Extension of Forward Physics Beyond 2030

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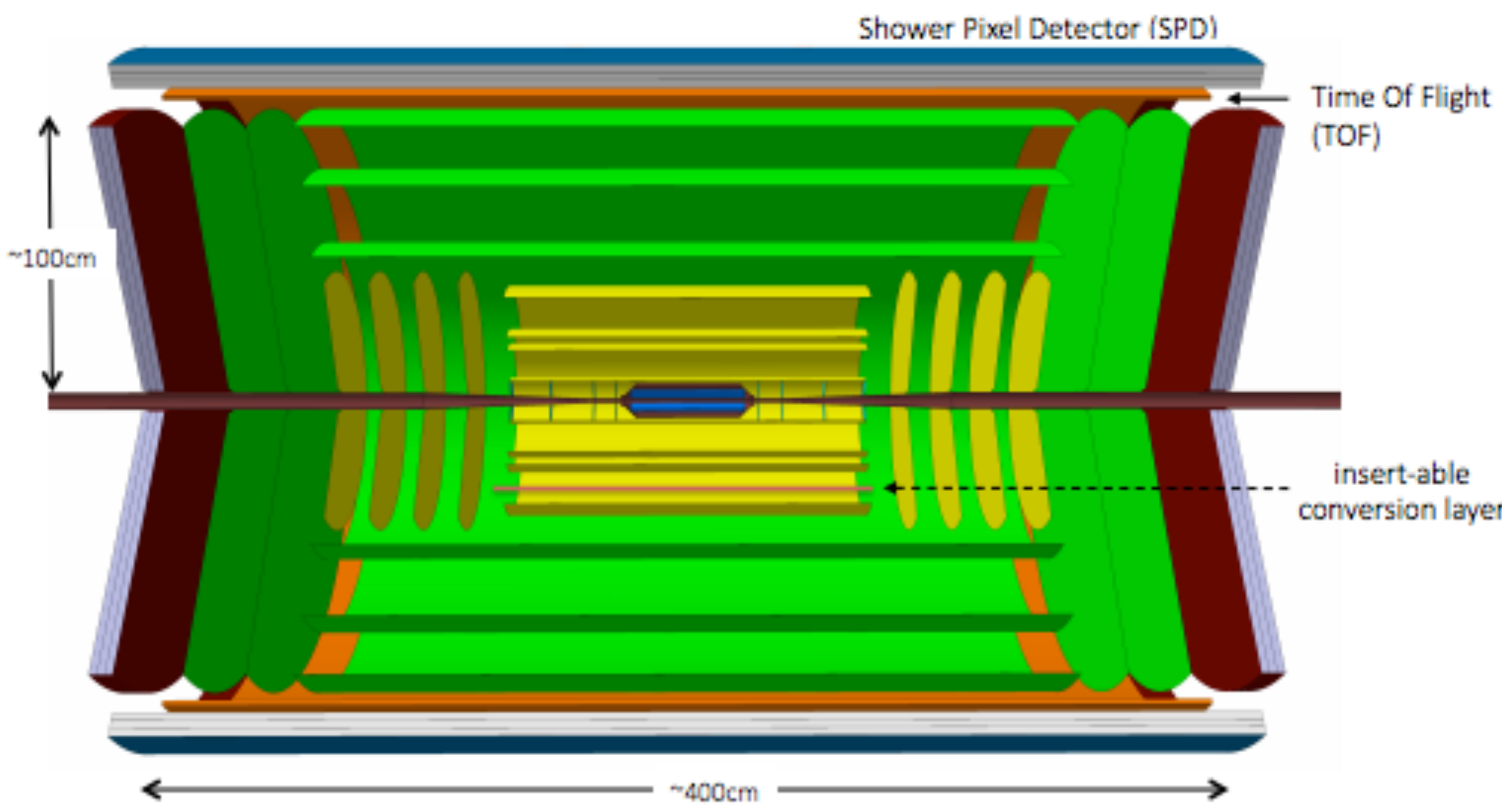
Outline

- Next generation of HI detector
- Forward spectrometer with PID capabilities and re-purpose of existing ALICE detectors
- Physics with next generation detector and forward PID detectors
- Summary

Discrimer:
- **This is just a rough idea** on what we could do with next generation of HI detector.
- Not yet validated via simulations if this idea works or not….
- There are many places that are completely wrong (conceptually and technically)…
- Measurement items still need to be considered.

Next generation of HI detector

- Next generation of HI detector



Compact & Multi-purpose detectors:

- Covering |η|<4
- Tracking and Vertexing with MAPS silicon layers
- hadron PID by 20ps resolution of Si-based TOF (|η|<1.4)
- Photon and electron ID with pre-shower (W+Si) (|η|<1.4)
- High rate capability (x20-50 luminosity)

A next-generation LHC heavy-ion experiment

Authors

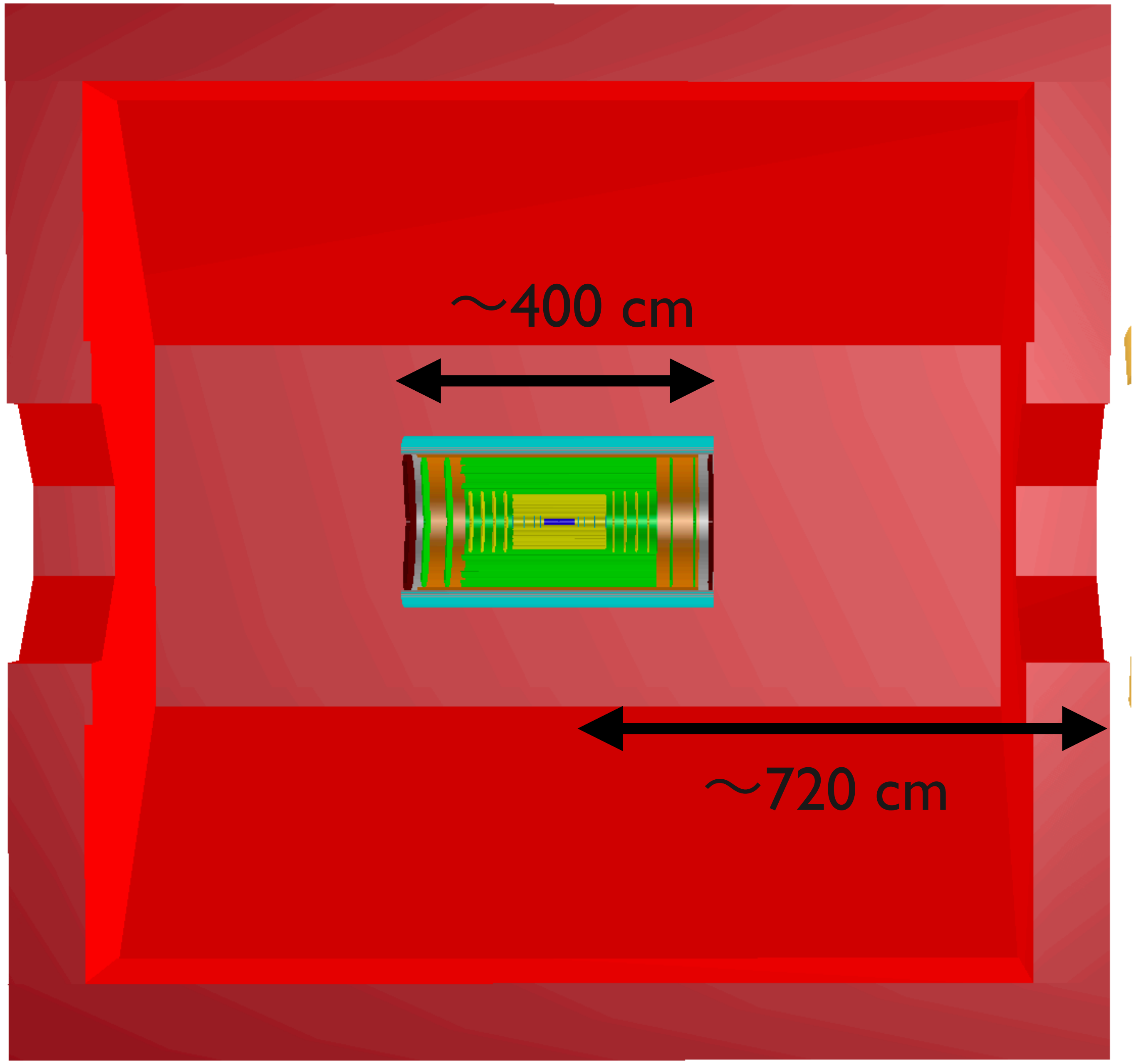
Abstract

The present document discusses plans for a compact, next-generation multi-purpose detector at the LHC as a follow-up to the present ALICE experiment. The aim is to build a nearly massless barrel detector consisting of truly cylindrical layers based on curved wafer-scale ultra-thin silicon sensors with MAPS technology, featuring an unprecedented low material budget of 0.05% X_0 per layer, with the innermost layers possibly positioned inside the beam pipe. In addition to superior tracking and vertexing capabilities over a wide momentum range down to a few tens of MeV/c, the detector will provide particle identification via time-of-flight determination with about 20 ps resolution. In addition, electron and photon identification will be performed in a separate shower detector. The proposed detector is conceived for studies of pp, pA and AA collisions at luminosities a factor of 20 to 50 times higher than possible with the upgraded ALICE detector, enabling a rich physics program ranging from measurements with electromagnetic probes at ultra-low transverse momenta to precision physics in the charm and beauty sector.

Geneva, Switzerland
December 10, 2018

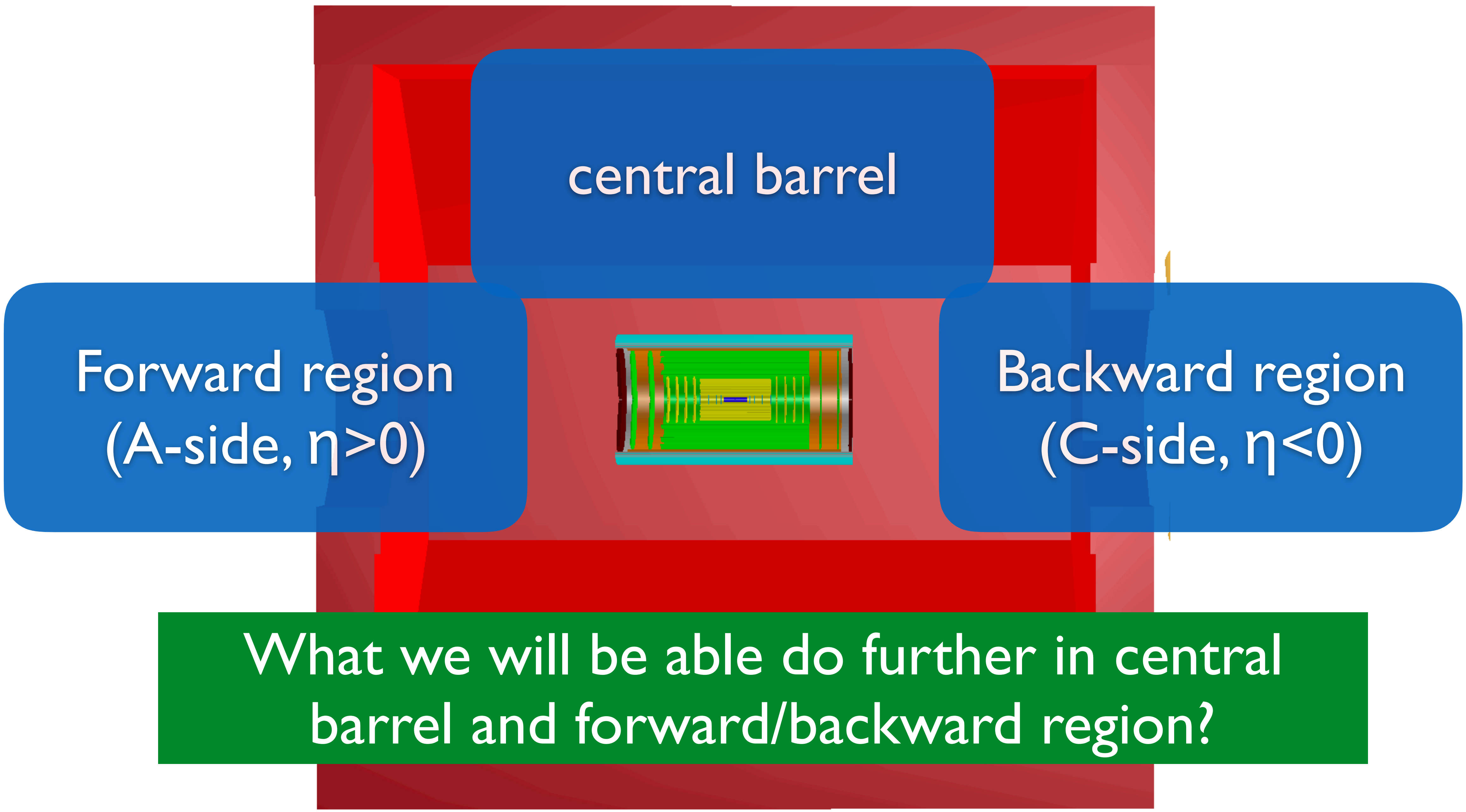
Next generation of HI detector

- Next generation of HI detector in L3 magnet



Next generation of HI detector

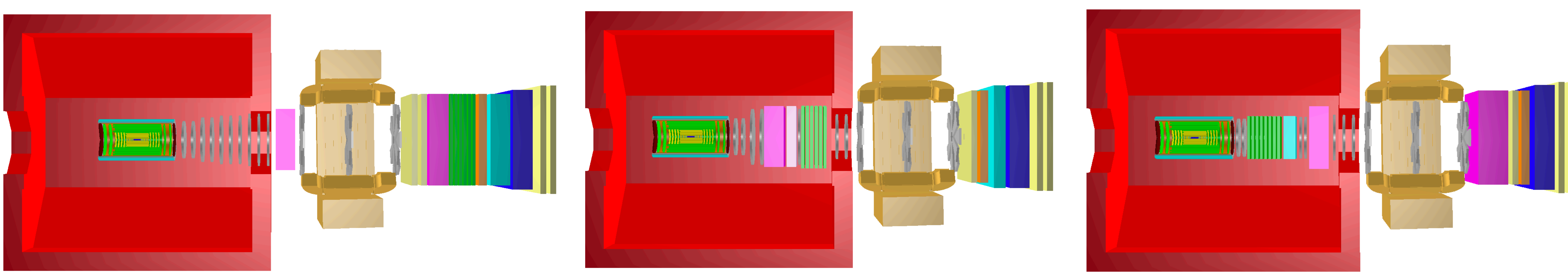
- Next generation of HI detector in L3 magnet



What we will be able do further in central barrel and forward/backward region?

New Idea on forward spectrometer

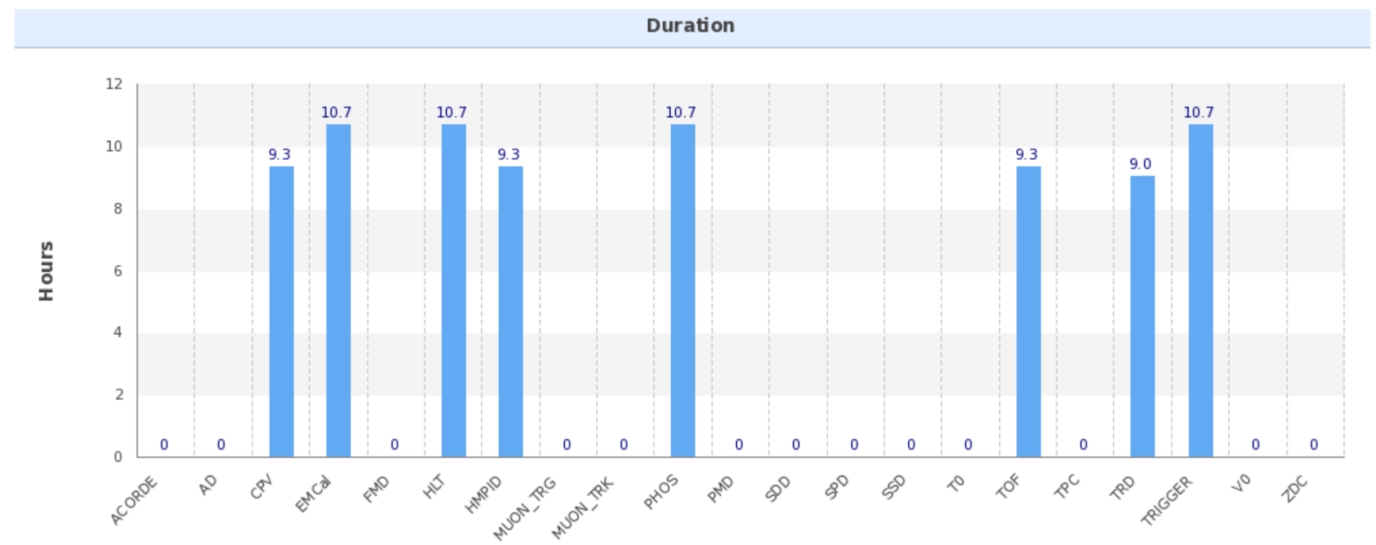
- Using our dipole magnet in backward direction (C-side, η<0)
- Tracking and full PID capabilities covering 2<η<4.6
- Try to be compact(?) and cheap by re-purposing some parts of existing detectors (GEM-TPC, TRD, TOF, HMPID, PHOS, EMCal, MCH)



Tracker TRD FoCAL+EMCal Tracker
RICH TOF HCAL

Run3 Pb-Pb equivalent tests in 2018

- TRD, TOF, HMPID, PHOS, EMCal joined 50 kHz Pb-Pb equivalent tests in 2018 (70 Hz/μb in pp → 4 MHz IR rate)
  - Fill 7264 (as one example) for 13h
  - No major issues were found.
    - 6 TRD HV trips
    - 4 EMCal PAR failures
    - TOF LV failures



- It is not still clear that they will survive at x20 larger luminosities…
- Following upgrades should be made to use them at forward rapidity.
  - TRD: wire → MPGD, fine granularity pads, electronics (no pretrigger, continuous readout)
  - TOF: more fine granularity pads, electronics, continuous readout
  - HMPID: wire → MPGD, new radiators with smaller index (ex, aerogel + CF_4 @ adjustable pressure. CF_4 also acts as the gas for amplification.)
  - PHOS+EMCal: electronics

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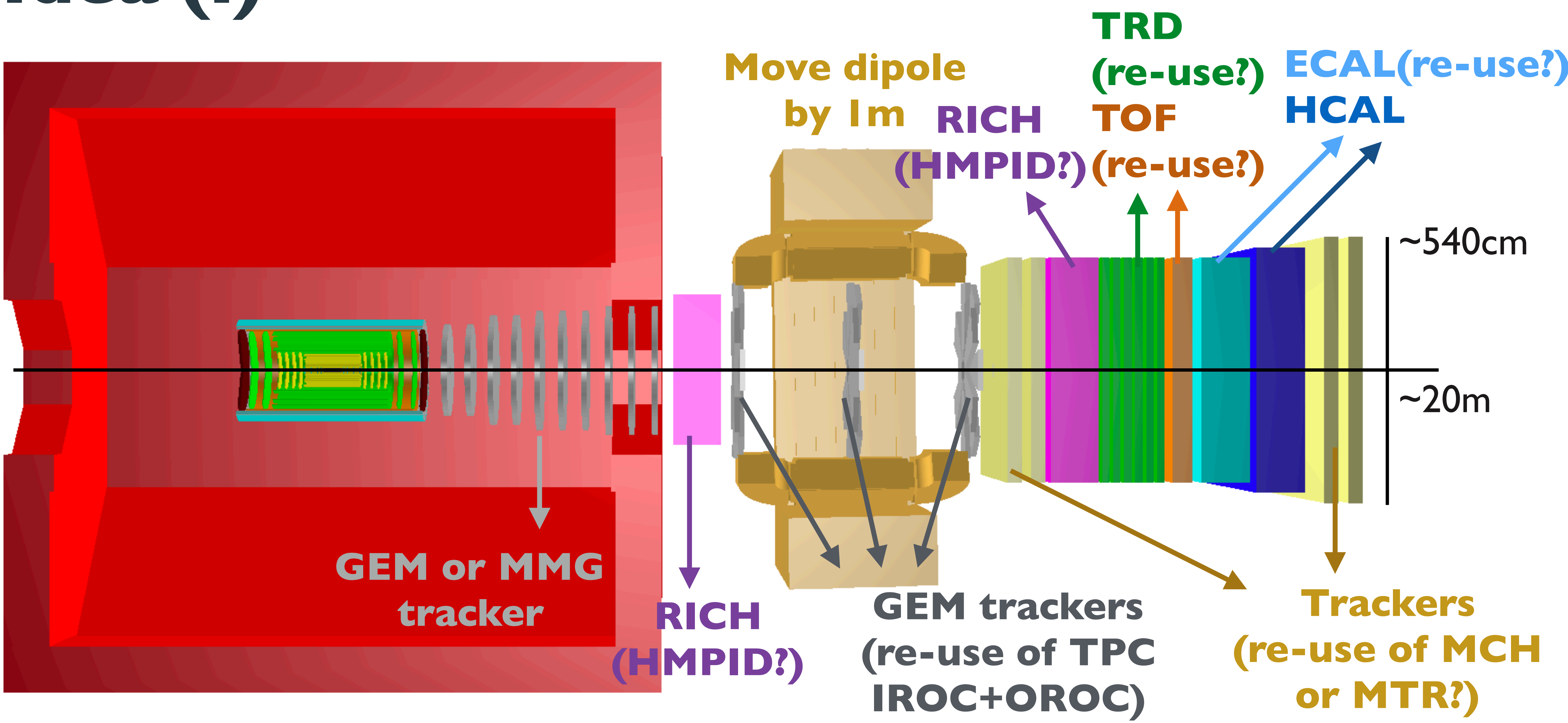
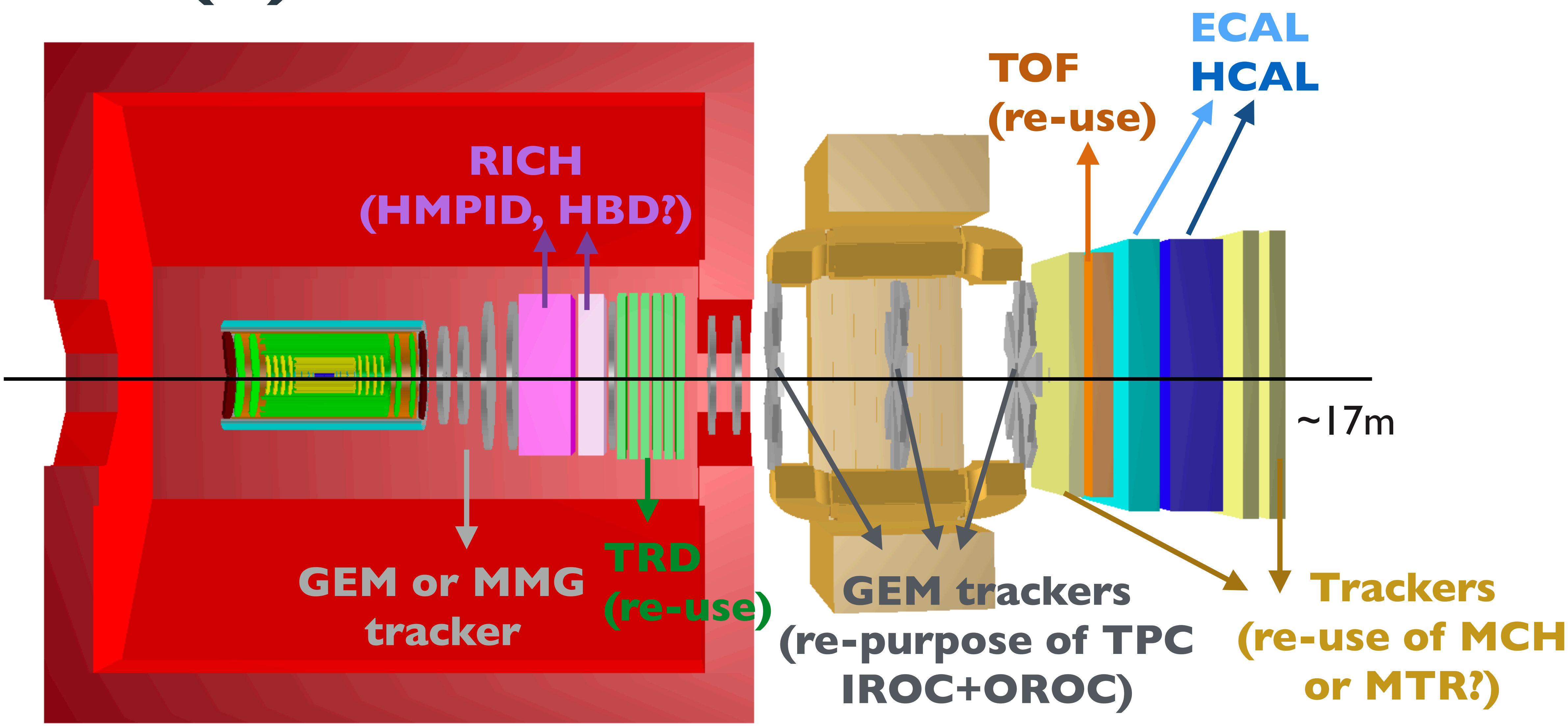
Idea (I)



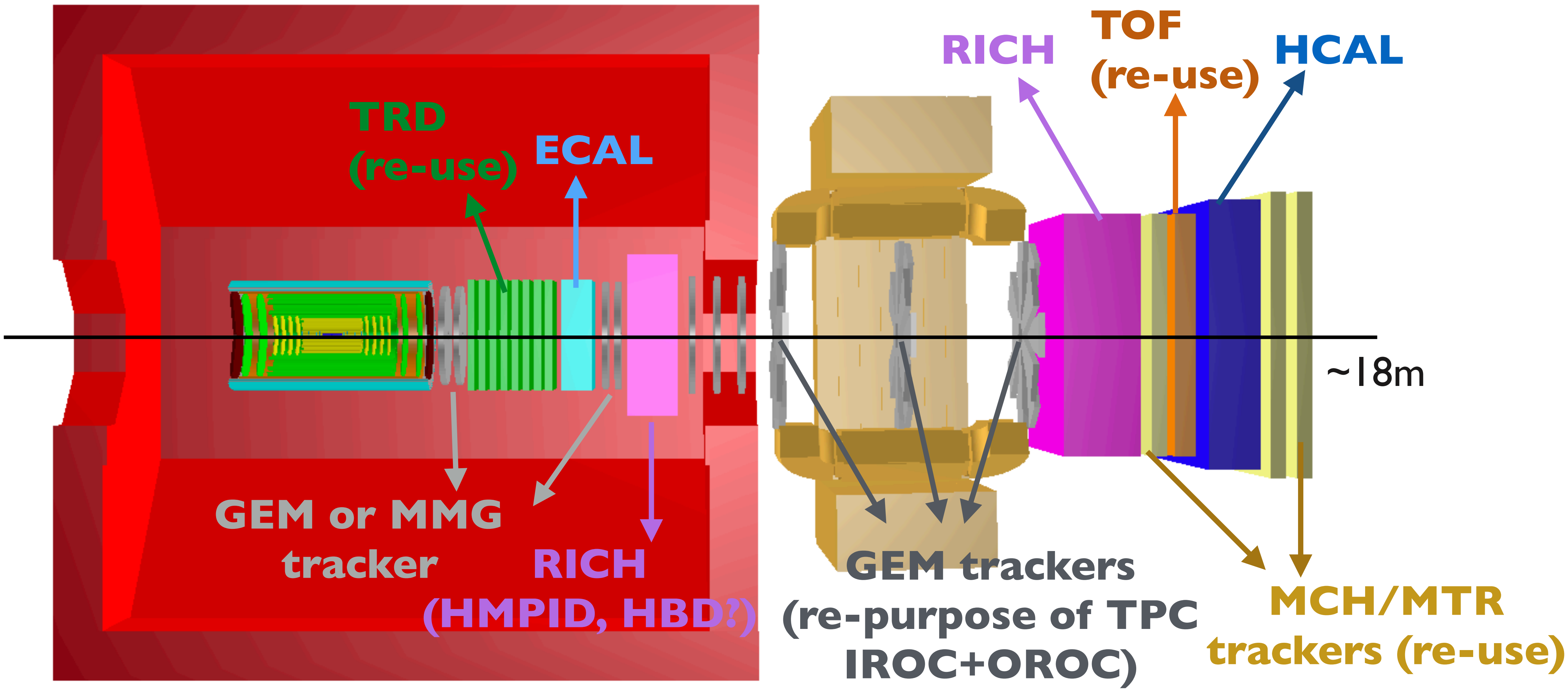
- **All PID detectors are out of L3 magnet.**
- 3 radiators in RICH (ex, aerogel, C_4F_{10}, CF_4)
- ECAL is composed of W+Si (FoCAL), $PbWO_4$ (PHOS), PbSc (EMCal)

Idea (II)



- **RICH + TRD are in L3 magnet.**
- 3 radiators in RICH (ex, aerogel, C_4F_{10}, CF_4)
- ECAL is composed of W+Si (FoCAL), $PbWO_4$ (PHOS), PbSc (EMCal)

Idea (III)



- **TRD + ECAL + RICH are in L3 magnet. e/γ identification in L3**
- 3 radiators in RICH (ex, aerogel, C_4F_{10}, CF_4)
- ECAL is composed of W+Si (FoCAL), $PbWO_4$ (PHOS), PbSc (EMCal)

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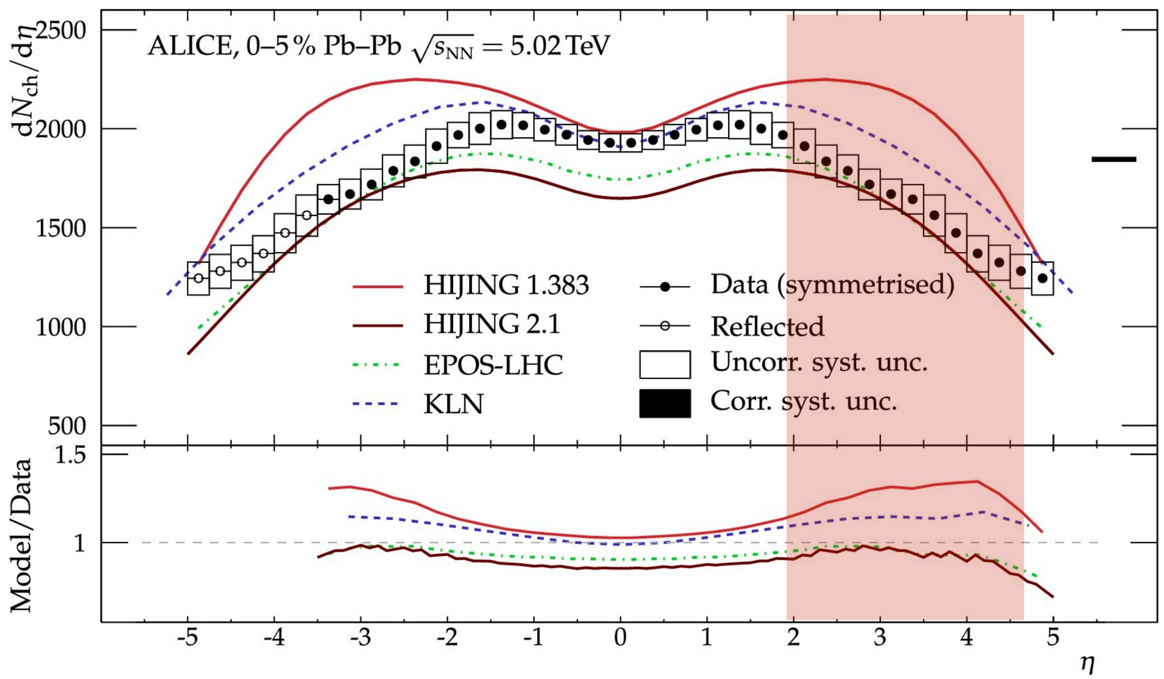
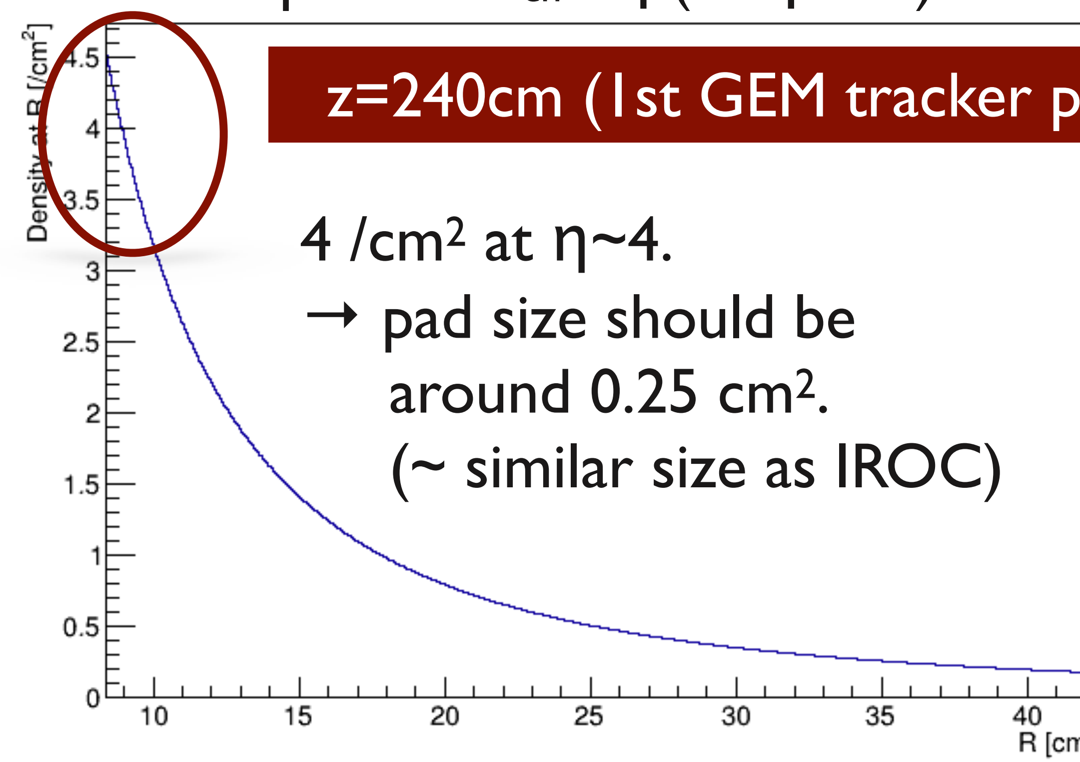
Particle density in Pb-Pb

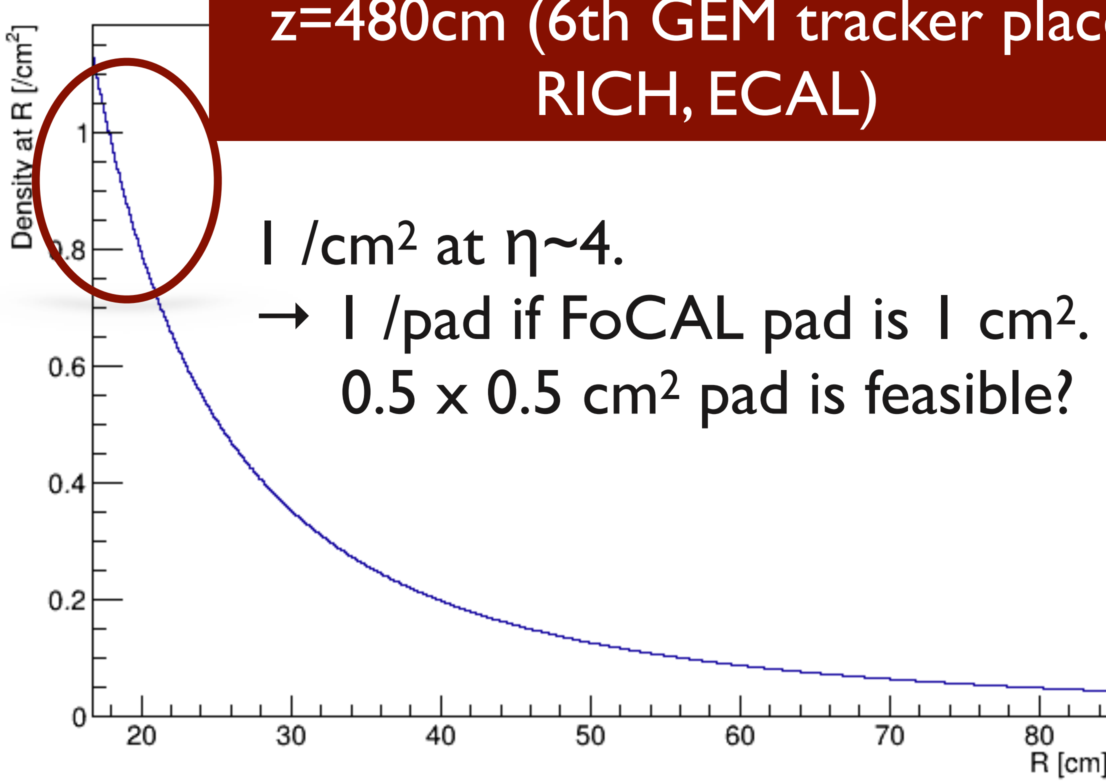
assumption: $dN_{ch}/d\eta$ $(2<\eta<4.6)$ = 2000





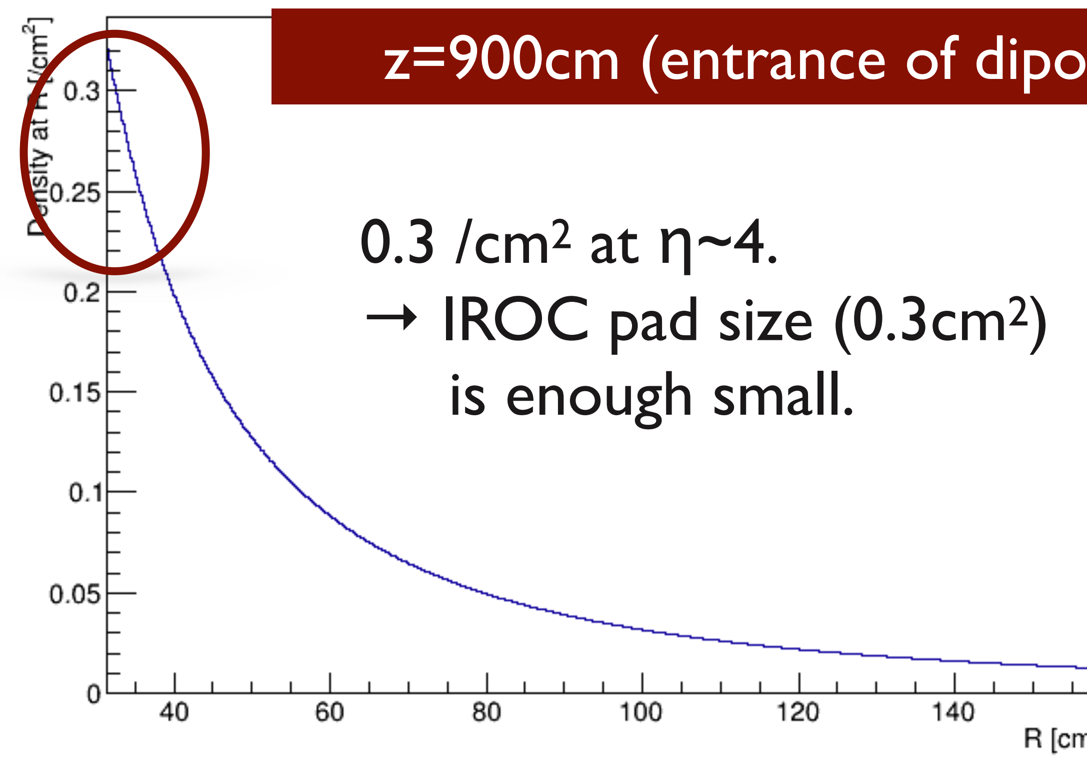
z=240cm (1st GEM tracker place)

4 /cm² at η~4.
→ pad size should be around 0.25 cm².
(~ similar size as IROC)



z=480cm (6th GEM tracker place, RICH, ECAL)

1 /cm² at η~4.
→ 1 /pad if FoCAL pad is 1 cm².
0.5 x 0.5 cm² pad is feasible?



z=900cm (entrance of dipole)

0.3 /cm² at η~4.
→ IROC pad size (0.3cm²) is enough small.

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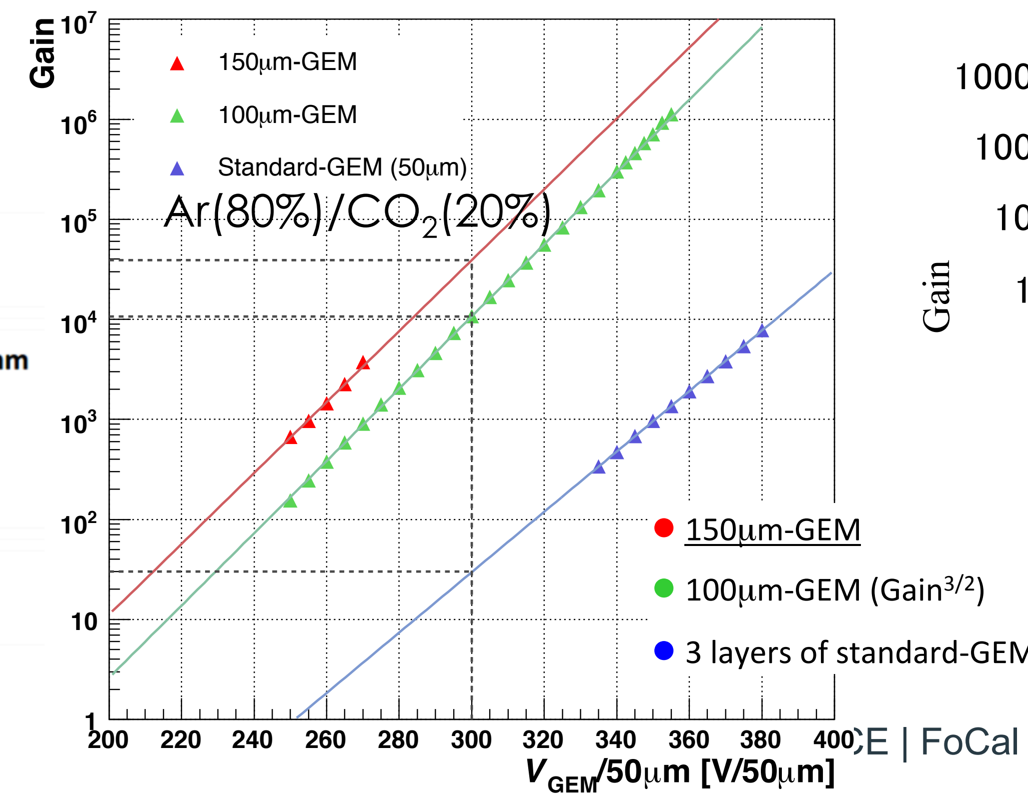
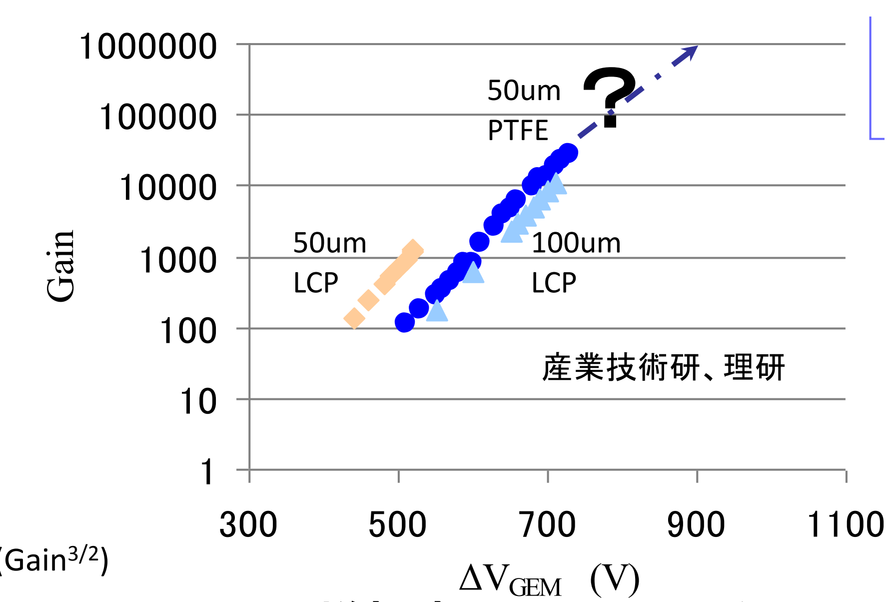
GEM or MMG trackers

- GEM or MMG trackers behind MAPS layers. MPGD technologies are getting matured.
- Pad size should be smaller than 0.25 cm^2. # of pads/plane = 125k
- Rate capability:
  - 4 /cm^2 → If Pb-Pb becomes 1MHz (x20 larger than Run3+4), flux reaches to 4 MHz/cm^2.
    - GEM and MMG are robust (no gain reduction) up to 10-100 MHz/cm^2.
  - Ultra-fast signals = t_{rise}(10-100ns) → Continues readout (of zero-suppressed data?)
    - 125k x 40 MHz x 10 bit = 6.25 TB/s. CRU could do enough reduction of raw data.
- New GEM technology?
  - Teflon-GEM (more robust against sparks)
  - 100 or 150um thick LCP-GEM → much safer operation than 50 um x 3 GEM stack

MPGD Projects….

•SBS tracker	GEM 600mm x 500mm
•ALICE TPC upgrade	GEM 600mm x 400mm
•CMS muon	GEM 1.2m x 450mm
•ATLAS NSW muon	Micromegas 2m x 1m
•COMPASS pixel Micromegas	GEM & Micromegas 500mm x 500mm
•BESIII	GEM 600mm x 400mm
•KLOE	GEM 700mm x 400mm
•SOLID	GEM 1.1m x 400mm
•CLAS 12	Micromegas 500mm x 500mm
•LSBB (geoscience)	Micromegas 1m x 500mm
•Prad	GEM 1.5m x 55cm
•CBM	GEM 1m x 450mm
•ASACUSA	Micromegas

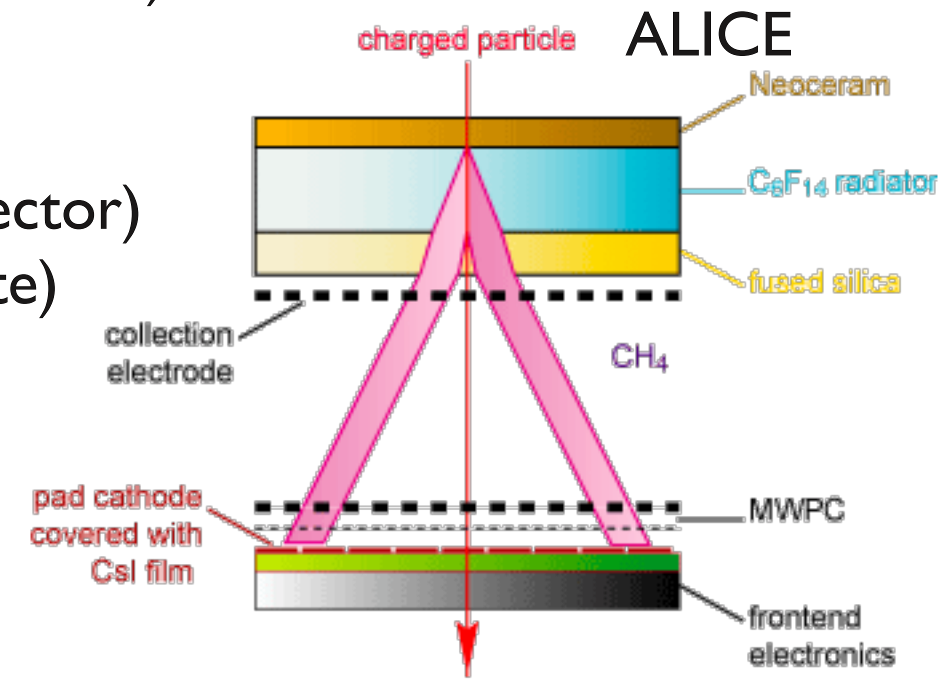


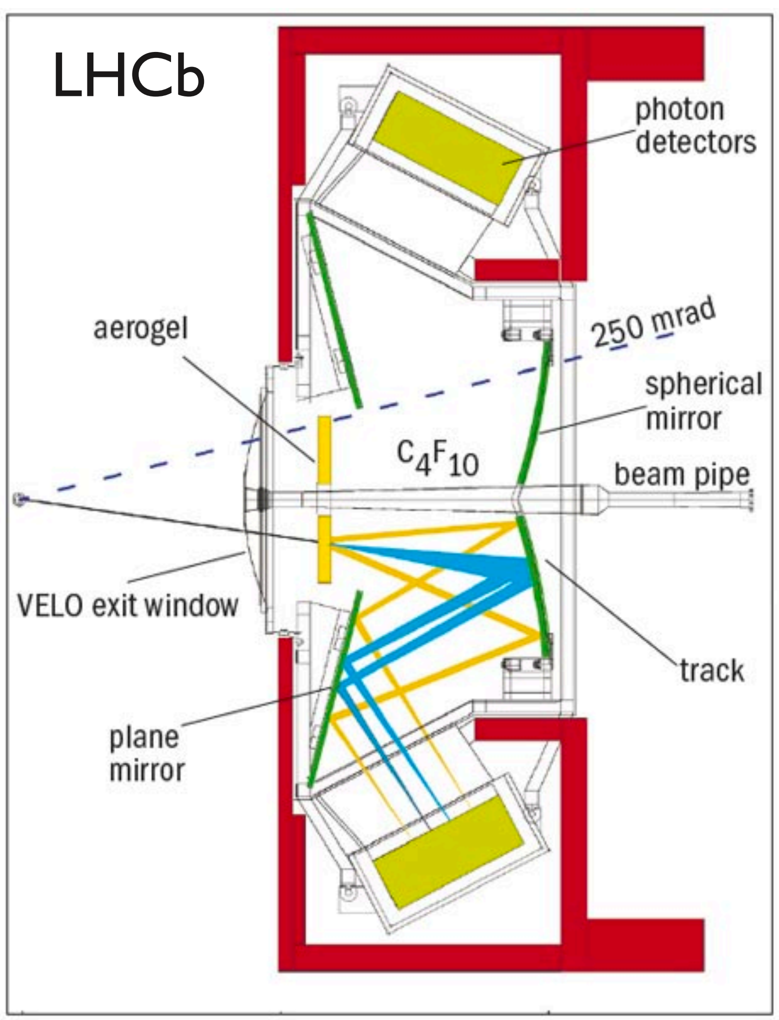


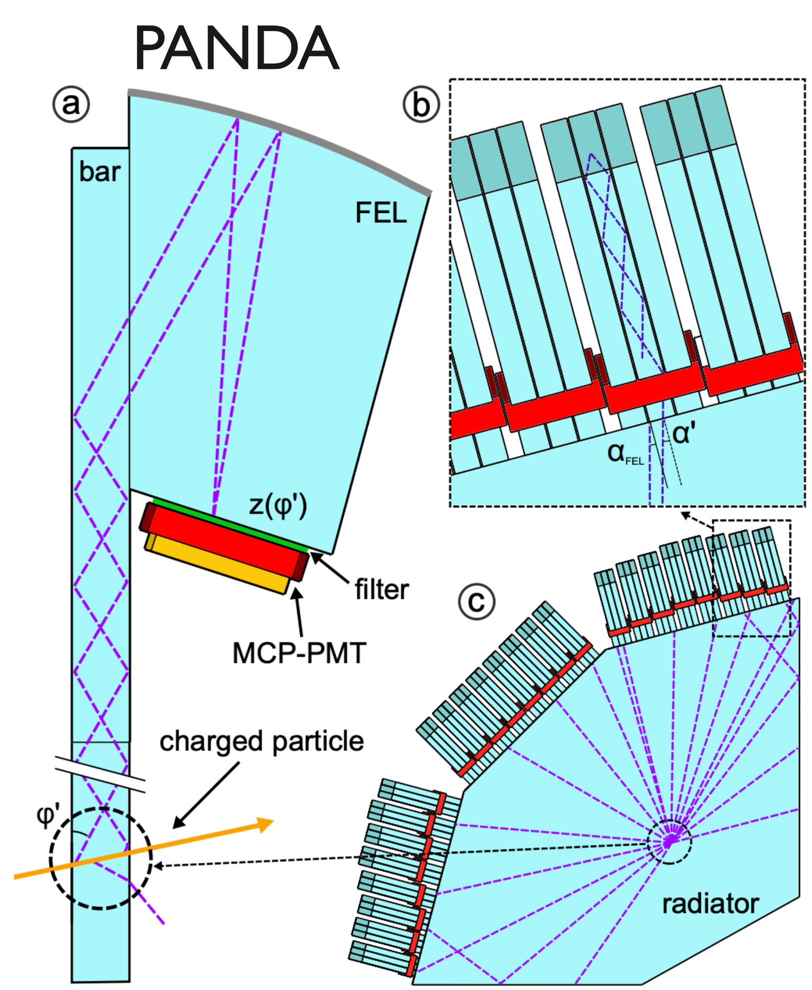
増幅率とΔV_{GEM}の関係

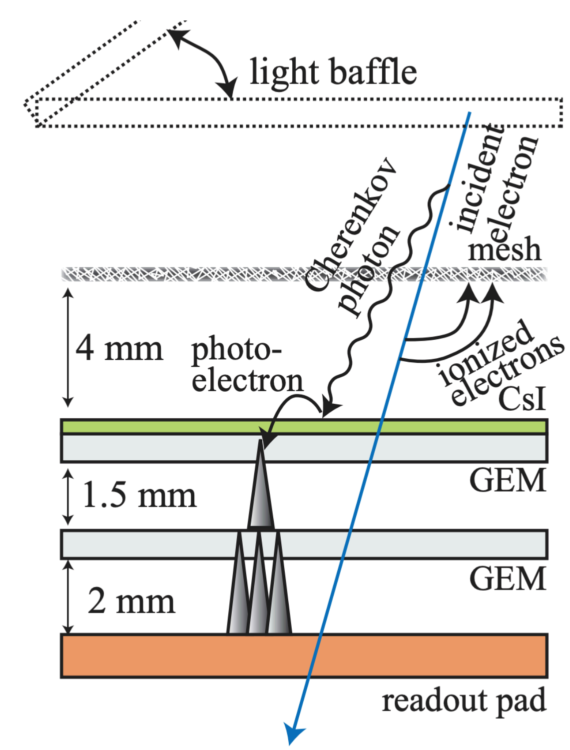
RICH

- 3 radiators are needed to perform PID over wide p_T range.
  - Ex, LHCb uses aerogel (n=1.03), C_4F_{10} (n=1.0014), CF_4(n=1.0005)
- There are many types of RICH.
  - Photon detection (mirror reflection + photon detector)
  - DIRC (transport of reflected light in radiator + photon detector)
  - Gaseous detector (conversion of photon on CsI coated plate)









PHENIX
J-PARC E16

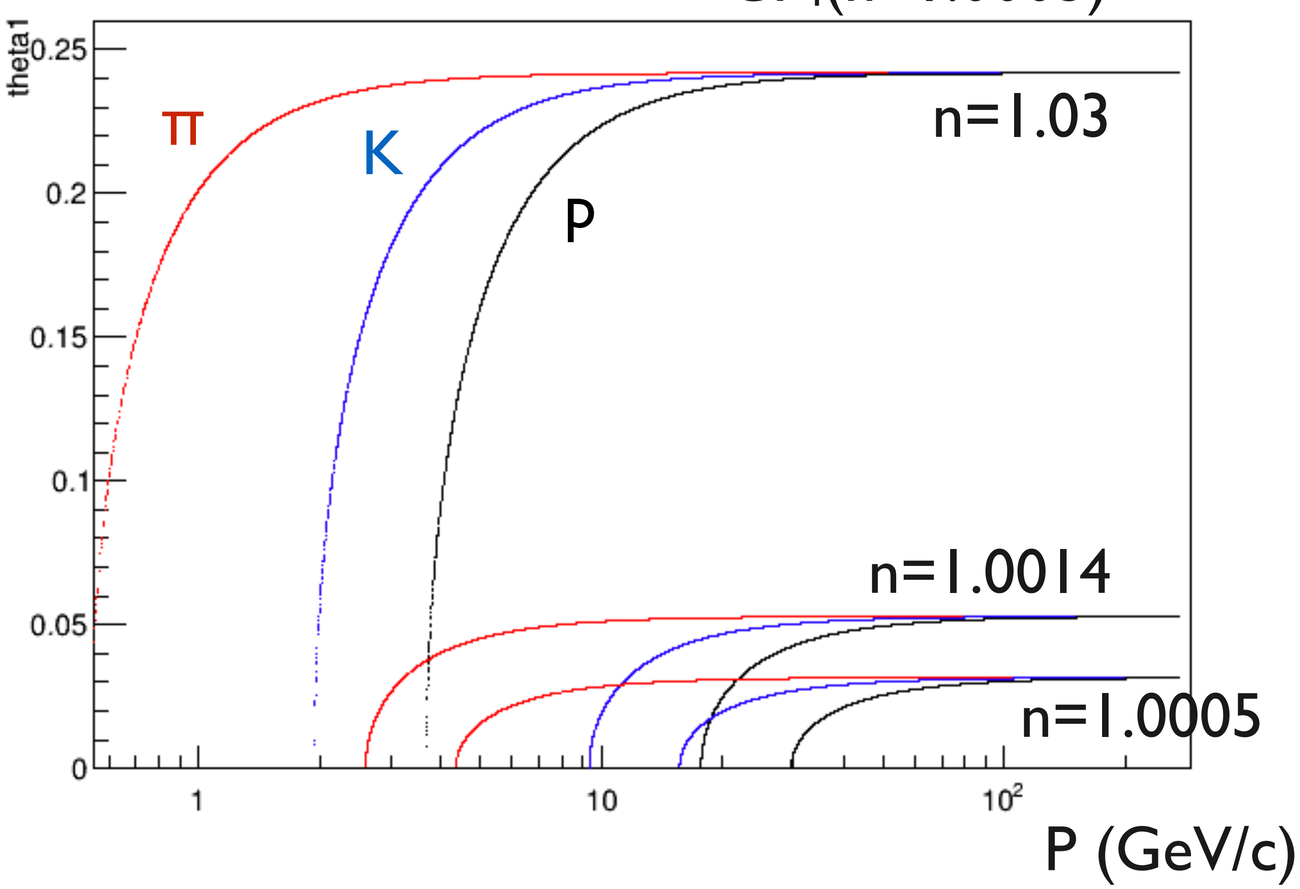
Hadron PID with RICH and TRD

- RICH

pion, kaon, proton identification up to 100 GeV.

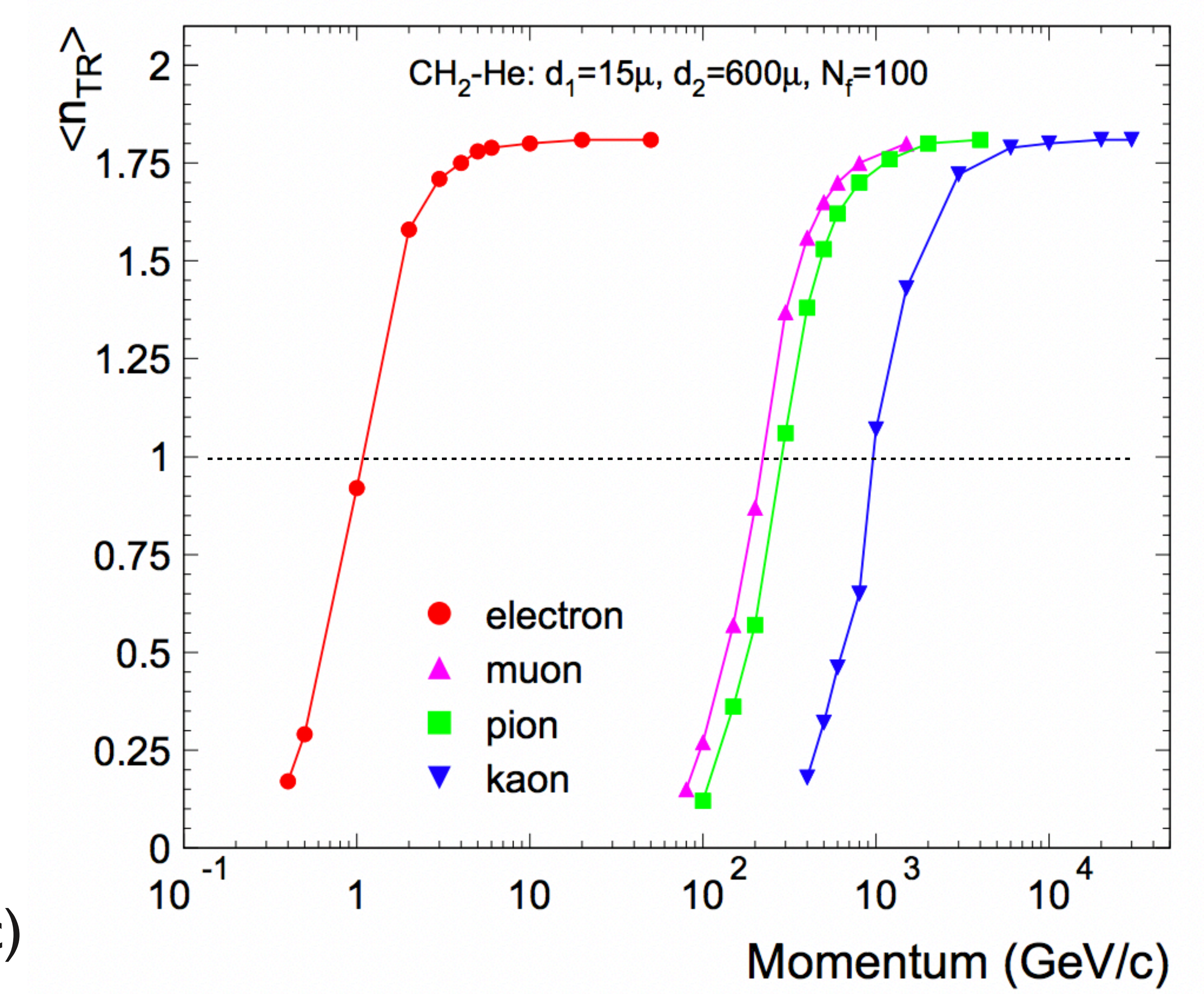
Aerogel (n=1.03)
C_4F_{10} (n=1.0014)
CF_4(n=1.0005)

Cherenkov angle



- TRD

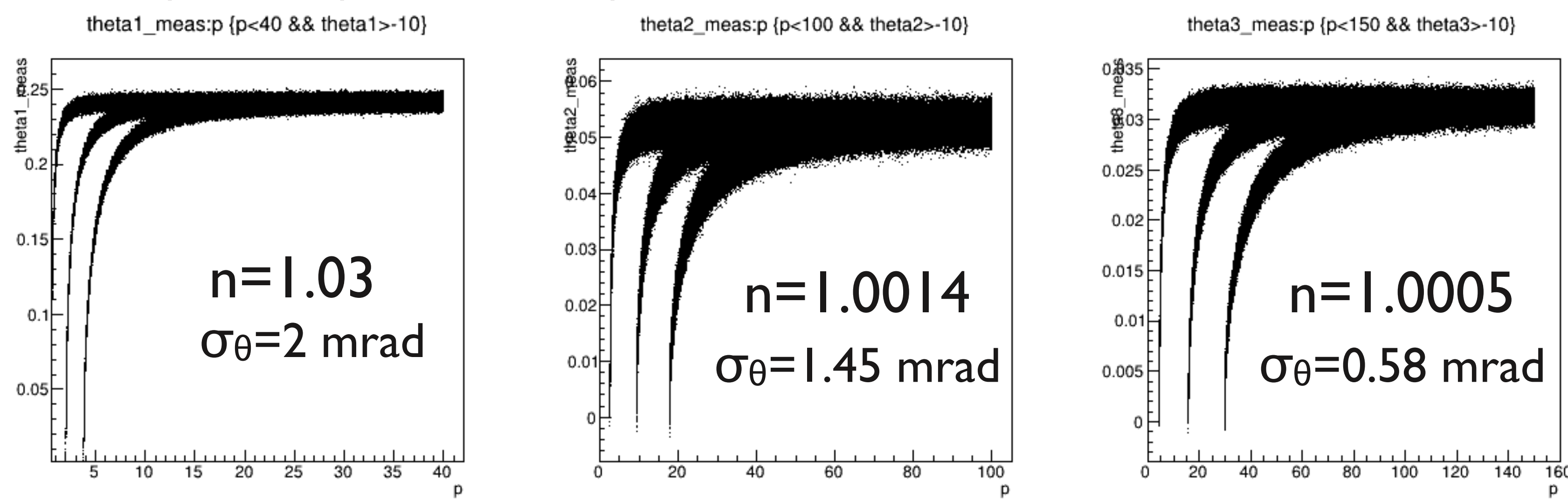
Electron up to 100 GeV and
high p_T pion from 100 to 500 GeV.



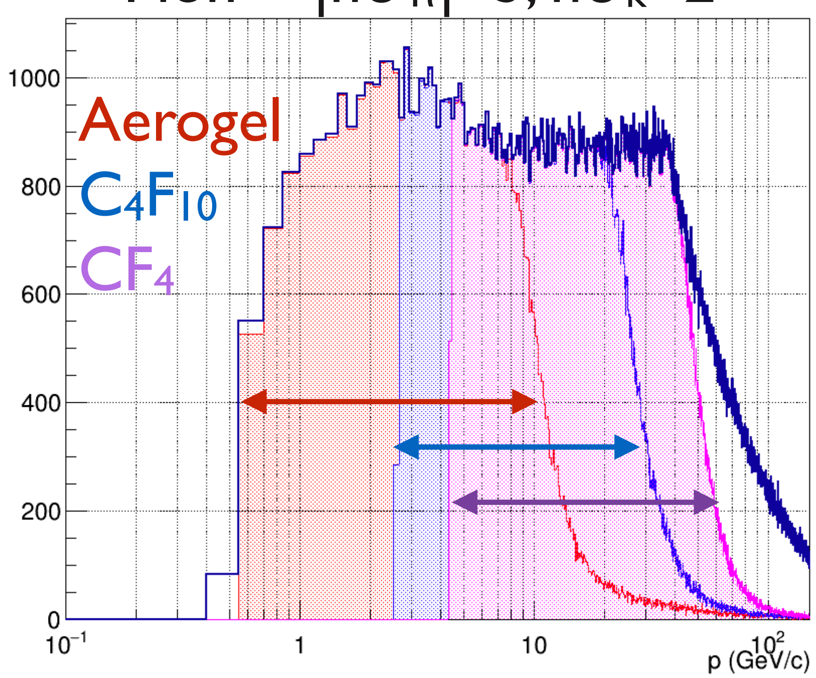
Hadron PID with RICH

- Aerogel (n=1.03), C_4F_{10} (n=1.0014), CF_4(n=1.0005)

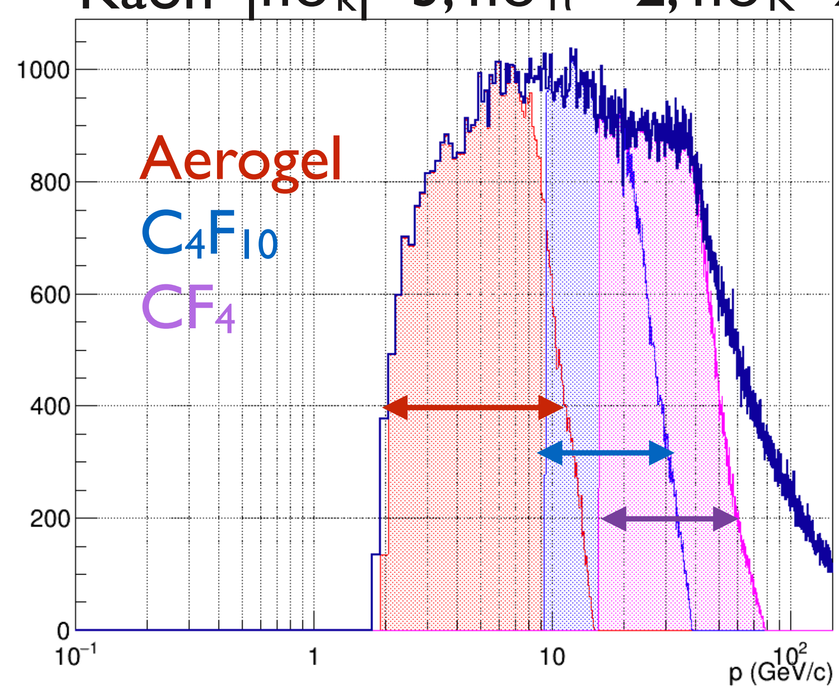
Single particle simulation:
flat p_T and y from
$0<p_T<10$ GeV/c and 2<y<4.
σ_θ from LHCb.



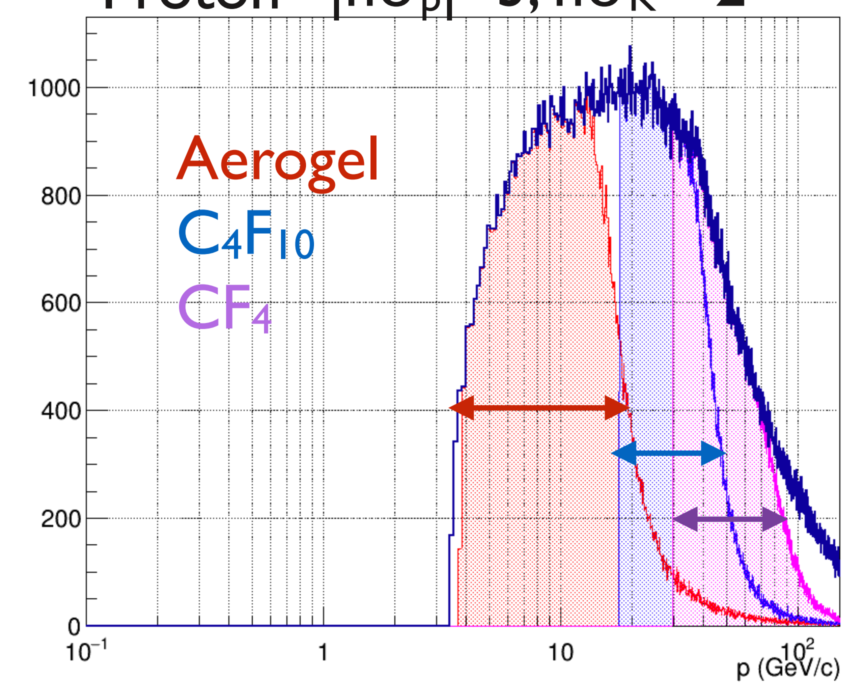
Pion $|n\sigma_\pi|<3$, $n\sigma_k>2$



Kaon $|n\sigma_k|<3$, $n\sigma_\pi<-2$, $n\sigma_K>2$

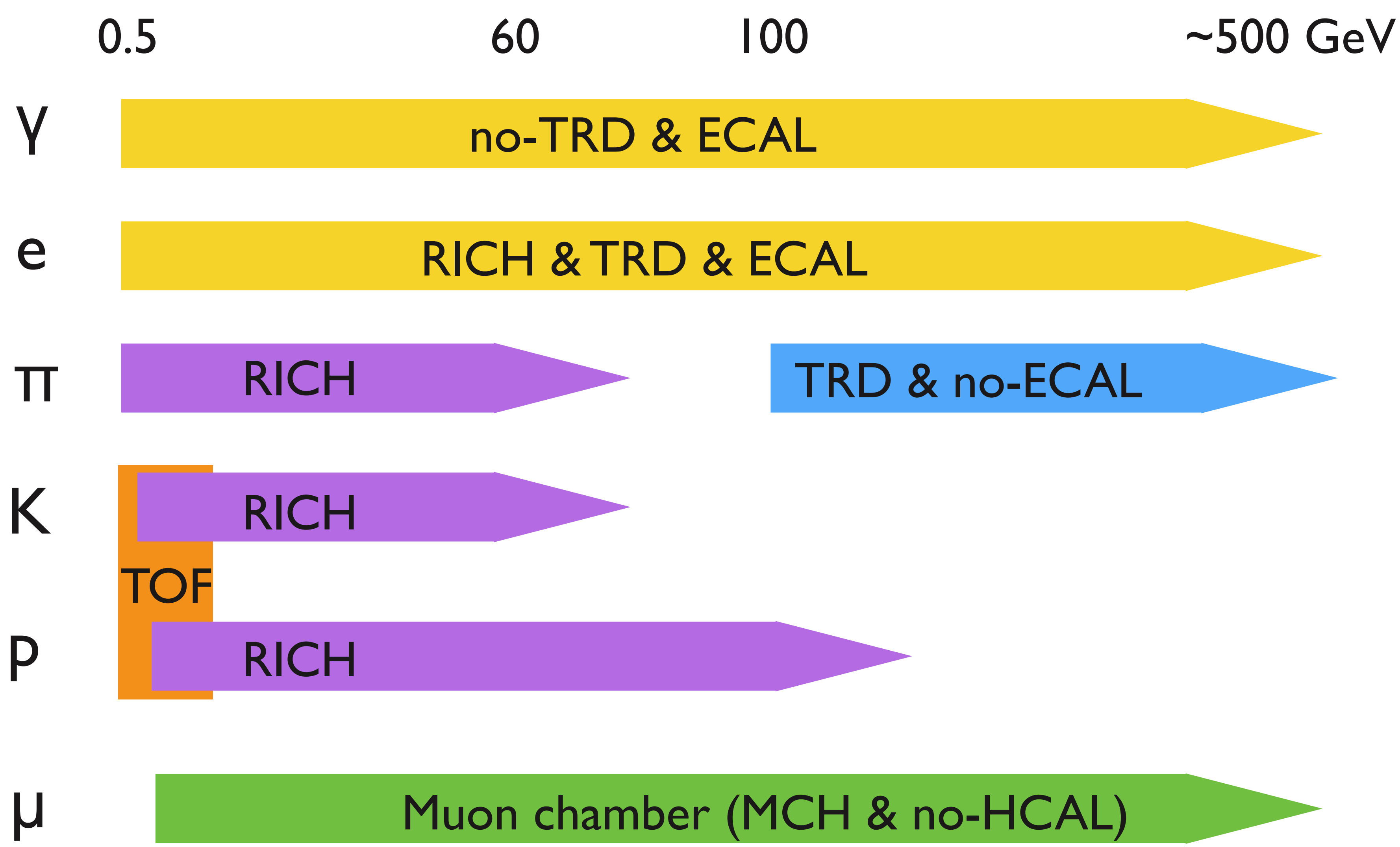


Proton $|n\sigma_p|<3$, $n\sigma_K<-2$



Pion and Kaon identification up to 60 GeV   Proton identification up to 100 GeV

PID capabilities



* Additional PID based on TOF is possible. For example, at z~18m and with Δt=50ps, π-K separation (3σ) for 0<p<7 GeV and K-p separation (3σ) for 0<p<12 GeV
* PID capabilities based on RICH can be adjustable by adjusting gas pressure…

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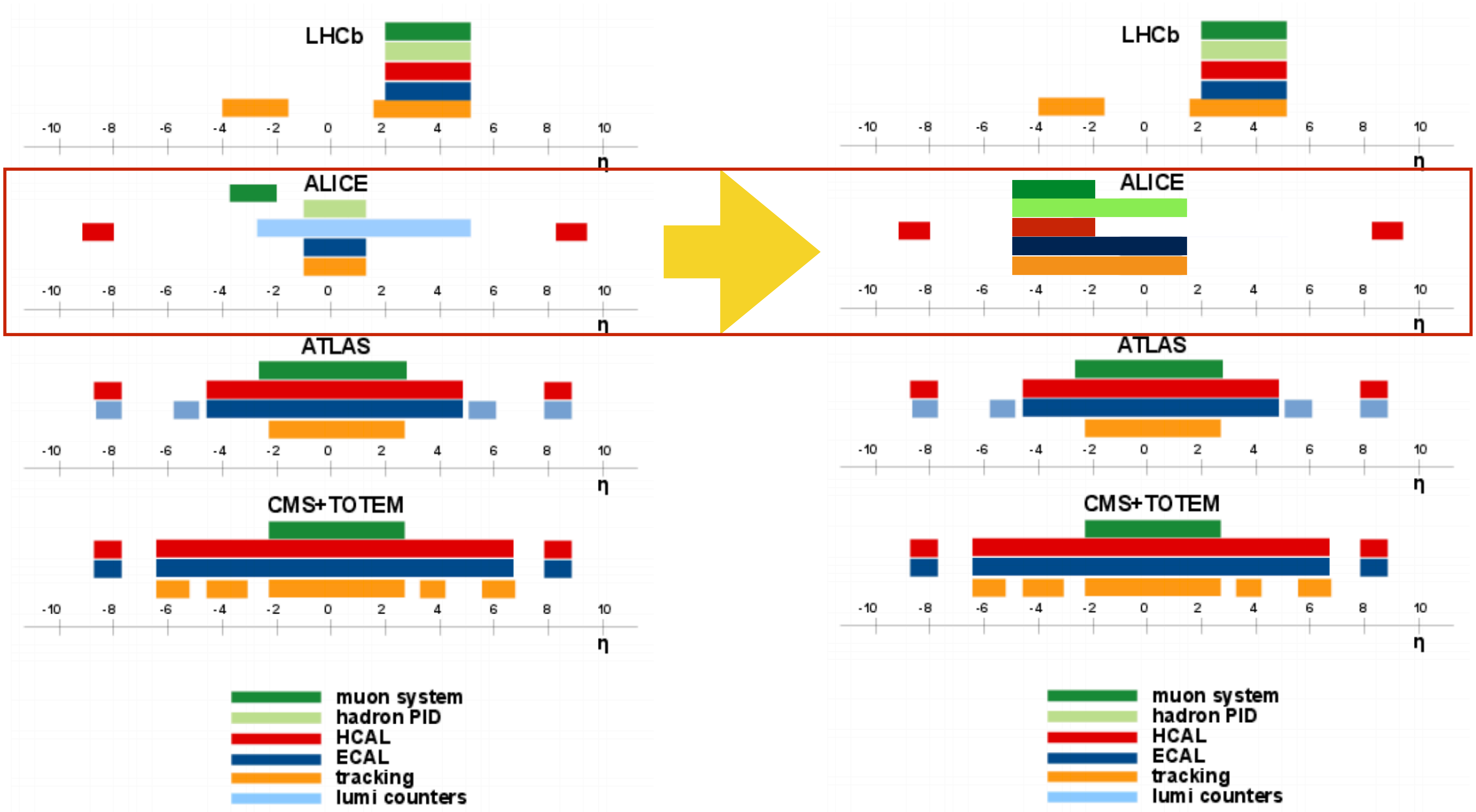
Acceptance



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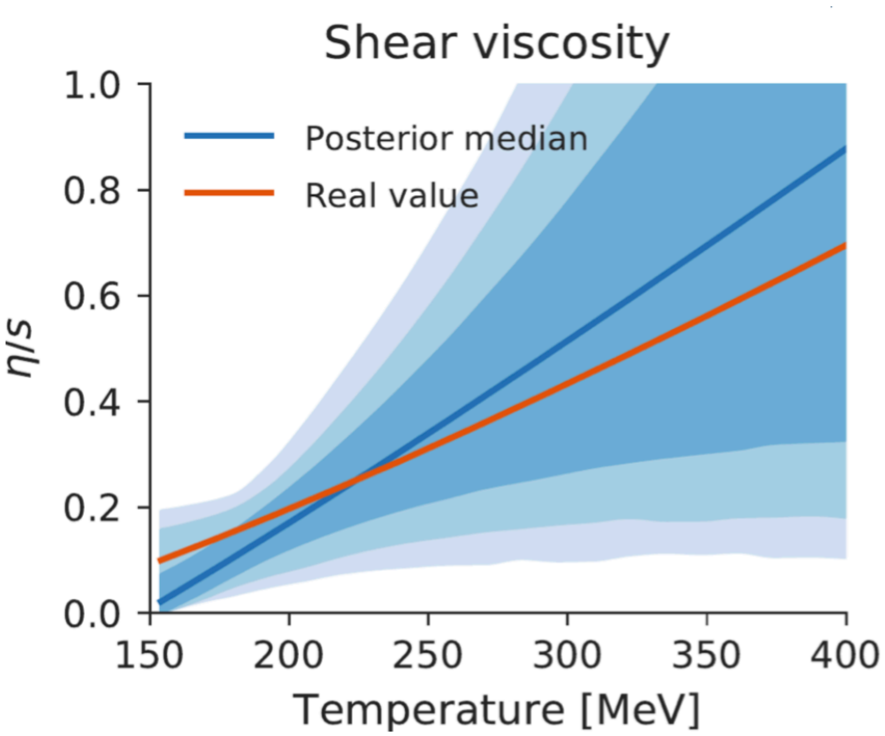
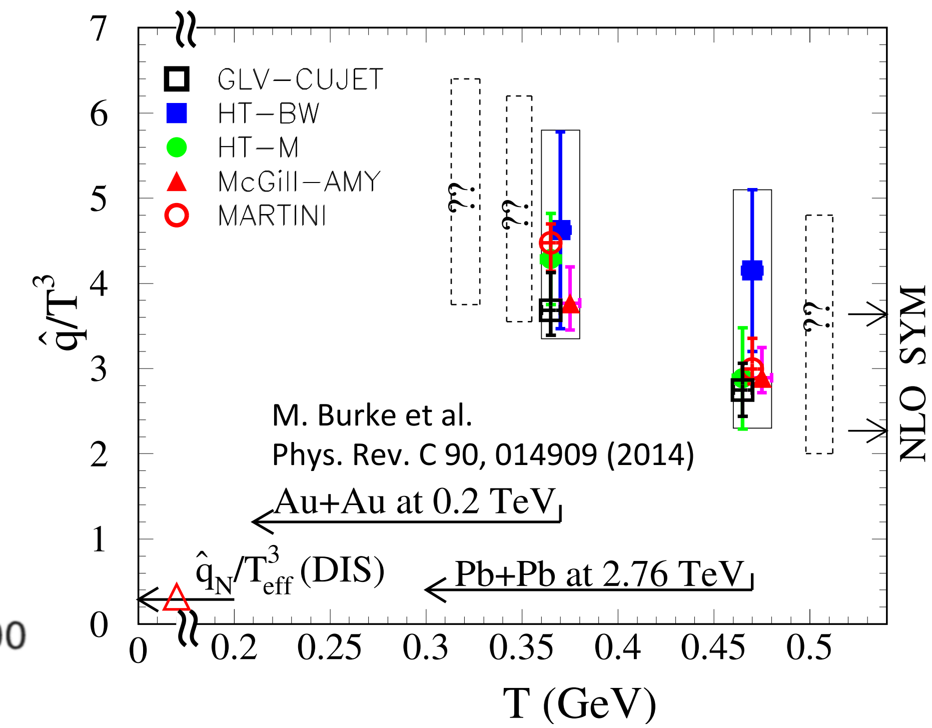
Physics with next generation detector and forward PID detectors

My personal shopping lists

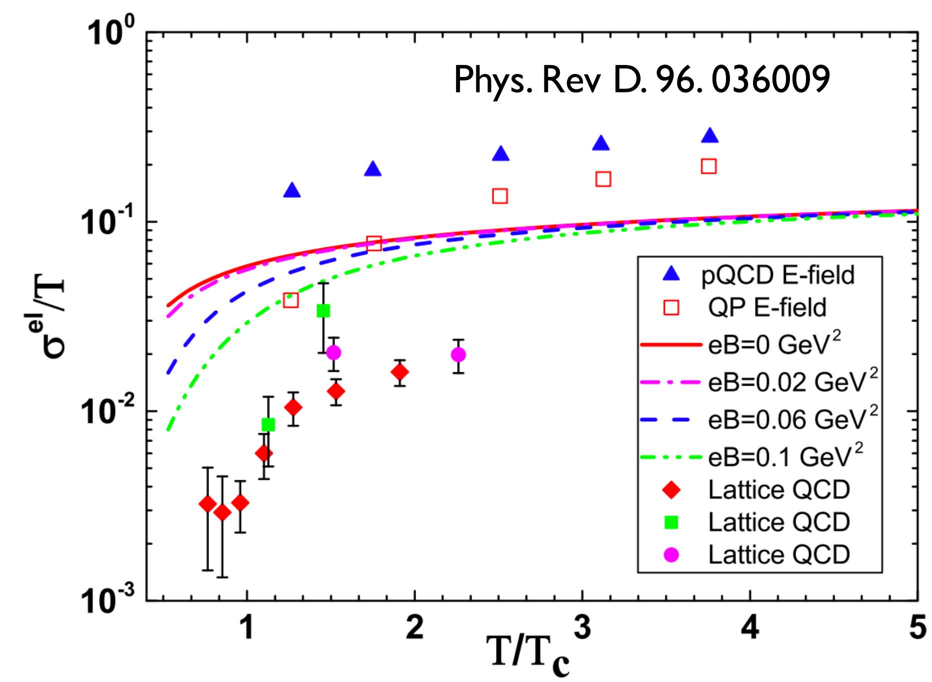
1. Detailed understanding of QGP properties:
   - What are the properties of QGP at different length scales (macroscopic and microscopic properties) and their temperature dependence?
     - η/s, ζ/s, D_s, qhat, electric conductivity, plasma frequency, etc?
   - Transition to wQGP?
   - Properties of QGP and evolution of system under strong magnetic field and vorticity?



S.A. Bass et al. QM2018

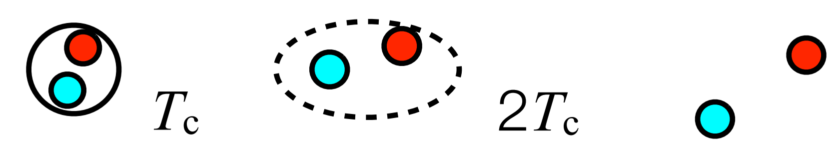


Phys. .Rev C.C90, 014909(2014)

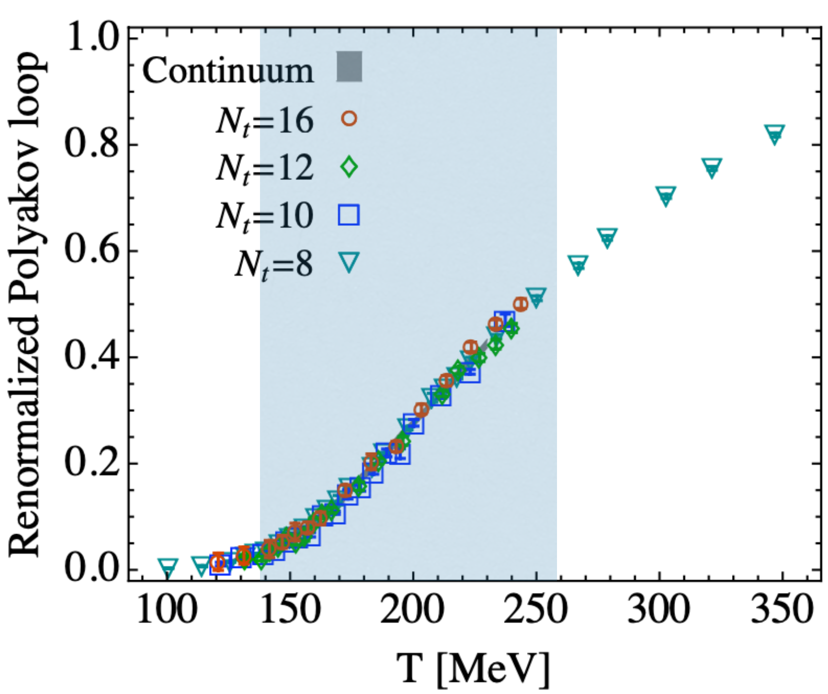


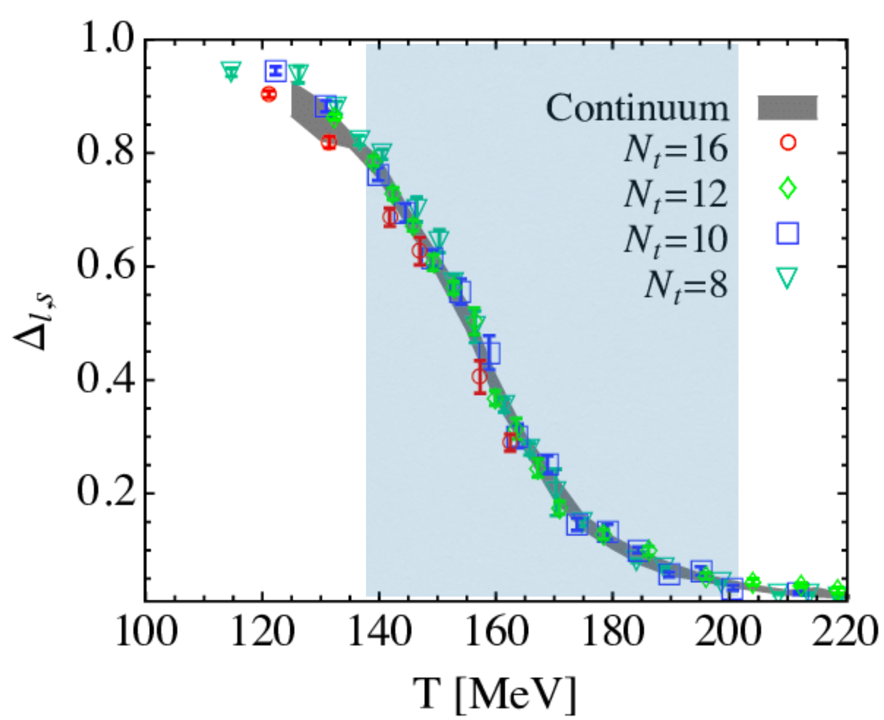
My personal shopping lists

2. Detailed understanding of the nature of cross-over transition (phase boundary)
   - How the degree of freedom and chiral condensate change around phase boundary?
     - purely quark and gluon DOF? diquark or qqbar correlation? quasi-particle states?
   - How they depend on the external magnetic fields?

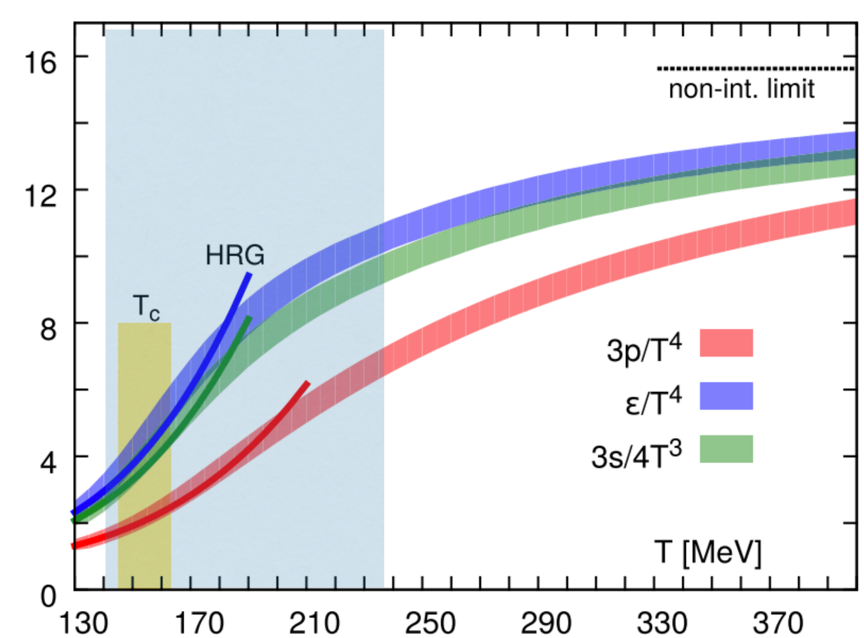


JHEP09(2010)073



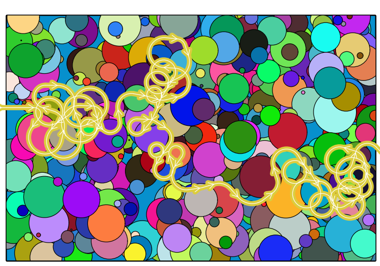


Nuclear Physics A 931 (2014) 867–871

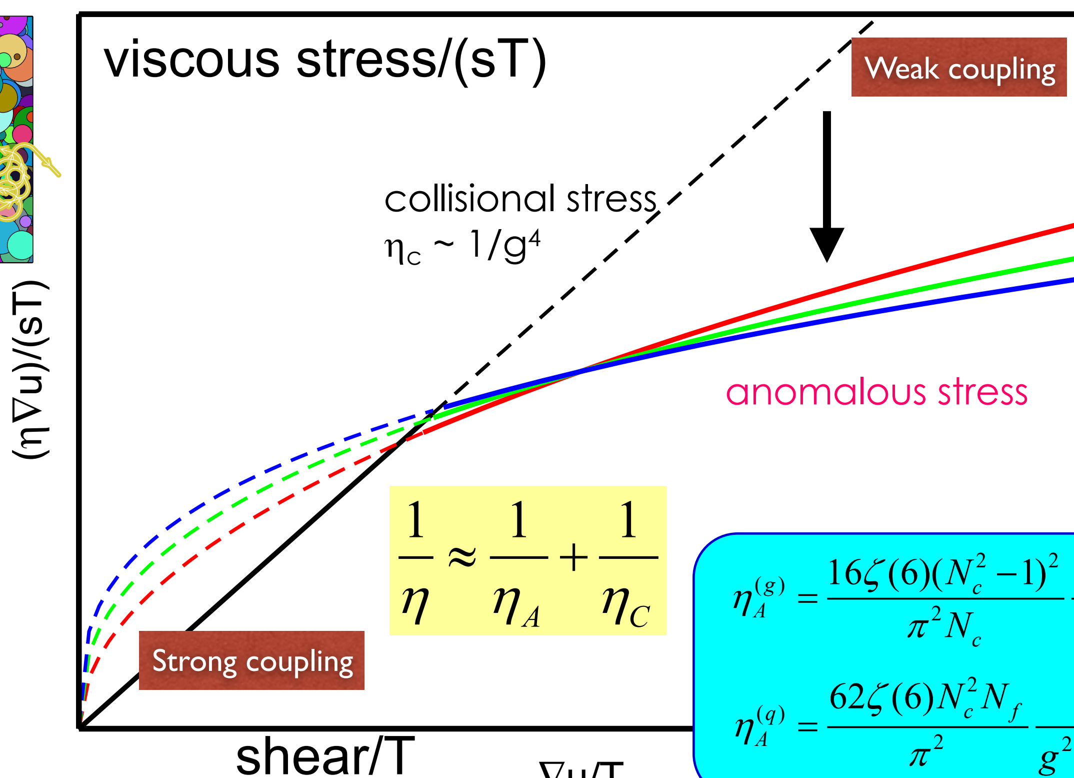


My personal shopping lists

3. What is the non-equilibrium dynamics to form QGP in HI collisions?
   - anomalous viscosity in strong field? Mechanisms for hydrodynamization or thermalization?
4. Critical phenomena (EM and color fields, chiral magnetic effects, vorticity)
5. Exotica (di-baryon, X/Y/Z, tetra/penta quarks, meson molecule, NΩ, ΩΩ, etc)
   - Internal structure from coalescence process or femtoscopy, hyperon interaction and EoS



M. Asakawa, PRL96 (2006) 252301



$$\frac{1}{\eta} \approx \frac{1}{\eta_A} + \frac{1}{\eta_C}$$

$$\eta_A^{(g)} = \frac{16\zeta(6)(N_c^2-1)^2}{\pi^2 N_c} \frac{T^6}{g^2 \langle B^2 \rangle \tau_m^{mag}}$$

$$\eta_A^{(q)} = \frac{62\zeta(6) N_c^2 N_f}{\pi^2} \frac{T^6}{g^2 \langle B^2 \rangle \tau_m^{mag}}$$

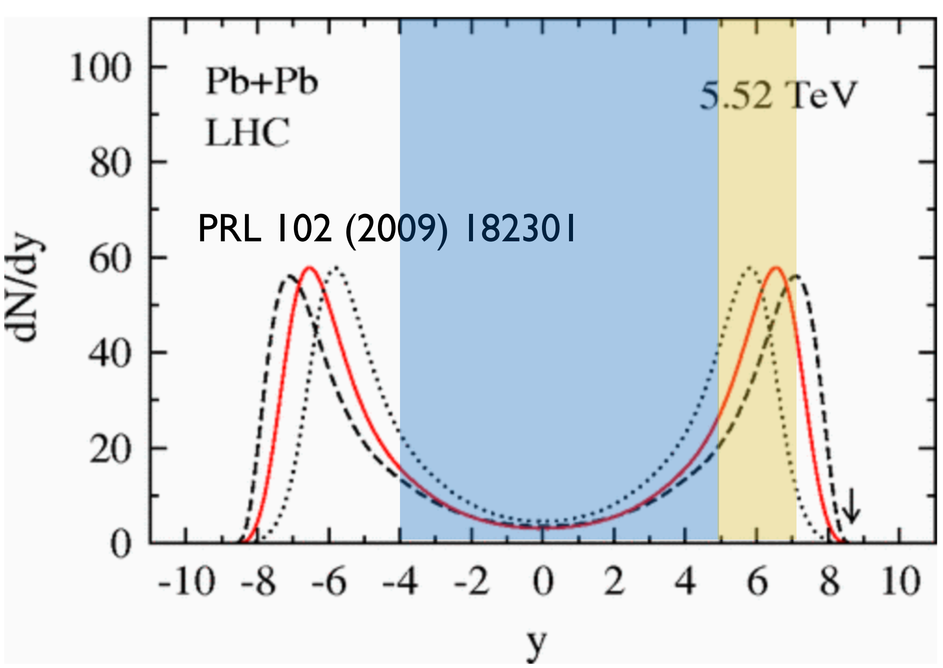
Phys.Rev. C84 (2011) 064910

	RHIC				LHC			
	$2q/3q/6q$	$4q/5q/8q$	Mol.	Stat.	$2q/3q/6q$	$4q/5q/8q$	Mol.	Stat.
Mesons								
$f_0(980)$	3.8, 0.73($s\bar{s}$)	0.10	13	5.6	10, 2.0 ($s\bar{s}$)	0.28	36	15
$a_0(980)$	11	0.31	40	17	31	0.83	1.1×10^{2}	46
$K(1460)$	—	0.59	3.6	1.3	—	1.6	9.3	3.2
$D_s(2317)$	1.3×10^{-2}	2.1×10^{-3}	1.6×10^{-2}	5.6×10^{-2}	8.7×10^{-2}	1.4×10^{-2}	0.10	0.35
T_{cc}^{1} †)	—	4.0×10^{-5}	2.4×10^{-5}	4.3×10^{-4}	—	6.6×10^{-4}	4.1×10^{-4}	7.1×10^{-3}
$X(3872)$	1.0×10^{-4}	4.0×10^{-5}	7.8×10^{-4}	2.9×10^{-4}	1.7×10^{-3}	6.6×10^{-4}	1.3×10^{-2}	4.7×10^{-3}
$Z^{+}(4430)$ ‡)	—	1.3×10^{-5}	2.0×10^{-5}	1.4×10^{-5}	—	2.1×10^{-4}	3.4×10^{-4}	2.4×10^{-4}
T_{cb}^{0} †)	—	6.1×10^{-8}	1.8×10^{-7}	6.9×10^{-7}	—	6.1×10^{-6}	1.9×10^{-5}	6.8×10^{-5}
Baryons								
$\Lambda(1405)$	0.81	0.11	1.8–8.3	1.7	2.2	0.29	4.7–21	4.2
Θ^{+} ‡)	—	2.9×10^{-2}	—	1.0	—	7.8×10^{-2}	—	2.3
$\bar{K}KN$ †)	—	1.9×10^{-2}	1.7	0.28	—	5.2×10^{-2}	4.2	0.67
$\bar{D}N$ †)	—	2.9×10^{-3}	4.6×10^{-2}	1.0×10^{-2}	—	2.0×10^{-2}	0.28	6.1×10^{-2}
$\bar{D}^{*}N$ †)	—	7.1×10^{-4}	4.5×10^{-2}	1.0×10^{-2}	—	4.7×10^{-3}	0.27	6.2×10^{-2}
Θ_{cs} †)	—	5.9×10^{-4}	—	7.2×10^{-3}	—	3.9×10^{-3}	—	4.5×10^{-2}
BN †)	—	1.9×10^{-5}	8.0×10^{-5}	3.9×10^{-5}	—	7.7×10^{-4}	2.8×10^{-3}	1.4×10^{-3}
$B^{*}N$ †)	—	5.3×10^{-6}	1.2×10^{-4}	6.6×10^{-5}	—	2.1×10^{-4}	4.4×10^{-3}	2.4×10^{-3}
Dibaryons								
H †)	3.0×10^{-3}	—	1.6×10^{-2}	1.3×10^{-2}	8.2×10^{-3}	—	3.8×10^{-2}	3.2×10^{-2}
$\bar{K}NN$ ‡)	5.0×10^{-3}	5.1×10^{-4}	0.011–0.24	1.6×10^{-2}	1.3×10^{-2}	1.4×10^{-3}	0.026 – 0.54	3.7×10^{-2}
$\Omega\Omega$ †)	3.2×10^{-5}	—	1.5×10^{-5}	6.4×10^{-5}	8.6×10^{-5}	—	4.4×10^{-5}	1.9×10^{-4}
H_c^{++} †)	3.0×10^{-4}	—	3.3×10^{-4}	7.5×10^{-4}	2.0×10^{-3}	—	1.9×10^{-3}	4.2×10^{-3}
$\bar{D}NN$ †)	—	2.9×10^{-5}	1.8×10^{-3}	7.9×10^{-5}	—	2.0×10^{-4}	9.8×10^{-3}	4.2×10^{-4}
BNN †)	—	2.3×10^{-7}	1.2×10^{-6}	2.4×10^{-7}	—	9.2×10^{-6}	3.7×10^{-5}	7.6×10^{-6}

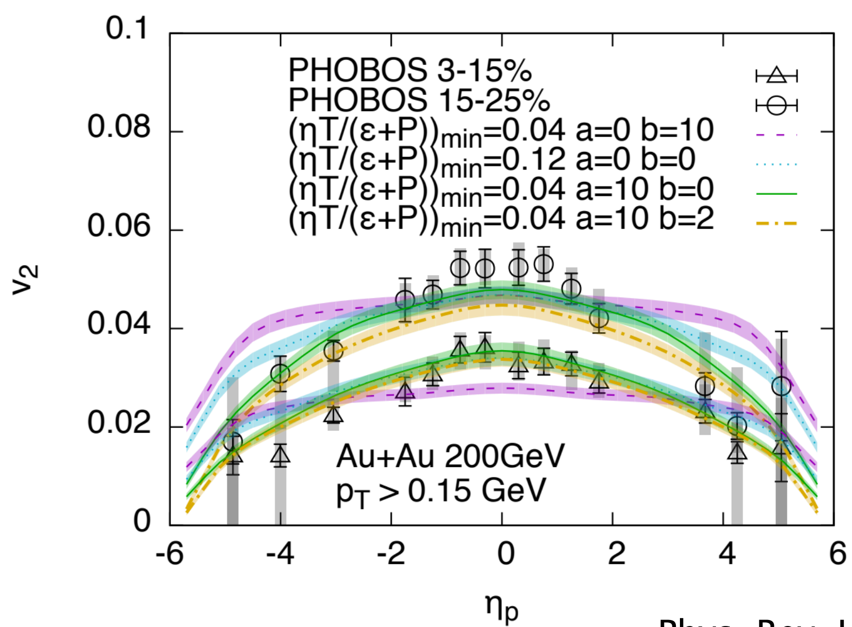
Topics with forward spectrometers

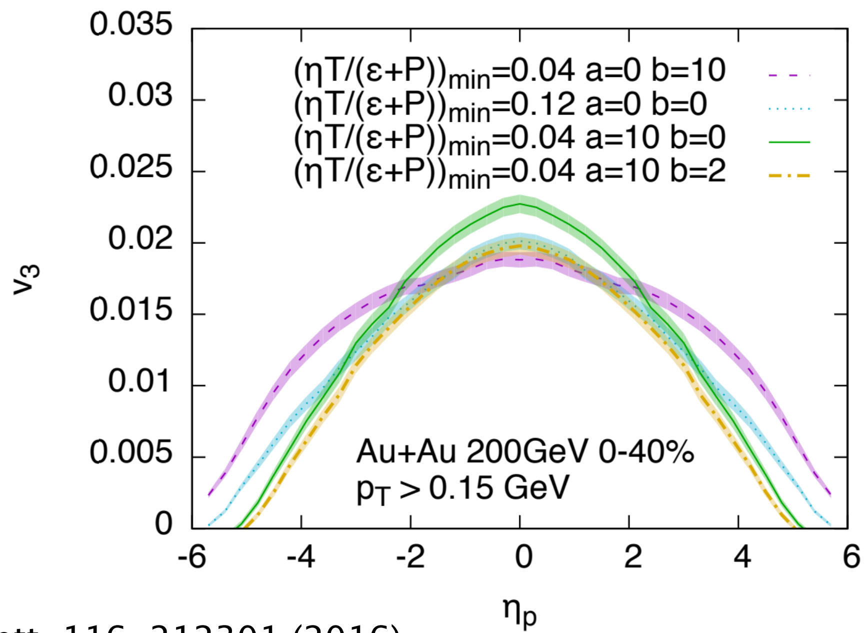
- Single particle measurements at forward rapidity
  - **Spectra and flow (v_n) of PID hadrons, hyperons, HF mesons and baryons, Quarkonia, dileptons and photons**
    - **Full characterization of space-time evolution and QGP properties as a function of rapidity → different (T, μ)**

Net proton dN/dy



$\eta/s(T)$ via forward v_2 and v_3 measurements of charged hadrons (at RHIC)





Phys. Rev. Lett. 116, 212301 (2016)

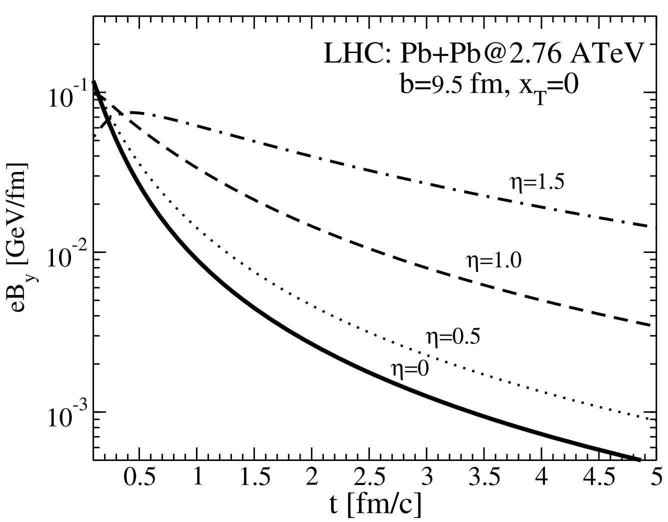
Competitive to LHCb?

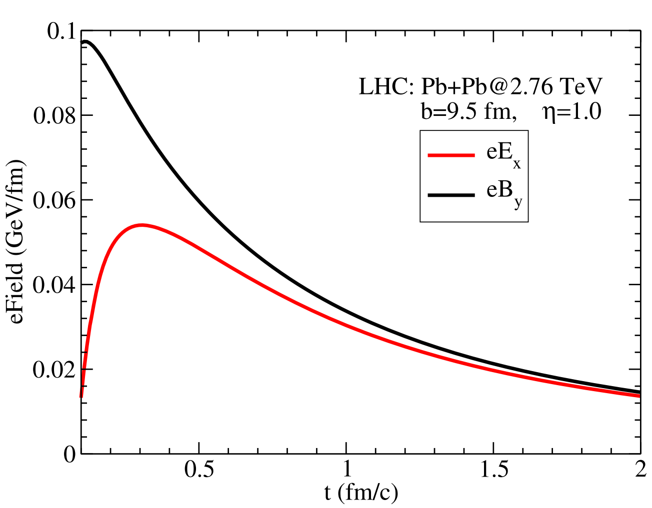
ALICE

Topics with forward spectrometers

- Single particle measurements at forward rapidity
  - **Direct flow of HFs (D and B) and charged PID hadrons over wide rapidity ranges.**
    - **New insights of dynamics in very early stage of collisions and inputs to magnetohydrodynamics**

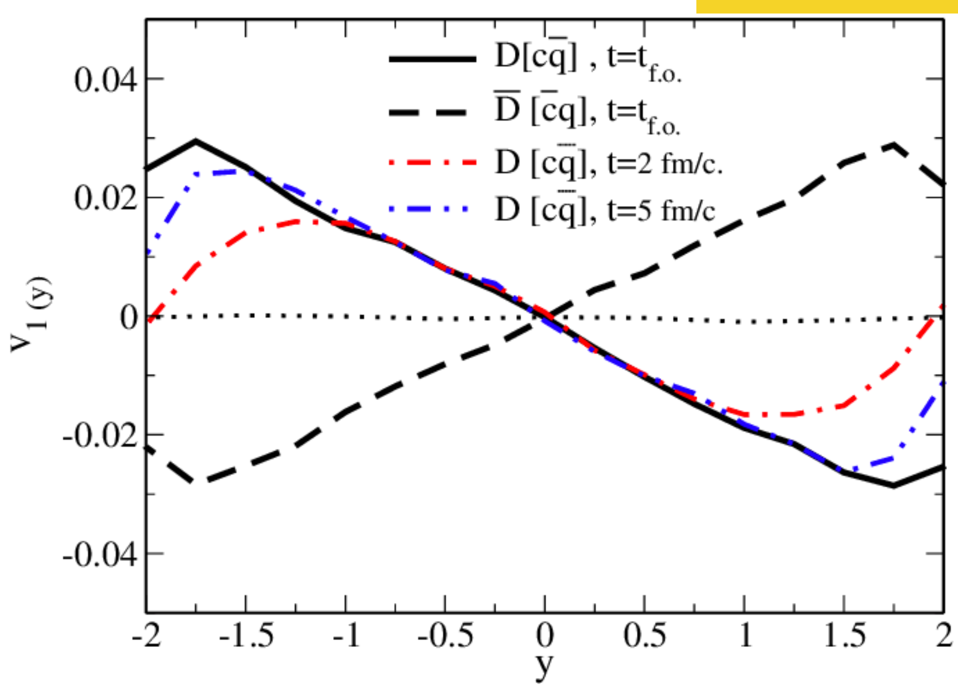
Phys. Rev. C 89, 054905 (2014)





arXiv:1608.02231

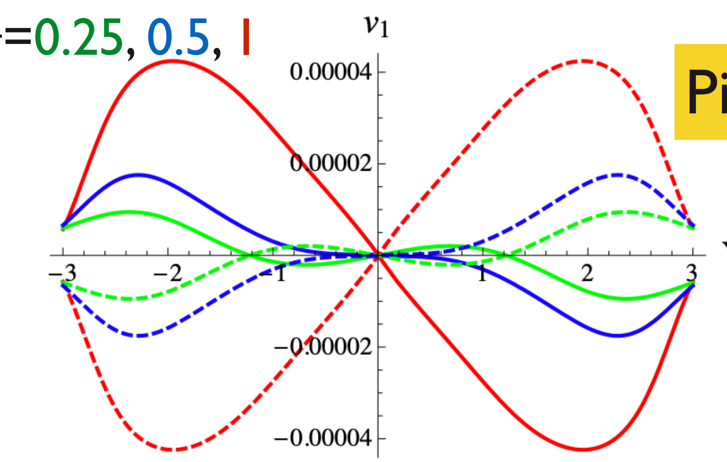
D meson



Competitive to LHCb?

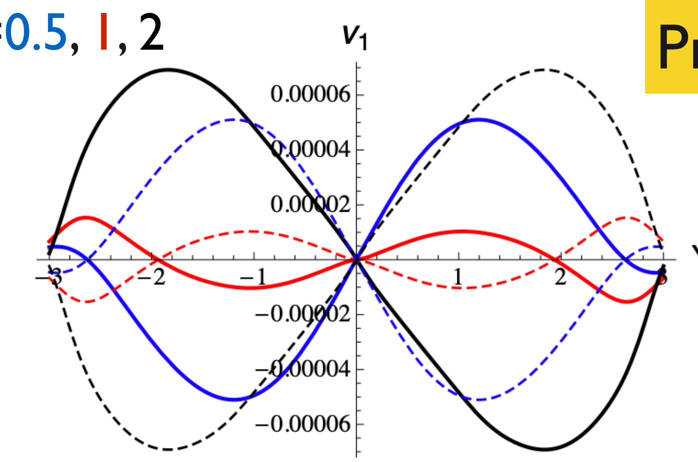
p_T=0.25, 0.5, 1

Pion



p_T=0.5, 1, 2

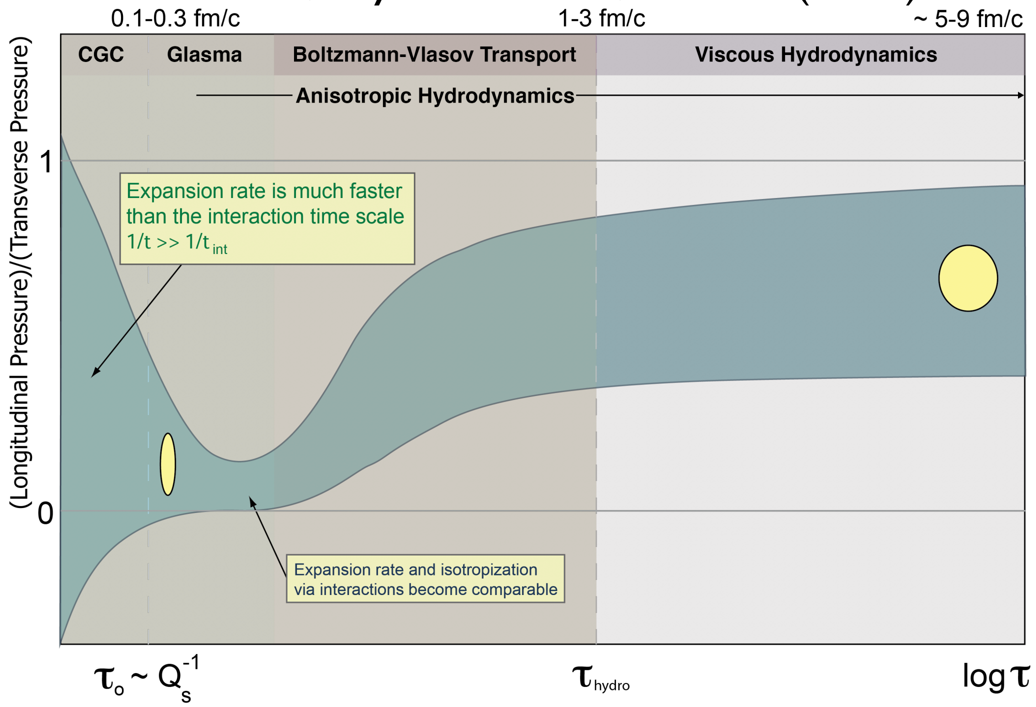
Proton

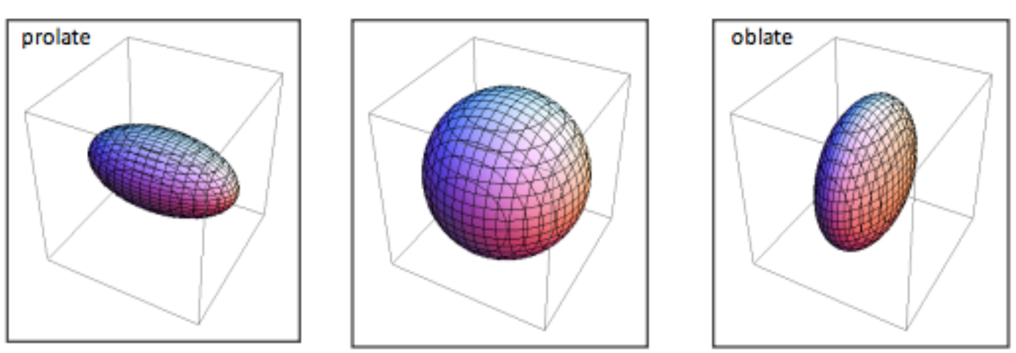


Topics with forward spectrometers

- Single particle measurements at forward rapidity
  - **Dilepton pair production at forward rapidity**
    - **Dynamics of very early stage of collisions toward hydrodynamization and thermalization (isotropization)**

ahydro: 1505.04018, Phys. Rev. D 92, 025026 (2015)

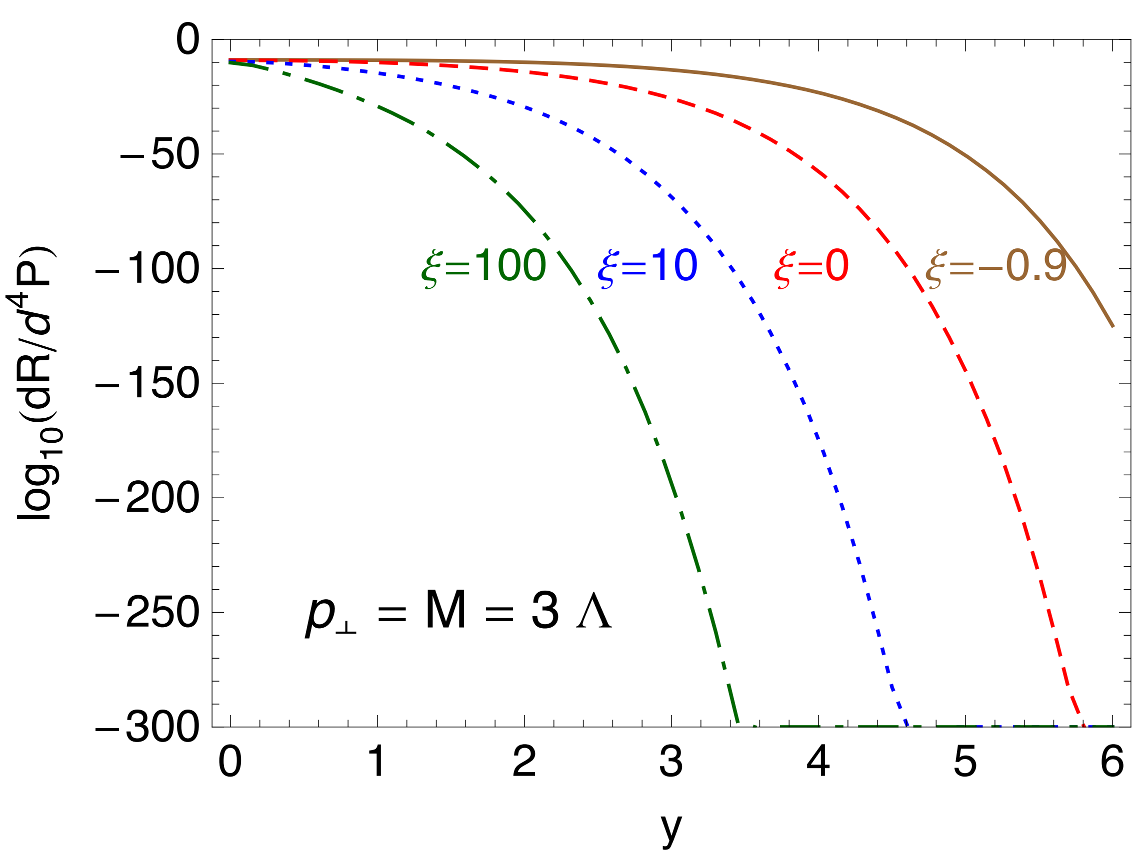




$-1 < \xi < 0$ $\quad$ $\xi = 0$ $\quad$ $\xi > 0$

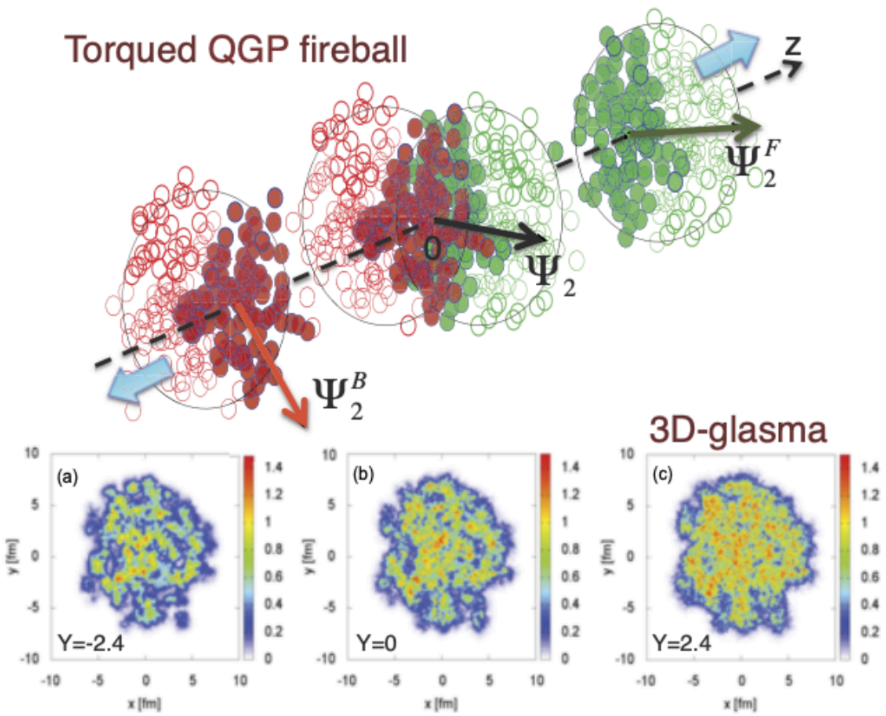
$4\pi\eta/s$ \ ξ_0	-0.9	0	10	100
0.1	-	72.11	-	-
1	12.98	64.53	235.86	714.31
3	13.69	60.44	215.61	660.74

ε_0 [GeV/fm³]

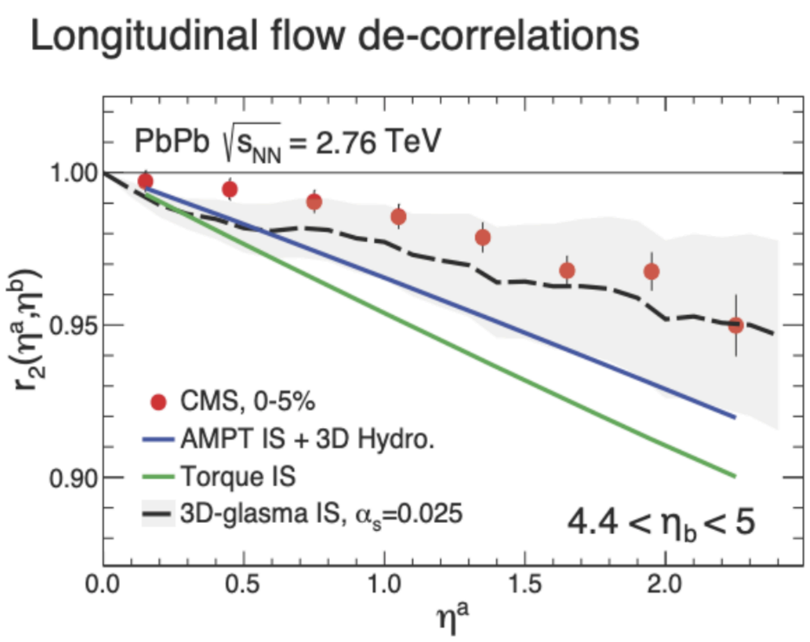


Topics with forward spectrometers

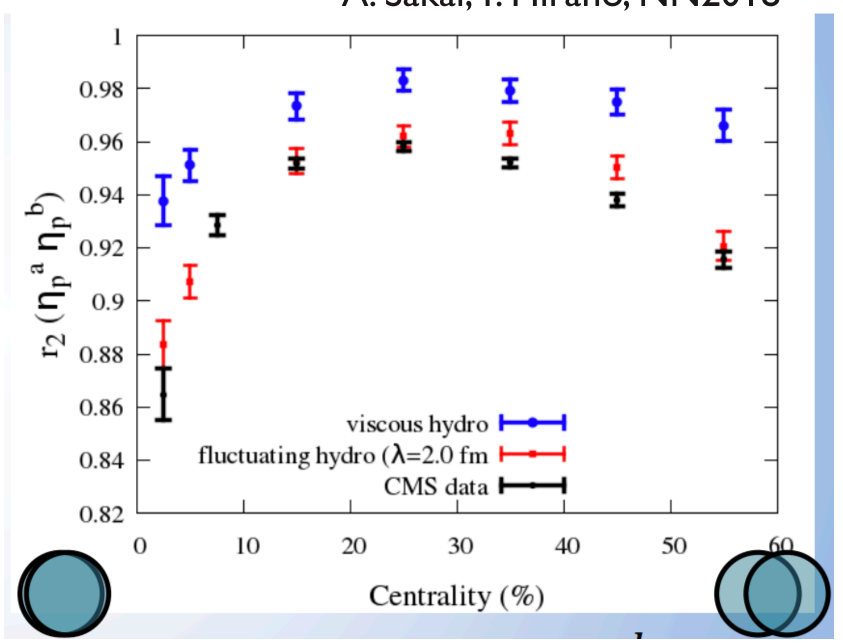
- Particle correlations between central rapidity and forward rapidity.
  - Only ALICE can do!
  - **PID dependent flow factorization vs. Δη? Azimuthally differential and PID dependent femtoscopy/HBT with Δη?**
    - **Source of the de-correlation (initial or hydro fluctuation)**
  - **PID dependent symmetric cumulant SC(n,m) with Δη?**



Nuclear Physics A 967 (2017) 59–66

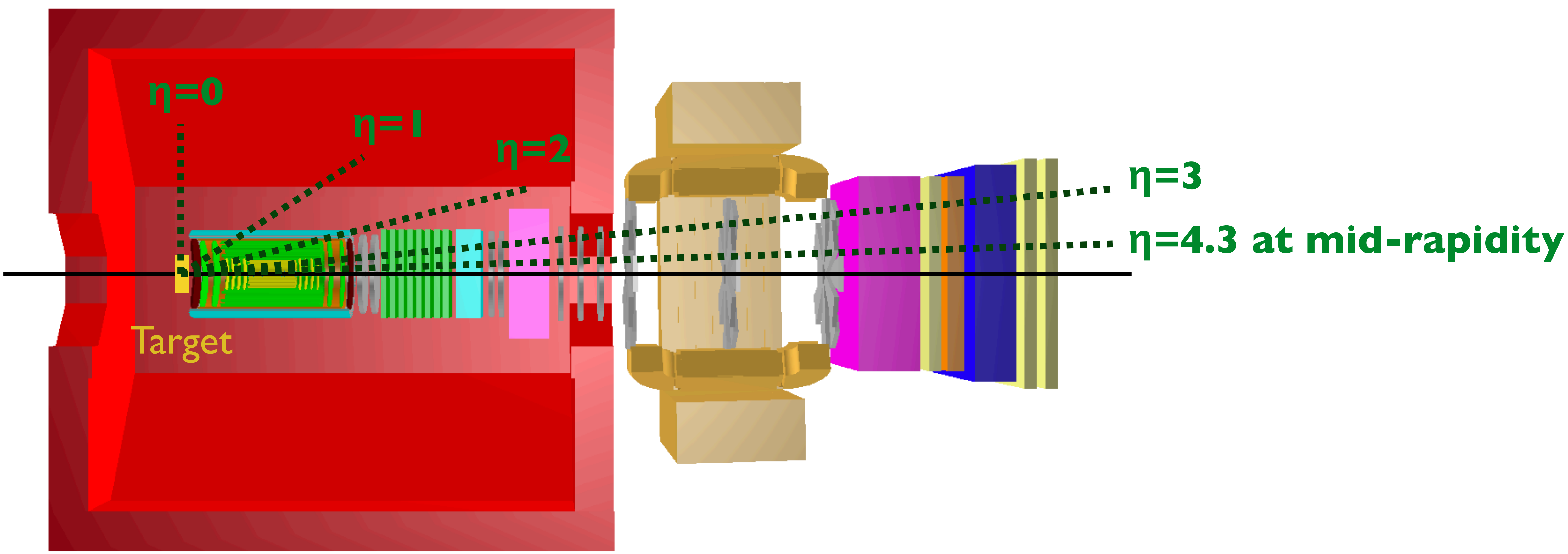


A. Sakai, T. Hirano, NN2018



Fixed Target experiment

- Central barrel and forward spectrometer can cover wide rapidity coverage (mid-rapidity - backward rapidity: $-4<\eta<0$).
- If there are no A+A collisions at RHIC after eRHIC is built, this fixed target experiment will be a unique place to cover $\sqrt{s_{NN}}$ ~ 70 GeV…
  - Sweet spot around the phase boundary?



ALICE

Summary

- One idea beyond 2030 on building forward PID spectrometer.
  - Using ALICE dipole magnet and covering $2<\eta<4.6$
  - Re-purposing existing ALICE detectors as much as possible
    - IROC/OROC chambers, HMPID, TRD, TOF, EMCal, PHOS → they were working at 70Hz/μb in pp.
    - Some modification will be needed (radiator, wire→MPGD, readout pads, front-end and back-end)
    - Need to verify whether they will be able to run under x20-x50 higher A-A luminosities.
- Physics goals:
  - Full characterization of QGP properties (macroscopic snd microscopic properties) as a function of temperature and magnetic field
  - Microscopic properties of cross-over transition (ex, diquark correlation)
  - Dynamics of very early stage of collisions and mechanisms of QGP formation (hydrohynamization, thermalization)
  - Exotics
- Some ideas on measurement items have to be considered.
  - Spectra and flow (vn) of PID hadrons, HFs, photons and dileptons at forward rapidity
  - Correlation with central barrel

Thanks to Andrea Dainese, Andrea Dubla, You Zhou, Alexander Kalweit, et al.

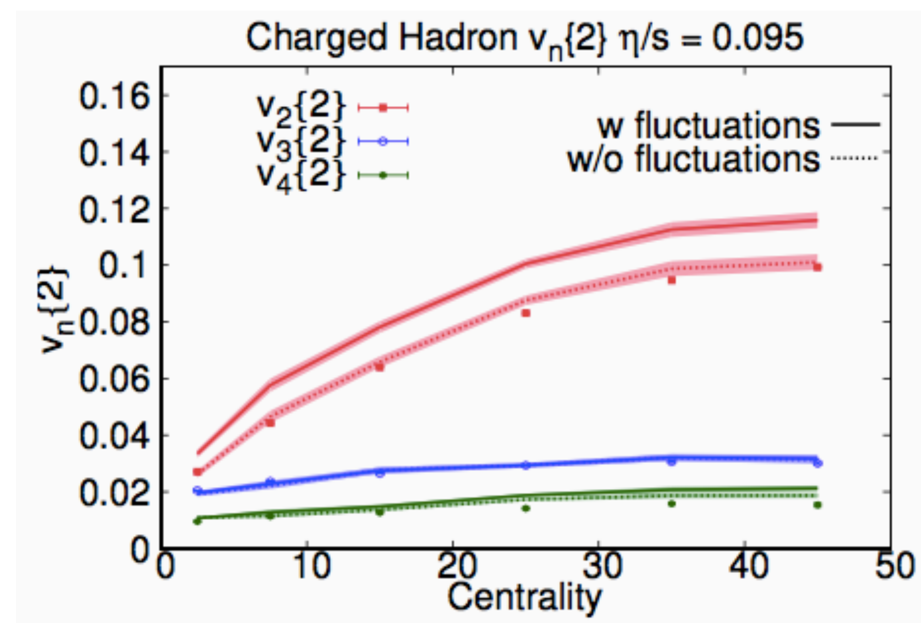
Backup slides

ALICE

What are the uncertainties of η/s

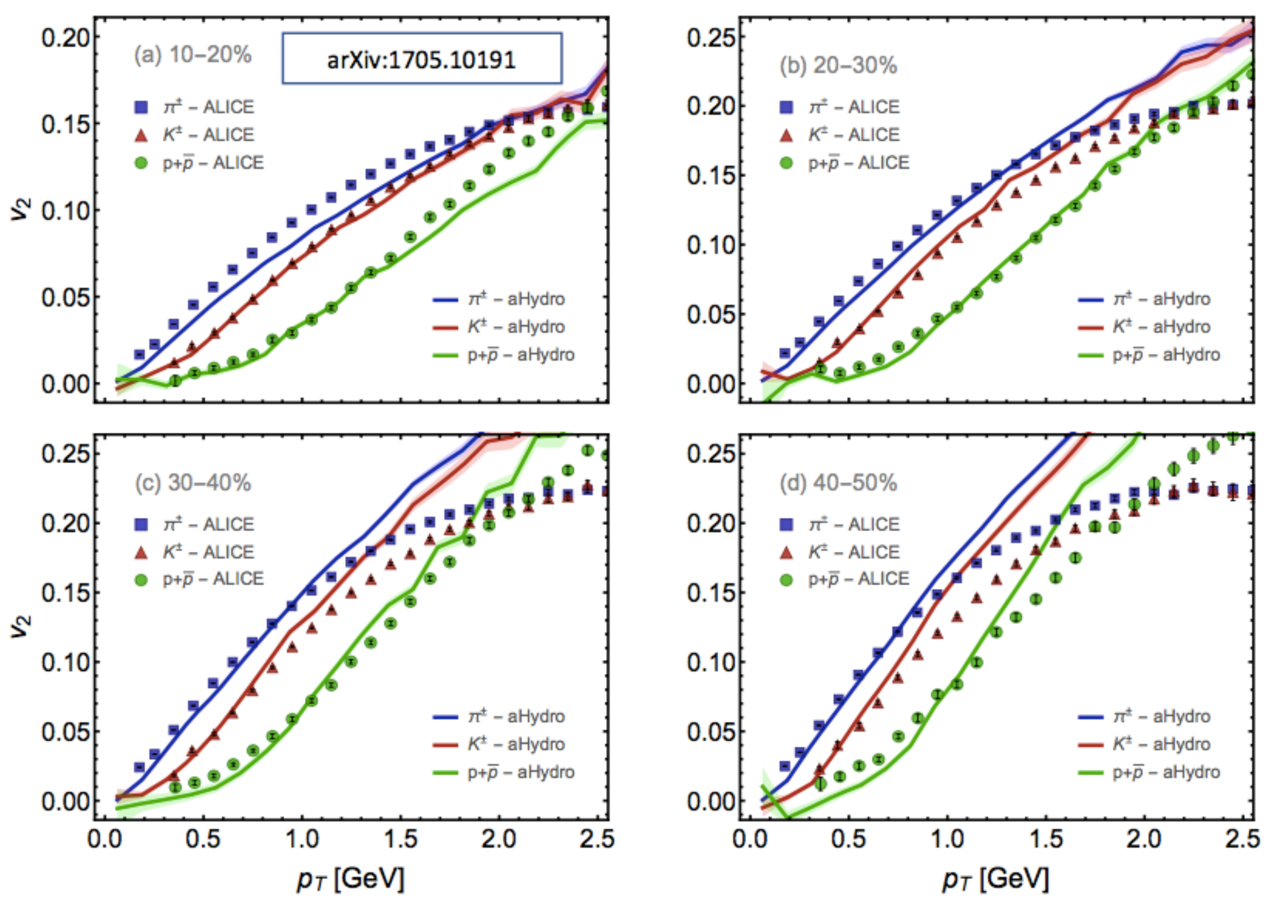
- Initial state (CGC, Glauber, IP-Glasma, Trento, etc)
- Dynamics of pre-equilibrium (anisotropic hydro)
- Hydro fluctuation

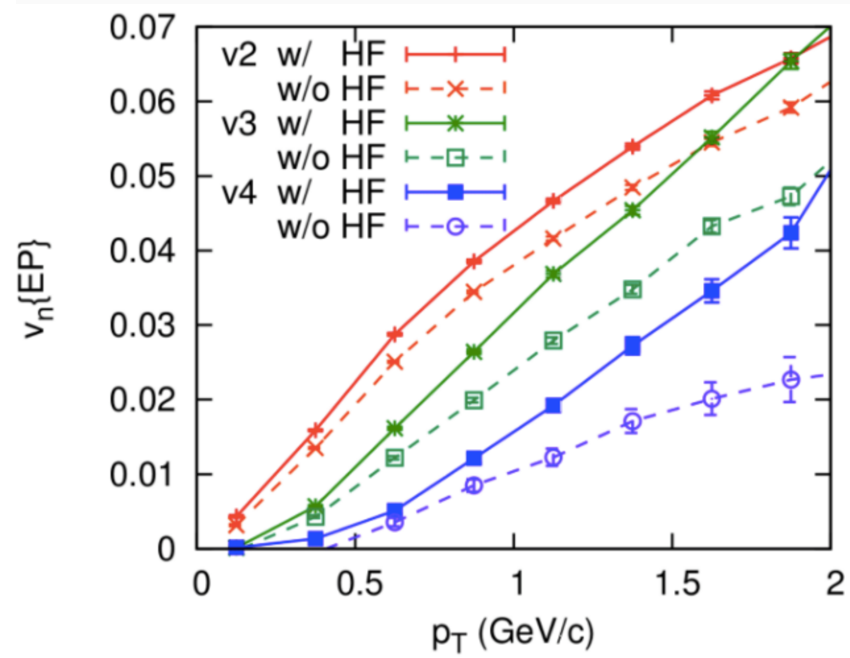
K. Murase, HIC
M. Singh, QM2018



η/s = 0.16 (Glauber I.C.).

A. Mazeliauskas, QM2018,
M. Alqahtani, QM2018



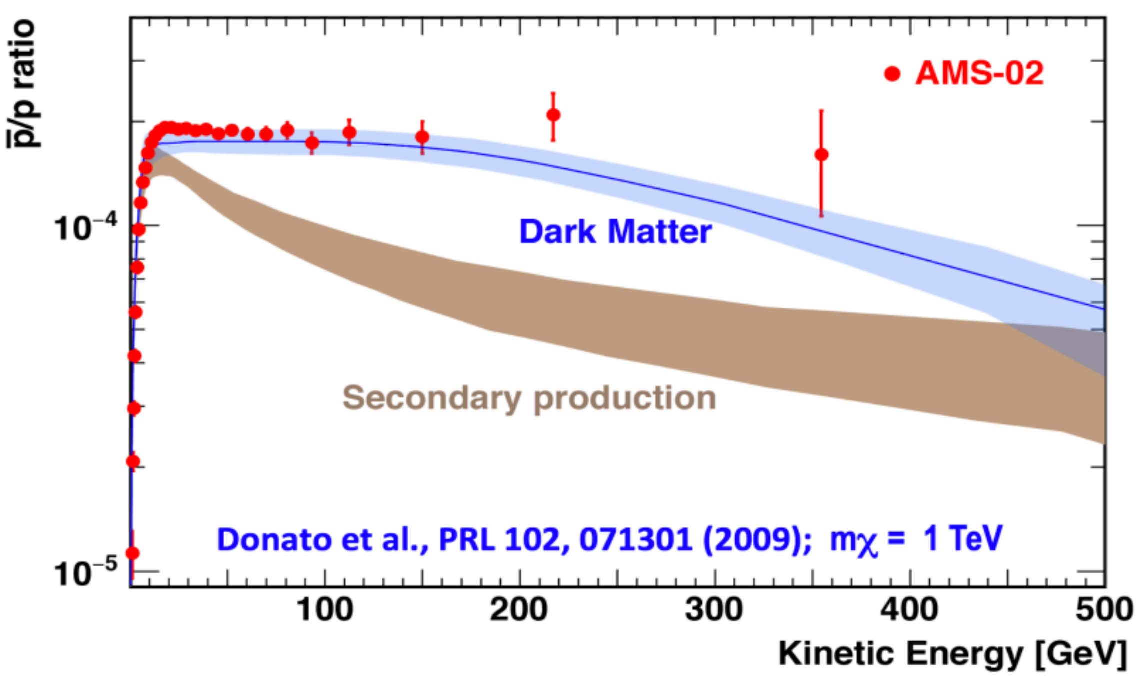


ALICE

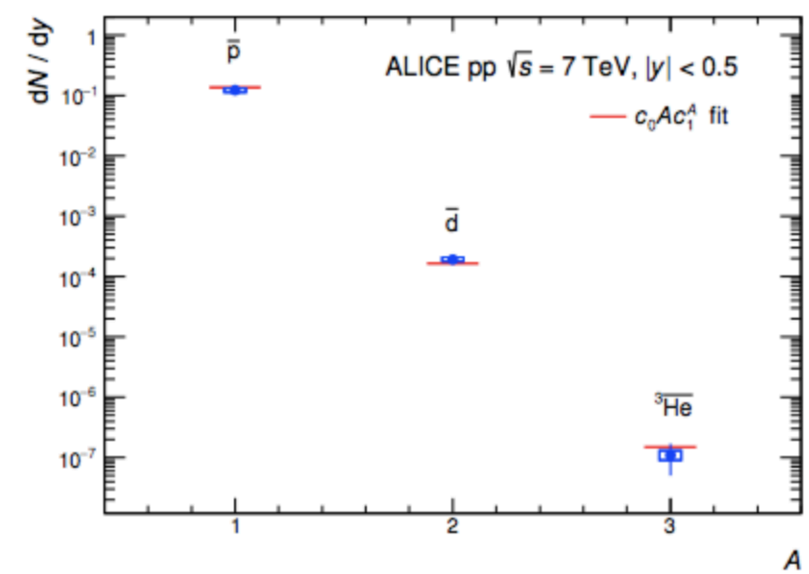
Topics with forward spectrometers

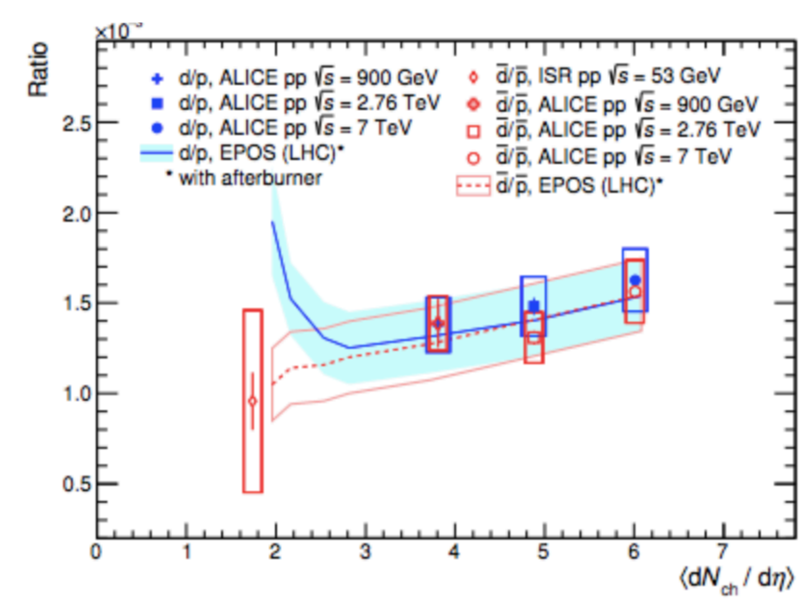
- Single particle measurements at forward rapidity
  - **Anti-proton, anti-nuclei, anti-hyperon at forward rapidity**
    - **understanding of secondary anti-proton production (background) in searches for anti-nuclei from primordial or dark matter origin**

AMS Coll., Cern 15.04.2015



Competitive to LHCb?

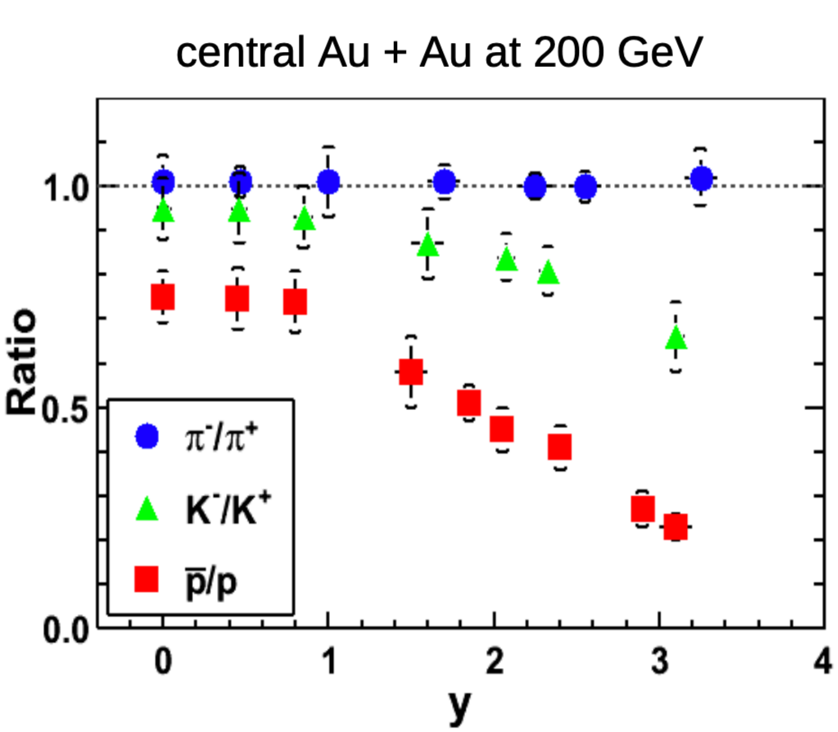




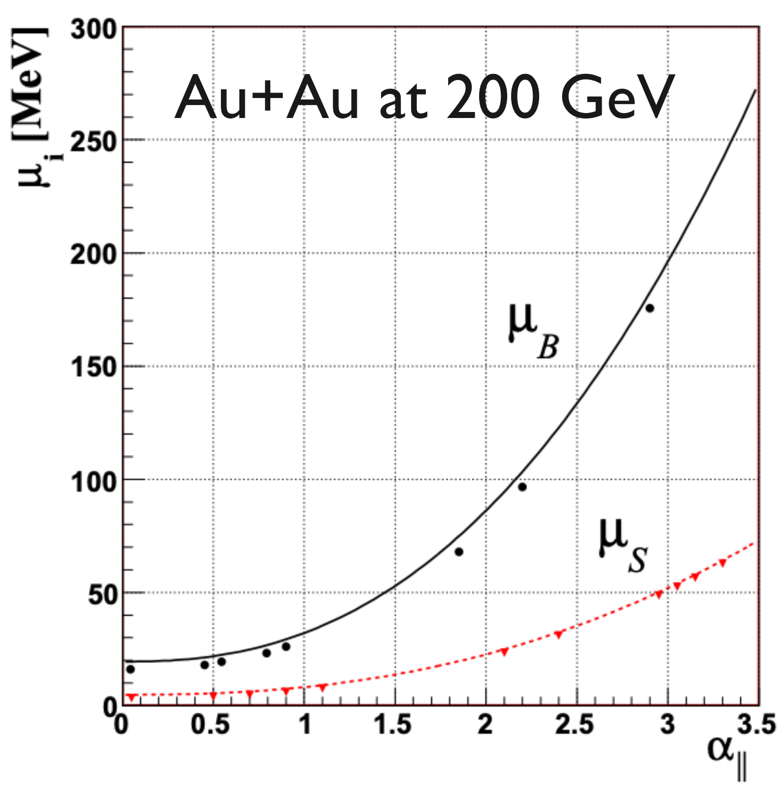
Topics with forward spectrometers

- Single particle measurements at forward rapidity
  - Competitive to LHCb
  - Spectra and flow (v_n) of PID hadrons, hyperons, HF mesons and baryons, Quarkonia, dileptons and photons
    - **(Ex) Full characterization of evolution and QGP properties as a function of rapidity → different (T, μ)**

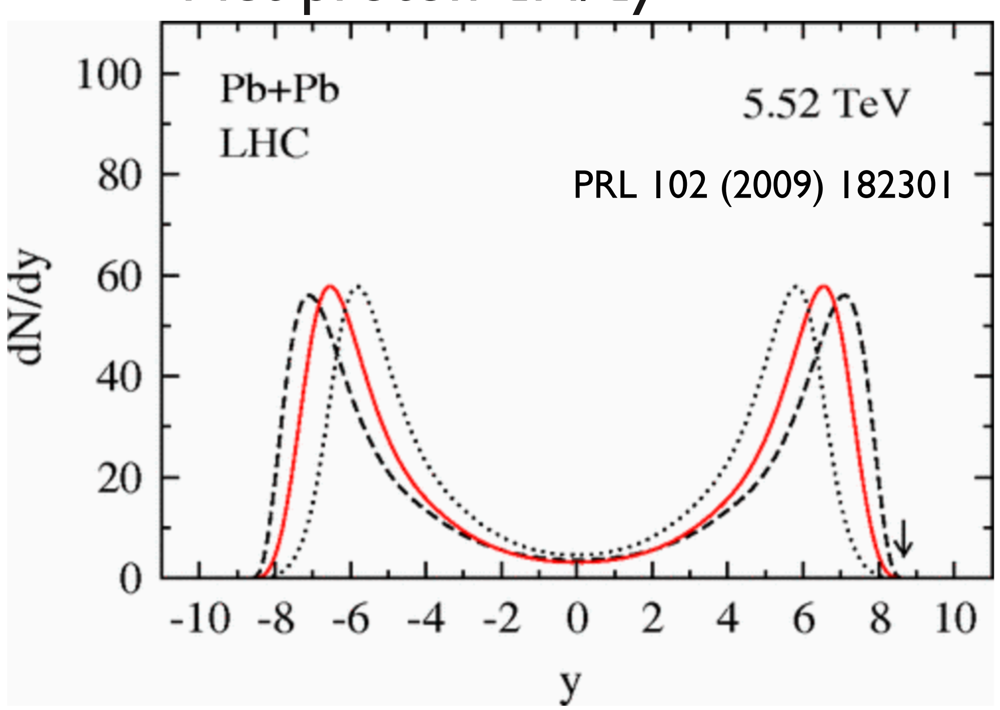
BRAHMS



Phys.Rev.C75:054905,2007



Net proton dN/dy



ALICE

3 major directions of HI physics

1. Properties of QGP at the highest collision energy
   - Precision measurements and development of analysis (bayesian analysis)

2. QGP formation in small systems
   - Source of collectivity (initial or final state effects)? Onset?

3. QCD phase diagram at high density
   - Critical point, 1st phase transition, QGP properties at high density