eALBA

An electron Beam in the ALBA synchrotron

Ivan López Paz - IFAE Pixel group
Pizza Seminar
5th May 2021

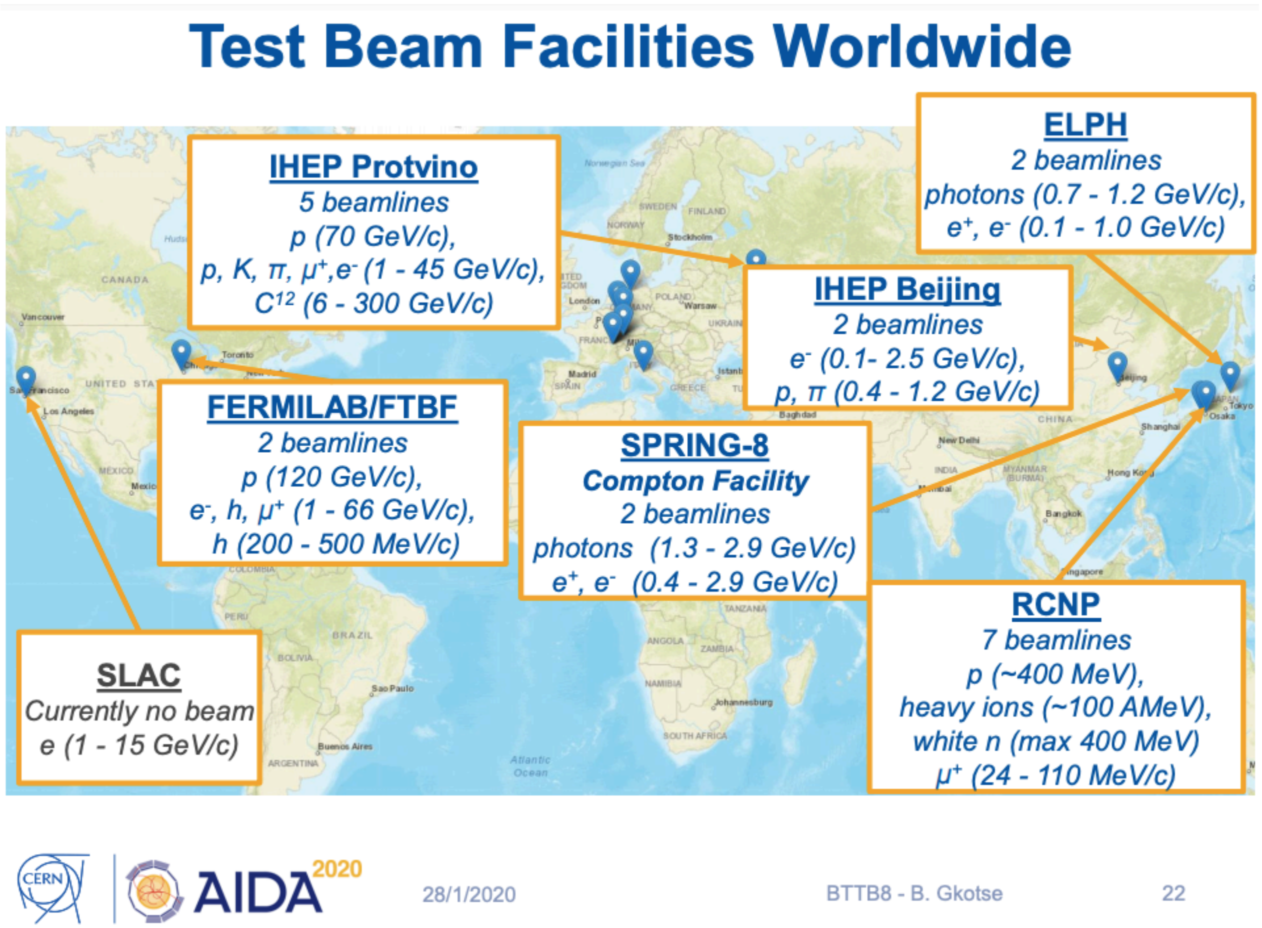
Background

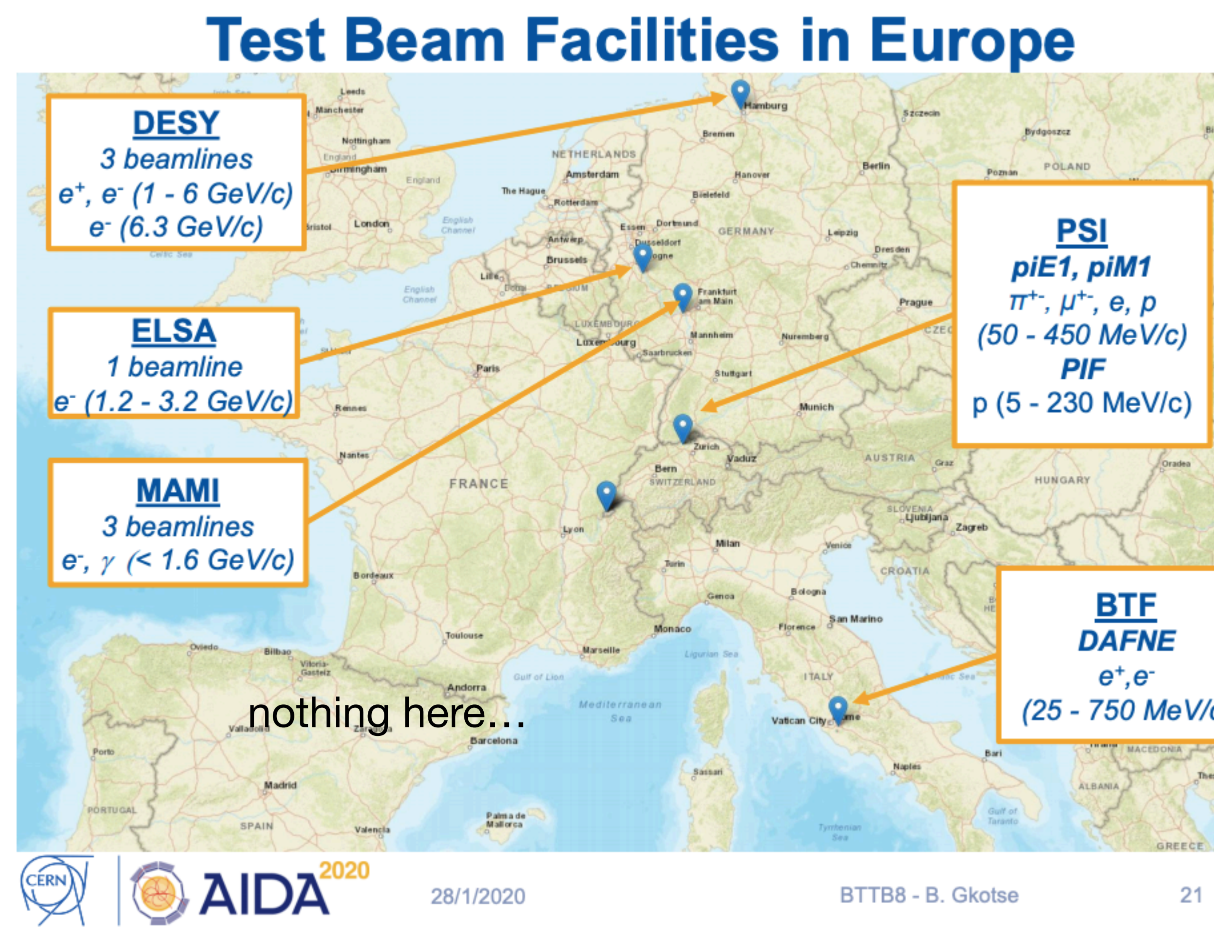
Electron testbeams 2.5km from IFAE?

- High energy charged particle beams are a widespread tool for research
    - Stays at DESY (Germany) and CERN for testbeams
- We have ALBA in Spain, cannot we do some tests there?
    - ALBA is a synchrotron facility (like DESY)
- Some existing ALBA photon beamlines might already be useful for tests but no electron beam until now
    - **Might be possible in the future (ALBA-II) !!**
- Call for new beamlines in 2nd half of 2021
    - Proposal requires a community of interested users
    - Users from HEP, Nuclear physics, medical physics, satellites, material science, outreach/education ...?

Current facilities

- Testbeam facilities in Europe available, but none with high energy charged particles close
- Fully booked over the year, some times over-booked…



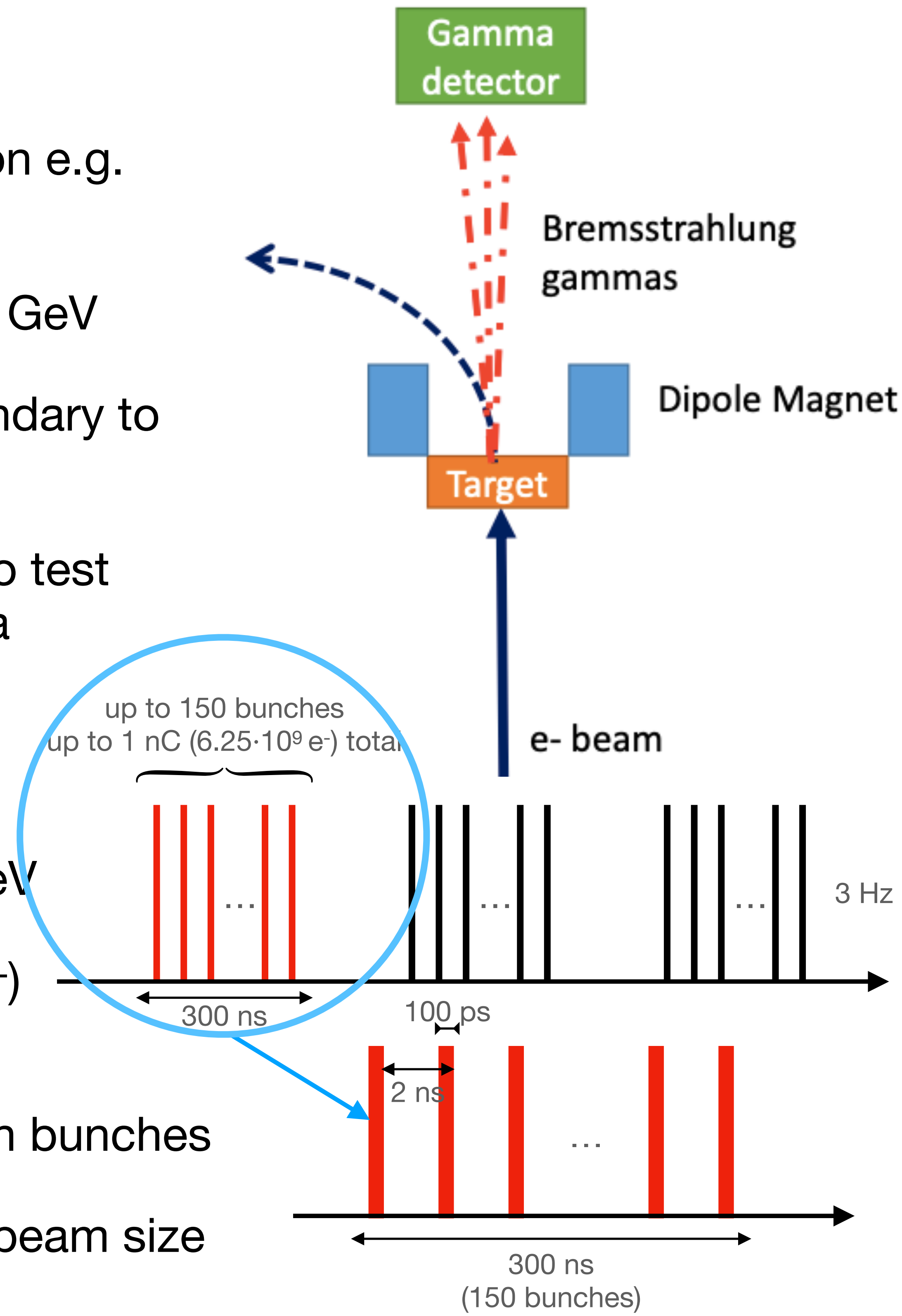


Would be nice to have an additional (close) testbeam facility

What could be done?

Beam parameters

- Baseline energy of 3 GeV very useful for instrumentation e.g. pixel detector characterization
    - Probably energy tunable between 100 MeV and 3 GeV
- We could use different targets, primary and even secondary to reduce beam energy further ...
- ... or produce gammas over a wide range of energies to test gamma detectors in a more flexible environment than a specilised ALBA beamline
- **Beam base parameters:**
    - Energy: prob. tunable between 100 MeV and 3 GeV
    - Trains: 3 Hz of 300 ns width, and 1 nC ($6.25 \cdot 10^9$ e^-) up to 150 bunches, less possible
    - Bunches: width of 100 ps and about 2 ns between bunches
    - Possibly down to few μm^2 and up to several cm^2 beam size



Ivan López Paz
Pizza Seminar
5th of May 2021

Possible applications

Some examples

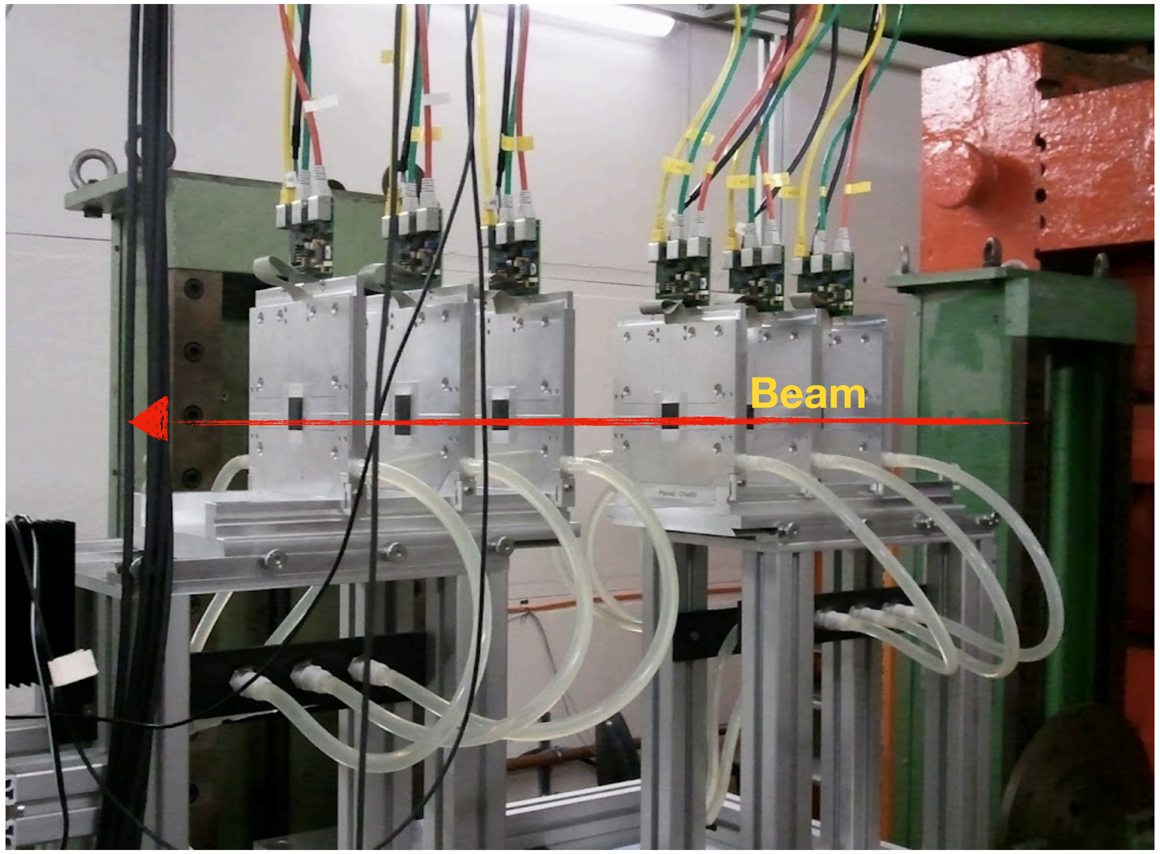
- Particle detector characterization for HEP/nuclear physics/ astroparticles
- Imaging material budget
- Gamma detector characterization with at least few MeV gammas: interesting also for medical detectors/PET detectors
- Irradiation of electronics to test radiation hardness as for example for satellite electronics
- Electron-Nucleus scattering experiments for neutrino studies
- Education/outreach, e.g. training of PhD students

Here we explore some of them
Note: biased towards Solid State detectors…

Particle detector characterisation
(from the POV of the pixel group)

Typical Characterisation Hardware

EUDET telescopes



- Reconstruct tracks from telescope and interpolated into a Device Under Test (DUT)
- Typically measured:
  - **Efficiencies**: hit/no hit near interpolated track
    Position resolutions: distance between hit and interpolated track
    Timing Resolution: hit time in DUT wrt hit in reference timing detector
- **EUDET telescopes:** Currently available in DESY and CERN SPS beam lines for detector charact. testbeams
- 6 Mimosa26 detectors for track reconstruction
  - Monolithic detectors, 14 μm thick, 18.4x18.4 μm^2 pixels and plane resolution of 3.26 μm

Study using EUDET as reference hardware for eALBA
could even develop our own/ improved telescope!

Ivan López Paz
Pizza Seminar
5th of May 2021

Reconstruction resolution

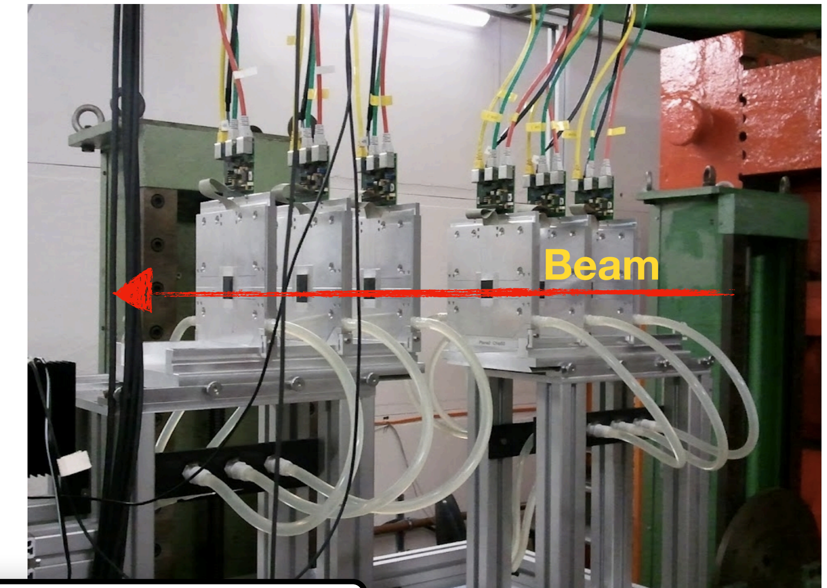
Multiple scattering effects

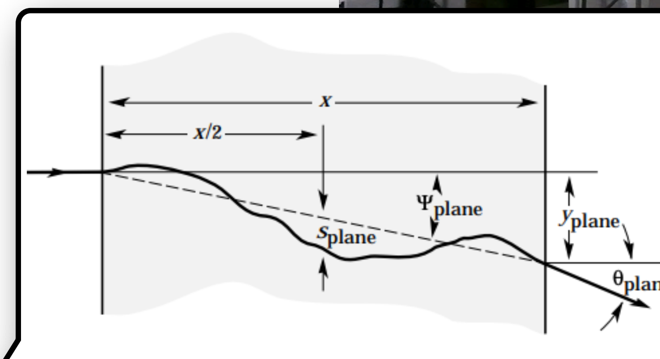
- Reconstruction resolution: **telescope plane resolution, multiple scattering** (material budget, particle type and energy) and **geometry**

- **Telescope plane resolution:**
  Roughly *σ≈pixel size/√12*, better plane resolution → Better reconstruction

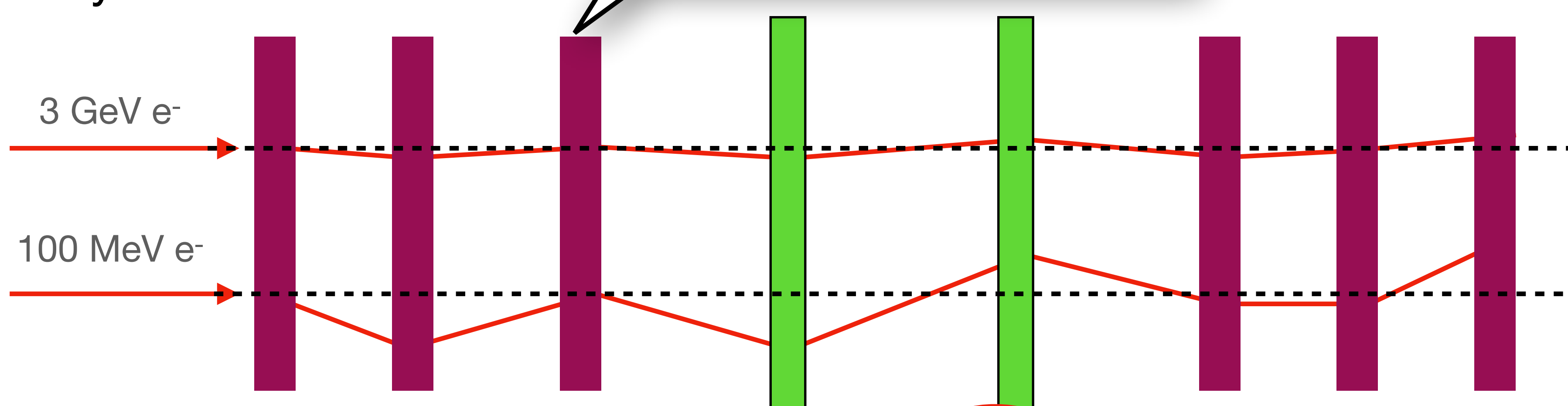
- **Multiple scattering:** Low energy → Higher scattering angle → Lower reconstruction resolution

  - Detectors under test may also contribute with material budget!





At 3 GeV e- and below multiple scattering starts to be an important factor! Study effect in reco resolution…



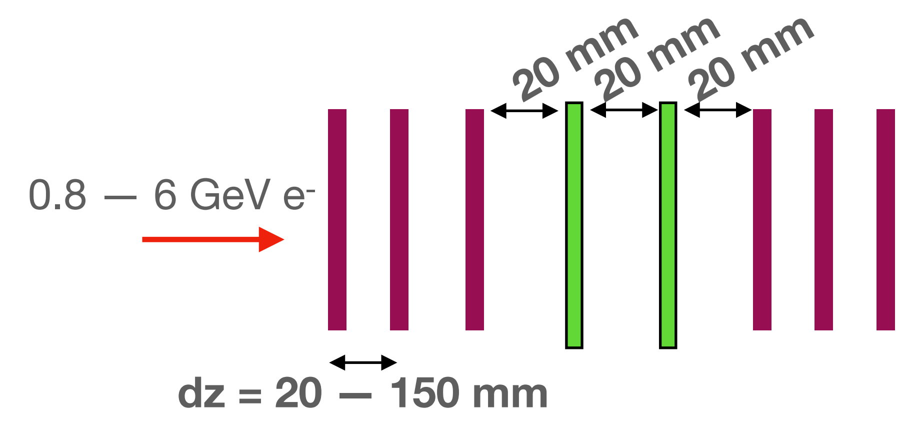
$$\theta = \left(\frac{13.6\ \mathrm{MeV}}{\beta c p} z\right) \sqrt{x/X_0}\left(1 + 0.038 \ln x/X_0\right)$$

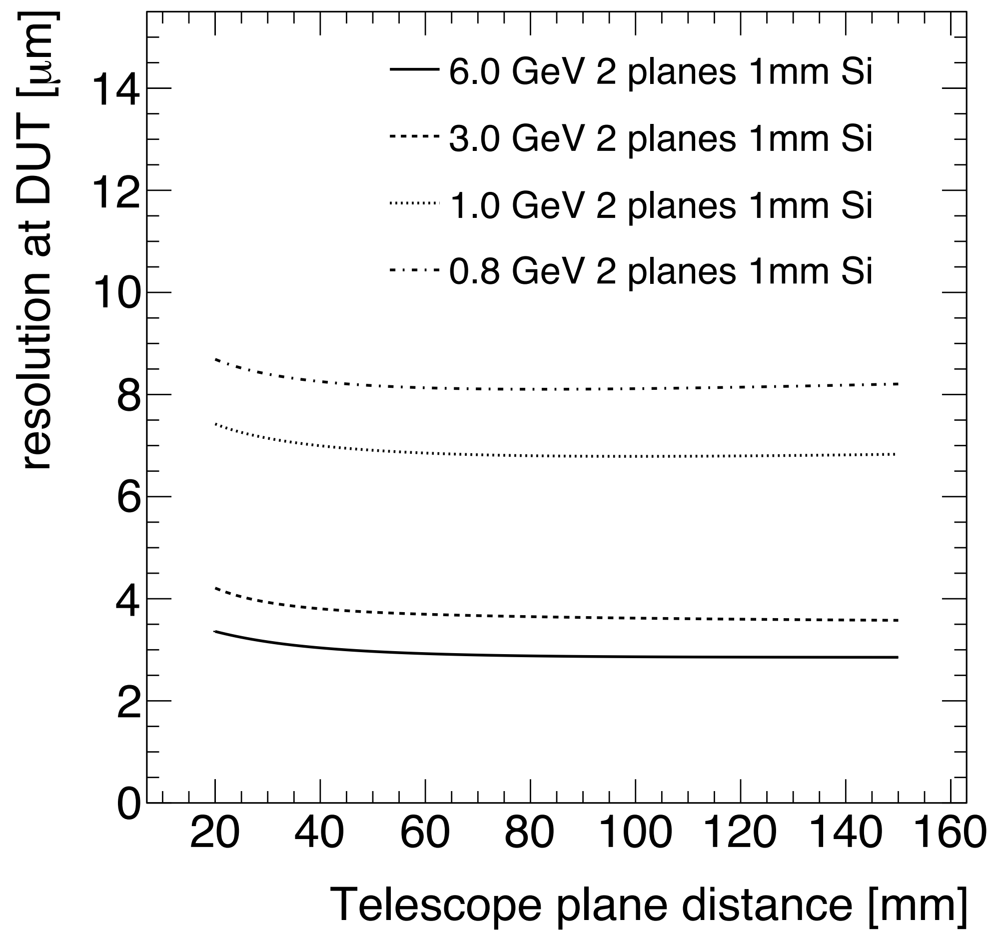
Ivan López Paz
Pizza Seminar
5th of May 2021

Track resolution

For Silicon Pixel Detectors

- Typically, 6 Mimosa plane telescope (σ_{M26}=3.25 µm) and 2 more planes: 1 Reference and a Device Under Test
    - Here ~1 mm thick planes (sensor+chip)
- Resolutions with 6 GeV and 3 GeV are comparable (~3-4 µm)
- Track resolution degraded at 1 GeV due to multiple scattering
- Pixel sizes of DUTs range in the 25-50 µm
    - Even 10 µm reconstruction resolution in DUT is good for many applications
    - 3-4 µm great for in-pixel studies too





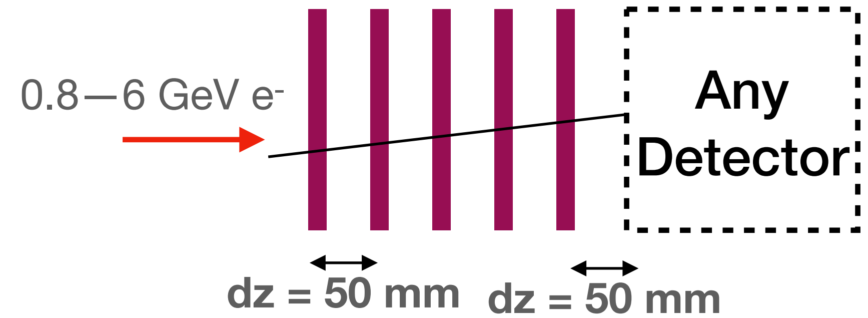
Good prospects for pixel detectors
but what about high material budget detectors?

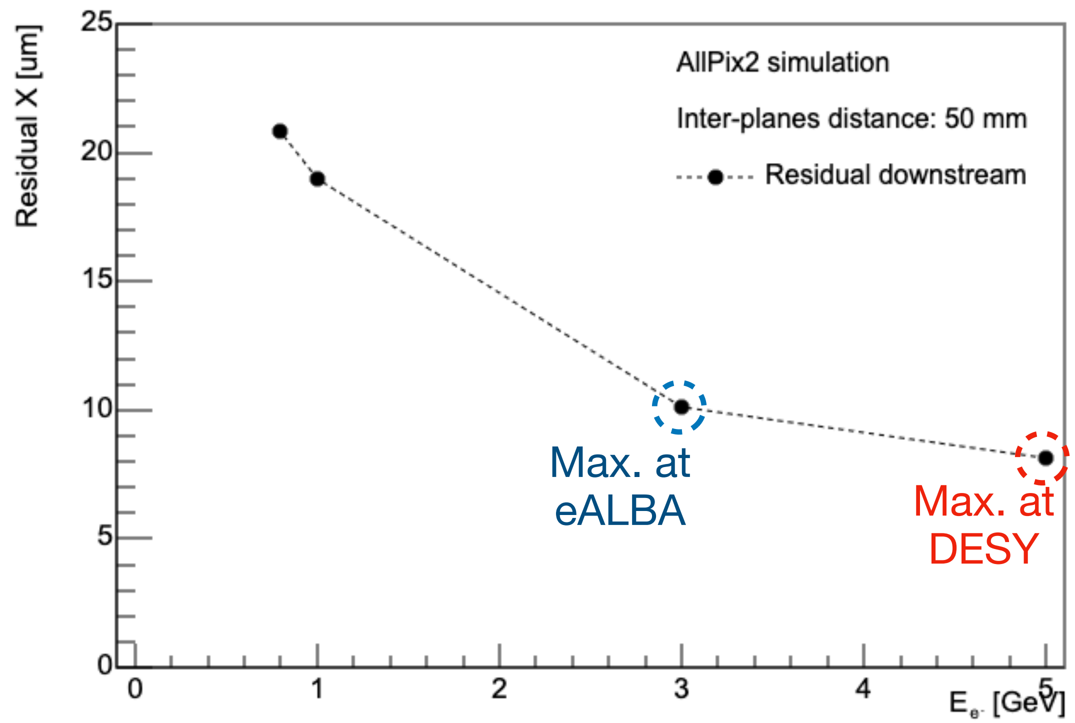
https://github.com/simonspa/resolution-simulator

Track resolution

Pointing at detectors downstream

- High material budget detector under test would worsen resolution or even absorb the beam before tracking…
- Move the detector downstream and extrapolate from the detectors upstream
  - No contribution of multiple scattering from the DUT (e.g. calorimeters)
- **Example:** 5 Mimosa planes, extrapolating into a 6th plane
- ~10-20 µm resolution at entry point with this geometry, enough for many applications!





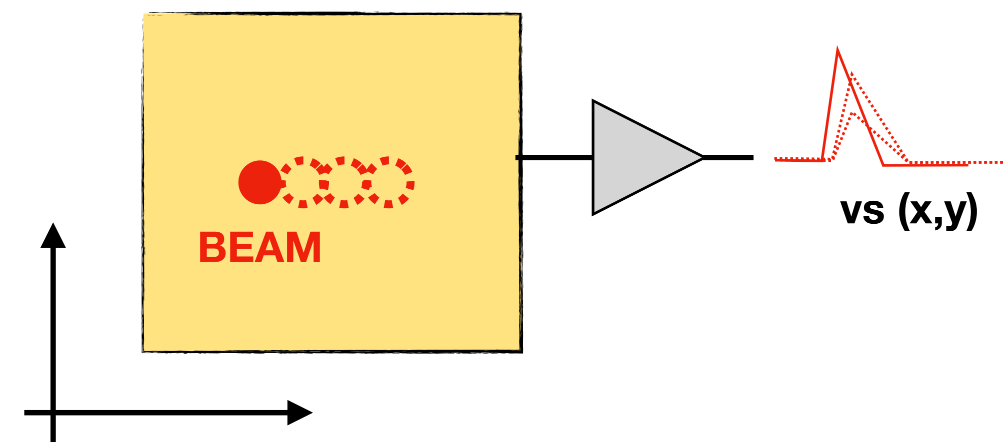
Useful for high material budget detector characterisation too!

Ivan López Paz
Pizza Seminar
Zth of YYY 2021

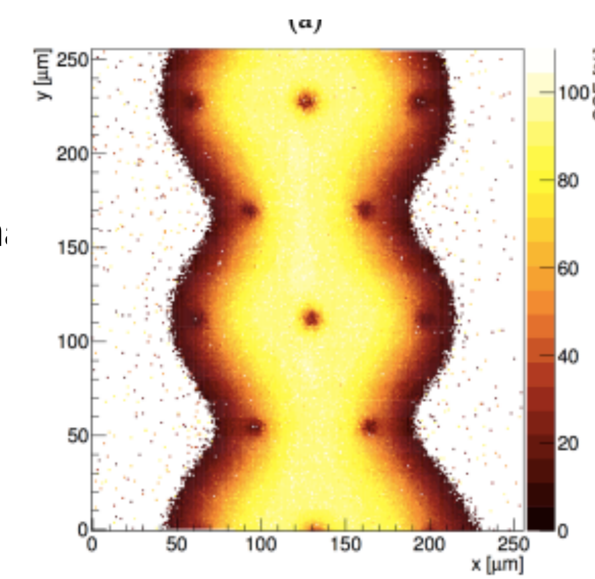
Other considerations for detector characterisation

(edge?) Electron Beam Induced Current

- If capable of achieving ~μm beam size, and with high precision movable stages
- Already reaching ~20-50 μm segmentation size: only makes sense if beam spot is small enough
- Edge measurements too?
    - Here multiple scattering might be a problem (e.g. ~cm of Silicon with 9.3 cm radiation length…)
- Intensity can be reduced from the accelerator, otherwise too much intensity in a very focused beam



EXAMPLE:
Charge collection efficiency in a hexagonal pixel diamond 3D detector (from Giulio Forcolin thesis)
~ 1 μm beam, 4MeV protons



![IFAE logo]

Ivan López Paz
Pizza Seminar
5th of May 2021

Imaging

Material Budget Imaging

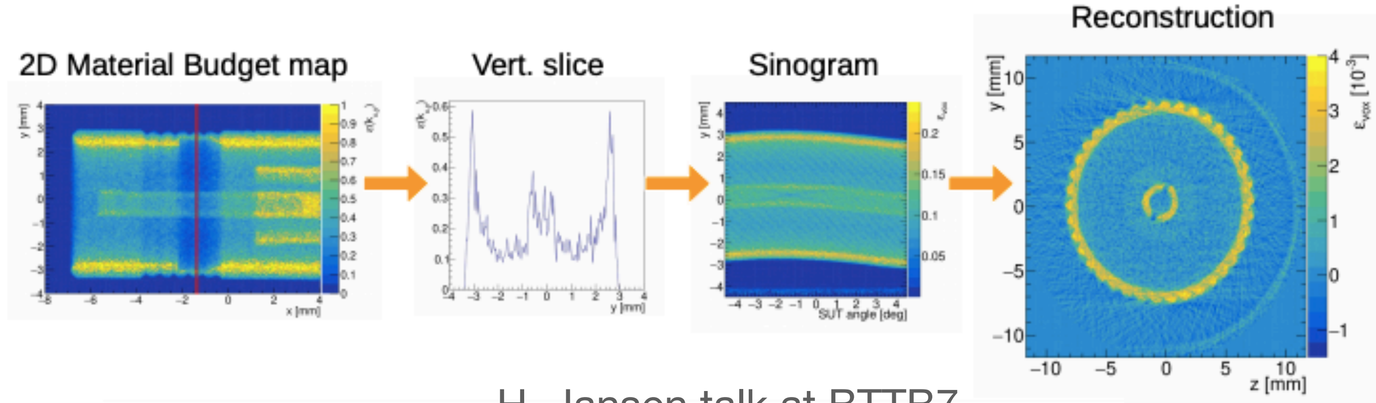
Measure multiple scattering

- Measure scattering angle by reconstructing tracks from both tel. arms
- Use Highland formula to calculate material budget

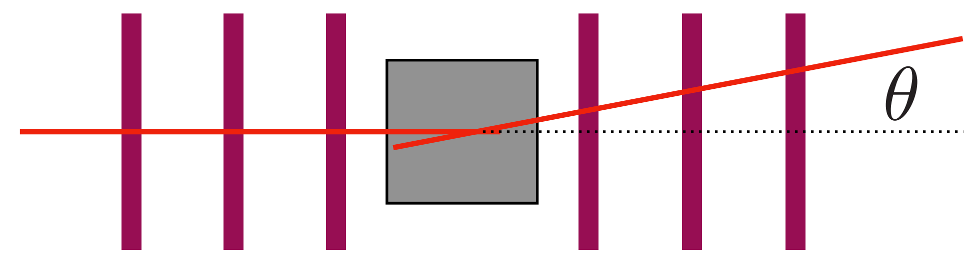
$$\theta = \left(\frac{13.6\ \text{MeV}}{\beta c p} z\right) \sqrt{x/X_0}(1 + 0.038 \ln x/X_0)$$

- Lower energy means higher sensitivity to scattering, but also lower telescope resolution…

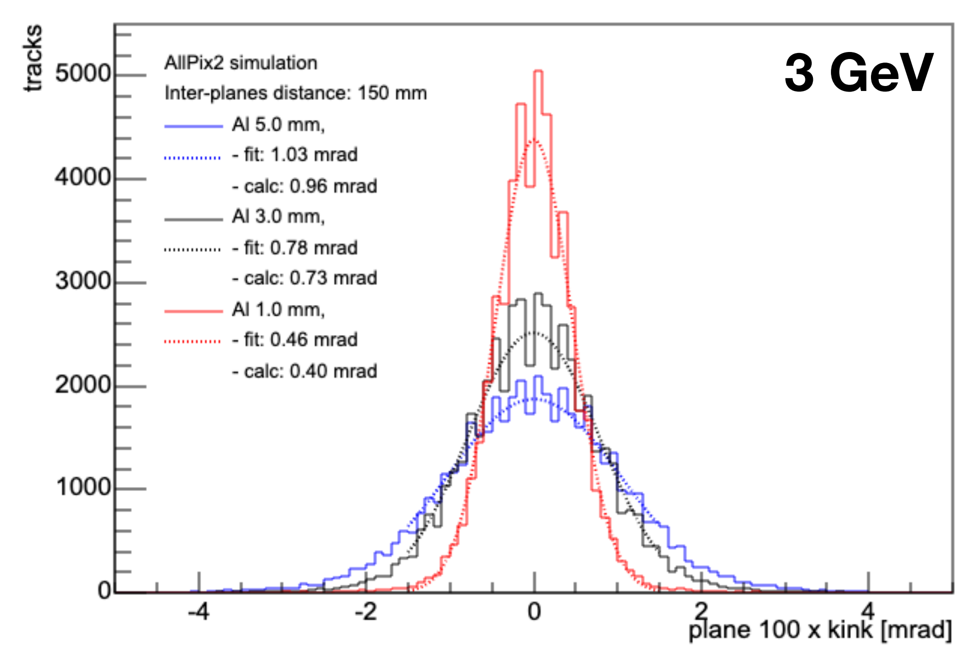
Examples of 3D MBI



H. Jansen talk at BTTB7



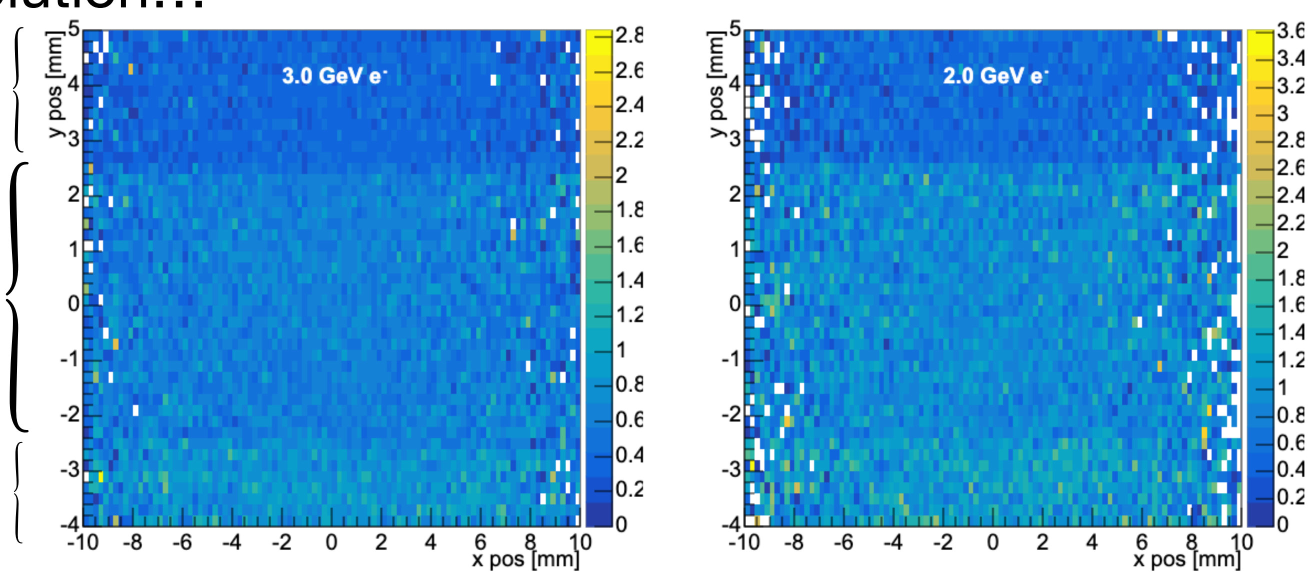
GBL kink angle at plane 100



1 mm Al

3 mm Al

5 mm Al



An interesting option for imaging!

Ivan López Paz
Pizza Seminar
5th of May 2021

Irradiation

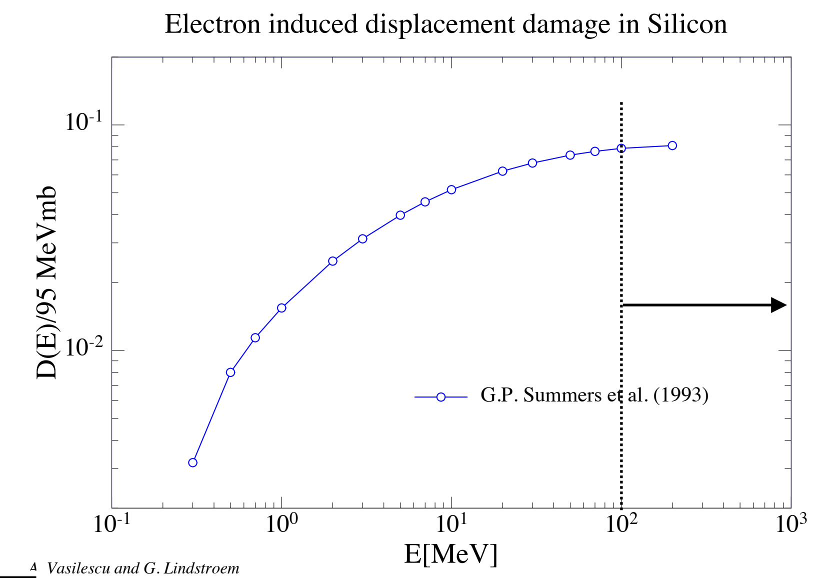
eALBA as an Irradiation Facility

NIEL Irradiation and Space Applications

- **NIEL:** Back-of-the-envelope calculation:
  - in Silicon, k ~ 0.08 (for E=200 MeV), with A_{beam} = 1 cm^2:

    $dF/dt = 6.75 \cdot 10^{13}$ e/(cm^2·hr)
    $d\Phi/dt = 5.47 \cdot 10^{12}$ n_{eq}/(cm^2·hr)

low for HEP… (~10^{15} n_{eq}/cm^2)



A. Vasilescu and G. Lindstroem

- For **space applications**, it is more relevant the Single-Event-Events cross-section
  - Example: SEU assessment for the JUICE space mission (ESA) in Jupiter
  - Vesper (CERN) facility goes up to 200 MeV electrons, eALBA could be used to complement these

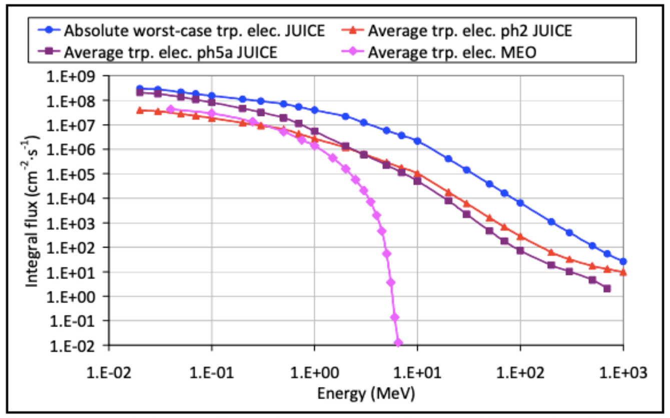


Fig. 1. Trapped electron fluxes for JUICE and for a Middle Earth Orbit.

N. Sukhaseum *et al.*, doi:10.1109/RADECS45761.2018.9328721.

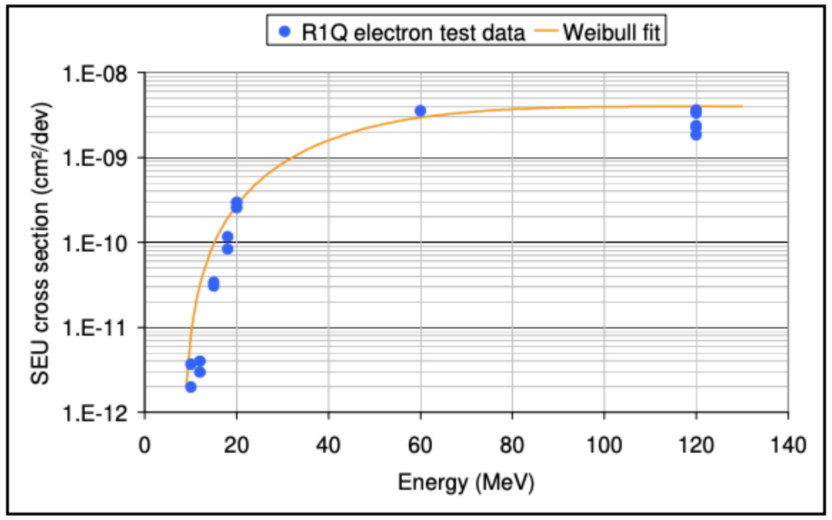


Fig. 3. R1QBA7218ABG electron SEU cross sections.

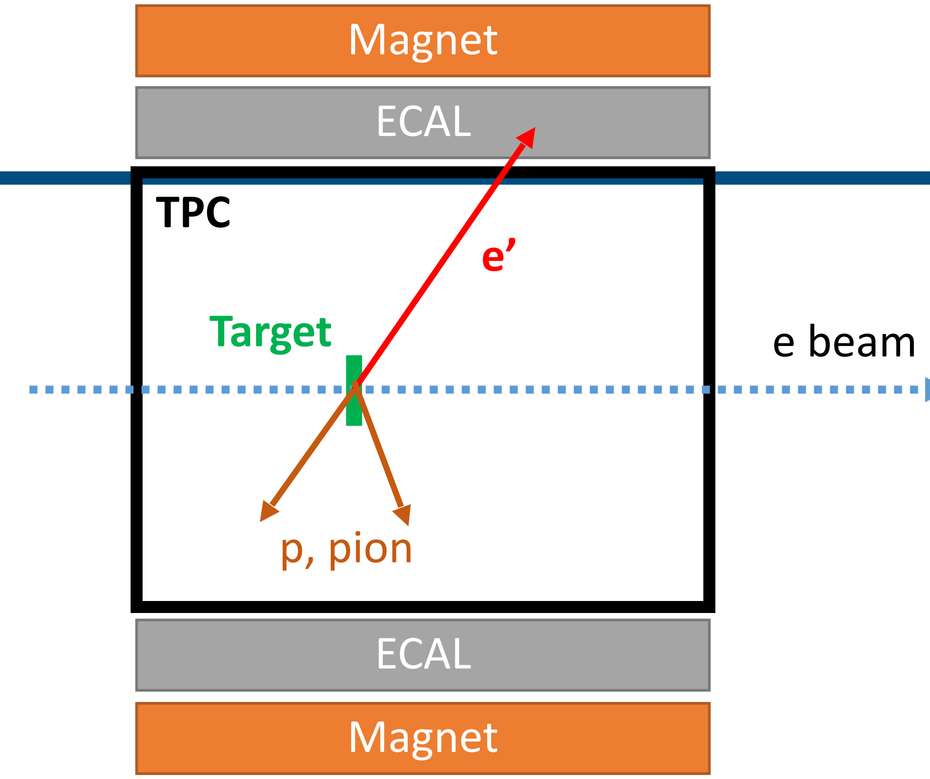
… but good for space applications!

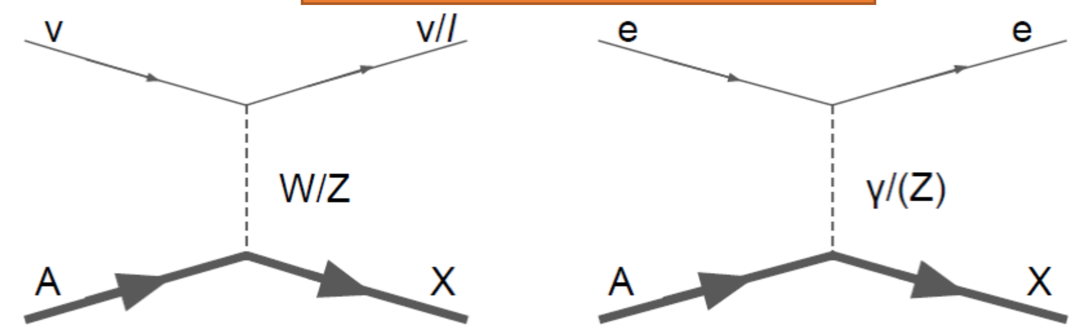
Electron nucleus scattering

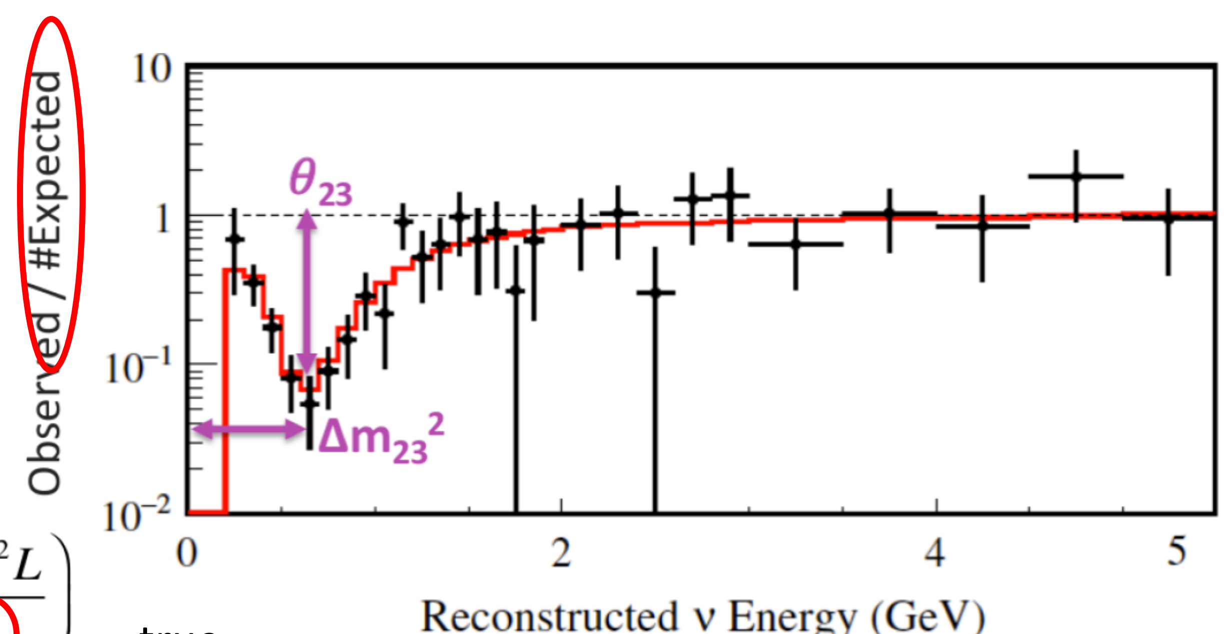
Electron Nucleus scattering

For neutrino experiments

- Similarities between νN and eN cross sections but electron energy well known and high statistics!
- Measured oscillation parameters depend on expected number of interactions and true neutrino energy:
  - MC generators for νN far from ideal
  - Reconstructed ν energy differs often from true one
- Tunable e beam in 100 MeV to 3 GeV energy range ideal for eN scattering







eN scattering could help to improve systematic uncertainties coming from this for HK and DUNE!

$$P(\nu_\mu \to \nu_\mu) = \sin^2(2\theta_{23}) \times \sin^2\left(\frac{\Delta m_{32}{}^2 L}{4E_\nu}\right)$$

← true

Conclusions

Summary and Outlook

- eALBA is a possible 0.1 to 3 GeV electron beam line for the ALBA synchrotron facility in Cerdanyola
- Beam parameters are interesting for tracking, imaging, irradiation, etc.
    - Preliminary studies show a good performance with such a beam!
- If well received, the facility could be ready in ~2 years
- Need your feedback! What would you do with this beam?

Back-up

DESY-II vs ALBA accelerators

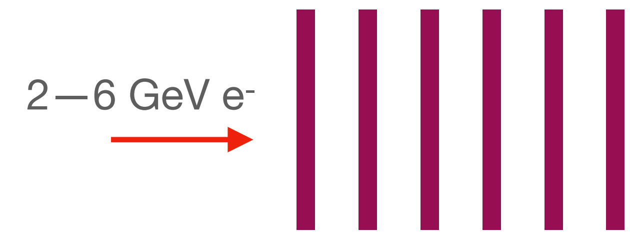
https://desy2.desy.de/

https://www.cells.es/ca/acceleradors/anell-de-p

Parameter	DESY II	eALBA
Umfang bei nominal Frequenz	292,8 m	249.6 m
Injection energy	450 MeV (e+/ e-)	100 MeV
Ejection energy	4,5 GeV (Doris) 6.0 GeV (Petra)	3 GeV
Repetition rate	12,5 Hz	3.125 Hz
Max. cavity voltage	13,5 MV	
Nominale Hf- Frequenz	499.6665 Mhz	500 MHz
Harmonic number	488	419
Number of cavities	8	
Anzahl der Hf- Klystron	2+1	
Max. Energie Verlust pro Umlauf	7,83 MeV	
Number of Bunches	1	150
Particles per bunch	1-3E10	4E7 (1nC/150 bnchs)
Nominale Tunes (Qx / Qy)	~6,7/~5,7	
Max.Syn. Tune (Qs)	56	
momentum compaction factor	0.0242	3.6E-4
Emittance	350 nm bei 6 GeV horiz. 35 nm bei 6 GeV vert.	50 nm rad (100 MeV) 9 mm rad (3 GeV)
Bunchlänge σz	23 mm	
Energiebreite (σe/E)	1.2*1E-3	0.25E-3

Tracking Simulation With AllPix2

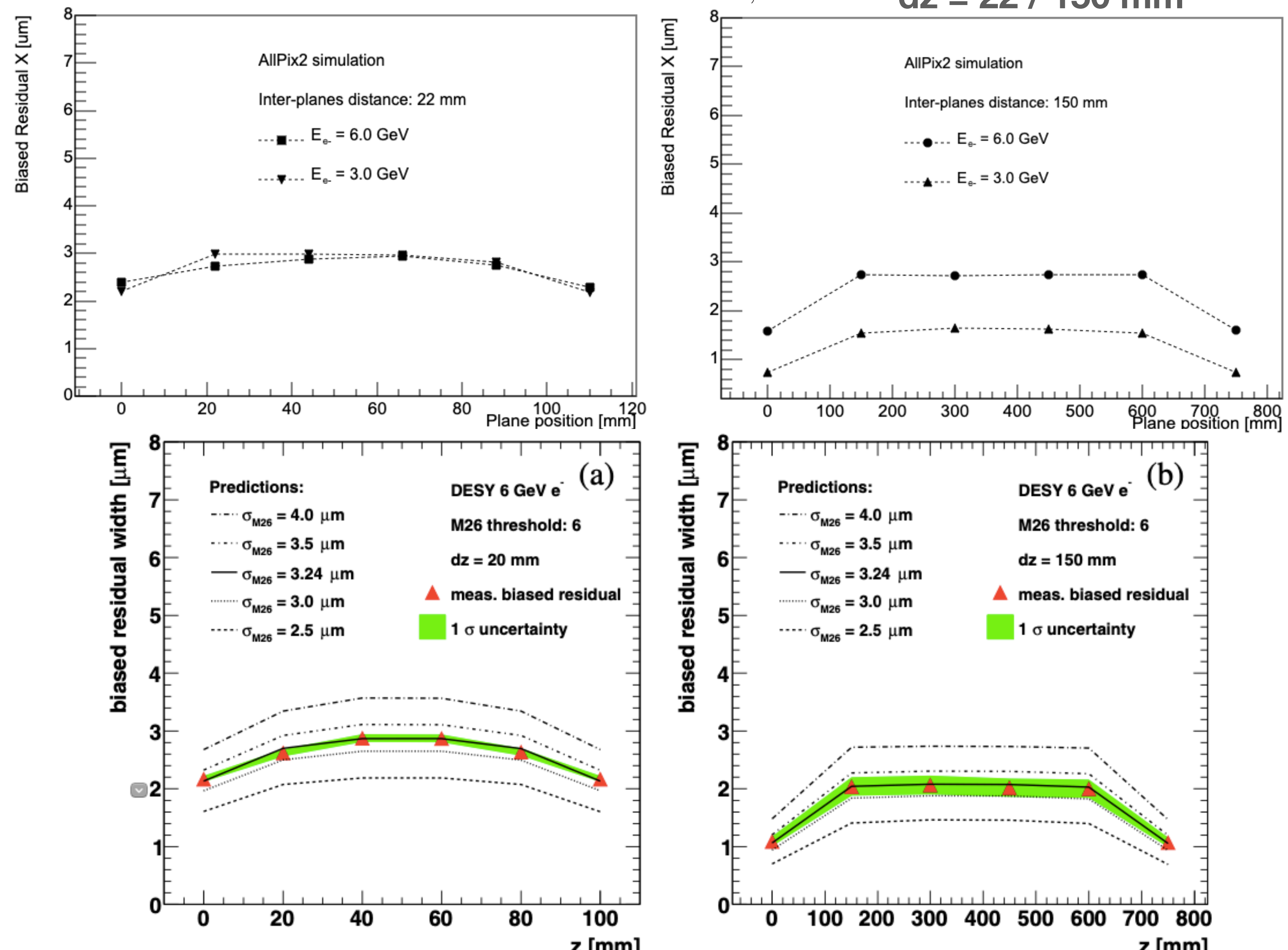
First tests, validation



$$r_{biased}(z)^2 = \sigma^2_{int}(z) - \sigma^2_{tel,biased}(z)$$

dz = 22 / 150 mm

- 6 Mimosa planes using Allpix2 example config
- Some possible outputs:
  - RCE root ntuple
  - EUTelescope LCIO
- Able to run EUTelescope reconstruction from AllPix2 data
- Compare with EUDET paper:
  - compatible results



H. Jansen *et al*. *EPJ Techniques and Instrumentation* (2016) 3:7

Ivan López Paz
Pizza Seminar
Zth of YYY 2021