ALICE update

Jan Rak

University of Jyväskylä & Helsinki Institute of Physics

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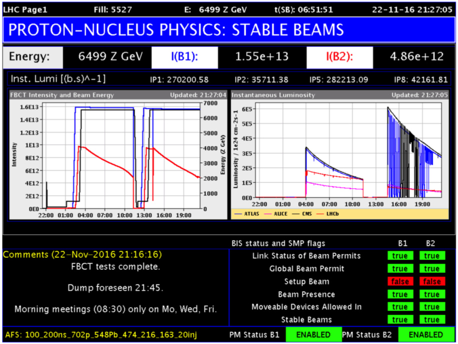
ALICE - in the second year of RUN2

URHI season 2016

- Successful p–Pb run at $\sqrt{s_{\mathrm{NN}}}=5$ TeV (ref for Pb–Pb, same $\sqrt{s_{\mathrm{NN}}}$)
- Currently collecting data at record p–Pb center of mass energy



6.5 TeV$\rightarrow$ p–Pb $\leftarrow$ 2.56 TeV
(Rigidity Z/A=82/208)

$$\begin{aligned}\sqrt{s_{\mathrm{NN}}} &= \sqrt{E_p + E_{Pb} - (p_p - p_{Pb})^2} \\ &= 8.16\ \text{TeV}\end{aligned}$$

Major activities

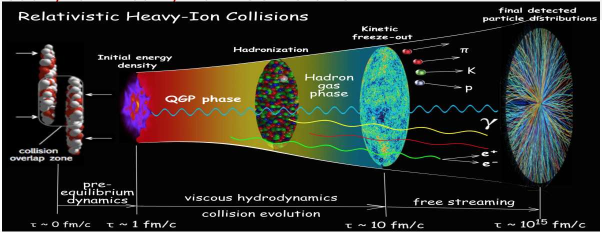
Physics: Quantitative characterization of Quark Gluon Plasma

- Sheer viscosity (η/s) - hydrodynamics.
- Transport coeeficient $\hat{q}$ - jet quenching.
- Speed of sound - Mach cone.
- Scaling (constituent quarks), modification of the jet fragmentation, and many more.

Upgrade:

- Inner Tracking System:
- Time Projection Chamber (TPC): GEM and Micro-pattern gaseous det., JYFL, HIP
- Fast Interaction Trigger (FIT): JYFL, HIP
- Muon detectors, DAQ, CTP and ...

Space-time history of Heavy-Ion Collisions



Initial geometry fluctuations $\to$ Transport $\delta_\mu T^{\mu\nu} = 0$ ($\eta/s(T)$) $\to$ final-state particles

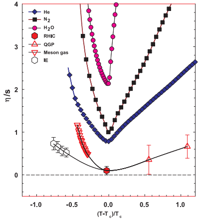


Figure: PRL98, 092301 (2007), "Min of η/s is indicative of thermodyn. trajectories close to the QCD critical end point."

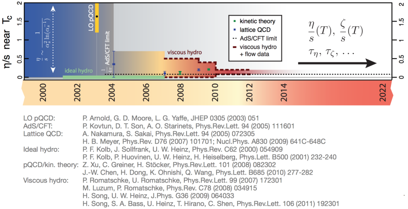
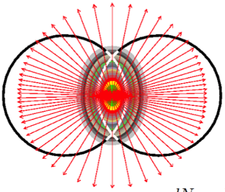
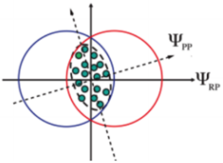


Figure: "String theory (AdS/CFT correspondence) finds $\eta/s \sim 1/4\pi$ a strongly coupled conformal theory $\to$ hints at a lower bound of that order."

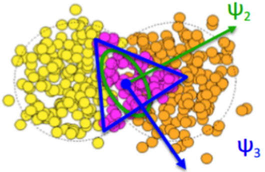
1992



2006

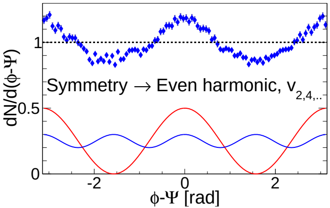


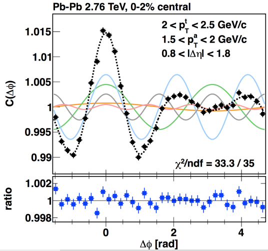
2010



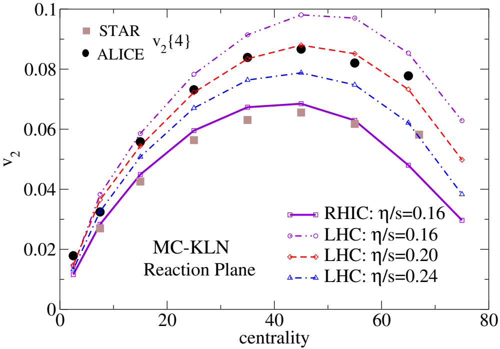
$$\frac{dN}{d\phi} = \frac{N}{2\pi}\left(1 + \sum_n (2v_n \cos(n(\phi - \psi_n)))\right) \quad v_n = \langle \cos[n(\phi - \psi_n)] \rangle$$

relative to it's own plane





Extracting η/s from experimental data: RHIC vs LHC



- $\eta/s \approx 0.16$ (RHIC $\sqrt{s_{\rm NN}}$=0.2 TeV) and
- $\eta/s \approx 0.20$ (LHC $\sqrt{s_{\rm NN}}$=2.76 TeV) ?

Temperature dependent $\eta/s(T)$?

- Present understanding
  - RHIC : highly sensitive to the viscosity in hadronic matter and almost independent of the viscosity in the QGP phase [a] ?
  - LHC : almost independent of the hadronic viscosity, but depends strongly on the QGP viscosity[2] ?
- How to discriminate the contributions from the different stages of the collsions?
  - need more differential observables which might be more sensitive to **initial conditions, QGP phase or freeze-out**?

[a] H. Niemi, G.S. Denicol, P. Huovinen, E. Molnar, D.H. Rischke, P

C. Shen, S. A. Bass, T. Hirano, P. Huovinen, Z. Qiu, H. Song and U. Heinz, J. Phys. G 38, 124045 (2011) [arXiv:1106.6350 [nucl-th]]

Symmetric 2-harmonic 4-particle Cumulants

New Observable : Symmetric 2-harmonic 4-particle Cumulants (SC) [1]

$$\langle\langle \cos(m\varphi_1 + n\varphi_2 - m\varphi_3 - n\varphi_4)\rangle\rangle_c = \langle\langle \cos(m\varphi_1 + n\varphi_2 - m\varphi_3 - n\varphi_4)\rangle\rangle - \langle\langle \cos[m(\varphi_1 - \varphi_2)]\rangle\rangle \langle\langle \cos[n(\varphi_1 - \varphi_2)]\rangle\rangle = \left\langle v_m^2 v_n^2 \right\rangle - \left\langle v_m^2 \right\rangle \left\langle v_n^2 \right\rangle$$

- By construction, not sensitive to
  - non flow effects
  - inter-correlations of various symmetry planes
- It is non-zero if the event-by-event amplitude fluctuations of v_n and v_m are (anti-)correlated.

Also SC(m,n) can be normalizable with $\left\langle v_m^2 \right\rangle \left\langle v_n^2 \right\rangle$

$$SC(m,n)_{norm} = SC(m,n) / \left\langle v_m^2 \right\rangle \left\langle v_n^2 \right\rangle$$

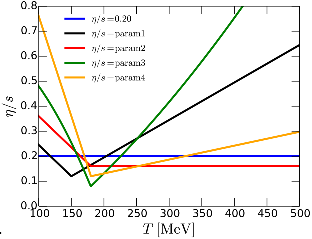
- Normalized SC(m,n) reflects the degree of the correlation.
- While SC(m,n) contains both the degree of the correlation and individual v_n.

[1] Ante Bilandzic et al., Phys. Rev. C 89, 064904 (2014)

Correlations of v_m and v_n

$\langle v_m^2 v_n^2 \rangle - \langle v_m^2 \rangle \langle v_n^2 \rangle$

Hydrodynamics H. Niemi,K.J. Eskola,R.Paatelainen (Phys. Rev. C 93, 024907 (2016))



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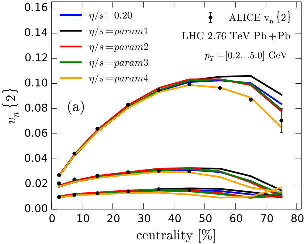
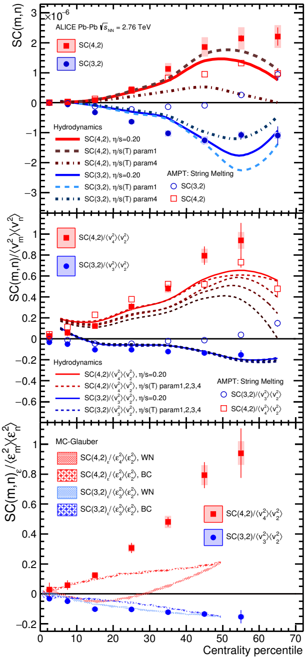


ALICE PRL 117 (2016) 182301, arXiv:1604.07663

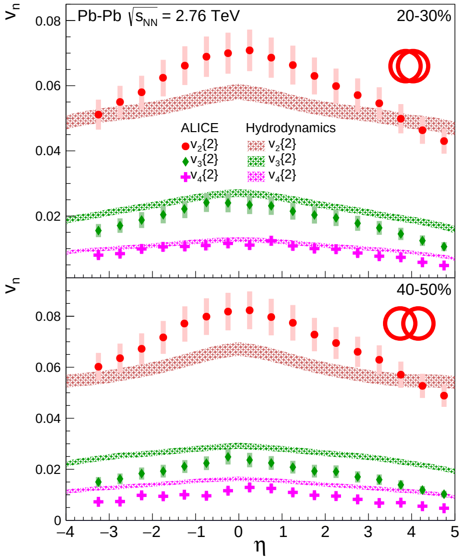


(4,2)

(3,2)

- Although Hydro describes the v_n fairly well, there is not a single centrality bin for which a given η/s parameterization describes simultaneously SC(4,2) and SC(3,2)
- provide stronger constrains on the $\eta/s(T)$ in hydro in combination with individual v_n.

Pseudorapidity dependence of v_n

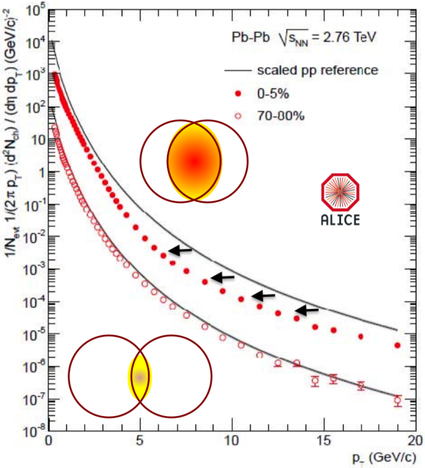


ALICE :
Phys.Lett. B762 (2016) 376-388

Hydrodynamics :
G. Denicol, B. Schenke et al.
Phys.Rev.Lett. 116, 212301 (2016)

- The shape of $v_n(\eta)$ is largely independent of centrality n=2,3,4
- v_3 and v_4 have weaker dependence on η than v_2
- Hydro calculation is tuned $\eta/s(T)$ to fit $v_n(\eta)$ at RHIC but can't describe the data, challenge to the theory community!

Phys.Lett., **2011**, B696, 30



Hard parton in QGP →

medium-induce gluon bremsstrahlung

Landau-Pomeranchuk-Migdal (LPM)

Formation time → suppressed radiation

Parton Energy Loss: $\frac{dE}{dz} = -\frac{\alpha_S N_C}{4} \left\langle p_\perp^2 \right\rangle$

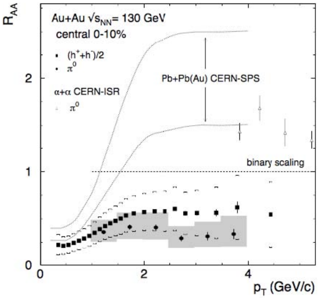
Momentum broadening: $\left\langle p_\perp^2 \right\rangle = \hat{q}L$

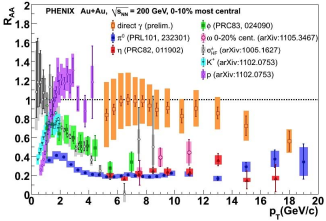
$\hat{q}$ = transport coefficient, mom. kick

L = Size of the Medium

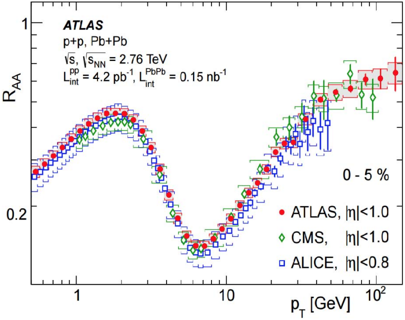
$\Delta E \approx \alpha_S \hat{q} L^{n\neq 1}$ non trivial L^n dependence of ΔE (QCD coherence)

Hard Probes R_{AA}=$\mathrm{Yield}_{AA}(p_T)/(N_{coll}\mathrm{Yield}_{pp}(p_T))$



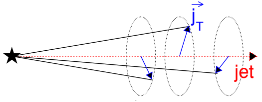


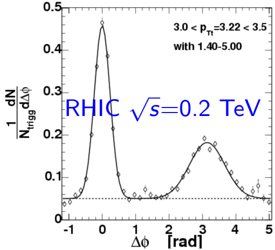
1. SPS $\rightarrow$ RHIC **DISCOVERY**, 2001 $h^{\pm}$ and π^0 $\sqrt{s_{NN}}$=130 GeV
2. PHENIX PID $\sqrt{s_{NN}}$=200 GeV
3. LHC, $\sqrt{s_{NN}}$=2760 GeV Shining QGP

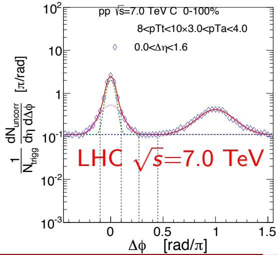


medium-induce gluon bremsstrahlung

Jet fragmentation - Jussi Viinikainen PhD thesis, p–p and p–Pb data

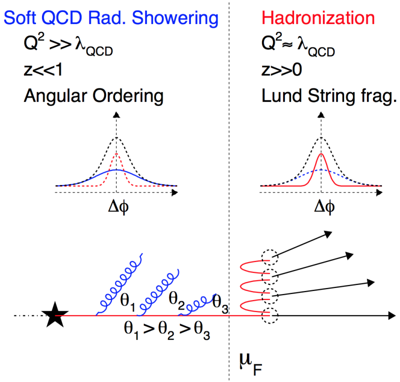






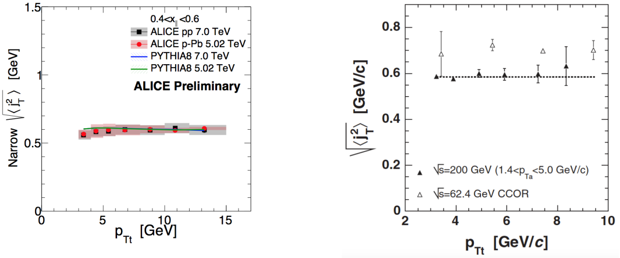
Fragmentation process:

- "Wide" : High virtuality, Soft QCD Radiation.
- "Narrow" :Universal $\sqrt{s}$-invar. hadronization.



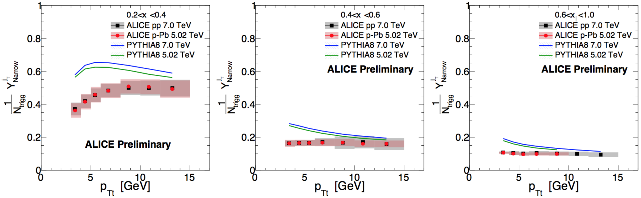
Narrow component $\langle j_T \rangle$

PHENIX: Phys.Rev. D74, 072002 (2006)
CCOR data: Phys.Lett. B97, 163 (1980)



Universality, $\langle j_T \rangle$ independent of $\sqrt{s}$

Wide component yield

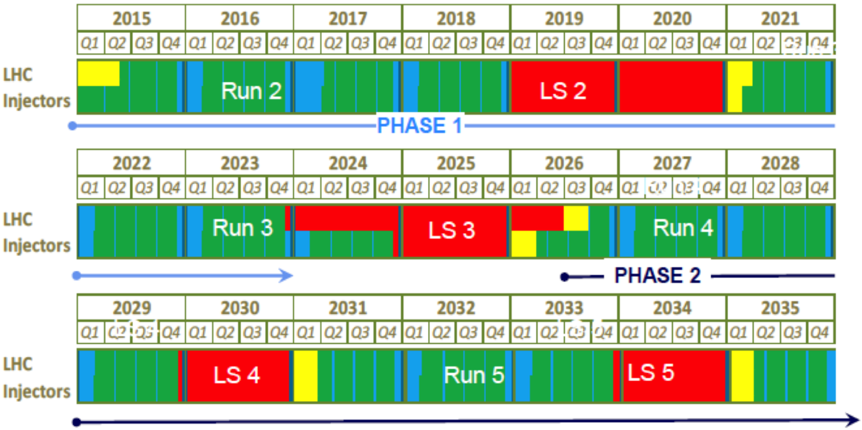


Not reproduced by MC generators (PYTHIA 8)

Same analysis of Pb–Pb data ongoing!

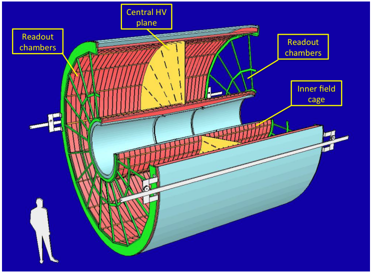
Upgrades - LHC Schedule

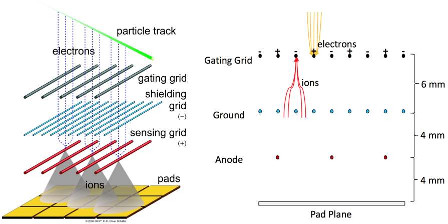
- Phase 1 ALICE, LHCb major upgrade, Heavy Ion $\mathcal{L} \sim 10^{27}$
- Phase 2 ATLAS, CMS major upgrade HL-LHC, pp $\mathcal{L} \sim 10^{34}$



TPC upgrade - HIP/JYFL Gas Electron Multiplier (GEM) production

The main tracking detector of ALICE **Time Projection Chamber (TPC)**





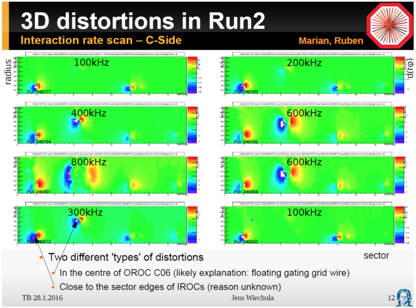
Gating Grid:

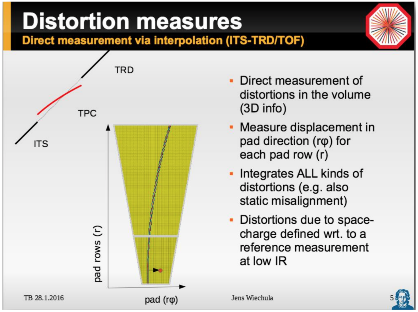
- Current design with the GG limits the readout rate to $\leq$ 300 Hz
- After LS2 - High Luminosity - requirement **50 kHz**

Gating Grid:

- Prevent positive ions from drifting into the drift volume.
- Prevent amplification of unwanted events.

The main ALICE Pb–Pb data taking period (Nov-Dec 2015) we encountered problems with TPC readout chambers during the high intensity data taking.



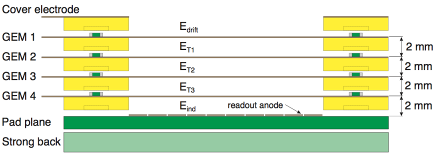


Due to the **ion backflow** and the induced charge on the TPC ROC's the track matching between ITS and TPC is impossible in the high-intensity runs. The new tracking scheme is developed (TRD+ITC$\rightarrow$ TPC). This was a strategy for RUN3, but we are forced to implement already in RUN2.

TPC upgrade - HIP/JYFL Gas Electron Multiplier (GEM) production

NEW READOUT CHAMBER DESIGN

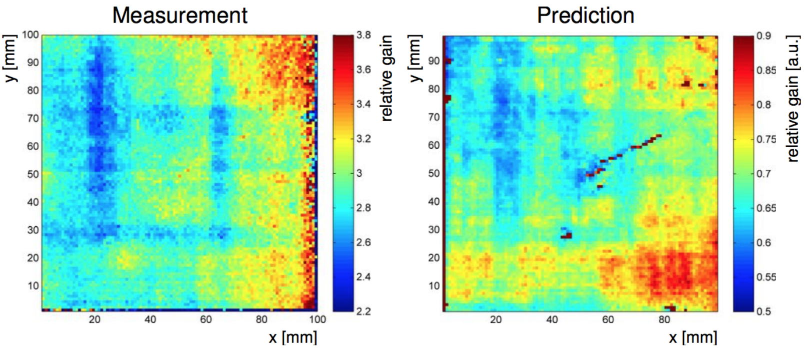
- Ion backflow $< 1\%$.
- Energy resolution $dE/dx < 12\%$ for ^{55}Fe
- The baseline design is a stack of 4 GEM foils



- Quality assurance test of about 300 m^2 of GEM foils in the Helsinki HIP clean rooms.
- Erik Brücken and Timo Hilden (HIP) and Marton Vargyas, Tomas Snellman (JYFL).
- Mass production about to start. Installation/commissioning 2018-2019.

TPC upgrade - HIP/JYFL Gas Electron Multiplier (GEM) production

Important R&D results - prediction of the gain from optical scan - see Nuclear Instruments and Methods in Physics Research A 770 (2015) 113-122

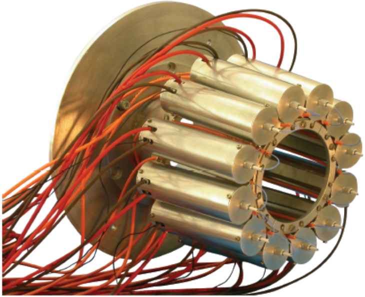


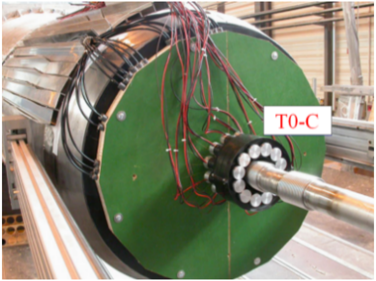
We (Erik and Timo) saved a lot of time and money by eliminating the gain map measurements.

Fast Interaction Trigger (FIT)

Another major upgrade activity of vital importance Fast Interaction Trigger detector.

Project leader W.H.Trzaska . It started with relatively small timing detector T0



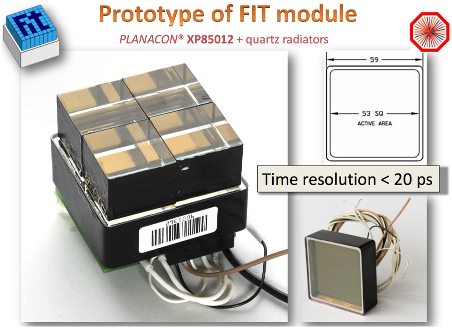


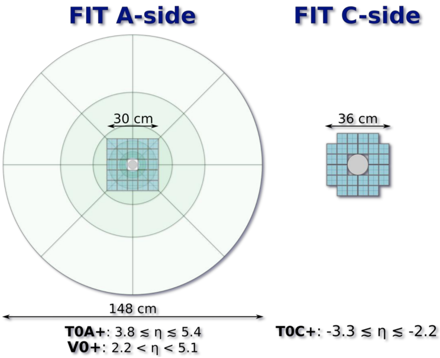
Very successful project. Due to the excellent time resolution $\sim$ 30 ps, T0:

- Luminosity monitor
- Pre-trigger for TRD
- Past/Future Protection -T0 selects collisions within $\pm$10 BC
- Vertex, centrality, multiplicity and reaction plane determination

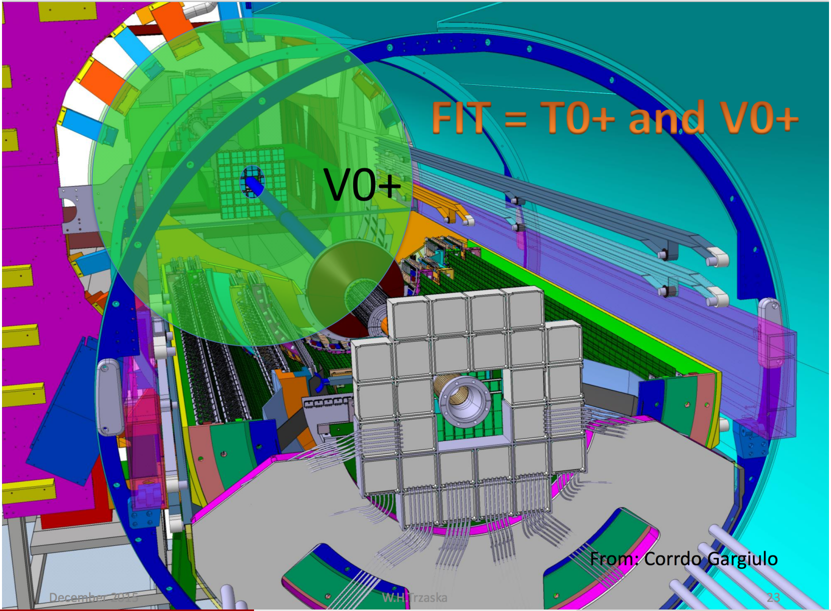
Fast Interaction Trigger (FIT)

Wladek proposed a new integrated scheme using a Cherenkov quartz radiator+Micro channel Plate (MPC) sensors.





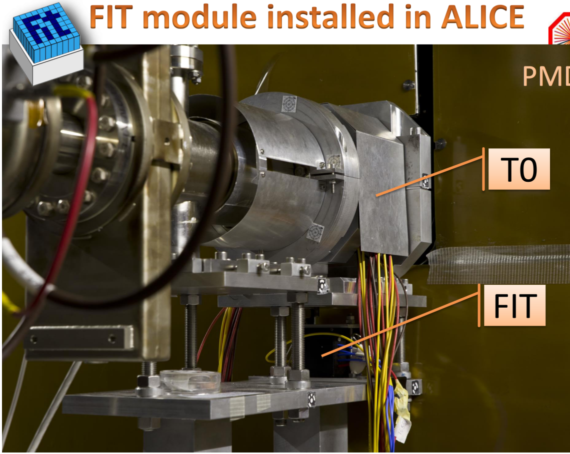
Fast Interaction Trigger (FIT)



Fast Interaction Trigger (FIT)

FIT purpose:

- Fast trigger designed to cope with 50 kHz readout rate.
- Luminometer, and collision time detector.
- It will also determine multiplicity, centrality, and reaction plane in heavy ion collisions.



FIT Collaboration

(~50 people, 14 institutes, 6 countries)

Country	City	Institute
Austria	Vienna	Stefan Meyer Institute
Denmark	Copenhagen	Niels Bohr Institute, University of Copenhagen
Finland	Jyväskylä	Helsinki Institute of Physics (HIP) and Univ. of Jyväskylä
Finland	Helsinki	Helsinki Institute of Physics (HIP) and Univ. of Helsinki
Mexico	Mexico City	Instituto de Física, UNAM
Mexico	Mexico City and Merida	CINVESTAV
Mexico	Mexico City	Instituto de Ciencias Nucleares, UNAM
Mexico	Puebla	Benemérita Universidad Autónoma de Puebla
Mexico	Culiacan, Sinaloa	Universidad Autónoma de Sinaloa
Russia	Moscow	Institute for Nuclear Research, RAS
Russia	Moscow	Moscow Engineering Physics Institute
Russia	Moscow	Russian Research Centre Kurchatov Institute
USA	Chicago	Chicago State University
USA	San Luis Obispo	California Polytechnic State University

Summary

Physics:

- I have mentioned not even the tip of an iceberg.
- New data at top energies allows precise determination of phase transition parameters like η/s. New methods of data analysis (e.g. Symmetric Cumulants) and new data ($v_n(\eta)$) challenge to hydrodynamical theory.
- Searching of other properties like QGP speed of sound (Mach cone) or even speed of light (Cherenkov radiation) ongoing.

Upgrade

- TPC upgrade processing well. HIP clean room laboratory prepared for the mass production. The same lab was replicated under the supervision of E. Brücken and T. Hilden in Budapes, Hungary.
- FIT upgrade also processing well. The first prototype tested in the real ALICE data taking.

We are doing our best to get ready for HL RUN3 :-)