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JLEIC Interaction Region working group:

Latifa Elouadrhiri: JLab physics
Marcy Stutzman: JLab accelerator
Andrey Kim: UConn physics
Kyungseon Joo: UConn physics
Charles Hyde: ODU physics
Mike Sullivan: SLAC physics
Vitaly Baturin: ODU physics
Pavel Degtiarenko: RadCon
Vasiliy Morozov: JLab accelerator
Yulia Furletova: JLab physics
Youri Sharabian: JLab physics
Frank Marhauser: JLab RF
Christine Ploen: ODU physics
Mark Wiseman: JLab engineering
Nick Markov: JLab physics

Group Research Goals

- **Background Studies** (synchrotron radiation and neutron fluence)

  and the Impact on the Interaction Region and **Detector design.**

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Vitaly Baturin

Joined JLEIC IR Group on April 2019.

Supervisor: Charles Hyde (ODU).

Research filed: Experimental Nuclear & Particle physics.

Brief History:

PNPI(St.Petersburg Russia)	- Experiments on pA- and πA- interactions. Reverse electroproduction of pions and Muon Catalized fusion.
PSI	- Experiments on Muon Catalized Fusion and R&D.
INFN	- R&D for Vertex Straw Detector for KLOE.
Penn State University/BNL	- E850 Color Transparency and SRC experiments, Straw Tube Detector Upgrade.
KNU(S.Korea)/Jlab	- Central Time of Flight Detector construction and R&D.

Previous employment: Jefferson LAB,

Current time employer: ODU Research Foundation since April 2019.

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Outline. Simulations of:

1. Synchrotron Radiation

Motivation:

- About **10 KW** of **Synchrotron Radiation** generated in beam line **magnets**
  passes **through Interaction Point.**
- Radiation has a **strong impact** on **Vertex Tracker** and **Beam Pipe design**.

2. Neutron Background

- Neutron fluence Impacts **lifetime** of critical **components,**
  dark currents in Si sensors , trackers, and SiPMs.
- Design of **beam optics** and detectors **depends** critically **on backgrounds**.
  Current effort is JLEIC-centric. Future effort will port to eRHIC design.

I. Simulation of Synchrotron Radiation.

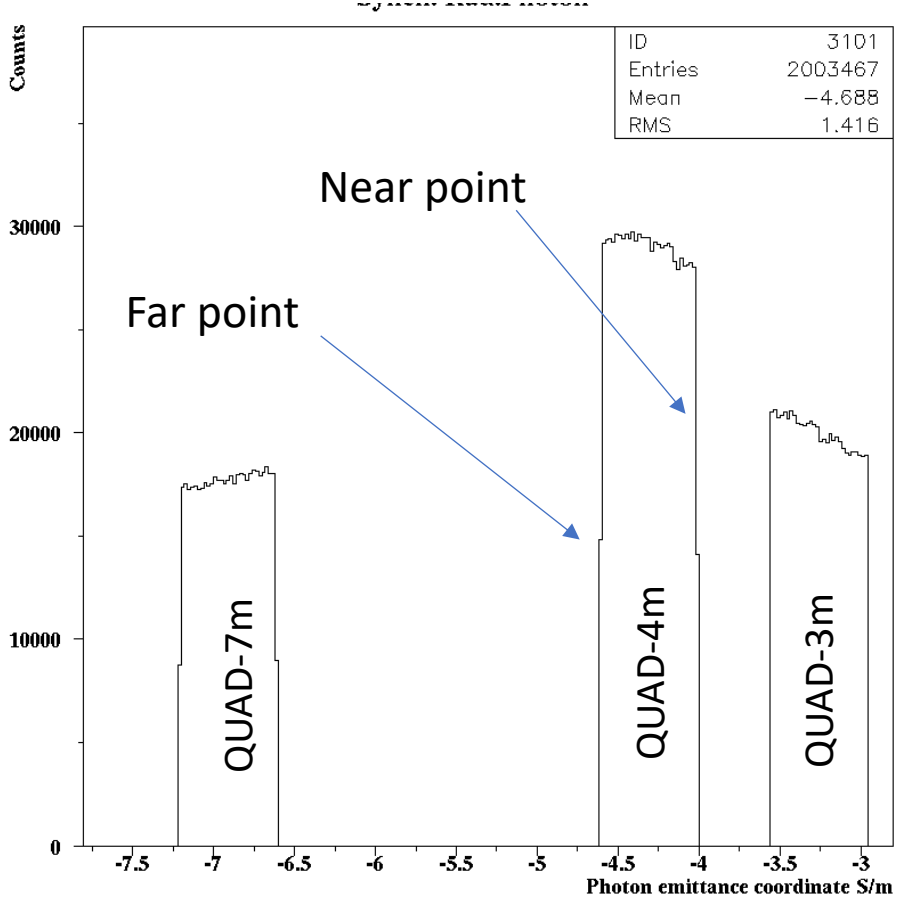
- Synchrotron Radiation code **SYNC_BKG.FOR** in continuous development since origin in 1980 at SLAC.
- This code performs **analytic calculation** of Synchrotron **Radiation** fluxes **from magnets**.
- Input information is **Array of Magnets specified** in terms specific for **Beam Line Optics**.
- Code ported to JLAB in cooperation with Mike Sullivan (SLAC).
- Modified code **(SYRAD) converts** Radiation to **flux of photons**

  suitable **for** GEANT4 detector **simulations**.

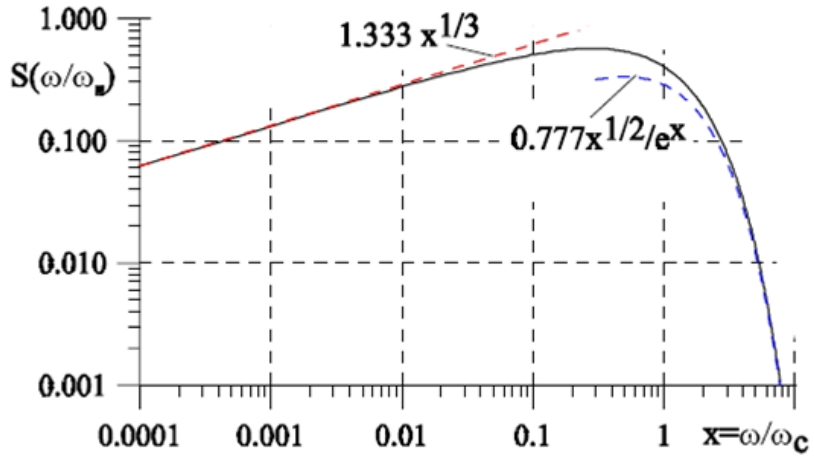
Example: S-profile of SR Photons.

- **Photon emission coordinates** along beam **(S)** are **randomized** between Far- & Near points given by SYRAD for each Quad.

$$\theta_c \simeq \frac{1}{\gamma}\left(\frac{2\omega_c}{\omega}\right)^{1/3}$$

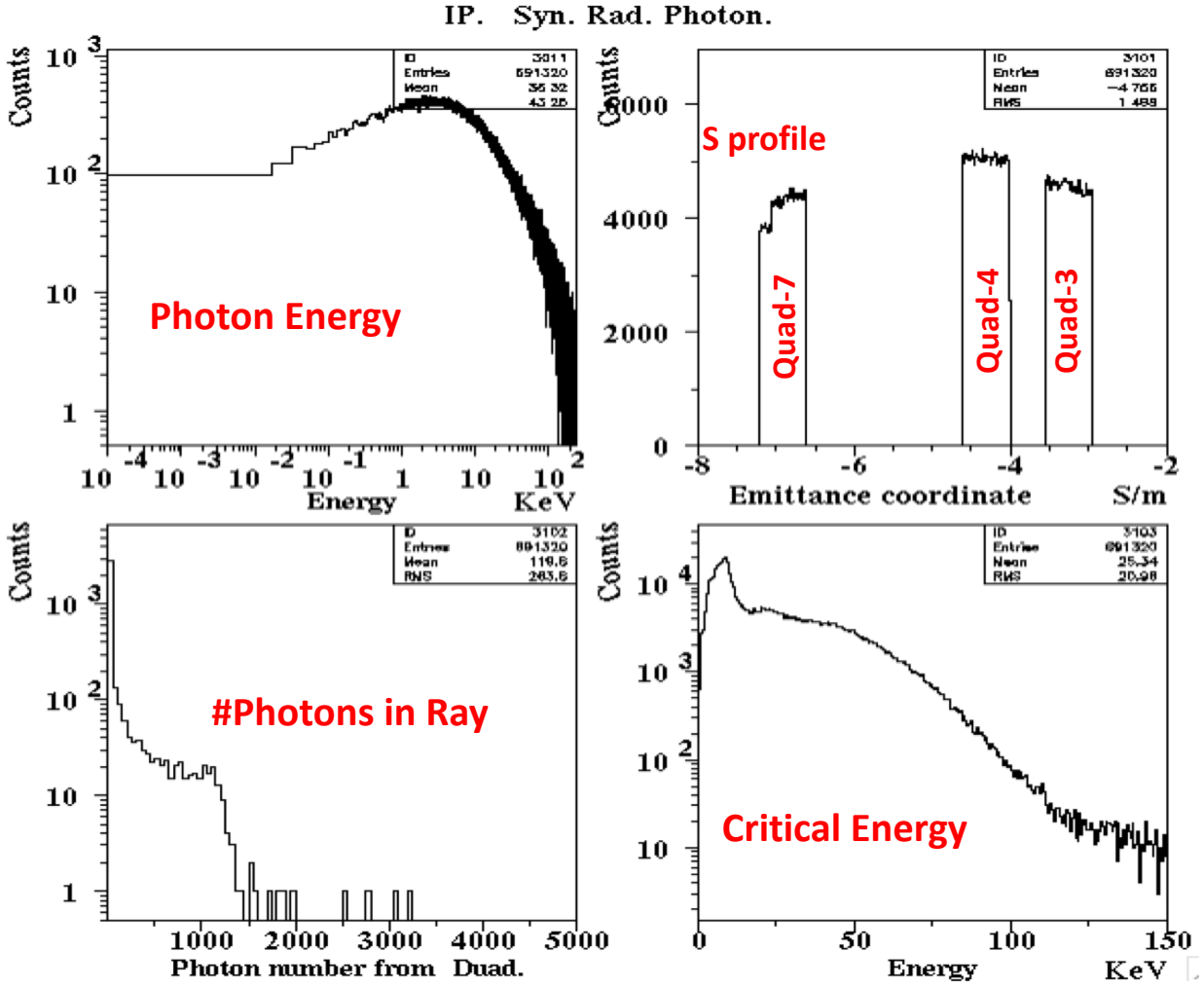


$$\omega_c = \frac{3}{2}\frac{c}{\rho}\gamma^3$$



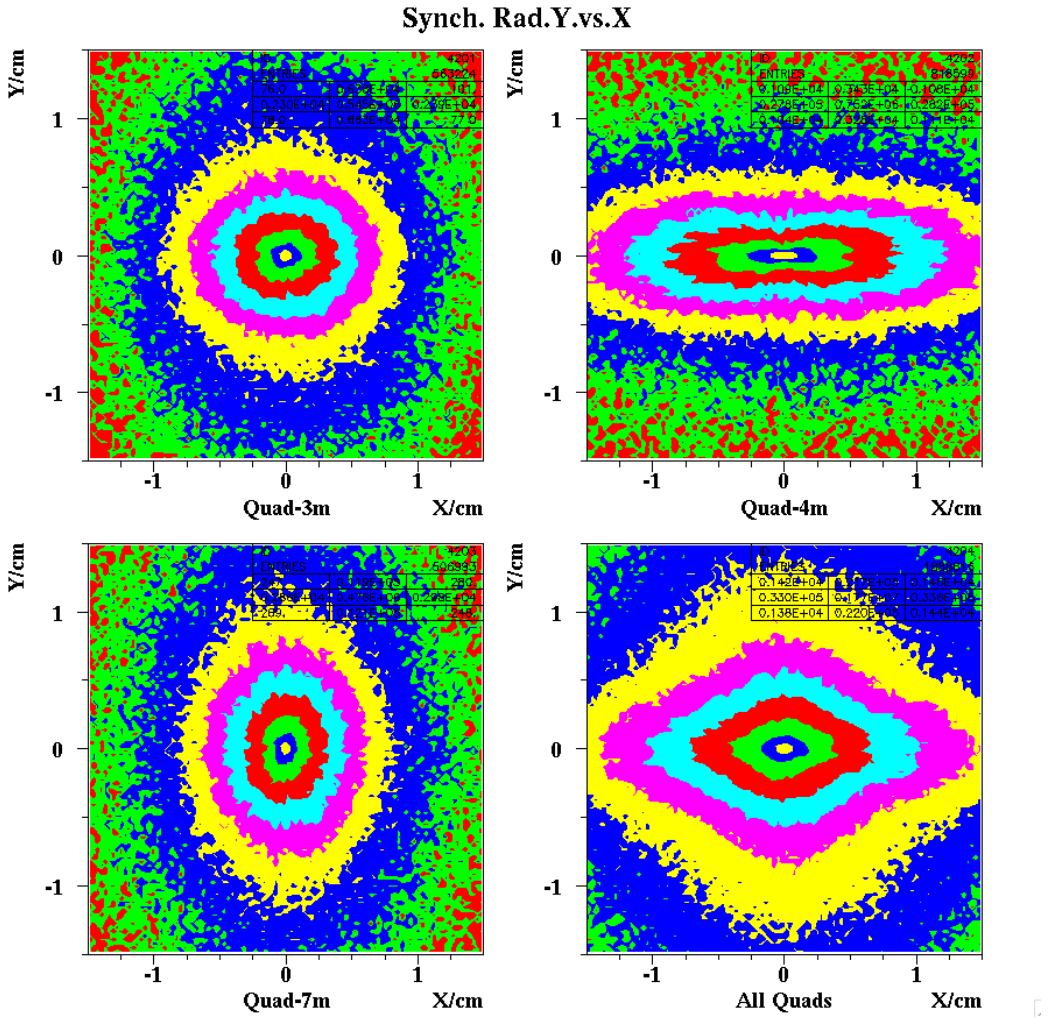
- **Photon energy is randomized** and follows the nominal distribution of SR energy in terms of Critical Energy for 10 GeV electrons in magnetic field.

Example: photon spectra at Reference Plane downstream IP (s=10 m).



$$\varepsilon_c = \hbar\omega_c = \frac{3}{2}\frac{\hbar c}{\rho}\gamma^3.$$

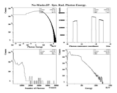
SR ray profiles at IP depending on the source Quad.



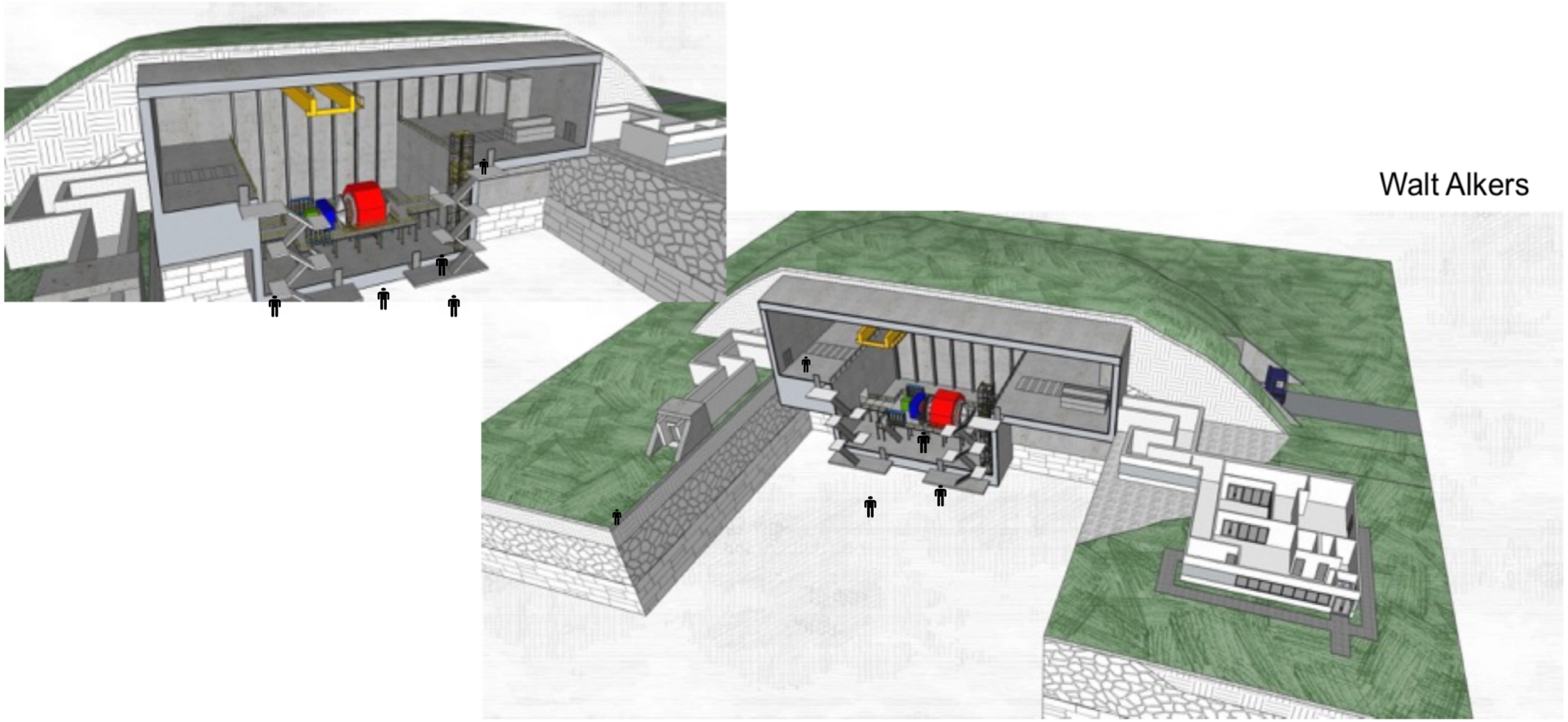
- Y vs. X distributions are reasonably **sensitive to source Quad**.
- Total distribution is incoherent sum of the three source terms.

I. Conclusion & Outlook

- Generated SR **photons are not limited** by masks or **intrinsic constraints** that allows a further **tracking through Geant4 models**.
- Photon **distributions** are **sensitive** to **Quad** parameters, **distance** along beam-line, and photon **energy.**
- Synchrotron Photon ensemble **output in LUND format file.**
- **Photon record** contains its 4-**momentum** and **emission vertex** coordinates.
- Meta-data on **electron energy**, **integrated charge** for each file.
- **Allows input to GEANT4** detector model for **full simulation of background in detector elements** (started by Christine Ploen, ODU).
- Files in JLab storage.



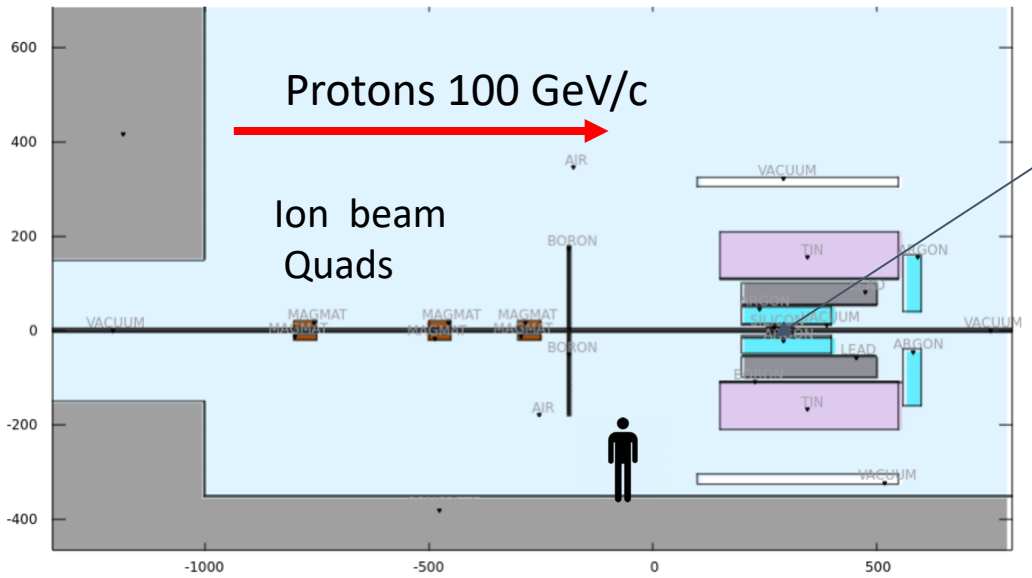
II. Neutron background in JLEIC Hall using FLUKA



Workshop Physics Detector at Zero Degree, Sep 24-26, 2019

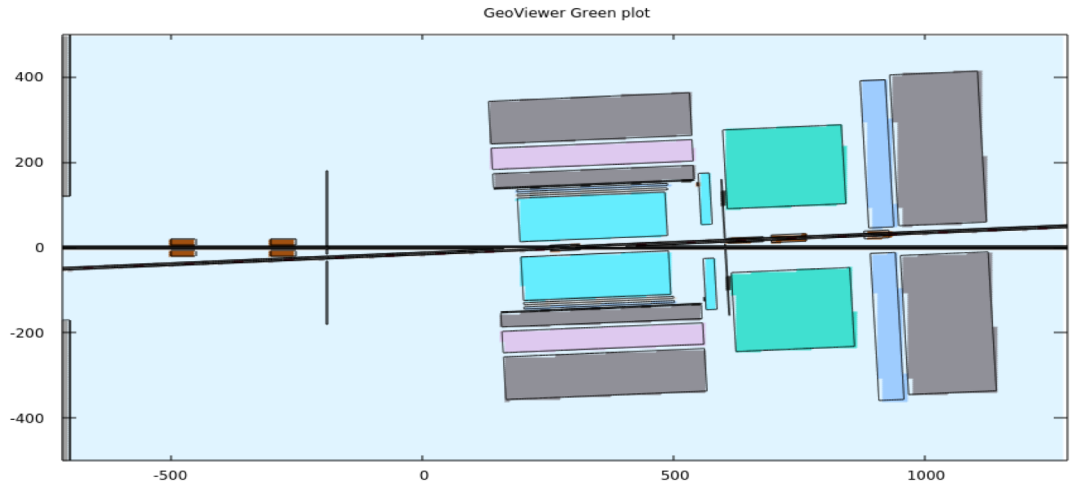
Jefferson Lal

JLEIC "Metro Station Hall" and Proton Beam

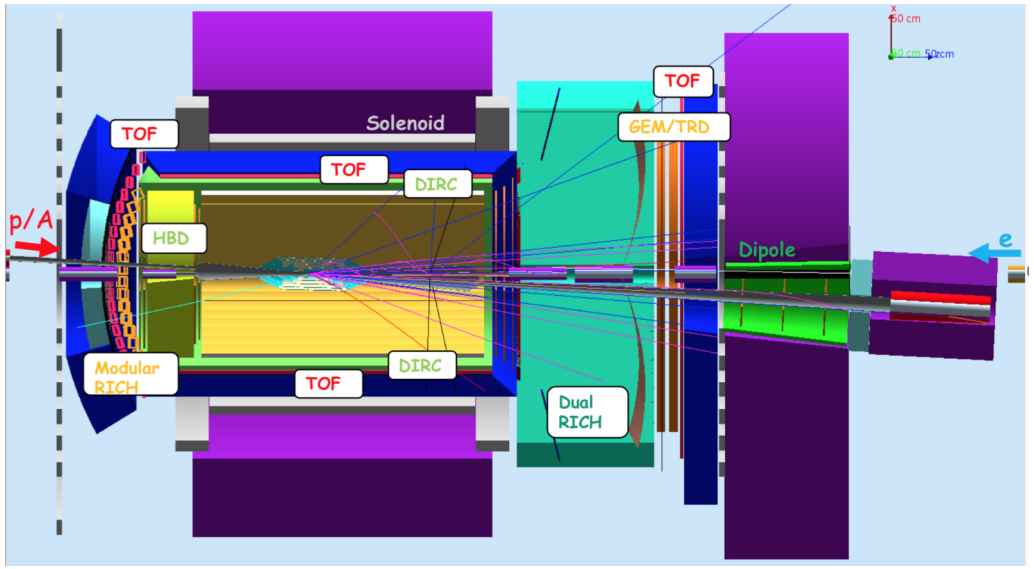


Electrons 10 GeV/c

IP



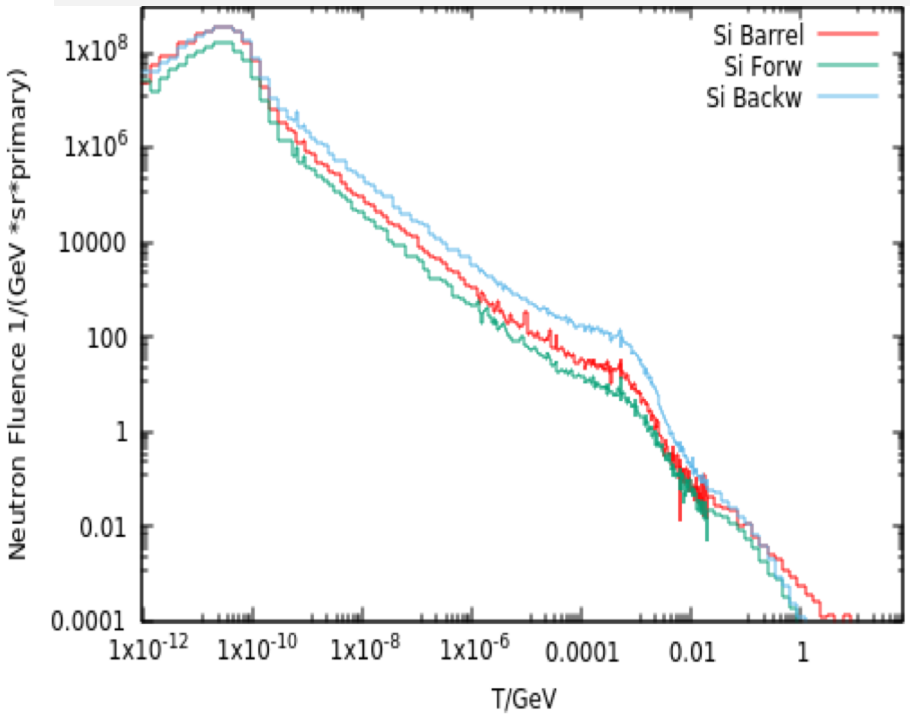
1. **"Metro Station Hall"** with 2 **Tunnels.**
2. **X-beam pipe** (Al).
3. **Central pipe** (Be) .
4. Ion and electron **Beam Quads** (Iron+Copper+Water).
5. Central detector **Solenoid** (Tin+Copper+Helium).
6. **Calorimeters** (Lead+Scintillators or PbWO4 for eEndcap).
7. **Tracker** (Argon)- central and forward.
8. **Silicon Detectors** (Central Si and SiPMs).
9. **Air** in the hall.

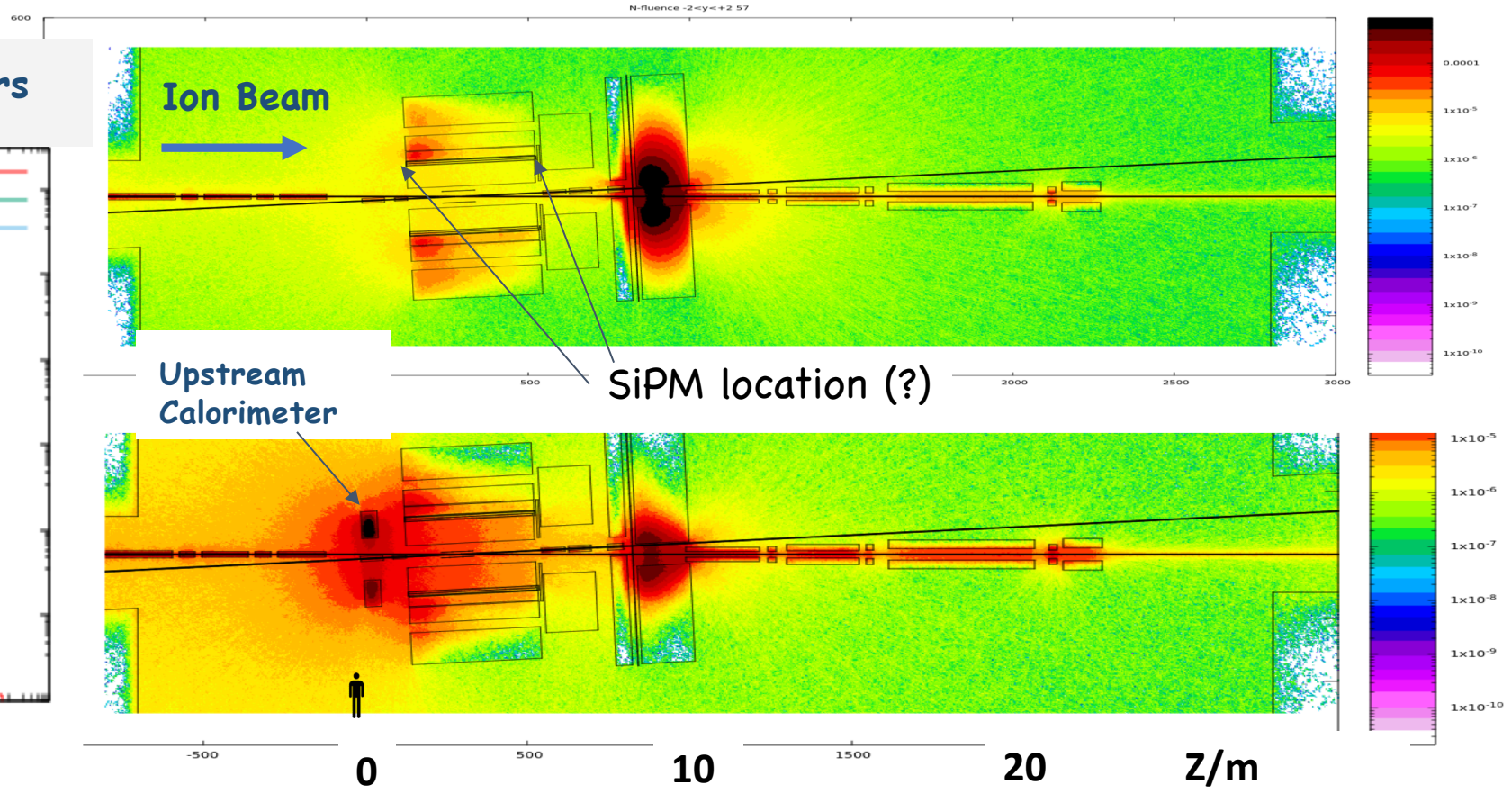


Neutron fluence and effect of Calorimeter Upstream Ion Beam.

A strong influence on the detector background is the detector itself.

Neutron fluence in Si based detectors

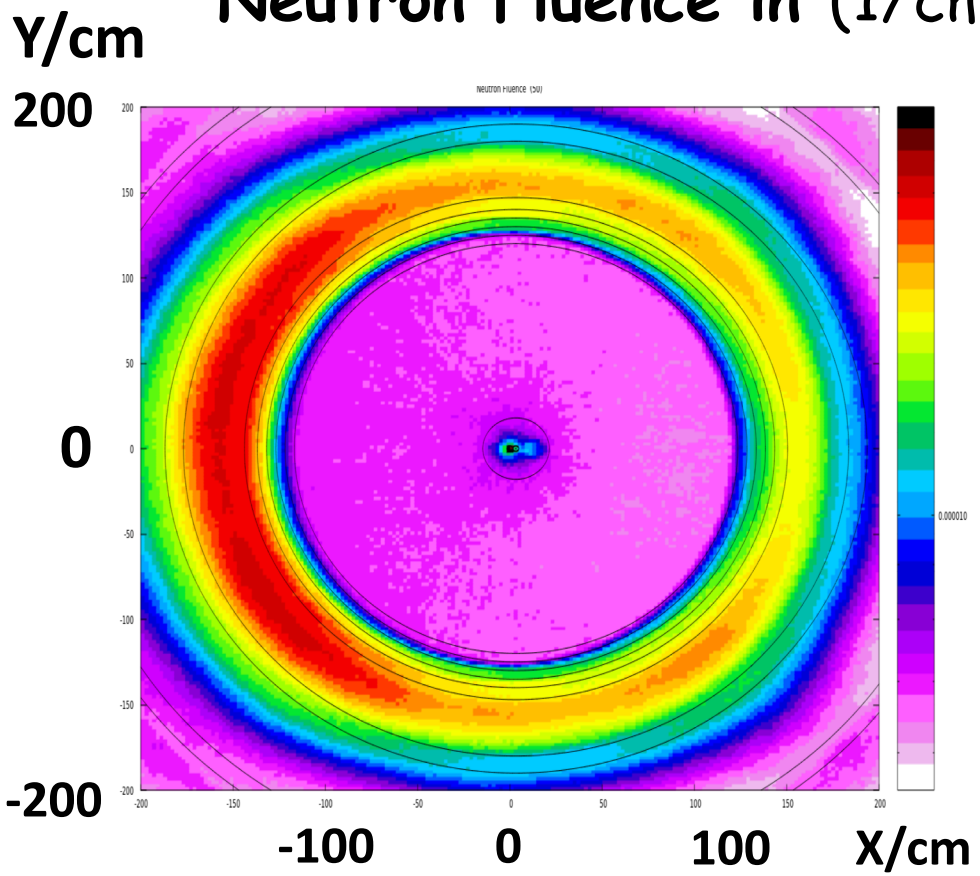




- Opposite to expectations **n-fluence** through **upstream** "SiPMs" (blue histogram) is **~20 times higher** than through **downstream** ones (green histogram).
- **Protons** propagating **in residual gas** (in vacuum pipe) from ~40 m upstream.

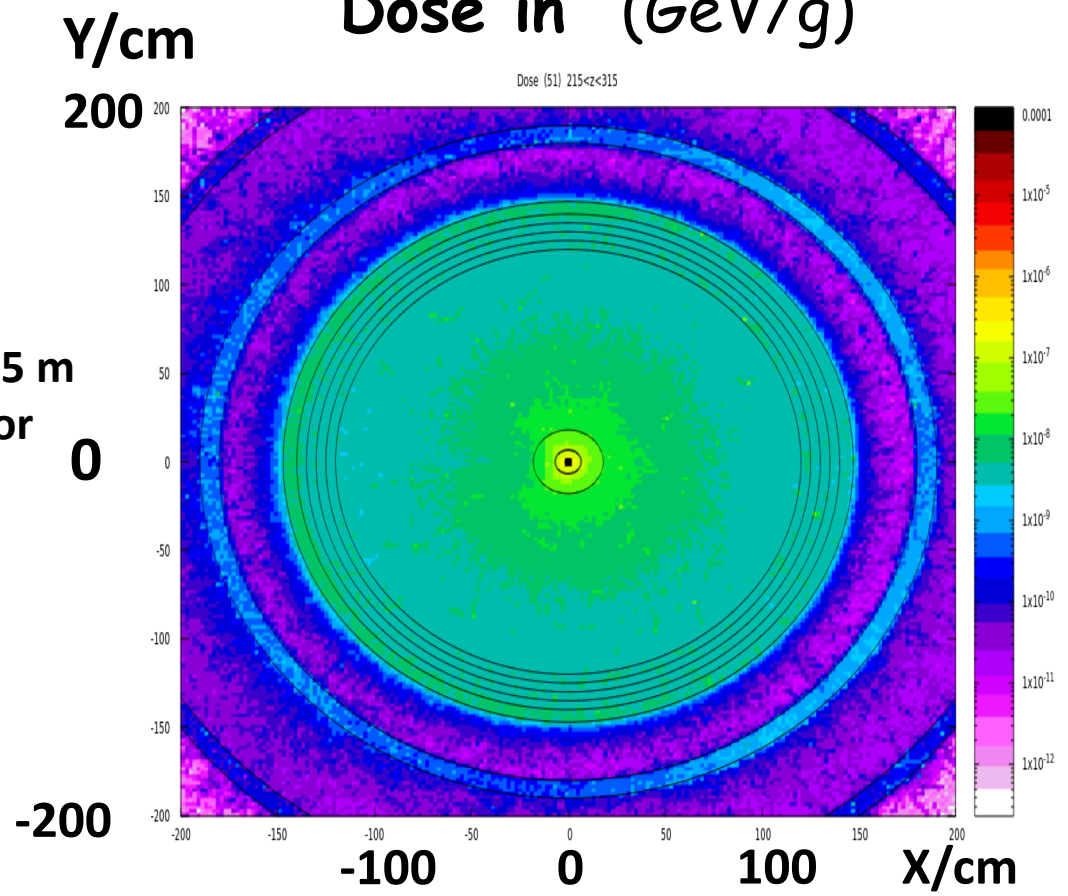
Example. Dose & Fluence per beam particle history.

Neutron Fluence in (1/cm2)



2.15 m < Z < 3.15 m
Inside Detector

Dose in (GeV/g)



- All **calculations done with** "pencil" of **residual gas** at 0.1 atm (blue) for simulation efficiency, scaling.
- All values shown here are **relative.** Absolute flux normalization in progress for next steps.

II. Conclusion and Outlook

- A realistic **FLUKA model** (1st approximation) of Experimental **Hall and Detector is constructed**.
- Preliminary **calculations of n-fluence** through **Si-based detectors** are performed for proton beam.

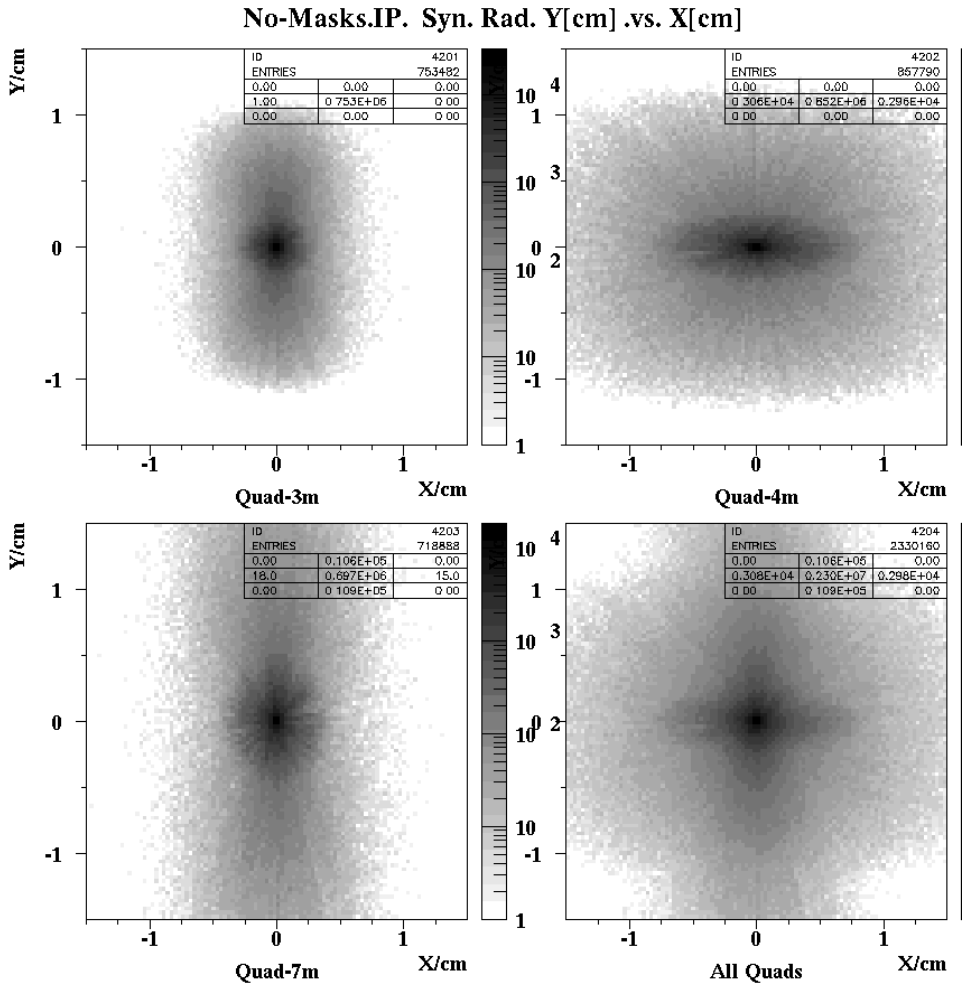
- **Near future plan :**

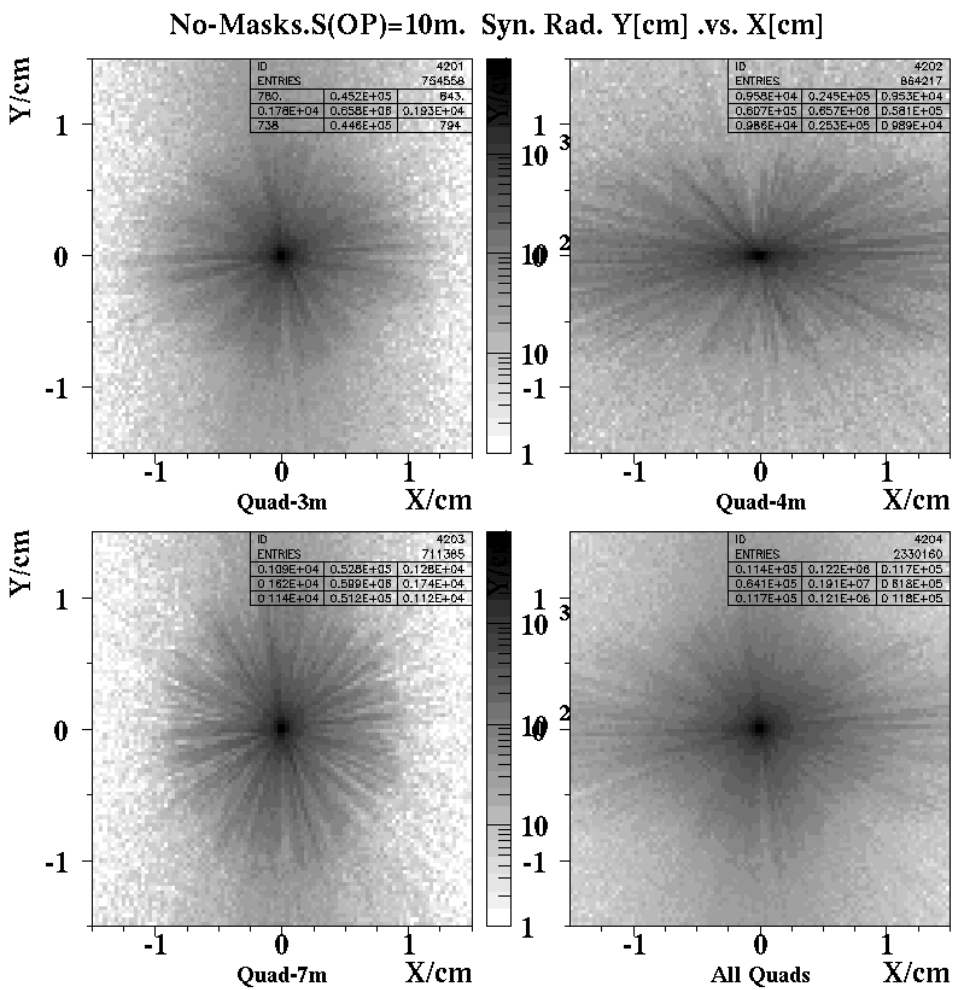
- **Develop models** with more **detailed detectors and beam** lines.
- Perform n-fluence **calculations** with **electron beam**.
- Calculate **n-fluence** for **electron-ion collisions**; this option is **not yet in the official version**.
- **Absolute normalization** of fluence and dose (vacuum model, beam current)
- Port to eRHIC **Interaction Region and Detector** design.

Thank YOU!

BACKUP SLIDES:

SR photon flux profiles from 3 Quads. IP vs. OP(+10 m).





Y%X at IP.

Is wider on OP at S = +10 m

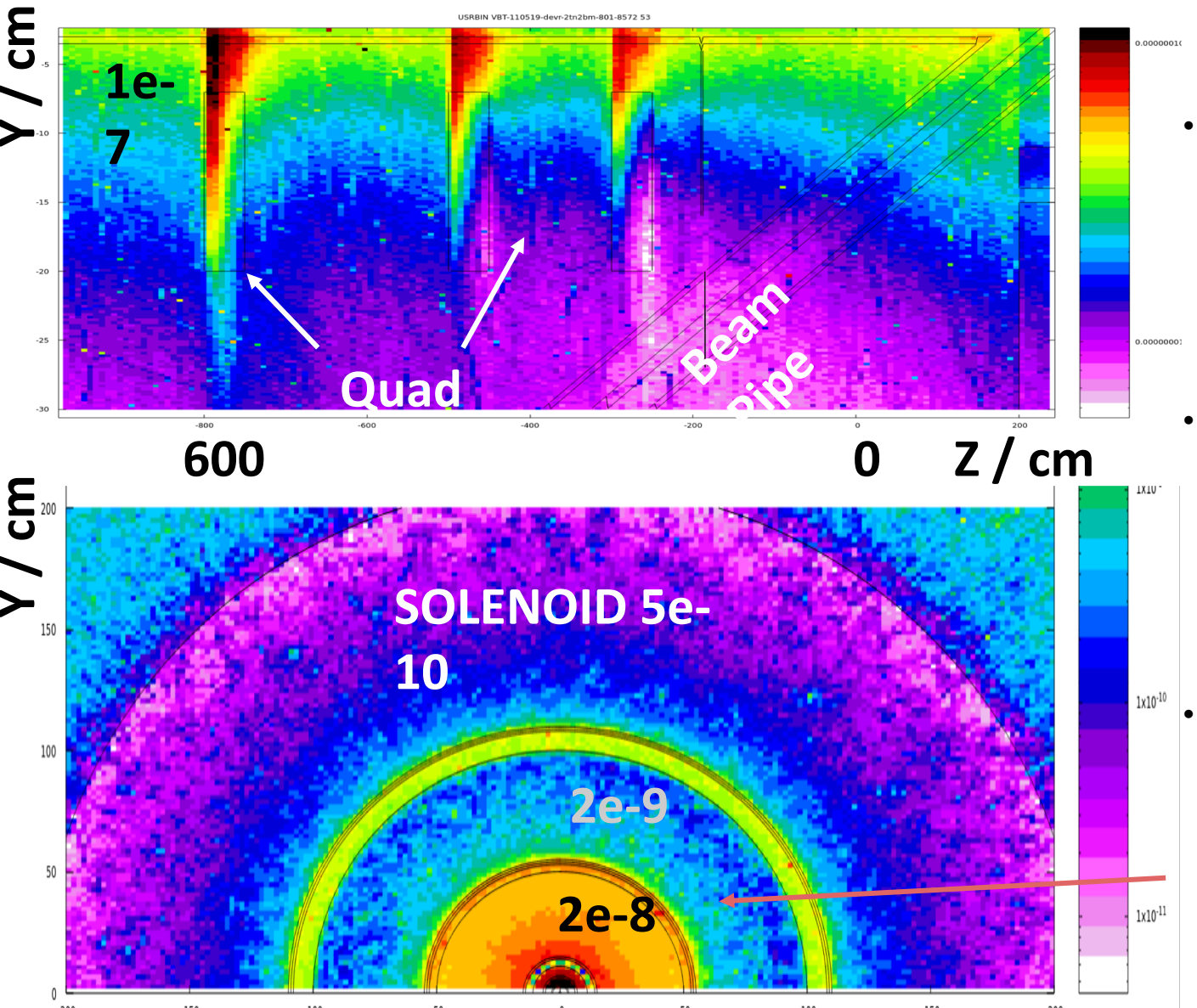
Marks from individual SR rays are seen.

Measuring Units

- **Energy deposition** : in (GeV/ cm**3) per primary particle.
- **Dose** : in (GeV/g) per primary particle.
- **Dose in Gy**: = Dose(GeV/g) * 1.602176462E-7
- **Fluence** : in (particles/cm2) per primary particle (history).
- **Counting rate**: Fluence*Beam intensity(part./s)*Air pressure (bar)*10
- For energy spectra **Differential Fluence** is given in units of Fluence per GeV.

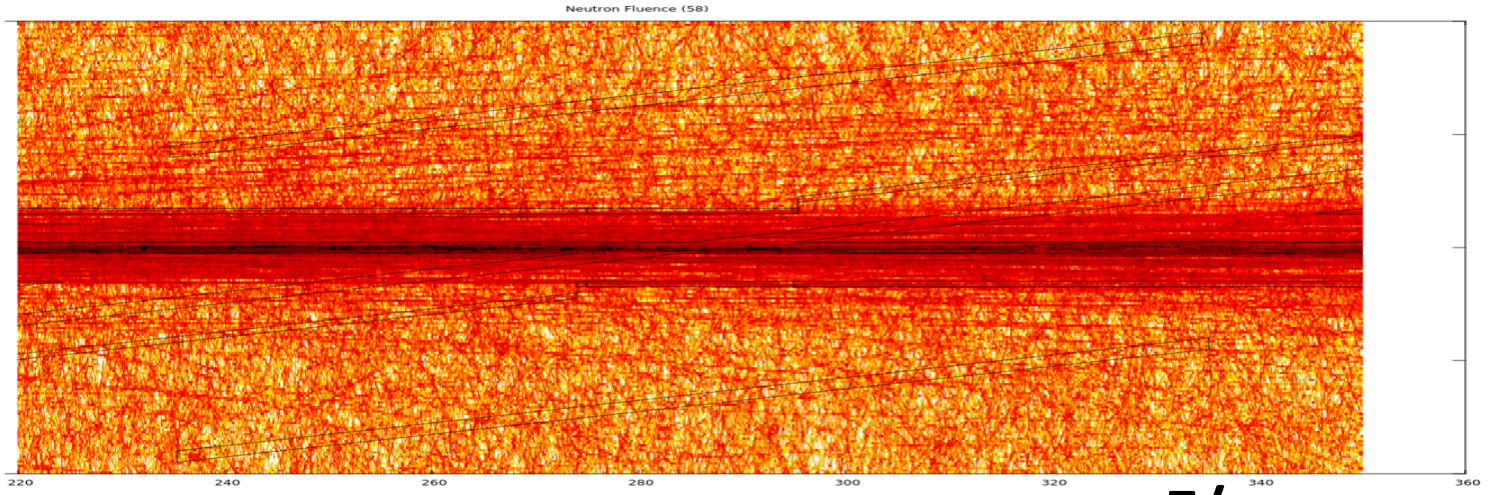
- All results shown here are relative. Absolute flux normalization in progress for next steps.

Dose is given by FLUKA in (GeV/g) per primary. Example.

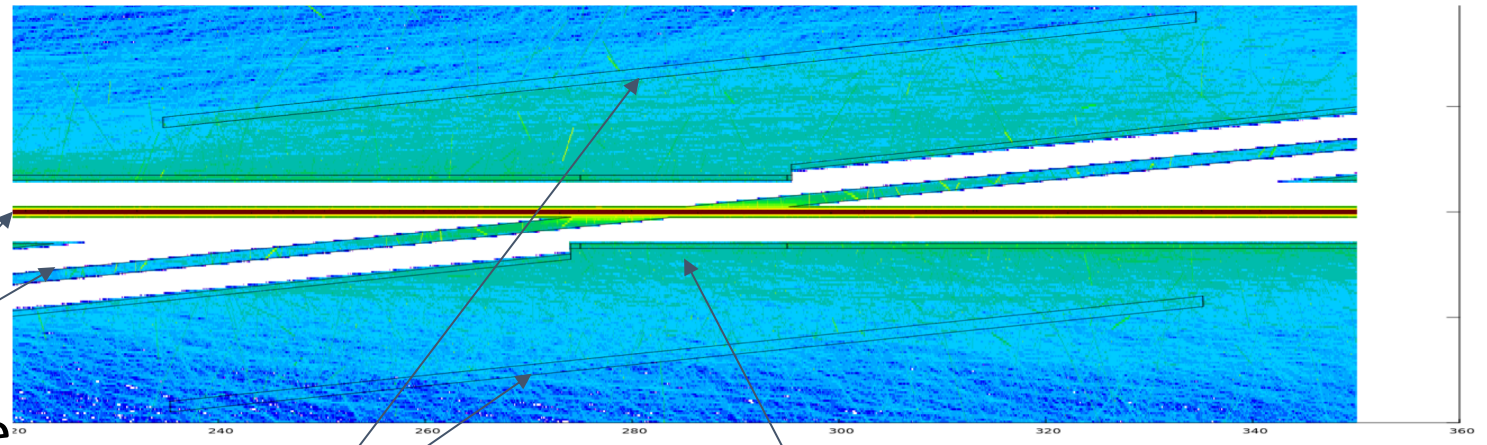


- Energy deposition: GeV per cm3 per primary particle history.
- Doses: GeV/g per unit primary particle .
- Fluence: particles/cm**2 per unit primary weight.

Dose and n-fluence in the IP region of the central X-pipe



Neutron fluence



Dose

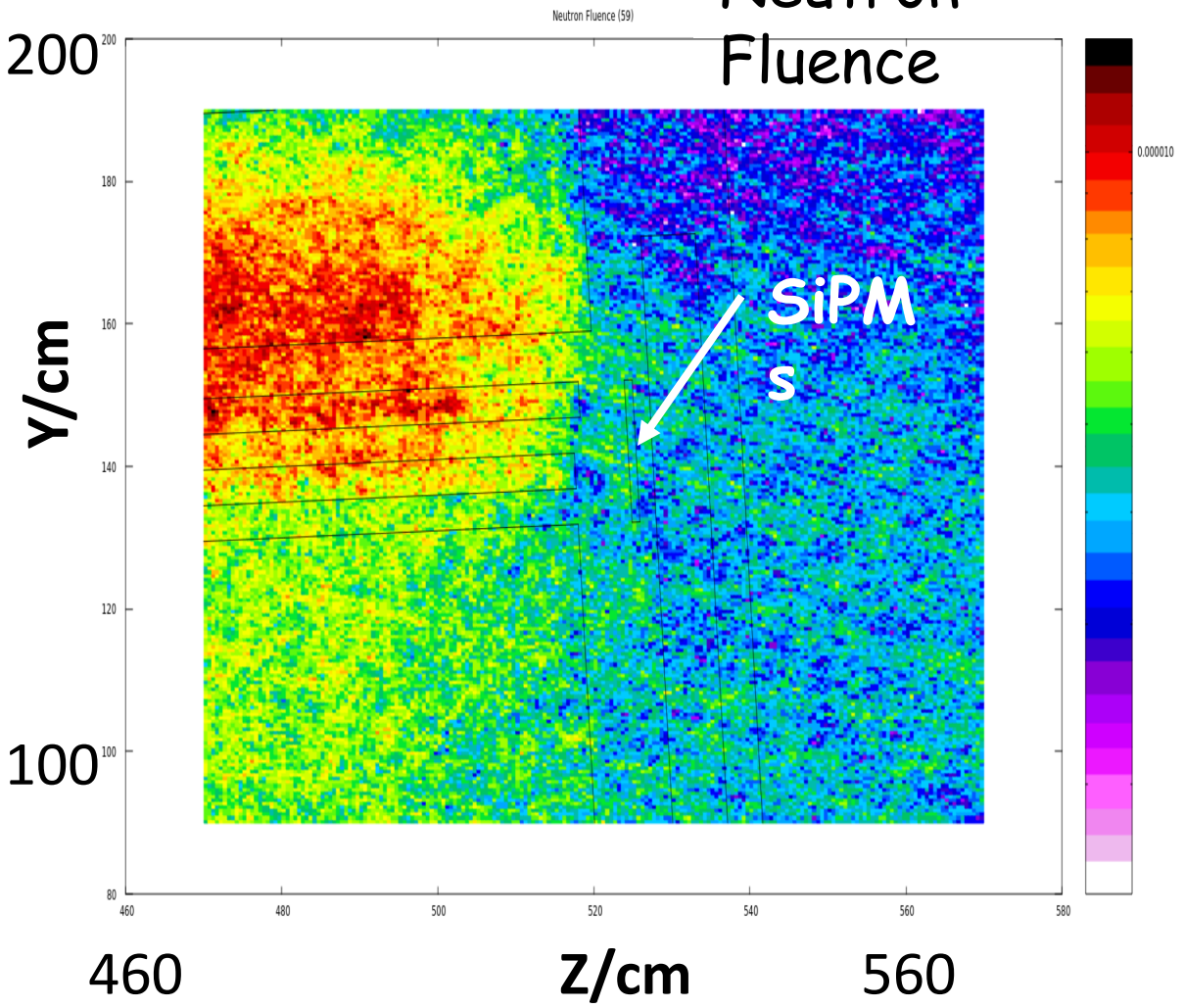
Beam X-pipie

Central Si barrel

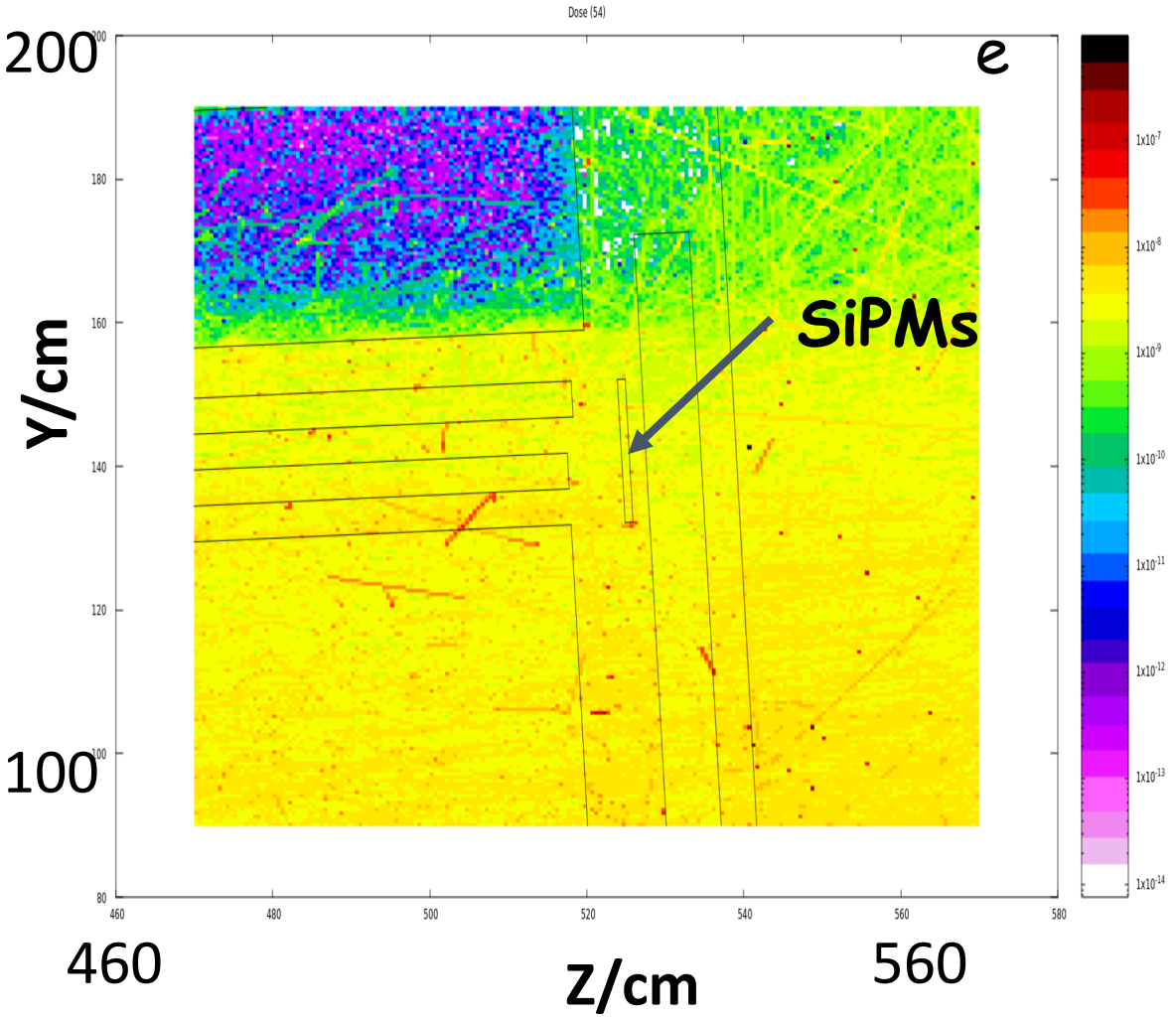
Central Be pipe

Dose and n-fluence in the SiPM region (forward Dual RICH)

Neutron Fluence



Dose



I. Modification of SYRAD code and SR-photon simulation.

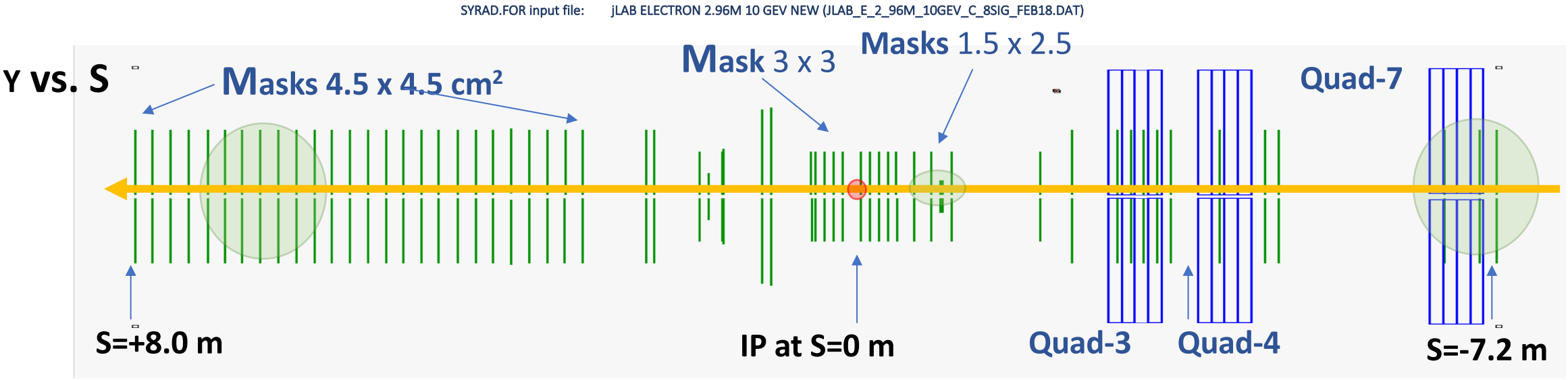
History: SYRAD.FOR code was written by

Al Lark, LBL to **calculate analytically** the SR **power deposition** in beam line elements.

The code was MODIFIED BY:

- BILL LOCKMAN , SLAC (1980)
- BILL LAVENDER, SLAC (1981)
- BILL LAVENDER, SLAC (1981)
- MIKE SULLIVAN (1985) TO INCLUDE BEAM HALO PARTICLE DISTRIBUTION.
- MIKE SULLIVAN (1986) TO INCLUDE BEAM EMITTANCE (SLOPE DISTRIBUTION AT EACH POSITION POINT)
- DOUG SHY, LBL (1988) TO BETTER APPROXIMATE THE EFFECTS OF STRONG QUADRUPOLES
- AL LARK, LBL (1989) to Remove all references to LPUNCH.
- **MIKE SULLIVAN (1990)** to include **background gaussians** in 4 dimensions of electron beam.
- H. de STABLER and M. SULLIVAN (1991) to recalculate the tail distribution WITHOUT the cross terms.
- **VITALY BATURIN, ODU (2019) to generate SR-photons in LUND format for further Geant4 simulations.**

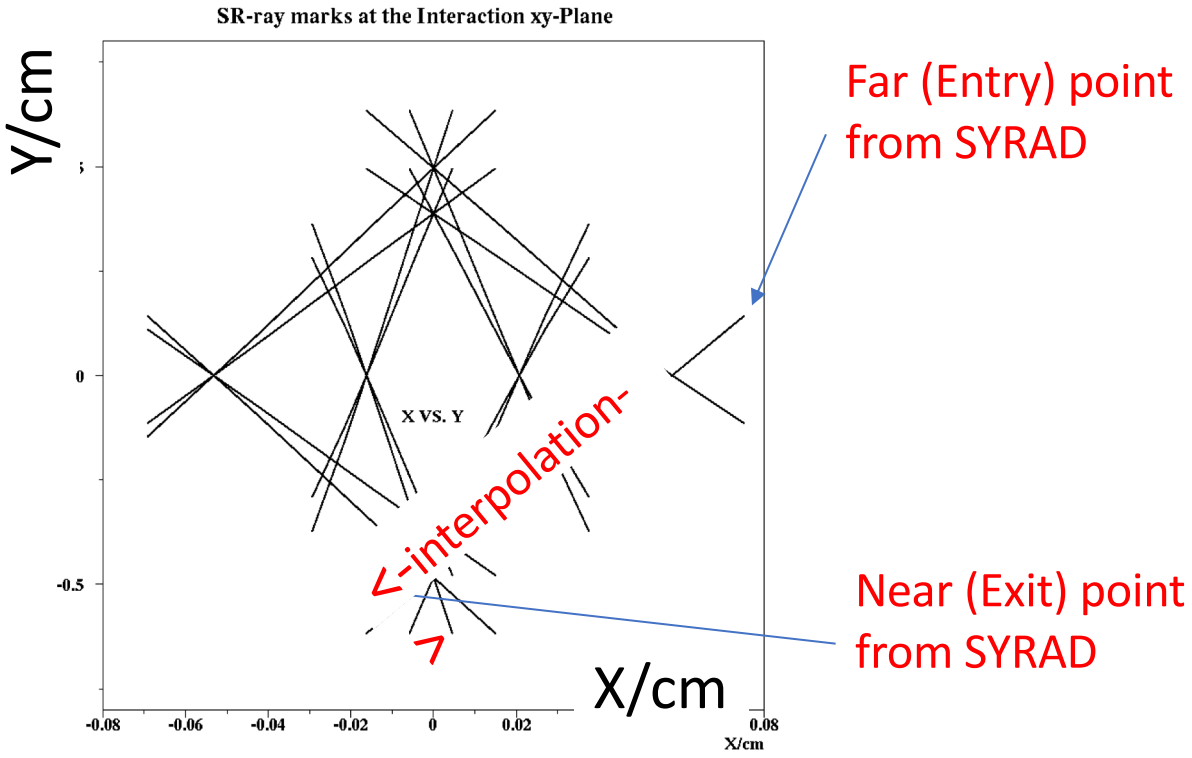
Layout of beam optics elements in SYRAD (M. Sullivan).

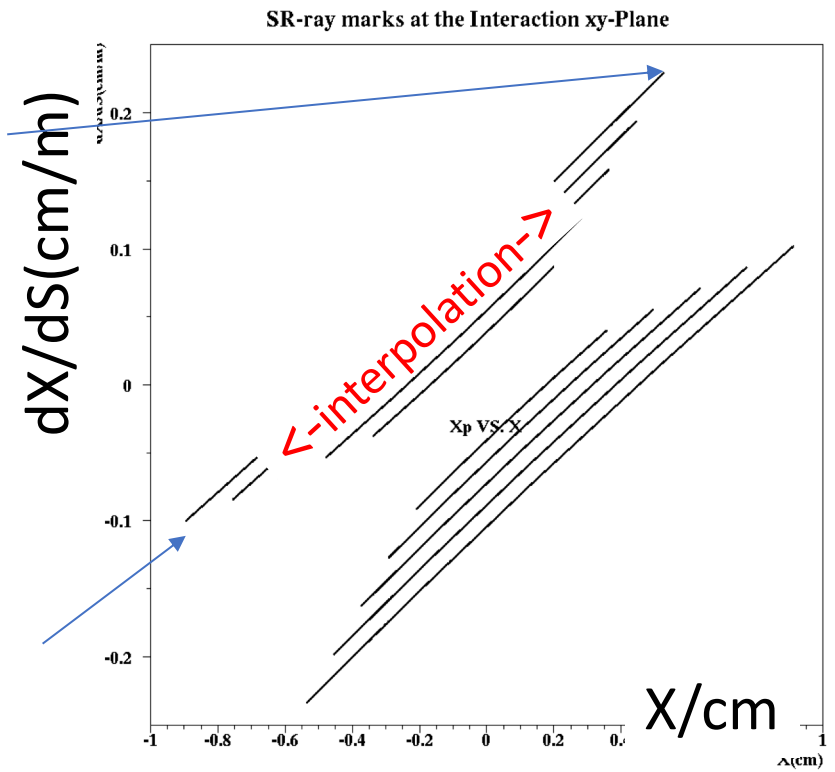


- All **masks** (mask opening shown in green) **are removed for calculations**.
- **Collimator** 1 cm radius at s=-1.0 m retained.
- **SR sources are 3 quadrupole magnets (Quads)** upstream the IP (subdivided in 4 blocks each) .
- XY-plane at specified S=10m is used as a **Reference Plane** to interface semi-analytic SYRAD flux to GEANT4 simulation of photons.

When electron **enter/exit Quad**, a narrow SR beam **"turns ON/OFF"** that makes **marks** on the Reference Plane .

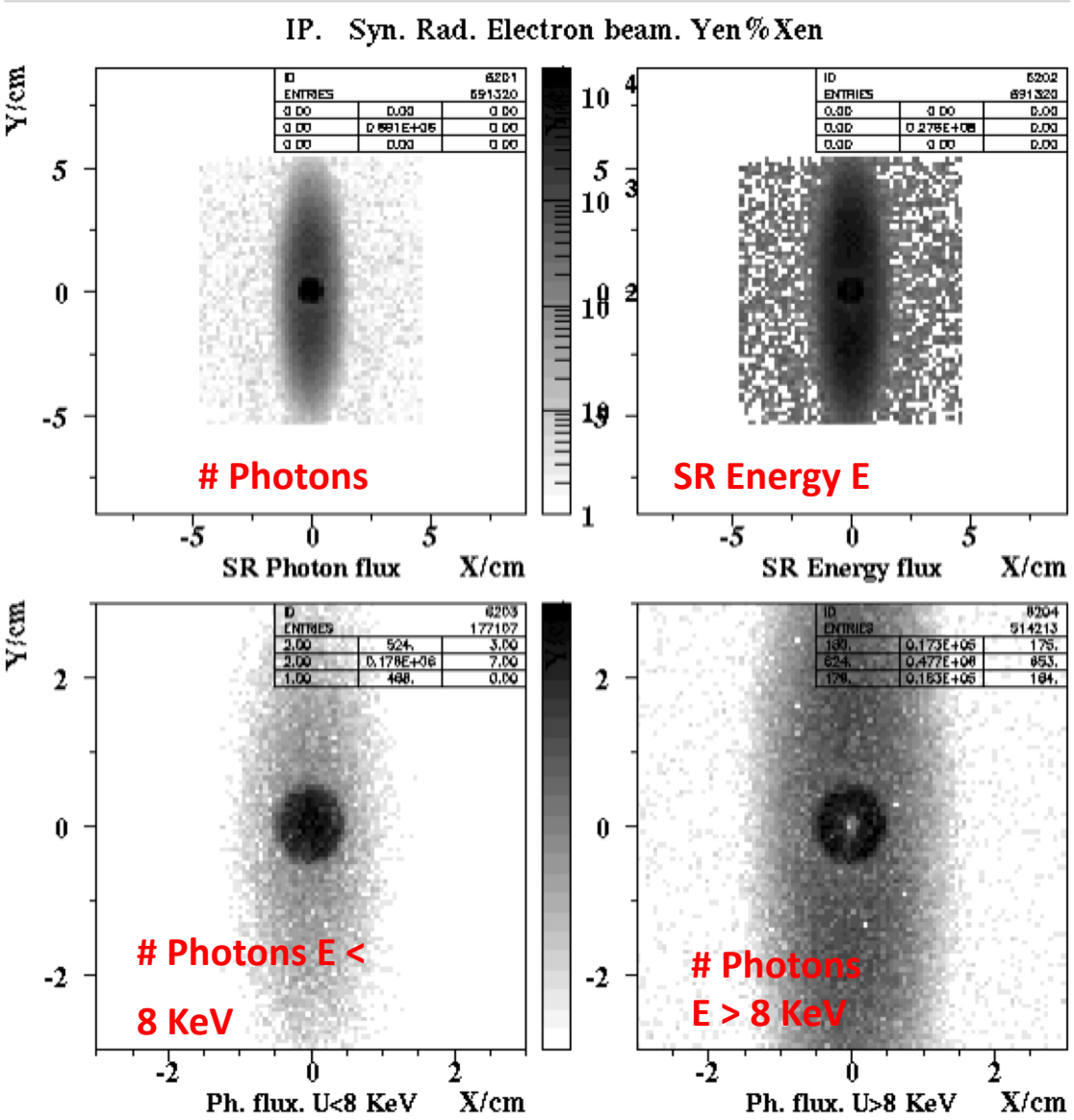
How SR-ray makes marks on Reference Plane

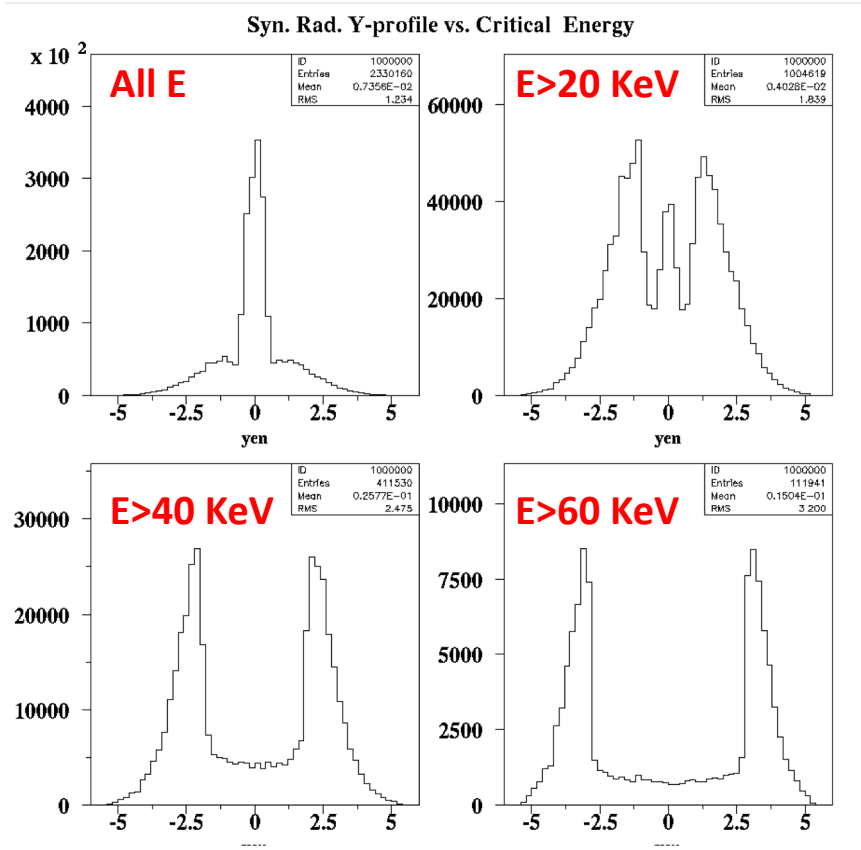




- **"Light-House"** approximation of **Synchrotron Radiation** for electrons at fixed transverse coordinates inside each Quad.
- **Coordinates & angles of electrons** are provided by **SYRAD** for **Entry & Exit-S** of a Quad.
- **S** is uniformly **randomized** between Entry- & Exit-points with **Linear Interpolation** for photon parameters.
- **Source COORDINATES and DIRECTION of photons may be reconstructed.**
- Each photon may be **tracked through the GEANT4** model.
- **Individual photon energy** in Ray is **randomized**. Total **Ray energy** is calculated analytically by **SYRAD**.

8.Electron beam emittance at the Lattice Entry provided SR photon is emitted with energy E.

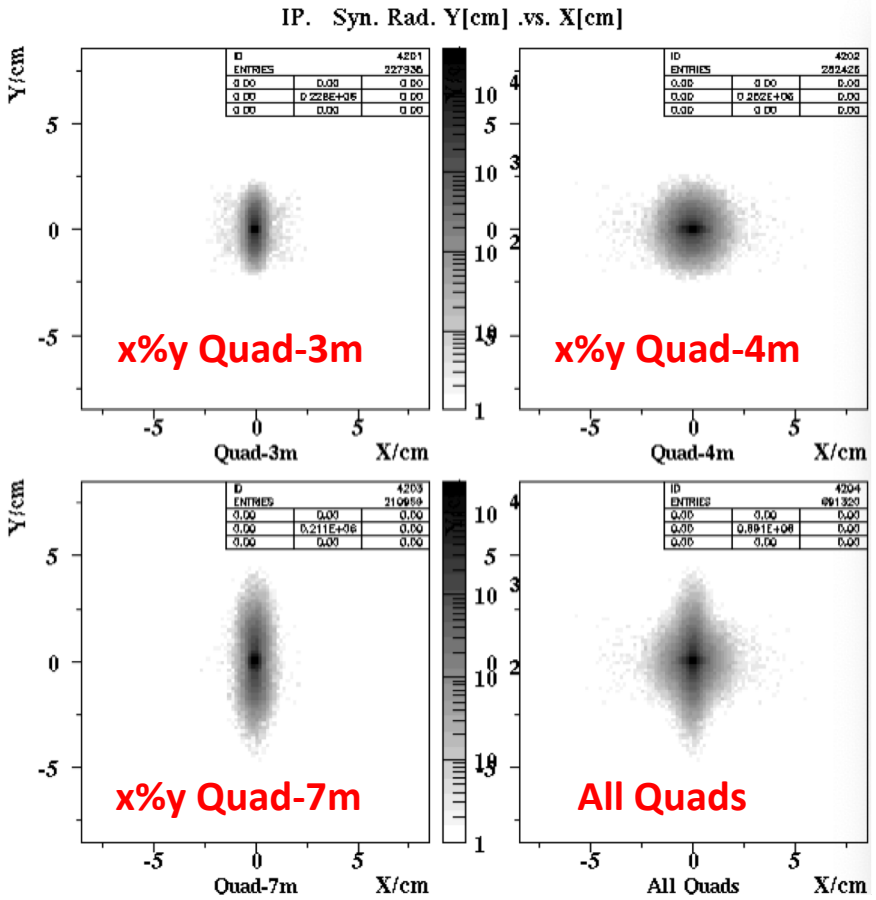




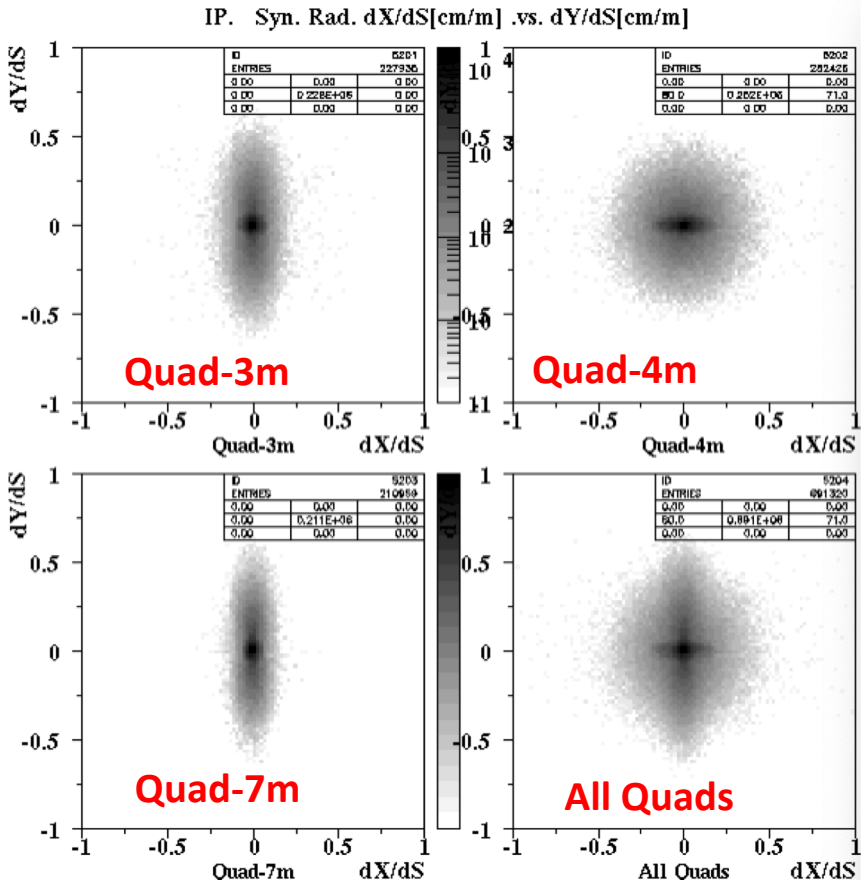
- **Reasonable sensitivity** to Photon Energy is demonstrated, including the **central hole** in X%Y-profiles at **higher Photon**

9.SR ray profiles at IP depending on the source Quad.

Y vs. X



Y' vs X'



- All distributions are reasonably **sensitive to source Quad**.
- Total distribution at IP is incoherent sum of the three source terms.