New tracking on the basis of Fast, Compact TPC and Pad Detectors (with Enhanced Electron ID Capabilities)

N. Smirnov, H.H.Wieman, C.L.Woody

- **Motivation and Physics Goals**
- **General Description, Simulation, Performance**
- **Today's Activities, Plan**

- *It is very difficult to forecast what part of the RHI Physics will be of most interest in 4 – 5 years.*

-- STAR Workshop on Future Physics and Detectors June 17-20.

-- Recent Data analysis.

-- QGP state discovery needs measurements of very low x-section phenomena with specific correlations.

"Fundamental questions" from LRP white paper

- What are the properties of the QCD vacuum and its connection to the masses of the hadrons?
- What is the origin of chiral symmetry breaking?

- Can we locate signatures of the deconfinement phase transition as the hot matter cools?
- Is the basic idea that this is best described using fundamental quarks and gluons correct?

- What are the properties of matter as the highest energy densities?
- Thermal equilibrium? Temperature?

LRP questions: What should we measure?

- The QCD vacuum
  - Mass?
  - Chiral Symmetry?
  - Transition T
- Confinement?
  - Signatures?
  - Transition T?
- Properties of matter at high energy density? Quarks and gluons correct?
- Understanding the system Created in Relativistic Heavy Ion collisions

- What would we like to measure?
  - Low mass VM in lepton channel vs energy density
  - Critical phenomena
  - Quark and gluon energy loss
    - Reaction plane
  - J/ ?
  - Open charm
  - Thermal
    - Photons
    - Dileptons
  - low-x phenomena
  - Strange/ anti-baryons, p_T spectra
  - HBT
  - Flow
  - Temp/Size/Time profile of the system

From R.Seto's presentation

What do we need to do to make the measurements?

- What would we like to measure?
  - Low mass VM in lepton channel vs energy density
  - Critical phenomena
  - Quark and gluon energy loss
    - Reaction plane
  - J/?
  - Open charm
  - Thermal
    - Photons
    - Dileptons
  - low-x phenomena
  - Strange/ anti-baryons, p_T spectra
  - HBT
  - Flow
  - Temp/Size/Time profile of the system

- What additional tools do we need?
  - Varying energy,species, pp,pA,dA
  - Low mass dileptons – need dalitz rejection
  - Low pt photons
  - Very Low p_T particles
  - Redundancy in lepton signatures
  - High rate
    - more Luminosity
    - High bandwidth
    - Good triggering
  - Very accurate Vertexing
  - Large coverage
  - Event by event capability
  - High p_T PID
  - Forward detectors

From R.Seto's presentation

pA and pP -- a fundamental and critical part of RHIC program.

- Specific demands for the Detector

  -- "forward" direction (pA)

  -- high rate experiment (pP)

What does an upgrade Luminosity mean

- For today STAR, TPC drift time – 40. μs.

- Au+Au, L -> 8. x 10^{27} cm^{-2} s^{-1}.
  X-section = 7.2 barn.

One average event → "Central"+5 MiniBias
or 6 vertexes, ~2500 ch. particles / event

- pP, L -> 2. x 10^{32} cm^{-2} s^{-1}
  X-section = 60. mbarn.

One average event -> 960 vertexes,
~2500 ch. particles / event.

The Main Statement of STAR R&D and upgrade activity

- Keep all advantages of today's STAR but improve the speed of tracking Detectors, PID and Trigger Power.

- Cover as broad of spectrum of Physics goals as possible, and follow the basic STAR philosophy to be a multi-purpose experiment.

Detector upgrades (general)

- Tracking
  - Good momentum resolution - low mass states/high mass states
  - Perhaps very low pt
  - Large back to back coverage EMCAL and tracking
  - Jet coverage for pp – to measure x_1,x_2,Q^2
  - High rate capacity
  - Tag of detached vertex Dalitz rejection
- PID
  - high Pt hadrons
  - Leptons (mu/e,dalitz)
- Good geometry measurements **(high precision Vertex Detector)**
- pA stuff
  - forward muon detector located in the tunnel; $x_2 \sim 10^{-4}$ for ✍>1✍
  - Large acceptance photon detector in the forward region
  - Forward tagging via roman pots
  - Tagging of nuclear fragments get a handle on Ncollisions
- DAQ
  - High Rate
  - High BW to “tape” (balance between acceptance and event count)
  - Good Level 1,2,3 triggering capability – at level 3 – sophisticated cuts

Detector upgrades (STAR specifics)

- *Tracking*
  - high rate
  - good two tracks resolution
  - good particle momentum reconstruction
  - not expensive
  - flexible

- *High precision, low mass Vertex Detector*

- *Additional PID capabilities*
  - room for new Detectors

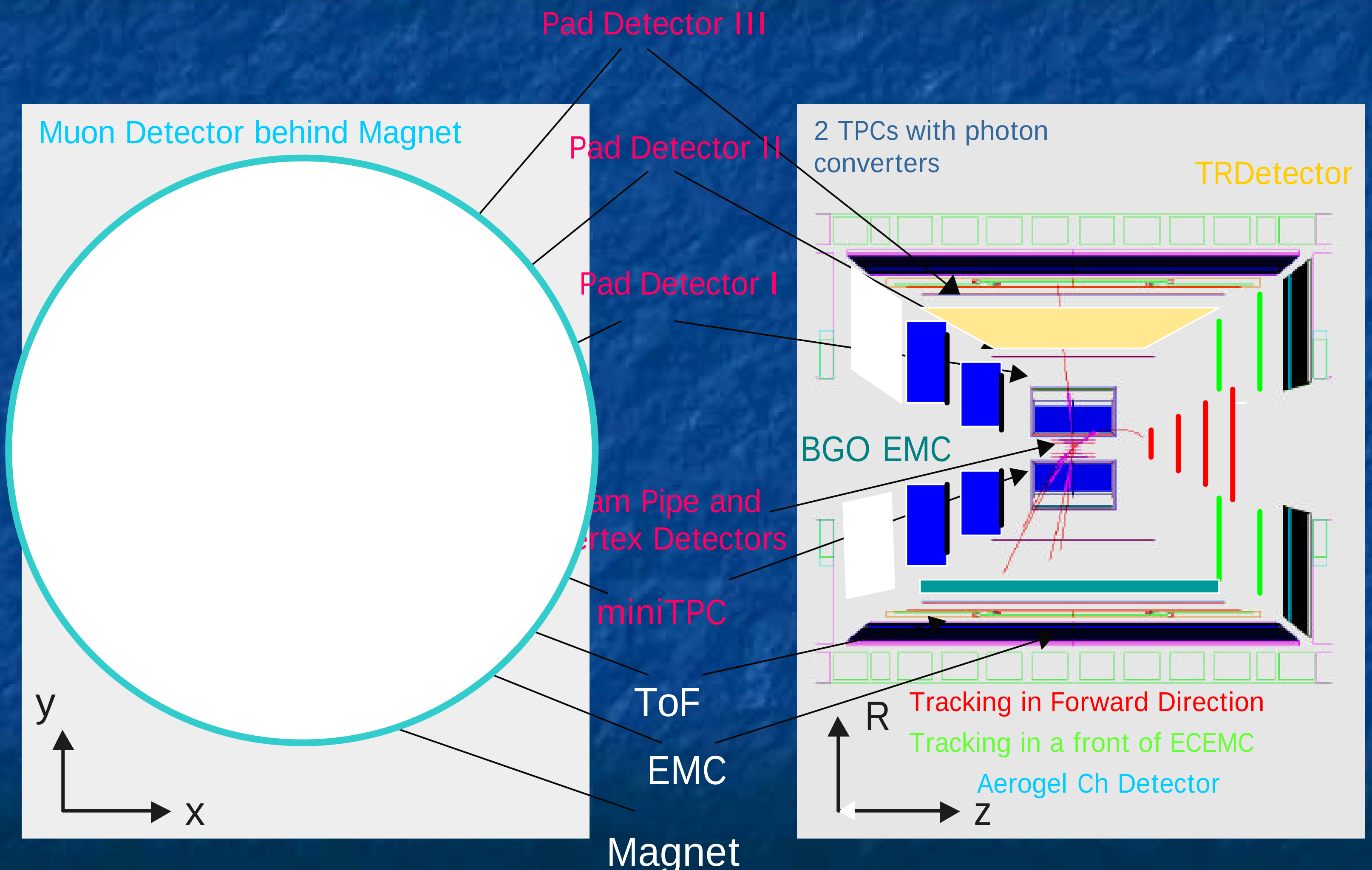
- *Dedicated Trigger power*
  - fast Detectors

New Knowledge and Experience

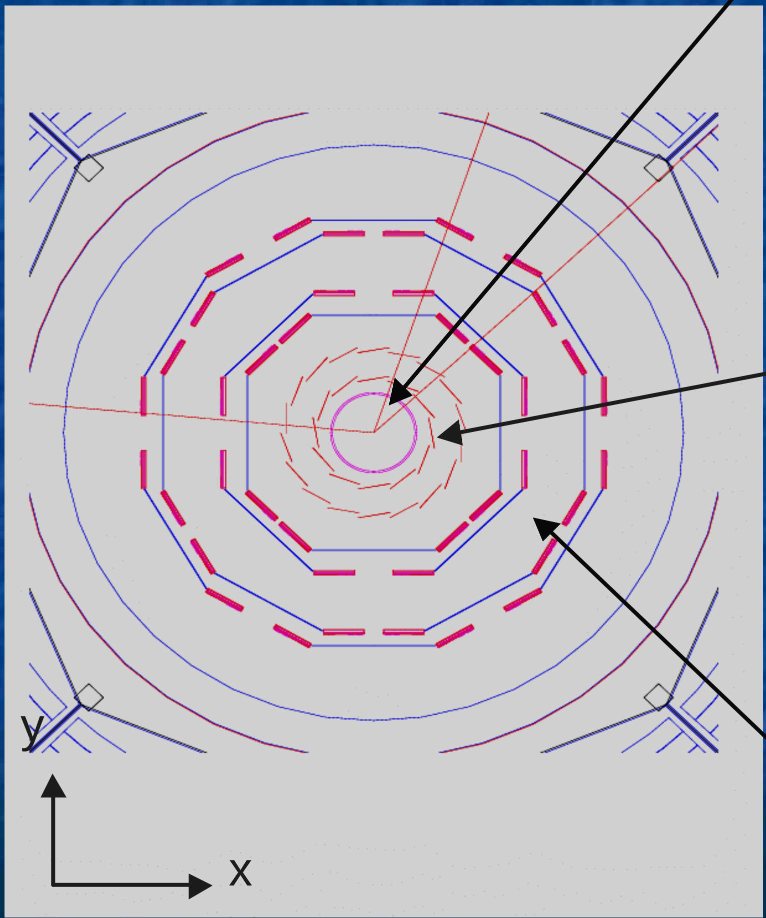
The new tracking proposal became possible because we got the knowledge from Detector development point of view gained at RHIC during first two years of STAR operation:

- dN/dY particle distribution for Central Au+Au events
- Momentum spectra of particles
- Background conditions; special – the ‘neutron albedo’ from construction elements
- The experience to work with a flamable gas in a very large volume
- The experience and knowledge of the construction and utilization of RICH Detector with the Pad-readout covered with CsI
- a lot of activities and the progress with construction of micropattern gas Detectors

STAR tracking, proposed variant

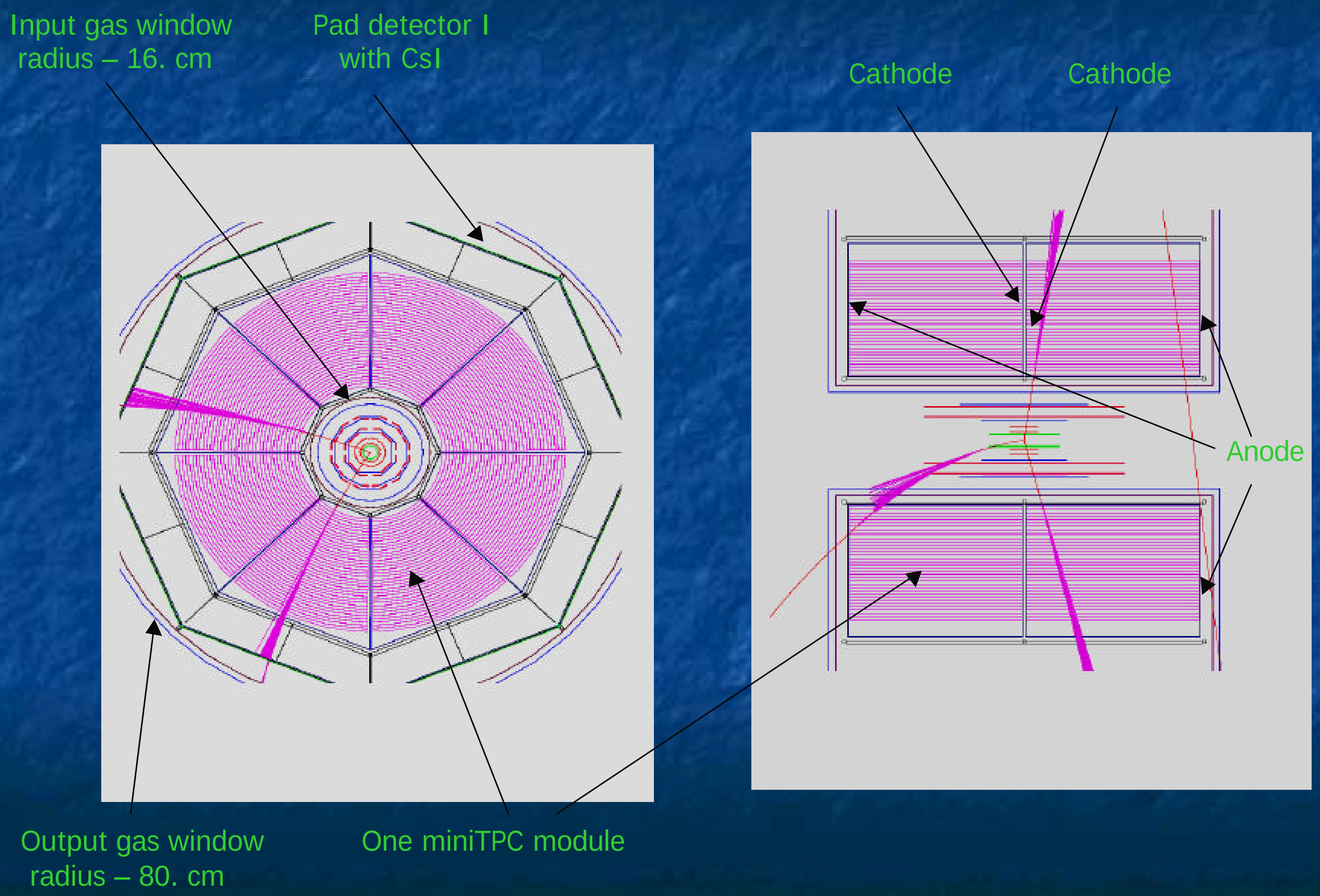


Vertex Detectors; proposed variant

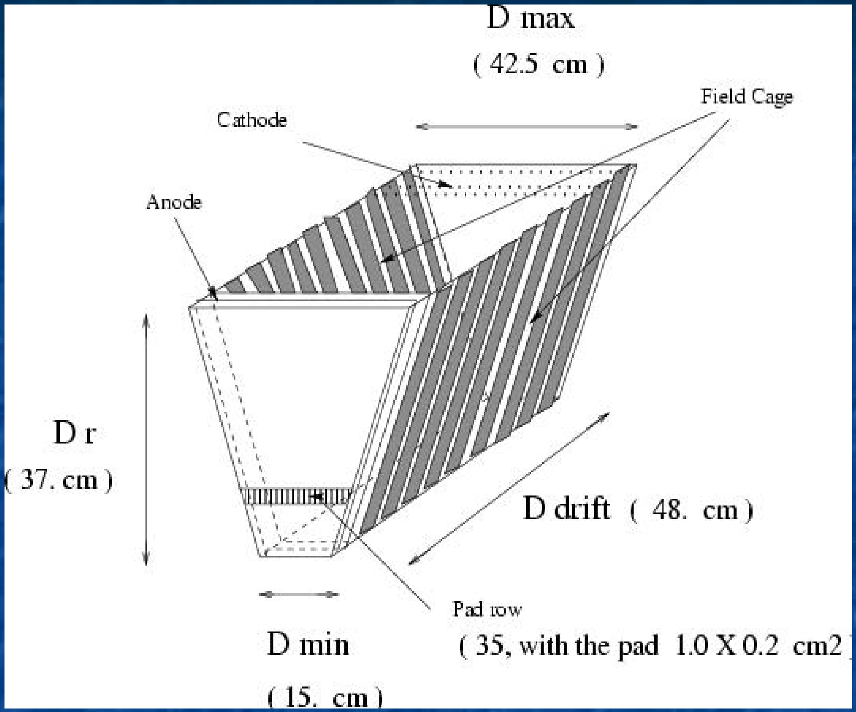


- New beam pipe.
  - in the simulation:
    Radius = 2. cm,
    L = 20. cm,
    wall thickness= 900 μm,
    Be.
- High precision, low mass Vertex Detector (APS technology).
  Radius: 2.8 and 4.3 cm.
  Dimensions of each Detector – $1.6x1.6x0.005\ cm^3$.
  First layer – 60, second – 80 detectors.
- Two layers of Silicon Drift Detectors (first and second layers of existing SVT)

miniTPC Detector, proposed variant



miniTPC module, proposed variant



Anode (Gas amplification, ReadOut): microPattern Gas Detector(s) with Printed pad structure on Kapton or Mylar (GEM, microMeGas,...)

- 16 identical miniTPC modules with the Drift distance 48. cm and its own Field Cage
- Common gas volume with double windows
- "working" gas – CH_4, but another gases (mixtures) will be studied to select the best and convenient one.
- Shape: trapezoid,

  Cathode: Kapton or Mylar

  Field Cage: Kapton or Mylar with printed strip structure (for bottom and sides, wires for a top)

  N of Pad-rows: 35

  Pad dimention: 1.x0.2 cm2

  All construction (support) elements: low mass composites material like STESALIT.
- 5400 readout channels / module

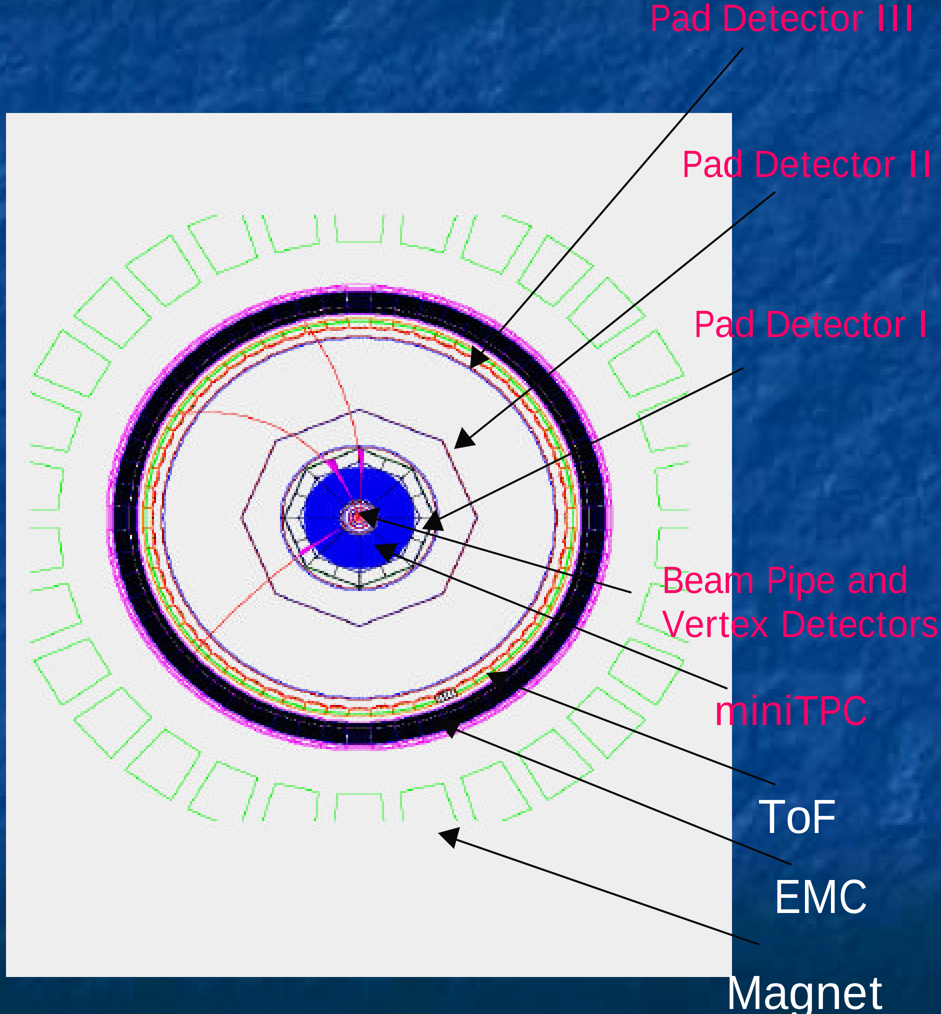
  86500 / Detector

miniTPC, possible improvements and losses.

- This approach allows 8 times faster Detector with 5 times smaller “effective” diffusion.
- The double (or triple) GEM structure guarantees that a very small percent of positive ions (from gas amplification stage) comes back to the volume, it means that a “gate electrode” can be avoided.
- The construction without anode wires and with its own field cage can be done as a “frameless” one.
- More room for more Detectors

- But smaller detector dimensions in R-direction and a reduction of the number of Pad-Rows will result a degradation of high Pt momentum reconstruction (using only data from miniTPC) and quality of dE/dX information.

STAR tracking, proposed variant.
Pad Detectors, high Pt particles reconstruction and Trigger



- three Pad Detectors on Radius: 75., 110. and 200. cm
- microPattern gas detector technology: fast response, needed space resolution, any pad shape, not expensive.
- Pad Detector III – CTB role, “hit” in a front of Aerogel Ch. Det, ToF, EMC.
- High Pt Trigger.
- “fast” – “slow” combination.

Detector responses simulation.

-- to "Raw - Data " level

-- in the frame of GSTAR, but with the modification of the "HITS" definition.

-- "fast" simulator: smearing hits positions

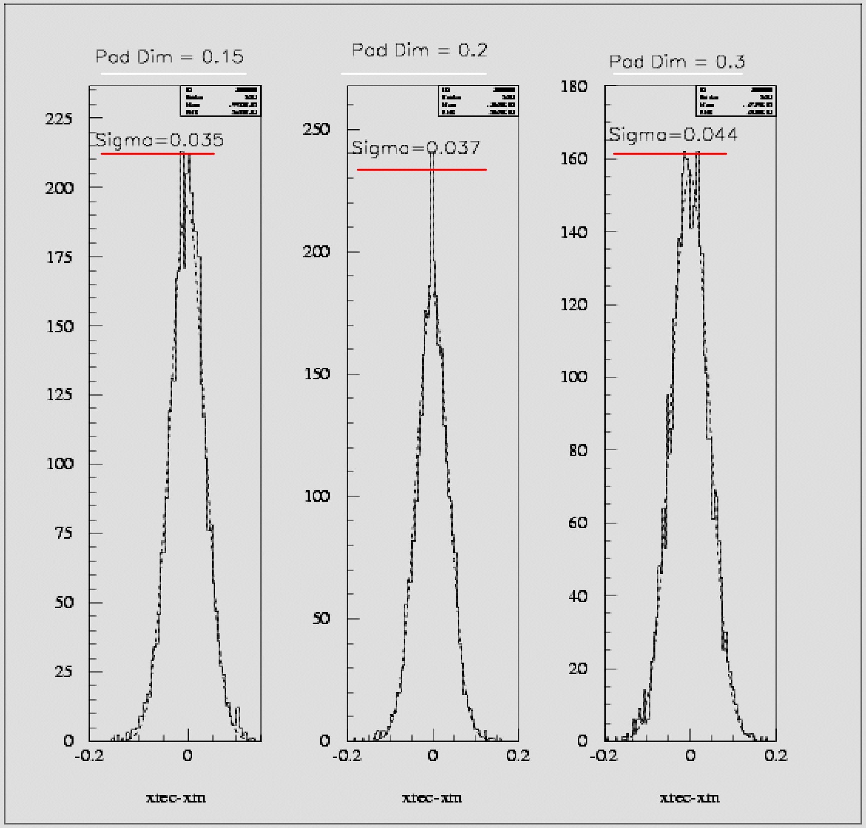
-- "slow" simulator: number of charge particle interactions with matter inside of "sensitive" volume, an energy transfer in each interaction, a number of ionisation electrons per interaction and their position in a space.
It allows to take into consideration: drift, diffusion, distortions, gas amplification, FEE shaping time and noise, cross-tolk, ...

-- Cherenkov Detector: all known data on UV light production, absorption, quantum efficiency, photoelectron extraction efficiency, feedback photons, and so on.

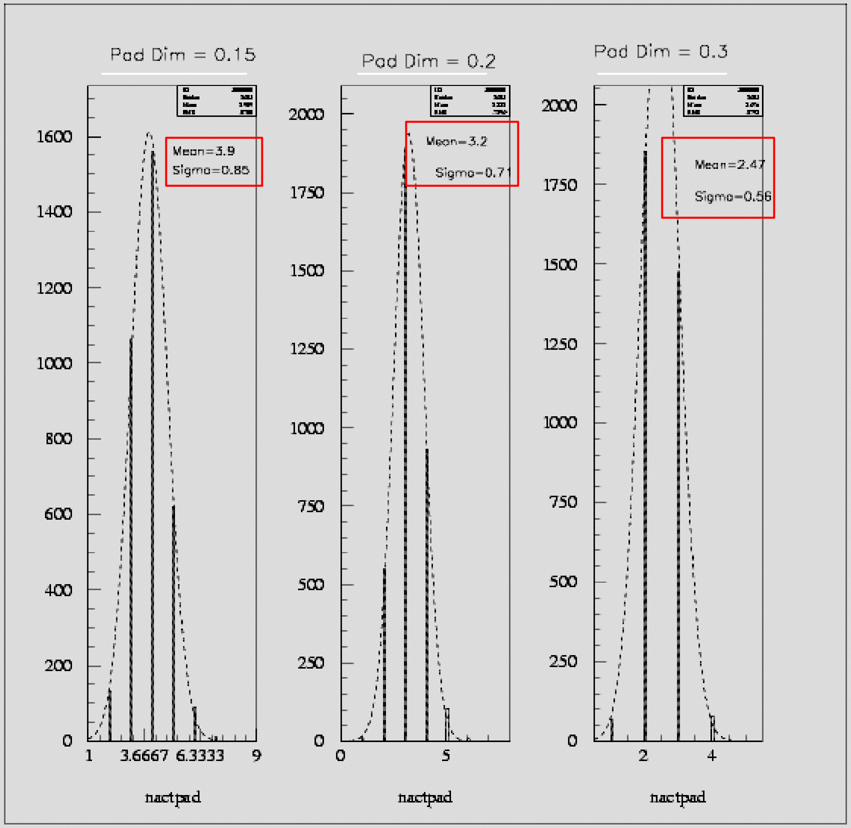
-- MWPC + Pad (possible variant for Pad Det I): an induced on pads charge are calculated as a function of the charge on a wire and geometrical parameters.

miniTPC, "full scale" simulation, one pion / event, GEM Detector as a read-out

Space resolution in Rphi, cm



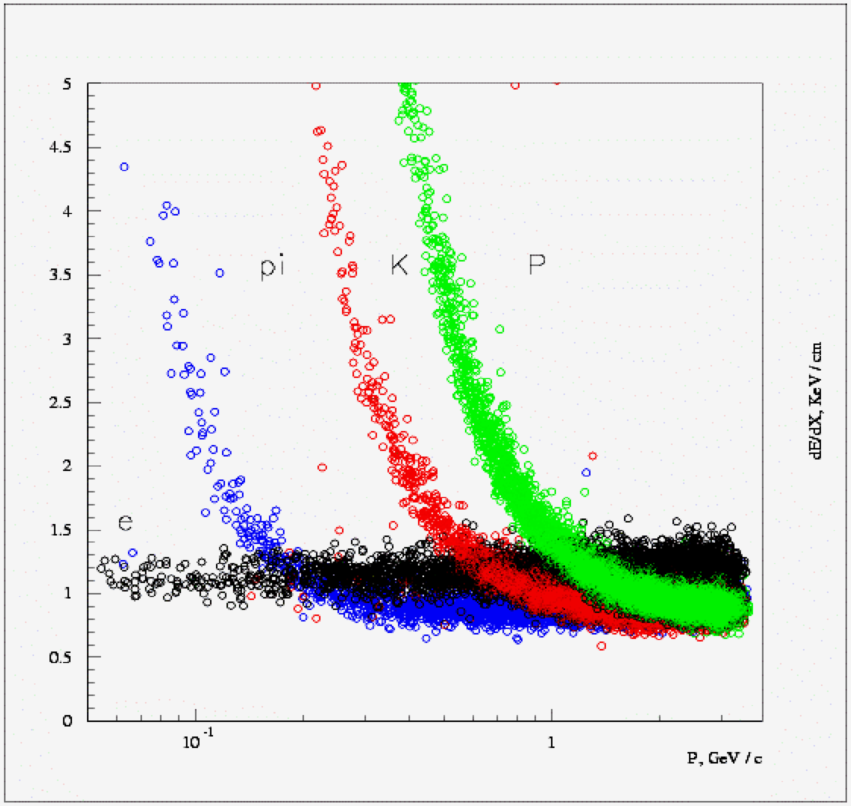
Number of "active" pads/cluster



As a function of a pad size in Rphi direction, cm

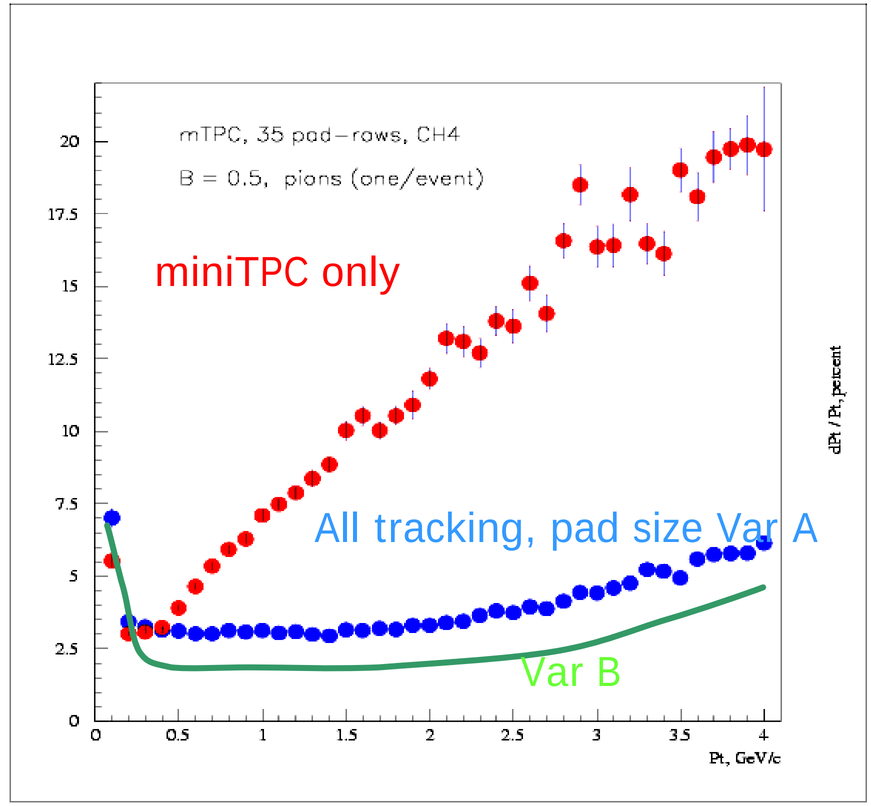
dE/dX and dPt/Pt performance

dE/dX, KeV/cm



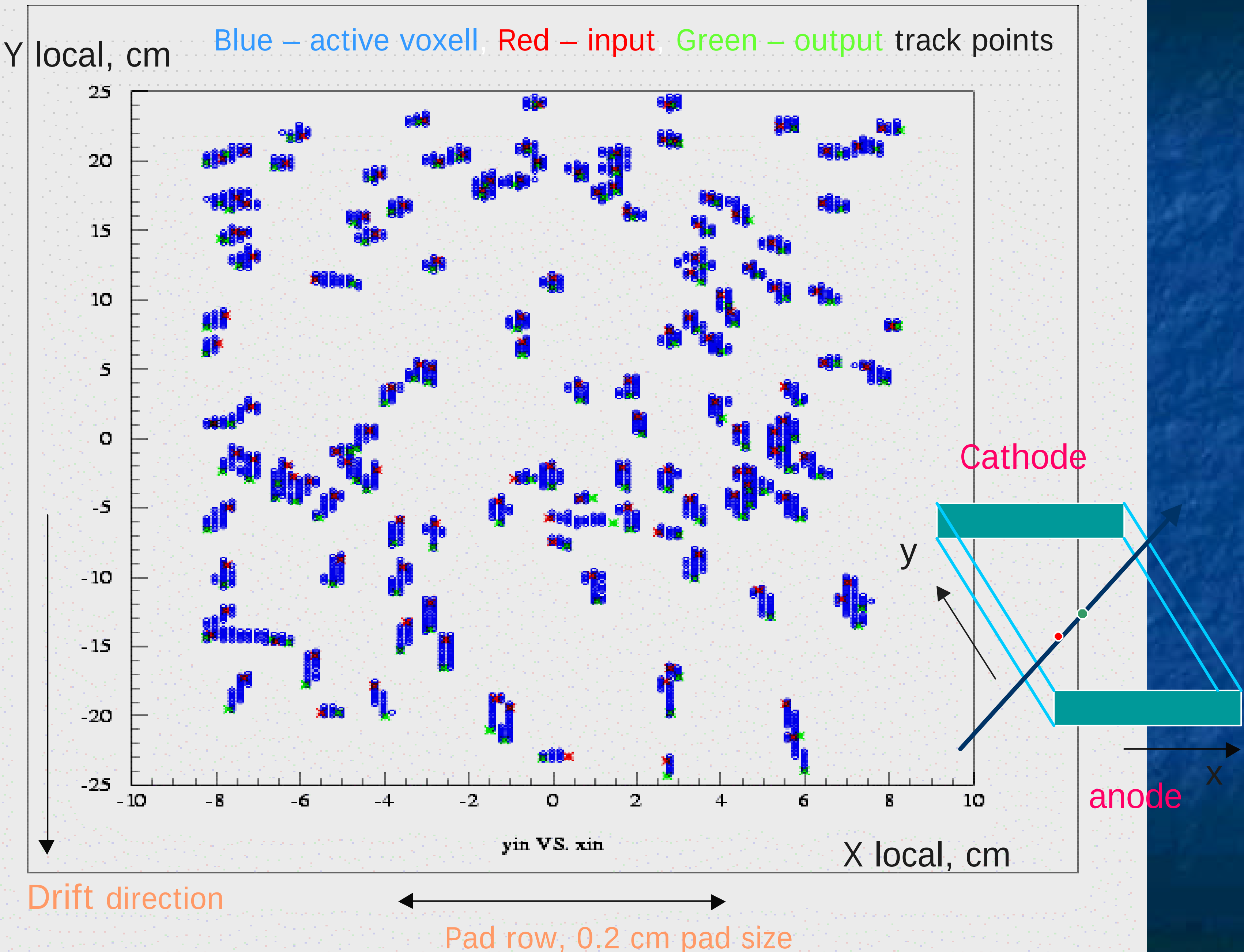
Simulation -> reconstruction ->
trancated mean, pad size = 0.2x1.cm2

dPt/Pt, percent



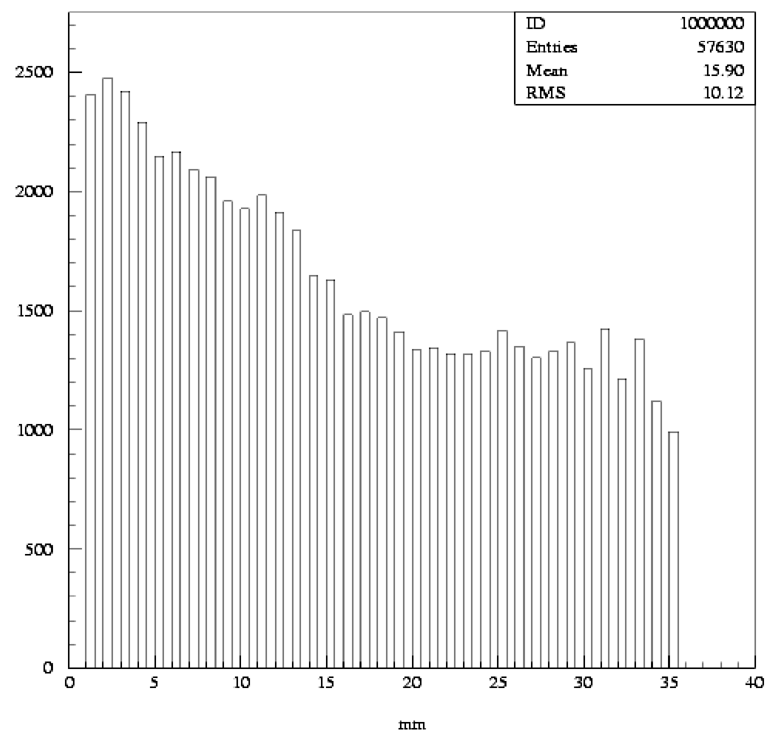
Pad size, in Rphi	Pad Det II	Pad Det III
Var A	0.8 cm	1.6 cm
Var B	0.2 cm	0.4 cm

HIJING event, one miniTPC module, first Pad-Row



Central HIJING event, miniTPC response

Average number of "active" voxells / event / pad-row



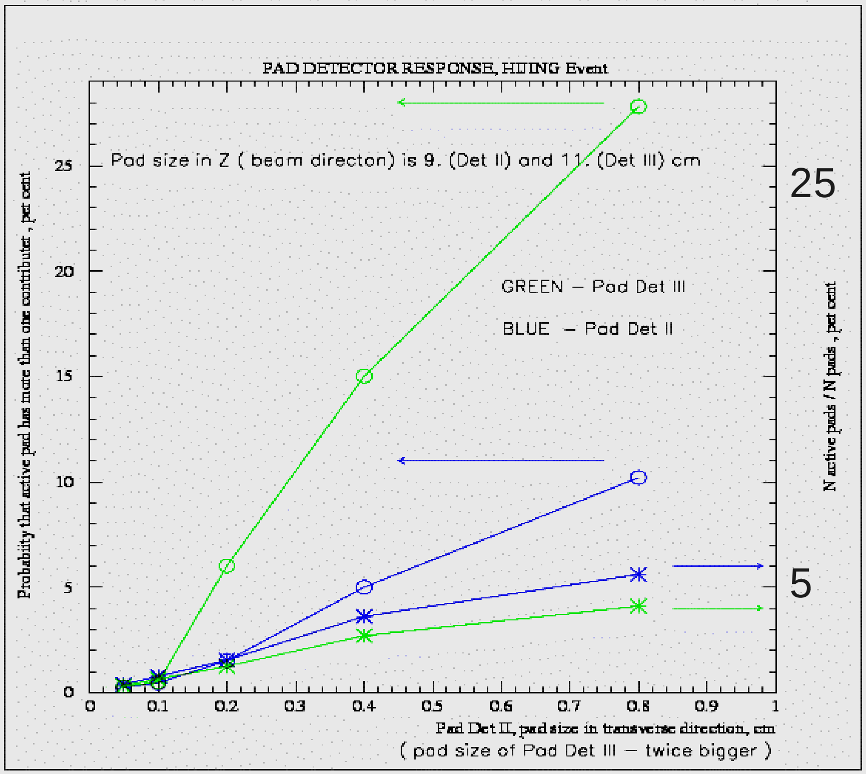
miniTPC Pad – row number

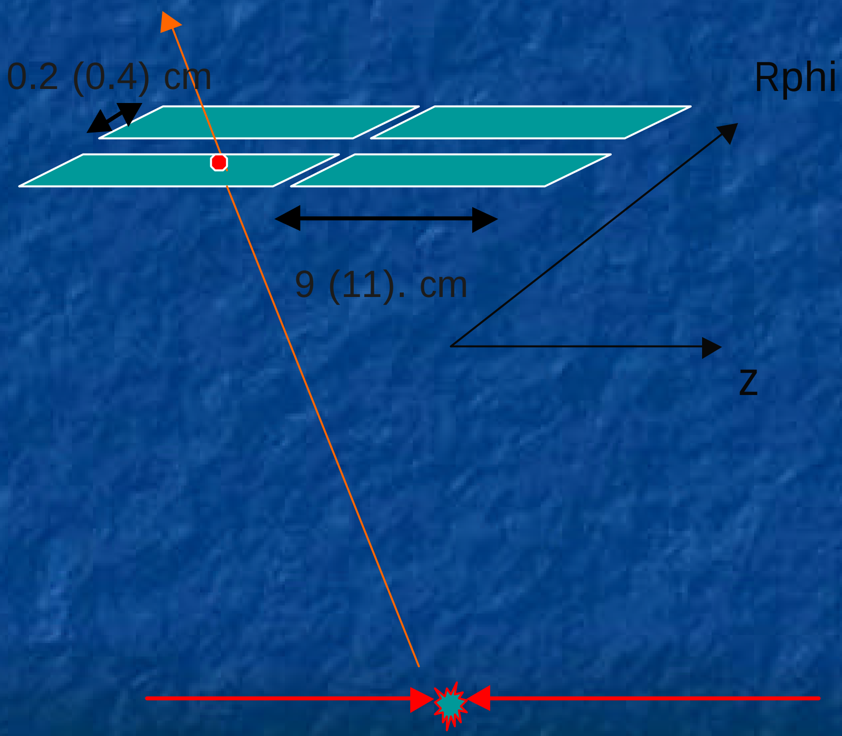
- "full scale" simulation
- Number of Voxells for pad-row #1 = 21000

  250 t-cells x 84 pads

It means 12% an occupancy.

Pad Detectors response as a function of pad size.





Pad Det I: pad size = 0.6x0.6 cm^2

The reason to install Pad Detector I in the same gas volume with miniTPC is:

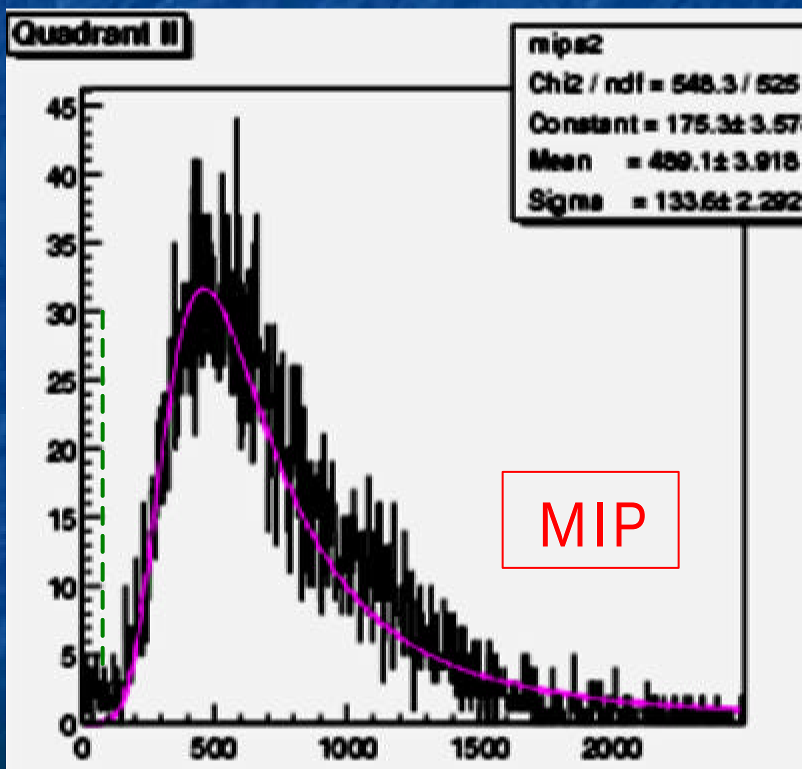
check and use the variant with miniTPC working gas as UV photons radiator, and the Pad Detector covered with CsI as both MIP and UV sensitive device using the same (CH_4) gas as a "working" one (no window).

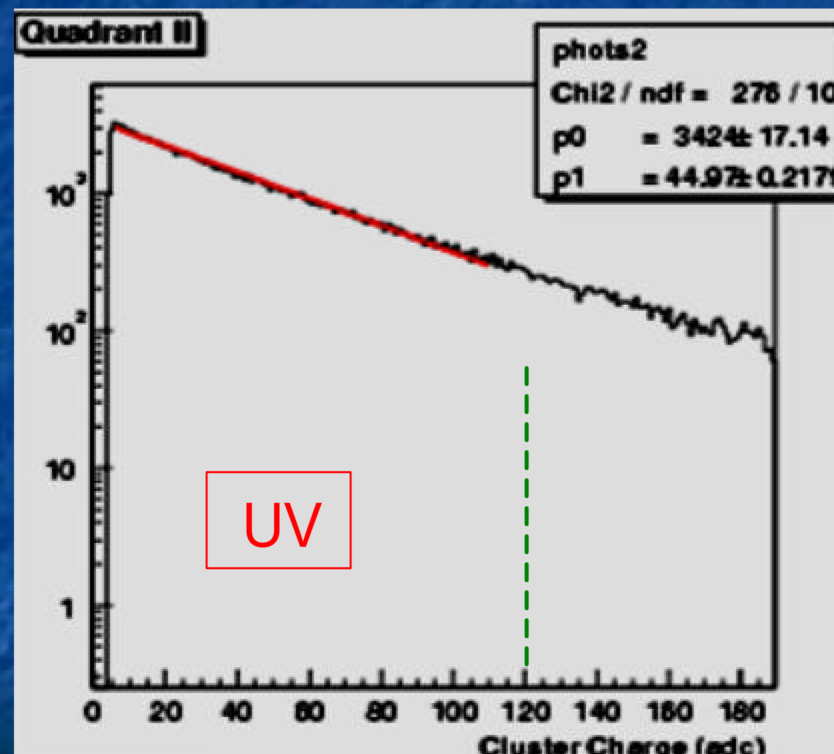
"Hadron Blind Detector" (e+/- PID)

- How it works
- Performance

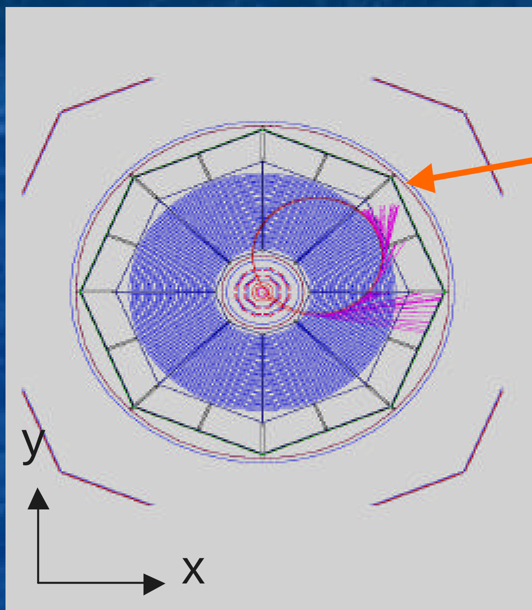
The result from CERN-STAR RICH Detector → the good distinction between MIP and UV photon responses.

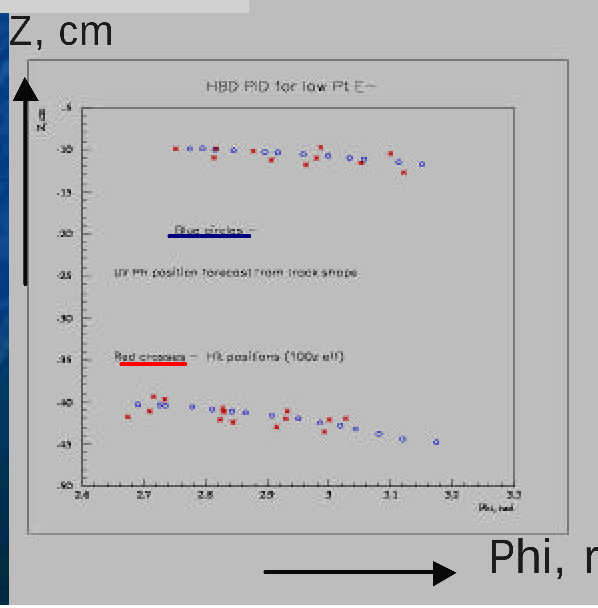
Cluster charge, ADC counts





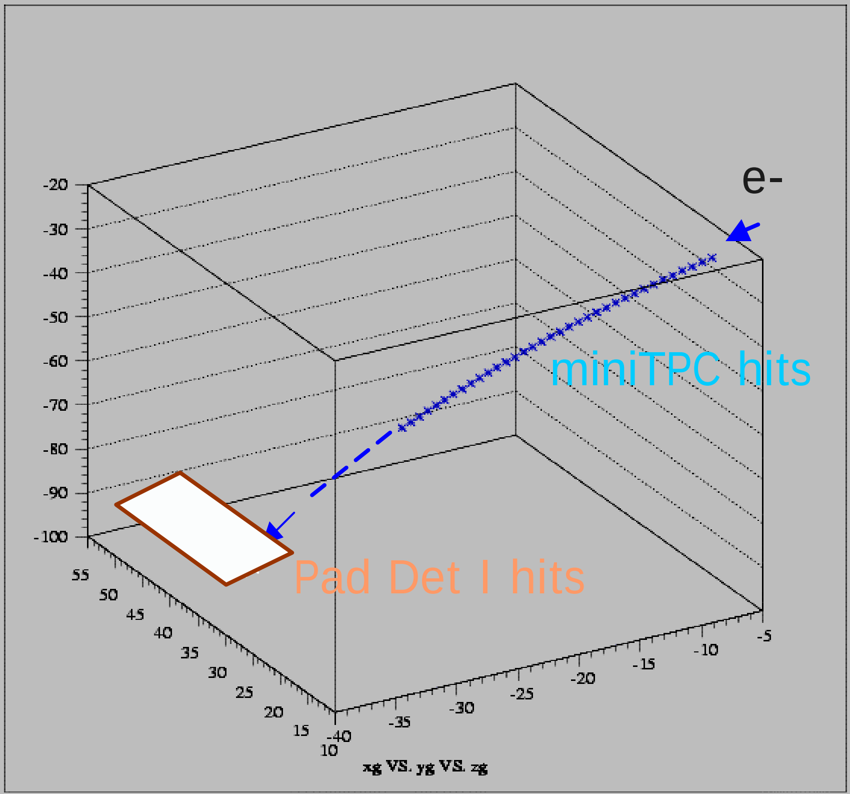
HBD PID, step 1 (for “low” Pt tracks)





- For all found in miniTPC tracks dE/dX analysis/ selection were done;
- then some number of tangents to selected tracks were calculated and “crossing” points with Pad Det I (if it was possible) were saved,
- and a “search corridor” was prepared.

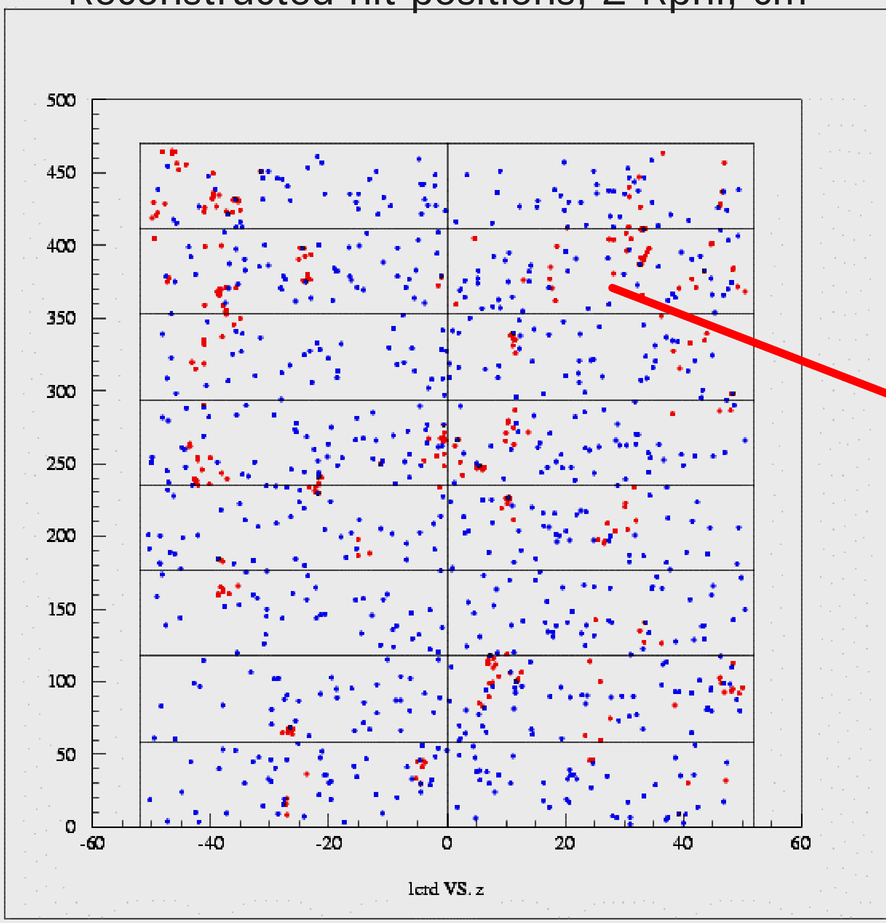
HBD PID, step 2
(for “high” Pt e+/-)



- For tracks that crossed Pad Detector I, a matching procedure was done (TPC track – Pad Det Hit), and an analysis took place to check the number of UV-photons hits inside of cut values (which are the function of Pt, Pz)

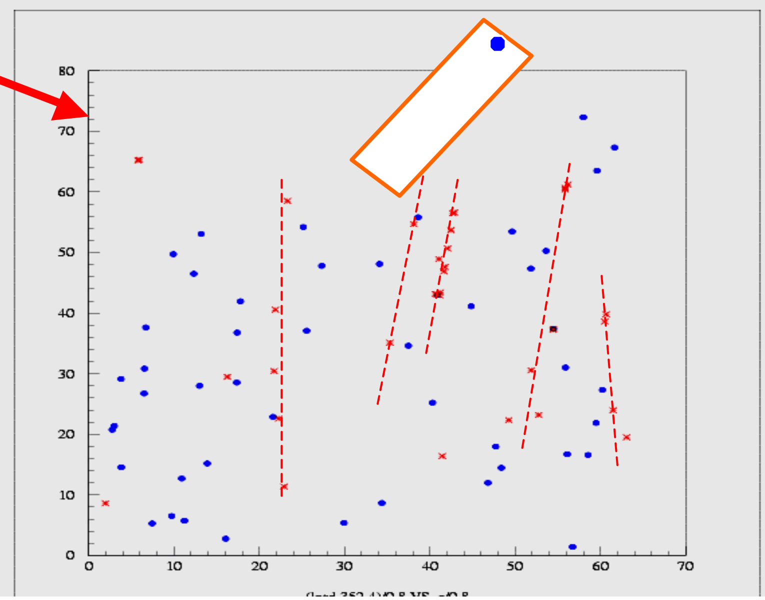
Pad Detector I response simulation, and e+/- PID

Central HIJING event, “full scale” simulation,
Reconstructed hit positions, Z-Rphi, cm



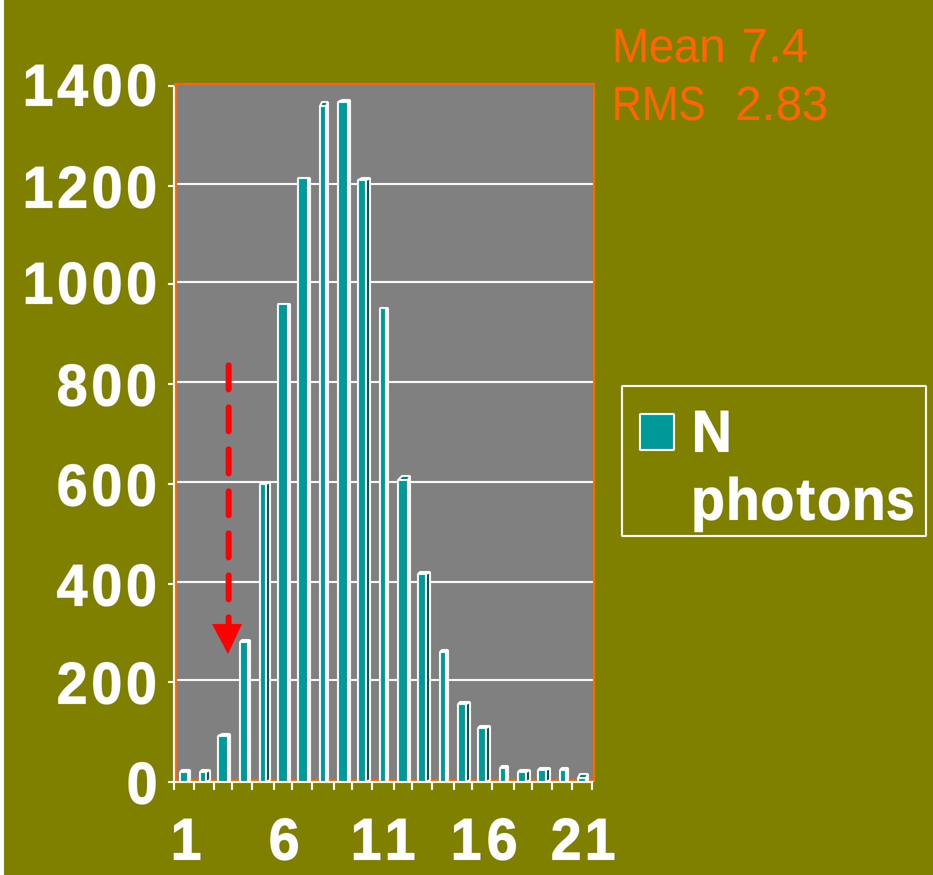
MIP – blue points
UV – red points

820 MIP hits → 4100 act. Pads
790 UV hits → 1185 act. Pads
Pad size = 0.6x0.6 cm2
Number of pads = 77824
Occupancy = 6.7%



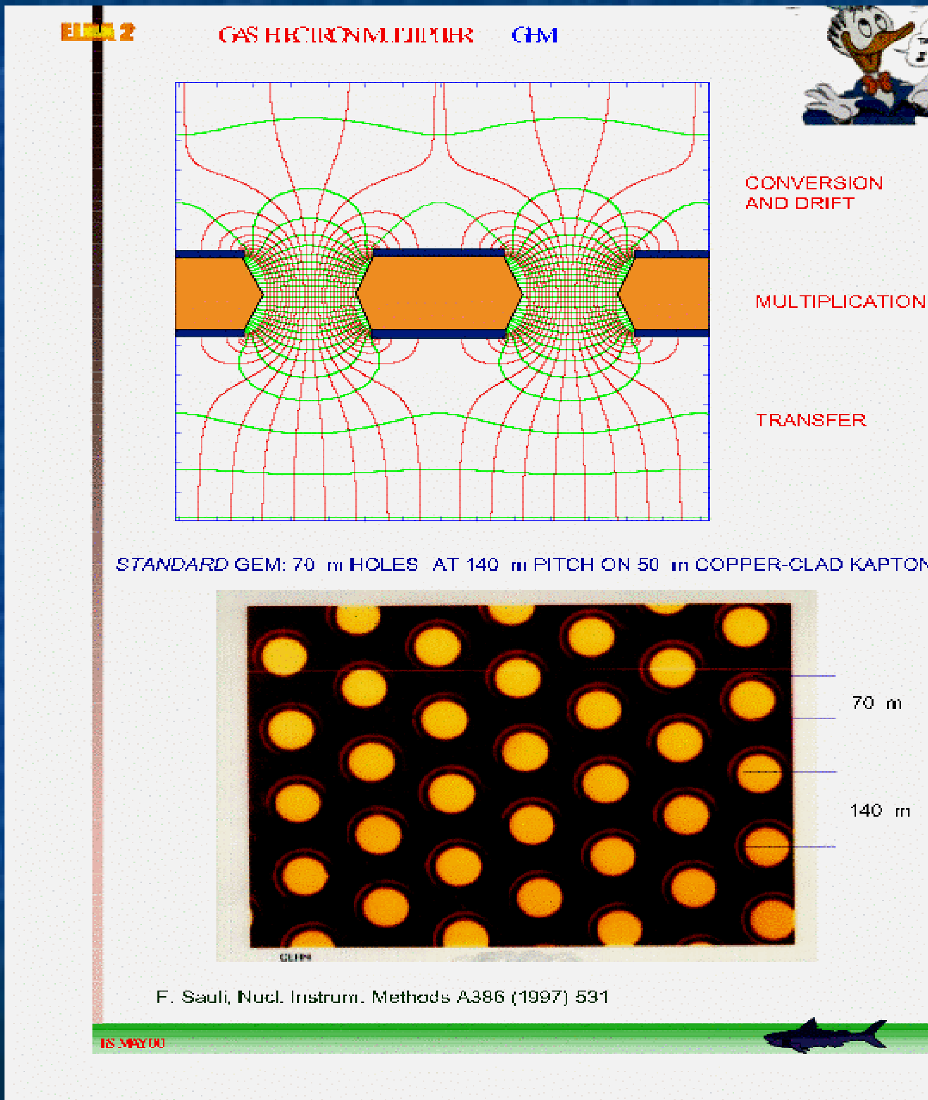
HBD performance (preliminary)

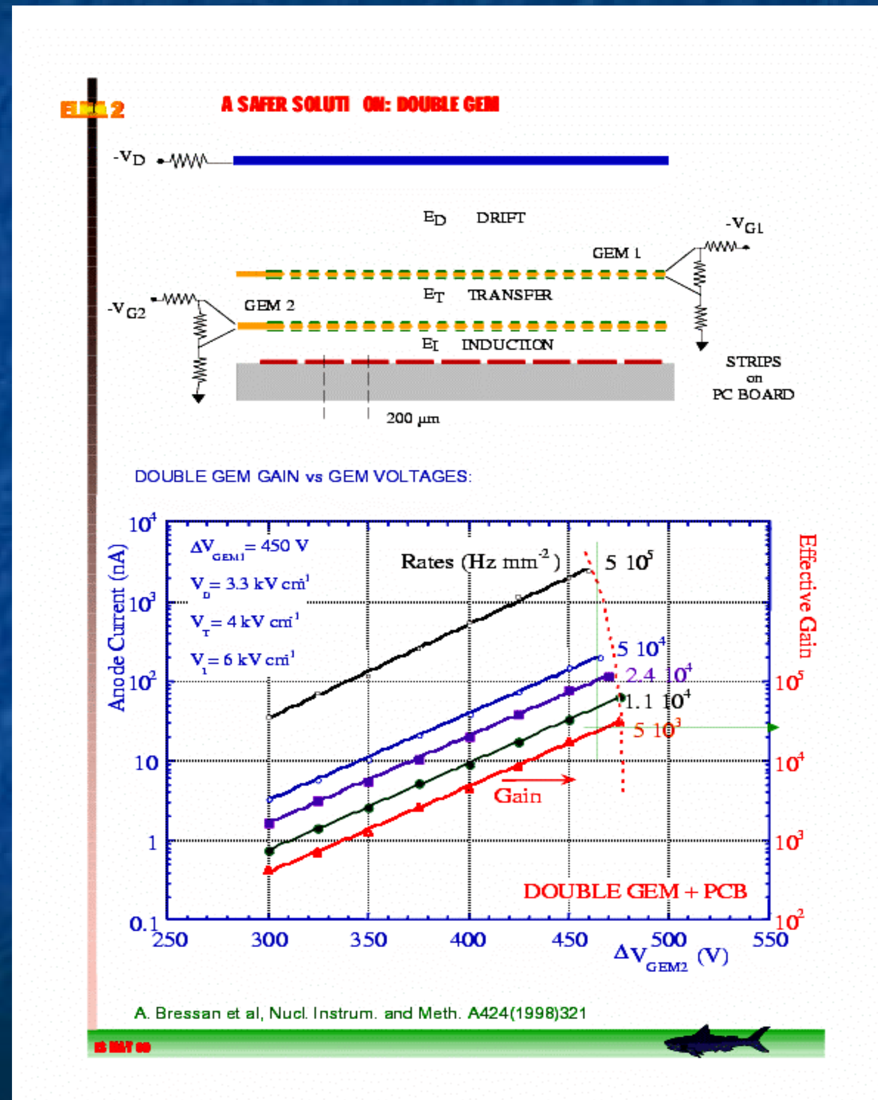
Number of reconstructed UV photons/track
(9 or more TPC hits)



- For "central" HIJING events:
  - the lepton PID efficiency (all found tracks in TPC) – 90.8%.
  - The number of wrong hadron identifications – 1.5 tracks/event.

GEM Detector





GEM Detector

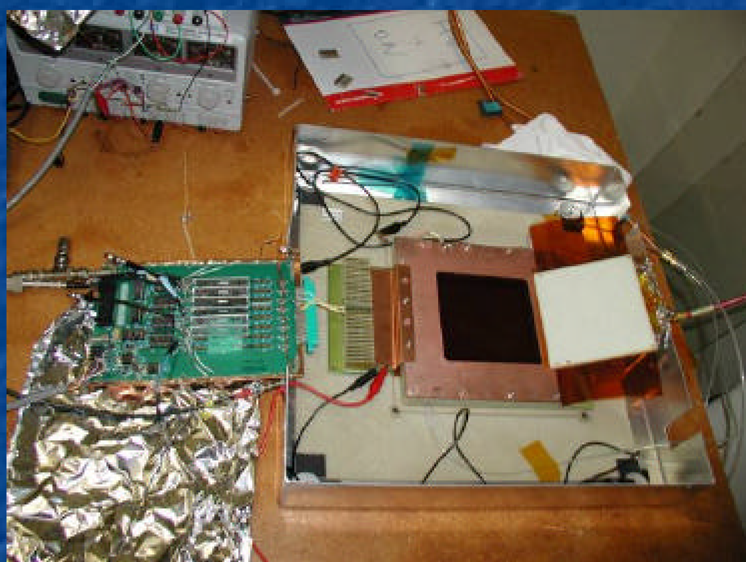
Double GEM has proven excellent properties as a tracking device:

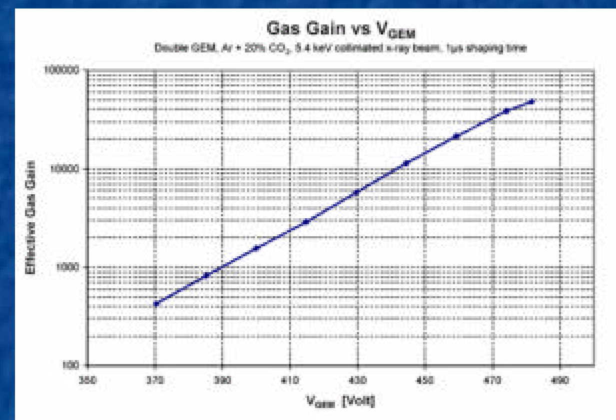
- rate capability up to 10^5 Hz/mm^2
- a comfortable efficiency plateau for minimum ionizing particles
- spatial resolution of 40 μm
- time resolution of 20 ns (FWHM)
- no aging up to 12 mC/cm
- simple implementation of two-dimensional readout is possible

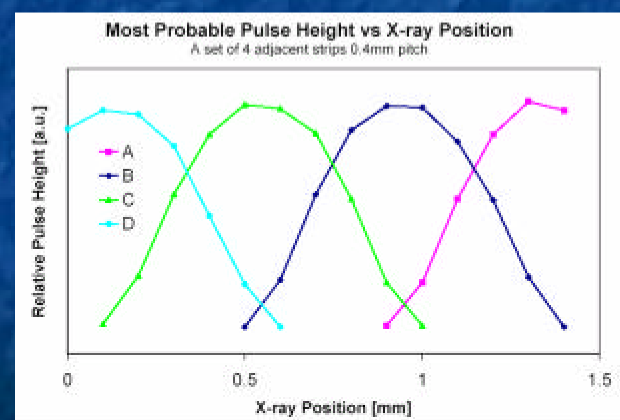
→ *A.Bressan et al. Nucl. Instr. And Meth, vol.A 425, pages 262-276, 1999*

S.Bachmann et al., Proc. Nucl. Science Symposium and Medical Imaging Conference, Seattle, October 24-30, 1999

GEM Detector, test at BNL

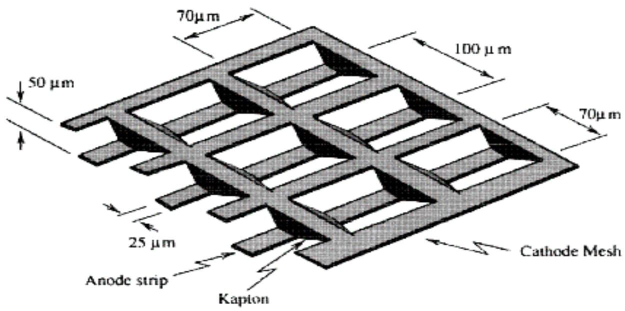






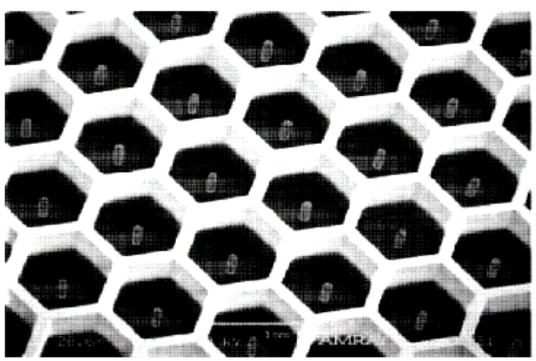
MIPA and MicroMeGas micropattern Detectors.

MICRO-WIRE CHAMBER:



B. Adeva et al. Nucl. Instr. and Meth. A435(199)402 *A. Iglesias*

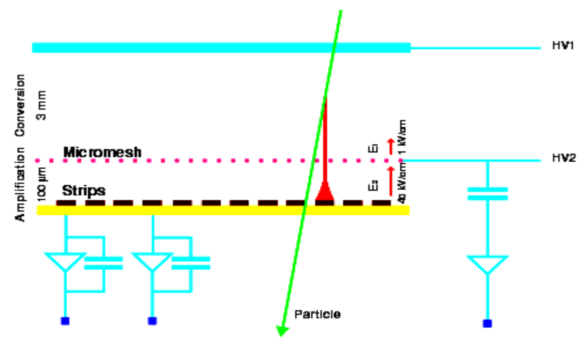
MIPA: MICRO PIN ARRAY DETECTOR (SILICON TECHNOLOGY)



P. Rehak et al. IEEE Nucl. Sci. Symposium Seattle 1999

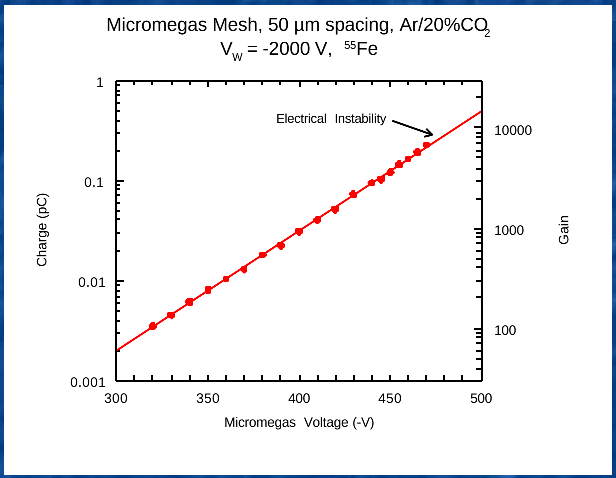
Micromegas

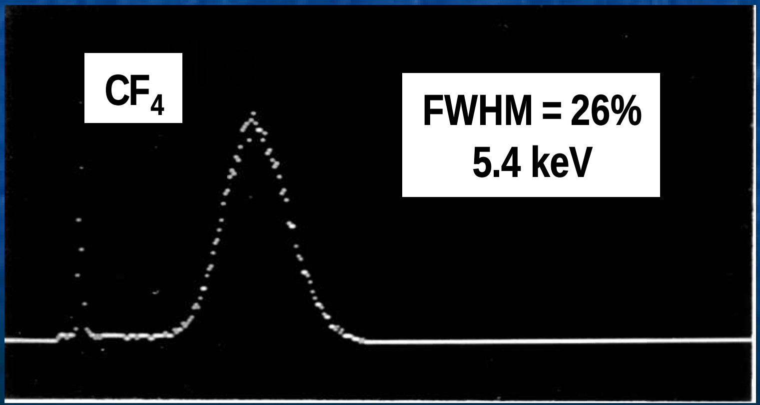
- NIM A376 (1996) 29
- A $15 \times 15 cm^2$ detector has been tested at PSI in a low energy hadron beam and at CERN PS with 10 GeV/c π^+
  - 100 μm amplification gap, 317 μm strip pitch



- At PSI a very high discharge probability per particle was observed
  - With $Ar - CO_2$ (60-40) at a gain of 6000 $P = 1.1 \times 10^{-5}$
  - With 50 KHz/mm^2 proton beam the sparking rate was as high as 3 KHz and the current was 2 mA
- No damage to the chamber has been observed

MicroMeGAs, test at BNL



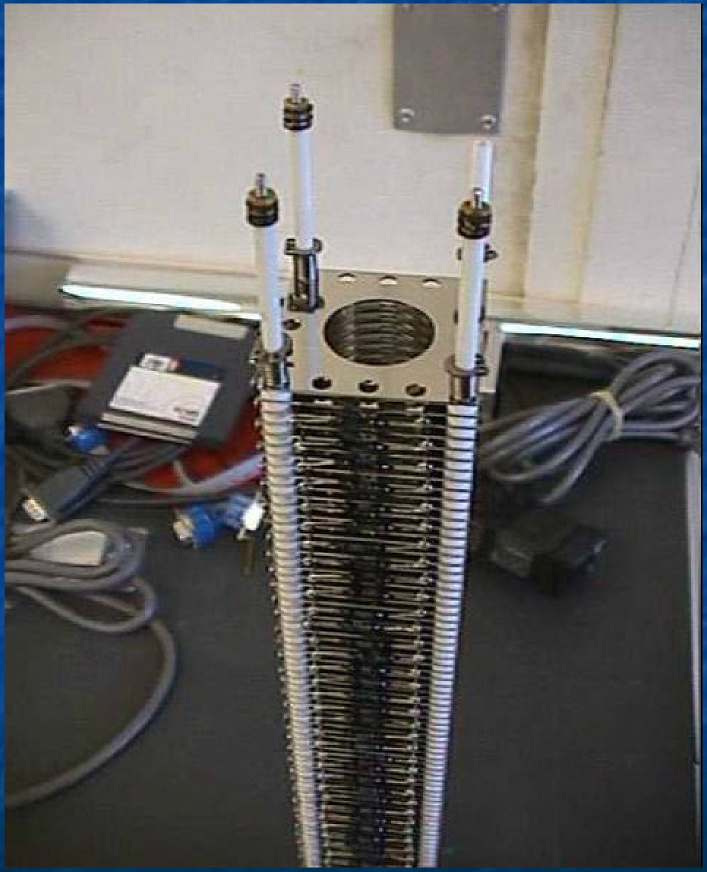


Status and Plan

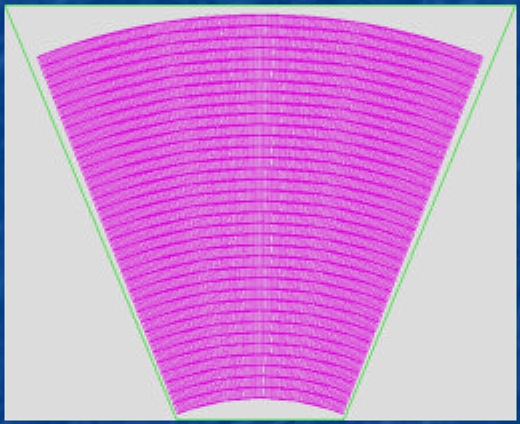
- R&D and software simulation /reconstruction activities were started, but STAR R&D team – two persons plus Berkeley group
- Another groups and experiments are very interested in the realization of STAR new tracking/PID proposal, including PHENIX (more than 10 persons team). That is why the joint R&D laboratory was organized at BNL.
- Good working relationship with BNL Instrumentation Division was installed

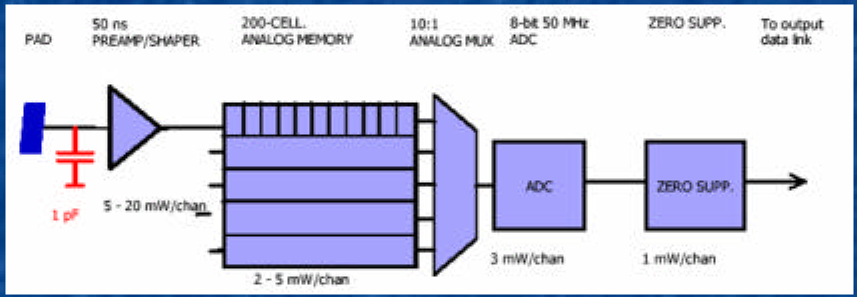
- During this year we are going to study different gasses (mixtures) as a TPC and micropattern Detectors "working" gas; UV-light transparency and scintillations.
- Different Pad shape and Read-Out scheme for micropattern Detectors.
- Install GEM Detector in PHENIX to check a "behaviour" and long term stability in "real" environment from background and occupancy point of view.
- Start the construction of miniTPC prototype.

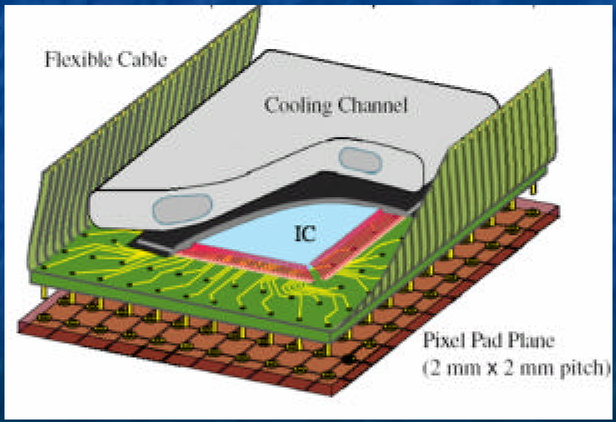
Gas vessel and Drift cell to study gas properties.

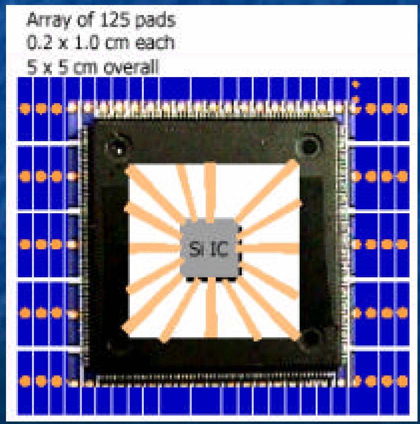


TPC FEE and ReadOut









What we can get ?

- Flexible Set-Up
  --different detectors/ configurations/ geometry as a function of the "Physics Goal" (AA, pA, pp, ….)
  -- from today's Physics up to high quality J/? and ?-measurements, ??-correlation study, very high Pt particles, ….
- Increase the Data Rate (DAQ !!!)
- "Destroy nothing" approach
- Low Pt particle measurement and Lepton PID (0.05 --->) GeV/c
- High Pt trigger, and "charged particle hit" in front of a ToF, EMC, ….
- High precision, low mass Vertex Detector
- More room ----> more Detectors ---> PID, Trigger
- Possibility to increase the Magnetic Field for "small R"
- Possibility to work "without TPC mode", only "fast" Detectors
- Possibility to realize an "on-line track finding\ reconstruction" algorithm using data from Pad Detectors as "pointers" for miniTPC (~80% of all tracks) and organize an independent/ parallel soft – ware activity for all 16 modules as a first step
- All Detectors can (should) be tested and calibrated (including miniTPC modules test with Magnetic Field (ExB, "space charge" corrections)) before they are installed

Instead of the Conclusion

- There is a good chance to continue the good Physics in STAR
- RHIC provides us with a powerful QCD laboratory: AA, pA, dA, pP, eA.
- QGP state should be “created” and found at RHIC.
- R&D activity should be started ASAP (DoE support, an R&D funding level $1M-$2M/yr beginning in FY 2004, with start-up funding of $.5M) to prepare the Proposal for the future collaboration decision.
- Some hardware and software results can be used in future experiments.

List of possible R&D activities

- New beam-pipe
- High precision, low mass vertex Detector (Berkeley team).
- Gasses (mixtures) study.
- Different variants of pad shape (structure) for microPattern gas Detectors.
- miniTpc prototype design, construction, test.
- General mechanical support construction design.
- “Special” Laboratory for GEM foils mass production.
- Low mass, “frameless” Pad Detectors on the basis of microPattern technology.
- PID Detectors: Cherenkov, RICH, TRD, … (AeroGel, (GJK)).
- New Photoconverters and new Detectors with CsI (BL).
- Drift cell with conductive Kapton as a “field cage”.
- Pad Detector read-out on the basis of the “passive delay line”.
- FEE, DAQ, SC, Trigger (different levels).
- How to increase Magnetic Field?
- Detector alignment, control (new Laser and/or X-ray system).
- Detailed and careful simulation / reconstruction.