Probing Strong-field QED at FACET-II (SLAC E-320)

FACET-II Science Workshop 2019

October 29 - November 1, 2019, SLAC

Sebastian Meuren

(representing the E-320 collaboration)

E-320 collaboration

International collaboration (15 institutions, 7 countries), all relevant scientific areas are represented:

SFQED theory & simulations, SFQED experiments (E-144, recent LWFA & crystal-based), strong-field AMO/x-ray science, HEDP/plasma physics, accelerator science, high-intensity laser & detector experts

Carleton University, Ottawa, Ontario, Canada	Thomas Koffas
Aarhus University, Aarhus, Denmark	Christian Nielsen, Allan Sørensen, Ulrik Uggerhøj
École Polytechnique, Paris, France	Sébastien Corde, Pablo San Miguel Claveria
Max-Planck-Institut für Kernphysik, Heidelberg, Germany	Antonino Di Piazza, Christoph Keitel, Matteo Tamburini, Tobias Wistisen
Helmholtz-Institut Jena, Germany	Harsh, Felipe Salgado, Christian Rödel, Matt Zepf
Universidade de Lisboa, Portugal	Thomas Grismayer, Luis Silva, Marija Vranic
Imperial College London, UK	Elias Gerstmayr, Stuart Mangles
Queen's University Belfast, UK	Niall Cavanagh, Gianluca Sarri
California Polytechnic State University, CA USA	Robert Holtzapple
Lawrence Livermore National Laboratory, CA USA	Felicie Albert
SLAC National Accelerator Laboratory, Menlo Park, CA USA	Dario Del Sorbo, Angelo Dragone, Frederico Fiuza, Alan Fry, Siegfried Glenzer, Tais Gorkhover, Carsten Hast, Christopher Kenney, Stephan Kuschel, SM, Doug Storey, Glen White
Stanford University, Stanford, CA USA	Phil Bucksbaum, David Reis
University of California Los Angeles, CA USA	Chan Joshi, Warren Mori Compton spectrometer: Brian Naranjo, James Rosenzweig
University of Colorado Boulder, CO USA	Michael Litos
University of Nebraska - Lincoln, NE USA	Matthias Fuchs

Initial scientific goals

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Collide 13 GeV e^- with ~10 TW laser pulses:

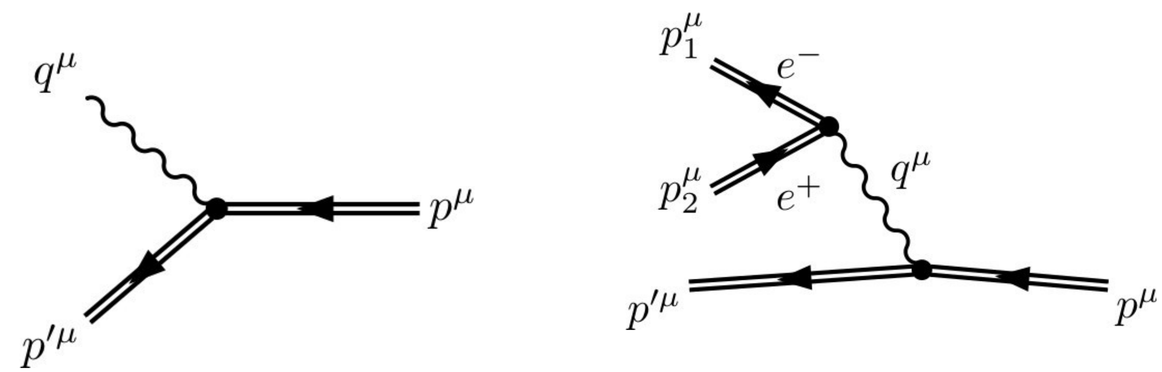
→ Intensity boost from ~10^{20} W/cm^2 (lab frame) to ~10^{29} W/cm^2 (electron rest frame)

→ **reach QED critical (Schwinger) field** $E_{cr} = mc^2/e\lambda\!\!\!^{-}_C \sim 10^{18}$ V/m ($\lambda\!\!\!^{-}_C = \hbar/mc \sim 10^{-13}$ m)

→ **E~0.1 E_{cr}: quantum beamstrahlung** recoil of individual photons is significant

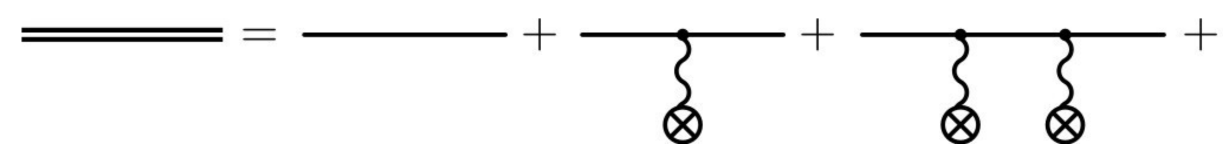
→ **E$\gtrsim$ E_{cr}: electron-positron pair production** (vacuum becomes unstable)

Fundamental strong-field QED processes

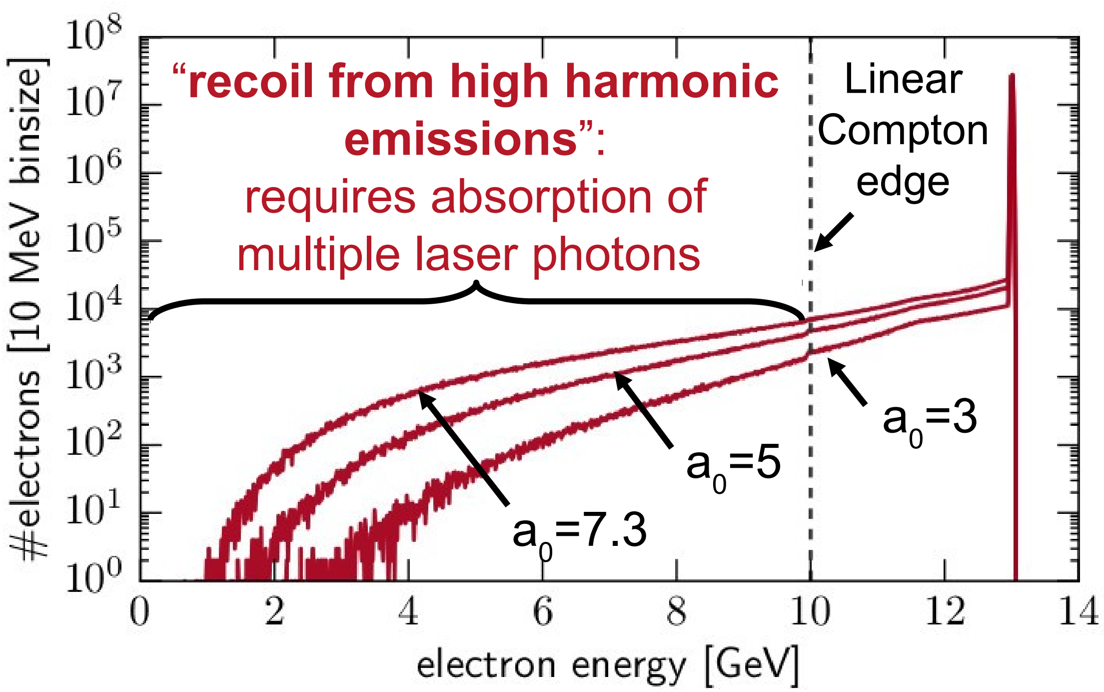


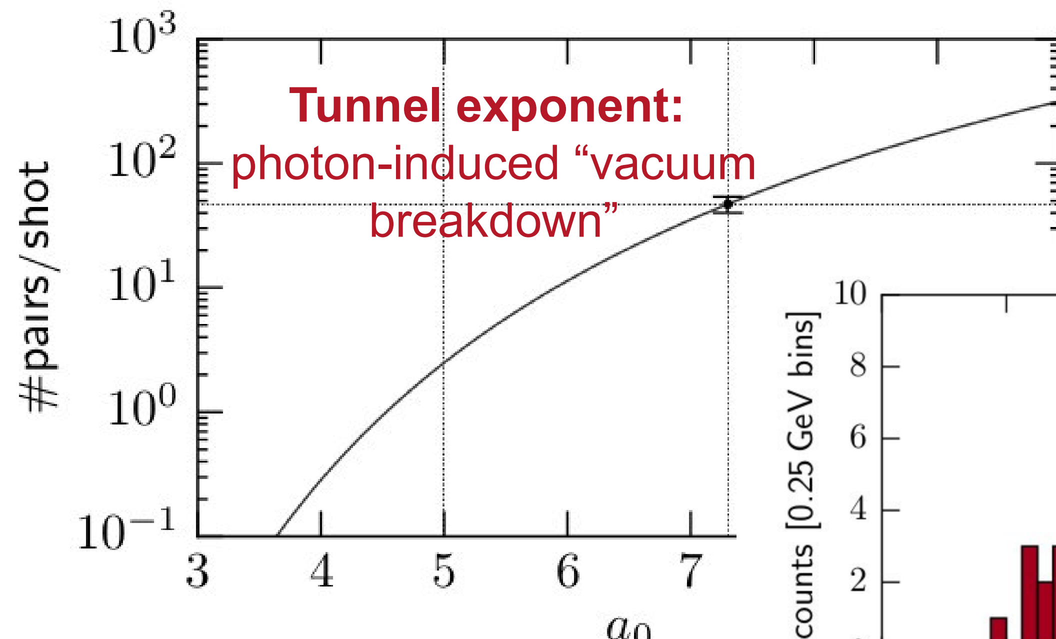
Quantum beamstrahlung

Electron/positron pair production

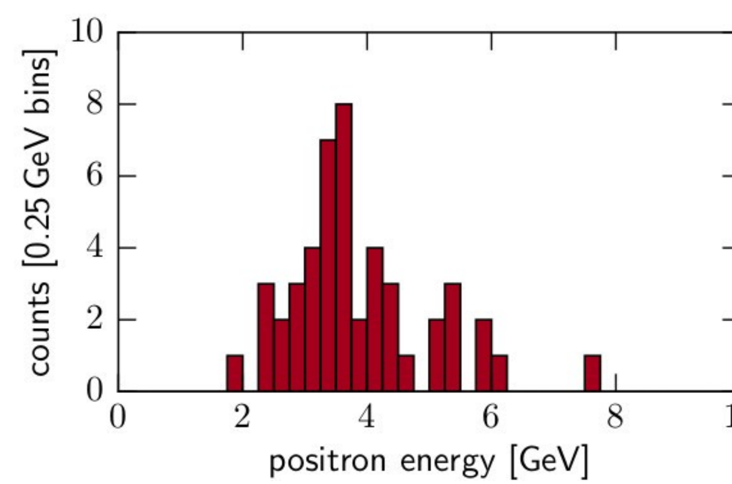


Dressed states ($a_0 \gtrsim 1$): laser becomes nonperturbative





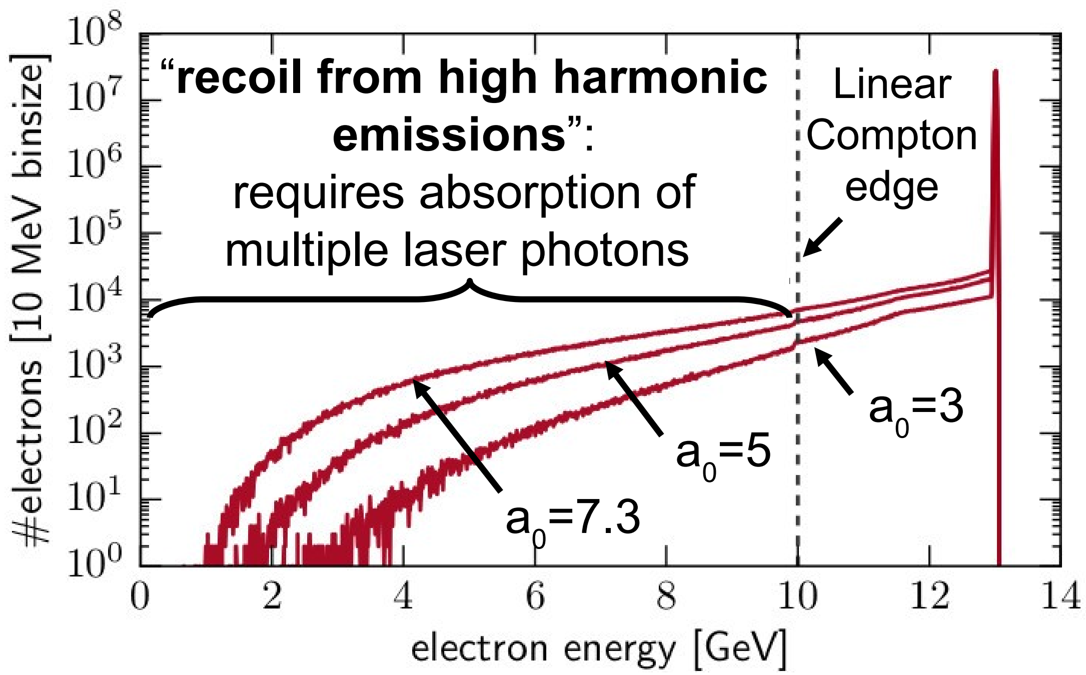
Positron Production



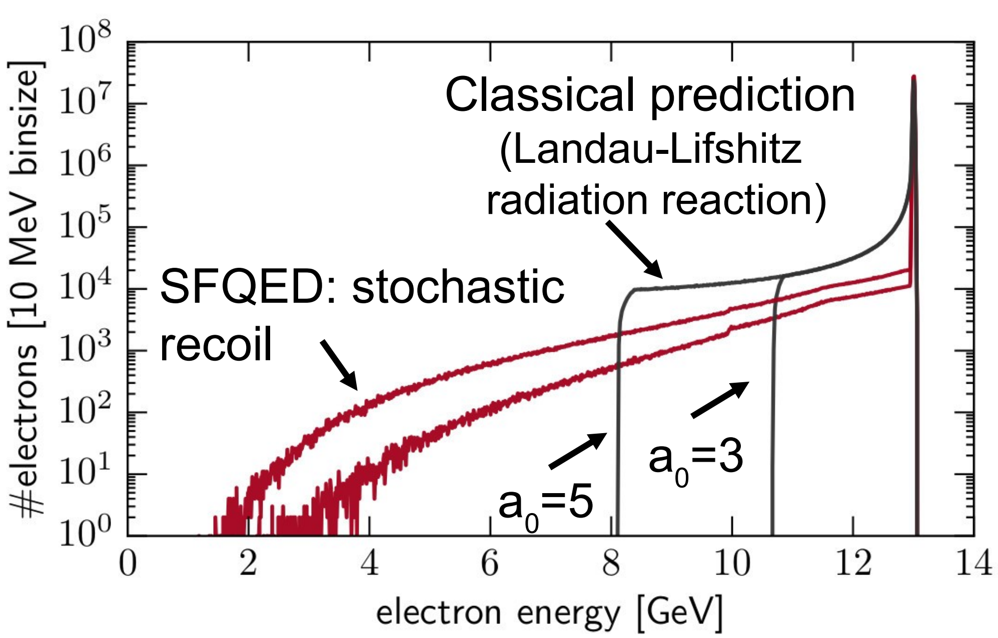
Simulations: M. Tamburini (MPIK) and M. Vranic (Lisbon)

Main innovation of the initial program

First measurement in the “quantum tunneling regime” ($a_0 \gg 1, \chi \gtrsim 1$)

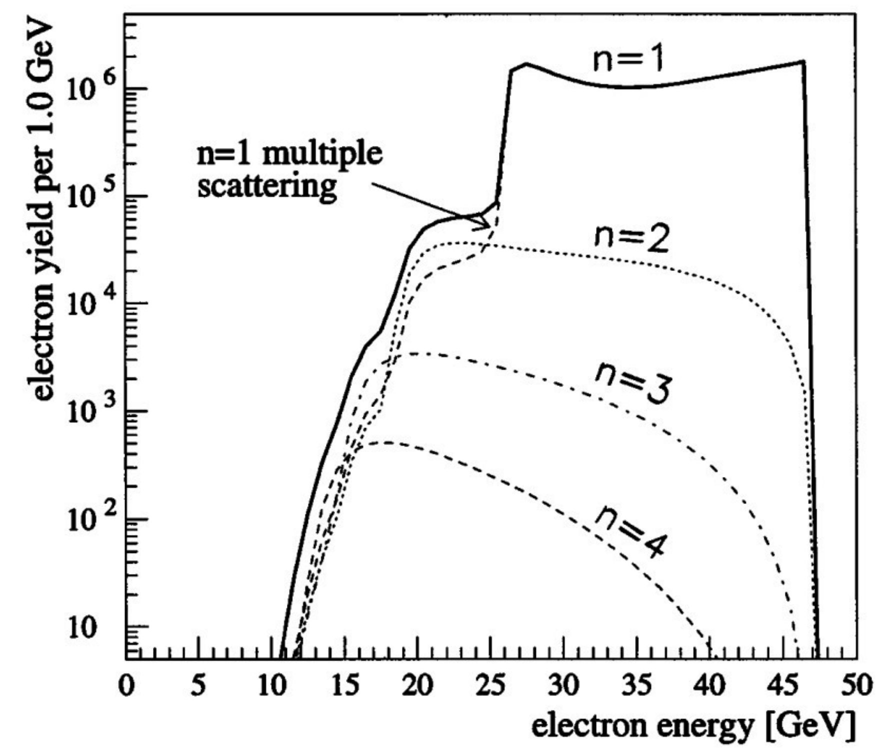


Classical electrodynamics fails ($\chi \gtrsim 0.1$)



- **Nonperturbative laser-electron interaction** (absorption of multiple laser photons important)
- **Radiation field becomes nonperturbative** (emission of multiple gamma photons dominant)

Perturbative QED fails ($a_0 \gtrsim 1$)



SLAC E-144: “perturbative multi-photon regime” ($a_0<1, \chi<1$)

Bula et al., PRL 76, 3116 (1996); perturbative scaling: $\sim a_0^{2n}$

FACET-II perturbative pair production threshold: $n > 4a_0/\chi \approx 26$

Neitz & Di Piazza, PRL 111, 054802 (2013); Vranic et al., PRL 113, 134801 (2014) & many recent publications;

Simulations: M. Tamburini & M. Vranic

Electron beam: initial configuration for SFQED

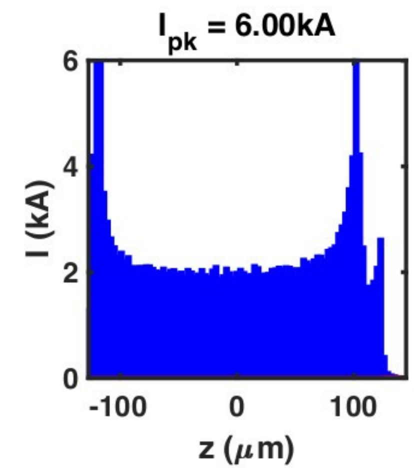
Main objectives for SFQED

- Highest possible energy: 13 GeV (~0.1% rms deviation)
- Low backgrounds, very clean beam
- → small divergence, large spot size

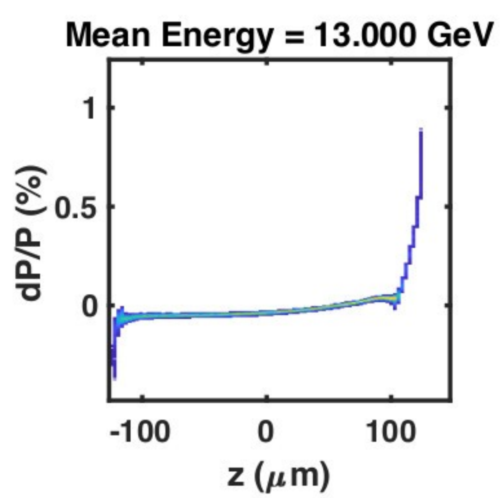
Beam parameters

Energy (E)	[GeV]	13.0
dE/E	[%]	$\lesssim 0.1$
Charge	[nC]	2.0
σ_x	[µm]	24.4
σ_y	[µm]	29.6
L	[µm]	250
$\gamma\epsilon_x$	[µm · rad]	3.7
$\gamma\epsilon_y$	[µm · rad]	4.0
$\sigma^*_{x'} = \epsilon_x/\sigma_x$	[µrad]	6.1
$\sigma^*_{y'} = \epsilon_y/\sigma_y$	[µrad]	5.4

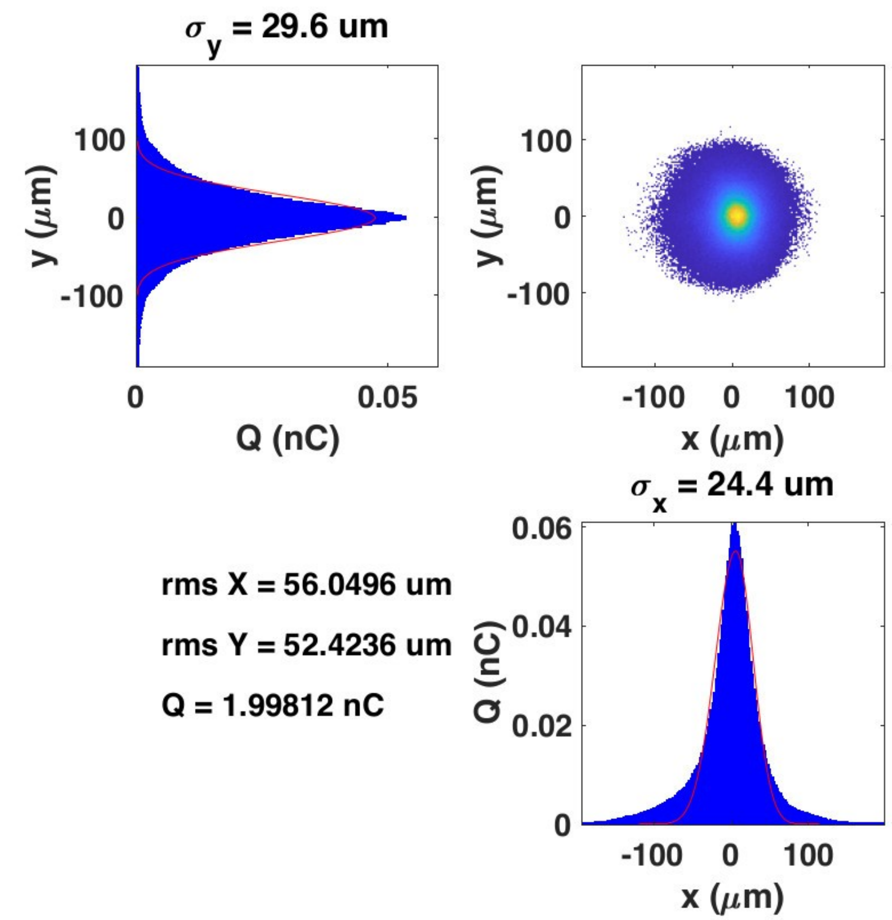
Longitudinal profile



Energy chirp



Transverse profile



- Flat-top beam: transverse Gaussian (σ_x= 24.4µm, σ_y= 29.6µm); longitudinal flat (length: 250µm)
- The beam contains ~ 10^{10} electrons (2nC), but we interact only with ~ 1% of the charge

Optimized by Glen White (SLAC)

Initial laser configuration

Main aim for SFQED

- Highest pulse energy $\mathscr{E}_L$ (0.6J on target)
- Shortest duration τ_0 (35fs FWHM intensity)
- Smallest possible spot size w_0 ($\lesssim$3μm)

→ **maximize peak field strength (a_0)**

Initial laser configuration
(after ongoing upgrade)

Parameter	Value
Power-amp pump	3.6 J
Power-amp output	1.1 J
Beam transport input	1.0 J
Compressor input	0.9 J
Beam size	4 cm diameter 150 ps FWHM
Compressor output	$\mathcal{E}_L = 0.61\,\mathrm{J}$
Pulse duration (FWHM)	$\tau_0 = 35\,\mathrm{fs}$
Laser power	$\mathcal{E}_L/\tau_0 = 17\,\mathrm{TW}$
Intensity ($w_0 = 3\,\mu\mathrm{m}$)	$10^{20}\,\mathrm{W/cm^2}$
Intensity parameter a_0 (peak)	7.3

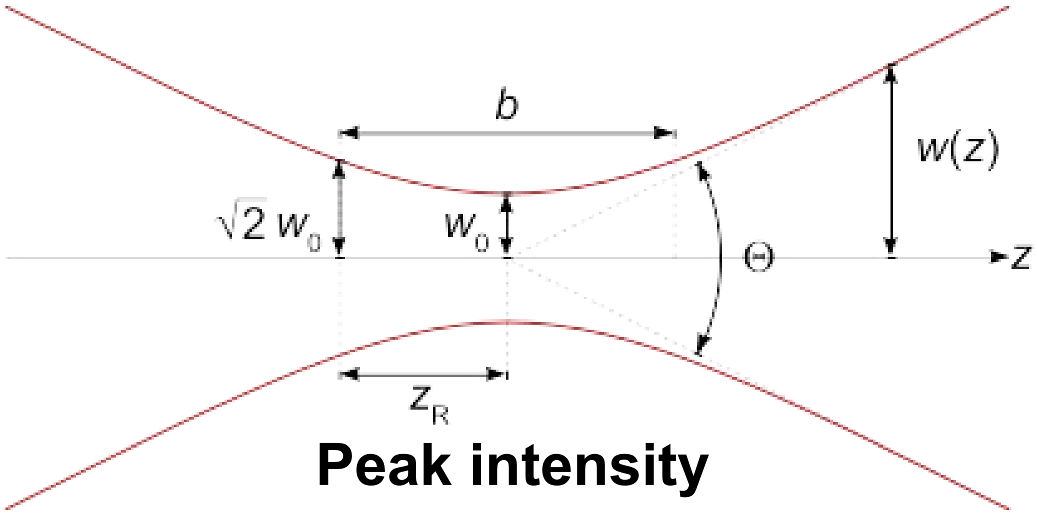
Temporal/longitudinal envelope

$$I(r,z,t) = I(r,z)\exp\left[-4\ln(2)\frac{(z-ct)^2}{c^2\tau_0^2}\right]$$

Transverse spatial envelope

$$I(r,z) = I_0\left[\frac{w_0}{w(z)}\right]^2\exp\left[-\frac{2r^2}{w^2(z)}\right]$$

$$w(z) = w_0\sqrt{1+(z/z_R)^2}, \quad z_R = \pi w_0^2/\lambda_L$$



Peak intensity

$$I_0 = \frac{n\mathcal{E}_L}{(\tau_0\pi w_0^2)}, \quad n = 4\sqrt{\frac{\ln 2}{\pi}} \approx \frac{3\pi}{5} \approx 1.88$$

Reduced vector potential

$$a_0 = \frac{eE_0}{mc\omega} \approx 0.60\,(\lambda_L[\mu\mathrm{m}])\sqrt{2I_0\,[10^{18}\,\mathrm{W/cm^2}]}$$

Idealized discussion, main safety factor: focus tighter than w_0 = 3μm

Picnic Basket (IP): OAPs & laser focus

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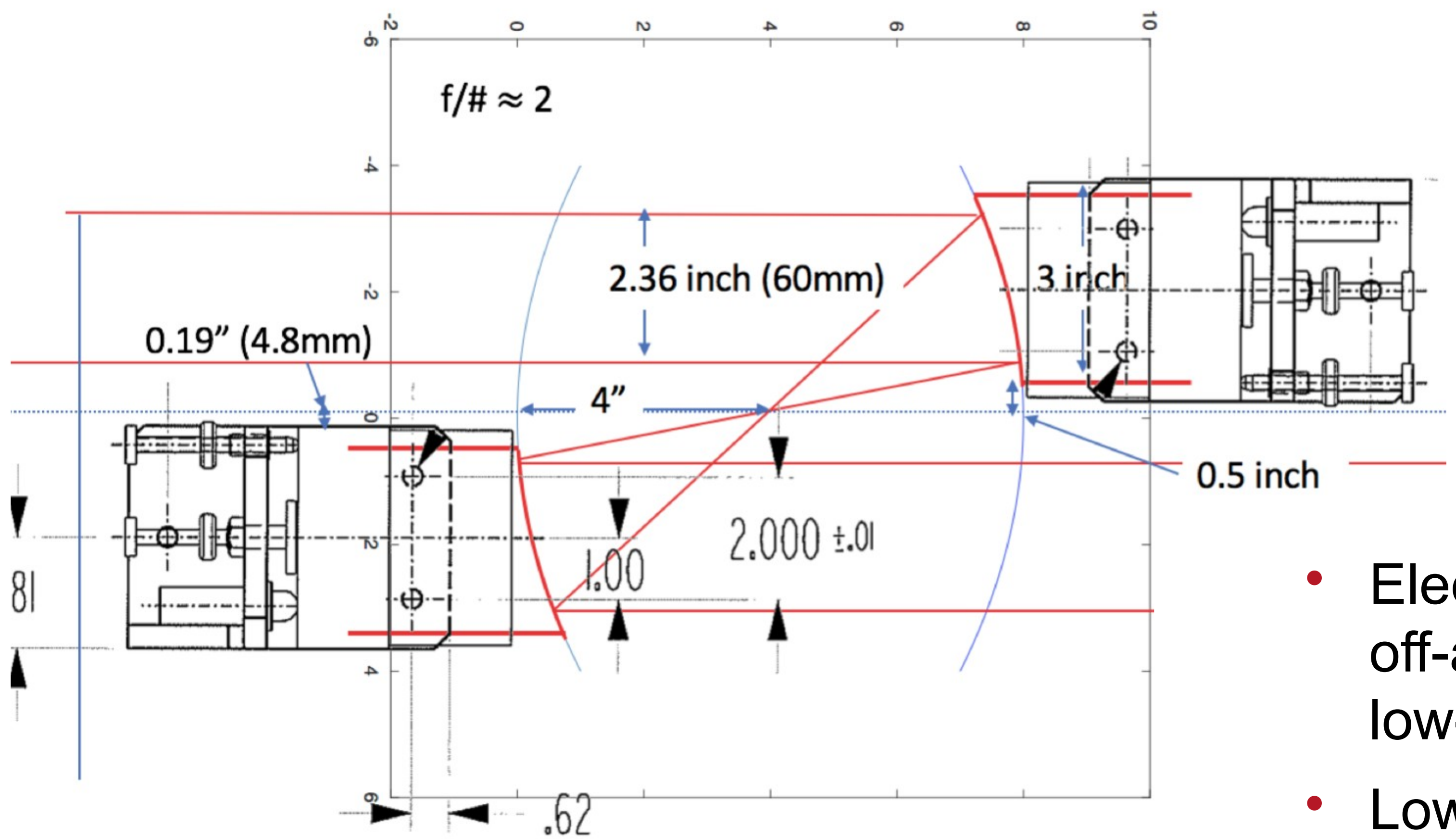
f/2 focusing geometry (concept)

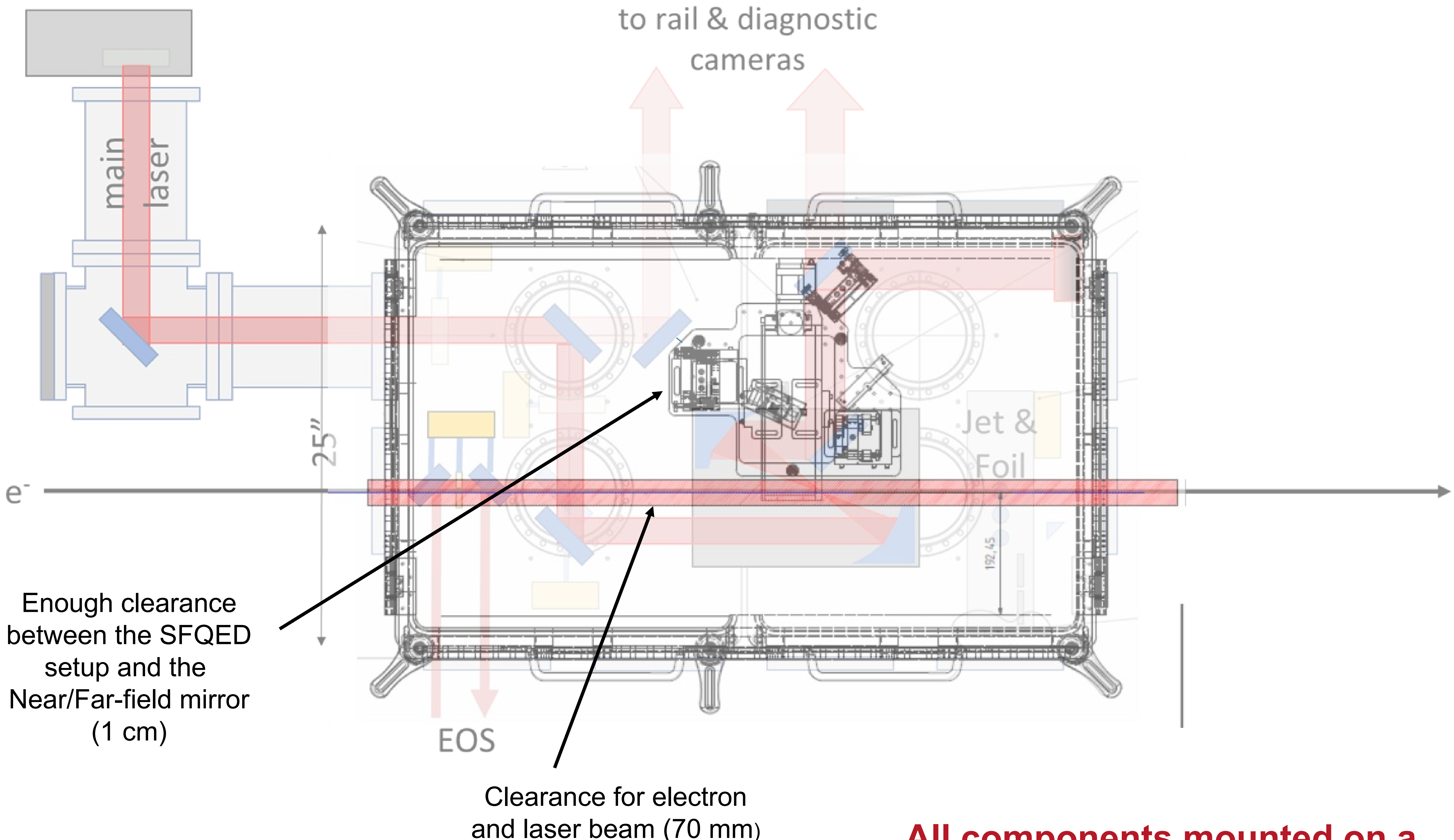


Off-axis parabolas ready by mid-January (SORL) + 3-4 weeks for coating (ARO)

- Electron-laser scattering angle: 180-26.5° off-axis: ~5% reduction in χ, while reducing low-intensity interaction out of focus
- Low surface roughness/errors
- 2nd OAP: telescope to re-collimate for dumping/far-field diagnostics; shot-to-shot high-intensity focus diagnostic
- High damage threshold dielectric coating
- Two configurations:
  - 40mm input (2" dia. 3" f.l. input, M= -1.5)
  - 60mm input (3" dia, 4" f.l. M= -1; upgrade)

Slide by: Felipe Salgado, Harsh, Christian Rödel, Matt Zepf

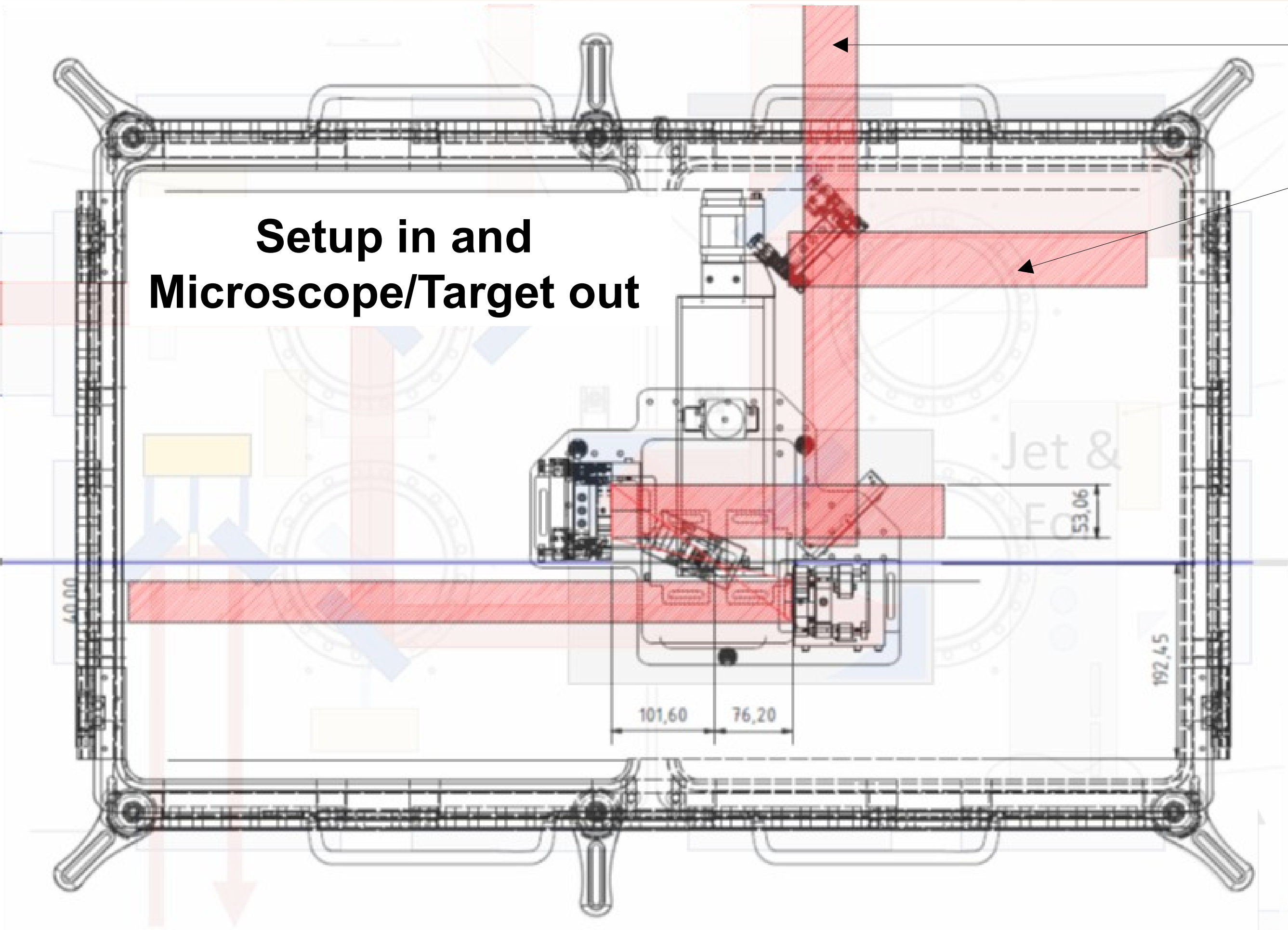
Picnic Basket (IP): SFQED moved out



All components mounted on a common plate

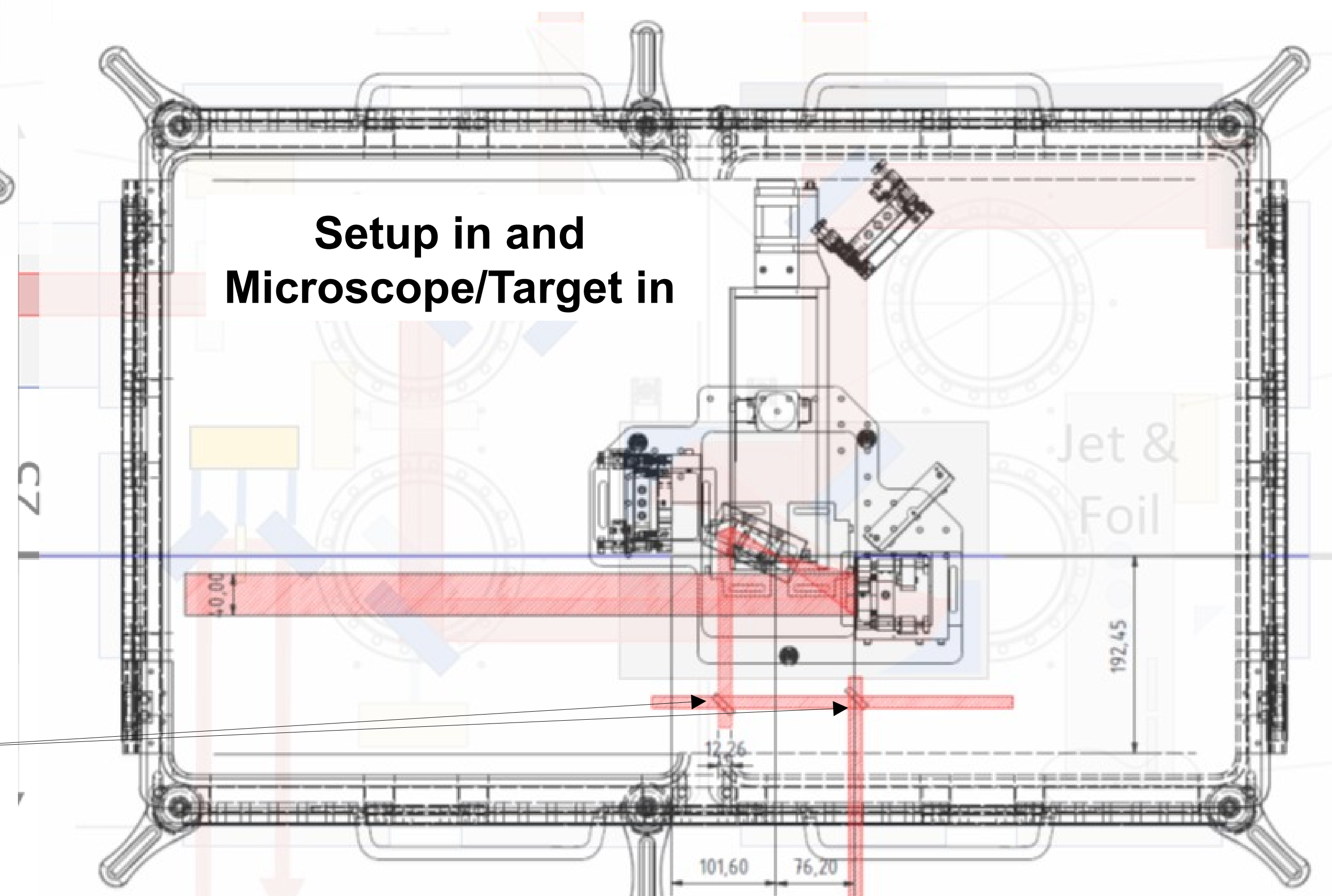
Slide by: Felipe Salgado, Harsh,
Christian Rödel, Matt Zepf

Picnic Basket (IP): setup moved into the beamline



Laser leakage (after focus diagnostics)

Laser beamdump somewhere (in PB)



1'' mirrors to steer out the light
from the microscope objective

Slide by: Felipe Salgado, Harsh, Christian Rödel, Matt Zepf

Picnic Basket (IP): list of stages and motors

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Component	Remarks	Motion	Stages	Number of motors
Parabola 1 (OAP1)	• Placed above the breadboard plate • Motorized with 5-axis • Mounting: 2 in clear edge picomotor mirror mounting	• 5-axis alignment stage: X-Y-Z-H-V • Picomotor mountings: H, V	5-axis alignment stage: Newport 8081M-UHV Mirror Mounting: Newport 8822	5x picomotors (5-axis) 2x picomotors (mirror mounting)
Parabola 2 (OAP2)	• Placed above the breadboard plate • Motorized with 5-axis • Mounting: 3 in clear edge picomotor mirror mounting	• 5-axis alignment stage: X-Y-Z-H-V • Picomotor mountings: H, V	5-axis alignment stage: Newport 8081M-UHV Mirror Mounting: Newport 8823	5x picomotors (5-axis) 2x picomotors (mirror mounting)
Microscope objective	• Placed in a vertical stage • Motorized with 1 linear stage for focus scan • 5-axis for alignment.	• Linear stage with 25.4 mm travel range • 5-axis alignment stage: X-Y-Z-H-V	Compact linear stage: Newport MFA-CCV6 5-axis alignment stage: Newport 8081M-UHV	1x stepper motor 5x picomotors (5-axis)
Stage for support of the microscope objective and alignment wire	• Placed on the breadboard plate • Supports the stages for the microscope objective and alignment components • Motorized in the vertical motion	• Linear motion in the vertical direction. • Load capacity: 30N • Travel range: 100 mm	Linear stage: Physik Instrumente (PI) VT-80, model: 62309240 (0.75 kg)	1x stepper motor with mechanical limit switches
YAG screen and (cross-) wire for alignment	• 5-axis for alignment.	• 5-axis alignment stage: X-Y-Z-H-V	5-axis alignment stage: Newport 8081M-UHV	5x picomotors (5-axis)
Base plate with all components	• Made of INVAR for low thermal expansion • Custom geometry • Motorized with miniature stepper motors (3-points)	• Miniature stepper motors • Minimum travel range: 10 mm (in the layout it has 25 mm)	3x Miniature stepper motors: Newport TRA25PPV6	3x stepper motor
Base plate with linear motion of all components (above the 150 mm linear stage)	• Made of INVAR for low thermal expansion • Custom geometry (same as the base plate above) • Motorized to remove/insert the entire setup. • Min travel range to remove the setup: 130 mm	• Linear stage with stepper motor + mechanical limit switch • Travel range: 154 mm	Linear Stage: Owis LTM 80F-200-MSM	1x stepper motor with mechanical limit switches

Number of Motors

Picomotors	24
Stepper Motors	6

Slide by: Felipe Salgado, Harsh,
Christian Rödel, Matt Zepf

Picnic Basket (IP): conceptual alignment procedure

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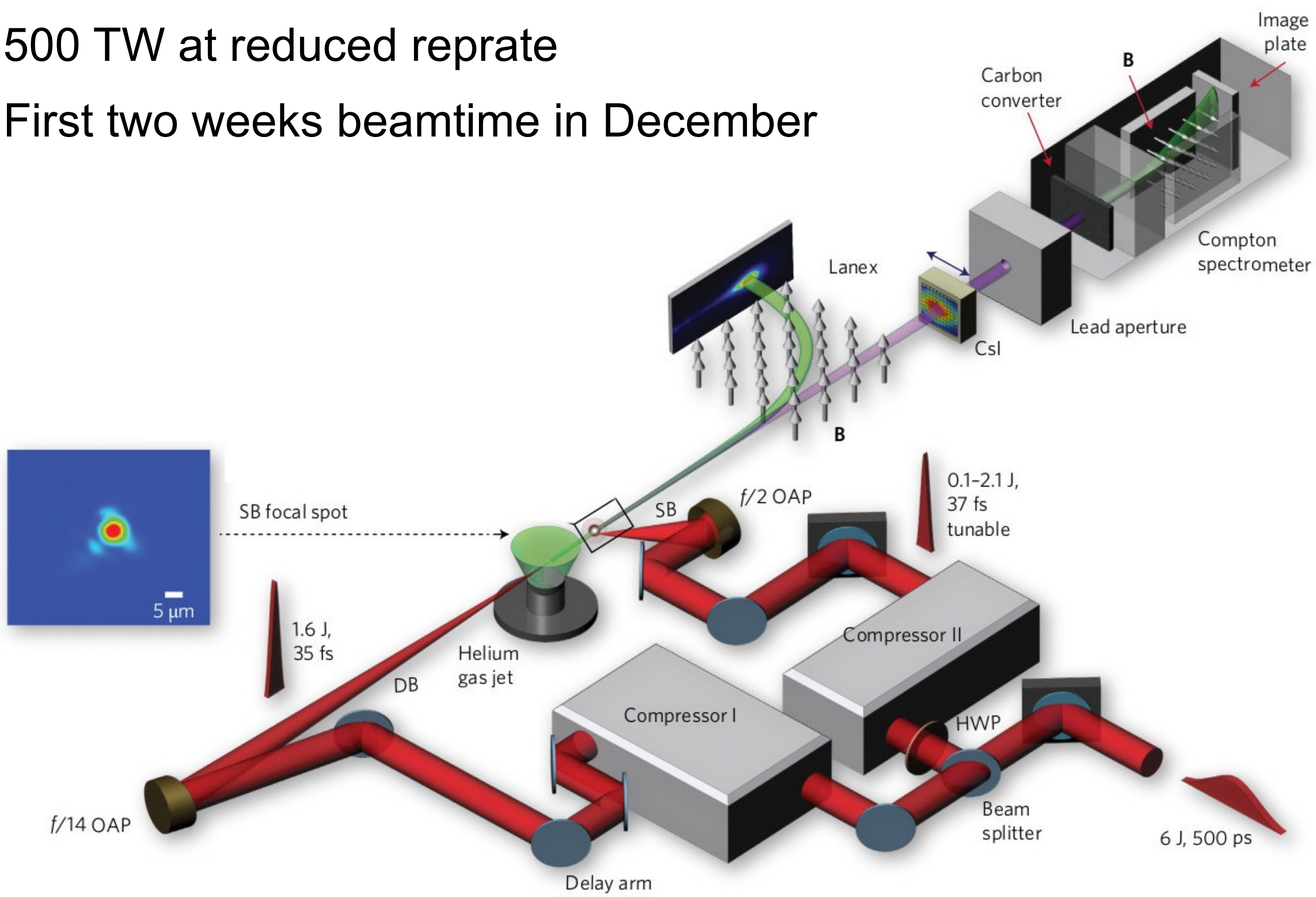
1. **Externally aligned OAPs and MO on common platform** using HeNe, Interferometer and Microscope
   - Place 2 µm pinhole in focal position and check the focal spot
   - Leave alignment wire in focal position
2. **Image out 2 µm pinhole with lens and camera to be used downstairs**
   - Confirm shape of pinhole is same on both images (microscope and OAP/lens imager)
3. **Bring setup to the Picnic Basket**
   - Align the setup with the common plate setup: linear stage (position) and 3-point mounts (angle)
4. **Optimize Focus Spot**
   - Bring MO/Target setup in
   - Perform a focus scan and fine alignment

LaserNetUS

Nebraska Beamtime

- Competitive LaserNetUS beamtime award (4 weeks)
- **Goal**: develop absolute intensity measurement, as well as fast monitor for tuning focus/compression
- **Idea**: measure relativistic ATI and high charge states of dilute heavy rare gas (Kr, Xe)
- 100 TW, 10 Hz system, demonstrated a_0~10 with angular asymmetry nonlinear Thomson emission with similar focusing
- 500 TW at reduced reprate
- First two weeks beamtime in December



Yan et al., Nature Photon. 11, 514 (2017)

Diocles 100 TW Mode

Parameter	Value	Unit	Additional Information
Center Wavelength	805	nm	
Pulse duration (I FWHM)	30	fs	
Max energy on target	3.5	J	
Shot energy stability	5	%	
Focal spot at target			
F/number	f/2		
intensity FWHM	2	µm	
Strehl ratio	0.9		
Energy containment	90	% within 3.6 µm radius	
F/number	f/15		
intensity FWHM	20	µm	
Strehl ratio	0.9		
Energy containment	90	%	within 36 µm radius
Pointing Stability	10	µrad	
Pre-pulse contrast			
ns scale	10^{-9}		@ >1 ns
ps scale	$5x10^{-9}$		@ 5 ps
	$3x10^{-8}$		1 ps
Repetition Rate	10	Hz	

Sebastian Meuren (representing the E-320 collaboration)

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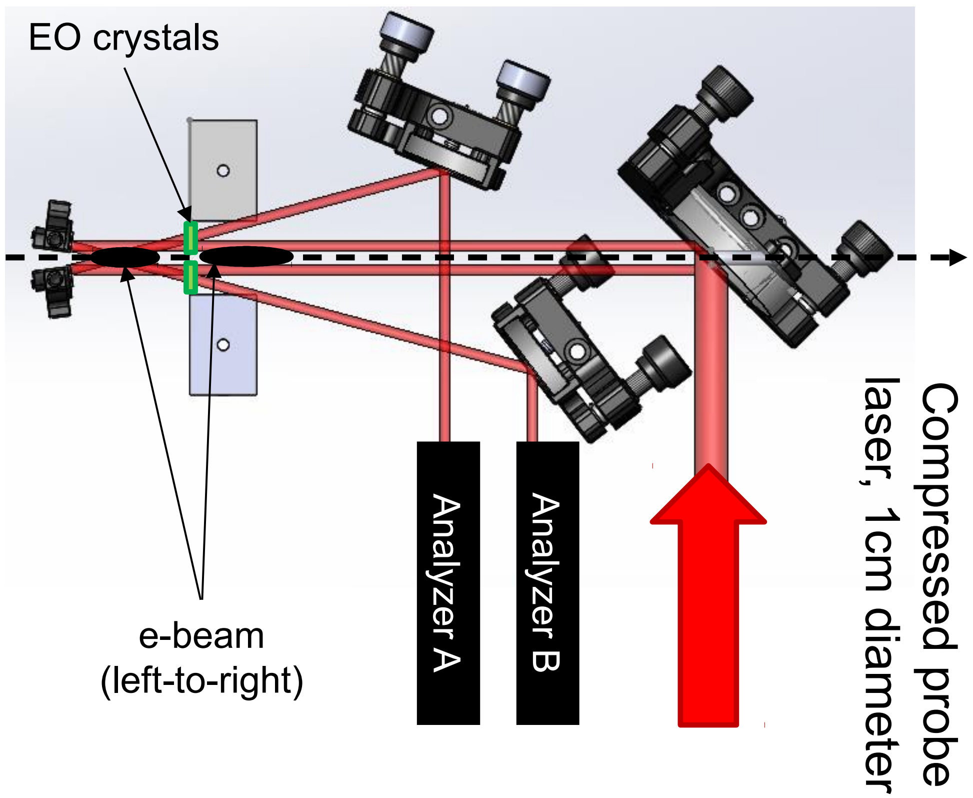
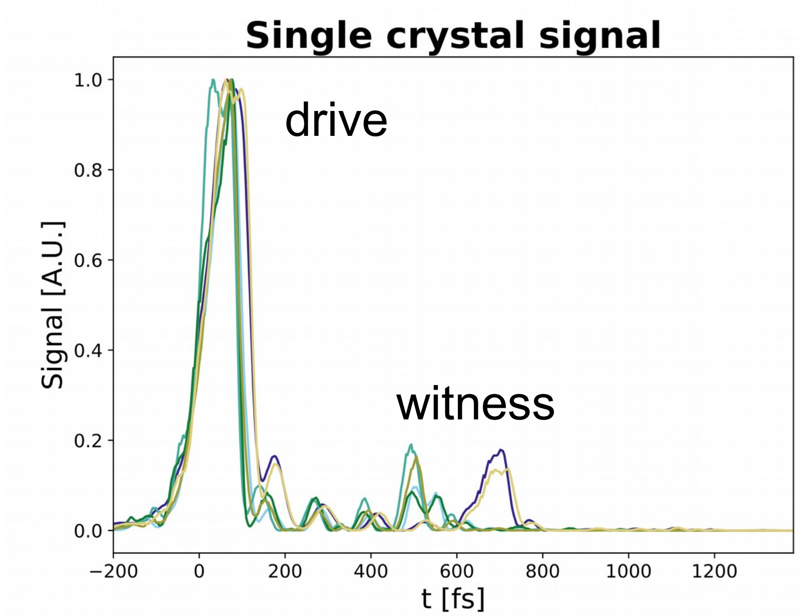
Electro-Optic Sampling Beam Position Monitor (EOS-BPM)



General idea: Uses spatial encoding; based on FACET EOS: two EO crystals straddle e-beam upstream of USHM Compressed, low-E probe laser split into two beams

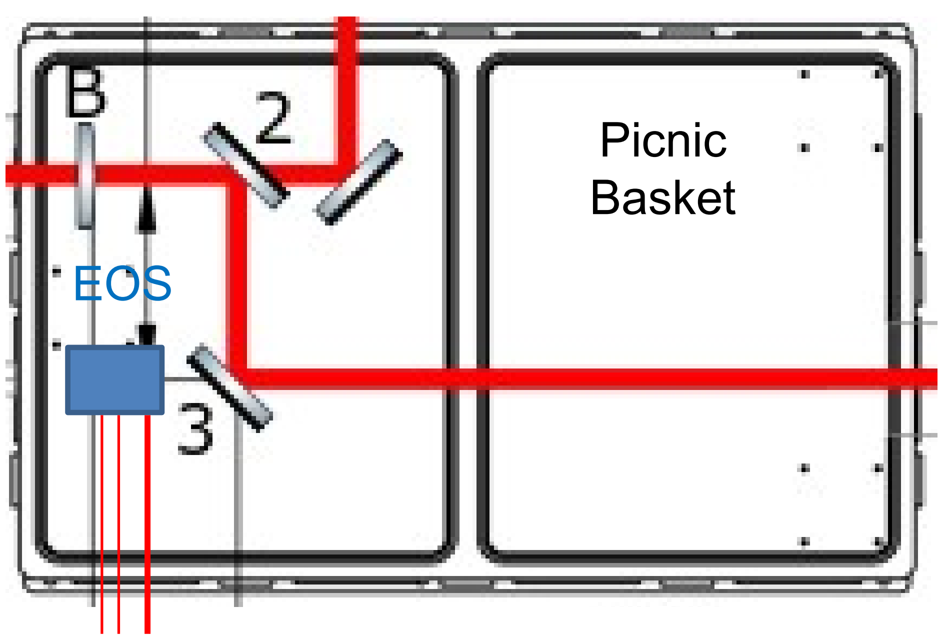


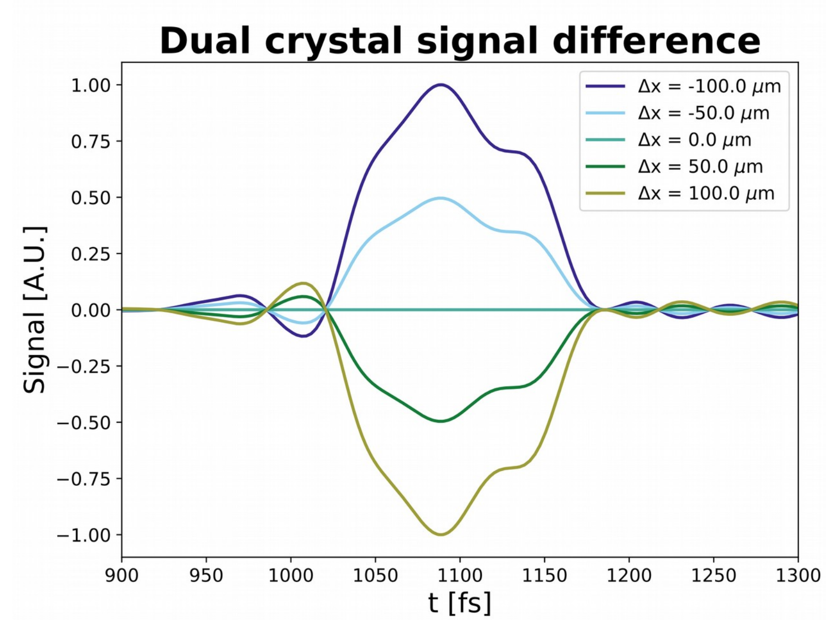
Estimated peak timing resolution: ~30 fs

FACET Values

Peak resolution: ~30 fs

Laser/e$^-$ jitter: ~110 fs





Estimated transverse sensitivity: 1% / μm

- 10% sensitivity: 10 μm
- 5% sensitivity: 5 μm
- 1% sensitivity: 1 μm

Mike Litos (Colorado)

Sebastian Meuren (representing the E-320 collaboration)

Electro-Optic Sampling as bunch duration/timing measurement

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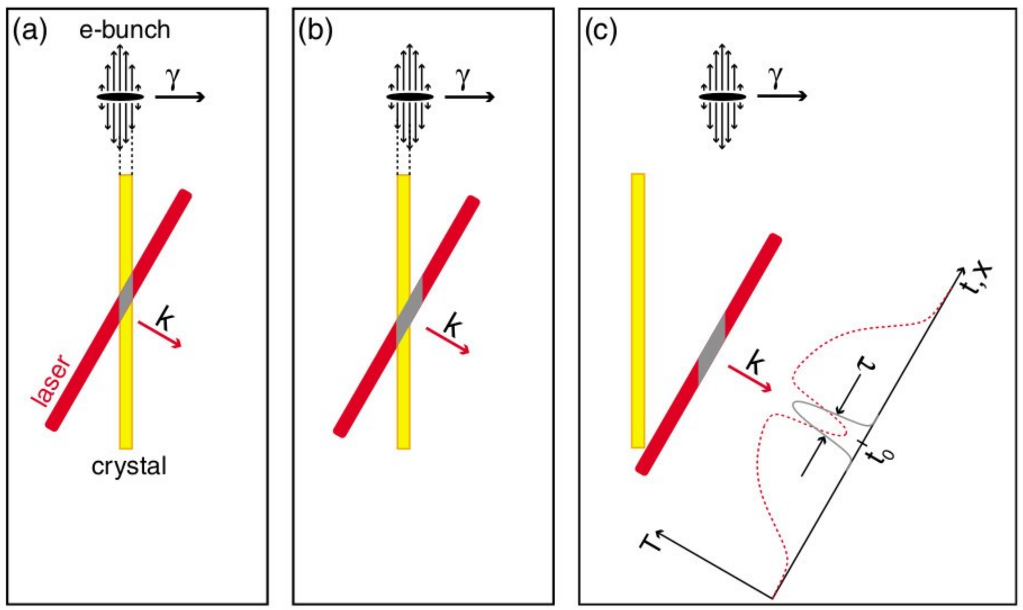
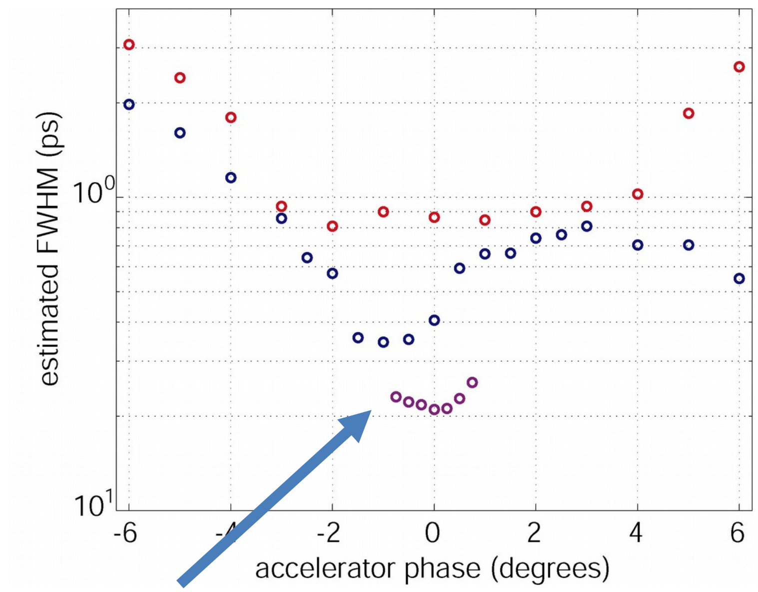
Cartoon illustration of EOS



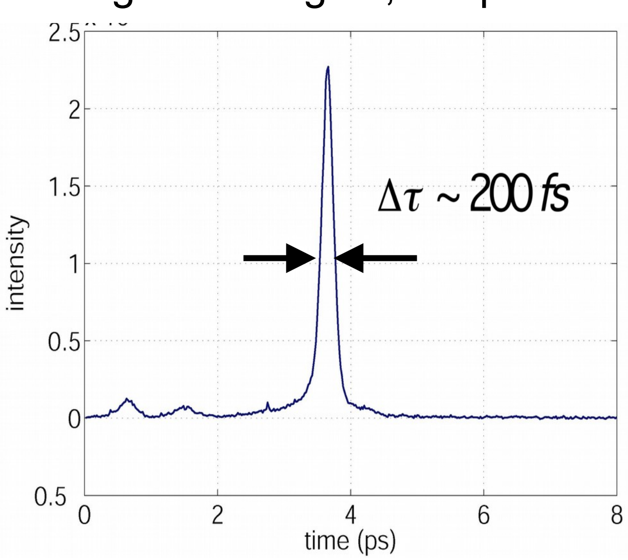
The electric field of the passing electron bunch changes the refractive index (Pockels effect); this changes the laser polarization

Compression scan (different crystals)

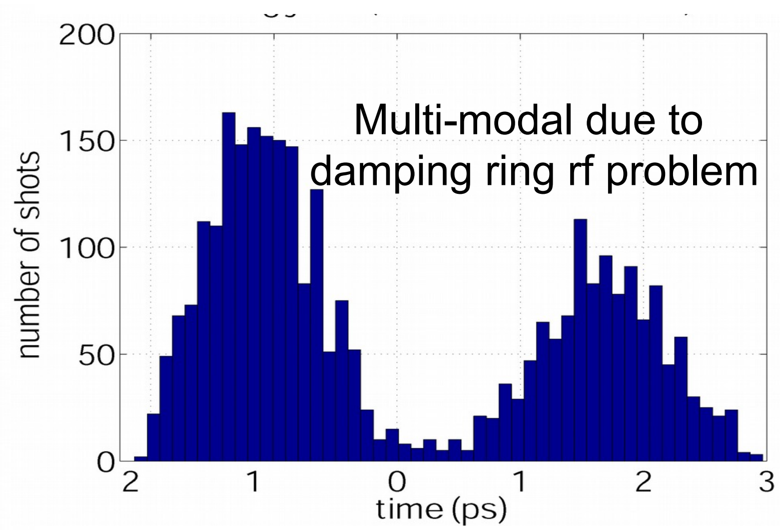


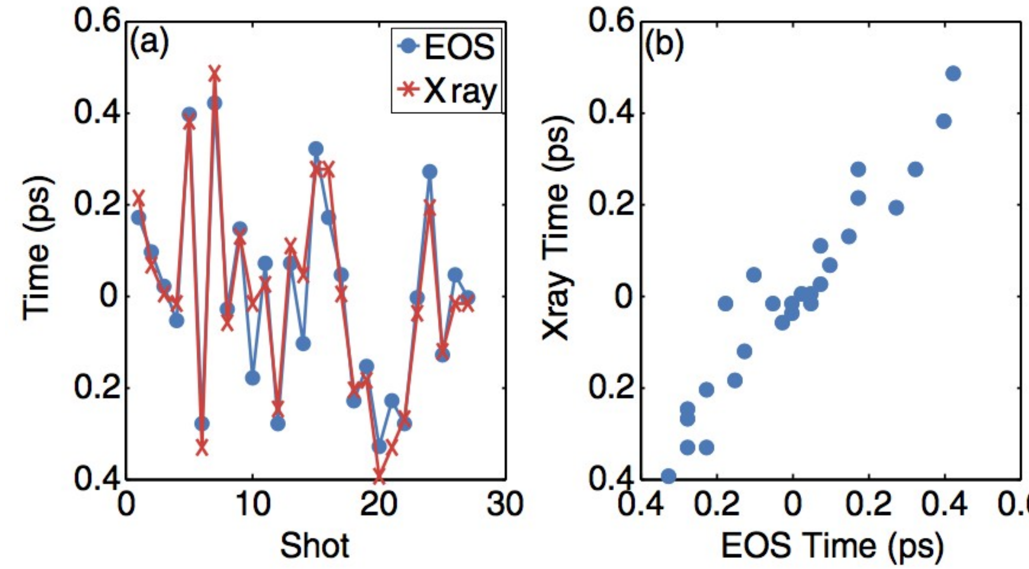
200 fs bunch length resolution limited by crystal

Single shot signal, 100μm ZnTe



Timing jitter 3000 shots@10Hz





Electron vs. x-ray timing: **60 fs relative precision** correlation between EOS and single-shot melting

Sebastian Meuren (representing the E-320 collaboration)

Cavalieri *et al.*, PRL 94 144801 (2005); Cavalieri, dissertation, U. Michigan

Slide by: D.Storey, P. San Miguel and S. Corde

Dump Table Diagnostics: overview

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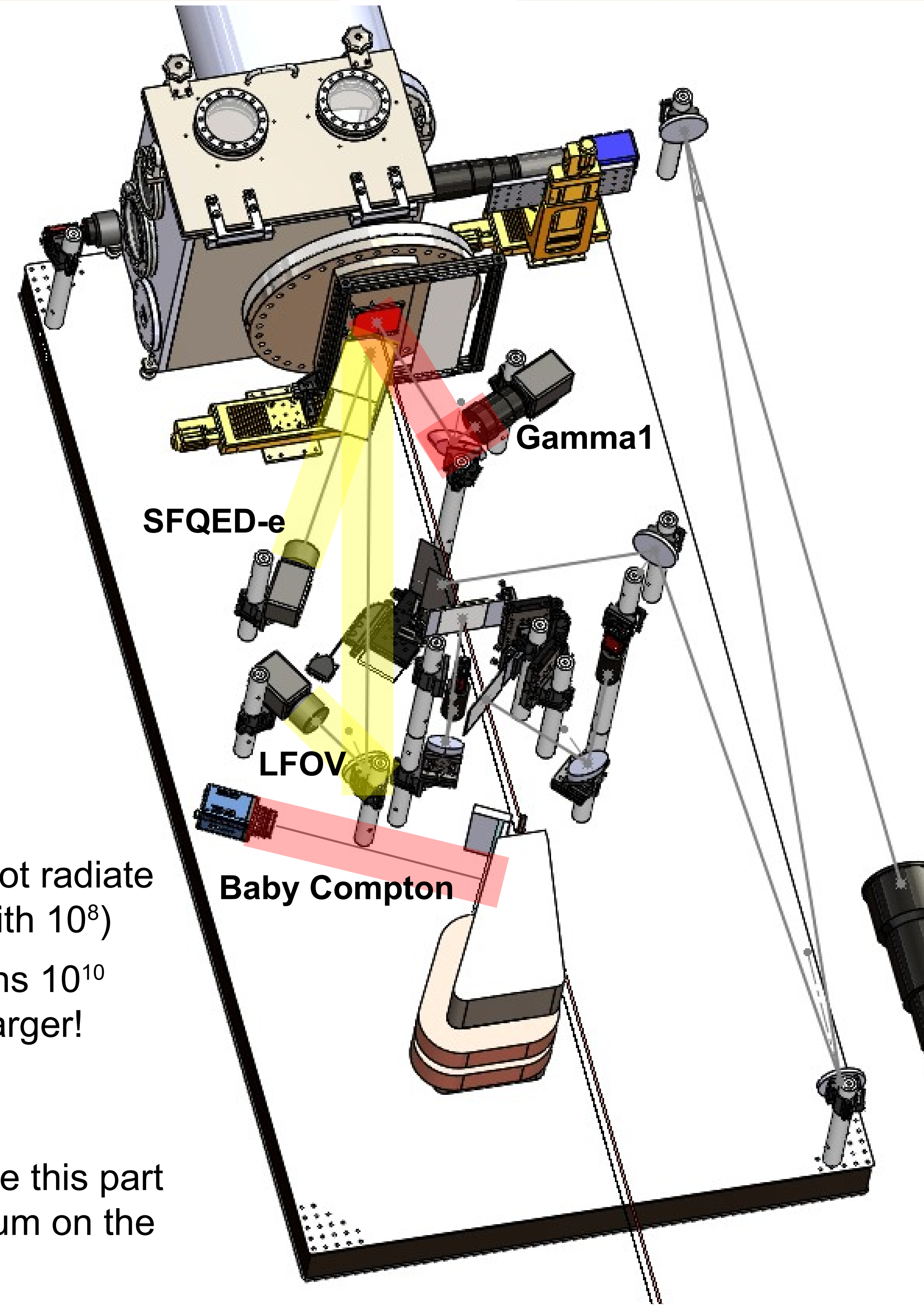
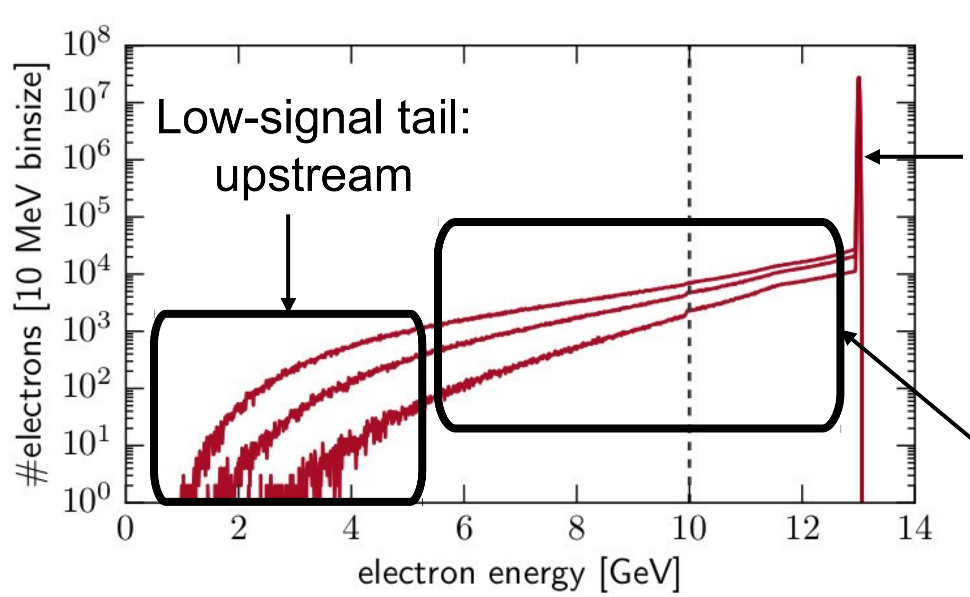
Gamma photon diagnostics

- **Gamma1** (CsI array with 0.5mm x 0.5mm pixels)
  → photon intensity/angular profile
- **Baby Compton** (future runs)
  → double differential (energy vs. angle) up to ~ 10 MeV

Electron diagnostics (high-energy part of the spectrum)

- **LFOV** (large FOV e^- profile monitor)
- **SFQED-e** (higher resolution, brighter e^- profile)
  → DRZ/CsI scintillator screens
  → electron energy resolution: ~15-30 MeV



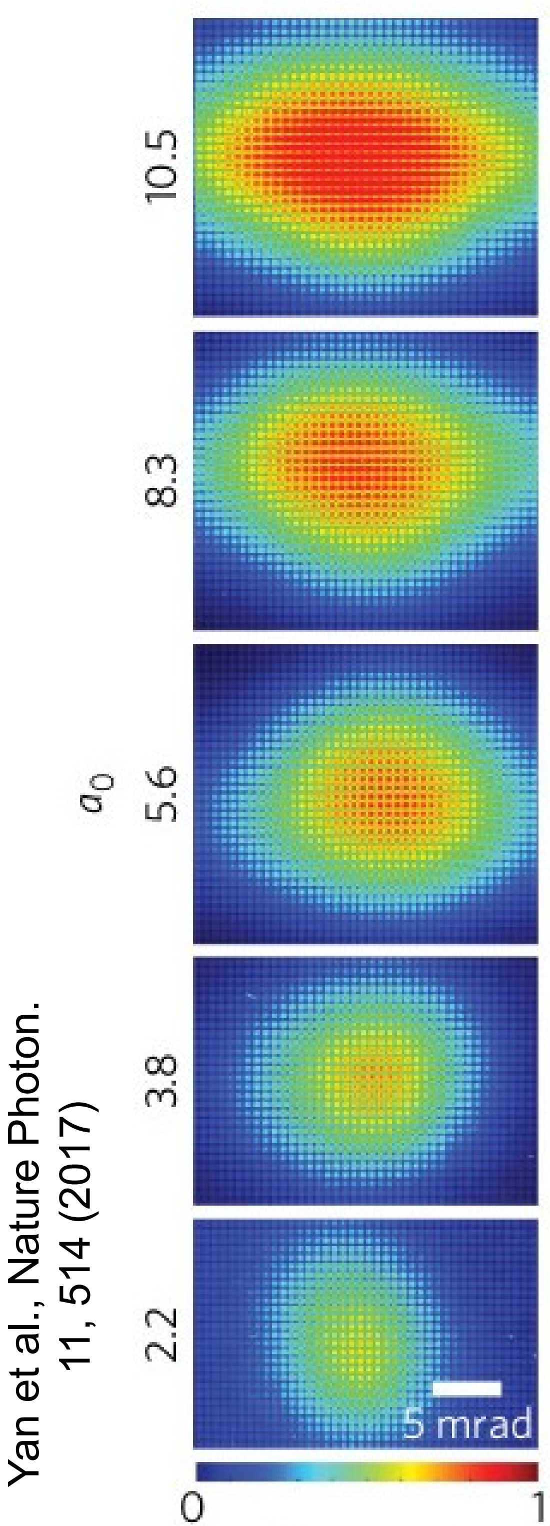


Electrons which do not radiate (we interact only with 10^8)

Total beam contains 10^{10}
→ actual peak larger!

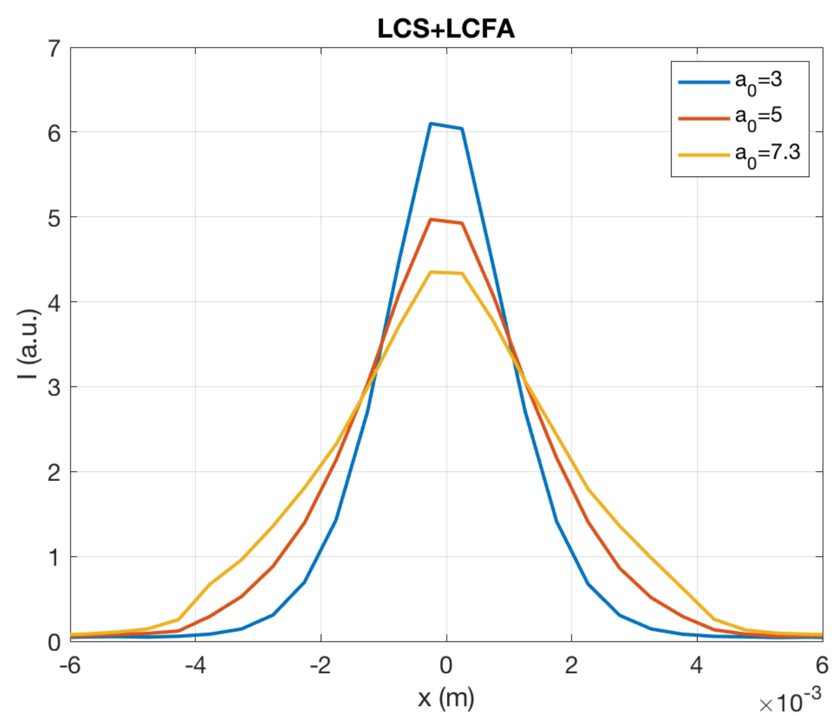
Aim: measure this part of the spectrum on the dump table

Dump Table Diagnostics: a_0 via gamma angular profile

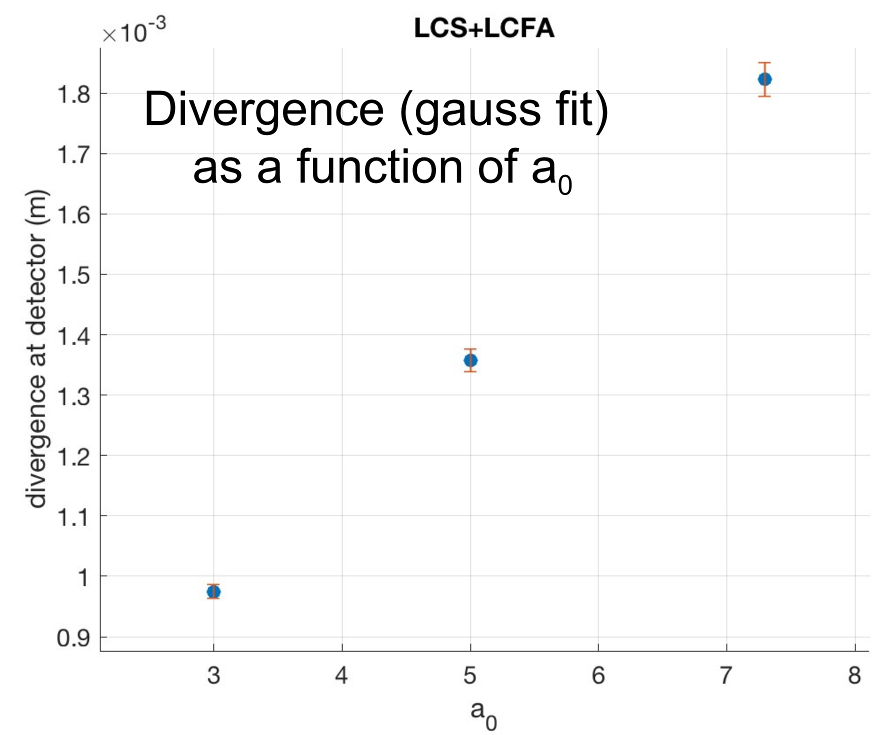


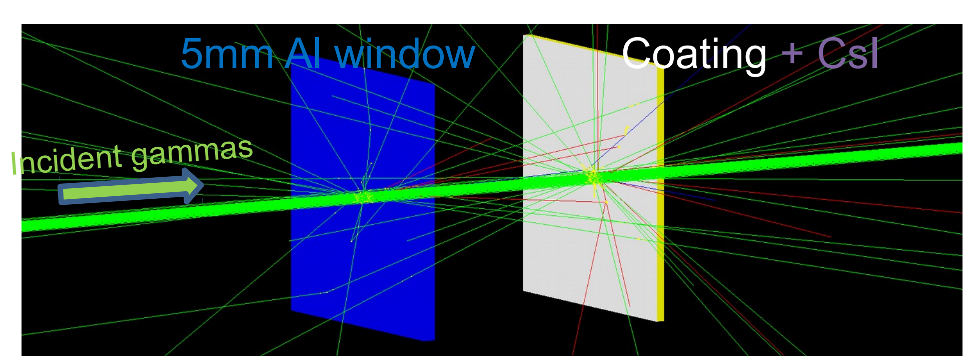
Gamma1 (CsI array with 0.5mm x 0.5mm pixels)

- High conversion efficiency: measure integrated signal and angular distribution
- Can be used for spatio-temporal alignment by maximizing integrated signal
- Can provide measurement of a_0 via "ellipticity" of the angular profile
- Geant4 simulations to account for the spectral response of the detector:



Polarization axis
(integrated horizontal signal)





Slide by: D.Storey, P. San Miguel and S. Corde

Dump Table Diagnostics: double-differential electron spectra

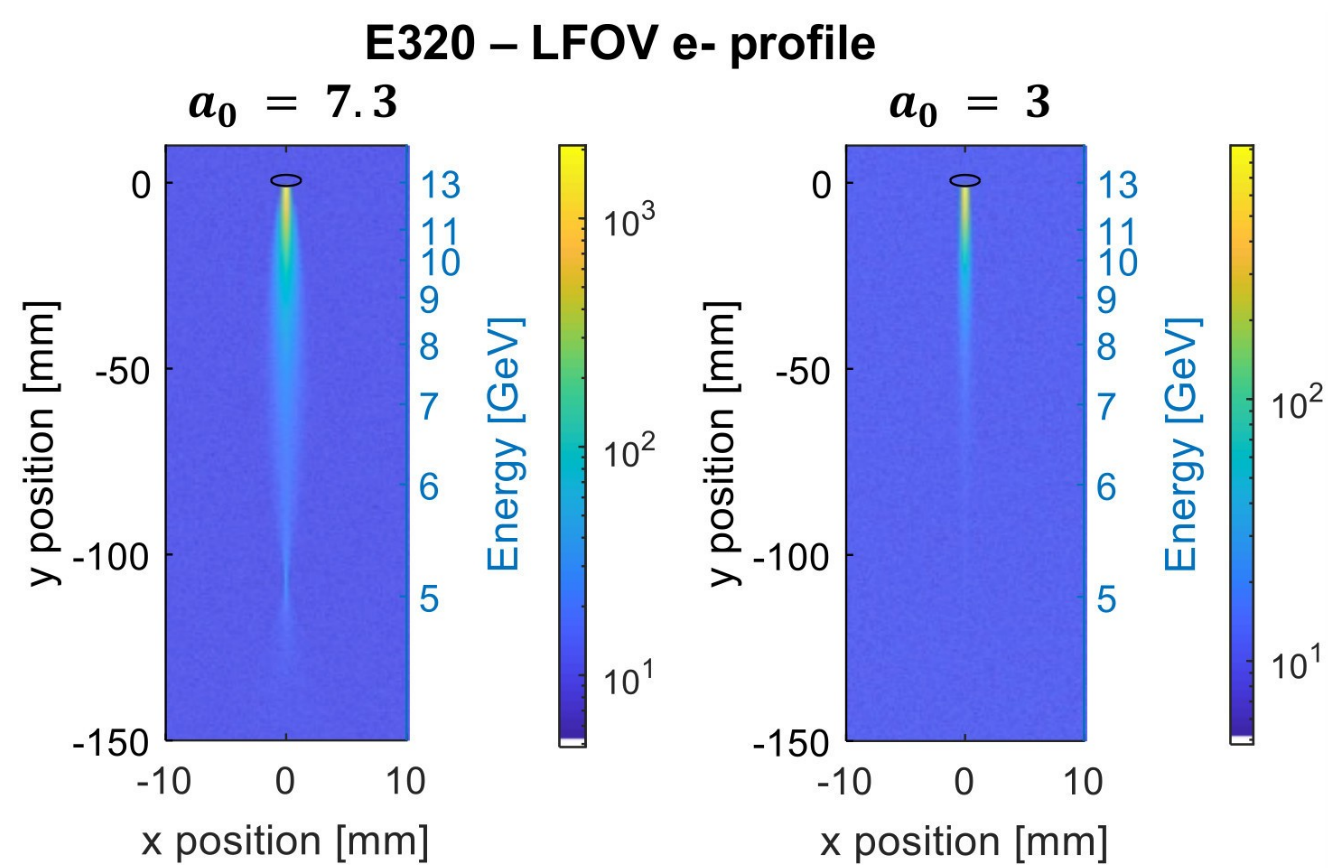
Aim: measure angle vs. energy double-differential spectra to learn details about the interaction

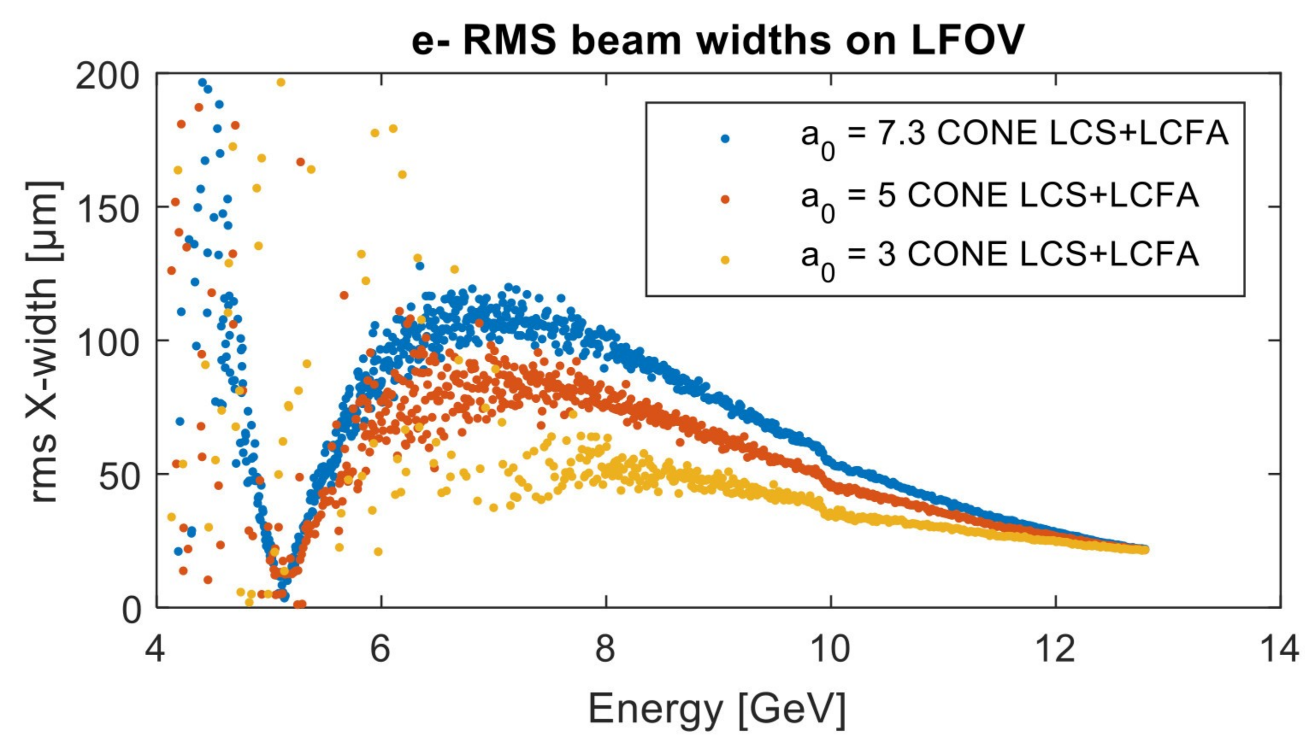
Top: estimated SNR using LFOV diagnostic:

- Scattered e^-'s tracked from IP to dump table
- SNR plots: LFOV imaging specs (assuming 10 counts readout noise)
- Measurement bandwidth:
  max: ~12.5 GeV (overshadowed by main beam)
  min: ~5-8 GeV (SNR becomes ≲ 10)

Bottom: measurement of a_0

- RMS width extracted from the e^- transverse distribution at the dump table
- Transverse signal shows a dependency on a_0, complimenting the Gamma1 measurement



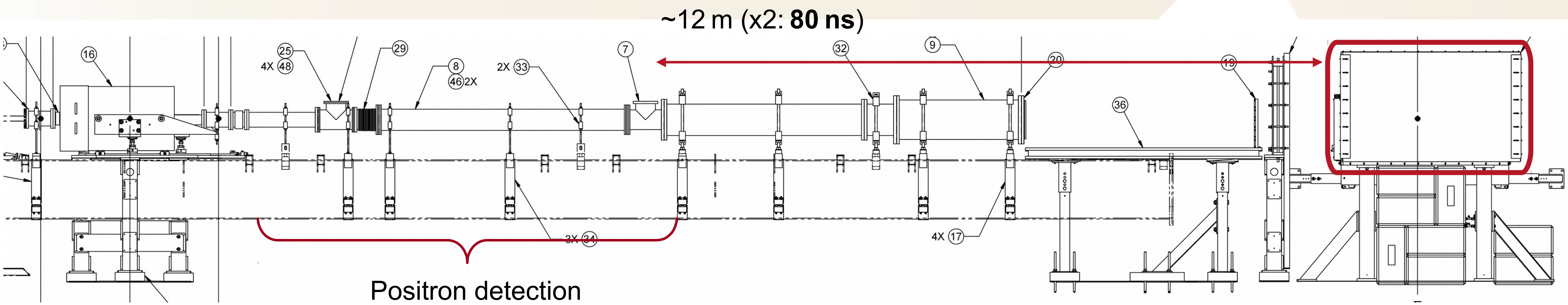


Electron beam dump simulations

John Adams Institute for Accelerator Science

Imperial College London

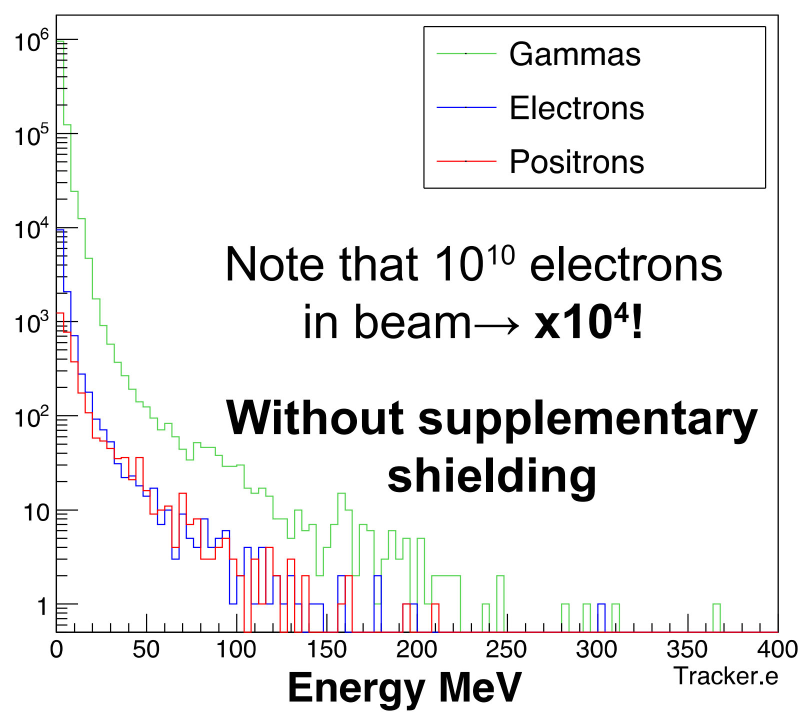
SLAC



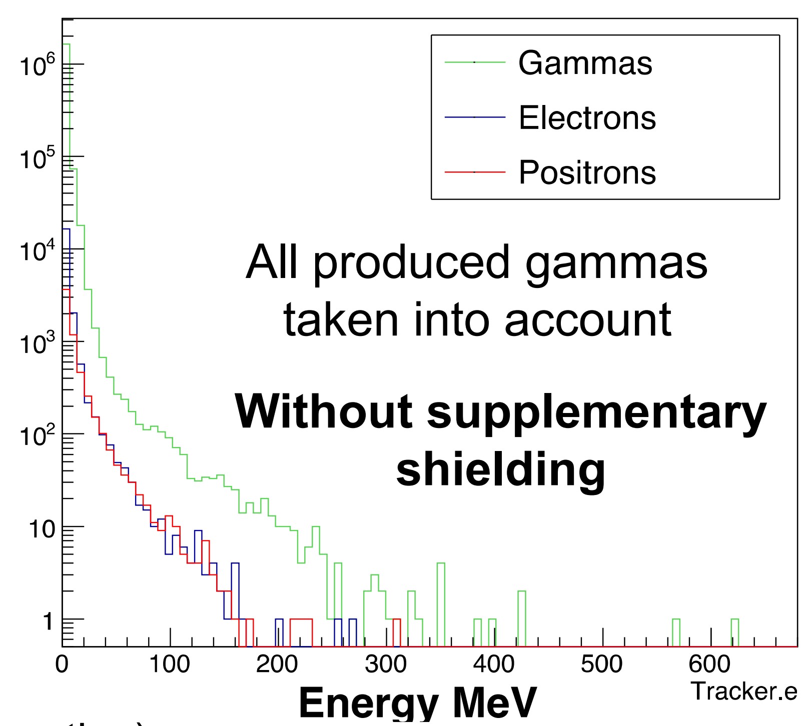
- We have to detect single(!) positrons, beam dump noise is potential issue
- Main motivation for upstream Positron Detection Chamber (PDC):

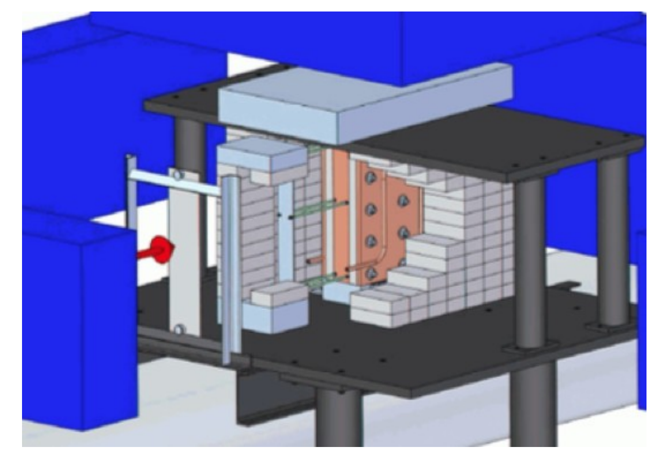
→ space for dedicated (bulky) detectors (tracking & calorimeter)
→ enough distance for gating (80 ns: LYSO decay time: ~40 ns)

Backscatter from 13 GeV electrons (1e6)

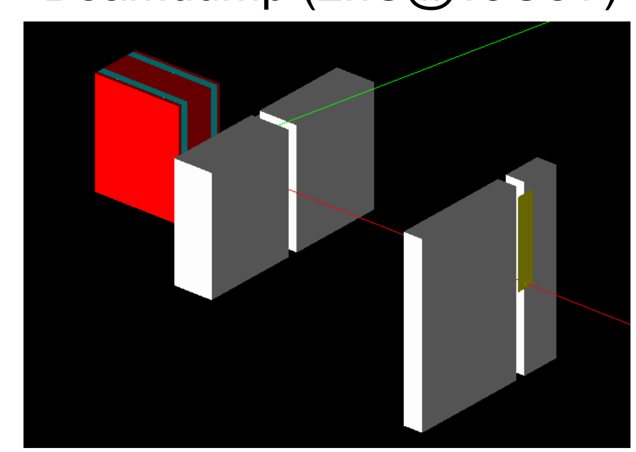


Backscatter from SFQED Gammas (1e7)





Beamdump (2nC@13GeV)

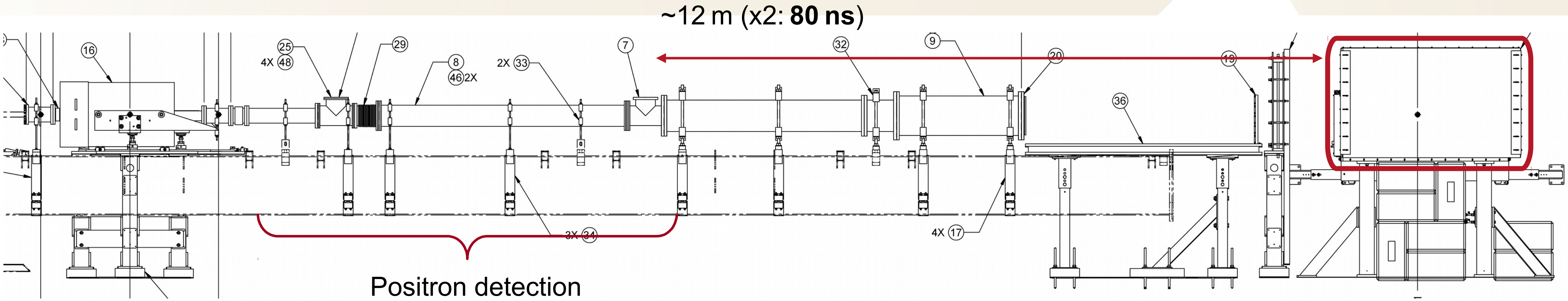


Gean4 model

Elias Gerstmayr and Stuart Mangles

Electron beam dump simulations

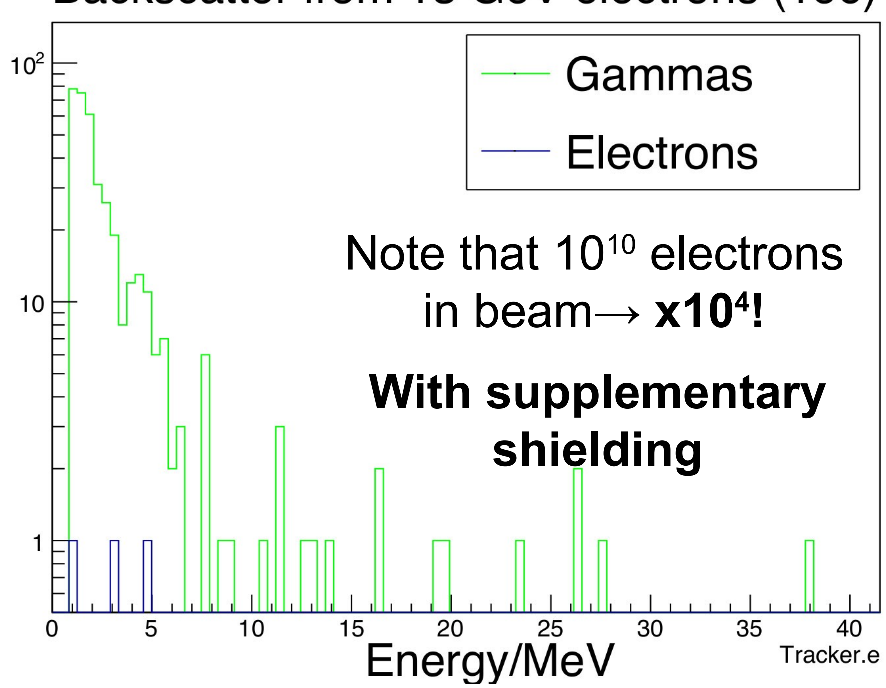
JAI
Imperial College London
John Adams Institute for Accelerator Science
SLAC



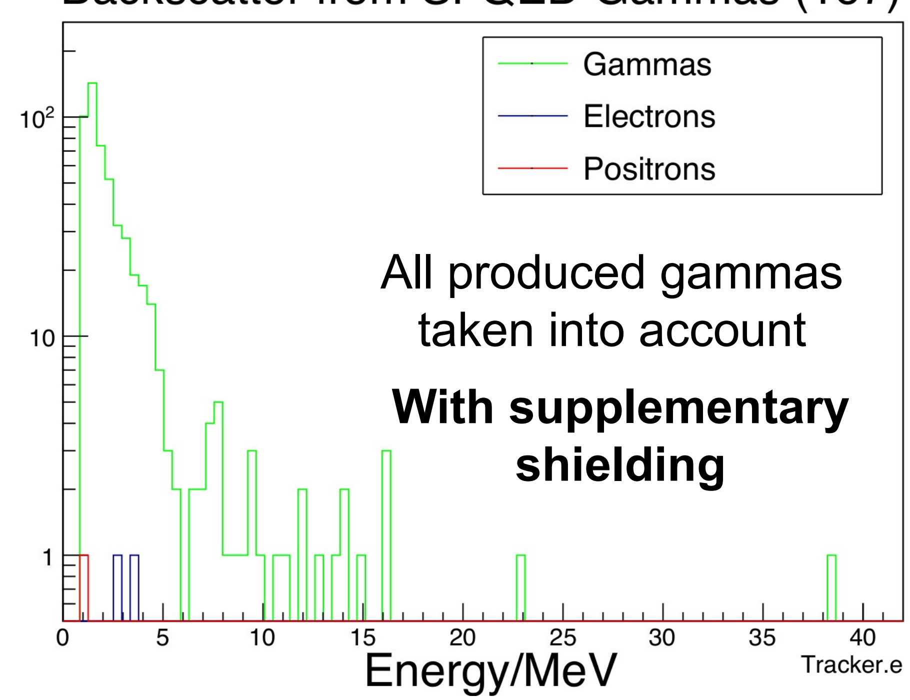
- We have to detect single(!) positrons, beam dump noise is potential issue
- Main motivation for upstream Positron Detection Chamber (PDC):

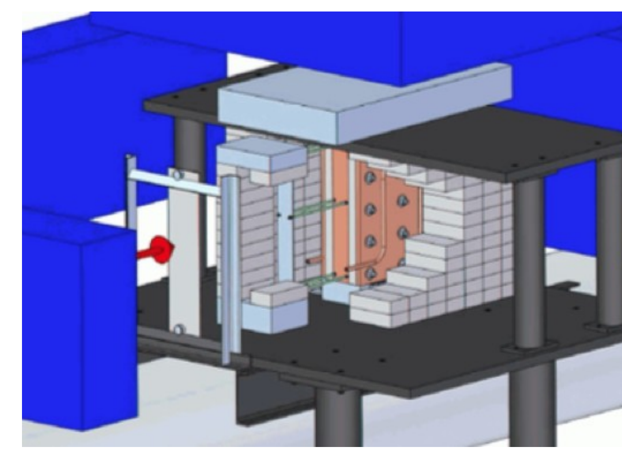
→ space for dedicated (bulky) detectors (tracking & calorimeter)
→ enough distance for gating (80 ns: LYSO decay time: ~40 ns)

Backscatter from 13 GeV electrons (1e6)

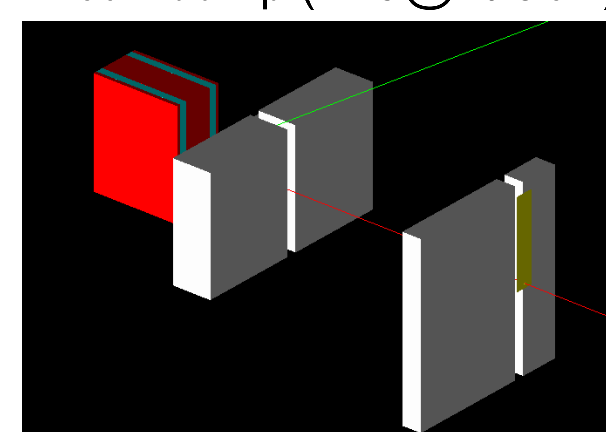


Backscatter from SFQED Gammas (1e7)





Beamdump (2nC@13GeV)



Gean4 model

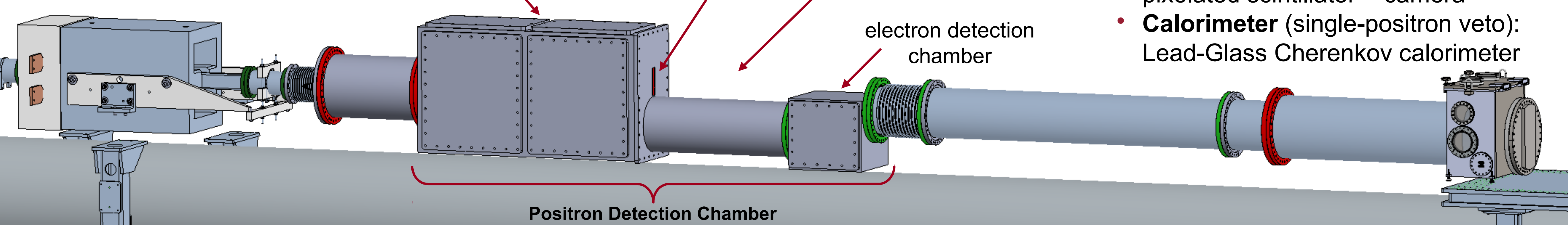
Sebastian Meuren (representing the E-320 collaboration)

Elias Gerstmayr and Stuart Mangles

Positron Detection Chamber (PDC)

Positron detection

- **Tracking** (background rejection): pixelated scintillator + camera
- **Calorimeter** (single-positron veto): Lead-Glass Cherenkov calorimeter



Compatible with all experimental beam configurations – clearance: 2.4mrad (photons, IP), 22mrad (electrons, dipole)

Measurable electron/positron energies

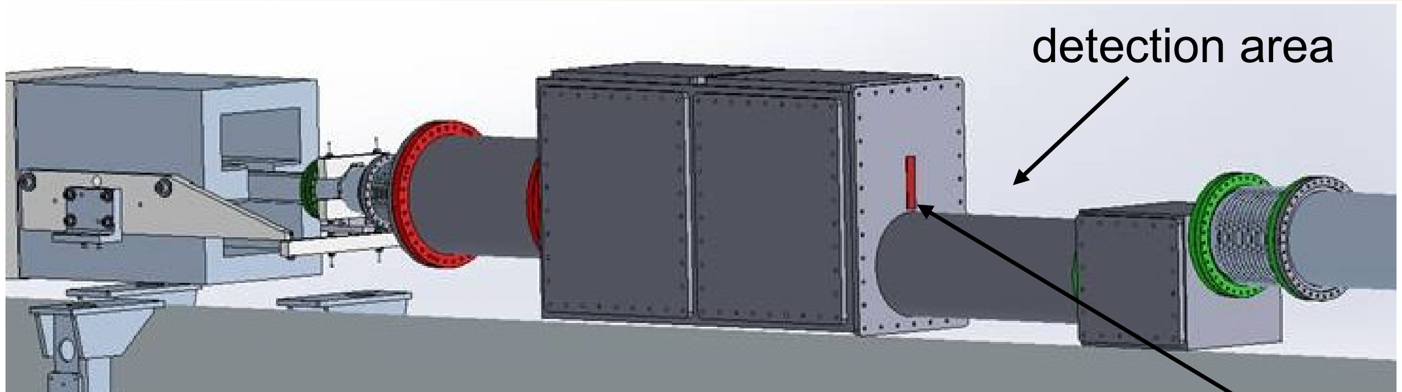
	angle	displacement after 3.5 m	28.1 MeV 2.16 mrad 4.89 GeV 2.2 cm	46.9 MeV 3.61 mrad 8.15 GeV 3.6 cm	87.2 MeV 6.71 mrad 15.2 GeV 6.7 cm	174.0 MeV 13.4 mrad 30.3 GeV 13.0 cm
positrons after PDC	0.0349 0.0156	12.0 cm 5.5 cm	0.81 GeV 1.8 GeV	1.3 GeV 3.0 GeV	2.5 GeV 5.6 GeV	5.0 GeV 11.0 GeV
electrons after PDC	0.0651 0.022	23.0 cm 7.7 cm	0.43 GeV 1.3 GeV	0.72 GeV 2.1 GeV	1.3 GeV 4.0 GeV	2.7 GeV 7.9 GeV
electrons (dump table)	0.021 0.007	7.4 cm 2.5 cm	1.3 GeV 4.0 GeV	2.2 GeV 6.7 GeV	4.2 GeV 12.0 GeV	8.3 GeV 25.0 GeV

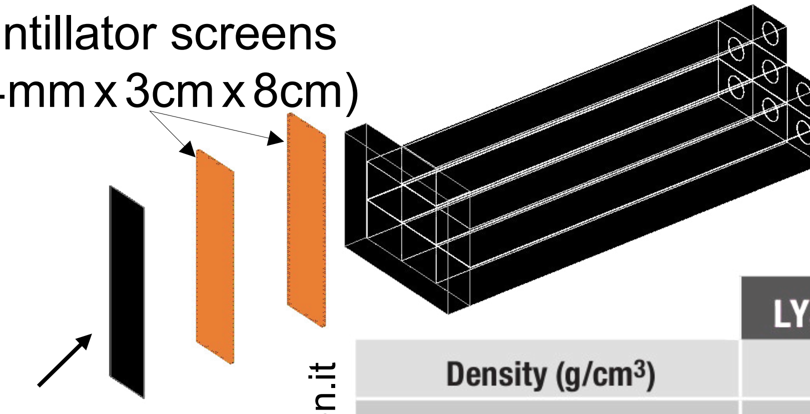
← main dipole kick
← 13 GeV deflection angle
← B5D36 setting
← 13 GeV deflection @10m

central region of the positron spectrum

Doug Storey & SM (SLAC)
with input from
Aarhus/Imperial/Jena/QUB

Single-positron detection concept





	LYSO(Ce)	CsI(Tl)
Density (g/cm^3)	7.4	4.51
Decay Time (ns)	40	1000
Light Yield (ph./MeV)	27000	52000
Peak emission (nm)	420	560
Radiation length (cm)	1.14	1.85
Reflective index	1.82	1.78

https://www.caen.it

	FL	NA	Collection Efficiency
Zeiss OTUS f1.4/28mm	28 mm	0.057	0.000827
AF-S NIKKOR f/1.4E ED	28 mm	0.041	0.000423
AF-S NIKKOR f/1.4G ED	24 mm	0.054	0.000727
Zeiss Milvus 1.4/25	25 mm	0.072	0.001283
Canon EF f1.4 II USM	24 mm	0.051	0.000654

Challenge: measure (down to) single positrons

- We pursue a standard HEP detector concept: tracking + calorimeter
- Calorimeter:
  → less sensitive to low-energy backgrounds (GeV positrons)
- Tracking:
  → upstream (co-propagating) background rejection
  → measure spectrum, increase calorimeter energy resolution

Tracking approaches

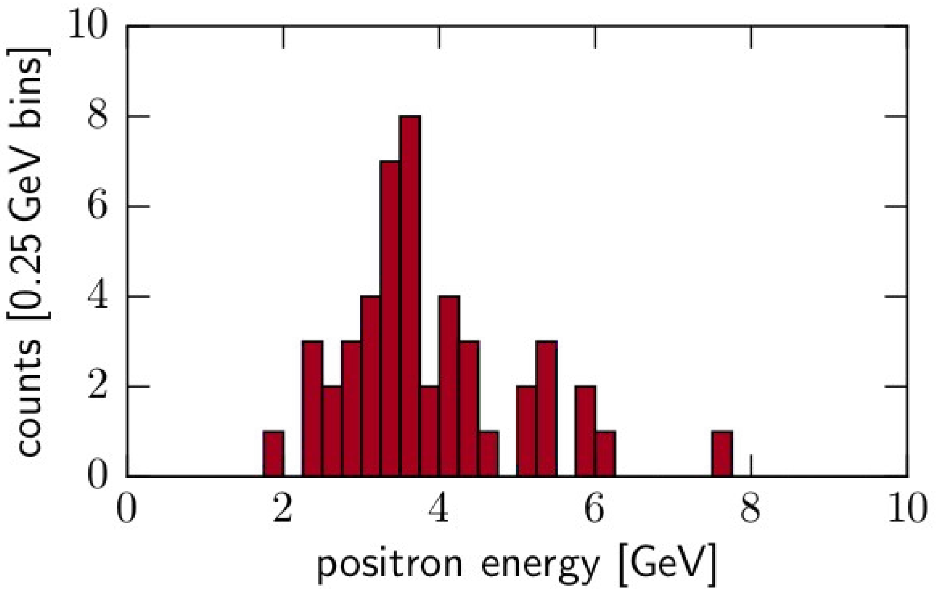
- Scintillator (~4mm CsI/LYSO) + objective (Zeiss Milvus) + camera (Orca):
  1 positron: ≈5 MeV deposition → 10^5 photons → 10^2 on camera → 1/pixel
- Improve light yield: CsI (no gating!), thicker crystal, intensifier
- Dump background rejection: fast scintillator + camera/intensifier gating
- Ultimately: silicon tracking detector

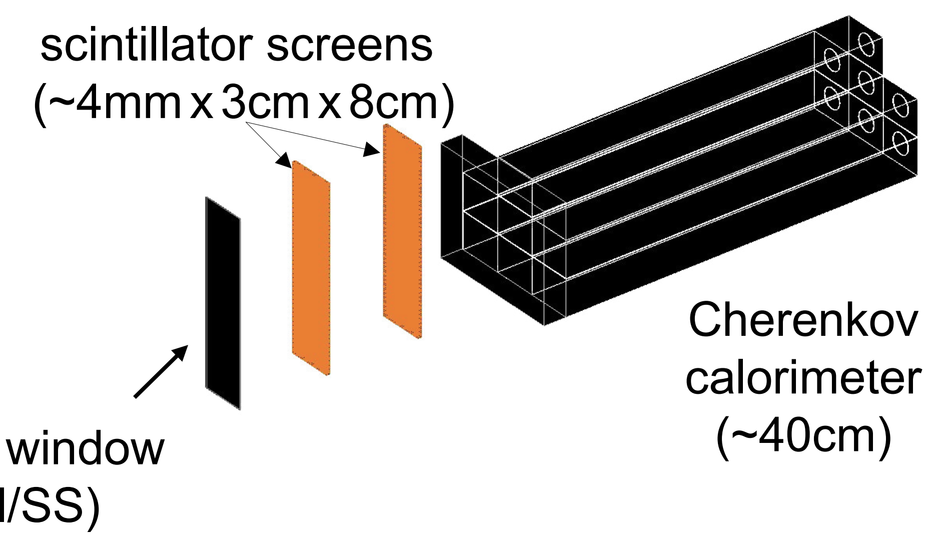
Hamamatsu Orca-Flash4.0

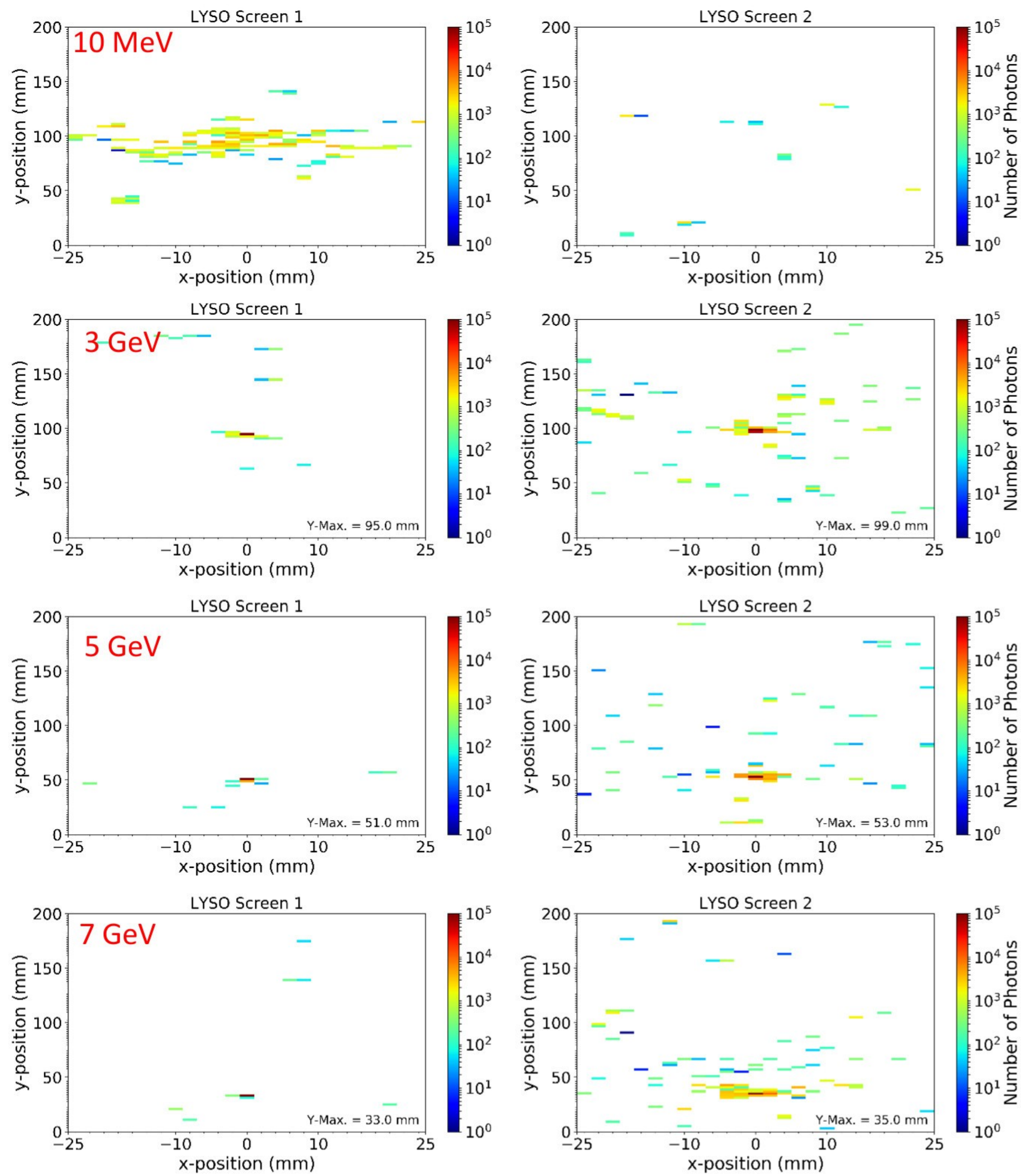
Product number	C13440-20CU
Imaging device	sCMOS
Cell (pixel) Size (μm^2)	6.5×6.5
Pixel Array (horizontal by vertical)	2048×2048
Effective Area (horizontal by vertical in mm)	13.312×13.312
Peak Quantum Efficiency (QE)[*1]	82 % @ 560 nm
Dynamic Range[*1]	37 000 : 1

Input from: Doug, Jena, Imperial

LYSO screens: simulations (signal)







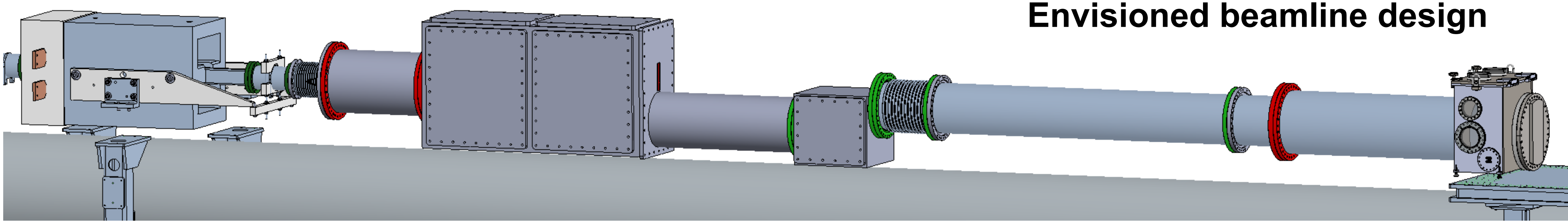
Simulation assumptions:

- 1mm Aluminum exit window
- LYSO with 4mm x 2mm x 2mm crystals
- Impact of single positron (3-7 GeV)

Simulations: Niall Cavanagh
& Gianluca Sarri (QUB)

LYSO screens: simulations (background)

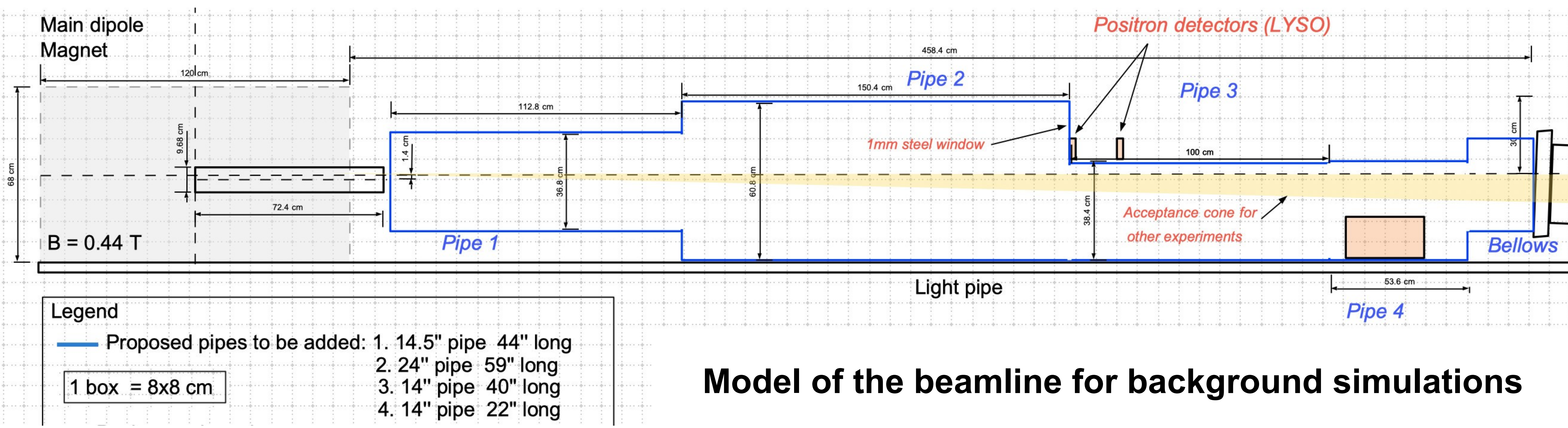
SLAC



Envisioned beamline design

Three main sources of background:

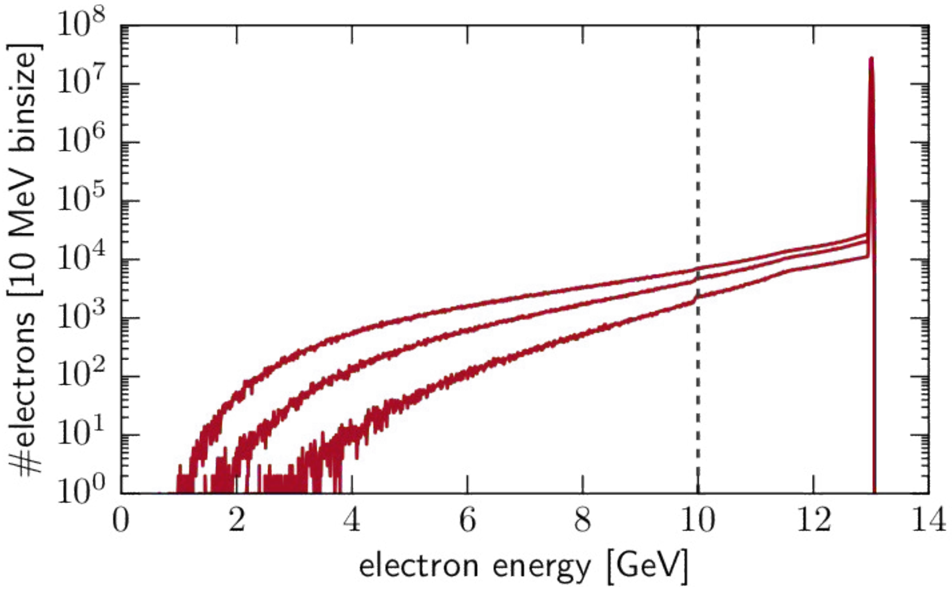
- High-energy particles coming along for the ride (upstream, prompt) → tracking
- Anything reflected/emitted by the dump (~80ns time delay) → shielding, gating
- Low-energy scattered electrons hitting chamber (local, prompt) → big chamber, calorimeter



Model of the beamline for background simulations

Simulations: Niall Cavanagh & Gianluca Sarri (QUB)

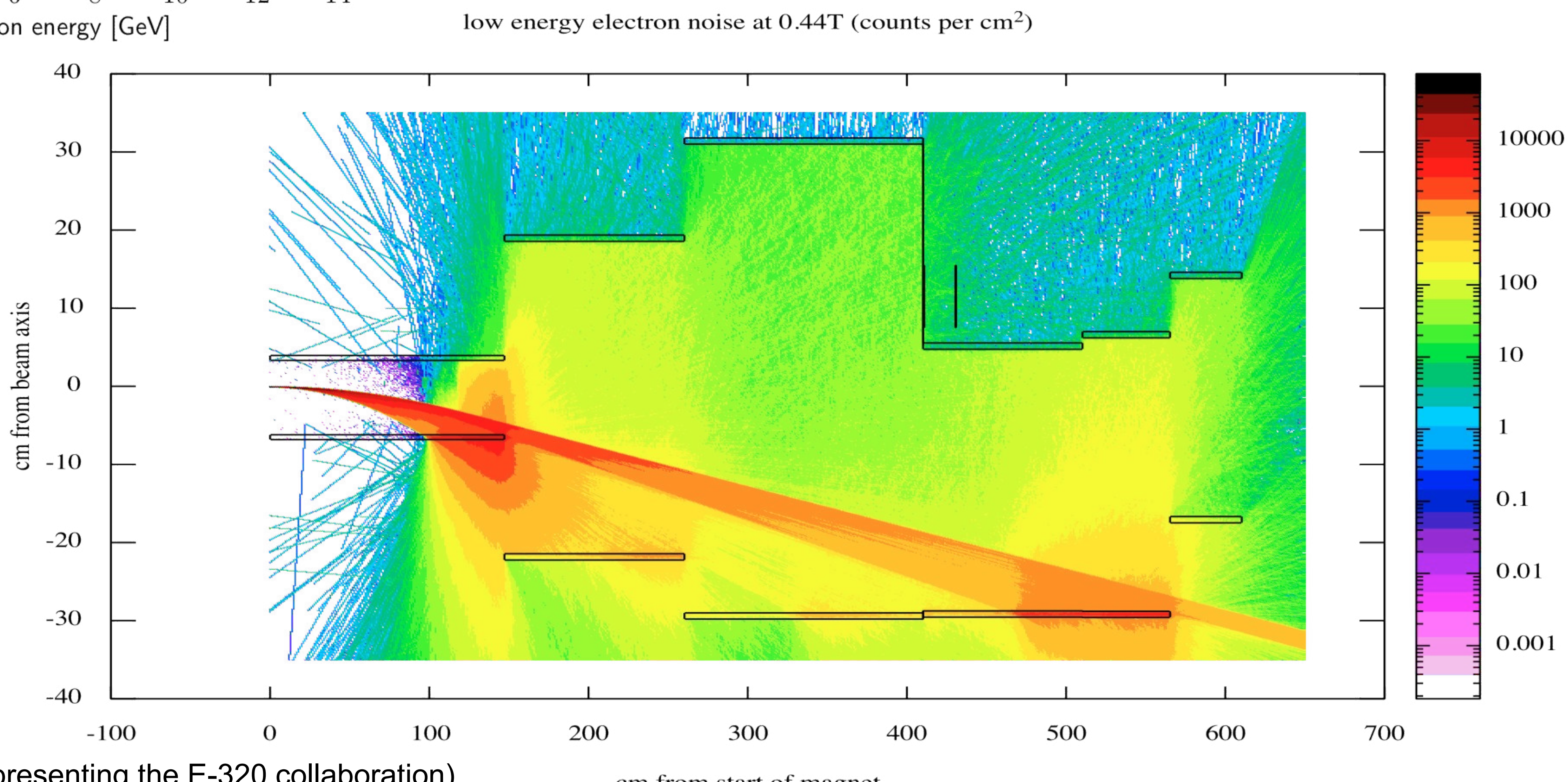
LYSO screens: simulations (background)



Background from scattered electrons hitting walls

- Stronger laser: more positrons *and* low-energy electrons
- The larger the dipole kick the more electrons hit the BPM
- Nominal setting (87 MeV): electrons ≲ 1.3 GeV hit the BPM

Energies GeV	Count
0-3	~10^4
0-1.5	~10^2
0-1.3	~50
0-1	~10

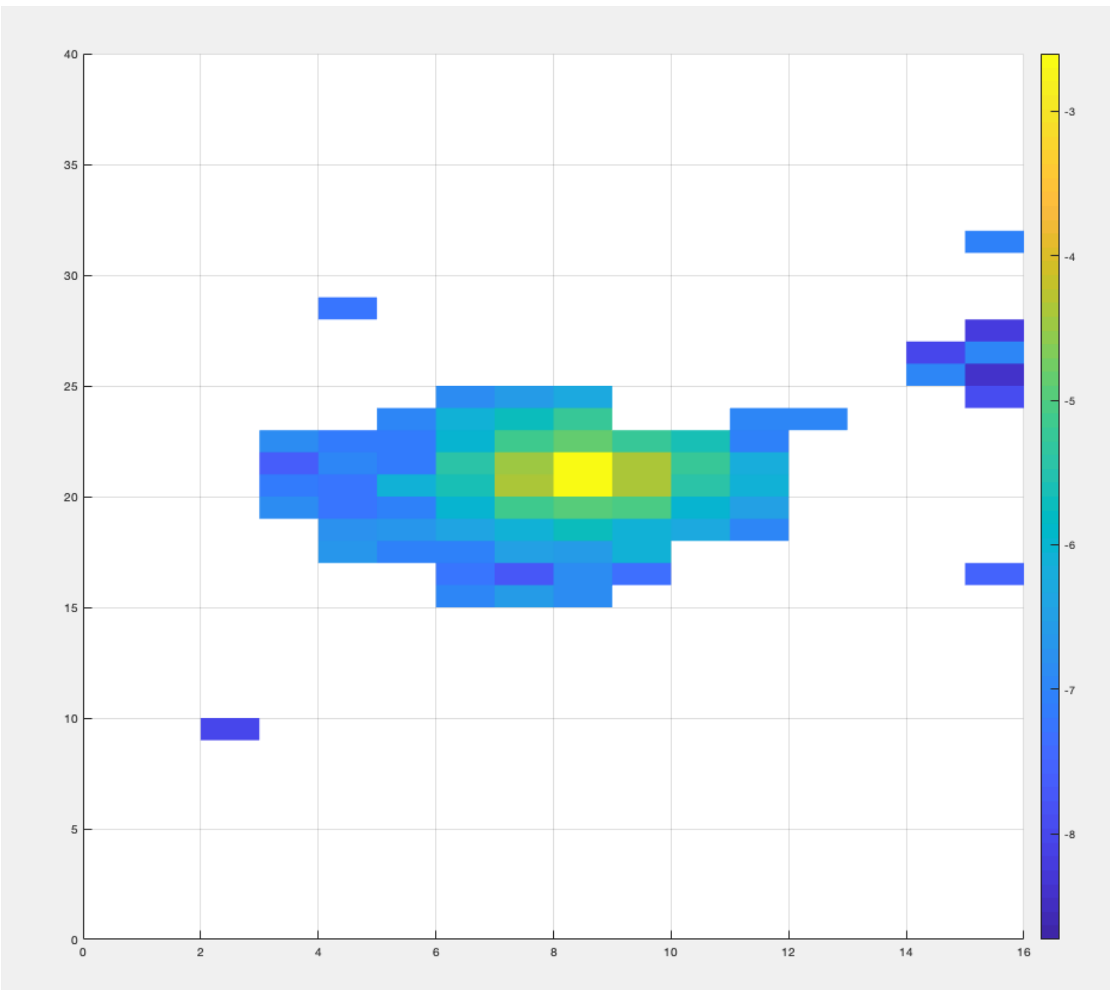


Simulations: Niall Cavanagh
& Gianluca Sarri (QUB)

LYSO screens: simulations (signal vs. background)

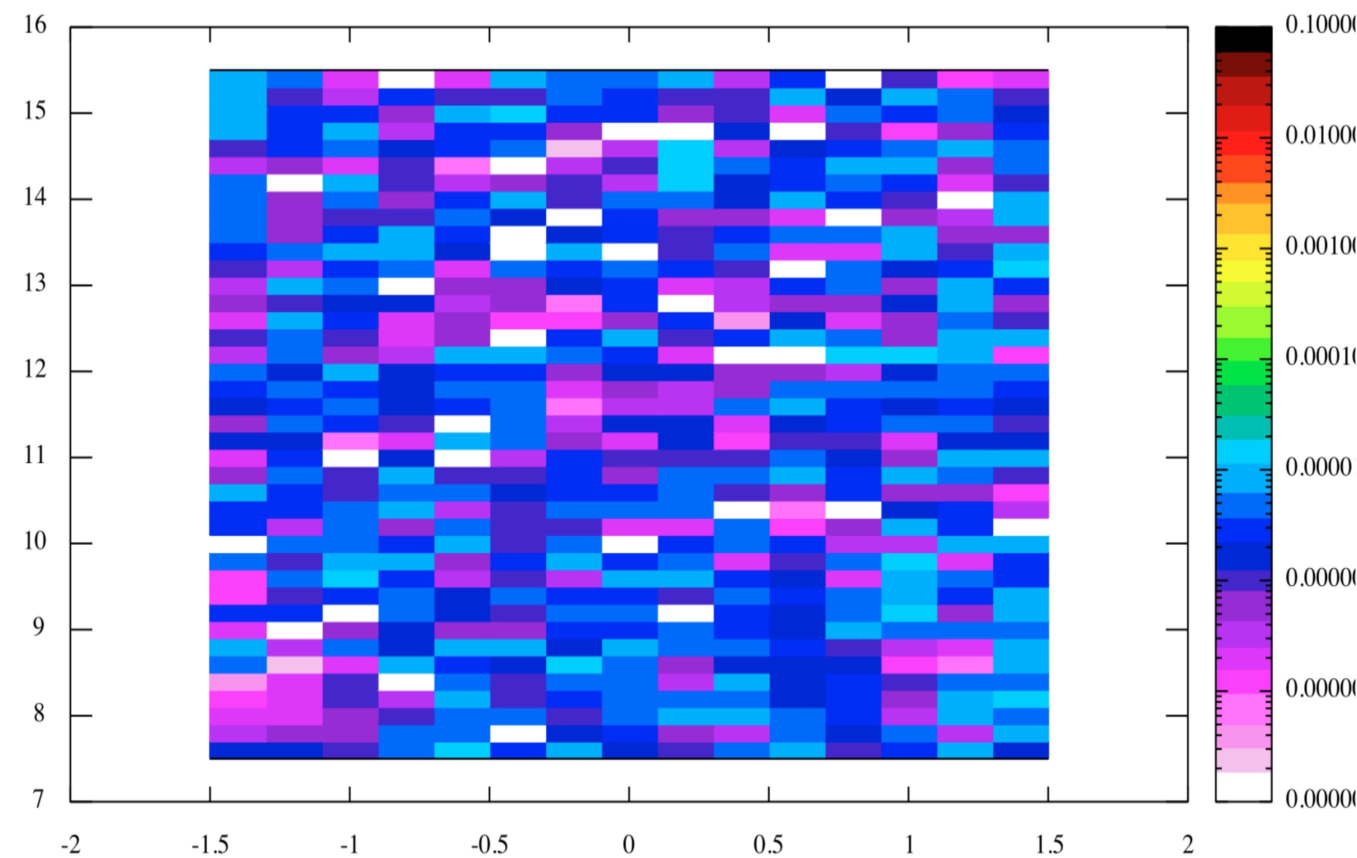
SLAC

Signal: single positron hit, 1st screen



0.5 GeV positron – total deposited energy (GeV/pixel/primary)

Background from low-energy electrons hitting the chamber



Electrons <1.3 GeV hitting BPM: ~0.05MeV/pixel (preliminary result)

We expect a signal-to-noise level of ~ 5 MeV : 0.05 MeV = 100

Advanced tracking: SLAC ePix10k detector

SLAC

Overview ePix10k

- Developed for LCLS (up to ~500 Hz)
- Optimized for high dynamic range
- 100 micron pixel pitch
- Auto-ranging pulse-by-pulse, and pixel-by-pixel
- Noise: 70; signal: 4×10^4 per ~ GeV positron
- Saturation: 20 million counts/pixel/pulse
- Basic unit is a 4 cm x 4 cm module
- Firmware & software chain exists

One ePix100 (2x2 cm) available for testing (C. Hast)

Open tasks

- Thermal mechanics needs to be shifted, displace sensor orthogonal to PCBs:
  minimize material in beam path
- Design monolithic thermal mechanical support for a plane of sensors
- Radiation hardness somehow unknown

Timeline for employing ePix

- Initial tracking configuration:
  pixelated scintillator screen + camera in air
- Mid-term goal (after initial measurements):
  silicon-based tracking detector in vacuum

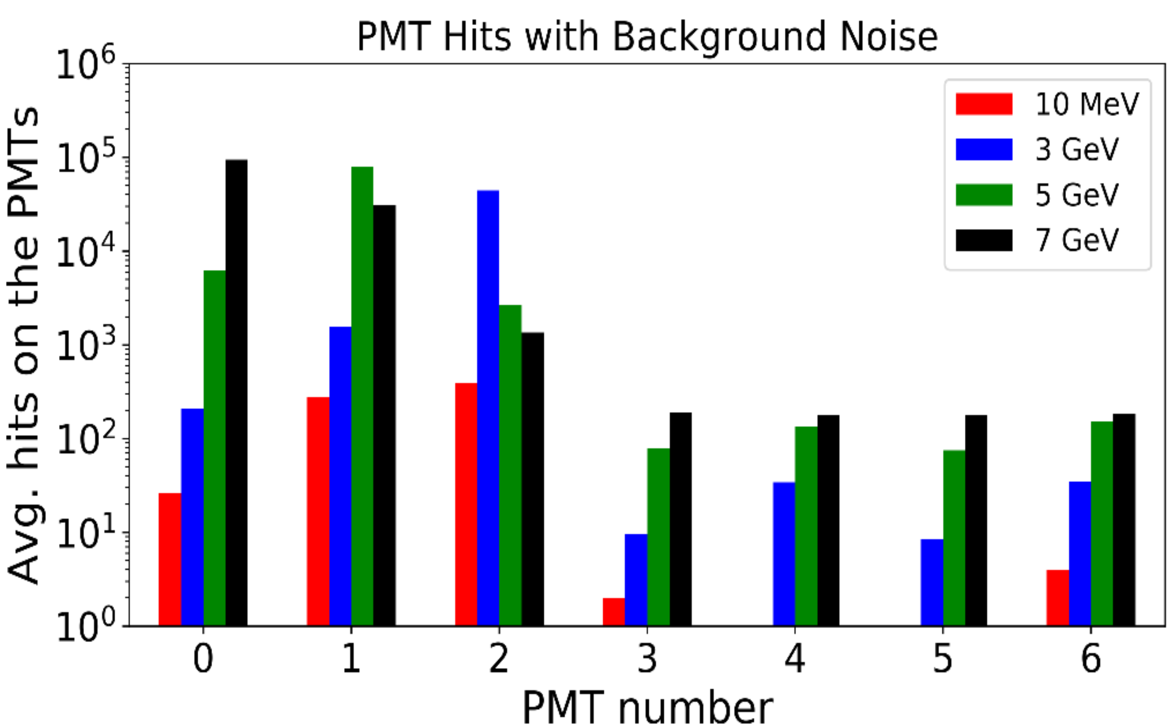
C. Kenney & SLAC Detector Team; SLAC-PUB-16340

Collaboration between Aarhus & Jena

Slide by: Felipe Salgado, Harsh, Christian Rödel, Matt Zepf

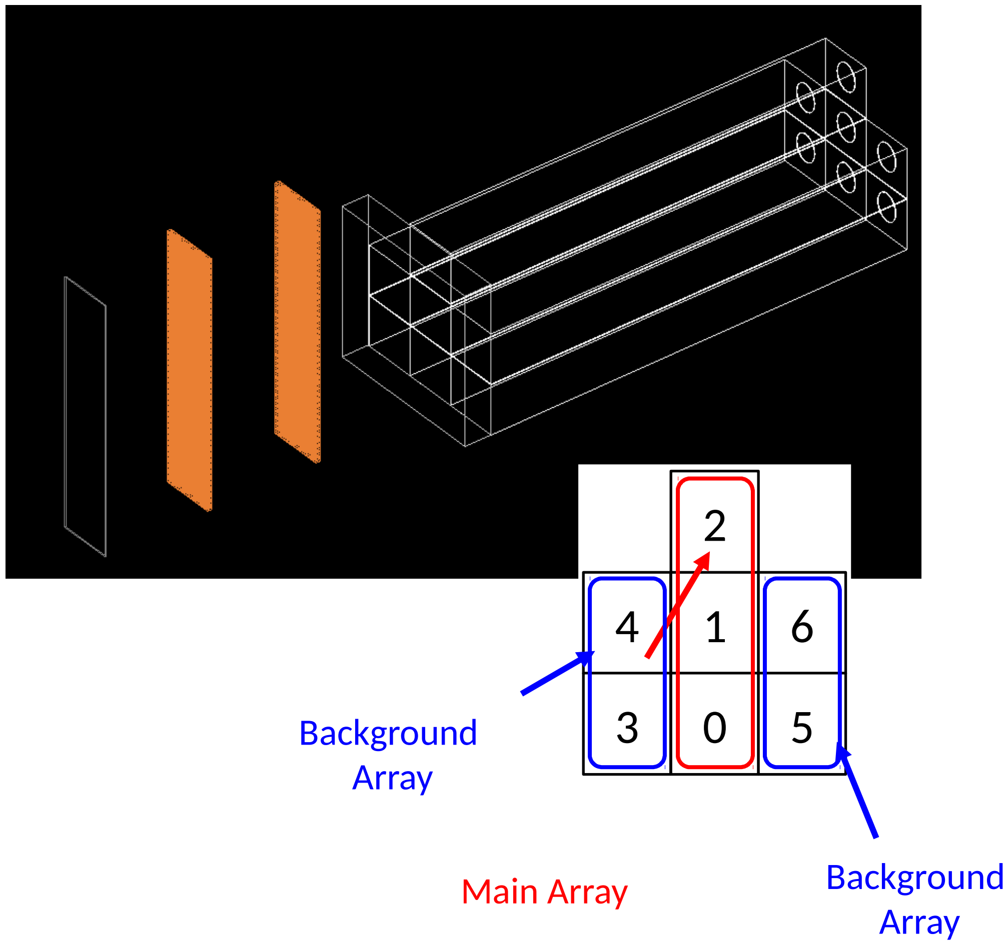
Cherenkov Calorimeter

Cherenkov Calorimeter capable of detecting single positron hits above background noise (mostly 10 MeV particles)



Signal-Noise-Ratio

	3 GeV	5 GeV	7 GeV
SNR	114	202	242



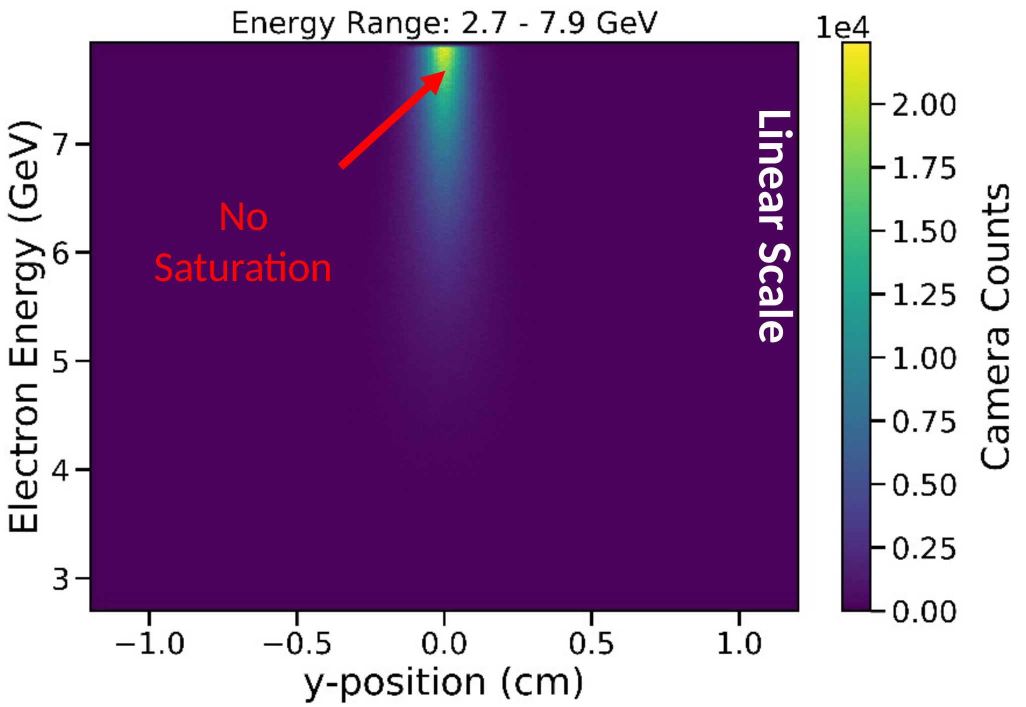
- Cherenkov Calorimeter
  - 7 x Schott F2 lead-glass:
  - Shielded with 2.5 cm of lead around it
- PMTs at the rear of each lead-glass block

Slide by: Felipe Salgado, Harsh,
Christian Rödel, Matt Zepf

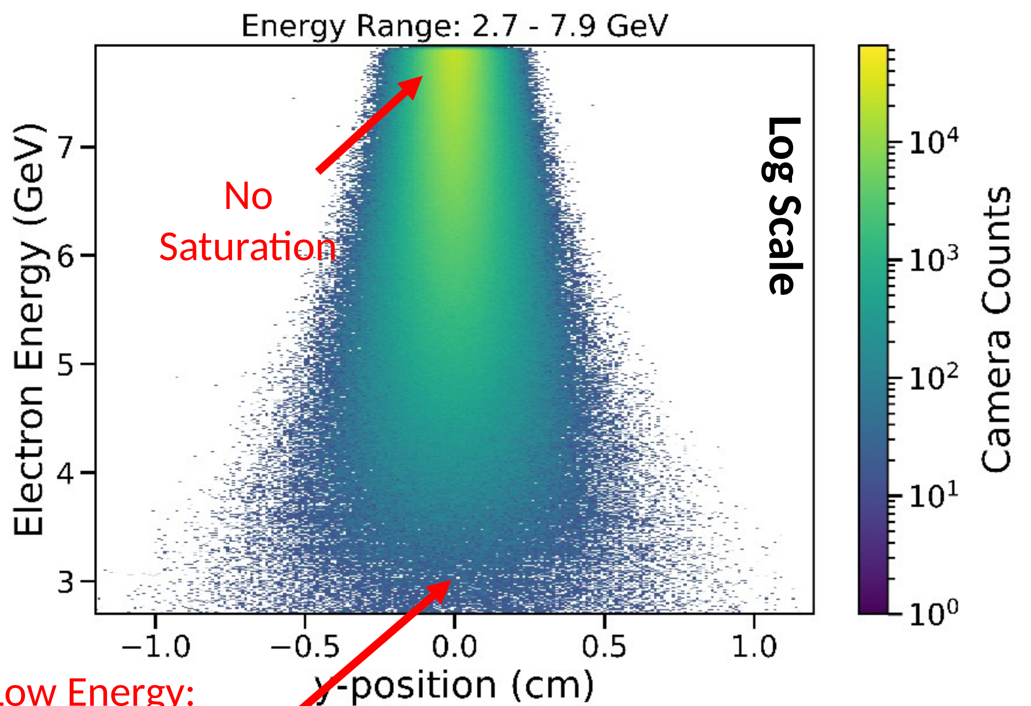
Upstream electron detection

Lanex Screen + ORCA camera can be used for electron diagnostic inside the PDC

→ Required crystal pixelated array for diagnosing < 3 GeV electrons



- LANEX Screen + ORCA FLASH
  - Full well: 30000 electrons
  - Digitalization: 16-bits
  - Quantum efficiency: 75 %
  - Collection efficiency: 10^{-3}
  - Read-out Noise: 1.6 electrons (3.5 counts)
  - LANEX DRZ-PLUS Light Yield: approx. 6 x 10^4 photons/MeV
- Low energy electrons < 3 GeV
  - Approx. 14 counts per lanex pixel
  - SNR = 4



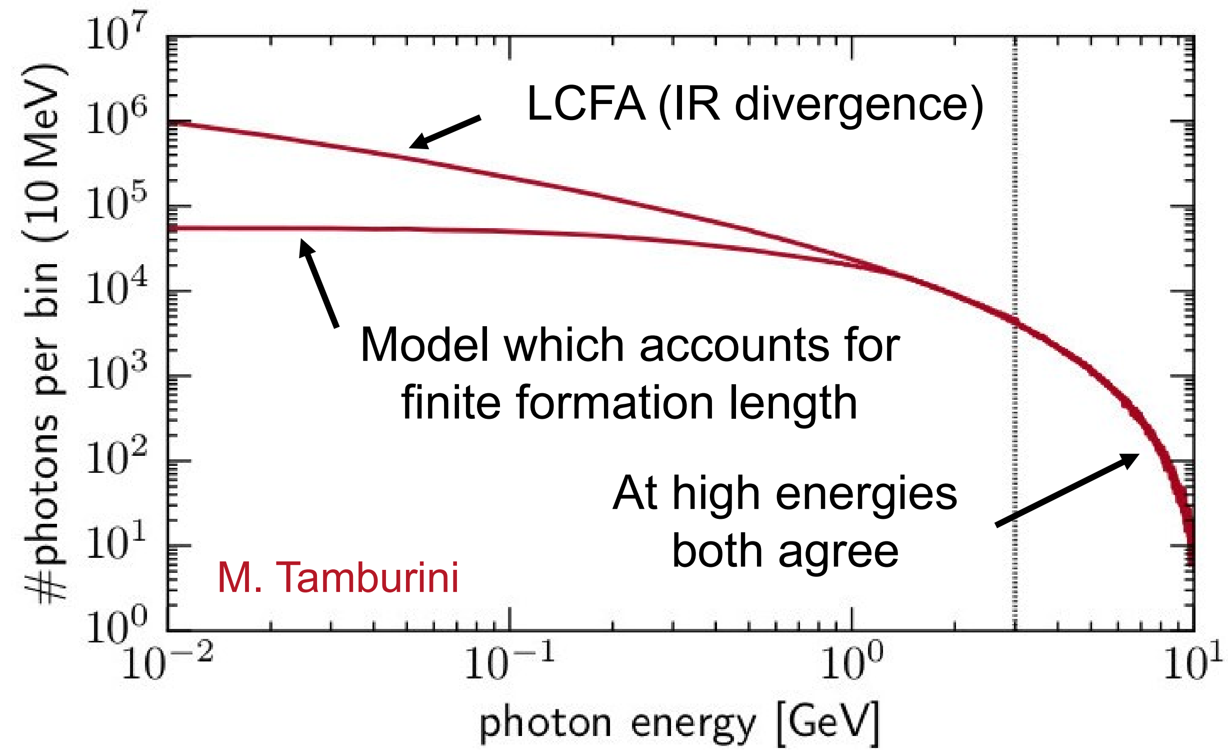
*No background noise included

Future upgrade: photon spectrometer (measure LCFA breakdown)

SLAC

- **Important aim: verify numerical methods** employed to simulate Strong-field QED (χ~1)

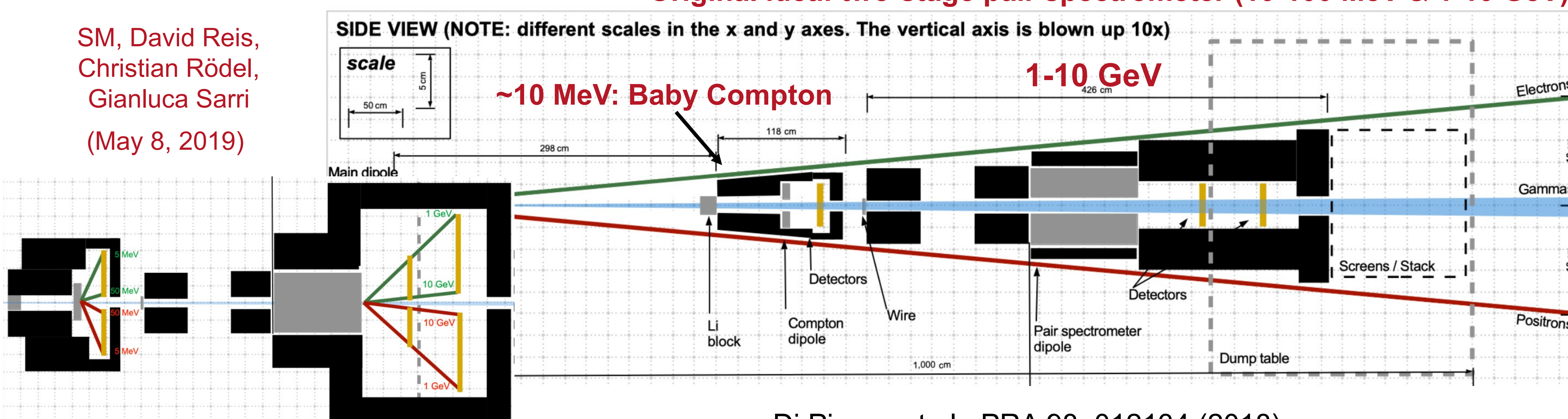
  → **QED-PIC** codes for HEDP/QED plasmas; **CAIN/GUINEA-PIG** for linear collider
- Existing numerical methods employ the **Local Constant Field Approximation (LCFA)**
- The formation length diverges for soft photons $l_f \sim (\varepsilon/m)(\lambda\!\!\!^-_C/\chi)(1+\chi/u)^{1/3}$, $u = \omega'/(\varepsilon-\omega')$



Original idea: two-stage pair spectrometer (10-100 MeV & 1-10 GeV)

SM, David Reis, Christian Rödel, Gianluca Sarri

(May 8, 2019)

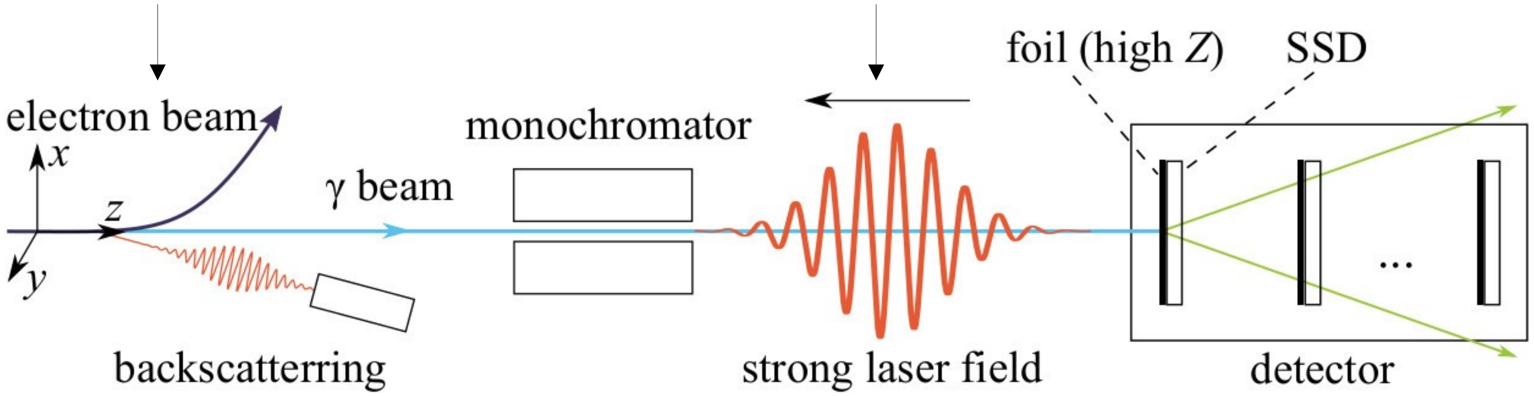


Di Piazza et al., PRA 98, 012134 (2018)

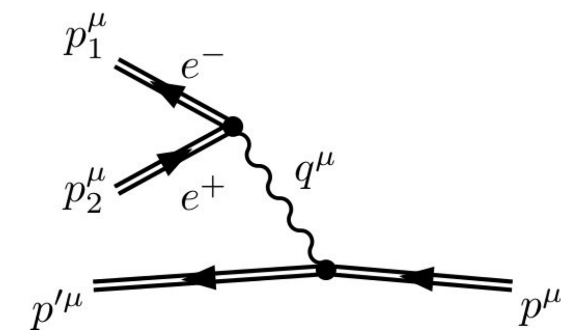
Baier, Katkov, & Strakhovenko Nucl. Phys. B328 387 (1989)

Future upgrade: polarized GeV photons + 100 TW laser

1st IP: gamma production **2nd IP**: photon-photon collisions



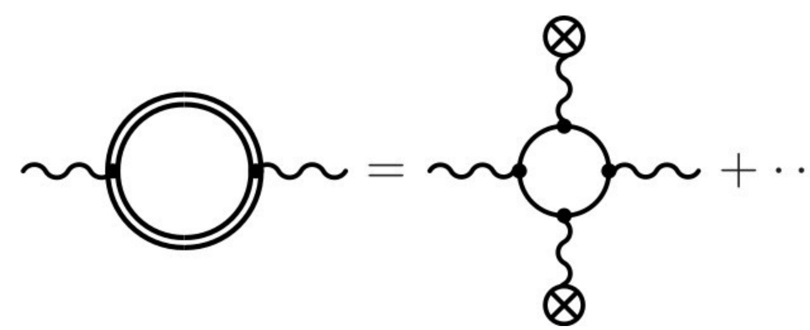
Bragin, SM et al., PRL 119, 250403 (2017)



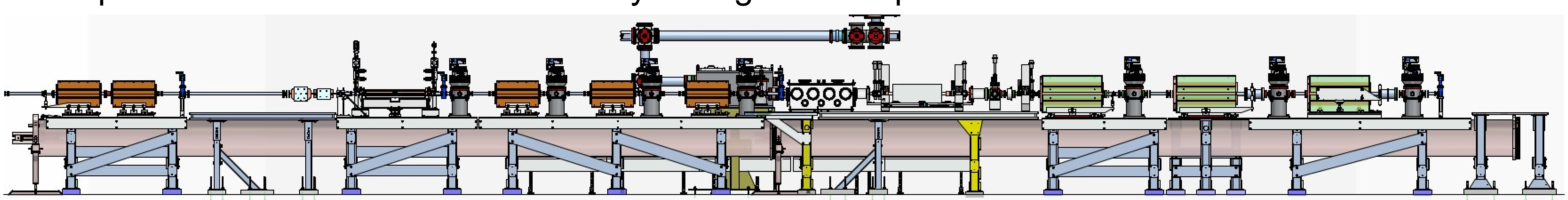
Open questions: contribution of virtual intermediate photons; one-step vs. two-step, etc.

- Establish a 2nd IP for Compton backscattering: 6 GeV photons
  → this was actually part of the original FACET-II proposal (“BIG”)
- Photon-photon collider – complementary physics accessible:

  → investigate the **importance of virtual photons**
  → investigate the role of **polarization & spin**
  → investigate **photon-photon scattering, vacuum fluctuations**
- Requires ≳100 TW laser for sufficiently strong vacuum polarization



Vacuum fluctuations change the photon dispersion relation



Current FACET-II beamline around the IP

Competition with other experiments: LUXE@DESY

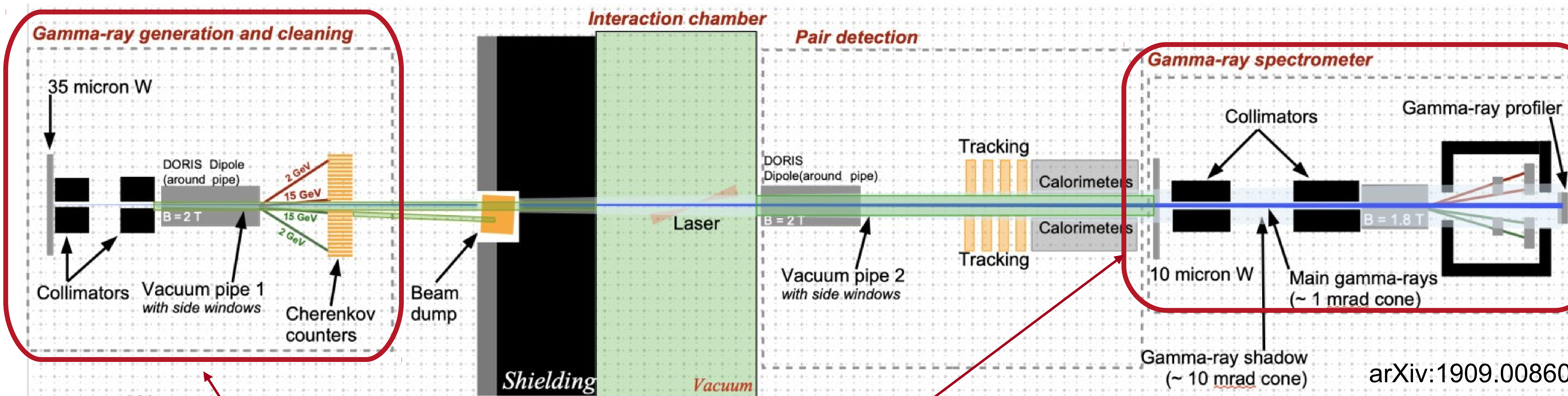
SLAC

Letter of Intent for the LUXE Experiment

H. Abramowicz[1], M. Altarelli[2], R. Aßmann[3], T. Behnke[3], Y. Benhammou[1], O. Borysov[3], M. Borysova[4], R. Brinkmann[3], F. Burkart[3], K. Büßer[3], O. Davidi[5], W. Decking[3], N. Elkina[6], H. Harsh[6], A. Hartin[7], I. Hartl[3], B. Heinemann[3,8], T. Heinzl[9], N. Tal Hod[5], M. Hoffmann[3], A. Ilderton[9], B. King[9], A. Levy[1], J. List[3], A. R. Maier[10], E. Negodin[3], G. Perez[5], I. Pomerantz[1], A. Ringwald[3], C. Rödel[6], M. Saimpert[3], F. Salgado[6], G. Sarri[11], I. Savoray[5], T. Teter[6], M. Wing[7], and M. Zepf[6,11,12]

European XFEL

DESY



arXiv:1909.00860

- Very similar layout/plans (common people)
- Also aiming at **gamma-laser collisions**
- Also planning with a **pair spectrometer**
- 30 TW laser, then upgrade to **300 TW**

→ **We have to upgrade our experiment in order to stay competitive**

	30 TW, 8μm	300 TW, 3μm
Laser energy after compression (J)	0.9	9
Percentage of laser in focus (%)	40	40
Laser energy in focus (J)	0.36	3.6
Laser pulse duration (fs)	30	30
Laser focal spot FWHM (μm)	8	3
Peak intensity in focus (Wcm^{-2})	1.6×10^{19}	1.1×10^{21}
Dimensionless peak intensity, ξ	2	16
Laser repetition rate (Hz)	1	1
Electron-laser crossing angle (rad))	0.35	0.35

Thank you for your attention