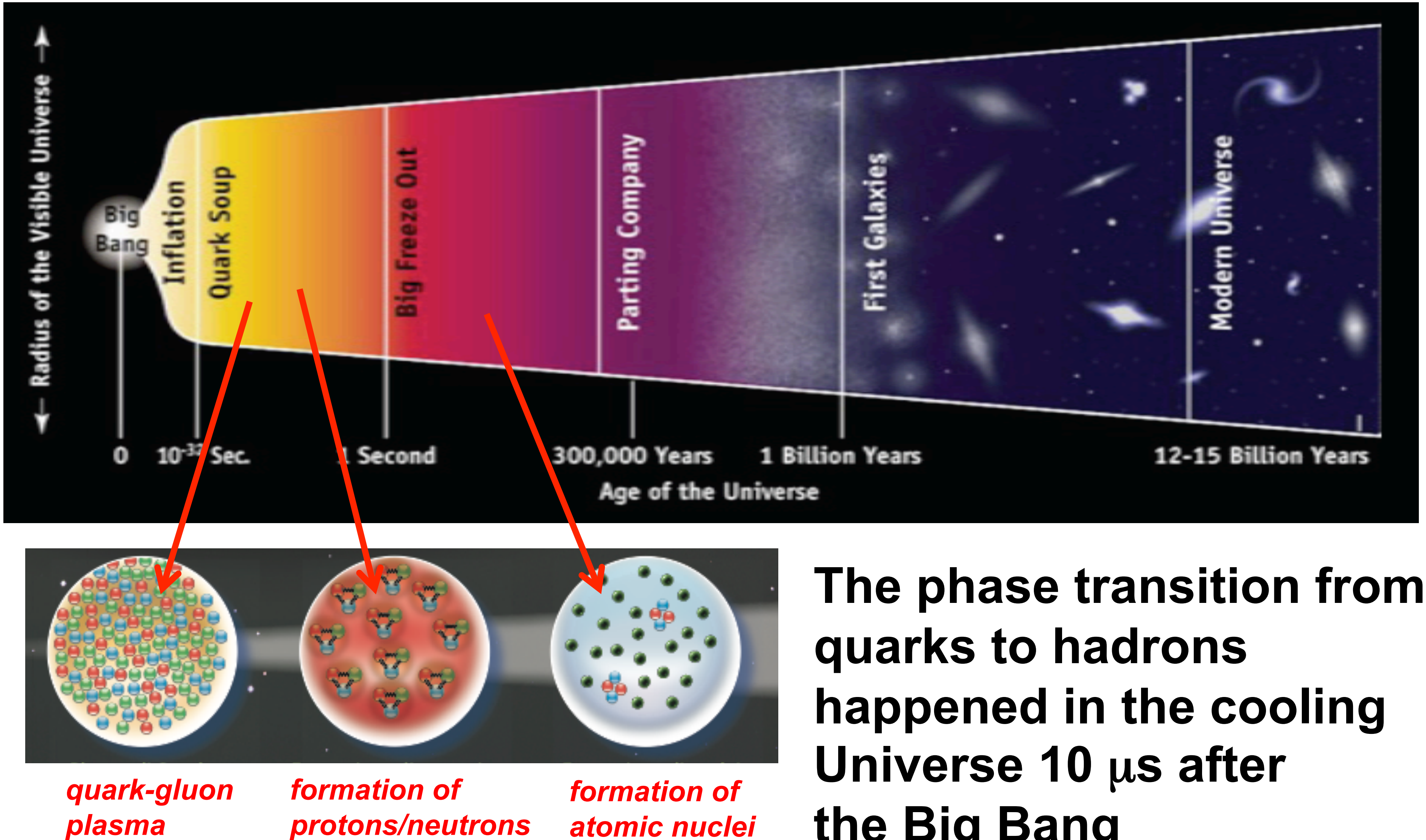
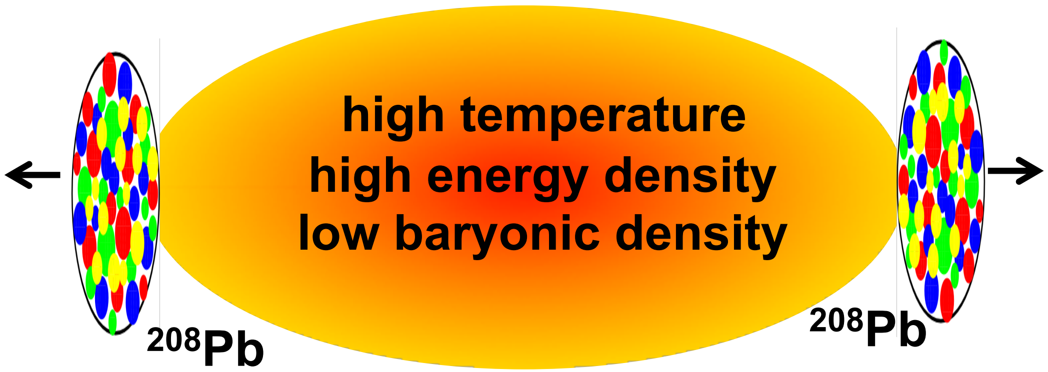
Quark-Gluon Plasma:
the first "matter" in the primordial Universe

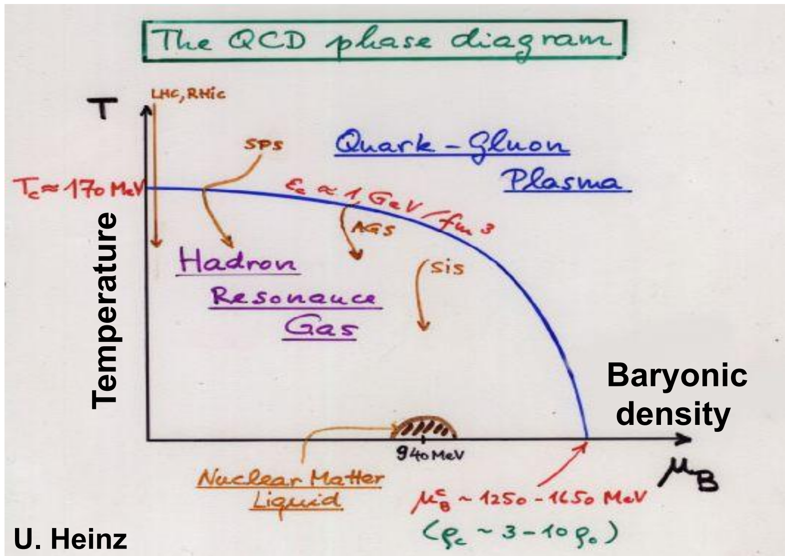


The phase transition from quarks to hadrons happened in the cooling Universe 10 μs after the Big Bang

The Little Bang in the lab

- QCD phase transition (QGP → hadrons) at $t_{Universe}$ ~10 μs
- In **high-energy heavy-ion** collisions, **large energy densities** (> 2–3 GeV/fm^3) are reached over **large volumes** (> 1000 fm^3)

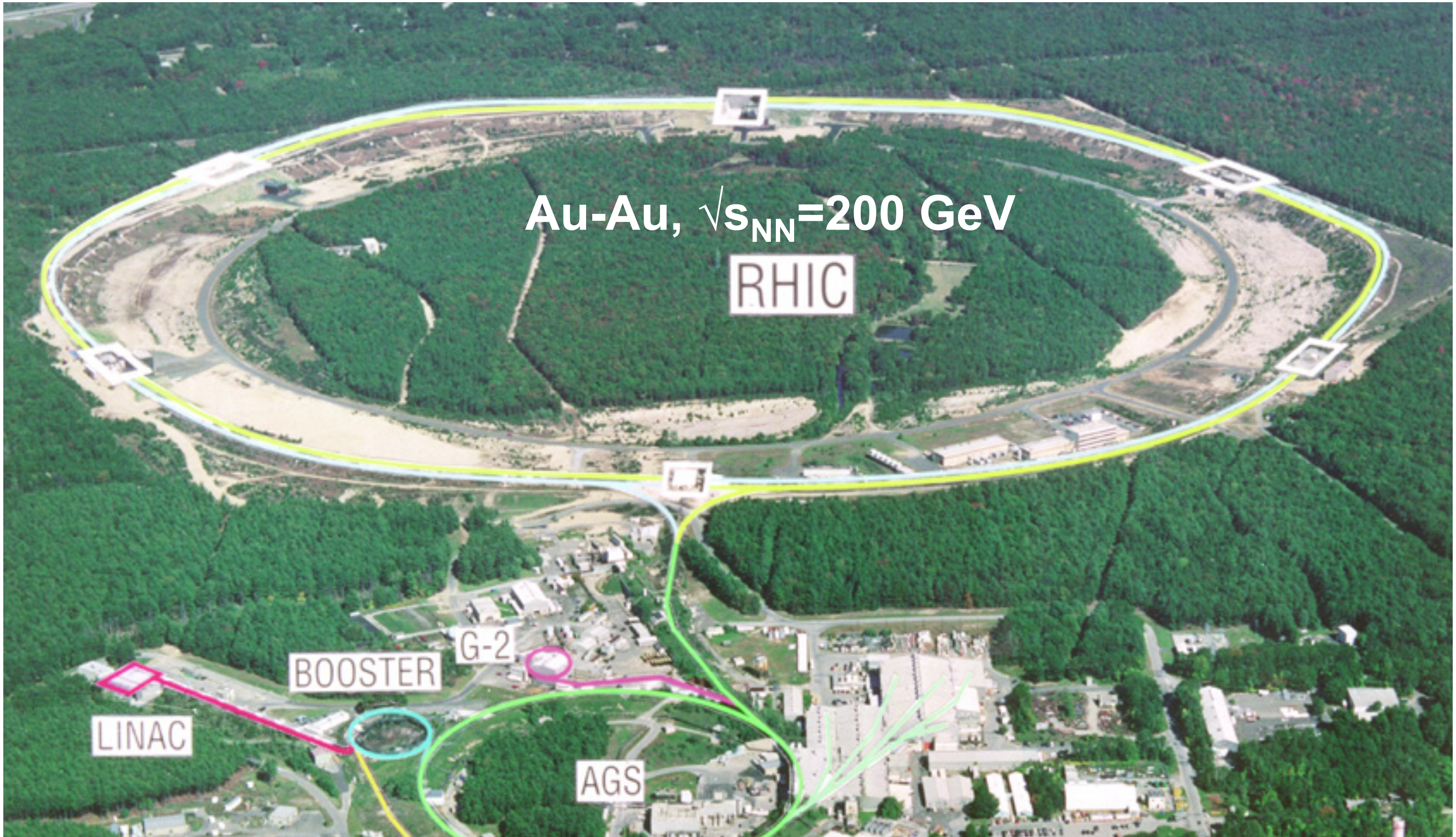




History of heavy-ion collisions

- QGP evidence at **CERN-SPS** (up to: Pb-Pb, $\sqrt{s_{NN}} = 17\,\text{GeV}$)
  - energy density ~ 1 × critical value ε_c
- First QGP properties at **BNL-RHIC**, Au-Au, $\sqrt{s_{NN}} = 200\,\text{GeV}$
  - energy density ~ 10 × critical value ε_c
- Next step: **LHC** with Pb-Pb, $\sqrt{s_{NN}} = 2.76 - 5.5\,\text{TeV}$
  - energy density ~ 30-50 × critical value ε_c
  - ***much higher initial temperature, closer to "ideal gas" of gluons***
  - ***also very important: more physis tools to study the system produced***
    - ***high-energy jets***
    - ***heavy quarks***
    - ***photons and vector bosons (W, Z^0)***
  - ***last but maybe first: the marvellous LHC detectors***

BNL-RHIC (2000s): beginning of the heavy-ion Collider Era



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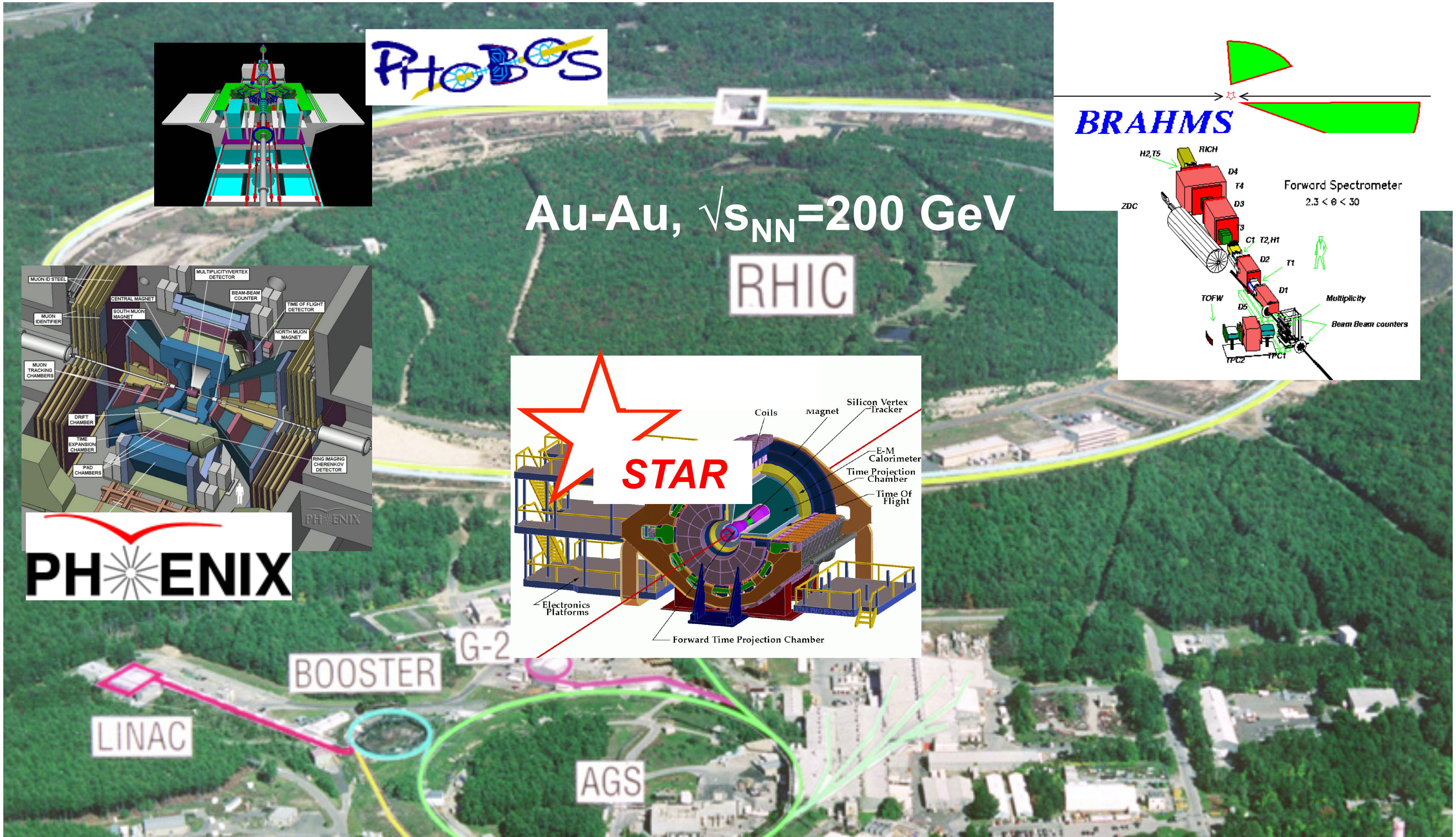
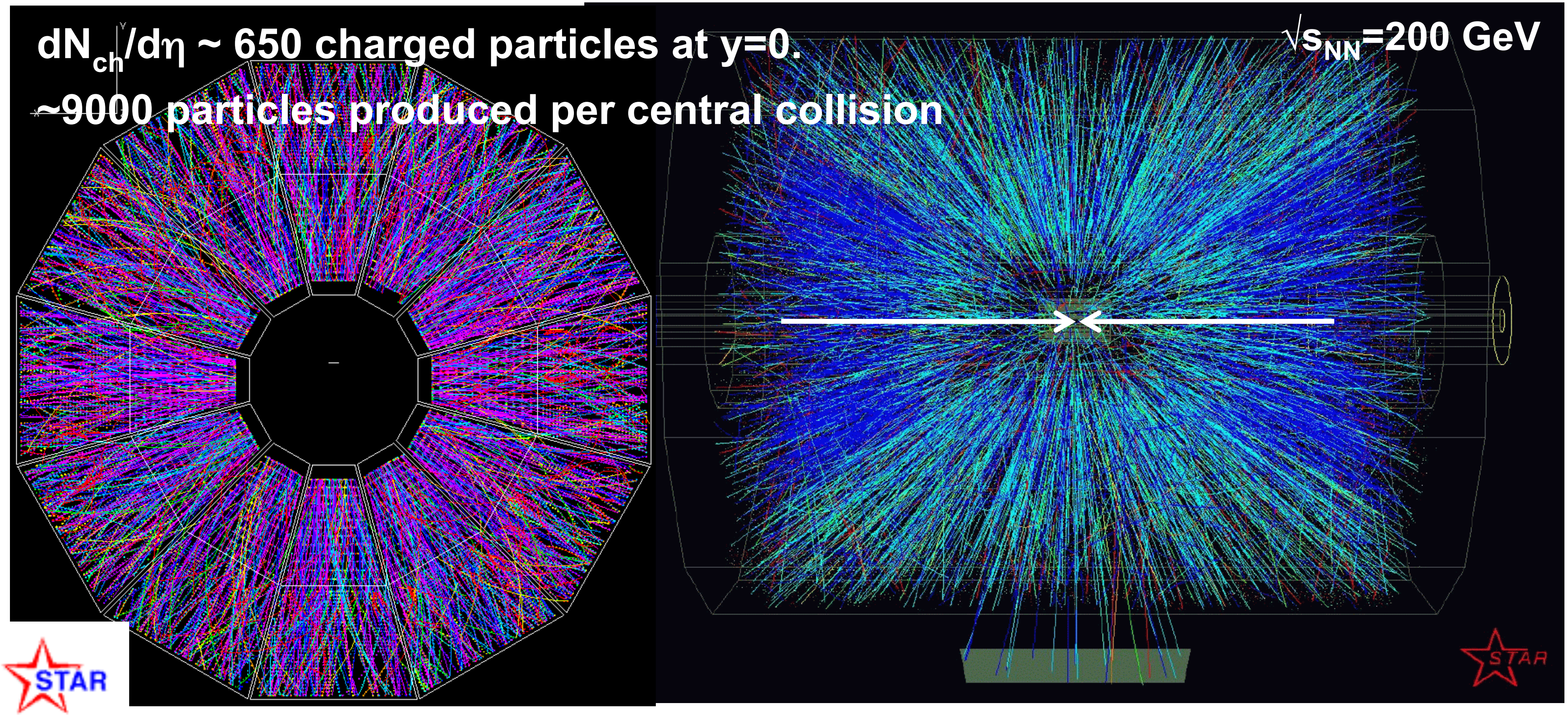


Central gold-gold collision at RHIC in the STAR Time Projection Chamber

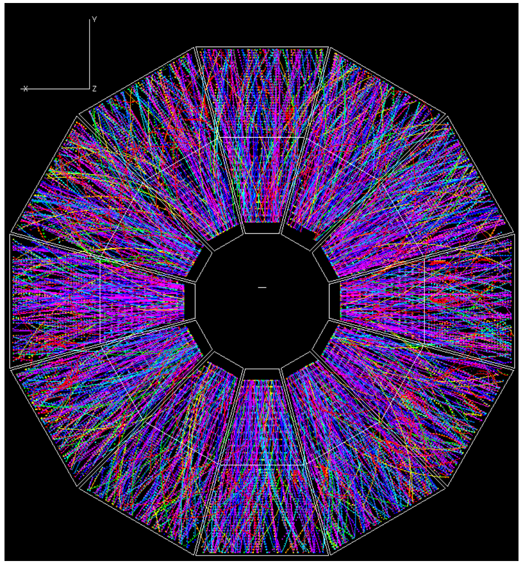


What to measure in Pb-Pb at LHC: bulk properties of the QCD medium

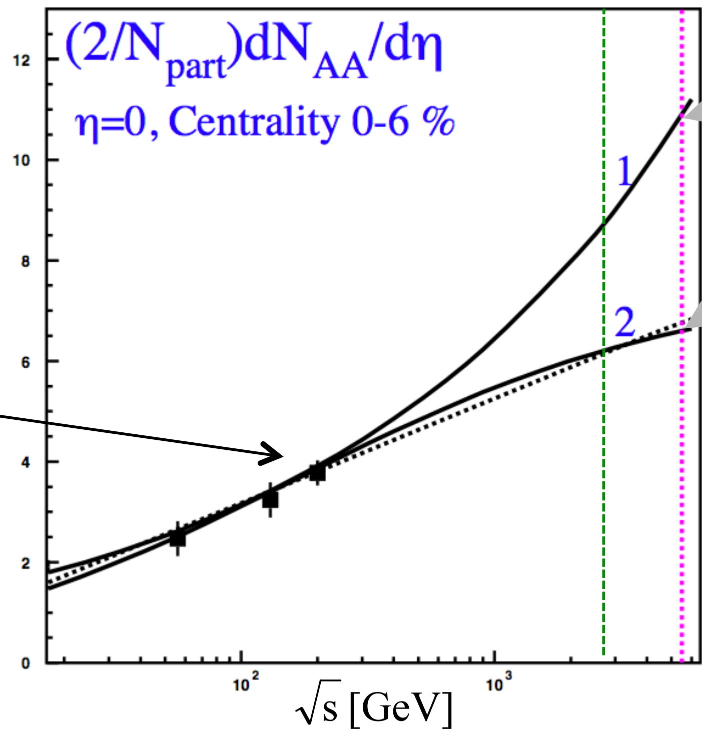
- Day-1 measurement:

Charged multiplicity:
first contact with new system
dN_{ch}/dy, n. of particles → n. of gluons
→ energy density

RHIC (200 GeV)
$dN_{ch}/d\eta$=650



LHC (2760-5500 GeV) ?



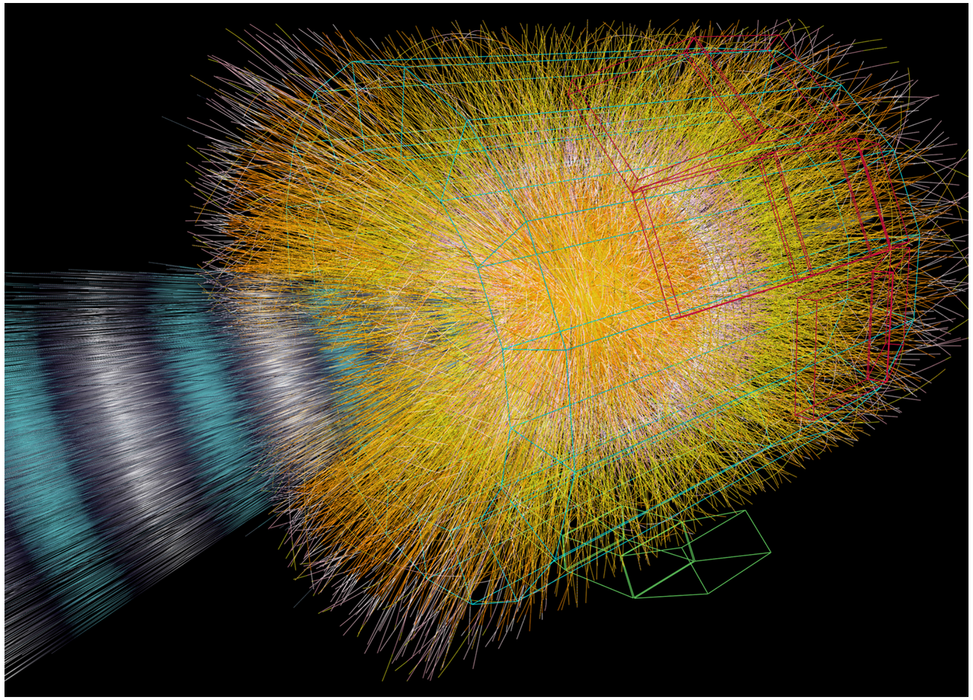
$dN_{ch}/d\eta$ ~2000-2500
Eskola et al., saturation model

$dN_{ch}/d\eta$ ~1200
Kharzeev et al., Color Glass Condensate

What to measure in Pb-Pb at LHC: bulk properties of the QCD medium

Detector requirements:

- Count and measure the properties (momentum, identity) of most of the particles produced in the collision
- Tracking (or "trackleting") down to very low momentum
  - robust tracking in high-multiplicity environment
- Particle identification



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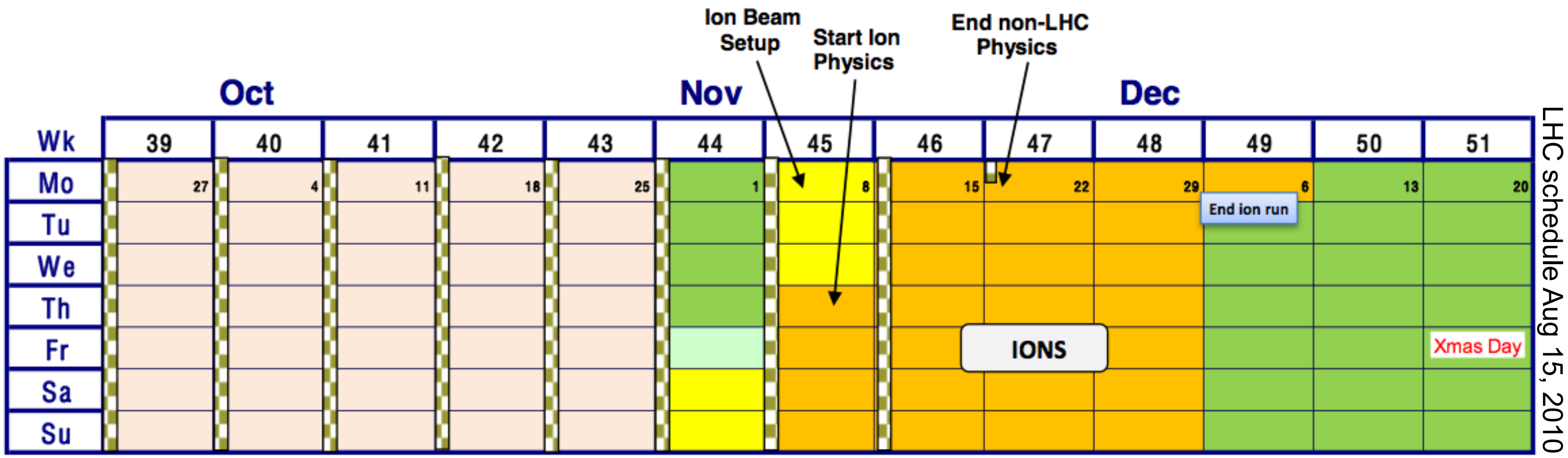
The LHC as a heavy-ion collider

- **Energy** per nucleon for a nucleus (A,Z): $p_N = (Z/A)\, p_p$
  - Pb-Pb c.m.s. energy: **2.76**-5.5 **TeV**, for pp energy 7-14 TeV
- **Luminosity**: nominal 10^{27} $cm^{-2}s^{-1}$
  - initial (2010): factor 100 lower → **10^{25} $cm^{-2}s^{-1}$**
- **When: Nov 11 – Dec 6, 2010**



- Later: one month heavy-ion per LHC year
  - Pb-Pb, p(d)-Pb, lighter ions (Ar? O?)

LHC Pb-Pb parameters

		Early (2010/11)	Nominal
$\sqrt{s_{NN}}$ (per colliding nucleon pair)	TeV	2.76	5.5
Number of bunches		62	592
Bunch spacing	ns	1350	99.8
β^*	m	$2 \rightarrow 3.5$	0.5
Pb ions/bunch		7×10^7	7×10^7
Transverse norm. emittance	μm	1.5	1.5
Initial Luminosity (L_0)	$cm^{-2}s^{-1}$	$(1.25 \rightarrow 0.7)$ 10^{25}	10^{27}
Stored energy (W)	MJ	0.2	3.8
Luminosity half life (1,2,3 expts.)	h	τ_{IBS}=7-30	8, 4.5, 3

courtesy J.Jowett

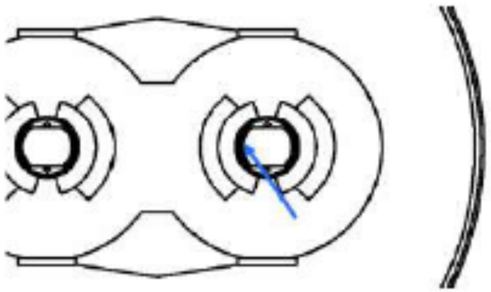
Pb-Pb Luminosity

- Main effect for machine max. luminosity limitation (10^{27}) and luminosity decay: Bound Free Pair Production

$$Z_1 + Z_2 \rightarrow Z_1 + e^- + e^+ + Z_2$$

$$^{208}Pb^{82+} + ^{208}Pb^{82+} \xrightarrow{\gamma} ^{208}Pb^{82+} + ^{208}Pb^{81+} + e^+$$

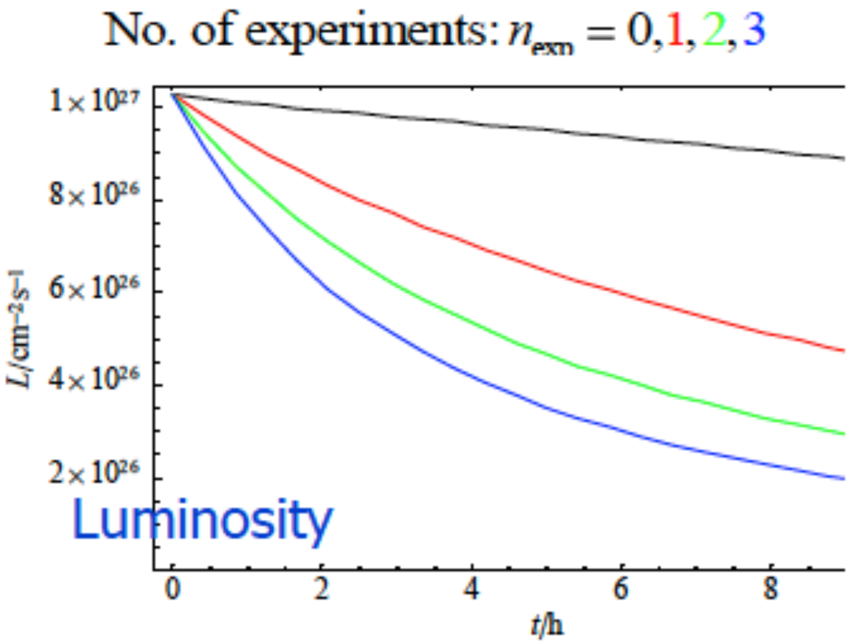
  - Bound Free Pair Production (BFPP) generates “secondary beams” with lower Z/A emerging from interaction points
  - 25 W heating power on dipole magnets at nominal lumi
  - magnets are not likely to quench
  - but quenches are not excluded within calculation uncertainties
  - collimation systems very important to protect the machine



courtesy J.Jowett

Pb-Pb Luminosity

- Luminosity decay (mainly by BFPP):



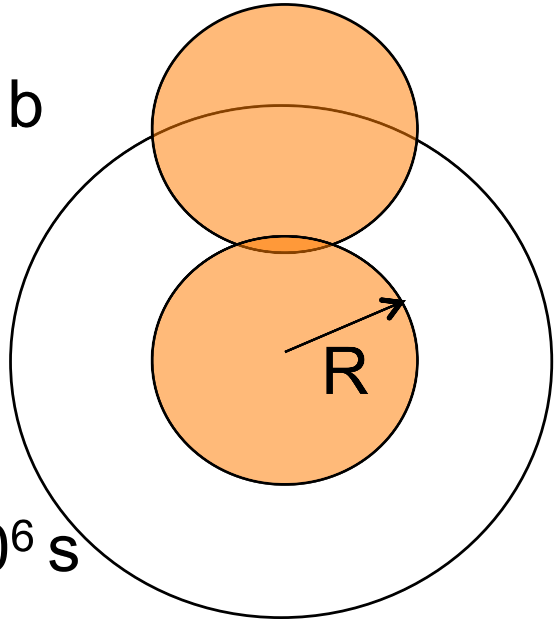
Increasing number of experiments reduces beam and luminosity lifetime.

<L> with 3 exps:
~0.5×10^{27} (design)
~0.5×10^{25} (2010)

courtesy J.Jowett

Pb run 2010: expected rates and int. lumi

- $L \sim 0.5\text{-}5 \times 10^{25}\ cm^{-2}s^{-1}$
- Pb-Pb interaction cross section: $\sigma_{geom} \sim 7.7$ b
  - ^{208}Pb radius, $R \sim 1.2 \cdot A^{1/3}$ fm ~ 7 fm
  - $\sigma_{geom} \sim \pi\,(2R)^2 \sim 7.7$ b
- Expected rate $L\,\sigma_{geom} \sim 30\text{-}300$ Hz
  - **average rate ~ 100 Hz**
- Statistics: up to 10^7 events (~1-3 μb^{-1}) in 10^6 s



- ***Collisions centrality***: specific to heavy ions

  - System size (i.e. Physics) depends on centrality
  - Experiments have to *measure centrality* and study everything vs. centrality

Heavy ions at LHC: radiation environment

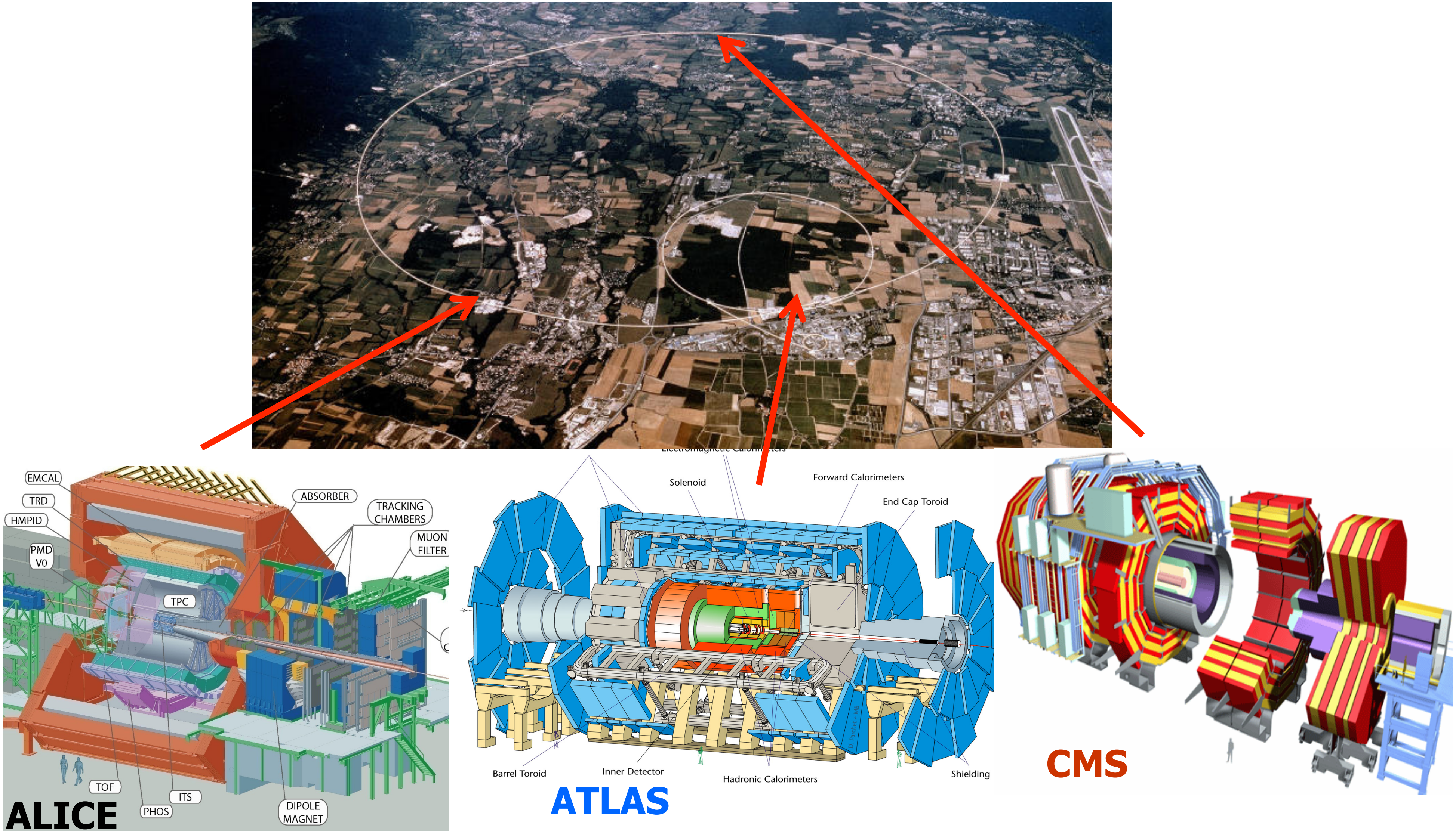
- LHC will run pp, Pb-Pb, d-Pb, Ar-Ar in the next 10-15 years
- Although the dose per collision is much higher for Pb-Pb (up to x100), the total dose will be dominated by far by the pp running (much higher rate and running time)
  - only in ALICE (reduced pp lumi) the Ar-Ar contribution would be comparable to that from pp

Table 2.5. Operation scenario for a 10-year run period, where $\langle \mathcal{L} \rangle$ is mean luminosity, and σ_{inel} is the inelastic cross section. One year of pp run corresponds to 10^7 s and 1 year of heavy-ion run corresponds to 10^6 s. **pp: ALICE (ATLAS/CMS)**

	pp	Ar–Ar	Ar–Ar	Pb–Pb	dPb
$\langle \mathcal{L} \rangle$ (cm^{-2} s^{-1})	3×10^{30} **(33)**	3×10^{27}	10^{29}	10^{27}	8×10^{28}
σ_{inel} (mb)	70	3000	3000	8000	2600
Rate (s^{-1})	2×10^5 **(8)**	9×10^3	3×10^5	8×10^3	2×10^5
Runtime (s)	10^8	1.0×10^6	2.0×10^6	5×10^6	2×10^6
Events	2×10^{13} **(16)**	9×10^9	6×10^{11}	4×10^{10}	4×10^{11}
Particles per event	100	2400	2400	14 200	500
N_{tot}	2.1×10^{15} **(18)**	2.2×10^{13}	1.4×10^{15}	5.7×10^{14}	2×10^{14}

ALICE PPR vol1

Heavy-ion experiments at the LHC



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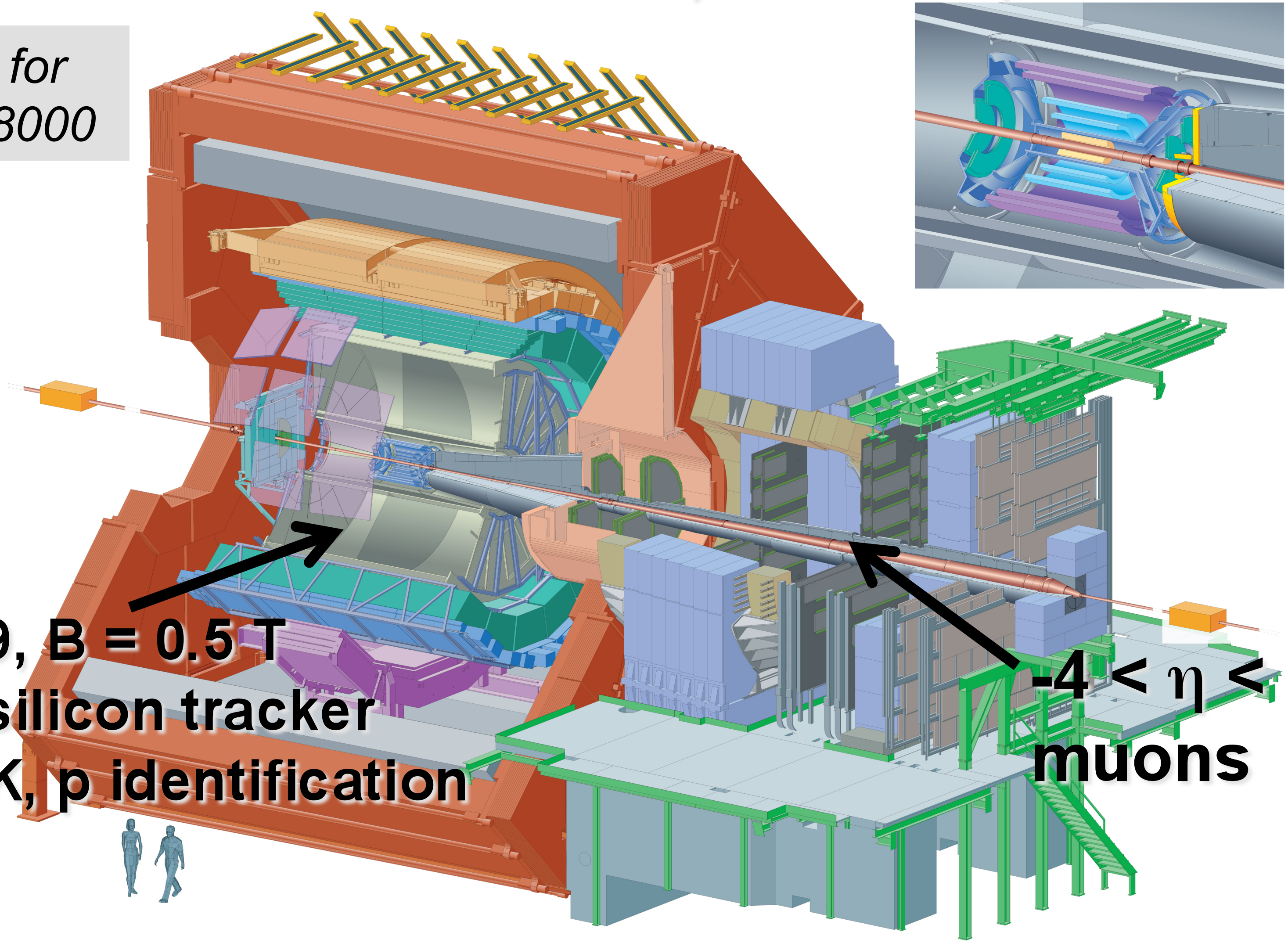
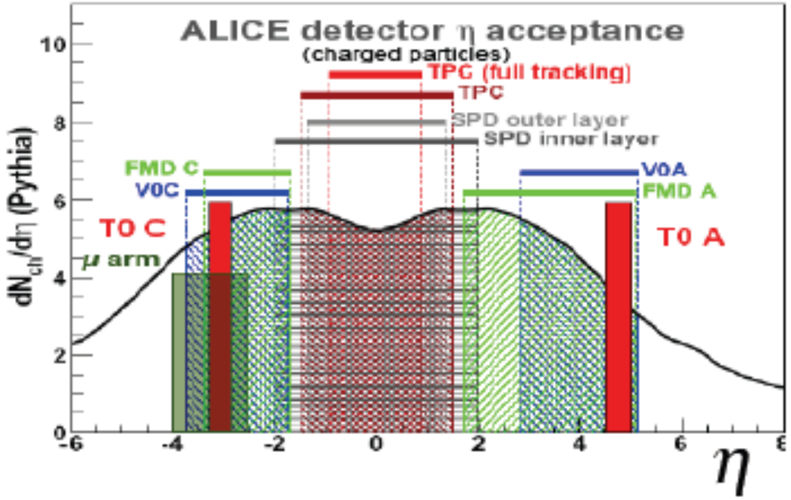
ALICE: the dedicated heavy-ion experiment

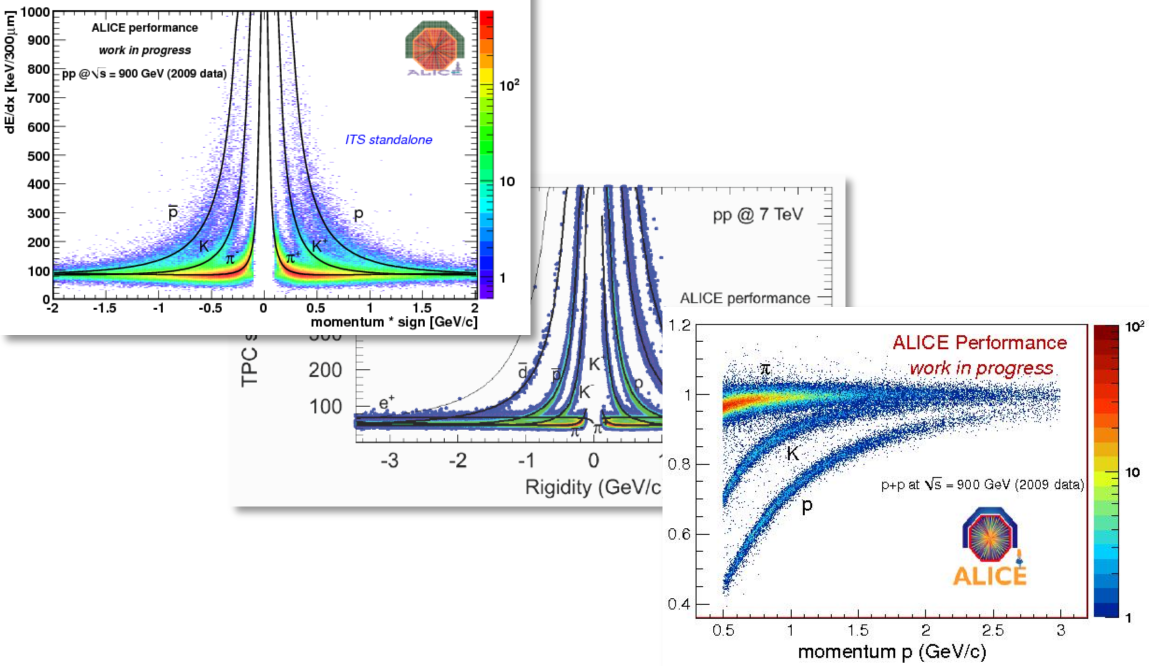
designed for dN_{ch}/dy=8000

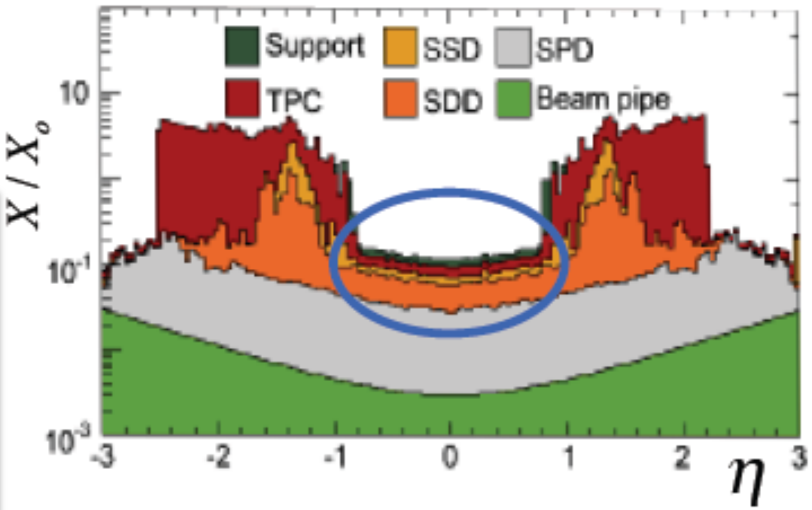


ALICE design guideline: reconstruct and identify most of the particles produced in the collision

- Low B field (0.5T)
- Low mat. budget (10%X_0 in $|\eta|<0.9$)
- Redundant tracking → TPC
- Redundant PID (7 detectors)

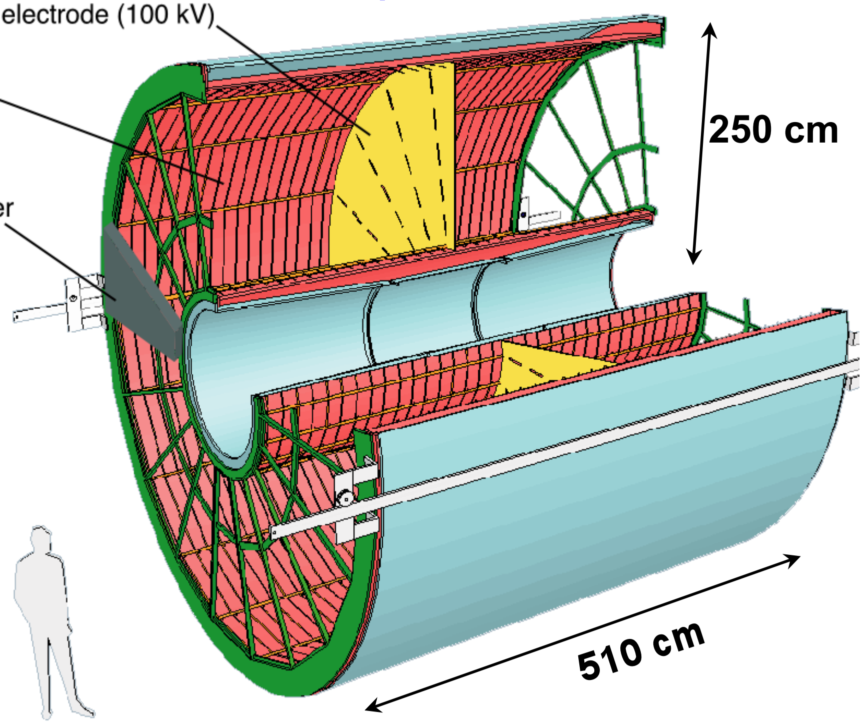


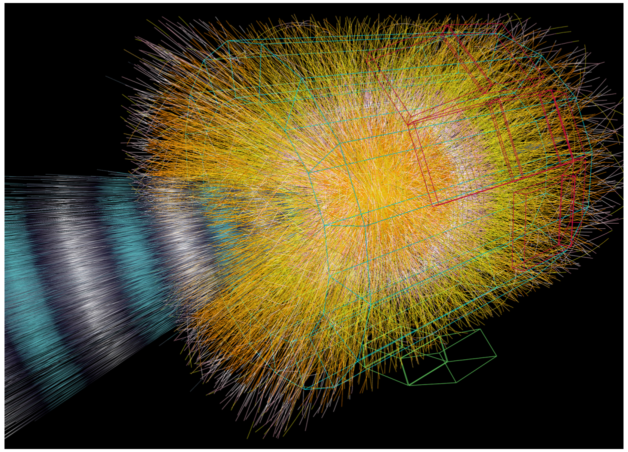




ALICE Time Projection Chamber: the largest TPC, tailored for heavy ions

- Large 3D tracking device (5×5×5 m), providing up to 160 hits/particle
- High particle density
  - low diffusion & low space charge 'cool' drift gas ($Ne/CO_2/N_2$)
  - high granularity (550k few mm wide pads)
- Minimal material budget for low momentum tracking
  - composite materials → 3.5% x/X_0
- Advanced readout electronics
  - digital pulse shaping and zero-suppression
  - > 2 kHz readout of 0.5×10^9 10-bit ADC's



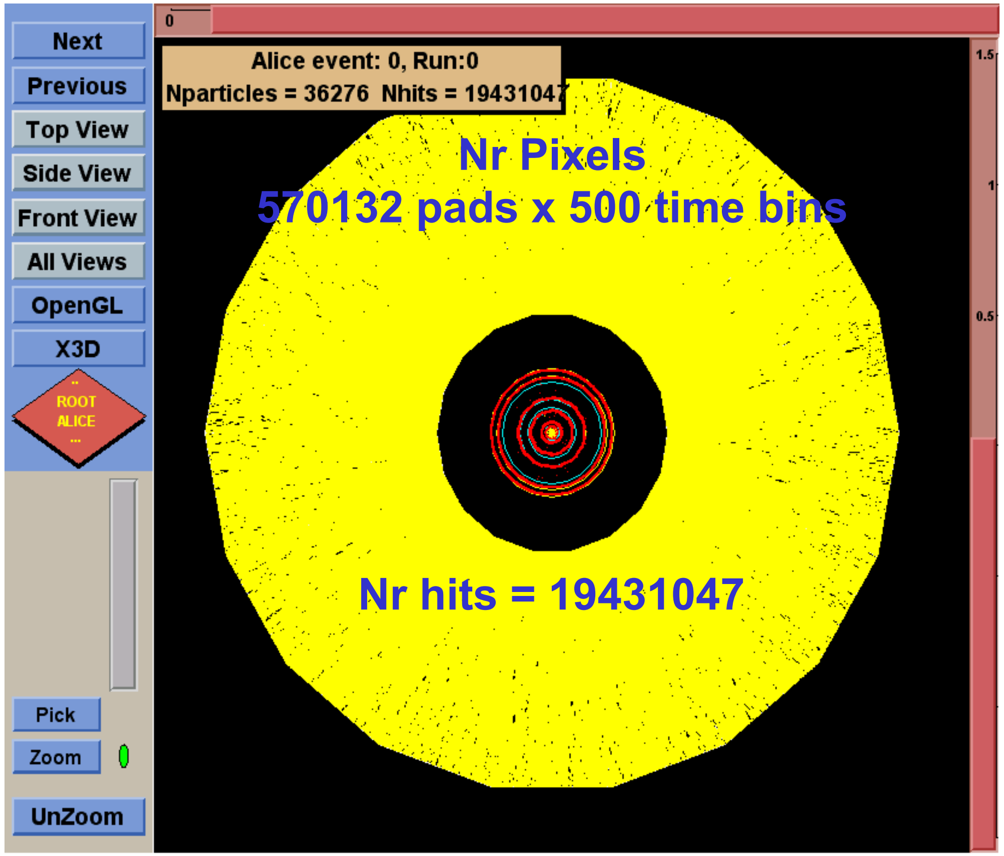


ALICE Time Projection Chamber in view of heavy ions at LHC

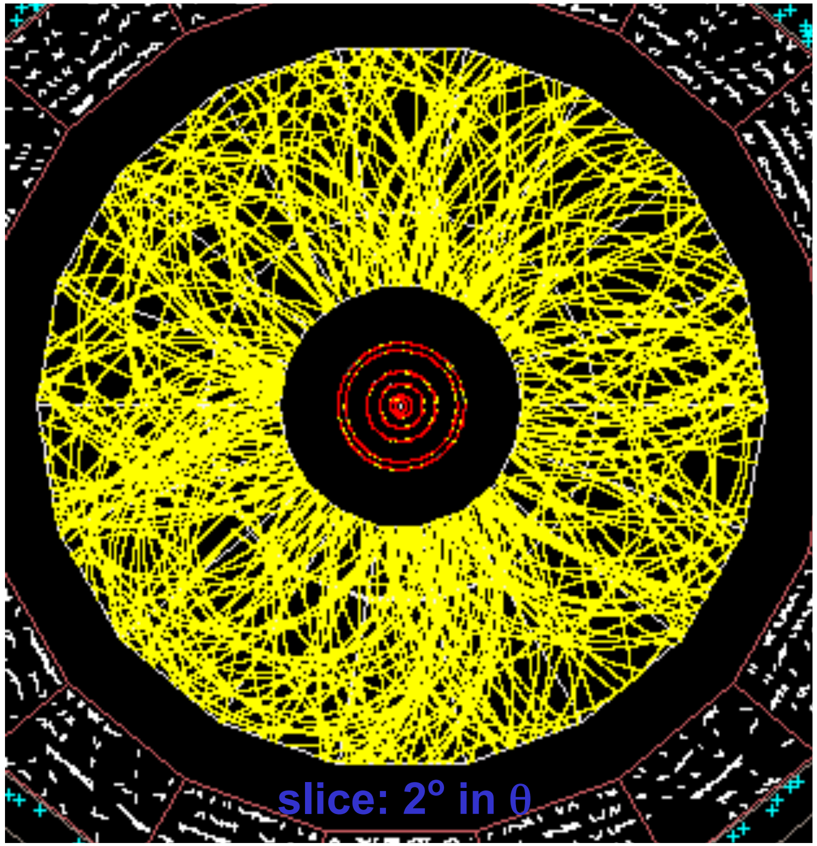
For $dN_{ch}/dy=8000$ (design reference):
occupancy (in pad-time space): mean 25% (from 17 to 50%)

Projection of the drift volume into the pad plane

dN_{ch} / dy = 8000 ➡ $2x10^4$ charged particles



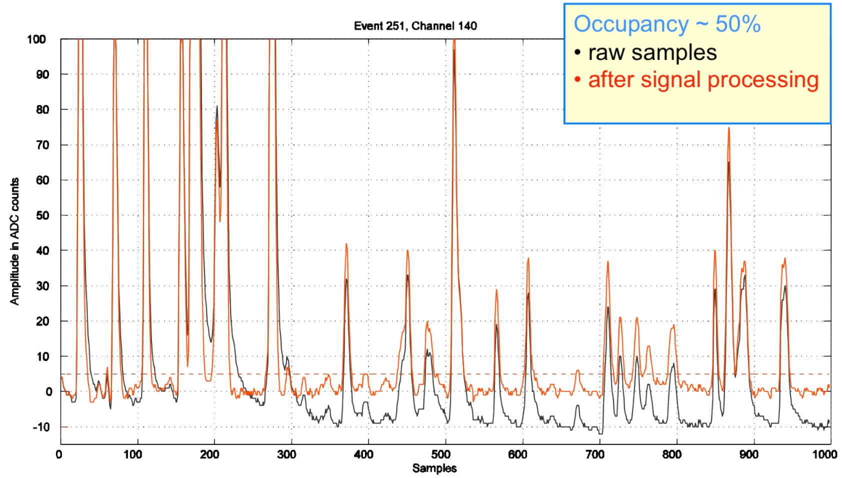
Projection of a slice (2° in θ)



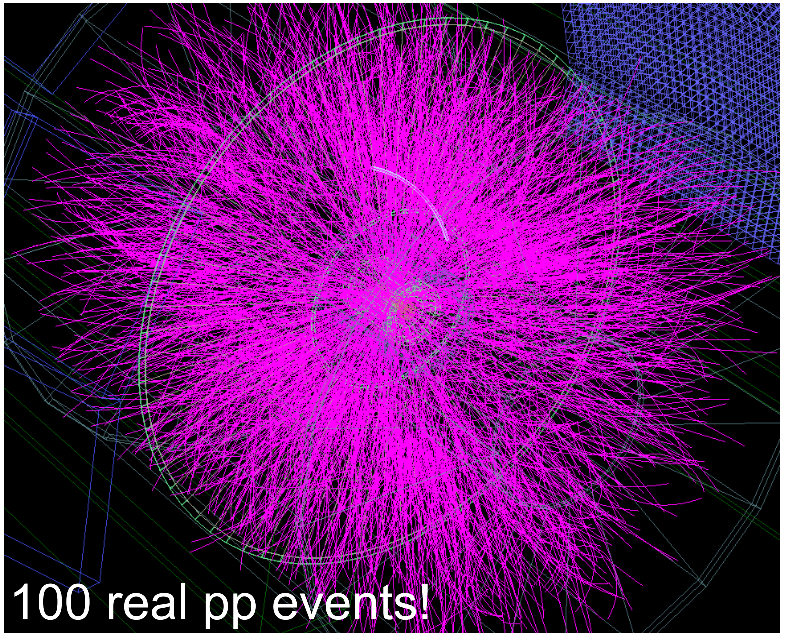
ALICE TPC Readout: high-occupancy tests

- ALTRO chip: baseline corr., tail cancellation, zero suppression
- Tail cancellation and baseline correction tests with high (50%) occupancy cosmic-ray events →

High Multiplicity cosmic rays

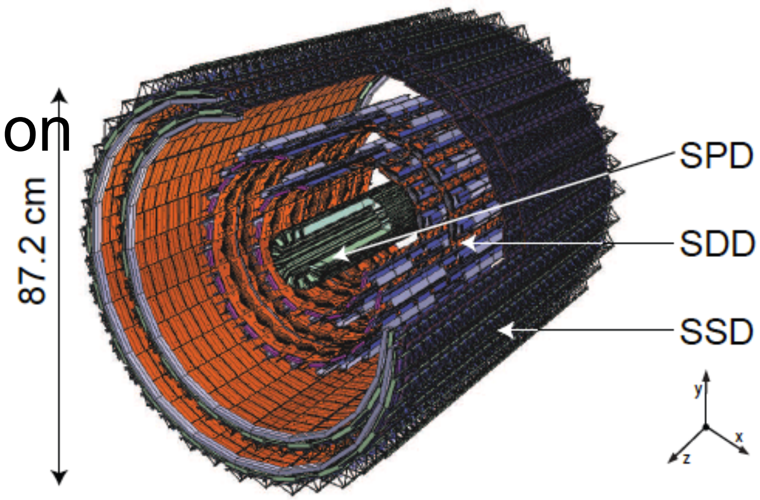


- And by overlapping and processing as a single event the raw detector signals from 100 real pp collisions →



ALICE Inner Tracking System

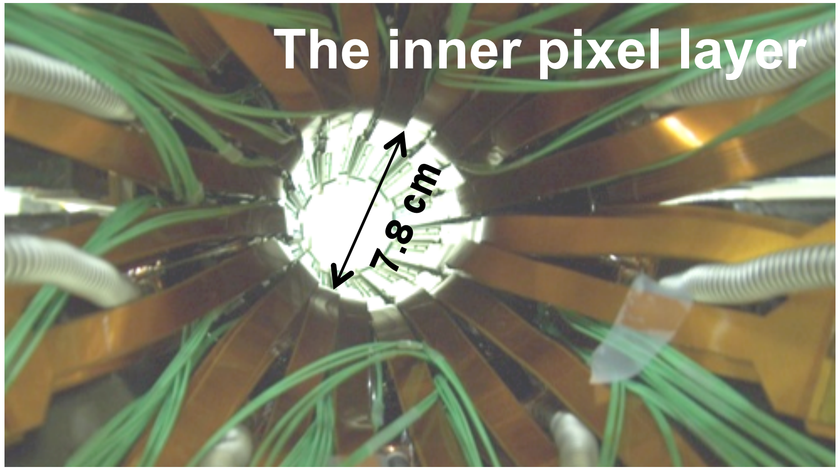
- 3 Silicon technologies (pixel, drift, strip)
- Low-momentum acceptance and precision
  → low material budget (x/X_0~7%)
- High granularity
  → occupancy < few %



Layer	Det. Type	Radius (cm)	Length (cm)	Resolution (μm)		Pb-Pb dN_{ch}/dy=3000	
				rϕ	z	Part./cm^2	Occupancy (%)
1	pixel	3.9	28.2	12	100	**18**	**1.05**
2	pixel	7.6	28.2	12	100	**6**	**0.6**
3	drift	15.0	44.4	35	25	**1.5**	**1.3**
4	drift	23.9	59.4	35	25	**0.8**	**0.5**
5	strip	38.0	86.2	20	830	**0.3**	**2.0**
6	strip	43.0	97.8	20	830	**0.3**	**1.8**

ALICE Pixels and heavy ions

- Innermost two layers of ITS: <r> = 3.9 and 7.6 cm
  - in Pb-Pb multiplicity environment needs high granularity to keep occupancy small
  - 50x425 μm^2 cells → occupancy of 1% for dN_{ch}/dy=3000

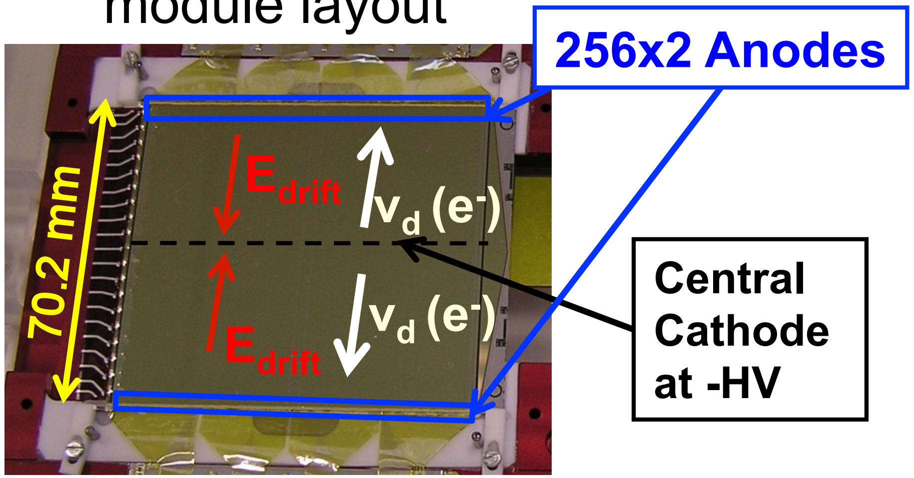


- No difference in the operation of the readout in pp and Pb-Pb
- Frontend ASICs designed to cope with expected high-mult.
- Zero suppression and formatting is done off detector in the control room → no inefficiencies (loss of hits) of the readout up to average pixel occupancy of 12.5% (x10 the expected)
- Specific tests carried out recently, e.g. increase data size to expected 250 kB/event by lowering thresholds on full detector → readout OK

ALICE SiDrifts and heavy ions

- Intermediate layers of ITS:
  <r> = 15 and 23 cm
- Si drift technology
  - high precision in two coordinates ($35 \times 25\ \mu m^2$) → low occupancy
  - calibration quite delicate
    - ongoing with pp

module layout

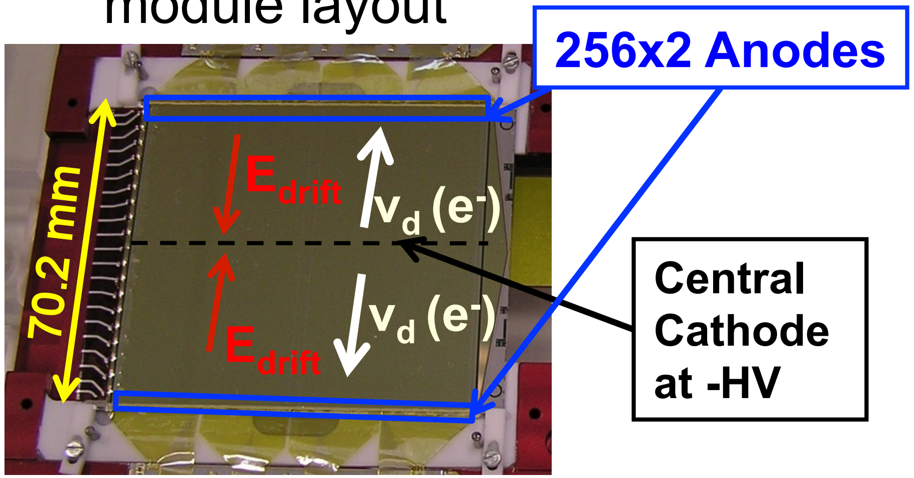


ALICE SiDrifts and heavy ions

Two readout frequencies:

Parameter	**20 MHz** sampling	**40 MHz** sampling
Time bin size	50 ns	25 ns
N. of time samples	128	256
Readout dead time	1 ms	2 ms
Max. event rate	1 kHz	500 Hz

module layout



- Different readout conditions for pp and Pb-Pb
- pp: amplifier sampling at 20MHz (→128 time-bins/anode)
  - lower readout (dead) time → allows to reach higher event rate
  - reduces data size (OK because ALICE bandwidth is smaller in pp)
  - two-track separation not crucial at low-occupancy
- Pb-Pb: amplifier sampling at 40 MHz (→256 time-bins/anode)
  - best performance on time resolution and two-track separation
  - dead time and event rate not crucial due to lower luminosity

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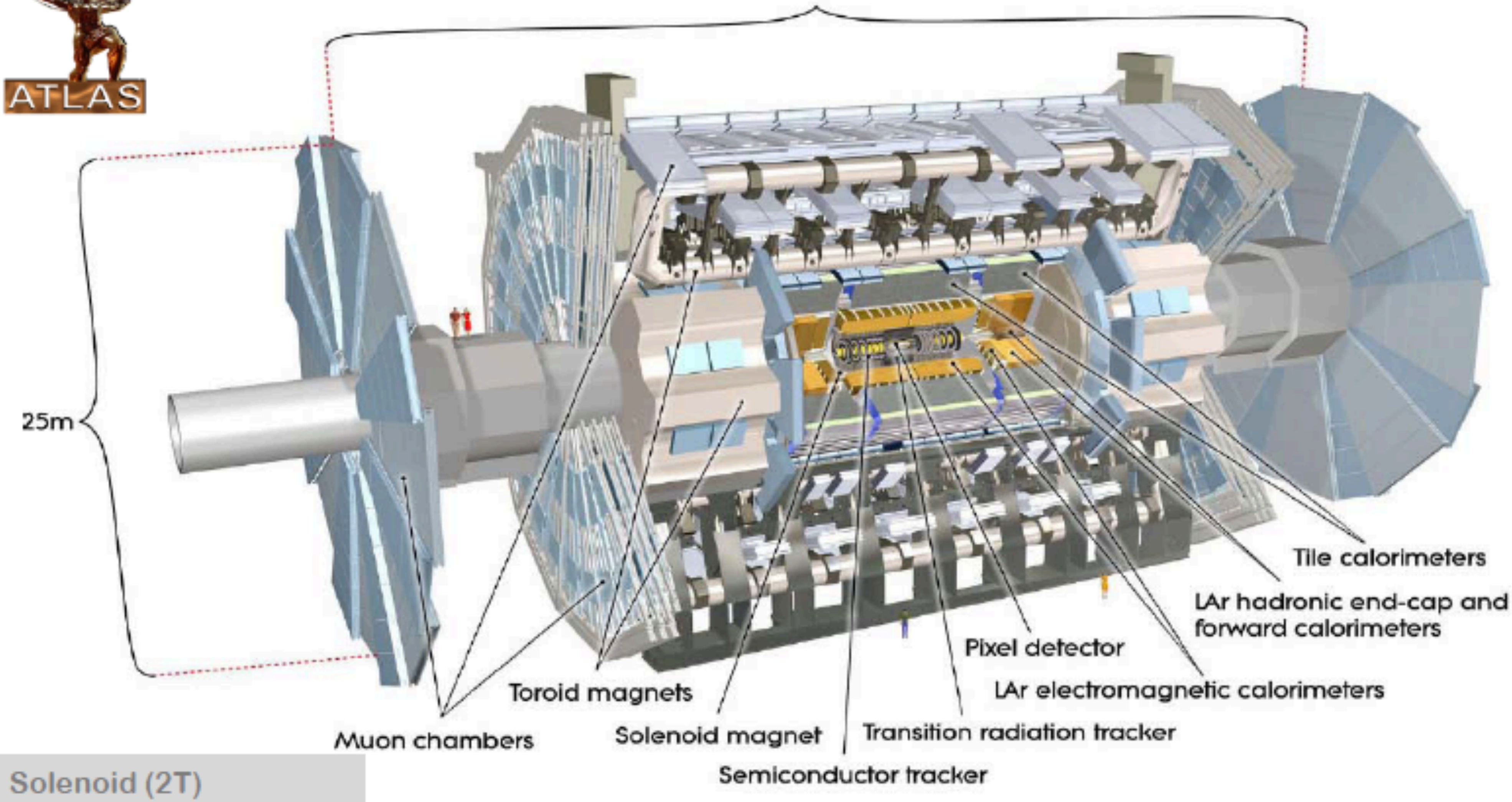
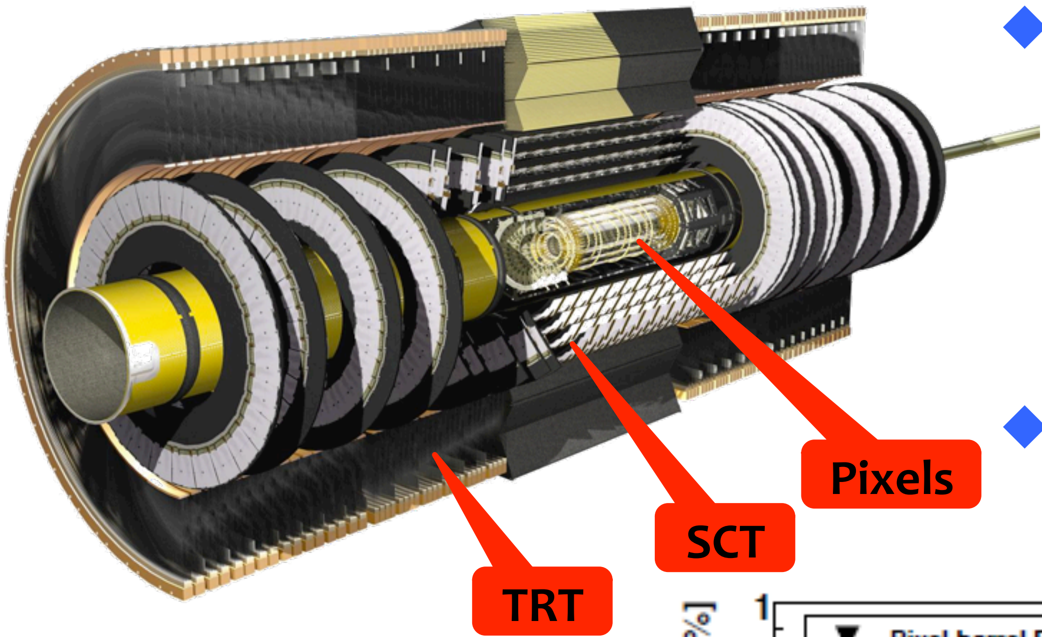
The ATLAS detector

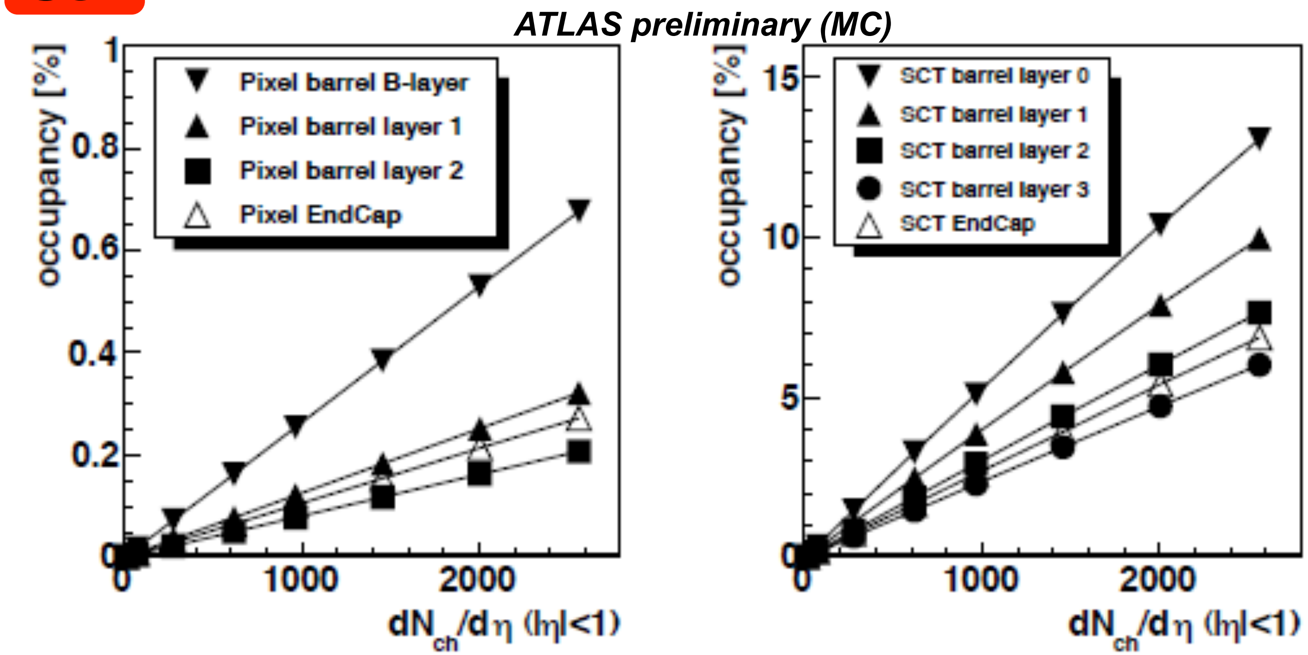


Solenoid (2T)
Toroids (∫Bdl=1-7.5 Tm)

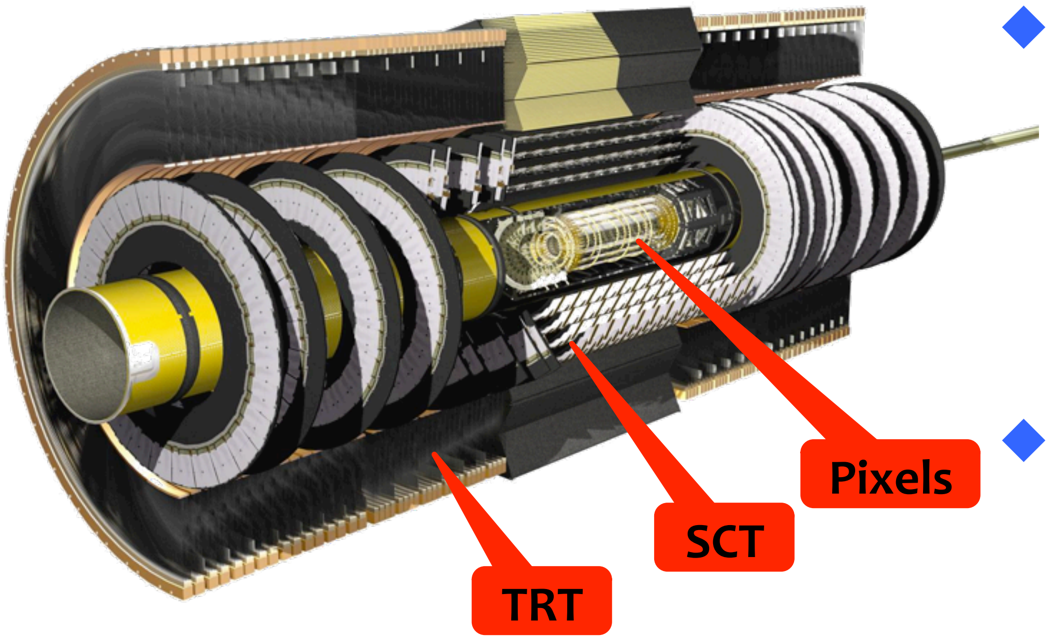
ATLAS Inner Detector



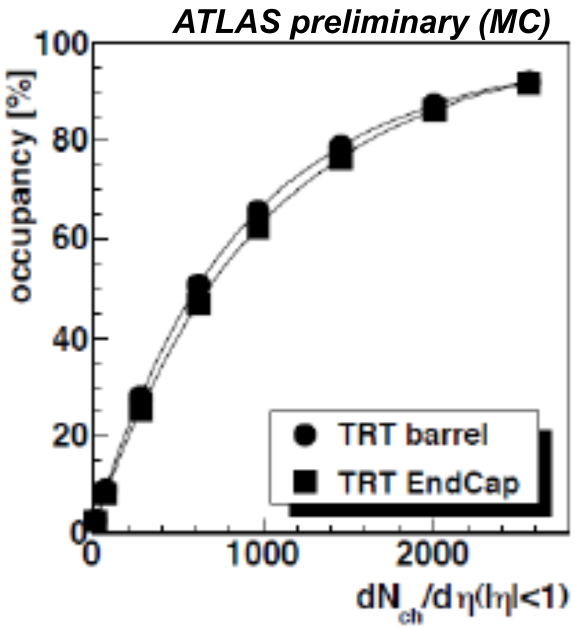
- Pixel occupancies <1% for dN_{ch}/dy=3000 (highish)
  - up to 1.5% for extreme case dN_{ch}/dy=6000
    - comparable to ALICE
- Strip occupancies up to 15%
  - may give fake tracks



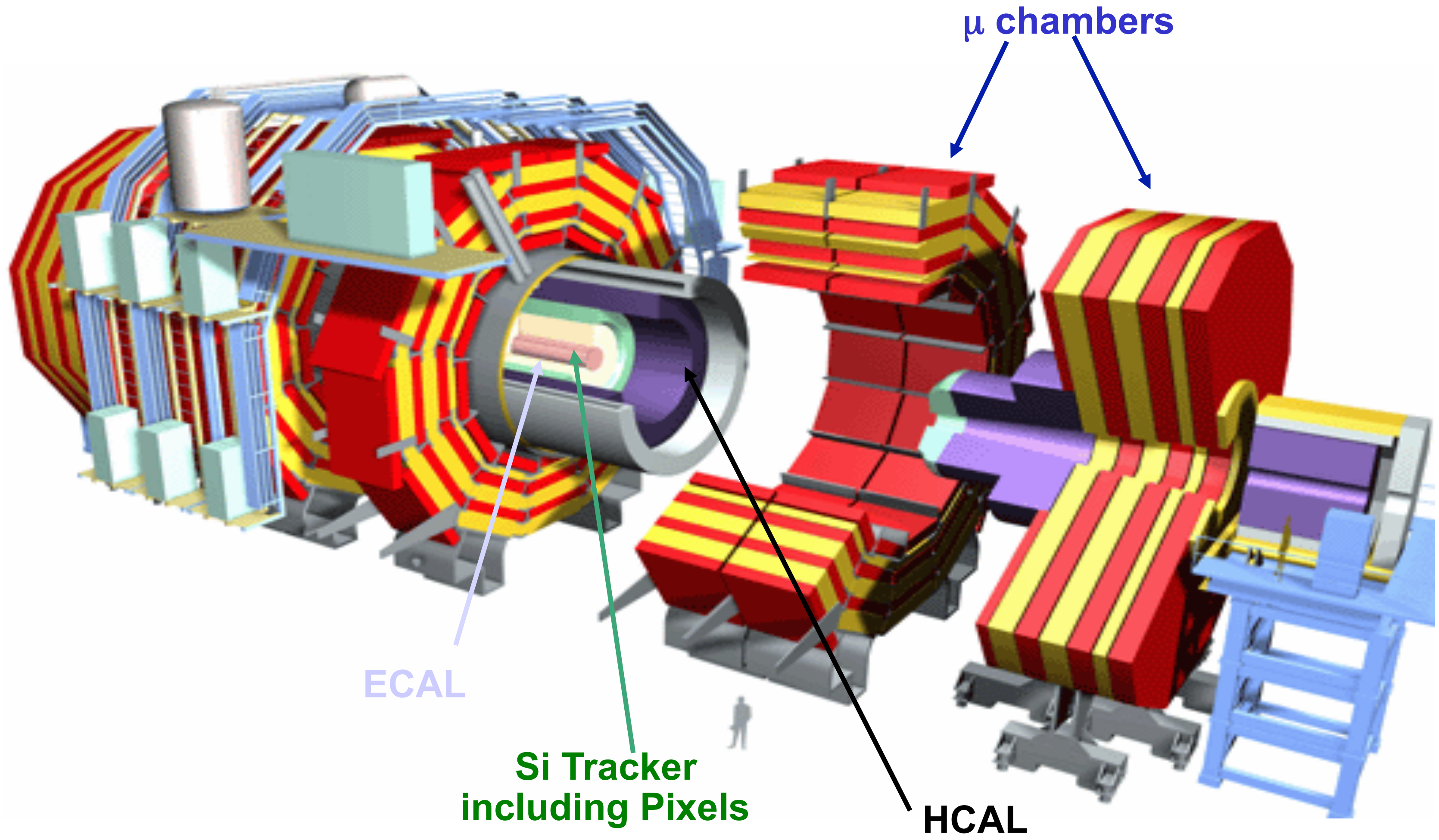
ATLAS Inner Detector



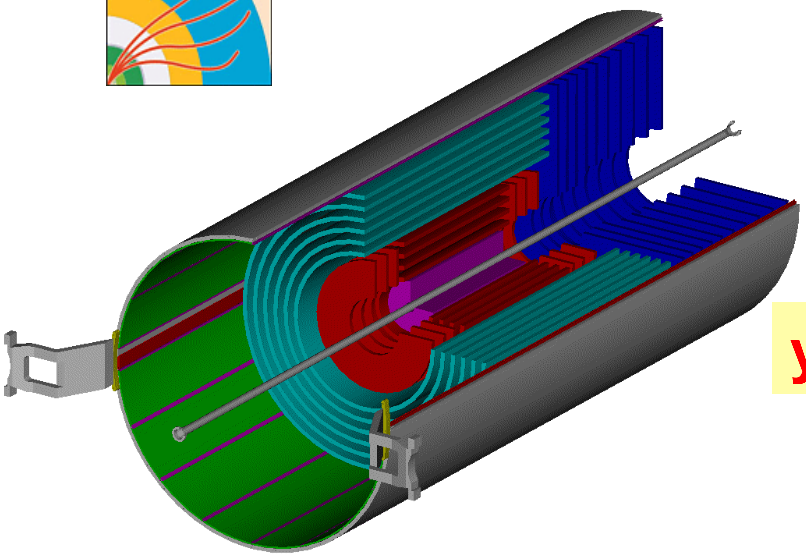
- Transition Radiation Tracker (TRT) will have very large occupancy: 70 (100)% for dN_{ch}/dy=1500 (3000)
  - difficult to use it for tracking
- Studies to use it for electron ID even with high occupancy



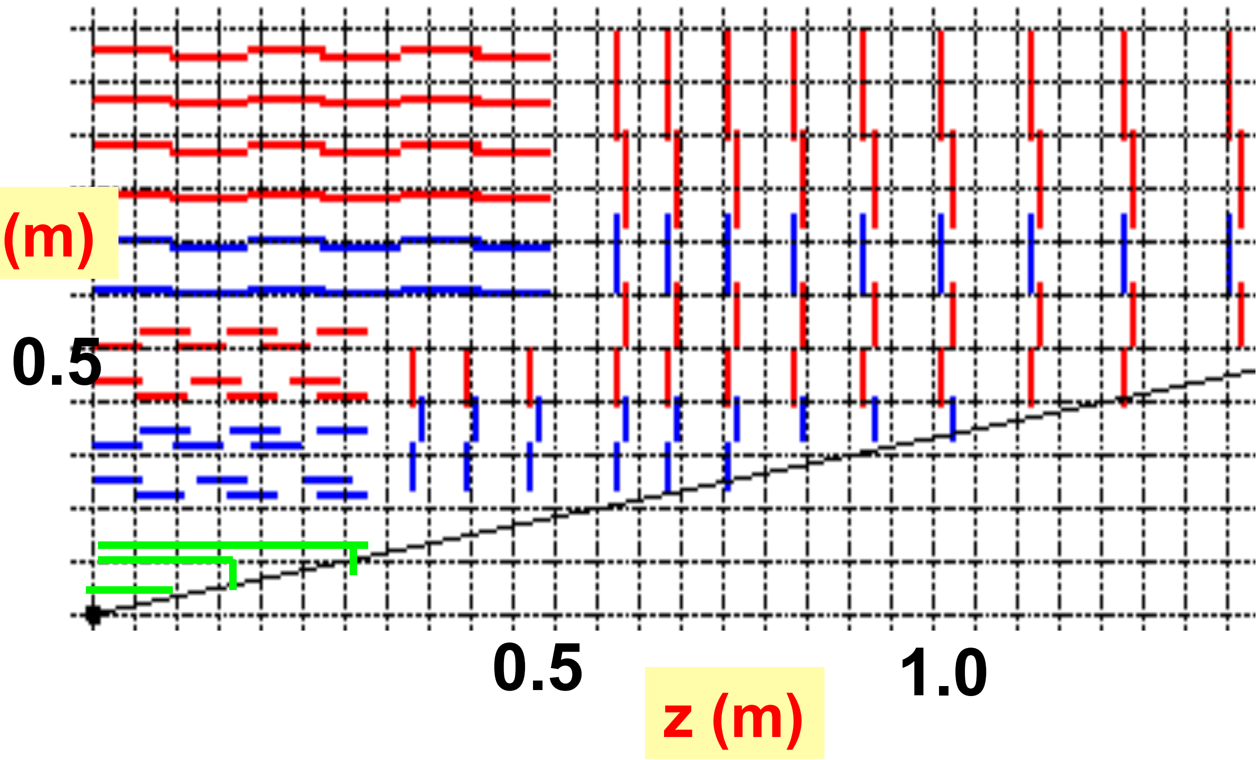
The CMS detector

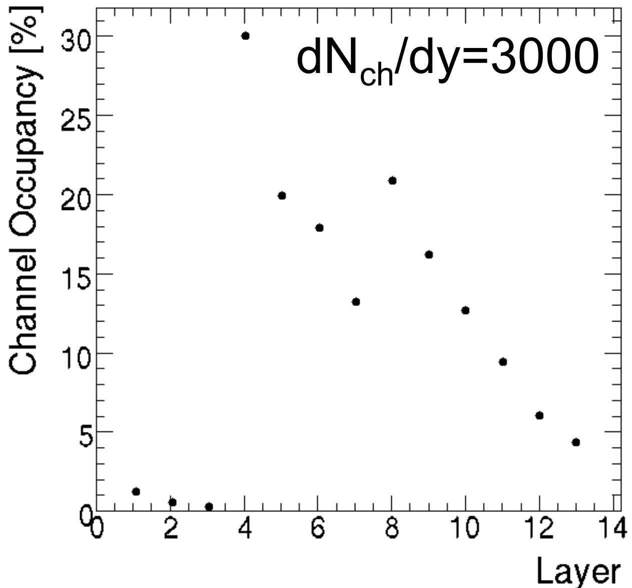


CMS Si tracker



Single strips
Double strips
Pixels





Occupancy in central Pb-Pb events:

- ~1% in Pixel Layers
- Up to 30% in strips @ $dN_{ch}/dy=3000$
    - innermost layer

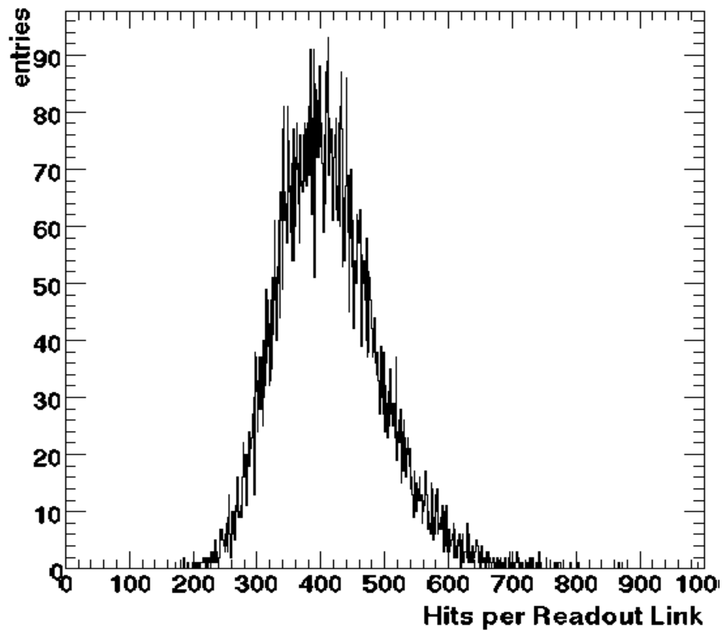
CMS Si hardware/readout effects

- The Readout chain of the CMS Tracker is optimized for proton-proton collisions
- Pb-Pb possible issues
- Si Pixels: Low occupancy but large data volume → Buffer overflows?
  - Static: Large hit multiplicity within one (central) event
    - may be a problem
  - Dynamic Effects: many subsequent events within one readout cycle
    - negligible at Pb-Pb rates
- Si Strips: High Occupancy → Common Mode Noise (CMN) & Highly Ionizing Particles (HIP)

CMS Pixels:
Readout Chip (ROC) and Front End Driver (FED)

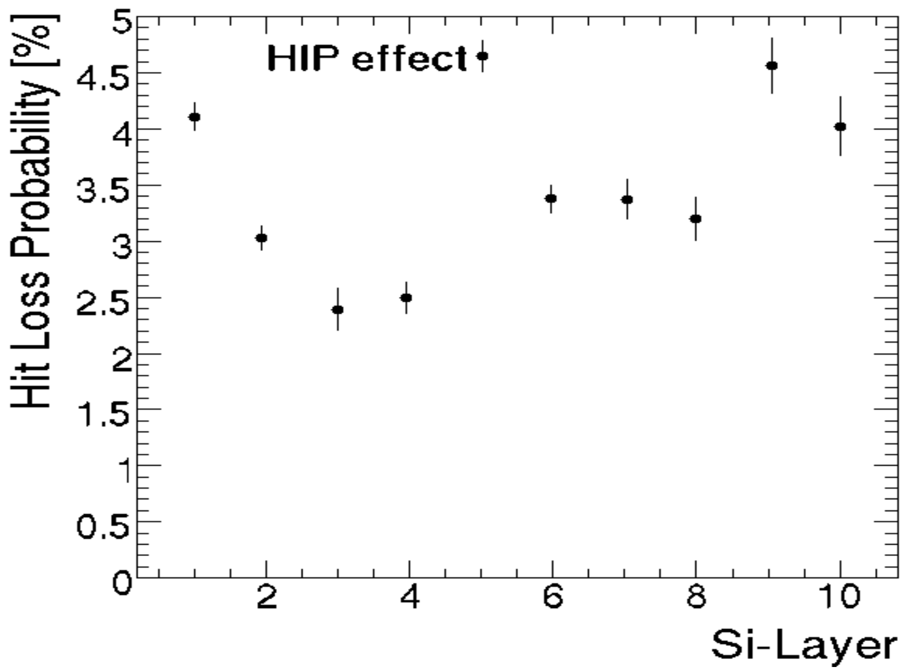
- Each ROC reads out an array of 52×80 pixels
  - Organized in double columns (DCOL) of 160 pixels
  - Each DCOL can take 31 hits before being reset
- In central events a fraction of 0.01% of all double columns see more than 31 hits → *acceptable*

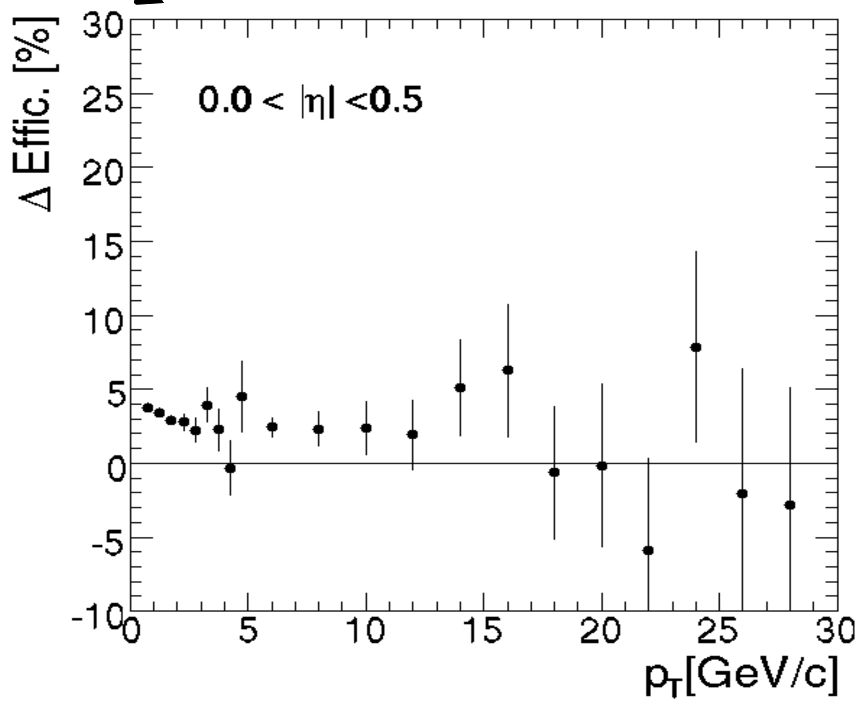
- For each link connecting a ROC to a FED 10^3 hits can be buffered
- The buffers are sufficiently large to fit heavy ion events → *OK*



CMS SiStrips: Highly Ionizing Particles

- Charge deposited in the silicon by highly ionizing particles saturates the APV → signal loss
  - Up to 2-4% hit loss probability in Pb-Pb
  - Up to 5% tracking efficiency loss

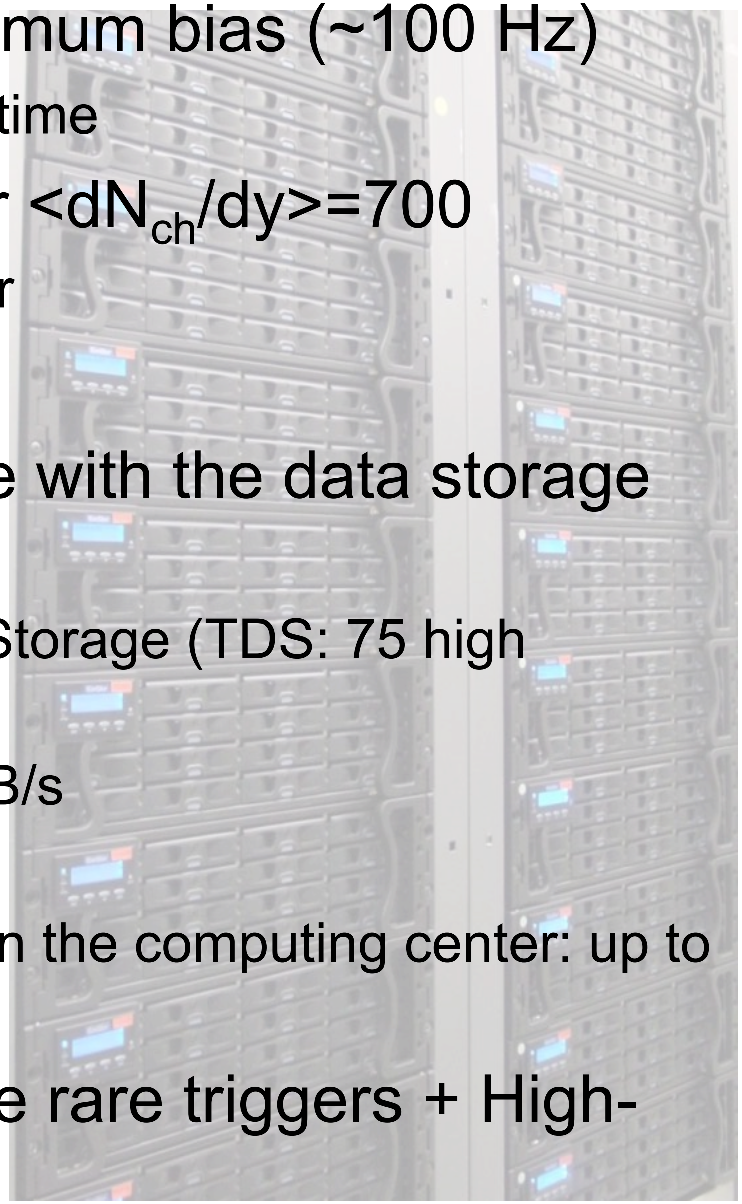




Outline

- Why Heavy Ions at the Large Hadron Collider?
  - strongly-interacting matter in extreme conditions
  - expectations for the LHC and first measurements
- LHC as a heavy-ion collider
  - experimental conditions for upcoming Pb run
- ALICE: an experiment designed for heavy ions
- ATLAS and CMS: the heavy ion challenge
- Trigger and DAQ for heavy ions
- First measurement: particle multiplicity
  - tracks and tracklets reconstruction
- Summary

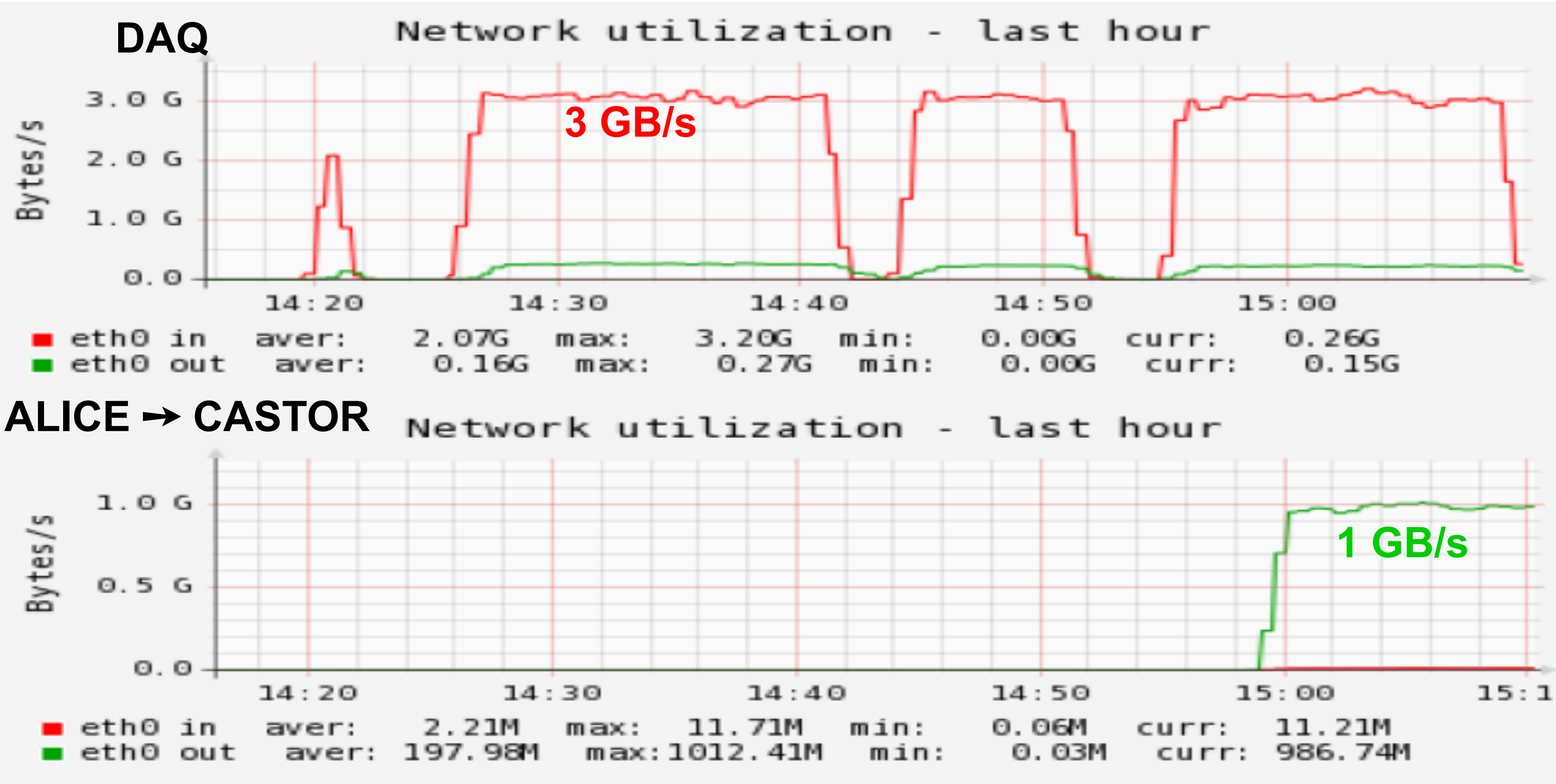
ALICE: Trigger and DAQ



- Trigger for Pb-Pb 2010: mostly minimum bias (~100 Hz)
  - reduced to 70 Hz with 4 ms TPC dead time
- Event size in Pb-Pb (av.): 40 MB for $\langle dN_{ch}/dy \rangle=700$
  - 83% from the Time Projection Chamber
- Data throughput ~3 GB/s
- DAQ performance designed to cope with the data storage bandwidth needed for heavy ions:
  - Bandwidth to the local Transient Data Storage (TDS: 75 high bandwidth disk buffers of 200 TB):
    - pp (measured in 2010): 300-600 MB/s
    - Pb-Pb (anticipated): up to 3 GB/s
  - Bandwidth to permanent data storage in the computing center: up to 1.25 GB/s
- Nominal luminosity Pb-Pb: introduce rare triggers + High-Level Trigger (HLT)

ALICE: Trigger and DAQ

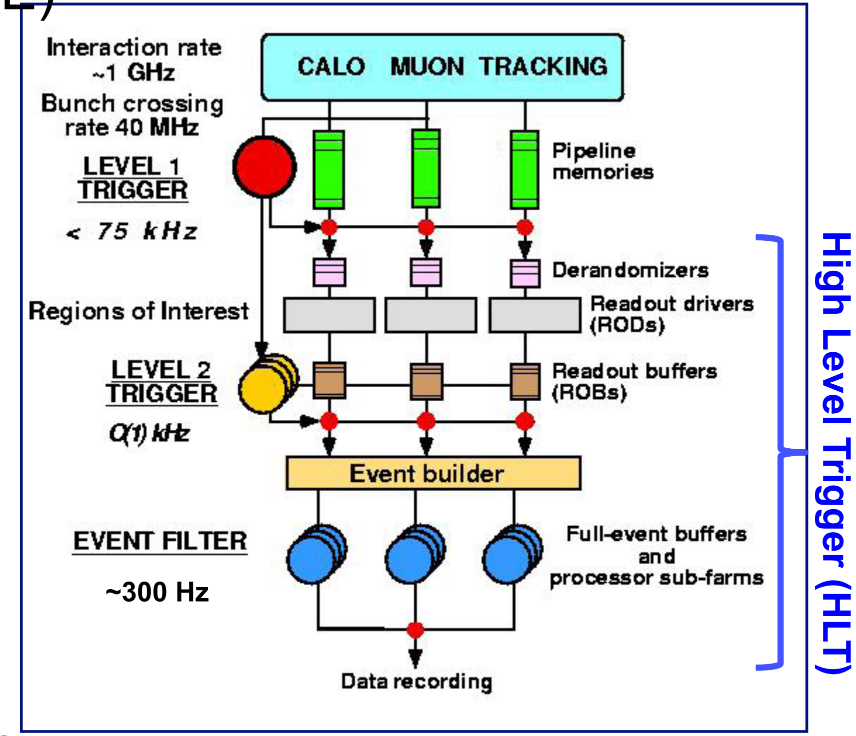
- Tests carried out in summer 2010 to measure the performance of the whole DAQ chain with heavy-ion-like data generated by the detector electronics



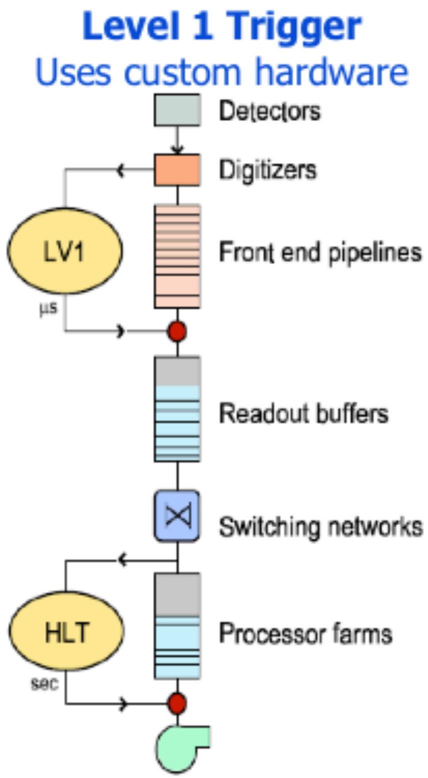
ATLAS: Trigger and DAQ in Pb-Pb

- Pb-Pb 2010 rate ~100 Hz → lower than pp recording rate (300 Hz after high-level trigger reduction)
- Event size: ~ 2-3 MB (1/10 of ALICE)
- Pb-Pb DAQ:
  - ~ 0.3 GB/s (1/10 of ALICE)
  - 90% bandwidth for min. bias
    - record all collisions
  - 10% for rare triggers (pp-like)
    - jets, muons, photons
- Pb-Pb nominal lumi (few kHz)
  - use HLT heavier to reduce rate
  - small fraction of bandwidth for min. bias

pp case:



CMS: Trigger and DAQ in Pb-Pb



	p+p	Pb+Pb (nominal lumi and detector configuration)
Collision rate	1GHz	3kHz (8kHz peak)
Event rate	40MHz	3kHz (8kHz peak)
L1 accept rate	100kHz	3kHz (8kHz peak)
HLT Input rate	100kHz	3kHz (8kHz peak)
Output rate	150Hz	10-100Hz
Rejection	99.85%	97-99.7%

- During the 2010 Pb run, the SiStrip tracker and the calorimeters will be operated w/o on-detector zero suppression
- Allows to study the high occupancy effects in electronics
- Increases event size from 3 MB to 12 MB
- ZS will be done in FED/HLT starting from 2011 Pb run

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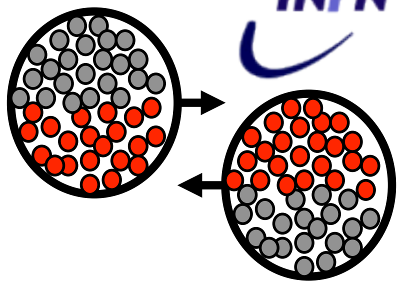
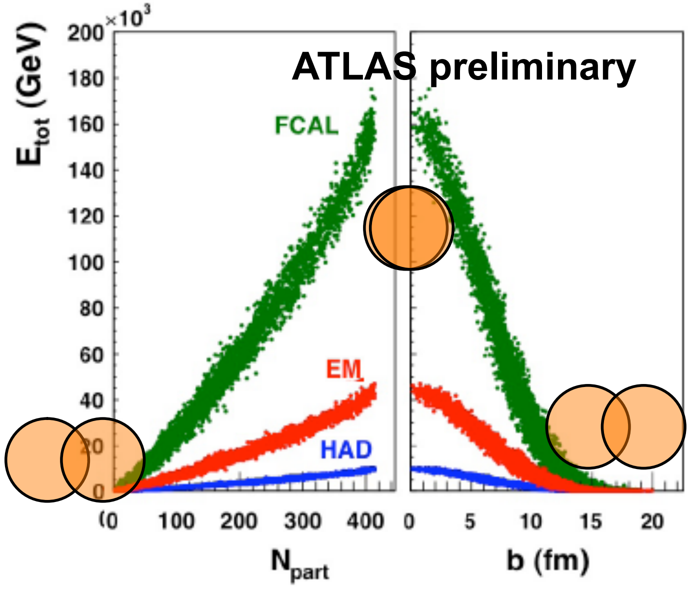
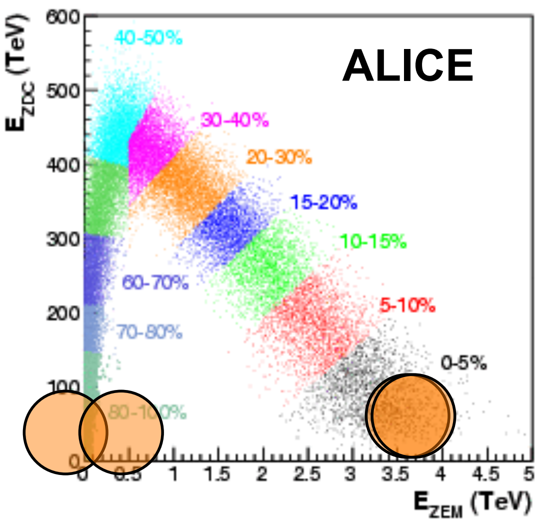
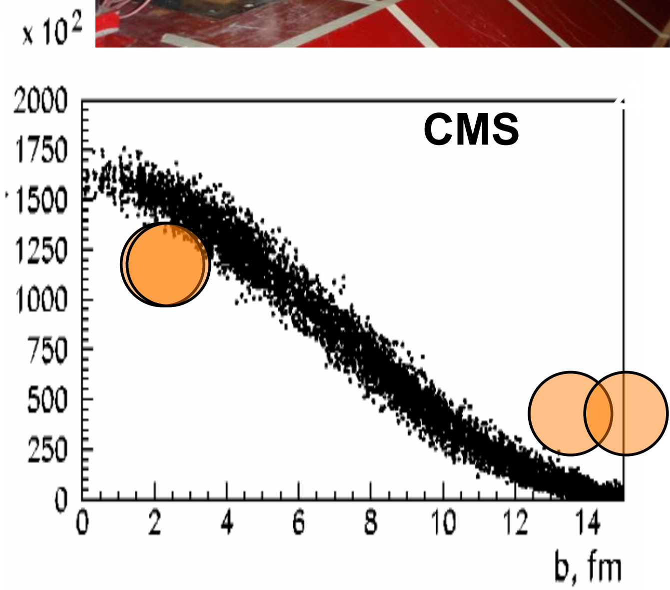
Collision centrality measurement in ALICE, ATLAS, CMS



- Centrality will be estimated from the energy deposited by the "spectator" nucleons (collision remnants) in Zero Degree Calorimeters (ZDCs)
- ALICE, ATLAS, CMS ZDCs placed at ~ ±150 m along beam line
  - not foreseen in ATLAS/CMS original design

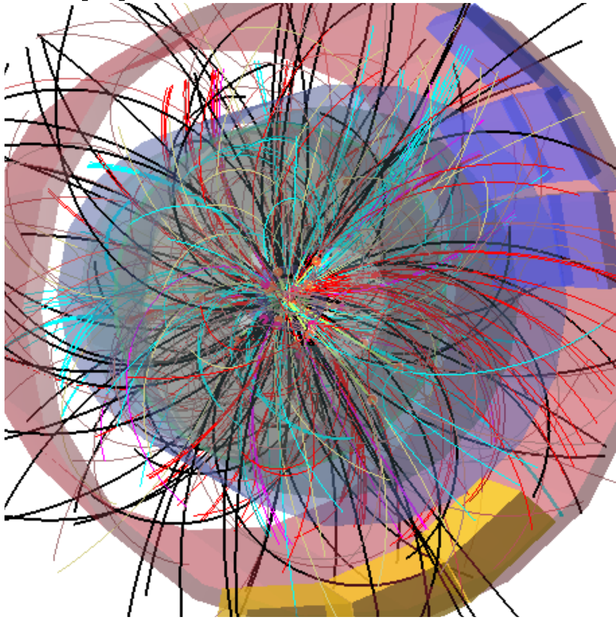






Track reconstruction in extreme conditions

- All three experiments use the Kalman-filter approach
  - simultaneous track recognition and reconstruction
  - natural way to take into account multiple scattering, E loss, magnetic field
  - efficient way to match tracks between detectors
- Start (track seeding) from detector with low occupancy and/or many hits:
  - ALICE from TPC (inward tracking)
  - ATLAS/CMS from pixel (outward tracking)
- Occupancies comparison ($dN_{ch}/d\eta=3000$):



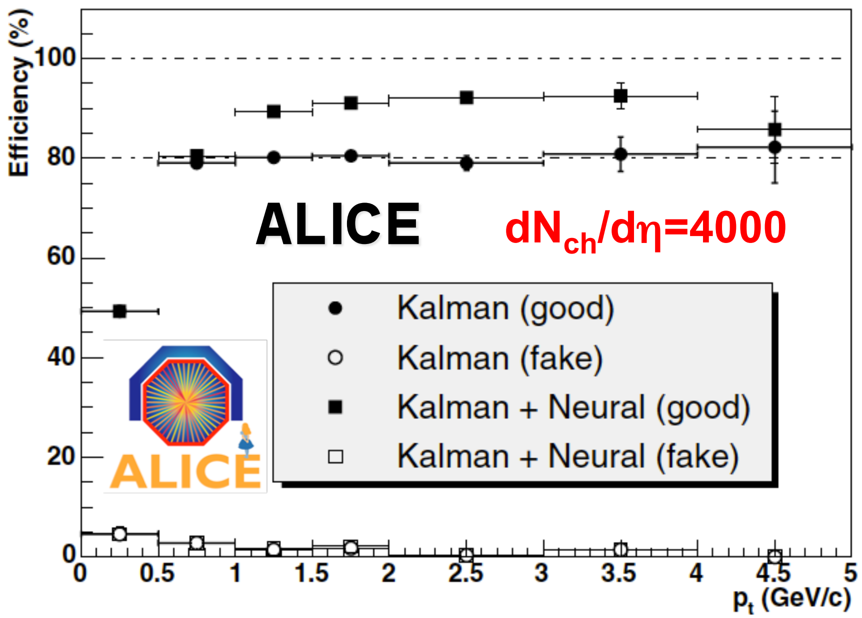
ALICE high-multiplicity pp event

Detector (hits)	Occ.
Si pixel (2)	< 1%
Si drift (2)	< 1.5%
Si strip (2)	< 2%
TPC (160)	6-20%

Detector (hits)	Occ.
Si pixel (3)	< 1%
Si strip (4)	7-15%
TRT (10)	< 90%

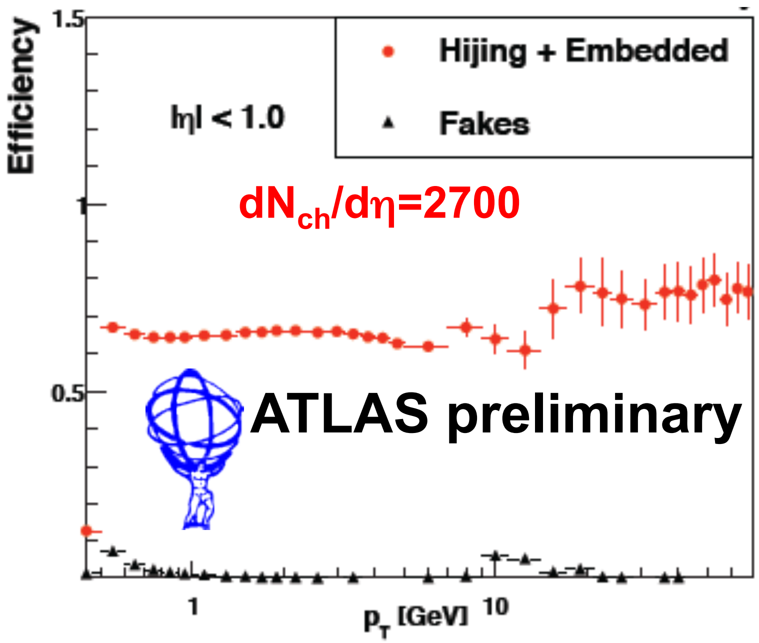
Detector (hits)	Occ.
Si pixel (3)	< 1%
Si strip (10)	4-30%

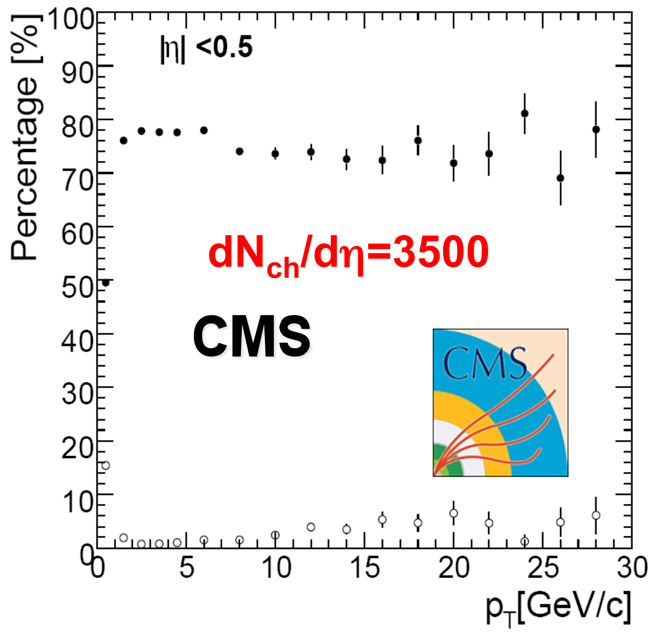
Tracking efficiency, fake track probability



For all three experiments tracking efficiencies ~ 70-80%

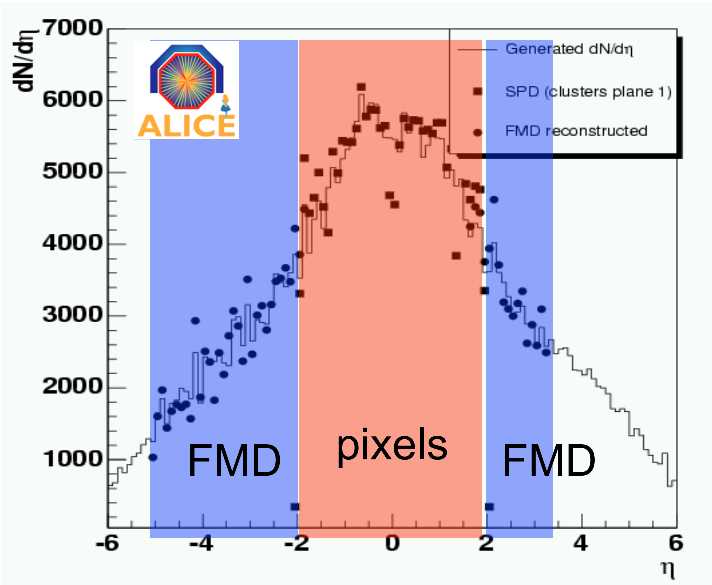
Fraction of fake tracks (wrongly associated hits) below 10%

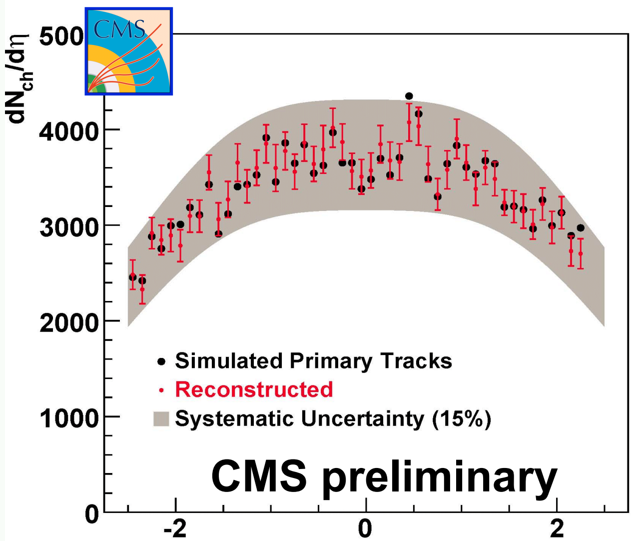


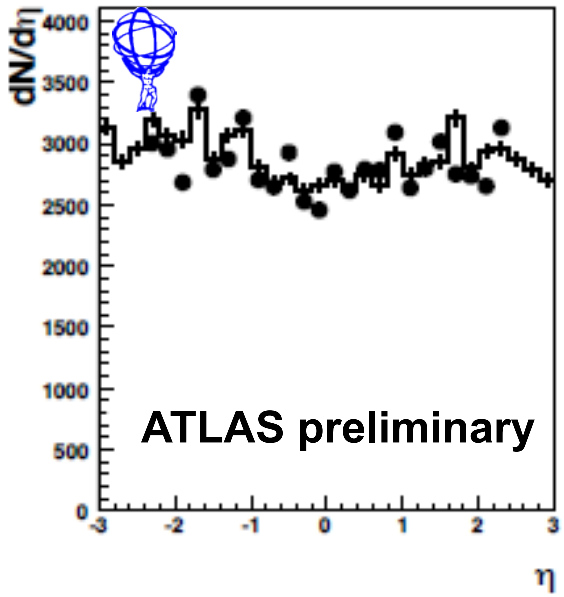


Day-1 measurement (~Nov 15, 2010?): Multiplicity in Pb-Pb at the LHC

- First snapshot of high-density QCD state at LHC energy
- Will be measured with first few thousand events
  - using different methods: track counting, pixel tracklet counting, pixel hit counting
  - as a function of collision centrality
- *Overlap of 3 pixel barrels in* $|\eta|<2$







Summary

- Nucleus-nucleus collisions at high energy are a unique tool to study the properties of the strong interaction (QCD) in extreme conditions: high-density extended systems

- Pb-Pb at LHC: ×15-30 jump in energy → discovery potential

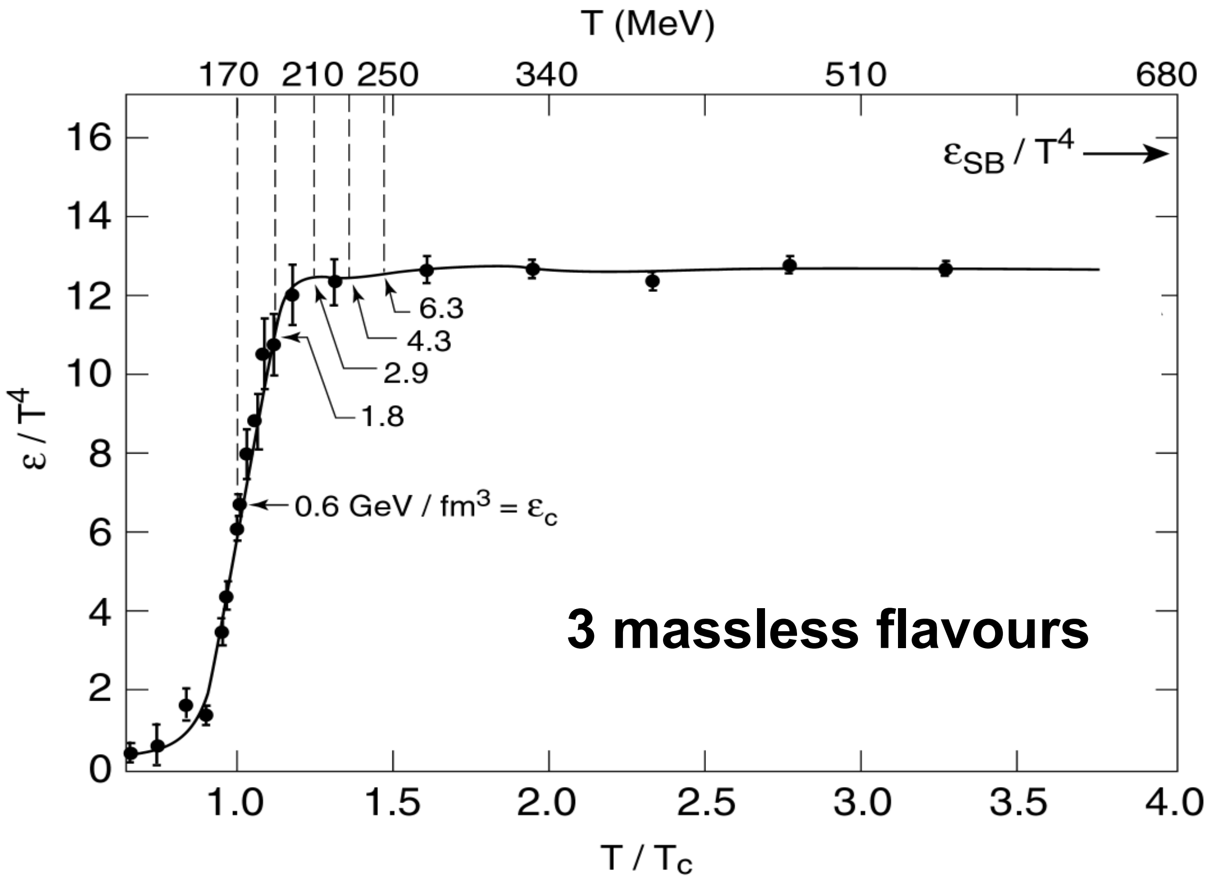
- More than 10,000 particles expected in central collisions!
- Main challenges for the detectors:
  - high channel occupancy → readout electronics, reconstruction algos
  - high data volume → DAQ
- ALICE, ATLAS, CMS experiments well prepared and looking forward to the challenge

EXTRA SLIDES

Physics of hot and dense QCD matter

Lattice QCD estimates the phase transition to the Quark-Gluon Plasma at:

temp. T_c ~ 170 MeV and energy density ε_c ~ 1 GeV/fm^3 ~ 5 $\varepsilon_{nucleus}$



$$\frac{\varepsilon}{T^4} \propto n_{\text{degrees of freedom}}$$

phase transition:

hadron gas → QGP

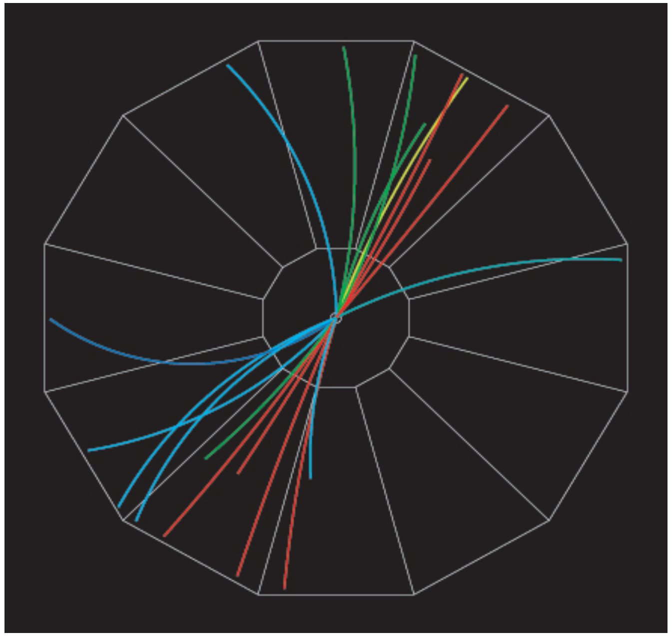
$$n_{\text{d.o.f.}}: \quad 3 \quad \rightarrow \quad 47$$

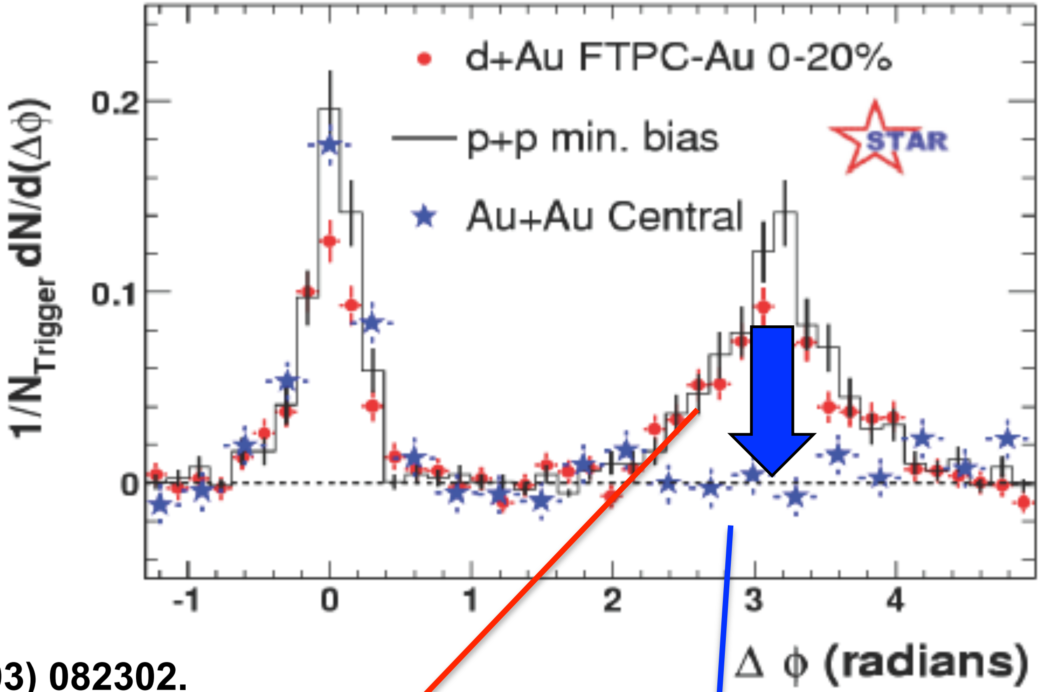
→ from hadron to quark and gluon degrees of freedom

Heavy-ion collisions at RHIC: first properties of the QCD medium

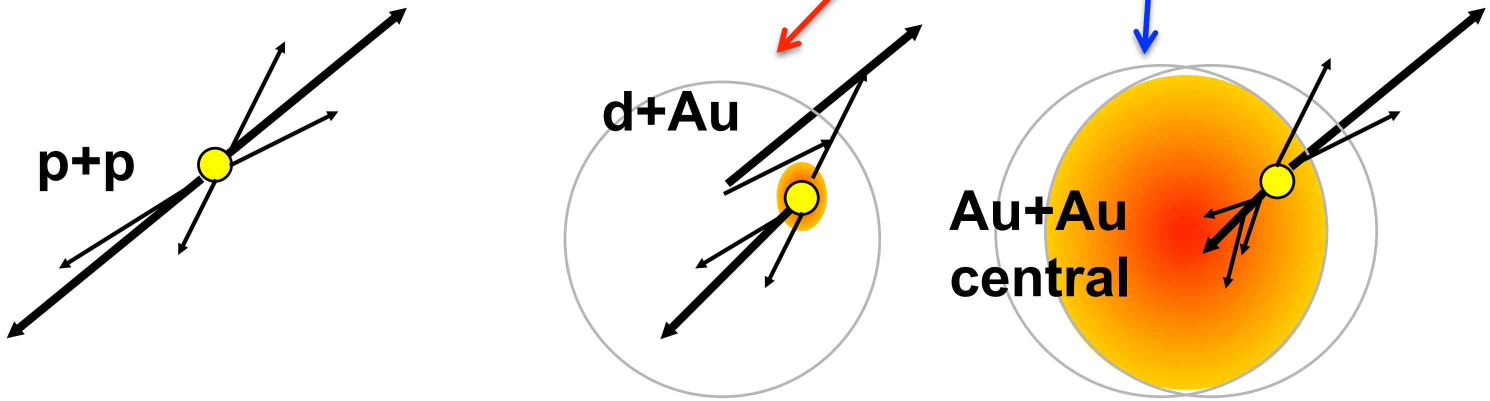
- Au-Au collisions at $\sqrt{s}$ = 200 GeV
- Energy density up to 5-15 GeV/fm^3 ~ 100 atomic nuclues density ~ 10 critical value ε_c
- Major findings of the 4 RHIC experiments in a nut-shell:
  - **The QCD medium behaves like a fluid**
    - **expands and flows according to hydrodynamics**
  - **The QCD medium is deconfined**
    - **screens colour interaction in quarkonium**
  - **The QCD medium is dense**
    - **jets lose energy while crossing the medium**

Jet quenching at RHIC:
away-side jet suppression





STAR Coll., PRL 90 (2003) 082302.

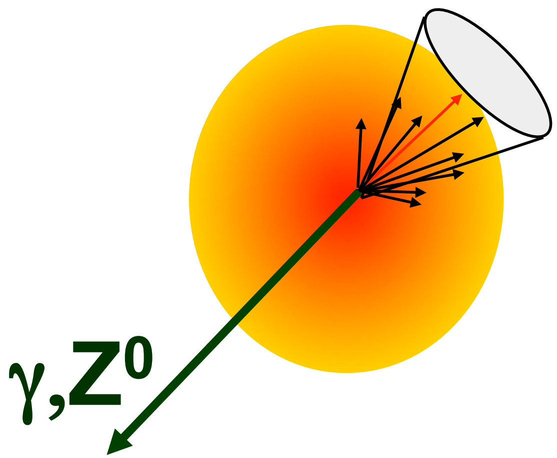


What to measure in Pb-Pb at LHC: interaction of jets with the QCD medium

- Jet quenching discovered at RHIC
- Hard Jets can be used to probe QCD medium properties
- Extend these studies using:
  - fully reconstructed high-energy jets
  - new physics processes accessible with large rates at LHC
    - heavy quarks (charm and beauty)
    - photons associated to jets

Example:
γ/Z^0-jet correlations

Unique tool:
$E^{\gamma/Z0} = E^{jet}$



Study modification in the QCD medium for a jet of known energy

What to measure in Pb-Pb at LHC: interaction of jets with the QCD medium

Detector requirements:

- Precise tracking for heavy quark identification
- Jet reconstruction in high-multiplicity environment
- High-granularity photon identification in high-multiplicity environment

ALICE Time Projection Chamber: Pb-Pb luminosity limit from the TPC

- As it is a drift detector (up to 2.5 m drift length), the full TPC readout is slow (94 μs max drift time)
- This limits the maximum tolerable rate (lumi)
- With $L=10^{27}$ $cm^{-2}s^{-1}$ (current limit from the machine), the pileup prob. is 3/4 in Pb-Pb (for σ_{geom}=8 b)
  - for 75% of collisions, a second collision occurs before TPC fully readout
  - probability to have >2 collisions is almost negligible
- The increase in track density is up to 30% for central collisions → tolerable

- *Thus, the TPC works well at the maximum Pb-Pb lumi*
  - if multiplicity turns out to be lower than dN_{ch}/dy=6000, can go even higher

CMS SiStrips: Common Mode Noise

- Need to subtract Common Mode Noise (CMN)
- Done by a zero suppression module on the readout chip (APV25)
  - Simple and fast algorithm implemented in FED firmware
  - pp: relies on a event-by-event baseline calculation using the median of all ADCs per Readout Chip
  - Pb-Pb: Perform multiple iterations to reject signal strips

→ <1% loss of tracking efficiency