Future ALICE Physics Perspectives and ALICE GEM-TPC upgrade

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Outline

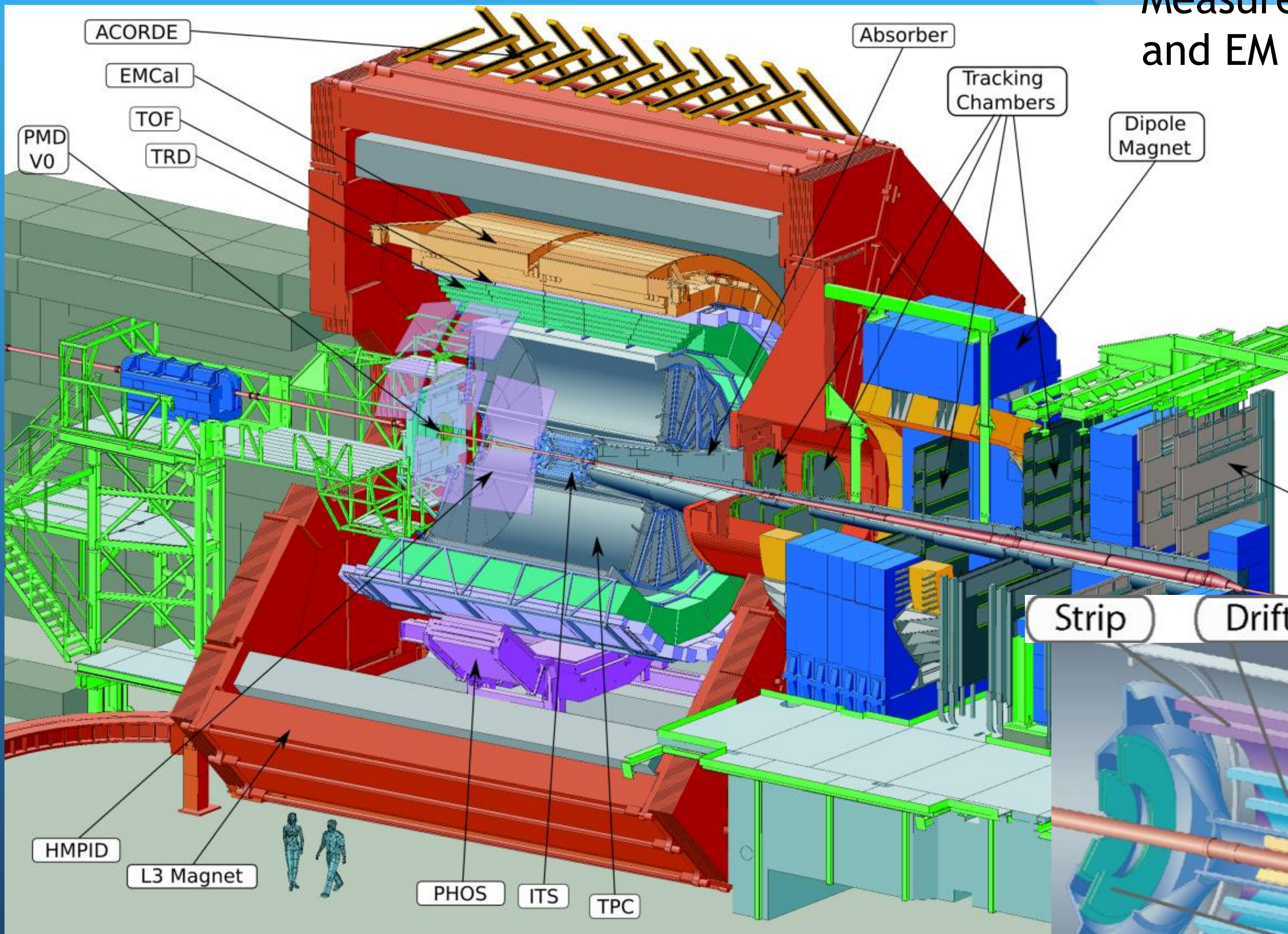
- *Heavy ion physics at LHC energy*
- *Current status of ALICE*
- *Experimental results (inputs for the upgrade)*
- *ALICE upgrade plans*
- *Physics perspectives*
- *GEM-TPC upgrades*
- *Summary and Outlook*

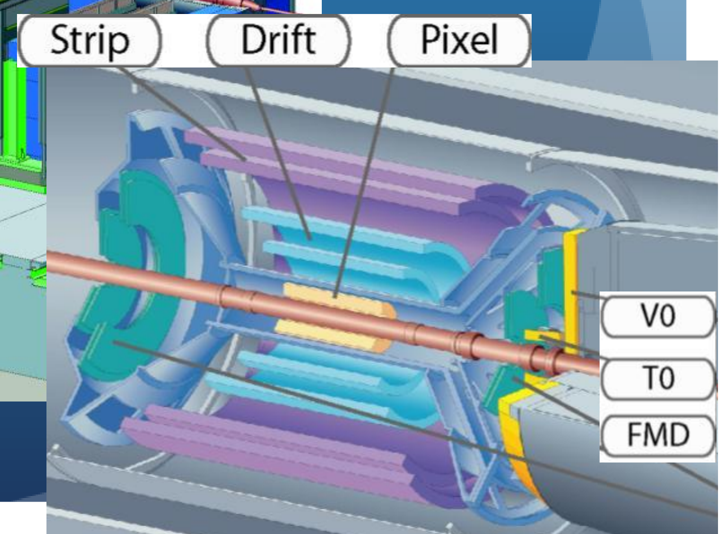
Heavy Ion Physics at LHC Energy

- To fully exploit scientific potential of the LHC – unique in
  - Large cross sections for hard probes
  - High initial temperature/long space-time evolution
    - Observables are more sensitive to the properties of QGP
  - Gluon saturation
    - less complexity in initial conditions???
  - Strongest (Color) EM field shortly after the collisions
    - Key to understand the dynamics just after the collisions
  - Collectivity in high multiplicity p-p and p-Pb collisions?
- Precision measurement of the QGP parameters at μ_b=0
  - Quantitative study of QGP in conjunction with RHIC
- Experiments need to have the capability to measure:
  - Soft probes(PID flow & spectra, correlation)/EM probes (ALICE)
  - Hard probes through jets (ATLAS/CMS and ALICE)

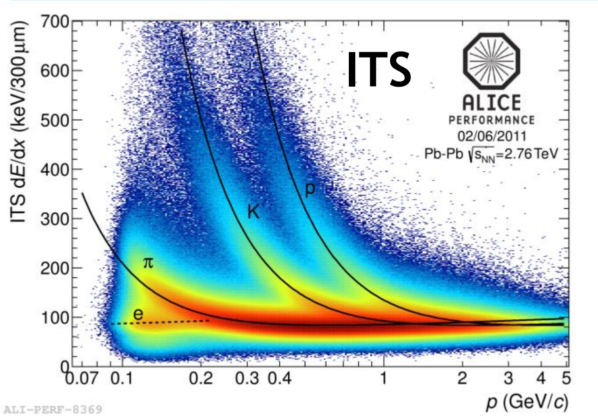
ALICE detector system

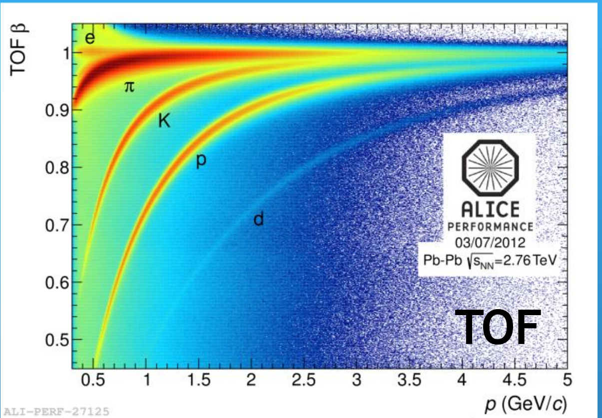
17 kinds of detectors
Dedicated to HI collisions
Measure soft~hard probes
and EM probes.

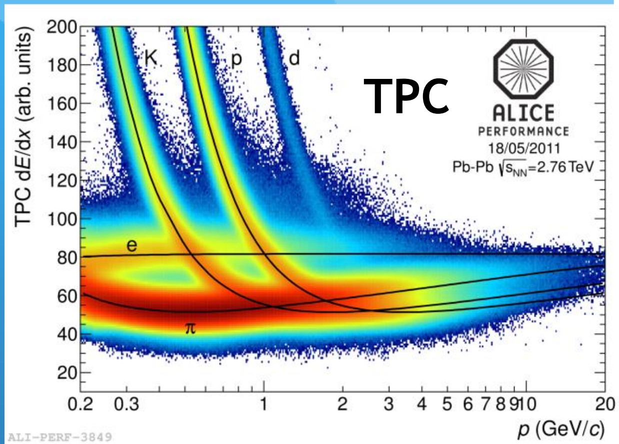


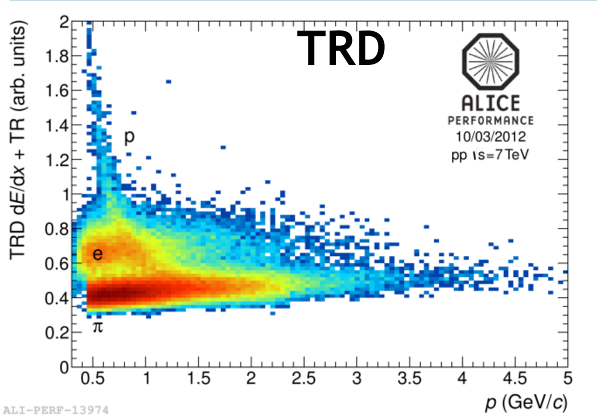


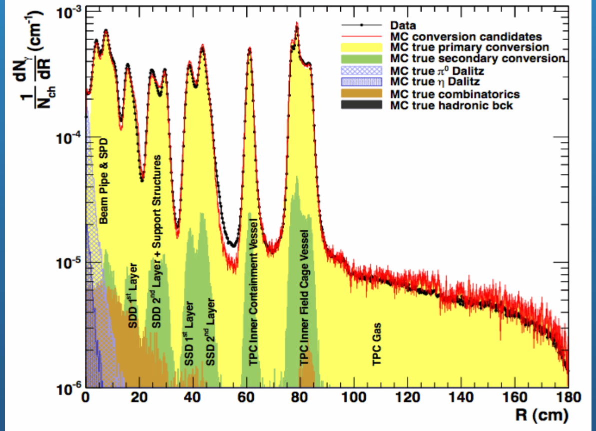
Detector Performance

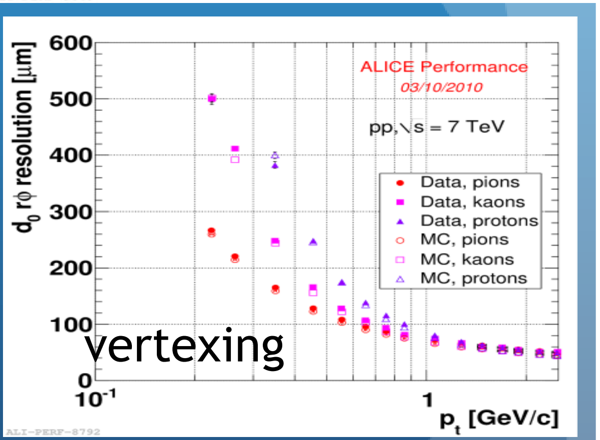










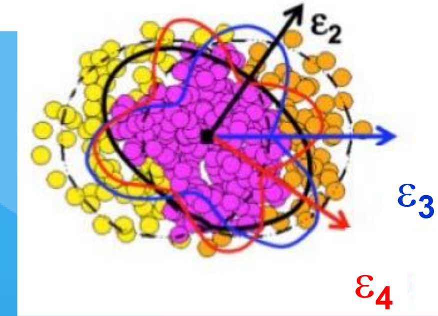


- Particle Identification (pi/K/P/e/mu) for wide p_T region
- Efficient low-momentum tracking – down to ~ 100MeV/c
- Excellent vertexing capability
- Low material budget (10% of X_0)
- good reconstruction capability of photon conversions

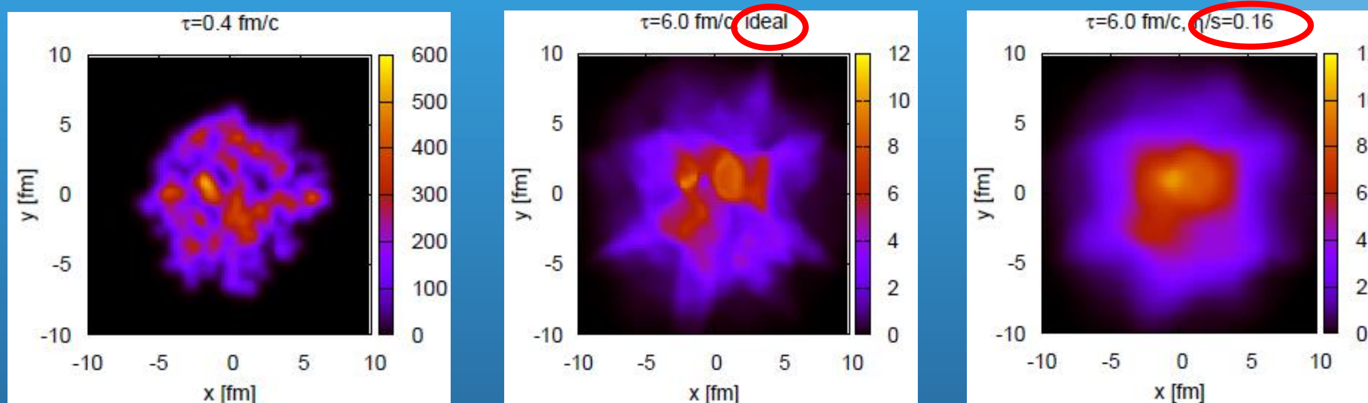
Experimental results (motivate the ALICE upgrades)

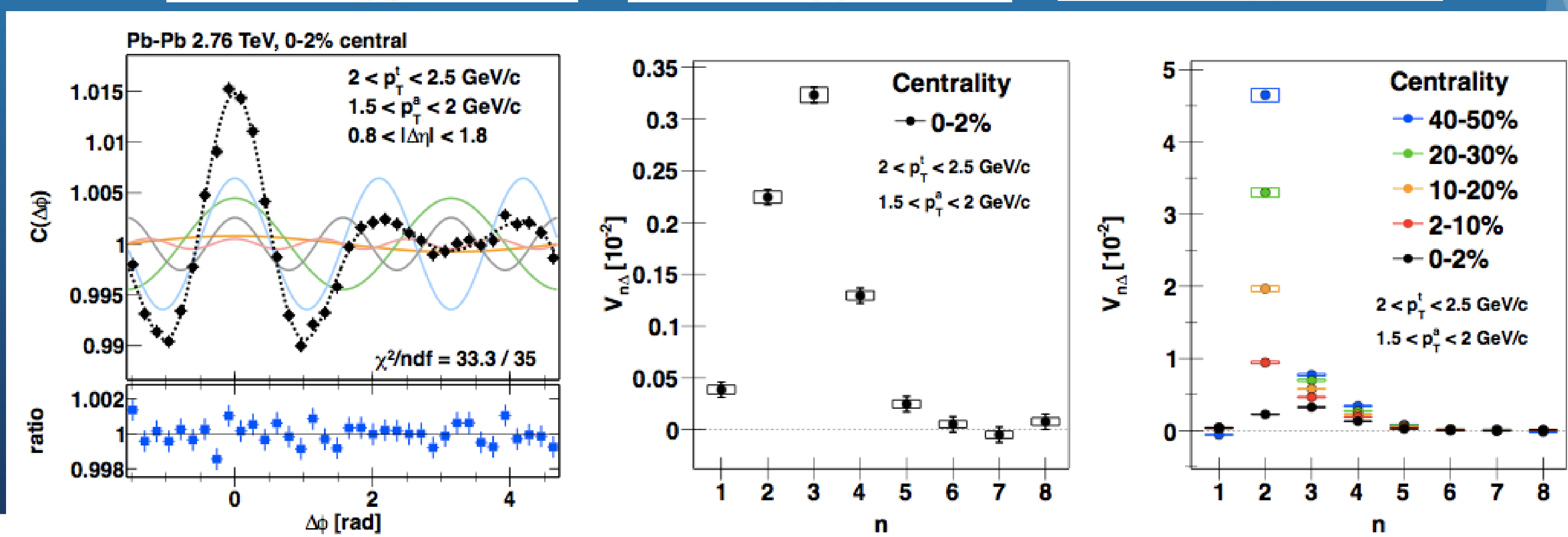
1. Higher order Flow
2. Event-by-event flow
3. Heavy flavor measurements
4. jets
5. Photon puzzle
6. Dielectron puzzle and thermal dilepton measurement

Higher Order Flow

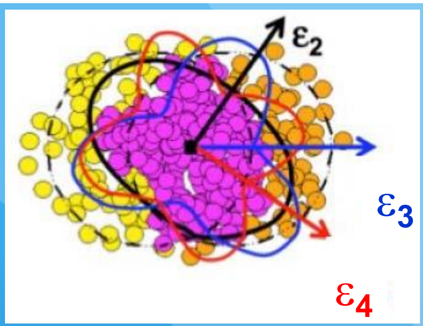


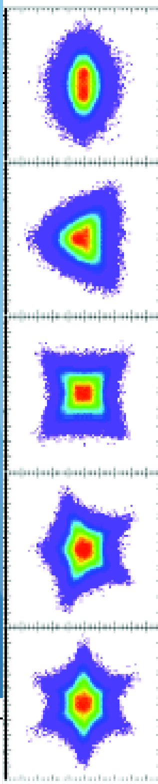
- Higher order Flow measurements
  - Initial conditions (correlation length, fluctuation), Viscosity



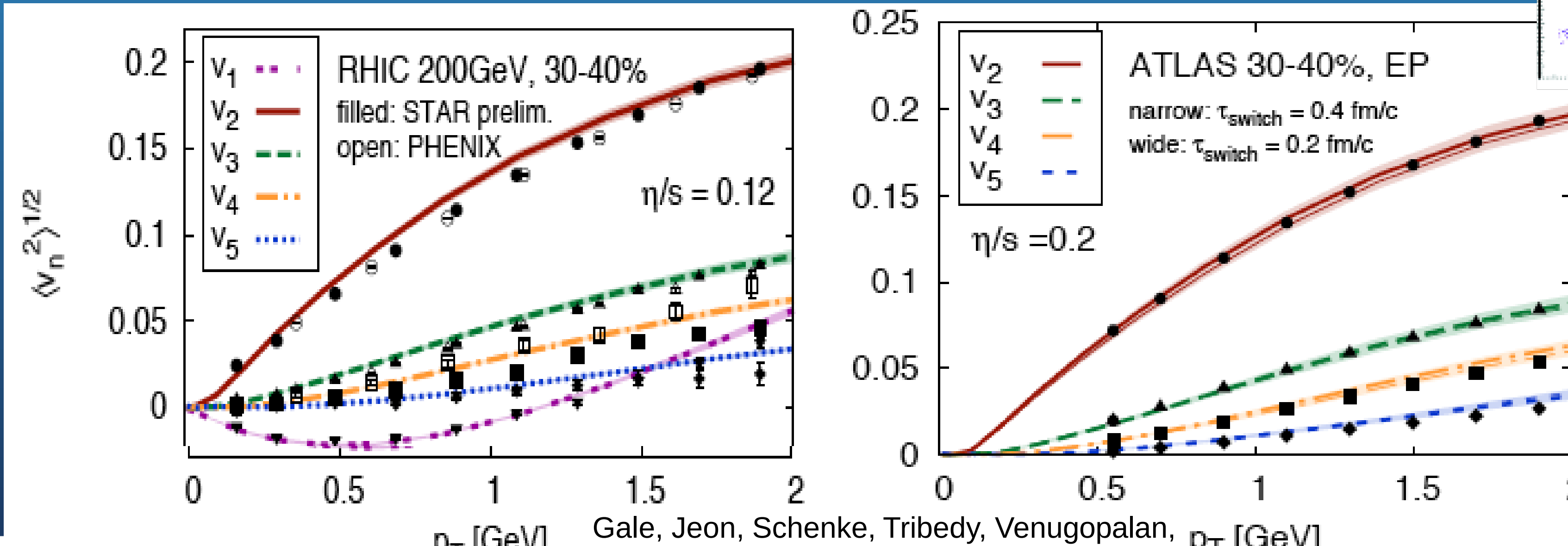


Higher Order Flow





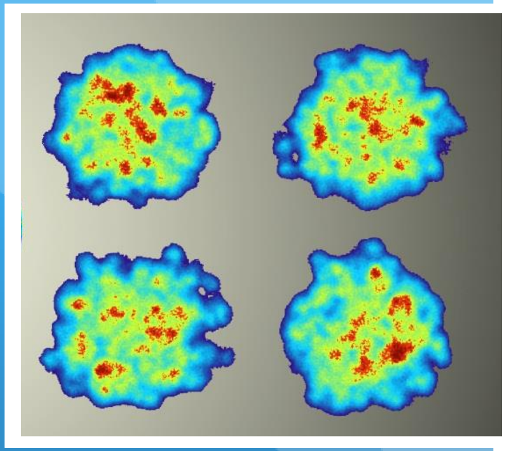
- Higher order Flow measurements
  - IP-Glasma model ($1/Q_s$)
    - η/s=0.12(RHIC), 0.2(LHC)
  - $v_n \propto \exp(-\beta n^2)$, $\beta \propto \eta/s$
- Temperature dependence of η/s???
  - Sensitivity to QGP η/s or hadronics η/s??? Can differentiate???

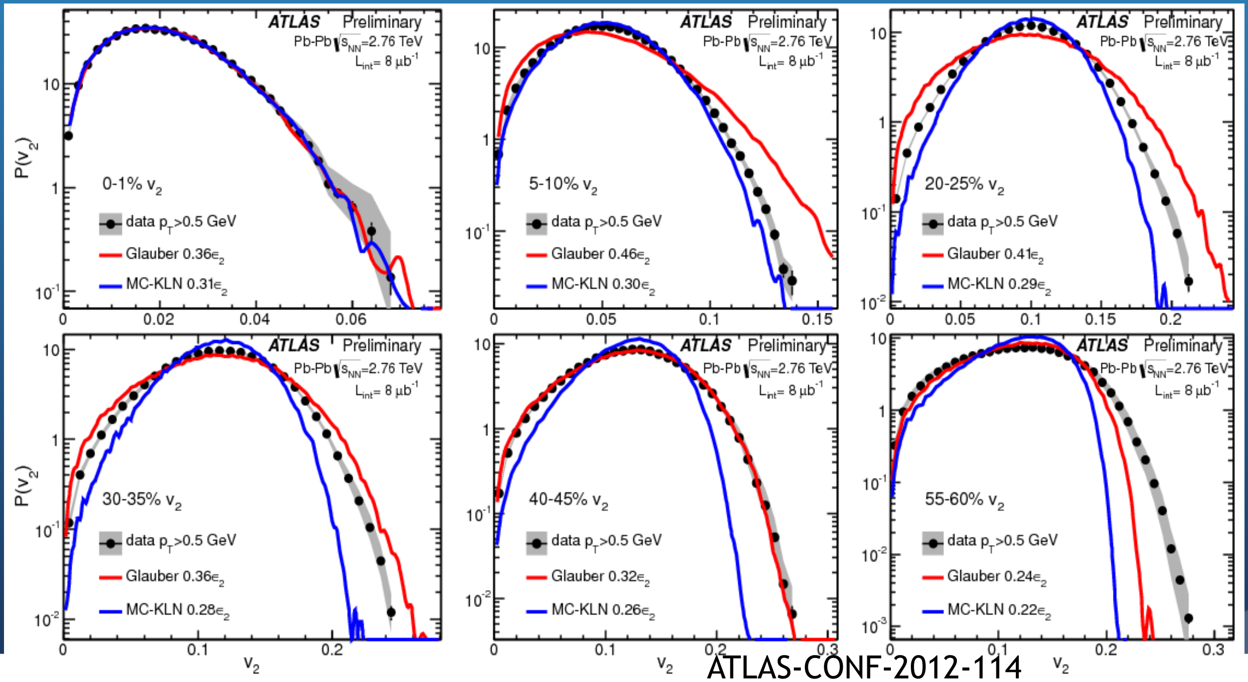


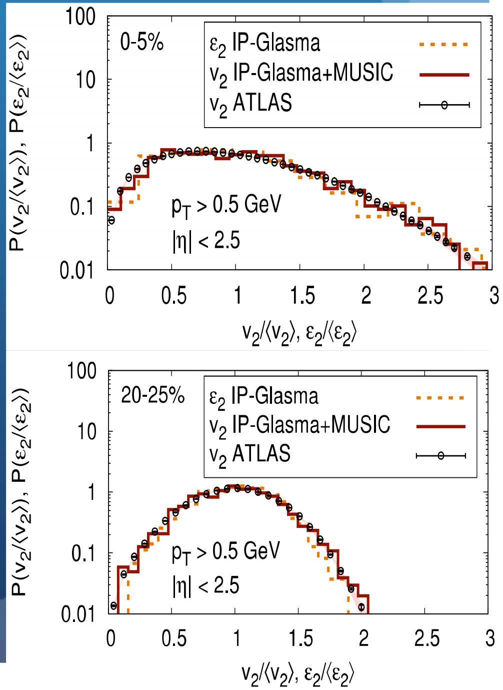
Gale, Jeon, Schenke, Tribedy, Venugopalan, arXiv:1209.6330

E-by-E Flow

- Event-by-event flow
  - Better understanding of initial conditions
  - Central: MC-KLN, IP-Glasma
  - Peripheral: MC-Glauber, IP-Glasma
- Firm conclusion??? Another cross-check???



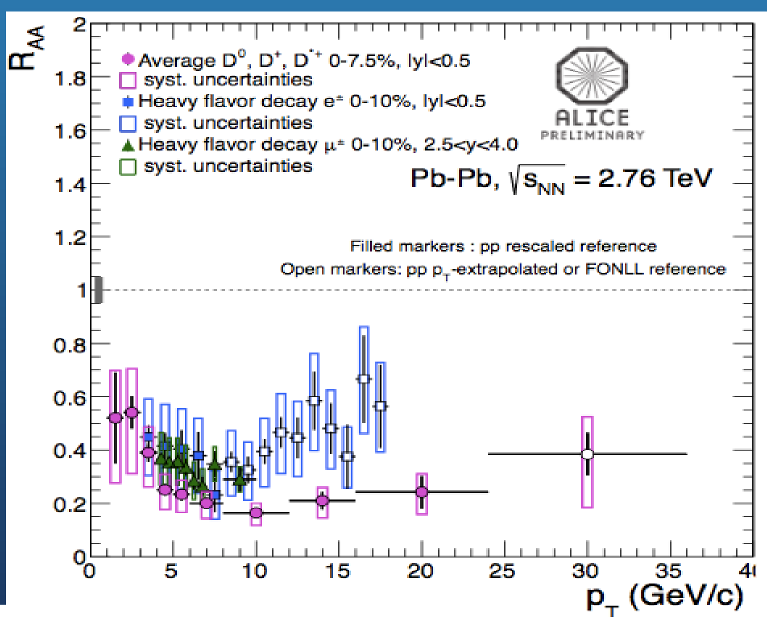


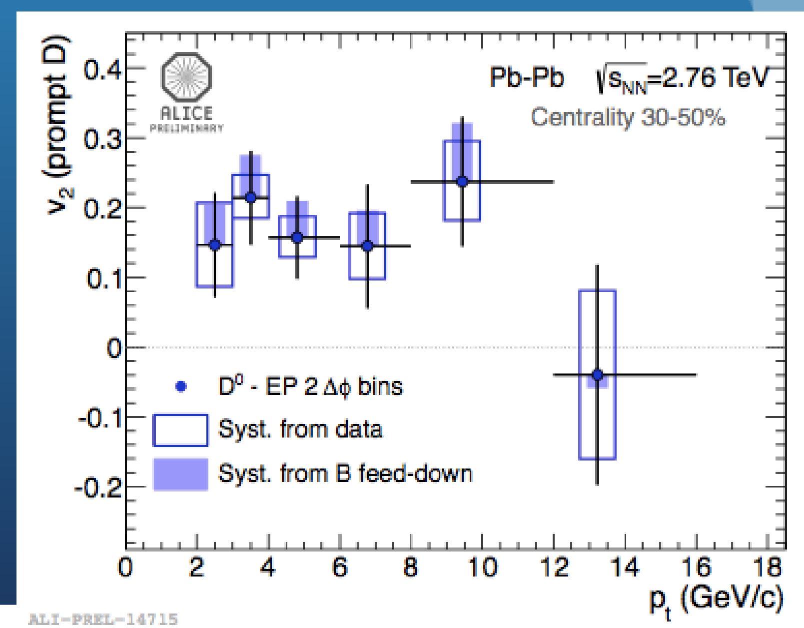


ATLAS-CONF-2012-114

Heavy Quarks

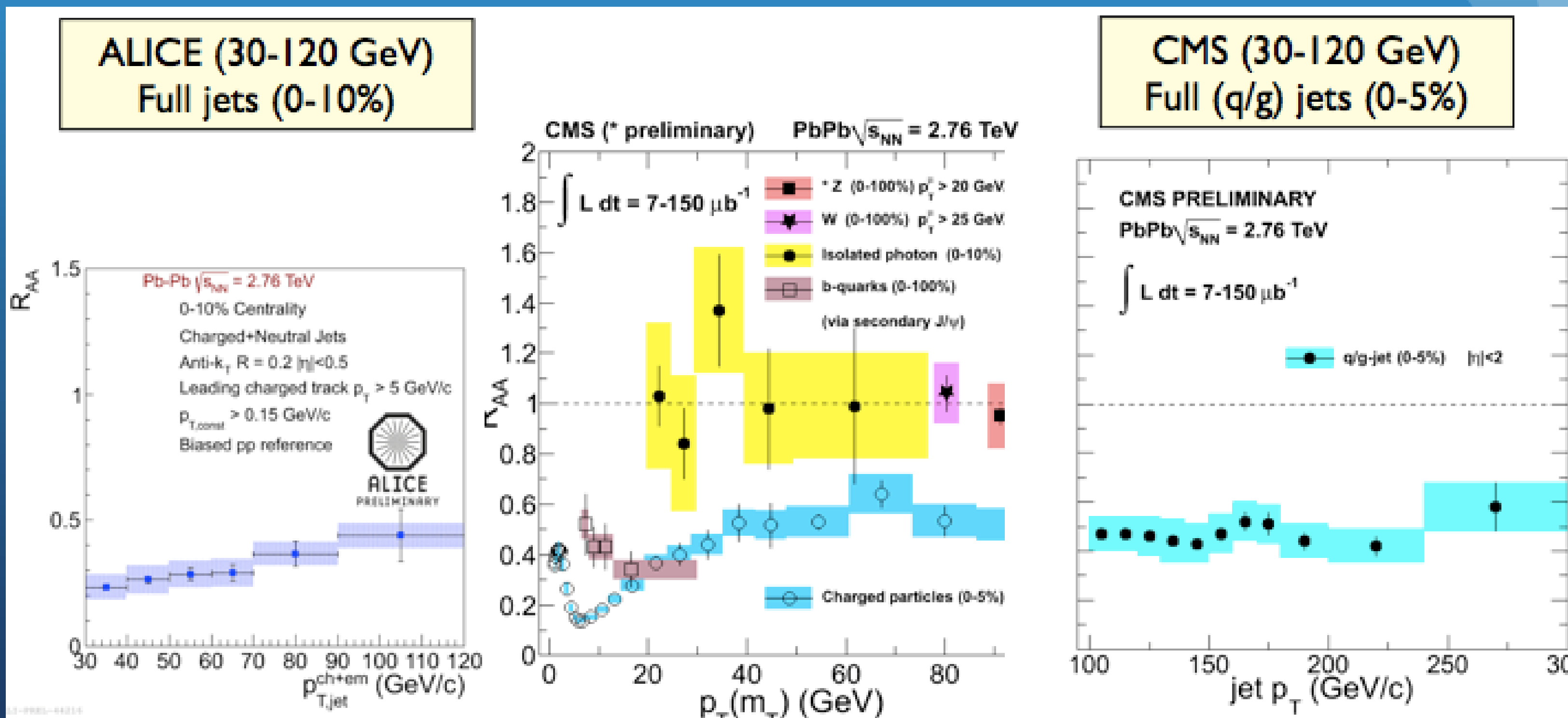
- Heavy flavors
  - Strong suppression like other hadrons. Hint of $R_{AA}(B) > R_{AA}(D)$
- More precision measurements needed!
  - Separation of D/B. Flow of heavy quarks (D, B). v_n measurements
  - Low p_T HQ R_{AA}. Violation of binary scaling??? Wide pT range (→ collisional/Radiative energy loss. → transport properties)





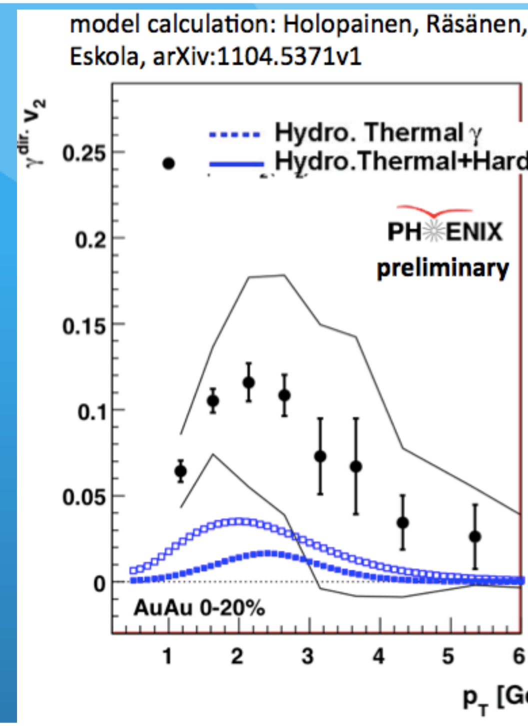
Jet measurements

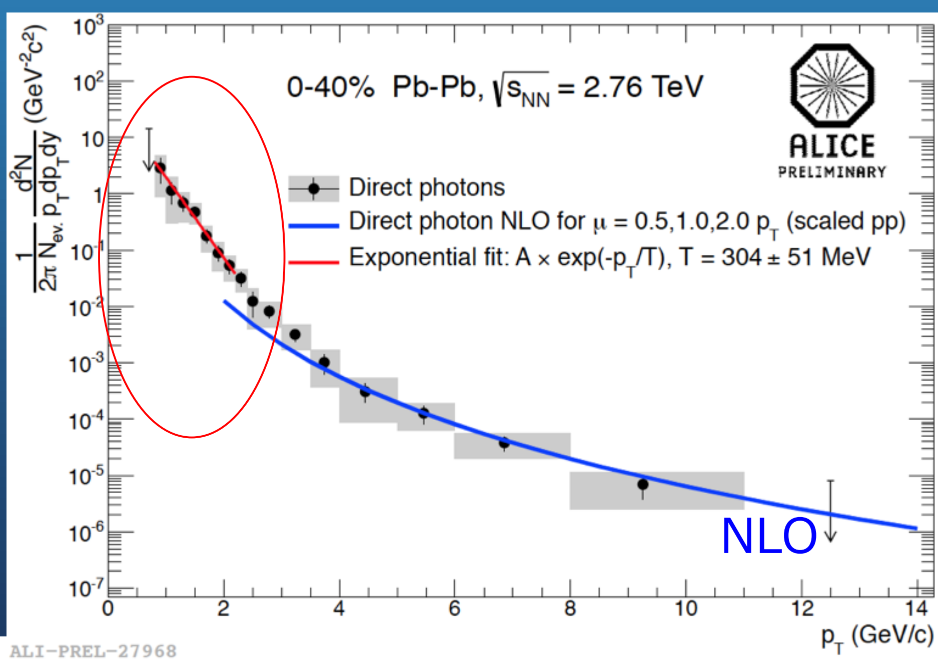
- High pT Jets
- Jet energy ←→spatial resolution of the medium
  - E-by-E jet analysis(?). Jet-Fluid interaction. Propagation of lost energy in the medium.

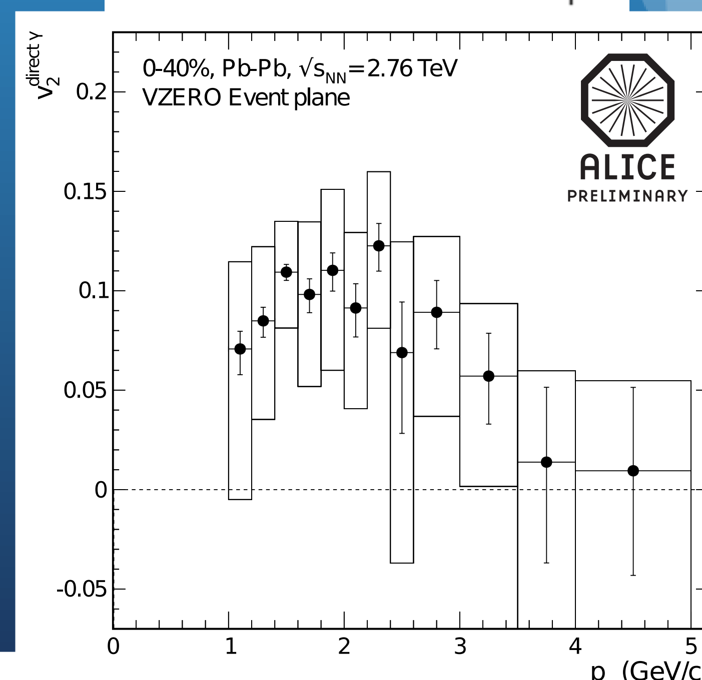


Photons

- Enhancement of low pT photon yield
- Production is well-understood???
  - Origin of large photon v2?
    - Hadronic phase? Strong EM field?
  - v_n of photon production. γ-γ HBT

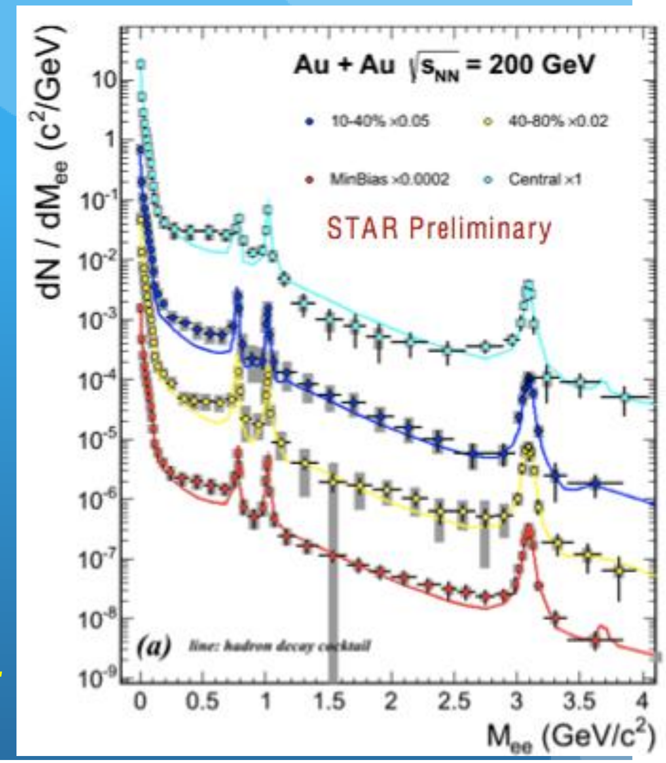


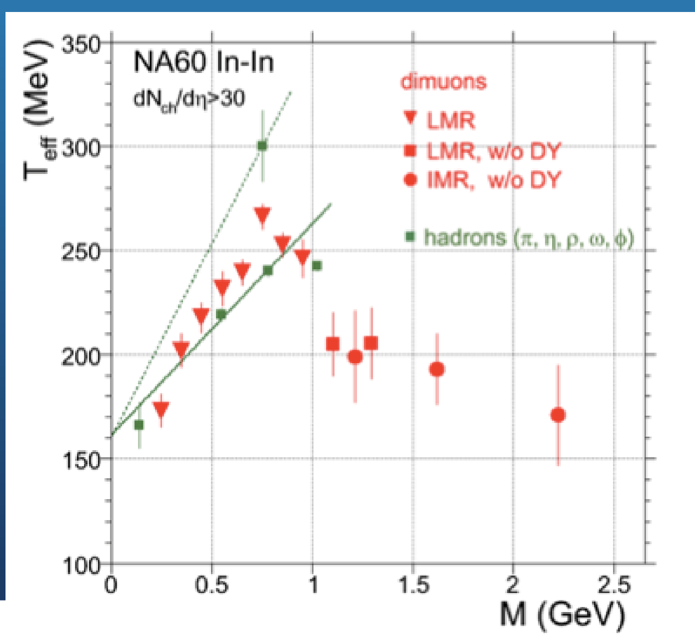


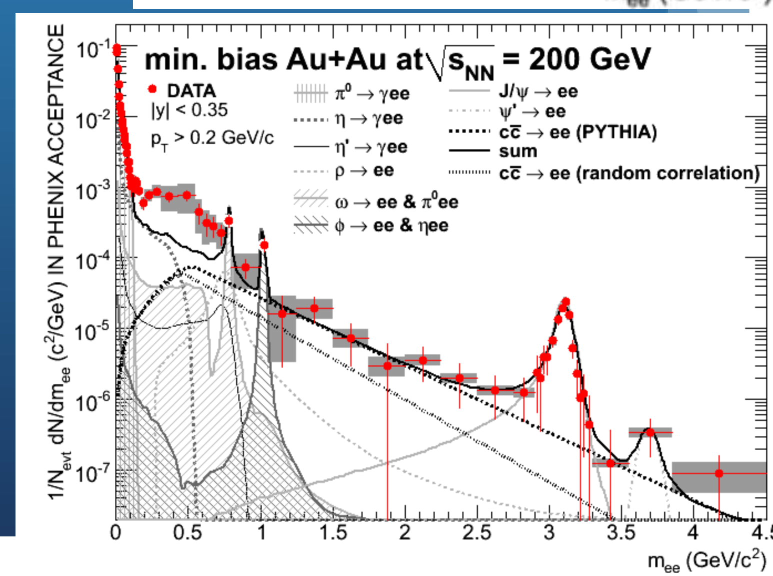


Dileptons

- Inconsistent between STAR and PHENIX
- ALICE is important!!
  - Mass modification of LVM
  - Virtual photons, radiation from EM field
  - direct thermal dielectrons (M_{ee}, p_T, v_n).
  - Energy loss (angular de-correlation) of HQ







What we have to understand

- Initial conditions
  - E-by-E, higher order flow not only from soft sectors but also from hard probes, p-p/p-Pb collisions
- Temperature dependence of the medium properties
  - E-by-E, higher order flow not only from soft sectors but also from hard probes, Leptons & Photons
- Thermalization mechanism, Dynamics of non-equilibrium QCD
  - Longidudinal correlation, Leptons & Photons, p-p and p-Pb
- What we need are:
  - High luminosity
  - High rate capability (for being able to inspect all MB collisions)
  - High performance detectors (jet, HQ, photons, leptons)

ALUCE upgrade plans

ALICE upgrade strategy

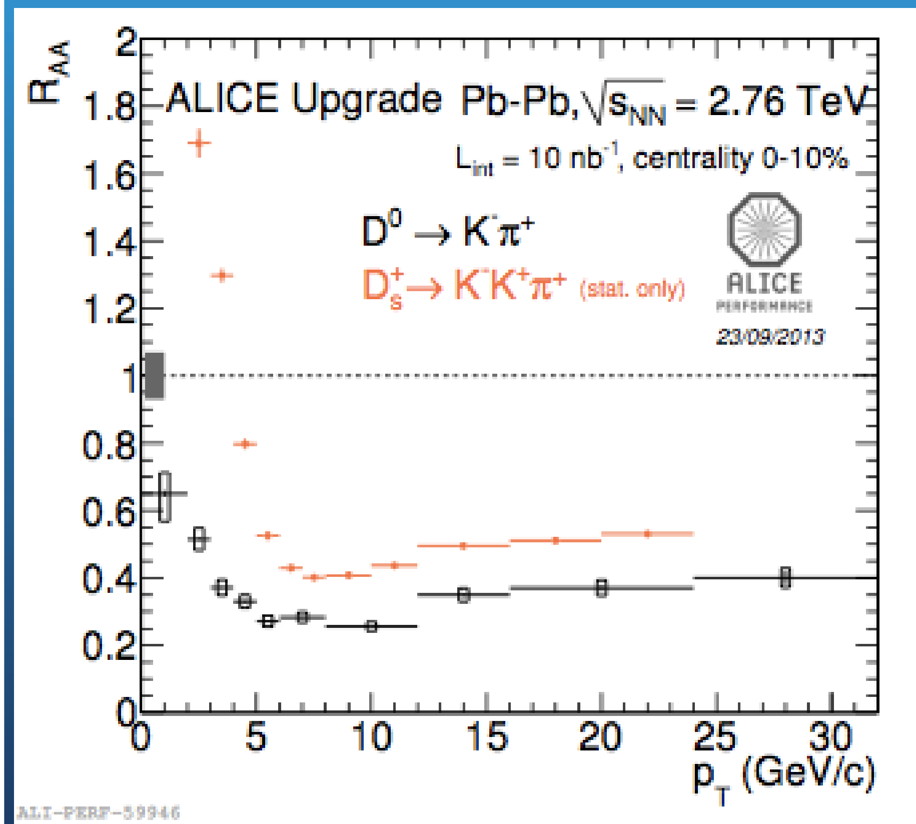
- Need to accumulate not only soft probes but also wide p_T jets, photons, dileptons, heavy quarks
  - Some of them = untriggerable
    - Require a large event samples on tape
  - Increase rate capabilities to inspect all MB heavy-ion collision
    - read out all Pb-Pb interactions at a maximum rate of 50~100kHz (i.e. L = $6x10^{27}$ $cm^{-2}s^{-1}$), with a minimum bias trigger
    - Replace dead-time detectors (TPC, SDD) or detector front-ends (pilepined readout, multi-event buffering)
    - DAQ (online tracking, data compression, HLT, event building)
- This is ALICE major upgrade in LS2 (2018)
  - ALICE upgrade proposal endorsed by LHCC

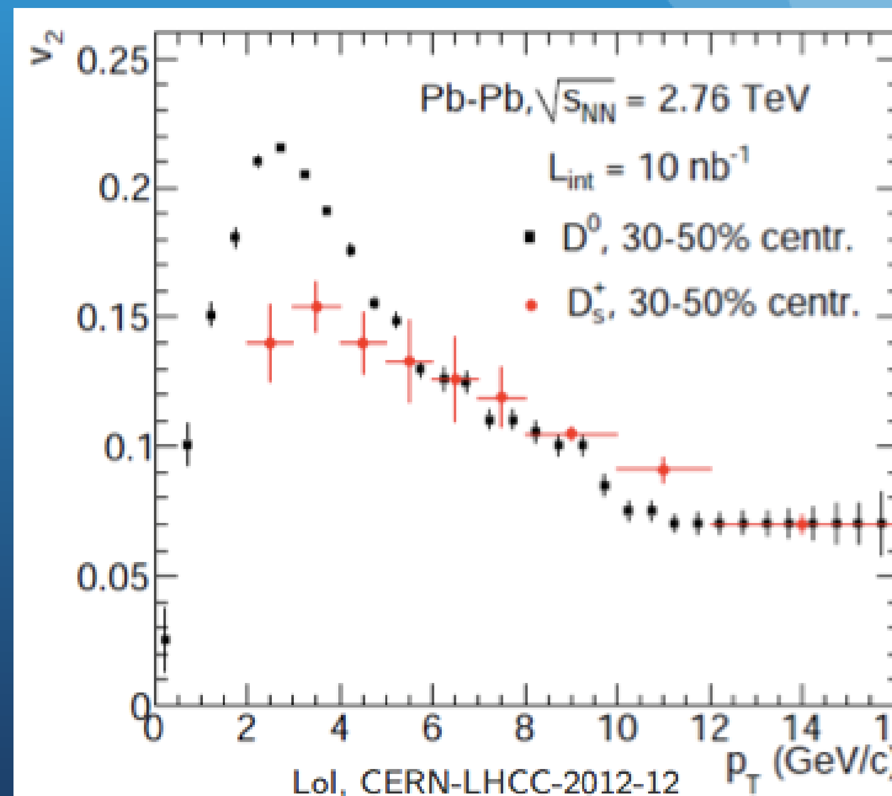
Core upgrade plans and Motivation

- New ITS
  - 7 layers of Silion Pixel Detector
  - Improvement vertex resolution → Heavy Flavor
  - Improvement low pT tracking efficiency → Dielectron
- TPC upgrade
  - Replacing MWPC readout chambers to GEM based readout chambers. No gating Grid operation
  - Improve rate capability → Heavy Flavor, Dielectrons, Jets,
- Muon Forward Tracker
  - 4 layers of Silion Pixel detector in front of Muon Absorber at forward rapidity
  - Improve secondary vertex and momentum resolution → Heavy Flavors, Quarkonia, Low Mas dimuons

Heavy Flavor Measurements

- Improvement of secondary vertex resolution by x2
  - Measurement of Λ_c, D_s, Λ_b
  - v2 and R_{AA} for wide pT range (down to low pT)





Heavy Flavor Measurements

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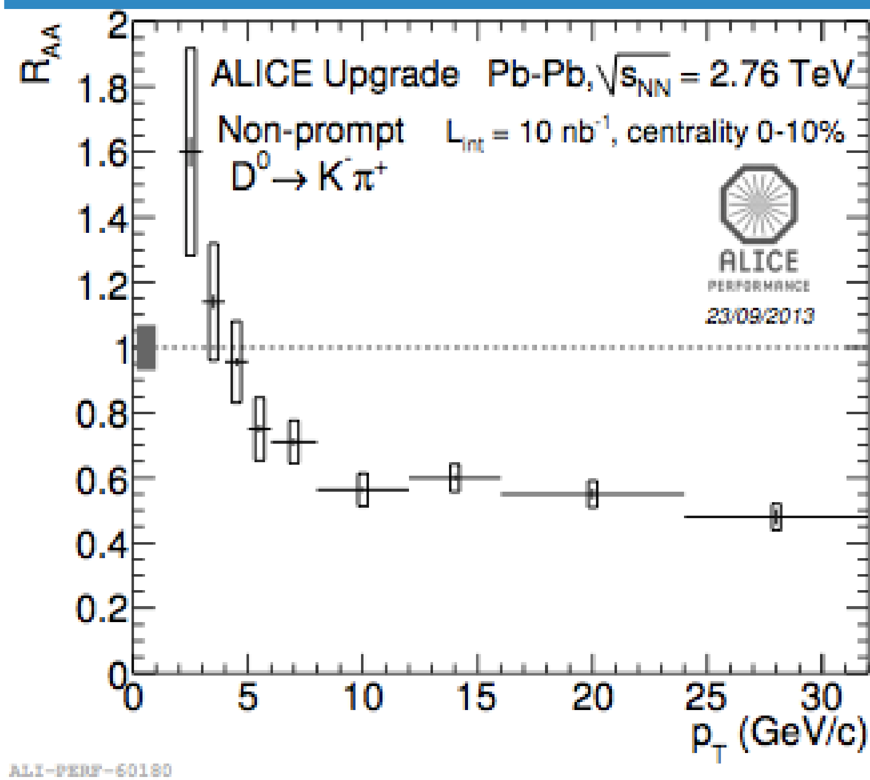
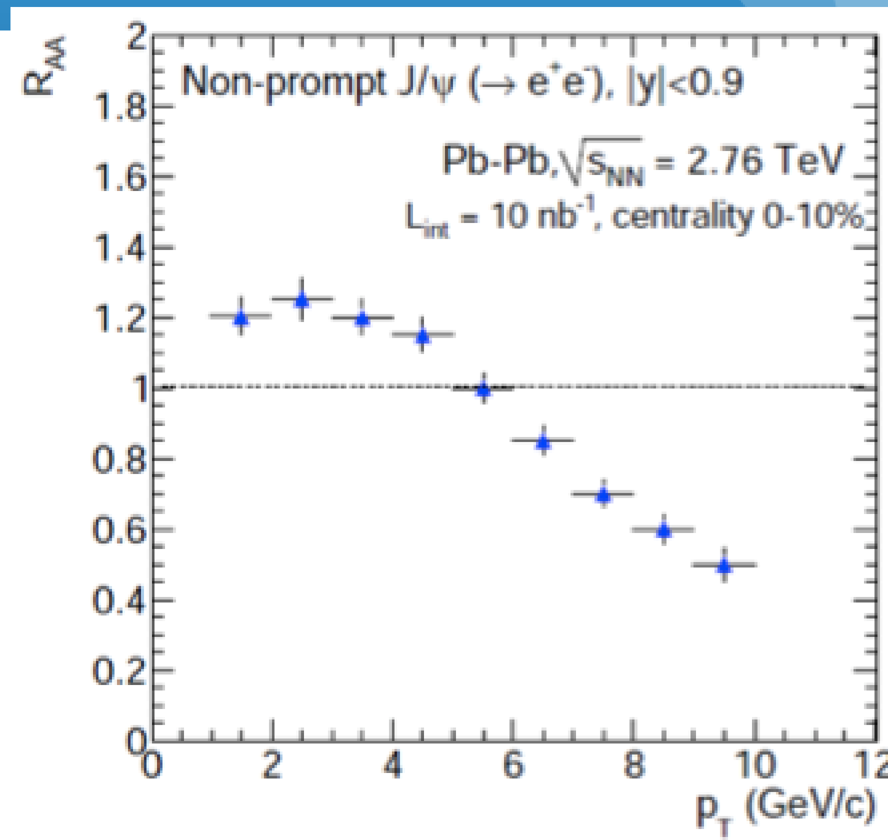
  - B measurements (B->D + displaced vertex, B->J/ψ)





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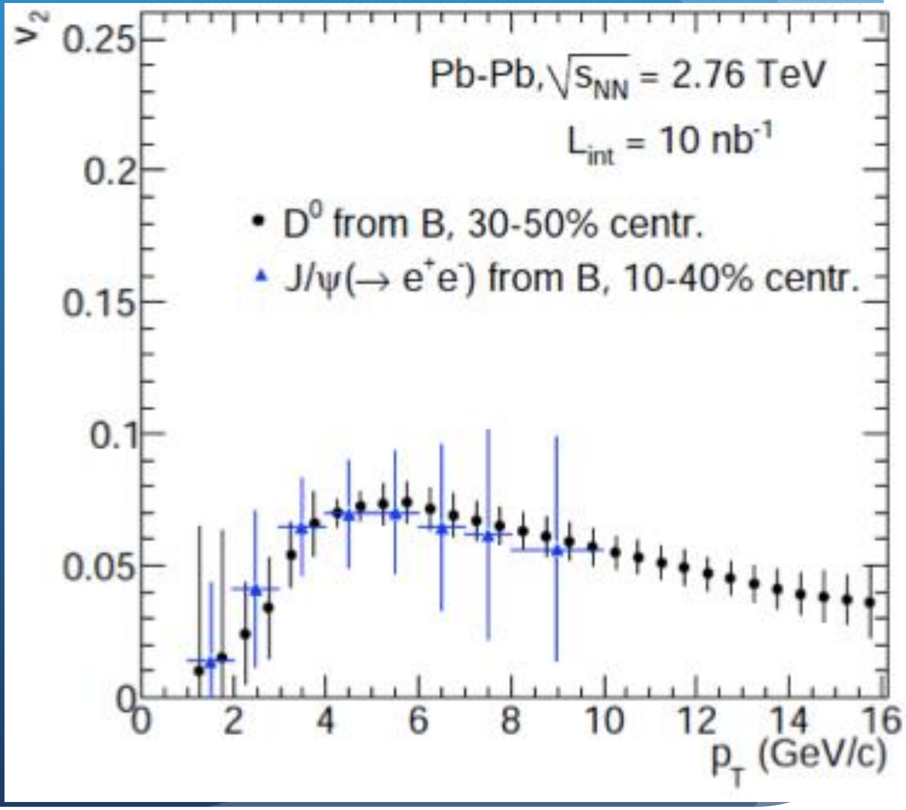
  - Measurement of Λ_c, D_s, Λ_b
  - v2 and R_{AA} for wide pT range (down to low pT)
  - B measurements (B->D + displaced vertex, B->J/ψ)
  - Prevision measurements

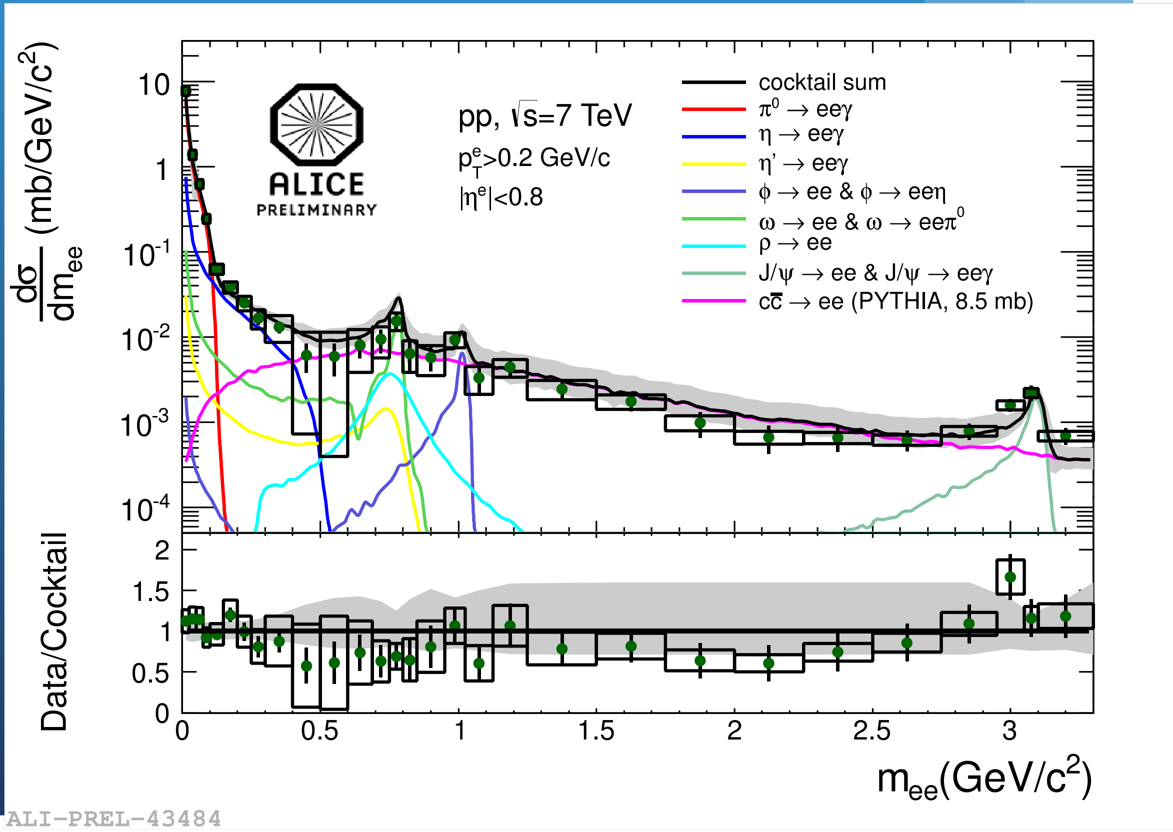
of direct B meson flow!



Di-electron Measurements

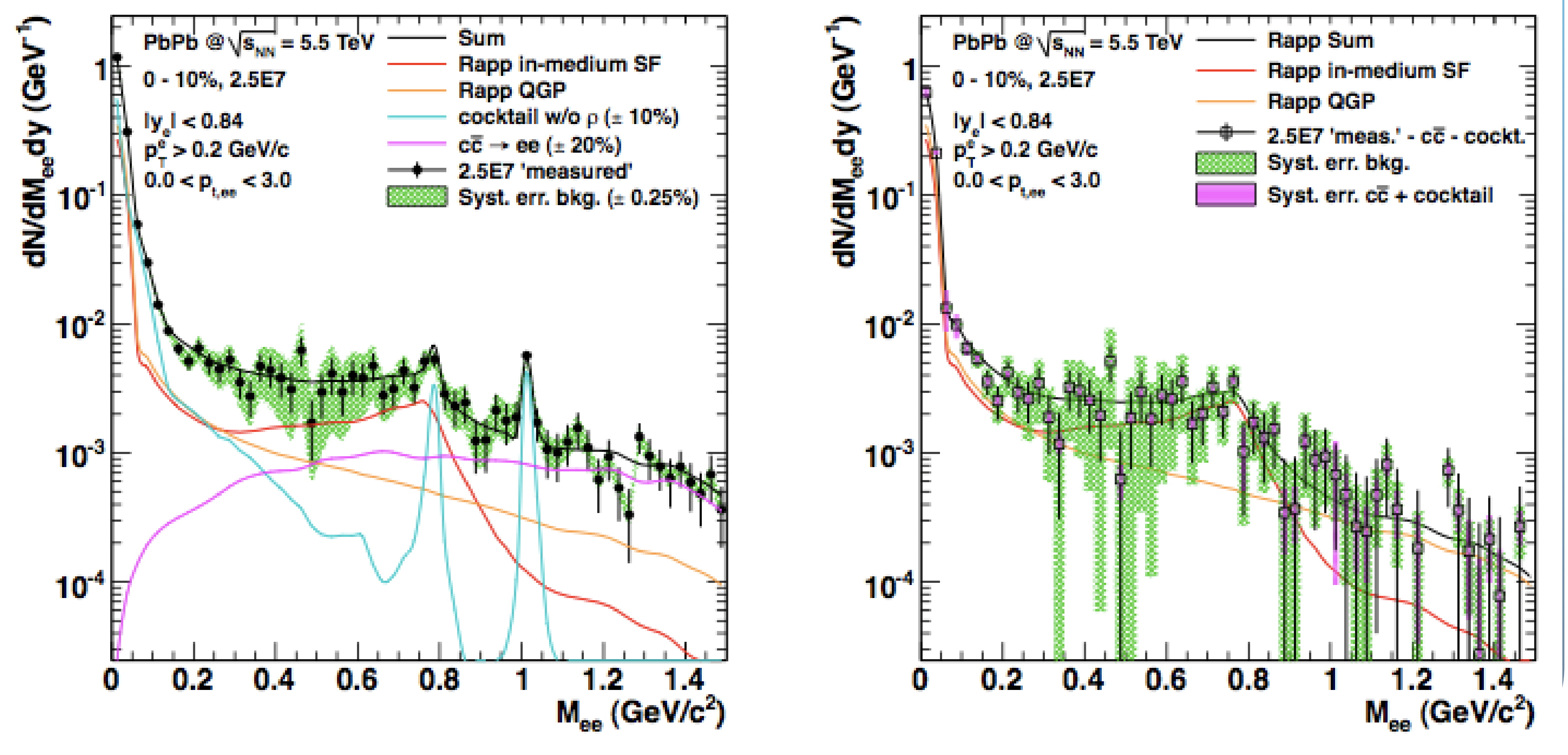
- Unique Physics and Measurement at the LHC
  - Chiral symmetry restoration
  - Virtual photons
  - Thermal radiation, Radiation from EM field

- Need to fight with:
  - Conversion/Dalitz
  - S/N (combinatorial)
  - Charm contributions
    - Charm yield
    - Correlation of pairs



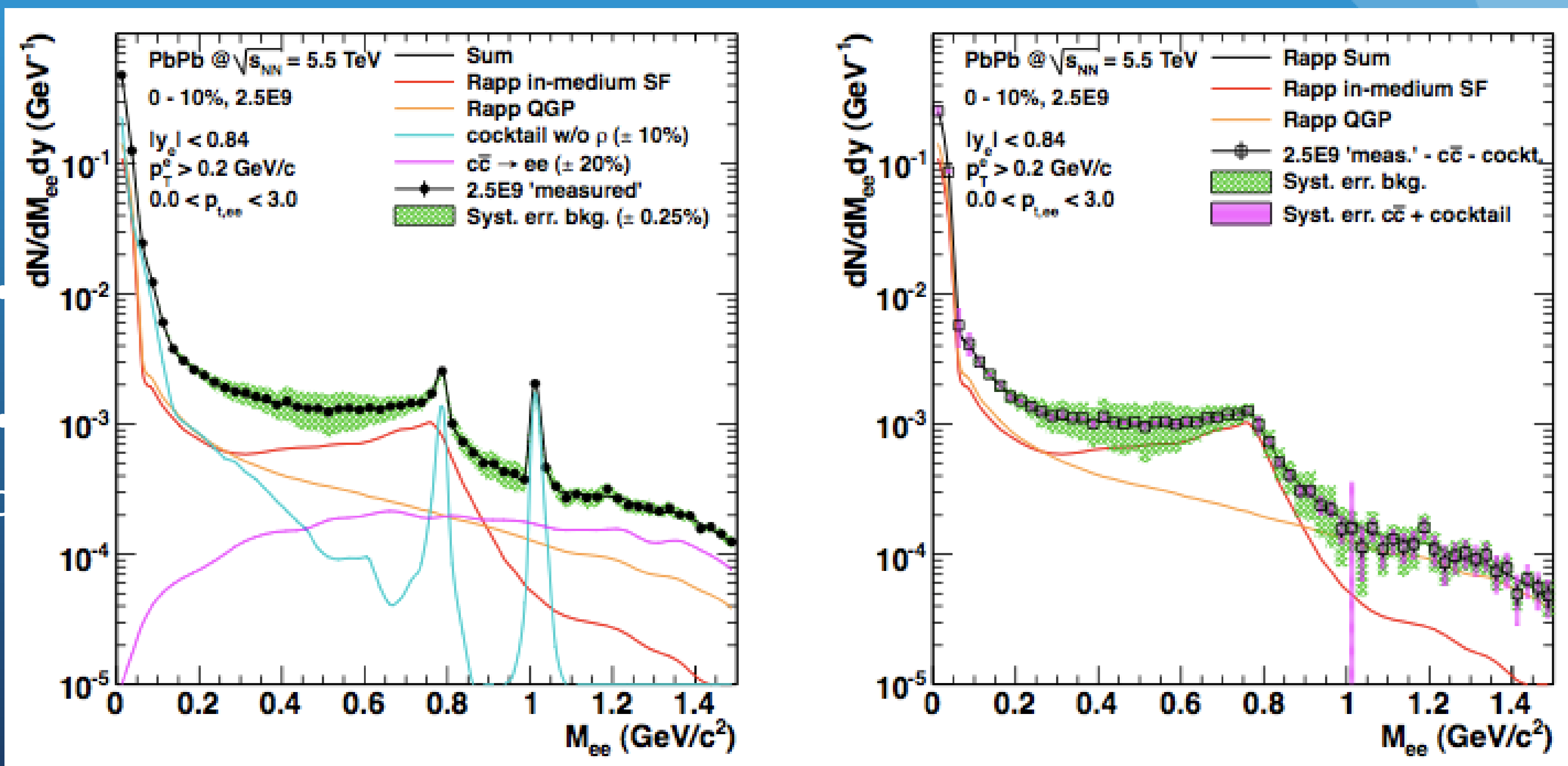
Di-electron Measurements

- Current scenario on statistics, tracking and PID capability, but B=0.2 T



Di-electron Measurements

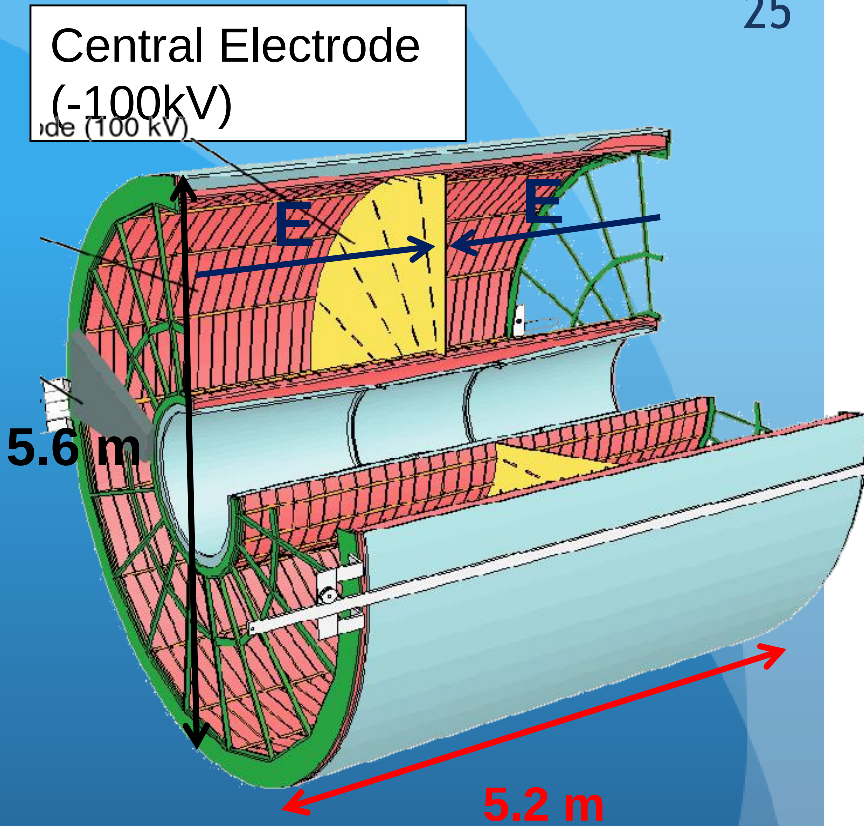
- New ITS + GEM-TPC (keep current tracking & PID capability)
  - Improve tracking efficiency, rejection of conversion and Dalitz
- 50kHz data taking. B=0.2 T

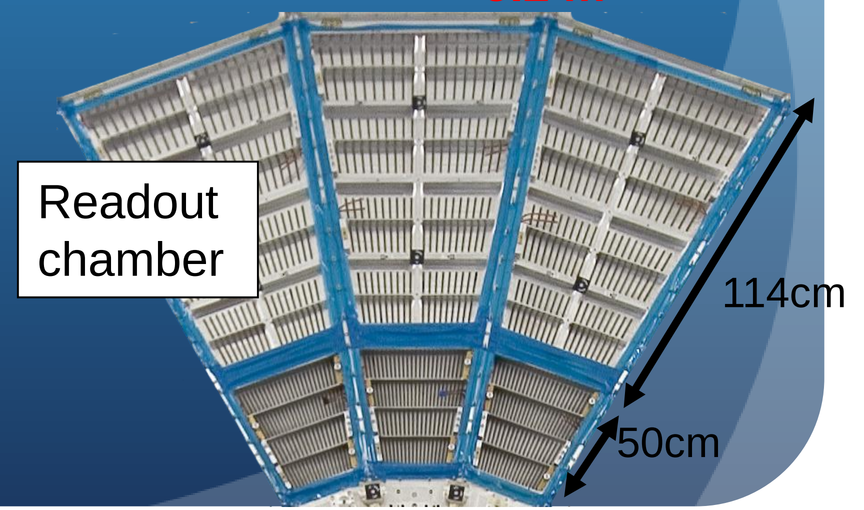


ALICE GEM-TPC upgrade

ALCIE TPC - I

- Diameter: 5.6 m, length: 5.2 m
- Acceptance: $|\eta|<0.9$, $\Delta\phi=2\pi$
- Readout Chambers: total = 72
  - Outer: 18 x 2, Inner: 18 x 2
  - Pad size
    - Inner: 4×7.5 mm^2
    - Outer: 6×10 mm^2
  - Pad channel number = 557,568
- Gas: Ne-CO_2-N_2 (90-10-5)
  at Drift field = 400V/cm
  - Diffusion ~0.2mm /1cm
  - Drift velocity ~0.8cm/μs
- Total drift time: 92μs

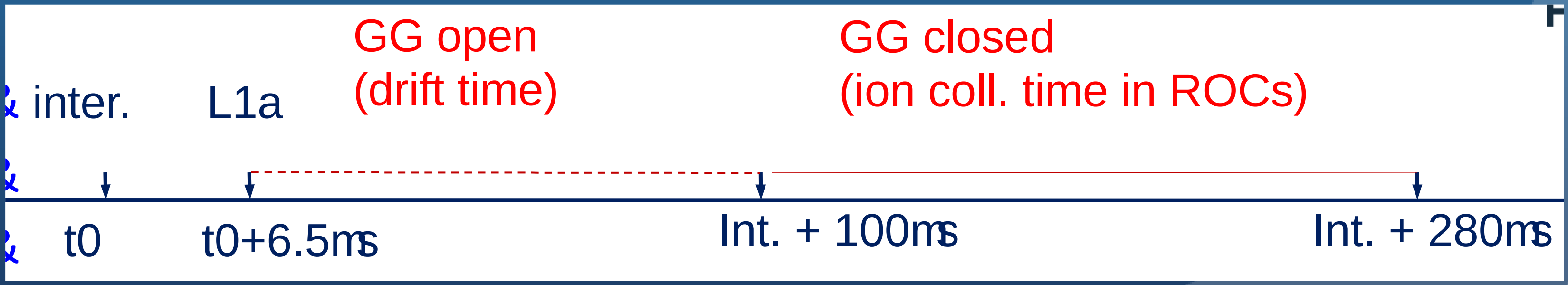




Current Rate limitation

- Gating Grid operation
  - Gating Grid (GG) is used to prevent ion back flow into the drift region
  - It takes ~180 μs for the ions generated in the MWPC to reach the GG → unavoidable dead time after each triggered event
  - Additional 100 μs for suppression of event pile-up

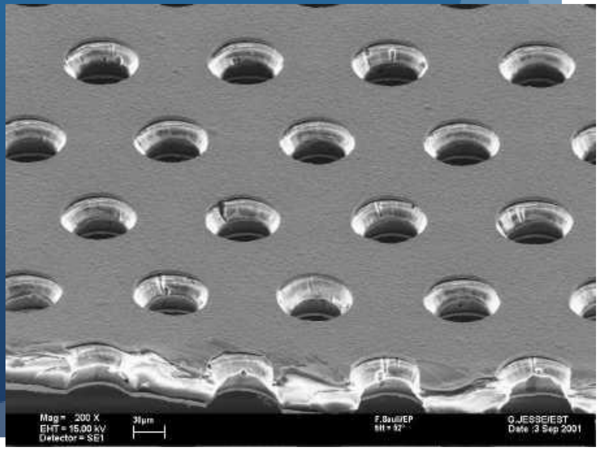
--> Maximum GG trigger rate is ~3.5 kHz



TPC Core Upgrade and strategy

- Goal, Requirements
  - No gating grid operation but keep small ion back flow capability to avoid a field distortion in the drift space
    - 0.25-1% of IBF at the gain of 2000 (= 5~20 ions per one seed)
  - Maintain the gain stability under 100 kHz/cm^2 particle rate
    - This is not possible with MWPC. Gain decreases by ~20%.
  - Keep current PID and tracking capabilities

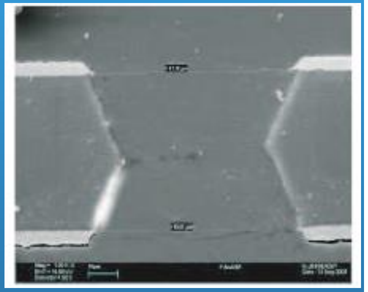
- Strategy
  - TPC Continuous readout without gating grid
    - No trigger, No deadtime
  - Replace MWPC readout by GEM readout
    - Efficient to block back-drifting ions
    - High rate capability
    - Preserve PID and tracking capability

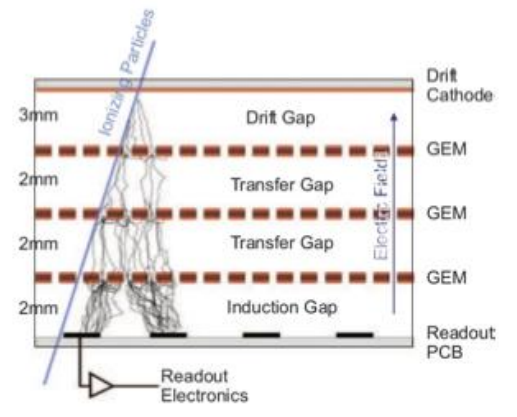


What is GEM?

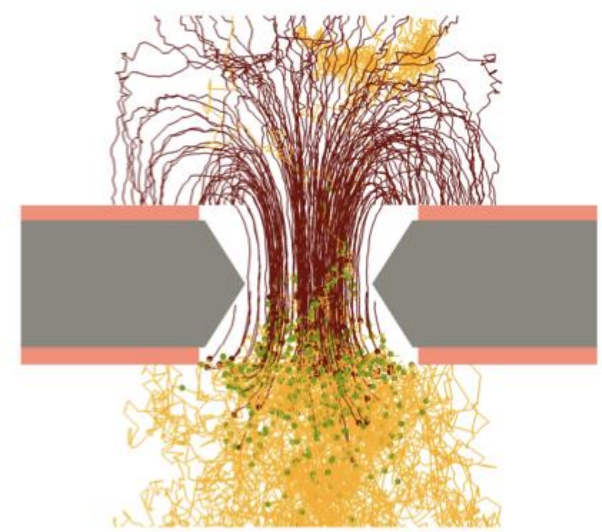
- Invented b F. Sauli (~1997)
- Standard GEM foil
  - 50um thick kapton
  - 5um Cu electrode
  - Pierce the hole

  (by chemical, laser, plasma etching)



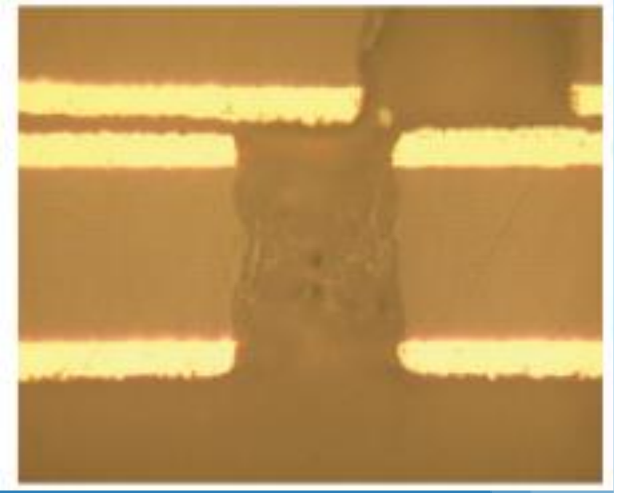


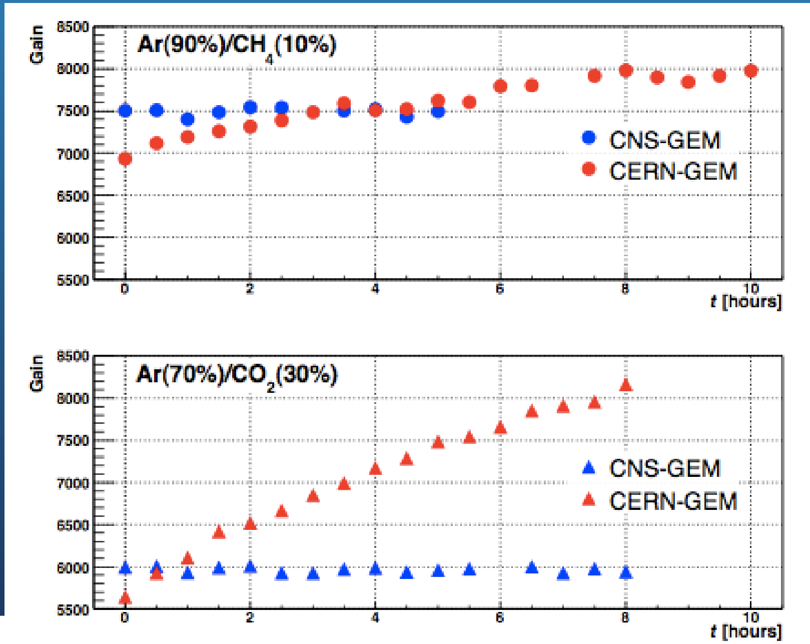
- Potential between upper and lower electrode
  - Avalanche inside of the hole
- Merit of the GEM (compared to MWPC)
  - Stable operation by stack configuration
  - High rate capability
  - Good IBF capability with asymmetric field
  - No ExB effect

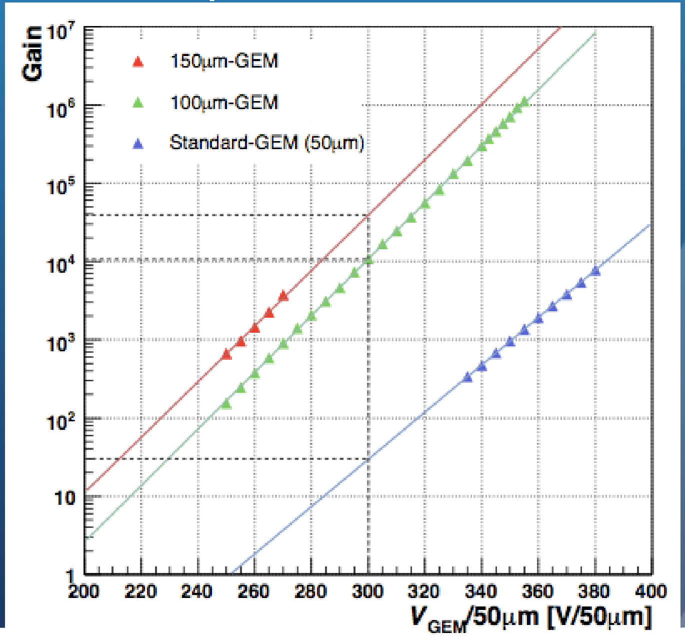


Experience of GEM in CNS

- We started GEM R&D since 2002.
- Fabrication of GEM in Japan (SciEnergy)
  - Plasma + Laser etching
  - Cylindrical holes
    - No charge up → stable operation
    - Thicker GEM (100um, 125um GEM) → stable operation

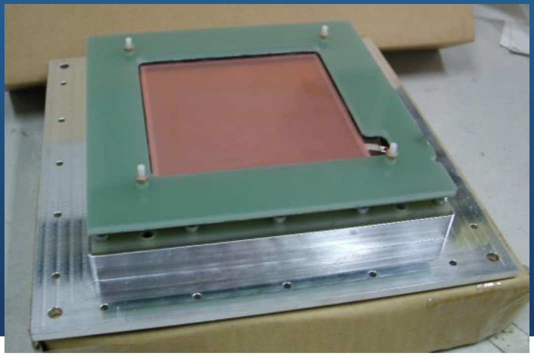


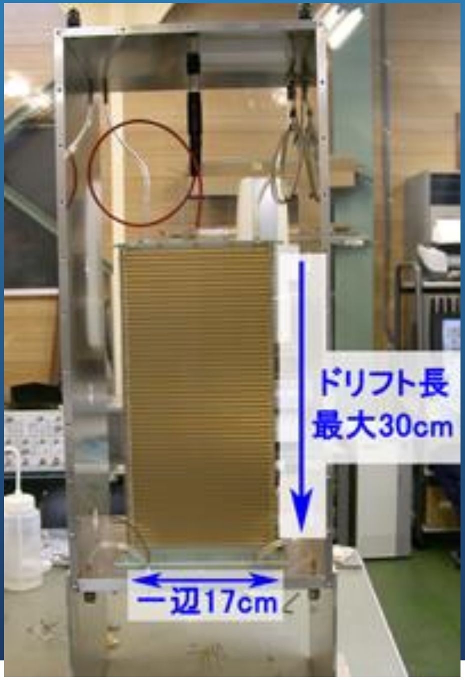


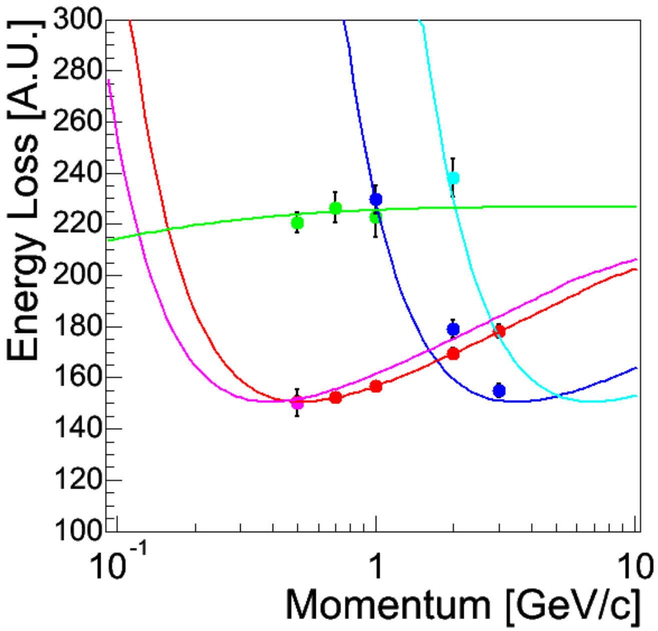


Experience of GEM in CNS

- Another type of GEM
  - COBRA-GEM for ion feedback suppression
  - Glass-GEM (no out gas, no neutron reaction with H, long term stability)
  - Telfon GEM (large arc resistance, robust against discharge/spark)
    - No short of GEM even after 10^4 times discharges (at single GEM gain~10^4)!
- Application
  - GEM-TPC (CF_4)
  - X-ray Imaging





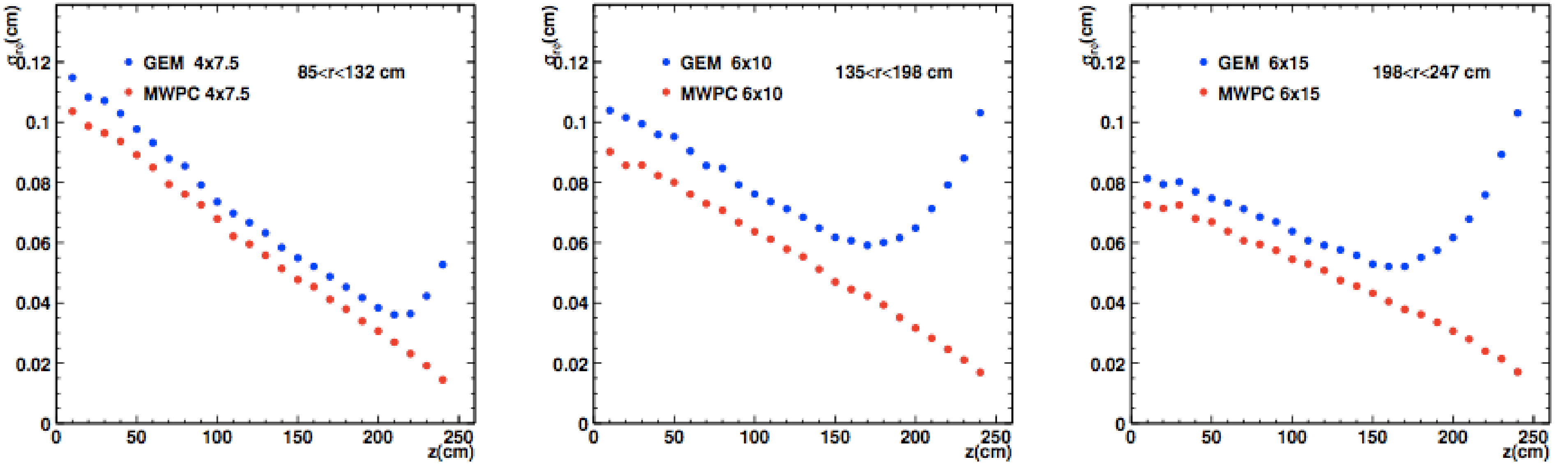


R&D items of GEM-TPC upgrade

- Gain stability of GEM under Ne/CO_2
- Systematic study of Ion back flow
  - 3-4 GEM layers (pitch, hole, transfer field dependence)
  - Another type of GEM (Cobra GEM)
  - Micromegas + 2 GEM systems
  - Garfield simulation
- Large size foil R&D, IROC Prototype and Beamtest
- Electronics R&D
  - SAMPA chip, GdSP chip
- Performance evaluation, reconstruct strategy

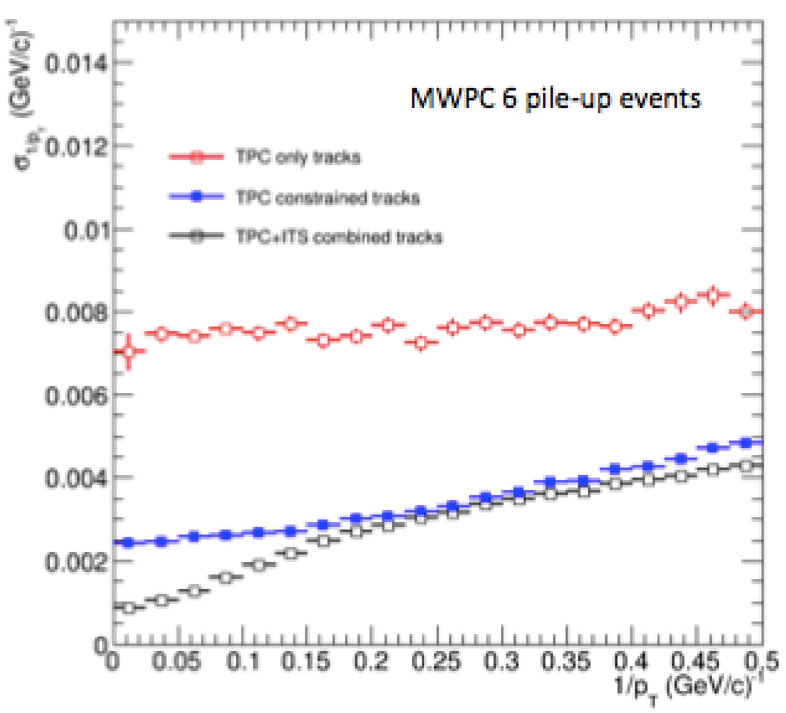
Expected Performance

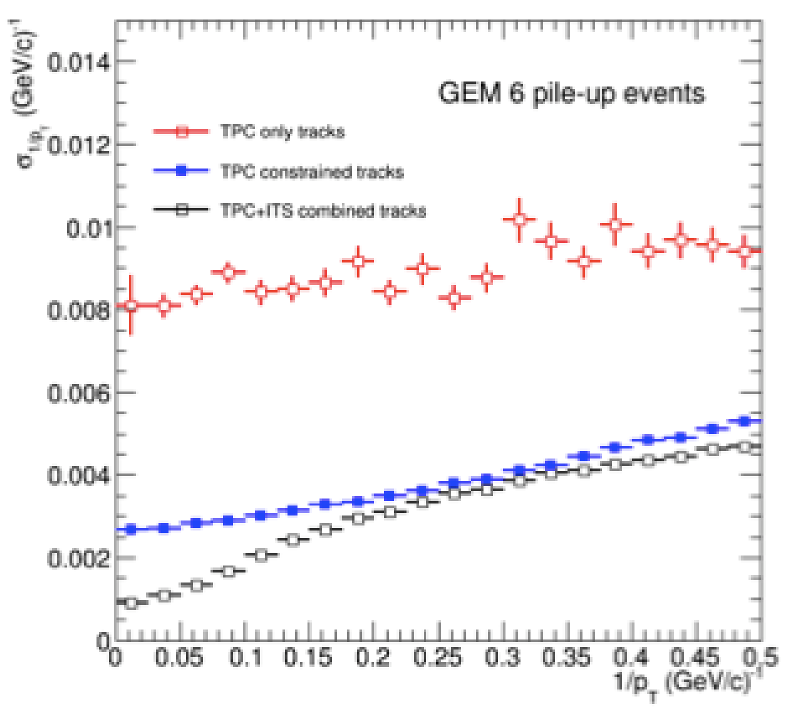
- Position Resolution
  - Slightly worse than MWPC due to lack of a Pad Response function in GEMs (narrow spread of signal over pads)
  - Near the chamber worse resolution due to low diffusion and narrow PRF



Expected Performance

- Momentum Resolution
  - Very little deterioration for TPC standalone and 6 pile-up events
    - Less merged cluster in case of GEMs: lack of PFR
  - No difference between MWPC and GEM in case of ITS vertex +TPC tracking



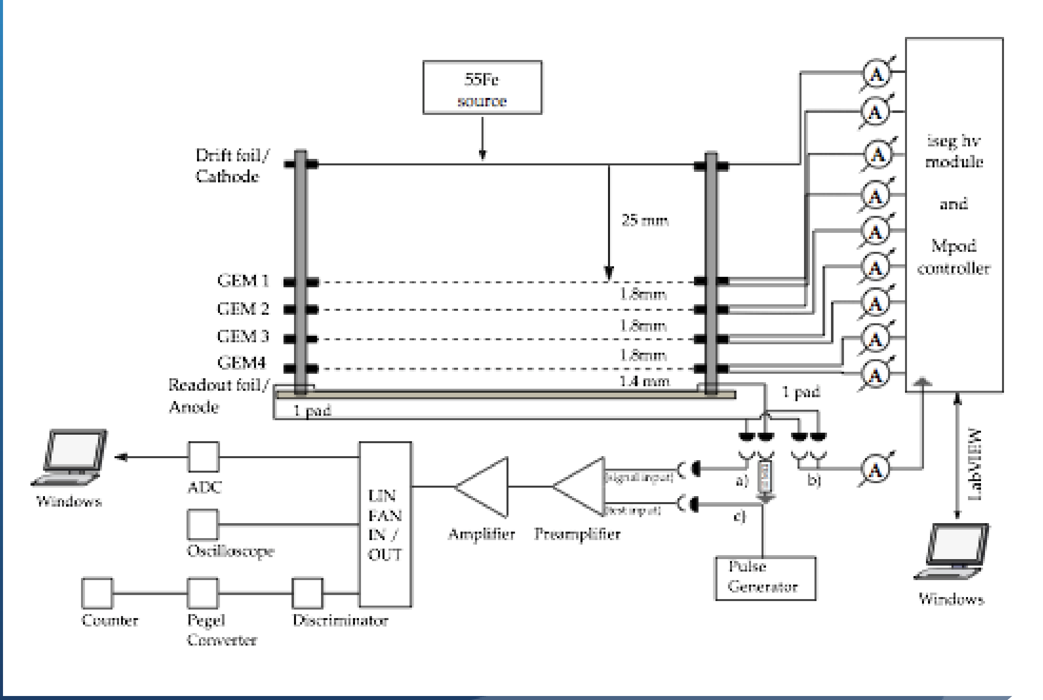


IBF studies

- Dedicated test setup at CERN, TUM, FRA, Tokyo
- Systematic studies as a function of:
  - rate → space-charge effect to the IBF
  - Field configuration, number of GEM layers, large pitch foil
- Measure the current

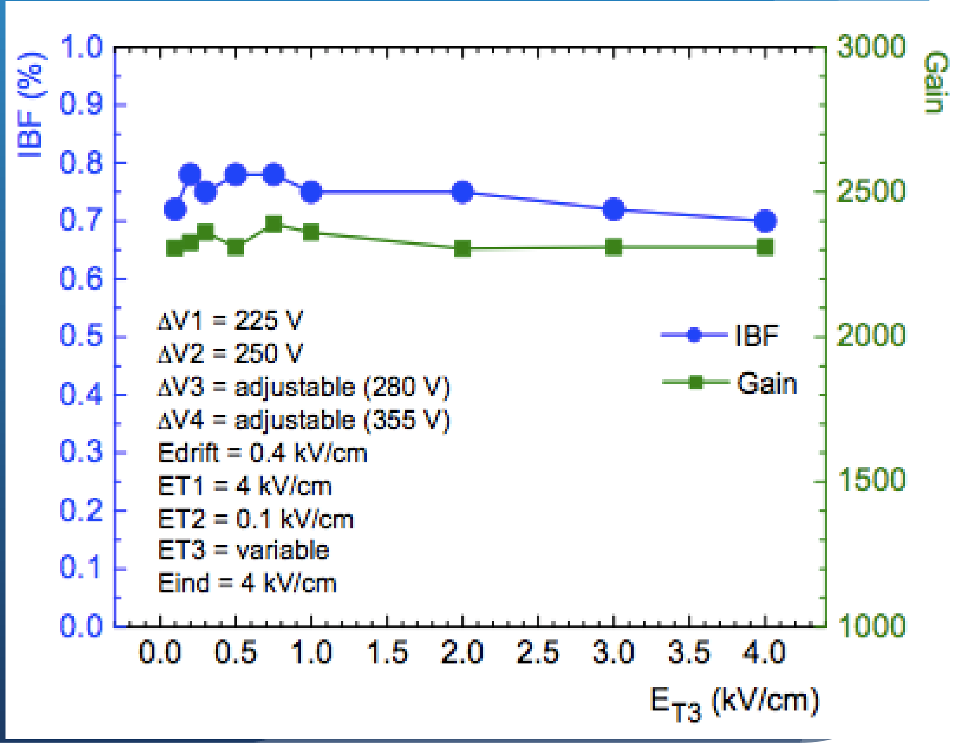
at cathode and anode pad.

$IBF=(I_c-I_c^0)/I_a$



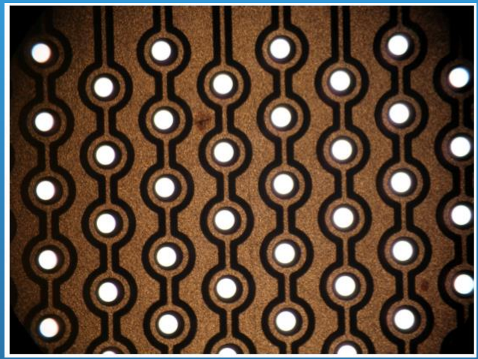
IBF studies

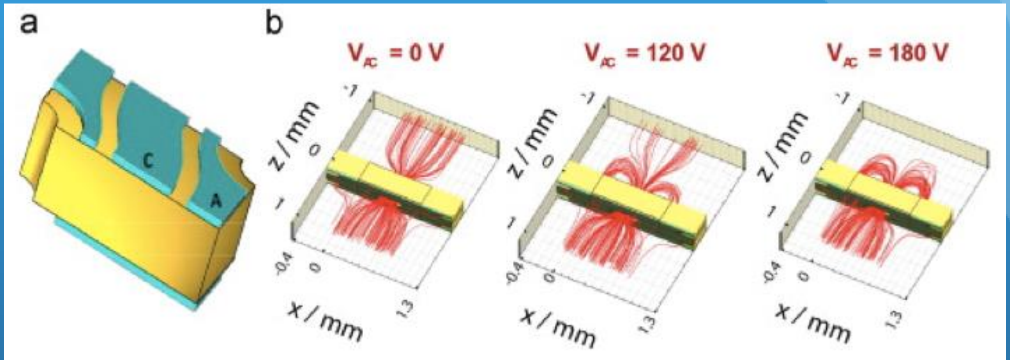
- 3 standard GEM setups ~ 2% of IBF
- 4 GEM setup with large pitch foils on GEM1 and GEM3
  - LP-S-LP-S: LP=280um pitch (S=140um pitch)
  - Reach 0.8% of IBF and secured some flexibility
- Further studies are on going
  - S-LP-LP-S setup
  - Resolution
  - Smaller pitch GEM
  - Conical GEM
  - etc…

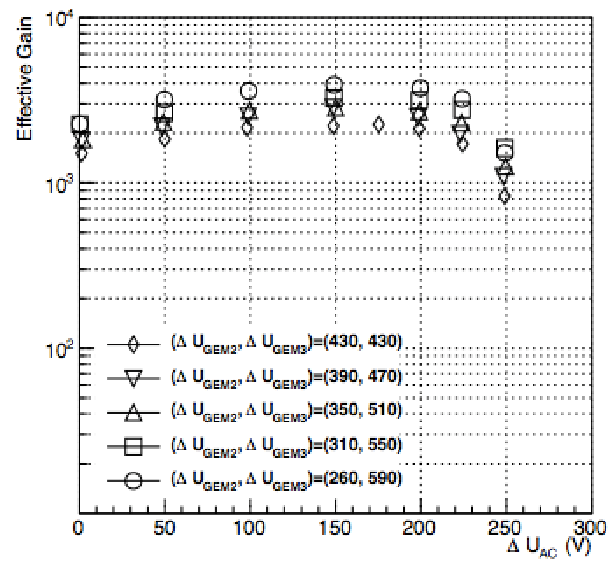


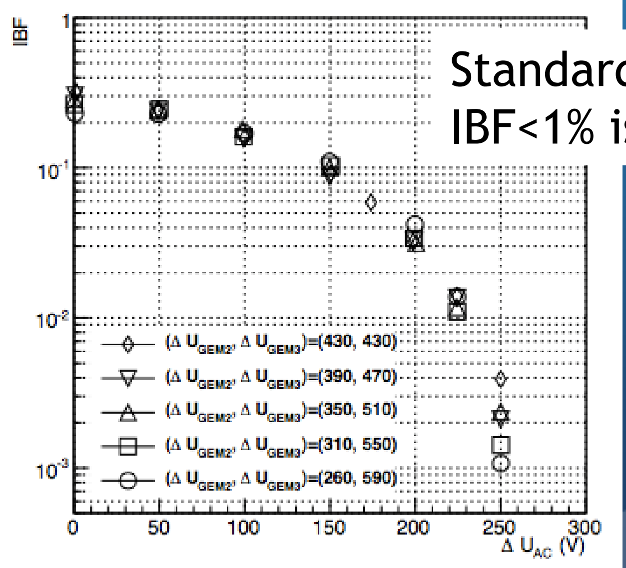
IBF studies

- Alternative options = "COBRA" GEMs
  - Additional electrode and potential difference to absorb ions







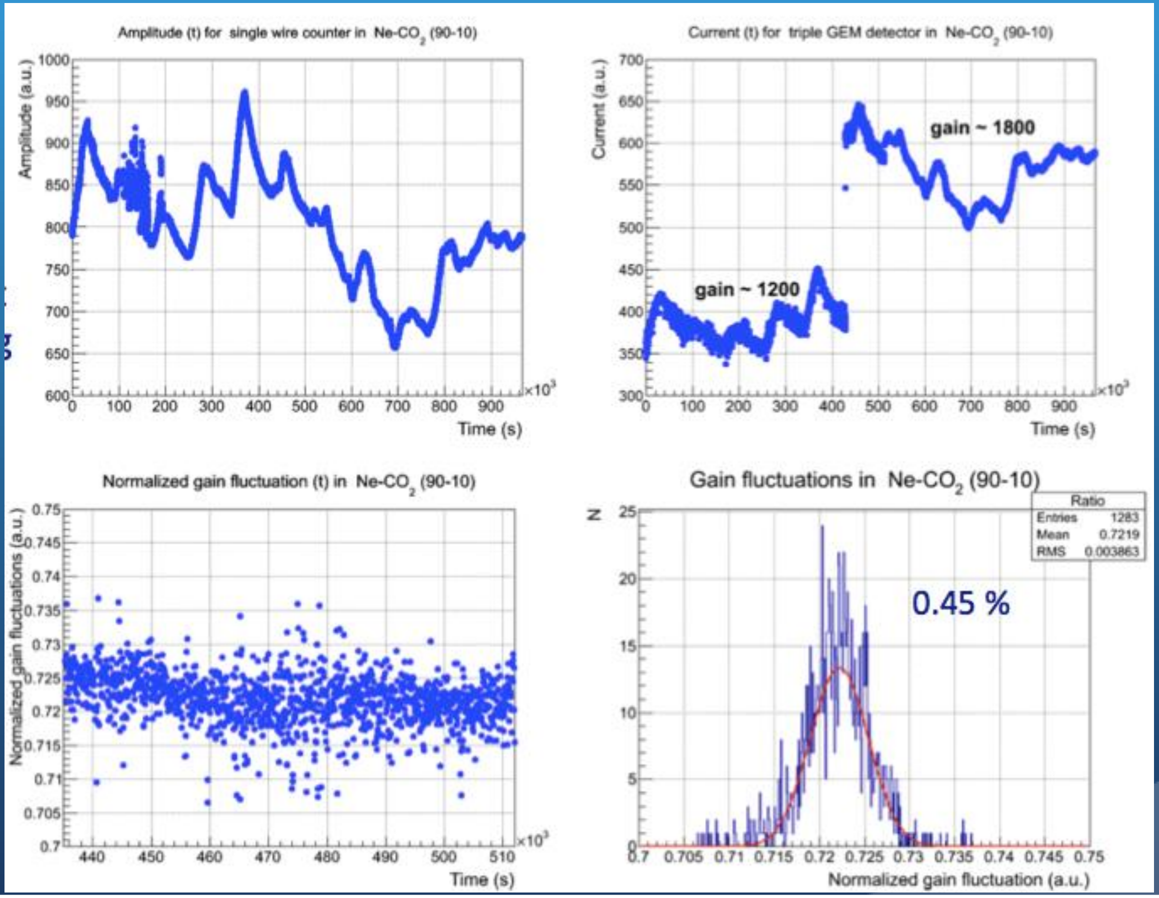


Standard - Cobra – Cobra
IBF<1% is reached!

COBRA-GEM
ϕ=150um
t=200um
Pitch=400um
Rim=50um

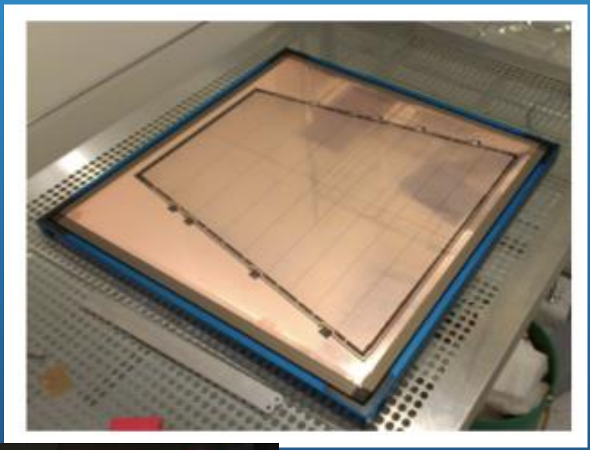
Stability

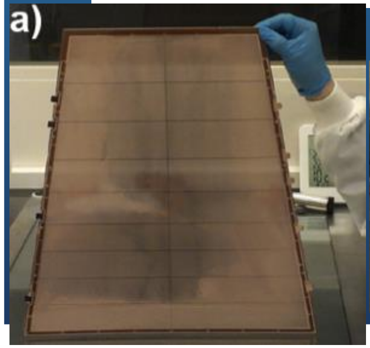
- GEM detector system and wire chamber system in one gas loop system. (common on gas concentration and P/T)
  - Wire-chamber is reference. Stability = 0.45%

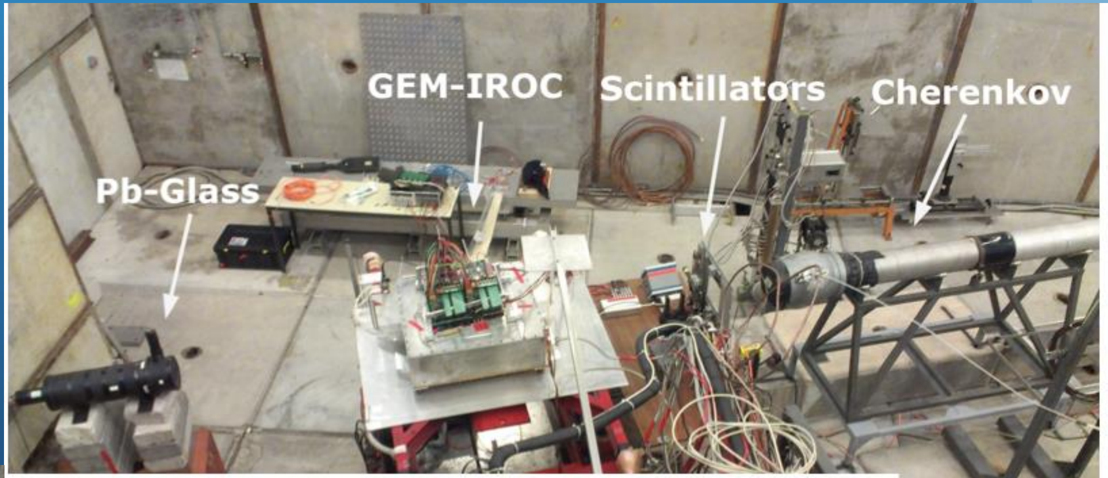


IROC Prototype and beamtest

- Large size GEM by “single” mask technology
  - 3 GEM layers for IROC size and prototype
  - Beamtest at CERN-PS T10 beamine (10-11. 2012)
    - PCA16 + ALTRO electronics (from LCTPC) + ALICE DAQ system





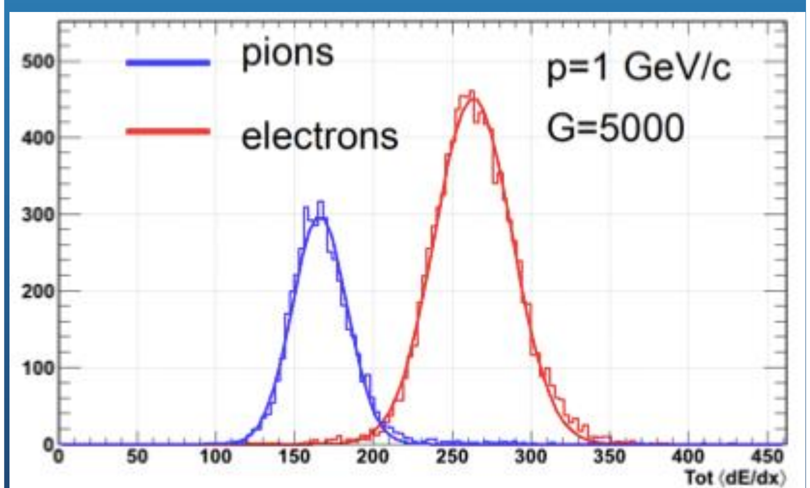


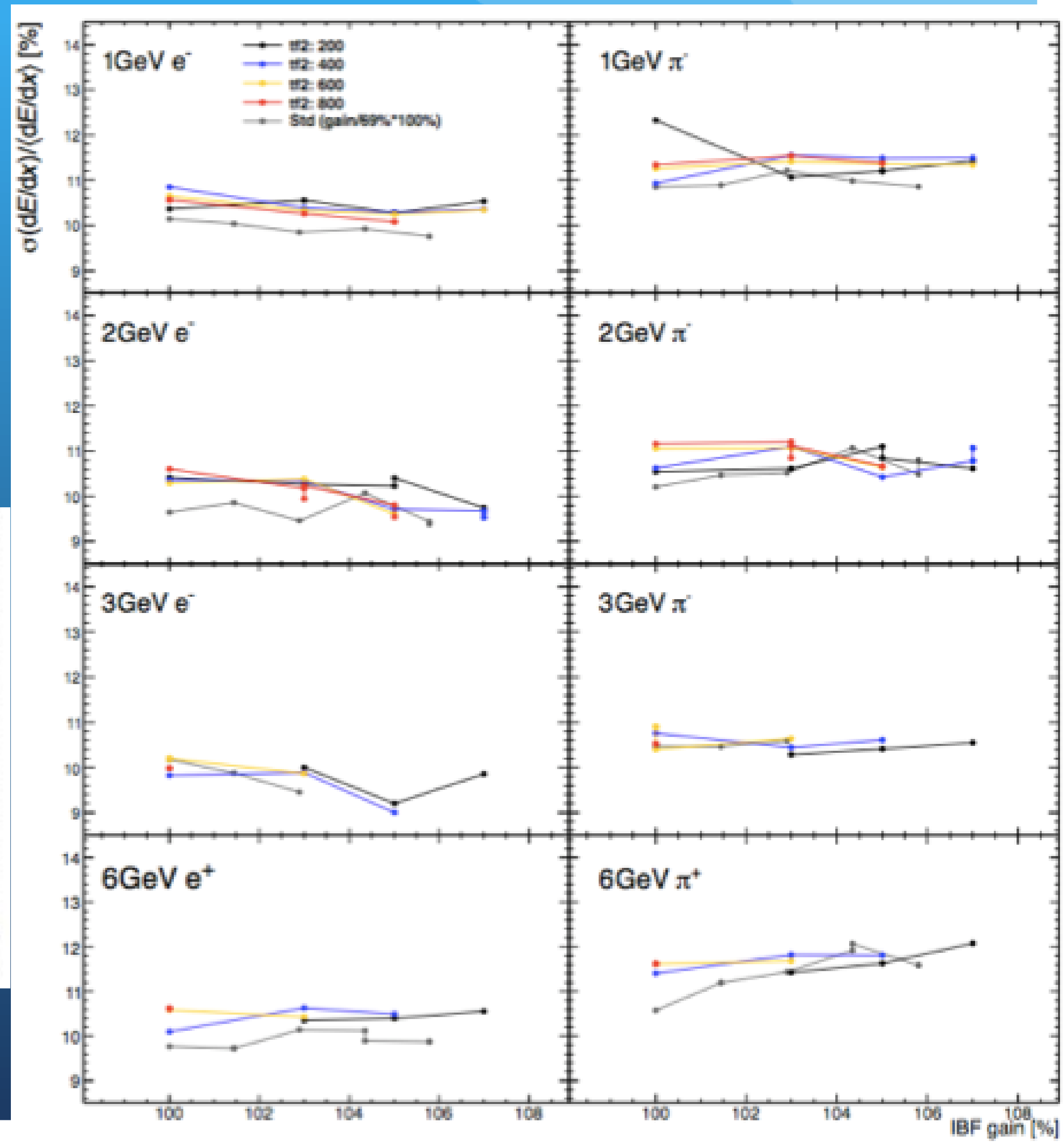
- p, π±, e± beam, 1/2/3/6 GeV/c
- 2000 particles / 0.5s
- Cherenkov and Pb glass detectors for external reference PID
- Goal: measure PID via dE/dx and dE/dx-separation power for different GEM settings

29

IROC Prototype

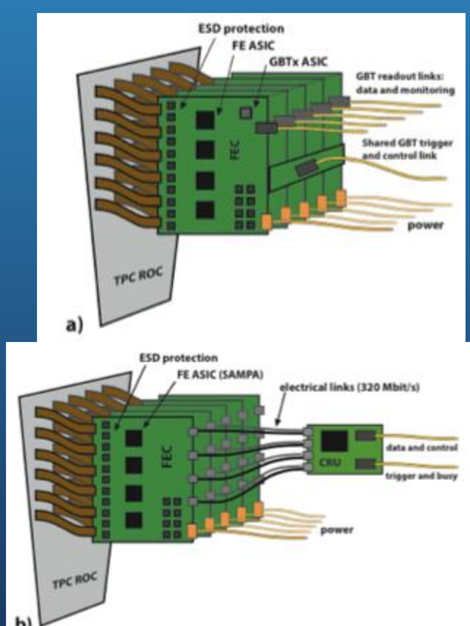
- dE/dx resolution
  - Only 46 rows are used.
  - Almost equal to the expected for MWPC. Performance is preserved.

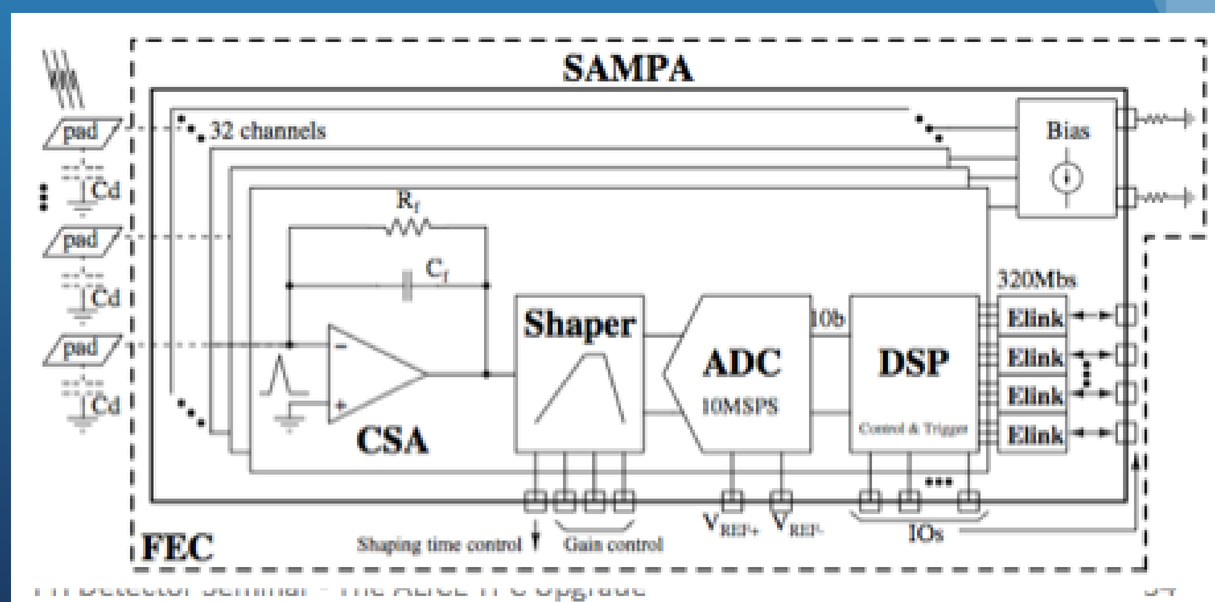




Readout system

- Readout system
  - Replace existing PASA+ALTRO to SAMPA system
  - SAMPA = 32channel PASA (dual polarity) + ALTRO in same die
    - 10~20MHz ADC capability, DSP, support trigger/continuous readout
  - Option = “GdSP” chip being developed at CERN
    - 40MHz, 128channel input, DSP, high speed data transmission via GBT





Status and Plans

- Technical Design Report will be submitted soon.
- 2013-2014: design and prototyping
- 2015-2016: production of GEMs (chambers) and FEE
- 2017-2018: Construction of ROCs, Installation and commissioning
    - Depending on shutdown schedule

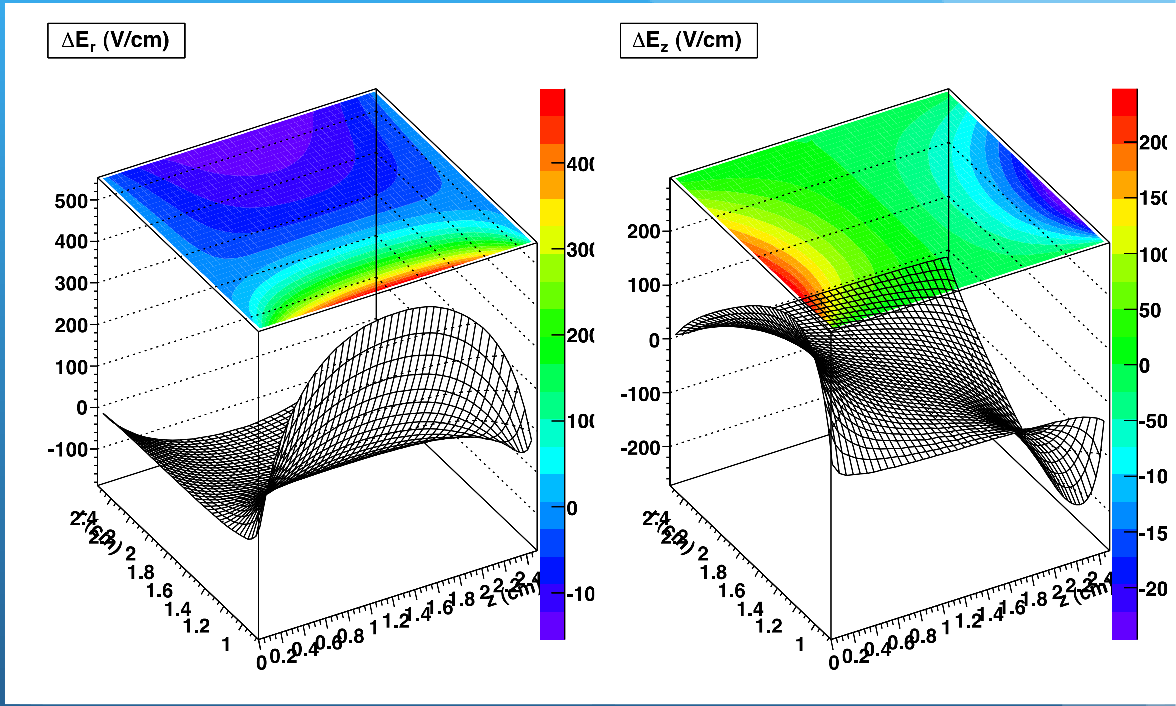
Summary and Outlook

- ALICE upgrades have been proposed to strengthen physics programs for precision QGP studies.
  - E-by-E flow, higher order flow for soft~hard probes, lepton, photons
  - ALICE is unique in low p_T physics, HQ measurements, dielectron measurement
  - Inspecting 50kHz of minimum bias Pb-Pb collisions
  - Require core upgrades (ITS, TPC, electronics, and DAQ), enhanced rate capabilities , and running beyond LS2/LS3.
    - Significant R&D efforts are on-going
  - GEM-TPC R&D is ongoing
    - To prove the principle, low IBF, space-charge distortion, online-offline corrections, continuous running.

Backup slides

Run at 50 kHz Pb-Pb after LS2

- With present MWPC readout, space-charge leads to unbearable distortions (order 1 m) and deterioration of dE/dx (10-20% gain drop)



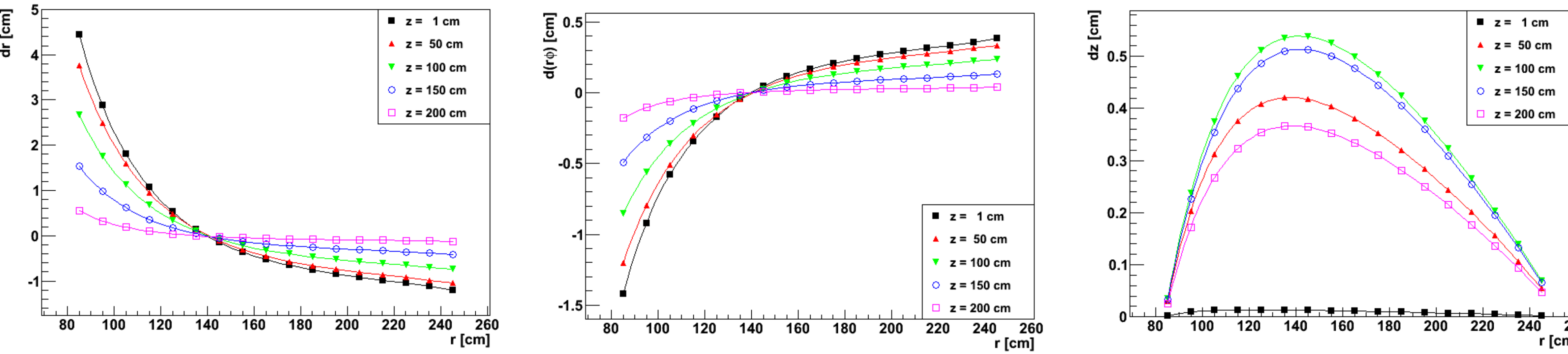
☞ GEMs offer the possibility to sustain continuous readout under high rates at a lower gain, while efficiently blocking ions to the % level

☞ 100 m^2 of large size foils, long drifts, high rates

Ongoing R&D: Ion Back Flow (IBF)

- High rates and long drifts: ‘standard’ GEM operation results in too large distortions (IBF 5-10%).
- IBF can be minimised by optimising electric fields, GEM geometry, gain sharing*: for IBF ~ 0.25% distortions stay well below 10 cm, as shown in simulations below
- Target value is IBF ~ 0.25% at gain 1000-2000

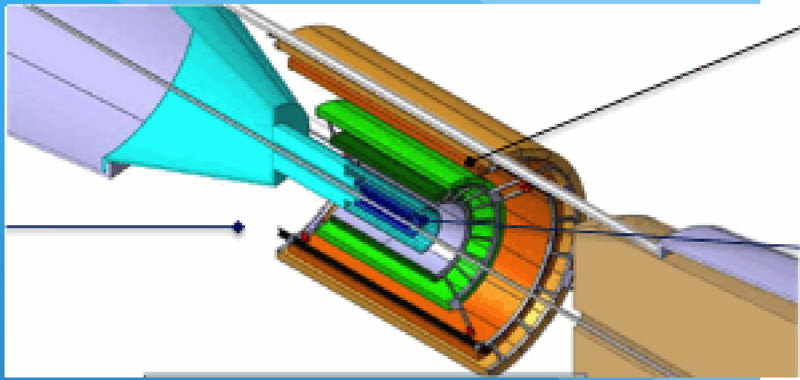
') :>$2333[$=>$D) 7E$a=X $30 2M Z $



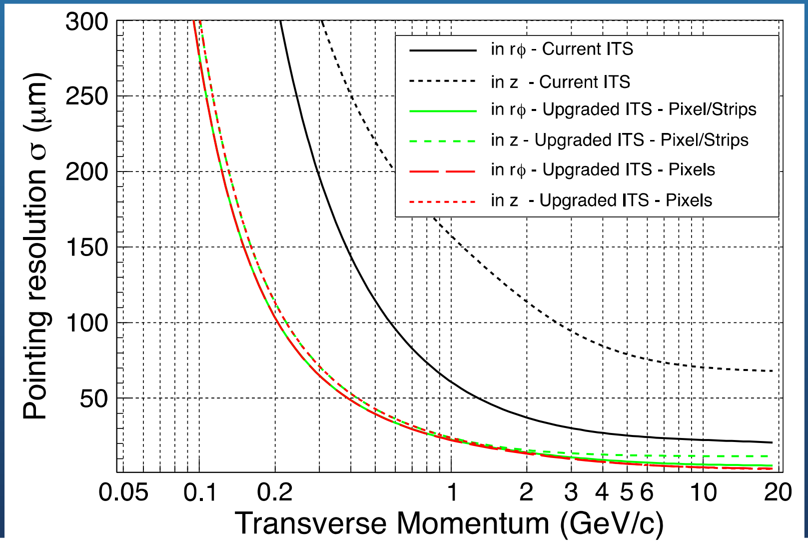
z = 1 cm
z = 50 cm
z = 100 cm
z = 150 cm
z = 200 cm

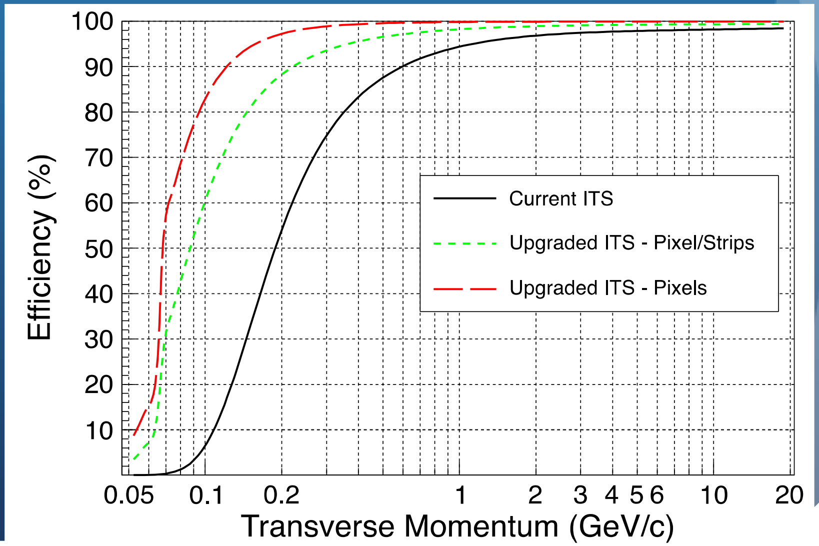
* M. Killenberg et al. NIM A530, 251 (2004) , B. Ketzer et al. arXiv:1207.0013

Core Detector Upgrades - ITS



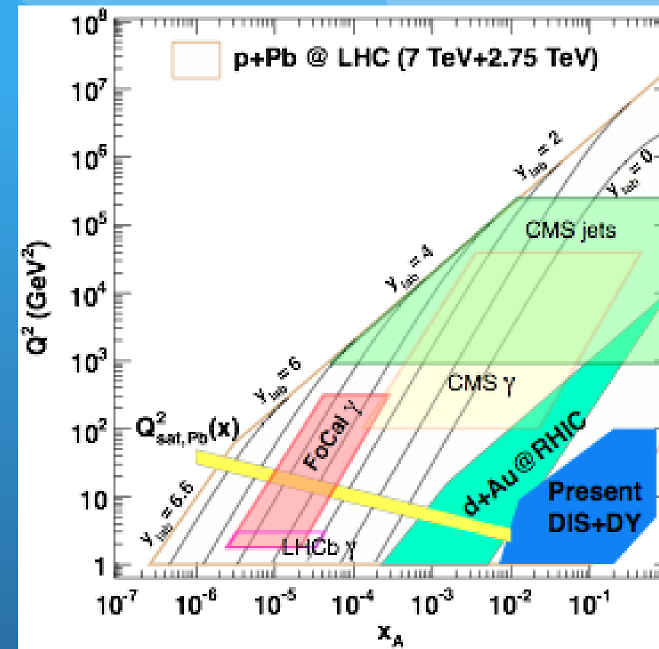
- 6->7 Si layers
  - 7 pixels or 3(pixel)+4(strip)
  - Inner most at R=2.2cm
  - Low material 0.3%X_0/lay (←1.14%X_0)
  - Hybrid-pixel or MAPS(MIMOSA, LePIX, INMAPS). Extensive R&D.
  - Improve vertex resolution by factor of 3
  - Improve low pT tracking efficiency





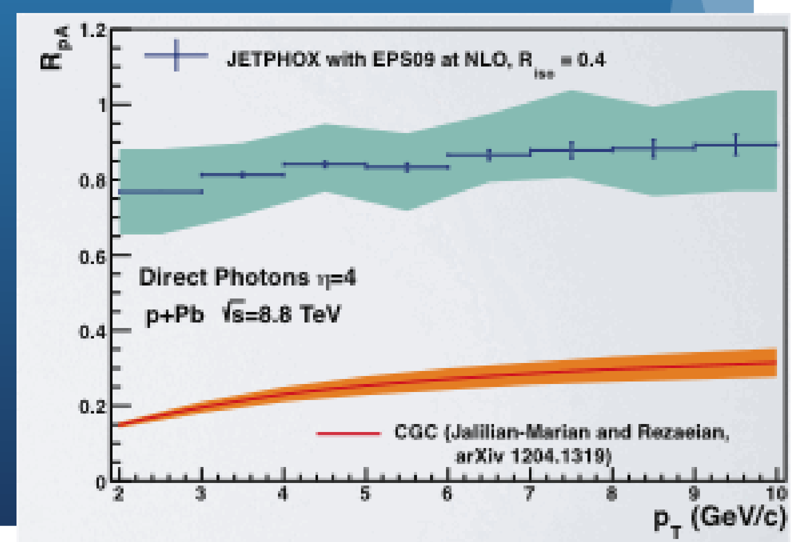
Other upgrades - FOCAL

C.A. Salgado, JPG 38 (2011) 124036



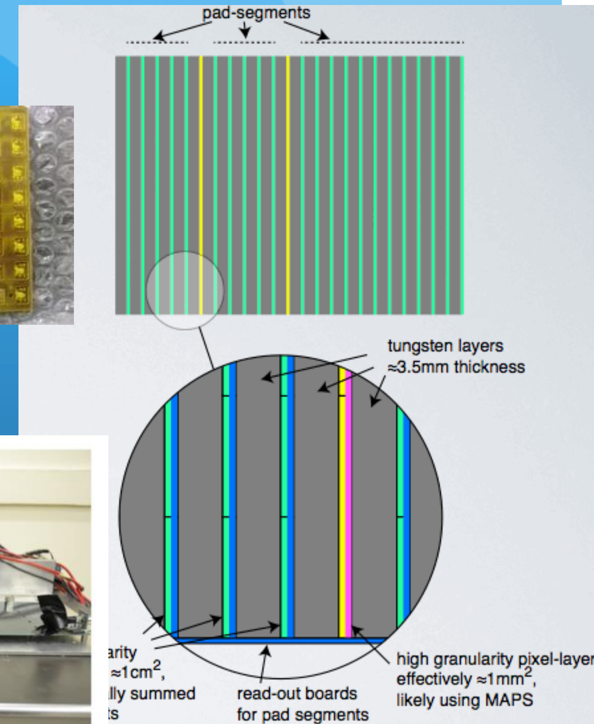
- FOCAL(Forward Calorimeter)
  - Gluon saturation at small-x
  - Early stage dynamics of HI collisions
- Unique opportunity for ALICE
  - highest eta(>3) with wide p_T coverage
  - Prompt photon, π^0, jets, (quarkonia)

  and correlation with rapidity gap
- W+Si EM Sampling Calorimeter
  - \+ H-CAL behind under consideration
  - Two possibilities on location
    - 3m (2.5<eta<4.2) from IP
    - 8m (3.3<eta<5.0) from IP



Other upgrades - FOCAL

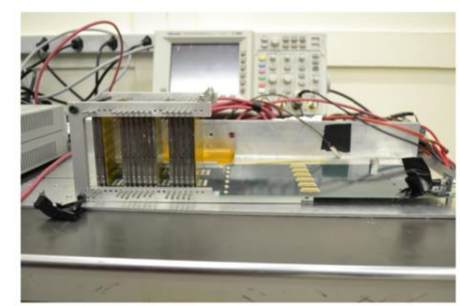
- FOCAL detector design
  - Two combination of the detector
    - Low granularity Si-Pad layers
    - High granularity Si pixel layers
      - Separation of $\pi^0 \rightarrow 2\gamma$ and prompt γ



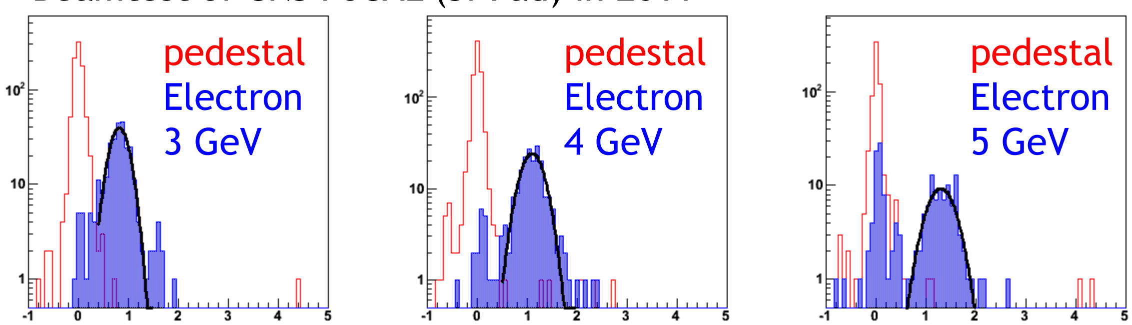
- Prototype R&D
  - Si-Pad and electronics

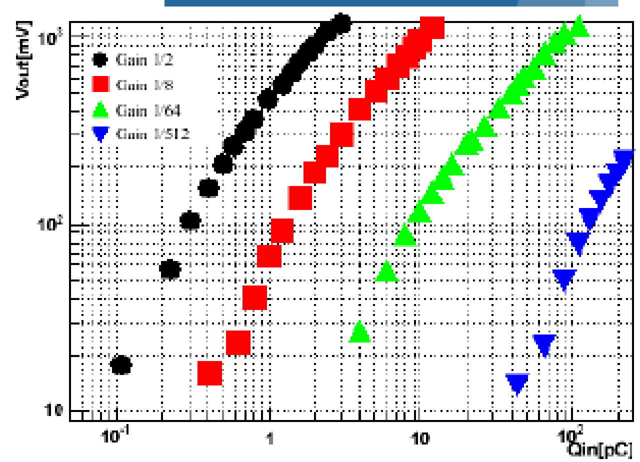
ASIC development (CNS et al.)

  - Si-Pixel (MAPS) development



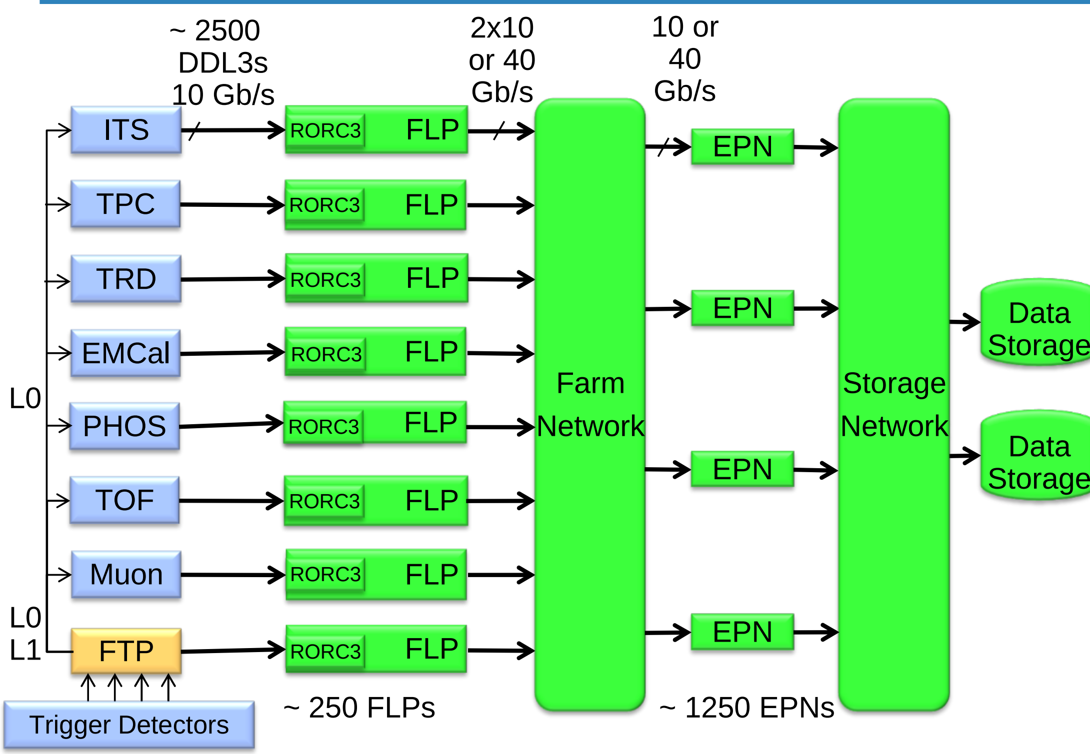
Beamtest of CNS FoCAL (Si-Pad) in 2011





Core Upgrade - DAQ

- DAQ upgrade
  - Requirements: ~1TByte/s detector readout, 20GB/s in storage
  - Strategy:
    - Data reduction by (partial) online reconstruction and compression.
    - Store only reconstructed data (tight coupling between online and offline)



FTP (Fast Trigger Processor)
- CLK/L0/L1, data tagging (ITS/TPC)

DDL/RORC
- DDL3(10GB/s)
- 10-12 DDL3, PCIe GEN3 in RORC3

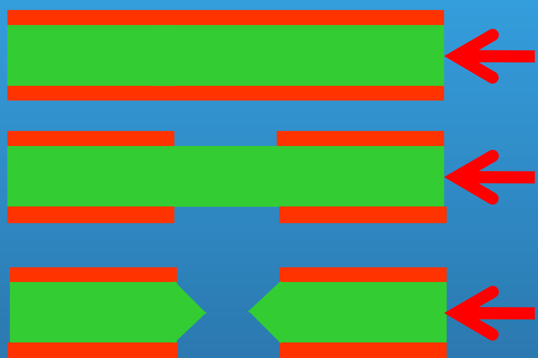
Network
- 10/100GBit Ethernet
- QDR/FDR Infiniband (42/50GBit)

FLP (First Level Processor)
- ZS, data compression/localized reconstruction

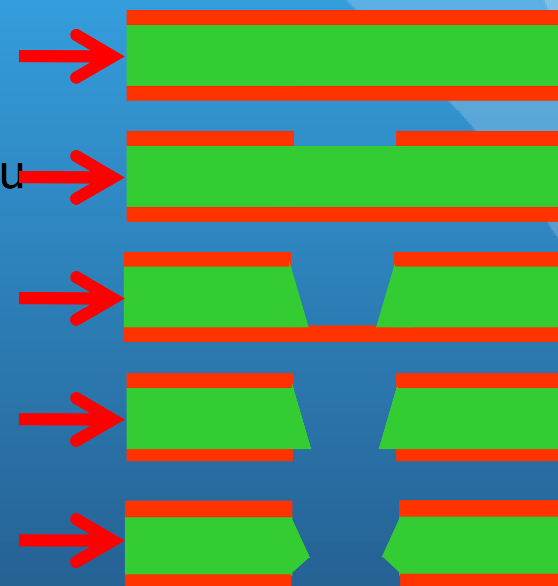
EPN (Event building and Processing Node)
- Event building/final data compression (CPU/GPU)

Single mask GEM

- Double mask



- Single mask



- Same base material
- Hole patterning in Cu
- Polyimide etch
- Bottom electro etch
- Second Polyimide Etch

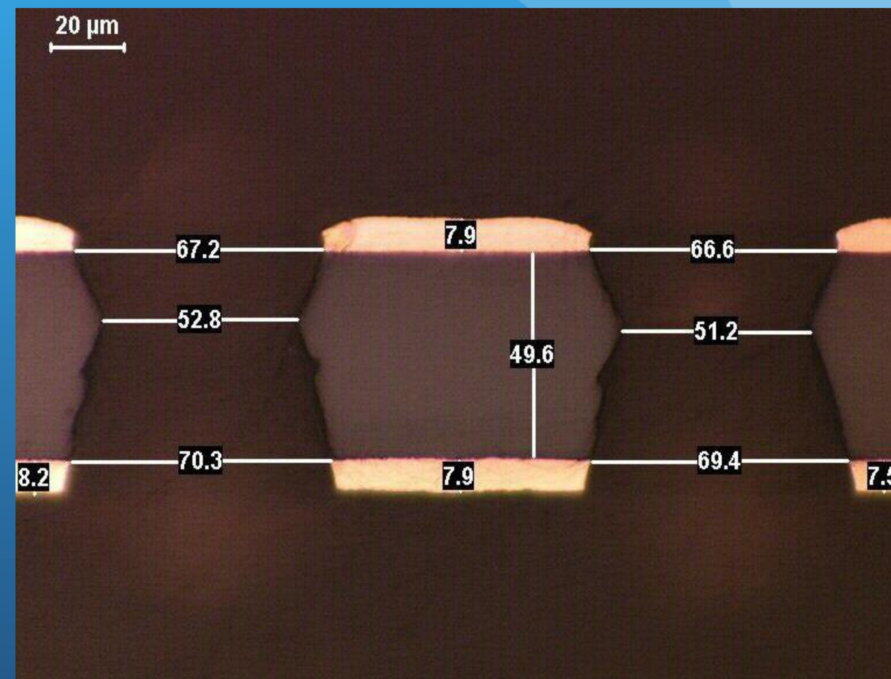
- Limited to 40cm x 40cm due to
  - Mask precision and alignment

- Limited to 2m x 60cm due to
  - Base material
  - Equipment

R. De Oliveira

Single mask GEM

R. De Oliveira

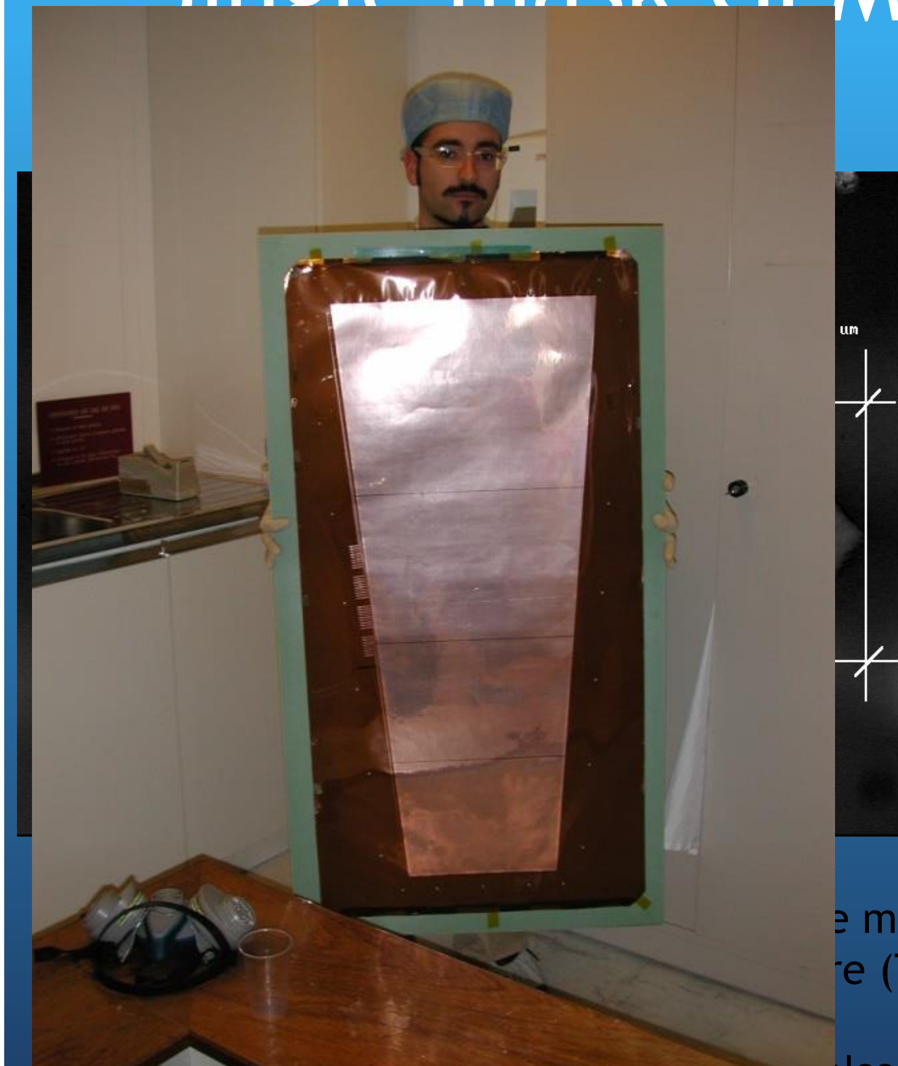


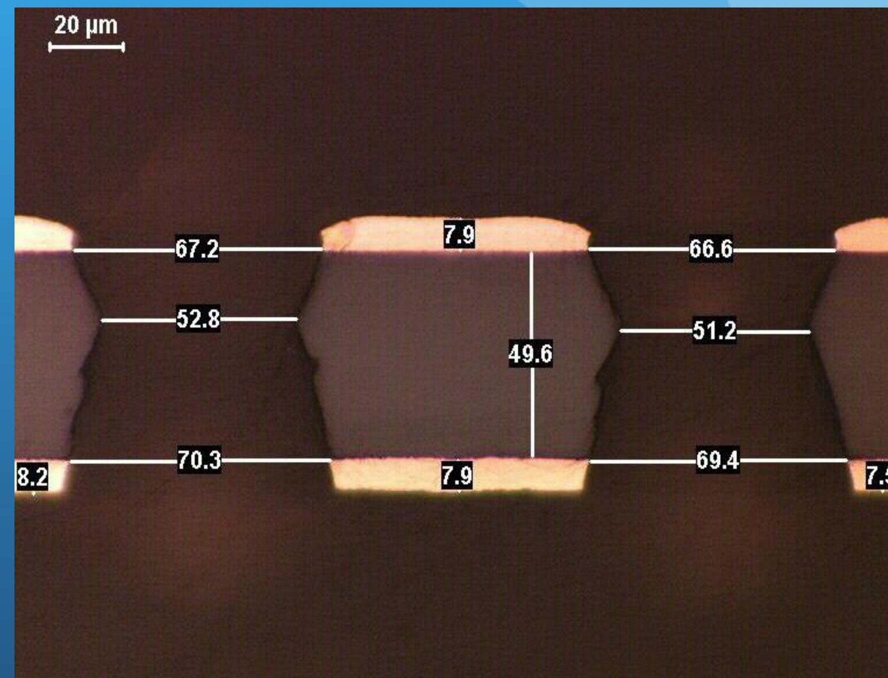
- Similar patterns , similar behavior, same material.
- Angles can be adjusted in both structure (Typ. value : 70um copper hole , 50um polyimide hole)

    Steeper angles give lower gain but also reduced charging up (similar as RIM in THGEM)

Single mask GEM

R. De Oliveira





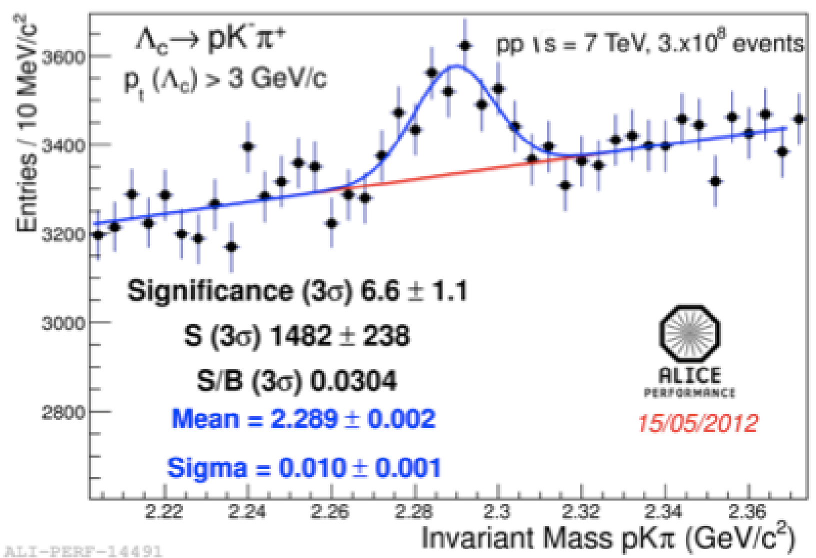
e material.
re (Typ. value : 70um copper hole , 50um

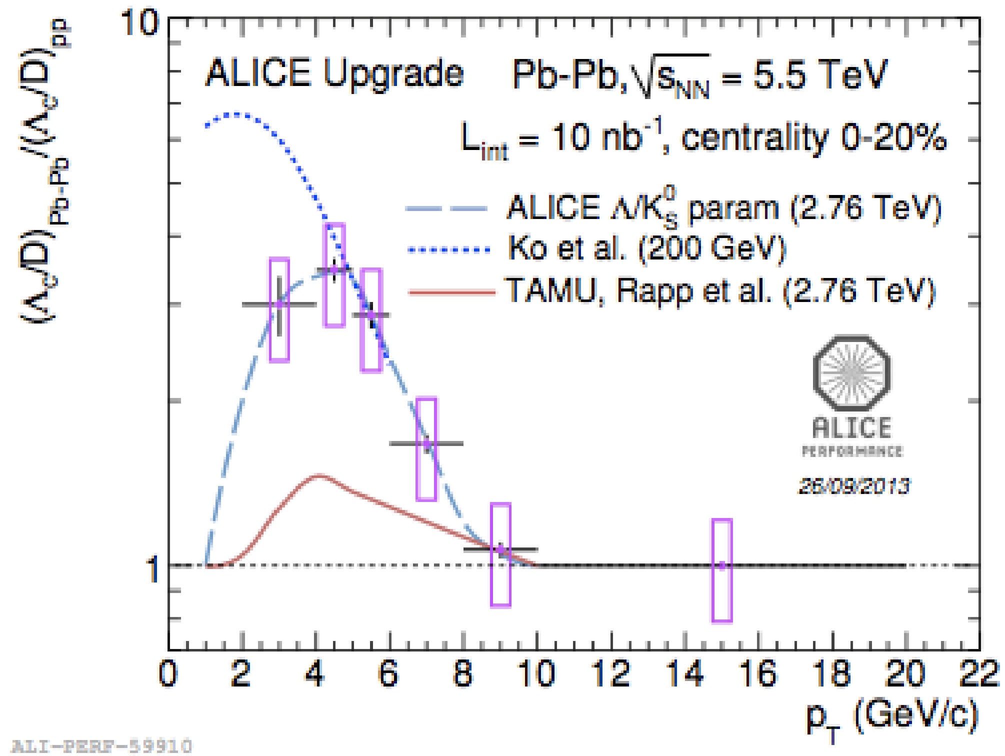
also reduced charging up (similar as RIM in
THGEM)

WILL BE USED FOR CMS FORWARD MUON TRACKER

Heavy Flavor Measurements

- Improvement of secondary vertex resolution by x2
  - Measurement of Λ_c, D_s, Λ_b
  - v2 and R_{AA} for wide pT range (down to low pT)
  - Better feasibility to measure Λ_c



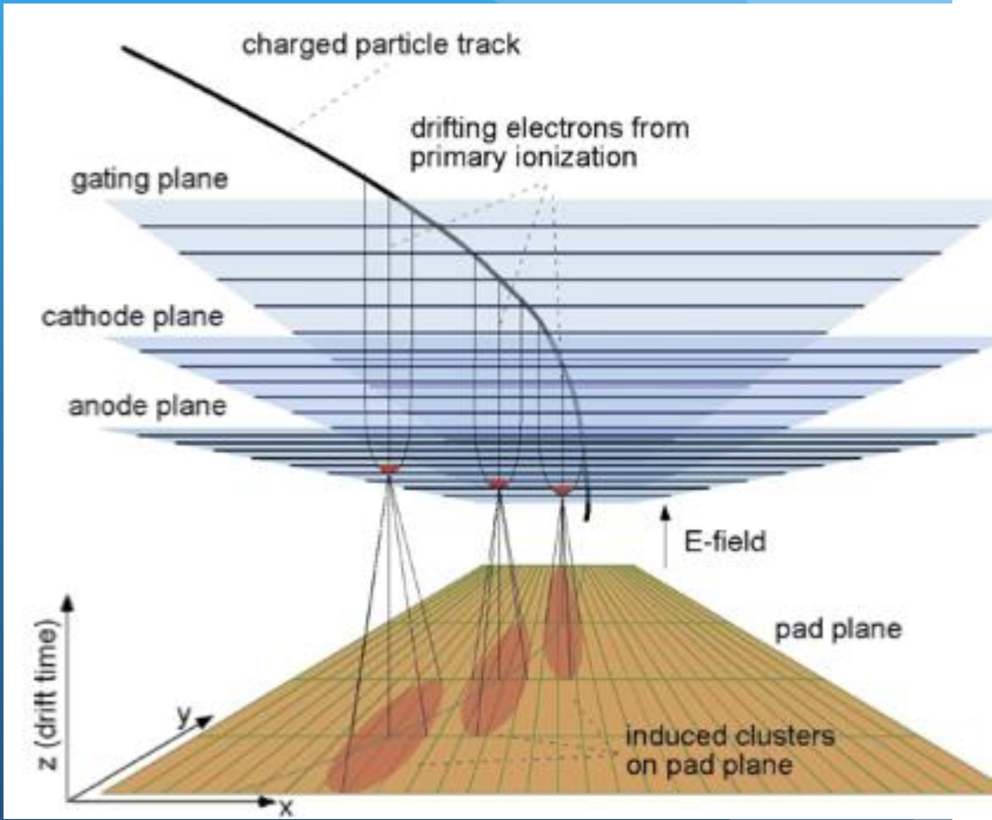


ALICE Status with the upgrades

		Status as of today	Reachable for approved	Reach with the upgrade
Bulk production	light flavours, v_2, HBT	quantitative	precision	precision
Intermediate p_t	v_2, correlations, baryon-meson	quantitative	precision	precision
High-p_t – jets	R_{AA}, correlations, jet fragm.	quantitative	precision	precision
	heavy-flavour in jets		hint	quantitative
	PID fragmentation	hint	quantitative	precision
Heavy flavour	D-mesons, R_{AA}	quantitative		precision
	D-meson v_2	hint		precision
	beauty, D_s	hint	quantitative	precision
	charm baryons		hint	quantitative
Charmonia	J/ψ forward, R_{AA}	quantitative	precision	precision
	J/ψ v_2	hint	quantitative	precision
	ψ', χ_c			quantitative
	J/ψ central, Υ family	hint	quantitative	precision
Dileptons – γ	virtual γ	hint		quantitative
	ρ-meson			quantitative
Heavy nuclei	hyper(anti)nuclei, H-dibaryon	hint	quantitative	precision

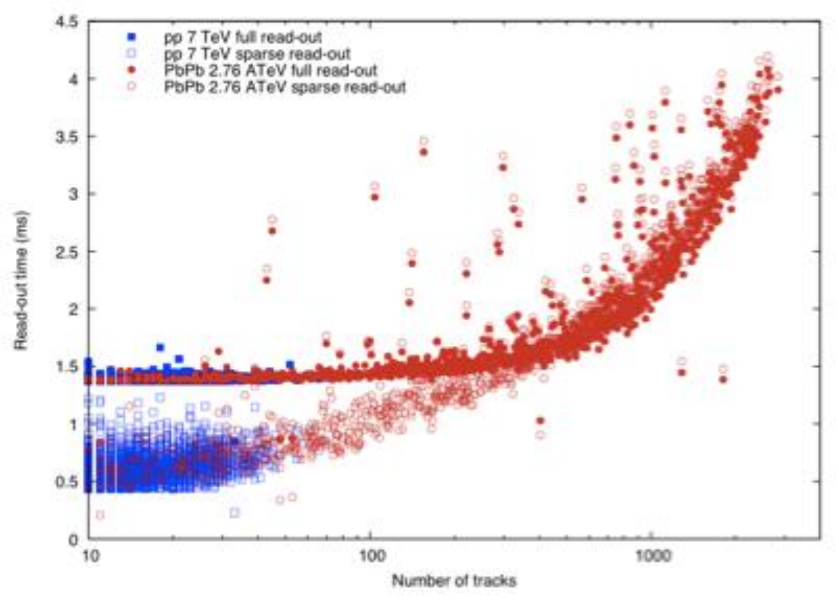
ALCIE TPC - II

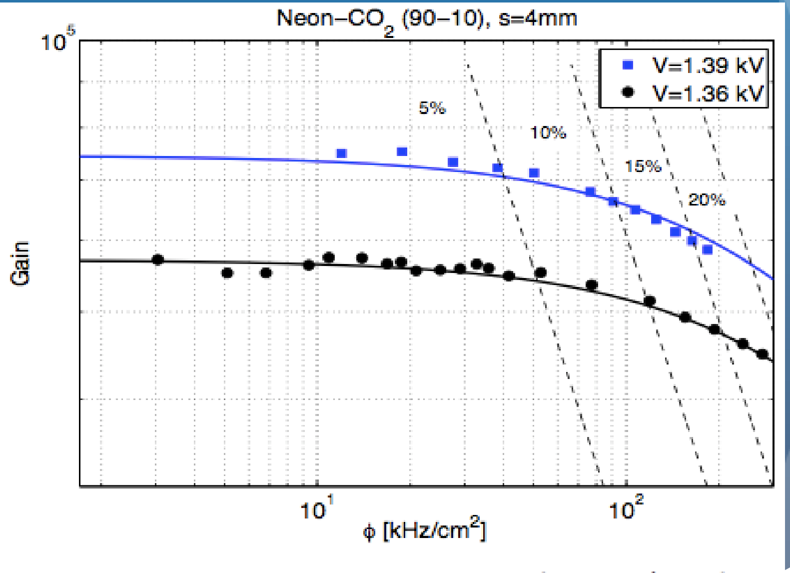
- Gating wire
  - Prevent ions from drifting back to the drift space
  - Important to avoid field distortion
- Cathod, anode wire planes
- Gas gain ~ $2x10^4$
- Multiplication of drift electrons at anode
- Induced current on the readout pad



Current Limitations - II

- Current readout capability is worse
  - Maximum is ~300 Hz due to TPC readout capability
  - LS1 upgrade (RCU upgrade) → 1kHz BW
- Rate tolerance of wire amplification. O(10kHz/cm^2)

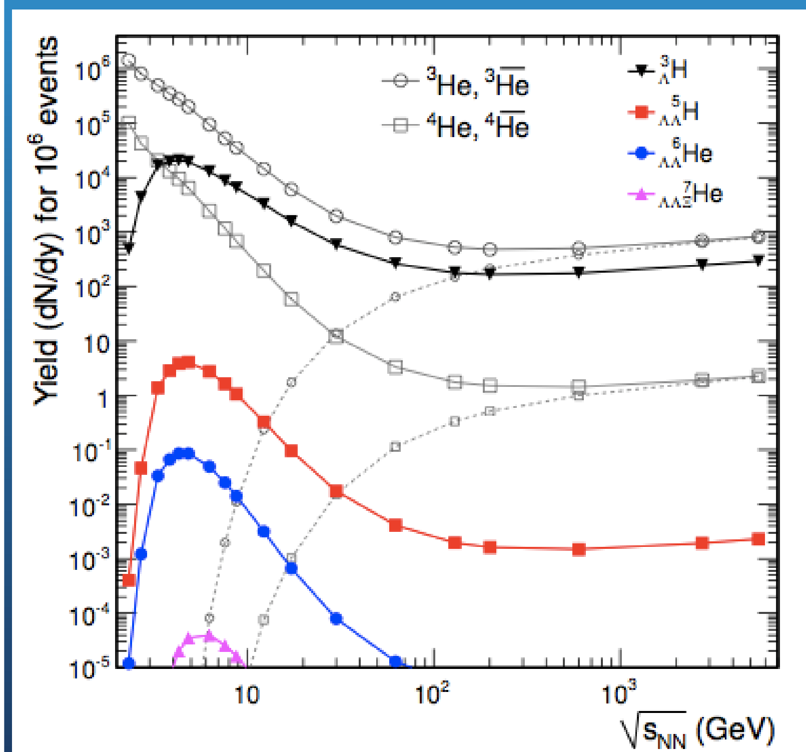




D. Gonzalez-Diaz[1] et al.

Exotics

- 10^{10} central events. Feasible for these measurements



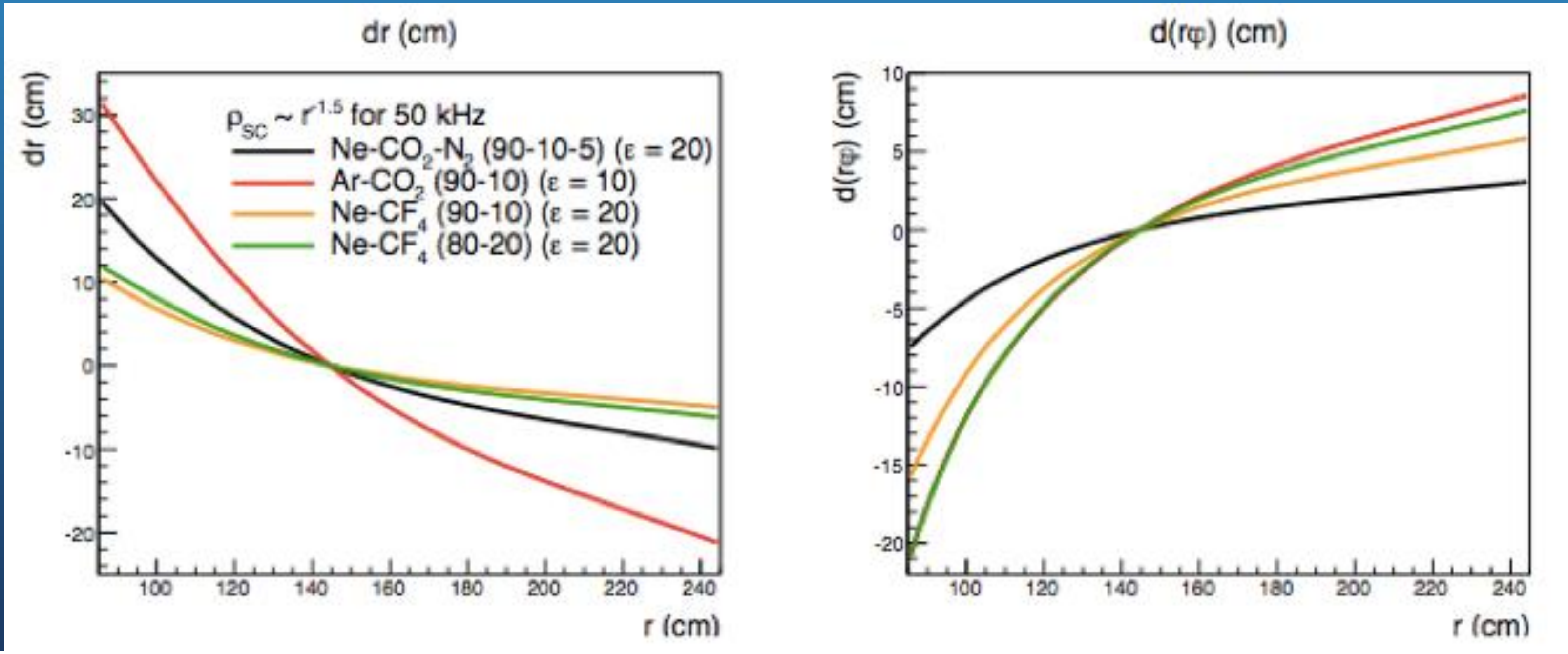
Particle	Yield
Anti-alpha $^4\overline{\text{He}}$	3.0×10^4
Anti-hypertriton $^3_{\bar{\Lambda}}\overline{\text{H}}$ $(\bar{\Lambda}\bar{p}\bar{n})$	3.0×10^5
$^4_{\bar{\Lambda}}\overline{\text{H}}$ $(\bar{\Lambda}\bar{p}\bar{n}\bar{n})$	8.0×10^2
$^5_{\bar{\Lambda}}\overline{\text{H}}$ $(\bar{\Lambda}\bar{p}\bar{n}\bar{n}\bar{n})$	3.0
$^4_{\bar{\Lambda}\bar{\Lambda}}\overline{\text{H}}$ $(\bar{\Lambda}\bar{\Lambda}\bar{p}\bar{n})$	3.4×10^1
$^5_{\bar{\Lambda}\bar{\Lambda}}\overline{\text{H}}$ $(\bar{\Lambda}\bar{\Lambda}\bar{p}\bar{n}\bar{n})$	0.2
H-Dibaryon $(\Lambda\Lambda)$	5.0×10^6
$\Xi\Xi$	1.5×10^5
Λn	8.0×10^7

Future ALICE Program

- ALICE heavy-ion program approved for 1~10nb^{-1}:
- Possible scenario
  - 2013–14 Long Shutdown 1 (LS1)
    - completion of TRD and installation of Di-jet CAL
  - 2015 Pb–Pb at $\sqrt{s_{NN}}$ = 5.1 TeV
  - 2016–17 Pb–Pb at $\sqrt{s_{NN}}$ = 5.5 TeV
  - 2018 Long Shutdown 2 (LS2)
  - 2019 Pb-Pb 2.85nb^{-1}
  - 2020 Pb-Pb 2.85nb^{-1} (low magnetic field)
  - 2021 p-p reference run
  - 2022-2023 Long Shutdown 3 (LS3)
  - 2024-2026: Pb-Pb/p-Pb run with ALICE upgrade
    (3.5 month/year for HI, 1 month with low B)

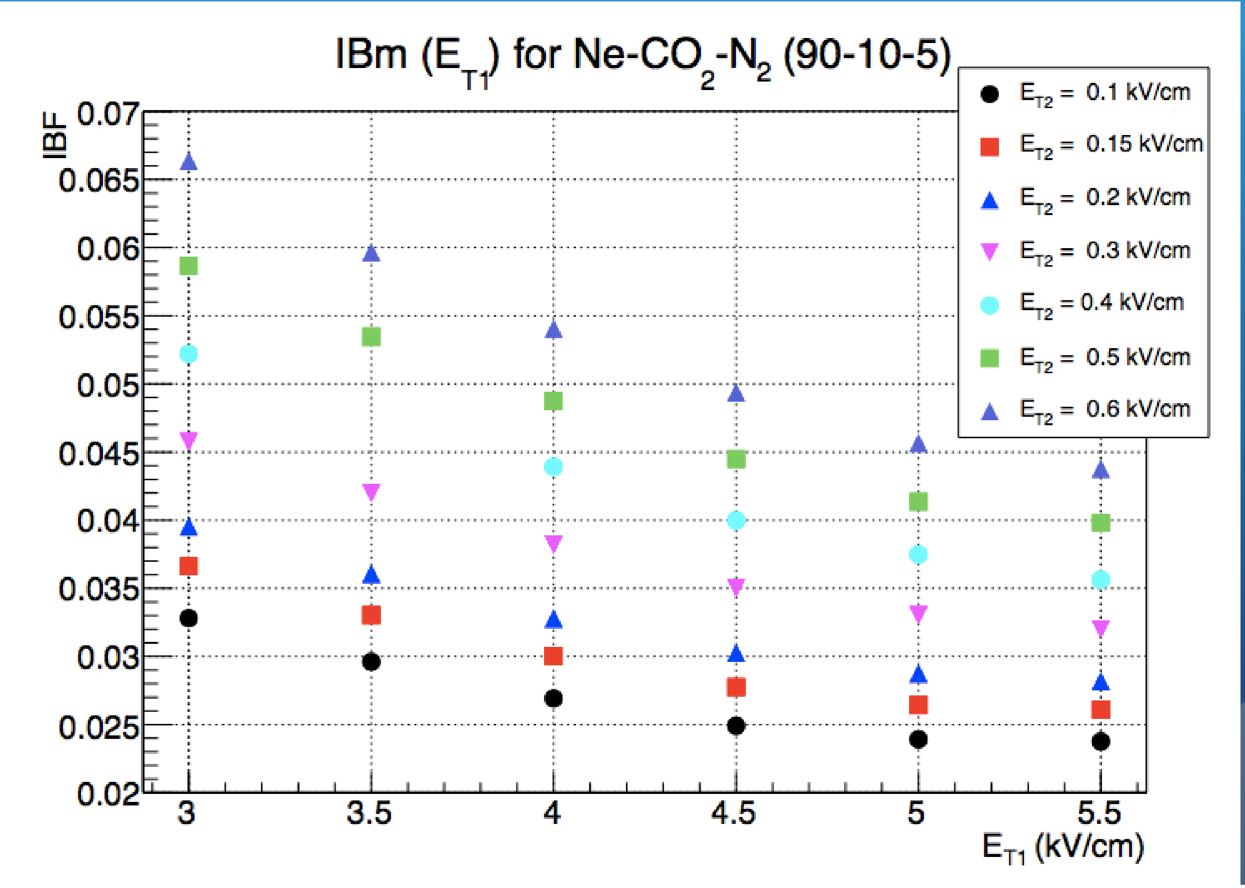
Space-charge distortion

- Maximum radial and azimuthal distortions for various gas mixtures at IBF=1% and gain=2000
- Ne-CO_2-N_2 is baseline gas mixture.
  - Online corrections to 0.01% (0.02cm) are required
  - Space-charge map, fluctuation map (from Pb-Pb raw data)



IBF studies

- 3 standard GEM setup
  - Measurement at gain = 2000
  - Better IBF with high Et1 and low Et2 but IBF=2%! Not enough!



IBF studies

- Another option = “2 GEM + Micromegas”
  - MMG has good IBF capability.
  - With 1000LPI mesh, IBF ~ E_1/E_2 ~ 1%.
  - Further IBF suppression with 2 GEMs x 10, IBF~0.1% can be possible.
  - On-going measurements!