Status for 2016 and plans for 2017, CERN NA63

U.I. Uggerhøj[1)], T.N. Wistisen
Department of Physics and Astronomy, Aarhus University, Denmark

A. Di Piazza
Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117, Germany

NA63

Measurements of the radiation reaction

CERN-SPSC-2016-024 / SPSC-SR-189
07/06/2016

Classical Radiation Reaction

Jackson 1975 p. 786-798

$$m\dot{\mathbf{v}} = \mathbf{F}_{ext}$$ N2

$$P(t) = \frac{2}{3}\frac{e^2}{c^3}(\dot{\mathbf{v}})^2$$ Larmor

$$m\dot{\mathbf{v}} = \mathbf{F}_{ext} + \mathbf{F}_{rad}$$

$\mathbf{F}_{rad}$ "must" vanish if $\dot{\mathbf{v}} = 0$ (no radiation)

$$m(\dot{\mathbf{v}} - \tau\ddot{\mathbf{v}}) = \mathbf{F}_{ext}$$

Lorentz-Abraham-Dirac (LAD) equation

$$\mathbf{F}_{rad} = \frac{2}{3}\frac{e^2}{c^3}\ddot{\mathbf{v}} = m\tau\ddot{\mathbf{v}} \qquad \tau = \frac{2}{3}\frac{e^2}{mc^3}$$

No field, solution to LAD eq.:
(runaway – energy conservation)

$$a(t) = a_0 e^{t/\tau},$$

$$\tau = 6 \times 10^{-24}\text{s}.$$

Step-fct. field, solution to LAD eq.:
(pre-acceleration - causality)

Classical Electrodynamics

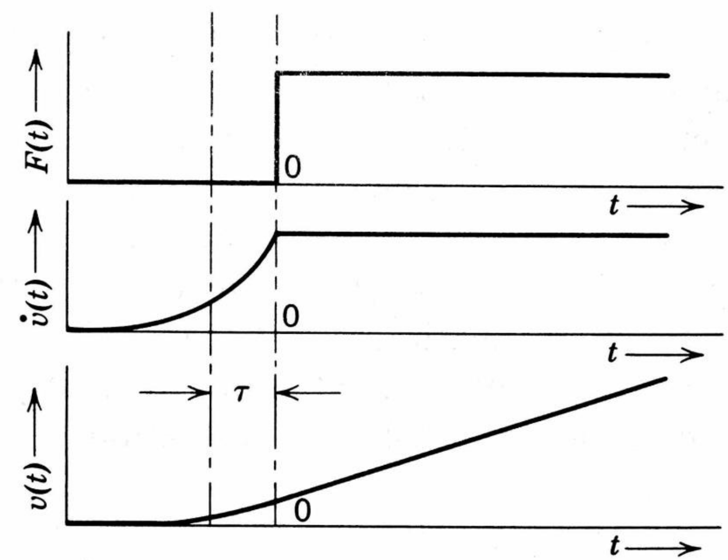
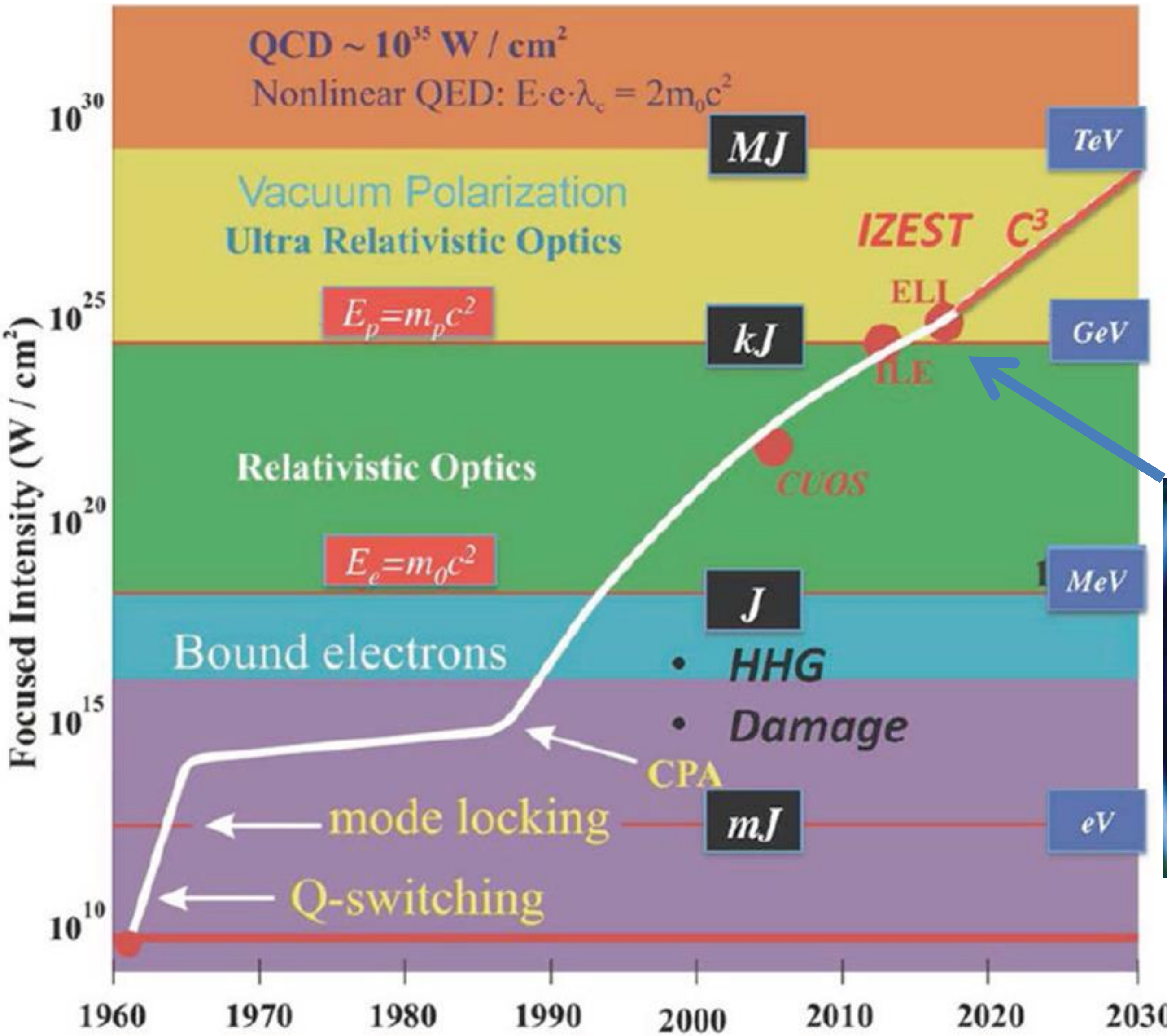


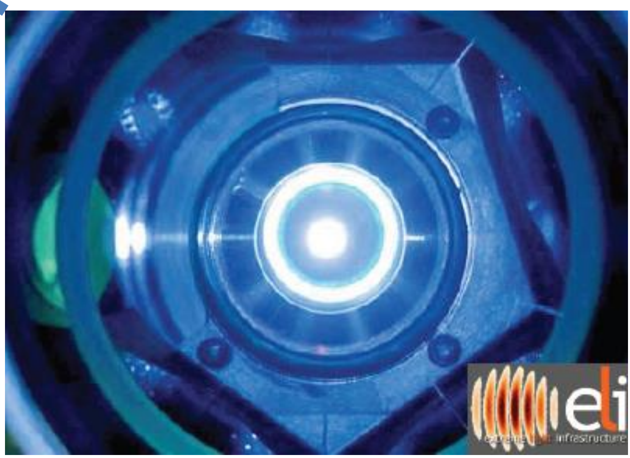
Fig. 17.1 "Preacceleration" of charged particle.

High-intensity laser interactions

(a short digression)



IZEST, ELI,
XCELS, HiPER,
XFEL, NIF,
GEKKO-EXA,
POLARIS, BELLA ...

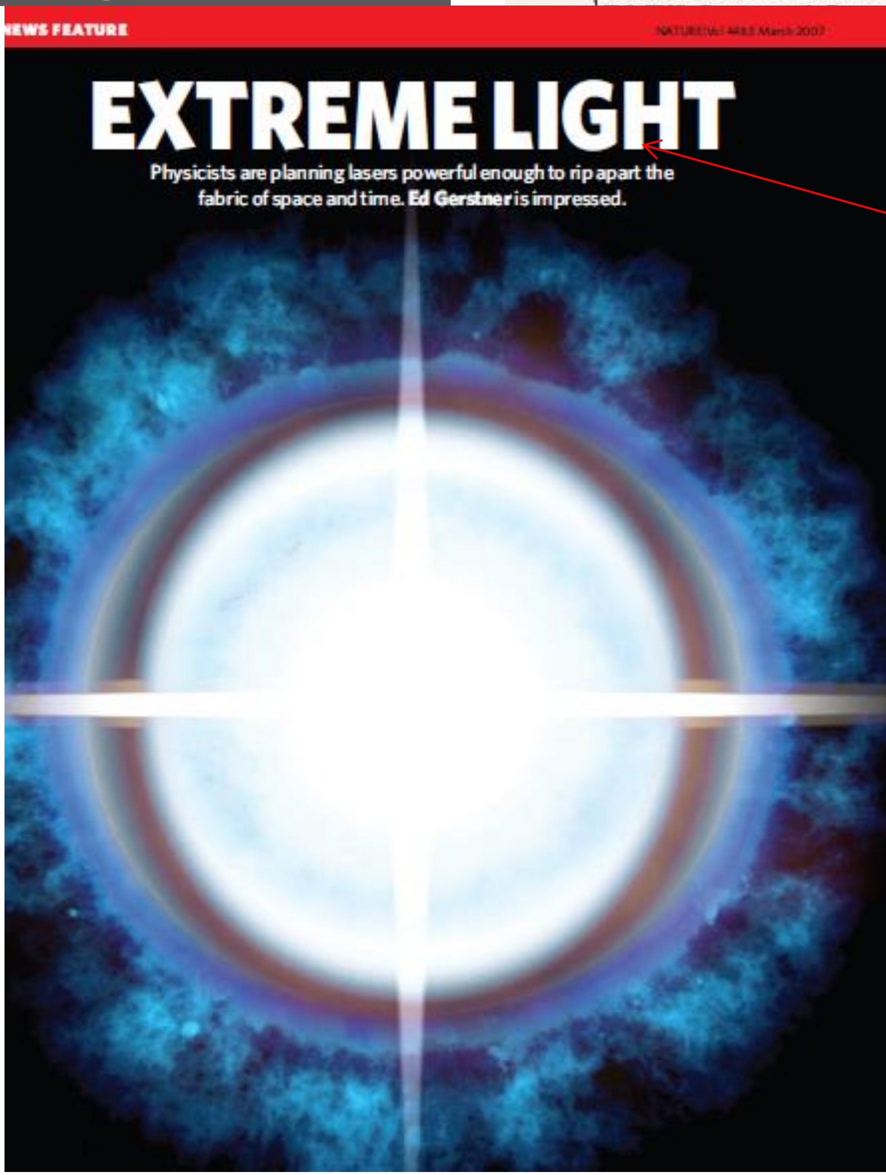


Mourou, Tajima

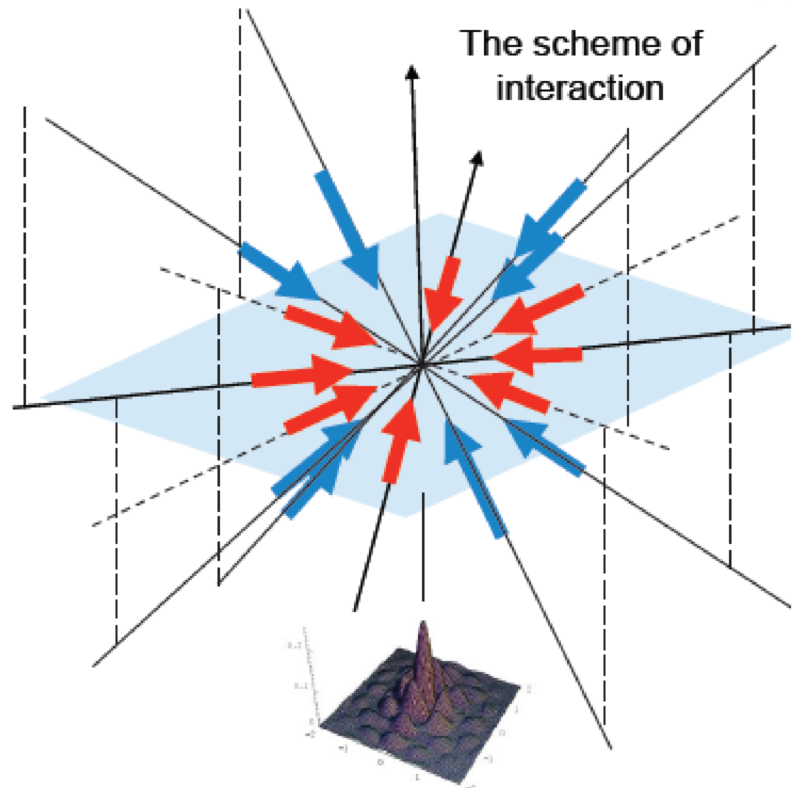
PRL 104, 220404 (2010) PHYSICAL REVIEW LETTERS week ending 4 JUNE 2010

Multiple Colliding Electromagnetic Pulses: A Way to Lower the Threshold of e^+e^- Pair Production from Vacuum

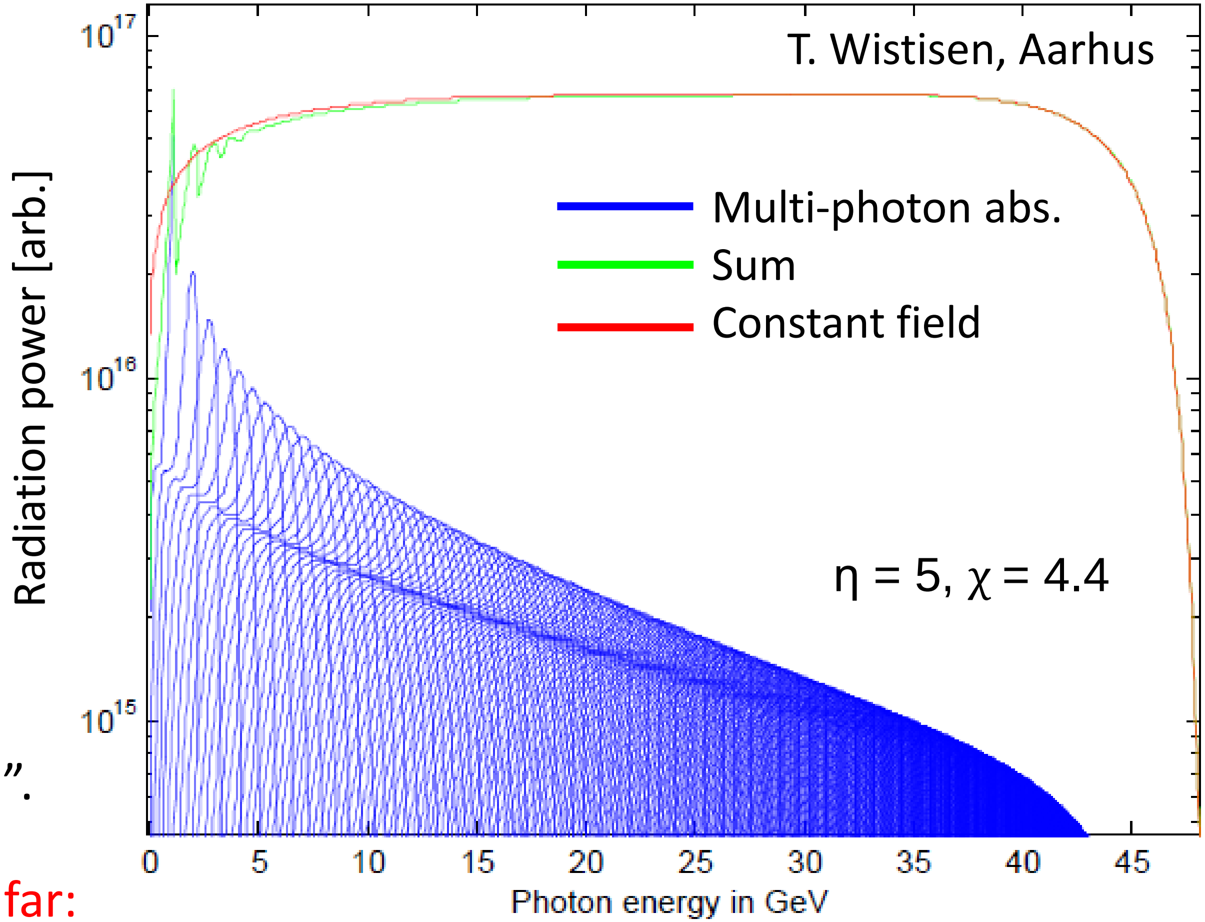
S. S. Bulanov,[1,2] V. D. Mur,[3] N. B. Narozhny,[3] J. Nees,[1] and V. S. Popov[2]
... for Ultrafast Optical Science, University of Michigan, Ann Arbor, Michigan 48109, USA
...e of Theoretical and Experimental Physics, Moscow 117218, Russia
...onal Research Nuclear University MEPhI, 115409 Moscow, Russia
(Received 2 March 2010; published 1 June 2010)



``Physicists are planning lasers powerful enough to rip apart the fabric of space and time''



"The location of ELI s fourth pillar, the highest intensity pillar, is still to be decided. Its laser power is expected to exceed that of the current ELI pillars by about one order of magnitude
[i.e. reach 10^{24} W/cm^2,
Schwinger limit = 10^{29} W/cm^2]".



The only laser experiment so far:
SLAC E-144: PRL **76**, 3116 (1996), PRL **79**, 1626 (1997)

Laser frequency

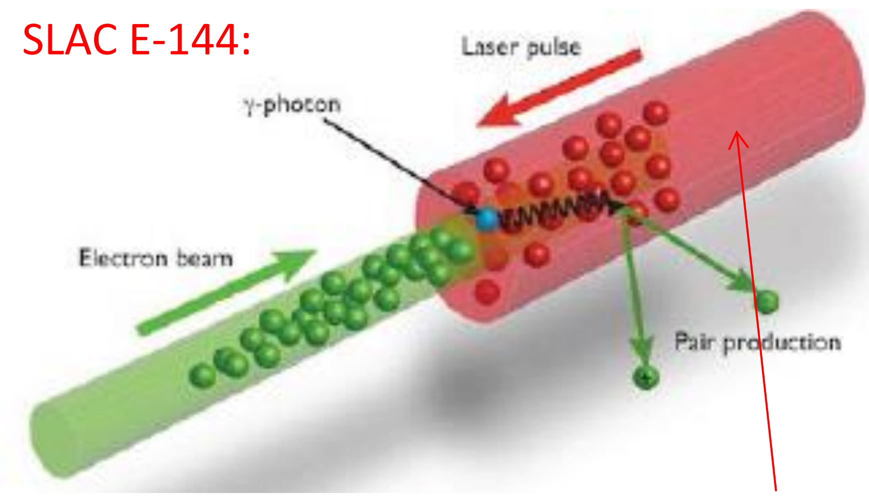
$$\eta = e\sqrt{\langle \bar{A}_\mu A^\mu \rangle}/mc^2 = e\bar{\mathcal{E}}_{\rm rms}/m\omega_0 c = e\bar{\mathcal{E}}_{\rm rms}\lambda\!\!\!^{-}_0/mc^2$$

$$\kappa = \sqrt{\langle (F_{\mu\nu}p^\nu)^2 \rangle}/(mc^2\mathcal{E}_{\rm crit})$$

$$\mathcal{E}_{\rm crit} = m^2c^3/e\hbar = mc^2/e\lambda\!\!\!^{-}_C = 1.3 \times 10^{16}\ {\rm V/cm}$$

Why not use a constant strong field instead?

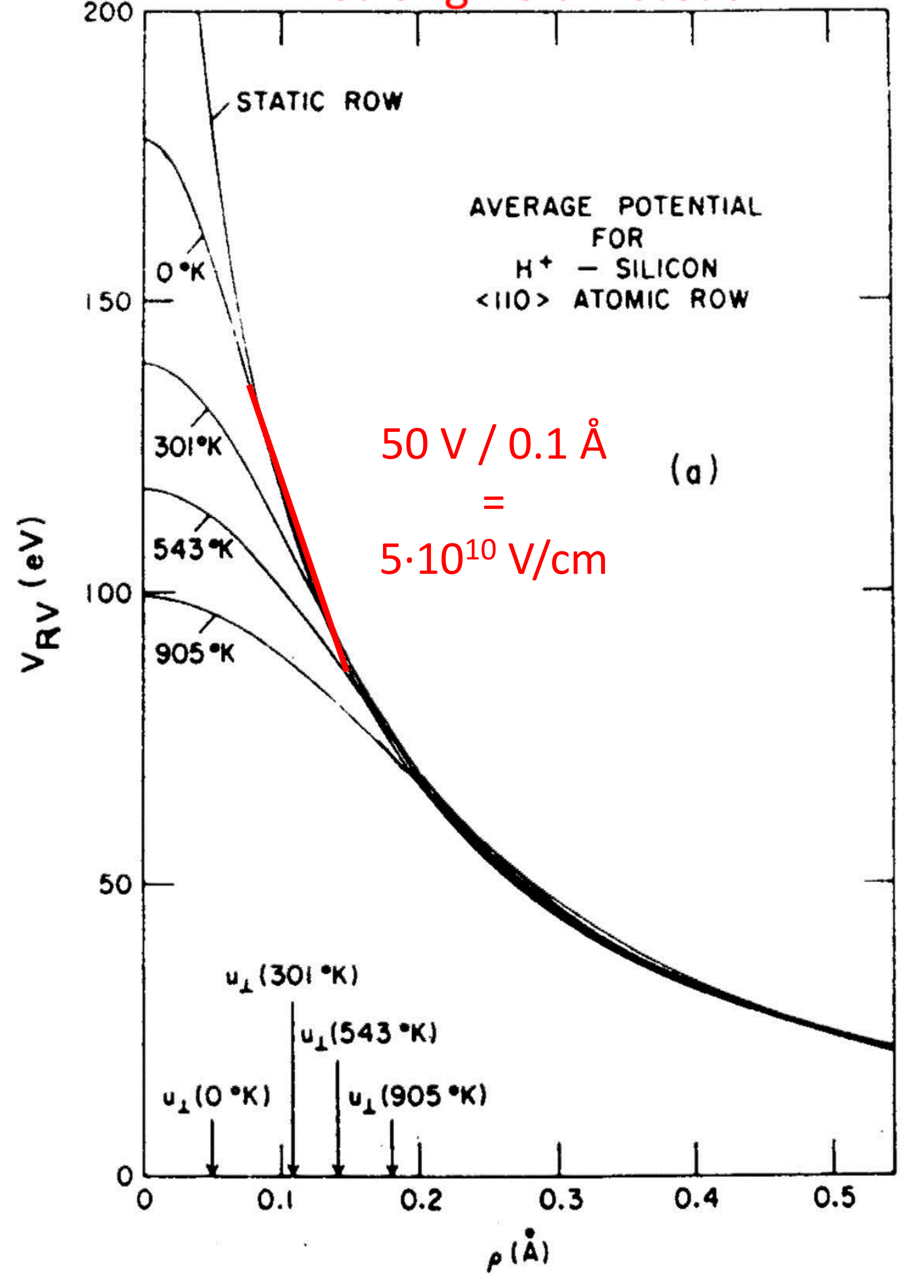
SLAC E-144:



Crystals

Replace laser-pulse by virtual photons

Why not use a constant strong field instead?



Extremely strong electric fields

10^{10}-10^{11} V/cm

Relativistic invariant:

$$\chi = \gamma \mathcal{E} / \mathcal{E}_0$$

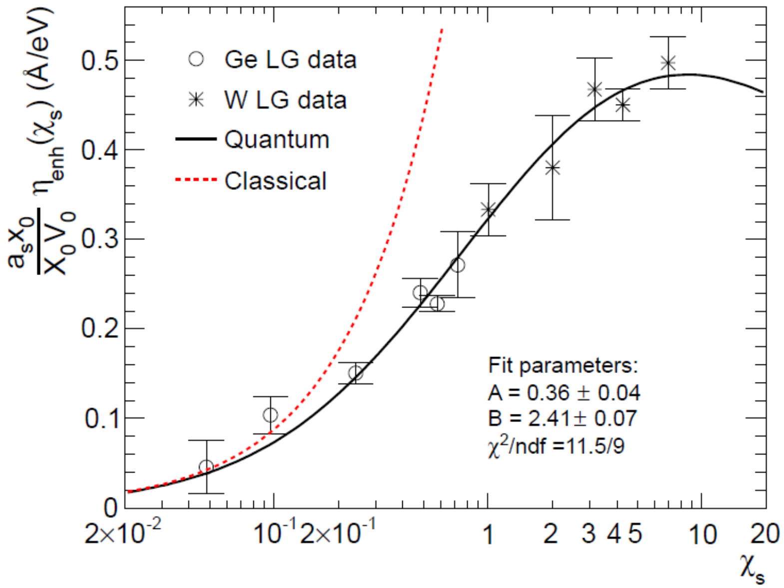
$$\mathcal{E}_0 = mc^2 / e\lambda\!\!\!^{-}_c$$

$= 1.32\cdot 10^{16}$ V/cm

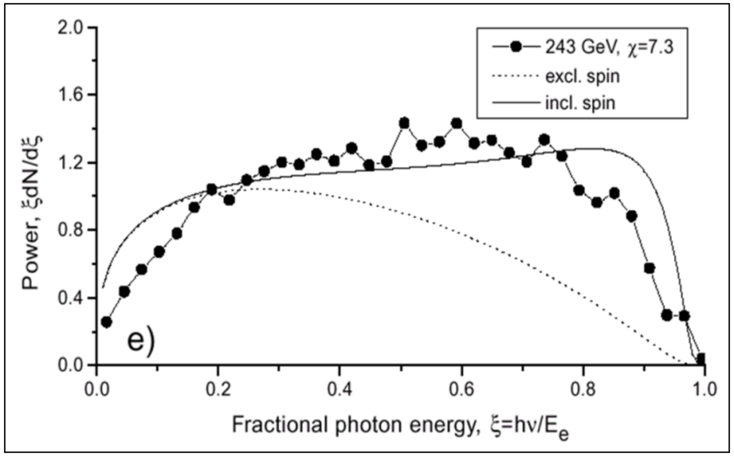
Previously presented by NA63

$$\frac{I_e}{I_{\rm cl}} = (1 + 4.8(1+\chi)\ln(1+1.7\chi) + 2.44\chi^2)^{-2/3}.$$

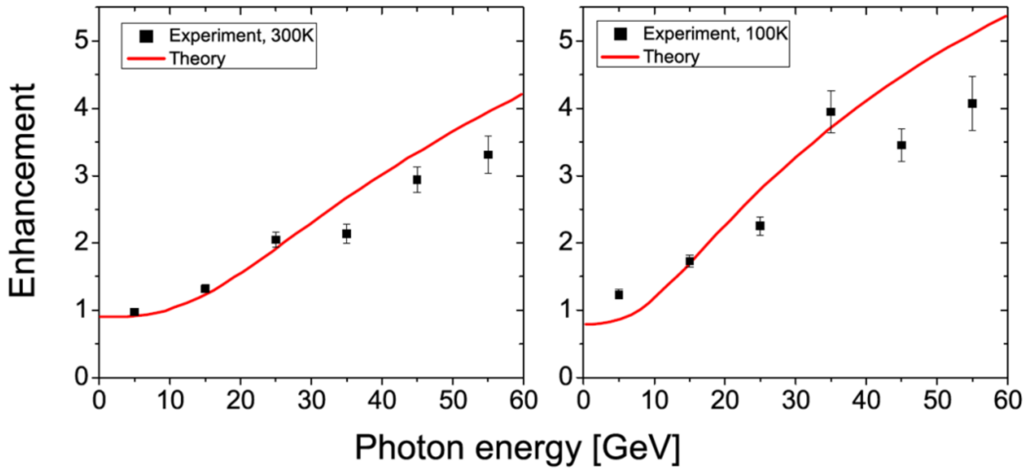
those directly relevant to high-power laser interactions…



1. 'Quantum-synchrotron'-rad.

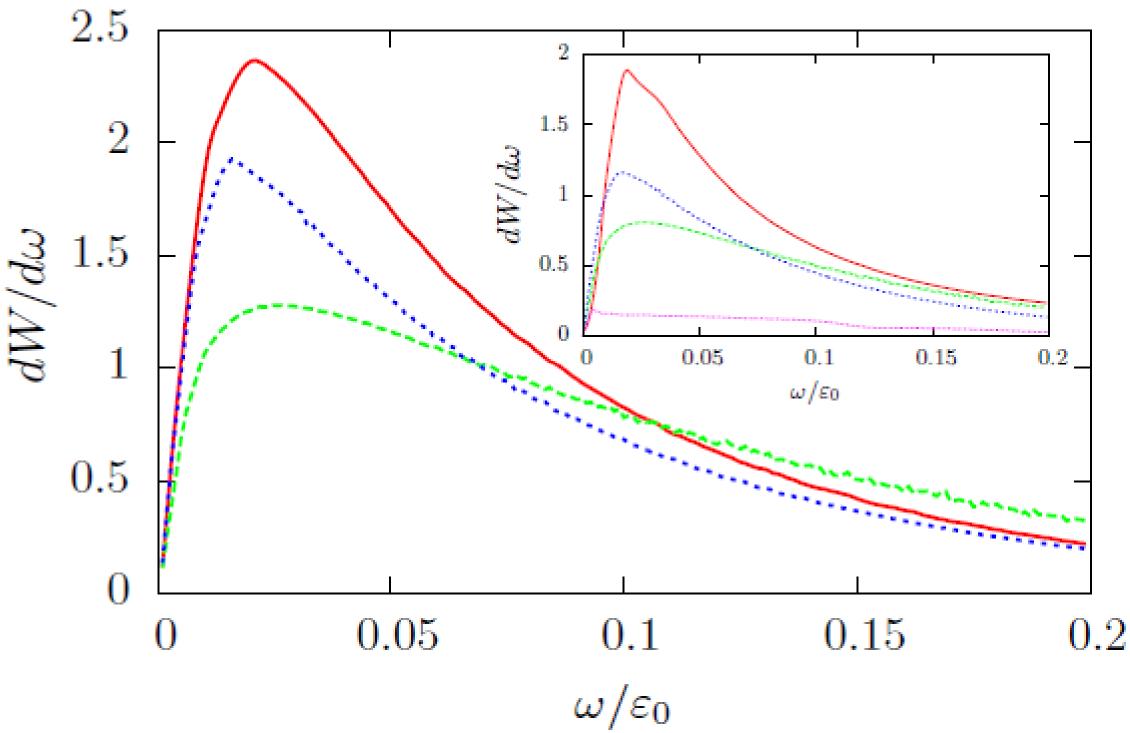


2. Spin-flip processes
3. 'Schwinger' pair prod.
4. Trident production



Investigation of classical radiation reaction with aligned crystals

A. Di Piazza ,Tobias N. Wistisen, Ulrik I. Uggerhøj



arXiv:1503.05717v2

Figure 3: (Color online) Radiation energy spectra for parameters given in the text without RR (dashed green curve), with RR and no derivative term (dotted blue curve), and with RR (continuous red curve). The inset shows the corresponding plots including dechanneling and the spectrum of coherent bremsstrahlung by dechanneled electrons (fine-dotted purple line).

Derivative term not accessible in laser interactions

In a purely electric field (in the lab frame), LL equation :

$$\boldsymbol{f} = \frac{2e^3}{3m}\gamma\left\{(\boldsymbol{v}\cdot\nabla)\boldsymbol{E}\right\} + \frac{2e^4}{3m^2}\left\{\boldsymbol{E}(\boldsymbol{v}\cdot\boldsymbol{E})\right\} - \frac{2e^4}{3m^2}\gamma^2\boldsymbol{v}\left\{(\boldsymbol{E})^2 - (\boldsymbol{E}\cdot\boldsymbol{v})^2\right\}$$

eli extreme light infrastructure

Some recent examples…

PHYSICAL REVIEW E **91**, 023207 (2015)

Detecting radiation reaction at moderate laser intensities

Thomas Heinzl,[1,*] Chris Harvey,[2,3] Anton Ilderton,[3] Mattias Marklund,[3,4] Stepan S. Bulanov,[5] Sergey Rykovanov,[6,†] Carl B. Schroeder,[6] Eric Esarey,[6] and Wim P. Leemans[6]

PRL **105**, 220403 (2010) PHYSICAL REVIEW LETTERS week ending 26 NOVEMBER 2010

Quantum Radiation Reaction Effects in Multiphoton Compton Scattering

A. Di Piazza,[*] K. Z. Hatsagortsyan, and C. H. Keitel
Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

PRL **116**, 090406 (2016) PHYSICAL REVIEW LETTERS week ending 4 MARCH 2016

Critical Schwinger Pair Production

Holger Gies[1,2,*] and Greger Torgrimsson[3,†]
[1]*Theoretisch-Physikalisches Institut, Abbe Center of Photonics, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, D-07743 Jena, Germany*

PRL **111**, 054802 (2013) PHYSICAL REVIEW LETTERS week ending 2 AUGUST 2013

Stochasticity Effects in Quantum Radiation Reaction

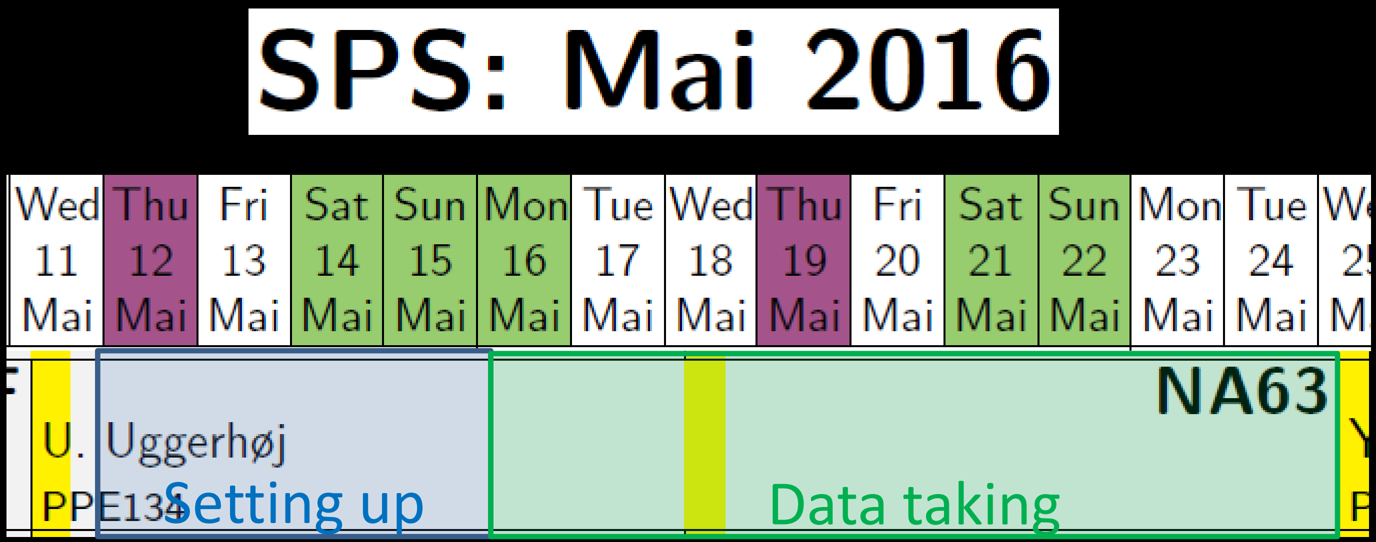
N. Neitz and A. Di Piazza[*]
Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany

PRL **116**, 044801 (2016) PHYSICAL REVIEW LETTERS week ending 29 JANUARY 2016

Quantum Radiation Reaction: From Interference to Incoherence

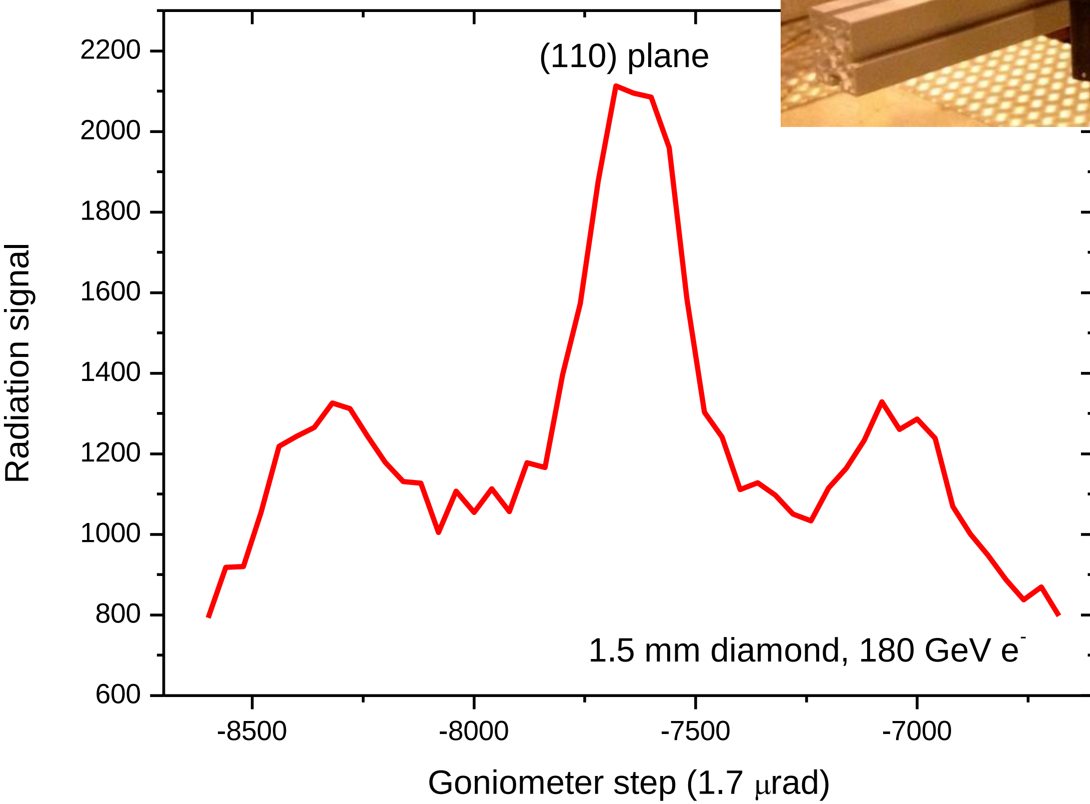
Victor Dinu,[1,*] Chris Harvey,[2,†] Anton Ilderton,[2,‡] Mattias Marklund,[2,§] and Greger Torgrimsson[2,‖]
[1]*Department of Physics, University of Bucharest, P.O. Box MG-11, Măgurele 077125, Romania*
[2]*Department of Physics, Chalmers University of Technology, SE-41296 Gothenburg, Sweden*

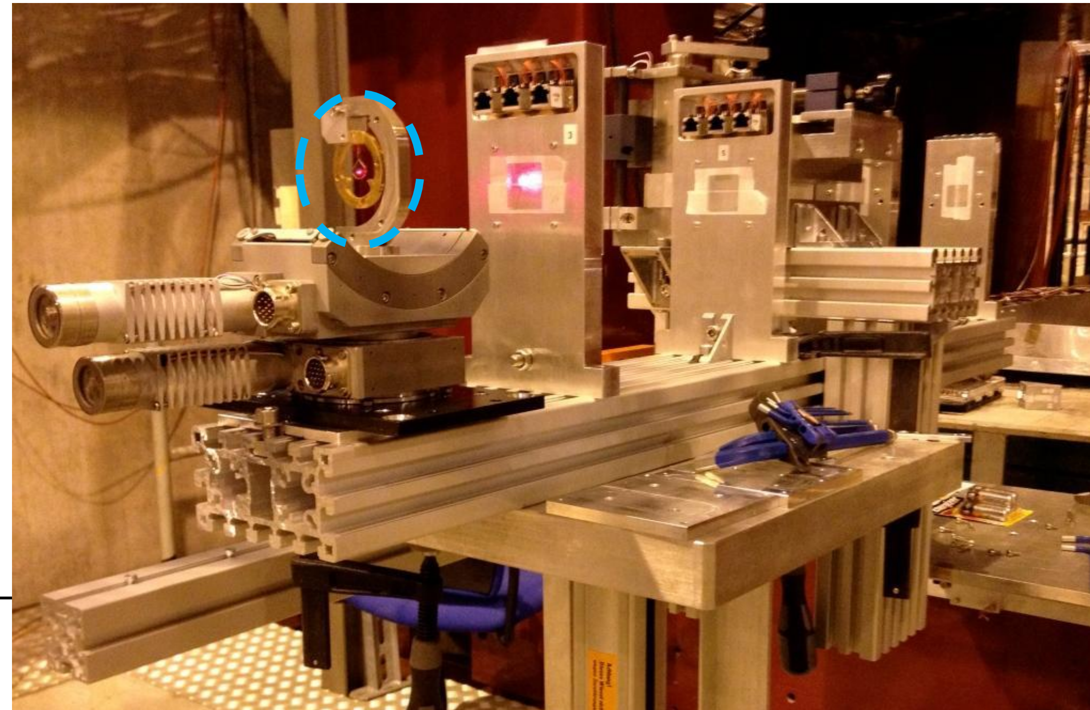
Experiment NA63
Run schedule

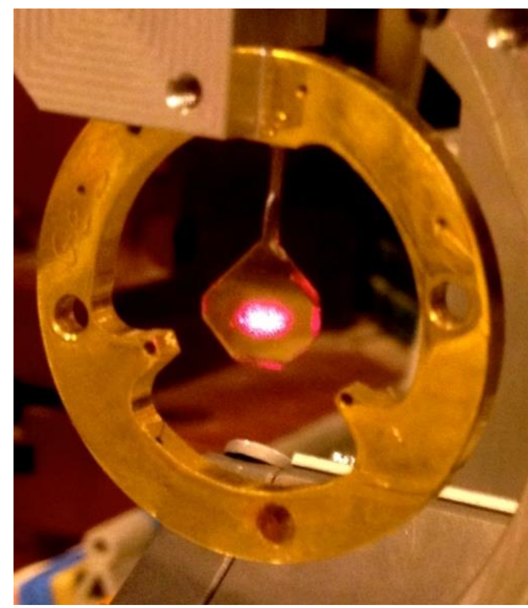


Angular scans

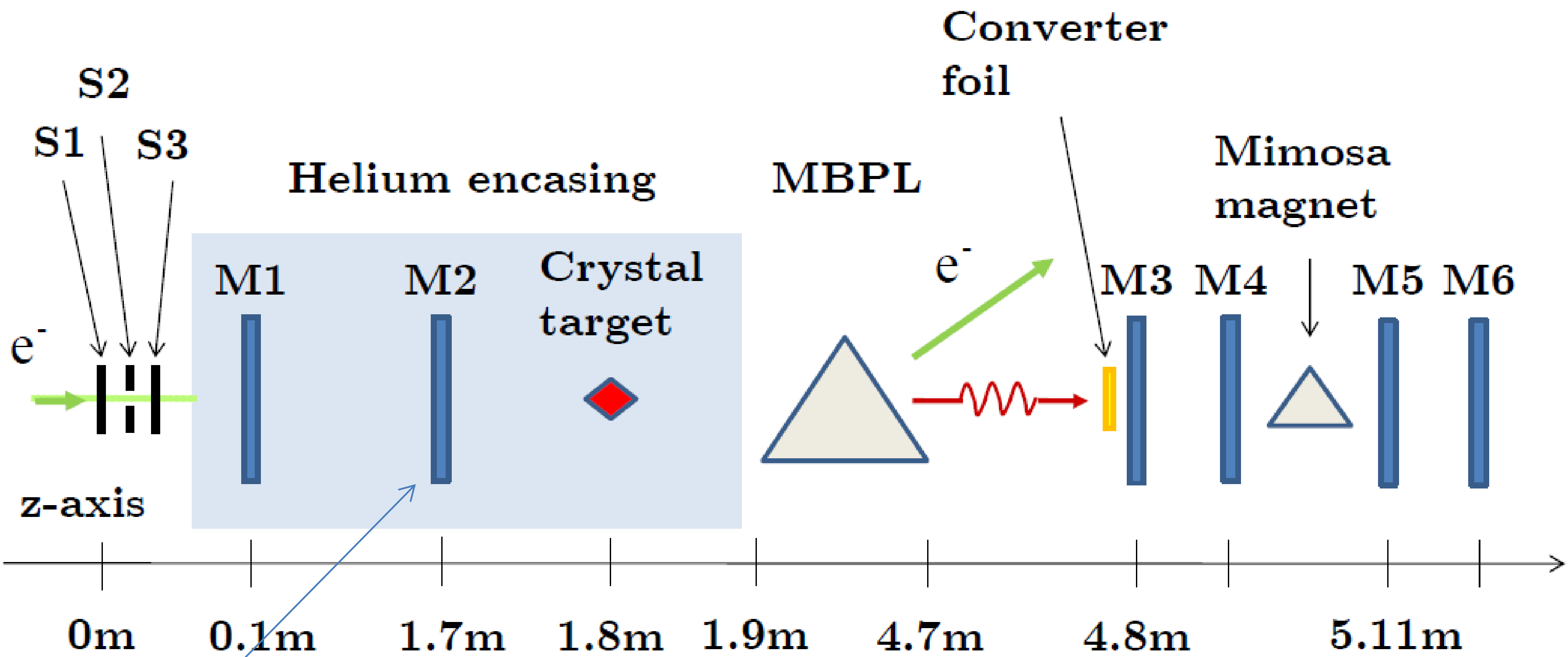
- Radiation enhancement observed w/ 180 GeV electrons (signal = radiation above 50 GeV, ‘strong field radiation’) with 1.5 mm diamond:







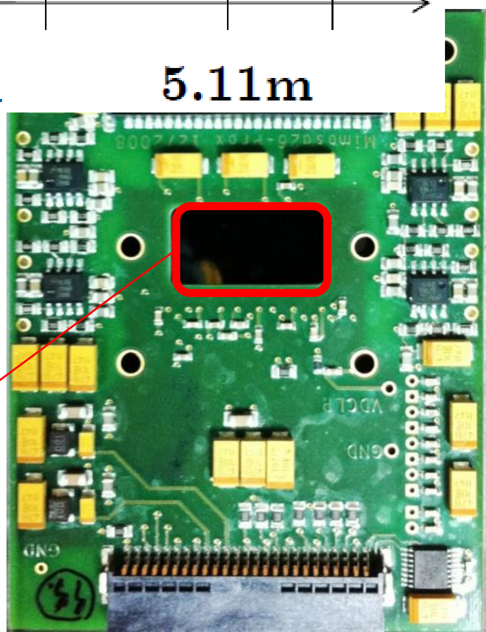
Setup for e+ measurement



MIMOSAs:

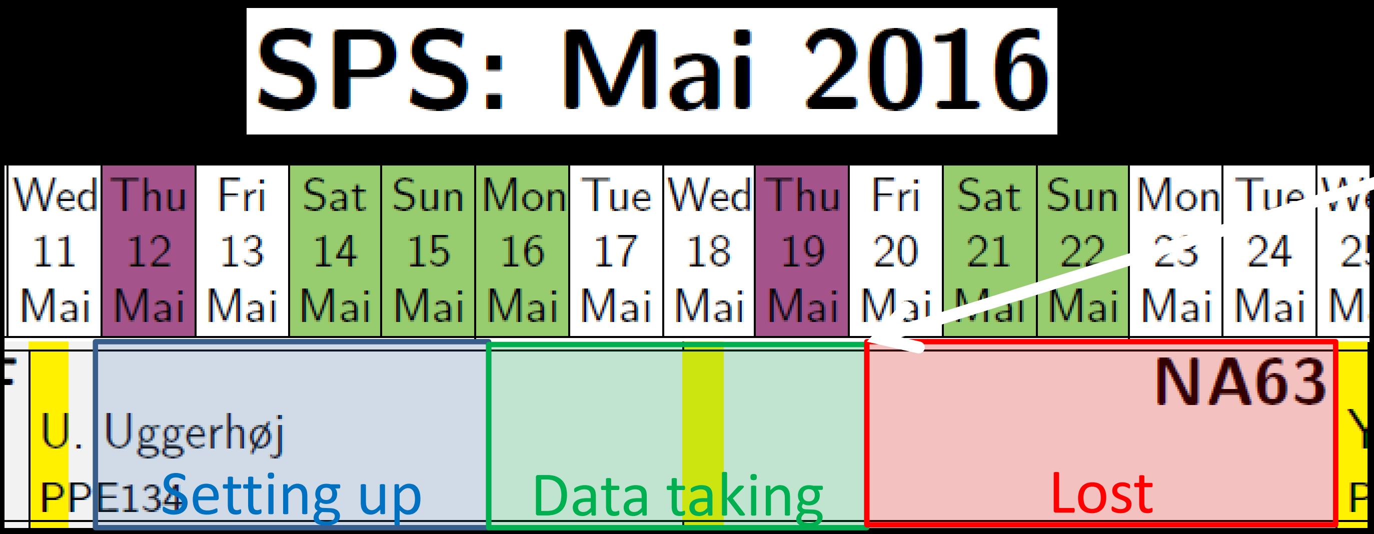
CMOS-based position sensitive detectors
1152 columns of 576 pixels, $\simeq$ 18.4 μm pitch
readout in 110 ms, $\simeq$ 3.5 μm resolution
true multi-hit capability
$\Delta t/X_0 \simeq 0.05\%$

1×2 cm^2



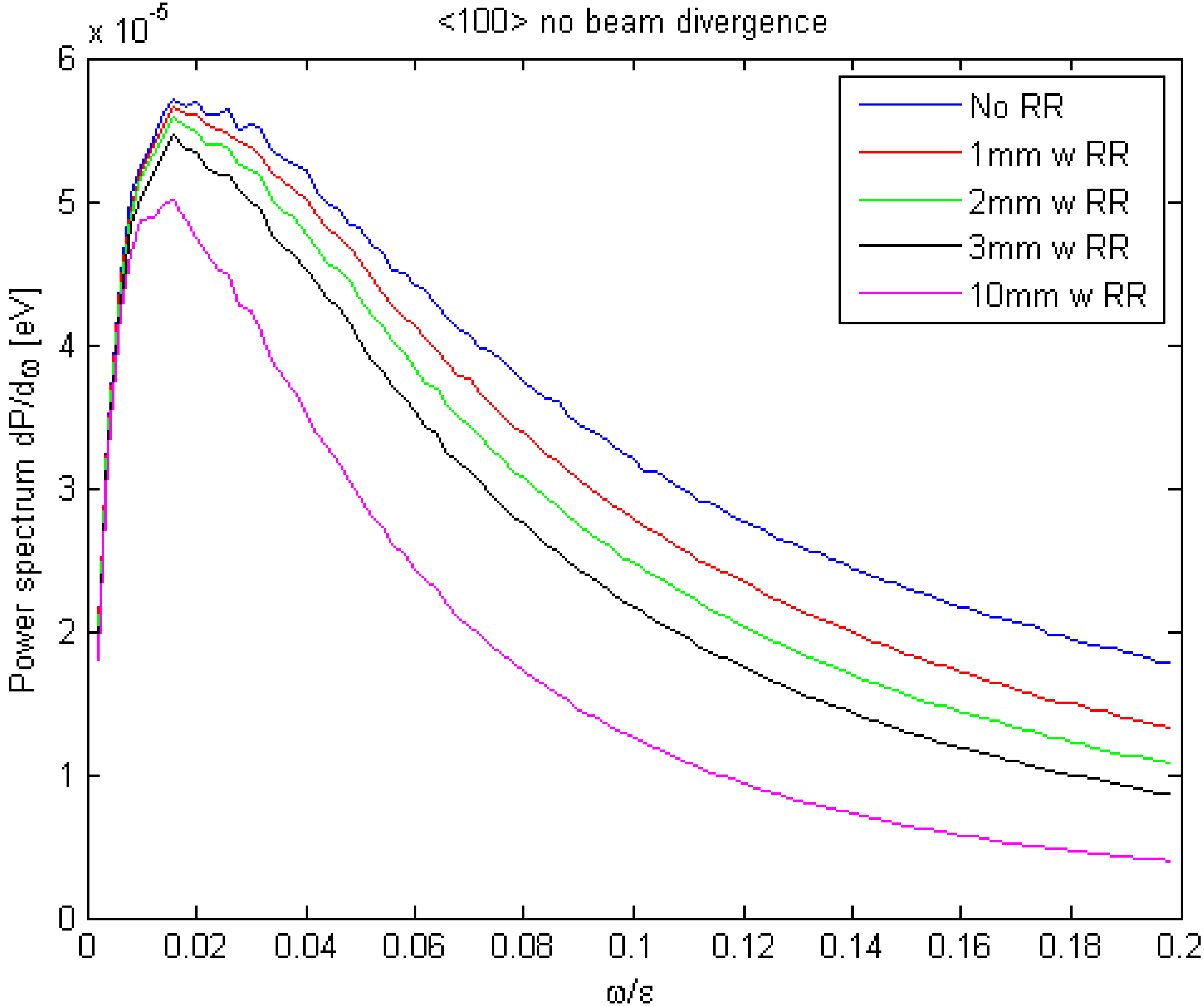

GOLIATH

”[Friday 20th of May in the] morning there was a fire at the PS main power supply (the rotating machine), and it will not be usable for the weeks to come.”

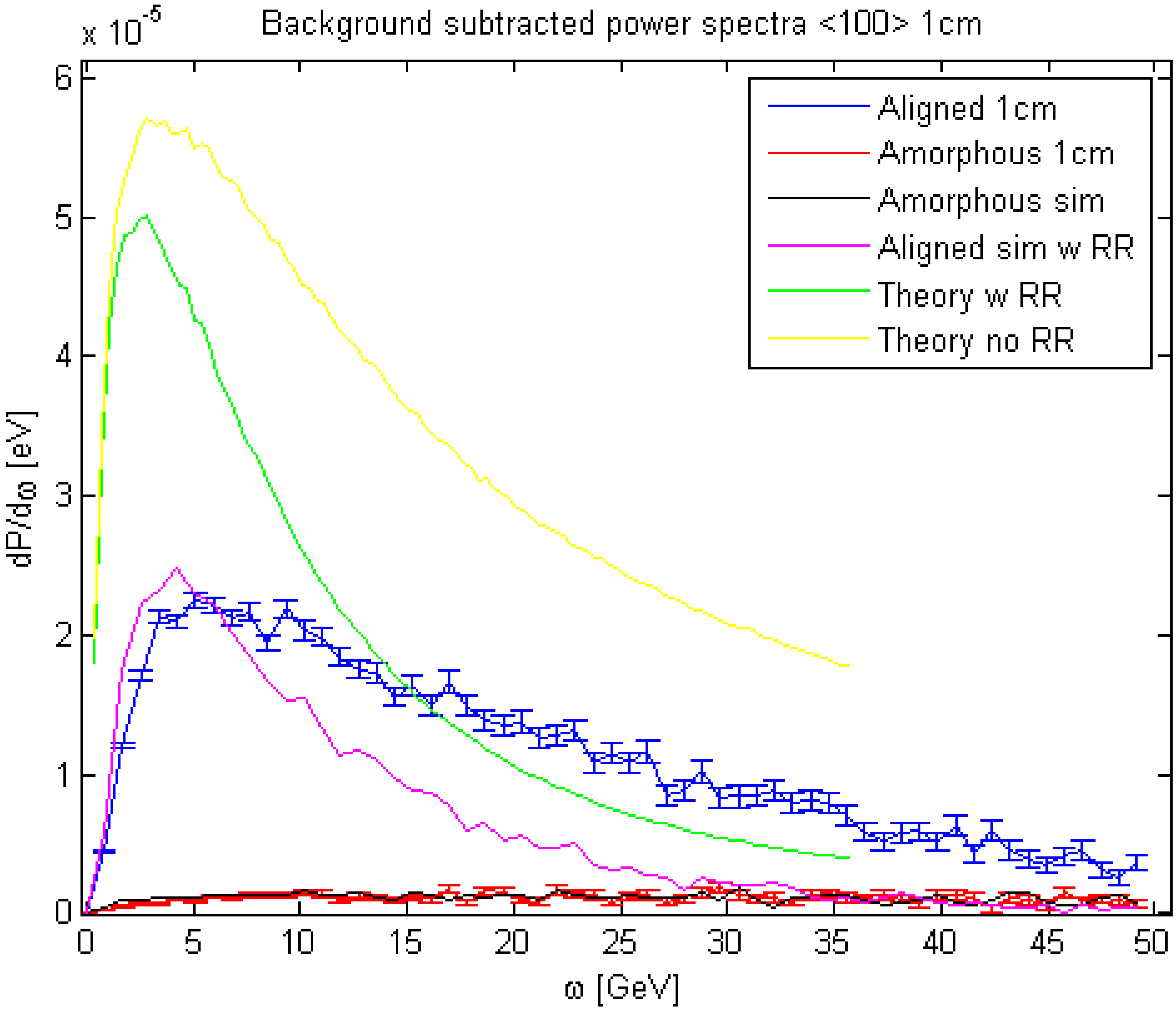


Graphs presented in the following are all **very preliminary**!

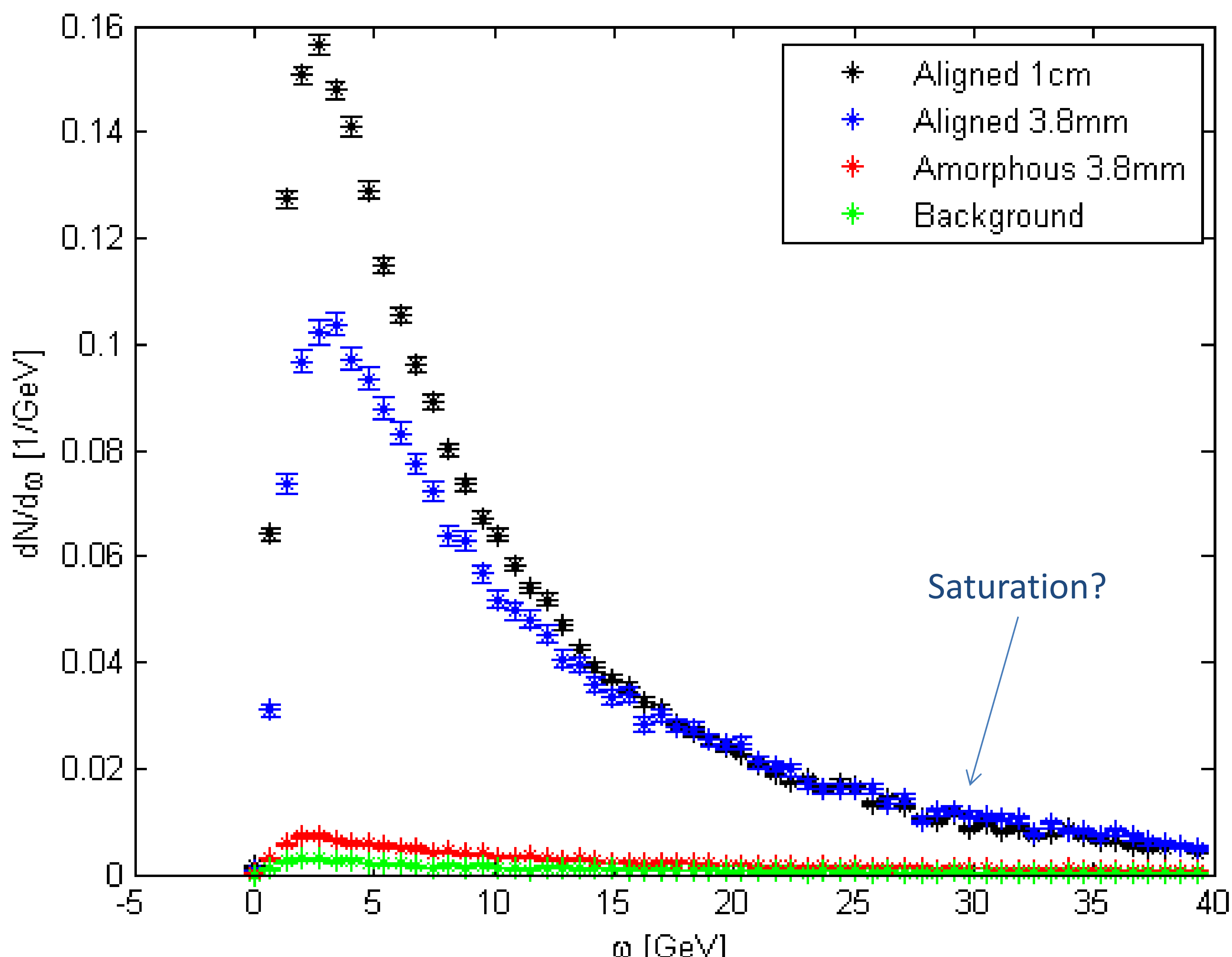
Si <100>, theory - simulated



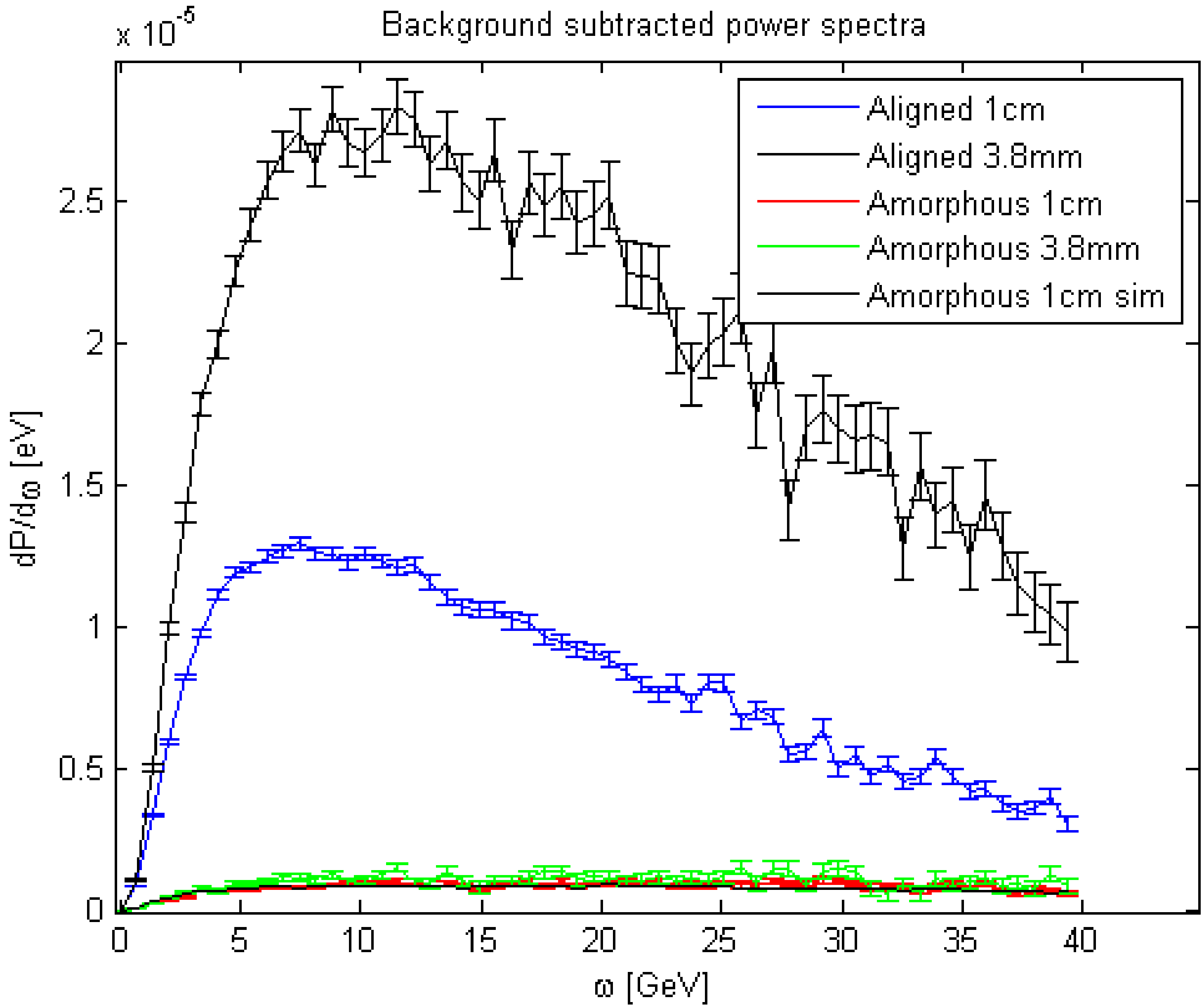
Si <100> power-spectrum



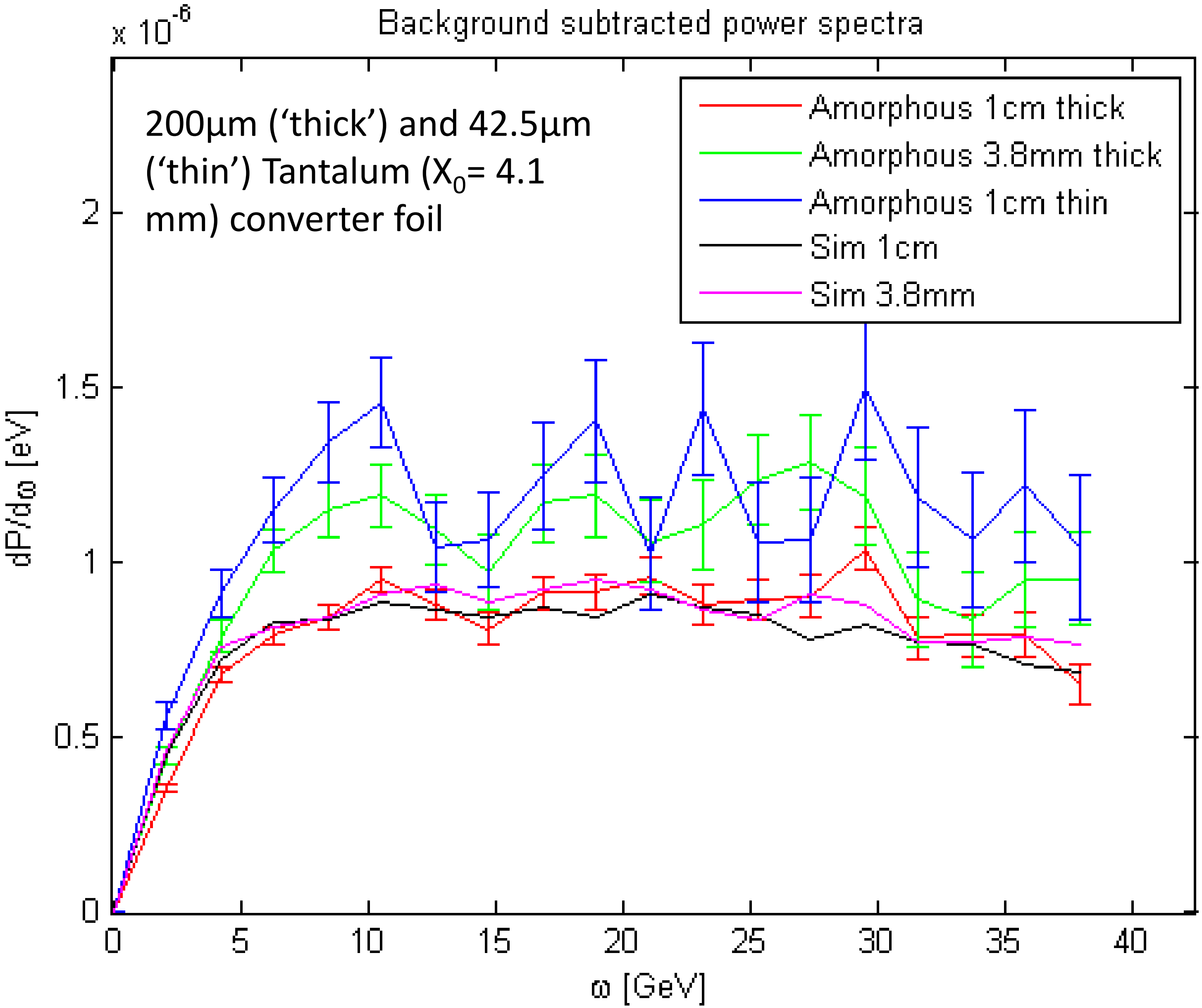
Si <111>, number spectra



Si <111> power-spectrum



Measurements and simulation, Si <111>



PLANS FOR 2017:

NA63 applies for

2 weeks of beam time in H4 in 2017,

to complete the series of measurements necessary for an experimental proof that radiation reaction can be observed using high-energy electrons in crystals

Publications, (related to) NA63

- Since previous SPSC presentation:

1. R.E. Mikkelsen, T. Poulsen, U.I. Uggerhøj and S.R. Klein: Characteristics of Cherenkov radiation in naturally occuring ice, Phys. Rev. D **93**, 053006 (2016)
2. R.E. Mikkelsen, A.H. Sørensen and U.I. Uggerhøj: Elastic photonuclear cross sections for bremsstrahlung from relativistic heavy ions, Nucl. Instr. Meth. B **372**, 58-66 (2016)
3. A. Di Piazza, T.N. Wistisen and U.I. Uggerhøj: *Investigation of classical radiation reaction with aligned crystals*, ArXiv: 1503.05717, subm. to Phys. Lett. B (2015); still under review

NA63 has produced 22 publications since 2008

What are the invariants?

$$\chi^2 = \frac{(F_{\mu\nu}p^{\nu})^2}{m^2c^2\mathcal{E}_0^2},$$

$$\Xi = \frac{F_{\mu\nu}^2}{\mathcal{E}_0^2} = \frac{2(\vec{B}^2 - \vec{\mathcal{E}}^2)}{\mathcal{E}_0^2},$$

$$\Gamma = \frac{e_{\lambda\mu\nu\rho}F^{\lambda\mu}F^{\nu\rho}}{\mathcal{E}_0^2} = \frac{8\vec{\mathcal{E}}\cdot\vec{B}}{\mathcal{E}_0^2},$$

$$\mathcal{E}_0 = \frac{m^2c^3}{e\hbar} = 1.323285\cdot 10^{16}\mathrm{V/cm} \quad B_0 = 4.414005\cdot 10^{9}\mathrm{T}$$

What are the invariants?

NA63

$$\chi^2 = \frac{(F_{\mu\nu}p^\nu)^2}{m^2c^4\mathcal{E}_0^2}$$

In terms of electric and magnetic fields:

$$\chi^2 = \frac{1}{\mathcal{E}_0^2 m^2 c^4}\left((\boldsymbol{p}c \times \boldsymbol{B} + E \cdot \boldsymbol{\mathcal{E}})^2 - (\boldsymbol{p}c \cdot \boldsymbol{\mathcal{E}})^2\right)$$

A particle moving perpendicularly to a purely electric/magnetic field:

$$\chi = \frac{\gamma\mathcal{E}}{\mathcal{E}_0} \qquad \Upsilon = \frac{2}{3}\frac{\hbar\omega_c}{E_0} = \gamma\frac{B}{B_0}$$

$$\mathcal{E}_0 = \frac{m^2c^3}{e\hbar} = 1.323285 \cdot 10^{16}\mathrm{V/cm} \quad B_0 = 4.414005 \cdot 10^9\mathrm{T}$$