PEP-N tracking concept

- Introduction to PEP-N tracking problem.

- Expected resolution.

- Distortions in dipole magnet as a function of:
    a) gas choice,
    b) magnetic field uniformity,
    c) drift field.

- Detector concept.

- Field cage design.

Acknowledgements for useful comments and help:

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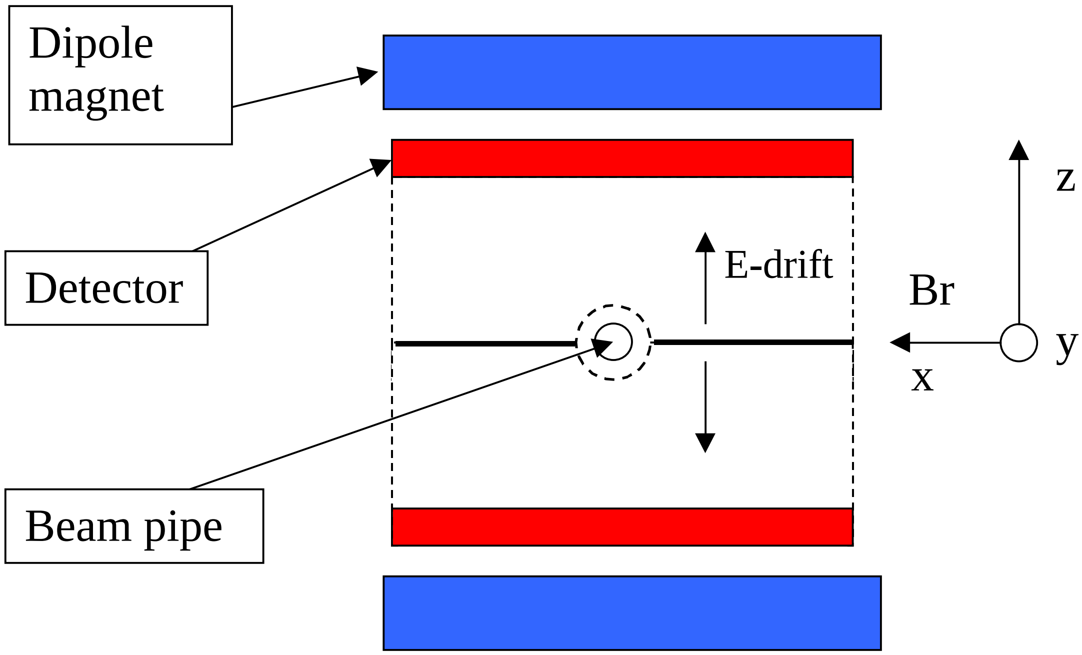
M. Negrini,
Giovanni Bencivenni (Frascati, LHC-b),
Thomas Meyer (CERN, ALICE TPC),
Howard Wieman (LBL, STAR TPC),

Thanks Rinaldo Baldini for asking me to do this.

Introduction to the PEP-N tracking problem

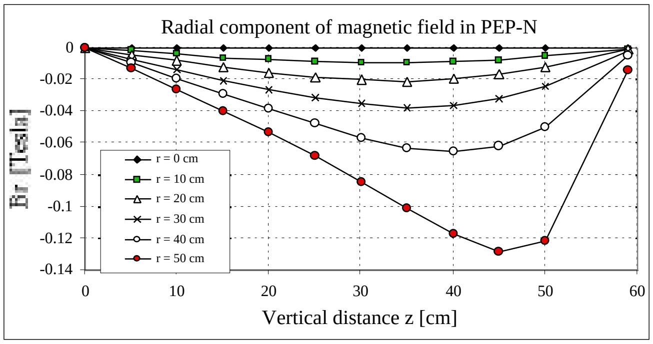


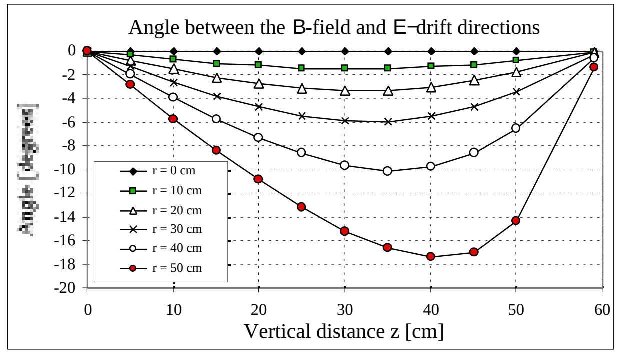
- Classical wire chamber with wires parallel to beam pipe.
  - drift cell has very asymmetrical drift as a function of azimuth.
- Classical wire chamber with wires parallel to magnetic field.
  - very "ugly" coverage near the vertex region; a lot of mass due to endplate, wire feedthroughs, etc.
- Classical TPC with electric field aligned with the magnetic field.
  - very large distortions because E vs. B angle was as much as 18^0 at radial distance r = 50cm in the initial dipole design!!!
  - possible low energy background, which normally goes through the beam pipe, can follow magnetic field lines into the TPC.

Magnetic field uniformity

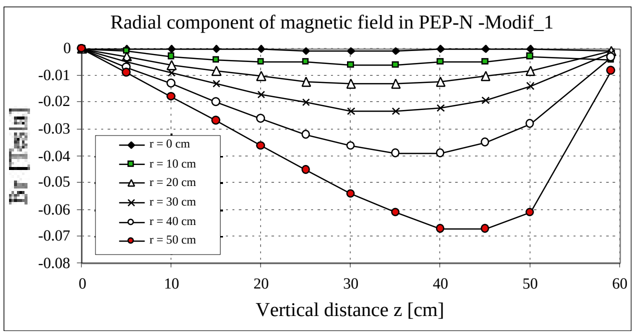
Field parameterization provided by Mario Posocco.

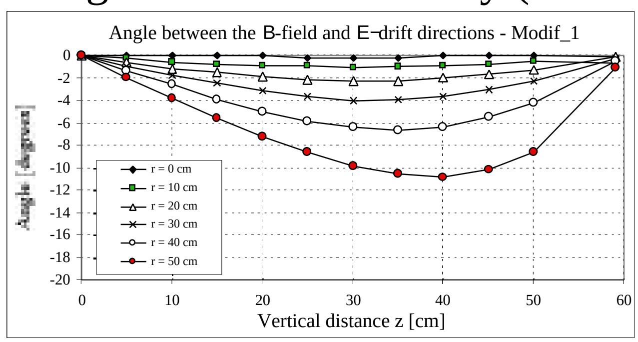
1) Initial dipole design (field map: DV02):



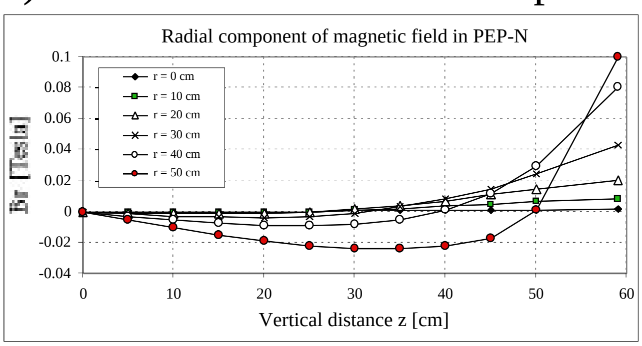


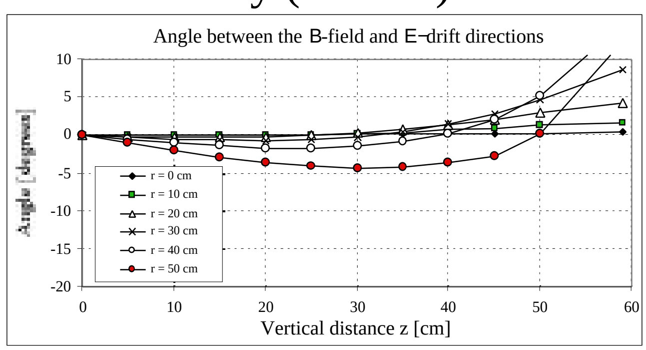
2) The first iteration to improve the magnetic field uniformity (DV03):





3) The second iteration to improve the uniformity (DV06b):





Boundary conditions for the design

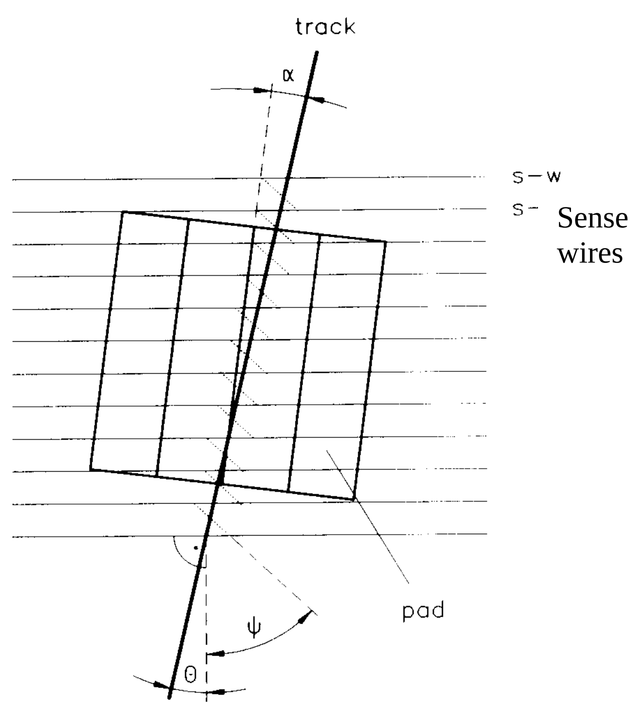
W. Blum and L. Rolandi, p.184:

$$\sigma^2_{resol} \approx \frac{1}{N(h, w, b, \sigma_{single})} \frac{\sigma^2_{single}}{\cos^2 \alpha} + \frac{b^2 (\tan\theta - \tan\psi)^2 \cos^2(\theta - \alpha)}{12\, N_{eff}(h, w, b, \sigma_{single})}$$

where

- σ_{single} - single electron transverse diffusion,
- h - pad length,
- w - pad width,
- b - wire pitch,
- N(h) - effective number of electrons in a given sample,
- $N_{eff}(h)$ - effective number of electrons clusters in a given sample,
- 1-st term - describes a diffusion term,
- 2-nd term - describes the clustering and the ExB effect near the wire plane.

Pad and wire layout, and definition of various angles:



Example of calculation for the ALEPH TPC design:

80%Ar+20%CH4, 8.5kG:

Number of electrons **N** [1/cm]	Number of clusters **Neff** [1/cm]	Drift length **L** [cm]	Single electron transverse diffusion σ [um/sqrt(cm)]	Wire pitch **b** [cm]	Pad length **h** [cm]	Pad width **w** [cm]	Mag. Field **B** [Tesla]	ExB angle **Psi** [degrees]	Omega*tau	Trans. Diff. reduction factor
89.1	24.8	50	480	0.4	3	0.67	0.85	32	0.624869	0.7191856
89.1	24.8	50	480	0.4	3	0.67	0.85	32	0.624869	0.7191856
89.1	24.8	50	480	0.4	3	0.67	0.85	32	0.624869	0.7191856
89.1	24.8	50	480	0.4	3	0.67	0.85	32	0.624869	0.7191856
89.1	24.8	50	480	0.4	3	0.67	0.85	32	0.624869	0.7191856
89.1	24.8	50	480	0.4	3	0.67	0.85	32	0.624869	0.7191856
89.1	24.8	50	480	0.4	3	0.67	0.85	32	0.624869	0.7191856
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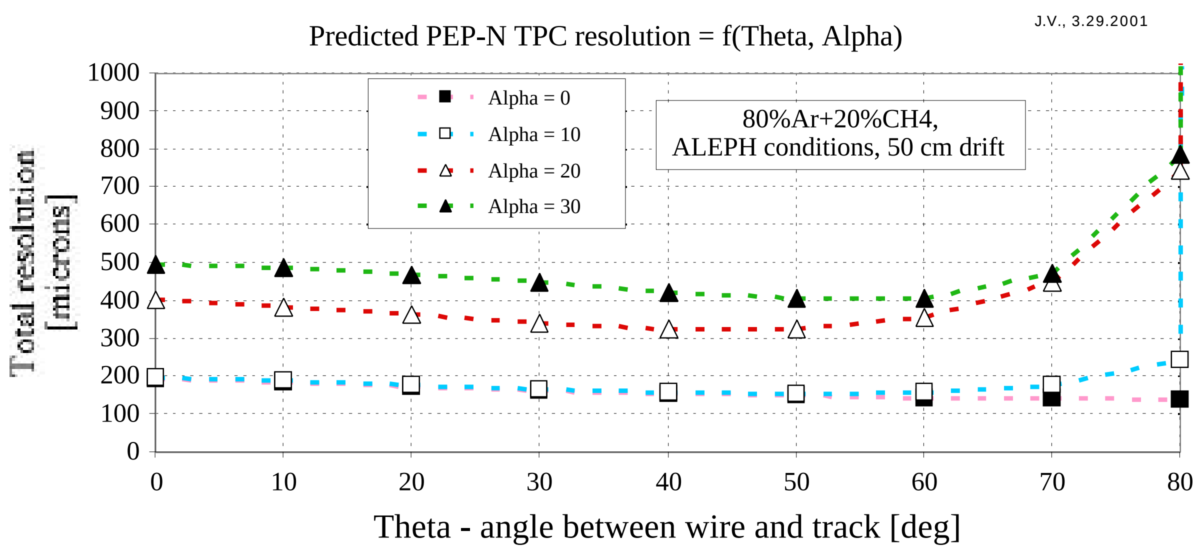
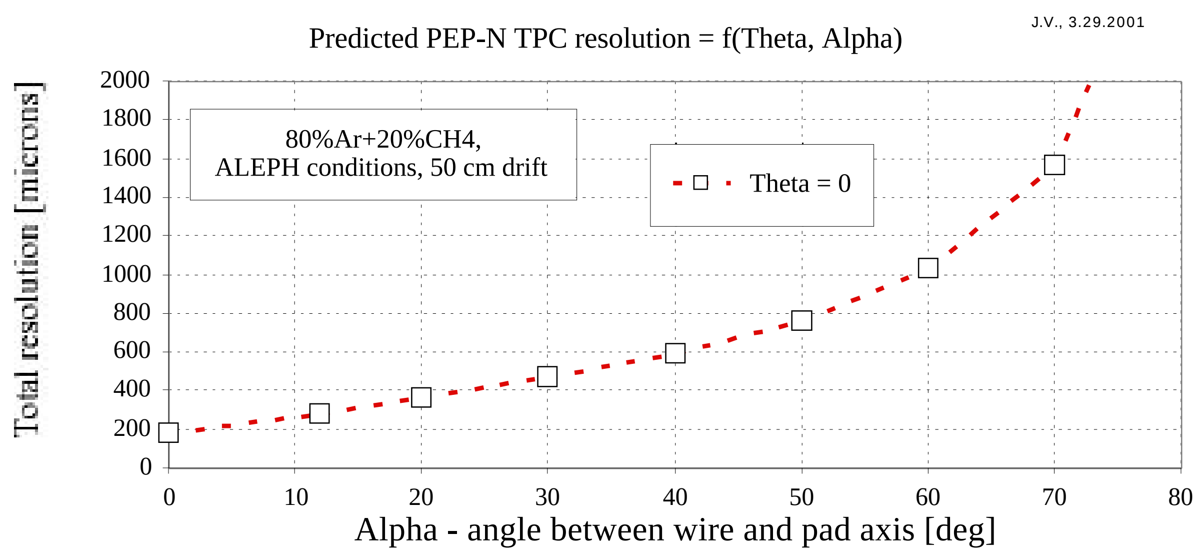
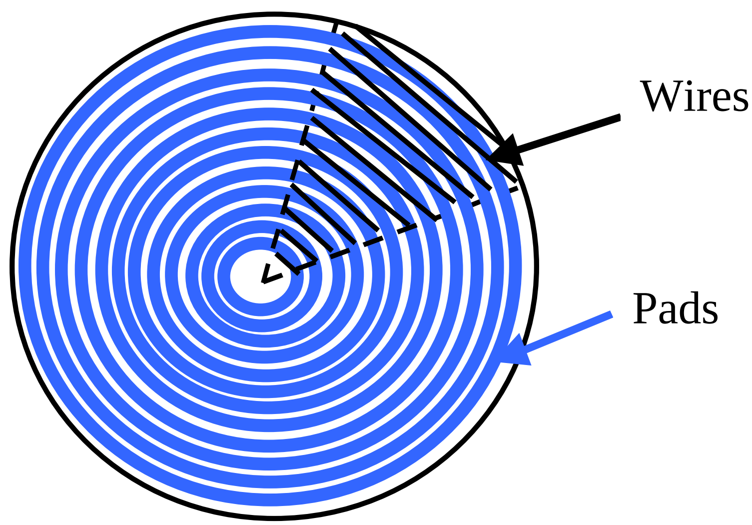




A consequence of the wire term:

- Tracks with $\theta > 70^0$ and $\alpha > 50^0$ are badly measured.

Therefore, one typically arranges the wire readout in a form of azimuthal sectors. Similarly, the pads are arranged in radial orientation:



. If one would use the GEM-based detector, the second term in the resolution equation does not exist.

Distortions

The Langevin theory, which has been used for many TPC designs, is only an approximate method; it does not predict ωτ. In fact, it turns out that there is no single ωτ, which would explain all three drift velocity components.

$$\vec{v} = \frac{\mu}{1+(\omega\tau)^2}[\vec{E} + \frac{\omega\tau}{B}[\vec{E}\times\vec{B}] + (\omega\tau)^2 \frac{\vec{E}\ \vec{B}}{B^2}\vec{B}]$$

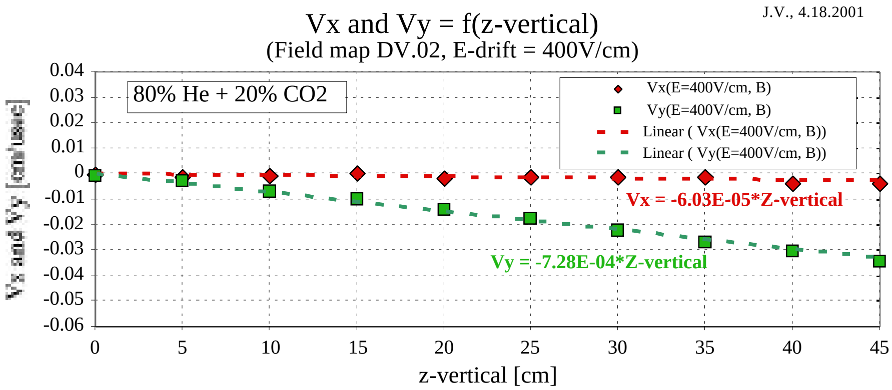
I will use the MAGBOLTZ-MONTE program to calculate the drift velocity components $v_{x,y,z}$ (E,B) gas. Once I know the drift velocity components as a function of z-vertical, I calculate the distortions in the detecting plane as follows:

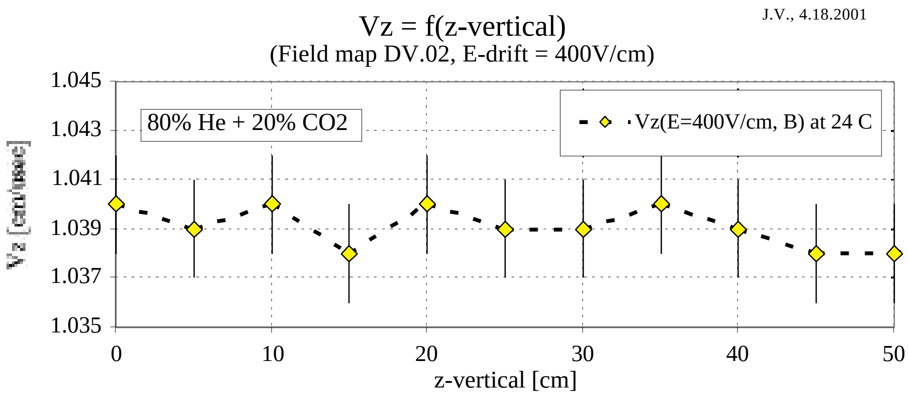
$$dx = \int_{t_1}^{t_2} v_x\ dt = \sum_i \langle v_x \rangle_i \frac{(dz)_i}{\langle v_z \rangle}$$

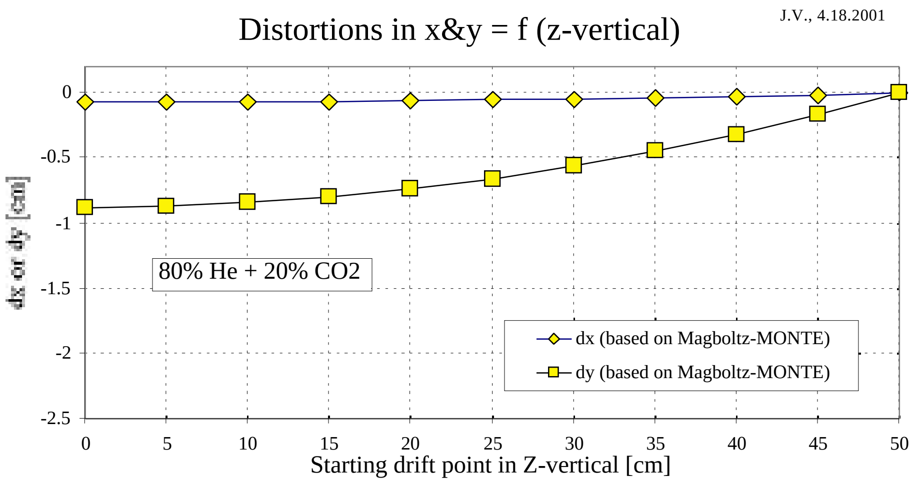
$$dy = \int_{t_1}^{t_2} v_y\ dt = \sum_i \langle v_y \rangle_i \frac{(dz)_i}{\langle v_z \rangle}$$

In the following, I calculate the worst case distortion at r = 50cm, and for the total drift of 50cm.

Distortion calculation using the Magboltz-MONTE program







It takes ~8 hours on my Linux box to do this calculation…

The worst case distortion dx & dy in the PEP-N TPC:

I. Distortions = f(gas choice) at r = 50cm & 50cm drift:

Gas	Field map	E-drift [V/cm]	dx [cm]	dy [cm]	Vz-ave [cm/us]
80%Ar+20%CH_4	DV.02	400	-4.2	-4.9	6.15
80%He+20%CO_2	DV.02	400	-.07	-0.9	1.039
80%He+19%CO_2+1%CH_4	DV.02	400	-0.1	-0.91	1.072
80%He+15%CO_2+5%CH_4	DV.02	400	-.12	-1.03	1.225
80%He+15%CO_2+5%iC_4H_{10}	DV.02	400	-0.1	-1.0	1.182
80%He+20%iC_4H_{10}	DV.02	400	-0.3	-1.5	1.72

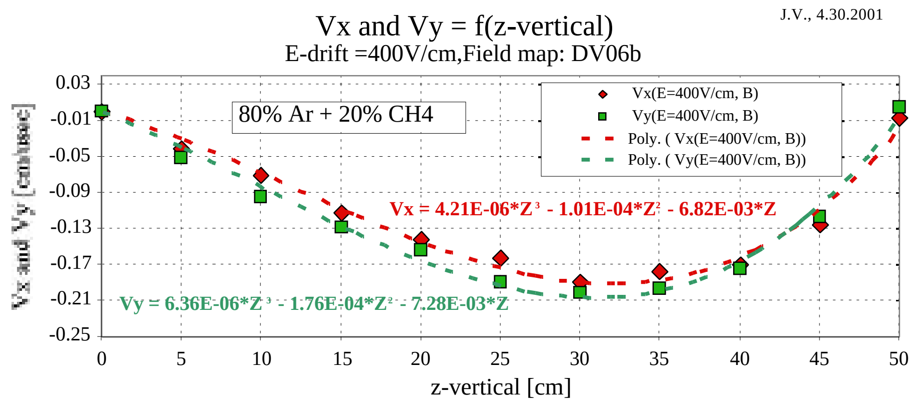
II. Distortions = f(E-drift) at r = 50cm & 50cm drift:

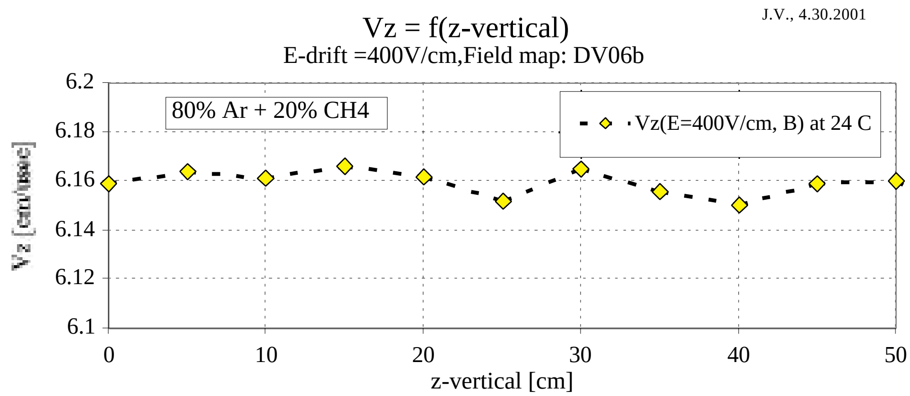
Gas	Field map	E-drift [V/cm]	dx [cm]	dy [cm]	Vz-ave [cm/us]
80%Ar+20%CH_4	DV.02	400	-4.2	-4.9	6.15
80%Ar+20%CH_4	DV.02	200	-6.8	-4.2	6.9
80%He+20%CO_2	DV.02	400	-.07	-0.9	1.039
80%He+20%CO_2	DV.02	200	-0.1	-0.9	0.53

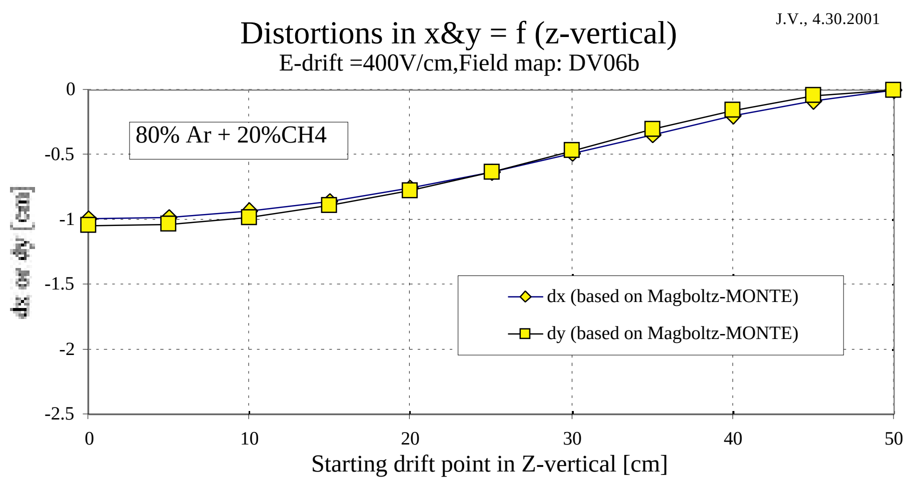
III. Distortions = f(field map) at r = 50cm & 50cm drift:

Gas	Field map	E-drift [V/cm]	dx [cm]	dy [cm]	Vz-ave [cm/us]
80%Ar+20%CH_4	DV.02	400	-4.2	-4.9	6.15
80%Ar+20%CH_4	DV.03	400	-2.7	-2.9	6.16
80%He+20%CO_2	DV.02	400	-.07	-0.9	1.039
80%He+20%CO_2	DV.03	400	-.04	-0.5	1.039
80%Ar+20%CH_4	DV.06b	400	-1.0	-1.04	6.15
80%He+20%CO_2	DV.06b	400	-.08	-0.25	1.039

Distortion with the best field map (DV06b)







This means that even the fast gas is the candidate. With a slow gas, the distortion is only few mm in the latest map.

How much of a distortion one can tolerate?

TPC	Max.Distortion	Final reduction factor
CRID	~1cm	~10
STAR	~1cm	~25
NA-45	~11cm	~600 (within a factor of 2 of achieving this !!)
PEP-N	~1cm	~50 (fast gas, DV06b)
PEP-N	~0.2cm	~10 (slow gas, DV06b)

Note:

1) Clearly, PEP-N needs an external tracking system.
2) One also needs a laser calibration system.
3) Make electrical distortions as small as possible.
4) Keep misalignment systematic errors small.

Should one go to the multi-GEM design ?

a) Advantages of GEM design:

- no wires,
- the second term in the resolution equation is zero. Because of this, the resolution should be more uniform.
- more simple construction,
- smaller number of positive ions leaking into the drift volume, although it still may need gating in the high background situation.

b) Disadvantages:

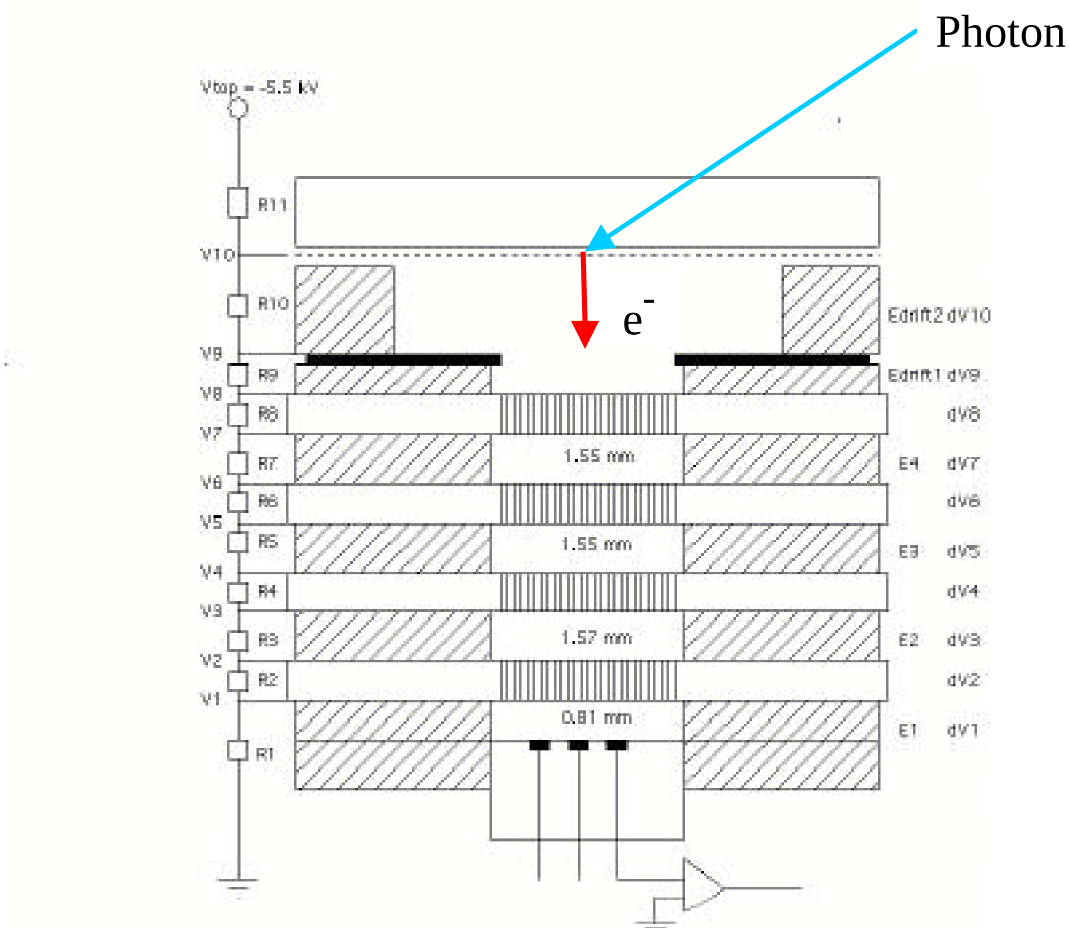
- GEM can be damaged.
- The gain uniformity may be worse compared to wires.

- The expected rates at PEP-N are much lower than in the hadron machines, such as HERA-B or LHC-b.

- I would not exceed the total gas gain of more than ~2-3x10^3.

Quadruple-GEM Detector design

J.Va'vra & A. Sharma, 2001 Vienna wire chamber conference



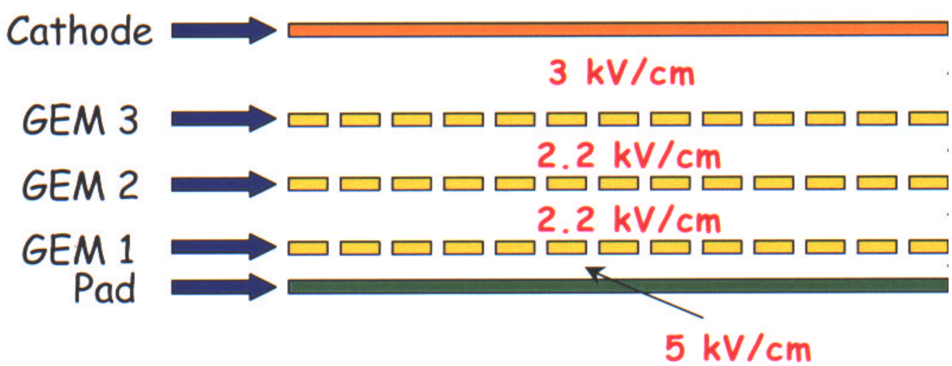
- I suggest the GEM because I have my own experience with it. In this case, single electron detection needed gas gain of ~2x10^5. The amplifier had a charge gain of ~2.7μV/electron, and the shaping time of 65ns.

- PEP-N will have ~3x53 electrons per 3cm-long sample in 80%He+ 20%C_4H_{10} gas. With a gas gain of ~2x10^3 it will have ~3x10^5 electrons available to the amplifier input. With a similar amplifier sensitivity it should achieve a sufficient S/N ratio. Moreover, one can work with much longer shaping time (200-250ns). A noise of σ_{noise}~1000el is a must.

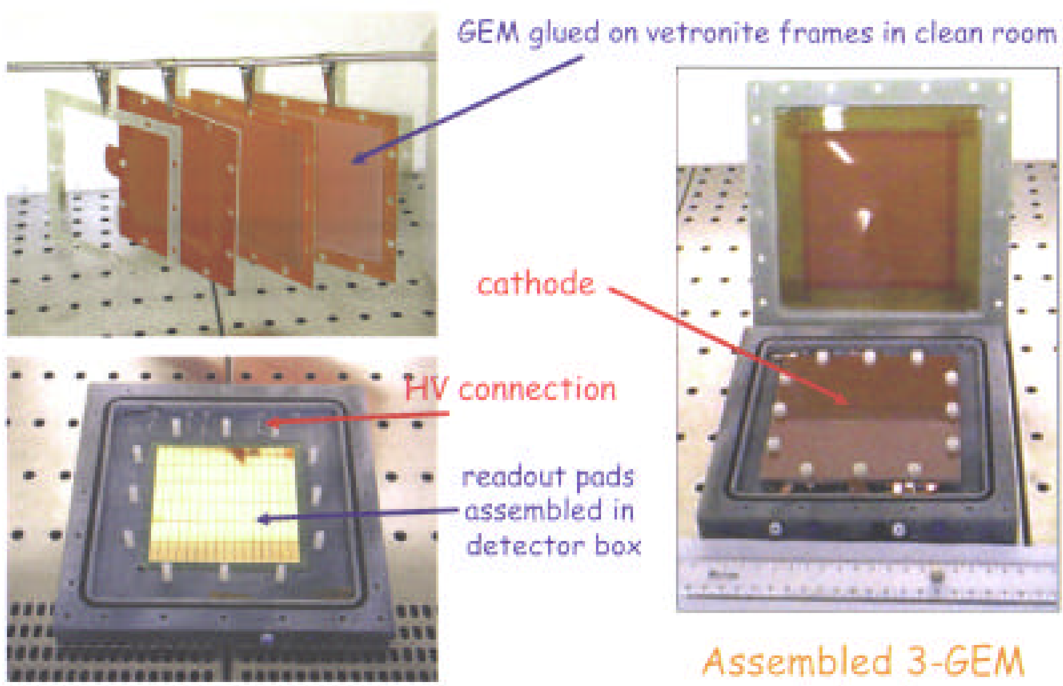
LHCb-GEM

G. Bencivenni[1], W. Bonivento[2,3], A. Cardini[2], C. Deplano[2], P. De Simone[1], G. Felici[1], A. Lai[2], F. Murtas[1], M. Palutan[1], D. Pinci[2,4], M. Poli Lener[1], B. Saitta[2,4].

1 - Laboratori Nazionali di Frascati - INFN, Frascati , Italy
2 - Sezione INFN di Cagliari – Cagliari, Italy
3 – CERN, Switzerland
4 - Universita' degli Studi di Cagliari, Cagliari, Italy



CERN Test-beam: 3-GEM Detector



Assembled 3-GEM detector

LHC-b test used the following parameters:

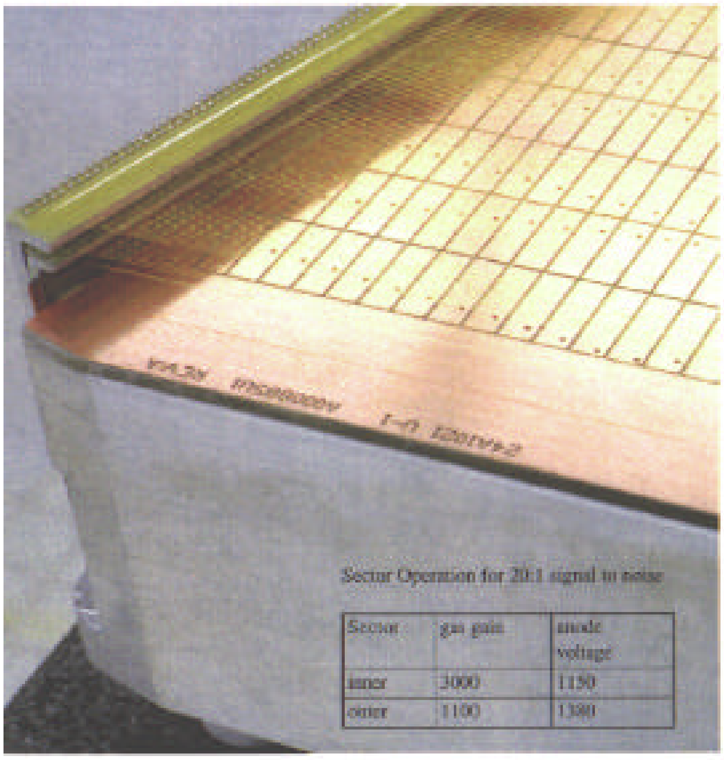
GEM size:	10cm x 10cm
Pad size:	10mm x 25mm
Number of pads:	40
Gaps between GEMs:	1mm
Experience	good
Efficiency obtained:	~96% in 25ns
Gases tested:	70%Ar+30%CO_2, 60%Ar+20%CO_2+20%CF_4, 70%Ar+10%CO_2+20%CF_4. They will also try some gases, which I mentioned in this talk.
Planned activity:	Systematic studies of aging at high rates and sensitivity to discharges are under way.

Literature: (F. Sauli's group tests)	Rate capability: up to ~10MHz/cm^2 Time resolution ~10ns (rms) Radiation hardness: up to ~5C/cm^2

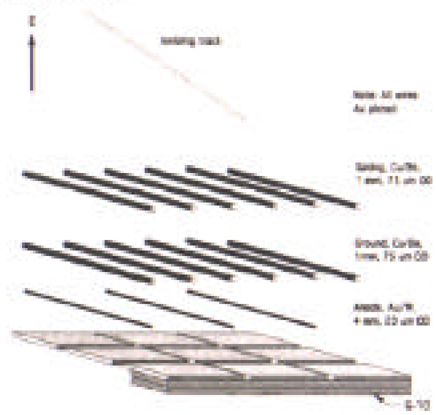
Are GEMs in large experiments?

- HERA-B tracking chambers (used with the MSGC detectors),
- COMPASS experiment at CERN (30cm x 30cm GEM foils),
- LHC-b R&D activity (muon chambers, etc.),
- NLC TPC R&D studies for TESLA.

If one would choose the wire readout instead, one would copy the STAR TPC design:



- Gating Grid
- Ground Plane of Wires
- Anodes
  - No field shaping wires
    - Simple and reliable
  - Individually terminated anode wires limit cross-talk
  - Low gain
- Pad Plane



. A beauty of the TPC detector concept is that one can change.

How many electrons are available per sample ?

Input data (minimum ionizing particle):

	Ion pairs per cm					
	Rieke, Prepejchal		Zarubin			Pansky et al.
Gas	N-prim	N-tot	N-prim	N-tot	Ratio = N-tot	N-prim
He	6		3.3	7.6	2.3030303	
H2	4.7		4.7	9.4		
Ne	24.1		10.9	39.9	3.66055046	
Ar	24.1		24.8	96.6	3.89516129	
Kr			33	197.5	5.98484848	
Xe	78.3		44.8	313.3	6.99330357	
CH4	26.6		24.8	59.3	2.39112903	26
C2H6	43.5		40.5	117.7	2.90617284	51
CO2	36		33.6	100	2.97619048	
C3H8	72.4		67.6	176.6	2.61242604	74
i-C4H10	89.6		83.6	232.8	2.784689	93
C2H5OH						
DME	66.2					62
TEA						144
TMAE						281

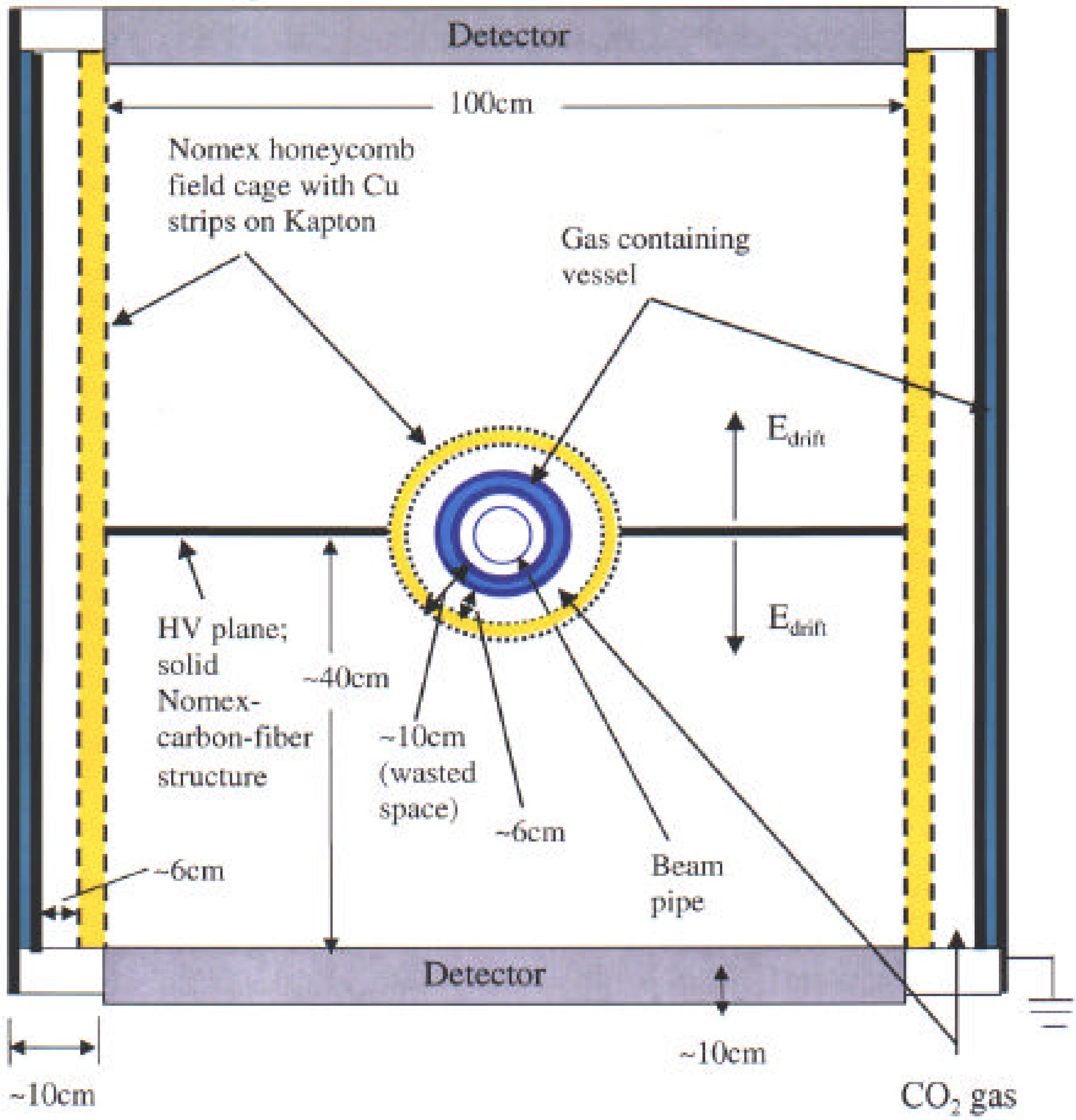
PEP-N gas candidates:

Gas	No. of electrons per 3cm sample	No. of clusters per 3cm sample
80%Ar+20%CH_4	~267	~74
80%He+20%CO_2	~78	~28
80%He+19%CO_2+1%CH_4	~77	~28
80%He+15%CO_2+5%CH_4	~72	~27
80%He+15%CO_2+5%iC_4H_{10}	~98	~36
80%He+20%iC_4H_{10}	~158	~58

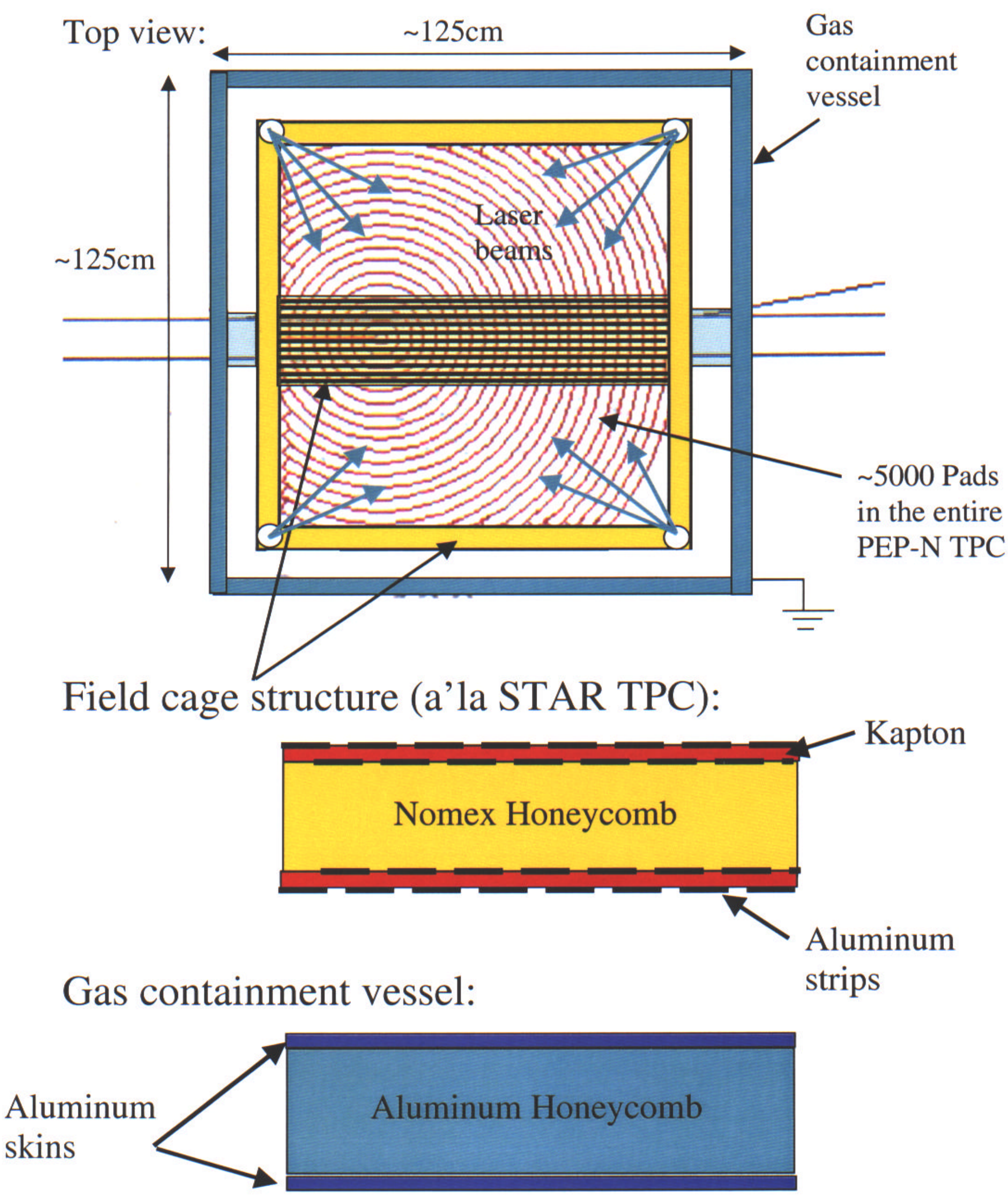
. One can work with the He-based gases.

1) Field cage design (a'la STAR):

View along the beam line:



(Schematic picture only – nothing to scale)



(Schematic picture only – nothing to scale)

ALICE field cage design:

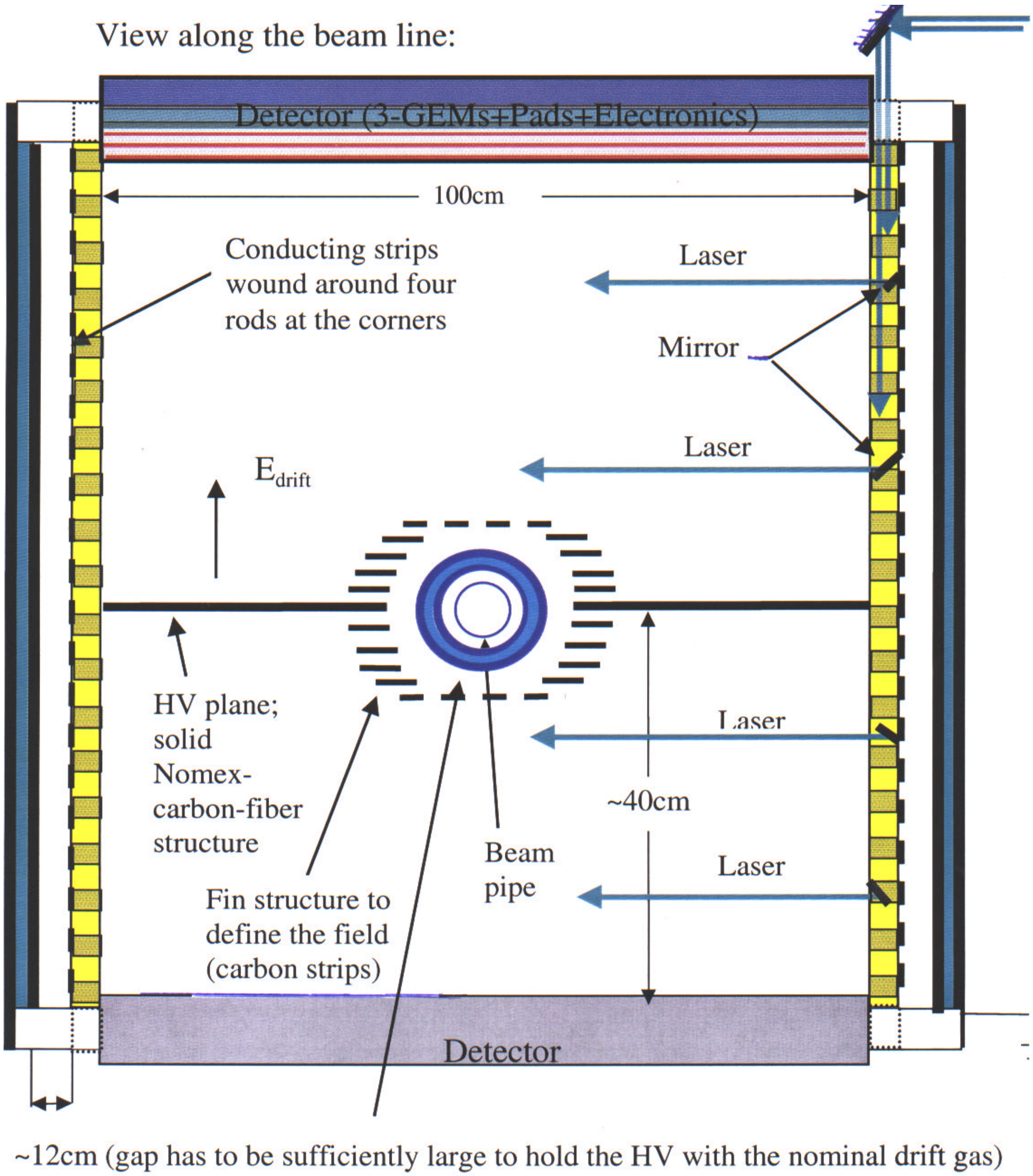
Note:

Rods can be used to transport the laser beams inside the TPC by having small mirrors in various spots along their length.

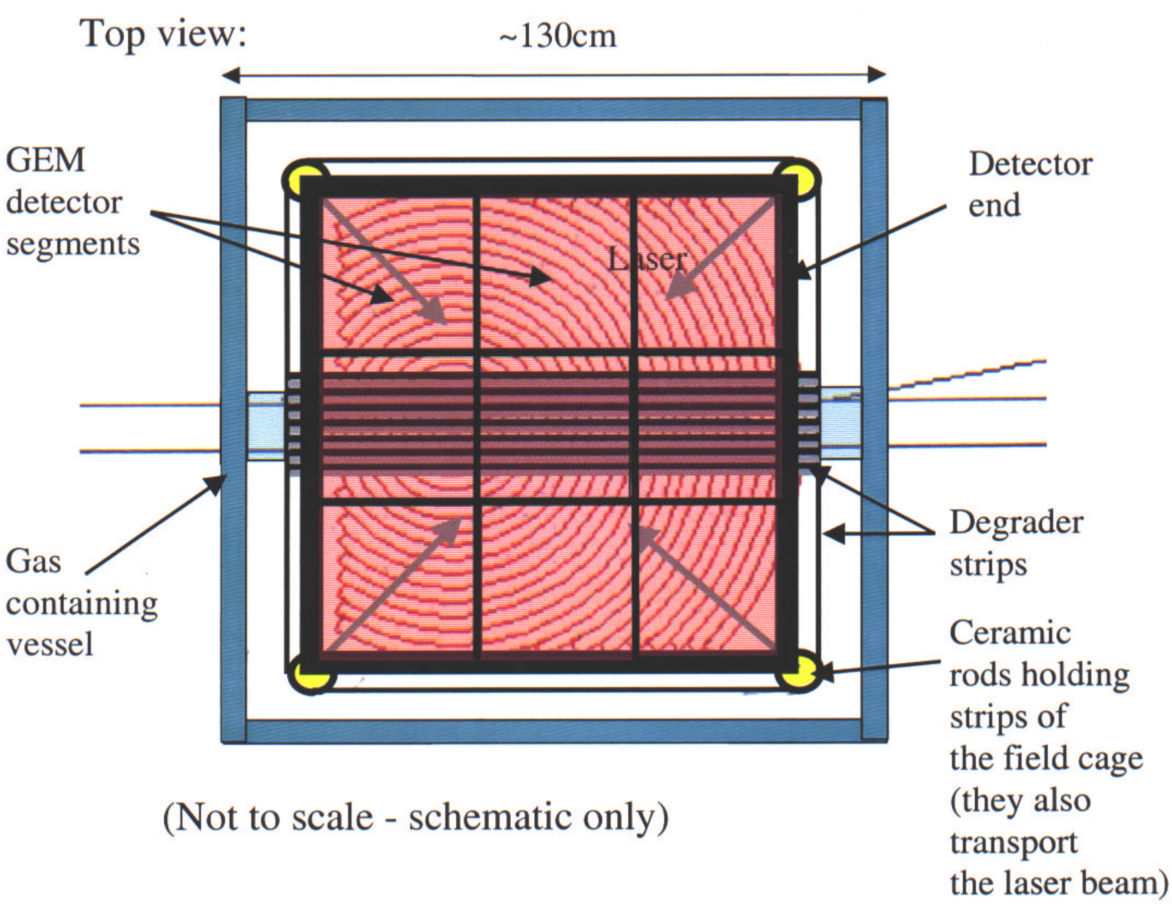
Thomas Meyer:

With a single strip layer, the distortions of electric field are only ~10^{-4} about 2cm away from the strips.

2) Field cage design (a'la ALICE)



(Schematic picture only – nothing to scale)



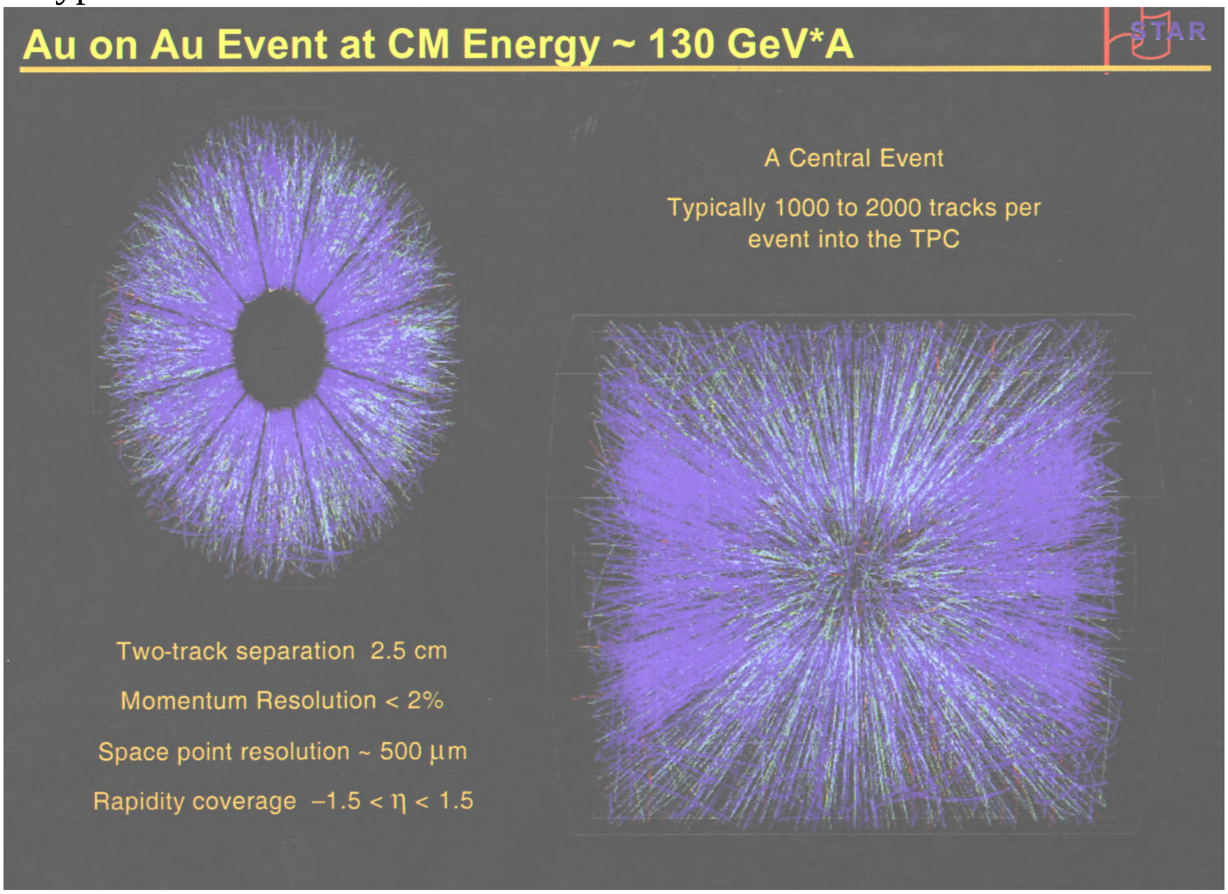
Note:

If the inner strip structure would prove to be difficult to build, one could make the STAR TPC inner degrader as discussed previously.

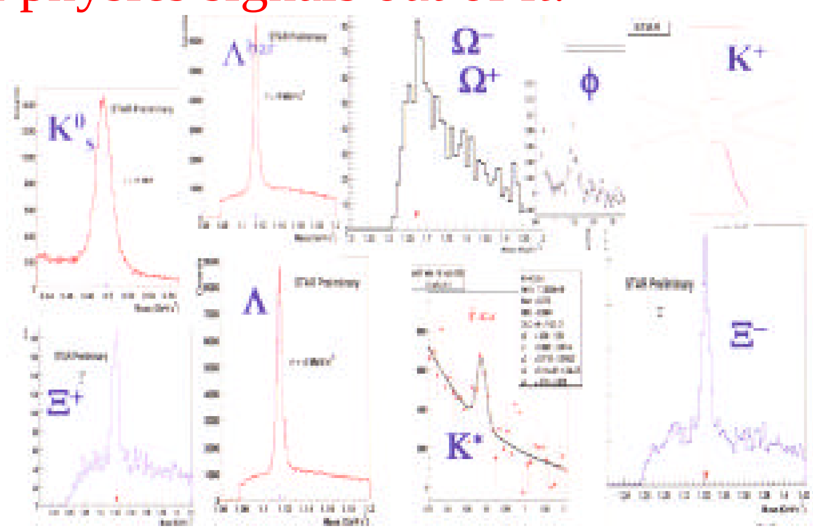
(Schematic picture only – nothing to scale)

No one doubts an extraordinary capability of TPC to handle a very high multiplicity of tracks:

A typical STAR TPC event:



and pull physics signals out of it:



Conclusions

- PEP-N TPC concept seems practical.

- Distortions with the field improvements and slow gas are very small indeed (less than 5mm at r = 50cm and total drift of 50cm). In fact, one does have an option, if one wants or needs, to go to the conventional fast gases (with the improved magnetic field), which would allow the faster drift.

- Detector based on the 3-GEM+pads design is a real option, but one can always go to a wire plane design if necessary.

- Typical track will have 15 points, each pad sample is 3cm long. Typical resolution per point is 200-300μm. Mario Posocco calculated the expected track resolutions (see talk on simulation)

- Although the design seems practical on the paper, one should not underestimate its complexity. One needs a group of ~6-8 people to build this kind of a device right.