EUROPEAN PLASMA RESEARCH ACCELERATOR WITH EXCELLENCE IN APPLICATIONS



High energy physics and detector testing applications at EuPRAXIA

Arnd Specka (LLR, Ecole Polytechnique, France)





This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101079773



- Applications of plasma generated radiation
 - imaging with betatron radiation -> EuAPS, EPAC, and many other
- With primary e- beam
 - test facility for bunch length diagnostics
 - medical (VHEE and ultra-high dose rate)
- Applications of primary & secondary e- beam high energy physics (HEP)
 - low E positron -> material science (e.g. PALS)
 - high E positrons -> positrons source for PA collider studies
 - high flux, high flux density: HE EM shower "simulation" in the lab
 - high flux, low flux density: big detector module calibration, timing, pile-up



Detector R&D and testing are vital



• ESPP 2020 Update:

Detector R&D programmes and associated infrastructures should be supported at CERN, national institutes, laboratories and universities. **Synergies between the needs of different scientific fields and industry should be identified and exploited** to boost efficiency in the development process and increase opportunities for more technology transfer benefiting society at large. Collaborative platforms and consortia must be adequately supported to provide coherence in these R&D activities.

• P5 report (Snowmass 2021):

Test beams and irradiation facilities[...])**are a vital element** of detector technology development and should be supported.



EUPRAXIA HEP detector testing & calibration with PA

- * * * * * * * Funded by the European Union
- modern big particle detectors require extensive R&D, simulation and testing
- test beams are available only at big accelerator labs (CERN, FNAL, DESY, LNF,...)
- e- from PA may pioneer complementary ways to test & calibrate detectors

but there are considerable differences:

- in conventional test beams
 - variety of available particles: π^{\pm} , K^{\pm} , p, n, μ^{\pm} , e^{\pm} , gamma
 - particles arrive randomly «one at a time» (= time that can be resolved by the detector, e.g. 1000 in 1sec), low average current, low pile-up (desired)
- in plasma accelerator generated beams (in framework of EuPRAXIA)
 - only electrons (primary beam)
 - electrons arrive at the same time: massive "pile-up", p < 5–10 GeV/c

-> turn differences to advantages





classical demand: measure single-particle response of a detector (module) with high statistical precision

- example: CERN North Area secondary beam
 - SPS: p(450GeV) \rightarrow primary target $\rightarrow \pi^+, \pi^-, \pi^0$
 - $\pi^+, \pi^- \rightarrow$ secondary target $\rightarrow \mu^+ \mu^-$, neutrinos
 - $\pi^0 \rightarrow$ decay to $2\gamma \rightarrow$ secondary target $\rightarrow e^+, e^-$ (max 80 GeV/c)
 - energy selection by dipole and collimator slit ($\Delta p/p < 1\%$)
 - one SPS "spill" (4sec) every 17sec
 - also: ions, neutrons, kaons,
- users are happy with (and actually want)
 - less than one particle every few ns (on average)
- large panel of users
 - physics experiments
 - particle detector development and calibration





Snowmass 21 survey of TB needs and



Facility	# of	Particles	Energy Range	Availability		
CERN/PS	2 Deams	e h u(sec)	0.5-10 GeV/c	9 mos/vr		
CERN/SPS	4	p(prim); $a = h u(soc)$;	20-400 CeV/c	9 mos/yr		
CERN/SF5	4	$p(prim.); e,n,\mu(sec.);$	20-400 Gev/c	9 mos/yr		
		e,n(tert.); FD(prim);	proton equiva-			
CEDN/CLEAD	1	other ion species	1ent 50.250 MeV/e	8 0 m as / m		
DARNE DARNE	1	e	30-230 MeV/c	8-9 mos/yr		
DAFNE Frascati	1	e'/e (prim. and sec.);	25-750 MeV/c	25-35 wks/yr		
DEDGEL (II		photons	10037/ 00			
DESY (Ham-	3	e ⁺ /e ⁻ (sec.); e ⁻ (prim.,	1-6 GeV/c; 6.3	11 mos/yr		
burg, GE)		planned)	GeV/c			
ELPH (Sendai,	2	photons (tagged); e ⁺ ,e ⁻	0.7-1.2 GeV/c;	2 mos/yr		
JP)		(conversion)	0.1-1 GeV/c			
ELSA (Bonn,	1	e ⁻	1.2-3.2 GeV/c	$\sim 30 \text{ days/yr}$		
GE)						
FTBF (Fermi-	2	p (prim.); e,h,µ (sec.); h	120 GeV/c; 1-66	8 mos/yr		
lab, US)		(ter.)	GeV/c; 200-500			
			MeV/c			
IHEP (Beijing,	2	e (prim.); e,p,π (sec.)	1.1-2.5 GeV/c;	3 mos/yr		
CN)			0.1-1.2 GeV/c			
IHEP (Protvino,	5	p,C-12 (prim.);	70 (6-300)	2 mos/yr		
RU)		p,K,π,μ,e (sec.)	GeV/c; 1-45			
,			GeV/c			
MAMI (Mainz,	3	e ⁻ ,photons	< 1.6 GeV/c	$\sim 30 \text{ days/yr}$		
GE)				0.70		
NSRL	1	p, heavy ions	0-1 GeV/n	10 mos/vr		
(Brookhaven,		F)				
US)						
piELppiMLetc.	2-4	π.н.е.р	50-450 MeV/c	6-8 mos/vr		
(PSI, CH)				0 0 11100, 31		
PIF (PSI, CH)	1	p	5-230 MeV/c	11 mos/yr		
RCNP (Osaka.	7	p,heavy ions, μ^+	24-400 MeV/c	7-8 mos/vr		
JP)		* ····· · · · · · · · · · · · · · · · ·		, ,		
SLAC (Stan-	0	e (prim.): e (sec.)	2.5-15 GeV/c: 1-	currently no		
ford, US)	ľ	- (January) - (1999)	14 GeV/c	beam		
SPRING-8						
	2	photons (tagged), e ⁺ e ⁻	0.4-2.9 GeV/c	>60 days/yr		
(Compton Facil-	2	photons (tagged), e ⁺ ,e ⁻ (conv.)	0.4-2.9 GeV/c	>60 days/yr		

.

*) and irradiation facilities

Survey Participants



- Energy
- = Cosmic
- Rare Processes and Precision
- Accelerator
- Instrumentation



M. Hartz, et al., Proceedings of Snowmass 2021 arXiv:2203.09944v1 [physics.acc-ph] 16 Mar 2022

www.eupraxia-pp.org



Snowmass 21 survey of TB*) needs and



Deams Deams <thdeams< th=""> <thdeams< th=""> <thde< th=""><th>Facility</th><th># of</th><th># of Particles Energy Range Availability *) and irradiation facilities</th><th></th></thde<></thdeams<></thdeams<>	Facility	# of	# of Particles Energy Range Availability *) and irradiation facilities						
CERN/SPS 4 p(prim.); e,h,µ(sec.); e,h(tert.); e,h(tert.); 20-400 proton proton equiva- lent GeV/c 9 mos/yr Survey Participants CERN/CLEAR 1	CERN/PS	2	$\frac{2}{2}$ e,h, μ (sec.) 0.5-10 GeV/c 9 mos/yr						
CERN/CLEAR 1 DAFNE Frascati 1 DAFNE Frascati 1 DESY (Ham-3) burg, GE) ELPH (Sendai, 2) JP) ELSA (Bonn, 1) GE) FTBF (Fermi-2) e. choert intenses bunches	CERN/SPS	4	4 p(prim.); e,h, μ (sec.); 20-400 GeV/c 9 mos/yr	c					
CERN/CLEAR 1 DAFNE Frascati 1 DESY (Ham- burg, GE) ELPH (Sendai, 2 JP) • ELSA (Bonn, 1 GE) FTBF (Fermi- 2) • choert interse burg, SE	-		e,h(tert.); Pb(prim); proton equiva-	2					
CERN/CLEAR 1 DAFNE Frascati 1 DESY (Ham- burg, GE) ELPH (Sendai, 2) JP) - ELSA (Bonn, 1) FTBF (Fermi- 2) • chort intenso hunshos			other ion species lent						
DAFNE Frascati 1 DESY (Ham- burg, GE) ELPH (Sendai, 2) JP) - ELSA (Bonn, 1) GE) - FTBF (Fermi: 2) - shorts - shorts	CERN/CLEAR	1							
$\frac{DESY (Ham-burg, GE)}{ELPH (Sendai, 2)} + timing jitter: 50ps -> O(1ps)$ $\frac{ELSA (Bonn, 1)}{GE} + chort intense hunches$	DAFNE Frascati	1	identified needs:						
$\frac{DESY (Ham-3)}{burg, GE} = timing jitter: 50ps -> O(1ps)$ $\frac{DESY (Ham-3)}{ELPH (Sendai, 2)} = timing jitter: 50ps -> O(1ps)$ $\frac{ELSA (Bonn, 1)}{GE} = timing jitter: 50ps -> O(1ps)$	DECK (II	-	iuentineu neeus.						
• timing jitter: 50ps -> O(1ps) $\frac{ELPH (Sendai, 2)}{IP}$ ELSA (Bonn, 1) GE) • the short intense hunches	DESY (Ham-	3	5						
• timing jitter: 50ps -> $O(1ps)$ ELSA (Bonn, 1 GE) • chort intense hunches	FIPU (Sondai	2							
ELSA (Bonn, 1 GE) FTBF (Fermi- 2 c chort intonco hunchoc	ID)	1	• timing litter: $50ps \rightarrow O(1ps)$						
GE) FTBF (Fermi- 2 • chart intonco hunchoc	ELSA (Bonn.	1		/					
FTBF (Fermi- 2 e chart intonco hunchoc	GE)								
	FTBF (Fermi-	2	• shart intonso hunchos						
lab, US) SHULL, INCENSE DUNCHES	lab, US)		Short, intense bunches						
IHEP (Beijing, 2	IHEP (Beijing,	2							
• new dedicated testbeams, e.g. for water Cherenkov neutrino	CN)		 new dedicated testbeams, e.g. for water Cherenkov neutrino 						
IHEP (Protvino, 5	IHEP (Protvino,	5							
RU)	RU)								
MAR Mar 2 detectors electro-nuclear scattering	MAML (Maing	2	detectors electro-nuclear scattering						
(F) UELECIUIS, ELECTIO-HUCLEAL SCALLETING	CE)	3							
NSRL 1	NSRL	1							
(Brookhaven,	(Brookhaven,								
• beamline instrumentation	US)		beamline instrumentation						
piEI,ppiMI,etc. 2-4	piEI,ppiMI,etc.	2-4	2-4						
(PSI, CH)	(PSI, CH)								
PIF (PSI, CH) 1	PIF (PSI, CH)	1							
RCNP (Osaka, 7	RCNP (Osaka,	7	7						
JP)	JP)								
SLAC (Stan- 0 e (prim.); e (sec.) 2.5-15 GeV/c; 1- currently no M. Hartz, et al., Proceedings of Snowmass 2021	SLAC (Stan-	0	¹ ^e (prim.); e (sec.) ^{2.5-15} GeV/c; ¹⁻ ^{currently no} M. Hartz, et al., Proceedings of Snowmass 2021						
$\frac{10 \text{ GeV}/\text{C}}{\text{SPDINC 8}} = \frac{1}{2} + \frac{14 \text{ GeV}/\text{C}}{\text{phatana}} + \frac{14 \text{ GeV}/\text{C}}{2} + \frac{56 \text{ dam}/\text{m}}{2} +$	SPRINC 8	0	$\frac{14 \text{ GeV/c}}{2} = \frac{14 \text{ GeV/c}}{2} = 14 \text{$						
(Compton Red) 2 photons (tagged), e ⁺ , e ⁻ 0.4-2.9 GeV/c ⁻ >00 days/yr arAiV:2203.09944V1 [physics.acc-ph] 10 IVIar 2022	Compton East	2	arAiv:2205.09944v1 [physics.acc-ph] 10 Mar 2022						
ity. JP)	ity. JP)		(conv.)						

. . . .

. .

.

. . . .



EuPRAXIA: HEP test beam requirements



nerry [GV]nois <th>e- beam requirements</th> <th colspan="2">HEP test beams</th> <th colspan="2">əlasma beam dumı</th> <th colspan="2">inverse compton gamma source (1)</th> <th colspan="2">inverse compton gamma source (2)</th> <th colspan="2">positron</th> <th colspan="2">narrowband source</th>	e- beam requirements	HEP test beams		əlasma beam dumı		inverse compton gamma source (1)		inverse compton gamma source (2)		positron		narrowband source	
energy [GeV] 0.5 1.1 5 0.3 1 0.5 1.0 5 1.0 1.0 energy fluctation [shot-to-shot] [X] 1.% 2.% 1.% 1.% 1.% 1.% 1.0% <		min	max	min	max	min	max	min	max	min	max	min	max
energy spread [after selection] [k] 1% 2% 1	energy [GeV]	0.5	5	1	5	0.3	1	0.5	10	5		1	2
energy fluctuation (shot-to-shot) [%] 1% 2% m 1% 5% 1% 10% 1% 1% 10% precision on delivered electrons [%] 10% 50% 1000	energy spread (after selection) [%]	1%	2%	1%		0.1%	2%	1%	10%	10%		1%	10%
number of delivered electrons 1 1000 \sim 30 pC 1000 10 N 10.N 10 10 10 10 10 50% 10 10 50% 10 10 50% 10 <th>energy fluctuation (shot-to-shot) [%]</th> <th>1%</th> <th>2%</th> <th></th> <th></th> <th>1%</th> <th>5%</th> <th>1%</th> <th>10%</th> <th>10%</th> <th></th> <th>1%</th> <th>10%</th>	energy fluctuation (shot-to-shot) [%]	1%	2%			1%	5%	1%	10%	10%		1%	10%
precision on n delivered electrons [%] 10% 50% 100% 10%	number of delivered electrons	1	1000			30 pC	100pc	10^8	10^9	1nC			
bunch duration [fs] 10000 10 100 10 10 30 50 10 10 repetition rate [Hz] 1 1 10 1 10 1 100 1 10 1 100 1 10 1 100 1 10 1 100 1 10 1 100 1 10 1 100 1 10 1 10 1 10 1 10 1 10 1 10 1 10 1 10 1 10 1 10 1 10 1 10 1 10 1 10 1 10 1 10 1 10 1 10 1 <t< th=""><th>precision on n delivered electrons [%]</th><th>10%</th><th>50%</th><th></th><th></th><th>10%</th><th></th><th></th><th></th><th>50%</th><th></th><th></th><th></th></t<>	precision on n delivered electrons [%]	10%	50%			10%				50%			
repetition rate [Hz] 1 10 1 100 10 <th< th=""><th>bunch duration [fs]</th><th>10000</th><th></th><th></th><th>1000</th><th>10</th><th></th><th>10</th><th>30</th><th>50</th><th></th><th></th><th></th></th<>	bunch duration [fs]	10000			1000	10		10	30	50			
number of del'd bunches per hour 1000 4000 number of del'd bunches per hour 1000 4000 number of del'd bunches per hour 1000 1000 nE-6 nE-6 nE-6 100-6 100-5 1,E-04 1,E-06 1,E-06 <t< th=""><th>repetition rate [Hz]</th><th>1</th><th>10</th><th></th><th></th><th>1</th><th>10</th><th>1</th><th>100</th><th></th><th></th><th>1</th><th>10</th></t<>	repetition rate [Hz]	1	10			1	10	1	100			1	10
beam diameter [m] 1,E-02 1,E+00 nE-6 nE-6 10^-6 10^-5 1,E-04 1,E-06 1,E-03 1 electron flux density per shot [m ²] 1 1000 max min	number of del'd bunches per hour	1000	4000										
beam divergence [mrad]11000.1a few0.10.50.011171,E-031,E-031electron flux density per shot [m ²]11000 $< < < < < < < < < < < < < < < < < < < $	beam diameter [m]	1,E-02	1,E+00	nE-6		nE-6		10^-6	10^-5	1,E-04		1,E-06	1,E-06
electron flux density per shot [m ⁻²] 1 1000 Image in the integration of the integratic	beam divergence [mrad]	1	100	0.1	a few	0.1	0.5	0.01	1	1?		1,E-03	1
infrastructure requirementsminmaxminmaxminmaxminmaxminmaxminmaxminmaxminmaxsize of setup zone (length, width, height) $5^{x4}3^{x3}$ 5^{x3} 3^{x3}	electron flux density per shot [m ⁻²]	1	1000										
infrastructure requirementsminmaxmi													
size of setup zone (length, width, height) 1.5×0.5×0. 1.5×1.5×3 1 m x 10 cm *10 Given by required gamma-ray shielding Im 1m													
size of user zone (length, width, height) $5\times4\times3$ m³depending onii<	infrastructure requirements	min	max	min	max	min	max	min	max	min	max	min	max
magnet (type, field strength, volume)nouniform (10 ²), 3 T,uniform (10 ²), 3 T,Image: second strength, second str	infrastructure requirements size of setup zone (length, width, height)	min 1.5×0.5×0. 5 m³	max 1.5×1.5×3 m ³	min	max 1 m x 10 cm * 10 cm	min Given by gamma-ra	max required by shielding	min	max	min	max	min 1m	max
additional laser (energy, duration) Image: signal (duration, jitter)	infrastructure requirements size of setup zone (length, width, height) size of user zone (length, width, height)	min 1.5×0.5×0. 5 m ³ 5×4×3 m ³	max 1.5×1.5×3 m ³	min depen	max 1 m x 10 cm * 10 cm ding on	min Given by gamma-ra	max required by shielding	min	max	min	max	min 1m	max
synchronisation signal (duration, jitter) Image: synchronisation signal (duration, jitter) Image: synchronization synchronization Image: synchronization synchronization synchronization Image: synchronization synchronization synchronization synchronization synchronization synchronization synchronization synchronization synchronization synchrose synchronization synchronization synchroniza	infrastructure requirements size of setup zone (length, width, height) size of user zone (length, width, height) magnet (type, field strength, volume)	min 1.5×0.5×0. 5 m ³ 5×4×3 m ³ no	max 1.5×1.5×3 m ³ uniform (10 ⁻²), 3 T,	min depen	max 1 m x 10 cm * 10 cm	min Given by gamma-ra	max required shielding	min Dipole maj 30cm, tri beam f	max gnets, 0.9 T iplet for e ocusing	min	max	min 1m	max
fiducial references yes yes <thyes< th=""> yes yes<!--</th--><th>infrastructure requirements size of setup zone (length, width, height) size of user zone (length, width, height) magnet (type, field strength, volume) additional laser (energy, duration)</th><th>min 1.5×0.5×0. 5 m³ 5×4×3 m³ no</th><th>max 1.5×1.5×3 m³ uniform (10⁻²), 3 T,</th><th>min depen</th><th>max 1 m x 10 cm * 10 cm ding on</th><th>min Given by gamma-ra <1ps, 0.5 J</th><th>max required ry shielding</th><th>min Dipole may 30cm, tri beam f 30fs las</th><th>max gnets, 0.9 T plet for e ocusing er 1-10 J</th><th>min</th><th>max</th><th>тіп 1т >1), 1µs</th><th>max</th></thyes<>	infrastructure requirements size of setup zone (length, width, height) size of user zone (length, width, height) magnet (type, field strength, volume) additional laser (energy, duration)	min 1.5×0.5×0. 5 m ³ 5×4×3 m ³ no	max 1.5×1.5×3 m ³ uniform (10 ⁻²), 3 T,	min depen	max 1 m x 10 cm * 10 cm ding on	min Given by gamma-ra <1ps, 0.5 J	max required ry shielding	min Dipole may 30cm, tri beam f 30fs las	max gnets, 0.9 T plet for e ocusing er 1-10 J	min	max	тіп 1т >1), 1µs	max
background monitoring yes yes yes yes xray spectrometer o <th< th=""><th>infrastructure requirements size of setup zone (length, width, height) size of user zone (length, width, height) magnet (type, field strength, volume) additional laser (energy, duration) synchronisation signal (duration, jitter)</th><th>min 1.5×0.5×0. 5 m³ 5×4×3 m³ no</th><th>max 1.5×1.5×3 m³ uniform (10⁻²), 3 T,</th><th>depen</th><th>max 1 m x 10 cm * 10 cm</th><th>min Given by gamma-ra <1ps, 0.5 J 100 fs level</th><th>max required y shielding <1ps, 2J</th><th>min Dipole maj 30cm, tri beam f 30fs las fs s synchro</th><th>max gnets, 0.9 T iplet for e ocusing er 1-10 J cale onization</th><th>min</th><th>max</th><th>min 1m >1J, 1μs < pulse</th><th>max</th></th<>	infrastructure requirements size of setup zone (length, width, height) size of user zone (length, width, height) magnet (type, field strength, volume) additional laser (energy, duration) synchronisation signal (duration, jitter)	min 1.5×0.5×0. 5 m ³ 5×4×3 m ³ no	max 1.5×1.5×3 m ³ uniform (10 ⁻²), 3 T,	depen	max 1 m x 10 cm * 10 cm	min Given by gamma-ra <1ps, 0.5 J 100 fs level	max required y shielding <1ps, 2J	min Dipole maj 30cm, tri beam f 30fs las fs s synchro	max gnets, 0.9 T iplet for e ocusing er 1-10 J cale onization	min	max	min 1m >1J, 1μs < pulse	max
radiation protection (sv/hour) Image: state in the	infrastructure requirements size of setup zone (length, width, height) size of user zone (length, width, height) magnet (type, field strength, volume) additional laser (energy, duration) synchronisation signal (duration, jitter) fiducial references	min 1.5×0.5×0. 5 m ³ 5×4×3 m ³ no yes	max 1.5×1.5×3 m³ uniform (10²), 3 T, yes	depen	max 1 m x 10 cm ding on	min Given by gamma-ra <1ps, 0.5 J 100 fs level	max required yshielding <1ps, 2J	min Dipole may 30cm, tri beam f 30fs las fs s synchro	max gnets, 0.9 T iplet for e ocusing er 1-10 J cale onization	min	max	min 1m >1J, 1μs < pulse	max
photon flux density per shot [m²]11000To be measuredTo be evaluatedTo be evaluatedImage: Constraint of the state of the	infrastructure requirements size of setup zone (length, width, height) size of user zone (length, width, height) magnet (type, field strength, volume) additional laser (energy, duration) synchronisation signal (duration, jitter) fiducial references background monitoring	min 1.5×0.5×0. 5 m ³ 5×4×3 m ³ no yes yes	max 1.5×1.5×3 m³ uniform (10²), 3 T, yes yes	depen	max 1 m x 10 cm ding on	min Given by gamma-ra (1ps, 0.5 J 100 fs level x-ray spe	max required yshielding <1ps, 2J ctrometer	min Dipole may 30cm, tri beam f 30fs las fs s synchro	max gnets, 0.9 T iplet for e ocusing er 1-10 J cale onization	min	max	min 1m >1J, 1μs < pulse	max
muon flux density per shot [m ⁻²] 1 10000 - - I	infrastructure requirements size of setup zone (length, width, height) size of user zone (length, width, height) magnet (type, field strength, volume) additional laser (energy, duration) synchronisation signal (duration, jitter) fiducial references background monitoring radiation protection (sv/hour)	min 1.5×0.5×0. 5 m ³ 5×4×3 m ³ no yes yes yes	max 1.5×1.5×3 m ³ uniform (10 ⁻²), 3 T, yes yes	depen	max 1 m x 10 cm * 10 ding on ding on and xray	min Given by gamma-ra (195, 0.5 J 100 fs level x-ray spe (high-res	max required hy shielding <1ps, 2J ctrometer s) gamma	min Dipole may 30cm, tri beam f 30fs las fs s synchro	max gnets, 0.9 T iplet for e ocusing er 1-10 J cale nnization	min	max	min 1m >1J, 1μs < pulse	max
moveable stage (range) 0.5m 1m Imoveable stage (range) Imoveable stage) Imoveable stage (range) Imoveable stage)	infrastructure requirements size of setup zone (length, width, height) size of user zone (length, width, height) magnet (type, field strength, volume) additional laser (energy, duration) synchronisation signal (duration, jitter) fiducial references background monitoring radiation protection (sv/hour) photon flux density per shot [m ⁻²]	min 1.5×0.5×0. 5 m³ 5×4×3 m³ no yes yes 1 1	max 1.5×1.5×3 m³ uniform (10²), 3 T, yes yes 1000	depen	max 1 m x 10 cm * 10 cm ding on and xray To be measured	min Given by gamma-ra (1ps, 0.5 J 100 fs level x-ray spe (high-res To be evaluated	max required yshielding <1ps, 2J ctrometer s) gamma	min Dipole may 30cm, tri beam f 30fs las fs s synchro	max gnets, 0.9 T iplet for e occusing er 1-10 J cale	min	max	<pre>min 1m 1m</pre>	max
cryogenics no	infrastructure requirements size of setup zone (length, width, height) size of user zone (length, width, height) magnet (type, field strength, volume) additional laser (energy, duration) synchronisation signal (duration, jitter) fiducial references background monitoring radiation protection (sv/hour) photon flux density per shot [m ⁻²] muon flux density per shot [m ⁻²]	min 1.5×0.5×0. 5 m³ 5×4×3 m³ no yes yes 1 1 1 1 1 1 1 1 1 1 1 1 1	max 1.5×1.5×3 m³ uniform (10²), 3 T, yes yes 1000 10000	depen depen Electron	max 1 m x 10 cm * 10 ding on ding on and xray To be measured	min Given by gamma-ra (1) (1) (1) (1) (1) (1) (1) (1) (1) (1)	max required yshielding <1ps, 2J ctrometer s) gamma	min Dipole may 30cm, tri beam f 30fs las fs s synchro	max gnets, 0.9 T plet for e occusing er 1-10 J cale onization	min	max	<pre>min 1m 1m</pre>	max
	infrastructure requirements size of setup zone (length, width, height) size of user zone (length, width, height) magnet (type, field strength, volume) additional laser (energy, duration) synchronisation signal (duration, jitter) fiducial references background monitoring radiation protection (sv/hour) photon flux density per shot [m ⁻²] muon flux density per shot [m ⁻²] moveable stage (range)	min 1.5×0.5×0. 5 m³ 5×4×3 m³ no yes yes 1 1 1 0.5m	max 1.5×1.5×3 m³ uniform (10²), 3 T, yes yes 10000 1m	depen depen Electron	max 1 m x 10 cm * 10 cm ding on and xray To be measured -	min Given by gamma-ra (1) (1) (1) (1) (1) (1) (1) (1) (1) (1)	max required y shielding <1ps, 2J ctrometer s) gamma	min Dipole may 30cm, tri beam f 30fs las fs s synchro	max gnets, 0.9 T plet for e occusing er 1-10 J cale onization	min	max	min 1m >1J, 1μs < pulse photons/s = 10^8-10^12	
	infrastructure requirements size of setup zone (length, width, height) size of user zone (length, width, height) magnet (type, field strength, volume) additional laser (energy, duration) synchronisation signal (duration, jitter) fiducial references background monitoring radiation protection (sv/hour) photon flux density per shot [m ⁻²] muon flux density per shot [m ⁻²] moveable stage (range) cryogenics	min 1.5×0.5×0. 5 m³ 5×4×3 m³ no ves yes yes 1 1 0.5m no	max 1.5×1.5×3 m³ uniform (10²), 3 T, yes yes 1000 10000 1m no	depen depen Electron	max 1 m x 10 cm * 10 cm ding on ding on and xray To be measured -	min Given by gamma-ra (1) (1) (1) (1) (1) (1) (1) (1) (1) (1)	max required y shielding <1ps, 2J ctrometer s) gamma	min Dipole may 30cm, tri beam f 30fs las fs s synchro	max gnets, 0.9 T plet for e ocusing er 1-10 J cale onization	min	max	min 1m >1J, 1μs < pulse photons/s = 10^8-10^12 	

PAEPA Workshop Oct 2016 Paris, Pilot Applications of electron plasma accelerators



www.eupraxia-pp.org





- (!!!) Manipulation space (50m²,4m height)
- (!!!) Timing signal (laser sync)
- (!!) Flux monitor with ind. particle capability
- (!) wide area pos. sensitive detector (tracker)
- (!!!) Crane and (!) moveable table
- (!!) Cooling water



infrastructure requirements	min	max
	1.5×0.5×0.	1.5×1.5×3
size of setup zone (length, width, height)	5 m ³	m ³
size of user zone (length, width, height)	5×4×3 m ³	
magnet (type field strength volume)	no	uniform
magnet (type, neid strength, volume)		(10 ²), 3 T,
additional laser (energy, duration)		
synchronisation signal (duration, jitter)		
fiducial references	yes	yes
background monitoring	yes	yes
radiation protection (sv/hour)		
	1	1000
photon flux density per shot [m ⁻²]		
muon flux density per shot [m ⁻²]	1	10000
moveable stage (range)	0.5m	1m
cryogenics	no	no
cooling	no	yes



Example : Particle Flow Analysis oriented detectors (e.g. HGCAL, CALICE)

1m

Electromagn

0m

Electron

Photon

Charged Hadron (e.g. Pion)

Tracker

Neutral Hadron (e.g. Neutron)

Muon

Key:



3m

Response to individual particles:

- Linearity
- Uniformity
 - vs E, θ, time

Standard Calibration

- single particle in beam (SPS)
 - e, μ, π, 1-200 GeV
 - 10–1000 Hz (×10s/60s)

PFA oriented detectors \Rightarrow 10⁸ channels

- mips calibration: cosmics, tracks-in-shower, halo-muons
- Simulation

High energy collaboration (e.g. at LHC) use big particle "detectors" composed of many subdetectors

2m

Vincent.Boudry@in2p3.fr Eupraxia.Workshop | Ecole polytechnique | 12/1

EuPRAXIA-PP Collaboration Meeting - Elba



Transverse slice through CMS



Use case 1: High flux density scanning of detector components/ detector cells



Particle Flow \Rightarrow Compact Showers

- ⇒ High density of particles in Shower core (3000 mips in 5×5mm²)
 - \Rightarrow sensitivity to small non-uniformities
 - Dead regions, Special regions (e.g. Guard rings)
 - Electronics Amplifiers

Pencil beams :

1000–10000 e⁻ (as mips \geq 100 MeV) in a few 1×1 mm² on thin elements

- Sensor studies (Scintillators, Silicon Wafers edges, µ-strips, local saturation [Birk's])
- SiPM, APD, ...
- Embedded ASICs (S.E.U.), FPGA, PCB, ...

Q?

- \Rightarrow Collimator...
- \Rightarrow Measure of Nb(e-) ~ 10% ?

Vincent.Boudry@n2p3.fr Eupraxia Workshop | Ecole polytechnique | 12/10/2016



• "Square events"

 cross talk between guard rings and pixels



 $\overline{\mathsf{Q}}$ map of a scintillator tile







<u>Calorimetry (in HEP)</u>: measurement of single particle kinetic energy by total absorption **→** particle shower

Motivation

E[•]**PRA** IA

- response linearity
- readout saturation
- detector calibration at unavailable energies
- Method
 - Produce bunch of N e- with identical energy ${\rm E_e}$ (by momentum selection)
 - Measure N precisely (enough): $\Delta E_B \sim \Delta N/N \times E_B$
 - concentrate to spot of the size of an EM shower after a few X0
 - What bunch characteristics are needed to simulate best energy deposit of one particle E_{0?}







- High flux (10³-10⁴ e/shot) high flux density -> fine effects
 - -> study detailed active element response (saturation, linearity)
 - -> study effect on embedded read-out electronics (ASICS)





- High flux (10³-10⁴ e/shot) high flux density -> fine effects
 - -> study detailed active element response (saturation, linearity)
 - -> study effect on embedded read-out electronics (ASICS)









- High flux (10³-10⁴ e/shot) high flux density -> fine effects
 -> study detailed active element response (saturation, linearity)
 -> study effect on embedded read-out electronics (ASICS)
- High flux (10³-10⁴ e/shot) low flux density -> faster/more stat

 simultaneous irradiation instead of scanning
 no internal triggering capability required-> absolute calibration of
 timing uniformity -> DAQ stress testing in real condition

suitable for detectors with high granularity (particle separation capacity)





- Trackers, calorimeters
 - in general: detectors with intrinsic particle separation capabilities
 - fine granularity: CMS HGCAL, CALICE, detectors
- occupancy: number of particles arriving simultaneously in one detector cell (transverse)





Use case 3: uniformity of timing response



High-Lumi LHC:

- HGCAL requir't



- Spatial separation ⇒ -spacing of vertices down to ~ 500 mm == 150 ps
- test of calorimeters with 20–30 ps time resolution.
 - 10-15 ps in Clock distribution

EAP: 1000 particles en \leq 10 ps

 \Rightarrow Time calibration (uniformity)

```
Q? possibility to generate \Delta t \sim 150 \text{ ps}? (chicane ?)
```

Vincent.Boudry@in2p3.fr Eupraxia Workshop | Ecole polytechnique | 12/10/2016







- High flux (10³-10⁴ e/shot) high flux density -> fine effects

 study detailed active element response (saturation, linearity)
 study effect on embedded read-out electronics (ASICS)
- High flux (10³-10⁴ e/shot) low flux density -> faster/more stat

 simultaneous irradiation instead of scanning
 no internal triggering capability required
 absolute calibration of timing uniformity
 DAQ stress testing in real condition
- Controlled bunch stretching (needs dedicated study)
 -> calibration of timing
 - -> identification of interaction bunch

Feasibility study of controlled bunch lengthening to O(100ps)?



Electron-positron cogeneration: e⁻ - arm





 Use a dog-leg spectrometer to separate the high energy electrons and photons from the low energy positrons

From Jim Clarke's presentation (EuPRAXIA week Frascati, Nov2018), source: Aarón Alejo, QUB





- reducing the peak particle flux (→ secondaries, momentum selection)
- focusing the selected beam to e.m. shower size dimensions
- expanding the beam to detector size
- Collimation, background and radiation protection studies (GEANT, BDSIM)
- Develop a robust flux monitoring (e.g. scintillator telescopes)

FEL is the flagship application.

HEP detector test beams for selected use cases could be "low hanging fruit" application

HEP detector test beams could help to promote PA in HEP community

Thank you for your attention