Work of a Physicist

- Experiment design, analysis?

  à mini-studies of technical issues
  - state the problem clearly
  - make (appropriate) approximations
  - do calculations
  - look for scaling laws, simple patterns in results
  - state conclusions clearly, including systematic errors

- Some real-life examples (of many!)

Particle Detector Optimization

- How To Design a Detector

  Physics à Detector Specs. à Detector Design

  Concrete example: central tracking detector

- How to estimate, parameterize, model, scale, etc. to understand various real-life situations:
  - Effect of Changing Magnet Specs
    - change in cryostat size
    - change in expected B-field strength
  - Trade-offs between detectors
    - allotting space between CTOF and CND

- Mistakes to Avoid

CLAS12 Tracking: physics a design

Start from the Physics

- Physics constraints:
  - electron beam
  - higher momentum tracks, smaller cross-sections
- Detector goals:
  - good momentum and angular resolution
  - capability to run at $L=10^{35} cm^{-2} s^{-1}$, good vertex resolution, robust
- Detector design:
  - central solenoid and Moller absorber; forward torus
  - forward tracker: Si strips + 3 stations of drift chambers
  - central tracker: Si strips

Physics goals a general design spec's

Goals:	Specifications:
measure flux-factor accurately	q ~ 1 mrad dp/p < 1%
select an exclusive reaction by missing momentum	dp < .05 GeV/c dq p < .02 GeV/c sinq df p < .02GeV/c
small cross-sections	$L = 10^{35}/cm^2/s$ high efficiency
good acceptance	Df ~ 50% at 5^o

Tracking Specifications Summary

	Fwd. Tracker	**Central Tracker**
Angular coverage	$5^{o} – 40^{o}$ (50% ϕ-coverage at 5^{o})	$35^{o} – 125^{o}$ (> 90% ϕ-coverage)
Momentum resolution	$dp/p < 1\%$	$dp/p < 5\%$
θ Resolution	1 mrad	5 – 10 mrad
ϕ Resolution	1 mrad/sinθ	5 mrad/sinθ
Luminosity	10^{35} cm^{-2} s^{-1}	10^{35} cm^{-2} s^{-1}

CLAS12 Tracker Early Design - 2007

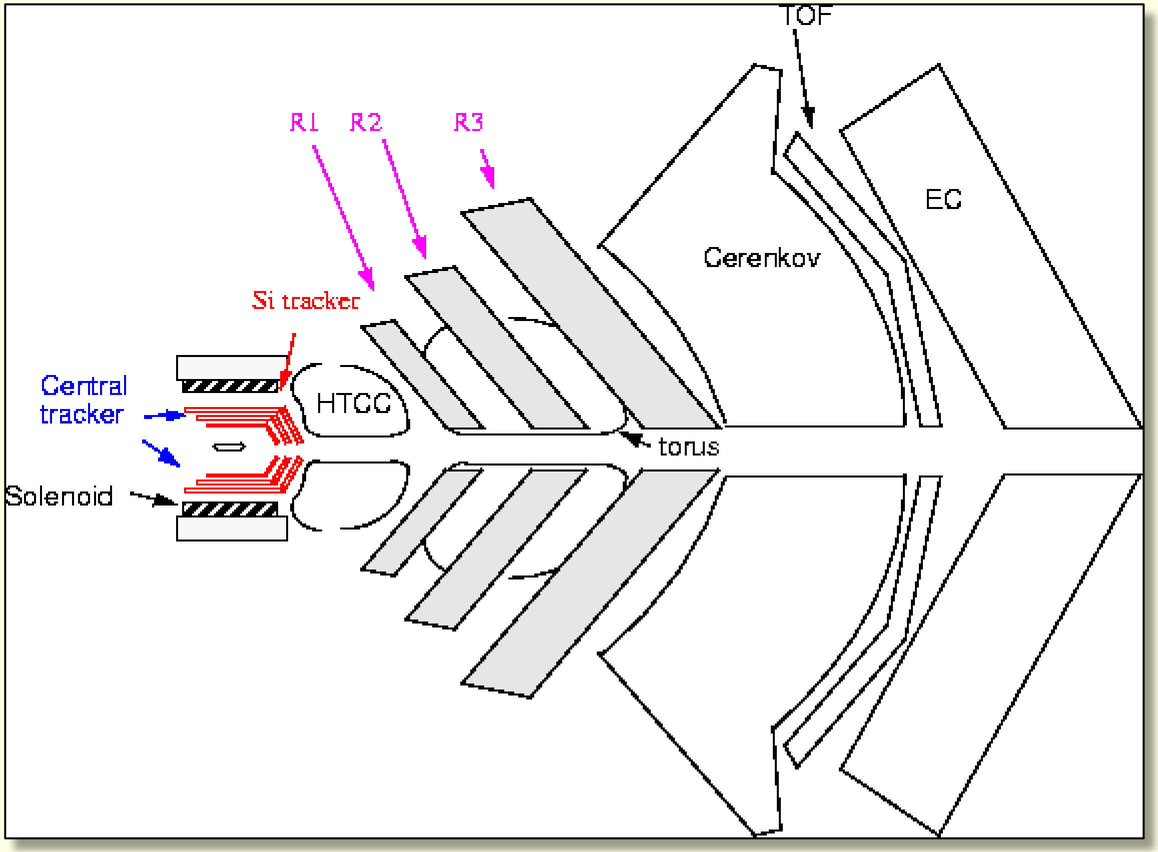
Central tracker:

•single-sided Si strips
•barrel: 4 x 2, fwd: 3 x 2

DC's: same concept as CLAS chambers

•hexagonal cells
•6 sectors, 3 regions
•2 super-layers/region
•6 layers/super-layer
•112 wires/layer (24192)
•angled endplates
•on-board pre-amps

• measure charged tracks (5^o – 140^o)

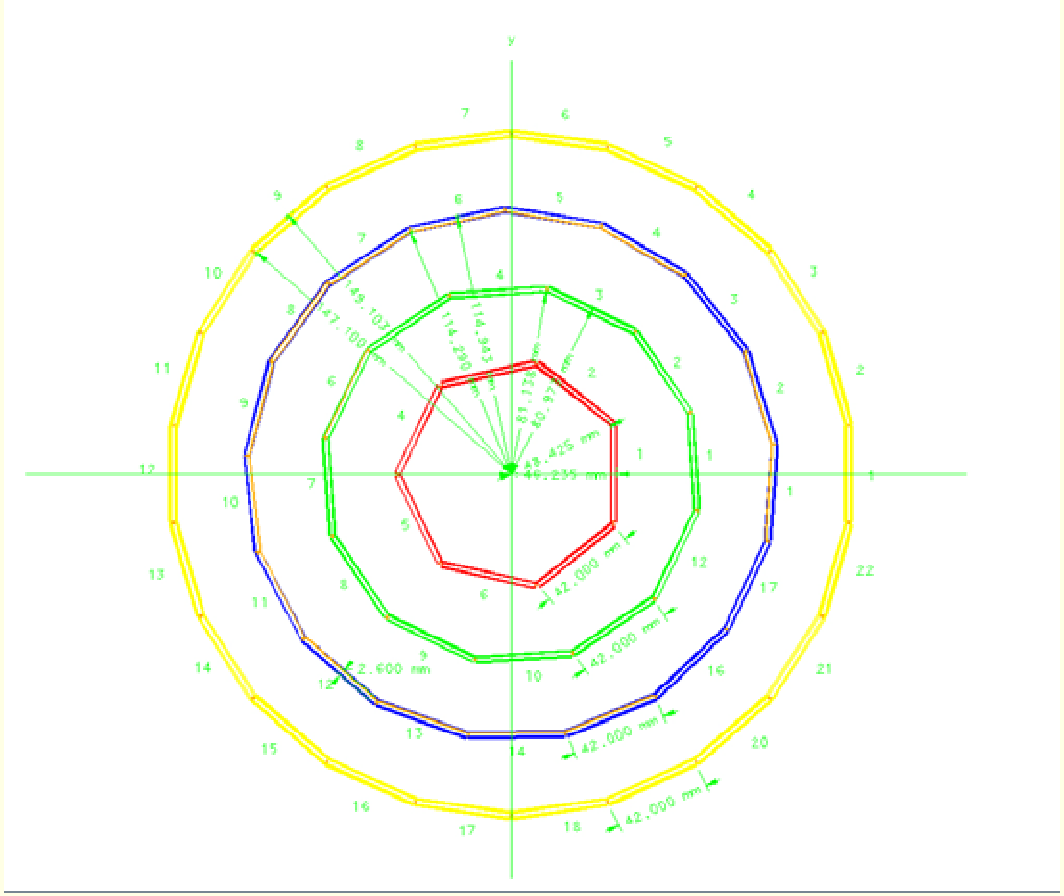


Discussion: physics a spec's a design

- are the tracking spec's adequate to do the physics?
  - (need feedback from proposers)
- what studies could confirm this?
  - specific studies with FASTMC; specifically, for an experiment with a charged track in the central region
- what are the options if the background rates are much higher than expected?
- what is the effect on the physics if the resolution went up by 1.5? if the minimum lab. angle were 6^o? or some other moderate change to the spec's?

Silicon Vertex Tracker: Conceptual Design

- Polygons formed from identical modules
- Concentric ‘rings’
- Good resolution in f
- Small-angle stereo means poor Z and q resolution



SVT: spec's a design concepts

Specifications:	Central Design Features
$L = 10^{35}/cm^2/s$ -solenoidal shield -separated fwd.-bck. - large backgrounds	many strips small stereo angle (fewer ambiguities) four 2-layer superlayers
good dp/p, dq	5 T central field 75 mm readout pitch $dp/p \sim 1/(r_{in} - r_{out})^2$ +/- 1.5^o stereo angles
good acceptance	butt-joint design wire-bonded staves
reliability	identical sensor cards

SVT Design Decisions

single-sided strips	mature technology; more material
75 μm strip pitch	read out: 150 μm
4x2 (SVT); 3x2 (FSVT)	robust track-finding
only two sensor types	rectangular (SVT) trapezoidal (FSVT)
1.5^{o} (stereo): SVT	good enough; $\delta\theta \sim \delta\phi$
9^{o} (stereo): FSVT	fits 20-gon; too many ambig.'s ?
butt-joint construction	simple; easy to simulate
wire-bonded staves	need good mechanical support
SVX4 chips	well-known

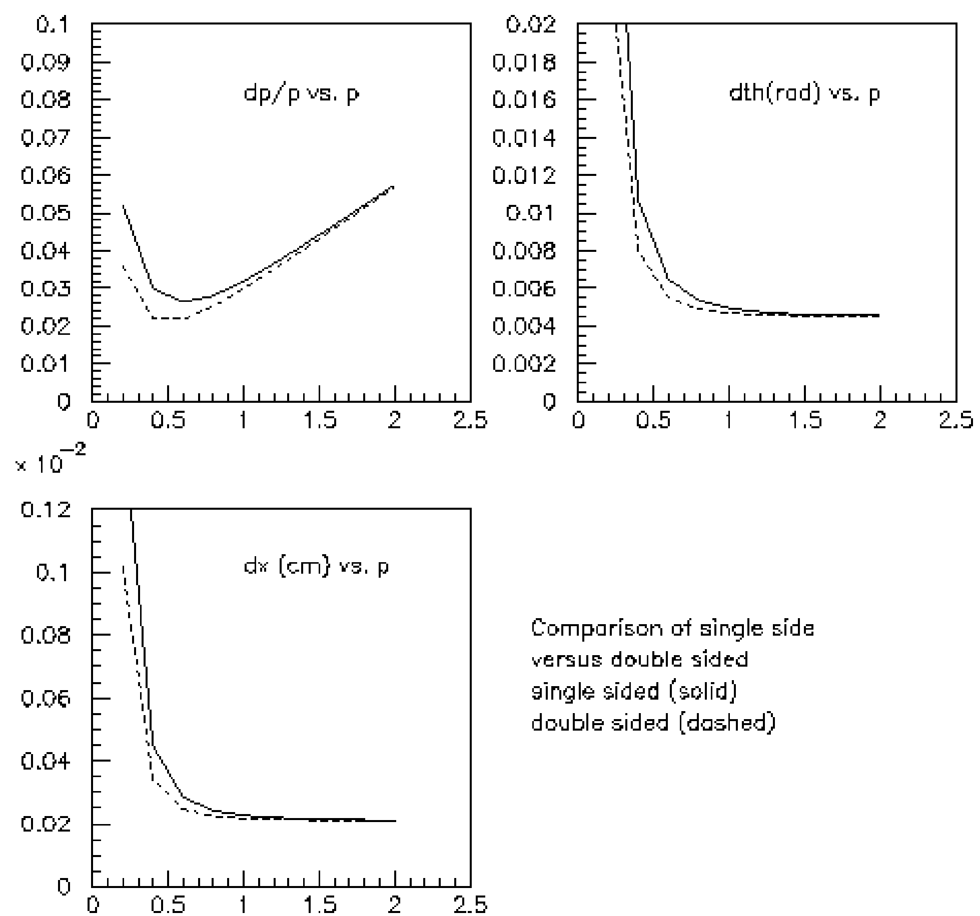
Major Questions: SVT design

- double-layer technology has less multiple scattering - why not use it?
- isn't 6 layers in fwd. direction overkill? - how many are needed?
- is the clocking of the central polygon optimal to minimize dead areas?
- why have we chosen SVX4? what is its time window and charge sensitivity?
- is wire-bonding too risky?
- place for MicroMegas? what about FSVT?

Effect of multiple scattering?

2008 study of effect of doubling Silicon thickness: comparing resolutions for double-sided vs. single-sided

- **affects dp/p for low momentum tracks**
- **dp/p at 0.4 GeV/c increases: 2.5 à 3.2% due to *doubling* of Si**
- **dp/p at 0.4 GeV/c increases from 3.2 à 3.4% due to *doubling* of C**
- **small effect; go single-sided**



Will SVT work at $L = 10^{35}/cm^2/s$?

Rate effects: fake tracks, stereo angle

High background

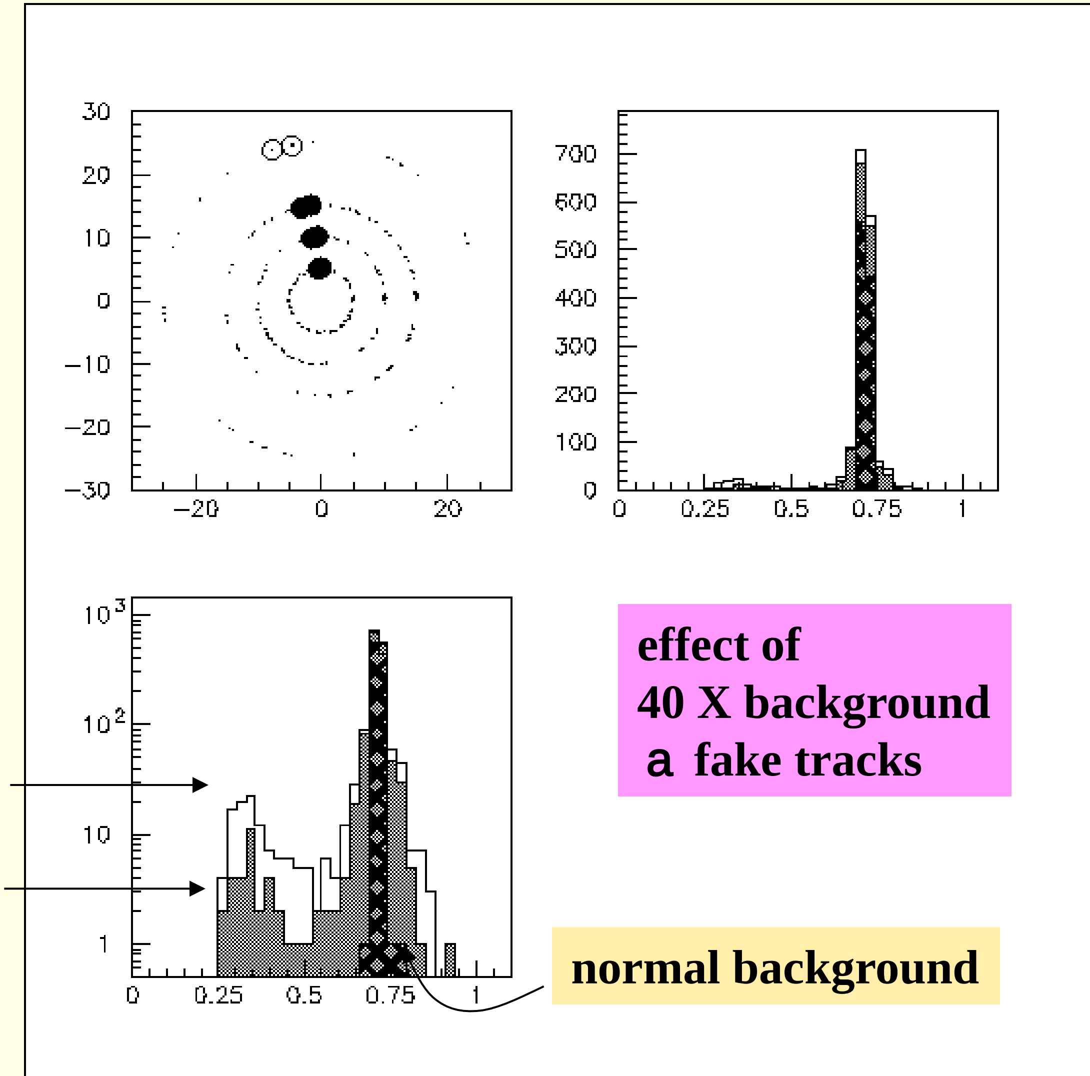
- **problem is NOT dead-time**
- **problem is FAKE rates**

Fake tracks

- **“sister” tracks (share hits)**
- **“independent fakes” are at low momentum**

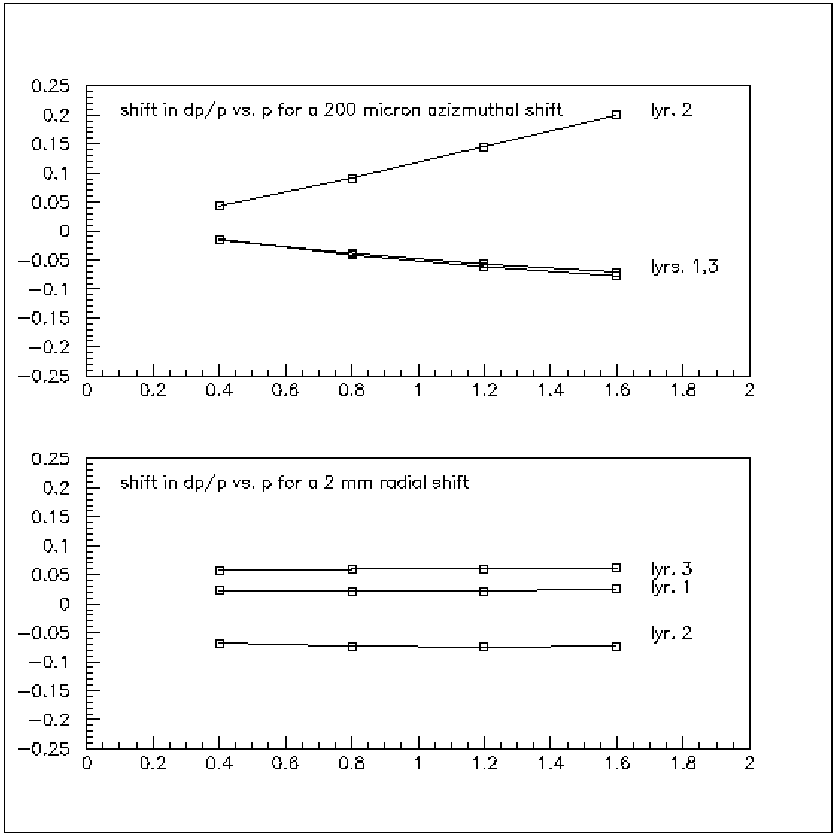
+/- 3^o stereo

+/ 1.5^o stereo



Effect of mis-alignment?

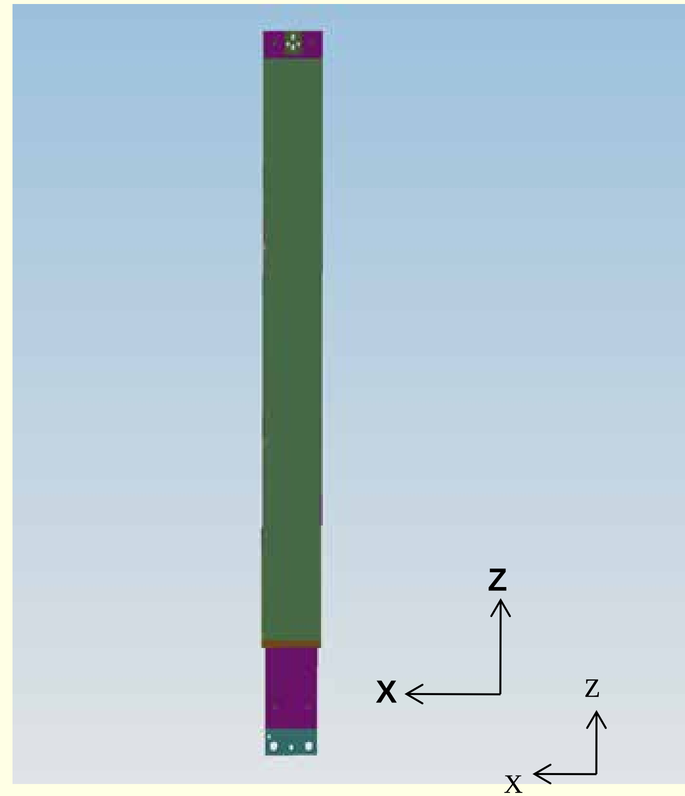
Study of effect of “region” mis-alignment in azimuthal and radial direction



- **20 micron azimuthal misalignment**
  à 2% momentum shift at 1.6 GeV/c
- **500 micron radial misalignment**
  à 2% momentum shift
- **750 micron misalignment in z-position**
  à 2% momentum shift
- **à azimuthal alignment is critical**
- **Write fabrication specifications**

Position Accuracy*

	Sensor position accuracy (µm) Module Fabrication***	Module position accuracy (µm) Detector Assembly***	Physics Requirement**
X	5 -10 ?	15 – 20 ?	20
Y	250 ?	250 ?	500
Z	10 – 20 ?	50 ?	750



*** Accuracy numbers given at the "1-s" level**

**** To achieve (dp/p < 2%) for momenta < 1.6 GeV/c**

***** After construction *and* survey**

à **azimuthal tolerance tight**

à **accurate construction and survey needed**

ctors

BST Resolution: Systematic Effects

Physics a tracking requirements
a detector specifications

Expected Resolution à <u>meets physics requirements</u>

Granularity (# channels) à <u>can run at L = $10^{35} cm^{-2} s^{-1}$</u>

Effects on resolution (design change, fabrication tolerance)
- Increased multiple scattering: small effect
- Construction mis-alignment:
  'extra' momentum resolution < 2%

"Design Validated"

CLAS12 Central Tracking
Add Micromegas ?

Two options:

SVT- only

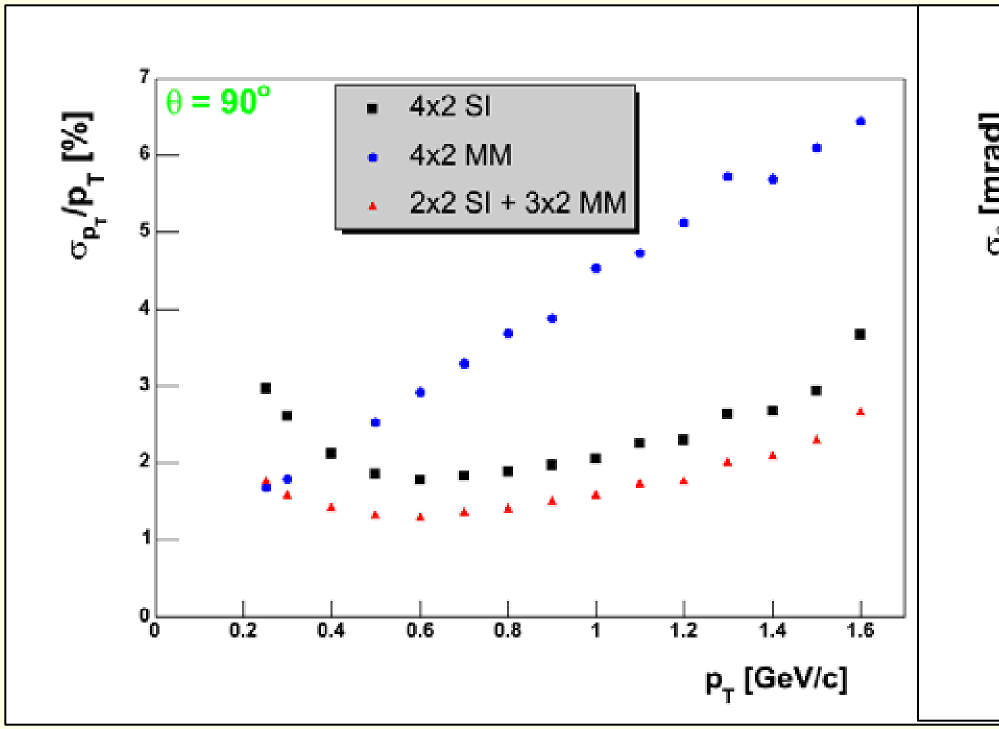
- Four double-layers (+/- 1.5^o stereo), central (35-135^o) region
- Three double-layers (+/- 9^o stereo), forward (5- 40^o) region
- Central part: rectangular sensors as polygonal "cylinders"
- Forward part: trapezoidal sensors arranged in disks

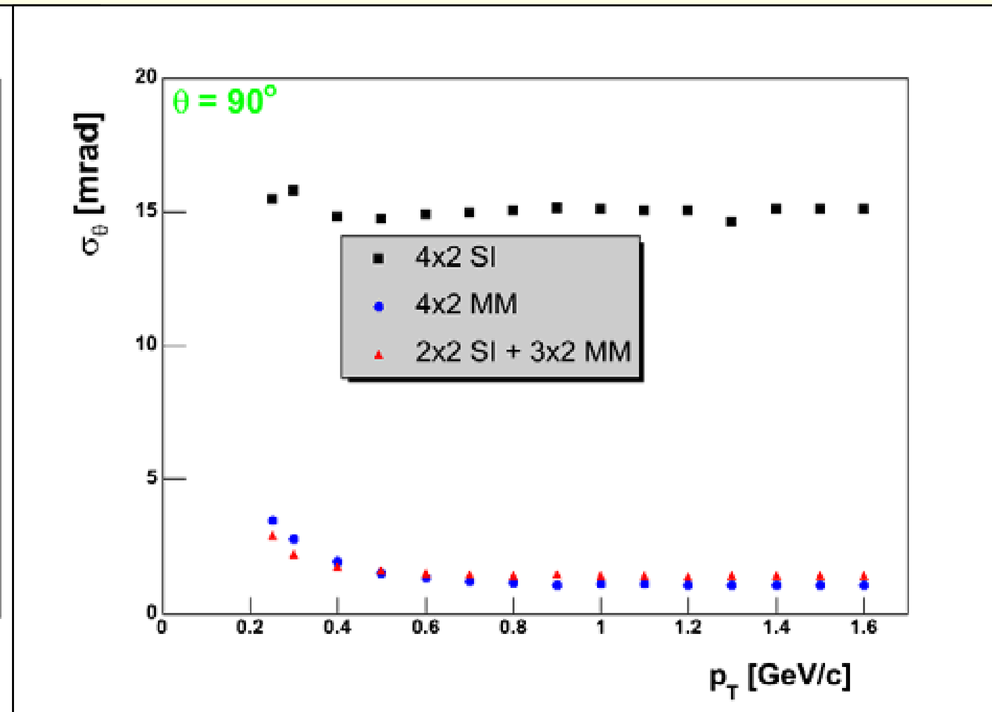
Mixed SVT - Micromegas

- Central: two double layers SVT, three double layers Micromegas
- Forward: ?, three double layers Micromegas in a disk

Résultats

3 dispositifs ont été étudiés:
- 4x2 SI (a = ±1.5°, et s = 43 mm)
- 4x2 MM (a = 0 et 90°)
- 2x2 SI+ 3x2 MM





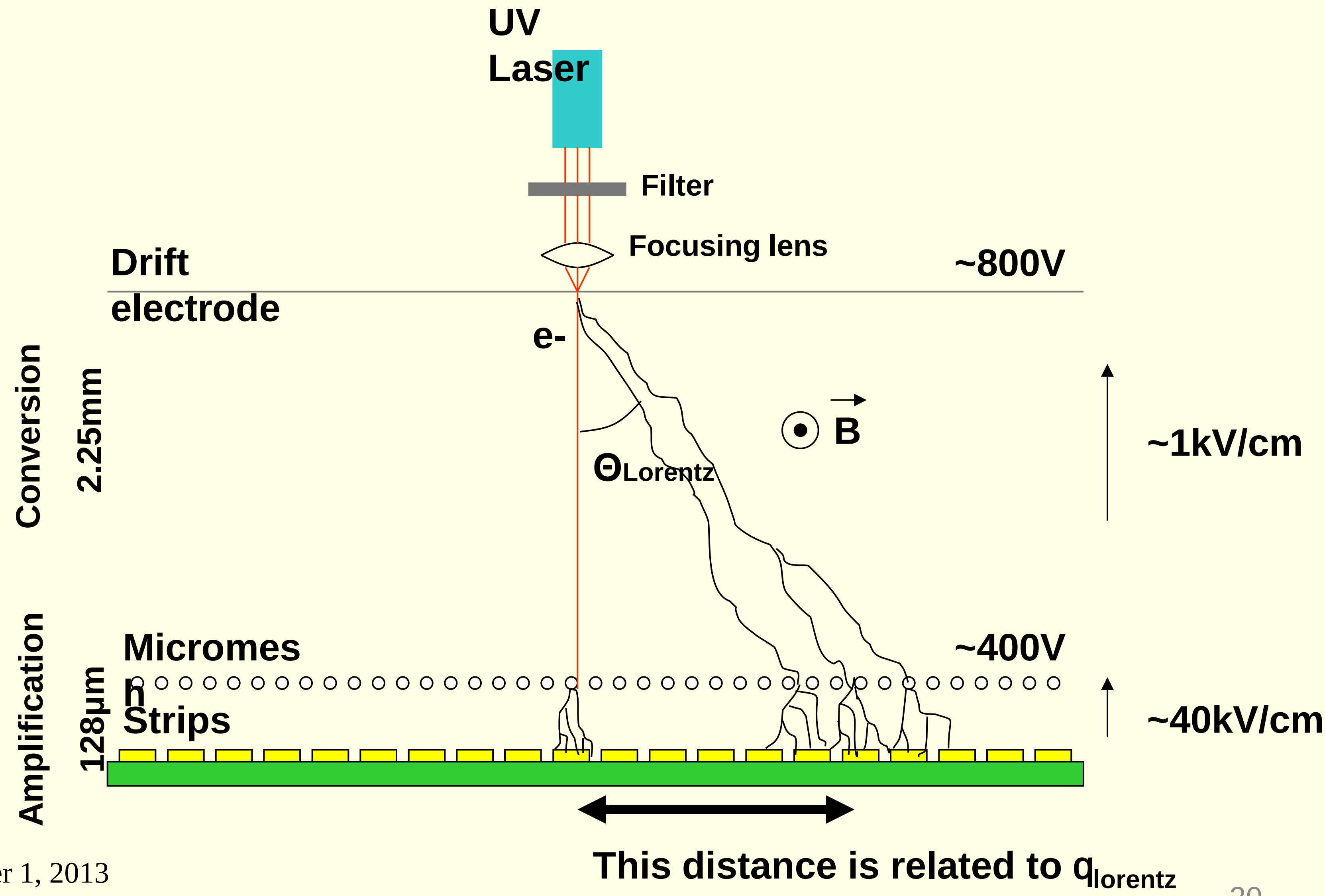
s_{pT}/p_T ® SI(+MM)

s_q ® MM

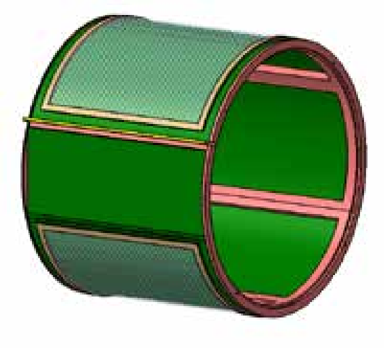
Silicon + Micromegas ?

- simulations show mixed solution best, but
  - can Micromegas work with a cylindrical geometry?
  - can Micromegas work in a high, transverse B-field ?
- Review the technology

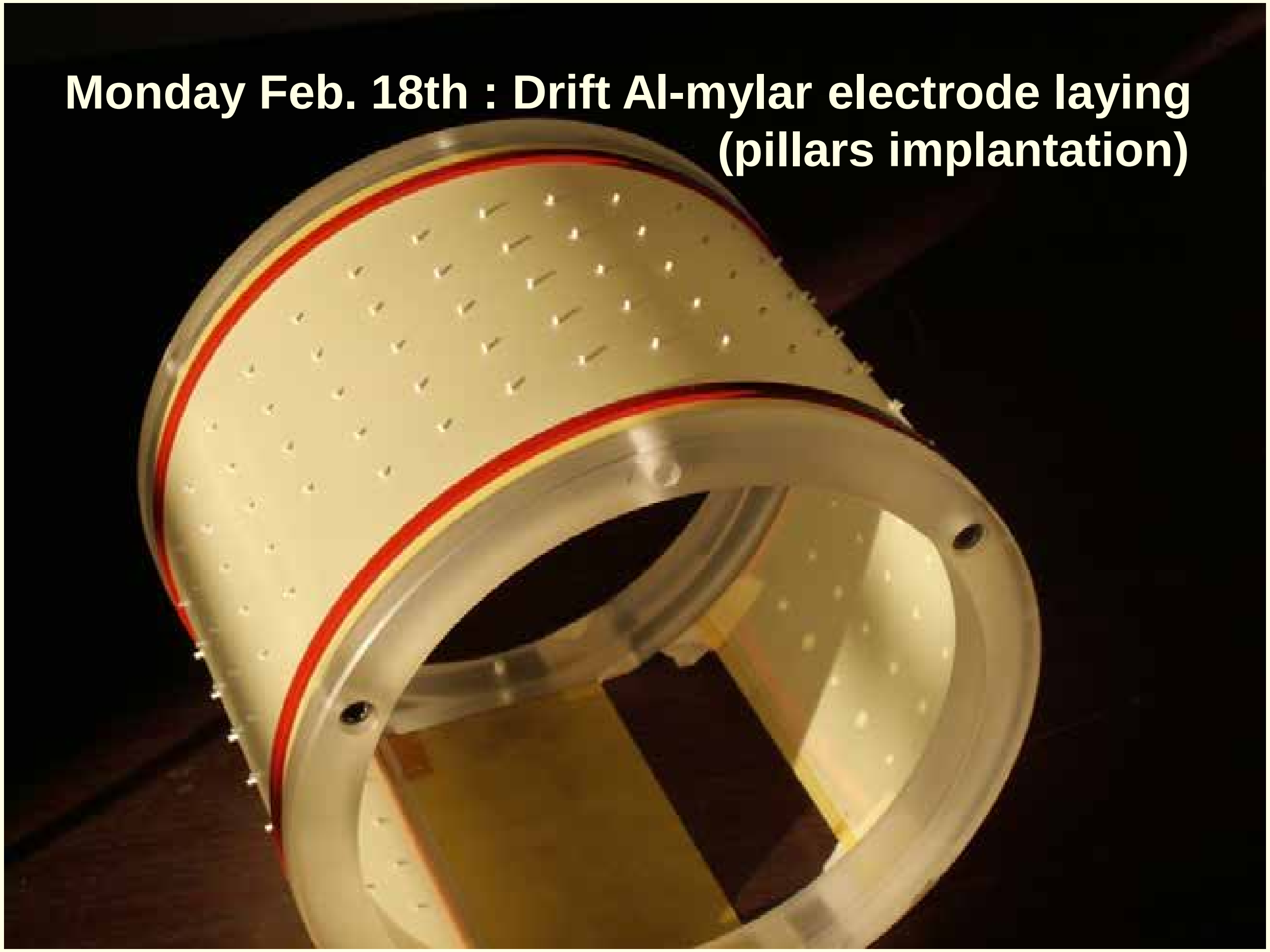
With a magnetic field



Prototype #1 : Y Cylinder

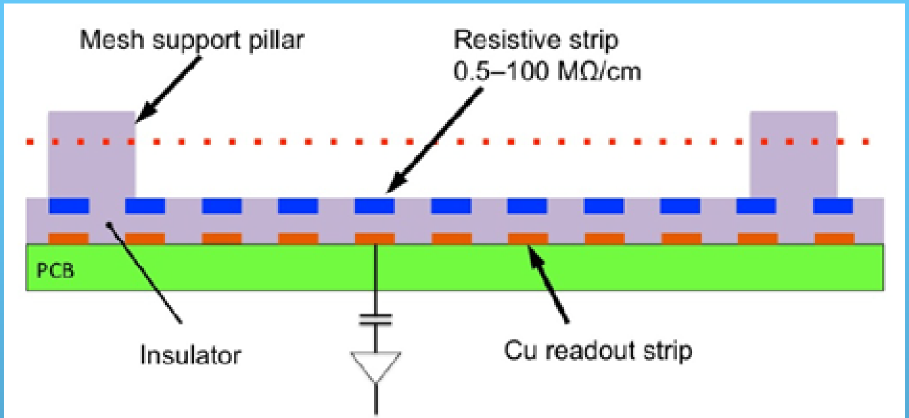


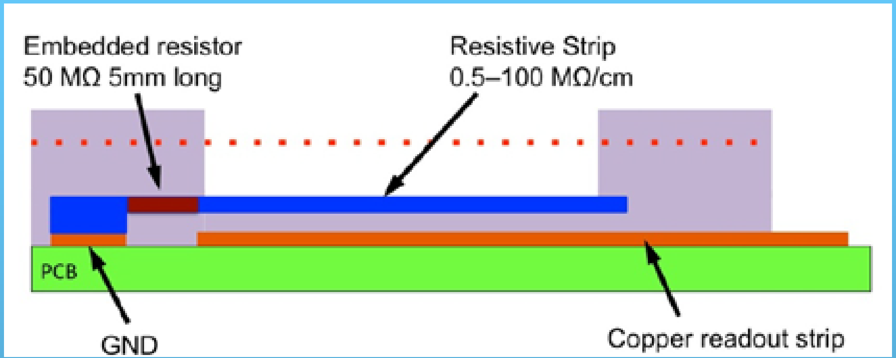
v1 mechanical structure just arrived for laying/implantation studies



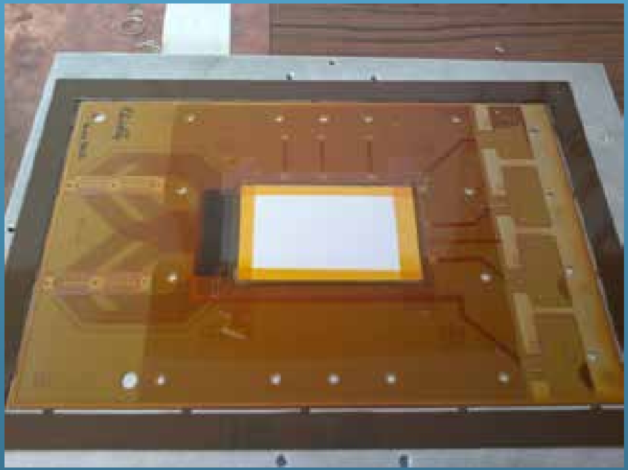
Test of a resistive detector

→ Resistive detectors planned for the Forward MM, and maybe the Barrel





→ 1st small prototype



- Same signal shape as for non resistive
- Excellent homogeneity so far
- Gains up to 40,000 (!)
- Ageing study in progress:
  already ~ 3 years of CLAS12 operation
- No visible sparks ⟹ no dead time
- May not need chip protections ⟹ higher S/B (+17%)

Summary: CLAS12 Vertex Detector Design

- Early studies established detector specifications
- Silicon-only design:
  - good rate dependence, good vertexing
  - moderate dp/p, poor q resolution (small-angle stereo)

à study combined Silicon + Micromegas

  - simulations showed mixed-system was best
  - review identified magnetic-field dependence and sparking as concerns
  - extensive prototyping and resistive-readout design resolved issues

- spec's à concept à simulate, proto-type à repeat

Effect of Torus Outer Dimensions on CLAS12 Tracking

What cryostat dimensions are important?

- hub radius, cryostat width

How does this affect drift chamber placement?

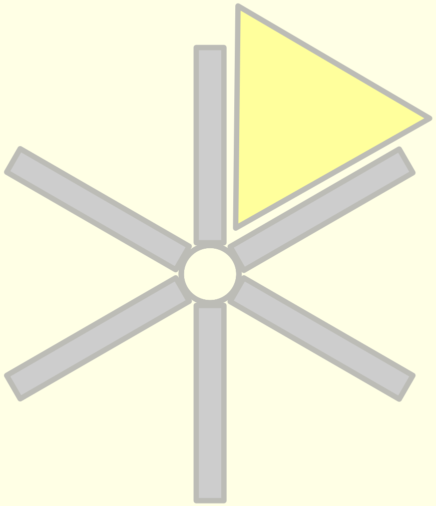
- the “region 2” chamber moves out radially
- the “coil shadow” increases

How does this affect forward tracking?

- no effect on resolution or efficiency
- decreases solid angle
    - no effect on momentum or polar angle coverage
    - reduces azimuthal coverage

Torus Geometry

Beam's eye view of torus with one chamber installed



If cryostat width increases, chamber moves outward; larger ‘shadow’

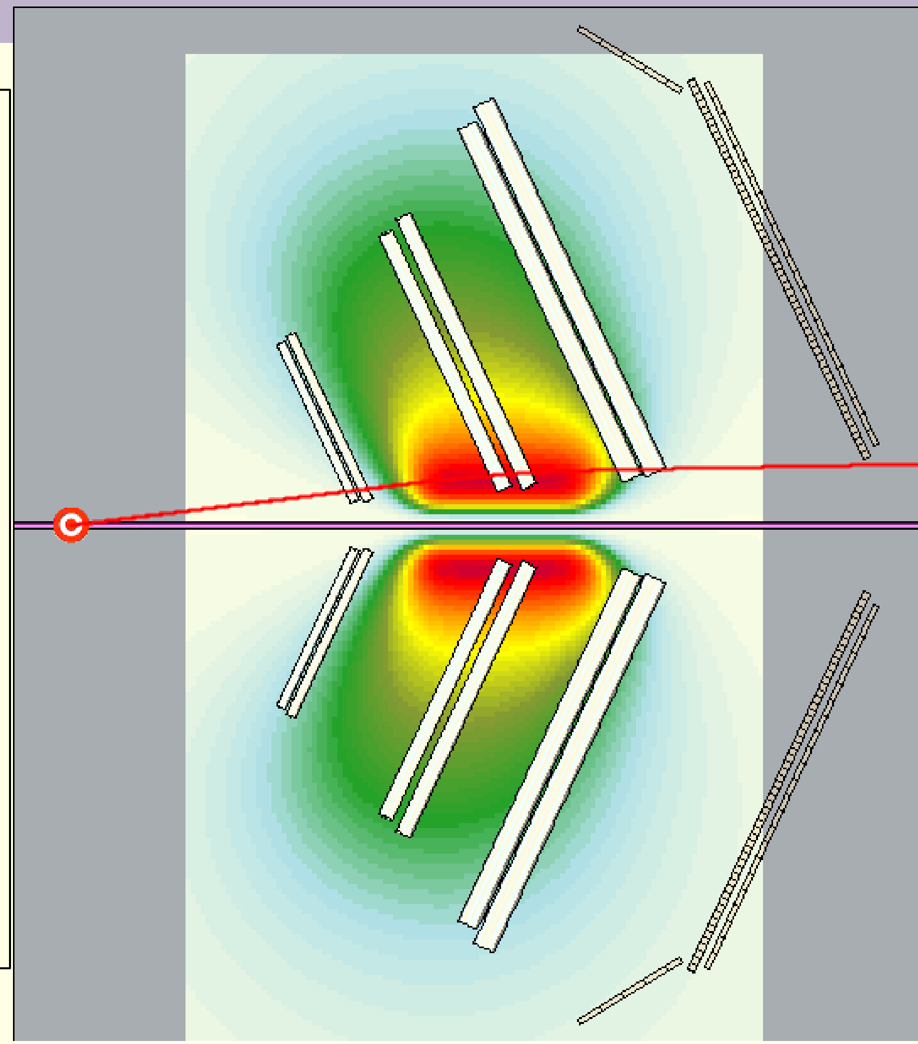
How does this affect solid angle ?

Example of a track on the edge of CLAS12 acceptance:
-an elastically scattered electron at 7°, 10.1 GeV/c

à note that if a track passes through region 1 and region 3, it goes through region 2 with more than 10 cm to spare

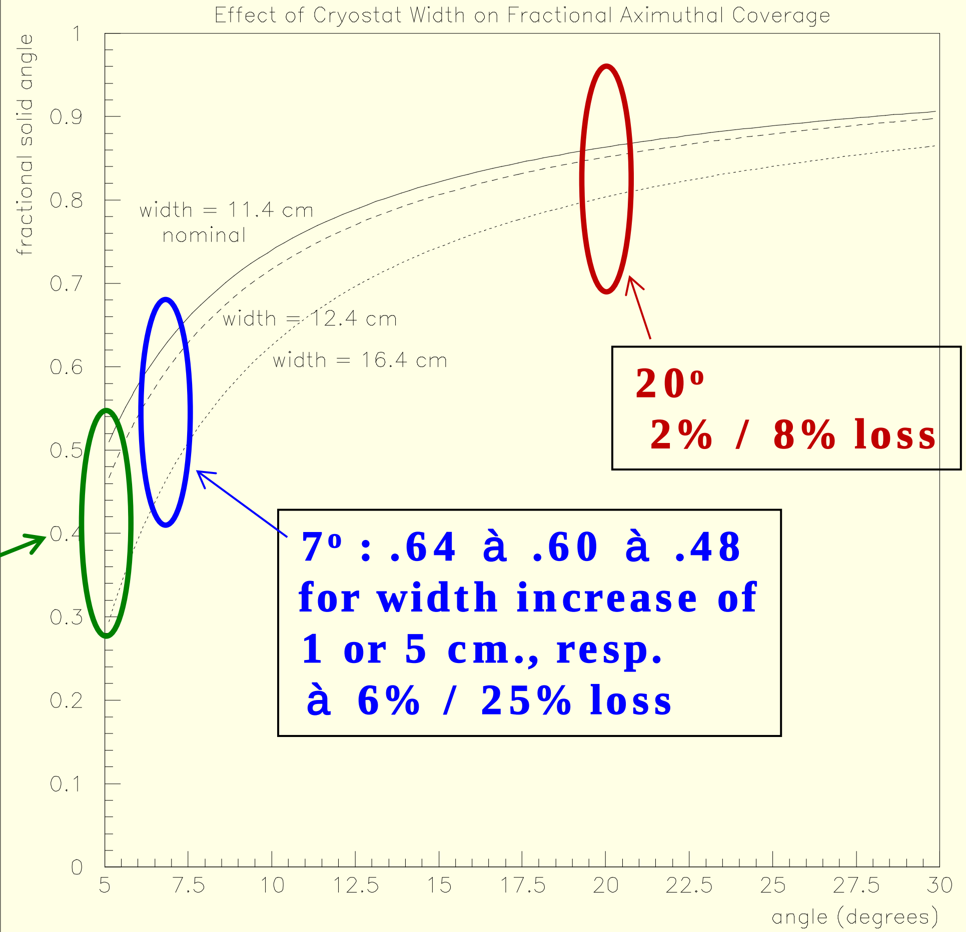
à no effect on p or q acceptance

à reduced azimuthal coverage due to 'coil shadowing'



CLAS12 Azimuthal Coverge

Fractional solid angle for nominal width (11.4 cm) and two examples of coil width increase



5º : .50 à .46 à .28 for width increase of 1 or 5 cm., resp. à 8% / 44% loss

7º : .64 à .60 à .48 for width increase of 1 or 5 cm., resp. à 6% / 25% loss

20º 2% / 8% loss

Effect on Accepted Number of Events?

Experiment type	Effect of 1cm Increase	Effect of 2cm Increase
7^0 Electron	6%	12%
5^o Electron (outbending)	8%	16%
20^o Hadron	2%	4%
20^o Photon	2%	4%
$e'K^+P(p^-)$	10% (12% outbending)	20% (24% outbending)
e'Pg	10% (12% outbending)	20% (24% outbending)

Summary: Effect of Changing Cryostat Width

What cryostat dimensions are important?

- cryostat width directly affects dead 'shadow' area

How does this affect drift chamber placement?

- the "region 2" chamber moves out radially

How does this affect forward tracking?

- no effect on resolution or efficiency
- decreases solid angle

à ~ 10 – 12 % loss in solid angle for a 1 cm increase

à approximately linear with size of change

Effect of Reducing B-Field by 25%

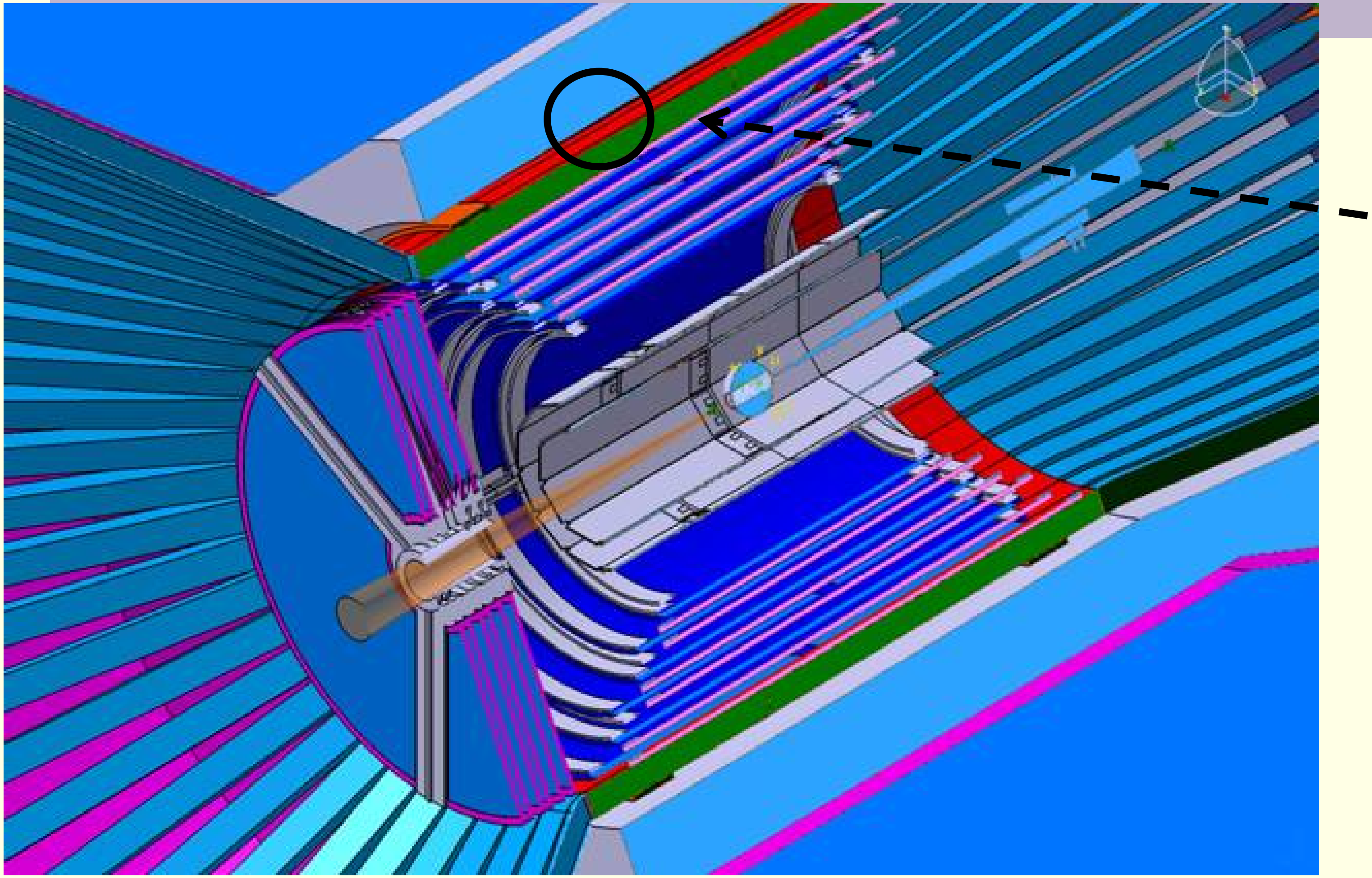
- 25% reduction in B-field increases dp/p by 30% and increases missing-mass resolution

- For an 11 GeV electron beam, total hadronic mass greater than 1.5 GeV, and a p^+N final state with the p^+ detected, the RMS of the mass distribution increases from 18 MeV to 23 MeV

à lower signal to noise ratio, and a worse statistical error.

- Assume S/N 1:1   Statistical error is ~ $\sqrt{S+B}/S$
- 30% increase in signal width will have the same statistical error if the beam time is increased by 15%.

Settling a ‘SpaceWar’



Area of conflict:

CTOF vs. CND

at stake:

4 mm of prime radial space !!

“apples” vs. “oranges”

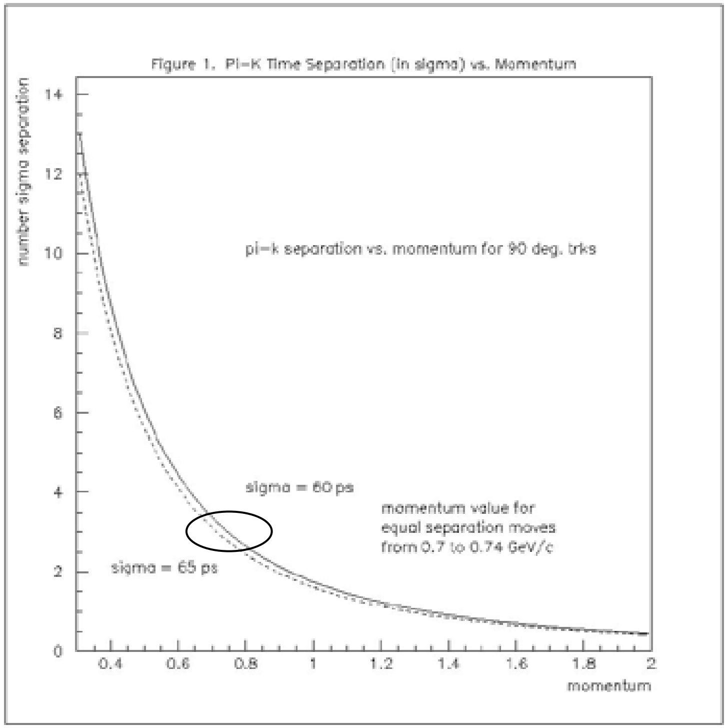
- 4mm thickness at stake
- CTOF ~ 3cm, CND ~ 10CM
- reducing CND by 4mm à lowers neutron efficiency by 4%
- reducing CTOF by 4mm à worsens its timing resolution from 60 to 65 ps

Neither big, but which is worse?

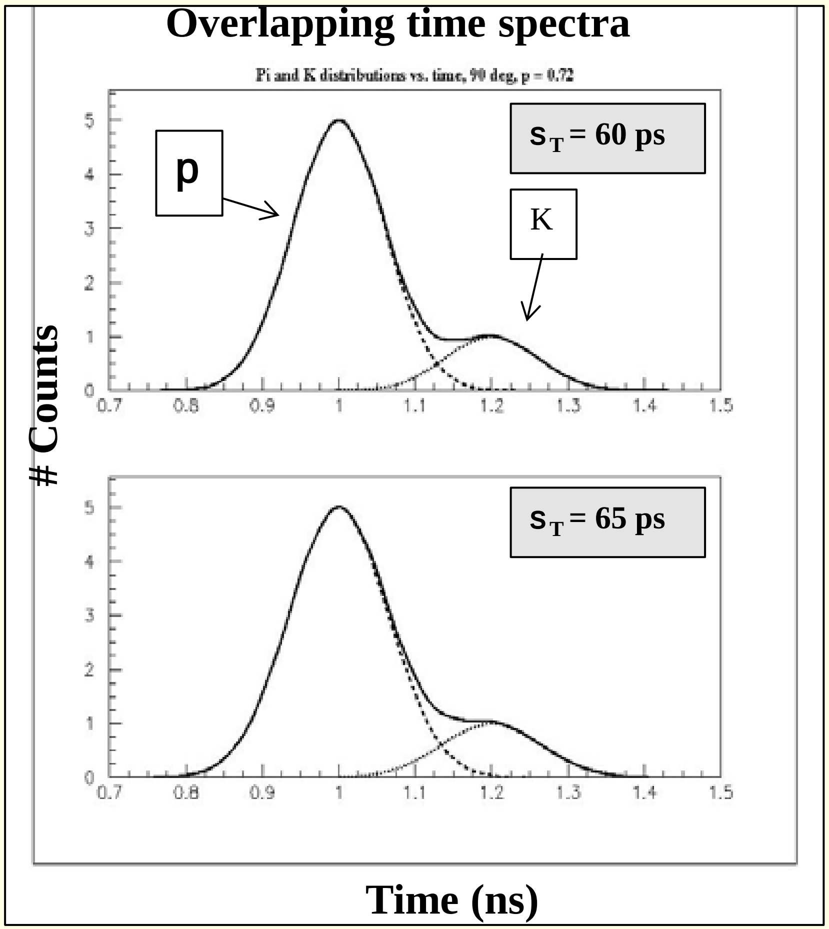
change of resolution à change of momentum range

- How do we analyze an experiment?
  - measure K^+ with p^+/K^+ = 5:1
  - CTOF: 30 cm flight path, 60ps resolution
- 3s separation for 65ps case at .70 GeV/c; moves to .74 GeV/c for 60ps resoltuion

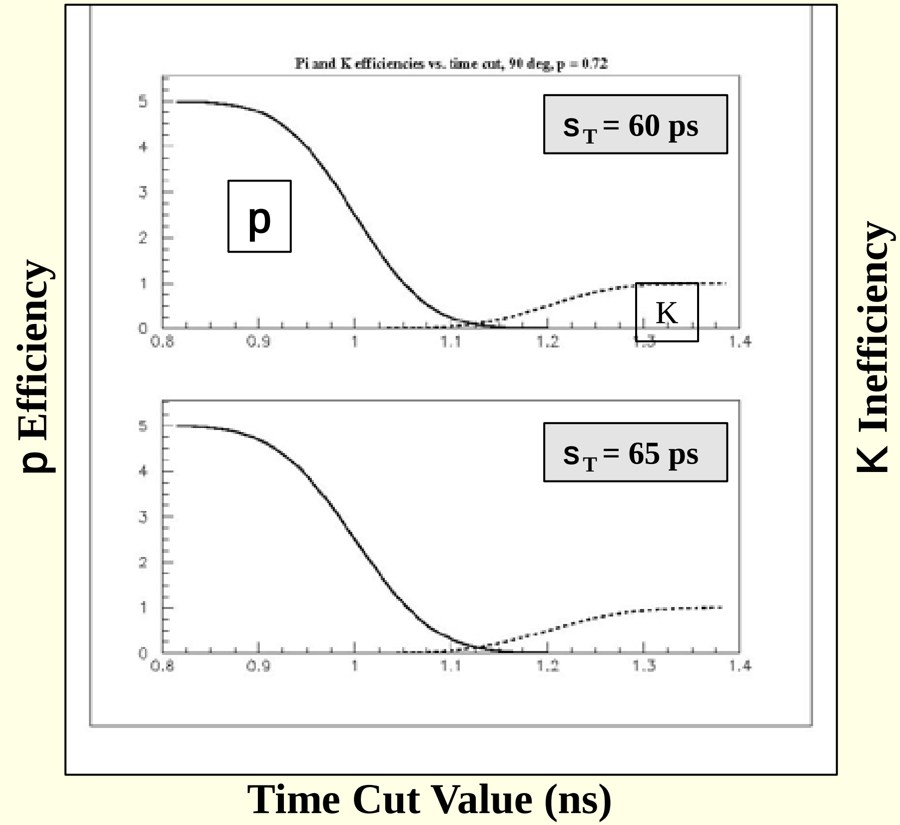
à extended momentum range from .7 to .74



change of resolution à change of efficiency



Integrate spectra to get efficiencies

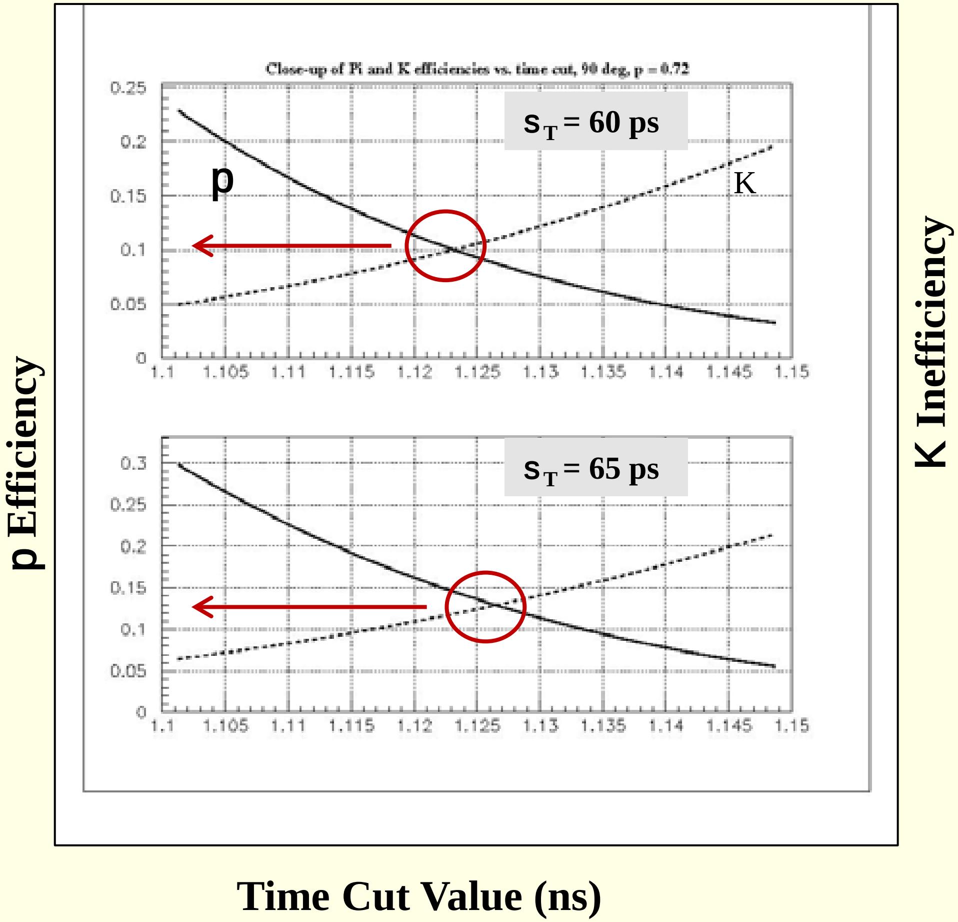


60 à 65 ps; 90 à 84% efficiency

60ps à “10% detector”
For some cut value, we have a 10% background and a 10% inefficiency; 90% efficiency., S/N = 9:1

65ps à “13% detector”
87% efficiency, S/N = 6.7:1

Raise cut to achieve 9:1
à K efficiency drops to 84%

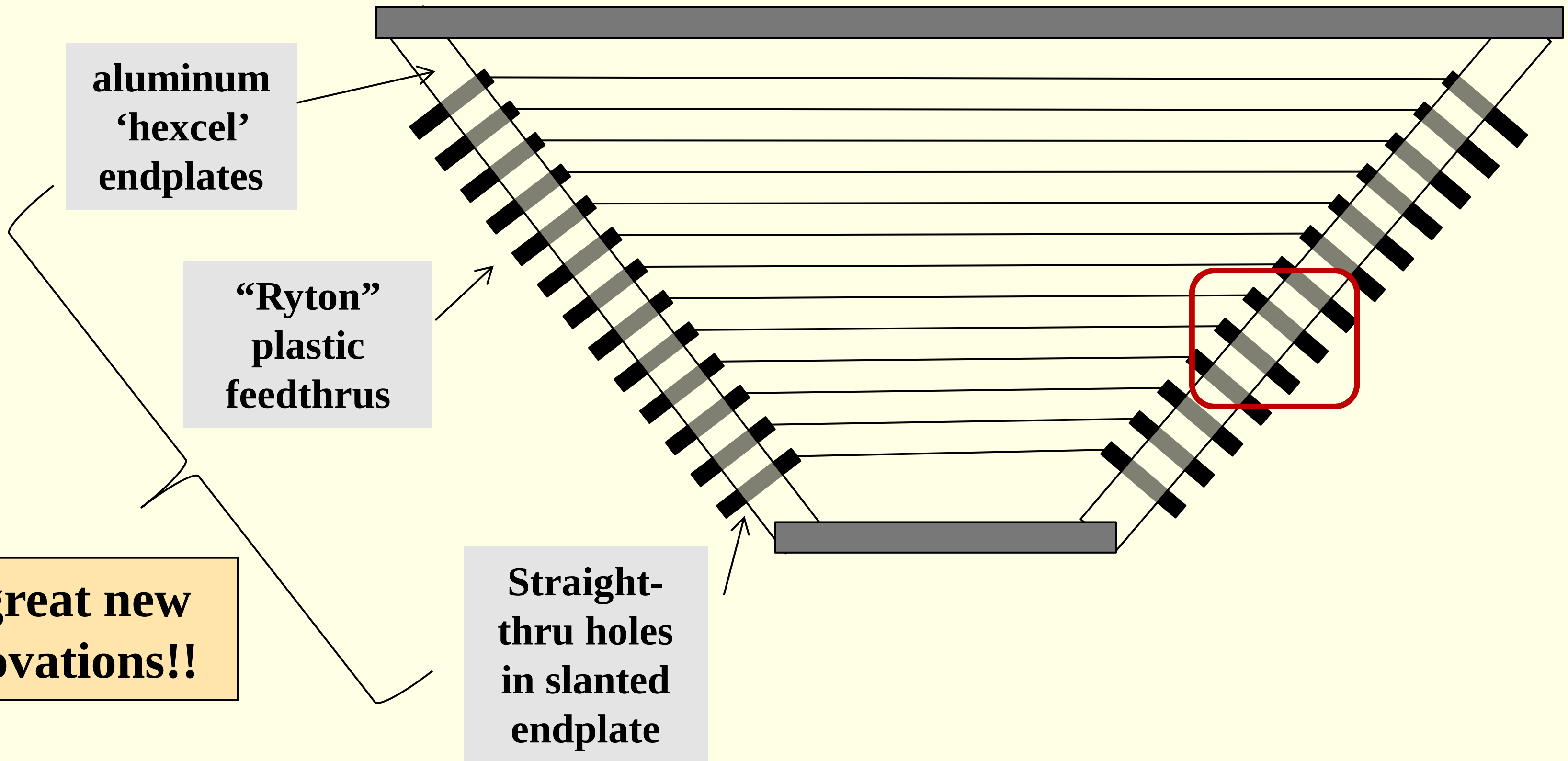


How Do Detectors Fail* ?

- design flaws
- fabrication flaws
- bad environment
  - high background rate
  - electronic noise
  - magnetic field
  - .....

*or fail to work properly

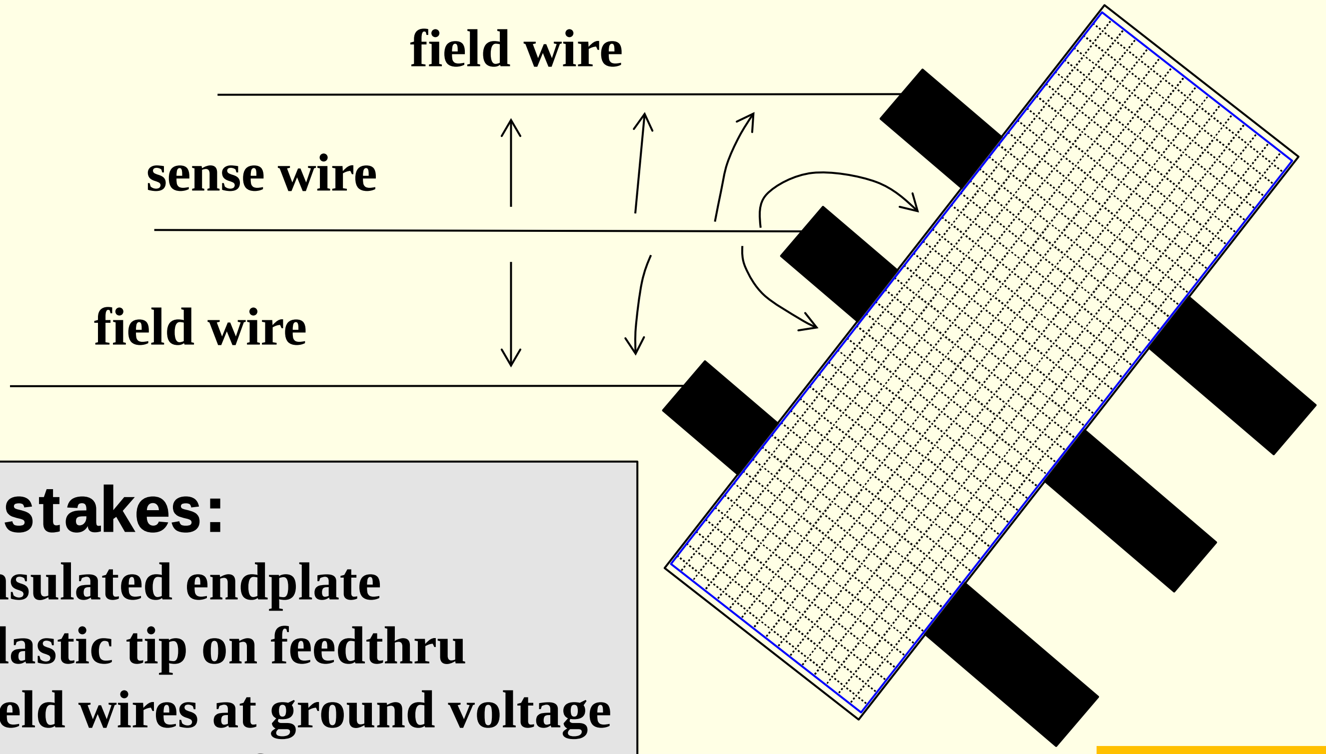
Prototype prototype prototype prototype



all great new innovations!!

The "Large Blue Prototype"

Prototype: reveals design flaws

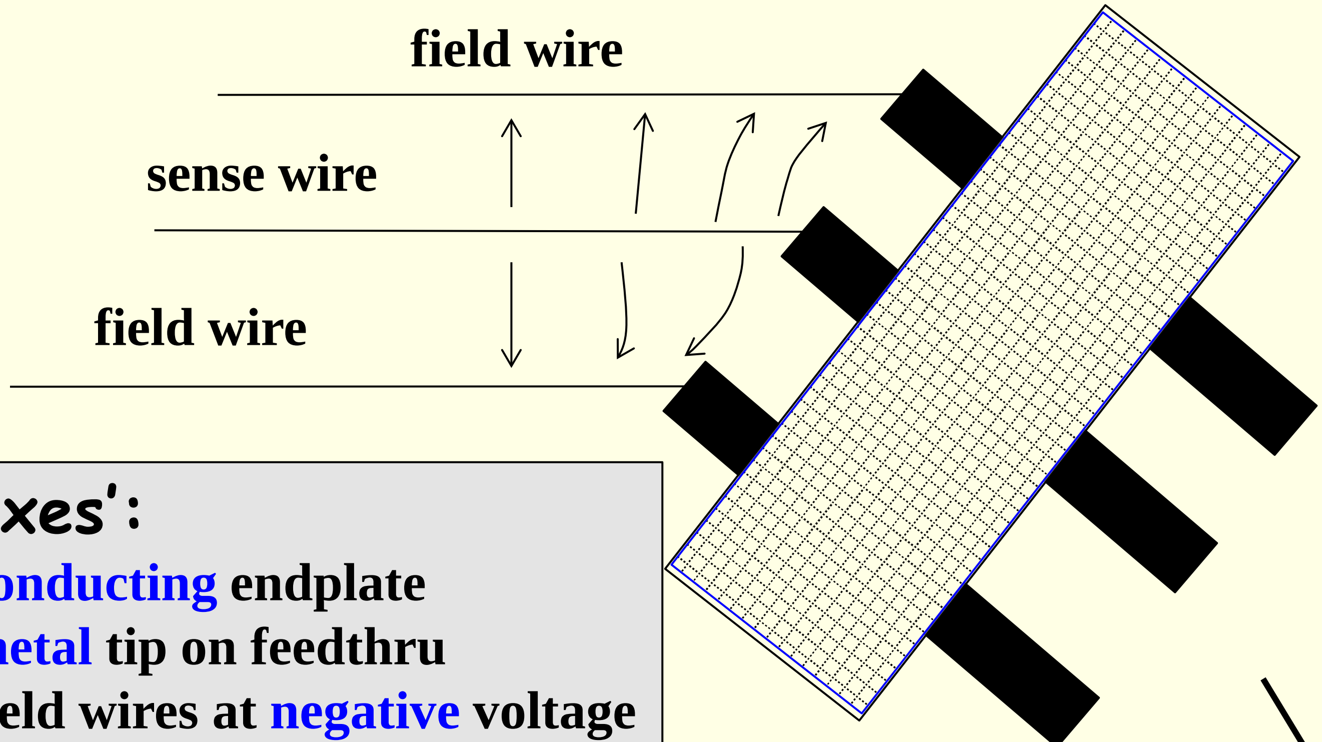


5 mistakes:

1. insulated endplate
2. plastic tip on feedthru
3. field wires at ground voltage
4. bad choice of plastic
5. ran voltage on 'auto-reset'

corona discharge
wire breakage

5 Improvements: Lots of Stress



5 'fixes':

1. **conducting endplate**
2. **metal tip on feedthru**
3. **field wires at negative voltage**
4. **glass-bead loaded plastic**
5. **ran voltage on 'trip-hold'**

Parting Words

When I was a post-doc at U-Chicago, I had a colleague, Carla Grosso-Pilcher. Her 5-year old son, Marco, told her he had done an experiment.

“What did you learn?”, Carla asked.

“Never make the wrong mistake.”

backups

CLAS12 Experiment Characteristics

- electron beam
- small cross-sections (exclusive reactions, Q^2-dep.)
- measure hadronic state
  - reject extra particles (missing mass)
  - other cuts: co-planarity, etc.
- forward-going particles
  - small laboratory angles
- broad coverage in center-of-mass

early GEANT4 ‘sketch’