THE ACTIVE TARGET TIME PROJECTION CHAMBER AT NSCL

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Luminosity with slow radioactive beams

- *Solid targets provide poor luminosity*
  - *Inverse kinematics reactions in solid targets (probe)*
  - *Target-like particle has little energy to leave target material*
  - *Compromise between resolution and number of nuclei in target (resolution goes against luminosity)*

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- *New approach: active target + time projection chamber*
  - *Target no longer inert material, but used also to detect particles*
  - *Gas target ideal for low energies*
  - *Time Projection Chamber tracks particles from the vertex of the reaction (no lost energy in inert target)*

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Active Target Time Projection Chamber

- *A detector tailored to low energy reactions*
  - *Active gas target and full 4π angular coverage*
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  - *Beam slowing in gas gives excitation function*

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  - *Time projection chamber is slow (rate limitation)*
- *Very well adapted to rare isotope beams!*

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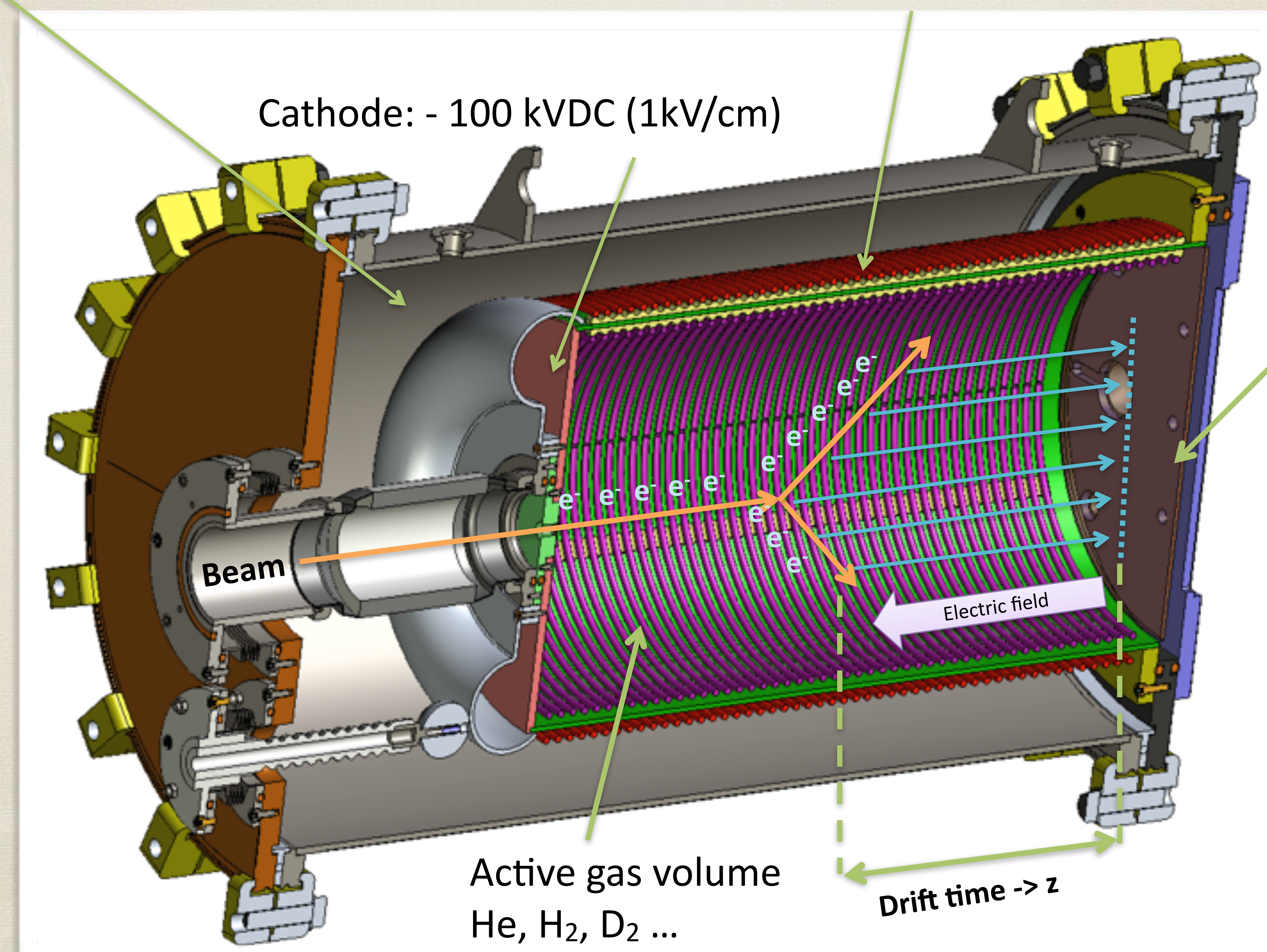
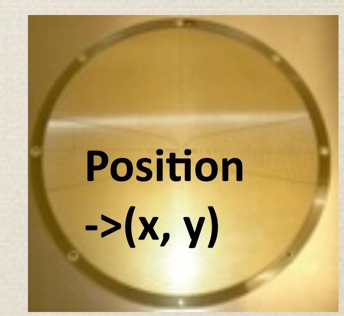
Principle of operation

Insulator gas volume (N_2)

Field shaping rings

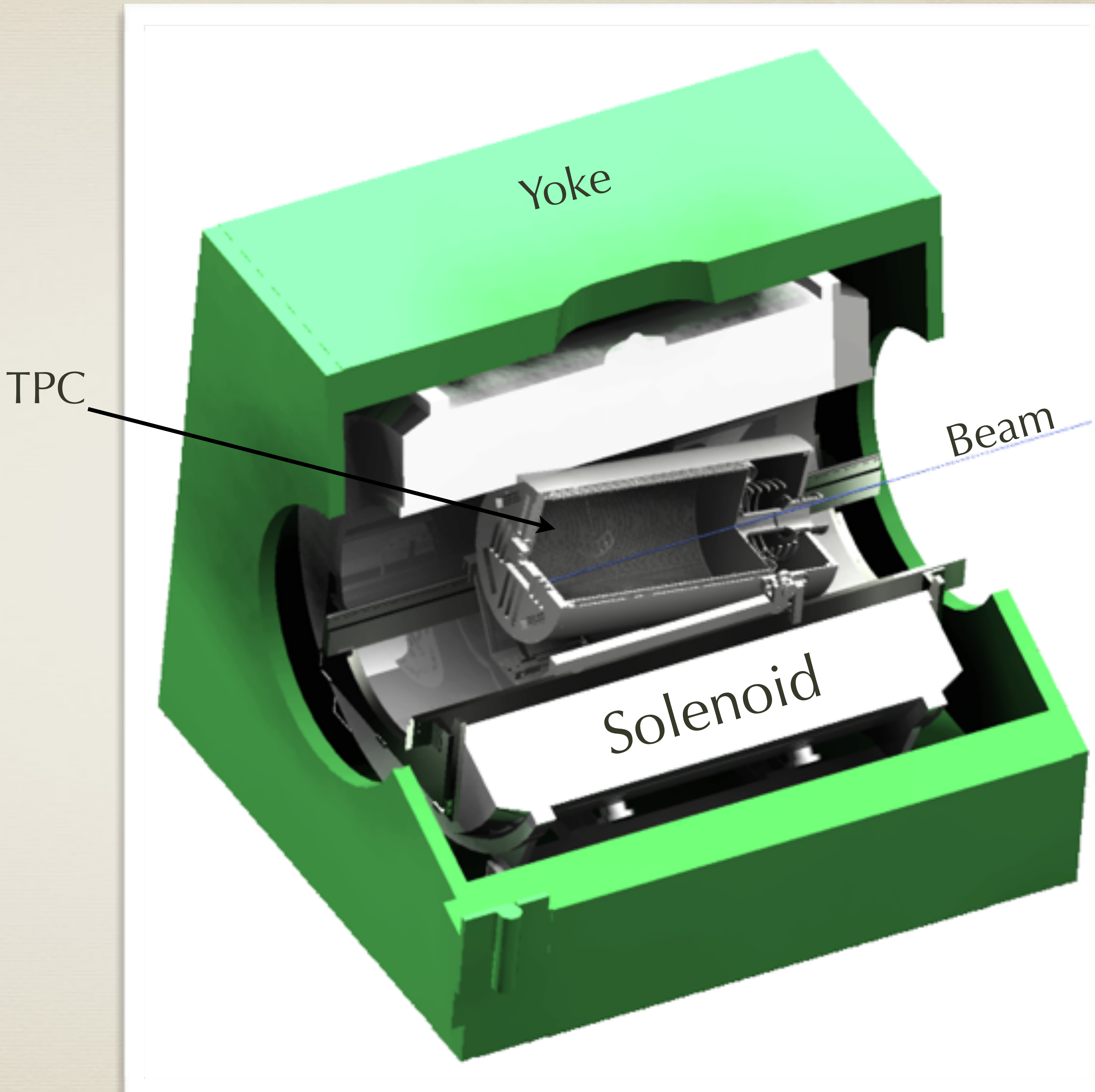


Pad plane and electron amplification device (Micromegas)



AT-TPC concept

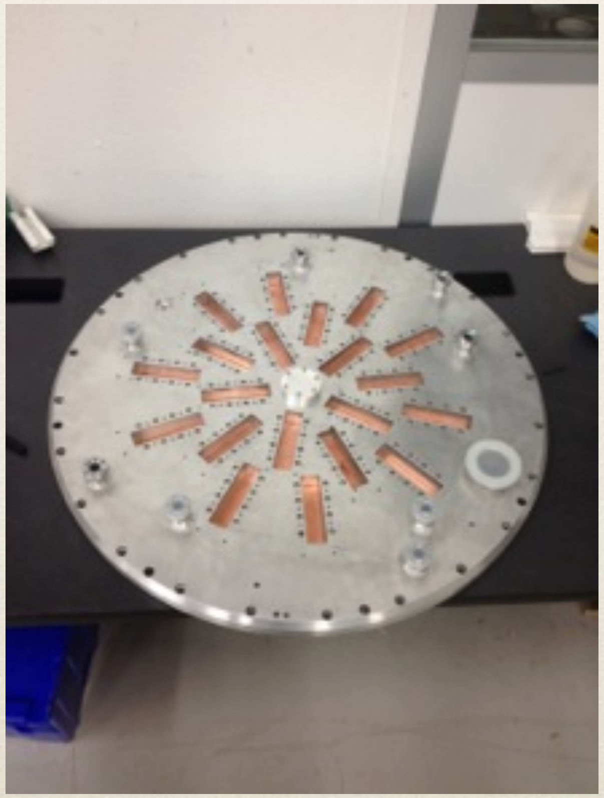
- *Straight and tilted (7°) configurations*
- *Tilt relative to beam axis to increase accuracy for small angles*
- *Placed inside 2 Tesla solenoid (increase range and measure Brho)*
- *250 liters (1 m by 55 cm) active volume*



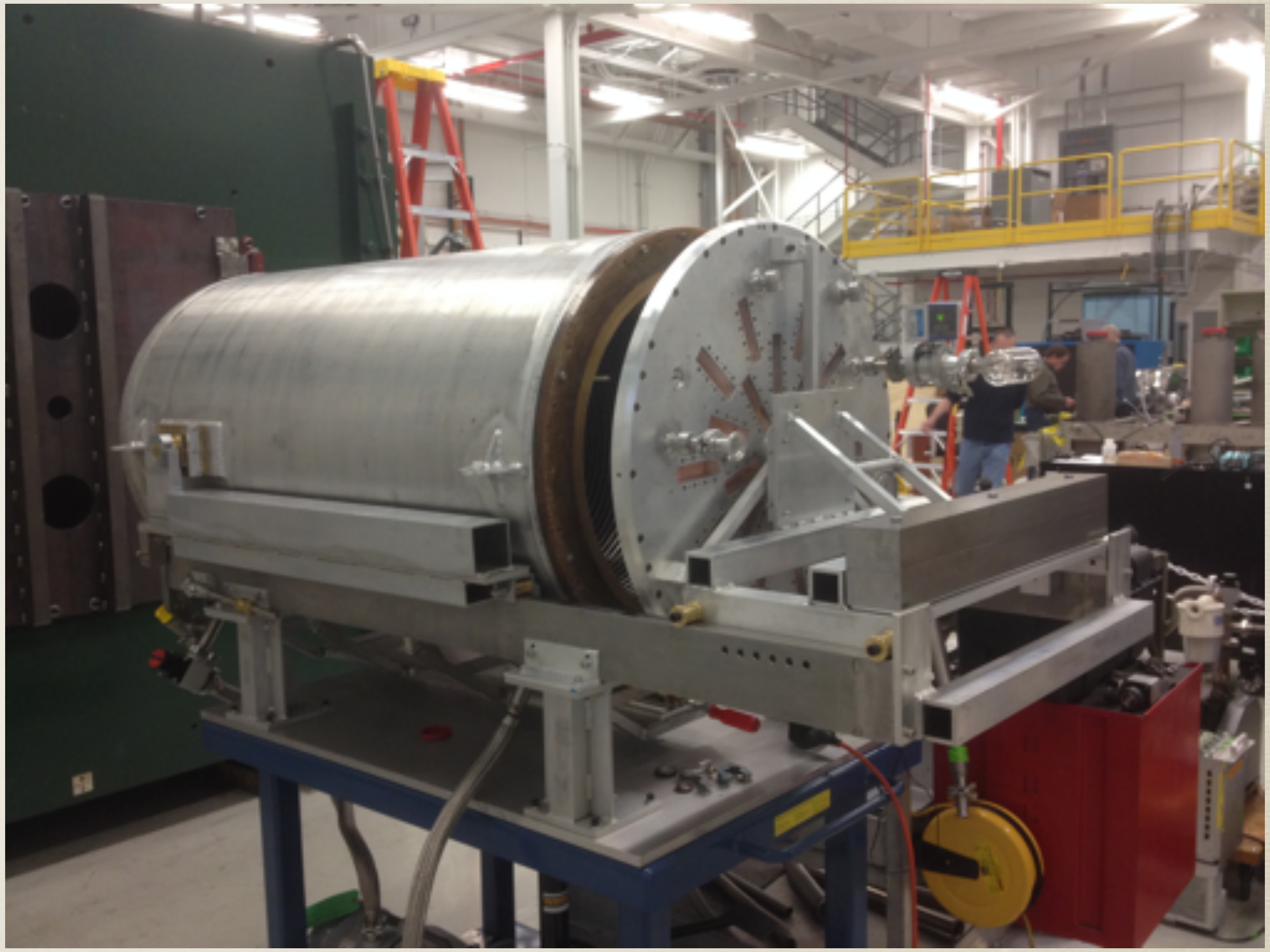
Detector details

- *Based on prototype design with few improvements*

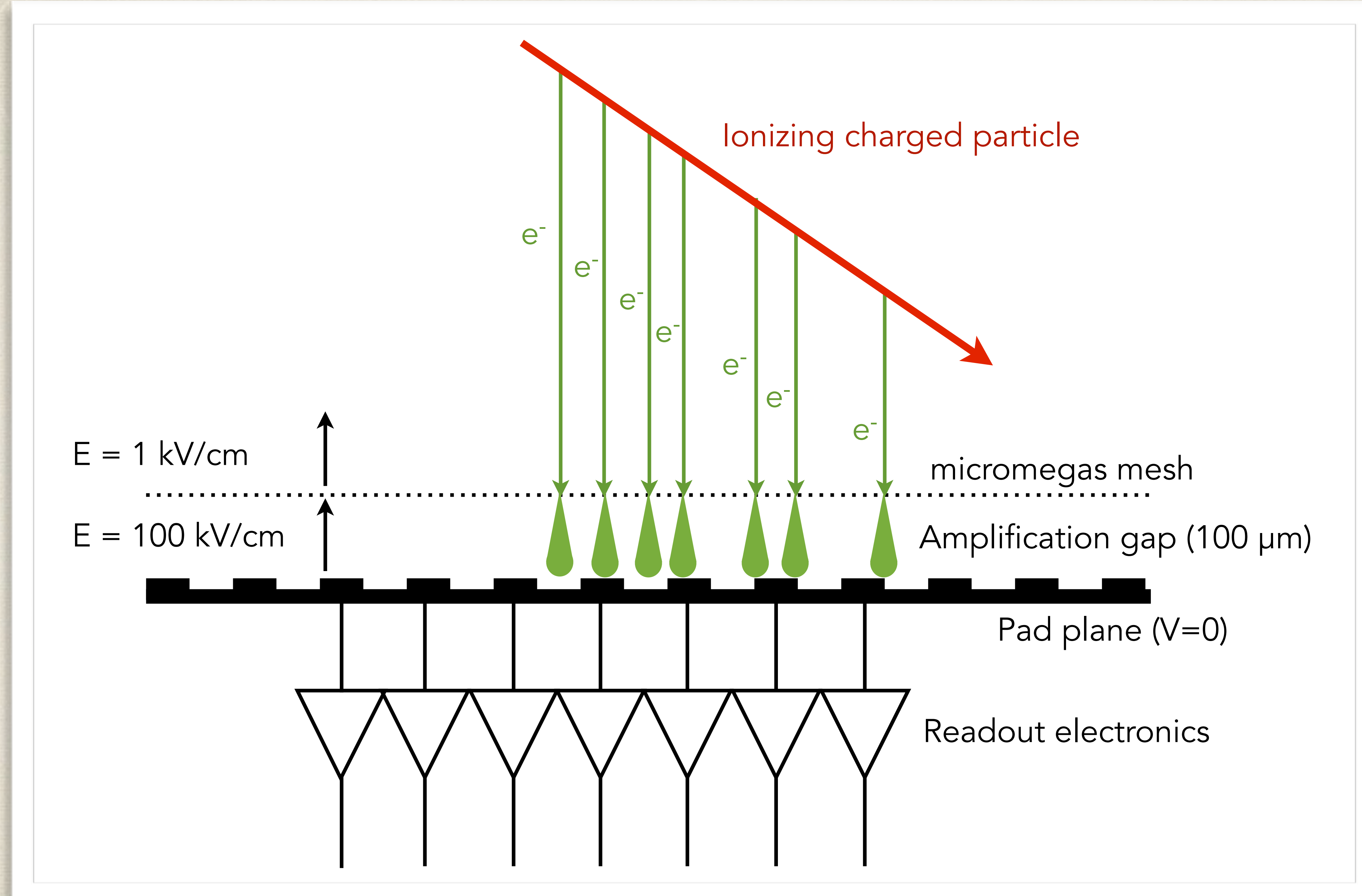





Detector installation & servicing

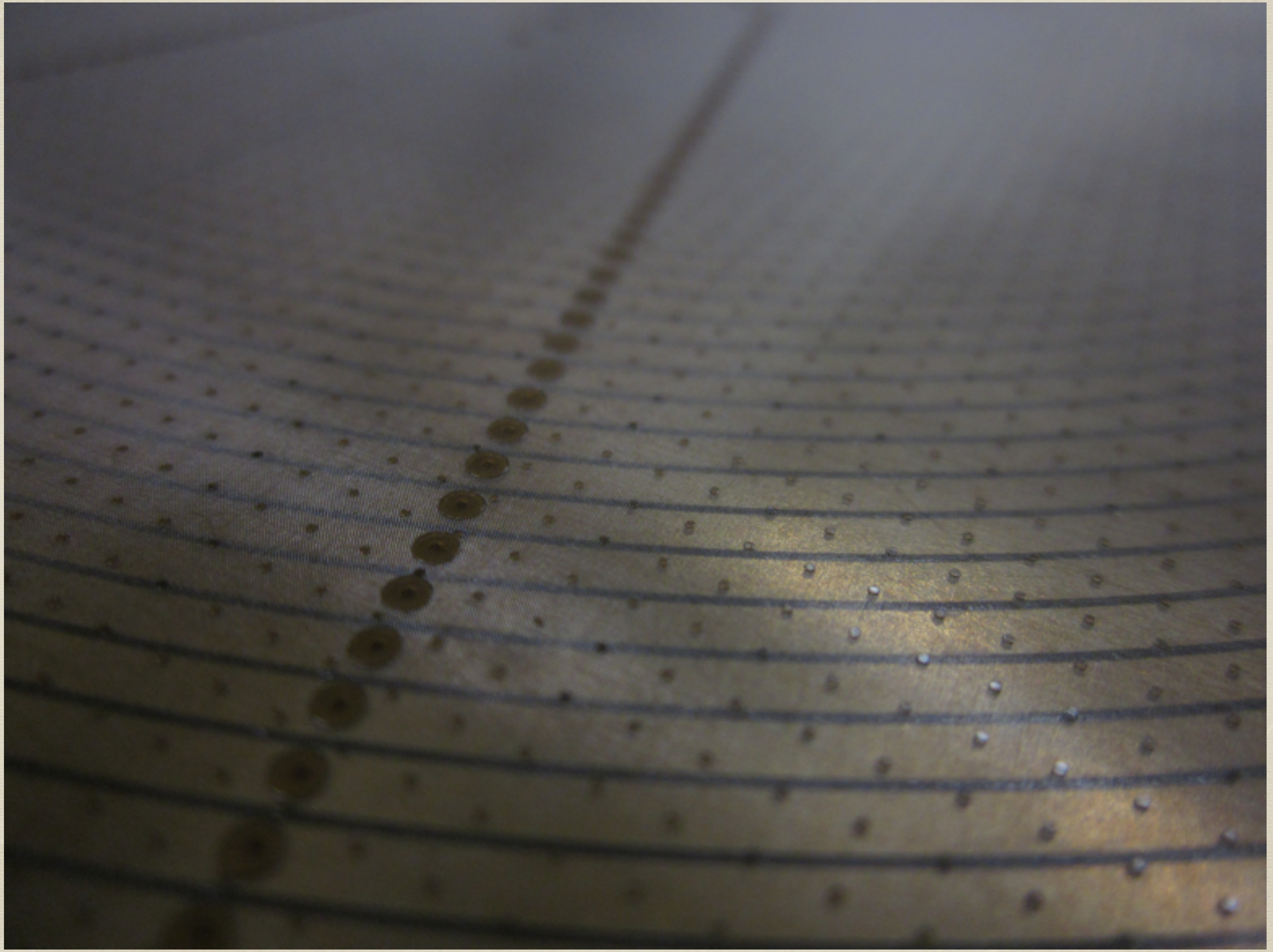


Electron amplifier: Micromegas



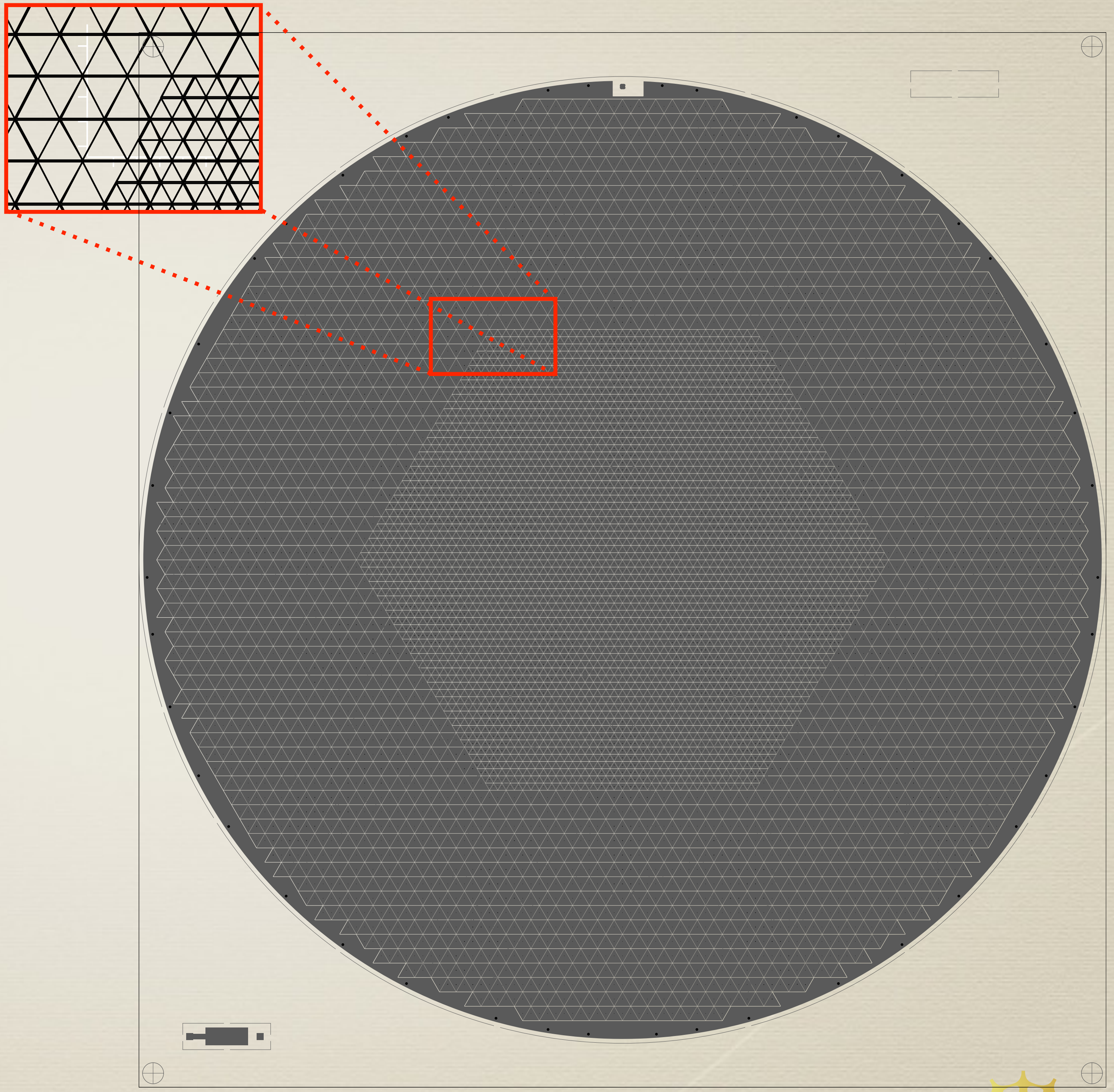
- *Negligible charge spread, sharp images*
- *Very robust against sparking*
- *Can operate in different conditions (gases, pressures)*

Close-up on Micromegas



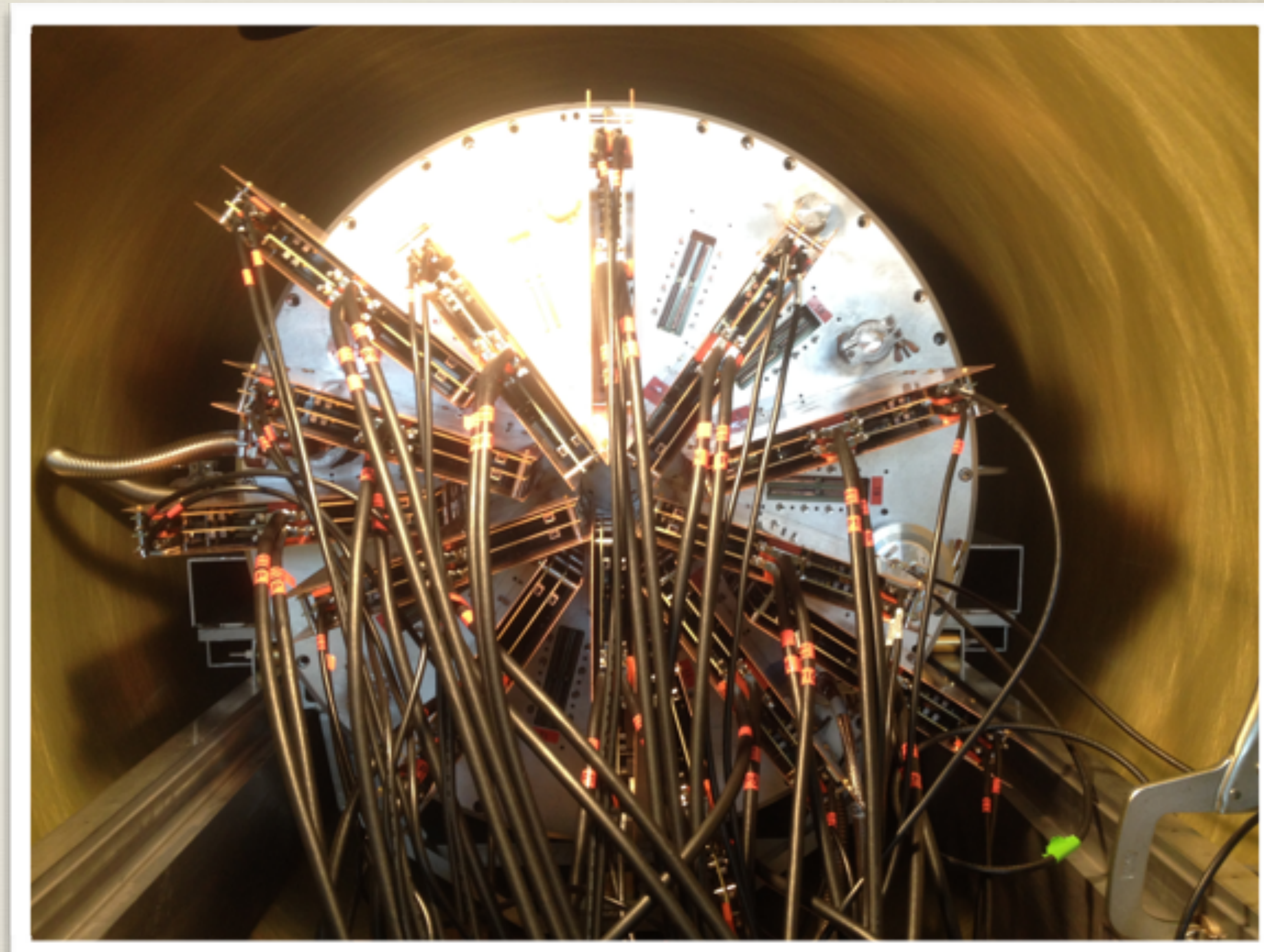
10,240 pad plane geometry

- *Optimized for detector inclinations from 0° to 7° relative to beam axis*
- *4 small triangles in a large one*
- *Small triangle side = 4.67 mm*
- *55 cm diameter disk*



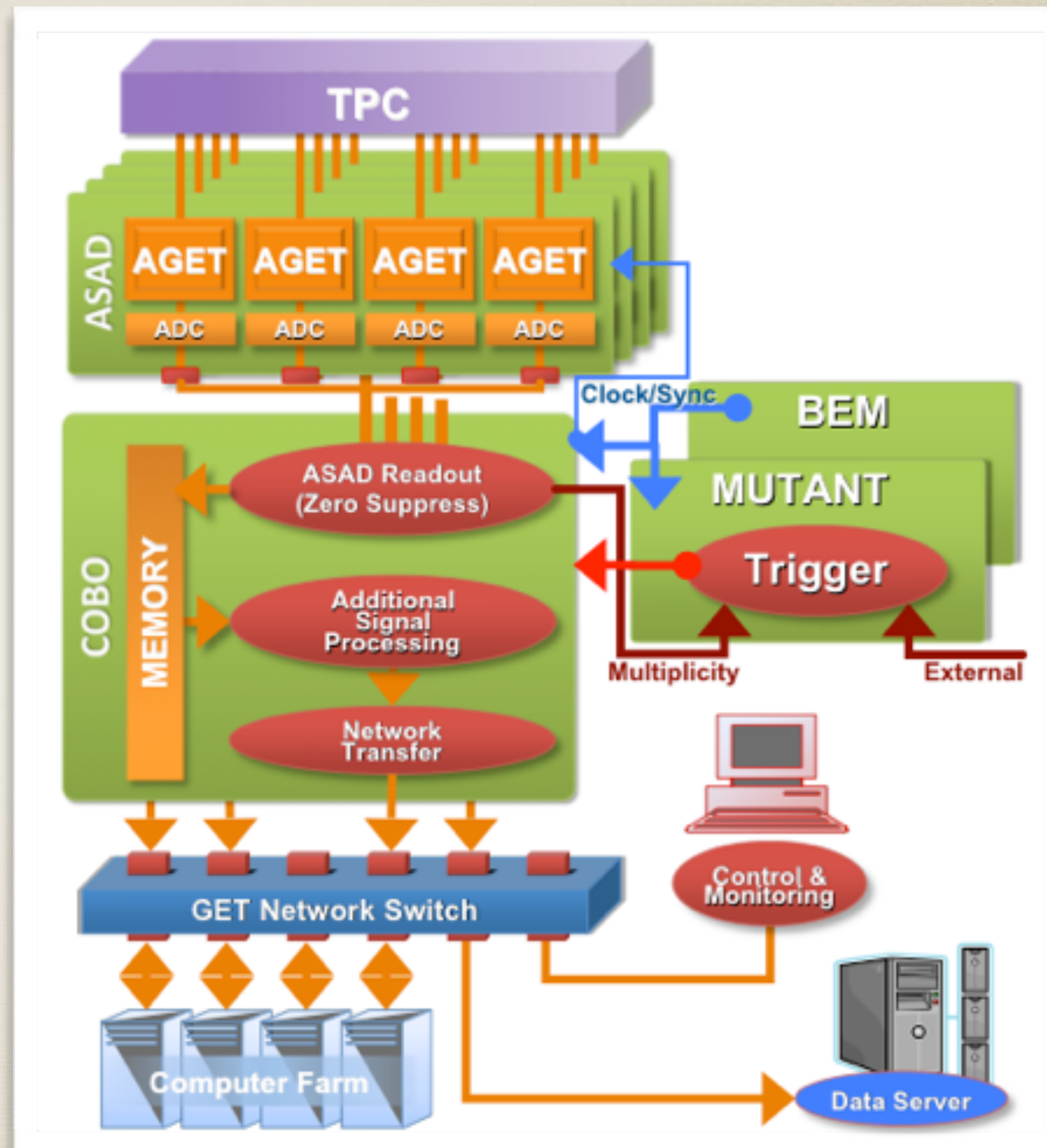
Digital Readout Electronics

- *Accommodate electronics for the 10,240 pads without cable connections*
- *40 front-end cards fit in pentagonal pattern*
- *Shielding covers electronics cards by pairs*
- *Only 7,000 channels instrumented (3 receiver cards on loan in France)*



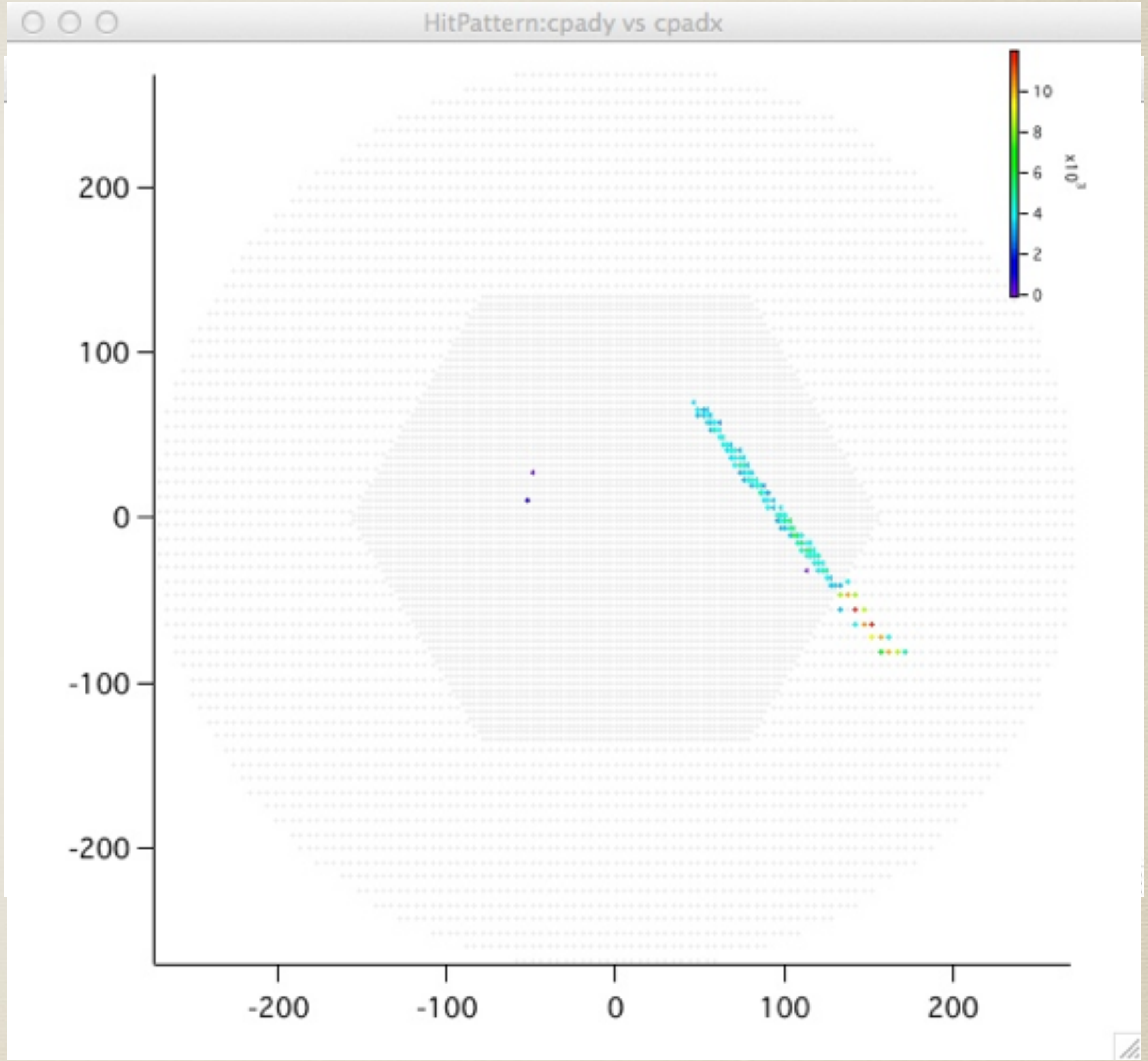
GET (General Electronics for TPCs)

- *Trigger needs to filter out unreacted beam events*
  - *GET electronics provides discriminators on each pad*
  - *Running multiplicities of each AsAd routed to MuTanT through CoBos*
  - *Trigger configuration can be programmed*
- *AGET front-end chips provide various gains and shaping times*
- *GET: CEA-Saclay, CENBG-Bordeaux, GANIL-Caen, NSCL*



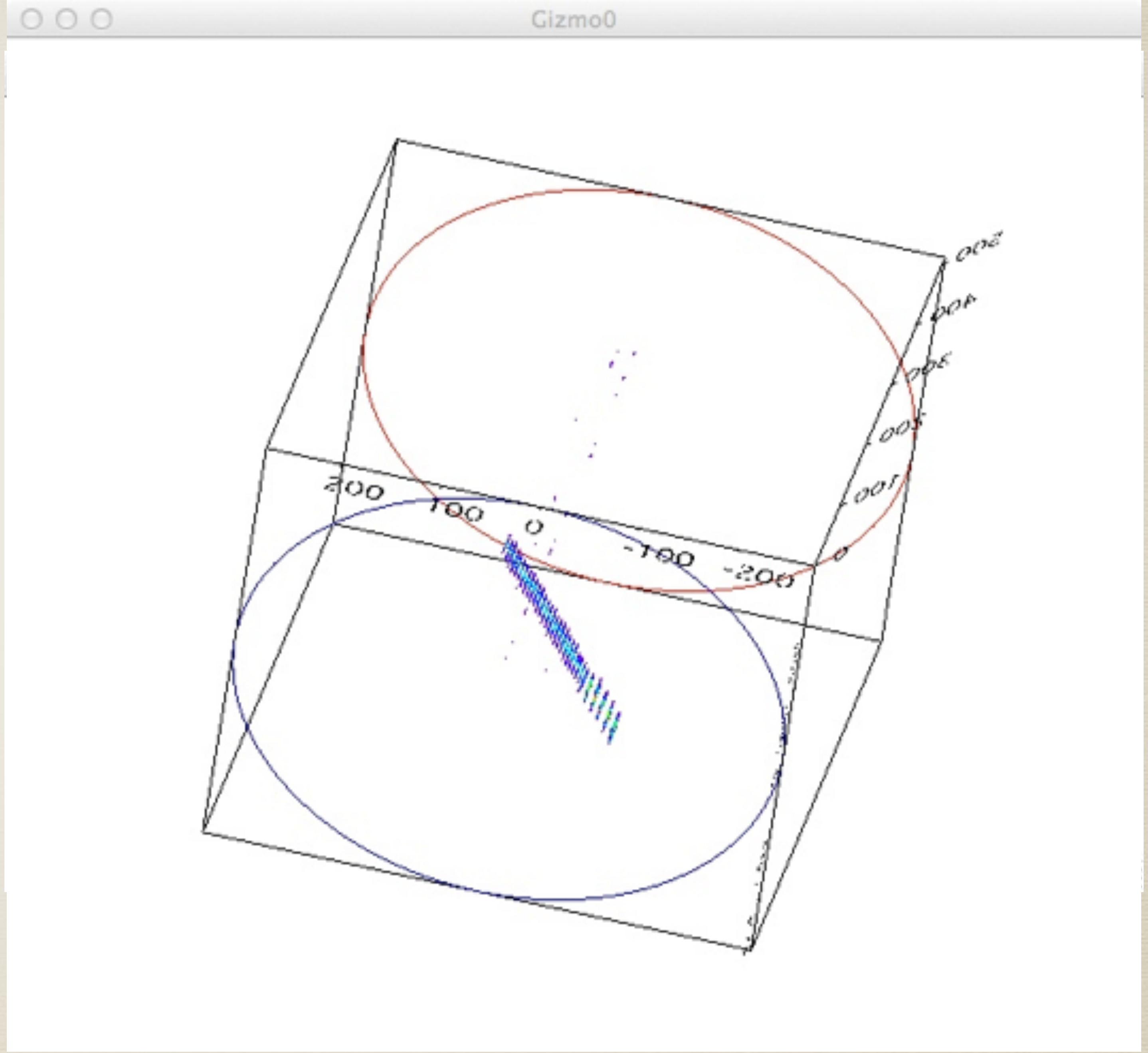
Example of reconstructed event

- *Track from alpha source placed inside the active volume*



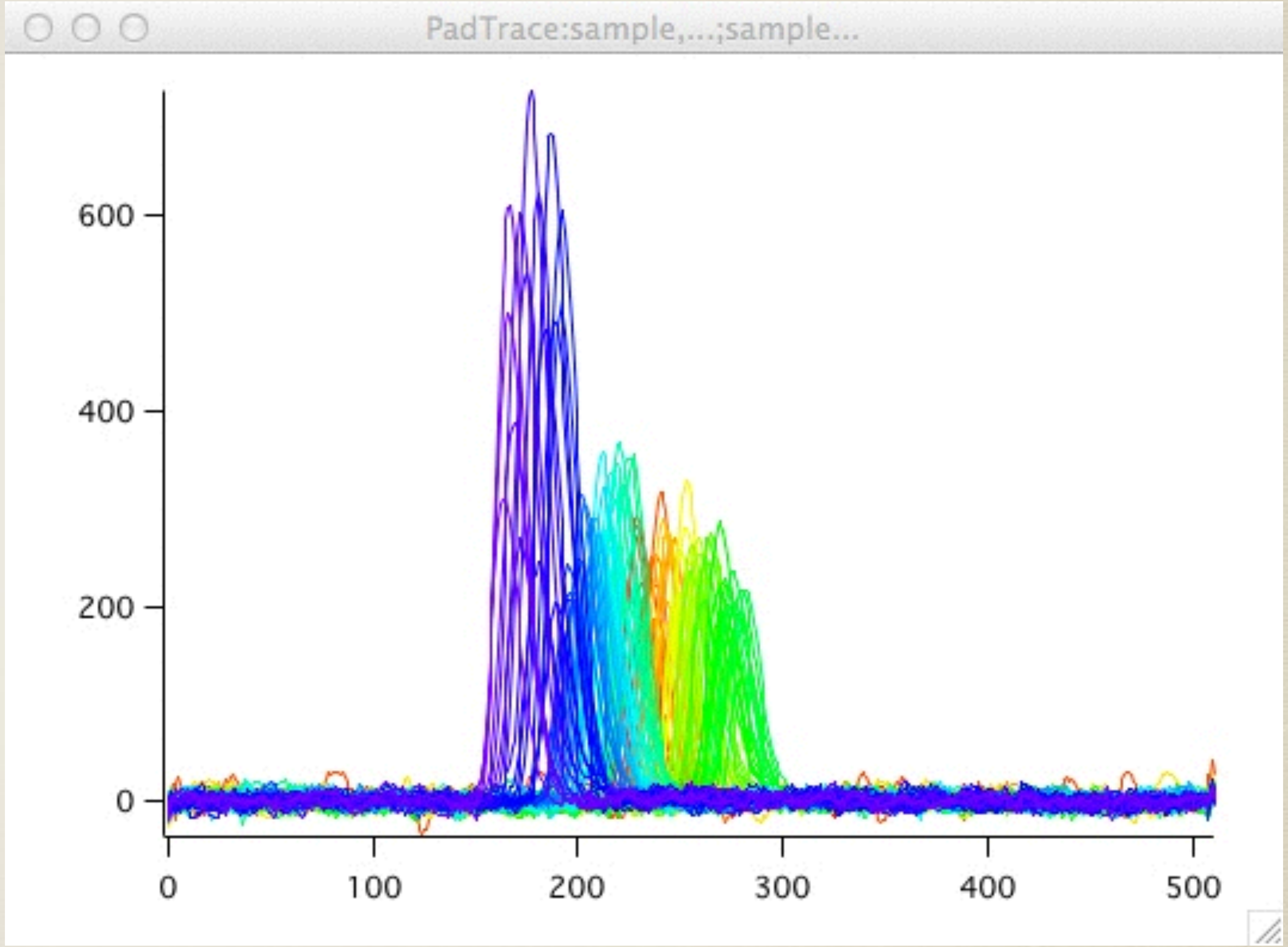
Example of reconstructed event

- *Track from alpha source placed inside the active volume*
- *3D plot clearly show time correlation*



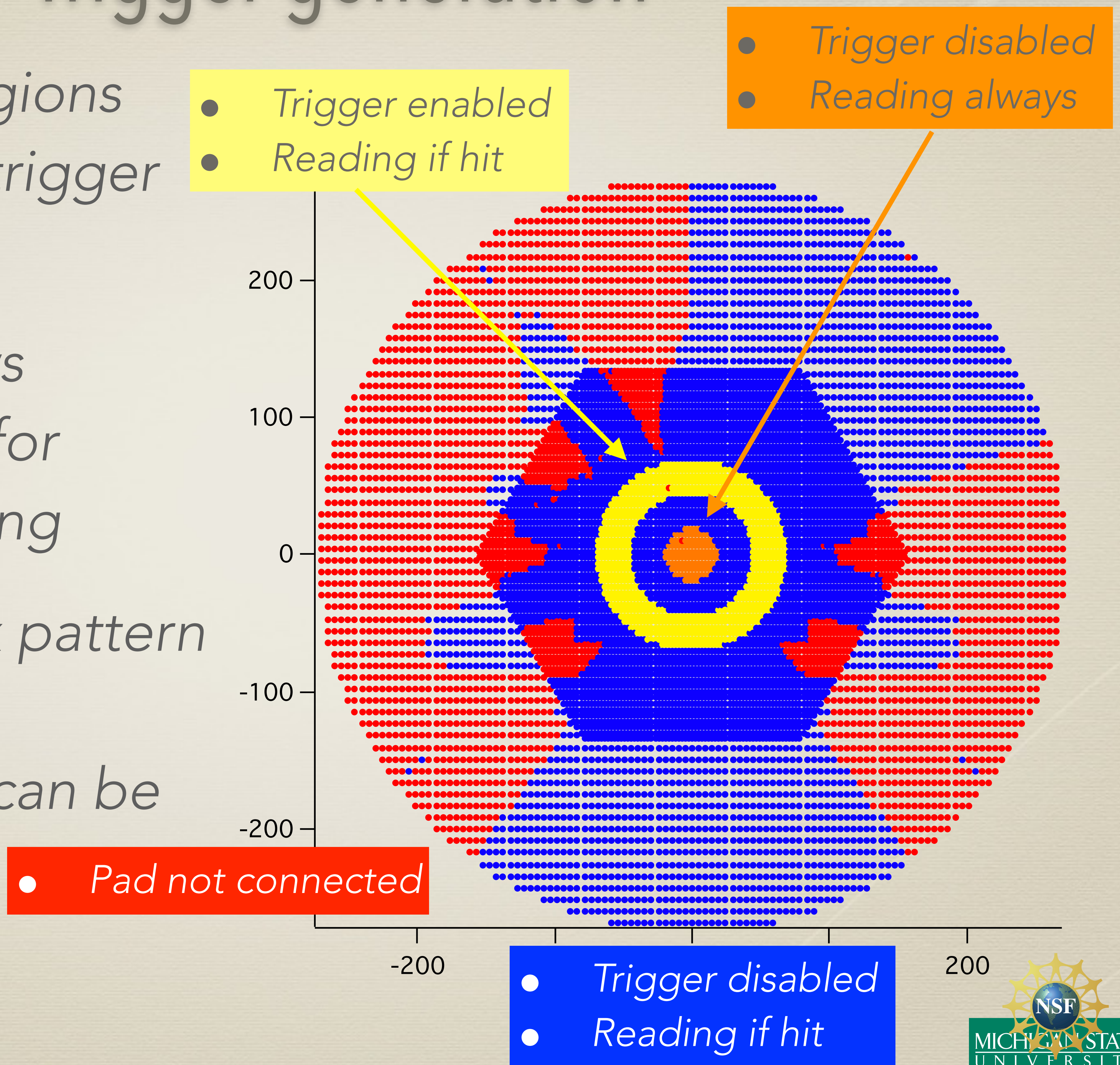
Example of reconstructed event

- *Track from alpha source placed inside the active volume*
- *3D plot clearly show time correlation*
- *Individual traces show difference in amplitude between small and large pads*



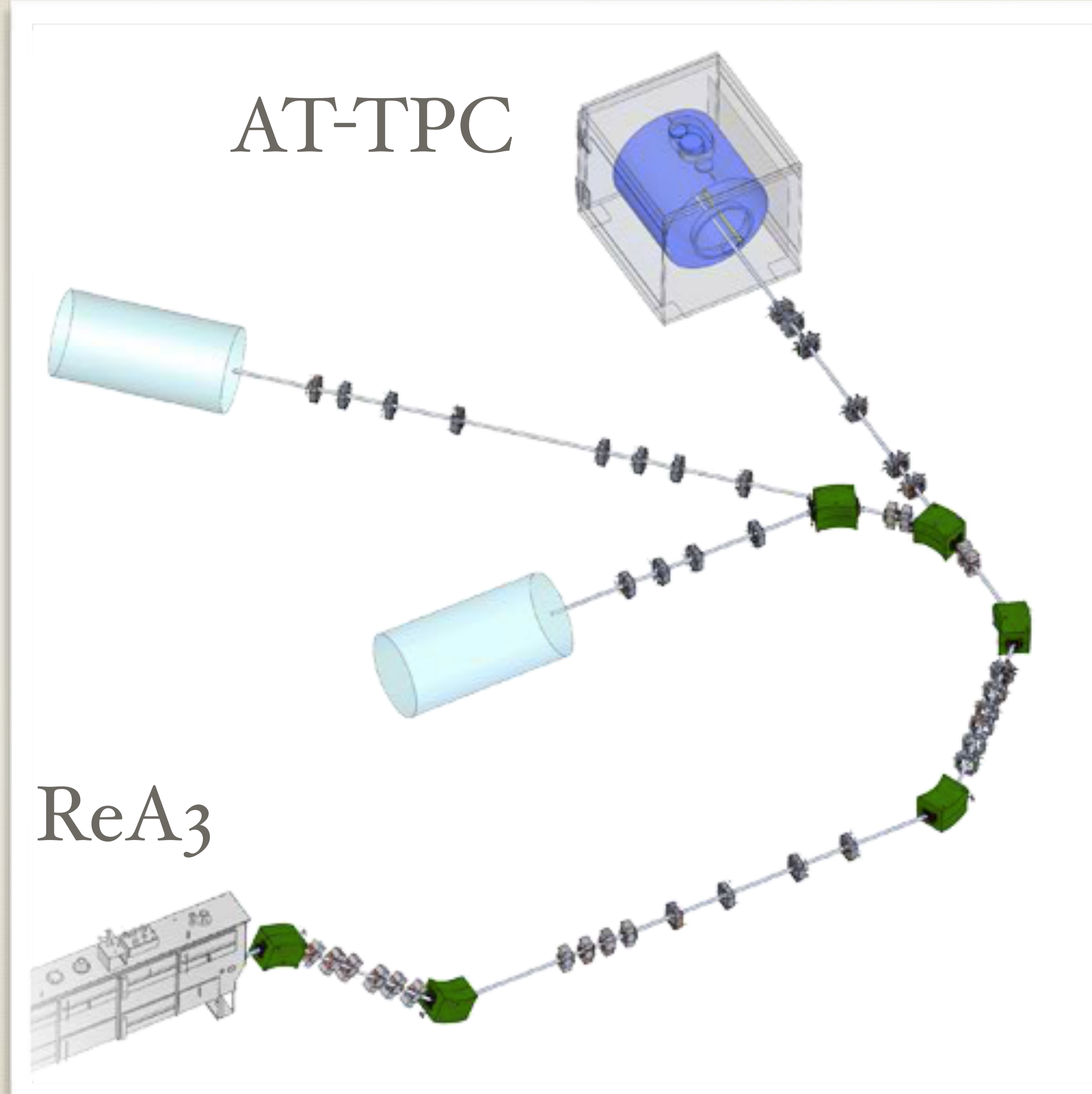
Trigger generation

- Define pad regions with different trigger attributes
- Example shows configuration for elastic scattering
- More complex pattern triggering configuration can be programmed



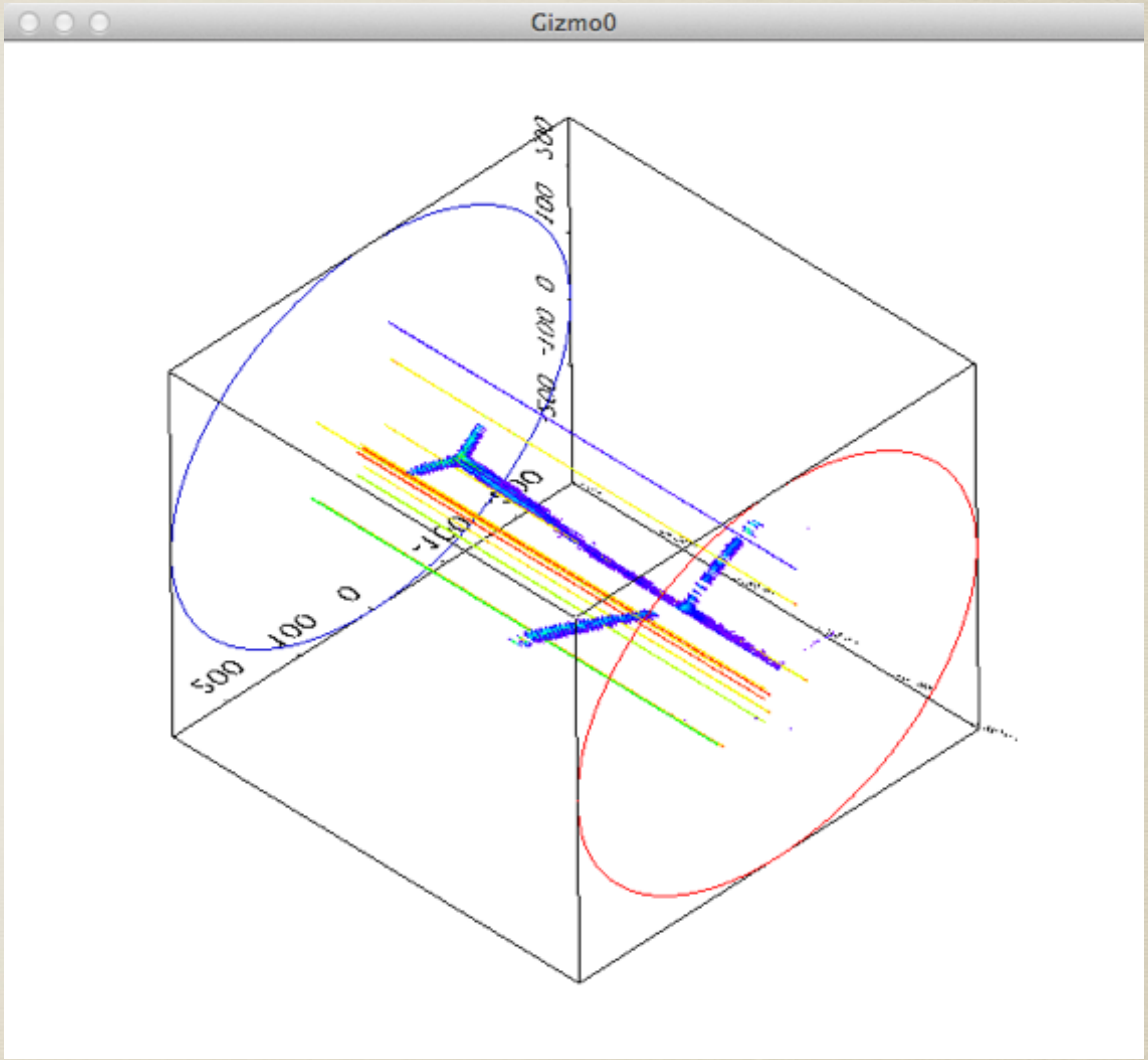
Commissioning on ReA3 linac

- Beam provided: ^4He @ 6 MeV
- Gas target: He (90%) CO_2 (10%) 100 Torr
- No magnetic field
- Measure excitation function of (^4He,^4He) elastic scattering



Online event display

- *Atypical event shows two scattering events in one shot*
- *Maximum drift time of 40 µs*
- *instantaneous beam rate of ~ 3kHz (600 Hz @ 20% duty cycle)*



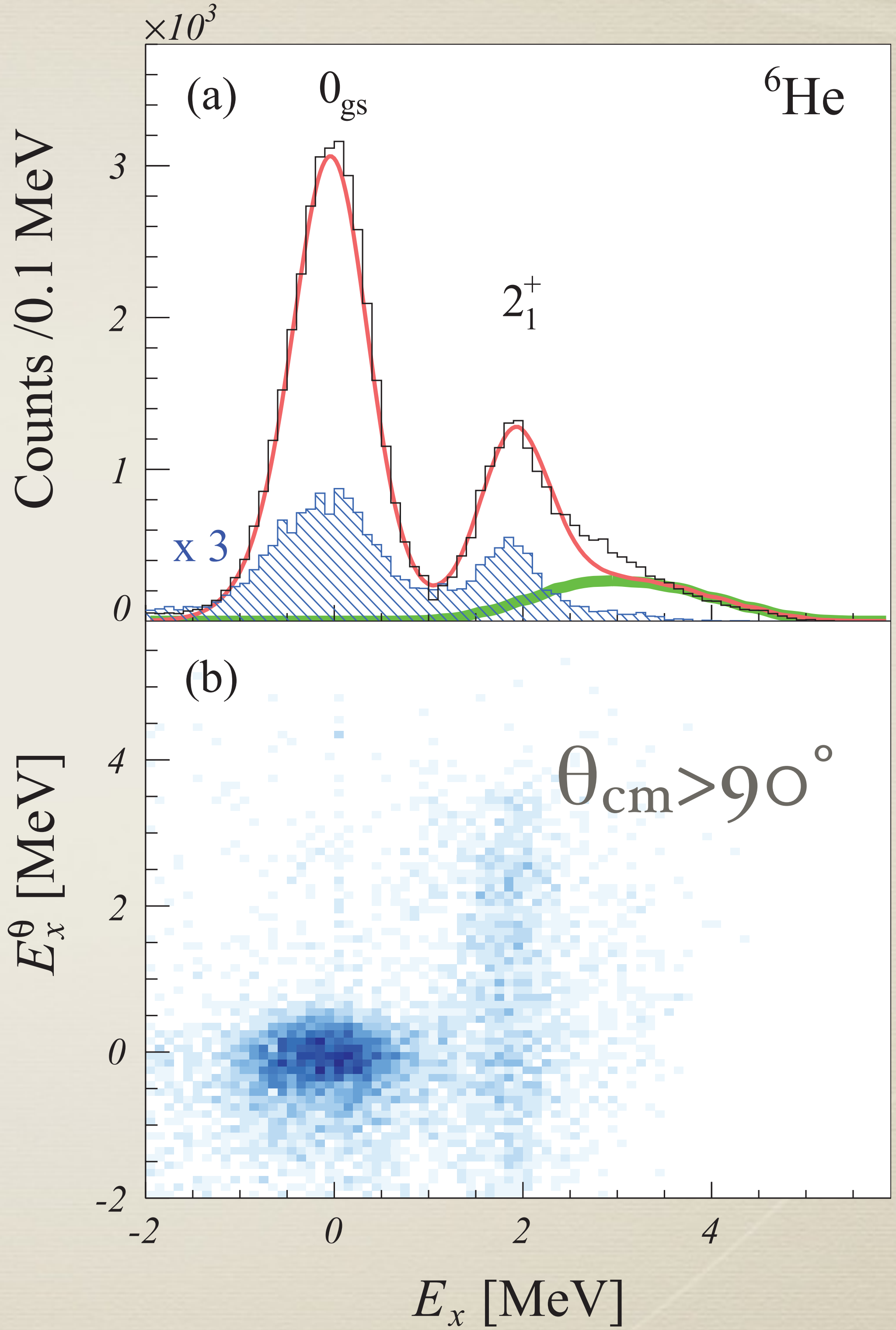
Experimental program with PAT-TPC

- *Alpha cluster structure of neutron-rich nuclei*
  - *Resonant scattering: ^{6}He+^{4}He, ^{10}Be+^{4}He, ^{8}He+^{4}He (not yet): TWINSOL @ U. of Notre-Dame, ISAC @ TRIUMF (not yet)*
- *Fusion cross section studies*
  - *^{6}He+^{40}Ar sub-barrier fusion cross sections: TWINSOL @ U. of Notre-Dame*
- *Isobaric analog proton scattering*
  - *Test on ^{124}Sn+p, experiment on ^{132}Sn+p (not yet): ATLAS @ Argonne National Laboratory*
- *3α decay mode of Hoyle state in ^{12}C*
  - *β-decay of ^{12}B implanted in PAT-TPC: TWINSOL @ U. of Notre-Dame*

D. Suzuki *et al.*, Nuclear Instruments and Methods in Physics Research A **691** (2012) 39–54

^{6}He+^{4}He scattering

- *Missing mass reconstruction*
- *E_x from TKE, scattering angle of ^{4}He and energy of ^{6}He*
- *Energy of ^{6}He before reaction known from vertex determination*
- *E_x^{θ} from angles only*
- *2^{+} scatter in E_x^{θ} from ^{6}He(^{4}He,2n)^{8}Be channel*



D. Suzuki *et al.*, Phys. Rev. C **87**, 054301 (2013)

Excitation functions & Angular distributions

- *Elastic and inelastic scattering measured between 2 and 6 MeV*
- *Angular distributions measured between 40° and 130°*
- *Peak at 2.56 MeV corresponds to 9.98(15) MeV resonance in ^{10}Be, identified as 4^+*
- *Deduced partial width Γ_α/Γ of 0.49(5) indicate highly developed α structure*

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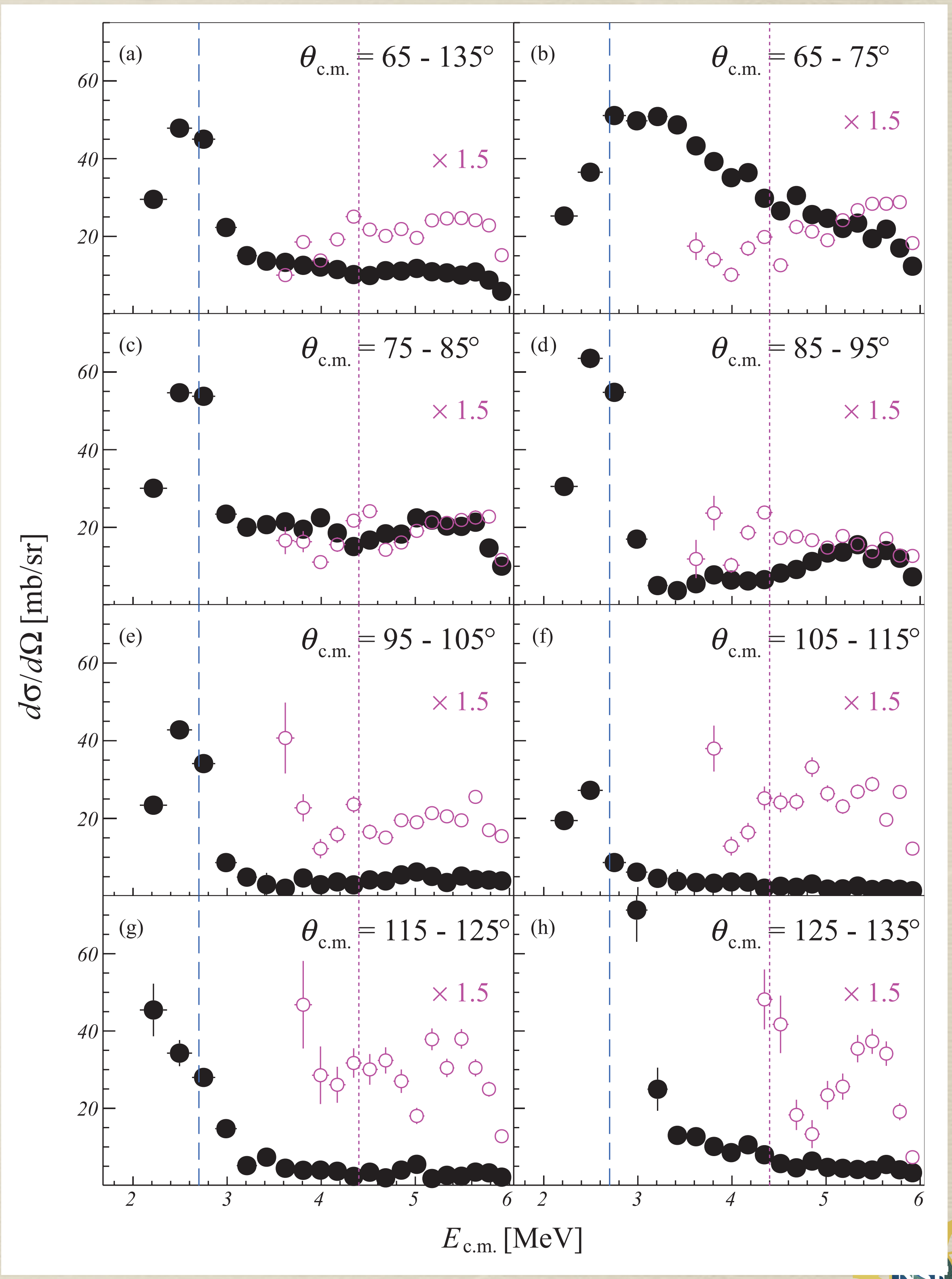

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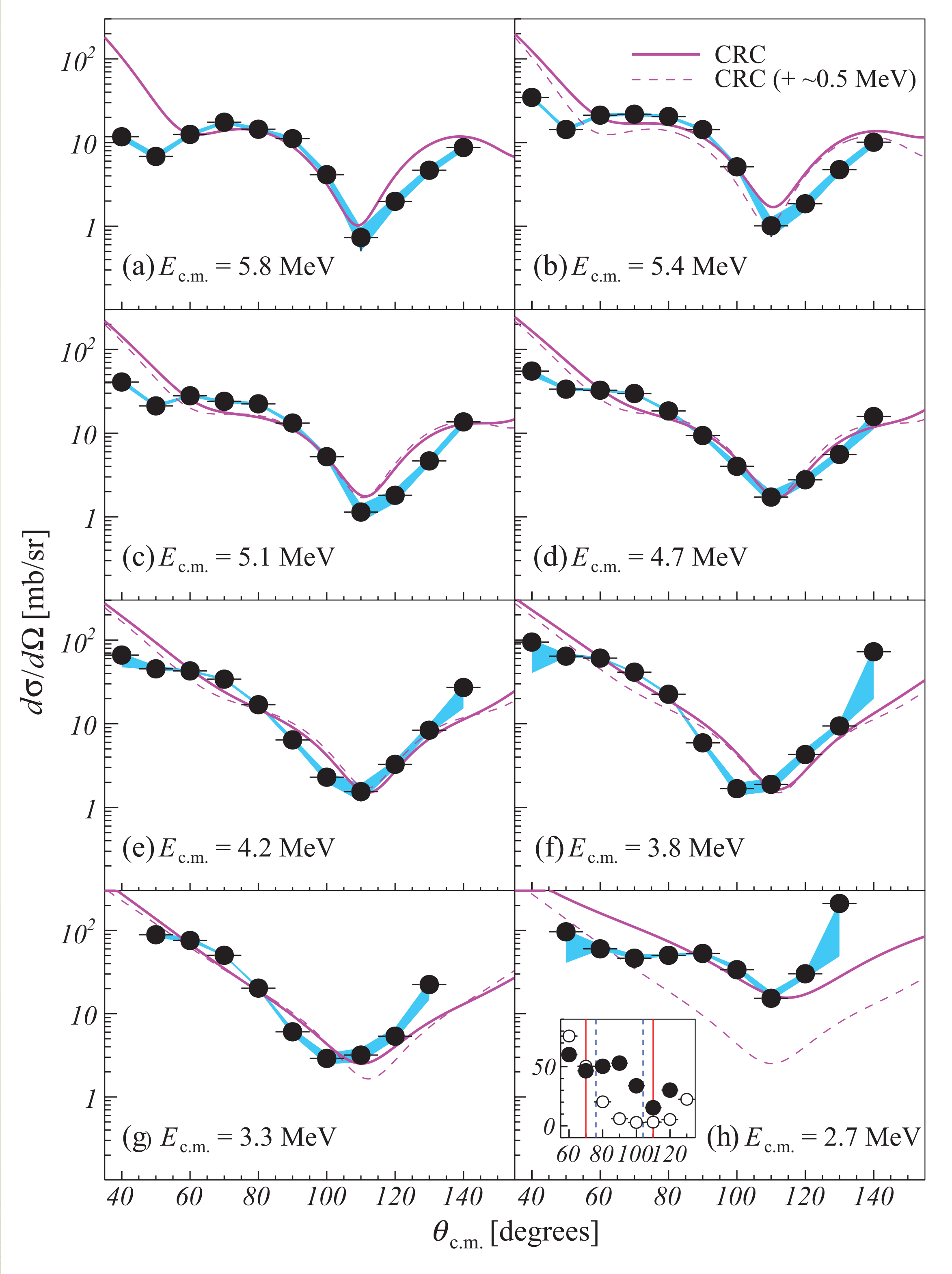

Original AT-TPC scientific program

- *National Science Foundation funding of $688k*
- *Exciting physics program planned and to develop!*

Table 1: Overview of the AT-TPC scientific program.

Measurement	Physics	Beam Examples	Beam Energy (A MeV)	Min Beam (pps)	Scientific Leader
Transfer & Resonant Reactions	Nuclear Structure	^{32}Mg(d,p)^{33}Mg ^{26}Ne(p,p)^{26}Ne $^{66,..,70}$Ni(p,p)	3	100	Kanungo
Astrophysical Reactions	Nucleosynthesis	^{25}Al(^{3}He,d)^{26}Si	3	100	Famiano, Montes
Fusion and Breakup	Nuclear Structure	^{8}B+^{40}Ar	3	1000	Kolata
Transfer	Pairing	^{56}Ni+^{3}He	5-19	1000	Macchiavelli
Fission Barriers	Nuclear Structure	^{199}Tl, ^{192}Pt	20 - 60	10,000	Phair
Giant Resonances	Nuclear EOS, Nuclear Astro.	^{54}Ni-^{70}Ni, ^{106}Sn-^{127}Sn	50 - 200	50,000	Garg
Heavy Ion Reactions	Nuclear EOS	^{106}Sn - ^{126}Sn, ^{37}Ca - ^{49}Ca	50 - 200	50,000	Lynch

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AT-TPC team and collaboration

- *NSCL team of 10 people*
  - *Faculty: D. Bazin, W. Mittig, B. Lynch*
  - *Engineers: N. Usher, F. Abu-Nimeh*
  - *Post-docs: D. Suzuki (until 2012), T. Ahn, S. Beceiro-Novo*
  - *Ph.D. students: A. Fritsch, J. Bradt*
- *Outside collaborators*
  - *J. Kolata, U. Garg (U. of Notre-Dame)*
  - *F. Bechetti (U. of Michigan)*
  - *R. Kanungo (Saint Mary's U.)*
  - *M. Heffner (LLNL)*
  - *I-Yang Lee, L. Phair (LBL)*

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