Onset of deconfinement and search for the critical point of strongly interacting matter at CERN SPS energies

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For the NA49 and NA61/SHINE collaborations
Exploration of phase diagram of strongly interacting matter

- QCD considerations suggest a 1st order phase boundary ending in a critical point
- hadro-chemical freeze-out points are obtained from statistical model fits to measured particle yields
- $T$ and $\mu_B$ approach phase boundary and estimated critical point at SPS
- evidence of onset of deconfinement from rapid changes of hadron production properties
- search for indications of the critical point as a maximum in fluctuations

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evidence for the onset of deconfinement (1)

the kink
pion yield per participant

\[ \langle \pi \rangle = 1.5 \cdot \langle \pi^+ \rangle + \langle \pi^- \rangle \]

central PbPb/AuAu

NA49, C. Alt et al., PRC77, 024903 (2008)

the horn
ratio of strange particle to pion yield

\[ E_s \]

\[ \sqrt{s_{NN}} \] (GeV)

- \( \pi \) yield related to entropy production
- steeper increase in A+A suggests 3-fold increase of initial d.o.f
- \( E_s \) related to strangeness/entropy ratio
- plateau consistent with prediction for deconfinement


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evidence for the onset of deconfinement (2)

- The step shape of transverse mass spectra
- The dale estimate of sound velocity

Softening of transverse (step) and longitudinal (minimum of $c_s$) features of EoS due to mixed phase (soft point of EoS)

Rapid changes of hadron production properties at low SPS energy most naturally explained by onset of deconfinement

NA49, C. Alt et al., PRC77, 024903 (2008); M. Gazdzicki et al., arXiv:1006.1765

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Verification of the NA49 results by STAR in progress

- presently available low statistics results from STAR compatible with NA49
- precise results from 2010 low energy run soon
Search for the critical point at the SPS

signature: enhanced fluctuations of multiplicity, \( p_T \), ...

effects of critical point are expected over a range of \( T, \mu_B \)

hydro predicts that evolution of the system is attracted to critical point


M. Asakawa et al., PRL 101, 122302 (2008)
Search strategy of NA49 and NA61

search for “hill” in fluctuation signals in 2d scan (T,μ_B) of phase diagram

- deconfinement necessary for observing CP effect (above 30A GeV)
- freeze-out occurs close to the critical point
- expected size of fluctuation signals limited by short lifetime and size of collision system (correlation lengths ~ 3 – 6 fm)

(M.Stephanov, K.Rajagopal, E.Shuryak, PRD60,114028(1999) )

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Estimates of effects due to the critical point

correlation length $\xi$ at the critical point is limited by finite size and lifetime of the fireball and was parameterized as:

$$\xi = \min( c_1 A^{1/3}, c_2 A^{1/9} )$$

suggesting $\xi(Pb+Pb) = 3 \to 6 \text{ fm}$ for $c_1 = 2 \to 1$

$\xi(p+p) = 1 \to 2 \text{ fm}$ for $c_2 = 3.32 \to 1.66$

(range of correlation effect estimated from QCD calculations:

$\sigma(\mu_B) = 30 \text{ MeV}, \sigma(T) = 10 \text{ MeV}$

considered examples:

- $\mu_B = 360 \text{ MeV}$ (lattice QCD), $T = 147 \text{ MeV}$ (chem. freeze-out line)
- $\mu_B = 250 \text{ MeV}$ (data 158A GeV), $T = 178 \text{ MeV}$ (fit of p+p data)
Fluctuation measures studied by NA49

- scaled variance $\omega$ of the multiplicity distribution $P(n)$

$$\omega = \frac{Var(n)}{<n>} = \frac{<n^2> - <n>^2}{<n>}$$

- intensive fluctuation measure
- independent particle emission: $\omega = 1$
- superposition model: $\omega(A+A)=\omega(N+N)+<N>\omega_{part}$
- $\omega$ affected by participant ($N_{part}$) fluctuations

- $\Phi_x$ measure of fluctuations of observable $x$ ($<p_T>$, $<\Phi>$, $Q$, identity, …)

$$\Phi_x = \sqrt{\frac{<Z^2>}{<N>}} - \sqrt{<Z^2>};$$

- superposition model: $\Phi_x(A+A)=\Phi_x(N+N)$
- independent particle emission: $\Phi_x=0$
- $\Phi_x$ strongly intensive fluctuation measure independent of $N_{part}$ and its fluctuations

- $\sigma_{dyn}$ measure of particle ratio fluctuations ($K/\pi$, $p/\pi$, $K/p$)

$$\sigma_{dyn} = \text{sign}(\sigma^2_{data} - \sigma^2_{mix})\sqrt{\left|\sigma^2_{data} - \sigma^2_{mix}\right|}; \quad \sigma^2_{dyn} = \left|\nu_{dyn}\right|$$

- $E$-by-$E$ fit of particle multiplicities required
- mixed events used as reference
- $1/N_{part}$ dependence, sensitive to fluctuations

- $F_2$ factorial moments of low mass $\pi^+\pi^-$ pair density fluctuations in $p_T$ space
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results of critical point search from NA49

T. Anticic et al., PRC70, 034902 (2004)
C. Alt et al., PRC75, 064904 (2007)
C. Alt et al., PRC78, 034914 (2008)
T. Anticic et al., PRC79, 044904 (2009)

first hint of the hill of fluctuations?
$\Phi^{(3)}_{p_T}$: 3rd moment of $<p_T>$ fluctuations

K. Grebieszkow and M. Bogusz, NA49 preliminary

$\Phi^{(n)}_{p_T} = \left( \frac{\left\langle Z^2_{p_T} \right\rangle}{\left\langle N \right\rangle} \right)^{1/n} - \left( \frac{\left\langle Z^n_{p_T} \right\rangle}{\left\langle N \right\rangle} \right)^{1/n}$

$\Phi^{(3)}_{p_T}$ has strongly intensive property like $\Phi_{p_T}$


higher moments are expected to be more sensitive to fluctuations

systematic errors are large

no indication of CP fluctuations

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\( \Phi_{\phi} \): fluctuations of average azimuthal angle

K. Grebieszkow, NA49 preliminary

- onset of deconfinement, critical point

- no significant energy \((\mu_B)\) dependence in central Pb+Pb collisions
- perhaps hint of maximum in nuclear size \((T)\) dependence
Event-by-event particle ratio fluctuations

E-by-E fit of particle ratios to dE/dx spectra in real and mixed events

\[ \sigma_{dyn} = \text{sign}(\sigma_{data}^2 - \sigma_{mix}^2) \sqrt{|\sigma_{data}^2 - \sigma_{mix}^2|} ; \quad \sigma_{dyn}^2 = \nu_{dyn} \]

NA49 data: PRC79,044910(2009)

T. Schuster, NA49 prel.

rise towards low \(\sqrt{s}\)?
low multiplicity effect?
deconfinement?

negative values
effect of nucleon resonances (UrQMD)

sign change at low \(\sqrt{s}\) related to \(C_{BS}\)
deconfinement?

Gorenstein et al., PLB585, 237
New measure $\Psi$ of particle ratio fluctuations

M.Gazdzicki, M.Mackowiak, S.Mrowczynski (more detail in talk at CPOD2010)

$\Psi$ generalizes the $\Phi_x$ measure to the situation of imperfect identification, retains advantages of $\Phi_x$: strongly intensive measure, no $1/N_{\text{part}}$ dilution not required: e-by-e fits of particle ratios mixed event reference: $\Psi_{\text{mix}} = 0$

Identity method:
- obtain inclusive probability distribution $\rho_h$ of particle type $h$
  from fit to inclusive $dE/dx$ distribution
  $\int \rho_h(m) dm = N_h$ ; $\int \rho(m) dm = N$
- $w_{h,i} = \rho_h(dE/dx_i)/\rho(dE/dx_i)$ probability for particle $i$ having identity $h$

$$
\Psi_{wh} = \frac{\langle Z^2 \rangle}{\langle N \rangle} - Z^2
$$

$$
z = w_{h,i} - w_h \quad \text{single-particle variable}
$$

$$
Z = \sum_{i=1}^{n} (w_{h,i} - w_h) \quad \text{event variable}
$$

- effect of limited resolution can be corrected in a model independent way
low mass $\pi^+\pi^-$ pair density: 2d intermittency in $p_T$ space


- critical point predicted to lead to power-law density fluctuations of $\sigma$ field
- observation via density fluctuations of low mass $\pi^+\pi^-$ pairs in $p_T$ space
- power law behavior of $F_2(M)$ factorial moment expected (intermittency)
- use $\pi^+\pi^-$ pairs near threshold to reduce combinatorial background
- estimate combinatorial background by mixed events and subtract

NA49 data indicate intermittency for Si+Si

(T. Anticic et al., PRC81, 064907 (2010))

$critical point close to freeze-out point of Si+Si system?
Onset of deconfinement and search for critical point at CERN SPS

NA61/SHINE – successor and extension of NA49
(SHINE – SPS Heavy Ion and Neutrino Experiment)

• study of the onset of deconfinement and search for the critical point
• precision particle production measurement for improving calculations of T2K neutrino beam and air shower (P.Auger,KASKADE) properties
• study of nuclear modification factor and Cronin effect using p+p and p+Pb interactions with extended range in $p_T$
Ion physics program of NA61/SHINE: scan in energy and system size $A$

- search for hill of fluctuations as signature of critical point

- extrapolation

- study onset of deconfinement: disappearance of horn etc.

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NA61/SHINE uses the upgraded NA49 detector

- forward TOF system for low momentum tracks in p+p, p+A collisions
- new TPC readout and DAQ → data taking rate increase x 10 (80 Hz)
- new zero degree calorimeter PSD with single nucleon resolution
- He-filled beam pipe through VTPCs to reduce δ-ray background
PSD – Projectile Spectator Detector (completion for 2012)

- 60 lead/scintillator sandwiches
- 10 longitudinal sections
- 6 WLS-fiber/MAPD
- 10 MAPDs/module
- 10 Amplifiers with gain~40

2007 beam test

\[ \sigma(E)/E = 36\%/\sqrt{E(\text{GeV})} + 0.2\% \]

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first physics results from p+C collisions at 31 GeV (2007 pilot run)

already low statistics pilot data provide significant constraints
present status of the ion program

- **2010**: p+p at 13 GeV/c, ~700k events
- **2009**: p+p at 20 GeV/c, 2M events
- **2009**: p+p at 31 GeV/c, 3M events
- **2009**: p+p at 40 GeV/c, 6M events
- **2009**: p+p at 80 GeV/c, 4M events
- **2009/10**: p+p at 158 GeV/c, 4M events

p+p energy scan data recorded, data analysis in progress
Status and plans for ion collisions at SPS energies

**NA61 ion program**

- **Pb+Pb**: NA49 (1996-2002)
- **Au+Au**: STAR (2008-10)
- **Xe+La**: 2014
- **Ar+Ca**: 2012 ?? (probably 2013)
- **B+C**: 2010/11(13)
- **p+p**: 2009/10
- **p+Pb**: 2011/12

- **13 20 30 40 80 158**

  - Test of secondary ion beams
  - Beam feasibility under study

Onset of deconfinement and search for critical point at CERN SPS

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### Experimental landscape of complementary programs of nucleus-nucleus collisions around the SPS energies

<table>
<thead>
<tr>
<th>Facility</th>
<th>SPS</th>
<th>RHIC</th>
<th>NICA</th>
<th>SIS-100 (SIS-300) CBM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp.</td>
<td>NA61</td>
<td>STAR PHENIX</td>
<td>MPD</td>
<td>CBM</td>
</tr>
<tr>
<td>Pb Energy (GeV/(N+N))</td>
<td>4.9-17.3</td>
<td>7.7-50</td>
<td>≤11</td>
<td>≤5 (&lt;8.5)</td>
</tr>
<tr>
<td>Event rate (at 8 GeV)</td>
<td>100 Hz</td>
<td>3-30 Hz</td>
<td>≤10 kHz</td>
<td>≤10 MHz</td>
</tr>
<tr>
<td>Physics</td>
<td>CP&amp;OD</td>
<td>CP&amp;OD</td>
<td>OD&amp;HDM</td>
<td>HDM (OD)</td>
</tr>
</tbody>
</table>

**CP** - critical point  
**OD** - onset of deconfinement, mixed phase, 1st order PT  
**HDM** - hadrons in dense matter

Onset of deconfinement and search for critical point at CERN SPS  
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QCD critical point searches – future experimental landscape

partly complementary programs planned at CERN SPS 2011
BNL RHIC 2010
DUBNA NICA 2015 ?
GSI SIS-CBM 2017 ?

strong points of NA61:
• tight constraint on spectators
• high event rate at all SPS energies
• flexibility to change A and energy
• overlap with AGS energy

Strong points of BNL/STAR:
• full uniform azimuthal acceptance
• excellent TOF identification
• low track density

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Conclusion

• verification of NA49 results on the onset of deconfinement by STAR low energy scan at RHIC in progress

• search for critical point of strongly interacting matter presently inconclusive

• 2D scan of fluctuations in $\mu_B, T$ phase diagram was started by NA61/SHINE

• future programs at NICA and CBM/FAIR plan to continue and augment these studies
Onset of deconfinement and search for critical point at CERN SPS


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The NA61/SHINE Collaboration

NA61: 130 physicists from 24 institutes and 13 countries:

University of Athens, Athens, Greece
University of Bergen, Bergen, Norway
University of Bern, Bern, Switzerland
KFKI IPNP, Budapest, Hungary
Jagiellonian University, Cracow, Poland
Joint Institute for Nuclear Research, Dubna, Russia
Fachhochschule Frankfurt, Frankfurt, Germany
University of Frankfurt, Frankfurt, Germany
University of Geneva, Geneva, Switzerland
Forschungszentrum Karlsruhe, Karlsruhe, Germany
Institute of Physics, University of Silesia, Katowice, Poland
Jan Kochanowski University, Kielce, Poland
Institute for Nuclear Research, Moscow, Russia
LPNHE, Universités de Paris VI et VII, Paris, France
Faculty of Physics, University of Sofia, Sofia, Bulgaria
St. Petersburg State University, St. Petersburg, Russia
State University of New York, Stony Brook, USA
KEK, Tsukuba, Japan
Soltan Institute for Nuclear Studies, Warsaw, Poland
Warsaw University of Technology, Warsaw, Poland
University of Warsaw, Warsaw, Poland
Universidad Tecnica Federico Santa Maria, Valparaiso, Chile
Rudjer Boskovic Institute, Zagreb, Croatia
ETH Zurich, Zurich, Switzerland

Onset of deconfinement and search for critical point at CERN SPS
P. Seyboth, WPCF2010, Kiev, 14-18/9/2010
additional / backup slides
transverse mass spectra of baryons and antibaryons

presence of critical point predicted to attract fireball evolution trajectory
altering average freeze-out time $\rightarrow \beta_T$ dependence of $p_{\bar{p}}/p$ ratio

critical point: $p_{\bar{p}}/p$ increases with $m_T$
annihilation: decreases

M. Asakawa et al., PRL101, 122302(2008)

similar data for $\Lambda$ and $\Xi$

no significant change with $\sqrt{s}$ of slope parameter $a$

no evidence for critical point effect
Electric charge fluctuations

- Smaller in a QGP than in a hadron gas
  (Jeon,Koch,Asakawa,Heinz,Müller)

Central Pb+Pb collisions 158A GeV

Global charge conservation

\[ \Phi_q = \sqrt{\frac{<Z^2>}{<N>}} - \sqrt{Z^2} \]

\[ z = q - \overline{q} \quad Z = \sum_{i=1}^{N} (q_i - \overline{q}) \]

QGP signature probably erased by hadronisation (Bialas) or the effect of resonance decays (Zaranek)
Balance Function: charge correlations in pseudo-rapidity

\[ B(\delta \eta) = \frac{1}{2} \left( \frac{N_{(+)}(\delta \eta) - N_{(-)}(\delta \eta)}{N_{-}} + \frac{N_{(-)}(\delta \eta) - N_{(+)}(\delta \eta)}{N_{+}} \right) \]

narrowing of the balance function proposed as QGP signature
(delayed hadronisation due to phase coexistence)

\[
\text{data compared to shuffled events: } \quad W = \frac{\langle \Delta \eta \rangle_{\text{shuff}} - \langle \Delta \eta \rangle_{\text{data}}}{\langle \Delta \eta \rangle_{\text{shuff}}} \times 100
\]
(scrambling of rapidities, retention of global charge conservation)
BF: model comparisons at mid-rapidity

- no anomaly at SPS energy: effects due to local charge conservation and radial flow may dominate (Pratt, Bialas)
- microscopic model AMPT with deconfined phase reproduces BF narrowing
$\Phi_\Phi$: fluctuations of average azimuthal angle

K. Grebieszkow, NA49 preliminary

- onset of deconfinement, critical point

**energy dependence**

$\Phi_\Phi$ [mrad]

<table>
<thead>
<tr>
<th>$p_t &lt; 1.5$ GeV/c</th>
<th>negatively charged</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y &lt; 2.6$</td>
<td>positively charged</td>
</tr>
<tr>
<td>$y &lt; y_{beam} - 0.5$</td>
<td>UrQMD neg. charged</td>
</tr>
<tr>
<td>$y &lt; y_{beam}$</td>
<td>UrQMD pos. charged</td>
</tr>
</tbody>
</table>

Pb+Pb 7% central

**system size dependence**

$\Phi_\Phi$ [mrad]

<table>
<thead>
<tr>
<th>$p_t &lt; 1.5$ GeV/c</th>
<th>negatively charged</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y &lt; 5.5$ (1.1 &lt; $y &lt; 2.6$)</td>
<td>positively charged</td>
</tr>
<tr>
<td>$y &lt; y_{beam}$</td>
<td>$N_w$</td>
</tr>
</tbody>
</table>

- no significant energy or A dependence in central collisions
- increase for peripheral Pb+Pb collision as for $\omega$, $\Phi_{pT}$; not understood
• experimental resolution of identification reduces the value of $\Psi$
• a correction was found which was proven (S. Mrowczynski) to work for all types of correlations, resolution and particle yields

Various model calculations

$\Psi_{\text{res}}$ value evaluated for data
$\Psi_{\text{corr}}$ correct value for ideal resolution

Variances of $\rho(m)$ for experimental and no resolution cases provide correction

$$Var_{\text{res}} = \frac{1}{M} \sum_{i=1}^{M} w_{h_i} \left( \frac{dE}{dx_i} \right) \cdot \left( 1 - w_{h_i} \left( \frac{dE}{dx_i} \right) \right)$$

$$Var_{\text{NR}} = w_{h_i} \cdot \left( 1 - w_{h_i} \right)$$

$$\frac{\Psi_{\text{res}}}{\Psi_{\text{corr}}} = \left( 1 - \frac{Var_{\text{res}}}{Var_{\text{NR}}} \right)^2$$
first look at NA49 data (preliminary)

proton number fluctuations in central Pb+Pb collisions at 40A GeV

Ranges of kinetic variables:
• q: neg. and pos. charge
• p_{tot}: 0-40 GeV/c
• p_T: 0-2 GeV/c
• φ from 0 to 2π

sample of 4k events

M = 661581
N = 165.40
N_p = 42.16 – value calculated from dE/dx fit
Var_B = 0.1899
Var_{res} = 0.0223
Ψ_{res} \cdot 1000 = -17.3823 ± 3.44916

correction Ψ_{corr}/Ψ_{res} = 1.2832
Ψ_{corr} \cdot 1000 = -22.3048 ± 4.4259
**Event-by-event transverse momentum and multiplicity fluctuations**

\( \Phi_{p_T} \) - measures transverse momentum fluctuations on event-by-event basis

\[ z_{p_T} = p_T - \bar{p}_T \]

\( \bar{p}_T \) - inclusive average

Event variable:
\[ Z_{p_T} = \sum_{i=1}^{N} (p_{T_i} - \bar{p}_T) \]

(summation runs over particles in a given event)

\[ \Phi_{p_T} = \sqrt{\frac{\langle Z_{p_T}^2 \rangle}{\langle N \rangle} - \langle z_{p_T}^2 \rangle} \]

\( \langle ... \rangle \) - averaging over events

If A+A is a **superposition** of independent N+N

\[ \Phi_{p_T} (A+A) = \Phi_{p_T} (N+N) \]

**\( \Phi_{p_T} \) is independent of \( N_{\text{part}} \) fluctuations**

\[ \omega \ (A+A) = \omega \ (N+N) + \langle n > \ \omega_{\text{part}} \]

\( \langle n > \) - mean multiplicity of hadrons from a single N+N

\( \omega_{\text{part}} \) - fluctuations in \( N_{\text{part}} \)

**\( \omega \) is strongly dependent on \( N_{\text{part}} \) fluctuations**

For a system of **independently emitted particles** (no inter-particle correlations)

\[ \Phi_{p_T} = 0 \]

For **Poissonian multiplicity distribution**

\[ \omega = 1 \]
Critical point predictions for multiplicity and transverse moment fluctuations

Magnitude of fluctuations at CP from Stephanov, Rajagopal, Shuryak PRD60, 114028 (1999) with correlation length $\xi = \min (c_1 A^{1/3}, c_2 A^{1/9}) = \min (\text{limit due to finite system size, limit due to finite life time})$

(M. Stephanov, private communication) where $c_1$ and $c_2$ are fixed such that

- $\xi(\text{Pb+Pb}) = 6 \text{ fm and } \xi(\text{p+p}) = 2 \text{ fm}$ ($c_1 = 2$, $c_2 = 3.32$)
- $\xi(\text{Pb+Pb}) = 3 \text{ fm and } \xi(\text{p+p}) = 1 \text{ fm}$ ($c_1 = 1$, $c_2 = 1.66$)

Width of CP region in $(T, \mu_B)$ plane based on Hatta, Ikeda PRD67, 014028 (2003)

$\sigma(\mu_B) \approx 30 \text{ MeV and } \sigma(T) \approx 10 \text{ MeV}$

Chemical freeze-out parameters, $T(A, \sqrt{s_{NN}})$ and $\mu_B(A, \sqrt{s_{NN}})$ from Beccatini, Manninen, Gaździcki PRC73, 044905 (2006)

Location of the Critical Point:

two examples considered

- $\mu_B(\text{CP}_1) = 360 \text{ MeV (Fodor, Katz JHEP 0404, 050 (2004))}$
  $T(\text{CP}_1) \approx 147$ (chemical freeze-out temperature $T_{\text{chem}}$ for central Pb+Pb at $\mu_B = 360 \text{ MeV}$)

- $\mu_B(\text{CP}_2) \approx 250 \text{ MeV (}\mu_B\text{ for A+A collisions at 158A GeV})$
  $T(\text{CP}_2) = 178 \text{ MeV (}\text{T}_{\text{chem}}\text{ for p+p collisions at 158 GeV)}$
### NA61/SHINE data taking plan

<table>
<thead>
<tr>
<th>Beam Primary</th>
<th>Beam Secondary</th>
<th>Target</th>
<th>Energy (A GeV)</th>
<th>Year</th>
<th>Duration days/MDs</th>
<th>Physics</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>p</td>
<td>p</td>
<td>p</td>
<td>400</td>
<td>158</td>
<td>77 d</td>
<td>High pT</td>
<td>recommended</td>
</tr>
<tr>
<td>Pb</td>
<td>11B</td>
<td>none</td>
<td>20,80</td>
<td>2010</td>
<td>10 MDs</td>
<td>FS test-1</td>
<td>to be discussed</td>
</tr>
<tr>
<td>p</td>
<td>Pb</td>
<td></td>
<td>400</td>
<td>158</td>
<td>77 d</td>
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<td>recommended</td>
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<tr>
<td>Pb</td>
<td>11B</td>
<td>C</td>
<td>10,20,30,40,80,158</td>
<td>2011</td>
<td>20 d</td>
<td>FS test-2</td>
<td>to be discussed</td>
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<tr>
<td>p</td>
<td>Pb</td>
<td></td>
<td>400</td>
<td>10,20,30,40,80,158</td>
<td>2012</td>
<td>6x8 d</td>
<td>CP,OD</td>
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<tr>
<td>Ar</td>
<td>Ca</td>
<td></td>
<td>10,20,30,40,80,158</td>
<td>2012</td>
<td>6x8 d</td>
<td>CP,OD</td>
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</tr>
<tr>
<td>Pb</td>
<td>11B</td>
<td>C</td>
<td>10,20,30,40,80,158</td>
<td>2013</td>
<td>6x10 d</td>
<td>CP,OD</td>
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<tr>
<td>Xe</td>
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<td>10,20,30,40,80,158</td>
<td>2014</td>
<td>6x8 d</td>
<td>CP,OD</td>
<td>to be discussed</td>
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