Compton polarimetry for EIC

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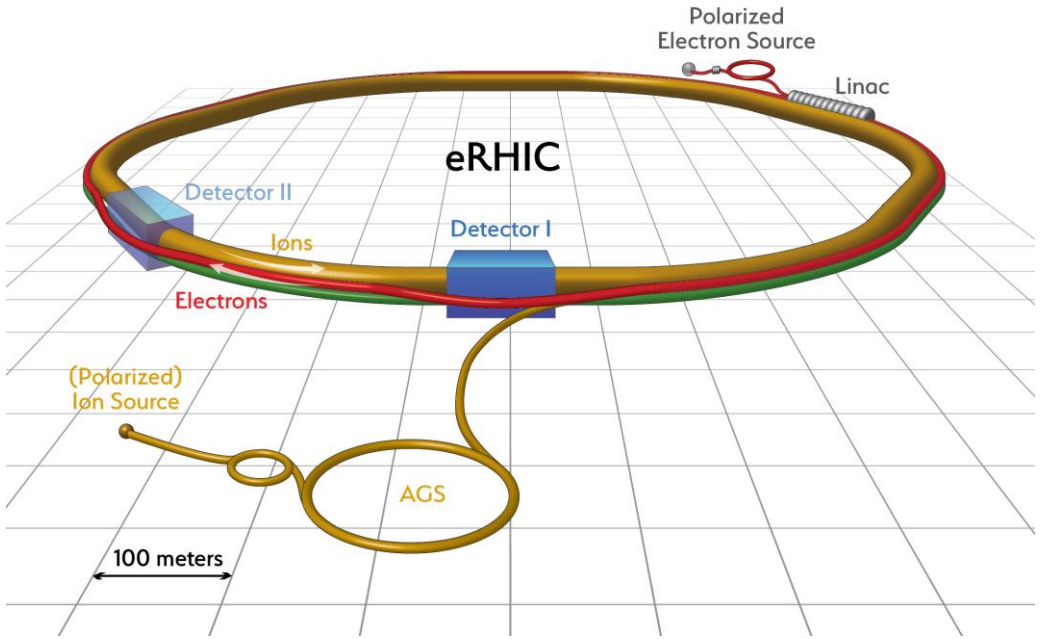
Outline

- eRHIC beam parameters
- Polarized Compton effect
- EIC challenges for polarimeter
- Possible locations
- Compton and background rates
- General requirements
- Photon source
- HERA Polarimeter
- Electron detector
- Photon detector
- IR6
- To do list
- Conclusion

eRHIC



Lower luminosity
560 MHz RF
330 bunches
33 ns between bunches
Electron current up to 1.2A
Ion current up to 0.46 A

High luminosity
560 MHz RF
1320 bunches
10 ns between bunches
Electron current up to 2.4
A
Ion current up to 0.92 A

High luminosity polarized electrons on polarized and unpolarized ions
For electron beam asymmetry measurements polarization can be the dominating error.
Aiming for 1% or better electron polarization accuracy

Main Parameters eRHIC ring-ring for Maximum Luminosity

E_p = 275 GeV, E_e= 10 GeV

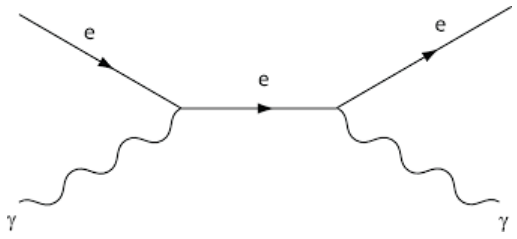
		No Hadron Cooling		Strong Hadron Cooling	
Parameter	**Units**	**Protons**	**Electrons**	Protons	Electrons
Center of Mass Energy	GeV	100		100	
Beam Energy	GeV	275	10	275	10
Particles/bunch	10^{10}	11.6	31	5.6	15.1
Beam Current	mA	456	1253	920	2480
Number of Bunches		330		1320	
Hor. Emittance	nm	17.6	24.4	8.3	24.4
Vertical Emittance	nm	6.76	3.5	3.1	1.7
β_{x*}	cm	94	62	47	16
β_y*	cm	4.2	7.3	2.1	3.7
σ_x'*	mrad	0.137	0.2	0.13	0.39
σ_y'*	mrad	0.401	0.22	0.38	0.21
Beam-Beam ξ_x		0.014	0.084	0.012	0.047
Beam-Beam ξ_y		0.0048	0.075	0.0043	0.084
τ_{IBS} long/hor	hours	10/8	-	4.4/2.0	-
Synchr. Rad Power	MW	-	6.5	-	10
Bunch Length	cm	7	0.3	3.5	0.3
Luminosity	$10^{34}cm^{-2}s^{-1}$	0.29		1.21	

New eRHIC ring ring design : beam interaction frequency going from initial RHIC 10 MHz to 30 MHz with 330 bunches and 100 MHz with 1320 bunches in a 3.8 km ring

Polarized Compton effect

The polarization of the beam can be measured using the Compton effect.

$$\sigma(\vec{e} + \gamma \rightarrow e' + \gamma') \neq \sigma(\overleftarrow{e} + \gamma \rightarrow e' + \gamma')$$

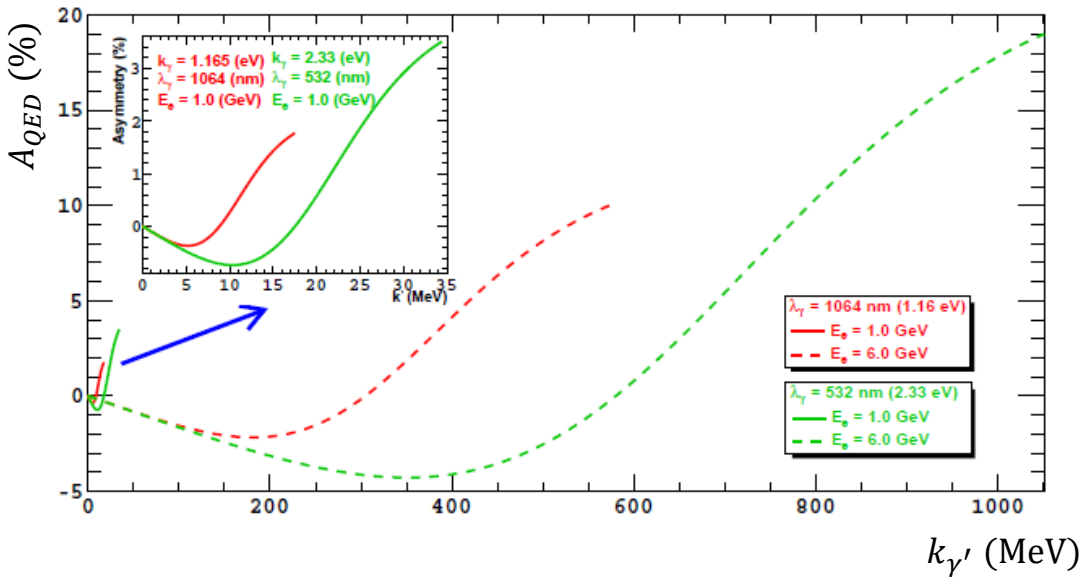


$$A_{EXP} \equiv \frac{N^+ - N^-}{N^+ + N^-} = \boldsymbol{P_e} * P_\gamma * A_{QED}(E_e, k_\gamma, k_{\gamma'})$$

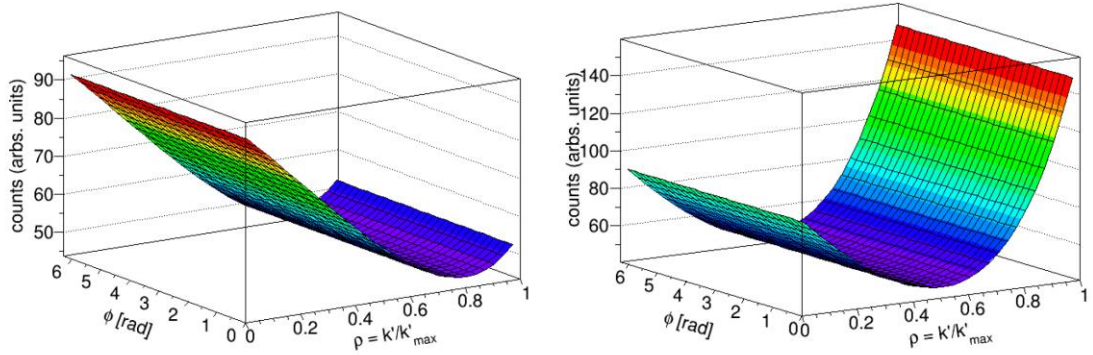
Measured asymmetry

Polarization of the photons (measurable)

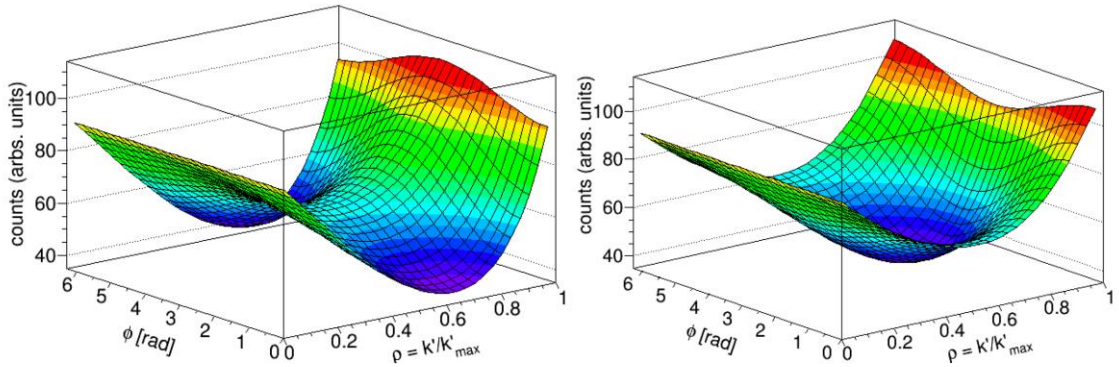
Asymmetry computed using QED



Polarized Compton process



Compton crossection for longitudinally polarized 20 GeV electrons on 2.33 eV photons

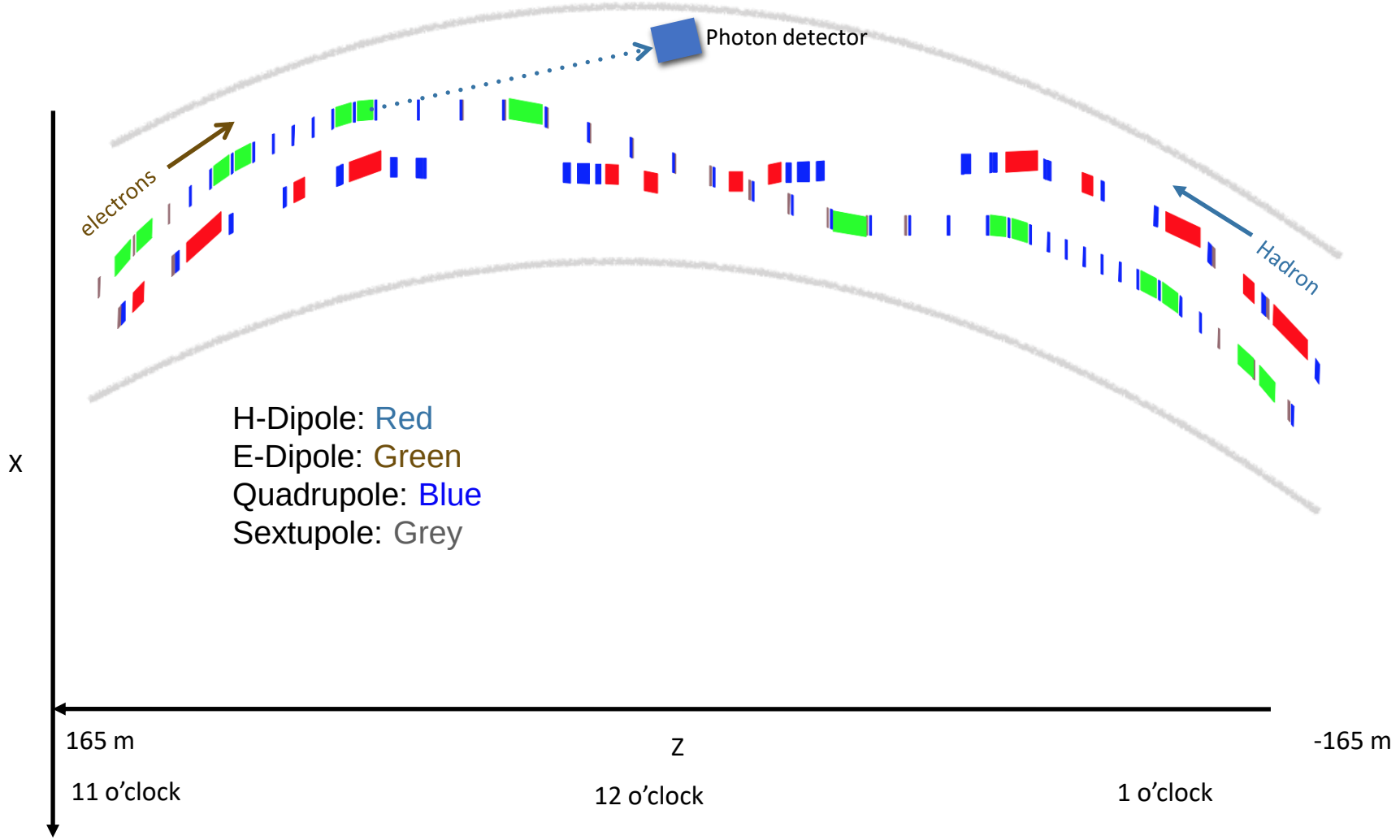


Compton crossection for transversally polarized electrons

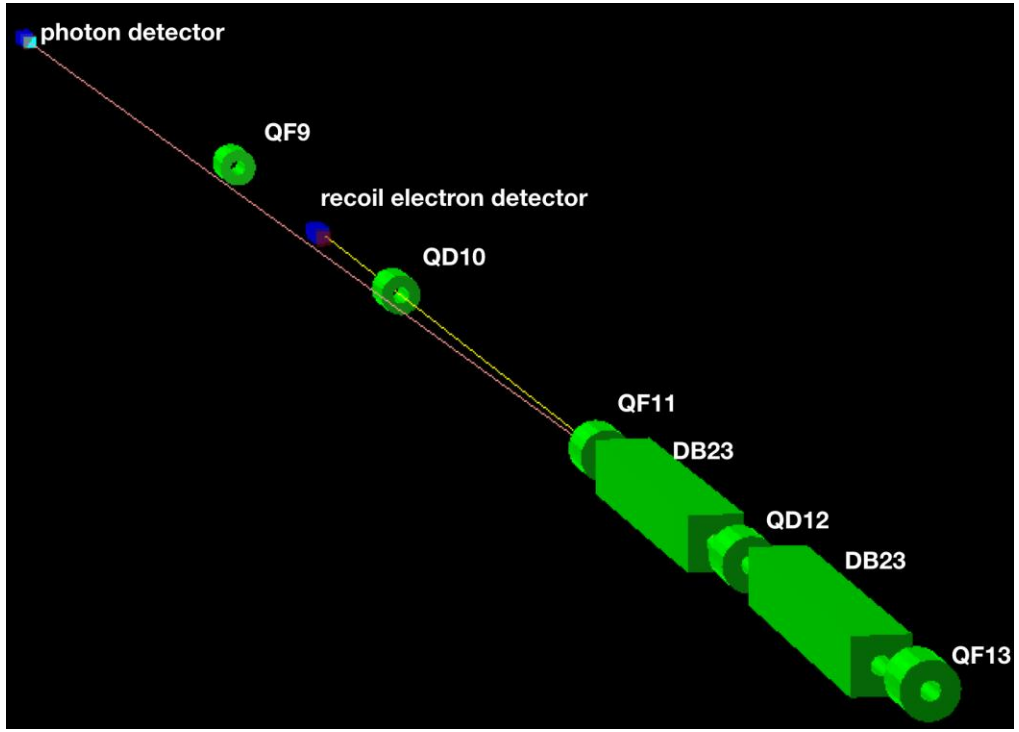
Challenges at EIC

- Large beam current (2.4 A vs 200 uA at JLab)
  - Wakefield power deposit by beam can be significant
  - Synchrotron radiation (more severe than JLab)
  - Background
    - Bremstrahlung
    - Halo
  - Detector radiation hardness
  - Bunch by bunch measurement : detector response better than 10 ns (33 ns) or high segmentation

IR12 layout

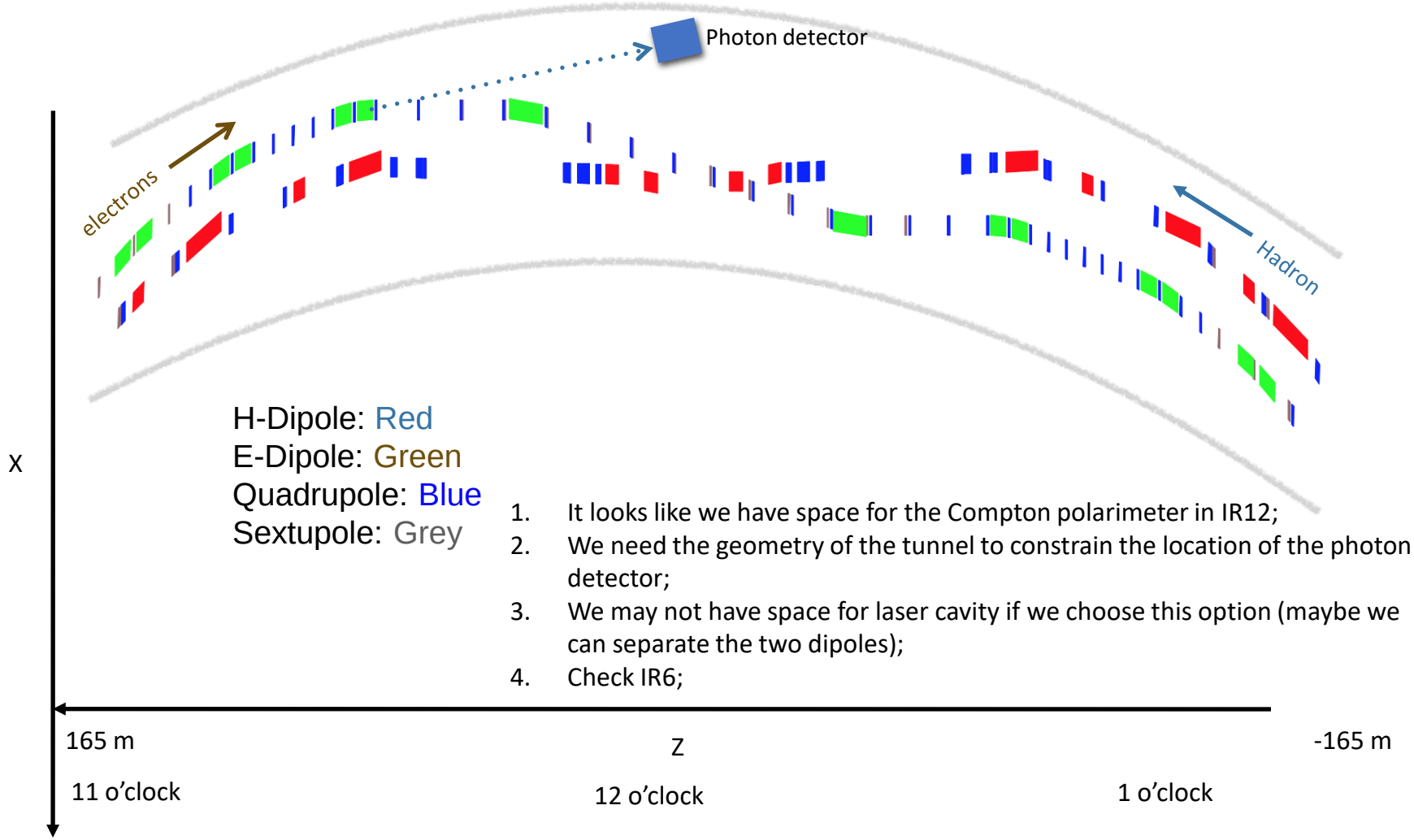

Photon detector
electrons
Hadron
H-Dipole: Red
E-Dipole: Green
Quadrupole: Blue
Sextupole: Grey
X
165 m
Z
-165 m
11 o'clock
12 o'clock
1 o'clock

IR12 layout



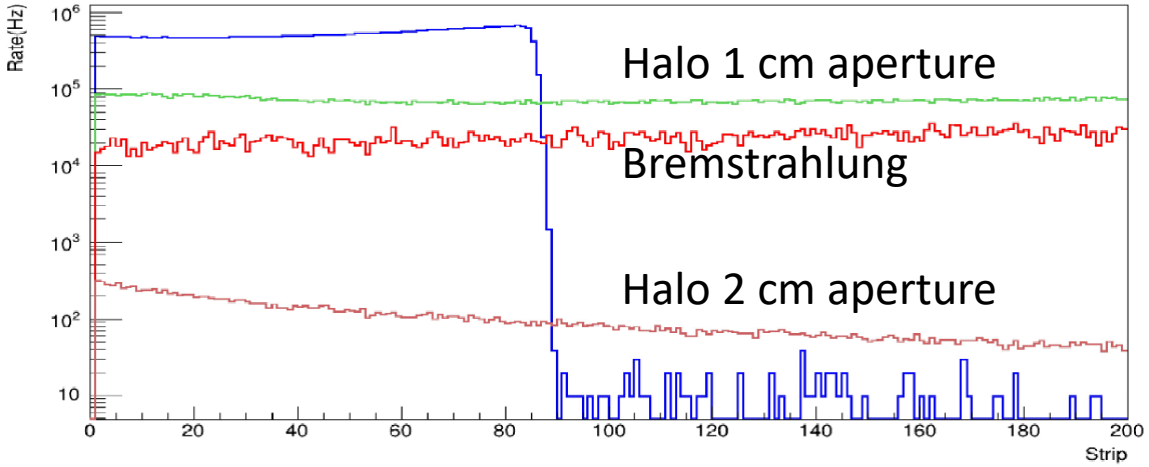
- The interaction portion of Compton scattering is at in IR12, just between the first DB23 and QD12;
- The entrance window of laser is near QF11 and the exit window is near QF13;
- The laser would go through five magnets from QF13 to QF11;
- The scattered photons can’t pass through the magnets if the inner radius is too small;

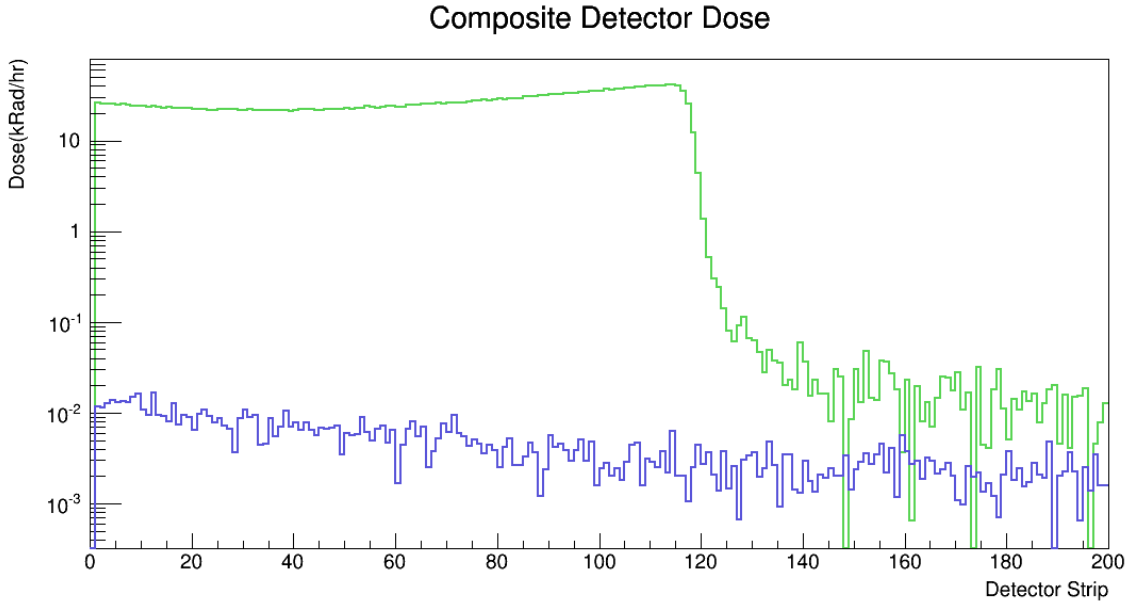
IR12 layout



1. It looks like we have space for the Compton polarimeter in IR12;
2. We need the geometry of the tunnel to constrain the location of the photon detector;
3. We may not have space for laser cavity if we choose this option (maybe we can separate the two dipoles);
4. Check IR6;

Compton Electron Detector Rates





Joshua Hoskins

- 10 W
- 1 A of beam
- Green laser

- Compton and Bremstrahlung assuming 10^{-9} Torr

- Corresponding radiation dose for signal and background

(typical silicon SNR divided by 2 after 1 Mrad
No change for diamond after 2 Mrad from Qweak)

20 krad/hour about 15 Mrad per month : 100 Mrad desired

General detector requirements

- Need to measure both longitudinal and transverse components
- requires highly segmented pre-shower and ECal with good energy resolution for gamma
- highly segmented ECal with good energy resolution and position resolution for recoil electron
- Need to measure bunch-by-bunch polarization
- The measurement precision should be less than 1%
- Compton scattering polarimeter in storage ring (non-interceptive)
- Radiation hardness : Compton crossection large and high beam current

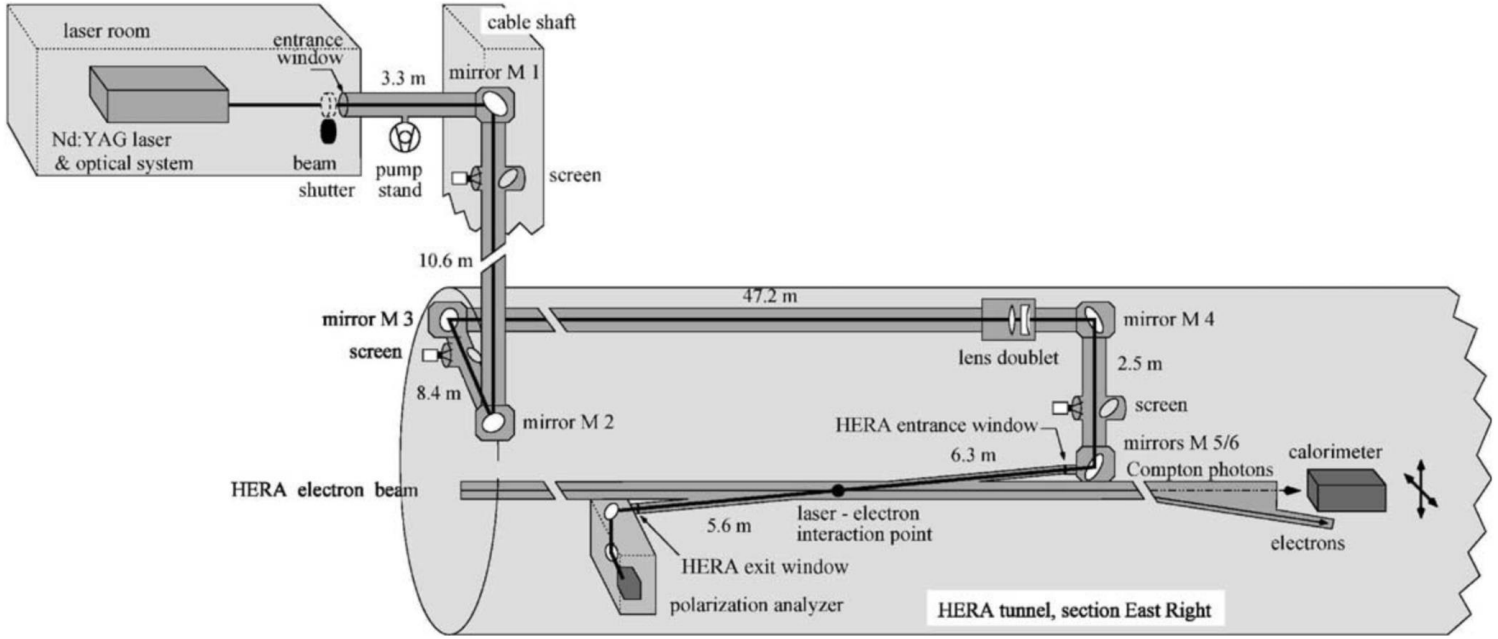
Photon source

- Single shot laser :
  - CW lasers up to a few 100 W
  - RF pulsed laser : increase luminosity per bunch
  - Pro
    - Simple
    - Less space
  - Cons
    - Power limited to a few 100 W

- Perot Fabry
  - CW up at 10 kW
  - RF pulse new RD maximum luminosity
  - Pro : highest energy available
  - Cons:
    - More complex system
    - Take more space
- RF pulsed option at subharmonic of beam structure could reduce timing requirements on detector

Electron polarimeter in HERA

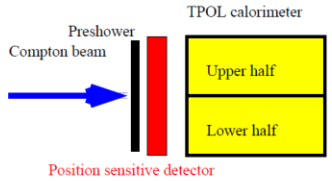
Layout of the Longitudinal Polarimeter in the HERA East section.

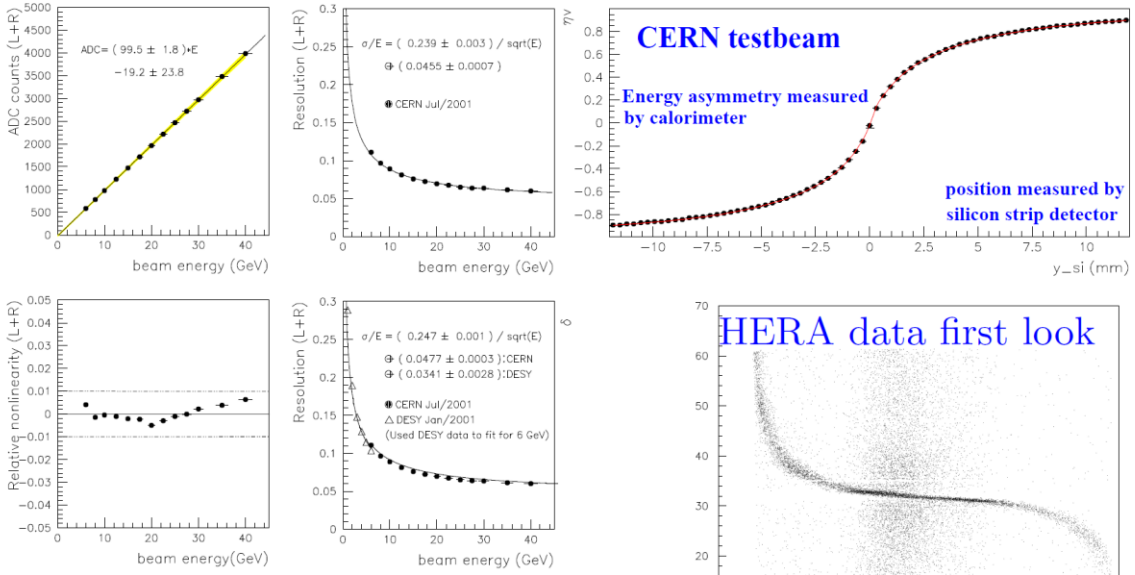


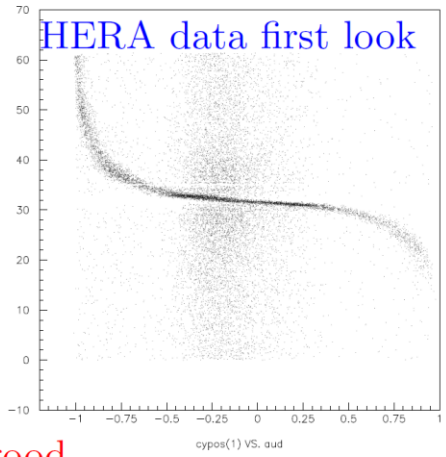
Beckmann M, Borissov A, Brauksiepe S, et al. The longitudinal polarimeter at HERA[J]. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2002, 479(2-3): 334-348.

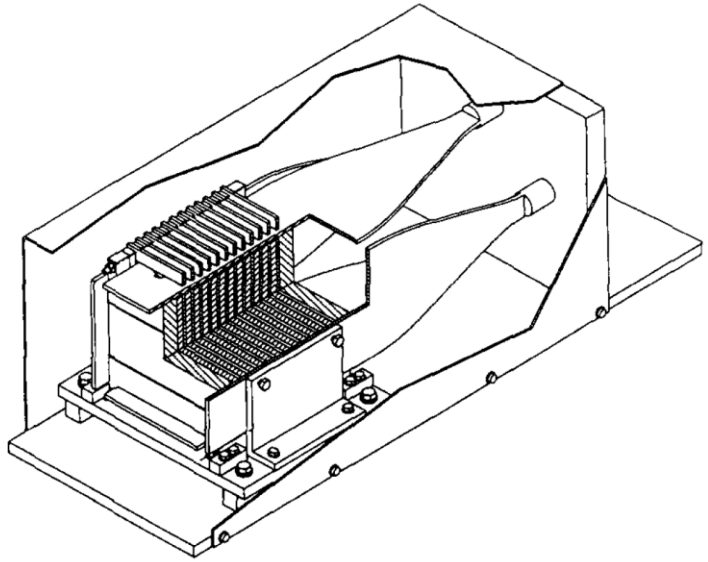
HERA transverse polarimeter

TPOL silicon detector



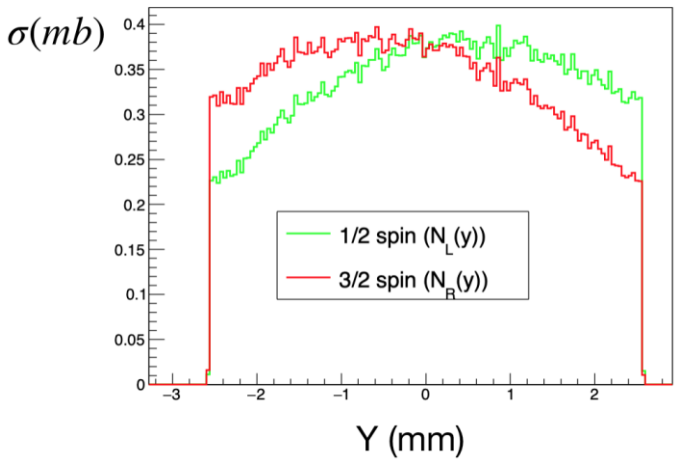


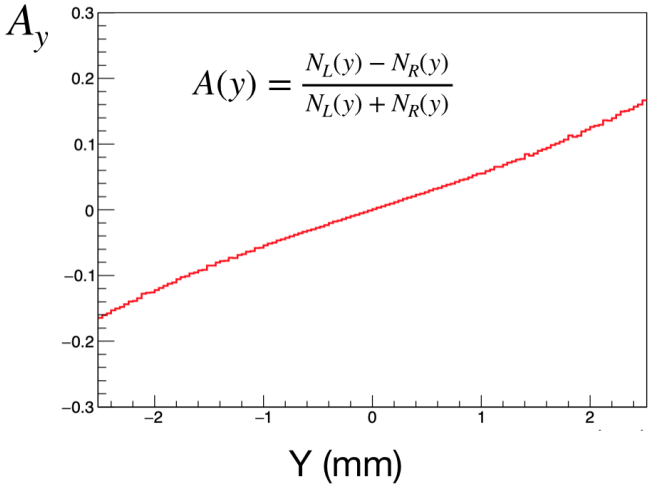




CERN and DESY testbeam results:
Calorimeter response confirmed
$\eta - y$ transformation determined
First results from HERA beam look good

Electron detector options



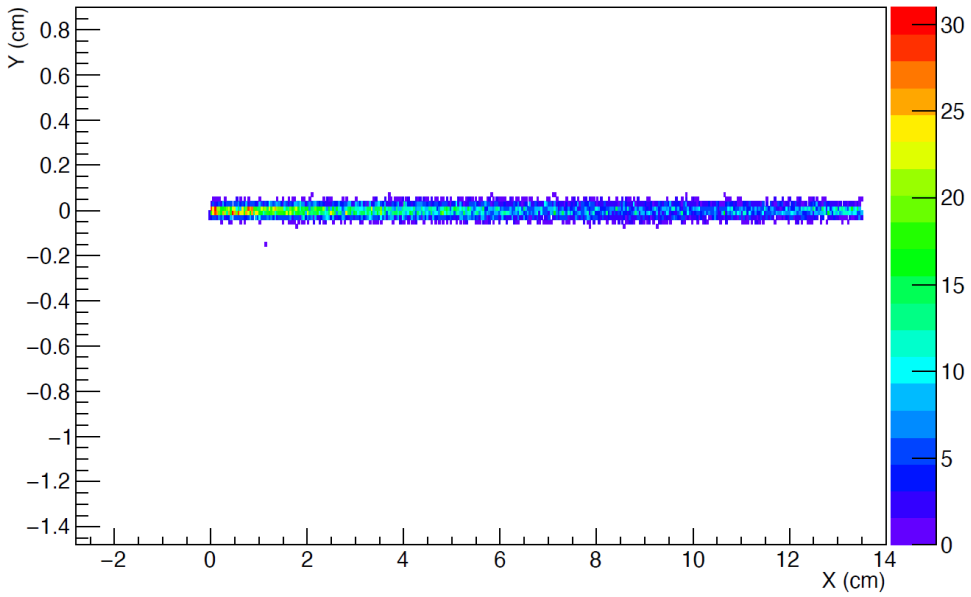


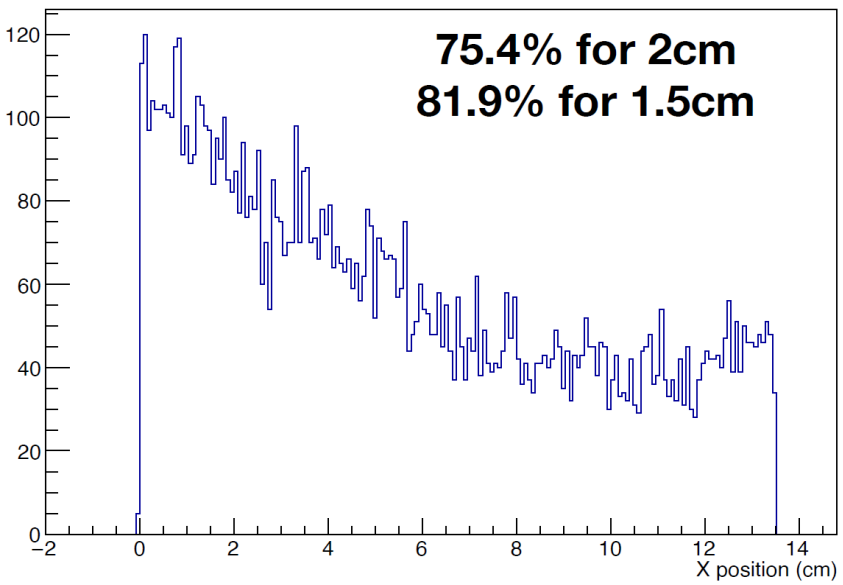
- **Tracking detector most likely in vacuum**
  - **Diamond detector : at least 10 Mrad radiation hardess**
  - **MAPS : good timing resolution, can be highly pixelized, need to determine radiation hardness but better than regular silicon since thinner**
  - **GEM : detectors if outside from vacuum or in Roman pot**
- Most likely need cooling at 1 kW to 100 W level for energy deposited by beam

- **Same requirements for calorimeter as photon with caveat needs to be as close to electron beam as possible**

Position of Compton electrons

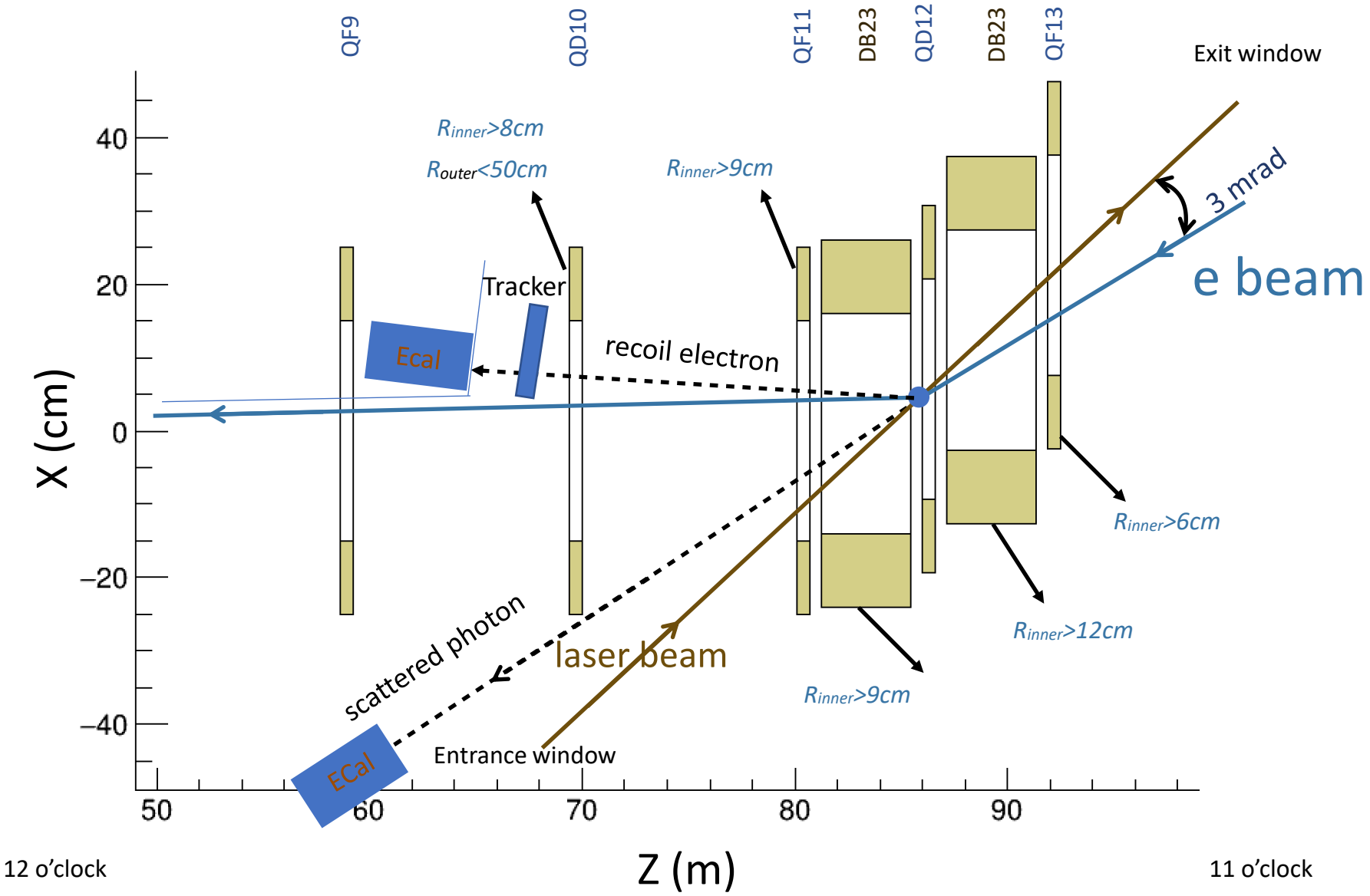
Beam parameters for recoil electron detector:
BetaX = 40m; emittanceX = 24nm;
SigmaX = 970 um;
15*sigmaX = 1.45 cm;





Zhengqiao Zhang

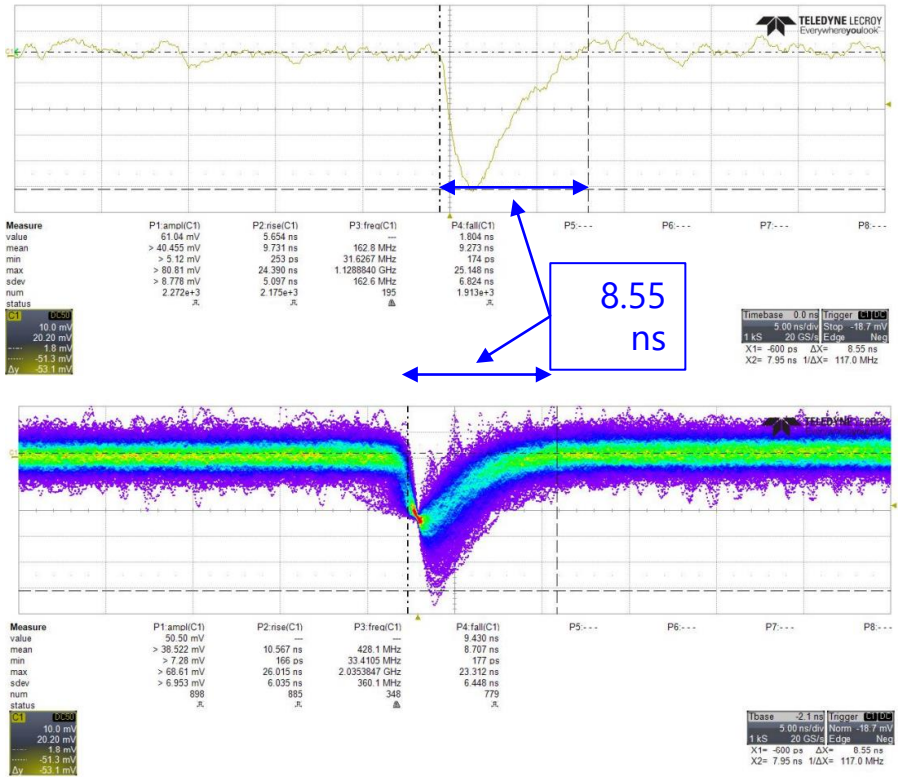
Large dispersion up to 13 cm : exit window possible

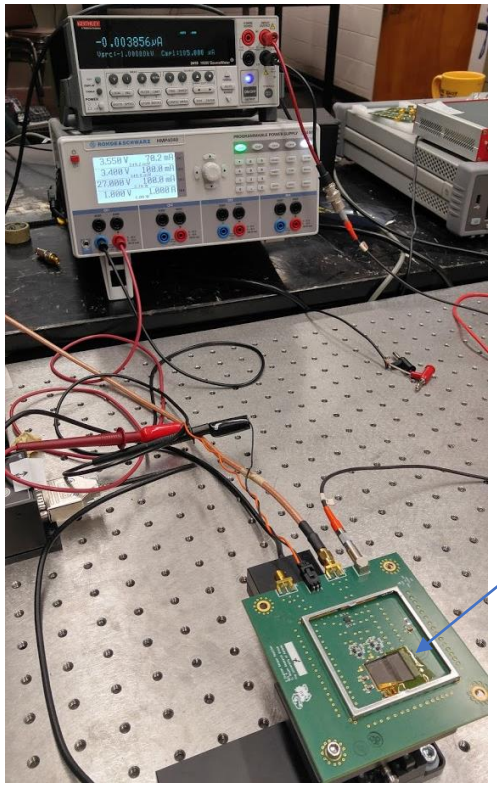


12 o'clock

11 o'clock

Diamond detector



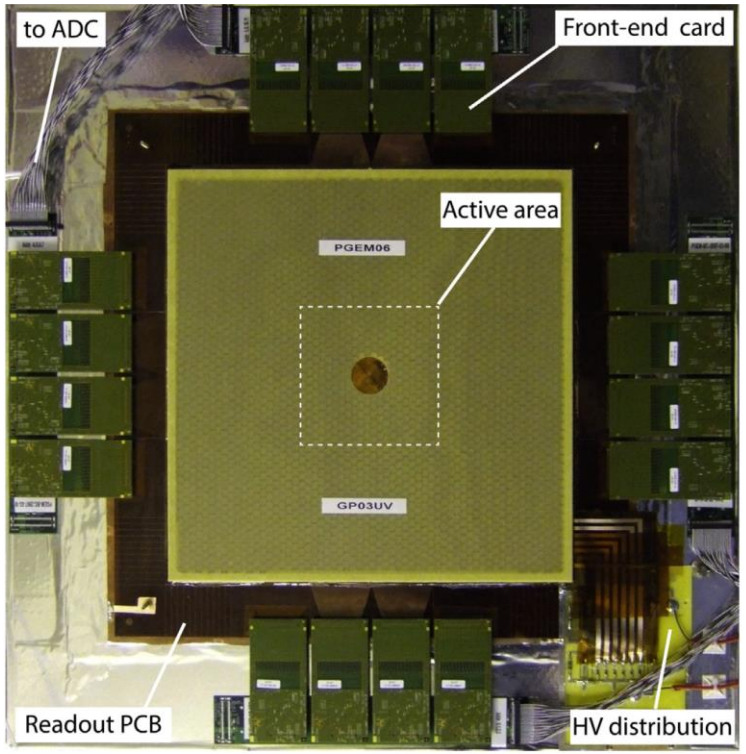


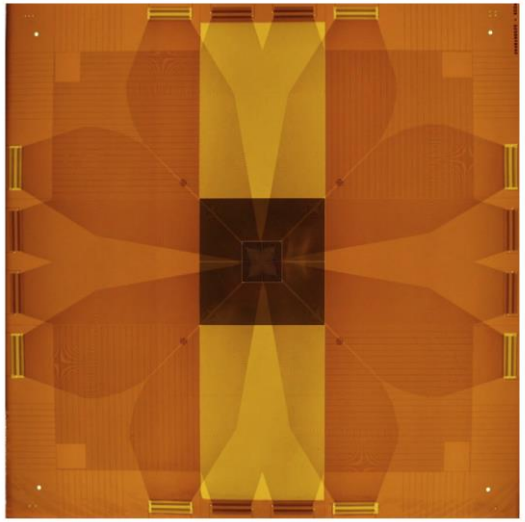
500 µm pcCVD diamond

- Fast 9 ns pulses
- Radiation hardness better than 2 Mrad
- Need preamplifier close from detector (might be issue for high density pixels)
- Can work in vacuum

MGPDs trackers

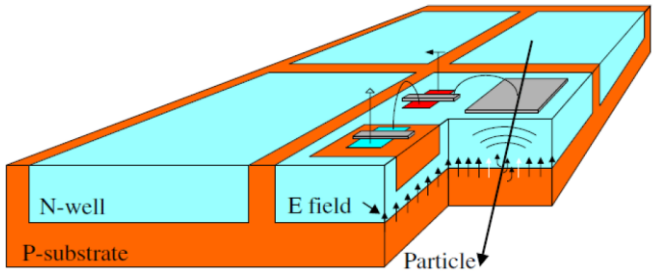
- Gaseous detector with separate drift space, amplification and readout
- Cost moderate
- Rather slow / long pulses
- Some R&D for small gap faster detector
- Might be ok with high granularity or low duty cycle of laser
- Radiations hardness mostly depends on total charge deposited in detector
- Most likely works better in atmospheric pressure outside from vacuum

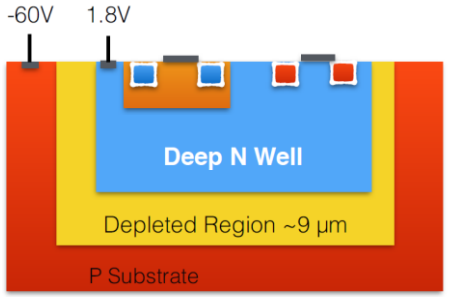


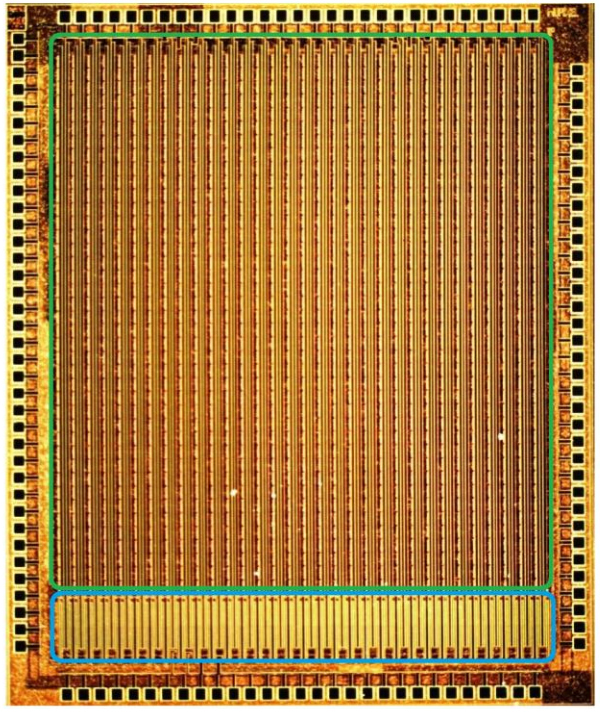


COMPASS Pixelated GEM

HV MAPS





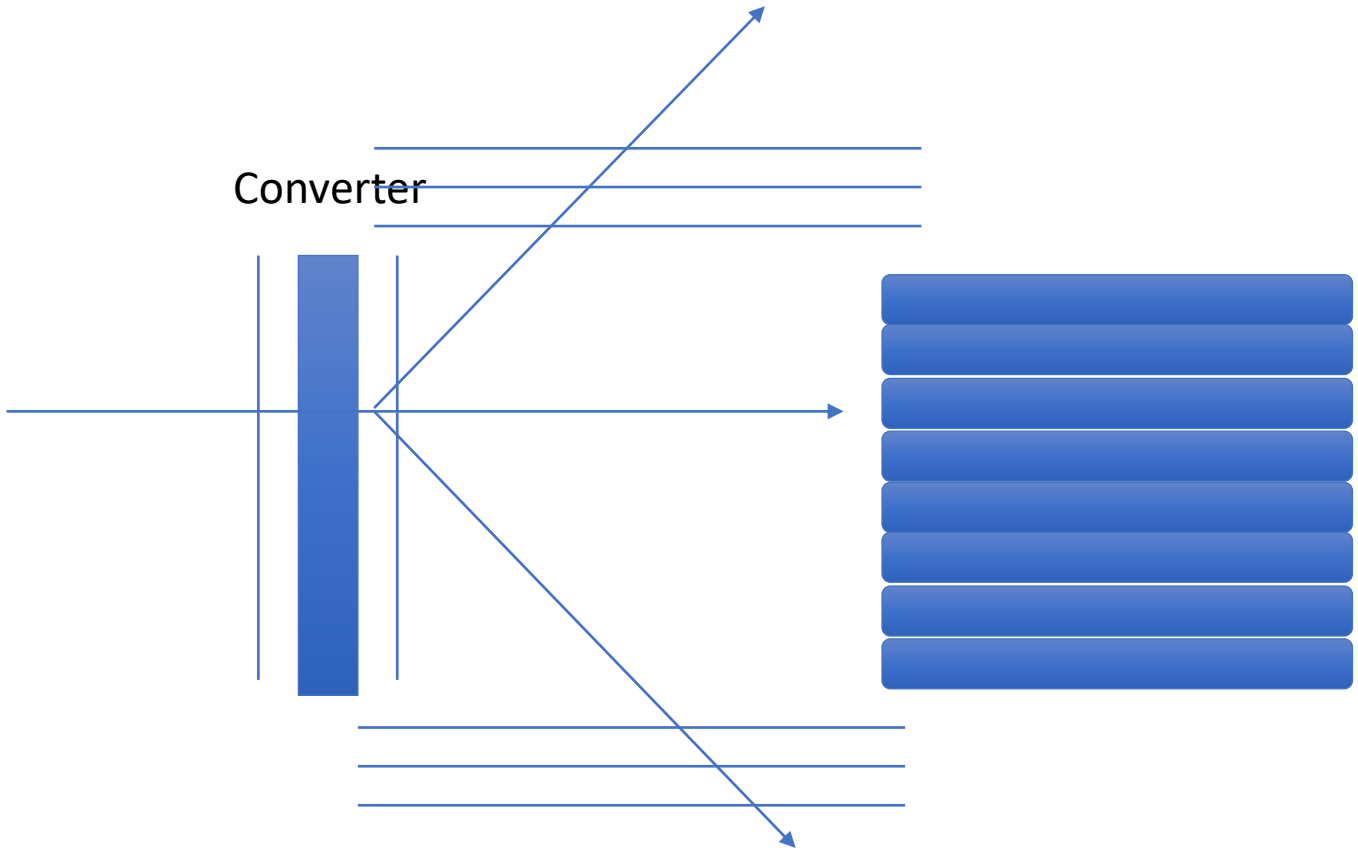


32x40 pixels Mupix4

- Pixellized detector MuPix for Mu3e
- 80 um x 80 um x 50 um
- Electronics in integrated with pixel (amplification and readout)
- Being investigated by University of Manitoba
- Timing resolution around 16 ns
- 380 Mrad radiation hardness
- Should work in vacuum
- Might work at low temperature

Photon detection

- Pair spectrometer



- Segmented calorimeter

- Trackers : GEM or MAPS

Photon detector options

- **Need energy resolution and position resolution**
- **Photon detection**
- **Most like outside from beamline**

- **Preradiator**
  - **Pixellized detector**
    - **GEM**
    - **MAPS**

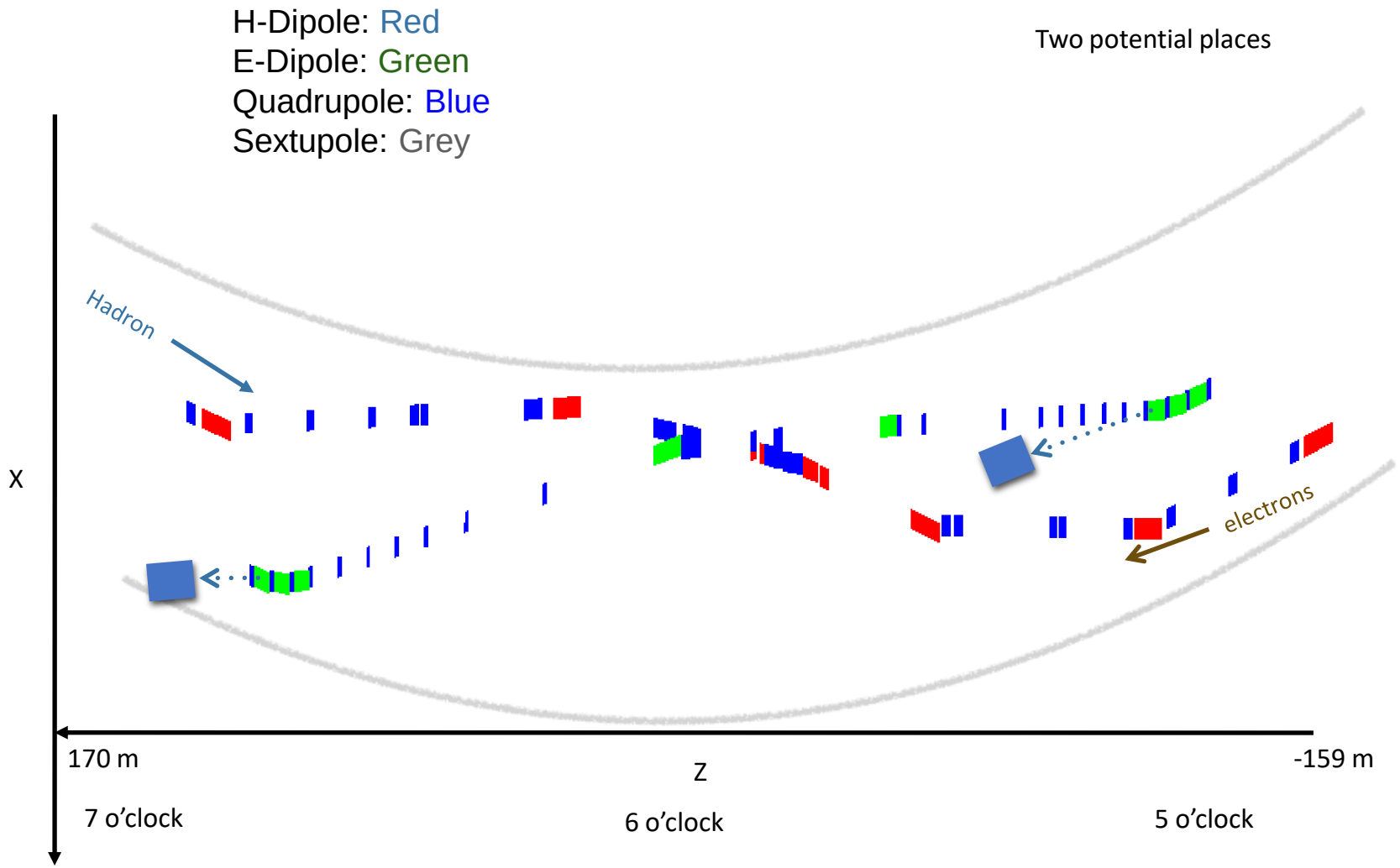
- Calorimeter technologies
  - **Fast Crystals :**
    - **PbWO4**
    - **PbF2**
  - **Sampling calorimeters (more radiation hard – worse energy resolution)**
    - **Shashlyk**
    - **SciFi**
    - **Quartz fiber**
  - **Photon readout**
    - **PMT : fine meshed PMT**
    - **MCP : PMTs**
    - **APDs**

Calorimeter properties

Material	Density g/cm^3	X_0 cm	R_M cm	λ_I cm	Refr. index	τ ns	Peak λ nm	Light yield	$\frac{N_{p.e.}}{GeV}$	rad	$\frac{\sigma E}{E}$
Crystals											
NaI(Tl)**	3.67	2.59	4.5	41.4	1.85	250	410	1.00	10^6	10^2	$1.5\%/E^{1/4}$
CsI *	4.53	1.85	3.8	36.5	1.80	30	420	0.05	10^4	10^4	$2.0\%/E^{1/2}$
CsI(Tl)*	4.53	1.85	3.8	36.5	1.80	1200	550	0.40	10^6	10^3	$1.5\%/E^{1/2}$
BGO	7.13	1.12	2.4	22.0	2.20	300	480	0.15	10^5	10^3	$2.\%/E^{1/2}$
$PbWO_4$	8.28	0.89	2.2	22.4	2.30	5/39%	420	0.013	10^4	10^6	$2.0\%/E^{1/2}$
LSO	7.40	1.14	2.3		1.81	15/60% 100/01% 40	440 440	0.7	10^6	10^6	$1.5\%/E^{1/2}$
PbF_2	7.77	0.93	2.2		1.82	Cher	Cher	0.001	10^3	10^6	$3.5\%/E^{1/2}$
Lead glass											
TF1	3.86	2.74	4.7		1.647	Cher	Cher	0.001	10^3	10^3	$5.0\%/E^{1/2}$
SF-5	4.08	2.54	4.3	21.4	1.673	Cher	Cher	0.001	10^3	10^3	$5.0\%/E^{1/2}$
SF57	5.51	1.54	2.6		1.89	Cher	Cher	0.001	10^3	10^3	$5.0\%/E^{1/2}$
Sampling: lead/scintillator											
SPACAL	5.0	1.6				5	425	0.3	$2 \cdot 10^4$	10^6	$6.0\%/E^{1/2}$
Shashlyk	5.0	1.6				5	425	0.3	10^3	10^6	$10.\%/E^{1/2}$
Shashlyk(K)	2.8	3.5	6.0			5	425	0.3	$4 \cdot 10^5$	10^5	$3.5\%/E^{1/2}$

* - hygroscopic

New IR6 layout



To do list

- Electron detection
  - Beam pipe / window design : evaluate beam deposit from beam
  - Calorimeter position
  - Is close Electron detector needed ?
  - Backgrounds : synchrotron / Brehmstrahlung
  - Effect of magnet optics on polarization extraction

- Photon detection
  - synchrotron / Brehmstrahlung
  - Effect of resolution on polarization extraction
  - Rates in detector : single / multiphotons, integrated measurement
  - Radiation damage

- Investigate IR6 location

Conclusion

- Location for transverse polarimeter found in IR12
- Detector technologies need to be investigated :
  - Detector response (might need up to 10 ns)
  - Radiation harness to be able to run several months at least
  - Position resolution for transverse polarimetry
  - Energy resolution for transverse and longitudinal polarimetry
- Need to determine IP accuracy with spin rotation
- Potential location at IP being investigates
- More studies on going: beam energy deposit, backgrounds in photon and electron detector