Gluodynamics

Laboratoire Leprince-Ringuet

Benjamin Audurier - journée P2IO - 27 nov. 2020

Gluodynamics - Activity reports

I. Gluodynamics: context and introduction.
II. Gluodynamics and LLR/LHCb.
III. Gluodynamics and LHCb upgrades.

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Gluodynamics: context and introduction

Gluodynamics

5 institutes (CPHT, IJCLab, IRFU, IPhT, LLR)

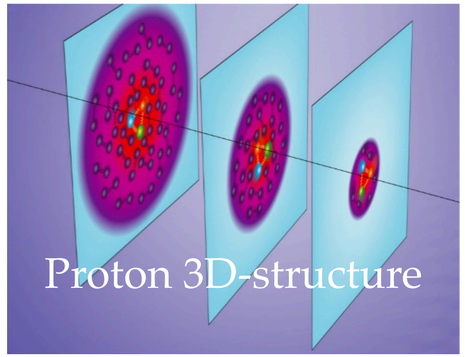
4 theory groups (CPHT, IPhT, ICJLab, DPhN)

6 experiments (ALICE, CMS, LHCb, CLAS12, Hall C, EIC)

- Two main thematics:
  - Study of the hadron structure.
  - Study of the QCD fluids.
- My work belongs to the *gluometer* section with LLR.
  - Activities just started but they benefit from previous work.

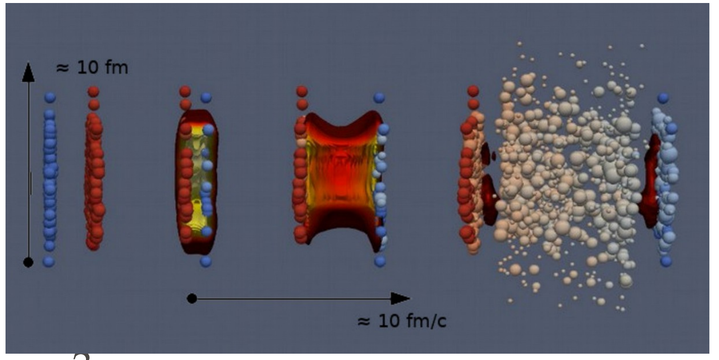
GLUODYNAMICS: probing the nature of dense gluonic systems			
Topics	**Subtopics**	**Institutes**	**Responsibles**
Geometry	nucleon ex	IPNO, LPT, DPhN, CPHT, IPhT	**C. Munoz, S. Wallon, L. Massacrier**
	nucleon theo		
	nucleus		
Unification	space	IPhT, CPHT, DPhN, IPNO, LPT	**J.-Y. Ollitrault, C. Marquet, J.-P. Lansberg, H. Moutarde**
	time		
	tools		
	cross education		
Gluometer	force collider	DPhN, LLR, IPNO, IPhT	**M. Winn, F. Fleuret, M. Nguyen**
	force fixed-target		
	radiation		
Future	p/A-p/A collider	LAL, DPhN, DEDIP,CPHT	**P. Robbe, F. Bossu**
	e-p/A collider		
	In. Stages conference		

Hadron structure



- Understand the dominant matter constituents.
  - *Study of the proton structure.*
  - *Study of the nuclear structure.*

QCD fluid

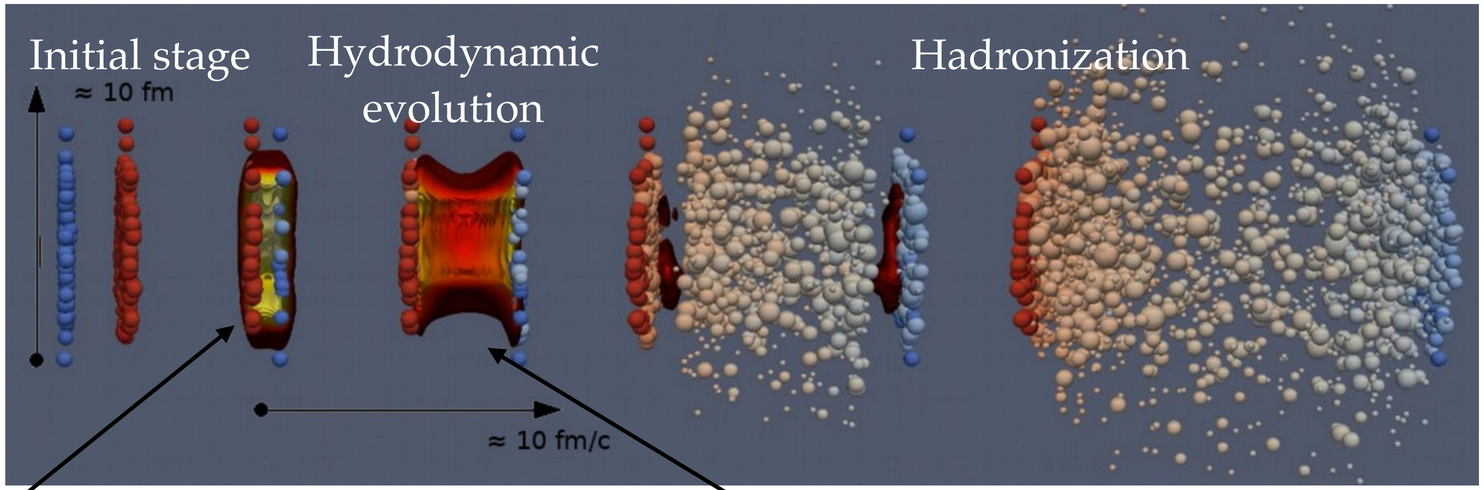


- Characterise Quark-Gluon Plasma:
  - *Size, temperature ….*
- Characterise initial state of strong gluon fields:
  - *QGP in pp and pA?*

QGP in heavy-ion collisions

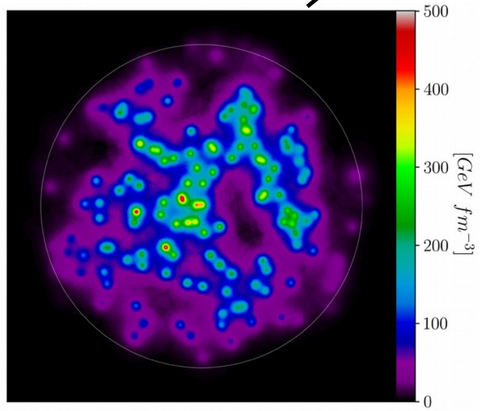
- Quark-gluon plasma (QGP) studied in high-energy heavy-ion collisions.
- QGP characterisation relies on:
  - Hard Probe studies (jets, heavy-quark productions…).
  - Good knowledge of the initial hadronic structure stage.
- Plenty of questions to answer:

Evolution of a PbPb collision

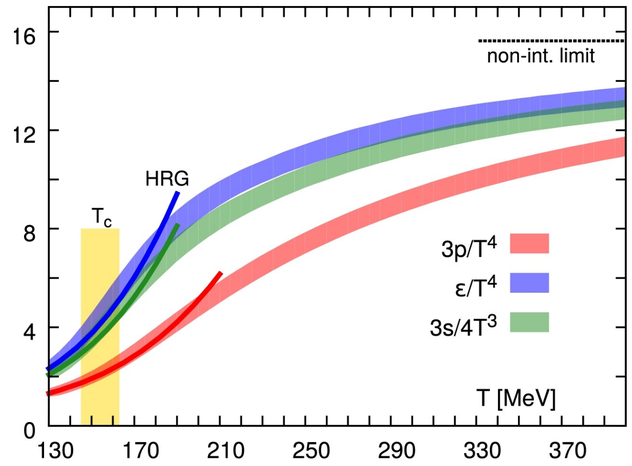


j.nuclphysa.2014.08.073

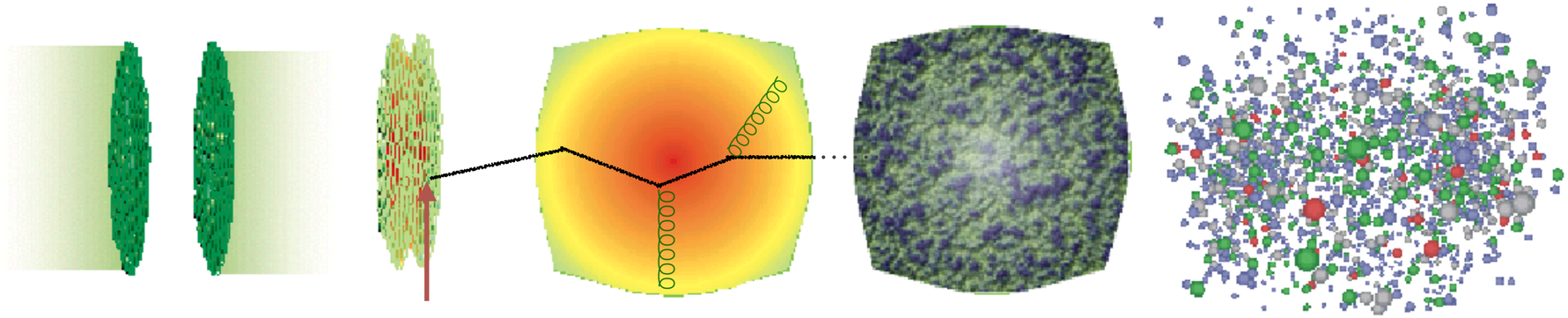
- QGP-like behaviour in pp/pA ?



- Studies of QGP properties:
  - *Temperature, pressure, viscosity ?*
- Study of the phase transition: deconfinement



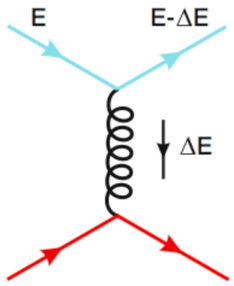
Example: Heavy-quarks in QGP studies



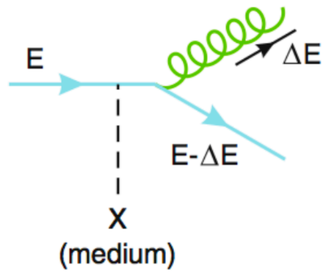
Heavy-quarks (c,b) formation time

Initial fluctuation — Quark-Gluon plasma — Hadronization and Freeze-out → time

Interaction processes



- *Collision energy-loss*



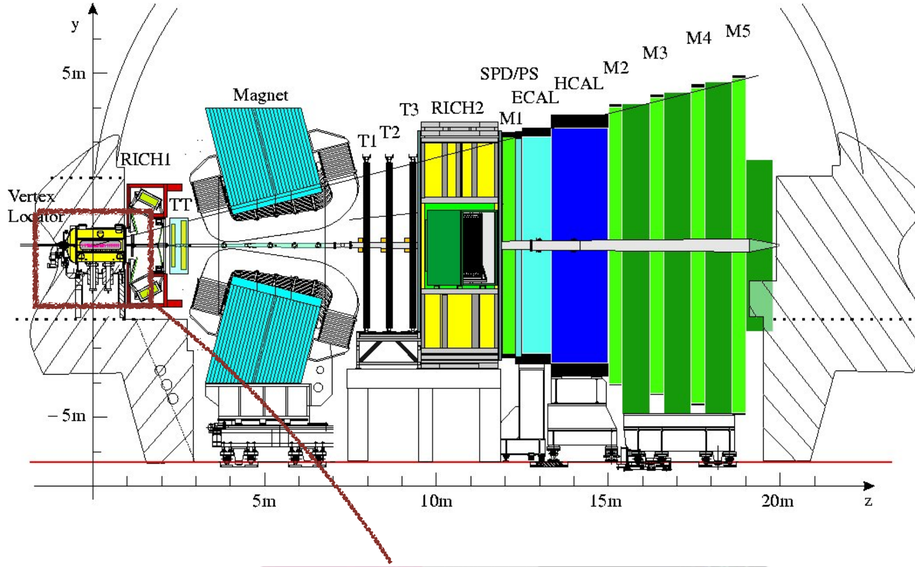
- *Radiative energy-loss*

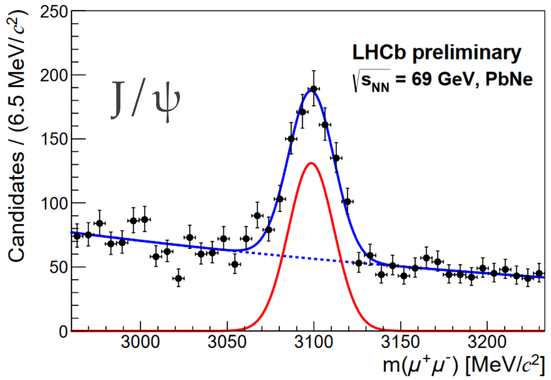
- Heavy-Quarks:
  - Produced at the earliest stage of the collision.
  - Sensitive to the deconfined phase of hadronic matter.
  - Gives access to medium properties (density, temperature …)

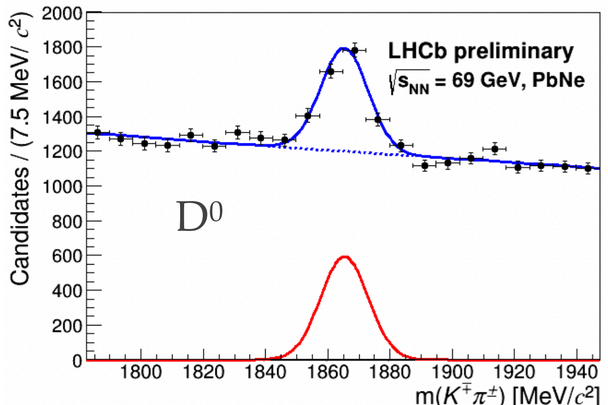
Gluodynamics and LLR/LHCb

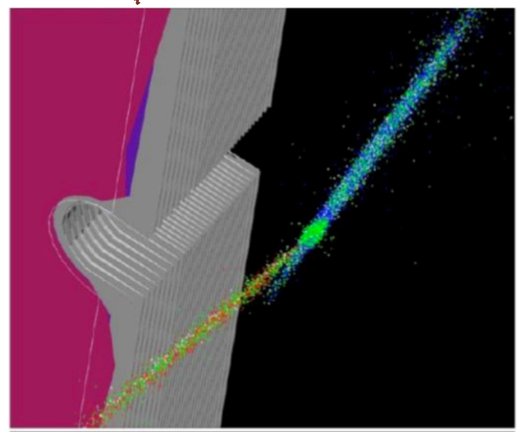
Gluodynamics@LLR

- The LHCb experiments:
  - fully instrumented forward spectrometer at the LHC initially dedicated to b-quark measurements.
  - can run both in collider and fixed-target mode simultaneously.
- LLR is member of the LHCb collaboration:
  - Expertise in fixed-target measurements.
  - Involved in the preparation of the next heavy-ion data taking.





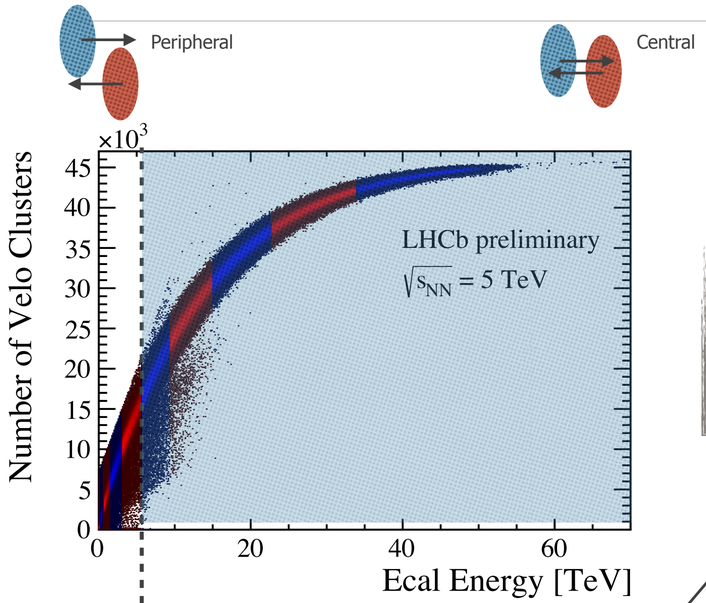


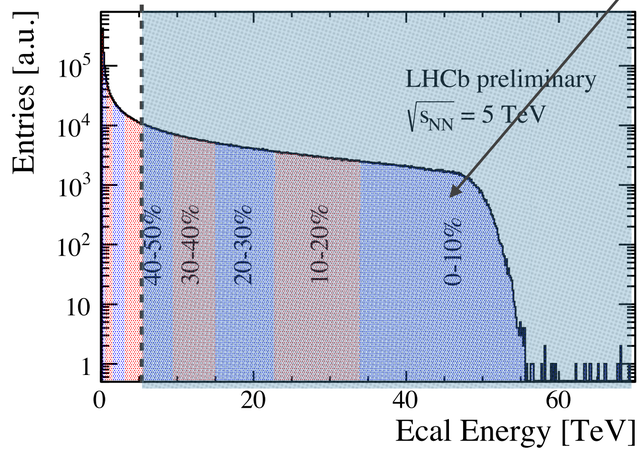


Distribution of vertices overlaid on detector display. z-axis is scaled by 1:100 compared to transverse dimensions to see the beam angle.

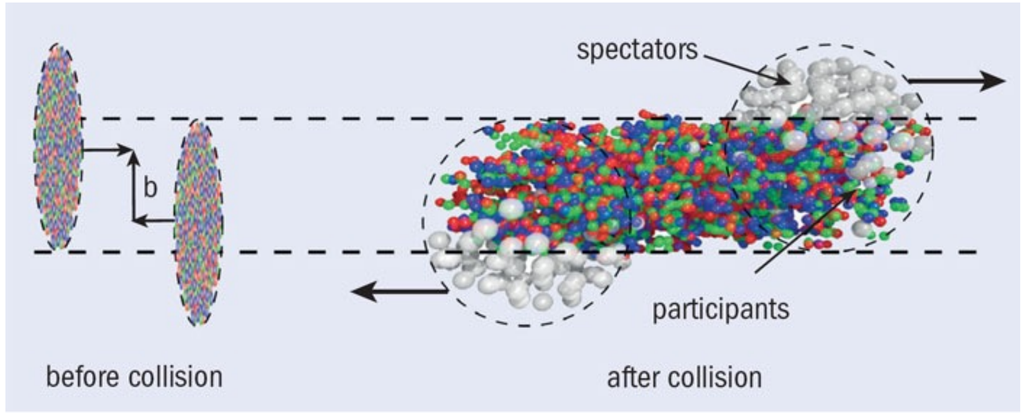
Beam 1 - Beam 2, Beam 1 - Gas, Beam 2 - Gas.

QGP studies limitation in LHCb: occupancy





~ 5000 charged particles in LHCb acceptance in 10% most central collisions.



- Small b → central collision → high particle multiplicity.
- Large b → peripheral collision → low particle multiplicity.

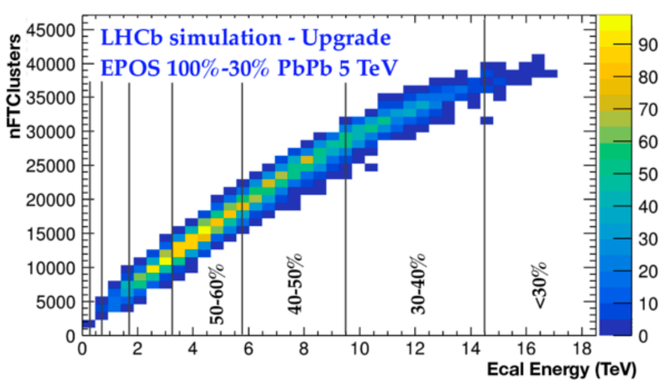
- VELO detector saturates in central collisions :
  - Current tracking algorithm efficient up to ~50%.
  - **Physics studies limited to ~50% less central events.**
  - **Could affects also fixed-target collisions in the future.**
- Better performances are needed to meet Gluodynamics objectives.

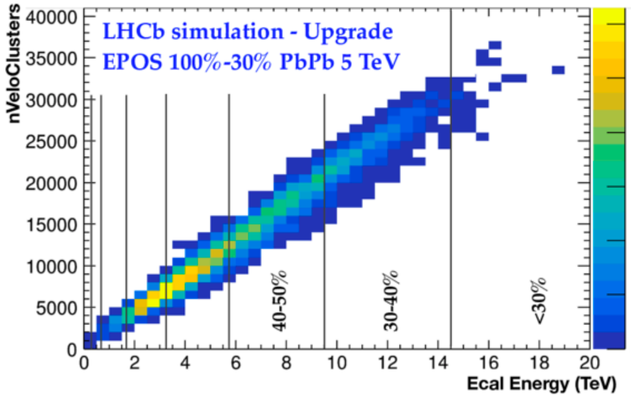
Small detour: the LHC agenda

- LHC is ongoing a shutdown → upgrades ongoing.
- Heavy-ion collisions scheduled in Run 3, Run 4 and Run 5.
- Early studies show an improvement of LHCb capabilities for Run 3, but likely not enough.

LHC schedule

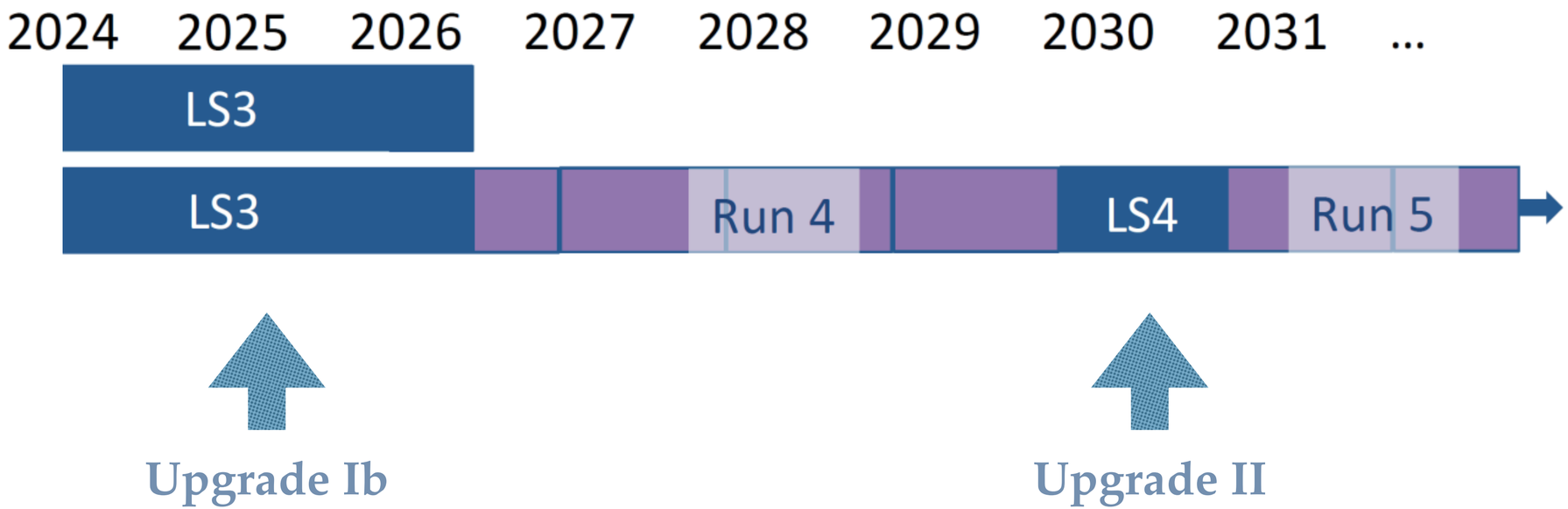
B. Audurier, LHCB-FIGURE-2019-021





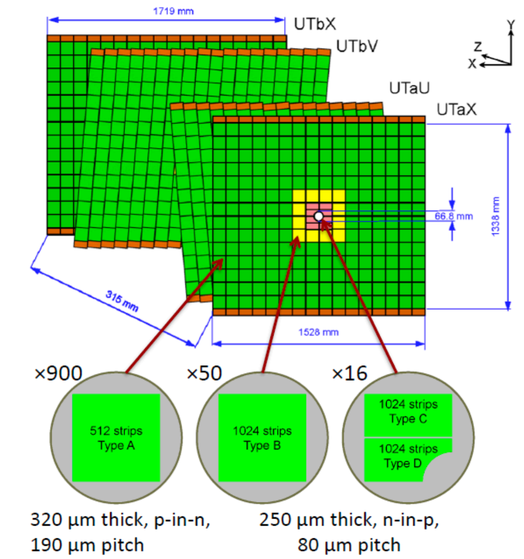
How do we insure full detector capabilities for the future to meet Gluodynamics objectives ?

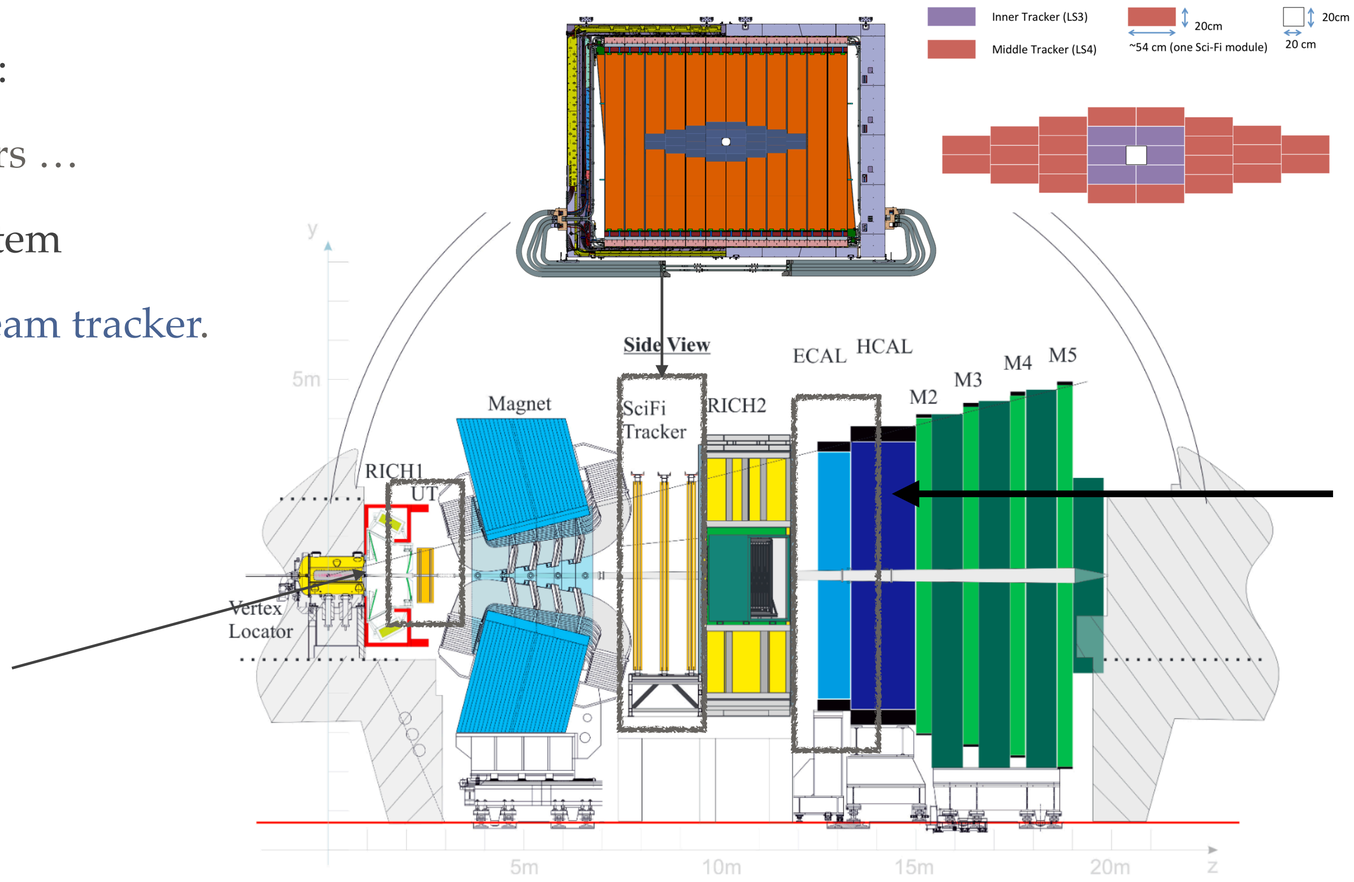
Gluodynamics and LHCb upgrades

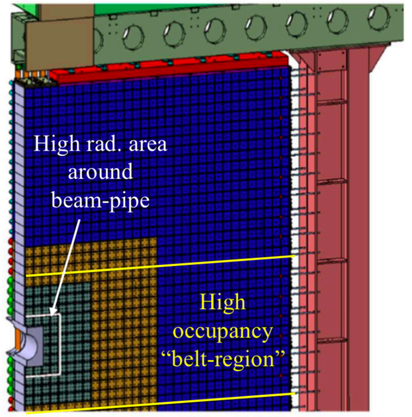


Upgrade II in a nutshell

- Many upgrades that won't be covered:
  - VELO, RICH detectors, calorimeters …
- The one discussed today: tracking system
  - Tracking system: MIGHTY / Upstream tracker.
  - Electromagnetic calorimeter.







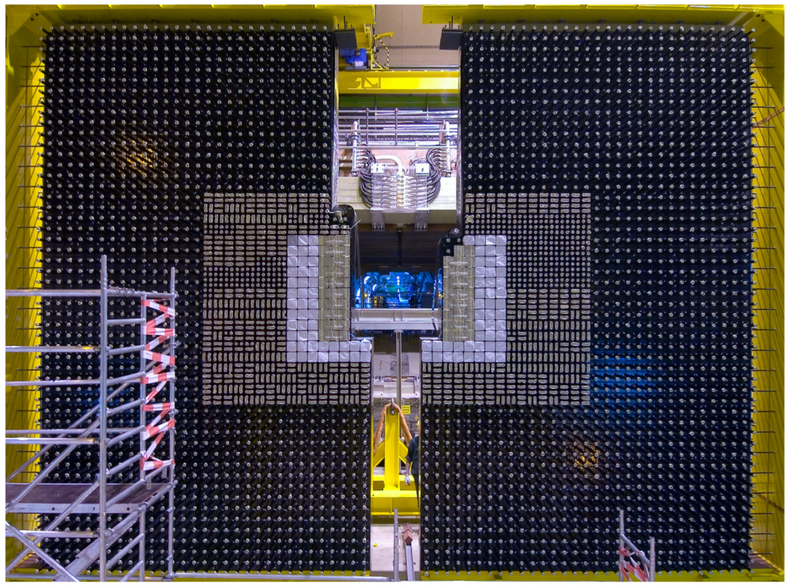
pp beam Upgrade I:
- Pile-up = 5 pp collisions

→

pp beam Upgrade II:
- Pile-up = 42 pp collisions

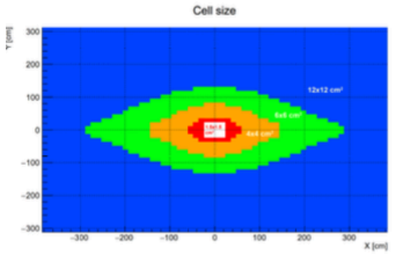
ECal upgrade@IJCLab

The current ECal

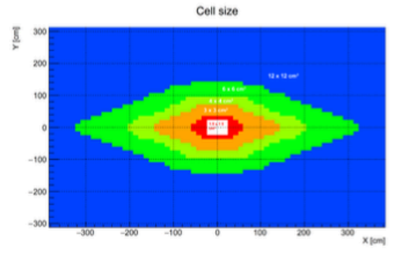


- Current ECal won't sustain the radiation dose expected after Upgrade II.
- Upgrade requirements:
  - Fast timing capabilities O(10) ps.
  - Increase granularity in the central region with more dense absorber.
  - Keep energy resolution at the percent level.
- Options for LS3:

Option 1:
(32 new modules)



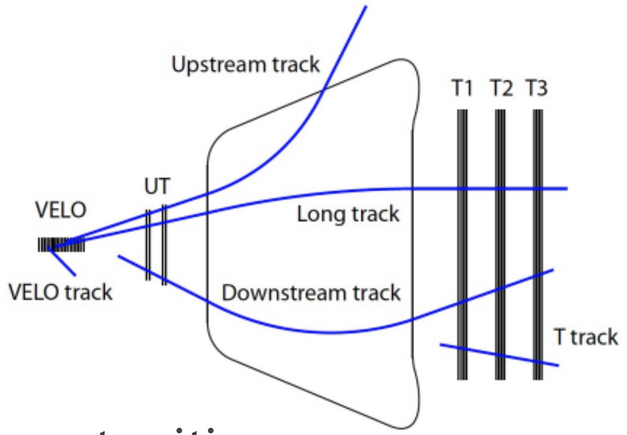
Option 2:
(32+144 new modules)

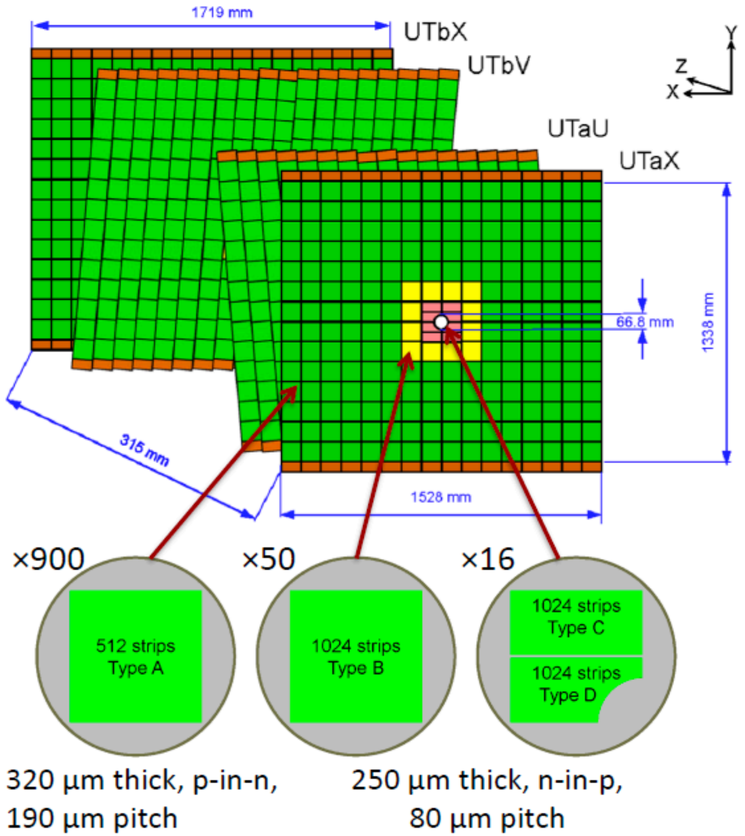


- A two-year post-doc (Manuel Guittiere) is starting on Dec. 4th to work on ECAL simulation studies in view of heavy-ion observables.

Tracking upgrade: Upstream Tracker (UT)

- Present detector: silicon micro-strip detector.
  - 968 silicon sensors.
  - 4 layers (x,u,v,x) upstream of magnet.
  - all enclosed in a openable box.
- UT upgrade **is mandatory** for Upgrade 2 → opportunities to improve the tracking (both for pp and PbPb):
  - Improve VeloUT track finding - reduce ghost rate.
  - **Reduce ghost rate** for LongTracks in central PbPb collisions.
  - **Improve Upstream-Downstream matching.**
  - Improve **low-momentum resolution.**

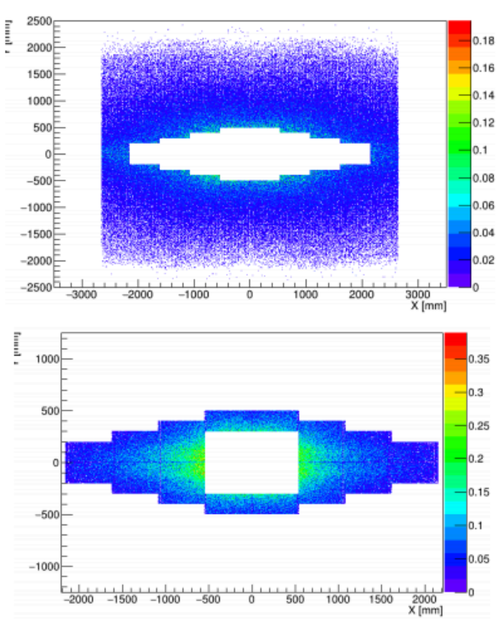


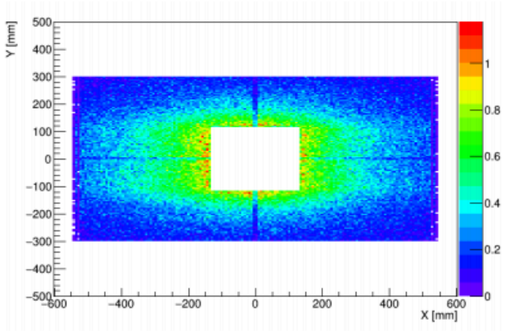


Plots: studies done with M. Coquet and C. Zhang

UT Upgrade 2: early studies in PbPb

MIGHTY hit density: 0-5% PbPb centrality





Max hit density T1 [hit/cm² event] :
- OT : 0.19
- IT : 1.18
- MT : 0.39

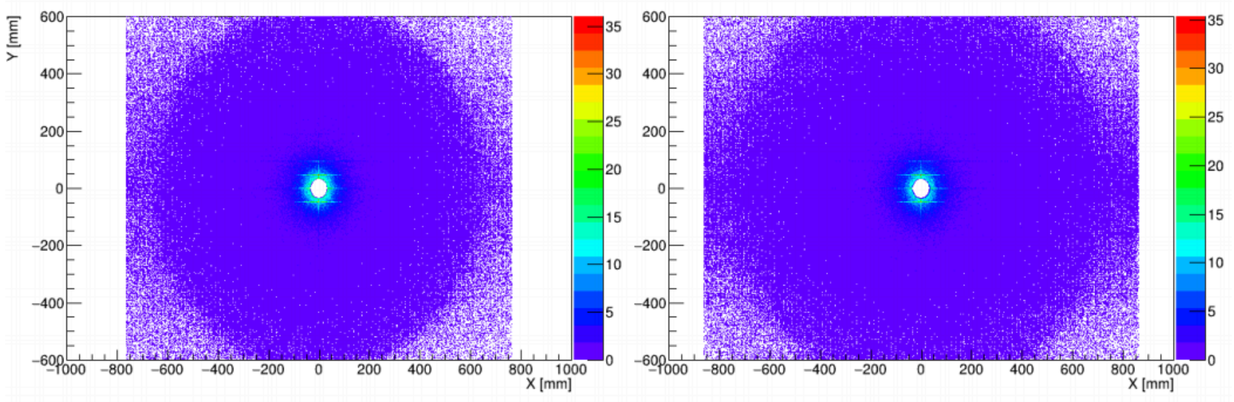
(Previous estimates :)
- OT : 0 .23
- IT : 6.67
- MT : 0.53

Bin size : 0.7 cm x 0.5 cm
(1000 bins in x & y)

Hit density for 0-5% PbPb centrality

Detection plane	Corresponding η	Corrected max hit density [hit/cm^2 event]
T1 OT	3.130	0.234425
T2 OT	3.403	0.231771
T3 OT	3.048	0.234425
T1 IT	4.633	1.612093
T2 IT	4.775	1.688841
T3 IT	4.802	1.571794
T1 MT	3.314	0.492514
T2 MT	3.427	0.507
T3 MT	3.474	0.492514

UT hit density: 0-5% PbPb centrality



Occupancy histograms [hit/cm² event] for UT first detection plane (left) and last detection plane (right)

- Production of full simulation samples (**LLR**) ongoing.
- Occupancy studies are ongoing (**LLR + IRFU**) for MIGHTY and UT.
- Tracking efficiency (**LLR + IRFU**) and data rate studies started.
- Open questions to answer:
  - Station design: Full pixel, strip + pixel, number of stations ?
  - Strip/pixel technology: size of the pixel, timing ?
  - Station position: move one close to the magnet ?

Conclusions

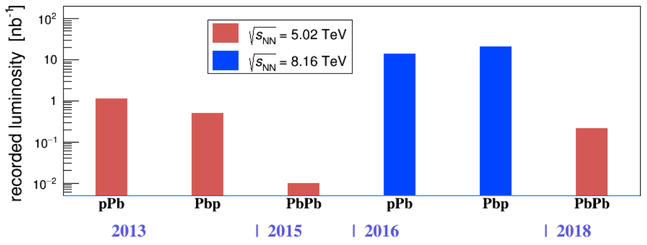
- Gluodynamics: collaborative effort among many laboratories toward the study of hadron structure and QCD fluid structure.
  - Gluometer: focus on Quark-Gluon Plasma studies and deconfined medium.
  - LLR@Gluodynamics: heavy-ion and fixed-target experts in the LHCb experiments.
- QGP studies and LHCb:
  - Great precision meets by the detector in pp/pA in heavy-quark measurements.
  - Performances limited in high-occupancy regime in PbPb collisions.
- Activities:
  - Forcemeter fixed-target: Occupancy studies based on simulations started (LLR + IRFU).
  - Future hadron collider: new post-doc to start working on Calo simulations (IJCLab + LLR).
  - Regular expertise exchanges between LLR-ICJLab-Saclay for the LHCb Upgrade 2.

Back-up

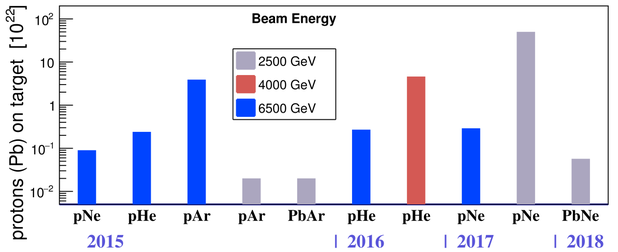
LHCb: general purpose detector for heavy-ions

- Large variety of data samples to study→large physics program !
- (Some) physics studies in LHCb:

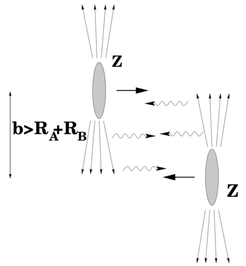
Collider mode

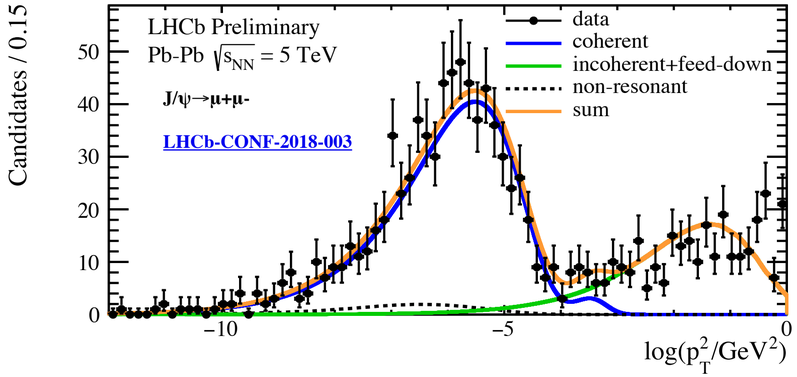


Fixed-target mode

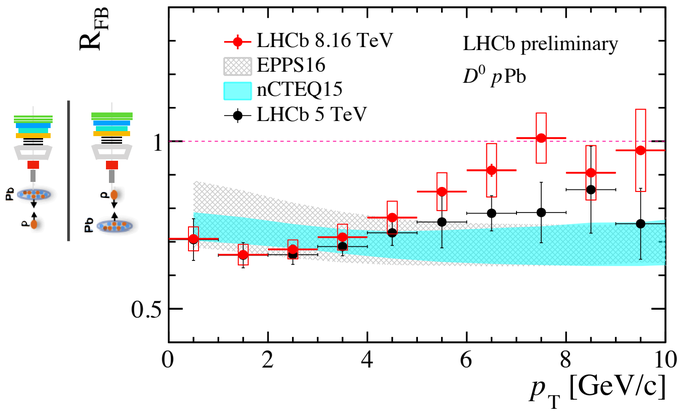


Vector meson production in Ultra-peripheral PbPb collisions.

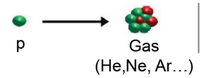


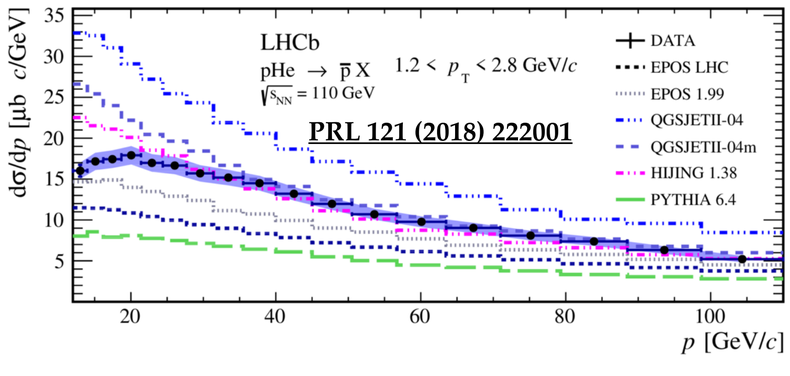


Nuclear Parton distribution functions with hard probes



Anti-proton cross-section: key ingredient in cosmic ray physics





Tracking system: Scintillating fibre tracker (SciFi)

- ~10000 km of scintillating fibres arranged in 6 layers with silicon photo-multipliers (SiPM) readout.
  - 3 stations.
  - 4 detection layers per station arranges in x-u-v-x configuration per stations.
  - 10 modules of 2x4 mats.