Measurement of the electromagnetic background during commissioning of SuperKEKB

2016 CAP Congress,
University of Ottawa, Ottawa (ON), CANADA
June 13th, 2016

Alexandre Beaulieu

University of Victoria

Belle II

SuperKEKB

The Menu

- Belle II and SuperKEKB
  - Challenges associated with commissioning a new collider experiment
- Machine-induced backgrounds
  - Expected background contributions
  - Experimental study: the BEAST effort
- The BEAST crystal calorimeter system
  - Goals
  - Description
- Early results
  - Beam-gas
  - Beam-beam
- Outlook

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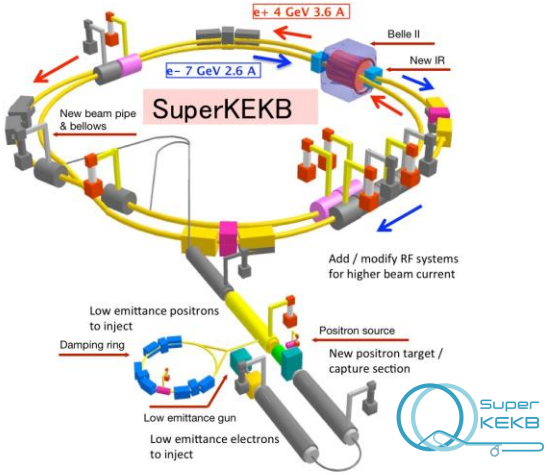
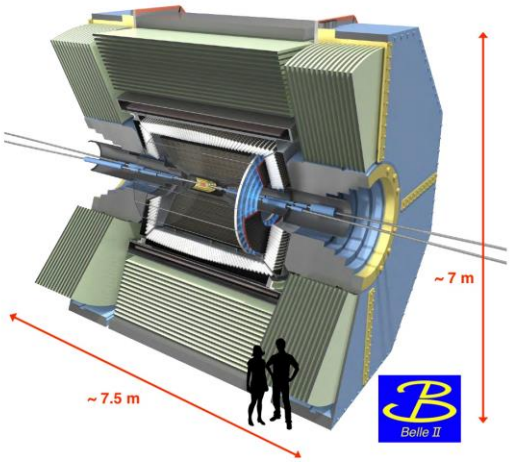
The Belle-II experiment at SuperKEKB

HER: e^- @ 7GeV LER: e^+ @ 4GeV





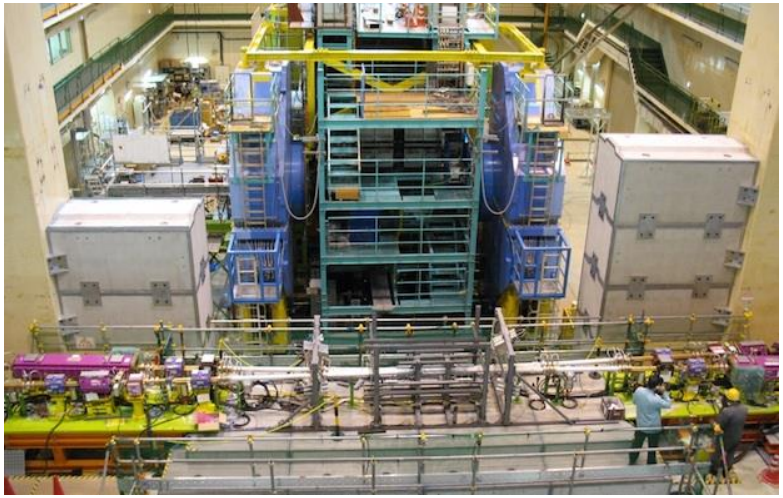
Key Scientific Goals

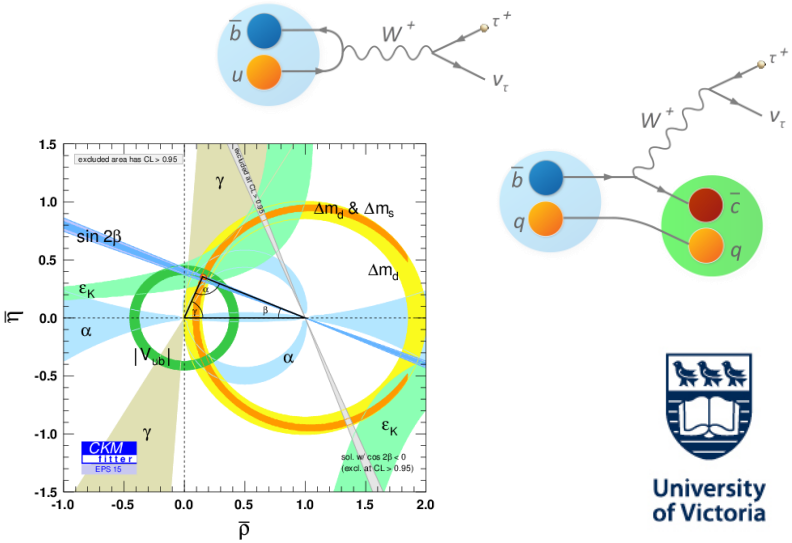
Address fundamental questions about the Universe with measurement at the Precision Frontier in collisions of electrons and positrons

- Why is the universe made only of matter and not anti-matter?
- Are there new fundamental forces in nature?
- What is the nature of the three generations of quarks and leptons?
- What is the nature of dark matter?

Examples of such precision measurements include

- *B*-meson decays to 3rd generation leptons
- The parameters of the Unitarity Triangle





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Challenges of commissioning a new collider
(a subset of..)

Interesting questions

- How to know when the vacuum chamber walls are clean enough?
- How to know if our machine-induced background models are appropriate?
  - Can we disentangle the different contributions?
  - Do each contribution scale as expected with respect to beam parameters (*e.g.* size, current, pressure, bunch structure)?
- Will detector upgrades be necessary during the lifetime of the experiment?
  - Effect of pile-up noise and channel occupancy on resolution and dead time.
  - Cumulative radiation damage
- How to determine the best settings to increase beam current and minimize machine-induced backgrounds?

Phased approach

- Phase 1 (2016): first beams (this talk)
  - No focussing (no luminosity)
  - Ad-hoc assembly of independent detectors
- Phase 2 (2017): Belle-II w/o vertexing. Conditions closer to actual experiment.

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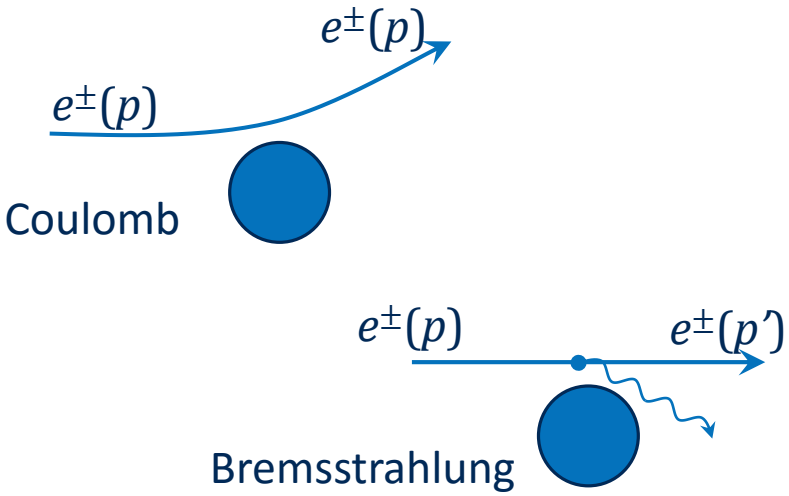
Expected background sources during phase 1

Beam-gas interactions

- Should dominate in the early days
- Coulomb and Bremsstrahlung processes
- Scale as function of beam current pressure and gas species

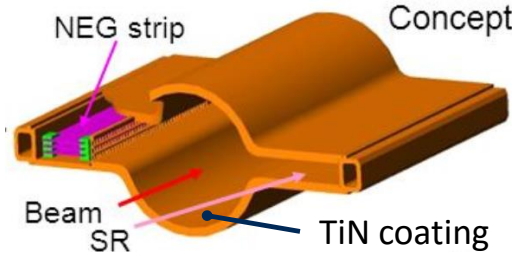


Beam-beam interactions

- Touschek losses
  - Intra-bunch scattering $(p_{\parallel} \leftrightarrow p_{\perp})$
  - Beam particle kicked out of acceptance

Electron-cloud effect

- Typical problem with e+ beams
- Counter measures exist in SuperKEKB design:



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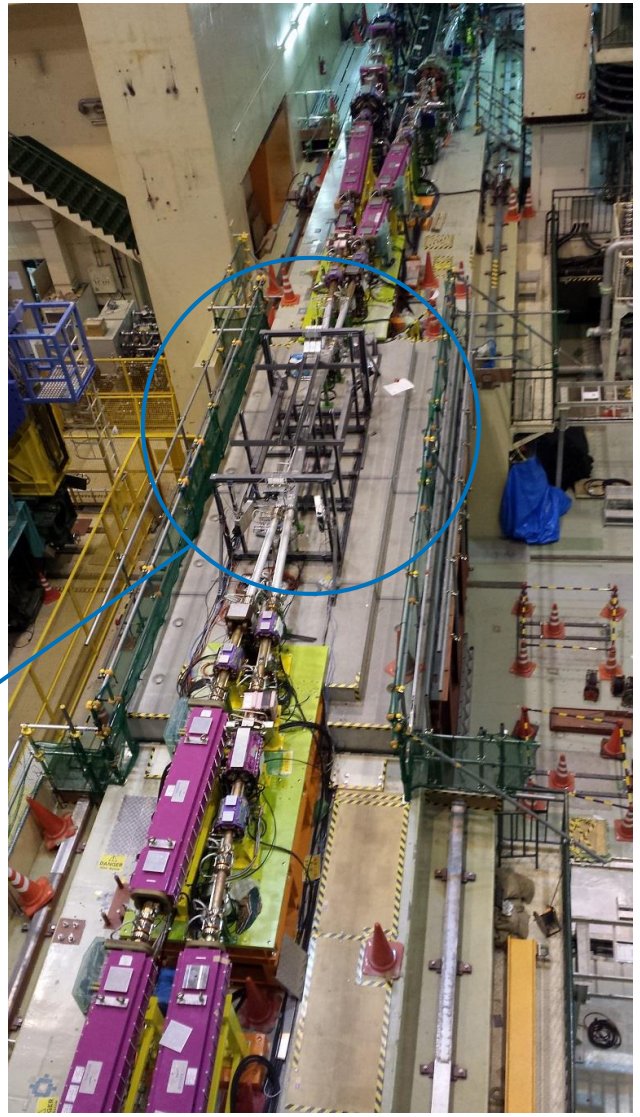
Meet the BEAST

- 4x He3 tubes (talk by S.R. de Jong)
  - Thermal neutron detectors
- 6x Crystal calorimeter units (this talk)
  - Electromagnetic radiation measurement
- 4x µTPCs (University of Hawaii)
  - Directional fast neutron detection
- 64x PIN diodes (Wayne State, UH, KEK)
  - x-ray dose along z-axis
- 4x diamond sensors (INFN Trieste)
  - Radiation-hard beam abort sensors
- 4x BGO crystals (Nat. Taiwan University)
  - Luminosity monitoring
- 8x Fast plastic scintillators (MPI Munich)
  - Injection background time-structure



BEAST Crystal Calorimeter system

Goals:

- Measure *e* and γ flux and spectrum v.s. beam conditions
- Compare performances of crystal materials
- Use the fast crystals to study injection noise time-structure

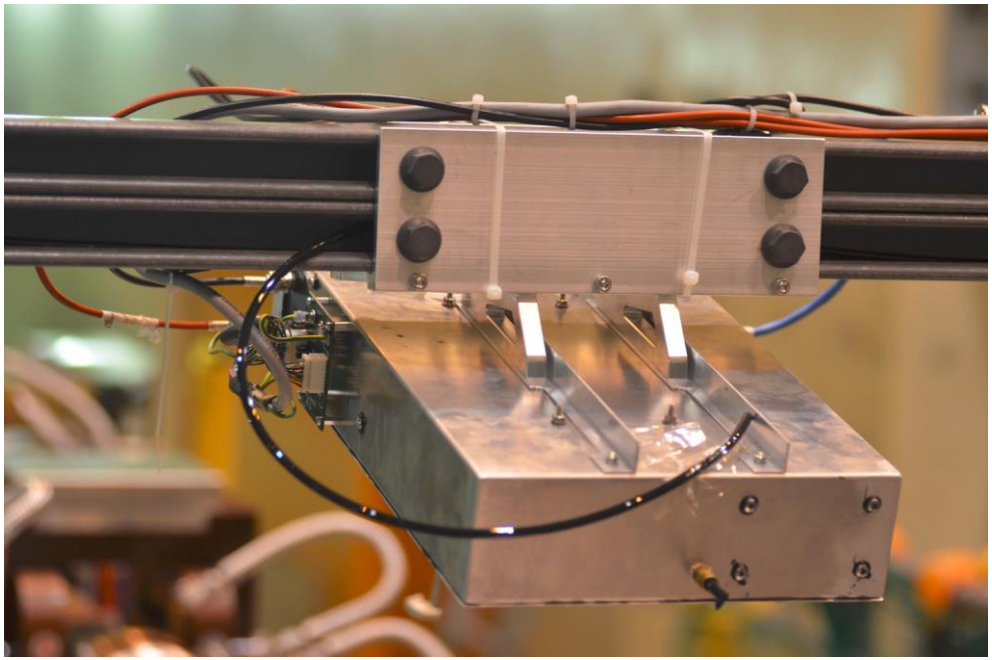


Photo credits : P.Lewis

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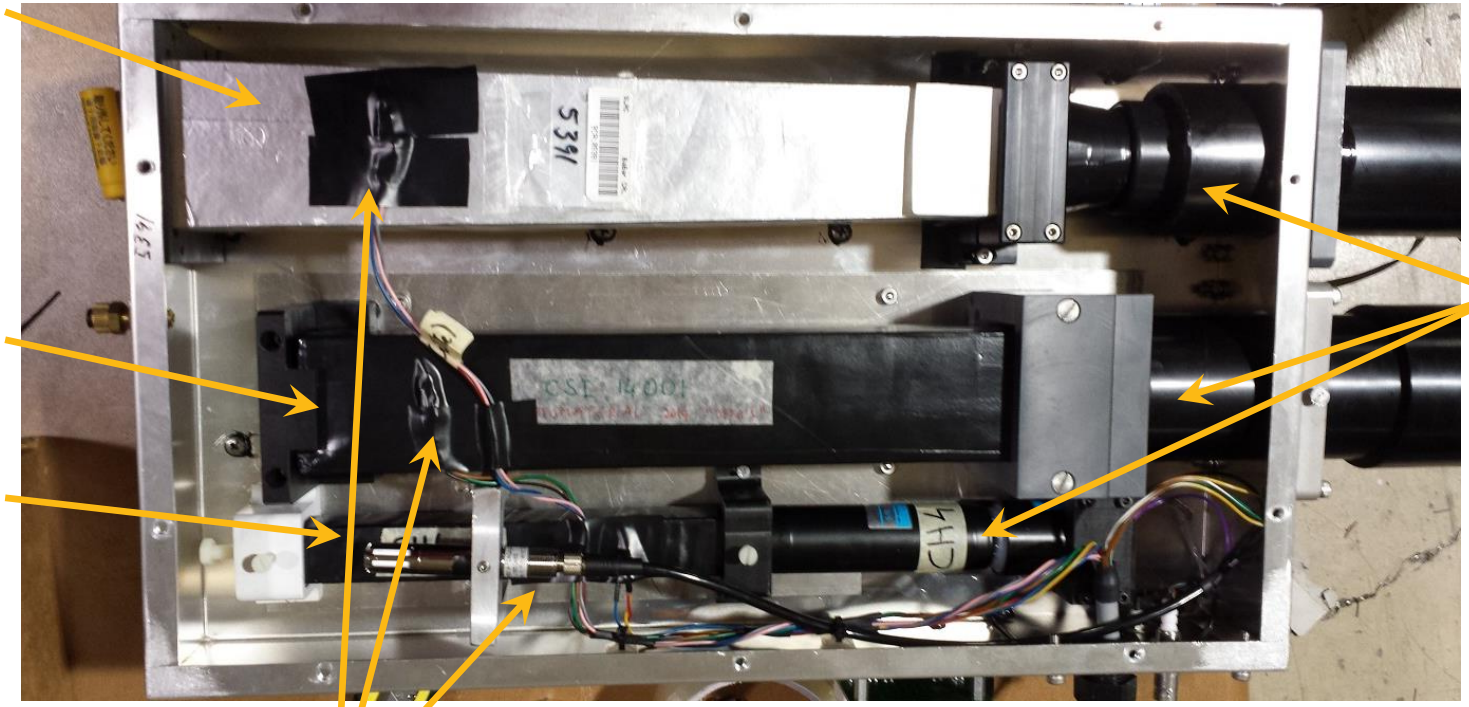
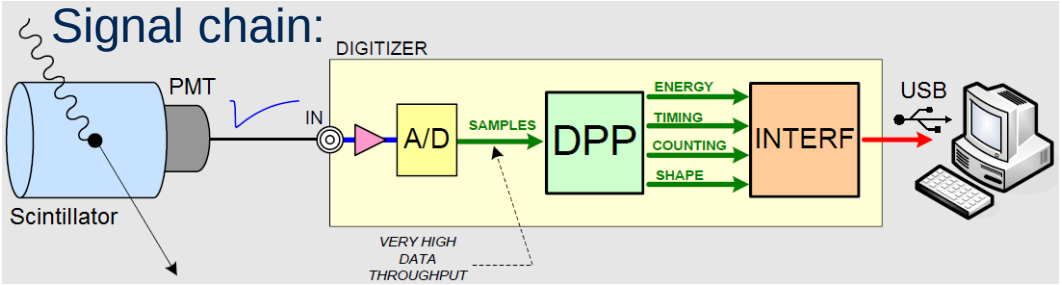
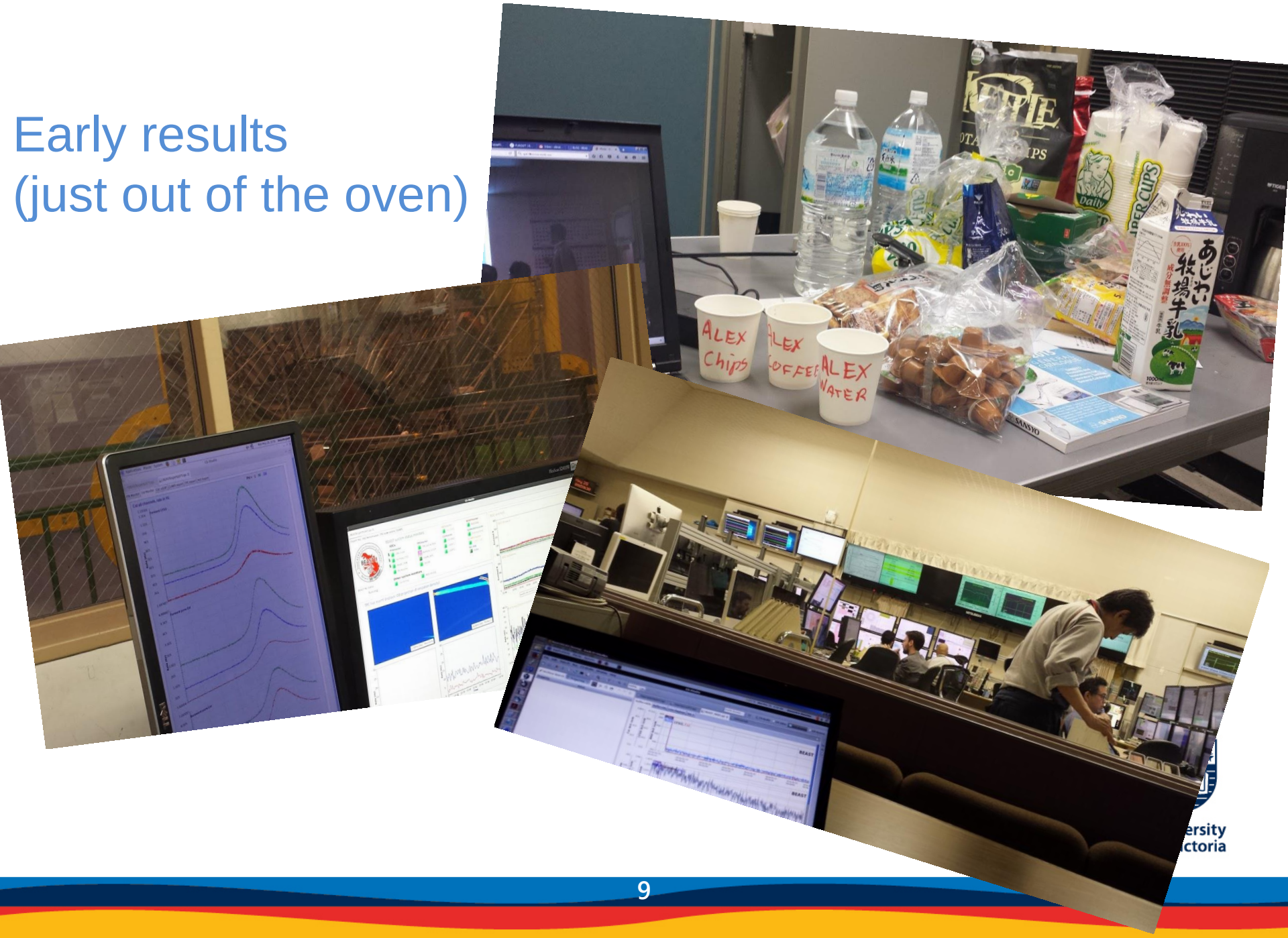
Inside one detector unit: three crystals and readout

Photograph of the BEAST Crystal setup at KEK before installation



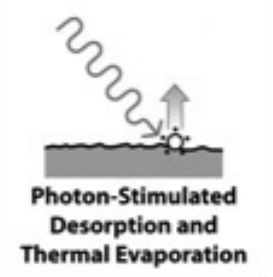


Early results
(just out of the oven)



Beam-gas interactions: Vacuum scrubbing

- During commissioning: photons and electrons hit the vacuum chamber walls, and eject molecules adsorbed on the surface
  - This is photon- and electron-stimulated desorption (PSD/ESD)
  - PSD yield η is expected to behave like a power law:
    - $\eta_{PSD} = \eta_0 \left(\frac{D_0}{D}\right)^{\beta}$ where
      - D is the beam dose (*e.g.* mA·h)
      - β is related to photon energy, material temperature and nature of adsorbed species
- What we observed during first months of operation (Feb 17 – Apr 28)



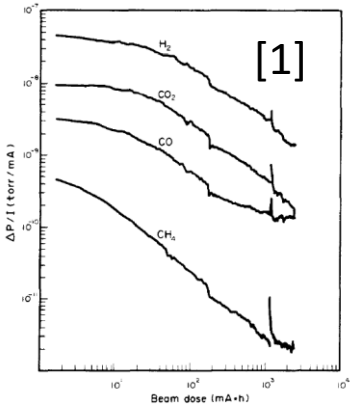
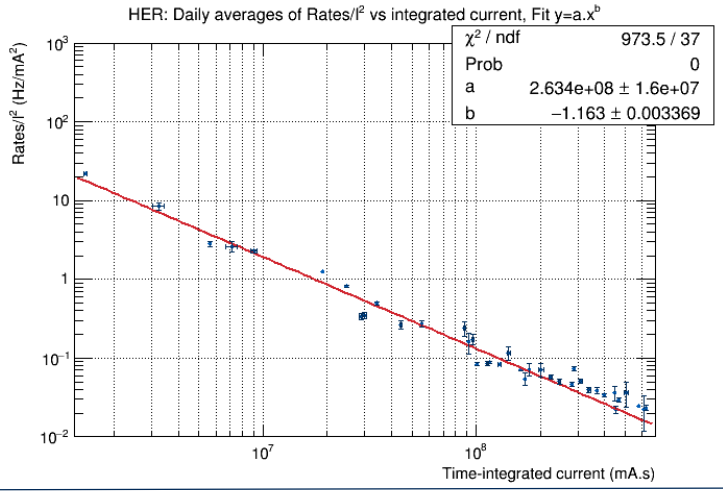
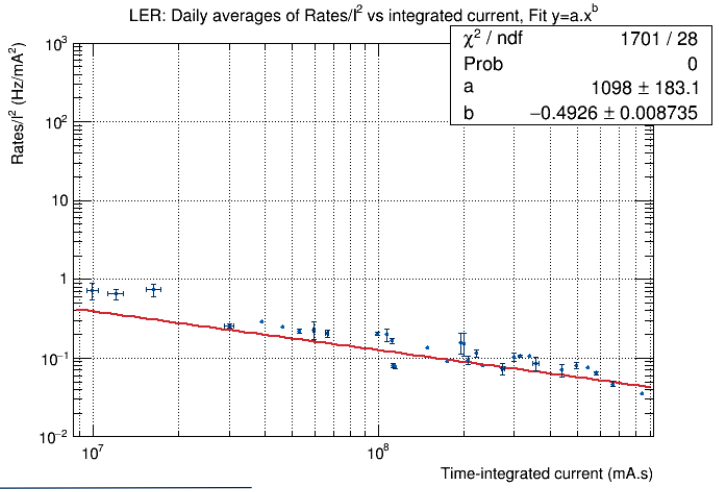


Figure 8. The specific partial pressure rise $\Delta P/I$ as a function of the beam dose for H_2, CH_4, CO and CO_2 for the third series of measurements—unbaked.





[1] O Gröbner, AG Mathewson, H Störi, P Strubin, R Souchet, Studies of photon induced gas desorption using synchrotron radiation, Vacuum, Volume 33, Issue 7, July 1983, Pages 397-406,

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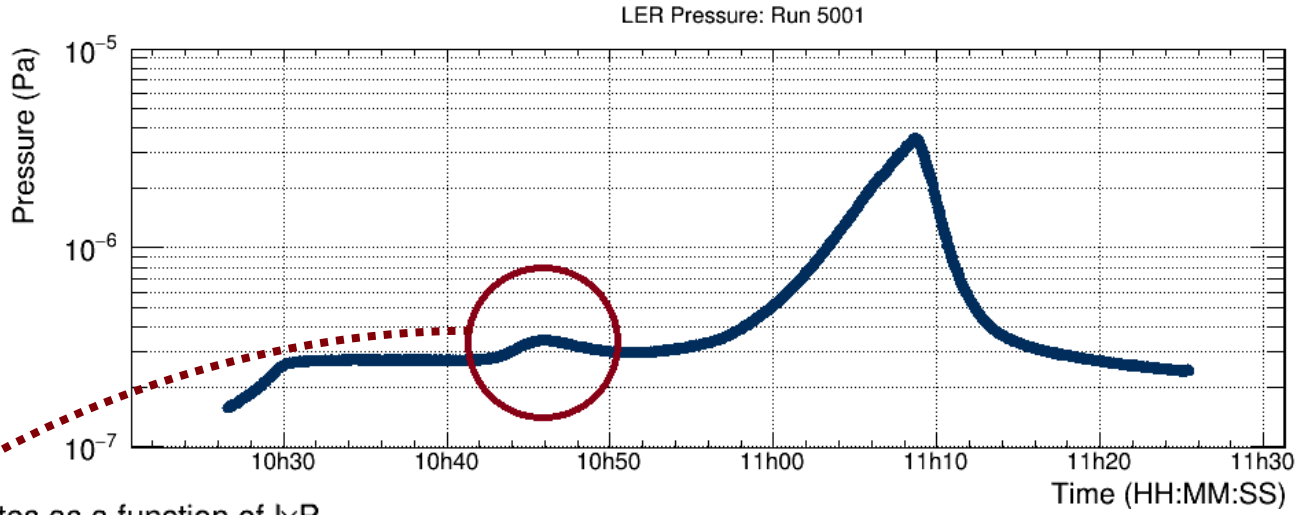
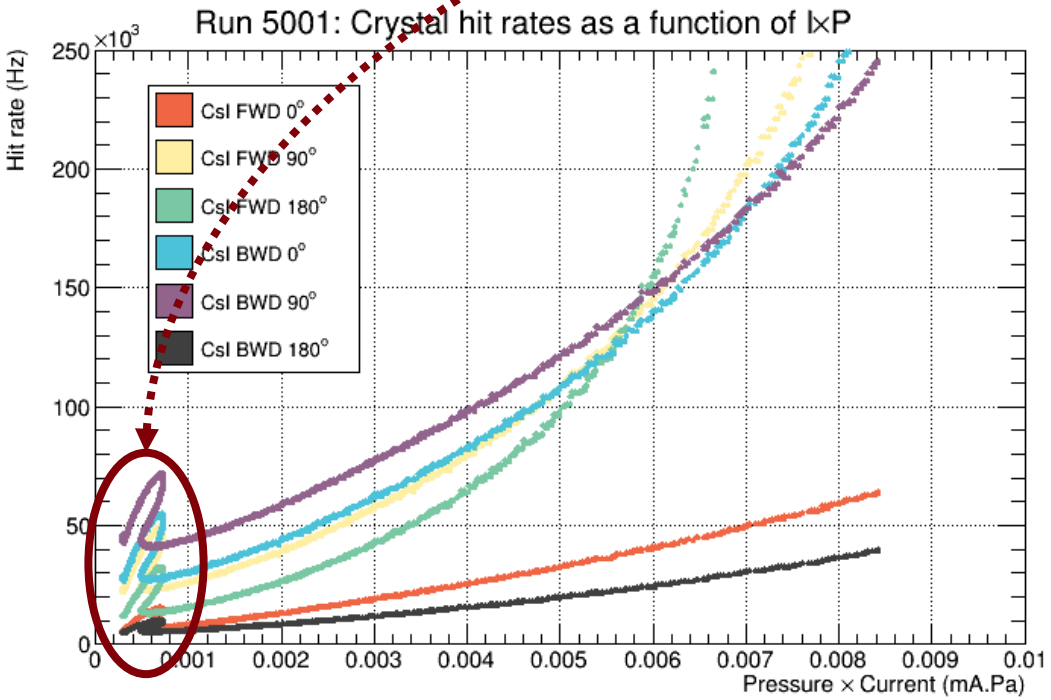
Beam-gas interactions: effect of pressure



Light elements released earlier



Elements to study:

- φ-dependence
- Gas-species dependence
- Location of the pressure bump

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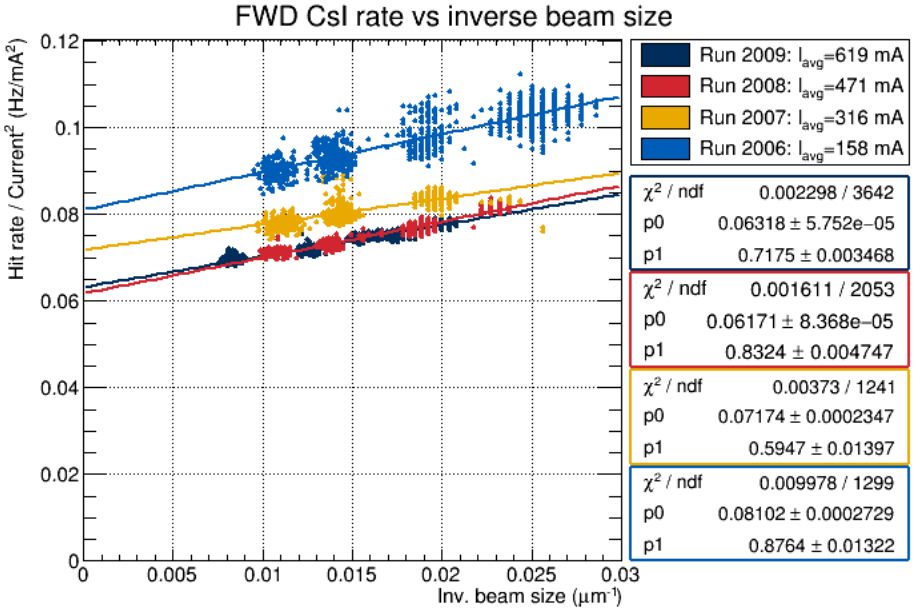
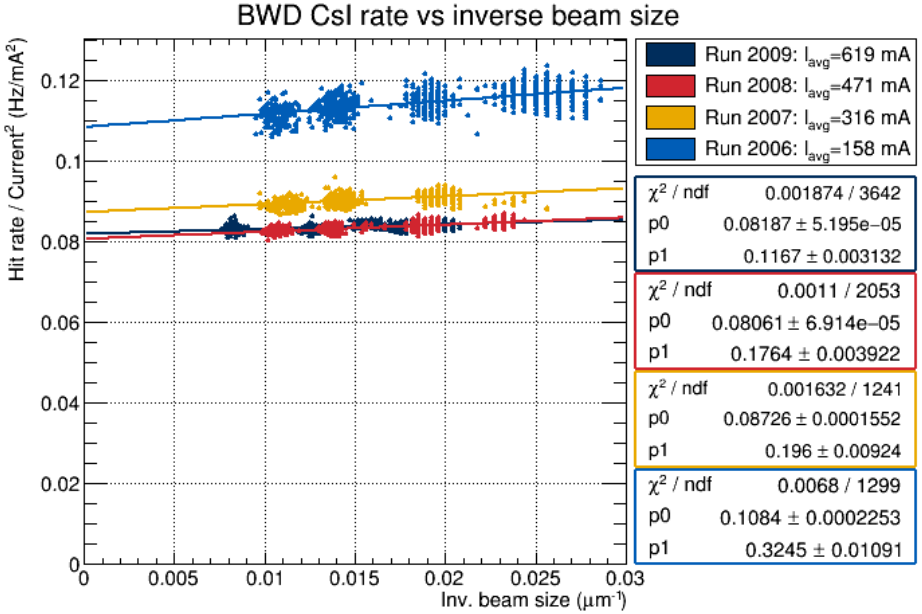
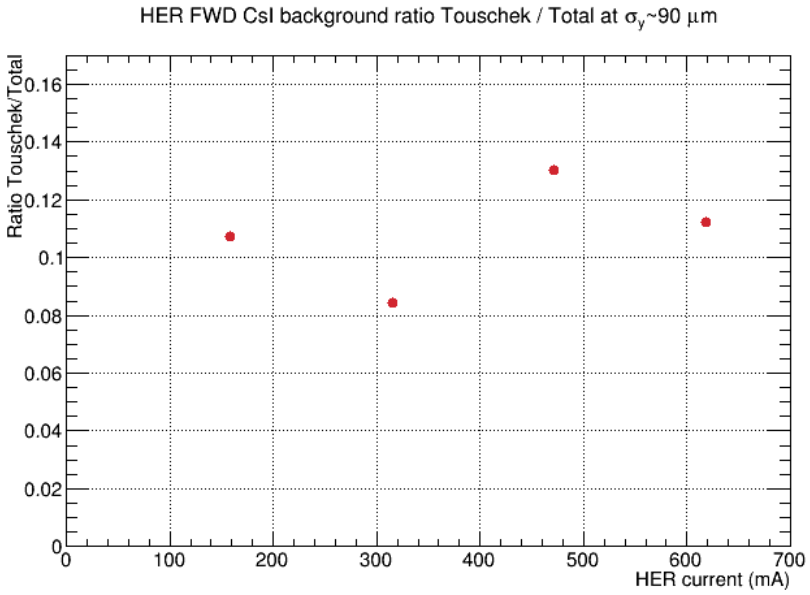
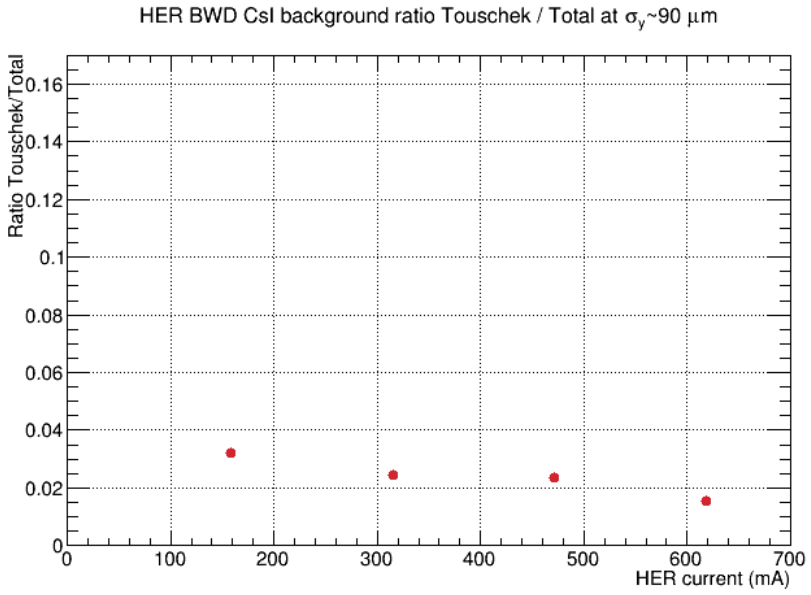
Beam-beam interactions: effect of beam size (electron ring)



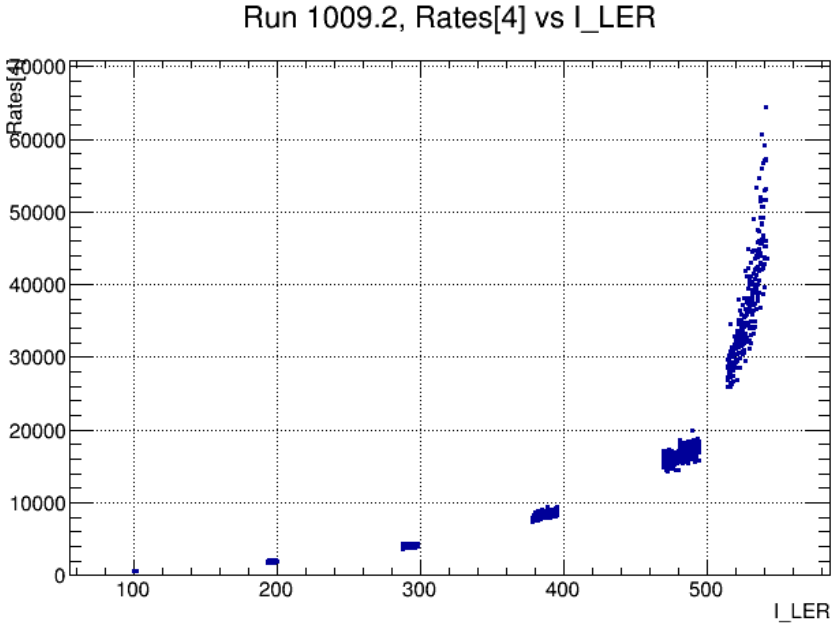




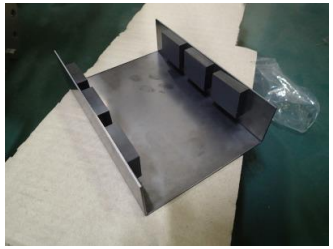


Observation of the electron-cloud effect
Beam blow-up at high currents

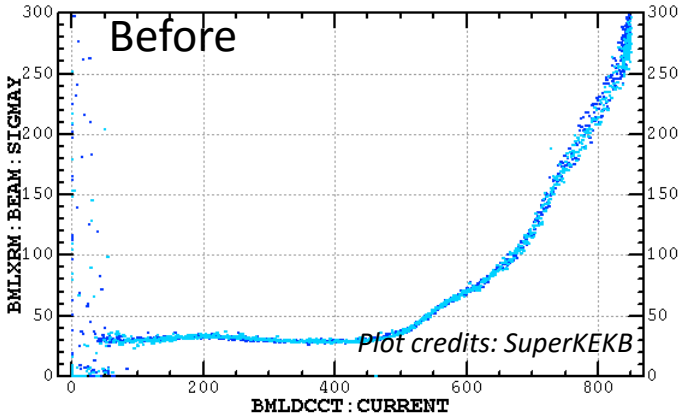
The BEAST crystal system noted very rapid increase of rates for $I_{LER} > 450$ mA

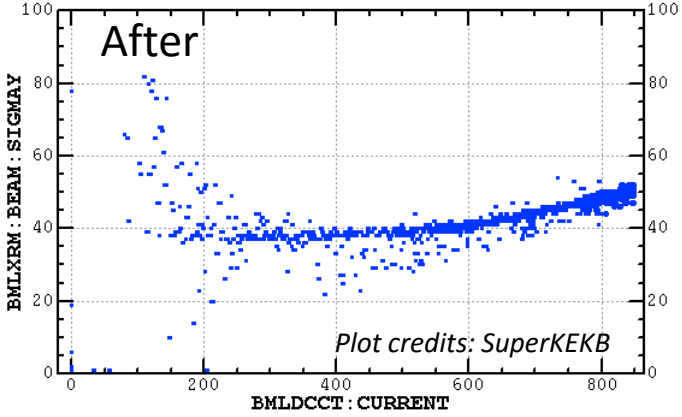


Corrections June 2-5: coils and permanent magnet solenoids



This is too fresh for us to analyse if we could see the difference in our reading… stay tuned!





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Conclusions

- The BEAST experiment provides critical data to test and improve our models of machine induce background
- Successful data taking currently ongoing (between February and June)
  - Data sanity checks conducted on all systems
- The crystals system were able to observe a great range of phenomenon:
  - Vacuum scrubbing
  - Effect of pressure and gas constituents on beam-gas losses
  - Effect of beam size on Touschek losses
  - Impact electron-cloud effect on beam size, and background
  - Time structure of injection noise (analyzed by INFN, see backup)
- More refined analyses will occur during the Summer and Fall
  - Geometric dependence
  - Absolute dose calculations
- Next major challenge: data-simulation comparisons

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Supplemental Material

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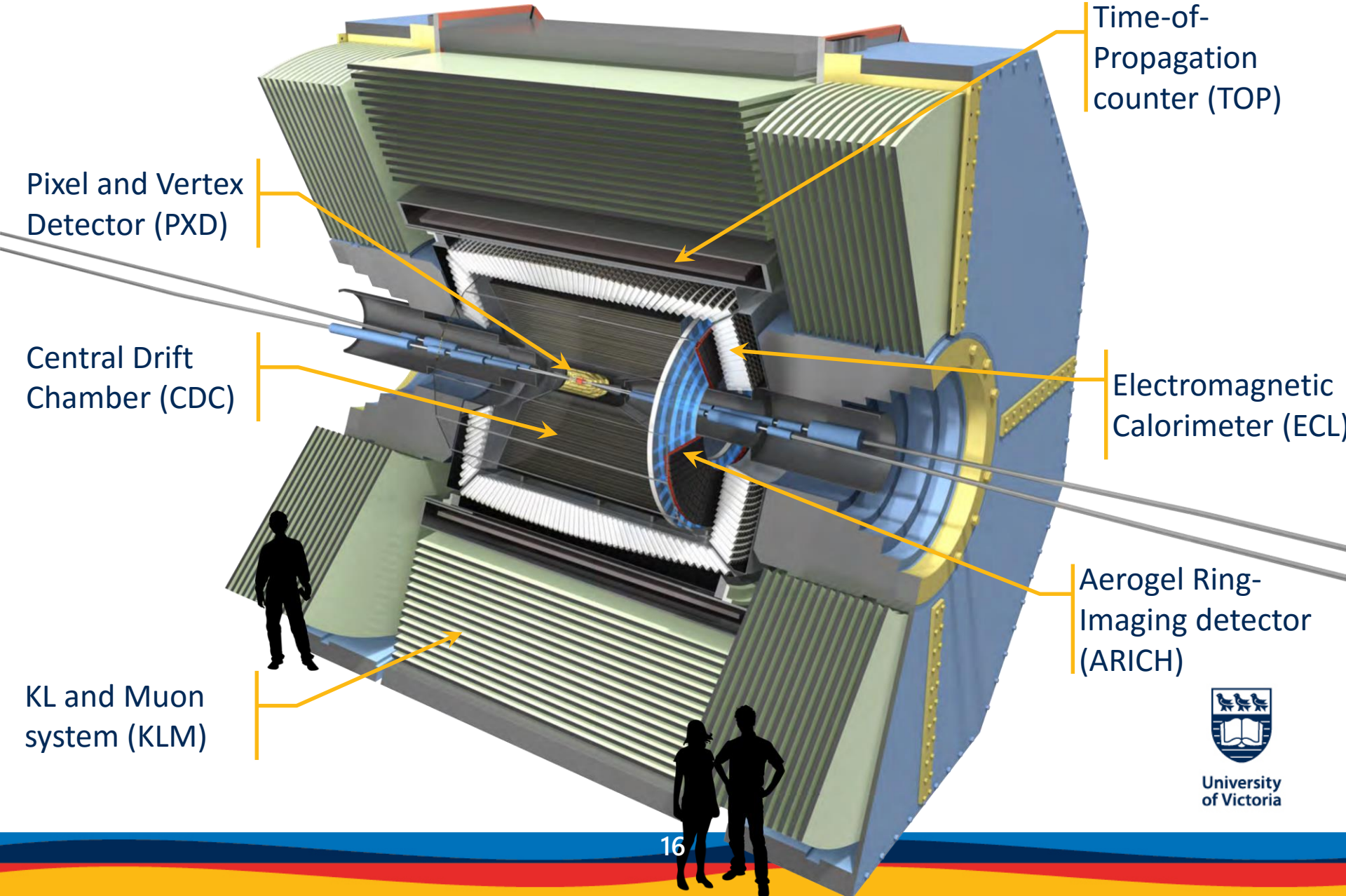
The Belle-II detector at a glance



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Pure CsI readout

XP2262

12-stage
51mm (2"), Round tube

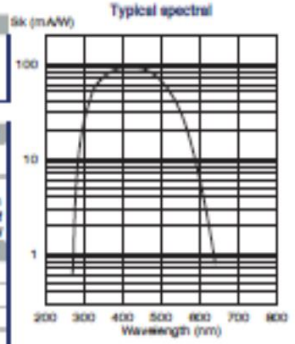
Application
✓ Energy physics

Feature
✓ Fast

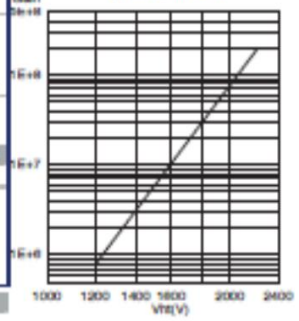
Description	
Window material	Lime glass
Photocathode	Bi-alkali
Refr. index at 420nm	1.54
Multiplier structure	Linear focused

Photocathode characteristics	Min	Typ	Max	Unit
Spectral range:		260-650		nm
Maximum sensitivity at		420		nm
Sensitivity:				
Luminous		70		μA/lm
Blue *	9	11.2		μA/lm
Radiant, at 420nm		90		mA/W
Characteristics with voltage divider A	**Min**	**Typ**	**Max**	**Unit**
Gain slope (vs supp. Volt., log/log)		9		
For a gain of		5x10⁶		V
Supply voltage *	1500	1800	2400	V
Anode dark current *		10		nA
Background noise *		1000	6000	cps
Single electron spectrum resolution		70		%
Peak to valley ratio		3		
Mean anode sensitivity deviation:				
Long term (16h)		1		%
After change of count rate		1		%
Vs temperature between 0 and +40°C at 420nm		-0.2		%/K
Gain halved for a magnetic field of:				
Perpendicular to axis "r"		0.2		mT
Parallel to axis "r"		0.1		mT
For a supply voltage of : 1900V	**Min**	**Typ**	**Max**	**Unit**
Linearity (2%) of anode current up to:		100		mA
Anode pulse:				
Rise time		2.3		ns
Duration at half height		3.7		ns
Transit Time		31		ns
Transit time Difference between center of PK and 18 mm from it		0.7		ns

Typical spectral



Typical gain curve



Recommended Voltage Divider

Type A for maximum gain

K	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	A	
4	1.1	0.9	1	1	1	1	1	1	1	1	1	1		(total : 16)

* characteristic measured and mentioned on the test ticket of each tube

PHOTONIS

16/06/2006

CsI(Tl) readout: R580

HAMAMATSU
PHOTON IS OUR BUSINESS

PHOTOMULTIPLIER TUBE
R580

For Scintillation Counting and High Energy Physics
38 mm (1-1/2 Inch) Diameter, 10-stage, Bialkali Photocathode, Head-on Type

GENERAL

Parameter		Description	Unit
Spectral Response		300 to 650	nm
Wavelength of Maximum Response		420	nm
Photocathode	Material	Bialkali	—
	Minimum Effective Area	φ34	mm
Window Material		Borosilicate glass	—
Dynode	Structure	Linear focused	—
	Number of Stages	10	—
Direct Interelectrode	Anode to Last Dynode	3	pF
Capacitances	Anode to All Other Electrodes	7	pF
Operating Ambient Temperature		-30 to +50	°C
Storage Temperature		-30 to +50	°C
Base		JEDEC No. B12-43	—
Suitable Socket		E678-12A (supplied)	—

MAXIMUM RATINGS (Absolute Maximum Values)

Parameter		Value	Unit
Supply Voltage	Between Anode and Cathode	1750	V
	Between Anode and Last Dynode	350	V
Average Anode Current		0.1	mA

CHARACTERISTICS (at 25 °C)

Parameter		Min.	Typ.	Max.	Unit
Cathode Sensitivity	Luminous (2856 K)	70	95	—	μA/lm
	Radiant at 420 nm	—	88	—	mA/W
	Blue Sensitivity Index (CS 5-58)	9	11	—	—
	Quantum Efficiency at 420 nm	—	27	—	%
Anode Sensitivity	Luminous (2856 K)	10	100		
Gain		—	1.1×10^7		
Anode Dark Current (after 30 min storage in darkness)		—	3		
Time Response	Anode Pulse Rise Time	—	2.7		
	Electron Transit Time	—	37		
	Transit Time Spread (FWHM)	—	4.5		
Pulse Linearity (±2 % deviation) *		—	150		

NOTE: Anode characteristics are measured with the voltage distribution ratio shown below.
* Measured with the special voltage distribution ratio shown below.

VOLTAGE DISTRIBUTION RATIO AND SUPPLY VOLTAGE

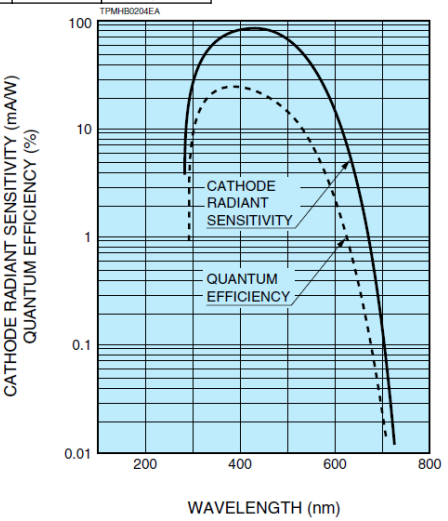
Electrodes	K	Dy1	Dy2	Dy3	Dy4	Dy5	Dy6	Dy7	Dy8	Dy9
Ratio	2	1	1	1	1	1	1	1	1	

Supply Voltage : 1250 V, K : Cathode, Dy : Dynode, P : Anode

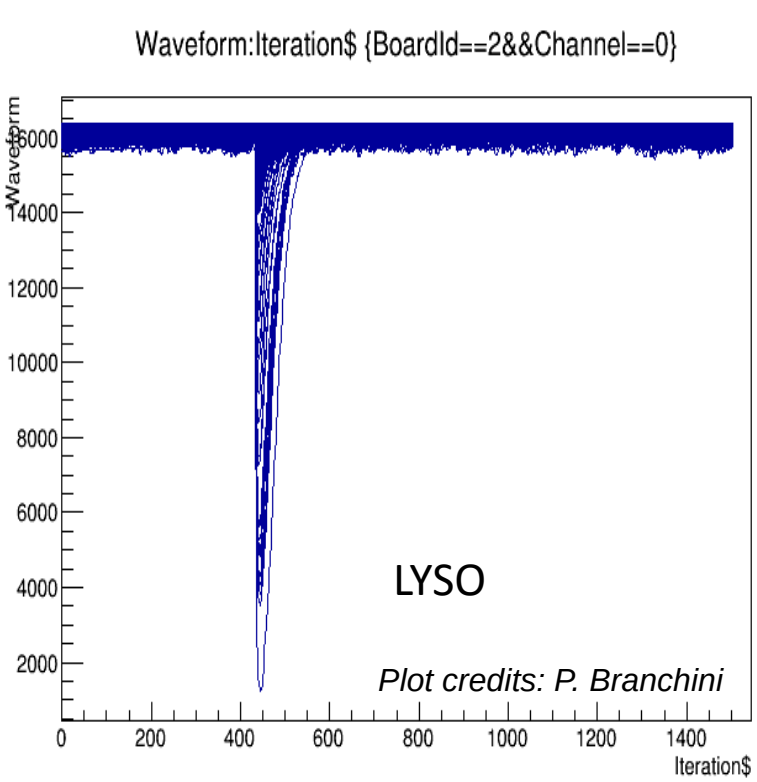
SPECIAL VOLTAGE DISTRIBUTION RATIO FOR PULSE LINEARITY M

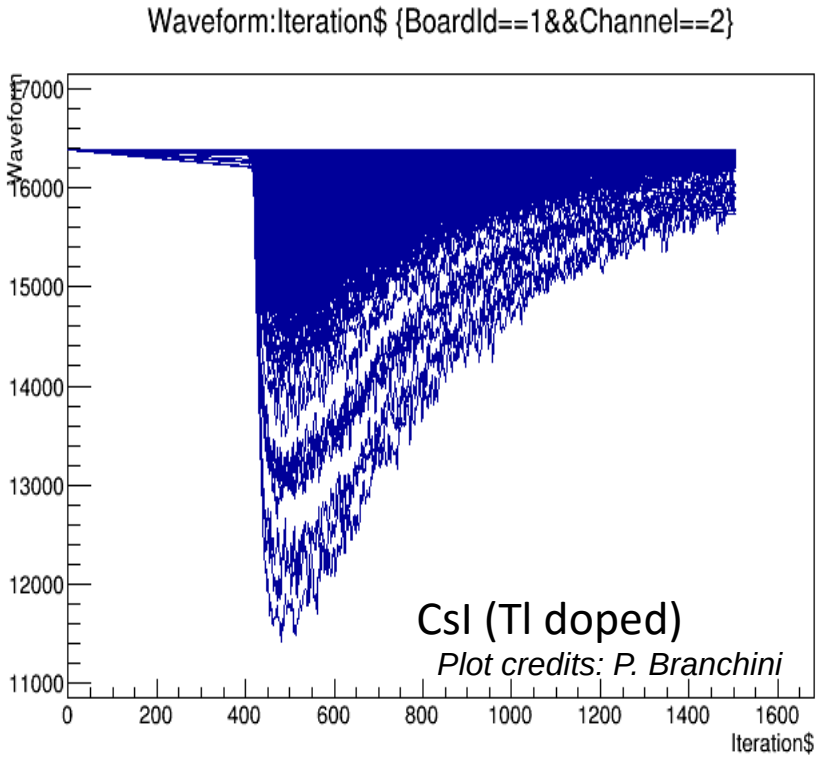
Electrodes	K	Dy1	Dy2	Dy3	Dy4	Dy5	Dy6	Dy7	Dy8	Dy9
Ratio	2	1	1	1	1	1	1.2	1.5	2.2	
Parallel Capacitors in μF								0.01	0.02	

Supply Voltage :1500 V



Crystal example plots





On the left side we have the LYSO waveform while on the right side we have the CsI(Tl doped) waveform.

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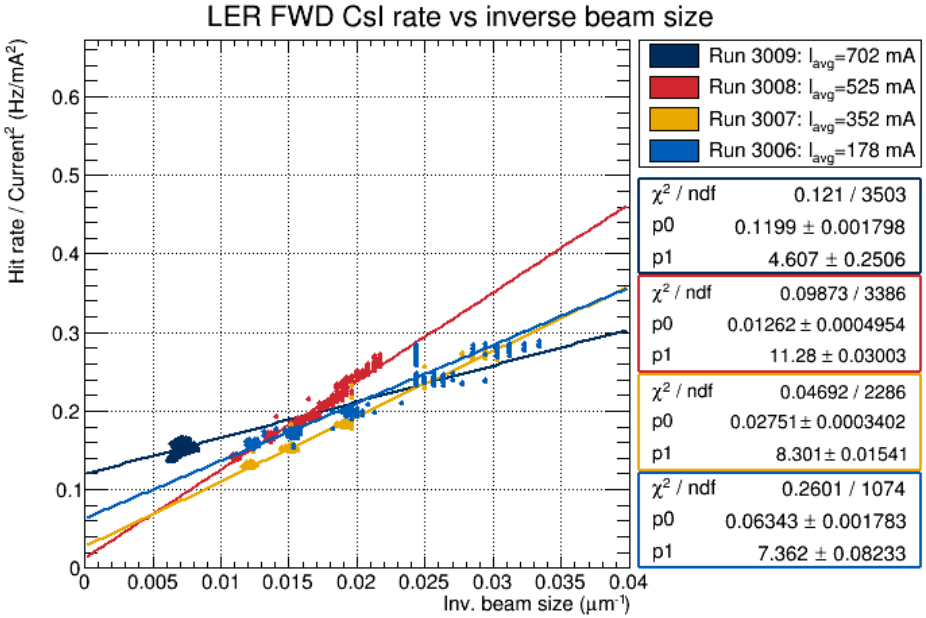
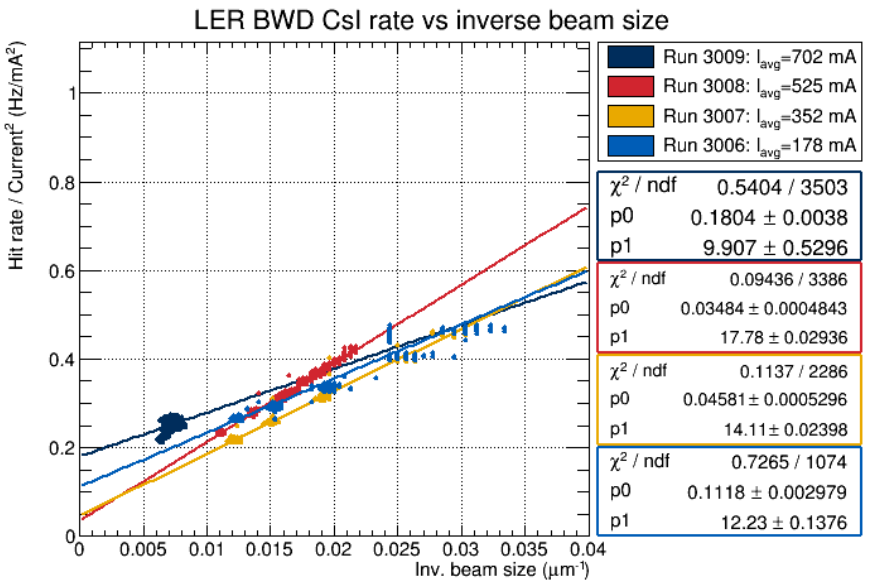
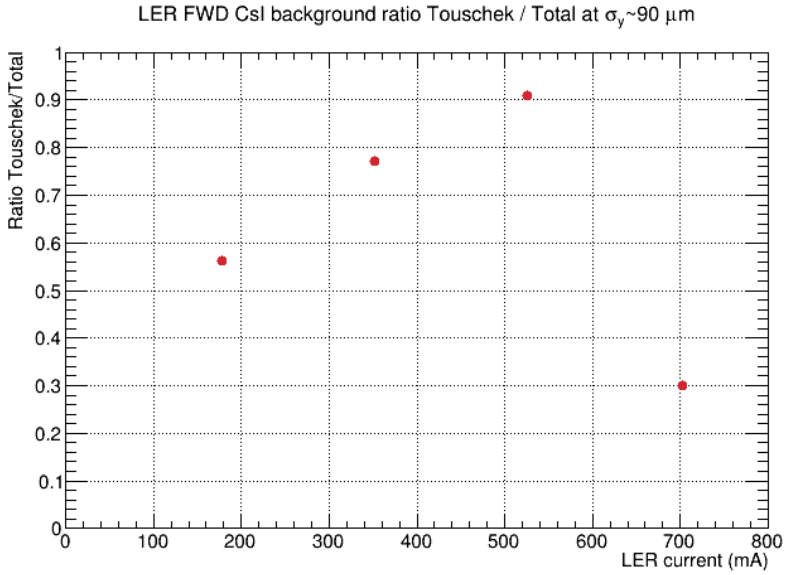
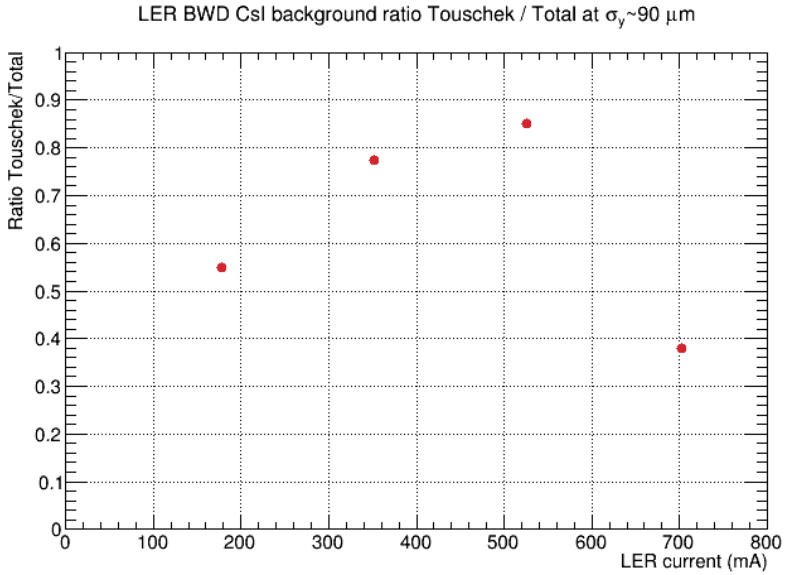
Beam-beam interactions: effect of beam size (positron ring)









Simulation

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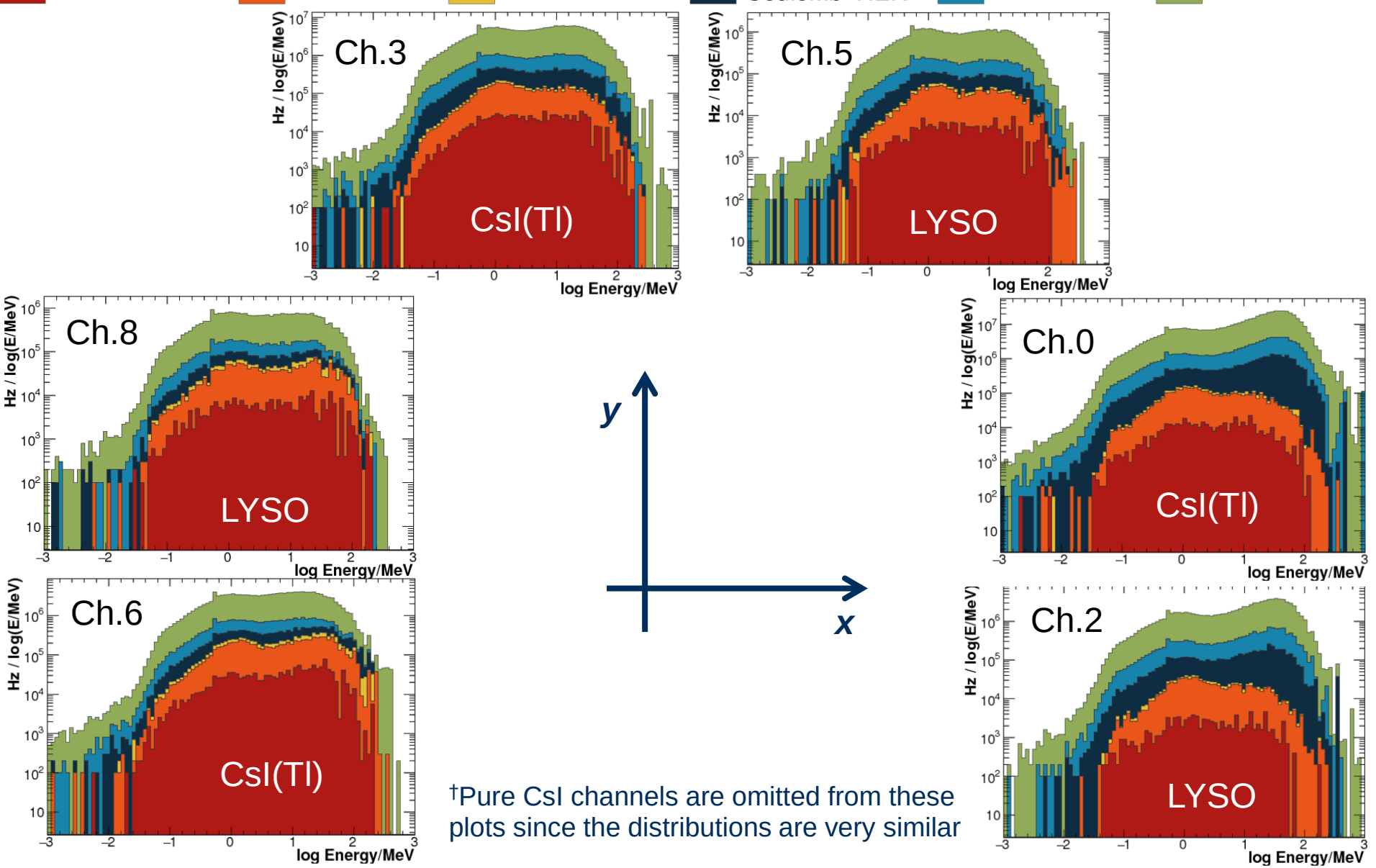
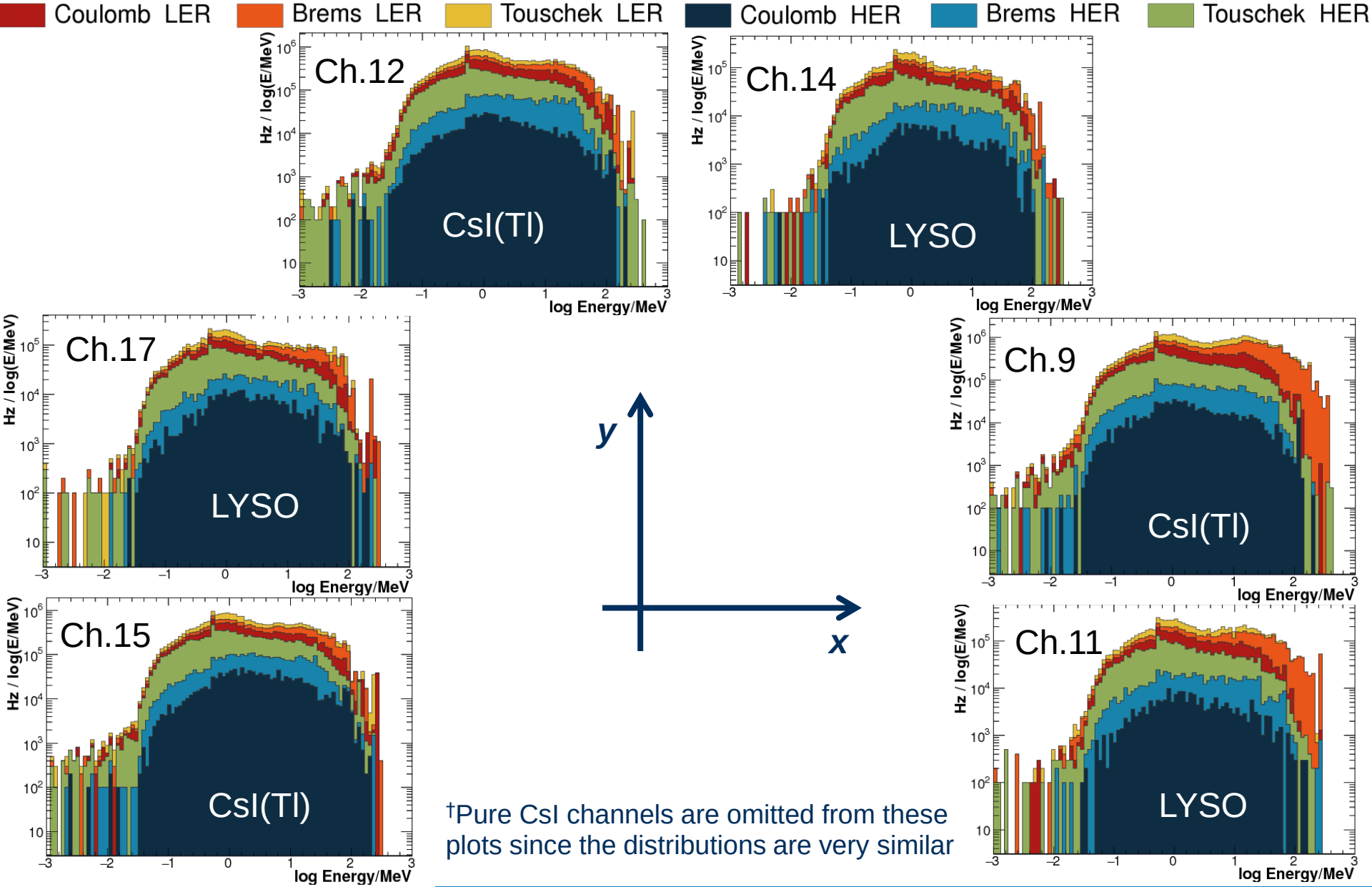
CsI(Tl) and LYSO – Forward channels†



†Pure CsI channels are omitted from these plots since the distributions are very similar

CsI(Tl) and LYSO – Backward channels†



†Pure CsI channels are omitted from these plots since the distributions are very similar

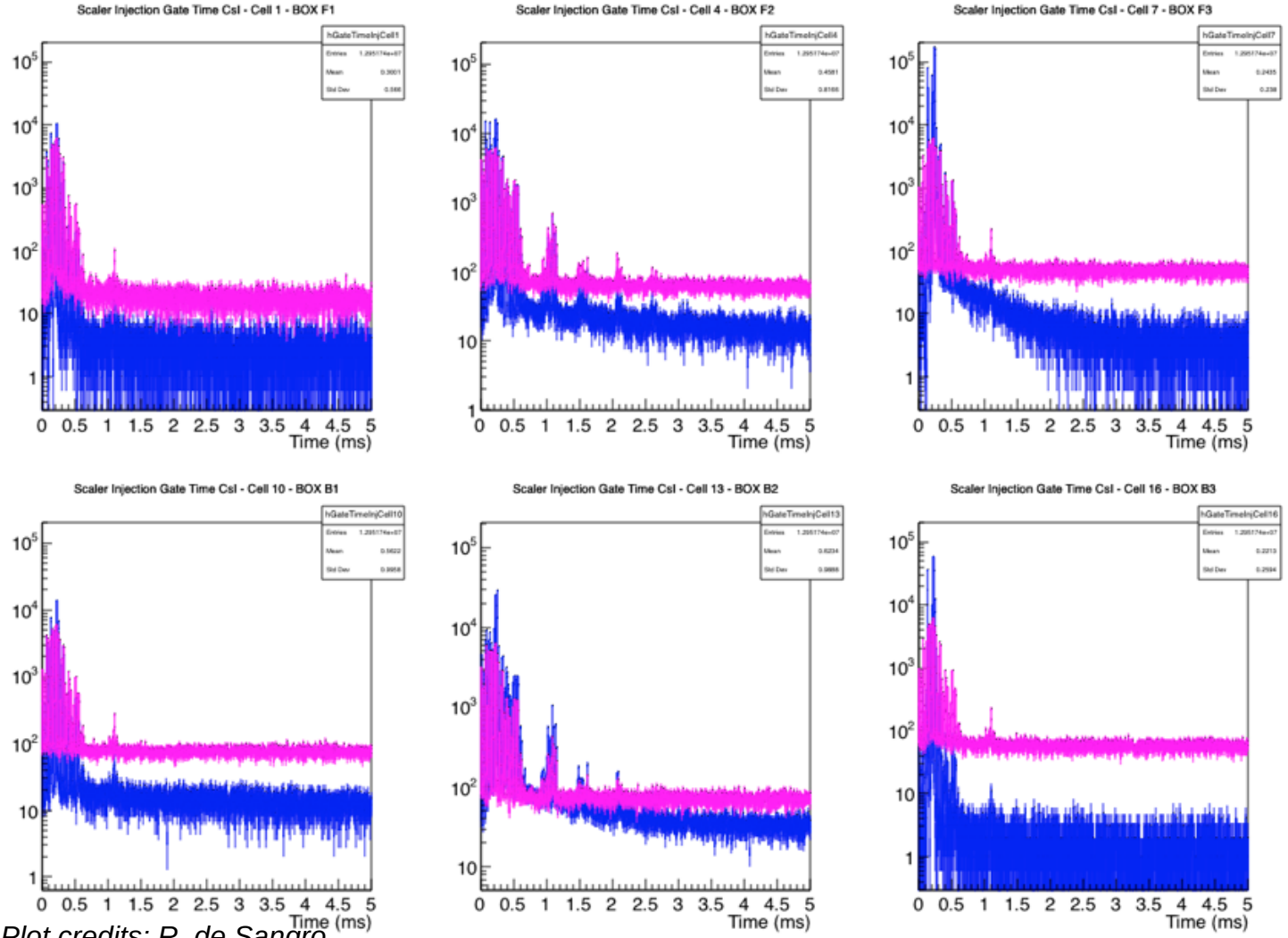
Injection background time structure

*Analysis conducted by R. de Sangro (INFN Frascati)

Magenta= LYSO

Blue = CsI

Reference 95% Injection efficiency



Plot credits: R. de Sangro

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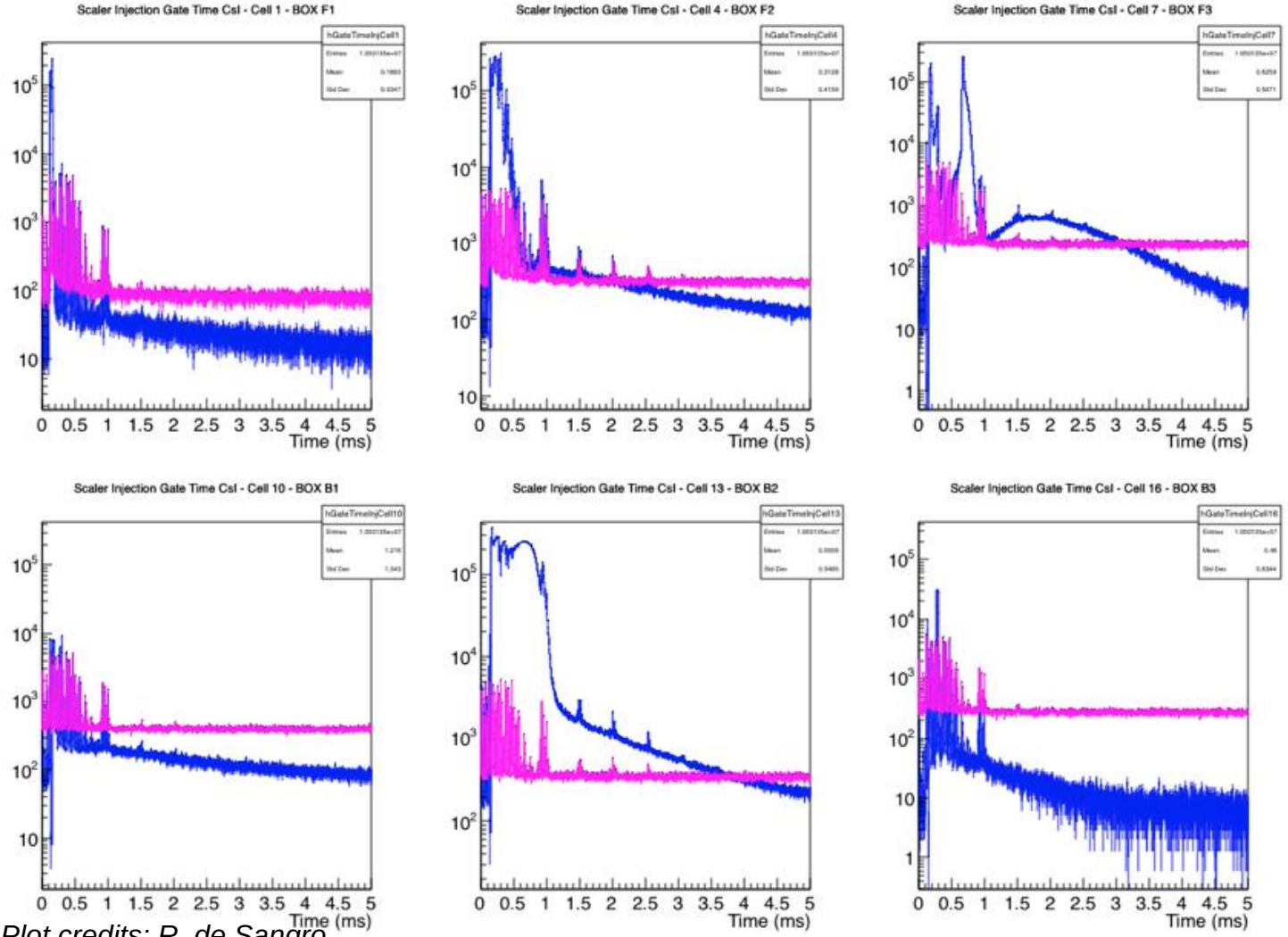
Injection background time structure

*Analysis conducted by R. de Sangro (INFN Frascati)

Magenta= LYSO

Blue = CsI

Phase Shift 31deg - ~70% Inj Eff.



Plot credits: R. de Sangro

University of Victoria