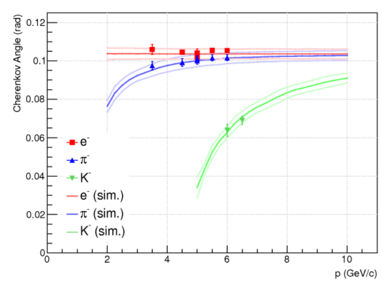
High momentum particle identification with a pressurized Cherenkov radiator

Michael Weber (University of Houston)
for the VHMPID collaboration

Outline:

- The VHMPID Collaboration
- Why we need high p_T PID in heavy ion collisions
- R&D overview
- Photon detector studies
- Radiator studies
- Alternative photon detectors



The VHMPID collaboration

***V**ery **H**igh **M**omentum **P**article **I**dentification **D**etector*

Participating Institutions:

Austin (USA), Bari (Italy), Budapest (Hungary), Campinas (Brazil), Chicago (USA), Gangneung (South Korea), Houston (USA), Kolkata (India), Mexico City (Mexico), Pusan (South Korea), Salerno (Italy)

12 institutions (~60 scientists)

+ major R&D contributions from CERN and Yale (USA)

Letter Of Intent: http://arxiv.org/abs/1309.5880 (submitted to EPJ)

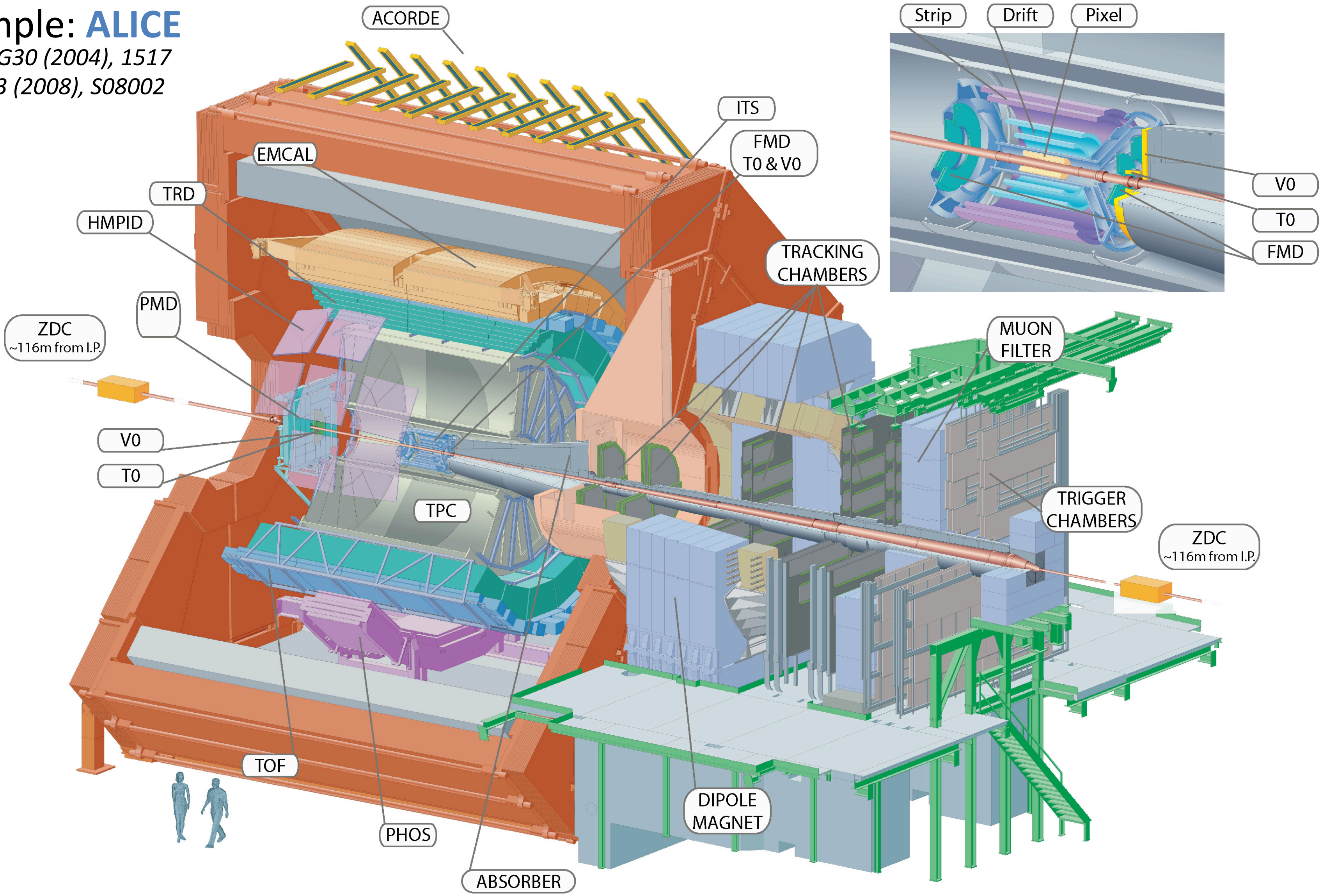
...proposal was not endorsed by the ALICE collaboration...

PID in heavy ion collisions

Example: **ALICE**

J.Phys.G30 (2004), 1517

JINST, 3 (2008), S08002



PID in heavy ion collisions

Example: **ALICE**

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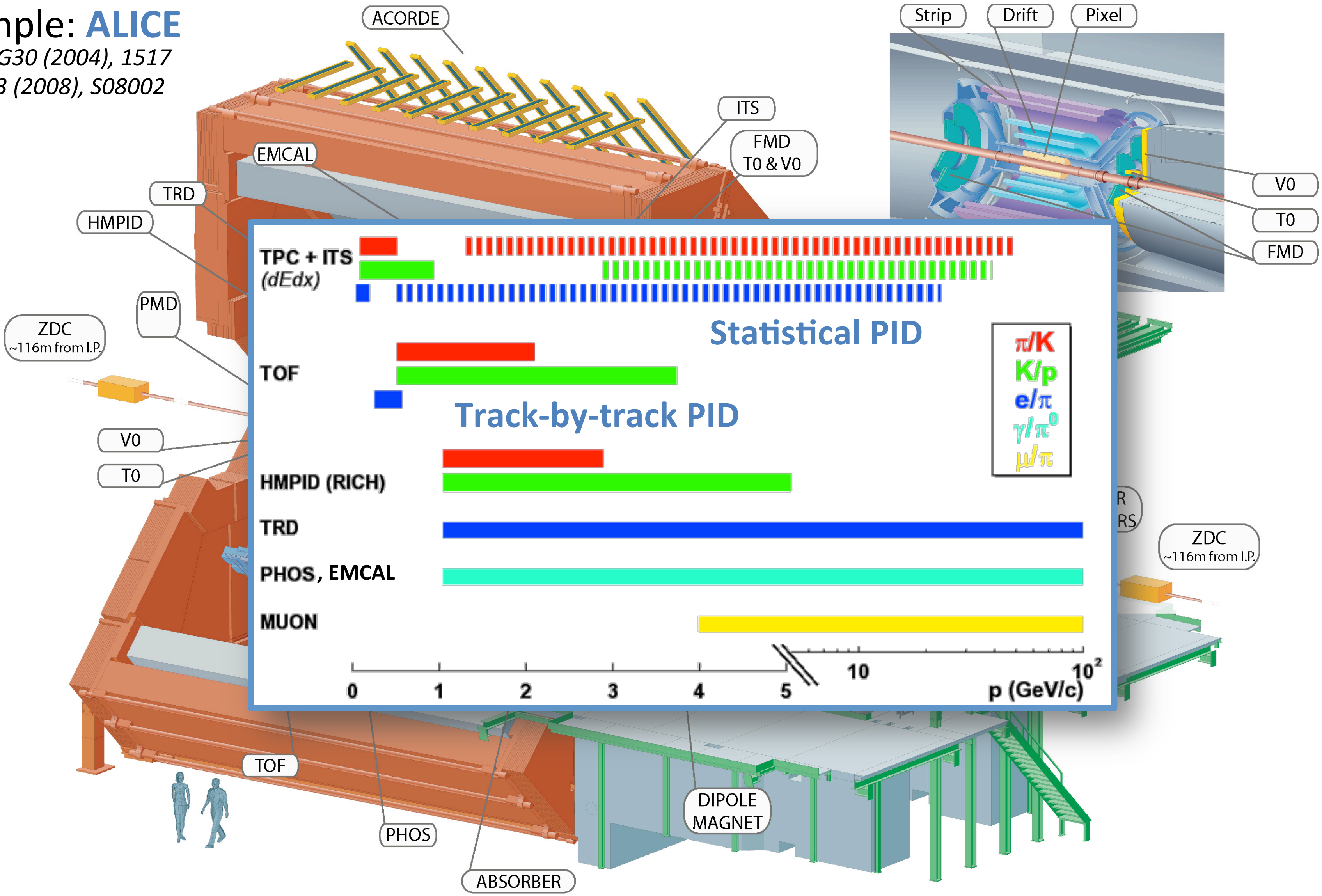
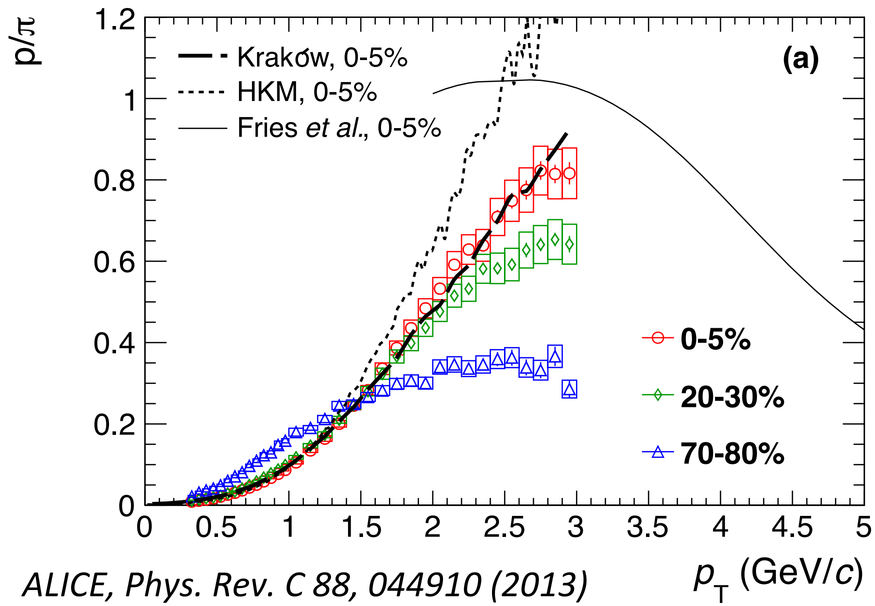
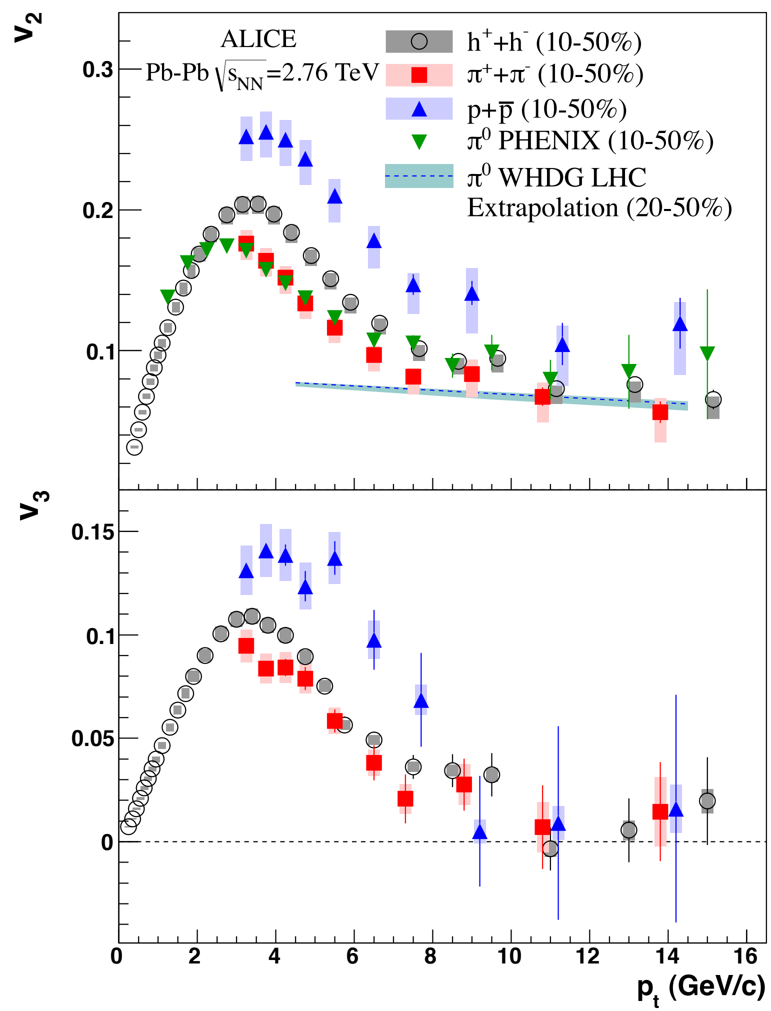


What we learned so far



ALICE, Phys. Rev. C 88, 044910 (2013)

... just a few examples



ALICE, Phys.Lett. B719 (2013) 18-28

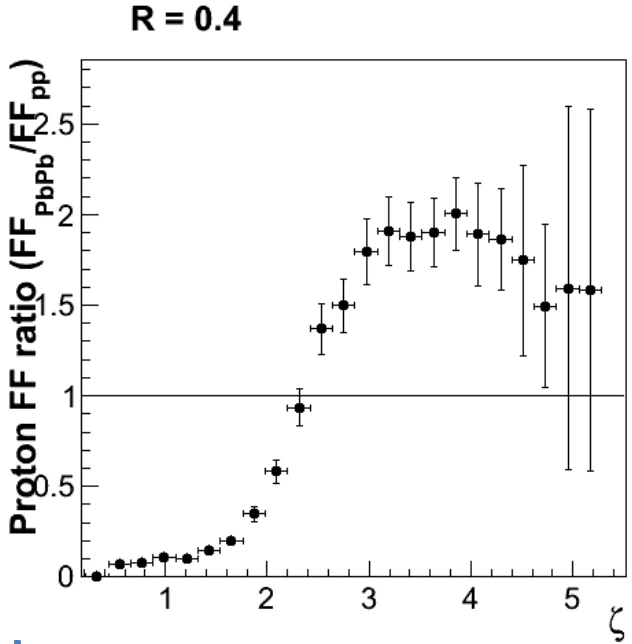
With:

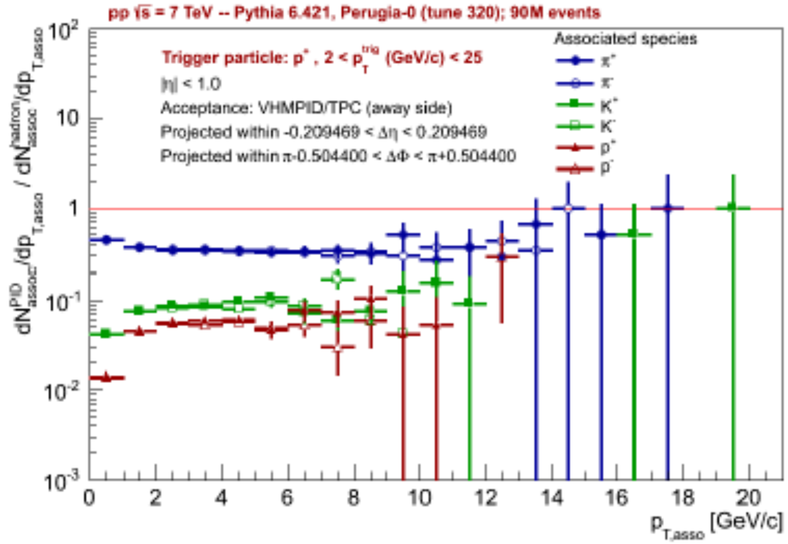
- Track-by-track PID (< 3 GeV/c)
- Above: statistical PID or high purity cuts (π/p only)

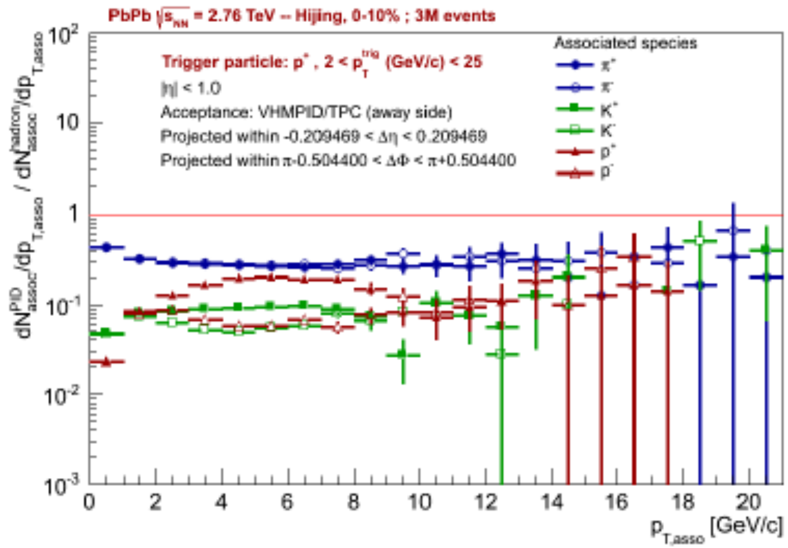
we get:

- Baryon-to-meson enhancement
- Elliptic flow: mass ordering

What we are missing still







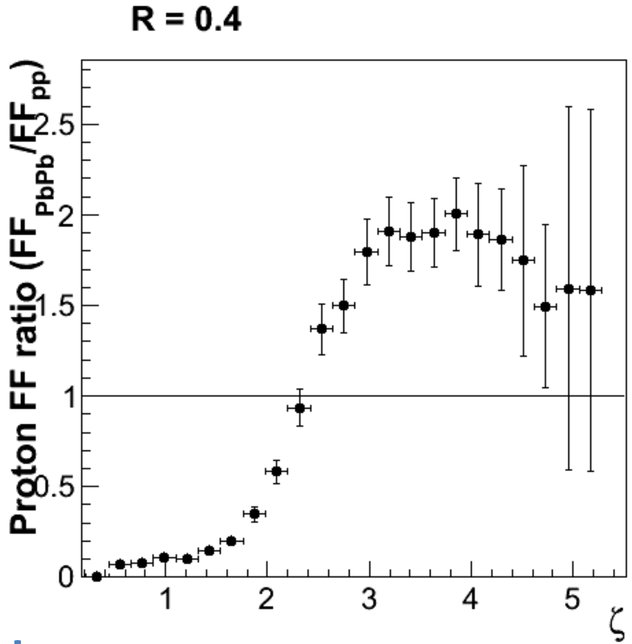
With:

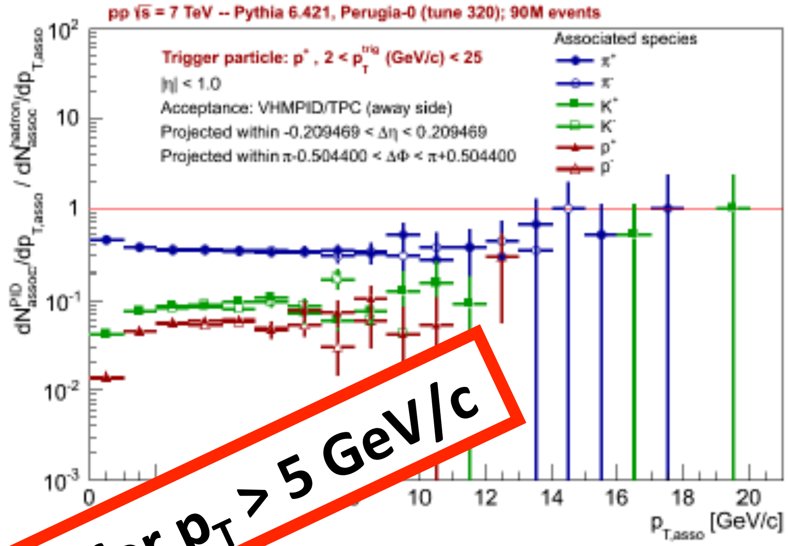
- Identified correlation functions (high p_T)
- PID in jets
- Identified fragmentation functions

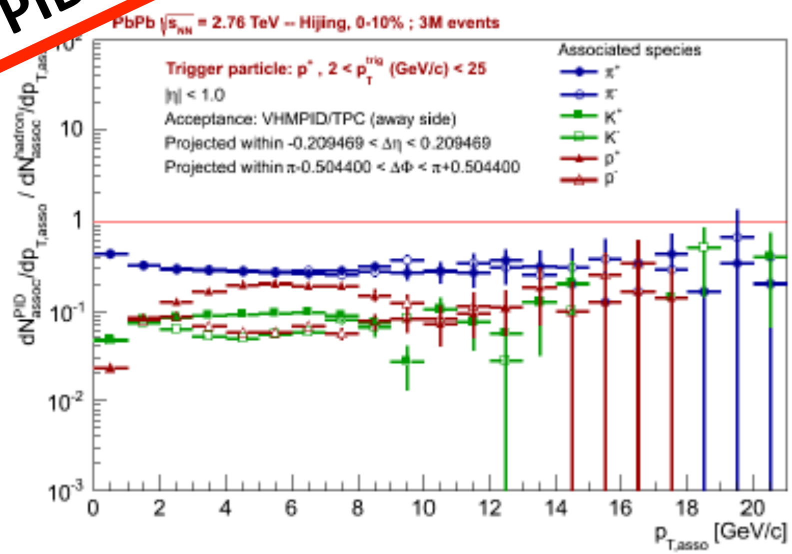
we answer:

- medium modification and gluon/quark fragmentation
- Hadro-chemistry in jets
- …

What we are missing still







Need track-by-track PID for p_T > 5 GeV/c

With:

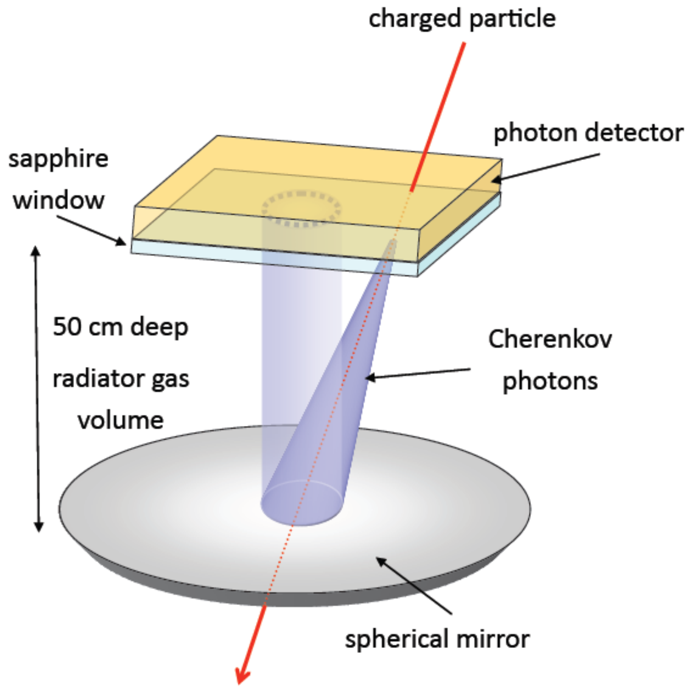
- Identified correlation fun… p_T)
- PID in jets
- Identified frag… functions

we answer:

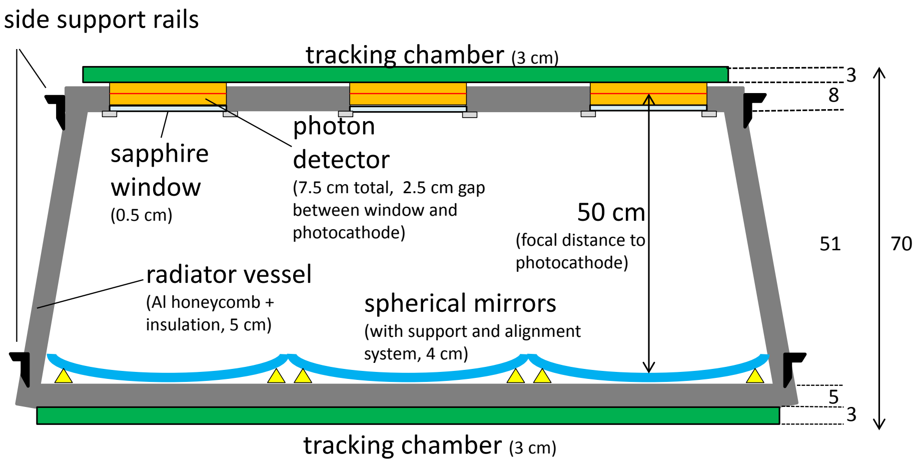
- medium modification and gluon/quark fragmentation
- Hadro-chemistry in jets
- …

VHMPID in one slide

A. Agocs et al. NIM A 732 (2013), 361-365



Details:
- Focusing RICH
- Radiator: 3.5 bar C_4F_8O (50 cm)
- Photon detector: CsI-MWPC (CH_4)
- Window: Sapphire
- Mirrors: 3x3

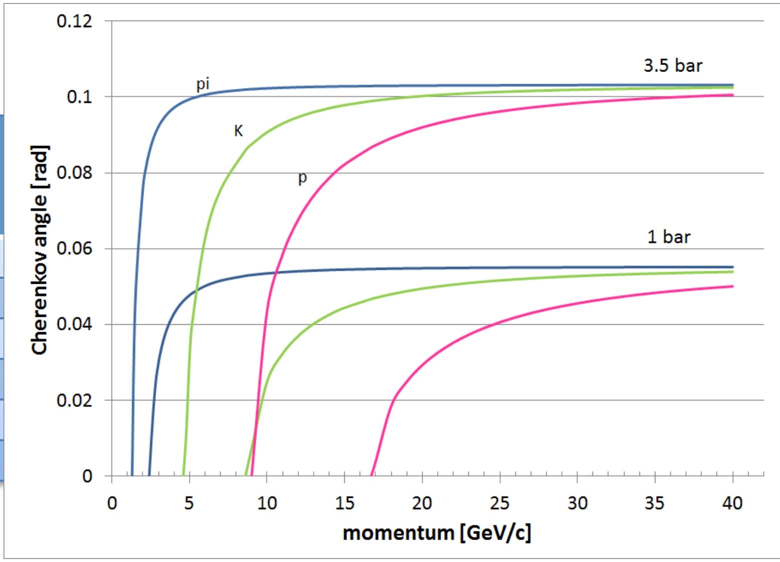


- Track-by-track PID in high momentum regime (**p_T = 5-25 GeV/c**)
- Requires a **pressurized gaseous RICH** detector.
- Thin layout (~70 cm) enables **integration in front of calorimeter**.
- Detector resolution (~1.5 mrad) allows for **3σ p/K separation up to 25 GeV/c, π/K separation from 5 GeV/c** on.

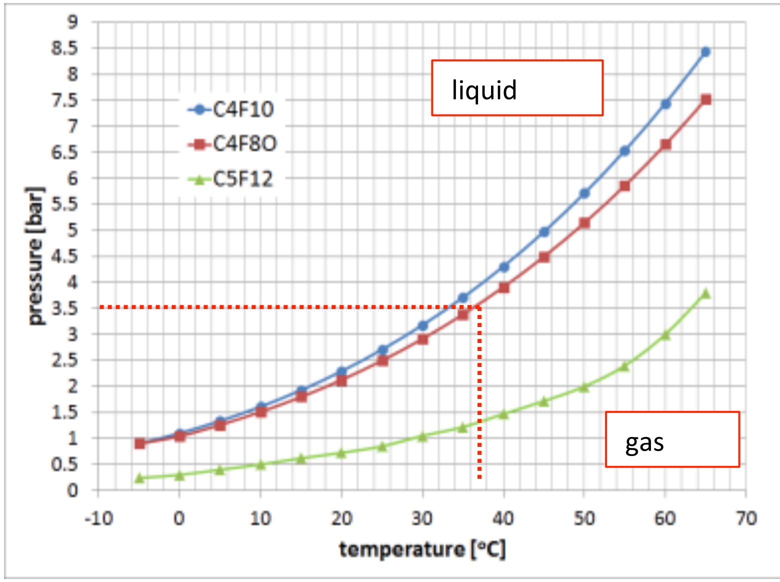
R&D I: Pressurized radiator gas

- Refractive index:

p [bar]	Refr. ind.@ 175 nm	Momentum threshold [GeV/c]			N_{ph} cm^{-1} eV^{-1} at saturation
		π	K	p	
1	1.00153	2.5	9	17	1.1
1.5	1.002295	2.1	7.3	13.5	1.7
2	1.00306	1.8	6.4	12	2.2
2.5	1.00383	1.6	5.6	10.7	2.9
3	1.0046	1.5	5.1	9.8	3.4
3.5	1.00535	1.3	4.8	9.1	3.9



- Optimization:
  - @ 3.5 bar and L= 50 cm
  - excellent photon yield and ring radius (~5 cm) suitable for pattern recognition
  - C_4F_8O needs heating at ~ 40 °C to prevent condensation

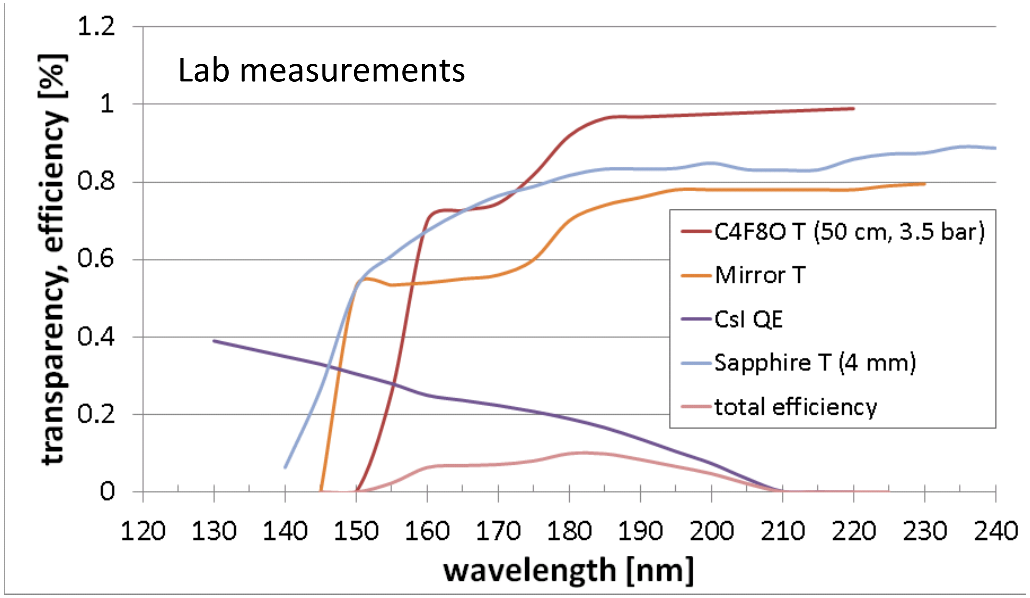


R&D II: Photon detector

- Large acceptance (up to 60 m^2) and large photosensitive area (up to 8 m^2) and working in magnetic field (B=0.5 T):
  - CsI-MWPC with reduced pad size (w.r.t. ALICE-HMPID) and anode-cathode gap: improved spatial resolution + smaller induction spread, detector gas: CH_4
  - CsI-based TGEM photon detectors (thick GEM)
  - Micro-channel plate detectors (Photonis Planacon XP85012Q with bialkali PC to work in the visible)

- Other topics:
  - Radiator vessel and mirror system engineering studies
  - Radiator gas cleaning and UV transparency measurement systems
  - Tracking detector based on CCC (Close-Cathode Chamber) to improve track-ring matching

Detector figure of merit N_0

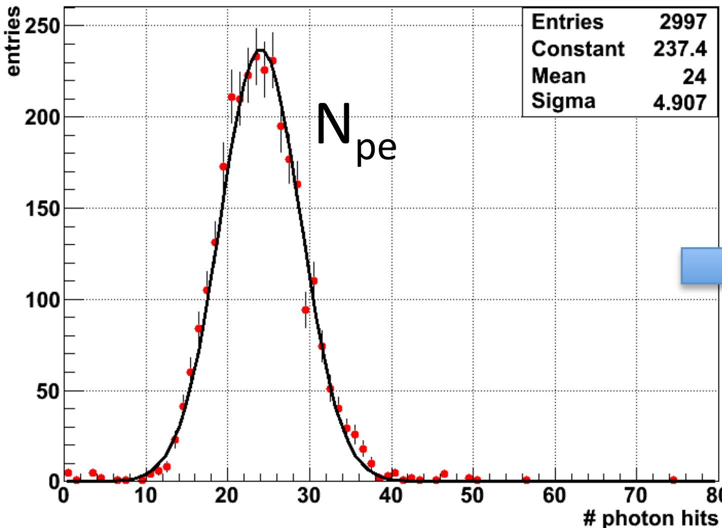


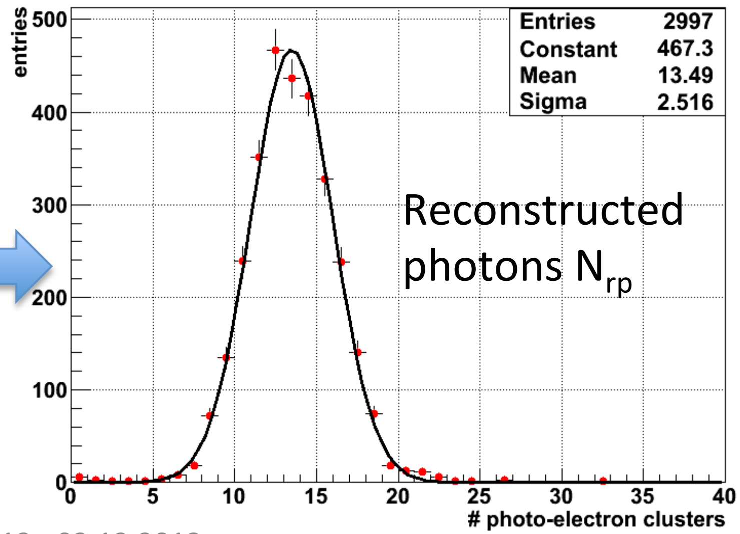
$$N_0 = 370 \int \varepsilon \cdot QE \cdot T \cdot R\, dE$$

$$N_{pe} = N_0 L \sin^2 \vartheta_c$$

	UV	Visible
N_0 [cm^{-1}]	60	130
N_{pe}	24	45

MC simulation: 15 GeV/c π, C_4F_8O @ 3.5 bar:

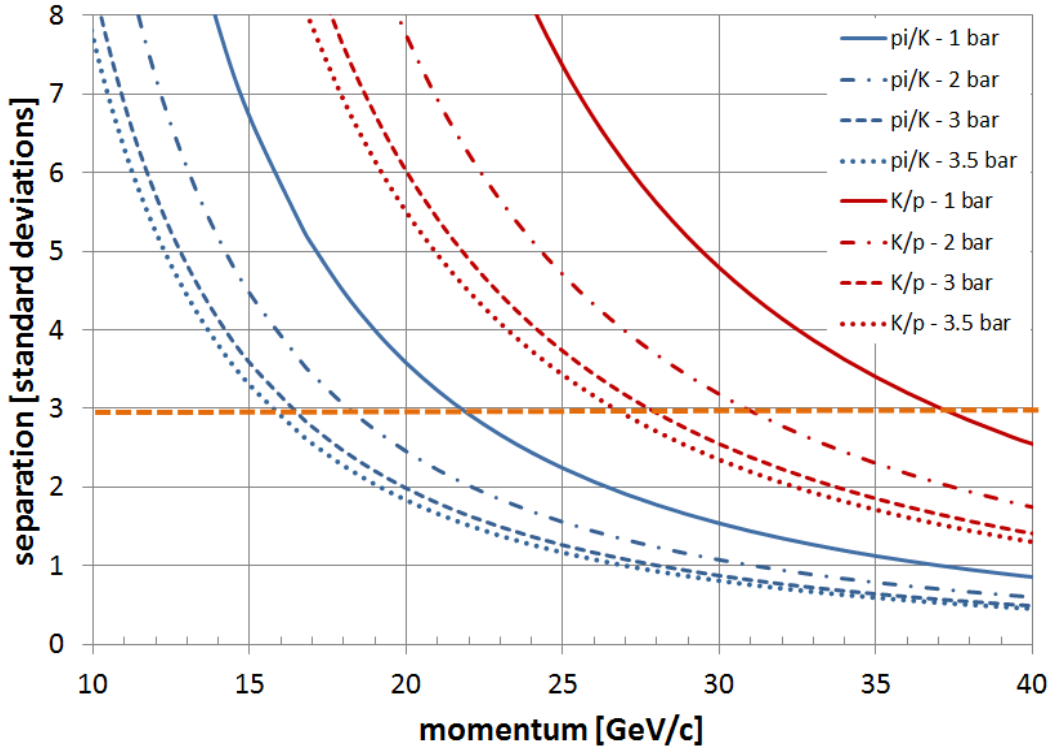




Particle separation

Resolution from theoretical estimation C_4F_8O @ 3.5 bar

	UV	Visible
$\sigma_q^{chromatic}$	2.0 mrad	1.2 mrad
$\sigma_q^{opt.aberr.}$	0.9 mrad	0.8 mrad
$\sigma_q^{granularity}$	2.3 mrad	2.3 mrad
$\sigma_q^{tracking}$	1.6 mrad	1.6 mrad
σ_q^{total}	3.6 mrad	3.2 mrad
N_{rp}	~ 13	~ 30
σ_q^{track}	~ 1 mrad	~ 0.6 mrad



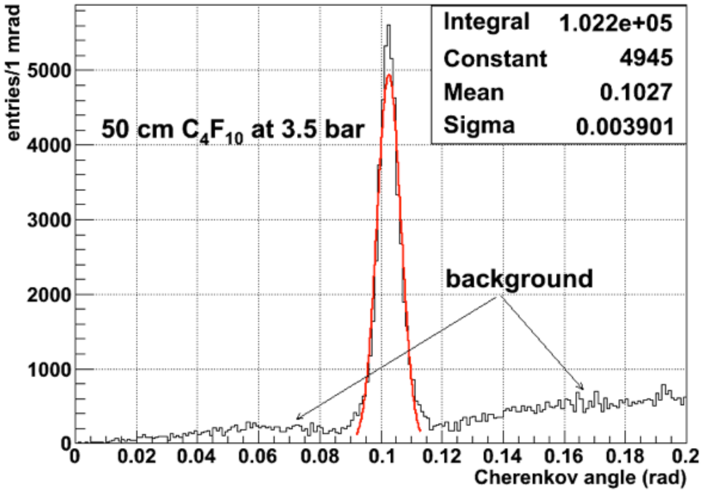
	Signal (GeV/c)	Absence of signal (GeV/c)
p	2-16	
K	5-16	
p	10-25	5-10

PID ranges
- Lower limit: cut N_{rp} >2
- Upper limit: 3σ separation

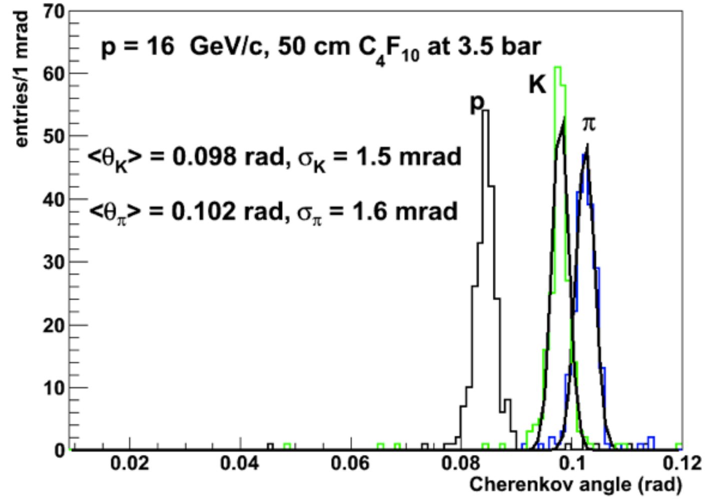
$$\frac{\sigma_\theta}{\sqrt{N_{rp}}} = \frac{m_2^2 - m_1^2}{2 n_\sigma p^2 \tan\vartheta_c}$$

PID performance (Simulation)

Cherenkov angle for single photons:



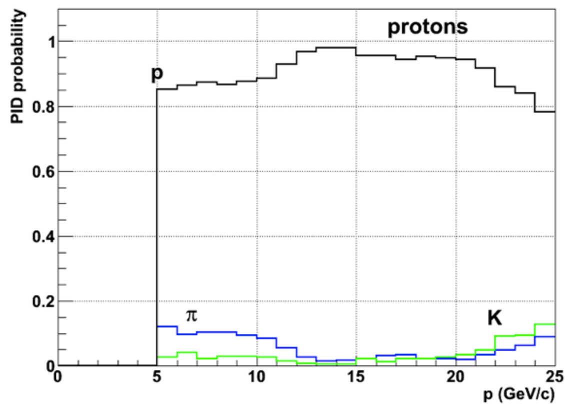
Cherenkov angle for particle species:



Details:

- Embedding π, K and p in background PbPb HIJING events at LHC energies.
- Pattern recognition procedure from HMPID
  → Cherenkov angle for photons
- Hough Transform to filter out the background and improve the signal of identified particles.
  → Cherenkov angle for particle species

Efficiency/Purity (protons)

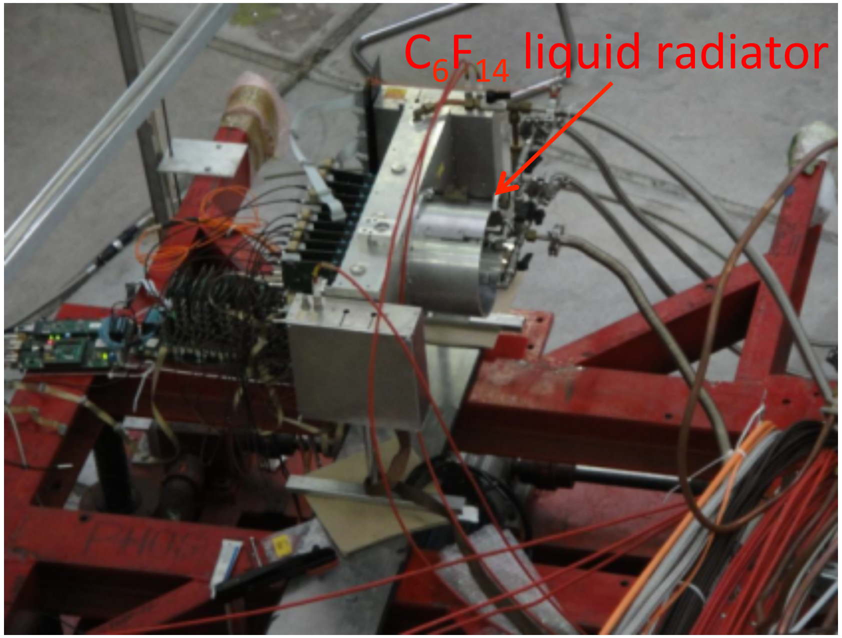


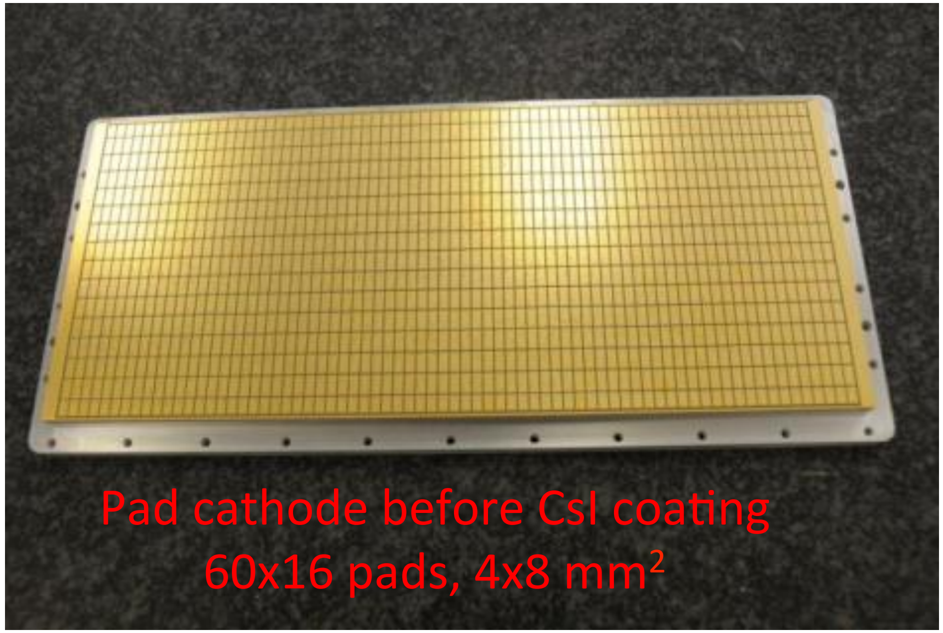
Testbeams at CERN PS/T10

- Radiator:
  - liquid C_6F_{14} radiator (in proximity focusing, HMPID-like)
  - C_4F_{10} or C_4F_8O at atmospheric pressure with mirror focusing
  - Heated and pressurized C_4F_8O radiator

- Photon detector:
  - MWPC prototype with adjustable anode-cathode gap (0.8-2 mm)
  - MWPC prototype with fixed gap
  - CsI-TGEM
  - CsI-TCPD
  - Planacon MCP

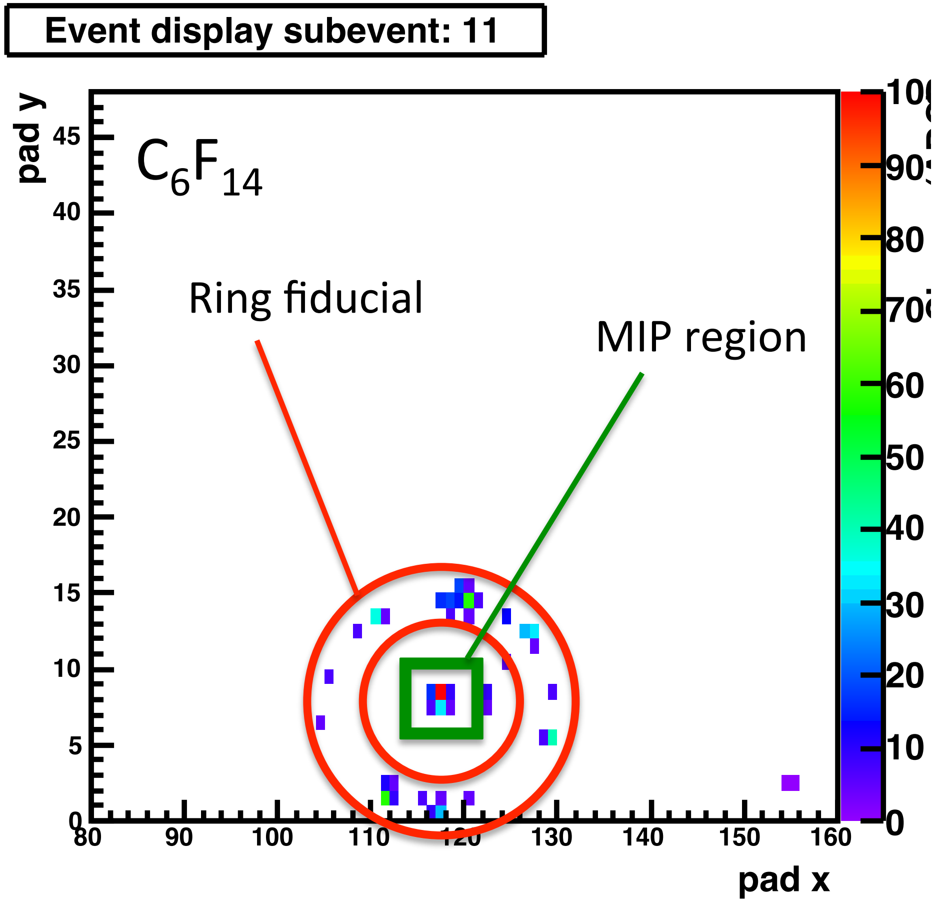
Anode-Cathode gap studies





- Refurbished old prototype (F. Piuz, RD26), anode-pad cathode gap adjustable in 0.8-2 mm (100 μm steps), anode-wire cathode 2 mm, 20 μm anode wires, pitch 4 mm
- Basic performance studies using liquid C_6F_{14} radiator, 3 mm thick: HV scan, gap scan
- proximity focusing with expansion gap such that to reproduce the same ring radius as with C_4F_8O with mirror focusing
- Negative pion beam, 6 GeV/c

Anode-Cathode gap studies



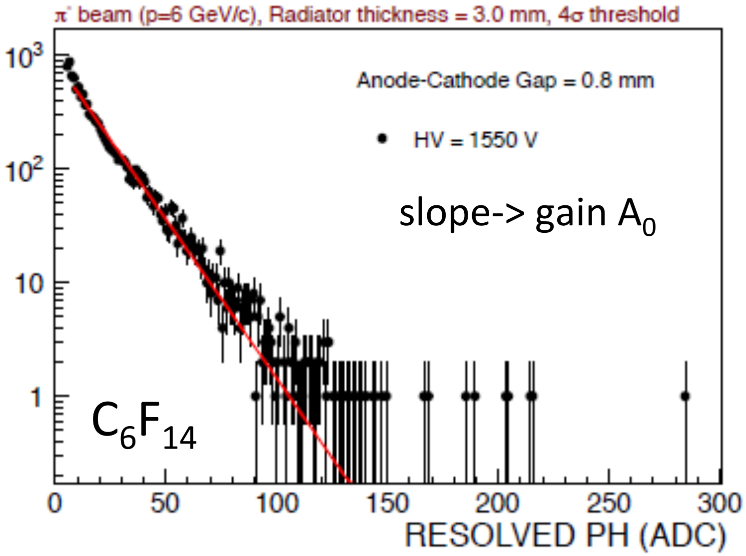
Offline analysis:

- Select good events (MIP)

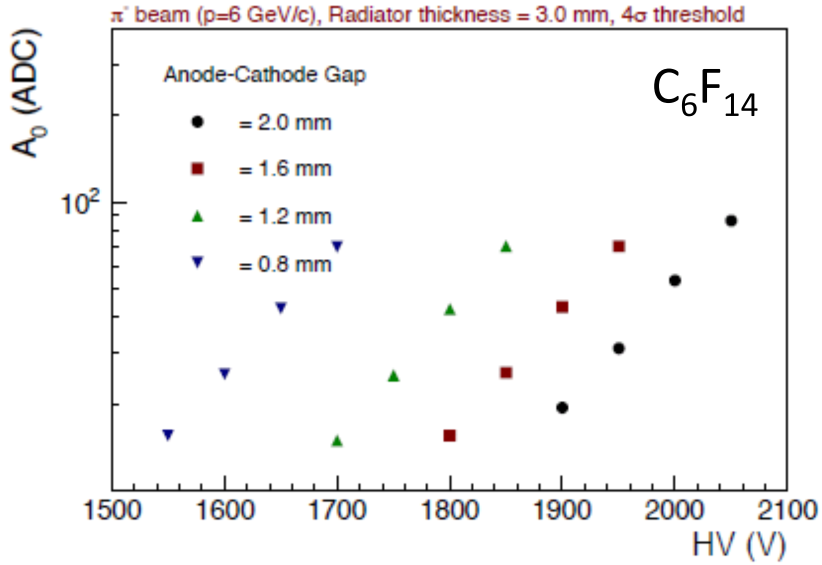
- Ring radius
- Gain in ring fiducial
- Number of clusters
- Cluster size
- Cluster and ring resolution

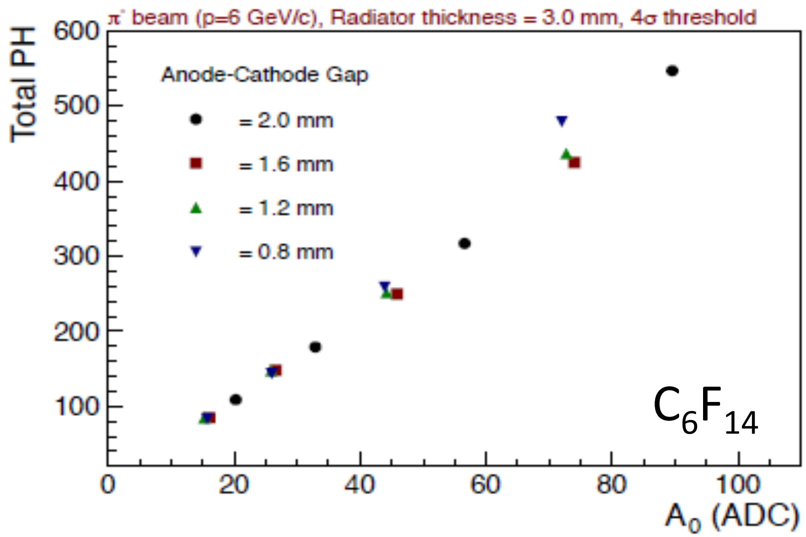
Gain and photon yield

Single e⁻ PH spectrum



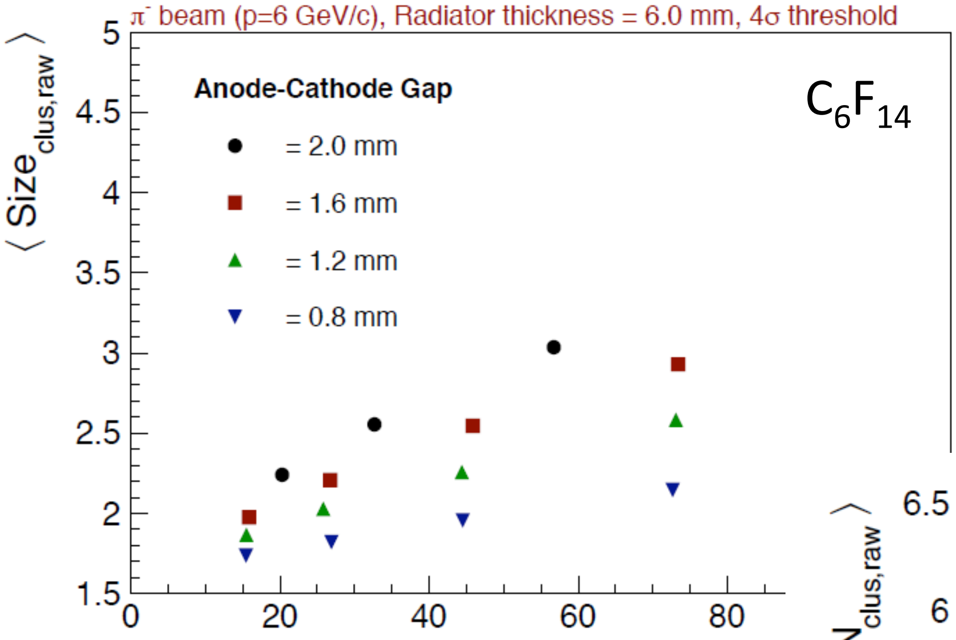
Gain vs HV at various gaps



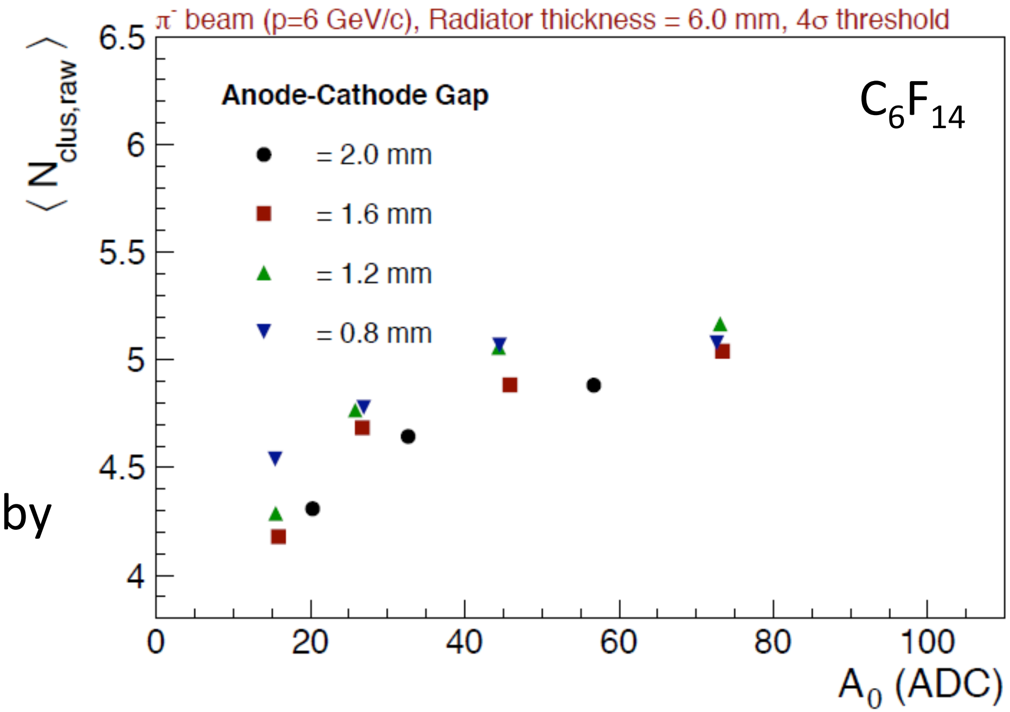


Equal amount of photons seen @ various gaps

Size and cluster yield

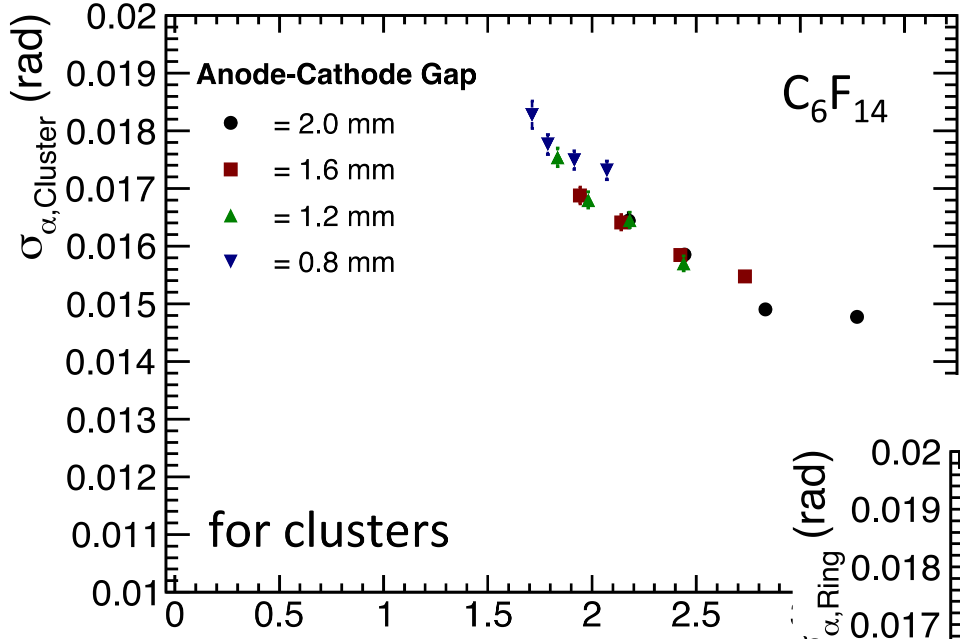


Cluster size proportional to gap

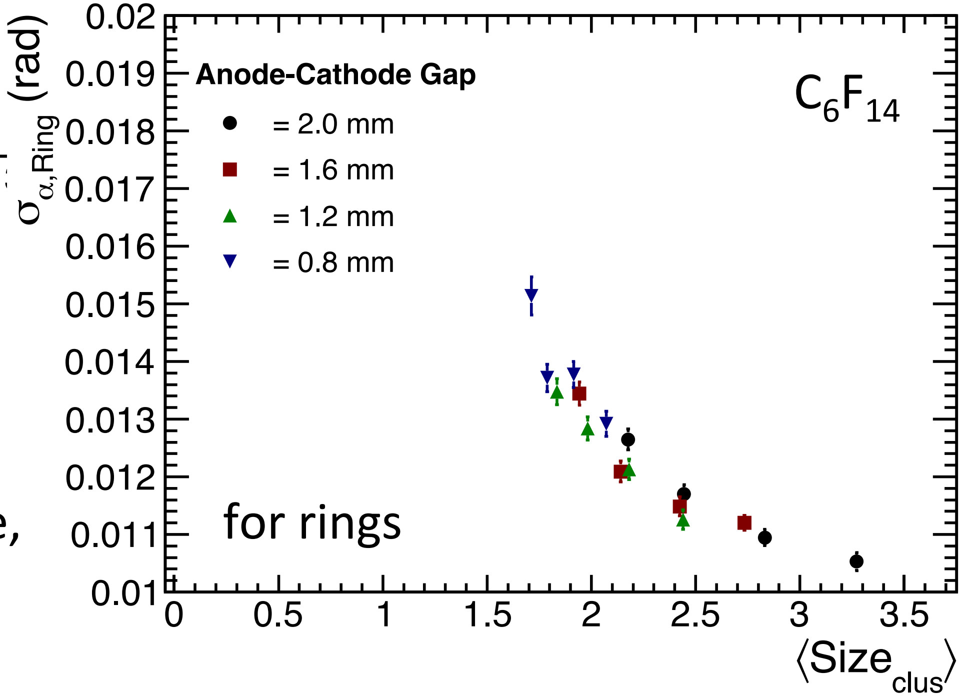


No. of raw clusters increase by reducing the gap

Cherenkov angle resolution

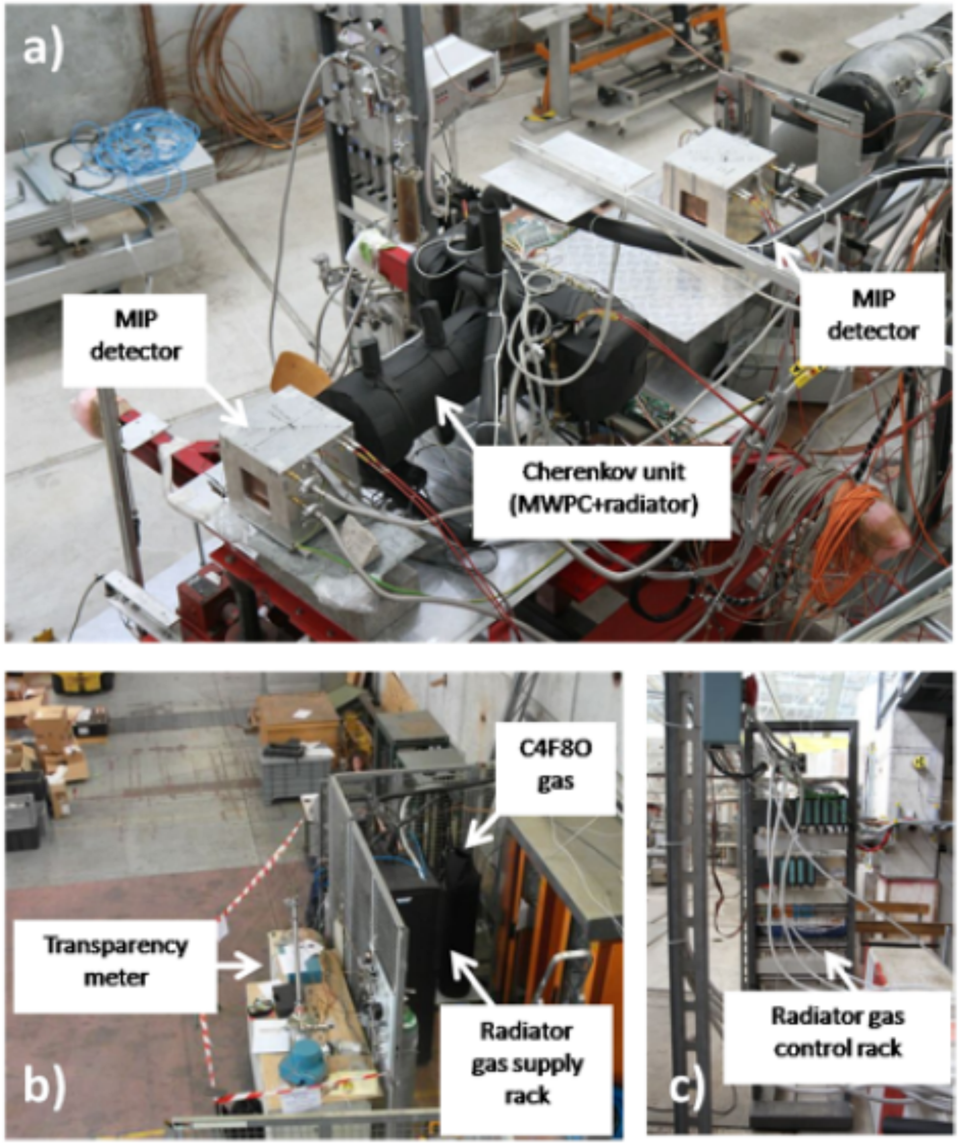


X-axis = mean cluster size in the ring fiducial at given gas gain
Y-axis = Cherenkov angle resolution for clusters and rings



Cluster resolution scales with size, not with anode-cathode gap

Pressurized C_4F_8O radiator



Full VHMPID setup:

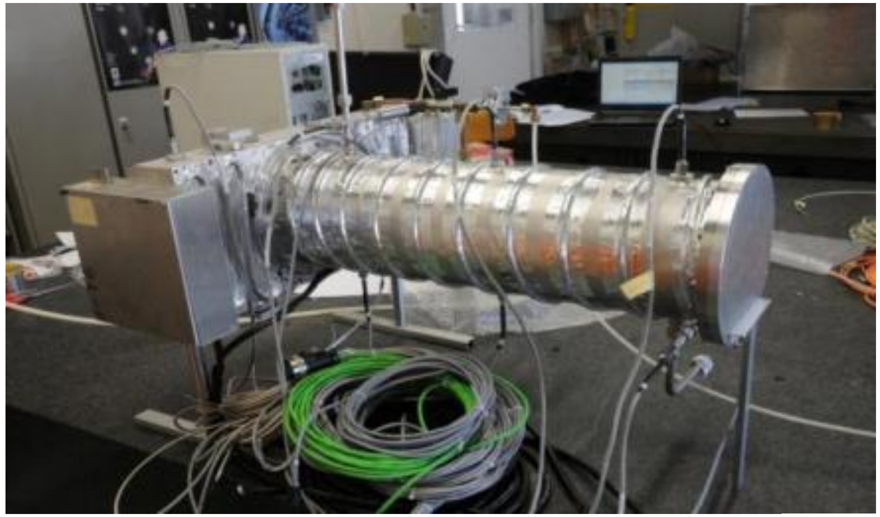
- MIP detectors
- Pressurized radiator (3.5 atm)
- Photon detector (var. gap MWPC, CH_4)
- Online radiator gas transparency meter
- Automatized radiator gas control

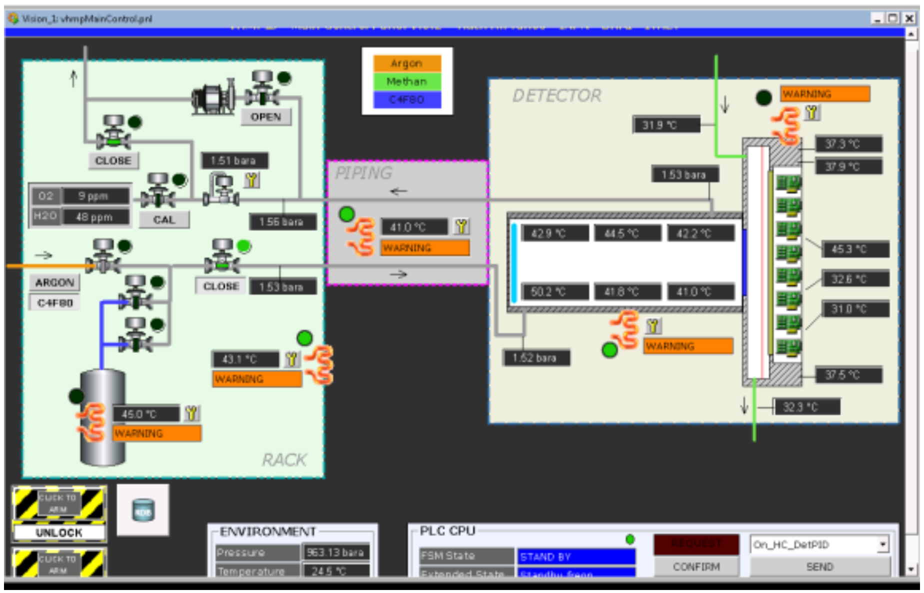
Test program:

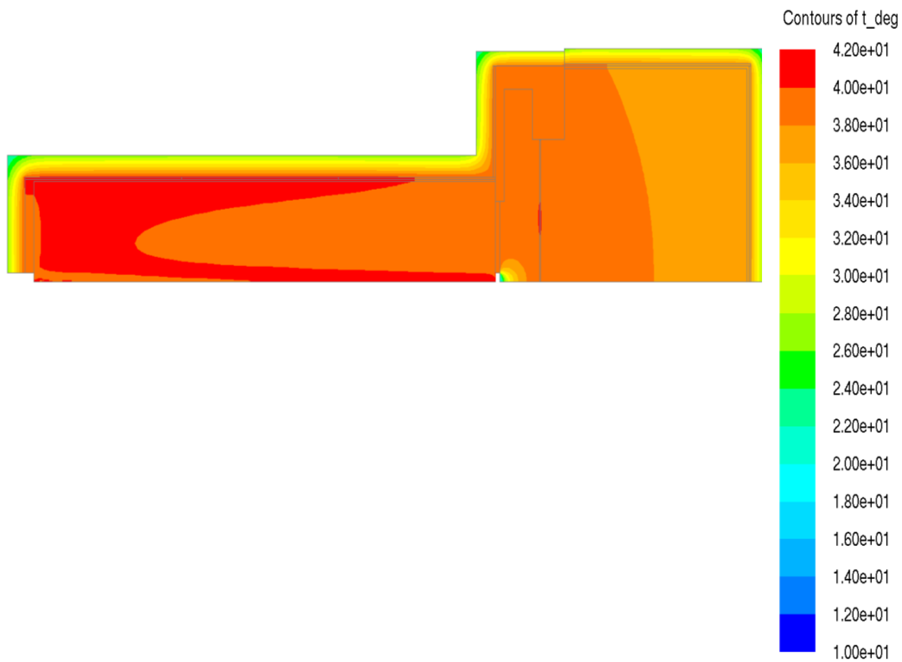
- Photon detection performance
- Cherenkov angle resolution
- Particle separation

Pressurization, heating

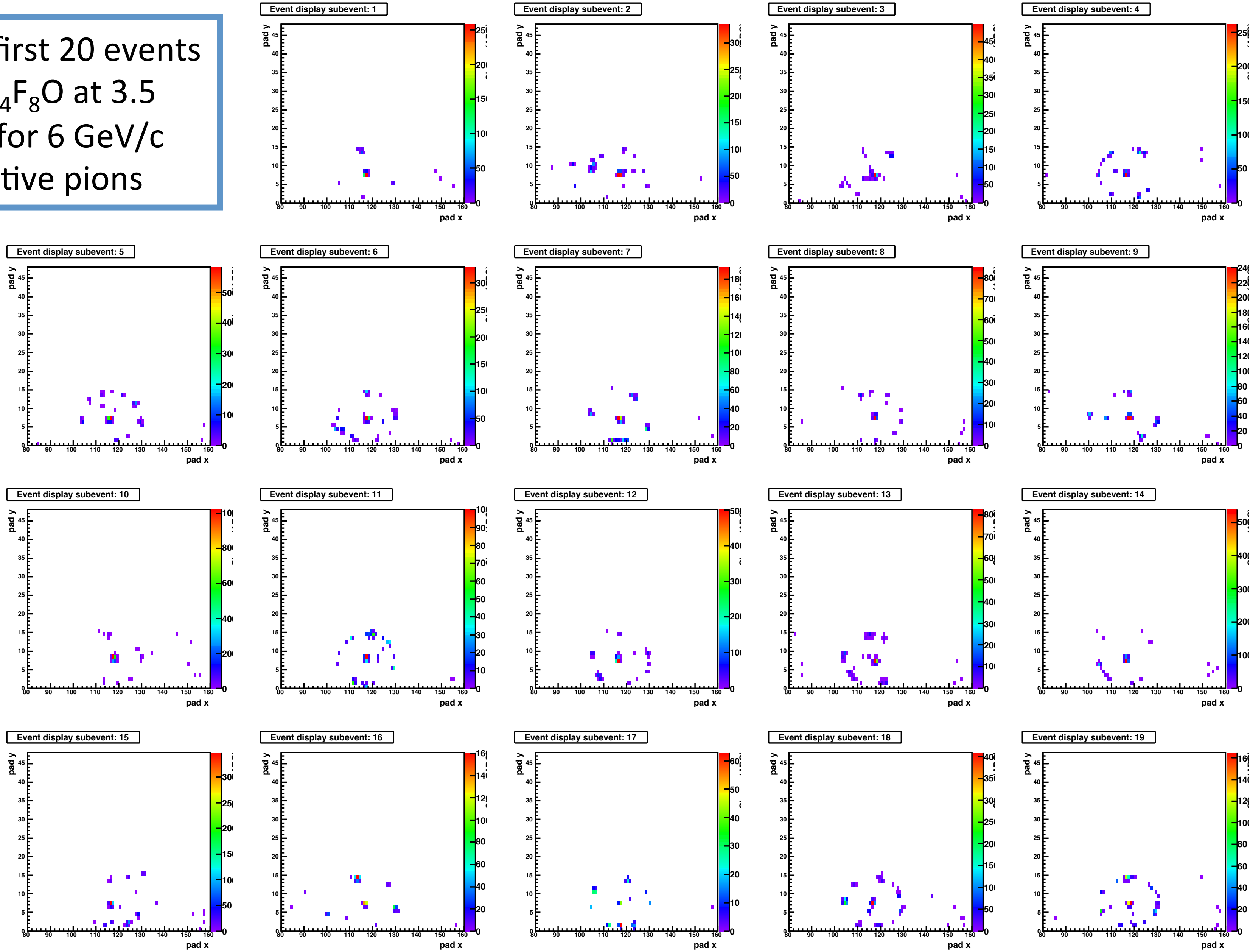
- Radiator equipped with heating wire and P, T probes
- Safety pressure test (@ 5 bar for 5 h)
- Heating studies with Fluent 6.0 to optimize insulation and ensure radiator temperature uniformity
- P, T control and monitoring



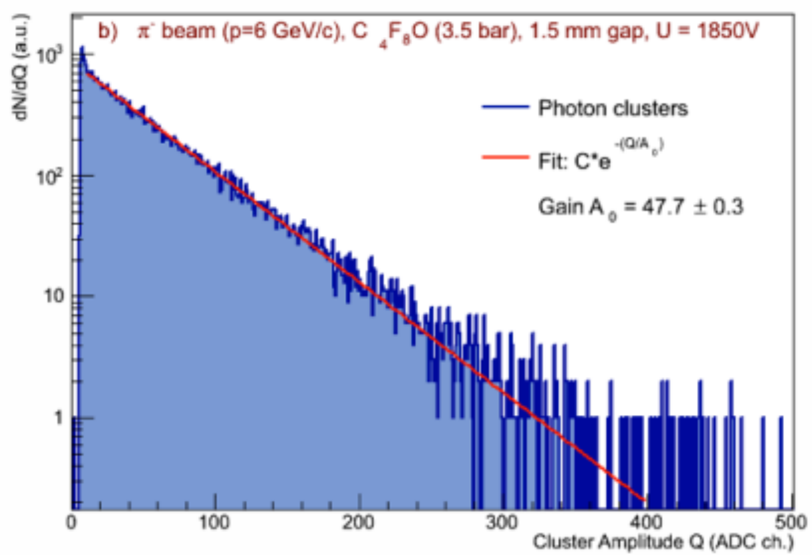


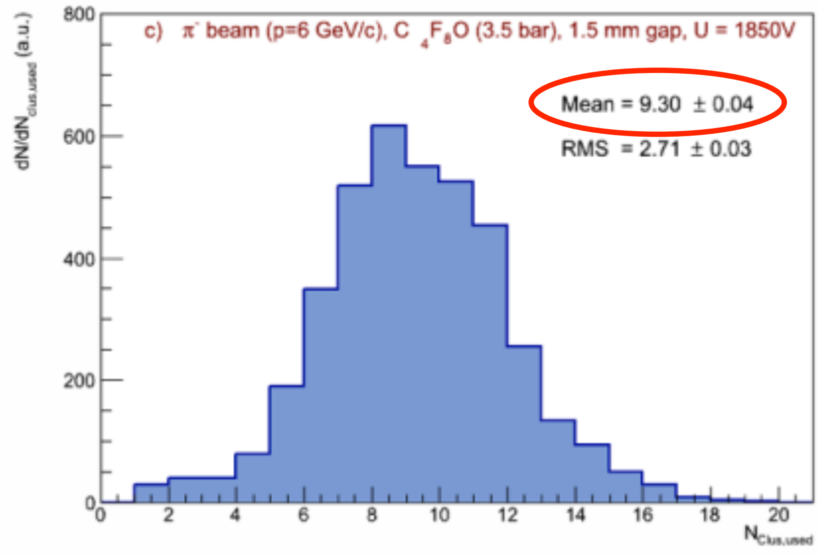


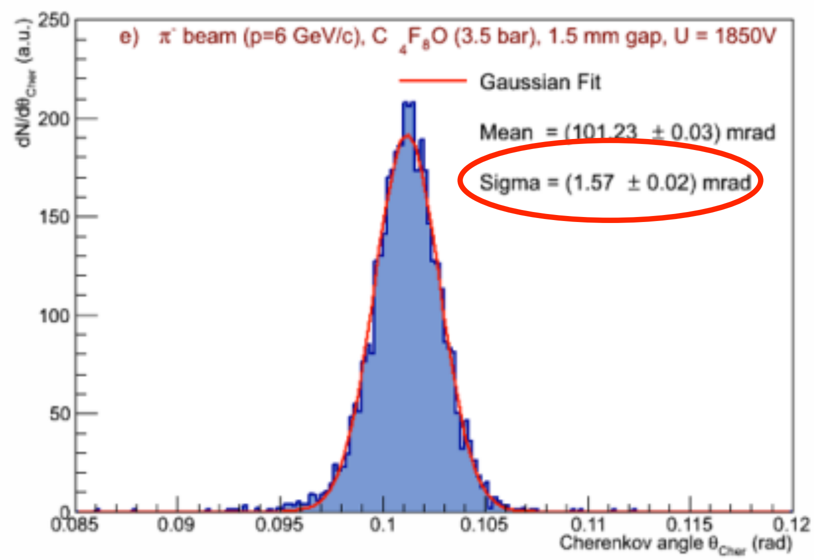
The first 20 events for C_4F_8O at 3.5 atm for 6 GeV/c negative pions

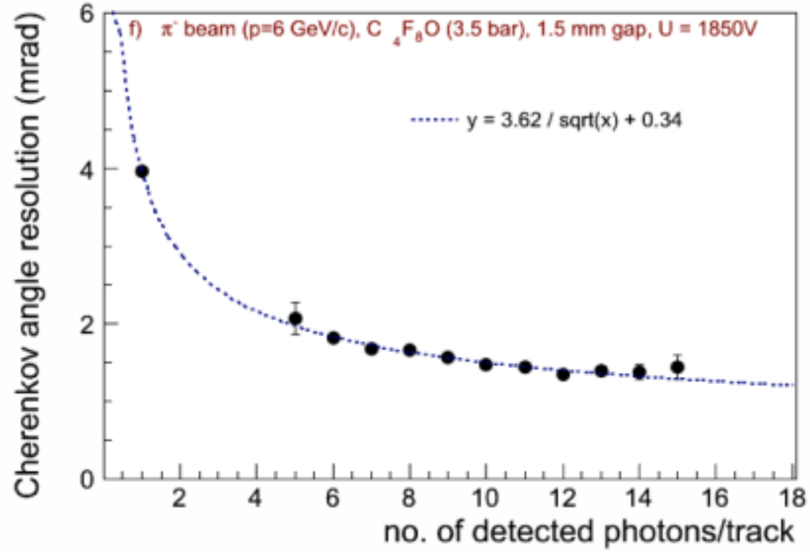


Pressurized C_4F_8O radiator

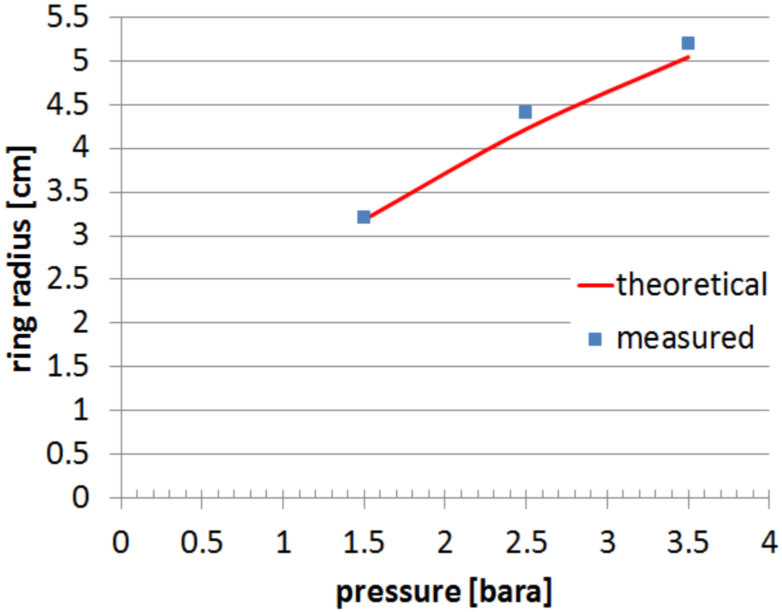






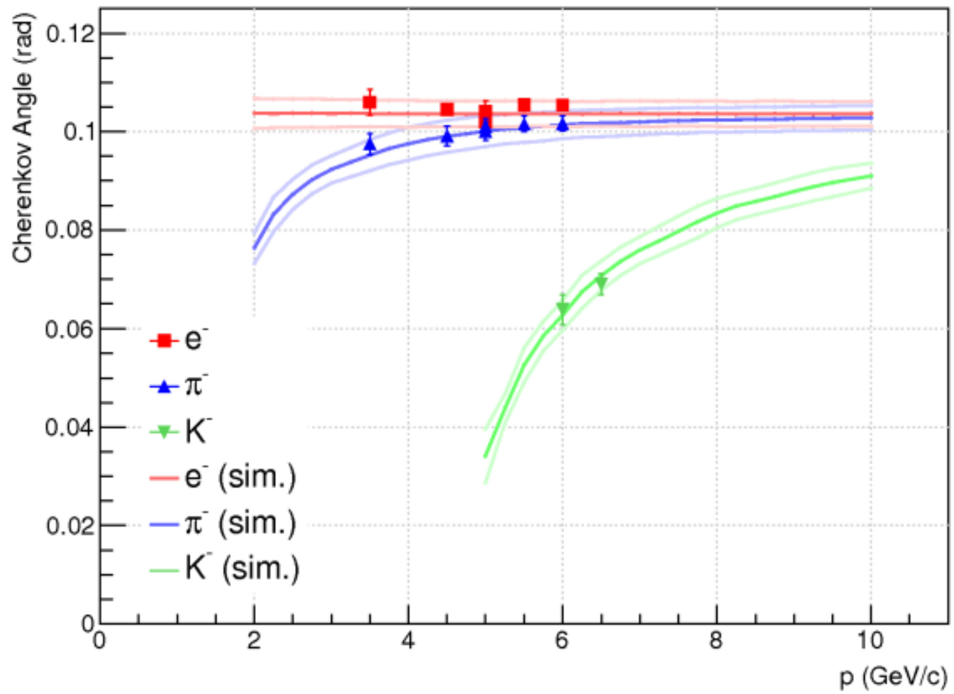


Pressurized C_4F_8O radiator



C_4F_8O refractive index in UV ~ C_4F_{10} (theoretical: correction factor [0.99974]* C_4F_{10} at 175 nm)

Contamination of kaons, electrons
→ Identified and compared to simulation



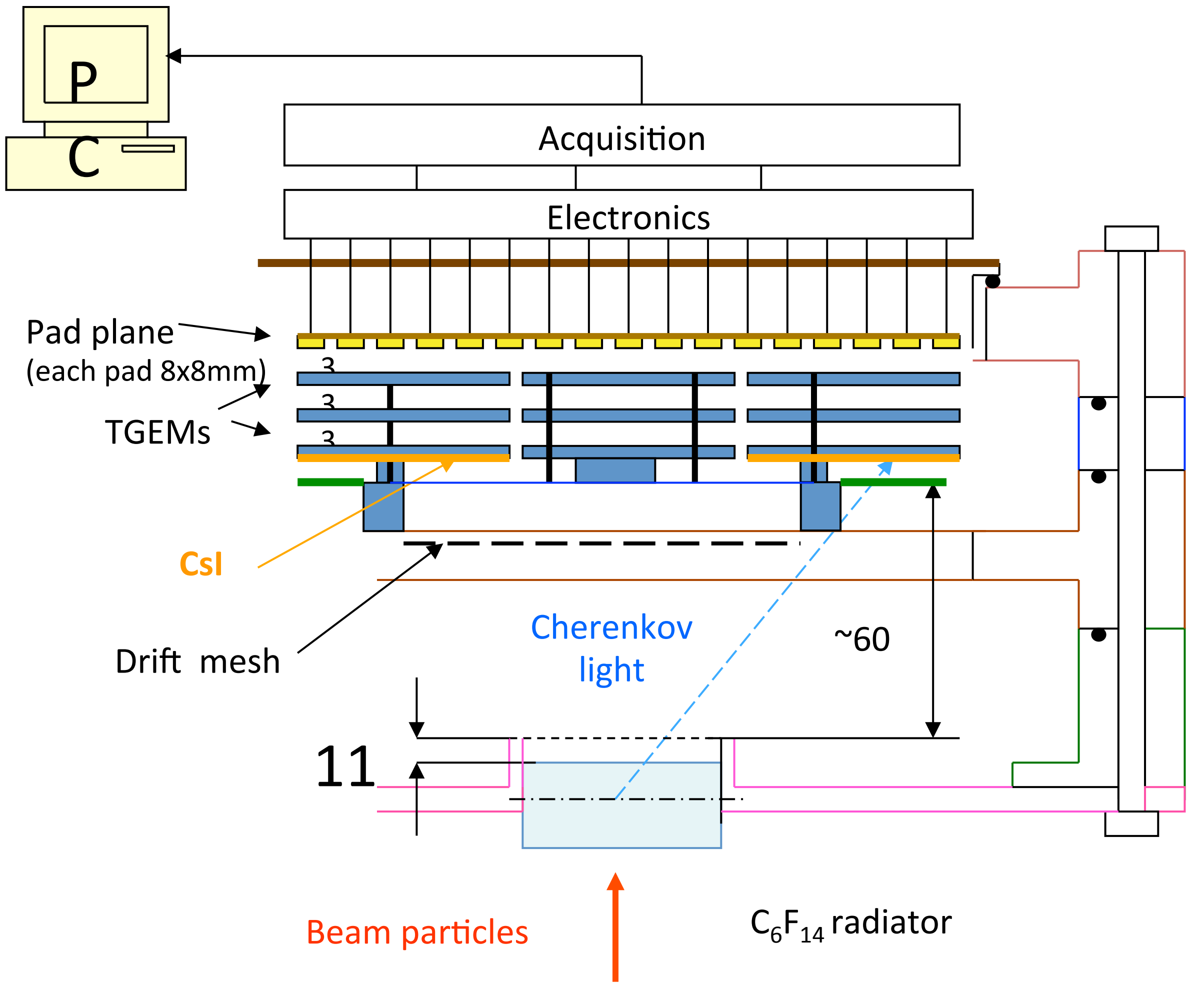
Results:

- Excellent chamber performance (gain, number of photons)
- Excellent Cherenkov angle resolution (~ 1.5 mrad)
- Agreement to simulations

→ Particle separation possible!

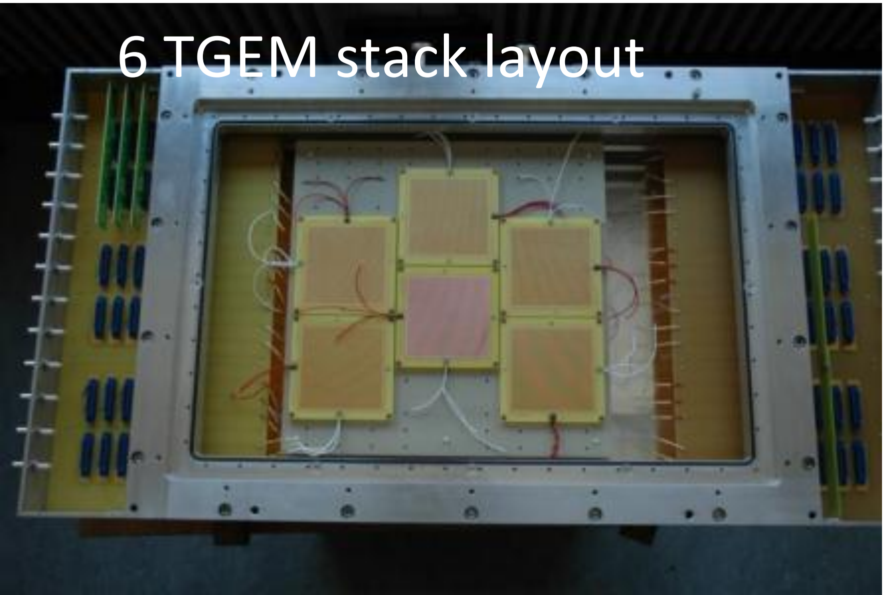
Photon detection alternatives: CsI-TGEM

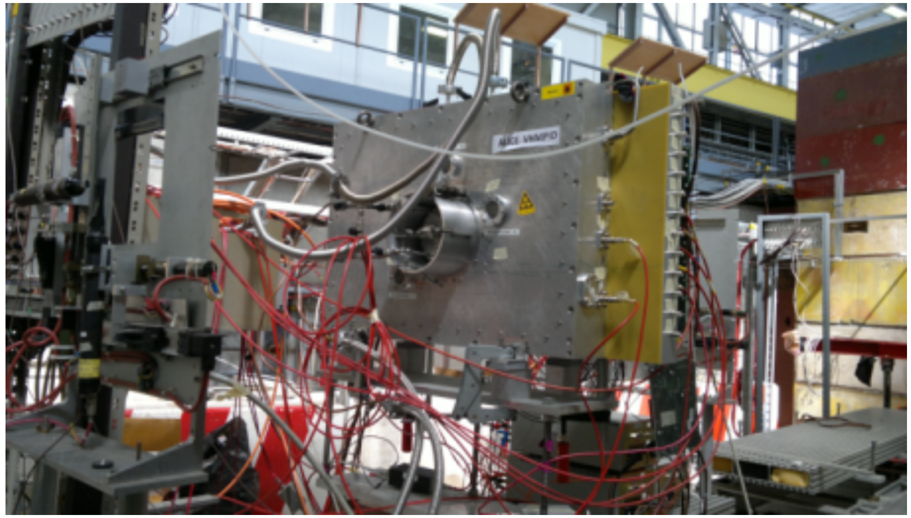
V. Peskov et al., NIM A 695 (2012), 154-158



Triple stack of Thick-GEMs:
Thickness: 0.45 mm
Hole d: 0.4 mm
Rims: <10 µm
Pitch: 0.8 mm
Active area: 77%

Photon detection alternatives: CsI-TGEM





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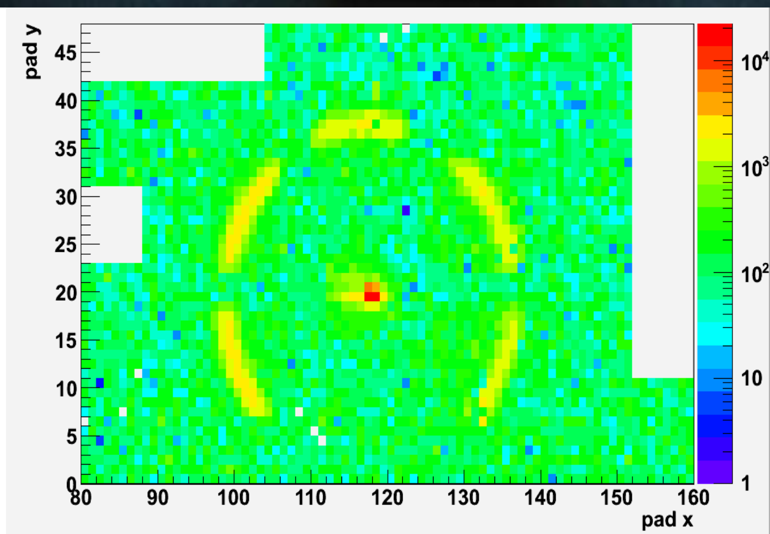
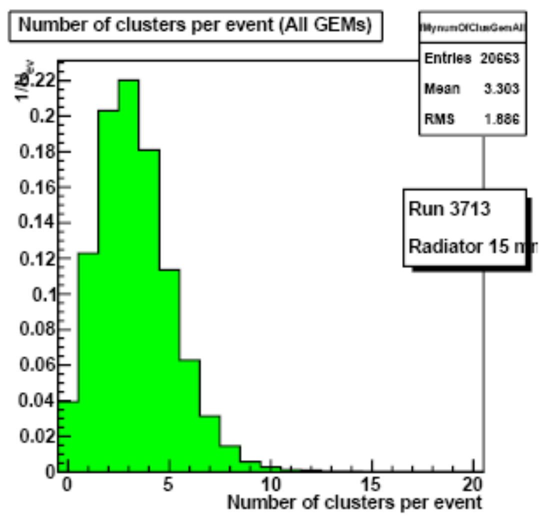
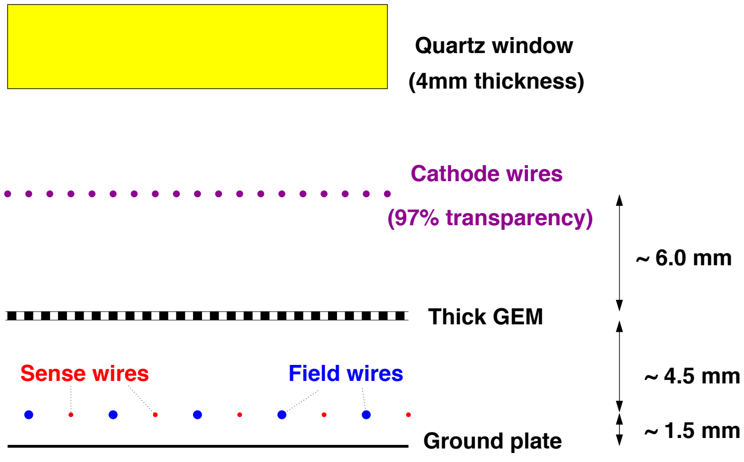




- Observed detection efficiency ~ 60% of HMPID, Gassiplex not optimized for TGEM
- First tests performed with APV25

Photon detection alternatives: TCPD

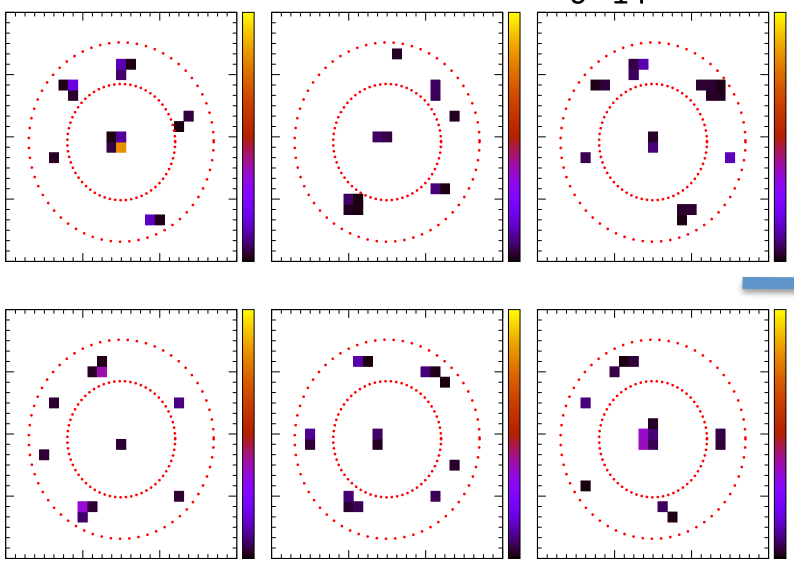
G. Hamar, 2013 JINST 8, MPGD 2013 proceedings

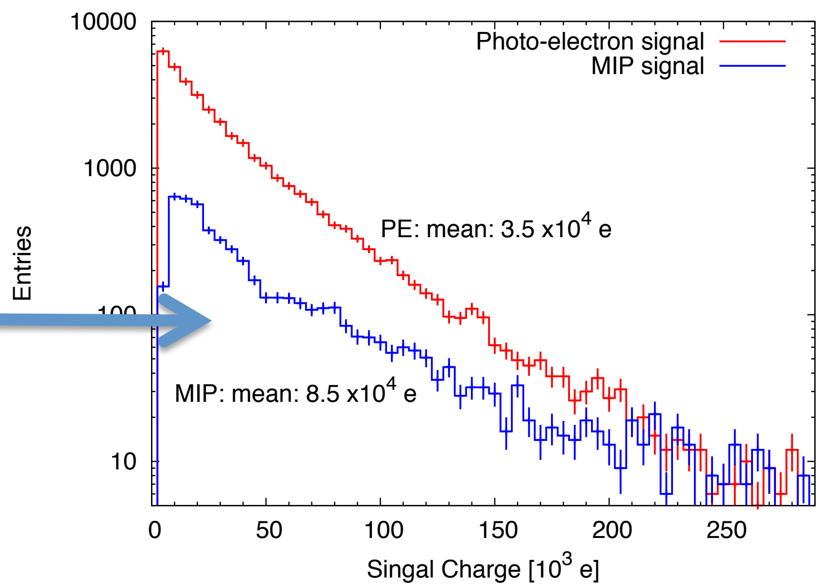


TGEM + CCC Photon Detector:

- Hybrid
- Close Cathode Chamber
- Thick GEM
- Detector gas: CH_4
- Reverse bias cathode: Reduce MIP signal and keep photon detection efficiency

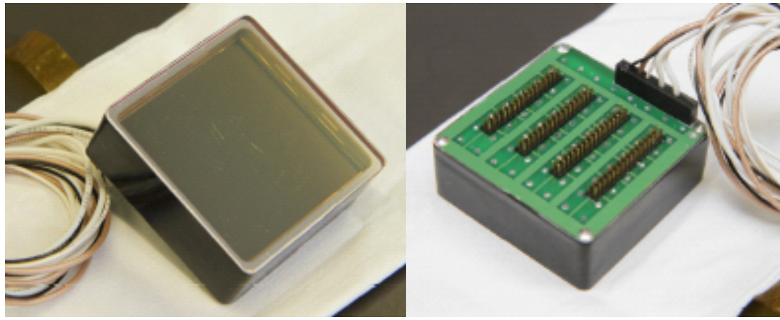
Single events (5 GeV/c π^-, C_6F_{14} radiator):



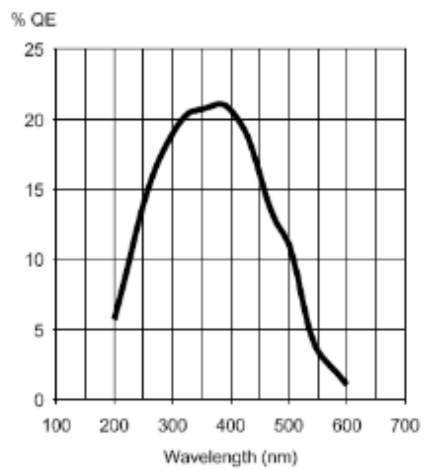


Photon detection alternatives: Photonis Planacon XP85012

Description	
Window material	UV-Glass, Schott 8337B or equivalent
Photocathode	Bialkali
Multiplier structure	MCP chevron (2), 25 μm pore, 40:1 L:D ratio
Anode structure	8×8 array, 5.9 / 6.5 mm (size / pitch)
Active area	53×53 mm
Package open-area-ratio	80%



- Due to delay on electronics production, it could not be tested before the end of testbeam at CERN/PS in 2012
- Ongoing lab tests with LED source

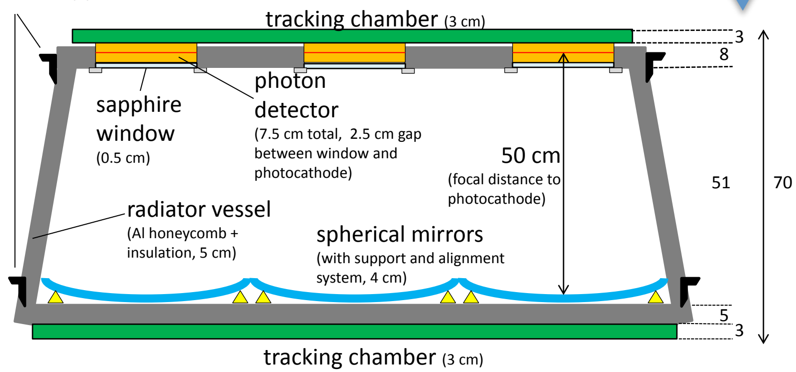


Pro's	Con's
Larger photon yield (larger bandwidth in visible), intrinsically faster	Cost (~ 8.8 K$ /piece) and timescale for full production
No issues from radiator gas transparency (purity, O_2 and H_2O contamination), less demanding systems	Chromatic error due to larger bandwidth, (compensated by photon yield, final performance similar to UV)
Can be mounted inside radiator vessel, sapphire windows not needed	Detection efficiency losses due to 80% packing factor
Commercial device, savings on work for photon detector, no CH_4 gas system	

Summary

track-by-track PID in high momentum regime

requires

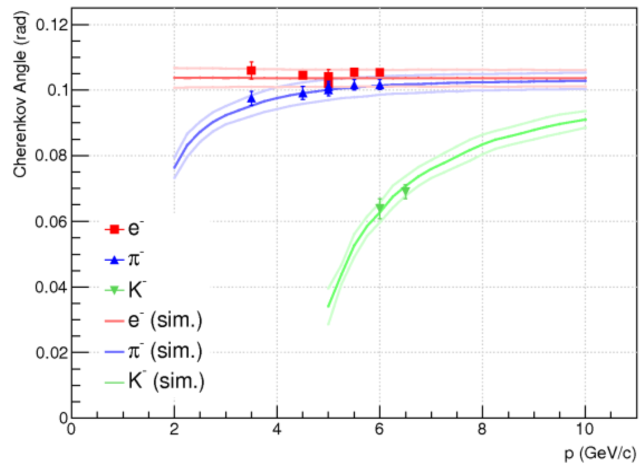


pressurized gaseous RICH:

- Radiator: 3.5 bar C_4F_8O (50 cm)
- Photon detector: CsI-MWPC (CH_4)
- Window: Sapphire
- Mirrors: 3x3

R&D

- smaller anode-cathode gap and pad size
- Excellent chamber performance (Number of photons ~ 10)
- Excellent Cherenkov angle resolution (~ 1.5 mrad)
- Photon detection alternatives (GEM, MCP)



Backup slides

Main physics goals

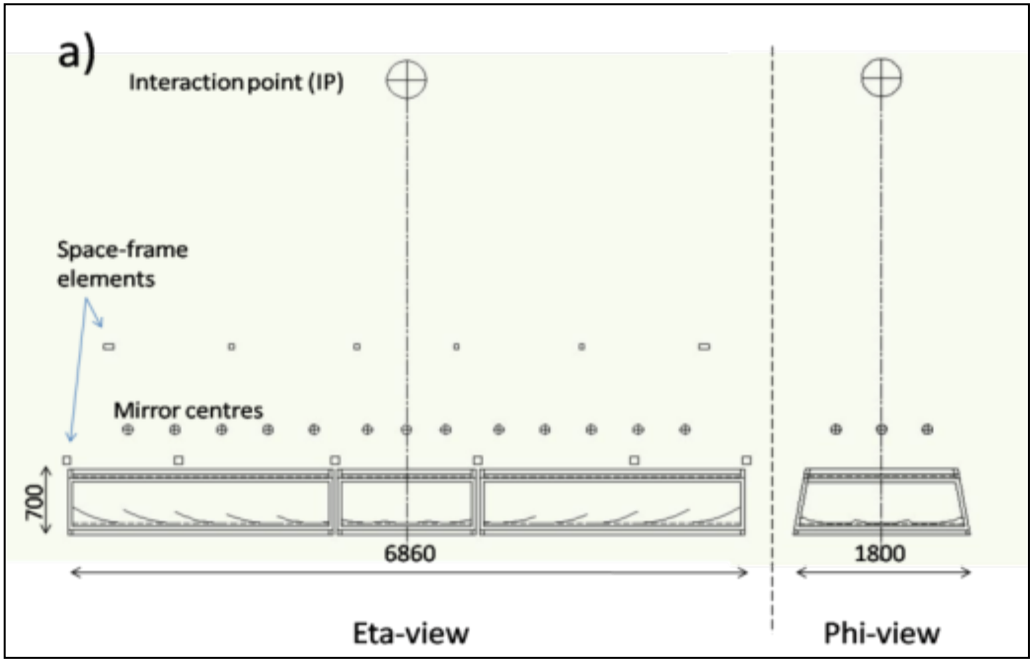
Unique proton-proton physics

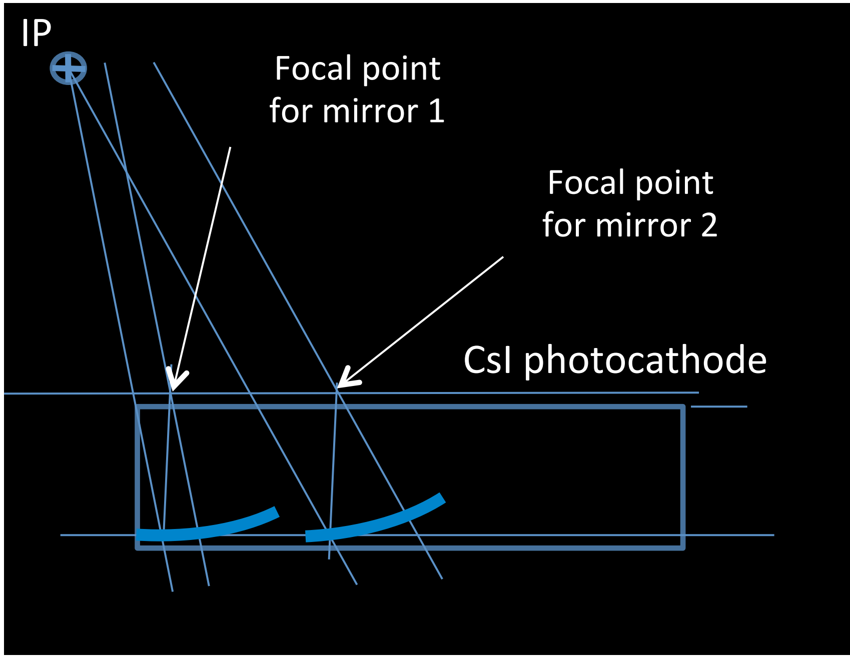
- Determination of **baryon fragmentation functions** via proton in jets
- Determination of **charmonium production process** via PID characteristics in sub-leading heavy quark jet.
- Determination of **quark vs gluon fragmentation** by measuring hadro-chemistry in tagged jets.

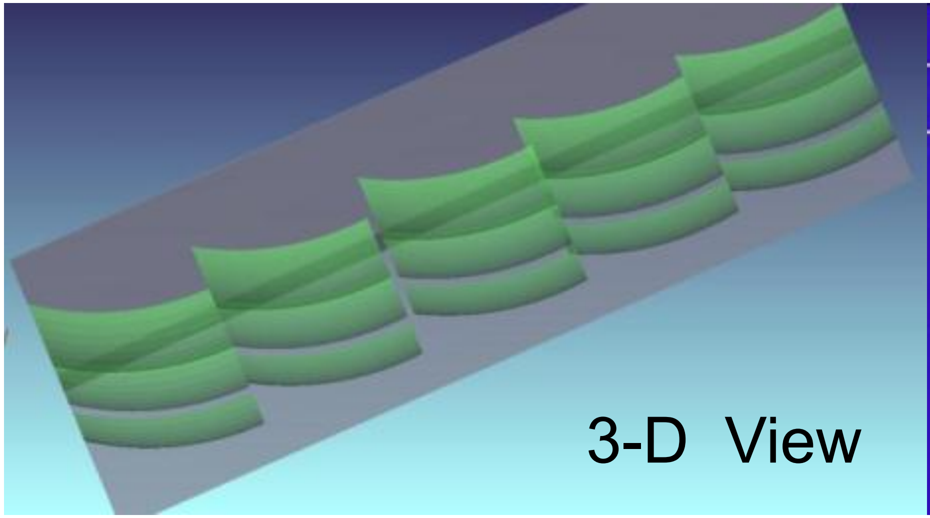
Unique heavy ion physics

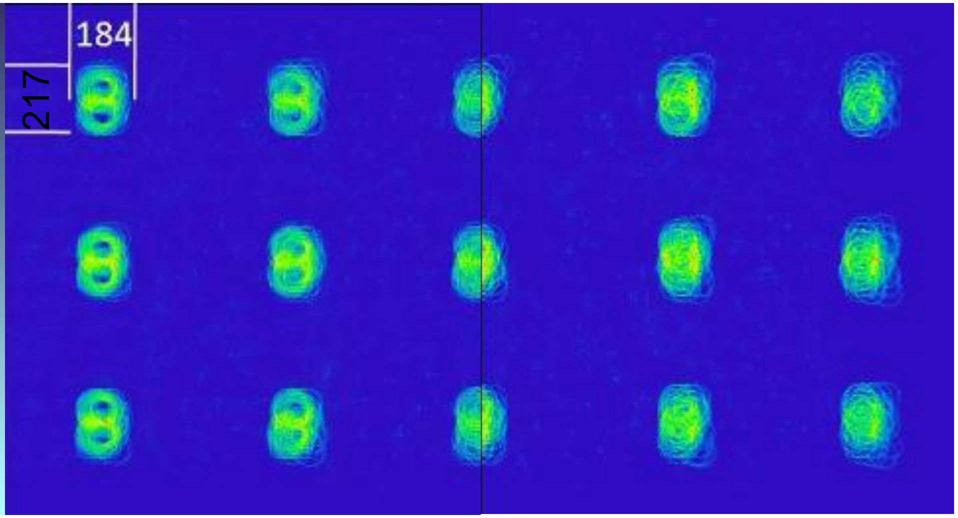
- Determination of cause of **baryon puzzle** at intermediate to high pT through measurement of hadro-chemistry in tagged jets
- Determination of **gluon splitting process** (energy loss in medium) through measurement of **hadro-chemistry in jets**.
- Determination of medium **modification and gluon/quark fragmentation**
- Determination of **baryon/anti-baryon imbalance** through pT dependent proton/anti-proton measurement in medium
- Determination of **hadronic resonance modification** in medium at high pT

Mirror studies (ZEMAX)









Cherenkov angle resolution